Chapter 11
Design for Operation, Safety, and Maintenance

11-1. General

The objective for design of modern navigation projects is to provide navigation locks that are operationally and functionally reliable. Important design objectives are to minimize staffing requirements, improve operational efficiency, and decrease lock downtime for maintenance and replacement of operating components. Other design objectives include providing low life-cycle maintenance costs, mobile access to all parts of the structure for operation and maintenance, access for the disabled, and safe operating conditions for personnel and navigation. This final objective can be achieved by installing automated operating systems; centralized control of lock and dam operations; automated visual, audio, and electronic surveillance systems; command and control communication systems; real-time condition sensors for lock gates; valves and operating equipment; automated data collection systems; and spare parts, spare gates, and spare operating equipment for fast replacement of damaged components. An operation and maintenance plan addressing these features is developed by the engineering division and submitted for review during the feasibility report stage of design.

11-2. Design for Operation

a. Operating control systems. The design of control systems for navigation locks can involve three levels of technology. Locks with low volumes of commercial traffic and higher volumes of recreational use may justify the installation of more manual systems. Locks with high volume of commercial traffic on main stem river navigation systems should incorporate automated technology. An intermediate system based on current technology could be a centralized semiautomated system backed up by a local control system as described in Appendix C.

(1) Local hardwired control systems. Hardwired control systems with control panels located at each gate have traditionally been used for operation of navigation locks and dams. This system is based on 1930's technology and has proved to be reliable and reasonably safe based on over 50 years of operational experience. However, some accidents have occurred because of the inability to detect if miter gates closed properly without the automated interlock controls. This system is manpower intensive requiring an operator to be present at each gate station.

(2) Computer-based control systems. With current technology, operating systems for navigation locks can be designed using computer hardware, software, electronic visual systems, and fiber optic networks to operate a complete lock and dam from a central control station with one operator. The present design of operating systems for navigation structures is moving in this direction. However, since this ultimate system has not been fully installed, the performance and safety of this system has not been measured. The design for navigation structure control systems should ease into this new technology with a blend of computerized systems backed up by the traditional system that allows control from local stations for emergencies and maintenance.

(3) Semiautomatic control system. A computer-based, semiautomatic control system has the capability to allow an operator to control one or two locks and a gated dam from one location. The following system is used at Melvin Price Locks and Dam on the Mississippi River and reflects the state of technology at the time of installation in 1992. This installation is more completely described in Appendix C. Control systems based on this concept use computers networked to programmable logic controllers (PLC's). Monitoring the lock project for both operational and security purposes is accomplished through closed circuit television (CCTV). A video and computer network link can be established with district or regional control centers for rapid communication of important developments. A semiautomatic control system can control a complete lockage through the initiation of several control sequences. The operator initiates the sequence through computer monitors and receives computer-generated feedback that prompts the operator through the complete sequence of a lockage. A manual mode provides individual operation of any piece of machinery from the central control console via a computer keyboard. Local control can be provided from control stations on the lock walls. In the manual and local control modes, all interlocking functions can be maintained, since control logic is still performed in the PLC. In the event of PLC failure, hardwired emergency controls can be provided for continued operation. A computerized, hierarchical graphics display system can provide supervision of equipment status and can alert the operator to equipment malfunctions (see Figure 11-1). The operator can select, in increasing levels of detail, computer-generated graphic displays of systems or subsystems. The last level of detail in the graphics system is operation and maintenance

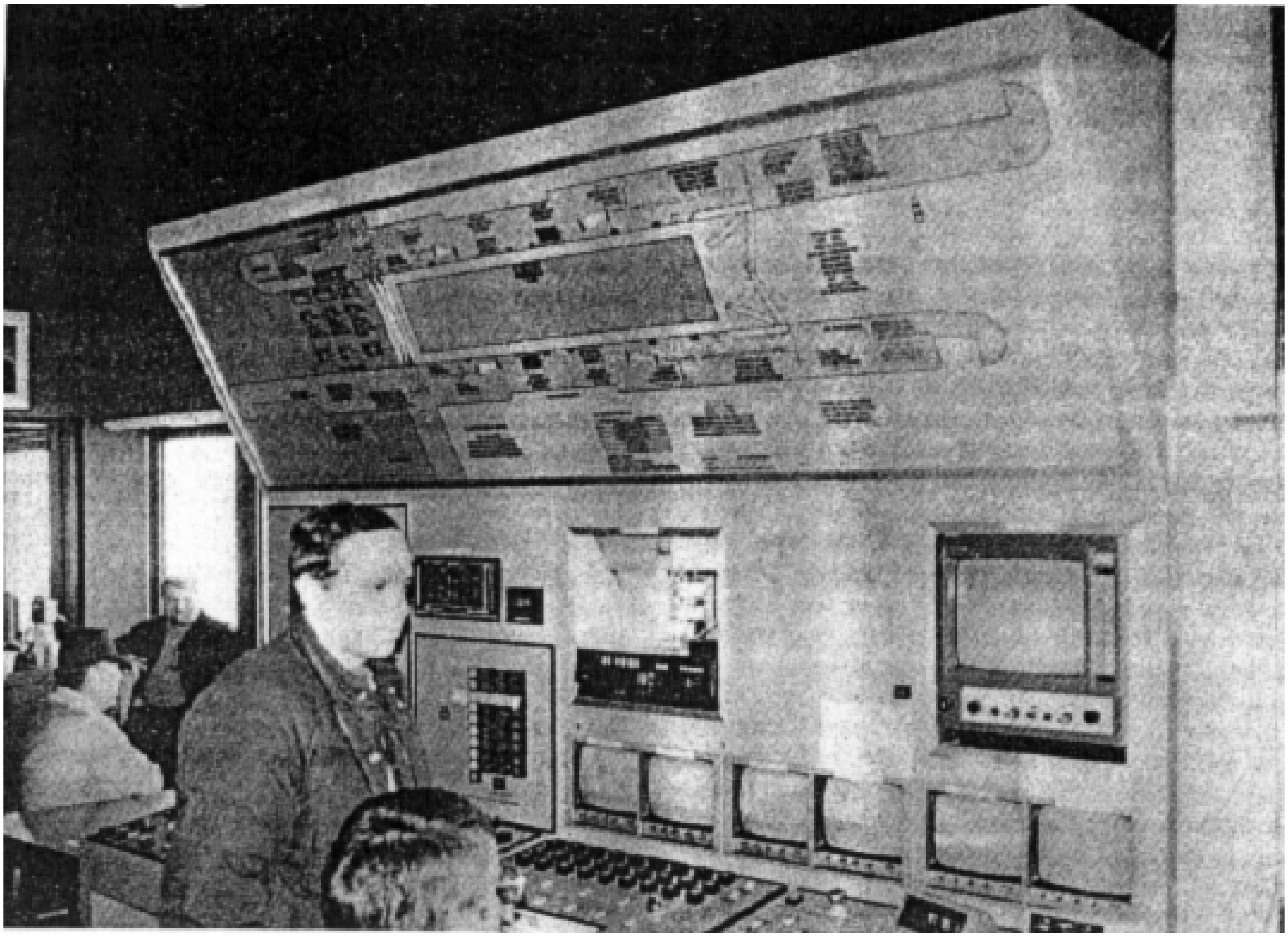

Figure 11-1. Graphics display system

information which can be output to a printer for rapid response to equipment failure. Daily, weekly, or scheduled maintenance and testing functions can be displayed and checked off when completed in the computer data base.

(4) Central control system. At Melvin Price Locks and Dam, the control of the entire facility will be accomplished by a network of distributed intelligence. A complete, independent PLC system will be used to control each lock (the main lock PLC will also provide remote control of the dam). The PLC's will gather and monitor data, perform logic and interlocking, and actuate equipment and devices. Each PLC will be directed by a series of personal computers (PC's). The PC's will communicate directly with the PLC's. The PC's will function as an operator interface, operate as a host to several algorithms for control, and will provide executive control of the PLC's. A PLC lockout system is provided at the central control console to prevent inadvertent operation of the system when the console is unattended. In the event of PLC malfunction, hardwired backup controls located at the local control stations can be used for continued operation. This system architecture will provide redundancy, reliability, and minimal impacts because of equipment failure. All lock gates, navigation approaches, lock chamber operations, and project areas will be monitored electronically at the central control house through CCTV, sound systems, and surveillance systems.

(5) Data acquisition. Using this system, data acquisition can be computerized for real-time inputs for lockage data, weather and river information, lock conditions, tow information, and all other system information. These data can be accessed at remote locations such as district offices, regional control centers, and other locks in the system.

(6) Command and control. River discharges, pool elevations, and gated spillways can be controlled from the computerized system, either at the project site or at a remote location such as a regional control center for several locks in a navigation system.

(7) Advantages and disadvantages. The semiautomatic system as described is based on present technology and has been implemented at the Melvin R. Price Locks and Dam on the Mississippi River. This system is economically advantageous with estimated operational savings of approximately $4.5 to $8 million over the life of the project. This system can be incorporated into the automated operation of several locks in the Upper Mississippi River project as additional locks in the system are modernized.

(a) Advantages. Computerized control systems offer certain inherent advantages over electromechanical relay systems. They are extremely flexible and can accommodate radical changes to control philosophies through simple programming changes. They offer the ability to develop complex control algorithms capable of executing complex instructions such as those required to automate pool levels. The computer systems used for the automated controls can also function as a convenient storage device for large databases, such as navigation data, operation procedures, equipment descriptions, maintenance instructions, and performance information.

(b) Disadvantages. The disadvantage to the operation of computer systems is the learning curve necessary for the lock personnel to operate and maintain the system, along with the associated computer literacy skills. Other disadvantages of computer systems involve human factors such as the difficulty in adjusting to remote interfaces that do not allow direct visualization of lockages. These systems are also more complex and require higher skill levels to maintain, although operationally they may provide more comprehensive operational command and control.

b. Surveillance, communication, and security systems.

(1) Centralized control with closed circuit television (CCTV) and radar. The automated systems described above are designed to operate the locks with a minimum of lock operating personnel (one in the control house, the other roving the structure). Therefore, while the centralized control station should be located to take advantage of direct visibility, it should be with supplemented electronic visual information. The CCTV should be strategically located to allow views of the entrance and egress of all navigation as well as the critical areas within the lock and dam. The CCTV should monitor all lock and spillway gate operations. Provisions should be made for the operator to exit to the local control stations should the CCTV equipment malfunction. Radar systems should also be considered to monitor navigation or barges during fog or low-visibility conditions.

(2) Signal and communications systems. Signal and communication systems need to be provided and should consist of the following components:

(a) Navigation traffic light signals to control movement of the vessels in and out of the lock.

(b) Strobe lights for recreational vessels to request a lockage.

(c) Public address system for communication around the complex and between the lock operator and persons on vessels in the lock.

(d) Horn signals for alerting persons on tows or recreational vessels. Sirens, if necessary, to signal opening of culvert valves. An emergency howler to alert lock personnel for emergencies.

(e) Portable communication walkie-talkies for communication with personnel around the navigation complex.

(f) FM and marine band radio equipment for communication with land stations and marine navigation.

(3) Security and surveillance systems. A plan should be developed for security of the installation, especially if a minimum of lock operating personnel are present. Security systems can consist of security fencing with remote electronic monitoring, alarm systems, motion detectors in sensitive areas, CCTV surveillance systems, sound monitoring of visitor areas, elevators and access points, and gated entry points operated from the control house. All security systems need to be controlled and displayed from the central control house. Emergency alert stations should be provided at strategic places on the lock structures.

c. Ice control measures. Although ice presents a difficult design problem, several design and operation features can improve the efficiency of lockages during icy conditions. While improving efficiency of lockages during ice conditions, these measures carry a penalty of higher cost and increased mechanical and operational complexity.

(1) Lock gates. At locations with dual locks or locks in a canal, submersible lift gates have been provided at one or both locks to pass ice over the top of the gates. The lift gates are mechanically more complex and not as economical as miter gates; however, they perform better in ice conditions. The floating ice in the approaches or ice being pushed by the tow can be flushed over the top of the lift gate and out of the lock chamber with the lower gates open. For a lock with miter gates, the ice has to be locked through with the operation of the miter gates being impeded by the floating ice. To operate miter gates with heavy floating ice generally requires the use of the prop wash from a switch boat to move the ice out of the miter gate recesses through the lock chamber. Projects that have dual locks of the same size present an ideal situation for handling ice. The land lock would have upstream miter gates while the river lock has a lift gate upstream. During normal operation, the land lock would be used for downbound traffic as the pilots prefer to remain close to the bank for downbound approaches. During icy conditions, the river lock would be used for downbound because the tow would push the ice in front over the lift gate to be flushed downstream. The land lock would be used for upbound as the tows would be exiting the lock pushing the ice on upstream away from the lock. The downstream approaches are generally free of ice below the spillway. The river lock with the lift gates requires a higher sill to recess the lift gate. The land lock can have a lower sill to allow the passage of emergency floating plant in case of loss of pool.

(2) Spillway gates in separation between locks. If the dual locks are separated, then spillway gates can be provided in the separation to keep floating ice flushed form the upstream approaches. The separated locks with controlled flow between the locks have the further advantage of aligning the flows parallel with the lock, thus reducing outdraft into the main dam. In addition, if the locks are separated sufficiently, then the tow can take advantage of simultaneous approaches and departures.

(3) Bubbler systems. High-volume air bubbler systems placed in gate and floating mooring bitt recesses can remove floating ice from these areas and also prevent ice from forming on the surfaces. Large-volume compressed air barriers have been installed in the approaches to Melvin R. Price Locks to shunt the ice from the approach into spillway gates in the gated dam in the separation between the locks. This type of system functions by raising the water with a compressed air curtain that creates a current away from the approaches to remove the floating ice from the approaches.

(4) Ice booms. Ice booms have been used to keep ice out of the approaches; however, these booms have to be moved, or an opening should be provided to allow passage of tows.

(5) Trickler systems. Trickler bubbler systems installed along the lock walls, recess, and gates at the lock floor elevation can raise water from the bottom of the lock that is one or two degrees warmer to prevent ice from forming on the surfaces.

(6) Copolymer coatings. The Cold Regions Research Laboratory (CRRL) has proposed the use of copolymer coatings on lock walls and lock miter gates to prevent ice buildup. The coating prevents ice adhesion to the wall. Because the Corps has not tested this application, CRRL should be contacted for information on this application.

(7) Miter gate recesses. Deeper recesses in the lock walls can be provided to allow room for the gates to open with ice or debris trapped in the recess. However, to fit the culverts, machinery, and galleries, this feature requires wider lock walls at the gate bay location.

(8) Heating elements. Heating elements can be used for gate and floating mooring bitt recesses. These elements can be embedded in the wall or on the steel gates and bulkheads. Steam systems have been successfully used to remove ice loadings from gates and walls.

11-3. Design for Safety

Safeguards should ensure that people who use, operate, or visit the navigation facility can do so without risk of personal injury. All possible measures should also be taken to minimize accidents and effects of accidents due to tow entrance or egress. All designs should be in compliance with EM 385-1-1 and OSHA safety standards.

a. Emergency barriers. Emergency barriers are devices that prevent barges from impacting the lock operating gates. These barriers can be composed of large steel cables or chains with counterweights on either end. When a ship or tow strikes a barrier, the kinetic energy of the barge is changed to potential energy by lifting the counterweight or compressing the shock absorber. Emergency barriers have been provided at locations where damage to or loss of gates would result in catastrophic consequences. Although used for deep draft locks (St. Lawrence Seaway and the Sault Ste. Marie Locks), a feasible emergency barrier has not been devised for inland waterway locks for raked shallow draft barges. In January 1978, a study was conducted for the Bay Springs Lock and Dam by the Nashville District of a rope cable barrier system. This study concluded the following:

(1) A tow could strike the barrier from underneath when the lock chamber is being filled. If the tow strikes the barrier at that time, the tow could sustain damage, destroy the barrier, and endanger the life of anyone on the tow. The same dangers could be present for a tow in the lock chamber when the lock is being emptied if the tow should hang in the ropes of the barrier.

(2) The cost of the barrier system could be better invested in improving the miter gates for preventing tow collision and providing spare units to replace any damaged portion of the gates.

b. Accidents involving barges. The design should incorporate an emergency plan of action for accidents from out of control barges impacting the structure. This plan should address emergency removal of sunken barges from the lock and dam structures. Equipment such as overhead cranes and floating plant with emergency procedures must be available to quickly remove these obstacles and restore the function of the structure. Heavy floating plant and cranes intended to service several lock projects may be located at a central location. Thus, in case of loss of pool, sufficient depth (8 ft or more) should be provided over the upper and lower sills to allow passage of the floating plant from a remote site. In addition, if a barge-mounted derrick crane is intended to service several projects, access to both the upstream or downstream end of the lock must be provided when the lock is obstructed and passage through the lock is impossible. Recommendations developed after the incident in 1967 at the Markland Lock and Dam on the Ohio River provide useful guidance to be considered during design (see Appendix D for detailed recommendations).

c. Accidents involving hazardous cargo. Plans should be developed to prevent, contain, and clean up spills from hazardous or HTRW. These plans should address emergency operations and evacuation of personnel and public. Provisions should be made to contain hazardous material in the event of a spill. A lock and dam project should be constructed to contain spills which occur either in the pool formed by the project or in the lock approach or lock chamber. Operating procedures should be developed for containing and collecting the spill material. Plans should be developed in coordination with other agencies.

d. Fire protection systems. A high volume, raw water pumping and piping system should be provided to all parts of the lock and dam structures. This system should provide water to extinguish small fires and provide water for spray systems to cool the lock gates in case of fire in the lock chamber. For projects that handle a large volume of traffic containing petroleum or other flammable material, special equipment should be considered to extinguish or control a fire in the lock chamber. Fire fighting and evacuation plans should be developed and coordinated with local officials for major emergencies caused by fire, explosions, or hazardous spills. Evacuation plans for surrounding public should be developed with the local agencies. See EM 1110-2-2608 for additional information.

e. Instrumentation. Instrumentation is provided to monitor the safety performance of lock structures. Special instrumentation may be provided to verify design assumptions and to provide data for research and development needs. Instrumentation requirements are covered in EM 1110-2-4300. The design for lock instrumentation, including automation of data collection with and schedule of readings, will be presented in a design memorandum. Instrumentation should be designed to monitor the lateral, vertical, and rotational movement of the lock monoliths. The movements should be correlated with the change in loading conditions (change in pool, tailwater, and uplift conditions). The degree of sophistication that can employed in the design will depend on the project site conditions. The types of instrumentation based on an automated data acquisition system (ADAS) that can be provided are as follows:

(1) Piezometers. Piezometers are necessary to monitor the uplift pressures beneath the lock structures during the service life. Piezometers can be the open-system type with stainless steel wire-wound well screens that are fitted with a vibrating wire pressure transducer to permit water level monitoring with the ADAS. Other piezometers can be designed to be monitored manually with a portable water level indicator.

(2) Inclinometers. Inclinometers installed in casings in selected lock monoliths monitor the lateral movement of the monolith through the service life. The inclinometers should be terminated in rock or deep enough to record zero movement. The inclinometers can be monitored using a cable-supported probe which is lowered in the casing and retrieved at 2-ft increments as the slope angle of the casing is measured.

(3) Trilateration target points. Trilateration target points can be mounted on the top of each lock monolith to monitor horizontal movements of the top of the lock using electronic distance measuring survey equipment. Coordinates of the points on the lock can be measured relative to fixed benchmarks located off the structure. Satellite global positioning systems (GPS) are being investigated for use as trilateration points.

(4) Tiltmeters. Biaxial tiltmeters can be mounted in galleries in the lock monoliths to monitor rotation of the lock monoliths during the service life. Tiltmeters can consist of permanently mounted biaxial servoaccelerometer devices which can be monitored with the ADAS or manually.

(5) Monolith joint indicators. Several types of monolith joint indicators can be used to monitor relative movements of adjacent lock monoliths. These types are manual and automatic devices. Manual devices can consist of the steel ball, shim, and feeler gage devices, and the surface reference bolt system monitored with a reference beam dial gage indicator. Automated devices connected to the ADAS can consist of linear motion potentiometers and direct current differential transformers. The transformers are the preferred automated devices.

(6) Inverted pendulum. Lock displacements can be monitored manually by trilateration and inclinometers. To make an automatic measurement of lock displacements, an inverted pendulum with an automatic monitoring system connected to the ADAS can be installed.

(7) Sounding wells. Sounding wells can be provided through the pile founded lock structures to monitor vertical displacement of the foundation materials below the structure.

(8) Seismic instrumentation. Seismic instrumentation in seismically active areas can also be a project requirement. This instrumentation can be connected to the ADAS.

(9) Automated data acquisition system (ADAS). An ADAS should be considered to automate the reading, recording, and evaluation of instrumentation data. The ADAS can be used to monitor the vibrating wire piezometers, biaxial tiltmeters, inverted pendulum, monolith joint movement indicators, and seismic instrumentation. These transducers can interface with the ADAS using a controller mounted on the lock structure. The controller can connect to water level transducers to read simultaneous pool and tailwater levels. In addition, water and air temperatures can also be recorded. The ADAS can be located at a remote site such as the district office or in the project central control house.

11-4. Design for Maintenance

a. Selection of materials. In general, materials should be selected for a minimum life cycle cost. Critical components (something that could cause lock shutdown for long periods to unwater and repair) should first be designed for long-term reliability. Critical components should also be designed for easy replacement.

(1) Concrete. Where concrete surfaces are subject to underwater abrasion, design alternatives should consider the use of polymer reinforced and resistant aggregate concretes. Concrete surfaces should be designed to minimize damage from ice and snow. A plan for snow and ice removal should be developed that does not include the use of corrosive deicers. The design should consider heating elements and openings on top of the lock walls to push snow through. Openings in handrails and parapets should also be provided for snow removal. All concrete surfaces should have adequate sloping surfaces for drainage. All structures that can pond water should have appropriate drain holes provided to remove moisture. Joints should be designed to prevent freeze-thaw spalling of concrete or attack from abrasion of rubbing barges.

(2) Metals. All designs for structural steel gates, bulkhead, valves, and other steel items should be reviewed to ensure that adequate drain and air escape holes have been provided. Any place where water may collect and pond should be drained. Gates that are submerged should have adequate air release holes to prevent any tendency for floatation during submergence. The use of corrosion-resistant (not plated) steel is encouraged for hydraulic piping, submerged items such as floating mooring bitts, and high-maintenance steel items that are difficult to access without shutting down and unwatering the lock. Special attention should be given to joining dissimilar metals to prevent the potential for cathodic corrosion.

(3) Corrosion protection. A number of different methods to prevent corrosion range from paints to cathodic protection. All of these alternatives should be studied to determine the most appropriate method of protection. This study should address life cycle evaluation of paints, galvanizing, metalizing, corrosion-resistant materials, and cathodic protection.

b. Spare gates and operating equipment. A study should be performed to determine the need for spare gates and operating equipment. If these features are justified, then a plan should be developed for providing spare lock gates, lock valves, spare machinery components, and spare floating mooring bitts to replace components in case of accidental damage. For critical locks, the design should include spares and equipment to complete replacement without the necessity to unwater. The lock must have access to the necessary floating and land-based equipment to facilitate the replacement of the components. In addition, the high-cost components should be designed so that the broken part of those components can be replaced at low costs or sacrificial items can be designed into the linkages. Components for several locks on a navigation system should be standardized so that parts are interchangeable. The plan developed for spare gates and operating equipment should be presented in the feasibility report or a design memorandum.

c. Lock unwatering. A plan for unwatering the lock chamber, gate bay, or culvert valve should be developed and presented in a design memorandum. In general, locks need to be capable of being unwatered for inspection and maintenance to an elevation which will not be exceeded by a 10 percent frequency for tailwater stages with freeboard sufficient both for swellhead and wave heights. Site-specific conditions may require deviation from these criteria. Built-in submerged pumps for unwatering should not be installed as they present long-term reliability problems. Pumps can be designed into the structure to facilitate the unwatering operation. A semicircular or box-type cofferdam that can be placed against the lock wall and unwatered to inspect and repair localized areas should be considered as equipment for unwatering.