

CHAPTER-ONE

DAM OUT LET WORKS

1.1 Introduction to Dam out lets

Introduction

Most of the water, which is stored in a reservoir for irrigation water supply or power penetration purposes, is stored below the spillway crest level. The spillway is provided at normal pool level, such that the floods are discharged safely above the spillway. But, in order to draw water from the reservoir as and when needed, for irrigation, water supply, power generation etc it is absolutely necessary that outlet works are provided either through the body of the dam or adjacent to it through some hillside at one end of the dam, or adjacent to it through some hillside at one end of the dam, this water may be discharged to the dome stream channel below the dam or may be transported at distances where required (to some power house, etc) through pipes or canals. The opening a pipe or tunnel provided for this withdrawal of water is known as a **dam out let**.

In certain instances the out let works of a dam maybe used as a service spillway in conjunction with an auxiliary or secondary spillway. In this event the usual outlet works installation might be modified to include a by pass overflow, so that the structure can serve both as an outlet work and spillway.

An outlet works may also act as a flood control regulator, to release waters temporarily stored in flood control storage space or to evacuate storage in anticipation of flood inflows. Further, the outlets may serve to empty the reservoir to permit inspection, to make needed repairs, or to maintain the upstream face of the dam or other structures normally inundated.

1.2 Determination of required dam outlet capacities

Outlet works controls are designed to release water as specific rates, as indicated by downstream needs, flood control regulation, storage canted regulation, storage considerations, or legal requirements. Delivery of irrigation water is usually determined from project or form needs and is related to the consumptive use and to any special water requirements of the irrigation system. Delivery for domestic are can be similarly established. Release of flows to satisfy prior rights must generally be included with other needed releases. Minimum d/s flows for pollution abatement, fish preservation, and other companion needs may often be accommodated through other required releases.

Flood control releases generally can be combined with the irrigation outlet release if the out let empties in to the river instead of into a canal. The capacity of the flood control outlet is determined by the required time of evacuation of a given storage space considering the inflow into the reservoir during this emptying period.

If an outlet is to serve as a service spillway in releasing surplus inflows from the reservoir, the required discharge for this purpose may fix the outlet capacity. Here again, the inflow into the reservoir during the emptying period must be considered.

1.3 Selection Criteria

Outlets must be designed to safely and effectively satisfy all of their functional requirements. Because of their high cost, outlets should be included in economic studies used to optimize dam design concepts. The costs of operation, maintenances, modification, and possible replacement should be included in these economic studies.

Project requirements are a primary consideration. Project requirements will include; properly positioning intakes gating, and terminal structures; sizing components; selecting appropriate components including operation controls; providing adequate means for maintenance and replacement of components.

Site conditions involve topography, climate, geology and seismcity. Each of these conditions influences the selection of outlet type and components.

The type of dam (concrete or embankment) greatly affects the design and the cost of an outlet. The lengths of waterways and the requirements for energy dissipation have important effects on costs.

1.4 Outlet works Position in relation to Reservoir Storage Levels

In order to attain the required discharge capacity, the outlet must be placed sufficiently below minimum reservoir operating level to provide head for effecting outlet works flows.

Outlet works for small detention dams are generally constructed near river bed level since permanent storage space, except for silt retention, is ordinarily not provided. For dams which impound water for irrigation, domestic are, or other conservation purposes, the outlet works must

be placed low enough to draw the reservoir down to the bottom of the allocated storage space; however it might be placed at some level above the river bed, depending on the elevation of the established minimum reservoir storage level.

It is usual practice to make an allowance in a storage reservoir for inactive storage for sediment deposition, fish and wildlife conservation, and recreation. The positioning of the intake sill then becomes an important consideration, since it must be high enough to prevent interference from the sediment deposits, but at the same time low enough to permit either a partial or a complete drawdown below the top of the inactive storage.

1.5 Location of outlet controls

Where an outlet work is ungated, as will be the case with many detention dams, flow in the conduit will be similar to that in a culvert spillway. Where water must be stored and the release regulated at specific rates, control gates or valves will need to be installed at some point along the conduit.

Operating gates and regulating valves are used to control and regulate the outlet works flow and are designed to operate in any position from closed to fully open. Emergency gates are designed to be utilized only to effect closure in the event of failure of the operating gates, or when on watering is required either to inspect the conduit below the emergency gates or to inspect & repair the operating gates.

A) Control at upstream end of the conduit

For an outlet works with an upstream control discharging into a free-flowing conduit, part full flow will occur throughout the length of the structure. Ordinarily, the operating head and the conduit slope will result in flow at supercritical stage.

With controls placed at the u/s end of a conduit, fish screens, stop log, slots, trash racks, emergency gates, and regulating gates or valves can all be combined in a single intake structure. In this case, the entire conduit may be readily unwatered for inspection or repair. The intake will consist of a tower rising from the base of an outlet conduit to an operating deck placed above maximum reservoir water level, with the tower located in the reservoir area near the upstream toe of the dam.

B) Control at intermediate point along the conduit

Where a control gate is placed at an intermediate point along a conduit and discharges freely into the d/s section, the internal pressure u/s from the control will be approximately equal to full reservoir head. The structural design and safety aspects of the u/s portion will then be concerned with the effects of both the external loadings and the internal hydrostatic pressure acting on the conduit shell.

The control gates or valves for a conduit through a concrete dam can be positioned at any point, either u/s to afford full flow or at the d/s end to provide pressure pipe flow. Where the sluices are provided in the overflow section of the dam (spillway), u/s gates controlling the entrance or valves operated from an interior gallery in the dam are ordinarily employed. Where the outlets are placed in the non-overflow section, either u/s gates or d/s valves are utilized.

1.6 Hydraulic design of outlet works

The hydraulics of outlet works usually involve either one or both of two conditions of flow—open channel (or free) flow and full conduit (or pressure) flow. Analysis of open channel flow in outlet works, either in an open water way or in a part full conduit, is based on the principle of *steady non uniform flow* conforming to the law of conservation of energy. Full pipe flow in closed conduits is based on pressure flow, which involves a study of hydraulic losses to determine the total heads needed to produce the required discharges.

Hydraulic jump basin, baffle or impact block dissipaters or other stilling devices normally are employed to dissipate the energy of flow at the downstream end of the outlet works. Many of these devices are designed on the basis of the law of conservation of momentum.

A) Open channel flow in outlet works

Flow in an open channel outlet works will be similar to that in open channel spillways. Where un-submerged radial or slide gates are used, discharge through the control with the gates completely opened will be computed by:

$$Q = CLH^{3/2}$$

When open channel outlet flow is controlled by partly opened surface gates, sluice flow will result. Discharges for such flow are given by the equation:

$$Q = \frac{2}{3} \sqrt{2g} CL \left(H_1^{3/2} - H_2^{3/2} \right)$$

where c is the discharge coefficient, L is the crest length & H is differential head causing flow.

In instances where there is high tail water due to canal water surfaces or to d/s influences in the streambed, the control openings may be partly or entirely submerged. For such conditions the discharge through the control will be in accordance with submerged orifice or tube flow as computed by the equation:

$$Q = CA\sqrt{2gH}$$

Where A = area of the opening

H = d.c.e d/n the u/s & d/s openings

C = coefficient of discharge

B) Pressure flow in outlet conduits

If a control gate is placed at some point down stream from the conduit entrance, that portion above the control gate will flow under pressure an un-gated conduit may also flow full depending

on the inlet geometry for a flow in a closed pipe system, Bernoulli's equation can be written as follows:

$$H_T = h_2 + \frac{V^2}{2g}$$

Where H_T is the total head needed to overcome the various head losses to produce discharge and, h_2 = the cumulative losses of the system.

$\frac{V^2}{2g}$ is velocity head at exit.

The above equation can be expanded to list each loss, as follows,

$$H_T = h_t + h_e + h_b + h_f + h_{ex} + h_c + h_g + \frac{V_1^2}{2g}$$

Where h_t = trash pack loss

h_e = entrance loss

h_b = bend loss

h_c = constriction loss

h_{ex} = expansion loss

h_g = gate or valve loss

h_f = friction loss, and

$\frac{V_1^2}{2g}$ = velocity head exit loss at the out let.

For a free discharging out let, H_T is measured from the reservoir water surface to the center of the outlet gate (opening). If the out flowing jet is supported on a d/s floor the head is measured to the top of the emerging jet at the point of greatest contraction; if the outlet portal is submerged the head is measured to the tail water level. When various losses are related to the individual component, h_i is written as

$$H_i = K_i \frac{V_1^2}{2g}$$

Where K_i is the summation of loss coefficients with continuity combined. Therefore the above equation can be written as

$$H_T = K_L \frac{v_1^2}{2g} \text{ Then } Q = a_1 \sqrt{\frac{2gH_T}{k_L}}$$

1.7 Hydraulic Design Considerations

Inlet and outlet channels

Inlet channels are primarily associated with bottom-level intakes. In some geological and topographical settings they are extremely vulnerable to clogging with sediment and material from unstable excavated and natural slopes. Where the accumulation of such material occurs at

or near an intake structure. The intake may become plugged. And its capacity may be greatly reduced.

Where inlet channel velocities are sufficient to move material into an outlet, the adverse result may be the erosion by abrasion of conduit linings gate and valve waterways, and steel pipes.

Intakes

Outlet intake structures have numerous configurations and features needed to satisfy project equipments and optimize site conditions. Intakes are positioned with respect to various reservoir levels. Such as the lowest level required for reservoir evacuation, the bottom of active storage, the minimum level for power generation. The bottom of flood control storage, the temperature and dissolved oxygen level, the sediment deposition level, or some other specified operating level. Intakes are also positioned laterally as required by the delivery point downstream from the dam, or to make best use of topography and geology.

Intake gating may be required in intake towers to satisfy selective withdrawal requirements, and in any type of in take for upstream control, emergency closure, and inspection of upstream conduits or other waterways. For such inspection, bulkheads may suffice. Where upstream control is used depends primarily on economic and operating considerations. Guard or emergency gates may be installed at or near the intake, as is commonly done for power outlets or penstocks.

Trashracks are required for most outlets. The size of trashracks is governed by limiting velocities and the size of the downstream water ways and gates. Where as the limiting velocities are governed by head loss and blockage considerations. In general, these velocities are limited to 3 to 4 ft/ sec, or even higher for large outlets used for flood releases.

The shape of intake flow surfaces varies from sharp-edged entrances where slide gates are mounted on the face of a concrete structure to carefully designed streamlined shapes where head losses must be minimized, as for power outlets.

Conveyance Structures

Conveyance structures include conduits, tunnels, chutes, pipes, and other water ways. These structures must be compatible with the upstream and down stream structures. Conduits and tunnels may be designed for free flow or pressure flow. Many outlets include a combination of two or more of the types of conveyance structures mentioned. A common type of outlets is composed of a pressure conduit or tunnel from an intake structure an emergency gate chamber near the axis of the dam, from which the flow is carried in a free- standing steel pipe with in a concrete access and maintenance conduit to a control structure. Downstream from the control structure, a concrete chute may be used to convey the flow to a stilling basin or flip bucket. Another common type has the emergency and the control gates located in the gate chamber and a free-flow conduit or tunnel downstream.

Gate Chambers and Shafts

The hydraulic design of gate chambers include the waterways connecting the upstream and downstream conveyance structures. Gate chambers are normally located near the axis of a dam and under or with in the dam section or in on both of the abutments. When the conveyance system pressurized throughout, the gate chamber houses an emergency or guard gate. A properly sized air vent is required at the gate to prevent collapse of the downstream portion when a downstream portion of the conveyance system vides for free flow, the gate chamber houses both gate and regulating (control) gates.

The waterways are normally transitioned from the stream conduit or tunnel configuration in the gate frames downstream to the configuration of the downstream tunnel or conduit. The downstream transition may increase where the flow changes from pressure flow to free flow.

Control Structures

Control structures for outlets may be located in the intake in a terminal structure, or at an intermediate point conveyance system. The location selected depends on economies, function, type of dam, and safety considerations.

It is good practice to provide guard or emergency gates upstream from control gates and valves to satisfy maintenance and inspection requirements. For control use when the control gate or valve is not available for use, and for replacement of certain types of control gates or valves.

Conveyance Structures

Conduits for concrete dams are typically located along the centerline of a spillway monolith. Alignments close to monolith joints are avoided. Air vent intakes for the conduits can be located in crest piers. The air vents should never be interconnected. Dividing outlet release requirements among two or more conduits is preferable to concentrating the releases in one conduit, so that inspection and maintenance can be performed in one conduit.

Gate Chambers and shafts

Gate chambers and shafts located under and within embankment dams and in abutments are suitable alternatives to intake towers in many cases. These chambers and shafts should be located at or upstream from the dam axis at the location of the grout curtain, if one is provided Gate shafts constructed in an embankment dam should be located at a sufficient distance from an abutment to ensure that lateral tilting will not result from settlement of the embankment toward the center of the mass.

1.8 Structural Design Consideration

General

The structural design of outlet works should be developed concurrently with the hydraulic design. By using a combined process. Starting with the conceptualization stage, extremely difficult structural design problems, and possibly redesign. Can be avoided, with considerable savings of time and effort. The design engineer should be constantly a ware of the need for economical, safe and reliable designs.

The operating life outlet works must be considered to be indefinite as replacement of most components is difficult and expensive. Hence, outlet works should be conservatively designed, and maintenance provisions should be carefully developed.

Design loads, temperature loads static live loads, dynamic live loads, temperature loadings, and unexpected and unusual loads caused by improper operation of gates and valves.

Static live loads include water pressures on interior and exterior surfaces. Embankment and backfill loads. Ice loads on intake structures and other structures exposed to ice loadings. Frost heave, temperature loadings, expansive soil loadings and construction loadings.

Dynamic loads include seismic loadings, impact loads from flowing water, hydraulic transient loadings, vibration loads from equipment and from fluctuating water pressures, wind loadings, and in some cases, loadings from reservoir wave action.

Inlet and Outlet channels

The structural design of inlet and outlet channels is similar to that for approach and exit channels for spillways. Channel protection for the inlet channels for outlet works is usually less important than protection for the approach channels for spillways because of the lower operating velocities of the inlet channels, except during the initial filling period or when the inlet channels are used for diversion flows during construction.

Outlet channels for outlet works should be more conservatively designed than exit channels for spillways, because of the greater frequency and longer duration of operation of the outlet channels.

Intakes

Intakes for outlet works frequently are subjected to differential water loads caused by partial blockage of trashracks. Intakes located near the water surface are more subject to trash accumulations than are deeply submerged intakes. However, waterlogged material tends to accumulate over time and should be considered a potential cause of area reduction of the trashracks. Many designers use arbitrary amounts of differential head, depending on the amount of submergence. A minimum of 5 ft (1.5 meters) and a maximum of 40ft (12.2 meters)

differential head are some times used. Another approach is to compute the actual amount of head loss across the trashracks. Based on an assumed percentage of net trashracks area.

In locations of high seismicity, tower-type intake must be designed for earthquake is in the range of 0.2 to 0.3g or above, alternatives to towers should be considered to reduce intake costs.

Location of Control Gates

Control gates can be place in an intake structure, a downstream control structure, or a centrally located gate chamber or shaft. The choice location depends on the outlet's function and economic of these factors. Where the release of water is to be through a pressure system, such as a pipeline or a penstock, the control should be at a downstream location. For deliveries to a canal, an outlet channel, or the river, the control gate may be located at the intake, at a downstream control structure, or at an intermediate location.

The choice between an intake tower equipped with control gates and a central control shaft or chamber should depend on an evaluation of the several factors involved.

The downstream control-structure location for free-flow outlet releases is selected when an evaluation of he various applicable factors favors this location. Usually economic factors control the selection. But indirectly the alignment of the waterway with respect to the river and use of the most suitable type of energy dissipater are important considerations.

Submerged Intakes

Intakes for embankment dam out-let works frequently are submerged shafts and horizontal intake types. These are simple and economical structures. They usually have trash racks or trash beams and stream lined entrances to a conduit or a tunnel. Where used primarily for flood control, they would not be deeply submerged, except during periods of flood control operations: so unwatering the conduit or tunnel for routine examination and maintenance would be relatively simple. However, if the intake must be located below a deep conservation pool, the problems associated with unwatering are more difficult. In either case, bulkheads are required.

Combined Intake and Gate Structure

The use of gated intake is appropriate where an upstream control is required for the outlet concept hat has been selected. Up-stream gating is common for sluices in concrete dams and for selective-level withdrawal intakes. The advantages and disadvantages of locating control gates in outlet intakes are discussed in the preceding subsection on "Location of Control Gates."

Selective Withdrawal Intakes

These intakes are designed to draw water from various levels in a reservoir for the purpose of satisfying water quality requirements. In some cases, upstream control is provided. Whereas in

other cases a means of opening or closing of intake ports is provided with flow regulation performed at a downstream gate. The difference in these concepts is due to the system required for conveying the water to a point of final use, a pressurized conveyance system usually will require down stream regulating gates. The type of intake selected will depend on the type of dam, foundation conditions and economic considerations. An intake tower makes installation of gates at several elevations a simple matter and provides a convenient location for an operating deck for the servicing of gates and cleaning of trash racks.

Gates and valves

Wide variety of gates and valves is used in outlet works. Their use depends on their purposes, operating characteristics, servicing requirements, life expectancy, and cost. Large gates and valves for high-head installation may require special designs. Gates intended for temporary use for the purpose of unwatering the outlet conduit or tunnel are usually of the bulkhead type, which frequently are designed for removal and on-land storage. These gates are constructed of reinforced concrete or steel, and require gate slots equipped with embedded metal sealing and bearing surfaces and slot covers for deeply submerged installations.

The cone dispersion (Howell-Bunger) valve is probably the most frequently used type of regulating valve installed at the end of outlets discharging into the atmosphere. It consists of a fixed 90° cone disperser, upstream of which is the opening covered by a sliding cylindrical sleeve.

The needle valve, or its variation the tube valve, has a bulb shaped fixed steel jacket, with the valve closing against the casing in the downstream direction. When open the valves produce solid circular jets and can also be used in a submerged condition. The valve may suffer from cavitation damage and produce unstable jets at small openings, and are expensive as they have to withstand reservoir pressures.