Is the North Spur dam safe?

I have written several articles about my concerns regarding the safety of the North Spur dam, concluding in my last article that the dam was not safe. However, on undertaking a more detailed analysis of the NALCOR reports, I have changed my mind, and now believe the dam to be safe.

In this analysis, I am referring to several reports as follows –

1. NALCOR "Engineering Report, North Spur Stabilization Works, Progressive Failure Study [2b], dated 21 December 2015". Referenced as the NALCOR 2015 report.
2. NALCOR "North Spur Stabilization Works – Design Report dated 30th Jan. 2016". Referenced as the NALCOR 2016 report.
3. Bernander "LOWER CHURCHILL RIVER RIVERBANK STABILITY REPORT" DATED NOV. 26, 2015, Referenced as the BERNANDER 2015 report
4. Bernander "COMMENTS ON THE ENGINEERING REPORT BY NALCOR/SNC-LAVALIN OF 21 DECEMBER 2015" dated 20 September 2016. Referenced as the Bernander 2016 report
5. AMEC "Geotechnical investigation: Edwards Island landslide, Churchill River", dated August 2011. Referenced as the AMEC 2011 report.

My initial concerns centered on the report by Dr. Bernander identifying many progressive landslides in the river valley near the North Spur. What is a progressive landslide – it is a landslide which can occur in soft (quick) clays where the land mass slides downhill on failure of a weak zone below the surface, as shown in Figure 1, sections (b) and (c).

As defined by Dr. A. Locat *"the concept of progressive failure may explain translational progressive landslides and spreads — large landslides occurring in sensitive clays. During progressive failure, the strain-softening behaviour of the soil causes unstable forces to propagate a failure surface further in the slope. Translational progressive landslides generally take place in long, gently inclined slopes. Instability in a steeper upslope area is followed by redistribution of stress, which increases earth pressure further downslope." Source* – Abstract to paper referenced in Figure 1.

Dr. Bernander is an expert on progressive landslides, having worked on assessing the safety of the land mass in slide-prone areas of Sweden. He has found that the normal methodology used to assess dam safety cannot be used on areas prone to progressive landslides, as recently confirmed by Dr. Locat, and instead has developed his own methodology.

Dr. Bernander has concluded that the landslides on the Churchill River banks are all due to progressive failures, and recommends "*a careful study related to progressive failure is an unavoidably necessary measure."* Source Bernander 2015 report page 1.

On the other hand, NALCOR reports all indicate that the landslides are due to flow slides. "*Three landslides on the downstream* side *(including the slide that occurred in 1978) are all of retrogressive behaviour similar to flowslides".* Source NALCOR 2016 report, page 137. Therefore, the normal methodologies for calculating the dam safety factor can be used. This contention is supported by Photo A5 in the AMEC 2011 report. In the photo, the transverse humps, each representing a flow slide are clearly evident. Also, the flow debris level is well below land surface level, with a scarp remaining as shown in Photos A4 and A8, again indicating a flowslide.

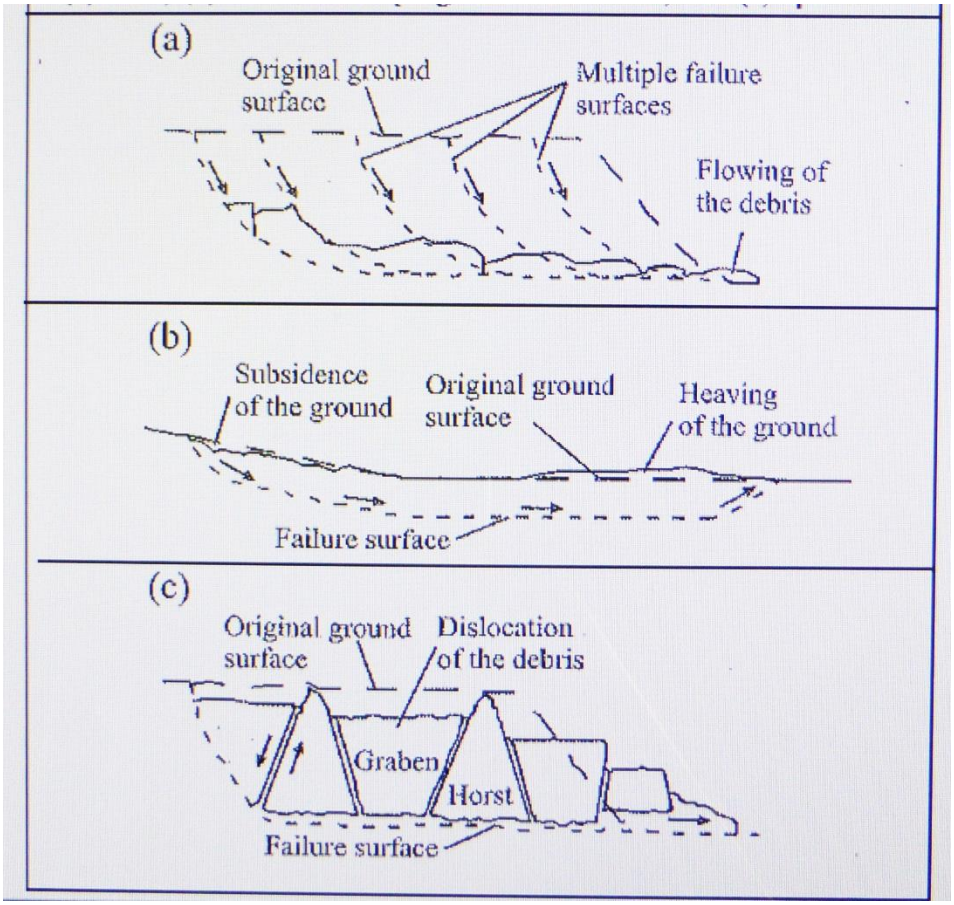

Figure 1.

(a) Flowslide (b) Downhill progressive landslide. (c) Uphill progressive landslide. Source Dr. Ariane Locat, Serge Leroueil, Stig Bernander, Denis Demers, Hans Petter Jostad, Lyes Ouehb . "Progressive failures in Eastern Canadian and Scandinavian sensitive clays" Canadian Geotechnical Journal, 2011. 48 (11).

Dr. Bernander, after inspecting the river banks and the North Spur shoreline, concluded "*For the most recent large slide in the North Spur, in 1978, Nalcor's own engineers found that the silty clay layer* ***had developed multiple failure surfaces and liquefied over a long lateral distance****".* Sources Bernander 2015 report, pages 7. No such statement could be found in the NALCOR 2015 report, on liquefaction in the 1978 landslide. In fact, the landslide is identified as being of the flow type – see Figure 1 (a) – "*The slide involved a block movement triggered by weak layers*

within the stratified drift, followed by retrogressive flow slides" Source NALCOR 2016 report, page 137, and NALCOR 2015 report, page 31.

However, there is mention of liquefaction in the AMEC 2011 report in the Edwards Island landslide failure slip surface "*With respect to the recent earth slide – earth flow, blocks of failed material were observed throughout the area of accumulation. … They are produced when the relatively dry upper sediments separate as a result of liquefaction in the flowing material along the slip surface"* Source - Page 2

The reference to liquefaction in the Edwards Island landslide is within the slip surface, a common occurrence in soft clay landslides. It is not a general liquefaction of the land mass as occurred at Rissa in Norway. (Google Rissa landslide Norway to view documentary on the slide).

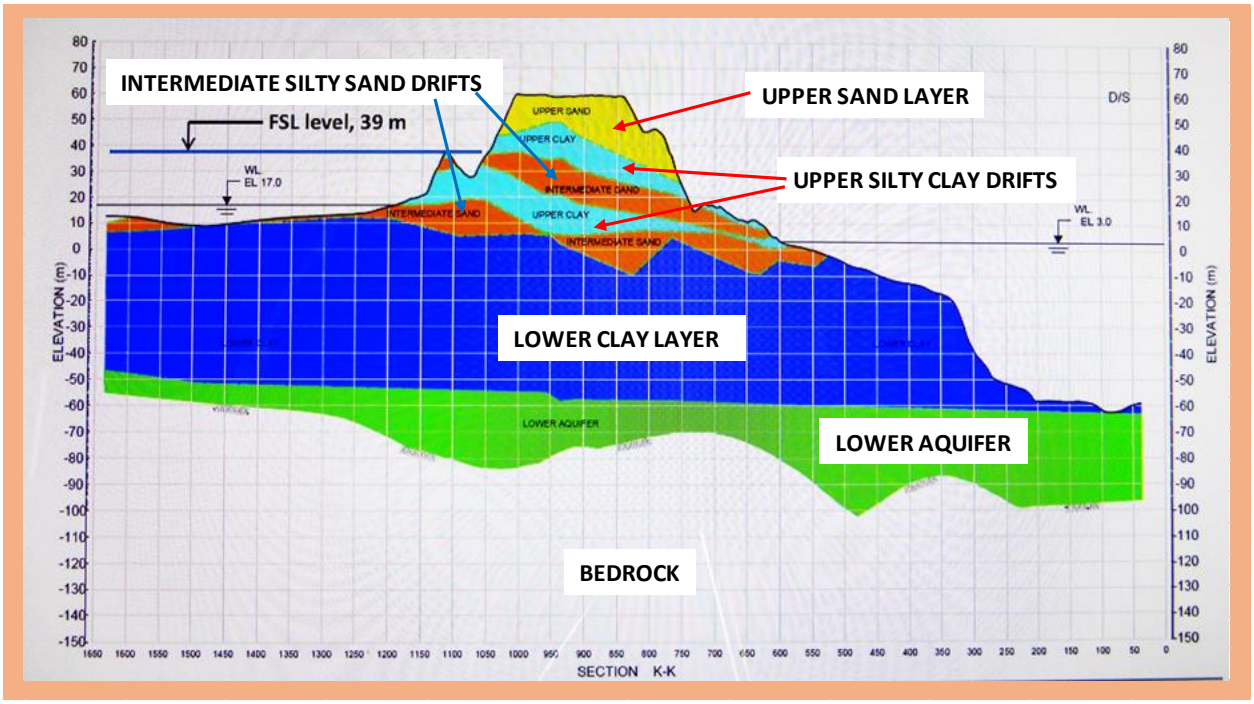

Figure 2.

Section through the North Spur – vertical scale exaggerated for clarity. Shows the layers of sands and clays within the Spur. Source – North Spur Updated, Independent Engineer, 21.7.14.

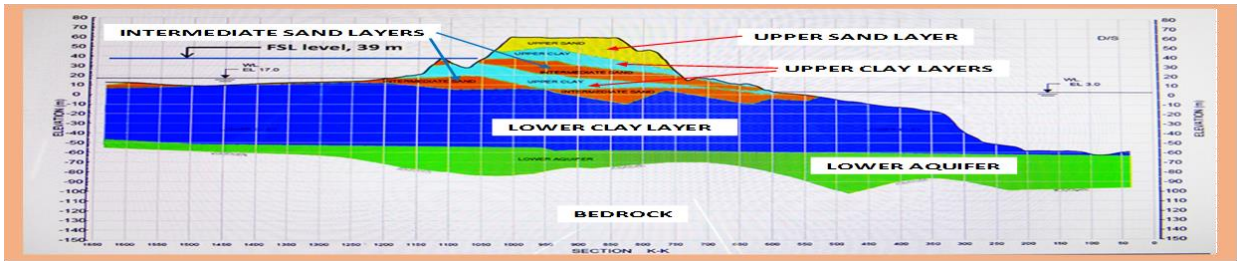

Figure 3.

Section through the North Spur – with no vertical scale exaggeration.

The foregoing analysis indicates that Dr. Bernander's interpretation of the landslide type does not agree with the NALCOR assessment, as expected. However, it must be pointed out that four geotechnical engineers and two geotechnical engineers with Ph.D.'s have reviewed the NALCOR work, and all agree that the landslides are due to flowslides.

The remaining sections of the Bernander 2015 report is devoted to a theoretical analysis of slope stability using the Bernander methodology. However, he did not have enough geotechnical data on the North Spur soils to undertake an analysis of the re-shaped dam's stability.

As mentioned, since the landslides are of the flowslide type, the normal methodologies can be used to determine dam safety factors. This has been completed in detail in the NALCOR 2016 report, with the re-shaped dam safety factors being within the Canadian Dam Safety guidelines.

Is there quick clay within the North Spur? According to Carlton University the sensitivity of soft clay must exceed 30 to be considered "quick" (Google Carlton University quick clay – a geotechnical lecture appears – third slide - quote – "*quick clays are defined by their behaviour. At their natural water content, these sediments have –sensitivity >30 and remoulded shear strength <0.5kPa. When disturbed, quick clays behave as a liquid. This allows very large, retrogressive flow slides to occur on landscapes that are essentially level.*"

A few tests on soil samples retrieved from the two "Upper Silty Clay Drifts" – see Figure 2 have indicated the presence of soft clays. The sensitivity ranged from 1 to 36 in 43 samples, with an average of 10. Source NALCOR 2016 report. Page 91. This is not soft enough to be considered "quick", according to Carlton U. Moreover, during the excavation work required to re-shape the North Spur, there were no instances of liquefaction nor small landslides. All clay removed by shovels and dumped into trucks remained in clumps. This indicates that the pockets of quick clay (if any) were far too small to cause landslides.

Nor were problems encountered during excavation of the two cut-off walls. If quick clay had been present, it would have liquefied on being disturbed by the excavation work, and would then flow into the trench, preventing further work.

Dr. Bernander also reviewed the data available on the lower clay layer (See figure 2). This layer provides the foundation for all the soils above water level in the North Spur. Again, Dr, Bernander concludes *"… that layers with high sensitivity also occur in the Lower Clay formation — a fact that allows the possibility of developing a progressive failure*". Source Bernander 2016 report, page 8.

On the other hand, NALCOR data from tests on soil samples retrieved from the lower clay layer do not indicate the presence of soft clays. Instead, the clay is characterised as "*stiff to very stiff".* All tests on this deposit indicate sensitivities well below 30, hence no quick clay. Quote - "*sensitivity values obtained for this unit vary between 2 and 11, with an average of 4*". Source – NALCOR 2016 report, page 98.

NALCOR has incorporated the usual slope stabilization techniques into the re-shaped North Spur. They were based on analysing the existing slopes to obtain a benchmark for the LEM calculations, as follows -

- *Calculations are based on slope geometry, soil properties, groundwater properties.*
- *Calculations are calibrated locally with an existing slope.*
- *Rotational, flowslide, spread stability is calculated with a first movement at the toe.*
- *There is no evidence of downhill progressive failure landslide along the Churchill River valley.*
- *Counter measure will be in place to control ''Human triggering.''.*

Source – North Spur Stabilization works, presentation 21 July 2014, slide 9.

NALCOR has used all the common measures to enhance slope stability, including flattening of the slopes, adding a toe berm, adding two cut-off walls, and improving drainage with wells and finger drains. All sound measures which will result in a stable slopes and a safe dam.

However, there is still the issue of toe erosion resulting in loss of rip-rap placed at the toe. The erodible material, silt and clay, extends down far below water level, but the rip-rap is placed only on the above-water soil, and perhaps for about a meter below water. It needs to be extended much further below water level to provide added protection. Also it would be prudent to place a large stockpile of suitable rip-rap somewhere on site, where it can be used by a maintenance crew, to replace lost toe rip-rap.

Finally, there is one unexplained issue, and that is the statement by a driller that the drill casing dropped 40ft. overnight, from 20ft. above ground to 20ft. below ground, indicating very soft material. Sonic (vibrating) drill hole locations and logs are included in the AMEC Appendix A for the FINAL – Geotechnical investigations Report, dated November 2013. A total of 4 sonic drill holes were undertaken. For drill hole NS 2-13, located on the Spur crest near the south end, there is a note that at El. 23.0m, "*the core barrel dropped from 3.35m*". And again at El. 7.7m "*Core barrel dropped from 4.88m".* Drilling continued down to El. -53.7m. Again for hole NS-05-13 at El. 48 - *"casing and drill rods settling into clay. Free weight. Driller not vibrating."* Unfortunately, there is no statement as to when the barrel stopped dropping. Presumably, these are the incidents described by the driller.

In both cases, the drill head was in "*Clay – some silt to silty, soft, medium to low plasticity, brown, saturated".*

No doubt, this analysis will not convince skeptics in Goose Bay and Happy Valley that the dam is safe. NALCOR needs to provide further assurance.

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