newfoundland labrador
hydro
a nalcor energy company

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March 3, 2017

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

Attention: Ms. Cheryl Blundon
Director of Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: An Application by Newfoundland and Labrador Hydro (Hydro) for the approval of the of the Refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine Major Overhaul.

Please find enclosed the original and 9 copies of the above-noted Application, plus supporting affidavit, project proposal, and draft order.

Bay d'Espoir Penstock 2

Bay d'Espoir Penstocks 1 and 2 have been in service for 50 years. In 2016, Penstock 1 experienced two weld failures, which led to the refurbishment of 900 m of original penstock weld material. Penstocks 1 and 2 were constructed under the same construction contract, and Hydro is concerned that the weld conditions in Penstock 2 could be similar to that discovered in Penstock 1 and could also experience weld failures. Penstock 2 supplies water to generating Units 3 and 4 at the Bay d'Espoir Generating Station and is essential to the reliable operation of Units 3 and 4. Based on the condition of the welds in Penstock 1, it is anticipated that the welds in Penstock 2 are in a similar deteriorated state and in need of refurbishment. A weld failure in Penstock 2 would result in a loss of 153 MW of generation capacity from the Bay d'Espoir plant, which will result in an unacceptable impact to the generation capacity plan for the Island Interconnected System. Hydro considers the risk of weld failure in Penstock 2 to be too high to delay inspection and refurbishment past 2017. If a weld failure was to result in an open crack in Penstock 2, especially during a winter season, the consequence would be the loss of 153 MW of supply from the Bay d'Espoir plant, affecting generation capacity for the island possibly during a critical time of year. Therefore, Hydro is proposing to refurbish Penstock 2 in 2017 at an estimated cost of $9.1 million and is expected to require eight weeks to complete, resulting in an outage affecting generating Units 3 and 4 at Bay d'Espoir during that time period.

Bay d'Espoir Unit 3
During the annual inspection of Bay d'Espoir Unit 4 turbine, primary turbine seal clearance measurements revealed accelerated reduction in the clearance between the stationary and rotating parts. As a result, Unit 4 was overhauled in 2016 pursuant to a supplemental capital application. Subsequent to that application, Hydro submitted, as part of its 2017 Capital Budget Application Five Year Capital Plan, a plan to complete one major generating unit overhaul annually of Unit 1, Unit 2, Unit 3, Unit 5, Unit 6 and Unit 7, starting with Unit 3 in 2019 and ending with Unit 7 in 2024. Considering Unit 1, Unit 2, Unit 3, Unit 5, and Unit 6 turbines are of similar vintage and design as Unit 4, the units have undergone equivalent protective and corrective maintenance programs, and their existing condition is based on information from Unit 4, Hydro anticipates the condition of these units are similar to that of Unit 4 prior to its 2016 major overhaul. To ensure reliable turbine operation, Hydro decided to advance the timing of each major overhaul in the plan by one year, starting in 2018, and all turbine major overhauls would completed by 2023. Hydro is now proposing to advance the Unit 3 turbine major overhaul such that it coincides with the Penstock 2 Refurbishment project. This will avoid an additional extended outage to Unit 3 for a turbine major overhaul in 2019 and will accelerate Hydro's plan for the remaining Bay d'Espoir turbine major overhauls from 2023 to 2022, with the remaining major overhauls of Units 1, 2, 5, 6 and 7 commencing in 2018 and ending in 2022. The cost of this project is estimated to be $2,361,500.

Should you have any questions, please contact the undersigned.

Yours truly,

Newfoundland & Labrador Hydro

Tracey Pennell

Tracey L. Pennell
Senior Counsel, Regulatory

TLP/bds

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey Stirling Scales
Sheryl Nisenbaum – Praxair Canada Inc.
Dennis Browne, Q.C. – Consumer Advocate
Thomas J. O'Reilly, Q.C. – Cox & Palmer

ecc: Larry Bartlett – Teck Resources Limited

IN THE MATTER OF the *Electrical Power Control Act,* RSNL 1994, Chapter E-5.1 (the *EPCA*) and the *Public Utilities Act*, RSNL 1990, Chapter P-47 (the *Act*), and regulations thereunder;

AND IN THE MATTER OF an Application by Newfoundland and Labrador Hydro for the approval of the Refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine Major Overhaul pursuant to Subsection 41(3) of the *Act*.

TO: The Board of Commissioners of Public Utilities (the Board)

THE APPLICATION OF NEWFOUNDLAND AND LABRADOR HYDRO (Hydro) STATES THAT:

1. Hydro is a corporation continued and existing under the *Hydro Corporation Act, 2007*, is a public utility within the meaning of the Act, and is subject to the provisions of the *Electrical Power Control Act, 1994*.

2. Hydro is the primary generator of electricity in Newfoundland and Labrador. The largest of Hydro's hydro-electric generating stations is located at Bay d'Espoir. The Bay d'Espoir Generating Station (Bay d'Espoir) provides 613 MW of electrical capacity and 2,560 GWH of energy annually to the Island Interconnected System. It consists of four penstocks which supply water to each of the seven generating units.

Bay d'Espoir Penstock 2

3. Bay d'Espoir Penstocks 1 and 2 have been in service for 50 years. Penstock 1 experienced two weld failures in 2016, which led to the refurbishment of 900 m of original penstock weld material using the Allowance for Unforeseen items account.

4. Penstocks 1 and 2 were constructed under the same construction contract, and there is a concern that the weld conditions in Penstock 2 could be similar to that discovered in Penstock 1 and that Penstock 2 could also experience weld failures. Penstock 2 supplies water to generating Units 3 and 4 at the Bay d'Espoir Generating Station. The integrity of this penstock is essential to the reliable operation of Units 3 and 4. Based on the condition of the welds in Penstock 1, it is anticipated that the welds in Penstock 2 are in a similar deteriorated state and in need of refurbishment. A weld failure in Penstock 2 would result in a loss of 153 MW of generation capacity from the Bay d'Espoir plant, which will result in an unacceptable impact to the generation capacity plan for the Island Interconnected System.

5. Hydro has considered keeping Penstock 2 in service until the next capital budget cycle; however, Hydro considered the risk of weld failure in Penstock 2 to be too high to delay inspection and refurbishment past 2017. If a weld failure was to result in an open crack in Penstock 2, especially during a winter season, the consequence would be the loss of 153 MW of supply from the Bay d'Espoir plant, affecting generation capacity for the island possibly during a critical time of year.

6. The scope of work is set out in the engineering report attached as Schedule 1 to this Application.

7. The estimated cost of this project is $9,063.700 and is expected to require eight weeks to complete, resulting in an outage affecting generating Units 3 and 4 at Bay d'Espoir during that time period.

Bay d'Espoir Unit 3

8. In 2016, during the Bay d'Espoir Unit 4 turbine annual inspection, primary turbine seal clearance measurements revealed accelerated reduction in the clearance between the stationary and rotating parts. As a result, Unit 4 was overhauled in 2016 pursuant to a supplemental capital budget application. Subsequent to the supplemental capital budget application for the major overhaul of Unit 4 and prior to the completion of that overhaul, Hydro submitted, as part of its 2017 Capital Budget Application Five Year Capital Plan, activities to complete one major generating unit overhaul annually of Unit 1, Unit 2, Unit 3, Unit 5, Unit 6, and Unit 7 (in successive years). Those activities were to start with Unit 3 in 2019 and be completed in 2024.

9. Considering Unit 1, Unit 2, Unit 3, Unit 5, and Unit 6 turbines are of similar vintage and design as Unit 4, the units have undergone equivalent protective and corrective maintenance programs, and their existing condition is based on information from Unit 4, Hydro anticipates the condition of these units are similar to that of Unit 4 prior to its

2016 major overhaul. To ensure reliable turbine operation, Hydro decided to advance the timing of each major overhaul in the plan by one year, starting in 2018, and all turbine major overhauls would completed by 2023.

10. Hydro is proposing to advance the Unit 3 turbine major overhaul such that it coincides with the Penstock 2 Refurbishment project to avoid an additional extended outage to Unit 3 for a turbine major overhaul and to accelerate its plan for the remaining Bay d'Espoir turbine major overhauls from 2023 to 2022, with the remaining major overhauls of Units 1, 2, 5, 6, and 7 commencing in 2018 and ending in 2022.

11. The scope of work is set out the engineering report attached as Schedule 2 to this Application.

12. The estimated cost of this project is $2,361,500 and, if commenced to coincide with the Refurbishment of Penstock 2, is expected to be completed by the end of August.

Summary

13. The Applicant submits that the proposed refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine are necessary to ensure that the Hydro can continue to provide service which is safe and adequate and just and reasonable as required by Section 37 of the *Act.* Engineering Reports supporting this application are attached.

14. Hydro therefore makes Application for an Order pursuant to section 41(3) of the *Act* approving the Refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine Major Overhaul, at an estimated capital cost of $9,063,700 and $2,361,500, respectively, all as set out in this Application and in the attached project descriptions and justification documents.

DATED at St. John's in the Province of Newfoundland and Labrador this 3rd day of March 2017.

Tracey Pennell

Tracey L. Pennell
Counsel for the Applicant
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Telephone: (709) 778-6671
Facsimile: (709) 737-1782

A REPORT TO
THE BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

<table>
<tr><td rowspan="7">REGISTERED PROFESSIONAL ENGINEER
PEG Newfoundland and Labrador
PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
Carissa M. Sparkes
SIGNATURE
March 3/17
DATE
NEWFOUNDLAND & LABRADOR</td><td>Electrical</td></tr>
<tr><td>Mechanical</td></tr>
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<tr><td>System Planning</td></tr>
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Refurbish Penstock 2

Bay d'Espoir Generating Station

March 3, 2017

newfoundland labrador hydro
a nalcor energy company

Summary

The Bay d'Espoir Hydroelectric Generating Station (Bay d'Espoir) relies on penstocks to supply water to each of the generating units. This proposal outlines a project required to complete a detailed inspection, analysis, and refurbishment of deteriorated welds on Bay d'Espoir's Penstock 2. Penstock 2 supplies water to Units 3 and 4 and is an integral component of the 153 MW of generation from these two units.

Penstock 1 experienced two weld failures in 2016. The first failure was repaired and the penstock was returned to service. After the second failure occurred, a more detailed assessment was undertaken, which led to the refurbishment of approximately 900 m of original penstock weld material.

Penstocks 1 and 2 were constructed in 1967 and have been in service for 50 years. There is a concern that the weld condition in Penstock 2 could be similar to that discovered in Penstock 1, since these penstocks were constructed by the same contractor under the one contract.

A condition assessment of Penstock 2 was completed in June 2016 after the initial weld failure of Penstock 1 in May 2016. There were localized interior coating failures noted with localized corrosion of the penstock steel. The welds were visually inspected in the areas where the coating had delaminated from the penstock metal. Given available information at the time of the Penstock 2 inspection, the welds were not inspected for microscopic cracking. A few months after the Penstock 2 inspection, the deteriorated condition of the welds in Penstock 1 was discovered and the consultant who performed the earlier Penstock 2 inspection recommended that a more detailed weld inspection be completed in Penstock 2 due to the possibility of significant weld deterioration similar to Penstock 1. The detailed inspection requires localized coating removal on the welds as well as weld inspection with specialized equipment.

Since the weld condition in Penstock 2 is considered to be similar to the weld condition in Penstock 1, Hydro has determined that there is a high risk of a Penstock 2 weld failure, significantly reducing Hydro's available capacity for the Island Interconnected System. As a result, Hydro is proposing to complete a detailed weld inspection and stress analysis, as well as refurbish an anticipated 900 m of deteriorated welds, in Penstock 2.

It is estimated that this project will require eight weeks to complete, resulting in an outage affecting generating Units 3 and 4 at Bay d'Espoir during that time period. The budget estimate to complete the Penstock 2 refurbishment is $9,063,700.

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1.0 Introduction

The Bay d'Espoir Hydroelectric Generating Station (Bay d'Espoir) relies on penstocks to supply water to each of the generating units. There are four penstocks that supply water for generation from the Long Pond Reservoir to the Bay d'Espoir Hydroelectric Generating Station, which produces a maximum of 613 MW of peak capacity.

Penstocks 1 and 2 have been in service for 50 years of the typical 80-year life expectancy for a steel penstock. Penstock 1 experienced two weld failures in 2016. The first failure was repaired and the penstock was returned to service. After the second failure occurred a more detailed assessment was undertaken, which led to the refurbishment of 900 m of original penstock weld material.

Penstocks 1 and 2 were constructed under the same construction contract, and there is a concern that the weld conditions in Penstock 2 could be similar to that discovered in Penstock 1. A weld failure in Penstock 2 would result in a loss of 153 MW of generation capacity from the Bay d'Espoir plant, which Hydro determines would result in an unacceptable impact to the generation capacity plan for the Island Interconnected System (IIS).

This report outlines a proposal to complete a detailed inspection, analysis, and refurbishment of welds of Penstock 2.

2.0 Project Description

This project involves the refurbishment of Penstock 2 at the Bay d'Espoir Hydroelectric Generating Station, similar to work executed under the Allowance for Unforeseen Items account completed in the fall of 2016 for Penstock 1, as detailed in the final report contained in Appendix A, submitted to the Board of Commissioners of Public Utilities (the Board) on January 9, 2017.

The scope includes:

- Completion of a Level 2 detailed condition assessment of the welds of Penstock 2;
- Anticipated refurbishment of 900 m of penstock weld based upon Penstock 1 scope; and
- Completion of a stress analysis for Penstock 2 by a specialized consultant.

It is anticipated that the work will be completed during an eight week outage scheduled for May and June 2017, affecting generating Units 3 and 4 at the Bay d'Espoir plant during that time period.

3.0 Justification

Penstock 2 supplies water to generating Units 3 and 4 at the Bay d'Espoir Generating Station. The integrity of this penstock is essential to the reliable operation of Units 3 and 4 and ultimately 153 MW of electricity from these two units.

Based on the condition of the welds in Penstock 1, it is anticipated that the welds in Penstock 2 are in a similar deteriorated state and in need of refurbishment. Hydro has considered keeping Penstock 2 in service until the next capital budget cycle; however, given the potential for weld failure in Penstock 2, delaying inspection and refurbishment past 2017 could result in a reduction of 153 MW of electricity from the IIS.

This project is justified on the requirement to refurbish deteriorated infrastructure in order for Hydro to provide reliable electrical service.

3.1 Existing System

Penstocks 1 and 2 were constructed in 1967 and supply water to Units 1 through 4. Penstock 3 was constructed in 1970 and supplies water to Units 5 and 6 while Penstock 4 was constructed in 1977 and supplies water to Unit 7. See Photo 1 for the layout of the four penstocks as they relate to the reservoir and the hydroelectric plant.

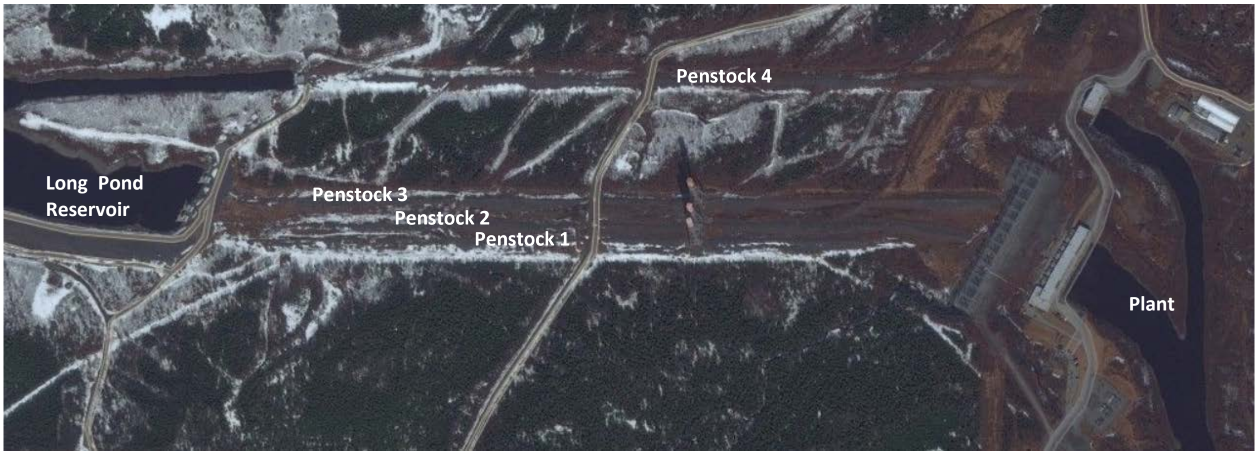

Photo 1: Layout of Penstocks, Reservoir and Plant

The penstocks are designed to handle expected live loads, such as water hammer and water pressure, as well as dead loads, such as the penstock material weight and backfill weight. The thickness of the penstock base plate material is selected as a result of the stresses developed in the steel by these noted loading combinations. Likewise, the welds are designed in a similar manner and must also effectively handle the expected load combinations without failure.

Weld investigations completed of the interior of Penstock 1 in September 2016 revealed corrosion and microscopic cracking concentrated in the weld with less pitting shown in the adjacent base plate material. This weld corrosion and resulting loss of the weld material thickness, as shown in Photo 2, indicate that the remaining weld thickness no longer meets minimum design requirements for Penstock 1. Detailed discussion can be found in the Bay d'Espoir Penstock 1 Refurbishment report submitted to the Board on January 9, 2017 (Appendix A). As a follow-up to the work on Penstock 1, a root cause analysis was performed by a third party consultant. The root cause analysis report is expected to be submitted to Hydro by mid-March and will be forwarded to the Board at that time.

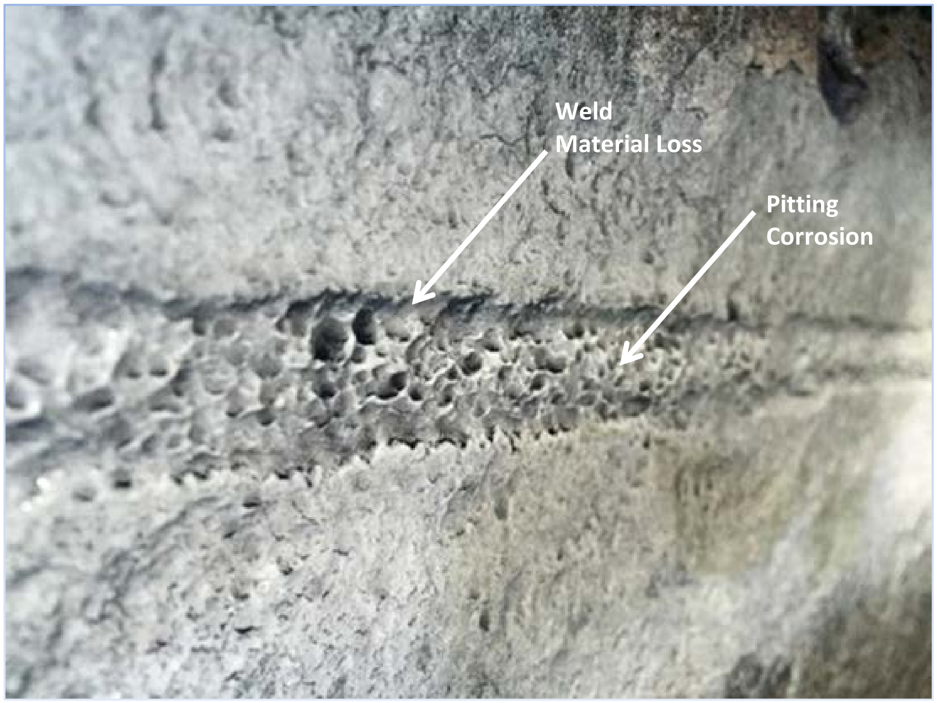

Photo 2: Deep Pitting Corrosion and Material Loss Shown in Weld

Penstock 2 was constructed immediately following the construction of Penstock 1, under the same contract. It is reasonable to expect that the weld condition in Penstock 2 is in a similar deteriorated condition to that found in Penstock 1 in late 2016.

3.2 Operating Experience

In June 2016, prior to the second weld failure of Penstock 1, a visual inspection of Penstock 2 was completed by Kleinschmidt Canada, Inc. (Kleinschmidt). Kleinschmidt employs a specialized penstock team and their lead penstock structural engineer visited Bay d'Espoir to complete the inspection. Penstock 2 was inspected prior to the September 2016 weld failure in Penstock 1 and prior to the detailed weld inspection of Penstock 1. The Kleinschmidt inspection report is attached in Appendix B.

The results of this inspection indicated that, like Penstock 1, the interior of Penstock 2 has algae covering the interior coating with localized areas noted where the algae, along with the coating, had peeled off the interior surface. This loss of coating and resulting corrosion is shown in photo 3. As a result of the algae, it was difficult to visually inspect most of the welds and the weld inspection was limited to the areas where the algae and coating had fallen off the metal surface. These areas showed corrosion; however, cracking was not visible. A recommendation of the report was to complete a detailed weld inspection, including microscopic crack testing of Penstock 2 in 2017. This level of inspection would include removal of sections of algae and coating in each penstock can[1] and testing for cracks using both magnetic particle equipment[2] and angled beam equipment.[3]

For planning purposes, it is anticipated that results of the detailed weld inspection for Penstock 2 will be similar to the results from Penstock 1 and that approximately 900 m of weld refurbishment will be required for Penstock 2.

Photo 3: Surface Corrosion Where Algae and Coating Have Fallen Off Surface

[1] The penstock is constructed of many cans, one connected to the next, end to end using a circumferential weld where each can touches the next. Each can was constructed individually by welding two halves together along the longitudinal axis (horizontal weld) of the can and then each can was welded end on end (circumferential weld).

[2] Magnetic particle test equipment helps to identify microscopic surface cracking of the weld and surrounding metal.

[3] Angled beam test equipment helps to identify cracking that is in the center of the weld thickness but has not progressed to the surface of the material.

3.2.1 Reliability Performance

Prior to the weld failure on Penstock 1, Hydro has not had this type of weld failure before in any of Hydro's penstocks. A weld failure in Penstock 2 would cause an extended forced outage for two Bay d'Espoir generating units with a combined generation capacity of 153MW. Bay d'Espoir Penstock 2 has not caused any forced outages in its operational history. However, due to the recent findings with Penstock 1, it can be reasonably assumed that the expected future reliability would reduce drastically without this proposed intervention. During times of system peak loads, an extended forced outage on this penstock would impact delivery to customers.

3.2.2 Legislative or Regulatory Requirements

There are no legislative or regulatory requirement issues related to the justification of this project.

3.2.3 Safety Performance

There are no past safety performance issues related to the justification of this project.

3.2.4 Environmental Performance

There are no past environmental performance issues related to the justification of this project.

3.2.5 Industry Experience

Although corrosion of steel can be a common occurrence in penstocks, the level of pitting corrosion observed in the Penstock 1 welds, as compared to the lack of pitting in the adjacent base metal, is not common. Hydro has no previous experience with this type of differential corrosion between weld and adjacent base metal.

3.2.6 Vendor Recommendations

Kleinschmidt has recommended a more detailed weld inspection be completed to determine if Penstock 2 weld condition is similar to the deteriorated weld condition of Penstock 1.

3.2.7 Maintenance or Support Arrangements

Hydraulic generating units are inspected and maintained by Hydro.

3.2.8 Maintenance History

The five-year maintenance history related to interior and exterior inspection for Penstock 2 is shown in the following table:

Table 1: Five-Year Maintenance History

Year	Preventive Maintenance ($000)	Corrective Maintenance ($000)	Total Maintenance ($ 000)
2016	73.5	2.1	75.6
2015	0.2	0	0.2
2014	0.2	0	0.2
2013	0.2	0	0.2
2012	0.2	0	0.2

3.2.2 Anticipated Useful Life

The typical life expectancy for a steel penstock is 80 years. This penstock is currently 50 years old so some deterioration is expected given its age. The Kleinschmidt inspection report concluded that Penstock 2 is in good condition with little loss of steel plate thickness; however, weld refurbishment, if required, and interior coating replacement are required to extend the service life of the asset. If the interior coating is replaced within manufacturer recommendations of every 20 years and any welding refurbishments are completed, the life of the penstock can be expected to be extended another 80 years.

3.3 Island Generation

Hydro filed its Energy Supply Risk Assessment with the Board on November 30, 2016.[4] This analysis considered Hydro's supply risk in advance of interconnection to the North American grid. It considered a number of factors including the projected unit availability across Hydro's asset classes, Hydro's load forecasts including sensitivity analysis, and existing transmission constraints within Hydro's system.

As part of that analysis, Hydro calculated its reserve margin and expected unserved energy in excess of planning criteria for a number of considered cases based on projected unit availability. The unavailability of Penstock 2 at Bay d'Espoir would result in a net reduction in IIS capacity of 153 MW, resultant from the unavailability of Units 3 and 4. This unavailability would result in violation of Hydro's planning criteria for all cases considered as part of Hydro's Energy Supply Risk Assessment in the immediate term, while bringing Hydro very close to its minimum reserve margin target of 240 MW in the near term. As such, Units 3 and 4 at Bay d'Espoir are critical to the reliability of the IIS in advance of interconnection. Reserve margin analysis for the unavailability of Units 3 and 4 is presented in Table 2 below.

[4] From NLH - Energy Supply Risk Assessment Report - UPDATED November 2016 - Revision 1 - 2017-01-26.

Table 2: Reserve Margin Analysis

Island Interconnected System	Winter 2016-17	Winter 2017-18	Winter 2018-19	Winter 2019-20
Expected Reference Case				
A: IIS Forecast Peak Demand	1,800	1,796	1,793	1,793
B: Less Available Capacity Assistance (90 MW)	1,710	1,706	1,703	1,703
C: Capacity at Peak	1,856	1,856	1,966	1,966
Reserve Margin (MW) (C-B)	146	151	263	263
Reserve Margin (%)	9%	9%	15%	15%
Fully Stressed Reference Case				
A: IIS Forecast Peak Demand	1,800	1,796	1,793	1,793
B: Less Available Capacity Assistance (90 MW)	1,710	1,706	1,703	1,703
C: Capacity at Peak	1,856	1,856	1,966	1,966
Reserve Margin (MW) (C-B)	146	151	263	263
Reserve Margin (%)	9%	9%	15%	15%
Fully Stressed Reference Case with Sensitivity Load Projection I				
A: IIS Forecast Peak Demand	1,800	1,804	1,803	1,802
B: Less Available Capacity Assistance (90 MW)	1,710	1,714	1,713	1,712
C: Capacity at Peak	1,856	1,856	1,966	1,966
Reserve Margin (MW) (C-B)	146	142	253	254
Reserve Margin (%)	9%	8%	15%	15%
Fully Stressed Reference Case with Sensitivity Load Projection II				
A: IIS Forecast Peak Demand	1,809	1,807	1,805	1,806
B: Less Available Capacity Assistance (90 MW)	1,719	1,717	1,715	1,716
C: Capacity at Peak	1,856	1,856	1,966	1,966
Reserve Margin (MW) (C-B)	137	140	251	250
Reserve Margin (%)	8%	8%	15%	15%
Fully Stressed Reference Case with Sensitivity Load Projection III				
A: IIS Forecast Peak Demand	1,812	1,807	1,805	1,805
B: Less Available Capacity Assistance (90 MW)	1,722	1,717	1,715	1,715
C: Capacity at Peak	1,856	1,856	1,966	1,966
Reserve Margin (MW) (C-B)	134	139	251	252
Reserve Margin (%)	8%	8%	15%	15%

Note: Installed capacity does not include 20 MW of voltage reduction

3.4 Development of Alternatives

Hydro does not believe there are other viable alternatives to refurbishing the Penstock 2 welds. Hydro considered the risk involved in keeping Penstock 2 in service until the next capital budget cycle; however, the associated timing would result in a condition assessment and weld refurbishment in 2018. Given that the condition of the welds in Penstock 2 are expected to be similar to that of Penstock 1, Hydro considered the risk of weld failure in Penstock 2 to be too high to delay inspection and refurbishment past 2017. If a weld failure was to result in an open crack in Penstock 2, especially during a winter season, the consequence would be the loss of 153 MW of supply from the Bay d'Espoir plant, affecting generation capacity for the island possibly during a critical time of year.

4.0 Conclusion

The generation of 153 MW using Penstock 2 is necessary to maintain generation planning criteria for the island interconnected system. The visual inspection of Penstock 2 completed in 2016 by Kleinschmidt recommended a more detailed weld inspection report be completed to determine if the Penstock 2 weld condition is similar to the deteriorated weld condition of Penstock 1.

The only viable option considered is to complete a detailed weld inspection and refurbish the deteriorated welds using the same method as for Penstock 1. Refurbishment will extend the life of the penstock while providing reliable power to the island system.

4.1 Budget Estimate

Table 3 outlines the capital cost required to complete the detailed weld inspections, stress analysis and weld refurbishment for Penstock 2.

Table 3: Project Budget Estimate

Project Cost:*($ x1,000)*	**2017**	**2018**	**Beyond**	**Total**
Material Supply	0.0	0.0	0.0	0.0
Labour	400.6	0.0	0.0	400.6
Consultant	547.5	0.0	0.0	547.5
Contract Work	6,350.0	0.0	0.0	6,350.0
Other Direct Costs	19.4	0.0	0.0	19.4
Interest and Escalation	282.7	0.0	0.0	282.7
Contingency	1,463.5	0.0	0.0	1,463.5
TOTAL	**9,063.7**	**0.0**	**0.0**	**9,063.7**

The cost to complete the Penstock 1 refurbishment, including engineering and construction, was approximately $7 million. The overall engineering and construction budget estimate to assess and refurbish Penstock 2 was increased to $7.3 million to account for increased difficulty with accessing Penstock 2 compared with Penstock 1, as well as the stress analysis required. Interest and escalation costs as well as contingency equate to $1.8 million, resulting in a total budget estimate of $9,063,700 for this project.

4.2 Project Schedule

Table 4 outlines the project schedule for the Penstock 2 refurbishment project.

Table 4: Project Schedule

Activity		Start Date	End Date
Planning	Planning	Jan 2017	Feb 2017
Design	Consultant procurement Design	Jan 2017 Feb 2017	 March 2017
Procurement	Tender and Award Construction	March 2017	April 21, 2017
Construction	Construction Contractor Mobilization Construction	April 2017 May 2017	May 2017 June 2017
Commissioning	Final Inspection Water up Penstock back in service	June 28, 2017 June 29, 2017	June 28, 2017 June29, 2017 June 30, 2017
Closeout	Closeout	July 2017	August 2017

APPENDIX A

Penstock 1 Refurbishment Report

newfoundland labrador
hydro
a nalcor energy company

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Canada A1B 4K7
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January 9, 2017

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

Attention: **Ms. Cheryl Blundon**
Director of Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: Bay d'Espoir Penstock 1 Refurbishment
Allowance for Unforeseen Notification

Please find enclosed the original and twelve copies of the final report in relation to the above-noted matter.

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Tracey Pennell

Tracey L. Pennell
Senior Counsel, Regulatory

TLP/lb

A REPORT TO
THE BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

BAY d'ESPOIR PENSTOCK 1 REFURBISHMENT

January 9, 2017

newfoundland labrador hydro
a nalcor energy company

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1. INTRODUCTION

On September 14, 2016, a leak was discovered in Penstock 1 at the Bay d'Espoir plant. Site investigation revealed a 1.1m open crack along a horizontal weld in the penstock (see Photo 1) approximately 230m downstream of the penstock intake gate. This open crack followed another open crack that had developed in May 2016, which was repaired at that time. Both open cracks were in close proximity. With the second open crack development, it was then suspected that the May crack was not an anomaly and that a more detailed investigation was required.

The penstock was removed from service to repair the open crack, complete a detailed inspection of the penstock to determine if any further issues existed affecting penstock reliability, and to determine the root cause of the failure. Hatch, having local metallurgy expertise, was engaged to assist Newfoundland and Labrador Hydro (Hydro) in completing the detailed inspection, developing the resulting refurbishment plan, and determining the root cause of failure.

Photo 1: Open crack in Penstock 1

As a result of removing Penstock 1 from service, generating units 1 and 2, totaling 153 MW, were unavailable to supply power for the refurbishment project duration.

This report details Hydro's investigation into the crack failure and refurbishment of Penstock 1 in order to ensure continued reliable operation of the penstock.

3. PROJECT DESCRIPTION

Upon discovery of the the second open crack in penstock 1, work commenced to restore the penstock to service prior to December 1, 2016. December 1 is date that Hydro commits to having its assets ready for the pending winter operating season (Winter Readiness). The scope of work for this project included:

- Detailed expert investigation of the weld cracks as well as root cause analysis;
- The refurbishment of 905m[1] of weld in Penstock 1 between the intake structure and surge tank 1; and
- The re-establishment of the backfill that was removed during welding rehabilitation.

The work tasks for each of these objectives included:

- Visual inspection and Magnetic Particle testing of the penstock welds from the intake to the scroll case to determine the extent of required refurbishment;
- Sampling and laboratory analysis of the affected welds, base plate metal, interior and exterior coating, interior algae, reservoir water;
- Development of work method and safety plan for welding refurbishment;
- Excavation and creation of access points and ventilation holes in the penstock between the intake and the surge tank;
- Refurbishment of welds with specialized equipment including automatic welding equipment;
- Testing of refurbished welds;

[1] The initial length of weld refurbishment reported to the Board of Commissioners of Public Utilities on October 14, 2016, was 700m. Upon completion of detailed weld testing it was found that a total of 905m of weld refurbishment was required.

- Re-establishment of exterior coating as required and backfill of penstock; and
- Water up of penstock using a slower water up rate than usual due to the extended dewatered state of penstock, as identified and recommened by Hatch.

Challenges that impacted the project work included:

- Tight confined space for the number of workers required, which reached 25 to 30 people at times inside the penstock;
- Specialized equipment was required to minimize the concentration of harmful emissions from welding activities in the penstock;
- There was only one existing manhole access to the penstock in the general location. Three additional access doors were cut into the penstock to improve access efficiency and reduce fall arrest and ladder use for multiple crews;
- Two additional ventilation holes were cut in the crown of the penstock to meet proper ventilation requirements and improve worker safety;
- Equipment procurement such as automatic welding machines were transported to the site from New Brunswick;
- Road washouts triggered by Hurricane Matthew caused delays during mobilization to the penstock site;
- Poor weather conditions, consisting of snow and rain, affected backfilling of the penstock as well as exterior site conditions;
- Logistics complications due to multiple work crews on site to meet the expedited work schedule;
- Increase in grade of penstock in the lower half of the work site presented a challenge for work crews for scaffolding set up and walking access, and;
- Limited accommodations in the local communities.

The welding work was completed by contractor work crews while exterior work was completed by contractor and Hydro operational work crews.

The welding refurbishments were completed by November 27, 2016 with the required penstock backfilling completed by November 29, 2016. Penstock water up was started on November 28, 2016 with the penstock placed back in service on November 30, 2016. The final project closeout was completed on December 15, 2016.

4. JUSTIFICATION

4.1 Existing System

There are 4 penstocks which supply water for generation from the Long Pond reservoir to the Bay d'Espoir generating station. Penstocks 1 and 2 were constructed in 1967 and supplies water to units 1 through 4. Penstock 3 was constructed in 1970 and supplies water to units 5 and 6 while Penstock 4 was constructed in 1977 and supplies water to unit 7. See Photo 2 for the layout of the 4 penstocks as it relates to the reservoir and the hydroelectric plant.

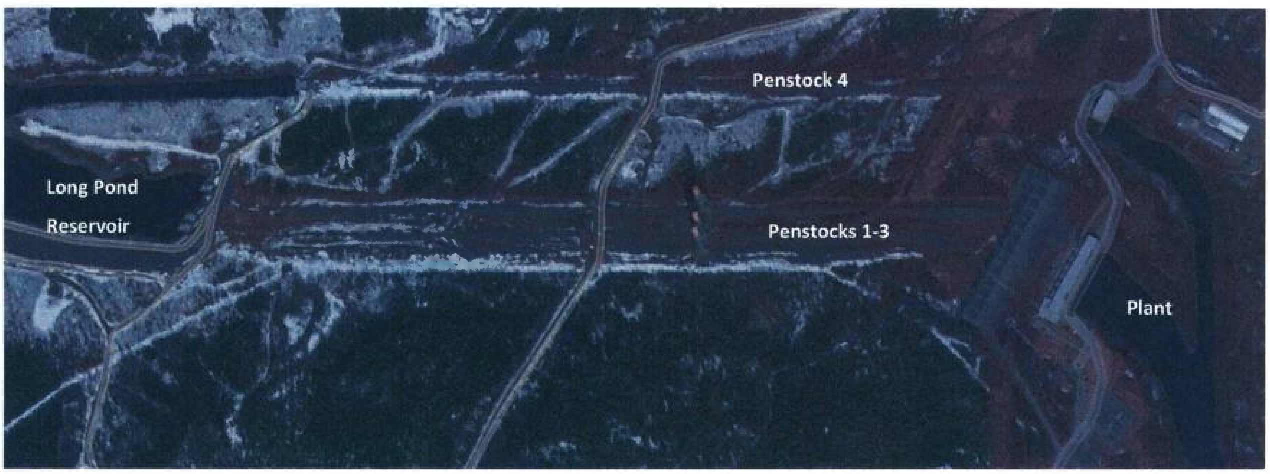

Photo 2: Layout of penstocks, reservoir and plant

The penstocks are designed to handle expected live loads such as water hammer and water pressure as well as dead loads such as penstock material weight and backfill weight. The thickness of the penstock base plate material is selected as a result of the stresses developed in the steel by these noted loading combinations. Likewise, the welds are designed in a similar manner and must also effectively handle the expected load combinations without failure. In the case of Penstock 1, the base plate steel design thickness varies throughout the length of the penstock. In the area of the open crack, the design penstock thickness is 11.7mm.

4.2 Investigation

Once the September 2016 leak was discovered, Penstock 1 was taken out of service so as to minimize further damage to the penstock and surrounding bedding support as well as investigate the leak.

Preliminary investigation revealed an open crack in a horizontal weld of Penstock 1. The open crack location is shown in Photo 3.

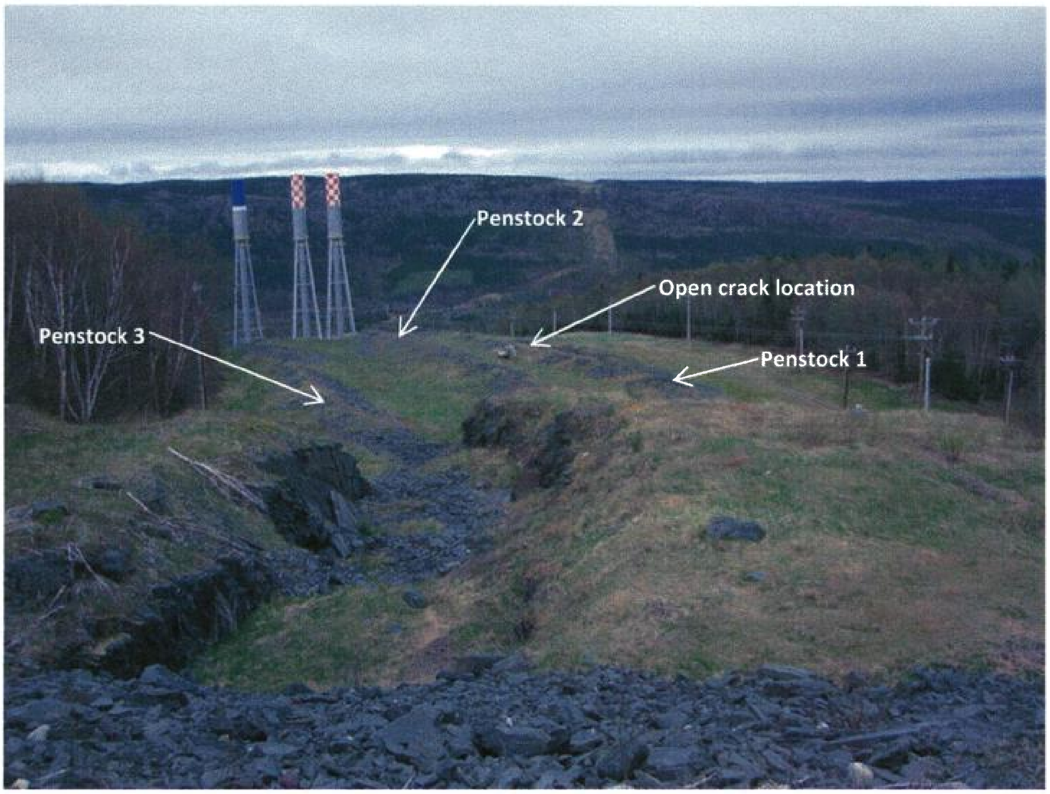

Photo 3: View of Penstocks 1, 2 and 3 as viewed from intake area

An investigation of the open crack area, initially including the area 10m upstream and downstream of the crack area, was completed by Hatch with Bay d'Espoir operations support. The welds in this area of the penstock displayed corrosion primarily concentrated in the weld with less pitting shown in the adjacent base metal. Photos 4 and 5 show the extent of the corrosion observed in the horizontal welds in the inspected area as compared to the base plate.

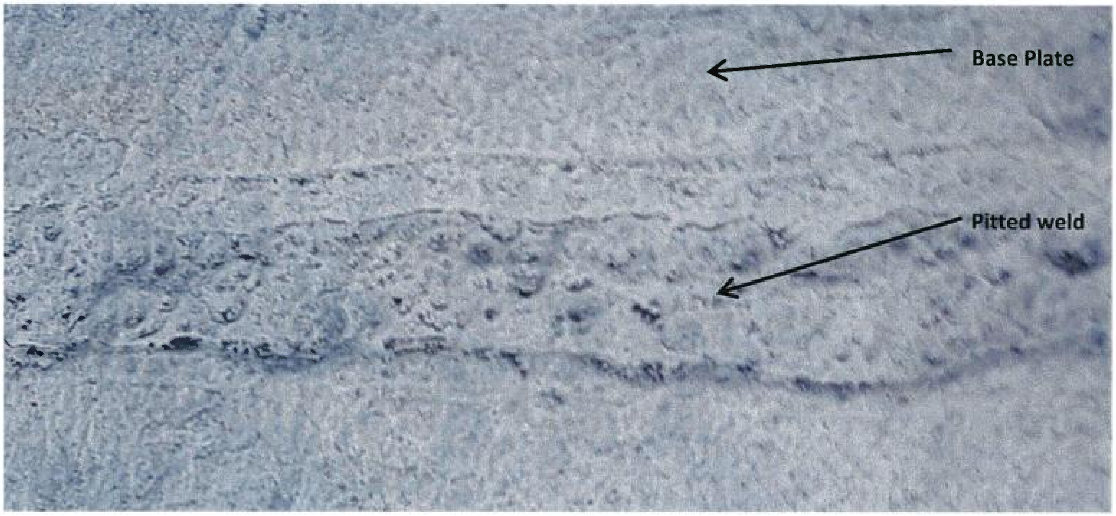

Photo 4: pitting in weld on interior of penstock

Photo 5: Deep pitting shown in weld

Given the visible pitting and general poor condition of the welds in this initial area, further investigation was undertaken to inspect the penstock from the intake gate to the scroll case, for a total distance of 1.2km. Weld deficiencies were identified between the intake gate and 460m downstream of the intake gate. Most of the welds between these stations displayed material loss in the weld adjacent to the base plate as shown in photos 6 and 7. As shown in these pictures, the surface of the weld material adjacent to the base plate appears to be below the surface of the base plate as is evidenced by the noted erosion channels each side of the weld.

Photo 6: Loss of weld material at interface with base metal

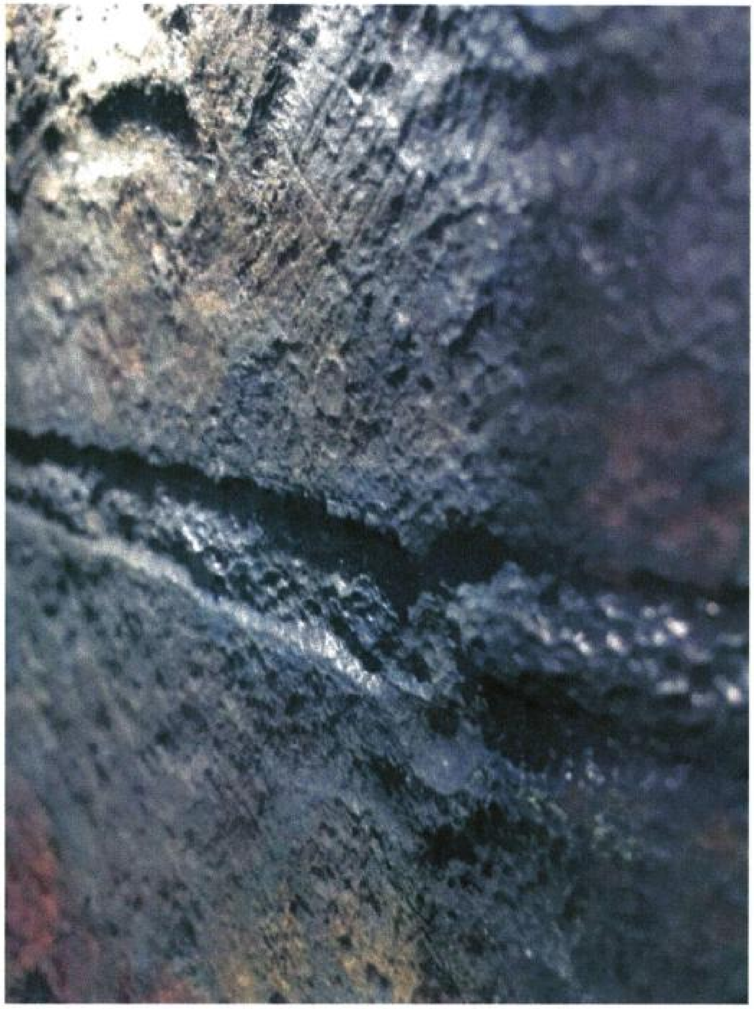

Photo 7: Weld thickness less than base plate thickness

These erosion channels represent loss of the weld material. Proper weld design dictates that the weld material needs be the same thickness or thicker than the adjacent base plate material. In the case of some of the welds in Penstock 1, it was noted that these erosion channels reduced the weld material thickness to less than that of the adjacent base plate thickness, thus the remaining weld thickness no longer met minimum design requirements of the penstock.

Cracking was also evident in the welds. Many of the weld cracks were, on average, found to be 2.5mm deep, and were located along the base plate / weld interface. Cracking in the weld also acts to reduce the effective thickness of the weld material. There were multiple areas discovered in the vicinity of the open crack where weld cracks were measured at more than half the thickness of the base plate; up to 6mm deep. Cracks in the weld material indicate a reduction in effective weld thickness and crack depths to 6mm indicate that failure of the weld is highly probable under normal loads. Given both the loss of material thickness due to corrosion as well as the weld cracking, refurbishment of these deficient welds was concluded by Hydro's consultant to be required before operation of Penstock 1 could safely be resumed.

The refurbishment work rendered Bay d'Espoir Units 1 and 2 unavailable for generation until the work to rehabilitate the welds could be completed. Due to the criticality of Bay d'Espoir to the Island Interconnected System, urgent and immediate work to refurbish these welds was determined to be necessary to ensure reliable service to customers.

4.3 Investigation Results

Hatch concluded that the majority of the horizontal welds between the intake and 460m downstream of the intake had enough material loss, as well as visible crack depth, to be ineffective at resisting the stresses caused by normal operation. For the most part, the circumferential welds displayed minimal corrosion; however, some of these welds were deteriorated to the extent where refurbishment was also required. Generally, the circumferential welds that were deteriorated were those located close to the intake.[2] The remaining welds 450m from the intake down to the scroll case were found to be in good condition with no need for refurbishment.

A root cause analysis to determine why the weld deterioration occurred is currently underway with a report expected in February 2017.

It was also determined that the almost 50 year old interior coating system had failed throughout the penstock. The coating system will also be considered as part of the root cause report.

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[2] The penstock is constructed of many cans, one connected to the next, end to end, using a circumferential weld where each can touches the next. Each can was constructed individually by welding two halves together along the longitudinal axis (horizontal weld) of the can and then each can was welded end on end (circumferential weld).

4.4 Refurbishment Effort

Due to the nature of the weld deficiencies, the existing welds in the area noted no longer met the minimum design requirements and therefore, it was recommended by Hatch that refurbishment of the deficient welds was required prior to repressurizing the penstock. Ultimately, 453m of the penstock (905m of total welding length) required gouging of the corroded and cracked weld material followed by installation of new welds.

In order to complete the amount of welding refurbishment required in the specified timeline, significant logistical challenges were overcome to complete the work. These challenges, as listed in section 3, included a lack of accommodations for the number of workers required to meet the schedule, Hurricane Matthew access damage, and transportation of specialized equipment from other provinces. In order to meet the challenging schedule, the contractor engaged a total of 70 construction crew members to work on the penstock, 7 days a week, in two 10 hours shifts per day. A considerable effort was made to complete this project before the winter readiness timeline and re-establish generation on units 1 and 2 at the Bay d'Espoir hydroelectric station.

5. CONCLUSION

This project was required to ensure the reliability of Penstock 1, especially with winter approaching. If Hydro had only repaired the open crack area and returned the penstock to service without investigating and subsequently refurbishing the other corroded and cracked welds, there was a high probability that another leak would have occurred in the next 3 to 4 months, forcing the penstock out of service for a period of time during the winter season. This type of shut down would result in losing the 153MW supply from units 1 and 2 at Bay d'Espoir over the winter which Hydro deems to be unacceptable.

Hydro recognizes the urgent interest of the Board and intervenors in the findings of the root cause analysis with respect to implications for reliability of other penstocks. Hydro continues to work with its consultant, Hatch, on the root cause report. Hatch has, in turn, engaged third party materials testing organizations to complete various materials testing as part of the root cause investigation into the penstock leaks. The sample testing results are important to the final findings of the report. Hatch will receive the final aspects of information from the third party in January. The results of these third party tests will then be reviewed and incorporated into the root cause report. Hydro expects to receive a draft of the root cause report in early February, and will work with Hatch to finalize the report by the end of February. The report, including any recommendations, will be communicated to the Board, once final.

The work to refurbish the welds was not contemplated in the annual capital budget as the condition of the welds, or the risk of a crack developing, was unknown. Hydro has modified its inspection program for its remaining penstocks, and will have those penstocks inspected internally over the next several years. The Hinds Lake penstock was inspected in Fall 2016 with the penstock and welds found to be in good condition, as was the penstock generally. Penstocks 2 and 3 at Bay d'Espoir will have detailed inspections completed in 2017. All remaining penstocks will have engineering inspections completed between 2018 and 2020. Hydro is coordinating the timing of the inspections with other work requiring the penstocks to be dewatered.

Hydro does not believe there were any other viable alternatives to refurbishing the penstock welds, as was completed. Hydro could have put Penstock 1 back in service following the repair of the known crack, and postponed the major refurbishment work. However, in Hydro's view, postponing the work until the next maintenance season would have carried unreasonable risk that an additional crack would develop, removing 153 MW of supply, which could have occurred in the middle of the critical winter season.

6. PROJECT COSTS

The expenditures for this project are shown in Table 1.

Table 1: Project Expenditures

Project Expenditures	
Material Supply	$19,828
Labour	$167,375
Overtime	$129,688
Contract Work	$6,030,497
Travel	$1,224
Equipment Rental	$7,000
Overheads	$170,617
TOTAL	**$6,526,229**[3]

The original estimate proposed to the Board for this work was $12,900,000 based on the original quote from the welding contractor developed after a site visit. The welding contract was based on a time and materials basis and their cost estimate was adjusted once the engineering refurbishment plan was finalized and construction began.

[3] Summation of costs reported to date. This value will change marginally as final invoicing is received from all vendors.

APPENDIX A

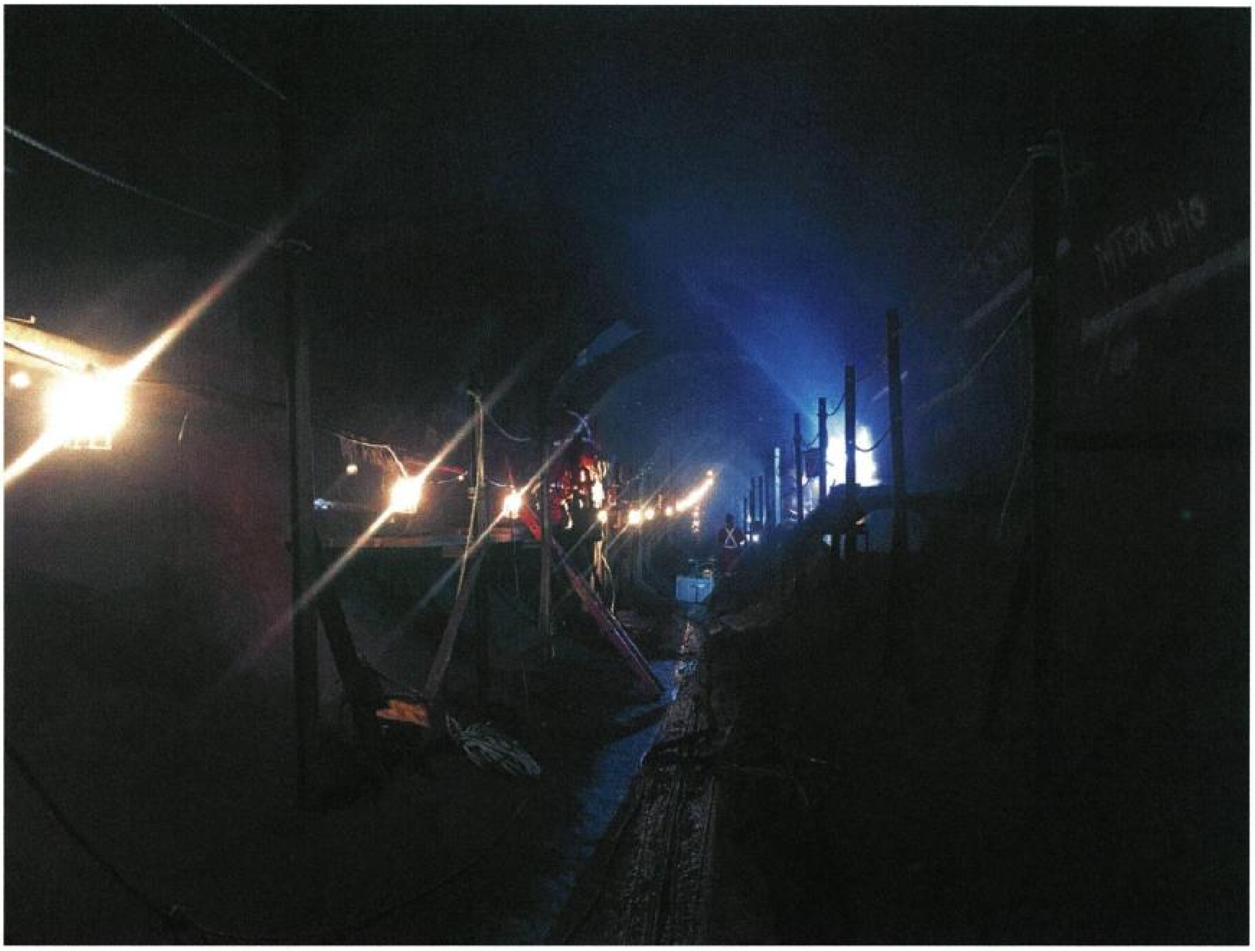

Photo A-1: Congestion with scaffolding and cables inside the penstock

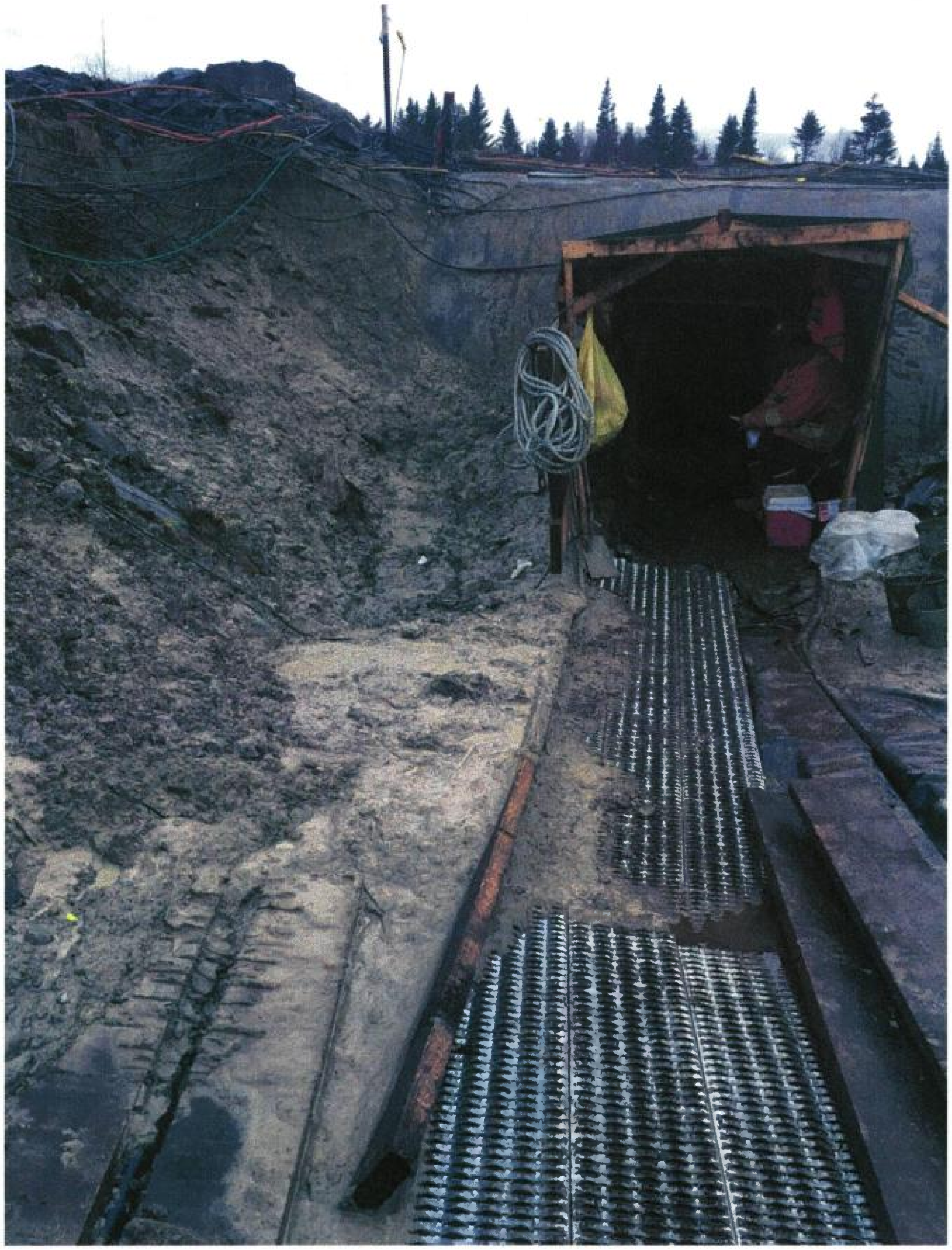

Photo A-2: Access door cut in side of penstock with muddy ground conditions

Photo A-3: Access road washouts due to Hurricane Matthew

Photo A-4: Automatic gouging machine setup

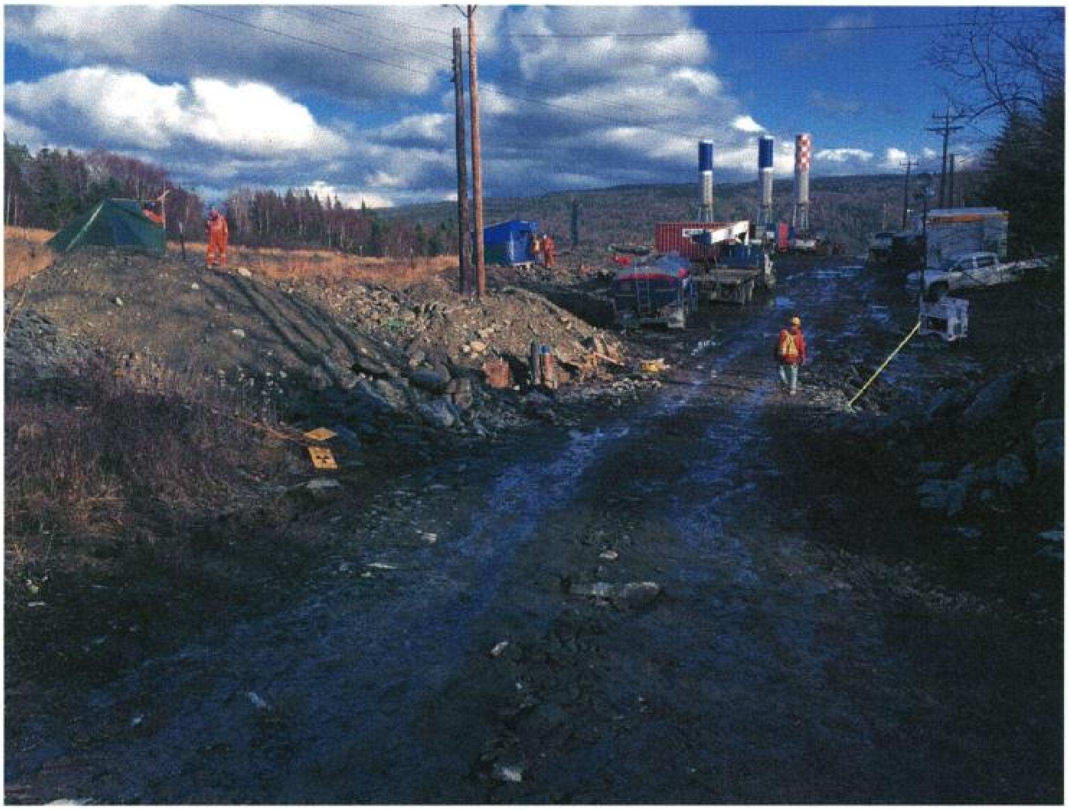

Photo A-5: Congestion on site

Photo A-6: Example of scaffolding required

Photo A-7: Weather conditions during penstock backfill requiring temporary shut down

APPENDIX B
Penstock 2 Inspection Report

PENSTOCK NO. 2
INSPECTION AND EVALUATION

BAY D'ESPOIR HYDROELECTRIC DEVELOPMENT

Prepared for:

Newfoundland and Labrador Hydro
St. John's, Newfoundland and Labrador

Prepared by:

Kleinschmidt
Nova Scotia, Canada
www.KleinschmidtGroup.com

December 2016

Penstock No. 2
Inspection and Evaluation

Bay d'Espoir Hydroelectric Development

Prepared for:

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December 2016

PENSTOCK NO. 2
INSPECTION AND EVALUATION

BAY D'ESPOIR HYDROELECTRIC DEVELOPMENT

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PENSTOCK NO. 2
INSPECTION AND EVALUATION

BAY D'ESPOIR HYDROELECTRIC DEVELOPMENT

1.0 INTRODUCTION

Newfoundland and Labrador Hydro (NL Hydro) contracted with Kleinschmidt on June 24, 2016 to inspect and evaluate the condition of their Bay d'Espoir Hydroelectric Development's Penstock No. 2. Kleinschmidt's inspection is the first external engineering consultant evaluation completed for Penstock No. 2 since the surge tanks were reviewed in 1988 and is part of NL Hydro's recent review of their preventive maintenance program for asset management, setting a baseline for NL Hydro to build on for future management of their penstocks.

In addition, NL Hydro discovered a 2-foot long crack in Bay d'Espoir's Penstock No. 1 in May 2016. Kleinschmidt responded and assisted with the design of the crack repair, *Crack Investigation and Repair Report – Penstock No. 1 Bay d'Espoir Hydroelectric Development* (June 2016). Penstock No. 2 was built at the same time as Penstock No. 1 which raised NL Hydro's concerns about the possibility of similar cracking occurring in Penstock No. 2. As Penstock No. 2 was dewatered for recoating of the surge tank during June/July 2016, NL Hydro opted to have Kleinschmidt provide a detailed penstock inspection and evaluation at this time.

Since the inspection was completed, a second large crack opened up in Bay d'Espoir's Penstock No. 1 in September 2016. This second crack lead to a detailed weld investigation that has discovered interior weld cracking throughout the penstock. The investigation was still ongoing at the time this report was submitted to NL Hydro.

This report presents our evaluation of the capacity of the penstock in its current condition, provides recommendations for inspection procedures in the future, and estimates the remaining service life.

2.0 PROJECT DESCRIPTION

NL Hydro owns and operates the Bay d'Espoir Hydroelectric Development in Bay d'Espoir Newfoundland, Canada. The Project went into service in 1967 and is supplied by Jeddore Lake with the tailrace feeding a canal leading to the tidal waters of Bay d'Espoir and the Atlantic Ocean. The plant has a hydraulic head of approximately 176 meters (577 feet) and seven generating units with a total capacity of 604 megawatts (MW). The development comprises two intake structures, feeding four penstocks into two powerhouses where seven units operate with a total annual generation of approximately 2,650 gigawatt hours (GWh). Penstocks No. 1, No. 2, and No. 3 have surge towers approximately 727 meters (2400 feet) upstream of the powerhouse. The first phase of the project construction involved the installation of the main intake structure and a four-unit powerhouse with Penstocks No. 1 and No. 2 connecting the two. The second phase consisted of installing Penstock No. 3, along with two additional units in the powerhouse, and a separate intake structure and powerhouse for Unit No. 7, connected by Penstock No. 4 in 1970. Penstock No. 2 supplies Units No. 3 and No. 4. The rated flow across all seven units is 397 cubic meters per second (m^3/s) (14,020 cubic feet per second (cfs)). Penstock No. 2 is buried along its entire length from the intake to the powerhouse. There are four original manholes: one manhole upstream of a turbine-isolation valve inside the powerhouse and three larger manholes on the crown of the penstock; (1) approximately halfway between the powerhouse and surge tower, (2) at the surge tower, and (3) halfway between the intake and the surge tower.

Appendix A includes the original 1965 profile drawings of the penstock including original plate thicknesses. The penstock steel plate thicknesses range from 11 millimeters (7/16 inches) at the intake to 41 millimeters (1 5/8 inches) at the powerhouse.

3.0 INSPECTION

Jillian Davis P.E., and Keenan Goslin P.E. of Kleinschmidt inspected the entire interior and exterior, of Penstock No. 2 between June 28, 2016, and June 30, 2016, with the assistance of personnel from Tacten (rope access safety support) and NL Hydro. Ray Buffet and other NL Hydro personnel assisted with safety procedures and site access and answered questions about the history, operation, and maintenance of the station.

Kleinschmidt's inspection consisted of measuring shell thicknesses, observing pitting and cracking and overall condition of the interior of the shell, inspecting the condition of the coating of the penstock and observing the exterior of the buried penstock for signs of leakage. Appendix B shows a table of our key field observations.

3.1 WORKING CONDITIONS

Kleinschmidt's inspection team entered the penstock on June 28 through the manhole at the surge tank and existed at the powerhouse manhole. On June 29 the team entered through the intake and exited manhole at the surge tank. On each day the intermediate manholes (each approximately 360 meters (1181 feet) and 253 meters (830 feet) downstream of the entry points respectively from the intake and surge tank) were used to re-rig the safety ropes. Photos 1 through 4 in Appendix B show each of the access points and manholes. The ropes were used to access the steep portions of the penstock and provide a means of rescue by Tacten if necessary. Kleinschmidt anchored the ropes to a ladder system at the intake and at each manhole as it was passed while Tacten and NL Hydro provided and manned a retrieval tripod at intermediate manholes of each section. Some leakage into the penstock was encountered from the upper and lower right hand corners of the headgate (looking downstream) during the inspection. This leakage can be seen in Photo 5. The penstock's interior was generally dry with the interior surface conditions mainly damp until just upstream of the powerhouse where a low spot has collected water and additional organic build-up. The penstock has varying slopes with two main steep sections. The penstock slopes range from 2 degrees to 7 degrees along most of its length but just upstream of the surge tank there is a section with a 16-degree slope for approximately 91 meters (300 feet) and just upstream of the powerhouse the penstock has a 19-degree slope for approximately 58 meters (190 feet) as noted in Appendix A. The slope levels out as the penstock enters the powerhouse.

The exterior of the penstock was inspected on June 30. The exterior was mainly rocky conditions covering the penstock. It rained before and during the inspection causing footing to be slippery and muddy where it was not rocky. The rain combined with poorly draining soils caused pooling in low areas including excavations completed the prior week for inspection of the crown of the penstock. The grade nominally followed the penstock slope between the intake and the switchyard.

3.2 INTERIOR INSPECTION

All stationing measured during Kleinschmidt's inspection is based on the downstream face of the headgate acting as STA 0+00 with stationing measured in feet rather than meters. The Appendix A Penstock Layout Drawings have the headgate at STA. 0+42 with stationing in feet as well. Where possible, the stationing presented herein is first shown in metric units (meters) based on Kleinschmidt's field measurements and the drawing stationing (in meters as well) is given in parentheses. This is then followed by the imperial equivalent stationing in brackets.

Kleinschmidt inspected the penstock interior from the headgate at STA 0+00 (STA 0+12.8 in Appendix A drawings) [STA 0+00 (STA. 0+42)] to the scroll case at the powerhouse, STA.11+71 (STA 11+88) [STA 38+42 (STA 38+96)].

Penstock thickness readings were recorded from the interior at various locations. Shell thickness measurements were taken with a Panametrics Model 38DL Plus Ultrasonic gage. A dual element transducer, Panametrics Model D790, was used and the readings were taken in the "standard" mode. In "standard" mode the paint thickness does not affect the steel thickness readings if the paint thickness is below 1/64 (0.0156) inch (15.6 mils). The gage was calibrated before the field measurements to an accuracy of 0.001 inch. Due to the fact that both the field measurements and Appendix A drawings give shell thicknesses in inches, this evaluation did so as well. However, where possible in this report, we give the metric equivalent first with the imperial thickness in parentheses.

Thickness readings were recorded from the interior of the penstock at several positions around the circumference of the penstock, typically near 5 o'clock, 6 o'clock and 7 o'clock based on an orientation looking downstream. All references to penstock left and right are also oriented looking downstream. Table C-1 in Appendix C summarizes the average shell thickness readings for each section of penstock.

The following sections describe the interior shell and joint condition and ovalization and present our observation of dents.

3.2.1 INTERIOR SURFACE, COATING AND JOINT CONDITION

The interior of the penstock was generally in good condition with some scattered moderate corrosion and pitting no more than 1.6 millimeters (1/16 inch) in depth (Photo 6). The steel in areas where the coating was intact showed little corrosion since the coating was well applied and in fair condition. There were many locations of localized delamination (Photo 7). Overall there appeared to be more delamination of the upper portion of the penstock than the lower, although actual areas of delamination were not counted or measured. This difference may be due to possible operating temperature differences (the upper penstock is closer to the ground surface than the lower) or possible change in construction conditions. If the interior coating was shop applied, then construction conditions should not affect delamination, but if the coating was applied in the field, weather and ambient temperatures could affect coating adhesion. One of the larger areas of coating loss was along the invert and crown of the lower section of penstock at STA 9+55 (Bend 9B and STA 9+58 in Appendix A drawings) [STA 31+32 (STA 31+42)], as the penstock incline changes, the water velocity increases which increases scour of the penstock coating.

Penstock No. 2 is fabricated from 20 different plate sizes. Inspection thickness readings were taken at 14 of these plates, ranging from 12 millimeters (1/2-inch) to 41 millimeters (1 5/8-inch). Many of these sections exhibited little to no appreciable material loss with thickness readings averaging up to 6-7% greater than the listed original plate thickness and the average thickness for all plates being 1.82% greater than the listed original. There is one exception, the 41 millimeter plate, near the powerhouse at STA 11+71 (STA 11+88) [STA 38+42 (STA 38+96)], exhibited a large material loss, averaging a 15.5% loss at three reading locations.

The welded joints were in good condition and did not have any apparent visible cracks. Both the longitudinal and circumferential welds were convex and there was no sign of significant deterioration along the weld edges. The invert of the circumferential joint at STA 1+95 [STA 6+60] was misaligned between adjacent sections during construction with an approximately 12 millimeters (Photo 8) and tapered to flush at approximately the 4 o'clock and

8 o'clock positions of the penstock. There were no visible cracks at this location but is a location to continue to monitor.

Kleinschmidt noted a "hollow ring" when taping the penstock shell with a steel hammer at STA 0+45.7 (STA 0+64.6) [STA 1+50 (2+12)], Bend 1B, along the invert of the penstock between 5 and 7 o'clock and extending approximately 1 meter upstream and downstream of the bend. This could be indicative of a void beneath the penstock. However, Kleinschmidt was unable to find signs of interior cracking that could be allowing leakage to pipe away the soil bedding. This is also where the penstock is still deep below grade of the earthen embankment, so there were no signs of settlement or leakage on the exterior.

3.2.2 OVALIZATION

Table 3-1 provides measurements of the penstock vertical internal diameters (ID) along the length of the penstock. Out of roundness percentages are comparisons to the specified penstock diameter per supplied design drawings as horizontal internal diameter measurements were not available due to the size of the penstock.

TABLE 3-1 INTERNAL DIAMETER MEASUREMENTS (STATIONING PER FIELD MEASUREMENTS)

STATION (FT)	VERTICAL ID			% OUT-OF-ROUNDNESS	STATION (FT)	VERTICAL ID			% OUT-OF-ROUNDNESS
	ft.		in			ft.		in	
0+25	16	-	11.24	0.38%	25+32	13	-	6.11	0.04%
1+50	**16**	-	**9.65**	**1.50%**	26+52	13	-	5.50	0.31%
3+75	16	-	11.91	0.05%	28+32	13	-	5.96	0.02%
7+50	16	-	10.34	0.82%	28+82	13	-	5.86	0.09%
9+25	17	-	0.82	0.40%	29+82	13	-	5.91	0.05%
11+50	**16**	-	**8.94**	**1.50%**	31+82	13	-	5.52	0.30%
14+60	15	-	2.84	0.09%	32+82	13	-	5.44	0.35%
16+40	15	-	2.85	0.08%	34+82	13	-	5.45	0.34%
18+75	15	-	1.83	0.64%	36+82	13	-	5.45	0.34%
22+32	13	-	5.19	0.50%	38+42	9	-	0.07	N/A

The penstock is not noticeably ovalized anywhere along the length of the penstock with a peak out-of-roundness measurement of 1.50%. The industry standard for new penstock fabrication limits out-of-roundness to 1% (ASME 2004); ASCE No. 79 (see Section 4.1 for full reference) recommends a minimum penstock thickness for shipping and handling concerns based on the maximum of D/288 or (D+20)/400. Based on these the minimum recommended thickness for each pipe section is 18 millimeters (0.71-inches) for 5182 millimeters (17-foot), 16 millimeters (0.635-inches) for 4572 millimeters (15.25-foot) and 14 millimeters (0.56 inches) for 4115 millimeters (13.5-foot). The minimum plate thickness for the 5.18 meter and 4.57-meter sections is 11 millimeters (0.4375 inches), less than the minimum recommended for shipping and handling, however, Kleinschmidt has seen ovalization existing between 5% and 10% in penstocks that continue to operate safely. Our evaluation of the penstock buckling capacity due to exterior loads is provided in Section 4.0. Included in the evaluation is the check for minimum recommended plate thicknesses for each diameter by ASCE No. 79 for shipping and handling.

Similar to the findings of the Penstock No. 1 inspection report which noted approximately 2% out-of-roundness near its crack, these amounts are not a concern and are common for buried large diameter penstocks with high diameter to thickness ratios. Based on the recommend ASCE No. 79 thicknesses for shipping and handling, the 5.18-meter diameter penstock and some of the 4.57-meter sections are the only ones of concern that may rely heavily on the surrounding soil support below spring line to maintain their roundness. Proper compaction and material of the bedding from the invert to the spring line is critical to these sections to help support and maintain shape and functionality. Since the ovalization of the 5.18-meter diameter penstock is less than 1.5%, the foundation material is not a major concern at this time.

3.2.3 APPURTENANCES

Penstock appurtenances include vents, valves, access ports, manholes, and other components of the penstock other than supports. Bay d'Espoir's Penstock No. 2 has four manholes, two vent openings at the intake, and a bifurcation wye at the powerhouse.

The manholes were in good condition with moderate corrosion to the interior surface of the manhole. Kleinschmidt understands that old bolts were troublesome to remove to open some manholes and would be replaced when the manhole covers are reinstalled (Photo 3).

The vent and access shafts are shown in Photo 9. The concrete structure did not show notable deterioration, spalling or delamination. The steel ladder was in fair condition with corrosion increasing with depth but not excessive.

The downstream face of the steel headgate appeared to be in good condition with some rust tubercles and minor leakage as shown in Photo 5. No thickness readings were taken of the headgate steel.

The bifurcation upstream of Units No. 3 and No. 4 was in good condition with minor corrosion as seen in Photo 10. Slightly more corrosion was visible near the invert of the penstocks than shown in this photo with similar conditions in the photo towards the upper portions of the penstock (Photo 11).

Mud and silt have accumulated at the invert of the penstock from the bottom of the slope beneath the bifurcation for approximately 3 meters to a maximum depth of about 100 millimeters. This is not an item of concern, but it does prohibit inspection of this area of the shell.

We were unable to verify drain locations during the site visit. If drains are not functioning or not installed as per design drawings, this could cause a problem with the compaction of backfill around the penstock. Kleinschmidt recommends locating the drains and clearing them as necessary. The drains should be regularly inspected and cleaned as necessary by NL Hydro maintenance personnel.

3.2.4 Surge Tank

A few days prior to Kleinschmidt's inspection of the No. 2 Penstock, Tacten notified NL Hydro of cracking at the surge tank interface with the penstock. Kleinschmidt reviewed the cracking and provided recommendations separately of the penstock inspection and evaluation. These are located Appendix E.

3.3 Exterior Inspection

Kleinschmidt began the exterior inspection at the intake and moved downstream. The penstock is buried along its entire length with rock fill over each of the penstocks as seen in Photo 12. Kleinschmidt observed the exterior ground surface for signs of leakage while walking the length of the penstock. The weather during the day of the exterior inspection was a steady, light rain with heavy rain at times. NL Hydro operations personnel hand dug to the crown of the penstock in several locations the previous week with more completed the afternoon of the exterior inspection. Typical exterior shell conditions can be seen in Photo 13. Several of the holes dug down to the penstock crown in the previous week were filled with water and not usable for inspections due to the rate of flow into the hole. Coating thickness and steel thickness measurements were taken at the locations that were not under water. The depth of cover varied from several millimeters to over half a meter. Shallower depths of cover are not a concern provided adequate cover is provided to protect the pipe where vehicles travel over it (at the intake and switchyard). There is adequate cover provided at these locations according to our evaluation in Section 4.

The location of the dug holes is estimated and shown in Appendix A. Coating thickness measurements were taken with a DeFesko PosiTest Dry Film Thickness (DFT) gauge and readings are summarized in Table 3-2.

TABLE 3-2 SUMMARY OF COATING THICKNESS MEASUREMENTS

STATION (FT)	AVERAGE COATING THICKNESS (mils)
2+96	12.9
14+60	24.4
26+31	13.4
30+81	18.0
33+17	17.6

4.0 EVALUATION

The purpose of the evaluation is to assess the condition of the penstock and its suitability for continued operation and to identify repairs or maintenance that may be required to ensure its safe operation. Based on Kleinschmidt's experience and judgment the four potential ways that the penstock could fail are (1) bursting due to excessive internal pressure or loss of shell thickness, (2) general buckling due to external pressure, (3) local buckling leading to tensile cracking or general buckling, and (4) local weld failure due to improper weld procedures during construction.

4.1 LOADING CONDITIONS AND ALLOWABLE STRESSES

The loading conditions and allowable stresses were determined from the criteria presented in the American Society of Civil Engineers (ASCE) Manuals and Reports on Engineering Practice No. 79 Steel Penstocks, 2nd Edition. The allowable primary stress intensity is the lesser of the material yield stress (F_y) divided by 1.5 or of the ultimate tensile stress (F_u) divided by 2.4. A summary of assumed yield stress, ultimate tensile stress, and allowable stress intensity for each section of penstock can be found in Appendix D. The allowable steel stress used in this analysis was 17,000 pounds per square inch (psi). This was conservatively estimated from the two types of steel used in the penstock construction, ASTM A285 and CSA G40.8 Grade B. ASTM A285 Grade B steel was used from the intake to STA 2+99 (STA 3+13) [STA 9+80 (10+26)] with CSA G40.8 Grade B steel used for the remainder.

The welded seams are not as strong as the original base material; these strength reductions are designated as "joint efficiency, E" and are calculated in Appendix D and included in the penstock stress tables in Appendix C. A joint efficiency of 70% was assumed for all welded joints per Table 3-3 of ASCE No. 79.

Load cases considered include:

- stresses in the penstock under normal operating conditions;
- stresses in the penstock under flood conditions;
- transient stresses in the penstock during a load rejection at normal pond elevations;
- allowable vent opening to prevent vacuum pressures; and
- external surcharge loads in a dewatered condition.

4.2 Shell Stresses Induced by Internal Pressure

Table 4-1 summarizes the statistical analysis of our steel-shell thickness data and internal pressure steel stress analysis results. See Appendix C for detailed thickness data and stress calculations. Stationing for the inspection originates at the intake and follows the path of the penstock until it reaches the powerhouse. Average thickness and a 97.5% confidence interval (CI) were calculated for each station. The 97.5% CI is the average thickness minus 1.96 times the standard deviation of the thickness readings; it is considered the minimum thickness likely in the penstock and conservatively accounts for thicknesses less than the average thickness (ASCE 1995).

The maximum hoop stress in the penstock shell is due to internal static and dynamic water pressures. The stress ratio is the maximum hoop stress divided by the allowable steel stress. A hoop stress less than 1.0 indicates that the penstock meets industry-standard factors of safety as designated in *ASCE Engineering Practice No. 79, Steel Penstocks* (2012).

Normal pond or Full Supply Level (FSL), flood, and dynamic water hammer pressures were determined based on elevations given in the Appendix A drawings, an extra 0.6 meters (2.08 feet) was added to all water elevations to match maximum levels described in the Regulation Study of Bay D'Espoir System by Acres International Limited in 1988.

Normal pond static pressures were based on a total head of 182.6 meters (599.08 feet) at the unit centerline. This head was given by original profile drawing provided in Appendix A with a headpond FSL of 181.7 meters (596.08 feet) with 0.63 meters (2.08 feet) added for the raised head pond level after original construction. The maximum flood elevation used in the analysis is 184.2 meters (604.3 feet) with a static head of 183.3 meters (601.3 feet). Dynamic head rise due to water hammer was found on the Appendix A reference drawings maximum dynamic head of 271.3 meters (890 feet) noted at the turbine.

The calculated stress ratio results for FSL and flood water levels are all less than 1.0 for the pipe including the reduced joint efficiency. The peak stress ratios for the FSL and Flood conditions, of 0.91 (Table C-1) and 1.08 (Table C-2) respectively, occurred at STA 6+74.2 [STA 22+12], 19 millimeter (¾-inch) original plate, and conservatively neglects overburden pressures. The maximum dynamic head stress ratios are presented in Table 4-1 and in Appendix C, Table C-3. The water hammer pressures over stresses almost all plate sections greater than or equal to the

14.3 millimeter (9/16-inch) original plate thickness which show an average material loss of approximately 1.2%. However, these ratios are based on current industry guidelines for new design. When the hoop stress is compared to the plate yield stress, also shown in Table 4-1, the minimum factor of safety is 1.31, acceptable for late 1960 steel pipe.

TABLE 4-1 SUMMARY OF THICKNESS DATA AND STRESSES DUE TO INTERNAL PRESSURE

STATION (ft.)	MAX JOINT STRESS[1,3] (psi)	DYNAMIC HOOP STRESS INCREASE[1,3] (psi)	TOTAL WATER HAMMER STRESS[1,3] (psi)	STRESS RATIO[1,2,3]	FACTOR OF SAFETY AGAINST YIELD
0+25	5913	78	5991	0.33	4.51
1+50	7182	579	7761	0.43	3.48
2+96	8386	1059	9444	0.52	2.86
3+75	9812	1414	11226	0.62	2.41
5+00	10465	1588	12054	0.67	2.24
7+50	13793	2878	16670	0.93	1.62
9+25	14676	3340	18016	1.00	1.50
11+50	16454	3984	20438	0.81	1.86
14+60	18971	4120	23091	0.91	1.65
16+40	21870	4152	26021	1.03	1.46
18+91	16769	3323	20091	0.79	1.89
20+25	20902	4248	25150	0.99	1.51
22+12	22570	4356	26926	1.06	1.41
22+32	18655	3175	21830	0.86	1.74
24+32	19781	5158	24939	0.98	1.52
25+32	19714	5744	25457	1.01	1.49
26+31	20672	6509	27182	1.07	1.40
26+52	19311	6268	25579	1.01	1.49
27+72	20811	7389	28200	1.11	1.35
28+32	19747	7405	27153	1.07	1.40
28+82	19179	8140	27319	1.08	1.39
29+82	17817	7356	25174	1.05	1.43
30+81	18813	8121	26934	1.12	1.34
31+82	18184	8315	26499	1.10	1.36
32+82	17745	8580	26325	1.10	1.37
33+17	18719	8808	27527	1.15	1.31
34+82	17061	8423	25484	1.06	1.41
36+82	17120	8772	25892	1.08	1.39
38+42	21302	5813	27115	1.13	1.33

[1] Joint efficiency of 0.7 included
[2] Total stress / Allowable stress
[3] Uses 97.5% confidence thickness
[4] SF = Fy/Total stress

4.3 General Buckling Induced by External Loads

General shell buckling occurs when an external pressure implodes the penstock shell along its longitudinal axis. Two external loading conditions were considered in the analysis of the penstock: combined soil surcharge and live load due to an AASHTO HS-20 design vehicle traveling through the switchyard or nominal 445 newtons per meter (100 pounds per linear foot) elsewhere, and subatmospheric internal penstock pressure. The penstock appears to be located in cohesive fine grained soil above the local ground water table and drainage piping provided in the in the soil; therefore, external water pressure on the dewatered penstock is not considered an applicable loading condition.

The penstock was analyzed for buckling due to external loads applied to the top 120 degrees of the pipe. The analysis was very conservative as it included the dead weight of the whole shell. The snow load calculated was approximately 6224 Pa (130 psf). The depth of soil cover on the penstock used was 0.6 meters (2 feet). Another conservative value applied to the top of the penstock was a live load of 445 N/m (100 plf). No vehicular loading was used in the analysis where it does not pass under roadways. Also, because the penstock is buried, wind and earthquake were not used in the analysis.

Typical load combinations were calculated and the one producing the maximum load was used. The maximum pressure calculated due to shell dead load, soil cover, live load, and snow load was 20.5 kPa (2.97 psi). This is less than the allowable buckling pressure of 40.4 kPa (5.86 psi).

4.3.1 Surcharge Load Analysis

Kleinschmidt evaluated the external loading on the penstock where it crosses under the switchyard. At this location the penstock has a diameter and a wall thickness, which result in different buckling pressures under an assumed equivalent surface pressure and circular cross section. The combined calculated external pressures resulted in an equivalent pressure of 53.57 kPa (7.77 psi) on the pipe, much less than the allowable buckling pressure of 254.69 kPa (36.94 psi) using a factor of safety of 2.0 beneath the switchyard. Low soil stiffness values were used assuming less than optimal soils used to backfill from around the pipe with conservative compaction levels. Kleinschmidt's feels these calculations are conservative and additional materials testing of the backfill is not required.

An HS-20 truck load is per AASHTO Standard Specifications (AWWA 2004) is a 72,000-pound, three-axle truck with axles spaced at 14 feet from the front axle to middle axle then variable from 14 feet to 28 feet to the rear axle. Both rear axles weight 32,000 pounds.

4.3.2 SUBATMOSPHERIC INTERNAL PENSTOCK PRESSURE ANALYSIS

Subatmospheric internal pressure can occur if the penstock is dewatered quickly without adequate venting downstream of a headgate or as the result of a negative transient wave pressure. Evaluating negative internal pressures due to transient pressures was outside the scope of this project and no detailed hydrodynamic model was created, but the likelihood of occurrence of subatmospheric pressure is minimal, and allowable buckling pressures are greater than potential negative pressures due to transient waves at startup. The two 1.5-meter by 1.67-meter (5-foot by 5-foot – 6-inch) vents at the intake structure were evaluated according the *Hydroelectric Handbook*, Section 31 – Air Inlets (Creager and Justin 1950), assuming that water is stopped due to a headgate closing and that the full flow of the penstock is stopped all at once at the intake. Based on this calculation the required vent area is approximately 0.29 square meters (3.07 square feet), which is well below the area provided by the approximately 5.1-square-meter (55-square-foot) existing openings.

4.4 LOCAL BUCKLING AND STRESSES

Local buckling occurs when a point load causes a small area of the shell to be stressed beyond its material buckling stress limits, and it becomes permanently deformed. Boulders and rocks could be a source of point loads but no serious deformations were noted in the inspection. The penstock is continuously supported by the soil so it is unlikely there are excessive local buckling stresses in the penstock.

4.5 LOCAL WELD CONDITIONS

As noted in Section 1.0, NL Hydro discovered a 0.6 meter (2-foot) long crack in Penstock No. 1 in May 2016. Kleinschmidt responded and assisted with the design of the crack repair, *Crack Investigation and Repair Report – Penstock No. 1 Bay d'Espoir Hydroelectric Development* (June 2016). Kleinschmidt's investigation theorized that the crack, which occurred near a weld, was caused by an improper weld procedure during construction that resulted in incomplete fusion. After repairing the crack NL Hydro rewatered the penstock A second crack then opened in the Penstock No. 1 in September 2016. This crack led to a detailed weld investigation that has found many other microscopic cracks in the welds and, upon submittal of this report in November 2016, was still ongoing and conclusions as to the cause of the cracks have not been finalized.

Penstock No. 2 was built immediately following Penstock No. 1 which raises a possibility of similar cracking and weld failures occurring in Penstock No. 2. Kleinschmidt’s inspection in June 2016 was a visual inspection only of the welds and there were no overt indications of cracking occurring in the penstock. With the microscopic cracking occurring in Penstock No. 1, Kleinschmidt’s inspection does not preclude the same happening in Penstock No. 2. For that reason, we recommend that NL Hydro complete a detailed weld investigation within Penstock No. 2 in 2017.

5.0 CONCLUSIONS

Based on our inspection findings and evaluation, the existing steel penstock has significant remaining service life. No cracks were found in this penstock and the coating was in fair condition.

5.1 SHELL CONDITION AND THICKNESS

Measurements of the penstock shell thickness indicate minimal loss of material thickness. Some pitting was noted with organic material buildup on the interior. Assuming similar rates of material loss, the penstock should have significant service life remaining.

5.2 INTERNAL PRESSURE STRENGTH

Stress ratios for a combined static and dynamic internal pressures peak at 1.15 (Table 4-1). This indicates that the penstock does not meet present day design criteria for new penstock design. However, when the hoop stress is compared to the plate yield stress the minimum factor of safety is 1.31, acceptable for late 1960 steel pipe.

5.3 REMAINING SERVICE LIFE

The expected service life for a steel penstock is typically at least 80 years (ASCE 2012). This 50-year-old penstock, however, has shown little loss of thickness from the original plate thicknesses. We therefore anticipate that the penstock has an additional 80 years of useful service life (est. 2096) provided that the penstock interior coating is replaced before the steel begins to significantly deteriorate and other recommendations discussed in Section 6.0 are completed.

6.0 RECOMMENDATIONS

The penstock is good condition but several maintenance and repairs are recommended to ensure the penstock continues to operate as required. These recommendations include recoating the interior of the penstock, monitoring of the exterior for signs of leakage, and continued inspections of the interior.

6.1 Coating

We recommend recoating the interior of the penstock in 10-15 years. Areas where the coating was intact were in very good condition whereas areas with delaminated coating showed greater corrosion. The penstock also has organic build-up along the pipe which can contribute to accelerated corrosion on bare steel. Stress ratios are high enough that it would be prudent to plan for a recoating to reduce loss of material thickness and extend the service life of the penstock. A quality field applied penstock coating can last 20-40 years or more. If the penstock is recoated prior to significant steel deterioration every 20-40 years, NL Hydro can anticipate extending the life of the penstock another 80 years (give or take). The coating will not prevent cracking comparable to what occurred in Penstock No. 1 and it will not prevent the eventual corrosion of the shell from the exterior. The exterior is currently coated but it is difficult to tell its condition.

6.2 Ovalization

Due to the limited ovalization, 1.5% or less, of the penstock that is well within expected tolerances, Kleinschmidt does not have any immediate recommendations for NL Hydro to address the issue. We recommend that NL Hydro continue to monitor ovalization during their interior inspections (see Section 6.4). The stations where ovalization was measured by Kleinschmidt are in Table 3-1, and it is at these locations that future readings should be taken. We recommend taking three measurements at each location and finding the average. If any trends of decreasing vertical diameter are noted, then the compaction of the bedding and backfill material should be investigated.

6.3 Monitor Exterior

Kleinschmidt noted two locations where the ground was depressed during the external inspection, both were located on the right side of the penstock between STA 4+41.9 [STA 14+50] and 5+18 [17+00] and were marked with a red ribbon (Photo 14). These locations could be original from construction or could be signs of unnoticed leakage. These locations and the entire length should continue to be monitored for leakage indicated by unusual wetness and/or slumping or depressions of the ground over and around the penstock. The drains should also continue to be monitored for unusual increases in water levels. These should be routinely inspected and cleaned as necessary by NL Hydro.

6.4 INTERIOR INSPECTIONS

6.4.1 GENERAL EVALUATION

Kleinschmidt recommends that NL Hydro conducts an internal inspection in 2021 and 2026. These two inspections, spaced at a 5-year interval, should take thickness readings and vertical diameters at each station noted in Kleinschmidt's inspection report. Due to the larger material loss in the 41-millimeter (1 5/8-inch) plate, which was also an outlier with the other plate data, we recommend taking additional readings during the next inspection to get a more accurate measurement of material loss. These inspections should give a good indication as to the rate of coating delamination, shell deterioration, and ovalization. If the current condition of the penstock remains essentially unchanged over the next 10 years, Kleinschmidt would recommend continuing to inspect the coating condition visually every 5 years until it is replaced. The more detailed inspection of thickness measurements and vertical diameters could then be extended to a 10-year interval which is more typical of industry standard for penstock inspections.

6.4.2 DETAILED WELD INSPECTION

Kleinschmidt recommends that NL Hydro conduct a detailed weld inspection of Penstock No. 2 in 2017. The weld inspection should proceed similar to the Penstock No. 1 investigation:

- Recommend inspecting longitudinal and circumferential welds within Bay d'Espoir Penstock No. 2.
- Since no cracks are visable, we recommend starting in a location near the two large cracks in Penstock No. 1 (cracks No. 1 and No. 2). Since this was the "weakest link" area in Penstock No. 1, it is possible to also be weaker in Penstock No. 2.
- The weld inspector should begin with a visual inspection, looking for signs of weld corrosion, premature wear, and cracking. Where weld corrosion is noted, mag particle and angled beam testing should be completed. Mag particle testing is the preferred method for finding surface cracks, however many of the cracks in the No. 1 Penstock were within the center of the weld and angled beam (or similar) was necessary to find those.

- Testing should focus on areas where the black algae has peeled off the coating and weld corrosion is already present.
- If cracking is found on these areas, the weld tester should begin methodically testing each penstock can until no more cracking is discovered for a minimum of 2-3 consecutive cans. Where the coating has not peeled, the welds should be pressure washed prior to testing.
- Where cracking is noted, grind out a bit of each surface cracked weld and complete the mag particle test again. Repeat this step until there is no more surface cracks.
- At locations with weld erosion and/or cracking, add new weld to bring it back flush to original. The general weld repair procedure should be similar to that detailed in Kleinschmidt's June 2016 Penstock No. 1 Crack Report.

7.0 REFERENCES

Acres International Limited. 1988. Regulation Study of Bay D'Espoir System. Study Report to Newfoundland and Labrador Hydro. St John's, Newfoundland.

American Society of Civil Engineers (ASCE). 2012. Steel Penstocks – ASCE Manuals and Reports on Engineering Practice No. 79. 2nd Edition. American Society of Civil Engineers. Reston, Virginia.

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Crack Investigation and Repair Report, Penstock No. 1 Bay d'Espoir Hydroelectric Development. 2016. Kleinschmidt Technical Report to Newfoundland and Labrador Hydro.

Creager, W. P., and J. D. Justin. 1950. Hydroelectric Handbook. 2nd Edition. Wiley. Minneapolis, Minnesota.

APPENDIX A

PENSTOCK LAYOUT DRAWINGS

PENSTOCK PROFILE SHOWING STEEPER SECTIONS

REFERENCE DRAWINGS

F-105-C-1 INTAKE - GENERAL LAYOUT.
F-106-C-7 PRESSURE CONDUIT - PLAN & PROFILE - PIPELINE "A".
F-106-C-12 " " - " " - " "B".
F-106-C-9 " " - " " - PENSTOCK "A".
F-106-C-10 " " - " " - " "B".
F-106-C-5 SURGE TANK - GENERAL LAYOUT & DETAILS.
F-106-C-6 POWERHOUSE - GENERAL LAYOUT.

PIPE	DATA	INTAKE	BEND 1	BEND 2	BEND 3	BEND 4	BEND 5	BEND 6	BEND 7 (SURGE TANKS)	BEND 8	BEND 9	BEND 10	BEND 11	BEND 12	℄ OF UNITS
A	CHAINAGE	0+00.00	2+31.68	5+50.00	8+00.00	12+50.00	16+00.00	19+50.00	22+50.00	26+23.87	30+97.09	36+10.17	37+25.80	37+85.95	38+31.05
A	NORTHING	49,975.55	49,927.38						50,421.08		50,628.28		50,666.51		
A	EASTING	49,754.80	49,981.42						51,938.43		52,759.79		53,387.34		
B	CHAINAGE	0+26.72	2+12.76	5+25.00	8+50.00	13+10.00	16+00.00	19+00.00	22+50.00	25+00.00	31+36.18	36+48.67	37+64.83	38+24.98	38+70.08
B	NORTHING	50,024.46	49,985.78								50,700.98		50,747.62		
B	EASTING	49,765.20	49,947.17								52,782.26		53,409.20		

ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
W. E. BONNELL
LICENCE TO PRACTICE

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
3	JAN. 25/66		I.D.s INDICATED.	J.P.	JHM
2	OCT. 18/65		STA. B-1B VERTICAL ANGLE REVISED	J.P.	JHM
1	SEPT. 27/65		PLANS & PROFILES REVISED	J.P.	JHM

REVISIONS

APPROVED FOR CONSTRUCTION
AUG 13 1965
APPROVED BY:
MANAGER ENGINEERING

TRANS'N | ELECT'L | CIVIL JHM
PASSED

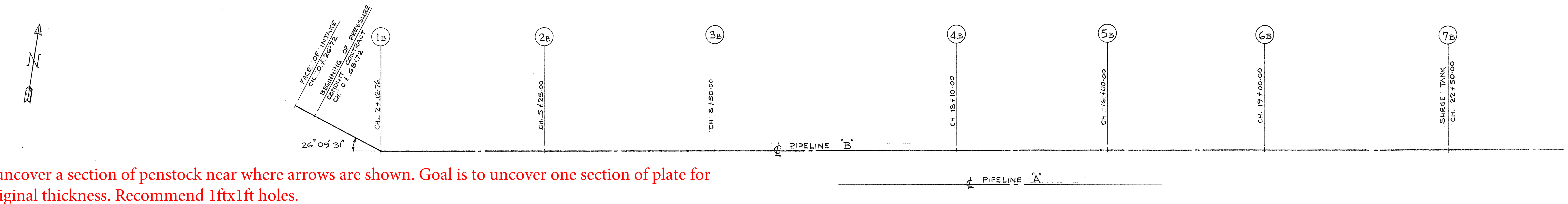
DESIGNED R. MAC D.
DRAWN J.P.
CHECKED A.P. HK
RECOMMENDED JH Mar

NEWFOUNDLAND AND LABRADOR POWER COMMISSION
BAY D'ESPOIR DEVELOPMENT
ENGINEERING AND DESIGN BY
SHAWMONT ENGINEERING NEWFOUNDLAND LIMITED
MONTREAL, QUEBEC

PRESSURE CONDUITS
LAYOUT & LOCATION DATA

CONTRACT	SCALE	FILE NO	DATE	DWG. NO.	REVISION
	1" = 100'-0"	PD - 11	SEPT. 27, 1965	F-106-C-11	3

PENSTOCK PROFILE SHOWING PLATE THICKNESS AND AREAS TO UNCOVER ON CROWN

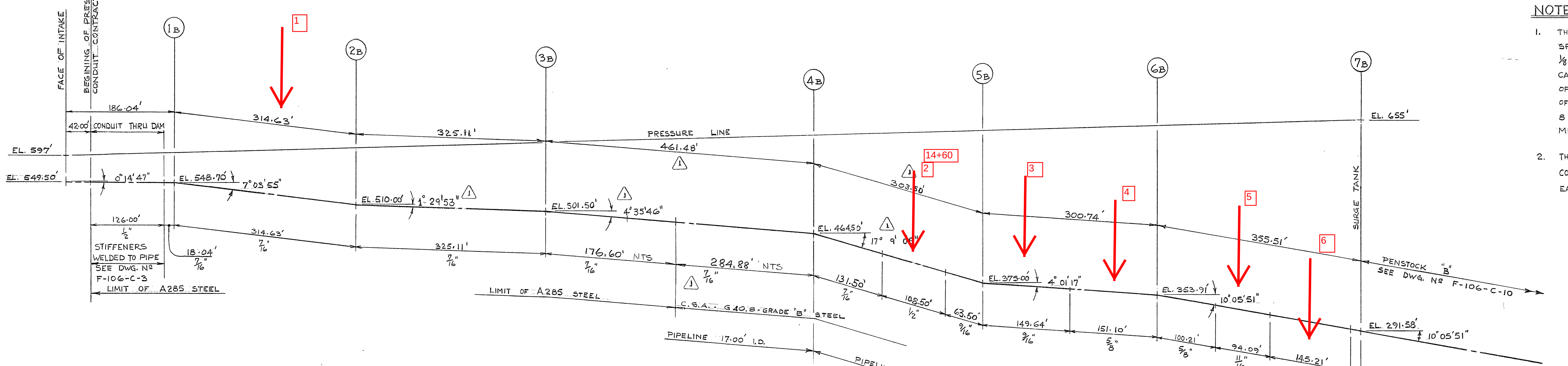


PLAN OF PIPELINE "B" ℄

SCALE 1" = 100'-0"

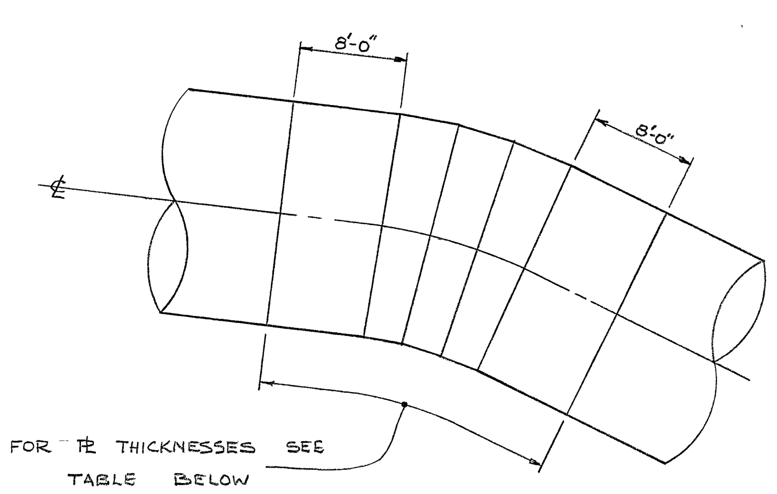
Please uncover a section of penstock near where arrows are shown. Goal is to uncover one section of plate for each original thickness. Recommend 1ftx1ft holes.

- Please note:
- We have not marked every plate thickness to try and limit the amount of excavation. We have skipped, where prudent, 1/16" plate thickness increases.
- Excavation of penstock is based on assuming 300-600mm of cover, once we get deeper if is NL Hydro's decision if the penstock should be uncovered or not.



PROFILE OF PIPELINE "B" ℄

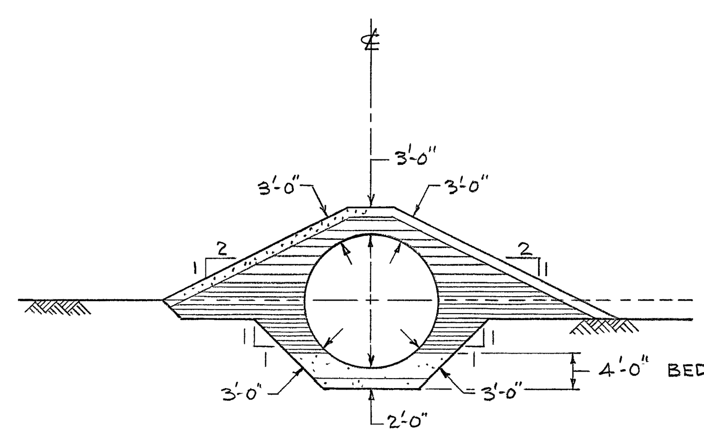
SCALE 1" = 100'-0"



TYPICAL BEND

SCALE 1" = 10'-0"

SEE SPEC M-3116



TYPICAL CROSS SECTION

(LOOKING DOWNSTREAM) SCALE 1" = 15'-0"

ANGLES & ℔ THICKNESSES AT BENDS

BEND	<A	<B	<C	TRUE ANGLE	℔ THICKNESS
1B	26° 09' 31"	0° 14' 47"	7° 03' 55"	26° 57' 55"	7/16"
2B	—	7° 03' 55"	1° 29' 53"	5° 34' 2"	1/2"
3B	—	1° 29' 53"	4° 35' 46"	3° 05' 53"	9/16"
4B	—	4° 35' 46"	17° 9' 05"	12° 33' 19"	9/16"
5B	—	17° 9' 05"	4° 01' 17"	13° 07' 48"	3/4"
6B	—	4° 01' 17"	10° 05' 51"	6° 04' 34"	13/16"
7B	—	10° 05' 51"	10° 05' 51"	0° 00' 00"	

ANGLE IN PLAN

VERTICAL ANGLES

NOTES

1. THE PIPELINE SHALL BE DESIGNED IN ACCORDANCE WITH SPECIFICATION Nº M-3116 EXCEPT FOR BENDS WHERE 1/8" SHALL BE ADDED TO PLATE THICKNESSES CALCULATED TO RESIST HOOP TENSION PLUS THE EFFECTS OF THE TORUS SHAPE OF BENDS. THIS EXTRA THICKNESS OF 1/8" SHALL EXTEND OVER THE BENDS AND AT LEAST 8 FEET UPSTREAM AND DOWNSTREAM OF THE LAST MITRE JOINT.
2. THERE ARE TWO SEPARATE CONDUITS CALLED "A" AND "B". CONDUIT "A" IS SOUTH OF CONDUIT "B". EACH CONDUIT CONSISTS OF A PIPELINE AND A PENSTOCK.

REFERENCE DRAWINGS

- F-106-C-3 CONDUITS THROUGH DAM.
- F-106-C-4 SURGE TANKS - DETAILS OF TEES.
- F-106-C-5 SURGE TANKS - GENERAL LAYOUT & DETAILS.
- F-106-C-6 PRESSURE CONDUITS - CLEARING.
- F-105-C-1 INTAKE GENERAL LAYOUT.
- F-106-C-11 PRESSURE CONDUITS - LAYOUT & LOCATION DATA.
- F-106-C-7 " " - PLAN & PROFILE PIPELINE "A".
- F-106-C-10 " " - " " PENSTOCK "B".

OTHER REFERENCES

1. SPECIFICATION Nº M-3116.

ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
W. E. BONNELL
LICENCE TO PRACTICE

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
1	28 SEPT 66		REV. ON PROFILE ℄ EL. AT 3B & 4B	C.C.	JHM

REVISIONS

APPROVED FOR CONSTRUCTION
OCT 21 1965
APPROVED BY:
MANAGER ENGINEERING

TRANS'N	ELECT'L	CIVIL
		JHM

PASSED

DESIGNED R. MAC D.
DRAWN J.P.
CHECKED HK
RECOMMENDED J H Marsh P Eng

NEWFOUNDLAND AND LABRADOR POWER COMMISSION

BAY D'ESPOIR DEVELOPMENT

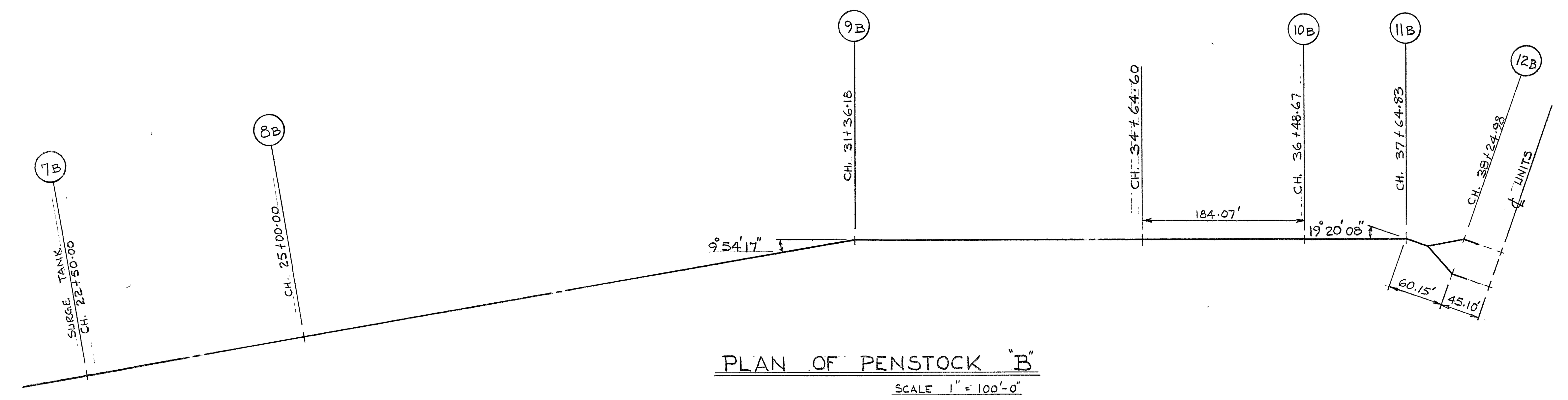
ENGINEERING AND DESIGN BY
SHAWMONT ENGINEERING NEWFOUNDLAND LIMITED
MONTREAL, QUEBEC

PRESSURE CONDUITS
PLAN & PROFILE PIPELINE "B"

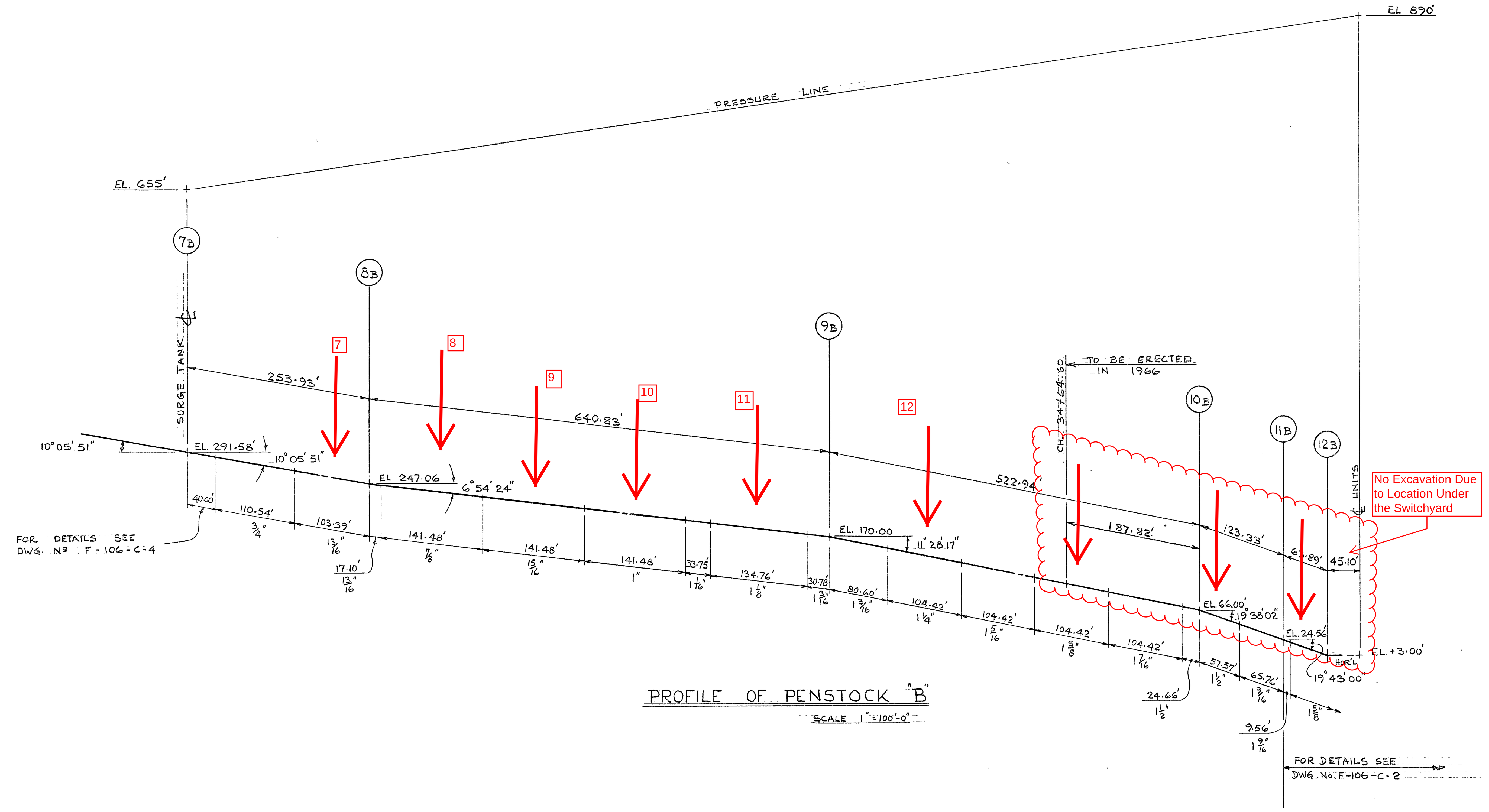
CONTRACT	SCALE	FILE NO.	DATE	DWG. NO.	REVISION
	NOTED	PD-11	OCT. 18, 1965	F-106-C-12	1

19

PENSTOCK PROFILE SHOWING PLATE THICKNESS AND AREAS TO UNCOVER ON CROWN



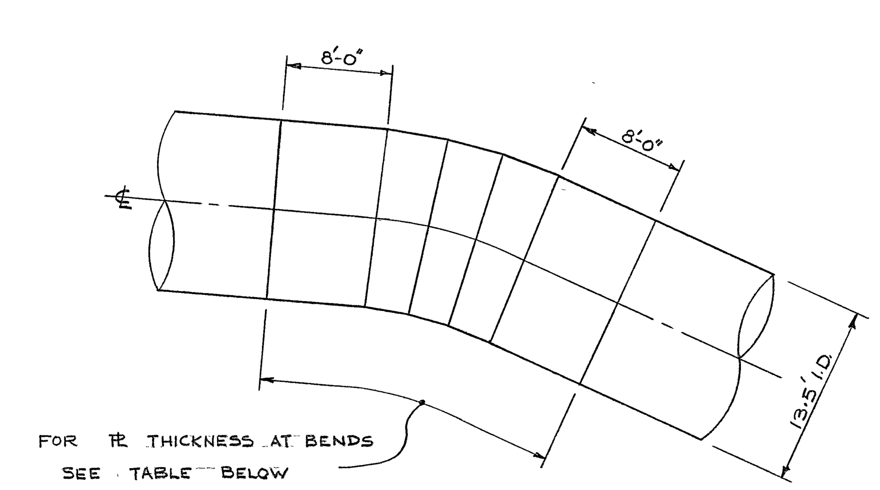
PLAN OF PENSTOCK "B"
SCALE 1" = 100'-0"



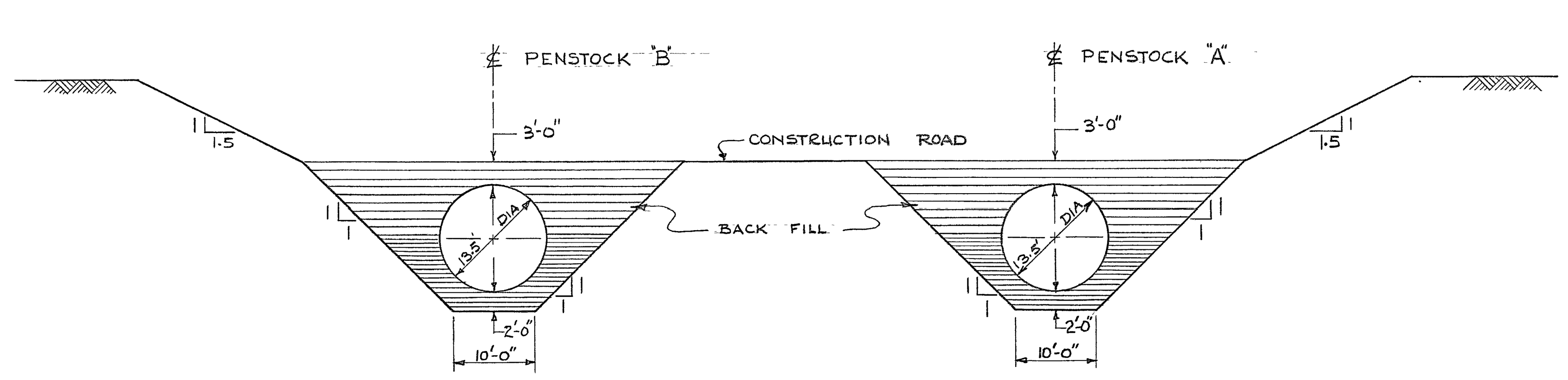
PROFILE OF PENSTOCK "B"
SCALE 1" = 100'-0"

NOTES

1. THE PENSTOCK SHALL BE DESIGNED IN ACCORDANCE WITH SPECIFICATION Nº M-3116 EXCEPT FOR BENDS WHERE 1/8" SHALL BE ADDED TO PLATE THICKNESSES CALCULATED TO RESIST HOOP TENSION AND THE EFFECTS OF THE TORUS SHAPE OF BENDS. THIS EXTRA THICKNESS OF 1/8" SHALL EXTEND OVER THE BENDS AND AT LEAST 8 FEET UPSTREAM AND DOWNSTREAM OF THE LAST MITRE JOINT.
2. THE INSIDE DIAMETER OF THE PENSTOCK IS 13.50'
3. STEEL SHALL BE C.S.A. G40.8 GRADE "B".
4. FOR TYPICAL CROSS SECTION FROM 7B TO 9B SEE DWG Nº F-106-C-7.
5. A PORTION AT THE DOWNSTREAM END OF THIS PENSTOCK "B" SHALL BE ERECTED IN 1966, THE REMAINDER IN 1967. SEE PROFILE.



TYPICAL BEND
SCALE 1" = 10'-0"



TYPICAL CROSS SECTION 9B TO 11B
SCALE 1" = 15'-0"

REFERENCE DRAWINGS

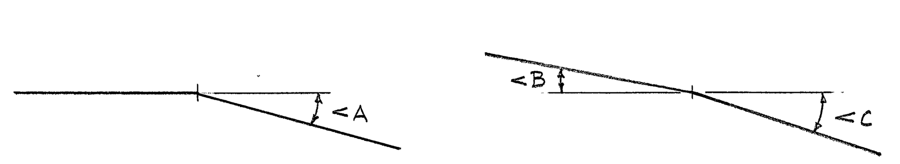
F-106-C-2	PRESSURE CONDUITS - LAYOUT & DETAILS OF BIFURCATION.
F-106-C-4	SURGE TANKS - DETAILS OF TEES,
F-106-C-5	SURGE TANKS - GENERAL LAYOUT & DETAILS.
F-106-C-6	PRESSURE CONDUITS - CLEARING.
F-106-C-11	PRESSURE CONDUITS - LAYOUT & LOCATION DATA.

OTHER REFERENCES

1. SPECIFICATION Nº M-3116

BEND	< A	< B	< C	TRUE ANGLE	PL THICKNESS
7 B	—	10° 05' 51"	10° 05' 51"	0° 00' 00"	—
8 B	—	10° 05' 51"	6° 54' 24"	3° 11' 27"	1 1/16"
9 B	9° 54' 17"	6° 54' 24"	11° 28' 17"	10° 47' 16"	1 7/16"
10 B	—	11° 28' 17"	19° 38' 02"	8° 09' 45"	1 3/4"
11 B	19°20' 08"	19° 38' 02"	19° 43' 00"	18° 11' 49"	1 7/8"

ANGLES AND PL THICKNESSES AT BENDS



ANGLE IN PLAN   VERTICAL ANGLES

ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
W. E. BONNELL
LICENCE TO PRACTICE

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
2	SEPT.		REVISED PLAN & PROFILE	J.P	

REVISIONS

APPROVED FOR CONSTRUCTION
SEP 29 1965
APPROVED BY:
MANAGER ENGINEERING

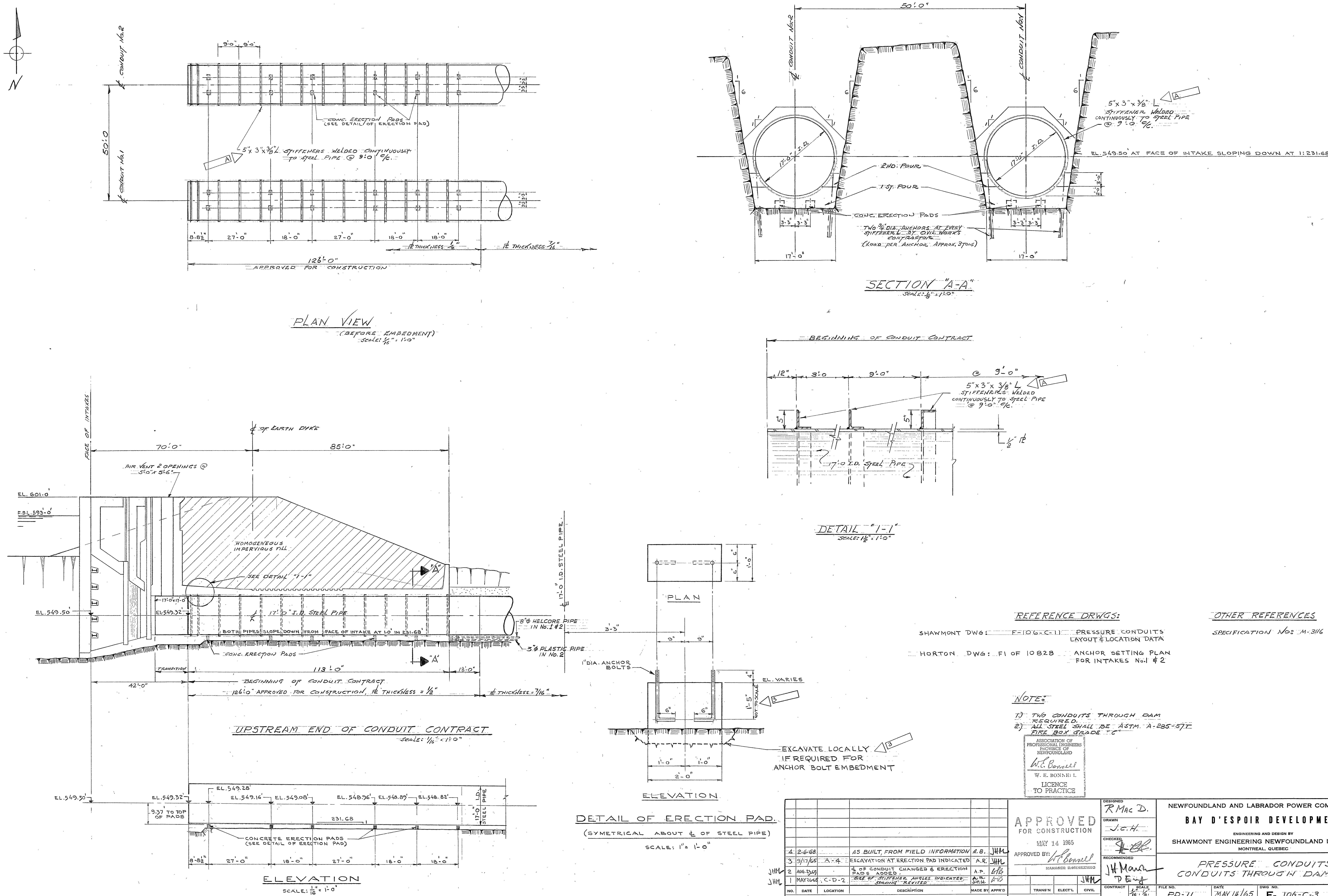
TRANS'N | ELECT'L | CIVIL
PASSED

DESIGNED R. MacD.
DRAWN J.P
CHECKED A.P.
RECOMMENDED P. Eng.

NEWFOUNDLAND AND LABRADOR POWER COMMISSION
BAY D'ESPOIR DEVELOPMENT
ENGINEERING AND DESIGN BY
SHAWMONT ENGINEERING NEWFOUNDLAND LIMITED
MONTREAL, QUEBEC

PRESSURE CONDUITS
PLAN & PROFILE PENSTOCK "B"

CONTRACT	SCALE	FILE NO.	DATE	DWG. NO	REVISION
	NOTED	PD-11	SEPT. 1965	F-106-C-10	2



REFERENCE DRWGS:

SHAWMONT DWG: F-106-C-11 PRESSURE CONDUITS LAYOUT & LOCATION DATA

HORTON DWG: F1 OF 10828 ANCHOR SETTING PLAN FOR INTAKES No. 1 & 2

OTHER REFERENCES

SPECIFICATION No: M-3116

NOTES:

1) TWO CONDUITS THROUGH DAM REQUIRED.
2) ALL STEEL SHALL BE ASTM. A-285-57T FIRE BOX GRADE "C"

ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
W. E. Bonnell
W. E. BONNELL
LICENCE TO PRACTICE

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
4	2-6-68		AS BUILT, FROM FIELD INFORMATION	A.B.	JHM
3	9/17/65	A-4	EXCAVATION AT ERECTION PAD INDICATED	A.R.	JHM
2	AUG.23,65		℄ OF CONDUIT CHANGED & ERECTION PADS ADDED.	A.P.	LB
1	MAY26-65	C-D-2	SIZE OF STIFFENER ANGLES INDICATED, SPACING REVISED	A.R. J.C.H.	LB

REVISIONS

APPROVED FOR CONSTRUCTION
MAY 14 1965
APPROVED BY: W. E. Bonnell
MANAGER ENGINEERING

TRANS'N | ELECT'L | CIVIL JHM
PASSED

DESIGNED: R MAC D.
DRAWN: J.C.H.
CHECKED:
RECOMMENDED: JH Marsh DEng

NEWFOUNDLAND AND LABRADOR POWER COMMISSION

BAY D'ESPOIR DEVELOPMENT

ENGINEERING AND DESIGN BY
SHAWMONT ENGINEERING NEWFOUNDLAND LIMITED
MONTREAL, QUEBEC

PRESSURE CONDUITS
CONDUITS THROUGH DAM

CONTRACT	SCALE	FILE NO.	DATE	DWG NO.	REVISION
	1/16", 1/8", 1½" = 1'-0"	PD-11	MAY 14/65	F-106-C-3	4

NOTES:- TRUE ANGLE AT (12) = 35° 23' 18"

TWO IDENTICAL BIFURCATIONS REQUIRED

REFERENCES:
SPECIFICATION No: M-3116

ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
W. F. BONNELL
LICENCE TO PRACTICE

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
4	FEB. 25/66		ANGLE RINGS & DETAIL "A" ADDED. CONCRETE OUTLINE REVISED.	J.P.	JHM
3	15-11-65	E-5, C-7	4" OUTLETS ADDED, UPSTR. EXTENT OF CONCR. GIVEN	A.R.	JHM
2	27-9-65		DIMENSIONS REVISED	A.R.	JHM
1	6/7/65		BIFURCATION INCLINED 19°43'		JHM

REVISIONS

APPROVED FOR CONSTRUCTION
JUL 6 1965
APPROVED BY:
MANAGER ENGINEERING

TRANS'N	ELECT'L	CIVIL
		JHM

PASSED

DESIGNED R. Mac D.
DRAWN R. Mac D.
CHECKED
RECOMMENDED JH Mawr PEng

NEWFOUNDLAND AND LABRADOR POWER COMMISSION
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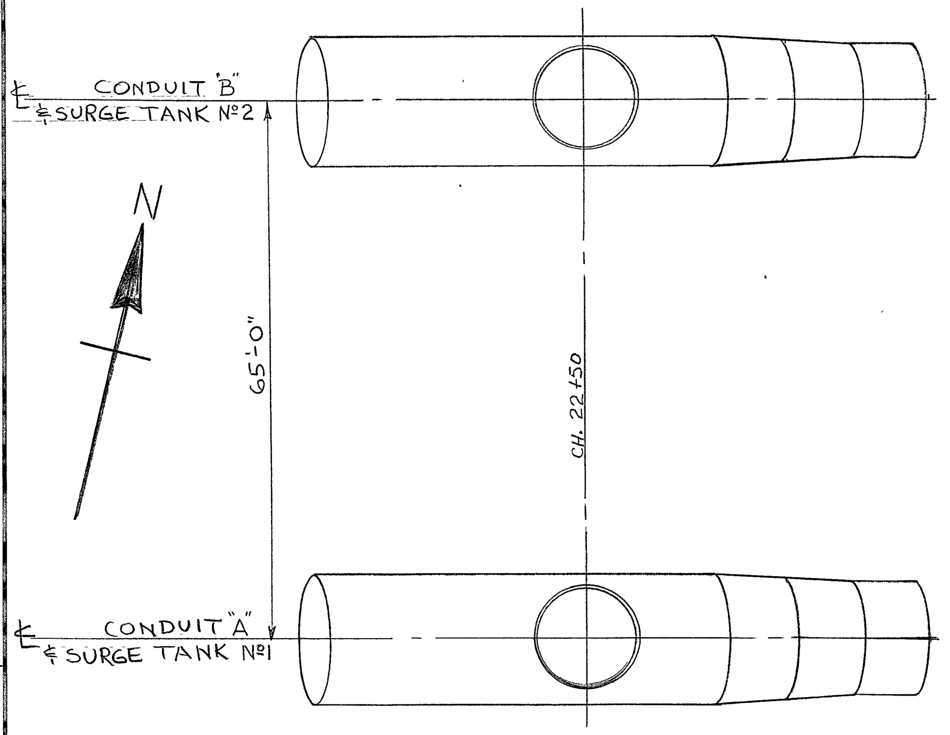
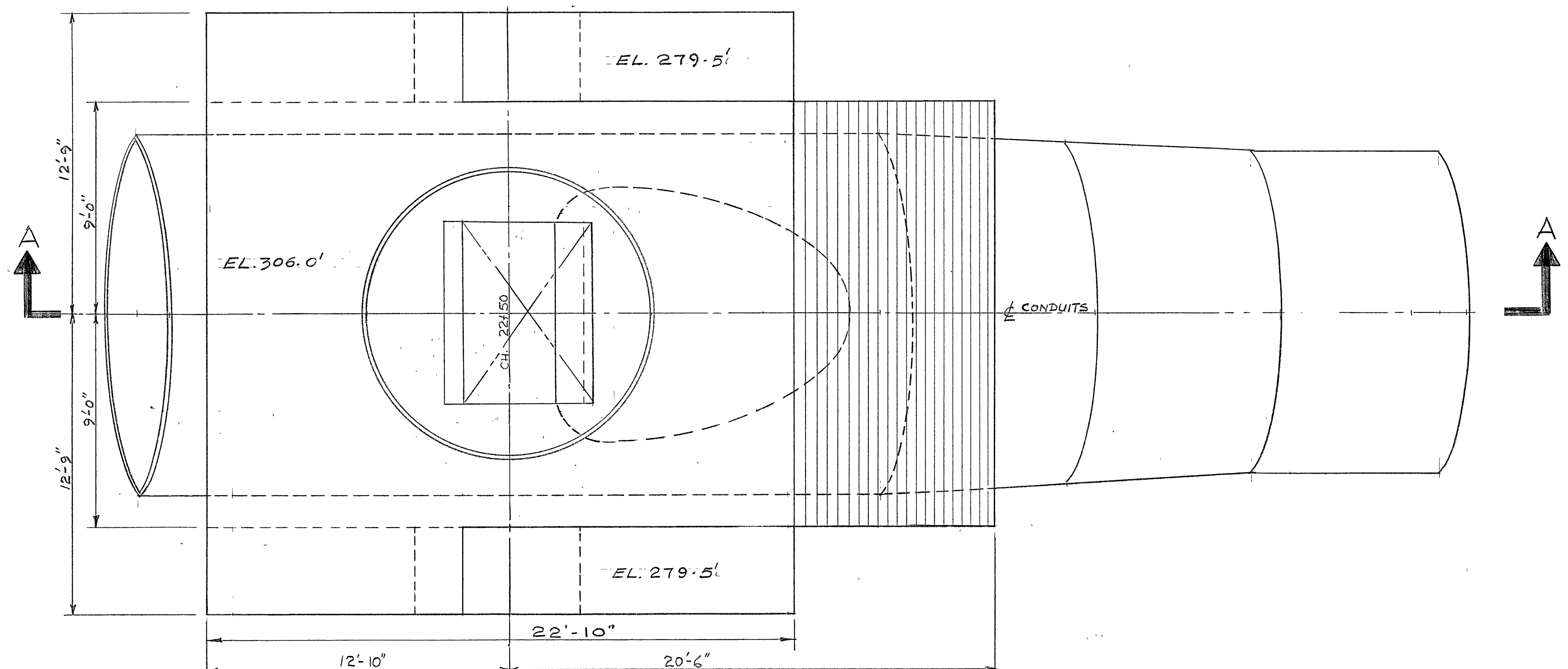
PRESSURE CONDUITS
LAYOUT OF BIFURCATION

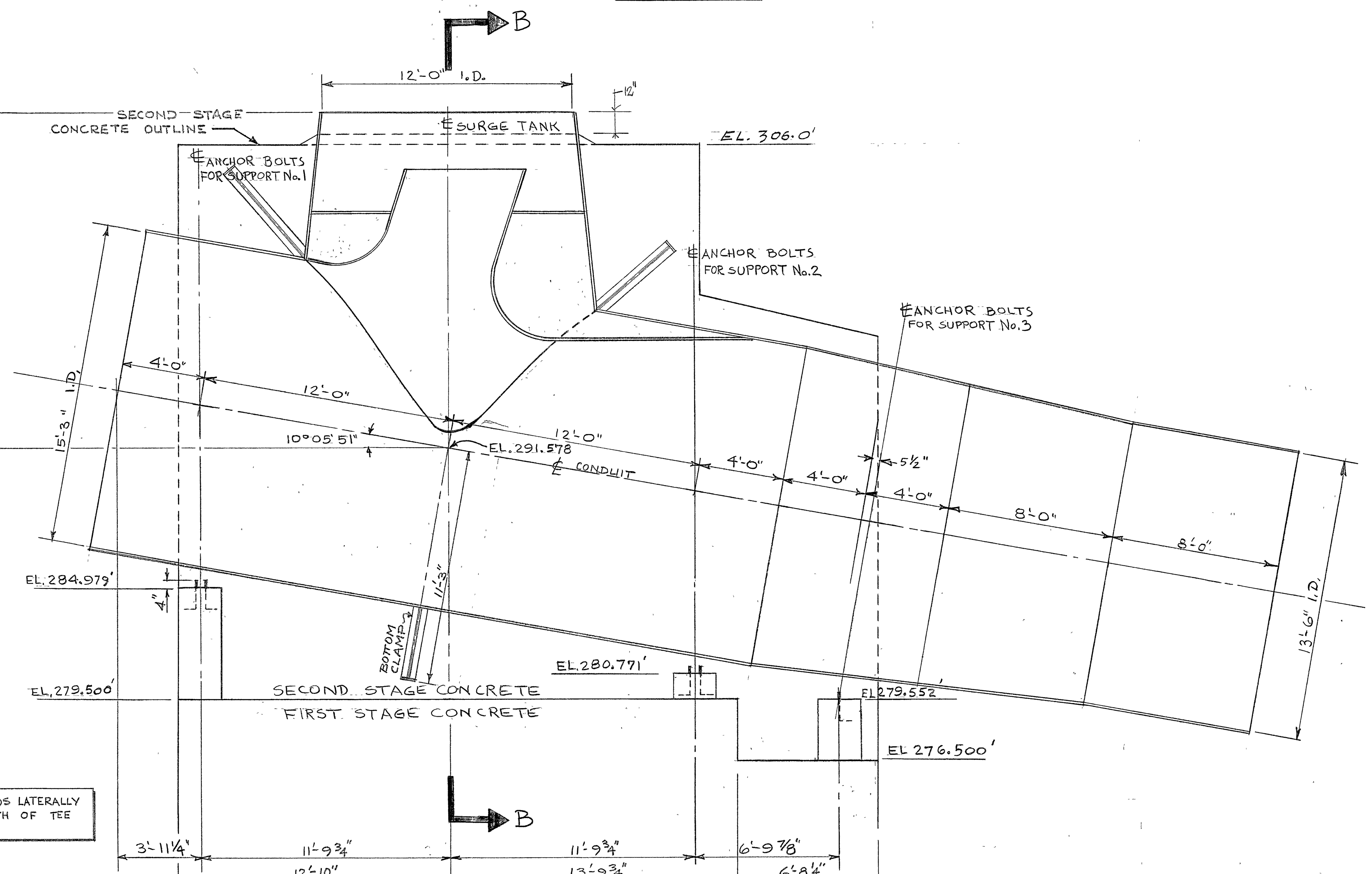
CONTRACT	SCALE	FILE NO.	DATE	DWG NO.	REVISION
	1/8" TO 1'	PD-11	6 July '65	F-106-C-2	4



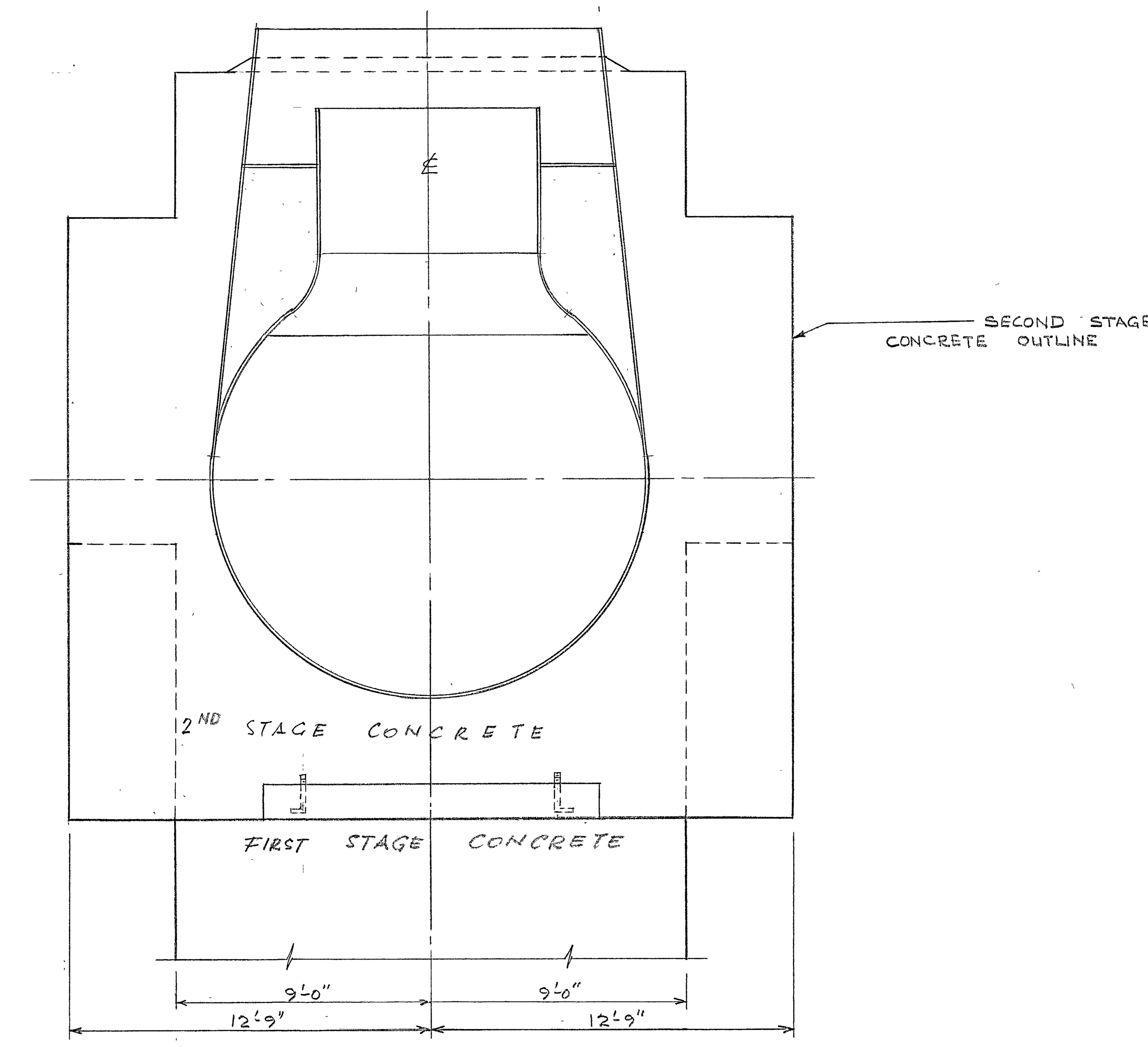
PLAN
SCALE 1/16" = 1'-0"



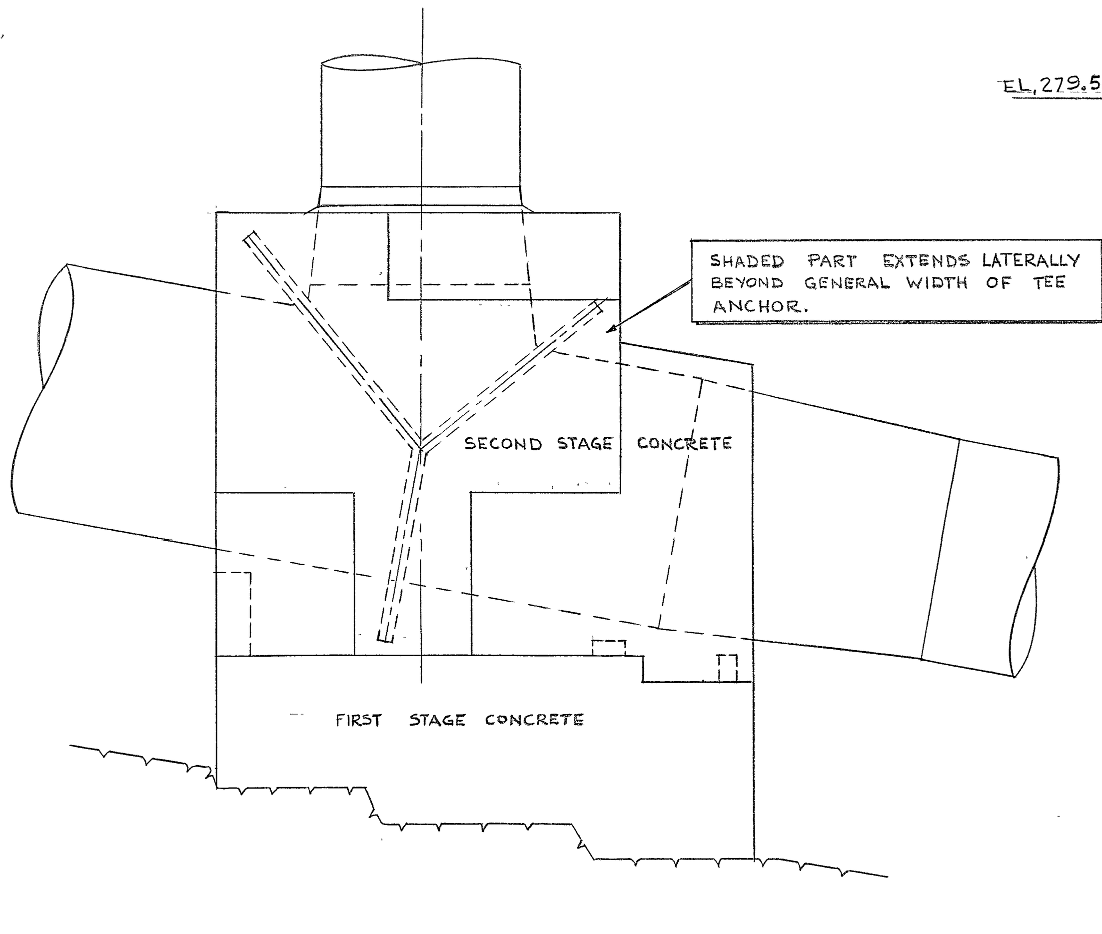
PLAN
SCALE 1/4" = 1'-0"



SECTION A-A
SCALE 1/4" = 1'-0"



SECTION B-B
SCALE 1/4" = 1'-0"



SIDE ELEVATION OF SURGE TANK TEE & CONCRETE
SCALE 1/8" = 1'-0"

MANUFACTURER'S DWGS. HORTON STEEL WORKS

SME 158-T-1 CONTRACT #10833 DWG F1 TEE ANCHOR SETTING.
" -2,3, & 5 " 1,2, & 4 TEE DETAILS.

REFERENCE DRAWINGS

F-106-C-13 SURGE TANKS - DETAILS OF RESTRICTED ORIFICE.
F-106-C-17 SURGE TANKS - TEE, STAGE I, OUTLINE AND REINFORCING.

NOTES.

1. TWO IDENTICAL TEES ARE REQUIRED.
2. EXTERNAL REINFORCING PLATES FOR TEES ARE ONLY PARTIALLY SHOWN.
3. PLATE THICKNESSES ARE NOT SHOWN.
4. ELEVATION OF PRESSURE LINE AT ℄ OF SURGE TANK = 655'
5. SURGE TANK Nº 1 IS ON CONDUIT "A"
" " Nº 2 " " " "B"

ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
W. E FONNE L
LICENCE TO PRACTICE

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
2	JAN. 10/66		CONCRETE SHAPE REVISED	J.P.	JHM
1	9/14/65	-	REDRAWN	A.R.	JHM

REVISIONS

APPROVED FOR CONSTRUCTION
SEP 24 1965
APPROVED BY:
MANAGER ENGINEERING

TRANS'N	ELECT'L	CIVIL
		JHM

PASSED

DESIGNED
DRAWN A.R.
CHECKED
RECOMMENDED JH Marica P.Eng

NEWFOUNDLAND AND LABRADOR POWER COMMISSION
BAY D'ESPOIR DEVELOPMENT
ENGINEERING AND DESIGN BY
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MONTREAL, QUEBEC

SURGE TANKS
DETAILS OF TEES

CONTRACT	SCALE	FILE NO	DATE	DWG. NO.	REVISION
	1/4"=1'-0"	PD-11		F-106-C-4	2

APPENDIX B

PHOTOGRAPHS

PHOTO 1 - INTAKE ACCESS SHAFT

PHOTO 2 - MANHOLE MIDWAY BETWEEN INTAKE AND SURGE TANK

PHOTO 3 - MANHOLE MIDWAY BETWEEN SURGE TANK AND POWERHOUSE

PHOTO 4 - EXIT AT MANHOLE AT POWERHOUSE

PHOTO 5 - LEAK AT BASE OF HEADGATE

PHOTO 6 - GENERAL CONDITION OF MODERATELY CORRODED UNCOATED STEEL

PHOTO 7 - CORROSION AT DELAMINATED COATING

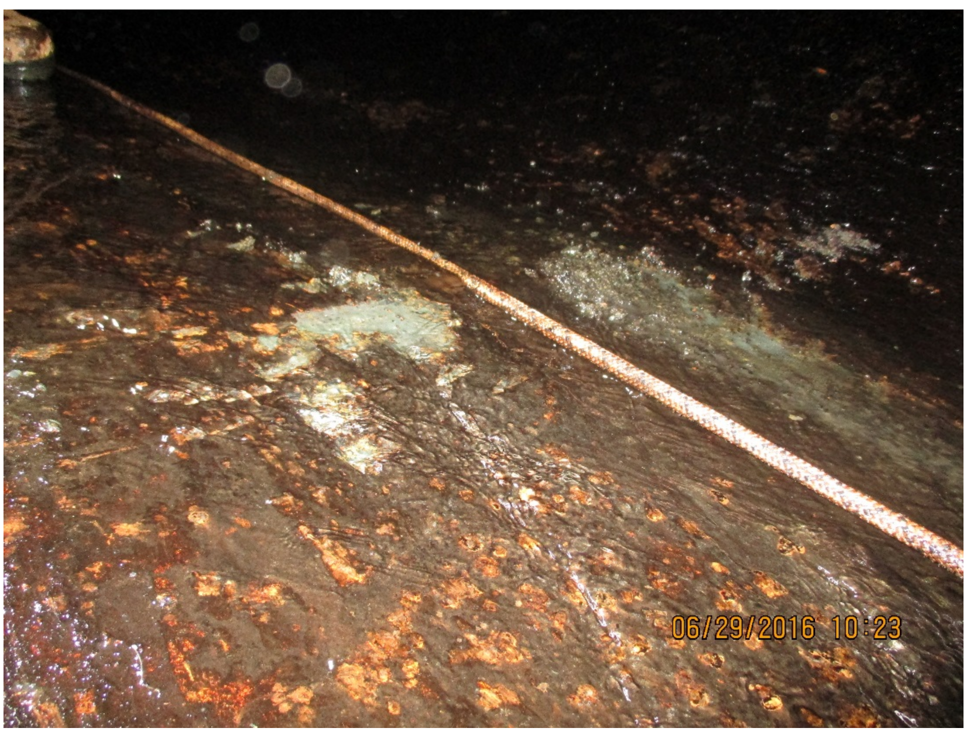

PHOTO 8 - 1/2" MISALIGNMENT BETWEEN ADJACENT CANS AT INVERT

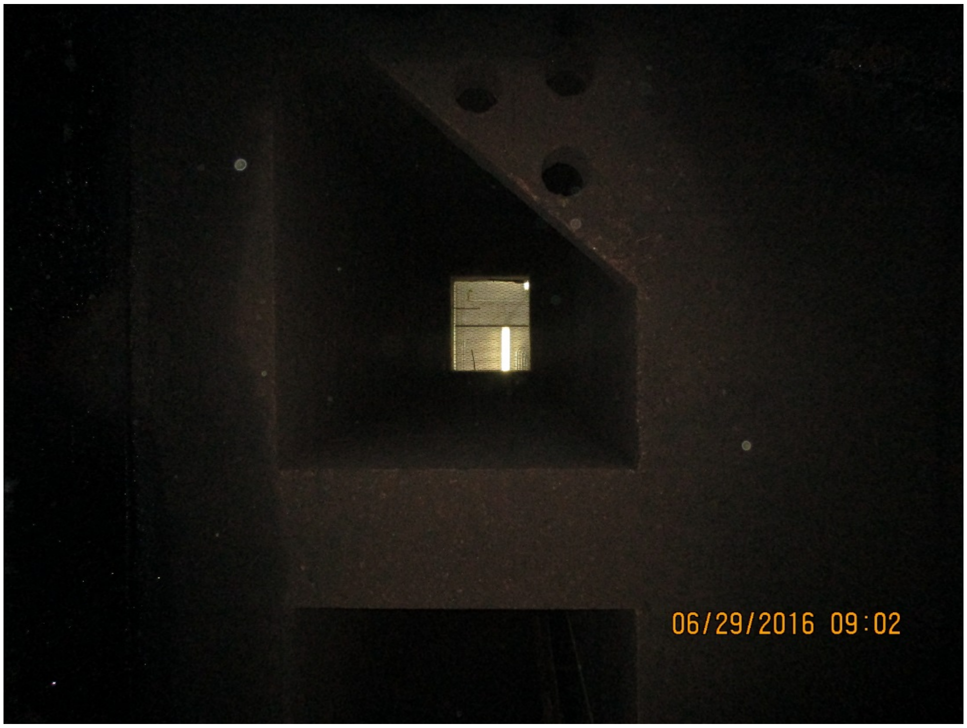

PHOTO 9 – VENT SHAFT AT INTAKE STRUCTURE

PHOTO 10 - SIDE VIEW AT UPSTREAM FACE OF WYE

PHOTO 11 - BIFURCATION OF PENSTOCK 2 UPSTREAM OF UNITS

PHOTO 12 - VIEW ON TOP OF PENSTOCK NO. 2 LOOKING UPSTREAM (INTAKE VISIBLE AT TOP OF HILL)

PHOTO 13 - TYPICAL PENSTOCK EXTERIOR SURFACE CONDITION AT EXCAVATION

PHOTO 14 – DEPRESSIONS NOTED WITH FLAGGING WRAPPED ROCKS

APPENDIX C

THICKNESS DATA AND STRESS CALCULATIONS

C-1 THICKNESS MEASUREMENTS AND STRESSES (FSL)
C-2 THICKNESS MEASUREMENTS AND STRESSES (FLOOD)
C-3 WATER HAMMER (DYNAMIC) STRESSES

TABLE C-1 - Full Supply Level (FSL)
PENSTOCK THICKNESS MEASURMENTS AND STRESSES

Location[1]		Clock Position[2]	Reading No.[3,4]	Thickness Reading (in)	Avg. Thickness (in)	Original Plate Thickness (in)	Difference from Original Plate thickness	C.L. Elev (ft)	at Joints Stress (psi)[7]	at Joints Stress Ratio[8]	Base Material Stress (psi)[7]	Base Material Stress Ratio[8]	Notes
P2-I	0+25	4	129	0.5310		1/2	6%	549.39	5989.5	0.35	4192.7	0.25	Headgate is Station 0+00
P2-I	0+25	4	130	0.5300		1/2							16.937
P2-I	0+25	4	131	0.5260	0.529	1/2							16.943
P2-I	0+25	6	132	0.5530		1/2	11%	549.39	5710.1	0.34	3997.1	0.24	16.929
P2-I	0+25	6	133	0.5600		1/2							
P2-I	0+25	6	134	0.5560	0.556	1/2							
P2-I	0+25	8	135	0.5270		1/2	5%	548.85	6040.2	0.36	4228.1	0.25	
P2-I	0+25	8	136	0.5280		1/2							
P2-I	0+25	8	137	0.5260	0.527	1/2							
P2-I	1+50	4	138	0.4330		7/16	-3%	548.85	7674.8	0.45	5372.3	0.32	At bend, 1/8" thicker than plates
P2-I	1+50	4	139	0.4220		7/16							16.775
P2-I	1+50	4	140	0.4220	0.426	7/16							16.839
P2-I	1+50	6	141	0.4500		7/16	3%	548.85	7101.3	0.42	4970.9	0.29	16.799
P2-I	1+50	6	142	0.4530		7/16							
P2-I	1+50	6	143	0.4490	0.451	7/16							
P2-I	1+50	8	144	0.4700		7/16	8%	548.85	6770.6	0.40	4739.4	0.28	
P2-I	1+50	8	145	0.4700		7/16							
P2-I	1+50	8	146	0.4720	0.471	7/16							hollow ring w/hammer 5 to 7 o'clock
P2-E	2+96	12	244	0.4470		7/16	2%	540.34	8385.6	0.49	5869.9	0.35	Excavation 1
P2-E	2+96	12	245	0.4450		7/16							10.9
P2-E	2+96	12	246	0.4440	0.445	7/16							Two locations noted with rocks with depressions as possible locations of seepage. NLH to look at when watered up.
P2-I	3+75	4	147	0.4270		7/16	-2%	530.62	10142.7	0.60	7099.9	0.42	3'-4' u/s to d/s
P2-I	3+75	4	148	0.4280		7/16							17.015
P2-I	3+75	4	149	0.4270	0.427	7/16							17.001
P2-I	3+75	6	150	0.4540		7/16	3%	530.62	9613.3	0.57	6729.3	0.40	16.961
P2-I	3+75	6	151	0.4530		7/16							
P2-I	3+75	6	152	0.4510	0.453	7/16							
P2-I	3+75	8	153	0.4520		7/16	3%	530.62	9679.3	0.57	6775.5	0.40	
P2-I	3+75	8	154	0.4490		7/16							
P2-I	3+75	8	155	0.4490	0.450	7/16							
P2-I	5+00	4	156	0.5080		1/2	1%	515.24	10457.6	0.62	7320.3	0.43	At vertical bend 2B
P2-I	5+00	4	157	0.5070		1/2							
P2-I	5+00	4	158	0.5070	0.507	1/2							
P2-I	5+00	6	159	0.5120		1/2	3%	515.24	10397.6	0.61	7278.3	0.43	
P2-I	5+00	6	160	0.5150		1/2							
P2-I	5+00	6	161	0.5180	0.515	1/2							
P2-I	5+00	8	162	0.5040		1/2	1%	515.24	10540.9	0.62	7378.6	0.43	
P2-I	5+00	8	163	0.5030		1/2							
P2-I	5+00	8	164	0.5030	0.503	1/2							
P2-I	6+60	N/A	N/A			7/16		506.94					Circumferential joint at invert has approx. 1/2" height difference between cans. No signs of cracking
P2-I	7+50	4	165	0.4220		7/16	-4%	504.59	14199.1	0.84	9939.3	0.58	16.856
P2-I	7+50	4	166	0.4210		7/16							16.874
P2-I	7+50	4	167	0.4210	0.421	7/16							16.854
P2-I	7+50	6	168	0.4510		7/16	3%	504.59	13400.2	0.79	9380.1	0.55	
P2-I	7+50	6	169	0.4500		7/16							
P2-I	7+50	6	170	0.4470	0.449	7/16							
P2-I	7+50	8	171	0.4370		7/16	0%	504.59	13778.3	0.81	9644.8	0.57	
P2-I	7+50	8	172	0.4380		7/16							
P2-I	7+50	8	173	0.4430	0.439	7/16							
P2-I	9+25	4	174	0.4420		7/16	1%	496.93	14652.1	0.86	10256.5	0.60	17.138
P2-I	9+25	4	175	0.4410		7/16							17.07
P2-I	9+25	4	176	0.4410	0.441	7/16							16.997
P2-I	9+25	6	177	0.4430		7/16	1%	496.93	14656.5	0.86	10259.5	0.60	
P2-I	9+25	6	178	0.4430		7/16							
P2-I	9+25	6	179	0.4410	0.442	7/16							Video of weld for closer look
P2-I	9+25	8	180	0.4390		7/16	0%	496.93	14719.0	0.87	10303.3	0.61	
P2-I	9+25	8	181	0.4400		7/16							
P2-I	9+25	8	182	0.4390	0.439	7/16							
P2-I	11+50	4	198	0.4660		7/16	6%	478.90	16604.3	0.66	11623.0	0.46	16.742
P2-I	11+50	4	199	0.4610		7/16							16.728
P2-I	11+50	4	200	0.4610	0.463	7/16							16.764
P2-I	11+50	6	201	0.4630		7/16	6%	478.90	16494.9	0.65	11546.4	0.46	
P2-I	11+50	6	202	0.4620		7/16							
P2-I	11+50	6	203	0.4610	0.462	7/16							
P2-I	11+50	8	204	0.4690		7/16	7%	478.90	16262.8	0.64	11384.0	0.45	
P2-I	11+50	8	205	0.4720		7/16							
P2-I	11+50	8	206	0.4690	0.470	7/16							
P2-I	14+60	4	207	0.5080		1/2	2%	425.87	19344.1	0.76	13540.8	0.53	15.243
P2-I	14+60	4	208	0.5090		1/2							15.22
P2-I	14+60	4	209	0.5080	0.508	1/2							15.246
P2-I	14+60	6	210	0.5210		1/2	4%	425.87	18860.6	0.74	13202.4	0.52	
P2-I	14+60	6	211	0.5220		1/2							
P2-I	14+60	6	212	0.5210	0.521	1/2							
P2-I	14+60	8	213	0.5240		1/2	5%	425.87	18819.5	0.74	13173.6	0.52	
P2-I	14+60	8	214	0.5230		1/2							

P2-I	14+60	8	215	0.5260	0.524	1/2							
P2-E	14+60	12	247	0.5400		1/2	7%	425.87	18860.0	0.74	13202.0	0.52	Excavation 2
P2-E	14+60	12	248	0.5290		1/2							29.2
P2-E	14+60	12	249	0.5290	0.533	1/2							
P2-I	16+40	4	216	0.5800		9/16	3%	374.51	21987.2	0.87	15391.0	0.61	15.206
P2-I	16+40	4	217	0.5800		9/16							15.335
P2-I	16+40	4	218	0.5790	0.580	9/16							15.172
P2-I	16+40	6	219	0.6010		9/16	6%	374.51	21393.6	0.84	14975.5	0.59	
P2-I	16+40	6	220	0.5980		9/16							
P2-I	16+40	6	221	0.5970	0.599	9/16							
P2-I	16+40	8	222	0.5740		9/16	2%	374.51	22227.9	0.88	15559.5	0.61	
P2-I	16+40	8	223	0.5730		9/16							
P2-I	16+40	8	224	0.5730		9/16							
P2-I	16+40	8	225	0.5730	0.573	9/16							
P2-I	18+91	4	226	0.8200		13/16	1%	356.91	16728.5	0.66	11710.0	0.46	at vert. bend. 6B
P2-I	18+91	4	227	0.8200		13/16							15.158
P2-I	18+91	4	228	0.8200	0.820	13/16							15.146
P2-I	18+91	6	229	0.8260		13/16	2%	356.91	16643.2	0.66	11650.3	0.46	15.153
P2-I	18+91	6	230	0.8250		13/16							
P2-I	18+91	6	231	0.8250	0.825	13/16							
P2-I	18+91	8	232	0.8130		13/16	0%	356.91	16934.2	0.67	11853.9	0.47	
P2-I	18+91	8	233	0.8120		13/16							
P2-I	18+91	8	234	0.8110	0.812	13/16							
P2-I	20+25	4	235	0.6980		11/16	0%	337.96	21850.8	0.86	15295.6	0.60	
P2-I	20+25	4	236	0.6840		11/16							
P2-I	20+25	4	237	0.6900	0.691	11/16							
P2-I	20+25	6	238	0.7380		11/16	7%	337.96	20298.2	0.80	14208.7	0.56	
P2-I	20+25	6	239	0.7340		11/16							
P2-I	20+25	6	240	0.7320	0.735	11/16							
P2-I	20+25	8	241	0.7200		11/16	5%	337.96	20556.1	0.81	14389.3	0.57	
P2-I	20+25	8	242	0.7210		11/16							
P2-I	20+25	8	243	0.7210	0.721	11/16							
P2-I	22+12							305.17					Man hole at surge tank
P2-I	22+12	4	1	0.7290		3/4	-3%	305.17	22929.7	0.91	16050.8	0.63	
P2-I	22+12	4	2	0.7270		3/4							
P2-I	22+12	4	3	0.7280	0.728	3/4							
P2-I	22+12	6	4	0.7550		3/4	1%	305.17	22137.0	0.87	15495.9	0.61	
P2-I	22+12	6	5	0.7540		3/4							
P2-I	22+12	6	6	0.7530	0.754	3/4							
P2-I	22+12	8	7	0.7430		3/4	-1%	305.17	22642.0	0.89	15849.4	0.63	
P2-I	22+12	8	8	0.7480		3/4							
P2-I	22+12	8	9	0.7500		3/4							
P2-I	22+12	8	10	0.7390	0.745	3/4							
P2-I	22+32	4	11	0.8850				291.58	19740.3	0.78	13818.2	0.55	CL Surge Tank
P2-I	22+32	4	12	0.8870									
P2-I	22+32	4	13	0.8840	0.885								
P2-I	22+32	6	14	0.8890				291.58	19672.0	0.78	13770.4	0.54	
P2-I	22+32	6	15	0.8870									
P2-I	22+32	6	16	0.8870	0.888								
P2-I	22+32	8	17	1.5330				291.58	11405.9	0.45	7984.1	0.32	
P2-I	22+32	8	18	1.5290									
P2-I	22+32	8	19	1.5310	1.531								
P2-I	23+32	4	20	0.7610		3/4	1%	291.58	20433.6	0.81	14303.5	0.56	13.431
P2-I	23+32	4	21	0.7580		3/4							13.444
P2-I	23+32	4	22	0.7570	0.759	3/4							13.423
P2-I	23+32	6	23	0.7700		3/4	2%	291.58	20137.8	0.80	14096.4	0.56	
P2-I	23+32	6	24	0.7690		3/4							
P2-I	23+32	6	25	0.7670	0.769	3/4							
P2-I	23+32	8	26	0.7760		3/4	2%	291.58	20539.3	0.81	14377.5	0.57	
P2-I	23+32	8	27	0.7630		3/4							
P2-I	23+32	8	28	0.7610	0.767	3/4							
P2-I	23+44	N/A	N/A					281.94					Old Vent hole & lugs for scaffolding
P2-I	24+32	4	29	0.8360		13/16	3%	266.51	19958.6	0.79	13971.0	0.55	
P2-I	24+32	4	30	0.8370		13/16							
P2-I	24+32	4	31	0.8370	0.837	13/16							
P2-I	24+32	6	32	0.8550		13/16	5%	266.51	19522.4	0.77	13665.7	0.54	13.436
P2-I	24+32	6	33	0.8550		13/16							13.472
P2-I	24+32	6	34	0.8560	0.855	13/16							13.431
P2-I	24+32	8	35	0.8410		13/16	3%	266.51	19863.5	0.78	13904.4	0.55	
P2-I	24+32	8	36	0.8410		13/16							
P2-I	24+32	8	37	0.8400	0.841	13/16							
P2-I	25+32	4	38	0.9030		7/8	3%	248.98	19512.9	0.77	13659.0	0.54	lugs for scaffolding
P2-I	25+32	4	39	0.9040		7/8							13.512
P2-I	25+32	4	40	0.9010	0.903	7/8							13.506
P2-I	25+32	6	41	0.8790		7/8	0%	248.98	20039.3	0.79	14027.5	0.55	13.509
P2-I	25+32	6	42	0.8780		7/8							
P2-I	25+32	6	43	0.8770	0.878	7/8							
P2-I	25+32	8	44	0.8970		7/8	3%	248.98	19588.4	0.77	13711.9	0.54	13.56
P2-I	25+32	8	45	0.8970		7/8							13.481
P2-I	25+32	8	46	0.8980	0.897	7/8							13.476
P2-I	26+23	N/A						237.44					Circumferential joint weld joing at crown. Noticed coating delamination, took video for closer look
P2-E	26+31	12	250	0.8810		7/8	1%	236.48	20672.2	0.82	14470.5	0.57	Excavation 8
P2-E	26+31	12	251	0.8810		7/8							19.3
P2-E	26+31	12	252	0.8800	0.881	7/8							
P2-I	26+52	4	47	0.9540		7/8	9%	233.95	19223.5	0.76	13456.5	0.53	13.453
P2-I	26+52	4	48	0.9560		7/8							13.457

P2-I	26+52	4	49	0.9540	0.955	7/8							13.464
P2-I	26+52	6	50	0.9560		7/8	9%	233.95	19257.3	0.76	13480.1	0.53	
P2-I	26+52	6	51	0.9530		7/8							
P2-I	26+52	6	52	0.9580	0.956	7/8							
P2-I	26+52	8	53	0.9430		7/8	8%	233.95	19452.3	0.77	13616.6	0.54	
P2-I	26+52	8	54	0.9420		7/8							
P2-I	26+52	8	55	0.9420	0.942	7/8							
P2-E	27+72	12	253	0.9160		15/16	-2%	219.52	20810.7	0.82	14567.5	0.58	Excavation 9
P2-E	27+72	12	254	0.9160		15/16							6.5
P2-E	27+72	12	255	0.9150	0.916	15/16							Measurements taken on bare steel
P2-I	28+32	4	56	1.0250		15/16	7%	212.31	20065.2	0.79	14045.7	0.55	13.48
P2-I	28+32	4	57	0.9930		15/16							13.484
P2-I	28+32	4	58	0.9920	1.003	15/16							13.527
P2-I	28+32	6	59	0.9970		15/16	6%	212.31	19467.8	0.77	13627.5	0.54	
P2-I	28+32	6	60	0.9970		15/16							
P2-I	28+32	6	61	0.9980	0.997	15/16							
P2-I	28+32	8	62	0.9860		15/16	5%	212.31	19708.4	0.78	13795.9	0.54	
P2-I	28+32	8	63	0.9870		15/16							
P2-I	28+32	8	64	0.9850	0.986	15/16							
P2-I	28+82	4	65	0.9930		1	-1%	206.29	19929.5	0.79	13950.6	0.55	13.503
P2-I	28+82	4	66	0.9940		1							13.471
P2-I	28+82	4	67	0.9900	0.992	1							13.49
P2-I	28+82	6	68	1.0230		1	2.3%	206.29	19252.6	0.76	13476.8	0.53	
P2-I	28+82	6	69	1.0230		1							
P2-I	28+82	6	70	1.0230	1.023	1							
P2-I	28+82	8	71	1.0040		1	0.2%	206.29	19708.4	0.78	13795.9	0.54	
P2-I	28+82	8	72	1.0010		1							
P2-I	28+82	8	73	1.0020	1.002	1							
P2-I	29+82	4	74	1.1400		1 1/8	1.5%	194.27	17826.3	0.74	12478.4	0.52	13.497
P2-I	29+82	4	75	1.1420		1 1/8							13.488
P2-I	29+82	4	76	1.1430	1.142	1 1/8							13.493
P2-I	29+82	6	77	1.1470		1 1/8	2.0%	194.27	17704.1	0.74	12392.9	0.52	
P2-I	29+82	6	78	1.1480		1 1/8							
P2-I	29+82	6	79	1.1480	1.148	1 1/8							
P2-I	29+82	8	80	1.1330		1 1/8	0.8%	194.27	17930.8	0.75	12551.6	0.52	
P2-I	29+82	8	81	1.1350		1 1/8							
P2-I	29+82	8	82	1.1340	1.134	1 1/8							
P2-I	30+47	N/A				1 1/8		186.45					Manhole
P2-E	30+81	12	256	1.1150		1 1/8	-1.0%	182.36	18813.2	0.78	13169.2	0.55	Excavation 11
P2-E	30+81	12	257	1.1120		1 1/8							24.6
P2-E	30+81	12	258	1.1140	1.114	1 1/8							Measurements taken on bare steel
													Invert of pipe on steeper slope ~14deg.
													Missing coating due to higher velocities,
P2-I	31+32							176.23					also more delamination on the crown
P2-I	31+82	4	83	1.1860		1 3/16	-0.4%	170.22	18355.6	0.76	12848.9	0.54	13.449
P2-I	31+82	4	84	1.1760		1 3/16							13.461
P2-I	31+82	4	85	1.1850	1.182	1 3/16							13.469
P2-I	31+82	6	86	1.1950		1 3/16	0.6%	170.22	18017.3	0.75	12612.1	0.53	
P2-I	31+82	6	87	1.1940		1 3/16							
P2-I	31+82	6	88	1.1950	1.195	1 3/16							
P2-I	31+82	8	89	1.1830		1 3/16	-0.4%	170.22	18177.8	0.76	12724.5	0.53	
P2-I	31+82	8	90	1.1830		1 3/16							
P2-I	31+82	8	91	1.1830	1.183	1 3/16							
P2-I	32+82	4	92	1.2690		1 1/4	1.4%	150.51	17790.0	0.74	12453.0	0.52	13.437
P2-I	32+82	4	93	1.2670		1 1/4							13.474
P2-I	32+82	4	94	1.2660	1.267	1 1/4							13.448
P2-I	32+82	6	95	1.3010		1 1/4	4.1%	150.51	17314.8	0.72	12120.3	0.51	
P2-I	32+82	6	96	1.3020		1 1/4							
P2-I	32+82	6	97	1.3000	1.301	1 1/4							
P2-I	32+82	8	98	1.2440		1 1/4	-0.4%	150.51	18130.6	0.76	12691.4	0.53	
P2-I	32+82	8	99	1.2470		1 1/4							
P2-I	32+82	8	100	1.2430	1.245	1 1/4							
P2-E	33+17	12	259	1.2580		1 1/4	-0.5%	143.55	18719.0	0.78	13103.3	0.55	Excavation 12
P2-E	33+17	12	260	1.2370		1 1/4							24.2
P2-E	33+17	12	261	1.2370	1.244	1 1/4							Measurements taken on bare steel
P2-I	34+82	4	101	1.4290		1 7/16	-0.6%	110.73	17167.8	0.72	12017.4	0.50	13.442
P2-I	34+82	4	102	1.4280		1 7/16							13.467
P2-I	34+82	4	103	1.4310	1.429	1 7/16							13.453
P2-I	34+82	6	104	1.4390		1 7/16	0.2%	110.73	17035.6	0.71	11924.9	0.50	
P2-I	34+82	6	105	1.4410		1 7/16							
P2-I	34+82	6	106	1.4390	1.440	1 7/16							
P2-I	34+82	8	107	1.4600		1 7/16	1.1%	110.73	16981.1	0.71	11886.8	0.50	Note: cans are ~9ft long
P2-I	34+82	8	108	1.4500		1 7/16							
P2-I	34+82	8	109	1.4500	1.453	1 7/16							
P2-I	36+82	4	110	1.5380		1 1/2	2.5%	70.96	17234.6	0.72	12064.2	0.50	13.442
P2-I	36+82	4	111	1.5380		1 1/2							13.426
P2-I	36+82	4	112	1.5370	1.538	1 1/2							13.494
P2-I	36+82	6	113	1.5520		1 1/2	3.3%	70.96	17122.4	0.71	11985.6	0.50	
P2-I	36+82	6	114	1.5490		1 1/2							
P2-I	36+82	6	115	1.5490	1.550	1 1/2							
P2-I	36+82	8	116	1.5600		1 1/2	4.0%	70.96	17004.3	0.71	11903.0	0.50	
P2-I	36+82	8	117	1.5620		1 1/2							
P2-I	36+82	8	118	1.5590	1.560	1 1/2							
P2-I	38+07							32.40					Start of bifurcation
P2-I	38+42	4	119			1 5/8	-14.8%	20.51	21054.1	0.88	14737.8	0.61	9.043
P2-I	38+42	4	120	1.3860		1 5/8							9.005

P2-I	38+42	4	121	1.3880		1 5/8							8.97
P2-I	38+42	4	122	1.3810	1.385	1 5/8							
P2-I	38+42	6	123	1.3550		1 5/8	-16%	20.51	21446.3	0.89	15012.4	0.63	
P2-I	38+42	6	124	1.3580		1 5/8							
P2-I	38+42	6	125	1.3600	1.358	1 5/8							
P2-I	38+42	8	126	1.3730		1 5/8	-16%	20.51	21157.4	0.88	14810.2	0.62	
P2-I	38+42	8	127	1.3720		1 5/8							
P2-I	38+42	8	128	1.3720	1.372	1 5/8							
									22929.73	0.91	16050.81	0.63	
CL Intake Elevatior	549.50 ft						-15.59%		5710.09	0.34	3997.07	0.24	
CL Unit Elevation	3.00 ft						1.82%						

Notes:

1 - Penstock Location:
P2 - Penstock No. 2
E = Exterior
I = Interior
Sta. 0+00 at D/S face of headgate, positive locations are downstream of headgate
2 - Looking D/S
3 - UT Thickness Gage Reading Number
5 - Penstock measured 6/28/16-6/30/16
7 - Hoop Stress = Pr/Et, where:
P = Pressure = γw*Head
γw = 62.4 pcf
Head = NP - C.L. Elev
NP = 599.08 ft (per Penstock No. 1 report June 2016).
Stresses shown use 97.5% confindence interval thickness for calculations
r = penstock radius
r1 = 102 in [Sta. < 13+29]
r2= 91.5 in [Sta. 13+29 to 22+89]
r3= 81 in [Sta. > 22+89]
E = joint efficiency 0.7 (See Mathcad calculations, pg 2)

t = avg. thickness

Ave thickness for 7/16" PL TRL:	0.447	in
Ave thickness for 1/2" PL TRL:	0.522	in
Ave thickness for 9/16" PL TRL:	0.583	in
Ave thickness of 11/16" PL TRB:	0.715	in
Ave thickness of 3/4" PL TRB:	0.753	in
Ave thickness for 13/16" PL TRL:	0.832	in
Ave thickness of 7/8" PL TRB:	0.916	in
Ave thickness of 15/16" PL TRB:	0.976	in
Ave thickness for 1" PL TRL:	1.006	in
Ave thickness for 1 1/8" PL TRL:	1.134	in
Ave thickness of 1 3/16" PL TRB:	1.187	in
Ave thickness of 1 1/4" PL TRB:	1.264	in
Ave thickness for 1 7/16" PL TRL:	1.441	in
Ave thickness of 1 1/2" PL TRB:	1.549	in
Ave thickness of 1 5/8" PL TRB:	1.372	in

8 - Stress Ratio = Actual Stress/Allowable Stress
σ_{allow} = 17 ksi (see Mathcad calcs for A285 Steel)
σ_{allow} = 24 ksi (see Mathcad calcs for CSA G40.8 Grade B steel)
σ_{allow} = 25.33 ksi (see Mathcad calcs for CSA G40.8 Grade B steel)

9 - 97.5% Confidence that the results will be at or above 'x'
= Avg - 1.96*StdDev

10 - CL Elevation:

EL_STA_2+28 =	548.70 ft	(per dwgs)
EL_STA_5+43=	510.00 ft	
EL_STA_8+68=	501.50 ft	
EL_STA_13+29 =	464.50 ft	
EL_STA_16+33=	375.00 ft	
EL_STA_19+34=	353.91 ft	
EL_STA_22+89=	291.58 ft	
EL_STA_25+43=	247.06 ft	
EL_STA_31+84 =	170.00 ft	
EL_STA_37+07=	66.00 ft	
EL_STA_38+30=	24.56 ft	
EL_STA_38+94=	3.00 ft	

11- Penstock incline angles:

θ1 =	0.25 deg	0.004 rad	(See Mathcad calculations, pg 2)
θ2 =	7.07 deg	0.123 rad	
θ3 =	1.50 deg	0.026 rad	
θ4 =	4.60 deg	0.080 rad	
θ5 =	17.15 deg	0.299 rad	
θ6 =	4.02 deg	0.070 rad	
θ7 =	10.10 deg	0.176 rad	
θ8 =	10.10 deg	0.176 rad	
θ9 =	6.91 deg	0.121 rad	
θ10 =	11.47 deg	0.200 rad	
θ11 =	19.63 deg	0.343 rad	
θ12 =	19.72 deg	0.344 rad	

TABLE C-2 - FLOOD WSEL
PENSTOCK THICKNESS MEASURMENTS AND STRESSES

Location[1]		Clock Position[2]	Reading No.[3,4]	Thickness Reading (in)	Avg. Thickness (in)	C.L. Elev (ft)	at Joints		Base Material		Notes
							Stress (psi)[7]	Stress Ratio[8]	Stress (psi)[7]	Stress Ratio[8]	
P2-I	0+25	4	129	0.5310	0.529	549.39	6618.8	0.39	4633.2	0.27	Headgate is Station 0+00
P2-I	0+25	4	130	0.5300							16.937
P2-I	0+25	4	131	0.5260							16.943
P2-I	0+25	6	132	0.5530	0.556	549.39	6310.0	0.37	4417.0	0.26	16.929
P2-I	0+25	6	133	0.5600							
P2-I	0+25	6	134	0.5560							
P2-I	0+25	8	135	0.5270	0.527	548.85	6668.0	0.39	4667.6	0.27	
P2-I	0+25	8	136	0.5280							
P2-I	0+25	8	137	0.5260							
P2-I	1+50	4	138	0.4330	0.426	548.85	8472.4	0.50	5930.7	0.35	At bend, 1/8" thicker than plates
P2-I	1+50	4	139	0.4220							16.775
P2-I	1+50	4	140	0.4220							16.839
P2-I	1+50	6	141	0.4500	0.451	548.85	7839.4	0.46	5487.6	0.32	16.799
P2-I	1+50	6	142	0.4530							
P2-I	1+50	6	143	0.4490							
P2-I	1+50	8	144	0.4700	0.471	548.85	7474.2	0.44	5232.0	0.31	
P2-I	1+50	8	145	0.4700							
P2-I	1+50	8	146	0.4720							hollow ring w/hammer 5 to 7 o'clock
P2-E	2+96	12	244	0.4470	0.445	540.34	9130.7	0.54	6391.5	0.38	Excavation 1
P2-E	2+96	12	245	0.4450							10.9
P2-E	2+96	12	246	0.4440							possible locations of seepage. NLH to look at when watered up.
P2-I	3+75	4	147	0.4270	0.427	530.62	10916.0	0.64	7641.2	0.45	3'-4' u/s to d/s
P2-I	3+75	4	148	0.4280							17.015
P2-I	3+75	4	149	0.4270							17.001
P2-I	3+75	6	150	0.4540	0.453	530.62	10346.3	0.61	7242.4	0.43	16.961
P2-I	3+75	6	151	0.4530							
P2-I	3+75	6	152	0.4510							
P2-I	3+75	8	153	0.4520	0.450	530.62	10417.3	0.61	7292.1	0.43	
P2-I	3+75	8	154	0.4490							
P2-I	3+75	8	155	0.4490							
P2-I	5+00	4	156	0.5080	0.507	515.24	11108.7	0.65	7776.1	0.46	At vertical bend 2B
P2-I	5+00	4	157	0.5070							
P2-I	5+00	4	158	0.5070							
P2-I	5+00	6	159	0.5120	0.515	515.24	11045.0	0.65	7731.5	0.45	
P2-I	5+00	6	160	0.5150							
P2-I	5+00	6	161	0.5180							
P2-I	5+00	8	162	0.5040	0.503	515.24	11197.2	0.66	7838.0	0.46	
P2-I	5+00	8	163	0.5030							
P2-I	5+00	8	164	0.5030							
P2-I	6+60	N/A	N/A			506.94					Circumferential joint at invert has approx. 1/2" height difference between cans. No signs of cracking
P2-I	7+50	4	165	0.4220	0.421	504.59	14983.5	0.88	10488.4	0.62	16.856
P2-I	7+50	4	166	0.4210							16.874
P2-I	7+50	4	167	0.4210							16.854
P2-I	7+50	6	168	0.4510	0.449	504.59	14140.4	0.83	9898.3	0.58	
P2-I	7+50	6	169	0.4500							
P2-I	7+50	6	170	0.4470							
P2-I	7+50	8	171	0.4370	0.439	504.59	14539.5	0.86	10177.6	0.60	
P2-I	7+50	8	172	0.4380							
P2-I	7+50	8	173	0.4430							
P2-I	9+25	4	174	0.4420	0.441	496.93	15400.9	0.91	10780.6	0.63	17.138
P2-I	9+25	4	175	0.4410							17.07
P2-I	9+25	4	176	0.4410							16.997
P2-I	9+25	6	177	0.4430	0.442	496.93	15405.5	0.91	10783.8	0.63	
P2-I	9+25	6	178	0.4430							
P2-I	9+25	6	179	0.4410							Video of weld for closer look
P2-I	9+25	8	180	0.4390	0.439	496.93	15471.2	0.91	10829.8	0.64	
P2-I	9+25	8	181	0.4400							
P2-I	9+25	8	182	0.4390							
P2-I	11+50	4	198	0.4660	0.463	478.90	17325.6	0.80	12127.9	0.56	16.742
P2-I	11+50	4	199	0.4610							16.728
P2-I	11+50	4	200	0.4610							16.764
P2-I	11+50	6	201	0.4630	0.462	478.90	17211.4	0.79	12048.0	0.56	
P2-I	11+50	6	202	0.4620							
P2-I	11+50	6	203	0.4610							
P2-I	11+50	8	204	0.4690	0.470	478.90	16969.2	0.78	11878.5	0.55	
P2-I	11+50	8	205	0.4720							
P2-I	11+50	8	206	0.4690							
P2-I	14+60	4	207	0.5080	0.508	425.87	19927.0	0.92	13948.9	0.64	15.243
P2-I	14+60	4	208	0.5090							15.22
P2-I	14+60	4	209	0.5080							15.246
P2-I	14+60	6	210	0.5210	0.521	425.87	19429.0	0.90	13600.3	0.63	
P2-I	14+60	6	211	0.5220							
P2-I	14+60	6	212	0.5210							
P2-I	14+60	8	213	0.5240	0.524	425.87	19386.6	0.89	13570.6	0.63	
P2-I	14+60	8	214	0.5230							
P2-I	14+60	8	215	0.5260							

P2-E	14+60	12	247	0.5400	0.533	425.87	19428.4	0.90	13599.9	0.63	Excavation 2
P2-E	14+60	12	248	0.5290							29.2
P2-E	14+60	12	249	0.5290							
P2-I	16+40	4	216	0.5800	0.580	374.51	22498.2	1.04	15748.8	0.73	15.206
P2-I	16+40	4	217	0.5800							15.335
P2-I	16+40	4	218	0.5790							15.172
P2-I	16+40	6	219	0.6010	0.599	374.51	21890.9	1.01	15323.6	0.71	
P2-I	16+40	6	220	0.5980							
P2-I	16+40	6	221	0.5970							
P2-I	16+40	8	222	0.5740	0.573	374.51	22744.5	1.05	15921.2	0.73	
P2-I	16+40	8	223	0.5730							
P2-I	16+40	8	224	0.5730							
P2-I	16+40	8	225	0.5730							
P2-I	18+91	4	226	0.8200	0.820	356.91	17089.1	0.79	11962.4	0.55	at vert. bend. 6B
P2-I	18+91	4	227	0.8200							15.158
P2-I	18+91	4	228	0.8200							15.146
P2-I	18+91	6	229	0.8260	0.825	356.91	17002.0	0.78	11901.4	0.55	15.153
P2-I	18+91	6	230	0.8250							
P2-I	18+91	6	231	0.8250							
P2-I	18+91	8	232	0.8130	0.812	356.91	17299.2	0.80	12109.5	0.56	
P2-I	18+91	8	233	0.8120							
P2-I	18+91	8	234	0.8110							
P2-I	20+25	4	235	0.6980	0.691	337.96	22287.6	1.03	15601.4	0.72	
P2-I	20+25	4	236	0.6840							
P2-I	20+25	4	237	0.6900							
P2-I	20+25	6	238	0.7380	0.735	337.96	20703.9	0.96	14492.7	0.67	
P2-I	20+25	6	239	0.7340							
P2-I	20+25	6	240	0.7320							
P2-I	20+25	8	241	0.7200	0.721	337.96	20967.0	0.97	14676.9	0.68	
P2-I	20+25	8	242	0.7210							
P2-I	20+25	8	243	0.7210							
P2-I	22+12					305.17					Man hole at surge tank
P2-I	22+12	4	1	0.7290	0.728	305.17	23337.0	1.08	16335.9	0.75	
P2-I	22+12	4	2	0.7270							
P2-I	22+12	4	3	0.7280							
P2-I	22+12	6	4	0.7550	0.754	305.17	22530.2	1.04	15771.1	0.73	
P2-I	22+12	6	5	0.7540							
P2-I	22+12	6	6	0.7530							
P2-I	22+12	8	7	0.7430	0.745	305.17	23044.2	1.06	16130.9	0.74	
P2-I	22+12	8	8	0.7480							
P2-I	22+12	8	9	0.7500							
P2-I	22+12	8	10	0.7390							
P2-I	22+32	4	11	0.8850	0.885	291.58	20075.4	0.93	14052.8	0.65	CL Surge Tank
P2-I	22+32	4	12	0.8870							
P2-I	22+32	4	13	0.8840							
P2-I	22+32	6	14	0.8890	0.888	291.58	20006.0	0.92	14004.2	0.65	
P2-I	22+32	6	15	0.8870							
P2-I	22+32	6	16	0.8870							
P2-I	22+32	8	17	1.5330	1.531	291.58	11599.5	0.54	8119.6	0.37	
P2-I	22+32	8	18	1.5290							
P2-I	22+32	8	19	1.5310							
P2-I	23+32	4	20	0.7610	0.759	291.58	20780.5	0.96	14546.3	0.67	13.431
P2-I	23+32	4	21	0.7580							13.444
P2-I	23+32	4	22	0.7570							13.423
P2-I	23+32	6	23	0.7700	0.769	291.58	20479.6	0.95	14335.7	0.66	
P2-I	23+32	6	24	0.7690							
P2-I	23+32	6	25	0.7670							
P2-I	23+32	8	26	0.7760	0.767	291.58	20888.0	0.96	14621.6	0.67	
P2-I	23+32	8	27	0.7630							
P2-I	23+32	8	28	0.7610							
P2-I	23+44	N/A	N/A			281.94					Old Vent hole & lugs for scaffolding
P2-I	24+32	4	29	0.8360	0.837	266.51	20271.8	0.94	14190.3	0.65	
P2-I	24+32	4	30	0.8370							
P2-I	24+32	4	31	0.8370							
P2-I	24+32	6	32	0.8550	0.855	266.51	19828.8	0.92	13880.2	0.64	13.436
P2-I	24+32	6	33	0.8550							13.472
P2-I	24+32	6	34	0.8560							13.431
P2-I	24+32	8	35	0.8410	0.841	266.51	20175.2	0.93	14122.7	0.65	
P2-I	24+32	8	36	0.8410							
P2-I	24+32	8	37	0.8400							
P2-I	25+32	4	38	0.9030	0.903	248.98	19803.8	0.91	13862.7	0.64	lugs for scaffolding
P2-I	25+32	4	39	0.9040							13.512
P2-I	25+32	4	40	0.9010							13.506
P2-I	25+32	6	41	0.8790	0.878	248.98	20338.0	0.94	14236.6	0.66	13.509
P2-I	25+32	6	42	0.8780							
P2-I	25+32	6	43	0.8770							
P2-I	25+32	8	44	0.8970	0.897	248.98	19880.5	0.92	13916.4	0.64	13.56
P2-I	25+32	8	45	0.8970							13.481
P2-I	25+32	8	46	0.8980							13.476
P2-I	26+23	N/A				237.44					Circumferential joint weld joing at crown. Noticed coating delamination, took video for closer look
P2-E	26+31	12	250	0.8810	0.881	236.48	20969.8	0.97	14678.8	0.68	Excavation 8
P2-E	26+31	12	251	0.8810							19.3
P2-E	26+31	12	252	0.8800							
P2-I	26+52	4	47	0.9540	0.955	233.95	19498.3	0.90	13648.8	0.63	13.453
P2-I	26+52	4	48	0.9560							13.457

P2-I	26+52	4	49	0.9540							13.464
P2-I	26+52	6	50	0.9560	0.956	233.95	19532.6	0.90	13672.8	0.63	
P2-I	26+52	6	51	0.9530							
P2-I	26+52	6	52	0.9580							
P2-I	26+52	8	53	0.9430	0.942	233.95	19730.4	0.91	13811.3	0.64	
P2-I	26+52	8	54	0.9420							
P2-I	26+52	8	55	0.9420							
P2-E	27+72	12	253	0.9160	0.916	219.52	21096.9	0.97	14767.8	0.68	Excavation 9
P2-E	27+72	12	254	0.9160							6.5
P2-E	27+72	12	255	0.9150							Measurements taken on bare steel
P2-I	28+32	4	56	1.0250	1.003	212.31	20336.0	0.94	14235.2	0.66	13.48
P2-I	28+32	4	57	0.9930							13.484
P2-I	28+32	4	58	0.9920							13.527
P2-I	28+32	6	59	0.9970	0.997	212.31	19730.6	0.91	13811.4	0.64	
P2-I	28+32	6	60	0.9970							
P2-I	28+32	6	61	0.9980							
P2-I	28+32	8	62	0.9860	0.986	212.31	19974.4	0.92	13982.1	0.65	
P2-I	28+32	8	63	0.9870							
P2-I	28+32	8	64	0.9850							
P2-I	28+82	4	65	0.9930	0.992	206.29	20194.4	0.93	14136.0	0.65	13.503
P2-I	28+82	4	66	0.9940							13.471
P2-I	28+82	4	67	0.9900							13.49
P2-I	28+82	6	68	1.0230	1.023	206.29	19508.4	0.90	13655.9	0.63	
P2-I	28+82	6	69	1.0230							
P2-I	28+82	6	70	1.0230							
P2-I	28+82	8	71	1.0040	1.002	206.29	19970.3	0.92	13979.2	0.65	
P2-I	28+82	8	72	1.0010							
P2-I	28+82	8	73	1.0020							
P2-I	29+82	4	74	1.1400	1.142	194.27	18056.2	0.83	12639.3	0.58	13.497
P2-I	29+82	4	75	1.1420							13.488
P2-I	29+82	4	76	1.1430							13.493
P2-I	29+82	6	77	1.1470	1.148	194.27	17932.4	0.83	12552.7	0.58	
P2-I	29+82	6	78	1.1480							
P2-I	29+82	6	79	1.1480							
P2-I	29+82	8	80	1.1330	1.134	194.27	18162.0	0.84	12713.4	0.59	
P2-I	29+82	8	81	1.1350							
P2-I	29+82	8	82	1.1340							
P2-I	30+47	N/A				186.45					Manhole
P2-E	30+81	12	256	1.1150	1.114	182.36	19048.9	0.88	13334.2	0.62	Excavation 11
P2-E	30+81	12	257	1.1120							24.6
P2-E	30+81	12	258	1.1140							Measurements taken on bare steel
P2-I	31+32					176.23					due to higher velocities, also more delamination on the crown
P2-I	31+82	4	83	1.1860	1.182	170.22	18579.1	0.86	13005.3	0.60	13.449
P2-I	31+82	4	84	1.1760							13.461
P2-I	31+82	4	85	1.1850							13.469
P2-I	31+82	6	86	1.1950	1.195	170.22	18236.6	0.84	12765.7	0.59	
P2-I	31+82	6	87	1.1940							
P2-I	31+82	6	88	1.1950							
P2-I	31+82	8	89	1.1830	1.183	170.22	18399.0	0.85	12879.3	0.59	
P2-I	31+82	8	90	1.1830							
P2-I	31+82	8	91	1.1830							
P2-I	32+82	4	92	1.2690	1.267	150.51	17997.0	0.83	12597.9	0.58	13.437
P2-I	32+82	4	93	1.2670							13.474
P2-I	32+82	4	94	1.2660							13.448
P2-I	32+82	6	95	1.3010	1.301	150.51	17516.3	0.81	12261.4	0.57	
P2-I	32+82	6	96	1.3020							
P2-I	32+82	6	97	1.3000							
P2-I	32+82	8	98	1.2440	1.245	150.51	18341.6	0.85	12839.1	0.59	
P2-I	32+82	8	99	1.2470							
P2-I	32+82	8	100	1.2430							
P2-E	33+17	12	259	1.2580	1.244	143.55	18933.5	0.87	13253.5	0.61	Excavation 12
P2-E	33+17	12	260	1.2370							24.2
P2-E	33+17	12	261	1.2370							Measurements taken on bare steel
P2-I	34+82	4	101	1.4290	1.429	110.73	17351.3	0.80	12145.9	0.56	13.442
P2-I	34+82	4	102	1.4280							13.467
P2-I	34+82	4	103	1.4310							13.453
P2-I	34+82	6	104	1.4390	1.440	110.73	17217.7	0.79	12052.4	0.56	
P2-I	34+82	6	105	1.4410							
P2-I	34+82	6	106	1.4390							
P2-I	34+82	8	107	1.4600	1.453	110.73	17162.6	0.79	12013.8	0.55	Note: cans are ~9ft long
P2-I	34+82	8	108	1.4500							
P2-I	34+82	8	109	1.4500							
P2-I	36+82	4	110	1.5380	1.538	70.96	17404.9	0.80	12183.4	0.56	13.442
P2-I	36+82	4	111	1.5380							13.426
P2-I	36+82	4	112	1.5370							13.494
P2-I	36+82	6	113	1.5520	1.550	70.96	17291.6	0.80	12104.1	0.56	
P2-I	36+82	6	114	1.5490							
P2-I	36+82	6	115	1.5490							
P2-I	36+82	8	116	1.5600	1.560	70.96	17172.4	0.79	12020.7	0.55	
P2-I	36+82	8	117	1.5620							
P2-I	36+82	8	118	1.5590							
P2-I	38+07					32.40					Start of bifurcation
P2-I	38+42	4	119		1.385	20.51	21244.0	0.98	14870.8	0.69	9.043
P2-I	38+42	4	120	1.3860							9.005
P2-I	38+42	4	121	1.3880							8.97

P2-I	38+42	4	122	1.3810						
P2-I	38+42	6	123	1.3550	1.358	20.51	21639.7	1.00	15147.8	0.70
P2-I	38+42	6	124	1.3580						
P2-I	38+42	6	125	1.3600						
P2-I	38+42	8	126	1.3730	1.372	20.51	21348.3	0.99	14943.8	0.69
P2-I	38+42	8	127	1.3720						
P2-I	38+42	8	128	1.3720						
						Max =	23336.98	1.08	16335.88	0.75
CL Intake Elevation	549.50 ft					Min =	6309.98	0.37	4416.98	0.26
CL Unit Elevation	3.00 ft									

Notes:
1 - Penstock Location:
P2 - Penstock No. 2
E = Exterior
I = Interior
Sta. 0+00 at D/S face of headgate, positive locations are downstream of headgate
2 - Looking D/S
3 - UT Thickness Gage Reading Number
5 - Penstock measured 6/28/16-6/30/16
7 - Hoop Stress = Pr/Et, where:
P = Pressure = γw*Head
γw = 62.4 pcf
Head = NP - C.L. Elev
Flood = 604.3 ft (per Penstock No. 1 report June 2016).
Stresses shown use 97.5% confindence interval thickness for calculations
r = penstock radius
r1 = 102 in [Sta. < 13+29]
r2= 91.5 in [Sta. 13+29 to 22+89]
r3= 81 in [Sta. > 22+89]
E = joint (See Mathcad calculations, pg 2) 0.7

t = avg. thickness

Ave thickness for 7/16" PL TRL:	0.447	in
Ave thickness for 1/2" PL TRL:	0.522	in
Ave thickness for 9/16" PL TRL:	0.583	in
Ave thickness of 11/16" PL TRB:	0.715	in
Ave thickness of 3/4" PL TRB:	0.753	in
Ave thickness for 13/16" PL TRL:	0.832	in
Ave thickness of 7/8" PL TRB:	0.916	in
Ave thickness of 15/16" PL TRB:	0.976	in
Ave thickness for 1" PL TRL:	1.006	in
Ave thickness for 1 1/8" PL TRL:	1.134	in
Ave thickness of 1 3/16" PL TRB:	1.187	in
Ave thickness of 1 1/4" PL TRB:	1.264	in
Ave thickness for 1 7/16" PL TRL:	1.441	in
Ave thickness of 1 1/2" PL TRB:	1.549	in
Ave thickness of 1 5/8" PL TRB:	1.372	in

8 - Stress Ratio = Actual Stress/Allowable Stress
σ_{allow} = 17 ksi (see Mathcad calcs for A285 Steel)
σ_{allow} = 25330 ksi (see Mathcad calcs for CSA G40.8 Grade B steel)
σ_{allow} = 24000 ksi (see Mathcad calcs for CSA G40.8 Grade B steel)
9 - 97.5% Confidence that the results will be at or above 'x'
= Avg - 1.96*StdDev

10 - CL Elevation:

EL_STA_2+28 =	548.70	ft	(per dwgs)
EL_STA_5+43=	510.00	ft	
EL_STA_8+68=	501.50	ft	
EL_STA_13+29 =	464.50	ft	
EL_STA_16+33=	375.00	ft	
EL_STA_19+34=	353.91	ft	
EL_STA_22+89=	291.58	ft	
EL_STA_25+43=	247.06	ft	
EL_STA_31+84 =	170.00	ft	
EL_STA_37+07=	66.00	ft	
EL_STA_38+30=	24.56	ft	
EL_STA_38+94=	3.00	ft	

11- Penstock incline angles:

θ1 =	0.25	deg	0.004	rad	(See Mathcad calculations, pg 2)
θ2 =	7.07	deg	0.123	rad	
θ3 =	1.50	deg	0.026	rad	
θ4 =	4.60	deg	0.080	rad	
θ5 =	17.15	deg	0.299	rad	
θ6 =	4.02	deg	0.070	rad	
θ7 =	10.10	deg	0.176	rad	
θ8 =	10.10	deg	0.176	rad	
θ9 =	6.91	deg	0.121	rad	
θ10 =	11.47	deg	0.200	rad	
θ11 =	19.63	deg	0.343	rad	
θ12 =	19.72	deg	0.344	rad	

Table C-3 - Water Hammer (Dynamic) Stresses

Dynamic Head Increase at powerhouse	291 ft	Surge Tank Location	22+32
Dynamic Head Increase at surge tank	55.92 ft		

Station (ft)	Max Joint Stress[1,3] (psi)	Dynamic Hoop Stress Increase[1,3] (psi)	Total Water Hammer Stress[1,3] (psi)	Stress Ratio[1,2,3]	Factor of Safety Against Yield[4]
0+25	5913	78	5991	0.33	4.51
1+50	7182	579	7761	0.43	3.48
2+96	8386	1059	9444	0.52	2.86
3+75	9812	1414	11226	0.62	2.41
5+00	10465	1588	12054	0.67	2.24
7+50	13793	2878	16670	0.93	1.62
9+25	14676	3340	18016	1.00	1.50
11+50	16454	3984	20438	0.81	1.86
14+60	18971	4120	23091	0.91	1.65
16+40	21870	4152	26021	1.03	1.46
18+91	16769	3323	20091	0.79	1.89
20+25	20902	4248	25150	0.99	1.51
22+12	22570	4356	26926	1.06	1.41
22+32	18655	3175	21830	0.86	1.74
24+32	19781	5158	24939	0.98	1.52
25+32	19714	5744	25457	1.01	1.49
26+31	20672	6509	27182	1.07	1.40
26+52	19311	6268	25579	1.01	1.49
27+72	20811	7389	28200	1.11	1.35
28+32	19747	7405	27153	1.07	1.40
28+82	19179	8140	27319	1.08	1.39
29+82	17817	7356	25174	1.05	1.43
30+81	18813	8121	26934	1.12	1.34
31+82	18184	8315	26499	1.10	1.36
32+82	17745	8580	26325	1.10	1.37
33+17	18719	8808	27527	1.15	1.31
34+82	17061	8423	25484	1.06	1.41
36+82	17120	8772	25892	1.08	1.39
38+42	21302	5813	27115	1.13	1.33

[1] Joint efficiency of 0.7 included

[2] Total stress / Allowable stress

[3] Uses 97.5% confidence thickness

[4] SF = Fy/Total Stress

APPENDIX D

PENSTOCK EVALUATION CALCULATIONS

Kleinschmidt	Page:	
	Project No.: 2670004.01	
Project: NL Hydro Bay d'Espoir Penstock No. 2 Evaluation	By: KMG	Date: 12-16-16
Subject: External and Internal Loading Analysis	Checked: JLD	Date: 12-16-16

References:

1. KMG & JLD Site Visit Notes (6/28/16-6/30/16)
2. Penstock Thickness Gage Readings (Tables 1 & 2 – Attached)
3. ASCE No. 79 2nd Edition, 2012
4. Existing Drawings: DWG No. F-106-C-10 through F106-C-12
5. ASCE 7-10 Minimum Design Loads for Buildings and Other Structures
6. AISI Buried Steel Penstocks Steel Plate Engineering Vol 4 1st Ed. 1992
7. American Water Works Association (AWWA) M11, 4th Ed.
8. AISC Steel Construction Manual, 6th Edition 1963
9. Obsolete Canadian Structural Steel Grades, 1935-1971 from http://www.slideruleera.net/CISC-Obsolete-Historical-Steel-Properties.pdf referenced 7/18/16
10. Hydroelectric Handbook, Justin and Creager 1950
11. Crack Investigation and Repair Report, Penstock No. 1, Bay d'Espoir Hydroelectric Development. 2016. Kleinschmidt Technical Report to Newfoundland and Labrador Hydro.

Assumptions:

All stationing reported is along the profile of the invert of the penstock beginning at the downstream face of the headgate.

Additional assumptions are stated in following calculations pages.

Contents:

1. External Pressure Analysis for 17ft diameter and 13.5ft diameter buried penstock.
2. Vacuum Pressure Analysis for Penstock No. 2

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Project: Bay d'Espoir Penstock 2 Inspection

Task: Penstock Calculations

Designed By:	KMG
Date:	9/9/16
Revised:	KMG
Date:	12-16-16
Checked By:	JLD
Date:	12/16/16
Job Number:	2670-004

Objective:

Determine the capacity of and the loads on the penstock. Penstock inspected on 6/28/16 - 6/30/16

References:

1. Site Visit Notes
2. Penstock Thickness Readings from UT Gage (see Tables 1 and 2)
3. ASCE No. 79, 2nd Edition, 2012
4. Existing Drawings:
   DWG no. F-106-C-10 thru F106-C-12
5. ASCE7-10 Minimum Design Loads For Buildings and Other Structures
6. AISI Buried Steel Penstocks Steel Plate Engineering Data Vol. 4 1st ED 1992
7. AWWA M11, 4th Ed.
8. AISC Manual of Steel Construction, 6th Ed. 1963
9. Obsolete Canadian Structural Steel Grades 1935-1971 from http://www.slideruleera.net/CISC-Obsolete-Historical-Steel-Properties.pdf referenced 7/18/16
10. Hydroelectric Handbook Justin & Creager 1950
11. Crack Investigation and Repair Report, Penstock No. 1 Bay d'Espoir Hydroelectric Development. 2016. Kleinschmidt Technical Report to Newfoundland and Labrador Hydro.

Inputs: (note all stationing is profile distance from beginning of pressure conduit per drawings in Reference 4)

Penstock Dimensions: *(per R.4)*

$D_{17} := \mathbf{17} \cdot ft$ — *Penstock Diameter (17 foot)* *(from Sta. 0+00 to 12+45)*

$D_{15} := \mathbf{15.25} \cdot ft$ — *Penstock Diameter (15.25 foot)* *(from Sta. 12+45 to 22+05)*

$D_{13} := \mathbf{13.5} ft$ — *Penstock Diameter (13.5 foot)* *(from Sta. 22+05 to PH)*

Average measured penstock thicknesses: *(per R.2 - note not all plate thicknesses measured resulting in stationing gaps below)*

$t_{7.16} := 0.447 in$ — *Average measured thickness of 7/16" Penstock* *(from Sta.1+26 to 13+77)*

$t_{1.2} := 0.522 in$ — *Average measured thickness of 1/2" Penstock* *(from Sta. 0+00 to 1+26 & 13+77 to 14+85)*

$t_{9.16} := 0.583 in$ — *Average measured thickness of 9/16" Penstock* *(from Sta. 14+85 to 16+98)*

$t_{11.16} := 0.715 in$ — *Average measured thickness of 11/16" Penstock* *(from Sta. 19+50 to 20+44)*

Average measured thickness of 3/4" Penstock

$t_{3.4} := 0.753\text{in}$ *(from Sta. 20+44 to 23+55)*

$t_{13.16} := 0.832\text{in}$ *Average measured thickness of 13/16" Penstock (from Sta. 23+55 to 24+76)*

$t_{7.8} := 0.916\text{in}$ *Average measured thickness of 7/8" Penstock (from Sta.24+76 to 26+18)*

$t_{15.16} := 0.976\text{in}$ *Average measured thickness of 15/16" Penstock (from Sta. 26+18 to 27+59)*

$t_1 := 1.006\text{in}$ *Average measured thickness of 1" Penstock (from Sta. 27+59 to 29+01)*

$t_{1.1.8} := 1.134\text{in}$ *Average measured thickness of 1 1/8" Penstock (from Sta. 29+01 to 30+69)*

$t_{1.3.16} := 1.187\text{in}$ *Average measured thickness of 1 3/16" Penstock (from Sta. 30+69 to 31+80)*

$t_{1.1.4} := 1.264\text{in}$ *Average measured thickness of 1 1/4" Penstock (from Sta. 31+80 to 32+85)*

$t_{1.7.16} := 1.441\text{in}$ *Average measured thickness of 1 7/16" Penstock (Sta. 34+94 to 35+98)*

$t_{1.5} := 1.549\text{in}$ *Average measured thickness of 1 1/2" Penstock (from Sta. 35+98 to 36+80)*

$t_{1.5.8} := 1.372\text{in}$ *Average measured thickness of 1 5/8" Penstock (from Sta. 36+80 to CL Unit)*

Material Properties: *(per R.9)*

$F_u := \mathbf{50}\text{ksi}$ *Penstock Upper Section (STA < 10+44) Ultimate Tensile Stress (ASTM A285 Gr B Plate steel per Ref 4)*

$F_y := \min(27\text{ksi}, 0.5 \cdot F_u) = 25000.00 \cdot \text{psi}$ *Penstock Upper Section Yield Stress (R.9)*

$\gamma_w := \mathbf{62.4}\text{pcf} \qquad \gamma_s := \mathbf{490}\text{pcf}$ *Unit Weight of Water and Steel*

$HW := \mathbf{182.6}\text{m} = 599.08\,\text{ft}$ *Headwater Elevation (Max Normal Pond) (Ref 4)*

$F_{u\_L} := 65\text{ksi}$ *Penstock Lower Section (STA 10+44 to PH) Ultimate Tensile Stress (CSA G40.8 Gr B Steel Plate per Ref 4)*

$F_{y\_L.625} := 40\text{ksi}$ *Penstock Lower Section Yield Stress for plate thicknesses less than 5/8" (R.9)*

$F_{y\_L.1} := 38\text{ksi}$ *Penstock Lower Section Yield Stress for plate thicknesses between 5/8" and 1" (R.9)*

$F_{y\_L.1.5} := 36\text{ksi}$ *Penstock Lower Section Yield Stress for plate thicknesses between 1" and 1.5" (R.9)*

$F_{y\_L} := F_{y\_L.1.5} = 36.00 \cdot \text{ksi}$ *Penstock Lower Section Yield Stress (R.9)*

Allowable Stress:

$S_A := \min\left(\frac{F_y}{1.5}, \frac{F_u}{2.4}\right) = 17 \cdot ksi$ *Allowable Stress in Upper Penstock Steel (Ref. 3, 3.5.3)*

$S_{A\_L} := \min\left(\frac{F_{y\_L}}{1.5}, \frac{F_{u\_L}}{2.4}\right) = 24.00 \cdot ksi$ *Allowable Stress in Lower Penstock Steel greater than 1" thick (Ref. 3, 3.5.3)*

$S_{A\_L\_5.8} := \min\left(\frac{F_{y\_L.1}}{1.5}, \frac{F_{u\_L}}{2.4}\right) = 25.33 \cdot ksi$ *Allowable Stress in Lower Penstock Steel between 5/8" and 1" thick (Ref. 3, 3.5.3)*

Joint Efficiency Per Ref. 3 - Section 3.5.1 Table 3-3:

Assume all welds (longitudinal and circumferential) are double-welded butt joints with no RT or UT

$J_{eL} := 0.70$ *Joint Efficiency of welded longitudinal joints*

$J_{eC} := 0.70$ *Joint Efficiency of welded circumferential joints*

External Pressure:

Dead Load on Conduit *- where buried beneath switchyard:*

$H_c := 3ft$ *Height of fill above conduit, minimum for sections with vehicles crossing over (conservative)*

$D_{13} = 13.50\ ft$ *Penstock Diameter at lower end*

$w := 120pcf$ *Unit Weight of fill, assumed saturated*

$w_s := \pi D_{13} \cdot t_{1.5} \cdot 490pcf$ *Weight of steel conduit per foot* $w_s = 2682.56 \cdot plf$

$W_{c135} := w \cdot H_c \cdot D_{13} + w_s$ *Dead Load on 13.5' Conduit, (EQN 6-4)* $W_{c135} = 7.543 \cdot klf$

Live Load on Conduit:

$P := 600psf$ *Superimposed Load, Table 6-3, assumed HS-20 Loading @ 3 foot cover*

$P_v := 0.03psi$ *Pressure Vacuum, assumed*

$W_{L135} := P \cdot D_{13}$ *Live Load on 13.5' Conduit* $W_{L135} = 8100 \cdot plf$

Allowable Buckling Pressure:

$h_w := H_c$ *Height of Water above conduit* $h_w = 36.00 \cdot in$

$h := H_c$ *Height of fill above conduit, (assumed)* $h = 36.00 \cdot in$

$R_w := 1 - 0.33 \cdot \left(\frac{h_w}{h}\right)$ *Water Buoyancy factor* $R_w = 0.67$

$H := \frac{H_c}{ft}$ *Height of fill above conduit, (ft) unitless* $H = 3.00$

$B_{prime} := \frac{1}{1 + 4e^{-0.065 \cdot H}}$ *Empirical coefficient of elastic support* $B_{prime} = 0.23$

$E_{prime} := 500psi$ — *Modulus of soil reaction, Table 6-1, assumed for fine grained soils with w/less than 25% sand @ 85% compaction @ 2ft-5ft cover*

$E := 30000000psi$ — *Modulus of elasticity for steel, ref. page 61*

$t_{1.5} = 1.55 \cdot in$ — *Thickness of shell, average measured thickness in 2016 inspection for 1.5" section*

$I := \frac{(t_{1.5})^3}{12}$ — *Transverse moment of inertia per unit length of pipe wall* $I = 3.7167 \cdot \frac{in^4}{ft}$

$E \cdot I = 298950975.476\ ft \cdot s^{-2} \cdot in \cdot lb$ — *Pipe wall stiffness*

$D_{13} = 13.50\ ft$ — *Penstock Diameter 2*

$FS := 2.0$ — *Factor of safety per AWWA M-11, 4th Ed., (ASCE No. 79 references 3rd Ed.)*

$q_{a13} := \frac{1}{FS} \cdot \left(32 \cdot R_w \cdot B_{prime} \cdot E_{prime} \cdot \frac{E \cdot I}{D_{13}{}^3}\right)^{0.5}$ — *Allowable Buckling Pressure on 144" Conduit, (EQN 6-7)* $q_{a13} = 36.94 \cdot psi$

External Pressure without Live Load:

$Q_{13} := \gamma_w \cdot h_w + R_w \cdot \frac{W_{c135}}{D_{13}} + P_v$ — *External Pressure w/ Vacuum Load on 13" conduit* $Q_{13} = 3.93 \cdot psi$

External Pressure with Live Load:

$Q_{L13} := \gamma_w \cdot h_w + R_w \cdot \frac{W_{c135}}{D_{13}} + \frac{W_{L135}}{D_{13}}$ — *External Pressure w/ Live Load on 13.5' conduit* $Q_{L13} = 8.07 \cdot psi$

Stress Ratios:

$\frac{Q_{13}}{q_{a13}} = 0.11$ — *External Pressure w/ FullVacuum on 13.5' Conduit*

$\frac{Q_{L13}}{q_{a13}} = 0.22$ — *External Pressure w/ HS-20 Live Load on 13.5' Conduit*

External Pressure for 17ft diameter conduit downstream of intake:

Dead Load on Conduit *- :*

$H_c := 2ft$ — *Height of fill above conduit, minimum for sections with vehicles crossing over (conservative)*

$D_{17} = 17.00\ ft$ — *Penstock Diameter at lower end*

$W_{c17} := w \cdot H_c \cdot D_{17}$ — *Dead Load on 17' Conduit, (EQN 6-4)* — $W_{c17} = 4.08 \cdot klf$

$w_s := \pi D_{17} \cdot t_{7.16} \cdot 490pcf$ — *Weight of steel conduit per foot* — $w_s = 974.81 \cdot plf$

Live Load on Conduit:

$Q_{snow} := 130psf$ — *Superimposed snow load (Ref 11)*

$P_v := 0.03psi$ — *Pressure Vacuum, assumed*

$W_{L17} := 100plf$ — *Live Load on 17' Conduit* — $W_{L17} = 100 \cdot plf$

Allowable Buckling Pressure:

$h_w := H_c$ — *Height of Water above conduit*

$h := H_c$ — *Height of fill above conduit, (assumed)*

$R_w := 1 - 0.33 \cdot \left(\frac{h_w}{h}\right)$ — *Water Buoyancy factor*

$H := \frac{H_c}{ft}$ — *Height of fill above conduit, (ft) unitless*

$B_{prime} := \frac{1}{1 + 4e^{-0.065 \cdot H}}$ — *Empirical coefficient of elastic support*

$E_{prime} := 700psi$ — *Modulus of soil reaction, Table 6-1, assumed for coarse grain w/ fines @ 85% @ 2ft depth*

$t_{7.16} = 0.45 \cdot in$ — *Thickness of shell, average measured thickness in 2016 inspection for 7/16" section*

$I := \frac{(t_{7.16})^3}{12}$ — *Transverse moment of inertia per unit length of pipe wall*

$E \cdot I = 7184032.543\ ft \cdot s^{-2} \cdot in \cdot lb$ — *Pipe wall stiffness*

$D_{17} = 17.00\ ft$ — *Penstock Diameter 2*

$FS := 2.0$ — *Factor of safety per AWWA M-11, 4th Ed., (ASCE No. 79 references 3rd Ed.)*

$q_{a17} := \frac{1}{FS} \cdot \left(32 \cdot R_w \cdot B_{prime} \cdot E_{prime} \cdot \frac{E \cdot I}{D_{17}^{\ 3}}\right)^{0.5}$ — *Allowable Buckling Pressure on 17' Conduit, (EQN 6-7)* — $q_{a17} = 32.24 \cdot kPa$

External Pressure without Live Load:

$Q_{17} := \gamma_w \cdot h_w + R_w \cdot \frac{W_{c17}}{D_{17}} + P_v$ — *External Pressure w/ Vacuum Load on 17' conduit* — $Q_{17} = 2.01 \cdot psi$

$Q_{LC3} := (W_{c17} + w_s + Q_{snow} \cdot D_{17}) \cdot \left(\frac{1}{D_{17}}\right)$ — *External Pressure w/ Snow Load on 17' conduit* — $Q_{LC3} = 20.46 \cdot kPa$

External Pressure without Live Load:

$$Q_{LC4} := \gamma_w \cdot h_w + R_w \cdot \frac{W_{c17}}{D_{17}} + \frac{.75 W_{L17}}{D_{17}} + .75 Q_{snow}$$

External Pressure w/ Live Load combination on 17' conduit $Q_{17} = 2.01 \cdot psi$

Stress Ratios:

$\frac{Q_{17}}{q_{a17}} = 0.43$ *External Pressure w/ FullVacuum on 17' Conduit*

$\frac{Q_{LC3}}{q_{a17}} = 0.63$ *External Pressure w/ Snow Load on 17' Conduit*

$\frac{Q_{LC4}}{q_{a17}} = 0.58$ *External Pressure w/ Live Load combination on 17' Conduit*

Recommended thickness for shipping and handling per Reference 3

$t_{17\_rec} := \frac{D_{17}}{288} = 0.71 \cdot in$ $\frac{7}{16} = 0.44$ *7/16" is **less** than minimum recommended for 17' diameter*

$t_{15.25\_rec} := \frac{D_{15}}{288} = 0.64 \cdot in$ *7/16" is **less** than minimum recommended for 15'-3" diameter*

$t_{13.5\_rec} := \frac{D_{13}}{288} = 0.56 \cdot in$ $\frac{3}{4} = 0.75$ *3/4" is **greater** than minimum recommended for 13'-6" diameter*

Project No: 2670004.01
By: Date:M.Hross 12-16-16
QC / Checked by: BEH Date: 12/20/2016

Project: Bay d'Espoir
Subject: Penstock Vacuum Pressures

Analysis Goals:

- Determine the change in pressure due to frictional and minor losses when air is entering the penstock through the air vent.
- Determine the vacuum pressure inside the penstock when the penstock is being drained and air is entering through the air vent.
- Determine the minimum pressures in the penstock for 12.5%-100% wicket gate opening. Maximum system flow is 1,564 cfs.

Analysis Description and Methodology:

The internal pressure inside the penstock when the headgates are closed and the wicket gates are open is calculated by solving for the pressure change from location 1 (the exterior of the penstock, at atmospheric pressure) to location 2 (just inside the penstock after exit from the air vent. The analysis determines the change in pressure by accounting for minor losses (entering and exiting the air vent) and frictional losses using the Darcy-Weisbach equation solved for pressure loss. The solution method is an iterative procedure, where the interior density is assumed to be equal to atmospheric pressure initially. However, because air is a compressible fluid assuming density is constant will introduce error. The Darcy-Weisbach is applicable for compressible flow calculations as long as the change in pressure is less than 40% of the initial pressure at location 1 (Crane, 2009). The pressure at location 2 is solved and a new density obtained based on this pressure, which is then averaged with the previously assumed density, which is then used to calculate a new interior pressure and so on. The calculation process is as folllows:

1 - The mass flow rate, $\dot{m}$, depending upon the density of the air in the vent and the flow rate (cfs) is calculated.
2 - The velocity of the air is calculated using V = Q/A.
3 - The Reynolds Number, **R**, is calculated for the air.
4 - The Mach Number, **M**, is calculated for the air.
5 - The friction factor, f, is calculated using the Haaland Approximation (Finnemore & Franzini, 2002).
6 - Minor pressure losses are calculated based upon the flow velocity (Engineeringtoolbox.com).
7 - Frictional pressure losses are calculated using the Darcy-Weisbach equation solved for pressure change.
8 - The absolute pressure in the penstock is determined by subtracting the pressure losses from the absolute atmospheric pressure.
9 - A new air density inside the penstock is calculated using the new pressure at location 2.
10 - The new density is averaged with the density used in step 1 to provide a new density for the vent.
11 - The gauge pressure in the penstock is determined by subtracting the atmospheric pressure from the absolute pressure inside the penstock.
12 - The calculation steps 1-11 are repeated using the newly determined average density until the interior pressure converges on a solution.

Assumptions:

1 - This is an isothermal process - the temperature does not change over distance.
2 - A constant temperature of 60°F is used to determine the initial physical parameters of the air.
3 - When the Mach Number (**M**) is > 0.3, air flow must be treated as compressible (Nguyen & Wereley, 2002). This is accomplished in the analysis by determining the change in pressure using ρ_1, at initial conditions, then solving for ρ_2, the density in the penstock, and then averaging the two densities and using $\rho_{average}$ to calculate the decrease in pressure.
3 - The flow rate of air into the penstock is equivalent to the rate of discharge of water (Q) through the turbine.
4 - The absolute pressure at the top of the vent (p_1) is atmospheric (14.696psi).
5 - The absolute roughness of the concrete pipe (ε) is assumed to be 0.01 due to the age of the structure.
6 - The Darcy-Weisbach equation, solved for pressure loss, is used to determine the loss in pressure due to friction.
The total pressure drop is the sum of the frictional losses plus the minor losses due to air entering and exiting the vent.
7 - The Bay d'Espoir penstock has two identical vents in parallel; the head loss across each is identical and the head loss across the vents result in the same pressure on the penstock interior.
8 - The air flow into the vents is identical for each vent and equal to half of the total station flow, which is 1,564 cfs.

References:

Crane Company. 2009. *Flow of Fluids through Valves, Fittings and Pipe (TP-410).*
Finnemore & Franzini. 2002. *Fluid Mechanics with Engineering Applications.* McGraw-Hill: New York, NY.
"Minor Loss Coefficients for Air Duct Components". Accessed July 8, 2014. http://www.engineeringtoolbox.com/surface-roughness-ventilation-ducts-d_209.html.
"Roughness & Surface Coefficients of Ventilation Ducts". Accessed July 8, 2013. http://www.engineeringtoolbox.com/minor-loss-air-ducts-fittings-d_208.html
Nguyen, N-T, & Wereley, S.T. *Fundamentals and Applications of Microfluidics.* 2002. ARTECH House, Inc.: Norwood, MA.

Analysis Parameters:

Vent and Penstock Parameters	
Penstock Diameter, D (ft) =	17
Air Vent Length, L (ft) =	43.18
Max Penstock Flow at 100% Gate, Q_{max} (cfs) =	782
Mass Flow Rate, ṁ (slug/ft^3) = ρQ =	1.97
Vent Width (ft) =	5.00
Vent Length (feet) =	5.50
Vent Effective Diameter (ft) =	5.24
Vent Internal Perimeter, P (ft) =	21.0
Vent Internal Area, A (ft^2) =	27.5
Air Vent Hydraulic Radius, R_h (A/P) (ft) =	1.310
Vent Absolute Roughness, ε* (ft) =	0.010
Vent Relative Roughness, ε/D =	0.002

*Value for a aged concrete pipe.

Air Parameters	
Density of Air at 30°F, ρ (slug/ft^3) =	0.00252
Absolute Viscosity, μ (lb*s/ft^2) =	0.000000358
p_1, Atmospheric pressure (Gauge pressure) (psi) =	0
p_1, Atmospheric pressure (Absolute pressure) (psi) =	14.696
p_1, Atmospheric pressure (Absolute pressure) (psf) =	2,116
Air Constant, R (ft*lb/slug°R) =	1,715
T in °R (°F+460) =	490
c = speed of sound, V = fluid velocity	
c (at 60°F) (ft/s) =	1,116.45
Room to Duct (Entrance) Minor Loss Coefficient, ξ =	2.50
Duct to Room (Exit) Minor Loss Coefficient, ξ =	1.0
Σξ = Sum of all Minor Loss Coefficients =	3.50

Analysis Equations

Reynold's Number:

$$\mathbf{Re} = \dot{m}D/\mu A$$

Mach Number, **M**:

$$M = V/c$$

Haaland Approximation of Friction Factor f:

$$f = (1/\{-1.8*\log[((\varepsilon/D)/3.7)^{1.11}+6.9/\mathbf{Re}]\})^2$$

Darcy-Weisbach Friction Loss solved for Pressure Change:

$$\Delta p = f*(L/D)*(\rho V^2)/2$$

Pressure Change due to minor losses:

$$p_{minor} = \xi*(1/2)*\rho*V_1^2$$

Interior Air Density:

$$\rho_2 = p_2/RT$$

Results

Percent of Total Capacity	Flow (cfs)	Interior Gauge Pressure (psi)
12.5%	98	0.00
20.0%	156	0.00
25.0%	196	0.00
37.5%	293	0.00
50.0%	391	-0.01
62.5%	489	-0.01
75.0%	587	-0.01
87.5%	684	-0.02
100.0%	782	-0.03

INTERNAL PENSTOCK PRESSURE AT 12.5% DISCHARGE CAPACITY

Flow (cfs) = 98

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, ṁ (slug/ft^3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	Friction Factor, f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	0.2463	3.55	131,061	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
2	0.00252	0.2462	3.55	131,015	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
3	0.00252	0.2462	3.55	130,991	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
4	0.00252	0.2462	3.55	130,979	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
5	0.00252	0.2462	3.55	130,973	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
6	0.00252	0.2462	3.55	130,971	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
7	0.00252	0.2462	3.55	130,969	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
8	0.00252	0.2462	3.55	130,968	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
9	0.00252	0.2462	3.55	130,968	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
10	0.00252	0.2462	3.55	130,968	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
11	0.00252	0.2462	3.55	130,968	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
12	0.00252	0.2462	3.55	130,968	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	-0.0004
13	0.00252	0.2462	3.55	130,968	0.003	0.024	0.06	0.000	0.003	0.0000	14.6956	0.0025182	0.00252	**-0.0004**

INTERNAL PENSTOCK PRESSURE AT 20% DISCHARGE CAPACITY

Flow (cfs) = 156

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft^3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	Friction Factor, f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	0.3941	5.69	209,698	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00226	-0.0010
2	0.00226	0.3535	5.69	188,063	0.005	0.024	0.13	0.001	0.007	0.0001	14.6951	0.0025181	0.00239	-0.0009
3	0.00239	0.3736	5.69	198,802	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00245	-0.0010
4	0.00245	0.3837	5.69	204,171	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00249	-0.0010
5	0.00249	0.3888	5.69	206,855	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00250	-0.0010
6	0.00250	0.3913	5.69	208,197	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00251	-0.0010
7	0.00251	0.3926	5.69	208,868	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00251	-0.0010
8	0.00251	0.3932	5.69	209,204	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00252	-0.0010
9	0.00252	0.3935	5.69	209,371	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00252	-0.0010
10	0.00252	0.3937	5.69	209,455	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00252	-0.0010
11	0.00252	0.3937	5.69	209,497	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00252	-0.0010
12	0.00252	0.3938	5.69	209,518	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00252	-0.0010
13	0.00252	0.3938	5.69	209,529	0.005	0.024	0.14	0.001	0.008	0.0001	14.6950	0.0025181	0.00252	**-0.0010**

INTERNAL PENSTOCK PRESSURE AT 25% DISCHARGE CAPACITY

Flow (cfs) = 196

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	0.4927	7.11	262,123	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
2	0.00252	0.4925	7.11	262,018	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
3	0.00252	0.4924	7.11	261,966	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
4	0.00252	0.4923	7.11	261,940	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
5	0.00252	0.4923	7.11	261,926	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
6	0.00252	0.4923	7.11	261,920	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
7	0.00252	0.4923	7.11	261,917	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
8	0.00252	0.4923	7.11	261,915	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
9	0.00252	0.4923	7.11	261,914	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
10	0.00252	0.4923	7.11	261,914	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
11	0.00252	0.4923	7.11	261,914	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
12	0.00252	0.4923	7.11	261,913	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
13	0.00252	0.4923	7.11	261,913	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
14	0.00252	0.4923	7.11	261,913	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
15	0.00252	0.4923	7.11	261,913	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
16	0.00252	0.4923	7.11	261,913	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	-0.002
17	0.00252	0.4923	7.11	261,913	0.006	0.0238	0.22	0.002	0.012	0.0001	14.6944	0.002518	0.00252	**-0.002**

INTERNAL PENSTOCK PRESSURE AT 37.5% DISCHARGE CAPACITY

Flow (cfs) = 293

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	0.7390	10.66	393,184	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
2	0.00252	0.7386	10.66	393,000	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
3	0.00252	0.7385	10.66	392,908	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
4	0.00252	0.7384	10.66	392,862	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
5	0.00252	0.7383	10.66	392,838	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
6	0.00252	0.7383	10.66	392,827	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
7	0.00252	0.7383	10.66	392,821	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
8	0.00252	0.7383	10.66	392,818	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
9	0.00252	0.7383	10.66	392,817	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
10	0.00252	0.7383	10.66	392,816	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
11	0.00252	0.7383	10.66	392,816	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
12	0.00252	0.7383	10.66	392,816	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
13	0.00252	0.7383	10.66	392,816	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
14	0.00252	0.7383	10.66	392,816	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
15	0.00252	0.7383	10.66	392,815	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
16	0.00252	0.7383	10.66	392,815	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	-0.004
17	0.00252	0.7383	10.66	392,815	0.010	0.0236	0.50	0.003	0.028	0.0002	14.6923	0.002518	0.00252	**-0.004**

INTERNAL PENSTOCK PRESSURE AT 50% DISCHARGE CAPACITY

Flow (cfs) = 391

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	0.9853	14.22	524,246	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
2	0.00252	0.9848	14.22	523,949	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
3	0.00252	0.9845	14.22	523,800	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
4	0.00252	0.9843	14.22	523,726	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
5	0.00252	0.9843	14.22	523,689	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
6	0.00252	0.9842	14.22	523,671	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
7	0.00252	0.9842	14.22	523,661	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
8	0.00252	0.9842	14.22	523,657	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
9	0.00252	0.9842	14.22	523,655	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
10	0.00252	0.9842	14.22	523,653	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
11	0.00252	0.9842	14.22	523,653	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
12	0.00252	0.9842	14.22	523,653	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
13	0.00252	0.9842	14.22	523,652	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
14	0.00252	0.9842	14.22	523,652	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
15	0.00252	0.9842	14.22	523,652	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
16	0.00252	0.9842	14.22	523,652	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	-0.007
17	0.00252	0.9842	14.22	523,652	0.013	0.0235	0.89	0.006	0.049	0.0003	14.6895	0.002517	0.00252	**-0.007**

INTERNAL PENSTOCK PRESSURE AT 62.5% DISCHARGE CAPACITY

Flow (cfs) = 489

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	*f*	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	1.2317	17.77	655,307	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
2	0.00252	1.2308	17.77	654,854	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
3	0.00252	1.2304	17.77	654,628	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
4	0.00252	1.2302	17.77	654,515	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
5	0.00252	1.2301	17.77	654,458	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
6	0.00252	1.2300	17.77	654,430	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
7	0.00252	1.2300	17.77	654,416	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
8	0.00252	1.2300	17.77	654,409	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
9	0.00252	1.2300	17.77	654,405	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
10	0.00252	1.2300	17.77	654,404	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
11	0.00252	1.2299	17.77	654,403	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
12	0.00252	1.2299	17.77	654,402	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
13	0.00252	1.2299	17.77	654,402	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
14	0.00252	1.2299	17.77	654,402	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
15	0.00252	1.2299	17.77	654,402	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
16	0.00252	1.2299	17.77	654,402	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	-0.010
17	0.00252	1.2299	17.77	654,402	0.016	0.0234	1.39	0.010	0.077	0.0005	14.6858	0.002517	0.00252	**-0.010**

INTERNAL PENSTOCK PRESSURE AT 75% DISCHARGE CAPACITY

Flow (cfs) = 587

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	*f*	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	1.4780	21.33	786,369	0.019	0.0234	2.01	0.014	0.111	0.0008	14.6813	0.002516	0.00252	-0.015
2	0.00252	1.4767	21.33	785,705	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
3	0.00252	1.4761	21.33	785,374	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
4	0.00252	1.4758	21.33	785,208	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
5	0.00252	1.4756	21.33	785,125	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
6	0.00252	1.4756	21.33	785,084	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
7	0.00252	1.4755	21.33	785,063	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
8	0.00252	1.4755	21.33	785,053	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
9	0.00252	1.4755	21.33	785,048	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
10	0.00252	1.4755	21.33	785,045	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
11	0.00252	1.4755	21.33	785,044	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
12	0.00252	1.4755	21.33	785,043	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
13	0.00252	1.4755	21.33	785,043	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
14	0.00252	1.4755	21.33	785,043	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
15	0.00252	1.4755	21.33	785,043	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
16	0.00252	1.4755	21.33	785,043	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	-0.015
17	0.00252	1.4755	21.33	785,043	0.019	0.0234	2.00	0.014	0.110	0.0008	14.6813	0.002516	0.00252	**-0.015**

INTERNAL PENSTOCK PRESSURE AT 87.5% DISCHARGE CAPACITY

Flow (cfs) = 684

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	1.7243	24.88	917,430	0.022	0.0234	2.73	0.019	0.150	0.0010	14.6760	0.002515	0.00252	-0.020
2	0.00252	1.7225	24.88	916,490	0.022	0.0234	2.73	0.019	0.150	0.0010	14.6760	0.002515	0.00252	-0.020
3	0.00252	1.7217	24.88	916,021	0.022	0.0234	2.73	0.019	0.150	0.0010	14.6760	0.002515	0.00252	-0.020
4	0.00252	1.7212	24.88	915,787	0.022	0.0234	2.73	0.019	0.150	0.0010	14.6760	0.002515	0.00252	-0.020
5	0.00252	1.7210	24.88	915,670	0.022	0.0234	2.73	0.019	0.150	0.0010	14.6760	0.002515	0.00252	-0.020
6	0.00252	1.7209	24.88	915,611	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
7	0.00251	1.7208	24.88	915,582	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
8	0.00251	1.7208	24.88	915,568	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
9	0.00251	1.7208	24.88	915,560	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
10	0.00251	1.7208	24.88	915,557	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
11	0.00251	1.7208	24.88	915,555	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
12	0.00251	1.7208	24.88	915,554	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
13	0.00251	1.7208	24.88	915,554	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
14	0.00251	1.7208	24.88	915,553	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
15	0.00251	1.7208	24.88	915,553	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
16	0.00251	1.7208	24.88	915,553	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	-0.020
17	0.00251	1.7208	24.88	915,553	0.022	0.0234	2.72	0.019	0.150	0.0010	14.6760	0.002515	0.00251	**-0.020**

INTERNAL PENSTOCK PRESSURE AT 100% DISCHARGE CAPACITY

Flow (cfs) = 782

Calculation Iteration #	Assumed Vent Air Density, ρ_1 (slug/ft^3)	Mass Flow Rate, $\dot{m}$ (slug/ft3)	Velocity (ft/s)	Reynold's Number, **R**	Mach Number, **M**	f	Minor Pressure Loss, p_{minor}, (lb/ft^2)	Minor Pressure Loss, p_{minor}, (lb/in^2)	Friction Pressure Loss, p_f (lb/ft^2)	Friction Pressure Loss, p_f (lb/in^2)	Absolute Pressure in Penstock (p_1 - p_2) (lb/in^2)	Density in Penstock, ρ_2 (slug/ft^3)	Average Air Density of at p_1 and p_2 (slug/ft^3)	Gauge Pressure Inside Penstock (lb/in^2)
1	0.00252	1.9706	28.44	1,048,492	0.025	0.0233	3.57	0.025	0.196	0.0014	14.6699	0.002514	0.00252	-0.026
2	0.00252	1.9682	28.44	1,047,199	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00252	-0.026
3	0.00252	1.9670	28.44	1,046,554	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
4	0.00251	1.9664	28.44	1,046,232	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
5	0.00251	1.9661	28.44	1,046,072	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
6	0.00251	1.9659	28.44	1,045,992	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
7	0.00251	1.9659	28.44	1,045,952	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
8	0.00251	1.9658	28.44	1,045,932	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
9	0.00251	1.9658	28.44	1,045,922	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
10	0.00251	1.9658	28.44	1,045,917	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
11	0.00251	1.9658	28.44	1,045,914	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
12	0.00251	1.9658	28.44	1,045,913	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
13	0.00251	1.9658	28.44	1,045,912	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
14	0.00251	1.9658	28.44	1,045,912	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
15	0.00251	1.9658	28.44	1,045,912	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
16	0.00251	1.9658	28.44	1,045,912	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	-0.026
17	0.00251	1.9658	28.44	1,045,912	0.025	0.0233	3.56	0.025	0.196	0.0014	14.6699	0.002514	0.00251	**-0.026**

APPENDIX E

SURGE TANK CRACKING

From:	Jillian Davis
To:	Keenan Goslin
Subject:	FW: Bay d"Espoir Cracking at No. 2 Surge Tank
Date:	Friday, September 09, 2016 8:12:02 AM
Attachments:	image002.png Cracking Locations.pdf Lookinig Up at All 4 Cracks.JPG Crack 1.JPG Crack 2.JPG Crack 3.JPG Crack 4.JPG

From: Jillian Davis
Sent: Thursday, July 07, 2016 11:29 AM
To: MatthewLambert@nlh.nl.ca
Cc: JabeHunter@nlh.nl.ca; RaymondBuffett@nlh.nl.ca; Keenan Goslin <keenan.goslin@kleinschmidtgroup.com>; Chris Vella <Chris.Vella@KleinschmidtGroup.com>
Subject: Bay d'Espoir Cracking at No. 2 Surge Tank

Matt,

Attached is a pdf of a drawing showing the crack locations as well as pictures of each crack.

Thickness measurements on the transition plate in the surge tank indicated that the material was approximately 3/8" thick. The drawings that Kleinschmidt has reviewed do not show the original material or thickness, but based on the penstock drawing we assume that it is CSA G40.8 Grade B. This is a low carbon steel similar to ASTM A285 Gr. C (material at Penstock No. 1 crack repair). Also similar to the No. 1 crack is the location of the cracking in respect to welds. The four cracks begin immediately next two the corner plate welds in the rectangular opening of the transition piece. The cracks then propagate downwards. The two upstream cracks (#1 and #2) branch out at intersections to other plates (other weld lines) when the rectangular opening begins to curve. The two downstream cracks (#3 and #4) do not intersect as many weld lines and do not appear to branch out. The recommended crack repair procedure is similar to the No. 1 Penstock repair. This repair will work in the short term and allow the penstock to be re-watered. However, we have some concerns as to what may have caused the cracking that we recommend be investigated to determine long term actions or possible additional remediation.

The cause of the cracking could be similar to the No. 1 penstock, location specific welder error (e.g. the slag wasn't properly cleaned in this area, or a crater crack, or improper heating causing brittleness of the steel). We recommend that NL Hydro have a metallurgist investigate the welds to determine if the welding procedure was poor (and caused the cracking) or adequate. On the other hand, with all 4 corners cracking, we are concerned that the cracking may be caused by secondary stresses in the corners of the rectangular opening. The transition piece is under internal pressure, pushing out on the plate and trying to force the square opening round. The lamellar tearing that historically occurred in "T" and corner joints is why many orifice openings and manways are circular. Kleinschmidt recommends that a finite element analysis (FEA) of the transition plate be conducted to determine the secondary stresses being developed in the plates. As part of that analysis, the following information would be helpful to verify the loading:

1. Do you have the Horton Steel shop drawings that show original plate thickness and specified weld procedures?

2. We assume that the void between the transition plate and the surge tank riser is filled with grout because, based on our understanding of the drawings, there is a bottom steel plate in the riser spanning between the transition's rectangular opening and the riser I.D. It is unlikely that this plate can support the weight of the water column in the surge tank without reinforcing plates or having the annular space grouted. If we can verify this with drawings (or testing) this will help us to determine what loads are being transferred to the plates.

3. We'd like to verify how the transitions plates are connected to the surge tank riser and how the riser is connected to the concrete anchor block. If the riser is transferring lateral wind loads into the transition plates, this could be placing additional stresses on them.

4. Is Bay d'Espoir used to regulate the grid? Is it run steady state or is there constant changes (opening and closing of the wicket gates) causing pressure changes or surges? Has there been any operational changes on the P2 units since they were constructed? If there have been changes, for example going from steady state to multiple pressure changes, the pressure waves could be causing fatigue in the transition plate and welds that they were not designed for.

<u>Recommended Repair Procedure</u>:

1. Remove interior coating for at least 6 inches to each side of the cracks to facilitate testing and welding. We also recommend cleaning along all the other weld lines in the transition piece for testing of those as well.

2. Test the transition plate(s) and welds to verify the length of the known cracks and verify that no other hairline cracks have occurred. Shear wave (or angled beam) testing is the preferred method to determine the length of the crack because it is better suited to find deep defects compared to magnetic particle testing.

3. Once the weld testing is complete and the length of the cracks has been verified the cracks can be cleaned and prepared for welding by grinding out the crack to clean surfaces with an opening large enough to allow for welding access/penetration.

4. Remove all existing cracking:
    a. Remove the existing crack by either grinding or carbon air arc gouging.
    b. Magnetic Particle (MT) test the cleaned area, particularly the crack ends to confirm that there is no residual cracking.
    c. If additional cracking is discovered, remove crack and extend removal at least 200mm (8 inches) into sound metal beyond the crack's end.
    d. Retest entire repair area by MT and repeat steps 4.c and 4.d if necessary.
    e. All Non-Destructive Testing (NDT) shall be performed by personnel currently

certified to CAN/CGSB-48.9712-2014 Level II or higher for the specific technique being used.

f. All NDT testing shall conform to the American Society of Mechanical Engineers (ASME) Pressure Vessel and procedures and acceptance criteria.

g. All MT testing shall be in accordance with ASTM E709-15 Standard Guide for Magnetic Particle Testing.

5. Welding Procedure:

    a. Per the *Profile of Pipeline "A" CL* on Newfoundland Drawing F-106-C-7, the penstock's base material appears to be CSA 40.8 Grade B steel in the area of the cracks. The material composition of this plate steel (based on CSA 40.21) is .15-.20% Carbon (C), 0.20-0.6% Copper (Cu), 0.5%-1.5%Manganese (Mn), 0.04% max Phosphorus (P), and 0.05% max Sulphur (S).

    b. The penstock's shell shall be welded with a full penetration groove weld in accordance with a welding procedure that complies with either the ASME Section IX Welding and Brazing Qualification, or CSA Standard W59-13 Welded steel construction (metal arc welding).

    c. It is anticipated that most of the welding shall be performed downhand from the interior of the penstock shell. The procedure shall include backgouging of the root pass.

6. Repair Execution:

    a. All welding shall be performed by personnel currently certified to either ASME Section IX or CSA Standard W47.1 Fusion Welding of Steel Company Certification for the approved welding procedure to be used.

    b. After the root pass is backgouged, the repair weld shall be MT tested before placing the cover pass(es).

7. After completion of all the welding the repair shall be either MT or Ultrasonic Tested (UT). All UT testing shall comply with the procedures in ASTM E1962-14 Standard Practice for Ultrasonic Surface Testing Using Electromagnetic Acoustic Transducer and acceptance criteria in ASME Section V Nondestructive Examination.

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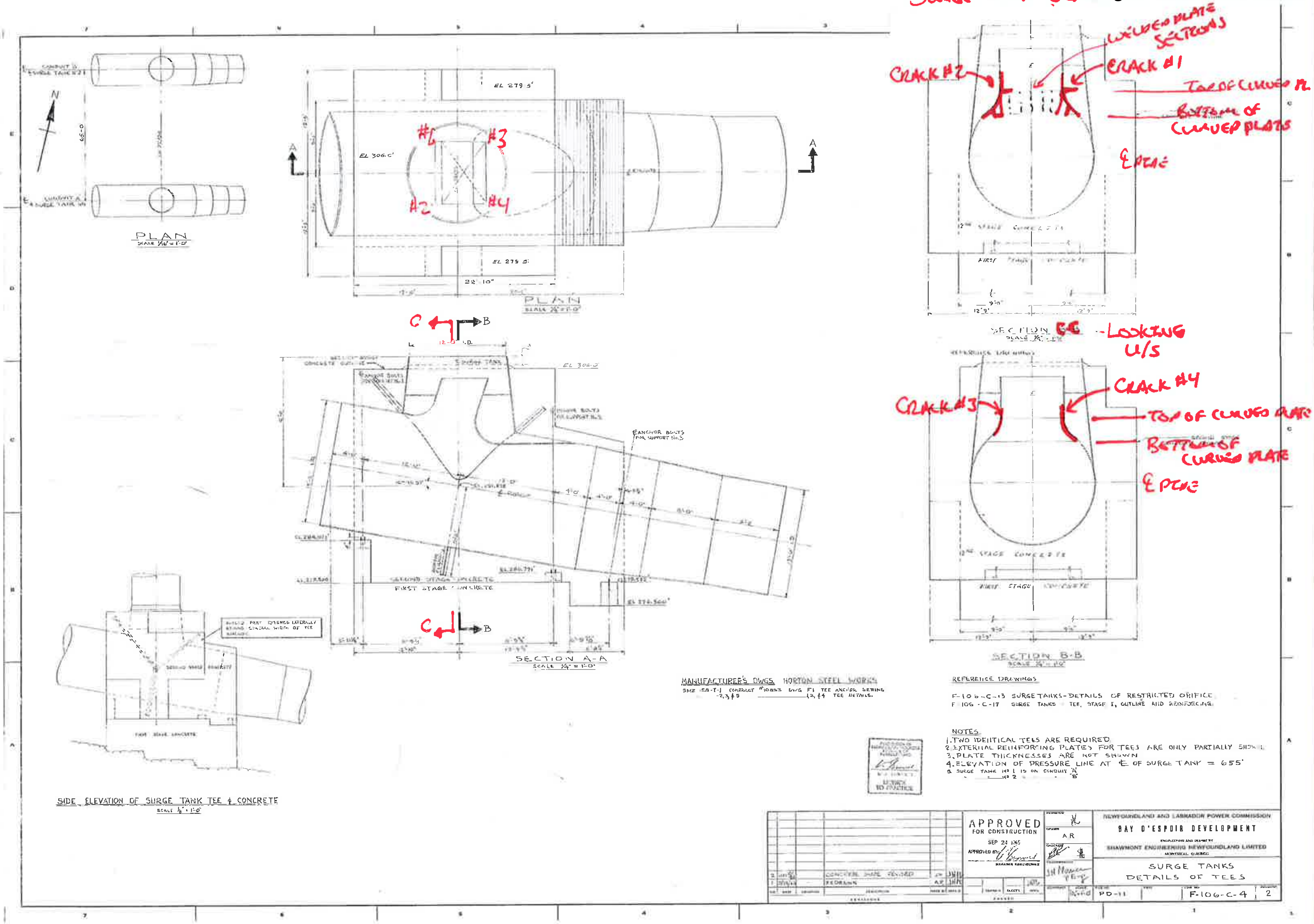
www.KleinschmidtGroup.com
Kleinschmidt 50 1966-2016

SURGE TANK CRACK OBSERVATIONS

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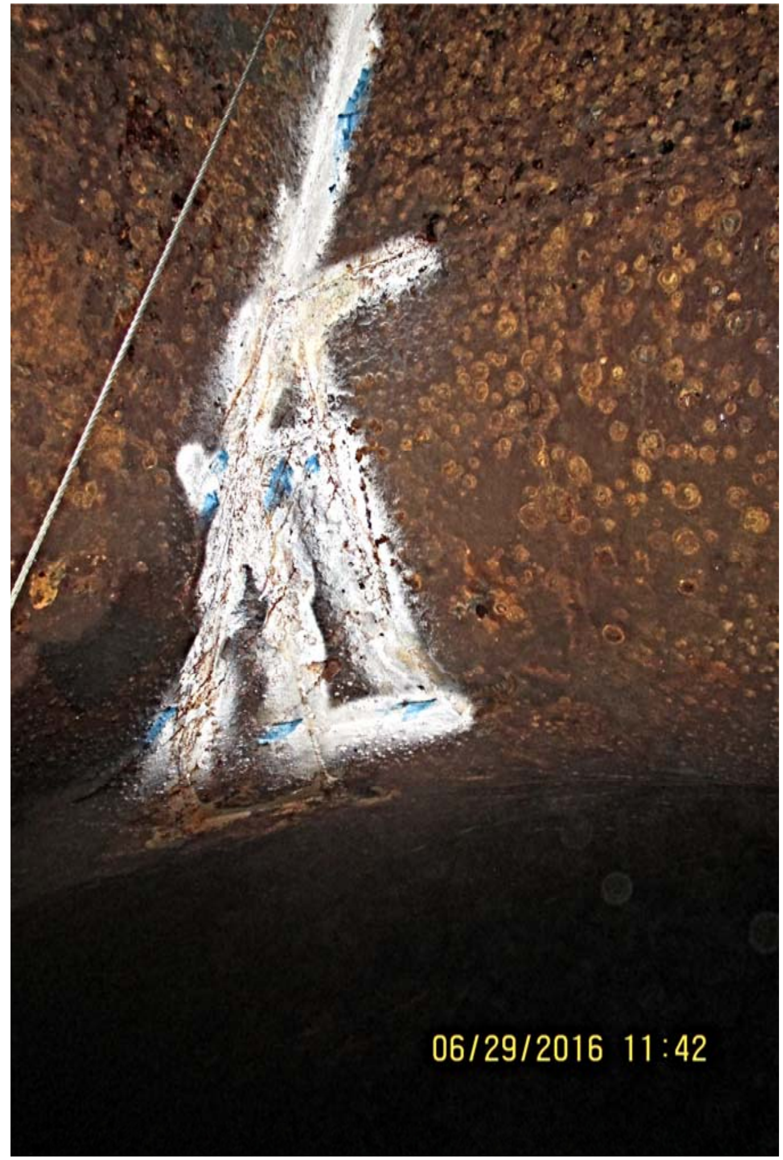
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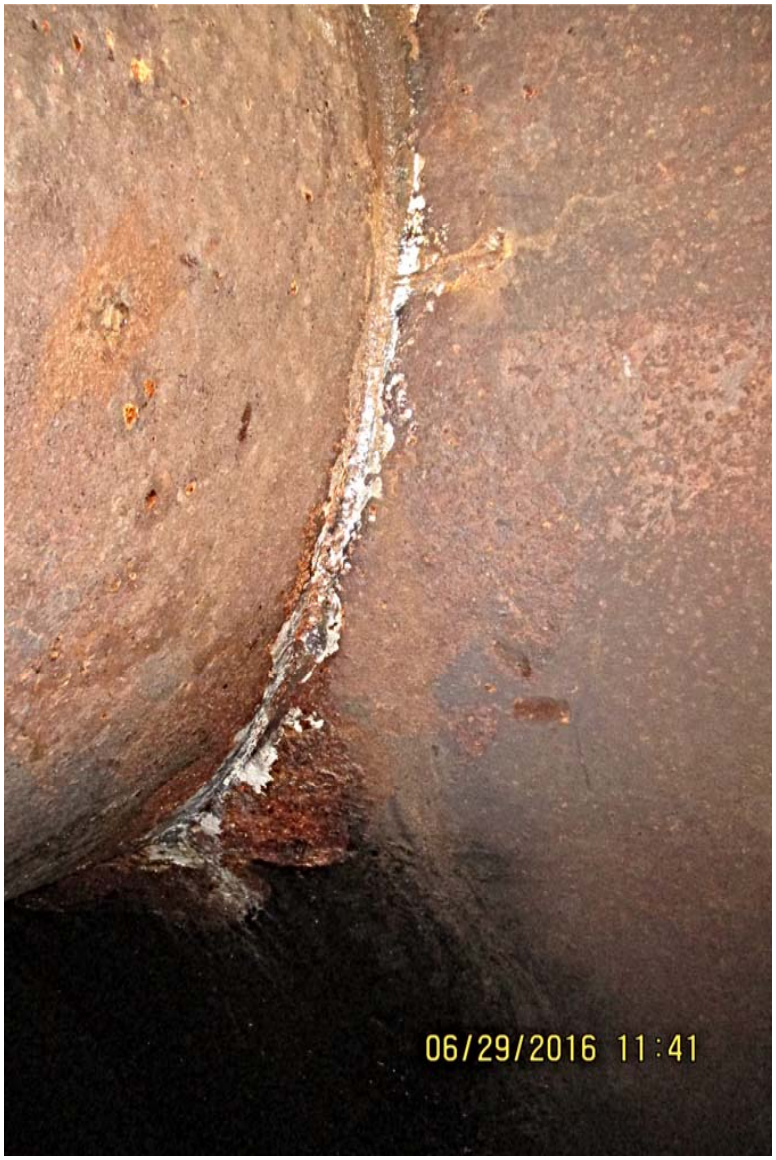
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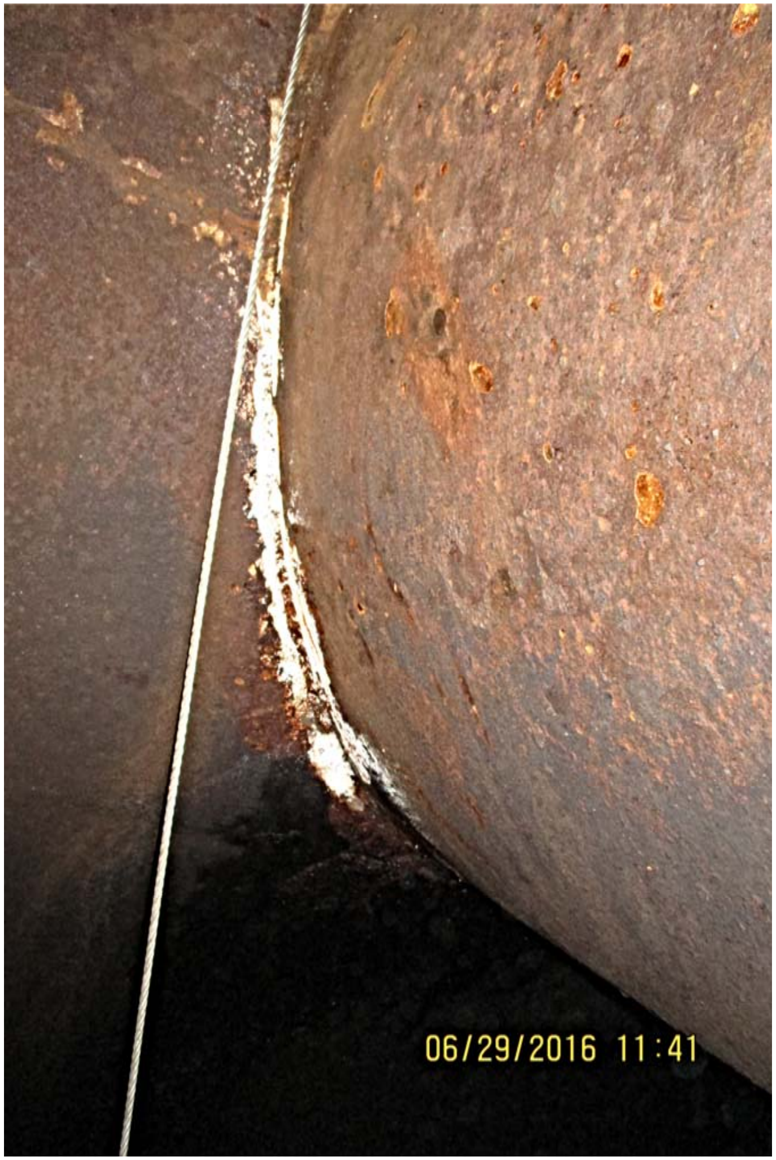
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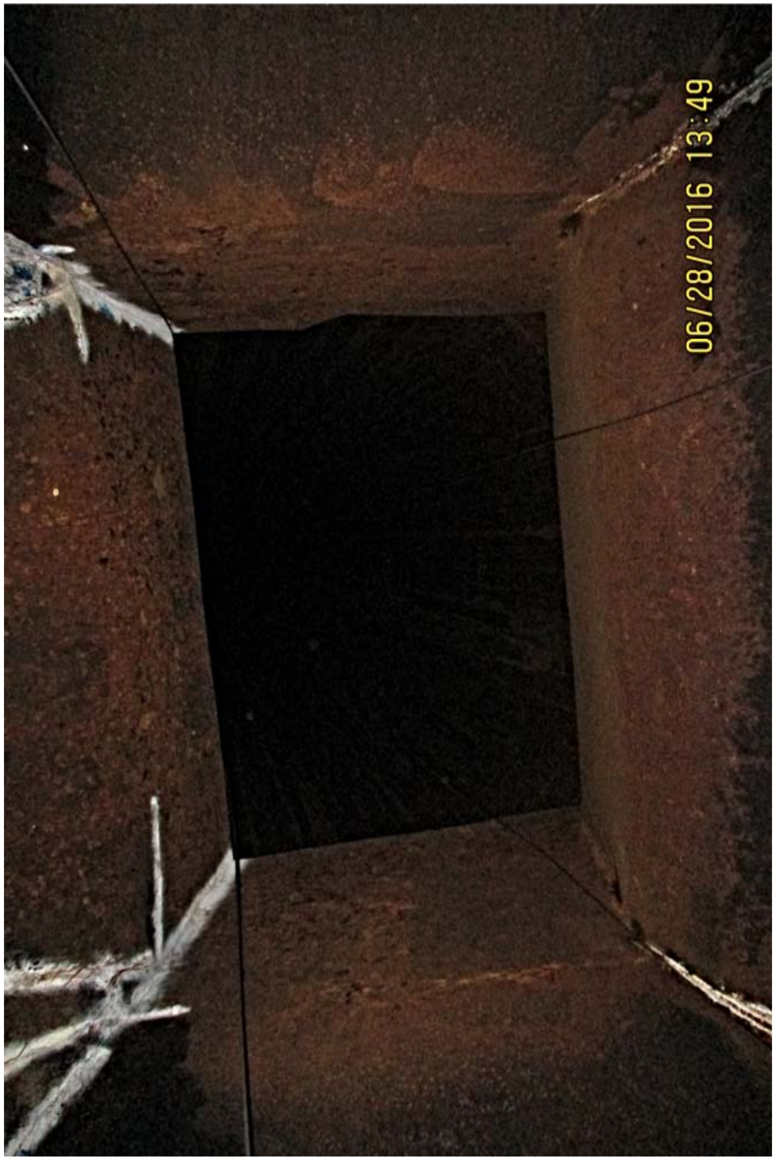
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A REPORT TO
THE BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

REGISTERED PROFESSIONAL ENGINEER PEG Newfoundland and Labrador DAVE ROYLE SIGNATURE 03/03/17 DATE NEWFOUNDLAND & LABRADOR	Electrical
	Mechanical
	Civil
	Protection & Control
	Transmission & Distribution
	Telecontrol
	System Planning

Unit 3 Turbine Major Overhaul
Bay d'Espoir Generating Station

March 3, 2017

newfoundland labrador
hydro
a nalcor energy company

Summary

Newfoundland and Labrador Hydro (Hydro) conducts on-going asset management activities to maintain reliable operation of its turbines. One of those activities is a major overhaul of the turbine components. To conduct a major overhaul, the generator must be removed from service, disassembled, inspected, refurbished as required, and reassembled. To complete a turbine major overhaul requires an extended outage to the generating unit.

Based on condition based information directly related to Bay d'Espoir Generating Station (Bay d'Espoir) Unit 3 turbine and information obtained from the 2016 Bay d'Espoir Unit 4 turbine major overhaul, Hydro has concluded that a major overall must be completed on Unit 3 turbine in order to maintain reliable operation of generating Unit 3.

If the Board approves this Supplemental Capital Budget Application to advance the Unit 3 turbine major overhaul, a future extended outage for Unit 3 major refurbishment can be avoided and the turbine major overhauls for all the Bay d'Espoir units can be accomplished by 2022. The project has a budget of $2,361,500 and is scheduled to have the refurbishment completed in August 2017.

TABLE OF CONTENTS

1.0 Introduction

The Bay d'Espoir Generating Station (Bay d'Espoir) provides 613 MW of electrical capacity and 2,560 GWH of energy annually to the Island Interconnected System (IIS). The station consists of seven generators. The nameplate capacity of each of the first six generators is 76.5 MW. The seventh unit has a nameplate capacity of 154 MW. Figure 1 is an image of a portion of the Provincial electricity grid with the Bay d'Espoir Generating Station highlighted in yellow.

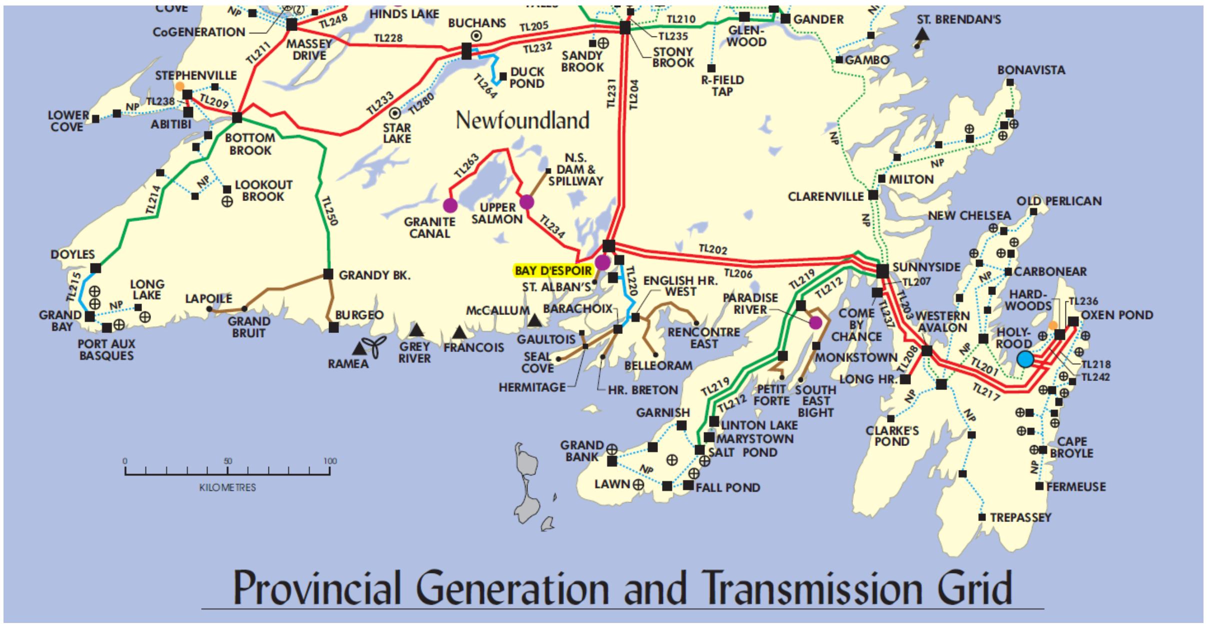

Figure 1: Provincial Generation and Transmission Grid

1.1 Turbine Asset Management

The two major sections of a generating unit are the turbine and the generator. The turbine is the part of the generating unit through which water from the penstock flows turning the turbine runner (Photograph of runner shown in Photo 1).

Photo 1: Turbine Runner and Shaft

The flow of the water is controlled by the wicket gates inside the turbine (Photograph of wicket gates shown Photo 2).

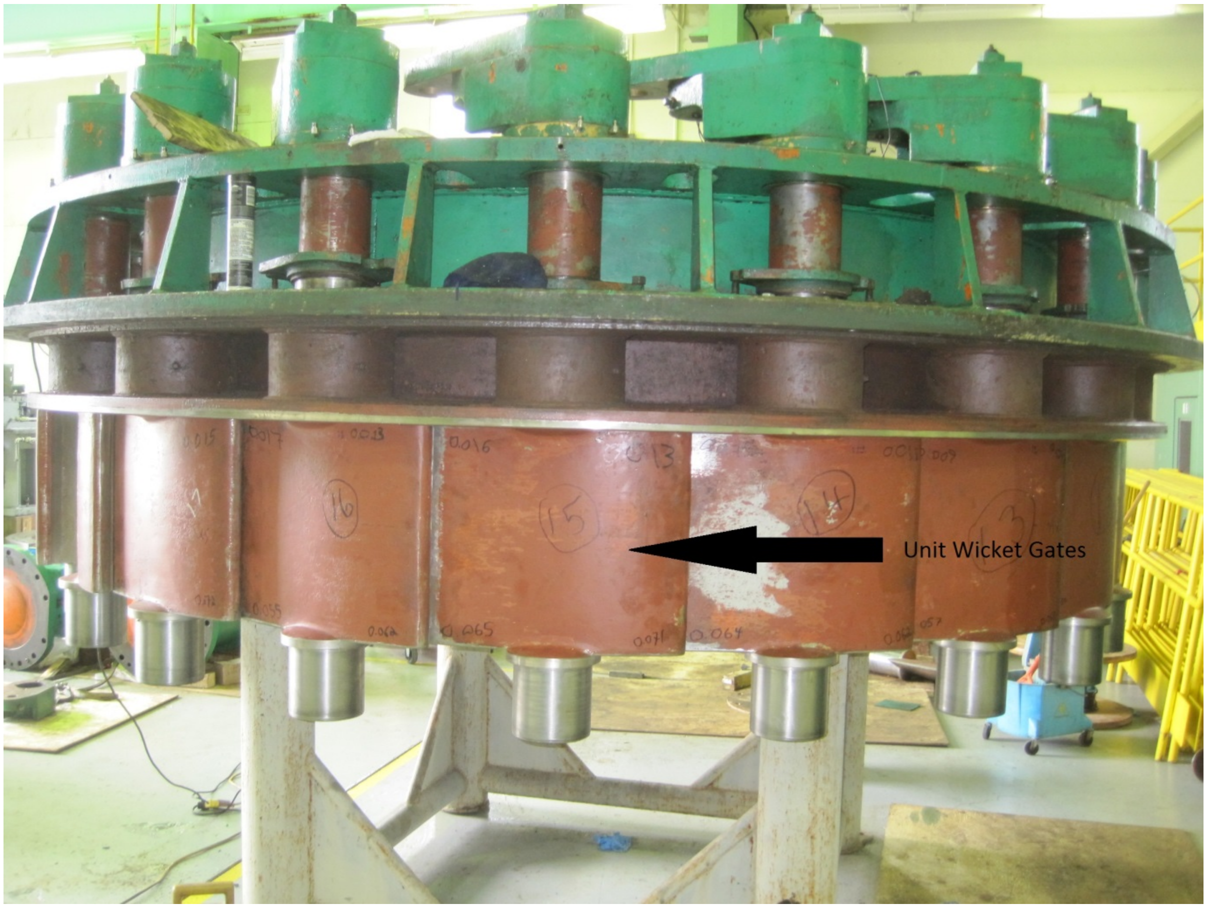

Photo 2: Unit Wicket Gates

1 The turbine is connected to the generating section so that as it turns so does the generator
2 rotating part (the rotor, Photo 3). As the generator rotor turns it can produce electricity.

Photo 3: Bay d'Espoir Generating Unit 4 Rotor being removed.

Hydro's asset management strategy for hydraulic turbines consists of three distinct points of intervention:

1. An annual preventative maintenance that primarily consists of non-intrusive visual inspections, measurements and tests, as well as the replacement of some regular wear parts, including carbon brushes;
2. A unit overhaul, on a six year frequency, which consists of a partial dismantle of the unit (generator rotor is removed) to perform a more intrusive condition based inspection and, if required, rehabilitation; and
3. A major overhaul to inspect and, as required, refurbish components which can only be addressed after a full disassembly of the turbine, e.g. runner, turbine seals, and wicket gates. The actual timing of a unit's major overhaul is based on assessment by Hydro asset management personnel of condition based information available, including information from sister units. Typically, a major overhaul occurs approximately every 25 years.

A critical item of condition based information in the assessment by Hydro is the seal clearance measurements. The seal clearance is the distance between the stationary wearing rings and the runner, Photo 4 (See Appendix A for a sectional drawing of a Bay d'Espoir generating unit). Acceptable clearance distances are required for the reliable operation of the turbine. It is normal for a turbine, which has operated for a long period of years, to experience seal clearance loss. This loss can be caused by the rings suffering a wearing phenomenon such as cavitation, corrosion, erosion, or distortion of the rings or the turbine runner incurring axial movement due to bearing wear or misalignment. Unacceptable clearances could result in inefficient operation and damage to the turbine.

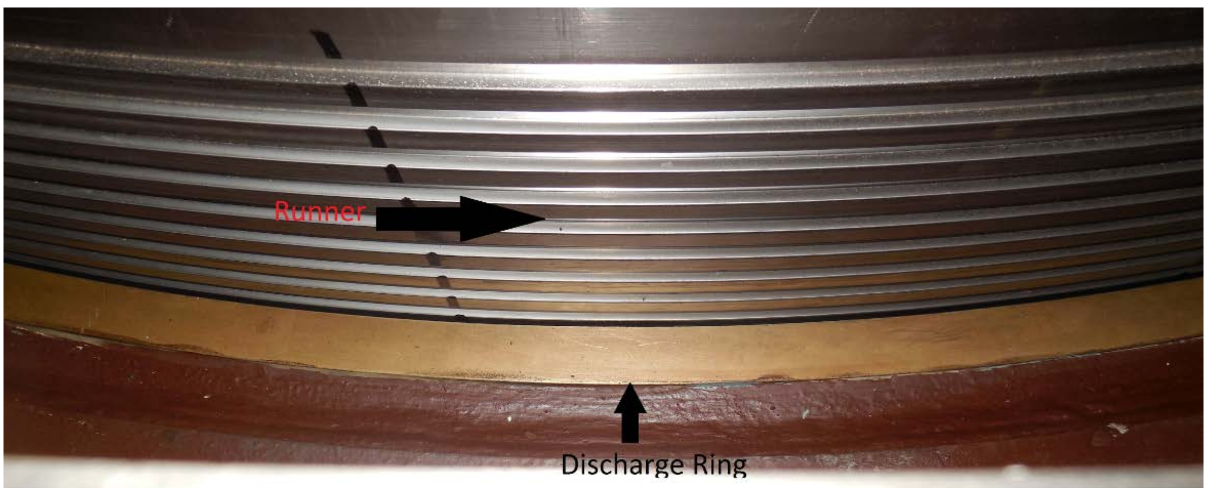

Photo 4: Runner being lowered to sit next to the Discharge Ring.

As part of the annual Bay d'Espoir turbine preventative maintenance, upper and lower primary seal clearances measurements are taken. These measurements are assessed by comparing them to previous measurements, to the design specifications and a guide (*Hydroelectric Turbine-Generator Units Guide for Erection Tolerances and Shaft System Alignment*) provided by the Centre for Energy Advancement through Technological Innovation[1] (CEATI) and, if required, with the assistance of industry expertise. From this assessment, Hydro determines when turbine major overalls are required.

[1] CEATI in conjunction with its associated electric generating utilities have published seal clearances which have been found to provide reliable turbine operation.

1.2 Turbine Major Overhauls Timing

In 2016, during the Bay d'Espoir Unit 4 turbine annual inspection, primary turbine seal clearance measurements revealed accelerated reduction in the clearance between the stationary and rotating parts. The clearances were such that a major overhaul was required to ensure future reliable turbine operation. Without such intervention, the continuing clearance loss would have resulted in damage to the turbine stationary and rotating parts and a forced outage. An extended period of at least several months would be required to refurbish the damage. On June 28, 2016, Hydro submitted a supplemental capital budget application for approval of a major overhaul of Unit 4.[2]

Subsequent to the supplemental capital budget application for the major overhaul of Unit 4 and prior to the completion of that overhaul, Hydro submitted, as part of its 2017 Capital Budget Application Five Year Capital Plan, activities to complete one major generating unit overhaul annually of Unit 1, Unit 2, Unit 3, Unit 5, Unit 6, and Unit 7 (in successive years).[3] Those activities were to start with a unit in 2019 and be completed in 2024.

1.3 Advancement of Turbine Major Overhaul timing

During the major overhaul of Unit 4, the runner seals and wicket gates were refurbished and rehabilitation of concrete support for the turbine was performed. The level of refurbishment required was more extensive than anticipated. Photos 5 and 6 show damage and non-damaged sections of the discharge ring.

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[2] Details of Bay d'Espoir Unit 4 Major Overhaul were outlined to the Board in *An Application by Newfoundland and Labrador Hydro pursuant to Subsection 41(3) of the Act for the approval of the Turbine Rehabilitation of Bay d'Espoir Unit 4*

[3] Unit 4 major overhaul was completed in 2016.

Photo 5: Damaged Section of Discharge Ring

Photo 6: Non-Damaged Section of Discharge Ring

Approximately half of the wicket gate bushings were worn to the point where they required replacement. Some were stuck and had to be destroyed to enable replacement. Binding of wicket gates increases the likelihood of shear pin failures. If a shear pin fails, the effected wicket gate cannot control the incoming water to the unit. Consequently, the generating unit may not be able to respond as designed to changes in electrical load and frequency. As well, there were 0.080 inch grooves in the runner seals, as shown in Photo 5. Considering Unit 1, Unit 2, Unit 3, Unit 5, and Unit 6 turbines are of similar vintage and design as Unit 4, the units have undergone equivalent protective and corrective maintenance programs, and their existing condition is based on information from Unit 4, Hydro anticipates the condition of these units are similar to that of Unit 4 prior to its 2016 major overhaul. To ensure reliable turbine operation, Hydro decided to advance the timing of each major overhaul in the plan by one year, starting in 2018, and all turbine major overhauls would completed by 2023.

1.4 Timing of Penstock 2 Refurbishment

On October 14, 2016, Hydro informed the Board that it would execute the refurbishment of Bay d'Espoir Penstock 1[4] due to welding failures using the Allowance for Unforeseen Items account. That project was completed in 2016 and required the refurbishment of approximately 900 m of welded seams.

Penstock 1 and 2 were manufactured and installed at the same time; therefore, it is anticipated that the condition of the welding in Penstock 2 is expected to be similar to that discovered in Penstock 1. As such, Hydro anticipates that Penstock 2 requires refurbishment as well. Hydro is submitting one Capital Budget Supplementary Application to address both the Penstock 2 Refurbishment and Unit 3 Turbine Major Overhaul, to the Board for approval to proceed with a project to assess the condition of Penstock 2 welding and, if required, complete refurbishment of the penstock. If the Board approves the Penstock 2 aspect of the Capital Budget Supplementary Application, the resulting project will necessitate an extended outage of approximately eight weeks to generators Unit 3 and Unit 4 in 2017,

[4] Details of Bay d'Espoir Penstock 1 Refurbishment were outlined to the Board in the final report issued for the project on January 9, 2017, as per the requirements of a project executed using Allowance for Unforeseen Items.

given that they are supplied water from penstock 2.

Hydro is proposing to advance the Unit 3 turbine major overhaul such that it coincides with the 2017 Penstock 2 Refurbishment project to avoid an additional extended outage to Unit 3 for a turbine major overhaul and to accelerate its plan for the remaining Bay d'Espoir turbine major overhauls from 2023 to 2022, with the remaining major overhauls of Units 1, 2, 5, 6 and 7 commencing in 2018 and ending in 2022.

2.0 Project Description

The Unit 3 Turbine Major Overhaul project consists of the complete dismantling of the turbine, inspections, refurbishment of deteriorated turbine components, and reassembly of the turbine. The work includes but is not limited to:

- Machining of rotating and stationary parts of the runner upper and lower seals to restore deteriorated runner clearances;
- Inspection of the head cover and bottom ring/bushings and replace worn parts;
- Inspection of operating ring bearings and linkage bushings; replacement of worn components where practical and refurbished otherwise;
- Replacement of wicket gate stem "V" packing;
- Refurbishment of runner cavitation to restore as close as practical to its original condition;
- Inspection of concrete behind the scroll case and draft tube; replacement where required;
- Replacement of various components, as required, based on disassembled condition assessment; and
- Grouting of discharge ring.

The execution of the major overhaul will be performed by a combination of Hydro personnel and contract resources. Critical work will be overseen by external experts. Spare parts are available for components that are reasonably expected to require replacement during this overhaul.

3.0 Justification

This application is submitted to allow the advancement of Unit 3 Turbine Major Overhaul to coincide with the execution of 2017 Penstock 2 Refurbishment. The Penstock 2 project will result in an extended outage to generation Unit 3 and Unit 4 of approximately eight weeks. Having these projects occur in 2017 will eliminate the need for an additional future extended outage to complete the turbine major overhaul for Unit 3 generator and will accelerate the plan for the remaining Bay d'Espoir turbine major overhauls to be completed in 2022.

The need to undertake a turbine major overhaul of Unit 3 is to ensure the turbine continues to operate reliably by completing refurbishments anticipated to be similar to those executed in 2016 for Unit 4.

3.1 Existing System

Generating Unit 3 was constructed in 1967 and its turbine runner, the rotating component of the turbine, was replaced in 1994. As part of the runner replacement, other components, including the primary stationary seals and wicket gate bushings, were replaced to complete the refurbishment.

A list of Unit 3 generating unit, major works or upgrades, performed since 1994 are listed in Table 1.

Table 1: Major Work or Upgrades Unit 3 Bay d'Espoir

Year	Major Work/Upgrade	Comments
2015	Realignment	
2015	Auto Grease System Replaced	
2015	Excitation Transformer Replaced	
2015	Thrust/Guide Bearing Coolers	
2014	Unit PM-9 Major Inspection	
2014	Thrust/Guide Bearing Coolers Replaced	
2014	Air Gap Monitoring & Continuous PDA Installed	Part of Generator Stator Rewind project
2014	Replaced/Upgraded Unit Protection	
2014	Generator Rotor Poles Refurbished	Part of Generator Stator Rewind project
2014	Generator Stator Rewind	
2009	Cooling Water Piping Replaced	
2004	Spherical Valve No. 3 controls upgrade to include automated control	
1999	Turbine Bearing Cooling coil installation	
1999	Generator Bearing Cooling coil installation	
1999	Replace thrust bearing cooler	
1997	Exciter Replacement	existing equipment at end of its useful life
1994	Runner Replacement, Voith	- Increased turbine efficiency; - Increased max. plant output; - Reduced vibration and power swings caused by draft tube surges; - Reduced maintenance downtime caused by cavitation and corrosion.
1983	Replaced discharge and outer head-cover wearing rings	
1982	Trabon greasing modified	
1981	Concrete repairs to draft tube	

3.2 Operating Experience

Table 2 details Unit 3 seal clearances from 2012 to 2016. Appendix A, Unit Cross-Section and Seal Details, and Figure 2 provide reference drawings of a generating unit to show where the seal clearances measurements were obtained.

Table 2: Clearances between Runner and Seal

	US	DS	US+DS	A1	A2	A1+A2
Design Min	0.040	0.040	0.080	0.040	0.040	0.080
Design Max	0.055	0.055	0.110	0.055	0.055	0.110
CEATI Max	0.083	0.083	0.166	0.083	0.083	0.166
CEATI Min	0.020	0.020	0.040	0.020	0.020	0.040
2012	0.065	0.055	0.120	0.022	0.050	0.072
2013*						
2014	0.045	0.037	0.082	0.017	0.045	0.062
2015*						
2016	0.055	0.085	0.140	0.032	0.026	0.058

*Readings not available.

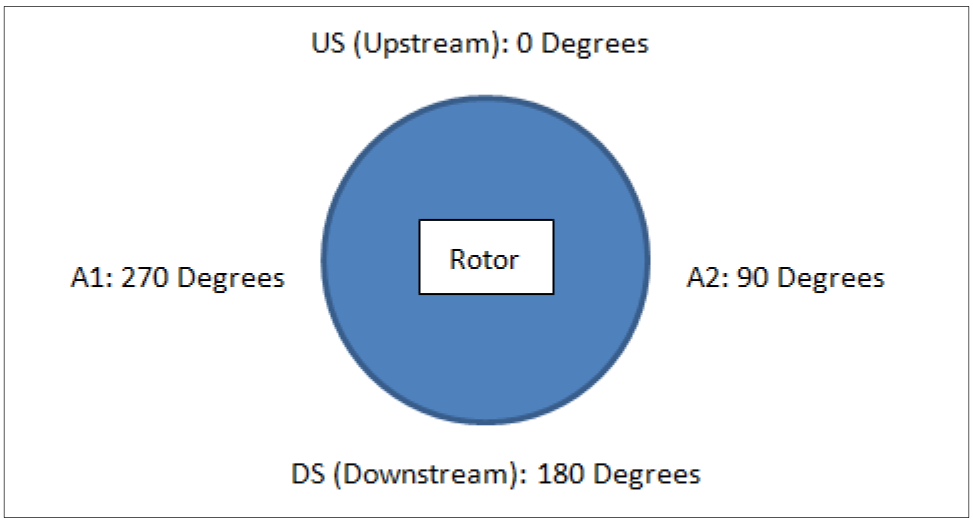


Figure 2: Position of the clearance readings as they relate to the data in Table 2

As indicated in Table 2, the readings on Axis 1 and 2 (A1 and A2) are getting smaller, indicating the seal clearances are closing in this direction. Conversely, the Upstream and Downstream (US and DS) readings are getting larger. This effect is known as Ovalling and Unit 3 has surpassed the minimum design clearance and therefore intervention is required.

3.2.1 Reliability Performance

There are no past reliability performance issues related to the justification of this project.

3.2.2 Legislative or Regulatory Requirements

There are no legislative or regulatory requirement issues related to the justification of this project.

3.2.3 Safety Performance

There are no past safety performance issues related to the justification of this project.

3.2.4 Environmental Performance

There are no past environmental performance issues related to the justification of this project.

3.2.5 Industry Experience

The occurrence of seal clearance loss is not uncommon for hydroelectric units. For example, a unit at Churchill Falls had to be refurbished due to contact between the rotating and stationary parts resulting in an extended outage. Also, Hydro's consultant at Hydro Expertise DL Inc. shared an example about a runner at a different site within Newfoundland that seized in operation when the runner contacted the primary stationary seal.

There are numerous examples of seal clearance loss over time at various utilities. Due to the frequency of this experience, CEATI published the guide "Hydroelectric Turbine-Generator Units Guide for Erection Tolerances and Shaft System Alignment" to compile its member utilities' experiences, and to develop and share required clearances and recommendations as to when action is required.

3.2.6 Vendor Recommendations

There are no vendor recommendations related to the justification of this project.

3.2.7 Maintenance or Support Arrangements

Hydraulic generating units are inspected and maintained by Hydro.

3.2.8 Maintenance History

Table 3 shows the maintenance expenditures from 2012 to 2016 for Unit 3 turbine.

Table 3: Five-Year Maintenance History

Year	Preventive Maintenance ($000)	Corrective Maintenance ($000)	Total Maintenance ($ 000)
2012	13.8	16.6	30.4
2013	5.2	4.9	10.1
2014	0.1	0.5	0.6
2015	21.1	1.9	23.0
2016	10.0	0.7	10.7

3.2.9 Historical Information

In 1994, due to cavitation damage, the original mild steel Unit 3 turbine runner was replaced with a stainless steel runner. The new runner improved the resistance to cavitation damage and improved turbine efficiency. At that time, the primary seals were also replaced with an aluminum bronze material and machined in place to create the proper clearance with the new runner. Additional turbine rehabilitation work was carried out including head cover and discharge ring modifications, wicket gate bushing replacement, carbon seal replacement, and a unit alignment.

3.2.10 Anticipated Useful Life

This project is part of a normal asset management activities required to extend the useful life of a turbine.

3.3 Forecast Customer Growth

Forecasted customer growth is not applicable to this project.

3.4 Development of Alternatives

There are no viable alternatives which would maintain reliable turbine operations.

3.5 Evaluation of Alternatives

As there are no viable alternatives to the work outlined for this project, no evaluation was completed.

3.5.1 Energy Efficiency Benefits

There are no energy efficiency benefits that can be attributed to this project.

3.5.2 Economic Analysis

As there is no viable alternative to the work outlined for this project and no energy efficiency benefits, no economic analysis was completed.

4.0 Conclusion

Assessment of seal clearances and the extensive refurbishment required for Unit 4 has shown that a turbine major overhaul of Unit 3 is required.

If the Bay d'Espoir Penstock 2 Refurbishment project is approved by the Board, that project will occur in 2017 and will necessitate an estimated eight week outage to Unit 3 and Unit 4 generators. By advancing the Unit 3 turbine major overhaul so that it can occur in 2017 in conjunction with the Refurbishment Penstock 2 project, a future additional extended outage to Unit 3 can be avoided and will accelerate the major overhaul plan for the remaining Bay d'Espoir turbines to be completed in 2022 versus 2023.

4.1 Budget Estimate

The budget estimate for this project is $2,361,500 with the breakdown provided in Table 4.

Table 4: Project Budget Estimate

Project Cost: *($ x1,000)*	**2017**	**2018**	**Beyond**	**Total**
Material Supply	252.5	0.0	0.0	252.5
Labour	767.7	0.0	0.0	767.7
Consultant	30.0	0.0	0.0	30.0
Contract Work	800.0	0.0	0.0	800.0
Other Direct Costs	35.8	0.0	0.0	35.8
Interest and Escalation	98.3	0.0	0.0	98.3
Contingency	377.2	0.0	0.0	377.2
TOTAL	**2,361.5**	**0.0**	**0.0**	**2,361.5**

4.2 Project Schedule

The anticipated project schedule is shown in Table 5.

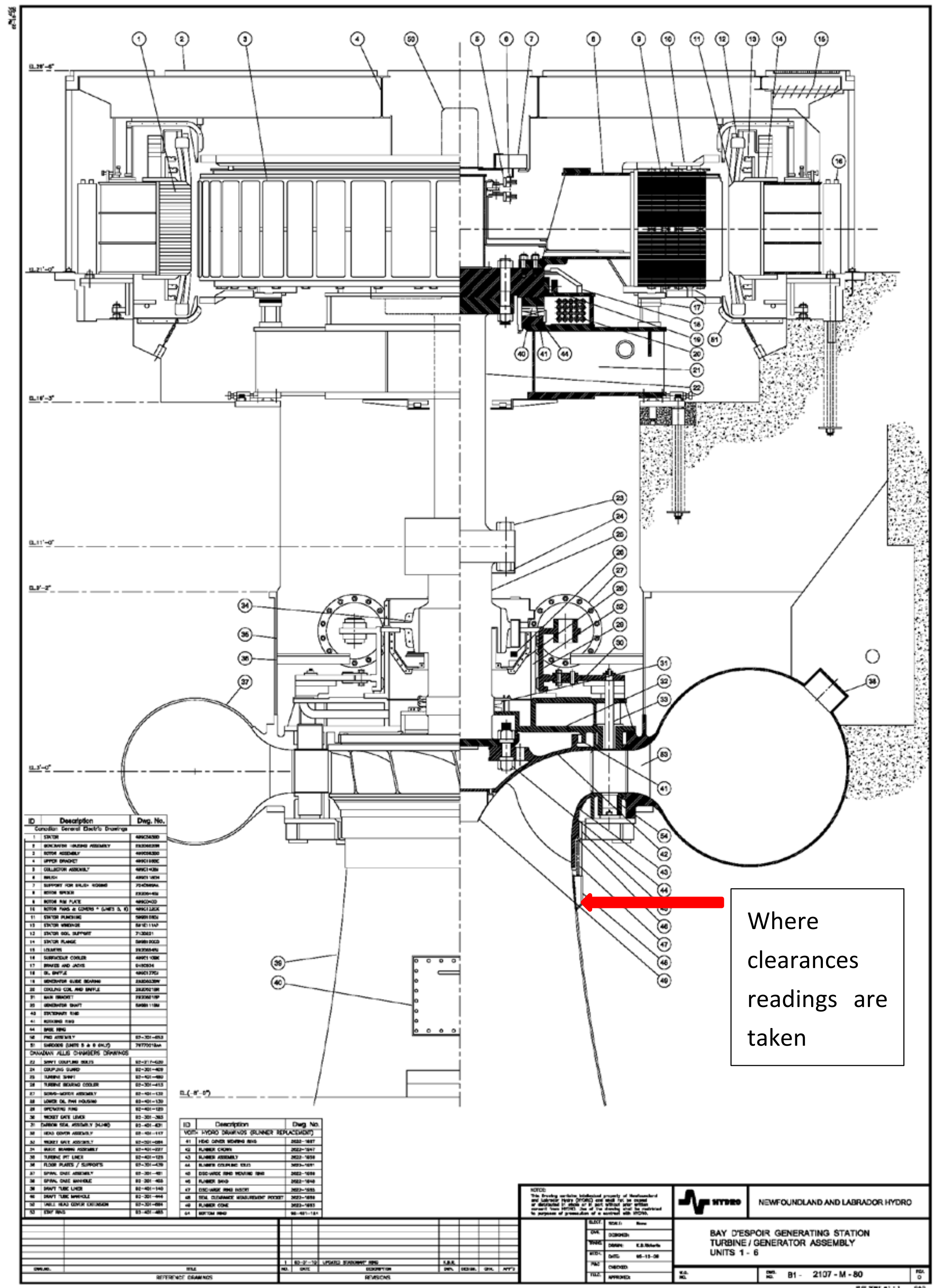
Table 5: Project Schedule

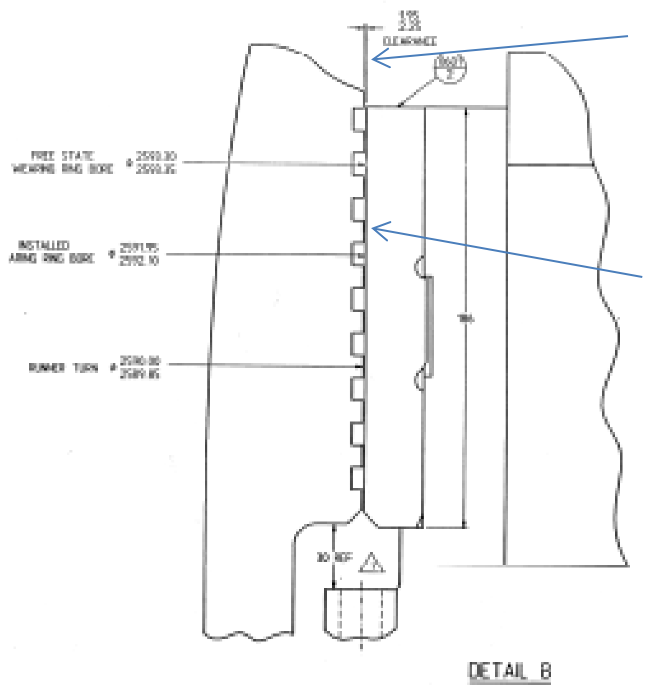
Activity	Start Date	End Date
Contract development and Award	January 2017	March 2017
Engineering and Material Procurement	January 2017	April 2017
Contractor Mobilize	May 2017	
Seal refurbishment	May 2017	July 2017
Unit reassembly, and start-up	July 2017	August 2017
Project Closeout	October 2017	October 2017

4.3 Future Plans

In its 2018 Capital Budget Application, Hydro will continue to include proposed turbine major overhauls at the Bay d'Espoir Generating Station.

APPENDIX A
Unit Cross-Section and Seal Details


Where clearances readings are taken
NEWFOUNDLAND AND LABRADOR HYDRO
BAY D'ESPOIR GENERATING STATION
TURBINE / GENERATOR ASSEMBLY
UNITS 1 - 6
B1 - 2107 - M - 80



This shows the clearance required between the components.

The dark lines in the valley of the saw tooth are actually two lines with the clearance between them.

Close up detail of the lower seal area

IN THE MATTER OF the *Electrical Power Control Act,* RSNL 1994, Chapter E-5.1 (the *EPCA*) and the *Public Utilities Act*, RSNL 1990, Chapter P-47 (the *Act*), and regulations thereunder;

AND IN THE MATTER OF an Application by Newfoundland and Labrador Hydro for the approval of the Refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine Major Overhaul pursuant to Subsection 41(3) of the *Act*.

AFFIDAVIT

I, Kyle B. Tucker, Professional Engineer, of St. John's in the Province of Newfoundland and Labrador, make oath and say as follows:

1. I am the Manager of Regulatory Engineering of Newfoundland and Labrador Hydro, the Applicant named in the attached Application.

2. I have read and understand the foregoing Application.

3. I have personal knowledge of the facts contained therein, except where otherwise indicated, and they are true to the best of my knowledge, information and belief.

SWORN at St. John's in the)
Province of Newfoundland and)
Labrador,)
this 3rd day of March, 2017,)
before me:)

Tracey Pennell

Barrister - Newfoundland and Labrador

Kyle B. Tucker, M. Eng., P. Eng.

(DRAFT ORDER)
NEWFOUNDLAND AND LABRADOR
BOARD OF COMMISSIONERS OF PUBLIC UTILITIES

AN ORDER OF THE BOARD

NO. P.U. __ (2017)

IN THE MATTER OF the *Electrical Power Control Act*, RSNL 1994, Chapter E-5.1 (the *EPCA*) and the *Public Utilities Act*, RSNL 1990, Chapter P-47 (the *Act*), and regulations thereunder;

AND IN THE MATTER OF an Application by Newfoundland and Labrador Hydro for the approval of the Refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine Major Overhaul pursuant to Subsection 41(3) of the *Act*.

WHEREAS the Applicant is a corporation continued and existing under the *Hydro Corporation Act, 2007,* is a public utility within the meaning of the Act and is subject to the provisions of the *Electrical Power Control Act*, 1994; and

WHEREAS Section 41(3) of the Act requires that a public utility not proceed with the construction, purchase or lease of improvements or additions to its property where:

a) the cost of construction or purchase is in excess of $50,000; or
b) the cost of the lease is in excess of $5,000 in a year of the lease,

without prior approval of the Board; and

WHEREAS in Order No. P.U. 45(2016) the Board approved Hydro's 2017 Capital Budget in the amount of $271,265,600; and

WHEREAS in Order No. P.U. 5(2017) the Board approved supplementary 2017 capital expenditures in the amount of $3,045,000 to construct a distribution feeder at the Bottom Waters Terminal Station; and

WHEREAS on Order No. P.U. 7(2017) the Board approved supplemental 2017 capital expenditures in the amount of $3,168,944 for: (i) the sublease of two 230 kV transmission lines that run from Churchill Falls to the Twin Falls generating plant site; (ii) the sublease of two 230 kV transmission lines that run from the Twin Falls generating plant site to the Wabush Terminal Station; (iii) the lease of electrical equipment situated in the Churchill Falls Switchyard; and (iv) the purchase of spare parts and inventory associated with the Wabush Terminal Station, the

Churchill Falls Switchyard and the transmission lines to acquire two 230 kV transmission lines serving Labrador West; and

WHEREAS on March 3, 2017, Hydro applied to the Board for approval to refurbish Bay d'Espoir Penstock 2 and overhaul Bay d'Espoir Unit 3 Turbine, at an estimated capital cost of $9,063.700 and $2,361,500, respectively; and

WHEREAS the Board is satisfied that the proposed capital expenditures for the refurbishment of Bay d'Espoir Penstock 2 and overhaul of Bay d'Espoir Unit 3 Turbine is necessary to allow Hydro to continue to provide service and facilities which are reasonably safe and adequate and just and reasonable.

IT IS THEREFORE ORDERED THAT:

1. The proposed capital expenditure to refurbish Bay d'Espoir Penstock 2 in the amount of $9,063,700, is approved.
2. The proposed capital expenditure to overhaul Bay d'Espoir Unit 3 Turbine in the amount of $2,361,500, is approved.
3. Hydro shall pay all expenses of the Board arising from this Application.

DATED at St. John's, Newfoundland and Labrador, this   day of   , 2017.

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