EA Commitment: EA-LITL-0013

EA Commitment #:

EA-LITL-0013

Asset:

Labrador Island Transmission Link

Source of Commitment:

EIS Section 5.4.2

EA Commitment Status:

Closed

Commitment:

The transmission towers for the Project will meet Nalcor's current ice load standard and are designed for a 50-year return period meteorological event.

References:

350 kV HVdc Line Tower Design Criteria

350 kV HVdc Line Tower Design Criteria

Document Front Sheet

nalcor energy LOWER CHURCHILL PROJECT

SNC·LAVALIN EPCM consultant for Nalcor

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REVIEW DOES NOT CONSTITUTE APPROVAL OF DESIGN DETAILS, CALCULATIONS, TEST METHODS OR MATERIAL DEVELOPED AND/OR SELECTED BY THE CONTRACTOR, NOR DOES IT RELIEVE THE CONTRACTOR FROM FULL COMPLIANCE WITH CONTRACTUAL OR OTHER OBLIGATIONS.

- [x] 01 – REVIEWED AND ACCEPTED – NO COMMENTS
- [ ] 02 – REVIEWED – INCORPORATE COMMENTS, REVISE AND RESUBMIT
- [ ] 03 – REVIEWED - NOT ACCEPTED
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General Comments:

LOWER CHURCHILL PROJECT

350 kV HVdc Line Tower Design Criteria

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REVISION LIST

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Appendices

1 INTRODUCTION

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This document defines the design considerations to adopt in the design process of latticed guyed and self-supported steel towers for overhead 350 kV HVdc transmission line including materials, loads classification, loads combination, strength factors, effective slenderness, limiting conditions, minimum thickness and member connections. It should be read in concurrence with the document design requirements drawings and is part of the following technical specifications:

- 350 kV HVdc Line Full Scale Tower Load Testing Technical Specification (Nalcor Doc. No. ILK-SN-CD-6200-TL-TS-0022-01)
- 350 kV HVdc Line Supply and Testing of Steel Towers Data Sheet (Nalcor Doc. No. ILK-SN-CD-6200-TL-DT-0009-01)

This document does not cover the design considerations for transposition, for river crossings and other long span crossings.

2 REFERENCES

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In general, the 350 kV HVdc transmission line supports will be engineered and designed in accordance with:

- Transmission Line Design Criteria for 350 kV HVdc Muskrat Falls to Soldiers Pond (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)
- 350 kV HVdc Foundation Design Criteria Muskrat Falls to Soldiers Pond (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0007-01)
- CSA C22.3 No. 60826-10, Design Criteria of Overhead Transmission Line
- ASCE 10-97, Design of Latticed Steel Transmission Structures
- IEC 60652, Loading Test of Overhead Line Structures
- Recommendation on Transmission Line Cascading with Particular Reference to Guyed-V and Guyed Single Mast Structures (Nalcor Doc. No. MFA-SN-CD-6000-TL-RP-0001-01)
- Lower Churchill Project – Basis of Design (Nalcor Doc. No. LCP-PT-ED-0000-EN-RP-0001-01)

- Design Philosophy for HVdc Transmission Lines (Nalcor Doc. No. LCP-PT-ED-0000-EN-PH-0022-01)
- DC1051, Field Investigations – HVdc TL – Gull Island to Soldiers Pond, AMEC Earth and Environmental, June 2009
- Overhead Transmission – Meteorological Loading for the Labrador – Island Transmission Link (Nalcor Doc. No. MFA-PT-ED-6200-TL-DC-0002-01)
- DC1070, Preliminary Meteorological Loads, Hatch, August 2008
- DC1080, Preliminary Tower Type Selection, Hatch, January 2009
- 350 kV HVdc Line Supply and Testing of Steel Towers Scope of Work (Nalcor Doc. No. ILK-SN-CD-6200-TL-SP-0010-01)
- 350 kV HVdc Line Supply of Steel Towers Technical Specification (Nalcor Doc. No. ILK-SN-CD-6200-TL-TS-0021-01)
- 350 kV HVdc Line Full Scale Tower Load Testing Technical Specification (Nalcor Doc. No. ILK-SN-CD-6200-TL-TS-0022-01)
- 350 kV HVdc Line Supply and Testing of Steel Towers Data Sheet (Nalcor Doc. No. ILK-SN-CD-6200-TL-DT-0009-01)

3 LANGUAGE AND UNITS

B2 The language to be used for all signage, correspondence, and documentation is English. The units of measurement will be the SI Metric System. Meanwhile, the design will use imperial members with metric designation.

B2 3.1 Abbreviations

ACSR: Aluminum Conductor Steel-Reinforced

EDT: Every Day Temperature

EMI: Electromagnetic Interference

ESDD: Equivalent Salt Deposit Density

HVac: High Voltage alternating current

HVdc: High Voltage direct current

IEEE: Institute of Electrical and Electronics Engineers

OPGW: Optical Ground Wire

PLS-CADD: Power Line Systems – Computer Aided Design and Drafting

ROW: Right-Of-Way

RTS: Rated Tensile Strength

SOBI: Strait of Belle Isle

SLI: SNC-Lavalin Inc.

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3.2 Definitions and Interpretations

Company: Nalcor Energy – Lower Churchill Project

Design Requirement Drawings: Drawings provided by Engineer/Company that list the design requirements of each tower type

Engineer: SNC-Lavalin Inc. (SLI)

Supplier: The party bidding on the requirements of this document.

4 DESIGN CRITERIA

4.1 General

4.1.1 Type of Towers

Guyed towers shall be used for suspension towers and self-supported towers shall be used for medium and large angle towers and dead end terminal supports.

4.1.2 Tower Geometry

The tower families are defined in Section 7. For the same family of towers the geometry of the structure sections should be as similar as possible. The same configuration of bracing should be maintained for all towers of the family.

The tower geometry will comply with all horizontal and vertical distances and all clearances as defined in the Design Requirement Drawings of each tower type.

B2 The pole conductor for Newfoundland and Labrador is the cable ACSR 3633 kcmil.

B2 Two types of OPGW will be used as defined within the design requirements drawings and the design loading drawings: Two OPGW 14.5 mm are used for the 50 mm zone areas and an OPGW 20.6 mm is used for the 75 mm and the alpine areas of Newfoundland and Labrador.

In Labrador, additional two electrode conductors will be strung on the HVdc towers, above the pole conductors. ACSR Grackle conductors will be used for the 50 mm ice zones and ACSR Falcon conductor will be used due to the required stronger mechanical properties in the alpine zone.

4.1.3 Structural Analysis

The structural analysis shall be done using PLS-TOWER software. The non-linear type of analysis shall be applied for guy towers while linear analysis can be applied for rigid towers.

B2 The vector loads for each of the load combinations are given on the design loading drawings, as listed in Appendix D.

B2 After the PLS-TOWER models are completed for the tower design, a second set of tower models shall include the single stub for tower types A1, A2, A3, A4 and B1, and the final pyramid steel foundation installed on the steel grillage for tower types B2, C1, C2, D1, D2, and E1. Two sets of reaction loads shall be defined. One set is at the base of the tower (at the level of the base of leg extension diagonal or at the base of the mast), and the other set of reaction is at the level of the steel grillage.

The 350 kV HVdc Line Foundation Design Criteria (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0007-01) defines the soil data to be used for the stub and grillage design, including the stub/beam/rock anchor design. The foundation design requirement drawings provide the basic geometry of the required foundation types.

B2 The rock foundation type shall be single stub with braces anchored to the rock.

4.1.4 Prototype Testing and Strength Factors

Section 8 defines the permissible stresses to be used. The strength factors are based on the CSA C22.3 No. 60826-10.

Full scale tower load testing shall be done for some towers of the 350 kV HVdc line.

B2

4.2 Bracing

4.2.1 Configuration and Connections

The bracing shall be designed in such a way to reduce the degree of model hyperstaticity and allow simple and clear load flow. It shall be a simple design without unusual eccentricity and allowing easy detailing.

The bracing shall be considered as a tension-compression system. Special care shall be taken in the presence of compression-compression situation in certain load cases, where the member capacity should be computed using the radius of gyration in the plane perpendicular to panel, as per ASCE 10-97.

The horizontal frame bracing shall be previewed in the following cases:

- At the point of change of the main member slope, body, cross-arms and bridge.
- Every sixth level of bracing for self-supporting towers.
- At the level of the lower chord of cross-arms.
- In the tower body at the level of the leg extension and in the body extension.

4.2.2 Redundant Bracing

Redundant bracing should limit the unbraced length of main legs to a maximum of 1.5 m to 2.0 m and assure an easy and secure support for linemen during the erection of the structure. A member at ±30° or less shall cut every big panel formed by the bracing. These values are based on regular practice.

Redundant bracing shall be completely triangulated to avoid any unstable structural mechanism. As a regular practice, the redundant bracing members are not part of the PLS-TOWER models, except for the crossarm bottom face and the ground wire peak faces. Special care needs to be brought on the redundant members when the angle between the main leg and the main bracing is less than 20°.

4.2.3 Member Angle Incidence

The angle between any two members common to a joint of a latticed frame shall be generally greater than 20° but definitely not less than 15° due to uncertainty of stress distribution between two closely spaced members. An angle between 15° and 20° could be acceptable, if Supplier proves the accuracy of the load distribution by calculations or an appropriate software model for Acceptance by Engineer.

B2

4.2.4 Bending in Diagonals

All horizontal and diagonal members with a large non-supported length may be subject to bending stress due to ice and combination of ice and wind. This situation shall be checked by Supplier. The panels shall be made more rigid if necessary.

4.3 Extension Dispositions

4.3.1 Guyed Towers

B2

Different configuration for guyed towers shall be considered including the height variation from minimum to maximum and guy position variation related to base level. Table 4.1 lists the mast extension sets to be used for tower types A1, A2, A3, A4, and B1.

B2

Table 4.1: Mast Extension Sets

TYPE OF SUSPENSION TOWER					MAST EXTENSION (m)				
A1	A2	A3	A4	B1	1.5	3.0	6.0	7.5	9.0
H + 0	H + 0	H + 0	H + 0	H + 0	-	-	-	-	-
H + 1.5	H + 1.5	H + 1.5	H + 1.5	H + 1.5	1	-	-	-	-
H + 3	H + 3	H + 3	H + 3	H + 3	-	1	-	-	-
H + 4.5	H + 4.5	H + 4.5	H + 4.5	H + 4.5	1	1	-	-	-
H + 6	H + 6	H + 6	H + 6	H + 6	-	-	1	-	-
H + 7.5	H + 7.5	H + 7.5	H + 7.5	H + 7.5	-	-	-	1	-
H + 9	H + 9	H + 9	H + 9	H + 9	-	-	-	-	1
H + 10.5	H + 10.5	H + 10.5	H + 10.5	H + 10.5	-	1	-	1	-
H + 12	H + 12	H + 12	H + 12	H + 12	-	-	2	-	-
H + 13.5	H + 13.5	H + 13.5	H + 13.5	H + 13.5	-	-	1	1	-
H + 15	H + 15	H + 15	H + 15	H + 15	-	-	-	2	-
H + 16.5	H + 16.5	H + 16.5	H + 16.5	H + 16.5	-	-	-	1	1
H + 18	H + 18		H + 18	H + 18	-	-	-	-	2
-	H + 19.5		H + 19.5	H + 19.5	-	-	2	1	-
-	-		-	H + 21	-	-	2	-	1
-	-		-	H + 22.5	-	-	-	3	-
-	-		-	H + 24	-	-	1	-	2
-	-		-	H + 25.5	-	-	-	1	2
-	-		-	H + 27	-	-	-	-	3

4.3.2 Self-Supported Towers

For self-supporting towers, different combinations of leg extensions with and without a body extension shall be analyzed. Tower heights shall be analyzed with all combinations of leg extensions shown in Table 4.2 for tower types B2, C1, C2, D1, D2, and E1.

B2

Table 4.2 is based on past experiences on similar tower types, displaying the most critical equal/unequal leg combinations.

Table 4.2: Leg Extension Configuration

	Legs			
Configuration	P1	P2	P3	P4
1	L_{min}	L_{min}	L_{min}	L_{min}
2	L_{max}	L_{max}	L_{max}	L_{max}
3	L_{min}	L_{min} + Gap	L_{min} + Gap	L_{min}
4	L_{min}	L_{min}	L_{min} + Gap	L_{min} + Gap
5	L_{min}	L_{min} + Gap	L_{min} + Gap	L_{min} + Gap
6	L_{min} + Gap	L_{min}	L_{min}	L_{min} + Gap
7	L_{min} + Gap	L_{min} + Gap	L_{min}	L_{min}
8	L_{min} + Gap	L_{min} + Gap	L_{min}	L_{min} + Gap

B2

Where:

L_{min} = Minimum length of leg
L_{max} = Maximum length of leg

Gap = Maximum length allowed as difference between the legs as per the design requirements drawings (+4.5 m or +6.0 m, see Table 4.4 for details)

Table 4.3 lists the definition of the body/leg extension and foundation design for the tower types B2, C1, C2, D1, D2, and E1.

B2

Table 4.3: Body/Leg Extension Sets

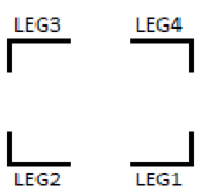
TYPE OF ANGLE AND DEAD-END TOWER						BODY EXT. (m)		LEG EXTENSION (m)						
B2	**C1**	**D1**	**C2**	**D2**	**E1**	**4.5**	**10.5**	**0**	**1.5**	**3.0**	**4.5**	**6.0**	**7.5**	**9.0**
H + 0	H + 0	H + 0	H + 0	H + 0	H + 0	-	-	4	-	-	-	-	-	-
H + 1.5	H + 1.5	H + 1.5	H + 1.5	H + 1.5	H + 1.5	-	-	-	4	-	-	-	-	-
H + 3	H + 3	H + 3	H + 3	H + 3	H + 3	-	-	-	-	4	-	-	-	-
H + 4.5	H + 4.5	H + 4.5	H + 4.5	H + 4.5	H + 4.5	-	-	-	-	-	4	-	-	-
H + 6	H + 6	H + 6	H + 6	H + 6	H + 6	-	-	-	-	-	-	4	-	-
H + 7.5	H + 7.5	H + 7.5	H + 7.5	H + 7.5	H + 7.5	-	-	-	-	-	-	-	4	-
H + 9	H + 9	H + 9	H + 9	H + 9	H + 9	-	-	-	-	-	-	-	-	4
H + 10.5	H + 10.5	H + 10.5	H + 10.5	H + 10.5	H + 10.5	1	-	-	-	-	-	4	-	-
H + 12	H + 12	H + 12	H + 12	H + 12	H + 12	1	-	-	-	-	-	-	4	-
H + 13.5	H + 13.5	H + 13.5	H + 13.5	H + 13.5	H + 13.5	1	-	-	-	-	-	-	-	4
H + 15	H + 15	H + 15	-	-	H + 15	-	1	-	-	-	4	-	-	-
H + 16.5	H + 16.5	H + 16.5	-	-	H + 16.5	-	1	-	-	-	-	4	-	-
H + 18	H + 18	H + 18	-	-	H + 18	-	1	-	-	-	-	-	4	-
H + 19.5	H + 19.5	H + 19.5	-	-	H + 19.5	-	1	-	-	-	-	-	-	4

Table 4.4: Leg Extension Arrangement

MODELS NAMES FOR HVdc LINE

LEG EXTENSION TOWER C2 AND D2

ARANGEMENT	Body Extension	LEG1	LEG2	LEG3	LEG4
C2A and D2A	--	0.0	0.0	0.0	0.0
C2B and D2B	--	9.0	9.0	9.0	9.0
C2C and D2C	--	0.0	6.0	6.0	0.0
C2D and D2D	--	0.0	0.0	6.0	6.0
C2E and D2E	--	0.0	6.0	6.0	6.0
C2F and D2F	--	6.0	0.0	0.0	6.0
C2G and D2G	--	6.0	6.0	0.0	0.0
C2H and D2H	--	6.0	6.0	0.0	6.0
C2I and D2I	--	3.0	9.0	9.0	3.0
C2J and D2J	--	3.0	3.0	9.0	9.0
C2AB and D2AB	+4.5	0.0	0.0	0.0	0.0
C2BB and D2BB	+4.5	9.0	9.0	9.0	9.0
C2CB and D2CB	+4.5	0.0	6.0	6.0	0.0
C2DB and D2DB	+4.5	0.0	0.0	6.0	6.0
C2EB and D2EB	+4.5	0.0	6.0	6.0	6.0
C2FB and D2FB	+4.5	6.0	0.0	0.0	6.0
C2GB and D2GB	+4.5	6.0	6.0	0.0	0.0
C2HB and D2HB	+4.5	6.0	6.0	0.0	6.0
C2IB and D2IB	+4.5	3.0	9.0	9.0	3.0
C2JB and D2JB	+4.5	3.0	3.0	9.0	9.0



LEG EXTENSION TOWER B2, C1 AND D1

ARANGEMENT	Body Extension	LEG1	LEG2	LEG3	LEG4
B2A, C1A and D1A	--	0.0	0.0	0.0	0.0
B2B, C1B and D1B	--	9.0	9.0	9.0	9.0
B2C, C1C and D1C	--	0.0	4.5	4.5	0.0
B2D, C1D and D1D	--	0.0	0.0	4.5	4.5
B2E, C1E and D1E	--	0.0	4.5	4.5	4.5
B2F, C1F and D1F	--	4.5	0.0	0.0	4.5
B2G, C1G and D1G	--	4.5	4.5	0.0	0.0
B2H, C1H and D1H	--	4.5	4.5	0.0	4.5
B2I, C1I and D1I	--	4.5	9.0	9.0	4.5
B2J, C1J and D1J	--	4.5	4.5	9.0	9.0
B1AB1, C1AB1 and D1AB1	+4.5	0.0	0.0	0.0	0.0
B1BB1, C1BB1 and D1BB1	+4.5	9.0	9.0	9.0	9.0
B1CB1, C1CB1 and D1CB1	+4.5	0.0	4.5	4.5	0.0
B1DB1, C1DB1 and D1DB1	+4.5	0.0	0.0	4.5	4.5
B1EB1, C1EB1 and D1EB1	+4.5	0.0	4.5	4.5	4.5
B1FB1, C1FB1 and D1FB1	+4.5	4.5	0.0	0.0	4.5
B1GB1, C1GB1 and D1GB1	+4.5	4.5	4.5	0.0	0.0
B1HB1, C1HB1 and D1HB1	+4.5	4.5	4.5	0.0	4.5
B1IB1, C1IB1 and D1IB1	+4.5	4.5	9.0	9.0	4.5
B1JB1, C1JB1 and D1JB1	+4.5	4.5	4.5	9.0	9.0
B1AB2, C1AB2 and D1AB2	+10.5	0.0	0.0	0.0	0.0
B1BB2,C1BB2 and D1BB2	+10.5	9.0	9.0	9.0	9.0
B1CB2,C1CB2 and D1CB2	+10.5	0.0	4.5	4.5	0.0
B1DB2,C1DB2 and D1DB2	+10.5	0.0	0.0	4.5	4.5
B1EB2,C1EB2 and D1EB2	+10.5	0.0	4.5	4.5	4.5
B1FB2,C1FB2 and D1FB2	+10.5	4.5	0.0	0.0	4.5
B1GB2,C1GB2 and D1GB2	+10.5	4.5	4.5	0.0	0.0
B1HB2,C1HB2 and D1HB2	+10.5	4.5	4.5	0.0	4.5
B1IB2,C1IB2 and D1IB2	+10.5	4.5	9.0	9.0	4.5
B1JB2,C1JB2 and D1JB2	+10.5	4.5	4.5	9.0	9.0

LEG EXTENSION TOWER E1

ARANGEMENT	Body Extension	LEG1	LEG2	LEG3	LEG4
E1A	--	0.0	0.0	0.0	0.0
E1B	--	9.0	9.0	9.0	9.0
E1C	--	0.0	6.0	6.0	0.0
E1D	--	0.0	0.0	6.0	6.0
E1E	--	0.0	6.0	6.0	6.0
E1F	--	6.0	0.0	0.0	6.0
E1G	--	6.0	6.0	0.0	0.0
E1H	--	6.0	6.0	0.0	6.0
E1I	--	3.0	9.0	9.0	3.0
E1J	--	3.0	3.0	9.0	9.0
E1AB1	+4.5	0.0	0.0	0.0	0.0
E1BB1	+4.5	9.0	9.0	9.0	9.0
E1CB1	+4.5	0.0	6.0	6.0	0.0
E1DB1	+4.5	0.0	0.0	6.0	6.0
E1EB1	+4.5	0.0	6.0	6.0	6.0
E1FB1	+4.5	6.0	0.0	0.0	6.0
E1GB1	+4.5	6.0	6.0	0.0	0.0
E1HB1	+4.5	6.0	6.0	0.0	6.0
E1IB1	+4.5	3.0	9.0	9.0	3.0
E1JB1	+4.5	3.0	3.0	9.0	9.0
E1AB2	+10.5	0.0	0.0	0.0	0.0
E1BB2	+10.5	9.0	9.0	9.0	9.0
E1CB2	+10.5	0.0	4.5	4.5	0.0
E1DB2	+10.5	0.0	0.0	4.5	4.5
E1EB2	+10.5	0.0	4.5	4.5	4.5
E1FB2	+10.5	4.5	0.0	0.0	4.5
E1GB2	+10.5	4.5	4.5	0.0	0.0
E1HB2	+10.5	4.5	4.5	0.0	4.5
E1IB2	+10.5	4.5	9.0	9.0	4.5
E1JB2	+10.5	4.5	4.5	9.0	9.0

4.4 Foundation Reactions

A table of maximum individual foundation reactions and the maximum combination of reaction for every configuration and every usage of towers shall be supplied on the drawings.

- Foundation reactions at the base of the tower.
- Foundation reactions at the level of the steel grillage.

B2 For each of these situations acting with uplift, the Supplier shall provide the reactions due to high wind, wind and ice, and other cases including unbalanced ice load and broken wire which are necessary for foundation design.

B2 The foundation reactions for self-supporting towers shall be also computed along the main leg axis with residual shear components (P_w and P_z acting perpendicular to the leg).

The impact of the unequal legs shall be quantified.

B2 The Supplier is responsible to complete the design of the steel foundation types 1 and 2 (stub or pyramid with grillage) and foundation type 3 (rock foundation).

4.5 Guyed Tower Design

4.5.1 Width of Mast

The width of mast shall be carefully chosen to facilitate the assembly of towers on site. Maximum width of mast shall not be beyond 2.5 m.

4.5.2 Guy Slope

The slope of guy wires shall be optimal and shall not be greater than 40° against the vertical axis of the structure, in general.

4.5.3 Guy Wire Crossarms

Guy wire crossarms shall be used for tower types A and B.

4.5.4 Wind and Ice on the Guy Wires

Wind load shall be applied perpendicular to the whole length of guy wires regardless of the orientation.

70% of the guy ice load and the guy dead load shall be applied at the structure. In the case of combined wind and ice, the increase in guy tension due to these loads shall be taken into account.

4.5.5 Guy Wire Tension

The design tension in the guy wires shall not exceed 0.70 times the specified minimum rated tensile strength (RTS) of the guy wire for intact load cases and 0.90 times the specified minimum RTS of the guy wire for broken conductor or broken OPGW load cases.

B2 Based on further investigation by the line hardware supplier, the insallation of dampers may be considered, if required.

4.5.6 Guy Wire Pretension

The guy wire pretension shall be between 5 and 10% of RTS, or maximum of 80 kN. The lesser of these two values shall be adopted in the design. These values are based on normal practice.

B2 The Supplier shall indicate on the drawings the guy wire tension under every day conditions (no ice, no wind) and from -30°C to +30°C, in steps of 10°C. The minimum and maximum acceptable values of tension shall be noted for the allowable installation tolerance.

4.5.7 Guy Wire Anchor Installation

The guy wire implantation tolerance related to the theoretical position of guy wires at the ground level, shall be within a 450 mm radius for design purpose. However, the permitted value of 300 mm shall be shown on construction drawings.

4.5.8 Ground Slope

For suspension towers, the analysis shall include the case of a ground slope of 15°. Moreover, a difference of 25 m shall be analyzed for maximum differential guy length.

4.5.9 Mast Buckling

B2 The Supplier shall verify the global buckling of the mast and correct the design if necessary. The buckling check shall be done by using a fictitious reduced modulus of elasticity, replacing the normal value of 200 GPa by a value of 70 GPa for all member groups or by one of known and approved method. If the tower is not showing instability, then the buckling check is completed. The buckling verification shall be performed without dummy members with an appropriate use of beam elements.

The result of this global check shall not be used for the strength verification of the individual member. If the buckling check is showing instability, then the tower design must be revised by Supplier.

4.5.10 Foundation Uplift

B2

The guyed structures are not considered for mast uplift. This requirement is withdrawn considering foundation is constructed below frost depth.

4.5.11 Tower Deflection

B2

The Supplier shall provide the horizontal displacement due to maximum wind, combined wind and ice, unbalanced ice, broken guy, and broken conductor for the minimum and maximum heights of the structure.

5 MATERIAL

5.1 Structural Steel

Structural steel for members of tower supports and gusset plates shall conform to the provision of the latest revisions of the following or equivalent standards:

- CSA G40.21 350WT or ASTM A572 Gr. 50, compliant with the minimum charpy test requirement of 20J at -20 deg C: minimum yield strength Fy = 345 MPa

B2

The steel material, angles and gussets may comply with imperial units but shall be described in drawings and in design computations in metric units.

The complete design shall be done by using the same steel quality for all steel members with values of F_y = 345 MPa and F_μ = 450 MPa.

Metric size steel angles from outside of North American mills can be used only if equivalent to North-American standards in all aspects, including the chemical characteristics, geometrical dimensions, strength capacity, detailing and erection.

5.2 Bolts, Nuts and Washers

All connecting material shall conform to ASTM or ANSI/ASME as follows:

- Threads according to ANSI/ASME B1.1 “Unified Inch Screw Threads”,
- Bolts ASTM A394 Type 1, hexagonal head, manufactured in USA or Canada,
- Nuts ASTM A563, Class A,

- Lock Washers ANSI/ASME B18.21.1 or equivalent,
- Plain washers ANSI/ASME B18.22.1 or equivalent,
- Beveled washers ASTM F436.

All bolts shall be provided with hot-dip galvanized steel spring lock washers.

5.3 Guy Wires

The material for guy wires shall be galvanized conforming to class A, coating throughout complying with ASTM A586, Grade 1 or with the CSA G12, GR.220. The diameter of guy wires shall be specified in imperial units on the drawings. Appendix A includes the table of guy wires, diameters and ultimate breaking strengths. Section 8 describes the applicable strength factors to be used. B2

5.4 Galvanizing

All structural steel members including bolts, nuts, washers and stub angles shall be hot-dip galvanized after manufacturing in accordance with the requirement of ASTM A123 and ASTM A143.

Protection against embrittlement shall be in accordance with ASTM A143. Protection against warpage and distortion shall be in accordance with ASTM A384. Zinc-coated tower bolts shall comply with ASTM A394.

6 LOAD CLASSIFICATION

The transmission line loads are classified into four distinct categories:

- Climatic loads: Loads due to environmental and ambient conditions imposed on tower supports by action of wind and ice associated with coincident temperatures.
- Failure containment loads: Loads due to conductor failure or line component failure, sabotage or cascade failure.
- Longitudinal unbalanced loads: Unbalanced ice.
- Construction and Maintenance loads: Loads due to erection, stringing and maintenance activities.

Tower supports shall be designed to withstand all climatic loads including their simultaneous application, failure containment loads, erection, stringing and maintenance as specified for each category.

6.1 Climatic Loads

B2 The climatic loads to be used for each of the zones are given in the following tables. All applicable vector loads are given on the design loading drawings (see Appendix D for the list of design drawings).

The bottom notes of each weather case table identify the tower types to be designed for those weather case areas.

B2

Table 6.1: Weather Data for Tower Family F1 (Loading Zone 1)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	105	980
Wind+Ice	-5	-5	25	900	60	305
Max ice	-5	-5	50	900	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-30	-30	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	295
Max Wind Swing	-20	-20	0	0	-	785
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable for tower types: A1, B1/B2*, C1, D1, and E1.
*-good for all loading zones.

B2

Table 6.2: Weather Data Table for Tower Family F2 (Loading Zone 2b)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	135	2070
Wind+Ice	-5	-5	70	500	95	970
Max ice	-5	-5	135	500	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-30	-30	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	620
Max Wind Swing	-20	-20	0	0	-	1655
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable for tower types: A2, B1/B2*, C2, D2, and E1.
*-good for all loading zones.

B2

Table 6.3: Weather Data for Tower Family F3 (Loading Zone 3a)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	120	1290
Wind+Ice	-5	-5	25	900	60	305
Max ice	-5	-5	50	900	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-30	-30	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	385
Max Wind Swing	-20	-20	0	0	-	1030
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable for tower types: A1, B1/B2*, C1, D1, and E1.
*-good for all loading zones.

B2

Table 6.4: Weather Data for Tower Family F4 (Loading Zone 8b, 10)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	105	980
Wind+Ice	-5	-5	25	900	60	305
Max ice	-5	-5	50	900	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-15	-15	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	295
Max Wind Swing	-20	-20	0	0	-	785
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable for tower types: A1, B1/B2*, C1, D1, and E1.
*-good for all loading zone

B2

Table 6.5: Weather Data for Tower Families F5 & F10 (Loading Zones 3b, 4b, 4a, 6, 8a)

Weather cases	Wire/ Conductor Temp (°C)	Ambient Temp (°C)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	120	1290
Wind+Ice	-5	-5	25	900	60	305
Max ice	-5	-5	50	900	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-15	-15	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	385
Max Wind Swing	-20	-20	0	0	-	1030
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable to tower types: A1, B1/B2*, C1, D1, and E1 for zones 4a, 6, and 8a
A3, B1/B2*. C1, D1, and E1 for zones 3b and 4b
*-good for all loading zones.

B2

Table 6.6: Weather Data Table for Tower Family F6 (Loading Zone 7b)

Weather cases	Wire/ Conductor Temp (°C)	Ambient Temp (°C)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	180	3460
Wind+Ice	-5	-5	125	500	125	1580
Max ice	-5	-5	135	500	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-38	-38	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	1040
Max Wind Swing	-20	-20	0	0	-	2770
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable to tower types: A4, B2, C2, D2, and E1

B2

Table 6.7: Weather Data Table for Tower Families F7 And F8 (Loading Zones 9, 11a, 11b)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	130	1515
Wind+Ice	-5	-5	45	900	60	305
Max ice	-5	-5	75	900	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-15	-15	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	455
Max Wind Swing	-20	-20	0	0	-	1210
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable to tower types: A3, B1/B2*, C1, D1, and E1.
*-good for all loading zones.

B2

Table 6.8: Weather Data Table for Tower Family F9 (loading zone 7a, 7c)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	180	3460
Wind+Ice	-5	-5	60	500	125	1580
Max ice	-5	-5	115	500	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-15	-15	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	1040
Max Wind Swing	-20	-20	0	0	-	2770
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable to tower types: A4, B2, C2, D2, and E1

B2

Table 6.9: Weather Data for Tower Family F11 (Loading Zones 2a, 2c)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	135	2070
Wind+Ice	-5	-5	70	500	95	970
Max ice	-5	-5	135	500	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-15	-15	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	620
Max Wind Swing	-20	-20	0	0	-	1655
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable to tower types: A2, B2, C2, D2, and E1

B2

Table 6.10: Weather Data Table for Tower Family F12 (loading zone 5)

Weather cases	Wire/ Conductor Temp (℃)	Ambient Temp (℃)	Radial Ice (mm)	Ice Density (kg/m^3)	Wind Speed (km/h)	Cable Wind Pressure (Pa)
EDT	0	0	0	0	-	0
Max wind	-20	-20	0	0	150	2450
Wind+Ice	-5	-5	60	500	105	1135
Max ice	-5	-5	115	500	-	0
Hot	85	30	0	0	-	0
45 Pa	-30	-30	0	0	-	45
Cold	-15	-15	0	0	-	0
Reduced Wind Swing	-20	-20	0	0	-	735
Max Wind Swing	-20	-20	0	0	-	1960
Galloping Swing	0	0	12.7	900	45	95.8
Galloping Sag	0	0	12.7	900	0	0

Note: These data are applicable to tower types: A2, B2, C2, D2, and E1

6.1.1 Wind Loads

Under these types of loads the following shall be considered:

- All wires intact
- Wind acting normal or oblique at 45° to the transverse/longitudinal face of tower supports
- The wind pressure acting on the structure shall be applied as per the tables above, on the vertical projection of area.
- The wind pressure acting on the conductor or ground wire shall be applied as per Tables 6.1 to 6.10, acting normal or oblique at 45° to the wires on the effective projection of area
- Wire tension corresponding to the applied pressure shall be the final condition conforming to the temperature given in Section 6.

6.1.2 Ice Loads

Under these types of loads, the following shall be considered:

- All wires intact
- Wire tension corresponding to the applied pressure shall be the final condition conforming to temperature in the table above
- The ice shall be considered as radial ice forming a cylinder around the conductor.

6.1.3 Wind and Ice Combination

Under these types of loads, the following shall be considered:

- All wires intact
- Wind acting normal to the longitudinal face of the tower supports only
- The wind pressure acting on the structure shall be applied as per Tables 6.1 to 6.10 on the vertical projection of steel area
- The wind pressure acting on the conductor or ground wire shall be applied as per Tables 6.1 to 6.10, acting normal to the wires on the effective projection of area including the conductor and the radial ice thickness
- Wire tension corresponding to the applied pressure shall be the final condition conforming to the temperature in the table given above

- The ice shall be considered as radial ice forming a cylinder around the conductor
- Wind load shall be applied on iced guy wire and iced tower members
- B2 For loading zones 2a-2c,2b,5,7a-7a and 7b, the appropriate ice- bridging indicated in the design requirement drawings on guyed tower mast shall be considered.

6.2 Failure Containment Loads

Longitudinal loads may occur on tower supports due to the failure of line components such as a broken conductor or a broken ground wire, insulator hardware component failure or tower component failure including dynamic effect or longitudinal unbalanced loads due to ice.

6.2.1 Torsion Loads – Broken Wire Loads

6.2.1.1 Broken Conductor or Ground Wire

350 kV HVdc transmission line is single circuit line with a horizontal pole configuration. The number of conductors/ground wires to consider in the case of broken wire load shall be one conductor at a time for the suspension tower types A and B. Each broken wire case shall be considered in a separate combination. For the tower types C, D and E, broken wire cases shall be considered for one or two or all of the broken cables. For the Labrador line portion with electrode conductor, suspension tower types A and B shall be designed for one pole and one electrode conductor at the same time.

6.2.1.2 Anti-Cascading Criteria

A dynamic impact of 1.5 shall be applied to the transverse and longitudinal loads for the everyday condition for the suspension tower types A and B one conductor at a time.

A dynamic impact of 2.0 shall be applied to the transverse and longitudinal loads for everyday conditions for the strain tower type C for any one of the wire locations, but with all conductors broken at the same time.

A dynamic impact of 2.5 shall be applied to the transverse and longitudinal loads for everyday conditions for the terminal towers type D and E for any one of the wire locations, but with all conductors broken at the same time.

All broken conductor loading cases shall be calculated under no ice, no wind and at 0°C. Dynamic impact factors are defined within Nalcor Doc. No. MFA-SN-CD-6000-TL-RP-0001-01, and are applicable to one conductor at a time.

6.2.2 Normal Unbalanced Ice

For suspension towers, unbalanced ice loads shall be checked by 100% of ice at one side and 70% of ice on the other side, one conductor at a time. The residual static load should not be considered.

For strain tower types C, D and E, unbalanced ice load shall be checked with ice load at one side and no ice at the other side, with any combination of one or two or all cables.

6.2.3 Extreme Unbalanced Ice

For strain towers, unbalanced ice loads shall be checked with full ice load on one side and no conductor on the other side, for one conductor at a time.

For unbalanced ice, no dynamic impact shall be used.

B2 Appendix D gives the list of the design loading drawings to be used with the PLS-TOWER software for each of the tower types.

B2 6.2.4 Broken Guy Wire - The requirement is withdrawn

6.3 Construction and Maintenance Loads

A construction-tie-down load shall be applied to all tower types. The tie-down angle is to be maintained at a 4H:1V slope and a 5° horizontal deviation angle (±2.5° for tangents only) shall be considered to account for any ROW constraints encountered while stringing in the case of tangent structures. The B2 design check is done with a tie-down angle of 3H:1V.

For angle structures, horizontal deviation can be achieved through reducing the pull-through angle and the tie-down shall be designed assuming the full tower design deflection angle with no additional horizontal deviation.

All attachment points in these load cases shall be charged with 4.0 kN, presenting the crew weight with tools.

Climatic condition to be used under these conditions are at condition no ice, 45 Pa wind, at -30°C.

All temporary lift or tension points used for maintenance or line operations shall be able to support twice the bare conductor loads at sagging tension.

All horizontal members or members with an angle smaller than 30° shall be designed to also carry a vertical load of 1.5 kN (weight of lineman with tools) applied at the member mid-point in combination with the stresses present during maintenance. This load shall be applied independently of all other loads without permanent distortion of the members.

For construction and maintenance loads, a strength factor of 0.5 shall be used.

6.4 Computation of Loads

6.4.1 Sag and Tension Values

Sag and tension values for the conductors and ground wires that are used for the computation of tower loads were determined for all loading cases while respecting the limit tension conditions specified in the Transmission Line Design Criteria for 350 kV HVdc (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01).

B2 PLS-CADD\LITE software is used for sag calculation and point load computations.

Transversal, longitudinal and vertical loads for various loading conditions specified in this document and on design loading drawing were determined in accordance with the procedures described in this document and shall be used when proceeding with stress calculations and design.

Tower supports shall be designed to withstand simultaneous action of these loads with application of strength factors depending on design condition. These factors are defined in CSA C22.3 No. 60826-10, Art. 7.3.3.

6.4.2 Transversal Loads

6.4.2.1 Wind on conductors and Ground Wires

Dynamic reference wind pressure: (See Appendix B for detailed calculations)

$$q_0 = 0.5 \times \tau \times \mu \times (K_R \times V_{RB})^2$$

Where:

	q_0	=	Design wind pressure in Pa
	τ	=	Air density correction factor
	μ	=	Air mass per unit volume equal 1.225 kg/m^3 at 15℃ at the sea level
	K_R	=	Coefficient of terrain roughness
	V_{RB}	=	Reference wind speed -10 minute wind speed

Load due to wind on conductor wire/ground wire (T_w):

$$T_w = q_0 \times C_c \times L \times d \times n \times G_c$$

Where:	C_c	=	Drag coefficient on the conductor considered equal to 1.0
	L	=	Wind span, being the sum of half the ahead and back spans in m
	d	=	Diameter of conductor/ground wire, in m
	n	=	Number of conductors in bundle
	G_c	=	See Appendix C for definition and reference

Note: The wind span is used to calculate the transverse vector load acting on tower, without any reduction resulting from the line deviation angle.

Load due to wind on insulator assembly (T_{iw}):

$$T_{iw} = q_0 \times C_{ci} \times G_t \times S_i$$

Where:	q_0	=	Design wind pressure in Pa
	C_{ci}	=	Drag coefficient considered equal to 1.2
	G_t	=	Combined wind factor
	S_i	=	Effective projected area of insulator strings in m^2

6.4.2.2 Wind on Conductors with Ice

The same equations will be applied with an adjustment of 2 x the radial thickness of ice added to the diameter of the conductor.

6.4.2.3 Line Deviation Load

Load due to line deviation:

For intact span

$$T_c = 2 \times n \times H \times \sin\left(\frac{\theta}{2}\right)$$

$$L_c = 0$$

For broken span

$$T_c = n \times H \times \sin\left(\frac{\theta}{2}\right)$$

$$L_c = n \times H \times \cos\left(\frac{\theta}{2}\right)$$

Where: n = Number of conductors in bundle
H = Tension of conductor or ground wire under given conditions in N
θ = Deviation angle of line in degrees
T_c = Transverse load acting on tower
L_c = Longitudinal load acting on tower

6.4.2.4 Wind on Structure

Wind load on latticed tower:

$$F_{wt} = q_0 \times S_t \times C_{xt} \times G_t$$

Where: q_o = Design wind pressure in Pa
S_t = Total area of the elements projected normally to the longitudinal face of the tower support
C_{tx} = Drag coefficient for the longitudinal face of the tower support, as per Figure 8 of the CSA C22.3 No. 60826-10, as function of the solidity ratio
G_t = Combined wind factor for the supports

The wind load calculation on the tower supports shall be done by using PLS-TOWER software, by using the appropriate section coefficient “wind on face”.

In all ice load cases, the ice on the structure elements shall be considered for the wind area with a drag coefficient of 1.0 for rounds and 1.8 for flat surfaces.

6.4.3 Vertical Loads

6.4.3.1 Weight of Conductors, Ground Wires and Hardware

Vertical load due to weights of line components shall be determined as per the following equation and applied at wire attachment points:

$$V = w_1 \times W_t \times n + w_2$$

Where: V = Total vector load acting on tower from conductors and accessories (with or without ice)
w_1 = Unit weight of conductor or ground wire in N/m
W_t = Weight span being horizontal distance between the lowest sag points on the two consecutive spans
n = Number of conductors in bundle
w_2 = Weight of spacers, spherical warning markers and hardware in N insulators and counterweight (180 kg)

Dead weight of tower shall be computed on the basis of the unit weight of each member of the tower and increased by a percentage to account for the weight of bolts and nuts, washers, cleats, plates, etc.

and distributed at panel points or shall be generated and distributed automatically by the applied design software. The software generated weight shall be increased by a suitable percentage not less than 15%.

6.4.3.2 Weight of Ice

Unit weight of glaze ice on the conductor or ground wire shall be calculated as per the following equation:

$$w_g = 0.0277 \times t \times (t + d)$$

Where: w_g = Unit weight of ice in N/m, using the ice area of $\pi(d+2t)^2/4-\pi d^2/4$, and the ice density of 900 kg/m^3 or 8825 N/m^3
t = Radial thickness of ice in mm
d = Conductor or ground wire diameter in mm

Vertical load due to the unit weight of glaze ice (v_i) shall be determined as per the following equation and applied at wire attachment points:

$$V_i = w_g \times W_t \times n$$

Where: W_t = Weight Span

This value shall be added to vertical loads due to weight of conductor (V_c).

$$V_c = w_c \times W_t \times n$$

Where: w_c = Unit weight of conductor

In the case of rime ice, the value of w_g shall be corrected by the factor of the density of rime ice/glaze ice.

6.4.4 Longitudinal Loads

All longitudinal loads shall be defined by using the design criteria of Section 6.2.

6.4.5 Stringing and Maintenance Loads

Stringing loads shall be computed according to the conditions specified in Section 6.3 and applied in the longitudinal, vertical and transversal directions:

- At any one attachment point at a time in case of suspension towers.
- Only at left side point attachments.
- Only at right side point attachments.
- At all conductor and ground wire attachment points simultaneously in the case of angle and dead end towers.

6.4.6 Redundant Member Loads

The redundant members shall be designed for 2.5% of the load in the supported member, acting perpendicular to the supported member. See Section 6.3 for additional construction and maintenance loads for redundant elements.

7 TOWERS

7.1 Tower Types – Line Deflection Angles and Spans

B2 The tower types for the 350 kV HVdc transmission line supports are defined as per the lines deflection and spans limits for all tower types defined in Appendix C.

B2 The following design aspects shall be respected:

- Tower type C is not used as a dead end terminal tower, but only as an angle tower.
- Tower types D and E have conductors on both sides or have conductors on one side only and are also used as anti-cascade towers.

B2 See Tables 6.1 to 6.10 for the definition of climatic data for each of the tower families.

The specified maximum angles of deviation will be applicable for the maximum wind span. However, the span may be increased up to an optimum limit by reducing the angle of line deviation providing the required ground and phase clearances.

B2 Dead end towers shall be designed to meet 0° to ±15° drop angle. That drop angle could control the steel or guy wire clearances when defining the final crossarm length.

The tower geometry criteria are shown on the tower design requirement drawings and defined using:

- Appropriate insulator length (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)

- Insulator swing angles (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)
- Shield wire protection angles (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)
- Air gaps (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)
- Wind pressure for insulator swing calculation (Appendix B)
- Ground clearance (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)
- Pole-to-Pole minimum clearance (Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0001-01)
- Pole-Electrode cable clearance (Nalcor Doc. No. ILK-SN-CD-6300-TL-RP-0001-01)
- Electrode cable to OPGW clearance (Nalcor Doc. No. ILK-SN-CD-6300-TL-RP-0001-01)

8 PERMISSIBLE STRESSES

8.1 Axial Stresses in Tension

The design tensile stress on the net cross-sectional area of axially loaded tension members shall not exceed the minimum guaranteed yield stress F_y of the applied material.

The strength factors to be used are shown in Table 8.1.

B2

Table 8.1: Strength Factors

Tower Type	Intact	Broken conductor
A and B (Susp.)	0.9	1.0
C, D and E (Strain insul.)	0.8	0.9
Guy Wires	0.7	0.9

In the case of the steel angle section connected by one leg only, the design tensile stress on the net section area shall be calculated by using an additional strength factor of 0.9, as per ASCE 10-97.

The net cross-sectional area is the gross cross-sectional area reduced by area of holes or other openings. In the case of chain of holes, the net width of an element shall be determined by deducting from the gross width the sum of diameters of all holes in the chain and adding for each gage space in the chain the quantity $s^2/4g$; where s = longitudinal spacing, and g = transverse spacing of any two consecutive holes.

For tension strength computation, the size of the bolt hole diameter shall be the hole diameter increased by 1.5 mm.

8.2 Axial Stresses in Compression

The design compression stress acting on the net cross-sectional area of concentrically loaded compression members shall not exceed the minimum guaranteed yield stress F_y of the applied material.

8.2.1 Design Compression Computation

The compression computation for all towers shall be done by the ASCE 10-97 method.

The design compressive stress, Fa in MPa, on the gross cross-sectional area, or on reduced area where specified, of axially loaded compression members shall be:

$$F_a = \left[1 - \frac{1}{2} \times (\frac{KL/r}{C_c})^2\right] \times F_y \quad when \quad \frac{KL}{r} \leq C_c$$

$$F_a = \frac{\pi^2 \times E}{(KL/r)^2} \quad when \quad \frac{KL}{r} > C_c$$

$$C_c = \pi \times \sqrt{\frac{2 \times E}{F_y}}$$

Where:			
	F_y	=	Minimum guaranteed yield stress of steel in MPa
	E	=	Modulus of elasticity of steel
	K	=	Effective Length coefficient, using eccentricity code and restraint codes as defined with the ASCE 10-97
	$\frac{KL}{r}$	=	Largest effective slenderness ratio of any unbraced segment of a compression member
	L	=	Unbraced length of the compression member
	r	=	Appropriate radius of gyration
	C_c	=	Column slenderness ratio separating elastic and inelastic buckling

8.2.2 Maximum $\frac{w}{t}$ Ratio

The previous formula is applied if the largest value of $\frac{w}{t}$ does not exceed the limiting value given by:

$$\frac{w}{t} \leq \frac{210}{F_y}$$

Where:			
	w	=	Flat width
	t	=	Thickness of compressed member

Where $\frac{w}{t} > \frac{210}{F_y}$, the following equations shall be used (F_y to be replaced by F_{cr} in MPa):

$$F_{cr} = \left[1.677 - \frac{0.677 \times \frac{w}{t}}{\frac{w}{t}lim}\right] \times F_y \quad where \quad \frac{w}{t}lim \le \frac{w}{t} \le \frac{378}{\sqrt{F_y}}$$

$$and\ F_{cr} = \frac{0.0332 \times \pi \times E}{\left(\frac{w}{t}\right)^2} \quad where \quad \frac{w}{t} > \frac{378}{\sqrt{F_y}}$$

The maximum permissible value of $\frac{w}{t}$ for any type of steel shall not exceed 25.

8.3 Stresses in Bolts

8.3.1 Shear Stress

The shear strengths of bolts shall conform to ASTM A394 Type 1 as in following table and will not be exceeded. For bolts in double shear the specified single shear values shall be multiplied by 2.

Table 8.2: Bolt Strengths

Nominal Bolt Size	Single Shear Strength through body (kN)
5/8" (15.9 mm)	101
3/4" (19.1 mm)	146

Metric bolt sizes are not allowed.

The shear plane shall not intercept the threaded portion of the bolts.

8.3.2 Bearing Stress

B2 For bolts conforming to ASTM A394 Type 1, the maximum bearing stress is calculated as the force on a bolt divided by the product of the bolt diameter times the thickness of the connected part and shall not exceed 1.5 times the specified minimum tensile strength F_u of the connected part of the bolt. The bearing capacity of the end bolt shall be reduced to take into account the end distance according to the ASCE 10-97.

9 EFFECTIVE SLENDERNESS RATIOS AND LIMITING CONDITIONS

9.1 Limiting Values for Slenderness

Limiting slenderness ratios for members carrying calculated compression stress will be:

- Leg members including ground wire peak members and main members of cross-arms in compression $\frac{Kl}{r} \leq 120$

- Others members carrying compression loads $\frac{Kl}{r} \leq 200$
- Redundant members $\frac{Kl}{r} \leq 240$
- Tension only members $\frac{Kl}{r} \leq 300$

9.2 Minimum Thickness

9.2.1 Members

The minimum thickness of structural members shall be as follows:

Table 9.1: Minimum Thickness of Members

Type of Members	Minimum Thickness (mm)
Leg members, main ground wire peak members and main members of crossarms in compression	6
Other compression carrying members	3.2
Redundant members	3.2
Stub Angle	8

B2

9.2.2 Gusset Plates

The gusset plates shall be designed to resist the shear and the direct and flexural stresses acting on the weakest or critical sections. Minimum thickness of gusset plate shall be the greater of 6.4 mm (1/4") or 1.6 mm (1/16") plus the thickness of connected member.

10 CONNECTIONS

Bolting connection for transmission towers are normally designed as bearing type connections.

The number of welded connections shall be reduced to a minimum.

The design of all bolt connections shall comply with ASCE 10-97.

10.1 Bolting

Bolts used for erection of 350 kV HVdc transmission line towers shall have a diameter of 15.9 mm (5/8") or 19.1 mm (3/4").

One size of connection bolts and nuts shall be used for suspension type towers. For angle, anchor and dead end types of towers, two sizes of connection bolts may be used.

The length of bolts shall be such that threaded portion does not lie in the shear plane of contact members.

B2 The projected portion of the bolt beyond the nut shall be between 3 to 8 mm and not less than three (3) effective threads.

The bolt area for bearing shall be taken as (d x t) where d is the nominal diameter of bolt and t is the thickness of the thinner of the joined parts.

The nominal area of bolts shall be taken as the shear area, as it is ensured that the threaded portion of bolt will not extend into the plane of contact of the connected members.

The diameter of drilled or punched holes shall be 1.6 mm (1/16") more than the nominal diameter of the bolt.

The end distance is the distance from the center of a hole to the end of the member, whether this is perpendicular or inclined to the line of force.

The edge distance is the distance from the center of a hole to the rolled or sheared edge. It is a perpendicular distance between nearest gage line of holes to the rolled or sheared edge running parallel to the gage line.

The required end distance is a function of the load being transferred in the bolt, the tensile strength and thickness of the connected part.

The minimum end and edge distances are given in the following table and shall never be compromised by fabrication or rolling tolerances.

B2 The minimum leg size to connect a 3/4" (19.1 mm) bolt is 64 mm.

B2 The L44 x 44 x 4.8 cannot be used to connect a 5/8" (15.9 mm) bolt.

Table 10.1: End and Edge Distances for Stressed Members

	Description	Bolt diameter (mm)			
		5/8"	3/4"	7/8"	1"
	Max. thickness for punched holes	16	20	22	24
Corner >75 mm	End distance-cut end	23	27	31	35
	Edge distance-rolled edge	23	27	31	35
Corner <65 mm	Edge distance-cut distance	23	27	31	-
	Edge distance-rolled edge	21.5	25.5	29.5	-
Gussets	Edge distance-cut distance	25	30	35	40
	Edge distance-rolled edge	-	-	-	-

10.2 Bolt Hole Spacing

The required end distance to provide the minimum strength shall be the largest value of e_{min} given by the following:

$$e_{min} = \frac{1.2 \times P}{F_u \times t}$$

$$e_{min} = 1.3 \times d$$

$$e_{min} = t + 0.5 + d$$

Where:

- e_{min} = Minimum distance measured from the center of a hole to the perpendicular or inclined end of a member in mm
- P = Load transmitted through the bolt in N
- F_u = Minimum tensile strength of steel in MPa
- t = Thickness of connected member in mm
- d = Diameter of bolt in mm

The minimum center to center bolt hole spacing shall not be less than:

$$S_{min} = \frac{1.2 \times P}{F_u \times t} + 0.6 \times d$$

The distance from the center of a hole to the edge of the member shall not be less than value given by the following equation:

$$f_{min} = 0.85 \times e_{min}$$ For a rolled edge and

$$f_{min} = 0.85 \times e_{min} + 0.0625\psi$$ For mechanically guided flame cut.

Where ψ = 1 in inches and 2.54 in mm.

Table 10.2: Minimum Center to Center Bolt Hole Spacing

Description	Bolt diameter (mm)			
	5/8”	3/4”	1/8”	1”
Minimum spacing (mm)	42	50	54	60
Maximum spacing (mm)	130	160	180	200

10.3 Stub

The unbraced portion of the stub between the last bracing connection (bottom of leg connections) and the foundation is subjected to combined axial and bending stresses. The stub angle shall be suitable to withstand combined stresses.

The thickness of the stub angle shall be at least 2 mm more than the thickness of the leg member to which it is connected. The stub to leg connection shall be a butt joint connection with steel angle and cover plates and not a lap joint connection.

10.4 Step Bolts

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Step bolts shall be provided on one of the legs from approximately 2.5 m above ground level to the shield wire peak. They shall be spaced not more than 380 mm ± 20 mm apart. Bolt holes shall be provided on diagonally opposite leg members, but step bolts shall only be provided for one leg only. All step bolts shall be 3/4” (19.1 mm) diameter, 9” long and a sketch shall be supplied by Engineer.

The step bolts shall be able to take a vertical load of 1.5 kN applied at the end of the bolt.

The bending stress shall be less than $0.50F_y$.

B2

If a step bolt is installed inside a connection, then the shear capacity of the step bolt is neglected.

11 PROTOTYPE TESTING

11.1 Tower Testing Philosophy

The fundamental purpose of full scale tower testing is to confirm the suitability of, firstly, the tower design process, and secondly, the tower detailing process. Indirectly the tests also confirm the

B2 correctness of the tower members themselves with respect to their connections, steel grades, sizes, fabrication capability and lengths.

B2 For the HVdc transmission line there are eleven tower types: the guyed suspension tower types A1, A2, A3, A4 and B1, and the self-supported angle/dead-end tower types B2, C1, C2, D1, D2, and E1.

While from a theoretical viewpoint it is useful and the usual practice for some utilities is to test each tower type; in practice, schedule and cost considerations dictate a minimum number of full scale tests to take place. The selection of the number of tests includes considerations about the importance of the line, the quantity of towers, schedule and cost restraints and the capabilities of the designers and suppliers.

11.2 Towers to be Tested

B2 It is sufficient to conduct full scale tower tests on five among the 11 tower types for the following reasons:

- Prototype testing will be performed on tower types A1, A2, B2, D1, and E1.
- Tower type A1 represents a good test for the tower type A3.
- Tower type A2 represents a good test for the tower type A4 and B1.
- Tower type B2 represents a good test for the tower to be used as self-supporting long-span heavy suspension type.
- Tower type D1 represents a good test for the tower type C1.
- Tower type E1 represents a good test for the tower type C2 and D2.
- As all the towers shall have been designed with the same design philosophy throughout, the confidence in the design process for the remaining tower types is increased after a successful test.

11.3 Prototype Testing Loads

B2 Five to seven governing loading cases shall be tested. These tests shall conform to the international standard IEC 60652. The last loading case will be tested by increasing the loads over the 100% limit requirement, to the tower failure or to a maximum of 120% of the maximum loads.

B2 All vector loads of tested load combination shall be increased to take into account the individual strength factors (vector loads divided by the strength factor). The increased loads are defined as the 100% loads for the tower test loading.

12 SETTING TOWERS WITH HELICOPTERS

B2 Setting towers with helicopters may be a requirement in locations with limited access or when Contractor prefers this option in order to save time. It is common to consult with the helicopter company to produce an adequate design and setting strategy.

The maximum available capacity for heavy lift helicopters is in the range of 9,000 kg to 11,000 kg. Several factors will reduce the available lifting capacity including the required distance of travel, wind conditions and pilot skill. In most cases, a practical lifting capacity of 5,000 kg to 6,000 kg is used. Erection and maintenance details relating to Tower types A, B, C, D and E shall include the estimated weights for complete towers and individual sections.

The majority of towers being used on the 350 kV HVdc lines are tangents and light angles that have a weight that falls within the practical lifting capacity. Therefore, complete towers can be set in most cases.

The practical lifting weight is exceeded by the C, D and E towers. In these cases, setting the towers in two or more pieces can be achieved if the sections fall within the weight limits and the sections are configured and assembled in a way that facilitates this approach. The helicopter company will provide specialized devices that allow individual sections to be packed together before the linemen climb the tower to assemble the splices and bracing.

Some of the taller B towers may also exceed the weight limit in some situations. It is not practical to set a guyed tower in two pieces. However, it may still be possible to transport the tower to site in two pieces, assemble the complete structure on the ground and then, with no travel distance required, use the higher capacity of the helicopter to set the complete structure. This approach might also apply to two sections of a self-supporting tower.

Design considerations normally incorporated into transmission towers that have to be set by helicopters include:

- Four lifting holes on the cross beam. These will be located near the shield wire peaks and provide a means of quickly connecting and disconnecting lifting slings
- Configuration of splices between sections that can be safely and quickly brought together and assembled
- Bracing (that cross the splicing locations) can be modified with additional splices or temporary detail arrangements.

Consultation between the helicopter company and the construction forces will determine the procedures and equipment required to perform the work efficiently and safely.

APPENDIX A

GUY WIRE TABLE

Nominal Diameter		Stranding (number of strands)	Net Section	Elasticity modulus	Unit weight	Thermal dilatation	Rated tensile stress
Inches	mm	-	mm²	GPa	kg/m	$10^{-6}/°C$	kN
1/2	12.7	19	97	160	0.8	11.5	138
9/16	14.3	19	123	160	1.0	11.5	168
5/8	15.9	19	151	160	1.2	11.5	205
11/16	17.5	19	183	160	1.5	11.5	245
3/4	19.1	19	218	160	1.8	11.5	298
13/16	20.6	19	256	150	2.1	11.5	343
7/8	22.2	19	296	150	2.4	11.5	410
15/16	23.8	19	340	150	2.8	11.5	460
1	25.4	19	387	150	3.1	11.5	525
1 - 1/8	28.6	34	490	140	4.0	11.5	694
1 - 1/4	31.8	36	606	140	4.9	11.5	854
1 - 3/8	34.9	37	729	135	5.9	11.5	1030
1 - 1/2	38.1	55	871	135	7.0	11.5	1228
1 - 5/8	41.3	59	1026	135	8.3	11.5	1440
1 - 3/4	44.5	62	1187	135	9.6	11.5	1670
1-7/8	47.6	82	1361	135	11.0	11.5	1920
2	50.8	88	1548	135	12.5	11.5	2180

Rated Tensile Strength:

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ASTM A586, Grade 1 Guy Wire, Class A Coating Inner Wires, Class B Coating Outer Wires
or
CSA G12-92, Grade 220 Guy Wire, Class B Coating

APPENDIX B

WIND PRESSURE CALCULATIONS ON CONDUCTOR

(ref.: CSA C22.3 No.60826-10)

B2

Table B.1 Wind Pressure on conductor (ref.: CSA C22.3 No.60826-10) for Zones 1 to 11 DC line

$q_o = 0.5\ \tau\mu(K_R V_{RB})^2$ (eq. 6)

With q_o dynamic wind pressure

τ air density correction factor (Table 5)

μ air mass per unit volume = 1.225 kg/m3

K_R terrain roughness factor = 0.85 for terrain type C and = 1.0 for terrain type B (Table 4)

V_{RB} reference wind speed in (m/s) at 10m above ground and with an average period of 10 min.

Pressure on cable = $q_o\ C_C\ G_C\ G_L$ (eq. 8)

C_C drag coefficient of the conductor = 1.0

G_C combined wind factor, (z=20m) and terrain categories C, G_C = 2.391, for terrain categories B, G_C =2.095 (figure 3)

G_L span factor (figure 4)

Zones	Loads Cases	V_{RB} (km/h)	Temp. °C	Min. Alti. (m)	Terrain categ.	K_R	τ	q_o (Pa)	G_c	RS(m)	G_L	Pressure on Conductors (Pa)	Swing* Wind Max (Pa)	Swing* Reduced Wind (Pa)
1, 8b & 10	Max Wind (km/h)	105	-20	0	C	0.85	1.14	429	2.391	370	0.955	980	785	295
	Wind +Ice (km/h)	60	-5				1.08	133				305		
2a, 2b & 2c	Max Wind (km/h)	135	-20	0	B	1.00	1.14	984	2.095	200	1.004	2070	1655	620
	Wind +Ice (km/h)	95	-5				1.08	460				970		
3a, 3b, 4b, 4a, 6 and 8a	Max Wind (km/h)	120	-20	0	C	0.85	1.14	562	2.391	360	0.958	1290	1030	385
	Wind +Ice (km/h)	60	-5				1.08	133				305		
5	Max Wind (km/h)	150	-20	185	B	1.00	1.12	1191	2.095	280	0.982	2450	1960	735
	Wind +Ice (km/h)	105	-5				1.06	552				1135		
7a, 7b & 7c	Max Wind (km/h)	180	-20	365	B	1.00	1.09	1669	2.095	250	0.990	3460	2770	1040
	Wind +Ice (km/h)	125	-5				1.03	761				1580		
9 11a & 11b	Max Wind (km/h)	130	-20	0	C	0.85	1.14	659	2.391	350	0.961	1515	1210	455
	Wind +Ice (km/h)	60	-5				1.08	133				305		

* Maximum insulator swing wind pressure = 0.8 x Maximum wind pressure: reduced insulator swing wind pressure = 0.3 x Maximum wind pressure
(See the Line Design Criteria document for the insulator swing wind pressure criteria, Document No. ILK-SN-CD-6200-TL-DC-0001-01)

B2

Table B.2 Wind Pressure on electrode conductor (ref.: CSA C22.3 No.60826-10) for Zones 1 to 11 DC line

$q_o = 0.5\ \tau\mu(K_R V_{RB})^2$ (eq. 6)

With q_o dynamic wind pressure

τ air density correction factor (Table 5)

μ air mass per unit volume = 1.225 kg/m3

K_R terrain roughness factor = 0.85 for terrain type C and = 1.0 for terrain type B (Table 4)

V_{RB} reference wind speed in (m/s) at 10m above ground and with an average period of 10 min.

Pressure on cable = $q_o\ C_C\ G_C\ G_L$ (eq. 8)

C_C drag coefficient of the conductor = 1.0

G_C combined wind factor, (z=30m) and terrain categories C, G_C = 2.591, for terrain categories B, G_C =2.246 (figure 3)

G_L span factor (figure 4)

Zones	Loads Cases	V_{RB} (km/h)	Temp. °C	Min. Alti. (m)	Terrain categ.	K_R	τ	q_o (Pa)	G_c	RS(m)	G_L	Pressure on Conductors (Pa)	Swing* Wind Max (Pa)	Swing* Reduced Wind (Pa)
1, 8b & 10	Max Wind (km/h)	105	-20	0	C	0.85	1.14	429	2.591	370	0.955	1062	850	319
	Wind +Ice (km/h)	60	-5				1.08	133				328		
2a, 2b & 2c	Max Wind (km/h)	135	-20	0	B	1.00	1.14	984	2.246	200	1.004	2217	1774	665
	Wind +Ice (km/h)	95	-5				1.08	460				1037		
3a, 3b, 4b, 4a, 6 and 8a	Max Wind (km/h)	120	-20	0	C	0.85	1.14	562	2.591	360	0.958	1395	1116	418
	Wind +Ice (km/h)	60	-5				1.08	133				329		
5	Max Wind (km/h)	150	-20	185	B	1.00	1.12	1191	2.246	280	0.982	2626	2101	788
	Wind +Ice (km/h)	105	-5				1.06	552				1218		
7a, 7b & 7c	Max Wind (km/h)	180	-20	365	B	1.00	1.09	1669	2.246	250	0.990	3712	2970	1114
	Wind +Ice (km/h)	125	-5				1.03	761				1692		
9 11a & 11b	Max Wind (km/h)	130	-20	0	C	0.85	1.14	659	2.591	350	0.961	1642	1313	493
	Wind +Ice (km/h)	60	-5				1.08	133				330		

* Maximum insulator swing wind pressure = 0.8 x Maximum wind pressure: reduced insulator swing wind pressure = 0.3 x Maximum wind pressure
(See the Line Design Criteria document for the insulator swing wind pressure criteria, Document No. ILK-SN-CD-6200-TL-DC-0001-01)

B2

Table B.3 Wind Pressure on OPGW (ref.: CSA C22.3 No.60826-10) for Zones 1 to 11 DC line

$q_o = 0.5\ \tau\mu(K_R V_{RB})^2$ (eq. 6)

With q_o dynamic wind pressure

τ air density correction factor (Table 5)

μ air mass per unit volume = 1.225 kg/m3

K_R terrain roughness factor = 0.85 for terrain type C and = 1.0 for terrain type B (Table 4)

V_{RB} reference wind speed in (m/s) at 10m above ground and with an average period of 10 min.

Pressure on cable = $q_o\ C_C\ G_C\ G_L$ (eq. 8)

C_C drag coefficient of the conductor = 1.0

G_C combined wind factor, (z=45m) and terrain categories C, G_C = 2.791, for terrain categories B, G_C =2.397 (figure 3)

G_L span factor (figure 4)

Zones	Loads Cases	V_{RB} (km/h)	Temp. °C	Min. Alti. (m)	Terrain categ.	K_R	τ	q_o (Pa)	G_c	RS(m)	G_L	Pressure on Conductors (Pa)	Swing* Wind Max (Pa)	Swing* Reduced Wind (Pa)
1, 8b & 10	Max Wind (km/h)	105	-20	0	C	0.85	1.14	429	2.791	370	0.955	1144	915	343
	Wind +Ice (km/h)	60	-5				1.08	133				353		
2a, 2b & 2c	Max Wind (km/h)	135	-20	0	B	1.00	1.14	984	2.397	200	1.004	2367	1894	710
	Wind +Ice (km/h)	95	-5				1.08	460				1107		
3a, 3b, 4b, 4a, 6 and 8a	Max Wind (km/h)	120	-20	0	C	0.85	1.14	562	2.791	360	0.958	1502	1202	451
	Wind +Ice (km/h)	60	-5				1.08	133				355		
5	Max Wind (km/h)	150	-20	185	B	1.00	1.12	1191	2.397	280	0.982	2803	2243	841
	Wind +Ice (km/h)	105	-5				1.06	552				1300		
7a, 7b & 7c	Max Wind (km/h)	180	-20	365	B	1.00	1.09	1669	2.397	250	0.990	3962	3170	1189
	Wind +Ice (km/h)	125	-5				1.03	761				1806		
9 11a & 11b	Max Wind (km/h)	130	-20	0	C	0.85	1.14	659	2.791	350	0.961	1769	1415	531
	Wind +Ice (km/h)	60	-5				1.08	133				356		

* Maximum insulator swing wind pressure = 0.8 x Maximum wind pressure: reduced insulator swing wind pressure = 0.3 x Maximum wind pressure

(See the Line Design Criteria document for the insulator swing wind pressure criteria, Document No. ILK-SN-CD-6200-TL-DC-0001-01)

APPENDIX C

SUMMARY OF ZONES, FAMILIES AND TOWER TYPES

SNC·LAVALIN	350 kV HVdc Line Tower Design Criteria	Revision		
	Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0006-01	B2	Date	Page
	SLI Doc. No. 505573-462B-43EC-0002	01	04-Nov-2013	C-1

Muskrat Falls
350 kV HVdc

21-Oct-2013

Tower Design Criteria - Appendix C

B2

Steel Tower Design

	Zone #	Length (km)	Ice (mm)	Ref. Wind Speed (km/h)	Electr. (Y/N)	Inland or Coastal	RS Span (m)	Tower Type A (0°-1°)	Tower Type A Wind Span (m)	Tower Type A Weight Span (m)	Tower Type B (0°-3°)	Tower Type B Wind Span at 3° (m)	Tower Type B Weight Span at 3° (m)	Tower Type B Wind Span at 0° (m)	Tower Type B Weight Span at 0° (m)	Tower Type C (0°-30°)	Tower Type C Wind Span (30°) (m)	Tower Type C Wind Span (20°) (m)	Tower Type C Wind Span (10°) (m)	Tower Type C Wind Span (0°) (m)	Tower Type C Min Weight Span (m)	Tower Type C Max Weight Span (m)
Labrador	1	272.2	50	105	Y	Inland	370	A1	410	465	B1	410	465	465	565	C1	410	460	500	540	-230	590
Labrador	2a	12.3	115*	135	Y	Inland	230	A2	255	300	B2	255	300	280	350	C2	255	290	310	340	-230	370
Labrador	2b	63.9	135*	135	Y	Inland	200	A2	220	250	B1	220	250	250	270	C2	220	250	270	290	-250	320
Labrador	2c	22.4	115*	135	Y	Inland	230	A2	255	300	B2	255	300	280	350	C2	255	290	310	340	-230	370
Labrador	3a	12.4	50	120	Y	Inland	360	A1	400	450	B1	400	450	450	550	C1	400	440	480	520	-235	575
Labrador	3b	13.1	50	120	N	Coastal	430	A3	475	540	B1	475	540	520	570	C1	475	530	570	620	-300	700
Newfoundland	4b	12.9	50	120	N	Coastal	430	A3	475	540	B1	475	540	520	570	C1	475	530	570	620	-300	700
Newfoundland	4a	56.2	50	120	N	Inland	430	A1	475	540	B1	475	540	520	570	C1	475	530	570	620	-300	700
Newfoundland	5	18.9	115*	150	N	Inland	280	A2	310	350	B2	320	360	350	400	C2	310	350	380	410	-250	460
Newfoundland	6	72.6	50	120	N	Inland	430	A1	475	540	B1	475	540	520	570	C1	475	530	570	620	-300	700
Newfoundland	7a	21.1	115*	180	N	Inland	250	A4	275	315	B2	275	315	320	380	C2	275	310	330	360	-250	400
Newfoundland	7b	7.1	135*	180	N	Inland	230	A4	255	300	B2	255	300	280	350	C2	255	290	310	340	-230	370
Newfoundland	7c	12.8	115*	180	N	Inland	250	A4	275	315	B2	275	315	320	380	C2	275	310	330	360	-250	400
Newfoundland	8a	12.9	50	120	N	Inland	430	A1	475	540	B1	475	540	520	570	C1	475	530	570	620	-300	700
Newfoundland	8b	74.9	50	105	N	Inland	440	A1	485	555	B1	485	555	535	585	C1	485	540	590	640	-295	715
Newfoundland	9	7.8	75	130	N	Inland	350	A3	385	440	B1	385	440	440	480	C1	385	430	470	510	-240	550
Newfoundland	10	221.0	50	105	N	Inland	440	A1	485	555	B1	485	555	535	585	C1	485	540	590	640	-295	715
Newfoundland	11a	89.4	75	130	N	Inland	350	A3	385	440	B1	385	440	440	480	C1	385	430	470	510	-240	550
Newfoundland	11b	88.7	75	130	N	Coastal	350	A3	385	440	B1	385	440	440	480	C1	385	430	470	510	-240	550

Zone #	Tower Type D (0°-45°)	Tower Type D Wind Span (45°) (m)	Tower Type D Wind Span (35°) (m)	Tower Type D Wind Span (25°) (m)	Tower Type D Wind Span (15°) (m)	Tower Type D Min Weight Span Angle (m)	Tower Type D Max Weight Span Angle (m)	Tower Type D Min Weight Span D. E. (m)	Tower Type D Max Weight Span D. E. (m)	Tower Type E (45°-90°)	Tower Type E Wind Span (90°) (m)	Tower Type E Wind Span (80°) (m)	Tower Type E Wind Span (70°) (m)	Tower Type E Wind Span (60°) (m)	Tower Type E Min Weight Span Angle (m)	Tower Type E Max Weight Span Angle (m)	Tower Type E Min Weight Span D. E. (m)	Tower Type E Max Weight Span D. E. (m)	Stick Model for PLS-CADD: Tower Stick Model Type A	Tower Stick Model Type B	Tower Stick Model Type C	Tower Stick Model Type D	Tower Stick Model Type E	Tower Stick Model Family
1	D1	410	460	500	540	-315	670	-245	515	E1	410	460	500	540	-315	670	-245	515	A1	B1	C1	D1	E1	F1
2a	D2	255	290	310	340	-300	420	-220	350	E1	255	290	310	340	-300	420	-220	350	A11	B11	C11	D11	E11	F11
2b	D2	220	250	270	290	-300	360	-200	275	E1	220	250	270	290	-300	360	-200	275	A2	B2	C2	D2	E2	F2
2c	D2	255	290	310	340	-300	420	-220	350	E1	255	290	310	340	-300	420	-220	350	A11	B11	C11	D11	E11	F11
3a	D1	400	440	480	520	-325	650	-250	500	E1	400	440	480	520	-325	650	-250	500	A3	B3	C3	D3	E3	F3
3b	D1	475	530	570	620	-400	750	-300	600	E1	475	530	570	620	-400	750	-300	600	A10	B10	C10	D10	E10	F10
4b	D1	475	530	570	620	-400	750	-300	600	E1	475	530	570	620	-400	750	-300	600	A10	B10	C10	D10	E10	F10
4a	D1	475	530	570	620	-400	750	-300	600	E1	475	530	570	620	-400	750	-300	600	A5	B5	C5	D5	E5	F5
5	D2	310	350	380	410	-300	520	-270	440	E1	310	350	380	410	-300	520	-270	440	A12	B12	C12	D12	E12	F12
6	D1	475	530	570	620	-400	750	-300	600	E1	475	530	570	620	-400	750	-300	600	A5	B5	C5	D5	E5	F5
7a	D2	275	310	330	360	-300	460	-250	400	E1	275	310	330	360	-300	460	-250	400	A9	B9	C9	D9	E9	F9
7b	D2	255	290	310	340	-300	420	-220	350	E1	255	290	310	340	-300	420	-220	350	A6	B6	C6	D6	E6	F6
7c	D2	275	310	330	360	-300	460	-250	400	E1	275	310	330	360	-300	460	-250	400	A9	B9	C9	D9	E9	F9
8a	D1	475	530	570	620	-400	750	-300	600	E1	475	530	570	620	-400	750	-300	600	A5	B5	C5	D5	E5	F5
8b	D1	485	540	590	640	-390	770	-295	615	E1	485	540	590	640	-390	770	-295	615	A4	B4	C4	D4	E4	F4
9	D1	385	430	470	510	-320	600	-240	480	E1	385	430	470	510	-320	600	-240	480	A7	B7	C7	D7	E7	F7
10	D1	485	540	590	640	-390	770	-295	615	E1	485	540	590	640	-390	770	-295	615	A4	B4	C4	D4	E4	F4
11a	D1	385	430	470	510	-320	600	-240	480	E1	385	430	470	510	-320	600	-240	480	A7	B7	C7	D7	E7	F7
11b	D1	385	430	470	510	-320	600	-240	480	E1	385	430	470	510	-320	600	-240	480	A8	B8	C8	D8	E8	F8

Total Length 1,092.6 km

* means rime ice 0.5 g/cm³ for zones 2a,2b,2c,5,7a,7b,7c

Prepared by Michel D. Belanger **as discussed with Nalcor**

Checked by Hamidreza Bakshi

Summary

- 16 ice/wind zones defined by Nalcor on 22-Dec-2011
  - 1, 2a, 2b, 2c, 3 (inland and costal), 4 (inland and costal), 5, 6, 7a, 7b, 7c, 8a, 8b, 9, 10 and 11 (inland and costal)
- 12 families of tower stick models defined for the tower spotting
  - F1 to F12 (as defined within the above Table).
- 11 tower types, with many of the tower types to be multiple purposes (good for various conditions and not necessarily optimized for each of the conditions as defined within the above Table).
  - A1, A2, A3, A4, B1, B2, C1, C2, D1, D2, E1
  - The multiple purpose towers are already a basic principle defined with Nalcor at the kickoff meeting, asking to combine the 75 mm ice zone with the alpine zones. Additional merging was defined to save on the total line cost and to simplify the component management.
  - This table is including two sets of tower naming convention: one set for the steel tower types (with PLS-TOWER models) and one set for the stick models (to be used for the tower spotting with PLS-CADD for families 1 to 12).

The zones of ice and wind are defined by the Nalcor Document No. ILK-PT-ED-6200-TL-DC-0001-01, "Overhead Transmission - Meteorological Loading for the Labrador - Island Transmission Link", Rev. B1, dated 20-Dec-2012. Zone 3 is partially Inland (3a) and partially Coastal (3b). Zone 4 is partially Inland (4a) and partially Coastal (4b). Zone 11 is partially Inland (11a) and partially Coastal (11b).

Prototype testing will be performed on tower Types A1 B1, D1, E1: those 4 towers represents a good test for 100% of the towers
Tower Type A1 represents a good test for tower Type A3
Tower Type A2 represents a good test for tower Type A4 and B1
Tower Type B2 represents a good test for the tower to be used as self-supporting long span heavy suspension type.
Tower Type D1 represents a good test for the tower Type C1
Tower Type E1 represents a good test for tower Types C2 and D2

APPENDIX D

DESIGN LOADING DRAWING REFERENCE FOR EACH OF THE TOWER TYPES

SNC·LAVALIN	350 kV HVdc Line Tower Design Criteria	Revision		
	Nalcor Doc. No. ILK-SN-CD-6200-TL-DC-0006-01	B2	Date	Page
	SLI Doc. No. 505573-462B-43EC-0002	01	04-Nov-2013	D-1

B2

Nalcor Doc. No.	SLI Doc. No.	Title
ILK-SN-CD-6200-TL-DD-0065-01	505573-4622-43DD-0001-SH1_02	350 kV HVdc Line Tower Type A1 (0° to 1°) Design Loading sheet 1 of 2
ILK-SN-CD-6200-TL-DD-0065-02	505573-4622-43DD-0001-SH2_02	350 kV HVdc Line Tower Type A1 (0° to 1°) Design Loading sheet 2 of 2
ILK-SN-CD-6200-TL-DD-0070-01	505573-4622-43DD-0009- SH1_02	350 kV HVdc Line Tower Type A2 (0° to 1°) Design Loading sheet 1 of 2
ILK-SN-CD-6200-TL-DD-0070-02	505573-4622-43DD-0009- SH2_02	350 kV HVdc Line Tower Type A2 (0° to 1°) Design Loading sheet 2 of 2
ILK-SN-CD-6200-TL-DD-0177-01	505573-4622-43DD-0033	350 kV HVdc Line Tower Type A3 (0° to 1°) Design Loading sheet 1 of 2
ILK-SN-CD-6200-TL-DD-0199-01	505573-4622-43DD-0057	350 kV HVdc Line Tower Type A4 (0° to 1°) Design Loading sheet 1 of 2
ILK-SN-CD-6200-TL-DD-0066-01	505573-4622-43DD-0003-SH1_04	350 kV HVdc Line Tower Type B1 (0° to 3°) Design Loading sheet 1 of 4
ILK-SN-CD-6200-TL-DD-0066-02	505573-4622-43DD-0003-SH2_04	350 kV HVdc Line Tower Type B1 (0° to3°) Design Loading sheet 2 of 4
ILK-SN-CD-6200-TL-DD-0066-03	505573-4622-43DD-0003-SH3_04	350 kV HVdc Line Tower Type B1 (0° to3°) Design Loading sheet 3 of 4
ILK-SN-CD-6200-TL-DD-0066-04	505573-4622-43DD-0003-SH4_04	350 kV HVdc Line Tower Type B1 (0° to 3°) Design Loading sheet 4 of 4
ILK-SN-CD-6200-TL-DD-0201-01	505573-4622-43DD-0059-SH1_06	350 kV HVdc Line Tower Type B2 (0° to 3°) Design Loading sheet 1 of 6
ILK-SN-CD-6200-TL-DD-0201-02	505573-4622-43DD-0059-SH2_06	350 kV HVdc Line Tower Type B2 (0° to 3°) Design Loading sheet 2 of 6
ILK-SN-CD-6200-TL-DD-0201-03	505573-4622-43DD-0059-SH3_06	350 kV HVdc Line Tower Type B2 (0° to 3°) Design Loading sheet 3 of 6
ILK-SN-CD-6200-TL-DD-0201-04	505573-4622-43DD-0059-SH4_06	350 kV HVdc Line Tower Type B2 (0° to 3°) Design Loading sheet 4 of 6
ILK-SN-CD-6200-TL-DD-0201-05	505573-4622-43DD-0059-SH5_06	350 kV HVdc Line Tower Type B2 (0° to 3°) Design Loading sheet 5 of 6
ILK-SN-CD-6200-TL-DD-0201-06	505573-4622-43DD-0059-SH6_06	350 kV HVdc Line Tower Type B2 (0° to 3°) Design Loading sheet 6 of 6
ILK-SN-CD-6200-TL-DD-0067-01	505573-4622-43DD-0005-SH1_03	350 kV HVdc Line Tower Type C1 (0° to 30°) Design Loading sheet 1 of 3
ILK-SN-CD-6200-TL-DD-0067-02	505573-4622-43DD-0005-SH2_03	350 kV HVdc Line Tower Type C1 (0° to 30°) Design Loading sheet 2 of 3
ILK-SN-CD-6200-TL-DD-0067-03	505573-4622-43DD-0005-SH3_03	350 kV HVdc Line Tower Type C1 (0° to 30°) Design Loading sheet 3 of 3
ILK-SN-CD-6200-TL-DD-0072-01	505573-4622-43DD-0013-SH1_03	350 kV HVdc Line Tower Type C2 (0° to 30°) Design Loading sheet 1 of 3
ILK-SN-CD-6200-TL-DD-0072-02	505573-4622-43DD-0013-SH2_03	350 kV HVdc Line Tower Type C2 (0° to 30°) Design Loading sheet 2 of 3
ILK-SN-CD-6200-TL-DD-0072-03	505573-4622-43DD-0013-SH3_03	350 kV HVdc Line Tower Type C2 (0° to 30°) Design Loading sheet 3 of 3
ILK-SN-CD-6200-TL-DD-0068-01	505573-4622-43DD-0006- SH1_03	350 kV HVdc Line Tower Type D1 (0° to 45°) Design Loading sheet 1 of 3
ILK-SN-CD-6200-TL-DD-0068-02	505573-4622-43DD-0006- SH2_03	350 kV HVdc Line Tower Type D1 (0° to 45°) Design Loading sheet 2 of 3
ILK-SN-CD-6200-TL-DD-0068-03	505573-4622-43DD-0006- SH3_03	350 kV HVdc Line Tower Type D1 (0° to 45°) Design Loading sheet 3 of 3
ILK-SN-CD-6200-TL-DD-0073-01	505573-4622-43DD-0014- SH1_03	350 kV HVdc Line Tower Type D2 (0° to 45°) Design Loading sheet 1 of 3
ILK-SN-CD-6200-TL-DD-0073-02	505573-4622-43DD-0014- SH2_03	350 kV HVdc Line Tower Type D2 (0° to 45°) Design Loading sheet 2 of 3
ILK-SN-CD-6200-TL-DD-0073-03	505573-4622-43DD-0014- SH3_03	350 kV HVdc Line Tower Type D2 (0° to 45°) Design Loading sheet 2 of 3
ILK-SN-CD-6200-TL-DD-0069-01	505573-4622-43DD-0008- SH1_03	350 kV HVdc Line Tower Type E1 (45° to 90°) Design Loading sheet 1 of 3
ILK-SN-CD-6200-TL-DD-0069-02	505573-4622-43DD-0008- SH2_03	350 kV HVdc Line Tower Type E1 (45° to 90°) Design Loading sheet 2 of 3
ILK-SN-CD-6200-TL-DD-0069-03	505573-4622-43DD-0008- SH3_03	350 kV HVdc Line Tower Type E1 (45° to 90°) Design Loading sheet 3 of 3