SNC·LAVALIN

MEMO

TO:	**File**	**DATE:**	1-May-2019
	Greg Snyder Gilbert Bennett Scott O'Brien Stephen Pellerin		
CC:	Michel Tremblay	**DOC NO.**	505573-0000-30CC-I-1539
FROM:		**LC REF:**	MEM-CH0008001-0004
SUBJECT:	**North Spur - Downstream Slope Stability – Sensitivity Analysis Addendum to the Post Construction Assessment Report (PCA)**		

1. Slope Stability Calculation

The purpose of this memo is to provide additional information on the sensitivity analysis that was undertaken for the downstream slope at the North Spur, as referenced in the Post Construction Assessment Report (PCA) prepared by SNC-Lavalin Inc. (SLI), document MFA-SN-CD-2800-GT-RP-0010-01.

The sensitivity analysis of the slope stability is referenced in Section 6.1 of the PCA report. During the preparation of the PCA report, an analysis was done for the slope stability under the slope conditions in Summer 2018, two years after the completion of the stabilization works. It was found that the safety factor of the slopes of the North Spur was greater than 1.5, which is in accordance with the design expectation.

In order to define the trigger conditions that may require action or intervention at the Spur, a sensitivity analysis has been performed. This is a "What-If" analysis to examine what conditions may result in a change or reduction to the safety factor.

The analysis was undertaken using "Sector 13", the northern part of the downstream slope. This area was selected because Sector 13 was found to be the most critical in term of slope stability during the pre-project investigations. In fact, there were 3 previous landslides scarps south of Sector 13 and one north of it. The northern one is north of the 3 Kettle Lakes outlet. The pre-project conditions at Sector 13 showed toe erosion and superficial sloughing on the slope. This information was used during the design to confirm a low Factor of Safety for that slope (close to 1.0) prior to remediation and stabilization work. In theory, a Factor of Safety of 1.0 means that the slope is not stable. During the design, all calculations on the stability were compared with the result coming from the slope in this area and Sector 13 was used to calibrate calculations and validate proposed methods enhancing slope stability analysis for all slopes at the North Spur.

In 2013, during design works the slope geometry, the soil stratigraphy, the soil properties and the ground water pressure distribution were defined and this information was used to extrapolate ("back analyze") to determine the values of the parameters to obtain the Factor of Safety of close to 1.0, as had been assumed from field observations. This is a usual approach used to calibrate the parameters in this type of stability analysis.

A similar analysis of the slope stability performed in 1977 at the location of the 1978 landslide was used to compare the parameters used in 2013. All these result confirm the precarious stability of Sector 13 pre-project and confirm the selection of the parameters used to perform the subsequent analysis for the stabilization of the North Spur slopes.

The stabilization works were designed based on these results and used the target safety factors in accordance with the CDA Guidelines. For the long term downstream stability the target Factor of Safety was 1.5. The approach is described in more detail in the North Spur Stabilization Works Design Report (MFA-SN-CD-2800-GT-RP-0004-01)

In 2018, two years after the completion of the stabilization works and impoundment of the reservoir to the interim ("Winter Headpond") level of el 23 m to el 25 m level, a post construction assessment was undertaken to include analysis with the actual conditions and material parameters at the site at that time. As part of that exercise, new calculations for the slope stability were done. In this analysis, it was found:

> "*On the upstream side, the observed and predicted conditions are as envisaged and no revision is required*". (PCA report page 55).
>
> "*On the downstream side, an additional analysis at Sector 9 has been carried out in order to verify the current state of the North Spur in the location of the 1978 slide. The profile is As-Built and the phreatic surface is derived from the instrument readings.*" "The *lowest value for the Factor of Safety is 1.46 for a shallow potential slide in the sand which has no significant effect on the overall downstream slope.*" (PCA report page 55)

For Sector 13, using the phreatic surface which was derived from piezometric measurements in 2018, the analysis indicated a minimum Factor of Safety above 1.5.

In order to understand the sensitivity of the Factor of Safety to a change in the water pressure, a sensitivity study has been performed. The main objective was to evaluate what condition could reduce the Factor of Safety to 1.3 and what is the time to reach that condition. This value was selected as a trigger level for intervention, although a Factor of Safety of 1.3 is below the recommended design value for long term stability, the slope is still stable for short term conditions, and such a value is normally used to indicate unusual conditions which may require intervention. For example, the CDA guidelines recommend 1.3 as the Factor of Safety to be considered for the condition of rapid drawdown.

There are three main changes that could have an impact on the slope stability:

- Change in soils stratigraphy and properties
- Change in slope geometry
- Change in ground water pressure distribution

It is very unlikely that the soils stratigraphy and properties would change. Tests results have been showing the same values since 1979 and the test results are consistent.

The slope geometry could potentially change but flattening of the slopes and provision of erosion protection at the toe as part of the Works are measures that were undertaken to prevent this from occurring. The North Spur is to be treated as a dam, and as such regular inspection and maintenance will be undertaken to ensure that the current geometry is maintained, as recommended by the CDA.

The slope stability variable which is most likely to have a potential impact is the groundwater pressure distribution. For this reason, 42 piezometers have been installed in the Spur to follow the behavior of this parameter.

To determine the groundwater pressure distribution which could reduce the Factor of Safety to 1.3, an increase in the pressure distribution was simulated using the slope stability analysis software. This analysis was also able to provide an estimate of the time required for the change to occur.

2 Reaction of North Spur to Groundwater Pressure Changes

The time required to cause an impact to the groundwater pressure in the North Spur and cause a reduction of the Factor of Safety from the current condition (greater than 1.5) to a value of 1.3 was examined. Data on the behavior of the North Spur collected during the past 38 years was used in the analysis.

The reaction time and the increasing or decreasing groundwater pressure was determined based on the observed piezometer reaction time as shown in this data. The maximum increasing rate (worst case scenario) in the piezometers in the North Spur was found to be 0.03 m/day.

The ground water pressure change which would be required to reduce the Factor of Safety to 1.3 was calculated to be an increase of 4 m to 12 m in equivalent pressure, depending of the location of piezometer being examined. It will take about 140 to 420 days to reach the condition which could reduce the Factor of Safety to 1.3.

The piezometers are currently read on a daily basis, and it is planned that they will be read regularly during operation. The data collection is automated and connected to a central location to facilitate the reading of the instruments. Therefore, any increasing trends will be identified well in advance of the change being a concern, allowing time for identification of the cause, and intervention, if required.

3 Corrective Action, If Required

If the Factor of Safety decreases to 1.3, there are a number of actions that could be taken to return the Factor of Safety to 1.5. These actions could include:

- Adding a berm at the toe of the slope to increase the weigh and therefore the Factor of Safety at that location.

- Installing relief wells in the intermediate aquifer to reduce the groundwater pressure in that way increase the Factor of Safety to 1.5.

4 Conclusion

The actual stability of the North Spur following the completion of the Stabilization Work is as expected in the design report and it is stable. The level of stability is in accordance with the good practice and consistent with the recommendations of the CDA guidelines.

In order to define the trigger conditions that may require action or intervention at the Spur, a sensitivity analysis of the slope stability was performed. A minimum acceptable short term Factor of Safety of 1.3 was selected as the trigger value and it was found that a significant rise in groundwater pressure would be required (4 to 12 m) and that significant time (140 to 420 days) would be required before values of concern to be reached. Regular monitoring and inspection is in place, so any change would be observed well in advance, allowing ample time for intervention, if required.

Regis Bouchard, ***P. Eng., M.Sc.***
Lead Geotechnical Engineer
Muskrat Falls Hydroelectric Project