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HYDRAULIC FEATURES OF FLEXIBLE CURTAINS USED FOR SELECTIVE WITHDRAWAL

BY

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ABSTRACT: Flexible curtain barriers are being investigated as a way to modify power penstock intakes to achieve selective withdrawal. The curtain barrier controls the elevation from which water is drawn. The curtain creates a reservoir within a reservoir. Stratification in the inner reservoir (between the curtain and the intake) depends on the stratification in the main reservoir, inflows from the main reservoir, outflows through the penstocks, and flow caused mixing. Withdrawal from the main reservoir (past the curtain) and withdrawal from the inner reservoir (through the penstock intake) create withdrawal layers as described by available theory. Comments presented in this paper are based on findings from a physical model study and design for Shasta Dam. To further develop these cost effective structures, efforts are currently being directed toward constructing an instrumented prototype.

The Concept

When a reservoir is density (temperature) stratified, it is possible to withdraw water from distinct horizontal layers. The vertical position and thickness of the withdrawal layer depends on the vertical position of the intake, the size and orientation of the intake, the withdrawal discharge, the density stratification profile, topography, and water surface influences. Positioning intakes at various elevations in the reservoir allows selection of the horizontal layer from which water is withdrawn (selective withdrawal). Numerous studies have been conducted to define the upper and lower bounds of the withdrawal layer (Bohan and Grace, 1969; Imberger, 1980; Smith et al., 1985). These studies typically were conducted in laboratory reservoirs (rectangular flumes) with simplified intake and reservoir geometry. The laboratory findings have been generally confirmed by field observations. There are

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however variations between theories which indicate uncertainties. In addition, site-specific geometry influences are not addressed by the basic theory. Thus, variations away from the withdrawal layer bounds predicted by theory can be expected. In particular if reservoir geometry is restrictive or if intake geometry is unusual, stratified physical models should be used to evaluate selective withdrawal performance. The physical model findings can be coupled with reservoir and down river mathematical models to determine reservoir and river response for guiding management of water quality resources.

Selective withdrawal is one tool that may be used to control reservoir release water quality. The effectiveness of selective withdrawal depends on the availability of water with acceptable quality, the ability to position an intake to access the desired water, and on the parameters that control the vertical extent of the withdrawal layer as defined by theory. Many dams have been built with power penstock and/or outlet works intakes at single elevations (no withdrawal level selectivity). Increasing efforts to improve release water quality have lead to consideration of retrofit selective withdrawal structures. Typically retrofits consist of rigid structure extensions of existing intakes. Even though rigid retrofits are often not designed to withstand full hydrostatic pressure (dewatering) they tend to be substantial and expensive.

To control down river water temperatures for the benefit of the salmon fishery the U.S. Bureau of Reclamation has considered alternative retrofit selective withdrawal options for the power intakes at Shasta Dam, California. Shasta Dam is a 183.5-m (602-ft) high concrete gravity structure. The maximum power discharge is 498 m^3/s (17,600 ft^3/s). The plant operates in a peaking mode with generation dependent on power and water demand. At Shasta the primary water quality objective is release of cold water through the summer and early fall. The power intakes are located on the right abutment, approximately 76 m (250 ft) above the reservoir bottom. In drought years, late summer and early fall water temperatures at the elevation of the penstock intakes exceeds acceptable levels for sustaining salmon eggs and salmon fry in down river spawning beds. Historically when this occurs, power generation has been terminated and releases made through the low level outlet works. Power revenue losses of $100,000 per day have resulted. Use of reservoir mathematical models show that in these cases, if cold water is accessed when the temperature of the water at the power intakes exceeds acceptable levels, insufficient volumes of cold water remain (below the penstock intakes) to meet needs through the remainder of the hot season. The math models show that withdrawals should be made from high in the reservoir through the spring which would greatly increase cold water reserves for later in the year. Numerous modifications which allowed both high level and deep withdrawals were considered (U.S. Bureau of Reclamation, 1987). Options included bulkheading of the trashrack structure to allow high level withdrawal, use of the diversion tunnel as a deep penstock intake, use of the low level outlets as deep penstock intakes, excavating a new deep level penstock through the dam, attaching a rigid steel multi-level intake to the dam face (over the penstock intakes), and using a flexible curtain barrier (figure 1).

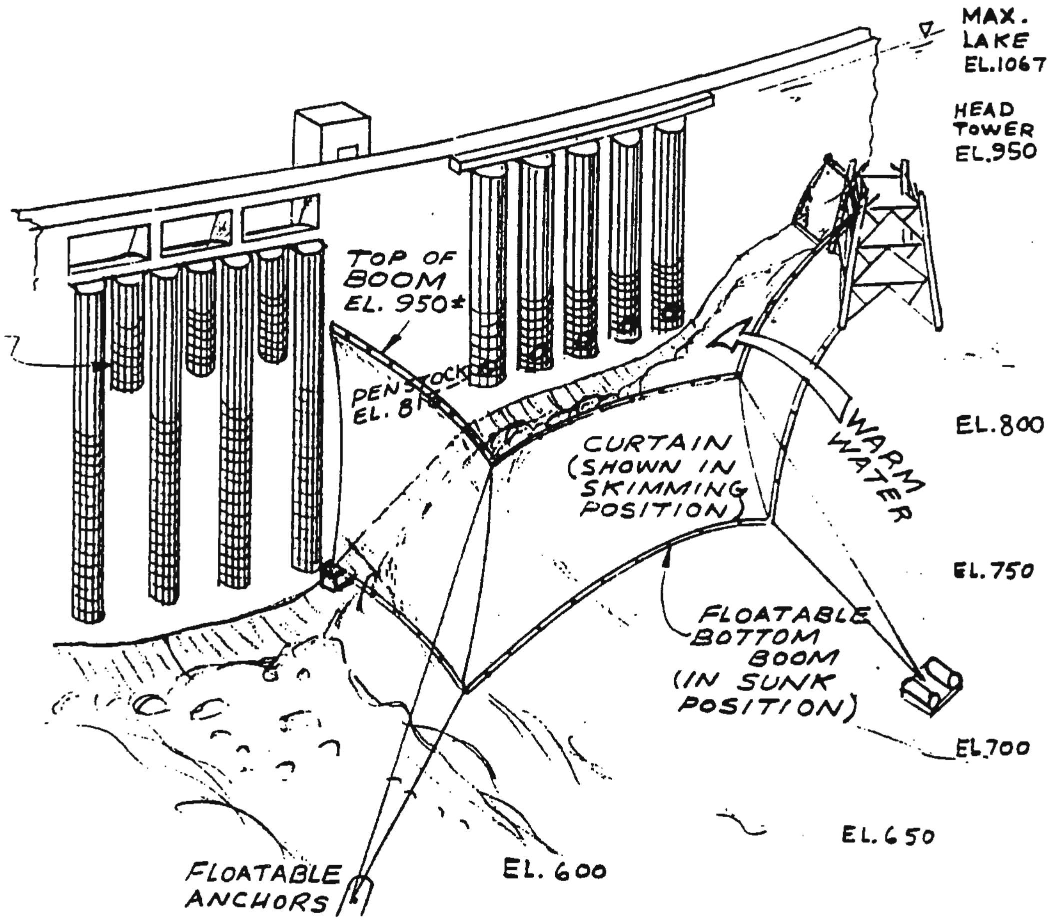

Figure 1. Flexible Curtain Option.

A value engineering study found the curtain barrier to be the lowest cost option. Consequently, a detailed design development was undertaken. Numerous curtain configurations were considered. The designs developed included cable and rigid-member-supported Hypalon curtains with floats and bottom anchors. The curtains had maximum vertical heights of approximately 90 m (300 ft) and top perimeter lengths of up to 365 m (1200 ft). The curtains included panels that could be lowered or raised to control deep water access. Also included were panels that could be lowered to access intermediate level water. The curtains were designed to operate with the top of the curtain submerged, however in low water years the top of the curtain would be at the water surface. The elevation of the top of the curtain was set based on the mathematical model findings which showed that spring withdrawals from this level would leave adequate cold water reserves.

Hydraulic Characteristics

As a part of the Shasta design effort, a 1:72 scale, density stratified model of the power intakes and approximately 400 m by 580 m (1300 ft by 1900 ft) of surrounding reservoir was used to study retrofit options (Johnson, 1991). The model was used to define the withdrawal characteristics of the retrofit, to define dynamic and density generated differentials, to establish operations guidelines, and to optimize the design.

With the top of the curtain submerged and with all flow drawn over the curtain (overdraw), it was found that the withdrawal layer in the main reservoir sheared with the warm surface water above. The shearing action pulled surface water over the curtain and into the inner reservoir zone. An equilibrium state resulted with a thickened surface water layer inside the curtain and with a fairly static surface water layer in the main reservoir (once the equilibrium state is reached surface water flow over the curtain was small). The strength of this action was dependent on submergence. With shallow submergence of the top of the curtain the withdrawal layer extend to the surface and surface water was actively passed. With moderate submergence the flow conditions described above were maximized. With large submergence (with the top of the curtain substantially below the warm surface water layer) little shear occurs with the surface water and consequently little thickening of the surface layer results. With moderate submergence, the withdrawal flow (beneath the surface layer) drops from the top of the curtain into the inner reservoir. The flow drops as a supercritical density flow until it reaches water of similar density. At that point the jet diffuses. The mixing entrains both surface water from above and cold water leakage from below. Typically, there was a zone inside the curtain below the mixing and below the penstock intakes that contained fairly stagnant cold water. The penstock intakes draw water from this modified stratification (thick surface layer, mixed transition layer, cold stagnant layer). The withdrawal layer from the inner reservoir, generated by the penstock intakes, appears to follow withdrawal layer theory with compensation for boundary influences. Overdraw generates the most severe density profile shifts across the curtain with warm water on the inside of the curtain and cold water on the reservoir side. The resulting differential was the critical design load.

Conversely when efforts were made to draw all flow under the curtain (underdraw), relatively small temperature and density profile shifts resulted across the Shasta curtain. Basically the cold water in the main reservoir, below the penstock intake elevation, was of similar temperature to the cold underdraw flow which fills the lower inner reservoir between the bottom of the curtain and the penstock intakes. A differential across the curtain is required to generate the underdraw flow. If the top of the curtain is submerged the differential can be created by a density profile shift. If the differential required (depending on the underdraw cross section and discharge) exceeds what can be generated by a temperature profile shift (depends on vertical water column height and temperature differentials) water is drawn both over and under the curtain. If the top of the curtain is at the reservoir surface a physical blockage to overdraw, except for leakage, is present and greater differentials are possible. This, however, creates the potential for misoperation where excessive curtain control could yield differentials that exceed the design capacity of the curtain.

When the top of the curtain is submerged and the curtain is operated in the underdraw mode, mixing caused by the rising underdraw will entrain water from above the penstock intakes. The quantity of entrained water and thus the resulting overdraw is dependent on the underdraw discharge and the curtain control. For typical underdraw operation of the Shasta curtain it appears that 10 to 20 percent of the total release will be entrained overdraw. Because surface temperatures are much warmer than deep water temperatures this entrainment can substantially reduce curtain effectiveness. Again withdrawal from the inner reservoir is approximately described by available withdrawal layer theory.

Leakage was also a concern. The curtain would attach to the dam face and would seat against the bottom topography. It was expected that leakage free attachments were not possible at either surface although closer tolerances could be achieved at the dam face. For various flow conditions (high level withdrawal, low level withdrawal, combined high and low level withdrawal) efforts were directed toward evaluating leakage discharge, distribution, and determining what constitutes acceptable leakage. Leakage discharge was dependent both on cross-sectional area and geometry of the leakage path and on local differential across the curtain. Differential was a function of curtain design, withdrawal operation, and temperature profile shifts (in particular with strong temperature gradients and large vertical water column heights). Differentials generated by dynamic effects are modified vertically by differences between the integrated density profiles on both sides of the curtain.

A final concern was dynamic loading on the curtain. It was noted that a flexible curtain might develop a periodic response to dynamic loading. In turn this curtain oscillation might case either fabric or support structure failure. Although it was not possible to exactly model the structural characteristics of the curtain, a very light weight flexible curtain was installed and observed for dynamic response. Noting physical model limitations indicated by reduced model Reynolds Numbers, no dynamic response was observed for the conditions tested. Detailed dynamic response tests have not been done and consequently curtain oscillation remains an uncertainty. As noted, development of the Shasta curtain found differentials generated in overdraw to be the controlling design load. The curtain was designed for a maximum differential of 73 kg/m^2 (15.0 lbs/ft^2). To minimize oscillation potential, underdraw cross sections were sized to yield maximum velocities of 0.3 m/s (1.0 ft/s). The stagnation pressure generated by the 0.3 m/s (1.0 ft/s) velocity is approximately 1/15 of the design load.

Future Work

Feasibility designs have shown the cost of a curtain structure to be less than half the cost of a conventional rigid structure. Because of uncertainties about hydraulic performance, deployment, operation, maintenance, and reliability a conventional structure design was selected for installation at Shasta. Reclamation, however, recognized the potential cost savings and thus has initiated an effort to install an instrumented prototype which would be used to develop and prove the concept. Currently a physical model of the proposed prototype (Lewiston Dam, California) is being studied. Results were not available for inclusion in this paper but will be reported on in the presentation.

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KEY WORDS

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