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BY

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Hydro Power Intake Design - Criteria and Experience

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ABSTRACT: This paper briefly addresses parameters to be considered in hydro power intake designs. Included are design approaches and criteria, specific examples, and applicable references. Concerns for high head, low head, and pump storage intakes are noted.

Hydraulics

Concern: Maintaining optimum hydraulic performance while minimizing the structure size, complexity, and cost which includes associated gates, bulkheads, accessory equipment, and trashracks.

Design: Low penstock velocities [less than 25 ft/s (7.6 m/s)] allow a small simplified intake. For large concrete dams (14, 16, 19) a compound radius provides an adequate bellmouth, a semicircular trashrack seat reduces intake losses, a gate area to penstock area ratio of between 1.00 and 1.11 produces good hydraulic performance, an intake height-to-width ratio of 1-1/2:1 minimizes structure cost, and the head loss with such an intake and transition will be between 0.08 and 0.14 of the penstock velocity head. A typical intake design is shown in Figure 1.

Low Head Hydro: The intake shape is dependent on turbine type. For bulb and rim generator turbines the velocity head in the intake is low (1 percent of total head). Consequently, a short, simplified intake with a small radius bellmouth (top radius equal to 0.40 of throat diameter, side radii equal to 0.20 of throat diameter) is adequate and reduces structure cost by up to 10 percent (15, 17).

Pump Storage: During the pumping cycle the intake functions as a diffuser, reducing flow velocities which could cause trashrack failure and allowing velocity head recovery (18). This requires an expensive long gradually expanding structure. Performance is dependent on approach flow and thus penstock alinement. A hydraulic model study is recommended to develop the design.

Vortices

Concern: Air-entraining vortices decrease turbine efficiency, pull floating debris into turbine (or onto trashrack), and cause rough turbine operation.

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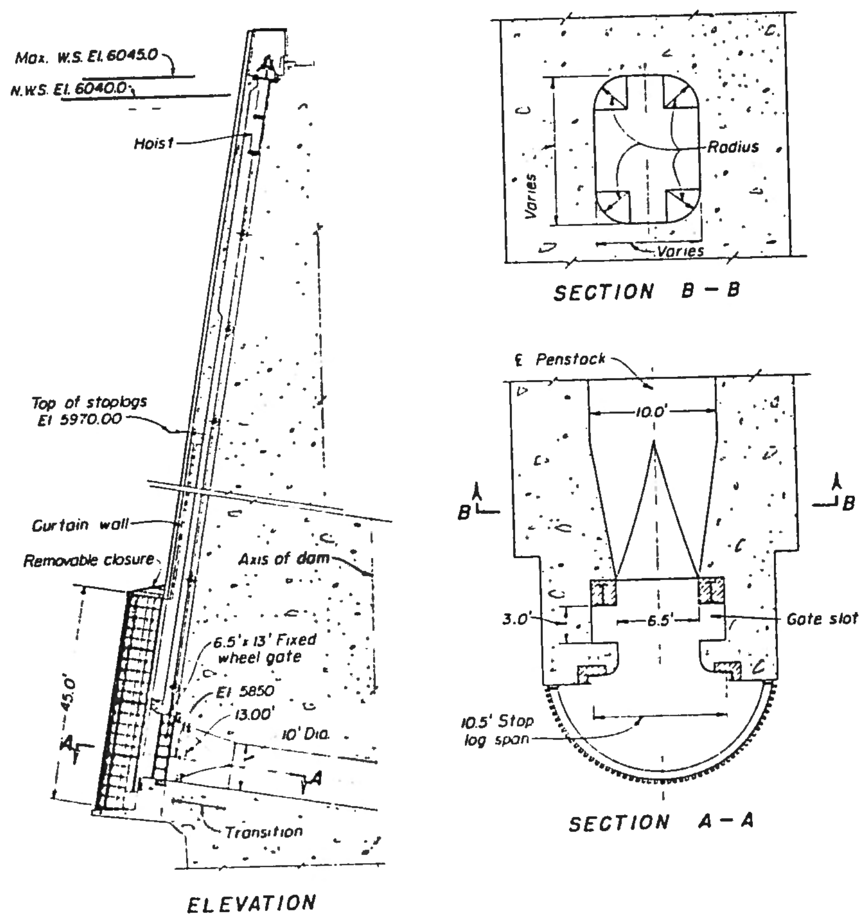

Figure 1. - Typical High Head Penstock Intake Design

Design: Vortex formation and strength is dependent on approach flow geometry, intake flow velocity, intake size and geometry, and submergence. Geometry influences are substantial and site specific. Generalized vortex prediction relationships cannot be developed. Relationships (Equation 1) are available that indicate potential for vortex development (3, 9).

$$\frac{S}{d} = C' \frac{V}{\sqrt{gd}} = C' F \qquad (1)$$

S is submergence required to prevent vortex formation, d is penstock diameter, V is intake velocity, C' is a coefficient (equal to 1.70 for symmetrical approach flow and 2.2 for lateral approach flow), and F is the Froude number. If available submergence is inadequate or questionable, care should be taken in the design. A model is recommended. Air core vortex prediction accuracy is limited by scale effects but lack of strong vortex tendencies can be accurately predicted (10). Antivortex devices such as rafts (12), injector shafts (2), fixed lattice walls (12), etc., can be used. Appropriate antivortex devices are site specific and might require a model study.

Selective Withdrawal

Concern: Withdrawal from temperature and water quality stratified reservoirs will influence both reservoir and downstream water quality.

Design: Reservoir stratification is a function of withdrawals, inflows, climatic conditions, oxygen demand, and numerous other dynamic parameters. Thus reservoir makeup will change through the seasons and from year to year. To position intakes and study intake influence on the reservoir and on releases, a reservoir mathematical model such as CE-QUAL-R1 (7) or WQRRS (11) should be used. These models are complex and require an experienced user. The model should be verified with field data.

Multilevel Intake Structures: Typically have light weight down wells on the dam face (Dworshak, Libby, Flaming Gorge). Gated intakes are positioned at elevations determined by mathematical model. Pressure relief panels are included to prevent structure collapse in case of intake blockage.

Mechanical Equipment

Concerns: There are numerous design problems associated with penstock intake mechanical equipment (Figure 1).

Trashracks: Deeply submerged trashracks have proven trouble free with trash accumulation only during initial filling. Alternately wet and dry racks require more maintenance. For shallow installations where the trashracks can be accessed and raked, trashracks are structurally designed for 5 feet (1.5 m) of differential head to safe stress. For deeply submerged racks where access is difficult, trashracks are designed for 20 feet (6.1 m) differential head to yield stress. For conventional intakes a velocity criteria of 2 ft/s based on gross area is used to size trashracks. Trashracks on pump storage intakes may be exposed to velocities equal to the penstock velocity [20 ft/s (6.1 m/s) or greater]. Under these conditions a hydraulic model study to define the flow field and a thorough vibration analysis are recommended.

Stoplogs: Provided to the height below which the gate slot wall (Figure 1) can no longer withstand the water load when the gate area is unwatered. For vertical or near vertical intakes metal guides are omitted above the upper log seal seat. The guides are sized and located to minimize intake losses.

Gates: Inclusion of a positive shutoff that can operate under full flow is recommended. If possible a fixed wheel or similar gate should be placed at or as near to the intake as possible to allow shutoff in the event of penstock or turbine failure. By seating the gate on an invert compression seal the gate can be located downstream of the bellmouth curve and gate size minimized. Gate slot width is minimized to reduce losses. Penstock filling valves operated by hoist stem overtravel are included in the gate. Metal tracks are provided up and through full gate open position.

Fish Diversion and Passage

Concern: Passage of fish through turbines may result in substantial mortalities.

Design: Initally a field survey of the fishery should be done to identify types, numbers, and development stage of species. Note that new impoundments may modify the fishery. The field survey should be conducted over a full year and should identify behavioral traits including occupied lateral and vertical zones and spawning and migration characteristics. A literature survey to define behavior including response to velocity fields, swimming strength, and response to light and dark should also be done. Few general references are available (1), references on specific species may be found. The field and literature data will guide design and may, for example, show times and/or places where fish are not present and thus where screening would not be required. Coordination should be maintained with the fishery agencies involved in that their design criteria and fish control preferences may be a dominant factor. Selection and design of a fish control is site specific. Critical factors include powerplant type (diversion to power canal, run-of-the-river, deep reservoir, pump storage), species and development stage, water quality, debris load, winter operation, and sedimentation. Shallow intakes are susceptible to debris, ice, and sediment problems but have numerous fish control alternatives (drum screens, passive screens, louvers, traveling screens, pressure screens, behavioral controls). Deep intakes while being relatively free of debris, ice, and sediment problems have fewer control options (traveling screens, pressure screens, behavioral controls) due to accessibility and structural limitations. Design references

are available (4, 21). What may prove to be the definitive reference is presently in preparation for the Electric Power Research Institute.

Ice

Concern: The primary concern is trashrack fouling. Secondary concerns include blockage of the stream above the plant with resulting intermittent decrease in stream flow, decreased head due to increased losses in approach channel or elevated tailwater due to downstream blockage, and ice thrust on structures (5).

Design: Generally, if shut down due to ice fouling cannot be tolerated, a forebay with adequate intake submergence to ensure unhindered flow passage must be provided. Velocities through such a forebay should be less than 1.5 ft/s (0.46 m/s). Deep reservoirs provide such a forebay and thus tend to be free of ice related intake problems. Ice problems, typically trashrack and thus intake fouling, are encountered at power diversion and run-of-the-river sites. Trashrack fouling may result from direct freezing of ice on the trashrack bars, which may be avoided by isolating the racks from the atmosphere (possibly by submerging all metal work). However, if the trashrack encounters large quantities of active frazil ice, it is practically impossible to prevent ice accumulation, even if the bars are heated. A second source of fouling is accumulation of float ice. Sluicing may be possible if the sluice is positioned to create a pronounced sweeping flow across the intake and sized to prevent fouling of the sluice itself. An ice cover that would reduce frazil ice production and accumulate float ice upstream of the intake could be created by reducing flow velocities and using ice booms (5). A final option, other than shut down, is to operate without racks. This is hazardous in that debris such as logs, boulders, and ice may enter the intake, jam gates, twist gate stems, and result in severe pounding of the unit. Trashracks should be designed for full static load if ice fouling appears possible.

Debris

Concern: Debris fouling of intakes.

Design: Debris problems are generally not experienced at deep penstock intakes except during initial reservoir filling. Debris fouling is a more common problem at shallow intakes. Depending on loading the debris may be either manually removed (when quantities are small and associated with short term events) or removed by automated power trashrack rakes. The design of power rakes is a fairly site specific problem and is dependent on both the structure and the debris type. Designs should be closely coordinated with rake manufacturers.

Sediment

Concern: Sediment fouling of intakes or sediment passage through turbines with associated abrasion.

Design: Except in severe cases, sediment is not a problem for penstock intakes at deep reservoir sites. Through use of a reservoir sedimentation analysis (20) the intake is positioned a sufficient distance off of the bottom to prevent sediment intake for a period in excess of 100 years. Use of a sedimentation analysis requires field evaluation of stream transport. Sediment related problems are common at power diversion and run-of-the-river sites. Bed load exclusion structures (curved training walls, undersluice tunnels, stream inlets, vortex tubes, etc.) and natural stream curvature (8) may be used to control coarse (sand size and larger) bedload sediment in shallow streams and rivers. These concepts are most effective at high discharges and have reduced effectiveness at low flows. Sediment exclusion structures generally require sluicing or wasting water. Settling basins may be used at power diversions. A settling basin design analysis is available (13, 18). Basin effectiveness increases with reduced discharge. Sluicing is not needed but substantial space and periodic cleaning are required. A final option is to allow sediment passage through the turbine. At one site, it was determined that sediment passage and resulting turbine maintenance were a less expensive option than settling basin construction and maintenance.

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