Chapter 5
Outlet Gates

5-1. General

Similar to navigation lock gates, outlet gates use a horizontal framing system. As with navigation lock gates, vertical framing systems are not structurally efficient and require special framing to accommodate roller guides for hoisting operations. Hence, vertical framing is not recommended for new vertical lift gates, except for replacement in kind. Outlet gates use fixed wheel, tractor, and slide end support systems. Paragraph 2-2*c* describes the different uses of outlet gates. Much of the information regarding framing, loads, and load types provided in this chapter references information provided in Chapter 3. Only information unique to outlet gates is provided here.

5-2. Framing Systems

Horizontal girder framing is the most common type of framing system used for outlet gates. They may be framed with plate girders or rolled shapes. This type of framing system is described in paragraph 3-2*a*. The main difference in framing compared with that of spillway crest gates and navigation lock gates is that outlet gates require a sloping bottom or flat bottom with lip extension on the downstream side to reduce downpull forces while operating with water flow.

5-3. Load Types

The following load types are applicable to vertical lift gates used for outlet gates:

a. Hydrostatic. The hydrostatic load H_s shall be determined based on site-specific conditions that account for the differential between headwater and sill bearing at the invert. Headwater is determined from reservoir regulation studies for the dam. Figures 5-1 and 5-2 represent loading diagrams for hydrostatic loading of an outlet gate with a downstream seal with an upstream skin plate. Figures 5-3 and 5-4 represent loading diagrams for hydrostatic loading of an outlet gate with an upstream seal with an upstream skin plate.

b. Hydrodynamic. Hydrodynamic loads for outlet gates shall account for water hammer.

c. Gravity. These loads shall be applied as described in paragraph 3-3*c*.

d. Operating equipment. These loads shall be applied as described in paragraph 3-3*d*.

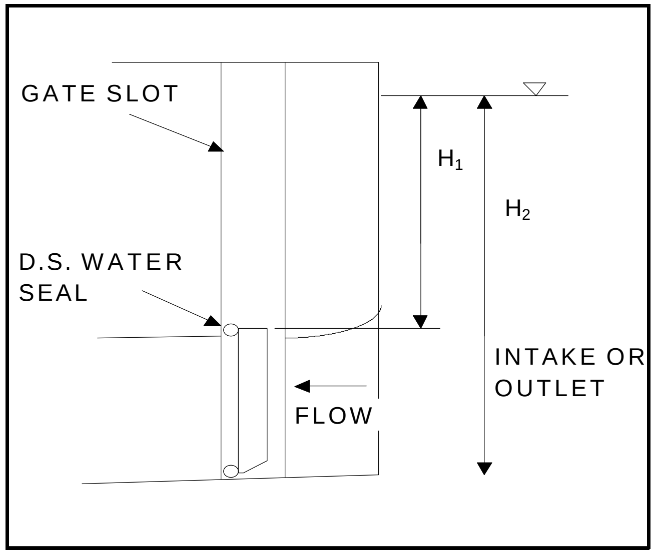

Figure 5-1. Outlet gate with downstream seal with an upstream skin plate

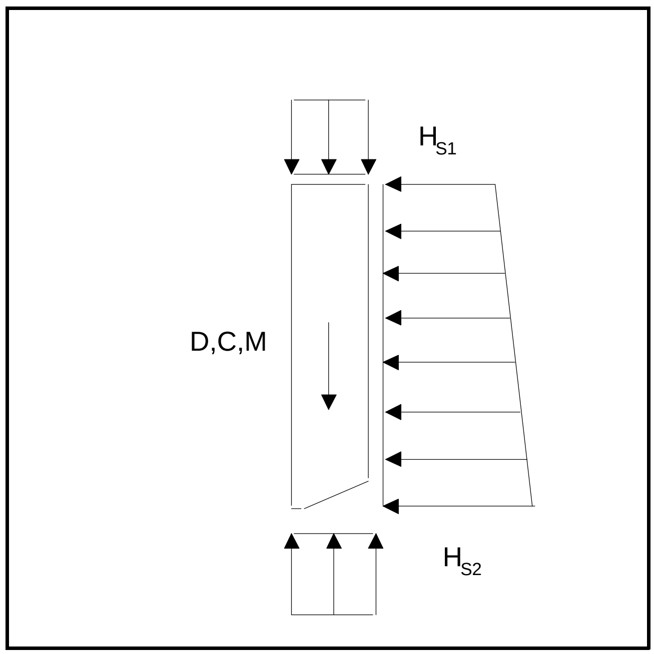

Figure 5-2. Outlet gate, hydrostatic loading, downstream seal with an upstream skin plate

e. Earthquake. These loads shall be applied as described in paragraph 3-3*f*.

f. Downpull. These loads shall be applied as described in paragraph 4-3*g*.

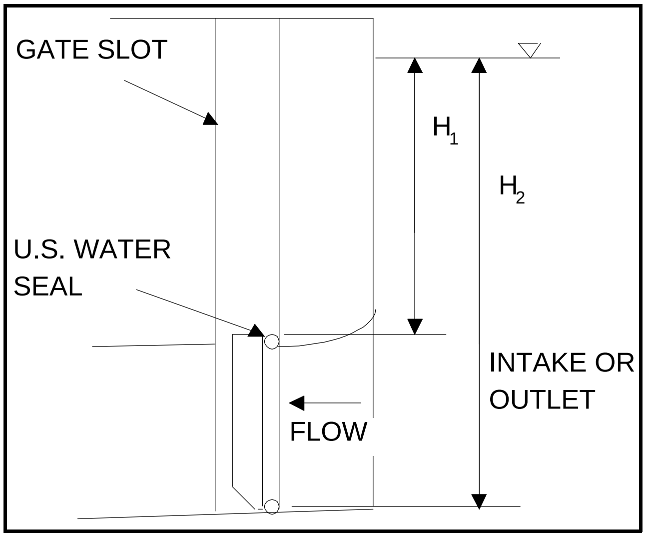

Figure 5-3. Outlet gate with upstream seal with an upstream skin plate

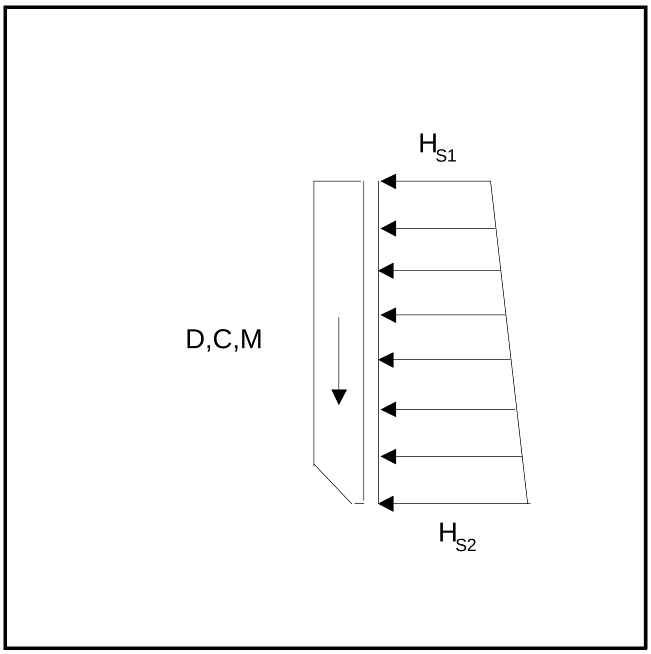

Figure 5-4. Outlet gate, hydrostatic loading, upstream seal with an upstream skin plate

5-4. Load and Resistance Factor Design

a. Design guidance. Outlet gates shall be designed using LRFD methods in accordance with EM 1110-2-2105. A brief synopsis of the methodology and general guidance for use of LRFD for HSS is presented in EM 1110-2-2105 and will not be repeated here. Design strength factors shall conform to the requirements in EM 1110-2-2105.

b. Load cases and load factors. Lift gates shall have design strengths at all sections at least equal to the required strengths calculated for the factored loads and forces in the following load combinations. The most unfavorable effect may occur when one or more of the loads in a particular load combination is equal to zero. For each load combination the gate should be considered supported on either its fixed supports or by the hoisting equipment. For Equation 5-1, *Q* or *R* should be taken as zero when resting on its fixed supports.

$$1.2D + 1.6(C + M) + (1.2Q \text{ or } 1.0R) \quad (5\text{-}1)$$

$$1.2D + 1.4H_s + 1.0\mathrm{H_d} \quad (5\text{-}2)$$

$$1.2D + 1.2\mathrm{H_s} + 1.0E \quad (5\text{-}3)$$

where

D = deadweight load of the gate

C = weight of ice

M = weight of mud or debris

Q = maximum intertial effects of machinery forces

R = downpull forces

H_s = hydrostatic load due to differential head

H_d = hydrodynamic load due to water hammer

E = lateral seismic forces from adjacent water

5-5. Commentary on Loads and Load Factors

a. Loads.

(1) Hydrostatic. Hydrostatic loads for outlet gates shall be as specified in paragraph 5-3*a*. Because there is only one operating leaf or section, no other special hydrostatic load conditions exist.

(2) Hydrodynamic. Hydrodynamic forces from flow either under or over the top of this type of gate are accounted for in downpull forces. Water hammer may develop depending on the type of application the gate will be subjected to. Variables associated with the magnitude of pressure change include the rate of change of the flow (closure time), the velocity of the water, and length of penstock or conduit. EM 1110-2-3001 provides information to determine the effects of water hammer and suggests that the hydraulic system be modeled using computer analysis for various operating conditions.

(3) Gravity. Gates used for outlet or emergency closures are normally stored in the gate slot. If they are stored out of the weather, ice will not be a consideration for loading to the gate. EM 1110-2-3001 provides further information on prevention of ice accumulation for powerhouse intakes. Because many emergency closure gates are stored below surface water, silt or mud will accumulate on the gate, the amount varying based on site-specific information. Data or observations for replacement of existing gates may be used to determine *C* or *M*.

(4) Operating equipment. Coordination between the structural and mechanical engineers is required to determine the operating equipment loading. The mechanical engineer will need gate deadweight *D* and hydrodynamic load H_d, ice *C*, mud *M*, and downpull *R* to determine operating equipment requirements, including inertial effects.

(5) Earthquake. See discussion in paragraph 3-5*a*(6).

(6) Downpull. Downpull forces are discussed in paragraph 4-5*a*(7). The same conditions apply for outlet gates, except the head on top of the gate is the static head in the gate well slot. All other references apply.

b. Load cases and load factors. The commentary presented in paragraph *3-5b is* applicable to outlet gates and is not repeated in this chapter except as noted. The addition of 1.0*R* to Equation 5-1 is to account for downpull. It need not be included in combination with *Q* since *Q* accounts for hoisting forces, while downpull forces account for deployment of the gate. The greater of the two shall be applied in combination with 1.6(*C* + *M*). Water hammer associated with emergency closure is considered an extreme event and is given a load factor of $1.0H_d$ in Equation 5-2. Gate closing speeds should be designed to eliminate water hammer for normal operating conditions.

5-6. Serviceability Requirements

Serviceability requirements presented in paragraph 3-6 for navigation lock vertical lift gates are applicable to outlet gates and are not repeated in this chapter.

5-7. Fatigue and Fracture Control

Fatigue and fracture control requirements for members and their connections are discussed in paragraph 3-7 for navigation lock vertical lift gates. For outlet gates, the total number of loading cycles is based on the projected frequency of usage over the life of the gate. Generally, outlet gates are operated infrequently; hence the fatigue is not a contributing factor to the design of the gate. Where projected usage of the gate is expected to place the members and connections into fatigue stress categories listed in AISC (1995), then the requirements in paragraph 3-7*a* for navigation lock vertical lift gates shall apply.

5-8. Material Selection

Material selection for outlet gates shall follow the same guidelines established in paragraph 3.8. In addition, intake gate guide tracks are normally fabricated from stainless steel type 304 and intake gate bearing tracks and roller chains from ASTM A564/A564M-95 (ASTM 1995) type 630 (17-4 PH; CUSTOM 450). Rollers and track require a Brinell hardness (ASTM 1996e) varying from 331 to 401 with pins and side bar having a Brinell hardness from 255 to 293.

5-9. Weldments

Weldments for outlet gates shall follow the same guidelines established in paragraph 3.9. Welding materials and procedures are similar to those for navigation lock vertical lift gates and are not repeated here.

5-10. Design Details

Design details for outlet gates shall follow the same guidelines established in paragraph 3-10. Seals, wheels, tracks, guides, and fatigue and fracturing detailing are similar to those for navigation lock vertical lift gates and are not repeated here except as noted for tractor roller gates. Because tractor roller gates are often used in high-head applications, additional considerations are required for seals and roller chain design.

For high-head installations, 60-m (200-ft) pressure-actuated seals are used. The designer is cautioned that a check should be made with the seal manufacturer before using a seal for a particular application. The pressure source is usually the head pressure of the reservoir itself. These seals are double-stem, center bulb type. To allow the seal to move toward the seal plate, the stem should be compressed only on the outer edge by the clamp bars and not toward the bulb. Observations of rubber seals indicate that the rubber has become extruded into the space between the clamp bar and the seal plate. To prevent this, brass-clad, or more recently, fluorocarbon-clad has been used. The fluorocarbon-clad has proven to be superior to the brass-clad because of its lower coefficient of friction (0.1) and greater flexibility and resiliency. The lower coefficient of friction reduces the load to hoisting equipment. The bottom rubber seal is normally a wedge seal that relies on the weight of the gate to provide the seal compression for sealing.

For tractor gates the roller trains are mounted on races supported either directly on the end girders or on weldments or castings bolted to the end girder webs. Rotation of the ends under load may cause excessive bearing pressures on the inside face of the rollers. This is corrected by articulating the roller race with the end girder. The tracks in the guide and roller races on the gate shall be machined to a surface roughness of 3.2 µm (125 microinches) and installed with a tolerance range of -0 mm to +2.0 mm (-0 in. to +1/32 in.). Slight deviations from linearity will cause large roller overloads; therefore, rotation of the girder should limit deflection across the rollers to 0.5 mm (1/64 in.).