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GATE REHABILITATION AT EXISTING HYDROELECTRIC PROJECTS

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ABSTRACT

Safety concerns and economic risks of aging water control gates are common problems facing many older hydroelectric projects. While the rehabilitation of existing gates shares many technical aspects with new gate construction, it also presents special considerations and unique challenges. This paper will first describe some of these typical issues and general strategies for addressing these considerations, and then illustrate how these strategies were applied at three recent projects.

GENERAL CONSIDERATIONS

EVALUATION PHASE

The typical first phase of a gate rehabilitation project is to determine if the existing gate presents an unacceptable risk that warrants rehabilitation. Risk is determined by considering both the gate's condition and the consequence of failure. While numerical risk analysis can be used to quantify the probability and costs of gate failures, most gate rehabilitation projects are rationalized by less formal risk evaluations.

GATE CONDITION CONSIDERATIONS:

- Structural Condition: The most fundamental consideration is a gate's structural competency. This is determined by analyzing the existing gate's complete load paths for both the pressure load bearing structural members and the operating system to determine the factors of safety based on the actual condition of the components. The components actual conditions are primarily determined by visual observation and measurements.
- Mechanical/Electrical Components: The condition of the mechanical and electrical components should be considered by both an on-site inspection and operational/reliability discussions with the station operators and maintenance personnel.
- Functional Obsolescence: The present gate operating system may not be appropriate for older hydroelectric stations that have less on-site station personnel than in the past, such as a station that has been converted to full remote automation.
- Gate Guide Condition: The condition of the permanently embedded gate guides is very important, particularly the seal mating surfaces. Failure to correct a deteriorated gate guide can invalidate an otherwise successful gate rehabilitation project. Conversely, since gate guide repairs, particularly if they require a cofferdam or underwater divers can add significant cost to a project, they should only be accomplished if needed. If a water retaining gate covers the guides the full condition of the seal mating surfaces may not be able to be determined until after the project is begun. One approach to economically addressing this uncertainty is to apply the geotechnical engineering observational approach, where alternative remediation measures are planned and costed on a per unit

basis during the project planning and/or bidding stages and then only those measures necessitated by the actual conditions are implemented.

GATE RISK CONSIDERATIONS:

- Evaluate the Risks of Gate Failure or Malfunction: The importance of any single gate needs to be considered by its site specific function and the consequences of both uncontrolled releases as well as the failure to release flows when needed (*e.g.* to prevent overtopping of an embankment dam). Obviously gates that pose higher threats to public safety (*e.g.* loss of live), economic loss (*e.g.* loss of generation water or head, damage to downstream facilities), environmental impact (*e.g.* uncontrolled sediment release), or social implications (*e.g.* loss of recreational use due to lowered reservoir) need to be more rigorously scrutinized than gates that pose lesser threats.

PROJECT PLANNING PHASE

- Dewatering Alternatives: One of the potentially most significant differences between gate rehabilitation and new construction is the ease and means of dewatering. Dewatering can range from not being an issue for rehabilitating temporary bulkhead or intake gates with upstream stoplog provisions, to extremely significant for deep sluice or large spillway gates that do not have any existing upstream bulkhead or stoplog provisions.
- Repair or Replacement: One of the primary considerations in a gate rehabilitation project is to determine if any or all or all of the existing gate and/or operating system components should be repaired or be replaced. Typically gates are more economically replaced if their condition does not meet the required safety requirements, while less costly repair may be appropriate for gates experiencing only serviceability deficiencies such as leakage or surface corrosion.
- Owner/Consultant versus Vendor Detail Design: There are various advantages and disadvantages to having the project detailed design performed by either the Owner/Consultant or the gate equipment vendor. While site conditions, levels of design competence, and owner preferences can vary greatly between projects, some general guidelines are:

    - It is typically more technically and cost effective to utilize Owner/Consultant detailed design if only selected components in a larger system are identified for repair/replacement. Conversely, vendor design work better if the extent of the gate system repair and the performance requirements can be unambiguously defined and comprehensively conveyed to the vendor.
    - Larger and less complicated gates may be more cost effectively procured from more local and sometimes costly fabricators by utilizing owner/consultant designs. Conversely, more complicated gates particularly if they can utilize an experienced gate vendor's standard components or details with previous proven performance may be more cost effective for smaller or more complicated gates. Kleinschmidt's rule of thumb experience has been that limiting the cost of consultant design to no more than 10% of the total cost of the fabricated gates should result in the least costly approach.

- Gate rehabilitations that involve extensive interfacing and modifications to the existing structures or equipment can typically be more efficiently completed by the Owner/Consultant engineer who more comprehensively understands the entire facility. Conversely, assigning the gate design and fabrication responsibility to a single party can reduce liability confusion if problems develop.

IMPLEMENTATION PHASE

- Expect the Unexpected: Unlike new construction, the condition of all of the gate's existing components can rarely be conclusively defined before the work begins. This additional risk needs to be acknowledged by the project's management, and project costs are best controlled by clearly defining the contractual scope's of work, with the owner sharing indefinable risk, such as discovering unanticipated deteriorated components, with the contractor.
- Record Drawings: At the project's conclusion comprehensive Record Drawings and documentation accurately reflecting the completed work should be compiled and archived. This is particularly important for any portions of the work that is difficult to observe such as submerged and embedded components. This documentation will prove invaluable in reducing the ambiguity and subsequent costs of inevitable future work.

EXAMPLE ONE – MIDDLESEX SLUICE GATE

Green Mountain Power Corporation's (GMP) Middlesex hydroelectric station has two 9 ft. square steel sluice gates with screw stem operators located at the spillway's base in a natural sharp rock gorge 45 feet below the normal reservoir level. These 1933 vintage gates play an important role in maintaining safe water levels preventing flooding along the upper Winooski River watershed in central Vermont. The condition of these gates began to be suspect in the 1990's, and they were repaired in 1999 by a combination of temporary headpond drawdown and underwater repair. The need to more permanently rehabilitate these gates was highlighted by an accidental sediment release that happened during a gate maintenance headpond drawdown in August 1999, and resulted in a substantial monetary fine from the state of Vermont.

EVALUATION AND PLANNING PHASES

Observations from the contractor and divers who performed the 1999 repairs indicated that both gates were in very poor structural condition. Also both gates had substantial leakage that tended to cause winter icing problems. Therefore, no further formal gate condition evaluation was needed in 2001 to justify the 2002 replacement of both gates. There were no problems or deterioration of the original gate operators. So they were reused, although the gates were upgraded with new remote control and position indication instrumentation.

As shown in the spillway cross section shown in Figure 1, these gates did not have any provisions for dewatering bulkheads, probably because when this spillway was built in 1929 it was envisioned that the headpond could simply be drained during low river flows. But changes in societal environmental aesthetics since then makes it currently impossible to obtain permits to simply open the gates and completely drain the headpond. This necessitated that replacing the gates would require some method of cofferdaming. During initial project planning in the fall of 2001 three options of installing a cofferdam in a suspected shallow area approximately a half mile upstream of the spillway, adapting an abandoned upstream timber crib dam used to cofferdam for the original 1928 spillway construction, and installing a braced sheet pile cofferdam on the upstream face of the gate openings. Because the first two options resulted in dewatering the gorge they were found to present significant permitting difficulties. The deep water and steep rock gorge profile upstream of the spillway made the third option very difficult technically and expensive with an estimated cost in the $150,000 to $200,000 range.

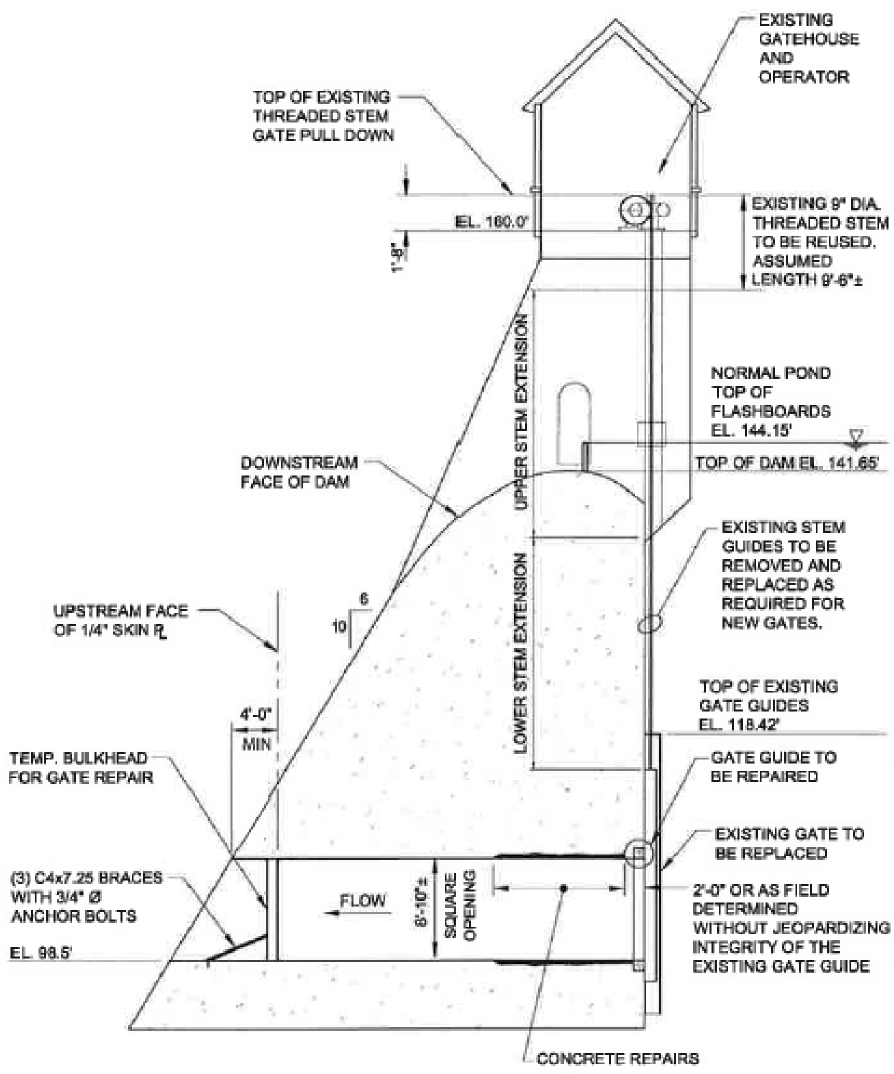


FIGURE 1

GREEN MOUNTAIN POWER MIDDLESEX STATION SLUICE GATES

Then GMP along with the project team of Kleinschmidt Associates as the design engineer and Fairbanks Mills of St. Johnsbury Vermont as the contractor conducted a joint inspection of the gates in early December 2001. Significant concrete deterioration behind the gates guides was discovered in the sluice tunnels. Also during this visit the team collaboratively formulated a new cofferdam alternative. As shown in Figure 1 it consisted of using a downstream tunnel bulkhead that would allow the gates to be removed without having to install an upstream cofferdam. Additional benefits were that it simplified permitting by eliminating any need to lower the headpond water elevation during the project, did not interfere with normal station operation, and was significantly less expensive than a traditional upstream cofferdam.

IMPLEMENTATION PHASE

Excellent record drawings showing complete dimensions and details of the 1936 vintage gates were available, and incorporated into a gate procurement specification that was able to unambiguously describe the existing gate and stem extension. Therefore, it was decided to solicit vendor designed replacement gates and reuse the existing operators. Competitive bids were solicited in February 2002 so that the schedule would maximize the time for gate fabrication and allow the new gates to be cost effectively fabricated in the early spring when specialty steel fabricators workloads are historically the lowest.

The gate replacement contract was awarded to Cross Machine of Berlin New Hampshire in March 2002, and the initial gate body design was reviewed by GMP, Kleinschmidt, and Fairbanks Mills in April and May. Because of the difficult installation site conditions, it was very helpful to also have the installation contractor, Fairbanks Mills, review the gate vendor drawings and they initiated several design details that facilitated gate installation. Because these deep sluice gates are typically closed except during occasional high river flow considerable attention was focused during the gate design phase on the gate seal details. Limited leakage was desired to minimize icing problems during the cold Vermont winters, and solid bulb fluorocarbon coated J seals were used on the vertical sides with double stem type seals on the top and bottom edges. The compatibility of the vendor’s new gate with the existing guides was also independently confirmed by Kleinschmidt during the gate design review to reduce the probability for any costly field revisions during the installation of these deep gates.

Because these gates are very inaccessible, particular attention was given to providing a quality paint system to extend the service life of the new gates. An epoxy mastic coating, having excellent performance characteristics such as a Salt Fog Test rating exceeding 5,000 hours was chosen. Careful attention was also placed on inspecting the gates’ paint.

Fairbanks Mills installed Gate No. 1 bulkhead in June 2002, and removed the gate. This allowed the gate’s guides to be completely inspected for the first time since their 1936 installation. Based upon the diver’s annotated underwater guide videotaping, Kleinschmidt finalized the gate guide repair drawings, and Fairbanks then completed the underwater guide repair in July. GMP, Kleinschmidt, and Fairbanks Mills conducted a joint shop inspection of the 80% complete gates in later July and the first new gate was installed in August.

During the disassembly of the gate stem it was discovered that four of the eight bolts attaching the threaded rod to the stem extension of Gate No. 1 were either completely sheared or severely distorted. This discovery highlights the value of GMP's pro-active maintenance program because this condition is undectable by normal inspections and would have resulted in the stem severing if the gate was attempted to be raised under flood conditions.

After the first gate was fully operational the bulkhead was removed and reinstalled behind the second gate in early September. The second gate was then removed, the underwater guide repairs completed, and the new second gate replaced. The tunnel concrete downstream of both of the gates was then repaired and the entire project was completed by the end of October 2003.

Both new gates had zero leakage and no significant problems were encountered during installation and operational shakedown.

EXAMPLE 2 - VERGENNES INTAKE GATES

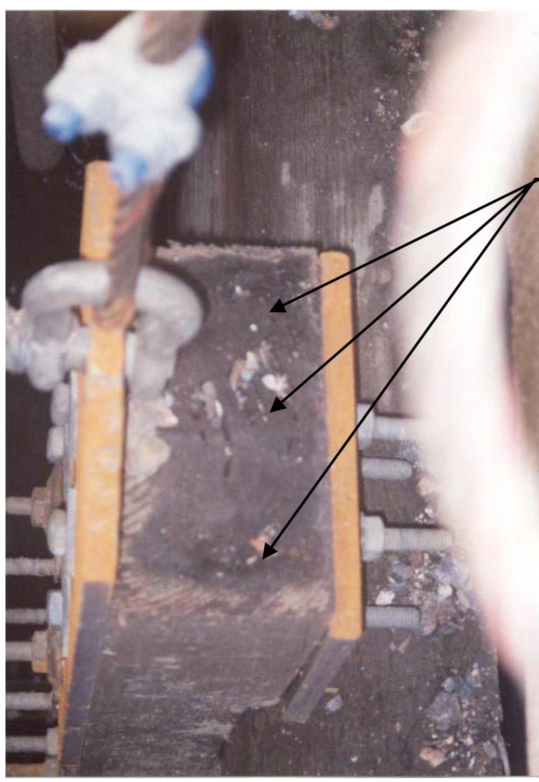
The intake for Plant 9 at GMP’s Vergennes hydroelectric project is on the south channel of Otter Creek between the south shore and Grist Mill Island. This shallow intake with 16 feet from the sill to normal pond water level had two 8 ft wide by 10 ft high wooden bulkhead intake gates with dual stem rack and pinion operators. Although the intake gate guides had been rebuilt and replaced with new steel guides during a 1992 dewatering of the south channel, the rack and pinion operating system was over 80 years old and the wooden gates probably more than 40 years old. The 1992 repairs were intended to be interim and the gates replaced as part of a general station rehabilitation planned for the later 1990’s, but project economics have forced these plans to be postponed indefinitely.

In December 2001 one of the wooden gate stems on Gate No. 1 broke suddenly while the gate was being lifted. Photograph No. 1 shows the intake with the original rack and pinion operators in December 2001. Both gates are in the full up position showing the gate rack stems for Gate No. 2. The broken stems for Gate No. 1 on the right have been removed. Photograph No. 2 shows the detail of the broken stem, where wood decay had reduced the stem’s load carrying cross section below the limit that could carry the gate reactions. Although Gate No. 1 was able to be lifted and temporarily secured by using a come-along attached to cables looped through the filler gate, it was obvious that because this station would not be renovated in the foreseeable future, both gates and operators needed to be replaced.

GATE NO. 2
ORIGINAL RACK
AND PINION
OPERATORS WITH
GATE FULL UP.

PHOTOGRAPH NO. 1

GATE NO. 1
FULL UP AND
BROKEN RACK
STEM REMOVED.



DETAIL OF BROKEN
GATE NO. 1 STEM.
DARK AREAS SHOW
DECAYED WOOD
WHERE STEM SEVER
INITIATED.

PHOTOGRAPH NO. 2

PLANNING PHASE

Because these shallow gates are used only a few times a year for turbine maintenance dewatering, it was determined that they would be simple slide gates operated by a standard monorail supported electric hoist. GMP decided to reduce project costs by installing the new gates with in-house maintenance personnel. The intake deck is very congested, and the monorail supports and gate access required some reconfiguring of access stairs and platforms. Also it was important that the monorail supports be placed where the lightly reinforced concrete intake is structurally adequate. This intake's structural adequacy was determined through a combination of site inspection and a review of original 1920 vintage intake rebar drawings.

Because the monorail design was very dependent on the intake's existing structure, and its load capacity had to correspond with the reactions needed for operating the gate, GMP decided to have Kleinschmidt prepare a single comprehensive final design package that fully integrated all of the project components including the gate, monorail system, and new access platforms and stairs. Simple neoprene backed Ultra High Molecular Weight (UHMW) polymer seals were selected for all four sides. Although the gates will typically be lowered under equal hydrostatic pressure with the turbine cylinder gates closed, the spaces upstream of the skinplate between the gate horizontal beams were filled with concrete to provide enough additional ballast so that the gates would gravity close under an emergency condition of full turbine discharge. Crane access at this congested site is limited by the river to the north, an upstream busy state highway to the east, a three story building to the south, and the penstock crossing a ravine to the south. Therefore, to reduce the necessary crane size the concrete ballast was added to the steel gates by GMP's crew after the gate weldments had been placed on the intake deck.

Although the monorail system was designed to raise each gate under full unequal static pressure, GMP wanted the new gates to have smaller penstock filler gates for normal operation. An unusual circumstance at this site is that the turbine cylinder gates have so much leakage that a second filler gate was necessary in each headgate to provide enough water flow into the penstock to compensate for the turbine leakage and equalize the gate's static water pressure.

Fortunately GMP had spent the effort during the 1992 repairs to compile complete record drawings that showed the actual dimensions of the reconstructed gate guides. These drawings proved invaluable in assisting Kleinschmidt to design the new steel replacement gates to correctly fit the existing guides.

IMPLEMENTATION PHASE

Kleinschmidt completed the final design over the winter of 2002, and GMP solicited bids for supply of the gates, monorail system, and new miscellaneous metals in March 2002. A local steel fabricator, Reliance Steel of Colchester Vermont was awarded the material supply in April and they fabricated the gates and monorail in May and June followed by the new stair and platform in July. GMP obtained the construction permits in the spring.

GMP's electrical line crew changed the intake's electrical service line in early July, and the hydro maintenance crew then installed the new gate and operator frame in about a week at the end of July and first of August 2002. They first erected the new monorail system, which they then used to place on the intake gate with a crane located approximately 130 feet away near the upstream highway bridge. First the concrete ballast was pumped to the intake deck and placed into the two gates. The monorail system was then used to raise the gates and place them into the slots the following day. The gate system has performed well and seals with minimal leakage.

EXAMPLE 3 – CLARK FALLS TAINTER GATES

Central Vermont Public Service Corporation's (CVPS) Clark Falls hydroelectric station has three 24 ft. wide by 23.5 ft. high 1938 vintage steel tainter gates. Although these gates were extensively refurbished in 1988, some gate problems began to develop in the later 1990's.

Although the original gates' wooden sills had lasted 50 years, by about 1999 small pieces of the gates' 1988 vintage wooden sills began to wear increasing bottom leakage. The gate leakage in itself was not a safety or serviceability problem, but the potential for sill ice buildup that could lock a gate closed when it would need to be raised during a winter thaw was a developing concern for CVPS. Winter gate ice buildup was exacerbated by the light beige color paint that was applied in 1988 that reduced the winter solar heat absorption compared to the gates' previous black color. The light color also clearly showed the rust bleeding from between the riveted faying surface between the downstream skin plate face and horizontal stiffeners.

The most troublesome gate problem that began to develop in 2000 was corrosion of the embedded vertical side seal face plates. These holes allowed water to enter the guide heater cavities and initiating leakage around the guides and long term deterioration such as the potential for the rough corroded face plate to damage the gates' vertical side rubber J seals.

EVALUATION AND PLANNING PHASE

Several alternatives for repairing the wooden bottom sill and side seal faceplates were evaluated in 2002. Because these are large gates without any permanent bulkhead provisions, these first repair options concentrated on less costly techniques that would not require cofferdaming (the 1988 tainter gate cofferdam costs were $100,000). The sill repair ideas concentrated on lag bolting a new steel plate on the downstream face of the current wooden sill, and the side seal repair consisted of wedging a new 3/16 inch thick stainless steel guide faceplate overlay upstream between the gates' neoprene J seals and the existing guide carbon steel face that was flush with the vertical abutment side walls. But after considering the advantages and disadvantages, CVPS decided that they wanted to rehabilitate these three gates in the dry behind cofferdams so that the gates could be more permanently repaired.

Project design drawings and project bid drawings were prepared in the late fall of 2002. Comprehensive record drawings and a project maintenance manual summarizing the 1988 repairs, materials, and cofferdams were incorporated into these documents and reduced the risk to the bidding contractors by incorporating the lessons that had been learned from the 1988 work.

The new design includes replacing the gates' wooden sill with a steel weldment that has a neoprene bottom seal that can be replaced from the downstream face without having to cofferdam the entire gate. A new 304 stainless steel faceplate will be added over the existing vertical embedded guide faceplate with heater tubes welded to the backside. The gate guide cavities will then be filled with closed cell foam.

Contractor prices were solicited in January 2003, and the contract is currently being negotiated (February 2003), and is planned for the summer of 2003.

AUTHOR

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