Chapter 7
Other Hydraulic Design Features

7-1. Scope

Hydraulics design features not directly related to the hydraulic filling-and-emptying system are discussed in the following sections.

Section I
Surge Reduction

7-2. Solutions

Surge reduction is accomplished by:

a. Slower filling-and-emptying systems or longer valving. This results in lower surges at the expense of long operation time.

b. Surge basins to suppress the rapid drawdown (filling) or upwelling (emptying) during the normally brief period of rapid change in discharge rate.

c. Hydraulic surge control methods as a means of removing or adding water to a small canal located between two locks. Additional volume is needed during filling of the lower lock; removal is needed during emptying upstream.

d. Staged lifts to reduce peak flow rates (as in *a* above) at substantial increase in operation time.

e. Broad approach channels to lower surges; i.e., canalized systems are more susceptible to surge effects than are broad river systems.

7-3. Computational Aids

Surge reduction is discussed in EM 1110-2-1606. Surge height calculations as presented in EM 1110-2-1606 are computer accessible in the CORPS program library (H5310). An example input/output is presented in Appendix F. For long canals or more complex geometries, study aids such as more comprehensive analytical (computer-based) solutions or physical model studies are needed.

Section II
Impact Barriers

7-4. Purpose

The purpose of a barrier is to provide an energy-absorbing device for barge tows to prevent damage to the gates in the event of a collision. Four such devices have been considered for use to protect lower miter gates. They are wire rope fenders, steel collision barriers, concrete collision barriers, and rope system impact barriers. The rope system impact barrier has been studied for use upstream of upper miter gates (the other three types appear less suitable for upstream use). These barriers are discussed in EM 1110-2-2602.

Section III
Water Saving

7-5. Water Supply

During periods of low water on canalized waterways, a sufficient supply of water is required to maintain all navigation pools at or above planned normal pool elevations. The following factors affect pool elevation:

a. Available hydrologic water supply.

b. Leakage, seepage, and multipurpose (hydroelectric plant, for example) consumption.

c. Water requirements for lockages.

d. Pumpage or diversion, and return flow (where applicable).

e. Evaporation.

The water supply must be equal to or exceed the algebraic sum of the other factors in order to maintain the navigation pools. The water supply may consist of the natural flow of the stream, the supply furnished by storage reservoirs, or a combination of the two. A thorough investigation should be made for all items when any doubt exists as to the adequacy of the water supply.

7-6. Design Needs

Low-flow lock operation is an overall project concern that places site-specific conditions on hydraulic design. Such factors as operational procedures, canal surges and approach conditions, valve siting, etc., designed for normal conditions may not be suited for low flows.

Section IV
Dewatering

7-7. Concerns

Hydraulic concerns during dewatering include the following:

a. Bulkhead locations.

b. Pumping facilities.

c. Outflow conditions.

7-8. Coordination

Dewatering exerts an extreme static loading on structural elements and requires specific considerations during lock structural detail design (see EM 1110-2-2703 and EM 1110-2-2602). Structures used for emergency closure are normally suitable for dewatering (item B5).

Section V
Emergency Closure

7-9. General Emergency Situations

Emergency situations occur at navigation locks when a lock gate becomes inoperative in an open or partially open position while a head differential exists between the chamber and upper or lower pool. Although the cause may be mechanical failure, the more frequent cause is a navigation error that holds the gate partially open. Although no universally accepted definition of *emergency closure* exists, the required action is generally understood to be that a closure structure must be rapidly placed in flowing water under head differential.

7-10. Consequences of Pool Loss

The main consequences of upper pool loss *downstream* of the project are due to the flood wave. Hazardous navigation conditions and rapid flooding of riverfront property are extreme possibilities. A less severe flood wave will commonly interfere with the operation of private and commercial boat docks. *Upstream* impacts of pool loss include the following:

a. Economic and safety problems occur at commercial and recreational boat terminals. Long periods of navigation suspension have a severe adverse impact on the economy of an entire region. The primary loss on major navigating systems is loss of navigation channel.

b. In many areas, small riverfront communities depend on the maintenance of normal pool for water supply. Loss of pool during low-flow periods causes inconvenience and, possibly, health and fire hazards.

c. Rapid loss of pool and resulting drawdown causes bank instability. This problem is especially severe where important structures, highways, or railroads are located in the reach of instability.

d. A navigation project that includes hydropower loses some or all of its power-generating capability in case of upper pool loss.

e. Upstream pool loss causes a severe and adverse impact on fish and wildlife.

f. Upstream pool loss affects other site-specific factors particularly during extremely low upper pools.

7-11. Preliminary Studies

In the design of most modern navigation lock and dam structures, emergency closures have been provided.

7-12. Types of Closure Systems

A broad range of structures are in place as emergency closure devices at existing CE locks. Operational and economic considerations, rather than purely function, limit the choices for new designs. Structural details are available in EM 1110-2-2703 and in other references (item B5, for example). Examples of the more common closure devices are as follows:

a. *Bulkheads.*

(1) The most common type of emergency closure for locks and spillway gate bays is a bulkhead consisting of one or more sections and commonly constructed of welded, high-strength steel. A watertight skin plate is generally provided on the upstream side. Top and bottom seals, side seals, and roller assemblies complete the

structure. The roller assemblies bear on bearing plates constructed in pier or lock wall recesses. The vertical height of the structure may vary from 3 to 12 ft depending on design constraints of a specific project. Several individual units are usually required for complete lock or dam closure.

(2) Most designs do not permit water flowing over and under the bulkhead units during lowering. Stacking units may be required for successful placement. Some bulkheads are equipped with an overflow plate attached to the top truss. The purpose of such design is to utilize bulkheads for flushing ice and debris, when necessary. If bulkheads are designed for placement in flowing water, hydraulic model studies of previously untested situations are needed.

(3) The units are either stored at the locks or retained in dogged position over the dam. In the former case, an overhead gantry crane is used to transport the individual units to the lock. The first unit is dogged over the bay or the lock and the next unit is moved from storage, latched to the first one, and then the assembly is lowered and dogged a second time. Additional bulkhead units are latched to the assembly until closure is achieved.

(4) Another method of placement uses a stiff-leg derrick positioned at the lock. The derrick raises and places individual units in bulkhead recesses. Additional units are added until closure is achieved. During lowering, the assembly is held in place by a stop log carriage.

b. Vertical lift gates.

(1) Emergency lift gates are either the single-leaf or the double-leaf type (see EM 1110-2-2703). The cost of the gate, storage arrangements, and hoist mechanisms for either type vary according to river stage and project (closure) lift. Economic studies are ultimately used to choose between single- or double-leaf gates. Double-leaf vertical lift gates have been constructed at several navigation locks on the Ohio River navigation system; other navigation systems use single-leaf vertical lift gates. In either system the gates are stored in submerged position under the lock emergency sill upstream of the upper miter gates. The double-leaf construction permits the utilization of locks as floodways when the river stage prohibits navigation. An emergency-closure single-leaf gate is illustrated in Plate 7-1.

(2) For the double-leaf type of design used in the Ohio River navigation system, only the downstream leaf is designed to permit closure in flowing water. However, the vertical height of one leaf is sufficient to effect closure under unbalanced head (flowing water) up to normal pool level. Should closure be required for stages above normal pool, then both leaves can be raised, since upstream and downstream heads are balanced. The operation of double-leaf-type emergency closure is shown in EM 1110-2-2703. For the single-leaf emergency gate, provisions must be made in the design to allow closure.

c. Upstream emergency dam. A type of emergency closure designed and constructed by the U.S. Army Engineer District, Nashville, for several locks on the Cumberland River navigation system is an emergency dam. This consists of several wickets that remain submerged on the floor of the emergency sill during normal locking operation, but they are raised into position during emergency conditions. Each wicket is raised individually by means of a chain hoist, sheaves, and a winch located on the top of the lock wall. When wicket No. 1 is in the lowered position, the landward hoist chain fits into a recess in the lock wall. As the first wicket is raised, it also raises the attached hoist chain of the next wicket. After locking the first wicket in position, the sheave is passed over to the riverward side and the second wicket is raised, which also raises the hoist chain for the third wicket. The operation continues in this manner until all wickets are raised. Similar closures have been constructed and operated on other navigation systems. In the original design, the wickets were constructed with flat skin plate; however, hydraulic model testing includes a curved skin plate.

d. Other systems.

(1) Stop logs, commonly consisting of wooden beams, can be placed in recesses upstream of spillway gates or lock miter gates using a hoisting mechanism. However, in general, operating heads on the dam usually must be reduced before placement. Since this arrangement would result in partial or total loss of pool, they cannot be considered a true emergency closure. Bulkheads, described in *a* above, are sometimes designated as stop logs. An older type of emergency closure is used for the auxiliary lock at McAlpine Lock and Dam on the Ohio River system. This type of closure includes a separate horizontal beam placed across the top of the lock walls with a derrick. Closure panels are vertically placed between the beam and the concrete sill to complete the closure operation.

(2) Submergible tainter gates are another alternate for emergency closure. Under normal operating conditions, the gates rest in a recess built in the emergency sill, upstream of the upper miter gates. During emergency closure, the gates are lifted to position by cables. Provisions must be made to clean the gate recess periodically to free it of accumulated silt and debris.

7-13. Design Loadings

An overview of design loadings (EM 1110-2-2703) is as follows.

a. Hydrodynamic forces result from the water flowing under the emergency closures. On emergency bulkheads, these forces can result in hydraulic uplift or downpull depending on the design. In order to lower bulkheads in flowing water, the uplift force must be less than the submerged weight of the bulkhead. Knowledge of the magnitude of hydraulic downpull is important for the design of the hoisting machinery. Overflow and underflow on emergency bulkheads are undesirable from the standpoint of hydrodynamic forces and should not be used. Hydraulic model studies are sometimes required to determine forces for a particular design.

b. The weight of the bulkhead is to be determined in the usual manner considering the structural elements and members of the closure. The majority of the bulkheads are of structural steel, but aluminum bulkheads have been used. The submerged weight is important in considering the ability to lower the closure structure in flowing water.

c. Frictional forces develop along the side support of closure structures. The magnitude of these forces depends on the type of bearings and side seals as well as on other loadings (*a* and *b* above, for example). Reference is made to EM 1110-2-2703 for details.

d. Some types of emergency closure systems, notably vertical lift gates, can be used in a dual role serving also as lock gates. Barge impact loads are considered for these designs. Reference is made to EM 1110-2-2703 for the magnitude of such loads.

e. Ice forces are considered, depending on the climatic condition at the location of the closure (see Section VI).

Section VI
Ice Control at Locks

7-14. Types of Ice

Ice in and around locks has always been a nuisance. Most lock operators have worked through the winter season using pike poles and steam to combat ice. Some locks, especially in more severe climates, simply close. However, recent interest in year-round navigation has led to closer identification of winter lock-operating problems and development of potential solutions to these problems. Three kinds of ice create problems for navigation: sheet ice, brash ice, and frazil ice. Sheet ice is a continuous cover of more or less equal thickness. Brash ice is an accumulation of ice fragments up to above 6 ft in the longest dimension that can pack to depths greater than the normal ice thickness. Frazil ice is an accumulation of small plates and spicules formed in turbulent water that often adheres to trashracks, gates, intakes, and other structures in the water. EM 1110-2-1612 gives additional background information and details of ice control measures.

7-15. Ice Problems

Ice problems at navigation locks are caused primarily by brash ice floating downstream or being pushed ahead of downbound traffic. The floating pieces of ice hinder gate opening and closing, stick to lock walls creating problems with vessel passage, and stick to lock gates causing operational problems. Large quantities of ice pushed ahead of a downbound ship can interfere with lock operation because a separate lock cycle solely for ice is often required by long ships using short locks. If ice could be prevented from entering the locks, most of these problems would not occur.

7-16. Air Screen

a. An air screen can keep ice from entering a lock. When large volumes of compressed air are released at depth across a channel, a high upstream and downstream surface water velocity is created that precludes the passage of ice or debris. This type of installation is called an air screen, and an application at Sault Ste. Marie has demonstrated its effectiveness. Air screens should be located between the upstream ends of the guide wall and guard wall; when placed closer to the lock, any ice pushed into the lock approach has nowhere to go and will accumulate. This same principle has been used successfully either as a single, point-source bubbler or as a line bubbler to keep ice out of miter gate recesses, allowing them to open fully.

b. An air screen was installed at the upper approach to the Poe Lock on the downstream, vertical face of an emergency stop log gate sill. The sill is located about 200 ft upstream of the lock gates. The riser line was installed in the stop log recess in the wall. The width of the lock at this point is 110 ft and the height from the top of the sill to the top of the lock wall is 39.2 ft. The manifold line was installed at a depth of 34.5 ft in December 1977 and was preassembled into four sections: two sections 27.75 ft long and two sections 24.5 ft long. Union connections joined the sections. The riser was assembled in one 38.5-ft section. The sections were light in weight; two to three people were able to move them by hand. All equipment for a hardhat diver and the preassembled pipes were placed on a 100-ft barge that served as the working platform. The barge was positioned above the sill, and sections were lowered on ropes to the diver below who made the union connections and strapped the line to the concrete sill. One flexible hose coupling, from the diffuser to the riser, was also made underwater. The above-water installation process consisted of simply connecting a 50-ft flexible hose from the top of the riser line to a rented compressor. A 10,000-gallon fuel tank was placed beside the compressor to supply fuel.

c. The air screen was put into operation on 12 January 1978 when ice started to cause problems with lock operations. It was continuously available for service until 30 April 1978, except for a 5-day repair period in late March. By 1 May ice no longer caused problems requiring the air screen, and the rented compressor was returned. During the 104 days of operation, the total running time on the compressor was 754 hr. Total fuel consumption of No. 1 fuel oil was about 7,750 gallons. The air screen has demonstrated that it can hold back ice pushed ahead of downbound traffic. With ships in the 70-ft beam class, the ice was held back until the bow entered the air stream. The stream was not as effective with the wider 105-ft beam ships. Once the bow passes the nose pier about 130 ft upstream of the screen, the approach is just a little over 110 ft wide; so most of the ice remaining in the track is pushed into the lock. The problem might be solved by relocating the air screen upstream of the nose pier area and by providing some area for the ice to be pushed outside the vessel track. The merits of the air screen cited by lock operating personnel, besides the reduction in vessel lockage time, were savings in wear and tear on the lock gate and operating mechanisms and savings in time and effort required to remove ice collar buildup on the lock walls.

7-17. Lock Wall De-icing

Ice buildup on lock walls occurs throughout the winter and presents no problems until it covers mooring bits or becomes so thick that the lock is effectively too narrow to admit vessels. If the lock is normally kept at low pool elevation, the lock walls cool to ambient temperature and upon filling are coated with a glaze of ice. Since this ice coat can continue to build (like dipping a candle) locks are normally kept nearly full during winter operations. When entering ships push ice into the lock, especially downbound, ice is often crushed against and adheres to the lock wall, exacerbating the problem. On rivers the standardization of barge width and the barges' square bows minimize this difficulty, but other locks such as those in the Great Lakes connecting channels can have severe problems.

a. Ice cutting saw. The U.S. Army Cold Regions Research and Engineering Laboratory designed and assembled a mechanical cutting system to remove the ice collars. The device consists of two parts: the cutting system and the drive and propulsion unit. The drive and propulsion unit is a 65-horsepower, four-wheel-drive tractor, originally manufactured as a trencher (the tractor can be purchased without the trencher attachment). The drive line for the trencher was modified to accommodate the cutting system by extending the drive shaft and attaching a drive sprocket to its end. While in the cutting mode, the engine powers the shaft and sprocket directly and the drive wheels indirectly through a separate hydraulic drive system so cutting power and propulsion power can be independently controlled. The cutting system is one used in the coal industry. It consists of a rugged bar and chain with cutting bits attached. The bar is 9.5 in. wide to the chain guide, 1.5 in. thick, and 15.9 ft long and is attached to the drive shaft housing. Movement of the bar is hydraulically controlled. Different kerf and bar thicknesses have been used, but earlier tests showed that a narrow logging saw was too flexible. The bar is grooved to accommodate the sprocket-driven chain and cutting bits and has a roller nose tip to reduce friction and wear. Chain tension is controlled by a high-pressure hydraulic cylinder capable of exerting 1,800 lb/ft at 10,000 lb/square inch (sq in.). The bar and chain hang about 30 in. past the side of the tractor and the drive wheels.

b. Operation of the ice cutting saw. When a problem ice collar has built up, the esplanade along the lock wall is cleared of snow. The tractor is then positioned with the right wheels close to the curbing along the wall so that there is about 1.5 in. of clearance between the wall and the bar and chain. A spacer on the wall side of the bar prevents the cutters from damaging the wall. A guide marker located off the right front wheel is positioned and set so the driver can maintain the proper position by keeping the marker and the reference point (top of curb) aligned. Looked at from the driver's point of view, the chain rotates clockwise with the tension cutting side on top of the bar. To start a slot for the bar, the underside of the saw is used until the tip cuts completely through the collar. The slot is cut with the tractor stationary. Once a slot is cut through, the bar is placed in a forward position about 70 deg from the horizontal. Full throttle operation in third gear produces a chain speed of 380 ft per min, although chain speeds of up to 510 ft per min are possible in fourth gear. A traverse speed of over 10 ft per min can be maintained while cutting ice collars 6 to 8 ft deep by operating the transmission in third gear at full throttle.

c. Copolymer coating. A chemical coating that reduces the adhesive force between the coated surface and the ice can also help solve icing problems, although the ideal material would prevent ice formation altogether. The coating that was developed does not prevent ice formation, but makes removal of ice from coated surfaces much easier. The basic material is a long chain copolymer compound made up of polycarbonates and polysiloxanes. The copolymer coating should not be applied to a concrete surface unless it is certain that the concrete behind the coating can resist frost action in a critically saturated condition. Proper application guidance for surface coatings to concrete can be found in EM 1110-2-2002.

d. Heating lock walls. Intermittent heating of the lock wall to release ice is probably the best solution. One lock has been retrofitted with electric heat tape installed in saw cuts; however, this is a time-consuming and expensive operation. Before new construction or rehabilitation of locks, options for lock wall heating should be investigated.

7-18. Lock Gate and Valve De-icing

The operating machinery for filling and emptying valves has been reported to have icing problems, but little is known beyond the verbal reports from specific lockmasters. Thought should be given to minimizing direct exposure to the atmosphere. Lock gates, especially the lower gate, should be insulated on their downstream side to minimize ice buildup on the upstream side that would make full opening of the lock impossible. On most existing gates, the downstream side of the gate is open, and while passing through the lock, ships push ice between the supports of the gate. To minimize this problem, gates should have a cover skin on the downstream side extending some 3 ft above and 6 ft below pool operating levels.

7-19. Considerations for Rehabilitation and New Construction

Whenever lock rehabilitation or new construction is considered, a number of ice-related concepts should be evaluated. Air screen and lock wall de-icing schemes have been covered in earlier paragraphs. The location of the filling intake should be situated so that filling currents do not pull ice into the lock approach. An ice and debris bypass should be considered whenever the approach channel is longer than a few hundred feet. Gate design should include insulation and a double skin to prevent ice from adding too much weight. Lastly, consideration should be given to a modified filling system that would add water to the upper end of the lock only. This would shorten the time required to flush the lock clear of ice and could be used as an emergency method of getting a disabled or burning vessel out of the locks.

Section VII
Repair and Rehabilitation

7-20. Purpose and Scope

Major rehabilitation includes work that is non-recurring in nature and is intended to either increase the reliability of deteriorated features or increase efficiency, or shall not consist of routine or deferred maintenance, which will continue to be considered in the U.S. Army Corps of Engineers Operation and Maintenance General budget appropriations.

7-21. Reliability Improvement

a. Rehabilitation for reliability is major project feature restoration consisting of structural work on a feature of the lock which is intended to improve reliability the result of which will be a deferral of capital expenditures to replace the structure.

b. Rehabilitation is considered as an alternative when it can significantly extend the physical life of the feature and can be economically be justified by benefit-cost analysis. The benefit-cost analysis is a product of a risk analysis which combines probability of unsatisfactory performance with consequences. The work will extend over at least two full construction seasons and will require a specified threshold cost to be exceeded. This amount is specified in the annual Major Rehabilitation Guidance Memorandum. Additional guidance for the major rehabilitation program and the associated reliability analysis is found in ETL 1110-2-532.

7-22. Efficiency Improvement

Rehabilitation for efficiency improvement is intended to enhance operational efficiency of major project components and increase outputs beyond their original project design. Threshold limits on a component that does not exhibit reliability problems is also specified in the annual Major Rehabilitation Guidance Memorandum. Efficiency items include the following:

a. Modern machinery.

b. Modern electrical equipment.

c. Remote controls.

d. Television surveillance system.

e. Floating mooring bits.

f. Tow haulage units.

g. Lock wall extensions.

h. Emergency closure system.

i. Lock gate impact barrier.

j. Improved filling system.

7-23. Threshold Amounts

The threshold amounts listed for the reliability and efficiency improvement categories are adjusted annually according to the Administration's economic assumption published each year as guidance in the Annual Program and Budget Request for Civil Works Activities Corps of Engineers.

7-24. Typical Study Items

The following are common items to consider for major navigation dam rehabilitation projects:

a. Dam stability.

(1) Replace upstream and downstream scour protection.

(2) Install tendons through structure into foundation.

b. Navigation improvement.

(1) Move lock guide/guard walls.

(2) Change approaches.

(3) Change approach currents with training structures.

c. Ice and debris control. Install the following:

(1) Lock wall de-icer.

(2) Lock gate de-icer.

(3) Control booms.

(4) Air screens.

d. Replacement in kind.

(1) Resurface concrete surfaces.

(2) Repair or replace gates.

(3) Fix gate anchorages.

(4) Replace imbedded metal.

Section VIII
Environmental Concerns

7-25. Effect of Lock

The massive character of a navigation lock suggests that environmental evaluations (normally nonhydraulic effects) are required for project construction as well as operation. Navigation locks affect the local economy both in the short term, by construction activities, and in the long term, by the presence of navigation traffic. Visual changes are the major aesthetic effects of navigation lock projects.

7-26. Water Quality

Concerns experienced at other types of hydraulics structure/s are uncommon. Even valve design, which may cause a small change in water quality during the time the valve is vented and significant air entrainment occurs, has not been a significant environmental concern, because of intermittent lockages. Very few studies of change in water quality due to lock operation (see item R8, for example) are available; these studies in general do not show a meaningful deterioration in water quality and very limited possibilities for enhancement.

7-27. Recreational Craft

For projects where recreational craft appear in considerable quantities, the introduction of separate handling facilities is considered particularly when the period of peak recreational demand corresponds to the period of peak commodity movement. Separate facilities (such as a canvas sling or steel tank to lift the craft, a separate small lock, an inclined plane moving lock) are discussed briefly in Appendix G.

7-28. Facility Alternatives

Several alternatives for providing separate facilities for recreational craft for the Upper Mississippi River have been considered. These included the following:

a. A 110-ft by 360-ft auxiliary chamber.

b. A 110-ft by 400-ft auxiliary chamber.

c. A mobile floating lock.

d. A small-scale steel lock.

e. A differential railway lift.

f. A steel tank on inclined rails.

g. A steel tank lift crane.

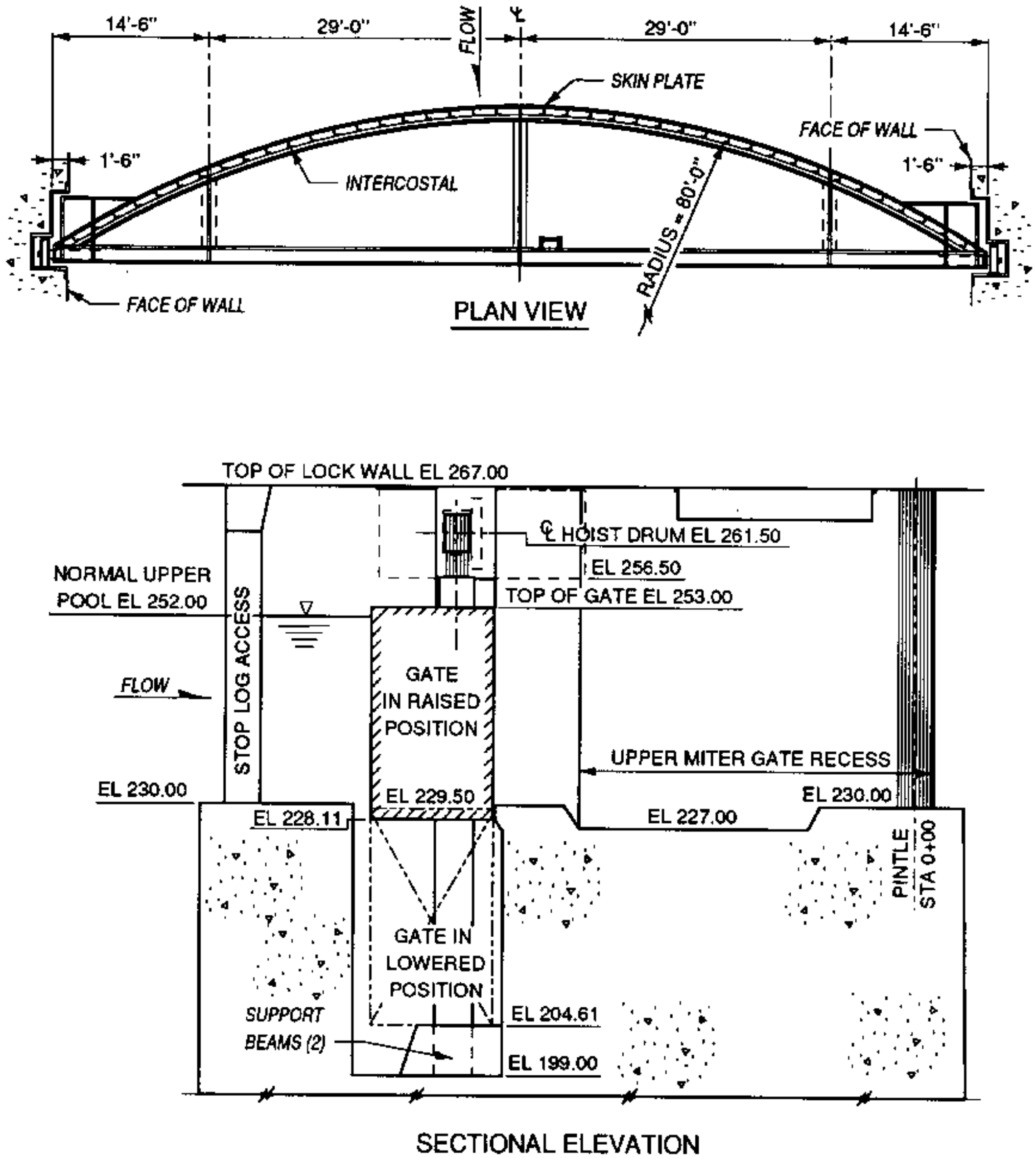
h. A mobile boat carrier.

i. An inclined channel lift.

j. An inclined plane lift.

7-29. Second Lock Chamber

Twenty of the Upper Mississippi River locks have partial provisions for a second lock chamber, 100 ft by 360 ft. These provisions include an upper gate sill, upper portion of the river wall, and recesses in the intermediate wall for the lower miter gate and gate machinery. Completion of this lock chamber would involve damming and dewatering the chamber area; removing accumulated debris and scour protection measures; constructing the river wall and chamber floor; removing and rehabilitating the upper miter gate; and installing gates, valves, operating machinery, and appurtenances.



EMERGENCY CLOSURE SYSTEM
PLAN II
VERTICAL LIFT GATE

Plate 7-1