Chapter 3
Navigation Lock Lift Gates

3-1. General

Almost all lift gates use a horizontal framing system. Vertical framing systems are not structurally efficient in transferring loads to the side bearing surfaces and require special framing to accommodate roller guides for hoisting operations. Vertical framing systems are not recommended for new vertical lift gates, except where being replaced in kind. For navigation locks, framing for either the upstream or downstream gate uses girders, trusses, or tied arches. The framing system selected will depend on span, hydrostatic head, and lift requirements.

3-2. Framing Systems

a. Girders. Horizontal plate girders are the main force-resisting members of the gate. They consist of built-up plate elements forming the stiffened webs and flanges of the girder. The spacing of the girders will depend on the head requirements, the height of the gate, and the clear span. For short gates, it is not advantageous to vary the spacing of the girders; however, for taller gates where the change in hydrostatic loading will be more significant from the bottom sill to the top, it is more economical to vary the spacing. Varying the spacing will require additional attention to design of the intercostals and skin plate to compensate for the varying hydrostatic pressure and span between girders. The girders frame into end posts that transfer end shear from the girders to bearing, either on the gate guides or through the types of end supports described in paragraph 2-3. Intercostals are framed plates or structural shapes that span the layers of horizontal girders used to create two-way plate bending action for the skin plate. Diaphragms are used to provide continuity of the gate by distributing horizontal loads more uniformly and supporting and distributing vertical loads. These other framing members are described in Chapter 6. Examples of horizontal girder framing are contained in Plates 4-6, 8, and 9.

b. Trusses. Trusses may be more economical or weigh less than plate girders. Horizontal trusses would be most economical for navigation locks with high-lift overhead gates or for long horizontal spans across navigation locks. It may be advantageous to vary the spacing of the main trusses to achieve an economical arrangement of the same truss and member sizes throughout the height of the gate. Plate 3 represents a typical use of horizontal trusses for navigation lock framing. Common members used for the trusses are wide flanges and structural T's. The main trusses frame into an end post supported by an end bearing similar to a stiffened plate girder. Special framing requirements need to be considered for the roller guides in the upstream/ downstream and lateral directions. As with girders, other framing members include intercostals, diaphragms, end posts, stiffeners, and skin plates. These are described in Chapter 6.

c. Tied arches. This type of framing, as with trusses, is normally employed for high-head and long span gates used in navigation locks. Because of the load transfer ability of the arch, this framing is generally more structurally efficient than plate girders. Particular care must be used in designing the main tension tie, as there is little redundancy if it fails. Therefore fatigue design becomes most critical for these members, particularly in the connection of the arch girders to the main tension tie. The members can be made of rolled shapes, built-up members, solid plates, or plate girder members. Normally the front arch is framed with structural T's, with the webs welded continuously to the skin plate. Plates 1 and 2 represent a vertical lift gate of this type. Most recently, in the case of the replacement of Ice Harbor's downstream vertical lift gate, the arch and tension tie consisted of horizontal plate members. This type of design was employed to eliminate poor fatigue performance at the connection of the upstream arch to the downstream tension tie. Details from Plate 1 should not be used for current design. Its connections experienced severe fatigue. Current design standards for fatigue were used for the design of the replacement gate. More information is provided in Appendix B. As with girders, other framing members include intercostals, diaphragms, end posts, stiffeners, and skin plates. These are described in Chapter 6.

d. Vertical framing. This type of framing system is not very common and is not recommended for use. However, this type of gate may be more economical if it is being used to replace a gate of the same type. Vertically framed gates most commonly use stiffened plate girders. With this type of system the main load is transferred from the skin plate to vertical girders that frame into a horizontal main girder at the top and bottom of the gate. The load transfer is through the top girders to the end wheels at the guide recess. This arrangement is unsuitable for large gates because of the concentration of load at the top and bottom of the end posts.

3-3. Load Types

The following load types are applicable to vertical lift gates used in navigation lock structures.

a. Hydrostatic. The hydrostatic load H_s shall be determined based on site-specific conditions for upper and lower pool elevations.

(1) For submersible gates, consideration must be given to the operation of a multiple-leaf gate, with the gate seals effective and ineffective. Figure 3-1 represents a typical

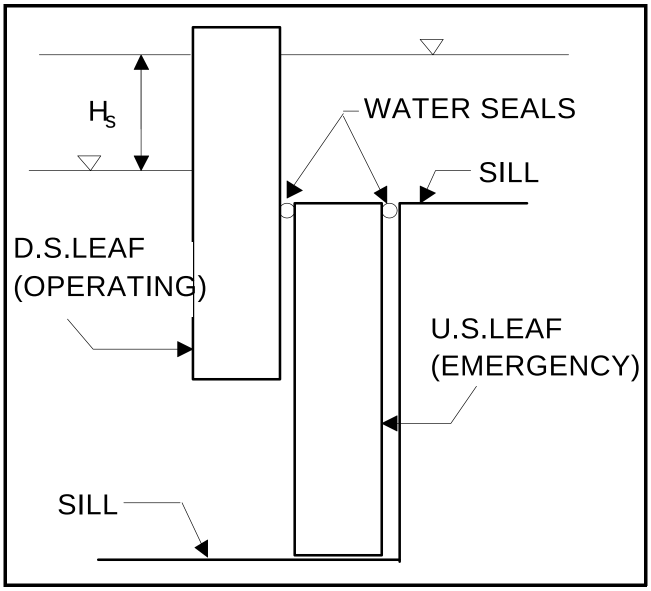

Figure 3-1. Submersible lift gate, normal operation

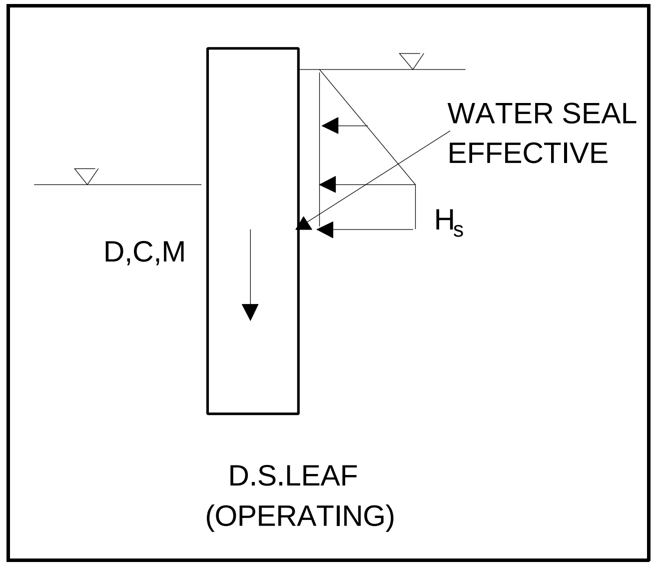

Figure 3-2. Submersible lift gate, hydrostatic loading diagram, downstream leaf, seals effective

double-leaf submersible gate configuration with seals noted. With this arrangement the two leaves will be subject to differing hydrostatic loads. This arrangement should consider normal operation, using the downstream leaf as the operating leaf; operation of the downstream leaf when skimming ice or debris (hydrodynamic load described in *b*(1) below); and use of the upstream leaf during emergency gate operation should the operating leaf fail. Figures 3-2 and 3-3 represent the case where the downstream leaf is used for normal operation, with the gate seal between the upstream and downstream leaf effective and ineffective, respectively. In this case, H_s represents the maximum head differential between upstream and navigation lock pool elevations. During normal operation, Figures 3-4 and 3-5 represent the hydrostatic load to the submerged (upstream) leaf with the seal between the upstream and downstream leaves effective and ineffective, respectively. For this condition H_s represents the maximum head differential from the upstream and navigation lock pools. When the upstream leaf is used for lock operation the same loadings must be applied to it, as in the case of the downstream leaf during normal operation.

(2) The hydrostatic load H_s and water seal arrangements for overhead gates with and without a crossover gallery are shown in Figures 3-6 and 3-7, respectively. For both conditions, H_s represents the maximum head differential between the navigation lock pool and downstream tailwater. For the case where an overhead gate is used for an upstream navigation lock gate, the loading conditions would be the same as for a single-leaf submersible gate, where H_s represents the maximum head differential between the upstream pool elevation and tailwater pool elevation, or upstream sill.

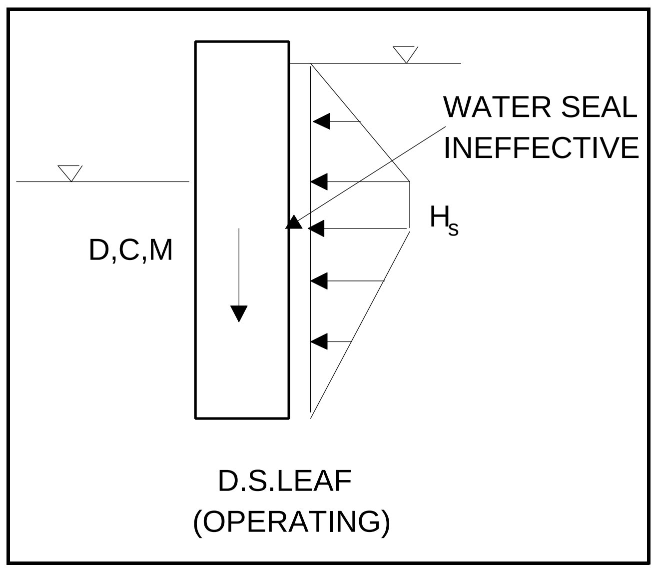

Figure 3-3. Submersible lift gate, hydrostatic loading diagram, downstream leaf, seals ineffective

b. Hydrodynamic. The hydrodynamic loads H_d shall be determined based on site-specific conditions for wave forces resulting from tides or coastal hurricanes applied to protection gates and for vertical loads from water flowing over leaves of submersible gates.

(1) For submersible gates, Figure 3-8 represents the operation of the downstream leaf when passing ice and debris. In this case, H_d represents the head from the flow overtopping the downstream leaf.

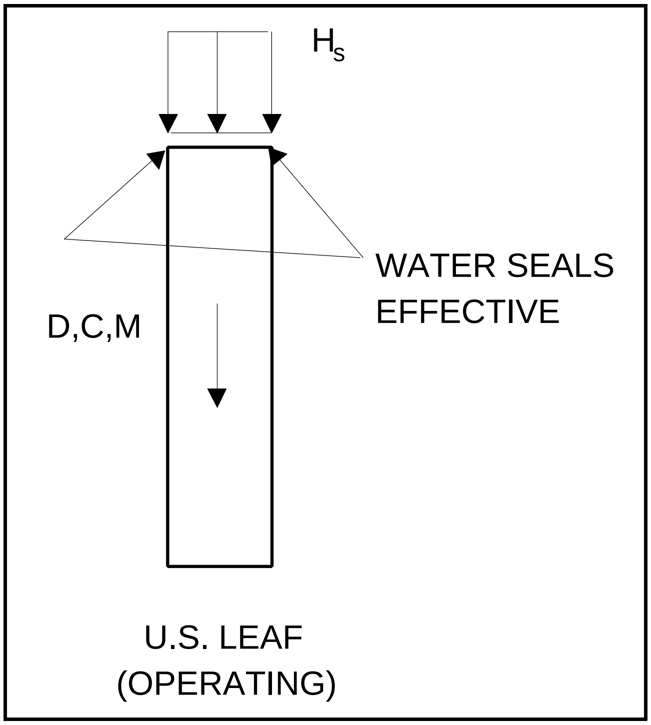

Figure 3-4. Submersible lift gate, hydrostatic loading diagram, upstream leaf, seals effective

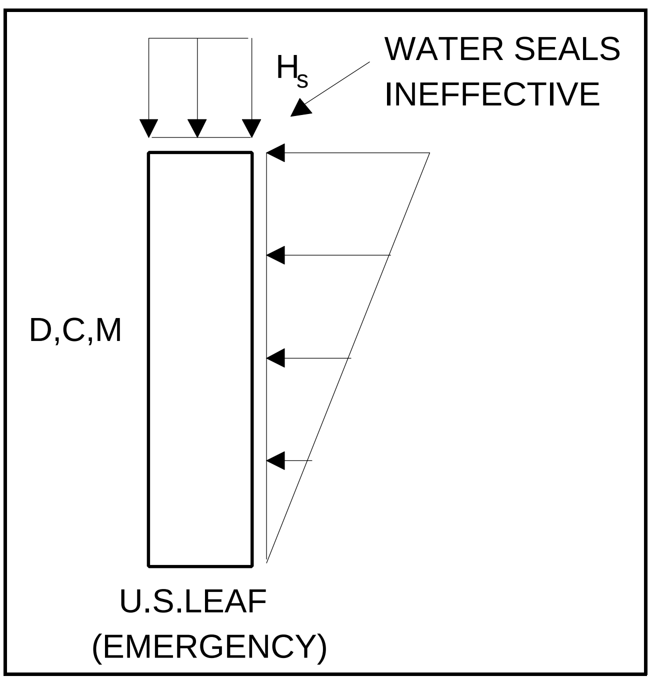

Figure 3-5. Submersible lift gate, hydrostatic loading diagram, upstream leaf, seals ineffective

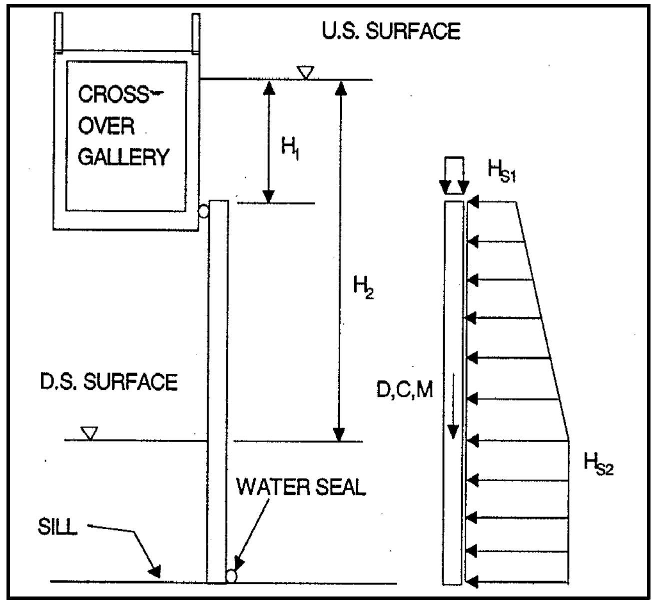

Figure 3-6. Overhead lift gate with crossover gallery, hydrostatic loading

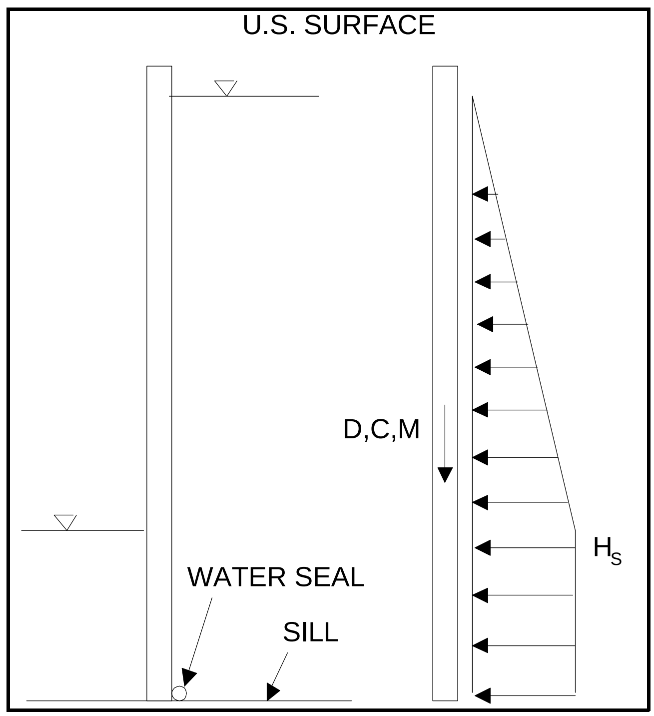

Figure 3-7. Overhead lift gate without crossover gallery, hydrostatic loading

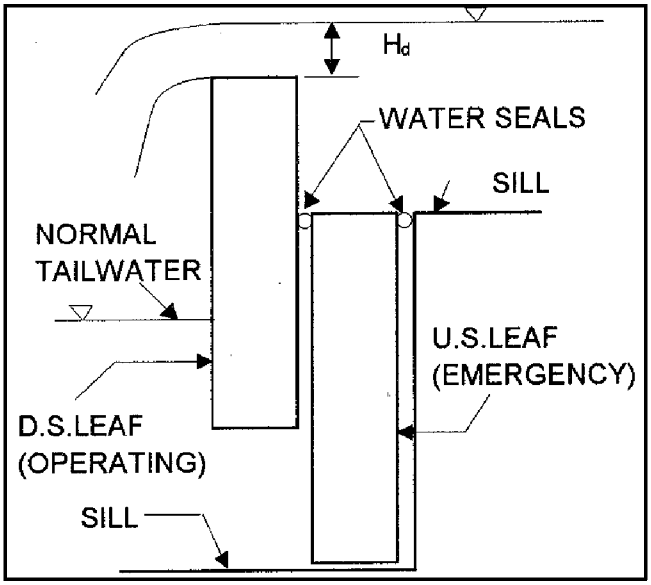

Figure 3-8. Submersible lift gate, hydrodynamic loading for passing ice and debris

(2) Hydrodynamic loads applied to tide or coastal hurricane gates shall be based on site-specific conditions. They shall include the effects of tidal hydraulics, water levels and wave heights, and necessary storm surge analysis to which the gate will be subjected. Distribution of wave forces is dependent on the wave height and depth of water at the structure. Their effects should be computed for a range of possible water levels and periods.

c. Gravity. Loads resulting from deadweight *D*, ice *C*, and mud *M* shall be based on site-specific conditions. Mud loads shall include silt loads where applicable. Ice loads are considered as gravity loads; lateral loads from ice are not considered in the load combinations.

d. Operating equipment. The maximum load that can be exerted by the operating machinery *Q* includes the effects of the deadweight *D*, ice *C*, and mud *M*; and in the case of submersible gates, the effects of the hydrodynamic load H_d when the gate is used for passing ice and debris; and the effects of friction and binding of seals, slides, and wheels.

e. Impact. Submersible and overhead gates used for navigation locks are subject to barge impact loading *I*. The barge impact loading *I* shall be 1112 kilonewtons (kN) (250 kips) applied at any point on the lift gate span. For submersible gates, barge impact *I* will occur along the top girder of the operating (downstream) leaf. For overhead gates, the barge impact *I* shall be applied at any point on the gate at which a barge may collide, and at the point that produces the maximum structural effect. Gates subject to barge impact loading need not be designed for ice and debris impact. Impact loads need be applied only to main load-carrying members.

f. Earthquake. Design earthquake load shall be determined based on an operational basis earthquake (OBE), defined in ER 1110-2-1806. The earthquake load *E* shall be based on inertial hydrodynamic effects of water moving with the structure. Sloshing liquid forces are small and may be ignored. The vertical distribution of the initial hydrodynamic pressures acting on the gate shall be determined from Westergaard's equation:

$$p = \frac{7}{8} g_w a_e \sqrt{Hy} \qquad (3\text{-}1)$$

where

p = lateral pressure at a distance y below the pool surface, meters (m) (feet (ft))

g_w = unit weight of water, kilograms per cubic meter (kg/m^3) (pounds per cubic foot (lb/ft^3))

a_e = maximum acceleration of the supporting lock wall due to the OBE (expressed as a fraction of the gravitational acceleration g), constant

H = pool depth, m (ft)

y = distance below the pool surface, m (ft)

The lock wall shall be assumed rigid in determination of a_e, and the assumed direction of a_e shall be perpendicular to the gate. The inertial forces resulting from the mass due to structural weight *D*, ice *C*, and mud *M* are insignificant to the effect of *p* and need not be considered. For overhead gates, the effects of *E* shall be applied to the towers.

g. Downpull. Downpull forces are not applicable for navigation lock gates.

h. Thermal. The effects of extreme thermal differentials *T*, caused by ambient air and water temperatures adjacent to the exposed faces of the gate, shall be determined based on the navigation lock at full pool, exposing the skin plate to the pool temperature and the downstream girders or tension ties to ambient conditions and tailwater. This shall include temperature differentials related to seasonal ambient and water temperatures. For moderate climates the ambient temperature range shall be from -18 to 49 °C (0 to 120 °F), and for cold climates from -34 to 49 °C (-30 to 120 °F). Pool temperatures shall be based on observed or recorded data and applied to the season during which the maximum ambient temperatures are predicted to occur.

i. Wind loads. Wind loads W shall be based on site specific conditions. American National Standards Institute (ANSI) A58.1/American Society of Civil Engineers (ASCE) 7-95 (ANSI/ASCE 1995) shall be used to determine wind pressures acting on the gate. Wind load shall be applied normal to the projected surface of the gate. For submersible gates, wind loads need not be applied.

3-4. Load and Resistance Factor Design

a. Design guidance. Navigation lock vertical lift gates shall be designed using LRFD methods in accordance with EM 1110-2-2105. A synopsis of the methodology and general guidance for use of LRFD for hydraulic steel structures (HSS) is presented in EM 1110-2-2105 and will not be repeated here. Design resistance and reliability 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.

$$1.2D + 1.6(C + M) + 1.3W \tag{3-2}$$

$$1.0D + 1.0(C + M + \mathrm{H_d}) + 1.2Q \tag{3-3}$$

$$1.2D + 1.4H_s + 1.2T + 1.0I \tag{3-4}$$

$$1.2D + 1.2\, H_s + 1.6\mathrm{H_d} \tag{3-5}$$

$$1.2D + 1.2H_s + 1.0E \tag{3-6}$$

3-5. Commentary on Loads and Load Factors

a. Loads.

(1) Hydrostatic.

(a) The loadings shown for submersible gates are based on typical two-leaf submersible gates. A single-leaf submersible gate will simplify the number of hydrostatic load cases, while multiple leaves greater than two will increase the hydrostatic head load cases. Operation of the gate is the critical factor that determines the number of load cases to check for the design of the gate. The load cases represented by Figures 3-3 and 3-5, where the seals between the leaves and the gate and upstream sill are ineffective, are the most extreme case where the seal is completely ineffective and does not resist H_s. These loadings may be neglected when they cause less effect than the full hydrostatic loading when the gates are raised. Figure 3-5 shows the hydrostatic loading on the upstream leaf when the seal at the upstream sill is ineffective. Because the upstream leaf of a submersible gate is adjusted to account for varying pool levels, no seal is made at the bottom of the leaf. Even with the upstream leaf lowered completely, no seal is made at the bottom. Gate rests at the bottom of the lock are generally individual pedestals that permit the free flow of water. Hence, the net pressure at the bottom of the leaf is zero. A linear load distribution is assumed to act between the bottom of the leaf and the upstream sill, where hydrostatic pressure H_s exists. Figure 3-3 represents the downstream leaf loading when the seal between the upstream and downstream leaves is ineffective. Because there is no seal at the bottom of the downstream leaf, the net pressure at the bottom of the leaf is zero. Similar to the upstream leaf, a linear load distribution is assumed to act between the bottom of the leaf and the location of the ineffective seal, varying from zero at the bottom of the leaf to H_s at the location of the ineffective seal. Conditions that may cause this type loading are neglected maintenance or damage to the seal or seal assembly. Even though the gate can resist this condition, the seal design should still ensure 100 percent effective seals under all operational conditions.

(b) Some navigation locks use a downstream crossover gallery, particularly when using a vertical lift gate. When this is a part of the water retention system for the navigation lock, the hydrostatic load H_{s1} is applied vertically to the top girder and horizontally to the top of the gate, and H_{s2} represents the maximum head differential between the upstream and downstream pool (Figure 3-6). Prior to acceptance of the gate during construction, the contractor may be required to demonstrate watertight requirements. For the bottom seal watertightness to be evaluated, the downstream area will have to be dry. In this case the designer is cautioned to provide an adequate design that will demonstrate seal effectiveness and yet assure that the gate can resist the test loading, without the downstream pool acting on the bottom portions of the gate.

(2) Hydrodynamic.

(a) The total amount of head overtopping the operating leaf shall be determined by investigation of river hydraulics and operational criteria. H_d shall be determined by existing operational data or conditions for submersible leaves that are replacing old gates in the same structure. For new projects, EM 1110-2-2602 refers to the use of hydrologic and hydraulic studies, including model studies, as a necessary part of defining the physical characteristics of the navigation lock. These studies should also define the operational characteristics of the project for passing ice and debris, including H_d. Further information on operational methods for passing ice and debris through navigation dams is found in EM 1110-2-2607.

(b) Hydrodynamic loads resulting from wave forces will occur as a result of differing water levels and direction of wave. During the development of coastal projects, complete analysis of tidal hydraulics, water levels and wave heights, and storm surge will determine the appropriate loading conditions for the gate. Preliminary design loads can be determined from EM's 1110-2-1412, 1110-2-1414, 1110-2-1614, and 1110-2-1607, which provide information to develop hydrodynamic loads for tidal gates. Pressure distributions for breaking and nonbreaking waves can be developed from criteria in EM 1110-2-1614. It should be noted that criteria in EM 1110-2-1614 require hydraulic model tests to be performed for most designs featuring coastal revetments, seawalls, and bulkheads. Hence, the structural engineer should consult with the hydraulic engineer for final determination of these loads.

(3) Gravity. Ice and silt or mud vary based on site-specific information. Data or observations for replacement of existing gates may be used to determine *C* or *M*. For new projects, EM 1110-2-2602 suggests that only model studies can indicate silt buildup, and that only the most conservative assumptions for depth of silt should be used. For gates being used in similar river systems, with similar silt loads, estimates based on other projects may be used.

(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*, hydrodynamic load H_d, ice *C*, mud *M*, and friction load to determine operating equipment requirements, including inertial effects.

(5) Impact. It is not reasonable to design a gate to resist a high-speed barge impact. Experience has shown that designing for an impact load of 1112 kN (250 kips) will provide adequate resistance to impact damage.

(6) Earthquake. The inertial hydrodynamic effects are consistent with past and present methods of analysis. The use of Westergaard's equation gives conservative results, and for gates of this type, earthquake loads normally do not control the design.

(7) Downpull. Downpull forces are not applicable for navigation lock gates. These loads are considered primarily for emergency closure or spillway crest gates, which are deployed during flowing conditions.

(8) Thermal. This condition may occur with navigation lock gates when the temperature of the skin plate against the full navigation lock pool may cause a considerable temperature differential between other structural members exposed to ambient conditions. Generally, *T* will not control the design; however, in some gate designs, there may be considerable stiffness in the downstream bracing between girders, or tension ties in arches, that will develop additional stress. Another contributing factor that should be considered is restraint due to friction at the end supports. This may require the member or connection to be designed differently when considering fatigue. The ambient temperatures specified are consistant with those specified in American Association of State Highway and Transportation Officials (AASHTO) (1996) for metal structures.

(9) Wind. Wind loads *W* for most navigation lock gates are small and can usually be ignored. However, in the case of an arch or truss girder system, wind may cause compressive loading to the tension tie or chord of the truss. This condition will require consideration of slenderness effects for those members.

b. Load cases and load factors.

(1) Load factors for miter gates have been developed and are presented in EM 1110-2-2105. The development of load factors for vertical lift gates included consideration of the respective load variability, definition, likeness to those loads specified in American Institute of Steel Construction (AISC) (1995), and likeness to load factors developed for miter gates. Postulated loads *I* and *E* are given a load factor of 1.0 since it is assumed that the conservatism necessary for design is taken into account in the associated hazard scenario and specification of the nominal load.

(2) Equation 3-2 provides a check for maximum vertical loads on members and lifting anchor points in combination with wind. Certain members in truss or arch type navigation lock gates such as tension ties or tension chords should be checked for slenderness effects caused by compression loads from *W*. Wind can cause reverse loading and should be considered when determining the maximum effects during hoisting operations. For horizontal girder type gates, the combination of *D*, *C*, and *M* will control the location of support spacing or bracing for out-of-plane loading in these members, and will provide adequate bracing for the compression flange.

(3) Equation 3-3 provides a check for maximum vertical loads from operating equipment. In this case *Q* represents the maximum load that can be applied to the gate considering that the gate may bind. Deadweight *D*, ice *C*, mud *M*, and hydrodynamic load H_d are opposing forces from the gate.

(4) Equation 3-4 provides a check for normal operating conditions with lateral impact forces. The effects of thermal temperature differentials shall be considered as part of the normal operating conditions when seasonal temperatures cause increased member stresses and as part of the fatigue life. Temperature effects may be neglected when they cause less effect than the full hydrostatic loading.

(5) Equation 3-5 provides a check for various conditions related to moving water for submersible gates supported by hoists when skimming ice and debris. It is also used to check for wave forces for coastal hurricane protection gates.

(6) Equation 3-6 combines seismic loading with hydrostatic loading. The hydrostatic loading for this combination should be one that occurs frequently during each year. Seismic loads should not be combined with other infrequent events such as floods or hurricanes.

3-6. Serviceability Requirements

Vertical lift gates shall be designed for an expected life of 50 years. Limiting values of structural behavior to ensure serviceability (i.e., maximum deflections, vibrations, ease of maintenance, etc.) shall be chosen to enable the structure to function as intended for its design life. Normally, serviceability can be evaluated using unfactored loads. As a minimum, the following guidance should be observed.

a. Testing during erection. Vertical lift gates should be completely fitted together in the shop, if size permits, to ensure satisfactory field connections. Tolerances should not exceed 2 millimeters (mm) (1/16 inch (in.)) for individual members up to 10 m (30 ft) in length and not more than 4 mm (1/8 in.) for members over 10 m (30 ft) in length. Structures made from two or more members shall not deviate from the overall dimension by more than the tolerance for any one member. Rubber seals should be fitted to the gate and assembled in the shop and then removed for shipment. Before disassembly of the gate, each piece should be match-marked to facilitate field erection. Care should be taken to ensure that all parts of the gate leaf are in proper alignment before any field welding is commenced. All necessary precautions should be taken to prevent distortion of the gate as a whole or of any of its components. Each unit shall be accurately aligned so that no binding of any moving parts or distortion of any members occurs before final connections are made.

b. Deflection. Skin plate deflection is limited to 0.4 times the plate thickness. This is to prevent excessive deflection of the skin plate, which may result in serviceability problems. If deflections exceed 0.4 times the thickness of the plate, the large deflection theory for plates must be considered. The overall deflection of the gate and hoist shall be minimized to prevent impairment of operability and performance.

c. Vibration. Vibration of the structure, seals, or operating equipment shall not impair operability or performance.

d. Corrosion. Structural components shall be designed to tolerate corrosion or be protected against corrosion that may impair the serviceability or operability of the structure. It is recommended that structural plates rather than flanged sections be used for stiffeners to facilitate application of the paint system.

e. Closure. Bulkhead slots should be placed to allow the gate to be taken out of service for maintenance. Bulkheads are discussed in Chapter 9.

3-7. Fatigue and Fracture Control

a. Fatigue requirements. Members and their connections subjected to repeated variations of load shall be designed for fatigue. For lift gates used at navigation locks, the total number of loading cycles shall be based on changes in load due to lock operation. The stress range of members and connections due to unfactored loads shall be less than or equal to the allowable stress range given in Appendix K of AISC (1995). Research and documentation of fatigue and fracture mechanic evaluations are presented in ETL 1110-2-346 and ETL 1110-2-351. They may be used as guidance in determining the material type and fatigue life of the structure. AISC (1995) does not require fatigue effects to be considered for members with a stress range that is completely in compression; however, because of the probability of large residual tensile stresses caused by welding processes, EM 1110-2-2105 requires that both tensile and compressive welded connections in hydraulic steel structures be checked for fatigue. Special considerations for vertical lift gates and recommended details for fatigue design of vertical lift gate components are discussed in *b* below. Because vibration results in unknown load magnitudes and number of cycles, details for all connections shall be selected to limit fatigue damage.

b. Special considerations for fatigue. The major factors governing fatigue strength are the applied stress range, the number of loading cycles, and the severity of an induced stress concentration. For design there are two options available: the type of connection and limiting the stress range to acceptable levels. Details that provide the lowest allowable stress range involve connections that experience fatigue crack growth from weld toes and weld ends where there is a high stress concentration. Often, high concentrations of residual stresses occur where two or more welds are allowed to intersect.

(1) Downstream bracing connections. Experience has shown that fatigue problems exist when downstream bracing members, usually structural angles or tees, are welded to the downstream flanges of the plate girders. The function of the downstream bracing is to provide stability for the downstream girder flanges and support for vertical loads. The problem is most severe with vertical lift gates used at navigation locks that support large vertical loads, due to a submerged head condition or a large dead load, in combination with a large number of

loading cycles. The standard procedure for connecting the bracing to the downstream flanges has been to use a welded gusset plate or weld the member directly to the girder flange. In this case it is extremely difficult to avoid a stress category E (AISC 1995, Appendix K), which may have a very low allowable stress range depending on the number of cycles of expected loading. Several options are available to design for this condition:

(a) Increase member sizes to reduce stresses.

(b) Increase girder spacing, thereby increasing the slope of diagonal members, which will tend to lower diagonal member forces.

(c) Bolt the gusset plate to the girder flange instead of welding. This will increase the gusset-to-flange connection to category B for the girder flange.

(d) Use a connection detail that embodies a transition radius. If a transition radius is used, the most benefit is obtained by using a larger radius (see AISC 1995, Appendix K).

(e) If girder spacing is not large, a more practical solution may be to eliminate the downstream bracing and connections by using a downstream skin plate (Plate 5). A downstream skin plate will require holes to allow for inspection and to release water or air as the gate is raised and lowered.

(2) Plate girder web stiffeners. Cracks in downstream girder flanges have occurred in existing vertical lift gates used at navigation locks, initiating at the intersection of the web-to-stiffener weld and the web-to-flange weld. The intersecting welds combined with a category E connection detail provide a point of crack initiation. To avoid this situation, plate girder web stiffeners shall be stopped short of the tension (downstream) flange, except where they may be required for bearing transfer. EM 1110-2-2105 requires that compression members also be checked for fatigue effects; therefore, do not extend web stiffener welds to the intersection with the web-to-compression-flange weld. A large chamfer or “rat hole” should be cut in the web stiffener to prevent the welds from intersecting. This procedure should also be used at the web stiffener-tension flange intersection where bearing transfer is required.

(3) Diaphragms. Cracks in downstream girder flanges have occurred at the intersection with vertical diaphragms in existing vertical lift gates used at navigation locks. The intersecting welds combined with a category E detail provide a point of crack initiation. To avoid this situation, the diaphragm should not be connected to the girder flange. Rather, the diaphragm should be coped so that no contact is made. Because EM 1110-2-2105 requires that compression members be considered for fatigue effects, the diaphragm should be coped around the compression flange as well.

(4) Intercostals. Avoid intersecting welds by using a chamfer or “rat hole” in the intercostal where it intersects with girder flanges or other intercostals. Intercostals running in two directions, as on the top damming surface of vertical lift gates used at navigation locks, should be placed on opposite sides of the skin plate or girder web. Not only will this avoid intersecting welds but will simplify construction as well.

(5) Tension ties. On tied arch vertical lift gates, a difficult situation exists at the connection of the tension tie to the compression arch. The problem is further complicated when the tension tie experiences a stress reversal. The case history for the Ice Harbor Navigation Lock downstream vertical lift gate (Appendix B) provides more information for designing arch tension ties to avoid fatigue.

c. Fracture control requirements. Fracture critical members (FCM’s) are defined in EM 1110-2-2105. For vertical lift gates, FCM’s may include downstream girder flanges and tensile downstream bracing members. For FCM’s, the designer shall enforce controls on fabrication and inspection procedures to minimize initial defects and residual stresses and specify the minimum fracture toughness requirements. See EM 1110-2-2105 for more information on fracture control requirements. There have been many problems with FCM’s of vertical lift gates used at navigation locks in the past. While most of the problems have involved fatigue (poor selection of connection geometry), they have been exacerbated by lack of a fracture control plan. Notchlike details of design or abrupt changes in shape cause stress concentrations. This becomes significant in members that are to be subjected to many loading cycles or sufficiently low service temperatures that ductile behavior and resistance to brittle fracture may be substantially impaired. Likewise, when severe impact loading, comparatively thick material, or severe multidirectional restraint is involved, more concern is warranted regarding the effect of notchlike details and stress concentrations. Therefore, members and connections of vertical lift gates shall strictly follow the provisions of AISC (1995), the provisions for welding FCM’s provided in AWS D1.5-96 (American Welding Society (AWS) 1996a), and provisions described elsewhere in this manual concerning design, detailing, and fabrication for fatigue loading. The fracture control requirements for FCM’s consist of specifying material toughness requirements, limiting the geometry of initial flaws, and selecting proper connection details.

(1) Toughness requirements. Material toughness requirements are specified in the form of minimum Charpy vee-notch (CVN) test values. A minimum CVN value is selected from Table 3-1, EM 1110-2-2105, based on expected service temperature, material thickness, and type of connection

to be used. The project specifications shall indicate the minimum CVN value required for FCM's of the specified gate material.

(2) Initial flaws. Part of the fracture control plan requires limiting initial flaws by imposing strict fabrication and inspection requirements. Specifications shall require qualification of welders and inspectors in accordance with AWS D1.5-96 (AWS 1996a). Initial flaws include nicks or gouges in base or weld material; any of the various weld discontinuities including incomplete fusion, inclusions, undercut, porosity, and cracks; and misalignment of members. Welds of FCM's shall be nondestructively tested. Discontinuities shall be noted and corrected.

(3) Connection details. The heat input due to welding can reduce the toughness properties of the base metal in the heat-affected zone. The toughness of base material is further affected in areas where the heat-affected zones from adjacent welds overlap. Care should be taken when connecting stiffeners or other members to FCM's to prevent overlap of heat-affected zones.

3-8. Material Selection

Proper selection of materials is important when considering the serviceability requirements, as well as the fatigue life of the gate. When fatigue is being taken into account, a high-strength, low-alloy steel may not be the most economical choice if the allowable stress range is low. As noted in the case history for Ice Harbor Vertical Lift Gate Replacement (Appendix B), all structural steel was American Society for Testing and Materials (ASTM) A572/A572M, Type 2, Grade 345 (50) (ASTM 1994a). Although the load cycles were high, the members and welded joints were capable of transferring higher allowable stresses. The deflection of members fabricated of high-strength low-alloy steel will always be more severe than if the member were of structural grade carbon steel. Materials listed in this section serve only as a guide and should not be considered as a complete listing of materials that may be used.

a. Structural steel. The gate body should be of a welding quality structural steel, either carbon or high-strength low-alloy as required by the design. Carbon steels include ASTM A36/A36M (ASTM 1996c), while high-strength, low-alloy steel should meet the requirements of ASTM A572/A572M (ASTM 1994a). ASTM A242/A242M (ASTM 1993) and A588/A588M (ASTM 1994b) weathering steel (atmospheric corrosion resistant, high-strength low-allow steel) that is uncoated is not recommended for use in construction of vertical lift gates. Coated weathering steel may be warranted in certain conditions, where it can be economically justified. Protective coatings applied to weathering steel typically provide longer corrosion life than other steels. In many cases high-strength low-alloy steels may be economical for the entire gate.

b. Stainless steel. Wheel axles should be fabricated from ASTM A564/A564M Type 630, refered to as 17-4 PH, Custom 450 (ASTM 1995). Embedded guides and seal plates should be fabricated from stainless steel type 304 or 410S. Seal bolts and cap screws should use type 304; 410 is not recommended. Use of a nitrogen enhanced stainless steel is recommended for nuts or cap screws covered in ASTM A193/A193M-96b Type B8N, B8NA, B8MN, or B8MNA, often referred to as Nitronic (ASTM 1996b). This provides better resistance to galling.

c. Cast steel. Lifting hooks, rollers, and lifting chain connections are normally fabricated of cast steel, using mild- to medium-strength carbon steel casting. For items that are subjected to higher stresses than medium-strength castings are capable of carrying, high-strength low-alloy steel castings may be used.

d. Forged steels. Dogging and link pins should be fabricated of carbon steel forgings rated for general industrial use. Forgings may be untreated or heat treated depending on the intended use and requirements.

e. Miscellaneous. Fixed wheels should be wrought steel. Rail heads and treads of wheels operating on crowned rails should be hardened to Brinell 325 (ASTM 1996e), minimum.

3-9. Weldments

All new gates use some form of welded fabrication. Because most of the fractures that have been found in vertical lift gates occur near or at welds, it is very important to select the proper weld material and the proper weld procedures.

a. Materials.

(1) Carbon and high-strength low-alloy steel. Use shielded metal arc welding (SMAW) or submerged arc welding (SAW) low-hydrogen electrodes (as applicable) or other weld processes that exclude air from the weld puddle.

(2) Stainless steel. Use low-carbon content weld consumables (0.03-0.04 percent) to help prevent intergranular corrosion. Intergranular corrosion occurs when a pronounced difference in reactivity exists between the grain boundaries and the remainder of the alloy. During welding, this difference is set up when chromium carbides form at the grain boundaries while heating the steel in the 480-760 °C (900-1400 °F) range. The grain-boundary is depleted in chromium and becomes anodic with respect to the surrounding alloy. Corrosion then occurs along the grain boundaries. Using

low-carbon content weld consumables such as E304L or E308L for stainless to stainless welding or E309L for stainless to mild steel welding can help prevent this. Welding stainless steel should follow the guides established in the current divisions of the Boiler and Pressure Vessel Code (American Society of Mechanical Engineers (ASME) 1995).

b. Fracture control. All factors that contribute to cracking should be taken into account in the design, fabrication, and field repair of vertical lift gates. Some vertical lift gates have experienced severe cracking problems where they were used in navigation locks. Cracks have progressed completely through the tension flange and into the web of horizontal girders in full-penetration welds, heat-affected zone of the welds, and in the base metal. The designer should follow the guidelines established in AWS D1.5-96 (AWS 1996a), AISC (1995), and ETL's 1110-2-346 and 1110-2-351 for proper detailing and design for fracture control. During initial fabrication, high joint restraint occurs when thick flange plates of the horizontal girders are connected with full-penetration welds to thick flange plates of the vertical end post. These thick plates become heat sinks that cause the weld to cool too quickly. The combination of this joint restraint and quick cooling causes high residual stress to remain in the joint. Since the gates are too large for normal stress relieving processes, this stress remains in the gate when it is put into service. The accumulative effect of residual stress, normal in-service stress, and fatigue stress can cause cracking. Other factors that can cause cracking include hydrogen embrittlement of the fusion zone through migration of hydrogen liberated from the weld metal, improper weld width-to-depth fusion ratio in the root pass, and stress risers such as notches or abrupt changes in shape. Items to control during fabrication that will reduce the possibility of cracking include the following:

(1) Hydrogen pickup. Toe cracks and under-bead cracks are usually hydrogen-induced cracks. Sources of hydrogen during welding are moisture in the air, moisture in the electrode coating, moisture in the joint, and contaminants on the surface of the base metal.

(2) Moisture in the air. Use SMAW low-hydrogen electrodes or other weld processes that exclude air from the weld puddle. Use proper storage and handling of low-hydrogen electrodes to avoid moisture pickup.

(3) Moisture in the joint. The base metal must be dry prior to welding. If preheating is not required, the joint should be heated sufficiently to drive off any moisture.

(4) Contaminants on the surface of the base metal. The base metal should be cleaned by power tool or brushoff blast followed by solvent cleaning 50 mm (2 in.) each side of the joint after the joint preparation has been completed and immediately prior to welding.

(5) Heat input.

(a) Preheat. Use preheat required by the code or calculated from the carbon equivalent derived from the base metal chemistry. Preheat retards the cooling rate, and thus prevents the formation of martensite.

(b) Welding heat. Controlling heat input lowers the shrinkage stresses and retards the cooling rate, which helps prevent excessive hardening in the heat-affected zone.

(c) Post heating. Slow cooling helps prevent shrinkage stresses. Insulated blankets or heat blankets placed over the completed welds will help retard the rate of cooling. Quenching the gate by placing it in service prior to slow cooling to ambient air temperature shall not be permitted.

(d) Bead shape. Deposit beads having a slightly convex surface and a width of a ratio of weld to depth of fusion of 1 to 1 minimum, to 1.4 to 1 maximum.

3-10. Design Details

a. Seals.

(1) General. Rubber is almost universally used for seals because of its ability to form a watertight contact against any reasonably smooth surface. The J-type seal mounted on either the upstream or downstream side of the gate is most suitable for vertical lift gates. It is not considered necessary to use cushion stock or an open hole in the bulb, either of which will add to the cost of the seal. Fabric reinforcement, which was used in years past, is not required. Fabric adds to the cost of the seals and has the disadvantages of shorter life and higher friction loads. Seals should be molded, not extruded, and selected based on availability. Seal types, sizes, and available molds are listed in catalogs of major rubber manufacturers who produce seals. For low and moderate head installations, the section most frequently used for side and top seals is the J type with a 45-mm (1-3/4-in.) bulb and a 14-mm (9/16-in.) stem with overall length up to 178 mm (7 in.). During gate operation, the seal does not add to hoisting friction because the pressure on both sides of the seal is the same. As the pressure downstream of the gate drops, the seal, under the influence of the head pressure, moves toward the seal plate.

(2) Design. To allow greater flexibility for the seal and allow it to deflect toward the seal plate, the stem should be attached to the gate on the outer edge by the clamp bars, and not toward the bulb. Seal mounting details should be carefully considered to prevent damage to the rubber under all conditions of operation. The side and top seals should be designed for a 6-mm (1/4-in.) preset space between seal and the sealing surface on the pier guide. This preset space should occur with no hydrostatic load on the gate and the bearing

shoes, wheels, or rollers bearing against the downstream guides. The design should prevent the seals from bearing on the guides when the gate is above the water passage in the upper portion of the slot. This will prevent excess friction and wear on the seal during operation of the gate. Care should be taken to provide support for the bulb so there is no possibility of water pressure rolling it. All top seals should be fluorocarbon-clad to help prevent rolling of the bulb during operation of the gate. The bottom rubber seal is normally a wedge seal that relies on the weight of the gate to provide the seal compression for sealing. Transitions from side seals to top, bottom, and intermediate seals should be made with molded corner pieces spliced to the main seal pieces at about 0.3 m (1 ft) from the corner. These special seal pieces should be as small as possible to minimize the cost of the molds. Sealing surfaces for rubber seals should be stainless steel or corrosion-resisting-clad steel. Seals can be mounted on the skin plate side or the flange plate side, oriented so that the water pressure is acting on the stem of the J seal increasing the contact pressure of the seal. The most common arrangement for emergency closure gates is to place the seal on the skin plate side. Placing the seal on the flange plate side creates a buoyant condition that will prevent the gate from submerging under its own weight or sealing properly due to lack of pressure on the bottom compression seal. This condition will cause out-of-plane bending on the web of the bottom girder. Typical seal details are provided in Plate 10.

(3) Material. Rubber hardness for all seals is normally 60 to 70 Shore Type A, Durometer Hardness (ASTM 1997a). For very low head gates, 3 m (10 ft) or less, a 50 durometer hardness may be used to provide greater flexibility and compression of the bulb on the seal plate. This will enhance the ability of the seal to prevent leaks. Seals should meet the physical characteristics in ASTM D395-89 (ASTM 1989), D412-97 (ASTM 1997b), D471-96 (ASTM 1996f), D572-88 (ASTM 1988), and D2240-97 (ASTM 1997a).

b. Wheels. For fixed-wheel gates, the end post may be a single girder supporting cantilevered wheels or a double girder with wheels mounted on pins bearing at both ends. The axle of the cantilevered wheel runs through the end post and to an interior diaphragm that transfers the reaction at the inner end of the axle. The portion of the axle on which the wheel is mounted is often turned about 3 mm (1/8 in.) eccentric with the portions that bear on the end post and inner diaphragm. This ensures that small inaccuracies in hole alignment may be compensated for by rotating the axles until all wheel treads are in line and then permanently securing the axles against further rotation. The tracks may be rails or flat bearing plates. When rails are used, the wheels are flanged to serve as guides, the tread is cylindrical, and the railhead is crowned to allow angular movement due to deflection of the gate. When a flat plate is used, the wheel tread is either cylindrical or crowned slightly, and independent guides are provided if required. Crowned tracks or wheel treads limit the allowable bearing; hence, another method used to compensate for gate deflection is with cylindrical wheel treads operating on a flat track with self-aligning, anti-friction wheel bearings in the wheels. To limit the misalignment in bearings, mountings for self-aligning bearings should incorporate stops or guides. Allowable misalignments should be in accordance with recommendations of the bearing manufacturers. Closely spaced wheels mounted individually in the end girders require very accurate track alignment to prevent local overloads. It is sometimes advantageous to mount the wheels by pairs in trucks to increase the spacing between points of support on the end girder. If only two trucks are used at each end of each gate section, the loads may be determined by statics, as they are independent of the elastic properties of the gate, track, and pier concrete. The problem of overload due to inaccuracy in track surface has been partially overcome in some designs by mounting individual wheels on spring-backed bearing pedestals. However, this construction is complicated and expensive and is not advocated. Bronze sleeve wheel bearings may be satisfactory for light loads, but the friction developed under moderate and heavy loads may prevent operating the gate under head. For this case self-aligning antifriction bearings are used. For either sleeve or antifriction bearings it is essential that proper provision be made for lubrication and for sealing the parts against entrance of water and grit. Bearing seals are subject to variations of internal and external pressures resulting from variations of temperature and hydrostatic head, and are seldom watertight. Design of bearing enclosures and wheel mountings should include provisions to facilitate inspection and maintenance. Grease pipelines should be routed to all inaccessible submerged grease fittings. This will allow lubrication of the wheel bearings when the gate remains closed for long periods of time. The wheels, bearings, axles, and gate structure shall be designed for the maximum radial load, acting simultaneously with an assumed side thrust applied at the wheel tread at the point of radial load. The magnitude of the actual side thrust will depend largely on the flexibility of the wheel mounting and adjacent gate structure and the sliding friction developed between wheel tread and track by any tendency of the gate to move sideways while being raised or lowered under load. Assumed side thrusts from 10 to 33-1/3 percent of the radial load have been used.

c. Tracks. Tracks consist of stainless steel plates for flat wheels or rollers, or railroad or crane rails for flanged wheels. In either case, the track surface must be hardened to withstand the bearing pressures without excessive deformation. The plate or rail must be backed by a structural member to properly distribute the wheel or roller loads to the concrete pier. This structural member is usually a wide flange beam section with the plate welded to the beam flange. The track assembly member is adjusted into position in a blockout in the pier, anchored rigidly in place, with the concrete cast around it. Plate 11 depicts this type of arrangement. Rails are usually attached to the structural support member with standard rail clips and corrosion-resisting steel bolts. Rail structural support members may be embedded in concrete and the rail attached later, or blockouts may be left for the entire assembly. If the structural support member is embedded, a means should be provided for adjusting the railhead into alignment. This may be done by closely spaced wedges between the rail and the beam flange. When the rail has been adjusted, the wedges are tack-welded in place. The structural support member should be designed to translate the maximum computed wheel loads, plus 100 percent for possible overload, from the track or rail supports to the concrete without exceeding permissible stresses for normal loads in either the beam or the concrete.

d. Guides. Structural steel guide members should be provided to limit the movement of the gate horizontally, either in the upstream or lateral direction. The maximum upstream movement may be determined by the allowable deflection of the seal, the depth of wheel flange, the clearance in the lifting or latching devices, or an established nominal clearance for handling. The clearance in the upstream direction is usually from 6 mm (1/4 in.) to 10 mm (3/8 in.). Side clearance between the edge of the gate and the slot should allow for thermal expansion and contraction of the gate body, fabrication clearance in the lifting or latching mechanism, permissible deviation of center line of wheels or rollers from center line of track, and deflection of the seal, if mounted with sealing surface parallel to the pier. Accurate installation of the guides is accomplished by leaving blockouts in the structural concrete. Double-nutted anchor bolts are installed in the piers to allow for guide adjustment in two directions. After the guide steel has been accurately aligned, it is grouted in place using nonshrink grout. Sills should be wide steel flanges set in a blockout. Accurate adjustment to line and slope is accomplished with anchor bolts through the bottom flange, with nuts top and bottom. This also prevents movement while the nonshrink grout is cast in the blockout. The bearing surface of the top flange of the sill should be a corrosion-resistant steel or have a stainless steel plate welded to it.