Concrete Expansion – R.H. Saunders GS Innovative Structural Rehabilitation & Mitigation Effectiveness

by

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ABSTRACT

Ontario Power Generation's R.H. Saunders GS experienced many operational and structural problems, including decreased generator air gaps and turbine runner clearances, commencing in 1972. In addition, the powerhouse concrete structure was deteriorating with extensive cracking and water leakage.

Concrete expansion due to Alkali-Aggregate Reaction (AAR) was diagnosed in 1991 as the root cause of concrete movement and ensuing generator and structural problems. A proactive concrete rehabilitation program was implemented from 1993 to 2000 to mitigate the effects of AAR induced concrete expansion and repair the concrete structural damage.

Slots were successfully cut between the generators along the expansion/contraction joints of the concrete structure, using diamond wire technology. The immediate results were encouraging with reduced compressive stresses in the concrete, increased runner clearances and partial rounding of the throat ring liners. The slots were also sized to provide allowance for future concrete expansion.

Numerous innovative techniques were implemented to rehabilitate structural components that were severely damaged by concrete expansion at the powerhouse. Specialized grouting and sealing technology to undertake repairs was provided by Kinectrics (formerly Ontario Hydro Technologies).

AAR has continued in the mass concrete of R.H. Saunders GS. This paper describes the continued effects of concrete expansion on the generating units and concrete structure subsequent to the concrete rehabilitation program. The overall effectiveness of the concrete slotting and structural rehabilitation program is discussed.

Background

R.H. Saunders GS is the second largest hydroelectric generating station operated by Ontario Power Generation. See Figure 1. The sixteen-unit facility, consisting of an equal number of General Electric and Westinghouse generators, has an available capacity of 1,030 MW. The powerhouse consists of sixteen monolithic concrete blocks each 80 ft long, 150 ft wide and 150 ft high separated by 5/16 in. expansion/contraction joints running transverse to the powerhouse. The headworks and powerhouse typical cross-section is shown in Figure 2.

Figure 1 - R.H. Saunders GS (foreground)

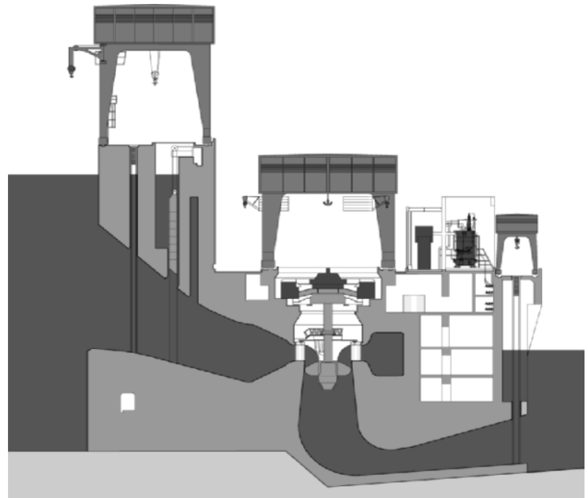

Figure 2 - Headworks and powerhouse cross-section

The generating units performed optimally for the first fourteen years of operation from 1958 to 1972. Then initial generating equipment operational and maintenance difficulties appeared. Subsequent generator inspections revealed that the stators were deformed elliptically. In 1978, it was found that the throat ring liners were similarly distorted. In some instances, runner clearances along the longitudinal axis were reduced from the installed clearance of 125 mils to 0 mils resulting in runner scrubbing. Runner clearances were increased to 450 mils on the upstream side.

These distortions are unacceptable to turbine runner operations. Scrubbing of the runner blades may cause serious damage to the blades and throat ring liner and lead to unit downtime and lost production to implement repairs. The increased runner clearances accelerated runner cavitation, with decreased unit efficiency and production capability. In addition, the powerhouse concrete structure was showing signs of extensive cracking, water leakage, spalling and complete closure of the transverse expansion/contraction joints.

Ad hoc measures were initiated to address the numerous generator and concrete structural issues. The generators were re-centered and the steel throat ring liners were ground to re-establish suitable runner clearances. The generator soleplates were modified with the addition of tapered keyways to accommodate radial movement and stabilize air gaps. On-line monitoring equipment was installed on each generator to track and trend generator air gaps.

An extensive investigation revealed in 1991, that concrete expansion due to Alkali-Aggregate Reaction (AAR) was the root cause of excessive concrete movement and subsequent generating equipment and concrete structural problems.

A proactive concrete rehabilitation program was implemented from 1993 to 2000 to mitigate the effects of AAR induced concrete expansion on the generating units and structural components.

Concrete Slotting

Localized concrete slotting of the expansion/contraction joints was implemented to mitigate the effects of AAR. Slots 9/16 in. wide were cut through the original expansion/contraction joints in the vicinity of the generator/turbine sets, using diamond wire cutting technology. The slots re-established and widened the joints thus relieving the longitudinal compressive stresses and partially rounding the throat ring liners.

From 1993 to 1996, sixteen concrete slots were established along the expansion/contraction joints between operating generating units. This was the first undertaking of its kind in a hydroelectric facility with adjacent generating units in-service.

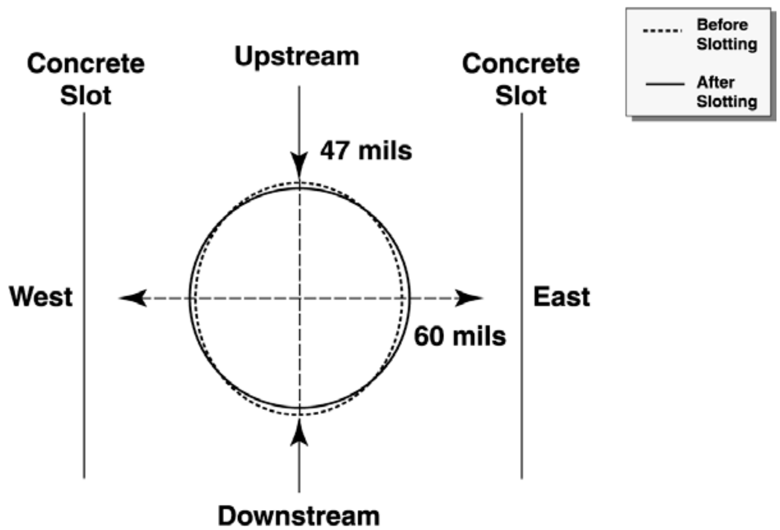

Figure 3 - Diametrical change in runner clearance

The immediate response of concrete slotting was beneficial. Re-establishment of the expansion/contraction joints resulted in reduced longitudinal compressive stresses in the concrete and partial rounding of the throat ring liners. The average diametrical runner clearance decreased 47 mils in the transverse direction and increased 60 mils longitudinally as predicted by the analytical model. See Figure 3.

Subsequent to the slotting program, however, the runner clearances have decreased, in the vicinity of the downstream proximity probes, at a rate of 10 mils/year. See Figure 4. This is due to the continued relief of longitudinal compressive stresses. It is expected that this trend will reverse once the compressive stresses due to continued concrete expansion overcome the temporary relief provided by the contraction joint slots.

Since concrete expansion continues at R.H. Saunders GS, the slots were designed to accommodate future concrete expansion without the need to re-slot the joints for at least ten years.

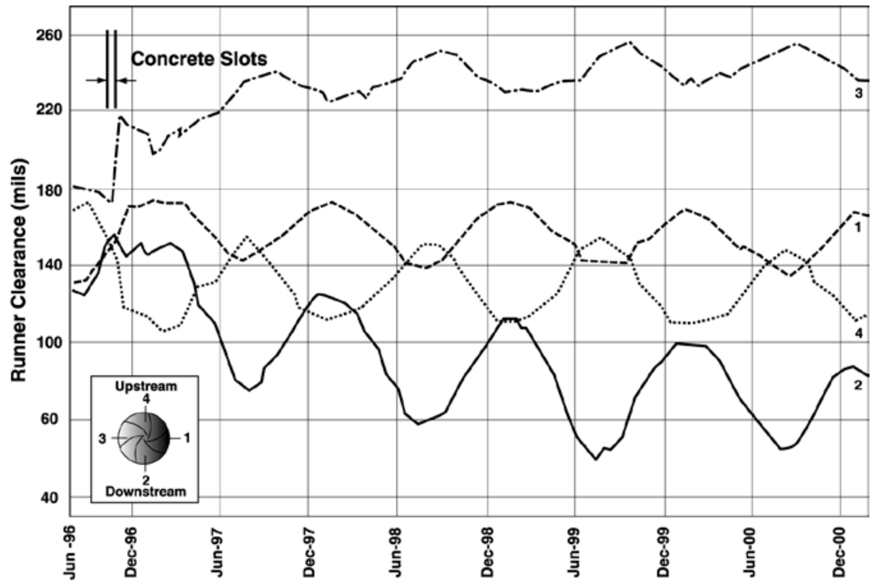

Figure 4 – Runner clearance – 10 mils/year decrease (downstream)

Concrete Structure Rehabilitation

Powerhouse Structural Beams

The generator roof deck longitudinal & transverse beams (quantity 96) provide structural support to the generator roof deck and switchgear building. As well, the longitudinal beams extending the full length of the plant (1,300 ft), support the powerhouse crane (300 ton) and provide bearing support to the transverse beams.

The movements caused by AAR resulted in significant damage to the concrete beam and slab bearing areas on three levels of the powerhouse. The extent of damage included:

- Shear cracking of the reinforced concrete beams and bearing support areas reducing bearing capacity of the transverse beams and floor/wall interfaces,
- Loss of effective bearing support,
- Tensile failure of the concrete causing spalling and delamination,
- Water seepage through fractures and joints from the generator roof deck contributing to concrete deterioration.

To address the structural damage and water seepage problems, several rehabilitation approaches were implemented. The repair method selected considered the extent of concrete damage as follows:

- Patching only,
- Structural grouting and patching,
- Structural grouting, patching and post-tensioning of beam supports including installation of concrete corbels to extend the bearing support area.

Where post-tensioning systems and corbels were installed at the slab/beam interfaces, the design modifications took into account the coefficient of friction to allow for future movement by applying either asphalt bond breakers or Teflon sliding pads.

Water Leakage Control

Water leakage in the powerhouse increased over the years from the combined effects of concrete expansion, degradation of water-proofing and joint sealing materials, movement of construction joints and concrete cracking. The leakage contributed to the disruption of generating unit operation, accelerated deterioration of concrete components and presented safety hazards to station staff.

An extensive grouting program utilizing a combination of epoxy, polyurethane, micro-fine and portland cements was implemented to reduce or eliminate water leakage from joints and cracks in the concrete. These products were applied in the following locations - generator floor, generating unit scrollcases, power cable tunnel, elevator shafts and inspection tunnels.

Several grouting materials and techniques were required to meet the varying site conditions, i.e. for crack injection, a range of low to high viscosity epoxy injection resins were used to displace water, provide the necessary penetration of fractures and provide structural as well as long-term water-proofing. Micro-fine and portland cements were selected for deep penetration of joints and fractures where large volumes were anticipated. Both single and two component polyurethane grouts with varying application and set properties were necessary to eliminate high flow water conditions and provide for future joint and crack movements.

Generator Floor Replacement

The generator floor rests on simply supported structural concrete slabs and mass concrete sections. An unreinforced topping slab overlaid with 2 in. thick mortar and ¾ in. thick ceramic tiles extends over the floor (40,000 ft^2). The floor has been subjected to concrete expansion due to the effects of AAR. The expansion induced significant stresses in the concrete structure, leading to tensile failure of the concrete, cracking/debonding of the tiles and tile mortar interface. This, in combination with water seepage, resulted in buckling of the tiles.

Figure 5 - Tile and mortar bed removed exposing extensive cracking of underlying concrete

Figure 6 - New generator floor

An assessment of the generator floor condition revealed that over 60% of the ceramic tiles had debonded from the underlying mortar bed and many tiles were damaged. In addition, 60% of the mortar bed had debonded from the underlying concrete and was found to be friable and damaged. Separation of the suspended slab along the mass concrete interface (i.e. bearing area) resulted in extensive cracking of the concrete, which contributed to failure of the tile floor system as illustrated in Figure 5. As a result, it was decided to replace the ceramic tiles and mortar bed.

Analysis of the failure mechanisms identified the need to isolate the new flooring system from the main concrete structure to allow for future concrete expansion.

Four flooring systems consisting of the following were considered for this project:

- Epoxy mortar overlay with self-levelling high build epoxy top-coat
- Fibre-reinforced cementitous mortar and epoxy top-coat
- Reinforced concrete slab
- New mortar bed and ceramic tiles

After assessing each system and experimenting with the epoxy-based systems, the existing floor was replaced with a new mortar bed and ceramic tiles. This was the most practical and cost effective option. The new floor is shown in Figure 6.

Governor Cabinet Concrete Supports

The governor cabinet concrete supports had been severely damaged due to concrete movement. Lateral movement (up to ¾ in.) caused severe cracking and spalling of the concrete. Repairs entailed the removal and replacement of the damaged concrete, addition of new steel column supports with sliding Teflon pads to accommodate future movement and extensive structural grouting of numerous fractures in the concrete. See Figures 7 and 8. Post tensioning of the existing reinforced concrete columns was undertaken. These solutions were implemented based on ease of construction, space restrictions and operating requirements

Figure 7 - Preparing to grout around a governor cabinet

Figure 8 - Structural grouting of columns and new steel column support

Erection Bay Floor Replacement

The erection bay floor (14,000 ft^2) consists of a structural reinforced concrete slab overlaid with a 6 in. thick non-reinforced concrete topping slab. The topping slab was covered with a 2 in. thick mortar bed that underlies a ¾ in. thick ceramic tile floor.

Over 90% of the ceramic floor tiles had debonded from the underlying mortar and numerous tiles had been damaged. The mortar bed had also been damaged and the topping slab was found to be intact.

Since the floor area is exposed to heavy traffic a new reinforced concrete slab and coloured floor shake hardener were installed. Expansion/isolation joints were installed around the perimeter of the floor area to create isolation and accommodate future movements in the floor. A 4,000 psi non-air entrained concrete containing water reducing and super plasticizing admixtures was used to increase workability during placement. Control joints were installed along both directions of the floor slab and where obstructions existed along the floor area. Both the control joints and existing expansion/contraction joints were filled with flexible epoxy and polyurethane sealant. See Figures 9 and 10.

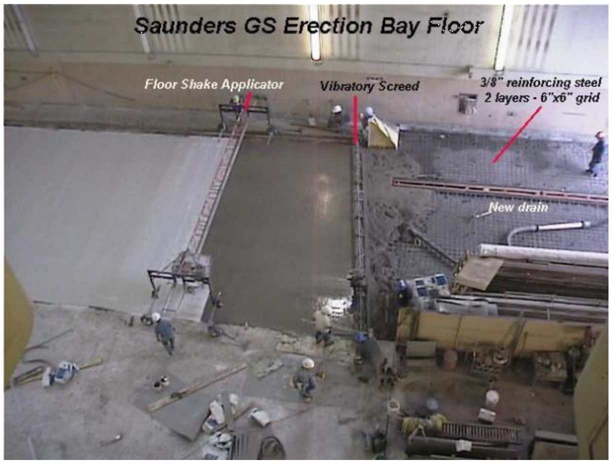

Figure 9 - Erection bay floor replacement

Figure 10 - New erection bay floor

Generator Roof Deck

Concrete expansion contributed to extensive water leakage from the generator roof deck onto the generator floor. The generator roof deck consists of a walkway, laydown areas and road. Nearly 40,000 ft^2 of topping slabs 6 in. thick and underlying waterproof membranes required removal and replacement. The waterproofing systems had deteriorated (i.e. embrittlement and cracking) over forty years and were further damaged by concrete movement. Extensive freeze-thaw damage to the topping slabs was the predominant mechanism of deterioration.

Prior to undertaking full-scale repairs a thorough review of waterproofing systems was undertaken. Trial sections of the most promising systems (EPDM torch applied and liquid applied) were installed to assess application methods, performance, and to optimize installation procedures. After one year of exposure, the trials indicated that the liquid applied waterproofing systems were more effective in providing long-term waterproofing (easier application methods, excellent bonding to underlying concrete and good crack bridging).

A single-component elastomeric polyurethane coating was selected to waterproof the concrete at the crane rail plinths and below the new topping slabs where heavy loads were anticipated. Hot rubberized asphalt was applied below the topping slabs where load deflections were not a concern. In order to provide a continuous waterproofing system along the generator roof deck, all of the construction joints were sealed with polyurethane elastomeric joint sealant.

Concrete deterioration was most extensive along the generator roof deck roadway. Thus, the entire topping slab required removal. See Figure 11. The condition of the existing topping slab along the walkway and laydown areas varied necessitating different rehabilitation methods. In areas of significant deterioration, the topping slabs were removed and replaced. Where localized damage and cracking were evident, the topping slabs were repaired. New waterproofing membranes were installed along the entire generator roof deck. New concrete topping slabs were placed along the entire the roadway and several laydown areas. The new topping slabs consist of 4,000 psi fibre-reinforced designed concrete. See Figure 12.

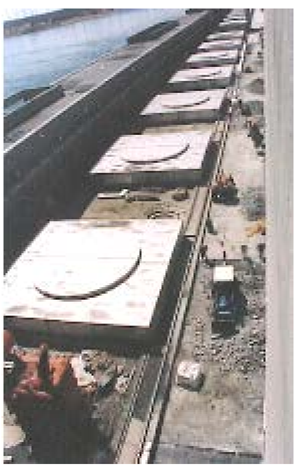

Figure 11 - Generator roof deck roadway and laydown area concrete removal

Figure 12 - New generator roof deck roadway, laydown areas and walkway

Transformer Bay Oil Containment Liner Installation

In order to upgrade the existing transformer oil containment liner system and comply with current environmental requirements, the transformer bays were retrofitted with a spray applied polysulphide secondary containment liner system.

There are four main output transformer banks located along the tailrace deck. Each bank contains three single-phase transformers located in transformer bays. In addition, four station service transformer bays are located inside the switchgear building. Previous inspections of the bays indicated that the liners were no longer completely water tight due to local cracking and deterioration of the concrete and joint sealant.

The repair consisted of local patching of the concrete, replacement of the existing deteriorated joint sealant, surface preparation of the concrete by sandblasting methods and application of a two-component polysulphide base coating. This material was selected as a result of its chemical and UV resistance, and flame retardant and crack bridging characteristics. It provides oil resistance and a leak-proof barrier to transformer oil in the event of a transformer oil spill. The coating also provides a protective layer over the concrete reducing the rate of deterioration and extends the life of the concrete structure. See Figure 13.

Figure 13 - Transformer bay oil containment liner

Transformer Bay Beam Supports

Reinforced concrete beams span the front of each transformer bay supported by fire separation walls. The sections of the beams within the wall bearing support area had sustained damage due to concrete movement and freeze-thaw action. The damage consisted of reduced beam bearing area, loss of reinforcing steel concrete cover, spalled and delaminated concrete, and fractures in the concrete accelerated by water infiltration. See Figure 14.

Figure 14 - Beam bearing area delaminated concrete

Although the beams appeared to be in relatively good condition, the extent of concrete damage within and along the beam bearing areas raised doubts as to their long-term stability. An assessment determined the need to undertake a rehabilitation program consisting of:

- Removal and replacement of all deteriorated concrete and joint sealant,
- Installation of steel knee brackets and post-tensioned anchors to provide additional bearing support for the transformer bay beams,
- Structural repair of major fractures in the concrete by epoxy grouting.

A silane-based water proofing sealer was also applied to the beams to extend their life. See Figure 15.

Figure 15 - Transformer bay beams and new steel brackets

Conclusions

The Concrete Rehabilitation Program implemented at R.H. Saunders GS was successful in mitigating the effects of concrete expansion due to AAR.

As expected, following concrete slotting, there was partial rounding of the throat ring liners and generator operation was stabilized. Changes in runner clearances demonstrate the continued effects of AAR and stress relief provided by concrete slotting.

The concrete structure rehabilitation utilized innovative designs to restore the power-house structural integrity and account for continued concrete movement. A monitoring program (visual inspections and instrumentation) has been implemented to provide a clear indication of the long-term performance of the structural techniques applied at R.H. Saunders GS.

References

Eastman K.T., Ho M.S., and Adeghe L.N., "Innovative Techniques to Mitigate Concrete Expansion – R.H. Saunders GS", Hydrovision Conference 1998, Reno, Nevada

Kee D.C, Liscio L., Ho M.S. and Eastman K.T., "Rehabilitating R.H. Saunders: Enhancing Value", Special Report, Hydro Review, Volume XVII, No. 7, December 1998, Pages 44-51.

HO M.S., Eastman K., and Adeghe L., "Recent Development in R.H. Saunders GS Concrete Growth Mitigation Project", USOLD Second International Conference on Alkali-Aggregate Reactions, Chattanooga, Tennessee, October 1995.

Deans J.J., "Repair of Concrete Structures Utilizing Polyurethane and Epoxy Gouts", ACI Fall Convention, Vancouver, 1993.

Deans J.J., "Power Utility and the Epoxy Resin Formulator", Society of Plastics Industry, Toronto, Ontario, November 1993.

Deans J.J., "Selecting Chemical Grouts for Water Control", International Concrete Repair Institute, Baltimore, Maryland, October 1993.

Deans J.J., "Repair and Protection of Concrete Structures", CRC Press, Boca Raton, Florida, 1992.

Authors

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Edward S. Li, P.Eng., Structural Engineer providing technical support for R.H. Saunders GS Concrete Rehabilitation Project, has twenty-eight years of design experience of structures related to nuclear, fossil and hydroelectric generating stations.