PAP-756

Selective Withdrawal at Hungry Horse Dam, Montana

by

Joseph Kubitschek

Prepared for the ASCE WATERPOWER '97 Conference,
Atlanta, Georgia

August 5-10, 1997

PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

Project Name Hungry Horse Selective Withdrawal - Paper Submitted for ASCE WATERPOWER'97 Conference, August 5-10, 1997, Atlanta, GA WOID ____________

Document Selective Withdrawal at Hungry Horse Dam, Montana

Document Date ____________ Date Transmitted to Client ____________

Team Leader ____________ Leadership Team Member ____________
(Peer Reviewer of Peer Review/QA Plan)

Peer Reviewer Tracy Vermeyen, P.E. Document Author(s)/Preparer(s) Joseph Kubitschek D-8560, Robert Sund D-8410, and Rick Christensen D-8410

Peer Reviewer ____________

Peer Reviewer ____________

REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain ____________

____

Part B: Document requires Peer Review : SCOPE OF PEER REVIEW

Peer Review restricted to the following Items/Section(s): Reviewer:

____________ ____________

____________ ____________

____________ ____________

REVIEW CERTIFICATION

Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: Tracy E. Vermeyen Review Date: 2/15/97
Signature

Preparer: I have discussed the above document and review requirements with the Peer Reviewer and believe that this review is completed, and that the document will meet the requirements of the project.

Team Member: Joseph P. Kubitschek Date: 2/18/97
Signature

SELECTIVE WITHDRAWAL AT HUNGRY HORSE DAM, MONTANA

Joseph Kubitschek[1], Robert Sund[2], and Rick Christensen[2]

Abstract

A unique selective withdrawal system has been developed and tested by the U.S. Bureau of Reclamation (Reclamation) for the purpose of controlling power plant release temperatures from Hungry Horse Reservoir, located on the South Fork of the Flathead River in Montana. In 1994 preliminary studies and the final design were completed. The system was constructed and installed in 1995. Preliminary hydraulic and biological performance data indicate the system conforms well with the results of the preliminary studies and the State of Montana water quality criteria which have been established to improve aquatic habitat in the Flathead River below the dam. This paper presents the unique design considerations and the general results of the Value Engineering and physical model studies associated with development of the Hungry Horse Dam selective withdrawal system.

Introduction

Hungry Horse Dam is located in northwestern Montana on the South Fork of the Flathead River about 8 km (5 miles) south of the west entrance to Glacier National Park. Hungry Horse Dam was built by Reclamation for the primary purposes of hydroelectric power generation and flood control. Construction started in 1948 and was completed in 1953. The concrete arch dam has a crest length of 645.5 m (2,115 ft) and a height of 172 m (564 ft). The reservoir has a total capacity of 427,769 hectare-m (3,468,000 acre-ft) and covers a surface area of 9,632 hectare (23,800 acres). There are four penstock intakes to the powerhouse with a combined capacity of 367 m^3/s (13,000 ft^3/s) at the maximum water surface elevation of 1,085 m (3,560 ft), three outlet works conduit pipes with a maximum capacity of 397 m^3/s (14,000

---

[1]Hydraulic Engineer, U.S. Bureau of Reclamation, Technical Service Center, Water Resources Research Laboratory, D-8560, P.O. Box 25007, Denver CO 80225-0007.

[2]Mechanical Engineer, U.S. Bureau of Reclamation, Technical Service Center, Mechanical Equipment Group, D-8410, P.O. Box 25007, Denver CO 80225-0007.

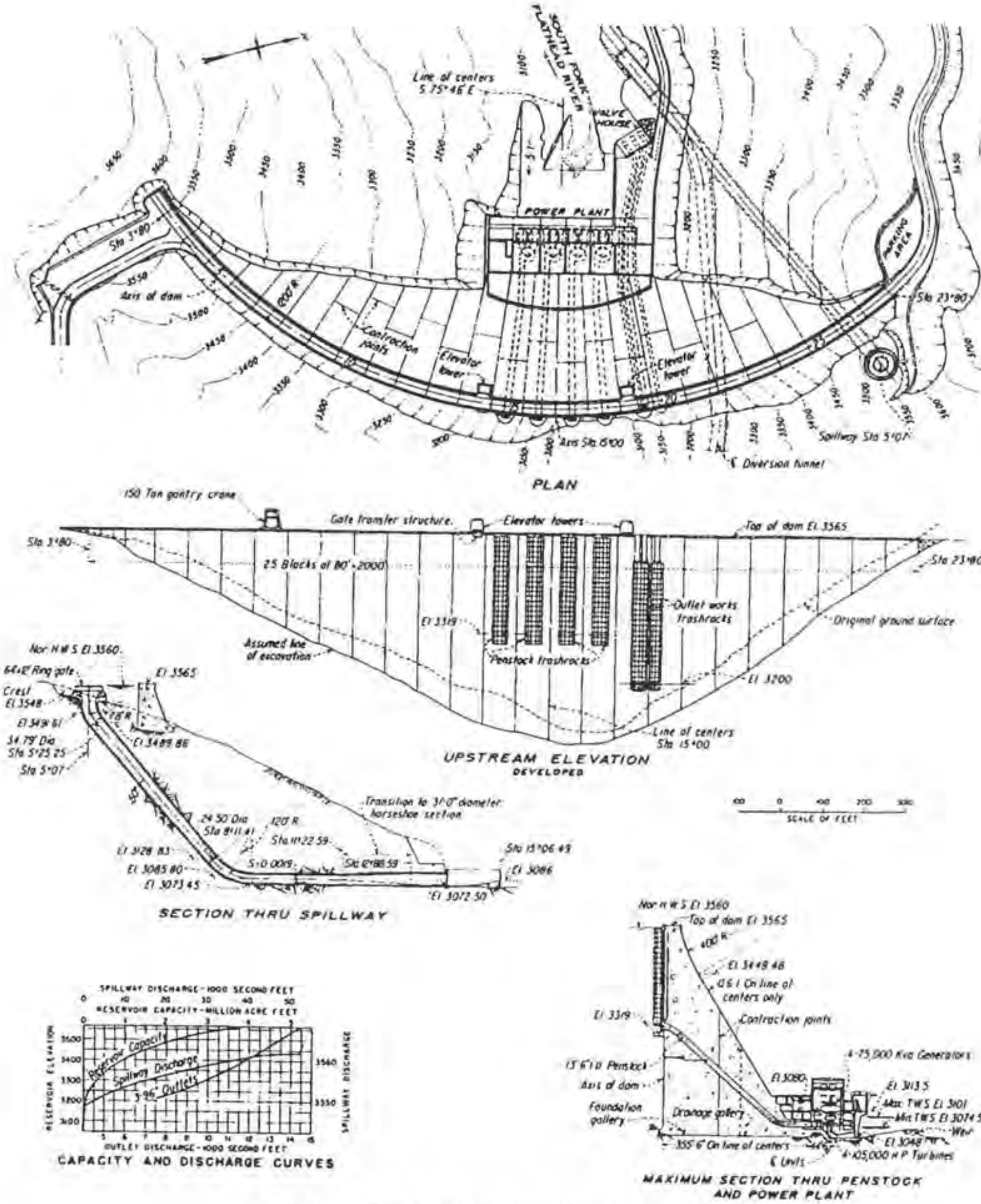

Figure 1. - Plan and elevation details. Hungry Horse Dam.

ft^3/s), and a morning-glory spillway with a maximum capacity of 1,416 m^3/s (50,000 ft^3/s). Figure 1 represents general plan and elevation details of Hungry Horse Dam. The total capacity of the power plant is 428 megawatts. Hydroelectric generation has averaged slightly less than one billion kilowatt-hours annually. The generators can be operated to meet base or peak power. Discharges through the power plant can range from 4.1 m^3/s (145 ft^3/s) up to 367 m^3/s (13,000 ft^3/s).

Background

The installation of a selective withdrawal system at Hungry Horse Dam has been under study for about 15 years and is the result of a long-term collaboration between Reclamation, the State of Montana, the confederated Salish and Kootenai tribes, Federal congressional representatives, Flathead Basin Commission, Northwest Power Planning Council, the environmental community, U.S. Forest Service and the Bonneville Power Administration. The penstock intakes which convey water from Hungry Horse Reservoir to the power plant are about 73.2 m (240 ft) below the maximum water surface elevation. Thus, releases from Hungry Horse power plant are extremely cold. Typically, reservoir drafting begins in the fall and continues through the winter to generate electric power and to provide storage space for flood control. Releases during the spring months are determined by anticipated runoff, power needs, reservoir space necessary for flood control, and the ability to refill by July. From July through September, an attempt is made to maintain a full reservoir for recreation. The cycle then begins again in October.

For a typical water year, the reservoir elevation will fluctuate approximately 24.4 m (80 ft). The maximum draw down of record was 57.3 m (188 ft). The reservoir elevation can be drawn down approximately 0.3 m (1.0 ft) in a 24-hour period with minimum inflow and full power plant operation.

During the spring and early summer, releases from Hungry Horse Dam provide a minor contribution to the total flow in the Flathead River system. As the other two forks of the Flathead River begin to decrease in natural flow, Hungry Horse Reservoir power generation releases become the major source for the main stem of the Flathead River, causing river temperature to decrease. Also, the Hungry Horse power plant has a history of providing peaking power generation which causes quick changes in river flows and consequently fluctuating river temperatures. Fluctuations in river temperature have resulted in thermal shock to fish and associated food chains.

Fishery Issues

Bull trout are currently proposed for listing under the Endangered Species Act. Cold releases from Hungry Horse Reservoir have been identified as a factor in their decline. In addition, predation by Lake trout which are drawn upstream from Flathead Lake by the cold river temperatures has compounded the problem. West Slope Cutthroat trout is also a species of special concern and has been affected by the unnatural temperature conditions of the Flathead River below Hungry Horse Dam. Hungry Horse release influences on river temperatures are most significant in the 29 km (18 mile) reach of the river located between the main stem confluences of the South Fork and Stillwater Rivers. This upper reach has been identified as having the most productive habitat for the species of special concern and is more typical of a natural river system. The environmental impacts have been quantified and include fish growth, fish reproduction, and aquatic insect communities. A computer model was developed by the Montana Department of Fish, Wildlife, and Parks (MDFWP) to monitor and predict the impact of temperature on fish growth. MDFWP has estimated that fish growth is likely to increase by a factor of three to five with the installation of selective withdrawal at Hungry Horse Dam.

Selective withdrawal of warmer surface water during the June through October period would likely entrain phytoplankton and zooplankton organisms from the reservoir. Computer modeling work done by MDFWP indicates that overall phytoplankton production in the reservoir could be increased by selective withdrawal. Warm water withdrawal could weaken the thermal stratification in the reservoir, causing a mix of deep water nutrients with remaining warm surface waters. Phytoplankton production would be stimulated and is predicted to increase beyond the amount estimated that would be entrained in the water flowing out through the selective withdrawal system. Reservoir zooplankton production is predicted to increase slightly with selective withdrawal. Zooplankton production would probably not increase to a level to compensate for reservoir losses. A corresponding decrease in reservoir fish growth could be expected. The selective withdrawal system has been designed to reduce the entrainment of zooplankton. Operational refinements would include stratified selective withdrawal by taking water from different depths and mixing it in order to achieve the desired temperatures, yet avoid the most biologically productive layers of the phytoplankton and zooplankton. Productivity and fish food supplies would be enriched in the tail water area below the dam.

Design Objective

The principle design objective was to provide an independent selective withdrawal system for each of the four penstock trashrack structures, with enough flexibility to allow selective withdrawal from the reservoir and produce natural temperatures in the downstream reach of the Flathead River. The system requires effective performance over the full range of reservoir level fluctuations of up to 48.8 m (160 ft) below the maximum reservoir water surface elevation of 1,085 m (3,560 ft). The system must also provide the capability of withdrawing directly into the penstock intakes during times when the reservoir is isothermal (winter months) to minimize the head loss (power loss) to the turbines.

System Description

A semi-cylindrical gate system was installed in each trashrack structure of the power penstock intakes to provide selective withdrawal control capability. Each gated system is made up of three gates. All three gates follow guides which extend from the top of the structure to their working locations. Figure 2 is a schematic of the selective withdrawal system. The gates are fabricated from rolled structural steel plates, reinforced with channel or wide flange beams. All equipment was designed to safely withstand a positive differential head of 2.1 m (7.0 ft) and a negative differential head (associated with water hammer) of 3.0 m (10 ft).

The lowest gate for each unit, called the relief gate, is approximately 11.6 m (38 ft) high. Each gate is semi-cylindrical in shape with an inside radius of 2.9 m (9.54 ft). Each relief gate contains 35 relief panels. Each panel is approximately 0.6 m (2 ft) high by 1.2 m (4 ft) long. Each relief panel has two shear pins designed to fail when a uniform load of 17.9 kPa (2.60 lb/in^2) is applied against the upstream side of the relief panel. This is equivalent to a head differential of 1.8 m (6.0 ft). The relief panels together provide approximately 23.9 m^2 (257 ft^2) of relief area for each unit, which is the relief area required to safely pass the unit's full capacity. The relief panels were designed to open inward. Opening will occur if the control gate or stationary gates are operated incorrectly, creating excessive differential pressures. The relief panels were not designed to relieve pressure transients due to water hammer which may result from a power generation load rejection. To minimize water hammer, the closure time of the generator governor wicket gates was increased.

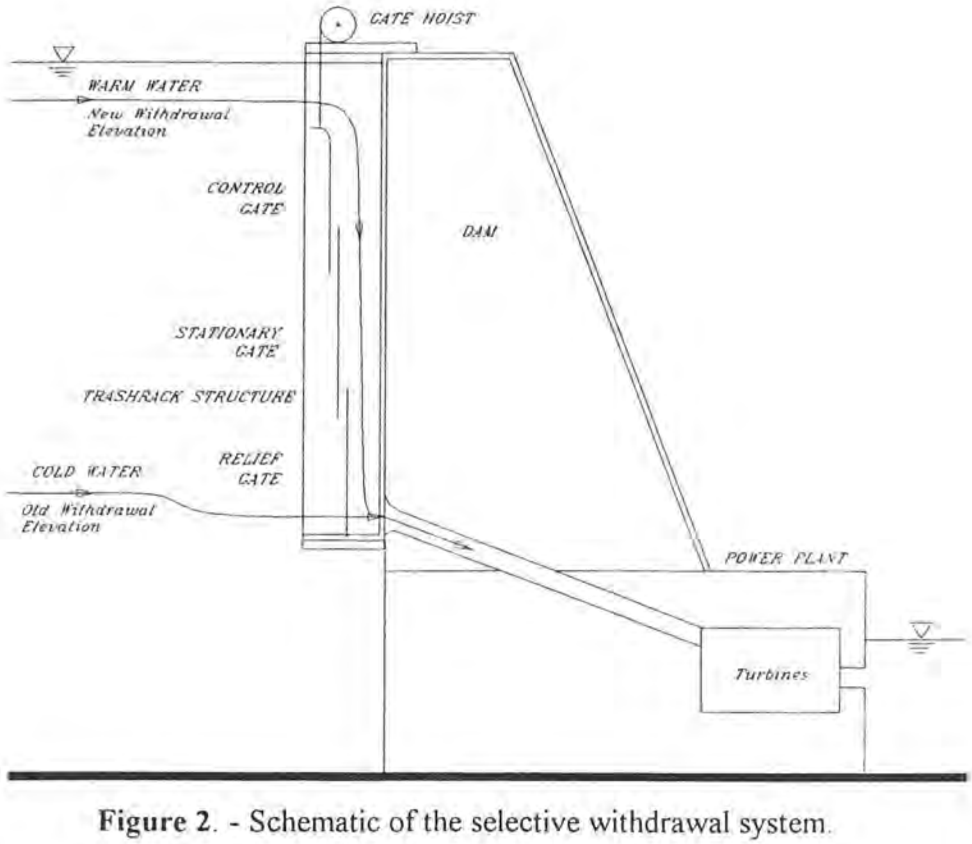

Figure 2. - Schematic of the selective withdrawal system.

The center gates, referred to as stationary gates, are actually three independent gates having a total height of 30.5 m (100 ft). The upper stationary gate is approximately 6.1 m (20 ft) high and the intermediate and lower gates are each 12.2 m (40 ft) high. The stationary gates are also semi-cylindrical in shape with an inside radius of 3.1 m (10.3 ft). The stationary gates are also installed in the gate guide system and are normally left in the lowered position.

The upper gate, referred to as the control gate, is approximately 30.5 m (100 ft) high and has a bell mouth-shaped crest to reduce entrance head losses. The control gates are also semi-cylindrical in shape with an inside radius of 3.3 m (10.9 ft). Each gate is suspended and operated by a 60-ton, dual drum, wire rope hoist. The hoist is capable of raising the gate to the hoist deck or lowering the gate 36.6 m (120 ft) with a travel rate of 0.5 m (1.6 ft) per minute. To minimize the hoist size, the control gate is equipped with bronze impregnated bearing surfaces to reduce friction. The gate can be raised or lowered under a 1.2 m (4.0 ft) maximum head differential load. As the control gate is lowered, it passes down around the stationary gates in telescopic fashion. The position (submergence) of the control gate determines the elevation of withdrawal. The control gates can be operated from the hoist deck of each intake structure or from the power plant control room.

Five small slide gates which are approximately 1.5 m (5.0 ft) wide by 2.1 (7.0 ft) high are located approximately 15.2 m (50 ft) from the top of the control gate. These slide gates are operated (opened and closed) by hydraulic actuators and provide additional operating flexibility. The hydraulic actuators have a 2.4 m (8.0 ft) stroke length and use a biodegradable operating fluid to operate all slide gates simultaneously. One of the actuators for each selective withdrawal unit is equipped with a position indicator.

Temperature sensors are placed in the reservoir and at each turbine to monitor the reservoir stratification and actual discharge temperatures. In the reservoir, a sensor was positioned every 1.5 m (5 ft) for the top 54.9 m (180 ft) starting at the maximum reservoir water surface. The reservoir temperature sensors, were installed in a metal well for protection. The signals from all the temperature sensors are sent to the control room at the power plant.

System Operation

Normally, the selective withdrawal system will be operated in the overdraw mode. During normal operating periods, the control gate should not be positioned less than 6.1 m (20 ft) below the reservoir surface. This minimum submergence is required to prevent air entraining vortex formation which could affect turbine operation. Other conditions that influence the amount of submergence selected by operating personnel include head losses, position of the slide gates, reservoir elevation, and the flow rate required by the power generating units.

Under normal conditions, the hoists will be operated to position the control gates at the required depth to provide the proper withdrawal elevation and desired release temperatures. Each control gate has a normal travel of approximately 30.5 m (100 ft) which is 36.6 m (120 ft) below the maximum reservoir water surface elevation. This travel length enables the control gate to maintain the minimum 6.1 m (20 ft) submergence over the full range of normal reservoir fluctuations. During certain periods of the year, it may be necessary to open the intermediate slide gates, located in the control gate. This is required to reduce the withdrawal of plankton-enriched water from the reservoir. As the control gate is lowered to follow the reservoir elevations, flow through the slide gates is restricted by the stationary gates. Depending on the control gate position, the upper and intermediate stationary gates can be raised to eliminate this restriction. During winter months the reservoir is isothermal and the selective withdrawal system will not be used. In this case, the control gates are lowered to their lowest position and the relief gates are raised to the top of the trashrack structure to minimize head loss associated with the system.

Preliminary Studies

Selective Withdrawal Analysis

A reservoir thermal model was developed by MDFWP and Montana State University as part of a biological model (HRMOD) (Marotz et al., 1993). Temperature profiles were measured twice monthly at various stations within the reservoir, approaching the dam, from April through November of 1983 through 1991. Sampling was terminated during ice formation. Data describing reservoir stratification were used to calibrate a modified version of a predictive mathematical model (Ferreira et al., 1992). Their modeling strategy was based on the original Flaming Gorge Reservoir model developed by Adams, 1974. Model simulations showed that selective withdrawal would return the South Fork and main stem Flathead River to nearly natural temperatures from June through November. Rapid temperature fluctuations and long-term cooling effects could be greatly reduced. The temperature correction imparted by the selective withdrawal system would aid the natural timing of adfluvial spawning migrations from Flathead Lake. Juvenile adfluvial species would experience favorable conditions in the river upon emigration from their natal tributaries. Growth potential would also be improved for fluvial trout populations inhabiting the affected reach. Also, these temperatures would be more conducive to the natural timing of insect life cycle events and help restore the natural insect community structure. Release fluctuations caused by power operations would continue to affect river stage and flow velocities, thus precluding full recovery of the historic insect assemblage.

Hydraulic Transient Study

A hydraulic transient study was conducted to determine the potential water hammer affects on the penstocks, turbines and the selective withdrawal system under start-up and load rejection conditions. The study was performed using the "Water Hammer Mass Oscillation Simulation Program" or WHAMO. Based on the WHAMO model, the current wicket gate opening speed during start-up, created a head differential across the selective withdrawal structure of 2.0 m (6.7 ft). To solve this problem, the governor opening speed was adjusted to reduce this differential to approximately 1.5 m (5.0 ft). Correspondingly, the modeling results indicated that a governor closure time for the wicket gates of 12 seconds may cause a transient pressure spike of approximately 3.0 m (10 ft) at the penstock entrance. The model also showed that water hammer pressure magnitudes within the selective withdrawal system or at the penstock entrance which are limited to 3.0 m (10 ft), would be within safe limits. These results allowed for a design which ensures structural integrity of the system.

Value Engineering Study

A value engineering study was completed in June 1994. An independent study team was assembled and charged with identifying alternative concepts to ensure cost effectiveness of the proposed Hungry Horse selective withdrawal system. The preliminary cost estimate for the original selective withdrawal concept was identified as $11.4 million. The study team identified three cost saving alternatives which achieved the selective withdrawal objectives, one of which became the final concept. Although the final concept reduced cost, a disadvantage was identified and consisted of the fact that the entire selective withdrawal gate system must be removed should stoplog installation be required. The accepted final project bid was approximately $6.3 million which represented a cost savings of more than $5 million. The cost of this value engineering savings was approximately $17,000.

Physical Model Study

Physical model investigations were conducted in 1994 for the purpose of establishing hydraulic characteristics of the original concept and the value engineering team concept (Kubitschek, 1994). A 1:18 scale Froude model of a single power penstock intake and trashrack structure was constructed at Reclamation's Water Resources Research Laboratory in Denver, Colorado. Testing consisted of evaluating each concept from both head loss and vortex formation potential standpoints. Figure 3 is a photograph of the physical model. The model study results indicated that the modified concept performed slightly better than the original concept over the full range of submergence and discharge conditions tested.

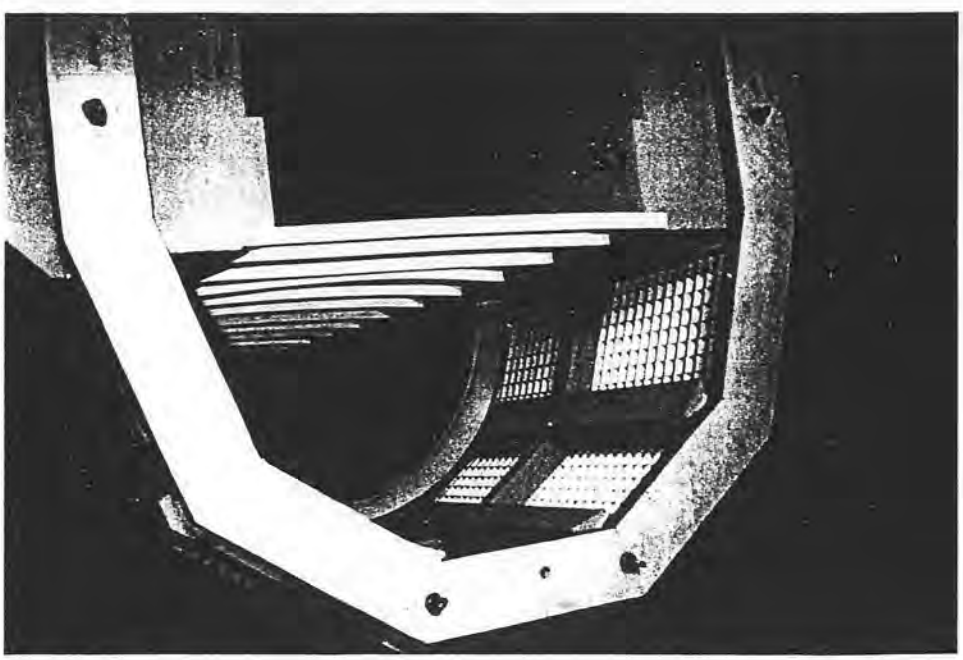

Figure 3. - Top view of 1:18 scale physical model of a single penstock intake and trashrack structure used to evaluate two selective withdrawal concepts.

The predicted maximum additional prototype head loss associated with the modified concept was found to be 1.5 m (5.0 ft) for the maximum intake discharge under the minimum submergence of 6.1 m (20.0 ft). For the same discharge and submergence conditions, the predicted maximum additional head loss for the original concept was found to be 2.0 m (6.6 ft). Based on these results and the significant cost savings identified by the value engineering team, the modified concept was selected for final design. In addition, the results of the physical model study provided designers with the necessary information to minimize head loss and ensure structural adequacy of the system. Additional investigations were conducted to determine the potential for air entraining vortex formation. Flow visualization techniques were used to determine the submergence limit for each concept. The submergence limit for both concepts was identified as 6.1 m (20 ft). Above this point (ie. submergences less than 6.1 m) the potential for air entraining vortex formation was significant.

Discussion

Construction and Cost

The construction contract was awarded to Dix Corporation for $6,321,945.20 in 1994, and by late 1995 all four selective withdrawal structures were operational.

Field Testing

Field tests were performed with turbine startups and load rejections at the full power output of 107 megawatts (Reclamation, 1996). To monitor pressures on the system, pressure transducers were placed at the turbine, at the penstock entrance, and on the relief gate of the first unit to be operated. The main variable which controlled the magnitude was the amount of wicket gate opening allowed when first starting the turbine.

The maximum head loss associated with the selective withdrawal system, which occurred at full power (107 megawatts) generation, at the minimum 6.1 m (20 ft) control gate submergence, and with all intermediate slide gates closed, was found to be approximately 10.3 kPa (1.5 lb/in^2) or 1.1 m (3.5 ft) of head. This result conformed well with the results of the physical model study which predicted a maximum head loss of 1.5 m (5.0 ft). The maximum transient pressure was found to be 13.8 kPa (2.0 lb/in^2) at the 6.1 m (20 ft) control gate submergence. All pressure readings for the operating head loss and water hammer were within acceptable ranges and were lower than predicted by both physical and computer model studies. At the minimum control gate submergence and maximum discharge, the wire ropes from the hoist exhibited flow generated vibration. It was obvious from field observations that the control gate position should never violate the minimum submergence requirement.

Acknowledgments

The authors gratefully acknowledge the key roles played by Dennis Christenson, Bureau of Reclamation and Brian Marotz, Montana Department of Fish, Wildlife, and Parks.

References

Adams, D.B. 1974. "A Predictive Mathematical Model for the Behavior of Thermal Stratification and Water Quality of Flaming Gorge Reservoir, Utah-Wyoming." Massachusetts Institute of Technology, unpublished M.S. Thesis.

Ferreira, R.F., D.B. Adams and R.E. Davis. 1992. "Development of Thermal Model for Hungry Horse Reservoir and Lake Koocanusa, Northwestern Montana and British Columbia." U.S. Geological Survey, Water Resources Investigations, Report No. 91-4134.

Kubitschek, Joseph P. 1994. "Hungry Horse Selective Withdrawal Hydraulic Model Study." U.S. Bureau of Reclamation, Report No. R-94-10.

Marotz B.L., C.L. Althen and D. Gustafson. 1993. "Aquatic Modeling Report: Selective Withdrawal System - Hungry Horse Dam, Montana." Montana Department of Fish, Wildlife, and Parks, Report to U.S. Fish and Wildlife Service.

U.S. Bureau of Reclamation. 1996. "Design Summary - Selective Withdrawal System, Hungry Horse Dam, Hungry Horse Project, Montana."

KEYWORDS: selective withdrawal, Hungry Horse Dam, release temperature, water quality, fisheries, fish habitat, physical modeling, head loss, vortex formation, environmental hydraulics.