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Lower Churchill Project

DESIGN CRITERIA - GEOTECHNICAL

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Prepared by:

Alvaro Ceballos
Geotechnical Engineer

FOR: Anthony Rattue
Geotechnical Specialist

Verified by:

Regis Bouchard
Lead Engineer- Geotechnical

Approved by:

Greg Snyder
Engineering Manager

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1 INTRODUCTION

The geotechnical aspects of the Muskrat Falls project apply to the following components:

- Cofferdams for the construction of the main civil works;
- Excavated slopes in soil for the structures;
- The North Spur stabilization works;
- Earth pressures at earth/structure interfaces;
- Construction material sources including concrete aggregates and
- Foundations for switchyard structures and transmission towers.

The criteria presented in this section are complimentary to other sections of the design criteria and shall be read in conjunction with those of other disciplines.

The crest elevations of cofferdams, the limits of slope protection and the selection of materials on surfaces exposed to water flow will be established according to the hydraulic design criteria.

Excavations in rock for the various structures are governed by the criteria presented in the Geological Design Criteria. The geometry of excavated slopes in soil will be defined during the course of the engineering studies and the location of the toe of such slopes may be controlled by the berm width requirements presented for the rock excavations.

The design of the earthworks will follow state-of-the-art methods and will comply with the appropriate standards and guidelines. For example, the guidelines prepared by the Canadian Dam Association (CDA) will be used as a basis for the design and will constitute the primary framework. Other documents may be used to complement the latter. In the context of the Lower Churchill project, the North Spur will be treated as a dam as far as design criteria are concerned.

The 2007 version of the CDA Dam Safety Guidelines presents several principles for the assessment of dam safety. These are equally applicable to the design stage of dam construction.

Principal 5a

The dam system and components under analysis shall be defined.

Principal 5b

Hazards external and internal to the dam shall be defined.

Principal 5c

Failure modes, sequences and combinations shall be identified for the dam.

Principal 5d

The dam shall safely retain the reservoir and any stored solids and it shall pass flows as required for all applicable loading conditions.

2 CREST ELEVATIONS

2.1 COFFERDAMS

The design maximum water levels and freeboard for various stages of construction are given in the Hydraulic Design criteria.

Thus the crest elevations for cofferdam design are as follows:

Riverside cofferdam – downstream section	21.0 m
Riverside cofferdam – upstream section	26.0 m
Main upstream cofferdam	26.0 m
Downstream cofferdam	9.0 m
Powerhouse intake channel cofferdam	26.0 m
Powerhouse tailrace rock plug	21.0 m

Powerhouse tailrace cofferdam	As required

2.2 NORTH SPUR

The North Spur forms a natural dam and is thus part of the reservoir retention works. The minimum crest elevation and the limits for slope protection are to be defined as they would be for an embankment dam, subject to the following water levels:

Full Supply Level (FSL)	39.0 m
Routing of Probable Maximum Flood (PMF) without Gull Island	45.1 m
Routing of Probable Maximum Flood (PMF) with Gull Island	44.3 m
Low Supply Level	38.5 m

However, the upstream slope of the spur will be exposed to water and potential wave attack for flood periods occurring during the diversion phase. Consequently, protection to an appropriate degree is required for the full slope height from normal pre-construction water levels of around 17 m to elevation 25 m, plus the required freeboard for wave action

The top of the permanent slope protection shall be established from the FSL plus wave run-up for the maximum design wind conditions or the PMF plus average wave conditions whichever is the greater.

3 STABILITY ANALYSIS – LOADING CASES AND CORRESPONDING MINIMUM FACTORS OF SAFETY

The stability of the soil slopes whether excavated slopes, cofferdams or the North Spur must be verified using limiting equilibrium or other appropriate methods by application of recognized software such as G-Slope, Slope-W or finite element software. The analyses will be under total or effective stress conditions as appropriate and utilizing circular or non-circular methods as applicable (Bishop’s simplified, Janbu or Morgenstern Price). The required minimum factors of safety are indicated on the following page.

	Loading case	Factor of Safety	
	Water retention structures	**U/S Slope**	**D/S Slope**
1	End of construction	1.3	1.3
2	Partial pool	1.3	N/A
3	Steady state at FSL	1.5	1.5
4	FSL with seismic loading	1.15/1.0*	1.15/1.0*
5	Rapid drawdown	1.3	N/A
6	Drawdown with seismic loading	1.1	N/A
	Non water retaining structures		
7	Temporary excavated slopes during construction	1.1	
8	Permanent excavated slopes	1.5	
9	Permanent slopes with seismic loading	1.15	
	N/A: Not applicable		

**The factor of safety of 1.15 for FSL meets the Seed (1979) criterion to ensure acceptable deformation when subject to a magnitude 6.5 earthquake when analyzed with an acceleration of 0.1 g (g: gravity acceleration), or a magnitude 8.25 when analyzed with an acceleration of 0.15 g. For Muskrat Falls the value of 0.1 g will be used.*

In addition, a verification will be made using the Hynes-Griffin and Franklin (1984) approach wherein a pseudo-static analysis is carried out with soil strength parameters reduced to 80% of peak values, a seismic coefficient of one half of the peak bedrock acceleration and a minimum acceptable factor of safety of 1.0. This is appropriate for sites where soil strength may be reduced during earthquake shaking. The Muskrat Falls site is located in a zone where PGA = 0.09 g on rock (See section 6 on Seismicity).

4 FILTER DESIGN

Filter design has evolved over the years but the criteria as published by Sherard and Dunnigan (1989) are still widely applied and are appropriate.

a. Criteria:

- For particle retention.

Base Soil Description	
Percent Finer than 0.08 mm	**Filter Criteria**
Less than 15%	$D_{15} \leq 4\ to\ 5 \times d_{85}$
15% to 39%	$D_{15} \leq \left(\frac{40 - A}{40 - 15}\right)[(4 \times D_{85}) - 0.7\ mm] + 0.7$
40% to 85%	$D_{15} \leq 0.7\ mm$
More than 85%	$D_{15} \leq 9 \times d_{85}$

Where “A” = percentage passing sieve 0.08 mm

“D” represents the filter material and “d” the material to be protected

- To ensure adequate drainage

  $D_{15}/d_{15} > 5$

  Note: The dimension d_{85} should be derived from the grain size curve of the fraction of material passing the 5 mm sieve.

b. The percentage of particles in the filter passing the 0.08 mm sieve shall be less than 5 %.

c. The largest particle size in the filter shall be less than 80 mm.

In addition:

- The coefficient of uniformity (D_{60}/D_{10}) for the filter material shall not exceed 20 to limit segregation potential;
- The fines content shall be non-plastic.

5 SLOPE PROTECTION

The essential items to cover the design of slope protection for slopes exposed to the reservoir and river water are presented in the Hydraulic Criteria. Wave run-up and reservoir set-up and the procedure for the design of the rip-rap are also covered in the Hydraulic Criteria.

The design of the rip-rap bedding layer is based on filter criteria as presented below:

$$\frac{D_{15}(rip-rap)}{D_{85}(bedding)} \leq 4$$

$$D_{85}(bedding) \geq 50\ \text{mm}$$

$$\frac{D_{15}(bedding)}{D_{85}(filter)} < 5$$

6 SEISMICITY

Earthquake loading is established according to the dam failure consequences. The risk classification places the Muskrat Falls structures in the Very High or Extreme category. The inflow design flood has been taken as the Probable Maximum Flood (PMF) which is in line with the Extreme classification and to be consistent, the Earthquake Design Ground Motion (EDGM) would be those established for an annual exceedance probability (AEP) of 1/10,000.

A site specific Earthquake Hazard Analysis was carried out by Gail Atkinson in 2008. The report of the analysis can be found in the Technical Report GI1170 – Seismicity Analysis, SNC-Lavalin report 7228250-GI1170-40ER-0001-00, July 2008. For the AEP of 1/10,000, the Peak Ground Acceleration on rock is given as 0.09 g. Rock is denoted as being a National Earthquake Hazard Reduction Program (NEHRP) A site.

The ground constituting the North Spur would be classed as an NEHRP D site and the amplification factor given in the above report is 1.23. From the same report, it is noted that for AEP of 1/1000 and 1/2500, the EDGM for the NEHRP A site are 0.02 g and 0.04 g respectively. Consequently:

EDGM for the dam (North Spur) and other critical permanent earth slopes: 0.11 g

EDGM for the cofferdams: not exceeding 0.02 g.

The design of the dam shall be checked to ensure resistance to seismic loading. The pseudo-static analyses mentioned in section 3 are considered to be an initial screening and thus constitute only a part of this verification. The resistance against soil liquefaction should be evaluated particularly for soils considered to be in a loose state. The method pioneered by Seed (Seed et al., 1971) and subsequent developments such as discussed in the National Center for Earthquake Engineering Research (NCEER) workshops (Youd et al, 2001) is used for such an evaluation. This method uses a correlation between the Cyclic Resistance Ratio that may be obtained from field tests such as the Standard Penetration Test (SPT) and the Cyclic Stress Ratio induced by the earthquake shaking. Additional field tests such as the Cone Penetration Test (CPT) and measurement of shear wave velocity have also been correlated.

If a part of the fill or foundation does not meet the minimum criteria for resistance, the evaluation proceeds with a post liquefaction stability analysis and/or an evaluation of potential deformation. This exercise is carried out initially by the simplified method of Makdisi and Seed (1978).

7 EARTH PRESSURE

7.1 ACTIVE PRESSURE

Against vertical or nearly vertical surfaces, Coulomb's theory will be used assuming the surface to be frictionless. Rankine's theory will be used wherever the pressure against a vertical plane within the soil is considered. For active conditions to exist the structure must tilt or yield at least 1/1,000 of its height under this pressure.

7.2 AT-REST PRESSURE

Soil pressure at rest will be applied wherever the structure yields or tilts under the load of a compacted fill less than 1/1,000 of its height. It will be taken as either twice the active pressure or based on the coefficient of earth pressure at-rest K_o= 1 - sin.∅´ (∅´: Effective frictional angle of soil).

7.3 PASSIVE PRESSURE

Passive soil pressure against vertical or nearly vertical structural surfaces shall be calculated using Coulomb's theory assuming surfaces to be frictionless. In order to develop full passive pressure the structure must yield or tilt towards the soil at least 1/1,000 of its height.

8 CONSTRUCTION MATERIAL SOURCES

Construction materials include earth and rockfill obtained in the proximity of the work sites, concrete aggregates also obtained wherever possible from local sites, and various imported materials. The present criteria apply to those materials obtained from pits and quarries in addition to the required excavations.

Earth and rockfill shall comply with the characteristics for the various material classifications that will be developed during the course of the engineering studies. These will be obtained by evaluation of the available natural materials and by the application of the above mentioned filter criteria, rip-rap design criteria, etc. Preference will be given to materials that can be obtained directly or by processing the products of the required excavations. The exploitation of borrow pits and quarries will be governed by the applicable provincial regulations.

A Contract Specific Environmental Protection Plan (C-SEPP) will be prepared to cover all aspects of construction.

The Design Criteria – Erosion and Sedimentation Control (MFA-SN-CD-0000-EV-DC-0001-01) and the Environmental Design Criteria - Site Water Control (MFA-SN-CD-2000-EV-DC-0002-01) will also apply and may cover:

- Quarrying and aggregate removal;
- Buffer zones;

- Erosion control;
- Dust control.

Concrete aggregates shall comply with the gradations established in the civil design process and by application of the CSA Standards.

9 REFERENCES

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