Design and construction of Nemiscau-1 Dam, the first Asphalt Core Rockfill Dam in North-America

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ABSTRACT:

The concept of asphalt as a waterproofing medium inside embankment dams was first developed in Germany in the 1960s. Since the first Asphalt Core Rockfill Dam (ACRD) was built, more than 100 dams have been completed or are under construction. All these dams have an excellent record with no seepage problems or required maintenance.

After using for more than 50 years the glacial till as waterproofing material for its embankment dams, Hydro-Québec is now looking forward to develop new dam concepts, mainly for the zones where natural waterproofing materials do not exist. In order to do so, Hydro-Québec has decided to design and construct the Nemiscau-1 Dam as a prototype Asphalt Concrete Core Rockfill Dam. Being one of the retaining structures of the Eastmain-1-A-Sarcelle-Rupert Diversion project, situated in the North of Quebec, the design of this 15 m high dam follows the experiences and standards of many constructed Hydro-Quebec dams that have a very good record. The given dam site, geology and materials are well suited for a dam with an asphalt core. The chosen core thickness of minimum 400 mm is appropriate, given the small net water head of 7.6 metres. The paper will present the detailed design criteria, technical specifications and finally, some information concerning the construction of the dam.

RÉSUMÉ:

Le concept de barrage avec un noyau en béton bitumineux comme élément d'étanchéité a été développé en Allemagne au début des années soixante. Par la suite, plus de 100 barrages de ce type ont été construits ou sont actuellement en construction. Tous les barrages en enrochement avec noyau en béton bitumineux ont une excellente et unique feuille de route, aucun problème de comportement ou besoin d'entretien n'étant signalés jusqu'à présent.

Après avoir utilisé pour plus de 50 ans la moraine comme matériau d'étanchéité pour ses barrages en remblai, Hydro-Québec veut maintenant faire appel à de nouveaux concepts de barrage, pour les appliquer dans les régions où les matériaux naturels imperméables sont déficitaires. Pour ce faire, Hydro-Québec a pris la décision de construire un barrage prototype en enrochement avec noyau en béton bitumineux et c'est le barrage de la Nemiscau-1, un des ouvrages de retenue de l'Aménagement hydroélectrique Eastmain-1-A-Sarcelle-Rupert qui a été choisi à cet effet. Les critères de conception de ce barrage de 15 m de haut reflètent bien les pratiques et l'expérience acquises par Hydro-Québec suite à la construction de nombreux ouvrages de retenue, qui ont enregistré un comportement très satisfaisant en exploitation. Les conditions géologiques du site, ainsi que les matériaux de construction disponibles sur place sont favorables pour la réalisation d'un barrage de ce type. En tenant compte que la charge hydraulique effective est de 7,6 m, le choix d'une épaisseur du noyau de seulement 400 mm est justifiée. L'article présente les critères détaillés de conception adoptés, les clauses techniques particulières pour la construction du noyau en béton bitumineux et des zones de transition et finalement, certaines informations concernant la construction du barrage.

1. Introduction

Through the design and construction of the Nemiscau-1 Dam, Hydro-Québec wanted to gain experience with asphalt concrete core construction, before proceeding with the final design and construction of the much larger dams or dykes for the La Romaine Complex. Hydro-Quebec has extensive and successful experience with the design and construction of earth core rockfill dams (ECRD) and wanted to use as much as possible of that practice, with respect to types of materials, dam zoning, compaction procedures, upstream slopes related to the riprap design, yet adapt the design to the special features and requirements of the Asphalt Core Rockfill Dam (ACRD) concept.

2. The Asphalt Core Rockfill Dam (ACRD), a safe and cost effective choice

Since the first Asphalt Core Rockfill Dam was built more than 45 years ago, some 100 dams have been completed or are under construction. All these dams have an excellent record with no seepage problems or required maintenance.

Asphalt core embankment dams have proved to be an economical and very safe alternative to other traditional designs. The dams have been constructed under various climatic and foundation conditions. The flexible properties of the asphalt make Asphalt Concrete Core dams especially suitable in earthquake areas. Furthermore, asphalt core construction is to some extent, independent of weather conditions. This concept has been proved to be cost efficient in both wet and cold areas.

3. Design and construction of Nemiscau-1 Dam, the first ACRD in North-America

3.1 General design considerations

The dam is located in a tail bay with many rock outcrops in the vicinity of the axis. The geology of the dam site consists of Precambrian rocks, generally massive, with high strength. Lower RQD's were estimated in the upper 2 m mainly due to the stress relief joints and at some places, to the weathering and infilling of those joints. Several shear zones were identified and treated after the excavation of the overburden. The water pressure tests showed, in general, low permeabilities and the grout consumption was low to moderate, with some local exceptions.

On the abutments, the loose to dense overburden of glacial till (silty sand and gravel, cobbles and boulders) is 0 to 2 m, locally exceeding 5 m. On the bottom of the river, the overburden consists of sandy silt, silty sand and locally of sand and gravel, with a density varying from very loose to compact, a similar situation being noticed between the two branches of the river.

The main reservoir levels considered for the design of the Nemiscau-1 Dam are presented in Table 1.

3.2 Characteristics of the dam

The cross section of the dam is presented on Figure 1; the present design has an upstream slope of 1.8H : 1.0V (imposed by the design criteria of the riprap) and a downstream slope of 1.45H : 1.0V, a crest width of 7.5 m and a free board of 3.0 m above the Maximum Operating Level.

The main characteristics of the dam as originally designed with a theoretical rock profile and respectively, with a modified axis adapted to the real rock longitudinal profile, plotted according to the field collected data after the excavation of the overburden, are presented in Table 2.

3.3 Design criteria

Given the small net water head of 7.6 m, a core thickness of 400 mm is considered to be very appropriate for the dam. Internationally, several dams have been constructed using 400 mm as width of the asphalt concrete core and the experience with these dams is excellent.

The requirements to foundation preparation and plinth design are, in general, similar to those for a Concrete Faced Rockfill Dam (CFRD), but the plinth and the connection to the impervious element is much simpler. The main purpose of the plinth is to serve as a grouting cap to ensure high quality grouting to the base and as a horizontal surface for placing the first layer of the asphalt core and transitions zones, 2B. The concrete reinforcement is primarily used to reduce shrinkage cracking. The steel reinforcement and the bolts of the plinth were structurally designed for a maximum grout pressure of 160 kPa. Minimum average calculated plinth thickness is 0.5 m and absolute minimum thickness is 0.4 m.

In this particular case, the longitudinal profile of the rock excavation under the concrete plinth is designed to keep the inclination of the plinth in all locations less than 45° and the angle change between adjacent plinth sections less than 30°.

On Figure 4 is presented the longitudinal profile of the plinth with its cross sections.

Asphalt mastic is applied at the interface between the concrete plinth and the first layer of asphalt core, into waterstop box outlets and as a sealant into joints in the plinth. The mastic must be liquid enough to stick to any unevenness on the concrete plinth, as well as being stable enough to build the specified thickness on steep surfaces. Mastic consists of bitumen, aggregates and filler, and an appropriate adhesion agent that secure necessary bonding to the concrete plinth, previously sandblasted or green cut.

3.4 Asphalt mix design

The preliminary asphalt mix was made and tested with a bitumen content of 7.3%. Voids content (less than 2 %) was calculated on laboratory samples with the above mentioned bitumen content after compaction with 2x30 blows as defined by the Marshall method (ASTM D6926-04).

As a part of the asphalt mix design process, the stress-strain strength properties of the AC (asphalt concrete) where documented through Triaxial Tests, performed at an established consultant laboratory, the Norwegian Geotechnical Institute. The tests were

Table 1: Main reservoir levels

Definition	Level (m)
Minimum Operating Level	292.7
Minimum Inferior Protection Level (riprap)	293.0
Maximum Operating Level	297.5
Maximum Extreme Level	297.5
Minimum Downstream Level (Q=10 m³/s)	289.9
Downstream Level (Q= 100 m³/s)	±291.4

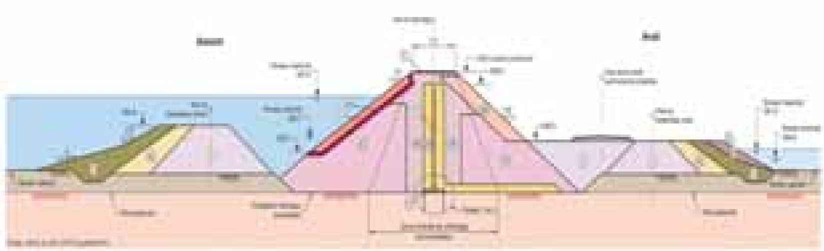

Figure 1: The Nemiscau-1 Dam, cross section

Table 2: Characteristics of the Nemiscau-1 Dam

Nemiscau-1 Dam: Characteristics	Original design with a theoretical rock profile	Reviewed design and axis with the real longitudinal profile of the bedrock
Maximum Height (m)	15	15
Top of the dam (elevation - m)	300.5	300.5
Crest length (m)	316	336
Crest width (m)	7.5	7.5
Upstream slope	(1.8 riprap); 1.6 H : 1.0 V	(1.8 riprap); 1.6 H : 1.0 V
Downstream slope	1.45 H : 1.0 V	1.45 H : 1.0 V
Total rockfill volume (m³) – without cofferdams	50,000	49,350
Total concrete volume – slab (m³)	410	504
Total asphalt concrete volume (m³)	750	650
Rock excavations (m³)	1,750	535
Overburden excavations (m³)	17,500	19,000

The zoning of the Nemiscau-1 Dam and the compaction pattern are described in Table 3.

Table 3: Nemiscau-1 Dam: zoning and compaction

Zone	Material	Compaction
9-Core	Asphalt concrete (bitumen type PG52-34)	3-4 passes, 0.5 to 1 tons vibratory roller (until void content <3%); layer thickness = 22.5 cm after compaction
2B – Transition zone	Well graded crushed gravel, max. 80 mm	3-4 passes, 1.5 to 2.5 tons vibratory roller; layer thickness = 22.5 cm after compaction
3B-Shoulder	Well graded crushed rock max. 150 mm	4 passes, 10 to 15 tons vibratory roller; layer thickness= 45 cm
3C-Shoulder	Well graded quarried max. 450 mm	4 passes, 10 to 15 tons vibratory roller; layer thickness = 90 cm
4B – Slope protection (downstream)	Selected rockfill max. 900 mm, with max. 20% < 200 mm	4 passes, 10 to 15 tons vibratory roller; layer thickness = 90 cm
4 – Riprap	Selected rockfill min. 400 mm - max. 600 mm	Placed with a backhoe

performed at a temperature of 5°C which corresponds to the main temperature estimated in the core; the confining stress was equal to 0.5 MPa. The maximum deviator stress for the Nemiscau-1 Dam tests was about 2.3 MPa. The ductility (horizontal plateau) of the Nemiscau-1 Dam specimens shows almost no strain softening and loss of resistance after the maximum level was reached, and excellent visco-elastic behaviour.

The AC (asphalt concrete) mix must be in accordance with the following requirements:

- o Density (kg/m^3) : >2.3 (ASTM D2041-03a)
- o Voids content on laboratory made Marshall specimens, compacted with 30 blows on each side (%) : < 2.0 (ASTM D3203-05)
- o Permeability factor (cm/s) : < 1.0 x10^{-8} (must be documented on 2 samples with a void content < 3.0 % as a part of initial mix design)
- o Marshall stability (N) : > 5000 (ASTM D6927-05, LC 26-060)

The aggregate size distribution should satisfy the Fuller gradation curve improved with approximately 13 % of filler (see Figure 7). The components weight adds up to 100%, before bitumen.

The aggregates shall comply with the specifications outlined in Table 5, page 17.

3.4 General construction of the dam

The construction of Nemiscau-1 Dam implies a General Contractor who is responsible for the construction of the upstream and downstream cofferdams, the excavations, including overburden and rock excavation, the foundation cleaning and treatment, the construction of the plinth, the grouting underneath the dam, the removal of any grouting spoils and the pumping/evacuating of any water from the surface before the beginning of the of core construction. The General Contractor must also build the dam embankment (zones 3B, 3C, 4, 4A, 4B and 5), with the exception of zones 9 (Asphalt Core, AC) and 2B (transition zones).

He must furnish and deliver material for transition zones 2B and natural sand and gravel 10 mm to 100 mm as a half – fabricate for the production of aggregates for the asphaltic core to the asphalt plant of the Specialized Sub-Contractor.

His tasks consist also in providing the geodetic survey of the center line of each layer of asphalt concrete and securing sufficient access to and on the dam for the Specialized Sub-Contractor.

The General Contractor is required to install the instrumentation in the dam and in the foundation of the dam including, vibrating wire piezometers, thermistors in the core, surface monuments, metallic rod on top of the asphaltic core and all associated cabling jointing equipment, terminal boxes, panels, readout equipment as shown on contractual drawings.

The Specialized Sub-Contractor is responsible for the placing of a mastic layer between the concrete slab and the AC core, the mixing and batching of the AC mix and he must place and compact the AC core; he must transport, place and compact the supporting transition zones 2B on each side of the AC core and carry on trial mixes and quality assurance testing for the AC.

Conventional practice established in Germany, Norway and elsewhere was to place and compact, on average, 2-3 layers of 200 mm asphalt concrete per day. On Nemiscau-1 Dam, the layers have a thickness of 225 mm after compaction and 2 to 3 layers should be placed each day. The asphalt core and the supporting transition zones must be built simultaneously in horizontal layers. This will be done in close coordination with the rest of the dam works, being under the responsibility of the General Contractor. The core and transition zones 2B shall never be more than two layers above or lower than the adjacent zones 3B. With a compacted layer thickness of the core and transition zones of 225 mm, this means a maximum level difference of 450 mm between the core and transition zones 2B and respectively, the zone 3B.

The machines and supplementary equipment for placing of the asphalt core (zone 9) and transition zones 2B were specially designed and constructed to meet the design specifications for this part of the dam. The paving machine is capable of placing simultaneously the core and transition zones 2B in 225 mm high layers (after compaction). The width of placed core material shall be 400 mm and the width of transition zones 2B shall be 1550 mm each.

Prior to starting any works on the dam, the Specialized Sub-Contractor shall carry out a trial section that proves the asphalt mix

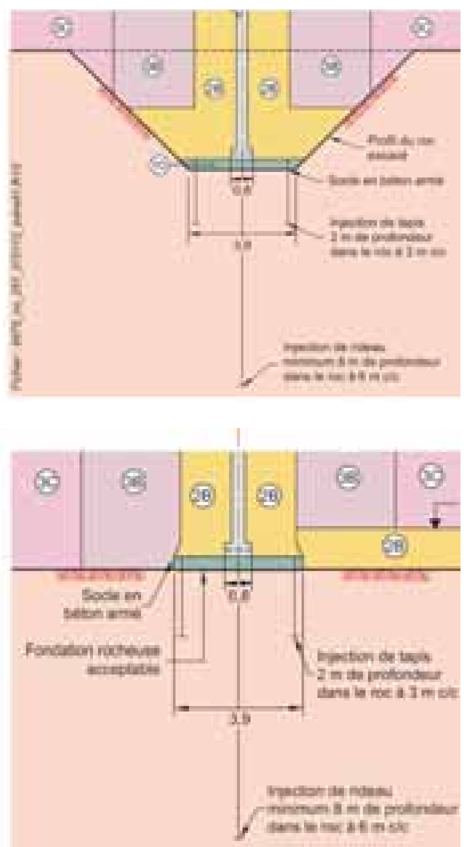

Figure 3: Rock excavation and plinth – details

Table 4: Testing the aggregates – tests, methods and requirements

Test	Test method	Requirements
Micro-Deval (MD), %	LC 21-070*	≤ 25
Los Angeles (LA), %	LC 21-400* (EN 1097-2) EN 1097-2	≤ 35
Micro-Deval and Los Angeles	MD+LA	≤ 70
Characteristics associated with the production of aggregates		
Fragmentation, %	LC 21-100**	≥ 20
Plate particles (grains), %	LC 21-265**	≤ 25
Flakiness Index, %	EN 933-3**	≤ 35
Elongated particles (grains), %	LC 21-265**	≤ 45
N.B.: Plate and elongated particles must be tested on the grain size retained by the 10 mm sieve		

*Standards of Quebec's Ministry of Transportation; ** To be performed at mix design

Nemiscau-1 Dam site – Rock excavation and concrete plinth

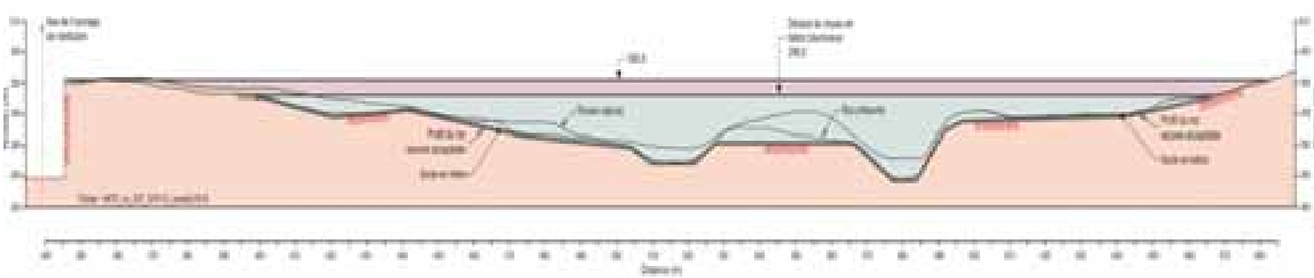

Figure 4: Nemiscau-1 Dam – longitudinal section of the plinth

production and conformity, the construction methods, machinery and personnel. Further, the trial shall be used to establish the compaction methods and compaction routine, and to prove that all machinery is fully operational and the personnel master their various duties.

The asphalt concrete mixing plant is a modern, automatically controlled batch plant (in compliance with the ASTM-D995-95b, 2002). The plant automatically loads and batches the correct weight for each constituent, with a computer printout showing the weight of each constituent and temperature of each batch. The automatic control alerts the operator if the weight of any constituent is outside preset limits for the temperature or if any part of the process is not within tolerance. Mixes that are outside tolerance will be rejected from the plant and will not be used on the permanent works. Temperature gauges are continuously monitoring the temperatures in the hot storage aggregate bins, of the bitumen and of the final mix.

Mixing temperatures for the asphalt with bitumen PG52-34 must respect the mixing temperature shown on the certificates proving the compliance with the technical specifications of the standard 4101 of Quebec's Ministry of Transportation.

The asphalt concrete will be analysed continuously during production and aggregate composition will not deviate beyond the tolerances specified in Table 5. Bitumen content must be within ± 0.3 % of that specified on the approved mix design which, as mentioned on section 3.4, is 7.3%.

Compaction of the core and the two transition zones 2B will be executed using three vibratory rollers. The AC core will be compacted by a vibratory roller spanning the core width, but no more than 100 mm wider than the core, with weight in the range of 500 - 1000 kg. After compaction, the layer thickness will be equal to 225 mm. The Specialized Sub-Contractor must provide an adequate number of passes, until the void content <3%. The AC must be compacted at a temperature of approximately 130°C – 150°C, before the temperature drops 14°C below the mixing temperature shown on the certificate of compliance of the bitumen.

The Specialized Sub-Contractor will present a formal Quality Plan (QP) including Working Procedures, where production, transport and placement are described, with special emphasis on Quality Assurance. The Specialized Sub-Contractor will supply and operate a fully equipped Site Testing Laboratory which includes equipment required for routine testing of samples taken from the batch plant and the core, and equipment for drilling of "in situ" cores/samples and testing for voids content.

The quality control program and tests are summarized in Table 5. (page 17)

4. Conclusion

Through the design and construction of Nemiscau-1 Dam, the first rockfill dam with an asphalt core in North America, Hydro-Québec wanted to gain experience with asphalt concrete core construction, before proceeding with the final design and construction of the dams or dykes for the La Romaine Complex. The construction of the Nemiscau-1 Dam started in May, 2008 and will be completed by September, 2008.

The first lesson learned from the construction of this dam was that the longitudinal profile of the rock excavation and concrete plinth must

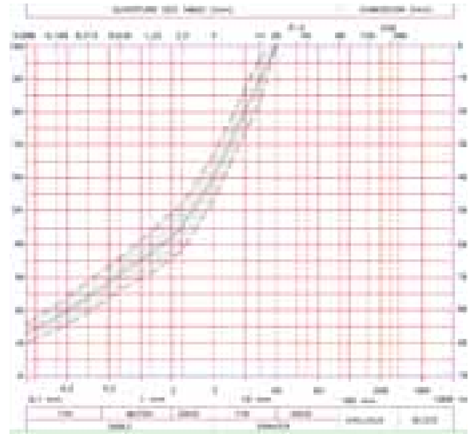

Figure 7: Aggregates for the asphalt concrete mix – grain size distribution

be optimized, with an optimum balance between the rock excavation, the volume and shape of the concrete plinth and finally, the placement of the asphalt core with the manual method. Several combinations of these 3 elements must be analyzed at the design stage and the most cost effective one should be applied on site.

Given its self compaction properties, imperviousness, flexibility and ductile behaviour, the asphalt mix designed for the Nemiscau-1 Dam, with an average bitumen content of 7.3 %, could be an interesting option for the construction of the dikes of La Romaine 2 facility and possibly, for other retaining structures of the Complex. ■

Construction of Nemiscau-1 Dam – The Asphalt Concrete (batch) plant

Table 5: Testing of Materials and Asphalt Core – Synthesis Table

Test	Frequency
o Quality certificate at delivery o Control tests of standard properties o Density	Delivery
o Grading curves	Weekly
o Los Angeles and Micro Deval values for the aggregates o Water absorption in aggregates o Adhesion to bitumen	At mix design and when there is a change in the source of material
On four Marshall specimens (ASTM D 1559-82): o Bitumen content o Aggregate size distribution o Bulk density o Maximum specific gravity o Voids content	Daily, for each layer
Three core specimens of AC (one tested by the Specialized Sub-contractor in his laboratory, another sent to a laboratory chosen by S.E.B.J. and the third one as a reserve): o Density o Voids content in the core o Water absorption o Marshall stability (N) o Bitumen content	One per week in the first two weeks and if satisfactory, Monthly
One measure for each layer	Daily
Nucleodensimeter apparatus or other non – destructive method	Daily, two per 1 layer
Measurement after compaction	Per 1 layer
o Grading curves (LC-21-040) o Density, min. and max. (vibrating table, CAN/BNQ 2501-058)	1 per week for the first two weeks and then, if satisfactory, monthly