Chapter 5
Types of Navigation Dam Structures

5-1. General

A navigation dam is composed of one or more types of structures that operate together to dam a pool of water. The components will be dictated by site flow conditions, geotechnical considerations, operational and maintenance requirements, construction considerations, and requirements of the user (the towing industry). Spillway types normally provided for navigation dams include the following: gated--nonnavigable, gated--navigable, fixed crest--overflow, and fixed crest--nonoverflow.

5-2. Gated Nonnavigable Spillway

The type of gate selected also controls the dam sill and associated piers. Gate types typically used for a nonnavigable spillway include tainter (radial) gates, hinged-crest gates (Bascule, Pelican, and flap), vertical-lift gates, roller gates, and wicket gates. (Gate types which have been used in the past but are not recommended for use, except in special situations, are bear trap gates, drum gates, and inflatable rubber gates.) The following discussion describes these gate types and presents advantages and disadvantages of each.

a. Tainter gates (radial gates).

(1) General. The radial gate most commonly used on navigational projects is the tainter gate (see Figure 5-1 and Plates 2, 6, 8, and 13). In its simplest form, a tainter gate is a segment of a cylinder mounted on radial arms that rotate on trunnions anchored to the piers. Because of its simple design, relatively light weight, and low hoist-capacity requirements, the tainter gate is considered one of the most economical and most suitable gates for controlled spillways. The use of side seals eliminates the need for gate slots that are conducive to local low-pressure areas and possible cavitation. Currently, the preferred practice is to carry the water load with a skin that transfers the load to vertical structural sections. The load is then transferred to deep horizontal beams (usually three) which then transfer the load to the trunnion arms, the trunnion yoke and hub, and the pier trunnion girder and anchorage. Several navigational projects (for example, Cannelton and Markland) use a “stressed skin” tainter gate, and although this gate may be somewhat lighter, it is more difficult to design and construct. The tainter gate is raised and lowered by wire rope (chains are also used at

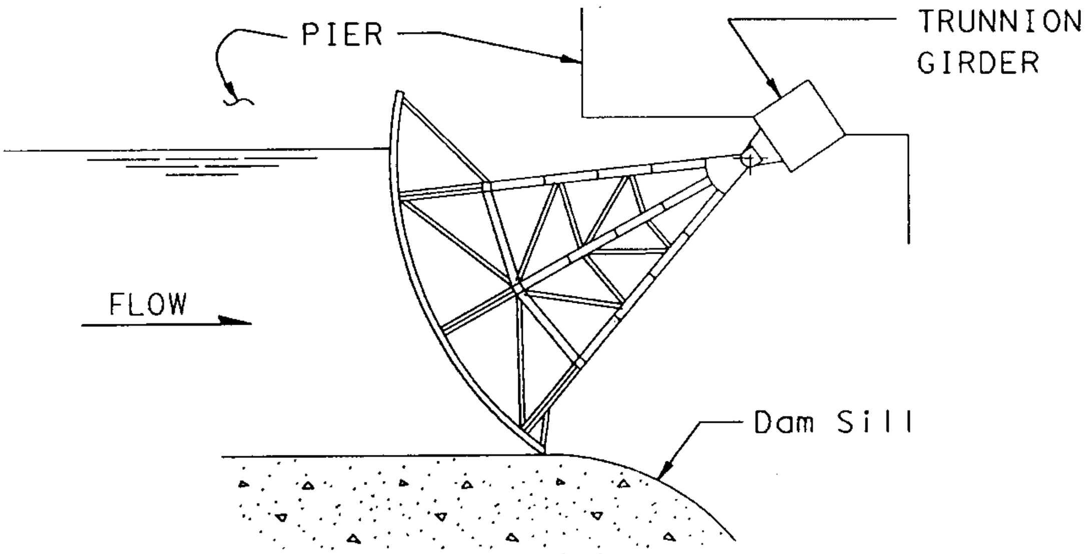

Figure 5-1. Tainter gate

older installations) attached at both ends to avoid introducing torsional stress into the gate. Gates are usually manipulated by individual hoists, one at each end of the gate. Counterweights on smaller gates will reduce required power but will add to the total weight of the structure. Tainter gates built to heights of 75 ft and lengths of 110 ft have been used for navigation dams.

(2) Gate and spillway geometry. In many cases, it may be advantageous to use same-width spillway bays and lock chamber so that the same emergency closure may be utilized on both. It is desirable, but not mandatory, that the trunnions of tainter gates be placed above high water, and essential that the gate itself be capable of being raised above high water. Trunnion elevation is set above most floods. Typical trunnion submergence allowed for trunnion girders is a maximum of 5 to 10 percent of the time. When in the closed position, the gates should have at least 1 ft of freeboard above the normal upstream pool. On large pools where fetch for wave setup is large and water conservation is important, more than 1 ft may be required. Gates should be designed to clear the highest flood with allowance for floating debris. Typical clearance is 1 to 5 ft above the PMF. Special consideration may be appropriate for projects with major flood levees along the overbanks. Often the maximum stage will occur just before the levees are overtopped. Subsequent discharge increases would result in lowered stages because of dispersion of flows through the protected areas. For spillways in such locations, the maximum gate-opening height would be set at 1 ft above the adjacent levee crown elevation. Another consideration is raising the bottom of the gates to allow accidental passage of barges through the gate bays without damage to the tainter gates (although speed of operation usually precludes such action). Skin plate radius ranges from 1.0 to 1.2 times the damming height of the gate. The radius of the gate is affected by the vertical distance between the bottom of the gate in the lowered position and the low steel of the gate in the raised position. Spillway bridge clearance may also be a factor in determining the gate radius and the trunnion location. For design guidance, refer to EM 1110-2-1603, EM 1110-2-1605, and EM 1110-2-2702.

(3) Advantages. Tainter gate installations, as opposed to other types, have the following advantages: lighter lifting weight with smaller hoist requirements; adaptable to fixed individual hoists and push-button operation (individual hoists may have a lower first cost than gantry cranes and require fewer operating personnel); less time required for overall gate operation (more than one gate can be operated at the same time); and favorable discharge characteristics.

(4) Disadvantages. Tainter gate installations, however, have the following disadvantages: radial arms requiring more pier concrete and foundation concrete, i.e. longer and higher structure; the encroachment of the radial arm on the water passage; the necessity for long radial arms where the flood level, to be cleared, is extremely high; and relatively tall, narrow piers which may not perform well during large magnitude seismic events, especially if the motion is applied perpendicular to normal river flow.

(5) Radial gates. Gates of a configuration similar to that of tainter gates, but which are raised or lowered with hydraulic cylinders instead of cables, are usually referred to as radial gates. In Europe, these gates are now normally used in lieu of cable-hoisted gates. Besides sharing the advantages listed above, the radial gates may be more economical.

(6) Reversed tainter gates. Reversed tainter gates are sometimes used (especially in Europe). This configuration transfers the water load by putting the steel trunnion arms in tension and the concrete pier in compression, which is advantageous. However, the overall length of pier and stilling basin will usually be increased. Passing pack ice and debris is not accomplished as well as with conventional tainter gates. The presence of ice, debris, and trash in U.S. waterways would probably preclude the use of the reversed tainter gate.

(7) Submergible tainter gates. Submergible tainter gates were developed to allow passage of ice without having to use large gate openings. Two types have evolved, one in which the top of the gate can be lowered below the normal upper pool elevation and the piggyback gate, in which a shaped lip on the top of the gate or a double skin plate can be used to keep the flow off the back of the gate. Hoist loads are much greater in deep submerged positions and must be considered in machinery costs. Vibration of submerged tainter gates has been so prevalent that such gates should not be considered without the concurrence of Corps of Engineers Civil Works, Engineering Division (CECW-ED).

(8) Tainter gate piers. Tainter gate piers are concrete with a precast/prestressed concrete or steel trunnion girder anchored into the pier with post-tensioned anchors. The pier thickness varies with height and loading conditions but is usually 10 to 15 ft. The gate sill is also

concrete with embedded metal sill plates. The pier and gate sill are separate gravity type structures on larger projects; however, they may be combined into one unit when maximum width-of-monolith requirements are met. These combined units may be shaped as a T, U, L, or some combination of these shapes. The overall size of the structure must conform to requirements designed to meet constructibility limitations and to control cracking. Most massive concrete structures require a special study (nonlinear, incremental structural analysis or NISA) which must be accomplished in accordance with the requirements of ETL 1110-2-365 (see Chapters 9, 11, and 12 also). Other considerations, such as batch plant size, navigation during construction, and cofferdamming concerns, may control the size of the monoliths.

b. Hinged-crest gates.

(1) General. Hinged-crest gates are known by a variety of names including Bascule, Pelican, and flap gates. These gates are hinged at the base to a dam sill and are raised to retain pool and lowered to pass flows. They can be straight or curved to fit the dam sill crest when in the lowered position. The plate is reinforced with vertical and horizontal members and is fitted with a torque tube at the base or separate hinges. These gates are normally sealed at the base and edges when in the raised position (see Figure 5-2).

(2) Automated operation. Automated operation of hinged-crest and Bascule gates may be considered. Such automation was included on the hydraulically operated Bascule gate on the Jonesville Dam, which began operation on the Ouachita-Black Rivers Navigation System around 1970. A signal initiating from a floatwell causes the hydraulic cylinders to lower the gate to compensate for flow which would cause the upper pool stage to exceed the desired level. The cylinders raise the gate when the upper pool begins to fall below the desired level. Some problems were encountered with the Jonesville Dam automated operation when there was a lot of wave action on the river, since the signaling process was extremely sensitive to constant cyclic variation in water level. (Stillwater operation did not present a problem.) Also, there was leaf vibration initially, and spoilers had to be fabricated on the gate leaf to prevent excessive oscillation.

(3) Torque tube construction. Where the gate is constructed with a torque tube, the torque tube is supported on bearings at intervals along the gate. The gate can be raised or lowered by a crank arm powered by a hydraulic cylinder. A hinged-crest gate can also be supported by a number of separate hinges, with an operating stem (a screw stem or hydraulic cylinder) attached to one or both ends of the gate at the top. As the stem is pulled, the gate rises. The screw or cylinder is supported

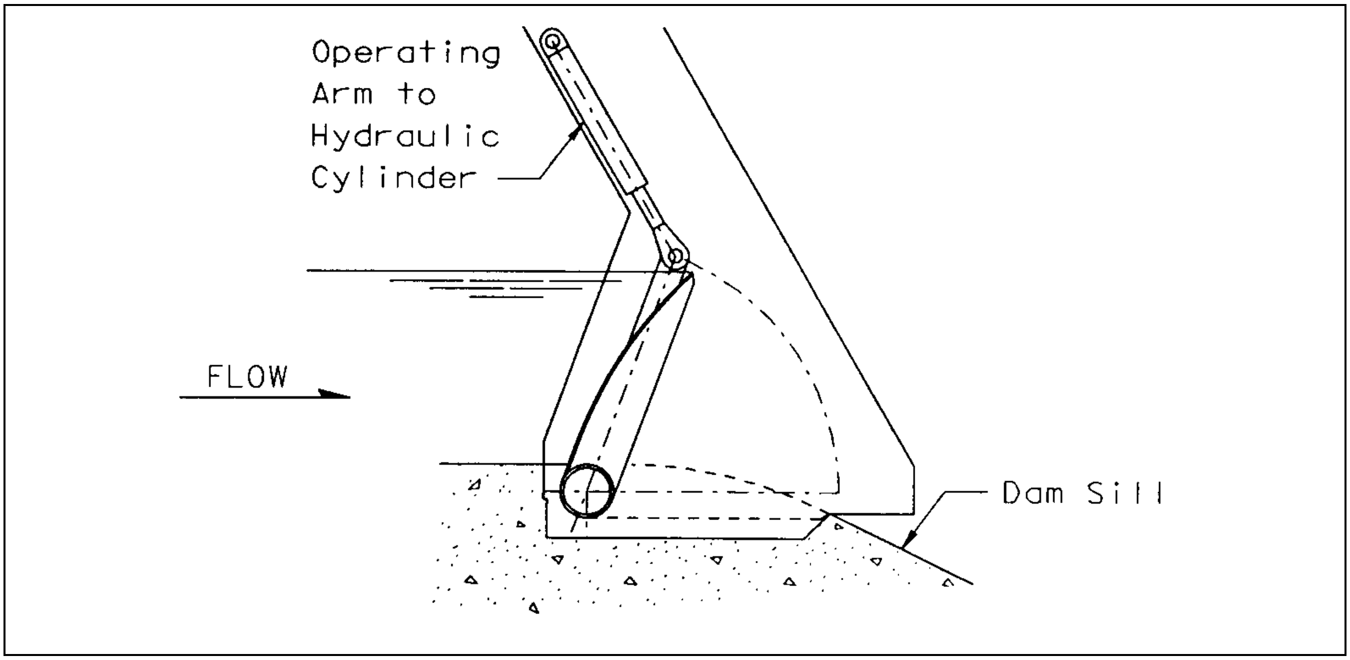

Figure 5-2. Hinged-crest gate

so that it can rotate to maintain alignment with the rotating gate. This same kind of gate can be operated by means of hydraulic cylinders mounted beneath it which push it to the up or closed position. One, two, or more cylinders can be used depending on the gate length. The hydraulic piping to the cylinders is interconnected so that the cylinders will move in unison.

(4) Gate design. The design of the crest gate itself and the means of actuation normally depend on the location of the gate, the application, the size of the gate, and the head on the gate.

(a) The simplest form of hinged-crest gate is the flat stiffened plate hinged at the bottom and operated by a screw stem or hydraulic cylinder connected to the top of the gate at one end. This type of hinged-crest gate is limited to approximately 35 ft of length by 8 ft of height. Gates that are longer or higher than this may require an actuator at each end.

(b) The torque tube-style hinged-crest gate, which uses the torque tube along the invert with the actuator mounted in a compartment in the abutment, produces an overflow between the abutments with no obstructions. The operator may be enclosed in a chamber where it is not exposed to the weather. Torque tube-style hinged-crest gates are normally limited to approximately 35 ft long by 10 ft high because of the size of the torque tube required for larger gates. However, 5-ft-high gates as long as 200 ft have been constructed with operators provided at each end.

(c) The hinged-crest gate with hydraulic cylinders underneath can be made in much longer lengths. The gate can be made in a number of sections (joined in the field) to total 200 ft or more. Hydraulic cylinders are placed at intervals beneath the gate to raise and lower it. The main advantage of this type of gate is the long lengths of gate that are possible. The disadvantage is that there must be a drop in elevation downstream of the ogee crest to be able to mount the cylinders, or the cylinders must be mounted in pits or holes downstream of the crest gate.

(d) The standard Bascule gate design consists of a torque tube with a leaf extension. The gate is rotated approximately 70 deg from fully raised (closed) to fully lowered (open) position. Bearings anchored at intervals along the length of the spillway support the torque tube. A lever arm extends from the torque tube and is positioned by a hydraulic cylinder operator. The standard Bascule gate is practical up to heights of approximately 10 ft, depending on the length of the gate, operator arrangement, and structural limitations.

(e) The Pelican gate usually proves to be more economical than the standard Bascule gate for many applications and is especially suitable for greater heights and lengths. Gates over 13 ft high have been built, and heights of over 20 ft are feasible. The Pelican gate design consists of two curved plates with internal braces and vertical bulkhead ribs forming a strong closed-shell structure. The ribs extend through the bottom of the gate and form supports for the gate hinge pins. The stationary portion of the gate bearings consists of a series of bearing supports anchored at intervals along the length of the spillway. A small diameter pipe section may be welded to the bottom portion of the gate to make contact with the longitudinal rubber seal at all gate positions. Hydraulic cylinder operators are located either on piers at the ends of the gate or on the downstream side of the gate.

(5) Dam sills and piers. Hinged-crest gate dam sills and piers are concrete. The sill and pier are normally constructed as a single monolith. Operating machinery is normally mounted on tall piers or housed in a watertight chamber so that it is not submerged, but current technology allows submerged hydraulic cylinders.

c. Vertical-lift gates.

(1) General. The vertical-lift gate, with wheels (rollers) at each end, moves vertically in slots formed in the piers and consists of a skin plate and horizontal girders that transmit the water load into the piers (see Figure 5-3). Reference is made to EM 1110-2-2701 and EM 1110-2-1603 for design of vertical-lift gates. The gate must be mounted on rollers to permit movement under water load. The vertical-lift gate, like the tainter gate, must be hoisted at both ends, and the entire weight is suspended from the hoisting chains or cables (cables are generally desirable). Piers must be extended to a considerable height above high water in order to provide guide slots for the gate in the fully raised position. Vertical-lift gates have been designed for spans in excess of 100 ft. High vertical-lift gates may consist of two or more sections in order to facilitate storage or ease passing of ice and debris. However, this does increase operating difficulties, because the top leaf or leaves have to be removed and placed in another gate slot. Historically, gantry cranes traveling on the spillway deck have been the standard method of operation for vertical-lift gates; however, fixed hoists may be justified, especially if speed is important or remote control is desired.

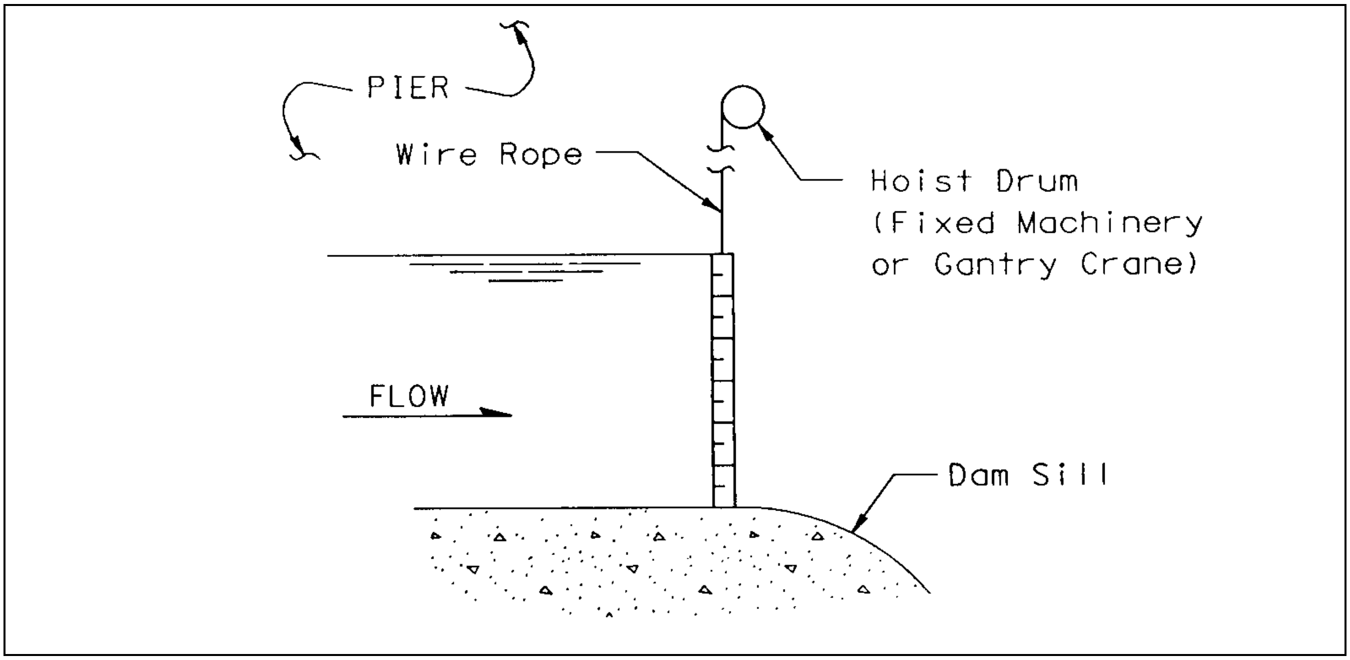

Figure 5-3. Vertical-lift gate

(2) Flow regulation. Regulation of flow is accomplished by means of single-section gates with variable discharge between the bottom of gate and the sill, and multiple-section gates consisting of two or more sections in the same slot with variable discharge between the sections or beneath the bottom section. The multiple-section gate may or may not be equipped with a latching mechanism permitting operation as a single-section gate when desired.

(3) Spillway discharge. The spillway discharge is controlled by raising the gates or the individual sections, as necessary, by increments. Dogging devices operated from the piers at the deck level engage projections spaced at intervals on the gate, permitting disengagement of the crane after the gate is raised to the proper elevation to give the required discharge.

(4) Gate types. Vertical-lift gates may be classified according to the method used to transfer the water load to the spillway piers, as follows:

(a) The fixed-wheel gate has wheels that revolve on fixed axles, which are either cantilevered from the body of the gate or supported at each end by the webs of a vertical double girder attached to the gate framing. The wheels may also be mounted by pairs in trucks which carry the wheel loads through center pins to the end girders attached to the gate frame.

(b) The tractor gate is equipped at each end with one or more endless trains of small rollers, which are mounted either directly on the end girder or on members attached to the end girder.

(c) The stoney gate has an end bearing consisting of a train of small rollers between the downstream flange of the end girder and the track on the pier. Since the rollers revolve in contact with both girder and track, the roller assembly moves in a vertical direction only half as fast as the gate and must be supported independently.

(5) Most common gate. Of the types mentioned, the fixed-wheel gate is the most common. It is adapted to long spans since provision can easily be made for rotation of the end bearings due to deflection of the gate body. It can transfer heavy, moving loads to the piers without the close track tolerances necessary for tractor or stoney gates. With cantilevered wheels, a gate slot of minimum depth can be used.

(6) Advantages. The advantages of a vertical-lift gate installation are numerous: it reduces pier dimension in upstream-downstream direction; its gate design is simple; it provides a clear gate opening with no encroachment, when raised, of any part of the gate structure on the water passage; it is more adaptable to extreme pool fluctuations because it is lifted bodily out of the water; it

eliminates design of complicated prestressing systems; and it may allow for other than in-place maintenance.

(7) Disadvantages. The disadvantages encountered in the use of vertical-lift gates include: a heavier lifting load, which requires greater hoist capacity; storage or pier-height requirements, which may necessitate use of a sectional gate; a more labor-intensive operation; greater time required for gate operation if only one crane is provided; and gate slots that can lead to cavitation and debris collection.

(8) Dam sills and piers. Vertical-lift gate dam sills and piers are concrete. The sill and piers may be constructed as separate monoliths or as a single monolith. Pier thicknesses of 8 to 15 ft are normally used, depending on gate width and height. Steel members should be embedded to serve as a sill plate and as bearing and armor members in the guide slots.

d. Roller gates. A roller gate is a long metal cylinder with “ring gears” at each end that mesh with inclined metal racks supported by the piers. The cylinder is braced internally to act as a beam to transmit the water load into the piers (see Figure 5-4). The effective damming height of the structural cylinder can be increased by means of a projecting apron that rotates into contact with the sill as the gate rolls down the inclined racks. The gate is raised and lowered by means of a chain or cable wrapped around one end of the cylinder and operated by a hoist permanently mounted in the pier. The rolling movement of the gate and the limited amount of frictional contact at the sealing points permit comparatively fast operation with a small expenditure of power. Roller gates have been built with a damming height of 30 ft, with lengths up to 125 ft on pile foundations and 150 ft on rock foundations. Roller gates are efficient in their power requirements and can be used for wider spillway bays than other types of gates. However, complexity of construction and the maintenance required by the hoisting and roller system are disadvantages of this type of gate. Sills and piers for roller gates are comparable to those of other gates of similar height and width.

e. Wicket gates.

(1) Wicket-type gates have been utilized for navigation dams for over 100 years. These gates are now normally considered for navigable pass dam spillways, but they will also function as nonnavigable spillways. Although several types have been utilized in the past, current new projects utilize a bottom-hinged wicket gate with consideration given to chanoine-type wickets. The gates can be lifted into position with a hydraulic cylinder applying force to the downstream side or to a crank, or they can be hoisted into position with a boat or gantry-operated crane or winch. Safety considerations and ease of operation during variable river stages and climatic conditions have generally led to the requirement for hydraulic cylinder operators. These cylinders may be located in a dry gallery or in a wet recess; however, silt must be excluded from any recesses. The wickets are generally held in an up position with a prop or strut which slides in a hurter track (see Figure 5-5). This allows the cylinder piston to be retracted except during operating cycles. A gate with the cylinder rod attached directly to the back to hold the gate in position, as well as to raise and lower it, is also being tested.

(2) Wickets constructed in the past were generally of steel or iron framing with timber leafs. Steel is the material most suitable for new construction, with composites, stainless steel, or aluminum as possible alternates. Wickets which are hinged at the base have the advantage of simplicity and cannot be “flipped” up by thrust from an upbound tow and then held partially up by river currents. The chanoine-type wicket is hinged just below its center point to a collapsible horse and held in place with a prop. This type of wicket is raised with the leaf in a horizontal position and then tilted into position by the force of water. This method requires less hoisting force than other methods, but the assembly is more complex and the wicket can be “kicked” up by a tow and held partially up under extreme conditions.

(3) Wicket gates are planned for the Olmsted Locks and Dam project on the Ohio River. These gates are bottom-hinged and are raised hydraulically. They are nominally 10 ft wide by approximately 26 ft long (see Plate 4). Wider gates are feasible. Advantages of wicket gates are low initial cost of construction, lighter weight (which allows offsite maintenance), variability in controlling pool, adaptability in incorporating redundant or protective features such as multiple ways to raise the wicket (hydraulically, with boat-operated backup), and breakaway props or dogging devices to limit damage in the event of towboat impact. Wicket dams are less subject to damage in high-seismic-force areas than a dam with piers, and are also more aesthetically appealing.

(4) The main disadvantage of wicket gates is the difficulty in providing for maintenance of the wicket assemblies. Maintenance may be accomplished with an unwatering box which is placed over the sill and dewatered to allow removal and replacement of one or more wickets at each setting. Proper floating plant,

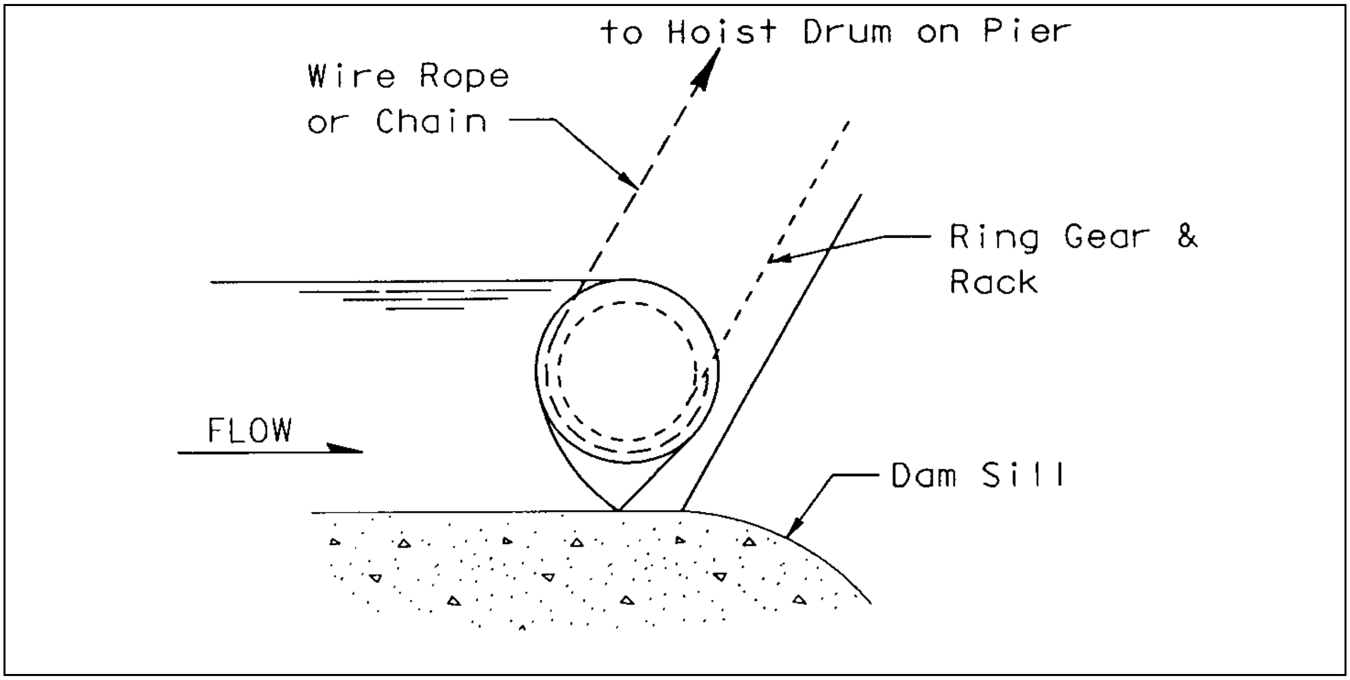

Figure 5-4. Roller gate

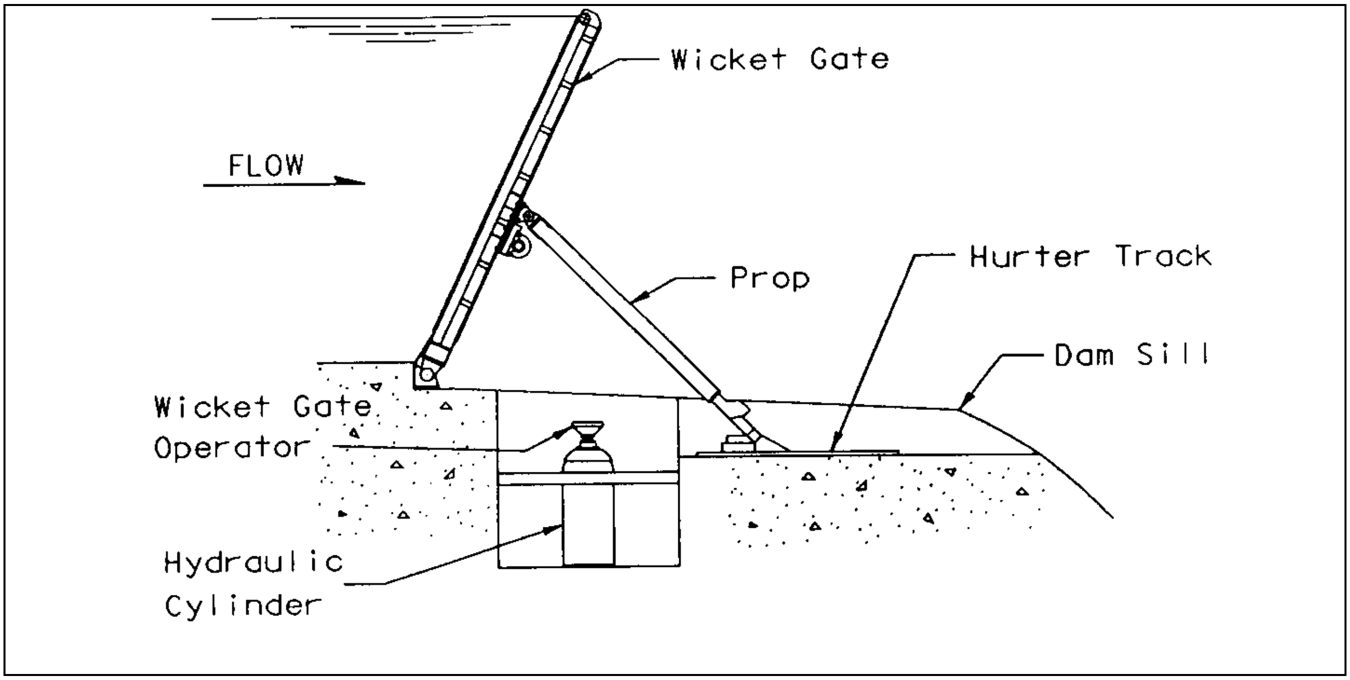

Figure 5-5. Wicket gate

anchorage, and equipment must be provided. This is most easily accomplished by providing quick change-out designs and spare wickets and operating machinery.

(5) Wicket dam sills are concrete. Piers are not required. The length of sill monoliths is controlled by cracking and constructibility requirements.

f. Bear trap gates, drum gates, and inflatable rubber gates. These gates have been utilized but are generally not recommended for current consideration. A brief discussion is included for reference (see Figures 5-6, 5-7, and 5-8).

(1) Bear trap gates consist of two leaves. When in the lowered position, the upstream leaf overlaps the downstream leaf. The gate is raised by applying upper pool pressure to a chamber under the leaves. This pressure, sometimes supplemented with air or hydraulic cylinders, raises the dam gate. These gates generally retain a pool differential of 20 ft or less and are normally about 90 ft wide. They are ingeniously conceived but can prove difficult to maintain. Silt or sand deposits in or under the gates are particularly likely and may make it impossible to fully lower or raise the gates.

(2) Drum gates are generally operated on a principle similar to the bear trap. The drum gate may be constructed as a segment of a circle and hinged on its downstream end. A watertight sill chamber is provided for the gate. To raise the gate, upper pool pressures are introduced to the chamber. This force may be supplemented by flotation chambers or hydraulic cylinders. The major difficulty encountered with this gate is the necessity to exclude silt and sand from and maintain seals on the chamber.

(3) Inflatable rubber dams are rubberized fabric tubes which are anchored to a sill and inflated to form a dam. These dams are limited to very low-head project usage, are subject to puncturing and vandalism, and are not recommended for major projects.

5-3. Gated Navigable Spillway

Navigable pass spillways permit the passage of tows over dams without the locking requirements. At some locations, natural river discharges are sufficient during a portion of the navigation season (which could be continual throughout the calendar year, or extend over part of the calendar year only) to obtain the authorized navigation depth. This is an advantage from the operational standpoint because locking delays are eliminated. However, during periods of low discharges, the dam must be raised to ensure sufficient depth for navigation. Movable gates which can be traversed may be attached to a sill to form such a dam.

a. Rationale. The primary need for a navigable pass is a dam which provides an area free of piers or other obstructions; therefore, the design of a navigable pass must provide for sufficient clear width for safe passage of tow traffic, including poorly aligned tows. At some locations this may include two-way traffic. In addition, the pass must have sufficient depth for tows of the authorized draft, including a buffer to account for overdraft, tow squat, etc. Model studies have shown that a navigable pass should have a *minimum* cross-sectional area 2-1/2 times the area blocked by a loaded tow. Current direction should be aligned normal to the axis of the navigable pass, and velocity through the pass must be low enough to allow passage of upbound loaded tows of the horsepower range that operates on the waterway. A model study should be considered in the design of a navigable pass. At the present time, the Corps is operating dams with navigable passes at projects on the Ohio, Ouachita, and Black Rivers. Pass widths vary from 200 ft on the Ouachita and Black Rivers to 932 and 1,248 ft on the Ohio River.

b. Gate types. In addition, the Corps operates dams on the Illinois Waterway at which tows transit the regulating wicket section during higher stages. Gate types usually considered for navigable passes include chanoine wickets, hydraulically operated bottom-hinged gates, and hinged-crest gates. Bottom-hinged wickets are currently being designed for the Olmsted Locks and Dam project on the Ohio River. These wickets are 26 ft long, 9 ft 8 in. wide, and have a 4-in. gap between gates. This project will provide a 2,200-ft-long navigable gated spillway dam which will regulate river flows as required for navigation (see Plates 3 and 4). Descriptions for wicket gates are included under paragraph 5-2*e*. Hinged-crest gates can provide the clear pass area required if designed without piers. Hinged-crest gates are being designed for the Montgomery Point project on the Arkansas River. These gates are nominally 30 ft long and retain a maximum pool differential of about 13 ft. Discussions of hinged-crest gates and drum gates are contained in paragraphs 5-2*b* and 5-2*f.*

c. Additional benefits. Navigable pass gate spillways may provide additional benefits. Because they are generally less massive they are less costly to construct. They are aesthetically pleasing because they are submerged a portion of the time and are less imposing than a

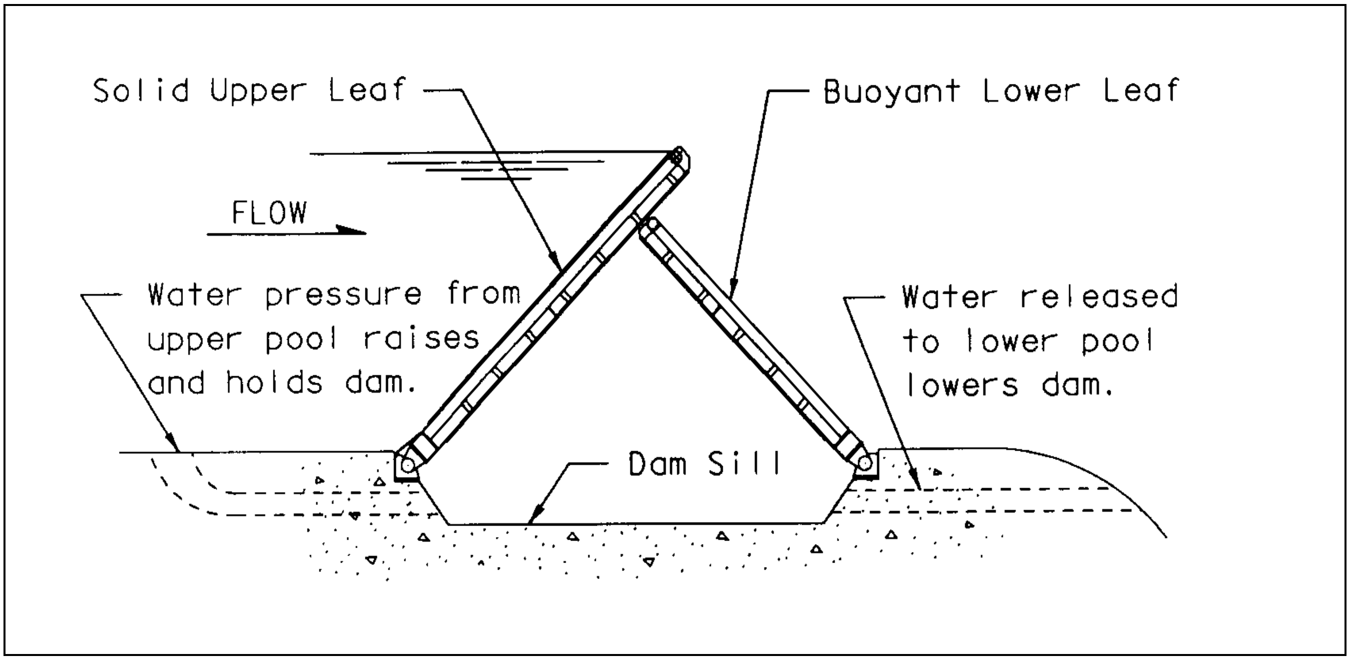

Figure 5-6. Bear trap gate

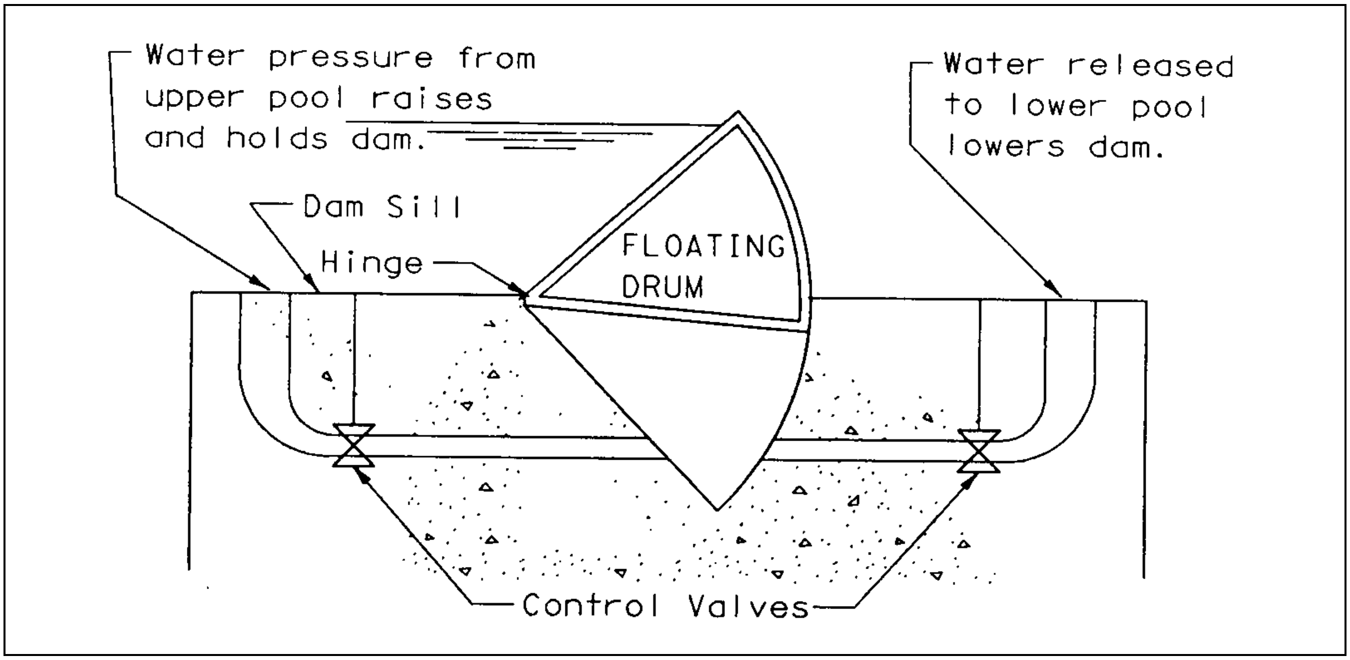

Figure 5-7. Drum gate

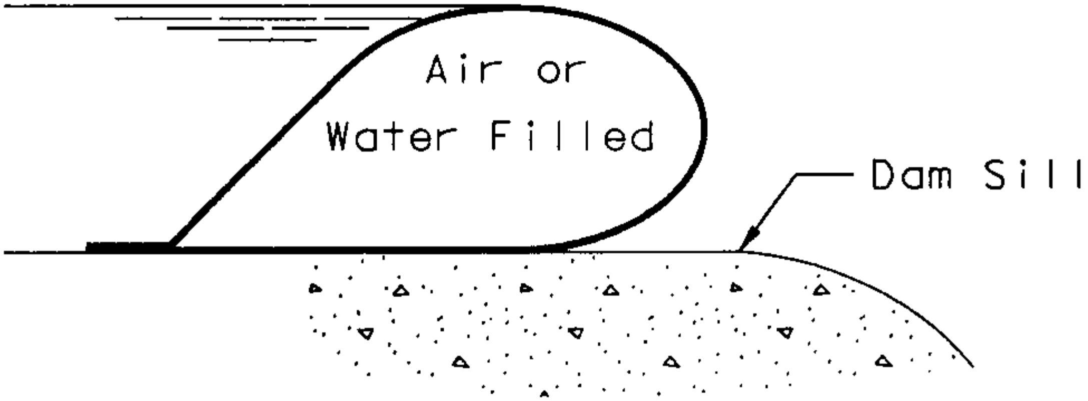

Figure 5-8. Inflatable rubber gate

tainter-gated structure when raised. They may be less likely to be struck by a tow because they are lowered during higher river conditions, and a weak-link protection is easily accommodated for excessive impact. These spillways generally offer more redundancy because the gates are smaller and there are more gates, and it is generally easier to provide them with a backup operating system, such as a normal system which raises the gate with hydraulic cylinders, as well as a boat-operated backup system. They may perform better in areas of high seismicity because of lower structural height and lower mass. They are also more adaptable to multiple operating settings which spread flow over the width of the river or concentrate it. The most important negative consideration is that maintenance of these spillways may be more difficult to accomplish and requires careful planning.

5-4. Fixed Crest

Fixed-crest (fixed-weir) dams are uncontrolled spillways. For overflow structures this spillway can constitute the entire navigation dam or a segment of it. This type of dam is commonly utilized to “tie” gated dam sections into the bank or abutment. The advantage of uncontrolled spillways is their simplicity of both operation and maintenance; the dam structure contains no moving parts or equipment that could be subject to malfunctioning. The toe of the weir is subject to high-velocity, turbulent flows which may necessitate significant scour protection downstream from the dam to preserve the integrity of the foundation (see EM 1110-2-1605). Additionally, the uncontrolled spillway may raise the flood level of certain frequency floods and may, therefore, require mitigation of this effect. Fixed-crest dams may be navigated, in some instances, during high water events which provide sufficient clearance over the weir. A lock and dam project with only an uncontrolled spillway will usually require higher lock walls than a project with a controlled spillway. An operational disadvantage of navigation projects with uncontrolled spillways is the increased possibility of pleasure boat accidents, because the drop in water surface at the weir is difficult to recognize from upstream. This hazard must be noted with proper warning signs and devices. As riverflows increase, a pool elevation may be reached where project navigation is suspended. In order to mitigate the effect of upstream flooding at uncontrolled spillways, locks are sometimes used as additional floodways by pinning the gates in an open position.

a. Structure types. Fixed-crest weir spillways normally utilized with navigation projects include concrete gravity monoliths, concrete-capped or concrete-filled cellular sheet pile structures, and rock fill dams with a sheet pile cutoff wall incorporated in the fill. Additional types of structures which may be utilized include roller-compacted concrete, reinforced-earth structures, I-walls, T-walls, counterforted or buttressed concrete walls, bin walls, and mechanically stabilized walls. If favorable foundation conditions exist, tied-back or tied-down walls may be appropriate.

b. Crest shape. The shape of the fixed crest is important. Under highly submerged conditions, the shape has little impact on capacity. However, overflow sections having significant head differentials will normally require an ogee-shaped crest, energy dissipation structures, and downstream channel protection. For this reason, many fixed-crest spillways which are combined with gated spillways to form the dam are constructed to a level somewhat above normal pool (2 ft is common), so that tailwater and headwater levels are approximately equal when flow over the crest is initiated. This may allow elimination of any energy dissipation structure.

c. Nonoverflow structures. Fixed-crest dams may also be nonoverflow structures. These structures may be earth or rock fill, cellular, concrete gravity, or any of the above-noted types of walls. For additional information, see EM 1110-2-1902, EM 1110-2-2300, and EM 1110-2-2503. Also, see Plates 10, 15, and 16.

5-5. Piers

a. General. Pier shapes and configurations affect the hydraulic performance and discharge capacity of dams. Piers for dams that have tainter-gated spillways must be wide enough and long enough to accommodate trunnion anchorages and girders, gate operating machinery, stairwells, recesses for unwatering bulkheads, and recesses for second-pour concrete for side seal rubbing plates. Piers for dams that have vertical-lift spillway gates need to be wide enough and long enough to allow for vertical operating recesses and bearing surfaces for the gates, gate operating machinery, gantry cranes, and recesses. Piers for dams with roller spillway gates require widths and lengths to accommodate the operating track (rack), bearing surfaces, gate operating machinery, and recesses for unwatering bulkheads. Spillway bay widths, pier height, and structural design requirements are also controlling factors. Corps dams in existence have pier thicknesses in the range of 8 to 15 ft. For piers, the most common and usually most satisfactory design is a semicircular pier nose shape. EM 1110-2-1605 provides more information on spillway pier configuration.

b. Trunnion girders and anchorages. Most recent tainter-gated dams designed and built by the Corps have prestressed concrete trunnion girders which bear against the downstream face of the pier and provide operational and stationary support for the tainter gates. Usually the girders are of the post-tensioned design. The larger girders are usually cast in place, whereas the smaller ones can be precast and then lifted into place by crane. The girder should be located above most flood elevations. However, submergence is sometimes allowed in the range of 5 to 10 percent of the time. These girders have functioned satisfactorily on many Corps projects with very little maintenance required and only a few instances of nonserious slippage of the anchorages. Structural steel trunnion girders have also been used successfully with the prestressed anchorage system described below.

(1) The trunnion anchorage assembly is composed of a grid of prestressing rods encased in steel pipes to allow for later stressing. The assemblies slope down within the pier toward the upstream face of the pier. Anchor plates are provided at the upstream end of the prestress rods. Bell- or ring-type anchors should not be used because it is difficult to ensure concrete consolidation within these devices. It is possible that the use of these anchorages has been the source of observed anchorage slippage. The assemblies are encased in a zone of high-strength concrete. The downstream end of the rods extends through pipe sleeves in the trunnion girder, and the rods are anchored on the downstream face of the girder. The rods extend beyond the girder to allow attachment of a hydraulic jack for initial stressing and for future jacking to check stress retention. After the initial stressing, a nonhardening compound such as NO-OX-ID is pumped into the annular space between the rod and the pipe sleeve to allow for future restressing of the rods, if it is found necessary. The downstream ends of the rods are coated with a rust-preventing compound and are enclosed in removable covers. Many installations have used steel pipes that have been grouted, in which case the anchors then become bonded anchors. However, in locations where rods are grouted, there is no opportunity to redress design concerns at a later date. If the pipe enclosures are grouted, then the grouting mix should be of a material that does not expose the rods to hydrogen embrittlement.

(2) Pier anchorages are not required for vertical and roller spillway gates because these gates transfer their load into the piers through bearing surfaces in pier recesses.

(3) Figure 5-9 and Plate 8 show a typical prestressed trunnion girder and anchorage. Further guidance for layout and design is contained in EM 1110-2-2702.

c. Finite element modeling of structure anchor forces. The prestressed trunnion girder and pier anchorage should be designed to resist all possible combinations of tainter gate reactions. A conventional beam theory usage will usually be satisfactory for preliminary design of the pier. However, a finite element analysis of a girder and pier section should be used to determine internal

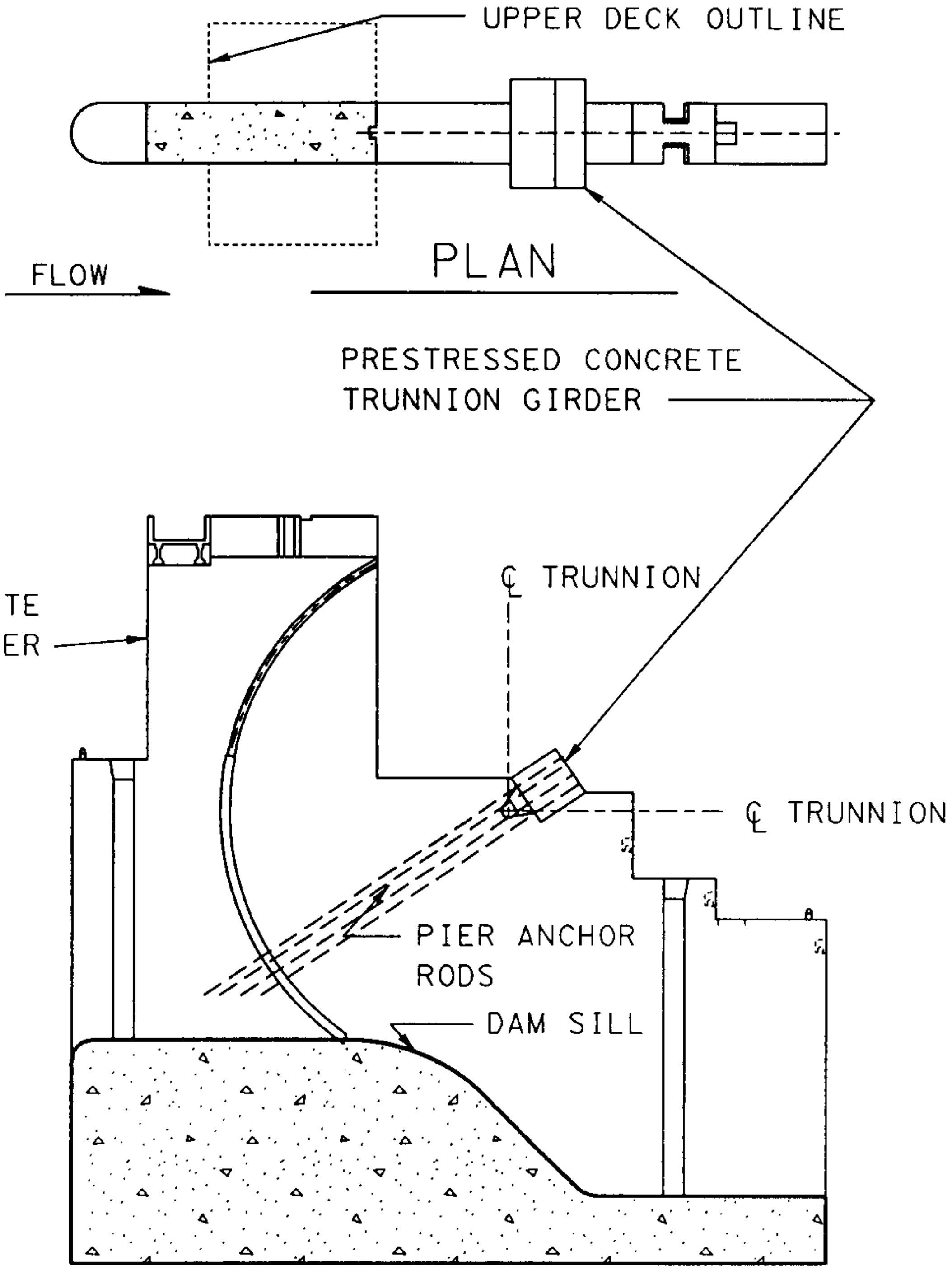

Figure 5-9. Prestressed concrete trunnion girder and anchor rods

stresses in the prestressed or post-tensioned areas. Use of the finite element analysis has shown that girder and pier internal stresses are greater than those resulting from calculations made using the straight-line conventional-beam theory.

d. Operation and fabrication parameters which determine pier dimensions. Pier width, length, and height are based primarily on the following operational features: spillway discharge flow-shape requirements for nose of pier, height of spillway gate in closed position, travel of spillway gate to fully open position, trunnion girder location and trunnion anchorage requirements (for tainter gate), machinery support requirements for spillway gate operation, elevation of service bridge and service bridge supports, recesses (slots) for upstream and downstream maintenance bulkheads, dogging devices for bulkheads, and interior personnel stairwell.

5-6. Miscellaneous Structural Features

a. General. Various monoliths are designed to satisfy hydraulic requirements, maintain foundation stability, provide foundation seepage control, and retain soil where differences in grade elevations exist.

b. Stilling basins. Stilling basins are designed primarily to prevent erosion of foundation materials downstream of the dam, to furnish an acceptable seepage gradient for permeable foundations, and to allow for energy dissipation. Expansion joints separate stilling basin slabs from each other, so each slab acts independently from other slab units. Sheet piles can be located below the stilling basin at the perimeter to prevent piping of foundation material due to seepage pressures. Stilling basin slabs (or spillway aprons) are typically constructed of reinforced concrete; however, roller-compacted concrete (RCC) slabs may be considered where reinforced concrete elements are not required. Stilling basin slabs are designed to withstand uplift loads acting over the stilling basin length. For permeable foundations, the slab thickness must be such that the submerged weight of the concrete is sufficient to overbalance the uplift effect resulting from the increase in static head below the hydraulic jump. Drain holes should be considered for relief of the pressure differential, provided the foundation material will not erode through the drain holes and compromise the stability of the slab. Slabs on rock foundations are typically anchored to the rock with steel bars in a grid configuration. If horizontal bedding planes are present in the foundation rock, the upper rock strata will be subjected to a net upward pressure, and the slab anchorage should be carried to a depth below which the upward pressure is balanced by the submerged weight of the slab and rock. When energy dissipation is accomplished with the aid of baffle piers and plain or dentated end sills, these structures are typically anchored to the slab and designed for the impact of the water jet and flowing ice or debris. However, such structures are usually at sufficient depth below tailwater to keep them submerged. The hydraulic loading may be estimated from the total pressure on the projected area computed from the maximum expected velocity of the impinging water (see EM 1110-2-1605).

c. Training walls. Training walls are designed to control flows upstream and downstream of the dam where variations in the project features may cause unwanted hydraulic effects. Flows through the dam may produce eddies which cause adverse navigation approach conditions, damage to streambed and slope protection, and sedimentation problems. Training walls are used to direct intake or discharge flows. The elevation of the top of the training walls is normally selected to prevent overtopping at all but the highest discharges. Training walls are normally extended at a constant top elevation to the end of the stilling basin. Adjacent project features and topography have a significant impact on training wall design (see Plate 16). Training walls are typically constructed of reinforced concrete with an inverted “T” cross-section configuration, and are designed to withstand the differential load effects caused by variations in hydraulic profile and the variation in sediment deposits that can occur on each side of the wall. The estimation of these loading conditions can be derived from hydraulic model studies. See EM 1110-2-1603 and EM 1110-2-1605 for determining hydraulic forces (static and dynamic) on stilling basin training walls.

d. Gate pier extensions. In accordance with EM 1110-2-1605, gate pier extensions are required to extend into the basin to a position 5 ft upstream of the baffles to prevent return flow from inoperative bays. The pier extensions can be extended farther downstream if required for stability. These extensions are required to ensure adequate stilling basin performance. The pier extension should be at least 1 ft higher than the tailwater used for the single gate half or fully opened criteria. Pier extension width can be less than the main spillway piers.

e. End sill. A sloping end sill is normally required to spread the flow for single gate operation. This slope is normally 1V on 5H. The higher the end sill, the more effective it will be in spreading the jet during single-gate operation, but there are limitations. The higher end sill results in shallower depths in the exit channel and possibly higher velocities over the riprap. The top of the end sill should not be appreciably above the exit channel. Also, the end sill should not be so high that it causes flow to drop through critical depth and form a secondary hydraulic jump downstream.

f. Grade separation walls. Grade separation walls are required where transitions between differing grade elevations cannot be achieved with a stable slope. The wall may also be configured to function as a training wall. Grade separation walls are designed as retaining walls with proper consideration of the fully submerged condition. The required factors of safety are the same as for the navigation lock and dam structures. Sedimentation buildup may cause retained soil loading significantly different from the constructed grades (see Plate 16). Grade separation walls are typically constructed of reinforced concrete with a “T,” or retaining wall, configuration. An unreinforced gravity wall RCC may be considered in appropriate cases.

g. Structural separation walls. Walls which separate individual lock structures or which separate a lock structure from the dam gate or abutment structures will vary considerably with the site and type of project selected. The top of the wall will, at minimum, equal the normal upper pool level plus freeboard (1 to 2 ft) but will most generally be equal to the top of the lock walls to allow proper navigation during higher river stages. See Plate 1.

5-7. Special Design Considerations

a. Low-flow and water quality releases. Provision for sluices as part of the main spillway or a separate outlet works to accomplish low-flow or multilevel releases should be designed according to EM 1110-2-1602.

b. Fish passage facilities. Most fish passage facilities are located at the dams on the Columbia and Snake Rivers. These structures are normally ladder type structures, fish screens, sluiceways, etc. See Plate 12 for typical fish ladder locations at a lock and dam project.

c. Ice control methods. It is desirable and often essential to continue operation of navigation dams and spillways during winter (see EM 1110-8-1(FR)). Traffic may be curtailed or even stopped on the waterway, but provision must be made to pass winter flows and to handle ice during winter and at breakup. Designers must consider ice passage procedures, possible ice retention, ice forces on the structures, and icing problems leading to blocking of moving parts or simply excess weight. Provisions to move ice past or through dams have been many and varied and none have met with perfect success. At some locations, it is preferable to retain the ice in the upstream pool, while at others an ice-passing capability is necessary. Regulating gates on a dam structure can be used to pass ice and debris by either underflow or overflow. In the first case, the gates are opened sufficiently wide to create enough flow that accumulated ice and debris are pulled from the upper pool to the lower pool, to be carried from the structure by the current. The magnitude of opening for successful operation depends on local conditions and experience; it is usually one-third to fully opened gate, depending on tailwater level. Hydraulic model tests give some indication of the required opening for new structures. One of the dangers of this operation is that it often causes downstream scour holes. To prevent occurrence of scour, proper scour protection and/or energy dissipation must be provided. Spillway openings should be as wide as practicable to minimize arching of ice across the openings. The primary factor controlling ice passage appears to be the velocity of the approaching ice. When the velocity is great enough, the floes are broken and pass through spillway bays. Passage of ice through a submerged outlet requires sufficient velocity to entrain the ice into the flow. Therefore, to maintain pool during periods of low flow, ice may be passed over the tops of gates; however, this has met with only limited success under certain ice and flow conditions. At low flows ice can be passed with one or more gates open at a time and arching broken by alternating gate openings. Physical models of ice control methods for specific projects can be made in the Ice Engineering Laboratory at CRREL. EM 1110-2-1612 provides additional information on ice control methods.