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June 3, 2020

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

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

Dear Ms. Blundon:

Re: 2019 Failure of Bay d'Espoir Penstock 1 and Plan Regarding Penstock Life Extension

On September 22, 2019, Penstock 1 experienced a failure along a previously refurbished longitudinal weld, approximately 30 metres downstream from previous failures.[1] Repairs were completed and the penstock was returned to service. Following the most recent failure, Newfoundland and Labrador Hydro ("Hydro") commissioned SNC Lavalin to complete an investigation into the cause of the failure of Penstock 1, including a review of previous reports[2] on the Bay d'Espoir penstocks and validation of the engineering content of the previous reports. Hatch was also engaged to provide the opportunity for incorporation, where appropriate, of SNC Lavalin's findings into its previously issued report.[3]

Following receipt of the consultants' reports, Hydro completed a review of the findings and developed a process to assess the life extension of the penstock, identified herein. Information collected through this process will result in a proposal for life extension for submission to the Board of Commissioners of Public Utilities ("Board").

SNC Lavalin – 2019 Penstock 1 Failure Investigation Report

The "Bay d'Espoir Penstock No. 1 – 2019 Failure Investigation Report" completed by SNC Lavalin in March 2020 ("SNC Lavalin Report") is included as Attachment 1. SNC Lavalin's investigation involved review of (i) the results of metallurgical tests completed on steel from the September 2019 penstock rupture area and (ii) previously issued reports on the Bay d'Espoir Penstocks. The review of previous reports included a review of results from previous metallurgical tests, analysis and interpretation of water chemistry results from reservoir water, review and interpretation of penstock pressure data from the time of the September 2019 failure, and finite element analysis of the penstock at the location of the September 2019 rupture.

The SNC Lavalin Report findings were similar in nature to those previously identified and there were no new root causes identified. The findings determined that the failures from 2016 to 2019 were initiated

[1] "Bay d'Espoir Penstock Failure and Analysis," Newfoundland and Labrador Hydro, November 12, 2019.
[2] "Bay d'Espoir Penstock 1 Refurbishment," Newfoundland and Labrador Hydro, January 9, 2017; "Bay d'Espoir Penstock 1 Emergency Refurbishment," Newfoundland and Labrador Hydro, January 19, 2018; "Bay d'Espoir Penstock 3 Emergency Refurbishment," Newfoundland and Labrador Hydro, August 2, 2018; "Bay d'Espoir Level II Condition Assessment of Penstocks No. 1, 2, and 3," Hatch, December 17, 2018; "Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3," Hatch, March 29, 2019; and "Penstock No.'s 1, 2 and 3 Life Extension Options," Hatch, July 30, 2019.
[3] "Penstock No.'s 1, 2 and 3 Life Extension Options," Hatch, July 30, 2019.

by high secondary and peak stresses in the vicinity of the longitudinal weld seams where "peaking"[4] is present. Once small cracks were initiated in the steel, they were propagated by normal cyclic stresses in the penstock over its life, ultimately leading to ruptures. These small cracks are more prone to propagate and lead to rupture in the 17' diameter sections of the penstocks with thinner steel walls than in the thicker walled section of the penstock further along its length.

Other key observations within the SNC Lavalin Report were:

- Metallurgical factors induced by welding alone did not cause the failures;
- The water passing through the penstock is acidic and corrosive. This corrosion may increase the failure risk in the uncoated steel of the penstocks;
- The original design strength of Penstock 1 meets the load requirements for the penstock in normal operating conditions; however, the 17' diameter thinner-walled section of the penstock where ruptures have been occurring does not meet the requirements of current design practices;
- The steel in the penstock met the manufacturing requirements for strength and ductility; however, it has low impact strength, which results in the steel having a lower resistance to fatigue or vibrational stresses;
- The backfill arrangement does not have a significant impact on the penstock stresses; and
- The engineering reports produced on the penstocks to date documented the failures and the refurbishments well, and have a sound engineering basis.

Hatch – Penstock No.'s 1, 2 and 3 Life Extension Options Report

Following review of the SNC Lavalin Report, Hatch revised its previously issued report on penstock life extension options. The original Hatch report recommended weld refurbishment and application of a protective coating in all penstocks, which Hatch based upon recent condition assessment inspections showing that previously refurbished weld seams were performing well.

In its revised report ("Revised Hatch Report"), issued in March 2020 (Attachment 2), Hatch modified its recommendations for penstock life extension to include replacement (versus refurbishment) of the thinner walled 17' diameter section of Penstock 1, while maintaining its previous recommendations of weld refurbishment of the remainder of the penstocks and application of protective coating for all penstocks. The recommendation was driven by the September 2019 failure, which occurred in a weld seam that had been previously refurbished and later re-inspected. The total estimated cost of the work for all three penstocks is approximately $104 million.[5]

Penstock Status and Plan Regarding Penstock Life

All three penstocks in Bay d'Espoir have undergone refurbishment work over the past several years to improve the reliability of the assets. Hydro has assessed the Bay d'Espoir penstocks as being a high risk to disrupting the reliable operation of the Bay d'Espoir plant. As a result, Hydro has developed the following plan to address the concern and ensure that any projects it proposes to undertake have been thoroughly vetted and are prudent investments.

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[4] "Bay d'Espoir Penstock No. 1 – 2019 Failure Investigation Report," SNC Lavalin, March 19, 2020, sec. 5.2 Penstock 1 Circularity, at p. 13, defines peaking as the deviation of the shell surface at the longitudinal weld seam from a smooth arc.
[5] "Penstock No.'s 1, 2 and 3 Life Extension Options, Rev. 1," Hatch, March 13, 2020, Table 4-1, at p. 20.

Stage 1: Confirmation of Long-Term Penstock Necessity

In May 2020, Hydro began its review of the life extension work recommended by Hatch. Using the recommendations in the Revised Hatch Report as a basis for review, Hydro's Production and Operations Planning group is confirming the long-term necessity of extending the service life of the penstocks to meet Hydro's long-term production needs. As the specific details of the life extension work may change in subsequent stages, cost sensitivity will be completed to guide future decision-making. Hydro expects these penstocks and the associated plant output will be necessary well into the future; however, to be prudent, Hydro is confirming their need with the now suggested level of investment.

Stage 2: Front End Engineering Design ("FEED")

While the above is ongoing, Hydro is engaging a consultant with experience in brownfield penstock replacement to refine the capital budget proposal. Award of the work for this consultant will take place once Stage 1 findings are confirmed, which is expected to be during summer 2020. Stage 2 activities include verification that the life extension recommendations in the Revised Hatch Report align with Hydro's long-term supply needs and the development of a detailed cost estimate, construction approach, and capital investment strategy for the completion of work. At the end of this stage, Hydro will confirm future timing and investment for these assets.

Stage 3: Development of Application to Board for Approval of Penstock Life Extension

Hydro's application will present the proposed project strategy and costs to the Board for review and approval.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

SWalsh

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Senior Legal Counsel, Regulatory
SAW/kd

Encl.

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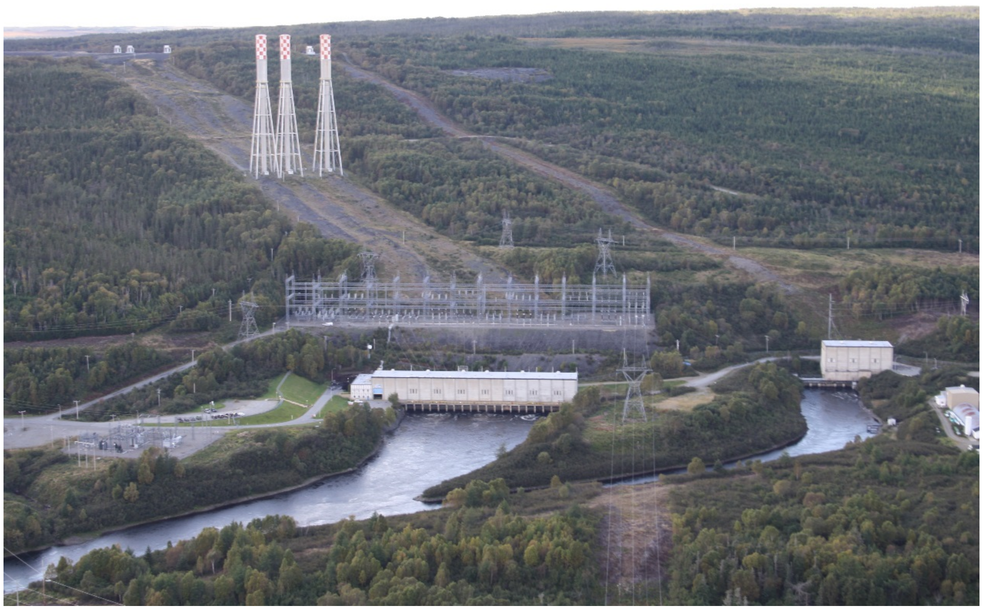
Attachment 1

Bay d'Espoir Penstock No. 1 – 2019 Failure Investigation Report

SNC·LAVALIN



Newfoundland and Labrador Hydro
Bay d'Espoir Penstock No. 1 – 2019 Failure Investigation Report

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March 19 2020

List of modifications

Revision				Revised pages	Comments
N°	By	App.	Date		
PA	HB	PG	2019-12-16		Draft Report
PB	RG	PG	2020-03-13		Draft of final incorporating Client comments
00	RG	PG	2020-03-19		Final report

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1. EXECUTIVE SUMMARY

The Bay d'Espoir Hydroelectric Generating Station contains four buried penstocks, three of which are connected to Powerhouse 1. Units 1 and 2 were commissioned in 1967, Units 3 and 4 were commissioned in 1967/1968 and Units 5 and 6 were commissioned in 1970.

From 2016 onwards, Penstocks No. 1, 2 and 3 have been subjected to engineering assessments and failure investigations following cracking that was uncovered in Penstock No. 1. The first rupture in the Bay d'Espoir Penstock No. 1 was found in May 2016 in the upper portion of the penstock, specifically in Can 96 (Can 1 being located at the intake and Can 253 at the surge tank). A second failure of the Penstock No.1 occurred in can 95 (adjacent to the previous failure that was repaired in May). This second failure has resulted in a significant program of refurbishment works on Penstock No. 1 where approximately 950m of welds were gouged out, repaired and inspected before the penstock were put back in service. On November 4, 2017, a third rupture in Penstock No. 1 occurred in Can 95, in the same weld seam and adjacent to the second crack that was repaired in September 2016. A fourth rupture occurred in September 2019; approximately 25 m downstream from the previous ruptures. At each event, the rupture was repaired, and the penstock returned to service.

SNC Lavalin was contacted by NL Hydro to assess and to investigate the failure of Bay d'Espoir Penstock No. 1 that occurred in 2019. The mandate includes a review of documentation related to previous engineering investigations into penstock ruptures and support for the testing and collection of information into this most recent failure. All previous refurbishment and failure had been well documented in multiple reports prepared by Hatch. All data as extracted from the various reports of Hatch had a sound engineering basis.

All investigations and laboratory testing confirm that the steel material used in the construction of upstream portion of the Bay d'Espoir Penstock No. 1 was complying to ASTM A285 requirements for strength and ductility. Also, there were no brittle microstructures induced by the welding process. Based on the macro-examination and hardness survey, it seems that there were no unusual microstructures evident for the initiation of the original crack. All investigations showed evidence of initial cracks mostly located along the internal surface of the plate between longitudinal weld and the base material. The initial crack then changes orientation and propagates through the base material plate leading to the penstock ruptures. Therefore, SNC-Lavalin believes that the main cause of the penstock No. 1 failures cannot be attributable to the metallurgical factors induced by the welding process only.

SNC-Lavalin performed a verification of the original penstock design for the normal operation condition in accordance with ASCE Steel Penstocks (Ref. 1). The calculation showed that the allowable hoop stresses in steel penstock are not exceeded at any location along the penstock. However, for the penstock portion between the intake and a point approximately 49 m downstream of elbow 4A (Can 1 to Can 161) where the multiple penstock No 1 failures occurred, the minimum thickness for modern penstock design, installation and various operational factors are not respected.

Also, it has been demonstrated from the finite element (FE) sensitivity analyses that the common backfill configuration and properties have very small impact on the structural performance of the buried penstock under hydrostatic internal pressure. It is our opinion that an out-of-roundness of 1% in buried steel penstock has very little impact on the stresses under internal pressure, and therefore could not be considered as the main root cause of the Penstock No. 1 failures in 2016, 2017 and in 2019.

Charpy test results indicate high impact properties in the welds (87 Joules at -20 °C) and in the heat affected zone HAZ (42 Joules at -20 °C), which is especially good for fatigue or vibrational stresses, while, in the base material, the measured impact values were around 10 Joules at -20 °C. For the Bay d'Espoir penstocks, a good low temperature impact property should be above or equal to 27 Joules at -20 °C. It is however our opinion that this is not the main root cause of the occurred failures. Quality of welding electrodes have always improved over the years and such electrodes were used for the various repairs over the years.

Based on the review of all previous engineering assessments by Hatch, the laboratory tests carried out by different laboratories and the FE analysis performed in this mandate, SNC-Lavalin believes that the failures in 2016 to 2019 were initiated by high secondary and peak stresses at the longitudinal weld seam under internal pressure. Once small cracks were initiated by high flexural secondary stresses, small cycling stresses due to normal pressure fluctuations during normal operation over the 50-year life-time help propagating the initial crack and lead to the ruptures in the Penstock No. 1. Such initial small cracks are more prone to propagation and ultimately to rupture in the thinner section of the penstock (7/16") than in the portion of the penstock with thicker plate (assuming same level or magnitude of primary hoop stress).

2. INTRODUCTION

The Bay d'Espoir Hydroelectric Generating Station contains four buried penstocks, three of which are connected to Powerhouse 1. Each of these three penstocks bifurcates near the powerhouse to feed two 75MW Vertical Francis Turbines through separate spherical valves. Units 1 and 2 were commissioned in 1967, Units 3 and 4 were commissioned in 1967/1968 and Units 5 and 6 were commissioned in 1970.

Since 2016, Penstocks No. 1, 2 and 3 have been subjected to many engineering assessments, failure investigations, engineering recommendations, repairs of penstock sections and many other engineering related work. All these works were done under guidance of Hatch Engineering.

The first rupture in Bay d'Espoir Penstock No. 1 was found in May 2016 in the upper portion of the penstock, specifically in Can 96 (Can 1 being located at the intake and Can 253 at the surge tank).

A second failure in Penstock No.1 occurred in September 2016 in Can 95 near to the previous failure that was repaired in May 2016. This has resulted in significant refurbishment work on Penstocks No. 1 where approximately 950m of welds were repaired and inspected before the penstock was put back in service.

On November 4, 2017, a third rupture occurred in Can 95 and in the same weld seam of Penstock No. 1 adjacent to the crack that was repaired in September 2016.

A fourth rupture in Penstock No. 1 occurred on September 2019; approximately 25 m downstream from the previous ruptures.

Following each event, the rupture was repaired and the penstock returned to service.

SNC Lavalin was contacted by NL Hydro to assess and to investigate the failure of Bay d'Espoir Penstock No 1 that occurred in 2019. The mandate includes a review of documentation related to previous engineering investigations into penstock ruptures and a support for the testing and collection of information into this most recent failure.

3. REVIEW OF DOCUMENTATION, FAILURE AND REPAIRS PERFORMED BETWEEN 2016 & 2018

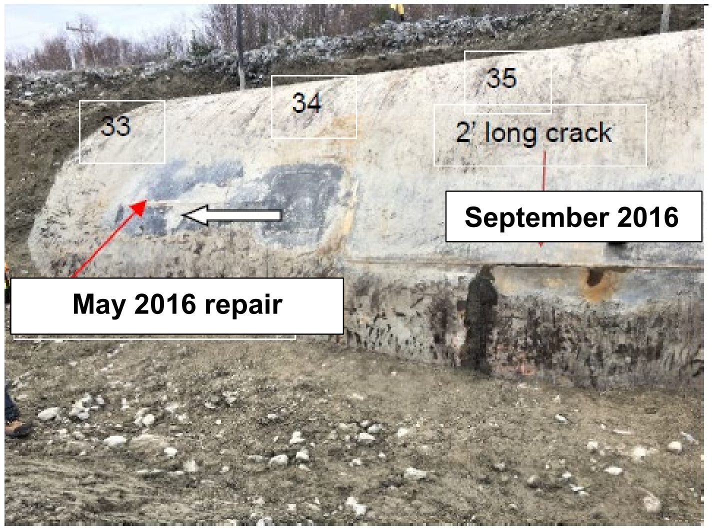
The original design drawings for Penstock No. 1 and the following reports prepared by Hatch engineering were provided by NL Hydro to SNC-Lavalin as baseline references of this work.

- H356043-00000-240-230-0003, Rev. 2 "Repair and Failure Investigation" Bay d'Espoir Penstock No. 1 Repairs – 2017, issued by Hatch in May of 2018;
- H356043-00000-240-230-0003, Rev. 0 "Repair and Failure Investigation" Bay d'Espoir Penstock No. 1 Repairs – 2017, issued by Hatch in March of 2018;
- H357395-00000-240-066-0002, Rev. 0 "Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3 "Bay d'Espoir Penstock Condition Assessment 1, 2 and 3, issued by Hatch in March of 2019.

APPENDIX A presents the general layout of the Bay d'Espoir Penstock No. 1 profile. The penstock is approximately 1,100 m long and is backfilled to varying depths. It was constructed from a series of rolled carbon steel cans with a diameter that reduces from 5.18m (17 ft) at the intake to 4.12m (13'-6") at the powerhouse. The steel thickness increases from 11.1 mm (7/16") at the intake to 36.5mm (1-7/16") at the powerhouse.

In May and September 2016, Penstock No 1 experienced two ruptures in Cans 96 and 95 respectively as shown in Figure 3-1 (Ref 3). These ruptures were repaired, and the penstock returned to service.

In November 2017, Penstock No 1 experienced a third rupture in Can 95 and in the same weld seam, adjacent to the crack that was repaired in September 2016. The failure consisted of a 2 foot long crack. The metallurgical analysis of the failed section confirmed that the 2017 rupture was initiated at the toe of the 2016 repair weld and then it propagated into the parent plate material in an orientation parallel to the weld. The material tests did not indicate any defects in plate material or the welds.

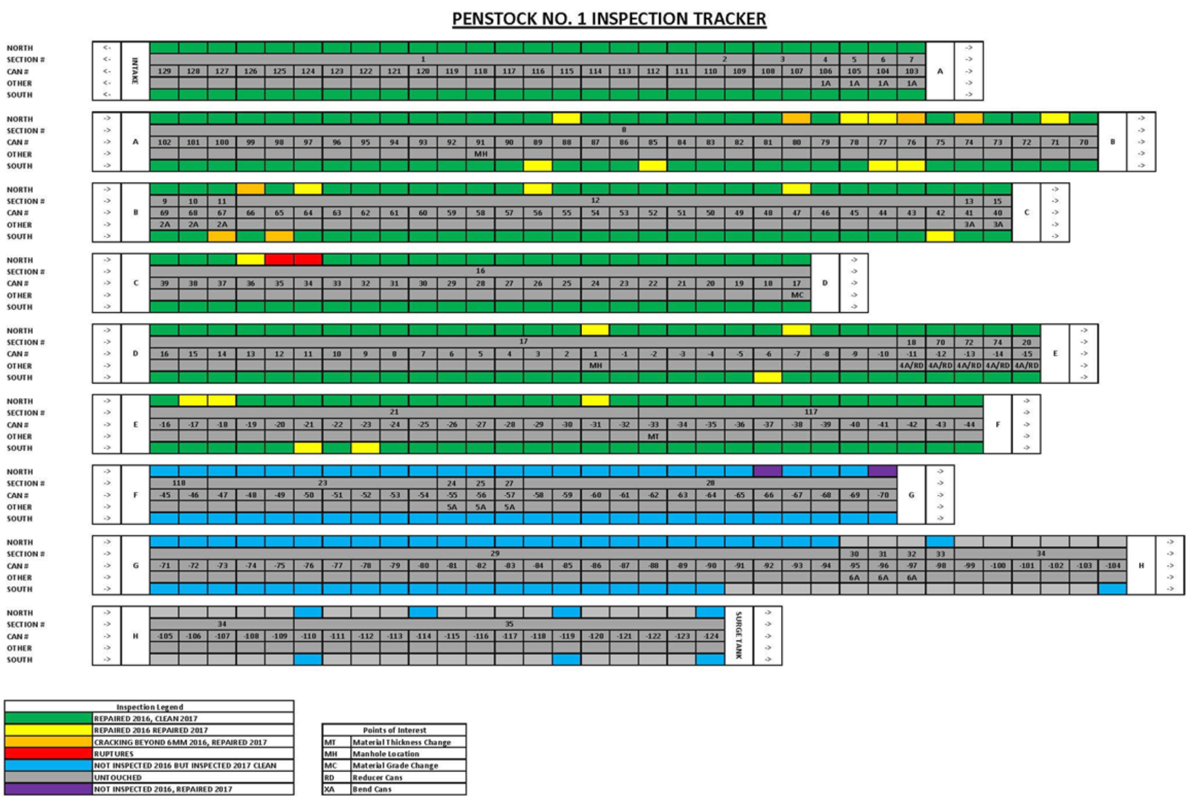


(Cans have been since renumbered, so Cans 34 and 35 are now Cans 96 and 95 respectively)

Figure 3-1: Penstock No. 1 - Failures occurred in 2016 (Ref. 3)

Figure 3-2: Penstock No. 1 - Failure occurred in 2017 (Ref. 3)

Significant weld degradation and cracking was uncovered in Penstock No. 1. Approximately 950m of welds were repaired as indicated in Figure 3-2. All repaired welds were inspected by Magnetic Test (MT) before the penstock was put back in service (Ref. 2). Note that MT of the repair welds could only reveal surface and subsurface defects. Volumetric defects are always detectable by Radiography (RT), however they are more expansive and require more organisation. Adoption of RT for all weld repairs may have added better assurance in the integrity to the repaired welds.



(Cans have since been renumbered, so Can 129 and -124 are now Cans 1 and 253 respectively)

Figure 3-3: Penstock 1- Inspection Tracker (Ref. 2)

To assist in determining the root cause of the multiple failures in Penstock No. 1, Hatch installed strain gauges inside and outside of the steel penstock in Cans 33-36 and 65 as well as pressure transducers to monitor pressure inside the penstock (see Figure 3-4 and Figure 3-5, Ref.3). The pressure data was collected for nearly two months and that includes a planned part-load rejection test in Unit No. 2.

All data and measurements included in various reports of Hatch had a sound engineering basis.

(Cans have since been renumbered, so Cans 33 and 36 are now Cans 97 and 94 respectively)

Figure 3-4: Strain gauges installation in Failed area of Penstock 1 (Ref. 3)

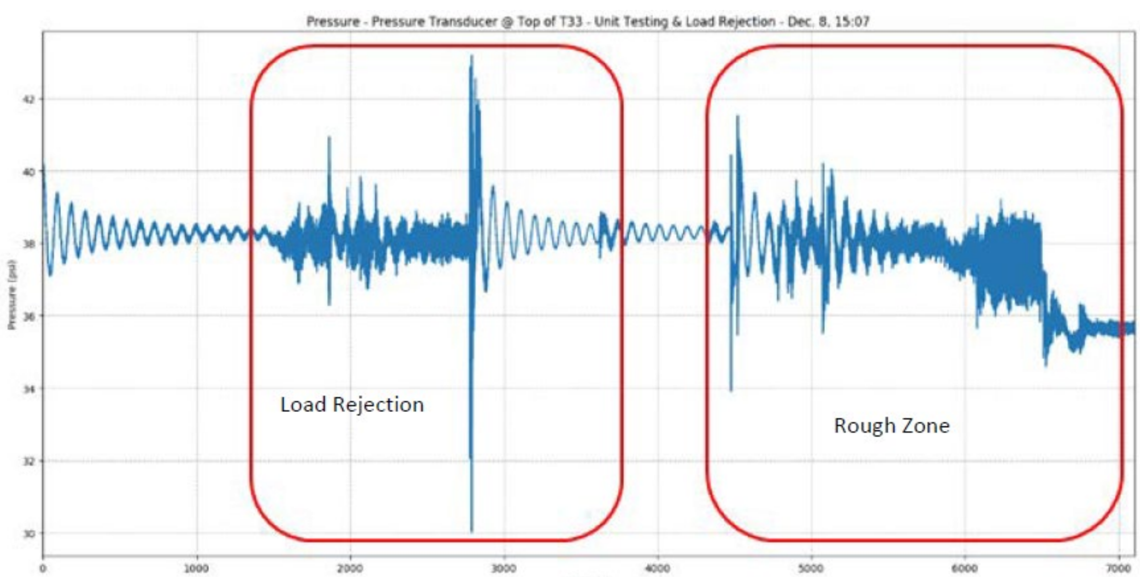


Figure 3-5: Pressure measurement at Can 33 during Rough Zone and Load Rejection (Ref. 3)

According to Hatch investigations, the four failures that have occurred in the Bay d'Espoir Penstock No 1 were most likely caused by a combination of the following factors:

1. Highly localized bending stresses due to the geometry discontinuity (peaking) at the longitudinal weld seam under internal pressure (measured and verified by FE modeling).
2. Fatigue caused by high cycle low amplitude stresses due to operation in the rough zone over the 50-year life-time of the installation and especially in recent years.
3. Fatigue caused by high cycle low amplitude stresses due to pressure fluctuations originating from inherent draft tube instability during normal operation over the 50-year life-time.
4. The as-built backfill was prone to sloughing due to insufficient depth of overburden (1' on top) and the shape of the backfill was unsymmetrical leading to unsymmetrical deformation of the penstock shell when empty

The Laboratory test report done at Atlantic Metallurgical Consulting (Report No. 17-AMC-395, March 14, 2018, and included in Ref. 3) showed the following:

- The materials used in the construction of the penstock No 1 are in conformance to ASTM A285 requirements for strength and ductility.
- There were no brittle microstructures induced by the welding process. No metallurgical factors were attributable to the fracture. There were no unusual microstructures evident to account for the initiation of the original crack. The microstructures were pearlitic with no unusual hard locations that would promote cracking. These stated factors are the common microstructural properties of ASTM A 285 grade steel.
- According to the same report, the 2017 penstock No 1 failure was initiated at the toe of the longitudinal repaired weld. The fracture mode showed an initial crack of 3mm deep then a change in orientation to propagate through the steel plate (see Figure 3-6 and Figure 3-7).
- AMC report states the following as potential causes of the crack initiation in Penstock No 1:

  "*The appearance of the fractures modes suggested high tensile stresses along the internal surface of the plate, similar to the <u>stresses that would result from bending</u>*"

  "*The areas away from the initial repair area showed evidence of initial cracking that did not result in complete fracture, suggesting that the <u>misalignment created</u> a significant portion of the stress that resulted in the failure*".

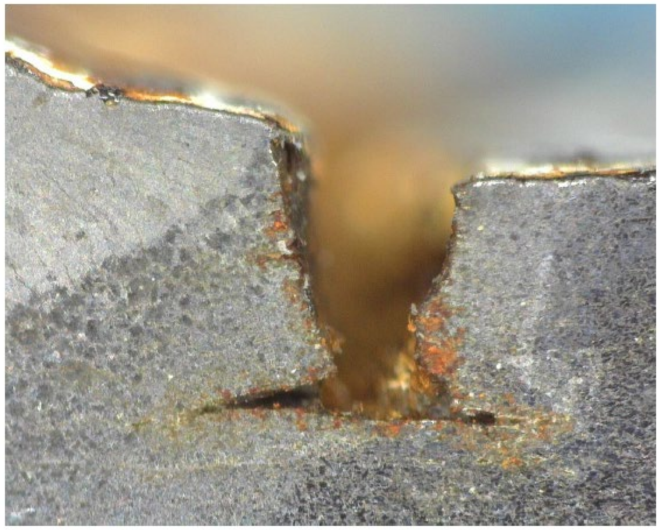


Figure 3-6: Crack initiation at the toe of the longitudinal weld (Ref. 3)

Figure 3-7: Crack propagation modes for 2017 Penstock 1 Failure (Ref. 3)

This failure is somewhat like typical fatigue failure. Initial fracture zone was smooth, followed by coarser fracture zones towards the end.

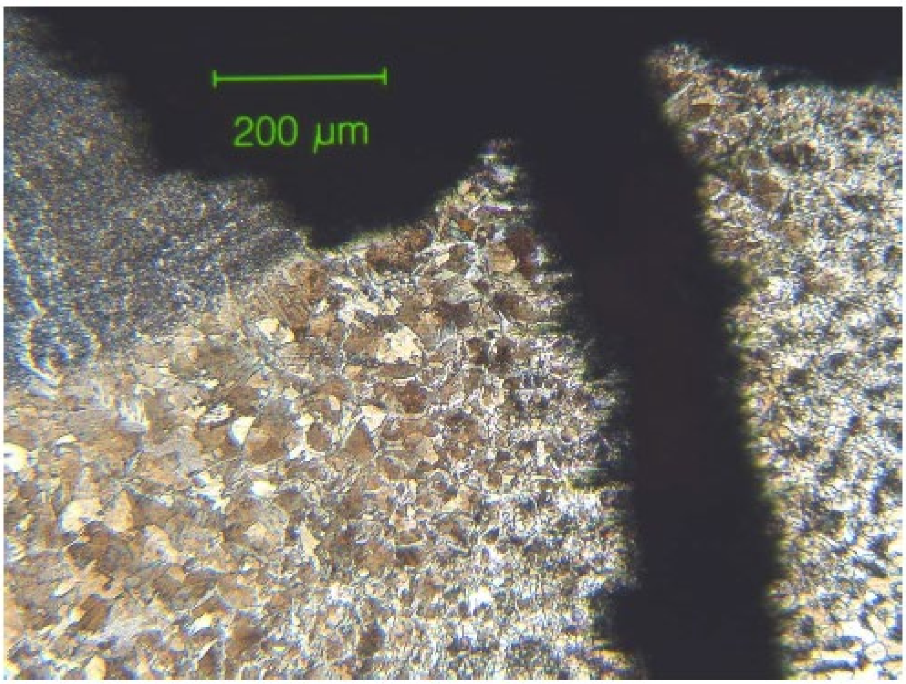
4. TEST RESULTS FOR SEPTEMBER 2019 PENSTOCK RUPTURE

To assist in determining the root cause for the Penstock No 1 rupture in September 2019, SNC-Lavalin suggested in this mandate that metallurgical failures, materials analysis, corrosion analysis be done in a different testing laboratory to see the consistency of results and for the betterment engineering assessments. The failed section of the penstock was shipped to RPC laboratory located in Fredericton New Brunswick.

The preliminary RPC Report is presented in APPENDIX B. Principal testing results and observations are summarized in the following:

- Tensile Testing: The results are consistent with the mechanical tensile properties of the base metal. Recorded UTS is @ 68-69 KSI which is consistent with the parent material, ASTM 285 Gr C (55-75 KSI) as per ASTM/ASME Specification.
- Guided Bend: Tests-Results are satisfactory, which is indicative of the facts that both BM& Weld metal has good ductility to prevent any Brittle Failure in service.
- Chemical Analysis: Chemical Analysis of the base metal is consistent with the composition of A 285 Gr C.
- Macro-examination and Hardness Survey: The hardness of the weld looks higher as compared to the base metal. However, it is within the safe range as that for typical C-Mn steel weld metal. Due to lower Mn content, the hardness of the base metal is relatively low, as compared to weld metal. This hardness factor is not a major concern, considering the service conditions the penstock steel undergoes.
- Charpy Impact Testing: The results indicates an average energy absorption of 87 Joules at -20°C for the welds and 57 Joules at -20°C for the heat affected zone (HAZ), which are significantly higher as compared to the base metal.
- For the base metal, Charpy impact average value is about 14 Joules at -20°C. Note that higher impact properties are better for long term design life, especially for fatigue/vibrational loads. Also, a good low temperature impact property should be above or equal to 27 Joules at -20°C. It seems that the original design did not consider necessary to have higher impact properties for the Bay d'Espoir penstocks.
- Metallographic Examination: The microstructures of the base metal were a typical ferrite/pearlite with no unusual hard locations that would promote cracking. The heat-affected zone shows a transition of coarse grains to fine grained refinement at approximately 0.5 mm from the fusion line. The weld caps show coarse columnar grains, while the underlaying weld beads are mostly small refined grains.

- RPC Report stated: "*The photomicrograph of the smaller crack just outside the weld region in the heat affected zone (HAZ) crack appears to have a wide mouth, which is usually seen with corrosion fatigue*" (see FIGURE 4-1).
- The complementary RPC Report on water corrosive testing reported a Langelier Index of -4.06 which is an indicator that the water is acidic and corrosive which aggravates general corrosion on prolonged exposure such as experienced by Bay d'Espoir penstocks.



Photomicrograph of the smaller crack just outside the weld region in the heat-affected zone (HAZ). Crack appears to have a wide mouth, which is usually seen with corrosion fatigue. The weld metal and coarse grain HAZ are to the left side of the crack. (Original image is taken at 100X magnification.)

Figure 4-1: Photomicrograph of small crack outside of the weld region (RCP Report, see Appendix B)

5. STRESS ANALYSIS FOR PENSTOCK No 1

5.1 Orginal Design

Based on the design drawings, Penstock No. 1 was designed for a pressure rise of 10% of the static head at the powerhouse. The piezometric line was assumed to vary linearly from the powerhouse to the headwater level at the intake. A pressure rise of 10% was measured at the powerhouse (259 psi+ 26 psi) during the load rejection test that was carried out on December 2017, which is consistent with the original design. The pressure fluctuation in the penstock measured at the zone of failures (Can 33 to 36) was about ±17% of the static head at that location (±6.8 psi).

In this mandate, SNC-Lavalin performed a verification of the original for the normal operation condition in accordance with ASCE Steel Penstocks design manual (Ref. 1). For more detail, See APPENDIX C.

The design calculations show that the allowable stresses in penstock No. 1 are not exceeded at any location along the penstock. However, for the penstock portion between the intake and 49 m downstream of elbow 4A (Can 1 to Can 161), where multiple failures occurred in Penstock No 1, the minimum plate thickness required for handling and installation is not respected. The minimum plate thickness should be 14.3 mm (9/16") instead of 10.9 mm (7/16'') as per original design. This should require adequate stulling and internal braces during installation to maintain roundness of the conduit within tolerance. For the upstream portion the penstock having a diameter of 5200 mm (17 ft), the allowable out-of-roundness should be less than 52 mm. The stulls and internal bracing should not be removed until backfill has been compacted to minimum high of 0.7 times the penstock diameter, as shown in Figure 5-1. To evaluate the impact of backfill properties on the penstock performance, stress analyses have been performed and results are discussed in Section 5.3 of this report.

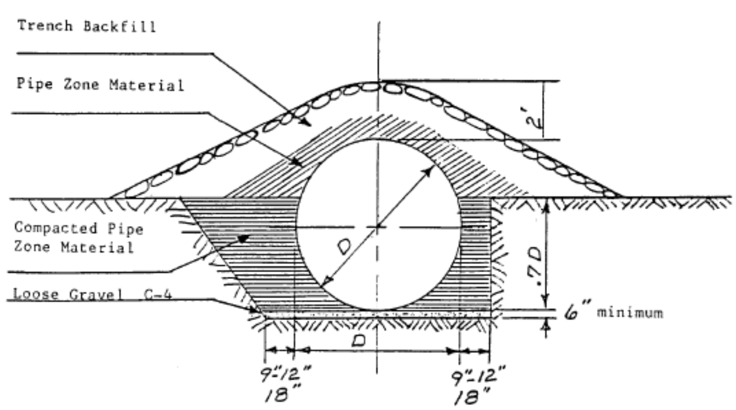


Figure 5-1: Typical trench installation for buried penstock (Ref. 1)

5.2 Penstock 1 Circularity

In 2018, 3D Laser Surveys were carried out to determine the interior shape of the penstocks 1, 2 and 3. The interpretation of the survey is presented in Hatch Report (Ref. 4).

The reported values in Ref 3 indicated the out-of-roundness (deviation from circularity) of the penstocks between 16 mm to 61 mm. Table A-8 in the same report presents deviation of the shell surface at the longitudinal weld seam from a smooth arc, called "peaking". The average deviation of "Peaking" at the welds varies between 2 mm to 17 mm, with maximum value of 60 mm in the upstream section of the penstocks.

Note that peaking or out of roundness is very common during longitudinal welding of any shell, due to angular distortion. Outward peaking (from circularity) is called ''Peak-Out''. Inward peaking is called ''Peak-In''. Peak-In could be corrected by shell re-rolling during penstock construction, which was not possible for Peak-Out such as those observed at some longitudinal welds of Penstock No. 1. Peak-Out areas may act as stress raisers in shells. As stated in Hatch reports (H356043-00000-240-003-0001_Rev 0 and H356043-00000-240-230-0003_Rev 2) due to the constraints of rolling/re-rolling techniques many shells with Peak-Out could not be corrected and had to be accepted as is.

To assess the impact of the penstock out-of-roundness as well as the effect of the Peak-Out at the longitudinal weld, SNC-Lavalin performed FE analyses and findings are presented in the following Sections.

5.3 FE Analysis

The objectives of the FE study are:

1) To evaluate the impact of the penstock circularity/roundness shape on the circumferential (hoop) stresses in the shell;
2) To investigate the influence of the common fill (backfill) properties on the penstock deformation and stresses;
3) To determine the impact of the geometrical discontinues at the longitudinal weld from a non-circularity, e.g. peaking.

5.3.1 FE Model

All models were developed for a unit length and using a plane-strain boundary condition for both backfill and the steel penstock.

For a comparison purpose with previous FE analysis done by Hatch (Ref. 4), similar material properties were considered in all FE models.

Figure 5-2 presents the FE model for a typical 5.2 m (17 ft) diameter penstock section installed in trench backfill.

Table 5.1 presents the parameters used in each FE model.

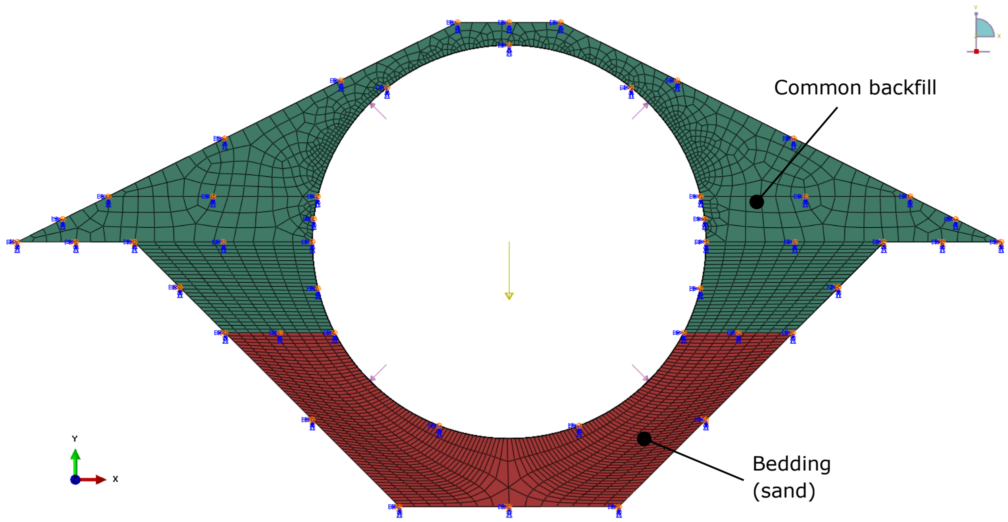


Figure 5-2: FE Model

Steel penstock:

- Shell thickness (7/16"): 10.7mm (0.422 in) + corrosion allowance 0.4 mm
- Elastic modulus: 200,000 MPa (29,000 ksi)
- Poisson ratio: 0.3

Bedding (sand):

- Elastic modulus: 22 MPa (3,191 psi)
- Density: 2,035 kg/m^3 (127 lb/ft3).
- Poisson ratio: 0.33

Common backfill

- Elastic modulus: 7 MPa (1,015 psi) uncompacted fill, and 14 MPa compacted backfill
- Density: 1,634 kg/m^3 (102 lb/ft3).
- Poisson ratio: 0.33

Table 5-1: Finite Element study

FE Model	Inside Diameter	Geometry/ Roundness	Internal pressure	Common Backfill properties	Peak-Out at the weld
Model 1 – Basis	5182mm (17 ft)	Circular	400 kPa (58 psi)	No backfill	No
Model 2	5182mm (17 ft)	Circular	400 kPa (58 psi)	Uncompacted Eb= 7 MPa	No
Model 3a	5182mm (17 ft)	Circular	400 kPa (58 psi)	Compacted to 0.5D Eb= 14 MPa	No
Model 3b	5182mm (17 ft)	Circular	400 kPa (58 psi)	Compacted to 0.7D Eb= 14 MPa	No
Model 3c	5182mm (17 ft)	Circular	400 kPa (58 psi)	Non-symmetric Eb= 7 MPa (south) Eb= 14 MPa (North)	No
Model 4	5182mm (17 ft)	Elliptic (1% out-of-roundness)	400 kPa (58 psi)	Uncompacted Eb= 7 MPa (Same as Model 2)	No
Model 5	5182mm (17 ft)	Circular + ''Peaking out'' at the weld	400 kPa (58 psi)	No backfill	17 mm

5.3.2 Allowable Stresses

The steel plates used for the construction of the upper portion of Penstock No. 1 has a nominal Ultimate Tensile Strength F_u= 379 MPa (55 ksi) and Yield Strength F_y= 206 MPa (30 ksi).

The allowable stresses for normal operation for each category of stresses are (Ref. 1):

- Primary hoop stress: min(Fu/3 ; Fy/1.5) = 126 MPa (18.3 ksi)
- Primary hoop stress plus bending stress: 1.5* min(Fu/3 ; Fy/1.5) = 190 MPa (27.5 ksi)
- The combination of primary and secondary stresses should be less than material tensile strength. Secondary and peak stresses are of concern in relation to fatigue.

5.3.3 FE Results

Table 5-2 shows the maximum stresses in the steel penstock for each FE model.

Table 5-2: FE Results

FE Model	Geometry/ Roundness	Common Backfill properties	Peaking at the weld	Maximum Stress (Membrane plus Bending) (MPa)	Allowable (MPa)
Model 1 – Basis	Circular	No backfill	No	97	126
Model 2	Circular	Uncompacted Eb= 7 MPa	No	121	190
Model 3a	Circular	Compacted to 0.5D Eb= 14 MPa	No	122 (empty)	190
Model 3b	Circular	Compacted to 0.7D Eb= 14 MPa	No	113	190
Model 3c	Circular	Non-symmetric Eb= 7 MPa (south) Eb= 14 MPa (North)	No	113	190
Model 4	Elliptic (1%out-of-roundness)	Uncompacted Eb= 7 MPa (Same as Model 2)	No	115	190
Model 5	Circular + "Peaking out" at the weld	No backfill	17 mm	600 to 750 (localized stress)	380(55 ksi)

Figure 5-3 shows the results for a circular steel pipe under internal pressure of 400 kPa with backfill. The membrane (hoop) stresses are of the order of 97 MPa, which is less than allowable value of 126 MPa for the membrane hoop stress.

Figure 5-4 shows FE results for an empty steel penstock and under internal pressure of 400 kPa. The maximum membrane and the bending stresses are of the order of 121 MPa, which is less than allowable value of 190 MPa.

It can be clearly seen from the results in Table 5-2 that the common backfill properties are not critical parameters for the penstock stresses under hydrostatic internal pressure.

Also, the FE results of Model 4 indicate that an out-of-roundness of 1% in penstock (elliptical shape) should not impact the structural performance of penstock under hydrostatic internal pressure.

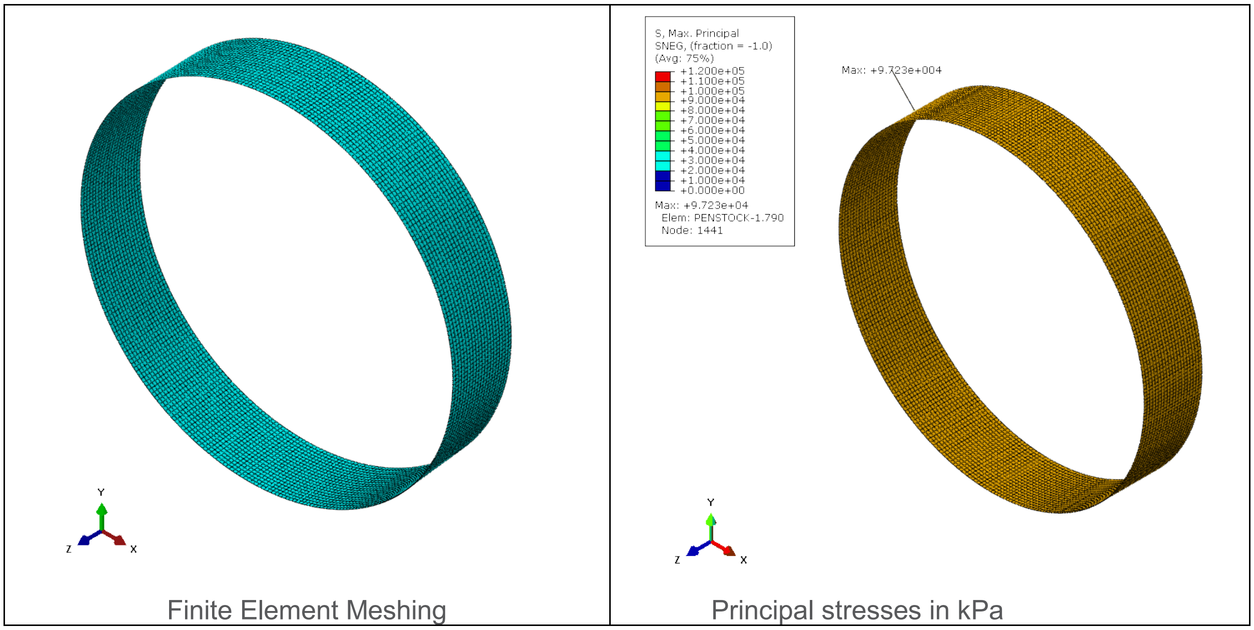


Figure 5-3 Model 1 - Circular steel pipe under internal pressure (no backfill)

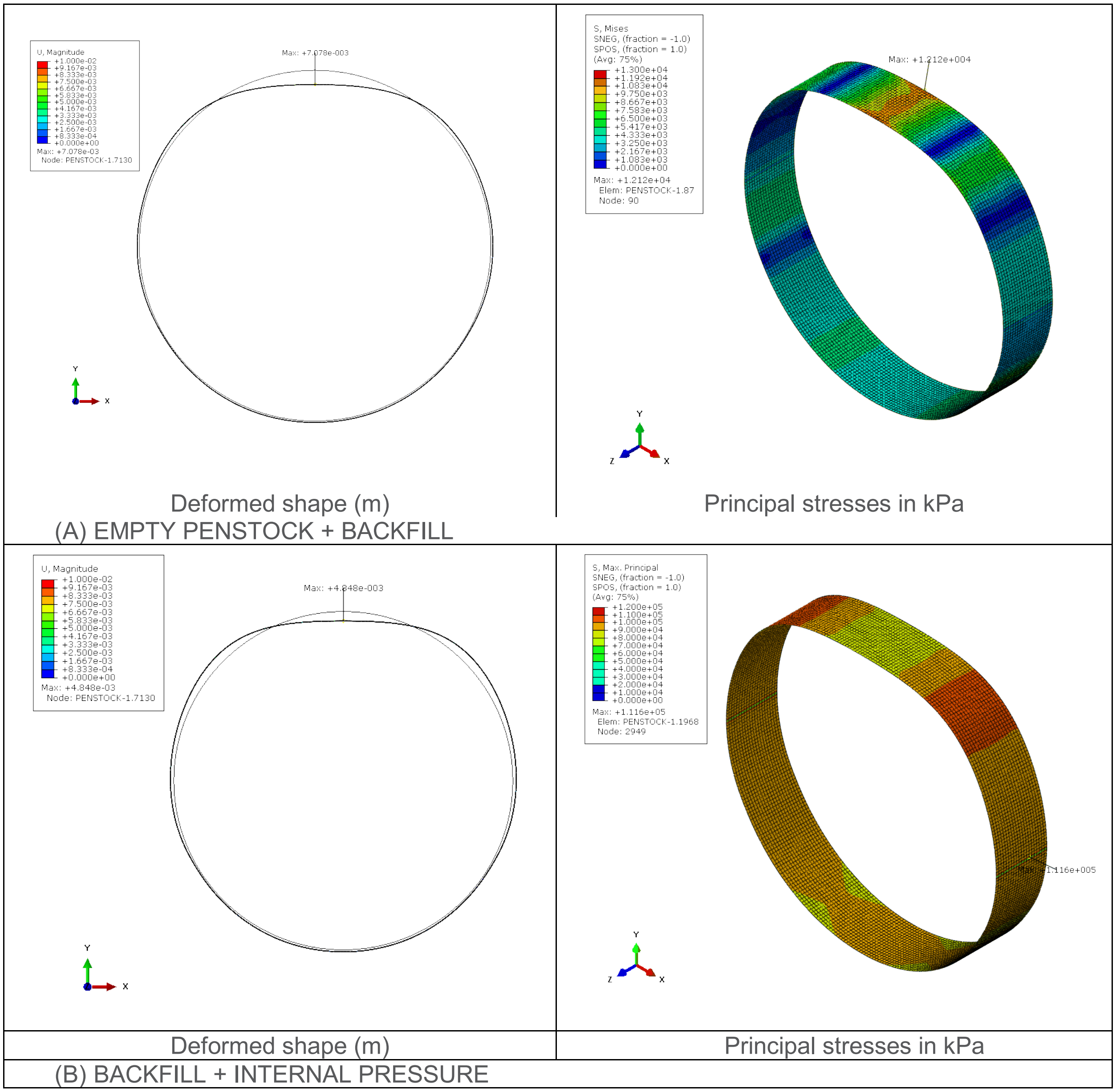
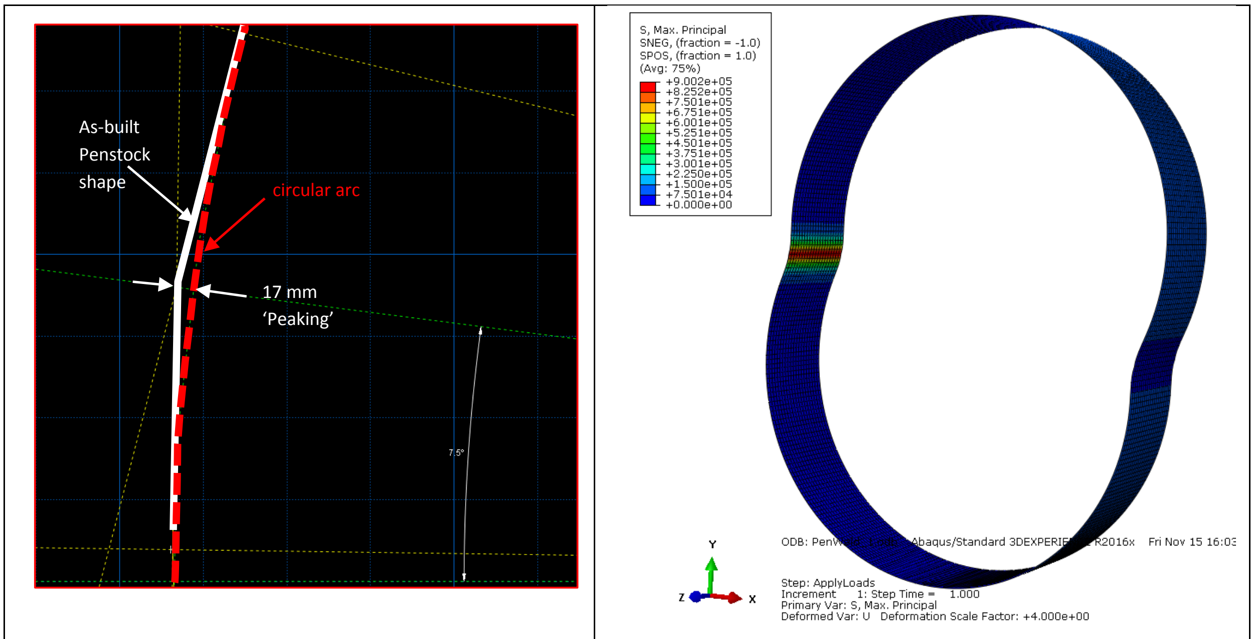


Figure 5-4: Model 2 - Penstock with backfill and under internal pressure

Figure 5-5 shows the impact of a geometrical discontinuity at the longitudinal weld from a smooth circular arc "Peaking out" (Model 5). A "Peaking out" of 17 mm was assumed in the FE analysis. The combined primary and secondary stresses (assuming a linear elastic material) are ranging between 600 MPa and 750 MPa, almost twice the nominal steel tensile strength of 380 MPa.

(Note that in figure 5-5, the figure shows the penstock peeking in. In reality, It is not the case, we get this impression because the figure includes displacements and the displacements have been magnified by a factor of 100. At the peaking out location the displacement is inward and near but less than 17mm while else where the displacement is outward and small. It is the inclusion of the magnified displacements in the image that creates the distortion.)



Geometry discontinuity at the longitudinal weld	Very high local stresses at the weld zone (in MPa)

Figure 5-5: High local stresses induced by geometrical discontinuity e.g. peaking

It is our opinion that these high peak stresses are of concern for the performance of the Bay d'Espoir Penstock No. 1. This situation can lead to crack initiation in the base material or in the weld zone. Once small cracks are initiated, the fatigue cause by small cycling stresses during normal operation can propagate the crack and lead to the ruptures that have occurred in Penstock No. 1.

6. PROBABLE CAUSE OF PENSTOCK 1 FAILURE

In this mandate, SNC-Lavalin has reviewed the documentation provided by NL Hydro to SNC-Lavalin as baseline references for the assessment and investigation of the Bay d'Espoir Penstock No. 1 failure in September 2019.

The laboratory tests carried out by AMC Metallurgist, and related for the failure that occurred in 2017, showed that the steel material used in the construction of Penstock No 1 complies to ASTM A285 requirements for strength and ductility. This was also confirmed by RPC laboratory based on the tests on the coupons taken from the penstock section failed in September 2019.

All laboratory investigations showed evidence of initial cracks mostly located along the internal surface of the plate between longitudinal weld and the base material then the fracture changes orientation and propagates through the plate leading to the penstock ruptures. From the macro-examination and hardness survey, it seems that there was no unusual microstructural evidence for the initiation of the cracks. Therefore, SNC-Lavalin believes that the main cause of Penstock No. 1 failures cannot be attributable to the metallurgical factors induced by the welding process.

Charpy test results indicate higher impact properties in the weld and in the heat affected zone (HAZ), which makes the welds especially resistant against failure by fatigue or vibrational stresses. For the base material, the measured impact values were around 10 Joules at -20 °C. For the Bay d'Espoir penstocks, a good low temperature impact property should be above or equal to 27 Joules at -20 °C. However, it is our opinion that it is not the main root cause of the failures which occurred.

SNC-Lavalin performed a verification of the original buried penstock design for the normal operation condition using conventional method. The calculation showed that the allowable stresses in steel penstock are not exceeded in any location along the penstock. For steel penstock having a diameter of 5200 mm (17 ft), the minimum plate thickness should be 14.3 mm (9/16") instead of 10.9 mm (7/16") as per original design. This suggests that the upstream section of the penstocks may be more subject to misalignment during handling and installation. Also, incorrect (lesser) design thickness together with services induced corrosion and loss of wall thickness could be precursors to premature failures also.

Based on the finite element analysis presented in section 5, SNC-Lavalin believes that the out-of-roundness of the buried penstock has minor impact on the stresses under internal pressure, and therefore should not be considered as a root cause of the Penstock No. 1 failures. It has been demonstrated from the FE sensitivity analyses that the common backfill configuration and its properties have very limited impact on the structural performance of the buried penstock under hydrostatic internal pressure.

Based on our review, the Bay d'Espoir Penstock No. 1 failures were first initiated by high secondary and peak stresses of flexural nature at the longitudinal weld seam under internal pressure most probably induced by geometrical discontinuity (peaking out) from the smooth circular arc at the longitudinal welds. Once small stress induced cracks were initiated, the fatigue from cycling stresses (even for small pressure fluctuations over the 50-year life-time of the penstock) has propagate the crack deeper in the material and ultimately lead to the ruptures in Penstock No. 1. It shall be noted that small shallow peaking out initiated cracks are more prone to initiate and propagate in the thinner section of the penstock (7/16") than in the portion of the penstock with thicker plates (assuming same level or magnitude for primary stress) simply because the secondary flexural stresses induced are inversely proportional to the plate thickness cube.

Also, considering a Langelier index of -4.06 for the Bay d'Espoir water which is an indicator that the water is acidic and corrosive, it is our opinion that it has aggravated general corrosion on prolonged exposure and that corrosion fatigue could have introduced a serious damage mechanism for the life-time of the Bay d'Espoir penstocks leading to premature failures of penstocks sections. In many instances, aligned corrosion pits may join to form cracks which may grow under fatigue loading conditions. This may be possible in a penstock which has undergone over 40 years of service and may have seen gradual thinning and loss of wall thickness due to corrosion.

Galvanic corrosion test results have also concluded that welds will corrode faster than the base metal although they did not reveal anything alarming. Welds always have residual stress, generated from welding. This residual stress added with more hardness, as compared to base metal, causes more preferential corrosion of the weld and the heat affected zone.

The corrosivity of the water and the low galvanic corrosion of welds have certainly contributed to the aggravation of the main root cause of failures being the high secondary and peak stresses of flexural nature under internal pressure induced by geometrical discontinuity (peaking out) at the longitudinal weld seam especially in thin sections of penstocks.

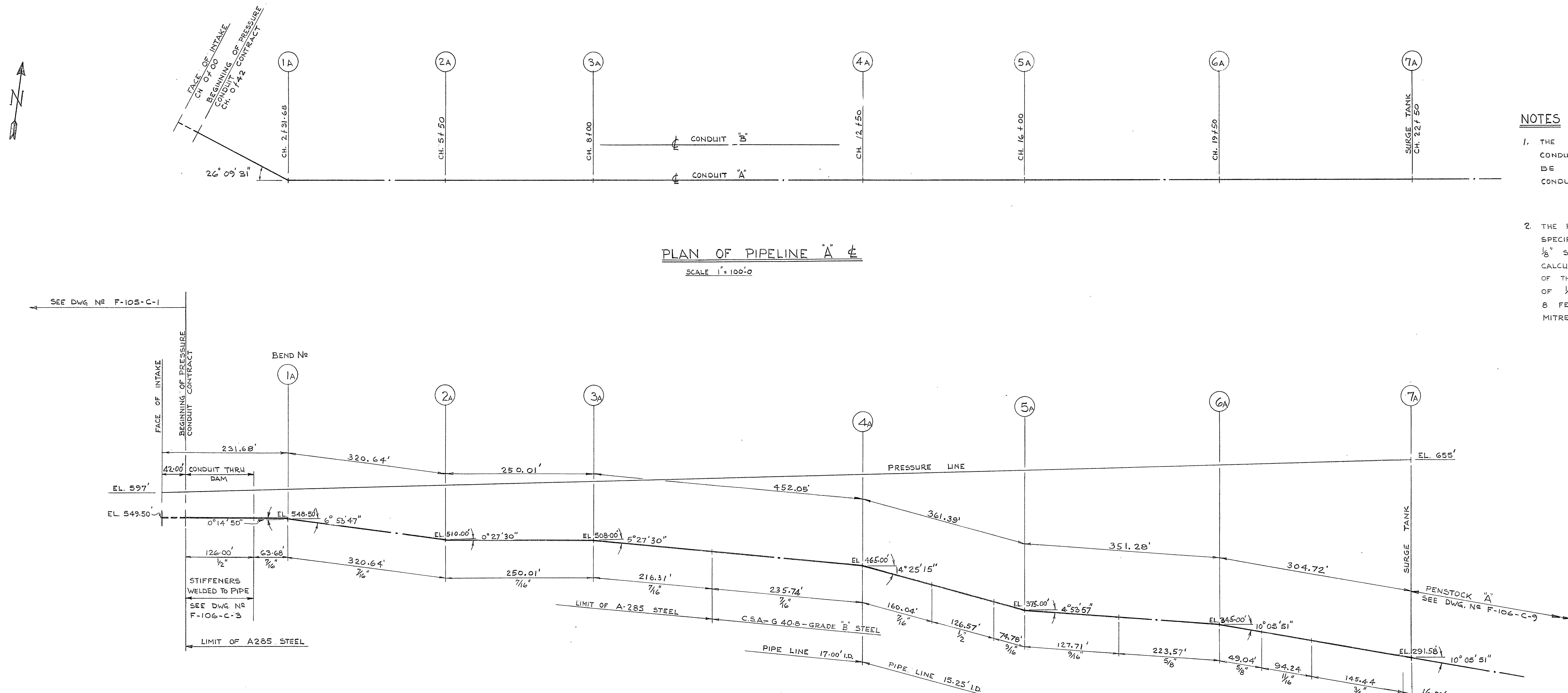
For refurbishment and/or replacement of Bay d'Espoir penstocks, the following protection possibilities may be evaluated by NL Hydro for the Penstock Life Extension Strategy:

- reduce stress concentration or redistribute stress at longitudinal weld seam.
- replacement of critical thinner sections having significant peaking.
- minimize cyclic stresses and provide measure against rapid changes of loading.
- limit corrosion factor in the corrosion-fatigue process (more resistant material / less corrosive environment).
- Better welding and Q.C process. All repair welds must be radiographed (not MT only as done in the past) for better volumetric inspection.
- Any penstock replacement should be done with SA 516 Gr70 steel as against original construction material SA 285 Gr C steel. This is so as SA 516/70 have superior material properties, at very little extra cost.

7. REFERENCES

1. ASCE Manuals and Reports on Engineering Practice No.79 - Steel Penstocks.
2. H356043-00000-240-230-0003, Rev. 2 "Repair and Failure Investigation" Bay d'Espoir Penstock No. 1 Repairs – 2017, issued by Hatch in May of 2018.
3. H356043-00000-240-230-0003, Rev. 0 "Repair and Failure Investigation" Bay d'Espoir Penstock No. 1 Repairs – 2017, issued by Hatch in March of 2018.
4. H352666-00000-240-230-0002, Rev. 0 "Bay d'Espoir Penstock No. 1 Stress Analyses " issued by Hatch in March of 2017.
5. H357395-00000-240-066-0002, Rev. 0 "Condition Assessment and Refurbishment Options for Penstocks No. 1, 2 and 3 "Bay d'Espoir Penstock Condition Assessment 1, 2 and 3, issued by Hatch in March of 2019.
6. ENG/19/J10187R2, "Water Corrosion Testing, Bay d'Espoir Penstock No. 1 Rupture Investigation " issued by RPC in January 2020

APPENDIX A
Design drawings

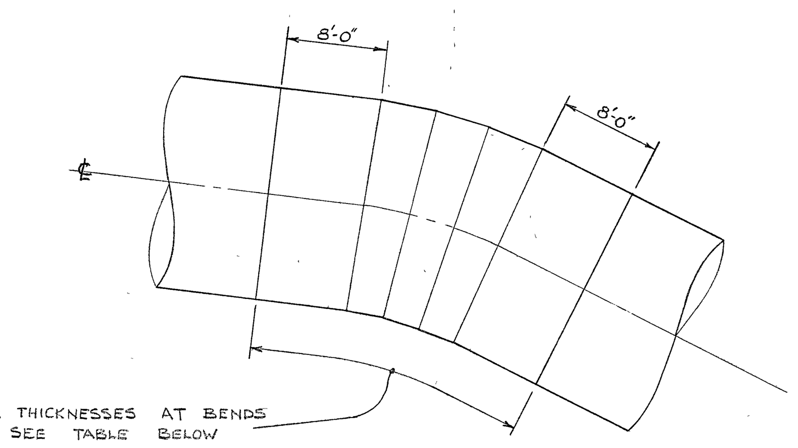


PLAN OF PIPELINE "A" ℄
SCALE 1" = 100'-0

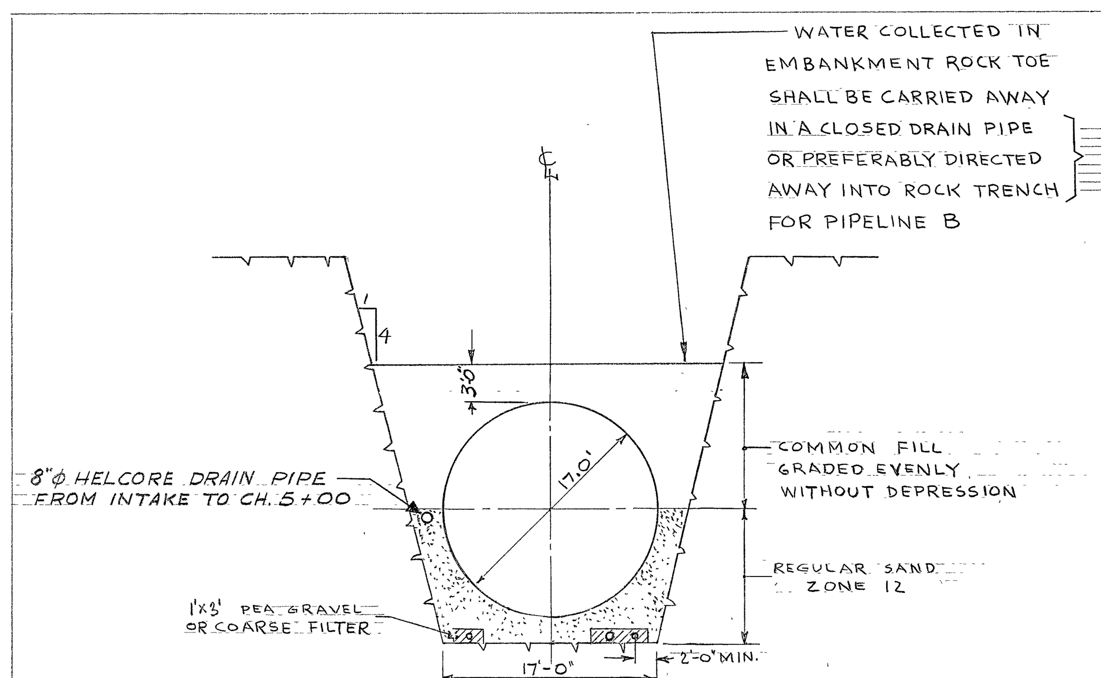
PROFILE OF PIPELINE "A" ℄
SCALE 1" = 100'-0"

NOTES

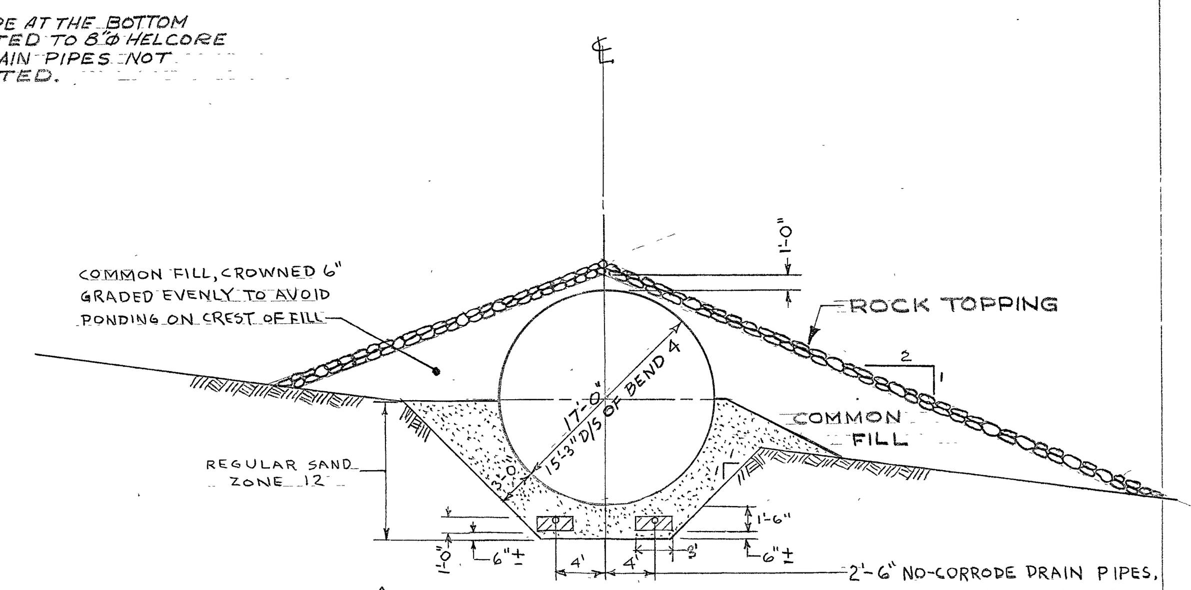
1. THE PRESSURE CONDUITS SHALL BE CALLED "A" AND "B". CONDUIT "A" IS SOUTH OF CONDUIT "B" AND SHALL BE COMPLETED IN 1966. CONDUIT "A" CONSISTS OF PIPELINE "A" AND PENSTOCK "A".
2. THE PIPELINE SHALL BE DESIGNED IN ACCORDANCE WITH SPECIFICATION Nº M-3116 EXCEPT FOR BENDS WHERE 1/8" SHALL BE ADDED TO PLATE THICKNESSES CALCULATED TO RESIST HOOP TENSION PLUS THE EFFECTS OF THE TORUS SHAPE OF BENDS. THIS EXTRA THICKNESS OF 1/8" SHALL EXTEND OVER THE BENDS AND AT LEAST 8 FEET UPSTREAM AND DOWNSTREAM OF THE LAST MITRE JOINT.



TYPICAL BEND
SCALE 1" = 10'-0"
SEE SPEC. M-3116



4 TYPICAL SECTION UPSTREAM OF BEND 7A IN ROCK CUT
SCALE 1" = 1'-0"



4 TYPICAL SECTION UPSTREAM OF BEND 7A IN EARTH TRENCH
SCALE 1" = 1'-0"

PERVIOUS LAYER ZONE 12 MATERIAL AND FILTER MUST BE SEALED WITH IMPERVIOUS FILL IMMEDIATELY DOWNSTREAM OF EACH CROSS DRAIN TO PREVENT SEEPAGE WATER FROM BY-PASSING THE CROSS DRAINS.

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W. F. B. [illegible]
LICENCE TO PRACTICE

ANGLES & PL THICKNESSES AT BENDS

BEND	<A	<B	<C	TRUE ANGLE	PL THICKNESS
1 A	26° 09' 31"	0° 14' 50"	6° 53' 47"	26° 55' 34"	7/16"
2 A	——	6° 53' 47"	0° 27' 30"	6° 26' 17"	1/2"
3 A	——	0° 27' 30"	5° 27' 30"	5° 00' 00"	1/2"
4 A	——	5° 27' 30"	14° 25' 15"	8° 57' 45"	9/16"
5 A	——	14° 25' 15"	4° 53' 57"	9° 31' 18"	3/4"
6 A	——	4° 53' 57"	10° 05' 51"	5° 11' 54"	13/16
7 A	——	10° 05' 51"	10° 05' 51"	0° 00' 00"	

ANGLE IN PLAN   VERTICAL ANGLES

REFERENCE DRAWINGS

F-106-C-3 CONDUITS THROUGH DAM
F-106-C-4 SURGE TANK - DETAILS OF TEES
F-106-C-5 " " - GENERAL LAYOUT & DETAILS
F-106-C-6 PRESSURE CONDUITS - CLEARING
F-106-C-8 " " - EXCAVATION & DRAINAGE
F-106-C-9 " " - PENSTOCK A
F-106-C-10 " " - PENSTOCK B

OTHER REFERENCES

1. SPECIFICATION No. M-3116

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
5	2-6-68		AS BUILT, FROM FIELD INFORMATION	A.B.	JHM
4	5JAN'67		2 TYP. SECTIONS CHANGED, ONE REMOVED	A.R.	[illegible]
3	9DEC'66	A/B-1,2,3,4	3 TYPICAL SECTIONS ADDED	A.R.	JHM
2	20SEPT'65		REVISED PROFILE & PLATE THICKNESSES	A.R.	[illegible]
1	AUG. 5/65		EL. @ BEND 4 CORRECTED, MINOR REVISIONS	J.P.	JHM

APPROVED FOR CONSTRUCTION
JUL 16 1965
APPROVED BY: [signature]
MANAGER ENGINEERING

TRANS'N | ELECT'L | CIVIL JHM

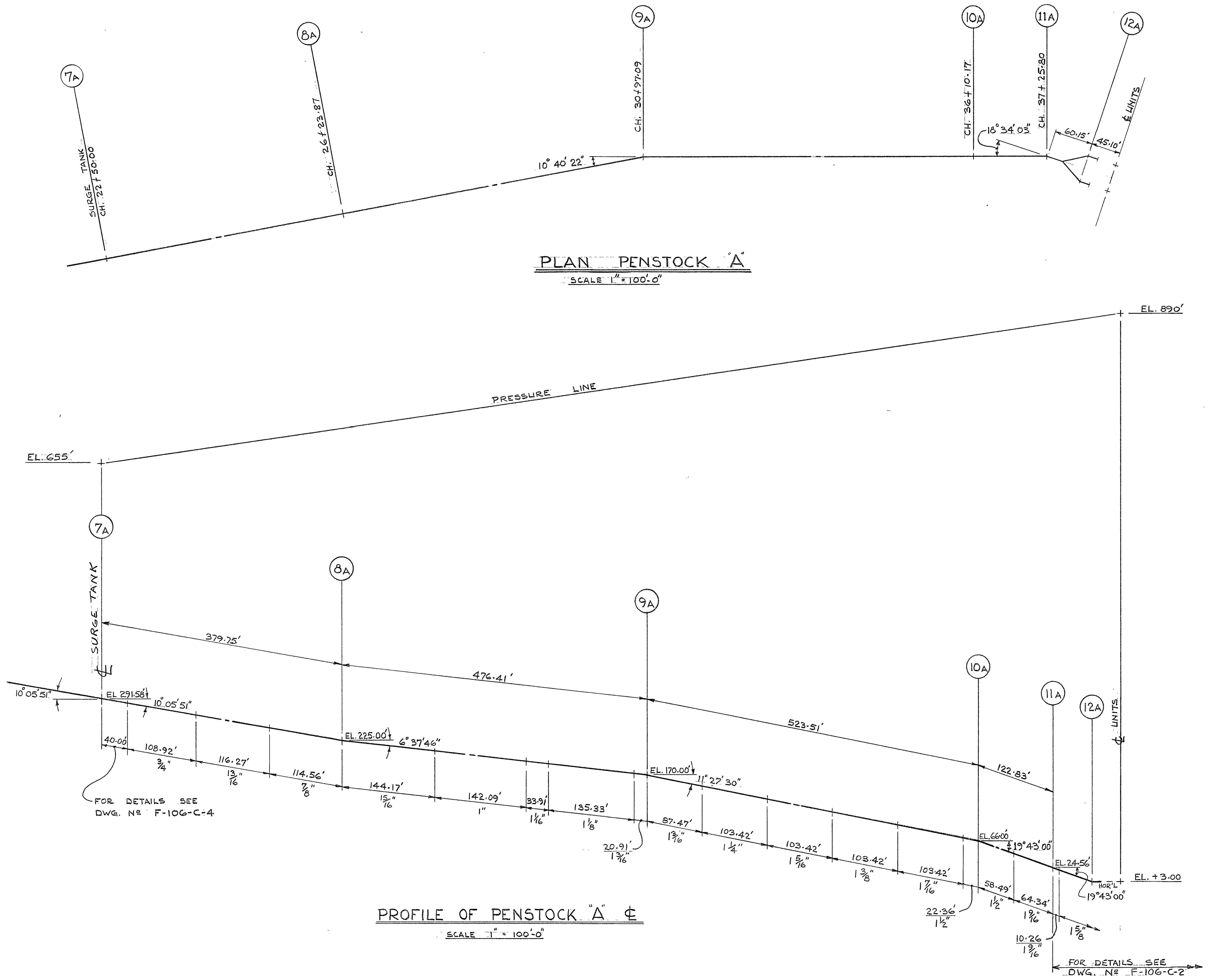
DESIGNED R. MacD.
DRAWN J.P.
CHECKED [signature]
RECOMMENDED J.H. Maries P.Eng.

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

PRESSURE CONDUITS
PLAN & PROFILE PIPELINE "A"

CONTRACT | SCALE | FILE NO. | DATE | DWG NO. F-106-C-7 | REVISION 5


NOTE
ROAD TO BE AT BEDROCK LEVEL TO AVOID EXTENSIVE ROCK EXCAVATION.
NOTE.
LOCATION OF TRENCHES TO BE DETERMINED BY SECTION ENGINEER IN THE FIELD TO MINIMIZE ROCK EXCAVATION.
IF SPACING FOR ABOVE REASON BECOMES 500 FEET OR MORE, CATCH BASINS AND DRAIN PIPES SHOULD BE DOUBLED.
BOTTOM OF TRENCH FOR LINE 'B'
DRAINAGE DITCH
STORAGE SITE FOR PIPELINE ASSEMBLY
END OF DIKE CH. 24+60
DRAINAGE TRENCH
8"Ø HELCORE PIPE
3"Ø PLASTIC PIPE
CH. 5+88
2-6"Ø NO-CO-RODE PIPES
5'Ø MANHOLE CH. 16+40
CONSTRUCTION ROAD
DIKE AT CH. 2+85
DITCH PIPELINE "A" CH. 6+00
DIKE AT CH. 11+50
2-6"Ø NO-CO-RODE PIPES TO DAYLIGHT
DIKE AT CH. 22+00
S.T. EXCAVATION
M/H CH. 27+94
M/H CH. 30+50
DIKE CH. 29+50
LOWER ENDS OF 6" PENSTOCK UNDERDRAINS PASS THRU CONCRETE OF AXIAL THRUST BLOCK SEE DWG. F-106-C-29
PLAN
SCALE 1" = 100'
18" CUT-OFF DRAIN PIPE SHALL BE INSTALLED JUST UPSTR. OF S.T. EXCAVATION. SEE ALSO SURGE TANK FOUND'N BACKFILL DRAWING F-106-C-23
ROAD SWINGS TO NORTH OF CONDUIT 'B'
CHAINAGES AT P.I. OF ROAD
CROSS DRAIN CH. 16+40
PROFILE OF BOTTOM OF TRENCH 'A'
PROFILE OF CONSTRUCTION ROAD BETWEEN CONDUITS
DIKE AT CH. 34+50 APP.
POWERHOUSE EXCAVATION
FOR S.T. EXCAVATION DETAILS SEE DWG. Nº F-106-C-12
ROAD DIVERSION INTO CONDUIT TRENCHES
SEE DWG. Nº F-107-C-2, F-107-C-5, F-106-C-2
PROFILE OF CONSTRUCTION ROAD & BOTTOM OF TRENCH 'A'
SCALE 1" = 100'-0" N.T.S.
BOTTOM OF TRENCH FOR LINE 'A'
PLAN
CATCH BASIN
18"Ø CORR. PIPE
SECTION E-E
CUT-OFF DRAIN PIPE EXCAVATION
SCALE 1" = 30'-0"
PERFORATE 18" PIPE (TOP HALF ONLY) ON A LENGTH OF 10 FT. UNDER ℄ CONDUITS. JOIN WITH 6" DRAINS AND BACKFILL WITH COARSE GRAVEL
NOTE: 18"Ø CORRUGATED PIPES SHALL BE PLACED WITH THE MINIMUM EXCAVATION NECESSARY AND BACKFILLED AS SOON AS POSSIBLE. PLACE 18"Ø PIPE TO AVOID FUTURE INTERRUPTION WITH TRENCH BOTTOM OF LINE 'B'. SEE DWG. Nº F-106-C-11 FOR LINE 'B' PROFILE.
JOINT FOR 6" DIA. NO-CO-RODE PIPE
18"Ø ASPHALT-COATED CORRUGATED PIPE (16 GAUGE)
6" DIA. NO-CO-RODE PIPE
CUT-OFF DRAIN PIPE – BACKFILLED
SCALE 1" = 30'-0"
DETAIL OF CATCH-BASIN
SCALE ½" = 1'-0"
5'-0"Ø COATED ARMCO PIPE
CONCRETE SLAB
SONOLASTIC SEALANT
8"Ø HELCORE PIPE CONNECTED TO INTAKE DRAINS
6" DIA. PERFORATED NO-CO-RODE PIPE
8"Ø HELCORE PIPE CONNECTED TO INTAKE DRAIN ALSO 3"Ø PLASTIC PIPE
TYPICAL SECTION AT INTAKE TRENCH
(LOOKING DOWNSTREAM) SCALE 1" = 20'-0"
NOTE: SIDESLOPE CHANGES AT CH. 1+55 ON LINE 'A' & CH. 1+83.60 ON LINE 'B' FROM 1:6 THRU DAM TO 1:4 IN REMAINDER OF ROCK TRENCH.
SEE DWG. Nº F-105-C-6.
1% SLOPE
18" GRAVEL LAYER
18" DIA. CORRUGATED PIPE IN GRAVEL DRAIN
SECTION AT STORAGE SITE
SCALE 1" = 40'-0"
AVOID ROCK CUTTING TO BUILD ACCESS ROAD.
DRAINAGE TRENCH
EARTH
FILL
ROCK
APPROX. ROCK LEVEL
6" NO-CO-RODE DRAIN PIPES SHALL BE INSTALLED IN SECOND LAYER
TYPICAL SECTION AT ROCK OUTCROP
(LOOKING DOWNSTREAM) SCALE 1" = 20'-0"
APPROX. EL. 104'-8"
SWITCHYARD BERM SUPERIMPOSED AFTER ERECTION OF PENSTOCKS
NOTE
STRIPPING SHALL BE LIMITED TO THE AREAS TO BE USED FOR ACCESS ROADS, STORAGE AREAS AND STOCKPILES.
NOTE
THE CENTRAL ROAD SHALL BE FOR THE USE OF HORTON STEEL ONLY. ANY OTHER ACCESS ROADS REQUIRED SHALL BE BUILT ON THE OUTSIDE BANKS OF THE EXCAVATION
DRAIN PIPE
INITIAL LAYER 1'-0" SCREENED GRAVEL
SECTION D-D AT SWITCHYARD
SCALE 1" = 20'-0" (LOOKING DOWNSTREAM)
PIPE SIZE & TRENCH WIDTH TABLE
BEND Nº | PIPE SIZES | MINIMUM TRENCH BASE WIDTH
1 TO 4 | 17'-0" I.D. | SEE SECTION AT INTAKE TRENCH
4 TO 7 | 15'-3" I.D. | 10'-11"
7 TO 12 | 13'-6" I.D. | 10'-1"
ASSOCIATION OF PROFESSIONAL ENGINEERS PROVINCE OF NEWFOUNDLAND
LICENCE TO PRACTICE
REFERENCE DRAWINGS
1. F-105-C-6 INTAKE Nos 1 & 2 EXCAVATION PLAN & SECTION.
2. F-106-C-3 CONDUITS THROUGH DAM.
3. F-106-C-11 PRESSURE CONDUITS - LAYOUT & LOCATION DATA.
4. F-106-C-14 OVERBURDEN EXCAVATION FOR SURGE TANKS
5. F-107-C-5 POWERHOUSE ROCK EXCAVATION - PLAN & SECTIONS.
6. F-106-C-2 PRESSURE CONDUITS - LAYOUT OF BIFURCATIONS.
7. F-107-C-2 POWERHOUSE EARTH EXCAVATION & DISPOSAL AREAS.
8 | 2-7-68 | | AS BUILT, FROM FIELD INFORMATION | A.B.
7 | 14 JUNE 66 | PLAN | CUT-OFF DITCH CH. 28+50 WAS CH. 26+50 DRAINAGE ABOVE AXIAL THRUST BLOCK ADDED | A.R.
6 | 2 MAY 66 | PLAN | CUT-OFF DITCHES & DRAINS DELETED | A.R.
5 | FEB 66 | | CUT-OFF DITCHES & DRAINS REVISED. | J.P.
4 | JAN 66 | A-5 | 6" DRAINS RELOCATED, 18" DRAINS RESPECIFIED | A.R.
3 | DEC 65 | A-7 | NOTE AT TYP. SECT. INTAKE TRENCH REVISED | J.P.
2 | OCT. 65 | | REVISED CH. & ELEV. LINES, & ROAD | J.P.
1 | AUG 65 | | APPR'D EXCAVATION DETAILS | J.P.
APPROVED FOR CONSTRUCTION
AUG 24 1965
APPROVED BY:
MANAGER ENGINEERING
DESIGNED R. MAC D.
DRAWN J.P. / A.R.
CHECKED
RECOMMENDED
NEWFOUNDLAND AND LABRADOR POWER COMMISSION
BAY D'ESPOIR DEVELOPMENT
ENGINEERING AND DESIGN BY
SHAWMONT ENGINEERING NEWFOUNDLAND LIMITED
MONTREAL, QUEBEC
PRESSURE CONDUITS
EXCAVATION & DRAINAGE – LAYOUT

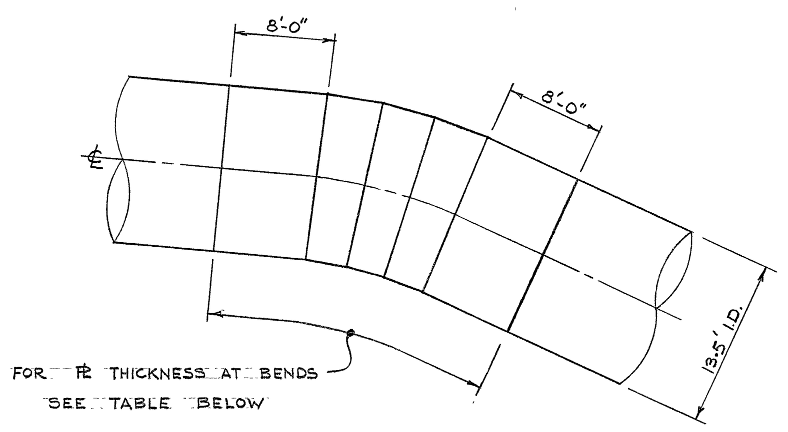


PLAN PENSTOCK "A"
SCALE 1" = 100'-0"

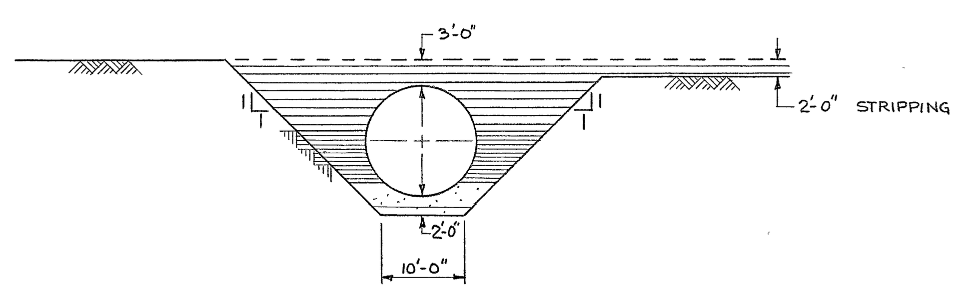
PROFILE OF PENSTOCK "A" ℄
SCALE 1" = 100'-0"

NOTES

1. THE PENSTOCK SHALL BE DESIGNED IN ACCORDANCE WITH SPECIFICATION Nº M-3116 EXCEPT FOR BENDS WHERE 1/8" SHALL BE ADDED TO PLATE THICKNESSES CALCULATED TO RESIST HOOP TENSION AND THE EFFECTS OF THE TORUS SHAPE OF BENDS. THIS EXTRA THICKNESS OF 1/8" SHALL EXTEND OVER THE BENDS AND AT LEAST 8 FEET UPSTREAM AND DOWNSTREAM OF THE LAST MITRE JOINT.
2. THE INTERNAL DIAMETER OF THE PENSTOCK IS 13'-6".
3. STEEL SHALL BE C.S.A. G40-8 GRADE "B".
4. FOR TYPICAL CROSS SECTION FROM 7A TO 9A SEE DWG. Nº F-106-C-7.



TYPICAL BEND
SCALE 1" = 10'-0"



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

REFERENCE DRAWINGS

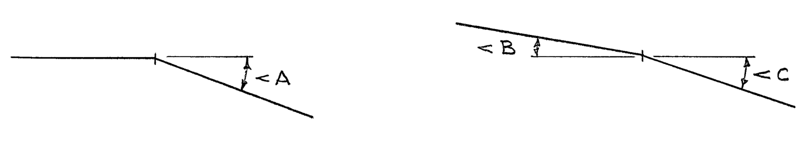
1. F-106-C-2 PRESSURE CONDUITS - LAYOUT & DETAILS OF BIFURCATION.
2. F-106-C-4 SURGE TANKS - DETAILS OF TEES.
3. F-106-C-5 SURGE TANKS - GENERAL LAYOUT & DETAILS.
4. F-106-C-6 PRESSURE CONDUITS - CLEARING.
5. F-106-C-7 PRESSURE CONDUITS - PLAN & PROFILE PIPE LINE "A".

OTHER REFERENCES

1. SPECIFICATION Nº M-3116

BEND	< A	< B	< C	TRUE ANGLE	ℙ THICKNESS
7 A	—	10° 05' 51"	10° 05' 51"	0° 00' 00"	—
8 A	—	10° 05' 51"	6° 37' 46"	3° 28' 05"	1 1/8"
9 A	10° 40' 22"	6° 37' 46"	11° 27' 30"	11° 35' 25"	1 3/8"
10 A	—	11° 27' 30"	19° 43' 00"	8° 15' 30"	1 3/4"
11 A	18° 34' 03"	19° 43' 00"	19° 43' 00"	17° 28' 12"	1 7/8"

ANGLES & ℙ THICKNESS AT BENDS



ANGLE IN PLAN VERTICAL ANGLES

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

NO.	DATE	LOCATION	DESCRIPTION	MADE BY	APPR'D
3	SEPT 21/65		PLAN & PROFILE REVISED	J.P.	

REVISIONS

APPROVED FOR CONSTRUCTION
SEP 22 1965
APPROVED BY:
MANAGER ENGINEERING

PASSED: TRANS'N | ELECT'L | CIVIL

DESIGNED: R. MAC D.
DRAWN: J.P.
CHECKED: A.P. HK
RECOMMENDED: P. Eng.

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

PRESSURE CONDUITS
PLAN & PROFILE PENSTOCK "A"

CONTRACT	SCALE	FILE NO.	DATE	DWG. NO.	REVISION
	NOTED	PD-11	SEPT. 21, 1965	F-106-C-9	3

APPENDIX B
RPC Reports

SCIENCE & ENGINEERING • SCIENCE ET INGÉNIERIE

21st November 2019

Dylan Drake
Newfoundland and Labrador Hydro.
500 Columbus Dr.
St. John's, NL A1B 4K7
Via email: DylanDrake@nlh.nl.ca

Dear Mr. Drake:

RE: MECHANICAL AND METALLURGICAL TESTING
BAY D'ESPOIR PENSTOCK 1 RUPTURE INVESTIGATION
PO NO. TC015-108829
RPC REPORT: ENG/19/J10187R1

A portion of a welded pipe assembly was received from Newfoundland and Labrador Hydro. for material testing. The assembly was reportedly removed from a penstock which had failed in service at the Bay D'Espoir Hyrdoelectric Generation Station. RPC was tasked to carry out a series of mechanical and metallurgical tests in assessing the penstock material. The tests performed included tensile testing, guided bend testing, hardness survey, Charpy impact testing, chemical composition and metallurgical assessment. All testing was performed in accordance with ASME Section IX and ASTM A370, including all applicable referenced standards. Please note, galvanic corrosion testing and water testing will follow upon the receival of the sample, the test results will be reported separately. The following letter summarizes our findings.

1.0 Tensile Testing

Two tensile specimens were prepared by RPC as per ASME Section IX (Figure QW 462.1(b)) and later pulled on our calibrated Instron tensile testing machine. Both specimens yielded a ductile fracture in the base metal. Further tensile results are provided below in Table 1.

Table 1 Tensile Test Results

RPC ID	Dimensions			Observations at Failure		
	Width (ins)	Thickness (ins)	Area (in^2)	Maximum Load (lbs)	UTS (ksi)	Type and Location
T1	0.753	0.301	0.227	15,560	68.6	Ductile, Base Metal
T2	0.751	0.298	0.224	15,440	68.9	Ductile, Base Metal

Note: UTS = ultimate tensile strength

2.0 Guided Bend Tests

Two bend specimens were cut out and prepared at RPC as per ASME Section IX (Figure QW 462.2). The guided bend specimens were tested in the side bend orientation on a wraparound ASME standard test jig and appropriate diameter reformer. The bend test results are summarized below in Table 2.

Table Bend Test Results

Sample ID	Test Results	
Side bend 1, SB1	o No Defects	**Pass**
Side bend 2, SB2	o No Defects	**Pass**

3.0 Macro-examination and Hardness Survey

A macro-section was prepared through the weld and polished to a 1-µm finish as per RPC SOP PM-0010 and etched using 5% Nital (5% Nitric Acid in Ethanol solution). A macro-examination was conducted up to 20x magnification under a stereo-microscope. The weld appears to be a double bevel joint. At the location of the macro-section, there are two separate cracks initiation from the same surface. Due to the limited availability of un-cracked material, the microsection was taken through one of the major visible through-wall cracks. As seen in Figure 1, one crack is through-wall and the other is a small linear crack, approximately 2.8 mm deep. Both cracks originate at the weld toe and for the smaller crack, there is a steep angle (transition) between the weld cap and penstock pipe surface potential serving as a stress-riser. There also appears to be lack of weld penetration within the double bevel joint.

Several Vickers' hardness readings were taken from the macro-section using a diamond pyramid indenter with a 10 kg load. Readings were taken in the parent metal, weld metal and heat-affected zone (HAZ) of the assembly. The maximum reading was 241 Vickers (HV_{10}) in the weld. A macrograph of the weld profile can be seen in Figure 1 and reading locations are illustrated in Figure 2. Hardness results are found in Table 3.

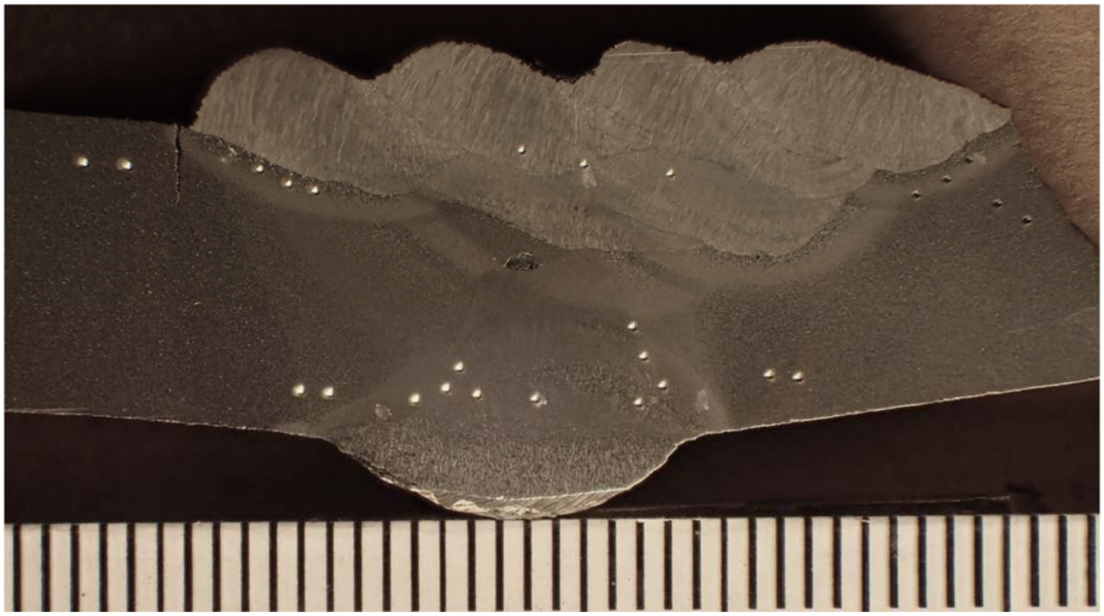


Figure 1 Macrograph of Hardness Profile

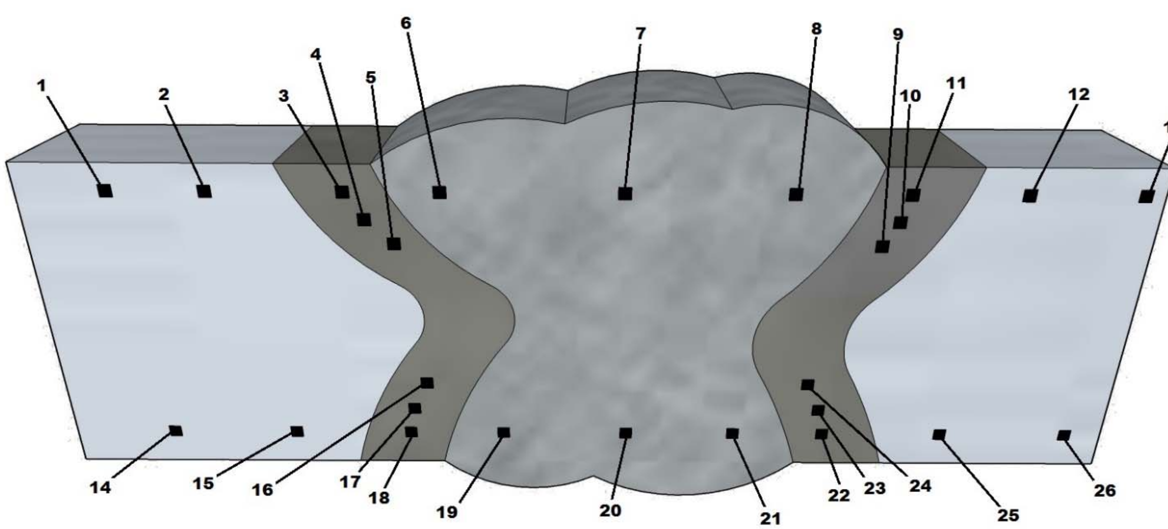


Figure 2 Illustration of Hardness Profile

Table 3 Vickers' Hardness Results

Location	Orientation	Description	Vickers, HV
1	Upper	Base Metal	162
2	Upper	Base Metal	155
3	Upper	HAZ	211
4	Upper	HAZ	198
5	Upper	HAZ	196
6	Upper	Weld	241
7	Upper	Weld	228
8	Upper	Weld	237
9	Upper	HAZ	180
10	Upper	HAZ	175
11	Upper	HAZ	181
12	Upper	Base Metal	164
13	Upper	Base Metal	151
14	Lower	Base Metal	154
15	Lower	Base Metal	153
16	Lower	HAZ	179
17	Lower	HAZ	182
18	Lower	HAZ	152
19	Lower	Weld	174
20	Lower	Weld	174
21	Lower	Weld	187
22	Lower	HAZ	162
23	Lower	HAZ	182
24	Lower	HAZ	172
25	Lower	Base Metal	160
26	Lower	Base Metal	158

4.0 Charpy Impact Testing

Nine sub-size Charpy impact specimens, 7.5 mm x 10 mm, were transversely notched and machined to meet the dimensional requirements outlined as per ASTM A370. The Charpy impact specimens for weld center (WC) and heat-affected zone (HAZ) were removed transversely across the weld. The base metal (base) specimens were removed in the orientation perpendicular to the weld, but due to the limited material, away from the weld. All specimens were chilled in a bath for at least 10 minutes at a temperature -20ºC prior to testing. The bath temperature was monitored by a calibrated digital thermometer and the Charpy impact machine was verified as per ASTM E23. Charpy impact results are given in Table 4.

Table 4 Charpy Impact Results

RPC ID	Temp (°C)	Notch Location	Energy Absorbed		Average Energy Absorbed Ft-lbs (Joules)
			Ft-lbs	Joules (converted)	
3010	-20	WC	70.0	94.9	64.3 Ft-lbs (87.2 J)
3011	-20	WC	51.0	69.2	
3012	-20	WC	72.0	97.6	
3013	-20	HAZ	33.0	44.7	42.0 Ft-lbs (57.0 J)
3014	-20	HAZ	44.0	59.7	
3015	-20	HAZ	49.0	66.4	
3016	-20	Base	14.3	19.3	7.9 Ft-lbs (10.7 J)
3017	-20	Base	5.0	6.8	
3018	-20	Base	4.5	6.1	

Charpy size is 7.5 x 10 mm

5.0 Metallographic Examination

A metallographic section was prepared from the weld and polished to a 1-µm finish as per RPC SOP PM-0010 and etched 5% Nital (5% Nitric Acid in Ethanol solution). The metallographic sample was then examined under an optical microscope at magnifications up to 650X. Each region of the weld joint, including weld metal, heat-affected zone and nearby base metal near the OD, ID and mid wall were reviewed. The base metal shows a typical ferrite/pearlite microstructure for a carbon steel. The heat-affected zone on one side (upper) shows a transition of coarse grains (at and near the fusion line), to fine grained refinement (at roughly 0.5 mm from the fusion line). The heat-affected zone, on the opposite side (lower side) of the double bevel joint, shows a narrow band of refined grains. The weld caps show coarse columnar grains, while the underlaying weld beads are mostly small refined grains. Photomicrographs of the base metal, heat-affected zone alongside the crack and weld metal are provided in Figures 3, 4 and 5.

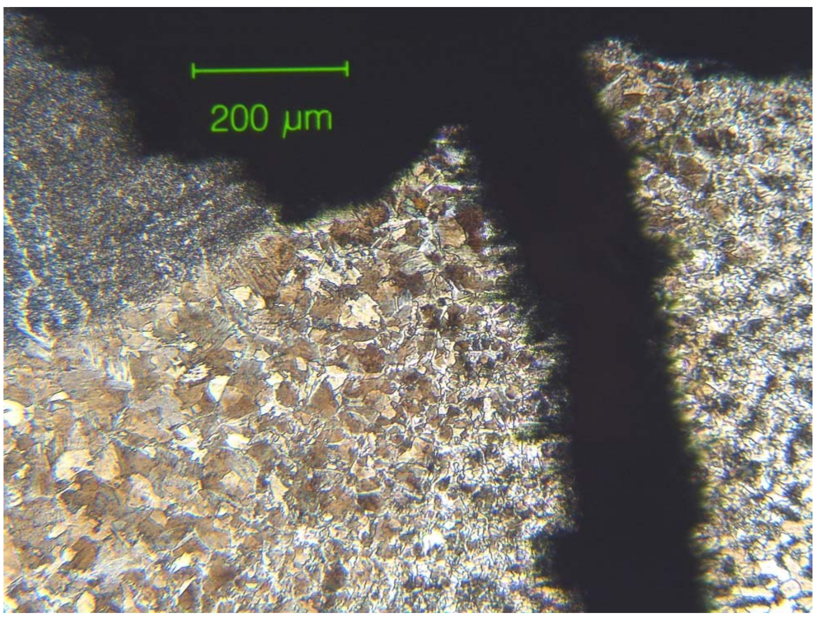


Figure 3 Photomicrograph of the smaller crack just outside the weld region in the heat-affected zone (HAZ). Crack appears to have a wide mouth, which is usually seen with corrosion fatigue. The weld metal and coarse grain HAZ are to the left side of the crack. (Original image is taken at 100X magnification.)

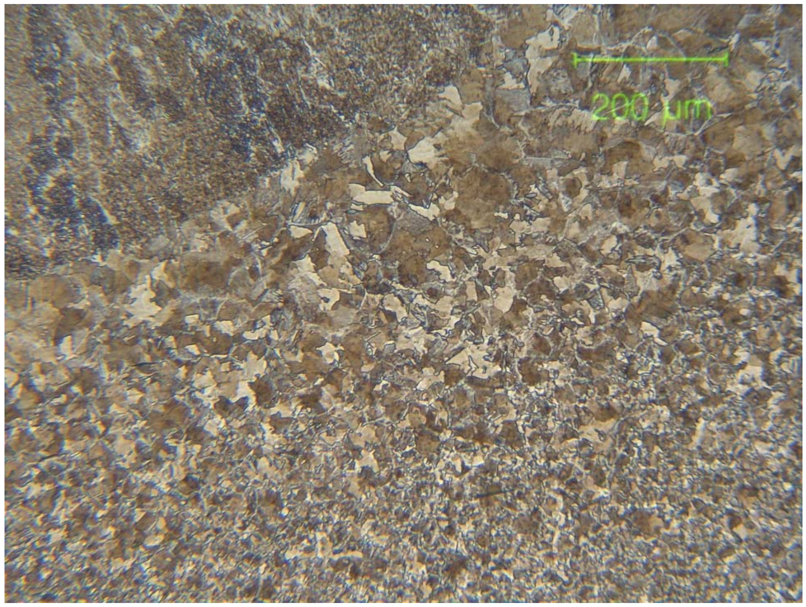


Figure 4 Photomicrograph of the heat-affected zone (HAZ) near the small crack (not shown). Note the weld metal (upper left corner), coarse grain region of the HAZ and the transformation to the small grain refinement region of the HAZ (lower right corner). (Original image is taken at 100X magnification.)

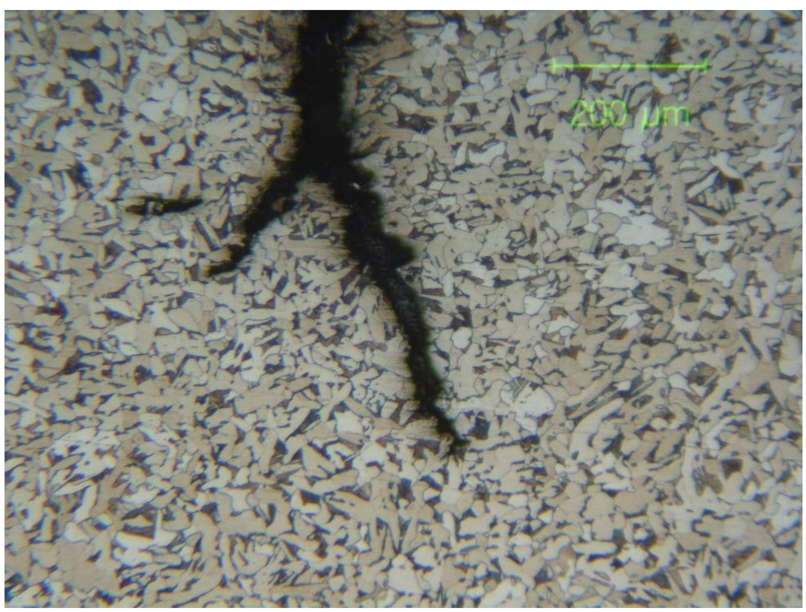


Figure 5 Photomicrograph of the tip of the smaller crack in base metal. Base metal has a typical ferrite and pearlite microstructure for carbon steels. (Original image is taken at 100X magnification.)

6.0 Chemical Analysis

A sample was sectioned from both the weld and parent metal and chemically analyzed using conventional ICP instrumentation in accordance with ASTM Standard D1976. The results of the chemical analysis are summarized in Table 5. The base metal is believed to be a plain carbon steel with trace amounts of nickel, chromium or molybdenum as alloying elements. The weld metal has appreciable amounts of nickel and manganese, suggesting a low-alloyed electrode. The chemical composition of SA-36 steel is included in Table 5 for information purposes.

Table 5 Chemical Composition of Steel Sample

Elements		Chemical Composition (%wt.)		
		Weld Metal	Base Metal	ASME SA 36
Carbon	C	0.08	0.194	0.25 max
Nickel	Ni	0.74	0.04	Trace
Sulfur	S	0.012	0.020	0.05 max
Chromium	Cr	0.05	0.04	Trace
Aluminum	Al	0.013	0.008	Trace
Copper	Cu	0.04	0.04	Trace
Manganese	Mn	1.26	0.56	0.3-1.0
Molybdenum	Mo	<0.01	<0.01	Trace
Silicon	Si	0.33	0.07	0.40 max
Phosphorus	P	0.010	0.020	0.04 max

I trust that the contents of this report are satisfactory. Please note that all test samples and components related to this job will be discarded after 60 days, unless further notification is received by RPC. If you have any questions about the report, please contact one of the undersigned.

Best Regards,

John Speelman, P.Eng.
Sr. Metallurgist
Engineering Services
506.460.5674

Ryan Tarr
Metallurgical Technician
Engineering Services
506.452.1358

rt/J10187R1

SCIENCE & ENGINEERING • SCIENCE ET INGÉNIERIE

17th January 2020

Dylan Drake
Newfoundland and Labrador Hydro.
500 Columbus Dr.
St. John's, NL A1B 4K7
Via email: DylanDrake@nlh.nl.ca

Dear Mr. Drake:

RE: WATER CORROSION TESTING
BAY D'ESPOIR PENSTOCK 1 RUPTURE INVESTIGATION
PO NO. TC015-108829
RPC REPORT: ENG/19/J10187R2

A portion of a welded pipe assembly was received from Newfoundland and Labrador Hydro. for material testing. The assembly was reportedly removed from a penstock which had failed in service at the Bay D'Espoir Hyrdoelectric Generation Station. RPC was tasked to carry out a series of mechanical and metallurgical tests in assessing the penstock material. Previous testing, as found in RPC report ENG/19/J10187, included tensile testing, guided bend testing, hardness survey, Charpy impact testing, chemical composition and metallurgical assessment. All previous testing was performed in accordance with ASME Section IX and ASTM A370, including all applicable referenced standards. Please note, following galvanic corrosion testing and water testing found in this report will serve as supplemental information to the previously mentioned RPC report. The following letter summarizes our findings.

1.0 Langelier Saturation Index (LSI)

A sample of the supplied water was chemically analyzed. The results of the chemical analysis are summarized in Table 1. The calculated Langelier Index was -4.06, meaning that the water will dissolve $CaCO_3$ and is less likely to settle out leaving no potential to scale.

Table 1 Analysis of Water

Analytes		Units	RL	
Sodium	Na	mg/L	0.05	1.54
Potassium	K	mg/L	0.02	0.19
Calcium	Ca	mg/L	0.05	1.14
Magnesium	Mn	mg/L	0.01	0.33
Iron	Fe	mg/L	0.02	0.06
Manganese	Mg	mg/L	0.001	0.004
Copper	Cu	mg/L	0.001	0.001
Zinc	Zn	mg/L	0.001	0.004
Ammonia (as N)		mg/L	0.05	< 0.05
pH		units	-	6.9
Alkalinity (as $CaCO_3$)		mg/L	2	3
Chloride		mg/L	0.5	3.4
Sulfate		mg/L	1	< 1
Nitrate + Nitrite (as N)		mg/L	0.05	0.06
o-Phosphate (as P)		mg/L	0.01	< 0.01
r-Silica (as SiO_2)		mg/L	0.1	1.1
Carbon - Total Organic		mg/L	0.5	4.4
Turbidity		NTU	0.1	0.8
Conductivity		µS/cm	1	18
Calculated Parameters				
Bicarbonate (as $CaCO_3$)		mg/L	-	3.0
Carbonate (as $CaCO_3$)		mg/L	-	0.002
Hydroxide (as $CaCO_3$)		mg/L	-	0.004
Cation Sum		meq/L	-	0.159
Anion Sum		meq/L	-	0.160
Percent Difference		%	-	-0.31
Theoretical Conductivity		µS/cm	-	18
Hardness (as $CaCO_3$)		mg/L	0.2	4.2
Ion Sum		mg/L	-	10
Saturation pH (5°C)		units	-	11.0
Langelier Index (5°C)		-	-	-4.06

RL= Reporting Limit

rpc

2.0 Galvanic Series

Sections were taken from both the weld metal and parent metal and machined to similar dimensions. Each sample was served as the anode of a galvanic series as per ASTM G82 to compare the corrosion potentials of each provided material. As illustrated in Figure 1, the sample was placed in series, with Ag/AgCl reference electrode. The two poles were immersed in the supplied electrolyte (supplied water), connected in series with a salt bridge and a multimeter to measure corrosion potential.

Figure 1 Galvanic Series Test Setup

The samples were immersed in the electrolyte for a six-hour duration recording potential throughout the extent of testing. Figure 2 illustrates the samples condition at the conclusion to testing. Voltage readings were taken at two-minute intervals throughout the duration of testing, a comparative graph illustrates the potential generated during testing. The potential of both the weld metal and base metal were similar in the corrosive potential generated in the galvanic cell, with the weld metal being slightly more active.

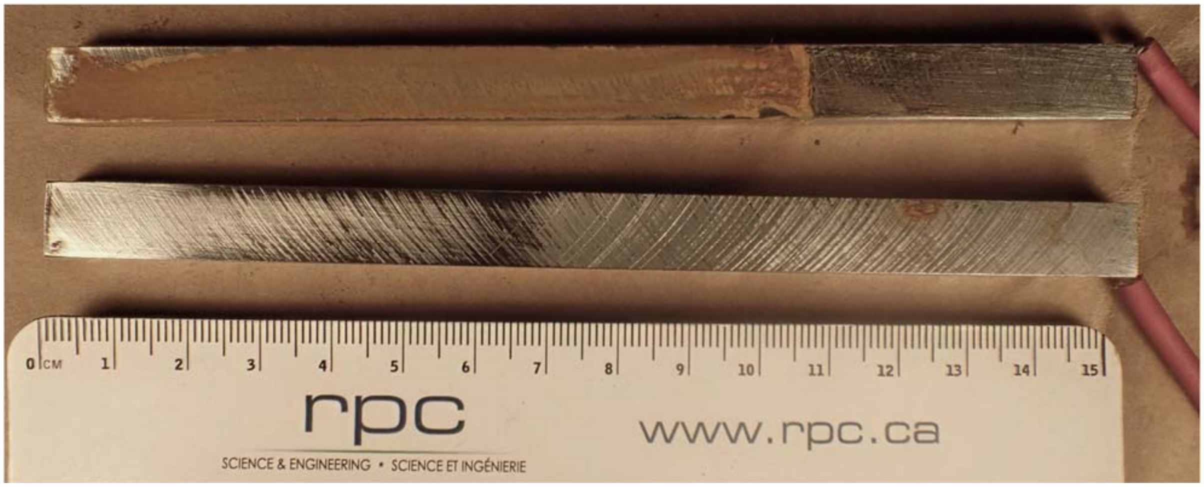


Figure 2 Samples at Conclusion of Testing. Weld Metal can be seen above and Parent Metal Below.

Figure 3 Samples at Conclusion of Testing. Greater Potential (larger negative value) Implies Greater Corrosion Potential.

I trust that the contents of this report are satisfactory. Please note that all test samples and components related to this job will be discarded after 60 days, unless further notification is received by RPC. If you have any questions about the report, please contact one of the undersigned.

Best Regards,

John Speelman, P.Eng.
Sr. Metallurgist
Engineering Services
506.460.5674

Ryan Tarr
Metallurgical Technician
Engineering Services
506.452.1358

rt/J10187R2

APPENDIX C
Design Calculations

SNC-LAVALIN	**PROJECT:** Bay D'Espoir Development - Penstock 1
SUBJECT: **STEEL LINER - Penstock 1**	**PAGE:** **DATE:**

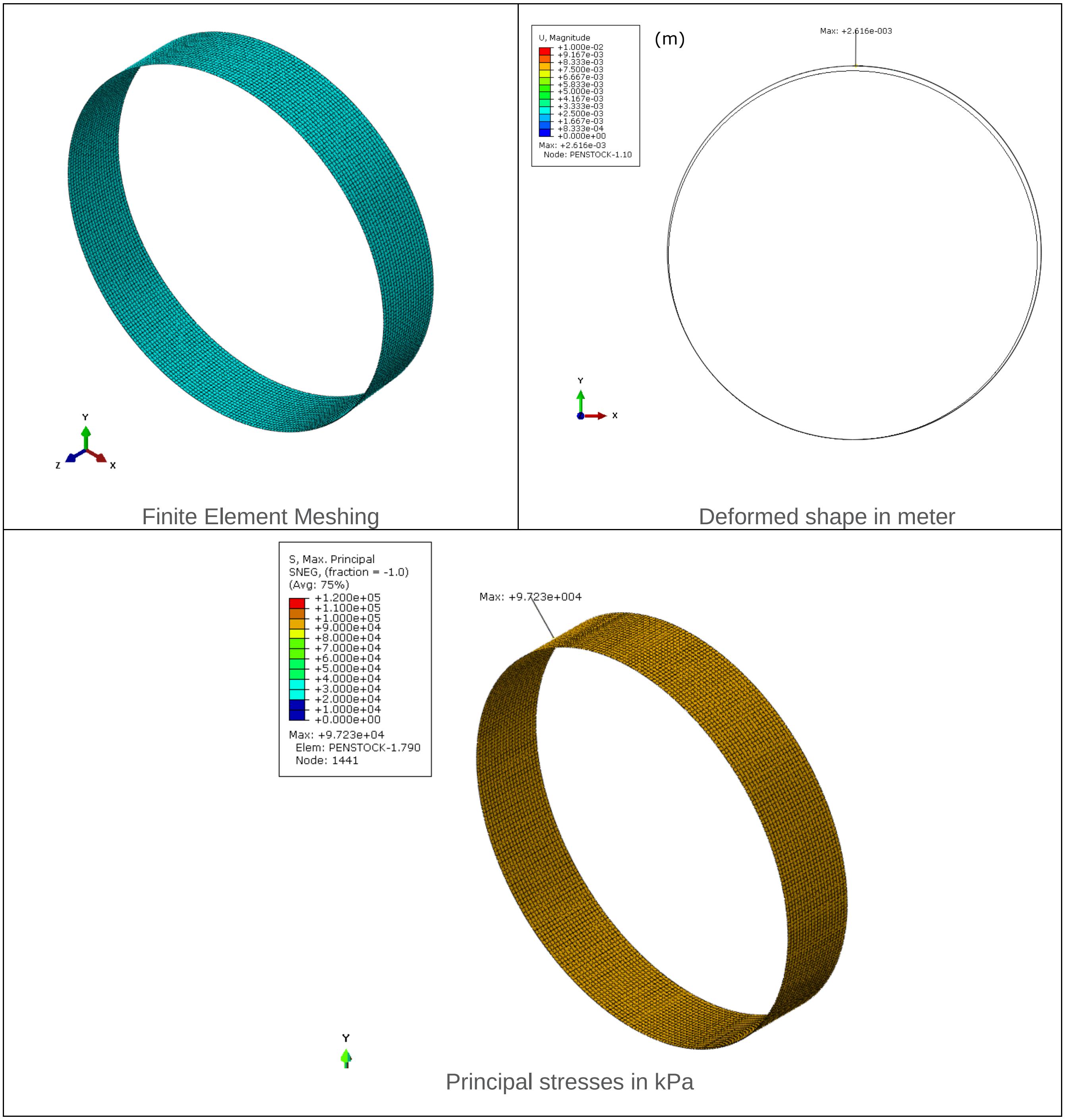
LOADING CONDITION: Loading condition with 10% Pressure Rise at the Powerhouse (orginal design)

Material ASTM A285 Grade C	Fy =	206 MPa	Slim=2/3Fy	137
	Fu=	379 MPa	Slim=Fu/3	126
Material CSA G40.8 Grade B	Fy =	275 MPa	Slim=2/3Fy	183
	Fu=	448 MPa	Slim=Fu/3	149

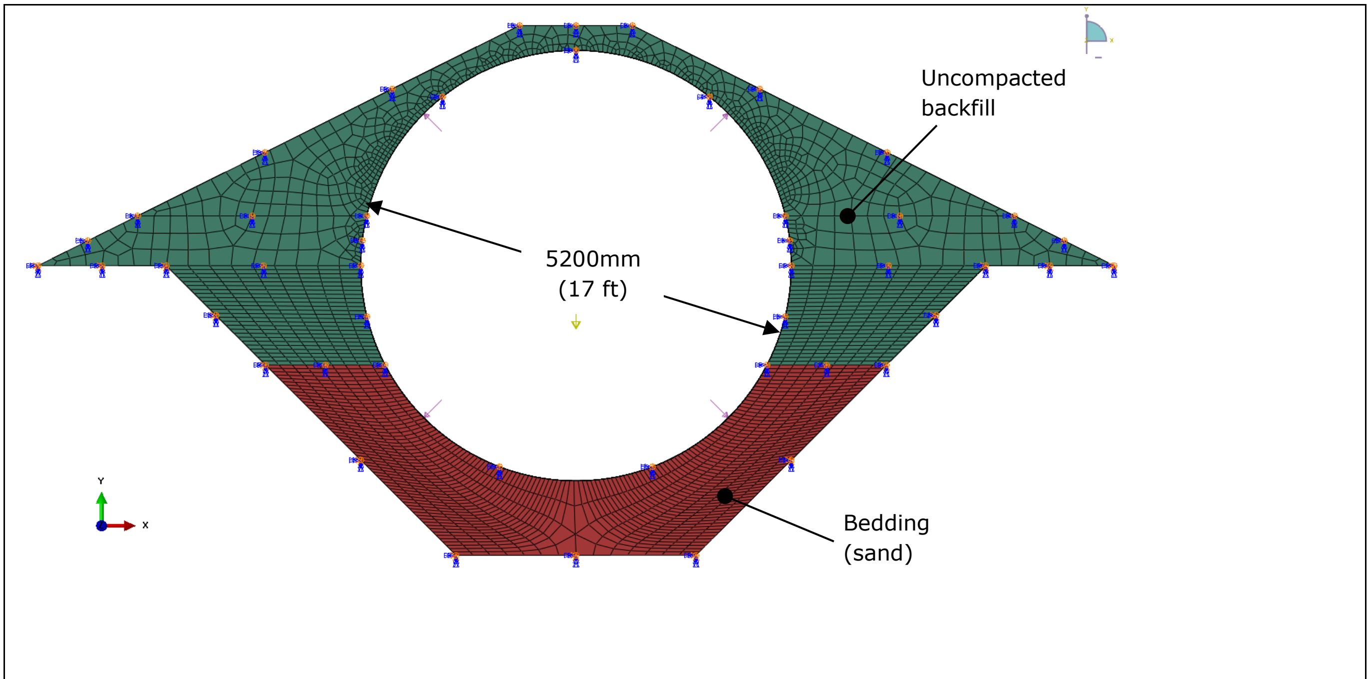
Maximum reservoir level:	181 m	TLS(i) = Length of liner section (m)
Chute brute:	180 m	Ls= Span of steel liner section
Level at intake point	181 m	Teta = inclination angle of liner section axis to horizontal (degree)
Level at PWH:	1 m	ti = thickness of liner with corrosion allowance (mm)
Pressure rise at PWH:	10 %	e(i) = effectivness of the capacity of welded joint
		He(i)= elevation of calcul point (m)
Inside radius of steel liner:	2591 mm	
Corrosion allow. for liner:	0.5 mm	

Section at calcul point i=0,1,2,3 ...	Thikness ti (mm)	Inside diameter (mm)	Outside diam. (mm)	Minimum thickness mm	Weld effect. coeff. e(i)	Elev. at calcul point He(i) (m)	Angle / Hor. Section length (m)	Angle / Hor. Teta deg.	Angle / Hor. Li/Lt %	Piez. Level including W.H. (m)	Internal Presure P(i) No W.H. (N/mm2)	Internal Presure P(i) With W.H. (N/mm2)	Pressure rise %	Hoop Stress SH(i) (N/mm2)	Allowable Stress N/mm2
1A	11	5182	5204	14	0.9	167.2	70.40	0.20	0.062	182.1	0.135	0.146	8	40	126
2A	11	5182	5204	14	0.9	155.4	97.50	6.90	0.148	183.7	0.251	0.277	10	76	126
3A	11	5182	5204	14	0.9	154.8	76.20	0.46	0.215	184.9	0.257	0.295	15	81	126
3A/4A	11	5182	5204	14	0.9	148.6	65.00	5.50	0.272	185.9	0.318	0.366	15	100	126
4A	11	5182	5204	14	0.9	141.7	72.00	5.50	0.335	187.0	0.386	0.445	15	122	149
5A	14.2	4648	4676.4	13	0.9	114.5	110.10	14.30	0.432	188.8	0.652	0.729	12	137	149
6A	15.9	4649	4681	13	0.9	105.2	107.00	4.90	0.526	190.5	0.744	0.837	13	140	149
Surge Tank	19	4650	4688	13	0.9	88.9	92.90	10.10	0.608	191.9	0.904	1.011	12	141	149
8A	22.2	4114	4158	12	0.9	77.7	116.00	10.10	0.710	193.8	1.013	1.139	12	120	149
9A	28.5	4114	4171	12	0.9	51.8	115.00	6.70	0.811	195.6	1.267	1.411	11	115	149
10A	36.5	4114	4187	12	0.9	20.1	160.00	11.50	0.952	198.1	1.578	1.746	11	111	149
12A (Units)	39.6	4114	4193	12	0.9	0.9	55.00	19.70	1.000	199.0	1.767	1.943	10	114	149

APPENDIX D
Finite Element Results

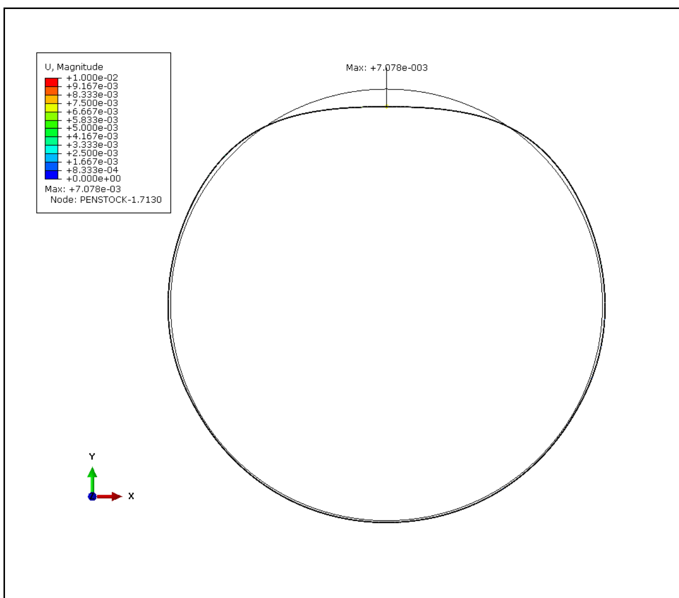


Model 1 - Steel Pipe under internal pressure (no backfill)

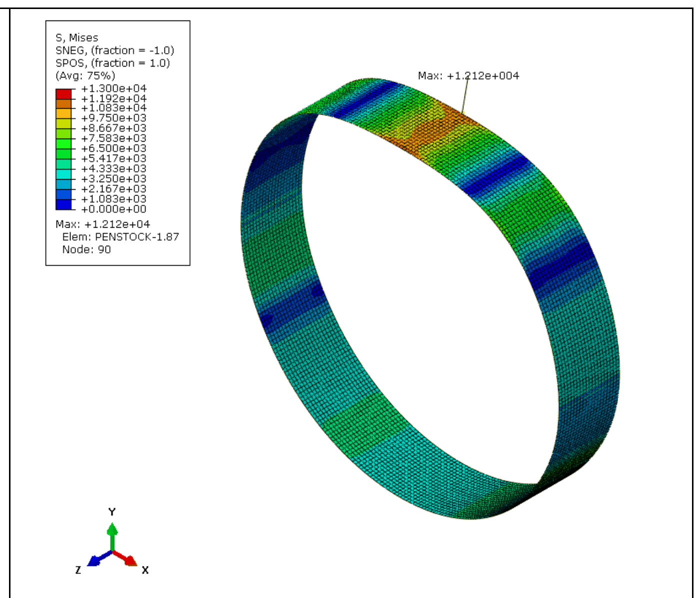


FE MODEL

Model 2 – Buried Penstock in uncompacted backfill (Eb= 7 MPa)



Deformed shape (m)



Principal stresses in kPa

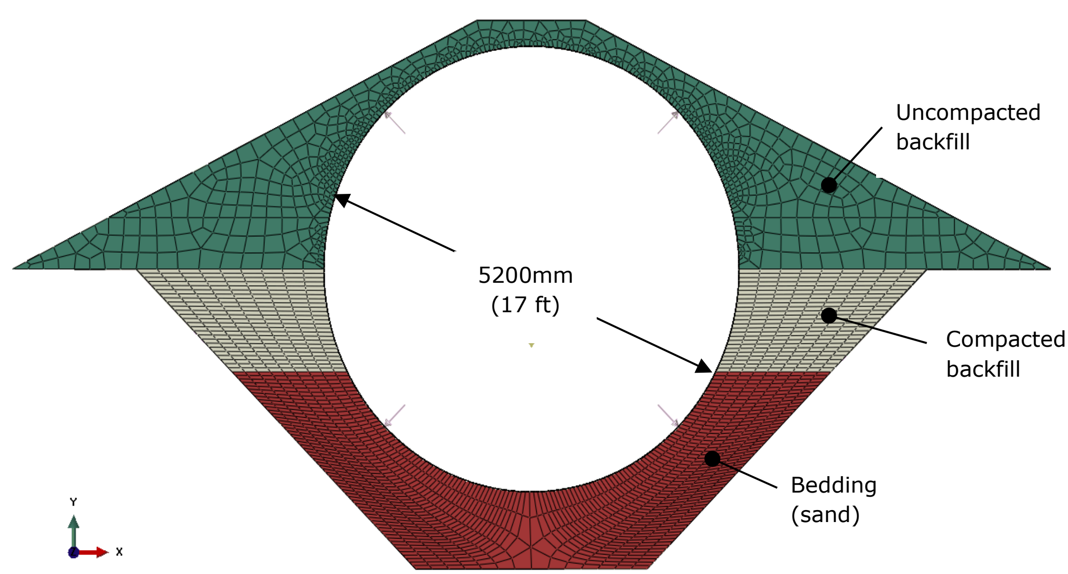
(A) EMPTY PENSTOCK + BACKFILL

(B)

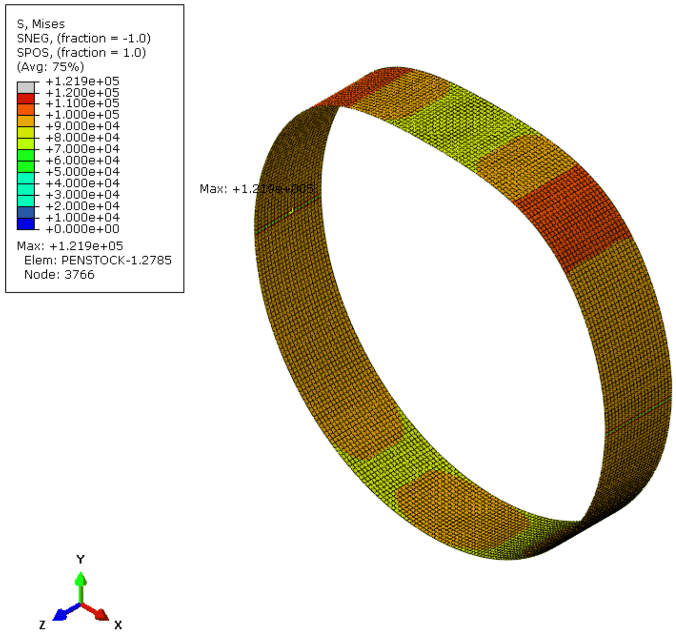
Deformed shape (m) Principal stresses in kPa

(C) BACKFILL + INTERNAL PRESSURE

Model 2 – Results for buried Penstock in uncompacted backfill (Eb= 7 MPa)

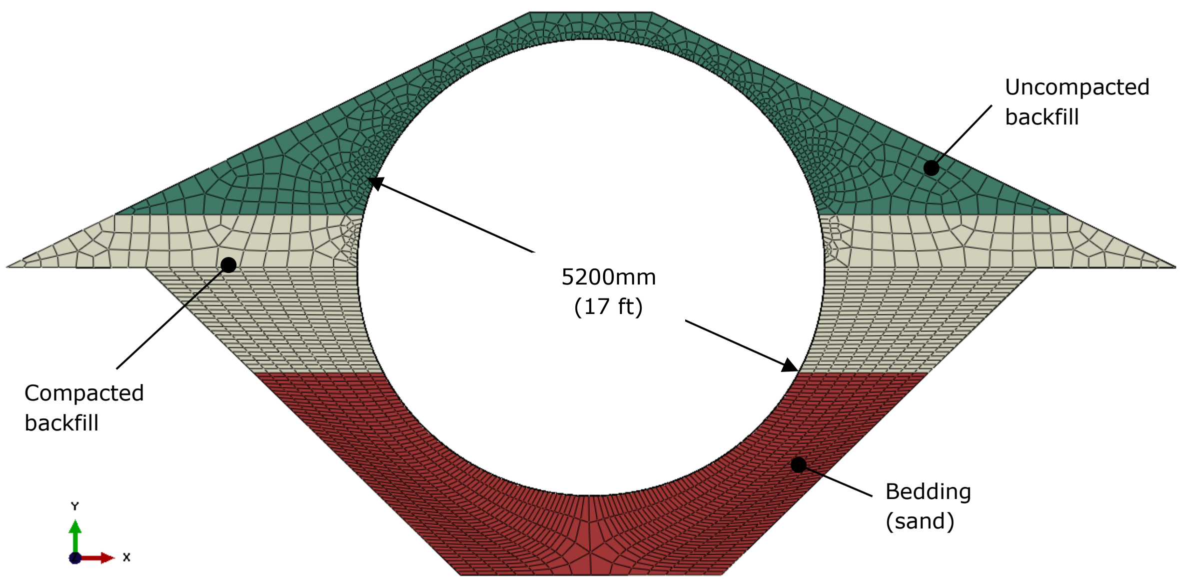


FE MODEL

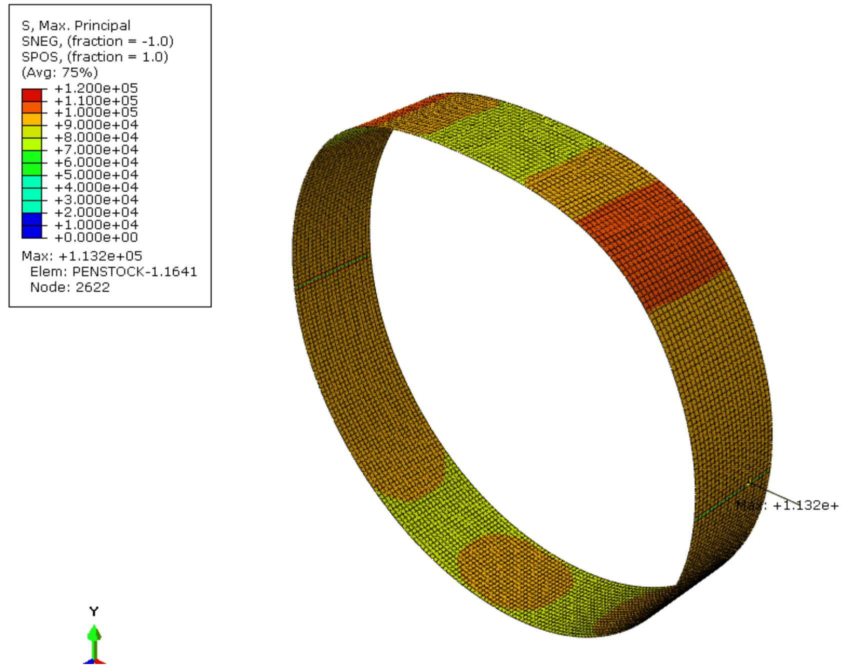


Principal stresses in kPa

Model 3a – Buried Penstock in compacted backfill to 0.5D (Eb= 7 MPa)

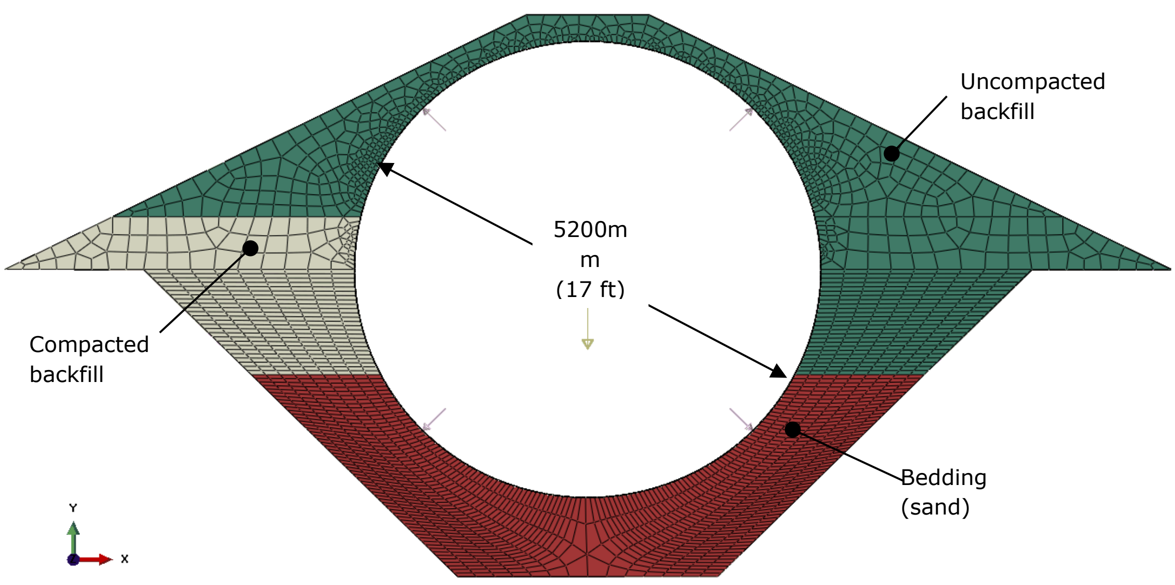


FE MODEL

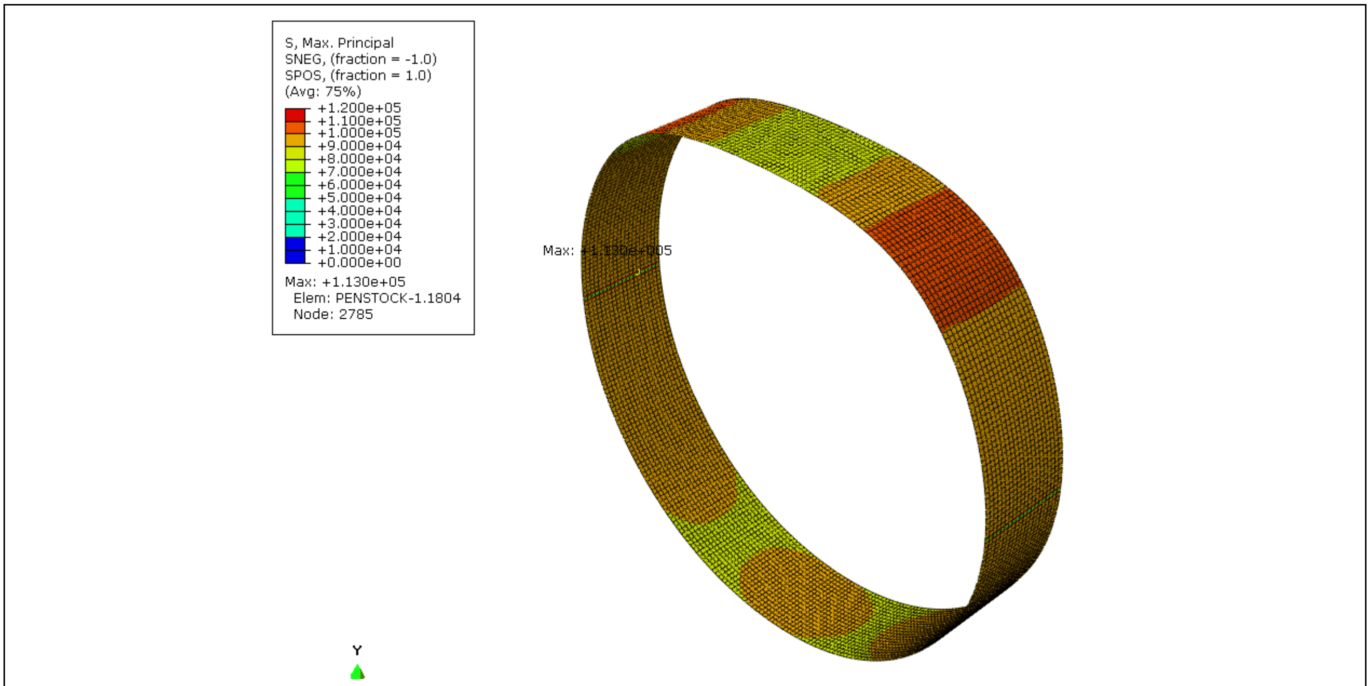


Principal stresses in kPa

Model 3b – Buried Penstock in compacted backfill to 0.7D (Eb= 7 MPa)

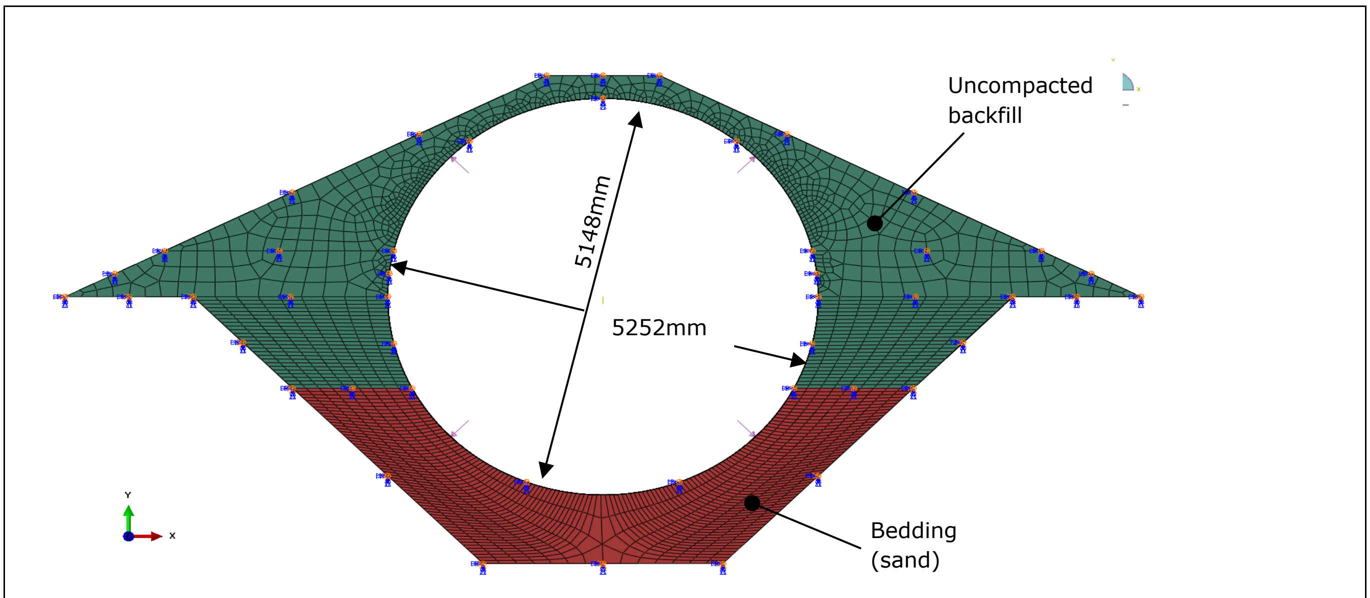


FE MODEL

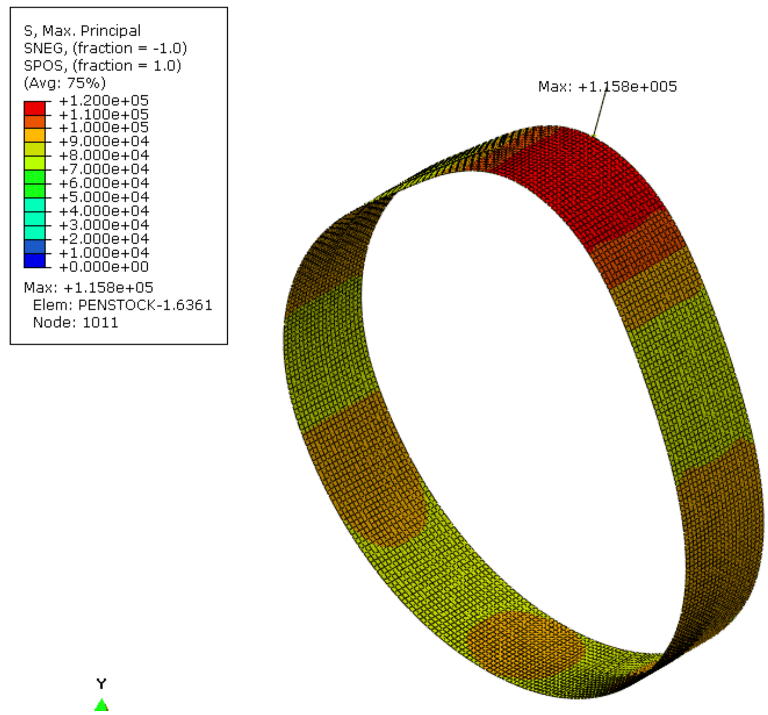


Principal stresses in kPa

Model 3c – Buried Penstock in unsymmetrical backfill properties

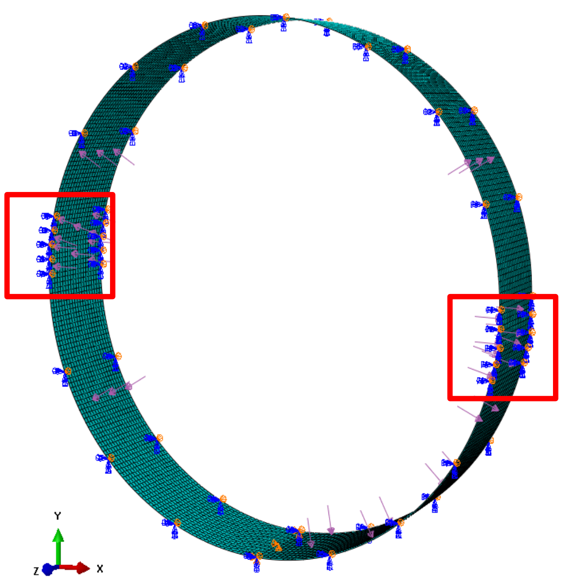


FE MODEL - Elliptical Shape

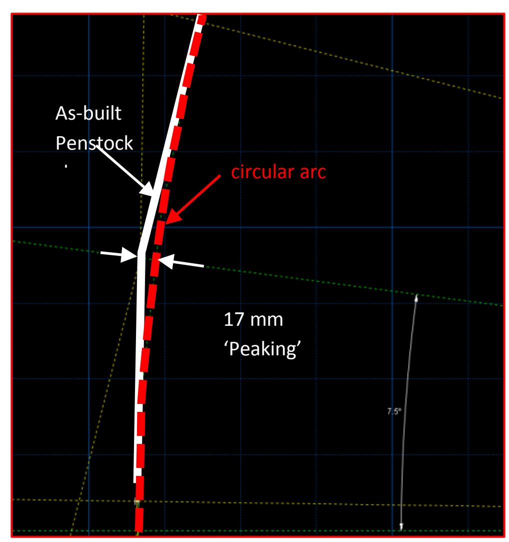


Principal stresses in kPa

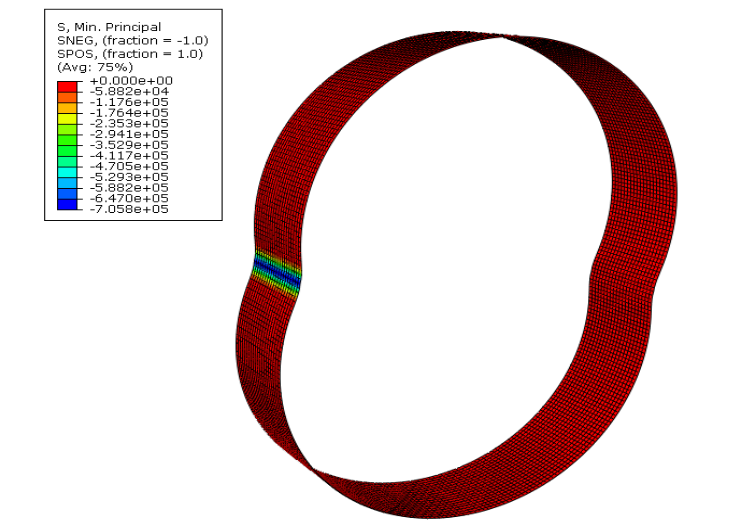
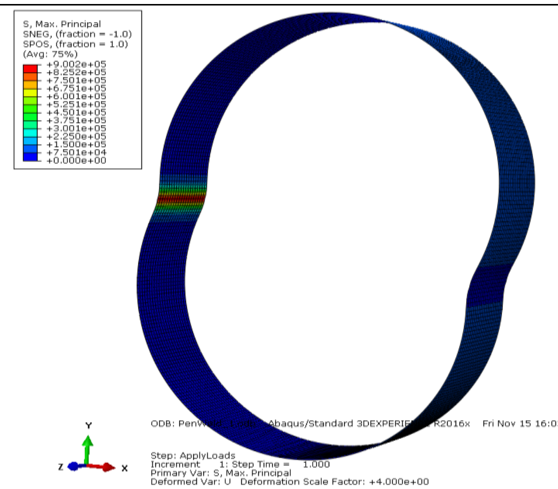
Model 4 – Buried Penstock with 1% out-of-roundness



Geometrical discontinuity at the longitudinal weld



Peak-Out

	
Principal stresses in MPa at outside fiber	Principal stresses in MPa at inside fiber

Model 5 – Steel pipe with geometrical discontinuity under hydrostatic pressure

Attachment 2

Penstock No.'s 1, 2 and 3 Life Extension Options

HATCH

Newfoundland and Labrador Hydro

Final Report

For

Penstock No.'s 1, 2 and 3 Life Extension Options

H357395-00000-240-066-0003
Rev. 1
March 13, 2020

Newfoundland and Labrador Hydro

Final Report

For

Penstock No.'s 1, 2 and 3 Life Extension Options

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Rev. 1
March 13, 2020

HATCH

Newfoundland and Labrador Hydro
Bay d'Espoir Penstock Condition Assessment 1, 2 and 3
H357395

Engineering Report
Mechanical Engineering
Penstock No.'s 1, 2 and 3 Life Extension Options

Penstock No.'s 1, 2 and 3 Life Extension Options

H357395-00000-240-066-0003

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ANTHONY CHISLETT
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Executive Summary

Newfoundland and Labrador Hydro (NL Hydro) engaged Hatch to conduct a condition assessment of Penstock No.'s 1, 2, and 3 at the Bay d'Espoir Hydroelectric Generating Facility during the 2018 operating season. Due to the nature of the 2018 outage schedule and NL Hydro's reporting requirements for items such as winter readiness and capital budget applications, the Condition Assessment report was developed in three phases, as shown below.

Report 1 – Bay d'Espoir Level II Condition Assessment of Penstock No.'s 1, 2 and 3.

Report 2 – Condition Assessment and Refurbishment Options for Penstock No.'s 1, 2 and 3.

Report 3 – Penstock No.'s 1, 2 and 3 Life Extension Options.

All three penstocks were inspected as part of a Level II Condition Assessment. Inspections and data collection included: detailed weld inspection, material testing, 3D scanning and water pressure monitoring.

The weld inspections consisted of, at a minimum, pressure washing, buffing, visually inspecting and magnetic particle inspection of the longitudinal welds at a frequency of 1 in every 10 cans for the total penstock length. The overview of the inspections consists of the following:

- Penstock No. 1 was inspected from August 13 to 24, 2018. Refurbished welds completed in 2016 and 2017 show no sign of additional degradation.
- Penstock No. 2 was inspected from September 17 to 28, 2018. Refurbished welds completed in 2017 show no sign of degradation.
- Penstock No. 3 was inspected from May 14 to June 21, 2018. This was the first detailed inspection carried out and extensive weld metal corrosion and cracking was discovered, similar to what was found during the earlier inspections of Penstocks No. 1 and No. 2 in 2016 and 2017. Approximately 1027 m (3369 ft) of internal weld refurbishment was completed on Penstock No. 3 in 2018.

Material samples were removed from Penstock No. 3 to determine the grade of steel and compare with samples removed from Penstock No. 1.

Laser scans were completed to create a more accurate 3D model of the penstock geometry. The data showed similar peaking in all three penstocks and consequently the FEA model results for Penstock No. 1 can be extrapolated to the similarly constructed Penstock No. 2 and No. 3. This geometric data is also valuable for future use should NL Hydro wish to review the penstocks for geometric changes, such as settlement.

In conjunction with the laser scans, pressure transducers were installed at key locations on all three penstocks and connected to a data logging device to assess any internal pressure transients. This data collection should continue until a life extension option is implemented for Penstock No.'s 1, 2, and 3 as all data gathered will assist in understanding the penstocks and may support future design efforts.

The penstocks have been in service for approximately 50 years. These are aging assets and as such require regular inspection and maintenance. To ensure the reliable long-term operation of these assets, refurbishment is required. This report details the refurbishment options that were chosen by NL Hydro for further analysis by Hatch.

Three life extension options were reviewed in this report for the purpose of further analysis and comparison of life extension options for the penstocks' refurbishment.

The cost estimates for the weld refurbishment option (Option 1) are in the range of $25M to $30M per penstock, cost estimates for partial penstock replacement (Option 2) are in the range of $47M to $52M per penstock, and the cost estimates for weld refurbishment with reinforcing plates (Option 3) are in the range of $34M to $36M.

The estimated costs are heavily influenced by the total length of the circumferential seams. To be conservative Hatch estimated 50 percent of all remaining seams require refurbishment. For example, the 17-foot section has a circumferential length of approximately 53 feet of which about of a third of the inspection, gouging and welding would be in the most difficult, overhead, position. NL Hydro could improve the accuracy of the estimates and possible reliability of the system with more detailed inspection of the circumferential seams.

With adequate maintenance of the coating systems, full replacement and installation of a new penstock can have an estimated design life of approximately 80 years. Hatch estimates the refurbishment options that include replacement of the interior coating will provide an additional life extension of at least 40 years provided there is no breakdown of the internal or external coating system and the structural integrity of the penstock is sound.

Revision 0 of this report suggested that Option 1, full weld refurbishment and application of an internal corrosion resistant coating, was the preferred option for the refurbishment of each penstock. However, in September 2019, a failure of a previously rewelded longitudinal seam in Penstock No. 1 indicates there could be a reliability issue with the refurbished welds in Penstock No. 1. To date there have been no failures in the refurbished welds in Penstock No.'s 2 and 3, consequently Hatch recommends the following;

- For Penstocks No.'s 2 and 3, refurbishment Option 1 may be selected as the preferred refurbishment strategy, as the reliability of this approach may be acceptable to NL Hydro.
- For Penstock No. 1, the recent rupture in previously rewelded longitudinal seam would suggest that Option 1 will not provide an acceptable level of long-term reliability, therefore, Option 2 is recommended.

1. Introduction

NL Hydro engaged Hatch to conduct a Level II Condition Assessment of Penstocks No.’s 1, 2, and 3 at the Bay d’Espoir Hydroelectric Generating Facility during the 2018 operating season. The findings from the condition assessment will ensure the penstocks are in reliable operating condition for the 2019 production season and will assist in verifying penstock life extension refurbishment options.

The contents of this report builds on the initial refurbishment/replacement analysis provided in the previous report; providing more detail into the three selected refurbishment/replacement options NL Hydro selected for further analysis. Due to the time intensive nature of inspection, data collection, analysis and refurbishment option evaluations, this work was completed in three phases each of which has had a report issued upon its completion. This third report completes the third phase of the work and provides further details on three refurbishment options chosen by NL Hydro for further analysis by Hatch. The following are the three report titles.

- Report 1 – Bay d’Espoir Level II Condition Assessment of Penstock No.’s 1, 2 and 3.
- Report 2 – Condition Assessment and Refurbishment Options for Penstock No.’s 1, 2 and 3.
- Report 3 – Penstock No.’s 1, 2 and 3 Life Extension Options.

The Bay d’Espoir Hydroelectric Generating Facility is comprised of four buried penstocks, three of which are connected to the main powerhouse containing six generating units. Each penstock bifurcates near the powerhouse to feed each unit through separate spherical valves. Units No.1 and No. 2 along with Penstock No. 1 were built in 1967. Units No. 3 and No. 4 along with Penstock No. 2 were built shortly after in 1968. The final addition to Powerhouse No.1 was completed in 1969 and consisted of the installation of generation Units No. 5 and No. 6 as well as Penstock No. 3. The penstocks run approximately 1,200 m (3,900 ft) in length and are constructed from a series of carbon steel cans[1] that vary in length, diameter and thickness.

The purpose of this report is to provide a more thorough review of the life extension options recommended for the penstock repair/refurbishment that were provided in Report 2 “Condition Assessment and Refurbishment Options for Penstock No.’s 1, 2 and 3” issued in the first quarter of 2019. The AACE Class 4 cost estimates included in this report are based on recent pricing information received from local construction companies, some of whom were involved with the refurbishment work on Penstock No.’s 1, 2, and 3.

[1] Lengths of penstock that are approximately 2.74 m (9 ft) long and constructed of two hemispheres of rolled plates longitudinally welded together to form a circumference.

To make this report more concise, the following sections that were included in Report 2 – Condition Assessment and Refurbishment Options for Penstock No. 1, 2 and 3, have not been included in this report:

- Condition Assessment Methodology
- Penstock Inspections and Refurbishments
- Finite Element and Fatigue Analysis
- Current Condition and Life Expectancy

2. Refurbishment or Replacement Options

Refurbishment or replacement options were investigated for each penstock. The options that NL Hydro has selected for Hatch's further review are as follows:

1. Refurbishment of deteriorated weld seams, both longitudinally and circumferentially, and re-coating the interior of the penstock (previously labelled Option 1 in Report 2 - H357395-00000-240-066-0002).
2. Replacement of penstock 17' ID section, weld refurbishment and recoating of the full penstock (previously labelled Option 2B in Report 2 - H357395-00000-240-066-0002).
3. Refurbishment of deteriorated weld seams, recoating of the entire penstock and installation of reinforcing plates over the longitudinal and circumferential weld seams of the 17 ft. section (previously labelled Option 4 in Report 2 - H357395-00000-240-066-0002).

The following options present varying degrees of life extension. Referencing published material from the American Society of Civil Engineers (ASCE), the design life of a steel penstock is normally in the range of 40-80 years with proper maintenance (ASCE, Guidelines for Evaluating Aging Penstocks). Since corrosion has been a major contributing factor relating to metal loss and in particular the welds, maintenance of a coating system is extremely important to the longevity.

Refurbishment options include replacement of the internal coating but not the external coating. Inspection of the external coating on Penstock No.'s 1, 2, and 3 from the brief sections that have been excavated during the penstock refurbishments and condition assessment have shown the coating is still intact. Additionally, wall thickness measurements were taken along the length of the penstock and showed no signs of metal loss due to external corrosion.

With adequate maintenance of the coating systems, full replacement and installation of a new penstock can have an estimated design life of approximately 80 years. Hatch estimates the refurbishment options that include replacement of the interior coating will provide an additional life extension of at least 40 years provided there is no breakdown of the internal or external coating system.

The AACE Class 4 cost estimates included in this report are based on recent pricing information received from a local construction companies, some of whom were involved with the refurbishment work on Penstock No.'s 1, 2 and 3. Additionally, information provided by local painting and fabrication companies were used to assist in the development of these cost estimates for the given options (supporting information can be found in Appendix A).

2.1 Refurbishment and Re-coating of Existing Penstocks

The first refurbishment option investigated for life extension of the penstocks includes completion of the weld refurbishment that started in 2016. This will include full inspection of all seams, both longitudinal and circumferential, and refurbishment of all deteriorated seams (Note: all options with weld refurbishment used a 50 percent refurbishment rate of non-refurbished longitudinal seams, as well as a 50 percent refurbishment rate of all circumferential seams).

As identified in previous reports, the circumferential seams have not yet been refurbished for multiple reasons. The stress in the penstock due to internal pressure is twice that in the longitudinal seams versus the circumferential seams. Past refurbishments concentrated on the longitudinal seams due to the higher probability of failure resulting from the increased stress (as all failures were on longitudinal seams). Longitudinal seam refurbishment was the target to ensure timely return of service and safe operation given the planned condition assessment and monitoring of the penstocks. Preliminary inspection indicated the circumferential seams were not in as bad condition as that of the longitudinal seams. Hence, due to the lower risk and lower priority of the circumferential welds, thorough inspection of circumferential seams was not conducted at this time. Therefore, due to outage time available, location of failures, higher stress, and condition of longitudinal seams, only longitudinal seams were refurbished. However, life extension of the penstocks must remediate all areas that could produce a negative effect on the penstocks long term operation.

Refurbishment of all cracked or severely corroded welds is required to ensure that a newly applied coating is not compromised from poor weld seam condition. If cracks are present, it could lead to premature coating failure in those areas. If weld imperfections do not run deeper than 2mm, they can be eliminated by grinding out the defect with no additional welding required. However, if the weld defects are deeper than 2mm it is recommended the defect be removed and the weld be repaired to bring it to original condition.

Each circumferential seam in the 17-foot ID section is approximately 53.4 feet versus that of 18 feet of longitudinal seams for the one can. Since the circumference results in a much longer seam length, the overall resulting cost of refurbishment is suspected to be greater for the circumferential seams. Based on the corrosion and cracking investigated thus far, a value of 50 percent refurbishment was selected to represent a conservative number for the circumferential seams. This number is an estimate as there has been limited inspection of the circumferential welds to date.

Following the completion of weld refurbishment, the penstock internals will have abrasive blasting to bare metal and a new internal coating installed. The following blasting and coating methodology were considered for all three refurbishment options mentioned within this report. The current coating option priced is for three coat paint system by the Wasser Corporation (Table 2-1).

Table 2-1: Proposed Coating System

Coat Number	Product	DFT
First	MC-Zinc 100	3.0 to 5.0 mils DFT
Second	MC-Tar 100	5.0 to 7.0 mils DFT
Third	MC-Tar 100	5.0 to 7.0 mils DFT
Total	**N/A**	**13.0 to 19.0 mils DFT**

The first coat would consist of MC-Zinc primer and be followed by two coats of MC-Tar moisture cure urethane that has similar performance to the coal tar epoxy that was originally installed, having a life span of approximately 15-20 years (recoating should be planned for every 15 years). The benefit of using the moisture cure product is that there will be significantly less environmental control and equipment required in the penstock during application. Other products can be assessed for this service; however, a large emphasis should be placed on the environmental application requirements (i.e., the internal penstock temperature, humidity, dew point, etc.). Hatch considers this important as NL Hydro and other companies such as Newfoundland Transshipment Limited have experienced difficulties in the past with trying to apply other coatings in high humidity environments.

The penstocks should have regular interior inspections following refurbishment work. Hatch recommends performing internal inspection after the first year of operation, with the system applied, to assess if any installation issues caused delamination of the coating and have repairs completed if required. After the initial warranty inspection, the frequency would be reduced to one interior inspection every 6 years. The interior inspection would be largely focused on coating condition and would include visual inspection and adhesion testing.

The total circumferential weld length was determined based on the number of cans (and associated seams) in each section of the penstocks multiplied by the circumference of that section. The penstock was broken up into three sections (17ft., 15.3ft.and 13.5ft.), the approximate number of cans for the 17ft. section was determined and multiplied by the circumference of the 17ft. section, the same process was used for the other two sections. Since no circumferential seams have been previously refurbished, half of the total circumferential length has been assumed for the estimated refurbished length as presented in Tables 2-2, 2-3, and 2-4.

Table 2-2: Circumferential Weld Lengths - Penstock No. 1

Section	Cans	# of Cans	50% Refurbished	Diameter ft	Circumferential Length (ft)
17 ft dia.	1-121	121	60.5	17	3231
15.3 ft dia.	121-230	109	54.5	15.3	2619
13.5 ft dia.	230-400	170	85	13.5	3605
			Total Circumferential Length (ft.)		9455

Table 2-3: Circumferential Weld Lengths – Penstock No. 2

Section	Cans	# of Cans	50% Refurbished	Diameter ft	Circumferential Length (ft)
17 ft dia.	1-128	128	64	17	3418
15.3 ft dia.	128-237	109	54.5	15.3	2620
13.5 ft dia.	237-400	163	81.5	13.5	3457
			Total Circumferential Length (ft.)		9495

Table 2-4: Circumferential Weld Lengths – Penstock No. 3

Section	Cans	# of Cans	50% Refurbished	Diameter ft	Circumferential Length (ft)
17 ft dia.	1-136	136	68	17	3,632
15.3 ft dia.	136-291	155	77.5	15.3	3,725
13.5 ft dia.	291-400	109	54.5	13.5	2,311
			Total Circumferential Length (ft.)		9,668

The total longitudinal weld seam length of the non-refurbished welds was estimated using the weld refurbished trackers, which were prepared during the various refurbishment projects. A summary is provided in Tables 2-5, 2-6, and 2-7.

Table 2-5: Longitudinal Weld Length - Penstock No. 1

Location	Length Previously Refurbished (ft)	Total Length of Penstock (ft)	Length not Refurbished (ft)	Both North/South Side (ft)	50% of Welds Assumed to be Refurbished (ft)
Can 1-173 Can 215 only South side	1,520	3,883	2,363	4,726	2,363

Table 2-6: Longitudinal Weld Length - Penstock No. 2

Location	Length Previously Refurbished (ft)	Total Length of Penstock (ft)	Length not Refurbished (ft)	Both North/South Side (ft)	50% of Welds Assumed to be Refurbished (ft)
Can 1-91 Can 230 and 270 only North side	752	3,896	3,144	6,288	3,144

Table 2-7: Longitudinal Weld Length - Penstock No. 3

Location	Length Previously Refurbished (total) (ft)	Total Length of Penstock (North and south) (ft)	Length not Refurbished (ft)	50% of Welds Assumed to be Refurbished (ft)
Approximation based on CAN 1-132; 132-175; 205-225; 302-342	3,500	7,420	3,920	1,960

Table 2-8 provides a summary of both the circumferential and longitudinal repair lengths for each penstock.

Table 2-8: Total Weld Refurbishment Lengths

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Total Circumferential Repair Length (ft)	9,455	9,495	9,668
Total Longitudinal Repair Length (ft)	2,363	3,144	1,960
Total Repair Length (ft)	11,818	12,639	11,628

Table 2-9 presents the AACE Class 4 cost estimate for Option1. Appendix B provides additional cost breakdown.

Table 2-9: Refurbishment and Re-coating Cost Estimate

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Contractor Mob/Demob	$1,670,000	$1,740,000	$1,600,000
Backfill Removal and Reinstatement	$50,000	$50,000	$50,000
Longitudinal Weld Refurbishment	$2,480,000	$3,260,000	$2,060,000
Circumferential Weld Refurbishment	$9,920,000	$9,850,000	$10,180,000
Doorsheet Removal and Re-installation	$110,000	$110,000	$110,000
Blasting/Coating	$3,700,000	$3,700,000	$3,560,000
Contractor Living out Allowance (LOA)	$700,000	$700,000	$700,000
Rescue / Safety	$480,000	$480,000	$480,000
TOTAL DIRECT COST	**$19,110,000**	**$19,890,000**	**$18,740,000**
EPCM(12% of direct)	$2,290,000	$2,390,000	$2,250,000
Temp site facilities and services (3% of direct)	$570,000	$600,000	$560,000
Owner's costs (5%)	$960,000	$990,000	$940,000
TOTAL INDIRECT COST	**$3,820,000**	**$3,980,000**	**$3,750,000**
Contingency (15% of direct + indirect)	$3,440,000	$3,580,000	$3,370,000
TOTAL COST	**$26,370,000**	**$27,450,000**	**$25,860,000**

2.2 Replacement of 17 ft. Diameter Section and Weld Refurbishment

Based on the recent refurbishment history and the results of the stress analysis, the part of the penstock which has required the most refurbishment is the 17 ft section which is located upstream of the Surge Tank. The cost estimate for this option (Option 2) considers replacing this section with materials designed to current standards, fully refurbishing all existing deteriorated welds and coating the penstock (refer to Section 2.1 for painting/coating methodology and refer to Table 2-15 for cost estimate). The 17-foot section will be coated in the shop with the exception of the field joints which will be coated on site along with the remainder of the unreplaced portion of the penstock.

The cost for replacing the 17 ft diameter section will be impacted by the constructability of a large diameter penstock, and the remote location of the site. The most significant constructability concern is the delivery of cans to the site. Shop manufacturing the cans will be far cheaper and produce a higher quality product. New penstock sections can be fabricated in St. John’s in 10 ft widths and 17 ft in diameter. Once fabricated, inspected, and painted, they can be shipped. Local transportation companies have provided budgetary estimates and indicated that two can sections can be shipped to the site on a low bed transport. Note, 17 ft is the upper limit set by the Department of Transportation for transport without escorts. Escort costs could increase transportation by up to 60 percent. This increase in cost was not considered in the cost estimate developed for this option.

Plate for fabrication of new can sections would need to be purchased requiring a two to three-month lead time due to the large tonnage quantity. Purchasing the plate as a free issue item would save the contractor markup on the material.

Shop fabrication is the most efficient and best way to control quality. The longitudinal seams would be welded using Submerged Arc automatic welding method and inspected using radiographic or ultrasonic inspection. Hatch recommends using ultrasonic inspection as it is more efficient and does not cause a shutdown of production during the inspection period.

Additional constructability considerations include:

1. Available site laydown area for equipment and penstock cans.
2. Access around operating penstocks, especially Penstock No. 2.
3. Access road condition.
4. Earthworks, backfill removal and bedding material supply installation for the new penstock section. Sand for bedding would likely need to be supplied from a significant distance.
5. Drainage under the penstock would need to be addressed.
6. Room and Board availability for the construction crew.
7. Length of available outage for demolition and construction.
8. Some contractors have used automatic or semiautomatic welding equipment for circumferential welds in the field. This possibility could be further investigated with contractors. Automatic welding requires significant hoarding around the welded joints and may not be practical for a thin shelled (approximately 5/8 inch) penstock.
9. There will be significantly higher costs for the NDE in the field plus availability of UT technicians on an as required basis could be a problem. Hatch recommends spot checking the circumferential joints due to the lower stress in these joints. Cost could be as high as four times the cost of shop inspection depending on the number of site visits.

The same methodology for determining weld refurbishment lengths for Option 1 was used, where the weld seam refurbishment lengths associated for the 17 ft. section was not included. The weld repair lengths for Option 2 are presented in Tables 2-10, 2-11, 2-12, 2-13, and 2-14.

Table 2-10: Circumferential Weld Lengths - Penstock No. 1

Section	Cans	# of Cans	50% Refurbished	Diameter	Circumferential Length (ft)
15.3 ft dia.	121-230	109	54.5	15.3	2620
13.5 ft dia.	230-400	170	85	13.5	3605
				Total Circumferential Length (ft)	6225

Table 2-11: Circumferential Weld Lengths - Penstock No. 2

Section	Cans	# of Cans	50% Refurbished	Diameter	Circumferential Length (ft)
15.3 ft dia.	128-237	109	54.5	15.3	2620
13.5 ft dia.	237-400	163	81.5	13.5	3457
				Total Circumferential Length (ft.)	6077

Table 2-12: Circumferential Weld Lengths - Penstock No. 3

Section	Cans	# of Cans	50% Refurbished	Diameter	Circumferential Length (ft)
15.3 ft dia.	136-291	155	77.5	15.3	3725
13.5 ft dia.	291-400	109	54.5	13.5	2311
				Total Circumferential Length (ft.)	6036

Table 2-13: Longitudinal Weld Lengths - Penstocks No. 1, 2 and 3

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Total Longitudinal Repair Length (ft.)	2363	2829	1924

Table 2-14: Total Weld Refurbishment Lengths

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Total Circumferential Repair Length (ft)	6225	6077	6036
Total Longitudinal Repair Length (ft)	2363	2829	1924
Total Repair Length (ft)	8588	8906	7960

Table 2-15 presents the AACE Class 4 cost estimate for Option 2.

Table 2-15: Partial Replacement and Refurbishment Cost Estimate

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Contractor Mob/Demob	$2,790,000	$2,890,000	$2,580,000
Backfill Removal, Reinstatement and Bedding	$830,000	$830,000	$830,000
Longitudinal Weld Refurbishment	$1,760,000	$2,330,000	$1,380,000
Circumferential Weld Refurbishment	$7,060,000	$7,050,000	$6,800,000
Doorsheet Removal and Re-installation	$70,000	$70,000	$70,000
Blasting/Coating	$3,700,000	$3,700,000	$3,560,000
Purchasing of steel -17' ID	$1,420,000	$1,460,000	$1,270,000
Installation Penstock 1 - 17' ID	$3,450,000	$3,550,000	$3,090,000
Shipping	$340,000	$350,000	$370,000
Cranes (rate plus Mob/Demob)	$770,000	$770,000	$770,000
Site Fabrication	$8,820,000	$9,130,000	$7,940,000
Demo of Existing Penstock	$880,000	$880,000	$880,000
Contractor Living out Allowance (LOA)	$1,130,000	$1,130,000	$1,130,000
Rescue / Safety	$720,000	$720,000	$720,000
TOTAL DIRECT COSTS	**$33,740,000**	**$34,860,000**	**$31,390,000**
EPCM(12% of direct)	$4,050,000	$4,180,000	$3,770,000
Temp site facilities and services (3% of direct)	$1,010,000	$1,050,000	$940,000
Owner's costs (5%)	$1,690,000	$1,740,000	$1,570,000
TOTAL INDIRECT COSTS	**$6,750,000**	**$6,970,000**	**$6,280,000**
Contingency (25% of direct + indirect)	$10,120,000	$10,460,000	$9,420,000
TOTAL COST	**$50,610,000**	**$52,290,000**	**$47,090,000**

2.3 Refurbishment with Reinforcing Plates

Building on the requirements of Option 1, reinforcing plates could be installed internally over all longitudinal and circumferential weld seams of the 17 ft. diameter section; noting that all deteriorated welds would need to be refurbished first before reinforcing plates could be welded on. Following the weld refurbishment of the penstock, plates similar to those installed in Penstock No. 1 (November 2017) would be installed in the 17ft. section, to stiffen the existing penstock (at the peaked seams) and provide additional protection to the weld seams. The reinforcing plates will need to be cut, rolled (to the same radius as the penstock), inserted into the penstock, fit to place, and then welded (refer to Appendix C for details). Following the completion of welding the reinforcing plates, Magnetic Particle testing (MT) and Visual testing (VT) is required on the fillet welds, as well as corrosion protection. Abrasive blasting to bare metal and installation of a coating system would still be required to prevent further corrosion of the steel penstock and to protect the welds (refer to section 2.1, for blasting/coating methodology).

The same weld lengths (both circumferential and longitudinal) from Option 1 was used in determining the weld refurbishment portion of the cost for this option. Table 2-16 presents the AACE Class 4 cost estimate for Option 3.

Table 2-16: Refurbishment with Reinforcing Plates Cost Estimate

	Penstock No. 1	Penstock No. 2	Penstock No. 3
Mob/Demob (10%)	$2,230,000	$2,300,000	$2,200,000
Backfill Removal and Reinstatement	$50,000	$50,000	$50,000
Longitudinal Weld Refurbishment	$2,480,000	$3,260,000	$2,060,000
Circumferential Weld Refurbishment	$9,920,000	$9,850,000	$10,180,000
Doorsheet Removal and Re-installation	$100,000	$100,000	$100,000
Site Labour For Repad Installations	$5,450,000	$5,450,000	$5,450,000
Shipping	$20,000	$20,000	$20,000
Blasting/Coating	$3,700,000	$3,700,000	$3,560,000
Contractor Living out Allowance (LOA)	$920,000	$920,000	$920,000
Rescue / Safety	$600,000	$600,000	$600,000
TOTAL DIRECT COST	**$24,870,000**	**$26,250,000**	**$25,140,000**
EPCM(12%)	$2,980,000	$3,150,000	$3,020,000
Temp site facilities and services (3% of direct)	$750,000	$790,000	$750,000
Owner's costs (5%)	$1,240,000	$1,310,000	$1,260,000
TOTAL INDIRECT COST	**$4,970,000**	**$5,250,000**	**$5,030,000**
Contingency (15% of direct + indirect)	$4,480,000	$4,730,000	$4,530,000
TOTAL COST	**$34,320,000**	**$36,230,000**	**$34,700,000**

3. Option Comparison

Due to the complexity of the various options, it was decided to include a brief comparison matrix ranking the options based on four key factors as presented in Table 3-2. The factors used for the comparison were reliability, cost, schedule/phasing and risk.

Reliability- considers the long-term reliable operation of the penstocks unimpeded by outages.

All the options scored high on reliability.

Cost – based on the estimated capital cost of the various options. Costing was provided in the previous sections of this report.

The estimates were based on industry norms and contractor consultations and do not consider inflation and cost adders associated with phasing the project over multiple outages. Potential cost savings would be possible if NL Hydro purchased materials in advance and free issued these items to a contractor.

Schedule/Phasing – all options allow for implementation in a phased manner.

Implementing the life extension program in a phased approach decreases the length of outages and allows for more cash flow flexibility. Option 2 would be the most difficult to phase due to existing irreplaceable infrastructure. It could be phased by section to make it more attractive; however, the outages would be substantial.

Risk – risk during construction were considered.

Risk scores are similar based on the majority of the options being largely interior work. However, the partial replacement option (Option 2) would be subject to weather delays, risk to bedding wash out, and would require lifting and other logistical construction related issues due to working around and over operating penstocks.

Prior to completing the ranking matrix, the life extension options were first analyzed with listed advantages and disadvantages as shown in Table 3-1. This table complements the ranking matrix and lists some of the reasoning for decided scoring for this ranking matrix.

Table 3-1: Option Comparison Table

Option Number	Description	Advantages	Disadvantages
1	Refurbish circumferential and non-refurbished longitudinal welds of penstock followed by water blasting to bare metal and internal re-coating of penstock	1. Reduced risk of failure, in particular areas where the penstock diameter is smaller, plate thickness is greater, and the longitudinal seam peaking is smaller. 2. Lowest cost of the three options. 3. Work is internal and weather delays would be minimal. 4. Reduction in surface roughness via new coating system. 5. Smaller labor force required and can be staged over multiple outages. 6. No large civil works required, minimal risk to existing infrastructure. 7. Minimal lifts over operational penstocks.	1. Multiple outages required. 2. Flexible 17' diameter section remains. 3. Poor fabrication alignment issues remain. 4. Interior is repaired but exterior coating from original construction remains. Life extension is limited by external coating condition. 5. No inclusion of corrosion allowance on existing wall thickness. Therefore, coating needs to remain intact over the lifespan of the penstock. Essentially the coating system should be budgeted for replacement every 15-20 years. 6. Existing bedding and drainage system cannot be upgraded. Bedding remains in contact with the penstock in areas checked. However, some sections of the bedding were saturated during inspection. 7. Due to a failure of a previously rewelded longitudinal seam in September 2020, there are concerns about the long term reliability of this refurbishment method.
2	Replacement of the 17ft. Section	1. Low risk of failure and highest level of reliability. 2. New sections can be constructed to meet current standards. 3. Reduction of surface roughness. 4. Existing flexible 17' diameter section is removed. 5. Inclusion of corrosion allowance would be included in wall thickness. Reduces risk of corrosion effect on the penstock shell. This would allow initial recoating interval to be greater (approximately 25-30 years). After the first recoating the interval would revert back to 15-20 years. 6. Life extension up to 80 years depending on maintenance schedule. 7. Bedding and drainage could be upgraded during replacements.	1. Highest cost of the three options. 2. Long outage required. 3. High likelihood of weather delays. 4. Lifts over operational penstocks. 5. Heavy civil works required that could cause damage to existing infrastructure. 6. Demo of existing penstock sections would leave bedding system exposed to elements which could lead to compromised bedding and/or washouts. 7. Road transport of steel will require special permits for transport due to size and most likely be shipped in sections. This requires at least 2 longitudinal joints in the field per can. 8. Barge transport could be expensive due to the volume of steel cans. 9. Supply of required steel would have to be ordered one year in advance (long procurement period).
3	Refurbishment with reinforcing plates	1. Lower risk of failure. 2. Construction can be phased. 3. Work is all internal and weather delays would be minimal. 4. Increased reinforcement over welded areas.	1. Multiple outages required. 2. Possible flow disturbances caused by plates protruding into flow contributing to head loss. 3. Reduced flow through penstock do to repetitive pressure disturbances. 4. Refurbishment of existing welds is required prior to installation, thus there is no cost saving by a reduction in refurbishment cost by installing reinforcement plates over the welds. 5. Contractors stated very difficult to undertake due to handling large plates inside a confined space with no crane access. This poses a significant logistical challenge. Deemed by contractors as not a practical option.

Table 3-2: Refurbishment Option Matrix

Option Number	Option Description	Ranking Factors (out of 5)				
		Reliability	Cost	Schedule / Phasing	Risk	Total Score
1	Refurbishment and Re-coating	2	5	5	3	75%
2	Partial Replacement and Refurbishment	5	3	3	3	70%
3	Refurbishment with Reinforcing Plates	3	4	4	3	70%

4. Conclusions

Based on the current condition of the penstocks and the lack of corrosion protection, Hatch cannot guarantee that further leakages or micro cracks (if not already present) will not occur for each of the three penstocks. Hatch believes the probability of a major rupture or failure is relatively low within the next 5 years; however, a pin hole leak or micro crack could eventually lead to a rupture or failure.

Penstock No.'s 1 and 2 have been in service 50 years and the internal coating in these penstocks has failed. There is a possibility that Penstock No. 3 was never internally coated.

The non-refurbished sections of the three penstocks, including circumferential seams, are showing signs of weld metal loss and preferential pitting corrosion of the HAZ. In the future these areas will need to be protected by application of a coating to avoid further deterioration.

Based on the rupture that occurred in a previously rewelded longitudinal seam in the 17 ft diameter section of Penstock No. 1, there are some concerns about the long-term reliability of this method of weld refurbishment. As there have been no failures in the longitudinal seams of the smaller diameter sections of any of the penstocks or the larger 17 ft diameter sections of Penstock No.'s 2 or 3, Hatch believes the refurbishment methodology has been successful in stabilizing most of the penstock sections. Hatch recommends that annual inspection of the penstocks should continue until a life extension program is completed. Hatch also suggests that the refurbishment of backfill around Penstock No. 1, as outlined in Report H356043-00000-240-230-0003, may be deferred until the execution of the selected life extension work is completed.

Hatch noted the following constructability concerns related to the 17 ft section replacement option (Option 2); access around the operating penstocks (especially Penstock No. 2), site access due to road conditions and available laydown area for equipment and penstock cans. Additionally, concerns were noted regarding the local availability of suitable bedding material, drainage under the penstock would require refurbishment and the fact that this option would require a long outage for demolition and construction. These constructability concerns make this option less desirable. It should be noted, that similar work required for the other two options has been completed successfully in the past and any constructability concerns related to either of these options are well understood and are manageable. Other than the amount of time it will take to refurbish and or reinforce the circumferential seams, Hatch does not see any major constructability concerns with Options 1 or 3.

AACE Class 4 cost estimates for three options have been presented as part of this Report 3 and a comparison of these costs is shown in Table 4-1. The least cost option is Option 1 - Refurbishment of weld seams and application of a new protective coating.

Based on the results of the Option Matrix (Table 3-2), the three refurbishment options show very similar outcomes (i.e. the total scores are very close). Looking at the numbers in detail, Option 1 is the lowest cost approach, but has the lowest long-term reliability. Conversely, Option 2 is the highest cost approach, and is expected to provide the highest level of reliability. Option 3 is expected to have slightly higher level of reliability than Option 1 but at a higher cost than Option 1, thus there does not appear to be is sufficient benefit achieved to warrant a recommendation of Option 3.

Consideration should be given to selecting a preferred option for each penstock individually, and not necessarily adopting a common strategy for all three penstocks.

After carefully reviewing the data collected, the yearly inspection of the previously completed refurbishments, the cost estimates for each penstock, and SNC Lavalin's draft report into the 2019 rupture of Penstock No. 1, Hatch recommends the following;

- For Penstock No.'s 2 and 3, refurbishment Option 1 may be selected as the preferred refurbishment strategy as these two penstocks have not shown signs of failure in the rewelded longitudinal seams. Therefore, the reliability of this approach may be acceptable to NL Hydro.
- For Penstock No. 1, the recent rupture in previously rewelded longitudinal seam would suggest that Option 1 will not provide an acceptable level of long-term reliability, therefore, Option 2 is recommended.

Hatch is not aware of NL Hydro's weighting systems and decision-making processes used for major capital projects. It is therefore suggested that NL Hydro complete an internal assessment of cost versus reliability to determine which refurbishment option(s) best suits their long-term objectives prior to preceding with implementation of any of the recommended options.

With refurbishment of the remaining seams (removal of surface cracks, deposition of new weld metal where required) and the application of a new protective coating, the service life of the penstocks could be extended for an additional 20 years. Further life extension could be accomplished depending on maintenance of the new coating, maintenance of existing backfill and maintaining the current reduction in rough zone operation. It is in Hatch's opinion that the reinforcing plate option does not provide any significant additional life extension benefits in relation to the high costs involved in the installation of reinforcing plates.

One of the biggest contributing factors to the overall cost of each option is the extent of the weld refurbishment of the circumferential seams. The current cost estimates have assumed 50 percent will need refurbishment. This assumption is based upon the findings of the Condition Assessment, however, a maximum of 10 percent to 15 percent of the circumferential welds were inspected. Additional inspection of these seams would likely increase the accuracy of the estimate by providing a larger sample size. The previous refurbishment of the three penstocks concentrated on the longitudinal seams as these are subject to twice the internal pressure stress as are the circumferential seams and the ruptures occurred in the longitudinal seams.

Based on inspections of the circumferential seams we know there is pitting corrosion in these seams. To understand the condition of these seams in the various sections of the penstock a more detailed scale removal and magnetic particle inspection could be performed, as noted above. It is possible that further inspection could reduce the requirements for significant weld refurbishment and increase the recommended refurbished period from three to five years to five to ten years. As most of the weld pitting corrosion occurred in the 17 ft section it is Hatch's opinion these portions of all three penstocks should be inspected, refurbished as needed, in particular the circumferential seams, and protected with a suitable coating system. This work should be completed in the next 5 years. Depending on the findings of the potential circumferential seam inspections and regular yearly penstock inspections the weld refurbishment and protective coating application for the remaining penstock sections could be completed in 10 years.

In addition, coating manufactures could potentially provide a system to coat the currently non-refurbished circumferential seams with minimal preparation and provide an expected coating service life of up to fifteen to twenty years.

Table 4-1: Cost Estimate Comparison

	Penstock No. 1	Penstock No. 2	Penstock No. 3	Total
Option 1: Refurbishment and Re-coating	$26,370,000	$27,450,000	$25,860,000	**$79,680,000**
Option 2: Partial Replacement and Refurbishment	$50,610,000	$52,290,000	$47,090,000	**$149,990,000**
Option 3: Refurbishment with Reinforcing Plates	$34,320,000	$36,230,000	$34,700,000	**$105,250,000**

Appendix A
Construction, Fabrication and Painting Supporting Documents

List of Supporting Documents

#	Supporting Document
1	[redacted] Pricing for Weld Refurbishment and 17ft. Section Replacement Option
2	[redacted] Pricing for Weld Refurbishment and 17ft. Section Replacement Option - Comments
3	[redacted] – Budgetary Quote for Painting/Blasting
4	[redacted] – Painting/Blasting Cost Estimate
5	[redacted] – Penstock Demolition and Removal Estimate
6	Shipment of Penstock Cans – Estimate and Comments
7	Penstock Plate Costs

From: Saunders, Greg
To: O"Grady, Kathleen
Cc: Drake, Dylan
Subject: FW: BDE Penstock #1,2 and 3 - Weld Refurbishment Pricing
Date: Friday, June 14, 2019 2:36:04 PM
Attachments: image003.png
image004.png
image007.png
image008.png

Regards,

Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

From: [redacted]
Sent: Friday, June 14, 2019 2:35 PM
To: Saunders, Greg <greg.saunders@hatch.com>
Subject: Fwd: BDE Penstock #1,2 and 3 - Weld Refurbishment Pricing

Sent from my iPhone

Begin forwarded message:

[redacted]

Subject: RE: BDE Penstock #1,2 and 3 - Weld Refurbishment Pricing

[redacted]

Option 7 with no Civil or Coating.

17' Diameter Replacement			
	Penstock #1	Penstock #2	Penstock #3
Total	23,227,564.42	23,920,523.33	21,148,687.73

Weld Refurbishment			
15.3 ft dia. Section	2619.6	2619.6	3725.1
13.5 ft dia. Section	3605	3456.5	2311.4
Total Circumferential Repair Length (ft)	6224.6	6076.1	6036.5
Total Longitudinal Repair Length (ft)	1800.4	2581.7	1337.1
Total Repair Length (ft)	8025	8657.8	7373.6
Sub Total	$ 13,448,655.95	$ 14,300,114.91	$ 12,472,085.64
Total	$ 33,254,797.40	$ 35,174,999.09	$ 32,038,456.53

[redacted]

[redacted]

Subject: RE: BDE Penstock #1,2 and 3 - Weld Refurbishment Pricing

[redacted]

The information below aligns with cost per liner M which we have submitted previously excluding coating.

Greg

Weld Refurbishment only:

	Penstock #1	Penstock #2	Penstock #3
Circumferential Repair Length (ft)			
17ft dia. Section	3231.1	3418.1	3631.7
15.3 ft dia. Section	2619.6	2619.6	3725.1
13.5 ft dia. Section	3605	3456.5	2311.4
Total Circumferential Repair Length (ft)	9455.7	9494.2	9668.3
Total Longitudinal Repair Length (ft)	2362.9	3144.2	1899.6
Total Repair Length (ft)	11818.6	12638.4	11567.8

Total	$ 19,806,141.45	$ 20,874,884.18	$ 19,566,370.88

Greg

From: Saunders, Greg
To: O"Grady, Kathleen; Kenneally, Zachary
Cc: DylanDrake@nlh.nl.ca
Subject: FW: NL Hydro BDE Penstock Replacement Option 17 ft Section
Date: Friday, June 28, 2019 1:33:10 PM
Attachments: image001.png
image003.png

Hi Guys

See the comments from [redacted] next to the questions.

Regards,
Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

From: Saunders, Greg
Sent: Thursday, June 27, 2019 5:04 PM
To: [redacted]
Cc: [redacted]
Subject: RE: NL Hydro BDE Penstock Replacement Option 17 ft Section

Thanks

Regards,
Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

From: [redacted]
Sent: Thursday, June 27, 2019 5:01 PM
To: Saunders, Greg <greg.saunders@hatch.com>
Cc: [redacted]
Subject: RE: NL Hydro BDE Penstock Replacement Option 17 ft Section

Greg,

I will get back to you first thing tomorrow morning.

[redacted]

From: Saunders, Greg [mailto:greg.saunders@hatch.com]
Sent: Thursday, June 27, 2019 9:31 AM
To: [redacted]
Cc: [redacted]
Subject: RE: NL Hydro BDE Penstock Replacement Option 17 ft Section

Hi Greg

Hydro reviewed our cost estimates and had some questions for us.

I would like to ask you a couple of questions to make sure we understand what you included or didn't include in your estimate. Also roughly how much contingency you used as we have also included some contingency in our final numbers.

For example:

1. Transportation to BDE full cans or partial needing longitudinal seams welded on site - [redacted] did not include any cost.
2. Site fabrication - [redacted] included fabrication of two half sections into a can on site and included welding 2 to 3 cans into an assembly to drop into the trench.
3. Demolition and disposal of existing penstock - [redacted] did not include demolition costs
4. Civil works, backfill removal, bedding reinstatement, backfill – [redacted] did not include any Civil Works costs
5. Craneage on site - [redacted] did include cranage (250ton at $180/hr + operator at $75/hr regular time OD is after 40hrs) , Mob and demob is around $5000 each so my estimate was good.
6. Housing of workforce in the area – rough idea of the number of workers and duration – [redacted] said the local area will probably max out at 40 people, LOA in the area costs around $180 to $200 per day.
7. Any indirect costs as a percentage of the total – [redacted] included an indirect cost which is around 25%
8. Any constructability concerns you see, in particular access to the middle penstock No. 2. - [redacted] stated there will be issues around Penstock No. 2 but didn't see anything insurmountable

Other notes.

[redacted] assumed a 5 to 6 month schedule for the work. They would work all day shift 10hrs per day 7 days a week and have a rotating crew. The total labour rate for the 70 hrs per week would be $100 per hour.
They included a 10% contingency on the top of their estimate.

Regards,

Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL

[redacted]

QUOTE

Quote No: 1576

Date: Jun 28, 2019

Sold To:
Hatch
NL

Business No.: [redacted]

Description	Amount
Re: Penstocks in Bay D'Espoir Our budgetary quote for sandblasting and applying specified coating as per your request is $15-$18 / sq ft.	
HST NOT INCLUDED IN QUOTE. QUOTE VALID FOR 30 DAYS **Total**	

From: Saunders, Greg
To: O"Grady, Kathleen; Kenneally, Zachary
Subject: FW: Bay D"Espoir - Penstock Painting
Date: Friday, June 28, 2019 10:55:08 AM
Attachments: image004.png

Hi

See cost per square foot below.

Regards,

Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

From: [redacted]
Sent: Friday, June 28, 2019 10:03 AM
To: Saunders, Greg <greg.saunders@hatch.com>
Subject: FW: Bay D'Espoir - Penstock

Greg,

See below.

[redacted]

From: [redacted]
Sent: Friday, June 28, 2019 10:00 AM
To: [redacted]
Subject: RE: Bay D'Espoir - Penstock

Hi [redacted]

I would use $18.00 - $22.00 sf. It really depends on the lining they want to use.

Note: Our hose bundle for spraying out the linings is 250' long, we would need access (manways?) 200' from each end of the penstock and then at approx. every 400'.

Regards,

[redacted]

From: [redacted]
Sent: Thursday, June 27, 2019 12:39 PM
To: [redacted]
Subject: RE: Bay D'Espoir - Penstock

Welded.

From: [redacted]
Sent: Thursday, June 27, 2019 12:01 PM
To: [redacted]
Subject: RE: Bay D'Espoir - Penstock

Hi [redacted]
Is it riveted or welded ?

From [redacted]
Sent: Thursday, June 27, 2019 10:45 AM
To: [redacted]
Subject: Bay D'Espoir - Penstock

[redacted]

I was just speaking with an Engineering Company here, Hatch, who is working with Hydro NL on options for repairs on the Bay D'Espoir Penstock. They were asking us some questions on welding and replacing sections of Penstock, etc.

They also asked me if I had any kind of norm and approx. budget method we could give them for their high level analysis of painting the inside of the penstock. If there anything off the cuff you can provide me for this. They say they would wan to apply a Polyurethane product, good for damp atmospheres where it is insite the penstock.

The penstock is almost 3800 ft long and 17 ft in diameter. Area Approx: 200,000 sq ft.

Would you be able to throw a number at this or even an approximate allowance per sq – ft?

Regards,

[redacted]

[redacted]

From: [redacted]
To: O"Grady, Kathleen
Cc: Saunders, Greg; Kenneally, Zachary
Subject: RE: Budgetary Pricing on Penstock Removal
Date: Thursday, June 27, 2019 10:33:18 PM
Attachments: image001.png

Morning all;

I've done up a budget number on the removal of the Penstocks as requested.

I've made a couple assumptions:

1. All fill to remain onsite
2. Concrete support for bottom of tank to remain.
3. Next's years work??

$875,000.00 + Hst

If got any questions give me a call.

[redacted]

[redacted]

From: O'Grady, Kathleen [mailto:kathleen.ogrady@hatch.com]
Sent: June 26, 2019 7:39 PM
To: [redacted]
Cc: Saunders, Greg <greg.saunders@hatch.com>; Kenneally, Zachary <zachary.kenneally@hatch.com>
Subject: Budgetary Pricing on Penstock Removal

Hi Jeff,

Following your discussion with Greg Saunders this morning, we are hoping to get a budgetary cost on the demolition/removal of 17ft. dia sections of penstocks located in Bay d'Espoir. The information is as followed:

	Penstock #1	Penstock #2	Penstock #3
Length	1087 ft.	1120 ft.	1125 ft.

Inside Diameter	17 ft.	17 ft.	17 ft.
Thickness	0.4375inch (11mm)	0.4375inch (11mm)	0.4375inch (11mm)
Approximate Imperial short Tons	521	537	540

The penstocks can be accessed by road. There is approximately 5000 m^3 of backfill that would need to be removed (this is total amount between all three penstocks). Please see attached drawings outlining the sections that require removal.

Thank you for your help!

Regards,
Kathleen

Kathleen O’Grady
Junior Mechancial EIT / Oil and Gas

Tel: +1 709 700 1391
Suite 100, 80 Hebron Way, St. John’s
Newfoundland Canada A1A 0L9

HATCH

From: Saunders, Greg
To: O"Grady, Kathleen; Kenneally, Zachary
Subject: FW: Shipment of Penstock to Bay D"Espoir
Date: Thursday, June 27, 2019 10:33:22 AM
Attachments: image004.png

FYI

Regards,

Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

From: [redacted]
Sent: Thursday, June 27, 2019 10:21 AM
To: Saunders, Greg <greg.saunders@hatch.com>
Subject: FW: Shipment of Penstock to Bay D'Espoir

From: [redacted]
Sent: Thursday, June 27, 2019 10:20 AM
To: [redacted]
Cc: [redacted]
Subject: RE: Shipment of Penstock to Bay D'Espoir

[redacted]

As a budget

$5500 per load – assuming 2 per truck
17 ft wide at the upper limit for DOT escort so price could go up 60+% if they have to get involved… in case you get over 17 ft wide

[redacted]

From: [redacted]
Sent: June 27, 2019 9:51 AM
To: [redacted]
Cc: [redacted]
Subject: RE: Shipment of Penstock to Bay D'Espoir

[redacted]

I'm working with Hatch to pull together some high level budgets on this. They are looking at options to supply to Hydro.

What's high level estimate to ship a load to Bay D'espoir?

Regards,

[redacted]

[redacted]

From: [redacted]
Sent: Thursday, June 27, 2019 9:26 AM
To: [redacted]
Cc: [redacted]
Subject: RE: Shipment of Penstock to Bay D'Espoir

[redacted]
Yes this wouldn't be an issue for highway or public road transport

[redacted]

From: [redacted]
Sent: June 27, 2019 9:20 AM
To: [redacted]

Cc: [redacted]
Subject: Shipment of Penstock to Bay D'Espoir

Hi [redacted]

Do you know if we would be able to ship a piece penstock pipe 17' in diameter x 10' long to Bay D'Espoir? We can sit the piece of penstock on its end so the height would be 10' and it would be 17' wide.

Thanks,

[redacted]

From: Saunders, Greg
To: O"Grady, Kathleen; Kenneally, Zachary
Subject: FW: Penstock Plate
Date: Friday, June 28, 2019 10:57:21 AM

Hi Guys

See cost for the plate. This is $0.82 per pound or $1.81 per kg.

Regards,
Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

From: [redacted]
Sent: Friday, June 28, 2019 10:08 AM
To: Saunders, Greg <greg.saunders@hatch.com>
Subject: RE: Penstock Plate

Hi Greg,
Based on current estimates and current lead time of approximately 2 months, $1,640.00 ton.
In reference to squaring material, our plasma table can handle maximum 40 FT lengths.
Thank you for your inquiry.
[redacted]

From: [redacted]
Sent: Thursday, June 27, 2019 3:10 PM
To: [redacted]
Subject: FW: Penstock Plate

From: Saunders, Greg <greg.saunders@hatch.com>
Sent: Thursday, June 27, 2019 1:44 PM
To: [redacted]
Cc: O'Grady, Kathleen <kathleen.ogrady@hatch.com>; Kenneally, Zachary <zachary.kenneally@hatch.com>
Subject: Penstock Plate

[redacted]

The plate we would be looking for is CSAW300WT or 350WT 27J at -20C

Plate thickness 0.625" and width 10 ft. Each can is 17 feet in diameter so 53.4 feet long. Probably need to be cut in 2 for shipping.

Total weight 850 tons.

Just looking for the mill run delivery time for the plate.

If you can give a rough budget price ($1.00/lb?) for the plate delivered to St. Johns cut and squared that would be great.

Regards,

Greg Saunders P.Eng.
Hatch St. John's, General Manager
Hatch Limited
Suite 100
80 Hebron Way, St. John's, NL
A1A 0L9
Ph: (709) 701-0081
Fax: (709) 754-2717
Cell: (709) 690 1932
e-mail: greg.saunders@hatch.com web : www.hatch.ca

Appendix B
Cost Estimate Breakdown

Option 1 - Weld Refurbishment and Coating

	Penstock No. 1	Penstock No. 2	Penstock No. 3	
Contractor Mob/Demob	$1,670,000	$1,740,000	$1,600,000	1.
Backfill Removal and Reinstatement	$50,000	$50,000	$50,000	2.
Longitudinal Weld Refurbishment	$2,480,000	$3,260,000	$2,060,000	3.
Circumferential Weld Refurbishment	$9,920,000	$9,850,000	$10,180,000	4.
Doorsheet Removal and Re-installation	$110,000	$110,000	$110,000	5.
Blasting/Coating	$3,700,000	$3,700,000	$3,560,000	6.
Contractor LOA	$700,000	$700,000	$700,000	7.
Rescue / Safety	$480,000	$480,000	$480,000	8.
TOTAL DIRECT COST	**$19,110,000**	**$19,890,000**	**$18,740,000**	
EPCM(12% of direct)	$2,290,000	$2,390,000	$2,250,000	
Temp site facilties and services (3% of direct)	$570,000	$600,000	$560,000	
Owner's costs 5%	$960,000	$990,000	$940,000	
TOTAL INDIRECT COST	**$3,820,000**	**$3,980,000**	**$3,750,000**	
Contingency (15% of direct + indirect)	$3,440,000	$3,580,000	$3,370,000	
TOTAL COST	**$26,370,000**	**$27,450,000**	**$25,860,000**	

1. factored 10% of the weld refurb direct cost provieded by [redacted] plus 10% each of all additional items, with the exception of Contractor LOA which was not inlcuded
2. 1000 m^3 per penstock, $50/m^3
3. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
4. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
5. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
6. Assumed $20/sq.ft. ([redacted] estimate of $18/sq.ft. and [redacted] estimate of 18-22sq.ft. For purpose of estimate used a price in between $20/sq.ft.)
7. 40 worker; 90 days: $180 prediem per day + 10 painters; 30 days; $180 prediem per day
8. 120 days; 10hrs shifts; $100/hr; 2 workers; night and day shift

Option 2 - 17ft. Section Replacement

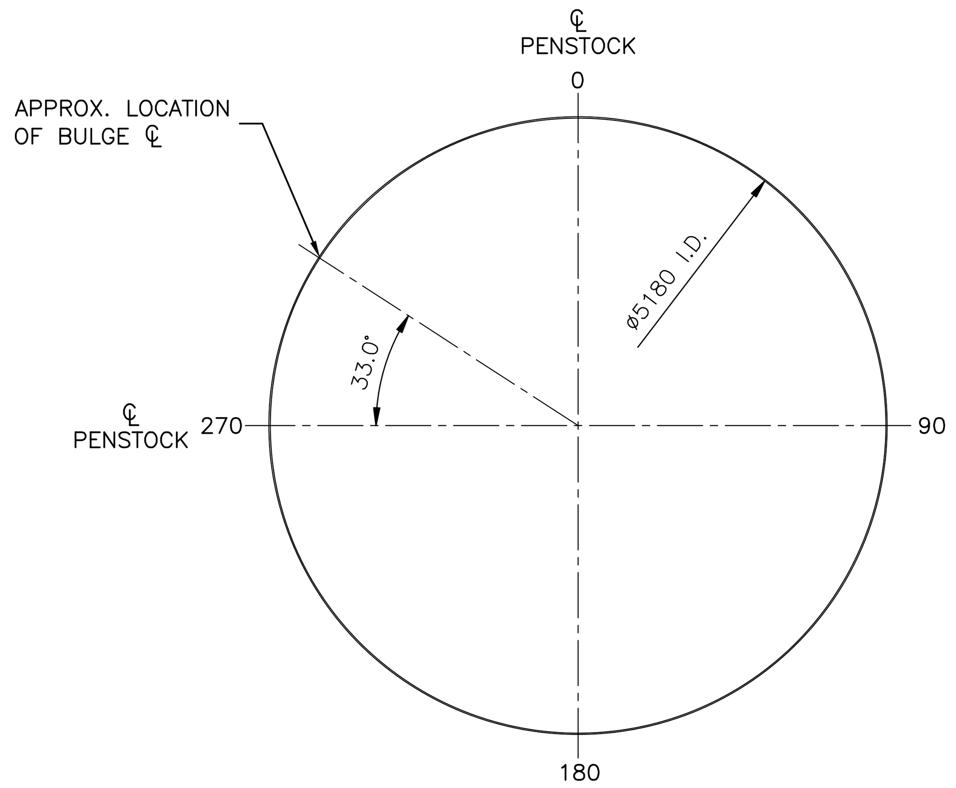
	Penstock No. 1	Penstock No. 2	Penstock No. 3	
Contractor Mob/Demob	$2,790,000	$2,890,000	$2,580,000	1.
Backfill Removal, Reinstatement and Bedding	$830,000	$830,000	$830,000	2.
Longitudinal Weld Refurbishment	$1,760,000	$2,330,000	$1,380,000	3.
Circumferential Weld Refurbishment	$7,060,000	$7,050,000	$6,800,000	4.
Doorsheet Removal and Re-installation	$70,000	$70,000	$70,000	5.
Blasting/Coating	$3,700,000	$3,700,000	$3,560,000	6.
Purchasing of steel -17' ID	$1,420,000	$1,460,000	$1,270,000	7.
Installation Penstock 1 - 17' ID	$3,450,000	$3,550,000	$3,090,000	8.
Shipping	$340,000	$350,000	$370,000	9.
Cranes (rate plus Mob/Demob)	$770,000	$770,000	$770,000	10.
Site Fabrication	$8,820,000	$9,130,000	$7,940,000	11.
Demo of Existing Penstock	$880,000	$880,000	$880,000	12.
Contractor LOA	$1,130,000	$1,130,000	$1,130,000	13.
Rescue / Safety	$720,000	$720,000	$720,000	14.
TOTAL DIRECT COSTS	**$33,740,000**	**$34,860,000**	**$31,390,000**	
EPCM(12% of direct)	$4,050,000	$4,180,000	$3,770,000	
Temp site facilties and services (3% of direct)	$1,010,000	$1,050,000	$940,000	
Owner's costs 5%	$1,690,000	$1,740,000	$1,570,000	
TOTAL INDIRECT COSTS	**$6,750,000**	**$6,970,000**	**$6,280,000**	
Contingency (25% of direct + indirect)	$10,120,000	$10,460,000	$9,420,000	
TOTAL COST	**$50,610,000**	**$52,290,000**	**$47,090,000**	

1. Factor of the weld refurb was taken as well as the factor of replacement cost. 10% of each additional item was included in the price, with the expception of the crane mob/demob being $10,000 and the Contractor LOA, Shipping and Demo not being included for cost
2. $25,000 was included for 15.3 and 13.5 section backfill (to be confirm as 17ft. Section was estimated high)
3. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
4. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
5. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
6. Assumed $20/sq.ft. ([redacted] estimate of $18/sq.ft. and [redacted] estimate of 18-22sq.ft. For purpose of estimate used a price in between $20/sq.ft.)
7. Based on direct cost of 17ft. replacement cost given by [redacted] and weighted each item based on previous estimate
8. Based on direct cost of 17ft. replacement cost given by [redacted] and weighted each item based on previous estimate
9. shipping per 2 cans
10. Based on $180/hr + operator at $75/hr regular time, 150 days + 10 hours + night and day shift
11. Based on direct cost of 17ft. replacement cost given by [redacted] and weighted each item based on previous estimate
12. Based on [redacted] Pricing
13. 40 worker; 150 days: $180 prediem per day + 10 painters; 30 days; $180 prediem per day
14. 180 days; 10hrs shifts; $100/hr; 2 workers; night and day shift

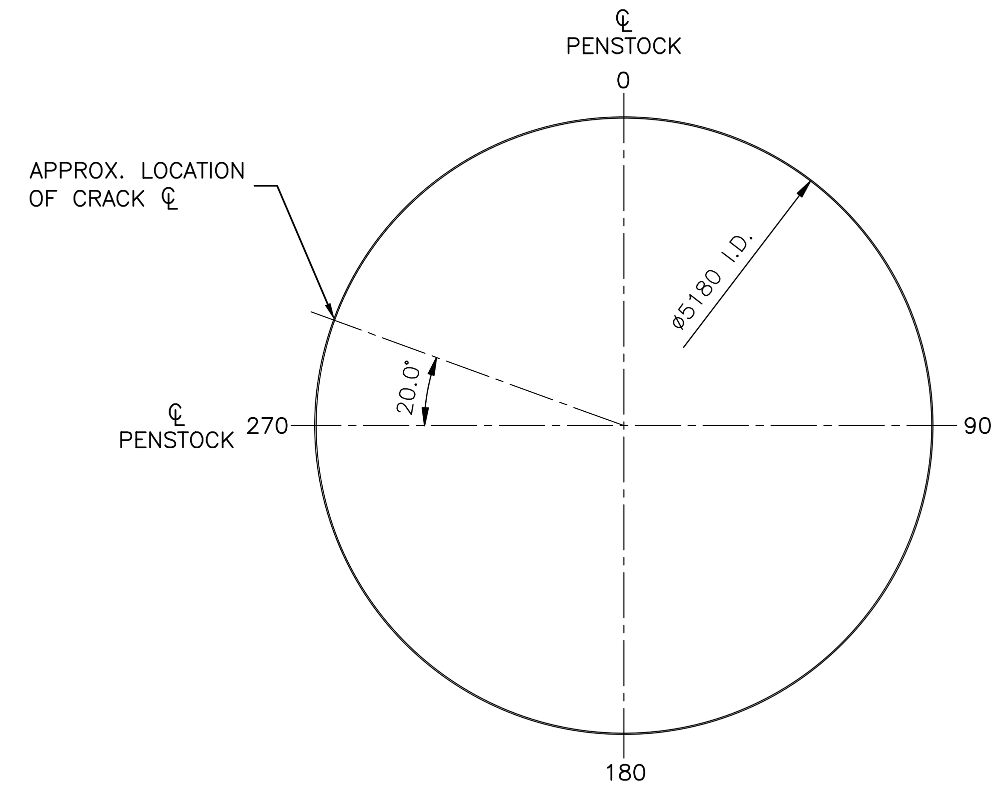
	Penstock No. 1	Penstock No. 2	Penstock No. 3	
Mob/Demob (10%)	$2,230,000	$2,300,000	$2,200,000	1.
Backfill Removal and Reinstatement	$50,000	$50,000	$50,000	2.
Longitudinal Weld Refurbishment	$2,480,000	$3,260,000	$2,060,000	3.
Circumferential Weld Refurbishment	$9,920,000	$9,850,000	$10,180,000	4.
Doorsheet Removal and Re-installation	$100,000	$100,000	$100,000	5.
Site Labour For Repad Installations	$5,450,000	$5,450,000	$5,450,000	6.
Shipping	$20,000	$20,000	$20,000	7'.
Blasting/Coating	$3,700,000	$3,700,000	$3,560,000	8.
Contractor LOA	$920,000	$920,000	$920,000	9.
Rescue / Safety	$600,000	$600,000	$600,000	10.
TOTAL DIRECT COST	**$24,870,000**	**$26,250,000**	**$25,140,000**	
EPCM(12%)	$2,980,000	$3,150,000	$3,020,000	
Temp site facilities and services (3% of direct)	$750,000	$790,000	$750,000	
Owner's costs (5%)	$1,240,000	$1,310,000	$1,260,000	
TOTAL INDIRECT COST	**$4,970,000**	**$5,250,000**	**$5,030,000**	
Contingency (15% of direct + indirect)	$4,480,000	$4,730,000	$4,530,000	
TOTAL COST	**$34,320,000**	**$36,230,000**	**$34,700,000**	

1. factored 10% of the weld refurb direct cost provieded by [redacted] plus 10% each of all additional items, with the exception of shipping and Contractor LOA which was not included
2. 1000 m^3 per penstock, $50/m^3
3. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
4. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
5. Cost was based on [redacted] direct cost for weld refrub. In order to break out cost further, each item included in the overall unit pricing was factored based on how items were weighted in previous estimate
6. 82.5 tonnes of normal welds; 82.5 tonnes of out of position welds; 88hr/tonne; $150/hr. Assumed half the welds were normal welds and half were out of position welds. Out of postiion welds were considered to cost 4 times as much as normal welds.
7. 36 tonnes/trip; 165 tonnes; approximately 5 trips; $3000/trip
8. Assumed $20/sq.ft. ([redacted] estimate of $18/sq.ft. and [redacted] estimate of 18-22sq.ft. For purpose of estimate used a price in between $20/sq.ft.)
9. 40 worker; 120 days: $180 prediem per day + 10 painters; 30 days; $180 prediem per day
10. 150 days; 10hrs shifts; $100/hr; 2 workers; night and day shift

Appendix C
Reinforcing Plate Detail



SECTION - CAN 34 (A)
SCALE: 1:50



SECTION - CAN 35 (B)
SCALE: 1:50

INSERT PLATE INSTALLATION SEQUENCE

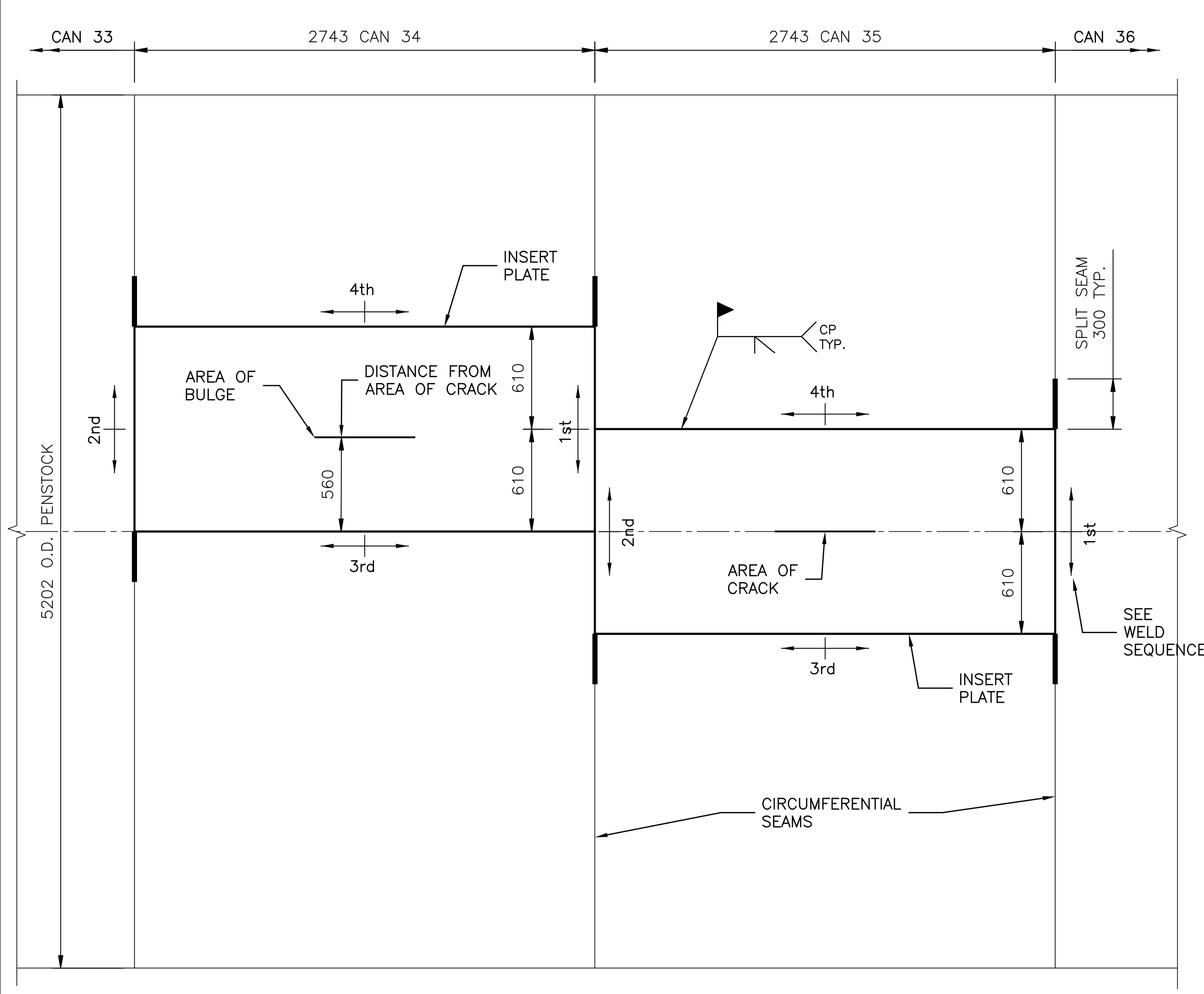
1. INSTALL THE INSERT PLATE FOR CAN 35 FIRST.
2. INSTALL THE INSERT PLATE FOR CAN 34 SECOND.
3. WHERE LONGITUDINAL JOINTS INTERSECT CIRCUMFERENTIAL JOINTS SPLIT THE CIRCUMFERENTIAL SEAM BACK 300mm PRIOR TO FITTING THE INSERT PLATE.
4. REINFORCING PLATES TO BE INSTALLED AS SHOWN ON DRAWING. BUTT WELDS TO BE INSPECTED AND FOUND ACCEPTABLE PRIOR TO THE INSTALLATION OF REINFORCING PLATES.

WELD SEQUENCE FOR DISTORTION CONTROL

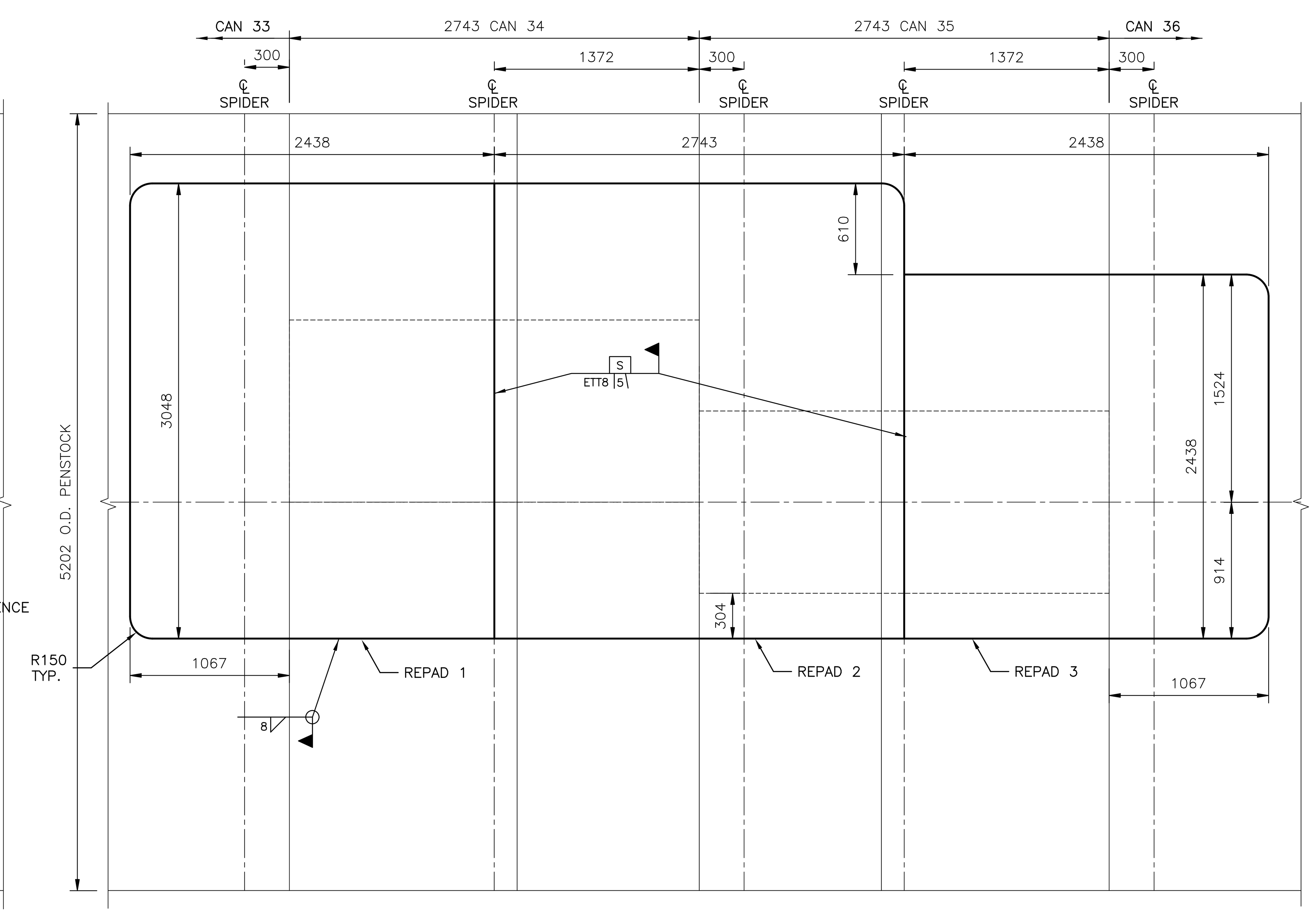
1. TACK WELD INSERT PLATE INTO OPENING AFTER AREA HAS BEEN GROUND AND CLEANED FOR WELDING. TACKS TO BE 50mm MIN. LENGTH AT 150mm c/c.
2. WELDING TO BE PERFORMED ON CIRCUMFERENTIAL SEAMS FIRST STARTING IN THE CENTER AND WORKING TO EDGES EQUALLY BOTH SIDES. SEE ELEVATION C.
3. AFTER TACK WELDING COMPLETE THE FIRST PASS USING THE SAME SEQUENCE AND BACK STEPPING THE WELDING.
4. COMPLETE THE SECOND PASS SAME AS THE FIRST PASS UNTIL THE JOINT IS APPROXIMATELY 50% FILLED.
5. BACK GOUGE TO SOUND METAL ON THE INSIDE AND FILL THE JOINT BY WELDING IN THE SAME SEQUENCE AS ABOVE.
6. COMPLETE THE WELD ON THE EXTERIOR IN THE SAME SEQUENCE AS ABOVE.
7. PERFORM A VT AND MT INSPECTION ON THE INTERIOR AND EXTERIOR SURFACES OF THE WELDS 12 HOURS AFTER WELDING.
8. GRIND THE INTERIOR AND EXTERIOR WELDS FLUSH WITH THE SURFACE.
9. PERFORM A VT AND MT INSPECTION ON THE SURFACE OF THE WELDS AT 48 HOURS AFTER WELDING.
10. COMPLETE RT AND UT INSPECTION OF THE WELDS.
11. THE COMMON CIRCUMFERENTIAL SEAM BETWEEN CAN 34 & CAN 35 SHALL ONLY BE WELDED 50%. THIS PORTION OF THE COMMON SEAM WILL BE COMPLETED WHEN THE INSERT FOR CAN 34 IS INSTALLED.

GENERAL NOTES:

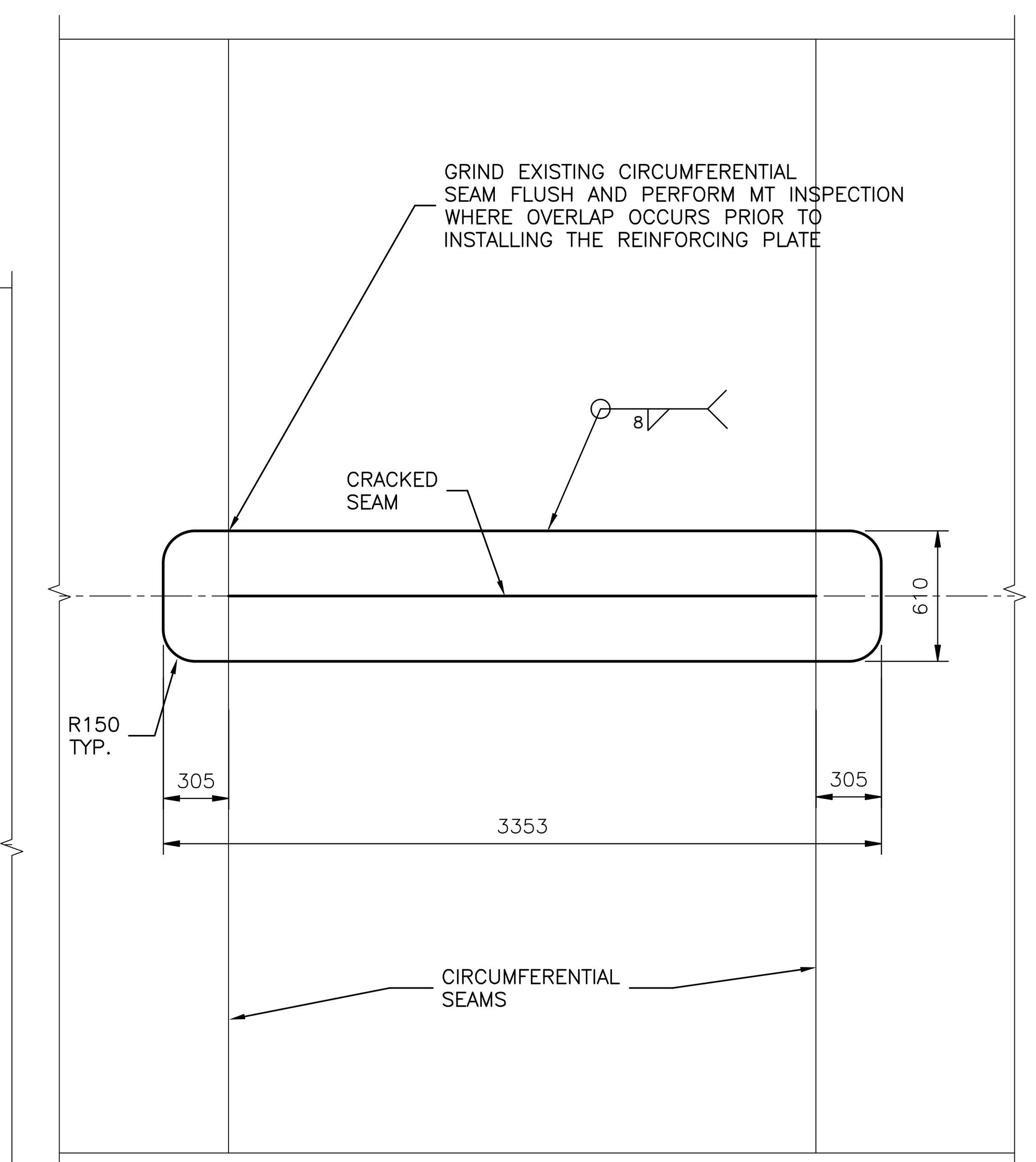
1. ALL DIMENSIONS IN MILLIMETERS.
2. DO NOT SCALE FROM DRAWING.
3. CONTRACTOR MUST VERIFY ALL DIMENSIONS & CONDITIONS ON SITE BEFORE PROCEEDING WITH ANY PORTION OF THIS WORK.
4. ALL STRUCTURAL STEEL IN ACCORDANCE WITH CAN/CSA–G40.20/G40.21. STEEL GRADE SHALL BE PLATE: 350WT U.N.O.
5. ALL STRUCTURAL STEEL WORK TO CAN/CSA S16.1 LATEST EDITION.
6. ALL WELDING IN ACCORDANCE WITH ASME IX BY WELDERS QUALIFIED TO ASME IX
7. ALL CP WELDS SHALL BE INSPECTED AS FOLLOWS:
   –100% VT
   –100% MT
   –100% RT
   –100% UT
   ALL FILLET WELDS TO BE INSPECTED 100% VT, MT
8. ALL FILLET WELDS SHALL BE 8mm ALL AROUND UNLESS NOTED OTHERWISE.
9. EXISTING PENSTOCK WALL THICKNESS: 11mm. ALL INSERT PLATES AND REPAD THICKNESS TO BE 13mm.



ELEVATION - INSERT PLATE (C)
SCALE: 1:25



ELEVATION - EXTERIOR REPAD DETAIL (D)
SCALE: 1:25



ELEVATION - INTERIOR REINFORCING PLATE DETAIL (E)
SCALE: 1:25

NO.	DATE	DESCRIPTION	DWN.	DESIGN.	CHK.	APP'D
1	JAN.19,2018	ISSUED AS RECORD SET	TB	GS	GS	GS
0	NOV.27,2017	ISSUED FOR CONSTRUCTION	RG	GS	GS	GS

REVISIONS

DWG.NO.	TITLE

REFERENCE DRAWINGS

HATCH

HATCH PROJECT NO. H352666
HATCH DRAWING NO. H352666–D–M–0001.1

newfoundland labrador hydro — a nalcor energy company

BAY D'ESPOIR HYDROELECTRIC GENERATING FACILITY

SCALE:	AS SHOWN
DESIGNED:	G. SAUNDERS
DRAWN:	R. GEORGE
DATE:	NOV.10, 2017
CHECKED:	G. SAUNDERS
APPROVED:	G. SAUNDERS

ELECT. / CIVIL / TRANS. / MECH. / P&C / TELC.

PENSTOCK No.1 MODIFICATIONS
ELEVATIONS, SECTIONS AND DETAILS
SHEET 1 OF 1

W.O. NO.
DWG. NO. H352666-D-M-0001-1
REV. 1

C.A.D.

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