# Conductor Proud Stranding Investigation

ClaimsPro Briefing, 18-Oct-2016

Boundless Energy

nalcor energy
LOWER CHURCHILL PROJECT

# Take a MOMENT for Safety

# Purpose

- Provide background and relevant status information on the occurrence of post installation proud stranding on the HVdc Conductor.

- Discuss how we move forward.

# Key Messages

1. **HVdc Conductor is a critical element of the HVdc system;** designed to withstand extreme mechanical loading.

2. **General Cable Canada ("GCC") selected to design, prototype, test and supply the HVdc Conductor**

3. **Manufactured conductor met FAT and QA checks, but subsequent to installation was out of specification**

4. **Root cause investigation remains underway;** fix underway to allow continuation of stringing

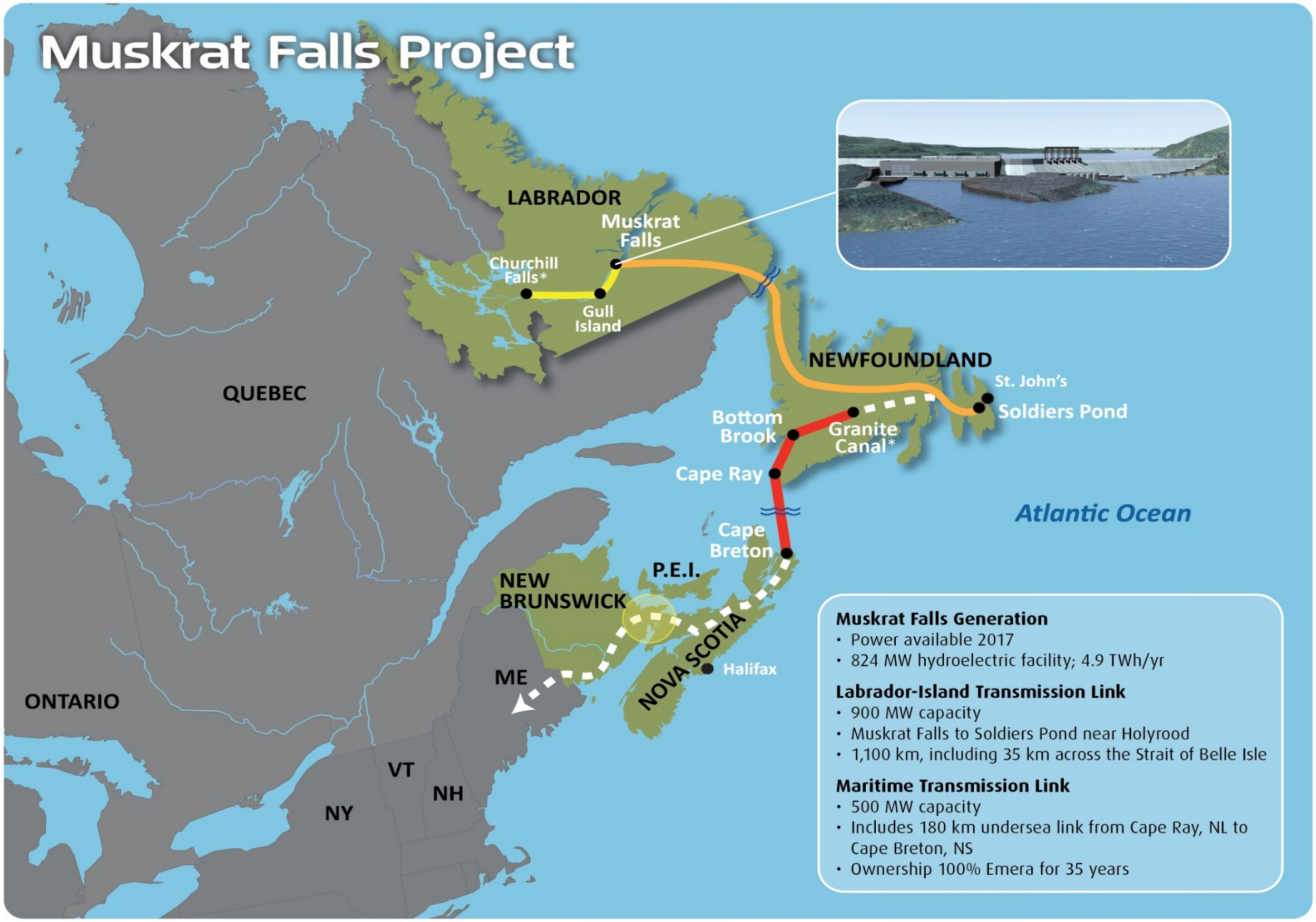
5. **Damaged conductor presents an unacceptable level of reliability risk and must be replaced**

6. **Implementation plan underway for replacement of 170km of damaged conductor**

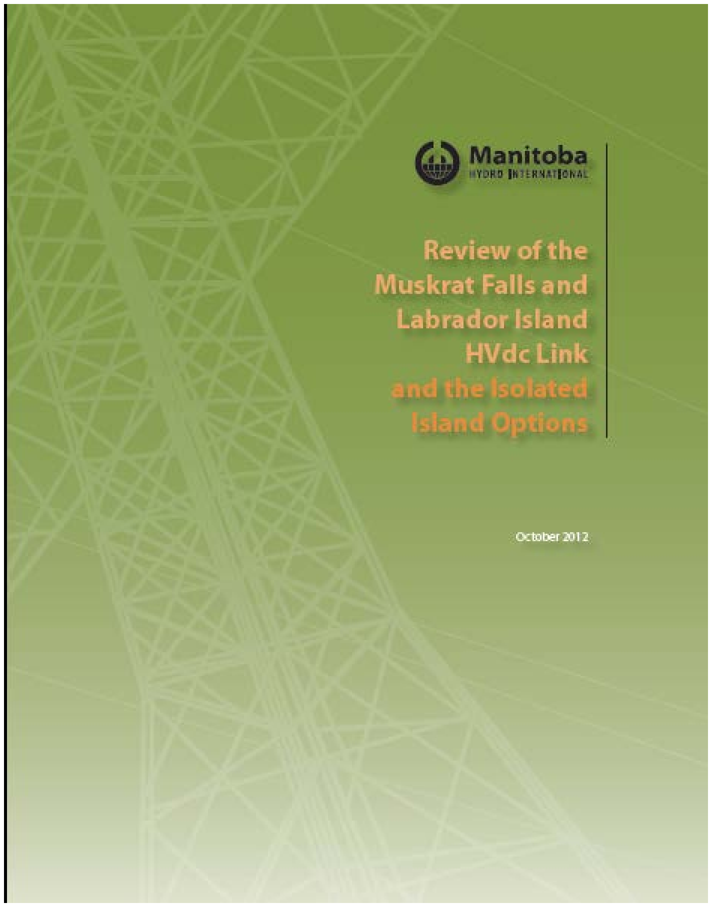
# 1 The Labrador-Island Transmission Link is of critical importance to the long-term reliable energy security of the Province.

- At nearly 1,100km in length, the HVdc overland transmission line will serve as the backbone for the Province's electrical grid. Significant time and financial investment has been made to ensure each and every aspect supports the overall system reliability.

# 1 Muskrat Falls will supply significant energy to Atlantic Canada through the LITL; no redundant parallel link exists



# 1 Both Nalcor and the Project have been scrutinized by the Public, Province, PUB and various third parties given the future reliance on this critical link.



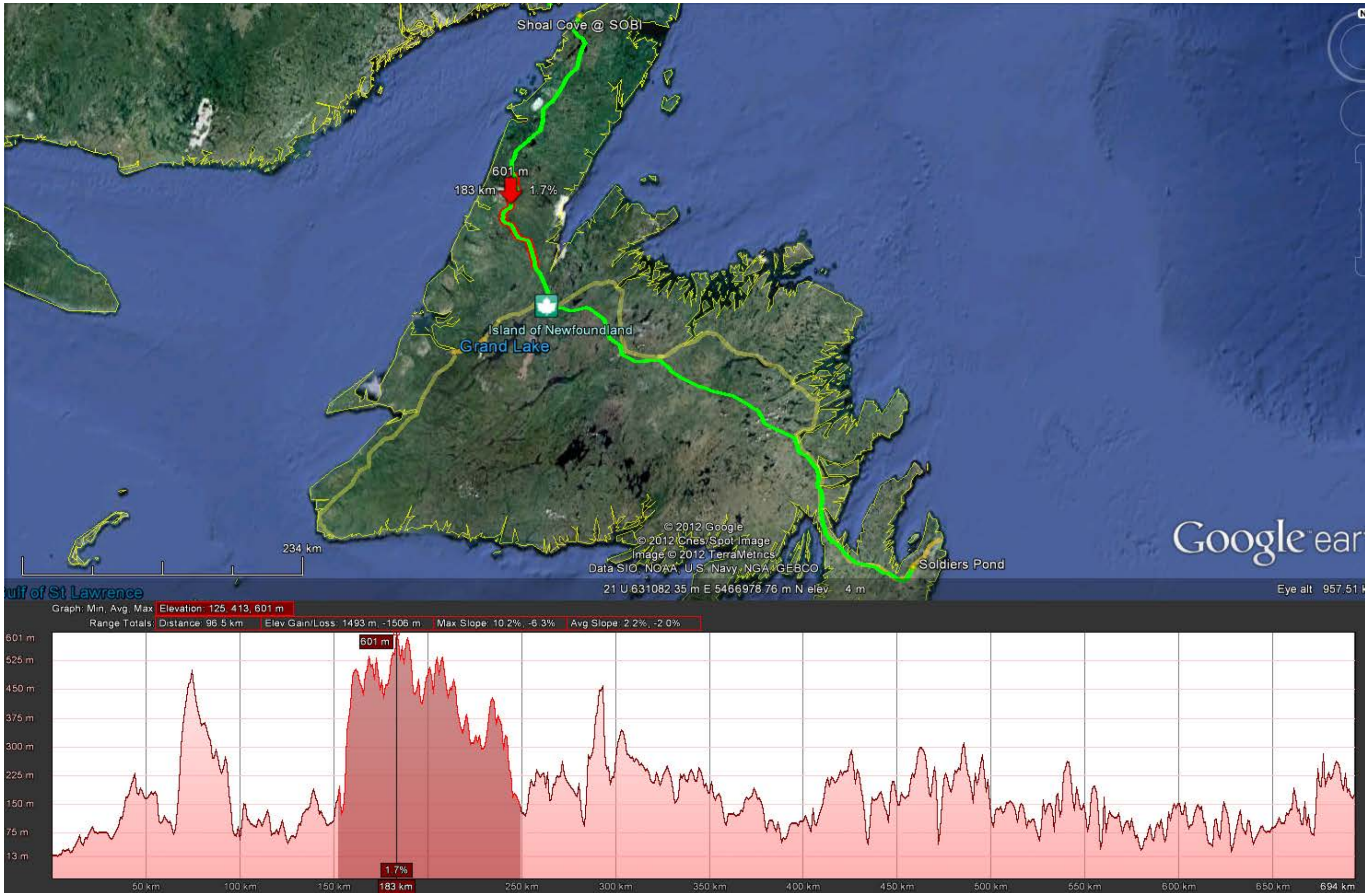

### 2.3.2 Reliability and Availability Assessment

The Reliability & Availability Assessment report presents the results of the reliability and availability analysis carried out to determine the expected reliability performance of the proposed Labrador-Island Link HVdc system. The Reliability and Availability performance indices for key system components including the converter stations, the HVdc transmission line from Muskrat Falls to Soldiers Pond, the submarine cables, the electrode lines and the composite reliability performance of the complete Labrador-Island Link HVdc system were derived and considered to be in the reliability performance range of the HVdc schemes in-operation today. The recommendations on provision of spare equipment such as converter transformers and smoothing reactors follow good utility practice.

The Nalcor study determined that the repair time of the HVdc transmission line failure has significant impact on the availability of the island HVdc link. Line design enhancement such as anti-cascading towers and a good emergency response plan are recommended for further evaluation as part of the detailed design stage post Decision Gate 3. Special care shall also be paid to the electrode line reliability, such as insulation coordination and arc extinguishing capability, due to its unique overload operation mode under pole outages and extreme long distance.

Manitoba HYDRO INTERNATIONAL October 2012 | 34

# 1 The line transverses each of Island and the remote interior of Labrador presenting unique challenges

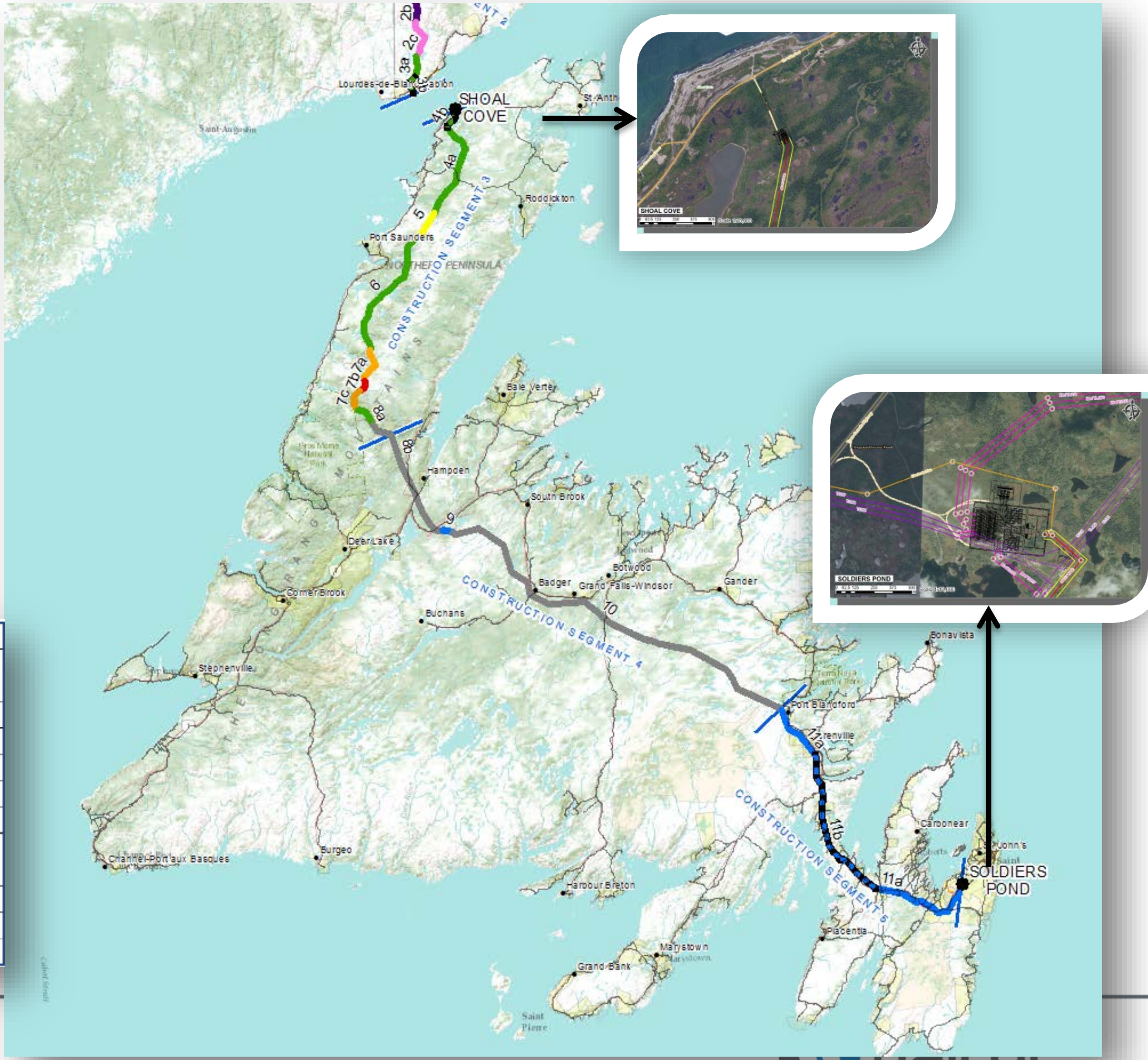



**Elevation ranges from 0m to 630m above MSL**

# 1 The line in Newfoundland subject to "challenging" metrological loading conditions

- 696km Island Portion
- Long Range Mountains
- Highly exposed coastal routing
- 13 Meteorological loading cases (135mm Rime Ice and 180 km/h winds)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Newfoundland | ③ | 4b | Average Zone 2 | 12.5 | 50 | Glaze | 120 | N | Coastal | 40 | F10 |
| | | 4a | Average Zone 2 | 56.4 | 50 | Glaze | 120 | N | Inland | 300 | F5 |
| | | 5 | HOSJ High Alpine | 18.9 | 115 | Rime | 150 | N | Inland | 500 | F12 |
| | | 6 | Average Zone 2 | 72.6 | 50 | Glaze | 120 | N | Inland | 480 | F5 |
| | | 7a | LRM High Alpine | 21.1 | 115 | Rime | 180 | N | Inland | 590 | F9 |
| | | 7b | LRM Extreme Alpine | 7.1 | 135 | Rime | 180 | N | Inland | 630 | F6 |
| | | 7c | LRM High Alpine | 12.8 | 115 | Rime | 180 | N | Inland | 600 | F9 |
| | | 8a | Average Zone 2 | 12.9 | 50 | Glaze | 120 | N | Inland | 550 | F5 |
| | ④ | 8b | Average Zone 1 | 74.9 | 50 | Glaze | 105 | N | Inland | 490 | F4 |
| | | 9 | Alpine | 7.8 | 75 | Glaze | 130 | N | Inland | 430 | F7 |
| | | 10 | Average Zone 1 | 221.0 | 50 | Glaze | 105 | N | Inland | 360 | F4 |
| | ⑤ | 11a | Eastern Zone | 89.4 | 75 | Glaze | 130 | N | Inland | 280 | F7 |
| | | 11b | Eastern Zone | 88.8 | 75 | Glaze | 130 | N | Coastal | 210 | F8 |



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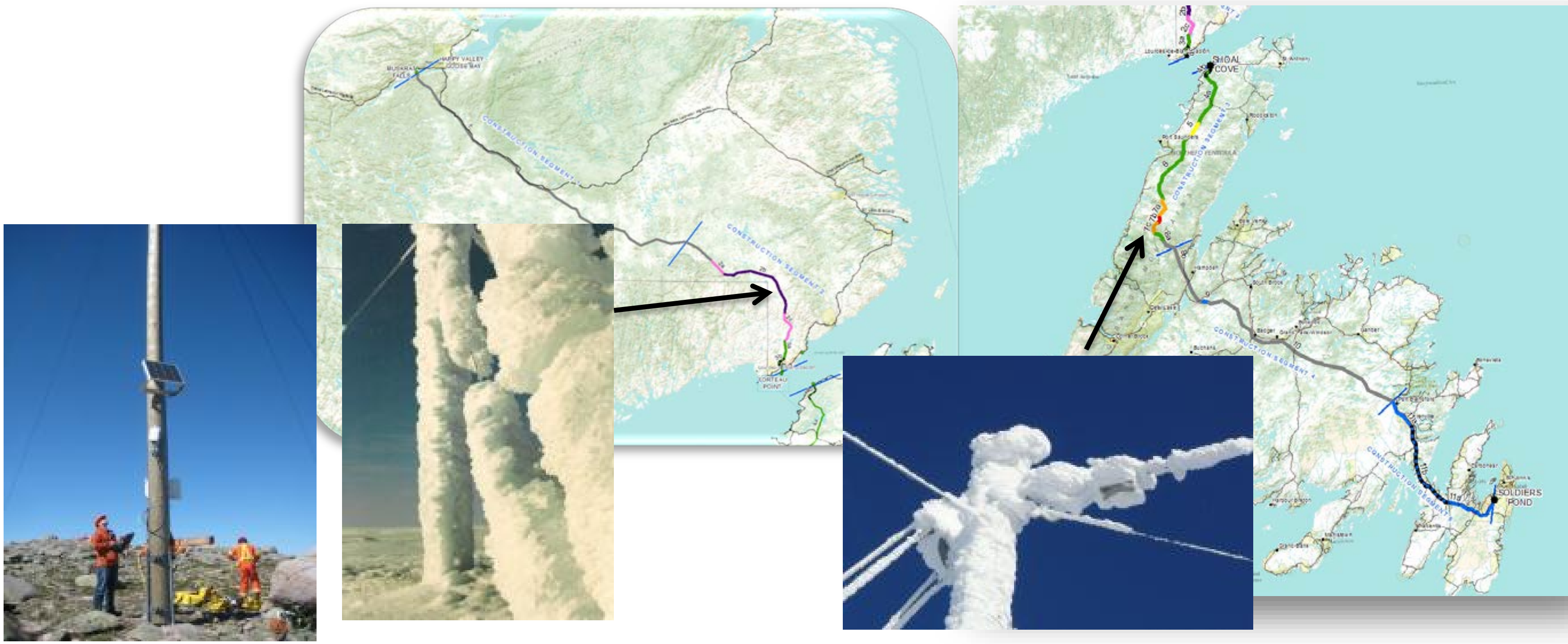
# Given this criticality of the single line, extensive effort made to design this new line to a robust standard

Line designed to withstand extreme loading conditions, in particular high alpine (Rime) and heavy glaze ice combined with intense wind loading



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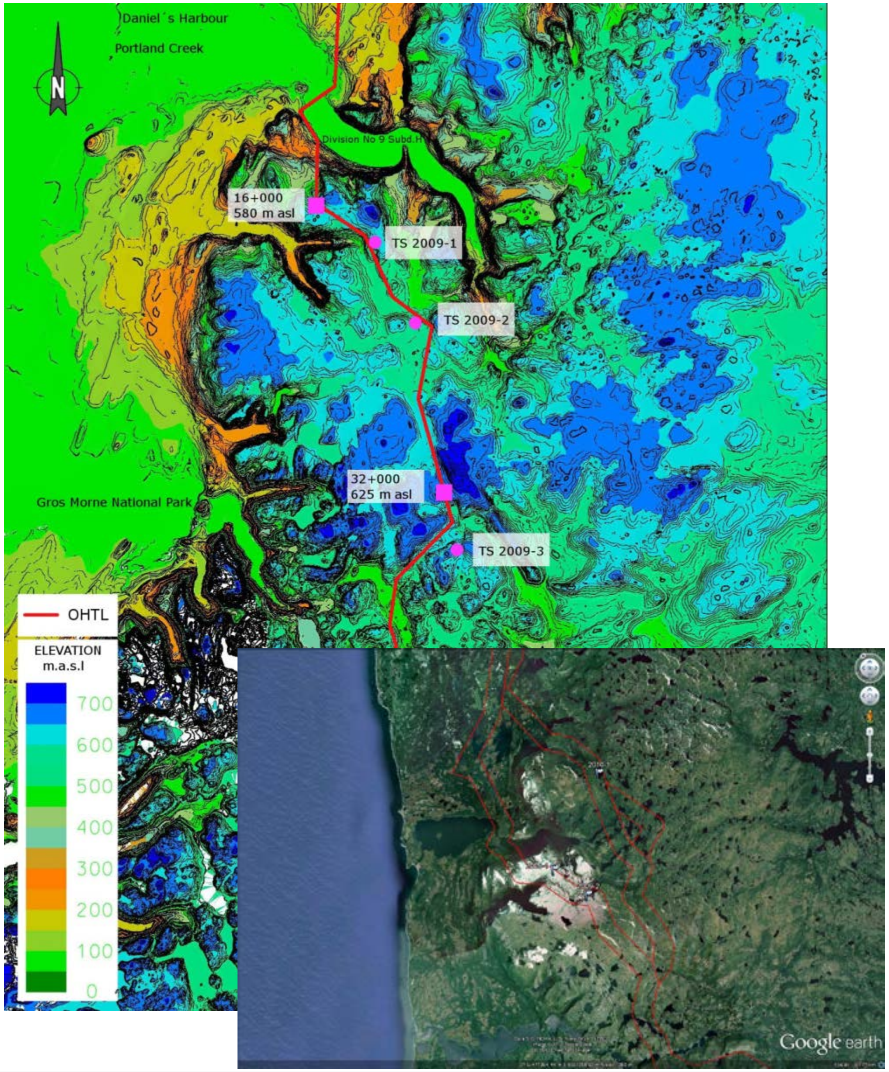
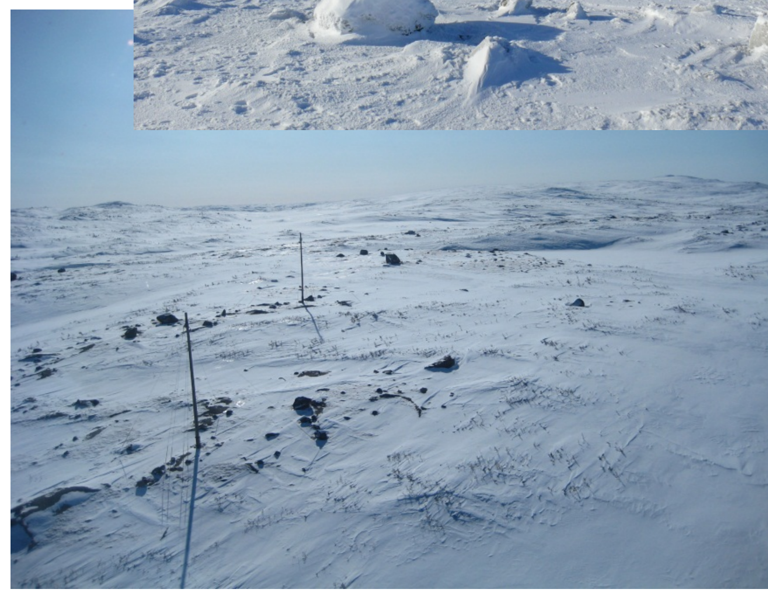
# … determine via extensive metrological field data collection in mountains areas



# 1 Criticality of Conductor Selection results in lengthy selection process

- Given the criticality of the conductor to the HVdc System, combined with the extreme environmental loadings, extensive effort and optimization of conductor occurred between 2007 – 2011
  - Key considerations include the use of a single or bundle of two conductors
- Conclusion of this work is the selection of a single conductor having the parameters set forth in the Conductor Data Sheet that must be "guaranteed" by the supplier during the procurement process

1

# Unique and extreme metrological conditions drive selection of a single-conductor. These conditions shape the design requirements that GCC must meet.

**1.3 Site and Climate Data**

Newfoundland and Labrador is the easternmost province of Canada, and consists of the Island of Newfoundland and the mainland region of Labrador, which is located to the north-west of the Island on the Canadian mainland. The Strait of Belle Isle divides the province into these two geographical components.

The transmission line is located in various terrains including flat, mountainous, and coastal regions. The mountainous terrain, mainly the Long Range Mountains located on the Northern Peninsula of the Island of Newfoundland is subjected to extreme rime icing conditions. For details of the environmental Site conditions, Supplier shall refer to *"350 kV HVdc Line Conductor Technical Specification – 3633 kcmil conductor"*, Nalcor Doc. No. ILK-SN-CD-6200-TL-TS-0027-01.

Extracted from: *350 kV HVdc Line Conductor Scope of Work 3633 kCMIL Conductor*, document no. ILK-SN-CD-6200-TL-SP-0019-01, Rev C1

# 1 Very severe environmental loading conditions are driven by a combination of ice and wind loading

**4.2 Environmental Site Conditions**

The conductors shall be suitable for reliable operations for the specified environmental conditions depicted in Table 4-1.

**Table 4-1 Environmental Conditions**

| Description | | Unit | Value |
|---|---|---|---|
| Range of elevation above sea level | | *m* | *0 - 630* |
| Keraunic Level | | *thunderstorm-days/year* | *5* |
| Range of contamination Level (ESDD) | Inland | *mm/kV* | *41* |
| | Coastal | *mm/kV* | *63* |
| Range of maximum Ice | Glaze ice (0.9 $g/cm^3$ density) | *mm* | *50-75* |
| | Rime ice (0.5 $g/cm^3$ density) | *mm* | *115-135* |
| Ambient Air Temperature | Maximum | $^oC$ | *30* |
| | Minimum | $^oC$ | *-38* |
| | Mean Annual | $^oC$ | *0* |
| Maximum conductor continuous operational temperature | | $^oC$ | *85* |
| Range of wind pressure on conductor | 50-Year Return | *(Min – Max)Pa* | *980 - 3460* |

Extracted from: *350 kV HVdc Line Conductor Scope of Work 3633 kCMIL Conductor*, document no. ILK-SN-CD-6200-TL-SP-0019-01, Rev C1

# Key Messages

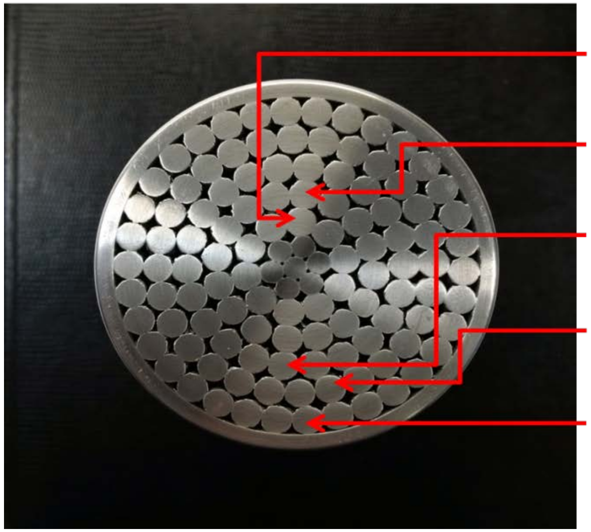
1. **HVdc Conductor is a critical element of the HVdc system;** designed to withstand extreme mechanical loading.
2. **General Cable Canada ("GCC") selected to design, prototype, test and supply the HVdc Conductor**
3. **Manufactured conductor met FAT and QA checks, but subsequent to installation was out of specification**
4. **Root cause investigation remains underway;** fix underway to allow continuation of stringing
5. **Damaged conductor presents an unacceptable level of reliability risk and must be replaced**
6. **Implementation plan underway for replacement of 170km of damaged conductor**

# 2 Following competitive RFP, General Cable selected to design, prototype test, and supply of the Conductor

## General Cable's Solution

- General Cable was contracted on 02-Jan-2014 to design and supply a 3633.0 kcmil 110/7 ACSR Conductor, guaranteeing to meet the stringent specification prepared by SNC-Lavalin.
- General Cable modified an existing Falcon conductor design by adding an additional two outer layers of aluminum. The final design consists of five (5) layers of aluminum supported by a steel core with each layer having an opposing lay.

**3633.0 kcmil 110/7 ACSR Conductor**



1. Layer 1, 10 wires, Right Lay
2. Layer 2, 16 wires, Left Lay
3. Layer 3, 22 Wires, Right Lay
4. Layer 4, 28 Wires, Left Lay
5. Layer 5, 34 Wires, Right Lay

2

# To ensure a quality product, SNC-Lavalin's Tech Spec includes an extensive list of standards that GCC must adhere too ….

| Standard | Application |
|---|---|
| ASTM B193 | Either of these standards is required to do direct current resistance test on the complete conductor. |
| ASTM B398 | |
| ASTM B857 | |
| ASTM B502 | This standard is required to do tensile strength and elongation tests on Aluminum – clad coated steel code of the conductor |
| CAN/CSA C61232 | This standard was proposed by General Cable to replace ASTM B502 since the ACSR conductor was being manufactured as per Canadian Standard. |
| CAN/CSA C60888-03 | This standard is required to do sample tests on the zinc coated steel wires as listed in the specification |
| CAN/CSA C60889-03 | This standard is required to do sample tests on the aluminum wires as listed in the specification |
| CAN/CSA C61089-11 | This standard is required to do type test and sample tests on the complete conductor as listed in the specification |
| IEC 61395 | This standard is required to do long term creep test on the complete conductor |
| IEEE 524 | This standard is required to guide to the Installation of overhead transmission line conductors |
| IEEE 1138 | This standard is required to do Sheave test on complete conductor |
| AS 3822 | This standard is required to do Co-efficient of Thermal Expansion for bare overhead conductors |

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# …. amongst which include specifications for finished outer surface dimensions of the conductor.

**4.3 Workmanship**

The outer surface of the complete conductor shall be clean, free from excess oil and without imperfections visible to the unaided eye (normal corrective lenses excepted) such as laps, slivers, nicks and inclusions of a frequency and magnitude consistent with good commercial practice when received at Site.

**5.4.2 Conductor Dimensions**

The outside diameter of the complete conductor shall be measured in the central straight conductor portion between the closing die of the stranded and the capstan. The measured diameter shall be its nominal value, plus or minus 1.0 percent (Clause 6.6.2 of CAN/CSA standard C61089-11). The nominal outside diameter of the 3633.0 kcmil 1841-A1/S1A-110/7 ACSR shall be 56.9 mm. Dimensional measurements shall be made with a micrometer caliper graduated to read in 0.01 mm. The layer

Extracted from: *350 kV HVdc Line Conductor Technical Specification 3633 kCMIL Conductor*, document no. ILK-SN-CD-6200-TL-TS-0027-01, Rev C1

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# GCC "guarantees" that its conductor will meet these standards and associated design parameters / dimensions.

| 1841-A1/S1A-110/7 ACSR CONDUCTOR (ALUMINUM-CLAD STEEL CORE) | | | | |
|---|---|---|---|---|
| ITEM | DESCRIPTION | UNIT | REQUIRED | GUARANTEED |
| 3.16 | Steel portion heat capacity | Watt-s/m-°C | | 133.6 |
| 3.17 | Nominal cross-sectional area (total) | $mm^2$ | 1,911 | 1,917 |
| 3.18 | Overall diameter | mm | 56.9 | 57.01 |
| 3.19 | Number of conductors per pole | unit | 1 | 1 |
| 3.20 | Number of aluminum wires (stranding) | unit | 110 | 110 |
| 3.21 | Diameter of aluminum wires | mm | 4.62 | 4.62 |
| 3.22 | Type of weld for aluminum wire joint | - | | |
| 3.23 | Number of steel wires (stranding) | unit | 7 | 7 |
| 3.24 | Diameter of steel wires | mm | 3.59 | 3.60 |
| 3.25 | Tensile requirement on Steel wire (As per ASTM B502) | - | | |
| 3.25.1 | Stress at 1.0% extension, min | MPa | 1,137 | |
| 3.25.2 | Ultimate tensile strength, min | MPa | 1,275 | |
| 3.25.3 | Elongation, min, 250 mm | % | 1.5 | |
| 3.26 | Aluminum – clad | - | | |
| 3.26.1 | *Density at 20°C* | $g/cm^3$ | 6.590 | |
| 3.26.2 | *Resistivity at 20°C* | $\Omega.mm^2/m$ | 0.08480 | |
| 3.27 | PLS-CADD conductor file (*.wir) provided | Yes/No | Yes | Yes |

Overall diameter is critical parameter to support custom designed and fabricated hardware and vibration dampening systems (by other that GCC)

Extracted from: *350 kV HVdc Line Conductor Data Sheet 3633 kCMIL Conductor*, document no. ILK-SN-CD-6200-TL-DT-0013-01, Rev C1

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# To confirm same, SNC-Lavalin specifies that prior to commencement of manufacturing GCC must first build a prototype conductor and subject it to a series of type tests

| Type Test | Test Objective | Acceptance Criteria | Outcome |
|---|---|---|---|
| **Stress Strain test** | The objective of the test is to provide the Stress-Strain characteristics of the conductor to be used in the calculation of sags and tensions during the design of overhead transmission lines. | There is no acceptance criteria for this test. The test is to produce the data required for sag tension calculations. Test was performed on both steel core and complete conductor | Passed |
| **Ultimate Tensile Strength Test** | The objective of the Ultimate Tensile Strength Test is to determine the ultimate tensile strength of the conductor. | The conductor shall not fail without fracture of any wire before achieving 95% of the rated tensile strength of the conductor. | Passed |
| **Long term Creep test** | The objective of the Creep Test is to measure the room temperature long-term tensile creep properties of the conductor. The data from this test might be used to assist in the calculation of sags and tensions during the design of overhead transmission lines. | There is no acceptance criteria for this test. Creep Test is to measure the room temperature long-term tensile creep properties of the conductor. | Passed |
| **dc resistance test** | The objective of the DC Resistance Test is to verify the measured direct current (DC) resistance of the conductor against the manufacturer's specified value as indicated in the conductor datasheet | The conductor DC Resistance shall not be greater than 0.0157 ohms/km | Passed |
| **Joint test** | The objective of the Aluminum Wire Joint Test is to verify the tensile strength at failure of the individual aluminum wire joints. | Cold pressure aluminum wire joint shall withstand not less than 150 MPa. | Passed |
| **Co-efficient of thermal expansion test** | The objective of the test is to determine the coefficient of thermal elongation of the 3633 kcmil ACSR Conductor up to the designed maximum operating temperature. The data from this test might be used to assist in the calculation of sags and tensions during the design of overhead transmission lines. | There is no acceptance criteria for this test. To measure the elongation characteristics of the conductor at various temperatures and used to assist in the calculation of sags and tensions during the design of overhead transmission lines | Passed |
| **Sheave Test** | The intent of the Sheave Test is to subject 3633 kcmil ACSR Conductor to a simulated pull over a number of sheaves during field conductor installation. | No damage to the aluminum or steel strands after completion of the test | Passed |

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# These tests are completed by GCC using Kinetrics (March 2014)

KINECTRICS

**To:** Mr. Jean-Marie Asselin
General Cable
156 Parkshore Drive
Brampton, ON
L6T 5M1

**KINECTRICS INC. TEST REPORT FOR GENERAL CABLE**

**TESTS ON 3633 KCMIL 1841-A1/S1A-110/7, TYPE 4, ACSR CONDUCTOR**

**Kinectrics Inc. Report No.: K-419561-RC-0001-R05**

**August 13, 2014**

Andrew Rizzetto

Transmission and Distribution Technologies Business

A series of eight (8) tests were performed on 3633 kcmil, **A**luminum **C**onductor **S**teel **R**einforced (ACSR) manufactured by General Cable. The test conductor was received in good condition on December 13, 2013. The outside diameter of the conductor was 57.01 mm (2.244 inch) and was designated as 3633 kcmil 1841-A1/S1A-110/7, Type 4 ACSR, Conductor. The test conductor consisted of seven (7) steel core strands covered by five (5) layers of one hundred and ten (110) round aluminum wires. The test conductor was verified against the complete specification as shown in Appendix A. In addition, the sheave dimensions were verified against the requirements of the technical specification and IEEE 524 "Guide to the Installation of Overhead Transmission Lines".

All tests were performed between March 17, 2014 and March 26, 2014 by Kinectrics Inc. personnel at 800 Kipling Avenue, Toronto, Ontario, M8Z 5G5, Canada, under General Cable Purchase Order No. 1302 TCS, dated November 18, 2013.

The tests were performed under Kinectrics' ISO 9001 Quality Management Program. A copy of Kinectrics ISO 9001 Registration Certificate is included in Appendix D. The conductor successfully met all the requirements of the specification listed below.

This document is a compilation of all the individual test reports. Each individual test report is self-contained with dedicated figures. The first three (3) appendices located at the back of this document are common to each test report.

**PRIVATE INFORMATION**

**Contents of this report shall not be disclosed without authority of the client. Kinectrics Inc., 800 Kipling Avenue, Unit 2, Toronto, Ontario M8Z 5G5.**

## Prototype Tests Undertaken by Kinetrics

| | TEST | TEST DATE | TEST STANDARD |
|---|---|---|---|
| 1. | Stress-Strain Test | March 17 – March 18, 2014 | CAN/CSA C61089-11 |
| 2. | Creep Test at 15% RTS | March 17, 2014 | Based on IEC 61395 |
| 3. | Creep Test at 25% RTS | March 17, 2014 | Based on IEC 61395 |
| 4. | Creep Test at 35% RTS | March 18, 2014 | Based on IEC 61395 |
| 5. | Ultimate Tensile Strength Test | March 19, 2014 | CAN/CSA C61089-11 |
| 6. | DC Resistance Test | March 19, 2014 | CSA C22.2 No. 2556-07 & ASTM B193-R92 |
| 7. | Coefficient of Thermal Elongation Test | March 20 – March 24, 2014 | AS 3822 |
| 8. | Sheave Test | March 24 – March 26, 2014 | Based on IEEE 1138 – 1994 |
| 9. | Aluminum Wire Joint Test | March 21, 2014 | CAN/CSA C61089-11 |

# 2 Sheave test reveals anomaly; slight proud stranding

## Sheave Test Acceptance Criteria [1]

***"There are to be no damage to the aluminum or steel strands after completion of the individual sheave tests and the entire sheave test program. This includes cracked or broken strands and conductor experiencing "proud stranding".*** *This will be determined through observation with the unaided eye. The ovality of the conductor at the measured locations shall not exceed 10%. In addition, there is no intention to perform a breaking load test after the sheave test program."*

[1]. Extracted from Kinetrics Type Test Report – Page 55

Figure 3b Slight protruding strand of the Conductor after Completing Sheave Test 2b
(Note: the strand is just outside of the test section)

# Key Messages

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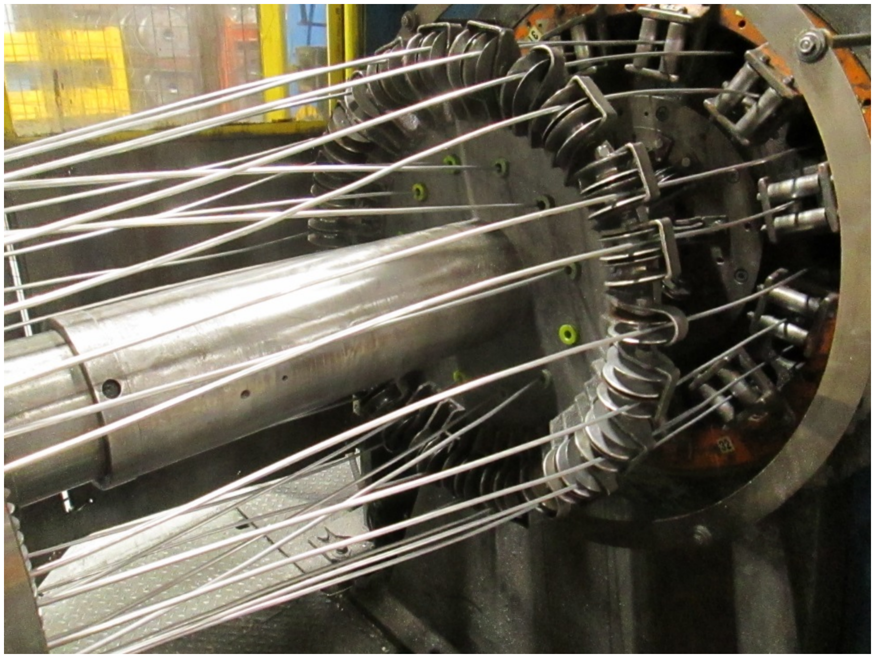
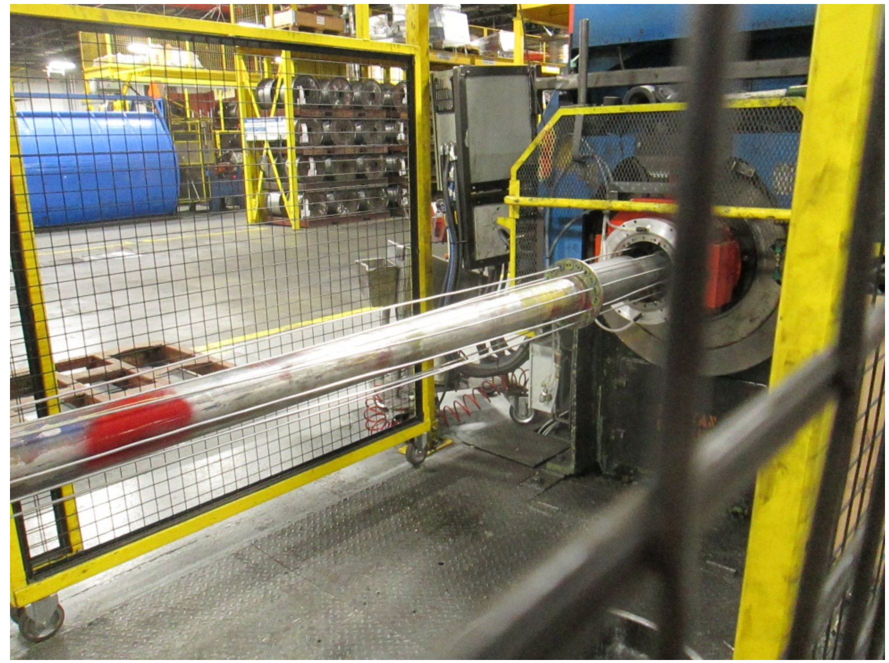
4. **Root cause investigation remains underway;** fix underway to allow continuation of stringing
5. **Damaged conductor presents an unacceptable level of reliability risk and must be replaced**
6. **Implementation plan underway for replacement of 170km of damaged conductor**

# 3 Following prototype testing, GCC manufacture 3 lots of conductor for delivery .....



4th and 5th layers being combined after 3rd machine



10 Wires brought forward from 4th Machine, to feed left image

# 3 No significant anomalies are detected and conductor passes our stringent pre-delivery inspection

**QUALITY SURVEILLANCE REPORT**

| | | |
|---|---|---|
| **Client:** Nalcor Energy | **Project:** Lower Churchill Project | **Date:** 01-MAY-2015 |
| **Project N°:** 505573 | **QSR No: 37** | **Page** 6 of 9 |

**6.2 Procedure Review:**
Repair procedure for three reels #872-873 and 874 was issued to Nalcor and was approved by Nalcor Engineer. The application of this procedure will be used to add on the missing wire of these reels. Procedure will have to be updated to include the acceptance criteria. No picture allowed on the internal procedure of GCC for the repair in the shop.

Shipping by boat will require a special procedure for latching the load of the reels. We will verify the procedure securing the reels for transportation on the ship to NFL; Mrs. Claudia Munoz ,in charge of coordinate the shipment, will send us the procedure with the date of shipments by boat. Not done yet on November 30th, 2015.
Documentations for ITP were verified by Mr. Adelin Gagnon to make sure latest revision are in use on GCC plants St-Maurice plant, GCC Lapointe plant (jumbo coil), Bekaert, galvanized steel core, Intral Alumoweld steel core and at George Evans fabrication of Steel reels. ITP are updated, see the table 4 up item ITP ILK-GC-SD-6200-TL-Q04-0001-01 rev. C1. All found acceptable.

**6.3 Documentation Review:**
- We reviewed test certification for lot 11, all found acceptable; test certification signed and stamped is attached to this report

**6.4 Material Receiving**
Production at Intral for Alumoweld steel core. Mr. Jean-Luc Allaire is replacing Mr. Gagnon. The visit to Intral for QA evaluation will be on May 4th, 2015. Quantity required by GCC PO is 3X41 Km and 1X38Km.

**6.5 In Process Inspections/Verification:**
We verified the product referring to ITP FS-13-02-05 rev. 6, cable with galvanized steel core. No revision has been done to ITP & is still at revision 6.

Verification was done at the machine 45; production was under final stage stranding, produced with Bekeart galvanized steel core. The single wire used is Churchill #3 (4250 meters coil) identified on small reels. We verified the number of wires applied on this layer; all found conform.

Draw machine #623 verification 9.5mm to 4.61. We verified the jumbo coil number and the diameter after draw with laser instrumentation. We also verified the records by operator. The produced wires were for the final stage: Repartition is as follow:
Phase 3 length required is 4250 meters

GCC has completed on April 30th, 2015, production of the reel 1254 at the final stage, all stored in yard; there is also Bekaert galvanized steel wire stored in yard.

There are 3 reels #1168-1169 and 1171 on quality hold (NC) see in table 3.2 above. Reels short length were accepted by Nalcor concession. Found acceptable

**6.6 Testing**
No test was done at the GCC Laboratory during our visit.

**6.7 Painting:**
Reel #891 short length will have to be marked with red paint as mentioned in concession PT0328001-009.
All NC reels stored at the Trois-Rivières Warf were identified with red X on both sides of the reels

**6.8 Fabrication:**
GCC has produced reels up to reel # 1254; reels #1045 to 1254 are stored in yard
At stage 2, 27 reels stored inside
Required on the contract, 1710 reels; there are 3 reels stolen in Quebec City and 3 more involved in accident, GCC

LCP-PT-MD-0000-QM-FR-0023-01, REV 55

**QUALITY SURVEILLANCE REPORT**

| | | |
|---|---|---|
| **Client:** Nalcor Energy | **Project:** Lower Churchill Project | **Date:** 01-MAY-2015 |
| **Project N°:** 505573 | **QSR No: 37** | **Page** 7 of 9 |

cannot save these 3 reels, damages are too large. GCC received a change order to produce 6 more reels.

**6.9 Shipping:**
Lot #10 is completely shipped to Trois-Rivières.

We went to Trois-Rivières Warf in order to verify the state of reels in storage and the handling equipment. There is no defined date for shipment by boat.
We contacted Mrs. Claudia Munoz, who coordinates transportation In order to have more information about when the boat will be at the Warf, what will be the procedure for latching that they will be using. She will copy us on the e-mail that she will send to NALCOR. Mrs Munoz supplied us the procedure for handling the reels.
So far lot #8 (135 reels), 9 (144 reels) are shipped to the Warf, lot 10 (144 reels) are shipped at the Trois-Rivières Warf

**7.0 Photos:**

Photo No : 1 final pass of layer at machine 45

Photo No: 2 final pass of layer at machine 45 (34 wires)

Photo No. 3 final pass at machine 45 replacing small reels of single wire

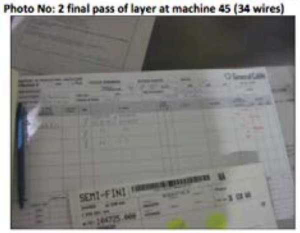


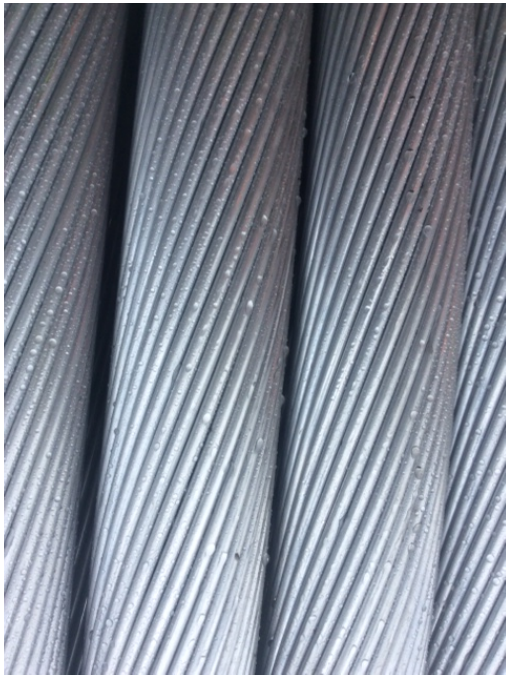

Photo No.4 final stage report at machine 45 by operator

# 3 In total ~1,700 in-spec reels were delivered by GCC in 2015

**Typical Reels at GCC Plant (1350m each)**

**A Closer Examination**

**Note no Proud Stranding**



# 3 Installation commences November 2015

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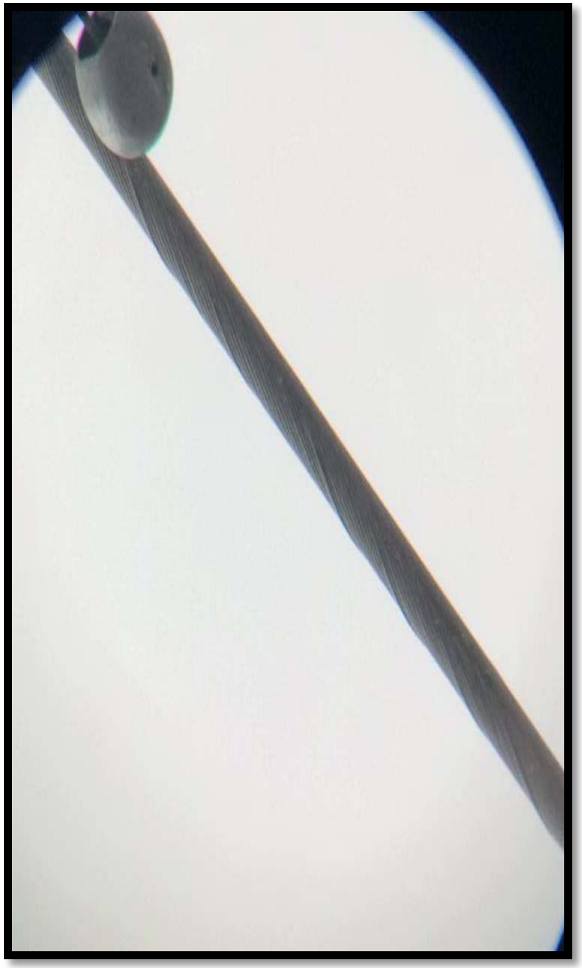
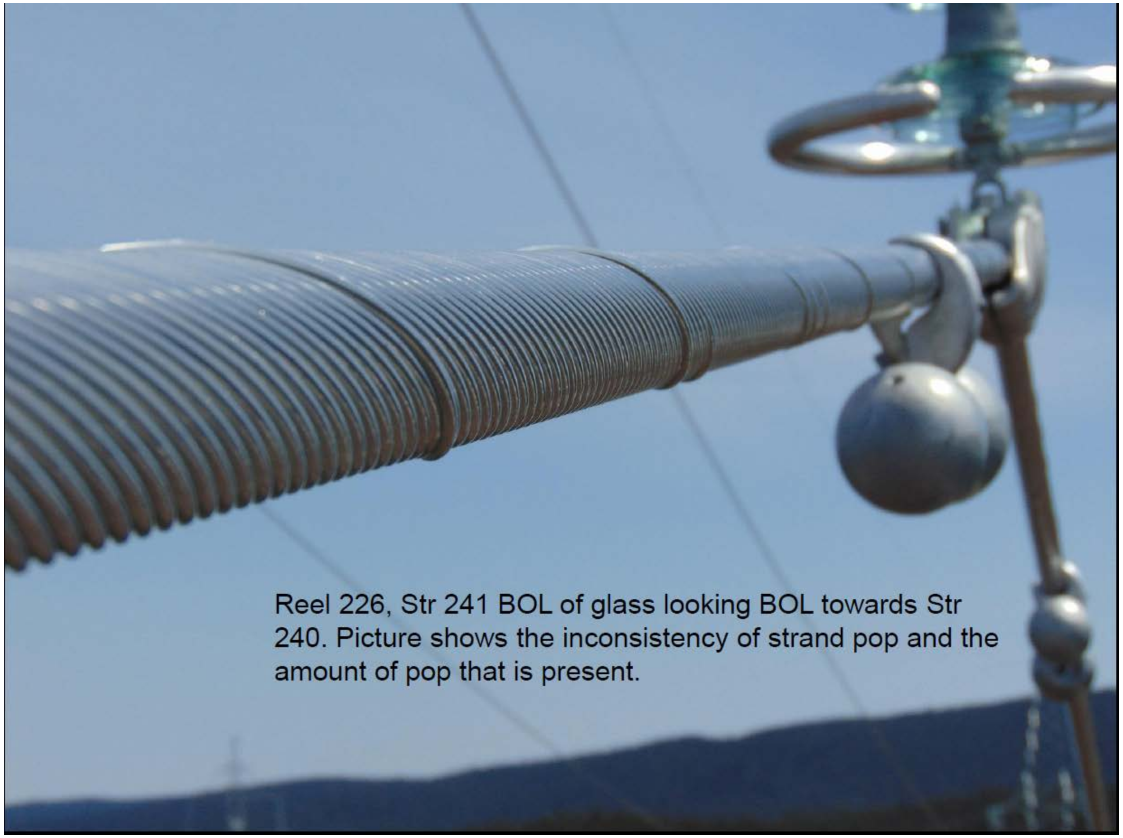
# In March 2016 an anomaly was detected by LCMC during post-installation surveys

- On 14-Mar-2016 during a tower inspection of structure S1-241, an LCMC representative first identified what appeared to a protruding or loose strand.
- This discovery generated a number of actions, one of which was to identify the extent of proud stranding.
- Stringing operations continued through until May as field data was collected and expertise engaged.
- Through subsequent surveys is was identified that it was a proud stranding that was widespread and random across the entire length of installed conductor.



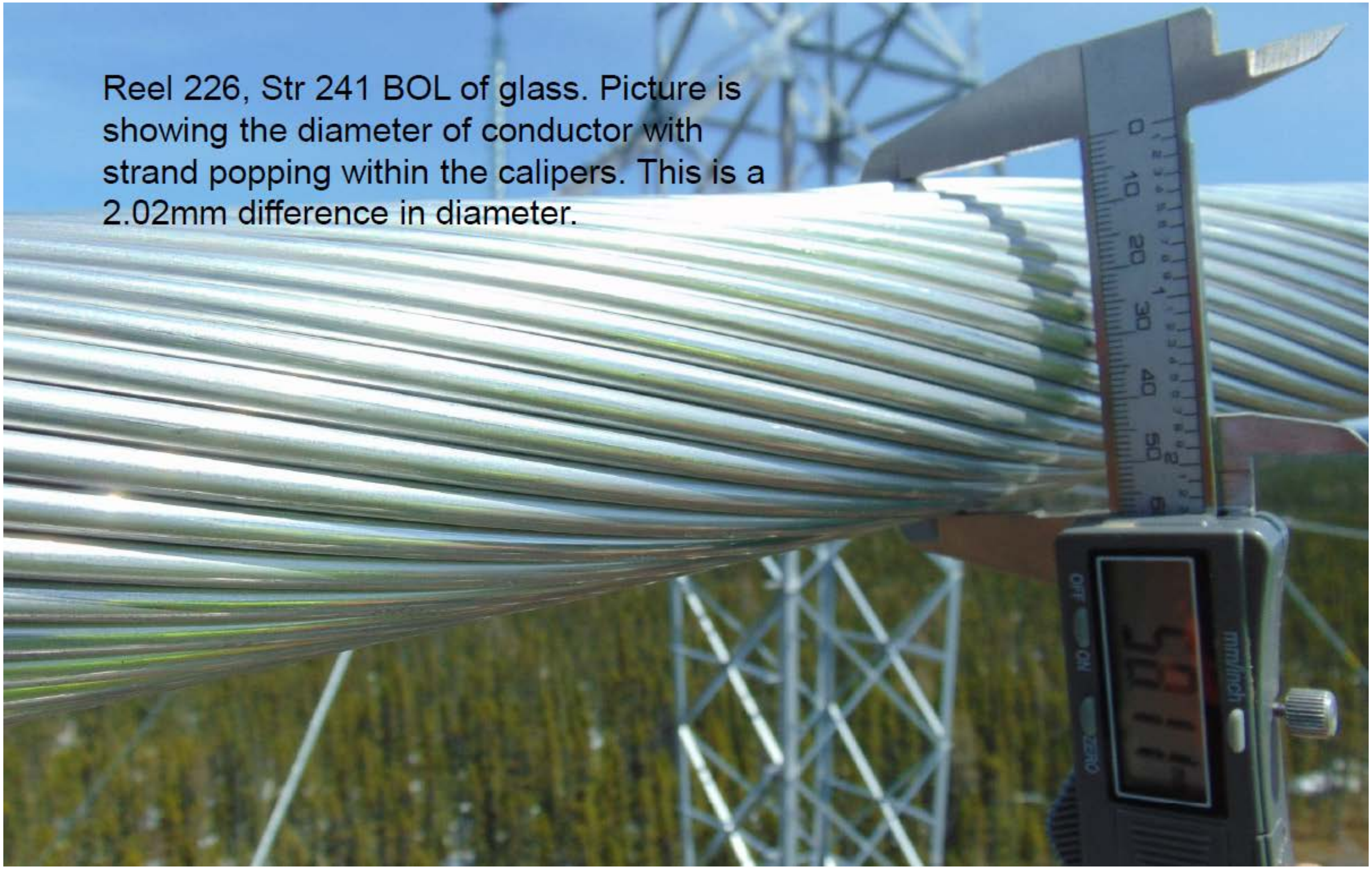
# 3 The situation revealed with further field survey is alarming

- The installed portion of the conductor is exhibiting what is being referred to as a “proud strand” phenomenon.
- Erratically, one of the strands in the outer most conductor layer is randomly rising, by approximately 2 mm (nearly ½ a strand diameter).
- This phenomenon has presented itself randomly throughout the installed conductor, irrespective of line location or geographical area.



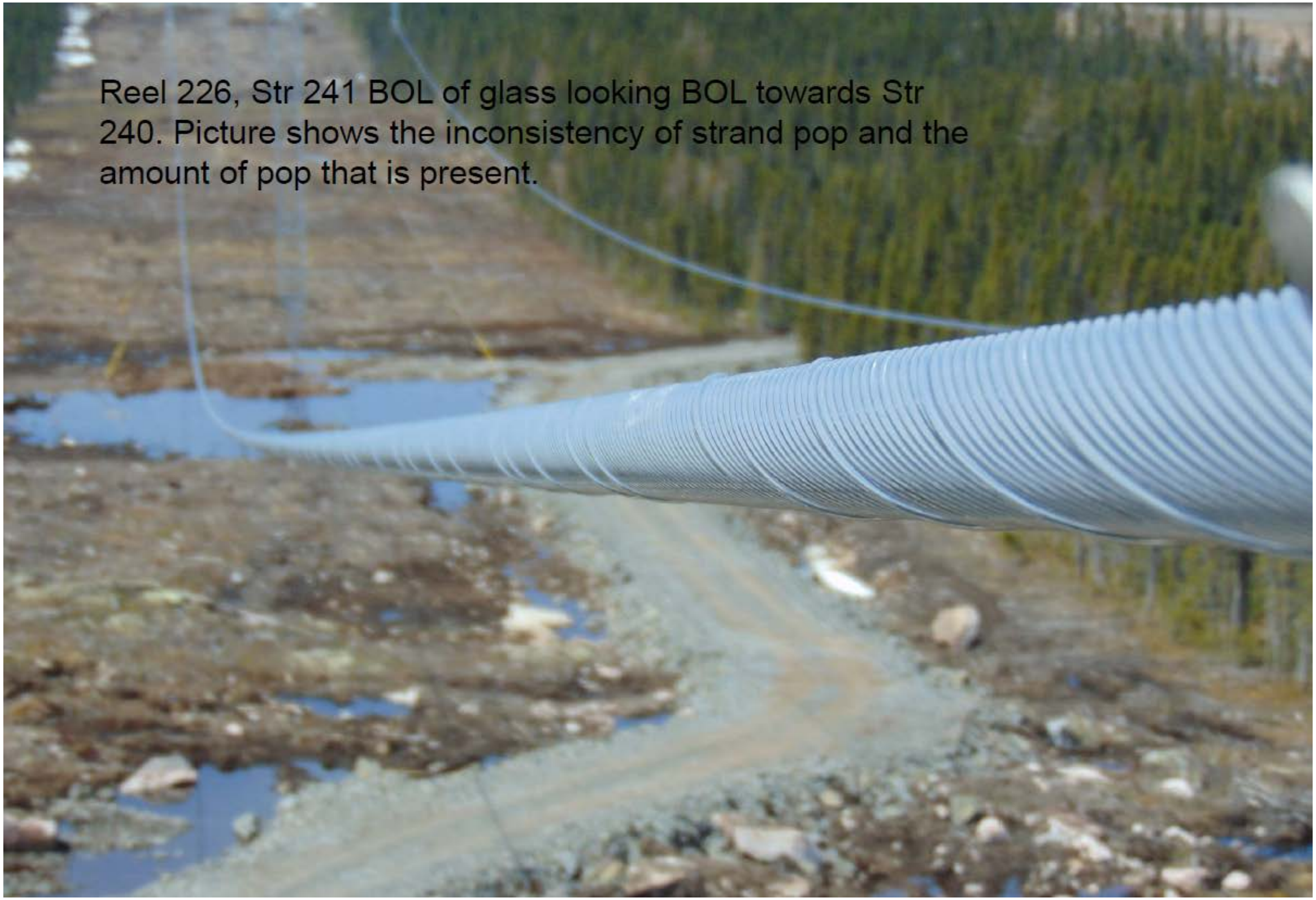
# 3 Typical as-installed condition with Conductor in a tension state in a section without proud stranding

# 3 Proud Stranding increases overall conductor diameter in excess of 2mm



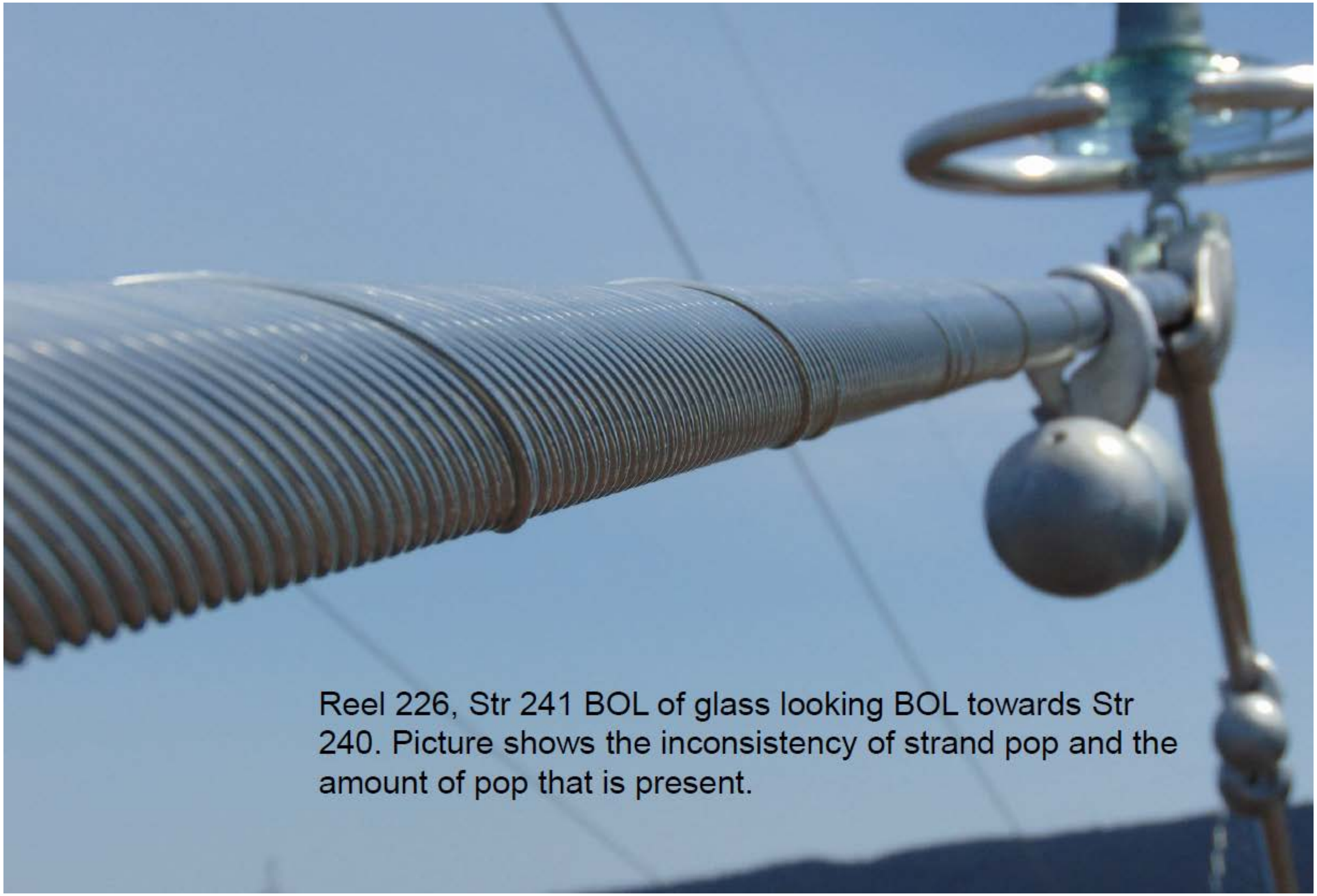
3

# Proud Stranding is random / inconsistent



3

# Typical Condition



3

# Proud Stranding results in loose hardware and damper clamps

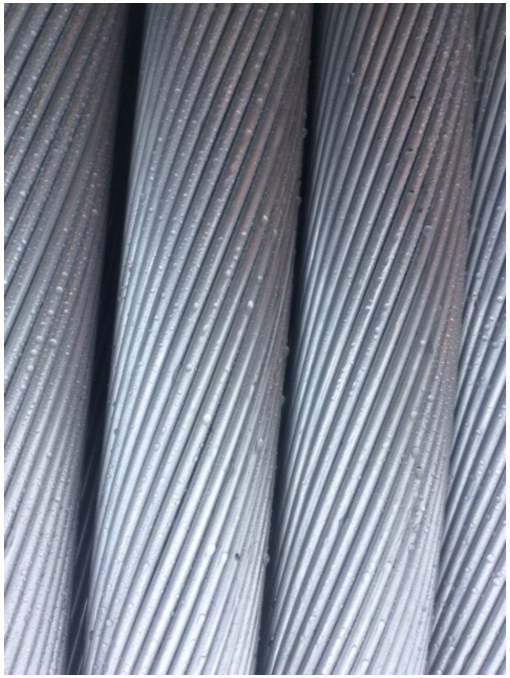
# 3 Field Survey Conclusions

- To date there has been 273 reels of 110/7 conductor installed, which equates to approximately 368 km
- Field survey indicates that proud stranding is present throughout the length of strung conductor
- Proud stranding not isolated to a specific area on the conductor, rather are somewhat random
  - Correlation efforts to-date have been non-conclusive

3

# In summary, following installation, conductor outer surface condition is out of specification

**As Delivered Condition (typical)**

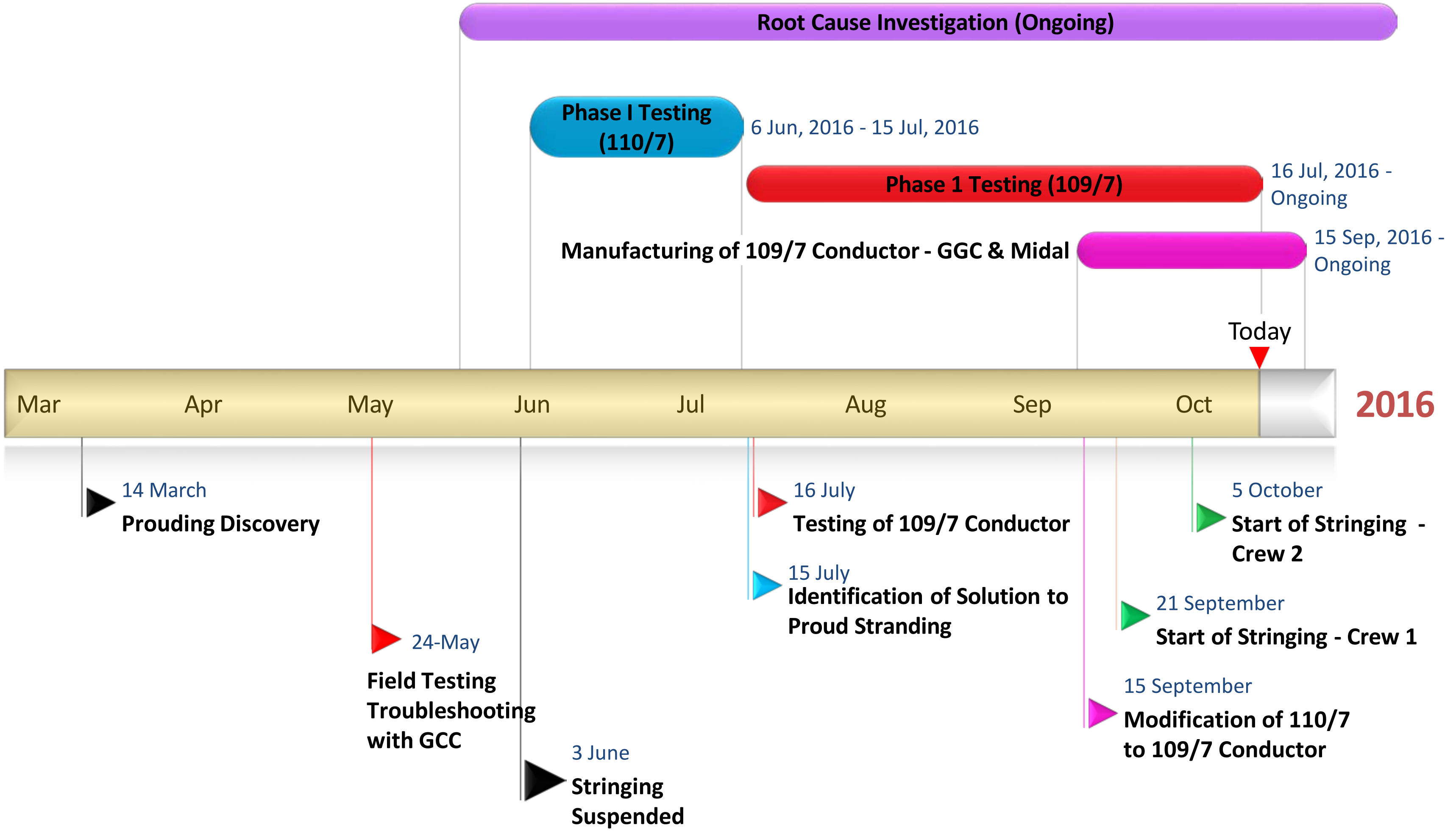


**Post Installation (typical)**

# Key Messages

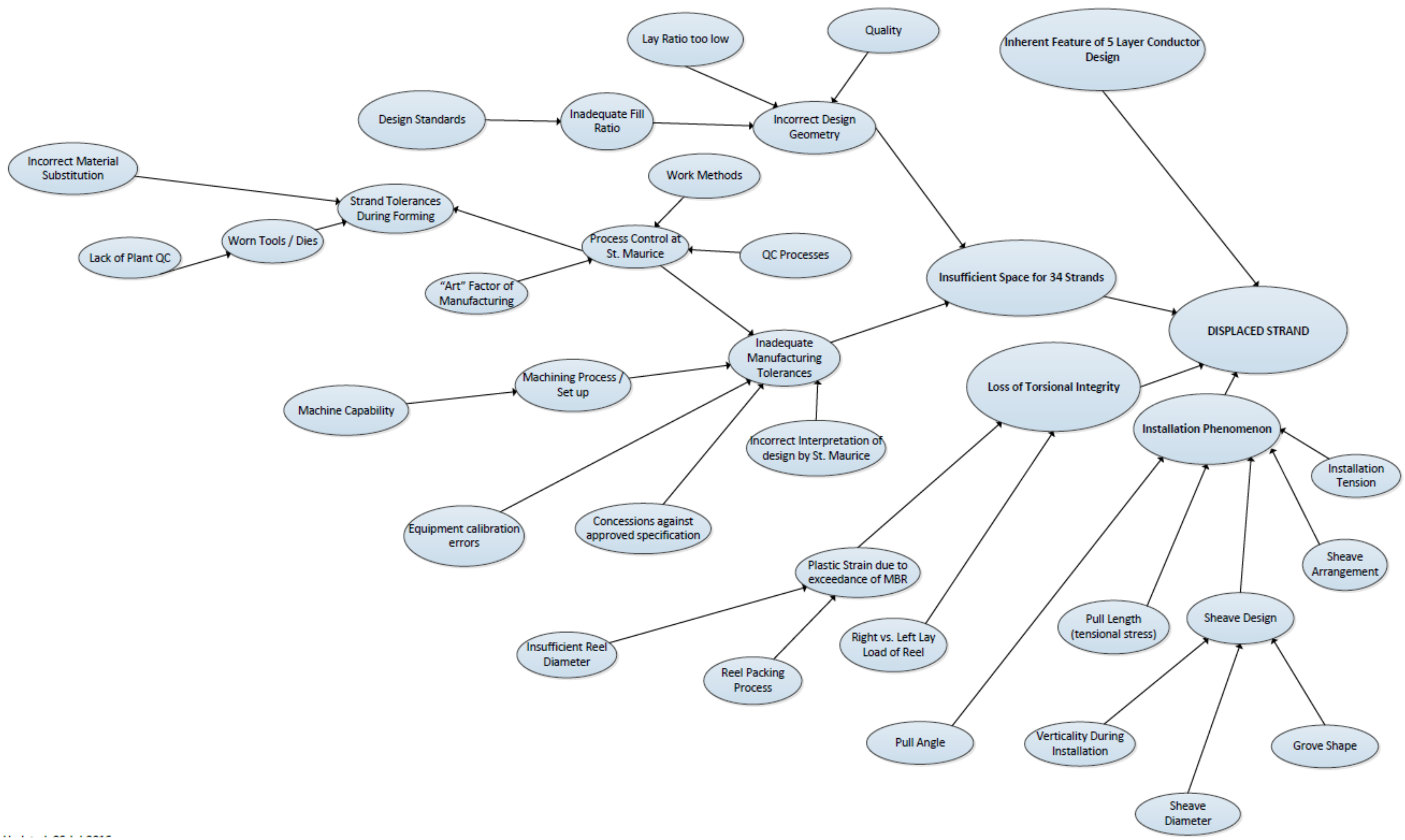
1. **HVdc Conductor is a critical element of the HVdc system;** designed to withstand extreme mechanical loading.
2. **General Cable Canada ("GCC") selected to design, prototype, test and supply the HVdc Conductor**
3. **Manufactured conductor met FAT and QA checks, but subsequent to installation was out of specification**
4. **Root cause investigation remains underway;** fix underway to allow continuation of stringing
5. **Damaged conductor presents an unacceptable level of reliability risk and must be replaced**
6. **Implementation plan underway for replacement of 170km of damaged conductor**

# 4 Root Cause Investigation Commences in May



# 4 Significant number of variables to be assessed

Influence Diagram – Displaced Conductor Root Cause "Theory Testing Framework"



# 4 Investigation has identified corrective measures to prevent proud stranding post installation

- Modified conductor with removal of one (1) outer strand (109/7) works
- Supports our need to find a solution to support our construction schedule
- Approximately 60km installed (2 poles) without observation of proud stranding

# 4 Investigation Status

- Inconclusive findings as to why this is the case; appears to be a combination of variables
- Significant focus on influence of tension during conductor "pulling" process and the likelihood that this aggravates the situation
- Further testing on conductor layer behavior will continue
- At this point we have not concluding any viable way to installing the 110/7 conductor to avoid the occurrence of proud stranding

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# 5 Proud Stranding is an extremely unique phenomena with little industry knowledge of why it occurs or how it will impact the long-term behavior of the Conductor

| | Areas of Risk |
|---|---|
| **Mechanical Performance** | ▪ Loss of effectiveness of the vibration dampening system leading to pre-mature strand or conductor failure (i.e. line break)<br>▪ Ineffective hardware clamping leading to pre-mature fatigue of hardware and eventually line failure<br>▪ Unknowns related to change in conductor geometry with thermal loading |
| **Electrical Performance** | ▪ Increased risk of electrical arcing leading to faults on the HVdc system beyond what the HVdc converter control system has been designed, thus leading to trips, power shedding and extended outages<br>▪ Short and long term Corona effects and line losses (which may change over time) |
| **Other Concerns** | ▪ Uncertainty of how the proud stranding will change the conductor over time (worse or better)<br>▪ Potential accelerated life of asset degradation under expected conditions (thermal loading, ice loading, etc.)<br>▪ Potential to attract more pollution, thus leading to electrical loss and faults<br>▪ Inability to accurate model the situation or time |

5

# Liberty Consulting recently emphasized the criticality and complexity of the HVdc System performance ....

Review of
Newfoundland and Labrador Hydro
Power Supply Adequacy and Reliability
Prior to and Post Muskrat Falls
Final Report

*Executive Summary*

Presented to:

The Board of Commissioners of Public Utilities
Newfoundland and Labrador
Presented by:

The Liberty Consulting Group

THE LIBERTY CONSULTING GROUP

August 19, 2016

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***Need for Added Power Supply - Post-Muskrat Falls***

- The IIS is a relatively small system, approximately 1,700 megawatts, with the majority of its load centered on the Avalon Peninsula. The size of Muskrat Falls (824 megawatts) and the associated delivery capacity, the LIL, is large for the size of the IIS. This presents challenges from a reliability perspective given the consequences of the instantaneous loss of the LIL. Hydro's system design seeks to minimize the potential for outages, but outages cannot be completely avoided.
- The LIL design includes many reliability features, including many redundancies. A key feature is that it essentially functions in two halves, called poles, which have been designed with overload capacity so that if one pole is out of service, a significant amount of power can still be delivered to the IIS. This feature and others are discussed in detail in the report and Liberty makes a number of recommendations to further enhance reliability.
- If a bipole (both poles) trip of the LIL is more than momentary, the loss of power from the LIL will result in under-frequency load shedding. Reliability analyses completed by Hydro for the LIL indicate a probability of a full LIL outage every three years with an average duration of twenty-nine hours. With sufficient backup supply, the duration of customer outages will be limited to a few hours, regardless of the length of the LIL outage. Liberty believes, however, that there will be more LIL bipole outages than estimated by Hydro.
- If there is not sufficient backup supply, there will be additional customer impact, including likely rotating outages for the balance of the LIL outage. Liberty recommends that strategies be implemented that contain loss of load on a bipole trip to limited under-frequency load shedding. In other words, adequate backup capacity should be available to prevent extensive and extended loss of load on loss of the LIL.
- Adequate backup capacity will be new combustion turbines or firm, dependable capacity from Nova Scotia via the Maritime Link. Liberty recommends that Hydro secure the necessary capacity commitments to mitigate the consequences of an extended LIL bipole outage.
- Extended LIL outages are possible, including failure of the overhead line. Although Hydro's stated objective is to complete repairs for the overhead lines within two weeks, it is difficult to have confidence that two weeks is the maximum limit for an OHL-related outage, recognizing the magnitude of the challenge of repairing significant OHL damage in potentially extreme weather and in harsh terrain.

***Role of the Maritime Link***

- Hydro's reliability analyses assume the Maritime Link is equivalent to a 300 MW generator with high availability for the IIS. The benefits of the ability to curtail the Maritime Link in the event of problems with the LIL are shown by the analyses to be considerable. The Maritime Link is thus a critical feature for the operation and reliability

5

# Even in the absence of this anomaly, Liberty pointed out that overhead line performance was of the utmost importance.

Board of Commissioners of Public Utilities — Newfoundland Hydro Supply Adequacy
Newfoundland and Labrador — Reliability of Muskrat Falls — Liberty Final Report

4. HVdc Overhead Line(OHL)

The number of outages and the outage duration for failures associated with the HVdc OHL reflect directly on the overall reliability and availability performance of the LIL.

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# 6 Prudently we have decided to replace the installed Conductor with a modified design

## Replacement Plans in Action

- Alternate design has been both laboratory and field tested – provides a conductor that can be installed with proud stranding
- Unused conductor (~1400 reels) presently being modified by General Cable under a service arrangement at an agreed cost per reel
- Replacement conductor has been ordered from Midal for delivery in late November (332 reels or ~170km)
- Proposal received from Valard for the removal and replacement which is being assessed
- Require replacement by end of October 2017 to meet targeted in-service date for the line

# 6 Cost impact of this event is substantive

**Replace 170km of conductor = $60M**

- Removal and Re-installation = $40M
- Replacement Conductor = $7.5M
- Shipping = $1.5M
- ROW Access = $6M
- Marshalling Yard = $2M
- PMT and Indirects = $3M

**Balance = $40M**

- Conductor modification by GCC = $5M
- Shipping = $7M
- Valard Standby = $15M
- ROW Access = $12 M
- Other PMT and In-directs = $1M

**Note: The above numbers are preliminary estimates only**

# Discussion and Questions

Sharing our ideas in an open and supportive manner to achieve excellence.

## Teamwork

## Open Communication

Fostering an environment where information moves freely in a timely manner.

## Honesty and Trust

Being sincere in everything we say and do.

Relentless commitment to protecting ourselves, our colleagues, and our community.

## Safety

## Respect and Dignity

Appreciating the individuality of others by our words and actions.

## Leadership

Empowering individuals to help, guide and inspire others.

Holding ourselves responsible for our actions and performance.

## Accountability