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February 5, 2026

Board of Commissioners of Public Utilities  
Prince Charles Building  
120 Torbay Road, P.O. Box 21040  
St. John's, NL A1A 5B2

Attention: Colleen Jones  
Assistant Board Secretary

**Re: Quarterly Report on Asset Performance in Support of Resource Adequacy for the Twelve Months Ended December 31, 2025**

Please find enclosed Newfoundland and Labrador Hydro's ("Hydro") Quarterly Report on Asset Performance in Support of Resource Adequacy for the Twelve Months Ended December 31, 2025.<sup>1</sup>

Appendix B to this report contains the updates specific to the Muskrat Falls Assets to provide the Board of Commissioners of Public Utilities with fulsome information as previously requested. Should you have any questions, please contact the undersigned.

Yours truly,

**NEWFOUNDLAND AND LABRADOR HYDRO**

Shirley A. Walsh  
Senior Legal Counsel, Regulatory  
SAW/rr

Encl.

ecc:

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Douglas W. Wright  
Regulatory Email

<sup>1</sup> Formerly titled "Quarterly Report of Generating Units for the Twelve Months Ended []."

# Quarterly Report on Asset Performance in Support of Resource Adequacy

For the Twelve Months Ended December 31, 2025

February 5, 2026

A report to the Board of Commissioners of Public Utilities



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## 1.0 Introduction

In this report, Newfoundland and Labrador Hydro (“Hydro”) provides data on forced outage rates of its generating facilities and the Labrador-Island Link (“LIL”). The data provided pertains to historical forced outage rates and assumptions Hydro uses in its assessments of resource adequacy. This report covers the performance for the current 12-month reporting period of January 1, 2025 to December 31, 2025 (“current period”).

This report contains forced outage rates for the current period for individual generating units at regulated hydraulic facilities:<sup>1</sup> the Holyrood Thermal Generating Station (“Holyrood TGS”), Hydro’s combustion turbines (“CT”), and the non-regulated Muskrat Falls Hydroelectric Generating Facility (“Muskrat Falls Facility”). In addition, equivalent forced outage rates are provided for the 900 MW LIL.<sup>2</sup> This report also provides, for comparison purposes, the individual asset forced outage rates for the 12-month reporting period of January 1, 2024 to December 31, 2024 (“previous period”). Further, total asset class data is presented based on the calendar year for the remainder of the ten most recent years, 2016 to 2023<sup>3</sup>—with the exception of the Muskrat Falls Facility<sup>4</sup> and the LIL.<sup>5</sup>

The forced outage rates of Hydro’s generating units are calculated using two measures:

- 1) Derated adjusted forced outage rate (“DAFOR”) for the continuous (base-loaded) units; and
- 2) Derated adjusted utilization forced outage probability (“DAUFOP”) for the standby units.

DAFOR is a metric that measures the percentage of time that a unit or group of units is unable to generate at its maximum continuous rating due to forced outages or unit deratings. The DAFOR for each unit is weighted to reflect differences in generating unit sizes to provide a combined total and reflect the relative impact a unit’s performance has on overall generating performance. This measure is applied to

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<sup>1</sup> Regulated hydraulic facilities include the Bay d’Espoir Hydroelectric Generating Facility (“Bay d’Espoir Facility” or “BDE”), the Cat Arm Hydroelectric Generating Station (“Cat Arm Station” or “CAT”), the Hinds Lake Hydroelectric Generating Station (“Hinds Lake Station” or “HLK”), the Upper Salmon Hydroelectric Generating Station (“Upper Salmon Station” or “USL”), the Granite Canal Hydroelectric Generating Station (“Granite Canal Station” or “GCL”), and the Paradise River Hydroelectric Generating Station (“Paradise River Station” or “PRV”).

<sup>2</sup> The LIL has been commissioned and is currently rated at 700 MW.

<sup>3</sup> Asset data for 2024 and 2025 is provided as the previous period (12 Months Ended December 2024) and the current period (12 Months Ended December 2025), respectively.

<sup>4</sup> The final generating unit at the Muskrat Falls Facility was released for commercial operation on November 25, 2021. Annual DAFOR performance data is available beginning in 2022.

<sup>5</sup> The LIL was officially commissioned on April 13, 2023. Annual equivalent forced outage rate (“EqFOR”) data is available beginning in 2024.

1 hydraulic units and, historically, was used for the thermal units; however, it does not apply to CTs  
2 because of their operation as standby units and their relatively low operating hours.

3 DAUFOP is a metric that measures the percentage of time that a unit or group of units will encounter a  
4 forced outage and not be available when required. DAUFOP is a measure primarily used for CTs;  
5 however, this measure may be applicable to thermal units should their operation move towards standby  
6 operation in the future. This metric includes the impact of unit deratings.

7 The forced outage rates include outages that remove a unit from service completely as well as instances  
8 when units are derated. If a unit's output is reduced by more than 2%, the unit is considered derated  
9 under Electricity Canada guidelines. These guidelines require that the derated levels of a generating unit  
10 be calculated by converting the operating time at the derated level into an equivalent outage time.

11 As the LIL is not a generating unit, the above-noted forced outage rate measures do not apply to this  
12 asset. Instead, Hydro has determined an appropriate metric to be an EqFOR to measure the  
13 performance of this asset as it relates to the supply of electricity to the Island. This EqFOR measures the  
14 percentage of time that the LIL bipole is unable to deliver its maximum continuous rating<sup>6</sup> to the Island  
15 due to forced outages, derates, or unplanned monopole outages. The effect of deratings and unplanned  
16 monopole outages is converted to equivalent bipole outage time using the same methodology as  
17 outlined above for generating units.

18 In addition to forced outage rates, this report provides details for those outages which occurred in the  
19 current period that contributed materially to forced outage rates exceeding those used in Hydro's  
20 resource adequacy planning analysis for both the near and long-term.

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<sup>6</sup> The LIL maximum continuous rating is 700 MW at present.

## 2.0 Assumptions Used in Hydro’s Assessment of System Reliability and Resource Adequacy

Hydro continually assesses the reliability of its system and its ability to meet customer requirements, filing both near- and long-term assessments with the Board of Commissioners of Public Utilities.<sup>7</sup>

As part of the ongoing *Reliability and Resource Adequacy Study Review* proceeding, Hydro detailed the process undertaken for determining the forced outage rates most appropriate for use in its near-term reliability assessments and long-term resource adequacy analysis. Table 1 and Table 2 summarize the most recent forced outage rate assumptions, as determined using the forced outage rate methodology.<sup>8</sup> Forced outage rate assumptions will be re-evaluated on an annual basis to incorporate the most recent data available.

**Table 1: Hydro’s Reliability and Resource Adequacy Study Analysis Values – Generating Units (%)**

Asset Type	Measure	Near-Term Analysis Value	Resource Planning Analysis Value
Hydraulic: Regulated	DAFOR	2.50	3.03
Hydraulic: Muskrat Falls	DAFOR	2.30	3.03
Thermal	DAUFOP	20.00 <sup>9</sup>	20.00
CTs			
Happy Valley	DAUFOP	4.65	4.65
Hardwoods and Stephenville	DAUFOP	30.00	30.00
Holyrood	DAUFOP	4.90	4.90

A three-year, capacity-weighted average was applied to the regulated hydraulic units (Bay d’Espoir Facility, Cat Arm Station, Hinds Lake Station, Granite Canal Station, Upper Salmon Station, and Paradise River Station) for a near-term analysis, resulting in a DAFOR of 2.50%, while a ten-year, capacity-weighted average was applied for use in the long-term resource planning model, resulting in a DAFOR of

<sup>7</sup> Hydro currently files an assessment of near-term system reliability and resource adequacy annually in November, the Near-Term Reliability Report. Hydro also files an assessment of longer-term system reliability and resource adequacy. The most recent filing was the “2024 Resource Adequacy Plan – An Update to the Reliability and Resource Adequacy Study,” Newfoundland and Labrador Hydro, rev. August 26, 2024 (originally filed July 9, 2024), (“2024 Resource Plan”).

<sup>8</sup> Values indicated for Hydro’s near-term analysis reflect those used in the 2024 Resource Plan and the “Reliability and Resource Adequacy Study Review – 2025 Near-Term Reliability Report – November Report,” Newfoundland and Labrador Hydro, November 20, 2025 (“November 2025 Near-Term Report”).

<sup>9</sup> The Holyrood TGS base assumption is 20.00%. The sensitivity assumption is 34.00%. A sensitivity value of 34.00% was chosen to reflect actual performance at the Holyrood TGS for the 2021–2022 winter operating period.

1 3.03%. The DAFOR value was based on historical data reflective of Hydro’s maintenance program over  
2 the long term.

3 For the Muskrat Falls Facility, the near-term forced outage rate was based on the forced outage rates of  
4 the units to date, to reflect the possibility of outages early in the lifetime of the Muskrat Falls Facility. In  
5 the long-term resource planning model, the regulated hydroelectric forced outage rate was used, as it is  
6 assumed that these assets will be maintained to the same standards as the remainder of the hydraulic  
7 fleet.

8 Historically, forced outage rates for the three units at the Holyrood TGS have been reported using the  
9 DAFOR metric, which is predominantly used for units that operate in a continuous (base-loaded)  
10 capacity. As presented in Hydro’s RRA Study 2022 Update,<sup>10</sup> there are reliability concerns associated  
11 with the operation of the units at the Holyrood TGS in an emergency standby capacity. When  
12 considering standby or peaking operations of units at the Holyrood TGS, DAFOR is no longer the most  
13 appropriate measure of forced outage rates; instead, UFOP<sup>11</sup> and DAUFOP should be considered. Given  
14 the frequency of deratings historically experienced by these units, DAUFOP is a more appropriate  
15 measure.

16 Analyses performed for a range of Holyrood TGS DAUFOP assumptions indicate the sensitivity of supply  
17 adequacy to changes in the availability of the Holyrood TGS. From this analysis, a forced outage rate of  
18 20.00% was recommended in the near-term, with a sensitivity value of 34.00%. Hydro will continue to  
19 analyze the operational data to ensure that forced outage rate assumptions for the Holyrood TGS are  
20 appropriate.

21 At the present time, the operation of the units at the Holyrood TGS remains base-loaded to ensure the  
22 availability of capacity for the power system, as the LIL has recently commissioned and is in the early  
23 operational stages. This will remain the case as Hydro continues to monitor LIL performance and  
24 reliability. If the LIL is found to perform well for an extended period, and system conditions permit,  
25 Hydro will have the opportunity to incrementally remove the Holyrood TGS units from service. To

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<sup>10</sup> “Reliability and Resource Adequacy Study – 2022 Update,” Newfoundland and Labrador Hydro, October 3, 2022 (“RRA Study 2022 Update”).

<sup>11</sup> Utilization forced outage probability (“UFOP”).

1 ensure alignment with the assumptions used in the resource planning model (PLEXOS)<sup>12</sup> while  
 2 appropriately reporting on current period versus historical performance, Hydro will continue to use the  
 3 DAFOR performance measure and the 20.00% forced outage rate for the units at the Holyrood TGS.

4 As the CTs in the existing fleet vary in age and condition, each was considered on an individual basis. For  
 5 the Happy Valley Gas Turbine (“GT”), a three-year, capacity-weighted average was applied to the unit  
 6 for the near-term analysis, while a ten-year capacity-weighted average was applied for use in the  
 7 resource planning model. The DAUFOP values were based on historical data to reflect the unit’s past  
 8 performance. For the Holyrood CT, the DAUFOP was calculated based on a scenario-based approach  
 9 rather than historical data, due to the unit’s minimal operating time and resultant small data set. For the  
 10 Hardwoods and Stephenville GTs, a fixed DAUFOP consistent with values considered in Hydro’s previous  
 11 near-term reliability reports was used for the near-term and long-term analyses.<sup>13</sup> As presented in  
 12 Hydro’s 2024 Resource Plan, the Hardwoods and Stephenville GTs are proposed for retirement in  
 13 2030.<sup>14</sup>

14 Now that the LIL is commissioned, multiple years of operational experience are required to better  
 15 inform the long-term selection of a bipole forced outage rate. In the interim, the bipole forced outage  
 16 rate will be addressed with a range of upper and lower limits as additional scenarios in the  
 17 analysis—currently 10% and 1%, respectively. As LIL performance statistics become available in the  
 18 coming years, the forced outage rate range may be narrowed. However, the current base-case  
 19 assumption is a 5% LIL forced outage rate.

**Table 2: Hydro’s Reliability and Resource Adequacy Study Analysis Values – LIL (%)**

Asset Type	Measure	Base Planning Analysis Value	Range of Planning Analysis Values
LIL	EqFOR	5	1–10

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<sup>12</sup> The resource planning model does not differentiate between DAFOR and DAUFOP metrics; rather, it applies a forced outage rate only.

<sup>13</sup> “Reliability and Resource Adequacy Study Review – 2024 Near-Term Reliability Report – November Report,” Newfoundland and Labrador Hydro, November 20, 2024.

<sup>14</sup> Assessment of the remaining useful life for the Hardwoods and Stephenville GTs, and the estimated capital operating costs up to 2035, is ongoing to inform the Reference Case.

### 1 **3.0 Current Period Overview**

2 Table 3 presents an overview of the current period performance, compared to previous period  
3 performance and most recent Planning Analysis values.

**Table 3: DAFOR and DAUFOP Overview (%)**

<b>Asset Type</b>	<b>Measure</b>	<b>1-Jan-2024 to 31-Dec-2024</b>	<b>1-Jan-2025 to 31-Dec-2025</b>	<b>Near-Term Planning Analysis Value</b>	<b>Resource Planning Analysis Value</b>
Hydraulic: Regulated	DAFOR	2.07	0.36	2.50	3.03
Hydraulic: Muskrat Falls Facility	DAFOR	1.70	1.35	2.30	3.03
Thermal	DAFOR/DAUFOP <sup>15</sup>	37.29	26.86	20.00	20.00
<b>CTs</b>					
Happy Valley	DAUFOP	40.59	10.57	4.65	4.65
Hardwoods/Stephenville	DAUFOP	6.29	2.76	30.00	30.00
Holyrood	DAUFOP	0.00	25.13	4.90	4.90

4 As shown in Table 3, regulated hydraulic DAFOR, Muskrat Falls Facility DAFOR and thermal DAFOR  
5 performance improved for the current period, when compared to the previous period.

6 The DAUFOP performance for the Happy Valley GT and the Hardwoods and Stephenville GTs has  
7 improved for the current period, while the Holyrood CT has declined in the current period, compared to  
8 the previous period.

9 Table 4 presents LIL data for the current and the previous period. Since the previous period, the  
10 performance of the LIL has improved, with no significant impacts to the EqFOR because of any  
11 operational events that have occurred.

**Table 4: EqFOR Overview (%)**

<b>Asset Type</b>	<b>Measure</b>	<b>1-Jan-2024 to 31-Dec-2024</b>	<b>1-Jan-2025 to 31-Dec-2025</b>	<b>Base Planning Analysis Value</b>	<b>Range of Planning Analysis Values</b>
LIL	EqFOR	3.37	0.96 <sup>16</sup>	5	1–10

<sup>15</sup> The resource planning model does not differentiate between DAFOR and DAUFOP; rather, it requires the selection of a forced outage rate percentage.

<sup>16</sup> This EqFOR is calculated on a base LIL capacity of 700 MW. On a base capacity of 900 MW, the EqFOR is calculated to be approximately 1.30%. Following the completion of the 900 MW test, all calculations will be adjusted to reflect the change in assumptions.

## 4.0 Hydraulic Unit DAFOR Performance – Regulated Hydro

Detailed results for the current period and the previous period are presented in Table 5 and Chart 1. These results are compared to Hydro’s near-term and resource planning analysis values for forced outage rates, as used in the 2024 Resource Plan and the November 2025 Near-Term Report. Any individual unit with forced outage rates which exceeded the established near-term and/or resource planning analysis values is discussed herein.

**Table 5: Hydraulic Weighted DAFOR – Regulated Hydro**

Generating Unit	Maximum Continuous Unit Rating (MW)	12 Months Ended Dec 2024 (%)	12 Months Ended Dec 2025 (%)	Near-Term Analysis Value (%)	Resource Planning Analysis Value (%)
<b>All Hydraulic Units – Weighted</b>	<b>954.4</b>	<b>2.07</b>	<b>0.36</b>	<b>2.50</b>	<b>3.03</b>
<b>Hydraulic Units</b>					
BDE Unit 1	76.5	0.00	0.00	2.50	3.03
BDE Unit 2	76.5	0.00	0.00	2.50	3.03
BDE Unit 3	76.5	2.75	0.00	2.50	3.03
BDE Unit 4	76.5	0.53	0.11	2.50	3.03
BDE Unit 5	76.5	4.37	0.00	2.50	3.03
BDE Unit 6	76.5	7.67	0.00	2.50	3.03
BDE Unit 7	154.4	3.87	0.00	2.50	3.03
CAT Unit 1	67.0	0.98	0.14	2.50	3.03
CAT Unit 2	67.0	0.07	0.35	2.50	3.03
HLK Unit	75.0	1.44	0.00	2.50	3.03
USL Unit	84.0	1.40	0.26	2.50	3.03
GCL Unit	40.0	1.07	5.21	2.50	3.03
PRV Unit	8.0	8.36	2.84	2.50	3.03

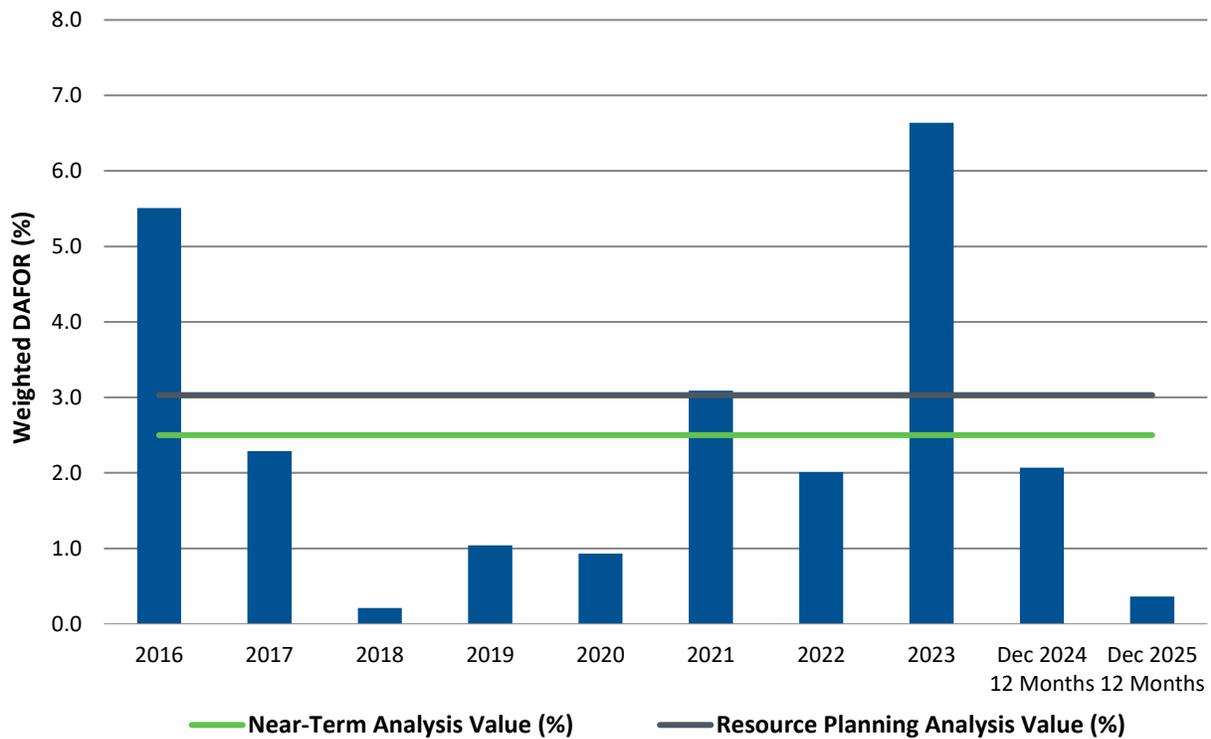


Chart 1: Hydraulic Weighted DAFOR – Regulated Hydro

1 **4.1 Granite Canal Facility**

2 The Granite Canal unit DAFOR of 5.21% for the current period is above the resource planning analysis  
3 value of 3.03% and the near-term planning analysis value of 2.50% for an individual hydraulic unit. This  
4 increase in DAFOR is the result of nine forced outages in the current period, including three that  
5 occurred since the previous filing.

6 Since the previous filing, an outage was required on October 6, 2025, to address communications issues  
7 at the Granite Canal Station. On October 20, 2025, and December 26, 2025, the unit tripped due to  
8 vibration while operating in the hydraulic rough zone.

9 **4.2 Paradise River Facility**

10 The Paradise River unit DAFOR of 2.84% for the current period is above the near-term planning analysis  
11 value of 2.50% but is below the resource planning analysis value of 3.03% for an individual hydraulic  
12 unit. Although above the near-term planning analysis value, this is an improvement in performance over

1 the previous period. The elevated DAFOR was the result of four forced outages in the current period, as  
2 previously reported. No additional outages have occurred since the previous filing.

### 3 **5.0 Hydraulic Unit DAFOR Performance – Muskrat Falls**

4 Detailed results for the current period and the previous period are presented in Table 6 and Chart 2.  
5 These results are compared to Hydro’s near-term and resource planning analysis values for forced  
6 outage rates, as used in the 2024 Resource Plan and the November 2025 Near-Term Report. Overall, the  
7 plant performance for the Muskrat Falls Facility shows improvement over the previous period. Any  
8 individual unit with performance not meeting the established near-term and resource planning analysis  
9 values is discussed below.

**Table 6: Hydraulic Weighted DAFOR – Muskrat Falls**

Generating Unit	Maximum Continuous Unit Rating (MW)	12 Months Ended Dec 2024 (%)	12 Months Ended Dec 2025 (%)	Near-Term Analysis Value (%)	Resource Planning Analysis Value (%)
<b>Muskrat Falls Units – Weighted</b>	<b>824</b>	<b>1.70</b>	<b>1.35</b>	<b>2.30</b>	<b>3.03</b>
<b>Muskrat Falls Units</b>					
Muskrat Falls 1	206	6.26	1.59	2.30	3.03
Muskrat Falls 2	206	0.45	0.94	2.30	3.03
Muskrat Falls 3	206	0.09	2.51	2.30	3.03
Muskrat Falls 4	206	0.02	0.03	2.30	3.03

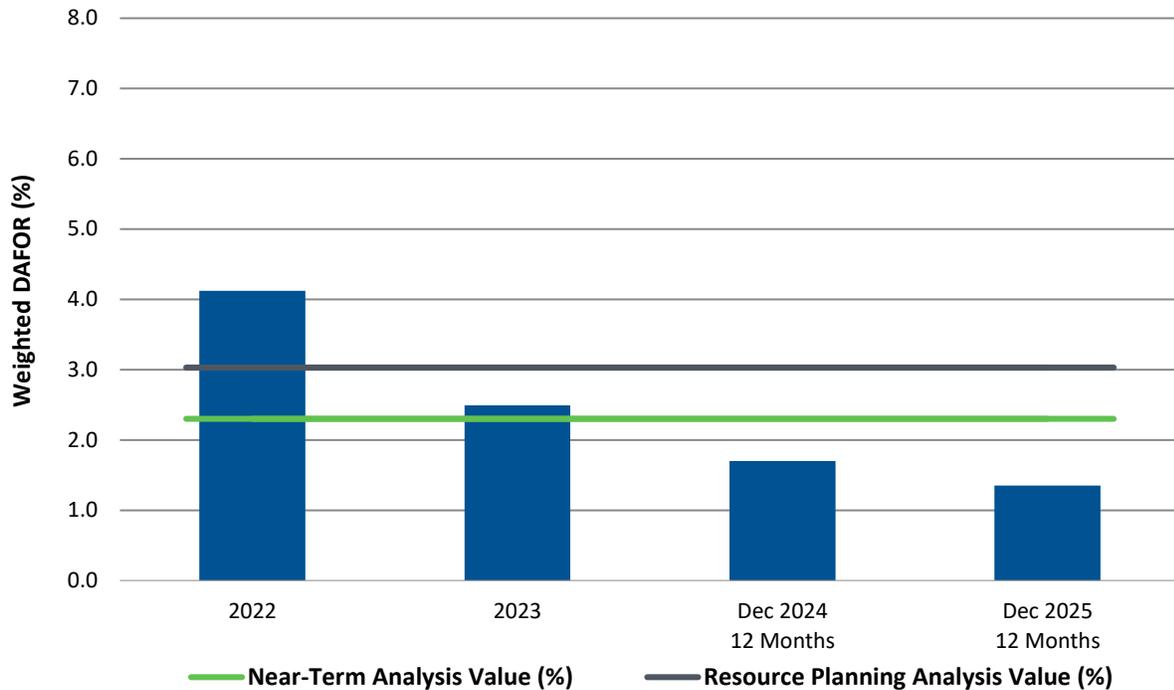


Chart 2: Hydraulic Weighted DAFOR – Muskrat Falls

1 **5.1 Muskrat Falls Unit 3**

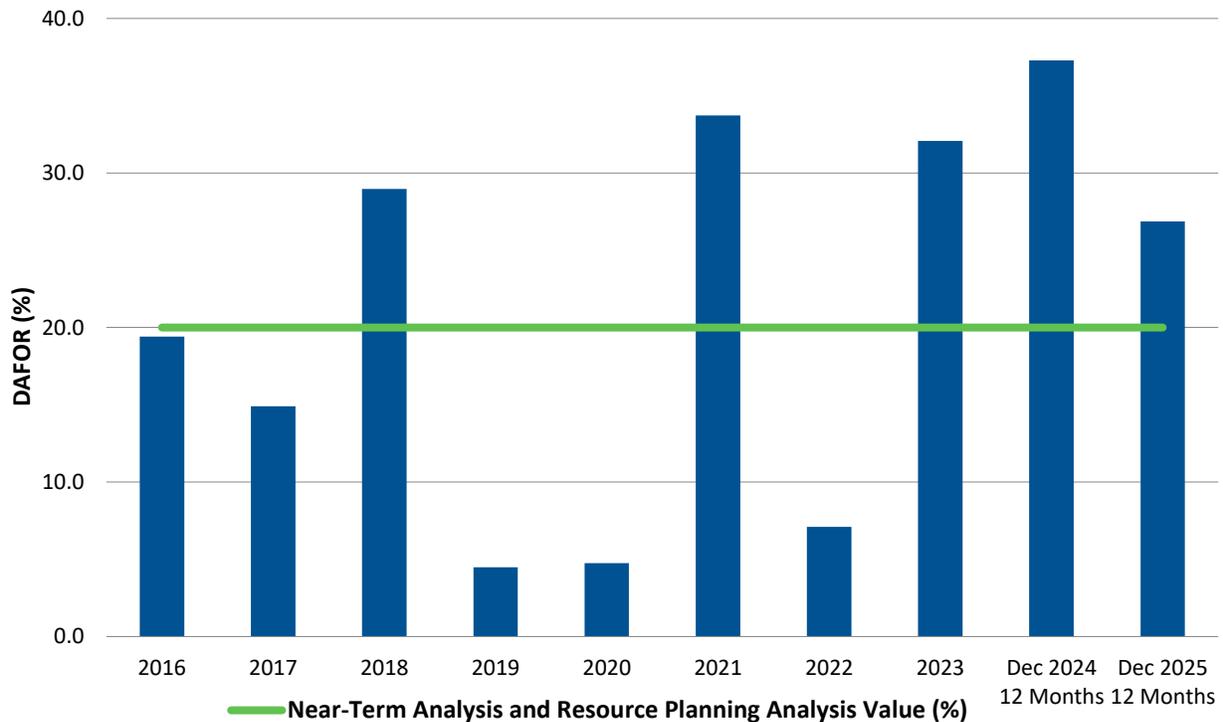
2 The Muskrat Falls Unit 3 DAFOR of 2.51% is below the resource planning analysis value of 3.03%, but is  
 3 above the near-term planning analysis value of 2.30% for an individual Muskrat Falls unit. This elevated  
 4 DAFOR is the result of three forced outages in the current period, as previously reported. No new  
 5 outages have occurred since the previous filing.

6 **6.0 Thermal Unit DAFOR Performance**

7 Detailed results for the current and previous periods are presented in Table 7 and Chart 3. These results  
 8 are compared to Hydro’s near-term and resource planning analysis values for forced outage rates, as  
 9 used in the 2024 Resource Plan and the November 2025 Near-Term Report. Any individual unit with  
 10 forced outage rates which exceed the established near-term and/or resource planning analysis values is  
 11 discussed herein.

**Table 7: Thermal Weighted DAFOR**

Generating Unit	Maximum Continuous Unit Rating (MW)	12 months Ended Dec 2024 (%)	12 months Ended Dec 2025 (%)	Near-Term Planning and Resource Planning Analysis Value (%)
<b>All Thermal Units – Weighted</b>	<b>490</b>	<b>37.29</b>	<b>26.86</b>	<b>20.00</b>
<b>Thermal Units</b>				
Holyrood TGS Unit 1	170	45.60	39.12	20.00
Holyrood TGS Unit 2	170	59.51	10.70	20.00
Holyrood TGS Unit 3	150	4.11	32.75	20.00



**Chart 3: Thermal DAFOR**

- 1 For the current period, the weighted DAFOR for all thermal units of 26.86% is above the 20.00%
- 2 near-term and resource planning analysis values. The individual unit DAFOR outcome for the current period
- 3 of 10.70% for Unit 2 at the Holyrood TGS is below the 20.00% analysis value. The performance of Unit 1
- 4 and Unit 3 at the Holyrood TGS is discussed in Sections 6.1 and 6.2.

1    **6.1    Holyrood TGS Unit 1**

2    Considering individual thermal unit performance, the DAFOR of 39.12% for Unit 1 at the Holyrood TGS is  
3    above the near-term and resource planning analysis value of 20.00% for a unit at the Holyrood TGS;  
4    however, it shows an improvement in performance over the previous period. This elevated DAFOR is the  
5    result of a forced extension to the planned unit outage in 2024 to overhaul the Unit 1 turbine and  
6    replace the L-0 and L-1 blades at the General Electric shop in the United States.<sup>17</sup> The outage was  
7    extended until the unit was brought online on February 12, 2025. Following return to service, an issue  
8    with the main steam controls valves prevented movement beyond 56% opening, which resulted in a  
9    forced derating to 105 MW. This derating remained until March 10, 2025, when a planned outage was  
10   taken to investigate and correct the issue with the control valves. The unit returned to operation on  
11   March 17, 2025, at full capacity.

12   Holyrood Unit 1 entered the annual planned outage on May 4, 2025, and returned to operation on  
13   September 18, 2025. Since returning to service, the unit has experienced issues with the main steam  
14   control valves, similar to the issues earlier in 2025, restricting the unit to 100 MW. This derate remained  
15   in effect until November 24, 2025, when the unit was taken offline for a planned outage to address the  
16   issue with the valves. The unit was returned to service on November 27, 2025, after successful  
17   resolution of the issue. Outstanding load testing, online safety valve testing, and confirmation of turbine  
18   control valve operation were completed by December 2, 2025. During load testing on Unit 1, a  
19   maximum load of 163 MW was reached, limited by condenser back pressure. This derating was further  
20   updated to 160 MW on December 17, 2025. This deration continued for the remainder of the month of  
21   December, and investigation into this issue is ongoing, with a condenser vendor engaged to perform air  
22   in-leakage testing on the condenser in early February 2026.

23   In addition to the derates described above, Holyrood Unit 1 also experienced seven forced outages, all  
24   of which were short in duration, totalling 60 hours of forced outage time for the current period.

25    **6.2    Holyrood TGS Unit 3**

26    Considering individual thermal unit performance, the DAFOR of 32.75% for Unit 3 at the Holyrood TGS is  
27    above the near-term and resource planning analysis value of 20.00% for a unit at the Holyrood TGS and

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<sup>17</sup> “2024 Capital Budget Application,” Newfoundland and Labrador Hydro, rev. September 21, 2023 (originally filed July 12, 2023), sch. 6, prog. 2.

1 shows a decline in performance over the previous period. Holyrood Unit 3 was unavailable due to  
 2 planned maintenance and overhaul work, beginning March 30, 2025 until December 2, 2025. From  
 3 December 2, 2025 to December 18, 2025, the unit was on a forced extension of the planned outage due  
 4 to additional work required to restore the stage #7 diaphragm in the intermediate pressure section of  
 5 the turbine. For the remainder of December, the unit was on a planned outage to complete the turbine  
 6 overhaul, which was extended due to an external cause; specifically, the failure of the turbine hall  
 7 overhead crane at Holyrood. The unit is currently undergoing re-assembly and commissioning activities,  
 8 with return to service scheduled for mid-February 2026.<sup>18</sup> Due to the extended period of unavailability,  
 9 the DAFOR is elevated mathematically.

## 10 **7.0 Combustion Turbine DAUFOP Performance**

11 DAUFOP Performance for the Hardwoods, Stephenville and Happy Valley GTs, as well as the Holyrood CT  
 12 for the period, are presented in the charts and tables below.

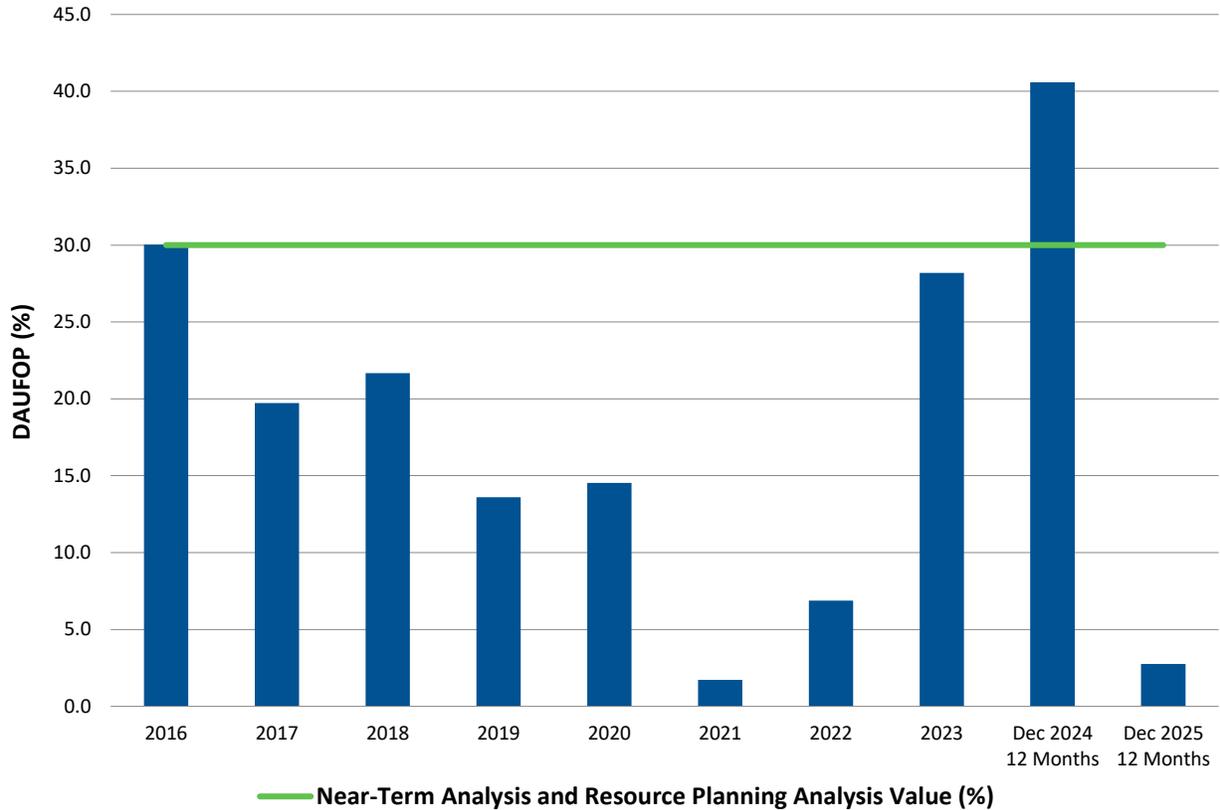
13 The combined DAUFOP for the Hardwoods and Stephenville GTs was 2.76% for the current period, as  
 14 shown in Table 8 and Chart 4. This is below the near-term and resource planning analysis value of  
 15 30.00%.

16 The Stephenville GT DAUFOP for the current period is 0.56%, which is below the near-term and  
 17 resourcing planning assumption of 30.00%. The Hardwoods GT DAUFOP for the current period is 3.97%,  
 18 which is below the near-term and resource planning assumption of 30.00%.

**Table 8: Hardwoods/Stephenville GT DAUFOP**

GT Units	Maximum Continuous Unit Rating (MW)	12 months Ended Dec 2024 (%)	12 months Ended Dec 2025 (%)	Near-Term Planning and Resource Planning Analysis Value (%)
<b>GTs</b>	<b>100</b>	<b>40.59</b>	<b>2.76</b>	<b>30.00</b>
Stephenville	50	77.24	0.56	30.00
Hardwoods	50	0.00	3.97	30.00

<sup>18</sup> The return to service date was originally scheduled for January 31, 2026; however, while commissioning the lube oil system, oil was discovered in Unit 3 generator. A generator specialist has arrived on site, and system cleaning and inspections continue to progress as planned, with cold commissioning activities expected to resume by February 8, 2026.

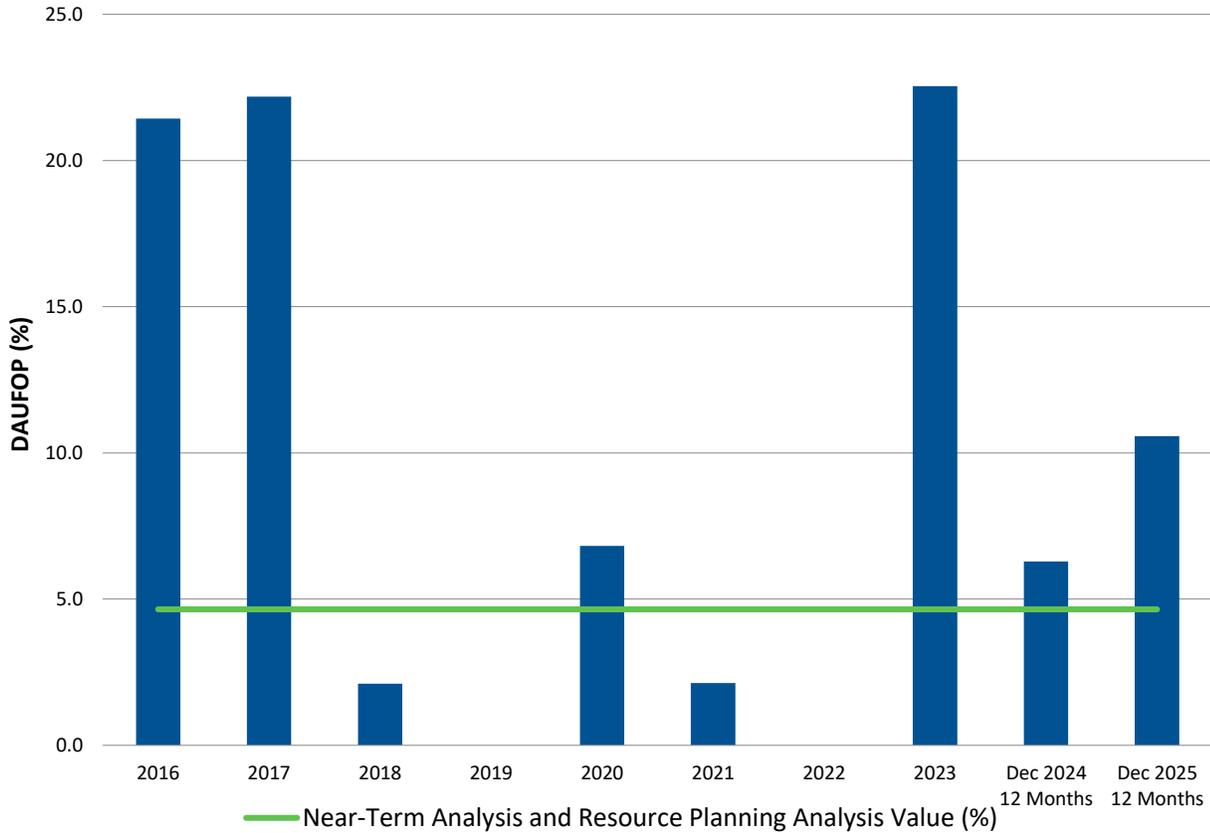


**Chart 4: GT DAUFOP: Hardwoods/Stephenville Units**

- 1 The DAUFOP for the Happy Valley GT was 10.57% for the current period, as shown in Table 9 and Chart
- 2 5. This is above the near-term and resource planning analysis value of 4.65% and indicates a decline in
- 3 performance over the previous period. As the forced outage rate for the Happy Valley GT exceeds the
- 4 established near-term and resource planning analysis values, a discussion on the same is included in
- 5 Section 7.1.

**Table 9: Happy Valley GT DAUFOP**

GT Unit	Maximum Continuous Unit Rating (MW)	12 months Ended Dec 2024 (%)	12 months Ended Dec 2025 (%)	Near-Term Planning and Resource Planning Analysis Value (%)
Happy Valley	25	6.29	10.57	4.65

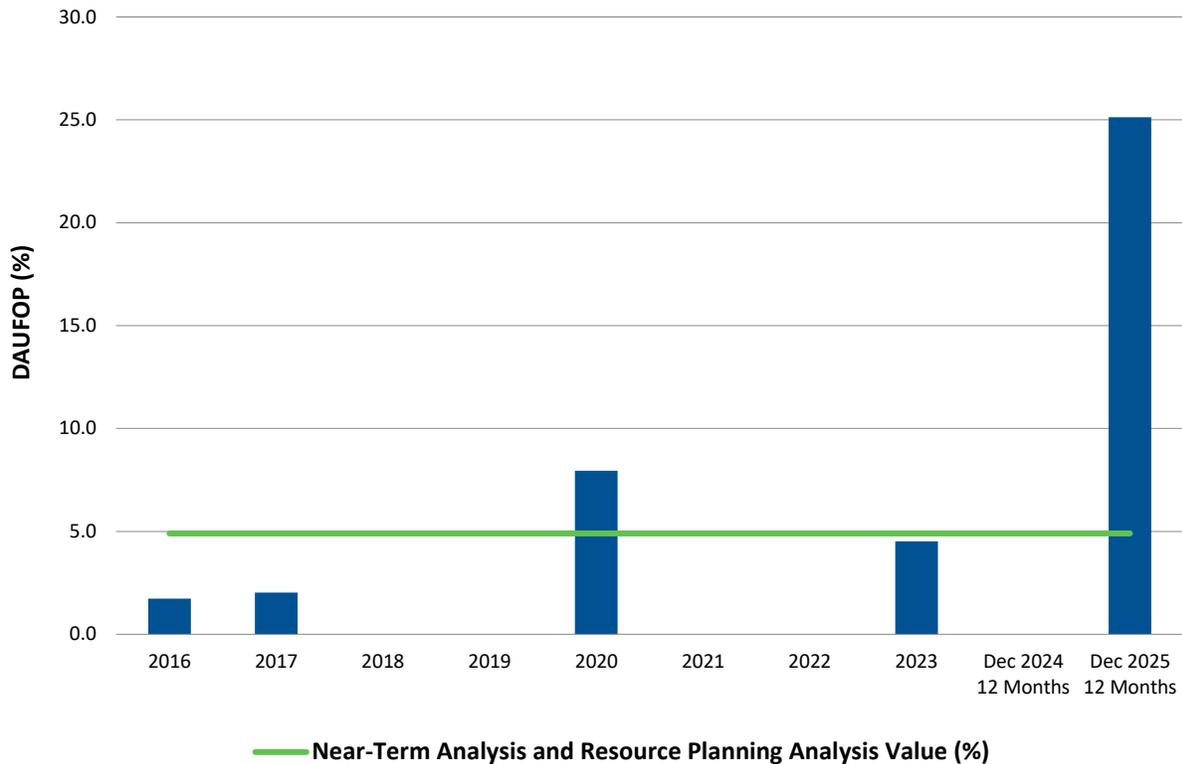


**Chart 5: GT DAUFOP: Happy Valley Unit**

1 The Holyrood CT DAUFOP of 25.13% for the current period is above the near-term and resource  
 2 planning analysis value of 4.90%, and indicates a decline in performance when compared to the previous  
 3 period, as shown in Table 10 and Chart 6. As the forced outage rate for the Holyrood CT exceeds the  
 4 established near-term and resource planning analysis values, a discussion on the same is included in  
 5 Section 7.2.

**Table 10: Holyrood CT DAUFOP**

CT Unit	Maximum Continuous Unit Rating (MW)	12 Months Ended Dec 2024 (%)	12 Months Ended Dec 2025 (%)	Near-Term Planning and Resource Planning Analysis Value (%)
Holyrood	123.5	0.00	25.13	4.90



**Chart 6: CT DAUFOP– Holyrood Unit**

**1 7.1 Happy Valley Gas Turbine**

2 The Happy Valley GT DAUFOP was 10.57% for the current period, which is above the near-term and  
 3 resource planning analysis value of 4.65%. This decline in performance is a result of outages experienced  
 4 on July 12, 2025. During start-up, the unit experienced two starting failures as previously reported,  
 5 which resulted in approximately four hours of outage time. Due to the low percentage of operating time  
 6 experienced by the Happy Valley unit, forced outages have a significant impact on the DAUFOP  
 7 performance.

**8 7.2 Holyrood Combustion Turbine**

9 The Holyrood CT DAUFOP was 25.13% for the current period, which is above the near-term and resource  
 10 planning analysis value of 4.90%. This decline in performance is the result of forced outages, as  
 11 previously reported, and one outage which occurred since the previous filing. Since the previous filing,  
 12 the Holyrood CT was unavailable between October 27, 2025 and November 12, 2025, due to a forced  
 13 extension of the planned annual outage as a result of unexpected issues encountered while returning

1 the unit to service, including the need to investigate and resolve a ground fault alarm which occurred  
2 upon energizing the generator.

### 3 **8.0 Labrador-Island Link EqFOR Performance**

4 The EqFOR for the LIL was 0.96%<sup>19</sup> for the current period, as shown in Table 11. This is below the range  
5 of values used by Hydro in the resource planning analysis scenarios.

**Table 11: LIL EqFOR (%)**

Asset Type	Measure	12 Months Ended Dec 2024	12 Months Ended Dec 2025	Base Planning Analysis Value	Range of Planning Analysis Values
LIL	EqFOR	3.37	0.96	5	1–10

6 The availability of the three Soldiers Pond Synchronous Condensers (“SCs”) is critical to the reliable  
7 delivery of electricity to the Island Interconnected System via the LIL. No operational issues concerning  
8 the Soldiers Pond SCs resulted in outages or derating to the LIL in the current period.

9 A fulsome update on the total number of hours of operation for the Soldiers Pond SCs for the rolling 12-  
10 month period is provided in Appendix A of this report.

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<sup>19</sup> This EqFOR is calculated on a base LIL capacity of 700 MW. On a base capacity of 900 MW, the EqFOR is calculated to be approximately 1.30%. Following the completion of the 900 MW test, all calculations will be adjusted to reflect the change in assumptions.

# Appendix A

## Soldiers Pond Synchronous Condensers



**Table A-1: Quarterly Rolling 12-Month Operating Hours for Soldiers Pond Synchronous Condensers (“SC”)**

<b>Unit</b>	<b>Operating Hours<sup>1</sup></b>	<b>% Availability<sup>2</sup></b>
SC1	8,091.02	92.36
SC2	8,284.37	94.57
SC3	7,813.33	89.19

- 1 Further information on the operation of the Soldiers Pond SCs is provided in Appendix B.

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<sup>1</sup> Newfoundland and Labrador Hydro has provided its best estimate of operating hours for each unit for the 12 months ended December 31, 2025, based on an assumption of 24/7 operation of all three SCs, and known outages (both planned and unplanned) recorded in its database.

<sup>2</sup> SC availability is calculated based on the unit's operating hours and therefore assumes that the unit is operating when available.

# Appendix B

## Muskrat Falls Assets Update

Reporting period up to December 31, 2025



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Attachment 1: LIL Strengthening Overview

## 1.0 Introduction

The Muskrat Falls Assets, made up of the Labrador-Island Link (“LIL”), which includes the Soldiers Pond Synchronous Condensers (“SCs”), the Labrador Transmission Assets and the Muskrat Falls Hydroelectric Generating Facility, have all been commissioned in recent years and are in the early years of their expected lifespans.

As is normal for the early operation of assets, Newfoundland and Labrador Hydro (“Hydro”) has encountered some challenges with equipment, primarily due to manufacturing issues or defective components. Such issues are expected early in the equipment’s life. Equipment failure rates plotted over time generally exhibit a ‘bathtub-shaped curve.’ Incidents of failure tend to be high when equipment is new, and again near the end of the equipment’s useful life, depending on equipment type. In addition to routine ongoing preventative maintenance activities and sustaining capital programs for each of these assets, there are a number of one-off capital projects, corrective maintenance activities and engineering studies ongoing. The purpose of this work is addressing and repairing these early life issues, with the ultimate goal of improving asset reliability to expected levels over time.

Hydro provides the following update to the Board of Commissioners of Public Utilities (“Board”) on the status of these activities and other information as requested by the Board.

## 2.0 Muskrat Falls Hydroelectric Generating Facility

Muskrat Falls was commissioned in November 2021. The Muskrat Falls Plant continues to outperform similar units across Canada, with a total plant derated adjusted forced outage rate performance through the end of the fourth quarter of 2025 of 1.35%, which was significantly better than the Electricity Canada average of 5.27%.

### 2.1 Capital Projects

#### *Muskrat Falls – Repair Unit 2 Turbine*

As recommended by the original equipment manufacturer (“OEM”) and reported by The Liberty Consulting Group in its June 2023 monitoring report, vibration issues observed on Unit 2 required permanent corrective action, including full unit dismantling, to be completed under warranty by the turbine OEM. There have been no issues with vibration, or the identification of other characteristics

1 through internal inspections, which would indicate a problem similar to that experienced on Unit 2  
2 affecting Units 1, 3, or 4.

3 Unit 2 was offline through the 2024–2025 winter season to complete the recommended repairs and was  
4 placed back in service on September 3, 2025. The issue is resolved, and the unit is operating normally.

## 5 **3.0 Soldiers Pond Synchronous Condensers**

6 Hydro continues to address the remaining items that were noted in punch list reports submitted with  
7 the commissioning certificate and outstanding warranty claims.

### 8 **3.1 Operations Items**

#### 9 ***Brush Gear***

10 Brush equipment performance on the Soldiers Pond SCs decreased in December 2023, resulting in  
11 several scheduled outages to replace damaged brushes, springs and brush holders.

12 Hydro, in consultation with the OEMs for the brush equipment and the SCs, has been working to identify  
13 the root cause of the brush performance issues. At the recommendation of the respective  
14 manufacturers, Hydro has implemented modified brush configurations and operational controls to  
15 ensure optimal operating conditions for patina development, which is necessary for the successful  
16 operation of the brush gear. These changes resulted in improved brush performance in 2025.

17 In Spring 2024, the slip ring was removed from SC1 and sent for machining to correct a runout causing  
18 excessive brush vibration. At that time, a modified brush with the ability to operate in a higher vibration  
19 environment was also provided by the OEM and installed. These modifications have resulted in  
20 improved performance to date. Hydro will continue to monitor the overall impact of these changes.

21 Corrective actions on all three units have yielded positive results, and changes performed in 2024 have  
22 aided in achieving acceptable brush performance across all three synchronous condensers. Inspections  
23 completed on SC1 and SC2 in November 2025 indicated continued improved performance from the  
24 brushgear. Inspection of the SC3 brushgear completed in mid-December 2025 indicated continued

1 improved performance on the main slip ring and brushes; however, investigation is ongoing regarding  
2 an issue on a grounding brush.<sup>1</sup>

### 3 **Forced Outages**

4 Outside of planned outages, the Soldiers Pond SCs have operated continuously during the quarter, with  
5 the exception of one event on SC2 and one event on SC3. The first event occurred on November 7, 2025,  
6 when SC2 failed to start as scheduled upon conclusion of its planned maintenance outage, due to a loss  
7 of excitation fault. The repairs were completed, and the unit was returned to service on  
8 November 13, 2025. The second event occurred on December 17, 2025, when SC3 was shut down for a  
9 planned one-day brush gear maintenance outage. During the shutdown, the liquid level detectors  
10 (“LLD”) reached the trip level.<sup>2</sup> In order to drain the LLDs, hydrogen gas must be removed from the unit  
11 (degassing). The unit was degassed to drain the LLDs and returned to service on December 22, 2025.  
12 There was no customer impact as a result of either event.

## 13 **4.0 Labrador-Island Link**

14 Since commissioning in April 2023, the LIL has been in service and successfully providing power to the  
15 provincial grid, exceeding planning assumptions for reliability. During the quarter, the LIL operated at  
16 various power transfer levels, as required by system load. In total, approximately 485.3 GWh of energy  
17 was delivered over the LIL from October 1, 2025 to December 31, 2025. Hydro continues to ensure the  
18 availability of generation at the Holyrood Thermal Generating Station (“Holyrood TGS”); however,  
19 energy and capacity delivered over the LIL minimize thermal generation requirements whenever  
20 possible.

21 In the early stages of its operation, as is normal for the operation of assets early in life, the current  
22 reliability of the LIL is anticipated to be lower than in the long-term, due to failures associated with new  
23 assets (e.g., due to manufacturing issues or defective components). In addition to routine ongoing  
24 corrective and preventative maintenance activities and sustaining capital programs, there are several  
25 capital projects identified to repair these issues.

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<sup>1</sup> As this issue is only occurring on SC3, the operational impact is minimal.

<sup>2</sup> LLDs are measuring devices located beneath the condensers in a confined space. Their function is to monitor a loss of liquid inside the unit; the liquid could come from internal damage or minor leaks during startup/shutdown, and is normally of very low volume—less than five litres.

1    **4.1    Operations Items**

2    ***Forced Outages***

3    During the fourth quarter of 2025, there were two trip events on the LIL. The first event occurred on  
4    October 7, 2025, when Pole 1 tripped while in monopole mode because of a Common Neutral Area  
5    Protection voltage differential at the Soldiers Pond Converter Station. An underfrequency load shedding  
6    event occurred during this outage as Pole 2 was out of service for planned maintenance. Pole 1 was  
7    returned to service on October 7, 2025, following an investigation that found a fault with a disconnect  
8    on an electrode line in Dowden’s Point; the disconnect has since been repaired.

9    The second event occurred on November 16, 2025, when Pole 1 blocked and tripped while in bi-pole  
10   configuration, transferring all load to Pole 2. There was no customer impact. Initial assessment indicated  
11   the cause of the “External Block and Trip” at Soldiers Pond Converter Station was a failed relay on Pole 1  
12   Lane 2. Pole 1 was returned to service on November 17, 2025, with Lane 2 out of service. Lane 2 was  
13   returned to service on November 18, 2025, following replacement of the failed relay.

14   ***Cable Switching***

15   As reported in Hydro’s final 2024–2025 Winter Readiness Report,<sup>3</sup> new equipment was successfully  
16   installed to mitigate cable switching transients at the LIL Transition Compounds in mid-October 2024.

17   Since that time, Hydro identified an icing issue with transition compound disconnects that can impact  
18   cable switching in winter conditions. An improved ice guard design to resolve this issue was developed  
19   by General Electric (“GE”), and the first ice guard was fabricated in the fourth quarter of 2025 in  
20   consultation with GE. Installation of the improved ice guard design is planned for early 2026, as GE  
21   resource availability and system conditions allow. In the interim, Hydro has developed operating  
22   procedures to ensure reliable operation in winter conditions.

23   ***Replacement of Direct Current Current Transformers***

24   In 2023, the OEM and Hydro determined that very low air temperatures at Muskrat Falls Converter  
25   Station were influencing the measurement accuracy of DCCTs<sup>4</sup>, resulting in false protection trips and

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<sup>3</sup> Reliability and Resource Adequacy Study Review – 2024–2025 Winter Readiness Planning Report – Final Report,”  
Newfoundland and Labrador Hydro, December 10, 2024.

<sup>4</sup> Direct Current Current Transformer (“DCCTs”).

1 power control issues on the LIL. The OEM identified the root cause of the issue to be a manufacturing  
2 defect with the Delay Coil Fiber Optical Cable located within the DCCTs; this issue occurred with a select  
3 batch of fiber optic cables, affecting six DCCTs at the Muskrat Falls HVdc<sup>5</sup> Converter Station, which have  
4 since been replaced.<sup>6</sup>

5 In November 2025, GE provided a revised plan to address DCCTs which have low risk indicators of the  
6 issues related to cold weather operation. GE has indicated that the plan includes working with a new  
7 DCCT provider and delivery of contractual spares in spring 2026. Hydro will continue to work with GE  
8 and the OEM to ensure proper mitigation of the issue.

### 9 **Conductor Testing**

10 Following a bipole trip on March 30, 2024, line patrol determined that the electrode conductor was  
11 broken and damaged during an ice storm at several locations in southern Labrador. As a result,  
12 conductor testing was completed and determined that there were no material issues with the  
13 conductor. Rather, it was found that the failure was due to overload, which is consistent with past  
14 findings. There is evidence that cyclic loading due to ice and wind on the conductor may be causing  
15 fatigue and could contribute to the failure, which is also consistent with previous testing results.  
16 Additional conductor testing has been completed, which determined no significant new findings.<sup>7</sup>

## 17 **4.2 Capital Projects**

### 18 **Optimizing Clamp Designs**

19 During December 2022, March 2024, and January 2025, there were issues with the electrode conductor  
20 during significant ice loading, the root cause of which was determined to be overloading due to ice and  
21 ice shedding. Three alternative suspension clamp designs have been installed on the electrode  
22 conductor at ten structures in critical sections of the line and will be inspected yearly for performance.<sup>8</sup>  
23 An assessment of the electrode suspension assembly and a redesign of the assembly were completed in

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<sup>5</sup> High-Voltage Direct Current (“HVdc”).

<sup>6</sup> One of these DCCTs has an operation rating to -40°C and will be replaced with a DCCT rated to -50°C in early 2026, as system conditions permit. An earlier outage planned to complete this replacement in mid-December 2025 was unable to proceed due to system conditions.

<sup>7</sup> For further information, please refer to Attachment 1 of “Quarterly Report on Asset Performance in Support of Resource Adequacy for the Twelve Months Ended September 30, 2025,” Newfoundland and Labrador Hydro, October 31, 2025.

<sup>8</sup> The alternative clamp design is intended to reduce static and dynamic stresses at the support point, protecting the conductor against the effects of oscillations.

1 2025, with the assemblies to be purchased and installed as required through a capital project.<sup>9</sup>  
2 Additional conductor testing has been completed from these incidents, with further recommendations  
3 outlined within the most recent investigation report.<sup>10</sup>

4 An alternative optical power ground wire (“OPGW”) suspension clamp assembly was designed and  
5 ordered in 2024 and will be installed as required during maintenance and repairs. These clamps have  
6 been installed in some areas in 2025. As the OPGW relates to communications functionality, Hydro does  
7 not anticipate that further occurrences of similar damage would result in a prolonged power  
8 interruption or customer outage. To mitigate risk to near-term reliability, Hydro has its Emergency  
9 Response Plan in place and has proceeded with the procurement of required materials to ensure they  
10 are on hand in the event a repair is required.

### 11 **Top Plate Design**

12 In December 2022, there were two incidents impacting two adjacent structures of the LIL where the  
13 connection of the top plate of the OPGW suspension detached from the tower, falling onto the cross  
14 arm. Analysis was completed in the second quarter of 2024 to determine the towers that were  
15 susceptible to top plate connection failures due to design error. This analysis confirmed that 63 towers  
16 across two tower types (A3 and A4) were identified to have top plates replaced; as of the end of 2024,  
17 61 of 63 were replaced, which represents all A3 towers. The two remaining top plates are on A4 tower  
18 types. Installation work to rectify the tower peaks and two remaining top plates is expected to begin in  
19 2026, with expected completion in 2028.<sup>11</sup>

20 The other structures, which include A2, A3, A4, B1, and B2 towers that did not have top plate  
21 reinforcement work completed, may experience bending of the top plate that would not result in failure  
22 of the OPGW connection or an outage of the line. An engineering consultant was engaged to complete  
23 the reinforcement design of these other tower types, and this design and cost estimate were completed  
24 in the third quarter of 2025. To date, there have been minimal issues with other tower types; these  
25 structures could be repaired as part of annual maintenance if required. Hydro will keep the alternate

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<sup>9</sup> The assembly was redesigned to increase its length to allow for a larger swing angle and decrease the force on the tower and conductor from unbalanced icing.

<sup>10</sup> *Supra*, f.n. 7.

<sup>11</sup> As detailed in Attachment 1 to this appendix, installation work to rectify the tower peaks and two remaining top plates is planned in the LIL Strengthening Capital Project, with top plate reinforcement scheduled in 2026.

1 design in stock as a precaution and will schedule installation on other tower types as required if  
2 deformation of the top plate occurs.

### 3 **Ice Monitoring**

4 In response to icing experienced on the LIL, Hydro has undertaken capital projects for the installation of  
5 a real-time weather station, as well as the installation of on-line ice and galloping monitoring  
6 equipment. In-line monitoring equipment has been installed in all three planned locations in 2025. A  
7 second real-time monitoring station is planned for installation in central Labrador in late 2026.

### 8 **4.3 High-Power Testing**

9 As previously reported in Hydro's final 2025–2026 Winter Readiness Report,<sup>12</sup> the high-power test of the  
10 LIL has been postponed because of Hydro's prioritization of reliable service to customers during the  
11 winter period, including supporting reservoir levels to meet peak load requirements. If system  
12 conditions permit, the high-power test will be conducted in the first quarter of 2026. As previously  
13 reported, the following are prerequisite conditions for the test to occur:

- 14 • Satisfactory system conditions are present, including both those in Newfoundland and Labrador,  
15 where a high system load can be reasonably expected to occur, and in neighbouring  
16 jurisdictions;
- 17 • Successful coordination with all relevant neighbouring system operators is attained; and
- 18 • Identification of risks and implementation of all necessary risk mitigation actions are in place.

### 19 **4.4 Software**

20 The new LIL software was commissioned in October 2024. This software, as with the previous version,  
21 allows for full operation of the LIL up to 900 MW. Through dynamic commissioning, non-critical  
22 software-related issues were identified. Hydro continues to work with GE on the development of a  
23 version of software to resolve these issues. A version of software was already delivered by GE, and an  
24 attempt was made to install it in April of 2025; however, a version control error by GE required that the  
25 software be removed before it was placed into service. A new version of the software was delivered in  
26 the fourth quarter of 2025; however, due to system constraints within the Newfoundland and Labrador

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<sup>12</sup> Reliability and Resource Adequacy Study Review – 2024–2025 Winter Readiness Planning Report – Final Report,"  
Newfoundland and Labrador Hydro, December 10, 2024.

1 Interconnected System as well as neighbouring provinces, software installation is delayed until mid-  
2 2026.

### 3 **4.5 Engineering Studies and Reports**

4 Since the commissioning of LIL in April 2023, Hydro has gained valuable insight into LIL operations. Using  
5 Hydro's operating experience and recommendations from its investigations, supplemented by the  
6 recommendations made by Halder & Associates Inc., Hydro has identified three potential  
7 reinforcements to LIL assets to sustain reliability, address common failure modes, and mitigate risks to  
8 the Island Interconnected System. While these potential reinforcements have been identified, further  
9 engineering assessment is required to determine the benefits, costs, schedule, and feasibility of these  
10 modifications. These include:

- 11 • Review of unbalanced ice loads for the entire line length to determine appropriate unbalanced  
12 ice loading design parameters, followed by design and cost estimates for tower design  
13 modifications to meet unbalanced design loads;
- 14 • Feasibility assessment and cost estimates for installation of mid-span structures to reduce tower  
15 loading in critical areas; and
- 16 • Engineering design and cost estimates to relocate electrode conductors from towers to wood  
17 poles in some sections, to reduce tower loading, improve access and logistics, and minimize  
18 outages to address electrode line issues in critical areas.

19 These assessments, designs and cost estimates have now been completed, and Hydro has evaluated  
20 these projects based on their anticipated reliability benefits and their estimated cost through the fourth  
21 quarter of 2025 to determine next steps. Hydro has provided a report summarizing these findings as  
22 Attachment 1 to this Appendix B.

### 23 **4.6 Ongoing Investigations**

24 All outstanding investigations have been completed for incidents related to the Muskrat Falls Assets,  
25 and the results have been reviewed and finalized by Hydro. There are no new investigation outcomes to  
26 report for this period.

1    **4.7    Restoration Plans and Operational Strategy**

2    In addition to engineering studies to inform potential reinforcements to mitigate the risk of component  
3    failures and outages, Hydro is currently in the process of contracting a consultant to review Hydro’s  
4    restoration plans, including review and development of specific restoration plans for a variety of  
5    potential and previously experienced scenarios. It is expected that this review will include the  
6    identification of alternative restoration approaches that can be selected based on the situation for the  
7    most efficient and effective execution of the work. Restoration plans will consider geographic and  
8    weather challenges. Restoration plan reviews will include estimates of the time to effect the repairs, as  
9    well as time challenges and opportunities for restoration duration and provide cost and benefit  
10   information to identify incremental investment in restoration time improvement and quantify the  
11   associated benefits.

12   **5.0    Conclusion**

13   Hydro recognizes the criticality of the Muskrat Falls Assets to the supply of the Island Interconnected  
14   System, which helps to limit the thermal generation required from the Holyrood TGS and impacts the  
15   overall reliability of the grid. Hydro will continue to monitor the performance of these assets to address  
16   early life incidents such as those due to manufacturing issues or defective components.

# Attachment 1

## LIL Strengthening Overview



# LIL Strengthening Overview

January 2026



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Appendix F: Analysis of Removing the Electrode Conductor from L3501/2

## 1 1.0 Introduction

2 The Labrador-Island Link (“LIL”) is an important transmission line for the provincial energy grid due to its  
3 power carrying capacity that is used to deliver a large portion of the winter peak energy and demand to  
4 the Island Interconnected System. In total, there have been ten failure events on L3501/2<sup>1</sup> over the past  
5 five years; each of these failures was a localized issue affecting a small number of specific transmission  
6 line components. These issues have not affected Newfoundland and Labrador Hydro’s (“Hydro”) ability  
7 to provide customers on the Island with reliable service, and all critical repairs resulting from the failures  
8 have been completed.

9 Due to the importance of L3501/2 to the provincial energy grid and the need to understand the line’s  
10 performance, investigations were completed for each event. The investigations determined that the  
11 root cause for many of these events was overloading due to icing and unbalanced icing. The  
12 investigation results helped Hydro understand the root cause of each incident so that proactive actions  
13 can be taken, where necessary, to mitigate against any impact on the long-term reliability of the LIL. The  
14 investigations were led by Hydro's Transmission Engineering team. Third party consultants were brought  
15 in as necessary for detailed calculations and modelling, material testing, laboratory simulations, and  
16 review of the process, findings, and recommendations. There were numerous recommendations from  
17 the investigations that required engineering analysis, design and cost estimation.

18 Through 2024 and 2025, Hydro undertook a series of studies to address the recommendations within  
19 the Investigation Reports in order to mitigate future issues, including:

- 20 • Installation of ice and galloping monitoring equipment;
- 21 • Further study into damper issues and a new damping system;
- 22 • Re-design and cost estimation for replacement of the top plate connections for A2, A4, B1, and  
23 B2 towers;
- 24 • Installation of alternate suspension clamps;

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<sup>1</sup> L3501 refers to Pole 1 and L3502 refers to Pole 2 of the line.

- 1 • Design and cost estimation for tower modifications to the peak and electrode crossarms;
- 2 • Feasibility analysis and cost estimation for moving the electrode conductor to wood pole
- 3 structures;
- 4 • Feasibility analysis and cost estimation for the installation of mid-span structures; and
- 5 • Re-design and cost estimation for an alternate electrode insulator assembly.

6 The completion of these analyses, designs, and cost estimates determined the scope of the 2026–2028  
7 “LIL Strengthening Capital Project” proposed within this report. The project scope includes  
8 reinforcement of the tower peak and electrode crossarms, reinforcement of the Optical Ground Wire  
9 (“OPGW”) top plate connection, installation of modified electrode insulator assemblies, and removing  
10 sections of the electrode conductor from the towers for installation on wood poles. These solutions will  
11 be used on different sections of the line as required to increase the reliability of the LIL and decrease the  
12 risk of failure due to ice loading.

## 13 **2.0 Background**

14 Line L3501/2 is the 350 kV High Voltage direct current (“HVdc”) overland transmission line portion of the  
15 LIL, traversing approximately 1,100 km through three major meteorological loading zones, referred to as  
16 average, alpine, and eastern. As shown in Figure 1, the HVdc line has two poles, one OPGW, and two  
17 electrode conductors, mounted on steel lattice towers. The electrode conductor is attached to the  
18 towers for a part of the line from Muskrat Falls to approximately 384 km southeast of Muskrat Falls,  
19 where it diverts to a separate right-of-way (“ROW”) on wood pole structures. From there, the electrode  
20 line (“EL”) travels to an electrode site approximately 16 km away, located in the L’Anse-au-Diable area.  
21 sections of L3501/2 without the electrode on the towers do not have electrode crossarms.

22 The HVdc transmission line corridor has been divided into the three major meteorological loading zones  
23 referenced above in combination with eight further subcategories related to loads, pollution levels  
24 (inland and coastal), and geographic location. This combination results in 19 separate loading zones. 11  
25 tower types (A1, A2, A3, A4, B1, B2, C1, C2, D1, D2, and E1) were designed to meet the loading  
26 requirements, which consist of a specified wind load, ice load, and combination of both applied to the  
27 line. The tower types consist of both guyed towers and self-support towers. The tower types are  
28 summarized in Table 1 and a depiction of the structure types is shown in Figure 1.

Table 1: Tower Types

Tower Type	Structure Type	Insulator Assembly Type	Deflection Angle Limit (degree)
A1, A2, A3, A4	Guyed	Suspension	0–1
B1	Guyed	Suspension	0–3
B2	Self-Support	Suspension	0–3
C1, C2	Self-Support	Dead-End	0–30
D1, D2	Self-Support	Dead-End	0–45
E1	Self-Support	Dead-End	45–90

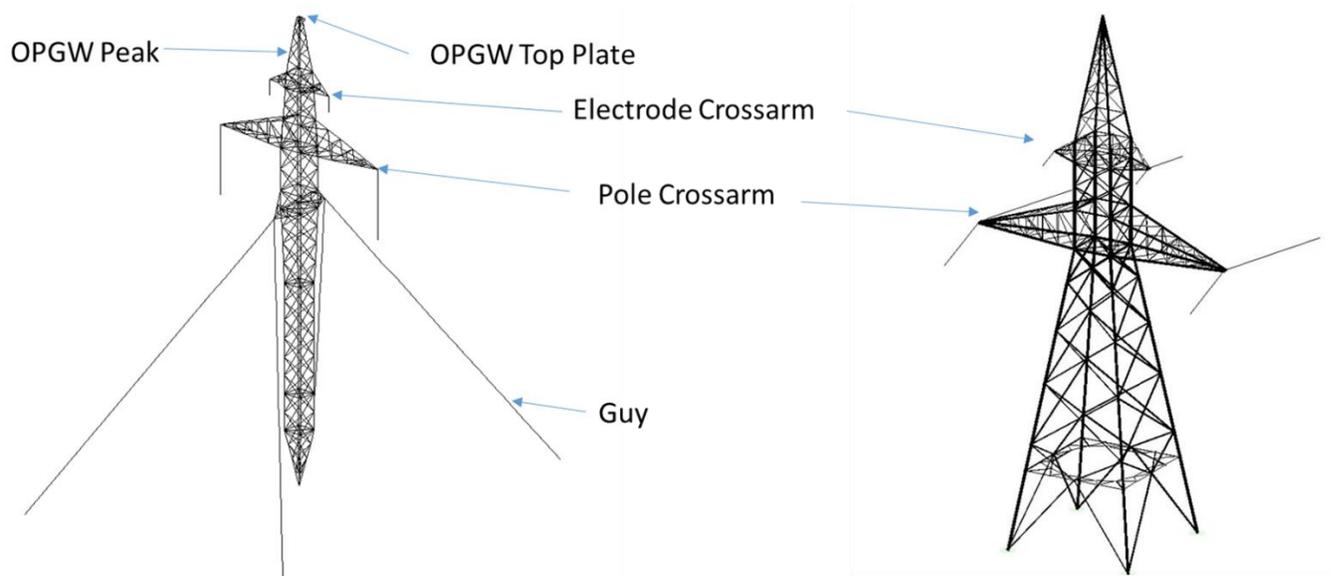


Figure 1: Suspension and Self-Support Tower Diagram

- 1 Of the total number of towers on L3501/2, 90% are suspension towers – types A1, A2, A3, A4, B1, and
- 2 B2. Figure 2 provides a breakdown of the tower distribution on L3501/2, with suspension towers shown
- 3 in red and self-support towers shown in blue.

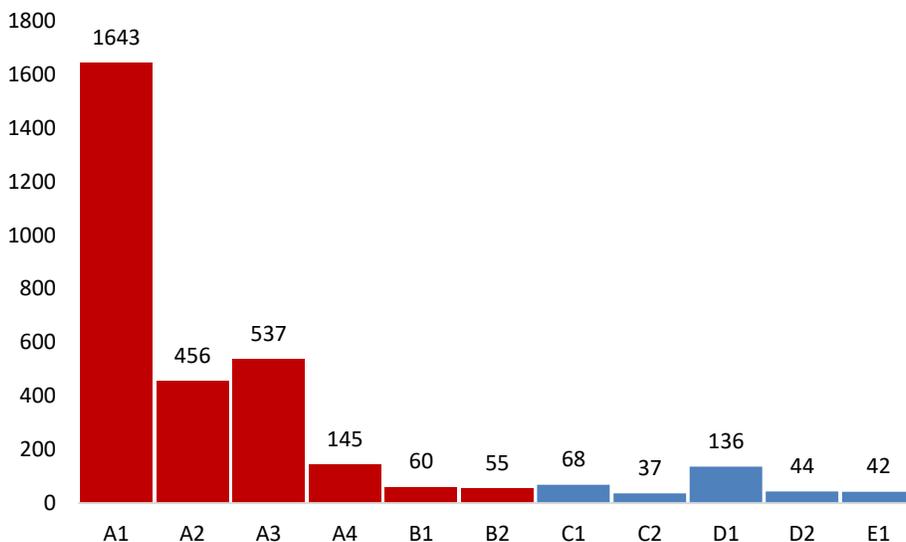


Figure 2: Distribution of Tower Type on L3501/2

### 1 3.0 Investigation Overview

2 Issues with components of the LIL during ice events over the past five years have primarily caused  
 3 damage to the electrode crossarms, OPGW tower peaks, and the electrode conductor. Investigations  
 4 determined that the root cause of the damage for seven of the 10 events was overloading due to  
 5 significant ice accumulation and unbalanced ice loads from ice shedding; the root cause of failure for the  
 6 remaining three investigations was determined to be galloping.<sup>2</sup> Information regarding six of the seven  
 7 events due to ice loading is shown in Table 2. All these events occurred on A1 type towers in sections of  
 8 the line with the electrode conductor attached to the tower. The maximum design ice load case for this  
 9 section of the line is 50 mm of radial glaze ice with a density of 0.9 g/cm<sup>3</sup> (equivalent to 11.9 kg/m on  
 10 the electrode conductor); all events shown in Table 1 exceeded the design ice load case, except for the  
 11 event in Southern Labrador in December 2022. The unbalanced ice load cases include 70% of the  
 12 maximum ice back span<sup>3</sup>, with 100% of the maximum ice ahead span on a tower (and vice versa) for one  
 13 wire at a time, while all other wires have 100% of the maximum ice load on both spans.

<sup>2</sup> Implementation of recommendations for two of these failures is complete; a capital project is proposed for 2026 to address recommendations from the final investigation. For further information, please refer to Failure Investigation Report – L3501/2 Pole Assembly Turnbuckle Failure – Failure Event February 2021 in Labrador; and L3501/2 Failure Investigation – Turnbuckle Failures Structure 1872, 1806 and 1014.

<sup>3</sup> Back span refers to the section of line that runs behind a specific tower, opposite the ahead span.

Table 2: Summary of Events

Date	Location	Number of Locations			Number of Damaged OPGW Top Plates	Approximate Radial Equivalent Ice Thickness (mm) <sup>4</sup>	Approximate Weight of Ice on EL Conductor (kg/m)
		Number of Damaged EL Crossarms	Number of Damaged EL Conductor	Number of Damaged OPGW Peaks			
Jan–2021	Central Labrador	12	34	0	0	54–65	13.1–17.8
Dec–2022	Central Labrador	0	3	0	0	70–72	20.6–21.6
Dec–2022	Southern Labrador	0	0	2	0	20–30	2.0–3.8
Feb–2024	Central Newfoundland	0	0	8	0	50–75	9.1–19.0 <sup>5</sup>
Mar–2024	Southern Labrador	16	17	4	0	79–99	25.2–37.4
Jan–2025	Central Labrador	4 <sup>6</sup>	2	0	0	55–60	10.8–12.4

1 The remaining event due to ice loading occurred during an icing event in Western Newfoundland in  
 2 December 2022, which caused damage to two OPGW top plates on two A3 towers. During this event,  
 3 the top plate connections failed and caused deformation and damage to the top plate and the hanger  
 4 bracket on two A3 towers. While there was approximately 70 mm of icing on the lines with a density of  
 5 0.9 g/cm<sup>3</sup> (17.9 kg/m) at the time of the event, this is less than the design ice load case for this tower  
 6 type, which is for 75 mm of radial glaze ice with a density of 0.9 g/cm<sup>3</sup> (20.3 kg/m). The root cause of  
 7 this issue was determined to be a design error – the connection capacity of the top plate and hanger  
 8 bracket was not sufficient for the vertical design load from ice. A contractor was engaged to reinforce  
 9 the top plate connection of the 61 critical A3 towers; this work was completed in 2024.

10 A complete list of the recommendations on ice related issues can be found in the Investigation Reports  
 11 listed in Table 2, and the status of each recommendation is summarized in Appendix A. Some  
 12 recommendations have been addressed through capital projects, while other recommendations require  
 13 more detailed analysis and engineering, and therefore remain ongoing.

<sup>4</sup> Ice loads converted to radial equivalent thickness based on a density of 0.9 g/cm<sup>3</sup> to compare to design ice load.

<sup>5</sup> The approximate weight of ice per m (kg/m) was on the OPGW in this event.

<sup>6</sup> The icing event caused damage to three electrode crossarms; the fourth electrode crossarm was damaged during planned ice removal activities.

**Table 3: Investigation Reports**

Report Title	Document Number
Failure Investigation Report – TL3501/2 Tower and Conductor Damage Icing Event January 2021 in Labrador <sup>7</sup>	ILK-EG-ED-6200-TL-H15-0001-01
L3501/2 Failure Investigation – OPGW Tower Peaks – Structure 1230 and 1231 <sup>8</sup>	ILK-EG-ED-6200-TL-H15-0004-01
L3501/2 Failure Investigation – OPGW Top Plates – Structure 2135 and 2136 <sup>9</sup>	ILK-EG-ED-6200-TL-H15-0005-01
L3501/2 Failure Investigation – OPGW Tower Peaks - Central Newfoundland <sup>10</sup>	ILK-EG-ED-6200-TL-H15-0006-01
L3501/2 Failure Investigation – Ice Storm Southern Labrador <sup>11</sup>	ILK-EG-ED-6200-TL-H15-0007-01
Failure Investigation Report – Icing Event December 2022 in Labrador <sup>12</sup>	ILK-EG-ED-6200-TL-H15-0008-01
L3501 Failure Investigation – Ice Storm Central Labrador – January 2025 <sup>13</sup>	ILK-EG-ED-6200-TL-H15-0010-01

## 1 **4.0 LIL Engineering Studies Capital Project (2024–2025)**

2 A 2024–2025 capital project was executed based on the recommendations within the Investigation  
3 Reports to mitigate future events. A summary of the scope items included within this capital project,  
4 and their status, is detailed below.

### 5 **Ice Monitoring**

6 A total of three sensors were installed on structures 514 (central Labrador), 1224 (southern Labrador)  
7 and 2597 (central Newfoundland) in 2025 to monitor ice load and galloping.

### 8 **Damping system**

9 In 2024, an engineering consultant was engaged to provide an updated damper technical specification  
10 based on past issues. A damper supplier was also engaged to determine the quantity and type of  
11 dampers to provide adequate damping for the line. Vibration equipment was installed on the line in  
12 2024 to gather information required for the damper study. The equipment experienced issues due to  
13 severe weather, and new equipment was installed in 2025 to continue monitoring and gather additional  
14 information. A recommendation for a new damping system is expected in 2026.

<sup>7</sup> Filed within “Reliability and Resource Adequacy Study Review – Labrador-Island Link Failure Investigation Reports,” Newfoundland and Labrador Hydro, May 31, 2021.

<sup>8</sup> *Supra*, f.n. 6.

<sup>9</sup> *Supra*, f.n. 6.

<sup>10</sup> “Quarterly Report on Asset Performance in Support of Resource Adequacy for the Twelve Months Ended March 31, 2025,” Newfoundland and Labrador Hydro, April 30, 2025, att. 1, app. B.

<sup>11</sup> “Quarterly Report on Asset Performance in Support of Resource Adequacy for the Twelve Months Ended March 31, 2025,” Newfoundland and Labrador Hydro, April 30, 2025, att. 2, app. B.

<sup>12</sup> *Supra*, f.n. 6.

<sup>13</sup> “Quarterly Report on Asset Performance in Support of Resource Adequacy for the Twelve Months Ended September 30, 2025,” Newfoundland and Labrador Hydro, October 31, 2025, att. 1, app. B.

1 **Top Plate Design**

2 Analysis was completed in 2024 to determine the towers that were susceptible to top plate connection  
3 issues due to design error. 61 A3 towers and 2 A4 towers were determined to be critical and should be  
4 fixed as soon as possible. A contractor was engaged to reinforce the top plate connection of the 61  
5 critical A3 towers. This work was completed in 2024.

6 An engineering consultant was engaged to complete the reinforcement design of the other tangent  
7 tower types (A2, A4, B1, and B2). This design and cost estimate were completed in 2025. There are two  
8 A4 towers that require top plate reinforcement; tower reinforcement will be purchased and installed as  
9 required. Installation work to replace the two remaining top plates is expected to begin in 2026, with  
10 expected completion in 2028.

11 Engineering analysis determined that the other structures, which includes A2, A3, A4, B1, and B2 towers  
12 that did not have top plate reinforcement work completed, may experience bending of the top plate  
13 that would not result in failure of the OPGW connection or an outage of the line. To date, there have  
14 been minimal issues with other tower types; these structures could be repaired as part of annual  
15 maintenance if required. Hydro will keep the alternate design in stock as a precaution and will schedule  
16 installation on other tower types as required if deformation of the top plate occurs.

17 **Optimizing Clamp Designs**

18 Three alternative suspension clamps were installed on the electrode conductor at 10 structures in 2024,  
19 and will be inspected annually for performance. These alternative clamp designs are intended to reduce  
20 static and dynamic stresses at the conductor support point, protecting the conductor against the effects  
21 of oscillations.

22 An alternative OPGW suspension clamp assembly was designed and ordered in 2024 and will be  
23 installed as required during maintenance and repairs. These clamps have been installed in some areas in  
24 2025.

25 Assessment, re-design and cost estimation for the electrode suspension assembly<sup>14</sup> was completed in  
26 2025 based on findings from the investigations. The assembly was re-designed to increase its length to

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<sup>14</sup> The assembly consists of the hardware and insulators between the tower and conductor.

1 allow for a larger swing angle, and decrease the force on the tower and conductor from unbalanced  
2 icing.

### 3 **Tower Analysis and Design Modifications**

4 An ice study was completed in 2024 to determine the ice load levels experienced on the geographic  
5 areas of the line where failures occurred, and has produced updated design ice loads. An engineering  
6 consultant was engaged to complete tower analysis and design modifications based on the updated  
7 design ice loads and provide a cost estimate for the implementation of these design changes.<sup>15</sup>

8 Tower reinforcement would require the replacement of the tower peak and electrode crossarms with  
9 reinforced sections and add additional bracing to the tower cage. Moving the electrode conductor to  
10 wood pole lines was technically feasible in some locations and would also reduce the loads on the  
11 tower. Installation of mid-span structures to reduce the loads on the towers were also assessed;  
12 however, the reduction was not sufficient to address the overloading due to the ice loading, and tower  
13 reinforcement was determined to be a better technical solution.

14 Actions to address these recommendations are planned in the capital project discussed in Section 5.0.

## 15 **5.0 LIL Strengthening Capital Project (2026–2028)**

### 16 **5.1 Evaluation of Alternatives**

17 For the LIL Strengthening Capital Project proposal, four alternatives were evaluated to address issues  
18 with the OPGW peak, the electrode crossarm and the electrode conductor:

- 19 • Installation of mid-span structures;
- 20 • Removal of electrode conductor from the towers and installation on wood poles;
- 21 • Re-design of the electrode assembly; and
- 22 • Reinforcement and re-design of the OPGW peak and electrode crossarm.

23 Note that some of these alternatives can be implemented concurrently; for example, the electrode  
24 conductor can be moved to a wood pole line, and the OPGW peaks can be reinforced. The electrode

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<sup>15</sup> The consultant reports for the Mid-Span Structure Addition, A1 Electrode Suspension Assembly, and Calculations for OPGW Peak Reinforcement are provided as Appendix B, C and D, respectively.

1 crossarms can be reinforced, and the electrode assembly can be re-designed and installed. Additionally,  
2 as these alternatives are recommended for multiple line sections and hundreds of towers, different  
3 alternatives may be recommended for different sections. All estimated costs per structure include  
4 allowance for mobilization and demobilization based on 230 structures. The cost estimate for the  
5 installation of a wood pole line or mid-span structures is provided as Appendix E. Additional detail  
6 related to the analysis to remove the electrode conductor from L3501/2 is provided as Appendix F.

### 7 **5.1.1 Mid-Span Structures**

8 This alternative would include the installation of mid-span structures to reduce the ice loads on the  
9 towers. Analysis determined that the reduction in loading on both the electrode crossarm and OPGW  
10 peaks is not sufficient to address the overstress due to increased ice and unbalanced ice loads. As a  
11 result, this alternative was determined not to be technically feasible.

### 12 **5.1.2 Remove Electrode Line Conductor from Towers and Install on Wood Poles**

13 This alternative would remove the EL from towers and install on a wood pole line. In addition to  
14 reducing the ice loads on the towers, there are several other advantages specific to this alternative. Due  
15 to the smaller size of the wood poles and the separation from the pole conductors, any required repairs  
16 to the electrode conductor or associated structures are made easier. The electrode conductors would  
17 also be at a lower elevation and likely to accumulate less ice.

18 Disadvantages for this alternative include the requirement to build a new ROW parallel to the existing  
19 L3501/2 ROW. This new ROW would have to be assessed for constructability and conflicts with existing  
20 infrastructure or land ownership.<sup>16</sup> Additionally, the removal of the electrode conductor will not address  
21 the issues with unbalanced ice loads on the OPGW.

22 The estimated cost of this alternative per LIL tower (not per wood pole structure) is approximately  
23 \$101,562. Due to the difference in span length, approximately five wood pole structures are required for  
24 each tower span.

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<sup>16</sup> The wood pole line will have shorter span lengths and may not be able to transverse obstacles such as waterbodies and large elevation changes.

### 1 **5.1.3 Re-design EL Assembly**

2 This alternative would include the installation of a newly designed electrode assembly on the electrode  
3 crossarm. Two options were designed under the 2024-2025 project: one that can be installed on the  
4 existing electrode crossarms, and one that can be installed on the newly designed, reinforced electrode  
5 crossarm. Both options increase the length of the electrode assembly and will allow more longitudinal  
6 swing under unbalanced ice loads, decreasing the chance of contact with the insulator and deformation  
7 of the conductor. This alternative would decrease the longitudinal load on the crossarm and address the  
8 forces on the conductor at the suspension clamp; however, loads on the electrode crossarm will not be  
9 reduced enough to address the high unbalanced ice loads, and it does not address the loads on the  
10 OPGW peak.

11 The estimated cost of this alternative per structure, including installation, is \$10,000 for the assembly  
12 that can be installed on the existing electrode crossarms, and \$29,000 for the assembly and newly  
13 designed, reinforced electrode crossarm.

### 14 **5.1.4 Reinforcement and Re-design of OPGW Peaks and EL Crossarms**

15 This alternative would include replacing the existing electrode crossarms and OPGW peak with new  
16 reinforced sections and adding reinforcing members to the existing cage.<sup>17,18</sup> The reinforcement is  
17 specifically designed for the ice and unbalanced ice loads that were encountered during past events, and  
18 installation can be completed during a monopole outage. This alternative will mitigate issues with both  
19 the electrode crossarm and OPGW with a relatively low cost per structure; however, it will not address  
20 the electrode conductor failures.

21 The estimated cost of this alternative per structure, including installation, is \$36,000 for the OPGW peak  
22 and the electrode crossarm, and \$29,000 for only the electrode crossarm.

## 23 **5.2 Recommended Alternative**

24 The recommended alternative is the Reinforcement and Re-design of OPGW Peaks and EL Crossarms  
25 with Re-design of the EL Assembly for most sections, with two exceptions. The combination of these  
26 alternatives will address issues with the OPGW peak, the electrode crossarm and the electrode

---

<sup>17</sup> The cage is the section of the tower located between the main tower body and the peak.

<sup>18</sup> It was determined that due to the amount of reinforcing steel required on the crossarms and peak, installation of new sections would be more cost effective than adding reinforcement to the existing sections.

1 conductor, resulting in the best alternative for increased reliability. This alternative is also considerably  
2 less costly than the installation of Mid-Span Structures or the option to Remove EL Conductor from  
3 Towers and Install on Wood Poles.

4 The first exception to the recommended alternative is for the section of line from structure 1209 to  
5 1229 in southern Labrador. For this section, the recommended alternative is to Remove EL Conductor  
6 from Towers and Install on Wood Poles, and the Reinforcement and Re-design of the OPGW Peaks only.  
7 This section of line has experienced higher icing than any other section considered for strengthening,  
8 and is located adjacent to a section (structures 1110 to 1209) designed for much higher ice loads.<sup>19</sup>  
9 Currently the EL taps off the steel lattice transmission line at structure 1229 and travels to the electrode  
10 site on a wood pole line; this alternative would require one tap from the line at structure 1209. This area  
11 also has light vegetation and would require minimum clearing.

12 The second exception to the recommended alternative is for the section of line from structure 1230 to  
13 1245 and structure 2520 to 2629. In these sections, the recommended alternative is the Reinforcement  
14 and Re-design of the OPGW Peaks only, as these sections of line do not have electrode conductor or  
15 electrode crossarms.

### 16 **5.3 Scope of Work**

17 The project scope includes procurement and installation work on a total of 309 Type A1 towers, as  
18 follows:

- 19 • Replacement of OPGW peaks, EL crossarms, and EL assemblies for 186 towers:
  - 20 o 18 A1 towers from structure 114 to 131
  - 21 o 33 A1 towers from structure 208 to 242
  - 22 o 37 A1 towers from structure 329 to 369
  - 23 o 57 A1 towers from structure 406 to 466
  - 24 o 41 A1 towers from structure 499 to 541

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<sup>19</sup> The maximum design ice load case for the section of line from structure 1209 to 1229 is 50 mm of radial glaze, while structures 1110 to 1209 are designed for 115 mm of radial rime ice.

- 1 • Replacement of OPGW peaks, and removal of EL conductor and installation on wood poles for  
2 18 towers:
  - 3 o 8 A1 towers from structure 1210 to 1228
- 4 • Replacement of OPGW peaks only for 105 towers:
  - 5 o 16 A1 towers from structure 1230 to 1245
  - 6 o 89 A1 towers from structure 2531 to 2628

7 Structures were selected based on priority, with the highest priority being the sections of line that have  
8 experienced multiple events; medium priority are locations that have experienced a single event; and  
9 low priority are locations that have not experienced failures but have similar characteristics<sup>20</sup> to  
10 locations where issues have been experienced.

11 The project scope will also include material procurement for reinforcement of the OPGW top plate  
12 connection for all affected tower types (A2, A3, A4, B1, and B2), and installation of the solution on two  
13 A4 towers. The towers selected to be fixed were determined to be at risk of bolt failure under maximum  
14 ice loads. The extra material will be procured for towers that are at risk of top plate bending. Although  
15 these plates will have to be replaced if bending occurs, there is no risk of outage from this issue, and the  
16 repairs are not urgent.

#### 16 **5.4 Project Budget**

17 The estimated cost for this project is \$21,800,000, with \$8,700,000 in 2026, \$6,700,000 in 2027 and  
18 \$6,300,000 in 2028.

#### 19 **5.5 Project Schedule**

20 The construction schedule for the 2026-2028 project is shown in Table 4. Procurement of all material  
21 will occur in year 1, and installation work will take place over a three-year period based on priority.

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<sup>20</sup> Similar characteristics include loading zones, tower types, icing, elevation, or elevation changes.

**Table 4: Project Schedule**

<b>Activity</b>	<b>Date</b>
Procurement:	
Materials ordered.	Year 1
Top Plate Reinforcement:	
2 A4 towers, structure 1831 and 1821	Year 1
Replacement of OPGW Peaks, and Removal of EL Conductor and Installation on Wood Poles:	
18 A1 towers, structure 1210 to 1228	Year 1
Replacement of OPGW Peaks only:	
16 A1 towers, structure 1230 to 1245	Year 1
89 A1 towers, structure 2531 to 2628	Year 2
Replacement of OPGW peaks, EL crossarms, and EL assemblies:	
41 A1 towers, structure 499 to 541	Year 1
37 A1 towers, structure 329 to 369	Year 2
18 A1 towers, structure 114 to 131	Year 2
33 A1 towers, structure 208 to 242	Year 3
57 A1 towers, structure 406 to 466	Year 3

## 1 **6.0 Conclusion**

2 There have been 10 failure events on L3501/2 over the past five years. These failures were localized  
 3 issues, affecting a small number of transmission line components. Due to the importance of L3501/2 to  
 4 the provincial energy grid and the need to understand the line’s performance, investigations have been  
 5 completed for each event to recommend actions to mitigate further damage to the line. Investigations  
 6 determined that the root cause of the damage for seven of the 10 events was overloading due to  
 7 significant ice accumulation and unbalanced ice loads from ice shedding. Recommendations from these  
 8 investigations were analyzed as part of a 2024–2025 capital project, which implemented some of the  
 9 recommended scope items, while others required additional analysis and design development. These  
 10 remaining recommendations are proposed to be actioned in a 2026–2028 capital project. The project  
 11 scope includes reinforcement of the tower peak and electrode crossarms, reinforcement of the OGPW  
 12 top plate connection, installation of modified electrode insulator assemblies, and removing sections of  
 13 the electrode conductor from the towers for installation on wood poles. These solutions will be used on  
 14 different sections of the line as required. The work proposed in the project will increase the reliability of  
 15 the LIL and will decrease the risk of failure due to ice loading.

# Appendix A

## Summary of all Failure Investigation Recommendations



Summary of all Failure Investigation Recommendations

Document Number	Report Title	Recommendation	Status	Comments
ILK-EG-ED-6200-TL-H15-0001-01	Failure Investigation Report - TL3501/2 Tower and Conductor Damage - Icing Event January 2021 in Labrador	Monitor ice by line patrol	Addressed	<ul style="list-style-type: none"> <li>Lines are monitored regularly during the winter by helicopter line patrol. Additional helicopter patrols are scheduled as needed after an icing event.</li> <li>One test span and weather monitoring station installed, another to be installed in 2026.</li> </ul>
		Install real time ice monitoring on lines	Ongoing	<ul style="list-style-type: none"> <li>Three sensors were installed on structures 514 (central Labrador), 1224 (southern Labrador) and 2597 (central Newfoundland) in Q3 of 2025 to monitor ice load and galloping.</li> </ul>
		Develop procedure of mechanical ice removal	Addressed	<ul style="list-style-type: none"> <li>Procedure has been implemented for Engineering, Operations, and Helicopter pilots.</li> </ul>
		Tower modifications to peak and electrode crossarms to increase tower capacity	Ongoing	<ul style="list-style-type: none"> <li>Ongoing through LIL Strengthening Capital Project.</li> <li>In 2024, an engineering consultant was engaged to provide an updated damper technical specification based on past failures. A damper supplier was also engaged to determine the quantity and type of dampers to provide adequate damping for the line.</li> <li>Vibration equipment was installed on the line in Q4 of 2024 to gather information required for the damper study. The equipment experienced issues due to severe weather, and new equipment was installed in Q3 of 2025 to continue monitoring and gather additional information.</li> <li>A recommendation for a new damping system is expected in 2026.</li> </ul>
ILK-EG-ED-6200-TL-H15-0004-01	L3501/2 Failure Investigation - OPGW Tower Peaks - Structure 1230 and 1231	Install air spoilers to reduce galloping	Addressed	<ul style="list-style-type: none"> <li>Air flow spoilers have been installed in areas with identified galloping issues. Spare air flow spoilers are on hand for any further installations as required.</li> </ul>
		Modify electrode insulator assembly to reduce load on tower and conductor	Ongoing	<ul style="list-style-type: none"> <li>Ongoing through LIL Strengthening Capital Project.</li> <li>Three alternative suspension dampers were installed on the electrode conductor at ten structures in Q3 of 2024, and will be inspected yearly for performance.</li> <li>Assessment, re-design and a cost estimate for the electrode suspension assembly was completed in Q3 of 2025.</li> </ul>
		All recommendations covered in other reports	Ongoing	
ILK-EG-ED-6200-TL-H15-0005-01	L3501/2 Failure Investigation - OPGW Top Plates - Structure 2135 and 2136	Redesign top plate connection on A3 towers	Addressed	<ul style="list-style-type: none"> <li>Redesign completed by consultant in 2023.</li> <li>A contractor was engaged to reinforce the top plate connection of the 61 critical A3 towers. This work was completed in 2024.</li> </ul>
		Fix all critical A3 tower top plates	Addressed	<ul style="list-style-type: none"> <li>An engineering consultant was engaged to complete the reinforcement design of the other tangent tower types (A2, A4, B1, and B2). This design and cost estimate were completed in Q3 of 2025.</li> </ul>
		Check and redesign all other tower type top plate connections	Addressed	<ul style="list-style-type: none"> <li>Ongoing through LIL Strengthening Capital Project.</li> <li>Two A4 towers require top plate reinforcement; tower reinforcement will be purchased and installed as required. Installation work is expected to be completed in 2026.</li> <li>To date, there have been minimal issues with other tower types. Hydro will keep the alternate design in stock as a precaution and will schedule installation on other tower types as required if deformation of the top plate occurs.</li> </ul>
		Fix all other critical tower type top plates	Ongoing	
ILK-EG-ED-6200-TL-H15-0006-01	L3501/2 Failure Investigation - OPGW Tower Peaks - Central Newfoundland Southern Labrador	All recommendations covered in other reports	Ongoing	
		Investigate radiography to evaluate conductor issues.	Ongoing	<ul style="list-style-type: none"> <li>Investigation ongoing. Pilot project in 2025, but looking for a solution that will detect damage at the clamp.</li> </ul>
		Determine protocols for evidence collection	Addressed	<ul style="list-style-type: none"> <li>Protocols are in place including check lists for damage and icing observations.</li> </ul>
ILK-EG-ED-6200-TL-H15-0008-01	Failure Investigation Report - Icing Event December 2022 in Labrador	Inspect conductor at suspension clamps to determine if different clamp types cause wear	Ongoing	<ul style="list-style-type: none"> <li>An alternative OPGW suspension clamp assembly was designed and ordered in 2024 and will be installed as required during maintenance and repairs. These clamps have been installed in some areas in 2025.</li> </ul>
		Move electrode to conductor to wood pole structures	Ongoing	<ul style="list-style-type: none"> <li>Ongoing through LIL Strengthening Capital Project.</li> </ul>
		Install mid-span structures to reduce loads	Ongoing	<ul style="list-style-type: none"> <li>Ongoing through LIL Strengthening Capital Project.</li> </ul>
ILK-EG-ED-6200-TL-H15-0010-01	L3501/2 Failure Investigation - Ice Storm Central Labrador - January 2025	Investigate thermal and mechanical methods to reduce ice accumulation	Ongoing	<ul style="list-style-type: none"> <li>Mechanical method known, and procedure in place. Thermal options being explored internally but may not be feasible.</li> </ul>

# Appendix B

## LIL Engineering Study – Mid-Span Structure Addition Report





# LIL Engineering Study – Mid-Span Structure Addition Report

Newfoundland and Labrador Hydro Report No. ILK-TT-CD-6200-TL-H15-0003-01  
TT Document Number 705-2579500100-REP-G0002-00  
May 23, 2025

## PRESENTED TO

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**REVISION HISTORY**

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## 1.0 INTRODUCTION

NL Hydro has experienced several performance issues for the Labrador-Island Transmission Link, +/- 350 kV HVDC. Performance issues include the following:

- Electrode conductor failure
- Electrode cross-arm structural failure
- Suspension clamp slippage on electrodes and OPGW
- OPGW cantilever failing and disconnecting from peak
- Tower peaks buckling

This technical memo discusses potential improvements that may be made by addition of mid-span structures. The introduction of mid-span structures on an existing line will reduce tower loading by changing the wind and weight span. Mid-span structures may also improve a back/ahead weight span imbalance (largely applicable to applied longitudinal loads).

## 2.0 STUDIED TOWER LOCATIONS

Six tower locations were inspected for potential candidates for mid-span structure additions. Locations were chosen to have unique characteristics that may represent a good sample space for potential highly loaded tower positions. The tower names are as per the PLS-CADD models provided by NL Hydro on January 15, 2025.

Table 1: Studied Tower Locations

Tower Location	Structure Number	Reason for Selection
S4-502	2469	Large span imbalance, back span coincident with a wet, low-lying area. No electrode strung.
S4-576	2543	Long weight spans both sides of the tower. Creates high vertical ice load. No electrode strung.
S4-598	2565	Large span imbalance, both spans running downhill relative to increasing stationing. No electrode strung.
S1-318	319	Long spans both sides of tower, long weight spans on both sides of the tower. Creates high transverse wind loads and high vertical ice loads.
S1-370	371	Ahead span crosses an area where the terrain is lower than both adjacent towers making it difficult to spot a new mid-span tower without experiencing uplift.
S1-307	308	Large span imbalance, both spans running uphill relative to increasing stationing. Similar to S4-598 (2565) but with strung electrodes.

## 3.0 METHODOLOGY

The following PLS-CADD modelling was completed for each tower location and is discussed in the following sections.

- The additional load cases from the tower A1 tower reinforcement scope were added to the Criteria Structure Loads table as follows:
  - UBI EL1 63 mm 70/100%
  - Ice Load 63 mm
  - UBI G 50 mm 100/50%
  - UBI G 55 mm 100/70%
  - UBI G 70 mm (50 mm on Pole) 100/80%
  - Ice Load 70 mm (50 mm on Pole)
- Existing load cases from the original design as per design loading drawings ILK-SN-CD-6200-TL-DD-0065-01-C1 & ILK-SN-CD-6200-TL-DD-0065-02-C1 were maintained.
- The subject existing tower model was replaced with a tower model that was created under the A1 tower reinforcement scope. The new model has all information verified against fabrication & insulator hardware drawings, connection capacities are added, and redundant members added.
- The load combination file for the existing tower configuration was output from the PLS-CADD model using level 2 analysis. Subject tower usage was calculated.
- One mid-span structure was added on the span that had the higher one-sided weight span for the MAX ICE weather condition to assist in balancing the weight spans on the subject structure. Mid-span structure heights were selected generally to provide the same suspension elevations as the subject tower to effectively reduce weight span and avoid uplift. The load combination file for the subject tower was output. Subject tower usage was calculated.
- If relevant for the subject tower position, a second mid-span structure was added on the other side of the subject tower to further reduce the wind and weight span. Subject tower usage was calculated.
- Finally, for comparison, the existing configuration load combination was run for a reinforced A1 tower.

### 3.1 S4-502 (2469)

Tower position S4-502 (2469) was chosen due to the presence of a significant ahead/back weight span imbalance with a ratio of approximately 1.63 for the 'Max ice' weather case. Weight span imbalances amplify unbalanced icing cases longitudinal loads relative to towers in a balanced ahead/back weight span condition.

This structure position does not have the electrode strung however it appears that when the A1 tower is used in this configuration, the span lengths are increased which causes higher loading locally in the peak. Tower type A1 peak failures have occurred in this configuration, see L3501/2 Failure Investigation (Doc No. ILK-EG-ED-6200-TL-H15-0006-01).

### 3.1.1 Wind and Weight Span

Table 2: Wind & Weight Span Comparison for S4-502 (2469)

Condition	Total Wind Span	Back Weight Span*	Ahead Weight Span*	Total Weight Span*
Existing	380 m	265 m	163 m	428 m
One mid-span structure	256 m	140 m	158 m	298 m
Change	-124 m (33%)	-125 m	-5 m	-130 m (30%)

\* Because maximum overstresses are in the peak, the OPGW weight spans are reported.

In the figure below, the blue catenaries represent the existing condition with no mid-span structures at 'Max ice' MAX SAG FE. The yellow catenaries represent the catenaries when one mid-span structure is added "S4-501A", also at 'Max ice' MAX SAG FE. The tick marks represent the low point on the conductor delineating the weight spans. A second mid-span structure was not considered because the ahead span is already short.

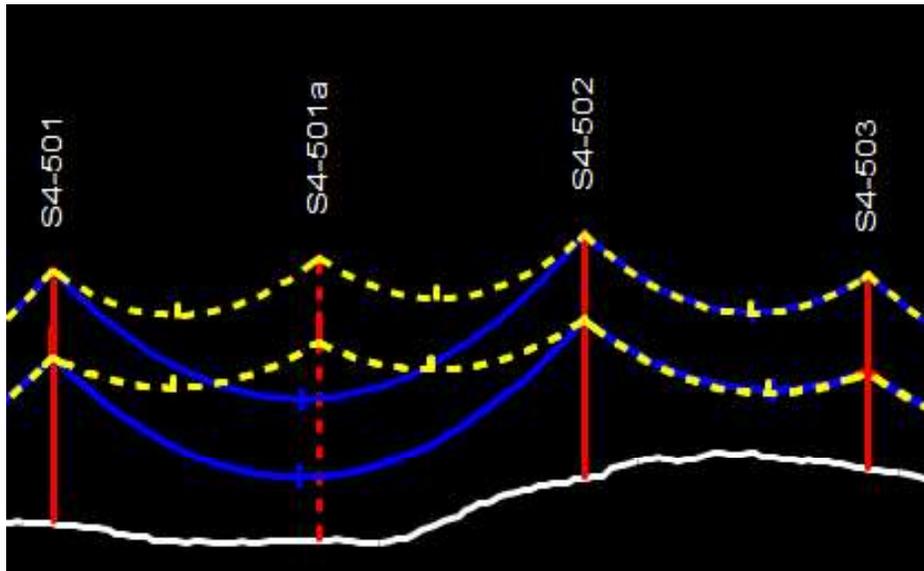


Figure 1: Profile for S4-502 (2469)

### 3.1.2 Maximum Structure Usage

Table 3: Maximum Structure Usage Comparison for S4-502 (2469)

Load Case	Existing		One Mid-Span Structure		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC70 AS UBI G 50mm 50/100%,C NA+	149.6	GW216YR	122.4	-27.2	94.3
F1 LC71 BS UBI G 50mm 50/100%,C NA+	145.9	GW214YR	119.7	-26.2	86.3
F1 LC75 BS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	107.3	GW210-212-5Y	83.1	-24.2	74.2
F1 LC72 AS UBI G 55mm 70/100%,C NA+	105.6	GW216YR	85.2	-20.4	69.6
F1 LC73 BS UBI G 55mm 70/100%,C NA+	103.0	GW214YR	83.5	-19.5	74.6

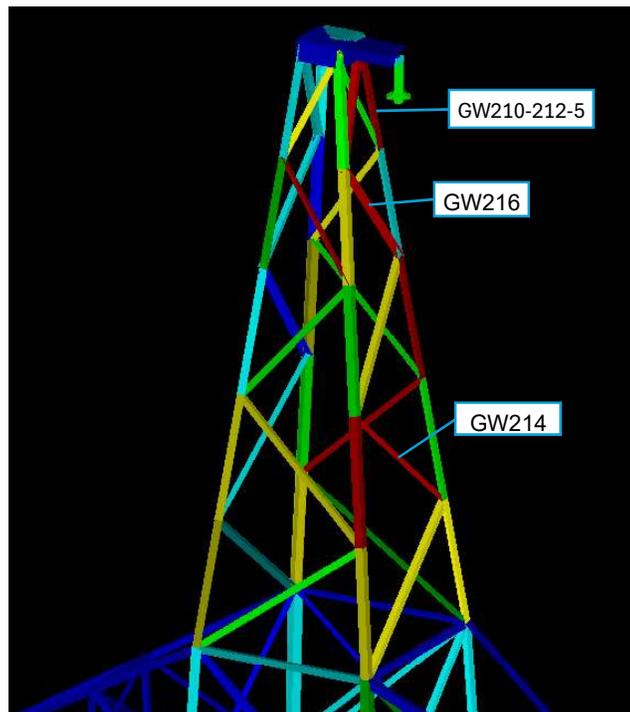


Figure 2: Overstressed Members Element Labels (No Electrode)

The existing configuration applied loads shows overstressed members in the peak, both braces and legs, as shown in Figure 2. All overstressed load cases are for unbalanced ice loading on the OPGW. All overstressed load cases are the additional load cases presented in the RFP. The mid-span structure addition provides significant reduction of the governing maximum overstress, remediating some cases but not all of them. The reinforced A1 tower does not experience any overstresses.

### 3.1.3 Discussion

The introduction of a mid-span tower between S4-501 (2468) and S4-502 (2469) provides significant reduction to the wind and weight spans for icing cases however does not address all structural overstresses in the peak members for the loading conditions considered. Some reinforcing of S4-502 (2469) would still be required to address all overstresses. Also, the mid-span position of tower S4-501A coincides with a wet low-lying area which would require significant construction costs to install.

The reinforced A1 tower in the position of S4-502 (2469) does not incur any structural overstresses for the load cases considered. Reinforcing S4-502 (2469) only would be more economical than the installation of mid-span structure S4-501A with reduced reinforcing of S4-502 (2469).

## 3.2 S4-576 (2543)

Tower position S4-576 (2543) was chosen due to long weight spans on both sides of the tower, as shown in Table 4. To avoid weight spans imbalance, it was decided to add two mid-span structures; one in the back span (BS) and one in the ahead span (AS). The presence of long weight ahead and back spans creates a high vertical load during ice weather cases. Although this tower does not have electrodes strung, local peak failures were observed during ice events.

### 3.2.1 Wind and Weight Span

Table 4: Wind & Weight Span Comparison for S4-576 (2543)

Condition	Total Wind Span	Back Weight Span*	Ahead Weight Span*	Total Weight Span*
Existing	478 m	274 m	234 m	508 m
One mid-span structure	365 m	156 m	235 m	391 m
Two mid-span structures (AS & BS)	239 m	155 m	126 m	281 m
Change (1 Structure)	-113 m (24%)	-118 m	-1 m	-117 m (23%)
Change (2 Structures)	-239 m (50%)	-119 m	-108 m	-227 m (45%)

\* Because maximum overstresses are in the peak, the OPGW weight spans are reported.

In Figure 3, the blue catenaries represent the existing condition with no mid-span structures. The yellow dotted catenaries represent the catenaries when one structure is added at the back span, while the red catenaries are for 2 mid-span structures added (one AS and one BS). All catenaries are shown at 'Max ice' MAX SAG FE.

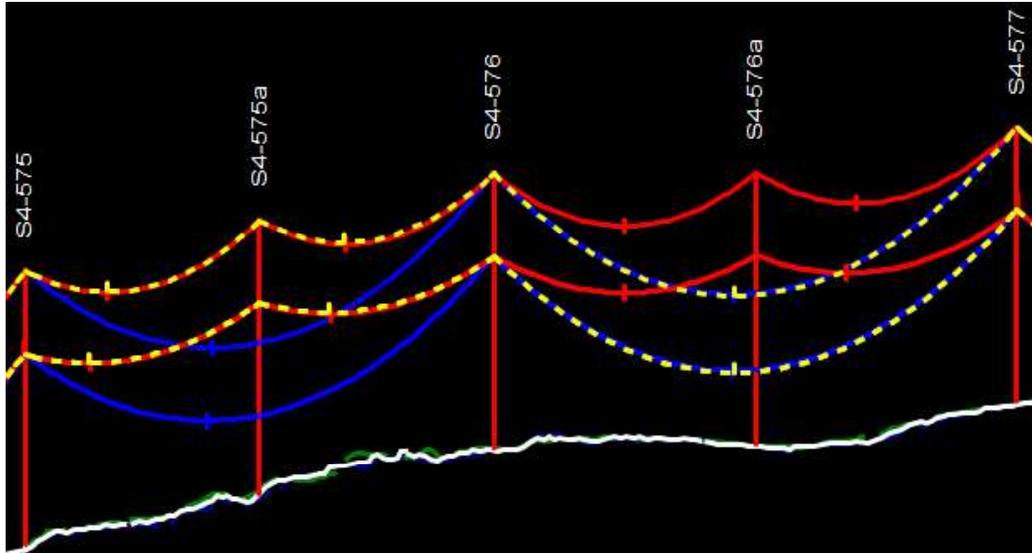


Figure 3: Profile for S4-576 (2543)

### 3.2.2 Maximum Structure Usage

Table 5: Maximum Structure Usage Comparison for S4-576 (2543)

Load Case	Existing		One Mid-Span Structure		Two Mid-Span Structures		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC70 AS UBI G 50mm 50/100%,C NA+	158.9	GW216YR	154.6	-4.3	149.3	-9.6	100.2*
F1 LC71 BS UBI G 50mm 50/100%,C NA+	155.2	GW214YR	151.6	-3.6	146.1	-9.1	92.8
F1 LC75 BS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	124.1	GW210- 212-5Y	110.4	-13.7	97.0	-27.1	83.4
F1 LC72 AS UBI G 55mm 70/100%,C NA+	112.8	GW216YR	109.5	-3.3	105.4	-7.4	79.8
F1 LC73 BS UBI G 55mm 70/100%,C NA+	110.1	GW214YR	107.3	-2.8	103.1	-7.0	78.7
F1 LC74 AS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	106.6	GW216YR	103.2	-3.4	99.0	-7.6	87.6

\* Reinforced model overstresses are discussed in section 3.7.

Similar to tower S4-502 (2469), the existing configuration shows overstressed members in the peak, both braces and legs. The overstressed members are labelled in Table 5 and shown in Figure 2.

The overstressed members in the S4-502 (2469) tower configuration are the same as those in the S4-576 (2543) configuration, and they are all for unbalanced ice loading on the OPGW (i.e., additional load cases in the RFP).

### 3.2.3 Discussion

As shown in Table 5, adding one mid-span structure only does not address the peak members over stresses. This is due to the unbalanced weight spans that were introduced when only one mid-span structure was added (i.e., imbalance over-usages). Also, adding two mid-span structures (AS and BS) addressed the over stresses in only 2 unbalanced ice loading cases but not for all of cases. Tower A1 in the configuration of S4-576 (2543) would still need reinforcement after adding the 2 mid-span structures. This scenario will be encountered in any 2 long spans at both sides of any tower with a relatively close wind/weight ratio. This would make the solution of adding two towers, one from each side, not practical because it will lead to the addition of multiple new towers along the line. The reinforced tower shows very minor over stresses which are discussed in section 3.7.

## 3.3 S4-598 (2565)

Tower S4-598 (2565) has no electrodes strung, and it was chosen due to its location on a downhill with increasing stationing, which causes high longitudinal loads due to the weight span imbalance with a ratio of approximately 2.4 for the 'Max ice' weather case. Similar to towers S4-502 (2469) and S4-576 (2543), local peak failures were observed during unbalanced ice weather cases.

### 3.3.1 Wind and Weight Span

Table 6: Wind & Weight Span Comparison for S4-598 (2565)

Condition	Total Wind Span	Back Weight Span*	Ahead Weight Span*	Total Weight Span*
Existing	392 m	153 m	368 m	521 m
One mid-span structure	316 m	154 m	238 m	392 m
Change	-76 m (19%)	1 m	-130 m	-129 m (25%)

\* Because maximum over stresses are in the peak, the OPGW weight spans are reported.

In Figure 4, the blue catenaries represent the existing condition with no mid-span structures. The yellow dotted catenaries represent the catenaries when one structure is added at the ahead span. All catenaries are shown at 'Max ice' MAX SAG FE.

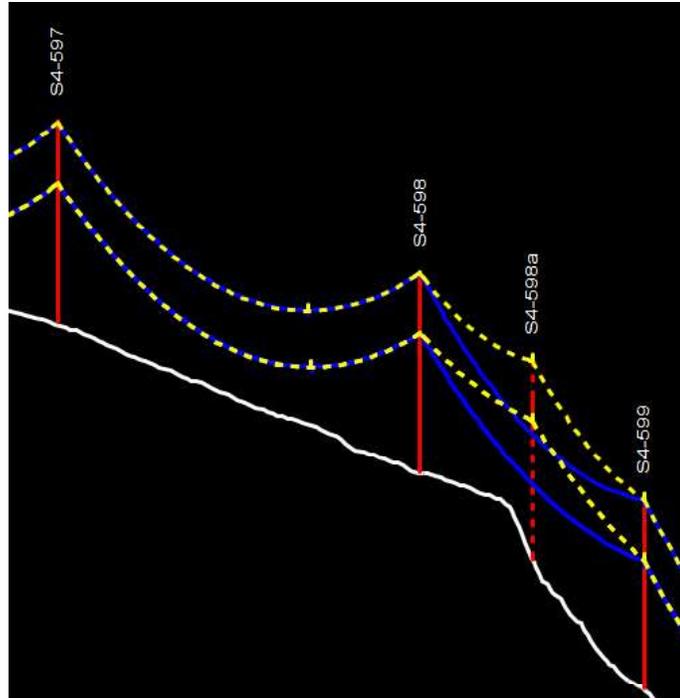


Figure 4: Profile for S4-598 (2565)

### 3.3.2 Maximum Structure Usage

Table 7: Maximum Structure Usage Comparison for S4-598 (2565)

Load Case	Existing		One Mid-Span Structure		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC70 AS UBI G 50mm 50/100%,C NA+	151.6	GW216YR	148.1	-3.5	95.0
F1 LC71 BS UBI G 50mm 50/100%,C NA+	148.6	GW214YR	144.9	-3.7	90.6
F1 LC75 BS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	123.5	GW210-212-5Y	103.8	-19.7	83.8
F1 LC72 AS UBI G 55mm 70/100%,C NA+	107.4	GW216YR	104.6	-2.8	80.8
F1 LC73 BS UBI G 55mm 70/100%,C NA+	105.1	GW214YR	102.3	-2.8	80.9
F1 LC74 AS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	101.5	GW216YR	98.6	-2.9	84.0

Similar to towers S4-502 (2469) and S4-576 (2543), local overstresses in the peak braces and legs were observed during the new unbalanced ice loading conditions, as shown in Figure 2.

### 3.3.3 Discussion

As shown in Table 7, adding one mid-span structure decreases the peak braces and legs overstresses, however, members reinforcement would still be required. The addition of the mid-span structure in this scenario of the line running downhill is not very effective based on the weight span reduction and member overstress reduction presented. Spotting this mid-span structure reduces the weight span imbalance of the subject structure but creates an imbalance on the mid-span structure itself and the following downhill structure S4-599. For these reasons, a mid-span structure in this scenario is not practical. Reinforcing the existing tower does not show any overstresses as shown in Table 7.

## 3.4 S1-318 (319)

Tower position S1-318 (319) was chosen due to the long wind spans as well as weight spans on both sides of the tower with electrode wires strung. This tower configuration induces high transverse loads during wind events and vertical loads during ice events. Due to the long spans, adding one mid-span structure on one side of the tower will cause weight spans imbalance and increase longitudinal loads. For this reason, it was decided to add 2 mid-span structures (AS and BS). In the current tower A1 configuration, local peak diagonals and legs, electrode cross arms, cage bracing overstresses have been observed.

### 3.4.1 Wind and Weight Span

Overstresses are observed in the peak, electrode cross-arms, and the cage above the pole compression chord connection, therefore the OPGW and electrode loads are most relevant. The OPGW and electrode wind & weight spans were found to be similar so only the OPGW is presented.

Table 8: OPGW Wind & Weight Span Comparison for S1-318 (319)

Condition	Total Wind Span	Back Weight Span*	Ahead Weight Span*	Total Weight Span*
Existing	419 m	252 m	232 m	484 m
One mid-span structure	305 m	250 m	108 m	358 m
Two mid-span structures (AS & BS)	209 m	129 m	109 m	238 m
Change (1 Structure)	-114 m (27%)	-2 m	-124 m	-126 m (26%)
Change (2 Structures)	-210 m (50%)	-123 m	-123 m	-246 m (51%)

In Figure 5, the blue catenaries represent the existing condition with no mid-span structures. The yellow dotted catenaries represent the catenaries when one structure is added at the ahead span, while the red catenaries represent the catenaries when two mid-span structures are added (AS and BS). All catenaries are shown at 'Max ice' MAX SAG FE.

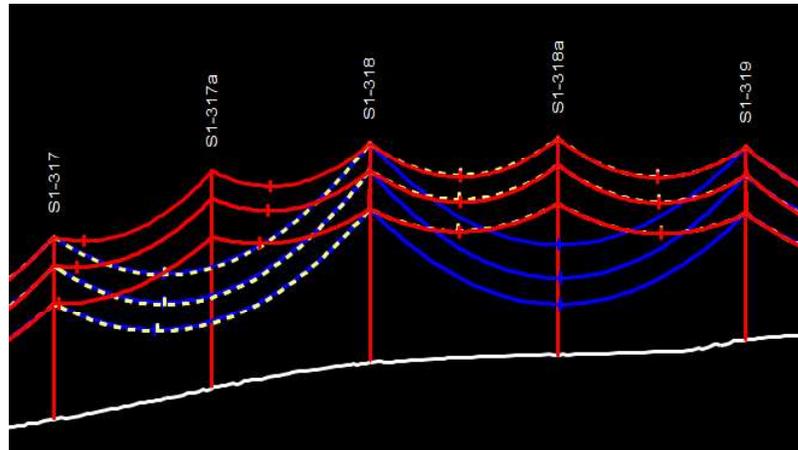


Figure 5: Profile for S1-318 (319)

### 3.4.2 Maximum Structure Usage

Table 9: Maximum Structure Usage Comparison for S1-318 (319)

Load Case	Existing		One Mid-Span Structure		Two Mid-Span Structures		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC70 AS UBI G 50mm 50/100%,C NA+	142.1	GW216YR	136.9	-5.2	133.1	-9.0	89.7
F1 LC71 BS UBI G 50mm 50/100%,C NA+	137.8	GW214YR	132.7	-5.1	129.8	-8.0	87.4
F1 LC75 BS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	131.8	EA188-189-2X	98.5	-33.3	85.3	-46.5	98.6
F1 LC74 AS UBI G 70mm (50 mm on Pole) 100/80%,C NA+	131.6	EA188-189-2XY	98.3	-33.3	87.6	-44.0	98.6
F1 LC76 Ice Load 70mm (50 mm on Pole),C NA+	128.9	EA188-189-2Y	95.8	-33.1	73.1	-55.8	93.0
F1 LC66 AS UBI EL2 63mm 70/100%,C NA+	120.0	EA188-189-2Y	104.2	-15.8	82.1	-37.9	95.4
F1 LC67 BS UBI EL1 63mm 70/100%,C NA+	119.9	EA188-189-2X	95.8	-24.1	81.3	-38.6	93.9
F1 LC65 AS UBI EL1 63mm 70/100%,C NA+	119.8	EA188-189-2XY	104.0	-15.8	82.1	-37.7	93.9
F1 LC68 BS UBI EL2 63mm 70/100%,C NA+	119.6	EA188-189-2P	95.7	-23.9	81.2	-38.4	95.4

LIL Strengthening Overview, Appendix B

LIL Engineering Study – Mid-Span Structure Addition Report

Newfoundland and Labrador Hydro

Load Case	Existing		One Mid-Span Structure		Two Mid-Span Structures		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC69 Ice Load 63mm,C NA+	<b>111.0</b>	EA188-189-2Y	82.6	-28.4	68.1	-42.9	88.3
F1 LC24 BR E1 + P1 D,C NA+	<b>109.2</b>	CG92-93P	<b>109.9</b>	0.7	<b>107.5</b>	-1.7	99.0
F1 LC25 BR E2 + P2 D,C NA+	<b>108.9</b>	CG92-93X	<b>109.7</b>	0.8	<b>107.4</b>	-1.5	99.0
F1 back LC24 BR E1 + P1 D,C NA+	<b>107.4</b>	CG92-93Y	<b>104.9</b>	-2.5	<b>106.1</b>	-1.3	99.0
F1 back LC25 BR E2 + P2 D,C NA+	<b>107.1</b>	CG92-93XY	<b>104.7</b>	-2.4	<b>105.9</b>	-1.2	99.0
F1 LC72 AS UBI G 55mm 70/100%,C NA+	<b>100.4</b>	GW216YR	96.3	-4.1	93.3	-7.1	81.9

The existing configuration shows overstressed members in the peak, electrode cross arms, and cage diagonals, as shown in Figure 6. Overstressed load cases are for unbalanced ice loading on the OPGW and electrodes, heavy ice event, or electrodes broken wire scenario. Although adding mid-span structures will reduce overstresses, reinforcement will still be required. No overstresses were observed with the reinforced A1 tower.

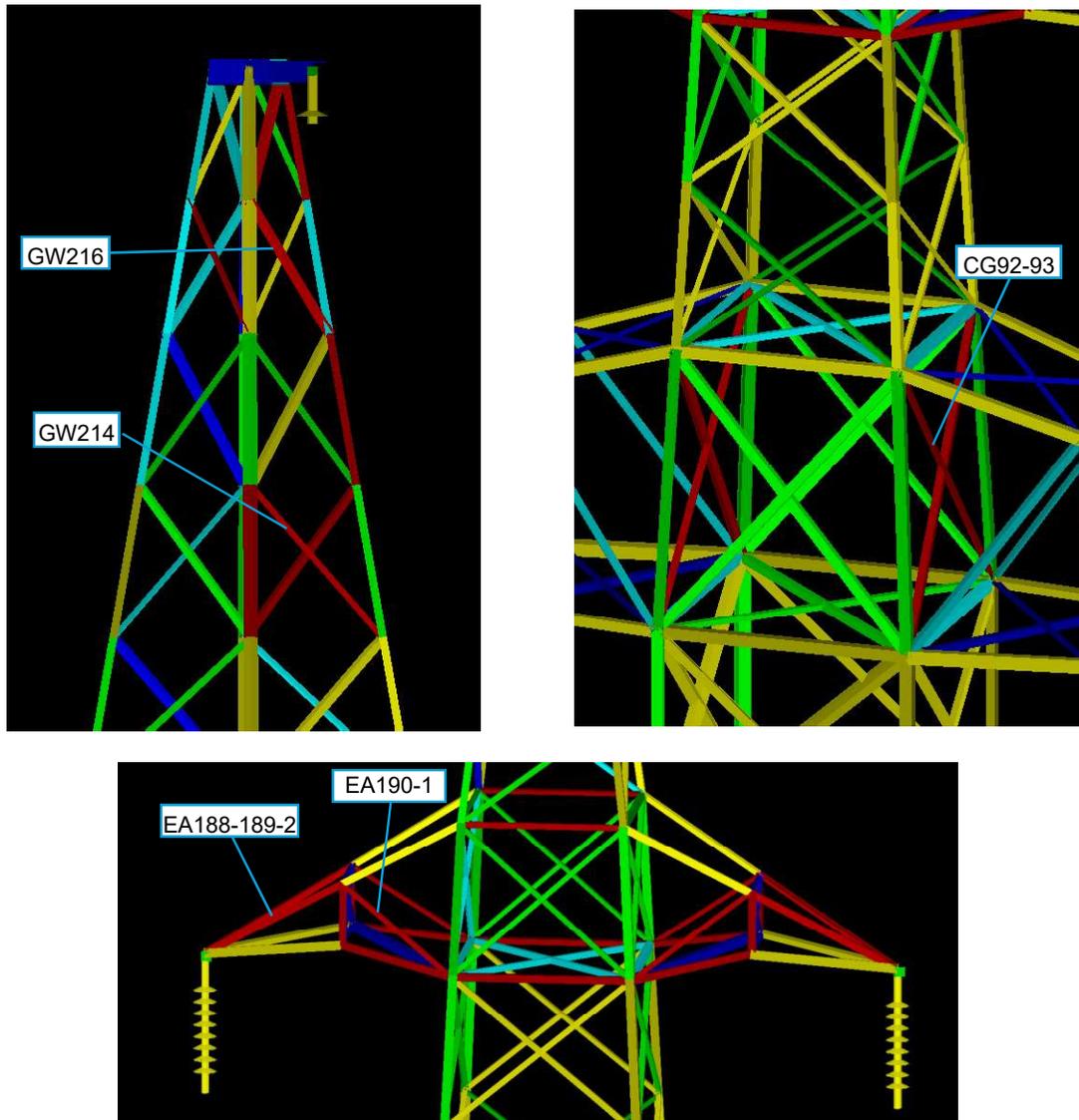


Figure 6: Overstressed Members Element Labels (Electrode Strung)

### 3.4.3 Discussion

Adding one or two mid-span structures will reduce tower S1-318 (319) overstresses. Reinforcing of overstressed members will still be required. This makes the mid-span structure addition not an economical solution in this scenario. Hence, existing tower reinforcement is a better approach.

## 3.5 S1-370 (371)

Tower S1-370 (371) has electrode wires strung, with a weight span imbalance ratio of approximately 2.4 for the 'Max ice' weather case. These conditions increase longitudinal loads during an ice event. A possible solution to fix imbalance is the addition of a new mid-span structure at the ahead span. However, the suggested new tower will be in a location where the terrain is lower than the adjacent towers, making it challenging to spot the new tower without experiencing significant uplift conditions.

### 3.5.1 Wind and Weight Span

Similar to tower S1-318 (319), the OPGW and electrode wind & weight spans were found to be similar so only the OPGW is presented.

Table 10: OPGW Wind & Weight Span Comparison for S1-370 (371)

Condition	Total Wind Span	Back Weight Span*	Ahead Weight Span*	Total Weight Span*
Existing	392 m	112 m	298 m	410 m
One mid-span structure	273 m	114 m	204 m	318 m
Change (1 Structure)	-119 m (30%)	2 m	-94 m	-92 m (22%)

Note that the added mid-span structure S1-370a is the tallest A1 extension (+18 m) available and only achieves a weight span reduction of 92 m. The weight span ratio is only reduced from 2.4 to a minimum of 1.8 because of the topography of the span.

In Figure 7, the blue catenaries represent the existing condition with no mid-span structures, while the yellow dotted catenaries represent the catenaries when one structure is added at the ahead span. catenaries are shown at 'Max ice' MAX SAG FE.

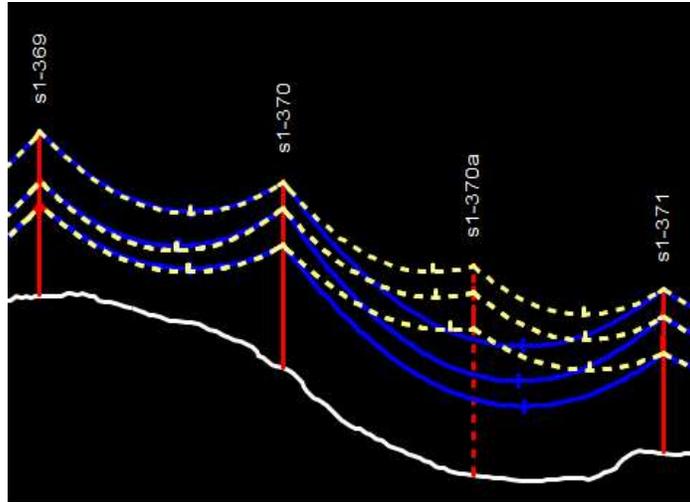


Figure 7: Profile for S1-370 (371)

### 3.5.2 Maximum Structure Usage

Table 11: Maximum Structure Usage Comparison for S1-370 (371)

Load Case	Existing		One Mid-Span Structure		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC70 AS UBI G 50mm 50/100%,C NA+	140.1	GW216YR	133.0	-7.1	84.7
F1 LC71 BS UBI G 50mm 50/100%,C NA+	136.5	GW214YR	129.5	-7.0	84.4
F1 LC75 BS UBI G 70mm (50 mm on Pole) 100/80%, C NA+	118.2	EA188-189-2X	91.5	-26.7	90.0
F1 LC74 AS UBI G 70mm (50 mm on Pole) 100/80%, C NA+	118.0	EA188-189-2XY	91.3	-26.7	89.3
F1 LC67 BS UBI EL1 63mm 70/100%,C NA+	116.0	EA190-1Y	97.4	-18.6	86.1
F1 LC68 BS UBI EL2 63mm 70/100%,C NA+	115.9	EA190-1XY	97.3	-18.6	87.1
F1 LC76 Ice Load 70mm (50 mm on Pole),C NA+	115.4	EA188-189-2Y	89.0	-26.4	83.9
F1 back LC24 BR E1 + P1 D,C NA+	110.3	CG92-93Y	109.1	-1.2	99.1
F1 back LC25 BR E2 + P2 D,C NA+	110.0	CG92-93XY	108.9	-1.1	99.1
F1 LC66 AS UBI EL2 63mm 70/100%,C NA+	108.1	EA190-1X	96.0	-12.1	86.9

Load Case	Existing		One Mid-Span Structure		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC65 AS UBI EL1 63mm 70/100%,C NA+	107.8	EA190-1P	95.8	-12.0	85.6
F1 LC24 BR E1 + P1 D,C NA+	103.9	CG92-93P	104.2	0.3	99.1
F1 LC25 BR E2 + P2 D,C NA+	103.6	CG92-93X	104.0	0.4	99.1

The existing configuration shows overstressed members in the peak, electrode cross arms, and cage diagonals as shown in Figure 6. All failures occurred during unbalanced conditions, either unbalanced iced or broken electrodes wire scenario. This is due to the weight span imbalance ratio. Adding a mid-span structure will address some overstresses but not all of them as shown in Table 11.

### 3.5.3 Discussion

Adding one mid-span structure will reduce tower S1-370 (371) overstresses, but does not eliminate all of them. Reinforcing of overstressed members will still be required. Due to the topography at the new mid-span structure location, even the tallest extension does not balance the ahead and back weight spans. Reinforcing the existing S1-370 (371) tower is a more feasible and reliable solution in this scenario.

## 3.6 S1-307 (308)

Tower S1-307 (308) has a large span imbalance due to both AS and BS running uphill relative to increasing stationing. This tower configuration shows local peak overstresses, in addition to overstresses in the electrode cross arms (due to the electrode wires tension) as well as cage diagonal overstresses.

### 3.6.1 Wind and Weight Span

Similar to tower S1-318 (319), the OPGW and electrode wind & weight spans were found to be similar so only the OPGW is presented.

Table 12: OPGW Wind & Weight Span Comparison for S1-307 (308)

Condition	Total Wind Span	Back Weight Span*	Ahead Weight Span*	Total Weight Span*
Existing	337 m	265 m	56 m	321 m
One mid-span structure	225 m	151 m	57 m	208 m
Change (1 Structure)	-112 m (33%)	-114 m	1 m	-113 m (35%)

In Figure 8, the blue catenaries represent the existing condition with no mid-span structures. The yellow dotted catenaries represent the catenaries when one structure is added at the ahead span. All catenaries are shown at 'Max ice' MAX SAG FE.

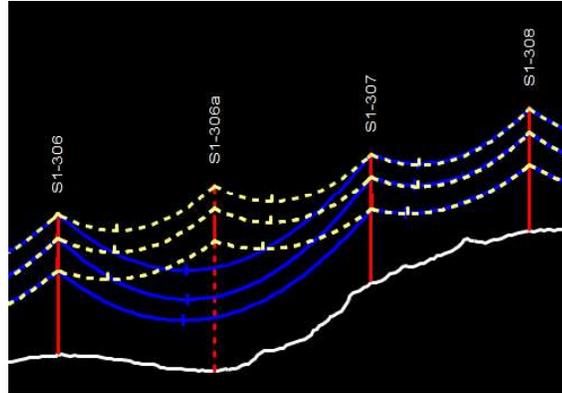


Figure 8: Profile for S1-307 (308)

### 3.6.2 Maximum Structure Usage

Table 13: Maximum Structure Usage Comparison for S1-307 (308)

Load Case	Existing		One Mid-Span Structure		Reinforcing Existing Tower
	Maximum Usage %	Element Label	Maximum Usage %	Maximum Usage Difference	Maximum Usage %
F1 LC70 AS UBI G 50mm 50/100%,C NA+	142.3	GW216YR	136.3	-6	87.9
F1 LC71 BS UBI G 50mm 50/100%,C NA+	138.0	GW214YR	132.8	-5.2	81.4
F1 LC24 BR E1 + P1 D,C NA+	111.8	CG92-93P	109.5	-2.3	101.9*
F1 LC25 BR E2 + P2 D,C NA+	111.6	CG92-93X	109.4	-2.2	101.9*
F1 back LC24 BR E1 + P1 D,C NA+	104.5	CG92-93Y	105.0	0.5	102.3*
F1 back LC25 BR E2 + P2 D,C NA+	104.4	CG92-93XY	104.9	0.5	102.3*
F1 LC66 AS UBI EL2 63mm 70/100%,C NA+	104.3	EA190-1X	82.2	-22.1	75.0
F1 LC65 AS UBI EL1 63mm 70/100%,C NA+	104.1	EA190-1P	82.1	-22	74.1
F1 LC72 AS UBI G 55mm 70/100%,C NA+	100.1	GW216YR	95.6	-4.5	74.6

\* Reinforced model overstresses will be discussed in section 3.7.

The existing configuration shows local peak overstresses in braces and legs, in addition to electrode cross arms and cage overstresses. The longitudinal loads caused by the large weight span imbalance has led to overstresses in unbalanced ice load cases as well as electrodes and OPGW broken wire cases.

### 3.6.3 Discussion

As shown in Table 13, adding a mid-span structure will slightly improve weight imbalance, but it won't be enough to avoid overstresses. This is due to the land topography at this section (towers running uphill), which introduced the weight imbalance. For this reason, reinforcing the existing tower is considered a more practical solution.

## 3.7 REINFORCED MODEL OVERSTRESSES

### 3.7.1 Tower S4-576 (2543) Reinforced Model Overstresses

As shown in Table 5, the reinforced model shows overstresses with a ratio of 100.2%. This scenario is encountered if no mid-span structures are added and only reinforcing of the existing tower A1 is implemented. The overstresses are seen due to the discrepancy between the envelope load cases provided for tower A1 reinforcement scope and the as built load cases obtained from PLS CADD. As shown in Figure 9, overstresses are seen in one of the peak diagonals (GW217).

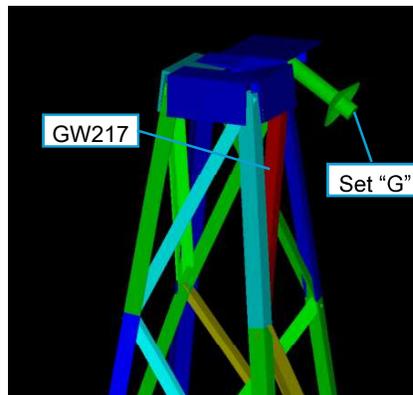


Figure 9: Reinforced Overstressed Member Element for S4-576 (2543)

Table 14 below shows a comparison between as built forces obtained from PLS CADD during this mid-span tower addition scope and envelope forces obtained from NL hydro for tower A1 reinforcement scope. The comparison is made for the governing load case (F1 LC70 AS UBI G 50mm 50/100%,C NA+). This load case is one of the new additional load cases provided by NL Hydro. The difference between the as-built forces and the envelope forces is shown below (negative indicates as-built loads exceeding the envelope loads). The increase in vertical load for the as-built condition is causing a higher axial force in member GW217 resulting in the minor overstress of 100.2%.

Table 14: Load Cases Comparison for S4-576 (2543) (As built VS Envelope Loads)

LCA/Set name	Load direction	Envelope forces (kN)	As built forces (kN)	Difference (kN)
G	V (Vertical)	31.2	34.7	-3.5
	T (Transverse)	-0.2	0	-0.2
	L (Longitudinal)	52.9	52.1	0.8

### 3.7.2 Tower S1-307 (308) Reinforced Model Overstresses

As shown in Table 13, the reinforced model shows overstress with a ratio of 102.3%. Similar to tower S4-576 (2543), the overstresses are seen due to the discrepancy between the envelope load cases and the as built load cases. Figure 11 shows the overstress occurs in the upper chord of the guy cross arm (GA136-137-2).

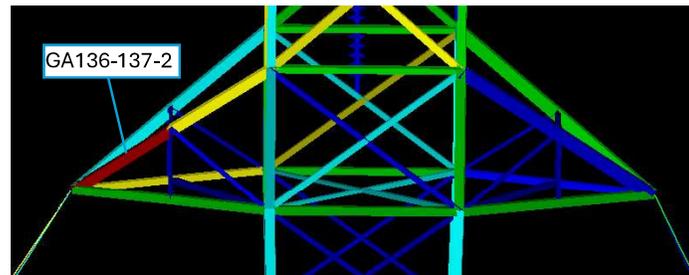


Figure 10: Reinforced Overstressed Member Element for S1-307 (308)

Similar to S4-576 (2543), the comparison between envelope and as built forces for all sets are shown in Table 15 below. The governing load case (F1 back LC25 BR E2 + P2 D,C NA+) causing overstresses is a broken wire scenario for sets E2 and P2 (electrode and pole wires respectively). As seen in the table, envelope forces are generally higher than as built forces (positive values), except for longitudinal loads of sets E2 and P2 (highlighted in grey). These increased loads are translated to overturning moments and torque on the cage, which is resisted by the guy cross arms, causing the overstress.

Table 15: Load Cases Comparison for S1-307 (308) (As built VS Envelope Loads)

LCA/Set name	Load direction	Envelope forces (N)	As built forces (N)	Difference (kN)
P1	V (Vertical)	29.2	21.6	7.6
	T (Transverse)	1.3	0.0	1.3
	L (Longitudinal)	0.0	0.0	0.0
P2	V (Vertical)	16.2	3.9	12.3
	T (Transverse)	1.0	0.0	1.0
	<b>L (Longitudinal)</b>	<b>-111.5</b>	<b>-112.9</b>	<b>-1.4</b>
E1	V (Vertical)	10.9	7.6	3.3
	T (Transverse)	0.6	0.0	0.6
	L (Longitudinal)	0.0	0.0	0.0
E2	V (Vertical)	10.9	1.3	9.6
	T (Transverse)	0.4	0	0.4
	<b>L (Longitudinal)</b>	<b>-24.0</b>	<b>-32.1</b>	<b>-8.1</b>
GP	V (Vertical)	3.8	2.4	1.4
	T (Transverse)	0.3	0.0	0.3
	L (Longitudinal)	0.0	0.0	0.0

## 4.0 CONCLUSIONS

The introduction of mid-span structures can effectively reduce the wind and weight spans and therefore the applied loads. The weight span imbalance may be improved to reduce longitudinal loads. For the structures studied, this reduction was not sufficient to address structural overstresses caused by the additional load cases in the RFP. The mid-span structure addition may allow for study structures to have reduced reinforcing effort, but some reinforcing is still required to address all structural overstresses. The position of mid-span structures may incur high construction costs due to wet low-lying areas or require tall extensions.

Reinforcing the A1 structures addressed structural overstresses in most studied structures, except for some cases where there were discrepancies between as built PLS CADD loads and envelope loads. Some reinforcing scope may not be required for a given structure location but would have to be inspected on a case-by-case basis.

In brief, it is more economical to reinforce the A1 structures than to add mid-span structures.

# Appendix C

## LIL Engineering Study – A1 Electrode Suspension Assembly





# LIL Engineering Study – A1 Electrode Suspension Assembly

Newfoundland and Labrador Hydro Report No. ILK-TT-CD-6200-TL-H15-0001-01  
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## APPENDICES

**APPENDIX A: GALLOPING ELLIPSE RESULTS**

**APPENDIX B: NEW HARDWARE CUTSHEETS**

**APPENDIX C: NEW HARDWARE DRAWINGS**

## 1.0 INTRODUCTION

NL Hydro has experienced several performance issues with the electrodes that are mounted on the same towers as the pole conductors (tower type A1) for the Labrador-Island Transmission Link, +/- 350 kV HVDC. Electrode performance issues include the following:

- Conductor failure
- Insulator units contacting conductor under longitudinal loading
- Cross-arm structural failure
- Suspension clamp slippage

This technical memo discusses potential improvements to address the performance issues identified. The challenges for available approaches are discussed and two recommendations are presented, one with minimal cost and effort to address the top priority improvements, and a second that requires more field work but will improve additional performance issues.

## 2.0 WORK COMPLETED TO DATE

Extensive study of the performance issues has previously been completed by NL Hydro and the root cause of most of the issues is that the line has experienced weather loading events that exceeded the initial design assumptions. The performance issues are caused by electrode suspension longitudinal loading during icing events whether through weight span imbalance, unbalanced ice accumulation, or unbalanced shedding. The following reports describe the performance issues.

- Failure Investigation Report – L3501/2 Tower and Conductor Damage (2021)
- L3501/2 Failure Investigation – Ice Storm Southern Labrador (2024)

## 3.0 PERMISSIBLE LENGTH INCREASE

The length that the electrode suspension insulator string can be increased is dependent on the required electrical clearances, minimum separations to pole conductors, and existing tower geometry. The main inputs are the electrical clearance drawing ILK-JY-SD-6200-TL-D99-0012-01-A3 and the design requirements drawing ILK-SN-CD-6200-TL-DD-0112-01-C4. The values in the drawing are inspected for accuracy and as-built conditions to maximize improvement in the following sections.

The tower ranges (final tower numbers) inspected for as-built conditions are from the PLS-CADD models provided by NL Hydro on January 15, 2025. Only tower types A1 where electrode is present were considered. The following ranges do not represent all of the A1 towers, they cover areas where damage has occurred, but the total number of tower type A1 positions of 239 is assumed to be a representative sample.

- 244-340
- 342-388
- 499-596
- 1210-1228

### 3.1 EXISTING INSULATION LENGTH (ELECTRODE AND POLE)

The electrode insulator length on the tower type A1 electrical clearance drawing ILK-JY-SD-6200-TL-D99-0012-01-A3 is listed as 1245 mm from string attachment point on tower to center of conductor. This matches what is in the existing PLS-TOWER models in the PLS-CADD line models. The same value from the suspension insulator assembly drawing ILK-SI-SD-6200-TL-D04-0016-01-C3 however is 1133 mm. The electrode insulator length of 1133 mm has more dimensional certainty and is used in this report.

The pole insulator length on the tower type A1 electrical clearance drawing ILK-JY-SD-6200-TL-D99-0012-01-A3 is listed as 6065 mm from string attachment point on tower to center of conductor. The existing PLS-TOWER models in the PLS-CADD line models however have a pole insulator length of 5757 mm. Furthermore, the insulator assembly drawing ILK-SI-SD-6200-TL-D04-0007-01-C4 has a value of 5562 for the same value (from table, tower family zones F1, F3, F4, F5). The pole insulator length of 5562 mm has more dimensional certainty and is used in this report.

### 3.2 ELECTRODE CONDUCTOR DROP

The electrode conductor drop on the tower type A1 electrical clearance drawing ILK-JY-SD-6200-TL-D99-0012-01-A3 is listed as 270 mm. This value is dependent on the vertical departure angle and describes decreased electrical clearance due to the conductor descending from the suspension clamp elevation before surpassing the tower width. The distribution of as-built occurrences of vertical departure angle for a condition of 0°C, no ice, no wind, max sag FE is shown in Figure 1 below.

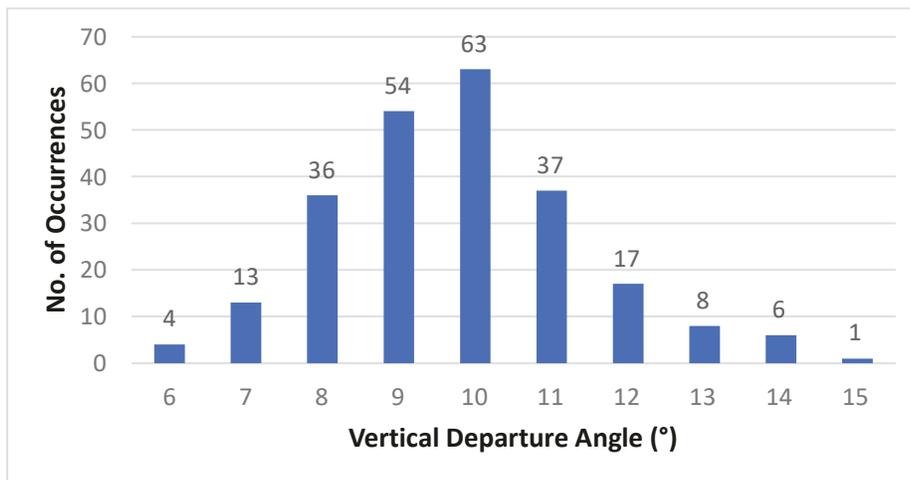


Figure 1: Vertical Departure Angles

The maximum vertical departure angle considered in this report is 14°. Note that the single occurrence of 15° may be neglected because a high vertical departure angle is not coincident with a high transverse swing angle. This is because a high vertical departure angle is correlated to a large weight span which will limit the transverse swing angle. As per Figure 2 below, the as-built conductor drop will be considered as 200 mm.

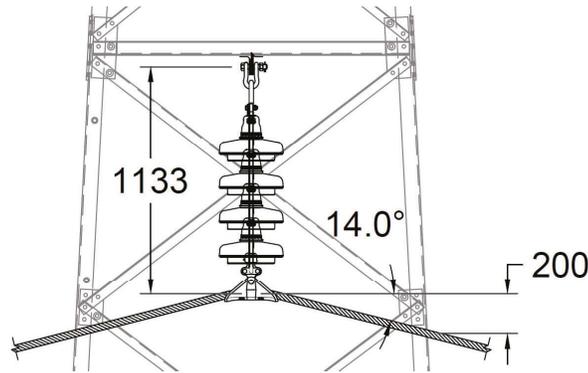


Figure 2: Conductor Drop

### 3.3 TRANSVERSE SWING UNDER MAXIMUM WIND SWING

The transverse swing angle on the tower type A1 electrical clearance drawing ILK-JY-SD-6200-TL-D99-0012-01-A3 is listed as 70°. The distribution of as-built transverse swing angles under maximum wind swing condition is presented in below in Figure 3.



Figure 3: Transverse Swing Angles

Both improvement options rely on a reduced maximum transverse swing angle. Improvement option 1 can accommodate a transverse swing angle of 67° before violating electrical clearance to the cage. Improvement option 2 can withstand a transverse swingle of 66° before violating electrical clearance to the bottom of a new straight bottom cross-arm chord.

Towers positions that exceed this maximum 66° transverse swing angle could be brought below the maximum with the addition of conductor weights. The preferred style of conductor weight to avoid interfacing with existing hardware and limit impacts on electrical clearance is Maclean Power Systems (MPS) HDW-100-SS, see Figure 4. Weight should be placed close to the suspension clamp to avoid adding energized diameter to the conductor at the conductor drop position. Due to the limited cases where the swing limit is exceeded, this hardware detail is not considered in scope for the drawing deliverable.



Figure 4: MPS HDW-100-SS

### 3.4 VERTICAL AND HORIZONTAL SEPARATIONS TO POLE CONDUCTORS

Tower type A1 design requirements drawing ILK-SN-CD-6200-TL-DD-0112-01-C4 outlines the required separation between the electrode and the poles. The limitations are as follows:

- Horizontal separation of  $\geq 4.9$  m in static position
- Vertical separation of tower attachment points of  $\geq 4.8$  m

The limitations are assumed to be related to galloping ellipse clearance. The true requirement for the separations in this case is from the conductor attachment points rather than the tower attachment points. Given the geometry in the drawing, the equivalent required vertical separation to between the conductor attachment points is as follows:

$$D = 4800 - \text{electrode vang} - \text{electrode insulator length} + \text{pole vang} + \text{pole insulator length}$$

$$D = 4800 - 285 - 1245 + 120 + 6065 = 9455 \text{ mm}$$

Because the insulator attachment points are set at the limits of the design criteria drawing on the layout and the pole insulator strings are shorter than anticipated (see Section 3.1), the minimum vertical separation is already exceeded in the existing design. Lengthening of the electrode insulator will cause further violation of minimum vertical separation and any horizontal attachment point offset increase will cause violation. Due to these reasons the galloping ellipse clearance must be studied to ensure encroaching on these minimums is acceptable.

### 3.5 GALLOPING ELLIPSE CLEARANCES

The galloping ellipse method used for the transmission line design is described in the 350 kV HVdc LINE DESIGN CRITERIA, document number ILK-SN-CD-6200-TL-DC-0001-01, Appendix A. No results or reporting was available for the evaluation of that method, so the impact of the proposed attachment geometry and insulator length had to be studied because the electrode insulator string lengthening brings the electrode and pole ellipses closer together.

Because galloping ellipse amplitude is related to sag, the longest span length was studied, assumed to be conservatively representative of any span on the line. The maximum span length for tower type A1 with electrode strung was between towers 258 and 259 at 496 m. The pole insulator length identified in section 3.1 was used, the new electrode cross-arm shown in Figure 6 was used, and the insulator geometry shown in Figure 9 was used.

Refer to Appendix A for the results of the study. There is adequate separation from the electrode galloping ellipse to the pole galloping ellipse with the new cross-arm and electrode insulator string.

### 3.6 OPTION 1 PERMISSIBLE INCREASE

The permissible increase for option 1 was determined to be 295 mm governed by the maximum wind swing case with electrical clearance to the cage, see Figure 5. Note that the EDT (0°C, 0 Pa) limit at 11° transverse swing and the REDUCED WIND SWING (-20°C, 296 Pa) limit at 47° swing are not shown because the required electrical clearances are the same and are covered by the MAXIMUM WIND SWING (-20°C, 788 Pa) limit at 67°. See previous section for justification of reduction of transverse swing angle from 70°. Note that electrode shielding angle improves with additional insulator length.

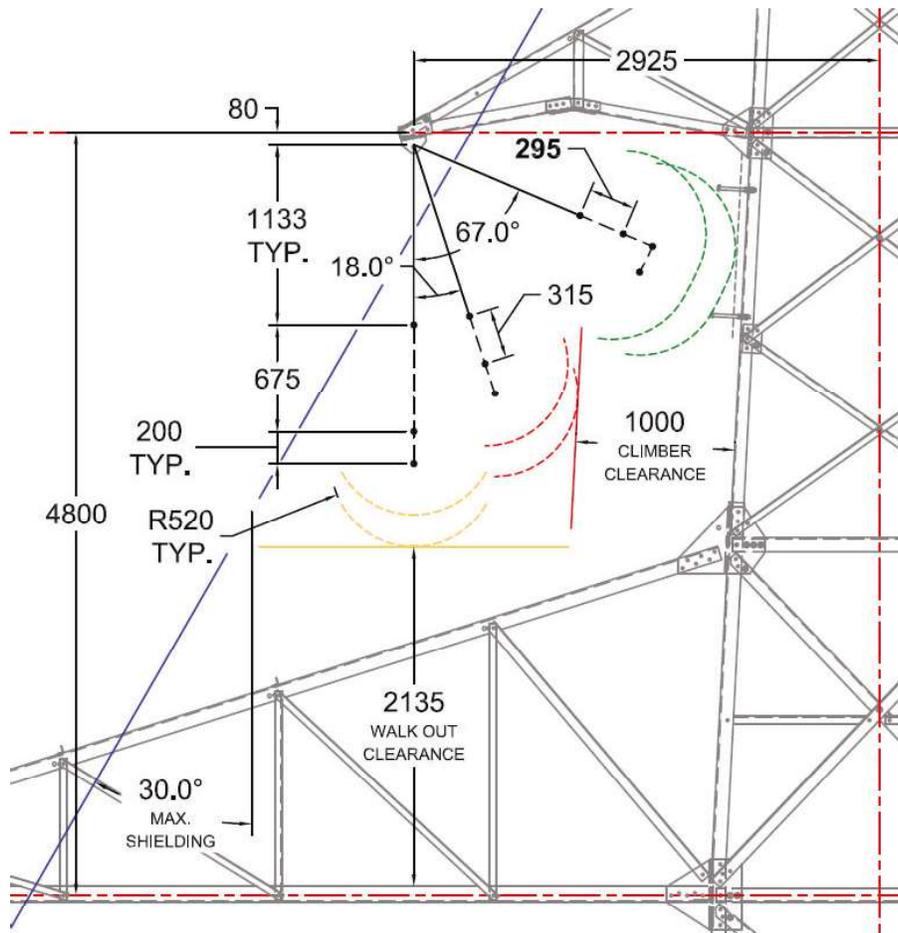


Figure 5: Option 1 Permissible Length Increase

### 3.7 OPTION 2 PERMISSIBLE INCREASE

The tower type A1 reinforcement scope showed significant overusages in most of the electrode cross-arm members that are not easily addressed with reinforcement. For this reason, it is more economical to design and construct a cross-arm replacement rather than implement reinforcements. An arm replacement offers the opportunity to improve several structural items identified in the *Failure Investigation Report – L3501/2 Tower and Conductor Damage* report, in addition to offering more insulator lengthening to balance longitudinal load. The insulator attachment offset from centerline increases from 2925 mm to 2985 mm, see the Option 2 design section for more details.

The permissible increase for option 2 after considering the new proposed arm geometry was determined to be 325 mm governed by the maximum wind swing case with electrical clearance to a climbing bolt. As with option 1, the EDT (0°C, 0 Pa) limit at 11° transverse swing and the REDUCED WIND SWING (-20°C, 296 Pa) limit at 47° swing are not shown because the required electrical clearances are the same and are covered by the MAXIMUM WIND SWING (-20°C, 788 Pa) limit at 66°. See previous section for justification of reduction of transverse swing angle from 70°. As with option 1, the electrode shielding angle improves with additional insulator length.

Note that an additional 50 mm of insulator length for a total of 375 mm increase may be included if the step bolt is removed. NL Hydro confirmed March 11, 2025 that the removal of the climbing bolt is acceptable.

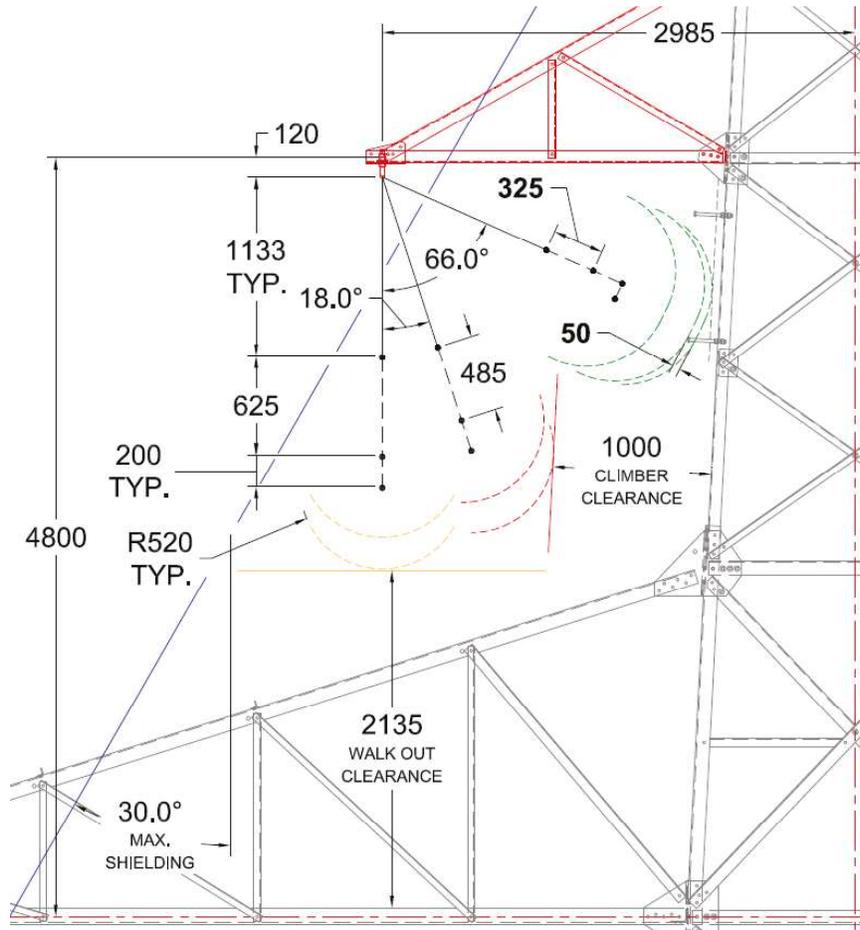


Figure 6: Option 2 Permissible Length Increase

## 4.0 LONGITUDINAL ARTICULATION ANGLE

One of the field observations from existing conditions is contact of the bottom insulator unit and the electrode conductor under longitudinal loading cases. Based on the geometry from the electrode insulator hardware drawing ILK-SI-SD-6200-TL-D04-0016-01-C3, the maximum permissible longitudinal articulation angle prior to contact is approximately  $50^\circ$  assuming a vertical take-off angle of  $0^\circ$ , see Figure 7 (left).

Ignoring broken wire cases, the maximum required longitudinal angle from the design loading drawings ILK-SN-CD-6200-TL-DD-0065-01-C1 & ILK-SN-CD-6200-TL-DD-0065-02-C2 and the additional loading table included in the RFP is  $33^\circ$  for load case “UBI EL1 64 mm 70/100%.” Because this is within the permissible range for the existing assembly, the target articulation angle is not defined. Photo 22 from the *Failure Investigation Report – L3501/2 Tower and Conductor Damage (2021)* shows a longitudinal swing angle of approximately  $60^\circ$ , see Figure 7 (middle).

Both options presented feature hardware length increase on the energized end to increase the longitudinal articulation angle. The permissible articulation is now expected to exceed  $70^\circ$ , see Figure 7 (right). The longitudinal articulation of the socket tongue fitting to suspension clamp was confirmed by SLACAN to also exceed  $70^\circ$  (approximately  $80^\circ$ ).

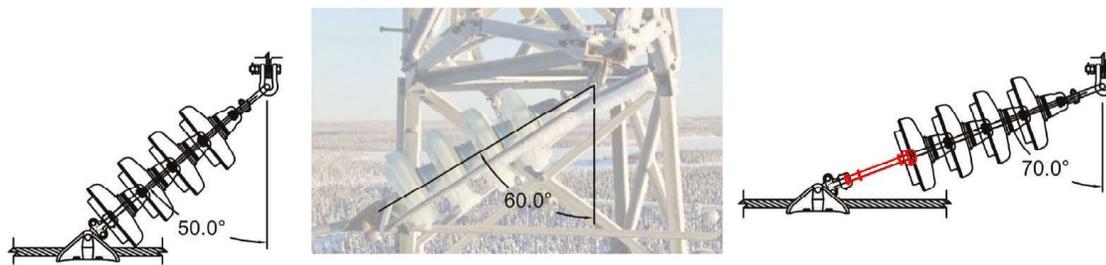


Figure 7: Longitudinal Articulation Angle

## 5.0 OPTION 1 DESIGN

The design solution for option 1 to meet the permissible insulator length increase of 295 mm is to add a socket ball extension SLACAN catalogue no. 63149 between the bottom insulator and the socket tongue, see Figure 8. See appendix B for cutsheet. With a spacing of 292 mm, this fits within the permissible length increase. This item meets the requirements of *350 kV HVdc LINE DESIGN, TESTING AND SUPPLY OF HARDWARE ASSEMBLIES TECHNICAL SPECIFICATION, DOC. NO. ILK-SN-CD-6200-TL-TS-0013-01*.

Adding this hardware item also requires the replacement of the arcing horn to maintain the spark gap geometry. It is expected that only lengthening the vertical leg of the lower arcing horn assembly will meet this requirement. See Appendix C for design drawing (ILK-TT-CD-6200-TL-D04-0004-01).

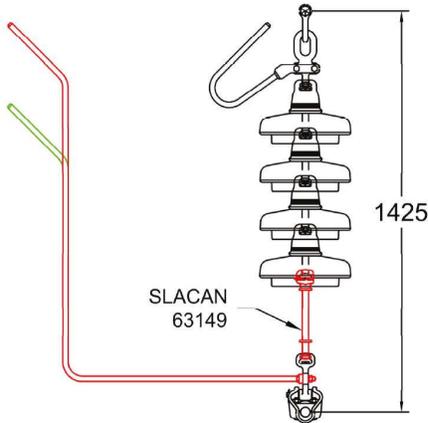


Figure 8: Option 1 Design

## 6.0 OPTION 2 DESIGN

The second design option is to further increase the insulator length and address structural shortcomings in the insulator attachment to the cross-arm as described in the Failure Investigation Report. The hardware changes include replacing the shackle with a U-bolt (SLACAN catalogue no. 83573), adding the same socket ball extension as option 1 (SLACAN catalogue no. 63149), and adding one insulator unit (SEDIVER N220P/C170DR), see Figure 9. The net increase in insulator length is 363 mm which requires the removal of the climbing bolt to meet the permissible length increase requirements, see Figure 6. These hardware items meet the requirements of *350 kV HVdc LINE DESIGN, TESTING AND SUPPLY OF HARDWARE ASSEMBLIES TECHNICAL SPECIFICATION, DOC. NO. ILK-SN-CD-6200-TL-TS-0013-01*.

The lower arcing horn will also have to be replaced in this option.

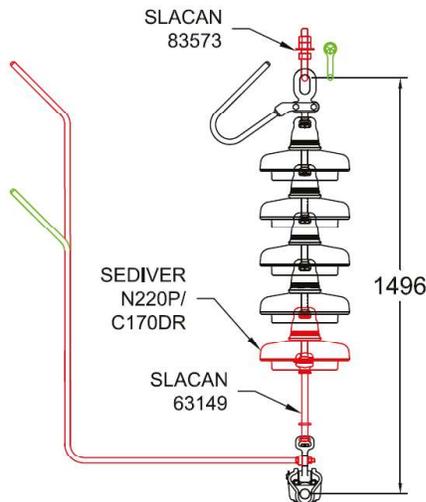


Figure 9: Option 2 Design

LIL Engineering Study – A1 Electrode Suspension Assembly

Newfoundland and Labrador Hydro

The following dimensions for the new electrode cross-arm are preliminary and subject to change pending final tower detailing. The attachment style will change from back to back angles and a shackle that does articulate in the longitudinal direction to a U-bolt. As a result, the longitudinal load moment arm will reduce from 162 mm to 111 mm. The plan eccentricity will reduce from 270 mm to 210 mm by extending the bottom chords and moving the attachment point out 60 mm, see Figure 10. By using a welded plate assembly, the torsional load will be distributed to bolts on the bottom face of the arm in tension as well as the front and back face in shear, mitigating the block shear failure seen in the Failure Investigation Report.

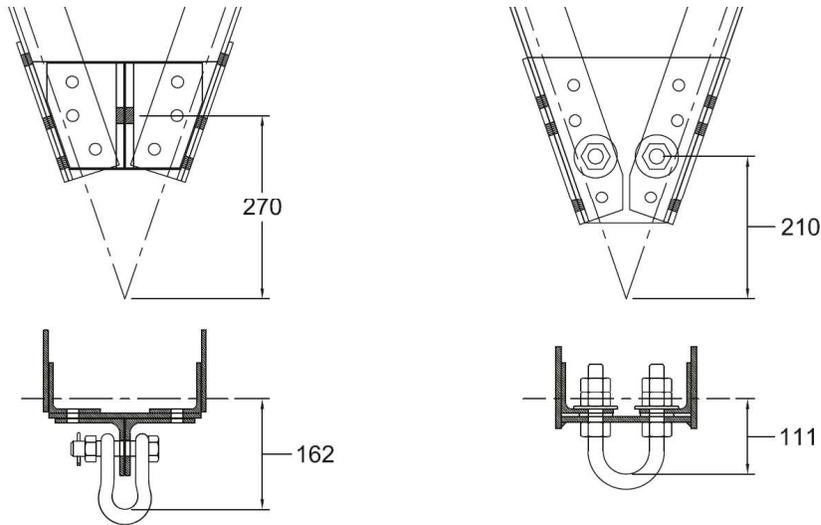


Figure 10: Option 2 Structural Improvements

The bottom chord of the cross-arm will be set level to simplify detailing, fabrication, and erection as well as avoid high axial forces in the bracing. This requires a maximum transverse swing angle of 66° to maintain electrical clearance to the bottom of the cross-arm, see Figure 11, and transverse swing angle section for justification. Bottom chord plan bracing will be framed on the top of the bottom face to avoid reductions in electrical clearance.

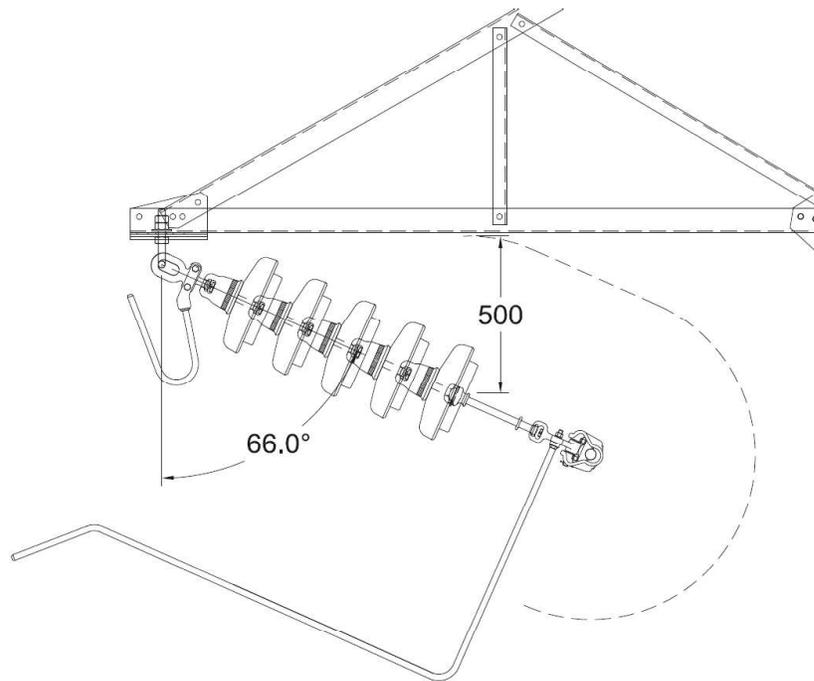


Figure 11: Option 2 Minimum Electrical Clearance

## 7.0 LONGITUDINAL LOAD REDUCTION

An assessment of longitudinal load reduction was completed to determine the benefit of the insulator lengthening of option 2. The following procedure was completed to compare the existing condition to the improved condition.

1. For towers in existing PLS-CADD models, change electrode insulator length from 1245 mm to 1133 mm and write structure loads in L4 for the unbalanced icing load cases. The difference between E1 and E2 cases is generally negligible and either the ahead or back case will experience more applied longitudinal applied load depending on the magnitude of the one-sided weight span. Only the maximum of the four load cases is reported for each structure.
  - a. F1 back LC29 UBL E1,T NA+
  - b. F1 back LC30 UBL E2,T NA+
  - c. F1 LC29 UBL E1,T NA+
  - d. F1 LC30 UBL E2,T NA+
2. Change the insulator string length from 1133 mm to 1496 mm. Write the same structure loads as described in step 1.
3. Compare the relative change (longitudinal load reduction) between the two conditions.

This procedure was completed for tower locations that were known to have electrode cross-arm damage during ice events. The average relative change in the locations inspected was found to be 10%.

Table 1: Relative Change for Insulator Lengthening Option 2

Tower No.	Long. Load Before (N)	Long. Load After (N)	Relative Change
335	16020	14226	11.2%
340	19779	17429	11.9%
343	20320	18408	9.4%
362	16209	14497	10.6%
363	21330	19415	9.0%
364	21083	19114	9.3%
366	20547	18649	9.2%
368	18061	16213	10.2%
526	19477	17663	9.3%
527	19099	17299	9.4%
1218	17715	15946	10.0%
1219	17752	16274	8.3%
1221	19321	17387	10.0%
1222	19343	17261	10.8%
1223	15881	14616	8.0%
1224	17855	16085	9.9%
1225	18736	16893	9.8%
1226	16712	15098	9.7%
1227	14530	13091	9.9%
1228	16565	14363	13.3%
		Average	10.0%

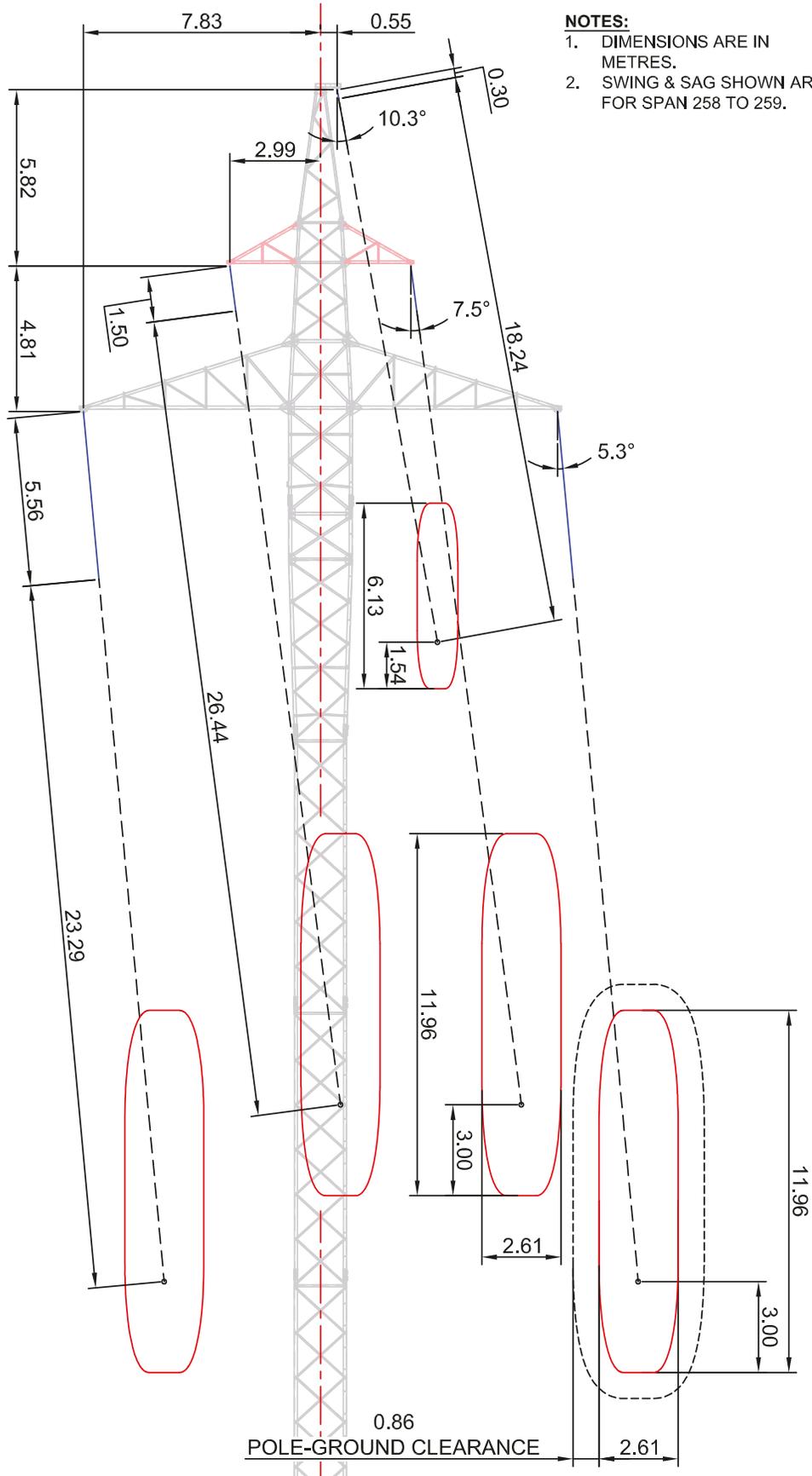
## 8.0 CONCLUSIONS

The two proposed options meet the required minimum electrical clearances and improve the performance issues seen on the electrode. The primary means of improvement is to increase the insulator length available to balance longitudinal loading under unbalanced ice conditions. Both options provide a significant improvement in permissible longitudinal articulation range to avoid insulators contacting the conductor.

Option 1 can be implemented with relatively minimal construction effort and no costs related to tower modifications. Option 2 provides additional insulator length for longitudinal load imbalance in addition to increasing the capacity of the insulator attachment to the cross-arm tip.

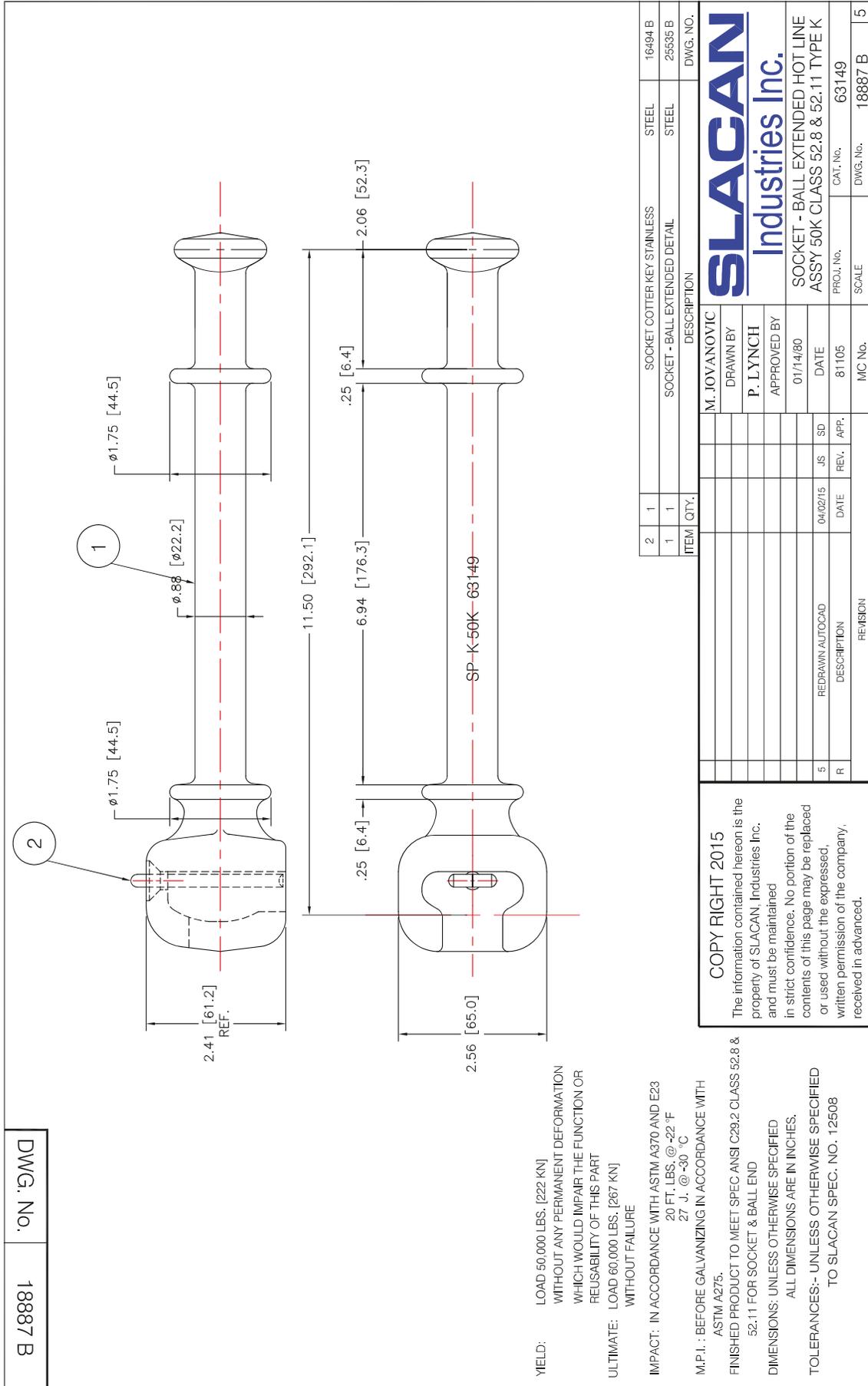
## APPENDIX A: GALLOPING ELLIPSE RESULTS

LIL Strengthening Overview, Appendix C



- NOTES:**
1. DIMENSIONS ARE IN METRES.
  2. SWING & SAG SHOWN ARE FOR SPAN 258 TO 259.

## APPENDIX B: NEW HARDWARE CUTSHEETS



B 18887 B DWG. No.

**YIELD:** LOAD 50,000 LBS. [222 KN] WITHOUT ANY PERMANENT DEFORMATION WHICH WOULD IMPAIR THE FUNCTION OR REUSABILITY OF THIS PART

**ULTIMATE:** LOAD 60,000 LBS. [267 KN] WITHOUT FAILURE

**IMPACT:** IN ACCORDANCE WITH ASTM A370 AND E23 20 FT. LBS. @ -22 °F 27 J. @ -30 °C

**M.P.I. :** BEFORE GALVANIZING IN ACCORDANCE WITH ASTM A275.

**FINISHED PRODUCT TO MEET SPEC ANSI C29.2 CLASS 52.8 & 52.11 FOR SOCKET & BALL END**

**DIMENSIONS:** UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.

**TOLERANCES:- UNLESS OTHERWISE SPECIFIED TO SLACAN SPEC. NO. 12508**

2	1	SOCKET COTTER KEY STAINLESS	STEEL	16494 B
1	1	SOCKET - BALL EXTENDED DETAIL	STEEL	25535 B
ITEM QTY.		DESCRIPTION		
		M. JOVANOVIC		
		DRAWN BY		
		P. LYNCH		
		APPROVED BY		
		01/14/80		
		DATE		
		04/02/15		
		REDRAWN AUTOCAD		
		DATE		
		REV. APP.		
		81105		
		CAT. No.		
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**TWO LAST NUMBER OF THE YEAR**

SEDIVER TEST  
25klbs TEST  
111KN

11 KT 210 W  
50 klbs M&E  
222KN

**DIMENSIONS**  
According to CAN/CSA C1325-99 and CAN/CSA C411.1-10

CSA Designation Type CSDC-3

DIAMETER OF SHELL (D) mm 320

SPACING (P) mm 170

MINIMAL NOMINAL CREPAGE DISTANCE mm 550

COUPLING ACCORDING TO CSA-C411.1-10 Type:CS-11

APPROXIMATE NET WEIGHT kg 10.5

**ELECTRICAL PERFORMANCES** According to CAN/CSA C1325-99

d.c. withstand voltage

- dry one minute ± kV 170
- wet one minute ± kV 65

50% dry d.c. flashover voltage ± kV 175

50% dry lightning impulse flashover voltage ± kV 150

d.c. puncture withstand voltage (SF6) kV 300

Max Radio Interference voltage at 1MHz 50µV ±30 kVdc

**MECHANICAL PERFORMANCES**

According to CAN/CSA C1325-99 and CAN/CSA C411.1-10

COMBINED MECHANICAL AND ELECTRICAL STRENGTH kN 222

TENSION PROOF kN 111

MECHANICAL IMPACT STRENGTH Nm 45

**COMPONENTS PARTS**

DIELECTRIC SHELL : HIGH RESISTIVITY HVDC TOUGHENED GLASS

CAP : HOT DIP GALVANIZED CAST IRON

PIN : HOT DIP GALVANIZED FORGED STEEL

COTTER KEY : STAINLESS STEEL

CEMENT : ALUMINOUS, hot cured

Sacrificial sleeve (1) : >99.8% ZINC (adherent sleeve)

**VERIFIED CORRECT FOR USE IN LOWER CHURCHILL PROJECT**  
PT0329-350kV HVdc  
SIGNED : J.M. GEORGE

\*\*\*\*\* DATUM REFERENCE: ALL ELEVATIONS ARE IN METRES REFERENCED TO GEODETIC. COORDINATE REFERENCE: UTM 6° (UNIVERSAL TRANSVERSE MERCATOR) PROJECTION, NAD83, ZONE CENTRAL MERRIDIAN 67 00 W, LONGITUDE \*\*\*\*\*

FOR INTERNAL USE ONLY

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2	31-Jan-2024	ADDED CAP IDENTIFICATION			
1	03-Dec-2023	ADDED GLASS IDENTIFICATION			
0	08-Nov-2013	ISSUED FOR REVIEW			

CLIENT: sediver

PROJECT: PT0329-350kV HVdc Transmission LinePurchase Order #PT0303-1001

DESIGNED: MJC

DRAWN: MJC

VERIFIED: ST

DATE: 27-Nov-2024

SCALE: 1/1

NE DOC No: Code: NCE20PP170EX.Y11KSI (G10309090N0)

SUPPLIER DOC No: IUK-SV-SD-020-TL-004-0002-01

ENG 68934

PROJECT MANAGER: M. Raissi\_18-Dec-2014

REVISION REGISTER

No.	DATE	REVISION	REVISION REGISTER

FORM: A81 D (22/04)

This document has been reviewed & coded electronically via Aconex.

## APPENDIX C: NEW HARDWARE DRAWINGS



# Appendix D

## LIL Engineering Study – Calculations for OPGW Peak Reinforcement





# LIL Engineering Study – Calculations for OPGW Peak Reinforcement

Newfoundland and Labrador Hydro Report No. ILK-TT-CD-6200-TL-H15-0002-01  
TT Document Number: 705-2579500100-REP-G0003-00  
July 21, 2025

## PRESENTED TO

**Newfoundland and Labrador Hydro**  
500 Columbus Drive, P 709.737.1400  
St. John's, Newfoundland nlhydro.com  
A1B 4K7

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Project Manager



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Tetra Tech REV. NO	ISSUE DATE	PREPARED BY	REVIEWED BY	APPROVED BY	DESCRIPTION OF REVISION
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## 1.0 INTRODUCTION

Newfoundland and Labrador Hydro have experienced structural failures on the suspension towers for the Labrador-Island Transmission Line, +/- 350 kV HVDC. One of these failures occurred on suspension tower type A3 where the OPGW support attaches to the peak of the tower. Report number ILK-EG-ED-6200-TL-H15-0005-01 outlines these observed failures.

Report ILK-AJ-6200-TL-H15-0001-01 investigates the capacity of the A3 tower as well as the other suspension and running angle towers A1, A2, A4, B1, and B2. Tower types A2, A3, A4, B1, and B2 were found to have an inadequate design to support the original design loads. The report discusses the design for peak reinforcements for A3.

This technical memo discusses the reinforcement methodology of the OPGW peak for tower groups A2, A4, B1 and B2, which was used to generate drawings 705-2579500100-DWG-H0008-00 to 705-2579500100-DWG-H0015-00. The design approach is similar to the approach completed for the A3 reinforcements.

## 2.0 METHODOLOGY

Finite element models using Autodesk Inventor's Nastran was performed for the studied tower groups (i.e., A2, A4, B1 and B2). Since all towers were modelled using the same methodology, only sample figures are presented in the following subsections. However, the analysis results for each tower family are presented separately in Section 3.

### 2.1 GEOMETRY

As seen in Figure 1 below, the grey members are the existing members, while the green members represent additional steel sections to be added for reinforcement. As shown in the figure, the suggested reinforcement includes adding one bent plate bolted to the existing connector plate and the bottom of the double angles. Also, 2 back-to-back angles will be bolted to the existing double angles from one side and bolted to a new bent plate from the other side. For towers A4 and B1, the addition of a stiffener was needed at the lower bent plate as shown in Figure 2.

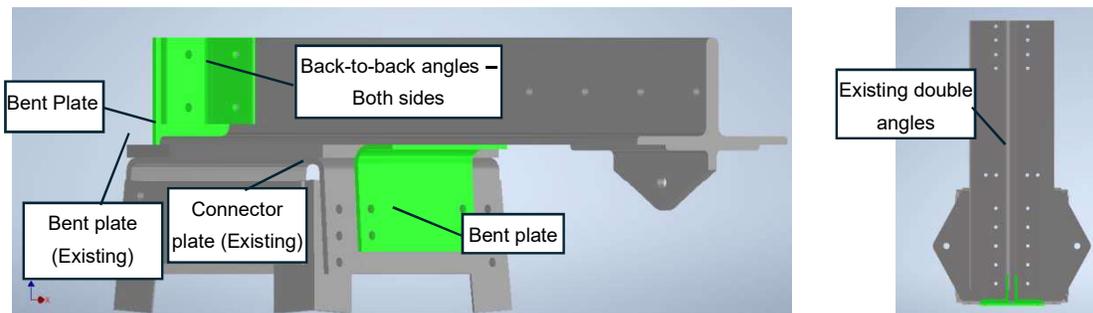


Figure 1: OPGW Peak Model for Towers A2 and B2

a) Isometric View

b) Plan View

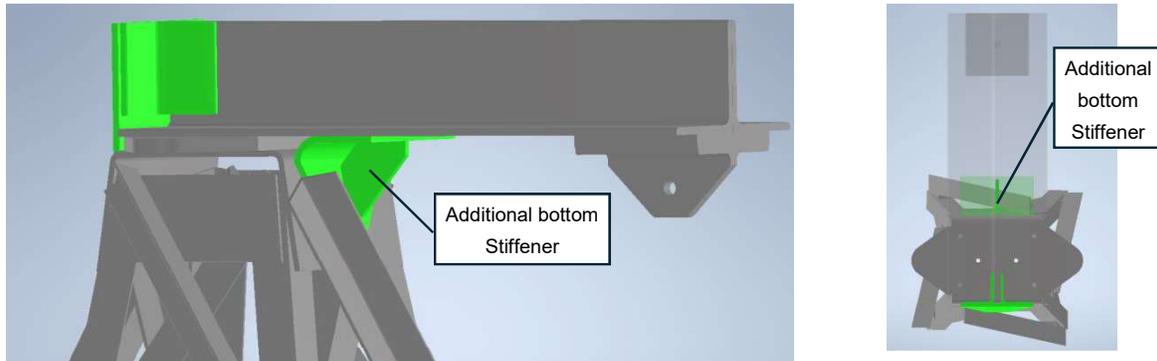


Figure 2: OPGW Peak Model for Towers A4 and B1

a) Isometric View

b) Plan View

## 2.2 CONSTRAINTS

As shown in Figure 3 below, only the tower peak was modelled since this is the scope of this study. Fixed constraints were assigned to the bottom of the legs (seen in blue color at the bottom of the legs). This prevents any rotation or translation at these nodes.

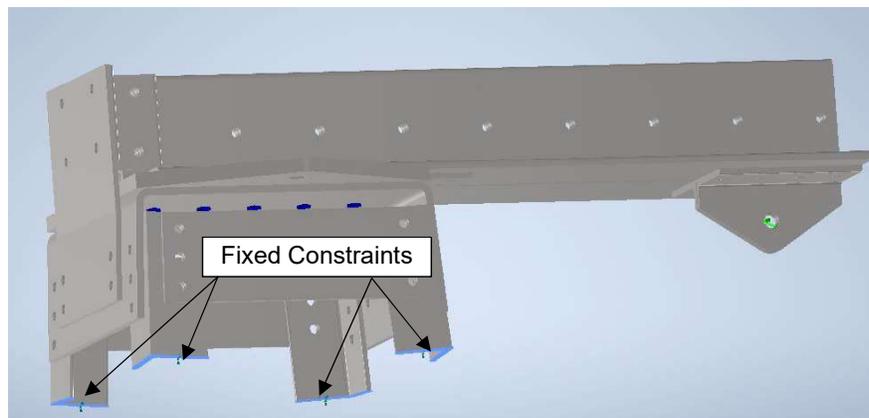


Figure 3: Finite Element Model Constraints

## 2.3 MATERIAL PROPERTIES

350 WT steel was used in the analysis, as per CSA G40.21 standard. The material properties are outlined in the table below. Since large deformations were not expected to occur, linear static analysis was performed. In other words, stresses will remain in the linear elastic range of the material.

Table 1: Material Properties

E (Modulus of Elasticity)	200 GPa
$\alpha$ (Coeff. of Thermal Exp.)	1.2e-5 (/k)
$\nu$ (Poisson Ratio)	0.29
$F_y$ (Yield Stress)	350 MPa
$F_u$ (Ultimate Stress)	480 MPa

## 2.4 LOADING

NL Hydro provided design loading drawings for each tower family listed below:

- Tower A2
  - ILK-SN-CD-6200-TL-DD-0070-01
  - ILK-SN-CD-6200-TL-DD-0070-02
- Tower A4
  - ILK-SN-CD-6200-TL-DD-0199-01
- Tower B1
  - ILK-SN-CD-6200-TL-DD-0066-01
  - ILK-SN-CD-6200-TL-DD-0066-02
  - ILK-SN-CD-6200-TL-DD-0066-03
  - ILK-SN-CD-6200-TL-DD-0066-04
- Tower B2
  - ILK-SN-CD-6200-TL-DD-0201-01
  - ILK-SN-CD-6200-TL-DD-0201-02
  - ILK-SN-CD-6200-TL-DD-0201-03
  - ILK-SN-CD-6200-TL-DD-0201-04
  - ILK-SN-CD-6200-TL-DD-0201-05
  - ILK-SN-CD-6200-TL-DD-0201-06

As shown in Table 2 below, four maximum loading cases were identified and chosen to be studied as follows:

1. Maximum vertical load case
2. Maximum positive transverse load case
3. Maximum negative transverse load case, and
4. Maximum longitudinal load case.

All four loading cases were applied at the insulator suspension insulator vang in vertical, transverse and longitudinal directions, as shown in the figure below.

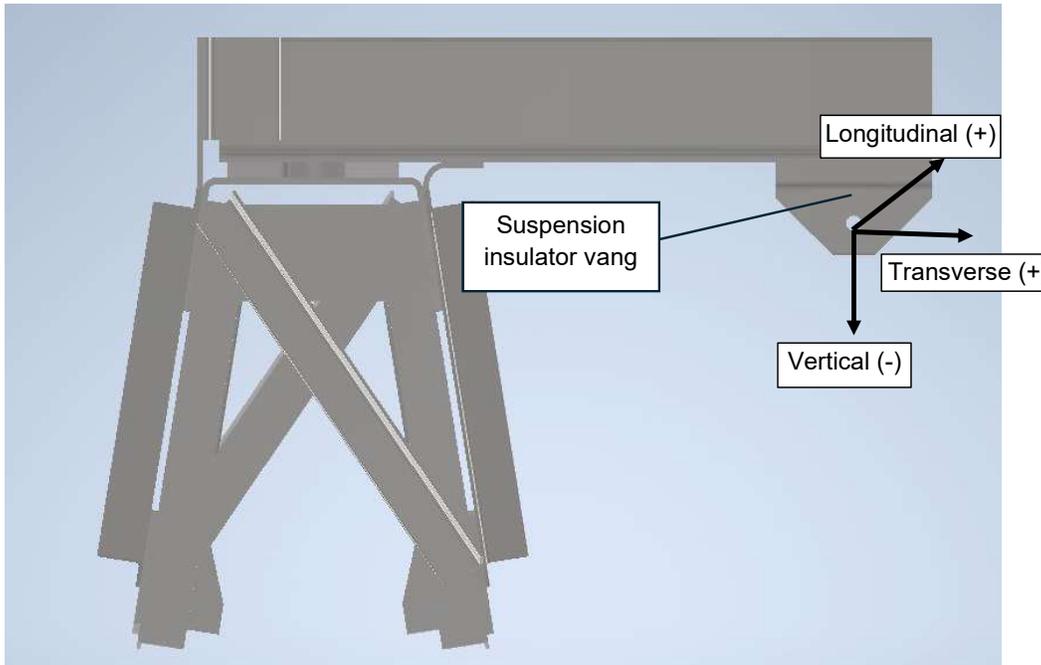


Figure 4: Loading Direction

Table 2: Loading Cases for Each Tower Family Group

Tower Family /LC	Max. Vertical Load (kN)			Max. Positive Transverse Load (kN)			Max. Negative Transverse Load (kN)			Max. Longitudinal Load (kN)		
	V	T	L	V	T	L	V	T	L	V	T	L
A2	-89.9	3.5	0.0	-31.9	60.9	0.0	-31.9	-54.8	0.0	-69.8	2.9	-60.0
A4	-119.0	3.7	0.0	-40.0	86.7	0.0	-40.0	-79.6	0.0	-91.7	3.1	-65.0
B1	-103.3	0.0	0.0	-28.6	47.9	0.0	-30.9	-45.6	0.0	-81.1	0.0	-59.3
B2	-119.0	0.0	0.0	-34.3	90.7	0.0	-40.0	-88.1	0.0	-2.7	2.2	-83.1

## 2.5 MESHING

Parabolic tetrahedron elements were used for meshing. Bolt holes were not modelled for some towers for simplicity, except for the bolts connecting the top double angles with the dead end and bent plates. These specific bolts were modeled to increase the model accuracy and capture the actual behavior of the connection at this location under the applied loads. These were at the location where on-site actual overstresses occurred for tower family group A3. It was expected that the rest of the towers will behave similarly. For sharp edges/curved, mesh control parameters were identified to decrease the mesh size at these locations to avoid stress concentration. Figure 5 below shows a sample snapshot of the mesh used for tower family B1.

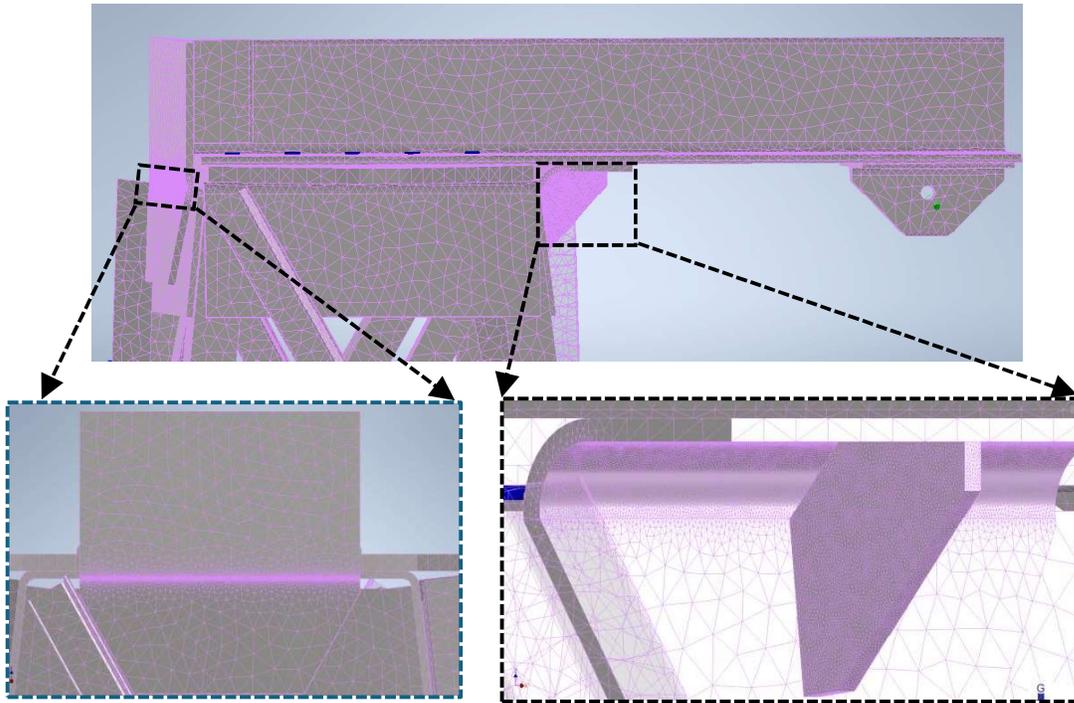


Figure 5: Mesh and Mesh Controls Used for Tower Family B1

## 2.6 CONNECTORS

As mentioned in Section 2.5, only the connection between the double back-to-back angles and the dead end, and bent plates were modeled. Connectors in Autodesk Inventor Nastran were used to represent the bolt assemblies. These connectors represent beam elements having the same material properties of ASTM A394 5/8" diameter bolts, as shown in Figure 6 below.

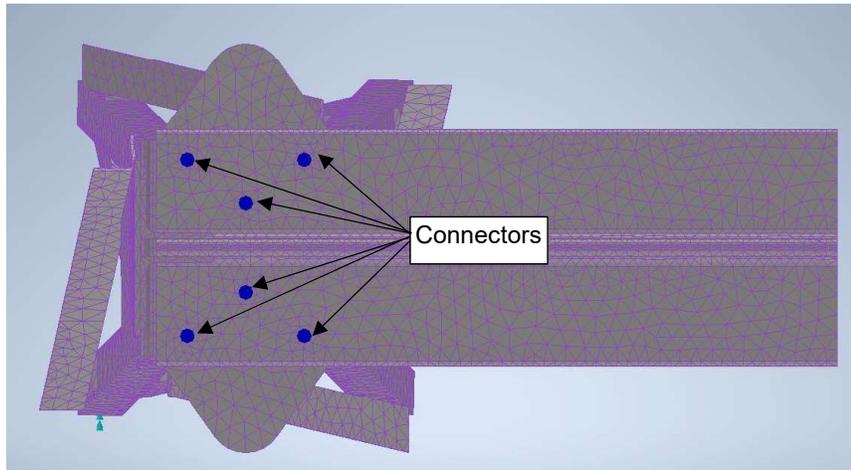


Figure 6: Connectors Used for Bolts Modeling.

## 2.7 CONTACT SURFACES

Separation contacts were used at 2 locations, between the bent plate and the dead-end bottom plate, as well as between the bottom of the back-to-back angles and the top of the dead-end plate, as shown in Figure 7 in blue. Assigning separation contacts were needed to simulate the movement of the assembly relative to each other. On the other hand, for all other surfaces that are bolted together with no relative movement to each other allowed, bonded surfaces were assigned.

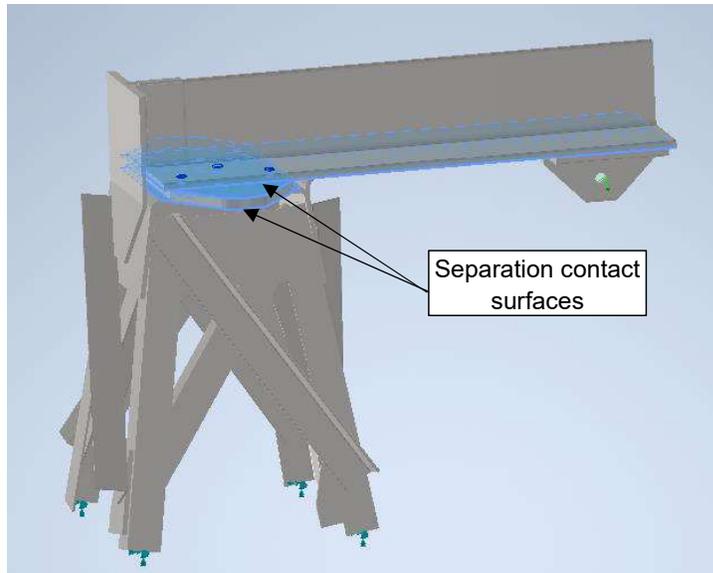


Figure 7: Assigned Separation Contact Surfaces

### 3.0 RESULTS

Finite element analysis was conducted for OPGW peak of each tower family (i.e., A2, A4, B1, and B2). Von mises stress distribution was checked for each of the 4 loading cases shown in Table 2. Stress values were compared to the yield stress of 350 WT steel ( $F_y=350$  MPa). Figures 8 to 11, show the Von Mises stresses distribution for towers A2, A4, B1, and B2 respectively, for the loading cases shown in Table 2. The deformed shape in the figures is magnified with a displacement factor of 10% for presentation purposes. As seen in the figures, the maximum stress for all load cases of the 4 tower groups was kept below 350 MPa, except for some areas, where sharp edges/change in geometry existed. These overstresses are only due to stress concentration and can be ignored.

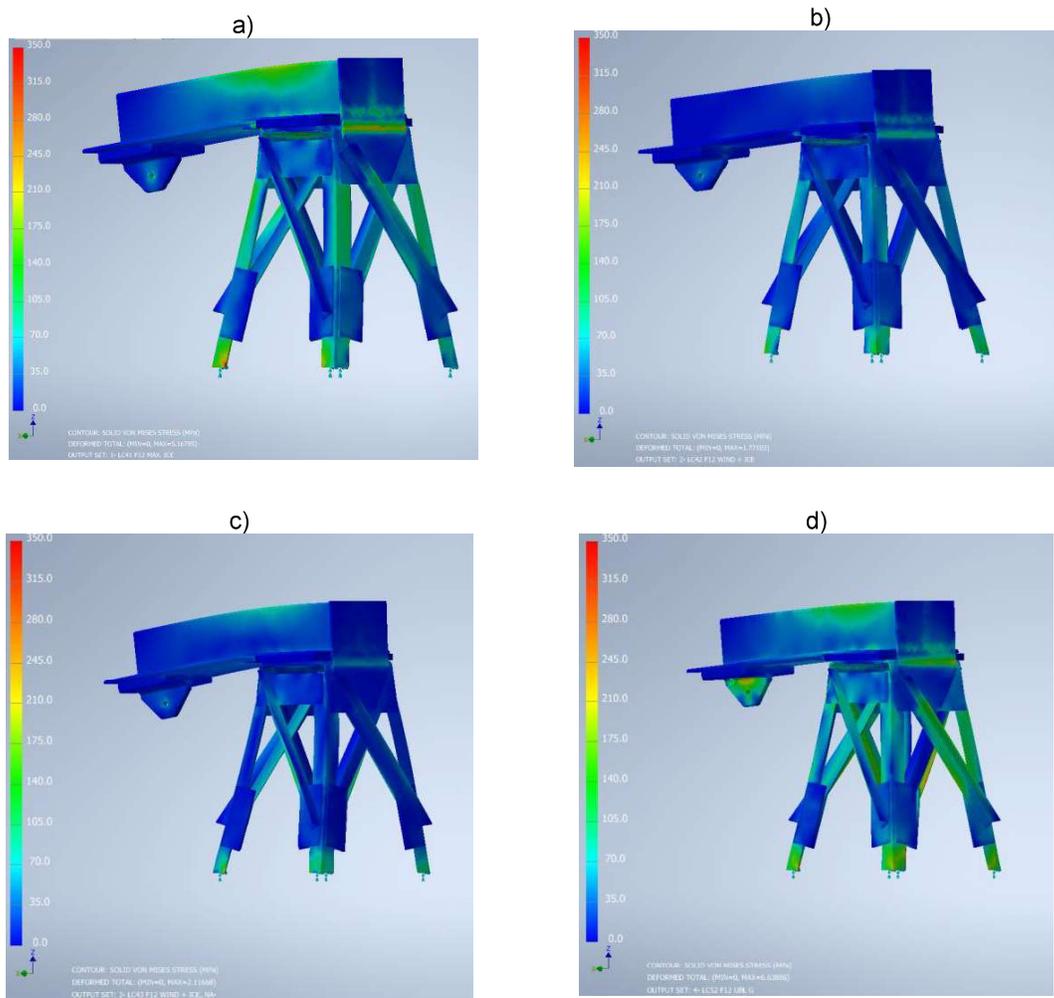


Figure 8: Von Mises Stress Distribution for Tower Group A2  
 a) Max. Vertical Load  
 b) Max. Positive Transverse Load  
 c) Max. Negative Transverse Load  
 d) Max. Longitudinal Load

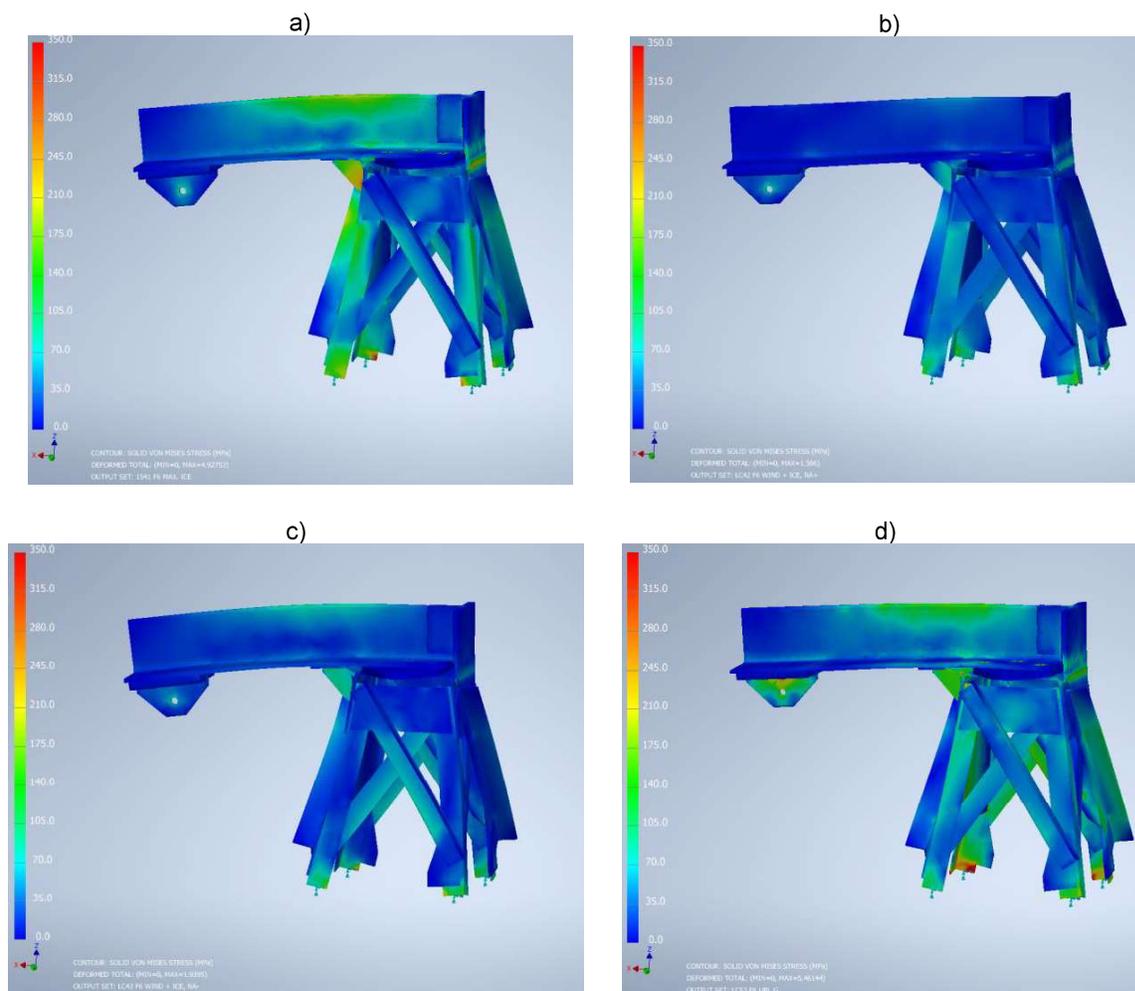


Figure 9: Von Mises Stress Distribution for Tower Group A4

- a) Max. Vertical Load
- b) Max. Positive Transverse Load
- c) Max. Negative Transverse Load
- d) Max. Longitudinal Load.

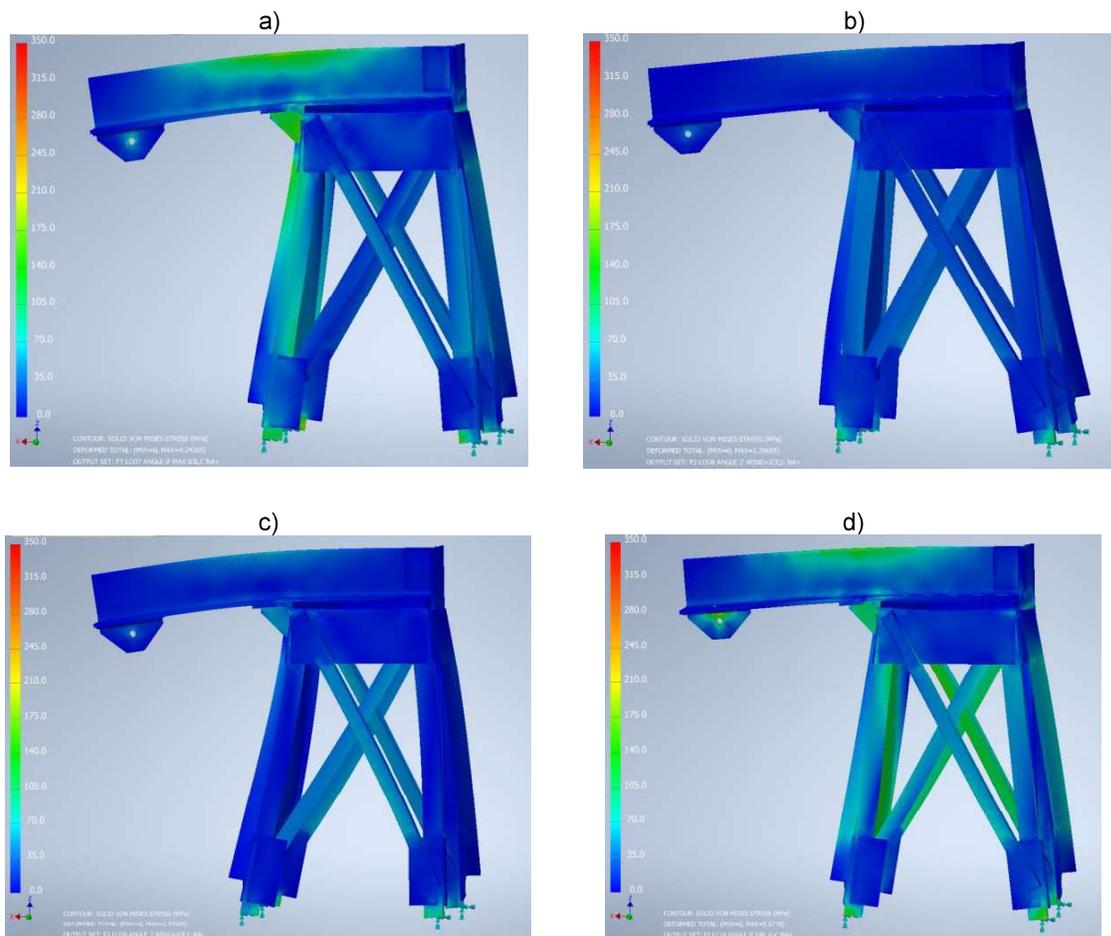


Figure 10: Von Mises Stress Distribution for Tower Group B1  
a) Max. Vertical Load  
b) Max. Positive Transverse Load  
c) Max. Negative Transverse Load  
d) Max. Longitudinal Load

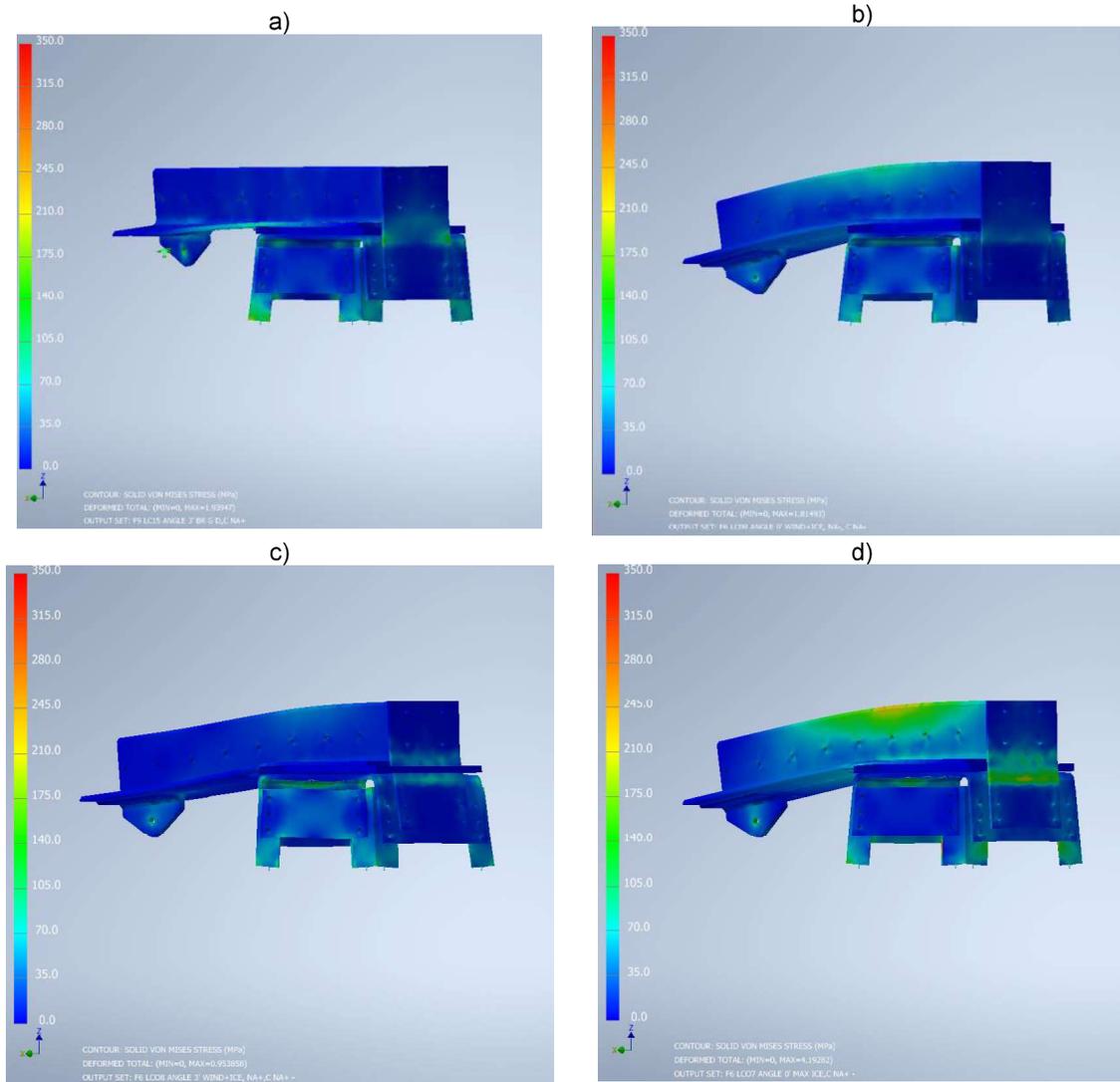


Figure 11: Von Mises Stress Distribution for Tower Group B2

- a) Max. Vertical Load
- b) Max. Positive Transverse Load
- c) Max. Negative Transverse Load
- d) Max. Longitudinal Load.

# Appendix E

## Wood Pole and Mid-Span Cost Estimates Summary





## Wood Pole and Mid-Span Cost Estimates Summary



Wood Pole and Mid-Span  
Cost Estimates Summary

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## **1.0 Executive Summary**

This report summarizes options to address electrode line failures along the Labrador Island Link (LIL). Various failures have occurred on the 350 kV HVdc line in Southern Labrador. Multiple factors, including large ice accumulations, have resulted in failures at various points throughout the line. High level cost estimates have been developed for two options to reduce loads on the existing infrastructure. Those options include installation of midspan structures in certain high risk areas and removal of the electrode lines from the transmission towers in favour of installation of adjacent wood pole structures. Refer to Section 3 for further information on these options and their associated costs.

## **2.0 Purpose**

The purpose of this report is to summarize costs for two options to reduce electrode conductor failures. Option 1 is to remove the existing electrode lines from the transmission towers and place them on nearby wood pole lines. Option 2 is to install midspan structures along the transmission corridor to reduce spans and thereby reduce loads on the existing infrastructure. Refer to Sections 3.1 and 3.2 for more information on these options respectively.

### 3.0 Cost Estimates

#### 3.1 Option 1: Wood Pole Line Installation

Two methods were utilized to develop a per km cost estimate for reinstatement of the electrode lines onto new wood pole line. The first method was to review a previous estimate for emergency work supplied by Locke’s Electrical in April 2024. Section 3.1.1 summarizes the findings of this method of cost estimate development.

##### 3.1.1 Method 1: Emergency Work Data

Locke’s Electrical Original Estimate =	\$1,286,374.75
Length of Line Considered in Original Estimate =	5.93 km
Estimated Emergency Factor =	1.5
<b>Labor Cost/km =</b>	<b>\$144,691.99</b>

The emergency work excluded material costs. An estimate of the material costs is provided below:

12 Wood poles/km=	\$35,504.82
Conductor=	\$17,434.00
160 KN Insulator CSDC-2 Type=	\$2,134.74
Tangent Cross Arm and V-Brace Assembly=	\$11,068.61
Dead-end (30-90°) Cross Arm Assembly=	\$2,573.46
Extension Bracket=	\$7,471.58
Estimated Inflation Factor Steel & Labor=	2
Estimated Inflation Factor Wood=	1.3
<b>Material Cost/km=</b>	<b>\$117,971.60</b>

The per km costs above are scaled from a previously supplied estimate of emergency work. Costs such as mobilization and demobilization cannot be scaled in this way. These costs are accounted for as a lump sum:

Mobilization =	\$140,000.00
Demobilization =	\$140,000.00
Estimated Inflation Factor=	2
<b>Total Mob/Demob Cost =</b>	<b>\$560,000.00</b>

Based on method 1, emergency work data, the total current cost to construct a line from structures would be approximately:

<b>Current Total Cost/km = Labor cost/km + Mat cost/km + Mod&amp;Demob</b>	<b>\$262,663.58/km + \$560,000.00</b>
--	---------------------------------------

### 3.1.2 Method 2: Previous Construction Data

The second method used to develop a per km cost estimate for reinstatement of the electrode lines onto new wood pole line was to review construction costs from when Locke’s electrical completed installation of a wood pole electrode line in Southern Labrador as part of the overall construction of the LIL. The following summarizes the findings of this method of cost estimate development:

**Table 1: Previous Construction Data Cost Estimate**

Item	Unit Price	#Units	Cost
Mobilization	LS		Refer to Section 3.1.1
Demobilization	LS		Refer to Section 3.1.1
Tree Clearing			\$0.00
Snow Clearing			\$0.00
Excavation Class A (Rock)	\$980.00	180	\$23,244.91
Rock Anchor Install	\$1,530.00	90	\$18,145.26
Pole Install – dist and erec 65 ft pole	\$4,900.00	90	\$58,112.28
Framing – str single pole light-angle (1-10 deg)	\$3,920.00	45	\$23,244.91
Framing - Structure Single Pole Tangent Guyed	\$3,430.00	22.5	\$10,169.65
Framing - Structure Single Pole Tangent	\$2,744.00	22.5	\$8,135.72
Framing - Two Pole Dead-End (30-90 degrees)	\$9,800.00	2	\$19,600.00
Slack span install	\$980.00	7.5	\$980.00
Stringing conductor and damper	\$35,280.00	7.5	\$35,280.00
Counterweights	\$1,519.00	5	\$1,519.00
Estimated Inflation Factor Steel & Labor=			2
Estimated Inflation Factor Wood=			1.3
<b>Total Cost=</b>			<b>\$313,379.68/km + \$560,000.00</b>

### 3.2 Option 2: Midspan Structures Installation

Original construction costs were utilized to evaluate the cost of installing midspan structures along the existing 350 kV HVdc line in Southern Labrador. The material costs of installing type A1 towers in Southern Labrador is summarized in the tables below:

**Table 2: Midspan Structure Material Costs**

<b>Material Cost</b>				
<b>Description</b>	<b>Unit</b>	<b>Unit Price</b>	<b>Units Per Tower</b>	<b>Price per Tower</b>
A1+6 Tower	EA	\$ 8,776	1	\$ 8,776
A1 Foundation	EA	\$ 4,000	1	\$ 4,000
A1 Guy Anchors	EA	\$ 1,760	4	\$ 7,040
A1 Guy Assembly	EA	\$ 168	8	\$ 1,344
A1 Guy Wire	M	\$ 12	108	\$ 1,296
Tangent Pole Assembly	EA	\$ 536	3	\$ 1,608
Tangent Pole Insulators	EA	\$ 66	52	\$ 3,432
Tangent Electrode Assembly	EA	\$ 128	2	\$ 256
Tangent Electrode Insulators	EA	\$ 48	8	\$ 384
OPGW Tangent Assembly	EA	\$ 162	1	\$ 162
Sub-Total				\$ <b>28,298</b>
Total with Inflation Factor				\$ <b>56,596</b>

**Table 3: Midspan Structure Installation Costs**

Install Cost				
Description	Unit	Unit Price	Units Per Tower	Price per Tower
A1+6 Tower	EA	\$ 65,300	1	\$ 65,300
A1 Foundation	EA	\$ 17,733	1	\$ 17,733
A1 Guy Anchors	EA	\$ 1,100	4	\$ 4,400
Pole Conductor	KM	\$ 94,000	0.3	\$ 28,200
Electrode Conductor	KM	\$ 43,000	0.3	\$ 12,900
OPGW	KM	\$ 25,000	0.3	\$ 7,500
Sub-Total				<b>\$ 136,033</b>
Total with Inflation Factor				<b>\$ 272,066</b>

Assuming an Estimated inflation factor of 2, the cost to install a single A1 tower in Southern Labrador is \$56,596.00 + \$272,066.00 = \$328,662.00 per tower.

Additionally, lump sum costs such as restringing and mobilization/demobilization must be accounted for. Restringing costs include removal and restringing of the existing conductors for a 21 structure Dead-end to Dead-end portion of the line. It has been estimated that removal would cost approximately \$5,000 per span and restringing would cost about \$10,000 per span. Resulting in a total cost of approximately \$315,000.

Due to construction complexity it is anticipated that mobilization and demobilization costs would be higher than the costs utilized in Section 3.1. Based on approximate estimation this cost would be \$700,000.00.

**Total Cost = \$328,662.00 per tower + \$315,000.00 + \$700,000.00**

## 4.0 Discussion

### 4.1 Option 1: Wood Pole Line Installation

The two methods utilized to develop cost estimates for Option 1: Wood Pole Line Installation result in total costs of **\$262,663.58/km** and **\$313,379.68/km** (+ mob and demob) respectively. These two values exhibit a variation in their values which could be accounted for by a number of factors including the assumptions made during their development. Assumptions have been listed below for consideration:

1. An general inflation factor of 2 was used to account for inflation of costs since the LIL was first installed.
2. A wood inflation factor of 1.3 was used to account for inflation of costs since the LIL was first installed.
3. An emergency factor of 1.5 was used to account for the probable mark up on costs when Locke's Electrical provided an estimate for emergency work in April 2024.
4. The number of poles per km was estimated based on the existing electrode line from the MF-Forteau junction to L'Anse Aux Diable.

Quotes for emergency work will inherently include a level of uncertainty due to the nature of the work. This uncertainty could result in a less accurate estimate than one developed under normal circumstances.

An additional consideration that will impact the feasibility of each option is the consideration of impacts from lost time. Presumably the wood pole line would be constructed alongside the existing transmission line. The electrode lines could be moved one conductor at a time with minimal outage requirements. These impacts require further investigation to quantify.

### 4.2 Option 2: Midspan Structures Installation

The cost of installing new midspan structures is approximately **\$328,662.00 per tower + \$315,000.00 + \$700,000.00**. Assumptions were made in the development of this estimate which can be reviewed to ensure accuracy. They are as follows:

1. An general inflation factor of 2 was used to account for inflation of costs since the LIL was first installed.
2. The midspan structure would be an A1 type structure.

An additional consideration that will impact the feasibility of each option is the consideration of impacts from lost time.. The new midspan structures would be constructed inside the path of the existing transmission lines. Completing the construction, and connecting the conductors to the new structures, would likely require outages on the LIL. Further investigation is required to determine if this is even a possibility and to quantify potential financial impacts. If an outage on the LIL is required costs in the ballpark of \$500,000/day have been mentioned.

## **5.0 Conclusion**

In conclusion the preliminary data suggests that out of these two options the most cost effective approach would be to install a dedicated wood pole electrode line near the existing transmission line in identified high risk zones. The cost of which would be approximately **\$313,379.68/km + \$560,000.00**. Further consideration should be given to the assumptions listed in this report, analysis of the options in PLS-CADD, the constructability and loss time implications of each option.

# Appendix F

## Analysis Removing the Electrode Conductor from L3501/2





# Analysis of Removing the Electrode Conductor from L3501/2

May-2025



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## 1. Background

Line L3501/2 is the 350 kV HVdc overland transmission line portion of LIL traversing a distance of approximately 1,100 km through three major meteorological loading zones: average, alpine and eastern. The HVdc line has two poles, one OPGW, and two electrode conductors for a portion of line. See Figure 1. The electrode conductor is attached to the lattice towers for a part of the line from Muskrat Falls to about 384 km southeast of Muskrat Falls where it diverts to a separate right of way (ROW) on wood poles to an electrode site approximately 16 km away, located in the L'Anse-au-Diable area. Note that sections of L3501/2 without the electrode on the towers do not have electrode cross arms.

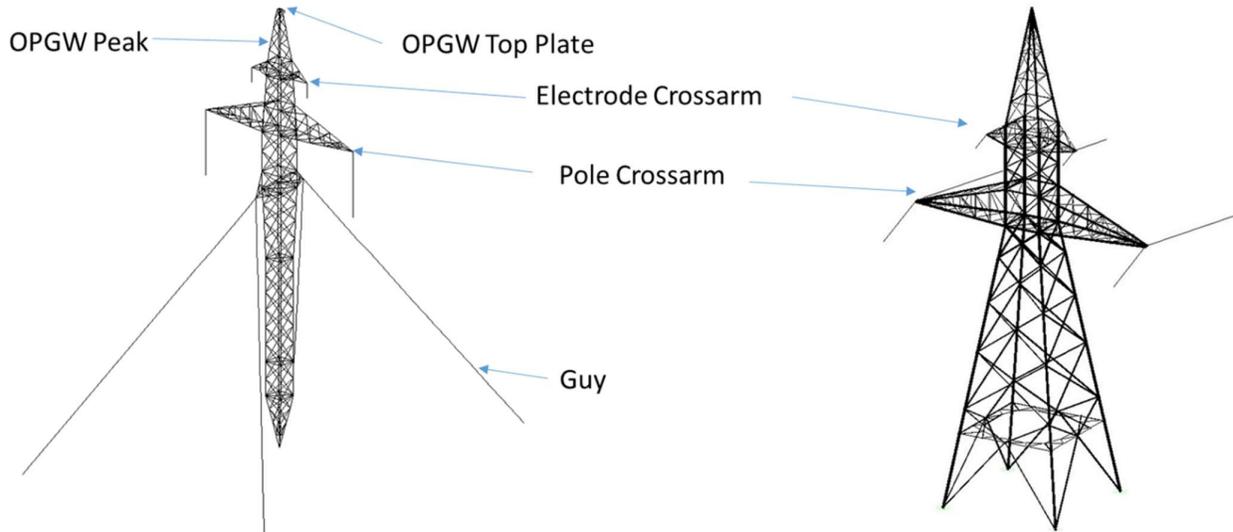


Figure 1 - Suspension and Deadend Tower Diagram

The HVdc transmission line corridor has been divided into three major meteorological loading zones referenced above in combination with 8 further subcategories related to meteoroidal loads, pollution levels (inland and coastal), and geographic location. The resulting combination led to the HVdc line consisting of 19 separate loading zones. Eleven tower types (A1, A2, A3, A4, B1, B2, C1, C2, D1, D2, and E1) were designed to meet the loading requirements, which consist of a specified wind load, ice load, and combination of both applied to the line.

There have been a number of failures to components of the transmission line during ice event over the past 4 years. The electrode crossarms and the electrode conductor are two components that are often damaged in these events. All the failures detailed below occurred on A1 type towers, in sections of the line with the electrode conductor attached to the tower. The maximum design ice loads case for this section of the line is 50 mm of radial glaze ice with a density of 0.9 g/cm<sup>3</sup> (equivalent to 11.9 kg/m on the electrode conductor). The unbalanced ice load cases include 70% of the maximum ice back span, with 100% of the maximum ice ahead span on a tower (and vice versa) for one wire at a time, while all other wires have 100% of the maximum ice load on both spans.

In January of 2021 there was an icing event in central Labrador that caused damage to 12 electrode crossarms and damage to the electrode conductor in 34 locations. The ice was estimated to be from 54 to 65 mm of radial glaze ice with a density of 0.88 g/cm<sup>3</sup> (13.1 to 17.8 kg/m), and the damage likely occurred due to unbalanced ice loads from ice shedding. There were no other components damaged in this icing event.

In December of 2022 there was an icing event in central Labrador that caused damage to the electrode conductor at 3 locations. The ice was estimated to be from 70 to 72 mm of equivalent radial glaze ice at a density of 0.9 g/cm<sup>3</sup> (20.6 to

LIL Strengthening Overview, Appendix F

21.6 kg/m), and the damage likely occurred due to unbalanced ice loads from ice shedding. There were no other components damaged in this icing event.

In March 2024 there was an icing event in southern Labrador that caused damage to 16 electrode crossarms and damage to the electrode conductor at 17 locations. The ice was estimated to be from 100 to 125 mm of radial glaze ice with a density of 0.6 g/cm<sup>3</sup> (25.2 to 37.4 kg/m), and the damage likely occurred due to unbalanced ice from ice shedding. During this icing event, there was also damage to the OPGW tower peaks.

In January of 2025 there was an icing event in central Labrador that caused damage to 3 electrode crossarms and damage to the electrode conductor at 2 locations. The ice was estimated to be from 55 to 60 mm of radial glazed ice with a density of 0.7 g/cm<sup>3</sup> (10.8 to 12.4 kg/m), and the damage likely occurred due to unbalanced ice from ice shedding. The only other components damaged during this event occurred during planned ice removal.

All failures are shown in Table 1. The total number of failures to electrode components is 30 electrode crossarms and damage to the electrode conductor at 56 locations.

Table 1- Summary of Electrode Damage All Events

Structure Number	Damaged Components				Structure Number	Damaged Components			
	Crossarm EL1	Crossarm EL1	Conductor EL1	Conductor EL2		Crossarm EL1	Crossarm EL1	Conductor EL1	Conductor EL2
127	*		*		507			X	
128	*				513			X	X
129					514				0
130	*		*		515				X0
335	X		X		516			X	
336			X		517				X0
338			X		518				X
339			X		519				X
340	X		X		520				X
342				X	521				X
343		X	X	X	522				X
344			X		523				X
351			X		525				X
352			X		526	X	X	X	X
361			X		527	X		X	
362	X		X		1218		#		#
363	X		X		1219		#		#
364	X				1220				#
365			X		1221		#		#
366	X				1222	#	#	#	#
367			X		1223	#	#	#	#
368	X		X		1224	#	#	#	#
369			X		1225	#	#	#	#
X - Jan 2021 Failure					1226	#	#	#	#
0 - Dec 2022 Failures					1227	#	#	#	#
# - Mach 2024 Failures					1228	#		#	
* - Jan 2025 Failures									

One of the ways to reduce damage to the lines due to icing would be to remove the electrode conductor from the towers and run it parallel to L3501/2 on a wood pole line. During 3 of the 4 icing events detailed in this report, only the

electrode components were damaged. This suggests that if the electrode conductors were on wood poles, there would be no damage to the towers during the 3 icing events. While damage could still occur to the electrode conductors and the wood pole structures during icing events, this damage would be easier and less time consuming to repair. Repairs could be complete without the need of a bi-pole outage and repairs to wood pole structures would require less time and equipment. In addition, the height of the electrode conductor likely contributes to the amount of ice that accretes on the line during an icing event, with less ice likely to accrete at the lower height of a wood pole line.

## 2. Sections for Consideration

Due to the cost of building a wood pole line from Muskrat Falls to the start of the existing wood pole electrode line at structure 1229 (approximately 376 km), the removal of the electrode line from L3501/2 will be consider for various sections of the line. The factors that will be considered in determining the sections of electrode removal will include areas with past failures, areas known for high icing, areas of high elevation (relative to surrounding area, areas of high elevation change), and area at risk for galloping. These factors are summarized in Figure 2. Figure 2 also shows the sections of line that will be considered for removal based on these factors.

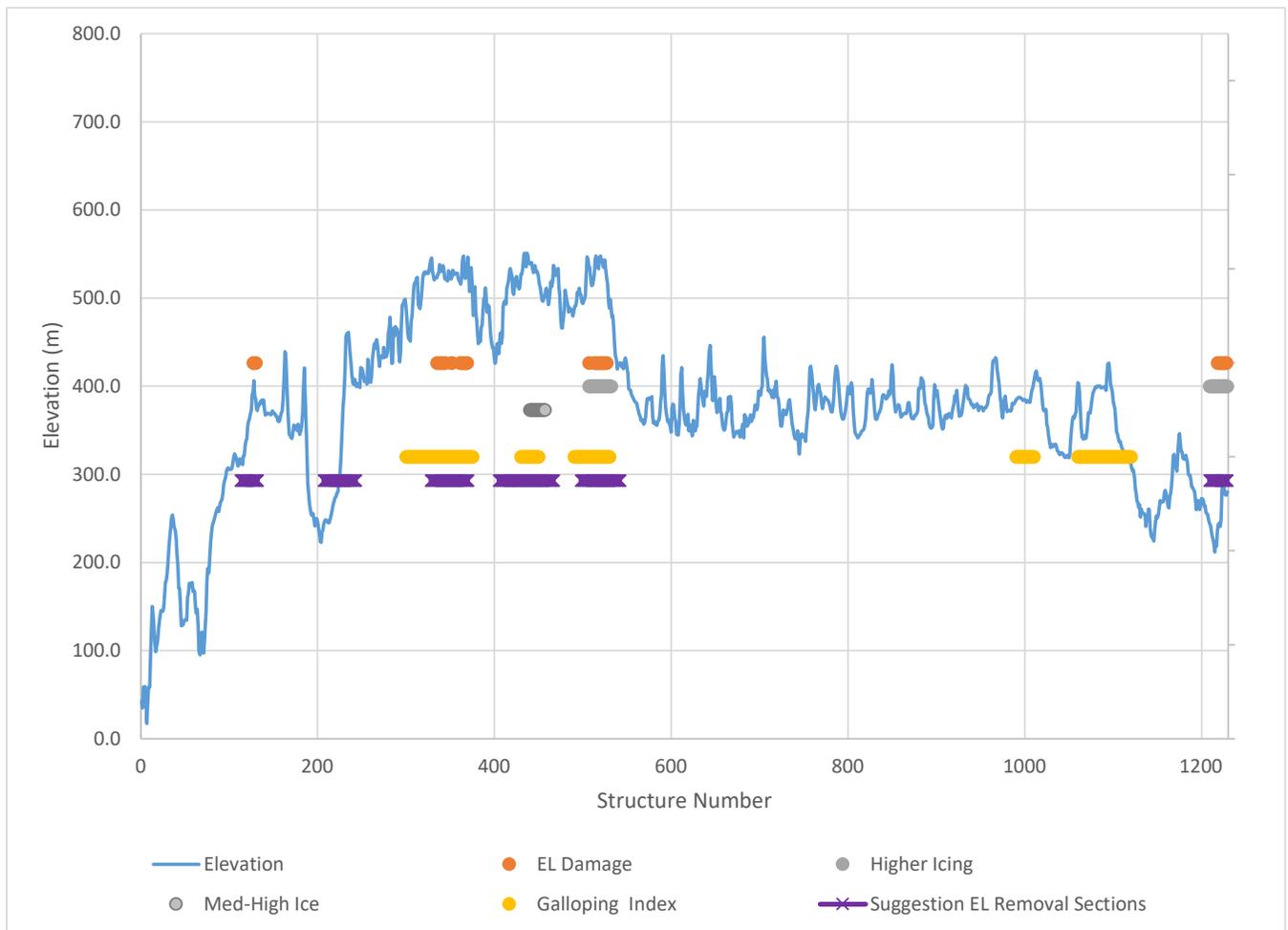


Figure 2 - Summary of Factors in Electrode Failures

There are 6 sections recommended for electrode removal from the towers or L3501/2. These 6 sections total approximately 85 km.

### 3. Analysis

The failure investigations of damage to the towers and conductors in past events determined the root cause was overloading due to unbalanced ice loads. To determine the benefits of removing the electrode conductor from the towers, the sections of the line to be considered were run for a series of balanced ice loads, and unbalanced ice loads both with and without the electrode conductor on the towers. The balanced ice loads cases include: 60, 70, 80, 90, 100 mm of radial glaze ice with a density of 0.9 g/cm<sup>3</sup>. Note that all these ice load cases are greater than the design maximum ice load. The unbalanced ice load cases include the unbalanced combinations of 50/100, 60/100, and 70/100% for 60, 70, 80 mm of radial ice on one wire at a time on the wires: OPGW (G), electrode 1 (EL1), electrode 2 (EL2), pole 1 (P1), and pole 2 (P2).

The results for each section of the line are shown in Figure 3 to Figure 8, with a summary of all the results shown in Figure 9. The charts show the percentage of failed structures for a particular section of the line for each load case for the line with the electrode conductor, and without the electrode conductor. A failure is defined as any member of the tower exceeding 100% of its capacity.

In the section from structure 113 to 132 (Figure 3) under balanced ice loading with the electrode attached to the structure, between 5% and 80% of the structures in the section will fail with 60 mm and 70 mm of radial ice respectively. Without the electrode attached to the structures, there are zero structure failures in this section for 60 mm and 70 mm of radial ice. This shows a clear benefit to removing the electrode in this section. Over 70 mm of balanced ice load, all structure will fail with the electrode attached to the structures and between 90% to 95% will fail without the electrode attached to the structures.

Under unbalanced ice load (UBL), with 60 mm of ice:

- structures with the electrode:
  - on the OPGW (G) the percentage of structure failures range between 60% to 85% as the unbalance increases,
  - on EL1, EL2, P1, and P2 the percentage of structure failures is much less, ranging from 5% to 60%,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 40% to 85% as the unbalanced increases,
  - on EL1, EL2, P1, and P2 there are no structure failures. (Note that load case with UBL on EL without EL conductor is equivalent to balanced ice on all other wires).

Under unbalanced ice load (UBL) with 70 mm of ice:

- structures with the electrode:
  - the percentage of structures failures range between 80% to 90% for all load cases,
- structure without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 60% to 85%
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 80 m of ice:

- structures with the electrode:
  - all structures failed for all load cases,
- structures without the electrode:

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- on the OPGW (G) the percentage of structure failure for 70/100% unbalanced is 85% (note that for load cases 60/100% and 50/100%, the loads are so high that the structure analysis failed to converge and all structures are assumed to have failed),
- on EL1, EL2, P1, and P2 the percentage of structure failures range from 30% to 45%.

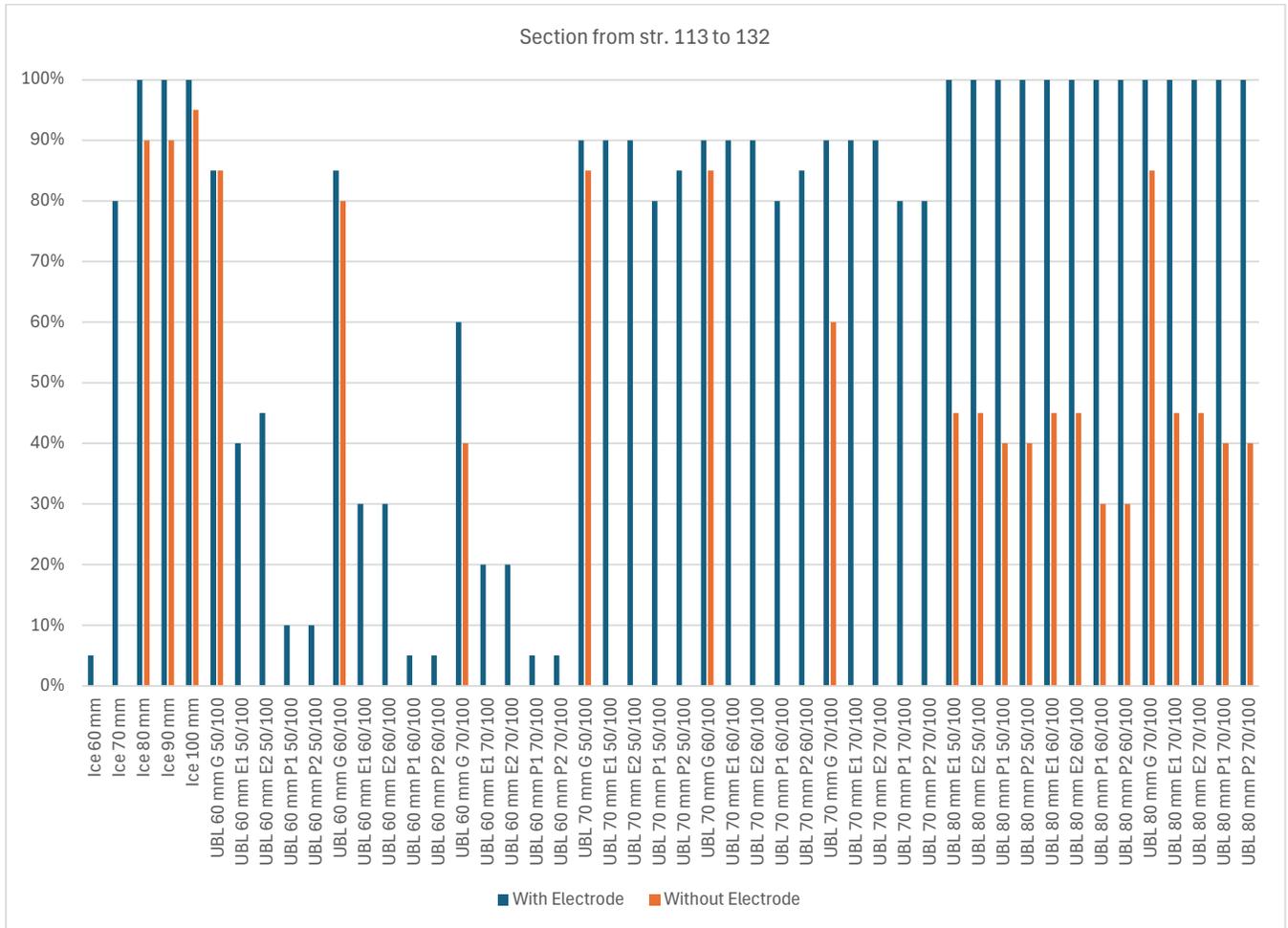


Figure 3 - Percentage of Structure Failures - Section 113 to 132

The results for the section from structure 222 to 243 (Figure 4) are similar to the section from 113 to 132, with slightly lower percentages of failures overall. Under balanced ice loading, between 0% and 77% of the structures with electrode in the section will fail with 60 mm and 70 mm of ice load, respectively. Without the electrode on the structure, there are zero structure failures in this section for 60 mm and 70 mm of ice load. This shows a clear benefit to removing the electrode in this section. Over 70 mm of balanced ice load, between 95% to 100% of structures will fail with the electrode and 82% to 95% will fail without the electrode.

Under unbalanced ice load (UBL), with 60 mm of ice:

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- structures with the electrode:
  - on the OPGW (G) the percentage of structure failures range between 55% to 86% as the unbalance increases,
  - on EL1, EL2, P1, and P2 the percentage of structure failures is much less, ranging from 14% to 32%.
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 41% to 86% as the unbalanced increases.
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 70 mm of ice:

- structures with the electrode:
  - the percentage of structure failure range between 77% to 91% for all load cases,
- structures without the electrode
  - on the OPGW (G) the percentage of structure failures range between 68% to 86%,
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 80 m of ice:

- structures with the electrode:
  - 95% of structures failed for all load cases,
- structures without the electrode:
  - on the OPGW (g) the percentage of structure failure for 70/100% unbalanced is 82%,
  - on EL1, EL2, P1, and P2 the percentage of structure failures range from 32% to 36%.

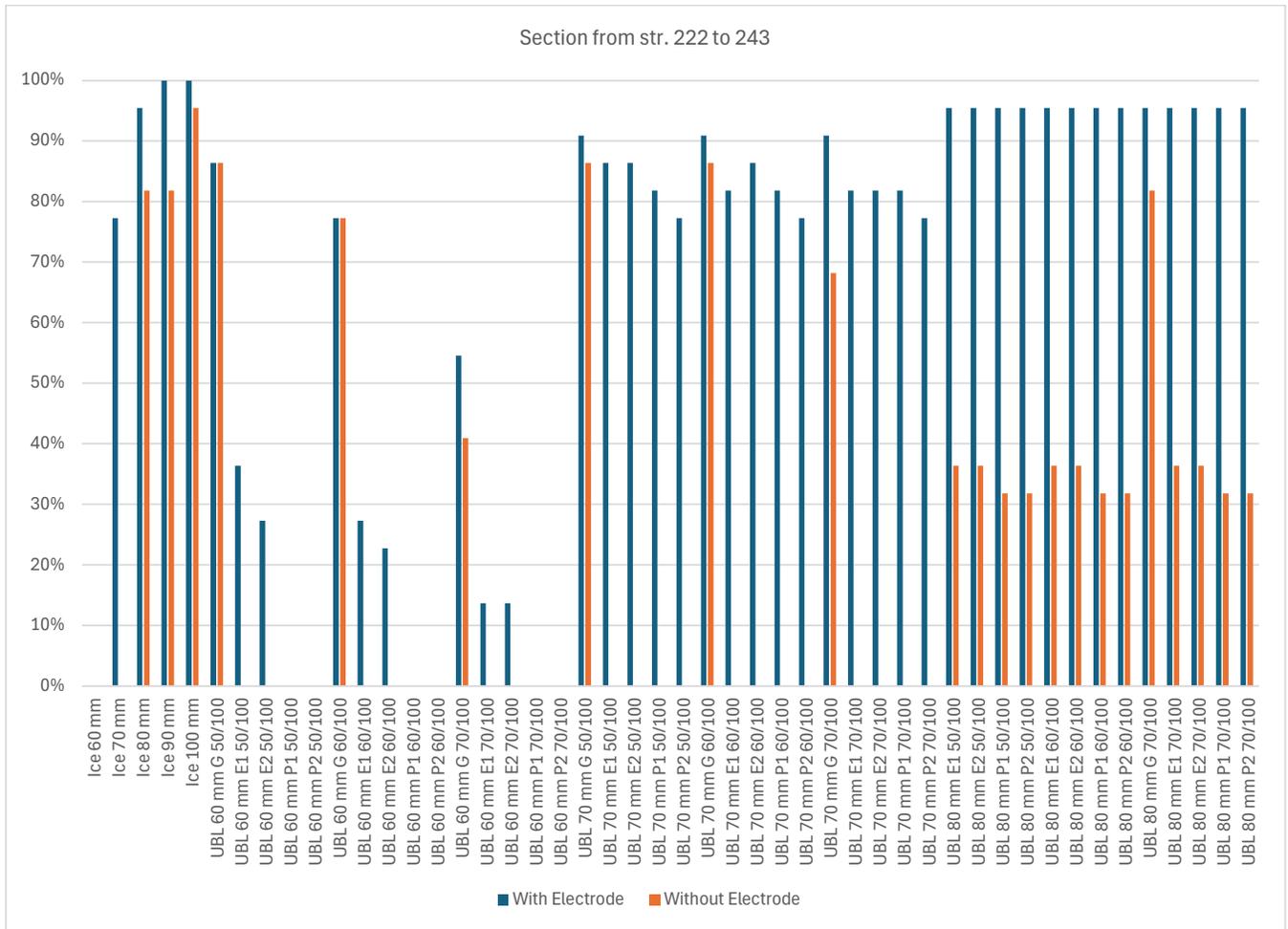


Figure 4- Percentage of Structure Failures - Structure 222 to 243

The results for the section from structure 328 to 370 (Figure 5) are very similar to the section from 222 to 243. Under balanced ice loading for structures with the electrode, between 7% and 81% of the structures in the section will fail with 60 mm and 70 mm of ice load, respectively. Without the electrode attached to the structure, there are zero structure failures in this section for 60 mm and 70 mm of ice load. This shows a clear benefit to removing the electrode from the structures in this section. Over 70 mm of balanced ice load, 100% of structures will fail with the electrode and 79% to 95% will fail without the electrode.

Under unbalanced ice load (UBL), with 60 mm of ice:

- structures with the electrode:
  - on the OPGW (G) the percentage of structure failures range between 51% to 81% as the unbalance increases,
  - on EL1, EL2, P1, and P2 the percentage of structure failures is much less, ranging from 7% to 35%,
- structures without the electrode:
  - on the OPGW (G) the percentage of failures range between 40% to 84% as the unbalanced increases.,
  - on EL1, EL2, P1, and P2 there are no failures.

Under unbalanced ice load (UBL) with 70 mm of ice:

- structures with the electrode:
  - the percentage of structure failures range between 81% to 95% for all load cases,
- structures without the electrode
  - on the OPGW (G) the percentage of structure failures range between 67% to 81%,
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 80 m of ice:

- structures with the electrode:
  - 95% of structures failed for all load cases,
- structures without the electrode:
  - on the OPGW (g) the percentage of structure failure for 70/100% unbalanced is 79%,
  - on EL1, EL2, P1, and P2 the percentage of structure failures range from 21% to 33%.

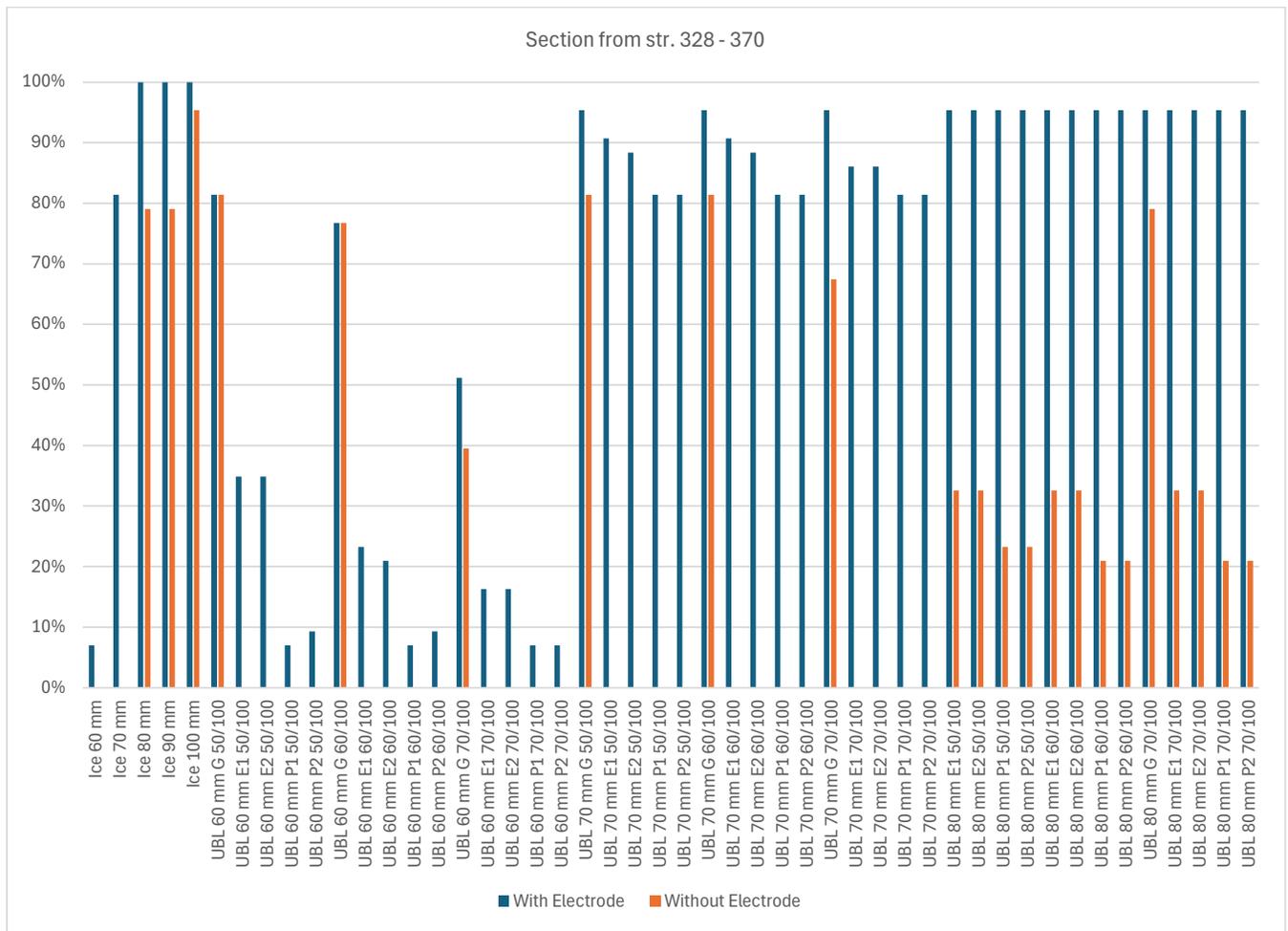


Figure 5 - Percentage of Structure Failures - Structures 328 to 370

The results for the section from structure 424 to 467 (Figure 6) are similar to the section from 113 to 132. Under unbalanced ice loading, between 9% and 77% of the structures with the electrode in the section will fail with 60 mm and

70 mm of ice load, respectively. Without the electrode attached to the structure, there are 2% failures in this section for 60 mm and 70 mm of ice load. With over 70 mm of balanced ice load, 98% of structures will fail with the electrode and 89% to 93% will fail without the electrode. This shows a clear benefit to removing the electrode in this section.

Under unbalanced ice load (UBL), with 60 mm of ice:

- structures with the electrode:
  - on the OPGW (G) the percentage of structure failures range between 57% to 84% as the unbalance increases,
  - on EL1, EL2, P1, and P2 the percentage of structure failures is much less, ranging from 9% to 41%.
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 41% to 84% as the unbalanced increases,
  - on EL1, EL2, P1, and P2 there are no failures.

Under unbalanced ice load (UBL) with 70 mm of ice:

- structures with the electrode:
  - the percentage of structure failures range between 77% to 91% for all load cases,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 68% to 84%,
  - on EL1, EL2, P1, and P2 there are 2% structure failures for all load cases.

Under unbalanced ice load (UBL) with 80 m of ice:

- structures with the electrode:
  - 98% of structures failed for all load cases,
- structures without the electrode:
  - on the OPGW (g) the percentage of structure failures for 70/100% unbalanced is 84%,
  - on EL1, EL2, P1, and P2 the percentage of structure failures range from 34% to 43%.

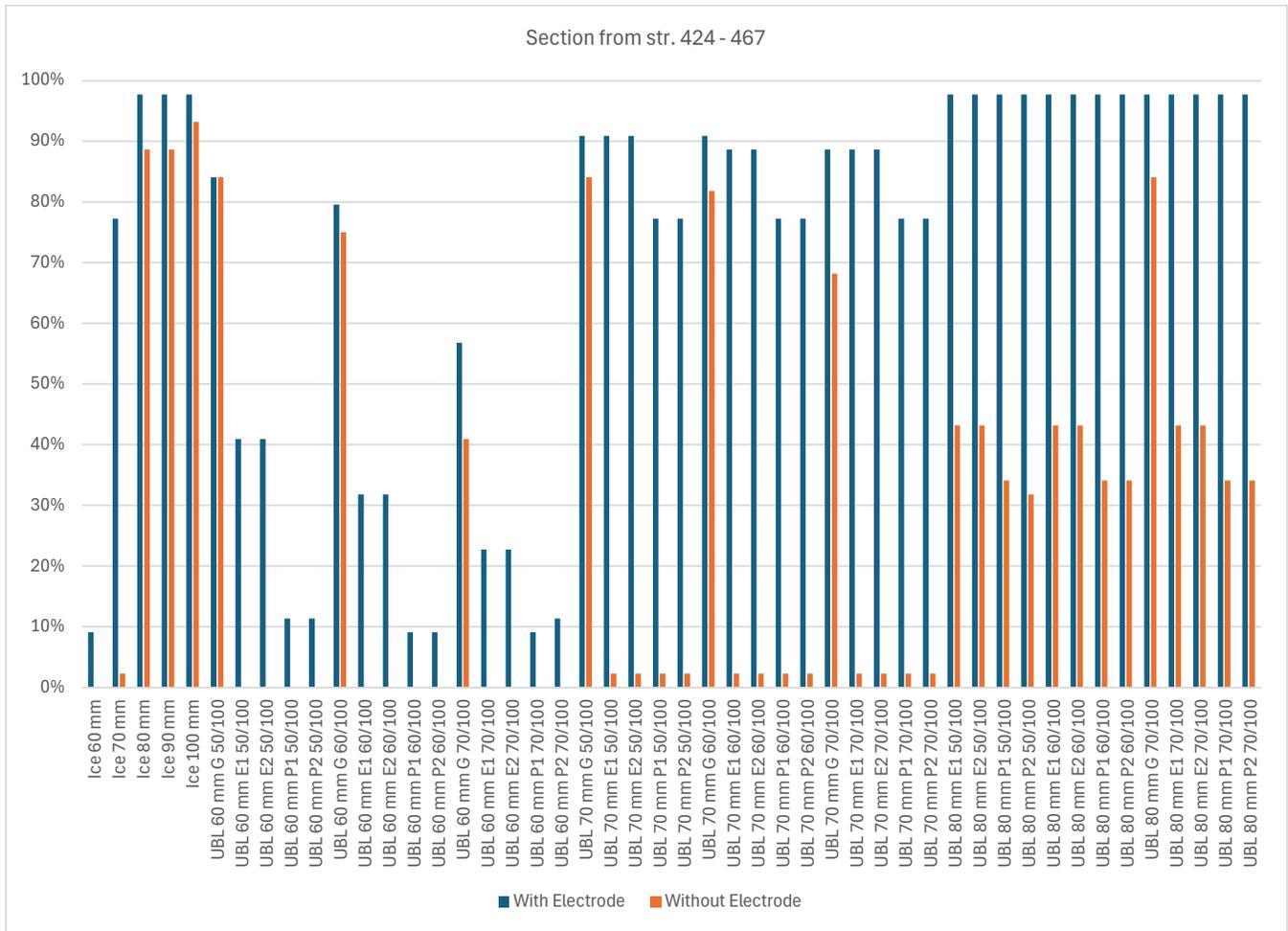


Figure 6 - Percentage of Structure Failures - Structures 424 to 467

The results for the section from structure 498 to 542 (Figure 7) are similar to the section from 113 to 132. Under balanced ice loading, between 9% and 82% of the structures with the electrode in the section will fail with 60 mm and 70 mm of ice load, respectively. Without the electrode attached to the structures, there are no failures in this section for 60 mm and 70 mm of ice load. With over 70 mm of balanced ice load, 100% of structures will fail with the electrode and between 80% to 91% will fail without the electrode. This shows a clear benefit to removing the electrode from the structures in this section.

Under unbalanced ice load (UBL), with 60 mm of ice:

- structures with the electrode:
  - on the OPGW (G) the percentage of structure failures range between 64% to 84% as the unbalance increases,
  - on EL1, EL2, P1, and P2 the percentage of structure failures is much less, ranging from 9% to 49%,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 40% to 82% as the unbalanced increases,
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 70 mm of ice:

- structures with the electrode:
  - the percentage of structure failures ranged between 82% to 100% for all load cases,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures ranges between 64% to 82%,
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 80 m of ice:

- structures with the electrode:
  - 98% to 100% of structures failed for all load cases,
- structures without the electrode:
  - on the OPGW (g) the percentage of structure failures for 70/100% unbalanced is 87%,
  - on EL1, EL2, P1, and P2 the percentage of structure failures range from 42% to 44%.

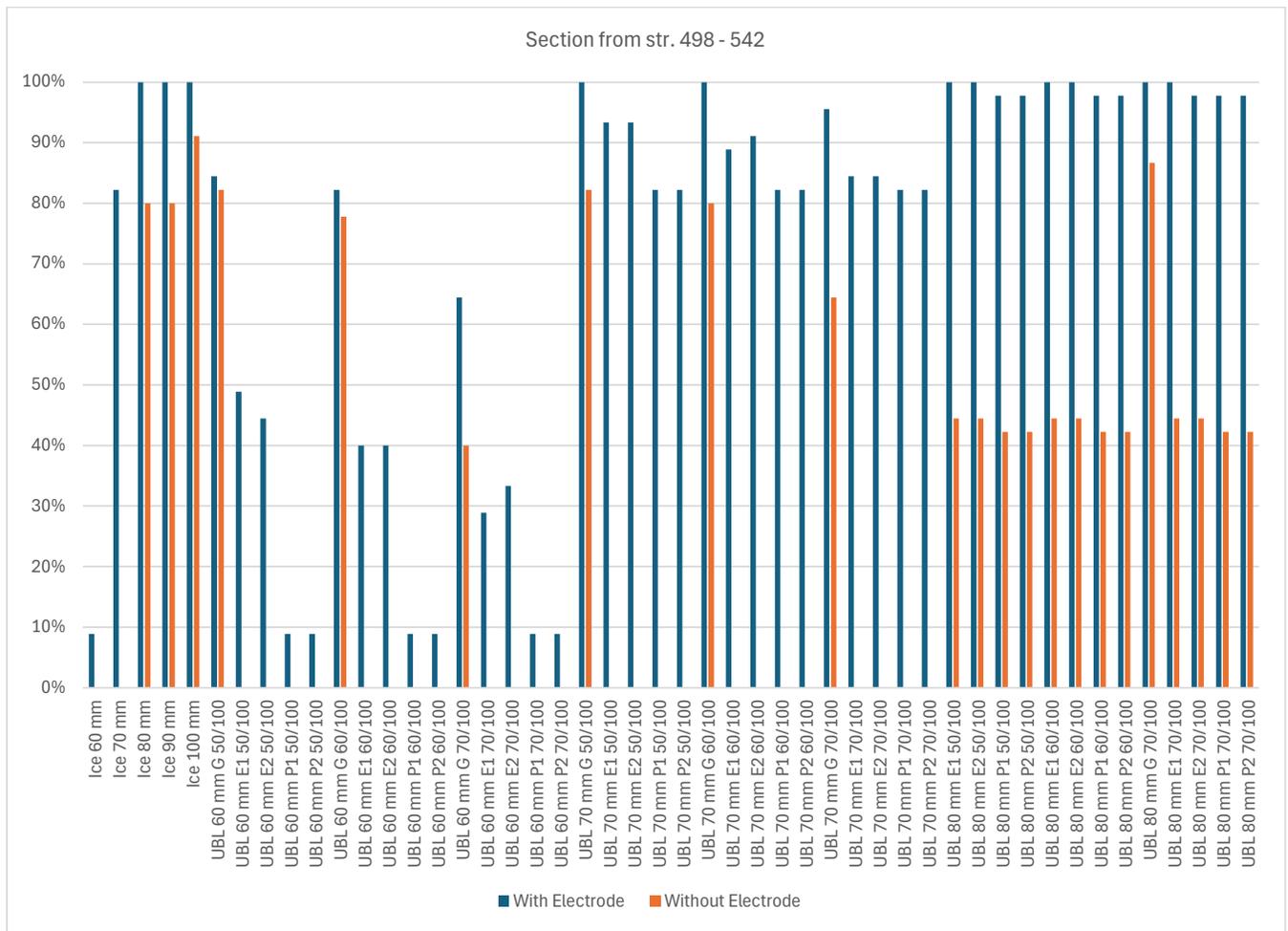


Figure 7- Percentage of Structure Failures - Structure 498 to 542

The results for the section from structure 1209 to 1229 (Figure 8) have less failures than all other section. Under unbalanced ice loading, between 0% and 43% of the structures with the electrode in the section will fail with 60 mm and

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70 mm of ice load, respectively. Without the electrode, there are no structure failures in this section for 60 mm and 70 mm of ice load. With over 70 mm of balanced ice load, 90% of structures will fail with the electrode and between 62% to 86% of structures will fail without the electrode. This shows a clear benefit to removing the electrode in this section.

Under unbalanced ice load (UBL), with 60 mm of ice:

- structures with the electrode:
  - on the OPGW (G) the percentage of structure failures range between 33% to 81% as the unbalance increases,
  - on EL1, EL2, P1, and P2 the percentage of structure failures is much less, ranging from 0% to 10%,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 29% to 81% as the unbalanced increases,
  - on EL1, EL2, P1, and P2 there are no failures.

Under unbalanced ice load (UBL) with 70 mm of ice:

- structures with the electrode:
  - the percentage of structure failures range between 43% to 86% for all load cases,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failures range between 62% to 81%,
  - on EL1, EL2, P1, and P2 there are no structure failures.

Under unbalanced ice load (UBL) with 80 m of ice:

- structures with the electrode:
  - 81% to 86% of structures failed for all load cases,
- structures without the electrode:
  - on the OPGW (G) the percentage of structure failure for 70/100% unbalanced is 71%,
  - on EL1, EL2, P1, and P2 the percentage of structure failures range from 5% to 10%.

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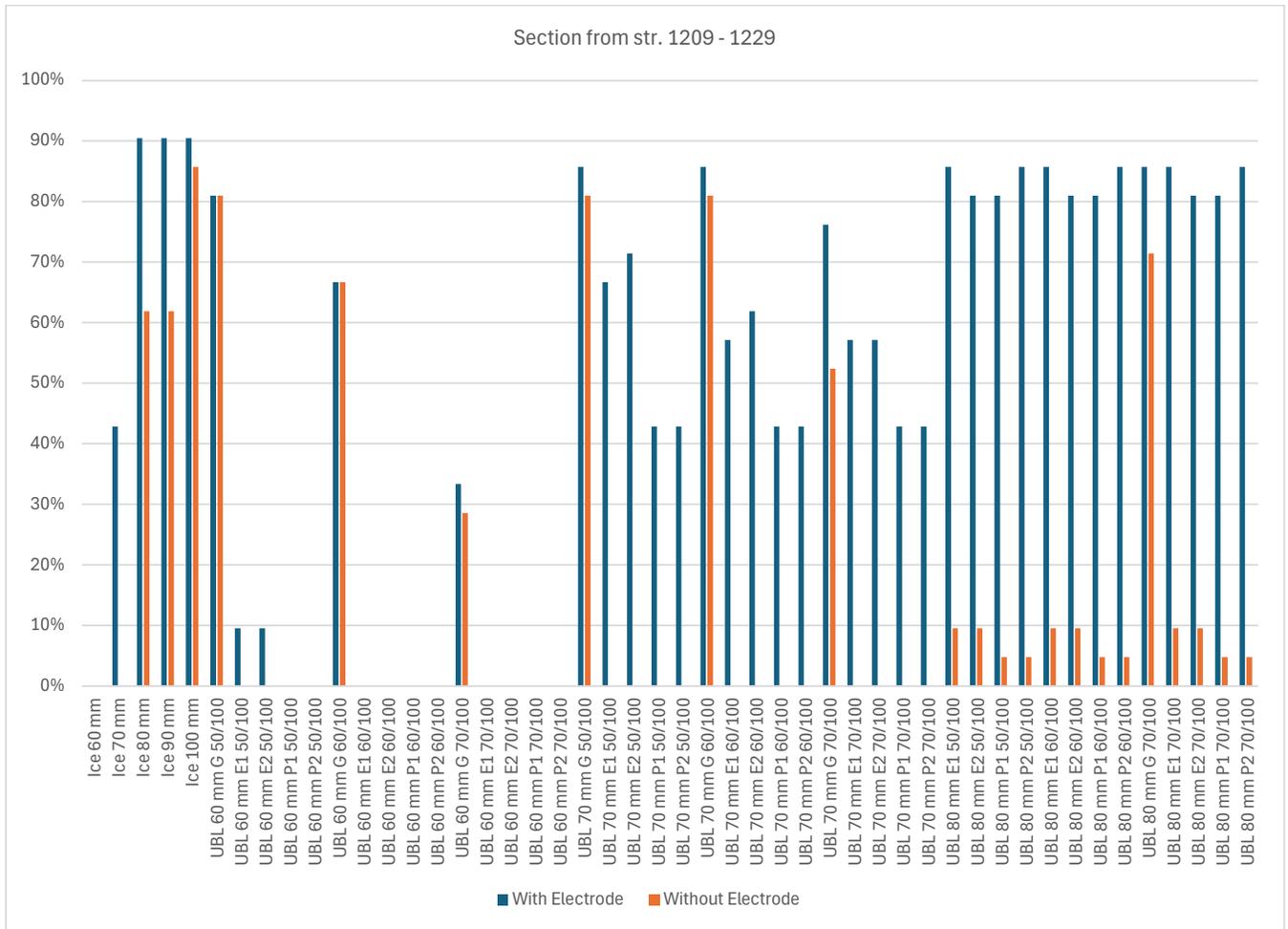


Figure 8 - Percentage of Structure Failures - Structures 1209 to 1229

Figure 9 shows the summary of all sections combined.

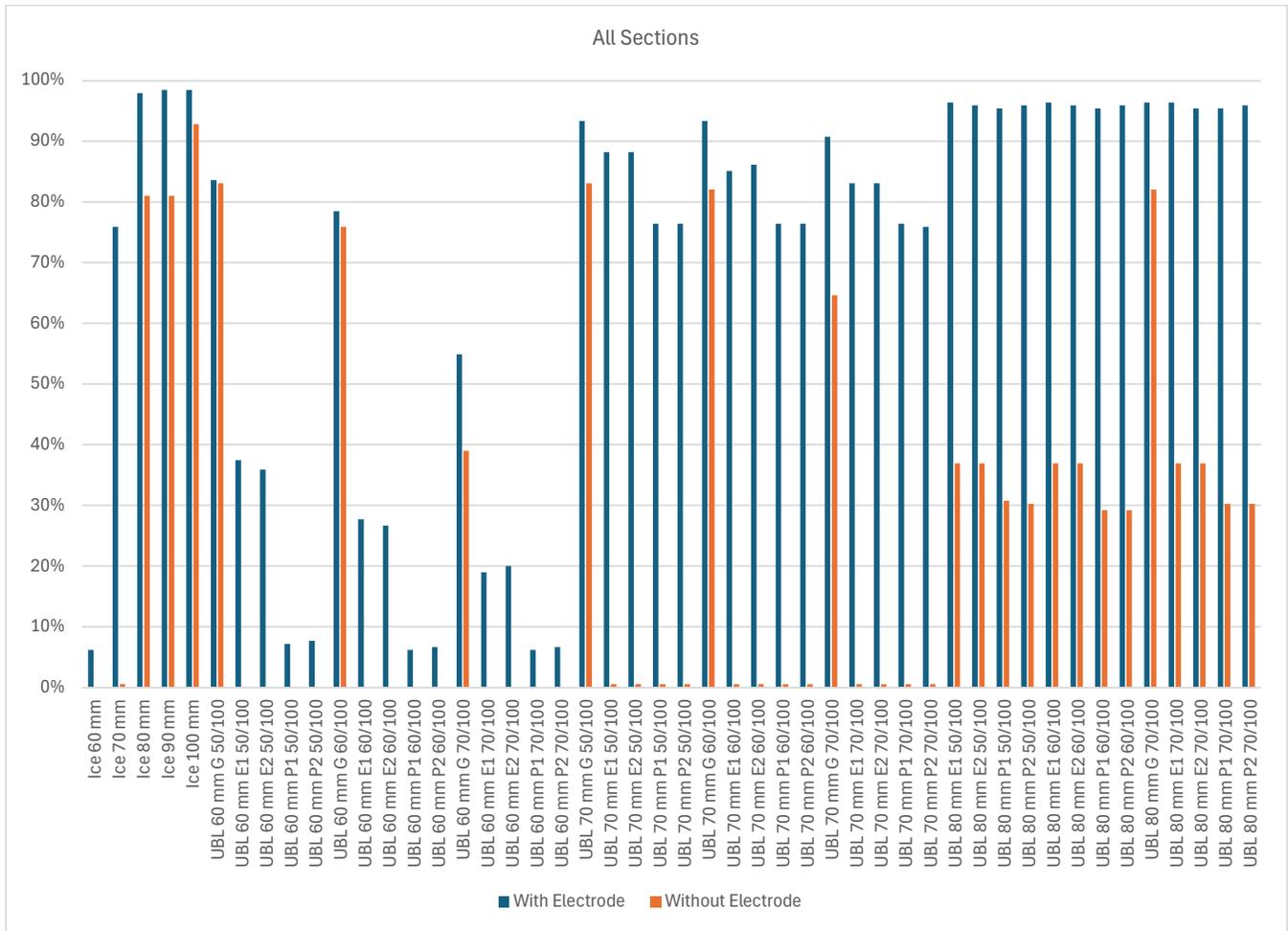


Figure 9 - Percentage of Structure Failures Summary of All Sections

#### 4. Summary, Conclusions, and Recommendations

There have been a number of failures on the L3501/2 transmission line due to ice events over the past 4 years. The electrode crossarms and the electrode conductor are two components that are often damaged in these events, and for all these failures the most probable root cause was determined to be overloading due to unbalanced ice loads.

A possible approach to reduced damage to towers due to icing would be to remove the electrode conductor from the towers and run it parallel to L3501/2 on a wood pole line. Sections where removing the electrode conductor would be beneficial were selected based on a number of factors including: areas with past failures, areas known for high icing, areas of high elevation change, and areas at risk for galloping. Six sections were selected and analyzed.

The analysis shows there is a benefit to removing the electrode conductor from the towers for all sections. Under high icing (greater than the design ice loads) there would be fewer failures of the tower with the electrode removed for both balanced and unbalanced ice. Table 2 shows the comparison of the difference in the percentage of failures in each section without and with the electrode attached to the towers for all load cases. A colour scale is used to show the most beneficial with the highest difference (80 – 90%, dark green) to least beneficial with the least difference (0 – 10%, dark red). The greatest benefits are identified for ice loads of 70 mm. This is to be expected and aligns with the amount of ice that is more likely to occur on the lines. Removal of the electrode conductor does not greatly improve failures due to

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unbalanced ice on the OPGW. The section from structure 498 to 542 shows the most benefit from removal of the electrode, followed by the section from structure 113 to 132. The section from structure 1209 to 1229 differs from the other sections in that the benefits are greater for the higher ice loads than lower ice loads.

*Table 2 - Difference in Percentage Without and With the Electrode Conductor*

Load Case	Difference between Without Electrode and With Electrode						
	All Sections	Str. 113 - 132	Str. 222 - 243	Str. 328 - 370	Str. 424 - 467	Str. 498 - 542	Str. 1209 - 1229
Ice 60 mm	6%	5%	0%	7%	9%	9%	0%
Ice 70 mm	75%	80%	77%	81%	75%	82%	43%
Ice 80 mm	17%	10%	14%	21%	9%	20%	29%
Ice 90 mm	17%	10%	18%	21%	9%	20%	29%
Ice 100 mm	6%	5%	5%	5%	5%	9%	5%
UBL 60 mm G 50/100	1%	0%	0%	0%	0%	2%	0%
UBL 60 mm E1 50/100	37%	40%	36%	35%	41%	49%	10%
UBL 60 mm E2 50/100	36%	45%	27%	35%	41%	44%	10%
UBL 60 mm P1 50/100	7%	10%	0%	7%	11%	9%	0%
UBL 60 mm P2 50/100	8%	10%	0%	9%	11%	9%	0%
UBL 60 mm G 60/100	3%	5%	0%	0%	5%	4%	0%
UBL 60 mm E1 60/100	28%	30%	27%	23%	32%	40%	0%
UBL 60 mm E2 60/100	27%	30%	23%	21%	32%	40%	0%
UBL 60 mm P1 60/100	6%	5%	0%	7%	9%	9%	0%
UBL 60 mm P2 60/100	7%	5%	0%	9%	9%	9%	0%
UBL 60 mm G 70/100	16%	20%	14%	12%	16%	24%	5%
UBL 60 mm E1 70/100	19%	20%	14%	16%	23%	29%	0%
UBL 60 mm E2 70/100	20%	20%	14%	16%	23%	33%	0%
UBL 60 mm P1 70/100	6%	5%	0%	7%	9%	9%	0%
UBL 60 mm P2 70/100	7%	5%	0%	7%	11%	9%	0%
UBL 70 mm G 50/100	10%	5%	5%	14%	7%	18%	5%
UBL 70 mm E1 50/100	88%	90%	86%	91%	89%	93%	67%
UBL 70 mm E2 50/100	88%	90%	86%	88%	89%	93%	71%
UBL 70 mm P1 50/100	76%	80%	82%	81%	75%	82%	43%
UBL 70 mm P2 50/100	76%	85%	77%	81%	75%	82%	43%
UBL 70 mm G 60/100	11%	5%	5%	14%	9%	20%	5%
UBL 70 mm E1 60/100	85%	90%	82%	91%	86%	89%	57%
UBL 70 mm E2 60/100	86%	90%	86%	88%	86%	91%	62%
UBL 70 mm P1 60/100	76%	80%	82%	81%	75%	82%	43%
UBL 70 mm P2 60/100	76%	85%	77%	81%	75%	82%	43%
UBL 70 mm G 70/100	26%	30%	23%	28%	20%	31%	24%
UBL 70 mm E1 70/100	83%	90%	82%	86%	86%	84%	57%
UBL 70 mm E2 70/100	83%	90%	82%	86%	86%	84%	57%
UBL 70 mm P1 70/100	76%	80%	82%	81%	75%	82%	43%
UBL 70 mm P2 70/100	75%	80%	77%	81%	75%	82%	43%
UBL 80 mm E1 50/100	59%	55%	59%	63%	55%	56%	76%
UBL 80 mm E2 50/100	59%	55%	59%	63%	55%	56%	71%
UBL 80 mm P1 50/100	65%	60%	64%	72%	64%	56%	76%
UBL 80 mm P2 50/100	66%	60%	64%	72%	66%	56%	81%
UBL 80 mm E1 60/100	59%	55%	59%	63%	55%	56%	76%
UBL 80 mm E2 60/100	59%	55%	59%	63%	55%	56%	71%

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UBL 80 mm P1 60/100	66%	70%	64%	74%	64%	56%	76%
UBL 80 mm P2 60/100	67%	70%	64%	74%	64%	56%	81%
UBL 80 mm G 70/100	14%	15%	14%	16%	14%	13%	14%
UBL 80 mm E1 70/100	59%	55%	59%	63%	55%	56%	76%
UBL 80 mm E2 70/100	58%	55%	59%	63%	55%	53%	71%
UBL 80 mm P1 70/100	65%	60%	64%	74%	64%	56%	76%
UBL 80 mm P2 70/100	66%	60%	64%	74%	64%	56%	81%

Based on the analysis, removal of sections of the electrode conductor from the towers is a viable technical option for reducing the load on the tower from ice accumulation and therefore reducing the likelihood of failures. This option will be compared to other options such as tower modification to strengthen the electrode crossarms and OPGW peaks, and the installation of midspan structures. The comparison will include the technical benefits of each option as well as the cost.

In addition to reducing the ice loads on the towers, there are several other advantages specific to this option. Any required repairs to the electrode conductor or structures are made easier due to the smaller structure size of the wood poles and the separation from the pole conductors. The electrode conductors would be at a lower elevation and therefore are likely to accumulate less ice.

There are also disadvantages specific to this option. A new right of way (ROW) would be required parallel to the existing L3501/2 ROW. This new ROW will have to be assessed for any conflicts with existing infrastructure or land ownership. The constructability along the new ROW will also have to be assessed. The wood pole line will have shorter span lengths and may not be able to transverse obstacles such as waterbodies and large elevation changes. The removal of the electrode conductor will not address the issues with unbalanced ice loads on the OPGW, which has also led to tower failures.