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Nalcor Energy - Lower Churchill Project

Assessment of North Spur Construction Processes

Draft Report

MFA-HE-CD-2800-GT-RP-0002-01
Rev. A1
September 18, 2015

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2015-09-18	A1	Client Review	R. Donnelly	T. Chislett	T. Chislett
DATE	REV.	STATUS	PREPARED BY	CHECKED BY	APPROVED BY

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This report, has been prepared by Hatch for the sole and exclusive use of Nalcor Energy (Nalcor) (the “Client”) for the purpose of assisting the management of the Client in making decisions with respect to certain construction practices presently being employed for the construction of the North Spur earth structures as part of the Muskrat Falls Hydroelectric Development and shall not be (a) used for any other purpose, or (b) provided to, relied upon or used by any third party.

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Executive Summary

In April of 2015, construction activities to implement the designs for the North Spur commenced. As part of the Quality Assurance program for this contract, Nalcor requested Mr. C. Richard Donnelly (the Constructability Advisor "CA") to visit the site and, based on his 38 years of experience in earthworks and heavy civil construction, offer an opinion on the following matters:

1. North Spur upstream blanket
   i) The requirements for processing Zone 1 and 1C fills.
   ii) The requirements for processing of Zone 2A and 2C filter materials.
   iii) Methods being used to produce riprap.
2. Bedding materials used for construction access roads.
3. Issues associated with the cement-bentonite cut-off wall.

On the basis of the additional information and assessments performed during this site visit, Hatch is of the opinion that the structures are of a conservative design and are being constructed in accordance with standard industry practice. On the basis of the inspection and interviews conducted, the CA is of the opinion that, in some cases, the planned methods to produce the specified fills introduce an unnecessary cost premium due to the fact that there are more simpler and more typical methods available that would achieve the required quality. In addition, there appears to be a lack of QA supervision at the work faces to ensure that these less costly methods are performed effectively.

The general conclusions and observations of the CA contained in this report are listed in Table ES-1

Table ES-1: Summary of Observations and Conclusions

Issue	Recommendation
Intended Method for Processing of Zone 1 fill	The overall quality of the Zone 1 fill in terms of consistency, homogeneity and oversize above the specified 300 mm maximum in pit was observed to be very good to excellent. The CA is of the opinion that selective exploitation and adequate QC/QA in the pit and at the borrow site would result in a good quality fill meeting the requirements of the specification. It is reported that this could result in cost savings of up to $1.0 million.
Zone 1C fill	The Zone 1C fill is intended to be placed overtop of the bedrock surface and overtop of the cement-bentonite wall. In this case, elimination of oversize greatly enhances the quality of the contact fills. As such, the processing measures that were used to achieve the good to excellent quality of fill observed are considered to be appropriate and prudent.

Issue	Recommendation
Zone 2A fill	The Zone 2A fill was processed to provide a high quality uniform fill free of oversized pieces and meeting the specified gradational limits. This zone forms part of the downstream inverse filter blanket. As oversized pieces in a filter zone increase the risk of segregation and piping, and a uniform fill provides a filter zone that is internally stable which also reduces any risk of piping, the processing measures that were used to achieve the good to excellent quality of fill observed are considered to be appropriate and prudent.
Zone 2C fill	Given the overall good quality of the Zone 1 fill and fine filter, it is the opinion of the CA that there is no material risk associated with an occasional oversized rock fragments in this zone. In addition, based on review of the oversized pieces observed in the waste pile from the processing activities, the percentage of fragments greater than 300 mm is sufficiently small that adequate QC/QA in the pit and at the fill site would result in a good quality fill meeting the requirements of the specification. As such, processing is not considered to be required that is reported to result in savings in the order of $0.5 million.
Risks	Given the overall good quality of the Zone 1 fill and filter it is the opinion of the CA that the risks associated with stability and piping of the blanket are insignificant.
Riprap	The riprap has been designed in accordance with standard and accepted methods. However, it was observed that a considerable amount of effort is being performed to down individually break down large rock fragments to meet the specification. This is unusual and, in the opinion of the CA is resulting in higher costs than are necessary. The CA would recommend the following for consideration • Make some adjustments in the quarry to avoid the production of excessively large rock fragments • Consider adjustment of the thickness of the specification to allow, for example, a thicker riprap layer and larger pieces • Undertake selective exploitation and stockpile the oversized pieces for use to armor the left abutment in the cofferdam closure area
Road Bedding	The CA observed that crushed rock was being used for road bedding. It was reported that this was considered to be less costly than using quarry run rock fill due to reduced quantities. This, in the experience of the CA is highly unusual. It is strongly recommended that a full bottom up estimate review be performed to verify the total costs associated with delivery of quarry run rock to the processing site, processing, excavating and hauling to the stockpile site, excavating from the stockpile, hauling and placing at the fill site be compared with direct haul from the quarry. In addition, the CA questions the use of a thin layer of bedding as a minimum thickness is needed to support haul trucks. There are also areas where the original ground is such that a bedding layer may not be required.
QA Supervision	In the opinion of the CA, at the time of the site visit the field supervision by Nalcor was inadequate, particularly for a time and materials style target price contract

Issue	Recommendation
Cement-Bentonite Wall	It was reported that the strength gain issues with the as-built wall compared with the original laboratory expectations are in the process of being resolved. In the opinion of the RE, the reasons for the anomalies need to be fully explained and the stress strain characteristics of the mix that is now being used verified to ensure that it meets the design intent for due diligence purposes The CA is, however, of the opinion that this matter will be successfully resolved such that no remedial action will be needed.
Borrow Utilization	A borrow utilization plan was not presented. The CA did note that there is extensive overburden materials in the quarry area that appear to be suitable for use as temporary fill for roads of lay down areas that is not being utilized. It is recommended that an overall borrow utilization plan be prepared if it does not already exist.

1. Introduction

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 forms part of the water retaining envelope and as such, 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. Such features are very common at hydroelectric sites in Canada. For example, the East Bank Terrace at the Steephill Falls GS and the East Terrace at the Dunford GS, both owned and operated by Brookfield Renewable power in Northern Ontario are very similar examples of very similar features. Both are functioning well but did require careful geotechnical designs and treatment to ensure their long-term reliability.

In the case of the North Spur, it is necessary to maintain and stabilize the asset against the natural degrading processes of landslides and mass wasting. This, therefore, requires a full and complete understanding of the stratigraphy and soil mechanics of the deposits to exploit the asset safely and economically.

Figure 1-1: The Muskrat Falls Development and the North Spur

The spur consists of 20 m of sand, 40 m of stratified sensitive clays and sands, then sensitive clay to 100 m below sea level. At the north limit of the spur, this clay is underlain by 200 m of alluvium (i.e., to 300 m below sea level). It is fed by groundwater emanating 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 leading to an increased potential for slope instabilities. In addition, turbulent eddies from the falls have eroded and still erode the toe of the spur and the river banks causing slides.

Figure 1-2: 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 tail water 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

The construction activities at the North Spur are to implement designs intended to ensure the long term stability of this natural dam and include upstream sealing and downstream filtering/slope stabilization. Conceptual details of the design are provided in Figure 1-1.

In April of 2015, construction activities to implement the designs for the North Spur commenced. As part of the Quality Assurance program for this contract, Nalcor requested Mr. C. Richard Donnelly to visit the site and, based on his 38 years of experience in earthworks and heavy civil construction, offer an opinion on the following matters;

1. North Spur upstream blanket
    i) The requirements for processing Zone 1 and 1C fills
    ii) The requirements for processing of Zone 2A and 2C filter materials
    iii) Methods being used to produce riprap
2. Bedding materials used for construction access roads
3. Issues associated with the cement-bentonite cut-off wall

This report summarizes the conclusions reached on the basis of the site visit and interviews personnel from the Lower Churchill Project.

2. Background

The design of the North Spur includes the following components;

- An upstream impervious blanket that ties into a cement-bentonite cut-off wall in order to reduce seepage volumes, gradients and pressures
- A downstream inverse filter blanket designed to collect and filter seepage that passes through the upstream seepage control measures
- Riprap and riprap bedding to protect the fills from erosion.

Details of the design of the upstream membrane are provided in Figure 2-1.

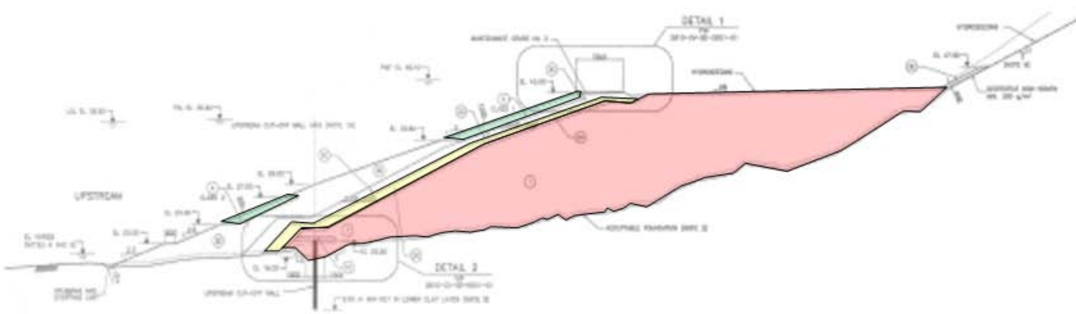

Figure 2-1: North Spur Upstream Impervious Blanket

Gradational characteristics of the fills that were assessed during the visit are summarized in Figure 2-2.

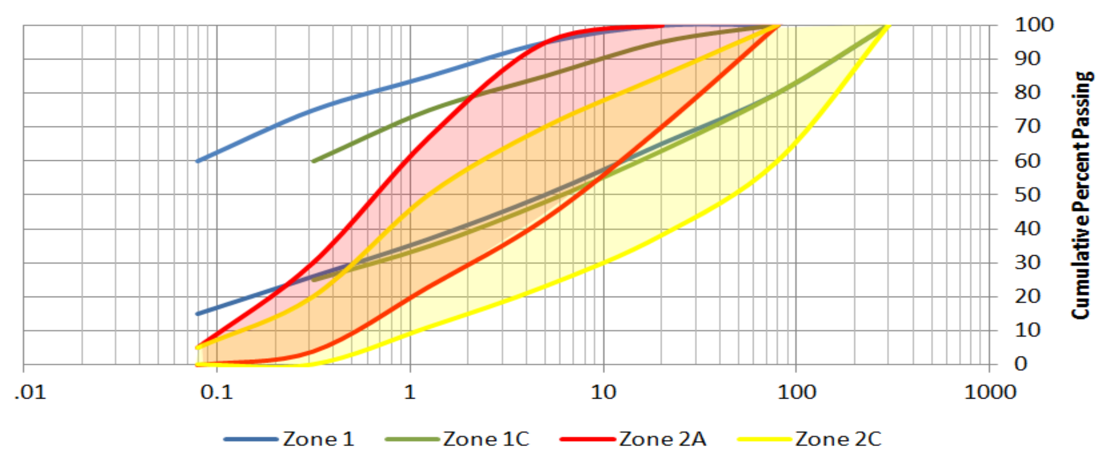

Figure 2-2: Gradational Characteristics of Impervious Blanket Fill Materials

A summary of the required volumes of the various fills and intended purpose are provided in Table 2-1.

Table 2-1: Estimated Quantities of Fill Materials

Zone	Max size (mm)	Quantity (m^3)	Remarks
1	300	225,000	Impervious Blanket
1C	80	9,500	Select impervious materials for placement over the bedrock surface and overtop of the cement-bentonite wall.
2A	80	103,000	Fine filter required on the downstream slopes to filter seepage waters within the downstream reverse filter.
2C	300	81,400	Course granular transition zone
4 (Class 1 to 3)	600 - 750	59,450	Rip rap, maximum sized varies depending on the location.

3. Observations

At the time of the visit to the North Spur the main activities included;

- Access Road construction
- Material processing
- Quarry operations

It was reported that there was an issue with respect to the strength gain of the cement-bentonite cut-off wall. For this reason, placement and compaction activities had been temporarily suspended.

3.1 General Observations

Overall, the site was observed to be well organized, neat and tidy. The limited fill placement that had been performed were seen to be of acceptable quality with due attention to layout. The quality of the Zone 1A fill was very good due to the use of screening to remove all but fine gravel from the fill. Similarly, the Zone 2a fine filter had been processed and stockpiled with no apparent oversized pieces present.

There did appear to be some equipment that were not being fully utilized and some issues associated with multiple handling of fill materials that will be discussed herein. Overall, the measures used to ensure the quality of the fills are effective but, in some cases, may be resulting in an unjustified cost premium due to the fact that other, more typical and less complicated method could produce fill materials of the required quality.

3.2 Impervious Fill

There are two types of impervious fill being used at the site. Zone 1A fill is intended to be used as fill to be placed over top of the bedrock surface and overtop of the cement-bentonite wall. In accordance with good engineering practice, this contact layer is specified to be free of rock fragments in excess of 80 mm in size and would typically be placed in reduced lift thicknesses slightly wet of optimum. To achieve this requirement the contractor screened the till deposit producing a uniform excellent quality fill free of oversized pieces. A view of the screened stockpile is provided in Figure 3-1.

Figure 3-1: View of Zone 1A Screened Stockpile

While the till materials in-situ did not appear to have an excessive amount of materials in excess of 80 mm in size, the processing that was performed is considered to be a prudent investment to ensure that the critical contact layer is well compacted and well sealed overtop of the wall and overtop of the bedrock surface. For this reason, the cost premium invested appears to have been effective and prudent.

In the case of the Zone 1 fill, the specification allows for a 300 mm maximum size and, given the width of the zone, an occasional rock fragment in excess of this size embedded in the fill would not result in a quality issue. Based on observation of the oversized materials stockpiled from the Zone 1C processing operation, a very small percentage appeared to be in excess of 300 mm (Figure 3-2). Therefore, the CA believes that the planned processing using a grizzly is not necessary. Normal QC procedures involving selective exploitation in the pit and raking as required at the fill site will be effective in producing a good quality fill meeting the specified requirements. It is understood that this would result in savings in the order of $5 to $7 per m3.

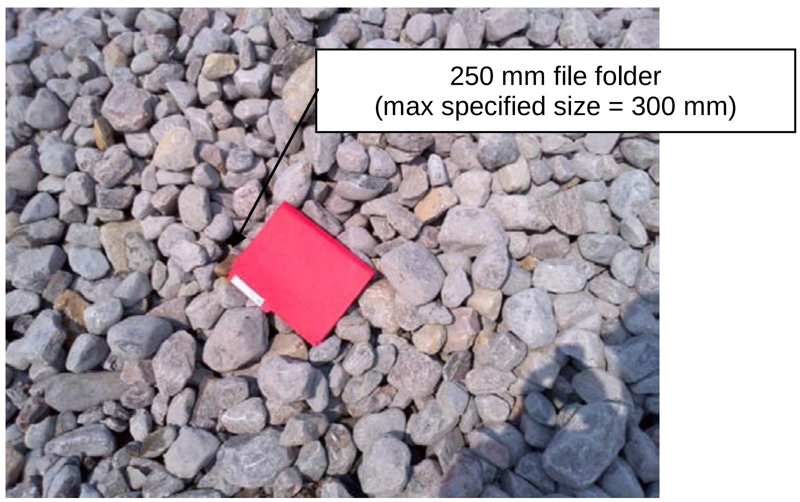

Figure 3-2: View of one of the Oversized Waste Stockpiles

3.3 Granular Fill

As with the Zone 1A fill, oversize control in any filter is an important requirement to avoid segregation which can be a trigger for the onset of piping. The Canadian Dam Association notes that;

> "…..In the case of internal erosion, the root cause is related to a lack of filter compatibility in situations where the voids of the filter material are too large to restrain movement of the finer base materials [in this case fines in the North Spur overburden]."

For piping and loss of fines to occur, there needs to be a release mechanism such as an incompatible downstream filter or segregation at the boundary between the filter and the base material to serve as a trigger to initiate the loss of fines from the base material into the filter and subsequently out of the filter blanket. Therefore, if an adequate downstream filter is provided, free of any significant segregation that can permit the initiation of piping, the literature shows that internal erosion incidents does not occur. For example, in Canada, in all but two cases, the problems only occurred in dams that either had no filters or filters that did not meet modern filter criteria. In the case of the two examples of dams that did have filters that satisfied modern criteria, one of the problems was associated with a incompatible foundation (personnel communication) and one had a suspected internal erosion problem that was successfully arrested due to a well designed filter.

Table 3-1: Canadian Dams with Reported Problems with Internal Erosion

Location	Dam Name	Year	Filter Characteristics*		Core		Incident
			d^{15} max	D Max	Type	% fines	
Ontario	Conostogo	1958	Homogeneous		Till	Unknown	Sinkhole after 2 years
	Kelso	1962	Homogeneous		Till	Unknown	Piping on first filling
Alberta	Whitmans	1951	1.6	64	clayey silt	80-90	Sinkhole after 44 years
Nova Scotia	Wreck Cove	1978	8	100	silty till	15-30	Sinkholes/piping on first filling
Labrador	Churchill Dykes	1970	17	200	silty till	10 to 35	Sinkholes after 2 years
Quebec	LG3 South dykes	1981	0.7	75	till	20-50	Sand boils within 1 year
	Manicougan 3	1975	0.2	Unknown	sandy silt	Unknown	Suffusion initiated but arrested by filter
BC	WAC Bennett	1996	Incompatible		Blended moraine		Deep sinkholes/ core softening after 30 years

** For typical Canadian tills, filters with a d_{15} max of 0.7 or less and a D max of 75 are typically resistant to internal erosion*

Processing of the Zone 1A fill has been performed that produced a good quality fill free of oversized rock fragments as illustrated in Figure 3-3. On the basis of these discussions the key issue to avoid internal erosion is ensuring that the filter meets modern criteria and that issues associated with segregation are materially avoided. For this reason, the processing performed for the Zone 1A fills is considered to be prudent and a worthwhile investment.

Figure 3-3: Example of the Processed Zone 3A Fill

The Zone 1C fills are intended to serve as a filter between the Zone 1 fill and the upstream erosion protection fills. In this case, given the width of the Zone 1 blanket planned and the fact that the potential for movement of fines only occurs when water level; fluctuations occur and only for a short period of time, the maximum size allowed is 300 mm. The CA considers this to be an appropriate and cost effective design that will allow pit run fills to be used without any processing required. Normal QC procedures involving selective exploitation in the pit and raking as required at the fill site will be effective in producing a good quality fill meeting the specified requirements. It is understood that this could result in savings in the order of $5 to $7 per m^3. During placement, full time QC/QA in the pit and particularly at the fill site is recommended to clean up any segregation that does occur.

3.4 Riprap

Blasting in the quarry is resulting in some of the rock fragments being larger than the maximum specified riprap size of 750 mm as is shown in Figure 3-4.

Figure 3-4: Example of Oversized Rock Fragments in the Quarry

These rock fragments are being loaded and hauled to a stockpile area where they are being individually broken down using a hoe ram and backhoes to move the materials. They will then need to be re-handled and hauled to the site for placement. It is reported that this is a continuous operation which, at the time of the visit involved the hoe ram and two backhoes working to produce smaller sized riprap

In the experience of the CA, this is a highly unusual operation and it is questionable if it is a cost effective method to produce riprap. The CA would offer the following suggestions for consideration;

1. Can operations in the quarry be modified in order to reduce the amount of oversize produced?
2. If not, can much of the oversize be simply used? Even if rock fragments exceed the maximum specified particle size, provided that they are randomly placed, the intent of the specification would be satisfied as it is the minimum size that is important to ensure adequate weight is available to resist wave action.

3. If this is not in accordance with the design requirements, can the larger riprap pieces be stockpiled and used to armor the left cofferdam abutment in advance of the closure activities?

The CA also observed that at least some of the riprap fragments hauled to the stockpile appeared to be within or very close to the specified maximum size. It is recommended that in-pit QC/QA be performed to ensure that only truly oversized pieces are hauled to the stockpile area, if this unusual methodology is to continue.

3.5 Construction Access Roads

As shown in Figure 3-5, crushed rock is being used for construction access road bedding. It was reported that this was considered to be less costly than using quarry run rock fill due to reduced quantities.

This, in the experience of the CA, is highly unusual. It was observed that the processing operations involved

- Excavating, hauling and dumping the quarry run rock fill to the crucher
- Excavating, hauling and dumping the crushed rock product to stockpile
- Excavating, hauling and dumping the crushed rock product to the placement site

It is strongly recommended that a full bottom up estimate review be performed to verify the total costs associated with processing the rock sand multiple handling be compared with direct haul from the quarry. In addition, the CA questions the use of a thin layer of bedding as a minimum thickness is needed to support the haul trucks. Therefore, even if it can be shown the costs of a crushed rock base is comparable to quarry run, the quality of the base is lower as the risk of punching through into the foundation is higher. In touring the site, the CA noted that all other roads have been built in a more traditional including the roads on the right bank and the Trans-Labrador highway.

Figure 3-5: Crushed Rock Road Base Spread over-top of what appears to be Suitable Natural Road Base Materials

Other observations with respect to haul roads include;

- There are areas where the original ground is such that a bedding layer may not be required.
- Overburden materials presently wasted in the quarry area may be suitable for use as road base
- It was reported that grubbing is not done in Labrador due to the fact that the vegetative mat is thin and offers considerable bearing strength

3.6 QA/QC Supervision

The CA did not observe any QA/QC supervision during the site inspection. While it is acknowledged that there was minimal activity due to the delay associated with the cement-bentonite wall, it was reported that QA supervision is minimal (one person per shift). It appears that the contractors QC is being achieved through the processing activities which would appear to be an expensive method (as discussed previously). In the opinion of the CA, investment in additional QA supervision, including full time inspection for critical activities and a qualified superintendent, should be considered.

3.7 Borrow Utilization

It is not clear if a formal borrow utilization plan was prepared. The CA did note that there is extensive overburden materials in the quarry area that appear to be suitable for use as temporary fill for roads or lay down areas that is not being utilized. There are also granular materials being excavated for the roads and the required excavations that may also be suitable as temporary fill. If one does not exist, It is recommended that an overall borrow utilization plan be prepared. If it does not already exist it should be updated.

3.8 Cement-Bentonite Cut-off Wall

At the time of the site inspection testing was being performed to verify the quality of the cement-bentonite mix design. It was reported that the results were positive, but that the strength gain characteristics were different than what had been measured in the laboratory prior to the commencement of the work.

The CA would recommend that the causes of the difference be determined and then as-built stress strain characteristics of the cement-bentonite wall be determined by means of triaxial testing to ensure they are in line with the design requirements.

4. Conclusions

On the basis of this current assessment the following was concluded;

- The processing for the Zones 1C and 2A fills is cost effective and providing a very good quality material with virtually no risk of segregation. The CA did note that the processed gradation of the fills generally appears to be finer than required under the specifications. Therefore, some savings might have been possible if a coarser screen was used.
- There is no need to process Class 1 or 2A fills. QC/QA inspection during placement provides a far most cost effective means of eliminating risks associated with segregation.
- The method of breaking down individual rock fragments for riprap does not appear to be cost effective. Adjustments to quarrying practices, the specification to permit the use of occasional oversized rock fragments or stockpiling to armor the left bank closure area are suggested.
- Road building practices are not in line with typical practices. The CA questions the cost effectiveness of using crushed rock as a road base. Quarry run rock fill provides a thicker, more robust base and is in line with normal practices in Labrador and elsewhere.
- There appears to be insufficient QA/QC inspection on the site. In particular, for the North Spur style of contract, full time QA supervision for critical activities often provides substantial cost savings if inefficiencies are identified.
- The methods used for producing riprap are unusual and do not appear to be cost effective. Several alternative suggestions were provided.
- There appears to be opportunity for improvement with respect to borrow utilization. If a formal borrow utilization has not been prepared it should be. If it has been prepared, it should be reviewed
- The as-built stress strain characteristics of the cement-bentonite wall for the mix presently being used should be established by means of triaxial testing to ensure they are in line with the design requirements.

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