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LOWER CHURCHILL PROJECT**TECHNICAL MEMORANDUM: Summary of Engineering Actions after DT2 Incident****1 Purpose**

This document provides a summary of the actions taken by ILF as they pertain to the Draft Tube 2 (DT2) incident of May 29, 2016.

2 Overview

On May 29, 2016 at 11:58pm at the Muskrat Falls Hydroelectric Project near Happy Valley – Goose Bay, Labrador, the wooden formwork and falsework supporting freshly poured concrete in DT2 failed nearing completion of the 530 m³ pour, resulting in collapse. On May 30, 2016, NL OH&S issued Stop Work Orders #0671924-01 and #0671924-02 pertaining to all concrete pours in all four draft tubes and associated works until the formwork and falsework systems were evaluated by a P. Eng. licensed to practice in the province.

ILF was contracted by Astaldi Canada Inc. (Astaldi) to perform an independent review of the incident, technical review of engineered systems, and to support the contractor in developing corrective actions as required by the review findings.

3 Summary Actions

After being contacted by Astaldi, ILF performed in-field inspection of all draft tubes and outlets, design review of CEI formwork and falsework associated with concrete lifts 2 through 5, and design modifications to CEI formwork and falsework for concrete lifts 3 through 5 to meet local code requirements. Field support and pre-pour inspections were performed by ILF up through the completion of lift 5 concrete pours for all CEI formwork and falsework in December 2016. A final engineering assessment report was developed, summarizing findings and identifying the potential cause and contributing factors of failure. A summary of key actions performed by ILF and their associated deliverables is provided below.

1. Tim Wellert, P.Eng mobilized to site for investigation of the collapse (June 2, 2016).
2. Development of an Engineering and Inspection Plan outlining steps to resume powerhouse work for respective draft tube units 1 through 4. This document provided a phased approach to releasing work from the stop work orders, beginning with zones unrelated to CEI formwork and then working to ensure formwork and falsework met local design codes and standards.

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- MFA-AT-SD-331A-EN-A99-0001-01 MUSKRAT FALLS - DRAFT TUBE - CIVIL - GENERAL REPORT - ENGINEERING & INSPECTION PLAN
3. Inspection of Draft Tube 1, 3, and 4 outlets for impacts due to CEI formwork and to release them for continued work. This document indicated the draft tube outlets were unaffected by the failure in DT2 and furthermore utilized an independent system of formwork and falsework made by a separate designer and manufacturer.
 - MFA-AT-SD-331A-EN-A99-0003-01 MUSKRAT FALLS - DRAFT TUBE UNIT 1, 3, 4 OUTLET - CIVIL - PHASE 1 REPORT
 4. Inspection of Draft Tube 2 outlets for impacts due to DT2-ESB-03 failure and to release them for continued work. These documents reviewed the impacts of the failure in DT2, noting the north outlet was unaffected while the south outlet had members that were damaged by the collapse and resulting debris.
 - MFA-AT-SD-331A-EN-A99-0006-01 MUSKRAT FALLS - DRAFT TUBE UNIT 2 OUTLET NORTH - CIVIL - PHASE 3A REPORT
 - MFA-AT-SD-331A-EN-A99-0007-01 MUSKRAT FALLS - DRAFT TUBE UNIT 2 SOUTH OUTLET- CIVIL PHASE 3B REPORT
 5. Engineering Review of CEI formwork systems to release respective work areas impacted by Stop Work Orders. These documents provide a summary of the engineering analysis and propose modifications to ensure CEI formwork and falsework were able to support construction loads in conformance with local codes and standards.
 - a) Draft Tube 1: Analysis of concrete lifts 4 and 5 and remedial actions. Formwork modifications were proposed and verified in place prior to placing additional concrete. Additional falsework (props) were added and formwork ribs strengthened to support the loads imposed by lift 4 and lift 5 concrete. At the time of the reports below, concrete was poured up to lift 3.
 - MFA-AT-SD-331A-EN-A99-0004-01 MUSKRAT FALLS - DRAFT TUBE UNIT 1 ELBOW - CIVIL - PHASE 2A REPORT - LEVEL 4 & 5 FORMWORK DESIGN CHECK AND INSPECTION
 - MFA-AT-SD-331A-EN-A99-0005-01 MUSKRAT FALLS - DRAFT TUBE UNIT 1 ELBOW - CIVIL - PHASE 2A REPORT - STRENGTHENING SYSTEM FOR EXISTING SHORING TOWER
 - b) Draft Tube 2:
 - 1) Inspection of debris from D2-ESB-03 failure to determine causes and documentation of findings. These documents provide comment to observed conditions in the field in addition to photos depicting site conditions after the failure.
 - MFA-AT-SD-331A-EN-A99-0002-01 MUSKRAT FALLS - DRAFT TUBE UNIT 2 OUTLET - CIVIL - GENERAL REPORT - MAN BASKET INSPECTION
 - MFA-AT-SD-331A-EN-A99-0015-01 GROUND LEVEL INSPECTION OF DT2
 - 2) Development of a remediation plan for removing debris and reinstating work in DT2. Significant debris and damaged formwork was required to be removed and/or remediated prior to re-instating work in DT2. Method statements were developed and the extent of damaged formwork was identified to allow for demolition and reconstruction to begin.

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- MFA-AT-SD-331A-EN-A99-0008-01 MUSKRAT FALLS - DRAFT TUBE - UNIT 2 ELBOW - PHASE 4B REPORT - REMOVAL OF DAMAGED FORMWORK AND REBAR
 - MFA-AT-SD-331A-EN-A99-0012-01 MUSKRAT FALLS - DT2 - CIVIL - SITE INSPECTION OF DRAFT TUBE 2 REPLACEMENT PANELS A11, A12, A16, A24, A25, A26, A27, A29 AND A30
- 3) Analysis of formwork and falsework for concrete lifts 2, 3, 4, and 5. Formwork modifications were proposed including strengthening of formwork ribs in 14 formwork modules and a re-design of falsework towers. Modifications were verified in place prior to placing concrete.
- See analysis for DT3
- c) Draft Tube 3: Analysis of formwork and falsework for concrete lifts 2, 3, 4, and 5. ILF proposed modifications to CEI system to meet local codes and verified remediation prior to Astaldi placing additional concrete. Formwork modifications included strengthening of formwork ribs in 14 formwork modules and a re-design of falsework towers. Modifications were verified in place prior to placing concrete.
- MFA-AT-SD-331A-EN-A99-0016-01 DT3 ELBOW - PHASE 2B REPORT - STRUCTURAL VERIFICATION OF CEI FORMWORK - LEVELS 2 AND 3
 - MFA-AT-SD-331A-EN-A99-0011-01 MUSKRAT FALLS - DRAFT TUBE UNIT 3 ELBOW - CIVIL - SITE INSPECTION OF DRAFT TUBE 3 FORMWORK
 - MFA-AT-SD-331A-EN-A99-0019-01 MUSKRAT FALLS - DRAFT TUBE - UNIT 3 ELBOW - LEVEL 3 FORMWORK PANELS A13 TO A15 & A24 TO A30 ENGINEERING REVIEW
 - MFA-AT-SD-331A-EN-A99-0020-01 MUSKRAT FALLS - DRAFT TUBE - UNIT 3 ELBOW - LEVEL 4 & 5 FORMWORK PANELS A37 TO A40
- d) Draft Tube 4: Formwork analysis is same as in DT3 except a unique falsework tower system was developed to utilize the existing CEI towers in place through the addition of additional structural and bracing members (whereas new towers were designed and installed in DT2 and DT3).
- MFA-AT-SD-331A-EN-A99-0018-01 MUSKRAT FALLS - DRAFT TUBE UNIT 4 – CIVIL PHASE 4A – GENERAL REPORT – SITE INSPECTION
 - MFA-AT-SD-331A-EN-A99-0023-01 MUSKRAT FALLS - DRAFT TUBE 4 - SHORING TOWER CALCULATION PACKAGE
 - See analysis for DT3
6. Review of Contractor's policies and procedures as they relate to temporary structures, change management, and pre-pour inspections.
- a) A temporary structures policy was developed for use on the project with input from ILF.
- MFA-AT-SD-0000-CV-K99-0007-01 TEMPORAY STRUCTURES POLICY
 - MFA-AT-SD-0000-CV-K99-0007-02 TEMPORARY STRUCTURE POLICY-MATRIX
- b) Astaldi modified change management procedures.
- MFA-AT-SD-0000-HS-A28-0097-01 MANAGEMENT OF CHANGE STANDARD
 - MFA-AT-SD-0000-HS-A28-0098-01 MANAGEMENT OF CHANGE CHECKLIST
- c) Astaldi modified pre-pour inspection documentation and procedures.
- F-AST-CAN-158-03 DRAFT TUBE FORMWORK CHECKLIST

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- 7. A summary Engineering Report of the DT2 Failure including a summary of field investigations, engineering analysis, fabrication and erection observations, care and preservation of materials observations, change management procedures, and the pre-pour inspection process.
 - MFA-AT-SD-331-EN-A99-0031-01 FINAL ENGINEERING ASSESSMENT REPORT OF DRAFT TUBE 2 FORMWORK/FALSEWORK FAILURE

Prepared by:



Tim Wellert P. Eng

