

for

DATA SOURCES: ESRI, NETWORK MAPPING 2010, NYSDOT, OPRHP, TDI, TRC

**CTRC** 

## **TEST BORING LOG**

PROJECT: TDI CHAMPLAIN HUDSON POWER EXPRESS

#### LOCATION: CSX RAILROAD ROW, NY

	GROU	NDWATER	R DATA	]	Ν	IETHOD C	F ADVANC	CING BO	REHOLE	
FIRST ENCOUNTERED 13.5 '					а	FROM	0.0 '	ТО	10.0 '	
DEPTH	HOUR	DATE	ELAPSED TIME	-	d	FROM	10.0 '	TO	25.0 '	
				1						

 BORING
 B219.5-1

 G.S. ELEV.
 N/A

 FILE
 195651

SHEET 1 OF 1

DRILLER	R. CARUSO
HELPER	C. SMART
INSPECTOR	C. POPPE
DATE STARTED	12/05/2012
DATE COMPLETED	12/05/2012

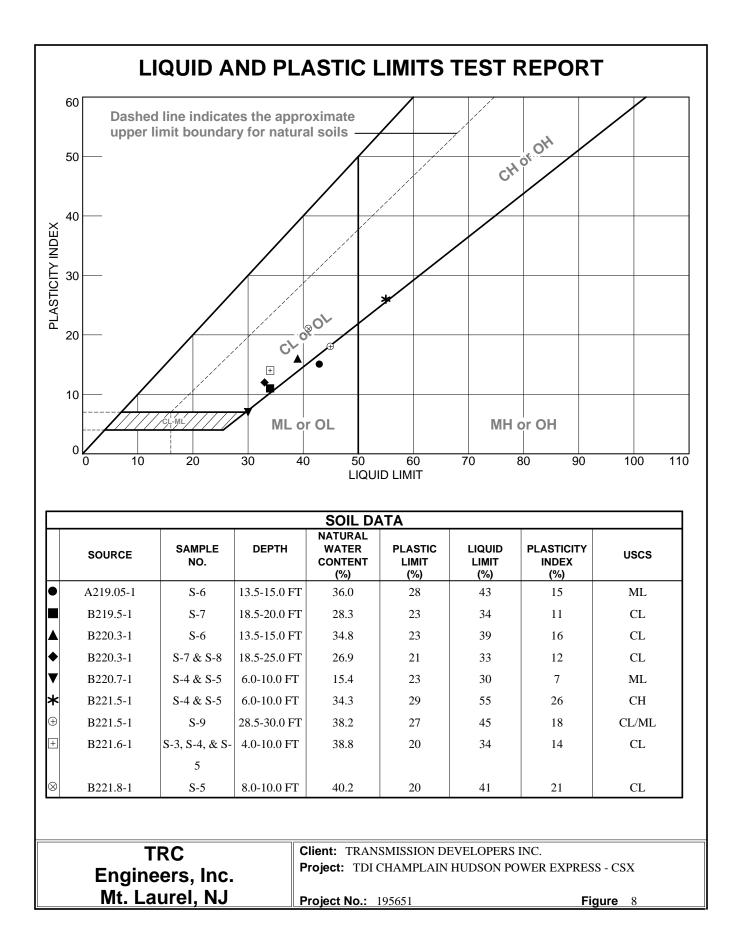
	DEPTH	1	А			В		0	2		DESCRIPTION	Wn	REMARKS
			S-1	8	7	6	8			2.0	BLACK M/C SANDY F/C GRAVEL-SIZED ROCK FRAGMENTS (FILL)		
			S-2	5	17		9			4.0	DARK BROWN M/F/C SAND, SM SILT, SM F/ GRAVEL (FILL)	9.1	
	5 _		S-3	9	50/					6.0	BROWN SILT, SM F/M SAND, TR F/ GRAVEL (FILL)	11.8	
			S-4	6	7	9	13			0.0	DARK BROWN TO BLACK SILTY C/F GRAVEL, SM M/F/C SAND (FILL)		
	10 _		S-5	5	8	6	13	$\bigotimes$	***	10.0	1	- 14.9	
Ā		_  _  _  _ T		11	47	47							WATER TABLE DETERMINED FROM WETNESS OF SAMPLE
	15 _		<u>S-6</u>	11	17	17					LIGHT BROWN TO BROWN CLAY, TR TO SM SILT, TR F/M SAND	31.2	WEINESS OF SAMPLE
/13	20 _		S-7	7	7	7		-				28.3	
TDI_CSX.GPJ SITE BLAUVELT.GDT 3/12/13										23.5			
SITE BI	25 _		S-8	1	2	1				25.0	GRAY SILT (THIXOTROPHIC)		
		_									END OF BORING AT 25'		
NG LOG 19565	30 _	_											
NEW PROJECTS TEST BORING LOG 195651	25	_											
PROJE	35		I								DRN.		TBT
NEW											CKD.		PWK

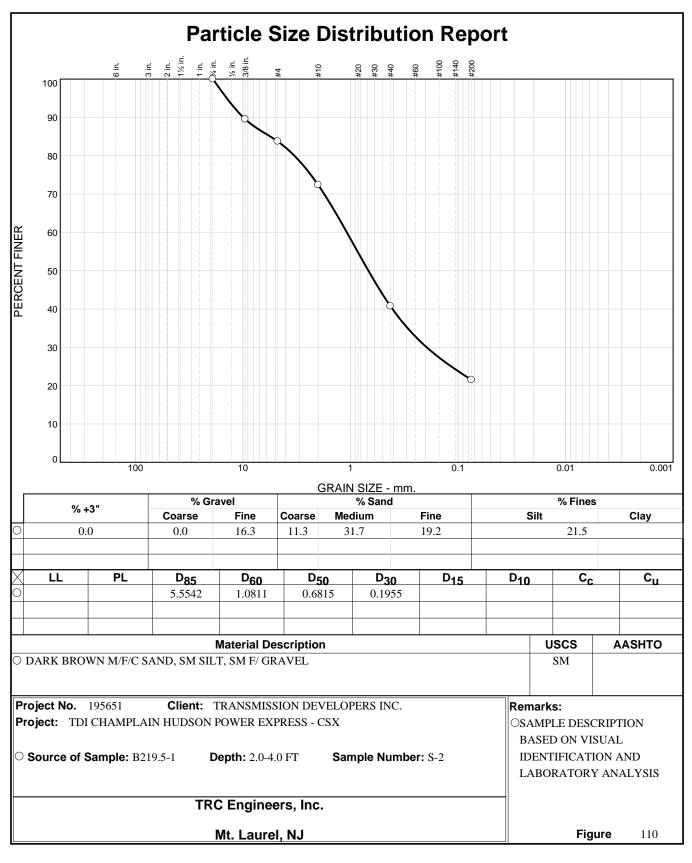


**Project Name:** Client Name: TRC Project #: TDI Champlain Hudson Power Express – CSX Transmission Developers, Inc. 195651

Organic Content (%) Soil Group (USCS System) **GRAIN SIZE** SAMPLE IDENTIFICATION PLASTICITY Moisture Content (%) Unit Weight (pcf) DISTRIBUTION Specific Gravity Compressive Strength (tsf) Gravel (%) Plasticity Index (%) Depth (ft) Liquidity Index) # Limit (%) Boring # Sand (%) Limit (%) Clay (%) Sample ∮ Plastic Silt (%) Liquid CH/MH 8.0-10.0 26 30.2 S-5 56 30 0.0 \_ \_ \_ \_ S-6 13.5-15.0 ML 43 28 15 0.5 \_ 36.0 99.3 \_ \_ \_ \_ \_ \_ S-2 2.0 - 4.0SM 16.3 62.2 21.5 9.1 \_ \_ \_ \_ \_ \_ \_ -S-3 4.0 - 4.911.8 \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ S-4 6.0-8.0 25.6 B219.5-1 GM 35.2 39.2 14.9 -\_ -\_ \_ \_ \_ \_ S-5 8.0-10.0 0.0 3.0 14.2 82.8 2.83 31.2 S-6 13.5-15.0 99.9 \_ \_ \_ \_ \_ \_ -S-7 18.5-20.0 CL 34 23 11 0.5 28.3 -\_ \_ \_ S-2 2.0 - 4.048.8 10.7 \_ \_ -\_ \_ \_ \_ \_ \_ \_ -\_ 4.0-6.0 24.0 103.8 B220.3-1 S-3 \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ S-5 8.0-10.0 4.9 23.5 71.5 2.80 27.6 0.0 \_ \_ \_ \_ \_ \_ \_ -

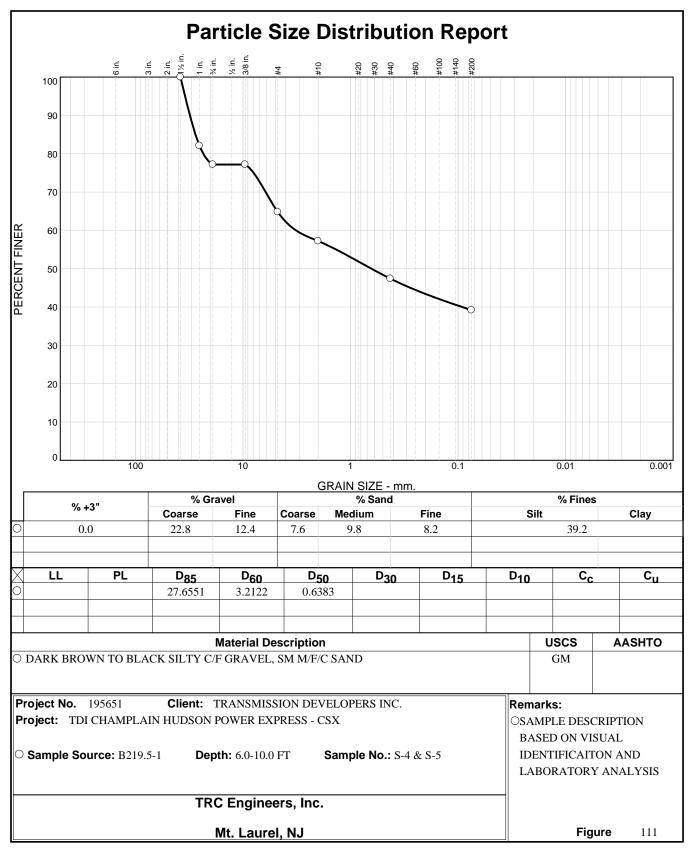
DRAWN BY: TBT rev 03/12/13





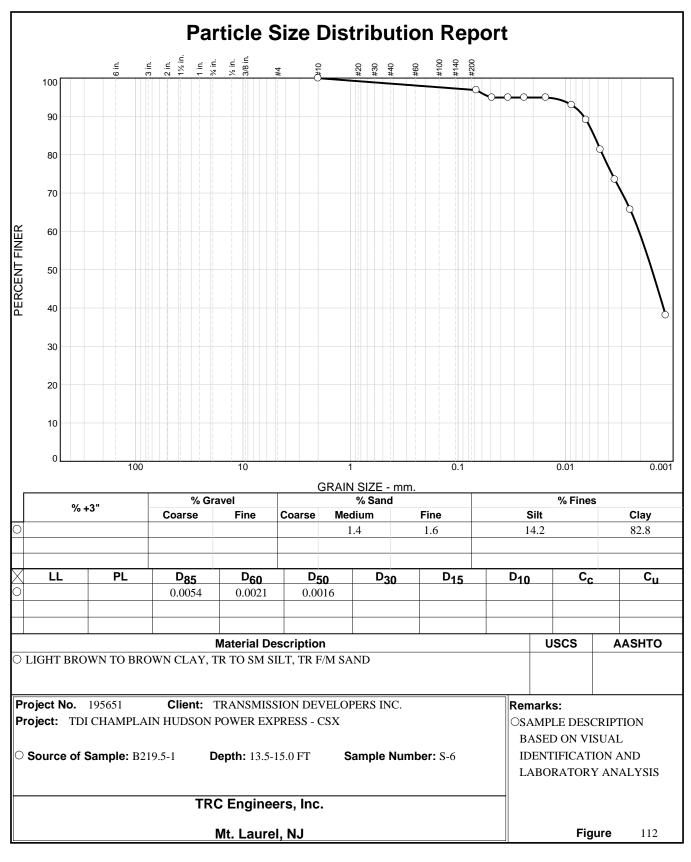
Tested By: <u>TBT 01/10/13</u>

\_\_\_\_\_ Checked By: JPB 03/12/13



Tested By: <u>TBT 01/10/13</u>

\_\_\_\_\_ Checked By: JPB 03/12/13



Tested By: <u>TBT 01/08/13</u>

\_\_\_\_\_ Checked By: JPB 03/12/13

#### **EXPLORATION PLAN**

Champlain-Hudson Power Express- Phase 4 HDD Borings – Package 6 and 7 Schenectady through Selkirk, NY April 25, 2023 – Terracon Project No. JB215256J





### **Geotechnical Data Report** Champlain-Hudson Power Express- Phase 4 HDD Borings – Package 6 and 7A – Rev 1 Schenectady through Selkirk, NY



April 25, 2023 Terracon Project No. JB215256J



#### Geotechnical Data Report Champlain-Hudson Power Express- Phase 4 HDD Borings – Package 6 and 7A – Rev 1 Schenectady through Selkirk, NY April 25, 2023 Terracon Project No. JB215256J





Page 1 of 4

#### **PROJECT:** Phase 4 Borings CLIENT: Kiewit Engineering (NY) Corp Lone Tree, CO SITE: Champlain to Hudson HDD Crossings ATTERBERG LIMITS PERCENT FINES LOCATION See Exploration Plan **GRAPHIC LOG** WATER LEVEL OBSERVATIONS SAMPLE TYPE RECOVERY (In. (%) FIELD TEST RESULTS DEPTH (Ft.) WATER CONTENT (° Latitude: 42.2497° Longitude: -73.8558° LL-PL-PI Surface Elev .: 120.73 (Ft.) ELEVATION (Ft.) DEPTH 120.4 1-2-3-3 FILL - SANDY SILT, orange and brown 10 N=5 5-6-8-8 20 N=14 116.7 SILTY GRAVEL WITH SAND (GM), occasional cobbles and boulders, brown, medium dense to dense, (GLACIAL TILL) 6-5-8-8 5 20 N=13 0.0 0.20 10-10-14-38 22 11.8 32 N=24 25-17-20-15 12 N=37 10-18-16-8-7 12 N=24 15.0 105.7 15 50/0 WEATHERED ROCK, gray, very dense 20.0 100.7 20 SHALE, occasional calcite veins, unweathered, close to wide fractured with near vertical fractures, good RQD, gray REC=100% RQD=85% 25.0 95.7 25 Stratification lines are approximate. In-situ, the transition may be gradual. Hammer Type: Automatic Advancement Method: Notes: See Exploration and Testing Procedures for a 0-15' 4" Casing description of field and laboratory procedures Hammer Efficiency Summary: Energy Transfer Ratio: 89.1% +/-4.4% Hammer Efficiency Correction (CE): 1.49 Logged by JCH/DO 15-20' Mud Rotary 20' -75' NQ Core Barrel used and additional data (If any) Supporting Information for explanation of Abandonment Method: symbols and abbreviations. Boring backfilled with bentonite grout upon completion Elevations were provided by others. WATER LEVEL OBSERVATIONS Boring Completed: 02-16-2023 Boring Started: 02-15-2023 No free water encountered Drill Rig: Mobil B-57 Driller: J. Swope 30 Corporate Cir Ste 201 Project No.: JB215256J Albany, NY

4/21/23

JB215256J PHASE 4 BORINGS.GPJ TERRACON\_DATATEMPLATE.GDT

GEO SMART LOG-NO WELL

REPORT.

THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL

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## **PROJECT:** Phase 4 Borings

SIT	E: Champlain to Hudson HDD Crossings
LOG	LOCATION See Exploration Plan
₽	Latitude: 42.2497° Longitude: -73.8558°

UCCATION See Exploration Plan Latitude: 42.2497° Longitude: -73.8558°		DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	ATTERBERG LIMITS	PERCENT FINES
DEPTH	Surface Elev.: 120.73 (Ft.) ELEVATION (Ft.)	DEPI	WATEI OBSER	SAMPI	RECOV	FIELD	CONT	LL-PL-PI	PERCE
SHALE, occasional calcite veins, i unweathered, very close to wide fr	nter bedded with greywacke,	-	-			REC=95% RQD=78%			
30.0 SHALE, occasional calcite veins, u	90.7 Inweathered, close to wide	- - 30-	-				_		
fractured, excellent RQD, gray		-	-			REC=100% RQD=90%			
35.0 GREYWACKE, occasional calcite v unweathered, very close to wide fr angled fractures, excellent RQD, g 40.0 SHALE, occasional calcite veins, i unweathered, close to moderate fr	actured with occasional high	- 35 -	-				_		
40.0	80.7	-	-			REC=100% RQD=96%			
SHALE, occasional calcite veins, i unweathered, close to moderate fr	nter bedded with greywacke, actured, good RQD, gray	40	-			REC=100% RQD=80%			
45.0 SHALE, occasional calcite veins, i unweathered, close to moderate fr	actured, fair RQD, gray	45-	-			REC=100% RQD=53%			
50.0 Stratification lines are approximate. In-situ, the	70.7 transition may be gradual.	50-	Ha	amme	er Type	e: Automatic			
Advancement Method: 0-15' 4" Casing 15-20' Mud Rotary 20' -75' NQ Core Barrel Abandonment Method: Boring backfilled with bentonite grout upon completic	See Exploration and Testing Procedure description of field and laboratory proce used and additional data (If any).           See Supporting Information for explana symbols and abbreviations.           n           Elevations were provided by others.		Hai Ene Hai	ergy 7 mmer	Transfe	ency Summary: er Ratio: 89.1% +/ ency Correction (C H/DO	-4.4% E): 1.49		
WATER LEVEL OBSERVATIONS No free water encountered	Terraco		Borir	ng Sta	arted:	02-15-2023	Boring Co	ompleted: 02-16	-2023
	ווכווטנע		Drill	Rig: I	Mobil E	B-57	Driller: J.	Swope	

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## SITE:

THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB215256J PHASE 4 BORINGS GPJ TERRACON\_DATATEMPLATE.GDT 4/21/23

PROJECT: Phase 4 Borings

SIT	E: Champlain to Hudson HDD Cr	ossings									
LOG	LOCATION See Exploration Plan			ť.)	VEL	ΥΡΕ	(In.)	sT	(%)	ATTERBERG LIMITS	INES
GRAPHIC LOG	Latitude: 42.2497° Longitude: -73.8558° DEPTH		ev.: 120.73 (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	LL-PL-PI	PERCENT FINES
	GREYWACKE, occasional calcite veins, inter unweathered, very close to close fractured w angled fractures, good RQD, gray	r bedded with shale,	<u>EVATION (Ft.)</u> 65.7					REC=100% RQD=78%			
	SHALE, occasional calcite veins, inter bedde unweathered, close to moderate fractured wi angled fractures, excellent RQD, gray 60.0	ed with greywacke, ith occasional high	60.7	-00  				REC=100% RQD=95%			
	<u>GREYWACKE</u> , occasional calcite veins, inte unweathered, wide fractured with occasional excellent RQD, gray 65.0	r bedded with shale, high angled fracture	2 <b>S</b> , 55.7	60				REC=100% RQD=100%			
	GREYWACKE, occasional calcite veins, unw close to wide fractured with occasional high a RQD, gray	eathered, extremely angled fractures, goo		65— - - -				REC=96% RQD=78%			
	SHALE, occasional calcite veins, unweathere moderate fractured with occasional high ang RQD, gray			70- - - 75-				REC=100% RQD=70%			
	Stratification lines are approximate. In-situ, the transition mate	ay be gradual.			l Ha	amme	er Type	: Automatic			L
00- 15-2 20' Aband	cement Method: 5' 4" Casing 20' Mud Rotary -75' NQ Core Barrel onment Method: ng backfilled with bentonite grout upon completion	See Exploration and Te description of field and used and additional dat See Supporting Informa symbols and abbreviati Elevations were provide	laboratory proce a (If any). ation for explana ons.	edures	Ha En Ha	ergy mme	Transfe	ency Summary: er Ratio: 89.1% +/- ency Correction (C 1/DO	4.4% E): 1.49		
	WATER LEVEL OBSERVATIONS No free water encountered	There	200		Bori	ng St	arted:	02-15-2023	Boring Co	ompleted: 02-16-	2023
			<b>DCO</b> e Cir Ste 201		Drill	Rig:	Mobil I	3-57	Driller: J.	Swope	
			ny, NY		Proj	ect N	o.: JB2	15256J			

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SITE:

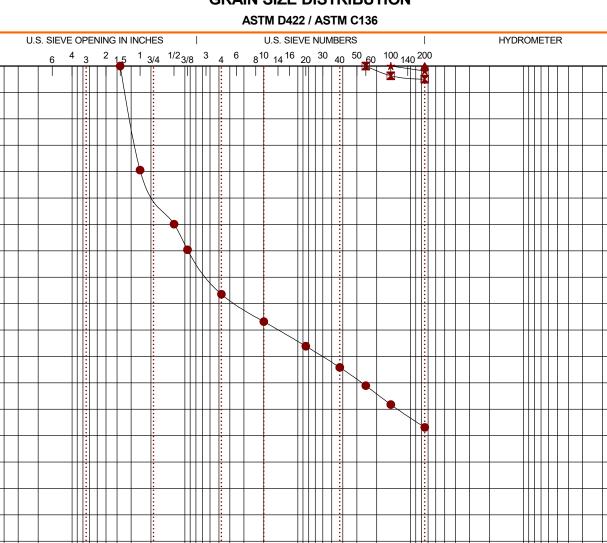
THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB215256J PHASE 4 BORINGS. GPJ TERRACON\_DATATEMPLATE. GDT 4/2/1/23

PROJECT: Phase 4 Borings

SI	LE: Champlain to Hudson HDD Cre	ossings									
LOG	LOCATION See Exploration Plan			ť.)	VEL	ΥΡΕ	(In.)	sT	(%)	ATTERBERG LIMITS	INES
<b>GRAPHIC LOG</b>	Latitude: 42.2497° Longitude: -73.8558°		/.: 120.73 (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	LL-PL-PI	PERCENT FINES
	DEPTH SHALE, occasional calcite veins, inter bedde unweathered, very close to close fractured w angled fractures, fair RQD, gray 80.0 Boring Terminated at 80 Feet	d with greywacke,	EVATION (Ft.) 40.7					REC=100% RQD=60%			
00- 15- 20' Abanc	Stratification lines are approximate. In-situ, the transition ma reement Method: 15 4" Casing 20' Mud Rotary -75' NQ Core Barrel tonment Method: ing backfilled with bentonite grout upon completion	See Exploration and Teg description of field and I used and additional data See Supporting Informa symbols and abbreviatio	aboratory proce a (If any). ion for explana ins.	edures	No Ha En Ha	tes: mme ergy mme	r Effici	ency Summary: er Ratio: 89.1% +/- ency Correction (C 1/DO	4.4% E): 1.49		
	WATER LEVEL OBSERVATIONS	Elevations were provide		_	Bori	ng St	arted:	02-15-2023	Boring Co	mpleted: 02-16-	2023
	No free water encountered	llerr	DCO	Π	$\vdash$	-	Mobil I		Driller: J.	-	
		30 Corporate Alban						215256J			

#### Sheet 1 of 1 Organic Content (%) BORING Water Liquid Plastic Plasticity Depth (Ft.) ID Index Content (%) Limit Limit KB-206.8 4-6 29.4 50 26 24 KB-206.8 15-17 32.9 40 23 17 KB-206.8 35-37 11.0 17 13 4 42 12 KB-207.0 4-6 23.7 30 KB-207.1 4-6 15.1 KB-209.7 30.3 2.8 4-6 64 32 32 KB-209.7 15-17 38.8 64 32 32 KB-209.7 25-27 38.8 54 25 29 4/14/23 KB-209.7 40-42 38.8 45 25 20 LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL REPORT. SMART LAB SUMMARY-PORTRAIT JB215256J PHASE 4 BORINGS GPJ TERRACON\_DATATEMPLATE.GDT KB-211.4B 4-6 58 32 26 32.8 KB-211.4B 15-17 48.0 55 31 24 KB-211.4B 40-42 36.7 63 32 31 KB-214.4 4-6 33.7 65 33 32 KB-214.4 57 15-17 37.6 29 28 KB-214.4 30-32 49.7 45 30 15 KB-219.4 6-8 11.8 KB-220.9 31.0 23 4-6 50 27 KB-220.9 20-22 39.6 47 26 21 KB-220.9 45-47 42 27 15 33.6 PROJECT: Phase 4 Borings PROJECT NUMBER: JB215256J 30 Corporate Cir Ste 201 Albany, NY CLIENT: Kiewit Engineering (NY) Corp SITE: Champlain to Hudson HDD Crossings Lone Tree, CO

#### **GRAIN SIZE DISTRIBUTION**



PERCENT FINER BY WEIGHT LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GRAIN SIZE: USCS-2 JB215256J PHASE 4 BORINGS GPJ TERRACON DATATEMPLATE.GDT 4/14/23 

1	0														
	0	100			10		1		0.1			0.01			0.001
				GRA		GRA	IN SIZE IN M		/IETERS	1					_
	COBB	LES	соа	arse	fine	coarse	medium		fine	-	S	SILT OR	CLAY		
Boi	ring ID	Dept	h (Ft)		U	SCS Cla	assification	1		WC (%)	LL	PL	PI	Сс	Cu
	KB-219.4		6 - 8		SILTY	GRAVEL	with SAND (	GM)		11.8					
	KB-220.9		4 - 6			FAT CI	_AY (CH)			31.0	50	27	23		
	KB-220.9	20	) - 22			LEAN C	CLAY (CL)			39.6	47	26	21		
*	KB-220.9	45	5 - 47			SIL	Г (ML)			33.6	42	27	15		
Boi	ring ID	Dept	h (Ft)	D <sub>100</sub>	D <sub>60</sub>	D	<sub>30</sub> D <sub>1</sub>	0	%Cobbles	%Grav	/el 🤋	%Sand	%Silt	%Fines	%Clay
	KB-219.4		6 - 8	37.5	6.191				0.0	43.2		25.2		31.6	
	KB-220.9		4 - 6	0.25					0.0	0.0		2.5		97.5	
	KB-220.9	20	) - 22	0.075					0.0	0.0		0.0		100.0	
*	KB-220.9	45	5 - 47	0.15					0.0	0.0		0.9		99.1	
		4.5									07.11				

PROJECT: Phase 4 Borings





PROJECT NUMBER: JB215256J



03:20

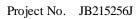
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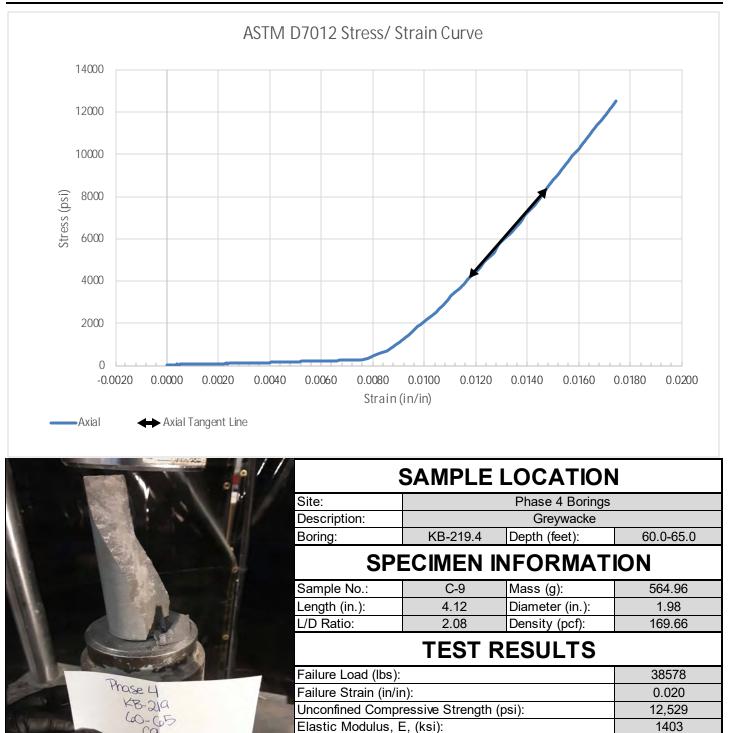
0.40%

Client

Kiewit Engineering

Project Phase 4 Borings





#

Time of Failure (min):

Rate of Loading (in/sec): Moisture Content Post-break:



Client		Project
Kiewit Engineering		Phase 4 Borings
		Project No. JB215256J
Equipment:	TICCS ID:	
Calipers	W-44049	
Scale	B-71466	
Dial Indicator	C-70608	
Compression (spherically seated)	C-48999	

Samples were prepared and tested in accordance with ASTM D4543 and D7012. Deviations, if any, are noted below: Notes:

Per ASTM D4543, this specimen has not met the requirements for flatness, by exceeding 0.001 inches. Per ASTM D4543, this specimen has not met the requirements for parallelism, by exceeding 0.25°. Per ASTM D4543, this specimen has not met the requirements for flatness, by exceeding 0.001 inches. Per ASTM D4543 and ASTM D7012, the desired specimen length to diameter are between 2.0:1 and 2.5:1. According to ASTM D7012 Section 8.2.1, this specimen, although not meeting all requirements of ASTM D4543 is acceptable for testing. However, the results reported may differ from results obtained from a test specimen that meets the requirements of D4543.



Client Kiewit Engineering Project

Phase 4 Borings

#### Project No. JB215256J

Boring	KI	3-219.4	Material I	Description	Greyw	/acke		
Sample No		C-9	Equipm	ent Used	Tinius Olsen (	120,000lbs)		
Depth (ft)	60	).0-65.0	TICCS ID	/Serial No.	C-48999,			
Lab No		2060	Calibra	11/2/2	2022			
			TEI	NSILE STREM	IGTH			
Lab No.		1	2	3	4	5		
Diameter (in)		1.98	1.98	1.98	1.98			
Length (in)		0.64	0.68	0.68	0.70			
Length Diameter Rat	io	0.32	0.34	0.34	0.35			
Rate of Loading		0.0064	0.0068	0.0068	0.0070			
Moisture Condition		0.43%	0.43%	0.43%	0.43%			
Maximum Applied Load	l (lbf)	4851	6229	4557	4142			
Splitting Tensile Streng	th (psi)	2438.3	2946.8	2155.8	1903.5			
		TENSILE STRENGTH						
Lab No.		6	7	8	9	10		
Diameter (in)								
Length (in)								
Length Diameter Rat	io							
Rate of Loading								
Moisture Condition								
Maximum Applied Load	l (lbf)							
Splitting Tensile Streng	th (psi)							



Client:	Terracon Consultants, Inc.				
Project:	Champlain-Hudson Power Express				
Location:				Project No:	GTX-316884
Boring ID: K	B-219.4	Sample Type:	cylinder	Tested By:	tlm
Sample ID:		Test Date:	03/09/23	Checked By:	smd
Depth :	60'-65'	Test Id:	707603		
Test Comm	ent:				
Visual Desc	cription:				
Sample Co	mment:				

## Abrasiveness of Rock Using the Cerchar Method by ASTM D7625

Boring ID	Sample ID	Depth	Stylus No	Reading 1	Reading 2	Average	Comments
KB-219.4		60-65 ft	1	0.2	0.2	0.20	
			2	0.3	0.4	0.35	
			3	0.3	0.4	0.35	
			4	0.2	0.2	0.20	
			5	0.3	0.4	0.35	
				Average CAIs	0.29		
				Average CAI *	0.77		
	1	ssification Low	abrasiveness				

Notes

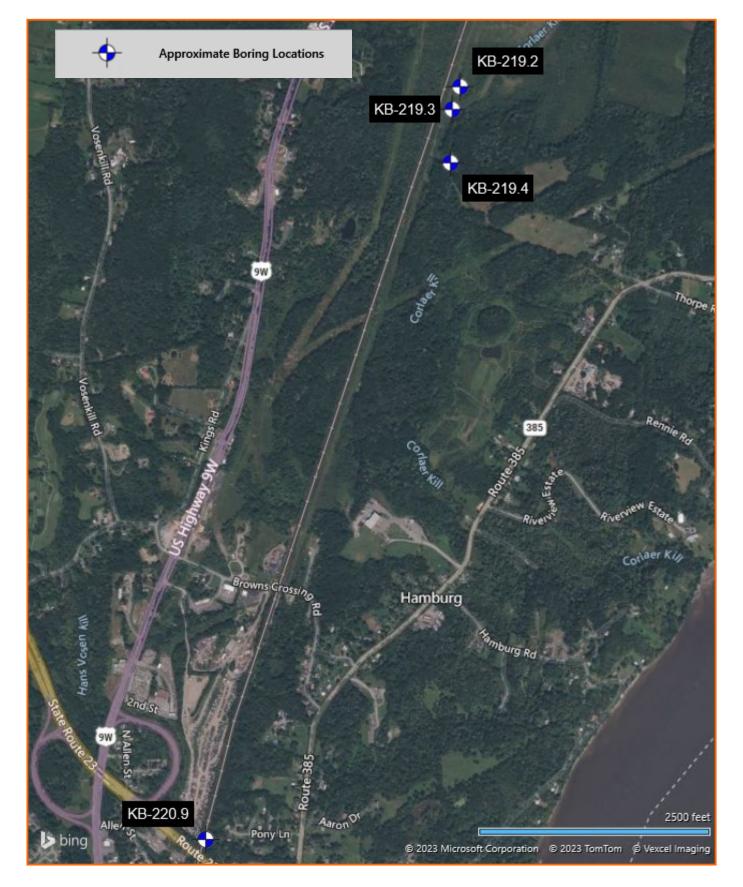
Test Surface: Saw Cut Moisture Condition: As Received Apparatus Type: Original CERCHAR Stylus Hardness: Rockwell Hardess 40/42 HRC Stylus Displacement Relative to Rock Fabric: Styli 1-3: Normal; Styli 4-5: Parallel \* CAI = (0.99 \* CAIs) + 0.48 CAIs = CERCHAR index for smooth (saw cut) surface CAI = CERCHAR index for natural surface Comments:



#### **EXPLORATION PLAN**

Champlain-Hudson Power Express- Phase 4 HDD Borings – Package 6 and 7 Schenectady through Selkirk, NY May 31, 2023 
Terracon Project No. JB215256J





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## PROJECT: Phase 4 Borings SITE: Champlain to Hudson HDD Crossings

0.		JSSINGS									
GRAPHIC LOG	LOCATION See Exploration Plan Latitude: 42.2519° Longitude: -73.8554°			DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	ATTERBERG LIMITS	PERCENT FINES
	DEPTH		: 116.683 (Ft.) EVATION (Ft.)		WATEF OBSER	SAMPL	RECOV	FIELD	CONTI	LL-PL-PI	PERCEI
	0.4 <u>TOPSOIL</u> LEAN CLAY (CL), varved silt and clay, brown stiff	, very soft to very	116.3	_		$\mathbb{N}$	12	1-1-2-3 N=3			
				_		$\left \right\rangle$	18	3-4-6-9 N=10			
				- 5		$\left \right\rangle$	10	4-4-9-10	27.5	42-23-19	96
				_		$\left \right\rangle$	04	N=13 11-12-13-14			
				_		$\square$	24	N=25	_		
				- 10-		X	24	11-9-8-8 N=17			
				-		X	24	WH/18"-4			
				_							
				_ 15—							
							24	WH/12"-3-4 N=3			
				_	-						
	20.0		96.7	_	-						
	ELASTIC SILT (MH), varved silt and clay, gra	y, very soft		20— _			24	WH/24"	40.8	50-35-15	99
				_							
				_							
	Stratification lines are approximate. In-situ, the transition ma	y be gradual.		25-	 Hi	amme	er Type	: Automatic			
	icement Method:	See Exploration and Tes description of field and la	sting Procedure	s for a	No	tes:					
10'-	0 4" Casing 57' Mud Rotary Ionment Method:	description of field and la used and additional data See Supporting Informat symbols and abbreviatio	i (If any). ion for explana		LO	gged	by DO	ency Summary: er Ratio: 84.7% +/-{ ency Correction (Cl L	5.0% E): 1.41		
	ing backfilled with bentonite grout upon completion	Elevations were provide			WI	H = V	/eight o	of hammer			
	WATER LEVEL OBSERVATIONS No free water encountered		racon		Boring Started: 04-20-2023				Boring Completed: 04-21-2023		
		30 Corporate	Cir Ste 201						Driller: S.	Morey	
		Alban			Proj	ect N	o.: JB2	15256J			

Page 2 of 3

## PROJECT: Phase 4 Borings SITE: Champlain to Hudson HDD Crossings

THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB215256J PHASE 4 BORINGS GPJ TERRACON\_DATATEMPLATE.GDT 5/31/23

31	E. Champiain to Hudson HDD Cro										
C LOG	LOCATION See Exploration Plan			(Ft.)	EVEL	түре	Y (In.)	EST TS	Т (%)	ATTERBERG LIMITS	FINES
GRAPHIC LOG	Latitude: 42.2519° Longitude: -73.8554°	Surface Elev.: 116.6	683 (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	LL-PL-PI	PERCENT FINES
ПТ	DEPTH ELASTIC SILT (MH), varved silt and clay, gray	ELEVATION /, very soft	ON (Ft.)		>0	s \	2				₫
	(continued)	•		_		X	24	WH/24"			
				_					1		
				_							
				30—		$\setminus$			-		
				_		X	24	WR/24"			
				_							
				_							
				35—		$\bigvee$	24	WR/24" 3" Split spoon			
				_		Δ	24	with ring sampler	_		
				_							
	40.0		76.7	- 40-							
	LEAN CLAY (CL), varved silt and clay, gray, v	rery soft to soft		40		M	24	WR/24"	43.4	41-24-17	94
				_		/ \					
				_							
				45—					-		
				_		X	14	WR/12"-4-4 N=4			
				_		/					
				_							
	Stratification lines are approximate. In situ, the transition ma			50-			r Type	· Automotio			
	Stratification lines are approximate. In-situ, the transition ma						. туре	: Automatic			
0-1	cement Method: ) 4" Casing 57' Mud Rotary	See Exploration and Testing Pr description of field and laborate used and additional data (If any	rocedures ory proce y).	for a dures	На	tes: mmei erav 7	· Efficie Fransfe	ency Summary: er Ratio: 84.7% +/-{	i.0%		
	onment Method: ng backfilled with bentonite grout upon completion	See Supporting Information for symbols and abbreviations. Elevations were provided by ot		ion of	Ha Log Wł	mmer gged H = W	<sup>-</sup> Efficie by DO	ency Correction (Cl L of hammer	E): 1.41		
	WATER LEVEL OBSERVATIONS				-				Boring Co	ompleted: 04-21-	2023
	No free water encountered	llerra		Π	Drill Rig: Diedrich D-50 Driller: S. Morey				-		
		30 Corporate Cir St Albany, NY	te 201		Proj	ect No	o.: JB2	15256J			

BORING	LOG NO	. KB-219.2
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CLIENT: Kiewit Engineering (NY) Corp

Page 3 of 3

PROJECT: Phase 4 Borings

PLATE.GDT 5/31/23	A: 7.0
PHASE 4 BORINGS.GPJ TERRACON_DATATEMPLATE.GDT	
B215256J PHASE 4 BORINGS.	
RT. GEO SMART LOG-NO WELL JB	
ED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB215256J PH	
VALID IF SEPARA	A
<b>TON SI DOT S</b>	A
THIS BORING	

			Lone Tree, CO								
SI	TE: Champlain to Hudson HDD Cro	ossings									
GRAPHIC LOG	LOCATION See Exploration Plan Latitude: 42.2519° Longitude: -73.8554°	Surface Elev.	: 116.683 (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
U	DEPTH LEAN CLAY (CL), varved silt and clay, gray, v	ELE	EVATION (Ft.)		≥®	s/	RE	-	0		H H
	(continued)			-		X	8	WH/12"-4-4 N=4	_		
	55.0		61.7	- 55					_		
	SANDY SILT WITH GRAVEL (SM), gray, hard	I, (GLACIAL TILL)	50.0	_		X	10	12-23-15-50/3 N=38	"		
<u>/0X/a</u>	Boring Terminated at 56.75 Feet		59.9								
	Stratification lines are approximate. In-situ, the transition ma	av be gradual.				amme	er Type	: Automatic			
<u>.</u>		 -									
0-1 10'- Abanc	icement Method: 0 4" Casing 57' Mud Rotary Ionment Method: ing backfilled with bentonite grout upon completion	See Exploration and Tes description of field and la used and additional data See Supporting Informat symbols and abbreviatio Elevations were provided	aboratory proce (If any). ion for explana ns.	edures	Ha En Ha Loo Wi	ergy <sup>·</sup> mme gged I = W	Transf r Effici by DC	of hammer	5.0% E): 1.41		
	WATER LEVEL OBSERVATIONS           No free water encountered	Torr	900			-			-	ompleted: 04-21-	2023
		30 Corporate Alban	Cir Ste 201			-		215256J	Driller: S.	Morey	
		Alball	y, iN I		I I I I	20114	J JU2	102000			

Lone Tree, CO

WATER LEVEL OBSERVATIONS

DEPTH (Ft.)

SAMPLE TYPE

RECOVERY (In.

12

FIELD TEST RESULTS

1-2-2-2

Page 1 of 3

ATTERBERG LIMITS

LL-PL-PI

WATER CONTENT (%)

PERCENT FINES

## **PROJECT:** Phase 4 Borings **CLIENT: Kiewit Engineering (NY) Corp** SITE: Champlain to Hudson HDD Crossings LOCATION See Exploration Plan **GRAPHIC LOG** Latitude: 42.2512° Longitude: -73.8557° Surface Elev .: 115.191 (Ft.) ELEVATION (Ft.) DEPTH 114.8 FAT CLAY (CH), varved silt and clay, brown, soft to very stiff THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB2152501 PHASE 4 BORINGS. GPJ TERRACON\_DATATEMPLATE. GDT 5/31/23

N=4 2-4-7-8 14 N=11 6-8-10-11 5 16 29.3 55-29-26 98 N=18 11-11-12-11 20 N=23 11-10-10-12 22 N=20 10-3-4-6-4 24 N=10 15 2-3-4-4 39.5 51-26-25 96 24 N=7 95.2 20.0 20 LEAN CLAY (CL), varved silt and clay, gray, very soft 24 WH/24" 25 Stratification lines are approximate. In-situ, the transition may be gradual. Hammer Type: Automatic Advancement Method: Notes: See Exploration and Testing Procedures for a 0-10 4" Casing description of field and laboratory procedures Hammer Efficiency Summary: Energy Transfer Ratio: 84.7% +/-5.0% Hammer Efficiency Correction (CE): 1.41 10'-52' 3" Casing used and additional data (If any) Supporting Information for explanation of Logged by DOL Abandonment Method: symbols and abbreviations. WH = Weight of hammer Boring backfilled with bentonite grout upon completion Elevations were provided by others. WATER LEVEL OBSERVATIONS Boring Started: 04-19-2023 Boring Completed: 04-20-2023 Drill Rig: Diedrich D-50 Driller: S. Morey 30 Corporate Cir Ste 201 Project No.: JB215256J Albany, NY

Page 2 of 3

# PROJECT: Phase 4 Borings SITE: Champlain to Hudson HDD Crossings g LOCATION See Exploration Plan

THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB215256J PHASE 4 BORINGS GPJ TERRACON\_DATATEMPLATE.GDT 5/31/23

511	E: Champiain to Hudson HDD Cr	bssings									
GRAPHIC LOG	LOCATION See Exploration Plan Latitude: 42.2512° Longitude: -73.8557° DEPTH	Surface Elev.: 115.19 ELEVATIO	• •	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	ATTERBERG LIMITS	PERCENT FINES
	<b>LEAN CLAY (CL)</b> , varved silt and clay, gray,	very soft (continued)		_		X	24	WH/24"			
				- 30- - -	s 2	X	24	WH/24" 3" Split spoor with ring samplers	1		
	35.0 LEAN CLAY WITH SAND (CL), varved silt an soft to stiff	d clay, gray, very	80.2	_ 35— _	,	X	24	WH/24"	23.5	27-18-9	73
	gravel noted in tip of sampler		73.2	_ _ 40— _	ŝ	X	1	6-6-6-3 N=12			
	SANDY SILT (ML), gray, stiff to hard, (GLAC	AL TILL)		- - 45- -			18	15-7-3-50 N=10	15.6		65
				_ _ 50—	į			N-10			
	Stratification lines are approximate. In-situ, the transition ma	y be gradual.			Ha	imme	r Type	: Automatic			
0-10 10' Aband	cement Method: 9 4" Casing 52' 3" Casing onment Method: ng backfilled with bentonite grout upon completion	See Exploration and Testing Prodescription of field and laboratory used and additional data (If any). See Supporting Information for esymbols and abbreviations. Elevations were provided by other	xplanatio		Log	mmer ergy T mmer iged	by DOl	ency Summary: er Ratio: 84.7% +/- ency Correction (C L of hammer	5.0% E): 1.41		
	WATER LEVEL OBSERVATIONS				Borir	ng Sta	arted: (	04-19-2023	Boring Co	mpleted: 04-20-	2023
					Drill Rig: Diedrich D-50 Drille				Driller: S.	er: S. Morey	
	30 Corporate Cir Ste 201 Albany, NY				Proje	ect No	o.: JB2	15256J			

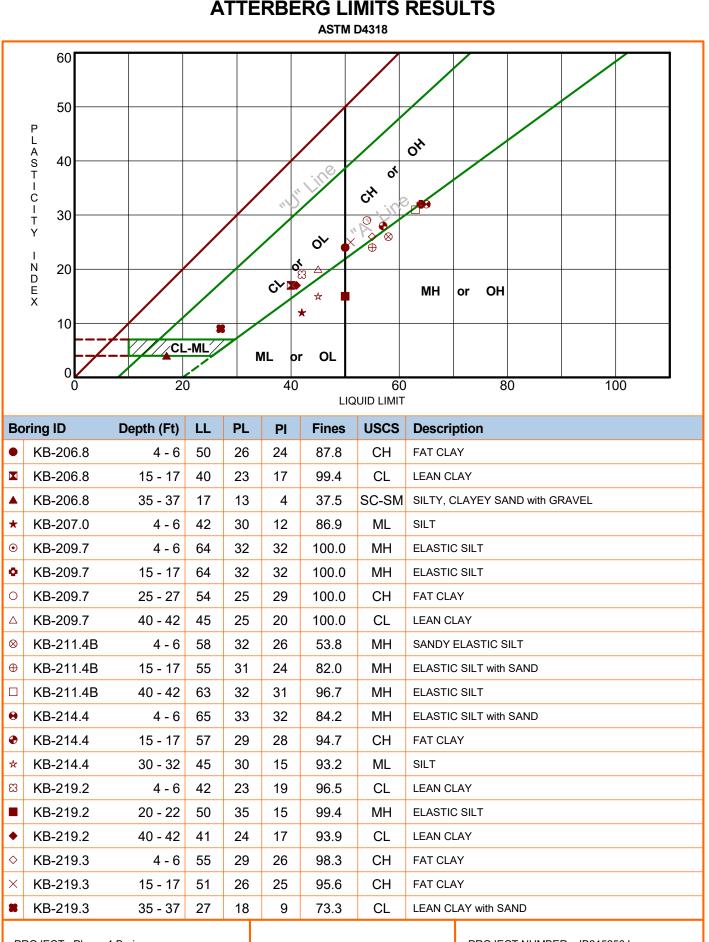
BORING	LOG NO.	KB-219.3
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Page 3 of 3

	PR	OJECT: Phase 4 Borings	CLIENT:	Kiew Lone							
	SIT	E: Champlain to Hudson HDD Crossings	_	_0		, ,					
	GRAPHIC LOG	LOCATION See Exploration Plan Latitude: 42.2512° Longitude: -73.8557° Surface DEPTH SANDY SILT (ML), gray, stiff to hard, (GLACIAL TILL) (continu	Elev.: 115.191 (Ft.) ELEVATION (Ft.) ed)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	RECOVERY (In.)	FIELD TEST RESULTS	WATER CONTENT (%)	ATTERBERG LIMITS	PERCENT FINES
		52.0	63.2	_	1	X	10	16-15-17-18 N=32			
THIS BORING LOG IS NOT VALID IF SEPARATED FROM ORIGINAL REPORT. GEO SMART LOG-NO WELL JB215256J PHASE 4 BORINGS. GPJ TERRACON_DATATEMPLATE. GDT 5/31/23		Boring Terminated at 52 Feet									
PARATE		Stratification lines are approximate. In-situ, the transition may be gradual.			H	amm	er Typ	e: Automatic			
<b>DG IS NOT VALID IF SEI</b>	0-10 10'-3 Aband	cement Method:     See Exploration and description of field a used and additional used and additional service of the service of th	nd laboratory proc data (If any). mation for explana iations.	edures	Ha En Ha Lo	iergy amme gged	Transf er Effici by DC	iency Summary: fer Ratio: 84.7% +/. iency Correction (C DL of hammer			
RING LC		WATER LEVEL OBSERVATIONS	raco			-		04-19-2023	Boring Co	ompleted: 04-20-	-2023
IIS BOF		30 Corp	orate Cir Ste 201			-		ch D-50	Driller: S	. Morey	
Ŧ			bany, NY		Proj	ect N	lo.: JB	215256J			

## Summary of Laboratory Results

BORING ID	Depth (Ft.)	Water Content (%)	Liquid Limit	Plastic Limit	Sheet 1 of 1 Plasticity Index			
KB-206.8	4-6	29.4	50	26	24			
KB-206.8	15-17	32.9	40	23	17			
KB-206.8	35-37	11.0	17	13	4			
KB-207.0	4-6	23.7	42	30	12			
KB-207.1	4-6	15.1						
KB-211.4B	4-6	32.8	58	32	26			
KB-211.4B	15-17	48.0	55	31	24			
KB-211.4B	40-42	36.7	63	32	31			
KB-214.4	4-6	33.7	65	33	32			
KB-214.4	15-17	37.6	57	29	28			
KB-214.4	30-32	49.7	45	30	15			
KB-219.2	4-6	27.5	42	23	19			
KB-219.2	20-22	40.8	50	35	15			
KB-219.2	40-42	43.4	41	24	17			
KB-219.3	4-6	29.3	55	29	26			
KB-219.3	15-17	39.5	51	26	25			
KB-219.3	35-37	23.5	27	18	9			
KB-219.3	45-47	15.6						
KB-220.9	4-6	31.0	50	27	23			
KB-220.9	20-22	39.6	47	26	21			
KB-220.9	45-47	33.6	42	27	15			
KB-211.4b         KB-214.4         KB-214.4         KB-219.2         KB-219.2         KB-219.3         KB-220.9         KB-220.9         KB-220.9         KB-220.9         SITE: Champ								
PROJECT: Phase 4 Borings SITE: Champlain to Hudson HDD Crossings			<b>Tigercacor</b> 30 Corporate Cir Ste 201 Albany, NY	CLIENT: Kiewit En	PROJECT NUMBER: JB215256J CLIENT: Kiewit Engineering (NY) Corp Lone Tree, CO			



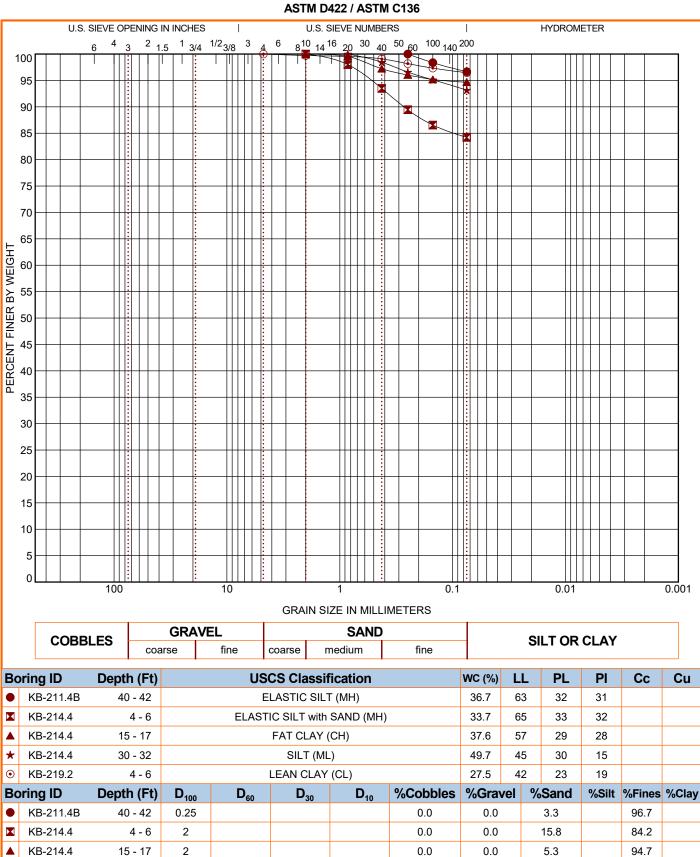
ATTERBERG LIMITS JB215256J PHASE 4 BORINGS.GPJ TERRACON\_DATATEMPLATE.GDT 5/31/23

LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL REPORT.

SITE: Champlain to Hudson HDD Crossings

Corporate Cir Ste 201 Albany, NY PROJECT NUMBER: JB215256J

#### **GRAIN SIZE DISTRIBUTION**



PROJECT: Phase 4 Borings

SITE: Champlain to Hudson HDD Crossings

30 - 32

4 - 6

0.85

4.75



0.0

0.0

0.0

0.0

PROJECT NUMBER: JB215256J

6.8

3.5

93.2

96.5

CLIENT: Kiewit Engineering (NY) Corp Lone Tree, CO

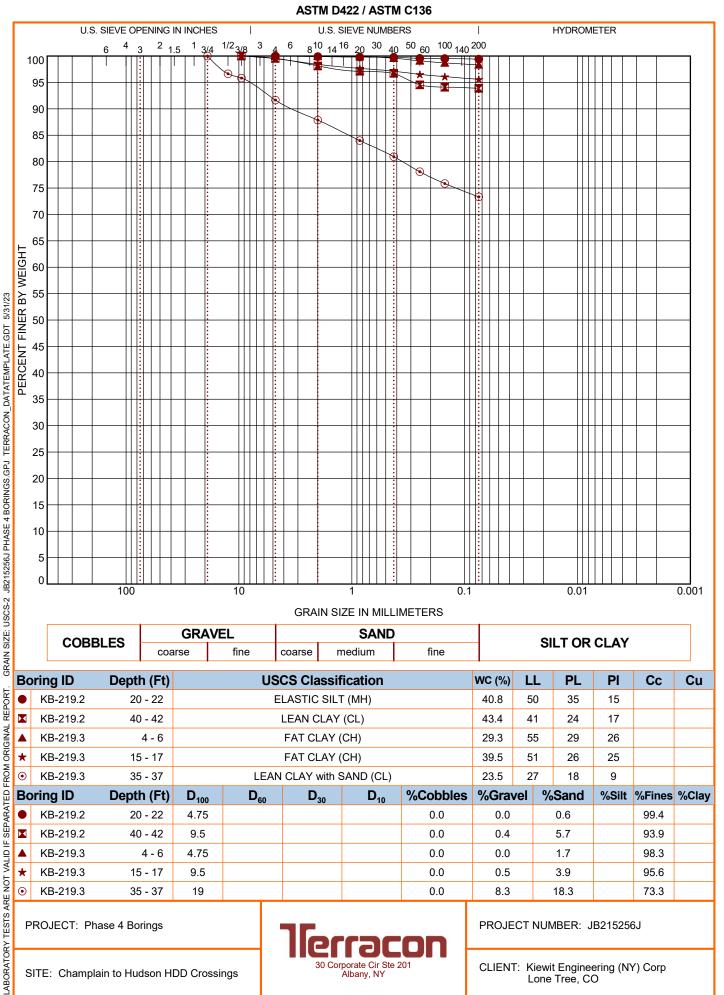
GRAIN SIZE: USCS-2 JB215266J PHASE 4 BORINGS.GPJ TERRACON\_DATATEMPLATE.GDT 5/31/23 REPORT. LABORATORY TESTS ARE NOT VALID IF SEPARATED FROM ORIGINAL

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KB-214.4

• KB-219.2

#### GRAIN SIZE DISTRIBUTION



30 Corporate Cir Ste 201

Albany, NY

SITE: Champlain to Hudson HDD Crossings

Appendix C

Calculation Package



Champlain Hudson Power Express - Package 6 Crossing #91\_C2 - Route 9 Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

	NW Date: 4/13/23
fining Parameters of Horizontal Direct	
$D_1 \coloneqq 10.75$ in	Pipe 1 outer diameter
$D_1 := 10.10$ m $D_2 := 2.375$ in	Pipe 2 outer diameter
$D_{rod} \coloneqq 3.5 \ in$	Assumed drill rod diameter
$DR_1 \coloneqq 9$	Dimension ratio of Pipe 1
$DR_1 = 0$ $DR_2 = 11$	Dimension ratio of Pipe 2
-	
$T_{n1} := \frac{D_1}{D_2} = 1.194 \ in$	Thickness of Pipe 1
$DR_1$	
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 2
	Dina circumforance of ning 1
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
N	
drill rig B D	A a
	Juninsenning finningin
H,	
pipe exit C	В
· · ·	*4
$\mathbf{L}_4$ : $\mathbf{L}_3$	C L <sub>2</sub> L <sub>1</sub>
Lpos	•
Lbor	
Illustration 1 - Schematic of	
Illustration 1 - Schematic of	Drive Cross-section
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396$ rad	Drive Cross-section Borehole entry angle (degrees, radians)
Illustration 1 - Schematic of $\alpha := 8 \circ \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 40.0 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor
Illustration 1 - Schematic of $\alpha := 8 \circ \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 40.0 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396$ rad $\beta := 8$ ° $\beta_{exit} := \beta = 0.1396$ rad $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8$ ° $\beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 40.0 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from
Illustration 1 - Schematic of $\alpha := 8 \circ \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 40.0 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \text{ ft}$ $L_{total} := 551.2 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\ \beta_{exit} := \beta = 0.1396 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 40.0 \ ft \\ H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft \\ L_{total} := 551.2 \ ft \\ L_1 := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing
Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\ \beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 40.0 \ ft \\ H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft \\ L_{total} := 551.2 \ ft$	Drive Cross-section         Borehole entry angle (degrees, radians)         Borehole exit angle (degrees, radians)         Final reamed bore diameter         Max depth of bore hole to final reamed bor         diameter         Max depth to bore hole springline from         ground surface         Total length of HDD crossing         Assumed pipe drag on surface, See         Illustration 1         Horizontal length to achieve depth -
Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad \\D_r := 18 \cdot in \\H_{max} := 40.0 \ ft \\H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft \\L_{total} := 551.2 \ ft \\L_1 := 150 \ ft \\L_2 := 203.7 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\ \beta_{exit} := \beta = 0.1396 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 40.0 \ ft \\ H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft \\ L_{total} := 551.2 \ ft \\ L_1 := 150 \ ft$	Drive Cross-sectionBorehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameterMax depth of bore hole to final reamed bor diameterMax depth to bore hole springline from ground surfaceTotal 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 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 40.0 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft$ $L_{total} := 551.2 \ ft$ $L_2 := 203.7 \ ft$ $L_3 := 149.1 \ ft$ $L_4 := 198.4 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1
Illustration 1 - Schematic of $\alpha := 8 \circ$ $\beta := 8 \circ$ $\beta_{exit} := \alpha = 0.1396 \ rad$ $\beta_{exit} := \beta = 0.1396 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 40.0 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft$ $L_{total} := 551.2 \ ft$ $L_1 := 150 \ ft$ $L_2 := 203.7 \ ft$ $L_3 := 149.1 \ ft$	Drive Cross-section         Borehole entry angle (degrees, radians)         Borehole exit angle (degrees, radians)         Final reamed bore diameter         Max depth of bore hole to final reamed bor         diameter         Max depth to bore hole springline from         ground surface         Total length of HDD crossing         Assumed pipe drag on surface, See         Illustration 1         Horizontal length to achieve depth -         provided by Contractor, See Illustration 1         Straight horizontal section         Horizontal distance to rise to surface, See         Illustration 1         Elevation difference between the lowest
Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \ rad \\D_r := 18 \cdot in \\H_{max} := 40.0 \ ft \\H_{max} := 40.0 \ ft \\H_{max1} := H_{max} + \frac{D_r}{2} = 40.75 \ ft \\L_{total} := 551.2 \ ft \\L_1 := 150 \ ft \\L_2 := 203.7 \ ft \\L_3 := 149.1 \ ft \\L_4 := 198.4 \ ft \\H_{a} := 198.4 \ ft \\H_{a} := 100 \ f$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1

Project:

Tunnel No.:

Description: Calculated by: DA

	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #91_C2 - Route 9 Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)
$ \rho_w \coloneqq 62.4 \ pcf $		Unit weight of water
$\gamma_a := 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 90 \ pcf$		Assumed unit weight of slurry
$\gamma_b := \frac{\gamma_m}{\rho_w} = 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
- Axial Bending Stress:		
$R_{avg.\_in}$ :=1000 $ft$		Radius of curvature at the entry, provided by Contractor
$R_{avg.\_out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg\_in} + R_{avg\_out}}{2} = 1000 \ .$	ft	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left( R_{avg.\_in} > r_{rod}, \text{``oka} \right)$	y", "not okay"	)="okay"
$Check \coloneqq \mathbf{if} \left( R_{avg.\_out} > r_{rod}, \text{``ok''} \right)$		

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
$\frac{E_{12hr}}{57500 \cdot psi}$	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  $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{\Lambda}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ 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:  $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 589 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B:  $T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_a + v_b \cdot \left| w_b \right| \cdot L_2 + w_b \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 6192 \ \textit{lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C:  $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 8352 \ lbf$ B1.7 - Pullback Force at D:  $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 11711 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe:  $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 12508\ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force:  $w_{bfilled} := \left(\frac{\left(\pi \cdot D_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)^{2}\right) - w_{a} = 24.6 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_3 + L_4 \right) \right) = 589 \ \textit{lbf} \quad \text{Pullback force enter ground}$ 



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$\boldsymbol{T_{bfilled}}\!\coloneqq\!\boldsymbol{e}^{\boldsymbol{v_b}\boldsymbol{\cdot}\boldsymbol{\alpha_{in}}}\left(\!\boldsymbol{T_{afilled}}\!+\!\boldsymbol{v_b}\boldsymbol{\cdot}\left \boldsymbol{w_{bfilled}}\!\right \boldsymbol{\cdot}\boldsymbol{L_2}\!+\!$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 3392$
B2.4 - Pullback Force Point C:	Pullback force increase and decrease depth
$\boldsymbol{T_{cfilled}} \coloneqq \boldsymbol{T_{bfilled}} + \left(\boldsymbol{v_b} \boldsymbol{\cdot} \left  \boldsymbol{w_{bfilled}} \right  \boldsymbol{\cdot} \boldsymbol{L_3} \right) - \boldsymbol{e}^{\left(\boldsymbol{v_b} \boldsymbol{\cdot} \boldsymbol{\alpha_i} \right)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 4363 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{\left(v_b \cdot \beta_{exil}\right)} \cdot \left(T_{cfilled} + v_b \cdot \left w_{bfilled}\right  \cdot L_4$	$-e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 5904 \ lb$
<u>B2.6 - Maximum Pullback Force - Filled Pip</u>	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$	$l_{l} = 5904 \ lbf$ Maximum Pullback Force
3 - Safe Pull Strength / Ultimate Tensil	e Load Check:
B3.1 Safe Pullback Check	
$A_1 := \frac{\pi}{4} \left( D_1^2 - \left( D_1 - T_{p1} \right)^2 \right) = 19 \ \boldsymbol{in}^2$	Cross-sectional area of Pipe 1
$A_{2} \coloneqq \frac{\pi}{4} \left( D_{2}^{2} - \left( D_{2} - T_{p2} \right)^{2} \right) = 0.8 \ \boldsymbol{in}^{2}$	Cross-sectional area of Pipe 2
$P_{11} := \frac{A_1 \cdot P_{max\_empty}}{A_1 + A_2} = 12022 \ lbf$	Pullback forces acting on Pipe 1 (Em
$P_{21} \coloneqq \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} = 485 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Emp
$P_{12} := \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 5674 \ lbf$	Pullback forces acting on Pipe 1 (Ball
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 229 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Ball
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table % p. 448, PPI)
<i>P</i> <sub>SPF2</sub> ≔1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table % p. 448, PPI)
$check \coloneqq if(P_{SPF1} > P_{11}, "okay", "not okay")$	
$check \coloneqq if (P_{SPF2} > P_{21}, "okay", "not okay)$ $check \coloneqq if (P_{SPF1} > P_{12}, "okay", "not okay]$	



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### **C - Allowable Mud Pressures:**

C1 - Max. Allowable Driling Fluid Pressure

#### Assumptions:

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

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

$H_w \coloneqq 1$	0.3• <b>ft</b>		Depth of the bore below groundwater elevation
<i>H<sub>c</sub></i> ≔ 40	0.0 <b>ft</b>		Vertical separation distance between critica structure and pipe (Route 9)
$\gamma \coloneqq 125$	5 pcf		Assumed unit weight silty sand (B-198.9-1 and SC-1A, ~3+00)
$\gamma_w \coloneqq 62$	2.4 <b>pcf</b>		Unit weight of water
·	$-\gamma_w = 62.6 \ p$	ocf	Effective unit weight
	$\cdot H_w = 4 psi$		Initial pore water pressure
$\phi \coloneqq 34$			Assumed friction Angle (KIE)
$c \coloneqq 0 p$	osf=0 psi		Assumed cohesion of encountered material
$R_0 \coloneqq \frac{L}{2}$	$\frac{D_{rod}}{2} = 1.75$ in	n	Initial radius of the borehole
$R_{pmax}$ :	$=\frac{2}{3} \cdot H_c = 27$	7 ft	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
Ŷ	, ,	$(y_{s}) + \gamma' \cdot H_{w} = 30.3 \ p$	<i>ssi</i> Initial effective stress (conservative assume all buoyant)
	e of Soil	$E_s$ (N/mm <sup>2</sup> )	
Clay	y Yerv soft	2-15	
	oft	5-25	
	ledium	15-50	N
	lard andy	50-100 25-250	$E_{a} = 7 - 1015 \text{ psi}$
Glac	cial till		$E_s \coloneqq 7 \frac{N}{mm^2} \equiv 1015 \ psi$
	oose Jense	10-153 144-720	
1	fery dense	478–1,440	Assumed modulus of elasticity
Loes		14-57	(silty sand)
	ilty	7-21	
	oose	10-24	
	ense d and gravel	48-81	
	oose	48-148 96-192	
Shal		144-14,400	
Silt		2-20	

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Table C.4 Typical values of Poisson's ratio ( $\mu$ ) for soils		
Type of soil $\mu$		
	s on type of rock)	$\nu_s := 0.25$ Poissions ratio of material encountered
$G \coloneqq \frac{E_s}{2 (1 + \nu_s)} = 406 \ psi$		Shear modulus of soil
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + \left(c \cdot \cos(\phi)\right)}{G}$	)) =0.0417	Coefficient of Delft Equation
$p'_{f} \coloneqq \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos \phi$		Mud pressure at which the first plastic deformation takes place $\frac{-\sin(\phi)}{+\sin(\phi)} - c \cdot \cot(\phi) = 147.5 \text{ psi}$
$p'_{max} \coloneqq \left(p'_f + \left(c \cdot \cot\left(\phi\right)\right)\right) \cdot \left  \left  \right  \right $	$\left(\frac{R_0}{R_{pmax}}\right) + Q$	
		Maximum allowable effective mud pressur (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 151.9 \ psi$		Maximum allowable mud pressure
C2 -Min. Allowable Drilling F	luid Pressure	
$D_{PT} = 5 in$	<u>iaia rressare</u>	Pilot tube diameter
$D_{D_1} = 9.5 $ in		Initial borehole diameter for pilot tube
$h \coloneqq 18.04 \ ft$		Elevation difference between level of bore hole front and structure point of mud flow
$\gamma_m = 90 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 11.3 \ psi$		Minimum required mud pressure to
$Q_f \coloneqq 200 \ gpm$		overcome differntial head 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
$v \coloneqq rac{Q_f}{0.785 \left({D_0}^2 - {D_{PT}}^2 ight)} = 75.$	$.2 \frac{ft}{min}$	Computed mud flow velocity

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$egin{aligned} & L_{structure} &\coloneqq 300 \ ft \ p_2 &\coloneqq L_{structure} & \cdot \left( \left( rac{\mu_{pl} \cdot v}{(D_0 - D_{PT})}  ight)  ight) \ p_{min.} &\coloneqq p_1 + p_2 &\equiv 12.2 \ psi \end{aligned}$	$\left(\frac{\tau_o}{\left(D_0 - D_{PT}\right)}\right)$	Length to sturcture = 0.9  psi Minimum required mud pressure to create flow inside the borehole Minimum required mud pressure
$check := if (p_{max} > p_{min.}, "ok$	ay", "not okay")         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a         a	



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<b>D1- Ring Deflection (Short &amp; Long Term):</b> D1.1 - Overburden Pressure (Considering Defo	rmed Borehole with Arching Mohilized)
$H_c := H_{max} = 40 \ ft$	Depth of cover
$\phi = 34 \ deg$	Friction angle of soil
$B := D_r = 18 in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 125 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{R} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.079$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 1  psi \qquad P_E = 199  psf$	Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
$E_{short} = 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \ psi$	Variable in earth load deflection equation
$\Delta y_{ELD\_short} \! \coloneqq \! \frac{0.0125 \cdot P_E}{k_{short}} \! = \! 0.2\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboo
D1.3 Earth Load Deflection (Long Term)	
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710 Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 0.4\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)

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D2 - Buoyant Deflection		
D2.1 Buoyant Deflection (S	hort Term)	
$D_1 = 10.75 \ in$		Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in		Thickness of casing pipe
<i>P</i> -		Apparent modulus of elasticity for
$E_{short} \!=\! 57500   psi$		PE4710, Base Temperature of 73
		Fahrenheit (Table B.1.1)
$\gamma_m = 90 \ pcf$		Assumed unit weight of fluid in
$t^3$ $im^4$		borehole (Slurry unit weight)
$I \coloneqq \frac{l}{12} = 0.14 \frac{l}{ln}$	$\lambda^4$	Moment of inertia of pipe wall cross section
$0.1169 \cdot \gamma_m \cdot \left  \frac{L}{c} \right $	$\frac{21}{2}$	Pipe ring deflection to buoyant force
$\gamma_m = 90 \text{ pcf}$ $I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$ $\Delta y_{bouyant} := \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{L}{2}\right)}{E_{short} \cdot I}$	2) = 0.1%	ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection (L		
D3 - Reissner Effect Deflect D3.1 - Reissner Effect Defle		
$\mu_{short} \coloneqq 0.35$		Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$R = 1000 \; ft$		Radius of curvature
$\frac{3}{2}$	4	
$\frac{1}{2} \cdot (1 - \mu_{short}^2) (D_1 - t)$	)	
$z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)}{16 \cdot t^{2} \cdot R^{2}}$	—=0.0000033	Deflection due to longitudinal bending
	$\cdot z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissner Effect Defle	<u>ection (Long Term)</u>	
$\mu_{long} \coloneqq 0.45$		Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)
$R = 1000 \; ft$		Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{long}^{2}\right) \left(D_{1} - t\right)}{16 \cdot t^{2} \cdot R^{2}}$	4 ==================================	Deflection due to longitudinal bending
$\Delta y_{R\_long} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot$	$z^2 = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect, long term

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<u> D4 - Net Ring Deflectio</u>	<u>n</u>	
$\Delta y_{lim}$ := 7.5%		Deflection limit for DR 9 non pressurized pipe (Table 2, p. 437, PPI Handbook)
D4.1 - Net Short Term		
$\Delta y_{short\_net}$ := $\Delta y_{ELD\_short}$	$_{t}+\Delta y_{bouyant}+\Delta y_{R\_show}$	$t_t = 0.2\%$ Percent ring deflection in short term analysis
$Check \coloneqq  ext{if} \left(  extsf{ } y_{short\_net} <  ight)$	$<\!\Delta y_{lim},$ "okay", "not of	okay") = "okay"
D4.2 - Net Long Term		
$\Delta y_{long\_net}$ := $\Delta y_{ELD\_long}$	$+\Delta y_{R\_long} = 0.4\%$	Percent ring deflection in long term analysis (50 years)
$Check \coloneqq \mathbf{if} \left( \Delta y_{long\_net} < \right)$	$\Delta y_{lim},$ "okay", "not o	kay") = "okay"



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	. Levy's Equation (Short Term-During Pull)
	increase the pipe's buckling strength, therefore ion 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 <sub>short</sub> =57500 <b>рsi</b> % DELFECLIOИ	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	
fo 6	- Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
10	$f_{o\_short} \coloneqq 0.98$
	$\frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure
H=18 <b>ft</b>	Elevation difference between the lowest
	point in borehole and entry or exit pit Pressure of drilling slurry
$P_{mud} \coloneqq \gamma_m \cdot H = 11.25 \ psi$	
$P_{mud} \coloneqq \gamma_m \cdot H = 11.25 \ psi$ $P_{net} \coloneqq P_{mud} = 11.25 \ psi$	Net external loading with open borehole
$P_{net} \coloneqq P_{mud} = 11.25 \ psi$	
$P_{net} := P_{mud} = 11.25 \ psi$ $Check := if \left( P_{UC\_short} > P_{net}, \text{``okay''} \right)$ D5.2 - Unconstrained Ring Buckling, Note that constraining the pipe will	, "not okay") = "okay"
$P_{net} := P_{mud} = 11.25 \ psi$ $Check := if \left( P_{UC\_short} > P_{net}, \text{``okay''} \right)$ D5.2 - Unconstrained Ring Buckling, Note that constraining the pipe will	,"not okay") = "okay" . Levy's Equation (Long Term) increase the pipe's buckling strength, therefore

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$E_{long} = 28200$ psi		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o\_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$P_{UC\_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^{2}}\right) \cdot \left(\frac{1 - \mu_{long}^{2}}{1 - \mu_{long}^{2}}\right) \cdot \left(1 - \mu_$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \frac{f_{o\_long}}{N} =$	31.1 <i>psi</i> Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 4.463 \ ps$	<i>i</i>	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check := if \left( P_{UC\_long} > P_{no} \right)$	, "okay", "not okay	$(\mathbf{v}^{n}) = \text{``okav''}$



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# **References**

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Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Calculated by: DA Date: 4/13/23 R1: 6/12/23 Checked by: NW Date: 4/17/23

fining Parameters of Horizontal Direct	
$D_1 \coloneqq 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$D_{rod} = 3.5 \ in$	Assumed drill rod diameter
$DR_1 \coloneqq 9$	Dimension ratio of Pipe 1
$DR_2 := 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} \!=\! 1.194 ~\textit{in} \\ T_{p2} \!\coloneqq\! \frac{D_2}{DR_2} \!=\! 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \pi \cdot D_2 = 7.5 \ in$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
drill rig B D	A a
pipe exit C	В
• • • • •	** ** *
$L_4$ : $L_3$	
	L <sub>2</sub> L <sub>1</sub>
• L <sub>bore</sub>	
• L <sub>bore</sub>	18 19
	18 19
Illustration 1 - Schematic of	Drive Cross-section
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \ rad$	Drive Cross-section Borehole entry angle (degrees, radians)
$L_{bore}$ Illustration 1 - Schematic of $\alpha := 8 ^{\circ} \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10 ^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$\mathbf{L}_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor
$\begin{aligned} & \qquad Illustration \ 1 - Schematic \ of \\ \alpha & = 8 \ ^{\circ} \qquad \alpha_{in} := \alpha = 0.1396 \ rad \\ \beta & = 10 \ ^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad \\ D_r & = 18 \cdot in \end{aligned}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$Illustration 1 - Schematic of$ $\alpha := 8 \circ \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10 \circ \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface
$L_{bore}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
$L_{bore}$ Illustration 1 - Schematic of $\alpha := 8 \circ \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10 \circ \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \text{ ft}$ $L_{total} := 1610.6 \text{ ft}$ $L_1 := 150 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$L_{bore}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \text{ ft}$ $L_{total} := 1610.6 \text{ ft}$	<sup>a</sup> Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
$\mathbf{L}_{bore}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \ ft$ $L_{total} := 1610.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 218.9 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_{bore}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \ ft$ $L_{total} := 1610.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 218.9 \ ft$ $L_3 := 1160 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section
$L_{bore}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \ ft$ $L_{total} := 1610.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 218.9 \ ft$ $L_3 := 1160 \ ft$ $L_4 := 231.7 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1
$L_{box}$ Illustration 1 - Schematic of $\alpha := 8 \circ \qquad \alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 23.2 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 23.95 \text{ ft}$ $L_{total} := 1610.6 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 218.9 \text{ ft}$ $L_3 := 1160 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See

Project: Tunnel No.:

Description:

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
$v_a \coloneqq 0.1$		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
$\gamma_m \coloneqq 67 \ pcf = 9 \ \frac{lbf}{gal}$		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
<u>A - Axial Bending Stress:</u>		
$R_{avg.\_in} \coloneqq 1000 \; ft$		Radius of curvature at the entry, provided by Contractor
$R_{avg\_out} \coloneqq 1000 \ \textbf{ft}$		Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg\_in} + R_{avg\_out}}{2} = 10$	00 <b>ft</b>	Average radius of curvature at entry
$r_{rod} \coloneqq 1200 \cdot D_{rod} = 350 \; ft$		ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left( R_{avg\_in} > r_{rod}, "\right)$	<mark>okay", "not okay"</mark>	)="okay"
$Check \coloneqq \mathbf{if} \left( R_{avg\_out} \! > \! r_{rod}  , \right.$		

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



Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road 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:  $w_{a} \coloneqq \frac{\pi}{4} \left( \left( D_{1}^{2} - \left( D_{1} - T_{p1} \right)^{2} \right) + \left( D_{2}^{2} - \left( D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ B1.2 - Upward Buoyant Force: Effective weight  $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{4}\right) \rho_w \cdot \gamma_b - w_a = 36 \ plf \qquad \text{Upward buoyant force of empty pipe}$ 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:  $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1480 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B:  $T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left( T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} + v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 5071 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C:  $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 16584 \ lbf$ B1.7 - Pullback Force at D:  $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 19905 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe:  $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 20701\ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force:  $w_{bfilled} \coloneqq \left( \frac{\left( \pi \cdot D_1^{\ 2} \right)}{4} \right) \cdot \rho_w \cdot \left( \gamma_b - \gamma_c \cdot \left( 1 - \left( \frac{2}{DR_1} \right) \right)^2 \right) - w_a = 10.2 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_3 + L_4 \right) \right) = 1480 \ \textit{lbf} \quad \text{Pullback force enter ground}$ 



Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

<u>B2.3 - Pullback Force Point B:</u>	
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_{afilled} + v_b \cdot \left  w_{bfilled} \right  \cdot L_2 + \right)$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 2675$ Pullback force increase and decrease
B2.4 - Pullback Force Point C:	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_3 \right) - e^{\left( v_b \cdot \alpha_i \right)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 5191 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot  w_{bfilled}  \cdot L_4\right)$	$-\boldsymbol{e}^{(v_a \cdot \alpha_{in})} \cdot \left( v_a \cdot w_a \cdot L_4 \cdot \boldsymbol{e}^{(v_a \cdot \alpha_{in})} \right) = 6005 \ \boldsymbol{l}$
<u>B2.6 - Maximum Pullback Force - Filled Pip</u>	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}, T_{$	$l = 6005 \ lbf$ Maximum Pullback Force
<u> - Safe Pull Strength / Ultimate Tensil</u>	e Load Check:
B3.1 Safe Pullback Check	
$A_1 := \frac{\pi}{4} \left( D_1^2 - \left( D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$	Cross-sectional area of Pipe 1
$A_{2} \coloneqq \frac{\pi}{4} \left( D_{2}^{2} - \left( D_{2} - T_{p2} \right)^{2} \right) = 0.8 \ in^{2}$	Cross-sectional area of Pipe 2
$P_{11} := \frac{A_1 \cdot P_{max\_empty}}{A_1 + A_2} = 19898 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (En
$P_{21} := \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} = 803 \ lbf$	Pullback forces acting on Pipe 2 (En
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 5772 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ba
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 233 \ lbf$	Pullback forces acting on Pipe 2 (Ba
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table % p. 448, PPI)
$P_{SPF2} \coloneqq 1683 \ \textit{lbf}$	Safe pullback forces Pipe 2 (Table % p. 448, PPI)
$check \coloneqq if(P_{SPF1} > P_{11}, "okay", "not okay$	
$check := \mathbf{if}(P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay''})$	
$check \coloneqq if (P_{SPF1} > P_{12}, "okay", "not okay check \coloneqq if (P_{SPF2} > P_{22}, "okay", "not okay $	



Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 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.

$H_w \coloneqq 19.7 \cdot ft$	Depth of the bore below groundwater elevation
<i>H<sub>c</sub></i> :=25.1 <i>ft</i>	Vertical separation distance between crit structure and pipe (Old Ravena Rd., ~8-
$\gamma \coloneqq 100 \ pcf$	Assumed unit weight soft to clay/silt (zero blow count clay)
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 37.6 \ pcf$	Effective unit weight
$u \coloneqq \gamma_w \cdot H_w = 9 \ psi$	Initial pore water pressure
$\phi \coloneqq 0 \ deg$	Assumed friction Angle
$c \coloneqq 450 \ psf = 3.13 \ psi$	
$R_0 := \frac{D_{rod}}{2} = 1.75$ in	Initial radius of the borehole
_ 1	
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 13 \; ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$R_{pmax} \coloneqq -\frac{13}{2} \cdot H_c = 13 \text{ ft}$ $\sigma'_0 \coloneqq \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) + \frac{1}{2} \right) = 0$	2/3 H in sands)
$\sigma'_0 \coloneqq ((\gamma \cdot (H_c - H_w)))$ + e C.2 Typical values of modulus of elas	2/3  H in sands - $\gamma' \cdot H_w = 9 \text{ psi}$ Initial effective stress
$\sigma'_0 \coloneqq ((\gamma \cdot (H_c - H_w))) +$ e C.2 Typical values of modulus of elas	$-\gamma' \cdot H_w = 9 \ psi$ Initial effective stress
$\sigma'_0 \coloneqq ((\gamma \cdot (H_c - H_w))) +$ e C.2 Typical values of modulus of elas $\frac{Type \text{ of Soil}}{Clay}$	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\underline{F_s(N/mm^2)}$
$\sigma'_0 \coloneqq ((\gamma \cdot (H_c - H_w))) +$ e C.2 Typical values of modulus of elas	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_r (\text{N/mm}^2)}{2-15}$
$\sigma'_0 \coloneqq ((\gamma \cdot (H_c - H_w))) +$ e C.2 Typical values of modulus of elas Type of Soil Clay Very soft	$2/3 \text{ H in sands}$ $-\gamma' \cdot H_w = 9 \text{ psi}$ Initial effective stress $\frac{E_r (\text{N/mm}^2)}{2-15}$
$\sigma'_{0} := ((\gamma \cdot (H_{c} - H_{w}))) + \frac{1}{2}$ e C.2 Typical values of modulus of elas $\frac{1}{2}$ Clay Very soft Soft	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_x (\text{N/mm}^2)}{2-15}$ $N$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elas $\frac{1}{2} \frac{1}{2} $	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_s(N/mn^2)}{2-15}$ $\frac{2-15}{5-25}$ $\frac{2-15}{5-50}$ $E_s:=2 \frac{N}{mm^2} = 290 \text{ psi}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass $\frac{1}{2} \left( \frac{1}{2} \right)$ Very soft Soft Medium Hard Sandy Glacial till	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_s(N/mn^2)}{2-15}$ $\frac{2-15}{5-50}$ $\frac{2-15}{5-50}$ $E_s:=2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass $\frac{1}{2} \left( \frac{1}{2} \right) \left( $	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{1}{2 - 15}$ $\frac{2 - 15}{5 - 25}$ $\frac{2 - 15}{15 - 50}$ $\frac{2 - 15}{5 - 25}$ $\frac{10 - 100}{25 - 250}$ $\frac{10 - 153}$ $E_{s} := 2 \frac{N}{mm^{2}} = 290 \text{ psi}$ Assumed modulus of elasticity
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elas $\boxed{\frac{\text{Type of Soil}}{\text{Clay}}}$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_s(N/mm^2)}{E_s(N/mm^2)}$ $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity $\frac{10-153}{144-720}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elas $\boxed{\frac{1}{2}} Clay$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_s(N/mm^2)}{E_s(N/mm^2)}$ $E_s:=2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity $\frac{10-153}{144-720}$ $478-1,440$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elas $\frac{Type \text{ of Soil}}{Clay}$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress $\frac{E_s(N/mm^2)}{E_s(N/mm^2)}$ $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity $\frac{10-153}{144-720}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elas $\frac{Type \text{ of Soil}}{Clay}$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand	$2/3 \text{ H in sands})$ $-\gamma' \cdot H_w) = 9 \text{ psi}$ Initial effective stress Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Initial effective stress $E_s := 2 \frac{N}{mm^2} = 290 \text{ psi}$ Assumed modulus of elasticity $Assumed \text{ modulus of elasticity}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass $\frac{Type \text{ of Soil}}{Clay}$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{10}{10} = 9 \text{ psi}$ $\frac{2}{15} = 2 \frac{N}{mm^2} = 290 \text{ psi}$ $\frac{10}{153} = 1200 \text{ psi}$ $\frac{10}{14} = 57$ $\frac{10}{7} = 2100 \text{ psi}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass $\frac{1}{2} \left( \frac{1}{2} \right)$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{10}{10^{-153}}$ $\frac{10-153}{144-720}$ $\frac{10-153}{144-57}$ $\frac{10-24}{7-21}$ $\frac{10-24}{7-21}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{10}{10} = 9 \text{ psi}$ $\frac{2}{15} = 2 \frac{N}{mm^2} = 290 \text{ psi}$ $\frac{10}{153} = 1200 \text{ psi}$ $\frac{10}{14} = 57$ $\frac{10}{7} = 2100 \text{ psi}$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{-\gamma' \cdot H_w) = 9 \text{ psi} \qquad \text{Initial effective stress}$ $\frac{1}{1000}$ $\frac{2-15}{5-25}$ $\frac{2-15}{5-25}$ $\frac{2-15}{5-25}$ $\frac{10-153}{144-720}$ $\frac{14-720}{478-1,440}$ $\frac{14-57}{7-21}$ $\frac{7-21}{10-24}$ $48-81$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{\sigma'_{0}}{2} \right)$ e C.2 Typical values of modulus of elas $\frac{Type \text{ of Soil}}{Clay}$ Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel Loose	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{1}{10} = 9 \text{ psi}$ $\frac{1}{10} = 153$ $\frac{1}{10} = $
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \frac{1}{2} \right)$ e C.2 Typical values of modulus of elass Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel	$\frac{2/3 \text{ H in sands}}{\text{Initial effective stress}}$ $\frac{-\gamma' \cdot H_w) = 9 \text{ psi} \qquad \text{Initial effective stress}$ $\frac{1}{1000}$ $\frac{2-15}{5-25}$ $\frac{2-15}{5-25}$ $\frac{2-15}{5-25}$ $\frac{10-153}{144-720}$ $\frac{14-720}{478-1,440}$ $\frac{14-57}{7-21}$ $\frac{7-21}{10-24}$ $48-81$

Table 4 Space states all double and $ \hline y_{ex} = 0.5$ $ \hline $	DERGROUND GINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
$\frac{1}{C_{py}} \frac{1}{C_{py}} 1$			
$\frac{1}{C_{0}:q_{1}=1}^{(n)} \frac{1}{C_{0}} + $			
$ \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c}$	Clay (saturated) 0.4 – 0.5		
$\frac{1}{C_{consc}} = \frac{1}{C_{consc}} = \frac{1}{C_{co$	Sandy clay 0.2 - 0.3		
$\frac{1}{1} = \frac{1}{2} \frac{1}{1} \frac{1}{2} $			$\nu_s \coloneqq 0.5$
$E_{contentionP_{c$	Rock 0.1-0.4 (depends	on type of rock)	
$Q_{i} = \frac{(\sigma'_{0} \cdot \sin(\phi)) + (c \cdot 0)}{G} = 0$ $p'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi}$ Mud pressure at which the first plastic deformation takes place $p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi}$ $p'_{max2} := p'_{f} + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressure $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $p'_{max} = 67 \text{ pcf}$ $q_{m} = 67 \text{ pcf}$ $q_{m} := 12.5 \text{ psi}$ Pilot tube diameter $T_{0} := 16 \frac{lbf}{100 \cdot ft^{2}}$ Assumed yield point of mud per 100 square feet	Ice 0.36		Poissions ratio of material encountered
$Q_{i} = \frac{(\sigma'_{0} \cdot \sin(\phi)) + (c \cdot 0)}{G} = 0$ $p'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi}$ Mud pressure at which the first plastic deformation takes place $p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi}$ $p'_{max2} := p'_{f} + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressure $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $p'_{max} = 67 \text{ pcf}$ $q_{m} = 67 \text{ pcf}$ $q_{m} := 12.5 \text{ psi}$ Pilot tube diameter $T_{0} := 16 \frac{lbf}{100 \cdot ft^{2}}$ Assumed yield point of mud per 100 square feet			
$Q_{i} = \frac{(\sigma'_{0} \cdot \sin(\phi)) + (c \cdot 0)}{G} = 0$ $p'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi}$ Mud pressure at which the first plastic deformation takes place $p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi}$ $p'_{max2} := p'_{f} + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressure $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $p'_{max} = 67 \text{ pcf}$ $q_{m} = 67 \text{ pcf}$ $q_{m} := 12.5 \text{ psi}$ Pilot tube diameter $T_{0} := 16 \frac{lbf}{100 \cdot ft^{2}}$ Assumed yield point of mud per 100 square feet	$E_{c}$		
$Q := \frac{(\sigma'_{0} \cdot \sin(\phi)) + (c \cdot 0)}{G} = 0$ $P'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi}$ Mud pressure at which the first plastic deformation takes place $p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi}$ $p'_{max2} := p'_{f} + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressure $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $p'_{max} = 67 \text{ pcf}$ $q_{1} := \gamma_{m} \cdot h = 12.5 \text{ psi}$ Pilot tube diameter $q_{0} := 200 \text{ gpm}$ $q_{0} := 16 \frac{16f}{100 \cdot ft^{2}}$ Assumed yield point of mud per 100 square feet	$G \coloneqq \frac{s}{2 (1+\kappa)} = 97 psi$		Shear modulus of soil
$\begin{aligned} & \text{Coefficient of Delft Equation} \\ p'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi} \\ & \text{Mud pressure at which the first plastic deformation takes place} \\ & p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi} \\ p'_{max2} := p'_{f} + c = 15.1 \text{ psi} \\ & \text{Maximum allowable effective mud pressure} \\ p_{max} := u + p'_{max2} = 23.7 \text{ psi} \\ \hline \text{C2-Min. Allowable Drilling Fluid Pressure} \\ D_{PT} := 5 \text{ in} \\ D_{0} := 9.5 \text{ in} \\ h := 26.9 \text{ ft} \\ h := 26.9 \text{ ft} \\ h := 26.9 \text{ ft} \\ h := 12.5 \text{ psi} \\ \hline \text{Minimum required mud pressure to overcome difference between level of bore hole front and exit point of mud flow and pressure to overcome differential head \\ Q_{f} := 200 \text{ gpm} \\ \hline T_{0} := 16 \frac{lbf}{100 \cdot ft^{2}} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline Maximum allowable point of mud per stare to overcome difference performance of the point of mud performance of the point of mud performance of the point of mud performance overcome difference performance overcome differential performance overcome difference performance overcome differ$	$2\left(1+\nu_s\right)$		
$\begin{aligned} & \text{Coefficient of Delft Equation} \\ p'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi} \\ & \text{Mud pressure at which the first plastic deformation takes place} \\ & p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi} \\ p'_{max2} := p'_{f} + c = 15.1 \text{ psi} \\ & \text{Maximum allowable effective mud pressure} \\ p_{max} := u + p'_{max2} = 23.7 \text{ psi} \\ \hline \text{C2-Min. Allowable Drilling Fluid Pressure} \\ D_{PT} := 5 \text{ in} \\ D_{0} := 9.5 \text{ in} \\ h := 26.9 \text{ ft} \\ h := 26.9 \text{ ft} \\ h := 26.9 \text{ ft} \\ h := 12.5 \text{ psi} \\ \hline \text{Minimum required mud pressure to overcome difference between level of bore hole front and exit point of mud flow and pressure to overcome differential head \\ Q_{f} := 200 \text{ gpm} \\ \hline T_{0} := 16 \frac{lbf}{100 \cdot ft^{2}} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline \text{Maximum allowable point of mud per 100 square feet} \\ \hline Maximum allowable point of mud per stare to overcome difference performance of the point of mud performance of the point of mud performance of the point of mud performance overcome difference performance overcome differential performance overcome difference performance overcome differ$	$(\sigma'_0 \cdot \sin(\phi)) + (c \cdot 0)$		
$\begin{aligned} & \text{Coefficient of Delft Equation} \\ p'_{f} &= \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi} \\ & \text{Mud pressure at which the first plastic deformation takes place} \\ & \begin{pmatrix} (-\sin(\phi)) \\ (\frac{(R_{0})}{R_{pmax}})^{2} + Q \end{pmatrix}^{2} + Q \end{pmatrix} \\ p'_{max1} &:= (p'_{f} + (c \cdot 0)) \cdot \left( \begin{pmatrix} (\frac{R_{0}}{R_{pmax}})^{2} + Q \end{pmatrix}^{2} + Q \end{pmatrix}^{-c \cdot 0 = 12 \text{ psi}} \\ p'_{max2} &:= p'_{f} + c = 15.1 \text{ psi} \\ p_{max} &:= u + p'_{max2} = 23.7 \text{ psi} \\ \hline \\ \textbf{C2-Min. Allowable Drilling Fluid Pressure} \\ D_{PT} &:= 5 \text{ in} \\ D_{0} &:= 9.5 \text{ in} \\ h &:= 26.9 \text{ ft} \\ h &:= 26.9 \text{ ft} \\ h &:= 26.9 \text{ ft} \\ h &:= 12.5 \text{ psi} \\ \hline \\ \textbf{Maximum allowable or of mud flow rate} \\ \hline \\ \textbf{Maximum allowable or of mud pressure to overcome differntial head} \\ \textbf{Q}_{f} &:= 200 \text{ gpm} \\ \hline \\ \textbf{Assumed yield point of mud per 100 square feet \\ \hline \\ \end{bmatrix} \end{aligned}$	$Q \coloneqq \frac{\langle 0 \rangle \langle 0 \rangle \langle 0 \rangle \langle 0 \rangle}{G} \equiv 0$		
$p'_{f} := \sigma'_{0} \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi) = 12 \text{ psi}$ Mud pressure at which the first plastic deformation takes place $p'_{max1} := (p'_{f} + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_{0}}{R_{pmax}} \right)^{2} + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi}$ $p'_{max2} := p'_{f} + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressure $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $p_{max} := 4 + p'_{max2} = 23.7 \text{ psi}$ Pilot tube diameter $D_{0} := 9.5 \text{ in}$ $h := 26.9 \text{ ft}$ Pilot tube diameter $p_{0} := 9.5 \text{ in}$ $h := 26.9 \text{ ft}$ Pilot tube diameter $p_{0} := 9.5 \text{ psi}$ Pilot tube diameter $p_{0} := 9.5  p$	, , , , , , , , , , , , , , , , , , ,		Coefficient of Dolft Fountion
$\begin{aligned} & \text{Mud pressure at which the first plastic deformation takes place} \\ & p'_{max1} \coloneqq (p'_f + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_0}{R_{pmax}} \right)^2 + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right)^{-} - c \cdot 0 = 12 \text{ psi} \\ & p'_{max2} \coloneqq p'_f + c = 15.1 \text{ psi} \\ & p'_{max2} \coloneqq p'_f + c = 15.1 \text{ psi} \\ & \text{Maximum allowable effective mud pressure} \\ & p_{max} \coloneqq u + p'_{max2} = 23.7 \text{ psi} \\ & \text{Maximum allowable mud pressure} \\ & \text{D}_{PT} \coloneqq 5 \text{ in} \\ & \text{D}_{PT} \coloneqq 5 \text{ in} \\ & \text{D}_{er} = 9.5 \text{ in} \\ & \text{h} \coloneqq 26.9 \text{ ft} \\ & \text{h} \coloneqq 26.9 \text{ ft} \\ & \text{h} \coloneqq 21.5 \text{ psi} \\ & \text{Q}_f \coloneqq 200 \text{ gpn} \\ & q_m \coloneqq 16 \frac{\text{lbf}}{100 \cdot ft^2} \\ & \text{Assumed yield point of mud per 100 square feet} \end{aligned}$		(4) 10	Coefficient of Delit Equation
$\begin{aligned} & \text{deformation takes place} \\ & p'_{max1} \coloneqq (p'_f + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_0}{R_{pmax}} \right)^2 + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12  psi \\ & p'_{max2} \coloneqq p'_f + c = 15.1  psi \\ & \text{Maximum allowable effective mud pressure} \\ & p_{max} \coloneqq u + p'_{max2} = 23.7  psi \\ & \text{Maximum allowable mud pressure} \\ & \text{D}_{PT} \coloneqq 5  in \\ & \text{D}_{D_1} \coloneqq 9.5  in \\ & \text{h} \coloneqq 26.9  ft \\ & \text{h} = 12.5  psi \\ & \text{Q}_f \coloneqq 200  gpm \\ & \text{Q}_f \coloneqq 200  gpm \\ & \text{T}_o \coloneqq 16 \frac{lbf}{100 \cdot ft^2} \\ & \text{Assumed yield point of mud per 100 } square feet \\ \end{aligned}$	$p_f \coloneqq \sigma_0 \cdot (1 + \sin(\phi)) + c \cdot \cos(\phi)$	$(\phi) = 12 psi$	Mud process at which the first plastic
$p'_{max1} \coloneqq (p'_f + (c \cdot 0)) \cdot \left( \left( \left( \frac{R_0}{R_{pmax}} \right)^2 + Q \right)^{\left( \frac{-\sin(\phi)}{1 + \sin(\phi)} \right)} \right) - c \cdot 0 = 12 \text{ psi}$ $p'_{max2} \coloneqq p'_f + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressure (Delft Equation) $p_{max} \coloneqq u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} \coloneqq 5 \text{ in}$ Pilot tube diameter $D_{0} \coloneqq 9.5 \text{ in}$ h $\coloneqq 26.9 \text{ ft}$ Pilot tube diameter for pilot tube h $\coloneqq 26.9 \text{ ft}$ Pilot tube diameter for pilot tube $p_{1} \coloneqq \gamma_m \cdot h = 12.5 \text{ psi}$ $Q_f \coloneqq 200 \text{ gpm}$ $\tau_o \coloneqq 16 \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet			
$p'_{max2} := p'_f + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressur (Delft Equation) $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ Pilot tube diameter $D_{0} := 9.5 \text{ in}$ Pilot tube diameter h := 26.9  ft Pilot tube diameter for pilot tube Elevation difference between level of bore hole front and exit point of mud flow Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head $Q_{f} := 200 \text{ gpm}$ Assumed mud flow rate $\overline{\tau_{o}} := 16 \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet	/	$(-\sin(\phi))$	
$p'_{max2} := p'_f + c = 15.1 \text{ psi}$ $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable effective mud pressur (Delft Equation) Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT}$		$\frac{1}{1+\sin(\phi)}$	-)
$p'_{max2} := p'_f + c = 15.1 \text{ psi}$ $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable effective mud pressur (Delft Equation) Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{0} := 9.5 \text{ in}$ $h := 26.9 \text{ ft}$ Pilot tube diameter h := 26.9  ft Pilot tube diameter for pilot tube Elevation difference between level of bore hole front and exit point of mud flow Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head $Q_f := 200 \text{ gpm}$ Assumed mud flow rate $\frac{1}{\tau_o := 16} \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet	n' = (n' + (a, 0))	$\Big)^{2}$	a = 0 - 12 mai
$p'_{max2} := p'_f + c = 15.1 \text{ psi}$ Maximum allowable effective mud pressur (Delft Equation) $p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ Maximum allowable mud pressure $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ Pilot tube diameter $D_{0} := 9.5 \text{ in}$ Pilot tube diameter h := 26.9  ft Pilot tube diameter for pilot tube Elevation difference between level of bore hole front and exit point of mud flow Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head $Q_{f} := 200 \text{ gpm}$ Assumed mud flow rate $\overline{\tau_{o}} := 16 \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet	$p_{max1} = (p_f + (c \cdot 0)) \cdot \left( \left( \frac{R_{max1}}{R_{max1}} \right) \right)$	$\frac{1}{2}$	$-c \cdot 0 = 12 psi$
Maximum allowable effective mud pressur (Delft Equation) $p_{max} := u + p'_{max2} = 23.7 \ psi$ Maximum allowable mud pressure $D_{max} := u + p'_{max2} = 23.7 \ psi$ Maximum allowable mud pressure $D_{pT} := 5 \ in$ $D_{0} := 9.5 \ in$ $h := 26.9 \ ft$ Pilot tube diameter Initial borehole diameter for pilot tube Elevation difference between level of bore hole front and exit point of mud flow $\gamma_m = 67 \ pcf$ $p_1 := \gamma_m \cdot h = 12.5 \ psi$ Unit weight of slury/mud Minimum required mud pressure to overcome differntial head $Q_f := 200 \ gpm$ Assumed mud flow rate $\tau_o := 16 \ \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet		, ,	
Maximum allowable effective mud pressur (Delft Equation) $p_{max} := u + p'_{max2} = 23.7 \ psi$ Maximum allowable effective mud pressur (Delft Equation) <b>C2 -Min. Allowable Drilling Fluid Pressure</b> $D_{PT} := 5 \ in$ $D_{0} := 9.5 \ in$ $h := 26.9 \ ft$ Pilot tube diameter Initial borehole diameter for pilot tube Elevation difference between level of bore hole front and exit point of mud flow Unit weight of slury/mud Minimum required mud pressure to overcome differntial head $Q_f := 200 \ gpm$ $Q_f := 200 \ gpm$ Assumed mud flow rate $\tau_o := 16 \ \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet	n' = n' + c - 15 1 nsi		
$p_{max} := u + p'_{max2} = 23.7 \text{ psi}$ $P_{max} := u + p'_{max2} = 23.7 \text{ psi}$ $Maximum allowable mud pressure$ $D_{PT} := 5 \text{ in}$ $D_{PT} := 5 \text{ in}$ $D_{0} := 9.5 \text{ in}$ $h := 26.9 \text{ ft}$ $h := 26.9 \text{ ft}$ $Pilot tube diameter$ $Initial borehole diameter for pilot tube$ $Elevation difference between level of borehole front and exit point of mud flow$ $V_m = 67 \text{ pcf}$ $p_1 := \gamma_m \cdot h = 12.5 \text{ psi}$ $Q_f := 200 \text{ gpm}$ $T_o := 16 \frac{lbf}{100 \cdot ft^2}$ $Assumed yield point of mud per 100 square feet$	$p max_2$ $p_f + c$ for por		Maximum allowable effective mud pressure
$p_{max} := u + p'_{max2} = 23.7 \ psi$ Maximum allowable mud pressure $D_{PT} := 5 \ in$ Pilot tube diameter $D_{p_T} := 5 \ in$ Pilot tube diameter $D_{0} := 9.5 \ in$ Pilot tube diameter $h := 26.9 \ ft$ Pilot tube diameter for pilot tube $h := 26.9 \ ft$ Unit weight of slurry/mud $\gamma_m = 67 \ pcf$ Maximum required mud pressure to overcome differntial head $Q_f := 200 \ gpm$ Assumed mud flow rate $\tau_o := 16 \ \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet			
$C2 - Min. Allowable Drilling Fluid PressureD_{PT} := 5 inD_{0} := 9.5 inh := 26.9 fth := 26.9 ft\gamma_m = 67 pcfp_1 := \gamma_m \cdot h = 12.5 psiQ_f := 200 gpm\tau_o := 16 \frac{lbf}{100 \cdot ft^2}Assumed yield point of mud per 100 square feet$	$p_{max} := u + p'_{max} = 23.7 $ <b>psi</b>		
$\begin{array}{llllllllllllllllllllllllllllllllllll$	P max a P max2 2000 poo		
$\begin{array}{llllllllllllllllllllllllllllllllllll$	<u>C2 -Min. Allowable Drilling Fl</u>	uid Pressure	
$D_{0} := 9.5 in$ $h := 26.9 ft$ Initial borehole diameter for pilot tube Elevation difference between level of borehole front and exit point of mud flow $\gamma_{m} = 67 pcf$ $p_{1} := \gamma_{m} \cdot h = 12.5 psi$ Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head $Q_{f} := 200 gpm$ Assumed mud flow rate $\tau_{o} := 16 \frac{lbf}{100 \cdot ft^{2}}$ Assumed yield point of mud per 100 square feet			Pilot tube diameter
$h \coloneqq 26.9 \ ft$ Elevation difference between level of bore hole front and exit point of mud flow Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head $\gamma_m = 67 \ pcf$ $p_1 \coloneqq \gamma_m \cdot h = 12.5 \ psi$ 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 square feet	11		
$\gamma_{m} = 67 \text{ pcf}$ $p_{1} := \gamma_{m} \cdot h = 12.5 \text{ psi}$ $Q_{f} := 200 \text{ gpm}$ $\tau_{o} := 16 \frac{lbf}{100 \cdot ft^{2}}$ hole front and exit point of mud flow Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head Assumed mud flow rate Assumed yield point of mud per 100 square feet			Elevation difference between level of bore
$\gamma_m = 67 \ pcf$ $p_1 := \gamma_m \cdot h = 12.5 \ psi$ Unit weight of slurry/mud Minimum required mud pressure to overcome differntial head $Q_f := 200 \ gpm$ Assumed mud flow rate $\tau_o := 16 \ \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet			
$p_1 \coloneqq \gamma_m \cdot h = 12.5 \ psi$ 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 square feet	$\gamma_m = 67 \ pcf$		-
$   \begin{array}{c}                                     $			
$\tau_{o} \coloneqq 16 \frac{lbf}{100 \cdot ft^{2}}$ Assumed yield point of mud per 100 square feet			
$\tau_o \coloneqq 16 \frac{lbf}{100 \cdot ft^2}$ Assumed yield point of mud per 100 square feet	$Q_f \coloneqq 200 \ qpm$		Assumed mud flow rate
	$\tau_{a} \coloneqq 16 - \frac{lbf}{lbf}$		Assumed yield point of mud per 100
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$ Assumed plastic viscosity of mud	$100 \cdot ft^2$		
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$ Assumed plastic viscosity of mud			
	$\mu_{nl} \coloneqq 25 \cdot \frac{poise}{m}$		Assumed plastic viscosity of mud

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23
$v \coloneqq rac{Q_f}{0.785 \left( {D_r}^2 - \left( {D_1}^2 + {D_2}^2 \right) \right)}$	$\overline{f}))=24.2 \frac{ft}{min}$	Computed mud flow velocity
$L_{structure} \coloneqq 800 \ ft$		Length to sturcture
$\begin{array}{l} L_{structure} \coloneqq 800 \; \textit{ft} \\ p_2 \coloneqq L_{structure} \cdot \left( \left( \frac{\mu_{pl} \cdot v}{\left( D_0 - D_{PT} \right)^2 \right)^2} \right) \\ \end{array}$	$\left(\frac{\tau_o}{(D_o - D_{DT})}\right)$	$=2.4 \ psi$
$\left(\left(\left(D_{0}-D_{PT}\right)\right)\right)$	) ((-0	<ul> <li>Minimum required mud pressure to create</li> <li>flow inside the borehole</li> </ul>
$p_{min.} \! \coloneqq \! p_1 \! + \! p_2 \! = \! 14.9   {\it psi}$		Minimum required mud pressure



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D1.1 - Overburden Pressure (Considering Defo	rmed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 23.2 \ ft$	Depth of cover
$\phi = 0  deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)}  k \coloneqq 1$	Arching factor (Eq. 6, p.432, PPI)
$P_E := k \cdot (\gamma - \gamma_w) \cdot (H_c) = 6 \ psi \qquad P_E = 872 \ psf$	Effective overburden pressure
D1.2 Earth Load Deflection (Short Term)	
$E_{short} = 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \ \textbf{psi}$	Variable in earth load deflection equation
$\Delta y_{ELD\_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 0.8\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handbool
D1.3 Earth Load Deflection (Long Term)	······································
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 1.6\%$	

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<b>D2 - Buoyant Deflection</b>		
D2.1 Buoyant Deflection (Sho	ort Term)	
$D_1 = 10.75 \ in$	-	Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in		Thickness of casing pipe
$E_{short}$ =57500 <b>psi</b>		Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1)
$\gamma_m = 67 \ pcf$		Assumed unit weight of fluid in borehole (Slurry unit weight)
$I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$	<u>\</u>	Moment of inertia of pipe wall cross
$\gamma_{m} = 67 \text{ pcf}$ $I := \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $0.1169 \cdot \gamma_{m} \cdot \left(\frac{D_{1}}{2}\right)$ $\Delta y_{bouyant} := \frac{0.1169 \cdot \gamma_{m} \cdot \left(\frac{D_{1}}{2}\right)}{E_{short} \cdot I}$	)=0.0	Pipe ring deflection to buoyant force ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection (Lon		
D3 - Reissner Effect Deflection		-
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$		short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$z \coloneqq \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2}$	-=0.0000033	Deflection due to longitudinal bending
$\Delta y_{R\_short} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z$	$^{2} = 0.0002\%$	Pipe ring deflection due to the Reisnner Effect
D3.2 - Reissner Effect Deflect	<u>tion (Long Term)</u>	
$\mu_{long} \coloneqq 0.45$ $R = 1000 \ ft$		Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature
$z := \frac{\frac{3}{2} \cdot (1 - \mu_{long}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}}$	=0.000003	Deflection due to longitudinal bending
$\Delta y_{R\_long} \coloneqq \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2$	<sup>2</sup> =0.0002%	Pipe ring deflection due to the Reisnner Effect, long term

	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Crossing	
D4 - Net Ring Deflection	<u>n</u>		
$\Delta y_{lim}$ :=7.5%			on limit for DR 9 non pressurized
D4.1 - Net Short Term		hihe (19	ble 2 , p. 437, PPI Handbook)
$\Delta y_{short\_net} \coloneqq \Delta y_{ELD\_short}$	$_{t}+ \Delta y_{bouyant}+ \Delta y_{R\_shor}$	<sub>t</sub> =0.9%	Percent ring deflection in short term analysis
$Check \coloneqq \mathbf{if} \left( \Delta y_{short\_net} < \right)$	$\Delta y_{lim},  ext{``okay''},  ext{``not o}$	•kay") = "	okay"
D4.2 - Net Long Term			
$\Delta y_{long\_net}$ := $\Delta y_{ELD\_long}$ -	$+\Delta y_{R_{long}} = 1.6\%$		ring deflection in long term (50 years)
$Check \coloneqq  ext{if} ig ( \varDelta y_{long\_net} <$	$\Delta y_{lim},$ "okay", "not ol	$\operatorname{kay"} = "o$	okay"



Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

D5.1 - Unconstrained Ring Buckling	g, Levy's Equation (Short Term-During Pull)
	l increase the pipe's buckling strength, therefore ition will produce a conservative value.
N:=2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
E <sub>short</sub> =57500 <b>psi</b>	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
2	12
f <sub>0</sub> 6	Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
8	$f_{o\_short} \coloneqq 0.98$
$P_{UC\_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$	$\int_{N}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure
$H = 26.9 \; ft$	Elevation difference between the lowest point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H \!=\! 12.52  psi$	Pressure of drilling slurry
$P_{net} := P_{mud} = 12.52 \ psi$	Net external loading with open borehole
$Check \coloneqq if \left( P_{UC\_short} > P_{net}, \text{``okay''} \right)$	", "not okay") = "okay"
D5.2 - Unconstrained Ring Buckling	<u>J, Levy's Equation (Long Term)</u>
	l increase the pipe's buckling strength, therefore ition will produce a conservative value.
	Factor of Safety

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing 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
$P_{UC\_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2}\right) \cdot \left(\frac{1}{2 \cdot 2}\right) \cdot \left(\frac{1}{2 \cdot 2$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \frac{f_{o\_long}}{N} =$	31.1 <i>psi</i> Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 8.5 \ psi$		Groundwater head pressure
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left( P_{UC\_long} > P_{ne} \right)$	, "okay", "not okay	(") = "okay"



Champlain Hudson Power Express - Package 6 Crossing #91.A- Old Ravena Road Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/17/23

# **References**

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92 & 92.A



Project:

Tunnel No.:

Description:

Calculated by: SA

Champlain Hudson Power Express - Package 6 Crossing #92&92.A- Stream S-14, S-12, S-11 S-10, and Old Ravena Rd. Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23

fining Parameters of Horizontal Direction	
$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 in$	Pipe 2 outer diameter
$D_{rod} \coloneqq 3.5 \ in$	Assumed drill rod diameter
$DR_1 \coloneqq 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
N	
drill rig B D	A
	January and
H	
pipe exit C	В
	*****
L <sub>4</sub> L <sub>3</sub>	1 L <sub>2</sub> L <sub>1</sub>
L Lbore	•
- L <sub>bore</sub>	•
Illustration 1 - Schematic of	
Illustration 1 - Schematic of	Drive Cross-section
Illustration 1 - Schematic of $\alpha := 12$ ° $\alpha_{in} := \alpha = 0.2094$ rad	Drive Cross-section Borehole entry angle (degrees, radians)
Illustration 1 - Schematic of $\alpha := 12^{\circ}$ $\alpha_{in} := \alpha = 0.2094$ rad $\beta := 12^{\circ}$ $\beta_{exit} := \beta = 0.2094$ rad	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
Illustration 1 - Schematic of $\alpha := 12$ ° $\alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12$ ° $\beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
Illustration 1 - Schematic of $\alpha := 12^{\circ}$ $\alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12^{\circ}$ $\beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
Illustration 1 - Schematic of $\alpha := 12^{\circ}$ $\alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12^{\circ}$ $\beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
Illustration 1 - Schematic of $\alpha := 12^{\circ}$ $\alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12^{\circ}$ $\beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from
Illustration 1 - Schematic of $\alpha := 12 \circ \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 12 \circ \beta_{exit} := \beta = 0.2094 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 148.35 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
Illustration 1 - Schematic of $\alpha := 12 \circ \alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12 \circ \beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 148.35 \ ft$ $L_{total} := 2092 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
Illustration 1 - Schematic of $\alpha := 12 \circ \qquad \alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12 \circ \qquad \beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 148.35 \ ft$ $L_{total} := 2092 \ ft$ $L_1 := 150 \ ft$ $L_2 := 702.5 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
Illustration 1 - Schematic of $\alpha := 12 \circ \qquad \alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12 \circ \qquad \beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 148.35 \ ft$ $L_{total} := 2092 \ ft$ $L_1 := 150 \ ft$ $L_2 := 702.5 \ ft$ $L_3 := 1058 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section
Illustration 1 - Schematic of $\alpha := 12 \circ \qquad \alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12 \circ \qquad \beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 148.35 \ ft$ $L_{total} := 2092 \ ft$ $L_1 := 150 \ ft$ $L_2 := 702.5 \ ft$ $L_3 := 1058 \ ft$ $L_4 := 331 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1
Illustration 1 - Schematic of $\alpha := 12$ ° $\alpha_{in} := \alpha = 0.2094 \ rad$ $\beta := 12$ ° $\beta_{exit} := \beta = 0.2094 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 147.6 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 148.35 \ ft$ $L_{total} := 2092 \ ft$ $L_1 := 150 \ ft$ $L_2 := 702.5 \ ft$ $L_3 := 1058 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See

KILDUFF       Project:         N D E R G R O U N D       Description:         Description:       Calculated by: S         Checked by: NW	
$v_a := 0.1$	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
$\gamma_a := 0.965$	Specific gravity of pipe
$\gamma_m := 90 \ pcf$	Assumed unit weight of slurry
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.4$	Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$	Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$	Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$	Gravitational Constant
- Axial Bending Stress:	
$R_{avg.\_in} \coloneqq 1000 \; ft$	Radius of curvature at the entry, provided by Contractor
$R_{avg\_out} \coloneqq 1000 \ ft$	Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg.\_in} + R_{avg.\_out}}{2} = 1000 \ ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left( R_{avg.\_in} > r_{rod}, \text{``okay''}, \text{``} \right)$	not okay") = "okay"
$Check \coloneqq \mathbf{if} \left( R_{avg.\_out} \! > \! r_{rod}, \text{``okay''}, \text{``} \right)$	"not okay") = "okay"
adius of curvature should exceed 40 time	es 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)

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



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Description:

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Champlain Hudson Power Express - Package 6 Crossing #92&92.A- Stream S-14, S-12, S-11 S-10, and Old Ravena Rd. Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23

<u>1 - Empty Pipe</u>			
B1.1 - Effective Weig	ht of Empty Pipe:		
$w_a := \frac{\pi}{4} \left( \left( D_1^2 - \left( D_1 - C_1 - C_$	$(-T_{p1})^2 + (D_2^2 - (D_2^2))^2$	$\left(2-T_{p2}\right)^{2}\left(\left(-T_{p2}\right)^{2}\right)\right)\cdot ho_{w}$	$\cdot \gamma_a = 8.3 \ plf$
B1.2 - Upward Buoya	ant Force:	Eff	ective weight
$w_b \coloneqq \left( \frac{\pi \cdot \left( D_1^2 + D_2^2 \right)}{4} \right)$	$\left( \begin{array}{c} 0 \\ - \end{array} \right)  ho_w \! \cdot \! \gamma_b \! - \! w_a \! = \! 51.2$	<b>plf</b> Upward	puoyant force of empty pipe
B1.3 - Hydrokinetic P	Pressure:		
$\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2\right)$	$-(D_1^2 + D_2^2)) = 796$	s <i>lbf</i> Hydrokin	etic force
B1.4 - Pullback Force	Point A:		
$T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot v_a)$	(I + I + I + I)) =	1807 <b>lbf</b>	
$I_a = e - (v_a \cdot w_a \cdot v_a)$	$(L_1 + L_2 + L_3 + L_4)) =$		force when pipe enters the grou
B1.5 - Pullback Force	Point B:		
$T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_a + v_b \cdot \right)$	$ w_1  \cdot L_0 + w_1 \cdot H +$	$v \cdot w \cdot L_{a} \cdot e^{\langle v_{a} \rangle}$	$(2^{\alpha_{in}}) = 22193 \ lbf$
	$ \sim b  = 2 + \infty b = max + b$		force increase with depth
B1.6 - Pullback Force	<u>e Point C:</u>		
$T_c \coloneqq T_b + \left( v_b \cdot w_b \cdot L_3 \right)$	$- e^{\langle v_b \cdot lpha_{in}  angle} \cdot ig( v_a \cdot w_a \cdot L_a ig)$	$_{3} \cdot e^{(v_{a} \cdot \alpha_{in})} = 37$	494 <i>lbf</i>
B1.7 - Pullback Force	at D:		
$T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot (T_c + v_b)$	$_{b}\!\cdot\!\left w_{b}\right \!\cdot\!L_{4}\!-\!e^{\left(v_{a}\cdotlpha_{in} ight)}\cdot($	$\langle v_a {f \cdot} w_a {f \cdot} L_4 {f \cdot} e^{\langle v  angle}$	$(a \cdot \alpha_{in})) = 45035 \ lbf$
B1.8 - Maximum Pull	back Force - Empty P	ipe:	
P = max/T	T $T$ $T$ $) + AT$	15021 ILF	
$P_{max\_empty} \coloneqq \max \left( T_a \right)$	$(a, I_b, I_c, I_d) + \Delta I = c$		n Pullback Force
2 - Filled Pipe with B2.1 - Upward Buoya			
	,	(2)	
$w_{bfilled} \coloneqq \left  \frac{(n \cdot D_1)}{n} \right $	$\cdot \rho_w \cdot \left( \gamma_b - \gamma_c \cdot \left( 1 - \left( \frac{1}{D} \right) \right) \right)$	$\left  -w_a \right  =$	24.6 <i>plf</i>
· ( 4 )	( $($ $($ $L$	<i>m</i> <sub>1</sub> )) )	

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_3 + L_4 \right) \right) = 1897 \ \textit{lbf} \ \text{Pullback force enter ground}$ 

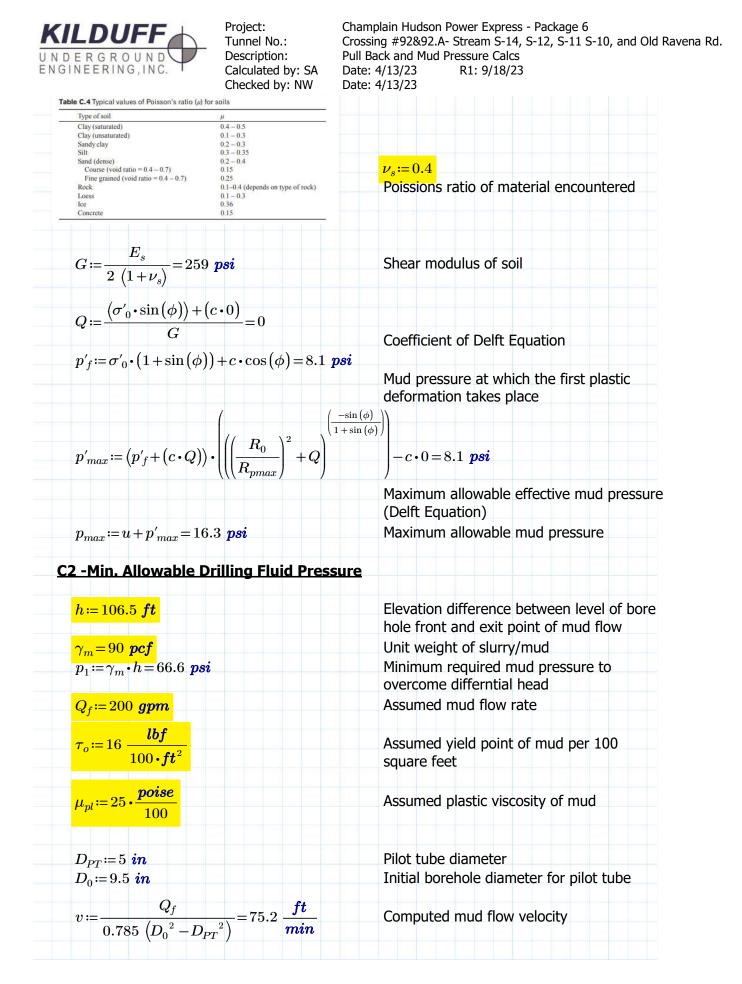
KILDUFF	Project: Tunnel No.:
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$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_{afilled} + v_b \cdot  w_{bfilled}  \cdot L_2 + \right)$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{\langle v_a \cdot \alpha_{in} \rangle} = 1205$
	Pullback force increase and decrease
B2.4 - Pullback Force Point C:	depth
$T_{cfilled} \coloneqq T_{bfilled} + \left(v_b \cdot \left  w_{bfilled} \right  \cdot L_3\right) - e^{(v_b \cdot \alpha_i)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 18927 \ lbf$
B2.5 - Pullback Force at D:	
$\overline{T_{dfilled}} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot (T_{cfilled} + v_b \cdot  w_{bfilled}  \cdot L_4$	$_{4}-e^{(v_{a}\cdot\alpha_{in})}\cdot(v_{a}\cdot w_{a}\cdot L_{4}\cdot e^{(v_{a}\cdot\alpha_{in})}))=22456\ l$
B2.6 - Maximum Pullback Force - Filled Pip	e with Water:
$P_{max} \! \coloneqq \! \max \left( T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled} \right)$	$_{d}) = 22456 \ lbf$ Maximum Pullback Force
<u> 3 - Safe Pull Strength / Ultimate Tensil</u>	le Load Check:
B3.1 Safe Pullback Check	
$A_1 := \frac{\pi}{4} \left( D_1^2 - \left( D_1 - T_{p1} \right)^2 \right) = 19 \ \boldsymbol{in}^2$	Cross-sectional area of Pipe 1
$A_{2} \coloneqq \frac{\pi}{4} \left( D_{2}^{2} - \left( D_{2} - T_{p2} \right)^{2} \right) = 0.8 \ \boldsymbol{in}^{2}$	Cross-sectional area of Pipe 2
$P_{11} := \frac{A_1 \cdot P_{max\_empty}}{A_1 + A_2} = 44053 \ lbf$	Pullback forces acting on Pipe 1 (Em
$P_{21} := \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} = 1778 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Em
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 21585 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ball
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 871 \ lbf$	Pullback forces acting on Pipe 2 (Ball
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table % p. 448, PPI)
<i>P</i> <sub>SPF2</sub> :=1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table % p. 448, PPI)
$check \coloneqq if(P_{SPF1} > P_{11}, "okay", "not okay")$	
$check := if(P_{SPF2} > P_{21}, "okay", "not okay)$	
$check := if (P_{SPF1} > P_{12}, "okay", "not okay")$	
$check \coloneqq if(P_{SPF2} > P_{22}, "okay", "not okay")$	) – Okay



Champlain Hudson Power Express - Package 6 Crossing #92&92.A- Stream S-14, S-12, S-11 S-10, and Old Ravena Rd. Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23

IGINEERING, INC.	Checked by: NW	Date: 4/13/23 R1: 9/16/23
- Allowable Mud Press		
<u>C1 - Max. Allowable D</u>	riling Fluid Pres	<u>isure</u>
Assumptions:		
HDD alignment crosses n hydrofracture graphs use	nultiple structures equations, as de	al structure as identified for each crossing. If the the one with least cover was used. Provided tailed herein, to identify potential frac-out areas. sceptible to frac-out due to low cover.
-Where applicable, soil p Package 1, dated Octobe		ed from Kiewit's Proposed Soil Properties for CHP
- Diameter/radius based	on the most critic	al stage (i.e. during pilot tube)
-Asssume $\cot(0 \text{ deg}) = 0$	theoretically infir	nite)
$D_{PT} \coloneqq 5 \ in$		Pilot tube diameter
$D_0 \coloneqq 9.5 \ in$		Initial borehole diameter for pilot tube
$\frac{H_w \coloneqq 0.9 \cdot ft}{H_w \coloneqq 18.9 \cdot ft}$		Depth of the bore below groundwater El.
		Vertical separation distance between criti
$H_c \coloneqq 18.9 \ ft$		structure and pipe (S-14)
$\gamma \coloneqq 100 \ pcf$		Assumed unit weight soft clay/silt (CL-ML
$\gamma_w \coloneqq 62.4 \ pcf$		Unit weight of water
$\gamma_w^{\prime} = \gamma - \gamma_w = 37.6 \ pcf$		Effective unit weight
$u \coloneqq \gamma_w \cdot H_w = 8.2 \text{ psi}$		Initial pore water pressure
$\phi \coloneqq 0 \ deg$		Assumed friction Angle
$c := 450 \ psf = 3.13 \ psf$	;	Assumed cohesion of encountered materi
		Taitistan di sa Cuta basahala
$R_0 := \frac{D_0}{2} = 4.75 \ in$		Initial radius of the borehole
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 9.5 \ \mathbf{f}$	t	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) - \right)$	$+\gamma' \cdot H_w  angle = 4.9 \ ps$	<i>i</i> Initial effective stress
Table C.2 Typical values of modulus of elasti	city (E <sub>c</sub> ) for different types of so	ils
Type of Soil	$E_x$ (N/mm <sup>2</sup> )	
Clay Very soft	2-15	
Soft	5-25	N
Medium Hard	15-50 50-100	$E_s \coloneqq 5 \frac{N}{mm^2} = 725 psi$
Sandy	25-250	
Glacial till Loose	10-153	Assumed modulus of elasticity
Dense	144-720	,
Very dense	478-1,440	
Loess Sand	14-57	
Silty	7-21	
Loose	1024	
Dense Sand and gravel	48-81	
Loose	48-148	
Dense	96-192	
Shale Silt	144-14,400 2-20	
om	2-20	



KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: SA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #92&92.A- Stream S-14, S-12, S-11 S-10, and Old Ravena Rd. Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23
$v = 1.3 \ \frac{ft}{s}$		Computed mud flow velocity (check on units)
$\frac{L_{structure}}{1825} \frac{ft}{ft}$		Length to sturcture
$\left( \left( rac{\mu_{pl} \cdot v}{\left( D_0 - D_{PT}  ight)^2}  ight) + \left( rac{\mu_{pl} \cdot v}{\left( I  ight)^2}  ight)  ight)$	$\left(\frac{\tau_o}{D_0 - D_{PT}}\right) = 0.003$	$3 \frac{psi}{ft}$ Check mud pressure units
$p_2 \coloneqq L_{structure} \cdot \left( \left( \frac{\mu}{(D_0 - 1)} \right)^{-1} \right) \right)$	$\left(\frac{v_{pl} \cdot v}{\left(D_0 - v\right)^2}\right) + \left(\frac{\tau_o}{\left(D_0 - v\right)^2}\right)$	$\left. \frac{o}{D_{PT}} \right) = 5.5 \ psi$
	$-D_{PT}$	Minimum required mud pressure to create flow inside the borehole
$p_{min.} \coloneqq p_1 + p_2 = 72 p_3$	si	Minimum required mud pressure



D1.1 - Overburden Pressure (Considering	Deformed Borehole with Arching Mobilized)
$H_c := H_{max} = 147.6 \; ft$	Depth of cover
$\phi = 0  deg$	Friction angle of soil
$B \coloneqq D_r = 18 in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2 = 2.624$	Earth pressure coefficient
$\gamma = 100 \ pcf$	Unit weight of soil, assumed
Can't divide by $0 \sim assume friction angle$	$e(\phi) = 1 \times 10^{-2}$
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{2} \cdot 1 \cdot 10^{-2}\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot 1 \cdot 10^{-2}\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot 1 \cdot 10^{-2}} = 0.193$	Arching factor (Eq. 6, p.432, PPI)
$B P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 7 psi P_E = 1069$	
D1.2 Earth Load Deflection (Short Term)	
	Apparent modulus of elasticity for
$E_{short} \coloneqq 57500 \cdot psi$ $k \coloneqq 1$	PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \text{ psi}$	Variable in earth load deflection equation
$0.0125 \cdot P_E$	
$\Delta y_{ELD\_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 1.0\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboc
D1.3 Earth Load Deflection (Long Term)	
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710 Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
	Pipe deflection to diameter as per
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 2.0\%$	PPI Equ. 10 (Chp 12, p 437)



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D2.1 Buoyant Deflection (Short Term)			
$D_1 = 10.75 in$	Outside diameter of casing pipe		
$t := T_{p1} = 1.194 $ in	Thickness of casing pipe		
$E_{short} \!=\! 57500  \mathbf{psi}$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1)		
$\gamma_m = 90 \ pcf$	Assumed unit weight of fluid in borehole (Slurry unit weight)		
$I := \frac{t^3}{12} = 0.14 \frac{in^4}{in}$	Moment of inertia of pipe wall cross section		
$\begin{split} \gamma_m &= 90 \ \textit{pcf} \\ I &\coloneqq \frac{t^3}{12} = 0.14 \ \frac{\textit{in}^4}{\textit{in}} \\ \Delta y_{bouyant} &\coloneqq \frac{0.1169 \cdot \gamma_m \cdot \left(\frac{D_1}{2}\right)^4}{E_{short} \cdot I} = 0.1\% \end{split}$	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 deflectio assumed to be cured after a 1-week period f 3 - Reissner Effect Deflection (Short Ter	from installation/pumping.		
D3.1 - Reissner Effect Deflection (Short Tern	-		
D3.1 - Reissner Effect Deflection (Short Term $\mu_{short} = 0.35$	-		
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material at		
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)		
$\mu_{short} \coloneqq 0.35$	n) Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)		
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	n) Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending		
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	<ul> <li>n)</li> <li>Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature</li> <li>Deflection due to longitudinal bending</li> <li>Pipe ring deflection due to the Reisnne Effect</li> </ul>		
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R\_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	<ul> <li>n)</li> <li>Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature</li> <li>Deflection due to longitudinal bending</li> <li>Pipe ring deflection due to the Reisnne Effect</li> </ul>		
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$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) \ (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$ $\Delta y_{R\_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^{2} = 0.0002\%$ D3.2 - Reissner Effect Deflection (Long Term $\mu_{long} := 0.45$	<ul> <li>n)</li> <li>Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2) Radius of curvature</li> <li>Deflection due to longitudinal bending</li> <li>Pipe ring deflection due to the Reisnne Effect</li> <li>n)</li> <li>Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2)</li> </ul>		



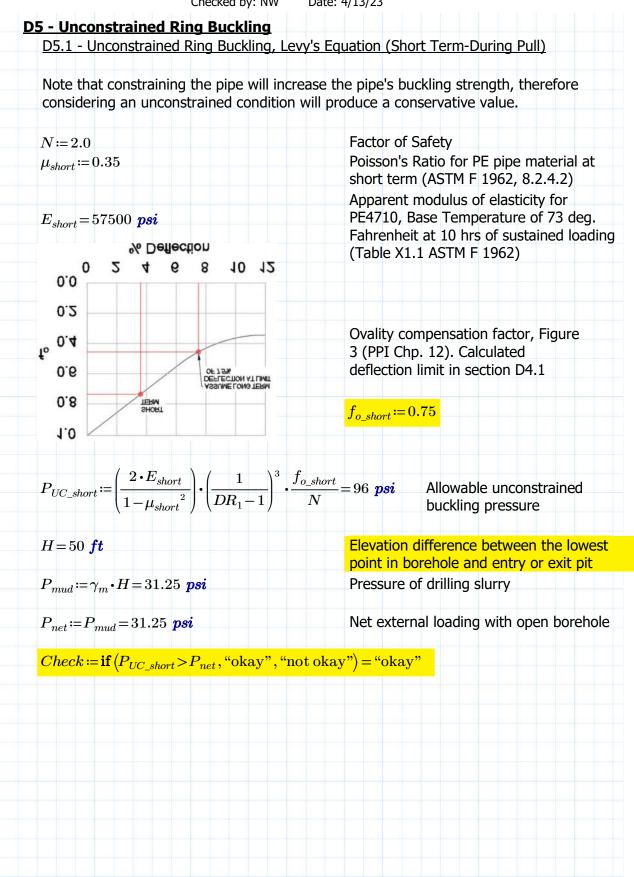
Project:

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Description: Calculated by: SA

INEERING, INC.	Calculated by: SA Checked by: NW	Date: 4/13/23 Date: 4/13/23	R1: 9/18/23
4 - Net Ring Defle	<u>ection</u>		
$\Delta y_{lim} \coloneqq 7.5\%$			on limit for DR 9 non pressurize ble 2 , p. 437, PPI Handbook)
D4.1 - Net Short	<u>Ferm</u>	p.p.e (14	
$\Delta y_{short\_net} \coloneqq \Delta y_{EL}$	$D_{bouyant} + \Delta y_{bouyant} + \Delta y_{bouyant}$	$y_{R\_short} = 1.1\%$	Percent ring deflection in shor term analysis
$Check \coloneqq \mathbf{if} \left( \Delta y_{shor} \right)$	$t_{l_{net}} < \Delta y_{lim}, \text{``okay''},$	, "not okay") = "	okay"
D4.2 - Net Long T	erm		
$\Delta y_{long net} \coloneqq \Delta y_{ELL}$	$b_{long} + \Delta y_{R_{long}} = 2.09$	% Percent	ring deflection in long term
		analysis	(50 years)
		·····	<b>7 1</b>
$Check \coloneqq \mathbf{if} \left( \Delta y_{long} \right)$	$_{net} < \Delta y_{lim},$ "okay",	"not okay") = "c	okay"







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Description: Calculated by: SA Champlain Hudson Power Express - Package 6 Crossing #92&92.A- Stream S-14, S-12, S-11 S-10, and Old Ravena Rd. Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23

	increase the pipe's buckling strength, therefore
$N \coloneqq 2.0$	ition will produce a conservative value. Factor of Safety
$\mu_{long} \coloneqq 0.45$	Poisson's Ratio for PE pipe material,
	long term (ASTM F 1962, 8.2.4.2)
$E_{long} = 28200 \ psi$	Apparent modulus of elasticity for
	PE4710, Base Temperature of 73 de
	Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o\_long} \coloneqq 0.45$	Ovality compensation factor, Figure
	3 (PPI Chp. 12). Use deflection limit
	calculated in Section D4.2
$P_{UC\_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^{2}}\right) \cdot \left(\frac{1}{DR_{1} - 1}\right)$	$f_{o\_long} = 31.1 \ psi$
$(1-\mu_{long}^2)$ $(DR_1-1)$	Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w \!=\! 8.19  \mathbf{psi}$	Groundwater head pressure
$P_{net} \coloneqq P_{GW}$	Net external loading with open bore
$Check \coloneqq \mathbf{if} \left( P_{UC\_long} > P_{net}, \text{``okay''} \right)$	, "not okay") = "okay"



## **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:

Tunnel No.:

Description: Calculated by: DA

Checked by: NW

Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

ning Parameters of Horizontal Directi	
$D_1 := 10.75 \ in$	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
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_1 \coloneqq \pi \cdot D_1 = 00.0 \text{ in}$ $C_2 \coloneqq \pi \cdot D_2 = 7.5 \text{ in}$	Pipe circumference of pipe 2
bara/aiaaaath	
bore/pipepath	pipe entry
drill rig B	
P D	Tuning many time to the second
H	
pipe exit C	B
pipeexit	
$L_4$ : $L_3$	L <sub>2</sub> L <sub>1</sub>
L4 · L3	L <sub>2</sub> L <sub>1</sub>
L <sub>4</sub> L <sub>3</sub>	
- L <sub>bore</sub>	
	•
L <sub>tore</sub> Illustration 1 - Schematic of	Drive Cross-section
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 ^{\circ} \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians)
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from
$L_{\text{tore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing
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$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$ $L_1 := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 221.8 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$ $L_1 := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \text{ rad}$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \text{ ft}$ $L_{total} := 1666.6 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 221.8 \text{ ft}$ $L_3 := 1249 \text{ ft}$ $L_4 := 195.8 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9 \circ \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10 \circ \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 221.8 \ ft$ $L_3 := 1249 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1 Elevation difference between the lowest
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 9^{\circ} \qquad \alpha_{in} := \alpha = 0.1571 \ rad$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 27.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 28.05 \ ft$ $L_{total} := 1666.6 \ ft$ $L_1 := 150 \ ft$ $L_2 := 221.8 \ ft$ $L_3 := 1249 \ ft$ $L_4 := 195.8 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section Horizontal distance to rise to surface, See Illustration 1

ver Express - Package 6 ds and Lafarge Private (Road and Structur ssure Calcs R1: 6/12/23
ficient before pipe enters med)
ficient for the bundle within brication assumed)
of water
ity of pipe
it weight of slurry
vity of slurry, assumed unit
ity of water to fill the pipe
Pressure (p. 443, Ch12 PPI
l Constant
rvature at the entry, provided
rvature at the exit, provided
ius of curvature at entry
2-99, Equation 1, p7

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
$E_{12hr} := 57500 \cdot psi$	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 #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

**B - Site Specific Analyses: Pullback Force: B1 - Empty Pipe** B1.1 - Effective Weight of Empty Pipe:  $w_{a} \coloneqq \frac{\pi}{4} \left( \left( D_{1}^{2} - \left( D_{1} - T_{p1} \right)^{2} \right) + \left( D_{2}^{2} - \left( D_{2} - T_{p2} \right)^{2} \right) \right) \cdot \rho_{w} \cdot \gamma_{a} = 8.3 \ plf$ B1.2 - Upward Buoyant Force: Effective weight  $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{4}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ B1.3 - Hydrokinetic Pressure:  $\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2 - \left(D_1^2 + D_2^2\right)\right) = 796 \ lbf \text{ Hydrokinetic force}$ B1.4 - Pullback Force Point A:  $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1529 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B:  $T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_a + v_b \cdot |w_b| \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 6445 \ \textit{lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C:  $T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 24530 \ lbf$ B1.7 - Pullback Force at D:  $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 27369 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe:  $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 28165\ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force:  $w_{bfilled} := \left(\frac{\left(\pi \cdot D_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)^{2}\right) - w_{a} = 24.6 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_3 + L_4 \right) \right) = 1529 \ \textit{lbf} \quad \text{Pullback force enter ground}$ 



Project:

Tunnel No.:

Description:

Calculated by: DA

Checked by: NW

Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

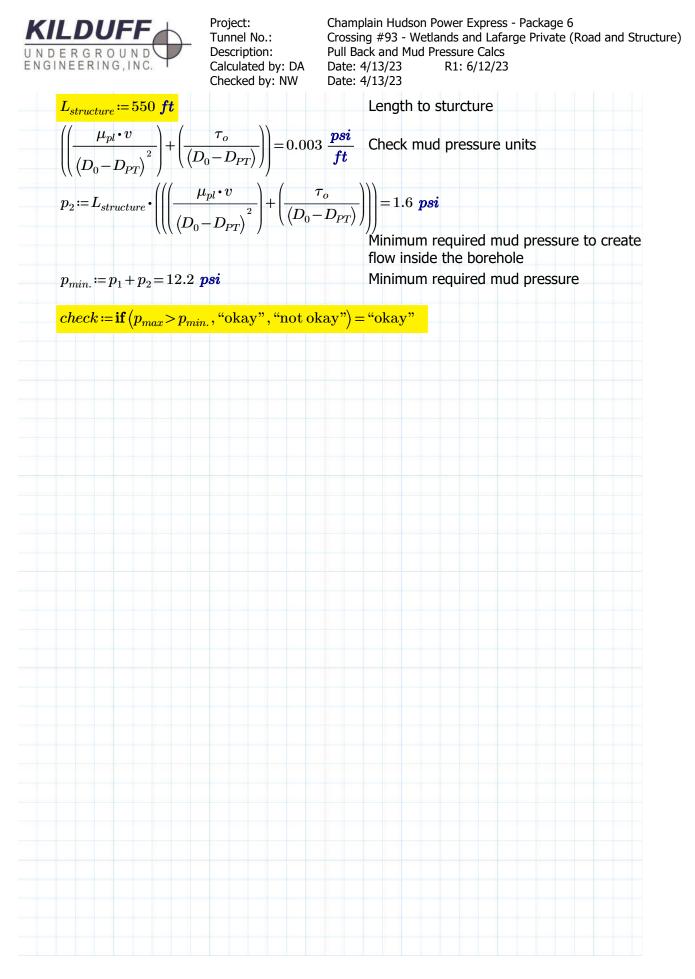
$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 4223 \ lagrage M_{a}$ Pullback force increase and decrease we depth
$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot lpha_{in})}) = 12356 \ lbf$
$(v_a \cdot \alpha_{in}) \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 14370$ lbf
e with Water:
$d_{d} = 14370 \ lbf$ Maximum Pullback Force
le Load Check:
Cross-sectional area of Pipe 1
Cross-sectional area of Pipe 2
Pullback forces acting on Pipe 1 (Empt
Pullback forces acting on Pipe 2 (Empt
Pullback forces acting on Pipe 1 (Ballas
Pullback forces acting on Pipe 2 (Balla
Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
") = "okay"
") = "okay"
") = "okay" ") = "okay"



Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

Checked by: NW	Date: 4/13/23
- Allowable Mud Pressures:	
C1 - Max. Allowable Driling Fluid Pro	essure
Assumptions:	
HDD alignment crosses multiple structure	tical structure as identified for each crossing. If the es the one with least cover was used. Provided detailed herein, to identify potential frac-out areas. susceptible to frac-out due to low cover.
-Where applicable, soil properties referen Package 1, dated October 12, 2022.	nced from Kiewit's Proposed Soil Properties for CHPE
- Diameter/radius based on the most crit	tical stage (i.e. during pilot tube)
-Asssume cot(0 deg) = 0 theoretically in	finite)
$D_{PT} \coloneqq 5 \ \boldsymbol{in}$	Pilot tube diameter
$D_{D_1} = 9.5 $ in	Initial borehole diameter for pilot tube
$\frac{H_{w} \coloneqq 17.4 \cdot ft}{H_{w} \coloneqq 17.4 \cdot ft}$	Depth of the bore below groundwater elevation
$H_c \coloneqq 17.4 \ ft$	Vertical separation distance between critic structure and pipe (wetlands; ~Sta 5+50)
$\gamma \coloneqq 110 \ pcf$	Assumed unit weight med stiff to stiff silty
	clay & silt (ML, CL-ML)
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma'_{w} = \gamma - \gamma_{w} = 47.6 \ pcf$	Effective unit weight
$u := \gamma_w \cdot H_w = 7.5 \ psi$	Initial pore water pressure
$\phi \coloneqq 0 \ deg$	Assumed friction Angle
$c := 800 \ psf = 5.56 \ psi$	Assumed cohesion of encountered materia
$R_0 := rac{D_{rod}}{2} = 1.75 \; in$	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 9 ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 5.8 \ \mu$	
Table C.2 Typical values of modulus of elasticity (E <sub>5</sub> ) for different types of soils	
Type of Soil E <sub>y</sub> (N/mm <sup>2</sup> )	
Clay Very soft 2-15	
Soft 5-25 Medium 15-50	87
Hard 50–100 Sandy 25–250	$E_s \coloneqq 15 \frac{N}{mm^2} \equiv 2176 \text{ psi}$
Glacial till Loose 10–153	$mm^2$
Dense 144–720 Very dense 478–1,440	Assumed modulus of elasticity
Loess 14–57 Sand	Assumed modulus of clasticity
Silty 7–21 Loose 10–24	
Dense 48-81 Sand and gravel	
Loose 48-148	
Dense 96–192 Shale 144–14,400	
Silt 2–20	

	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Struct Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23
Table C.4 Typical values of Poisson's ratio (µ) for	or soils	
Type of soil Clay (saturated)	μ 0.4 – 0.5	
Clay (unsaturated) Sandy clay	0.1 - 0.3 0.2 - 0.3	
Silt Sand (dense)	0.3 - 0.35 0.2 - 0.4	
Course (void ratio = $0.4 - 0.7$ ) Fine grained (void ratio = $0.4 - 0.7$ )	0.15 0.25	$\nu_s \coloneqq 0.4$
Rock Loess	0.1-0.4 (depends on type of rock) 0.1-0.3	Poissions ratio of material encountered
Ice Concrete	0.36 0.15	
$G \coloneqq \frac{E_s}{2 \left(1 + \nu_s\right)} = 777$	psi	Shear modulus of soil
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + \left(}{G}$	$\frac{c \cdot 0}{2} = 0$	Coofficient of Dolft Equation
		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi))$	$+c \cdot \cos(\phi) = 11.3$	
		Mud pressure at which the first plastic deformation takes place
	(	$\frac{-\sin\left(\phi\right)}{1+\sin\left(\phi\right)}\right)$
$p'_{max} \coloneqq \left( p'_f + (c \cdot 0) \right) \cdot$	$\left( \left( \left( \frac{R_0}{R_{pmax}} \right)^2 + Q \right) \right)$	$ \left  -c \cdot 0 = 11.3  psi \right  $
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} \equiv 18$	.8 <b>psi</b>	Maximum allowable mud pressure
<u>C2 -Min. Allowable D</u>	rilling Fluid Pres	<u>sure</u>
<u>h≔16.85</u> <b>ft</b>		Elevation difference between level of bore hole front and exit point of mud flow
$\gamma_m = 90 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 10.5 \ psi$		Minimum required mud pressure to
		overcome differntial head
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
τ16 <b>lbf</b>		Assumed yield point of mud per 100
$\tau_o \coloneqq 16 \ \frac{lbf}{100 \cdot ft^2}$		square feet
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		Assumed plastic viscosity of mud
100		
$v \coloneqq rac{Q_f}{0.785 \left({D_0}^2 - D_P ight)}$	$\frac{ft}{m^2} = 75.2 \frac{ft}{min}$	Computed mud flow velocity





Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

D1.1 - Overburden Pressure (Considering	Deformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 27.3 \ ft$	Depth of cover
$\phi = 0  deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$ $K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	"Silo" width, conservative value =
$E \left( 4\pi - \phi \right)^2$	reamed hole diameter
$K \coloneqq \tan\left(\frac{45 - \frac{1}{2}}{2}\right)$	Earth pressure coefficient
$\gamma = 110 \ pcf$	Unit weight of soil, assumed
Can't divide by $0 \sim assume k$ goes to $1$ (ie	e full soil column height)
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{t} \cdot tan\left(\frac{\phi}{t}\right)\right)$	
$k \coloneqq \frac{B}{2} = \frac{B}{2} \left( \frac{B}{2} \right) k \coloneqq 1$	Arching factor (Eg. 6, p.432, PPI)
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)}  k \coloneqq 1$	
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 9 \ psi \qquad P_E = 1299$	
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)
$k_{short} := \underbrace{E_{short}}_{= 9.36 \text{ psi}}$	Variable in earth load deflection equation
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36  psi$	
$0.0125 \cdot P_E$ 1.0%	Dine deflection to dispector on non
$\Delta y_{ELD\_short} \! \coloneqq \! \frac{0.0125 \cdot P_E}{k_{short}} \! = \! 1.2\%$	Pipe deflection to diameter as per 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
	ASTM F 1962)
$k := \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$	Variable in earth load deflection equation
	Pipe deflection to diameter as per
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 2.5\%$	PPI Equ. 10 (Chp 12, p 437)



Project:

Tunnel No.:

Description:

Calculated by: DA

Checked by: NW

Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

D2.1 Buoyant Deflection (Short Term)	
$D_1 = 10.75 \ in$	Outside diameter of casing pipe
$t := T_{p1} = 1.194 \ in$	Thickness of casing pipe
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73
	Fahrenheit (Table B.1.1)
$\gamma_{m} = 90 \text{ pcf}$ $I \coloneqq \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_{m} \cdot \left(\frac{D_{1}}{2}\right)^{4}}{E_{short} \cdot I} = 0.1\%$	Assumed unit weight of fluid in
.3 . 4	borehole (Slurry unit weight)
$I \coloneqq \frac{t^{\circ}}{1} = 0.14 \frac{\mathbf{i} \mathbf{n}^{*}}{\mathbf{n}^{*}}$	Moment of inertia of pipe wall cross
12 in $(D)^4$	section
$0.1169 \cdot \gamma_m \cdot \left  \frac{D_1}{\dots} \right $	Pipe ring deflection to buoyant force
$\Delta u_{1} = \frac{100}{2} = 0.1\%$	ASTM F 1962 (Eq. X2.6, p.6)
$= 9_{bouyant} $ $E_{short} \cdot I$	
D2.1 Buoyant Deflection (Long Term)	
<u></u>	
Please note that long term buoyant deflectio	n was assumed negibile, since grout is
assumed to be cured after a 1-week period f	
<u> 3 - Reissner Effect Deflection (Short Terr</u>	m)
D3.1 - Reissner Effect Deflection (Short Terr	-
	<u>'</u>
$u \rightarrow 0.35$	Poisson's Ratio for PE nine material at
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at
$\mu_{short} \coloneqq 0.35$	short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	
R=1000 <b>ft</b>	short term (ASTM F 1962, 8.2.4.2)
R=1000 <b>ft</b>	short term (ASTM F 1962, 8.2.4.2) Radius of curvature
R=1000 <i>ft</i>	short term (ASTM F 1962, 8.2.4.2)
$\mu_{short} := 0.35$ $R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot (1 - \mu_{short}^{2}) (D_{1} - t)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	short term (ASTM F 1962, 8.2.4.2) Radius of curvature
$R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending
$R = 1000 \ ft$ $\frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne
$R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R\_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$	<ul> <li>short term (ASTM F 1962, 8.2.4.2)</li> <li>Radius of curvature</li> <li>Deflection due to longitudinal bending</li> <li>Pipe ring deflection due to the Reisnne Effect</li> </ul>
$R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^{2}\right) \left(D_{1} - t\right)^{4}}{16 \cdot t^{2} \cdot R^{2}} = 0.0000033$	<ul> <li>short term (ASTM F 1962, 8.2.4.2)</li> <li>Radius of curvature</li> <li>Deflection due to longitudinal bending</li> <li>Pipe ring deflection due to the Reisnne Effect</li> </ul>
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$R = 1000 \ ft$ $z := \frac{\frac{3}{2} \cdot \left(1 - \mu_{short}^2\right) \left(D_1 - t\right)^4}{16 \cdot t^2 \cdot R^2} = 0.0000033$ $\Delta y_{R\_short} := \left(\frac{2}{3}\right) \cdot z + \left(\frac{71}{135}\right) \cdot z^2 = 0.0002\%$ $D3.2 - \text{Reissner Effect Deflection (Long Term)}$ $\mu_{long} := 0.45$ $R = 1000 \ ft$	short term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending Pipe ring deflection due to the Reisnne Effect Poisson's Ratio for PE pipe material at long term (ASTM F 1962, 8.2.4.2) Radius of curvature Deflection due to longitudinal bending

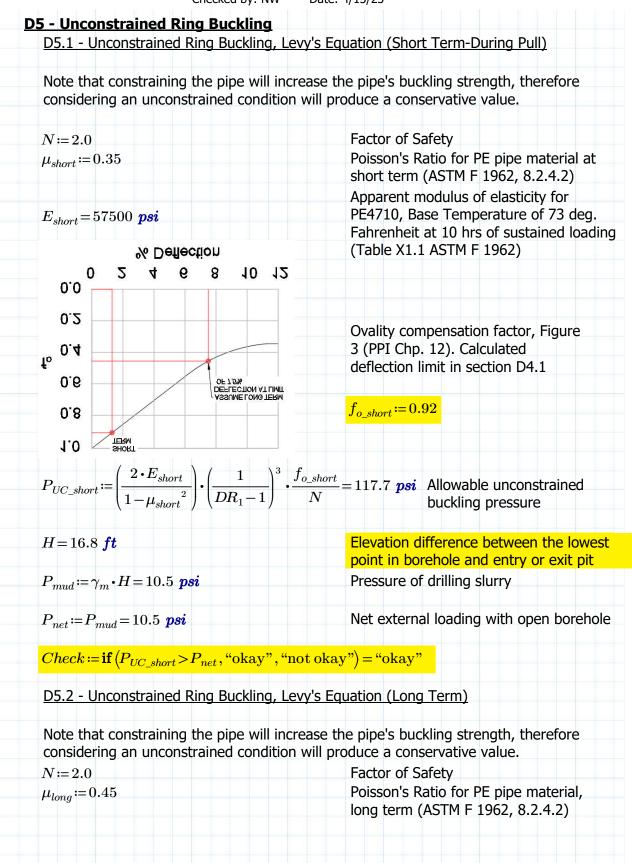


Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

eflection limit for DR 9 non pressurized ipe (Table 2 , p. 437, PPI Handbook) 1.3% Percent ring deflection in short term analysis (y") = "okay" ercent ring deflection in long term nalysis (50 years)
term analysis y")="okay" ercent ring deflection in long term
ercent ring deflection in long term
y") = "okay"



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KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structu Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23	re)
$E_{long} {=} 28200 \; psi$		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	
$P_{UC\_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2}\right)^2$	$\left(\frac{1}{DR_1-1}\right)^3 \cdot \frac{f_o}{dr_0}$	$\frac{D_{long}}{N} = 31.1 \text{ psi}$ Allowable unconstrained buckling pressure	
$P_{GW} \coloneqq \gamma_w \cdot H_w = 7.54$	psi	Groundwater head pressure	
$P_{net} \coloneqq P_{GW}$		Net external loading with open borehole	
$\frac{Check \coloneqq \mathbf{if} \left( P_{UC\_long} > \right)}{Check \coloneqq \mathbf{if} \left( P_{UC\_long} > \right)}$	∙P <sub>net</sub> , "okay", "no	$\operatorname{ot}\operatorname{okay}") = \operatorname{"okay"}$	



Champlain Hudson Power Express - Package 6 Crossing #93 - Wetlands and Lafarge Private (Road and Structure) Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

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- 4. Handbook of Polyethylete Pipe, 2008, Plastics Pipe Institute (PPI), Second Edition
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93.A



Champlain Hudson Power Express - Package 6 Crossing #93.A- Ravine & Stream S-14 Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$\overline{D_{rod}} := 3.5 \ in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 := 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \text{ in}$	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	pipeentry
rill rig B D	A a
C C	B
pipe exit	
- L <sub>bore</sub>	
- L <sub>bore</sub>	
Illustration 1 - Schematic of	
Illustration 1 - Schematic of	Drive Cross-section
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$	Drive Cross-section Borehole entry angle (degrees, radians)
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443$	Drive Cross-section
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 44.7 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 44.7 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 44.7 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 45.45 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745$ rad $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443$ rad $D_r := 18 \cdot in$ $H_{max} := 44.7$ ft	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 44.7 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 45.45 \ ft$ $L_{total} := 744.0 \ ft$ $L_1 := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
Illustration 1 - Schematic of $\alpha := 10 \circ \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 14 \circ \beta_{exit} := \beta = 0.2443 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 44.7 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 45.45 \text{ ft}$ $L_{total} := 744.0 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 14^{\circ}$ $\beta_{exit} := \beta = 0.2443 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 44.7 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 45.45 \ ft$ $L_{total} := 744.0 \ ft$ $L_1 := 150 \ ft$ $L_2 := 370.1 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1

KILDUFF UNDERGROUND ENGINEERING, INC.	Project: Tunnel No.: Description: Calculated by: DA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #93.A- Ravine & Stream S-14 Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23	
$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)	
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)	
$ ho_w \coloneqq 62.4 \ pcf$		Unit weight of water	
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe	
$\gamma_m \coloneqq 80 \; pcf$		Assumed unit weight of slurry	
$\gamma_b \coloneqq \frac{\gamma_m}{\rho_w} = 1.3$		Specific gravity of slurry, assumed unit weight	
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe	
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)	
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant	
<u>A - Axial Bending Stress</u>	<u>81</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	
$R \coloneqq \frac{R_{avg.\_in} + R_{avg.\_ou}}{2}$	$\frac{ut}{t} = 1000 \; ft$	Average radius of curvature at entry	
$r_{rod} := 1200 \cdot D_{rod} = 35$	50 <b>ft</b>	ASTM F 1962-99, Equation 1, p7	
$Check \coloneqq$ if $\left< R_{avg.\_in} > \right>$	r <sub>rod</sub> , "okay", "not	(okay") = "okay"	
$Check \coloneqq \mathbf{if} \left( R_{avg.\_out} \right)$	$>$ $r_{rod}$ , "okay", "no	tokay") = "okay"	

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

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



Champlain Hudson Power Express - Package 6 Crossing #93.A- Ravine & Stream S-14 Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 6/12/23 Date: 4/13/23

	Checked by: NW	Date: 4/13/23	
- Site Specific Analyse	es: Pullback Force:	<u></u>	
B1 - Empty Pipe B1.1 - Effective Weig	iht of Empty Pipe:		
		2 \ \	
$w_a \coloneqq \frac{\pi}{4} \left( \left( D_1^2 - \left( D_1 \right) \right) \right)$	$(-T_{p1})^{2} + (D_{2}^{2} - (D_{2}^{2})^{2}) + (D_{2}^{2}) + (D_{2}$	$\left( p_2 - T_{p2} \right)^2 \left( \right) \cdot \rho_w \cdot $	$\gamma_a = 8.3 \ plf$
B1.2 - Upward Buoya	ant Force:	Effe	ective weight
$w_b \! \coloneqq \! \left( \frac{\pi \cdot \left( {D_1}^2 + {D_2}^2 \right)}{4} \right)$	$\left(\frac{)}{b}\right) ho_w\!\cdot\!\gamma_b\!-\!w_a\!=\!44.6$	<i>plf</i> Upward t	puoyant force of empty pipe
B1.3 - Hydrokinetic F	Pressure:		
$\Delta T \coloneqq \Delta P \cdot \left(\frac{\pi}{8}\right) \left(D_r^2\right)$	$-(D_1^2 + D_2^2)) = 79$	6 <i>lbf</i> Hydrokin	etic force
B1.4 - Pullback Force	e Point A:		
$T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot$	$(L_1 + L_2 + L_3 + L_4)) =$		
B1.5 - Pullback Force	Point B.	Pullback	force when pipe enters the ground
DI.J - FUIDACK FOICE			
$T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_a + v_b \cdot \right)$	$ w_b  \cdot L_2 + w_b \cdot H_{max}$ -	$\cdot v_a \cdot w_a \cdot L_2 \cdot e^{\langle v_a \rangle}$	$(\alpha_{in}) = 7778 \ lbf$
			force increase with depth
B1.6 - Pullback Force	e Point C:		
$T_c \coloneqq T_b + (v_b \cdot w_b \cdot L_3)$	$-e^{\langle v_b \cdot \alpha_{in} \rangle} \cdot (\eta \cdot \eta \cdot \eta) \cdot I$	$\left(v_a \cdot \alpha_{in}\right) = 86$	60 <i>lbf</i>
$1_{c} = 1_{b} + (0_{b} - \omega_{b} - \omega_{3})$		<i><sup>1</sup></i> <sup>3</sup> <sup>2</sup> /=00	
B1.7 - Pullback Force	e at D:		
$T_d \coloneqq e^{(v_b \cdot \rho_{exit})} \cdot (T_c + v)$	$ w_b \cdot  w_b  \cdot L_4 - w_b \cdot H_{max}$	$x - e^{(v_a \cdot \alpha_{in})} \cdot (v_a \cdot \alpha_{in})$	$(\mathbf{w}_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})})) = 11168 \ lbf$
<u>B1.8 - Maximum Pull</u>	hack Force - Empty I	Pine	
DI.O Maximum run	back roice Empty	<u>-ipe.</u>	
$P_{max\_empty} \coloneqq \max(T_{e})$	$(T_b, T_c, T_d) + \Delta T =$	11965 <i>lbf</i>	
	,		n Pullback Force
B2 - Filled Pipe with B2.1 - Upward Buoya			
$w_{bfilled} \! \coloneqq \! \left( \! \left( \! \left( \! \pi \cdot D_1^{\; 2}  ight) \! \left( \! \left( \! \pi \cdot D_1^{\; 2}  ight) \! \left( \! 4 \! \right) \! \right) \! \right) \! \left( \! 4 \! \right) \!$	$\cdot \rho_w \cdot \left( \gamma_b - \gamma_c \cdot \left( 1 - \left( \frac{1}{R} \right) \right) \right) \right)$	$\left(\frac{2}{DR_1}\right)$ $-w_a =$	18.3 <i>plf</i>
		Upward b	puoyant force of pipe filled with wat
B2.2 - Pullback Force	e Point A:		

$T_{afillod} := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot$	$w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 748 \ lbf$	Pullback force enter ground
ujiiieu (*u	$a \left( 1 \cdot 2 \cdot 3 \cdot 4 \right) = b \cdot b$	J



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B2.3 - Pullback Force Point B:	
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_{afilled} + v_b \cdot  w_{bfilled}  \cdot L_2 + \frac{B2.4 - Pullback Force Point C:}{2} \right)$	$w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{\langle v_a \cdot \alpha_{in} \rangle} = 4128 \ lb_a$ Pullback force increase and decrease widepth
$T_{cfilled} \coloneqq T_{bfilled} + \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_3 \right) - e^{\left( v_b \cdot \alpha_b \right)}$	$(v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})}) = 4453 \ lbf$
B2.5 - Pullback Force at D:	
$T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{cfilled} + v_b \cdot  w_{bfilled}  \cdot L_{d}\right)$	$_{\mathbf{A}} - e^{\left(v_{a} \cdot \alpha_{in}\right)} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{\left(v_{a} \cdot \alpha_{in}\right)}\right) = 6274 \ lbf$
B2.6 - Maximum Pullback Force - Filled Pip	e with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$	$_{d}) = 6274 \ lbf$ Maximum Pullback Force
3 - Safe Pull Strength / Ultimate Tensil B3.1 Safe Pullback Check	le Load 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
$A_2 \coloneqq \frac{\pi}{4} \left( D_2^2 - \left( D_2 - T_{p2} \right)^2 \right) = 0.8 \ in^2$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max\_empty}}{A_1 + A_2} = 11500 \ lbf$	Pullback forces acting on Pipe 1 (Empty
$P_{21} \coloneqq \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} = 464 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 6031 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ballas
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 243 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Ballas
$P_{SPF1} \coloneqq 41214 \ \textit{lbf}$	Safe pullback forces Pipe 1 (Table %, p. 448, PPI)
<i>P</i> <sub>SPF2</sub> ≔1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$check := if(P_{SPF1} > P_{11}, "okay", "not okay")$	
$check \coloneqq if(P_{SPF2} > P_{21}, "okay", "not okay")$	
$check \coloneqq if (P_{SPF1} > P_{12}, "okay", "not okay)$	
$check \coloneqq if(P_{SPF2} > P_{22}, "okay", "not okay)$	") = "okay"

4



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Calculated by: DA	
Allowable Mud Pressures:	
C1 - Max. Allowable Driling Fluid Pr Assumptions:	<u>'essure</u>
-MathCAD calculations are used for a cri HDD alignment crosses multiple structur	itical structure as identified for each crossing. If the res the one with least cover was used. Provided detailed herein, to identify potential frac-out areas. susceptible to frac-out due to low cover.
-Where applicable, soil properties refere Package 1, dated October 12, 2022.	nced from Kiewit's Proposed Soil Properties for CHPE
-Assume soil conditions of soft clay (CL) HDD alginment.	, B202.1-1 does not extend to bottom tangent of
- Diameter/radius based on the most cri	tical stage (i.e. during pilot tube)
-Asssume $\cot(0 \text{ deg}) = 0$ theoretically in	ıfinite)
$D_{PT} \coloneqq 5$ in	Pilot tube diameter
$D_0 \coloneqq 9.5 \ in$ $H_w \coloneqq 26.1 \cdot ft$	Initial borehole diameter for pilot tube Depth of the bore below groundwater elevation
$H_c \coloneqq 26.1 \ ft$	Vertical separation distance between critic structure and pipe (Stream, ~2+25)
$\gamma \coloneqq 110 \ pcf$	Assumed unit weight soft clay
$\begin{array}{l} \gamma_w \coloneqq 62.4 \ pcf \\ \gamma' \coloneqq \gamma - \gamma_w = 47.6 \ pcf \\ u \coloneqq \gamma_w \cdot H_w = 11 \ psi \\ \phi \coloneqq 0 \ deg \end{array}$	Unit weight of water Effective unit weight Initial pore water pressure Assumed friction Angle
$c \coloneqq 800 \ psf = 5.56 \ psi$	Assumed cohesion of encountered materi
$R_0 := rac{D_{rod}}{2} = 1.75 \; in$	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{1}{2} \cdot H_c = 13 \ ft$	Radius of plastic zone (H/2 in clays & 2/3 H in sands)
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 9 \ ps$ $Table C.2 Typical values of modulus of elasticity (£) for different types of soils \overline{\frac{Type of Soil}{E_{s}}} = \frac{E_{s}(Nimm^{2})}{E_{s}(Nimm^{2})}$	i Initial effective stress
Very soft 2–15 Soft 5–25 Medium 15–50 Hard 50–100	
11ad         50-100           Sandy         25-250           Glacial III         Loose           Loose         10-153	$E_s \coloneqq 15 \frac{N}{mm^2} = 2176 psi$
Dense 144-720 Very dense 478-1440 Loeses 14-57	
Lores 14-37 Sand Sinty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose 96-192	Assumed modulus of elasticity
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	
Clay (saturated) Clay (unsaturated)	0.4 - 0.5 0.1 - 0.3	
Sandy clay Silt	0.2 - 0.3 0.3 - 0.35	
Sand (dense) Course (void ratio = $0.4 - 0.7$ )	0.2 - 0.4 0.15	$\nu_s \coloneqq 0.4$
Fine grained (void ratio = $0.4 - 0.7$ ) Rock	0.25 0.1-0.4 (depends on type of rock)	Poissions ratio of material encountered
Loess Ice	0.1 – 0.3 0.36	
Concrete	0.15	
$E_s$ 777	nai	Shear modulus of soil
$G \coloneqq \frac{E_s}{2 \left(1 + \nu_s\right)} = 777$	psi	
= (- + - s)		
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + \left(\sigma'_{0} \cdot \sin(\phi)\right)}{G}$	e•0)	
$Q \coloneqq \frac{G}{G}$	=0	
C		Coefficient of Delft Equation
$m' = -(1 + \sin(4))$	1 0 000 (4) 14 5	
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi))$	$+c \cdot \cos(\varphi) = 14.2$	
		Mud pressure at which the first plastic
		deformation takes place
	(	$-\sin(\phi)$
	$((\mathbf{D})^2)^{(1)}$	$1 + \sin(\phi)$
$p'_{max} \coloneqq \left( p'_f + (c \cdot 0) \right) \cdot$	$\left(\left(\frac{R_0}{R_{pmax}}\right) + Q\right)$	$\left  -c \cdot 0 = 14.2  psi \right $
		Maximum allowable effective mud pressure (Delft Equation)
$p_{max} \coloneqq u + p'_{max} = 25.$	5 <b>psi</b>	Maximum allowable mud pressure
<u>C2 -Min. Allowable Dr</u>	illing Fluid Pres	sure
$h \coloneqq 41.4 \ ft$		Elevation difference between level of bore hole front and exit point of mud flow
$\gamma_m = 80 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 23 \ psi$		Minimum required mud pressure to
		overcome differntial head
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
lbf		
$\tau_o \coloneqq 16 \ \frac{lbf}{100 \cdot ft^2}$		Assumed yield point of mud per 100
		square feet
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		
$\mu_{pl} \coloneqq 25 \cdot \frac{\mu_{pl}}{100}$		Assumed plastic viscosity of mud
100		
$v \coloneqq \frac{Q_f}{0.785 (D_0^2 - D_{PT})}$	-75.2 ft	Computed mud flow velocity
$0\frac{0.785}{0.785}(D_0^2 - D_{m})$	$\frac{1}{m^2}$ - 13.2 $\frac{1}{min}$	
	/	

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$L_{structure} \coloneqq 225 \; ft$		Length to sturcture
$\left( \left( \frac{\mu_{pl} \cdot v}{\left( D_0 - D_{PT} \right)^2} \right) + \left( \frac{1}{\left( \frac{1}{2} \right)^2} \right) \right)$	$\left(\frac{\tau_o}{D_0 - D_{PT}}\right) = 0.003$	$\left(\frac{psi}{ft}\right) = 0.7 \ psi$ $\left(\frac{p}{D_{PT}}\right) = 0.7 \ psi$ Minimum required mud pressure to create
$p_2 \coloneqq L_{structure} \cdot \left( \left( \frac{P_1}{(D_0)} \right) \right)$	$\frac{u_{pl} \cdot v}{-D_{PT}}\Big)^2 + \left(\frac{\tau_a}{(D_0 - I_0)}\right)^2 + \frac{\tau_a}{(D_0 - I_0)} + \frac{\tau_a}{$	$ \left( \begin{array}{c} D_{PT} \\ D_{PT} \end{array} \right) = 0.7 \ \textbf{psi} $ Minimum required mud pressure to create flow inside the borehole
$p_{min.} := p_1 + p_2 = 23.7$	psi	Minimum required mud pressure
abaaba <b>if</b> (maaama	"alarr" "ratal	
$check \coloneqq \mathbf{if} \left( p_{max} > p_m \right)$	<sub>lin.</sub> , "Okay", "not ok	(ay'') = "okay"



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D1.1 - Overburden Pressure (Considering	Deformed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 44.7 \ ft$	Depth of cover
$\phi = 0 \ deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 110 \ pcf$	Unit weight of soil, assumed
Can't divide by 0 $\sim$ assume k goes to 1 (i	
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} \qquad k \coloneqq$	1 Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 15 \ psi \ P_E = 2123$	
D1.2 Earth Load Deflection (Short Term)	
$E_{short} = 57500 \cdot psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \text{ psi}$	Variable in earth load deflection equation
$\Delta y_{ELD\_short} \coloneqq \frac{0.0125 \cdot P_E}{k_{short}} = 2.0\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboo
D1.3 Earth Load Deflection (Long Term)	
$E_{long} \coloneqq 28200 \cdot psi$	Apparent modulus of elasticity for PE4710 Base Temperature of 73 Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 4.0\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)



 $\mu_{long} \coloneqq 0.45$ 

 $R = 1000 \ ft$ 

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2 - 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
$E_{short} = 57500 \ psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1)
$\gamma_m = 80 \ pcf$	Assumed unit weight of fluid in borehole (Slurry unit weight)
$I := \frac{t^{\circ}}{12} = 0.14 \frac{in^{\circ}}{in} (D)^{4}$	Moment of inertia of pipe wall cross section
$\gamma_{m} = 80 \text{ pcf}$ $I \coloneqq \frac{t^{3}}{12} = 0.14 \frac{in^{4}}{in}$ $\Delta y_{bouyant} \coloneqq \frac{0.1169 \cdot \gamma_{m} \cdot \left(\frac{D_{1}}{2}\right)^{4}}{E_{short} \cdot I} = 0.1\%$	Pipe ring deflection to buoyant forc ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Deflection (Long Term)	
Please note that long term buoyant deflection assumed to be cured after a 1-week period f	
<u>3 - Reissner Effect Deflection (Short Terr</u> D3.1 - Reissner Effect Deflection (Short Term	
	D) Poisson's Ratio for PE pipe material
D3.1 - Reissner Effect Deflection (Short Term $\mu_{short} := 0.35$	Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2)
D3.1 - Reissner Effect Deflection (Short Term $\mu_{short} \coloneqq 0.35$ $R = 1000 \ ft$	Poisson's Ratio for PE pipe material short term (ASTM F 1962, 8.2.4.2) Radius of curvature

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



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$\Delta y_{lim} \coloneqq 7.5$	%			n limit for DR 9 non p ble 2 , p. 437, PPI Ha	
D4.1 - Net	Short Term	P		лс <i>2</i> , р. 137, 111 на	nubbook)
$\Delta y_{short\_net}$ :=	$=\Delta y_{ELD\_short} + \Delta y_{bouyant}$	$t + \Delta y_{R\_short} =$		Percent ring deflectio term analysis	n in sho
$\frac{Check := if}{} ($	$\langle \Delta y_{short\_net} < \Delta y_{lim},$ "ok	<mark>ay", "not oka</mark>	ay") = "c	bkay"	
<u>D4.2 - Net</u>	Long Term				
$\Delta y_{long\_net}$ :=	$\Delta y_{ELD\_long} + \Delta y_{R\_long} =$			ing deflection in long (50 years)	term
$Check \coloneqq \mathbf{if} \left( \right)$	$(\Delta y_{long\_net}\!<\!\Delta y_{lim},$ "oka	ıy", "not oka	y") = "o]	kay"	



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D5.1 - Unconstrained Ring Buckling, Levy	's Equation (Short Term-During Pull)
Note that constraining the pipe will increat considering an unconstrained condition w	ase the pipe's buckling strength, therefore vill produce a conservative value.
N := 2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$E_{short} \!=\! 57500 \; psi$	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg.
% Deflection	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
0 2 4 6 8 10 12	
0.0	
0.2	
0.4	Ovality compensation factor, Figure
f <sub>0</sub> 0.4	3 (PPI Chp. 12). Calculated deflection limit in section D4.1
0.6	deflection limit in section D4.1
0.8	$f_{o \ short} := 0.87$
1.0	Jo_snort 0101
$P_{UC\_short} := \left( \frac{2 \cdot L_{short}}{2} \right) \cdot \left( \frac{1}{DD} \right)^{\circ} \cdot \frac{J_{o}}{2}$	$\frac{-short}{N} = 111.3 \ psi$ Allowable unconstrained buckling pressure
$= \left(1 - \mu_{short}^2\right) \left(DR_1 - 1\right)$	N buckling pressure
$H = 44.3 \ ft$	Elevation difference between the lowest
	point in borehole and entry or exit pit
$P_{mud} \coloneqq \gamma_m \cdot H = 24.61 \ psi$	Pressure of drilling slurry
$P_{net} \coloneqq P_{mud} = 24.61 \ psi$	Net external loading with open borehole
$Check \coloneqq if \left( P_{UC\_short} > P_{net}, \text{``okay''}, \text{``not} \right)$	tokay") = "okay"
D5.2 - Unconstrained Ring Buckling, Levy	<u>/'s Equation (Long Term)</u>
Note that constraining the pipe will increa	ase the pipe's buckling strength, therefore
considering an unconstrained condition w	
N:=2.0	Factor of Safety
$\mu_{long} \coloneqq 0.45$	Poisson's Ratio for PE pipe material,
$\mu_{long} = 0.45$	long term (ASTM F 1962, 8.2.4.2)

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$E_{long} \!=\! 28200 \; psi$		PE4710, Ba Fahrenheit	nodulus of elasticity for use Temperature of 73 deg. at 50 years of sustained uble X1.1 ASTM F 1962)	
$f_{o\_long} \coloneqq 0.45$		3 (PPI Chp	npensation factor, Figure . 12). Use deflection limit n Section D4.2	
$(2 \cdot E_{long})$	$(1)^{3} f_{c}$	ong		
$P_{UC\_long} \coloneqq \left(\frac{2 \cdot E_{long}}{1 - \mu_{long}^2}\right)$	$\left  \cdot \left( \overline{DR_1 - 1} \right) \right  \cdot $	Allowable u pressure	inconstrained buckling	
$P_{GW} \coloneqq \gamma_w \cdot H_w = 11.31$	psi	-	er head pressure	
$P_{net} \coloneqq P_{GW}$		Net externa	al loading with open borehole	9
$Check \coloneqq if \left( P_{UC\_long} > \right)$	$P_{net}$ , "okay", "no	okay") = "okay"		
			•	



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ning Parameters of Horizontal Direct D₁ ≔ 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
$DR_1 \coloneqq 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216$ in	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 := \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
N	
drill rig B	A a
pipe exit C	В
· · ·	** ** *
$L_4$ ! $L_3$	
	L <sub>2</sub> L <sub>1</sub>
	L <sub>2</sub> L <sub>1</sub>
	18
Illustration 1 - Schematic of	18
Illustration 1 - Schematic of	<sup>•</sup> Drive Cross-section
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396$ rad	Drive Cross-section Borehole entry angle (degrees, radians)
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo
Illustration 1 - Schematic of $\alpha := 8^{\circ}$ $\alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10^{\circ}$ $\beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$	<sup>5</sup> Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 44.05 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 44.05 \ ft$ $L_{total} := 1176.5 \ ft$	<sup>5</sup> Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 44.05 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
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Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 44.05 \text{ ft}$ $L_{total} := 1176.5 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 234.6 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter 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 of $\alpha := 8^{\circ}$ $\alpha_{in} := \alpha = 0.1396 \ rad$ $\beta := 10^{\circ}$ $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 44.05 \ ft$ $L_{total} := 1176.5 \ ft$ $L_2 := 234.6 \ ft$ $L_{3_1} := 174.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
Illustration 1 - Schematic of $\alpha := 8$ ° $\alpha_{in} := \alpha = 0.1396 \text{ rad}$ $\beta := 10$ ° $\beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 43.3 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 44.05 \text{ ft}$ $L_{total} := 1176.5 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 234.6 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter 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

	roject: unnel No.: escription: alculated by: SA hecked by: NW	Champlain Hudson Power Express - Package 6 Crossing #94- Main Street & CSX Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23
$L_4 := 285.9 \; ft$		Horizontal distance to rise to surface, See Illustration 1
<i>H</i> ≔ 32 <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)
$\rho_w := 62.4 \ pcf$		Unit weight of water
$\gamma_a := 0.965$		Specific gravity of pipe
$\gamma_m \coloneqq 90 \ pcf$		Assumed unit weight of slurry
$\gamma_b \! \coloneqq \! \frac{\gamma_m}{\rho_w} \! = \! 1.4$		Specific gravity of slurry, assumed unit weight
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant
A - Axial Bending Stress:		
$R_{avg.\_in}$ :=1000 $ft$		Radius of curvature at the entry, provided by Contractor
$\frac{R_{avg.\_out} \coloneqq 1000 \ ft}{ft}$		Radius of curvature at the exit, provided by Contractor
$R \coloneqq rac{R_{avg\_in} + R_{avg\_out}}{2} =$	1000 <b>ft</b>	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350$ j	ft	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left( R_{avg.\_in} > r_{rot} \right)$	<sub>d</sub> , "okay", "not	cokay") = "okay"
$Check \coloneqq \mathbf{if} \left( R_{avg.\_out} > r_{re} \right)$	od, "okay", "no	t o kay") = "o kay"

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  $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{4}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ 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:  $T_a \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4 \right) \right) = 845 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B:  $T_{b} \coloneqq e^{v_{b} \cdot \alpha_{in}} \left( T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 6746 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C1:  $T_{c_1} := T_b + (v_b \cdot w_b \cdot L_{3-1}) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_{3-1} \cdot e^{(v_a \cdot \alpha_{in})}) = 9276 \ lbf$ B1.7 - Pullback Force Point C2:  $\alpha_{curve} \coloneqq 18.9$  $T_{c_{2}} := e^{v_{b} \cdot \alpha_{curve}} \left( T_{c_{1}} + v_{b} \cdot |w_{b}| \cdot L_{3_{2}} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{3_{2}} \cdot e^{(v_{a} \cdot \alpha_{curve})} \right) = 13215 \ lbf$ B1.8 - Pullback Force Point C3:  $T_{c_{3}} := T_{c_{2}} + (v_{b} \cdot w_{b} \cdot L_{3_{3}}) - e^{(v_{b} \cdot \alpha_{curve})} \cdot (v_{a} \cdot w_{a} \cdot L_{3_{3}} \cdot e^{(v_{a} \cdot \alpha_{curve})}) = 15059 \ lbf$ B1.9 - Pullback Force at D:  $T_{d} := e^{(v_{b} \cdot \beta_{exit})} \cdot \left(T_{c \ 3} + v_{b} \cdot |w_{b}| \cdot L_{4} - w_{b} \cdot H_{max} - e^{(v_{a} \cdot \alpha_{in})} \cdot \left(v_{a} \cdot w_{a} \cdot L_{4} \cdot e^{(v_{a} \cdot \alpha_{in})}\right)\right) = 17904 \ lbf$ B1.10 - Maximum Pullback Force - Empty Pipe:  $P_{max\_empty} \coloneqq \max \left( T_a, T_b, T_{c\_1}, T_{c\_2}, T_{c\_3}, T_d \right) + \Delta T = 18700 \ \textit{lbf}$ Maximum Pullback Force



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	2)
$w_{bfilled} \coloneqq \left(\frac{\left(\boldsymbol{\pi} \cdot \boldsymbol{D}_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{1}{2}\right)\right)\right)$	$\left(\frac{2}{DR_1}\right)\right) \left(-w_a = 24.6 \ plf\right)$
	Upward buoyant force of pipe filled with water
B2.2 - Pullback Force Point A:	
$T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_{3_1} + L_3 \right) \right) + C_{afilled} = C_{afilled} = C_{afilled} = C_{afilled} + C_{afilled} = C_{afilled} + C_{afilled} +$	
D2 2 Dullhack Favor Daint D	Pullback force enter ground
B2.3 - Pullback Force Point B:	
	$+ w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 4009 \ lbf$ Pullback force increase and decrease with
B2.4 - Pullback Force Point C1:	depth
$T_{c1\_filled} \coloneqq T_{bfilled} + \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_{3\_1} \right) - e^{-\frac{1}{2}} \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_{3\_1} \right) - e^{-\frac{1}{2}} \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_{3\_1} \right) \right) = e^{-\frac{1}{2}} \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_{3\_1} \right) - e^{-\frac{1}{2}} \left( v_b \cdot \left  w_{bfilled} \right  \cdot L_{3\_1} \right) \right)$	$e^{(v_b \cdot lpha_{in})} \cdot \left( v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot lpha_{in})}  ight) = 5147 \ lbf$
$\frac{\text{B2.5 - Pullback Force Point C2:}}{\alpha_{curve} = 18.9} ^{\circ}$	
$\sigma_{iilled} \coloneqq e^{v_b \cdot \alpha_{curve}} \left( T_{c1\_filled} + v_b \cdot \left  w_{bfilled} \right  \cdot L_{3\_2} \right)$	$ + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curve})} ) = 7160 $
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) - $	$-e^{\left(v_b \cdot \alpha_{curve}\right)} \cdot \left(v_a \cdot w_a \cdot L_{3_{-1}} \cdot e^{\left(v_a \cdot \alpha_{curve}\right)}\right) = 7941 \ lbf$
B2.7 - Pullback Force at D:	
$T_{dfilled} := e^{(v_b \cdot \beta_{exit})} \cdot (T_{c3} filled + v_b \cdot  w_{bfilled} $	$  \cdot L_4 - e^{(v_a \cdot lpha_{in})} \cdot (v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot lpha_{in})})) = 10338 \ lbf$
B2.8 - Maximum Pullback Force - Filled P	Pipe with Water:
B2.8 - Maximum Pullback Force - Filled P $P_{max}$ := max $(T_{afilled}, T_{bfilled}, T_{c1_filled}, T_{c2_filled}, T_{c2_fille$	$T_{2_{filled}}, T_{c3_{filled}}, T_{dfilled}) = 10338 \ \textit{lbf}$ Maximum Pullback Force
B2.8 - Maximum Pullback Force - Filled P $P_{max} \coloneqq \max \left( T_{afilled}, T_{bfilled}, T_{c1_{filled}}, T_{c1_{fil$	$T_{2_{filled}}, T_{c3_{filled}}, T_{dfilled}) = 10338 \ \textit{lbf}$ Maximum Pullback Force
B2.8 - Maximum Pullback Force - Filled P $P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{c1_filled}, T_{c2}\right)$ <b>3 - Safe Pull Strength / Ultimate Tens</b> B3.1 Safe Pullback Check $A_1 \coloneqq \frac{\pi}{4} \left(D_1^2 - \left(D_1 - T_{p1}\right)^2\right) = 19 \ in^2$	$T_{2_{filled}}, T_{c3_{filled}}, T_{dfilled}) = 10338 \ \textit{lbf}$ Maximum Pullback Force
B2.8 - Maximum Pullback Force - Filled P $P_{max} \coloneqq \max \left(T_{afilled}, T_{bfilled}, T_{c1_{filled}}, T_{c1_{fill$	$T_{c3\_filled}, T_{dfilled}, T_{dfilled}$ = 10338 <b><i>lbf</i></b> Maximum Pullback Force <b>sile Load Check:</b>

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$P_{21} \coloneqq \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} =$	=726 <b>lbf</b>	Pullback forces acting on Pipe 2 (Empty)	!
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 9937$	7 <b>lbf</b>	Pullback forces acting on Pipe 1 (Ballast)	)
$P_{22} \! \coloneqq \! \frac{A_2 \! \cdot \! P_{max}}{A_1 \! + \! A_2} \! = \! 401$	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)	
$check \coloneqq if (P_{SPF1} > P_1)$	, "okay", "not ol	ay") = "okay"	
$\underline{\qquad} check \coloneqq \mathbf{if} \left( P_{SPF2} > P_2 \right)$			
$\underline{\qquad} check \coloneqq \mathbf{if} \left( P_{SPF1} > P_1 \right)$			
$\underline{\qquad} check \coloneqq \mathbf{if} \left( P_{SPF2} > P_{22} \right)$	$_2,$ "okay", "not ol	tay") = "okay"	



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

<u>C1 -</u>	Max.	Allov	vable	Driling	Fluid	Pressure

Assumptions:

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

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

- Geologic conditions through alignment will vary from very poor (inferred from weathered rock) to fair rock mass quality based on Boring K204.2. Assume critical section is silty sand based on boring K-203.5 & -.6 for Mathcad.

$H_w \coloneqq 16.5 \cdot ft$	Depth of the bore below groundwater elevation
$H_c \coloneqq 27 \ ft$	Vertical separation distance between critica structure and pipe (Main St)
$\gamma \coloneqq 125 \ pcf$	Assumed unit weight silty sand (SM)
$\gamma_w \coloneqq 62.4 \ pcf$	Unit weight of water
$\gamma' \coloneqq \gamma - \gamma_w = 62.6 \ pcf$	Effective unit weight
$u \coloneqq \gamma_w \cdot H_w = 7 \ psi$	Initial pore water pressure
$\phi \coloneqq 34 \ deg$	Assumed friction Angle
$c \coloneqq 0 \ psf = 0 \ psi$	Assumed cohesion of encountered material
$R_0 := rac{D_{rod}}{2} = 1.75$ in	Initial radius of the borehole
$R_{pmax} \coloneqq \frac{2}{3} \cdot H_c = 18 \ ft$	Radius of plastic zone (H/2 in clays &
3	2/3 H in sands)
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$	2/3 H in sands)
J	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ <b>Table C.2</b> Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\underbrace{\frac{\text{Type of Soil}  E_{s} \left( \text{N/mm}^{2} \right)}{\text{Clay}}$	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{\frac{\text{Type of Soil}  E_{s} \left( \text{N/mm}^{2} \right) \\ \text{Clay}}_{\text{Very soft}}  2-15}$	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ <b>Table C.2</b> Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{\frac{\text{Type of Soil}  E_{s} (\text{N/mm}^{2})}{\text{Clay}}}_{\text{Very soft}}$ Soft $5-25$	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} \coloneqq \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{\frac{\text{Type of Soil}  E_{s} \left( \text{N/mm}^{2} \right) \\ \text{Clay}}_{\text{Very soft}}  2-15}$	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ <b>Table C.2</b> Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{\frac{\text{Type of Soil}  E_{s} (\text{N/mm}^{2})}{\text{Clay}}}_{\text{Very soft}}$ Soft $5-25$ Medium $15-50$	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ <b>Table C.2</b> Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{\frac{\text{Type of Soil}  E_{x} (N/\text{mm}^{2})}{\text{Clay}}}$ $\boxed{\frac{\text{Clay}}{\text{Very soft}}  2-15}$ $\boxed{\text{Soft}  5-25}$ $\boxed{\text{Medium}  15-50}$ $\boxed{\text{Hard}  50-100}$ $\boxed{\text{Sandy}  25-250}$ $\boxed{\text{Glacial till}}$	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ Table C.2 Typical values of modulus of elasticity (E <sub>3</sub> ) for different types $\boxed{Type \text{ of Soil} \qquad E_{s}(\text{N/mm}^{2})}$ Clay Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{Type of Soil \qquad E_{s} (N/mm^{2})}$ 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	2/3 H in sands) 16 <i>psi</i> Initial effective stress
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E</i> <sub>s</sub> ) for different types $\boxed{\frac{\text{Type of Soil}  E_{s} (\text{N/mm}^{2})}{\text{Clay}}}$ Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153 Dense 144-720 Very dense 478-1,440	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w}\right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types $\boxed{Type of Soil \qquad E_{s} (N/mm^{2})}$ 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	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E<sub>s</sub></i> ) for different types           Type of Soil <i>E<sub>x</sub></i> (N/mm <sup>2</sup> )           Clay         Very soft         2-15           Soft         5-25           Medium         15-50           Hard         50-100           Sandy         25-250           Glacial till         Loose           Lose         10-153           Dense         478-1,440           Loess         14-57	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w}\right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E</i> <sub>s</sub> ) for different types $\boxed{Type of Soil \qquad E_{s}(N/mm^{2})}$ 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 144-720 Very dense 144-720 Very dense 14-57 Sand Silty 7-21 Loose 10-24	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) + \gamma' \cdot H_{w} \right) = 1$ <b>Table C.2</b> Typical values of modulus of elasticity ( <i>E</i> <sub>s</sub> ) for different types $\boxed{\text{Type of Soil} \qquad E_{s} (N/mm^{2})}$ Clay Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153 Dense 144-720 Very dense 478-1,440 Loess 14-57 Sand Silty 7-21 Loose 10-24 Dense 48-81	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w}\right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E</i> <sub>s</sub> ) for different types $\boxed{Type of Soil \qquad E_{s}(N/mm^{2})}$ 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 144-720 Very dense 144-57 Sand Silty 7-21 Loose 10-24 Dense 10-24 Dense 48-81 Sand and gravel	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w}\right) = 1$ Table C.2 Typical values of modulus of elasticity ( <i>E</i> <sub>s</sub> ) for different types $\boxed{Type of Soil \qquad E_{s} (N/mm^{2})}$ Clay Very soft 2-15 Soft 5-25 Medium 15-50 Hard 50-100 Sandy 25-250 Glacial till Loose 10-153 Dense 144-720 Very dense 478-1,440 Loess 14-57 Sand Sitty 7-21 Loose 10-24 Dense 48-81 Sand and gravel Loose 48-148	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$
$\sigma'_{0} := \left(\left(\gamma \cdot \left(H_{c} - H_{w}\right)\right) + \gamma' \cdot H_{w}\right) = 1$ <b>Table C.2</b> Typical values of modulus of elasticity ( <i>E</i> <sub>s</sub> ) for different types $\boxed{Type of Soil \qquad E_{s} (N/mm^{2})}$ 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 144-720 Very dense 144-720 Very dense 144-57 Sand Sitty 7-21 Loose 10-24 Dense 10-24 Dense 48-81 Sand and gravel	2/3 H in sands) 16 <i>psi</i> Initial effective stress s of soils $E_s := 7 \frac{N}{mm^2} = 1015 \ psi$

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Table C.4 Typical values of Poisson's ratio (μ) fo	soils	
Clay (saturated) Clay (unsaturated)	$\mu$ 0.4 - 0.5 0.1 - 0.3	
Sandy clay Silt	0.2 - 0.3 0.3 - 0.35	
Sand (dense) Course (void ratio = $0.4 - 0.7$ )	0.2 - 0.4 0.15	$\nu_s = 0.25$
Fine grained (void ratio = 0.4 – 0.7) Rock	0.25 0.1-0.4 (depends on type of rock)	Poissions ratio of material encountered
Loess Ice Concrete	0.1 – 0.3 0.36 0.15	
E.		
$G \coloneqq \frac{E_s}{2 \left(1 + \nu_s\right)} = 406$	psi	Shear modulus of soil
$(\sigma'_0 \cdot \sin(\phi)) + (\phi)$	$c \cdot \cot(\phi)$	
$Q \coloneqq \frac{\left(\sigma'_{0} \cdot \sin(\phi)\right) + \left(\phi'_{0} \cdot \sin(\phi)\right)}{G}$	=0.022	4
		Coefficient of Delft Equation
$p'_f \coloneqq \sigma'_0 \cdot (1 + \sin(\phi))$	$+c \cdot \cos{(\phi)} = 25.4$	
		Mud pressure at which the first plastic deformation takes place
	(	$(-\sin(\phi)))$
		$\left(\overline{1+\sin(\phi)}\right)$
$p'_{max} \coloneqq (p'_f + (c \cdot \cot ($	$(\phi))) \cdot \left( \left( \left( \frac{R_0}{R_{pmax}} \right)^2 \right) \right)$	$+Q \left  \begin{array}{c} \left( \frac{-\sin(\phi)}{1+\sin(\phi)} \right) \\ -c \cdot \cot(\phi) = 99 \ psi \end{array} \right $
		Maximum allowable effective mud pressu
		(Delft Equation)
$p_{max} \coloneqq u + p'_{max} \equiv 100$	3.2 <i>psi</i>	Maximum allowable mud pressure
<u>C2 -Min. Allowable D</u>	rillina Fluid Pres	sure
$D_{PT} \coloneqq 5 in$		Pilot tube diameter
$D_0 \coloneqq 9.5 \ in$		Initial borehole diameter for pilot tube
$h \approx 23.18 \text{ ft}$		Elevation difference between level of bore
		hole front and exit point of mud flow
$\gamma_m = 90 \ pcf$		Unit weight of slurry/mud
$p_1 \coloneqq \gamma_m \cdot h = 14.5 \ psi$		Minimum required mud pressure to
		overcome differntial head
$Q_f \coloneqq 200 \ gpm$		Assumed mud flow rate
lbf		Assumed vield point of mud per 100
$\tau_o \coloneqq 16 \; \frac{lbf}{100 \cdot ft^2}$		Assumed yield point of mud per 100 square feet
, poise		Assumed plastic viscosity of mud
$\mu_{pl} \coloneqq 25 \cdot \frac{poise}{100}$		
D <sub>eff</sub> ≔13.4870 <b>in</b>		Effective diameter of bundle

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D1.1 - Overburgen Pressure (Considering Der	ormed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 43.3 \ ft$	Depth of cover
$\phi = 34  deg$	Friction angle of soil
$B \coloneqq D_r = 18 \ in$	"Silo" width, conservative value =
$\left( \begin{array}{c} 1 \end{array} \right)^2$	reamed hole diameter
$B \coloneqq D_r = 18 \ in$ $K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 125 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{2} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k := \frac{1 - \cos \left( \frac{1}{2} - \frac{1}{2} $	Arching factor (Eq. 6, p.432, PPI)
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.073$	
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 1  psi \qquad P_E = 199  psf$	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.
	Fahrenheit at 10 hrs of sustained loading
F	(Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{3} = 9.36 \ psi$	Variable in earth load deflection equation
$k_{short} \coloneqq rac{E_{short}}{12 \cdot \left(DR_1 - 1 ight)^3} = 9.36 \ psi$	
$\Delta y_{ELD\_short} \! \coloneqq \! \frac{0.0125 \cdot P_E}{k_{short}} \! = \! 0.2\%$	Dine deflection to diameter as nor
$\Delta y_{ELD\_short} \coloneqq \underbrace{k_{short}}_{k_{short}} \equiv 0.2\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handboo
D1.3 Earth Load Deflection (Long Term)	PPI Equ. 10 (Chp 12, p 437, PPI handboo
	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
E	ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot \left(DR_1 - 1\right)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$12 \cdot (DR_1 - 1)^3$	
	Pipe deflection to diameter as per
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 0.4\%$	PPI Equ. 10 (Chp 12, p 437)



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	Checked by: NW	Date: 4/13/23
D2 - Buoyant Defle	<u>ction</u> ection (Short Term)	
$D_1 = 10.75 \ in$		Outside diameter of casing pipe
$t := T_{p1} = 1.194$ in		Thickness of casing pipe
$E_{short} = 57500 \ psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 Fahrenheit (Table B.1.1)
$\gamma_m = 90 \ pcf$		Assumed unit weight of fluid in borehole (Slurry unit weight)
$I \coloneqq \frac{t}{12} = 0.14 \frac{in}{in}$	$(D_1)^4$	Moment of inertia of pipe wall cross section
$0.1169$ $\Delta y_{bouyant} \coloneqq$	$\frac{1}{D_{short} \cdot I} \cdot \frac{\left(\frac{D_1}{2}\right)^4}{\left(\frac{D_1}{2}\right)^4} = 0.1\%$	Pipe ring deflection to buoyant force ASTM F 1962 (Eq. X2.6, p.6)
D2.1 Buoyant Defle	ection (Long Term)	
	-	ection was assumed negibile, since grout is iod from installation/pumping.
<u>D3 - Reissner Effec</u>	t Deflection (Short	Term)
D3.1 - Reissner Eff	ect Deflection (Short	Term)
$\mu_{short} := 0.35$		Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
$R = 1000 \ ft$		Radius of curvature

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



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D4 -	Net Rind	Deflection

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

D4.1 - Net Short Term

 $\Delta y_{short\_net} \coloneqq \Delta y_{ELD\_short} + \Delta y_{bouyant} + \Delta y_{R\_short} = 0.2\%$  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

 $\Delta y_{long\_net} \! \coloneqq \! \Delta y_{ELD\_long} \! + \Delta y_{R\_long} \! = \! 0.4\%$ 

Percent ring deflection in long term analysis (50 years)

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



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D5.1 - Unconstrained Ring Buckling	g, Levy's Equation (Short Term-During Pull)
Note that constraining the pipe will	l increase the pipe's buckling strength, therefore
considering an unconstrained cond	lition will produce a conservative value.
N:=2.0	Factor of Safety
$\mu_{short} \coloneqq 0.35$	Poisson's Ratio for PE pipe material at short term (ASTM F 1962, 8.2.4.2)
	Apparent modulus of elasticity for
$E_{short} = 57500 \ psi$	PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loading
% Deflection	(Table X1.1 ASTM F 1962)
0 2 4 6 8 10 12	
0.0	
0.2	Ovality compensation factor, Figure
fo 0.4	3 (PPI Chp. 12). Calculated
0.6	deflection limit in section D4.1
ASSUME LONG TERM	
1.0 TEPN 0.8 Assume LOND TEPN	$\frac{f_{o\_short} \coloneqq 0.98}{}$
1.0 TEPM 0.8 Assume LOND TEPM	$\frac{f_{o\_short} \coloneqq 0.98}{}$
$\begin{array}{c} \textbf{O'8} \\ \textbf{J'0} \\ \textbf{J'0} \\ \textbf{HOGEL} \end{array} \\ P_{UC\_short} \coloneqq \left( \frac{2 \cdot E_{short}}{1 - \mu_{short}^2} \right) \cdot \left( \frac{1}{DR_1 - 1} \right) \\ \end{array}$	$\int_{0\_short}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure
$P_{UC\_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$	$\int_{0-short}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit
$\begin{array}{c} \textbf{0'8} \\ \textbf{1'0} \\ \textbf{1'0} \\ \textbf{2'NOGL} \end{array} \\ P_{UC\_short} \coloneqq \left( \frac{2 \cdot E_{short}}{1 - \mu_{short}^2} \right) \cdot \left( \frac{1}{DR_1 - 1} \right) \\ \end{array}$	$\int_{0-1}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest
$P_{UC\_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$	$\int_{0-short}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit
$P_{UC\_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 20 \ psi$	$\int_{0-short}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole
$P_{UC\_short} \coloneqq \left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$ $P_{mud} \coloneqq \gamma_m \cdot H = 20 \ psi$ $P_{net} \coloneqq P_{mud} = 20 \ psi$	$f_{o\_short} := 0.98$ $\int_{0}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \ psi$ 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 pressure of drilling slurry between the lowest point in borehole of drilling slurry between the lowest pressure between the lowest pressure of drilling slurry between the lowest pressure between the lowest pressure of drilling slurry between the lowest pressure between the lowest pressure of drilling slurry between the lowest pressure between the lowest pressure of drilling slurry between the lowest pressure between the lowest pressure between the lowest pressure of drilling slurry between the lowest pressure between the lowest pressure between the lowest pressure of drilling slurry between the lowest pressure between the lowes
<b>O'8</b> <b>I O</b> <b>P</b> <sub>UC_short</sub> := $\left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$ $P_{mud} := \gamma_m \cdot H = 20 \ psi$ $P_{net} := P_{mud} = 20 \ psi$ $Check := if (P_{UC_short} > P_{net}, "okay")$ <b>D5.2 - Unconstrained Ring Buckling</b> Note that constraining the pipe will	$f_{o\_short} := 0.98$ $\int_{0}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi} \text{ Allowable unconstrained buckling pressure}$ 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" g, Levy's Equation (Long Term) I increase the pipe's buckling strength, therefore
<b>0'8</b> <b>1'0</b> <b>P</b> <sub>UC_short</sub> := $\left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$ $P_{mud} := \gamma_m \cdot H = 20 \ psi$ $P_{net} := P_{mud} = 20 \ psi$ $Check := if (P_{UC_short} > P_{net}, "okay")$ <b>D5.2 - Unconstrained Ring Buckling</b> Note that constraining the pipe will	$\int_{0\_short}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole ", "not okay") = "okay" g, Levy's Equation (Long Term) I increase the pipe's buckling strength, therefore lition will produce a conservative value.
<b>O'B</b> <b>I'O</b> <b>I'O</b> <b>P</b> <sub>UC_short</sub> := $\left(\frac{2 \cdot E_{short}}{1 - \mu_{short}^2}\right) \cdot \left(\frac{1}{DR_1 - 1}\right)$ $H = 32 \ ft$ $P_{mud} := \gamma_m \cdot H = 20 \ psi$ $P_{net} := P_{mud} = 20 \ psi$ $Check := if \left(P_{UC_short} > P_{net}, \text{``okay'}\right)$ <b>D5.2 - Unconstrained Ring Buckling</b> Note that constraining the pipe will considering an unconstrained cond	$f_{o\_short} \coloneqq 0.98$ $\int_{0}^{3} \cdot \frac{f_{o\_short}}{N} = 125.4 \text{ psi}$ Allowable unconstrained buckling pressure Elevation difference between the lowest point in borehole and entry or exit pit Pressure of drilling slurry Net external loading with open borehole ", "not okay") = "okay" g, Levy's Equation (Long Term) I increase the pipe's buckling strength, therefore

	Project: Tunnel No.: Description: Calculated by: SA Checked by: NW	Champlain Hudson Power Express - Package 6 Crossing #94- Main Street & CSX Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R1: 9/18/23 Date: 4/13/23
$E_{long} {=} 28200 \; psi$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o\_long} \coloneqq 0.45$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
		$\frac{b\_long}{N} = 31.1 \text{ psi}$ Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 7.15$	psi	Groundwater head pressure
$P_{net} := P_{GW}$		Net external loading with open borehole
$Check := \mathbf{if} \langle P_{UC\_long} \rangle$	• P <sub>net</sub> , "okay" , "no	ot okay") = "okay"



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# **References**

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Champlain Hudson Power Express - Package 6 Crossing #95- Ravine Crossing Pull Back and Mud Pressure Calcs Date: 4/13/23 R2: 9/18/23 Date: 4/17/23

ning Parameters of Horizontal Directi D <sub>1</sub> := 10.75 <i>in</i>	Pipe 1 outer diameter
$D_1 := 10.15$ <i>in</i>	Pipe 2 outer diameter
$D_{2} = 2.515 \ in$ $D_{rod} = 3.5 \ in$	Assumed drill rod diameter
$DR_{1} := 9$	Dimension ratio of Pipe 1
$DR_1 := 5$ $DR_2 := 11$	Dimension ratio of Pipe 2
-	
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 := \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \pi \cdot D_2 = 7.5 $ in	Pipe circumference of pipe 2
bore/pipepath	pipe entry
drill rig 6	
β p	A a
H	
	B
pipeexit	
* <u> </u>	• • • • • • • •
L <sub>4</sub> L <sub>3</sub>	
- L <sub>bore</sub>	
L <sub>bore</sub> Illustration 1 - Schematic of	Drive Cross-section
Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$	Drive Cross-section Borehole entry angle (degrees, radians)
$\begin{array}{c} \textbf{L}_{\text{bore}} \\ \textbf{Illustration 1 - Schematic of} \\ \alpha \coloneqq 10 \\ \beta \coloneqq 10 \\ \beta \coloneqq \alpha_{in} \coloneqq \alpha = 0.1745 \\ \alpha_{in} \coloneqq \alpha = 0.1745 \\ \textbf{rad} \\ \beta_{exit} \coloneqq \beta = 0.1745 \\ \textbf{rad} \end{array}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians)
$\mathbf{L}_{\text{bore}}$ Illustration 1 - Schematic of $\alpha \coloneqq 10^{\circ} \qquad \alpha_{in} \coloneqq \alpha = 0.1745 \text{ rad}$ $\beta \coloneqq 10^{\circ} \qquad \beta_{exit} \coloneqq \beta = 0.1745 \text{ rad}$ $D_r \coloneqq 18 \cdot in$ $H_{max} \coloneqq 53 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bore
$\mathbf{\alpha} := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\boldsymbol{\beta} := 10^{\circ} \qquad \boldsymbol{\beta}_{exit} := \boldsymbol{\beta} = 0.1745 \ rad$ $\boldsymbol{D}_r := 18 \cdot in$ $\boldsymbol{H}_{max} := 53 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bore diameter Max depth to bore hole springline from
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 53 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \text{ ft}$ $L_{total} := 1241.4 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bore diameter Max depth to bore hole springline from ground surface
$L_{\text{tore}}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 53 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 53 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \ ft$ $L_{total} := 1241.4 \ ft$ $L_1 := 150 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \text{ rad}$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 53 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \text{ ft}$ $L_{total} := 1241.4 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 53 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \ ft$ $L_{total} := 1241.4 \ ft$ $L_1 := 150 \ ft$ $L_2 := 472.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad \\ \beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad \\ D_r := 18 \cdot in \\ H_{max} := 53 \ ft \\ H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \ ft \\ L_{total} := 1241.4 \ ft \\ L_1 := 150 \ ft \\ L_2 := 472.6 \ ft \\ L_{3_1} := 100 \ ft \\ \end{bmatrix}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 10^{\circ}$ $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 53 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \ ft$ $L_{total} := 1241.4 \ ft$ $L_1 := 150 \ ft$ $L_2 := 472.6 \ ft$ $L_{3_1} := 100 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section, before curve
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 10^{\circ} \qquad \alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 10^{\circ} \qquad \beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 53 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \ ft$ $L_{total} := 1241.4 \ ft$ $L_1 := 150 \ ft$ $L_2 := 472.6 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bor diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 10^{\circ}$ $\alpha_{in} := \alpha = 0.1745 \ rad$ $\beta := 10^{\circ}$ $\beta_{exit} := \beta = 0.1745 \ rad$ $D_r := 18 \cdot in$ $H_{max} := 53 \ ft$ $H_{max1} := H_{max} + \frac{D_r}{2} = 53.75 \ ft$ $L_{total} := 1241.4 \ ft$ $L_1 := 150 \ ft$ $L_2 := 472.6 \ ft$ $L_{3_1} := 100 \ ft$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bore diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1 Straight horizontal section, before curve

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$L_4 := 361.6 \ ft$	Horizontal distance to rise to surface, See Illustration 1
$H \coloneqq 46 \ ft$	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)
<i>v<sub>b</sub></i> :=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
xial Bending Stress:	
$R_{avg.\_in} \coloneqq 1000 \ ft$	Radius of curvature at the entry, provided by Contractor
$R_{avg.\_out} \coloneqq 1000 \ ft$	Radius of curvature at the exit, provided by Contractor
$R \coloneqq \frac{R_{avg\_in} + R_{avg\_out}}{2} = 1000 \ ft$	Average radius of curvature at entry
$r_{rod} := 1200 \cdot D_{rod} = 350 \; ft$	ASTM F 1962-99, Equation 1, p7
$Check \coloneqq \mathbf{if} \left( R_{avg.\_in} > r_{rod}, \text{``okay''}, \text{``}\right)$	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:  $T_a := e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_{3_1} + L_{3_2} + L_{3_3} + L_4 \right) \right) = 1175 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B:  $T_{b} := e^{v_{b} \cdot \alpha_{in}} \left( T_{a} + v_{b} \cdot |w_{b}| \cdot L_{2} + w_{b} \cdot H_{max} - v_{a} \cdot w_{a} \cdot L_{2} \cdot e^{(v_{a} \cdot \alpha_{in})} \right) = 8615 \ lbf$ Pullback force increase with depth B1.6 - Pullback Force Point C1:  $T_{c_1} := T_b + (v_b \cdot w_b \cdot L_{3_1}) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_{3_1} \cdot e^{(v_a \cdot \alpha_{in})}) = 9666 \ lbf$ B1.7 - Pullback Force Point C2:  $\alpha_{curve} \coloneqq 8.18$  $\frac{\alpha_{curve} = 0.00}{T_{c_{-2}} := e^{v_b \cdot \alpha_{curve}}} \left( T_{c_{-1}} + v_b \cdot |w_b| \cdot L_{3_2} + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_{3_2} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 13784 \ lbf$ B1.8 - Pullback Force Point C3:  $T_{c_{3}} := T_{c_{2}} + (v_{b} \cdot w_{b} \cdot L_{3_{3}}) - e^{(v_{b} \cdot \alpha_{curve})} \cdot (v_{a} \cdot w_{a} \cdot L_{3_{3}} \cdot e^{(v_{a} \cdot \alpha_{curve})}) = 15515 \ lbf$ B1.9 - Pullback Force at D:  $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_{c-3} + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 18243 \ lbf$ B1.10 - Maximum Pullback Force - Empty Pipe:  $P_{max\_empty} \coloneqq \max \left( T_a, T_b, T_{c\_1}, T_{c\_2}, T_{c\_3}, T_d \right) + \Delta T = 19039 \ \textit{lbf}$ Maximum Pullback Force



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**B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force:  $w_{bfilled} \coloneqq \left( \frac{\left( \pi \cdot D_1^{\ 2} \right)}{4} \right) \cdot \rho_w \cdot \left( \gamma_b - \gamma_c \cdot \left( 1 - \left( \frac{2}{DR_1} \right) \right)^2 \right) - w_a = 12 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:  $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_3 + L_3 + L_3 + L_4)) = 1175 \ lbf$ Pullback force enter ground B2.3 - Pullback Force Point B:  $T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_{afilled} + v_b \cdot \left| w_{bfilled} \right| \cdot L_2 + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 4130 \ \textit{lbf}$ Pullback force increase and decrease with **B2.4 - Pullback Force Point C1:** depth  $T_{c1 \ filled} \coloneqq T_{bfilled} + (v_b \cdot |w_{bfilled}| \cdot L_{3 \ 1}) - e^{(v_b \cdot \alpha_{in})} \cdot (v_a \cdot w_a \cdot L_{3 \ 1} \cdot e^{(v_a \cdot \alpha_{in})}) = 4402 \ lbf$ B2.5 - Pullback Force Point C2:  $\alpha_{curve} = 8.18$  °  $T_{c2\_filled} \coloneqq e^{v_b \cdot \alpha_{curve}} \left( T_{c1\_filled} + v_b \cdot \left| w_{bfilled} \right| \cdot L_{3\_2} + w_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_{3\_2} \cdot e^{(v_a \cdot \alpha_{curve})} \right) = 5933 \ lbf$ B2.6 - Pullback Force Point C3:  $T_{c3\_filled} \coloneqq T_{c2\_filled} + (v_b \cdot |w_{bfilled}| \cdot L_{3\_3}) - e^{(v_b \cdot \alpha_{curve})} \cdot (v_a \cdot w_a \cdot L_{3\_1} \cdot e^{(v_a \cdot \alpha_{curve})}) = 6440 \ \textit{lbf}$ B2.7 - Pullback Force at D:  $T_{dfilled} \coloneqq e^{(v_b \cdot \beta_{exil})} \cdot \left(T_{c3} |_{filled} + v_b \cdot |w_{bfilled}| \cdot L_4 - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 7835 \ lbf$ B2.8 - Maximum Pullback Force - Filled Pipe with Water:  $P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{c1\_filled}, T_{c2\_filled}, T_{c3\_filled}, T_{dfilled}\right) = 7835 \ lbf$ Maximum Pullback Force B3 - Safe Pull Strength / Ultimate Tensile Load Check: B3.1 Safe Pullback Check  $A_1 := \frac{\pi}{4} \left( D_1^2 - \left( D_1 - T_{p1} \right)^2 \right) = 19 \ in^2$ Cross-sectional area of Pipe 1  $A_2 := \frac{\pi}{4} \left( D_2^2 - \left( D_2 - T_{p2} \right)^2 \right) = 0.8 \ in^2$ Cross-sectional area of Pipe 2  $P_{11} := \frac{A_1 \cdot P_{max\_empty}}{A_1 + A_2} = 18300 \ lbf$ Pullback forces acting on Pipe 1 (Empty)

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$P_{21} \coloneqq \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} =$	=739 <i>lbf</i>	Pullback forces acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 7531$	1 <i>lbf</i>	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} \coloneqq \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 304$	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)
$\begin{array}{l} check \coloneqq \mathbf{if} \left( P_{SPF1} > P_1 \right) \\ check \coloneqq \mathbf{if} \left( P_{SPF2} > P_2 \right) \end{array}$		
$\frac{check := \mathbf{if} (P_{SPF1} > P_{12})}{check := \mathbf{if} (P_{SPF1} > P_{12})}$		
$\underline{check} \coloneqq \mathbf{if} \left\langle P_{SPF2} > P_{22} \right\rangle$	$_2,$ "okay", "not ok	xay") = "okay"



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

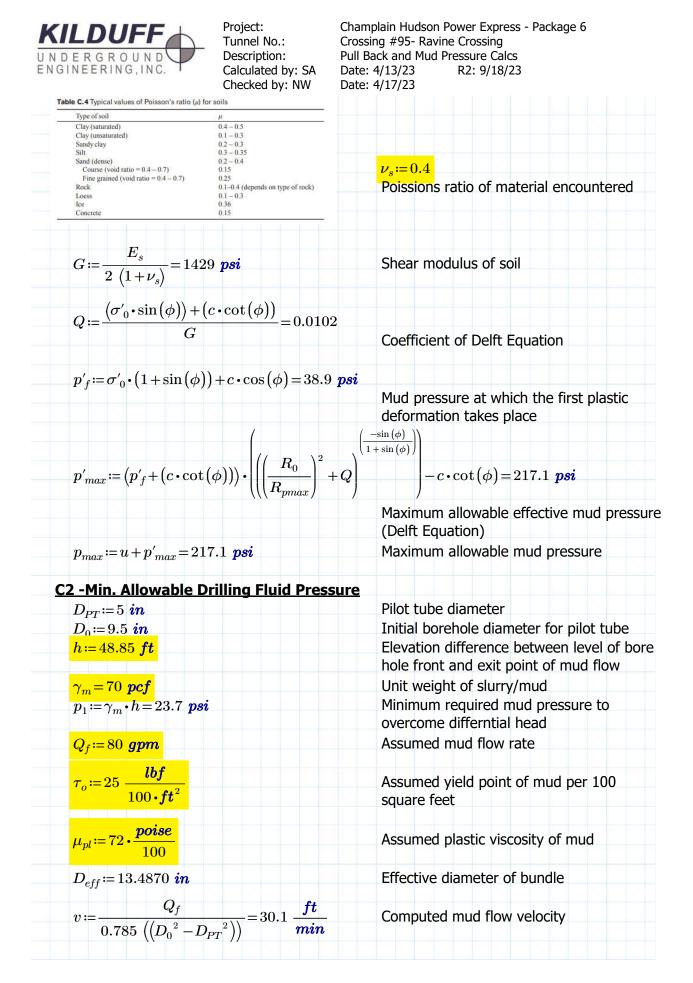
<u>C1 -</u>	Max.	Allow	vable	Driling	Fluid	Pressure

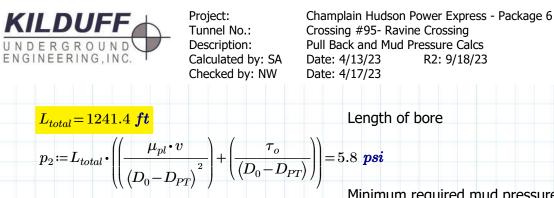
Assumptions:

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

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

$H_w \coloneqq 0 \cdot ft$		Depth of the bore below groundwater elevation
$H_c \coloneqq 25.0 \ ft$		Vertical separation distance between critica structure and pipe (Coyemans Creek)
$\gamma \coloneqq 140 \ pcf$		Assumed unit weight shale bedrock
$\gamma_w \coloneqq 62.4 \ pcf$		Unit weight of water
$\gamma' := \gamma - \gamma_w = 77.6 \ p$	of	Effective unit weight
	c j	
$u \coloneqq \gamma_w \cdot H_w = 0 \ psi$		Initial pore water pressure
$\phi \coloneqq 37 \text{ deg}$		Assumed friction Angle
$c \coloneqq 0 \ psf = 0 \ psi$		Assumed cohesion of encountered material
$R_0 := \frac{D_{rod}}{2} = 1.75$ in	L	Initial radius of the borehole
4		
J	$ft \\ )) + \gamma' \cdot H_w ) = 24 \ psi$	Radius of plastic zone (H/2 in clays & 2/3 H in sands) Initial effective stress
$\sigma'_{0} \coloneqq \left( \left\langle \gamma \cdot \left( H_{c} - H_{w} \right) \right\rangle \right)$	$\rangle\rangle + \gamma' \cdot H_w \rangle = 24 \ psi$	2/3 H in sands)
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ <b>C.2</b> Typical values of modulus of ela $Type \text{ of Soil}$ Clay Very soft Soft	$ (\mathbf{y}) + \gamma' \cdot H_w = 24 \ psi$	2/3 H in sands) Initial effective stress
$\tau'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ <b>C.2</b> Typical values of modulus of ela $\frac{\text{Type of Soil}}{\text{Clay}}$ Very soft	$(\gamma) + \gamma' \cdot H_w = 24 psi$ $(E_s) \text{ for different types of soils}$ $E_s (N/mm^2)$ 2-15	2/3 H in sands)
$\sigma'_0 \coloneqq \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$	$ (i) + \gamma' \cdot H_w = 24 psi$ $ \underline{F_s(N/m^2)} = 24 psi$ $ \underline{F_s(N/m^2)} = 2-15$ $ 5-25$ $ 15-50$	2/3 H in sands) Initial effective stress
$\tau'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ <b>C.2</b> Typical values of modulus of ela $\frac{1}{\text{Clay}}$ Very soft Soft Medium Hard	$ (F_{s}) + \gamma' \cdot H_{w} = 24 \ psi$	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense	$ (i) + \gamma' \cdot H_w = 24 psi$ $ (E_s) \text{ for different types of soils} $ $ (E_s (N/mm^2)) $ $ 2-15 $ $ 5-25 $ $ 15-50 $ $ 50-100 $ $ 25-250 $ $ 10-153 $ $ 144-720 $	2/3 H in sands) Initial effective stress
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ <b>C.2</b> Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glaciat till Loose Dense Very dense	$\gamma' \cdot H_w = 24 \text{ psi}$ sticity (E <sub>s</sub> ) for different types of soils $E_s (N/mm^2)$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ e C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense	$ (i) + \gamma' \cdot H_w = 24 psi$ $ (E_s) \text{ for different types of soils} $ $ (E_s (N/mm^2)) $ $ 2-15 $ $ 5-25 $ $ 15-50 $ $ 50-100 $ $ 25-250 $ $ 10-153 $ $ 144-720 $	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( \eta \cdot \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( \left( H_c - H_w \right) \right)$ $\sigma'_0 := \left( H_c - H_w \right)$ $\sigma'_0 := \left( H_c -$	$\gamma' \cdot H_w = 24 \text{ psi}$ sticity (E <sub>s</sub> ) for different types of soils $E_s (N/mm^2)$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_0 := \left( \left( \gamma \cdot \left( H_c - H_w \right) \right) \right)$ e C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose	$ (y) + \gamma' \cdot H_w = 24 \ psi$ $ (E_3) \text{ for different types of soils} \\ \hline E_4 (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 \\ \end{array} $	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
e C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense	$ ()) + \gamma' \cdot H_w ) = 24 \ psi$ Insticity (E <sub>3</sub> ) for different types of soils $ E_i (N/mm^2) $ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57 7-21	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ e C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand and gravel	$y) + \gamma' \cdot H_w) = 24 \ psi$ sticity (E <sub>5</sub> ) for different types of soils $E_i (N/mm^2)$ 2-15 5-25 15-50 50-100 25-250 10-153 144-720 478-1,440 14-57 7-21 10-24 48-81	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ e C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Verse Loose Dense	$ (y) + \gamma' \cdot H_w = 24 \ psi$ $ (E_3) \text{ for different types of soils} \\ \hline E_4 (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 \\ \end{array} $	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$
$\sigma'_{0} := \left( \left( \gamma \cdot \left( H_{c} - H_{w} \right) \right) \right)$ e C.2 Typical values of modulus of ela Type of Soil Clay Very soft Soft Medium Hard Sandy Glacial till Loose Dense Very dense Loess Sand Silty Loose Dense Sand agravel Loose	$ ()) + \gamma' \cdot H_w ) = 24 \ psi$ $ (E_s) \text{ for different types of soils} $ $ E_s (N/mm^2) $ $ 2-15  5-25  15-50  50-100  25-250  10-153  144-720  478-1,440  14-57  7-21  10-24  48-81  48-148 $	2/3 H in sands) Initial effective stress $E_s := 4000 \ psi$





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

R2: 9/18/23

 $p_{min.} = p_1 + p_2 = 29.5 \ psi$ 

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



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D1.1 - Overburden Pressure (Considering Defe	ormed Borehole with Arching Mobilized)
$H_c \coloneqq H_{max} = 53 \ ft$	Depth of cover
$\phi = 37 \ deg$	Friction angle of soil
$B \coloneqq D_r = 18 in$	"Silo" width, conservative value = reamed hole diameter
$K \coloneqq \tan\left(45 - \frac{\phi}{2}\right)^2$	Earth pressure coefficient
$\gamma = 140 \ pcf$	Unit weight of soil, assumed
$1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)$	
$k \coloneqq \frac{1 - \exp\left(-2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)\right)}{2 \cdot \frac{K \cdot H_c}{B} \cdot \tan\left(\frac{\phi}{2}\right)} = 0.061$	Arching factor (Eq. 6, p.432, PPI)
$P_E \coloneqq k \cdot (\gamma - \gamma_w) \cdot (H_c) = 2 psi  P_E = 250 psf$	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.
	Fahrenheit at 10 hrs of sustained loading (Table X1.1 ASTM F 1962)
$k_{short} \coloneqq \frac{E_{short}}{12 \cdot \left(DR_1 - 1\right)^3} = 9.36 \text{ psi}$	Variable in earth load deflection equation
, , ,	
$\Delta y_{ELD\_short} \! \coloneqq \! \frac{0.0125 \cdot P_E}{k_{short}} \! = \! 0.2\%$	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437, PPI Handbool
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
Elong	ASTM F 1962)
$k \coloneqq \frac{E_{long}}{12 \cdot (DR_1 - 1)^3} = 4.6 \ psi$	Variable in earth load deflection equation
$12 \cdot (DR_1 - 1)$	Dipo deflection to dispectance new
An $0.0125 \cdot P_E$ 0.507	Pipe deflection to diameter as per PPI Equ. 10 (Chp 12, p 437)
$\Delta y_{ELD\_long} \coloneqq \frac{0.0125 \cdot P_E}{k} = 0.5\%$	···· Equ. 10 (Crip 12, p +37)



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D2 -	<b>Buoyant Deflection</b>	

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

D2.1 Buoyant Deflection (Long Term)

- 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)

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

## D3 - Reissner Effect Deflection (Short Term)

D3.1 - Reissner Effect Deflection (Short Term)

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



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	<u>D4 -</u>	Net	Ring	Deflection
--	-------------	-----	------	------------

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

D4.1 - Net Short Term

 $\Delta y_{short\_net} \coloneqq \Delta y_{ELD\_short} + \Delta y_{bouyant} + \Delta y_{R\_short} = 0.3\%$  Percent ring deflection in short term analysis

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

D4.2 - Net Long Term

 $\Delta y_{long\_net} \! \coloneqq \! \Delta y_{ELD\_long} \! + \! \Delta y_{R\_long} \! = \! 0.5\%$ 

Percent ring deflection in long term analysis (50 years)

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



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D5.1 - Unconstrained Ring Buckling,	Levy's Equation (Short Term-During Pull)
	ncrease the pipe's buckling strength, therefore ion 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 <sub>short</sub> =57500 <b>рsi</b> % Delfection	Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 10 hrs of sustained loadin (Table X1.1 ASTM F 1962)
0.0 2 4 6 8 10	12
f <sub>0</sub> 6	Ovality compensation factor, Figure 3 (PPI Chp. 12). Calculated deflection limit in section D4.1
1.0	$f_{o\_short} \coloneqq 0.99$
	$\frac{f_{o\_short}}{N} = 126.7 \text{ psi}$ Allowable unconstrained buckling pressure
H=46 <b>ft</b>	Elevation difference between the lowest
$P_{mud} \coloneqq \gamma_m \cdot H = 22.36 \ psi$	point in borehole and entry or exit pit Pressure of drilling slurry
$P_{net} := P_{mud} = 22.36 \ psi$	Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left\langle P_{UC\_short} \! > \! P_{net}, \text{``okay''}, \right.$	"not okay") = "okay"
D5.2 - Unconstrained Ring Buckling,	Levy's Equation (Long Term)
	ncrease the pipe's buckling strength, therefore ion will produce a conservative value.
$N \coloneqq 2.0$	Factor of Safety
	-
$\mu_{long} := 0.45$	Poisson's Ratio for PE pipe material,

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$E_{long} \!=\! 28200 \; {psi}$		Apparent modulus of elasticity for PE4710, Base Temperature of 73 deg. Fahrenheit at 50 years of sustained loading (Table X1.1 ASTM F 1962)
$f_{o\_long} := 0.9$		Ovality compensation factor, Figure 3 (PPI Chp. 12). Use deflection limit calculated in Section D4.2
$(2 \cdot E_{long})$	) $(1)^3 f_a$	o long an a
$P_{UC\_long} \coloneqq \left( \frac{1}{1 - \mu_{long}^2} \right)^2$	$\left  \cdot \left( \overline{DR_1 - 1} \right) \right  \cdot$	$\frac{p_long}{N} = 62.2 \ psi$ Allowable unconstrained buckling pressure
$P_{GW} \coloneqq \gamma_w \cdot H_w = 0 \ ps$	į	Groundwater head pressure
$P_{net} := P_{GW}$		Net external loading with open borehole
$Check \coloneqq \mathbf{if} \left\langle P_{UC\_long} \right\rangle$	$P_{net}$ , "okay", "no	ot okay") = "okay"



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# **References**

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$D_1 := 10.75 \ in$	Pipe 1 outer diameter
$D_2 := 2.375 \ in$	Pipe 2 outer diameter
$D_{rod} := 3.5 \ in$	Assumed drill rod diameter
$DR_1 := 9$	Dimension ratio of Pipe 1
$DR_2 \coloneqq 11$	Dimension ratio of Pipe 2
$\begin{split} T_{p1} &\coloneqq \frac{D_1}{DR_1} {=} 1.194 ~\textit{in} \\ T_{p2} &\coloneqq \frac{D_2}{DR_2} {=} 0.216 ~\textit{in} \end{split}$	Thickness of Pipe 1
$T_{p2} := \frac{D_2}{DR_2} = 0.216 \ in$	Thickness of Pipe 2
$C_1 \coloneqq \pi \cdot D_1 = 33.8 \ in$	Pipe circumference of pipe 1
$C_2 \coloneqq \boldsymbol{\pi} \cdot D_2 = 7.5 \ \boldsymbol{in}$	Pipe circumference of pipe 2
bore/pipepath	pipe entry
N	
rill rig B D	A a
	10
pipeexit	В
I I I I	
$L_4$ : $L_3$	L <sub>2</sub> L <sub>1</sub>
L <sub>4</sub> : L <sub>3</sub>	
<l< td=""><td></td></l<>	
<l< td=""><td></td></l<>	
L <sub>tore</sub>	Drive Cross-section
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 12^{\circ}$ $\alpha_{in} := \alpha = 0.2094 \text{ rad}$	Drive Cross-section Borehole entry angle (degrees, radians)
$L_{\text{torse}}$ Illustration 1 - Schematic of $\alpha := 12^{\circ} \qquad \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter
$L_{\text{torse}}$ Illustration 1 - Schematic of $\alpha := 12^{\circ} \qquad \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8^{\circ} \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from
$L_{\text{torse}}$ Illustration 1 - Schematic of $\alpha := 12 \circ \qquad \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 12 \circ \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$ $L_{total} := 2124.6 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing
$L_{\text{torse}}$ Illustration 1 - Schematic of $\alpha := 12 \circ \qquad \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 12 \circ \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$ $L_{total} := 2124.6 \text{ ft}$ $L_1 := 150 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1
$L_{\text{bore}}$ Illustration 1 - Schematic of $\alpha := 12 \circ \qquad \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \qquad \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$ $L_{total} := 2124.6 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -
$L_{tors}$ Illustration 1 - Schematic of $\alpha := 12 \circ \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$ $L_{total} := 2124.6 \text{ ft}$ $L_1 := 150 \text{ ft}$ $L_2 := 208.2 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth - provided by Contractor, See Illustration 1
$L_{tore}$ Illustration 1 - Schematic of $\alpha := 12 \circ \alpha_{in} := \alpha = 0.2094 \text{ rad}$ $\beta := 8 \circ \beta_{exit} := \beta = 0.1396 \text{ rad}$ $D_r := 18 \cdot in$ $H_{max} := 79.8 \text{ ft}$ $H_{max1} := H_{max} + \frac{D_r}{2} = 80.55 \text{ ft}$ $L_{total} := 2124.6 \text{ ft}$ $L_1 := 150 \text{ ft}$	Drive Cross-section Borehole entry angle (degrees, radians) Borehole exit angle (degrees, radians) Final reamed bore diameter Max depth of bore hole to final reamed bo diameter Max depth to bore hole springline from ground surface Total length of HDD crossing Assumed pipe drag on surface, See Illustration 1 Horizontal length to achieve depth -

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$v_a := 0.1$		Friction coefficient before pipe enters (rollers assumed)	
$v_b := 0.3$		Friction coefficient for the bundle within borehole (lubrication assumed)	
$ ho_w \coloneqq 62.4 \ pcf$		Unit weight of water	
$\gamma_a \coloneqq 0.965$		Specific gravity of pipe	
$\gamma_m := 90 \ pcf$		Assumed unit weight of slurry	
$\gamma_b \! \coloneqq \! \frac{\gamma_m}{\rho_w} \! = \! 1.4$		Specific gravity of slurry, assumed unit weight	
$\gamma_c \coloneqq 1.0$		Specific gravity of water to fill the pipe	
$\Delta P \coloneqq 10 \ psi$		Hydrokinetic Pressure (p. 443, Ch12 PPI Handbook)	
$g \coloneqq 32.2 \frac{ft}{s^2}$		Gravitational Constant	
<u>A - Axial Bending Stress</u>	<u>::</u>		
$R_{avg.\_in}$ :=1000 $ft$		Radius of curvature at the entry, provided by Contractor	
$R_{avg\_out} \coloneqq 1000 \ ft$		Radius of curvature at the exit, provided by Contractor	
$ = R \coloneqq \frac{R_{avg\_in} + R_{avg\_on}}{2} $	$\frac{t}{t} = 1000 \; ft$	Average radius of curvature at entry	
$r_{rod} := 1200 \cdot D_{rod} = 35$	50 <b>ft</b>	ASTM F 1962-99, Equation 1, p7	
$Check \coloneqq$ if $\left( R_{avg.\_in} > \right)$	r <sub>rod</sub> , "okay", "not	tokay") = "okay"	
$Check \coloneqq \mathbf{if} \left( R_{avg.\_out} > r_{rod}, \text{``okay''}, \text{``not okay''} \right) = \text{``okay''}$			

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

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



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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  $w_b \coloneqq \left(\frac{\pi \cdot \left(D_1^2 + D_2^2\right)}{4}\right) \rho_w \cdot \gamma_b - w_a = 51.2 \ plf \quad \text{Upward buoyant force of empty pipe}$ 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:  $T_a := e^{v_a \cdot \alpha_{in}} \cdot (v_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4)) = 1925 \ lbf$ Pullback force when pipe enters the ground B1.5 - Pullback Force Point B:  $T_b \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_a + v_b \cdot \left| w_b \right| \cdot L_2 + w_b \cdot H_{max} - v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 9619 \ \textit{lbf}$ Pullback force increase with depth B1.6 - Pullback Force Point C:  $T_{c} \coloneqq T_{b} + (v_{b} \cdot w_{b} \cdot L_{3}) - e^{(v_{b} \cdot \alpha_{in})} \cdot (v_{a} \cdot w_{a} \cdot L_{3} \cdot e^{(v_{a} \cdot \alpha_{in})}) = 32888 \ lbf$ B1.7 - Pullback Force at D:  $T_d \coloneqq e^{(v_b \cdot \beta_{exit})} \cdot \left(T_c + v_b \cdot |w_b| \cdot L_4 - w_b \cdot H_{max} - e^{(v_a \cdot \alpha_{in})} \cdot \left(v_a \cdot w_a \cdot L_4 \cdot e^{(v_a \cdot \alpha_{in})}\right)\right) = 34681 \ lbf$ B1.8 - Maximum Pullback Force - Empty Pipe:  $P_{max\ empty} \coloneqq \max\left(T_a, T_b, T_c, T_d\right) + \Delta T = 35477\ lbf$ Maximum Pullback Force **B2 - Filled Pipe with Water** B2.1 - Upward Buovant Force:  $w_{bfilled} := \left(\frac{\left(\pi \cdot D_{1}^{2}\right)}{4}\right) \cdot \rho_{w} \cdot \left(\gamma_{b} - \gamma_{c} \cdot \left(1 - \left(\frac{2}{DR_{1}}\right)\right)^{2}\right) - w_{a} = 24.6 \ plf$ Upward buoyant force of pipe filled with water B2.2 - Pullback Force Point A:

 $T_{afilled} \coloneqq e^{v_a \cdot \alpha_{in}} \cdot \left( v_a \cdot w_a \cdot \left( L_1 + L_2 + L_3 + L_4 \right) \right) = 1925 \ \textit{lbf} \quad \text{Pullback force enter ground}$ 



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B2.3 - Pullback Force Point B:	
$T_{bfilled} \coloneqq e^{v_b \cdot \alpha_{in}} \left( T_{afilled} + v_b \cdot  w_{bfilled}  \cdot L_2 + w_b \right)$ B2.4 - Pullback Force Point C:	$b_{bfilled} \cdot H_{max} + v_a \cdot w_a \cdot L_2 \cdot e^{(v_a \cdot \alpha_{in})} = 5971 \ lbf$ Pullback force increase and decrease with depth
$T_{cfilled} \coloneqq T_{bfilled} + \left( v_b ullet \left  w_{bfilled} \right  ullet L_3  ight) - e^{\left( v_b ullet lpha_{in}  ight)}$	$\cdot \left( v_a \cdot w_a \cdot L_3 \cdot e^{(v_a \cdot \alpha_{in})} \right) = 16418 \ lbf$
B2.5 - Pullback Force at D:	
$\boldsymbol{T_{dfilled}} \! \coloneqq \! \boldsymbol{e}^{(\boldsymbol{v}_{b} \boldsymbol{\cdot} \boldsymbol{\beta}_{exit})} \boldsymbol{\cdot} \left( \boldsymbol{T_{cfilled}} \! + \! \boldsymbol{v}_{b} \boldsymbol{\cdot} \left  \boldsymbol{w}_{bfilled} \right  \boldsymbol{\cdot} \boldsymbol{L}_{4} \! - \!$	$\cdot e^{\langle v_a \cdot \alpha_{in} \rangle} \cdot \left( v_a \cdot w_a \cdot L_4 \cdot e^{\langle v_a \cdot \alpha_{in} \rangle} \right) = 19214 \ lbf$
B2.6 - Maximum Pullback Force - Filled Pipe	with Water:
$P_{max} \coloneqq \max\left(T_{afilled}, T_{bfilled}, T_{cfilled}, T_{dfilled}\right)$	= 19214 <i>lbf</i> Maximum Pullback Force
<u>B3 - Safe Pull Strength / Ultimate Tensile</u>	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
$A_{2} \coloneqq \frac{\pi}{4} \left( D_{2}^{2} - \left( D_{2} - T_{p2} \right)^{2} \right) = 0.8 \ in^{2}$	Cross-sectional area of Pipe 2
$P_{11} \coloneqq \frac{A_1 \cdot P_{max\_empty}}{A_1 + A_2} = 34101 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Empty)
$P_{21} \coloneqq \frac{A_2 \cdot P_{max\_empty}}{A_1 + A_2} = 1376 \ \textit{lbf}$	Pullback forces acting on Pipe 2 (Empty)
$P_{12} \coloneqq \frac{A_1 \cdot P_{max}}{A_1 + A_2} = 18468 \ \textit{lbf}$	Pullback forces acting on Pipe 1 (Ballast)
$P_{22} := \frac{A_2 \cdot P_{max}}{A_1 + A_2} = 745 \ lbf$	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> <sub><i>SPF</i>2</sub> :=1683 <i>lbf</i>	Safe pullback forces Pipe 2 (Table %, p. 448, PPI)
$check \coloneqq if (P_{SPF1} > P_{11}, "okay", "not okay")$	e="okay"
$check \coloneqq \mathbf{if} \left( P_{SPF2} > P_{21}, \text{``okay''}, \text{``not okay''} \right)$	
$check \coloneqq \mathbf{if} \left( P_{SPF1} > P_{12}, \text{``okay''}, \text{``not okay''} \right)$	
$check \coloneqq if \left( P_{SPF2} > P_{22}, \text{``okay''}, \text{``not okay''} \right)$	= "okay"