newfoundland labrador
hydro
a nalcor energy company

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June 8, 2018

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

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

Dear Ms. Blundon:

Re: An Application by Newfoundland and Labrador Hydro (Hydro) for approval of capital expenditures to complete a Level 2 condition assessment on Penstocks 1 and 2, and a report on Penstocks 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Station

Please find enclosed one (1) original and ten (10) copies of Hydro's Application, plus supporting affidavit, project proposal, and draft order.

The Bay d'Espoir Generating Station (Bay d'Espoir) is the largest of Hydro's hydro-electric generating stations. 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 that supply water to each of the seven generating units. Penstocks 1, 2, and 3 supply water to Units 1-6 in Bay d'Espoir Powerhouse 1 and are integral components of the 459 MW of generation from these six units.

Penstock 1 experienced two ruptures in 2016, leading to the refurbishment of the original penstock weld material. In the summer of 2017 a proactive inspection and refurbishment project took place within Penstock 2, also resulting in refurbishment of the penstock longitudinal welds. Upon a third failure of Penstock 1 in November 2017, further reinforcement of the welded areas was completed, allowing for the penstock to return to service, and additional testing and analysis was performed by an external consultant to determine the cause of the failure.

In May 2018, Hydro commenced an inspection of Penstock 3 that identified cracks in the existing longitudinal seam welds and it was determined that, due to the significant number of cracks in the welds, refurbishment was necessary. This refurbishment of Penstock 3 is underway utilizing the Allowance for Unforeseen Items Account, which includes the majority of the Level 2 condition assessment scope for that Penstock given the requirement to identify the extent of the refurbishment.

To evaluate various alternatives to address any similar issues that may exist, as those identified in all three penstocks, and to ensure the long-term reliability of Penstocks 1, 2, and 3; Hydro is recommending completion of a Level 2 condition assessment of Penstocks 1 and 2, and providing a report on Penstocks 1, 2, and 3.

The estimated capital cost of this project is $1,120,600, the scope of which is set out in Schedule 1 of the Application. Hydro submits the proposed capital expenditure is necessary to ensure that Hydro can continue to provide service which is safe and adequate and just and reasonable as required by Section 37 of the *Act*.

Should you have any questions, please contact the undersigned.

Yours truly,

Newfoundland & Labrador Hydro

Michael Ladha
Legal Counsel & Assistant Corporate Secretary
MSL/skc

Encl.

cc: Gerard Hayes – Newfoundland Power
Paul Coxworthy – Stewart McKelvey
Dennis Browne, Q.C. – Browne Fitzgerald Morgan & Avis
Sheryl Nisenbaum – Praxair Canada Inc.

ecc: Larry Bartlett – Teck Resources Limited
Dean Porter – Poole Althouse
Denis Fleming – Cox & Palmer

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 approval of capital expenditures to complete a Level 2 condition assessment on Penstocks 1 and 2, and, a report on Penstocks 1, 2 and 3 at the Bay d'Espoir Hydroelectric Generating Station 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 hydroelectric 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 that supply water to each of the seven generating units. Penstocks 1, 2 and 3 supply water to Units 1-6 in Bay d'Espoir Powerhouse 1 and are integral components of the 459 MW of generation from these six units.

3. Penstock 1 experienced two ruptures in 2016, leading to the refurbishment of the original penstock weld material. In the summer of 2017 a proactive inspection and refurbishment project took place within Penstock 2, also resulting in refurbishment of the penstock longitudinal welds. Upon a third failure of Penstock 1 in November 2017, further reinforcement of the welded areas was completed, allowing for the penstock to return to service, and, additional testing and analysis was performed by an external consultant to determine the cause of the failure.

4. After reviewing the original design documents and the operating history of Penstocks 1, 2, and 3, a recommendation was made to perform a Level 2 condition assessment on Penstocks 1, 2, and 3, and, as a pre-cursor to these Level 2 condition assessments, an initial inspection was undertaken on Penstock 3 in May 2018.

5. The initial inspection of Penstock 3 in May 2018 identified cracks in the existing seam welds and by May 15, 2018, it was determined that due to the significant number of cracks in the welds, refurbishment was necessary.

6. Refurbishment of Penstock 3 is now ongoing using Allowance for Unforeseen Items funding. The work being completed on Penstock 3 will include most of the condition assessment scope and therefore, the condition assessment aspect for Penstock 3 is not included in this proposal. Some remaining items will be executed using capital expenditure less than $50,000.

7. To evaluate various alternatives to address any similar issues that may exist, as those identified in all three penstocks, and ensure the long term reliability of Penstocks 1, 2 and 3, Hydro is now recommending completion of a Level 2 condition assessment of Penstocks 1 and 2, and, providing a report on Penstocks 1, 2 and 3 at Bay d'Espoir.

8. The estimated capital cost of the project is \$1,120,600. The scope of work for this project is set out in the project description and justification document attached hereto as Schedule 1.

9. Hydro submits that the proposed capital expenditure is necessary to ensure that Hydro can continue to provide service which is safe and adequate and just and reasonable as required by Section 37 of the *Act*.

10. Therefore, Hydro makes Application that the Board make an Order pursuant to section 41(3) of the *Act* approving the capital expenditure of approximately \$1,120,600 to complete Level 2 condition assessments on Penstocks 1 and 2, and, a report on Penstocks 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Station, as more particularly described in this Application and in the project description and justification document attached hereto as Schedule 1.

DATED at St. John's in the Province of Newfoundland and Labrador this 8th day of June 2018.

Michael Ladha
Counsel for the Applicant
Newfoundland and Labrador Hydro
500 Columbus Drive P.O. Box 12400
St. John's, NL A1B 4K7
Telephone: (709) 737-1268
Facsimile: (709) 737-1782

REGISTERED PROFESSIONAL ENGINEER PEG Newfoundland and Labrador DAVE ROYLE SIGNATURE 6/8/2018 DATE NEWFOUNDLAND & LABRADOR	Electrical
	Mechanical
	Civil
	Protection & Control
	Transmission & Distribution
	Telecontrol
	System Planning

Condition Assessment – Powerhouse 1 Penstocks

Bay d'Espoir Hydroelectric Generating Station

June 2018

A Report to the Board of Commissioners of Public Utilities

newfoundland labrador hydro
a nalcor energy company

Executive Summary

The Bay d'Espoir Hydroelectric Generating Station (Bay d'Espoir) relies on penstocks to supply water to each of its generating units. Penstocks 1, 2, and 3 supply water to Units 1-6 in Bay d'Espoir Powerhouse 1 and are an integral component of the 459 MW of generation from these six units.

Penstock 1 experienced two ruptures in 2016, leading to the refurbishment of the original penstock weld material. In the summer of 2017 a proactive inspection and refurbishment project took place within Penstock 2, also resulting in refurbishment of the penstock longitudinal welds. Upon a third failure of Penstock 1 in November 2017, further reinforcement of the welded areas was completed, allowing for the penstock to return to service, and additional testing and analysis was performed by an external consultant to determine the cause of the failure.

After reviewing the original design documents and the operating history of Penstocks 1, 2, and 3, a recommendation was made to perform Level 2 condition assessments[1] on Penstocks 1, 2, and 3. This was viewed as a first-step measure aimed at ensuring long-term reliability of all three penstocks. As a pre-cursor to these Level 2 condition assessments, an initial inspection was undertaken on Penstock 3 in May 2018. Due to the discovery of weld cracking in Penstock 3, refurbishment is ongoing using Allowance for Unforeseen Items funding. The work being completed on Penstock 3 will include most of the condition assessment scope and therefore, the condition assessment aspect for Penstock 3 is not included in this proposal.

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[1] A Level 2 Condition Assessment is an assessment undertaken by a professional or certified specialist having the knowledge, skill, and experience in the design, construction, and operation of the facility type and may require knowledge and use of specialized equipment in the assessment of the facility.

The expected duration of the Level 2 condition assessment on Penstocks 1 and 2 is two weeks per penstock with a project estimate of $1,120,600. This project will further advance the development of a plan to ensure long-term reliability of the Bay d'Espoir plant. The project will also include a report on the condition of penstocks 1, 2, and 3,[2] and provide recommendations for the safe and reliable long-term operation of the penstocks.

[2] Penstock 3 Condition Assessment field data compilation is currently underway during the execution of the weld refurbishment project executed under Allowance for Unforeseen Items project funding.

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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 613 MW of peak capacity generation at the Bay d'Espoir Hydroelectric Generating Station.

The life expectancy of a steel penstock, such as those installed at Bay d'Espoir, is generally 80 years. Penstocks 1 and 2 have been in service for 51 years, Penstock 3 for 48 years, and Penstock 4 for 41 years.

Penstock 1 experienced two ruptures in 2016 and one in November 2017. The first rupture in May 2016 was repaired and the penstock was returned to service. The second rupture occurred in September 2016, after which a detailed assessment was undertaken using provincial engineering expertise, leading to refurbishment of 900 metres of original penstock weld material.

In the summer of 2017 a proactive inspection and refurbishment project took place within Penstock 2. This work was planned and undertaken based on the recent experiences with Penstock 1, as Penstocks 1 and 2 were constructed under the same contract and expected to be in similar condition.

A third rupture of Penstock 1 occurred in November 2017. Hydro engaged a nationally recognized penstock engineering consultant[3] to perform a more detailed investigation and make recommendations for refurbishment aimed at returning the penstock to service as soon as possible for reliable upcoming winter operation. Refurbishment work was subsequently completed.

[3] See Appendix A for "*Repair and Failure Investigation*" report by Hatch, the root cause report discussing the findings of the analysis completed.

Hydro engaged the specialist consultant to review the original design documents and operating history of Penstocks 1, 2, and 3 to make recommendations regarding the measures necessary to ensure long-term reliability. Penstock 4 was not part of a review at this time because of its younger age and differing design.

In light of the past failures on Penstock 1, and considering the similarity in the design and operating conditions of the three penstocks, the consultant recommended a Level 2 condition assessment[4] for Penstocks 1, 2, and 3.

With the consultant's recommendation, Hydro's intention was to perform the condition assessments on Penstocks 1 and 2 in 2018, and to execute a reduced scope of work in 2018 for Penstock 3 due to outages schedules, with the full scope executed in 2019. On May 9, 2018, an external consultant commenced the reduced scope inspection of the longitudinal weld seams on Penstock 3. The inspection identified cracks in the existing seam welds and, by May 15, 2018, it was determined that refurbishment was necessary due to the significant number of cracks in the welds. This refurbishment of Penstock 3 will utilize the Allowance for Unforeseen Items Account. Notification of Hydro's intent was communicated to the Board of Commissioners of Public Utilities (the Board) on May 18, 2018. Components of the condition assessment for Penstock 3, originally intended to be performed in 2019, are now required, as refurbishment of Penstock 3 is currently on-going. These items included visual inspections, chipper hammer testing, and non-destructive testing of the weld seams. The laser scanning and installation of pressure transducers for Penstock 3 will be handled in a separate, less than $50,000 project.

The condition assessments will provide Hydro a fuller understanding of the current condition of the penstocks allowing for further advancements in the development of a long-term reliability plan for the Bay d'Espoir plant. The result of this study will likely mean a

[4] A Level 2 condition assessment is an assessment undertaken by a professional engineer or certified specialist having the knowledge, skill and experience in the design, construction and operation of the facility type and may require knowledge and use of specialized equipment in the assessment of the penstocks.

modified maintenance and investment program to provide reliable operation of Penstocks 1, 2, and 3 in Bay d'Espoir. Any recommendations that are applicable across Hydro's fleet of Hydroelectric generating stations will be implemented.

2.0 Project Description

This proposed project is to conduct Level 2 condition assessments of Bay d'Espoir Penstocks 1 and 2,[5] and the development of a report on Penstocks 1, 2, and 3.

The results of the condition assessment work to be undertaken by this project will allow Hydro to evaluate various alternatives to address any similar issues that may exist, such as those identified for Penstock 1, and ensure the long term reliability of Penstocks 1, 2, and 3. These alternatives will consider a range of actions that could be taken to provide reliable long-term service from the Bay d'Espoir plant.

The detailed scope of the Level 2 condition assessment of Penstocks 1 and 2 includes:

- Visual inspection of all longitudinal and circumferential welds from the surge tanks to the powerhouse in every tenth penstock can,[6] and additional cans as deemed necessary;
- Chipper hammer tests at various sections from the intakes to the powerhouse to determine integrity of welds and further Non-destructive Testing (NDT)[7] testing if required;
- NDT of weld seams from the intakes to the surge tanks in every tenth penstock can, and additional cans as deemed necessary;
- Laser measurement of deviations from circularity of Penstocks 1 and 2 profile at longitudinal welds; and

[5] Given the current project to refurbish Penstock 3, additional Level 2 Condition Assessment is not required under this proposed project.
[6] A penstock is constructed by welding together curved sheets of metal to form a "can"; each can is then welded to the next can to form a pipe called the penstock.
[7] Non-destructive testing (NDT) is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage.

- Installation of pressure sensors on Penstock 2[8] to monitor the penstock stresses.[9]

The provision of a detailed report for Penstocks 1, 2, and 3[10] includes but is not limited to:

- Scope of the condition assessments;
- Field study performed;
- Interpretation of the results of the Level 2 condition assessments;
- Recommendations to provide for reliable operation of each penstock; and
- Current condition conclusions for each penstock.

3.0 Justification

This project is justified on the requirement to provide for reliable operation of the Bay d'Espoir plant.

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; and, Penstock 4 was constructed in 1977 and supplies water to Unit 7. Please refer to Figure 1 for the layout of the four penstocks as they relate to the reservoir and the hydroelectric plant.

[8] Pressure sensors were installed on penstock 1 in 2017, and will be installed on penstock 3 during its current outage.
[9] Should additional pressure transducers be required while completing the field assessment, for either penstocks 1 or 3, these will be added under this project. Approximate cost per installed transducer is $5,000.
[10] Refurbishment of Penstock 3 requires the condition assessment to be performed in order to use the results of the assessment to properly execute the refurbishment program. The information collected during the 2018 refurbishment will be part of the interpretation of results and recommendations for life extension of all three penstocks.

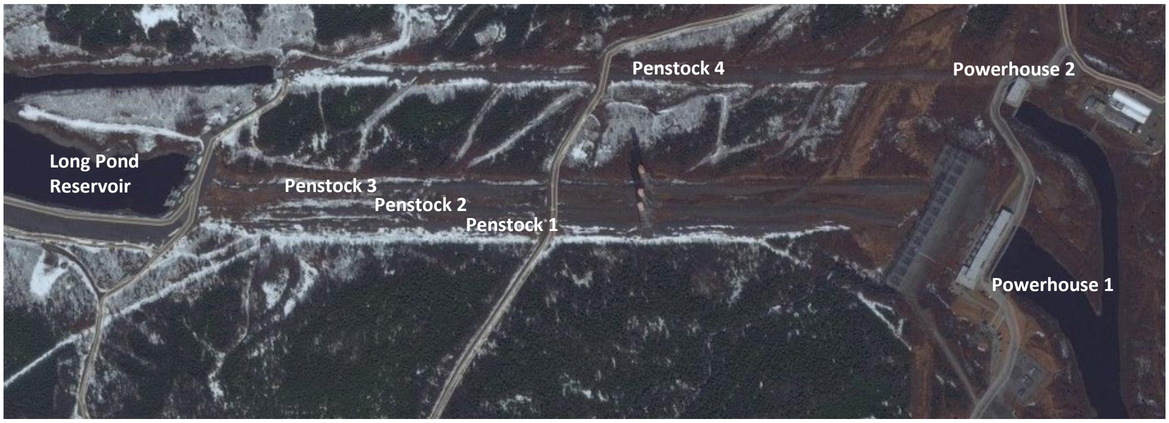

Figure 1: Layout of the Penstocks, Reservoir, and Plant

Each penstock is approximately 1200 metres long and varies in diameter throughout its length between 4.1 metres and 5.2 metres. They were 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 plate material was selected to withstand stresses expected to develop in the steel wall. Likewise, the weld specifications are developed to handle the expected load combinations.

3.2 Operating Experience

The following is a summary of the three Penstock 1 ruptures experienced since 2016:

- May 2016: Rupture in penstock wall. Unplanned outage for two weeks.
- September 2016: Rupture in penstock wall slightly upstream of the May 2016 failure. Unplanned outage for ten weeks.
- November 2017: Rupture in penstock wall directly above the September 2016 failure. Unplanned outage for five weeks.

The location of the penstock ruptures have been in close proximity to each other as seen in Figure 2.

Figure 2: Rupture locations on Penstock 1 Bay d'Espoir

Each of these ruptures have resulted in a forced outage to two generation units at Bay d'Espoir. These outages amounted to approximately 153 MW of lost generation capacity. After the second rupture occurred in September 2016, Hydro consulted with an engineering firm before welding the rupture; an internal inspection of the penstock was also carried out to determine if any additional remediation measures were required to ensure reliability of the penstock. The internal inspection revealed deteriorated conditions of the welds from the intake to the surge tank and the welds were no longer acceptable for in-service use of the penstock. To restore the integrity of the penstock, a capital project to rehabilitate approximately 900 metres of welds was required. This work was completed and the penstock was placed back in service at the end of November 2016.

Penstock 2 is the same age and design as Penstock 1. To ensure the reliability of Penstock 2, a capital project was executed for its inspection and rehabilitation in 2017 during a planned outage. Similar to Penstock 1, Penstock 2 exhibited weld deterioration and rehabilitation of approximately 450 metres of welded seams was undertaken during June 2017.[11]

In November 2017, a third rupture occurred on Penstock 1 in the same area as the initial rupture in May 2016. A detailed consultant assessment revealed fatigue and high stress in the area of the welds. In addition to addressing the November 2017 rupture, multiple areas were inspected inside the penstock to ensure that the welds refurbished in 2016 were still acceptable. The inspection revealed that some areas had micro cracks and the necessary refurbishment was completed. Approximately 8% of previously refurbished welds required additional reinforcement.

After the most recent rupture in November 2017, Hydro engaged a consultant (Hatch) to perform a root cause investigation on the ruptures and make recommendations to ensure reliable operation of Penstock 1 for the upcoming winter operation (i.e., short-term operation) and also recommendations for long-term operation (see Appendix A, filed with the Board on May 18, 2018).

In May 2018, Hydro initiated a reduced scope inspection of Penstock 3. The preliminary results of this inspection identified the condition of Penstock 3 to be in a similar condition to that of Penstocks 1 and 2 and required refurbishment of the weld seams before it could be returned to service. It is anticipated that the 2018 refurbishment work on Penstock 3 will take approximately six to eight weeks to complete and is estimated to cost approximately $6,000,000, executed using the Allowance for Unforeseen Items Account. Notification of Hydro's intent to use this account was communicated to the Board on May 18, 2018. During this time Units 5 and 6, which are rated for 153 MW combined, will remain out of service until the refurbishment work is complete.

[11] Refer to the 2017 supplemental project, "*Refurbishment of Bay d'Espoir Penstock 2 and Bay d'Espoir Unit 3 Turbine Major Overhaul*", approved by the Board on April 21, 2017 (P.U. 13(2017).

The areas of the penstock that were focused on during the assessment by Hatch included the localized area that had experienced all three ruptures, adjacent areas, and other select areas throughout the penstock considered to be high risk in the near-term. To ensure long-term reliability, the consultant recommended more assessment work be completed in 2018 on all three penstocks to verify the condition of refurbishment work completed in late 2017 and to determine if additional refurbishment is required. In addition to the recommendations for Penstock 1, Hydro requested that the consultant make recommendations to ensure long-term reliability of Penstocks 2 and 3.

3.2.1 Maintenance History

The five-year maintenance history for all three penstocks including the capital and operating expenditures for the penstock failures are shown in Table 1.

Table 1: Five-Year Operating Maintenance History and Capital Expenditures ($000)

Year	Preventive Maintenance/ Corrective Maintenance	Capital Expenditures (Actual)	Unplanned Operating (Actual)
2017	91.5	November: 4,598.8	215.7
		June: 3,586.6	0
2016	105.4	September: 7,171.1	May: 99.4
2015	6.3	0	0
2014	0.6	0	0
2013	0.2	0	0

3.2.2 Anticipated Useful Life

The typical life expectancy for a steel penstock is 80 years. Penstocks 1 and 2 are 51 years old, and Penstock 3 is 48 years old so some deterioration is expected. Hydro will be able to make informed decisions on future reliability and any potential rehabilitation program to maintain reliability for the expected life, or to extend the life, of the penstocks upon completion of the condition assessments.

3.3 Development of Alternatives

There are no viable alternatives to the Level 2 condition assessments required for Penstocks 1 and 2. These assessments are required to be able to fully evaluate the state and, if required, develop solutions to ensure the penstocks integrity. If Hydro does not proceed with the Level 2 condition assessments, the condition of the penstocks will be unknown and there would be a continued potential for unplanned outages to the penstocks.

4.0 Conclusion

With repeated ruptures of Penstock 1, and with Penstocks 2 and 3 being of similar design vintage, and condition, completing Level 2 condition assessments will allow Hydro to enhance long-term planning focused on reliability of the Bay d'Espoir plant. This will result in measures to ensure the integrity of Penstocks 1, 2, and 3. The proposed Level 2 condition assessments will enable Hydro to better understand the current condition of all penstocks including the performance of recent refurbishment work on Penstock 1 and 2. After the condition assessment work is complete, Hydro will use the information to evaluate alternatives using a cost benefit analysis to determine the least cost alternative to ensure the penstocks operate reliably and thereby ensure reliability of the Bay d'Espoir Powerhouse 1 generating units.

4.1 Budget Estimate

Table 2 outlines the capital cost required to complete the Level 2 condition assessments for Penstocks 1and 2, and to provide the report for all three penstocks.

Table 2: Project Budget Estimates ($000)

Project Cost	2018	2019	Beyond	Total
Material Supply	10.0	0.0	0.0	10.0
Labour	117.5	0.0	0.0	117.5
Consultant	160.0	0.0	0.0	160.0
Contract Work	526.5	0.0	0.0	526.5
Other Direct Costs	102.1	0.0	0.0	102.1
Interest and Escalation	21.3	0.0	0.0	21.3
Contingency	183.2	0.0	0.0	183.2
Total	**1,120.6**	**0.0**	**0.0**	**1,120.6**

4.2 Project Schedule

Table 3 outlines the anticipated project schedule.

Table 3: Project Schedule

Activity		Start Date	End Date
Planning	Open project in JDE, open work orders for project, review schedule.	June 2018	July 2018
Procurement	Develop and award contracts for contractor for the condition assessments.	June 2018	July 2018
Construction	2018 Site Inspection Activities	June 2018	August 2018
Report	Report to be issued	November 2018	November 2018
Closeout	Project close out	November 2018	November 2018

Appendix A

Repair and Failure Investigation

Newfoundland and Labrador Hydro

Final Report

For

Repair and Failure Investigation

H356043-00000-240-230-0003
Rev. 2
May 17, 2018

Newfoundland and Labrador Hydro

Final Report

For

Repair and Failure Investigation

H356043-00000-240-230-0003
Rev. 2
May 17, 2018

HATCH

Newfoundland and Labrador Hydro
Bay d'Espoir Penstock No. 1 Refurbishment - 2017
H356043

Engineering Report
Mechanical Engineering
Refurbishment and Failure Investigation Final Report

Refurbishment and Failure Investigation Final Report

H356043-00000-240-230-0003

REGISTERED PROFESSIONAL ENGINEER
PEG Newfoundland and Labrador
PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
MICHAEL A. J. PYNE
SIGNATURE
2018-05-17
DATE
NEWFOUNDLAND & LABRADOR

PROVINCE OF NEWFOUNDLAND AND LABRADOR
PEG Newfoundland and Labrador
PROFESSIONAL ENGINEERS AND GEOSCIENTISTS
PERMIT HOLDER
This Permit Allows
HATCH LTD
MIRC #: 01626
To practice Professional Engineering in Newfoundland and Labrador.
Permit No. as issued by PEG D0090 which is valid for the year 2018

2018-05-17	2	Approved for Use	M. Pyne	S. Bhan	G. Saunders
DATE	REV.	STATUS	PREPARED BY	CHECKED BY	APPROVED BY

Ver: 04.03

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1. Executive Summary

A third rupture of Penstock No. 1 at Bay d'Espoir (BDE) occurred on November 4, 2017. The rupture occurred in the form of a 2' long crack just below the crack that was refurbished 14 months earlier (September 2016) in Can 35.

The May 2016 crack occurred in the can adjacent to the 2017 rupture. This crack also occurred at the longitudinal weld on the north side of the penstock. All three ruptures occurred in the upper circumferential section of the penstock.

A metallurgical analysis of the failed section confirmed that the latest rupture in Can 35 initiated at the toe of the 2016 refurbished weld and then propagated into the parent plate material in an orientation parallel to the weld. Extensive material tests did not indicate any defects in plate material or the welds.

During the original refurbishment in September 2016 on Penstock No.1, defects found in many longitudinal seams on the inside led to the refurbishment of 346 internal weld seams (approximately 1,500' of the total 3,900' length), in the upper portion of the penstock. All refurbished cans were inspected visually and with magnetic particle examination, prior to return to service.

During the refurbishment of the latest penstock rupture in November 2017, the majority of the longitudinal welds inside the penstock, from the intake to the surge tank were re-inspected. The 2017 NDT extended beyond the examination completed in 2016 and utilized the same inspection method. Of the 346 weld seams refurbished in 2016, 27 exhibited defects – plus the two seams in the ruptured portion of the penstock – resulting in 29 weld seams (8.4%) completed in 2016 requiring rework. Additionally, two new seams with cracks were discovered beyond the 2016 refurbished cans, for a total of 31 seams requiring refurbishment in 2017. All defects or cracks found during this inspection were refurbished, reinforced and inspected.

To assist in determining the root cause of the penstock ruptures, strain gauges and pressure transducers were installed. The instrumentation was monitored during filling of the refurbished penstock, during a planned part-load rejection test of Unit No. 2 and during normal operations for six weeks after the load rejection test. Hatch has carried out a detailed analysis of all measured data, a finite-element (FE) analysis of the penstock geometry interaction with the backfill and a fatigue analysis.

The investigations to-date indicate that the latest rupture was most likely caused by a combination of the following factors:

1. High residual stress due to fitting and re-welding of the ruptured seam in 2016.
2. High localized bending stresses at the longitudinal joint.
3. Fatigue caused by high-cycle low-amplitude stresses due to pressure fluctuations in the penstock transmitted from the turbine.
4. Sloughing of the soil/backfill.

Hatch believes that the risk of failure of the refurbished Penstock No. 1 from now until the next inspection (summer 2018) is low.

Several alternatives for a long-term solution to achieve safe and reliable operation of the penstock were examined.

Penstock No. 1, Unit No. 1 and Unit No. 2 operation may be continued with the following considerations:

- Operation of the units in the rough zones should be limited to that absolutely necessary. Additionally, transitioning through the rough zone should be as quickly as practical; there is no limit on the maximum load that the units can be operated at.
- Walk the penstock once a day and after unusual pressure transients, such as load rejections, and monitor regularly by camera for evidence of leaks.
- Internal inspection of Penstock No. 1 during the summer of 2018 and determine inspection frequency based on findings.

Penstock No. 1 remedial work:

- Backfill and re-coating operations should be postponed until completion and evaluation of inspection summer 2018.

Inspection of Penstock No. 2 and Penstock No. 3 is also recommended since they are of similar design and vintage as Penstock No. 1. While previous inspections of these penstocks have been completed, they have not been focused on the recently determined sources of the Penstock No. 1 failures.

2. Introduction

Hydro engaged Hatch's engineering services in response to a rupture in Penstock No. 1 at the Bay d'Espoir (BDE) hydroelectric generating station on November 4, 2017.

Hatch designed a solution and mobilized to oversee inspection and refurbishment work. A test program was prepared to monitor pressure and stresses in the rupture area of the penstock. The penstock was placed back in service on December 8, 2017.

The instrumentation installed on the penstock for the commissioning tests on December 8, 2017 continued to collect data after the tests until February 20, 2018 when the data acquisition system was returned to the National Research Council. The measurements taken over a six-week period showed insignificant change, indicating that the penstock rehabilitation remains stable.

This final report presents results of the site inspection, refurbishment design and execution, testing, finite element (FE) analysis and interpretation of the test measurements, as well as a fatigue analysis. Several alternatives for a long-term solution were examined at a preliminary level, and recommendations provided. The recommendations include considerations for inspection and evaluation of Penstock No. 2 and Penstock No. 3.

3. Background

The BDE main powerhouse consists of six generating units fed from three penstocks. Penstock No.1 feeds Units No. 1 and No. 2, Penstock No. 2 feeds Units No. 3 and No. 4 and Penstock No. 3 feeds Units No. 5 and No. 6. Each penstock bifurcates near the powerhouse to feed water to two separate units through two spherical valves. Units No.1 and No. 2 along with Penstock No. 1 were built in 1967. Penstocks No. 2 and No. 3 were built in 1968 and 1969, respectively, and, based on project As Built Drawings, were thought to have identical designs to Penstock No. 1. However, two differences have been discovered during refurbishment, analysis, and investigation.

1. Penstock No. 1 design and as-built backfill depth on top (1 ft) is less than as-built backfill depth on Penstock No.2 (2 ft) and Penstock No. 3 (2 ft). This may cause Penstock No.1 to undergo larger deformation than the other penstocks during dewatering.
2. In 2016, during inspection, external stiffening rings were discovered in the upper sections of Penstock No. 2. As these rings are not shown on design drawings or specifications, it is hypothesized that they may have been installed as construction and lifting aids for handling. It is unknown if Penstock No. 3 was also built with external ribs (none shown on design drawings).

Penstock No. 1 is approximately 3,900 feet long and is constructed from a series of carbon steel cans that vary in length depending on location, but in general the cans are approximately 9' long with shorter mitered cans to form bends. Each can consist of two rolled semi-cylindrical steel plates welded together longitudinally. There are no circumferential stiffener rings except in areas such as bends and concrete embedded sections. The penstock is supported on a prepared granular bedding and covered with backfill.

The penstock diameter varies from 17' near the intake to 13'6" near the powerhouse, and the wall thickness varies from 7/16" near the intake to 1-7/16" near the powerhouse. The upper 1100 feet of the penstock steel conforms to ASTM A285 Gr. C and the remainder CSA G40.8 Gr. B. Cracks in longitudinal welds have been discovered in both sections. However, all the ruptures have occurred in the sections constructed of ASTM A285 Gr. C. All cracking in the CSA G40.8 section have occurred in the sections fabricated with 7/16" plates.

The penstock sections are subject to varying internal pressure starting from 43.5' of water (18.8 psi or 130 kPa) near the intake to 590' (255.7 psi or 1,763 kPa) at the powerhouse under static hydraulic conditions.

During the era (1965-1966) in which Penstock No. 1 was constructed, plate rolling was generally accomplished utilizing a three-roll single pinch point roll. When rolling plates with this type of roller, the start and end of each plate will be flat (unless other techniques are used such as pre-bending or by cutting off the flat section). This causes the cross-section of cans at the longitudinal weld seams to appear as a cone rather than a circular arc, which is termed as "peaking" for the purpose of discussion in this report. The level of peaking is characterized by the radial gap between the longitudinal joint and the theoretical circular arc. Peaking (10 to 30 mm) was noted on all Cans inspected. Peaking is not normal in the fabrication of penstock shells today due to better plate rolling techniques. This discontinuity in the circular geometry at the longitudinal seam induces localized bending stresses under internal pressure (confirmed by FE modeling).

On May 21, 2016 BDE Penstock No. 1 was found to have a leak from a two-foot (600 mm) long rupture along a longitudinal weld seam in Can 34. The crack was repaired and the penstock was put back into service. On September 14, 2016 Penstock No. 1 experienced another longitudinal seam rupture in Can 35, approximately 16' (5 m) upstream from the previous rupture in the adjacent can. Newfoundland and Labrador Hydro repaired this rupture. Hatch was then engaged on September 22, 2016, to assess the penstock, at which time it was discovered that significant amounts of interior weld in the upper section of the penstock showed weld erosion and deterioration with partial depth cracking.

Upon completion of inspections in September 2016, it was confirmed that the majority of longitudinal weld joints from the intake down to Section 117 (Dwg.10830, approximately 3000' of weld length), had experienced a significant amount of weld metal loss due to corrosion. A total of three hundred and forty-six (346) longitudinal seam welds (3114') in this section of the penstock were refurbished by gouging out the old weld from the inside, rewelding and inspection before the penstock was put back in service.

Hatch provided a refurbishment method and construction assistance during work. The penstock was put back into service on November 30, 2016.

A third rupture was discovered on November 4, 2017. This rupture was on the same can just below the rupture that was last repaired (September 2016). Hydro immediately engaged the services of Hatch to assist in the inspection, rehabilitation and assessment of the penstock.

The root cause analysis conducted by Hatch in 2016 concluded that the 2016 failures occurred most likely due to stress corrosion cracking resulting from the presence of high stresses at the corroded longitudinal welds and the corrosive environment resulting from the loss of internal penstock coating. The report also attributed the higher stresses to insufficient backfill on top of the penstock and high residual stresses induced during penstock fabrication.

4. Inspection

The latest penstock rupture on November 4, 2017 was inspected visually (Figure 1-1). The entire length of the affected can around the crack was cut and shipped to a metallurgical laboratory for metallurgical analysis and material testing (Figure 4-1). The majority of longitudinal welds on the interior of the penstock from the intake to the surge tank (2272' or 690 m) were inspected visually, by magnetic particle, and using laser survey. Laser survey of the interior of the penstock was used to determine the interior shape of the penstock and confirm the level of peaking present. Cracks or defects were discovered on twenty-nine (29) longitudinal welds out of 430 seams inspected. Twenty-seven (27) of these were on 2016 refurbished weld seams and two (2) were on original weld seams. Including the 2 longitudinal weld seams from the ruptured portion of the penstock makes the total 31 repaired seams. A detailed inspection chart is shown on the following page that shows the 2016 repair/refurbishment, 2017 repair/refurbishment, cleared cans, cans that exhibited new defects, and cans that exhibited extensive cracking in 2016. The backfill and settlement monitoring posts over the same length of penstock were surveyed and the data is presented.

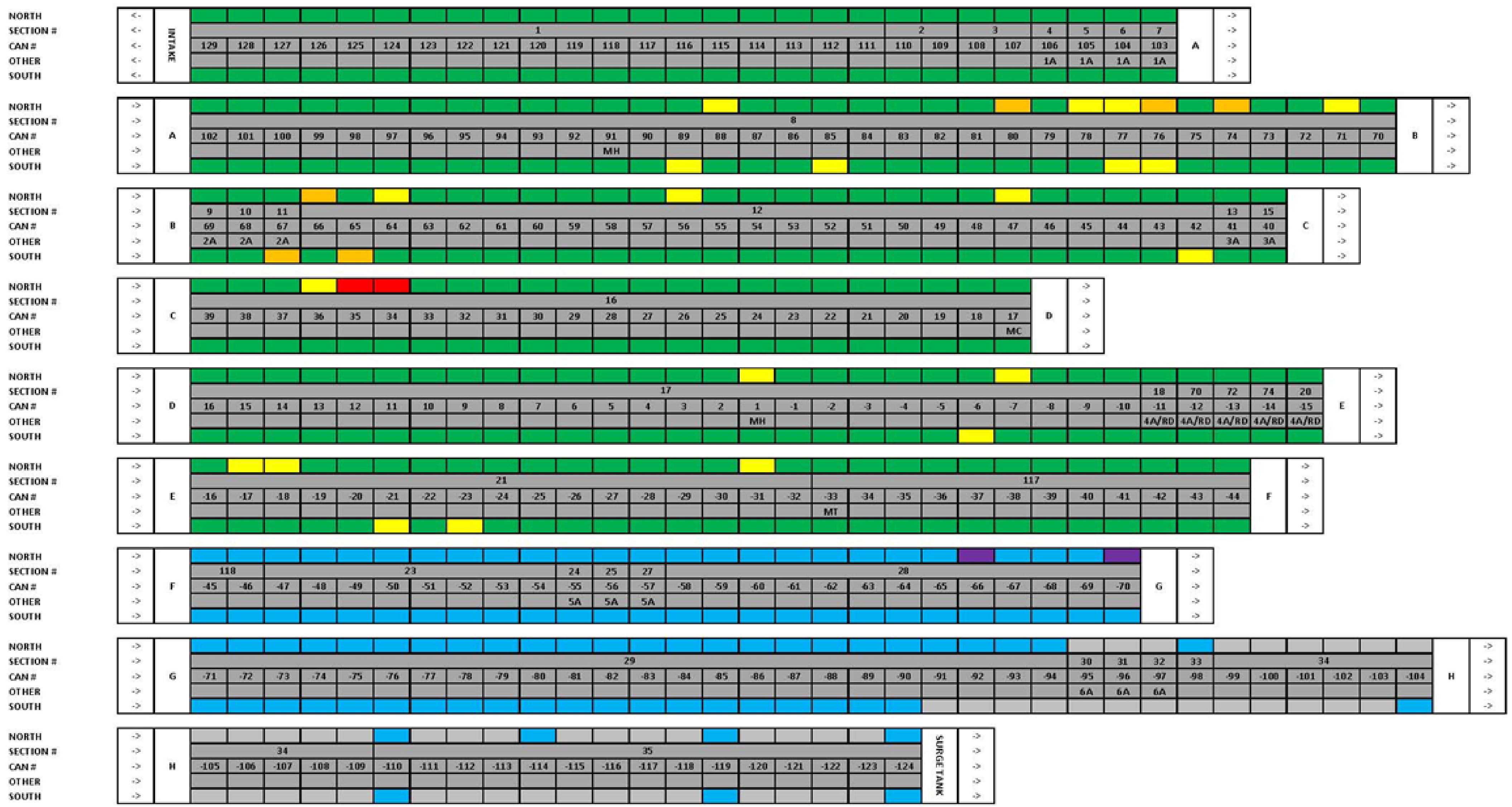
None of the circumferential welds were inspected as no cracks were found in 2016 and these joints only have half the stress due to internal pressure as compared to the longitudinal joints.

Hatch investigated if there was any loss of support at the bottom of the failed cans and adjacent area by drilling through 3" couplings welded to the bottom of the penstock at four different longitudinal locations. The visual examination of the bedding below the penstock, and the laser survey of the penstock invert and external settlement monitoring posts showed insignificant bedding loss.

The penstock between the surge tank and the powerhouse was not inspected as no cracks were found in this section in 2016. The plate in these sections is thicker and the penstock diameter is smaller. Additionally, no significant weld seam corrosion was found during the 2016 inspections. Absence of peaking at the longitudinal welds in the penstock downstream of the surge tank should be confirmed at the next inspection.

Figure 4-1: Close-up View of the Rupture in Can 35 (in the Laboratory for Material Tests)

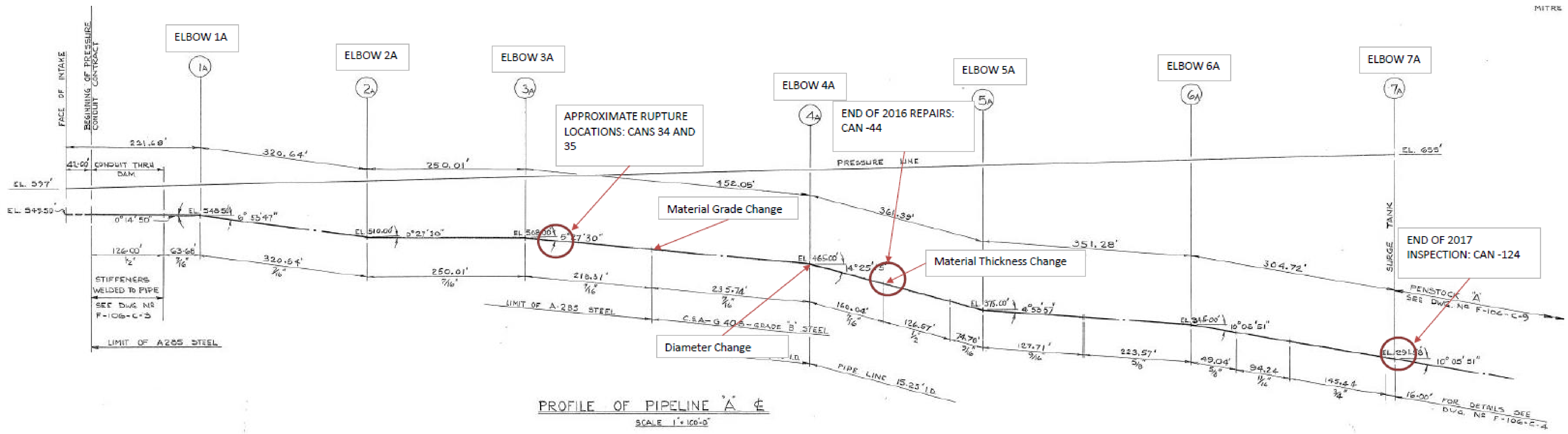
PENSTOCK NO. 1 INSPECTION TRACKER



Inspection Legend
REPAIRED 2016, CLEAN 2017
REPAIRED 2016 REPAIRED 2017
CRACKING BEYOND 6MM 2016, REPAIRED 2017
RUPTURES
NOT INSPECTED 2016 BUT INSPECTED 2017 CLEAN
UNTOUCHED
NOT INSPECTED 2016, REPAIRED 2017

Points of Interest	
MT	Material Thickness Change
MH	Manhole Location
MC	Material Grade Change
RD	Reducer Cans
XA	Bend Cans

Figure 4-2: Inspection Tracker



Bay d'Espoir Penstock No.1- Profile from Intake (left) to Surge Tank

Figure 4-3: Penstock Profile

5. 2017 Refurbishment

Hatch designed the refurbishment of the ruptured penstock can. It involved removal of a 2' wide 9' long longitudinal strip of the penstock can with the crack in the middle (Figure 4-1) and inserting a 1/2" thick pre-rolled (8'6" radius) plate (CSA G40.21 350WT-CAT 4, which is superior to existing) and welding it in place according to the procedure provided by Hatch. For safety, the longitudinal weld in Can 34, repaired originally in May 2016, was also removed and replaced by inserting another 1/2" thick pre-rolled plate. To reinforce the new refurbished area and the one from May 2016, spliced reinforcing plates (8'6" radius, 1/2" thick) were welded on the exterior of cans 33, 34, 35 and 36 (see Hatch drawing 352666-D-M-0001.1, rev B).

For the 29 longitudinal seams in other cans with defects or cracks, existing weld metal was removed from inside of the penstock and rewelded. Prior to the installation of the reinforcing plates the excess weld reinforcement on the longitudinal welds was ground flush to reduce the stress concentration at the welds and allowing the reinforcing plates to sit tighter to the existing plate surface. In each case a 22" wide 9' long rolled patch plate (8'6" radius, 1/2" thick) was welded in place on the inside of the refurbished longitudinal welds, as shown schematically in Figure 5-1 below. Figure 5-1 also shows peaking at the weld.

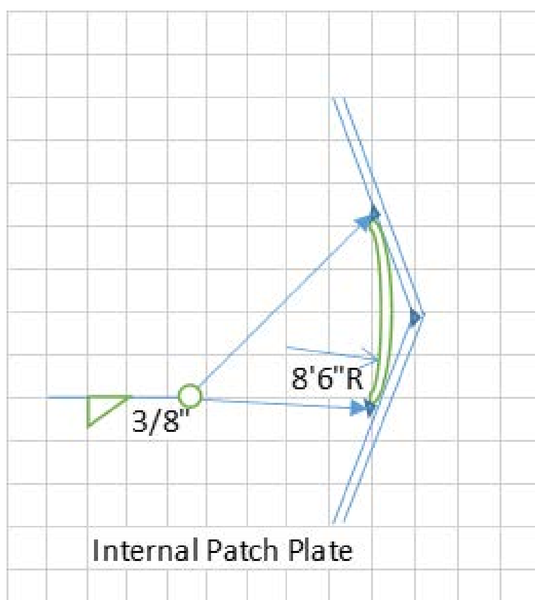


Figure 5-1: Refurbishment of Internal Longitudinal Seams

Table 5-1 shows the statistics of the longitudinal weld inspection and refurbishment.

There were 346 weld seams refurbished in 2016. The 2017 weld inspection showed defects in 8.38% of the welds refurbished in 2016, and the majority of these defects occurred on the north side of the penstock. All ruptures to date have occurred on the north side.

Table 5-1: Longitudinal Weld Statistics

Item	Description	Number	Units
1	2017 Internal Longitudinal Seams Repaired/Refurbished	31	Count
2	2016 Internal Longitudinal Seams with Defects	29	Count
3	2017 Welds Showing Defects from Original Construction	2	Count
4	2017 South Internal Seams Repaired/Refurbished	10	Count
5	2017 North Internal Seams Repaired/Refurbished	21	Count
6	2016 Total Seams Repaired/Refurbished	346	Count
7	2016 Total South Seams Repaired/Refurbished	173	Count
8	2016 Total North Seams Repaired/Refurbished	173	Count
9	Approximate Seam Total (Intake to Powerhouse)	870	Count
10	Seams Inspected 2017	430	Count
11	Approximate Total Longitudinal Seam Length	7830	ft
12	Approximate Visual (VT) and Magnetic Particle (MT) Length 2017	3870	ft
13	Approximate Seam Repair/Refurbishment Length 2017	279	ft
14	Approximate Seam Repair/Refurbishment Length 2016	3114	ft
15	2017 Defects Vs Inspection	7.21	%
16	2017 Inspection Percentage	49.43	%
17	2017 South Internal Defects vs Total	32.26	%
18	2017 North Internal Defects vs Total	67.74	%
19	2017 Defects on 2016 Welds	8.38	%
20	Approximate 2016 Repair/Refurbishment Vs Total Penstock	39.77	%
21	Approximate 2017 Repair/Refurbishment Vs Total Penstock	3.56	%

6. Testing

To investigate the cause of penstock cracking, Hatch developed a test program to monitor pressure and stresses in the penstock during penstock filling and operation. The penstock was instrumented with strain gauges on the inside and outside adjacent to the penstock failures and at a randomly selected location about 280’ (85m) upstream from the last rupture location. Backfill was partially removed at the randomly selected location to expose the external surface of the penstock for applying the strain gauges.

A data acquisition system was installed to record measurements of strains and pressure in the penstock at the test locations. Hydro Operations also recorded unit operating parameters and penstock pressure at the powerhouse.

Data was recorded for the following milestones:

- base measurement with strain gauges installed but no backfill replaced
- after backfilling penstock to the original design profile
- after completing the backfill to the geometry recommended by Hatch
- when water reached the bottom and top of test locations during penstock filling
- penstock full of water at intake forebay level
- during Unit No. 2 start up and speed-no-load
- during Unit No. 2 rough zone operation
- Unit No. 2- 40 MW load rejection
- Unit No. 1 start up
- Unit No. 1 and No. 2 in rough zone
- Unit No. 1 and No. 2 operating at 70 MW.

The steel in this region of the penstock has a yield strength of 206 MPa, and an ultimate tensile strength of 380 MPa. Design is generally performed to keep stress in the steel below the yield strength, as strains or deflections below this point are elastic and the material returns to its original condition when loading is removed. Tensile rupture should not develop in a material until the stress exceeds the ultimate tensile strength, however, plastic or permanent (non-recoverable) deformations develop in a material once the stress level has exceeded the yield strength. Additionally, material with stresses above the yield strength generally deflects more rapidly as additional load is applied. Stresses above the yield strength of a material likely indicates that the material is operating beyond the intended design values, but do not necessarily mean structural failure is imminent.

Strain gauge measurements on the inside of the penstock adjacent to the longitudinal weld seam indicated high stresses are present (280 MPa) with penstock under normal pressure, which are above the yield strength but still below the ultimate tensile strength. In addition to the high localized stress, cyclic (alternating) stresses of the order of ±15 MPa (2.2 ksi) and ±7 MPa (1 ksi) were measured by the strain gauges adjacent to the longitudinal welds during load rejection and rough zone operation, respectively. Stresses adjacent to the weld seams were also determined analytically by the finite element model of the penstock, with results also showing high stresses similar to those measured by the strain gauges in the field.

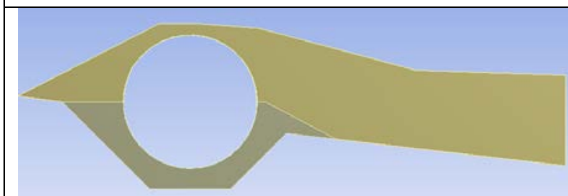
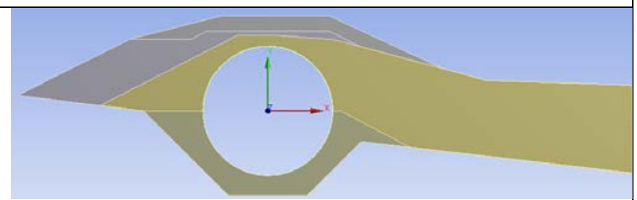
A spectral analysis of the measured stresses showed that a few frequencies were predominant in the measurements of internal pressure as well as strains. Further detailed analysis of the data measured shows the penstock is subject to cyclic stresses of lower amplitude and frequency during other events as discussed in Section 8.4.

7. Numerical Analysis

A two-dimensional finite-element (FE) model of the steel shell with the abnormal peaking at the longitudinal weld seam and the surrounding backfill was analyzed using the commercially available software ANSYS. The behavior of the backfill was modeled using large deflection non-linear characteristics of the soil.

The results of the FE analysis are shown graphically in Figures 7-1 to 7-4 (see also Appendix C for enlarged view) and the principal conclusions are:

- The geometrical discontinuity due to peaking at the longitudinal weld seam creates very high localized bending stresses.
- The unsymmetrical as-built backfill creates unsymmetrical backfill loads resulting in large deflection of the empty shell and higher stresses during penstock filling (σ_0-red line and σ_1-blue line in Figure 7-1); however, the stresses in penstock under full pressure are not impacted in the same manner by the unsymmetrical backfill (σ_2-black line in Figure 7-1).
- Additional backfill recommended by Hatch creates uniform support of the shell and reduces overall stresses with penstock empty and during filling (σ_0-red line and σ_1-blue line in Figure 7-2 vs Figure 7-1); however, there is only a small reduction in stresses with penstock under full pressure (σ_2-black line Figure 7-2 vs Figure 7-1). Also, increasing the backfill more than that recommended by Hatch (>2') has no incremental benefit in reducing the stresses in the penstock shell when empty, filling or under full pressure.
- Additional backfill beyond the 2 ft cover recommended by Hatch, does not reduce the high local bending stresses in the vicinity of the longitudinal weld seam (30^{o} position in Figure 7-2Figure 7-2 vs Figure 7-1) under internal pressure.
- Figure 7-4 shows that when the penstock is empty and filling with no internal pressure (t=1) the maximum bending stress reduces from 250 MPa to 150 MPa if the backfill is symmetrical relative to the as-is unsymmetrical backfill. However, with internal pressure applied, the maximum bending stress at the weld seam reverses to about 650 MPa and the backfill has little or no impact on the amplitude. However, variations in pressure (30 to 45 psi) increases the maximum bending stress from 450 MPa to 650 MPa. It is concluded from this analysis that improving the backfill significantly reduces circumferential bending stress during de-watering/watering up and when the penstock is empty but has insignificant effect on a pressurized penstock. This information was extracted from a theoretical linear elastic model. This allows a comparison of stresses only as the material thickness remains constant and the material does not self-relieve stresses that exceed yield. In reality, material strain hardening takes place progressively in ductile materials once the stresses exceed the yield stress of the material. It is likely that these stresses are lower in the penstock as at the location of high stress the material permanently deforms which reduces the localized stress.

FE Model Looking downstream-Backfill-original	FE Model-Recommended Backfil
	
Legend: 0=empty penstock (soil + steel weight); 1=filled with water (soil + steel + water weight) 2= pressurized (soil + steel +water weight + 38.21 psi internal pressure	

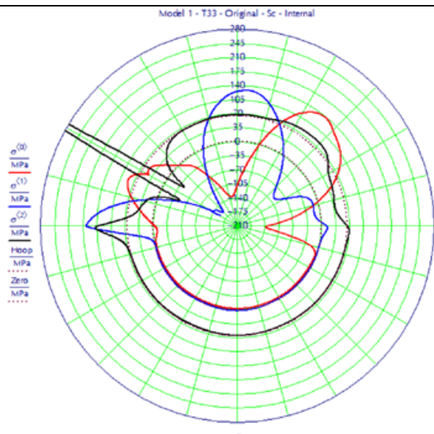
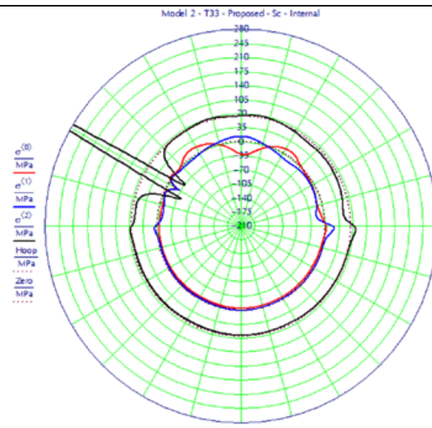
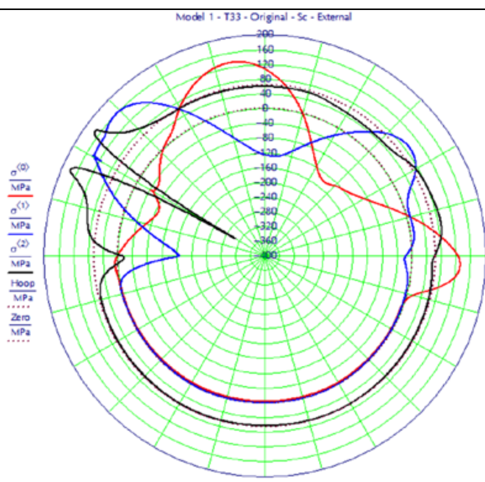
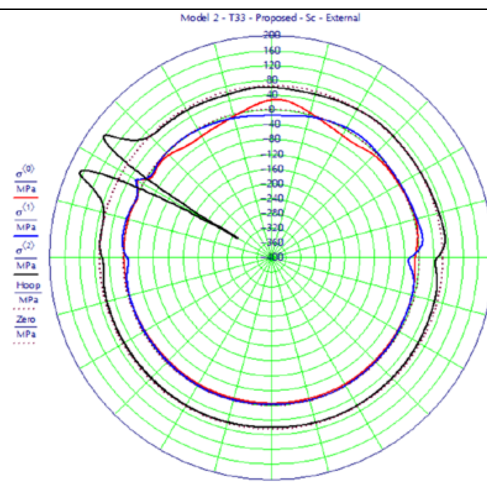

	
	

Figure 7-1: Circumferential Stresses - As is Backfill - (looking downstream)	**Figure 7-2: Circumferential Stresses - Additional Backfill by Hatch**

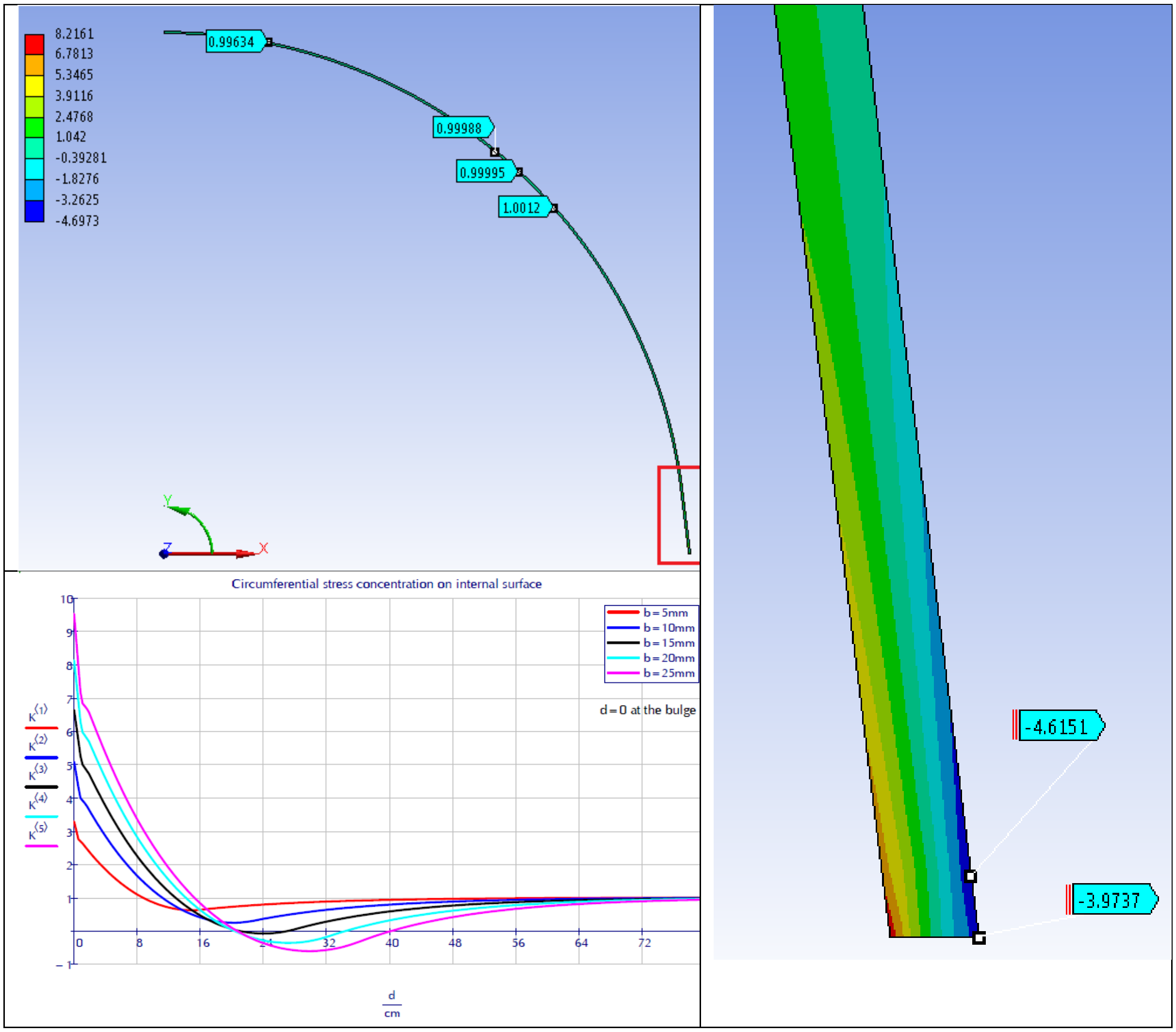
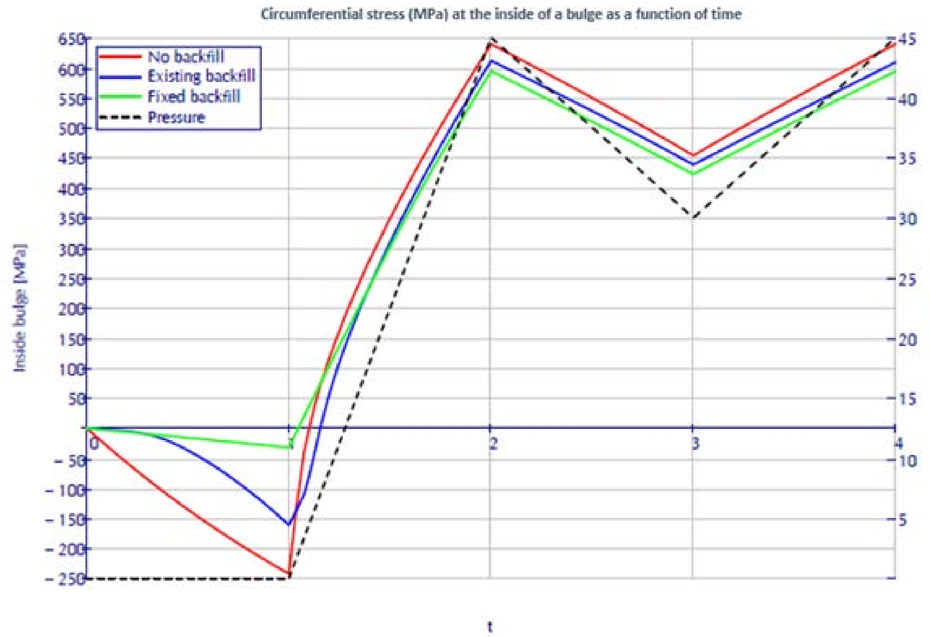


Figure 7-3: Influence of Non-Circular Geometry at Longitudinal Welds Under Pressure



Water weight = hydrostatic pressure gradient with 0psi at the top and 7.4psi at the bottom applied at the internal surface
Pressure = a constant pressure applied at the internal surface

t=1 : Water weight + Backfill weight + 0psi
t=2 : Water weight + Backfill weight +45 psi
t=3 : Water weight + Backfill weight +30 psi
t=4 : Water weight + Backfill weight +45 psi

Figure 7-4: Linear Variation of Maximum Bending Stress at the Weld with Pressure and Change in Backfill

8. Failure Analysis

8.1 Metallurgical Analysis

The penstock shell strip containing the latest rupture was shipped to Atlantic Metallurgical Consulting and Wayland Engineering for metallurgical analysis and material testing. These samples yielded similar material properties to those determined in the 2016 metallurgical analysis completed by Cambridge Materials Testing. The shell material for the penstock was confirmed to be compliant with 1982 chemical requirements for ASTM A 285 Grade C. Additionally, the chemical compositions from both 2016 and 2017 tests noted the presence of higher than normal sulphur content (0.032%) within the shell material by todays standards (0.025%). The AMC report is included in Appendix E.

Initial visual inspection of the fracture surface showed (Figure 4-1) that the crack was approximately 43 inches long and propagated along the toe of the weld for a large portion of the seam and veered into the base metal along one end. During sample removal, the crack continued to propagate parallel to the weld. This would indicate large residual stresses being present within the weld joint. Figure 8-1 maps out different areas of a weld cross section for clarity with regards to the metallurgical summary.

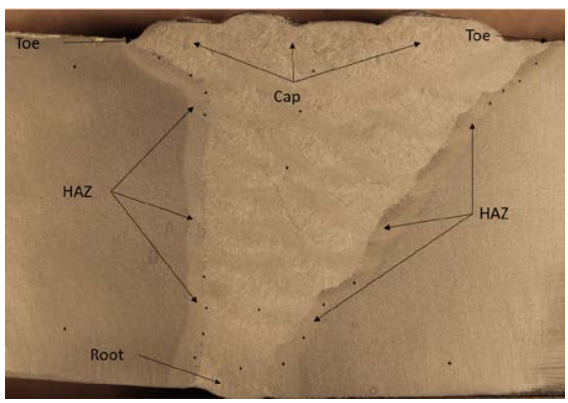


Figure 8-1: Weld Nomenclature

Macroscopic examination of numerous cross-sectional samples showed no evidence of appreciable weld defects or anomalies (porosity, lack of fusion, incomplete penetration). Several macro samples had additional hardness readings completed. The hardness values ranged from 151-164 Hv10 for the base metal, 175-183 Hv10 for the weld metal, and 175-182 Hv10 in the area close to the cracks. The Hv10 hardness test is the Vickers diamond indenter method with 10 kg load on the indenter. Additionally, the microstructures were pearlitic (which is a ductile crystalline structure) in nature and showed no signs of a martensitic (which is a brittle crystalline structure) structure. These results indicate there was no formation of hard phases (that could cause brittleness or accelerated corrosion), that can be caused by rapid cooling after welding. These results generally indicate that the original welds were well executed.

Two different types of cracks were discovered through macro examination and are shown in Figure 8-2. The primary cracks (through thickness) generally propagate from the toe of the weld through the heat affected zone (HAZ). All observed crack micro examinations had pearlitic structures which is a desirable trait and would indicate that the cracks were not caused by brittle structures. There is evidence of bending and high tensile loading when analyzing the micro photographs. Several of the samples had secondary cracking (interplanar) present. The secondary cracks appear to follow sulphide inclusions that are present within the base material and can likely be attributed to the presence of said inclusions. It seems unlikely the secondary cracking is the primary cause of the rupture but could have accelerated the failure.

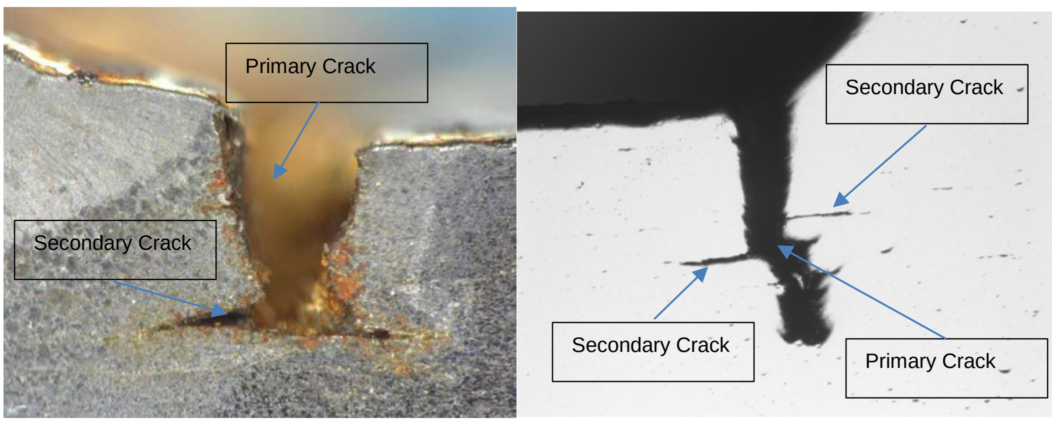


Figure 8-2: Primary Cracks (Vertical) and Secondary Cracks (Horizontal)

Further to the visual, macro, micro and chemical analysis, a set of mechanical testing was completed. The testing consisted of tensile testing for the base metal and the weld metal. The tensile samples failed within the base metal and were also ductile in nature (similar to the results determined in the 2016 investigation). The tensile test in Figure 8-3 shows an extensive reduction in area and significant cupping which is typical of a ductile failure. This testing is further evidence that brittle fracture was not involved and that the material and weld metal is ductile, which is preferred practice for design of steel structures.

Figure 8-3: Ductile Failure Tensile Tests Penstock No. 1

8.2 Analysis of Test Data

The following is a summary of key observations from the analysis of the test data. Since the strain gauges were installed with no backfill at the gauge locations but the penstock was already under stress from backfill on adjacent sections, the measurements do not represent accurately the stresses due to the backfill in other sections of the penstock. Similarly, the gauges do not measure residual stress already in the material at the time of gauge installation. The same is not true with the changes in measurements due to internal pressure. It may be observed in Figure 7-1 that the stresses due to backfill (σ_0-red line) are substantially lower than stresses under pressure (σ_2-black line). This would imply that measured stresses may actually be slightly lower than true values. However, this does not affect the measurements of alternating stresses from pressure fluctuations, which appear to be the more likely cause of metal fatigue contributing to penstock rupture.

The principal stresses calculated based on the strain measurements at Can 65 show an observable increase in stress from the static internal pressure of (38 psi) of the fully watered up penstock, when compared to the principal stresses observed when the water level reaches only to the top of Can 65. These stresses vary slightly with unit operating (lower dynamic pressure).

The following are some observations from the recorded measurements:

- As would be expected, the maximum stresses occur when the penstock is under dynamic pressure and subject to a load rejection. The highest measured stress was on the inside in the vicinity of the longitudinal weld seams in Can 65. Stresses in the order of 280 MPa [above the yield strength of 30 ksi (206 MPa) but below the ultimate tensile strength of 55 ksi (380 MPa)] were measured in the ASTM A285 Gr. C section with the penstock full and during a load rejection. The measured values suggest that the operational stresses were 25% less than the ultimate strength and 37% above the yield strength of ASTM A285 Gr. C. The high stress is attributed to the penstock peaking at the longitudinal weld caused by the lack of rolling radius of the two mating edges.

- A load rejection results in pressure rise of 10% at the powerhouse (259 psi+26 psi). The corresponding pressure waves up the penstock cause fluctuations in pressure at Can 33 of the order of ±17%(±6.8 psi) in the area where the rupture occurred (Figure 8-4). The corresponding fluctuation in the maximum stress is 280 ± 25 MPa during load rejection (Figure 8-5). Load rejection occurs between 1500 and 3500 seconds and the peak was at approximately 2700 seconds.
- The fluctuations in maximum stress during rough zone operation are of the order of ±7 MPa (1.0) ksi) and ±5 MPa (0.7 ksi) with two units and one unit in the rough zone, respectively (Figures 8-5 and 8-6). This is interesting as it was not anticipated that the rough zone operations would result in significant stress fluctuations in the penstock. Rough zone occurs from approximately 4500 seconds onward.

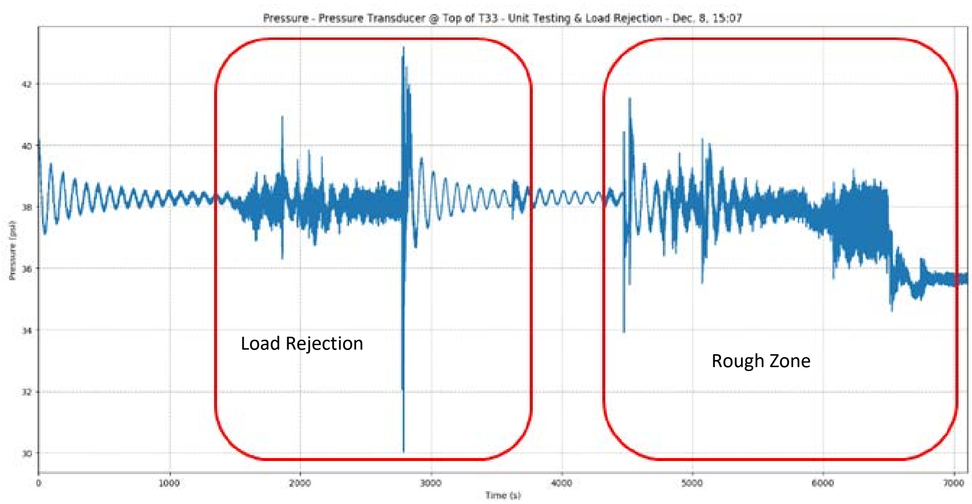


Figure 8-4: Pressure Measurement in Penstock at Can 33 during Rough Zone and Load Rejection

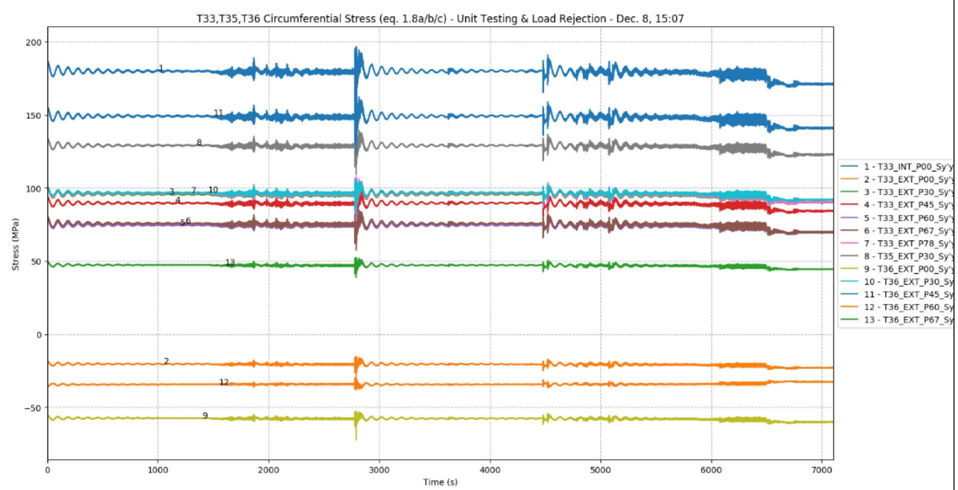


Figure 8-5: Circumferential Stresses in Penstock at Can 33 - Rough Zone and Load Rejection

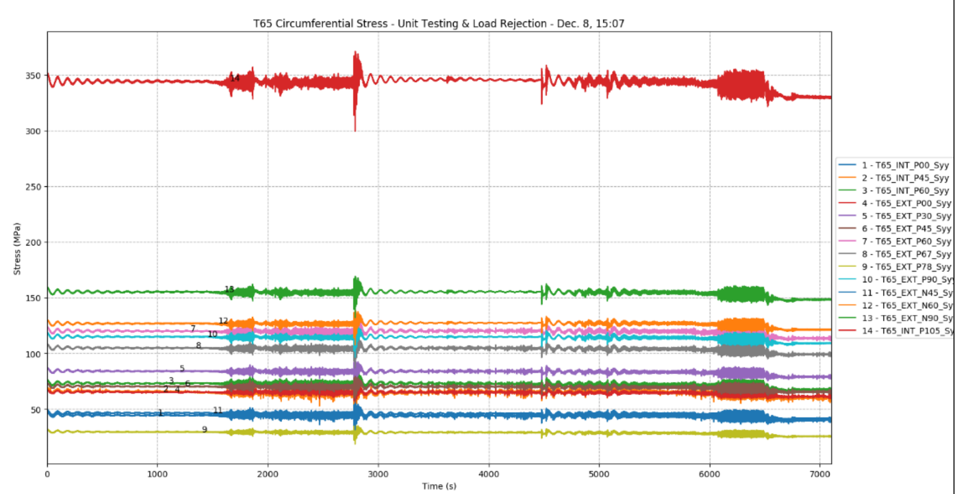


Figure 8-6: Circumferential Stresses in Penstock at Can 65 - Rough Zone and Load Rejection

8.3 Operational History

Newfoundland and Labrador Hydro provided the last five years of operational data to Hatch for analysis. The operational data provided shows decreasing amounts of starts/stops for each unit over the five years analyzed, and high hourly time spent within the rough zone (between 25 to 40 MW based on the measured test results). In general, eliminating unnecessary starts/stops is a common recommendation to increase the life of a hydraulic turbine. However, in this instance operating the units at low loads to meet the power demand resulted in these units spending an increased amount of time operating in the rough zone. The amount of time spent within the rough zone over the last five years is shown in Figure 8-7, and the number of annual starts/stops is shown in Figure 8-8.

Analyzing the data and approximating the total hydraulic rough zone time shows that over the last five years Penstock No. 1 averaged more than 400 hours in the hydraulic rough zone per year, with a peak of over 800 hours in 2014. Tt should be noted that 2016 and 2017 had significant down time for repairs and the duration of rough zone operation was reduced as a result.

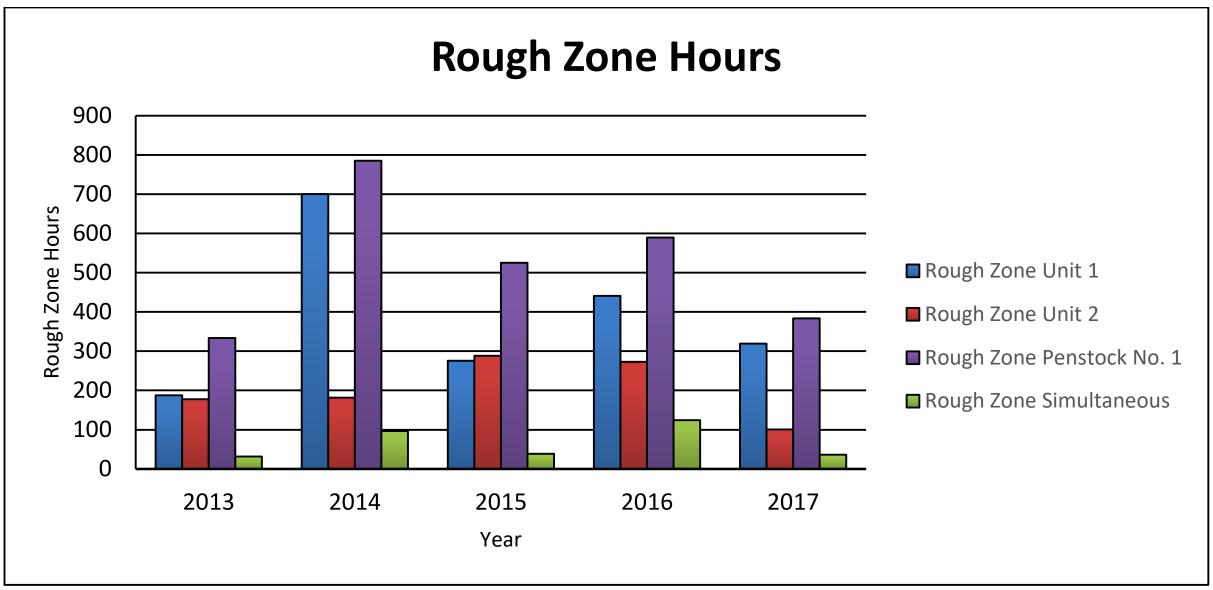


Figure 8-7: Rough Zone Trends

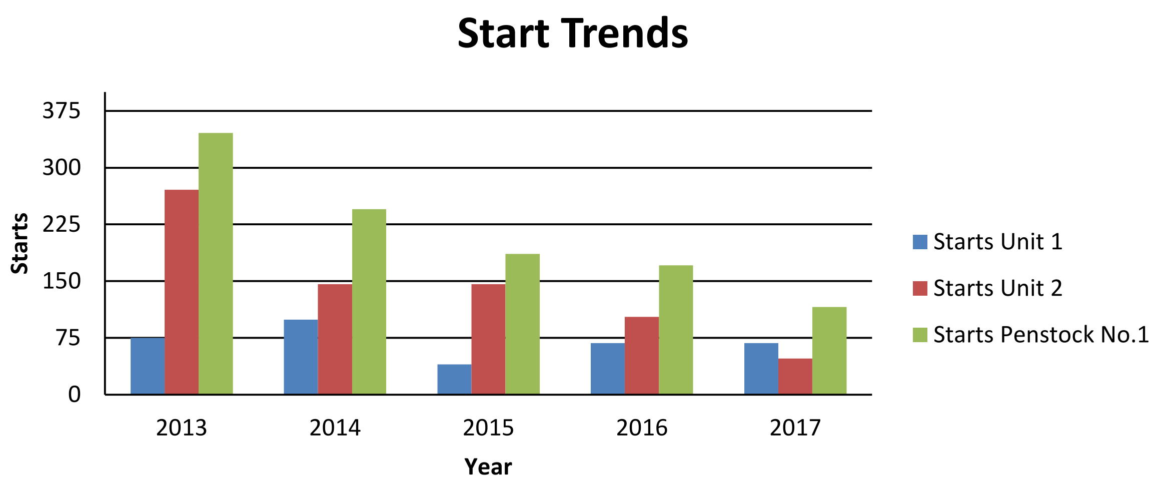


Figure 8-8: Start Trends

8.4 Fatigue Analysis

A comprehensive elastic fatigue analysis was carried out using the measured strains inside the penstock by the gauge closest to the longitudinal weld. The procedure prescribed in Section VIII Division 2 of the ASME Boiler and Pressure Vessel Code (Annex 3F) was used.

The maximum stress in the weld was calculated by extrapolating the measurements by the strain gauge and a factor (1.42) determined from finite element analysis. The contribution to fatigue by the various modes of operations and associated cyclic stress and number of cycles is summarized in Table 8-1 below.

Table 8-1: Fatigue Assessment – Total Cycle Damage (No Environmental Factor)

Zone	Fatigue Damage, D
Spherical Valve Opening	0.0025
2 Unit Rough Zone	0.1606
1 Unit Rough Zone	0.4512
Spherical Valve Closing	0.0036
Load Rejection	0.0024
Wicket Gate Opening	0.0258
Wicket Gate Closing	0.0433
Normal Operation	0.2428
Sum	**0.9322**

Note: A cumulative Fatigue Damage value of 1.00 indicates the design life has been reached.

The above table used a lifetime of cycles (~50 years) for all zones, except the rough zones. The lifetime of cycles used estimated frequencies of event cycles (i.e., number of times the spherical valve is closed in a given year) representative of the Bay d'Espoir facility. As the only available data for rough zone operation was from 2013-2017 these five years of rough zone data was used, and no rough zone operation was applied to the remaining 45 years of the penstock lifetime.

ASME BPVC VIII.2 notes an environmental modification factor should be applied to this calculation to account for fluid environment, loading frequency, temperature, and material variables, however, a factor for this specific application is not provided. ASME nuclear codes make reference to the environmental factor and these codes can be considered for general reference, but do not directly relate to penstock design. For example, NUREG/CR-6815 ANL-02/39 provides an environmental factor of 1.74 for carbon steels with temperatures less than 150°C. NUREG/CR-6815 also defines a factor of 4 for "moderate or acceptable environmental effects". As the internal penstock environment is known to be corrosive it seems highly likely that the inclusion of the environmental factor will result in a fatigue damage factor greater than 1.00, indicating that the design life has been reached.

Additionally, this analysis does not consider the fact that the penstock has undergone stresses exceeding the elastic limit of the material. This would increase the damage factor as well.

While several assumptions were required in this analysis, the results show that metal fatigue near the longitudinal seam is a large contributing factor of the most recent failure of Penstock No. 1.

A FE elastic perfectly plastic model was used to determine the plastic strain induced in the penstock at the peaking region from the first pressurization and each consecutive de-water and water up (de-pressurization to re-pressurization). The model used a pressure range of 0 psi (uniform pressure) to 45 psi (maximum pressure during high level head pond and load rejection). The elastic perfectly plastic model does not account for strain hardening which is conservative in nature as strain hardening would increase the yield stress upon each successive cycle until failure. The penstock material is able to withstand approximately 15% plastic strain induced before failure. Upon the first pressurization, the penstock has an induced strain of approximately 1.5%. Once plastic strain is induced, each successive cycle only adds a small additional amount of plastic strain until the point of failure. This amounts to approximately 100 dewatering cycles for design backfill geometry, or approximately 580 dewatering cycles for updated backfill geometry, before a failure point is reached.

8.5 Probable Cause of Failure

The strain gauge measurements have confirmed the presence of very high stresses (greater than Yield Strength) in the vicinity of the penstock longitudinal welds on the inside. It is not uncommon for ductile materials to redistribute high localized stress by yielding locally. A failure in such circumstances can result from fatigue due to cyclic loading. The cyclic stresses measured during rough zone operations are most likely to have contributed significantly to fatigue failure. This is interesting as it was not anticipated that the rough zone operations would result in significant stress fluctuations in the penstock.

Based on recent discussions, we understand the September 2016 repair was carried out by forcing the split plates together in order to close the gap to allow it to be welded together. This would have caused very high residual stresses in the parent material and the weld. The combination of the residual stress, the high localized stresses due to internal pressure and newly discovered cycling loading from rough zone operation are likely to have resulted in the November 4, 2017 failure. The failure occurred within 14 months of the original 2016 failure so corrosion would not have played a role this time.

Although the magnitude of stress range due to load rejection is higher (2 to 3 times) than that due to rough zone operation, the number of high stress cycles at each load rejection is less than 10, whereas the rough zone operation involves many more cycles (hundreds of thousands to upwards of millions each year).

It is unlikely that a repeat failure such as that occurred at Can 35, 14 months after the previous failure, can occur prior to any inspections during the summer of 2018. This conclusion is based on the following:

- The residual stresses introduced by the method of repairing the failure in Sept 2016 are absent in the current refurbishment.
- The reinforcing plate welded over the refurbished weld seam in 2017 shares the pressure load and reduces stress in the refurbished weld by nearly 50%.
- The high localized stress due to peaking at the original longitudinal weld in Cans 34 and 35 does not exist as the peaking is not there anymore; a new plate was inserted which blends well with the radius of the penstock shell.
- The 29 cans with weld defects were refurbished and have a reinforcing plate to reduce the localized stress due to peaking geometry. It is noted that not all longitudinal welds were refurbished and a majority of them still exhibit peaking from original fabrication along with the accompanying high localized stress. However, with no previous signs of cracking in these longitudinal seams it is not anticipated there will be problems over the next 6 months.
- With the discovery of rough zone impact on the penstock, the number of alternating load cycles while operating in the rough zone is expected to be reduced significantly as operation in the rough zone will be reduced significantly to suit these new findings.

Fatigue analysis indicates that a combination of alternating stresses in the penstock measured during rough zone operation combined with the operation of the spherical valves, wicket gate opening and closing, and operation of the units outside the rough zone have contributed to significant fatigue of the penstock. Amongst these the highest contribution is from rough zone operation (61%), followed by operation outside the rough zone (21%). It should be noted that the latter (normal operation outside the rough zone) is accumulated over the 50-year life-time.

9. Risk Assessment

This section examines the risk of penstock failure during the 2018 year.

	Description of Risk	Mitigation	Risk Ranking	Consequences	Actions
1	Cracks develop at the location of previous repairs	Peaking geometry causing high local stresses has been removed. An overlapping patch plate has been welded to cover the longitudinal welds and thus share the load due to internal pressure. All welds have been inspected by magnetic particle examination (MT).	Low	Failure resulting in Units No.1 and No. 2 being unavailable for power generation	None
2	Cracks develop at other longitudinal welds in the upper section of the penstock.	All welds were MT inspected. Defects were removed and refurbished by welding followed by MT. A 22' wide patch plate was welded on top of each refurbished longitudinal weld on the inside to reduce high local bending stresses caused by peaking geometry.	Low	Failure resulting in Units 1 and 2 being unavailable for generation	Inspect Penstock No. 1 during the 2018 summer and determine future inspection frequency.
3	Accelerated growth of cracks in longitudinal welds due to cyclic Loading	It is recommended that Units No. 1 and No. 2 are operated in the rough zone no longer than necessary during load ramp up and shut-downs	Low	Failure resulting in Units No. 1 and No. 2 being unavailable for generation	Do not operate in the rough zone
4	Other sources of transient pressure due to unknown events such as malfunction of spherical valve operation	Investigate spherical valve operation; measure pressure at the valve and in the penstock during valve closing, closed and opening. Remove any potential of hunting in the seal controls which may cause pressure transients	Low	Failure resulting in Units No. 1 and No. 2 being unavailable for generation	No unknown events have been observed during this study, recommend continued monitoring of pressure data.
5	Adequacy of backfill support for the penstock	Backfill has been added on top and the backfill profile on the penstock has been upgraded to reduce risk of sloughing or unsymmetrical loading on the penstock	Very Low	High stresses in the penstock due to longitudinal bending	None in 2018
6	Penstock failure resulting in loss of bedding due to erosion by release of water	Based on the lower pressures and history of previous ruptures, the failed section of the penstock exhibits "Leak before catastrophic failure" characteristics. Therefore, monitoring can reduce consequences of failure. It is recommended that the penstock	Low	High stresses in the penstock due to longitudinal bending could result in a massive failure	Daily inspection; install camera for monitoring; investigate source of any observed leaks.

	Description of Risk	Mitigation	Risk Ranking	Consequences	Actions
		be inspected visually every day for water leakage. Cameras should be used to give the plant operator a view of the upper reaches of the penstock. Installation of an infra-red camera should be explored.			
7	Damage caused by Load Rejection	The penstock was commissioned and tested for one-unit load rejection. Theoretically, a simultaneous two-unit load rejection could double the range of pressure cycles and hence the localized stresses near the longitudinal welds. It is recommended that a visual inspection of the penstock be carried out after each load rejection (one or both units).	Very Low	Premature penstock failure causing unavailability of the units	Visually inspect penstock after each load rejection,

10. Long-Term Solutions for Penstock No. 1

The refurbishment of Penstock No. 1 in November 2017 was carried out with the primary purpose of reinstating it into service at the earliest possible date while ensuring penstock rupture would not occur during the winter months. The investigation into the cause of recent failures discussed in this report leads to the conclusion that there is a structural concern with Penstock No.1; the original fabricated deviation from the circular geometry at the longitudinal welds. ASME BPVC VIII.1 states the permissible out-of-roundness of cylindrical shells shall not have a cross sectional difference exceeding 1% between the maximum and minimum diameter (1% of 17' diameter equals ~50.8 mm; measurements of peaking is upwards of 60 mm on the diameter), therefore the penstock is not within the permissible limits. This combined with the pressure fluctuations resulting from turbine operation, the corrosiveness of the water and the age have all contributed to the recent ruptures. While the penstock may last several more years before the next failure, long-term solutions should be examined.

Table 10-1 is a preliminary list of possible long-term solutions with advantages and disadvantages of each.

The scope of this study and time constraints do not permit an analysis or discussion of these alternatives at this time. The identification of a long-term solution requires further study.

Table 10-1: Long Term Solution Matrix

Item Number	Description	Advantages	Disadvantages
1	Replace entire penstock (or portions of penstock) with new penstock run parallel to existing structure.	1. Low risk of failure 2. New penstock can be constructed to meet current standards 3. Existing penstock can remain in operation until final tie ins	1. High cost 2. Large amount of civil work required 3. Encroaching on Penstock No. 2 backfill and cover is likely 4. Heavy machinery, lifting activities, and excavation around two operational penstocks. 5. High likelihood of weather delays 6. High likelihood of requiring rock blasting.
2	Replace sections of penstock in phases in-situ	1. Low risk of failure 2. New penstock can be constructed to meet current standards 3. Construction can be phased 4. Not disturbing Penstock No. 2	1. High cost 2. Multiple outages required 3. Cost of removal of existing penstock will be incurred 4. High likelihood of weather delays
3	Install internal weld seam reinforcing similar to work completed in 2017 on Cans 34 and 35.	1. Lower risk of failure 2. Construction can be phased 3. Work is all internal and weather delays would be minimal 4. Not disturbing Penstock No. 2	1. High cost 2. Multiple outages required 3. Work is confined space 4. Extensive scaffolding requirement 5. Possible flow disturbances caused by plates protruding into flow contributing to head loss 6. Long-term effectiveness not predictable
4	Install external weld seam reinforcing similar to the refurbishment completed in 2017 on Cans 33 through 36.	1. Low risk of failure 2. Construction can be phased	1. High cost 2. Requires removal and reinstatement of backfill for exterior shell access. 3. High likelihood of weather delays 4. Long-term effectiveness not predictable
5	Form around penstock and encase in concrete	1. Low risk of failure 2. Construction can be phased 3. No outages required 4. Not disturbing Penstock No. 2	1. High cost 2. High likelihood of weather delays 3. Corrosion due to moisture between steel and encasement could lead to premature failure
6	Install external stiffener rings	1. Low risk of failure 2. Construction can be phased	1. High cost 2. Requires removal and reinstatement of backfill for exterior shell access. 3. Extensive excavation and shoring requirements to install full 360 degree stiffeners. 4. High likelihood of weather delays. 5. Due to extensive excavation requirements there is a possibility of encroaching on Penstock No. 2. 6. Existing material is prone to sloughing which presents a large safety risk to personnel working inside extensive trenches. 7. Requires multiple outages 8. Does not eliminate the stress intensification at the bulge except in the vicinity of the stiffener rings
7	Install internal stiffener rings	1. Low risk of failure 2. Construction can be phased 3. Work is all internal and weather delays would be minimal 4. Not disturbing Penstock No. 2	1. High cost 2. Multiple outages required 3. Work is confined space 4. Extensive scaffolding requirements 5. Increased head loss due to flow disturbances caused by rings protruding into flow. 6. Does not eliminate the stress intensification at the bulge except in the vicinity of the stiffener rings 7. Potential output reduction
8	Install new steel liner inside existing penstock	1. Low risk of failure 2. Construction can be phased 3. Work is all internal and weather delays would be minimal 4. Not disturbing Penstock No. 2	1. High cost 2. Multiple outages required 3. Work is confined space 4. Extensive scaffolding requirements. 5. Risk of corrosion due to moisture trapped between the two shells. 6. No access for full penetration welds of circumferential joints. 7. Higher head loss due to reduced cross-section

Item Number	Description	Advantages	Disadvantages
9	Install Fiberglass liner	1. Low risk of failure 2. Construction can be phased 3. Work is all internal and weather delays would be minimal 4. Not disturbing Penstock No. 2	1. High cost 2. Multiple outages required 3. Work is confined space 4. Extensive scaffolding requirements
10	Install concrete liner	1. Low risk of failure 2. Construction can be phased 3. Work is all internal and weather delays would be minimal 4. Not disturbing Penstock No. 2	1. High cost 2. Multiple outages required 3. Work is confined space 4. Extensive scaffolding requirements 5. Possibility of concrete becoming dislodging during operation and migrating into the turbine 6. Higher head loss due to reduced X-section.
11	Cut top off of existing penstock and install new penstock inside	1. Low risk of failure 2. New penstock can be constructed to meet current standards 3. Construction can be phased 4. Not disturbing Penstock No. 2 5. Reduced excavation costs	1. High cost 2. Multiple outages required 3. Cost of removal of existing penstock material will be incurred 4. High likelihood of weather delays 5. The material of the lower half of the old penstock has corroded and has been subjected to cyclic loading which could shorten its life.
12	Increase inspection frequency (once per year) and keep existing penstock in service	1. Medium risk of failure 2. No capital cost incurred 3. Existing penstock can remain in operation	1. Increased operational cost 2. Possibility of failures occurring in heating season 3. Units not available for production during inspection outages.
13	Cut out a section of the shell plate around each longitudinal seam and weld in place a rolled plate section, similar to the manner in which the 2017 refurbishment was carried out but without any external reinforcing plates	1. Lower risk of failure 2. The stress concentration at the longitudinal weld due to non-circular geometry is reduced significantly. 3. Construction can be phased 4. Not disturbing Penstock No. 2	1. Labor intensive with higher cost 2. Multiple outages required 3. Cost of removal of existing penstock material and backfill will be incurred 4. High likelihood of weather delays 5. Longevity of the solution is not predictable.
14	Combination of Alternatives (12) and (13): Inspect the penstock annually and if defects continue to show up, remove section of plate with the longitudinal weld and weld in place a new inserted rolled plate	1. Medium risk of failure 2. Moderate capital cost incurred to allow deferment of high capital requirement for total replacement 3. Existing penstock can remain in operation	1. Increased operational cost 2. Reduced possibility of failures occurring in heating season 3. Units not available for production during inspection outages.
15	Installation of Unit number 8 on Penstock No.4 and utilizing Penstock No.1 as back up and repair on an as needed basis	1. Lower risk of failure 2. Operational time of failure prone penstock is greatly reduced. 3. Construction can be phased 4. Not disturbing Penstock No. 2 5. Allows reserve capacity for more maintenance flexibility which is required for aging assets.	1. High cost 2. Large amount of civil work required 3. Heavy machinery, lifting activities, and excavation around one operational penstock. 4. High likelihood of weather delays 5. Higher head loss = less output

11. Penstock No. 2 and No. 3

Penstock No. 2 was built to the same design and specifications as Penstock No. 1 and was constructed a year later. External rings on Penstock 2 were discovered during inspection in 2016. However, these rings are not detailed on any drawings, nor mentioned in any historical information, and therefore the reason for them is not understood. Under similar operating conditions and depending on their design, a penstock with external rings would be expected to last longer. NDT of internal longitudinal welds in 2016 showed significantly fewer defects as compared to Penstock No.1.

Penstock No. 3 which is a similar design was built a couple of years later than Penstock No.2. However, the drawings show a symmetrical and improved backfill design. These drawings, and those for the other two penstocks, do not show any external reinforcing rings.

Considering the similarity in the design and operating conditions of the three penstocks and the recent ruptures in Penstock No. 1, it is prudent to have a comprehensive inspection and assessment program for Penstocks No. 2 and 3. This should include measurement of any deviations from circularity of the penstock profiles at the longitudinal welds. This can be performed by laser survey similar to Penstock No. 1 as completed in 2017. Backfill should be removed at a few locations to ascertain the size and spacing of any external stiffener rings. NDT of the longitudinal seams and shell thickness measurements should be carried out inside the penstock. Since all 6 of the BDE units are known to suffer from instability due to draft tube surges, instrumentation should be installed to determine the pressure variations in the penstock during start, stops and regular operation.

12. Conclusions

Visual inspection of the November 4, 2017 failure and metallurgical examination of the material indicates that the failure originated at the toe of the previous repair weld and progressed through the parent material. Metallurgical testing completed by Atlantic Metallurgical Consulting and Wayland Engineering concluded the material in the penstock met the criteria for the specifications on the design drawings and there were no brittle microstructures induced by the welding process. No metallurgical contribution can be attributed to the rupture. This failure was most likely caused by a combination of the following factors:

- High residual stress due to re-welding of the failed seam in 2016 under high load that was used to bring the two edges of the ruptured joint together.
- Highly localized bending stresses due to the original construction geometry (peaking) at the longitudinal weld seam under internal pressure (measured and verified by FE modeling).
- Fatigue caused by high cycle low amplitude stresses due to extended operation in the rough zone.
- Fatigue caused by high cycle low amplitude stresses due to pressure fluctuations during normal operation over the 50-year life-time.

Hatch believes that the risk of failure of Penstock No. 1 from now until the next inspection, which will take place in the summer of 2018, is relatively low. Based on the observation in November 2017 that showed defects appear in 8% of the longitudinal welds refurbished the previous year, it is possible that similar cracks may begin to form but is unlikely they will progress to a critical depth to cause a rupture within this timeframe. However, it should be noted that very high stresses were measured in the vicinity of the longitudinal welds under normal pressure and that the penstock has accumulated damage over its life time in other areas not detectable by the inspections carried out.

Backfill has only a marginal improvement of stresses for a pressurized penstock but significantly reduces the circumferential bending stresses when de-watering, empty, and watering up the penstock.

13. Recommendations

The following recommendations have been already implemented.

- Refurbish the section of the failed penstock (Can 34) by removing the entire segment with the crack, insert a new ½" thick plate and weld in place followed by MT. Install a reinforcing overlap plate over the ruptures in Cans 34 and 35.
- MT all longitudinal welds between the intake and the surge tank on the inside. Remove defects, reweld and MT. Install a 22" wide patch plate over the refurbished weld on the inside to reduce the localized bending stress due to the peaking at the weld.
- Add backfill to make it symmetrical and prevent sloughing over the penstock where this has not already been completed.
- Install strain gauges and pressure transducers in the vicinity of the failed areas (Cans 34 and 35) of the penstock and monitor during commissioning and periodically thereafter (unusual events such as load rejections until February 2018.
- Operation of the units in the rough zones has been limited to that necessary to ramp up and down through the rough zone.
- Walk the penstock once a day and after unusual pressure transients, such as load rejections, for evidence of leaks and regularly observe the area by camera.
- Develop alternatives for long-term mitigation.

It is recommended that Penstock No.1 which serves Unit No. 1 and No. 2 operation may be continued with the following considerations:

- Continued operation of the units in the rough zones should be limited to that necessary to ramp up and down through the rough zone.
- Continue to walk the penstock once a day and after unusual pressure transients, such as load rejections, for evidence of leaks and regularly observe the area by camera.
- Verify integrity of existing strain gauge signals by testing continuity. Purchase a data acquisition system capable of receiving data from the existing instrumentation. Continue to monitor the remaining strain gauges and pressure transducer periodically.
- Further develop alternatives for long-term mitigation.
- Inspect Penstock No. 1 during the summer of 2018. Inspection procedure should be as follows:
  - Inspect interior welds on new plates welded into penstock using visual and magnetic particle. Welds need to be cleaned prior to inspection.

- Inspect 5 additional cans upstream and downstream of the ruptured area (Cans 34-36) visually and with magnetic particle. Once complete, inspect every 10th can upstream of the rupture area to the intake and similarly downstream to the surge tank. If defects are found in welds, increased inspection frequency may be recommended.
- Inspect the penstock downstream of the surge tank by laser scanning for out of roundness at the longitudinal welds present in the upper reaches of the penstock.

Penstock No. 2 should be inspected at the next available outage as follows:

- Inspect welds on every 10th can between the intake and the surge tank with visual and with magnetic particle. Prior to inspection, welds need to be cleaned. If defects are found in welds, increased inspection frequency may be recommended.
- Complete internal laser survey to check ovality and peaking.
- Install a pressure transducer to determine if pressure variations similar to Penstock No. 1 exist.

Penstock No. 3 should be inspected at the next available outage as follows:

- Inspect welds on every 10th can between the intake and the surge tank with visual and with magnetic particle. Prior to inspection, welds need to be cleaned. If defects are found in welds, increased inspection frequency may be recommended.
- Complete shell thickness measurements.
- Complete laser survey to check ovality and peaking.
- Install a pressure transducer to determine if pressure variations similar to Penstock No. 1 exist.
- Depending on findings, testing to determine mechanical and chemical properties of penstock material may be recommended.

Planned backfill and future re-coating operations for Penstock 1 should be postponed. Based on findings from planned inspections, if no further deterioration of the welds is discovered, replacement of the penstock would likely be unnecessary in the short term. Backfill and re-coating would then be required for long term operation if the penstock, or sections of it, are not replaced. If further deterioration is encountered, the long-term solutions should be revisited.

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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 approval of capital expenditures to complete a Level 2 condition assessment on Penstocks 1 and 2, and, a report on Penstocks 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Station pursuant to Subsection 41(3) of the *Act*.

AFFIDAVIT

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

1. I am the VP, Production 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 8th day of June 2018, before me:)

Barrister – Newfoundland and Labrador

Jennifer Williams

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

AN ORDER OF THE BOARD

NO. P.U. __(2018)

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 approval of capital expenditures to complete a Level 2 condition assessment on Penstocks 1 and 2, and, a report on Penstocks 1, 2 and 3 at the Bay d'Espoir Hydroelectric Generating Station pursuant to Subsection 41(3) of the *Act*.

WHEREAS Newfoundland and Labrador Hydro (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*, RSNL 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. 43(2017) the Board approved Hydro's 2018 Capital Budget in the amount of $170,868,300; and

WHEREAS in Order No. P.U. 5(2018) the Board approved Hydro's proposed capital expenditures for Hydraulic Generation Refurbishment and Modernization in the amount of $10,325,400 in 2018 and $4,283,100 in 2019; and

WHEREAS on June 8, 2018, Hydro applied to the Board for approval to proceed with capital expenditures to complete a Level 2 condition assessment for Bay d'Espoir Penstocks 1 and 2, and complete a report addressing the condition of Penstocks 1, 2, and 3 to provide recommendations for the safe and reliable long term operation of the penstocks; and

WHEREAS the capital cost of the project is estimated to be $1,120,600; and

WHEREAS the Board is satisfied that the capital expenditures at the Bay d'Espoir Generating Station are necessary to allow Hydro to provide service and facilities which are reasonably safe and adequate and just and reasonable.

IT IS THEREFORE ORDERED THAT:

1. The proposed capital expenditures to complete a Level 2 condition assessment for Bay d'Espoir Penstocks 1 and 2, and complete a report addressing the condition of Penstocks 1, 2, and 3 to provide recommendations for the safe and reliable long term operation of the penstocks, at an estimated capital cost of $1,120,600 is approved.

2. Hydro shall pay all expenses of the Board arising from this Application.

DATED at St. John's, Newfoundland and Labrador, this day of , 2018.

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