THE NORTH SPUR – MY FINAL COMMENTS

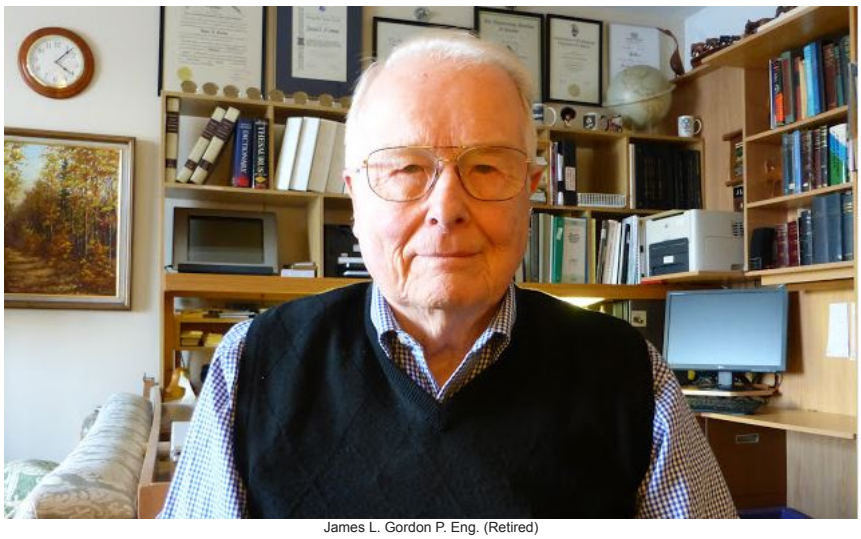
Guest Post by James L. Gordon P.Eng.(Retired)

Way back in 2014, my interest in the North Spur started when I read a short book byCabot Martin titled "Muskrat Madness". It concentrated on the questionable stability of anatural side dam called the North Spur which contained layers of sandy silt and sensitiveclay. I emailed Cabot, a member of the 2041 committee, on August 27th commenting onhis book, and have commented several times on the Uncle Gnarley blog on the North Spur safety. NALCOR describes the Spur as -

The north spur forms a natural earthfill dam, with a crest elevation of about 60 m, and about one km long, which connects the rock knoll to the north bank of the valley.....The crest width varies from about 1,000 m at its north end to about 70m at its southend where it has been narrowed by erosion and landslide activity in the past. The headacross the spur is presently 16 m from river level upstream to downstream. Theimpounding of the reservoir to El. 39 m will increase the hydraulic head across thespur to 36 m and stabilization measures are then necessary to ensure its long-termstability under both normal and extreme water levels. The soils forming the spurconsist of a complex interbedded sequence of relatively low permeability silty sandsand sands, and sensitive marine clays.

Unfortunately, there is a history of landslides in the valley, with several occurring on theupstream and downstream banks of the Spur. A very large landslide occurred at E Island, some 65km upstream of Goose Bay about the end of February 2010. It involvedabout 2,000,000m^3 of material. Source – AMEC Geotechnical investigation: EdwardsIsland Landslide, August 2011. There are many other landslides both upstream anddownstream of Muskrat Rapids.

Due to the questionable stability of the Spur, Dr. Stig Bernander was requested byGrand Riverkeepers Labrador in Happy Valley-Goose Bay to undertake an analysis of thestability, all pro bono, with travel expenses paid by various concerned citizens. He issuedthree extensive reports. A remarkable achievement, since he has just turned 90!



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Dr. Bernander is not convinced that the Spur will fail, but that its stability has not beenproven. His conclusion is that the safety and reliability of the Muskrat Falls dam have not been demonstrated. To do so, which is of course essential given the economic and human consequences should it fail, would require further geotechnical work, the nature of which he describes in detail.

Dr. Bernander's report is far too technical to explain. It is filled with geotechnical engineering terms and equations, to such an extent that only someone with a doctorate ingeotechnical engineering and extensive experience with sensitive clays will be able tofollow the reasoning. His conclusions are as follows –

1. The SNC Lavalin elastic-plastic methodology used to determine stability isincorrect.
2. Insufficient analysis of failureplanes.
3. The use of the Limit Equilibrium Method (LEM) of analysis is not justified.
4. The applicability of the "elastic-plastic" (see comment #1) methodology is not proven.
5. The safety factors determined using the SNC-Lavalin methodology are not correct.
6. Finger drains are not effective.
7. The cutoff wall may be detrimental to the stability.

His conclusions were so alarming that I authored several articles requesting theformation of a Review Board, under a government mandate, to look into his concernsand determine the Spur stability. Only an expert Review Board which is independent of Nalcor and has full access to data and third-party expertise, working under transparently set terms of reference, can provide definitive conclusions in a situation like this.

The NL government never acted upon this recommendation. Instead, NALCORconvened a Geotechnical Peer Review Panel (GPRP) at the end of 2017. The membersincluded –

- Prof. Bipul C. Hawlader. Geotechnical Professor at Memorial University, St. John's.
- Prof. Serge Leroueil. Retired professor at Université Laval, Québec City, Canada.
- Dr. Jean-Sébastien L'Heureux. Technical Lead, Norwegian Geotechnical Institute, Norway
- Prof. Ariane Locat. Professor at Université Laval, Québec City, Canada.

They issued a report titled Geotechnical Peer Review of Dr. S. Bernander's Reports andAnalysis of the North Spur, dated 2nd February, 2018. The 30 page report concludedthat:

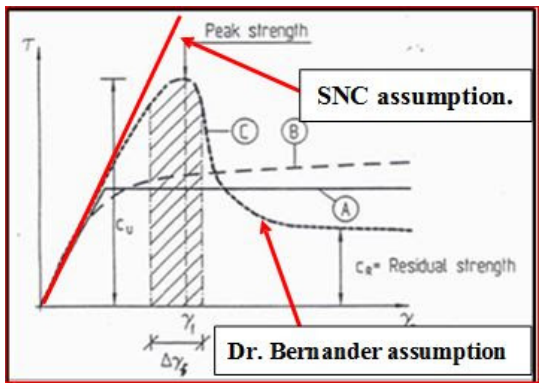
1. *... most of the landslides along the Churchill River valley and at the North Spurare either rotational slides or retrogressive flowslides, and that they arecomparable to many of the landslides observed in sensitive clays elsewhere inEastern Canada and Norway.*
2. *... The clayey soils found at the North Spur are comparable to those found inEastern Canada and Norway.....*
3. *The methodology applied using the LEM by SLI (SNC-Lavalin Inc.) to evaluate thestability of the North Spur for an initial landslide corresponds to the current state of practice.*
4. *In view of the analyses performed by SLI, the GPRP finds that the approachused is conceptually acceptable to take into account the initiation of progressivefailure.*
5. *The GPRP considers that SLI used State-of-the-Art methodology to assess theresistance of the North Spur to earthquakes.*
6. *The GPRP does not expect that the cut-off walls will "create a gigantic force", ascalculated by Dury and Bernander, which could trigger a downward progressive failure. Actually, the existing piezometer data show that water pressure withinthe Spur is already at a level similar to the level of the reservoir after impoundment.*
7. *The GPRP agrees that the finger drains are necessary to maintain appropriatedrainage on the slopes on the downstream face of the North Spur and to reduceinfiltrations.*

It is unfortunate and unusual that the GPRP did not consult Dr. Bernander, or give him any opportunity to respond to their concerns. Also, it is unfortunate that none ofthe staff within the NALCOR organization have the experience to discuss and questionthe GPRP findings. Nevertheless, in view of the recent revelation that NALCOR edited reports by the "Independent Engineer" this inexperience may not have prevented NALCOR staff from "marking-up" or "vetting" the report of the GPRP or setting parameters/mandates that the GPRP had to follow which would only give the answer sought by NALCOR.

I still question whether the North Spur is safe, based on the lack of data and absence of geotechnical analysis in the GPRP report to support their conclusions. The report was prepared in three days, totally insufficient to assess the vast amount of geotechnical data on the Spur. This can be compared with the time required to investigate the Mount Polley dam failure, which occurred on August 4th, 2015, and the failure report was issued 5 months later on 30th January 2015. It is available here.

In particular, I prefer to have seen –

1. The results of stress-strain tests on the soils. This is where Dr. Berdander and theconsultant SNC-Lavalin depart in their expectation of the soil strength. SNC-Lavalin have assumed a linear relationship with a softening factor, whereas Dr.Bernander assumes a loss of strength at relatively low levels of strain, as shown inthe following diagram extracted from his report.



Such tests must have been undertaken. But results have not been divulged.

There is a reference to the strength reduction in the report as follows - *Recent research in Norway (refs. (29) and (30)) recommends the use of the LEM approach in practice for the analysis of slope stability in sensitive and quick clays, with the addition of a correction factor, called* $F_{softening}$, *to account for the reduction of the clay shear strength after the peak shear strength has been reached, and to partially account for strain compatibility on the failure surface. (Report page 15)*

The report then states - *As an example of the effect of the mitigation measures for a slope on the Eastern side of the North Spur, the critical factor of safety was increased from 1.0 to 1.6. This is a 60% increase in the stability of the slopes, and within the reduction associated with* $F_{softening}$, *if one should use the results of some of the most recent researches.*

However, there is no discussion on how the $F_{softening}$, factor was determined for the soils in the Spur. It has been assumed from other studies. Since the safety of the Spur is so critical, stress-strain test results should be available for the North Spur soils.

2.

Dr. Bernander has based his analysis on the lowest strength soils, whereas theGPRP has used the average soil strength, stating – *Atterberg limits indicate that the clay has low to medium plasticity. Plasticity charts based on soil testing in 1979 and 2013 investigation are presented in Figure 6 for the Upper Clay and Lower Clay. For the Upper Clay, the plasticity index ranges between 3 and 22, with an average of 11. Only a few values are below 7 and most of them seem to be associated with a mixture of silty layers and clayey layers. (Report, page 10)*

There has been no justification for this. What is the saying – the strength of a chainis equal to the strength of its weakest link. The soils in the Spur have beendeposited in layers, with each layer having a different strength and characteristic. Ifthere is a layer of weak soil, then the Spur will fail by sliding on that layer asoccurred at Mount Polley in BC. The GPRP has not demonstrated that there is nosuch layer. The extent of soft and low-strength materials is unknown at this time.I would have preferred to see a three-dimensional computer model of the Spur showing the layer strength.

Mount Polley dam in BC. The downstream slope failed on August 14th, 2014.

Report extract - *(The) Independent Expert Engineering Investigation and ReviewPanel concluded that the dominant contribution to the failure resides in thedesign. The design did not take into account the complexity of the sub-glacialand pre-glacial geological environment associated with the Perimeter Embankment foundation. As a result, foundation investigations and associated site characterization failed to identify a continuous (soft) layer in the vicinity ofthe breach and to recognize that it was susceptible to undrained failure.*

3. The GPRP concludes that the cut-off wall is a necessary component of the Spursafety enhancement. My experience with such walls is that they contain defects inthe form of permeable windows caused by the permeable material falling off thevertical sides of the wall during the back-filling process. Impermeability can beseriously affected, and will not be known until the reservoir is filled.

Also, the GPRP rejects Dr. Bernander's description of a "gigantic force" applied to the wall, pointing out, correctly, that the location and height of the wall has been misinterpreted by Dr. Bernander. The GPRP report states –

In their analyses, Dury and Bernander assumed "a gigantic external force (locally on the (cut-off wall) COW)", assuming the water pressure resulting from impoundment on only one side of the COW ……., in addition to using incorrect geometry and incorrect location for the COW. Actually, the many piezometers installed in the North Spur show that the water pressure in the Spur will be acting on both sides of the COW (red triangle on Figure 19). If the equation is

performed for a COW at the actual location, the force on the wall would be much less than the force calculated by Dr. Bernander. (Page 21)

This statement is patently not correct and indicates a misunderstanding of the hydraulic forces exerted by the reservoir waters on the Spur. There has to be an impervious barrier to the headpond water within the Spur to avoid excessive seepage. It makes is no difference to the hydraulic forces if the barrier is a cut-off wall constructed from the dam crest down to the impervious clay layer below the spur, as assumed by Dr. Bernander, or if the barrier is a short cut-off wall topped by an impervious blanket, as built at the upstream face of the Spur. Moreover, the impervious barrier can be located anywhere within the upstream half of the natural dam formed by the Spur.

To reinforce their theory about the forces acting on the cut-off wall, the GPRP has added a counterforce on the downstream face of the cut-off wall (Report Figure 13) equal to the pressure on the upstream face. If this was the case, then the cut-off wall and blanket would not be required.

What Dr. Bernander is describing is the concentration of the forces at the watertight barrier resulting in high compressive forces on the soil immediately downstream of the watertight barrier. Without the watertight barrier, the dam would be built with a homogeneous glacial till, as at Bay d'Espoir and Cat Arm, and the hydraulic forces would be dissipated throughout the dam, instead of being concentrated at the watertight barrier.

The effect of the force concentration has not been determined. It would have to be undertaken by a fine-mesh finite element analysis.

Teton Dam failure due to excessive seepage on first filling. June 5th, 1976. Thiswas the unexpected event which started the dam safety campaigns in North America.

4. The GPRP has assumed that the safety factors applicable to the Spur stability arethose recommended by the Canadian Dam Association. As first mentioned by PhilHelwig, these safety factors were developed for dams constructed with knownhomogeneous materials such as rock, gravel, and silt, all within a determined size,placed and compacted under strict specification requirements, and testedthroughout construction. On the other hand, the North Spur contains a mixtureof sand, silt and clay, resting naturally, and not compacted, nor tested as in anengineered dam. The safety factor for such a natural dam should be higher. The GPRP has not demonstrated that the CDA factors can be applied to the Spur.

   Also, I would refer the GPRP to a paper (reference provided by Phil Helwig) authored by J. Michael Duncan, titled "Factors of safety and reliability in Geotechnical engineering" which demonstrates that using a simple factor of safety is insufficient, and that a reliability analysis is also required. (ASCE Geotechnical Journal, Oct. 1999. *1) A reliability analysis has not been undertaken by the GPRP.

   *1 Factors of Safety and Reliability in Geotechnical Engineering 1999 J Michael Duncan The Seventh-Spencer J Buchanan Lecture

So what can be concluded from all this? – is the North spur absolutely safe? The reservoir spillway has been designed to pass a 1/10,000 flood, and the Spur is able to withstand a 1/10,000 earthquake. But is the risk of a slope failure at the NorthSpur also assessed at 1/10,000? If not, then how risky is it? Nobody knows, since a reliability analysis has not been undertaken.

Recommendations:
The government of NL should appoint an eminent panel of geophysical experts, completely independent of Nalcor, to assess the scientific evidence and undertake all necessary additional research, and undertake a comprehensive review of the safety and stability of the North Spur. The Panel's work should include:

1. **Giving Dr. Bernander and his associate Dr. Elfgren the opportunity to respond to the GPRP report, and include their comments therein.**
2. **Assessing the results of stress-strain tests on the various soils within the Spur, to demonstrate that the linear relationship and softening factors have been correctly determined and applied to the geotechnical calculations.**
3. **Producing a three-dimensional computer model of the strength of the various soil layers within the spur, to demonstrate that there are no extensive layers having a strength below average strength, which could form a sliding plane.**
4. **Undertake a reliability analysis of the safety of the Spur.**
5. **Seeking precedents for the use of CDA dam safety factors in slope safety calculations in a natural dam.**

Given the recent revelations that Nalcor staff have been "marking-up" reports by the "Independent" Engineer, it is imperative that the chosen Panel is verified to be Independent of Nalcor. Only then will the residents downstream of the Spur — and those who are responsible for paying for the dam — feel that Government has done its utmost to ensure their safety and the safety of the Spur.

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