RELIABILITY STUDY
OF TRANSMISSION LINES
ON THE AVALON AND CONNAIGRE PENINSULAS

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DATE: April, 1996

HYDRO

LETTER OF TRANSMITTAL

MEMO TO: Fred Martin
Director, Engineering TRO

FROM: Asim Haldar

DATE: 16 April, 1996

SUBJECT: Reliability Study Report

I am pleased to submit the final report entitled "Reliability Study of Transmission Lines on Avalon and Connaigre Peninsulas". I have received several comments and these have now been incorporated as necessary.

This report, in detail, assesses the ultimate capacity of the line "as-built", provides an estimate of 25-year and 50-year design ice load based on the available historical data duly adjusted for various line failures since '65, reliability analyses of various line components treating the whole line as a system and a cost-benefit analysis to justify and select a particular option for future upgrading work. It is quite evident from the current study that reliability of major lines on the Avalon as well as TL220 are quite low and probability of further failure is high.

Five options were considered for Avalon lines. Although cost-benefit analysis supports only Option 1 and Option 2 strictly based on economic choices, it is my recommendation that Option 4 for wood pole lines and Option 3 for steel lines be considered seriously for reconductoring with particular reference to reliability and line security. Upgrading of wood pole line with reconductoring is only practical provided it is ensured that the majority of wood pole structures have not experienced loss of in-service strength due to ageing of wood poles. This will require some follow-up work with Operations to collect large samples of data from the field to draw any meaningful conclusions for statistical purposes. However, upgrading work of steel lines TL217 and remaining part of TL207 and TL237 should be initiated and when implemented, we will have at least one (1) well secured line on the Avalon Peninsula.

Five scenarios were also considered for TL220, a 69 kV line on the Connaigre Peninsula. A long section of the line over a high plain is quite exposed to severe combined wind and ice loads that exceeds the original design load and has failed four (4) times over the past 25 years. It is recommended that a section of this line be rerouted to lower elevation and be built for a 50-year new design load that takes into account the previous failure records. Although Option 3, 4 and 5 are all feasible, it is my recommendation that Option 4 be considered for upgrading TL220. This will provide an economic balance between initial cost and future failure cost.

Should you have any questions, please let me know.

Asim Haldar

AH/mmcd

Attach.

EXECUTIVE SUMMARY

Technical Support has carried out a detailed study entitled "Reliability Study of Transmission Lines on Avalon and Connaigre Peninsulas". This study was initiated in view of the many failures that these lines have experienced in the past specifically the recent sleet storm damage of TL201 near Western Avalon Station in December 8-10, 94.

It is well known that lines on the Avalon Peninsula are highly exposed particularly to glaze ice load due to severe freezing precipitation coupled with some in-cloud icing. Failures have occurred uniformly over various segments of 160 km long transmission line route that covers two (2) major lines which supply the bulk power to St. John's area. TL208 is excluded from the study because the plant is no longer operating and TL242, because the line is a short line and "well built" with high strength ACSR conductor and six (6) pole dead-end structures.

Based on the annual failure rate derived from the past and recent failure data, and combining this information with the results of an earlier meteorological study that was conducted for Avalon & Burin lines, new probabilistic ice loads are estimated for 10-year, 25-year and 50-year return period values. It is shown clearly that these load values far exceed the original design loads and even a 5-year return period ice load exceeds the ultimate capacities of many of these lines on the Avalon Peninsula. This indicates that the reliability of the line is very low and does not meet the commonly accepted target design loading of 50-year return period which is estimated to be 3.0 inches (75 mm) radial of glaze ice.

To increase the reliability and security of these lines, five (5) options were considered for wood pole lines and four (4) options were considered for steel tower lines on the Avalon Peninsula. These options include 1)replacement of welded eye bolt, 2)addition of mid-span structures to reduce weight spans and dead-end structures at strategic locations to improve the line security, 3)re-conductoring with high strength alloy conductor and 4)changing of dead-end hardware (eye bolt) by full dead-end assembly and finally 5)building a new line to withstand new 50-year load.

Except Options 4 and 5 for wood pole lines and Options 3 and 4 for steel tower lines, implementation of all other options will provide marginal improvement in line reliability; significant improvement of line security will be achieved through Options 2, 3, 4 and 5 respectively. Building new lines will be the most expensive options; however technical support strongly believes re-conductoring both lines would provide adequate reliability and security for remaining 25 years service lives of these lines provided there is no loss of in-service strengths of wood poles due to ageing. This will require some further follow-up work. However, upgrading of steel tower lines, can be done separately and this will provide at least, a well secured 230 kV line east of Sunnyside.

In view of this, Technical Support Group is recommending to upgrade these lines on the Avalon Peninsula with the re-conductoring Option i.e. <u>Option 4</u> for wood pole lines and <u>Option 3</u> for steel tower lines.

Five scenarios were also considered for TL220, a 69 kV line on the Connaigre Peninsula. A long section of the line over a high plain is quite exposed to severe combined wind and ice load that exceeds the original design load and has failed four (4) times over the past 25 years. It is recommended that a section of this line be re-routed to lower elevation and be built for a 50-year new design load that takes into account the previous failure records. Although Option, 3, 4 and 5 are all feasible, Technical Support recommends that Option 4 be considered for upgrading TL220 in view of providing an economic balance between initial cost and future failure cost.

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SECTION 1

1.0 INTRODUCTION

1.1 General

Hydro operates two (2) parallel transmission lines at 230 kV level between Sunnyside and Oxen Pond terminal stations. Since their commissioning between mid-sixties and late-sixties, these lines have experienced severe ice loadings almost every year. These lines are located on the Avalon Peninsula, eastern part of Newfoundland, which is characterized by a maritime regional climate and is affected by almost all low pressure systems that cross North America in addition to those maritime systems passing along the eastern seaboard. Several large ice accumulations have been actually observed and since 1965, there were at least four (4) major line failures on this peninsula. These failures occurred in 1970, 1984, 1988 and 1994 respectively.

From Sunnyside terminal station, there are two (2) lines (TL237 and TL203) which run almost parallel towards Western Avalon station and are approximately 54 km long. From Western Avalon station, these lines (TL217/TL201) run again parallel towards Holyrood Terminal Station where one of these lines (TL217) is terminated, while the other line (TL201) proceeds towards Hardwoods terminal station. Each of these lines is approximately 80 km long. From Holyrood terminal station, a separate steel line (TL218) carries power at 230 kV level toward Hardwoods terminal station. From Hardwoods station, one double circuit wood pole line (TL218/TL236) carries power towards Oxen Pond station. In addition to this, there is another wood pole line (TL242) which also connects Holyrood and Hardwoods terminal stations and carries power at 230 kV level.

Transmission line TL220, a 69 kv line from Bay D'Espoir to Barachoix (via English Harbour terminal station) is 48 km long and was built in 1970 on the Connaigre Peninsula. Since its commissioning, this line has experienced at least four (4) failures due to combined wind and ice loads that exceed the original design load.

Figure 1.1 depicts the schematic representation of High Voltage (HV) transmission lines on Avalon and Connaigre Peninsulas.

Figures 1.2 and 1.3 depict the overall layout of these lines on topo maps with particular reference to various substations. Table 1.1 presents the total number of various structure types in each line.

1.2 Purpose of the Study

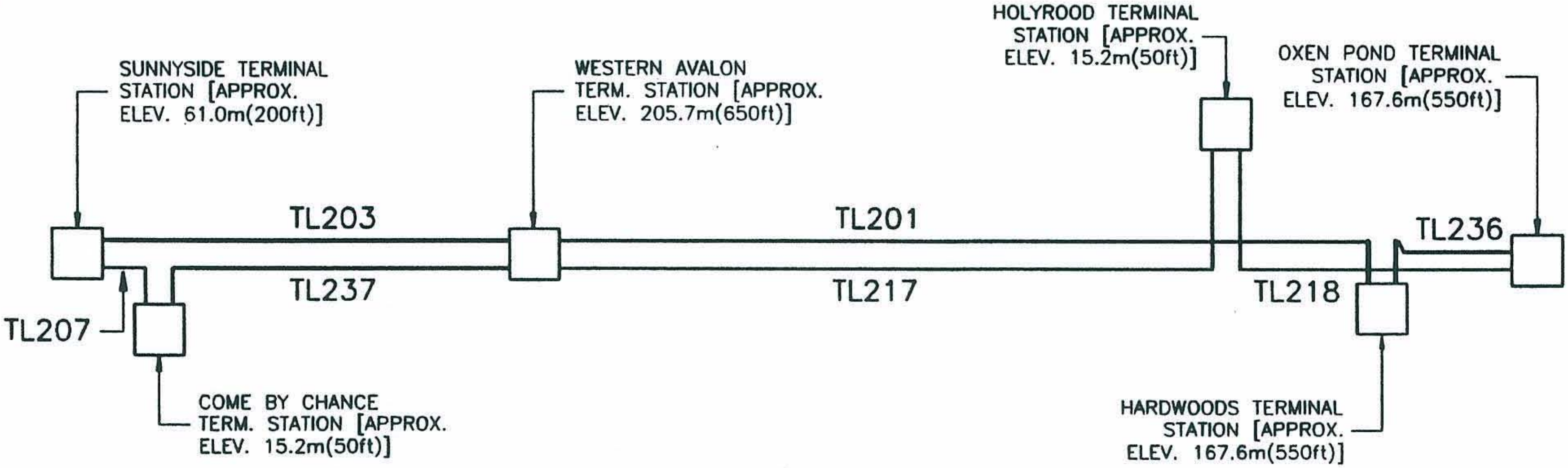
As a result of two (2) line failures in December 1994 on the Avalon Peninsula and one (1) failure on the Connaigre Peninsula in January, 1995, the Operations Division of Hydro requested Technical Support Department to undertake a detailed study on the assessment of the existing line reliability of both transmission line systems located on the Avalon and Connaigre peninsulas and to recommend what courses of action are necessary to increase the level of reliability of these lines. This report deals with several options and scenarios that have been considered to upgrade these lines with various reliability levels.

1.3 Scope of the Study

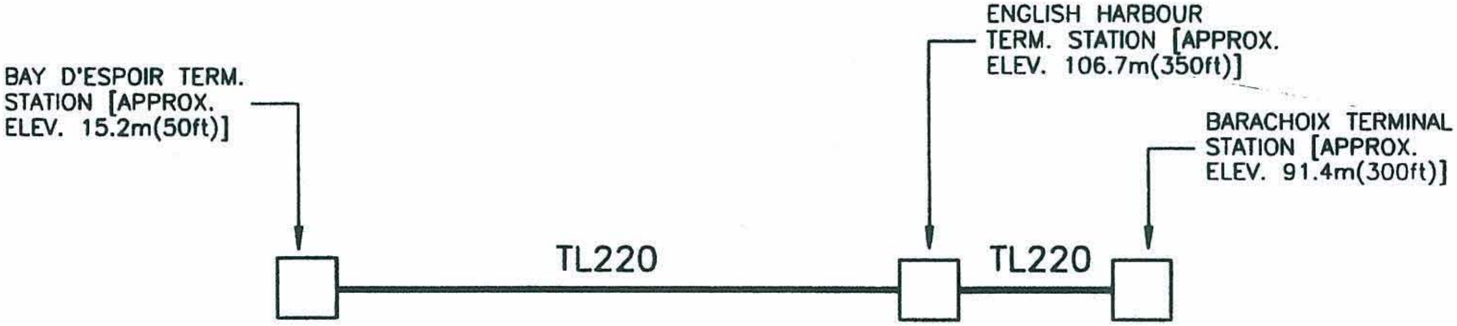
The scope of the study will include specifically the following:

(a) To address the concerns raised on page 14 and 15 of "Power System Outage Report" of December 8-11/94 (Ref. 1).

- "It is concluded that heavy icing of the conductors, in excess of design, initiated the failure of a welded eyebolt at both locations on TL201. It has been decided to review the use of the "welded eyebolts design" of transmission line hardware on all transmission lines and determine the



SCHEMATIC REPRESENTATION OF H.V. TRANSMISSION LINES ON THE AVALON PENINSULA



SCHEMATIC REPRESENTATION OF TL220

(FROM BAY D'ESPOIR T/S TO ENGLISH HR. T/S TO BARACHOIX T/S)

FIGURE 1.1

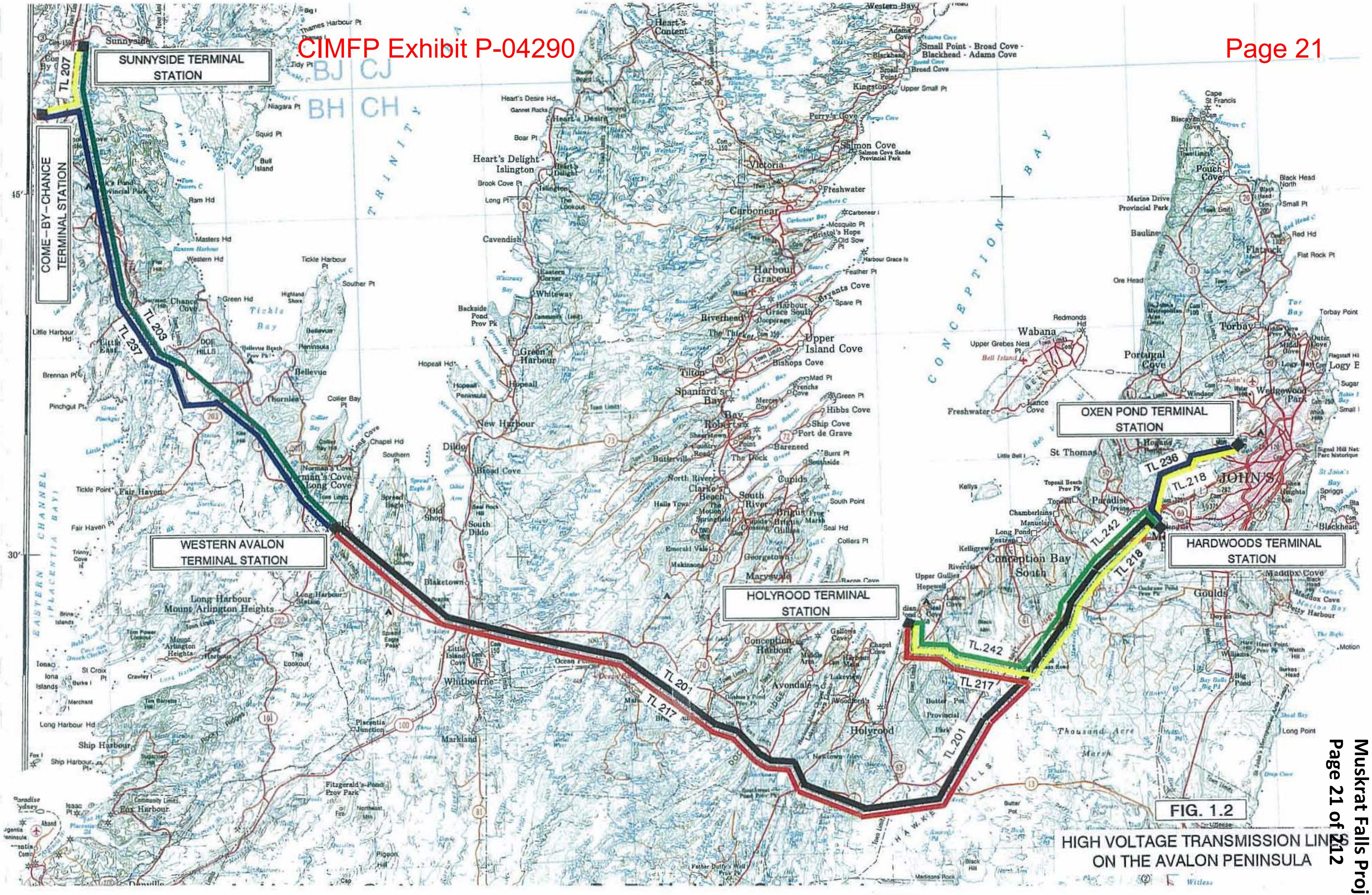


FIG. 1.2

HIGH VOLTAGE TRANSMISSION LINES ON THE AVALON PENINSULA

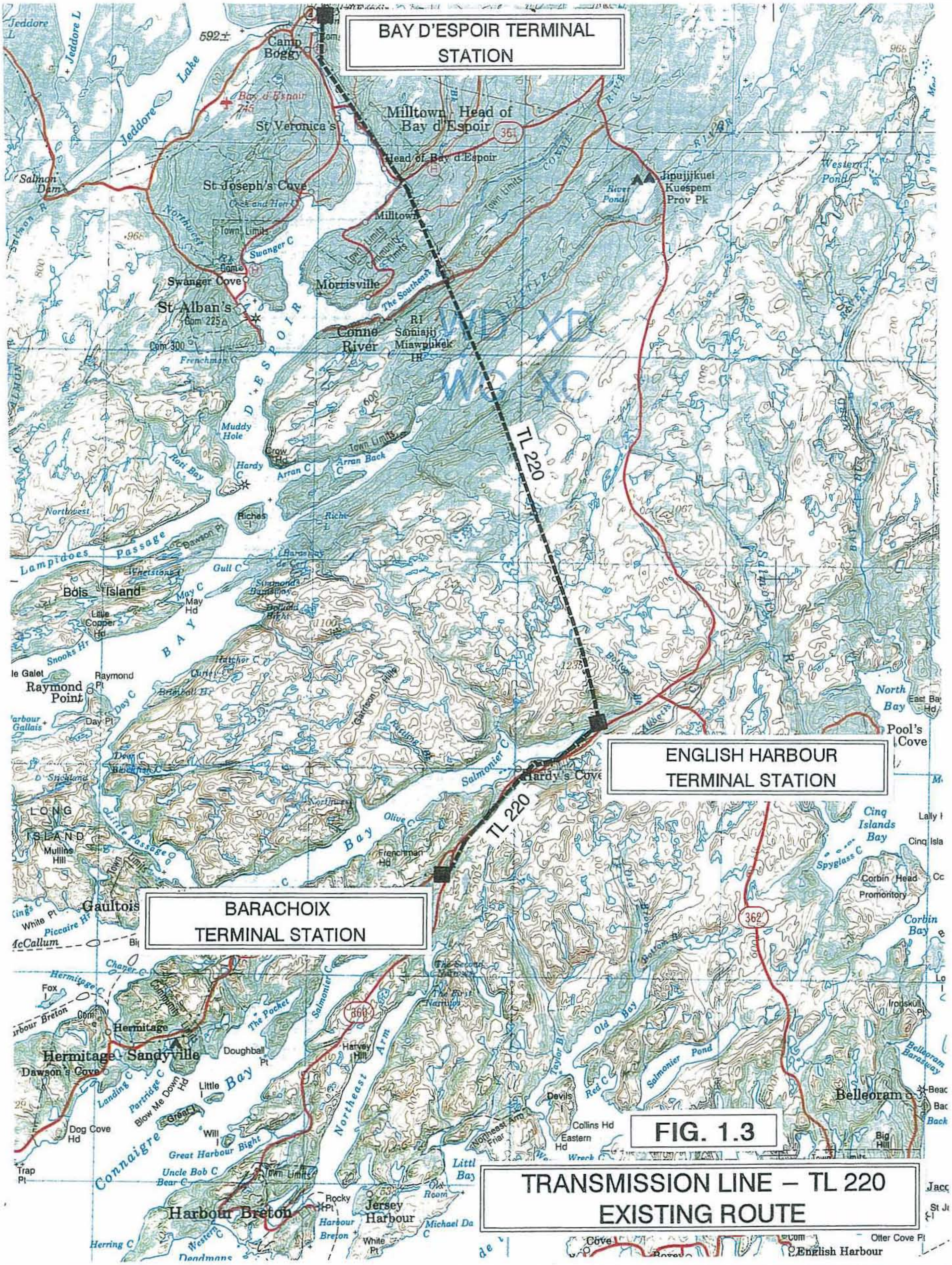


FIG. 1.3

TRANSMISSION LINE – TL 220
EXISTING ROUTE

TABLE 1.1

SUMMARY OF STRUCTURE TYPES ON H.V. TRANSMISSION LINES

File Name: E:\AVALON\GEN\STRSUM

WOOD POLE LINES

TRANSMISSION LINE NAME	TL 201 (WAV–HWD)	TL 203 (SSD–WAV)	TL 220 (BDE–EHW)	TL 218/236 (HWD– OPD)
LINE LENGTH (km)	81.3	44.5	47.8	(See Note 1) 10.3
SUSPENSION STRUCTURES	320	141	151	42
LIGHT & MEDIUM ANGLE STRUCTURES	12	1	6	0
DEADEND STRUCTURES	28	43	55	11

STEEL TOWER LINES

TRANSMISSION LINE NAME	TL 207 (SSD–CBS)	TL 217 (WAV–HRD)	TL 218 (HRD–HWD)	TL 237 (CBS–WAV)
LINE LENGTH (km)	8.2	76.6	(See Note 1) 26.9	44.2
SUSPENSION STRUCTURES	20	195	57	106
LIGHT & MEDIUM ANGLE STRUCTURES	1	23	9	14
DEADEND STRUCTURES	10	11	5	10

NOTE 1

TL 218 is a 230kV Transmission Line which runs from the Holyrood Terminal Station to the Oxen Pond Terminal Station. This transmission line consists of a combination of STEEL TOWER and WOOD POLE structures and may be described as follows...

- Holyrood T/S to Str. No. 70 – Steel Tower. (25.2 km.)
- Str. No. 71 to 79 – Wood pole, double circuit combined with TL 201. (1.7 km.)
- Str. No. 80 to Oxen Pond T/S – Wood pole, double cir. combined with TL 236. (10.

need for replacement."

- "It is probable that aeolian vibration was a factor in the failure of the conductor clamp on TL217. Presently, Hydro is studying the problem of aeolian vibration on transmission lines on the Avalon Peninsula. This work will be continued so as to cover all the transmission lines exposed to aeolian vibration, particularly on the Avalon Peninsula."

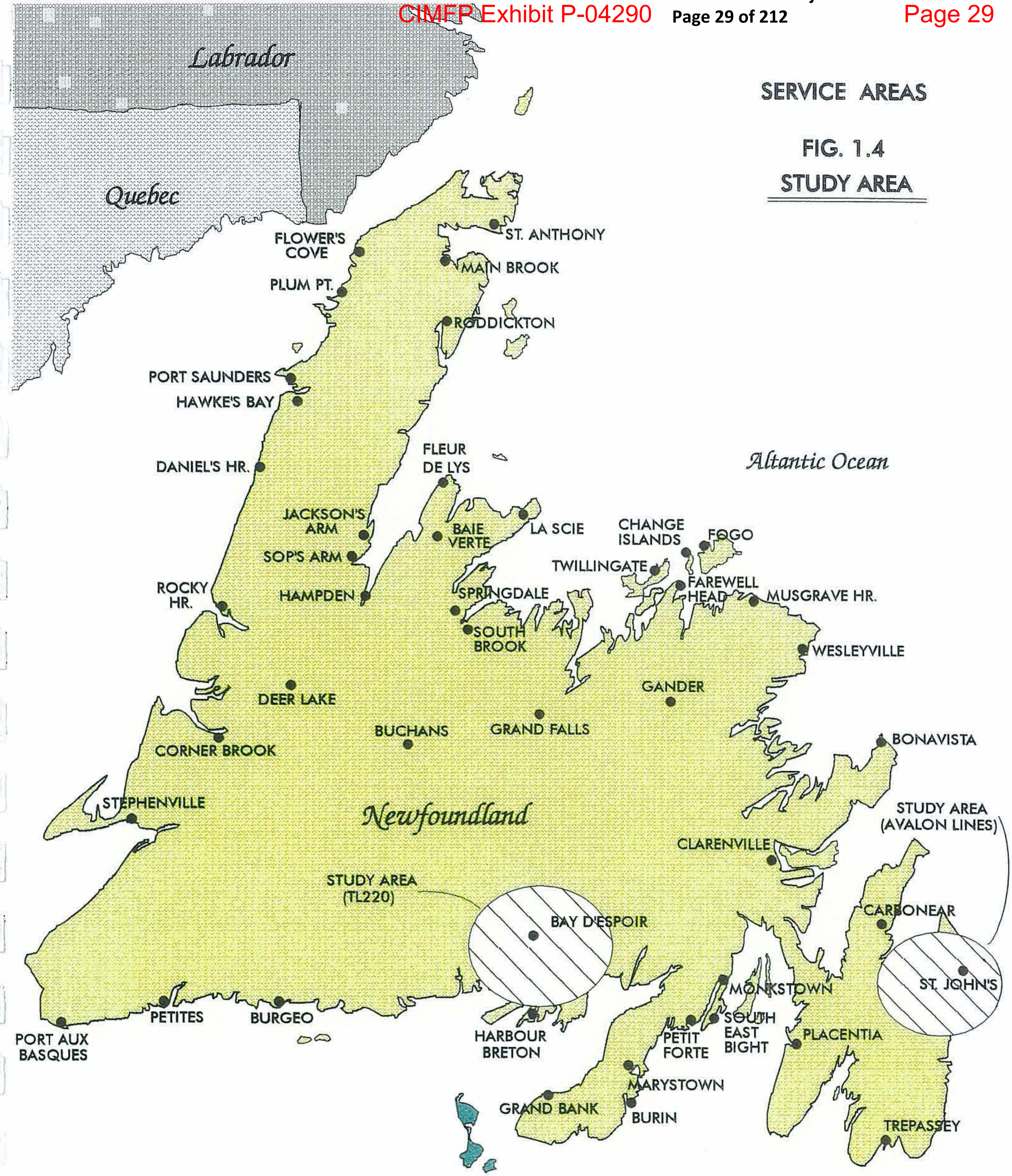
- "A contributing factor to the failure of TL201 (Str. #2 - #9) is the existence of long spans in the range of 1500 ft to 2000 ft. Although constructed to meet the design criteria, with the type of icing and winds experienced on the Avalon Peninsula, these spans can leave the line severely exposed. A review of the lines will be undertaken to identify the areas with these long spans."

(b) In addition to this, several options will be developed to improve the reliabilities of these lines on the Avalon Peninsula. Similarly, various upgrading scenarios for TL220 will be also developed.

(c) Prepare capital cost estimates for budgetary purposes for any remedial measures that are necessary; this will also include the upgrading cost for TL220. Several recommendations will be made based on a detailed cost benefit analysis.

1.4 Study Area

The study area includes major lines on the Avalon Peninsula and TL220 on the Connaigre Peninsula as shown in Figure 1.4. Lines on the Avalon Peninsula include TL201, TL203, TL218/TL236, TL217 and TL207/TL237 and TL220 on the Connaigre Peninsula, respectively. TL208 and TL242 have not been included in this study.



SERVICE AREAS

FIG. 1.4

STUDY AREA

1.5 Layout of Various Sections

Section 1 primarily defines the purpose and scope of this study with figures showing the overall schematic representation of Hydro's transmission line systems on these two peninsulas.

Section 2 deals with the history of various past and recent failures, extent of damages (foot prints), statistics of forced outage time and finally annual failure rate of these lines in terms of line length.

Section 3 describes laboratory testings that were carried out on several wood pole samples and a few welded eye bolt samples and discusses the aging effect on degradation of strength of wood pole lines.

Section 4 reviews the procedure for developing climatological loadings on these lines based on weather data from AES stations (airports) and relates these loadings in terms of various return periods and annual failure rate.

Section 5 deals with reliability-based design philosophy with particular reference to treating the transmission line as a system, discusses sequence of failure and points out some of the flaws that exist in terms of lack of coordination of strength of various components in the original design when the design load is exceeded. This section is very critical because various options and scenarios are developed as alternatives to improve the existing line reliability in terms of reconductoring, modifications of existing structures, hardware replacement and finally selective rerouting of a specific line (TL220).

Section 6 provides some background information on Aeolian Vibration and its effects on the long term damage of conductors with particular reference to fatigue of strands if not protected properly. This section also discusses the future work that will be pursued in

SECTION 2

2.0 HISTORICAL INFORMATION ON VARIOUS LINE FAILURES

2.1 General

During the development of Bay d'Espoir, Phase I, it was known that lines on the Avalon Peninsula would be subjected to extreme wind and ice loads. Therefore, when the first 230 kV lines were designed in 1963, allowances were made for heavier ice and wind loads than those specified in the CSA Code (Ref. 2). Loads specified at the time in CSA was 13 mm glaze ice plus 117 km/hr wind as combined wind and ice loads .

With the imminent island-wide construction of the several hundred miles of 230 kV and 138 kV transmission lines associated with the Bay D'Espoir Development, a review of the meteorological conditions experienced by different organizations in Newfoundland was undertaken. These organizations included the Meteorological Branch of the Department of Transport, Canadian National Telegraphs, whose facilities crossed the Island with the railway, United Towns Electric, Price Newfoundland Limited, Newfoundland Light and Power, and Bowater Power Company. From this review, two basic load conditions evolved; Normal Zone and Ice Zone loads. These loading zones are summarized in Table 2.1 (Young and Schell, 1970) and are located as shown on Figure 2.1

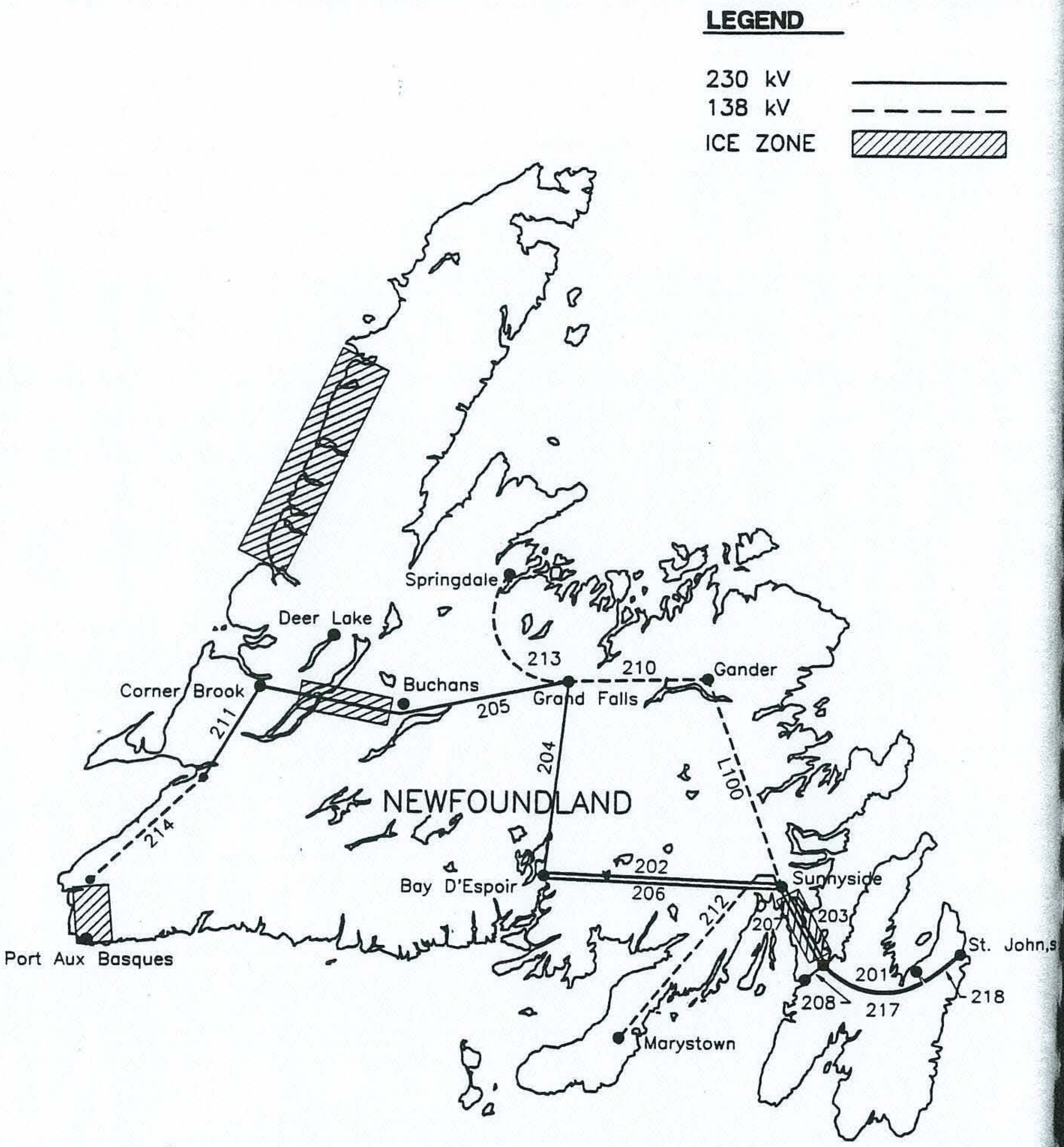
TABLE 2.1

DESIGN WIND AND ICE LOADS FOR BAY D'ESPOIR POWER DEVELOPMENT

Load Zone	Radial Ice		Gust Wind Speed		Temp		Max.Cond. Tension % RTS*
	inch	(mm)	mph	(km/hr)	0°F	(-°C)	
Normal Zone	1.0	(25)	0	(0)	0.0	(-18)	70
	0.5	(13)	73	(117)	0.0	(-18)	50
	0	(0)	110	(176)	0.0	(-18)	50
Ice Zone	1.5	(38)	0	(0)	0.0	(-18)	70
	1.0	(25)	73	(117)	0.0	(-18)	50
	0	(0)	110	(176)	0.0	(-18)	50

* NOTES: 1) RTS is defined as Rated Tensile Strength.
2) Vibration is often controlled by 20% to 25% of RTS under everyday temperature at 40°F (4°C) and 30% under extreme cold temperature at -50°F (-46°C).

FIGURE 2.1



ICE ZONE LOCATIONS

It was also recognized that a 17 mile (27 km) area immediately southeast of Sunnyside was noted for severe ice storms and the first 230 kV line built through this area (TL203 a wood pole in 1965) was designed to the criteria of 2 inches (50 mm) radial ice combined with a 73 mph (117 km/hr) gust. This loading was greater than the ice zone loading. The second 230 kV line through this area (TL207 a steel tower line in 1968) was built to the Ice Zone criteria. The overload factor on the maximum design loads was taken as 1.33 on the 230 kV steel and 138 kV aluminum towers, and 2.0 on all wood structures. Unequal ice loading on adjacent spans was also incorporated into the metal tower designs.

In the Utility Industry, it is common practice to design major transmission lines to withstand a 50-year return period load. The return period of an event is the average time elapsed between occurrences. A wind speed with a 100 - year return period called "100 Year Wind" will occur on average every 100 years. It will not necessarily be reached or exceeded in every 100-year interval, or may even occur more than once in the same interval. A typical service (economic) life of 50-years is assumed for steel line while for wood line, this is assumed to be 40-years. Prediction of actual design value of a climatic event (e.g., wind, ice and combined wind and ice) with a specific return period (50-year) is an extremely difficult problem in lieu of the lack of site specific data. Use of a 50-year return period load translates into a 64% chance that this load will be exceeded at least once, a 20% chance that this load will be exceed twice and 8% chance that this load will be exceed thrice, respectively during the 50-year service life of the line (Ref. 4). Details on the development of appropriate loading criteria with various return period values will be discussed further in Section 4.

Since these lines were built in mid-sixties, a number of failures have occurred resulting in significant forced outage time associated with considerable repair, and replacement costs. Tables 2.2 to 2.6 present the extent of the damage and duration of various outages that have occurred on the Avalon Peninsula during line failures in 1970, 1984, 1988, 1990 and 1994 respectively. Figure 2.2 depicts the foot prints of these failures. In a similar manner, Table 2.7 and Fig 2.3 depict the history and foot prints of failures of line TL220 on the Connaigre Peninsula.

TABLE 2.2

SUMMARY OF DAMAGE & DURATION - 1970

Line	Out	In	Duration	Line Type & Damage
202	0320 hrs. Feb. 28/70	1100 hrs. Mar. 18/70	19 days	230 kV steel; 5 towers 19 conductor miles
203	1916 hrs. Feb. 27/70	1903 hrs. April 18/70	50 days	230 kV wood; 28 structures 14 conductor miles
206	0443 hrs. Feb. 28/70	1722 hrs. Mar. 11/70	12 days	230 kV steel; 4 structures 8 conductor miles
207	1706 hrs. Feb. 27/70	1616 hrs. Mar. 11/70	13 days	230 kV steel; 3 structures 17 conductor miles
212	2020 hrs. Feb. 27/70	1646 hrs. Apr. 10/70	42 days	138 kV aluminum; 71 structures 62 conductor miles
Total Damage				111 structures 120 conductor miles

TABLE 2.3

SUMMARY OF DAMAGE & DURATION - 1984

Line	Out	In	Duration	Line Type & Damage
201	1628 hrs. April 13/84	1524 hrs. May 12/84	29 days	230 kV wood; 38 structures 5 conductor miles
217	0120 hrs. April 14/84	1430 hrs. April 27/84	14 days	230 kV steel; 12 structures 7.5 conductor miles
218*	0120 hrs. April 14/84	1353 hrs. April 22/84	9 days	230 kV steel/wood; 12 structures 5 conductor miles
237	1400 hrs. April 9/84	1903 hrs. May 14/84	35 days	230 kV steel; 7 structures 5 conductor miles
236*	0120 hrs. April 14/84	1151 hrs. April 29/84	14 days	230 kV wood; 12 structures 5 conductor miles (same as TL218)
Total Damage				69 structures; 22.5 conductor miles

*NOTE: Failure occurred only on the TL218/TL236 double circuit portion between Hardwoods Oxen Pond stations.

TABLE 2.4

SUMMARY OF DAMAGE & DURATION - 1988

Line	Out	In	Duration	Line Type & Damage
217	1248 hrs. April 14, 1988	1647 hrs. May 1, 1988	18 days	230 kV steel; 4 towers 4 conductor miles
Total Damage				4 Towers 4 conductor miles

TABLE 2.5

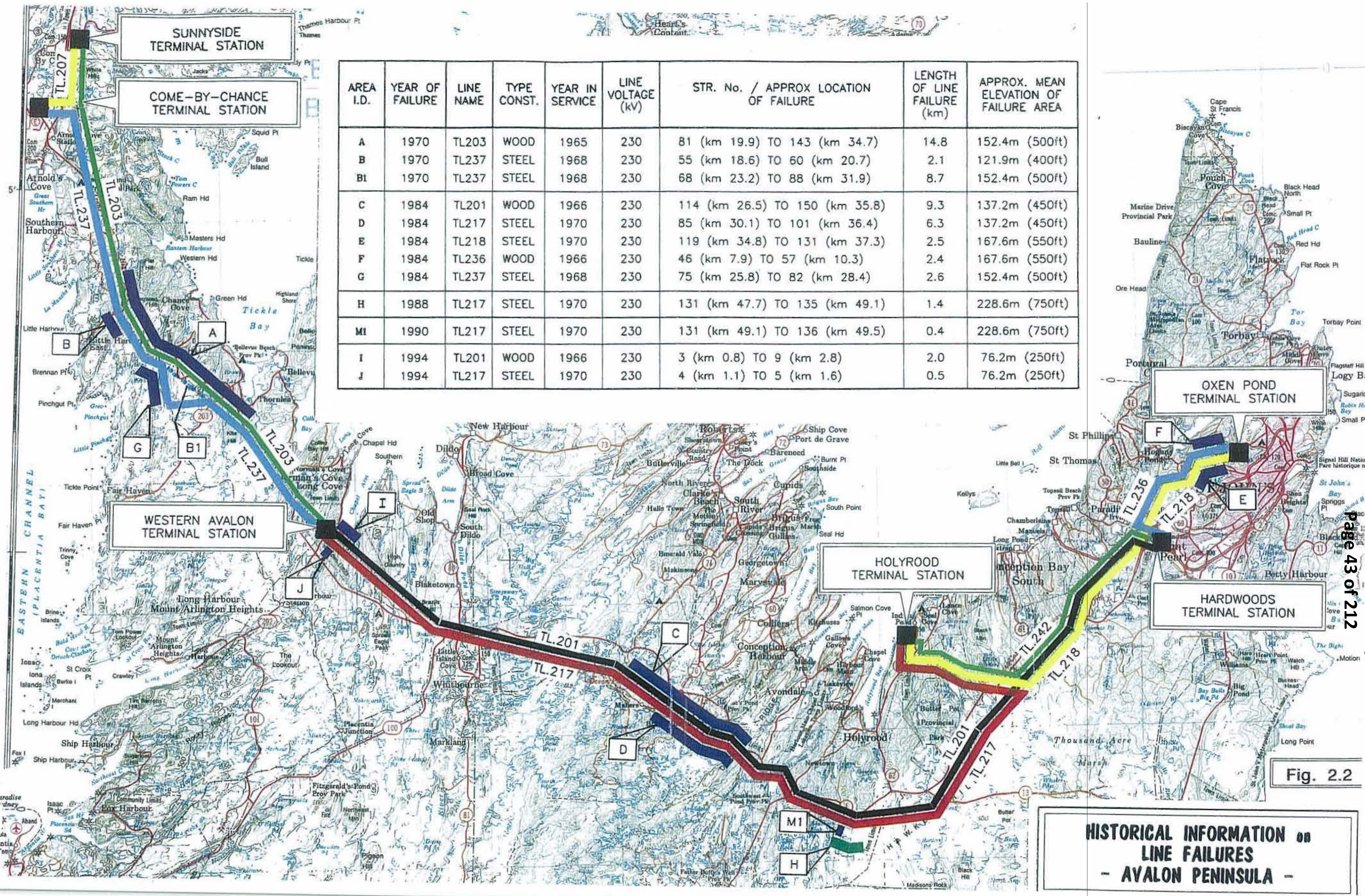
SUMMARY OF DAMAGE & DURATION - 1990

Line	Out	In	Duration	Line Type & Damage
217	1204 hrs. April 25, 1990	1154 hrs. April 26, 1990	1 days	1 conductor span

TABLE 2.6

SUMMARY OF DAMAGE & DURATION - 1994

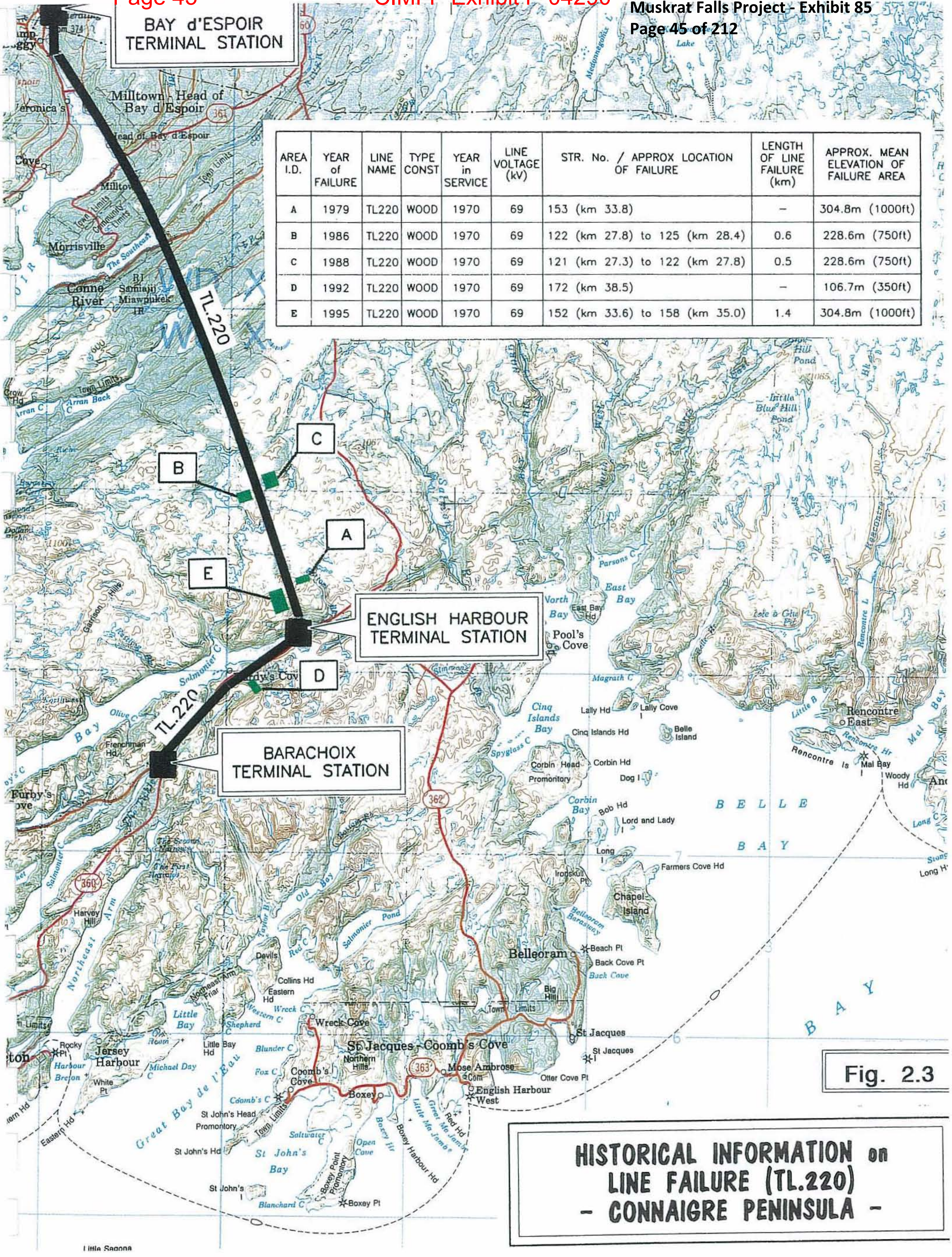
Line	Out	In	Duration	Line Type & Damage
201	2304 hrs. Dec.8, 1994	1748 hrs. Dec. 22/94	14 days	230 kV wood; 8 structures 6 conductor miles
217	0853 hrs. Dec. 9, 1994	1429 hrs. Dec. 10/94	1 1/4 days	230 kV steel; conductor close to ground on Str. #76-77
	1809 hrs. Dec. 10, 1994	0919 hrs. Dec. 11/94	15 hrs.	230 kV steel/wood; Clamp Failure in Str. #5 & #6
Total Damage				8 structures 6 conductor miles



AREA I.D.	YEAR OF FAILURE	LINE NAME	TYPE CONST.	YEAR IN SERVICE	LINE VOLTAGE (kV)	STR. No. / APPROX LOCATION OF FAILURE	LENGTH OF LINE FAILURE (km)	APPROX. MEAN ELEVATION OF FAILURE AREA
A	1970	TL203	WOOD	1965	230	81 (km 19.9) TO 143 (km 34.7)	14.8	152.4m (500ft)
B	1970	TL237	STEEL	1968	230	55 (km 18.6) TO 60 (km 20.7)	2.1	121.9m (400ft)
B1	1970	TL237	STEEL	1968	230	68 (km 23.2) TO 88 (km 31.9)	8.7	152.4m (500ft)
C	1984	TL201	WOOD	1966	230	114 (km 26.5) TO 150 (km 35.8)	9.3	137.2m (450ft)
D	1984	TL217	STEEL	1970	230	85 (km 30.1) TO 101 (km 36.4)	6.3	137.2m (450ft)
E	1984	TL218	STEEL	1970	230	119 (km 34.8) TO 131 (km 37.3)	2.5	167.6m (550ft)
F	1984	TL236	WOOD	1966	230	46 (km 7.9) TO 57 (km 10.3)	2.4	167.6m (550ft)
G	1984	TL237	STEEL	1968	230	75 (km 25.8) TO 82 (km 28.4)	2.6	152.4m (500ft)
H	1988	TL217	STEEL	1970	230	131 (km 47.7) TO 135 (km 49.1)	1.4	228.6m (750ft)
M1	1990	TL217	STEEL	1970	230	131 (km 49.1) TO 136 (km 49.5)	0.4	228.6m (750ft)
I	1994	TL201	WOOD	1966	230	3 (km 0.8) TO 9 (km 2.8)	2.0	76.2m (250ft)
J	1994	TL217	STEEL	1970	230	4 (km 1.1) TO 5 (km 1.6)	0.5	76.2m (250ft)

Fig. 2.2

HISTORICAL INFORMATION on
LINE FAILURES
- AVALON PENINSULA -



AREA I.D.	YEAR of FAILURE	LINE NAME	TYPE CONST	YEAR in SERVICE	LINE VOLTAGE (kV)	STR. No. / APPROX LOCATION OF FAILURE	LENGTH OF LINE FAILURE (km)	APPROX. MEAN ELEVATION OF FAILURE AREA
A	1979	TL220	WOOD	1970	69	153 (km 33.8)	–	304.8m (1000ft)
B	1986	TL220	WOOD	1970	69	122 (km 27.8) to 125 (km 28.4)	0.6	228.6m (750ft)
C	1988	TL220	WOOD	1970	69	121 (km 27.3) to 122 (km 27.8)	0.5	228.6m (750ft)
D	1992	TL220	WOOD	1970	69	172 (km 38.5)	–	106.7m (350ft)
E	1995	TL220	WOOD	1970	69	152 (km 33.6) to 158 (km 35.0)	1.4	304.8m (1000ft)

Fig. 2.3

HISTORICAL INFORMATION on
LINE FAILURE (TL.220)
- CONNAIGRE PENINSULA -

TABLE 2.7

SUMMARY OF DAMAGE AND DURATION FOR LINE TL220

LINE	OUT	IN	DURATION	LINE TYPE & DAMAGE
TL220	March 1, 1979	March 2, 1979	2 Hours	1 str. cross arm broken
	0217 hrs. March 29, 1986	1141 hrs. March 31, 1986	33 hrs. 24 min.	4 strs. Damaged. cross arms broken
	0206 hrs. Feb. 12, 1988	1447 hrs. Feb. 18, 1988	36 hrs. 41 min.	Conductor broken between str. #121 and str. #122
	2300 hrs. Oct. 19, 1992	1606 hrs. Oct. 21, 1992	41 hrs. 6 min.	Str #176; pole broke
	0109 hrs. Jan. 17, 1995	1932 hrs. Jan 21, 1995	90 hrs. 23 min.	5 structures; conductor broke
TOTAL DAMAGE				11 structures; 2 conductor span

2.2 Description of Various Lines on Avalon and Connaigre Peninsulas

The following Section provides a short description of each line including number of failures that it has experienced since its commissioning. Specific locations of various types of conductors on these transmission lines are shown graphically in Figures 2.4 and 2.5 respectively, and documented in Table 2.8 with information on conductor characteristics such as diameter, weight, segment length, etc., and original design loading.

a) Wood Pole Lines

i) TL203

This line was commissioned in 1965 and consists of tangent structures (H-Frame knee braced and cross-braced) with 3-pole dead end and angle structures (refer Figures A2.1[1] to A2.4). It runs from Sunnyside to Western Avalon Terminal Station, a distance of approximately 45 km. The line was designed for two loading zones: Ice Zone and Normal Zone. In the Ice Zone section, the conductor is a special aluminum alloy 562.5 Kcmil AACSR 30/19 with a rated strength of 53,000 lb while in the Normal Zone section, the conductor is a 636 Kcmil ACSR 26/7 with a rated strength of 25,000 lb. To-date, this line has experienced only one (1) major failure due to heavy icing in 1970.

ii) TL201

This line was commissioned in 1966 and consists of tangent structures (H-Frame knee-braced and cross-braced) with 3-pole dead end and angle structures (Figures A2.5 to A2.7). It runs from Western Avalon to Hardwoods Terminal Station, a distance of approximately 81 km. The line was designed for Normal Loading Zone and the conductor is primarily a 636 Kcmil ACSR 26/7 with a rated strength of 25,000 lb. To-date, this line has experienced two (2) major failures due to heavy icing and these failures occurred in 1984 and 1995 respectively.

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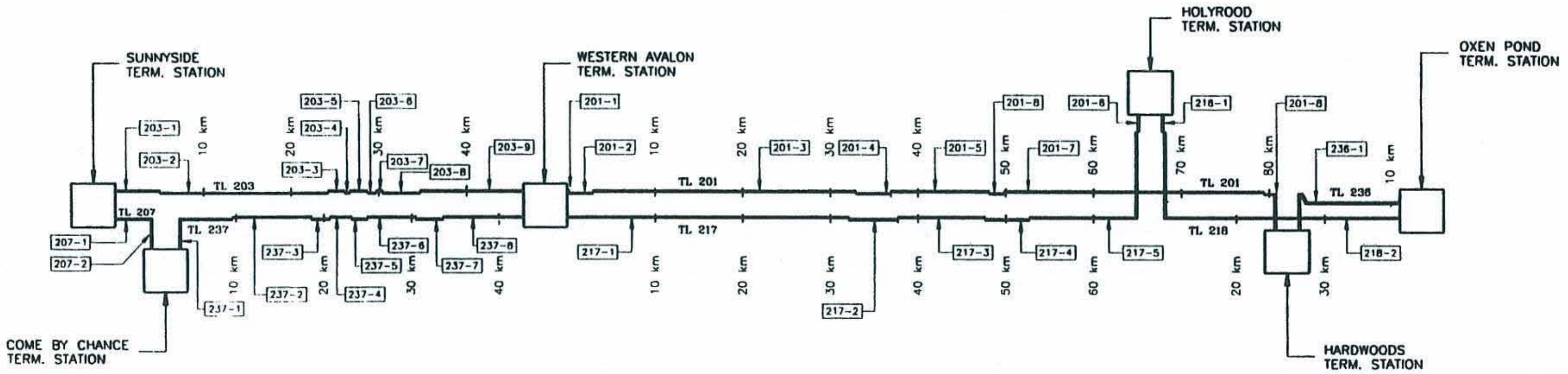
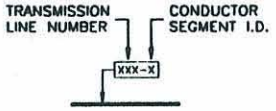
[1] *"A" before Figure Number (i.e.: Figure A2.1) applies to Figures in Appendix*



GRAPHICAL LOCATION OF HV TRANSMISSION LINE CONDUCTORS ON THE AVALON PENINSULA BETWEEN SUNNYSIDE AND OXEN POND TERMINAL STATIONS

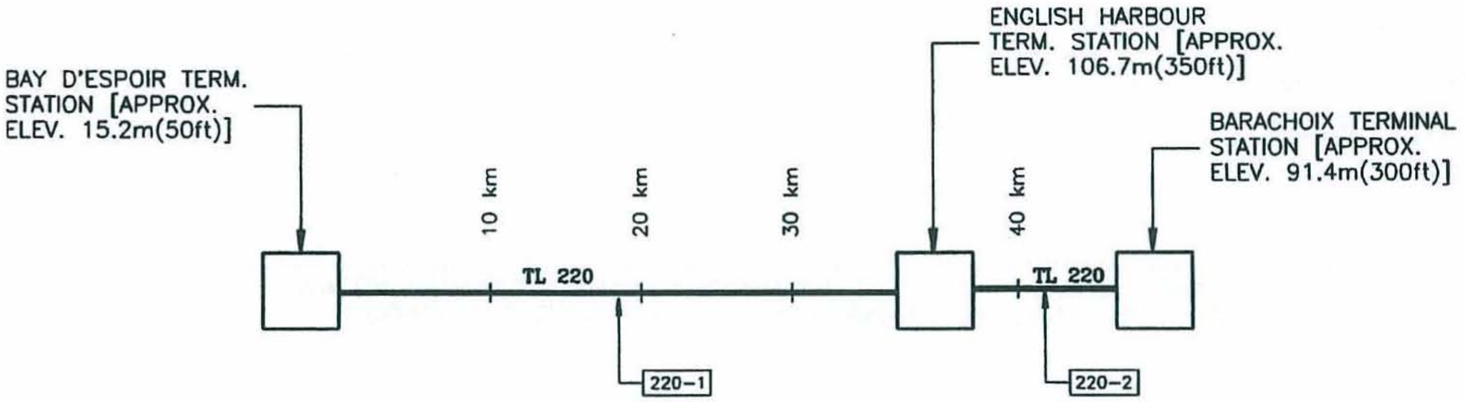
LEGEND :



NOTES :

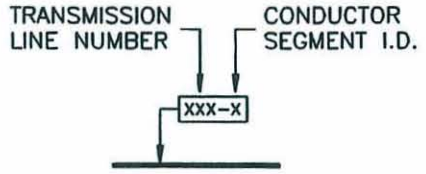
1. REFER TO TABLE 7 FOR CONDUCTOR TYPE, LOCATION AND LOADING.

FIGURE 2.4



GRAPHICAL LOCATION OF HV TRANSMISSION LINE CONDUCTORS ON TL220 BETWEEN BAY D'ESPOIR AND BARACHOIX TERMINAL STATIONS

LEGEND :



NOTES :

1. REFER TO TABLE 7 FOR CONDUCTOR TYPE, LOCATION AND LOADING.

FIGURE 2.5

HV TRANSMISSION LINE – CONDUCTOR TYPE, LOCATION AND LOADING
File Name: E:\AVALON\GEN\CLOADING

TRANS. LINE NO.	LINE VOLT. (kV)	LINE LT. (km)	YEAR IN SERVICE & CONST'N.	COND. I.D. CODE	CONDUCTOR & LOCATION	SAGTEN FILENAME	CONDUCTOR DATA				CONDUCTOR LOADING					REMARKS
							BARE DIA. (mm)	RTS (kN)	BARE MASS (kg/m)	CODE NAME	ICE	WIND	ICE/WIND COMBINED	EVERY–DAY	COLD	
TL 201	230	81.3	1966 WOOD POLE	201.1 201.3 201.5 201.7	**636 ACSR, 26/7 (70.1 km)** T/S (km 0) TO STR. 2 (km 0.2) STR 9 (km 2.7) TO STR 139 (32.9) STR 154A (km 36.9) TO STR 200A(km 48.1) STR 210 (km 49.8) TO STR 351(km 79.4)	201WIS1 201WIS3 201WIS5 201WIS7	25.16	111	1.299	GROSBEAK	1 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	WESTERN AVALON TO HARDWOODS ORIGINAL LOADING CRITERIA. from: 1986 DESIGN REVIEW & DESIGN BASIS SUMMARY.
				201.8	**795 ACSR, 26/7 (1.9 km)** STR 351 (km 79.4) TO T/S (km 81.3)	201WIS8	28.13	139	1.623	DRAKE	1 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	WESTERN AVALON TO HARDWOODS ORIGINAL LOADING CRITERIA from: 1986 DESIGN REVIEW & DESIGN BASIS SUMMARY.
			1988 WOOD POLE	201.4 201.5	**795 ACSR, 26/7 (6.8 km)** STR 139 (km 32.9) TO STR 154A (36.9) STR 200A (km 48.1) TO STR 210 (49.8) **(UPGRADED)**	– –	28.13	139	1.623	DRAKE	3 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	WESTERN AVALON TO HARDWOODS UPGRADE LOADING CRITERIA (1988)
			1994 WOOD POLE	201.2	**1192 ACSR, 54/19 (2.5 km)** STR 2 (km 0.2) TO STR 9 (km 2.7) **(UPGRADED)**	–	34.00	191	2.267	–	2 INCH ICE 0 MPH. WIND 0 DEG. F (80 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F	1 INCH ICE 73 MPH. WIND 0 DEG. F	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	WESTERN AVALON TO HARDWOODS UPGRADE LOADING CRITERIA (1994) from: 1994 ICE DAMAGE REPORT
TL 207	230	8.2	1968 STEEL TOWER	207.1	**636 ACSR 30/19 (4.7 km)** T/S (km 0) TO STR 14 (km 4.7)	207SIS1 207SIS2	25.89	141	1.466	EGRET	1.5 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F (50 % RTS (F))	1 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	SUNNYSIDE TO COME BY CHANCE ORIGINAL LOADING CRITERIA – ICE ZONE from: 1970 ICE DAMAGE REPORT & DESIGN BASIS SUMMARY
				207.2	**795 ACSR, 26/7 (3.5 km)** STR. 14 (km 4.7) TO T/S (km 8.2)	207SIS3	28.13	139	1.623	DRAKE	1.5 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F (50 % RTS (F))	1 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	SUNNYSIDE TO COME BY CHANCE ORIGINAL LOADING CRITERIA – ICE ZONE from: 1970 ICE DAMAGE REPORT
TL 217	230	76.6	1970 STEEL TOWER	217.1 217.3 217.5	**795 ACSR, 26/7 (64.1 km)** T/S (km 0) to STR 90 (km 32.1) STR 104 (km 37.7) to STR 130–1 (km 47.6) STR 144 (km 52.7) to STR 203 (km 74.8)	217SIS1 217SIS3 217SIS5	28.13	139	1.623	DRAKE	1 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	WESTERN AVALON TO HOLYROOD ORIGINAL LOADING CRITERIA from: 1986 DESIGN REVIEW & DESIGN BASIS SUMMARY.
				217.6	**37 STRAND AASC, ARVIDAL (1.8 km)** STR 203 (km 74.8) to T/S (km 76.6)	–	27.97	141	1.278	–	1 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	WESTERN AVALON TO HOLYROOD UPGRADE LOADING CRITERIA (1990)
			1990 STEEL TOWER	217.2 217.4	**795 ACSR, 26/7 (10.7 km)** STR 90 (km 32.1) to STR 104(km 37.7) STR 130–1 (km 47.6) to STR 144 (km 52.7) **(UPGRADED)**	– –	28.13	139	1.623	DRAKE	3 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	
TL 218	230	37.3	1970 WOOD POLE & STEEL TOWER	218.1	**37 STRAND AASC, ARVIDAL (1.8 km)** T/S (km 0) to STR 6 (km 1.8)	–	27.97	141	1.278	–	1 INCH ICE 0 MPH. WIND 0 DEG. F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	HOLYROOD TO OXEN POND ORIGINAL LOADING CRITERIA from: 1986 DESIGN REVIEW & DESIGN BASIS SUMMARY.
				218.2	**795 ACSR, 26/7 (35.5 km)** STR 6 (km 1.8) to T/S (km 37.3)	218SIS1 218WIS1	28.13	139	1.623	DRAKE	1 INCH ICE 0 MPH. WIND 0 DEG F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F –	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	HOLYROOD TO OXEN POND ORIGINAL LOADING CRITERIA from: 1986 DESIGN REVIEW & DESIGN BASIS SUMMARY.
TL 236	230	10.3	1966 WOOD POLE	236.1	**795 ACSR, 26/7 (10.3 km)** T/S (km 0) to T/S 10.3)	236WIS1	28.13	139	1.623	DRAKE	1 INCH ICE 0 MPH. WIND 0 DEG F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	HARDWOODS TO OXEN POND ORIGINAL LOADING CRITERIA from: 1986 DESIGN REVIEW & DESIGN BASIS SUMMARY.

TABLE 2.8

HV TRANSMISSION LINE – CONDUCTOR TYPE, LOCATION AND LOADING

HV TRANSMISSION LINE – CONDUCTOR TYPE, LOCATION AND LOADING
File Name: E:\AVALON\GEN\CLOADING

TRANS. LINE NO.	LINE VOLT. (kV)	LINE LT. (km)	YEAR IN SERVICE & CONST'N.	COND. I.D. CODE	CONDUCTOR & LOCATION	SAGTEN FILENAME	CONDUCTOR DATA				CONDUCTOR LOADING					REMARKS
							BARE DIA. (mm)	RTS (kN)	BARE MASS (kg/m)	CODE NAME	ICE	WIND	ICE/WIND COMBINED	EVERY–DAY	COLD	
TL 237	230	44.2	1968 STEEL TOWER	237.1 237.3 237.5 237.7	**795 ACSR, 26/7 (10.3 km)** T/S (km 0) TO STR 13 (km 3.3) STR 55 (km 18.6) TO STR 60 (km 20.7) STR 68 (km 23.2) TO STR 72–1 (km 25.0) STR 84 (km 30.5) TO STR 88 (km 33.6)	237SIS1 237SIS2 237SIS2 237SIS4	28.13	139	1.623	DRAKE	1.5 INCH ICE 0 MPH. WIND 0 DEG F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F	0.5 INCH ICE 73 MPH. WIND 0 DEG. F	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	COME BY CHANCE TO WESTERN AVALON. ORIGINAL LOADING CRITERIA. from: 1986 DESIGN REVIEW
				237.2 237.4 237.8	**636 ACSR, 30/19 (28.4 km)** STR 13 (km 3.3) TO STR 55 (km 18.6) STR 60 (km 20.7) TO STR 68 (km 23.2) STR 88 (km 33.6) TO T/S (km 44.2)	237SIS2 237SIS2 237SIS4	25.89	141	1.466	EGRET	1.5 INCH ICE 0 MPH. WIND 0 DEG F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F (50 % RTS (F))	1 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	COME BY CHANCE TO WESTERN AVALON. ORIGINAL LOADING CRITERIA. from: DESIGN BASIS SUMMARY
			1988 STEEL TOWER	237.6	**795 ACSR, 26/7 (5.5 km)** STR 72–1 (km 25.0) TO STR 84 (km 30.5) **(UPGRADED)**	–	28.13	139	1.623	DRAKE	58.40 mm ICE 0 Pa. WIND –18 DEG C (89.9 % RTS (F))	0 mm ICE 861.0 Pa. WIND –18 DEG C (50 % RTS (F))	25.4 mm ICE 386.0 Pa. WIND –18 DEG C (50 % RTS (F))	4 DEG C (20 % RTS (F))	–18 DEG C (33.3 % RTS (I))	COME BY CHANCE TO WESTERN AVALON. 1988 REROUTED SECTION OF TL 237 UPGRADE LOADING CRITERIA (1988)
TL 203	230	44.5	1965 WOOD POLE	203.1 203.9	**636 ACSR, 26/7 (14.8 km)** T/S (km 0) to STR. 20 (km 5) STR. 143 (km 34.7) to T/S (km 44.5)	203WIS1 203WIS5	25.16	111	1.299	GROSBEAK	1 INCH ICE 0 MPH. WIND 0 DEG F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F (50 % RTS (F))	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	SUNNYSIDE TO WESTERN AVALON ORIGINAL LOADING CRITERIA – NORMAL ZONE from: 1970 ICE DAMAGE REPORT & DESIGN BASIS SUMMARY.
				203.2 203.4 203.6 203.8	**562.5 AACSR, 36/19, 6101/EHSS (25.1 km)** STR 20 (km 5) TO STR 99 (km 24.2) STR 106 (km 26.1) TO STR 110 (km 26.7) STR 119 (km 28.7) TO STR 124 (km 29.7) STR 126 (km 30.4) TO STR 143 (km 34.7)	203WIS2 203WIS4 203WIS4 203WIS4	25.40	239	1.555		– – – –	0 INCH ICE 110 MPH. WIND 0 DEG. F (50 % RTS (F))	2 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F)) **	40 DEG. F (20 % RTS (F))	–20 DEG. F (33.3 % RTS (I))	SUNNYSIDE TO WESTERN AVALON ORIGINAL LOADING CRITERIA – ICE ZONE ** 70% RTS LATER REDUCED TO 50 % TO DECREASE QUANTITY OF UPLIFT STR'S. from: 1970 ICE DAMAGE REPORT & DESIGN BASIS SUMMARY.
				203.3 203.5 203.7	**795 ACSR, 26/7 (4.6 km)** STR 99 (km 24.2) TO STR 106 (km 26.1) STR 110 (km 26.7) TO STR 119 (km 28.7) STR 124 (km 29.7) TO STR 126 (km 30.4)	203WIS3 203WIS4 203WIS4	28.13	139	1.623	DRAKE	1 INCH ICE 0 MPH. WIND 0 DEG F (70 % RTS (F))	0 INCH ICE 110 MPH. WIND 0 DEG. F (50 % RTS (F))	0.5 INCH ICE 73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	SUNNYSIDE TO WESTERN AVALON ORIGINAL LOADING CRITERIA
TL 220	69	47.6	1970 WOOD POLE	220.1 220.2	**266.8 ACSR, 26/7** T/S(km 0) TO T/S(km 37.1) T/S(km 37.1) TO T/S(km 47.6)	220WIS1 –	16.30	50	0.545	PARTRIDGE	0 MPH. WIND 0 DEG. F (70 % RTS (F))	110 MPH. WIND 0 DEG. F (50 % RTS (F))	73 MPH. WIND 0 DEG. F (50 % RTS (F))	40 DEG. F (20 % RTS (F))	0 DEG. F (33.3 % RTS (I))	BAY D'ESPOIN TO ENGLISH HARBOUR ENGLISH HARBOUR TO BARACHOIX ORIGINAL LOADING CRITERIA ORIGINAL LOADING CRITERIA

TABLE 2.8 (Continued)

HV TRANSMISSION LINE – CONDUCTOR TYPE, LOCATION AND LOADING

ii) TL201 (cont'd.)

In 1988, part of this line was upgraded at selected locations (Hawke Hill and Brigus Junction) to withstand increased ice loading (3.00 inches of radial glaze ice) by adding more "in-span" structures and reconducting with a 795 Kcmil 26/7 ACSR conductor with a rated strength of 31,000 lb. After the 1994 failure, line was further upgraded near Western Avalon Station with a 1192 Kcmil ACSR 54/19 conductor with a rated strength of 42,000 lb.

iii) TL218/TL236

This double circuit wood pole line was commissioned in 1966 and consists of tangent structures and six (6) pole dead end and angle structures (refer Figs A2.8 and A2.9). It runs from Hardwoods Terminal Station to Oxen Pond, a distance of approximately 10 km. The line was designed for Normal Loading zone and the conductor is a 795 Kcmil ACSR 26/7 with a rated strength of 31,000 lb. To-date, the line has experienced only one (1) major failure in 1984, due to heavy icing.

b) Steel Tower Lines:

i) TL207/TL237

This line was originally built from Sunnyside Terminal Station to Western Avalon Station and commissioned in 1966. Line consists of suspension and medium angle towers (guyed - V Type) with self-supported towers used as heavy angle and dead end structures (refer Figs. A2.10 to A2.13). This line is approximately 54 km in length. Subsequently, part of this line was rerouted to Come-By-Chance as TL207 and the line from Come-By-Chance to Western Avalon was named as TL237. The line was built to the Ice Zone loading criteria, runs almost parallel to existing TL203 line and was originally designed with a conductor 636 Kcmil ACSR 30/19 with a rated tensile strength of 32,700 lb. Subsequently, at several places 795 Kcmil ACSR 26/7 conductor was spliced with the existing conductor 636 Kcmil thus producing a line with mixed conductor. This 795 Kcmil conductor was not necessarily spliced between dead-end to dead-end and therefore, subsequent estimation of existing strength of the line with regard to conductor strength based on sag-tension data for these segments will only be very approximate. To-date, this line has experienced several failures including two (2) major failures in 1970 and 1984 respectively. After the failure of 1984, part of this line near S-Turn (Isthmus) was rerouted to lower elevation (further down South) and reconductored with a 795 Kcmil 26/7 ACSR conductor. Upgrading of this section included adding more "mid-span" structures to reduce the weight and wind spans and deadend structures as anti-cascading towers.

ii) <u>TL217</u>

This line was commissioned in 1970 and consists of suspension and light angle towers (guyed -V Type) and self supported structures at heavy angle and dead end locations. It runs from Western Avalon to Holyrood Terminal Station, a distance of 76 km. From Western Avalon to Soldier's Pond, it runs parallel to TL201, a wood pole line and is designed based on <u>Normal Zone</u> loading criteria. The conductor is a 795 Kcmil ACSR 26/7 with a rated tensile strength of 31,000 lb. To-date, this line has experienced several failures including the two (2) major failures in 1984 and 1988 and one (1) minor failure in 1990 respectively. A portion of this line over Hawke Hill and near Brigus Junction was <u>upgraded</u> to withstand <u>63mm</u> of glaze ice loading by adding more "mid-span" structures and dead end towers in 1991.

iii) <u>TL218</u>

This line was commissioned in 1968 and also consists of lattice towers (guyed V-Type) at suspension and medium angle locations and self-supported towers at heavy angle and dead end locations. It runs parallel to TL217 from Holyrood Terminal Station to the Soldier's Pond Tap and from this tap it runs parallel to TL201 towards Hardwoods Terminal Station. From Hardwoods Terminal Station it runs with TL236, as a double circuit wood pole line which has been described before. This line was designed based on Normal Zone loading criteria and is approximately 38 km in length. The conductor is a 795 Kcmil ACSR 26/7 conductor with a rated tensile strength of 31,000 lb. To-date, portion of this line (steel line) has not experienced any failure although, the double circuit wood pole section did experience one (1) major failure in 1984 which has been described earlier.

iv) TL220

This is a 69 kV wood pole line and was commissioned in 1970. The line runs from Bay d'Espoir to Barachoix Terminal Station via English Harbour Station. The line is approximately 48 km long and was originally designed for Normal Zone and consists of H-frame structures (knee-braced and cross-braced) with 3-pole structures at dead end locations (refer Figs. A2.14 and A2.15). The conductor for this line is a 266 Kcmil 26/7 ACSR conductor with a rated tensile strength of 11,000 lb. To-date, this line has experienced several major failures with a long forced outage time due to the remoteness and general inaccessibility of the line route. Although a significant portion of this line has been upgraded with double-crossarm arrangement to withstand heavy ice loading, the conductor of this line is still a "weak-link" with particular reference to design loadings and very long spans. The line has a difficult access and everytime there is a failure, operation crews had to spend several days before they could reach the actual failure site.

2.3 Line Failures

Following section provides a brief review of the several line failures that have occurred on the Avalon and Connaigre Peninsulas. Review primarily focuses on the causes of line failures and discusses the weaknesses in the current design process that need to be improved.

a) Avalon Peninsula

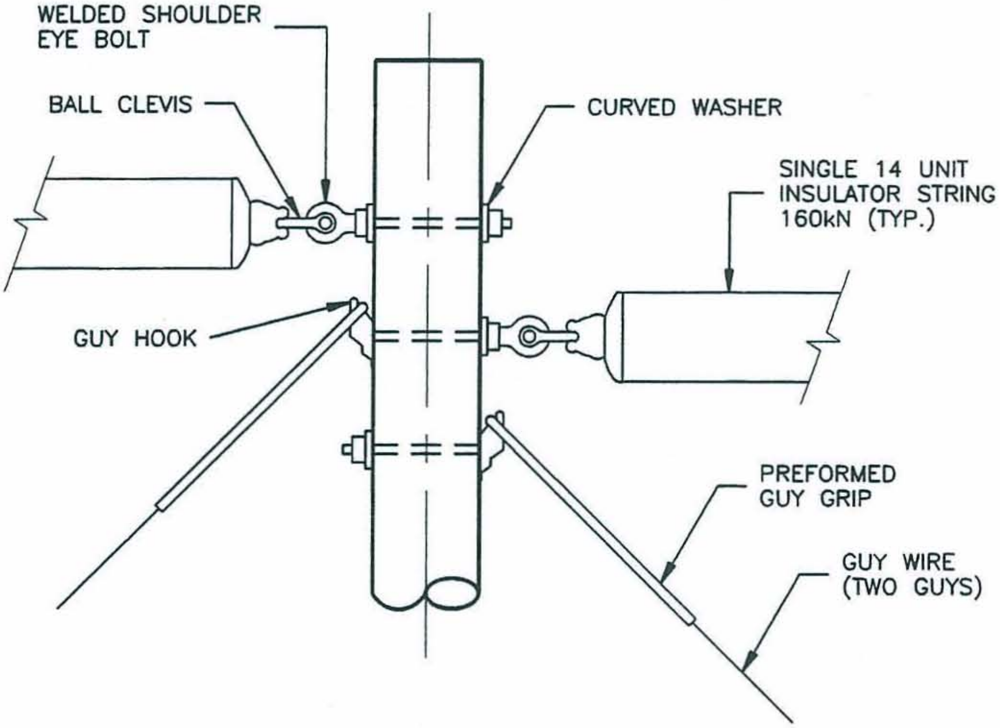
i) 1970 Storm (Ref. 3 & 4)

As a result of the Ice Storm of February, 1970, a total of 111 structures on 5 Newfoundland Hydro's 138kV and 230kV transmission lines were downed or damaged beyond repair and a total of 120 miles of conductor had to be replaced. Primary cause of failure on wood pole line (e.g. TL203) was the opening of a welded 7/8" (22 mm) eye bolt on a dead end structure (refer Fig. 2.6)thus releasing the conductor while it was fully loaded with ice and this precipitated the cascading collapse of 14 tangent structures until it came to stop at an angle structure where the structure deflected heavily to absorb the energy. Observed ice loadings were 6 inch (150 mm) diameter plus icicles and in one instance, a large piece of ice with icicles that probably fell from either TL203 or TL207 conductor was measured and the calculated ice load in this instance was 30 to 40 pounds per foot (Young and Schell, 1970). On steel lines, failures were primarily caused by conductor breakage and slippage and in all cases, ice load far exceeded the design criteria of these transmission lines (Refer Table 2.1).

ii) 1984 Storm (Ref. 5)

During this sleet storm, a number of lines that failed are detailed in Table 2.3. TL201 failed due to significant movement of a guying arrangement at a large angle structure location and this guying arrangement was subsequently modified (refer Fig. 2.7) under Work Order No. 5092 and implemented at various locations by Hydro forces in 1985. Failure of TL217 was also caused due to the collapse of a large angle (self-supported) structure (C-Type) thus causing a severe cascading failure. TL237 failure was primarily caused due to the conductor breakage in tension under 1.60 inches (41 mm) radial ice load. In all areas, ice load far exceeded the original design criteria and more than 2.0 inches (50 mm) of radial ice was observed at various places (refer Photos #2.1 and #2.2).

FIGURE 2.6



FRONT ELEVATION

230kV TANGENT DEADEND ARRANGEMENT

(ORIGINAL DESIGN)

iii) 1988 Storm

During this storm, TL217 failed over Hawke Hill and details of this damage are described in Table 2.4. A large angle structure (Tower Type - C) collapsed due to combined wind and ice load that far exceeded the original design load, thus causing a cascading failure. Ice load was also estimated approximately as 2 inches (50 mm) radial combined with 35 - 45 mph gust wind (refer to Photos #2.3 and #2.4).

iv) 1990 Storm

Conductor was loaded with severe glaze ice and came close to the ground, burned and severed causing one day outage. Ice was estimated as 1 3/4 inches (44 mm) radial approximately.

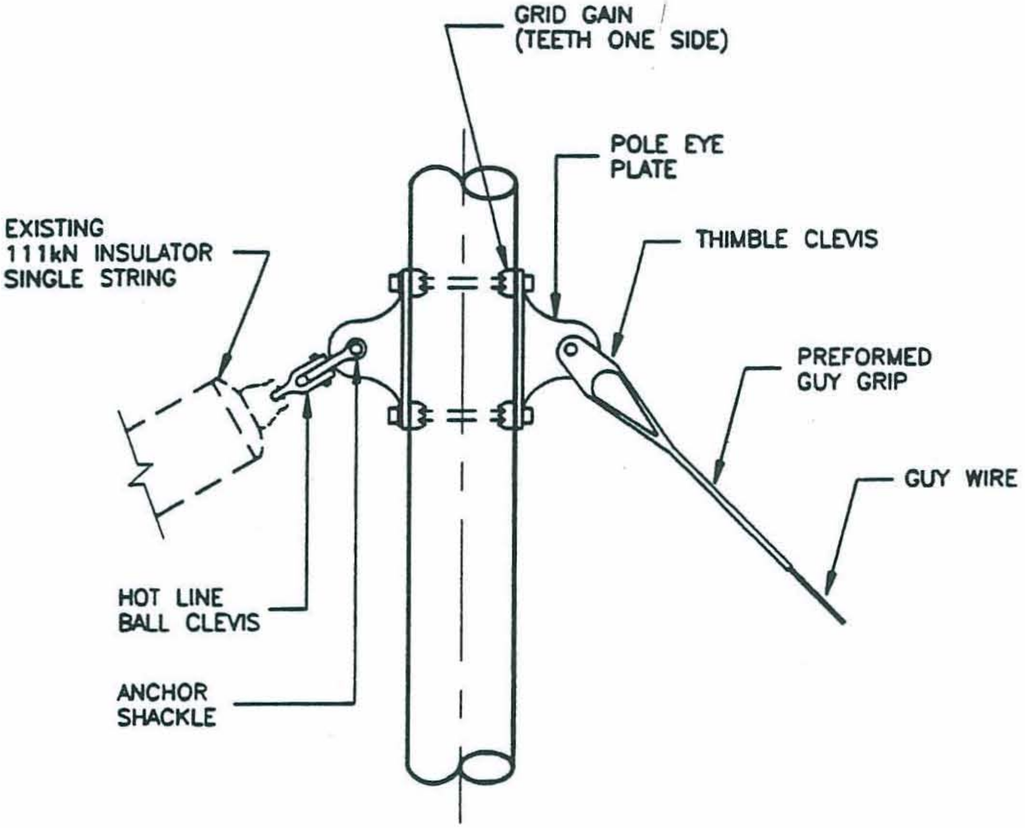
v) 1994 Storm (Ref. 5)

A welded eye bolt, 7/8" Ø (22 mm) diameter, on a dead-end structure having a 2000' long span opened below its rated strength when the original design load of 1.0 inch radial glaze ice was exceeded thus allowing the phase conductors to have a severe imbalance on both sides of the structure eventually leading to a cascade failure; combined wind and ice loads was estimated to be 2.0 inches (50 mm) radial with a 40~60 mph northerly wind (refer to Photos #2.5 and 2.6). Suspension clamps on structure #5 and #6 failed, most likely, due to wearing related to excessive aeolian vibration coupled with heavy ice loading during December 8 - 10, 1994.

b) Connaigre Peninsula

TL220 has experienced five (5) major outages over the past 25 years, the most recent, resulting from the 266.8 ACSR, 26/7 conductor coming close to the ground, due to heavy ice loading, arcing and causing conductor breakage,

FIGURE 2.7



FRONT ELEVATION

POLE EYE PLATE ARRANGEMENT ON
230kV ANGLE STRUCTURE TYPE "C" – TL201 & TL203

(REPLACES EXISTING GUY HOOK & BALL LINK EYE BOLT ARRANGEMENT)

Photo No. 2–1
April 1984
Glaze Ice sample from Conductor–TL–237
(weight 7.8 kg/m)

Photo No. 2–2
April 1984
Failed single eye Anchor Rod (TL–217)

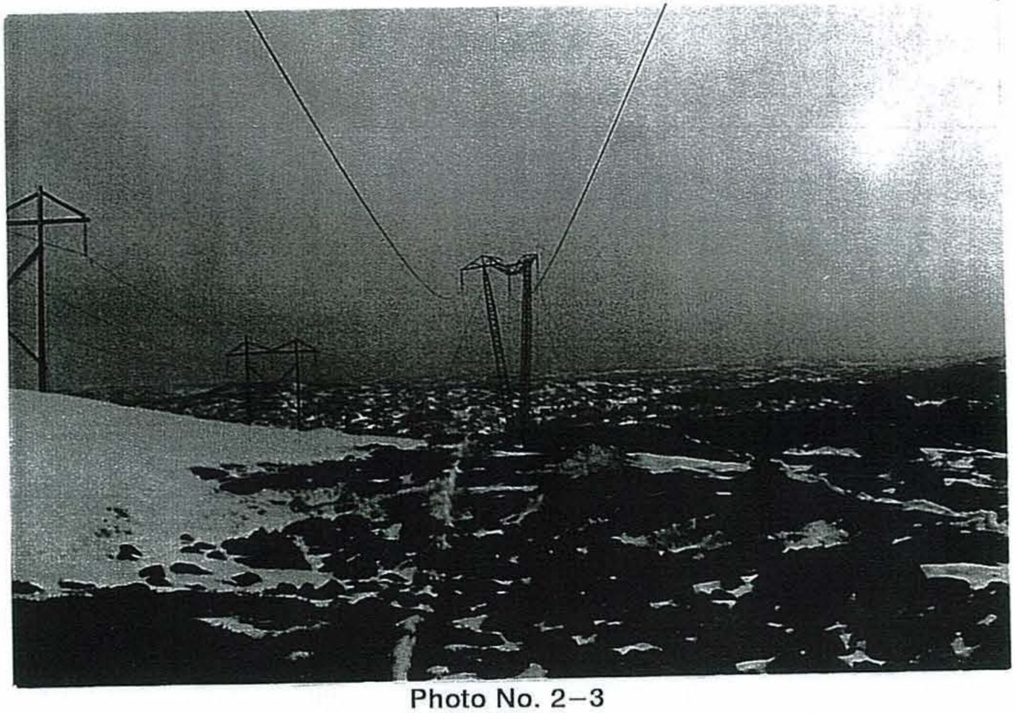


Photo No. 2–3
April 1988
Failure of bridge on Suspension Tower
(TL–217) at Hawke Hill

Photo No. 2–4
April 1988
"C" Tower (Heavy Angle) Failure on TL–217

resulting in downed structures. Design loading was exceeded since the clearnace under ice was violated. Glaze ice was typically observed on the line 3/4 inch (19 mm) to 1 1/4 inches (31 mm) radial. One of these failures was related to only "wind storm" damage. Due to the remoteness and general inaccessibility of the line, repairs have been difficult, time consuming and costly, resulting in prolonged power outages.

(c) Bonavista Peninsula

Newfoundland Power reported the cascade failure of 18 structures on a 138 kV wood pole line between Clarenville and Catalina in April 25, 1990. The line has a 397.5 Kcmil ACSR conductor and was built in 1976. Cause of failure was due to conductor breakage under 2.0 inches ~ 2 1/2 inches (50 mm ~ 63 mm) radial ice load. Newfoundland Power originally used one (1) inch ice as the design load for this line (discussion with Mr. M. Jardine of NLP).

2.4 Failure Rates of HV Transmission Lines

Tables 2.9 and 2.10 present the annual failure rates of wood pole and steel tower lines on the Avalon Peninsula. These failure rates have been derived based on actual service life and the number of damages occurring within the service life. Table 2.11 presents the combined annual failure rate for all major lines on the Avalon Peninsula. Except TL218 and TL218/TL236, combined annual failure rates of all other lines are quite high; typically on average, 1 failure in 3 years to 1 failure in 6 years per 100 km of line (refer Table 2.8). This table also provides the annual rate of failure for TL220 (excluding the wind storm damage). Later these failure rates will be used to derive the new loading agenda in Section 4 with particular reference to various return period values and risk of this loading being exceeded, in future, within a typical service life of a line.

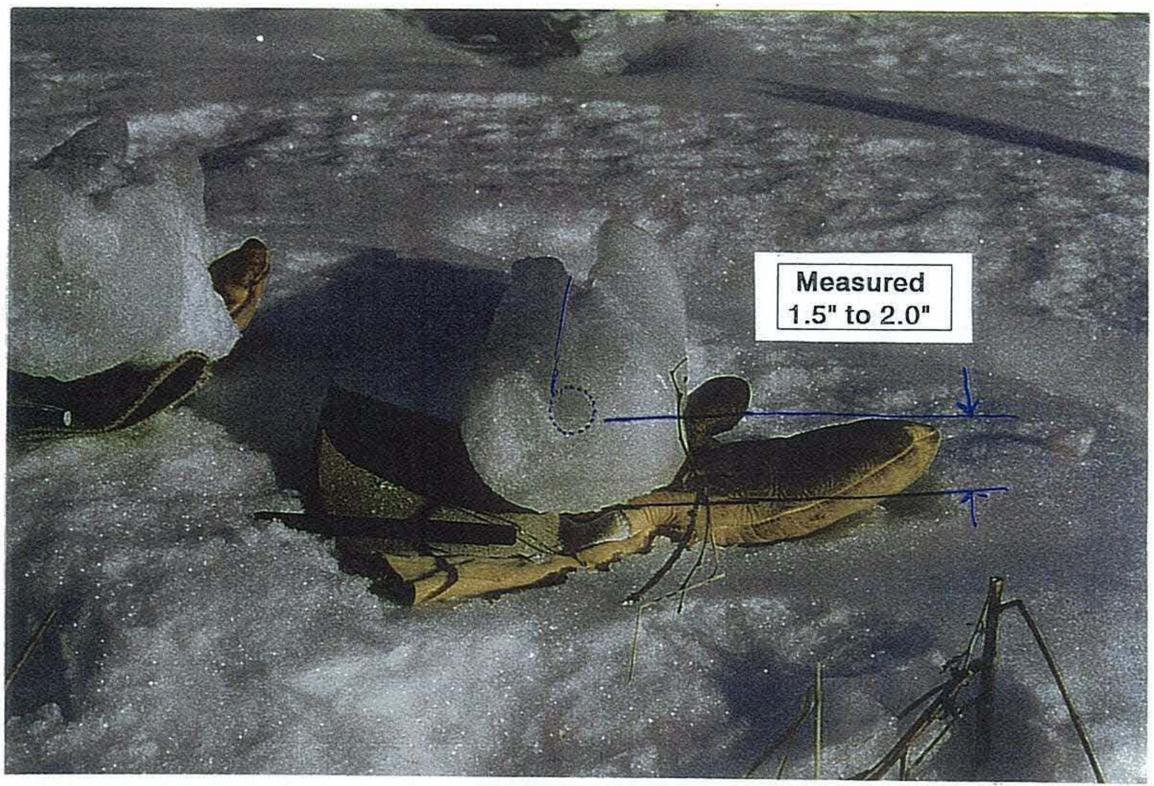


Photo No. 2–5
9 Dec. 1994
Icing observed on TL–201 1.5" to 2.0" (Radial)

Photo No. 2–6
20 Dec. 1994
7/8" diameter welded Eye Bolt failure on TL–201

TABLE 2.9 FAILURE RATES OF WOOD LINES

	TL203	TL201	TL218/236
Line Length (km)	45	81	10
Number of Storm Damage	1	2	1
Year In Service	1965	1966	1966
Annual Failure Rate	1 failure in 30 years (≈.033)	2 failures in 30 years (≈.066)	1 failure in 30 years (≈.033)
Annual Failure Rate Per 100 km	0.0733 1 failure in 14 years	0.0815 1 failure in 12 years	0.33 1 failure in 3 years

TABLE 2.10 FAILURE RATES OF STEEL LINES

	TL207/237	TL217	TL218
Line Length (km)	54	76	25
Number of Storm Damage	2	2	--
Year In Service	1968	1970	1970
Annual Failure Rate	1 failure in 15 years (≈.066)	2 failures in 25 years (≈.08)	N/A
Annual Failure Rate per 100 kM	0.122 1 failure in 8 years	0.1053 1 failure in 9 years	--

TABLE 2.11 COMBINED FAILURE RATES OF ALL HV LINES

	TL203/TL207/TL237	TL201/TL217	TL218/236	TL220
Line Length (km)	54	81	35	48
Number of Storm Damage (combined)	3	4	1	4
Year In Service	1965	1966	1966	1970
Annual Failure Rate	1 failure in 10 years (≈0.10)	4 failures in 30 years (≈0.14)	1 failure in 30 years (≈.033)	4 failures in 25 years (≈0.16)
Annual Failure Rate Per 100 km	0.1852 1 failure in 5 years	.1728 1 failure in 6 years	0.0688 1 failure in 11 years	0.33 1 failure in 3 years

*NOTE: Failure rates are derived based on combined wind and ice load and ice loads; wind alone is not being considered.

2.5 Summary

This section primarily describes major lines on the Avalon and Connaigre Peninsulas together with all the past and recent failures that each of these lines has encountered over the last 30 years. Major failures can be categorized into four classes:

a) failure of welded eye bolt on wood pole dead end structures.;
b) failure of guying arrangement at large angle structures;
c) cascading failure of structures due to conductor breakage in tension under ice load; and
d) cascading failure of structures due to conductor coming close to the ground because of excessive sag under heavy ice load resulting in arcing and subsequent breakage.

In all these cases, original design load was exceeded several times indicating the need for better prediction of ice and wind loads on these lines based on observed data.

From all these reported failures, conductor - hardware assembly and the conductor itself appear to be the "weak-link" in Hydro's transmission line system once the design load is exceeded. In reviewing the observed ice load on the conductor during failures, it is noted that 2.0 inches (50 mm) radial ice was found to be on conductors and/or guy lines in many instances. Actual ice observed on TL220, after failures, was 3/4 inch ~ 1 1/4 inches (19 mm - 31 mm) radial. Later this information with annual failure rate will be used to develop new loading agenda for these lines in Section 4.

SECTION 3

3.0 LABORATORY TESTINGS

After the failure of TL201 near Western Avalon Station in December, 1994, serious concerns were expressed with regard to the strength degradation of wood poles (aging) over time. Failure of the 7/8 inch (22 mm) diameter welded eye bolt (refer Fig. 2.6) on structure #3 also raised concern with regard to the rated strength of these welded eye bolts which are still in operation at various locations of these wood pole lines.

A program was undertaken to carry out some sample laboratory testings of selected wood pole sections and a few welded eye bolts to determine their actual in-service strengths. For wood pole sections this will be expressed in terms of modulus of rupture (bending stress) and for welded bolts, ultimate strength will be defined in terms of the failure load.

3.1 Wood Poles

Laboratory tests performed on the wood samples included determination of moisture content and flexural strength. These tests were conducted in accordance with applicable ASTM standards. Engineering properties were obtained for each sample.

The moisture contents were obtained by taking small sections from selected samples and placing the samples in an oven at 60°C until a constant temperature was reached. This temperature allowed for drying without affecting preservatives in the wood. Moisture contents on samples taken from TL201-STR-3 were performed on separate samples taken from the specimen, not on the flexural test samples. The values presented for this specimen are an average of moisture content values obtained during the test.

The flexural tests on sample TL201-STR-3 (right) were performed January 31 and February 1, 1995. Each sample was tested as a simply supported beam with a point load applied at midspan. The span length of 28" was chosen as per ASTM D143-83. Two dial gauges were mounted at the machine bed to obtain midspan deflections. The gauges were read to the nearest 0.0001 inch (0.0025 mm). Each sample was measured at the centre to determine the dimensions. Loading was applied in increments to allow for determination of load-deflection characteristics. Each sample was loaded in increments until a breaking load (maximum load) was obtained. The load-deflection data was recorded and a curve was plotted for each sample. The results of the flexural tests, sample details, and failure types are presented in a report prepared by Newfoundland Geosciences Limited (NGL, 1995). The load-deflection relationships for each sample are also presented in the same report.

Table 3.1 summarizes the results of typical flexural tests that were carried out on three (3) samples obtained from structure #3. The table includes the moisture content, breaking load, rupture modulus, and modulus of elasticity for each sample. The mean value, standard deviation, and relative variation of the modulus of elasticity are also given for each wood pole sample. Mean Value of the rupture modulus (not shown in Table 3.1) is 47.5 MPa, approximately with a coefficient of variation as 0.26. It appears that the obtained mean value from laboratory testing is lower than the published mean value (55.0 MPa); coefficient of variation is also higher than the published value (0.20) and this may be due to the fact that sample size is very small. Modulus of elasticity value is 50% of the published value with a large variation of strength.

TABLE 3.1 RESULTS OF LABORATORY TESTS

Pole	Sample	Moisture Content (%)	Breaking Load (N)	Rupture Modulus (kPa)	Modulus Elasticity E (MPa)	Mean E (MPa)	Standard deviation E (MPa)	Relative variation E (%)
TL201 -STR-3 (right)	A	24.6	5997	44789	5860	6533.25	1785.04	27.32
	B	24.6	5775	42528	4780			
	C	24.6	6440	54980	8960			

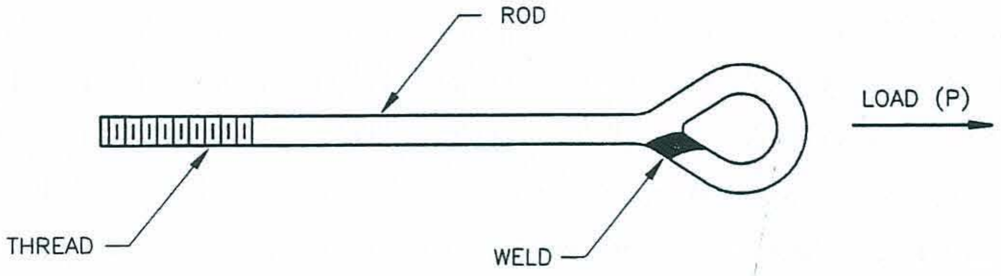
3.2 Welded Eye Bolts

Eye bolts received from the failed line were taken to the strength laboratory of Memorial University and a direct pull test was performed on each bolt sample. Fig. 3.1 depicts the direction of the pull with the Table 3.2 presenting the mean value and standard deviation of the rated strength. Minimum guaranteed rated strength of this bolt should be approximately 25,000 lb (based on 3 standard deviation) with a coefficient or variation of 5%. One (1) failure out of four (4) tests occurred at the weld where it opened prematurely. Strength reported under Test No. 5 was not carried out at the laboratory rather estimated based on the strength coordination of heavily loaded iced conductor with the failure of the welded eye bolt. In this case, conductor did experience approximately 1 1/2 ~ 2.0 inches (38 mm - 50 mm) radial ice on December 8, 1994 (refer Photo #2.5) between structure #2 and #3 with a span of 2039 feet (620 meters). It is estimated that conductor tension will be approximately 24,000 lb under this load which is very close to the strength of these bolts considering the failure occurring at weld.

3.3 Summary

This section provides information on laboratory test results related to the in-service strengths of a few wood pole and welded eye bolt samples. Results show that mean value of modulus of rupture (bending stress) of wood pole sections tested is fourteen percent (14%) lower while the modulus of elasticity is significantly lower (almost half) compared to the published values. Bending stress will determine the transverse capacity of the structure while reduction in the modulus of elasticity value will considerably influence the buckling capacity of the structure to carry the vertical load due to severe ice loading. It is not clear whether these sections have degraded with regard to strength due to ageing although a large number of samples need to be tested further before any reasonable conclusions can be drawn. With regard to welded eye bolt test results, it is clearly shown that these bolts can fail prematurely although mean value of the ultimate strength is still higher than the rated strength. Coefficient of variation of strength of twenty percent (20%) is quite large compared to the acceptable value recommended five

FIGURE 3.1



WELDED EYE BOLT

TABLE 3.2 WELDED EYE BOLT TEST OBSERVATIONS

TEST No.	FAILURE LOAD (lbs)	MEAN (lbs)	STD. DEVIATION (lbs)	REMARKS
1	31,050	31,360	6,272	FAILED AT WELD; ROD O.K.
2	40,600			FAILED AT THREAD; WELD O.K.
3	24,000			WELD CRACKED; ROD O.K.
4	37,500			FAILED AT MIDDLE OF ROD
5*	25,000*			FAILED AT WELD (RECOVERED FROM SITE)

* FAILURE LOAD UNDER TEST No.5 WAS ESTIMATED BY EQUALIZING THE RATED STRENGTH OF THE CONDUCTOR UNDER 1.5 TO 1.75 INCHES UNIFORM RADIAL ICE LOADING TO THE RATED STRENGTH OF THESE BOLTS.

percent (5%). More work is required in this area to develop a proper wood pole management program that would include non-destructive and possibly limited destructive testing of wood poles to generate a field data base to guide systematic pole replacement in the future.

SECTION 4

4.0 CLIMATOLOGICAL LOADS

In designing transmission lines, climatological loads which are of prime interest to the line designer are wind, ice, and combined wind and ice. In the northeastern and southeastern regions of the island, freezing precipitation is by far the greatest problem related to ice accretion. This was evidenced by the damage caused by the previous storms in various regions of Newfoundland (Young and Schell, 1971), Hydro (1984, 88,89) and more recently damage caused by icing storm near the Western Avalon Station (Hydro, 1994). In addition to this, TL220 on the Connaigre Peninsula has also experienced several line failures due to severe icing. The ability to account for realistic ice and combined ice and wind loads when evaluating the design of present and future transmission lines is currently hampered severely by the lack of site specific data and associated meteorological parameters. One alternative approach is to review the meteorological data from nearby weather stations and use a specific model to predict the wind and ice loads on the lines.

Four types of ice accretion, normally occurs on transmission lines. These are classified as glaze, rime (soft and hard), wet snow and hoar frost. With the exception of the high altitudes in the northwest, (e.g., Long Range Mountains, Hind's Plain), glaze will be the dominating type of icing in Newfoundland while rime icing will dominate most areas in Labrador.

During the late 60's, design ice load on transmission lines was primarily obtained following CSA and information gathered through the Climatological Branch of Environment Canada. This involved running a specific empirical ice model (Chaine model) with the meteorological data obtained from the Airport. In addition to this, quite often a review of the meteorological information was undertaken and has been described in Section 2.1. A considerable amount of work has been done during the past twenty-five (25) years with regard to the development of various icing models but validation of these models with regard to field data has been very limited. Advantage of using a specific model or models provides guidelines with regard to long term forecasting although uncertainties associated with these predictions could be high due to lack of validation of these models by actual field measurements or observed data from line failures.

4.1 Modelling of Ice Accretion on Cable

Advancements in the field of modelling ice accretion on circular cylinders has made it possible to simulate the conditions necessary to form ice on the transmission line conductor from the known weather data. In an earlier study, Haldar (1988) and Haldar, Mitten and Makkonen (1988) reported long-term combined wind and ice loads on the Avalon and Burin Peninsulas using meterological data from several AES (Atmospheric Environment Services) first-order weather stations. In order to quantify accumulation of ice on a conductor, Makkonen (1984) icing model was first used to predict the maximum ice accretion resulting from the worst storm of each year for seven (7) AES weather stations. Historical storm data from six weather stations were used to derive the input required by the icing model. Model input parameters included wind speed, air temperature, liquid water content, median droplet diameter, and conductor diameter. The obvious advantage of using the Makkonen model is that this model accommodates the time dependencies, changes from wet to dry growth conditions (or vice versa) during the ice accretion process, and variations in the ice density and the relative angle between the wind direction and the conductor. Details of this work has been reported earlier; however, the important part of the above study results will only be reported here.

Tables 4.1 summarizes the wind speeds for selected return period values computed for seven (7) stations. Two (2) of these stations namely Torbay and Bonavista are relevant to this study.

TABLE 4.1
MAXIMUM WIND SPEED (km/h) FOR SELECTED RETURN PERIOD VALUES

		Return Periods					
Stations	Elevation(s)	10-yr (km/h)	25-yr (km/h)	50 yr (km/h)	Maximum Hourly Wind (km/h)	99.9 Confidence Limit on 50-Yr Rtn Period Values (km/h)	Max Gust For 50 yr Return Period (km/h)
St. John's-Torbay	140	110	122	130	136	±31	160
Gander	151	99	108	115	117	±26	157
Argentia	14	104	114	122	111	±31	152
Bonavista	25	115	124	132	126	±31	162
St. Lawrence	49	126	141	152	144	±67	184
St. Alban's	13	80	90	96	98	±48	135
Arnold's Cove	16	91	99	104	93	±39	142

Table 4.2 summarizes the glaze ice thicknesses (in mm) for selected return period values as predicted by the model. For a 50 year return period, ice thickness predicted by the model for St. John's-Torbay Airport is 41 mm (1.60 inches), while for Gander (inland), this is 24 mm (≈1.0 inch). Actual comparison cannot be made because ice accretion data on conductor are not available at these airports. However, ice accretion, in general, can be compared with those observed during the 1984 storm near the Oxen Pond terminal station which was well above the model prediction.

TABLE 4.2
GLAZE ICE THICKNESSES (in mm) FOR SELECTED RETURN PERIOD VALUES

		Return Periods				
Stations	Elevation(s)	10-yr (mm)	25-yr (mm)	50 yr (mm)	99.9 Confidence Limit on 50-Yr Rtn Values (mm)	Max Glaze Ice Thickness Period (mm)
St. John's-Torbay	140	28	35	41	±21	59
Bonavista	25	18	22	25	±12	28
Gander	151	16	21	24	±13	27
Argentia	14	15	19	22	±14	21
St. Lawrence	49	13	16	19	±14	18
St. Alban's	13	6	7	8	±9	7

4.2 Validation of Icing Models

Although Makkonen model (1984) can predict wind and ice loads on a cable based on the input meteorological data from a weather station, there is no guarantee that this predicted load will be conservative with regard to the line design. There are two other models also available for predicting cable load due to freezing precipitation. These are: Chaine (1974) and MRI (Meteorological Research Institute, 1977) models. However, none of these models has been validated by field data. In view of this, Technical Support Group developed an instrumented test site on Hawke Hill to monitor wind and ice loads in 1993. This site is operating and has generated data with regard to a few icing storms. This test site is designed to serve as an instrumented monitoring station to continuously record: wind speed, wind direction, temperature, precipitation, ice accretion, load at the insulator attachment point, swing angles in both directions (transverse and longitudinal) on the conductor, conductor tension, strain in one selected member of the tower and finally, load in the guy wires (Refer to Fig. 4.1).

Data collected from this test site will be used to validate several ice models. An attempt will also be made to compare icing rate at Hawke Hill with particular reference to Airport to develop, in future, an extrapolation model. This will be discussed in the next section. Part of this project is funded through Canadian Electrical Association and two other major Utilities (Ontario Hydro and Hydro Quebec) in Canada are also participating in this project.

4.3 Ice Loadings at Remote Sites

The problem of extrapolating ice load estimates from those determined objectively at first-order AES Airport Stations using a specific model to remote transmission line sites with different elevations and topographic exposures to the storm wind is still in the research stage. WECAN (Weather Engineering Corporation of Canada, 1985) has used Cooling Power Equation and the gradient wind/surface roughness method to predict ice loads at a remote site. This method permits adjustment factors based on the elevations of the remote site above the airport base elevation to be derived for fully exposed conditions. Independently, Haldar, et al (1988) has also extrapolated both St. John's and Bonavista data to remote site near Sunnyside Station after adjusting elevations for the remote site and by accounting for the higher and/or lower wind using a gradient wind model. Both these results are presented here in terms of elevation above the Torbay Station. Elevation of the Torbay Airport is 450 feet above the Mean Sea Level.

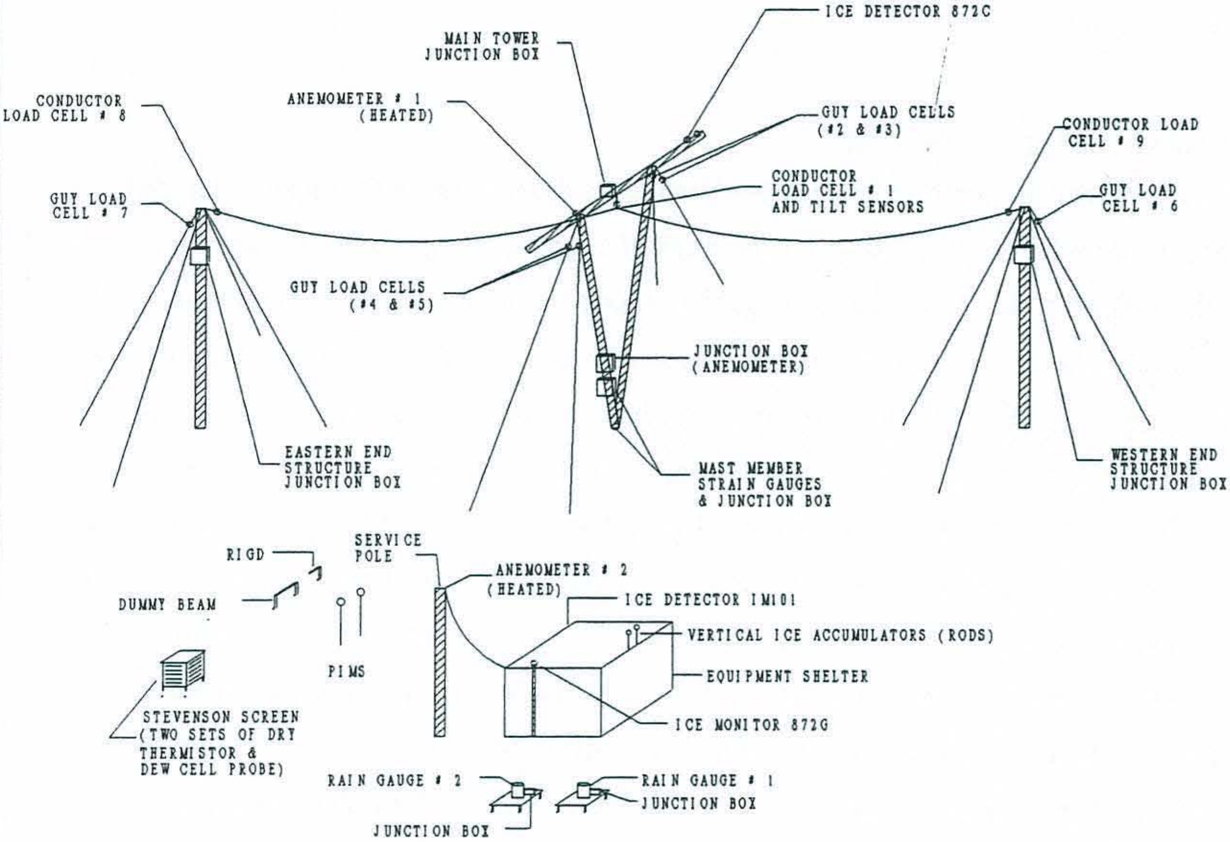


Figure 4.1: Hawke Hill Test Site - Instrumentation Layout

TABLE 4.3
GLAZE ICE THICKNESS ADJUSTED TO FULLY EXPOSED ELEVATIONS (WECAN, 1985)

RETURN PERIOD (Years)	RADIAL ICE THICKNESS AT AIRPORT (inch)	ICE THICKNESS AT REMOTE SITE (Inches)			
		100*	200	300	400
10	1.13	1.61	1.84	2.06	2.27
25	1.42	1.98	2.26	2.51	2.77
50	1.65	2.28	2.59	2.88	3.16

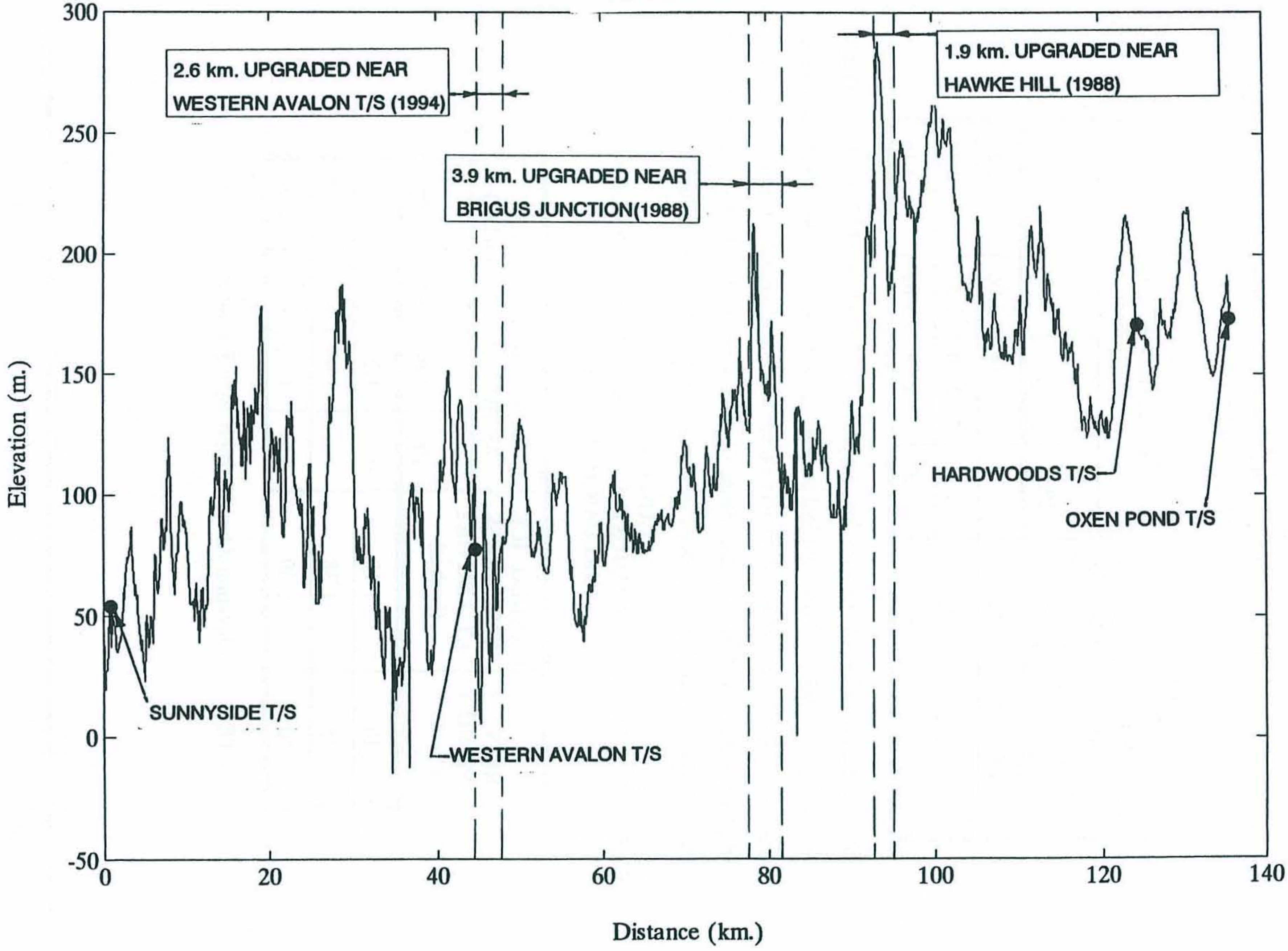
Fig. 4.2 depicts the profile information of typical wood pole lines (TL203/TL201/TL236) from Sunnyside to Oxen Pond terminal station. On average, elevations of these lines are approximately 150 meters to 200 meters except in some instances where elevation could be 260 meters (near Hawke Hill). Some of these sections with higher elevations have already been upgraded for increased ice loading after 1984 storm failure.

TABLE 4.4
GLAZE ICE THICKNESS ADJUSTED TO FULLY EXPOSED ELEVATION (HALDAR et al, 1988)

RETURN PERIOD (Years)	RADIAL ICE THICKNESS AT AIRPORT (Inches)	ICE THICKNESS AT REMOTE SITES (Inches)			
		100	200	300	400
10	1.10	--	1.21	--	1.21
25	1.38	--	1.47	--	1.56
50	1.60	--	2.62	--	2.66

*NOTE: Elevation Above Airport Base Elevation

FIGURE 4.2



PROFILE: SUNNYSIDE T/S TO WESTERN AVALON T/S TO HARDWOODS T/S TO OXEN POND T/S.

4.4 Development of Return Period - Service Life Relationship

The probability an event having a return period T to occur in a given year is equal to 1/T, thus the yearly probability of a "100 year wind" is 1% and that of a 25-year ice load is 4%. If the yearly probability of occurrence P_o of an event with a return period T is 1/T, the probability P_u of this event not being exceeded in a year is given by:

$$P_u = 1 - P_o = (1 - 1/T)$$

and in n - years:

$$P_{un}\ (P_u \text{ in n-years}) = (1 - 1/T)^n$$

Thus the probability - P_{on} that a weather event, with a return period T, will be exceeded, at least <u>once</u> within the length of the service life of the line n - years is given by:

$$P_{on} = 1 - P_{un} = 1 - (1 - 1/T)^n$$

The probability P_{on} for various return periods during different service lives of the line is given in Table 4.5. While the probability P_{on} is a useful indicator of load occurrence, it does not correspond directly to the probability of failure of the transmission line, because failure is a combination of load events magnitude exceeding strength and thus cannot be derived on the basis of load magnitude alone. This will be further discussed in <u>Section 5</u>. Tables 4.6 and 4.7 provide information that a weather event with a return period T, will be exceeded at least <u>once</u>, <u>twice</u>, etc. within the length of service life of the line n years and is computed based on <u>Poisson distribution</u>. A computer program was developed to generate these tables and details are given in <u>Appendix 4</u>.

TABLE 4.5
PROBABILITY OF OCCURRENCE P_{ON} OF A WEATHER EVENT OF A GIVEN RETURN PERIOD IN A NUMBER - N OF YEARS.
(In Percent)

Return Period of Loads, T (Years)	Service Life of the Line n (years)					
	10	15	20	25	40	50
25	33	45	55	64	80	87
50	18	26	33	39	55	64

TABLE 4.6
PROBABILITY OF ENCOUNTERING (In Percent) A STORM (More than Once) WITH KNOWN FAILURE RATES

Return Period of Load Based on Observed Failure*	Service Life of the Line - 40 (years)					
	1 - Storm	2 - Storm	3 - Storm	4 - Storm	5 - Storm	6 - Storm
7.5	99.5	96.9	89.9	77.6	61.4	44.0
10	98.0	91.0	76.0	56.0	37.0	21.5
15	93.0	74.0	49.0	27.0	12.8	5.2
30	73.0	38.0	14.8	4.5	1.2	--
50	55.0	19.0	5.0	1.0	--	--

* NOTE: Return Period of Load based on Observed Failure Rate is derived from Table 2.11.

TABLE 4.7
PROBABILITY OF ENCOUNTERING (In Percent) A STORM (More than Once) WITH KNOWN FAILURE RATES

Return Period of Loads; Based on Observed Failure	Service Life of the Line 50 (years)					
	1 - Storm	2 - Storm	3 - Storm	4 - Storm	5 - Storm	6 - Storm
7.5	99.8	99.0	96.1	89.8	79.3	
10	99.0	96.0	87.0	73.0	56.0	
15	96.0	84.0	64.0	42.0	24.0	
30	81.0	49.0	23.0	8.6	2.7	--
50	63.0	26.0	8.0	1.9	--	--

Table 4.8 provides information on the conversion factors that are necessary to modify a climatic variable with T-year return period value to other return period values.

TABLE 4.8
CONVERSION FACTORS TO ESTIMATE ICE THICKNESSES FOR VARIOUS RETURN PERIOD VALUES BASED ON KNOWN OBSERVED FAILURE RATE

RETURN PERIOD OF LOAD BASED ON OBSERVED FAILURE (Refer Table 2.11)	CONVERSION FACTOR				
	Return Period in Years				
	2	3	10	25	50
6*	-	-	1.17	4.46	1.68
7.5	-	-	1.12	1.49	1.76
10	-	0.58	1.0	1.30	1.51
15	-	0.52	0.89	1.15	1.34
30	-	-	0.74	0.96	1.12

*NOTE: Typical Return Period of Failure of TL220 is 6 Years (Refer Table 2.11)

Details of calculating these factors are given in Appendix 4 and are based on extreme value distribution. Approximate values of coefficients of variation of ice thicknesses are also assumed in generating these factors. Coefficient of variation of 50-year return period is given by AES (Ref. 2) and for other return period values, some adjustments have been made.

4.5 New Loading Agenda for Line Assessment

For example, if we know that based on observed failure rate of existing transmission lines on the Avalon Peninsula is on average one (1) failure in every 10 years (refer Table 2.11) and ice thickness observed (or measured) is 50 mm, then a 50-year return period ice thickness should be estimated from Table 4.8 as t_i = 50 X 1.51 = 75 mm. Therefore if the line is designed with this ice thickness, there is a 64% chance of being exceeded once and a 26% chance of being exceeded twice during a 50-year service life as per Table 4.7. On the other hand, if we believe that the failure rate due to ice on some lines is 1 in every 15 years (2 failures in 30 years as per Table 2.9) and associated ice thickness is still t_i = 50 mm, then 50-year load should be estimated as t_i = 50 X 1.34 = 67 mm as per Table 4.8. If the line is designed with this ice thickness, there is a 96% chance of being exceeded once, 84% chance of being exceeded twice during a 50-year service life as per Table. 4.7. Similar interpretations can be made using Table 4.6 and Table 4.8 for wood pole lines with a service life of 40-years.

Table 4.9 presents the return periods associated with radial ice thicknesses (inches) of 1.0, 1.5 and 1.75 respectively, based on the known failure rates (e.g. 7.5 year, 10 year, etc. as per Table 2.11). It is obvious from this table, that the original design radial ice thicknesses of 1.0 inch or 1.50 inch do not meet the 50-year return period criteria rather it is somewhere between 2 1/2 years to 10 years; obviously, original design load was grossly underestimated. This is always the problem when designer tries to estimate ice load on lines without having any site specific data. It is also true if the ice load is not estimated correctly, one could end up selecting a wrong conductor with particular reference to mechanical strength characteristics and this could lead to a very unrealistic design causing

TABLE 4.9
RETURN PERIOD (YEARS) OF KNOWN ICE THICKNESSES BASED ON OBSERVED LINE FAILURES

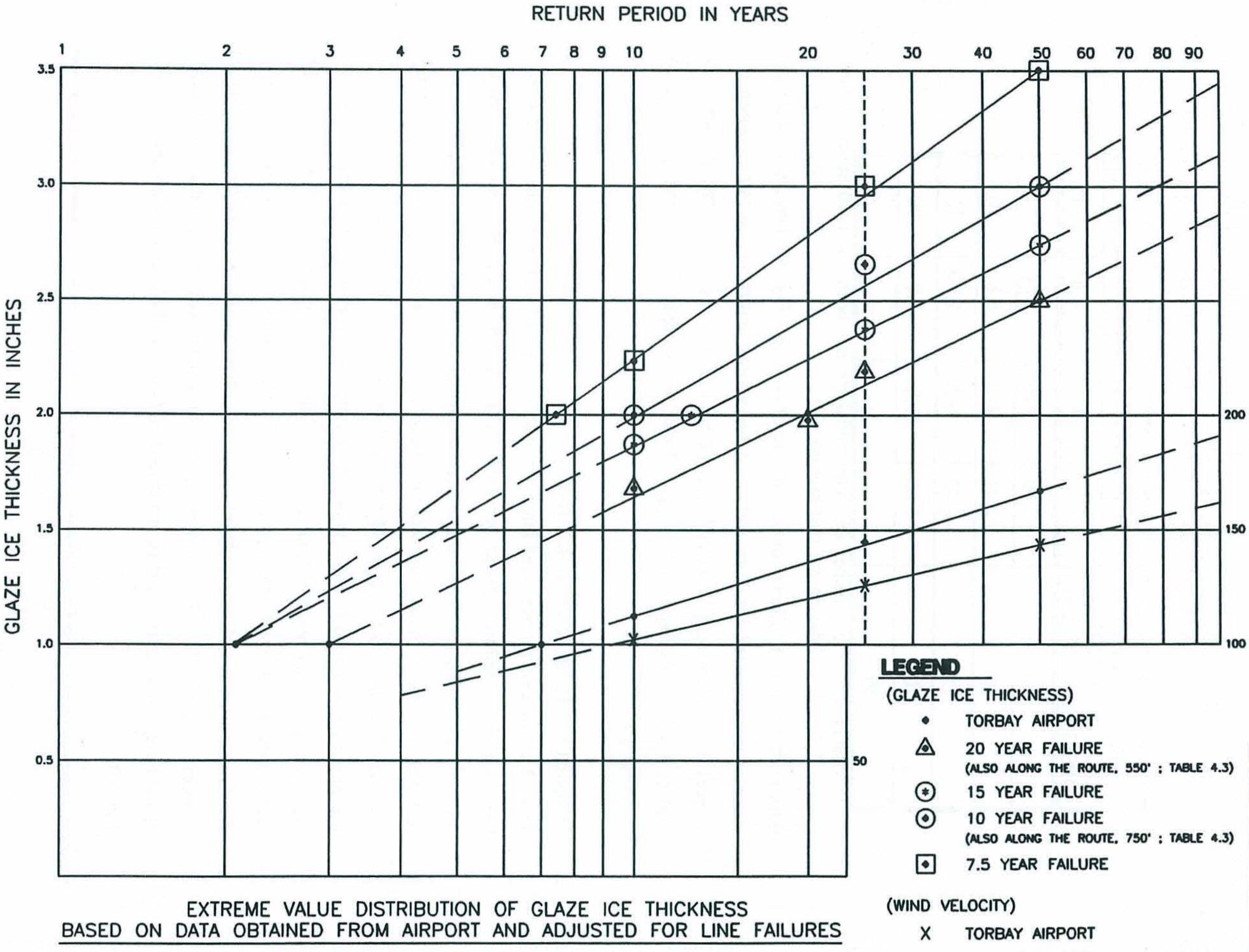
RETURN PERIOD OF LOADS BASED ON OBSERVED FAILURE	RADIAL ICE THICKNESS (Inches)			
	1.0	1.50	1.70	2.0*
7.5	2.50	4.20	5.58	7.5
10	2.45	4.78	6.87	10
15	2.85	6.30	9.70	15
20	3.65	10.0	13.0	20
30	--	--	--	--

*NOTE: 2.0 inches (50 mm) radial ice has been observed several times during the past failures.

significant number of failures, during the life of the line. Fig. 4.3 depicts the extreme value of the projected load (ice thickness) for various return period values based on Airport data (Table 4.2), WECAN Data (Table 4.8) for remote site and Failure data (Tables 4.8 and 4.9) respectively. Fig. 4.3 also shows prediction of wind speeds based on Table 4.1.

4.6 Predicted Future Ice Loads on HV Lines

Table 4.10 presents the predicted future ice loads in terms of various return period values based on known failure rates as per Table 2.11. Based on the reported observed ice thickness of 2.0 inches radial (minimum), estimated new loads could range from 1.50 inches to 3.50 inches radial depending on the selected annual failure rate. For example, assuming 7.5-year return period (4 failures over 30 years, Table 2.11) would give the maximum projected load on all major lines on the Avalon Peninsula. However, should we choose a 10-year return period as average failure rate, estimate could range from 2.0 inches radial for 10-year return period to 3.0 inches radial for a 50-year return period. As the return period of the line failure increases, the estimated value of the ice thickness reduces. For TL220, a 50-year return period of new ice load is estimated as 2.0 inches radial based on a six (6) year return period of failure (4 failures over 25 years service life) rate.



EXTREME VALUE DISTRIBUTION OF GLAZE ICE THICKNESS
BASED ON DATA OBTAINED FROM AIRPORT AND ADJUSTED FOR LINE FAILURES

FIGURE 4.3

TABLE 4.10
PREDICTED FUTURE LOAD (ICE THICKNESS) BASED ON OBSERVED FAILURE RATE

LINE FAILURE RATE (Table 2.11)	LINE NAME	RETURN PERIOD OF LOAD (YEARS)		
		10	25	50
6	TL220	1.50	1.80	2.1
7.5	MAJOR LINES ON AVALON (Combined)	2.25	3.0	3.50
10	TL201/217	2.0	2.60	3.0
15	TL203/237	1.8	2.30	2.70
30	TL218/236	1.50	1.90	2.35

4.7 Summary

This section reviewed the relevant meteorological data from an earlier study and documented results that are relevant to this study such as 50-year ice and wind data with regard to AES Weather Stations. Theoretical basis was presented to calculate the various risk levels of individual event occurring within a specified service life and chances of exceeding this event (more than once) within the service life. A simple table was produced to convert the actual observed ice thickness with a known failure rate of a line to future loading with new return period values (10-year, 25-year, 50-year, etc.). All data were also summarized graphically for the purpose of comparisons. In most cases, observed ice thickness was noted directly or back-calculated based on sag tension characteristics of the conductor after the line has failed (refer Fig. 3.1). Obviously, this is the most expensive way of collecting wind and ice data in the field. It was also pointed out that estimating ice loads along a line route without any site-specific data could lead to gross underestimation of the load resulting in the selection of a conductor that does not have adequate strength leading to frequent failures of the line. It is also emphasised here that current work on monitoring wind and ice load on Hawke Hill to validate several models and developing further strategy to collect site specific data are extremely important with respect to future line design as well as maintaining the existing lines with greater reliability.

SECTION 5

5.0 RELIABILITY ANALYSIS

5.1 General

The basic concept in Reliability Based Design (RBD) is that design procedure explicitly considers the probability that the structure will fail during its design life. Thus development of a RBD procedure begins with the mathematical theory of probability which takes into account the interference of strength (resistance) and stress (effects of various loads). Failure probability is computed in terms of a dimensionless quantity often referred to as reliability index, beta (ß), which typically lies in the range of one to five, with most values for transmission structures in the two to four range (Ref. 13).

Of the many possible designer-oriented RBD procedures, the Load and Resistance Factor Design (LRFD) procedure is generally recognized as providing the best balance of correctly considering the variability, providing a method by which the designer can control reliability and its simplicity of use (Ref. 13). The basic concept in the LRFD type of design equation is expressed by:

$$\phi R_n > \gamma Q_r \quad \ldots(5.1)$$

Where R_n = nominal resistance, Q_r = member forces/stresses due to extreme loadings with specific return period T, ϕ - resistance reduction, and γ = load factor.

In words, this equation states that the factored resistance must not be less than the effects of the factored loads, or that supply (R) must not be less than demand (Q). The resistance factor, ϕ, can be used both to reduce the resistance, to systematically account for the variability of material and component strengths, and to modify component strengths to provide preferred sequences of component failures in a completed structure. The load factor, γ, can be used to both increase loads to properly account for their variable nature, and to change the global reliability of the complete structure. The R and Q terms symbolize single values of resistance and aggregate load effects. Since resistance and loads are variables described by their probability distributions, R and Q also symbolize the selection of single values from these distributions. These single values can be preset as means, lower exclusion values of R, return period values of loads, or other measures. The conversion of loads to load effects is made through structural analysis.

5.2 Computation of Reliability Index (ß)

Figure 5.1(a) depicts the probability of failure P_F, for a critical member or a component when the load effects exceed the strength of the member. To compute the reliability index, ß, an appropriate failure function (a function which indicates failure ($R < Q$) when its value is less than zero) is assumed. In the literature, it has been noted that the accuracy of the computed probability of failure for a typical component is highly dependent upon the shape of the probability distributions describing the load effect and resistance in the overlap region as shown in Fig. 5.1(a). However, in the absence of any specific data on load and strength distribution, various studies have also indicated that lognormal distributions for resistance (R) and load effects (Q), are well suited for practical purposes.

When both coefficients of variation of load, V_Q and resistance V_R are less than about 0.3, little accuracy is lost by using the following approximation for ß. (Ref. 4).

$$\beta = \frac{l_n(R/Q)}{\sqrt{V_R^2 + V_Q^2}} \qquad \ldots(5.2)$$

Fig. 5.1(b) depicts the plot of P_f versus values while Table 5.1 provides beta (ß) and corresponding probability of failure values.

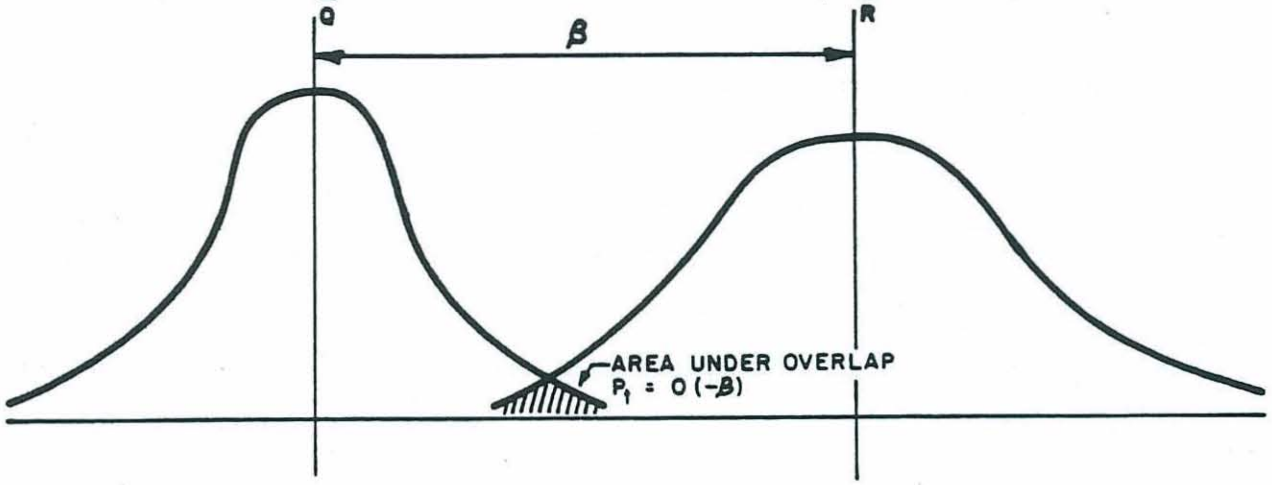


FIGURE 5.1A

PROBABILITY DENSITY FUNCTION FOR LOAD AND RESISTANCE
(Area under overlap equals risk of failure)

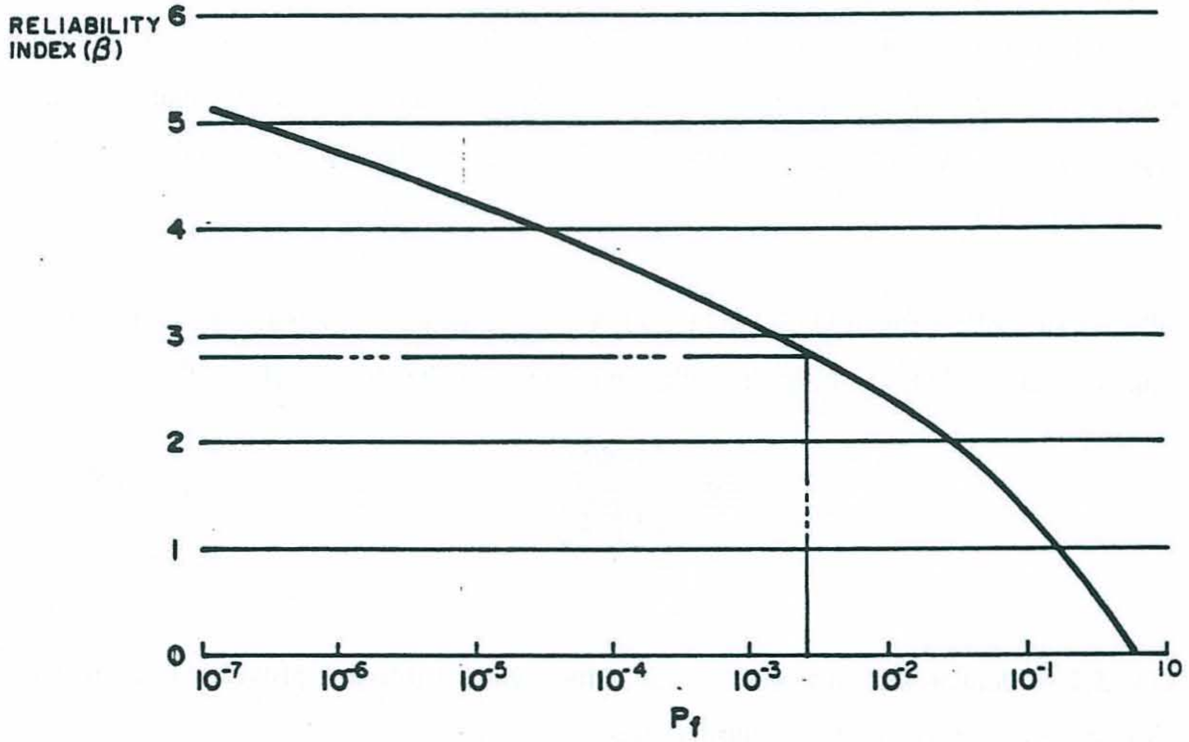


FIGURE 5.1B

GRAPHICAL RELATIONSHIP BETWEEN RELIABILITY INDEX (β) VERSUS RISK OF FAILURE, P_f

5.3 Relationship Between Lifetime and Annual Probability of Failure

When considering the reliability of a transmission line, one generally thinks in terms of probability of failure over some expected life. In other words, what is the probability that the line will be incapable of transmitting power over a life of 50 years. Subsequent structural reliability analyses carried out in this study deal only with the lifetime reliability or expected lifetime probability of failure.

TABLE 5.1

TABLE OF BETA (ß) AND CORRESPONDING PROBABILITY OF FAILURE VALUES*

Beta	Probability of Failure	Beta	Probability of Failure
0.00	0.50000017 (1 out of 2)	3.00	0.00134997 (1 out of 750)
0.50	0.30853144 (1 out of 3)	3.50	0.00023267 (1 out of 9000)
1.00	0.15865522 (1 out of 6)	4.00	0.00003169 (1 out of 30,000)
1.50	0.06680722 (1 out of 16)	4.50	0.00000349 (1 out of 300,000)
2.00	0.02275006 (1 out of 44)	5.00	0.00000029 (1 out of 3,500,000)
2.50	0.00620968 (1 out of 160)		

*NOTE: (1) Beta Values are shown here at 0.50 intervals. Any values in between can be obtained from the standard normal table.

(2) A reliability index, ß, equal to 3.00 for a structure or component (e.g. Hardware) corresponds to a probability of failure of .00136, or failure of 1 out of every 750 structures.

However, it is desirable to develop a relationship between the probability of failure of the line over its lifetime and the annual probability of failure of the structures.

Unfortunately, it is not easy to determine this relationship due to unknown properties of the load, such as the front width, number of structures subjected to the load, and percent utilization of each structure capability. Work toward establishing this relationship is continuing. However, to simplify the situation for the purpose of this study, it has been assumed that all structures are utilized one-hundred percent (100%), and each load event covers the entire transmission line. With this simplified relationship, the probability of failure of the line over its life is the same as the probability of failure of the structures or its components. A beta value (ß) greater than 4.0 is considered that the chance of a failure is extremely low.

5.4 System Concept

A transmission line is a continuous electrical/mechanical system. Its function is electrical, namely, to transport power from one end to the other. The failure of a transmission line occurs when it is unable to perform its function as a power transporter. A line system primarily consists of three subsystems from mechanical strength point of view (see Figure 5.2). These are:

(1) Suspension Tower Subsystem ☞ (i) Structure - Foundation system
(ii) Hardware - Insulator system
(2) Dead End Tower Subsystem ☞ (i) Structure - Foundation system
(3) Conductor - Hardware - Insulator Subsystem.

Failure of a transmission line is normally initiated by the mechanical failure of a component in the above sub-systems except in the case, where the failure is governed by flashover (electrical failure for other reasons such as corona, insulation breakdown, etc;) System performance can be best described in terms of the following levels:

☞Reliability:

The ability to sustain a design loads particularly climatic loads such as wind, ice and combined wind and ice.

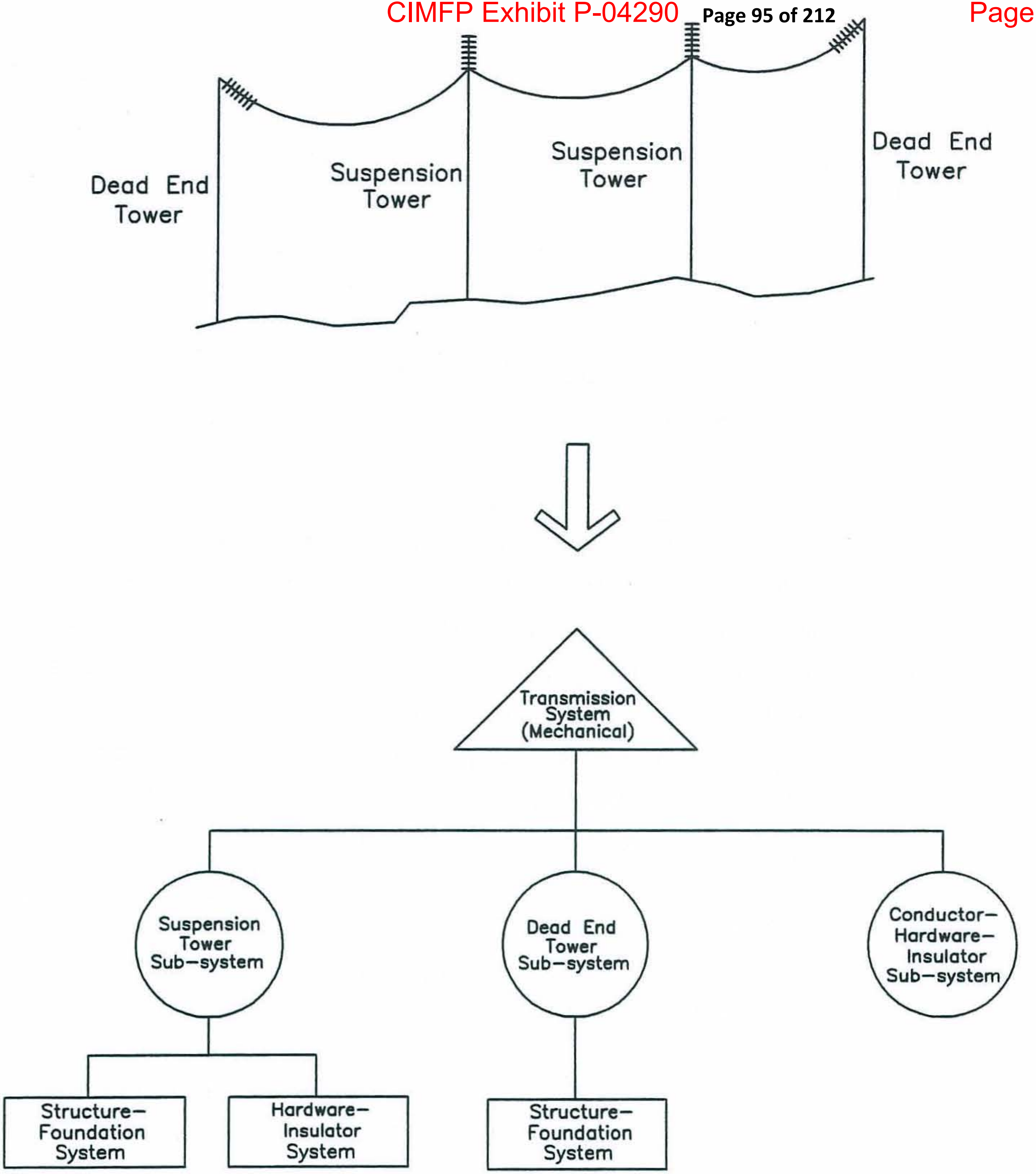


FIGURE 5.2
TRANSMISSION LINE SYSTEM

☞ Security:

The ability to sustain a secondary failure such as cascading after the failure of an initial component eg. hardware, in this case a welded eye bolt and to contain the failure within a limited number of structures.

☞ Safety:

The ability to maintain and inspect the line through its service life; also to withstand design construction loads.

Current philosophy in the design of transmission line treats the line as composed of various interactive elements (e.g. towers, foundation, conductor, etc.) and when loaded, failure of the weakest element yields the failure of the line. The reserve strength that remains in the other components does not have any effect on the failure load (limit load), but may influence the secondary consequence of a failure. Based on a system approach where the strength of an individual component is properly co-ordinated with other components according to a preferred sequence of failure, it has been recommended in CSA draft document (Ref. 2) that the conductor subsystem should be considered as the strongest component in the design of a transmission line.

5.4.1 Sequence of Failure (Co-ordination of Strength)

The following criteria have been used in the industry in order to decide on an appropriate sequence of failure.

a) The first component to fail should be chosen so as to introduce the least secondary load effect (dynamic or static) on other components, which may result in cascading failure.

b) Repair time and costs following a failure should be kept to a minimum.

c) The first component to fail should ideally have a ratio of the damage limit (yield limit) to the failure limit (ultimate load) near 1.0.

d) A low cost component in series (in this case welded eye bolt) with a high cost component (conductor) should be designed to be at least as strong and reliable as the major component if the consequences of failure are as severe as failure of that major component.

If line components such as tangent towers, tension towers (angle and dead-end structures), conductors, foundations and hardware are analyzed using the above criteria, it is found that: conductors should not be the first component to fail because of a, b and c; hardware because of d; tension towers because of a and b; and foundations because of b and c.

With these criteria an appropriate strength coordination is given in Table 5.2 where tangent towers are the first component to fail when the line is subjected to weather related loads exceeding design values.

TABLE 5.2
TYPICAL STRENGTH COORDINATION (Ref. 4)

	Major Components	Coordination within Major Components*
To Fail First	Tangent Tower	Tower, foundations, hardware
Not to fail first with 90% confidence	Angle Tower	Tower, foundations, hardware
		Tower, foundations, hardware
	Dead-end Tower	Tower, foundations hardware
	Conductor	Conductor, Insulator, hardware

* Within each major component, the underlined component is the weakest with 90% confidence.

Some components end up being naturally designed more reliable than others (not the first component to fail). Conductors are a typical case of such components:

When ice load is less than 3 times the conductor weight, vibration limit prevents the maximum tension to exceed 60 to 70% of the rated tensile strength of the conductor. In this case, the conductor has an additional built-in strength to withstand loads in excess of the design values, and thus will not be the first component to fail if design loads are exceeded. Even with severe ice loads, conductors are not used at tensions higher than 75% (i.e. their damage limit). Again in this case, conductors should not break first if ice accretion exceeds design values, unless weight spans of suspension towers are underused (utilization factor significantly lower than 1.0).

5.5 Analysis of HV Lines (Avalon Peninsula)

In view of the above explanation with regard to co-ordination of strength of line components, let us examine some segments of transmission lines between Sunnyside terminal station and Oxen Pond terminal station and see how good our suspension towers meet the criteria of first component to fail when the line is subjected to weather related loads exceeding design values.

5.5.1 In-Service Strength of Conductors

Table 5.3 presents the in-service strength of the existing conductors on each line segment in terms of percentage of total structures in the line. In-service strength of the conductor is determined by equating the tension due to imposed ice loadings to 85% of the rated tensile strength (RTS) of the conductor in a particular segment. In general, conductors on both wood pole and steel tower lines have in-service strength to withstand tensile loads resulting from 1 1/2 to 3 inches radial ice. Estimated radial ice based on limiting the tension to 85% UTS does not take into account the fact that a typical long span in any segment could still come close to the ground due to excessive sag, arc and then trigger a failure, probably cascading type. Except part of TL203 which was originally designed for 2.0 inch (50 mm) radial, all major lines on the Avalon were primarily

TABLE 5.3 (a)

IN–SERVICE STRENGTH OF CONDUCTORS ON VARIOUS HV LINES
IN TERMS OF ESTIMATED RADIAL ICE THICKNESS (INCHES) *

WOOD POLES

LINE NAME	LINE LENGTH (%)	IN–SERVICE CONDUCTOR STRENGTH RADIAL ICE (INCHES)	ORIGINAL DESIGN ICE LOAD (INCH) RADIAL	ESTIMATED RETURN PERIOD (YEARS)	PROPOSED 25 YEAR LOAD	PROPOSED 50 YEAR LOAD
TL–203	29	>3.0	2.0	10	2.5	3.0
	15	3.0	2.0	10		
	20	2.5	2.0	10		
	2	>1.75	1.0	2.5		
	31	1.75	1.0	2.5		
	3	1.5	1.0	2.5		
TL–201	29	2.0	1.0	2.5		
	61	1.75	1.0	2.5		
	10	3.0	1.0	2.5		
TL–236	100	>2.0	1.0	>3.0		

TABLE 5.3 (b)

IN–SERVICE STRENGTH OF CONDUCTORS ON VARIOUS HV LINES
IN TERMS OF ESTIMATED RADIAL ICE THICKNESS (INCHES) *

STEEL TOWERS

LINE NAME	LINE LENGTH (%)	IN–SERVICE CONDUCTOR STRENGTH RADIAL ICE (INCHES)	ORIGINAL DESIGN ICE LOAD (INCH) RADIAL	ESTIMATED RETURN PERIOD (YEARS)	PROPOSED 25 YEAR LOAD	PROPOSED 50 YEAR LOAD
TL–207	52	2.0	1.5	4.5	2.5	3.0
	48	1.75	1.5	4.5		
TL–237	12	3.0	1.5	4.5		
	2	2.0	1.5	4.5		
	86	1.75	1.5	4.5		
TL–217	9	3.0	1.5	4.5		
	81	1.75	1.0	2.5		
	10	1.50	1.0	2.5		
TL–218	6	>2.0	1.0	>3.0		
	3	2.0	1.0	>3.0		
	91	1.75	1.0	>3.0		

*** Notes (a)** In–service strength of conductor does not take into account the degradation of strength due to corrosion.

(b) Excessive sag would occur under these loadings due to profile layout and still cause conductor breakage due to icing.

(c) Estimated return periods (in years) are for original design loads.

designed for 1.0 inch (25 mm) radial ice. Therefore, it is estimated based on checking the plan and profile information, that a more realistic ice load based on in-service strength for all these lines (except TL203) would be 1 1/4 to 1.50 inches, approximately (2 1/2 to 10 year return period based on Table 4.9).

Although in-service strengths of these ACSR (Aluminum Conductor Steel Reinforced) conductors are assumed to be RTS of new conductors, there may be great variability with regard to conditions (degradation) of these conductors due to corrosion process i.e.: loss of zinc from the galvanized steel core wires. Normally, design factor of safety does not take into account the loss of strength due to corrosion. This loss can be detected non-destructively using an overhead line conductor - corrosion detector. However, at this time, there is no data available to quantify the actual in-service strength of conductor operating in Hydro's system taking into account the effect of corrosion. Future work is necessary in this area to assess further the in-service strength of these conductors in a quantitive manner.

5.5.2 Reliability Analysis

To carry out this part of the study, TL201 is chosen as an example for the purpose of presentation. Table 5.4 presents the various segments of this line and number of structures which are located within each segment. A segment will typically consist of a number of sections, which are defined as line section between two dead-end structures. Each section consists of a series of suspension structures (wood/steel), a few light to medium angle structures connected by conductors which are terminated at dead-end locations. For all lines east of Sunnyside (excluding TL208 and TL242) detailed plan and profile information was reviewed and digitized which included structure location, conductor attachment point, conductor characteristics and span lengths, pole classes or tower types etc.; a separate study was also conducted to evaluate various sag-tension

TABLE 5.4

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 201

File Name: E:\AVALON\TL201\201MAXT

SEG. NO.	SECT–IONS	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	1	1 to 2	2.00	437.00	437	1.00	636 ACS4, 26/7	This portion of TL 201
							RTS = 24953 LB	at Western Avalon T/S
2	1	2 to 3	2.00	2039.00	2039	1.00	1192 ACSR, 54/19	was upgraded in 1994
	2	3 to 5	2.00	514.00	560	1.08	RTS = 43100 LB	
	3	5 to 6	2.00	916.00	700	0.76		Includes Str # 5A
	4	6 to 9	2.00	1465.00	1468	1.00		
3	1	9 to 52	1.75	840.62	1425	1.70	636 ACS4, 26/7	
	2	52 to 53	>2.25	550.00	489	0.89	RTS = 24953 LB	
	3	53 to 124	1.75	850.97	1188	1.40		
	4	124 to 134	1.75	885.29	1054	1.19		
	5	134 to 139	1.75	852.39	1241	1.46		
	6	139 to 140		990.00	990	1.00		
4	1	140 to 147A	3.00	526.90	1110	2.11	795 ACSR, 26/7	This portion of TL 201
	2	147A to 149	3.00	907.70	820	0.90	RTS = 31250 LB	near Brigus Junction
	3	149 to 149A	3.00	700.00	700	1.00		was upgraded in 1988
	4	149A to 154A	3.00	722.20	900	1.25		
5	1	154A to 169	1.75	859.66	1030	1.20	636 ACS4, 26/7	
	2	169 to 177	1.75	821.58	1018	1.24	RTS = 24953 LB	
	3	177 to 200A	1.75	880.85	1583	1.80		
6	4	200A to 210	3.00	492.60	800	1.62	795 ACSR, 26/7	This portion of TL 201
							RTS = 31250 LB	near Hawke Hill
								was upgraded in 1988
7	1	210 to 227	2	770.36	869	1.13	636 ACS4, 26/7	
	2	227 to 297	2	715.73	1117	1.56	RTS = 24953 LB	
	3	297 to 303	2	785.43	1175	1.50		
	4	303 to 340	1.75	797.73	1093	1.37		
	5	340 to 351	2	709.29	998	1.41		
8	1	351 to 353	2	840.37	614	0.73	795 ACSR, 26/7	
	2	353 to 354	>2.25	300.00	631	2.10	RTS = 31250 LB	
	3	354 to 357	2	893.48	826	0.92		

runs for different conductors that exist on these lines. Using this information, strength of conductors for various ice loadings that include the design load plus any other "freak" loads were evaluated. For all structures, wind and weight spans were also computed and maximum values of these spans between each segment were also noted. A data base program in "Lotus" was developed to document the wind and weight spans of every structure east of Sunnyside. Table 5.4 presents the summary sheet indicating conductor strength (in-service), ruling span and maximum weight span for each section of a particular segment.

Let us take the Section 3 Segment 3 which consists of structure No. 53 to Structure No. 124 from Table 5.4. This section has 72 structures and approximately 7 miles (11.0 km) long. Table 5.5 shows the results of the analysis of various components e.g. structure, insulator and conductor- hardware assembly for original design load (1.0 in. radial ice) as well as loads exceeding the design value. Under 1.0 inch ice, Table 5.5(a) shows that dead-end hardware has 43% utilization factor compared to 54% for conductor, 39% for structure against pole buckling and 37% for insulator against M&E strength. Utilization factor is defined as the ratio of imposed stress due to ice load to the mean value of the ultimate load. Thence different weight span levels (1425 feet, 1000 feet and 850 feet) were considered with regard to one ruling span (850 feet) for the entire section (Table 5.4). Should the ice load reach to 2.0 inches radial (most likely, a 10-year load according to Table 2.9, 2.10 and 2.11), conductor is shown to be stressed beyond 85% limit. As mentioned before, the strength calculation does not take into account any degradation of ACSR conductor strength that might have occurred due to corrosion. Table 5.5(b) presents the reliability analysis and it is noted that under 2.0 inches radial ice load, hardware has the greater likelihood of failure compared to the failure of pole against buckling for a span of 850 feet. Results also show that conductor-hardware assembly has the good likelihood of failure should the design load exceed. This trend was consistently observed in the analysis of various line segments. Ideally, there should be a good separation between the beta values (reliability - indices) of conductor - hardware

TABLE 5.5.a: UTILIZATION FACTORS FOR VARIOUS LINE COMPONENTS (EXISTING) – TL201

SYSTEM	SUBSYSTEM	COMPONENT	LOAD	FAILURE MODE	SPAN (feet)	ULTIMATE CAPACITY (kips)	UTILIZATION FACTORS FOR VARIOUS RADIAL ICE THICKNESSES (Inches)			
							1.0	1.5	1.75	2.0
Typical Segment # 3 From Str. # 53 To Str. # 124	Structure	Kneebrace	Vertical	Tension	1425	16.0	0.29	0.48	0.60	0.73
		Pole	Vertical	Buckling		18.0	0.38	0.65	0.80	0.97
		Kneebrace	Vertical	Tension	1000	16.0	0.20	0.34	0.42	0.51
		Pole	Vertical	Buckling		18.0	0.28	0.46	0.56	0.69
		Kneebrace	Vertical	Tension	850	16.0	0.17	0.29	0.36	0.44
		Pole	Vertical	Buckling		18.0	0.24	0.39	0.48	0.58
	Insulator Conductor and Hardware Assembly	Insulator	Horizontal	Tension	850	36.0	0.37	0.48	0.54	0.60
		Conductor	Spatial Vertical	Tension	850	25.0	0.54	0.69	0.78	0.88
		Hardware	Horizontal	Tension	850	31.0	0.43	0.55	0.62	0.69

TABLE 5.5.b: RELIABILITY INDICES FOR VARIOUS LINE COMPONENTS (EXISTING) – TL201

SYSTEM	SUBSYSTEM	COMPONENT	LOAD	FAILURE MODE	SPAN (feet)	ULTIMATE CAPACITY (kips)	RELIABILITY INDEX FOR VARIOUS RADIAL ICE THICKNESSES (Inches)			
							1.0	1.5	1.75	2.0
Typical Segment # 3 From Str. # 53 To Str. # 124	Structure	Kneebrace	Vertical	Tension	1425	16.0	12.2	7.20	5.06	3.07
		Pole	Vertical	Buckling		18.0	3.45	1.60	0.80	0.09
		Kneebrace	Vertical	Tension	1000	16.0	15.73	10.75	8.75	6.67
		Pole	Vertical	Buckling		18.0	4.75	2.92	2.13	1.40
		Kneebrace	Vertical	Tension	850	16.0	17.35	12.35	10.30	8.30
		Pole	Vertical	Buckling		18.0	14.50	3.52	2.75	2.00
	Insulator Conductor and Hardware Assembly	Insulator	Horizontal	Tension	850	36.0	9.89	7.30	6.10	5.00
		Conductor	Spatial Vertical	Tension	850	25.0	12.5	7.20	4.85	2.67
		Hardware	Horizontal	Tension	850	31.0	4.30	2.98	2.40	1.85

*** Note: Beta values greater than 4.0 should be ignored, a chance of encountering a failure is very low. Beta values for conductor, hardware and structure for 850' span are very close under 2" ice loading.**

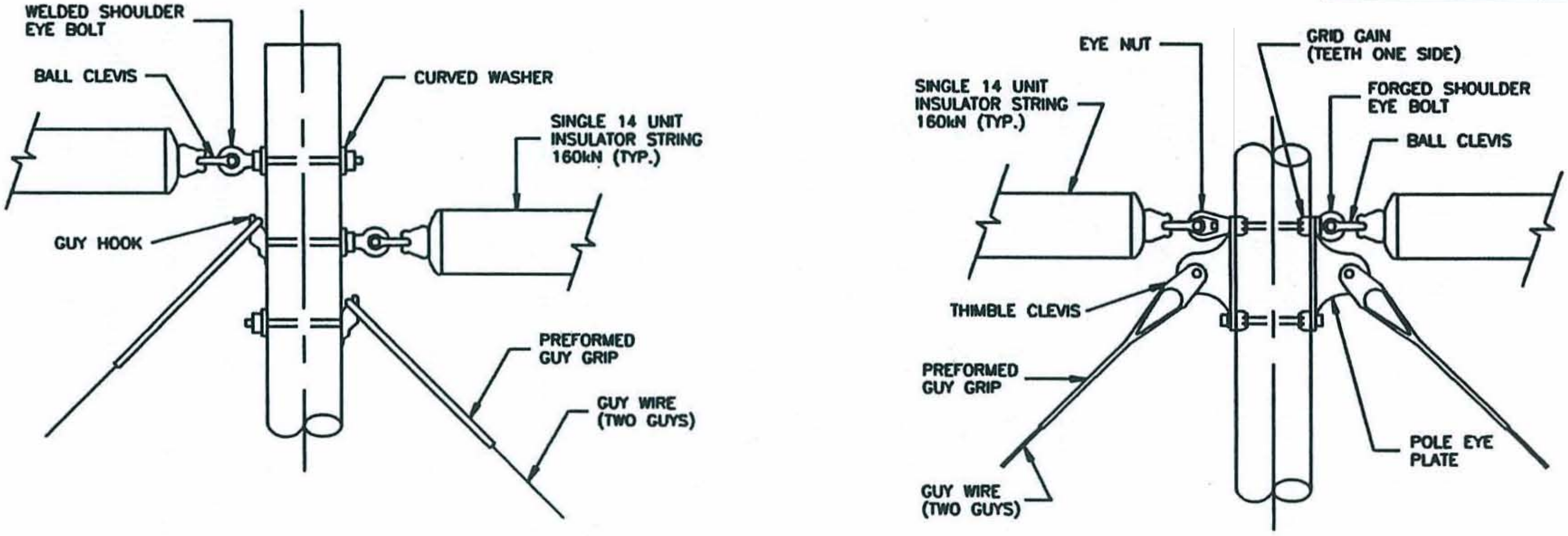
and structure to ensure that the conductor/hardware subsystem does not fail first.

From our past experience, this observation can also be verified in view of the conclusions as drawn in Section 2. This was also observed during the failure of December 8, 1994 storm when a welded eye bolt at dead-end location (Refer Fig. 2.6) failed prematurely during icing causing a severe imbalance of loads in the phases thus causing a cascading failure.

5.5.3 Reliability Improvement

To improve the strength of the conductor hardware assembly, it is recommended that all welded eye bolts should at least be replaced by forged eye bolts where the strength of the bolt will only be governed by failure occurring at the threaded root. However, this still will not provide adequate strength when ice load on the conductor is being exceeded. TL201 and TL217, in general, have experienced 4 major failures (combined) in the past 30 years (Table 2.11), with an average failure rate of 1 failure in 7.5 years. TL201 alone has experienced 2 major failures in the past 30 years i.e.: 1 failure in 15 years (Table 2.9). Table 4.6 provides information on probability of encountering an ice storm as 49% (third storm) which is quite high when compared to a 50-year load which is only 5%. As these lines were designed with ice load as 1.0 inch (25 mm) radial which has been underestimated severely with regard to a real 50-year load, probability of a line failure, in future, is extremely high. Therefore, standard dead-end assembly shown in Fig. 5.3 is strongly being recommended in view of Item (d) in Section 5.4.1. To improve the strength of the conductor itself, several discussions were held with Aluminum Company of Canada (ALCAN) (Ref. 14) and it was suggested that a high strength special alloy conductor (equivalent to "Drake" 795 ACSR 26/7 in ampacity) be used for re-conductoring option. Strength of this 804 kcmil conductor is twice that of "Drake" and Table 5.6

FIGURE 5.3

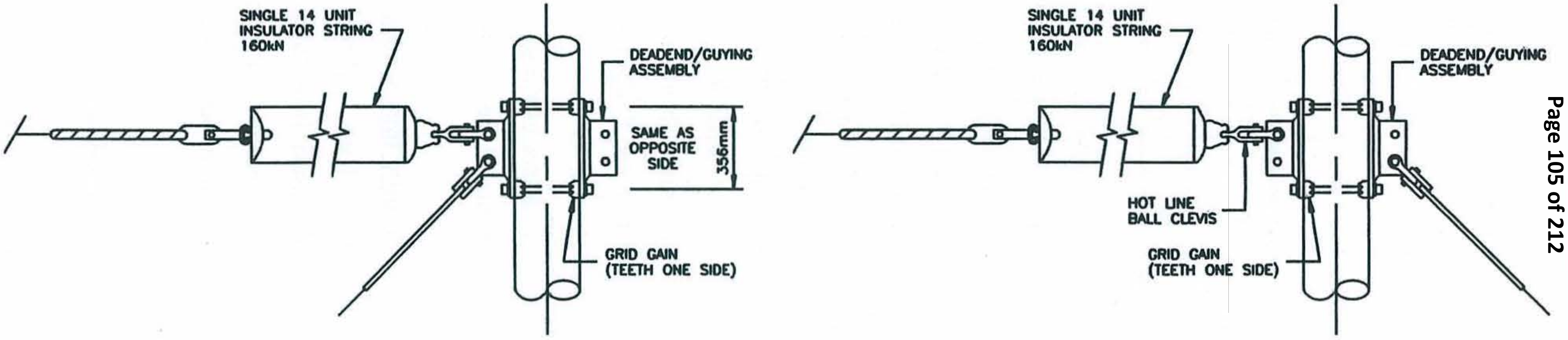


230kV TANGENT DEADEND ARRANGEMENT

(ORIGINAL DESIGN)

230kV TANGENT DEADEND ARRANGEMENT

(MODIFIED DESIGN – 1987)



230kV TANGENT DEADEND ARRANGEMENT

(SINGLE INSULATOR STRING – CURRENT STANDARD)

230kV ANGLE DEADEND ARRANGEMENT

(SINGLE INSULATOR STRING – CURRENT STANDARD) provides the conductor information.

TABLE 5.6 COMPARISON OF VARIOUS CONDUCTORS CHARACTERISTICS

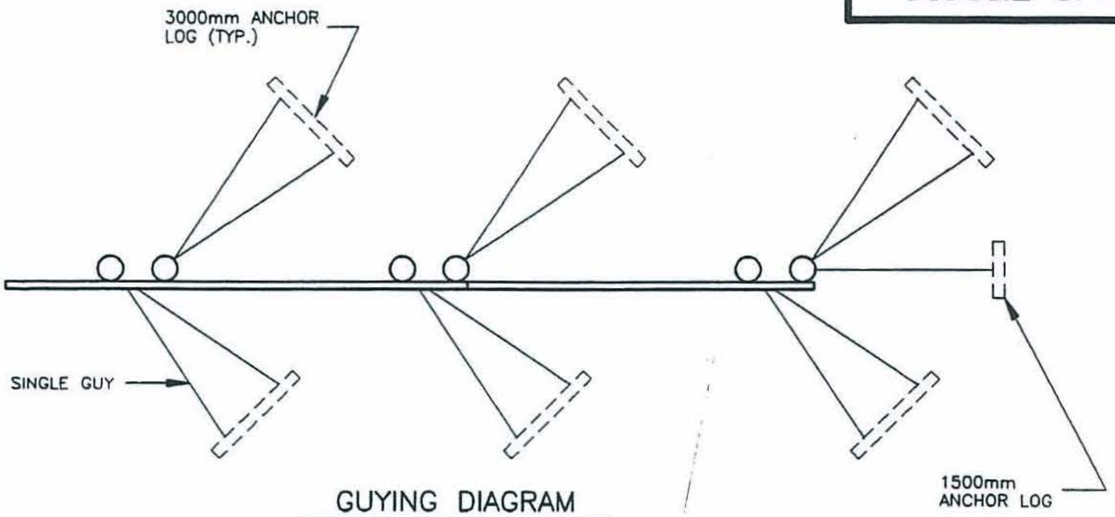
CONDUCTOR TYPE	KCMIL	STRANDING	AREA (TOTAL) (in^2)	DIA. (Inch)	MASS (lb/ft)	UTS (lbs)	UTS/m (ft)
DRAKE	795	26/7	0.7260	1.108	1.091	31,250	28643
GROSSBECK	636	26/7	0.580	1.027	0.872	24,952	28615
SPECIAL	804	23/19	0.8430	1.107	1.483	64,000	43155

Preliminary checking of the plan & profile indicates that clearance under heavy ice load will improve substantially without introducing any significant additional vertical load on suspension towers. However, use of this high strength conductor will significantly impose additional loads on light & medium angle structures because of line tension. It will also add substantial load on dead-end structures due to pole buckling. To eliminate major modifications on dead-end structures, it is recommended to add three additional poles to the existing 3-pole dead-end structures (refer to Fig. 5.4) thus doubling the load carrying capacity of these existing structures. Guying arrangements for all running light and medium angle structures should also be upgraded according to Fig. 5.5 and Fig. 5.6. Tables 5.6(a) and 5.6(b) provide the revised analyses based on re-conductoring option. Here it is shown that under 2.0 inches and 2.50 inches radial ice load, conductor/hardware subsystem has a beta value greater than 5.0 ensuring that the failure of the structure is guaranteed.

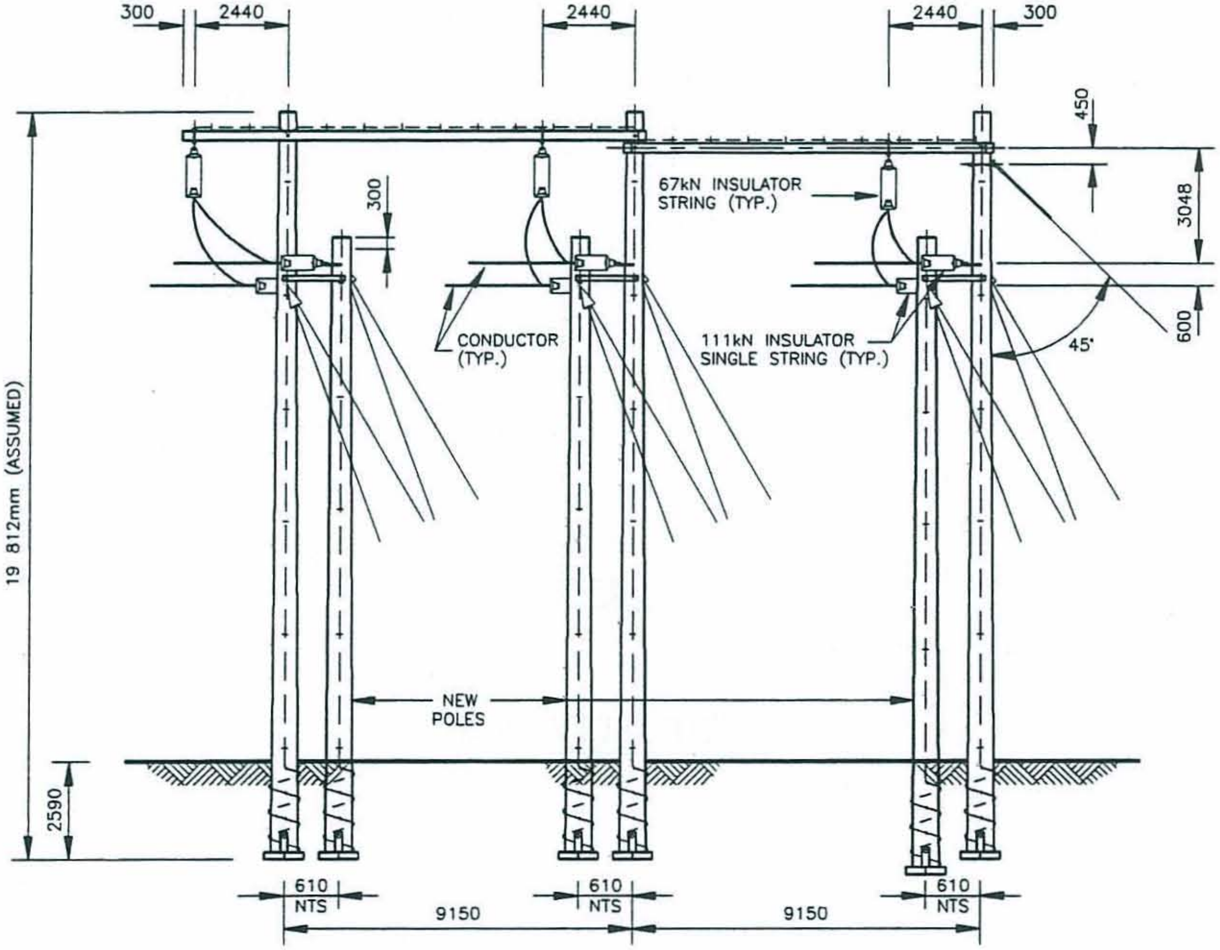
5.5.4 Security Improvement

One of the weaknesses that has generally been observed in lines on Avalon Peninsula is minimum protection against failure containment loads (security requirements) particularly with regard to wood pole lines such as TL201. There may have been more than seventy (70)structures placed in "series" without any

FIGURE 5.4



GUYING DIAGRAM

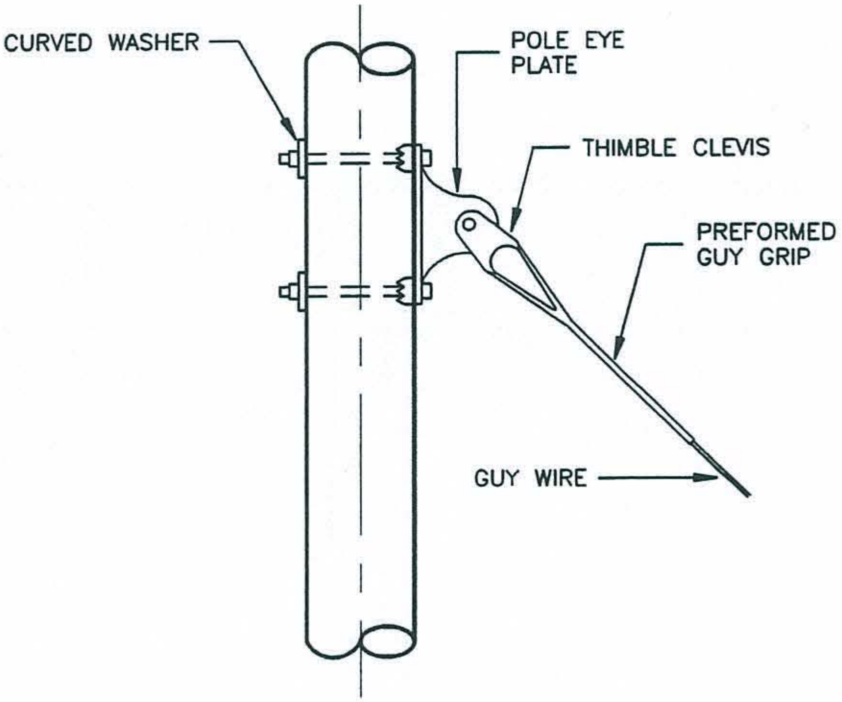


TYPICAL 230kV STRUCTURE TYPE "D" UPGRADED TO 6 POLE DEADEND

(ANGLE DEADEND – NORMAL ZONE – TL201)

SCALE 1:200

FIGURE 5.5

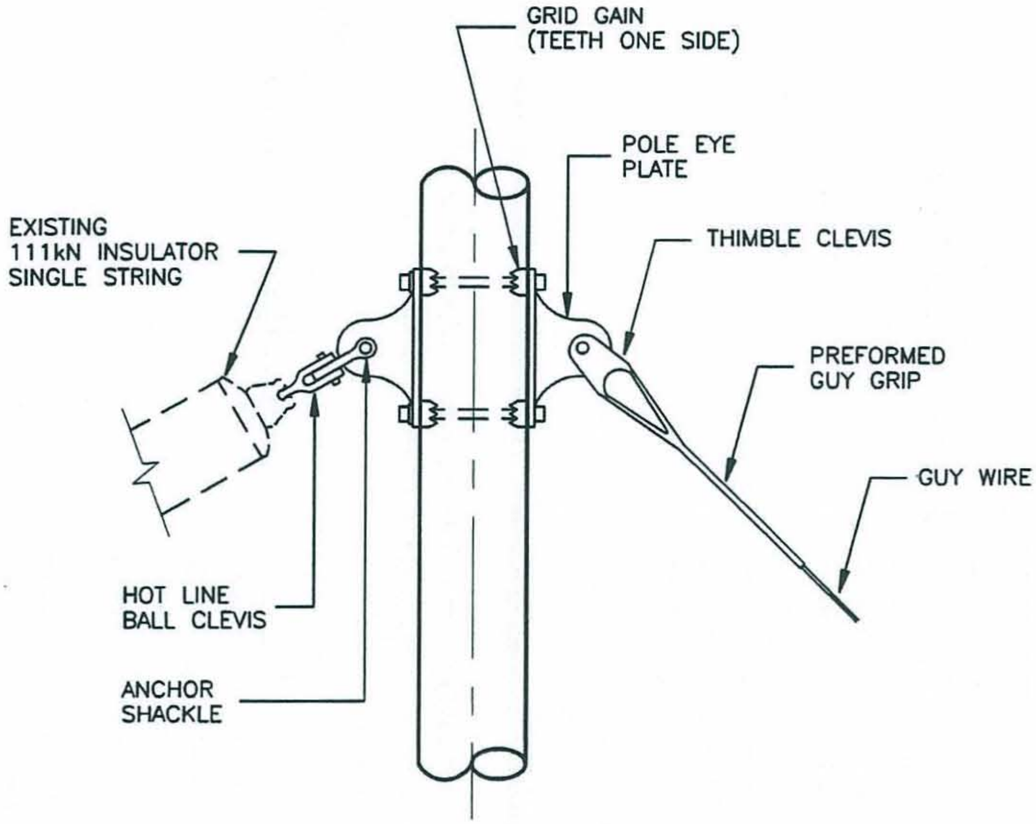


FRONT ELEVATION

POLE EYE PLATE ARRANGEMENT ON
230kV ANGLE STRUCTURE TYPE "B" – TL201 & TL203

(REPLACES EXISTING GUY HOOK ARRANGEMENT)

FIGURE 5.6



FRONT ELEVATION

POLE EYE PLATE ARRANGEMENT ON
230kV ANGLE STRUCTURE TYPE "C" – TL201 & TL203

(REPLACES EXISTING GUY HOOK & BALL LINK EYE BOLT ARRANGEMENT)

TABLE 5.6.a: UTILIZATION FACTORS FOR VARIOUS LINE COMPONENTS (PROPOSED UPGRADING WITH HIGH STRENGTH ALLOY CONDUCTORS) – TL201

SYSTEM	SUBSYSTEM	COMPONENT	LOAD	FAILURE MODE	SPAN (feet)	ULTIMATE CAPACITY (kips)	UTILIZATION FACTORS FOR VARIOUS RADIAL ICE THICKNESSES (Inches)			
							1.0	1.5	2.0	2.5
Typical Segment # 3	Structure	Kneebrace	Vertical	Tension	*	16.0				
		Pole	Vertical	Buckling		18.0				
		Kneebrace	Vertical	Tension	*	16.0				
		Pole	Vertical	Buckling		18.0				
		Kneebrace	Vertical	Tension	850	16.0			0.56	0.66
		Pole	Vertical	Buckling		18.0			0.76	0.89
From Str. # 52 To Str. # 124	Insulator Conductor and Hardware Assembly	Insulator	Horizontal	Tension	850	72.0			0.52	0.58
		Conductor	Spatial Vertical	Tension	850	64.0			0.59	0.64
		Hardware	Horizontal	Tension	850	70.0			0.54	0.59

TABLE 5.6.b: RELIABILITY INDICES FOR VARIOUS LINE COMPONENTS (PROPOSED UPGRADING WITH HIGH STRENGTH ALLOY CONDUCTORS) – TL201

SYSTEM	SUBSYSTEM	COMPONENT	LOAD	FAILURE MODE	SPAN (feet)	ULTIMATE CAPACITY (kips)	RELIABILITY INDEX FOR VARIOUS RADIAL ICE THICKNESSES (Inches)			
							1.0	1.5	2.0	2.5
Typical Segment # 3	Structure	Kneebrace	Vertical	Tension	*	16.0				
		Pole	Vertical	Buckling		18.0				
		Kneebrace	Vertical	Tension	*	16.0				
		Pole	Vertical	Buckling		18.0				
		Kneebrace	Vertical	Tension	850	16.0			5.66	4.05
		Pole	Vertical	Buckling		18.0			1.02	0.45*
From Str. # 52 To Str. # 124	Insulator Conductor and Hardware Assembly	Insulator	Horizontal	Tension	850	72.0			12.95	5.52*
		Conductor	Spatial Vertical	Tension	850	64.0			12.30	5.52*
		Hardware	Horizontal	Tension	850	70.0			10.57	10.49*

* Notes: Due to upgrading, spans will be reduced to 850' level; There is also a good spread in Beta values between conductor and tangent structure.

anti-cascading structures being placed in between. Should the conductor fail due to excessive icing either "in-span" or come close to the ground sufficient enough to sever and burn, it is highly probable that this will result in a severe cascading failure. In fact all our failures since 1970 have resulted in severe cascading failure, including the recent failure of TL201 near Western Avalon. In view of this, it is strongly recommended to put strategically located dead-end type structures in several long sections of these lines to increase the located line security significantly.

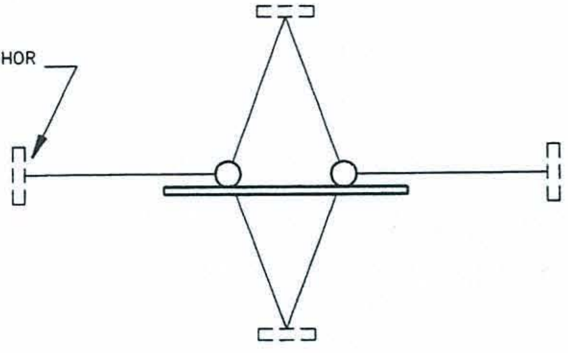
For both wood pole and steel tower lines, 50-year revised design ice load (Table 4.10) was used to prepare Capital Cost Estimates for building new lines parallel to existing routes. All these cost estimates are further discussed in Section 7.

5.6 Analysis of HV Line (Connaigre Peninsula)

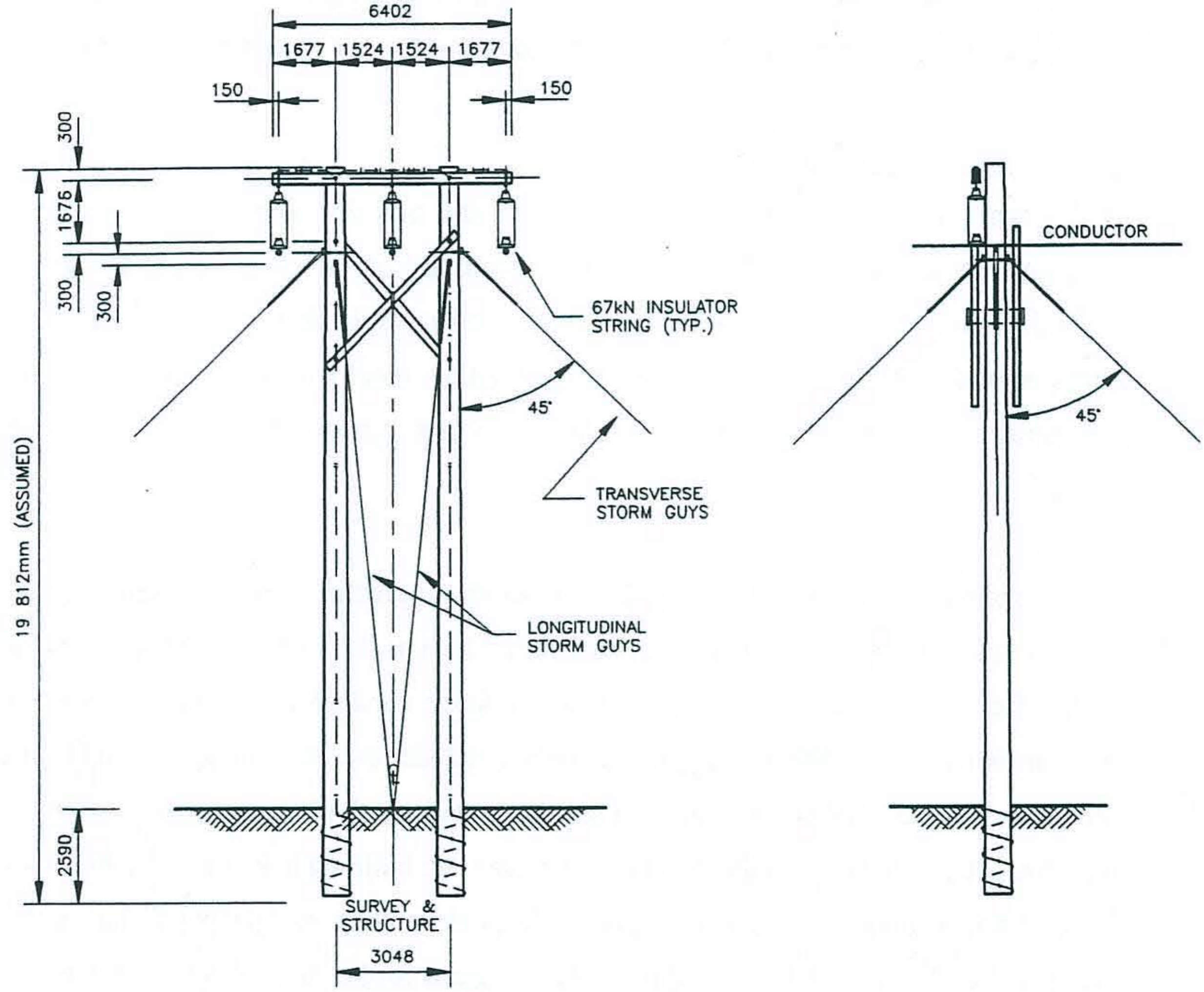
TL220 has experienced five major outages over the past 25 years, the most recent, resulting from the 266.8 ACSR, 26/7 conductor coming close to the ground under severe ice load, arcing and causing conductor breakage, resulting in downed structures. Due to the remoteness and general inaccessibility of the line, repairs have been difficult, time consuming and costly, resulting in prolonged power outages for the communities affected.

The suggested improvement of TL220 is based on upgrading and/or building a new section of the line to revised 50-year, return period load as 2.0 inches radial (refer Table 4.10). Conductor was chosen as a 559 Kcmil Alloy conductor and typical structure would be wood pole H-Frame. Upgrading would include re-conductoring 17 km section from Str. #89 to English Harbour station by installing double crossarms on every structures, strengthening 3-pole dead-end structures etc; building new line sections would include approximately 18 km to 35 km of lines depending on the particular option selected. Details of these various options are discussed further in Section 7. Due to one (1) wind storm damage earlier, Fig. 5.7 presents the typical storm guying arrangement that needs to be implemented on TL220.

FIGURE 5.7



GUYING DIAGRAM



EXISTING 69kV STRUCTURE TYPE "A" WITH STORM GUYS ADDED

(TANGENT – TL220)

SCALE 1:200

5.7 Summary

This section discusses the basis for reliability-based design philosophy, introduces system concept to transmission line design and provides guidelines for selecting a preferred "Sequence of failure" with particular reference to minimum outage time. Estimated in-service strengths of conductors on various segments of major lines on the Avalon Peninsula are also presented coupled with analyses which show that conductor and dead-end hardware assembly is the weak link. To improve this situation and alter the event that conductor and hardware do not fail first, a high strength alloy conductor is chosen for re-conductoring option. It is shown that by re-conductoring, and making modifications to angle and dead-end structures reliability and security of these lines can be improved substantially and thus reducing the probability of failure of the conductor/hardware system significantly. Finally, building new lines with 50-year revised design load is also considered as one option for the purpose of comparison.

SECTION 6

6.0 AEOLIAN VIBRATION OF HV LINES

6.1 General

In the eastern region, operations maintenance crew has experienced severe aeolian vibration problems which include damage of the outer layer and sometimes steel core in the conductor, excessive wear on ball link eye bolts, worn stirrups on suspension clamps, excessive wear on suspension clamps, conductor strand breakage at the suspension clamp due to fretting etc; details of these have been summarized in a recent letter by Mr. Herb Woolfrey to Mr. H. F. Young dated April 12, 1995 (Appendix 6). Normally, vibration induced problems are handled through a well designed damper protection plan. If the problems are not addressed in the early stages, a major line failure could occur.

Aeolian vibration is a forced vibration phenomenon caused by low velocity wind blowing across conductors under tension. Resonant vibration is caused by the small eddy forces synchronized with the natural frequency of the cable under tension. Frequency of this vibration is directly proportional to the wind velocity and inversely proportional to the conductor diameter and is expressed as

$$f = 0.2 \frac{V}{D} \quad \ldots(6.1)$$

where f = frequency in Hz
v = wind velocity in metre/sec.
and d = diameter in metre.

Experience with conductor vibration has shown that the normal range of interest covers winds from about 2 metre/second (2.24 mph) to 7 metre/second (15.7 mph). Under some conditions the upper velocity may be 9 m/s (20 mph). Conductor diameter may range from abut 6 mm (0.25 in.) for ground wires to about 50 mm (2.0 in.) for large conductors.

6.2 Contributing Variables

The terrain where a line is strung has a considerable influence in determining whether a line will vibrate at significant or dangerous levels. Any terrain feature which helps to create turbulence in the wind reaching the conductor is likely to reduce vibration problems. The most severe conditions can be expected in the absence of such features. This usually implies a vast plain as a body of water. Vegetation will increase turbulence but a snow cover may do the opposite.

Lines which run at right angles to prevailing winds generally receive the highest vibration exposure. Lines strung at tensions less than 15% of rated breaking strength have usually been less susceptible to vibration fatigue damage than lines strung at 25% or higher. A lowering of the ambient temperature increases the line tension.

An increase in the mechanical tension of a conductor causes a reduction in its self-damping. Higher tensions increase the tendency of the strands to lock, so that internal damping through strand slippage decreases. A second factor in self-damping reduction is related to loop length. Span frequency is a function of conductor diameter and wind velocity. Increased tension results in a higher travelling wave velocity, which is another way of stating that the product of frequency and loop length is larger. For a given wind velocity, increased conductor tension therefore results in the same frequency, but a longer loop length. For a given amplitude of vibration, a longer loop length decreases the severity of conductor flexing, with a corresponding decrease in the inter-strand motion that causes conductor self-damping. The net result of a tension increase is an increase in the severity of vibration.

6.3 Protection Methods and Devices

The most commonly used method of line protection is the addition of external damping devices to existing conductors such as stockbridge dampers. Dampers provide a means of dissipating some of the mechanical energy present in the vibrating span. Since some motion is always necessary to activate the damper, a reduction of the line amplitude to lower levels is possible, but a reduction to zero vibration cannot be expected.

6.4 In-house Work on Vibration Monitoring

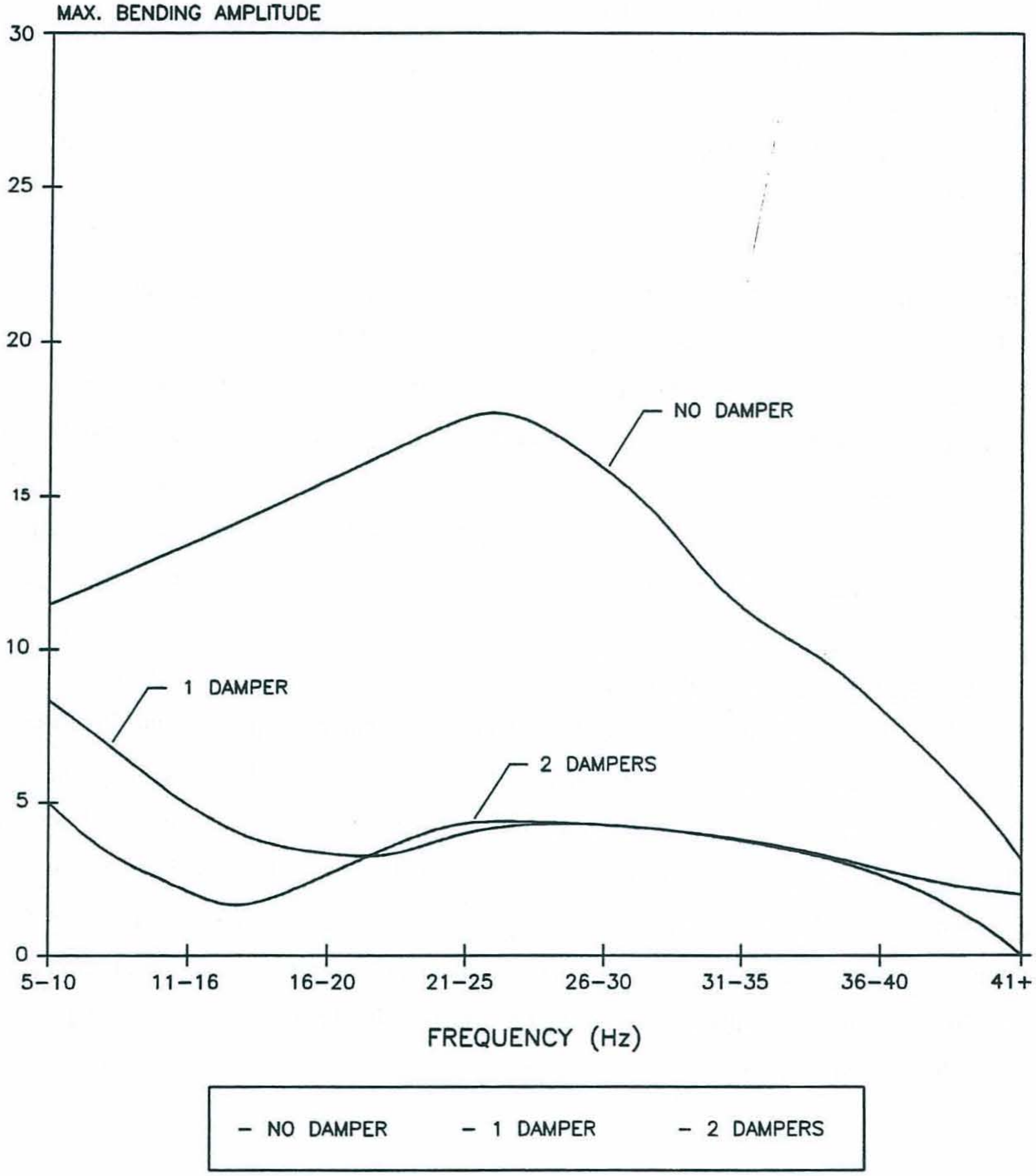
Technical Support Group, TRO Division initiated a program of on-line vibration monitoring of HV lines in 1990. As part of this program, two (2) sections of a 138 kV wood pole line on the Burin Peninsula (TL219) were monitored from May, 1990 to May, 1991 using Ontario Hydro vibration recorders and with the analysis and interpretation of the data using IEEE bending amplitude method. This project laid the framework of long-term vibration monitoring program for TRO division. Results of this study were published and presented at a CEA meeting in 1992 (Haldar, Pon and Torok, 1992). Subsequently, a major study was undertaken to carry out some specific field measurements on a HV line (TL217, Western Avalon - Holyrood) near Witless Bay Line.

The results of this study indicated that the line would face severe problems without dampers and, in certain cases, two (2) dampers per span were required. In many places, it was observed that dampers were not in the proper position; i.e., at antinode points, and the condition of these dampers was in poor shape. A typical stockbridge damper can withstand one hundred (100) million cycles of vibration with certain amplitude levels. Field measurements in TL217 indicated that line could have a central frequency of vibration 20-25 cycles/second with no damper, one damper and two dampers (refer Fig. 6.1). This control frequency of vibration relates to a steady laminar wind of 5 - 6 mph and will provide an expected service life of five to ten years for a typical damper. Therefore, on-line monitoring is very important to ensure that these dampers are working effectively to reduce bending near the clamp to an acceptable level (EPRI, 1979).

FIGURE 6.1

MAX. BENDING AMPLITUDE VS. FREQUENCY

AUGUST 30, 1991 – MARCH 17, 1992



NOTE: EXTRANEOUS VALUES REMOVED

VIBRATION MEASUREMENTS ON TL217

Periodic inspection of clamps is also necessary and if required, laboratory tests should be carried out to detect any cracks in the clamp or in the conductor strands that could lead to premature failure under climatic loading. Most of the time, clamp failure is related to vibration problem and can be avoided through on-going well designed vibration monitoring program. Based on the TL217 Study, a work order for Operations was raised to implement the proper damper protection plan and this work has been on-going for the last two years.

Besides this, the Technical Support Group of Hydro is currently working with Memorial University of Newfoundland on a joint CEA project 319T883 entitled "Mechanical Characteristics of Trapezoidal Wires". In this project, work is being carried out with particular reference to measurements of internal damping of various types of conductors (ACSR, Trapezoidal shape wires etc;) and prediction of fatigue life for circular and trapezoidal strands. Considerable amount of expertise has been developed through MUN to carry out future testing of hardware and conductor strand due to vibration problems.

6.5 Future Work on Vibration Monitoring

In 1995, Technical Support Group has proposed a budget proposal for Operations (Eastern Region) to systematically replace these deflective dampers on existing lines on the Avalon and Burin Peninsulas. In principle, this proposal has been accepted by the Management Committee and approximately $290,000 has been approved for 1996. Work on this area will be on-going for at least five (5) to seven (7) years before the full damper replacement program can be implemented and monitored on the Avalon and Burin Peninsulas. Similar programs should also be initiated on other HV lines located on different parts of the Island.

6.6 Summary

An overview has been presented with regard to the aeolian vibration problem, causes together with proper protection plan to reduce and/or control it. Considerable work has been done during the past five (5) years to develop the in-house expertise and future work should emphasis earlier detection of defective clamps due to wearing hardware, dampers and conductor strands near clamps through non-destructive testing (NDT) and/or supplemented by laboratory testing. Visual inspection is also important and should periodically be supplemented by the above two (2) testing procedures. Future work should also focus on the development of a data base to determine the loss of conductor strength due to <u>zinc loss</u> in steel core (effect or corrosion). Technologies are currently available to detect degradation of conductor strength. A condition based maintenance program rather than time-based should be developed in consultation with Operations to systematically collect data with particular reference to causes of clamp failures, dampers, hardware and in-service conductor strengths based on NDT techniques.

SECTION 7

7.0 COST STUDY

7.1 General

Based on the various analyses carried out in Section 5, several options were developed to upgrade major HV lines on Avalon and Connaigre Peninsulas. Each of these options was associated with a specific scope for upgrading work supplemented by an engineering cost estimate. Scope of the Work for a typical option could range from replacement of welded eye bolt (with forged eye bolt or full dead-end assembly) to building a new section of line by rerouting the selected section of an existing line to lower elevation. Overall scope of the work was broken down into several components and unit prices were developed in consultation with Operations (in-house estimate) or soliciting quotations from a prospective contractor such as Comstock Canada Ltd; cost for most of the items for materials were taken from the GNP project except in some instances such as dead-end assembly, conductor were obtained from the supplier for budgetary prices. Various costs reported in this section refer only to direct material and construction costs. Engineering (direct and indirect), construction project management and contingency will be added, later, in terms of percentage of material plus construction costs. To summarize, five options were developed for upgrading major lines on the Avalon Peninsula. Similarly, five options were also considered for upgrading TL220 on the Connaigre Peninsula.

7.2 Upgrading Options for Avalon Lines

Five Options that were developed are described as follows:

OPTION 1:

This option includes replacement of all welded eye bolts by forged bolts on running angle and deadend structures of wood pole lines i.e.: TL203 (5 structures), TL201 (23 structures) and TL218/TL236 (12 structures). This option also includes elimination of large spans by adding "in-span" tangent structures. This option is not applicable for steel lines.

OPTION 2

This option includes implementation of all works associated with installation of full dead-end assembly on all existing dead end structures (Fig. 5.3). These are 19 on TL201, 43 on TL203 and 11 on TL236 respectively. In addition, scope of work includes installation of pole eye plates (Fig. 5.5 and 5.6) on light and medium angle wood pole structures (11 structures on TL201 and 1 structure on TL203, respectively) and replacement of fifteen (15) type F structures (uplift structures) on TL201, six (6) on TL203 by dead-end. Under this option, six (6) dead-end (anti-cascading) structures on TL201, two (2) on Tl203 and eleven (11) on TL236 will be added to wood pole lines with particular reference to security containment. For steel tower lines, one (1) structure on TL207, three (3) structures on TL237, four (4) structures on TL217 and two (2) structures on TL218 will be added as anti-cascading towers with particular reference to secruity containment. Even though reliability increase will be marginal, security will be improved substantially.

OPTION 3 (Only for Wood Pole Lines)

This option includes all work associated with OPTION 2 and replacement of all angle structures with full dead-end and numbers are give under OPTION 2. Under this option, reliability of the hardware assembly as well as line security will improve substantially. Conductor will still be the "weak-link" with regard to new ice loading.

OPTION 4

This option considers re-conductoring of both lines (wood pole and steel) with a high strength special alloy conductor based on a revised 25-year return period load (Table 4.10). Following indicates the percentage of line in length to be reconductored to withstand the revised 25-year ice loading (refer to Table 5.3).

TL203	-	36%	TL207	-	100%
TL201	-	90%	TL237	-	88%
TL218/236	-	100%	TL217	-	91%

TL218 - 100%

Under this option, both reliability and security will increase significantly compared to OPTIONS 1, 2 and 3 respectively.

OPTION 5

This option considers building new lines parallel to existing wood pole and steel tower lines to new 50-year loading criteria derived based on the historical failure rate (Refer Table 2.11, 4.10 and Fig. 4.3). Obviously, reliability will be according to current standard of the industry. Security will also improve substantially by strategically adding anti-cascading towers.

TABLES 7.1 and 7.2 present the relative comparisons of five options for major lines on the Avalon Peninsula with particular reference to performance factors such as reliability and security.

7.3 Upgrading Options for TL220 on Connaigre Peninsula

(a) Option 1 - Re-Conductoring of TL220 (STR. 89 to English Harbour)

OPTION 1 would involve the re-conductoring of approximately 17 circuit km of TL220, from structure #89 to the English Harbour Terminal Station. All structures would remain in the same location with the installation of double crossarms on thirty - four (34) tangent structures having weight spans greater than 183 metres. Seventeen (17) dead-end structures have to be replaced to accommodate the increased conductor tension. No new right-of-way would have to be acquired under this option. Apart from the new dead-ends, the main disadvantage of this option is that the tangent structures would still be 25 years old with poles remaining at class 4. Access will be still difficult should the design load exceed in future.

TABLE 7.1: SUMMARY OF COST ESTIMATES (X Millions of Dollars) AND VARIOUS OPTIONS FOR WOOD POLE LINES *

OPTIONS	TL203–SUNNY SIDE TO WESTERN AVALON	TL201–WESTERN AVALON TO HARDWOOD	TL236–HARDWOOD TO OXEN POND
OPTION 1 *Replace Welded Eye Bolt and Reduce Span Wt.* COST	0.370	1.500	0.170
RELIABILITY SECURITY	Reliability will not improve except that few structures will have some reduced weight spans; line system is only good for 1.0 or 1 1/4 inch radial ice load which has a very low return period value; Securtiy is not adequate except in part of TL203 and TL236		
OPTION 2 *D/End Guying Assembly Plus Adding Anti–Cascading Towers* COST	1.300	2.500	0.200
RELIABILITY SECURITY	Reliability will be the same as in OPTION 1; However, Security will improve substantially.		
OPTION 3 *Option 2 Plus Changing Angle Structures to D/Ends* COST	1.930	3.300	0.500
RELIABILITY SECURITY	Reliability of hardware will improve substantially although conductor would be still "weak–link" with regards to ice load; Security will improve substantially.		
OPTION 4 *Reconductoring With High Strength Conductor* COST	2.200	8.000	0.900
RELIABILITY SECURITY	Both reliability and security of these lines will increase significantly because of higher conductor strength, shorter spans to withstand new 25–Year load as per Table 4.10.		
OPTION 5 *New Lines With 50–Year Load* COST	8.500	15.50	2.200
RELIABILITY SECURITY	Reliability will be according to current industry standards because design considers a 50–Year new load based on observed failure rate; Security will be adequate because of anti–cascading towers		

* Notes: Aeolian Vibration problem is being addressed separately through a 1996 Capital Budget Proposal.

TABLE 7.2: SUMMARY OF COST ESTIMATES (X Millions of Dollars) AND VARIOUS OPTIONS FOR STEEL TOWER LINES *

OPTIONS	TL207–SUNNY SIDE TO COME BY CHANCE	TL237–COME BY CHANCE TO WESTERN AVALON	TL217–WESTERN AVALON TO HOLYROOD	TL218–HOLYROOD TO HARDWOOD
OPTION 1 *Replace Welded Eye Bolt and Reduce Span Wt.* COST RELIABILITY SECURITY	NOT APPLICABLE			
OPTION 2 *Addition of Anti–Cascading Towers, Reduce Wt. Spans*				
COST	0.052	1.450	0.900	0.360
RELIABILITY SECURITY	Reliability of these lines will improve marginally due to some selective reduction of weight spans; Conductor is still the "weak–link" with regards to new ice load; Security will improve substantially.			
OPTION 3 *Reconductoring With High Strength Alloy Conductor*				
COST	1.850	8.450	11.20	3.400
RELIABILITY SECURITY	Both reliability and security of these lines will increase significantly because of increased conductor strength, shorter spans to withstand the new 25–year ice load as shown in Table 4.10			
OPTION 4 *New Lines With 50–Year Load*				
COST	3.200	12.53	17.30	7.800
RELIABILITY SECURITY	Reliability will be according to current industry standard because design considers a 50–year new load based on observed failure rate. Security will be adequate because of anti–cascading towers.			

*** Notes: Aeolian Vibration Problem is being addressed separately through a 1996 Capital Budget Proposal.**

FIGURE

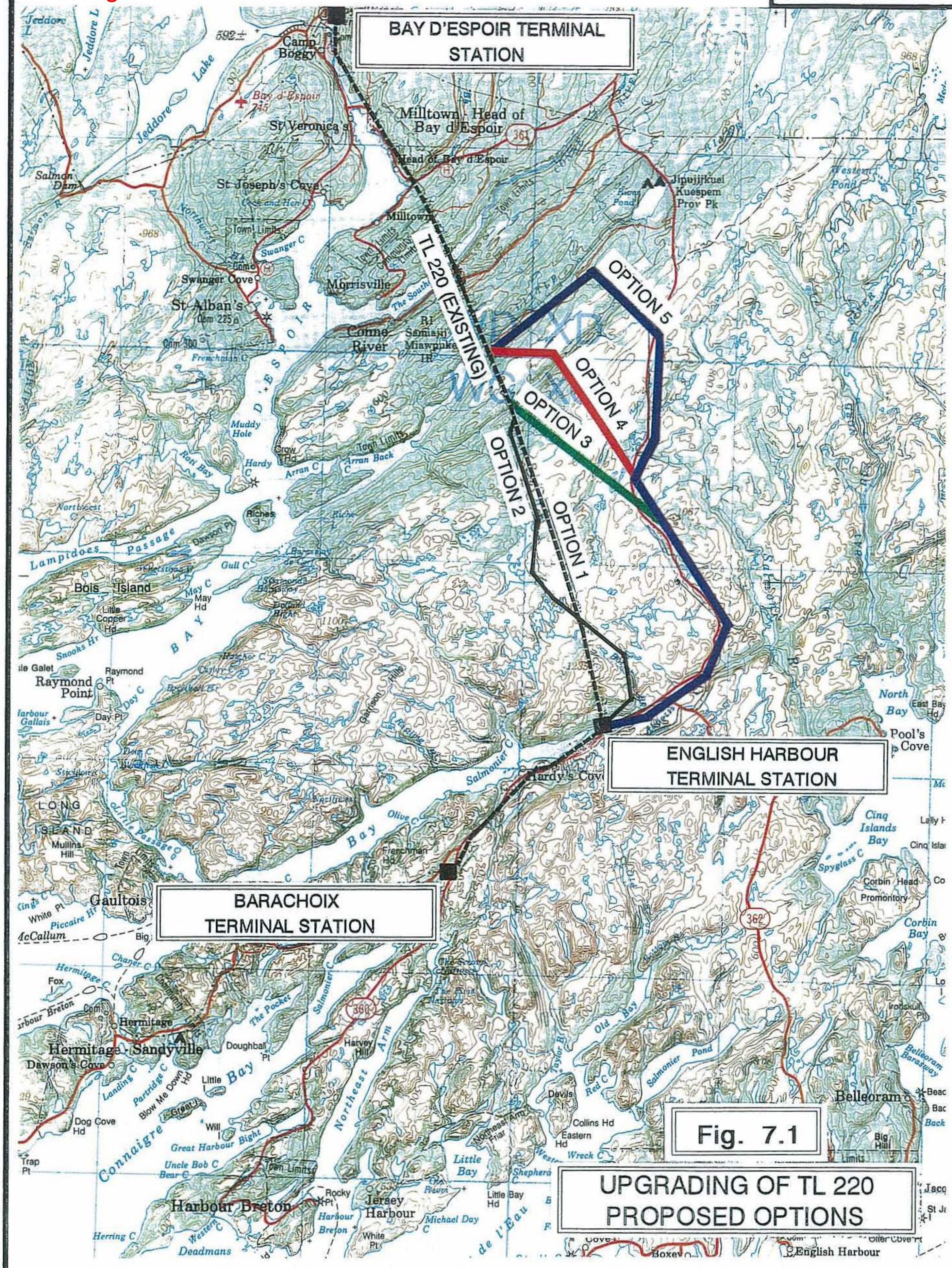


Fig. 7.1

UPGRADING OF TL 220
PROPOSED OPTIONS

It is estimated that a minimum of 2 months outage time would be required to re-conductor TL220, install extra crossarms and upgrade dead-ends. During this time an alternate source of generation needs to be arranged by means of a "gas turbine" rented from Newfoundland Power and the cost of renting this equipment has been included. This equipment is very expensive to rent and operate thus increasing the cost of OPTION 1 substantially.

(b) <u>OPTION 2 - Building of New Lines Between Structure 89 to English Harbour</u>

OPTION 2 entails the building of a completely new line adjacent to existing TL220, from structure 89 to structure 116. Beyond structure 116, OPTION 2 deviates from the existing line to take advantage of theterrain (eg. valleys) in order to minimize potential exposures to severe ice loads.Structures and conductor will be new, built to 138 kV standard to withstand two (2) inches of radial glaze ice. The class of pole will be increased from class 4 to class 2. These improvements will have the effect of making the line more reliable, much less susceptible to ice and wind damage. From structure 116 to the English Harbour Terminal Station, OPTION 2 deviates from the existing line in order to avoid high points, which are susceptible to extreme wind and ice loading. Under OPTION 2, TL220 will be upgraded while the existing line is still in service. This will eliminate the need for expensive, alternate generation and will reduce the outage time, to a matter of hours instead of months.

OPTION 2 has the advantage of being the least expensive of all the options proposed. Under this option, access to the line will still be difficult and time consuming should the loading exceed in future to cause another failure.

(c) OPTION 3

Under OPTION 3, TL220 will be rerouted from existing structure 88 in a generally south-easterly direction until it intersects Route 360 where it follows along the highway until it reaches the English Harbour Terminal Station. Structures and conductor will be new, to withstand heavier design loads. The grade of pole will be increased from class 4 to class 2. These improvements will have the effect of making the line more reliable, much less susceptible to ice and wind damage. From structure 88 to 6 km south-east of structure 88, TL220 traverses some very rough and inaccessible terrain. Access, however, continues to improve as the line moves in the south-easterly direction toward the main road. Once TL220 meets the highway, access from there to English Harbour Terminal Station is excellent. This would greatly facilitate maintenance, especially along the main road, and minimize repair/outage time should storm damage occur in the future.

OPTION 3 still does not avoid the worst of the difficult terrain, namely the Collins Brook area. To carry out repairs in this vicinity involves travel time of, at least one day, 7 to 8 hours before repairs could even begin. OPTION 3 is more expensive than OPTION 2. (See attached estimates).

(d) OPTION 4

Under OPTION 4, TL220 starts at existing structure 78 and proceeds almost due east for 3 km. From thence it turns approximately 45 degrees south-east until it intersects the main road, along which it runs parallel to the highway for the remainder of its length. Structures and conductor will be new, and built to withstand heavier design loads. The grade of pole will be increased from class 4 to class 2. These improvements will have the effect of making the line more reliable, much less susceptible to ice and wind damage because of lower elevation. OPTION 4 has excellent access along route 360 and good access from secondary roads in the area. Most importantly it avoids partially the difficult terrain at Collins Brook.

(e) OPTION 5

OPTION 5 starts at existing structure number 78 and proceeds 7 km along a secondary road in a north easterly direction. From thence it turns 90 degrees and runs south-east for 3.5 km until it meets the main road (route 360). After intersecting route 360, TL220 parallels the highway until it reaches the English Harbour Terminal Station. Structures and conductor will be new, and built to withstand heavier design loads. The class of pole will be increased from class 4 to class 2. These improvements will have the effect of making the line more reliable, much less susceptible to ice and wind damage. Under OPTION 5 access from structure 78 to English Harbour Terminal Station is excellent, running along the secondary road and the main highway for the entirety of its length. OPTION 5 avoids the difficult terrain especially crossing Collins Brook. This will greatly facilitate maintenance and minimize repair/outage time should storm damage occur in the future. This option has been favoured by Operations Central Region.

Under OPTIONS 3, 4 and 5, TL220 will be upgraded while the existing line is still in service. This will eliminate the need for expensive, alternate generation and will reduce the outage time to a matter of hours instead of months. OPTION 5 is the longest and most expensive of all 5 options.

Table 7.3 presents all costs associated with the upgrading work of TL220 including some comments on the relative improvement on Reliability, Security and access.

7.4 Summary

Detailed cost estimates have been made for budgetary purposes with regard to various options presented earlier. Cost figures include only direct material and erection costs. Section provides a useful means of identifying the cost and performance factors such as reliability and security which contribute to decisions regarding the usefulness of upgrading by re-conductoring. Re-conductoring of both wood pole and steel tower lines on the Avalon Peninsula will certainly improve the reliability and security of these lines significantly. OPTION 4 and OPTION 5 for TL220 are both feasible although OPTION 4 will be more cost effective when one considers the balance between the initial cost of building a new line to 50-year load (2.0 inches radial) and the future failure cost.

TABLE 7.3: SUMMARY OF COST ESTIMATES (X Millions of Dollars) AND VARIOUS OPTIONS FOR TL220

PARAMETERS	OPTIONS				
	#1	#2	#3	#4	#5
Description of Work	Reconductoring of existing line from STR# 89 to English Harbour; Adding storm guys to selective structures.	Building a section of new line from STR# 89 to English Harbour plus adding storm guys to selective structures.	Building a section of new line to lower elevation along the existing highway.	Building a section of new line between STR# 78 and English Harbour station along route 360.	Building a section of new line between STR# 78 and English Harbour station along route 360.
COST	2.50	2.70	3.20	3.50	4.50
RELIABILITY	Some improvement but poles will be still CL4 (25 years old).	Significant improvement to withstand full 50–year ice load.			
SECURITY	Security will improve because of addition of selective Dead End Structures. at strategic locations to contain the cascade failure in future.				
ADVANTAGE	No clearing required.	Very short outage required for connection.			
DISADVANTAGE	Poles will be still CL4; Access will still be difficult Require additional gas turbine support to supply power during construction.	Access will still be difficult.	Access will improve marginally.	Access will improve significantly.	No problem with access.

SECTION 8

8.0 COST BENEFIT ANALYSIS

8.1 General

This section describes various steps that are required to carry out a cost-risk analysis of various options described before in a systematic manner. Risk analysis is a technique for identifying, characterizing, quantifying and evaluating exposures. It consists of two distinct phases: a qualitative step of identifying, characterizing and ranking exposures and a quantitative step of risk evaluation, which includes estimating the likelihood (e.g. frequencies) and consequences of exposure occurrence. For example, what is the chance of exceeding the design ice load and, should this happen, what is the probability of occurrence of a line failure? Tables 4.5, 4.6 and 4.7 provide some guide to assess the actual risk level when the design load is exceeded within the service life of a line. After risk has been quantified, appropriate risk management options can be devised and considered; risk-benefit or cost-benefit analysis may be performed; a rational decision can then be formulated to implement corrective actions. The main goals of risk management are to minimize the occurrence of severe events that would cost significant capital loss or revenues by reducing the likelihood of their occurrence, for example reducing the risk of cascade failure. The estimation of likelihood or frequency of severe "ice-storm" damage depends greatly on the reliability of various system components as discussed in Section 5.

8.2 Determination of Risk Values

There are two major parts in risk analysis:

- Determination of the likelihood i.e.: probability P_i of an undesirable event, E_i such as ice-storm exposure;

- Evaluation of the consequence, C_i, of this exposure or the event, eg. damage cost.

Therefore, risk analysis quite often involves the following three steps.

(1) Selection of a specific event, E_i or scenarios (sequence or chain of events) for quantitative analysis. For example, selecting an ice-storm that would cause a failure of the conductor hardware assembly system;

(2) Estimation of the likelihood of this event, P_i, i.e. return period of the specific event (Refer to Table 2.11 or Table 4.9).

(3) Estimation of the consequences of this event, C_i, i.e. cost of damage, cost of repairs, loss of revenue and unknown social cost.

Total expected risk value, R is defined as:

$$R = \sum_i P_i \; x \; C_i \qquad \ldots(8.1)$$

Expected values are most useful when the consequences C_i are measured in terms of financial losses. The expected risk value R_i (or expected loss) associated with event E_i is the product of its probability P_i and consequence values as described by Equation (8.1). Thus if the event occurs with a frequency of .01 per year (1 in 100 year return period) and if the associated loss is \$1.0 million, then the expected loss (or risk value) is: R_i = .01 X \$ 1,000,000 = \$10,000. Conversely, if the frequency of event occurrence is 1 per year but the loss is \$10,000, the risk value is still R_i = 1 X \$10,000 = \$10,000. Thus the risk value for these two situations is the same i.e. both events are equally risky.

Since this is the expected annual loss, the total expected loss over 20 years (assuming this is the service life and based on constant dollar value) would be \$200,000. This cost can be adjusted based on escalation rates and interest; however, it will be discussed later in terms of present value analysis (PVA).

8.3 Cost of Damage

Cost of damage is primarily defined here as the cost of replacement of lines after the failure. Costs associated with several past failures were studied and a data base was developed in terms of 1995 dollars. Table 8.1 presents this cost data due to various ice storm damage indicated in Tables 2.4 - 2.7.

TABLE 8.1
COST OF DAMAGE DATA FROM PAST AND RECENT FAILURES
(1995 DOLLARS)

YEAR OF DAMAGE	DESCRIPTION	DAMAGE COST (x 10^6 DOLLARS)
1970	LINES ON AVALON AND PARTLY ON BURIN	$4.0
1984	LINES ON AVALON	$2.5
1988	LINES ON AVALON	$0.4
1994	LINES ON AVALON	$0.6
1995	LINES ON CONNAIGRE	$0.3

8.4 Present Value Analysis (PVA)

The present value factor is normally calculated to define P, dollars that should be spent today, by accounting the interest rate that should be compounded annually on a sum of money, A which will be spent in the future, n years from today.

The present value of an icing event that could lead to a cascading failure in future is obtained by multiplying the typical cost of a single event (C_e) by the present value factor:

$$PVF = \frac{1}{(1 + i)^n} \quad \text{.....(8.2)}$$

Where i = annual interest rate in (%) for each year and summing them up to n - years or more conveniently by multiplying the annual damage cost by the present value factor of an annuity / PVA

$$PVA = \frac{1 - \frac{1}{(1 + i)^n}}{i} \qquad \ldots(8.3)$$

Cost of an event = cost of a single event x Probability of occurrence, P_i x PVA

Typical cost of a single event is given in Table 8.1. Probability of occurrence can be obtained from Table 4.10 with various risk levels assessed from Tables 4.6 and 4.7 respectively.

a) Cost/Benefit Considerations

Cost of upgrading, C_u = Cost of materials plus erection associated with a particular option (Tables 7.1 or 7.2 or 7.3)

$$= C_m + C_E \qquad \ldots(8.4)$$

Cost of damage, C_D = Cost of damage due to icing storm, C_i x Probability of occurrence, P_i x PVA

$$C_D = C_i \times p_i \times PVA \qquad \ldots(8.5)$$

or:

at break even point,

$$C_u/C_D = 1$$

Therefore, Break Even Index is defined as:

$$BEI = \frac{C_u}{C_D} = \frac{C_M + C_E}{C_D} = P_i x\ PVA \qquad \ldots(8.7)$$

where (P_i x PVA) may be thought as Break Even Index (BEI)

The above approach clearly shows possible rationales for choosing various upgrading options (at different reliability levels) to existing transmission lines on the Avalon and Connaigre Peninsulas. Some of the cost data associated with upgrading options such as cost of materials, erection, survey and engineering can be obtained readily. However, other cost data such as cost of future outages (forced) due to sleet storm damage are difficult to quantify and have been estimated based on cost figures derived from past failures. Loss of revenue could also be a major factor and has not been included in this study.

8.5 Decision Making Process for Upgrading

Cost of upgrading under various options should be compared with risk value to determine the break even point; Break Even Index (BEI) is defined as the ratio of cost of upgrading to the cost of damage i.e.: expected risk value.

- If the ratio of upgrading cost to cost of damage under a specific option is equal to or less than BEI, it is cost effective to upgrade.

- If the ratio of upgrading cost to cost of damage under a specific option is greater than BEI, it is not cost effective to upgrade.

Based on the above criteria, Tables 8.2 to 8.6 present the BEI values for various options for upgrading and/or building new lines on the Avalon Peninsula. It is clear that OPTIONS 1, 2 and 3 can probably be only justified based on BEI values. It is also shown in Table 7.1 and 7.2, these options will provide very little improvement in Reliability .

The following data were used in calculating the BEI values in Tables 8.2 to 8.6:

Service Life: 25-years for OPTIONS 1 - 4;
50-years for OPTION 5;

Interest Rate: 8%

Probability of
Occurrence: 0.10 for OPTIONS 1 - 5

Cost of
Damage: (0.5 ~ 3.0) x 10^6 dollars

It must be also noted that the cost-risk analysis based on economic approach only provides a useful guide to make decisions regarding upgrading, there are other factors to be considered. There are factors that cannot be assessed readily in terms of monetary values. They include improved public relations image for the Utility - due to less frequent forced outages due to sleet storm damage, and creation of a more attractive environment for industrial growth resulting from a more reliable supply of power. Therefore, considering the above factors, some selective choices should be made which will combine a significant improvement of reliability and security that is somewhat greater than that justified solely by economic considerations. Periodic major failure of transmission lines may lead to "lack of credibility" and may more influence the decision making process rather than the BEI values alone.

TABLE 8.2: UPGRADING OPTION BASED ON REPLACEMENT OF WELDED EYE BOLTS AND LONG SPANS (WOOD POLE LINES) - OPTION-1 (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL203	TL201	TL218/236	REMARKS
Upgrading Cost (Cu)	0.37	1.50	0.17	Table 7.1
Cost of Damage (B) Due to Ice Storm	0.50 ~ 3.0			Table 8.1
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	10.67 - Eqn(8.3) @ 8%(i)			25-yr. service life
Total Cost of Damage (Cd)	0.54			Eqn. (8.5)
(Cd = B*C*D)	3.20			
Break Even Index (C*D)	1.067			Eqn. (8.7)
Ratio of Cu/Cd	0.68*	2.75	0.32*	*Upgrading Justified
	0.12*	0.47*	0.05*	Based on Economics

TABLE 8.2: UPGRADING OPTION-1 (NOT APPLICABLE FOR STEEL LINES)

PARAMETERS	TL207/TL237	TL217	TL218	REMARKS
Upgrading Cost (Cu)	NOT APPLICABLE			
Cost of Damage (B) Due to Ice Storm				
Prob. of Occurrence (C)				
PVA (D)				
Total Cost of Damage (Cd) (Cd =B*C*D)				
Break Even Index (C*D)				
Ratio of Cu/Cd				

TABLE 8.3: UPGRADING OPTION BASED ON FULL D/END GUYING ASSEMBLY AND ANTI-CASCADING STRUCTURES

(WOOD POLE LINES) - OPTION-2 (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL203	TL201	TL218/236	REMARKS
Upgrading Cost (Cu)	1.30	2.50	0.20	Table 7.1
Cost of Damage (B)	0.50 ~ 3.0			Table 8.1
Due to Ice Storm				
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	10.67 - Eqn(8.3) @ 8%(i)			25-yr. service life
Total Cost of Damage (Cd)	0.54			Eqn. (8.5)
(Cd = B*C*D)	3.20			
Break Even Index (C*D)	1.067			Eqn. (8.7)
Ratio of Cu/Cd	2.40	4.62	0.37*	*Upgrading Justified
	0.40*	0.78*	0.06*	Based on Economics

TABLE 8.3: UPGRADING OPTION BASED ON ANTI-CASCADING TOWERS AND REDUCED WT. SPANS

(STEEL TOWER LINES) - OPTION-2 (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL207/TL237	TL217	TL218	REMARKS
Upgrading Cost (Cu)	2.0	0.90	0.36	Table 7.2
Cost of Damage (B)	0.50 ~ 3.0			Table 8.1
Due to Ice Storm				
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	10.67 - Eqn(8.3) @ 8%(i)			25-yr. service life
Total Cost of Damage (Cd)	0.54			Eqn. (8.5)
(Cd =B*C*D)	3.20			
Break Even Index (C*D)	1.067			Eqn. (8.7)
Ratio of Cu/Cd	3.70	1.67	0.66*	*Upgrading Justified
	0.62*	0.28*	0.11*	Based on Economics

TABLE 8.4: UPGRADING OPTION BASED ON FULL D/ENDS ON ANGLE LOCATIONS (WOOD POLE LINES) - OPTION-3 (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL203	TL201	TL218/236	REMARKS
Upgrading Cost (Cu)	1.93	3.30	0.50	Table 7.1
Cost of Damage (B) Due to Ice Storm	0.50 ~ 3.0			Table 8.1
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	10.67 - Eqn(8.3) @ 8%(i)			25-yr. service life
Total Cost of Damage (Cd = B*C*D)	0.54			Eqn. (8.5)
	3.20			
Break Even Index (C*D)	1.067			Eqn. (8.7)
Ratio of Cu/Cd	3.57	6.11	0.92*	*Upgrading Justified
	1.16	1.03*	0.16*	Based on Economics

TABLE 8.4: UPGRADING OPTION-3 (NOT APPLICABLE FOR STEEL LINES)

PARAMETERS	TL207/TL237	TL217	TL218	REMARKS
Upgrading Cost (Cu)	NOT APPLICABLE			
Cost of Damage (B) Due to Ice Storm				
Prob. of Occurrence (C)				
PVA (D)				
Total Cost of Damage (Cd) (Cd = B*C*D)				
Break Even Index (C*D)				
Ratio of Cu/Cd				

TABLE 8.5: UPGRADING OPTION BASED ON RECONDUCTORING (WOOD POLE LINES) - OPTION-4 (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL203	TL201	TL218/236	REMARKS
Upgrading Cost (Cu)	2.20	8.0	1.90	Table 7.1
Cost of Damage (B)	0.50 ~ 3.0			Table 8.1
Due to Ice Storm				
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	10.67 - Eqn(8.3) @ 8%(i)			25-yr. service life
Total Cost of Damage (Cd)	0.54			Eqn. (8.5)
(Cd = B*C*D)	3.20			
Break Even Index (C*D)	1.067			Eqn. (8.7)
Ratio of Cu/Cd	4.0	14.8	3.5	*Upgrading Justified
	0.68*	2.50	0.60*	Based on Economics

TABLE 8.5: UPGRADING OPTION BASED ON RECONDUCTORING (STEEL TOWER LINES) - OPTION-3 (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL207/TL237	TL217	TL218	REMARKS
Upgrading Cost (Cu)	10.30	11.20	3.40	Table 7.2
Cost of Damage (B)	0.50 ~ 3.0			Table 8.1
Due to Ice Storm				
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	10.67 - Eqn(8.3) @ 8%(i)			25-yr. service life
Total Cost of Damage (Cd)	0.54			Eqn. (8.5)
(Cd = B*C*D)	3.20			
Break Even Index	1.067			Eqn. (8.7)
Ratio of Cu/Cd	19.0	20.7	6.32	*Upgrading Justified
	3.20	3.50	1.06*	Based on Economics

TABLE 8.6: UPGRADING OPTION BASED ON NEW LINE 50-YEAR LOAD (WOOD POLE LINES) - (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL203	TL201	TL218/236	REMARKS
Upgrading Cost (Cu)	8.50	15.50	2.20	Table 7.1
Cost of Damage (B)	0.50 ~ 3.0			Table 8.1
Due to Ice Storm				
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	12.23 - Eqn(8.3) @ 8%(i)			50-yr. service life
Total Cost of Damage (Cd)	0.62			Eqn. (8.5)
(Cd = B*C*D)	3.65			
Break Even Index (C*D)	1.223			Eqn. (8.7)
Ratio of Cu/Cd	13.7	25.0	3.55	*Upgrading Justified
	2.32	4.30	0.60*	Based on Economics

TABLE 8.6: UPGRADING OPTION BASED ON NEW LINE 50-YEAR LOAD (STEEL POLE LINES) - (ALL COSTS ARE IN MILLIONS OF DOLLARS)

PARAMETERS	TL207/TL237	TL217	TL218	REMARKS
Upgrading Cost (Cu)	15.60	17.30	7.80	Table 7.2
Cost of Damage (B)	0.50 ~ 3.0			Table 8.1
Due to Ice Storm				
Prob. of Occurrence (C)	0.10 (1 failure in every 10 years)			Table 4.10
PVA (D)	12.23 - Eqn(8.3) @ 8%(i)			50-yr. Service Life
Total Cost of Damage (Cd)	0.62			Eqn. (8.5)
(Cd = B*C*D)	3.65			
Break Even Index (C*D)	1.223			Eqn. (8.7)
Ratio of Cu/Cd	25.0	27.9	12.6	*Upgrading Justified
	4.30	4.70	2.20	Based on Economics

In view of the above, it may be prudent to consider the re-conductoring options in Table 7.1 and 7.2 under OPTION 4 and OPTION 3 respectively, to provide well secured reliable lines from Sunnyside to Oxen Pond Terminal Stations. Similarly, OPTION 4 can be also chosen for TL220 to provide a well built reliable and secure line for future.

8.6 Summary

This section presents rationales for choosing a particular option based on cost benefit analysis.

Although OPTION 1 can only be justified based on cost benefit analysis above, it is also identified that there are other factors that need to be considered in making a rational decision such as public perception with regard to frequent forced outages due to sleet storm damage. It is recommended that the re-conductoring option be considered for the Avalon lines which will provide a substantial improvement of reliability and security that will not necessarily be justified solely by economic considerations.

SECTION 9

9.0 SUMMARY AND CONCLUSIONS

9.1 General

Technical Support Group has carried out a detailed study entitled "Reliability Study of Transmission Lines on the Avalon and Connaigre Peninsulas". The study was primarily based on the past experiences in operating high voltage lines on both peninsulas and analyses of several failures that these lines have experienced since the mid-sixties. The following approach was adopted to carry out the study.

1. An analysis of all major failures of lines on these peninsulas was completed. Analysis shows clearly conductor - hardware assembly and conductor itself are "weak-links" in the system once the design ice load is exceeded.

2. Some samples of wood pole sections and welded eye bolts taken from a failed structure near Western Avalon Station were tested to determine in-service strength. Results showed that wood pole samples did show some reduction in bending strength and considerable reduction with particular reference to the modules of elasticity. However, number of samples taken from failed TL201 line was only three (3). More samples need to be tested before a definite conclusion can be drawn with particular reference to wood pole ageing. Results from the bolt tests clearly showed that one (1) bolt out of four (4) bolts tested, failed at the weld location and dispersion of the strength was quite large. These welded-eye bolts were the primary cause of failure due to overloading and the actual ice loading observed (2.0 inches radial) was well above the original design ice load (1.0 inch radial) during the ice storm of December 8, 1994 on TL201.

3. Review of meteorological data from Airport Stations was carried out based on an earlier Study (Haldar et al, 1988). A projection of extreme ice loadings from St. John's Torbay Airport indicates a 50-year return period load of 1.60 inches (41

mm) radial ice on a one (1) inch diameter conductor due to freezing precipitation. Theoretically there is a 64% chance this loading will be exceeded at least once during the 50-year service life of the line. However, analyzing the line failure data, it appears that actual observed icing on various lines on the Avalon Peninsula ranged from 1.50 ~ 2.0 inches radial with a more realistic return period of 7.5-year to 10-year (refer Table 4.9). Extrapolating this data from the line failure and using an extreme value distribution (Fig. 4.3) probable future loads with various return periods i.e: 10-year, 25-year and 50-year are also projected for all major Avalon lines (Table 4.10). These projected loads appear to be reasonable based on the observed icing that have occurred on the Avalon Peninsula.

4. A comparative analysis based on deterministic (utilization factors in Table 5.5(a) and probabilistic (reliability index, β in Table 5.5(b)) approaches was carried out for all major line segments on the Avalon Peninsula. From these analyses several options were developed for various levels of upgrading to improve line reliability and security for all major lines on the Avalon Peninsula. For TL220, several options were also developed related to major upgrading work and/or building a new section of the line to withstand 2.0 inches (50 mm) radial ice load with a 50-year return period.

5. A section was included to review parameters that affect aeolian vibration and discuss proper protection plan using Stockbridge damper. Work on this area is already on-going and a Capital Budget Proposal was put forward in 1995 to cover various lines on the Avalon and Burin Peninsulas. Funding has been provided for 1996 and a Work Order will be in place in early 1996. Budget will be revised again in 1996 based on this study.

6. A detailed cost study was carried out with various Options defined clearly for all

major lines on the Avalon Peninsula and TL220 on the Connaigre Peninsula. Tables 7.1 and 7.2 show clearly the improvements in both reliability and security (containment against cascading) with regard to various cost alternatives. Similarly, Table 7.3 presents cost data for upgrading TL220 line with particular reference to various alternatives that address advantages and disadvantages of each option.

7. To evaluate various options, a cost-risk analysis was carried out for each alternative and reference Break Even Index (BEI) was used as a guide to aid the decision making process with particular reference to economic choice; however, final decision may not depend only on BEI values, but rather on other issues such as public perception, loss of gross domestic product, loss of revenue on sales, etc.

9.2 Recommended Options for Improving Line Reliability and Security

(a) Avalon Peninsula:

Bulk power is supplied by one (1) steel tower line and one (1) wood pole line. To improve the line reliability and security substantially, both steel and wood lines should be upgraded by re-conductoring with a high strength alloy conductor as discussed in Section 5. This is also summarized in Tables 7.1 and 7.2 under OPTION 3 and OPTION 4 respectively. By re-conductoring and adding strategic anti-cascading structures, both lines should be able to withstand at least a 25-year new design load (2.5 inch radial glaze ice load) and therefore improving the reliability of these lines significantly. However, re-conductoring of wood pole lines (TL203/TL201/TL236) would be simpler and less costly provided the in-service strength of a large number of wood pole structures on these lines is within acceptable limits with particular reference to loss of strength due to ageing. This will require some follow-up work to ensure that the majority of these suspension structures have adequate in-service strength to carry the new design load for at least 25-years. Alternatively, one could also consider the upgrading of steel lines

(TL207/TL237/ TL217/TL218) with new alloy conductor to provide the same reliability and security at a 40% increased higher cost compared to wood pole lines. Upgrading of steel lines with new conductor would be more involved because of moving and/or adding a large number of towers to reduce the ruling span to 800 feet level (currently, typical ruling span is 1300 feet). It is recommended that Hydro implements re-conductoring option for at least one major circuit (steel tower lines) as soon as feasible to ensure a well secured transmission system from Sunnyside to Oxen Pond, in future.

(b) TL220 on the Connaigre Peninsula

Bulk power on the Connaigre Peninsula is supplied through a 69 kV line from Bay d'Espoir to Barachoix Terminal Station. Since this is the only line that supplies power to this peninsula without having any system redundancy, it is extremely important that this line is upgraded including building a new section to ensure that the line has a high degree of reliability and security with regard to its ability to withstand severe wind and ice loads. Several options have been considered and evaluated, and it appears that Options 3, 4 and 5 in Fig. 7.3 should be considered seriously. OPTION 4 appears to be cost-effective when one considers the balance between the initial cost of building a new line and future failure cost. Sections of line between English Harbour station and Barachoix station, requires some selective upgrading work with storm guys on suspension and dead-end structures due to exposures of this line to severe wind loading.

9.3 Recommendations for Further Work

i) During the study, it was observed that there are significant discrepancies between the information provided by Operations and the plan and profile with regard to TL220. Therefore, it is suggested that a full survey of the existing line should be conducted before any upgrading work is pursued. This may also affect the final cost figures for upgrading work.

ii) On TL237, it was observed that in many places, conductor type is not consistent with the original design. Two types of conductors have been spliced in-span thus complicating not only the prediction of actual sag and tension in the segment but also damaging the conductor system with regard to aeolian vibration. This should be corrected to ensure that any conductor installed should be terminated only on dead-end locations.

iii) A database has been created which includes, information on structures, conductors, design loading and digitized plan and profile (approximate) for terrain checking under various loading scenarios. This database should be accurately maintained to avoid any duplication of work in the future.

9.3.1 Technical Work (Follow-Up)

a) Current work on monitoring wind and ice loads on Hawke Hill should continue to collect data for the validation of models. Requirements for long term data is very critical to have any confidences in the model prediction with particular reference to statistical significance. Work should also begin to develop three sites where data can be collected on-line from the energised line. Technology is currently available and when implemented, this would provide some site specific data along the line route and can be correlated with Hawke Hill and Airport data.

b) A pilot project should be initiated to assess the conductor strength near the clamp due to vibration and corrosion, in general. Technology is currently available and a budget proposal on this will be submitted in 1997.

c) A pilot project on wood pole management should be initiated to assess the residual life of many wood pole structures on the Avalon Peninsula. A budget proposal on this will be submitted in 1997.

d) On-going vibration monitoring work should continue and a systematic database should be developed to record all failures related to system vibration problems.

e) Periodic meetings with Operations should be held to exchange information on current problems and their solutions.

SECTION 10

10.0 REFERENCES

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AH/mmcd

①

Failure of HV Transmission Lines Due to Wind and Ice

Eastern Section (Avalon and Burin Peninsulas)

Failure Year	***Line Name***	***Line Length (km)***	***Year in Service***	***Line Voltage***	***Location***	***Length of line failure (km)***	***Cost of Replacement***	***1995 Dollars (Millions)***	***Restoration Work***
Feb, 1970	TL202 (Steel)	140	1966	230 kV	Str.#328-355	11.0	Total ≈ $1,300,000	$3.75	To restore the line to it's original condition.
	TL203 (Wood)	45	1965	230 kV	Str.#81-143	8.0			To restore the line to it's original condition.
	TL206 (Steel)	142	1968	230 kV	Str.#335-346	5.0			To restore the line to it's original condition.
	TL207 (Steel)	8	1968	230 kV	Str.#55-60 & Str.#68-88	9.0			To restore the line to it's original condition.
	TL212 (Aluminum)	139	1966	138 kV	Extensive Damage Str.#21 - 49 Str.#67 - 72 Str.#127 - 143 Str.#149 - 180 Str.#187 - 198 Str.#228 - 232	33.0			Significant number of structures were down and these were replaced with 143 wood pole structures.
April, 1984	TL201 (Wood)	81	1966	230 kV	Str.#114 - 150	6.0	$430,000	$0.55	To restore the line to it's original condition.
	TL217 (Steel)	76	1970	230 kV	Str.#85 - #101	5.0	$560,000	$0.73	To restore the line to it's original condition.

Failure of HV Transmission Lines Due to Wind and Ice

Eastern Section (Avalon and Burin Peninsulas)

Failure Year	Line Name	Line Length (km)	Year In Service	Line Voltage	Location	Length of Line Failure (km)	Cost of Replacement	1995 Dollars (Millions)	Restoration Work
April, 1984	TL218 (Wood)	37	1970	230 kV	Str.#119 - 131	2.0	$250,000	$0.32	To restore the line to its original condition.
	TL236 (Wood)	11	1966	230 kV	Str.#46 - 57		$251,000	$0.33	To restore the line to its original condition.
	TL237 (Steel)	44	1968	230 kV	Str.#75 - 82	2.0	$443,000	$0.57	To restore the line to its original condition.
April, 1988	TL217 (Steel)	76	1970	230 kV	Str.#131 - 135	2.0	$320,000	$0.35	To restore the line to its original condition.
Dec., 1994	TL201 (Wood)	81	1966	230 kV	Near Western Avalon Str.#3 - 9	1.6	$575,000	$0.58	Line was rebuilt with stronger conductors and structures with a greater number of dead-ends.
	TL217 (Steel)	76	1970	230 kV	Str.#4 - 5	-	$25,000	$0.03	To restore the conductor by splicing and changing the clamps

Failure of HV Transmission Lines Due to Wind and Ice

Eastern Section (Avalon & Burin Peninsulas): Follow-up Action Upgrading

W/O	Year	Line Name	Line Voltage	Location	Type of Work	Cost of Upgrading	1995 Dollars (Millions)
5092	1985	TL201/218/236	230 kV	-	To install new guy attachment hardware	$247,200	$0.32
6092 & 7066	1986 & 1987	TL201	230 kV	Str.#134 - 154 Str.#201-210	Upgrading (Mid-Span Strs. & Reconductoring)	$681,000	$0.82
6091 & 7076	1986 & 1987	TL237	230 kV	Str.#73 - 83	Rerouting (Shorter Spans)	$1,019,000	$1.22
0087	1990	TL217/218	230 kV	Str.#90 - 104 Str.#131 - 144	Upgrading (Mid-Span Strs. & Reconductoring)	$4,040,000	$4.16
9074	1990	TL212	138 kV	Entire Line	Upgrading (Adding guys at mid-mast level and replacing hanger plates)	$436,000	$0.45

Failure of HV Transmission Lines Due to Wind and Ice

Central Section

Failure Year	*Line Name*	*Line Length (km)*	*Year In Service*	*Line Voltage*	*Location*	*Length of line failure (km)*	*Cost of Replacement*	*1995 Dollars (Millions)*	*Restoration Work*
March, 1970	TL210 (Wood)	85	1969	138 kV	Str.#151, 153 & 154	-			Installed cross-arms 1 - 4"×10"
January, 1979	TL210 (Wood)	85	1969	138 kV	Str.#152	-			Installed double cross-arms 2 - 4"×10"
March 1979	TL220 (Wood)	48	1970	69 kV	Str.#153	-	-		Structure replaced with double cross-arm
Dec. 1979	TL228 (Steel)	84	1967	230 kV	Str.#73	-			Replaced Str.#73
Nov., 1980	TL210 (Wood)	85	1969	138 kV	Str.#242 & 273	-			Installed double cross-arms 2 - 4"×10"
Dec., 1981	TL210 (Wood)	85	1969	138 kV	Str.#200	-			Installed double cross-arms 2 - 4"×10"
April 1983	TL228 (Steel)	84	1967	230 kV	Str.#90 & 91	-			Replaced with new conductor and re-sagged

Failure of HV Transmission Lines Due to Wind and Ice

Central Section

Failure Year	Line Name	Line Length (km)	Year In Service	Line Voltage	Location	Length of line failure (km)	Cost of Replacement	1995 Dollars (Millions)	Restoration Work
March, 1984	TL210 (Wood)	85	1969	138 kV	Str.# 157 - 172	6.0			Installed double cross-arms; After 1984, all cross-arms were replaced with either single (1) 5"×10" or double (2) 4"×10"
March 1986	TL220 (Wood)	48	1970	69 kV	Str.#122 - 125	1	-		Structure replaced with cross-arm, higher class of pole
Dec. 1987	TL228 (Steel)	84	1967	230 kV	Str.#68 - 75	4.0	$450,000	$0.54	Replaced all SAE Towers with CAC-Towers and new conductor installed. After this, a thorough study was undertaken and TL228 line was upgraded with shorter spans, more D-End structures, new conductor, etc. Study Report #3-2-51
February 1988	TL220 (Wood)	48	1970	69 kV	Str.#121 - 122	-	-		New conductor spliced in between two structures
October 1992	TL220 (Wood)	48	1970	69 kV	Str.#172	-	-		Higher class of poles
January 1995	TL220 (Wood)	48	1970	69 kV	Str.# 152 - 158		$300,000*	$0.30	Higher class of poles & double cross-arms

* Does not include the cost of renting Gas Turbine.

Failure of HV Transmission Lines Due to Wind and Ice

Central Section: Follow-up Action Upgrading

W/O	Year	Line Name	Line Voltage	Location	Type of Work	Cost of Upgrading	1995 Dollars (Millions)
9137	1990	TL228	230 kV	Str.#50 - 111	Addition of mid-span structures	$5,500,000	$5.66

Failure of HV Transmission Lines Due to Wind and Ice

Western Section

Failure Year	Line Name	Line Length (km)	Year in Service	Line Voltage	Location	Length of line failure (km)	Cost of Replacement	1995 Dollars (Millions)	Restoration Work
1967-71	TL228 (Wood)	84.0	1967	230 kV	North Harbour Crossing	Insulator Assembly Failed			Three (3) towers added to reduce the span length
1975	TL209 (Wood/ Steel)	20.0	1971	230 kV	-	-			All welded eye bolts on dead-end structures were replaced with forged eye bolts
1976	TL214 (Aluminum)	122.0	1968	138 kV	Chicknick Brook	Two (2) Towers			
1976	TL233 (Wood)	135	1973	230 kV	-	1			All welded eye bolts on dead-end structures were replaced with forged eye bolt

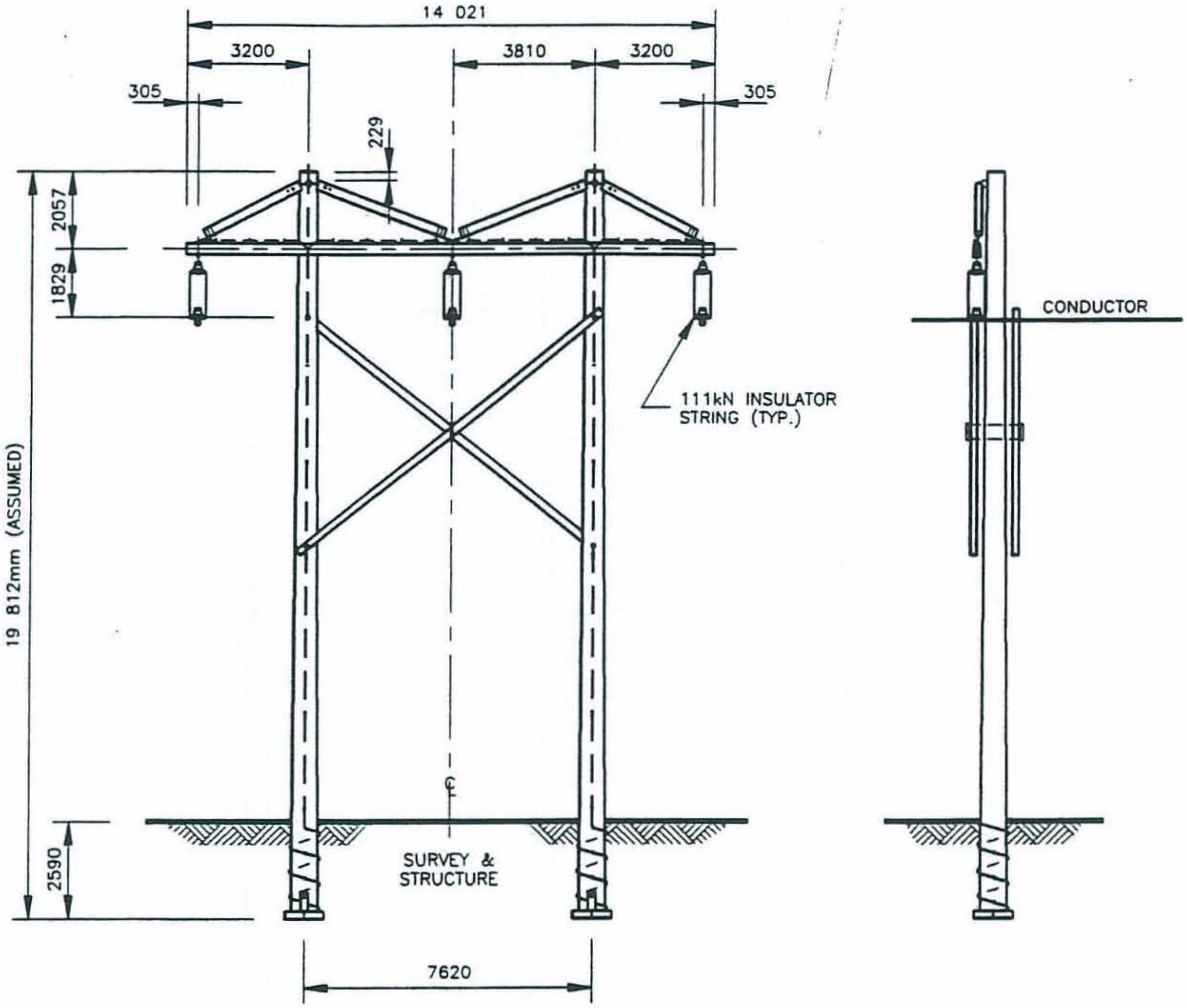
Failure of HV Transmission Lines Due to Wind and Ice

Western Section: Follow-up Action Upgrading

W/O	Year	Line Name	Line Voltage	Location	Type of Work	Cost of Upgrading	1995 Dollars (Millions)
	1981	TL214	138 kV	Entire Line	Adding guys at mid-mast level and replacing hanger plates		
9137	1991	TL228	230 kV	Str.#177-205	Addition of mid-span, dead-end and reconductoring	$3,800,000	$4.0
		TL226 TL227	69 kV		Adding of storm guys, insulator		
		TL221	69 kV		Replacement etc., Str. relocation		
		TL239	138 kV		Replacement of synthetic insulators		
4074	1994	TL214	138 kV	Robinson River	Replacement of Str.#146 Flooded Area	$40,000	$0.04

②

FIGURE A2.1

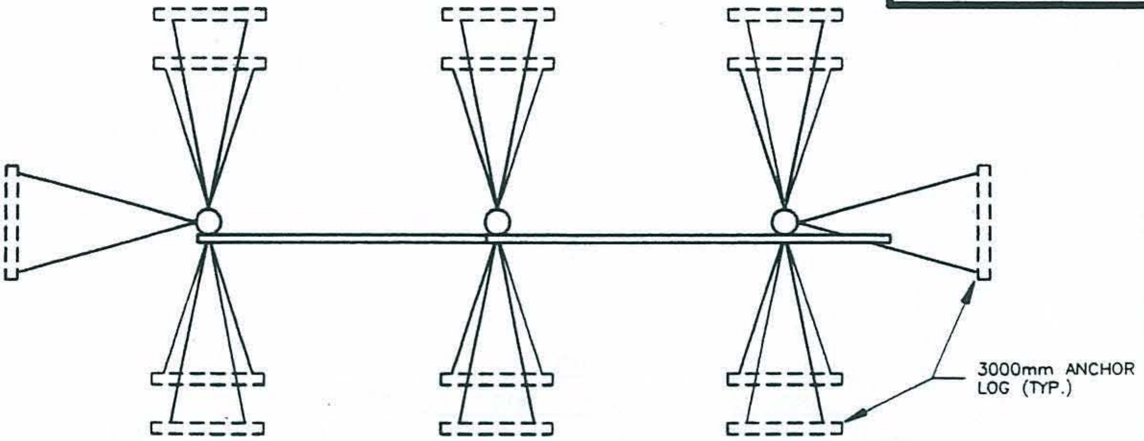


TYPICAL 230kV STRUCTURE TYPE "HA"

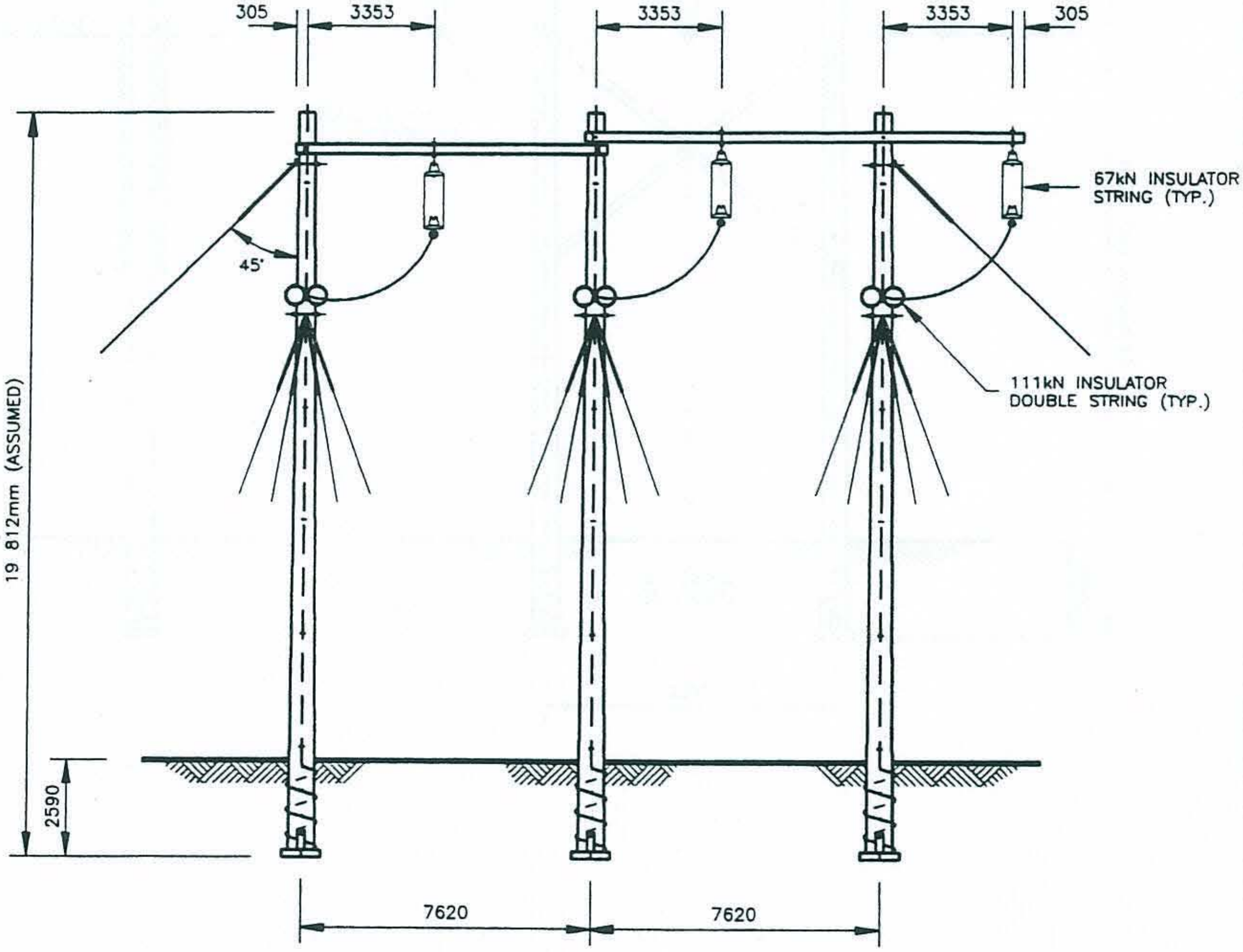
(TANGENT – ICING ZONE – TL203)

SCALE 1:200

FIGURE A2.2



GUYING DIAGRAM

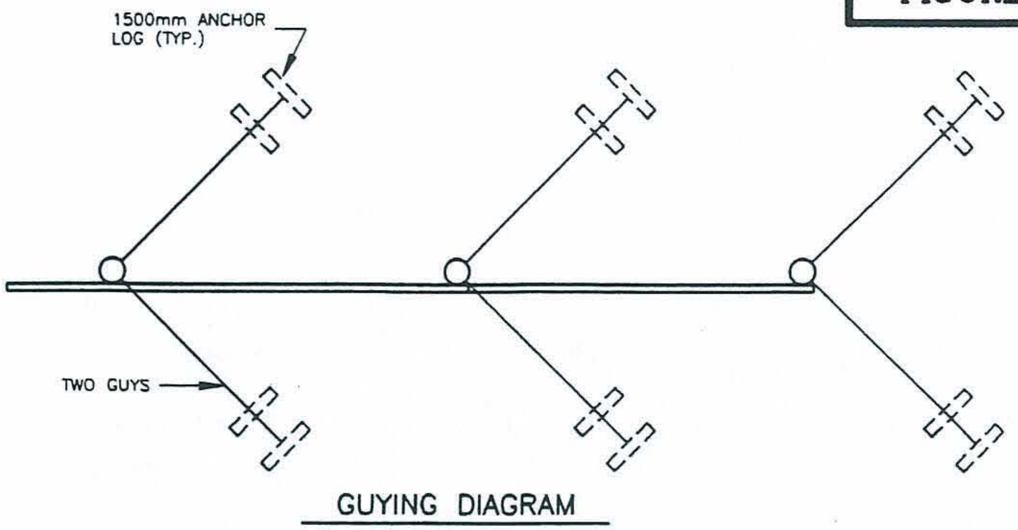


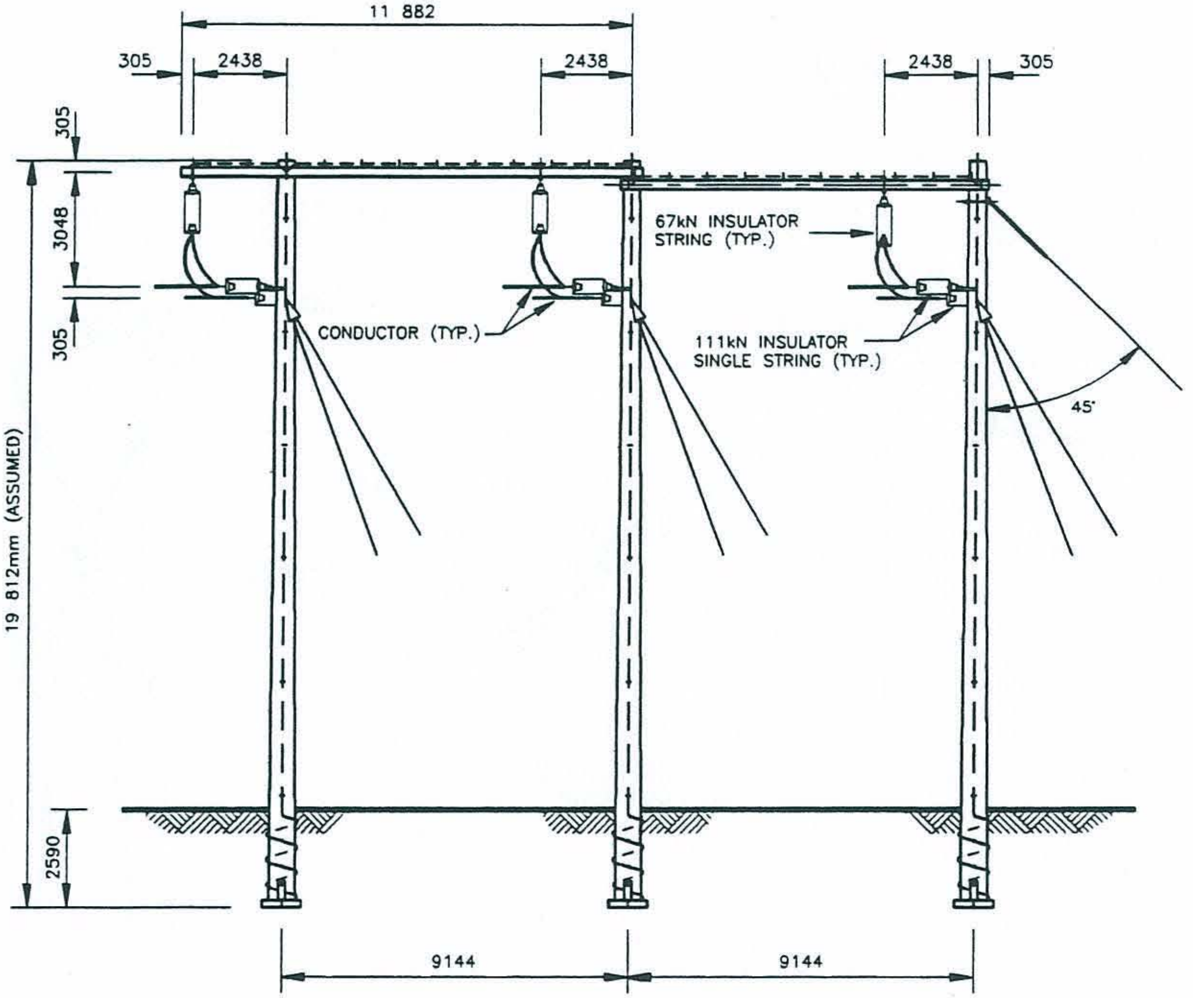
TYPICAL 230kV STRUCTURE TYPE "HD"

(TANGENT DEADEND – ICING ZONE – TL203)

SCALE 1:200

FIGURE A2.3



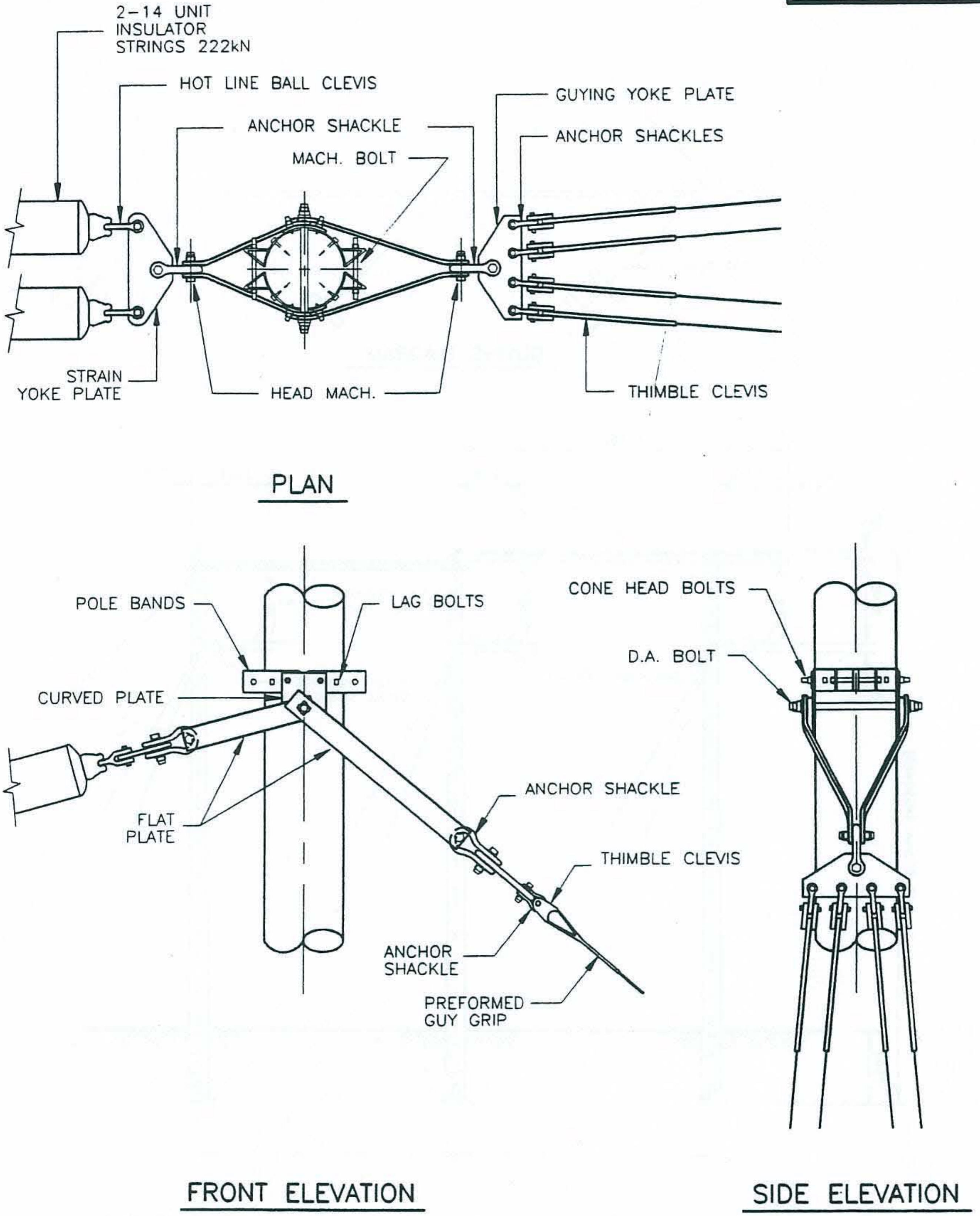


TYPICAL 230kV STRUCTURE TYPE "D"

(ANGLE DEADEND – NORMAL ZONE – TL203)

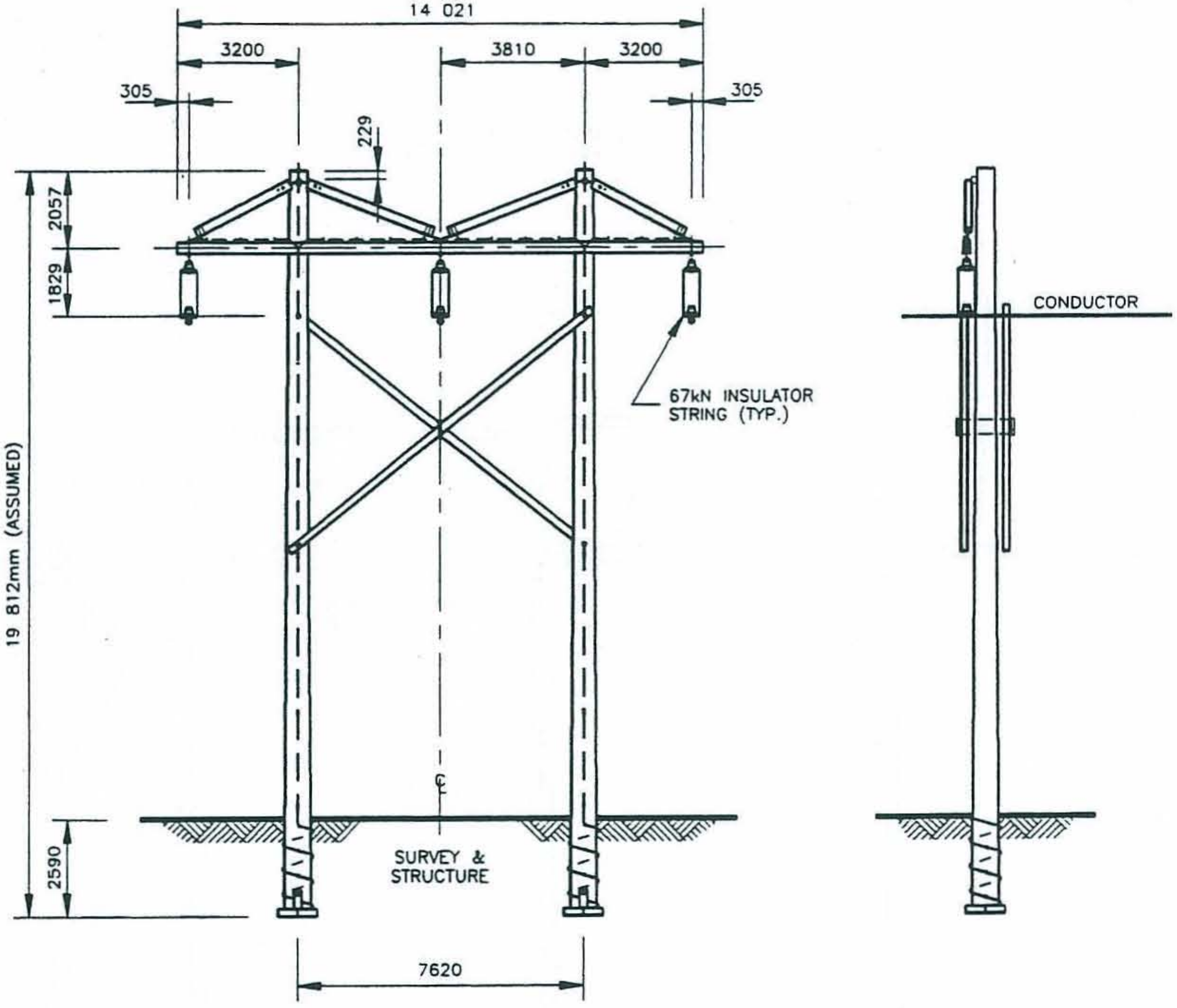
SCALE 1:200

FIGURE A2.4



TYPICAL POLE BAND ASSEMBLY TL203

FIGURE A2.5

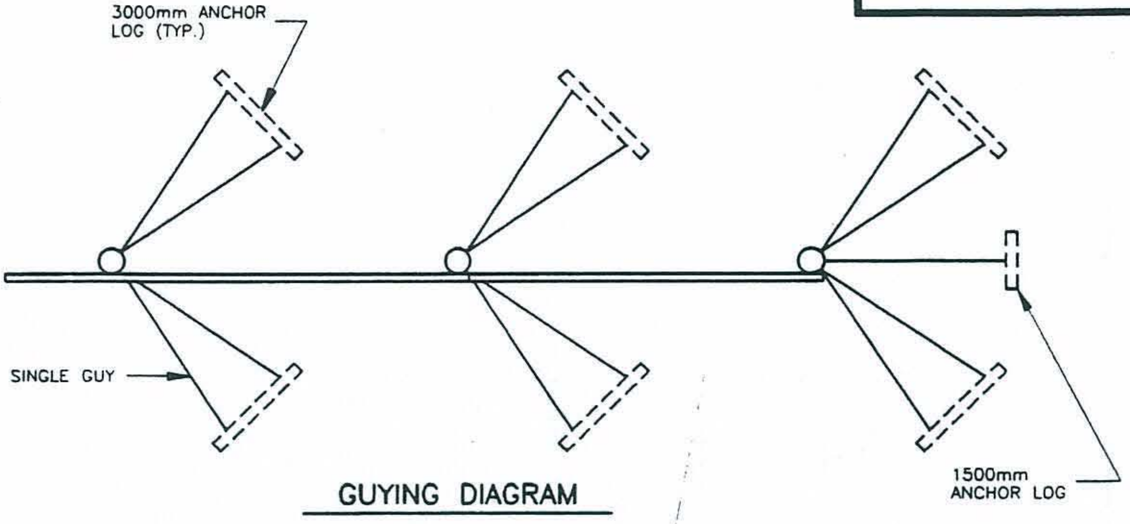


TYPICAL 230kV STRUCTURE TYPE "A"

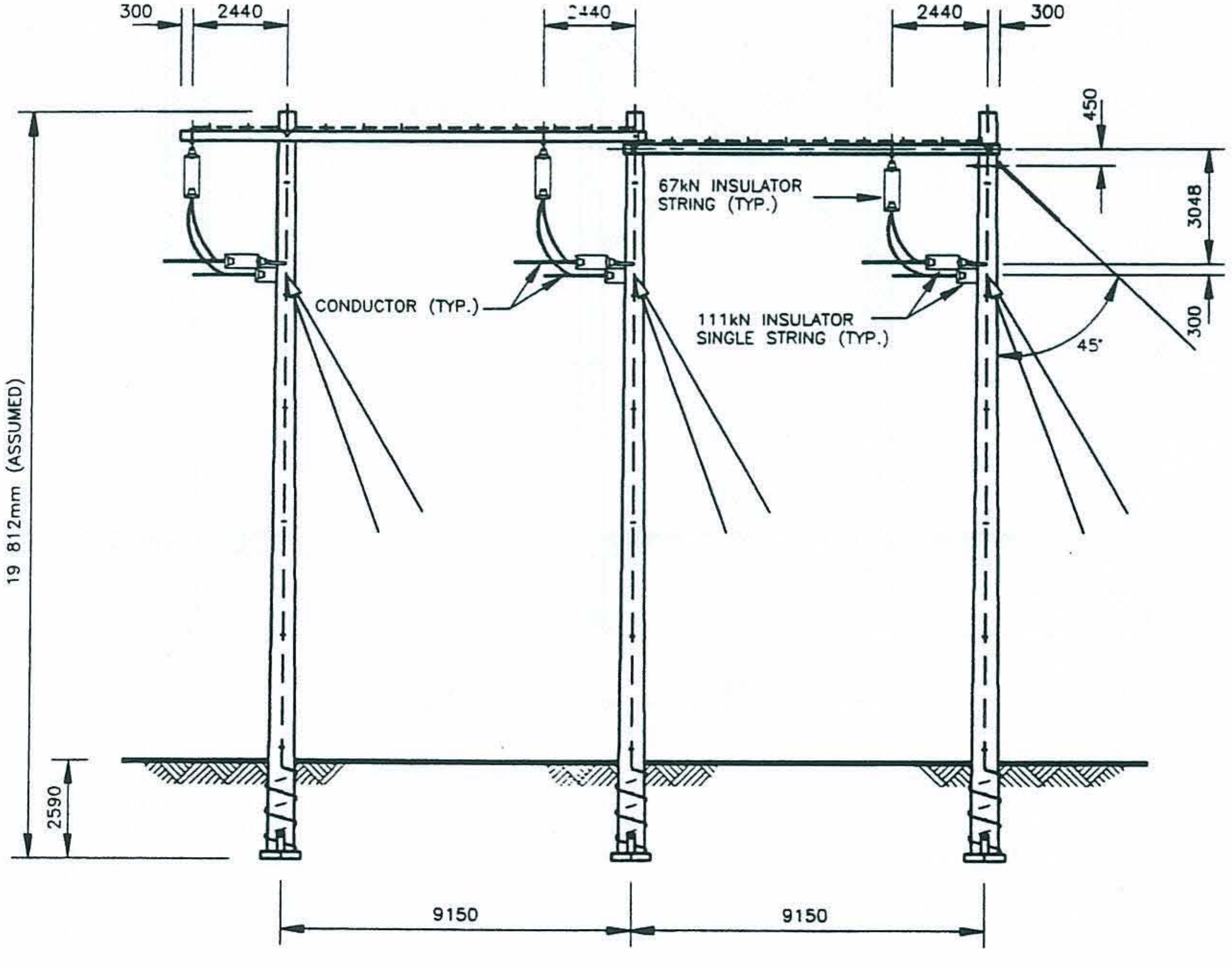
(TANGENT – NORMAL ZONE – TL201 & TL203)

SCALE 1:200

FIGURE A2.6



GUYING DIAGRAM

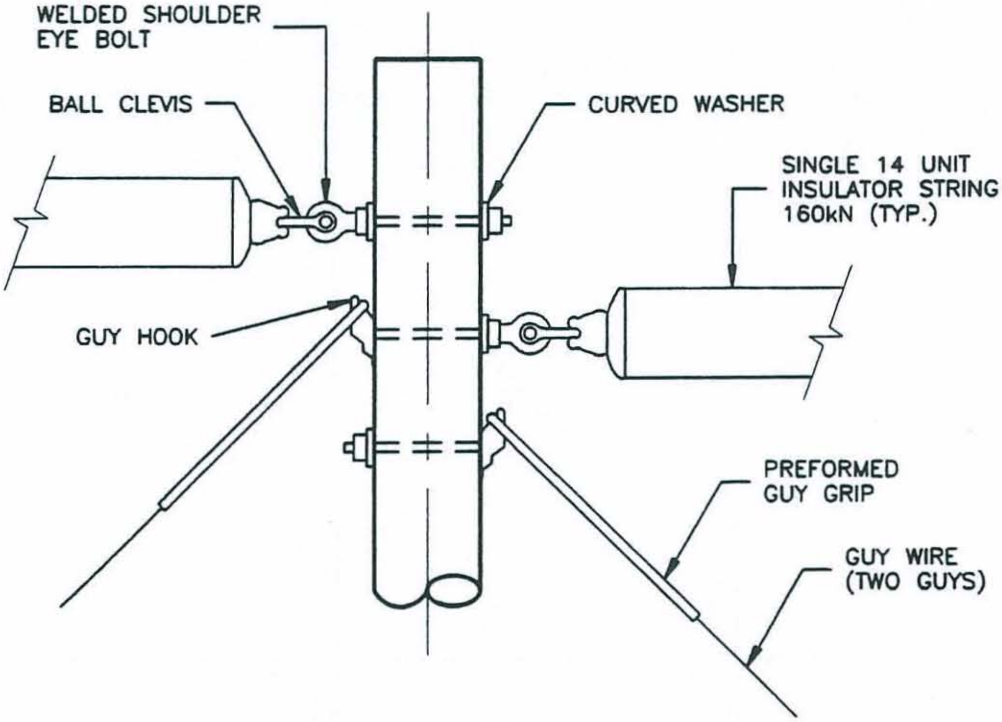


TYPICAL 230kV STRUCTURE TYPE "D"

(ANGLE DEADEND – NORMAL ZONE – TL201)

SCALE 1:200

FIGURE A2.7

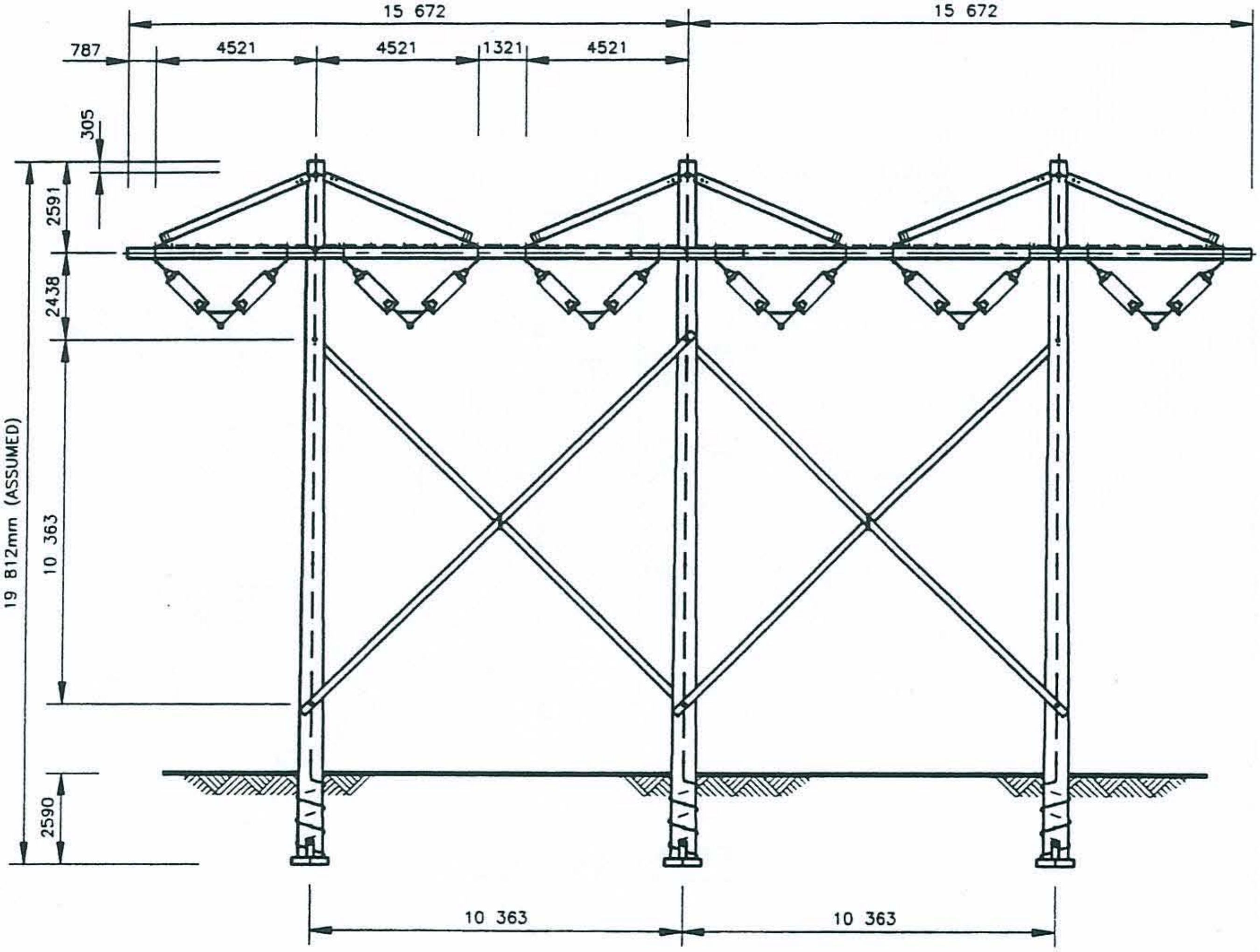


FRONT ELEVATION

230kV TANGENT DEADEND ARRANGEMENT

(ORIGINAL DESIGN)

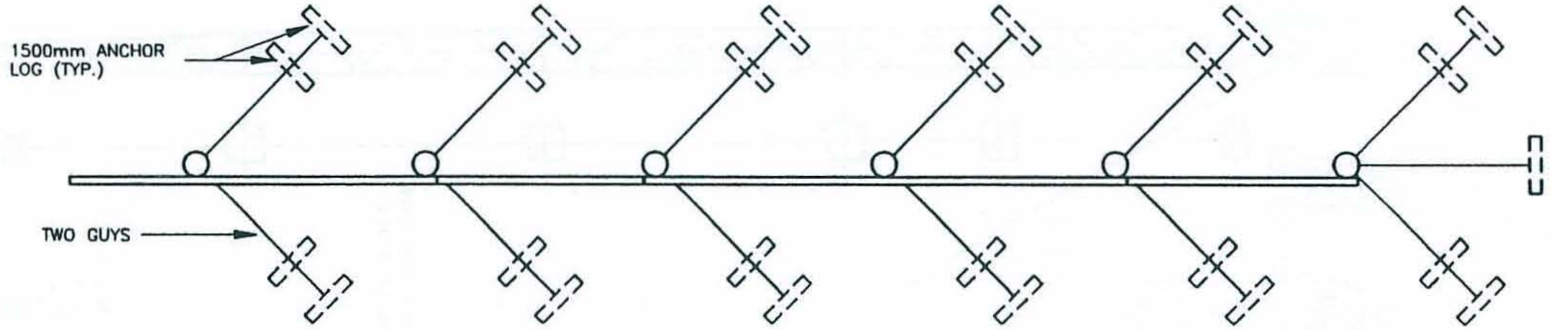
FIGURE A2.8



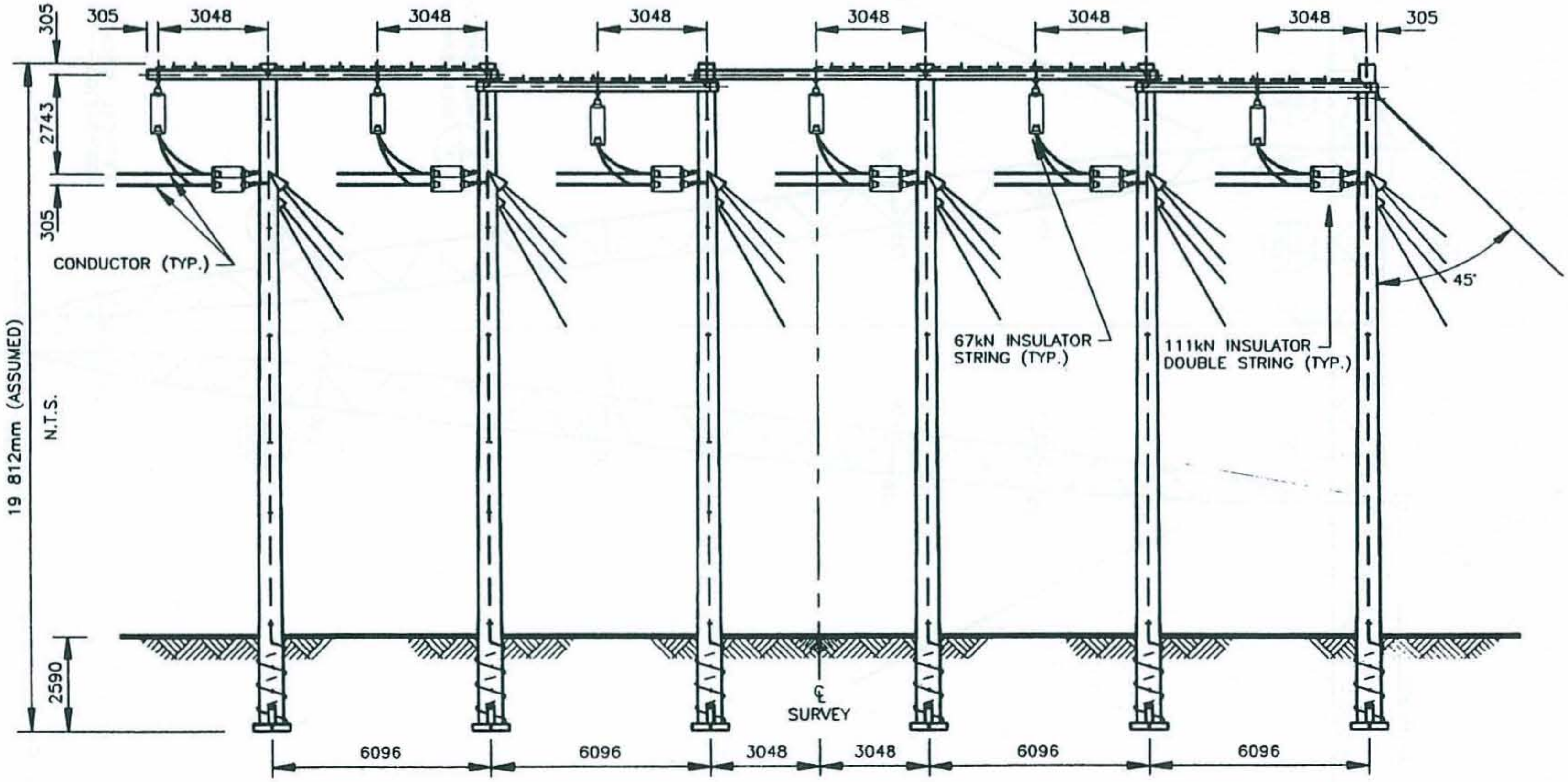
TYPICAL 230kV DOUBLE CIRCUIT STRUCTURE TYPE "DA"

(TANGENT)

SCALE 1:200



GUYING DIAGRAM



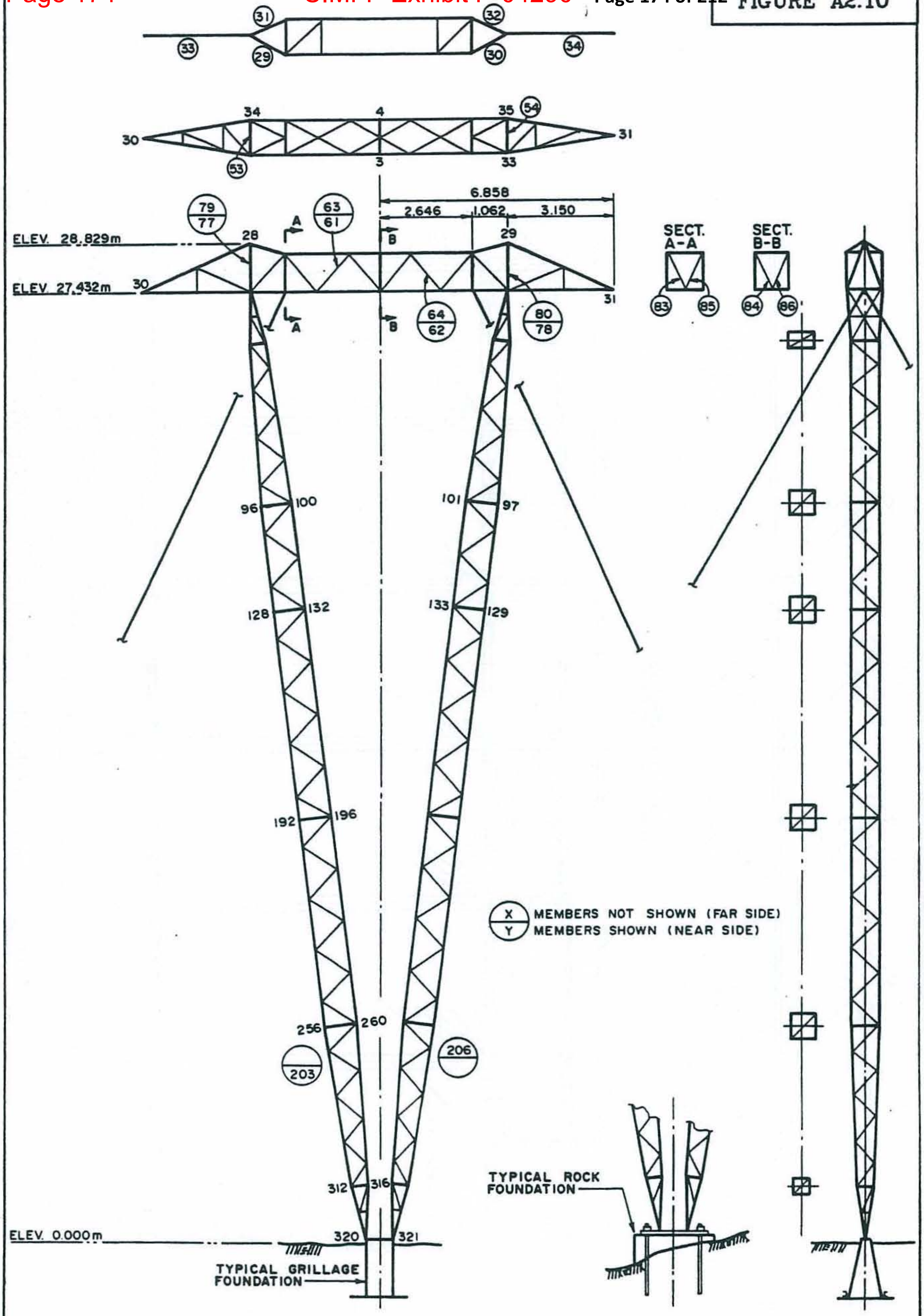
TYPICAL 230kV DOUBLE CIRCUIT STRUCTURE TYPE "DD"

(TANGENT/ANGLE DEADEND)

SCALE 1:200

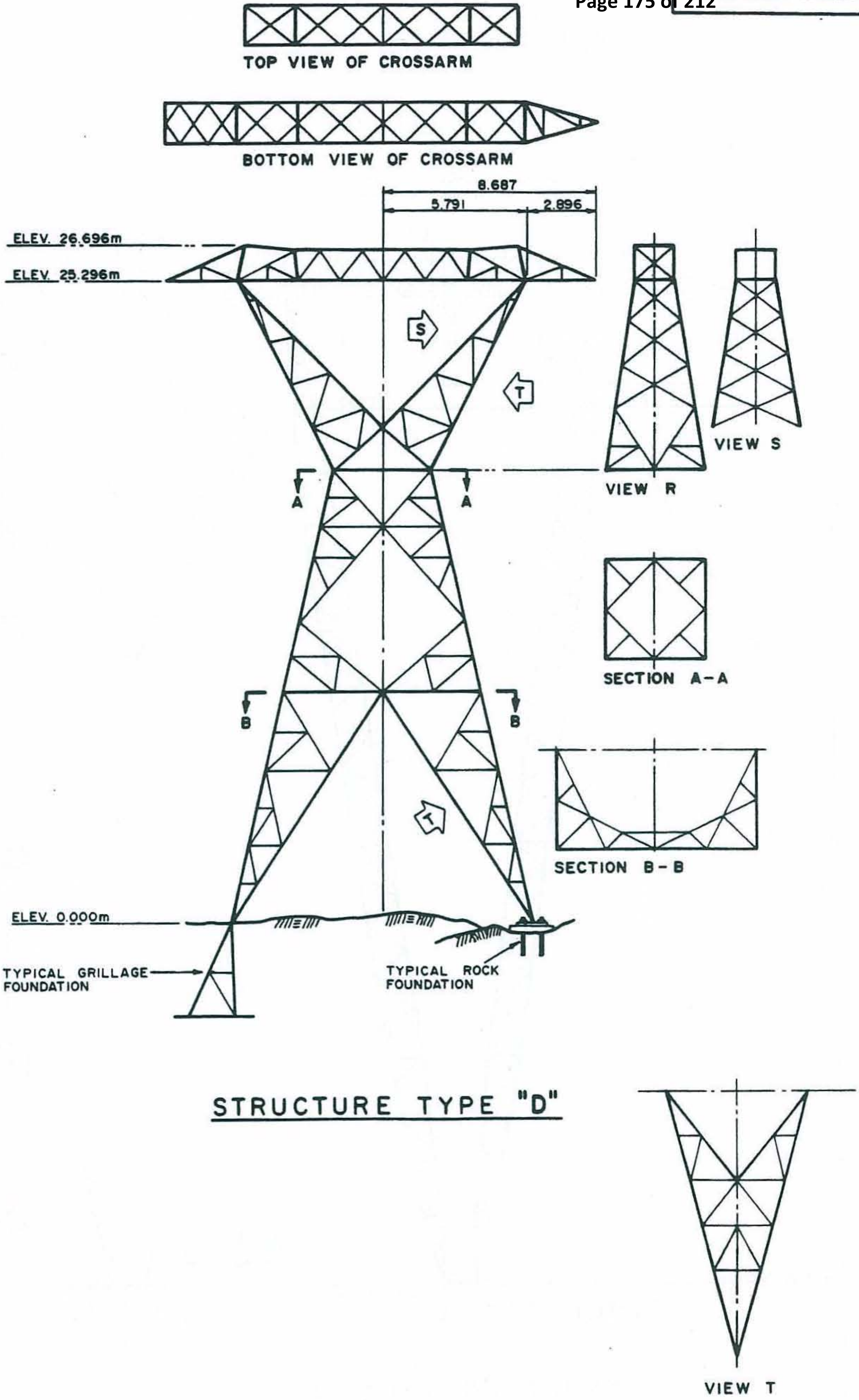
FIGURE A2.9

FIGURE A2.10



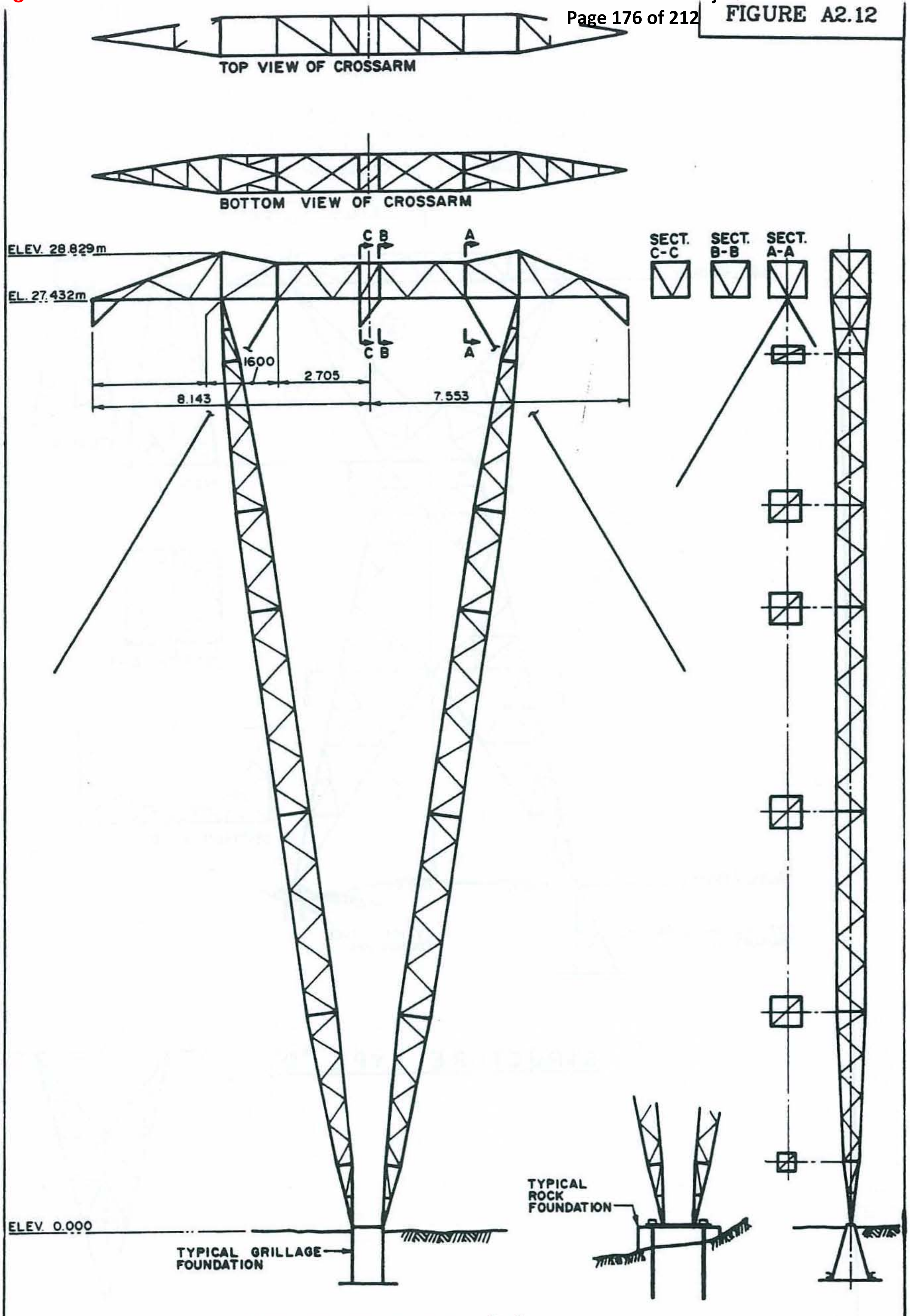
STRUCTURE TYPE "A"

FIGURE A2.11



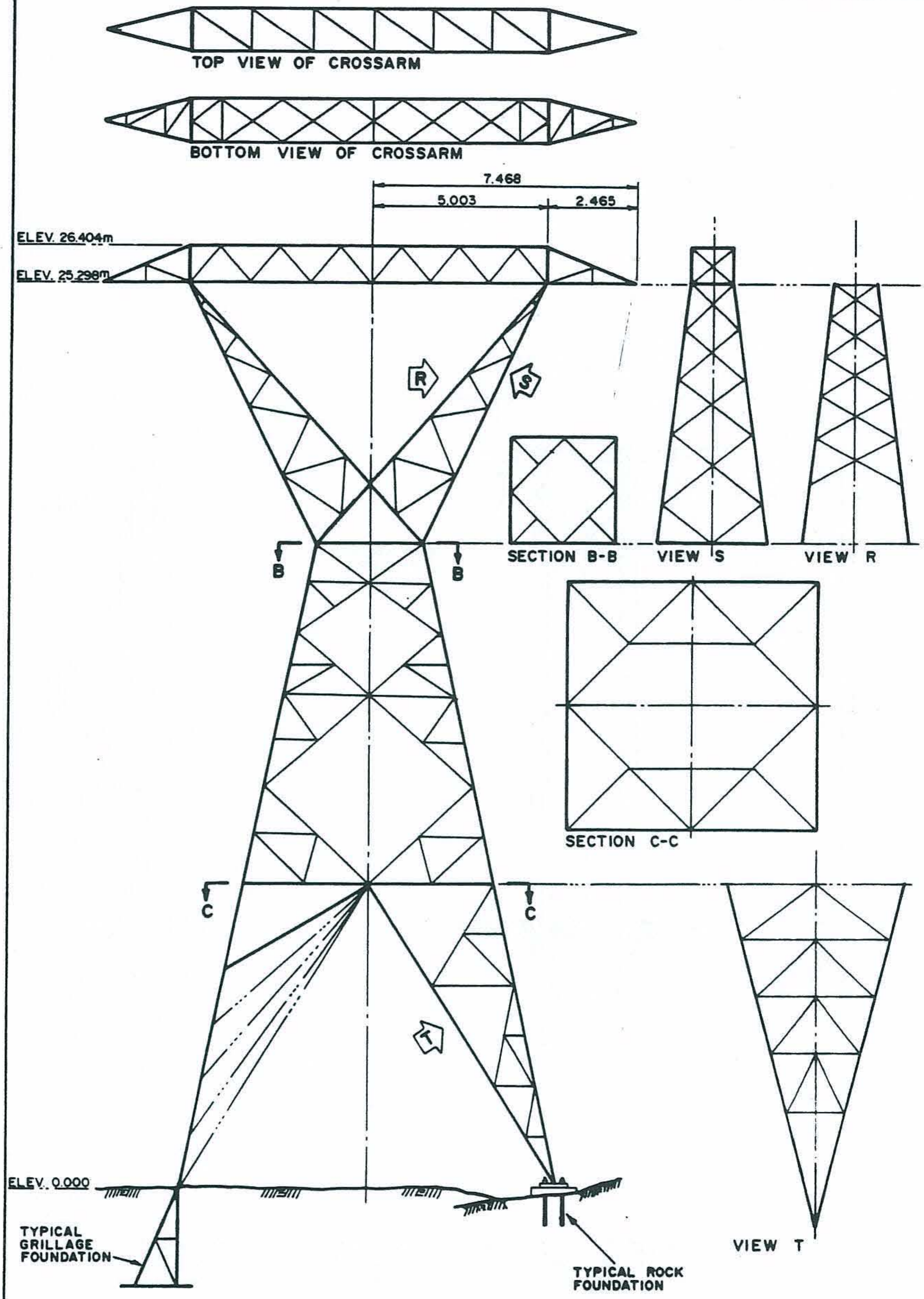
STRUCTURE TYPE "D"

FIGURE A2.12



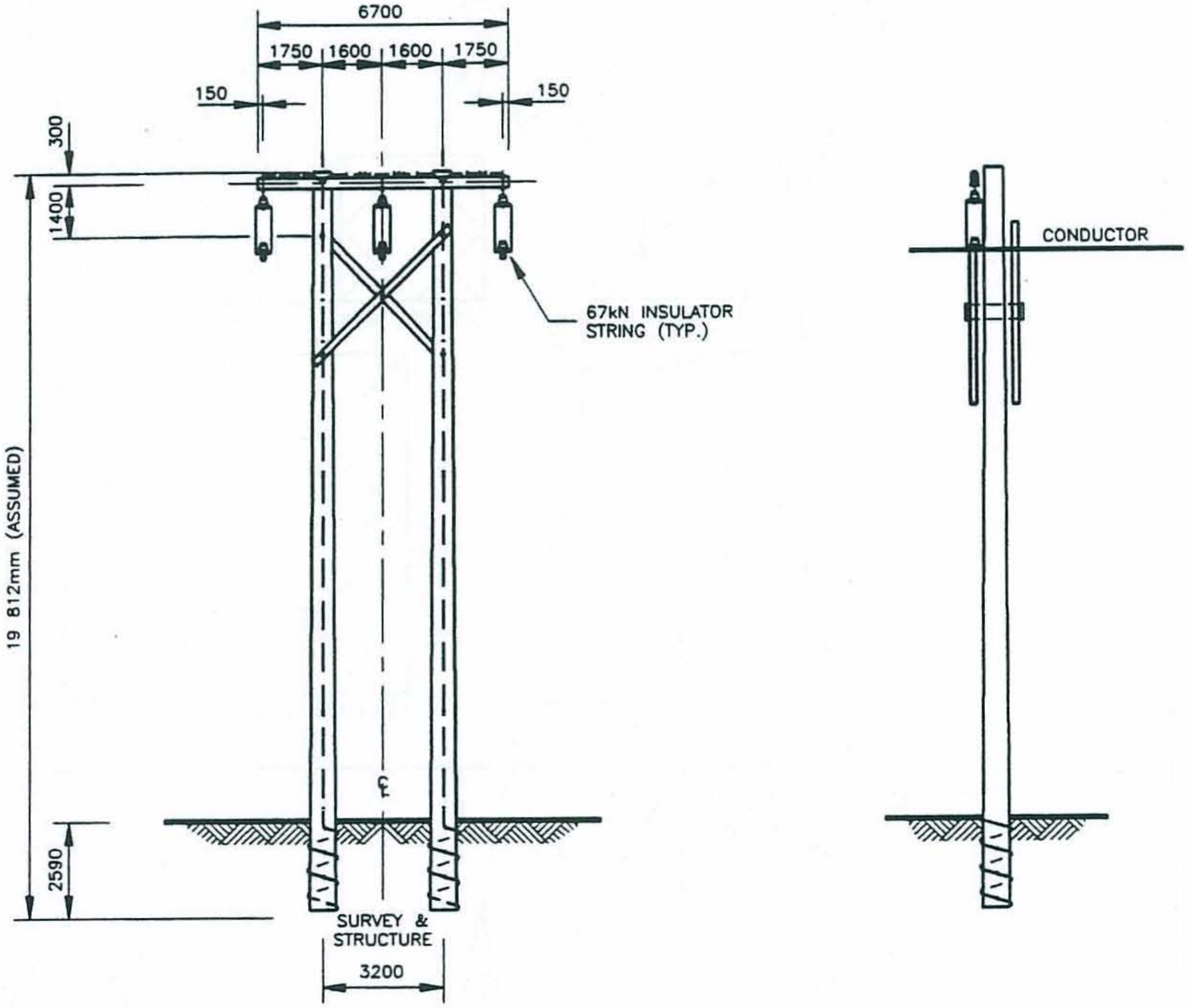
STRUCTURE TYPE "B"

FIGURE A2.13



STRUCTURE TYPE "C"

FIGURE A2.14

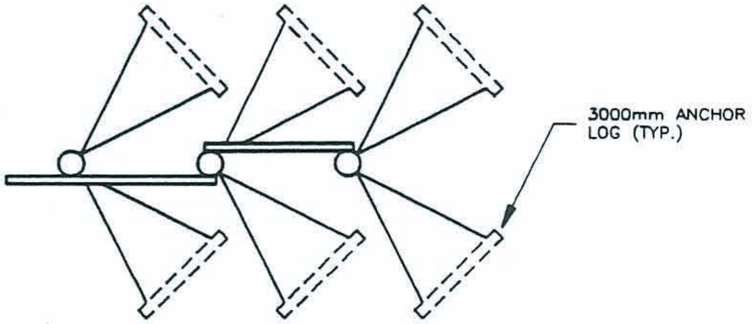


STANDARD 69kV STRUCTURE TYPE "A"

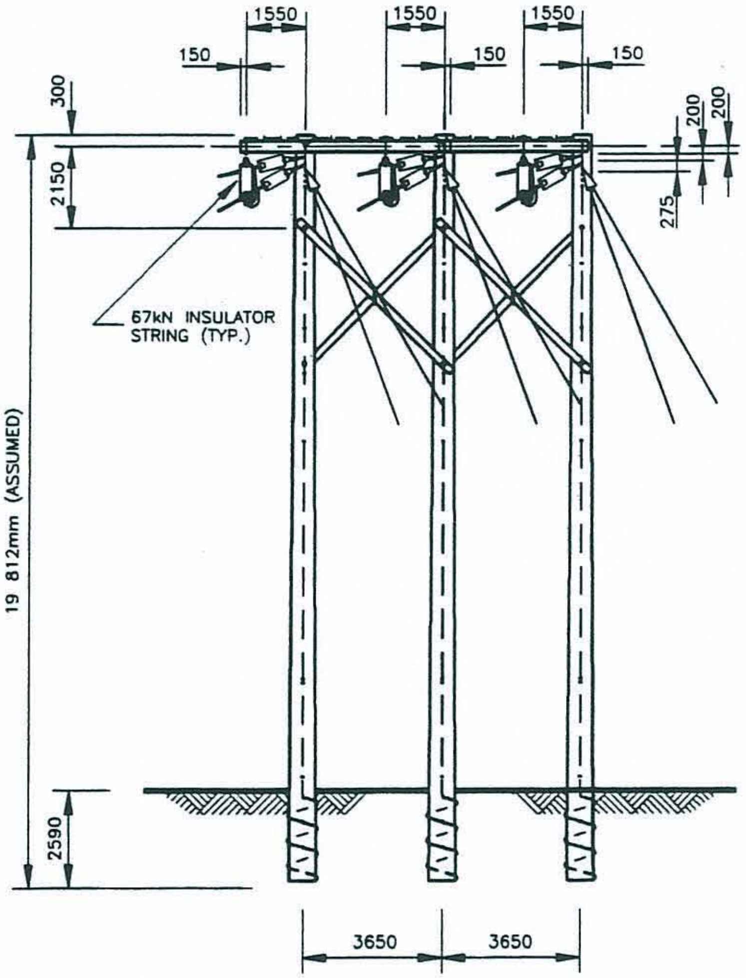
(TANGENT)

SCALE 1:200

FIGURE A2.15



GUYING DIAGRAM



STANDARD 69kV STRUCTURE TYPE "E"

(ANGLE/TANGENT DEADEND)

SCALE 1:200

③

④

Appendix 4

From Extreme Value Distribution,

$$X_T = \mu_X' + K(T)\,\sigma_X'$$

Where:

X_T = Predicted value with a T-year return period

μ_X' = Mean value

σ_X' = Standard deviation

$K(T) = [(-6^{1/2}/\Pi)\ \ (0.5772 + \ln(\ln(T/T-1)))]$

After some manipulation,

$$X_T = X_{50}\,[\,1 - 0.7797\,(3.902 + \ln(\ln(T/T-1)))\,Y\,]$$

Where:

$Y = \sigma_X' / X_{50}$

X_{50} = 50 - year Return Period value of X

To the extent that Y is known and constant over a large area, and assuming the value of X_{50} is known either based on model prediction or observed failure value. Equation above can then be used to generate any T-year return period estimates of X;

Similar equations can also be generated for other known T-year event (e.g. 7.5, 10, 15 and 20-year) provided corresponding values of $Y = \sigma_X' / X_{7.5}$, σ_X' / X_{10}, σ_X' / X_{15} and σ_X' / X_{20} are also known or reasonably assumed. AES has published value of $Y = \sigma_X' / X_{50}$ as 0.266 and this value has been adjusted for other return period value in deriving the following equation:

$$X_T = X_{10} \left[1 - 0.7797 \left(2.2504 + \ln(\ln(T/T\text{-}1))\right) Y \right]$$

$$X_T = X_{15} \left[1 - 0.7797 \left(2.6738 + \ln(\ln(T/T\text{-}1))\right) Y \right]$$

$$X_T = X_{20} \left[1 - 0.7797 \left(2.9702 + \ln(\ln(T/T\text{-}1))\right) Y \right]$$

and $$X_T = X_{7.5} \left[1 - 0.7797 \left(1.9442 + \ln(\ln(T/T\text{-}1))\right) Y \right]$$

Values of ice thicknesses are estimated form various known failure rates and 10-year, 15-year, 20-year and 50-year return period values are then generated from the above equations and are shown in Table 4.8. Return period of an event, T can also be calculated knowing the values of X_T and X_{20} ; For example, if $X_{20} = 2.0$ inches of glaze ice thickness, and we want to find out the return period of encountering a $X_T = 1.0$ inch ice thickness will be approximately 3.65 years. These values are also shown in Table 4.9.

```
RTNPD SERVICE   0-STORM    1-STORM    2-STORM    3-STORM    4-STORM    5-STORM    6-STORM
 7.52   1.00    0.87547    0.12453    0.00810    0.00036    0.00001    0.00000    0.00000
 7.52   5.00    0.51427    0.48573    0.14373    0.03002    0.00482    0.00063    0.00007
 7.52  10.00    0.26448    0.73552    0.38377    0.14985    0.04615    0.01167    0.00249
 7.52  15.00    0.13601    0.86399    0.59264    0.32197    0.14198    0.05220    0.01638
 7.52  20.00    0.06995    0.93005    0.74399    0.49653    0.27711    0.13120    0.05357
 7.52  25.00    0.03597    0.96403    0.84442    0.64557    0.42518    0.24198    0.12015
 7.52  30.00    0.01850    0.98150    0.90769    0.76043    0.56457    0.36921    0.21331
 7.52  40.00    0.00489    0.99511    0.96908    0.89984    0.77706    0.61376    0.44000
 7.52  50.00    0.00129    0.99871    0.99010    0.96149    0.89806    0.79262    0.65238

RTNPD SERVICE   0-STORM    1-STORM    2-STORM    3-STORM    4-STORM    5-STORM    6-STORM
10.00   1.00    0.90484    0.09516    0.00468    0.00015    0.00000    0.00000    0.00000
10.00   5.00    0.60653    0.39347    0.09020    0.01439    0.00175    0.00017    0.00001
10.00  10.00    0.36788    0.63212    0.26424    0.08030    0.01899    0.00366    0.00059
10.00  15.00    0.22313    0.77687    0.44217    0.19115    0.06564    0.01858    0.00446
10.00  20.00    0.13534    0.86466    0.59399    0.32332    0.14288    0.05265    0.01656
10.00  25.00    0.08209    0.91791    0.71270    0.45619    0.24242    0.10882    0.04202
10.00  30.00    0.04979    0.95021    0.80085    0.57681    0.35277    0.18474    0.08392
10.00  40.00    0.01832    0.98168    0.90842    0.76190    0.56653    0.37116    0.21487
10.00  50.00    0.00674    0.99326    0.95957    0.87535    0.73497    0.55951    0.38404

RTNPD SERVICE   0-STORM    1-STORM    2-STORM    3-STORM    4-STORM    5-STORM    6-STORM
14.99   1.00    0.93548    0.06452    0.00213    0.00005    0.00000    0.00000    0.00000
14.99   5.00    0.71641    0.28359    0.04466    0.00482    0.00040    0.00003    0.00000
14.99  10.00    0.51325    0.48675    0.14442    0.03025    0.00487    0.00063    0.00007
14.99  15.00    0.36770    0.63230    0.26443    0.08039    0.01902    0.00367    0.00060
14.99  20.00    0.26342    0.73658    0.38517    0.15079    0.04656    0.01181    0.00253
14.99  25.00    0.18872    0.81128    0.49659    0.23422    0.08839    0.02759    0.00732
14.99  30.00    0.13520    0.86480    0.59426    0.32359    0.14306    0.05274    0.01660
14.99  40.00    0.06939    0.93061    0.74547    0.49850    0.27887    0.13237    0.05420
14.99  50.00    0.03561    0.96439    0.84561    0.64755    0.42738    0.24381    0.12137

RTNPD SERVICE   0-STORM    1-STORM    2-STORM    3-STORM    4-STORM    5-STORM    6-STORM
30.30   1.00    0.96754    0.03246    0.00053    0.00001    0.00000    0.00000    0.00000
30.30   5.00    0.84789    0.15211    0.01220    0.00066    0.00003    0.00000    0.00000
30.30  10.00    0.71892    0.28108    0.04383    0.00469    0.00038    0.00002    0.00000
30.30  15.00    0.60957    0.39043    0.08869    0.01401    0.00169    0.00016    0.00001
30.30  20.00    0.51685    0.48315    0.14203    0.02946    0.00469    0.00060    0.00007
30.30  25.00    0.43823    0.56177    0.20022    0.05108    0.01007    0.00161    0.00022
30.30  30.00    0.37158    0.62842    0.26056    0.07847    0.01838    0.00351    0.00056
30.30  40.00    0.26714    0.73286    0.38025    0.14752    0.04512    0.01133    0.00240
30.30  50.00    0.19205    0.80795    0.49107    0.22964    0.08585    0.02654    0.00697

RTNPD SERVICE   0-STORM    1-STORM    2-STORM    3-STORM    4-STORM    5-STORM    6-STORM
25.00   1.00    0.96079    0.03921    0.00078    0.00001    0.00000    0.00000    0.00000
25.00   5.00    0.81873    0.18127    0.01752    0.00115    0.00006    0.00000    0.00000
25.00  10.00    0.67032    0.32968    0.06155    0.00793    0.00078    0.00006    0.00000
25.00  15.00    0.54881    0.45119    0.12190    0.02312    0.00336    0.00039    0.00004
25.00  20.00    0.44933    0.55067    0.19121    0.04742    0.00908    0.00141    0.00018
25.00  25.00    0.36788    0.63212    0.26424    0.08030    0.01899    0.00366    0.00059
25.00  30.00    0.30119    0.69881    0.33737    0.12051    0.03377    0.00775    0.00150
25.00  40.00    0.20190    0.79810    0.47507    0.21664    0.07881    0.02368    0.00604
25.00  50.00    0.13534    0.86466    0.59399    0.32332    0.14288    0.05265    0.01656
```

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50.00  1.00    0.98020    0.01980    0.00020    0.00000    0.00000    0.00000    0.00000
50.00  5.00    0.90484    0.09516    0.00468    0.00015    0.00000    0.00000    0.00000
50.00 10.00    0.81873    0.18127    0.01752    0.00115    0.00006    0.00000    0.00000
50.00 15.00    0.74082    0.25918    0.03694    0.00360    0.00027    0.00002    0.00000
50.00 20.00    0.67032    0.32968    0.06155    0.00793    0.00078    0.00006    0.00000
50.00 25.00    0.60653    0.39347    0.09020    0.01439    0.00175    0.00017    0.00001
50.00 30.00    0.54881    0.45119    0.12190    0.02312    0.00336    0.00039    0.00004
50.00 40.00    0.44933    0.55067    0.19121    0.04742    0.00908    0.00141    0.00018
50.00 50.00    0.36788    0.63212    0.26424    0.08030    0.01899    0.00366    0.00059
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⑤

TABLE 5.1

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 203

File Name: E:\AVALON\TL203\203MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (inches)	RATIO MAX. WT. SPAN TO R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	1 TO 2	1.5	1220.00	–	–	636 ACSR, 26/7 RTS = 24953 LB	
	2 TO 13	1.75	923.59	1641.3	1.78		
	13 TO 20	1.75	808.68	1208.0	1.49		
2	20 TO 23	>3.5	923.76	900.5	0.97	562.5 AACSR, 36/19 RTS = 53760 LB	
	23 TO 24	>3.5	490.00	1072.5	2.19		
	24 TO 26	3	1209.50	1100.4	0.91		
	26 TO 31	>3.5	898.00	1050.6	1.17		
	31 TO 33	>3.5	677.72	1284.6	1.90		
	33 TO 35	>3.5	657.95	677.2	1.03		
	35 TO 45	>3.5	840.44	946.9	1.13		
	45 TO 46	>3.5	700.00	595.9	0.85		
	46 TO 54	3.5	936.71	1201.7	1.28		
	54 TO 56	3	1111.77	1378.7	1.24		
	56 TO 58	>3.5	788.23	1346.7	1.71		
	58 TO 59	3	1575.00	636.8	0.40		
	59 TO 60	>3.5	700.00	1177.2	1.68		
	60 TO 63	>3.5	665.00	503.8	0.76		
	63 TO 64	3	1060.00	1378.4	1.30		
	64 TO 66	>3.5	799.00	1102.8	1.38		
	66 TO 79	3	1028.13	1221.1	1.19		
	79 TO 80	3	1020.00	727.8	0.71		
	80 TO 81	3	1198.40	1059.8	0.88		
	81 TO 86	3.5	921.16	1514.7	1.64		
	86 TO 87	3	1050.00	605.5	0.58		
	87 TO 88	3	1040.00	372.6	0.36		
	88 TO 89	>3.5	710.00	1353.6	1.91		
	89 TO 92	>3.5	659.25	1026.1	1.56		
	92 TO 95	>3.5	797.94	835.4	1.05		
	95 TO 98	3.5	890.23	1018.9	1.14		
	98 TO 99	>3.5	880.00	503.8	0.57		
3	99 TO 102	>2.25	616.69	1100.3	1.78	795 ACSR, 26/7 RTS = 31250 LB	
	102 TO 104	2	819.23	736.0	0.90		
	104 TO 105	1.5	1630.00	1296.7	0.80		
	105 TO 106	1.5	1280.00	1093.6	0.85		
4	106 TO 109	>2.50	709.91	580.0	0.82	562.5 AACSR, 36/19 RTS = 53760 LB	Sag Tension program run for 562.5 AACSR, – conductors mixed. 106 to 110 – 562.5 AACSR. 110 to 119 – 795 ACSR. 119 to 124 – 562.5 AACSR. 124 to 126 – 795 ACSR. 126 to 143 – 562.5 AACSR.
	109 TO 112	>2.50	765.52	1279.1	1.67		
	112 TO 134	>2.50	862.77	1173.4	1.36		
	134 TO 135	>2.50	1315.00	1446.9	1.10		
	135 TO 143	>2.50	871.72	1311.8	1.50		
5	143 TO 182	1.75	944.07	1825.5	1.93	636 ACSR, 26/7 RTS = 24953 LB	
	182 TO 183	2.25	595.00	–	–		

TABLE 5.2

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 201

File Name: E:\AVALON\TL201\201MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	1 TO 2					636 ACS4, 26/7 RTS = 24953 LB	This portion of TL 201 at Western Avalon T/S was upgraded in 1994
2	2 TO 3					1192 ACSR, 54/19 RTS = 43100 LB	
	3 TO 5						
	5 TO 6						
	6 TO 9						
3	9 TO 52	1.75	840.62	1425	1.70	636 ACS4, 26/7 RTS = 24953 LB	
	52 TO 53	>2.25	550.00	489	0.89		
	53 TO 124	1.75	850.97	1188	1.40		
	124 TO 134	1.75	885.29	1054	1.19		
	134 TO 139	1.75	852.39	1241	1.46		
	139 TO 140		990.00	990	1.00		
4	140 TO 147A					795 ACSR, 26/7 RTS = 31250 LB	This portion of TL 201 near Brigus Junction was upgraded in 1988
	147A TO 149						
	149 TO 149A						
	149A TO 154A						
5	154A TO 169	1.75	859.6	1030	1.20	636 ACS4, 26/7 RTS = 24953 LB	
	169 TO 177	1.75	821.5	1018	1.24		
	177 TO 200A	1.75	880.8	1583	1.80		
6	200A TO 210					795 ACSR, 26/7 RTS = 31250 LB	This portion of TL 201 near Hawke Hill was upgraded in 1988
7	210 TO 227	2	770.3	869	1.13	636 ACS4, 26/7 RTS = 24953 LB	
	227 TO 297	2	715.7	1117	1.56		
	297 TO 303	2	785.4	1175	1.50		
	303 TO 340	1.75	797.7	1093	1.37		
	340 TO 351	2	709.2	998	1.41		
8	351 TO 353	2	840.37	614	0.73	795 ACSR, 26/7 RTS = 31250 LB	
	353 TO 354	>2.25	300.00	631	2.10		
	354 TO 357	2	893.48	826	0.92		

TABLE 5.3

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 236

File Name: E:\AVALON\TL236\236MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	5 TO 6	>2.25	192.00	362.3	1.89	795 ACSR, 26/7	Double Circuit
	6 TO 11	>2.25	724.23	658.3	0.91	RTS = 31250	Wood Pole Structures
	11 TO 12	>2.25	342.00	503.9	1.47		
	12 TO 15	2.00	833.90	1126.9	1.35		
	15 TO 23	>2.25	761.30	928.1	1.22		
	23 TO 33	>2.25	726.18	852.7	1.17		
	33 TO 37	>2.25	634.43	754.5	1.19		
	37 TO 48	>2.25	701.34	812.8	1.16		
	48 TO 56	>2.25	662.20	972.1	1.47		
	56 TO 57	2.00	889.20	–			
	57						

TABLE 5.4

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 207

File Name: E:\AVALON\TL207\207MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	1 TO 1A		771.00	–	0.00	636 ACSR, 30/19	
	1A TO 1C	>2.0	449.80	635.5	1.41	RTS = 31690	
	1C TO 1E	>2.0	474.25	385.7	0.81		
	1E TO 2	>2.0	531.00	865.7	1.63		
2	2 TO 14	1.75	1195.15	1470.6	1.23		
3	14 TO 17	>2.0	1042.44	1281.8	1.23	795 ACSR, 26/7	
	17 TO 18	>2.0	900.00	937.4	1.04	RTS = 31250	
	18 TO 24	>2.0	1039.78	1151.5	1.11		
	24 TO 26	>2.0	828.80	655.9	0.79		

TABLE 5.5

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 237

File Name: E:\AVALON\TL237\237MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	1 TO 3	2.00	840.82	915.6	1.09	795 ACSR, 26/7 RTS = 31250 LB	
	3 TO 9	1.75	1032.45	1637.1	1.59		
	9 TO 10	2.00	890.00	1034.2	1.16		
	10 TO 13	1.75	1045.02	1320.7	1.26		
2	13 TO 72–1	1.75	1268.39	1681.6	1.33	636 ACSR, 26/7 RTS = 24953 LB SEE REMARKS	Sag Tension program run for 636 ACSR, 26/7 –conductors mixed. 13 to 55 – 636 ACSR, 26/7 55 to 60 – 795 ACSR, 26/7 60 to 68 – 636 ACSR, 26/7 68 to 84 – 795 ACSR, 26/7
3	72–1 TO 78					795 ACSR, 26/7 RTS = 31250 LB	UPGRADED 1988
	78 TO 83						
	83 TO 84						
4	84 TO 123	1.75	1298.91	1621.1	1.25	636 ACSR, 26/7 RTS = 24953 LB SEE REMARKS	Sag Tension program run for 636 ACSR, 26/7 –conductors mixed. 84 to 88 – 795 ACSR, 26/7 88 to 123 – 636 ACSR, 26/7
	123 TO			–			

TABLE 5.6

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 217

File Name: E:\AVALON\TL217\217MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	1 TO 2	>2.25	665.00	637.3	0.96	795 ACSR, 26/7	
	2 TO 4	1.5	1802.25	2566.4	1.42	RTS = 31250	
	4 TO 90	1.75	1256.38	2474.5	1.97		
2	90 TO 104						Upgraded 1990
3	104 TO 112	1.5	1380.16	1766.4	1.28		
	112 TO 117	1.75	1313.38	1801.3	1.37		
	117 TO 130–1	1.75	1306.92	1953.5	1.49		
4	130–1 TO 144						Upgraded 1990
5	144 TO 147	1.75	1198.35	1310.3	1.09		
	147 TO 177	1.75	1310.70	1970.4	1.50		

TABLE 5.7

STRENGTH OF CONDUCTOR FOR VARIOUS ICE LOADINGS – TL 218

File Name: E:\AVALON\TL28\218MAXT

SEG. NO.	STR. NO. TO STR. NO.	RADIAL ICE ALLOWABLE (inches)	RULING SPAN (feet)	MAX. WT. SPAN (feet)	RATIO MAX. WT. SPAN / R/S	CONDUCTOR TYPE & RATED TENSILE STRENGTH	REMARKS
1	32 TO 71	1.75	1283.58	1710.6	1.33	795 ACSR, 26/7	Steel Tower Section
2	71 TO 73	2.00	839.51	660.7	0.79	RTS = 31250	Double Circuit.
	73 TO 74	>2.25	322.00	651.7	2.02		Wood Pole Section
	74 TO 77	2.25	815.68	788.4	0.97		
	77 TO 78	>2.25	114.00	16.26	0.14		
	78 TO 79	>2.25	167.00	–			

6

7

TABLE 7.1

OPTIONS FOR THE UPGRADING OF TL 203
SUNNYSIDE T/S TO WESTERN AVALON T/S.

File Name: E:\AVALON\TL203\203OPTS

OPTION 1	Minimal Upgrading.	
	Welded eyebolts replaced with forged eye bolts.	
	Aeolian vibration corrected	
	Tangent structures added	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$369,840
	COST OF SURVEY	$10,200
	COST OF ENGINEERING & MANAGEMENT @ 12%	$45,605
	CONTINGENCY @ 8%	$34,052
	TOTAL COST	$459,697
OPTION 2	Welded eyebolts replaced with deadend/guying ass'y.	
	Aeolian vibration corrected. (See Note 1)	
	Pole eye plates installed on "B" str.	
	Str's. type "F" & "HF" replaced with standard 3 pole deadend.	
	Selective re-conductoring to eliminate mixed conductors.	
	Anti-cascading structures added.	
	Tangent structures added	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$1,302,450
	COST OF SURVEY	$16,200
	COST OF ENGINEERING & MANAGEMENT @ 12%	$158,238
	CONTINGENCY @ 8%	$118,151
	TOTAL COST	$1,595,039
OPTION 3	Re-conductor with high strength alloy conductor.	
	Welded eyebolts replaced with deadend/guying ass'y.	
	Aeolian vibration corrected. (See Note 1)	
	Str. "B" replaced with 3 pole deadend.	
	Str. type "F" replaced with 3 pole deadend.	
	Existing deadends upgraded to 6 pole deadend.	
	Anti-cascading structures added.	
	Tangent structures added	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$2,173,310
	COST OF SURVEY	$24,600
	COST OF ENGINEERING & MANAGEMENT @ 12%	$263,749
	CONTINGENCY @ 8%	$196,933
	TOTAL COST	$2,658,592
OPTION 4	New line with 1192 ACSR, 54/19 conductor.	
	All structures built to 230kV standards	
	Anti-cascading structures employed.	
	COST OF MATERIAL & ERECTION	$8,562,007
	COST OF SURVEY	$230,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$1,055,041
	CONTINGENCY @ 10%	$984,705
	TOTAL COST	$10,831,753

NOTE 1 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.2

OPTIONS FOR THE UPGRADING OF TL 201
WESTERN AVALON T/S TO HARDWOOD T/S

File Name E:\AVALON\TL201\201OPTS

OPTION 1
Minimal Upgrading.
Welded eyebolts replaced with forged eye botls.
Aeolian vibration corrected. (See Note 1)
Tangent structures added.
Long spans eliminated.
Weight on heavily loaded structures decreased.

COST OF MATERIAL & ERECTION	$1,426,940
COST OF SURVEY	$40,800
COST OF ENGINEERING & MANAGEMENT @ 12%	$176,129
CONTINGENCY @ 8%	$131,510
TOTAL COST	$1,775,379

OPTION 2
Welded eyebolts replaced with deadend/guying assembly.
Aeolian vibration corrected. (See Note 1)
Pole eye plates installed on "B" & "C" str's.
Str. type "F" replaced with standard deadend.
Anti–cascading structures added.
Tangent structures added.
Long spans eliminated.
Weight on heavily loaded structures decreased.

COST OF MATERIAL & ERECTION	$2,479,840
COST OF SURVEY	$54,600
COST OF ENGINEERING & MANAGEMENT @ 12%	$304,133
CONTINGENCY @ 8%	$227,086
TOTAL COST	$3,065,659

OPTION 3
Re–conductor with high strength alloy conductor.
Welded eyebolts replaced with deadend/guying assembly.
Aeolian vibration corrected. (See Note 1)
Str's "B" and "C" replaced with 3 pole deadend.
Str. type "F" replaced with 3 pole deadend.
Existing deadends upgraded to 6 pole.
Anti–cascading structures added.
Tangent structures added.
Long spans eliminated.
Weight on heavily loaded structures decreased.

COST OF MATERIAL & ERECTION	$7,939,900
COST OF SURVEY	$91,200
COST OF ENGINEERING & MANAGEMENT @ 12%	$963,732
CONTINGENCY @ 8%	$719,587
TOTAL COST	$9,714,419

OPTION 4
New line with 1192 ACSR, 54/19 conductor.
All structures built to 230kV standards
Anti–cascading structures employed.

COST OF MATERIAL & ERECTION	$15,504,879
COST OF SURVEY	$410,000
COST OF ENGINEERING & MANAGEMENT @ 12%	$1,909,786
CONTINGENCY @ 10%	$1,782,466
TOTAL COST	$19,607,131

NOTE 1 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.3

OPTIONS FOR THE UPGRADING OF TL 236/218 (DBL. CIR.) HARDWOODS T/S TO OXEN POND T/S

File Name: E:\AVALON\TL236\236OPTS

OPTION 1	Minimal Upgrading.	
	Welded eyebolts replaced with forged eye bolt.	
	Aeolian vibration corrected. (See Note 1)	
	Tangent structures added.	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$166,340
	COST OF SURVEY	$1,200
	COST OF ENGINEERING & MANAGEMENT @ 12%	$20,105
	CONTINGENCY @ 8%	$15,012
	TOTAL COST	$202,657
OPTION 2	Welded eyebolts replaced with guying/deadend ass'y.	
	Aeolian vibration corrected. (See Note 1)	
	Tangent structures added.	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$191,300
	COST OF SURVEY	$1,200
	COST OF ENGINEERING & MANAGEMENT @ 12%	$23,100
	CONTINGENCY @ 8%	$17,248
	TOTAL COST	$232,848
OPTION 3	Re–conductor with high strength alloy conductor.	
	Welded eyebolts replaced with guying/deadend ass'y.	
	Aeolian vibration corrected. (See Note 1)	
	Existing deadends upgraded to 6 pole.	
	Tangent structures added.	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$1,852,800
	COST OF SURVEY	$45,600
	COST OF ENGINEERING & MANAGEMENT @ 12%	$227,808
	CONTINGENCY @ 8%	$170,097
	TOTAL COST	$2,296,305
OPTION 4	New line with 1192 ACSR, 54/19 conductor.	
	All structures built to 230kV standards	
	COST OF MATERIAL & ERECTION	$2,178,972
	COST OF SURVEY	$55,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$268,077
	CONTINGENCY @ 10%	$250,205
	TOTAL COST	$2,752,254

NOTE 1 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.4

OPTIONS FOR THE UPGRADING OF TL 207
SUNNYSIDE T/S TO COME–BY–CHANCE T/S

File Name: E:\AVALON\TL207\207OPTS

OPTION 1	Aeolian vibration corrected. (See Note 1)	–
	COST OF MATERIAL & ERECTION	$0
	COST OF SURVEY	$0
	COST OF ENGINEERING & MANAGEMENT	$0
	CONTINGENCY	$0
	TOTAL COST	$0
OPTION 2	Aeolian vibration corrected. (See Note 1) Tangent structure added. Long spans eliminated.	
	COST OF MATERIAL & ERECTION	$52,364
	COST OF SURVEY	$1,200
	COST OF ENGINEERING & MANAGEMENT @ 12%	$6,428
	CONTINGENCY @ 8%	$4,799
	TOTAL COST	$64,791
OPTION 3	Re–conductor with extra high strength alloy conductor. Aeolian vibration corrected. (See Note 1) Bridge strengthened on existing tower type "A" Anti–cascading structures added. Tangent structures added Long spans eliminated. Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$1,842,304
	COST OF SURVEY	$18,600
	COST OF ENGINEERING & MANAGEMENT @ 12%	$223,308
	CONTINGENCY @ 8%	$166,737
	TOTAL COST	$2,250,949
OPTION 4	New line with 1192 ACSR, 54/19 conductor. All structures built to 230kV standards Anti–cascading structures employed.	
	COST OF MATERIAL & ERECTION	$3,178,659
	COST OF SURVEY	$45,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$386,839
	CONTINGENCY @ 10%	$361,050
	TOTAL COST	$3,971,548

NOTE 1 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.5

OPTIONS FOR THE UPGRADING OF TL 237
COME–BY–CHANCE T/S TO WESTERN AVALON T/S.

File Name: E:\AVALON\TL237\237OPTS

OPTION 1	Aeolian vibration corrected. (See Note 1)	
	COST OF MATERIAL & ERECTION	$0
	COST OF SURVEY	$0
	COST OF ENGINEERING & MANAGEMENT	$0
	CONTINGENCY	$0
	TOTAL COST	$0
OPTION 2	Aeolian vibration corrected. (See Note 1) Anti–cascading structures added. Tangent structures added Long spans eliminated. Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$1,441,436
	COST OF SURVEY	$32,400
	COST OF ENGINEERING & MANAGEMENT @ 12%	$176,860
	CONTINGENCY @ 8%	$132,056
	TOTAL COST	$1,782,752
OPTION 3	Re–conductor with high strength alloy conductor. Aeolian vibration corrected. (See Note 1) Bridge strengthened on existing tower type "A" Anti–cascading structures added. Tangent structures added Long spans eliminated. Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$8,427,548
	COST OF SURVEY	$99,600
	COST OF ENGINEERING & MANAGEMENT @ 12%	$1,023,258
	CONTINGENCY @ 8%	$764,032
	TOTAL COST	$10,314,438
OPTION 4	New line with 1192 ACSR, 54/19 conductor. All structures built to 230kV standards Anti–cascading structures employed.	
	COST OF MATERIAL & ERECTION	$12,522,765
	COST OF SURVEY	$235,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$1,530,932
	CONTINGENCY @ 10%	$1,428,870
	TOTAL COST	$15,717,567

NOTE 1 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.6

OPTIONS FOR THE UPGRADING OF TL 217
WESTERN AVALON T/S TO HOLYROOD T/S

File Name: E:\AVALON\TL217\217OPTS

OPTION 1	Aeolian vibration corrected. (See Note 2)	
	Conductor attachment points improved on existing tower type "C".	
	COST OF MATERIAL & ERECTION	$0
	COST OF SURVEY	$0
	COST OF ENGINEERING & MANAGEMENT	$0
	CONTINGENCY	$0
	TOTAL COST	$0
OPTION 2	Aeolian vibration corrected. (See Note 2)	
	Conductor attachment points improved on existing tower type "C".	
	Anti-cascading structures added.	
	Tangent structures added	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$894,848
	COST OF SURVEY	$13,200
	COST OF ENGINEERING & MANAGEMENT @ 12%	$108,966
	CONTINGENCY @ 8%	$81,361
	TOTAL COST (See Note 1)	$1,098,375
OPTION 3	Re-conductor with high strength alloy conductor.	
	Aeolian vibration corrected. (See Note 2)	
	Bridge strengthened on existing tower type "A"	
	Conductor attachment points improved on existing tower type "C".	
	Anti-cascading structures added.	
	Tangent structures added	
	Long spans eliminated.	
	Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$11,181,740
	COST OF SURVEY	$144,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$1,359,089
	CONTINGENCY @ 8%	$1,014,786
	TOTAL COST (See Note 1)	$13,699,615
OPTION 4	New line with 1192 ACSR, 54/19 conductor.	
	All structures built to 230kV standards.	
	Anti-cascading structures employed.	
	COST OF MATERIAL & ERECTION	$17,269,767
	COST OF SURVEY	$335,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$2,112,572
	CONTINGENCY @ 10%	$1,971,734
	TOTAL COST (See Note 1)	$21,689,073

NOTE 1 The actual upgrading cost estimated for TL 217 is based on only 64.9 km. of transmission line from Western Avalon T/S to the Holyrood tap. The estimated cost for the remaining 11.7 km. is obtained on a pro rata basis. The total length of TL 217 is 76.6 km.

NOTE 2 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.7

OPTIONS FOR THE UPGRADING OF TL 218
HOLYROOD T/S TO OXEN POND T/S

File Name: E:\AVALON\TL218\218OPTS

OPTION 1	Aeolian vibration corrected. (See Note 3)	
	COST OF MATERIAL & ERECTION	$0
	COST OF SURVEY	$0
	COST OF ENGINEERING & MANAGEMENT	$0
	CONTINGENCY	$0
	TOTAL COST	$0
OPTION 2	Aeolian vibration corrected. (See Note 3) Anti–cascading structures added. Tangent structures added Long spans eliminated. Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$359,232
	COST OF SURVEY	$75,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$52,108
	CONTINGENCY @ 8%	$38,907
	TOTAL COST (See Note 1)	$525,247
OPTION 3	Re–conductor with high strength alloy conductor. Aeolian vibration corrected. (See Note 3) Bridge strengthened on existing tower type "A" Anti–cascading structures added. Tangent structures added Long spans eliminated. Weight on heavily loaded structures decreased.	
	COST OF MATERIAL & ERECTION	$3,408,916
	COST OF SURVEY	$45,600
	COST OF ENGINEERING & MANAGEMENT @ 12%	$414,542
	CONTINGENCY @ 8%	$309,525
	TOTAL COST (See Note 1)	$4,178,583
OPTION 4	New line with 1192 ACSR, 54/19 conductor. All structures built to 230kV standards Anti–cascading structures employed.	
	COST OF MATERIAL & ERECTION	$7,781,947
	COST OF SURVEY	$135,000
	COST OF ENGINEERING & MANAGEMENT @ 12%	$950,034
	CONTINGENCY @ 10%	$886,698
	TOTAL COST (See Note 2)	$9,753,679

NOTE 1 The OPTIONS 1, 2, & 3 upgrading cost, estimated for TL 218, is based on 14.3 km. of the steel tower portion of TL 218 runing from the Holyrood tap to str. no. 70. The estimated cost for the remaining 11.1 km. is obtained on a pro rata basis. The total length of the steel tower portion of TL 218 is 25.4 km.

NOTE 2 The OPTION 4 upgrading cost, estimated for TL 218, is based on 26.2 km. of transmission line runing from the Holyrood tap to the Oxen Pond T/S. The estimated cost for the remaining 11.1 km. is obtained on a pro rata basis. The total length of TL 218 is 37.3 km.

NOTE 3 Under OPTIONS 1, 2 and 3, Aeolian vibration protection work will be covered under Newfoundland and Labrador Hydro's on going vibration protection program.

TABLE 7.8

OPTIONS FOR THE UPGRADING OF TL 220
BAY D'ESPOIR T/S TO ENGLISH HARBOUR T/S.

File Name: E:\AVALON\TL220\220OPTS

OPTION 1 Upgrade all deadend structures to 138kV standard.
Install double crossarms to accommodate large weight span.
Re-conductor from Str. 89 to the English Harbour T/S. (17 km.)

COST OF MATERIAL & ERECTION	$2,121,970
COST OF SURVEY	$119,000
COST OF ENGINEERING & MANAGEMENT @ 12%	$268,916
CONTINGENCY @ 8%	$200,791
TOTAL COST	$2,710,677

OPTION 2 Build new 18.8 km. line from Str. 89 to the English Harbour T/S.
Install all structures to current 138kV standard.
String new conductor from Str. 89 to the English Harbour T/S.

COST OF MATERIAL & ERECTION	$2,278,772
COST OF SURVEY	$131,600
COST OF ENGINEERING & MANAGEMENT @ 12%	$289,245
CONTINGENCY @ 10%	$269,962
TOTAL COST	$2,969,579

OPTION 3 Build new 23.7 km. line from Str. 88 to the English Harbour T/S.
Install all structures to current 138kV standard.
String new conductor from Str. 88 to the English Harbour T/S.

COST OF MATERIAL & ERECTION	$2,747,806
COST OF SURVEY	$144,000
COST OF ENGINEERING & MANAGEMENT @ 12%	$347,017
CONTINGENCY @ 10%	$323,882
TOTAL COST	$3,562,705

OPTION 4 Build new 26.7 km. line from Str. 78 to the English Harbour T/S.
Install all structures to current 138kV standard.
String new conductor from Str. 78 to the English Harbour T/S.

COST OF MATERIAL & ERECTION	$3,104,414
COST OF SURVEY	$162,000
COST OF ENGINEERING & MANAGEMENT @ 12%	$391,970
CONTINGENCY @ 10%	$365,838
TOTAL COST	$4,024,222

OPTION 5 Build new 34.6 km. line from Str. 78 to the English Harbour T/S.
Install all structures to current 138kV standard.
String new conductor from Str. 78 to the English Harbour T/S.

COST OF MATERIAL & ERECTION	$4,137,572
COST OF SURVEY	$210,000
COST OF ENGINEERING & MANAGEMENT @ 12%	$521,709
CONTINGENCY @ 10%	$486,928
TOTAL COST	$5,356,209

ESTIMATED COST FOR THE UPGRADING OF TL 220
ENGLISH HARBOUR T/S TO BARACHOIX T/S

File Name: E:\AVALON\TL220\220SOUTH

Add new deadend structures with class 2 poles.
Add new side guys on tangent structures.
Add new longitudinal guy on tangent stuctures.

COST OF MATERIAL & ERECTION	$396,240
COST OF SURVEY	$6,500
COST OF ENGINEERING & MANAGEMENT @ 12%	$48,329
CONTINGENCY @ 8%	$36,086
TOTAL COST	$487,155

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