Dam Safety and Seismicity

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Topics

1. The Practice of Dam Safety in BC Hydro
2. Bennett Dam Safety
3. Site C Project Dam Safety
4. Seismicity
The Practice of Dam Safety in BC Hydro
Dam Safety - Definition

- Encompasses all aspects of the safe retention and passage of water through and around BCH’s power facilities to avoid uncontrolled release of water
Dam Safety Governance

- BOARD OF DIRECTORS
- CHIEF EXECUTIVE OFFICER
- EXECUTIVE VICE-PRESIDENT GENERATION
- COMPTROLLER OF WATER RIGHTS
- DIRECTOR, DAM SAFETY
- CORPORATE COMMUNICATIONS
- STRATEGIC EMERGENCY MANAGEMENT (T&D)
  (Emergency Preparedness)

**DAM SAFETY PROGRAM**
- Surveillance
- Regulatory Requirements
- Investigations
- Risk Analysis & Prioritization
- Project Initiation & Technical Oversight
- Liaison with Other Owners

**KEY:**
- BC Hydro line management
- Important information or decision interface
Dam Safety Dept. – Surveillance Activities

• Visual Surveillance – weekly, 6 month intervals
  – General condition, depressions
  – Cracking, seepage
  – Anything unusual

• Special Inspections
  – Instrumentation Alarms
  – Spills, floods
  – Earthquake
  – High wind event

• Instrumentation – automatic and manual
  – Water levels and pressures
  – Flows, turbidity, temperature
  – Settlement, movement

• Yearly report to Comptroller of Water Rights
  – Audit maintenance and testing
41 Dam sites
10 Monitored Landslides
3000 km Reservoir Shoreline
Dam Safety Process

• Continual surveillance
• If the dam does not meet all performance expectations:
  • Initiate Investigations
  • Assess, prioritize and initiate capital improvements, if required
• Undergo external review
• Meet all requirements of the water license and the BC Dam Safety regulation
Bennett Dam Safety
Largest Energy Producer – WAC Bennett Dam

- Completed in 1968
- Located on Peace River
- 183 m high zoned earthfill dam w/ 2 km crest length
- Volume = 44 million m$^3$
- Reservoir volume = $41.3 \times 10^9$ m$^3$
- Total capacity of 2,730 MW from 10 U/G units

Now the 8th largest dam in North America by volume (Mica Dam @ 243m is highest in North America)
June 1996
Sinkhole Investigations

Survey Benchmark Tube
Why did the sinkhole occur?

2 sinkholes at 2 unique locations

"Impervious" core

Filters/Drains
Sands/Coarse sands/Gravels
Immediately following discovery of the sinkhole:

- Dam safety response initiated in accordance with Emergency Preparedness Plan, including notification to Comptroller of Water Rights
- Initiation of 24/7 surveillance
- Notifications to public

Investigation and remediation from 1996 to mid-1997:

- Continued 24/7 surveillance, emergency preparedness and public communications
- Extensive site investigations and installation/enhancement of dam safety instruments
- Sinkholes successfully remediated by compaction grouting using a soil mixture similar to original dam core material
Enhanced Instrumentation:

• Over 1,100 instrumentation points
• 230 key indicators on automatic data acquisition system:
  – Seepage flows and turbidity
  – Deformation monitoring, inclinometers
  – Piezometric monitoring
  – Thermal monitoring
  – Vertical flow measurements
Special External Reviews

1996 to 2000: Yearly Advisory Board meeting

2001 to 2006: Norwegian Geotechnical Institute concluded

- monitoring and reporting continuing in a very professional way
- no significant changes in the behavior of the dam
- suggested an external reviewer was no longer required unless there was a significant change in the monitoring equipment and surveillance program
2009 External Review by Hatch Chief Dam Designer concluded:

- System of instruments, monitoring, data assessment, and annual reporting is first class and highly reliable
- Program is well planned and executed
- Instrumentation system, process of data review is comprehensive
- Eminently capable of detecting anomalous behavior
- No anomalous behavior detected
2012 External Review by Expert Engineering Panel of three International Experts:

Concluded:

• Well designed and constructed
• Seepage flow rates stable for a number of years
• Pore pressures in the Core steady state
• Some erosion of the Core may have initiated in cracks formed by hydraulic fracture during first filling
• Good filter system that may allow a small amount of erosion but will prevent on-going erosion
• Large capacity to discharge leaks and to prevent instability
Site C Project Dam Safety
Overview

Dam safety a key element:

• Design by a highly experienced integrated engineering team

• Designed and constructed to Canadian & international standards, guidelines & best practices

• Comprehensive quality management, review and oversight will continue during design and construction

• Project would be operated, managed, maintained & monitored to Canadian & international dam safety practices
Integrated Engineering Team

BC Hydro (BCH) Engineering
• BCH’s in-house Engineering group with 50 years experience in design, construction, operation, maintenance, upgrade and dam safety management of hydroelectric facilities

Klohn Crippen Berger (KCB)
• Vancouver based consulting company with over 60 years experience with the design and construction of hydroelectric projects and dams

SNC-Lavalin Inc. (SLI)
• Canadian engineering and construction group with over 100 years experience with the design and construction of hydroelectric and water supply projects
Recent Sample Projects

- 30 m high Ruti earthfill dam (1975)
- 35 m high Dixon earthfill dam (1983)
- 43 m high Nipawin earthfill dam (1986)
- 137 MW Balambano Project with 92 m high RCC dam (2000)
- 185 MW Arrow Lakes Generating Station (2002)
- 120 MW Brilliant Expansion Project (2007)
- 1070 MW Nam Theun 2 Project (2010)
- 250 MW Puah Project with 78 m high earthfill dam (2014)
- Four embankment dams up to 40 m at Ambatovy Nickel Project (2014)
- 335 MW Waneta expansion projects (2015)
- 824 MW Muskrat Falls Project (2018)
Dam Safety and Design

- Project has adopted the highest Canadian Dam Association (CDA) classification for design, including the highest levels for flood & earthquake design
- Extensive investigations of site foundation and reservoir shoreline have been carried out over many years
- Earthfill dam and roller compacted concrete (RCC) right abutment buttress have been selected as best dam type & configuration for the shale foundation
- Instruments would be incorporated into the final design of the Project for future dam safety monitoring
Dam Safety and Floods

• Probable Maximum Flood (19,300 m$^3$/s)
• A free overflow auxiliary spillway:
  – spill capacity in the unlikely event of inoperable spillway gates
  – passing floating debris in a flood
  – Even with all generating units and spillway gates out of service, the Project could pass a flow of 4,000 m$^3$/s
Physical Hydraulic Model to validate design
Dam Freeboard (7.6 m) provides protection from:

- With the maximum normal reservoir level:
  - Set-up and waves by 1 in 1,000 year wind
  - Landslide-generated waves
  - Seismic seiche and settlements due to design earthquake
  - Freezing of the impervious core
  - Malfunction of spillway gates

- With the maximum flood level:
  - Set-up and waves by the 100 year wind
Specialist Advisors/Reviewers in addition to Integrated Engineering Team

**Dams, Excavations & Earthworks:**
- Mr. J. Gordon (Dam Layout)
- Dr. Derek Martin (Geomechanics)
- Dr. G. Mesri (Geotechnical)
- Dr. J. Fannin (Till Core Material)
- Dr. K.Y. Lo (Rock Swell Testing)

**Roller Compacted Concrete:**
- Mr. F. Andriolo
- Mr. B. Forbes

**Diversion Risk:**
- Dr. G. Baecher

**Reservoir Filling:**
- Dr. R. Boes

**Probable Maximum Precipitation/Probable Maximum Flood:**
- Mr. R. Hopkinson
- Mr. E. Tomlinson
- Mr. S. Hui

**Spillway Design:**
- Mr. H. Falvey
- Dr. P. Mason
- Mr. J. Cassidy

**Dissolved Gas Pressures:**
- Dr. J. Gulliver
- Dr. D. Weitkamp

**Hydraulic Modelling:**
- LaSalle Laboratories (Physical Models)
- Northwest Hydraulics (Numerical Models)
Technical Advisory Board:

- Members are globally recognized for their technical knowledge and experience with the design of hydroelectric projects around the world
- Provides independent due diligence, opinions, and advice on the technical aspects of the project design
- Reports to BC Hydro Executive Team and committee of the Board
- Continue to provide input to the Project as it progresses through final design and implementation
Construction

Under the Water Act:

- A conditional water licence would be required from the Comptroller of Water Rights (CWR) authorizing construction of the Project and would likely include a requirement that the proponent/licensee must retain an Independent Engineer.

- The CWR designates The Engineer, who is responsible for granting:
  - Leave to Commence Construction
  - Leaves to Construct (Project components, e.g. cofferdams, dam)
  - Leave to Commence Operation

- Once the Project is constructed and all conditions met, the CWR may issue a “final licence” authorizing the diversion and use of the approved quantity of water for a specified time period.
Independent Engineer

- The *Independent Engineer (IE)* will provide an independent review of the Project drawings, other relevant documents and water licence & environmental certificate requirements & commitments.

- Once satisfied that everything necessary is in place, the *IE* will make a recommendation to *The Engineer* that a Leave should be issued.

- *The Engineer* will review the recommendation, and if satisfied, issue the Leave to BC Hydro.

- Throughout construction, the *IE* will monitor the progress of detailed design and construction, compliance with water licence & environmental certificate requirements and commitments, and will make regular visits to the project site. The *IE* will provide regular progress reports on these activities to *The Engineer*.
Dam Safety During Construction and Operation

• BC Hydro is committed to integrating safety in all it does. BC Hydro conducts its operations to minimize the chance of injury to employees, contractors and the public.

• Site C would be incorporated into BC Hydro’s Dam Safety program, which complies with the BC Dam Safety Regulation.

• Emergency Preparedness Plans would be in place for each phase.
Seismic Considerations
Probabilistic Seismic Hazard Assessment

• BC Hydro recently completed a major system-wide probabilistic seismic hazard analysis (PSHA) that provides site-specific ground motions for all of its 41 existing dams and Site C

• The PSHA incorporated sets of weighted alternative models intended to represent the centre, body and range of technically-defensible interpretations of possible seismic source and ground motion prediction models

• For the region around Site C, the seismic source model included the potential for large earthquakes (up to M7.6) to occur on faults in the Peace River Arch, even though there is no known evidence that these faults are active
EIS Figure 11.2.14

Faults
Historic Earthquakes and Source Zones

EIS Figure 11.2.15
• EIS describes the performance of dams that have experienced large earthquakes and that lessons learned have been incorporated into the design

• The seismic performance of the Project is being evaluated for up to the 1/10,000 year ground motions (horizontal peak ground acceleration 0.25g)

• Expected movements under the 1/10,000 year ground motions would be much smaller than these structures could accommodate and would not impair their ability to retain the reservoir
Summary:

- BC Hydro has undertaken the largest and most comprehensive seismic hazard analysis in Canada to date
- Design of the Site C Project is robust
- The dam would withstand earthquakes greater than 1/10,000