UPGRADING OF BOUNDARY DAM SPILLWAY

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ABSTRACT

The paper presents a challenging dam safety upgrade project, from the initial dam safety review performed in 2005 through to the $40 M rebuilding and upgrade of the gated spillway in 2008 through to 2010. In 2005 SaskPower retained KGS Group to perform the first dam safety reviews of several of their hydroelectric and water retention dams, including Boundary Dam. The 29 m high dam and concrete spillway impounds a reservoir used for cooling water for SaskPower's 980 MW Boundary Dam thermal generating station. The dam safety review identified a number of concerns, the most critical of which were the insufficient spillway capacity and deficiencies with the condition of the existing spillway. Minor remedial measures were performed in 2006 to 2007, and following additional investigations in 2007, SaskPower retained KGS Group to increase the design spillway capacity to 1200 m^3/s (a design flow increase of over 50%) and remedy the observed defects. The final design included maintaining the reservoir at full supply level while the 230 m long spillway chute and stilling basin below were completely replaced. The challenging foundation includes weak bentonite seams within siltstone, mudstones, and coal layers, which when combined with high groundwater pressures, led to slope stability concerns as well as rebound and settlement of the foundation. A critical site challenge was to design and complete each year's construction such that the spillway could potentially pass spring flood flows. Work commenced in 2008 and was completed in 2010.

RÉSUMÉ

Cet article présente un projet de révision de sécurité de barrage, de l'examen initial de sécurité réalisé en 2005 jusqu'à la construction de 2008 à 2010 d'un déversoir réglable d'une capacité accrue et d'une valeur totale de 40 millions de dollars. En 2005, KGS Group a été engagé par SaskPower pour effectuer les premiers examens de sécurité sur plusieurs de leurs réservoirs hydroélectriques ou de rétention d'eau, dont le Barrage Boundary. Ce barrage, d'une hauteur de 29m, et son déversoir en béton forment une réserve d'eau utilisée pour le refroidissement de la centrale thermique de Boundary exploitée par SaskPower et d'une capacité de 980 MW. Lors de l'examen de sécurité, de nombreuses préoccupations furent identifiées, les plus critiques étant la capacité insuffisante du déversoir et son état dégradé. Des mesures correctives mineures furent appliquées en 2006 et 2007, et à la suite de nouvelles investigations en 2007, SaskPower a retenu KGS Group pour l'augmentation de capacité du déversoir à 1200 m^3/s (une augmentation du débit à pleine capacité de plus de 50%) et la correction des défectuosités préalablement observées. La conception finale a dû prendre en considération le maintien du réservoir à son niveau de pleine capacité tandis que la chute du déversoir, d'une longueur de 230m, et son bassin de dissipation furent remplacés. Les fondations étaient composées de bentonite stratifiée en alternance avec des couches de siltstone, mudstone et de charbon. L'un des principaux défis du site fut de réaliser chaque phase de la construction de telle sorte que le déversoir puisse potentiellement passer les débits de crue printanière. La construction débuta en 2008 et fut terminée en 2010.

1 INTRODUCTION

The Boundary Dam Reservoir serves as a source of cooling water for the 980 MW Boundary Dam Power Station that is owned and operated by SaskPower. Boundary Dam is situated on Long Creek approximately 5 km upstream of the confluence with the Souris River, and about 5.5 km southwest of the community of Estevan, Saskatchewan. There is extensive community infrastructure and housing adjacent to Long Creek immediately downstream of the dam.

The project was designed by PFRA (Government of Canada) for SaskPower and was constructed between 1956 and 1958. In 1999 the dam crest was widened and a bridge constructed across the spillway to improve access for coal hauling to the adjacent thermal generating station. The project and spillway general arrangement is shown on Figure 1.

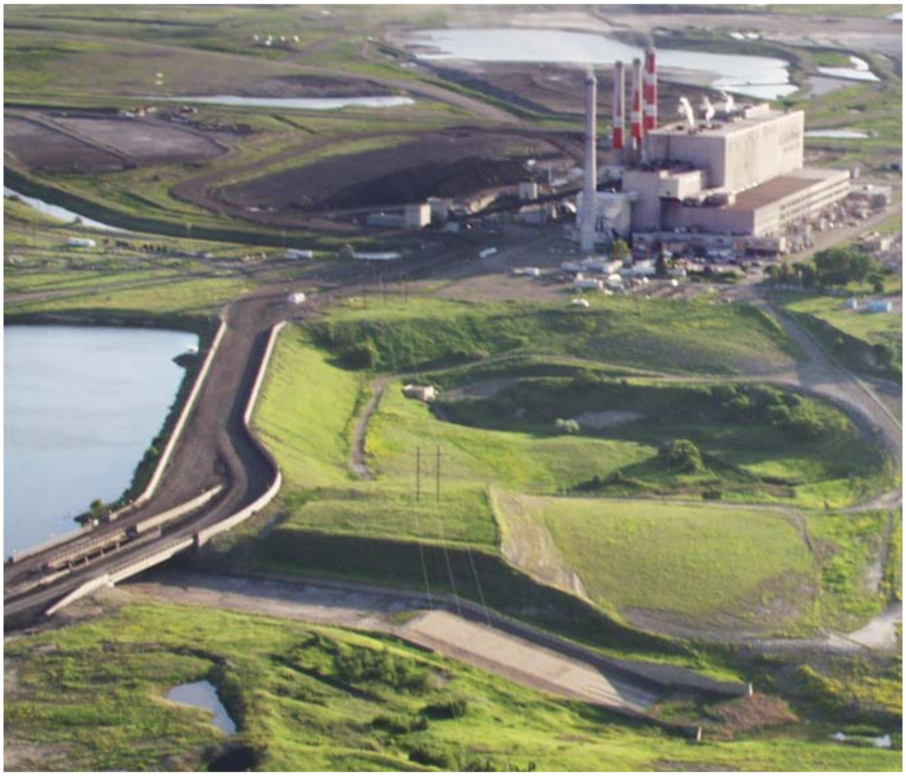

Figure 1: Boundary Dam and Spillway in 2005, Power Station in Background.

Since its construction over 50 years ago, periodic site inspections and condition assessments have typically been conducted on an annual to semi-annual basis. In 2005, SaskPower made the conscious decision to adopt the Canadian Dam Association (CDA) Dam Safety Guidelines in the absence of any provincial regulation and retained KGS group to perform a Dam Safety Review (DSR) of the project. A number of condition assessment reports had been completed previously, however, this was the first formal DSR.

The review performed was a standards-based review as outlined in Section 2.0, Dam Safety Review of the 1999 CDA Dam Safety Guidelines. In areas where the CDA Guidelines are insufficient to define quantitative standards, other commonly accepted standards such as the US Federal Energy Regulatory Commission (FERC) were used as well.

2 PROJECT COMPONENTS

Main Dam and Abutments

Boundary Dam is a zoned, rolled earth fill constructed of shale bedrock, alluvial clay and granular materials. In 1998, the embankment crest was increased from 12.5 m to 25.3 m wide to accommodate the 165 ton trucks used to haul coal from a new mine site located on the east side of the dam.

The foundation consists of shale bedrock with a shallow glacial clay mantle on the abutments and varying depths of alluvium overlying bedrock in the valley bottom. The dam is about 335 m long, has a crest elevation of approximately 563.9 m and has a maximum height above the valley bottom of approximately 29 m. The storage capacity of the reservoir at full supply level (FSL = El. 560.83 m) is 61.7 Million m^3.

Spillway

The original reinforced concrete spillway is located on the east abutment of the dam and consisted of a 42.37 m wide ogee-crest control section with 5 radial gates; a parallel-walled, 185 m long spillway chute having slopes of 63 horizontal to 1 vertical and then 4 horizontal to 1 vertical, with a 15 m long stilling basin. Five (5) steel radial gates, 7.62 m wide by 3.04 m high, provide a means of reservoir regulation above the weir crest elevation.

The spillway structure was originally designed with an operating spillway design flood of the 1:200 year flood event, which in 1956 was estimated to be a discharge of 425 m^3/s at a reservoir elevation of 560.9 m. The spillway was also designed to pass with limited damage (ie. safety of dam design flood) the probable maximum flood, which in 1956 was estimated to be 850 m^3/s with the reservoir elevation surcharged to 562.7 m.

Riparian Outlet

The project included a low level riparian outlet with a 1.2 m square reinforced concrete conduit complete with an 8.38 m long concrete inlet structure, a 26.2 m high gate control shaft and a 21.34 m long concrete outlet structure with a maximum flow rate of 14 m^3/s. Flows are controlled by two vertical slide gates.

Boundary Dam – Rafferty Diversion Channel

A diversion channel and control structure was constructed in 1992 between the Boundary Dam Reservoir and the Rafferty Dam Reservoir. The capacity of this channel is between 45 m^3/s and 60 m^3/s and is available to assist the Boundary Dam spillway with the passage of floods.

A summary of key data for the Boundary Dam is presented below.

Table 1: Overview of Physical Characteristics of Boundary Dam

Characteristic	**Data for Existing (and New) Facility**
Height of Dam (base to crest)	29 m at maximum height
Dam type / Spillway Type	Earthfill / Concrete Chute
Date of construction	1956 to 1958 (2008 to 2010)
Reservoir Storage (m^3) at FSL (560.83 m)	61.7 million m^3
Concrete Chute Spillway Size	42 m wide by 200 m long - existing (42 m wide by 220 m long - 2010)
Radial Spillway Gates (5 in all)	3.04 m high by 7.62 m wide
1956 Operating Spillway Design Flood (m^3/s)	425 m^3/s
1956 Safety of Dam Design Flood – PMF (m^3/s)	850 m^3/s
2005 Inflow Design Flood – PMF (m^3/s)	1,330 m^3/s

3 DAM SAFETY REVIEW

In accordance with CDA, the Dam Safety Review performed included review of all pertinent information regarding performance history, instrumentation, previous condition assessments, operating conditions, changes in operating conditions and changes in standards and procedures. The review utilized information developed in previous flood and condition assessments to the extent that its reliability and validity could be verified. All available relevant information was provided by SaskPower to the team for the Dam Safety Review, and the SaskPower personnel proved invaluable in assisting the review team both on site aw well as in providing the available documentation.

The scope of work for the standard based Dam Safety Review included the following items:

- review of previous dam safety related or flood hydrology reports available
- review and update the Probable Maximum Flood (PMF)
- dam break analyses and preparation of inundation mapping
- dam classification
- perform detailed visual field inspections of the water retaining structures
- field confirm major dimensions, as necessary to properly assess the structures
- assess flow control equipment and perform testing
- review records of design and construction
- evaluate the dam performance based on inspection, instrumentation, monitoring data, and stability assessments
- prepare an EPP as well as assist with "tabletop" tests of the EPP
- review Operation/Maintenance and Surveillance manuals and procedures
- prepare a comprehensive report that documents the findings

Based the 2005 assessment by KGS Group, the Incremental Consequence Classification (ICC) for the Boundary Dam would be in the Very High category for virtually all dam safety guidelines or legislation in Canada and consequently it was recommended that the ICC for Boundary Dam be adopted as Very High under the system proposed by the CDA. An ICC of Very High requires the adoption of the PMF as the Inflow Design Flood for the dam, according to the recommendations of the CDA Guidelines, as well as virtually all other relevant Guidelines in Canada. In accordance with this, the IDF for Boundary Dam was recommended to be the PMF.

The major conclusions and recommendations of the Dam Safety Review for the Boundary Dam were summarized in the DSR report, with the recommendations ranked using a priority system. The most critical of these were the need to upgrade the spillway condition and its discharge capacity.

On the basis of the DSR, and as was later confirmed in subsequent more detailed investigations, the major concerns with the existing spillway included:

- Lower portions of the spillway had heaved vertically up to 400 mm despite belled hold down piles
- The upper spillway chute slabs are relatively thin (300 mm) and have no waterstops, and many of the slab joints had deteriorated due to freeze thaw
- The subsurface drainage system is critical to overall stability of the chute and the slabs, but had failed, with the drain pipes collapsed, infilled with coal dust fines and/or large stones, and many of the pipes were separated and now offset.
- As a result of the inflows from the slab joints and the failed drainage system, there were large eroded voids in the granular fill under the spillway slabs, up to 1 m deep by 10 m wide by 10 m long beneath the slabs (see Figure 2 below)
- the existing chute did not have sufficient discharge capacity, and required the basin be lowered and extended as well as the chute walls raised.

As a result of the combination of these observed deficiencies, the safe operating capacity of the existing spillway was difficult to fully ascertain, but was estimated to be 70 m^3/s or less.

Figure 2: Void in granular beneath spillway chute slab. Note erosion channels and 150 mm diameter core in background, which was cored and dropped through void onto granular substrate.

4 DESIGN AND IMPLEMENTATION OF THE BOUNDARY DAM SPILLWAY UPGRADE

In response to the concerns identified in the 2005 DSR, SaskPower initiated immediate remedial measures and additional assessments. In 2007, KGS Group were retained to prepare a preliminary and then final design of the required spillway measures. The upgrade would extend the life as well as the safe discharge capacity of the spillway, which was selected as near the peak discharge of the PMF, providing a peak outflow capacity of 1220 cms.

To expedite the aggressive schedule selected for project construction, a rather unique implementation approach was developed by the SaskPower and KGS team. During the preliminary design phase, a panel of external experts were retained by SaskPower to review and critique the design methodology used by KGS. The discussions and input from the committee proved very valuable and provided Saskpower with further confidence that the funding allocated was being optimized. In addition, an Expression of Interest was issued to identify and retain three pre-qualified contractors to provide assistance to the design team on constructability issues and costing during the preliminary and final design phase.

SaskPower consulted with regulators early on; primarily Department of Fisheries and Oceans, Saskatchewan Ministry of the Environment and the Saskatchewan Watershed Authority. This proved valuable as their concerns were addressed early on and the corresponding mitigation implemented. All permits were in place well in advance of construction starting.

On the basis of the preliminary design work by KGS and the input received from the external experts and the contractors, the project selected by SaskPower for implementation consisted of replacing the entire concrete spillway below the crest section, with the chute walls raised and the stilling basin floor deepened (lowered) and the basin length extended.

To limit swelling of the complex foundation beneath the lower chute and basin (portions of the original spillway had swelled almost 400 mm vertically despite belled concrete holddown piles) the upgraded basin and lower chute are held down with over 480 post tensioned anchors extending up to 35 m below the slab. Given the many bentonite seams and challenging foundation conditions (including coal seams) beneath, the anchors were designed on the basis of results from an anchor test program performed under the direction of KGS Group in 2007, and include post-grouting strand anchors that are instrumented to verify their continued loads. In addition, the excavation was designed to extend below sensitive bentonitic seams to minimize future swelling below the basin. Construction depressurization of the low permeability foundation strata was determined to be critical during excavation to maintain the necessary minimum slope stability conditions, and to limit potential swelling.

Once the final design components had been identified, the work was quoted on by each of the three contractors on a unit cost basis. Due to the implementation schedule target dates, the Phase I work for the first year of construction was completely designed and detailed on the bid drawings, however, the Phase II work was a preliminary indicative design presented for unit cost bidding only. The detailed design for the Phase II work was then issued later during construction of the Phase I work.

Following review of the quotations from the three pre-qualified contractors, the work was awarded to PCL Construction Management Inc. The Phase I work commenced in the summer of 2008 with the removal and reconstruction of the spillway chute between the rollway crest and the start of the steep portion. The Phase 1 work was largely completed in December of 2008. The demolition and the construction of the Phase I work is presented in Figures 3 and 4.

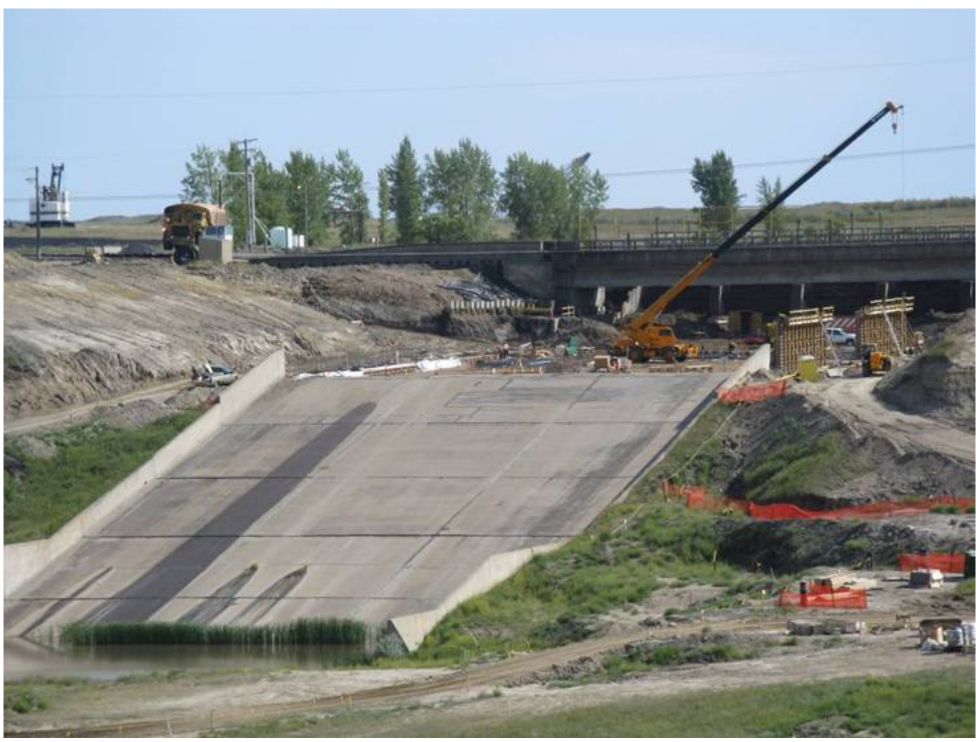

Figure 3: Phase I Work Underway in Summer of 2008.

Figure 4: Phase I Spillway Chute Construction Underway in Summer of 2008

In the spring of 2009, the contingency requirement to have the spillway ready to discharge spring flood flows was realized, as the only partially replaced Phase I/existing spillway had to be operated for spring flood passage for the first time in over 20 years (see Figure 5).

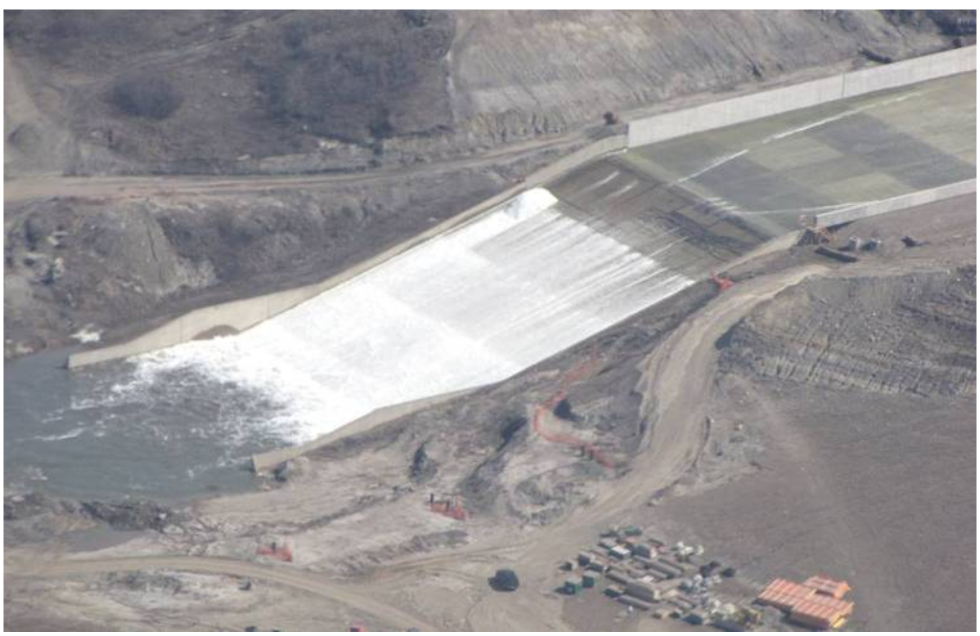

Figure 5: 2009 Spring Flood Passage Through Partially Replaced Spillway (Phase I / Existing)

The Phase 2 work included the replacement of the steep portion and the new deeper and longer stilling basin. The work commenced in May of 2009, as work was delayed by the spring flood passage, and was substantially completed in April of 2010. Figure 6 presents the Phase 2 work underway in 2009, while Figure 7 presents the hoarding that proved necessary to allow the Phase 2 concrete and anchoring work to be completed by the spring of 2010.

Figure 6: Phase 2 Spillway Chute and Basin Construction Underway in 2009

Figure 7: Hoarding for completion of Phase 2 Spillway Concrete and Anchoring in 2010

Final work on all aspects of the project was completed in the summer of 2010. Like most rehabilitation projects of aged structures, some scope and cost changes occurred as the work progressed to address unforeseen issues (including operation of the spillway between the two work phases), with the final total costs being approximately 15% greater than originally anticipated.

Figure 8: Boundary Dam Spillway Upgrade Completed – Spring of 2010

5 CHALLENGES AND LESSONS LEARNED

The challenges encountered and overcome during the work, as well as the lessons learned included:

- Rehabilitation and life extension of a +50 year old concrete spillway requires a flexible design to accommodate the “as found” conditions and details, which invariably are similar to but can deviate from that presented on the “as built” drawings.

- Spillway / stilling basins on erodible foundations need to include a competent subsurface drainage system with at least one level of redundancy (root cause of much of problems in the existing spillway), and design details that facilitate periodic inspection, maintenance, and cleanout of the drainage system.

- Securing funding for a large capital investment in an asset that does not directly generate electricity was challenging. Significant effort was required to inform decision makers of the potential risks and consequences and why the investment was needed.

- The new IDF for the new spillway resulted in a depth of flow on the crest that was much higher than the original design head used to define the ogee crest geometry. The effects of this increased flow depth were analyzed using FLOW3D numerical model to determine the expected discharge capacity. The three dimensional analyses provided a high level of confidence to proceed with the design in spite of the complex hydraulic conditions resulting from increasing the spillway crest design capacity by 100%.

- The potential for vibrations of the relatively shallow spillway ogee crest during passage of increased flows with flow depths considerably greater than the original design head were assessed based on the pressure fluctuation predicted using FLOW-3D numerical model.

- Complex interactions were assessed to evaluate potential foundation movements due to freeze-thaw, offloading and swelling to determine the required design measures. This included excavation to remove the most susceptible bentonite layers and the addition of loading by new soil anchors to minimize the swelling or heave potential of the foundation bentonitic soft sedimentary bedrock, as the existing spillway slabs had swelled and heaved upward over 400 mm in some locations.

- Thorough investigations, testing and analysis are important to assess the sliding friction stability, swelling, and settlement potential of soft sedimentary bedrock foundations, which include weak bentonitic layers and coal seams.

- The complex interaction between artesian pressure and surface water, their effects and how to control them during construction needs to be well understood at the outset of the job. The required foundation depressurization system worked well, but required year round maintenance and was challenging to integrate into the overall construction sequencing.

- Coordination of anchor installation and post tensioning on a congested site needs to be well planned and integrated with other site construction activities.

- To accommodate the anticipated slab settlement while maintaining long term compression of the spillway basin foundation, the tensioning of the anchors had to be phased, with the slabs taking two to four rounds of tensioning before final anchor lock-off. This resulted in a high degree of confidence in the system, but did take additional time. The time required for slab settlement proved slower than predicted from the limited data available, and consequently the phased anchoring portion of the work extended the schedule from that anticipated. The anchors are instrumented to confirm continued long term performance.

- Basin and Chute design loads considered varying hydraulic jump conditions to ensure that potential unbalanced loads are considered throughout the spectrum of hydraulic conditions and tailwater levels.

- This project involved a peer review committee of both internal as well as external experts experienced in work of this nature. A number of risk based decisions were made to balance potential risks versus costs of additional protection and reliability against budget constraints. Decisions were made in this context using expert judgement as well as qualitative and quantitative risk analysis.

- A critical challenge during the construction phase were the prolonged periods when portions of the spillway were removed and under repair and the spillway is unable to safely pass any flow. Measures implemented during construction to reduce the risk of flood passage through the partially completed spillway included: close monitoring of forecast flood flows; splitting the construction into two phases and scheduling the work to reinstate spillway capacity during the high flood risk period spring freshet (April); temporary reservoir level decreases; diverting limited inflows into the adjacent Rafferty reservoir, and by adding temporary barriers onto the top of the crest gates to allow additional reservoir surcharging if needed.

- Phase I consisted of the replacement of the upper flatter portion with a new spillway with higher walls temporarily connected to the existing steep section and basin. This allowed for the passage of spring flood waters after completion of the Phase I work and before Phase 2, if required. As it turned out, this contingency was used as the spillway had to be operated for flood passage at the end of Phase 1 after not being operated for nearly 20 years. The contingency plans and measures developed to manage the water during such an event was seamlessly executed by the project team (see Figure 5).

- Early in the Phase 1 work, there was a need to disrupt the supply of coal to the thermal power station for 2 weeks to modify the approaches for the coal haul bridge across the spillway. This presented challenges for Saskatchewan’s largest thermal generating station, as adequate coal had to be stock-piled at the station and the spillway contractor’s work planned with great care. Close coordination with the power station, the contractor and the design team resulted in the successful completion of this aspect with no operational problems to the 980 MW plant.

- Delays at the start of Phase 2, due in part to the passage of flood waters through the spillway, lead to a significant extension to the Phase 2 schedule and resulted in unanticipated winter work. With the need to have the Phase 2 spillway work largely complete for potential flood control in the spring of 2010, extra efforts were required to allow the work to progress right through the winter of 2009/2010. This included the use of a large hoarding enclosure to permit anchor installation and concrete placement in the winter (see Figure 7).

- During the spring of 2010, work continued up until early April to ensure the new spillway was sufficiently complete to operate should spring flood passage prove necessary, which the preliminary forecasts in the spring of 2010 indicated was possible. The 2010 spring runoff eventually proved insufficient to require operation of the nearly completed spillway. Close coordination with the Saskatchewan Watershed Authority was essential to ensuring the risk was kept as low as possible.

5 CONCLUSIONS

- The dam safety review process outlined in the CDA guidelines provides a good framework to assess and identify potential deficiencies with existing dams and water retaining structures, and identified concerns not evident from condition assessments alone.

- The upgrade measures selected for implementation were developed through close dialogue between the owner and the designers, with valuable input provided by a panel of external experts as well as from contractors participating in the design process.

- The upgrading of the +50 year old Boundary Dam spillway provided many challenges. These were handled successfully through close coordination and cooperation of the design and site team personnel from SaskPower, KGS Group, and PCL.

REFERENCES

KGS 2005 - Dam Safety Review of Boundary Dam
KGS 2007 – Preliminary Design of Boundary Dam Upgrades