Nalcor Energy - Lower Churchill Project
St. John's, NL

Cold Eye Review of Design and Technical Specifications, North Spur Stabilization Works

Final Report

MFA-HE-CD-2800-GT-RP-0001-01
Rev. B1
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1. Introduction

Nalcor requested Hatch to provide a "Cold Eye" review of the design and technical specifications for the North Spur stabilization works which form an integral part of the Muskrat Falls Hydro project. As such a team of three specialists was mobilized which constituted the Review Team (RT). Team members travelled to the Lower Churchill Project Office in St. John's where the review was undertaken during the week of September 16, 2013.

Documents, Reports and Drawings were provided to the Review Team by the Lower Churchill Project Team (LCPT). In addition one on one meetings were held with the senior geotechnical staff of the LCPT to obtain additional information. An overall group meeting was also held with the LCPT and a short presentation was made to Nalcor Management by the RT to outline the main findings of the review process.

The LCPT informed the RT that the engineering design and the associated drawings and specifications were a work in progress and were not as yet in a completed form. Also, the results of the recent geotechnical investigations conducted in 2013 were not available in their entirety. Appendix data was provided for review. A list of the documents and drawings provided is listed in reference section.

The review concentrated on the overall design approach. Detailed checking of such items as slope stability analysis. Liquefaction potential and filter criteria etc was not undertaken but recommendations were made for further analysis where appropriate.

Section 2 of the Review Report provides an overview description of the North Spur at the Muskrat Falls Hydro Site and its role as an integral part of the Muskrat Falls Reservoir and includes a topographical and geological description, a historical perspective of its behaviour, past remediation measures and an overview of the Geotechnical investigations carried out over the years.

Section 3 discusses the design of the Stabilization measures as presented by the LCPT.

Section 4 discusses the technical specifications and Section 5 outlines the RT's conclusions and recommendations.

2. Description of the North Spur

2.1 General Description and Background

The most prominent geotechnical feature at the Muskrat Falls site is the North Spur, a glacial feature connecting the north bank of the river to the "rock knob" in the centre of the river channel. The spur forms a natural dam and forces river flow to the south of the "rock knob" and across a bedrock controlled set of rapids. This natural dam is part of the basis of the economic viability of the site and major physical efforts and financial resources have been expended by the Province over the last, almost 30 years.

As the North Spur forms an integral part of the reservoir retention works it is necessary to maintain and stabilize the asset against the natural degrading processes of landslides and mass wasting. Landslides on the downstream side of the Spur have demonstrated the fragility of the natural soil deposits in the spur and their susceptibility to groundwater level variations, toe erosion, ice accumulation at the toe and rapid drawdown effects caused by the sudden drop of water that occurs during the spring freshet. In the last several decades action has been taken with the installation of piezometers and pump wells to maintain the integrity of the downstream slopes.

Other issues associated with the North Spur include:

- The spur, between the north bank and the "rock knoll" is composed of stratified sensitive clays interbedded with granular deposits that create complex geological and hydrogeological conditions.
- The spur is fed by groundwater from upstream and from the north bank which, prior to the installation of the presently operating dewatering system, led to high phreatic surfaces on the downstream slope.
- In the past, turbulent eddies from the Falls have eroded and still erode the toe of the spur and the river banks causing slides.


Instabilities along the North Spur

- In the spring of each year, a hanging ice dam is created downstream of the lower falls which causes a raised tailwater level. When the dam collapses, a rapid drawdown condition is created at the toe of the downstream slope.
- The effect of the rapid drawdown plus the high groundwater plus the erosion has produced very large slides.
- A slide in 1978 reduced the width of the top of the neck by half.
  - following this, the dewatering system was installed and no large slides were observed from that time. Small erosion triggered events still occur.


General Overview and the 1978 Slide

The northern extremity of the Muskrat Falls Development features a wide terrace, at about elevation 60 m, that borders the Churchill River. The terrace narrows to a narrow spur about 80 m wide at its southern limit. The southern limit of the spur rests against a higher domed shaped bedrock knoll, comprising Precambrian gneisses, that separates the terrace from the river at this location (Figure 1).

The geological development and the principal soil infilling of the North Spur has occurred since the last ice age in a marine and estuarine environment bordering a glacial highland.

The landscape surface in the immediate area to the north of the spur features a succession of smaller terraces, glacially formed kettle lakes, till deposits and glacio-fluvial alluvium.

The boundaries of the Spur are defined by a rock knoll to the south, three kettle lakes to the north and the Churchill River on the west and east sides. Part of the northwestern limit of the Spur is defined by an inflowing stream that has created an incised and narrow wall along this remote limit of the Spur.

The spur extends in a north-south direction for a distance of about 1000 m. In the kettle lakes area the crest of the Spur is about 1000 m wide in an east-west direction. However, towards the south, close to the rock knoll, the width of the Spur reduces to 80 m over a distance of several hundred meters.

2.2 Landslides

There has been a history of landslide activity along the banks of the Churchill River. The failures recognized at the North Spur are indicated on Figure 1. Three major landslides exists on the downstream side of the Spur, #s 1, 2 and 3, while 4 slides have produced scars on the upstream side. The # 2 (1978) slide is the most recent and together with slides #1 and #3 will be part of the stabilization works on the downstream side.

2.3 Geology

The Spur stratigraphy and soil characteristics are obtained from Ref 1. After or during the various glacial periods that have shaped this site, the Churchill River valley was submerged up to Gull Island. The sea invasion produced a succession of marine clay deposits capped with a fine sand layer which likely represents estuarine sand beaches at Muskrat falls.

2.3.1 Lower Aquifer Layer

Sitting directly on the pre-Cambrian bedrock is a thick layer of sand and gravel referred to as the Lower Aquifer (Figure 2). This layer is generally observed below El. -50 m. This unit is missing or thinner in boreholes near the knoll where overburden is shallow.

2.3.2 Lower Clay Layer

The Lower Clay sits above the Lower Aquifer generally between El. 10 to -50 m. This layer consists of clay of low to medium plasticity with a liquidity index that would classify the clay as slightly sensitive. Traces of silt and sandy silt strata exist within this clay. The consistency of the clay is stiff to very stiff with an undrained shear strength of 70-200 kPa.

The cement-bentonite cutoff walls that are planned to be constructed along the upstream edge of the North Spur will extend through the upper deposits to tie into the Lower Clay layer. These cutoff walls are referred to on the drawings as the Upstream and the Northwest cutoff walls. The top of the Lower Clay layer has been defined reasonably well by cone penetration tests (CPT) during the 2013 investigation campaign.

2.3.3 Stratified Drift

The upstream and downstream slopes of the Spur are situated in stratified drift which is a succession of sediments, approximately from El. 50 to El. 10 that lie above the Lower Clay

Layer. It consists of alternating layers of low to medium plastic silty clay (2 distinct layers of Upper Clay) with occasional sand seams called Intermediate Sand layers.

The Upper Clay strata is low to high sensitive silty clay of low to medium plasticity. The in-situ undrained shear strength obtained by vane shear tests range from 40 to 120 kPa which indicates clay material of firm to very stiff consistency in intact condition.

The Liquidity Index averages 1.5 with a range of 0.7 to 3. Values in excess of 1 are an indication of the potential for both liquefaction and flow type failures.

The upper portion of the intermediate sand is about 5-10 m thick and separated by two clay layers; this sand layer is believed to be recharged from the north side of the Spur and drains to the upstream and downstream slopes. The lower portion is 10-15 m thick and connected to the river at its upstream and downstream sides. The sand in these layers can be silty and N_{SPT} values indicate dense to very dense conditions.

2.3.4 Upper Sand Layer

The Upper Sand layer covers the surface of the Spur generally from elevation 60-50 m. This layer consists mainly of compact to dense sand with a low fines content. The thickness of the layer is about 4 m at the south side of the Spur increasing to 10-15 m for most of the Spur surface. The sand layer reaches a maximum of 26-30 m in the kettle lake area.

A perched water table exists in the Upper Sand layer. The water is recharged by precipitation and infiltration from the top of the Spur.

Figure 1: Aerial photo of the North Spur (source Google earth and Ref 1)

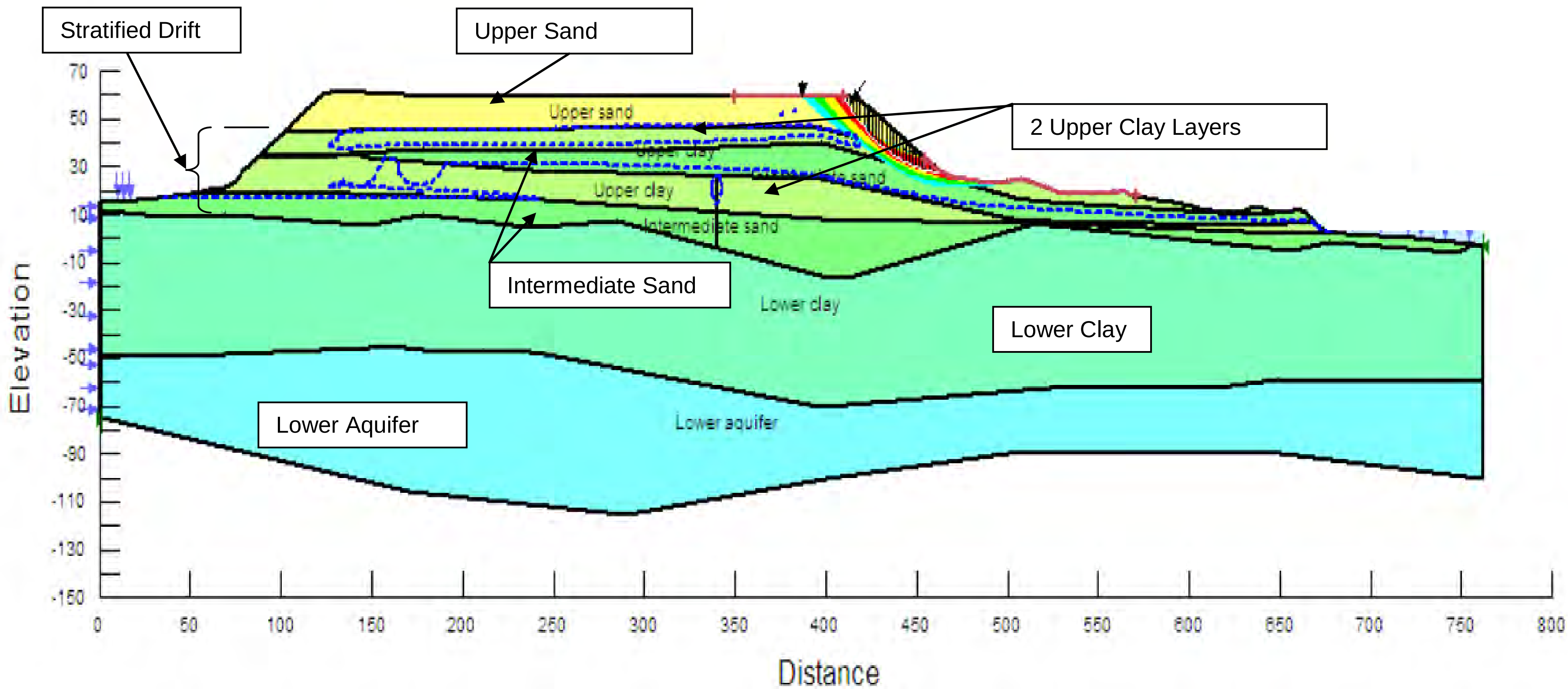

Figure 2: General Stratigraphy, North Spur (source Ref 1)

2.4 Past Remediation Measures

An aquifer exists in the stratified drift. To lower pore pressures in this aquifer, a system of 22 pump wells (three are not functioning) were installed in the upper intermediate sand layer. Most of the piezometers which are currently functioning on the Spur are also installed in this aquifer.

The wells had an impact on the water levels as measured in the piezometers. The water level dropped by 10-20 m in the intermediate sand layer in the southern and central areas of the Spur. However, the dewatering system is less effective in the stratified drift in the northern area.

2.5 Geotechnical Investigations

Several subsurface investigation campaigns, pumping well installation and piezometer installations have been performed on the North spur from 1965 to 2009. The outcome of these investigations form the basis in understanding the soil profile, geology and hydrogeology of the Spur. This knowledge has been broadened by additional subsurface investigations undertaken in May to July, 2013 to supplement the geological and geotechnical data available for the design of the North Spur stabilization.

The 2013 program included the following:

- Four Rotary Boreholes to depths of between 20 m and 70 m, total 152 m, plus two shear vane profiles to 30 m and 20 m respectively.
- Four Sonic Boreholes to depths of between 70 m and 115 m, total 295 m.
- Twenty Four Cone Penetration Tests (CPTs) to depth of between 20 m and 80 m, total 1,010 m.
- Eleven test pits to investigate borrow materials and three test pits to investigate thickness of downstream side colluviums.

The broad conclusions from the investigations:

Spur Stratigraphy

- The thickness of the clean Upper Sand layer is 8 to 10 m in the vicinity of the Northwest cut-off wall (material to be re-used in construction as filter sand).
- There is no clean sand (less than 5% fines) below El. 35 m to 40 m. Below this elevation the material is not highly permeable.
- LCPT has performed Vs (shear wave velocities) and CPT tests for the purposes of establishing whether or not the marine clays are susceptible to cyclic softening and/or liquefaction.
- The Upper Sand contains zones of silty sand and clayey silt.
- A layer previously identified as Intermediate Sand is not encountered everywhere and where present is a silty sand.

Upstream Stratigraphy

- Lower Clay is present at and below El. 14 m (except in CPT-19, El. 5m). The top of the Lower Clay is deeper in front of the scarp slope.
- Rock is present at the south end of the upstream side, near the knoll.
- Sand layer(s) present on the upstream beach are not continuous through the body of the Spur. The sand fills the gullies following landslide or erosion.

Downstream Stratigraphy

- Slide debris or colluvium is generally thicker than anticipated.
- Landslide slip planes were detected.
- Blocks of tilted clay are present at the base of the slope at the north end of the beach.

The CPT investigations made it possible to fully define the top of the Lower Clay on the upstream shoreline. The north-west cut off was less defined. The results of the investigation had a positive impact on the design. The depth of the cut-off walls were raised by about 10 m and more slide debris added issues to the constructability of the finger drains. The drains will have to follow the sinuosity of gullies instead of cutting through the slide debris.

3. North Spur Stabilization Design

The review of the North Spur design relied on the Engineering Report - SLI document No. 505573-XXXX – XXER- rev # which is dated November 2012 (Ref 1). It is understood that this report is in a preliminary form and does not contain much of the analysis and design that has been undertaken more recently. A set of Drawings was also provided to the RT as listed in the reference section. The drawings show in some detail the intended stabilization works envisioned for the North Spur.

3.1 Design Approach

The design approach of the North spur stabilization works is geared, for the most part, towards improving the stability of the downstream slope by means of flattening the slope, placement of granular berms, providing drainage both surficial and in the underlying aquifers, reducing pore pressures, providing protection against toe erosion and providing impervious barriers along the upstream face of the North Spur tying into the lower clay layer in order to reduce seepage flows and piezometric pressures.

This design approach is considered to meet the general requirements for the satisfactory and long term stability of the North Spur.

Many of the comments provided in this report are related to potential improvements that can be made with respect to the constructability of the design. In addition, there is a need to substantiate some of the design decisions that have been reached which, as noted earlier, have not been covered in the design report due to its current preliminary nature.

The design utilized conventional solutions and means of analysis but also relied on both judgment and past experience of the LCPT. The RT was also verbally informed by the LCPT that an observational method would be employed during both partial reservoir impoundment for the diversion works and on completion of impoundment to make adjustments to the final stabilization work particularly with regards to extent of the pressure relief requirements based on piezometric information.

It is understood that, as of this date, no overall hydrogeologic model for the North Spur has been developed. This is strongly recommended due to the fact that the site hydrogeologic conditions are quite complex. The spur is composed of several aquifers and aquacludes in addition to complexities that result from the perched water tables and the kettle ponds. A detailed three dimensional hydrogeologic model would be of great value to assist in determining the most effective location of pressure relief systems and the efficacy of the Northwest cutoff wall. In addition, it will be of significant benefit as data from the piezometers becomes available during the impoundment stages which will allow for the further calibration and enhancement of the model.

3.2 The Upstream and Downstream Slopes

The upstream and downstream slopes of the North Spur have been designed to meet normally accepted slope stability factors of safety criteria under various loading conditions. The results of the slope stability analysis was provided on the last day of the RT's visit. The analysis requires some additional information such as the characteristics of the slide debris materials in order to be finalized.

The drawings detail the various stabilization works envisioned for both the upstream and downstream slopes. The work will require construction activities at and below water level. On the downstream slope loose materials that were deposited as a result of the 1978 slide exist. It is understood that rock groins will be constructed to facilitate removal of these materials and fill placement. However, these are not shown on the drawings and the general sequence of construction is not detailed. The RT notes that, although in such situations a cofferdam is preferable to allow construction in the dry, the planned use of rock groins is considered to be an adequate and cost effective alternative provided that suitable full time supervision is provided throughout the construction activities.

3.2.1 The Upstream Slope

The upstream slope will be covered by an impervious glacial till blanket with a minimum thickness of 6.0m and connected to a cement bentonite cutoff wall which extends to the lower marine clay. The cutoff wall extends northwards from the rock knoll along both the upstream slope and continues in a northwest direction towards the kettle ponds. The slope is protected by granular, rockfill and riprap zones as per normal practice.

This approach is considered to be an effective means of reducing inflow into the North Spur.

The RT has some specific recommendations with regards to this design which are as follows:

- The basis of the extent of the Northwest cutoff wall is not provided in the design documents and it is suggested that a seepage analysis be carried to determine its effectiveness.
- The depth of penetration of the cutoff wall into the lower marine clay is stated to be 2.0m on the drawings which conflicts with the 1.0m in the engineering report. It is understood that the former is the intended depth. It is recommended that the cutoff wall be extended at least 3.0 m into the lower marine clay as its elevation may not be accurately defined at all points. It is also recommended that a specific assessment be made to confirm the minimum embedment needed to ensure hydraulic gradients are at acceptable levels at the interface between the lower clay layer and the overlying horizon. This analysis should be performed taking into account that there will be a high likelihood that sand interbeds and lenses will be present in the upper few meters of the lower clay layer.
- At the cutoff wall contact with the rock knoll on the south side it is recommended that provision for grouting the upper bedrock is included. This can be undertaken easily through the cutoff wall. These measures have little incremental cost and could prove to be beneficial in ensuring an effective sealing in the marine clay and bedrock.
- It is recommended that a provision of a chisel be made in the technical specification should boulders be encountered in the cutoff wall excavation and for removing any weak and open jointed rock at the bedrock contact.

- The technical specification states that the minimum strength of the cutoff wall shall be 200 kpa. This appears to be low and a review of the stiffness of the cutoff wall and the surrounding soil should be undertaken so as to closely match the two so as to minimize deformation and or cracking of the cutoff wall. The LCPT is aware of this issue.
- Some form of protection of the upper part of the cutoff wall needs to be included during compaction of the overlying till blanket.

3.2.2 The Downstream Slope

The downstream slope has slopes that vary between 3H:1V to 7H:1V and several berms as part of the design. The toe berm is founded on overburden. The slopes are protected by several zones of granular material and rockfill. Rip rap is also provided as protection against toe erosion. Internal drainage of the downstream slope is provided for by finger drains located in four specific locations. It is understood that these locations are where seepage and springs have been observed and where erosion of the slope has occurred. At this time 4 pressure relief wells are shown on the lower part of the slope and penetrating into the Lower Aquifer. The RT was verbally informed that additional relief wells would be considered during the initial impoundment for diversion both in the Lower Aquifer and higher up the slope in the upper aquifer. With regards to the existing pump wells in the upper aquifer it is understood that the plan is to keep them on standby but not operational for a period of two years after full impoundment at which time a decision as to their long term requirement will be made.

A surficial drainage trench has been included to collect flows from the kettle ponds to the north of the Spur.

The downstream slope protection work is, in general, appropriate as a deterrent against instability.

The RT has some specific recommendations with regards to the downstream stabilization measures which are as follows:

- The large number of zones on the downstream slope may lead to constructability difficulties and quality assurance issues particularly as many of the zones have gradations that are very similar. The RT recognizes that this was probably implemented to ensure filter and drainage requirements are met. However it is suggested that some simplification of the zoning should be attempted. It was later communicated to the RT that zones 2F and 2G would be combined as 2F. A constructability/design review is recommended when the final configuration is established
- The finger drains as currently shown will be quite difficult to construct both because of their relatively small size but also the complexity of working with geotextiles and various granular zones in what will be disturbed and eroded overburden material. Also the RT has a concern regarding the long term efficiency of the geotextile as it may be prone to clogging from mineral deposition.
- The number of pressure relief wells at the toe which penetrate into the Lower Aquifer needs to be justified notwithstanding that additional relief wells may be added depending

on piezometric data after impoundment as a significant change to the design after construction commences could have implications on cost and schedule.

- The number and spacing of the potential upper wells needs to be designed accounting for various piezometric scenarios so that alternative measures can be implemented quickly should they be deemed necessary.
- The discharge of water from the pressure relief system at the toe is not well defined on the drawings.
- To prevent rain and surface infiltration into the Spur the engineering report refers to a geomembrane cover on the surface of the spur to a distance of 200m from the rock knoll at the narrowest part of the spur. The RT was informed that this will only be installed if deemed beneficial after observations post impoundment. The RT questions the efficacy of such a measure as water infiltration would still occur over the rest of the spur surface and penetrate into the water table. It is recommended that the need for this measure be reviewed, particularly given the comprehensive seepage defence measures that have been developed
- Due to the complex nature of the works on the North Spur slopes, the nature of the soft/loose debris material on the downstream slope, the currently planned complex zoning arrangements, there is a need for specific expertise in constructing the upstream cutoff wall. For this reason, it is suggested that the following be considered:
  - A description of the conditions the contractor will encounter be included in the data for tender package.
  - A mandatory pre-bid meeting where the site conditions are explained.
  - The need for an experienced geotechnical engineer on site during construction and preferably an individual who was involved in the design process.

3.3 Seismicity and Liquefaction

One of the main considerations for the long term stability of the North Spur relates to the seismicity and the potential liquefaction of the sands and silts and the possible loss of strength of the sensitive marine clay deposits once the cementation strength has been exceeded which can occur at relatively low strains and the consequent generation of pore water pressures and liquefaction.

The project seismicity analysis (not provided to the RT) carried out by the LCPT for the Muskrat Falls Project reported peak ground acceleration of 0.09g for a probability of 1:10,000. An amplification factor for the site of 1.23 was used resulting in an Earthquake design Ground motion of 0.11 g.

An assessment of the liquefaction potential of the north spur, and specifically the sand and silt layers as opposed to the marine clay, was analyzed using the method presented by Youd et al (2001). This method compares the Cyclic stress ratio to the Cyclic resistance ratio using either SPT, CPT or shear wave velocities. The Analysis presented in the Engineering report utilized the SPT data gathered from the various boreholes. The results indicated that a minimum factor of safety of 1.5 was achieved except in the areas of the slide debris from the 1978 slide. These materials are being excavated and replaced with granular material. The method outlined by Youd et. al., although intended for flat terrain has been considered adequate for use in this instance by LCPT.

The RT recommends that additional assessment be performed accounting for topographic effects as this could affect amplification factors.

The LCPT more recently undertook further analysis utilizing the recently collected CPT and shear velocity information from the 2013 geotechnical investigations and a verbal report on this work was briefly presented by the LCPT. The following is a brief summary of the additional analysis carried out by the LCPT as given to the RT by Regis Bouchard Lead Discpline Engineer – Geotechnical for the LCPT.

> *" A dynamic analysis to assess the liquefaction potential was carried out based on material parameters coming from the 1979 and 2013 geotechnical investigation results on the North Spur.*
>
> *The design earthquake used to do this analysis came from a site-specific seismic hazard assessment by Gail Atkinson, (2008).*
>
> *In accordance with the CDA Guidelines, a 1/10 000 probability level was used. A Uniform Hazard Spectrum (UHS) from the Atkinson assessment has been used for the level of the event expected. This spectrum was adjusted to a magnitude of M=7.5 (300 km), at low frequencies (<1H_z) and with an event of M=6 at 50 km and M=5.5 at 30 km for the intermediate to high frequencies. Based on the UHS, F-RISK software was used to generate the time history signal. More than 5 synthetic and more than 5 adjusted natural signals were created and used.*
>
> *A profile of soil stratigraphy was developed, based on previous investigations considering: SPT (Standard Penetration Test), CPT (Cone Penetration Test), V_S (Shear Wave Velocity) measurements. The V_S profile was calibrated with site natural frequency measurements. Damping and modulus degradation have also been taken into account.*
>
> *The Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) were evaluated using PRO SHAKE software in accordance with Seed et al. (1971 and later publications) . In addition, CLiq software has been also used to do this calculation.*
>
> *Results derived from these calculations show that the safety factor against the potential sand liquefaction for these evaluations is adequate.*
>
> *Based on Boulanger and Idriss, 2006 and 2007, a quick verification on the cyclic softening and liquefaction susceptibility criteria for cohesive soils was also performed for the North Spur site. The results show that there is no cyclic softening induced by the expected earthquake. A complete description of data, method and results will be included in the design report."*

The sensitivity of the upper marine clay has been reported to be in the range of 2 to 28 with an average of 11 as obtained from cone tests carried out in 1979. This does not agree with the results from the 1978 Acres report which indicate sensitivities one magnitude higher.

Apart from the above noted evaluation based on Boulanger and Idriss, the RT is not aware of any other analysis performed to assess the behaviour of the sensitive marine clay. For a project of this size, a more detailed analysis should be performed to examine the impact of topographic effects on the Peak Ground Acceleration (PGA) in hilly terrain and assess cyclic strains. The RT believes that it is critical that an analysis be undertaken to resolve the outstanding issues.

As such the RT recommends the following:

- Resolve discrepancies in the values of the sensitivities reported for both the upper and lower marine clays
- Carry out a 2D Flac analysis utilizing an appropriate time history for the relevant Earthquake and soil parameters from existing data to determine the strains generated which would then be compared to the peak strain from the triaxial testing. In addition, stresses at the toe need to be examined carefully as local overstressing can lead to a progressive failure even in slopes with an adequate factor of safety. It is realized that the existing information on the required marine clay geotechnical parameters is limited and would need to be augmented. It is further noted that, at this stage, to conduct additional investigations to obtain undisturbed samples of the marine clay may be difficult particularly in the Lower Clay. However it may be possible to excavate a test pit in the Upper Clay which, in any case, is the more sensitive deposit. This then would permit high quality undisturbed samples to be obtained to obtain reliable parameters for the additional recommended analyses
- In addition, soil parameters from similar sensitive marine clays in Eastern Canada should be used for comparative purposes.
- Engage at least two senior consultants with expertise in the behavior of sensitive marine clays. These consultants should be requested to provide guidance before implementation of any analyses and then to review the results when the work is completed. Potential candidates were discussed with the LCPT.

3.4 Instrumentation

Currently the instrumentation consists of an array of piezometers on the downstream slope which will be installed in addition to the existing piezometers. The piezometers are of the vibrating wire type installed in standpipes.

The RT recommends that seepage measurement devices be installed in the collector pipes from the pressure relief wells. In addition the possible installation of slope indicators is considered to be of benefit and should be considered.

3.5 Permanent Roads

The RT discussed with LCPT that for constructability the layout and grades of the permanent roads could be improved. This is being reviewed by the LCPT.

4. North Spur Stabilization Technical Specifications

4.1 General

A major focus of the review of the specifications and exhibits was to note items where the Contract could be exploited by a Contractor. Similar to the procedure of the review of Contracts CH0007 and CH0032, that was previously done, the RT reviewed the Technical Specifications, the Site Conditions (Exhibit 12) and the Basis of Measurement and Payment (Exhibit 1). A contractor could take advantage of items not clearly defined or not well coordinated in basis of measurement and payment or unclear or confusing language in the Specification. This could also apply to any design or details thereof and such observations were noted on drawings given to the LCPT or in the specifications, as well.

In general, the Technical Specifications and the Exhibits reviewed (Exhibit 1 and Exhibit 12) were well written and complete.

The RT noted some specific items and these have been provided to the LCPT by direct mark-up of the Word files with “track changes” on. It was agreed with the LCPT that this would be a more efficient way to convey the information.

5. Main Conclusions and Recommendations

The main conclusions of the RT in regards to the design of the stabilization works for the North Spur and are:

- The basis of the design is in general robust and all the main elements for the most part have been considered.
- The engineering report is yet to be completed and needs to be augmented with more information which would include but not limited to: The design philosophy including the observational method alluded to in the meetings, results of analysis of the slope stability, justification for the length of the northwest cutoff wall, the number, spacing and location of the pressure relief wells and finger drains and to include the additional work already carried out on the liquefaction potential.
- A detailed hydrogeologic model for the North Spur and 3D seepage analysis is required.
- Further analysis on the sensitive marine clays with regards to potential loss in strength when subjected to seismic loading is required. This should be coupled with engaging two eminent consultants with specific expertise on sensitive marine clays.
- The large number of zones on the downstream slope may lead to constructability difficulties and quality assurance as currently designed. This will also lead to increased costs. A design and constructability review aimed at simplifying this design is recommended.
- The specifications and drawings should be reviewed and amended based on the marked up copy provided to the LCPT and in light of potential cost exposures.
- The RT does not recommend the use of geotextiles in the finger drains due to concerns with respect to their longevity and the likelihood that clogging will occur as a result of mineral deposition.
- The following is recommended with respect to ensuring the quality of the construction works for the North Spur stabilization program:
  - A description of the conditions the contractor will encounter be included in the data for tender package.
  - A mandatory pre-bid meeting where the site conditions are explained.
  - The need for an experienced geotechnical engineer on site during construction and preferably an individual who was involved in the design process.

6. References

1. Engineering Report, North Spur Stabilization, SLI Document No. 505573-XXXX-XXER-XXXX-Rev #, undated, report in progress.
2. Construction Materials-Borrow Areas and Quarries, MFA-SN-CD-0000-EN-RP-0006-01, 20 Dec 2012.
3. Nalcor Energy-Lower Churchill Project, Geotechnical Investigations Report, 2013 Field Investigations, Muskrat Falls Hydroelectric Development, amec, September 2013, Appendix A and B
4. List of Drawings
   - MFA-SN-CD-0000-CV-PL-0003-01 Project location and Drainage Basins
   - MFA-SN-CD-0000-CV-PL-0004-01Plan and Profile
   - MFA-SN-CD-2800-CV-GA-0002-01 General Arrangement of Works
   - MFA-SN-CD-2800-CV-GA-0003-01 Acess Roads, Accom. and Laydown Areas
   - MFA-SN-CD-2800-CV-PL-0010-01 North Spur Stablization Works Existing Conditions
   - MFA-SN-CD-2800-CV-PL-0011-01 North Spur Stablization Works General Arrangement of Works
   - MFA-SN-CD-2800-CV-PL-0012-01 North Spur Stabilization Works company, contractor's Laydown and Spoil Disposal Areas
   - MFA-SN-CD-2800-CV-DD-0005-01 Spur Stabilization Works Hydrometeorological Data
   - MFA-SN-CD-2800-CV-PL-0013-01 North Spur Stabilization Works Borrow Areas and Quarries
   - MFA-SN-CD-2800-GT-DD-0006-01 North Spur Stabilization Works Clearing
   - MFA-SN-CD-2800-CV-PL-0014-01 North Spur Stabilization Works Foundation Preparation Plan, Section and Details
   - MFA-SN-CD-2800-GT-DD-0005-01 North Spur Stabilization Works Embankment Materials Grain Size Distribution
   - MFA-SN-CD-2800-CV-PL-0009-01 North Spur Stabilization Works Plan
   - MFA-SN-CD-2810-CV-SE-0001-01 to 04 North Spur Stabilization Works Upstream Typical Cross-Section and Details
   - MFA-SN-CD-2800-CV-SE-0004-01 North Spur Stabilization Works Northwest and Uupstream Cut-off Walls Sections and Details

- MFA-SN-CD-2810-CV-DD-0006-01 to 03 North Spur Stabilization Works Cut-off Walls Work Platform and Construction Stages
- MFA-SN-CD-2820-CV-SE-0001-01 to 03 North Spur Stabilization Works Downstream Typical Cross-Section and Details
- MFA-SN-CD-2820-CV-SE-0002-01 to 02 North Spur Stabilization Works Finger Drains Sections
- MFA-SN-CD-2800-EL-PL-0002-01 North Spur Stabilization Works Instrumentation
- MFA-SN-CD-2800-EL-SN-0001-01 to 02 North Spur Stabilization Works Instrumentation Section and Details
- MFA-SN-CD-2800-GT-SN-0004-01 North Spur Stabilization Works Relief Wells Plans, Section and Details
- MFA-SN-CD-2800-GT-PL-0013-01 North Spur Stabilization Works Permanent Access Road Plan
- MFA-SN-CD-2800-GT-SN-0005-01 North Spur Stabilization Works Permanent Access Road Sections and Details
- MFA-SN-CD-2800-GT-SN-0003-01 North Spur Stabilization Works Logbooms Sections and Details

5. Lower Churchill Project, CH0008 North Spur Stabilization Works, Scope of Work specification and technical specifications
   - 31 11 00 Clearing Grubbing and Stripping
   - 01 55 00 company and Contractor's Laydown Area, spoil Disposal Area and Roads
   - 31 23 19 Dewatering and Water Management
   - 31 15 00 Sources of Materials
   - 31 23 00 Excavation
   - 31 16 00 Foundation Preparation
   - 31 23 23 Embankment construction
   - 31 05 09 Geotextile for Earthworks
   - 31 56 00 Cement Bentonite Cut-off Wall
   - 33 26 00 Relief Wells
   - 32 92 19 Hydroseeding
   - 31 09 00 Geotechnical Instrumentation

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