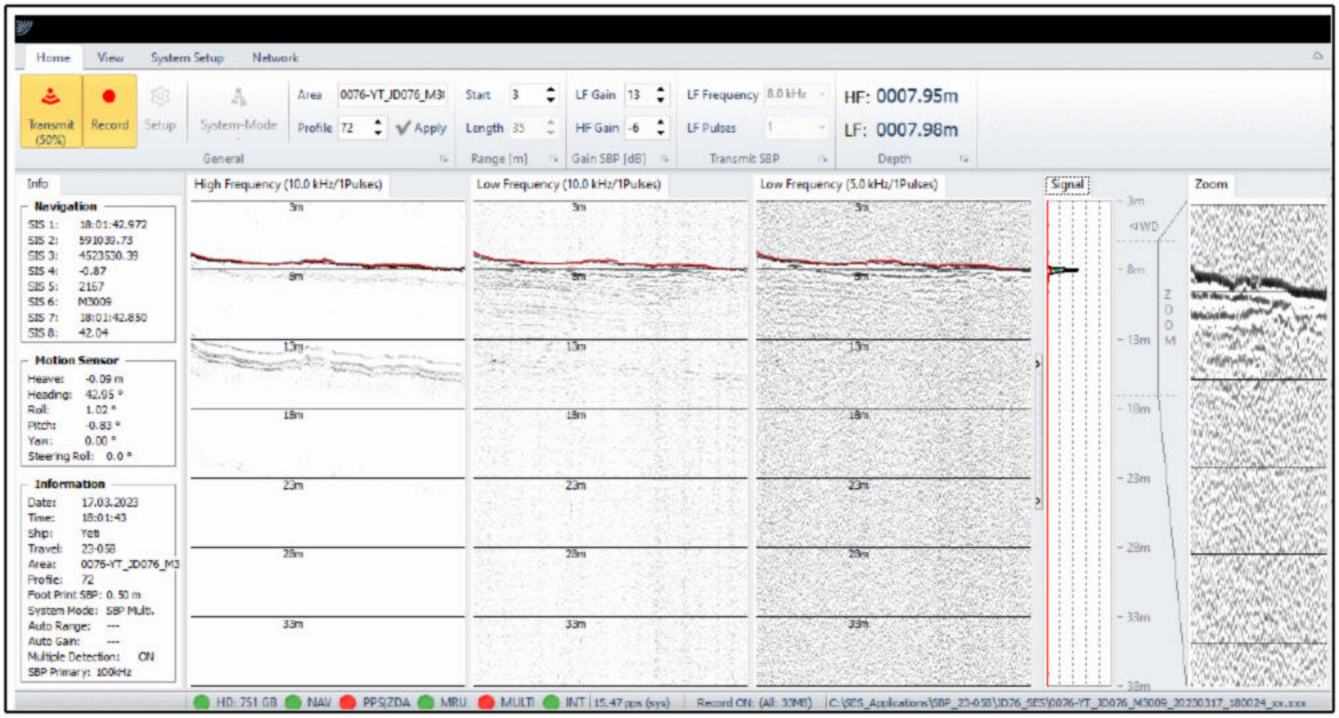


Area: 0076-YT_JD076_M3
Profile: 72
Start: 3
Length: 35
LF Gain: 13
HF Gain: -6
LF Frequency: 8.0 kHz
LF Pulses: 1
HF: 0007.95m
LF: 0007.98m

Navigation
SIS 1: 18:01:42.972
SIS 2: 591039.73
SIS 3: 4523530.39
SIS 4: -0.87
SIS 5: 2167
SIS 6: M3009
SIS 7: 18:01:42.850
SIS 8: 42.04

Motion Sensor
Heave: -0.09 m
Heading: 42.95 °
Roll: 1.02 °
Pitch: -0.83 °
Yaw: 0.00 °
Steering Roll: 0.0 °

Information
Date: 17.03.2023
Time: 18:01:43
Ship: Yeti
Travel: 23-058
Area: 0076-YT_JD076_M3
Profile: 72
Foot Print SBP: 0.50 m
System Mode: SBP Mult.
Auto Range: ---
Auto Gain: ---
Multiple Detection: ON
SBP Primary: 100kHz

15.47 pps (sys) | Record ON: (All: 33MB) | C:\SES_Applications\SBP_23-058\JD76_SES\0076-YT_JD076_M3009_20230317_180024_xx.xxx

Figure 16. SBP Wet Test

4.4.2 Positional Verification

Reciprocal lines were run over a known linear target within the Hudson River while the system operated fully with all data being recorded (sonar, time, heave, navigation, and fix). The contact was picked on the SBP lines and compared against the magnetometer data (Table 13).

Table 13. SBP Position Check

MAG Position Check						
Target	**SBP X**	**SBP Y**	**MAG X**	**MAG Y**	**Delta X (m)**	**Delta Y (m)**
1	580829.28	4497204.64	580828.90	4497204.76	0.38	-0.12

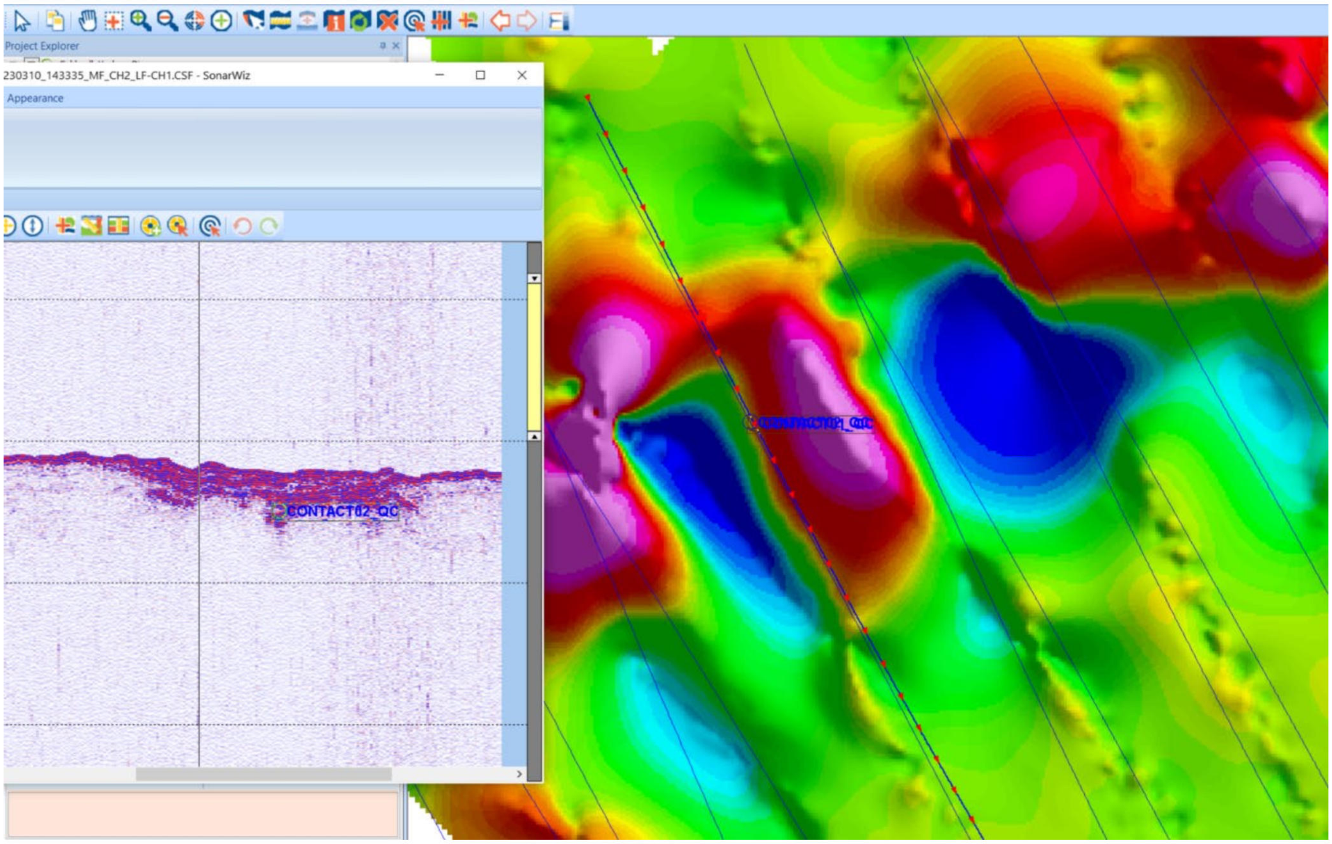


Figure 17. SBP Position Check against Magnetometer

4.4.3 Geological Assessment Test

SBP data were reviewed to assess interpretability to 10ft BSB (where acoustic penetration was achieved based on substrate conditions). Data quality demonstrated interpretability well below the 10ft requirement. (Figure 18).

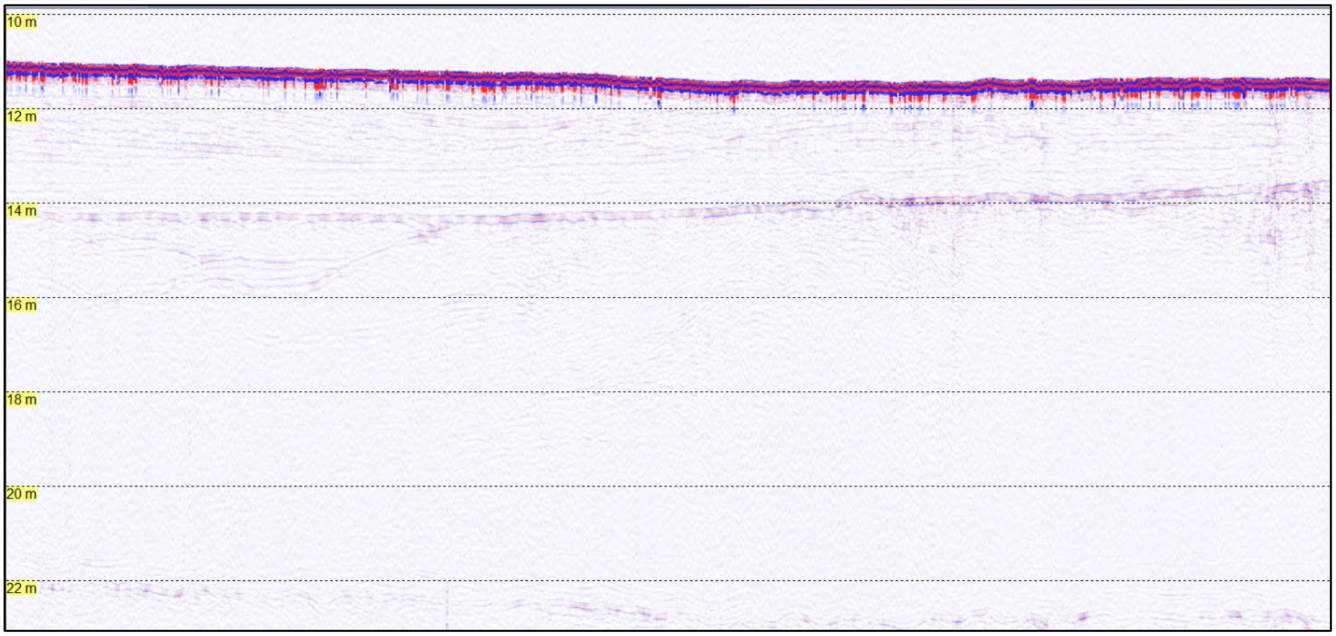


Figure 18. SBP Geological Assessment

4.4.4 Noise Test

No noise or interference was observed in the SBP from the other survey systems. The image below shows the wiggle trace of a subset of returns from the SBP (Figure 19). The seafloor return was observed as a thick black line due to the amplitude. The water column can be seen above and is acoustically quiet. No regular or chaotic noise was observed within the WC or after the seafloor return.

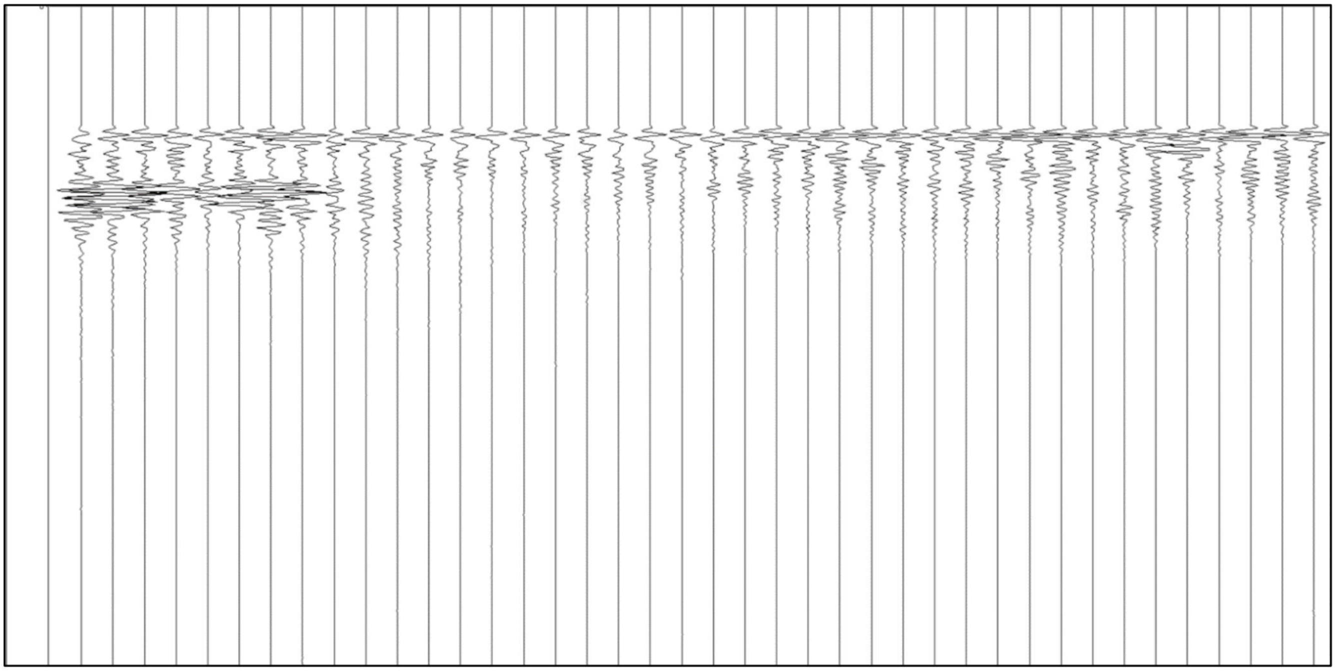


Figure 19. SBP Noise Test

This page has been intentionally left blank.

APPENDIX D. CHPE CABLE SPECIFICATION

[6 Pages]

2.2 Submarine Cable Design Sheet – 1,250 MW

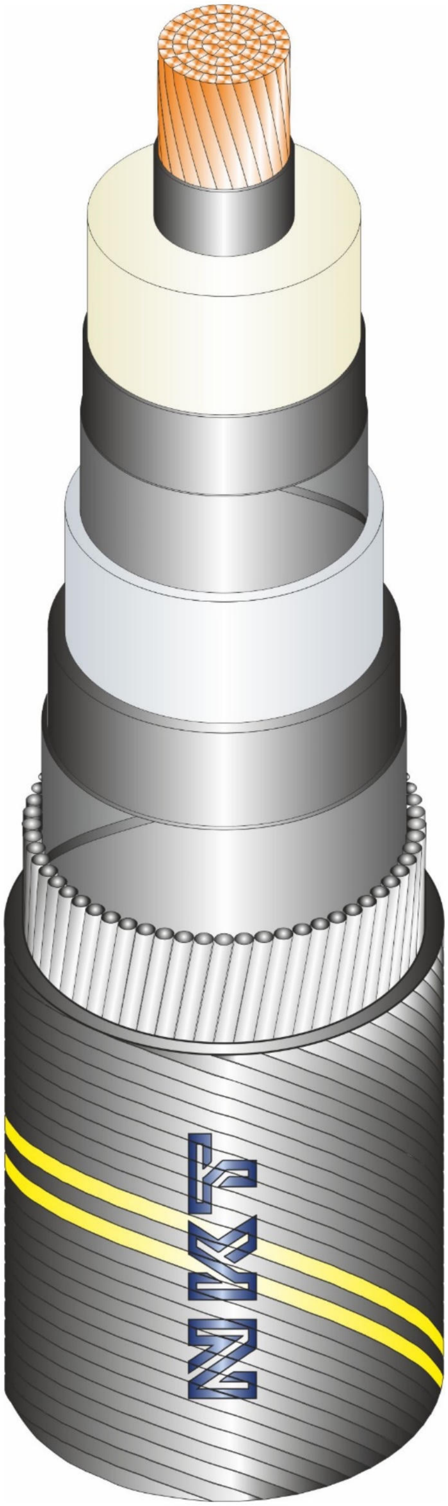
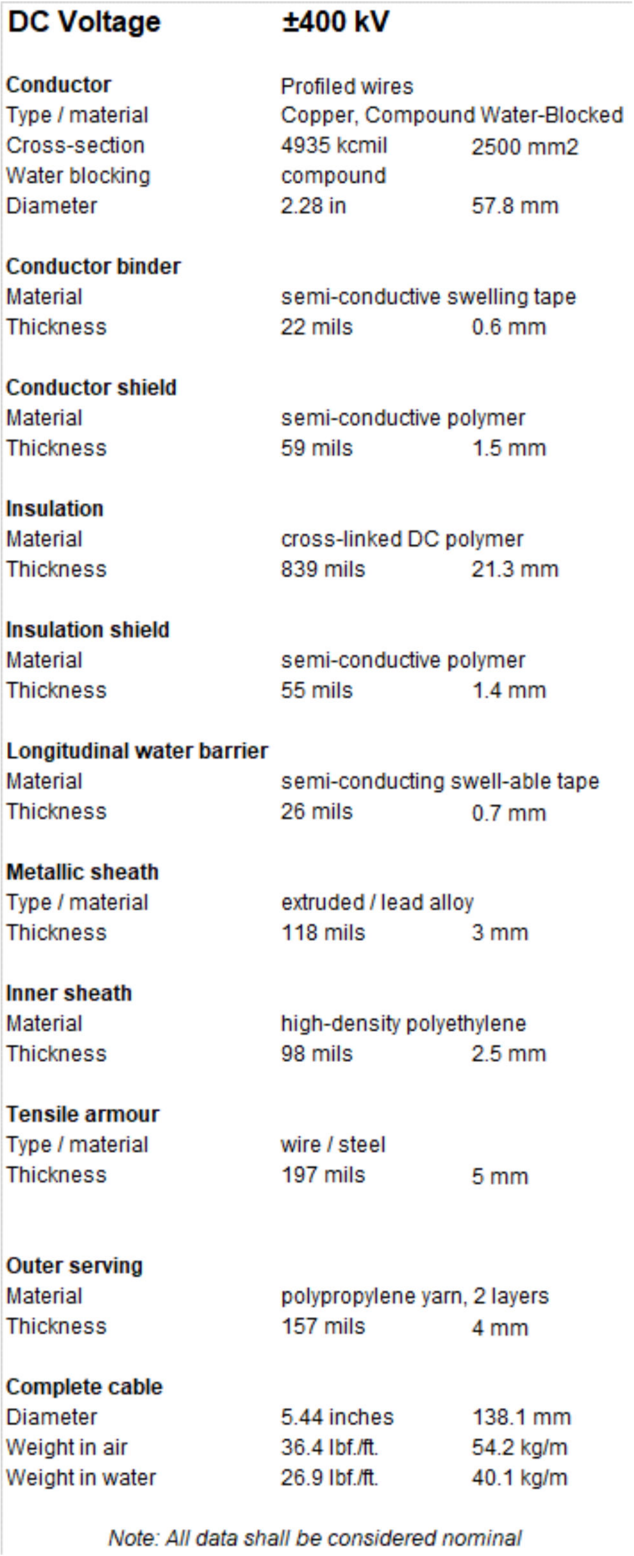


Figure 2: HVDC Submarine Cable Drawing



DC Voltage	**±400 kV**	
Conductor	Profiled wires	
Type / material	Copper, Compound Water-Blocked	
Cross-section	4935 kcmil	2500 mm2
Water blocking	compound	
Diameter	2.28 in	57.8 mm
Conductor binder		
Material	semi-conductive swelling tape	
Thickness	22 mils	0.6 mm
Conductor shield		
Material	semi-conductive polymer	
Thickness	59 mils	1.5 mm
Insulation		
Material	cross-linked DC polymer	
Thickness	839 mils	21.3 mm
Insulation shield		
Material	semi-conductive polymer	
Thickness	55 mils	1.4 mm
Longitudinal water barrier		
Material	semi-conducting swell-able tape	
Thickness	26 mils	0.7 mm
Metallic sheath		
Type / material	extruded / lead alloy	
Thickness	118 mils	3 mm
Inner sheath		
Material	high-density polyethylene	
Thickness	98 mils	2.5 mm
Tensile armour		
Type / material	wire / steel	
Thickness	197 mils	5 mm
Outer serving		
Material	polypropylene yarn, 2 layers	
Thickness	157 mils	4 mm
Complete cable		
Diameter	5.44 inches	138.1 mm
Weight in air	36.4 lbf./ft.	54.2 kg/m
Weight in water	26.9 lbf./ft.	40.1 kg/m

Note: All data shall be considered nominal

2.3 Electrical Cable Properties

The submarine cable has the following electrical properties:

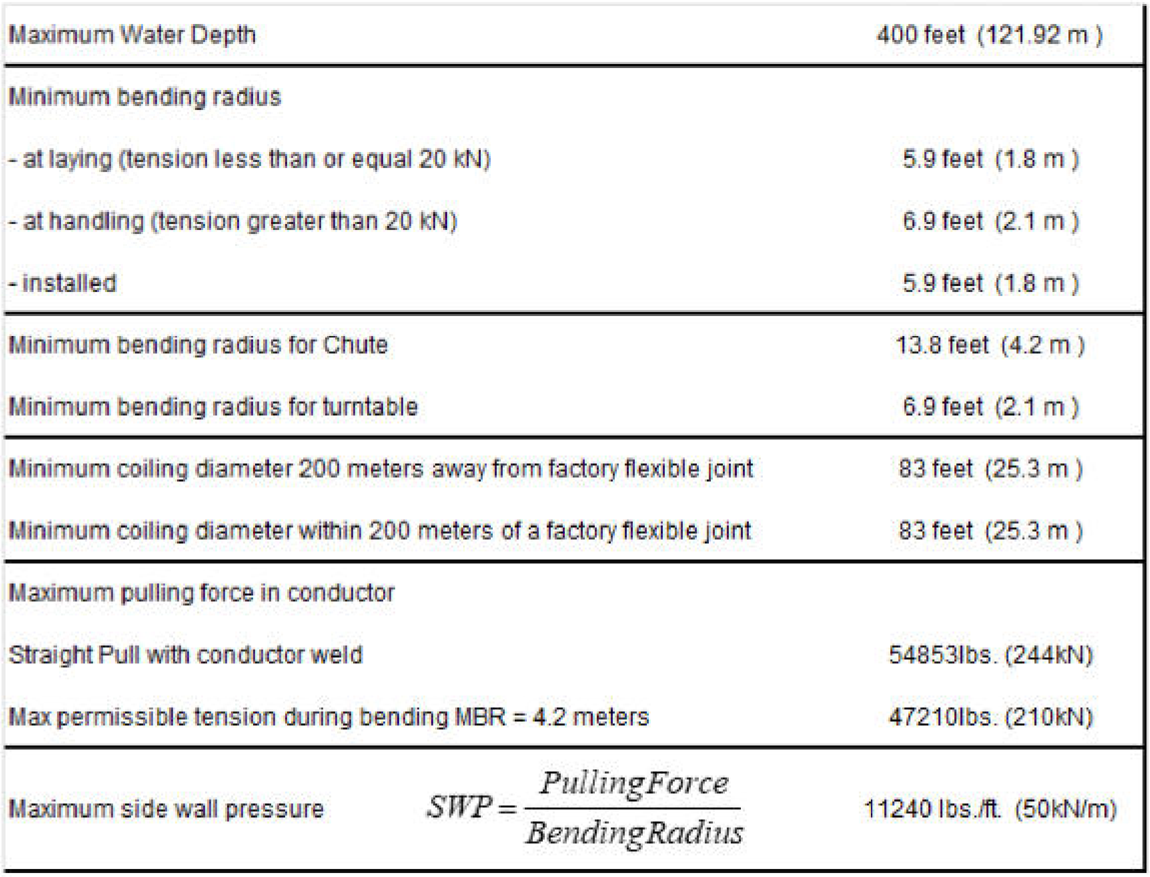
Table 1: Submarine Cable Electrical Properties

Rated continuous DC voltage, U_0	400 kV
Switching impulse withstand level (SIWL) started from U_0	900 kV
Subtractive SIWL started from U_0 to voltage at opposite polarity	400 kV
Rated continuous current under the installation conditions	1,638 A
Maximum conductor temperature in normal operation	70 °C
Max. Δθ over insulation	15 K
DC resistance at 20 °C	0.0022 ohm/1,000 ft. (0.0072 ohm/km)
DC resistance at maximum conductor temperature	0.0026 ohm/1,000 ft. (0.0086 ohm/km)
Losses at rated current	7.6 W/ft. and cable (25.0 W/m)
Capacitance	0.081 µF/1,000 ft. (0.265 µF/km)
Inductance (between conductor and metallic sheath)	0.040 mH/1,000 ft. (0.132 mH/km)
Surge impedance	22.3 ohm
Max. non-adiabatic short circuit current in conductor (0,1 s) in accordance with IEC 60949	860 kA
Max. non-adiabatic earth fault current in metal screen/sheath (0,1 s) in accordance with IEC 60949	77 kA

2.4 Mechanical Cable Properties

The submarine cable has the following mechanical properties:

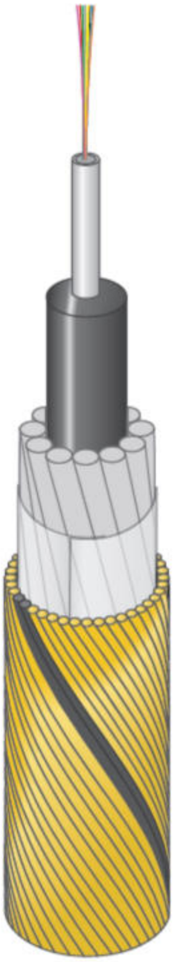
Table 2: Submarine Cable Mechanical Properties



Maximum Water Depth		400 feet (121.92 m)
Minimum bending radius		
- at laying (tension less than or equal 20 kN)		5.9 feet (1.8 m)
- at handling (tension greater than 20 kN)		6.9 feet (2.1 m)
- installed		5.9 feet (1.8 m)
Minimum bending radius for Chute		13.8 feet (4.2 m)
Minimum bending radius for turntable		6.9 feet (2.1 m)
Minimum coiling diameter 200 meters away from factory flexible joint		83 feet (25.3 m)
Minimum coiling diameter within 200 meters of a factory flexible joint		83 feet (25.3 m)
Maximum pulling force in conductor		
Straight Pull with conductor weld		54853lbs. (244kN)
Max permissible tension during bending MBR = 4.2 meters		47210lbs. (210kN)
Maximum side wall pressure	$SWP = \frac{PullingForce}{BendingRadius}$	11240 lbs./ft. (50kN/m)

GJLTM 10-ton SA, 12-192 Fibers

Loose Tube Submarine Fiber Optic Cable



Features

- For unrepeatered systems
- Water depth 3000 m
- Compact design, only 22 mm in diameter
- 12-192 optical fibers
- With or without electroding conductor
- Single layer steel wire reinforcement
- Hydrogen protected
- Outer protection polypropylene yarns or polyethylene sheath

Application

GJLTM, 10-ton SA is a single layer armored, loose tube cable for submarine installation where moderate protection is required.

This submarine cable is based on a hermetically sealed stainless tube. Inside the tube the fibers are free to move in a thixotropic water blocking compound. The steel tube is protected by a polyethylene sheath. Outside the sheath there is one layer of galvanized steel wires. The steel wires are flooded in bitumen.

The complete cable is wrapped with a layer of polypropylene yarns or a polyethylene sheath.

The steel wire reinforcement provides reliable mechanical protection, enabling installation and operation during rough conditions.

High packing density of the fibers is provided by the loose tube technique. This permits a small outer diameter and easy handling of the cable.

The fibers are easy to identify due to color and colored yarns.

GJLTM 10-ton SA, 12-192 Fibers

Typical Data

Temperature range

Operation	-30 till +60°C
Storage	-40 till +70°C
Installation	-15 till +40°C

Maximum water depths

	3000 m

Bend radius

No tensile load	≥ 0.5 m
With tensile load	≥ 1.5 m
Coiling	≥ 1.5 m

Dimensions

Diameter	22 mm

Weight

In air	1.1 kg/m
In seawater	0.8 kg/m

Tensile force

UTS	≥ 130 kN
FBL	≥ 130 kN
NTTS	100 kN
NOTS	70 kN
NPTS	50 kN

Crush resistance

	≤ 10 kN/10 cm

Impact resistance

	≤ 200 J

Mechanical and environmental test in accordance with IEC 60794-1-21 and IEC 60794-1-22

Electroding conductor

Electrical resistance	7 Ω /km

Ordering Information

Upon ordering, specify the following parameters:

- Fiber type
- Number of fibers
- Fiber color coding scheme
- With- or without electroding conductor
- Sheath type (PP yarns or PE Sheath)
- Length

Contact Hexatronic for further assistance.

Cable markers

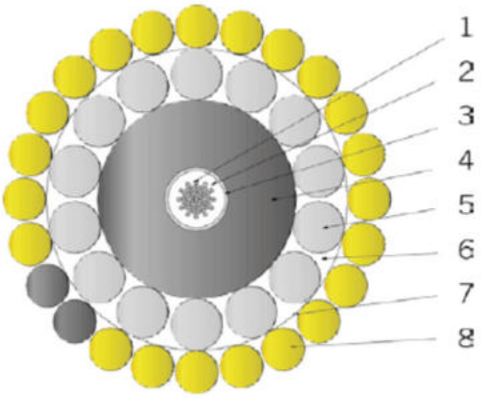
The submarine cable is marked with kilometer markers and factory joint markers.

Delivery information

The cable is supplied in any length in coil

Design

1. Primary coated fiber	Silica, acrylate
2. Filling compound	Thixotropic compound
3. Tube	Stainless steel
4. Sheath	Polyethylene, black
5. Armoring	Galvanized steel wires, single layer 14 x ø3.0 mm
6 Filling compound	Bitumen
7 Wrapping	Polyester tape
8 Wrapping	Polypropylene yarns or HDPE sheath



PRODUCT SPECIFICATION 1 (1)

Produktansvarig HCI/T Tobias Borg	*Nr – No.* 1301-25887-002		
Godkänd HCI/T Thomas Ericsson	Datum 2022-02-03	Rev A	File

Characteristics of Submarine G.654.C single-mode optical fiber and cable

1 Transmission

Attenuation 1550 nm (dB/km)	≤ 0.17

Chromatic dispersion 1550 nm (ps/nm.km) ≤ 18

PMD coefficient	M	20 cables
	Q	0.01%
	Maximum PMD_Q	0.20 ps/√km

Cable cut-off, λ_{cc} (nm)	≤ 1520
Effective area (typical) (μm^2)	83

2 Geometry

Core concentricity error (µm)	≤ 0.5
Cladding diameter (µm)	125.0 ± 1.0
Cladding non-circularity (%)	≤ 2
Coating diameter (µm)	245 ± 10
Fiber	

3 Mechanical performance

Proof test (%)	≥ 1.0

4 Reference

ITU-T Rec. G.654.C	Characteristics of a cut-off shifted single-mode optical fiber and cable

All values are nominal unless otherwise specified.

APPENDIX E. CHPE CABLE SPLICE

[2 Pages]

Doc. ID.:	1AA0548863	Classification:	Technical report	Prepared date:	2023-03-22
Revision:	B	Project ID:	G22002	Approved date:	2023-03-22
Status:	Approved	Function:	Engineering	Security level:	Confidential
Customer:	CHPE LLC (9988)	Submittal ID:	NKT-SUB-0115	Customer Rev:	02

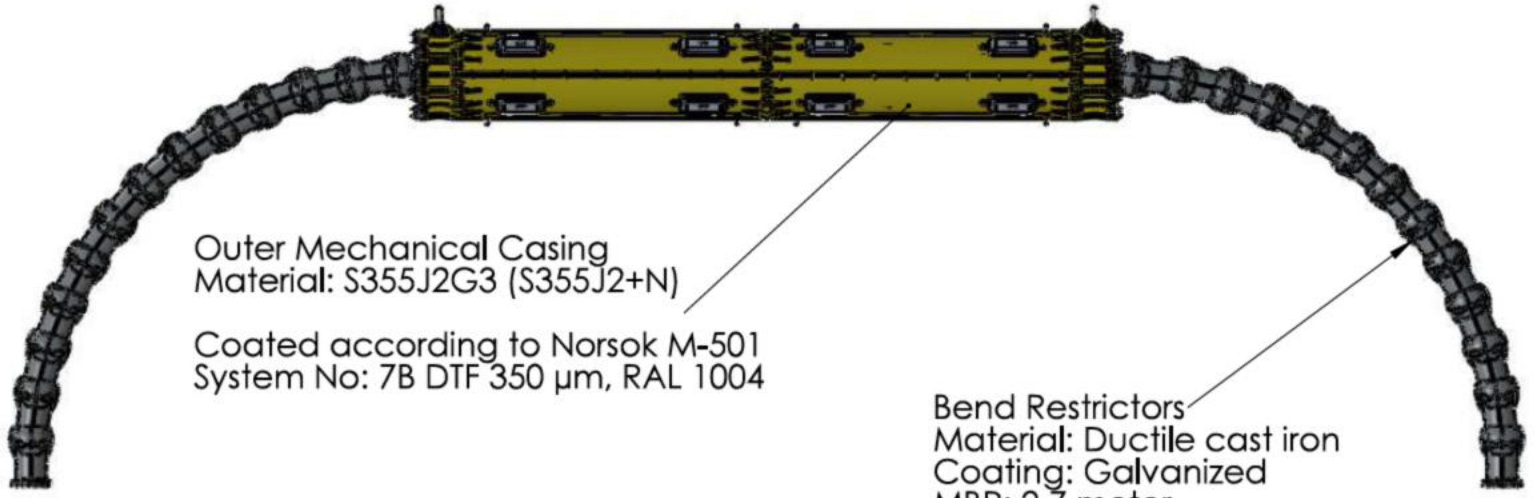
Datasheet - HVDC Rigid Submarine Joint

Champlain Hudson Power Express

CHPE

Rev.	Purpose	Date	Description	Prepared	Reviewed	Approved
01	IFR	2023-02-10	Issued For Review	Sverker Nyberg	Henrik Warngren	Arne Abrahamsson
02	IFR	2023-03-22	Issued For Review	Sverker Nyberg	Henrik Warngren	Arne Abrahamsson

Rev.	CN No.	Description	Revised By	Reviewed By	Approved By	Approved Date
B	NA	Added Length and Weight for Bend Restrictor	BJZE	ANOH	ANOH	2023-03-15
A	NA	First issue	BJZE	ANOH	ANOH	2022-12-15



Outer Mechanical Casing
Material: S355J2G3 (S355J2+N)

Coated according to Norsok M-501
System No: 7B DTF 350 µm, RAL 1004

Bend Restrictors
Material: Ductile cast iron
Coating: Galvanized
MBR: 2.7 meter
Length: Approx. 4.5 meter
Weight: Approx. 500 kg

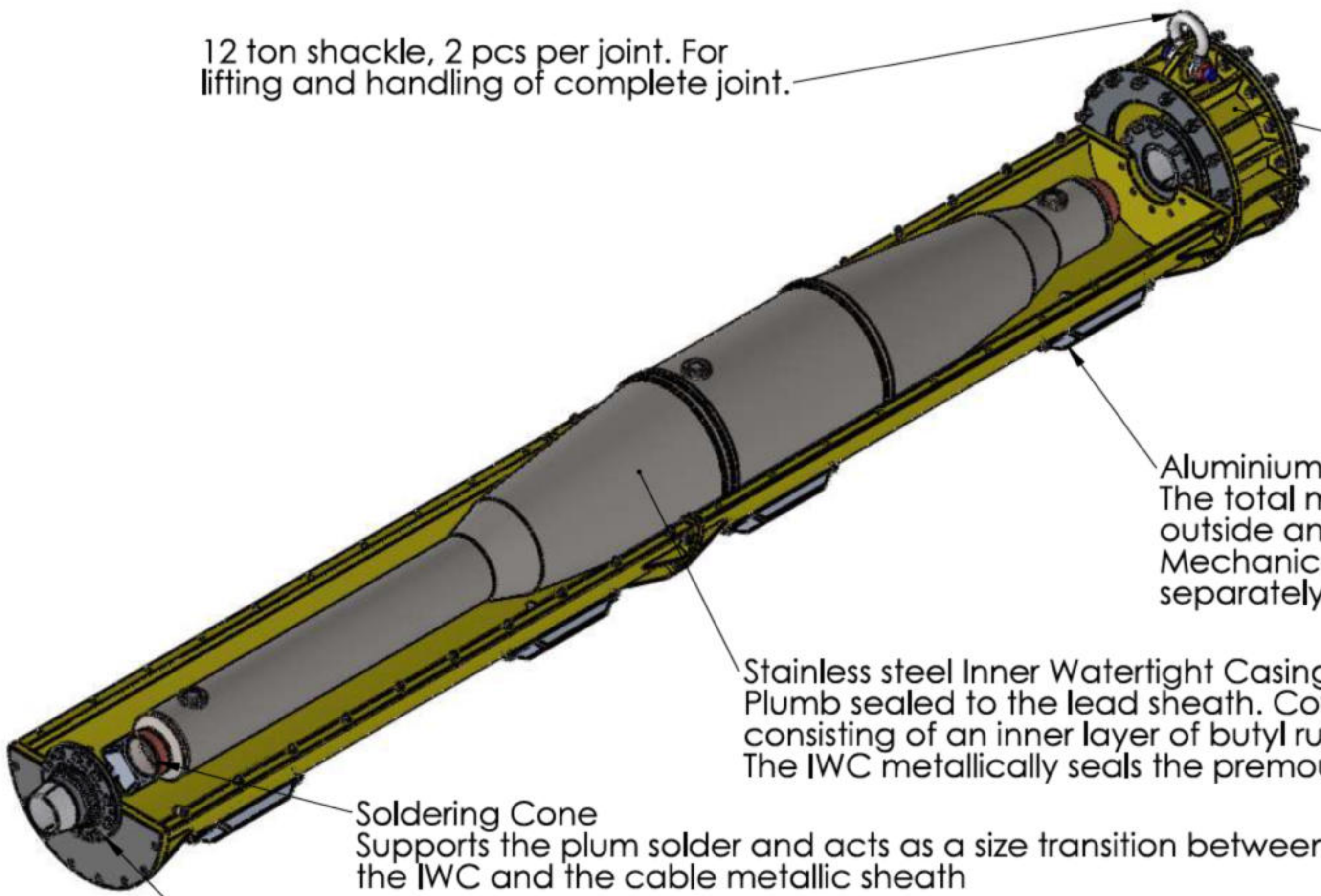
Data/ Technical specification

Weight joint excl. cable outside rigid part
Weight in air 2,7 T
Weight in water 2,0 T

Weight joint excl. cable outside rigid part and Bend Restrictors
Weight in air 1,7 T
Weight in water 1,2 T

Overall Dimensions	
Outer diameter	0,62 m
Length Rigid section	4,85 m
Length incl. Bend Restrictors	13,8m

Anodes
Total mass approx 86,4 kg
Bolted to joint hull
Calculated cathodic protection to the joint for 40 years design life



12 ton shackle, 2 pcs per joint. For lifting and handling of complete joint.

Distance Flange
the distance flange house the armour attachment, supports the lifting lug and connects the Bend restrictor to the OMC

Coated according to Norsok M-501
System No: 7B DTF 350 µm, RAL 1004

Aluminium anodes
The total mass of anodes needed on the outside and inside of the Outer Mechanical Casing is calculated separately according to DNV-RP-B401

Stainless steel Inner Watertight Casing
Plumb sealed to the lead sheath. Covered with a corrosion protective sheath consisting of an inner layer of butyl rubber and an outer sheath of XLPE.
The IWC metallically seals the premoulded cable joint from NKT, JDC 525 kV DC.

Soldering Cone
Supports the plum solder and acts as a size transition between the IWC and the cable metallic sheath

Weld flange
Cable armour attachment flange, the armour is attached to the flange by welding and flange is bolted to the OMC

NKT HV Cables AB Engineering	RSJ JDC525			Scale: 1:50	View	Sheet Size: A3
				State: Approved	Rel. Phase Code	
	General arrangement drawing			General Tolerance: SS-ISO 2768-mK SS-EN-ISO 13920-BF		
	Drawn By: BJZE	Reviewed By: ANOH	Approved By: ANOH	Approved Date: 2022-12-15	Sheet No.: 1/1	Drawing No.: 1GG0080565 Rev.: B

APPENDIX F. THERMAL & AMPACITY STUDY

[12 Pages]

CHPE LLC

HVDC LAKE CHAMPLAIN CROSSINGS

Thermal Impact on Crossed Utility Infrastructure – Protective Duct (Uraguard)

70082351-TN-018
JULY 2023

PUBLIC

CHPE LLC

Thermal Impact on Crossed Utility Infrastructure – Protective Duct (Uraguard)

TYPE OF DOCUMENT (VERSION) PUBLIC

PROJECT NO. 70082351
OUR REF. NO. 70082351-TN-018

DATE: JULY 2023

WSP

2 London Square
Cross Lanes
Guildford, Surrey
GU1 1UN

Phone: +44 148 352 8400

WSP.com

QUALITY CONTROL

Issue/revision	First Issue
Remarks	Original
Date	19/07/2023
Prepared by	**Joe Stubbs**
Signature	Stubbs, Joseph (UKJJS012) Digitally signed by Stubbs, Joseph (UKJJS012) DN: cn=Stubbs, Joseph (UKJJS012), ou=Active, email=Joseph.Stubbs@wsp.com Reason: I am the author of this document Date: 2023.07.20 15:46:51 +01'00'
Checked by	**Marc Rosales**
Signature	Rosales, Marc (UKMJR009) Digitally signed by Rosales, Marc (UKMJR009) DN: cn=Rosales, Marc (UKMJR009), ou=Active, email=marc.rosales@wsp.com Reason: I am the checker of this document Date: 2023.07.20 15:54:37 +01'00'
Authorised by	**Dan Evans**
Signature	D. Evans Digitally signed by Evans, Dan (UKDLE002) DN: cn=Evans, Dan (UKDLE002), ou=Active, email=Daniel.Evans@wsp.com Date: 2023.07.20 15:51:03 +01'00'
Project number	70082351
Report number	70082351-TN-018
File reference	70082351-TN-018

CONTENTS

EXECUTIVE SUMMARY

The Champlain Hudson Power Express (CHPE) high voltage direct current (HVDC) submarine cables will cross utility assets at various points along its route. CHPE requested that WSP establishes the expected temperature rise of utility assets due to the HVDC submarine cables at Lake Champlain crossing locations where alternate (non-burial) means of cable protection are required.

WSP has carried out thermal modelling to determine an indicative temperature rise of the lake bed beneath the HVDC submarine cables when considering the proposed crossing installation arrangements. This report relates to deep water crossings where the HVDC cables are installed within a protective duct.

The proposed crossing arrangement is unlikely to significantly restrict convection in its ‘as-laid’ form, as free water should be able to flow around both the protective duct and utility asset. Over time, however, there may be a build-up of lakebed material around the assets at the crossing location and this would present a more onerous thermal environment for both assets.

A model has been prepared to approximate the installation arrangement at the crossing location. The model and assumptions used are intended to represent a worst-case scenario and hence, where no other heat sources are present, the temperatures presented can be considered as maximum values.

The maximum temperature rise beneath the HVDC submarine cables due to heat being dissipated by the cables has been found to be approximately 5 K (9 °F).

For utility assets which do not themselves generate heat, this can be considered as the maximum temperature rise of the asset. If there is no build up in lakebed material around the assets, the temperature rise would be reduced.

Where the utility asset being crossed is a heat source, such as a power cable, the maximum temperature rise due to the HVDC cables of 5 K (9 °F) will result in a slight de-rating of the asset at the crossing location.

The ampacity of a power cable is defined by the thermal pinch point along its length. If elsewhere the asset is buried deeper in the lake bed, or installed in another more onerous environment (e.g. within a horizontal directional drilled (HDD) section), then the crossing location is unlikely to represent a thermal pinch-point and would not impact the ampacity of the cable.

REFERENCED DOCUMENTS

Author	Document Number	Document Title
NKT	1AA0557110	Datasheet – Submarine Cable
NKT	1AA0529714	Design Report Submarine Cable

1 INTRODUCTION

The CHPE HVDC submarine cables will cross third party utility assets at various points along its route. CHPE requested that WSP establishes the expected temperature rise of these unburied utility assets due to the HVDC submarine cables at Lake Champlain crossing locations, where alternate (non-burial) means of cable protection are required.

WSP has carried out thermal modelling to determine an indicative temperature rise of the lake bed beneath the HVDC submarine cables when considering the proposed crossing installation arrangements. This report covers an arrangement for deep water depths of more than 150 feet (ft), where a protective duct (e.g. Uraguard) solution will be employed.

This report details the modelling that has been carried out and presents the results.

2 CABLE AND INSTALLATION DETAILS

2.1 CABLE DESIGN AND LOADING

The design of the HVDC submarine cable is detailed in NKT document ‘1AA0557110’.

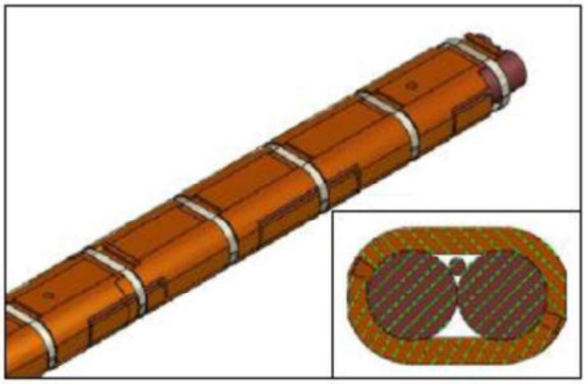
As per NKT document ‘1AA0529714’ each cable will carry a maximum continuous load of 1638 Amps (A).

2.2 CROSSING ARRANGEMENTS

The method of alternate (non-burial) cable protection to be employed is subject to the local water depth.

For water depths greater than 150 ft, the HVDC submarine cables will be brought to the surface of the lake bed and enclosed in a protective duct (e.g. Uraguard), Figure 2-1, as they cross the existing asset. The HVDC bundle will be laid directly on top of the existing asset.

Figure 2-1 - Indicative cable bundle with Uraguard protection



CHPE - CABLE BUNDLE W/URAGUARD PROTECTION (or SIMILAR)

SCALE: N.T.S.

3 MODELLING

3.1 GENERAL

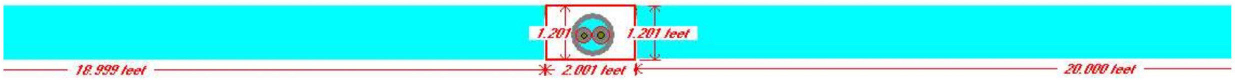
Modelling has been conducted using the CYMCAP v 8.2 software package to out to determine the temperature rise beneath the HVDC submarine cables for the installation described in Section 2.

The installation arrangement has been approximated using the multiple backfill module in CYMCAP.

Due to limitations of the modelling software (2D only), each backfill segment has been modelled with infinite length in the z-direction. The protective duct arrangement has been modelled with the cables having a surround of lake bed material, as opposed to being on top of the lake bed (and the crossed asset). This is intended to represent a scenario where lake bed movement has resulted in material being deposited around the assets, and represents a worst case in terms of the heat dissipation capability of the cables.

The model layout used is shown in Figure 3-1, with water shown in blue.

Figure 3-1 – Model layout for protective duct scenario



3.2 ASSUMPTIONS

The following assumptions have been made:

- HVDC cables carrying their maximum continuous load of 1638 A.
- Lake bed thermal resistivity is 1.54 Kelvin metres per Watt (K.m/W) (worst case in NKT document '1AA0529714');
- A range of ambient temperatures between 40 and 70 °F have been considered. In a lake environment, ambient temperature will vary with depth and season. The effect of seasons becomes minor at water depths beyond approximately 30 feet. It is therefore expected that values toward the lower end of this range will be applicable for crossing location.
- Protective duct wall (polyurethane) thermal resistivity is 3.50 K.m/W;
- Region between protective duct and cable is water filled;
- Boundary of water and lake bed surface is isothermal;
- Losses due to harmonic content are negligible;
- No longitudinal heat transfer.

3.3 VALIDATION

In order to confirm that the cable model had been established correctly, a comparison was made with a scenario presented in the NKT design report. Good agreement between the model and report confirmed the validity of the model.

3.4 RESULTS

An isothermal plot of the temperature rise around the HVDC submarine cables, where they are installed within a protective duct surrounded by lakebed material, is shown in Figure 3-2**Error! Reference source not found.**.

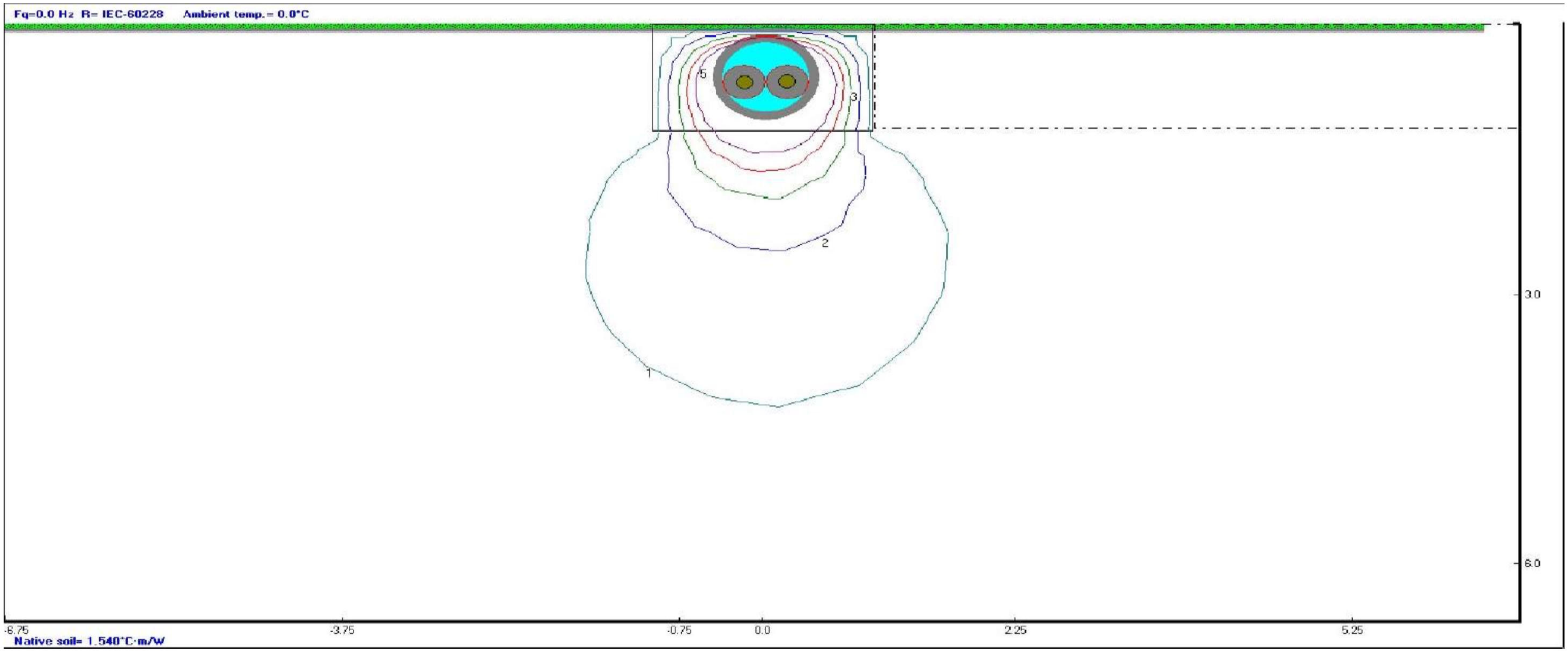
The 1 °C isotherm provides an indication of the boundary, outside of which the thermal influence of the HVDC cables will be negligible.

Immediately beneath the mattress protection, the ambient temperature is increased by approximately 5 °C (9 °F). This would be the maximum temperature rise that a crossed asset might experience. The impact of this temperature rise on a range of ambient temperatures is outlined in Table 3-1.

Table 3-1 – Impact of temperature rise at crossing due to HVDC cables

Ambient temperature, °F	Temperature rise, °F	New temperature, °F
40	9	49
50	9	59
60	9	69
70	9	79

Figure 3-2 - Plot of temperature rise isotherms with protective duct



Note: temperatures in °C; distances in ft.

4 DISCUSSION AND CONCLUSIONS

The proposed crossing arrangement is unlikely to significantly restrict convection in its ‘as-laid’ form, as free water should be able to flow around both the protective duct and utility asset. Over time, however, there may be a build-up of lakebed material around the assets at the crossing location and this would present a more onerous thermal environment for both assets.

A model has been prepared to approximate the installation arrangement at the crossing location. The model and assumptions used are intended to represent a worst-case scenario and hence, where no other heat sources are present, the temperatures presented can be considered as maximum values.

The maximum temperature rise beneath the HVDC submarine cables due to heat being dissipated by the cables has been found to be approximately 5 K (9 °F).

For utility assets which do not themselves generate heat, this can be considered as the maximum temperature rise of the asset. If there is no build up in lakebed material around the assets, the temperature rise would be reduced.

Where the utility asset being crossed is a heat source, such as a power cable, the maximum temperature rise due to the HVDC cables of 5 K (9 °F) will result in a slight de-rating of the asset at the crossing location.

The ampacity of a power cable is defined by the thermal pinch point along its length. If elsewhere the asset is buried deeper in the lake bed, or installed in another more onerous environment (e.g. within a horizontal directional drilled (HDD) section), then the crossing location is unlikely to represent a thermal pinch-point and would not impact the ampacity of the cable.

APPENDIX G. ELECTRICAL EFFECTS STUDY

[15 Pages]

CHPE LLC

SUBMARINE DC CABLES

Potential Effects of Submarine DC Cables on Co-Located Infrastructure

70082351-TN-015
JULY 2023

CONFIDENTIAL

CHPE LLC

Potential Effects of Submarine DC Cables on Co-Located Infrastructure

TYPE OF DOCUMENT (VERSION) CONFIDENTIAL

PROJECT NO. 70082351
OUR REF. NO. 70082351-TN-015

DATE: JULY 2023

WSP

2 London Square
Cross Lanes
Guildford, Surrey
GU1 1UN

Phone: +44 148 352 8400

WSP.com

QUALITY CONTROL

Issue/revision	First Issue
Remarks	Original
Date	14/07/2023
Prepared by	**Marc Rosales**
Signature	Rosales, Marc (UKMJR009) Digitally signed by Rosales, Marc (UKMJR009) DN: cn=Rosales, Marc (UKMJR009), ou=Active, email=marc.rosales@wsp.com Reason: I am the author of this document Date: 2023.07.14 14:00:13 +01'00'
Checked by	**Joe Stubbs**
Signature	Stubbs, Joseph (UKJJS012) Digitally signed by Stubbs, Joseph (UKJJS012) DN: cn=Stubbs, Joseph (UKJJS012), ou=Active, email=Joseph.Stubbs@wsp.com Reason: I have reviewed this document Date: 2023.07.14 15:26:25 +01'00'
Authorised by	**Dan Evans**
Signature	D. Evans Digitally signed by Evans, Dan (UKDLE002) DN: cn=Evans, Dan (UKDLE002), ou=Active, email=Daniel.Evans@wsp.com Date: 2023.07.14 16:37:12 +01'00'
Project number	70082351
Report number	70082351-TN-015
File reference	70082351-TN-015

CONTENTS

1 INTRODUCTION AND EXECUTIVE SUMMARY

1.1 INTRODUCTION

The Champlain Hudson Power Express (CHPE) project will deliver 1250MW of renewable power from Hydro-Quebec TransEnergie's Hertel substation near La Prairie Quebec to NYPA's Astoria Annex 345kV substation located in the Astoria neighbourhood in the New York City borough of Queens.

A high voltage direct current (HVDC) transmission system will be used to achieve this. The HVDC transmission system will comprise a single AC to DC converter at each end of the link connected by two DC cables, one positive and one negative.

The HVDC cable route within the United States will comprise approximately 193 miles of submarine cable route and approximately 147 miles of land cable route.

The proposed submarine HVDC cable route will enter and exit Lake Champlain through horizontal directionally drilled (HDD) ducts. In water depths less than 150 feet (mean water level) the two cables are to be laid together in a trench at approximately 4 feet below the lake bottom. In water depths greater than 150 feet, the cables are to be laid directly on the lake bottom, without burial or protection, and are expected to settle 1 foot below the lake bottom.

At various points of the underwater route there are assets and infrastructure co-located in the same right of way (ROW).

CHPE has asked WSP to carry out an assessment of the potential effects of the HVDC cables on co-located infrastructure.

This report details the assessment that has been carried out and presents the findings. It should be noted that any future modification of the design may impact this assessment.

1.2 EXECUTIVE SUMMARY

The topology and design of the CHPE interconnector, and the associated configuration of the submarine DC cables, have been taken into account when assessing the potential interference effects on co-located utility assets. The effects that have been considered are:

- Electric fields
- Magnetic fields
- Induced voltages
- Corrosion effects
- Transient fault conditions

Indicative studies have been carried out and these studies indicate that the proposed HVDC cable system will have no adverse effect on any co-located utility assets or infrastructure, with regard to electric and magnetic fields, induced voltages, corrosion and transient fault conditions.

Thermal effects at crossing locations have been considered separately to this report.

2 REFERENCED DOCUMENTS

Document Number	Document Title
1AA0557110	Datasheet – Submarine Cable
1AA0529714	Design Report Submarine Cable
IEC 60287-1-1	Electric cables- Calculation of current rating – Part 1: Current rating equations (100% load factor) and calculation of losses
CIGRE TB 283	Special Bonding of High Voltage Power Cables
ISO 18086:2019	Corrosion of metals and alloys – Determination of AC corrosion – Protection criteria

3 HVDC TRANSMISSION OVERVIEW

3.1 HVDC TECHNOLOGY

The CHPE Interconnector will use the latest HVDC technology, known as Voltage Source Converter (VSC). This has now become the dominant technology used for HVDC interconnectors as it provides additional functionality when compared with the earlier generation of Line Commutated Converters (LCC).

The VSC is designed as a Modular Multi-level Converter (MMC) in which the DC capacitor, which maintains the DC voltage, is segmented into many small units each of which is switched in and out by a semi-conductor switching device. The voltage on each DC capacitor is about 2 kV. By progressively switching in and out steps of DC voltage in the correct sequence a stepped voltage waveform can be generated which, with many hundreds of steps, becomes a good approximation to an AC sinusoidal waveform. The quality of this voltage waveform may be sufficient that AC side harmonic filters are not required.

On the DC side of the converter, the “ripple” voltage generated by the switching action, i.e. AC harmonic distortion, which is superimposed on the DC voltage will induce voltages in adjacent metallic assets and infrastructure and has the potential for interference with telecommunication systems. The spectrum of harmonic currents flowing in the DC cable loop that are the source of any interference issues is from 100 Hz to 5000 Hz.

The design of the modern VSC scheme used by CHPE inherently requires no, or only very small, harmonic filters at the AC terminal to achieve compliance with the standards for acceptable distortion levels in the AC transmission network (in comparison to LCC technology and earlier generations of VSC schemes, which required larger harmonic filters). Similarly, no harmonic filters are normally required at the DC terminal to avoid interference to adjacent telecommunication circuits from the HVDC cable circuit.

3.2 HVDC TOPOLOGY

The chosen circuit topology for CHPE HVDC interconnector is a Symmetrical Monopole.

This topology consists of a single AC to DC converter at each end of the link connected by 2 DC cables, one positive and one negative. A simplified diagram of the symmetrical monopole topology is shown in Figure 3-1.

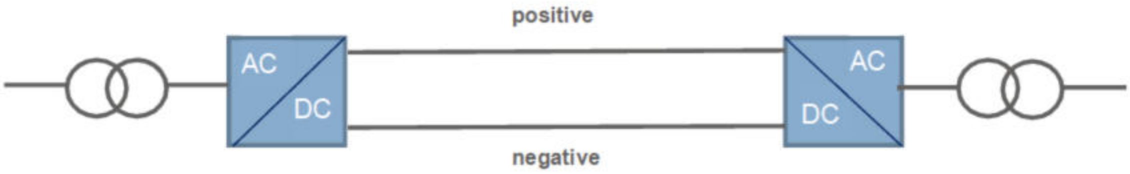


Figure 3-1 – Symmetrical monopole topology

The DC current in the submarine and underground cables flows in the loop between the positive and negative cables and between the two converter stations. In operation there is no path for DC current outside of this loop, thus there can be no DC current flowing in the water or the ground.

In the event of a fault on the AC or DC systems of the interconnector, automatic protection systems will disconnect the complete scheme by opening circuit breakers at the Grid connection points in less than 0.1 seconds. A fault in a submarine (or land) cable would occur between the central high voltage core and the outer sheath, which is connected to ground potential.

4 DC CABLE EFFECTS ON CO-LOCATED INFRASTRUCTURE

4.1 GENERAL

In the following sections the possible effects of the following interactions between DC cable and co-located infrastructure are discussed:

- Electric fields
- Magnetic fields
- Induced voltages
- Corrosion effects
- Transient fault conditions

Where appropriate, indicative studies have been carried out to determine the influence of the CHPE interconnector on susceptible co-located assets. The topology and design of the CHPE interconnector, as well as the associated configuration of the submarine DC cables, have been taken into account for these studies.

It should be noted that a detailed study requires detailed design of the DC cable system to determine the harmonic distortion generated at the DC terminals of the converter stations and a detailed model of the submarine and underground cables. Both models will only be available after the suppliers selected to construct the converter stations and DC cable system have completed detailed designs.

Thermal effects at crossing locations have been considered separately to this report.

4.2 ELECTRIC FIELDS

The electric field of the CHPE DC cables will be fully contained by their earthed metallic sheaths. As such, there will be no electric field external to the cables.

4.3 MAGNETIC FIELDS

The DC cables will generate a magnetic field. This magnetic field will be composed of two types of field: -

- a static field associated with the DC current in the cable conductor
- a field that varies over time as the AC current in the cable conductor varies with time.

The AC current is the result of unwanted “ripple currents” due to the converter not perfectly converting AC current to DC current, and they are significantly less than the DC current. However, the cable sheath will be earthed at both ends of the cable route and any AC current in the conductor will induce a current in the opposite direction in the cable sheath, thereby reducing the overall magnetic field of the cable.

The static field associated with the DC current will interact with the earth’s magnetic field causing a localised increase or decrease in field strength which will decay rapidly as the distance from the centre line of the cable increases. For context, the geomagnetic field varies throughout the Earth from 25 to 65μT. In the New York area, the Earth’s magnetic field is approximately 50μT.

A preliminary calculation of the potential magnetic field generated by the DC cables is given below:

1. Static Field

The DC current of 1638A flowing in the DC cables will generate a static magnetic field of approximately 36μT directly above the trench, 3' above ground level. This field strength decreases rapidly with distance away from the cables, at 10' from the centre of the trench the field is approximately 13μT and at 20' the field is approximately 5μT. These figures can be compared to the earth's natural magnetic field, which is in the region of 50μT at the latitude of New York. The stray magnetic field may add (e.g. 63μT at 10' distance) or subtract from (e.g. 37μT at 10' distance) the natural background field. These are very small changes in the DC magnetic field environment

Static magnetic fields of this magnitude will have no effect on any asset or infrastructure, whether metallic or otherwise.

2. Time Varying Field

The time varying field strength is a function of the superimposed AC harmonic currents, or "ripple", present on the cable system due to the conversion effects from AC to DC. This "ripple" is approximately 1-2% of the DC system current, giving a magnitude in the order of 30 A.

The field strength is also impacted by:

1. The induced sheath current, known as circulating current. This flows in the opposite direction to the current in the cable's conductor and acts to reduce the overall magnitude of the magnetic field. The overall effect is equivalent to the conductor current minus the sheath current. The amount of circulating current will depend on the electrical resistance of the sheath (lower resistance gives higher circulating current) and spacing of cables (greater spacing gives higher circulating currents).
2. The spacing between the conductors, as the current in each cable is in opposite directions so will tend to cancel each other out. Lower cable separation will result in a higher degree of cancellation and lower magnetic fields.

4.4 INDUCED VOLTAGE

4.4.1. General

The time-varying interaction of a cable's magnetic field with a parallel metallic asset (e.g. a pipeline) can result in a voltage being induced on the asset. If the asset is earthed or connected in a loop, the induced voltage will act to drive a circulating current. Such induced voltages and currents can cause safety, interference, damage, and corrosion concerns.

The magnitude of induced voltage is influenced by the magnetic field strength (as discussed in Section 4.3), its rate of change, the separation of the cable and asset, and the length of parallelism.

As per Faraday's Law of Induction, where an asset is perpendicular to the cable there will be no induced voltage as only the parallel component of a magnetic field contributes to this phenomenon. When assessing the possibility of an interaction it is generally considered that where an asset runs at an angle of greater than 45° to a cable, the interaction can be neglected, as any inductive effect would be negligible. For crossing angles of less than 45 °, the assets are modelled as being parallel, as a worst case.

The major component of the current in the cables is DC, which generates a static magnetic field and will not induce a voltage on co-located utility assets. Hence, the only concern relates to the time varying magnetic field resulting from AC harmonic currents. The actual magnitude and frequency of these harmonic currents will not be known until detailed design of the converter system has been completed. At this stage, they are expected to have a magnitude of approximately 1-2 % of the DC system current, in the order of 30 A.

All identified assets that cross the HVDC cables do so at angles greater than 45° meaning the interactions would be negligible, as described above. Despite this, an indicative study has been conducted to demonstrate the level of induced voltage that could be expected on a metallic asset that ran parallel to the DC cables.

4.4.2. Calculation methodology and assumptions

The levels of voltage that could be induced on parallel assets by the DC cables have been calculated using established formulae. Details of the formulae, parameters and assumptions used are given below.

The induced voltage is derived from the following series of formulae:

The reactance per unit length of sheath

$$X = 2\omega 10^{-7} ln\left(\frac{2s}{d}\right) \quad \Omega/\text{m} \qquad \text{(see IEC 60287-1-1 Section 2.3.1)}$$

Where:

ω = angular frequency (2 π f) (1/s)
S = axial spacing between cables (mm)
d = mean diameter of sheath (mm)

The current in the sheath induced by the current in the conductor

$$I_s = \frac{I}{\sqrt{1+\left(\frac{R_s}{X}\right)^2}} \quad \text{A} \qquad \text{(see IEC 60287-1-1 Section 2.3.1)}$$

Where:

I = current in conductor (A)
R_s = the sheath resistance (Ω)

The reactance per unit length between the DC cables (cable m and cable n) and the parallel conductor (p) per unit length

$$X_{mnp} = 2\omega 10^{-7} ln\left(\frac{d_{mp}}{d_{np}}\right) \quad \Omega/\text{m} \qquad \text{(derived from CIGRE TB 283 equation A6)}$$

Where:

d_{mp} = distance between DC cable m and parallel conductor p
d_{np} = distance between DC cable n and parallel conductor p

Induced voltage on parallel conductor per unit length is

$$V = (I - I_S)X_{mnp}L \qquad \text{V}$$

Where:

L = length of parallelism

The following inputs were assumed:

Harmonic current (I) - 2% of rated current, 32.76A, selected as the upper limit of the expected value.

Frequency (f) – 60Hz

Cable spacing (S) – 5.43” (0.138 m) – selected to represent the distance between the cable conductors as the cables would be touching in the trench.

Cable dimensions and resistances (d, R_s) – selected from NKT design information provided in document 1AA0529714 Rev A or calculated by the methods of IEC 60287-1-1 Section 2.4.3.

Spacing to asset (d_{mp}, d_{np}) – An indicative horizontal separation of 5’ has been assumed between the nearest cable and parallel asset.

Length of parallelism (L) – An indicative length of 1640’ (500m) was assumed.

Notes;-

- Calculations are based on the fundamental frequency (60Hz), rather than a spectrum of smaller components at different frequencies. As mentioned previously this report gives an approximation of the induced voltages to be expected. Detailed studies only being possible after the completion of the converter and cable systems detailed designs by the contractors. In this case, as the level of induced voltage is so low, further studies are considered unnecessary.
- As noted previously, where the angle between cables and utility assets is 90° there will theoretically be no induced voltage.

4.4.3. Discussion

All identified assets that cross the HVDC cables do so at angles greater than 45° meaning that any induced voltage would be negligible. Despite this, an indicative study has been conducted to demonstrate the level of induced voltage that could be expected on a metallic asset that ran parallel to the DC cables.

The induced voltage on the indicative parallel asset was calculated to be 0.0739V, or approximately 0.1478mV/m. This is the maximum voltage that would be present at one end of the parallel section. This level of induced voltage is considerably below typical limits but has also been considered in more detail from a corrosion perspective in the following section.

If the parallel asset is non-metallic, there will be no induced voltage.

It should be noted that the calculated induced voltage values represent a worst-case figure, present at one end of the parallel section. Depending on the phase relationship, this voltage may act to add or subtract from any existing voltage on an asset. Furthermore, if the asset has any discontinuity, or regular earthing, the induced voltage in one section will not transfer across the discontinuity into the next section. This would result in lower induced voltage values.

4.5 CORROSION EFFECTS

The risk of corrosion of buried metallic utility assets is related to the effects of stray DC currents and induced AC voltages.

For CHPE, the chosen HVDC topology is symmetrical monopole. The DC current in the submarine and underground cables flow in the loop through the positive and negative cables between the two converter stations. There is no path for a DC current outside of this loop under normal operating conditions. During faults, current will return via the path of least resistance which will be predominantly through the cable metallic layers. Any stray DC current return via the mass of earth is expected to be negligible, due to its relatively very high resistance. Due to the negligible DC current and short duration, this would not result in any corrosion concerns.

As discussed in Section 4.4, an AC voltage will be induced on parallel metallic assets (e.g. a pipeline) as a result of the AC component of current carried by the DC cable system. For coated metallic pipelines, where the asset has a defect in its coating, the AC voltage can act to drive a current to earth. If the AC voltage is large enough, this can potentially cause corrosion.

In this case all the identified assets are running perpendicular and so there will theoretically be no induced voltage. There will consequently be no AC corrosion concerns as a result of the HVDC cables.

In order to provide an indication of the effect the HVDC cables have on an asset that did run parallel, an indicative assessment has been carried out below.

For the indicative assessment, an AC induced voltage of 0.0739 V has been assumed as discussed in section 4.4. To assess whether this would cause corrosion concerns, the guidance in ISO 18086:2019 has been applied. ISO 18086:2019 suggests two conditions should be met to avoid AC corrosion. Firstly, the AC voltage should be 15 V rms or lower. Secondly, the AC average current density should be lower than 30 A/m^2 on a 1 cm^2 coupon.

The first condition is met in this case, with a maximum induced voltage of < 0.1 V.

To assess the second condition, the AC current density must be considered, which is a function of the induced voltage, local soil resistivity and the size of coating defect.

The representative AC current density is given by:

$$J_{AC} = \frac{8\,V_{AC}}{\rho \pi d} \qquad \Omega/\text{m}$$

Where:

J_{AC} = AC current density (Am^{-2})
V_{AC} = AC voltage (V)
ρ = Soil resistivity (Ω.m)

d = Defect diameter (m)

With regard to soil resistivity, ISO 18086 provides an indication of the risk of AC corrosion associated with different values of soil resistivity, Table 4-1. The actual soil resistivity along the route is currently unknown and hence a range of values have been considered.

Table 4-1 – AC corrosion risk for soil resistivity (ISO 18086)

Soil resistivity (Ω.m)	AC corrosion risk
< 25	Very high
25 to 100	High
100 to 300	Medium
> 300	Low

The calculated AC current density values for a range of soil resistivities are presented in Table 4-2.

Table 4-2 – AC current density for different soil resistivities

Soil resistivity, (Ω.m)	AC current density (Am^{-2})
25	0.7
50	0.3
75	0.2
100	0.2

As mentioned in section 4.4 all interactions with co-located assets are perpendicular meaning there would theoretically be no induced voltage and consequently no AC corrosion concern.

An indicative assessment for a parallel asset has shown that even if an asset were to run parallel, the induced voltage and corrosion risk would be minimal.

4.6 TRANSIENT FAULT CONDITIONS

A fault on the system will result in a short-term disturbance to the steady state (normal) system voltage and current.

In the event of a fault, the current in the DC cable system will rise by a factor of approximately 10 for a period of time of around 100 ms, which is the time taken for the main circuit breakers to open and isolate the fault.

During this short time the magnetic fields and induced voltage resulting from the DC cable system will rise to a level proportional to the increase in current due to the fault.

Under fault conditions the level of induced voltage on parallel assets may be expected to increase to a maximum of approximately 0.739 V. This is below typical limits and would not present any safety concern.

4.7 THERMAL EFFECTS

Thermal effects at crossing locations have been considered separately to this report.

[END OF DOCUMENT]

Crossing packages for the following co-located infrastructure owners will be provided once crossing agreements are final:

- NYPA
- Vermont Telecom
- AT&T
- Fort Ticonderoga Ferry