운하계획에서의 갑문설계의 중요성
(THE IMPORTANCE OF LOCK DESIGN FOR NAVIGATION WATERWAY)

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INTRODUCTION

Locks are the most important features of a navigation waterway. A good lock design will provide a properly functioning waterway and allow the smooth flow of vessel traffic. The design goal for a modern inland waterway, as stated by McCartney(1986), is to provide a navigation project that is safe, efficient, reliable and cost effective with appropriate consideration of environmental and social aspects, safety, efficiency, and reliability should be achieved before cost is optimized. Another goal of the design is to provide an environmentally compatible project where adverse impacts are avoided or minimized.

This paper will focus on the importance of safety, efficiency and reliability for a navigable waterway and how a good lock design can achieve these goals.

SAFETY, EFFICIENCY AND RELIABILITY OF THE WATERWAY SYSTEM

The safety of the waterway system relates to minimizing vessel collisions with other vessels, lock walls and gates, and other structural features(bridges, port facilities, etc.). Vessel accidents create three problems; First, the cost to repair the vessels and structures impacted. Second, the waterway may be closed down until the vessel is removed and the navigation structure is repaired. If a lock gate was damaged, a repair or replacement might take weeks or months. Thus a large loss to revenue would results. Third, a vessel accident might result in an oil spill or discharge of other hazardous material into the waterway. This can cause serious environmental harm and the waterway could be closed until clean up is completed.

Efficiency of a waterway is very dependent on the lock design. The lock approach must be designed to allow smooth lock entry and exit without delays. Waiting areas need to be close to the lock to speed vessel passage. The lock needs to be large enough to avoid the need to breakup a tow which would require two lockages with breakup and reassemble of the tow. The filling system needs to fill and empty rapidly to avoid delays. The gates need to open and close rapidly. If two or more locks are located at the same site, their layout should allow no interference of traffic

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when two locks are in use.

The final design goal is reliability. Lock approaches should be kept ice and sediment free. Lock gates should operate with a minimum of repair and down time, and lock guide walls and chamber walls should be able to resist vessl impacts with no damage. Concrete guide walls and chambers are preferred for the waterway system in the U.S.A. because of their durability and reliability. Figure 1 shows common lock features for a lock with culverts in the side wall(U.S. Army Corps of Engineers, 1995)

LOCK DESIGN

The design of a lock typically involves the following:

- Site Selection
- Development of layout for approach channel an guide walls
- Selection of filling and emptying system
- Selection of type of gates

Site Selection

Some good guidance on the siting of locks is contained in U.S. Army Corps of Engineers Engineering manual EM 1110-2-1611(1980) as summarized below:

Navigation conditions in the approaches to locks placed in a flowing stream will depend largely on the alignment of the channel and channel configuration upstream and downstream. It is important that currents approaching the lock be slow to moderate and reasonable straight within the approach for a considerable distance upstream. Generally, the lock should be sited where downbound tows can complete any change of direction and become properly aligned for the approach before having to reduce speed. Also there should be sufficient site distance to preclude the danger of collision or interference with other traffic and to permit the tow to maneuver as required for the approach. These requriements indicate the need for locks to be located in reasonable straight reaches.

This siting criteria can be summarized as follows:

- Locks should be sited in straight channel reaches.
- Currents should be slow to moderate with no cross currents.
- Tows should have sufficient approach channel length to become aligned with the lock guide walls before having to reduce speed
- There should be no interference from other traffic while the tow is maneuvering in the lock approaches.

The consequences of a poorly designed site layout reduces waterway capacity because of excessive maneuvering time in lock approaches and potential waterway closure for accident clean up. Rectification of a poor site design is usually relocation of the lock to a more favorable location. The cost of relocation usually exceeds the original lock construction cost.

Approach Channel and Guide Wall

The second critical element in the design of the lock approach is the location and length

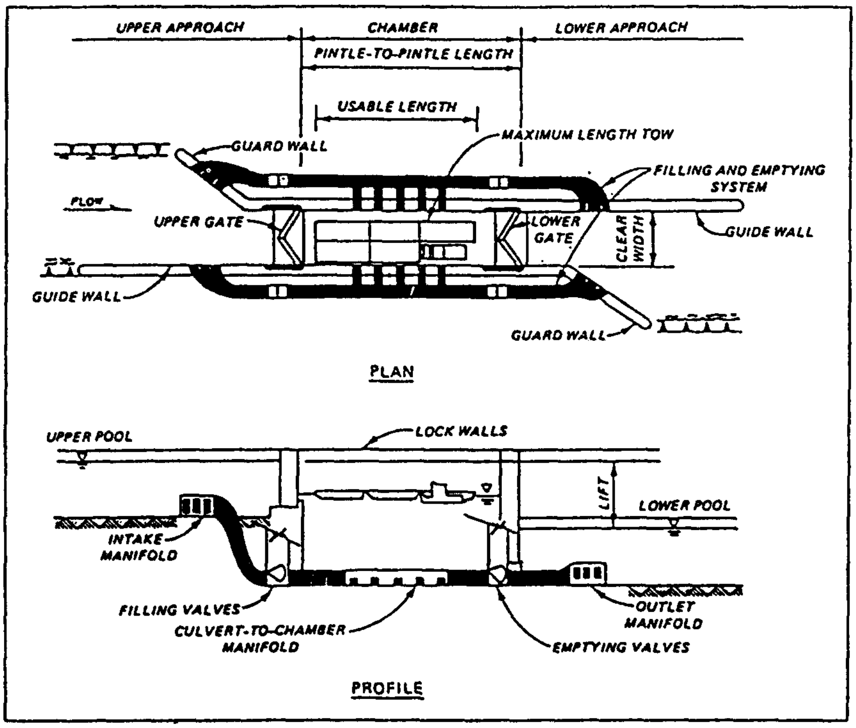

Figure 1. Common lock Features for a Lock with Culvert in the Sidewall (Source : U. S. Army Corps of Engineers, EM 1110-2-1604, 1995)

of the guide wall. The function of the guide wall is to allow the tow to become aligned with the lock chamber so lock entry is smooth and rapid. General design criteria for guide walls have been developed by U.S. Army Corps of Engineers(1980) as summarized below.

Navigation conditions within the upper approach to a lock can affect the safety of tows approaching or leaving the lock and the time required for tows to transit the lock. Conditions for downbound tows can be particularly hazardous if high current velocities and crosscurrents prevail. Properly designed guard and guide walls can assist tows in approaching and leaving the lock. Locks with long guide walls and short guard walls will tend to develop crosscurrents near the end of the guard walls. The intensity of the effects of crosscurrents can be reduced or eliminated by providing ports in the upper guard wall, by reducing velocities in the approach channel by means of structures, or by extension of the guard wall using cells. Conditions in the upper approach can also be affected adversely by the alignment of currents upstream if the guard wall and uneven channel depths in the lock approach. Examples of guide and guard wall configuration for two adjacent locks are shown in Figures 2 and 3.

The design of a good lock location and approach condition will usually include the use

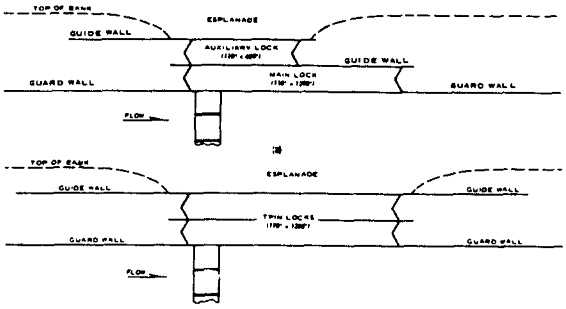

Figure 2. Arrangement with Adjacent Locks (Source : U. S. Army Corps of Engineers, EM 1110-2-1604, 1995)

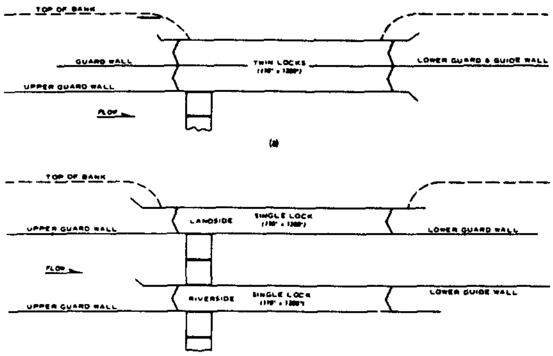

Figure 3. New Concept in Lock Arrangement (Source : U. S. Army Corps of Engineers, EM 1110-2-1604, 1995)

of physical hydraulic models or vessel simulators. These models will identify potential navigation problems and evaluate site modifications before a construction commitment is made.

Another important design cosideration for the lock layout is the location of a second lock if additional locks are needed in the future. The addition of locks at a future time is discussed in U. S. Army Corps of Engineers(1995)

In the initial development stage of a waterway transportation system, common practice has been to provide one chamber at each project; then, as traffic increased, additional chambers have been added. For a new project on a developed waterway, where traffic patterns are well-established and continued growth is assured, two or more chambers may be initially justified on an economic basis. A need for continuous operation may lead to double chambers since, in the event of outage of one lock, essential traffic can be handled on a priority basis. In redevelopment of the Ohio River system, a minimum of two locks have been provided at each of 19 locations.

If two or more locks are anticipated at one site but, initial construction is for a single lock, the initial design should consider location, approaches and construction method for the additional locks.

Filling and Emptying System

The third design consideration for a navigation lock design is the type of filling and emptying system. The goal of a good filling/emptying system is to fill for empty rapidly with a minimum of turbulence. The U.S. Army Corps of Engineers(1980) recommends filling or emptying in 6 to 12 mimutes and recommends the following systems to achieve this goal.

Lock Life, Feet	Filling System
0–10	Front end(section gate or lock culvert)
10–40	Side Port
over 40	Bottom Longitudinal

Sketches of the filling systems are shown in Figures 4, 5 and 6.

Type of Gate

The fourth design consideration for a lock is the type of gates.

A list of gate types that have been used or considered for lock follws:

- Miter gate
- Submerged vertical-lift gate
- Overhead verical-lift gate
- Submerged tainter gate
- Vertical axis sector gate
- Rolling gate
- Tumbler gate
- Rising sector gate

A detailed description of these gate types is provided in the U.S. Army Corps of Engineers, EM 1110-2-1604 (1995)

Gate selection is based on several factors, which include:

- Lock lift (this effects gate height)
- Reversing head or one directional head on gate
- Type of filling system

Some examples of how these factors influence gate selection follow:

High lift locks could use a overhead vertical lift gates but low lift lock would not have enough clearance for tows to pass under the gate.

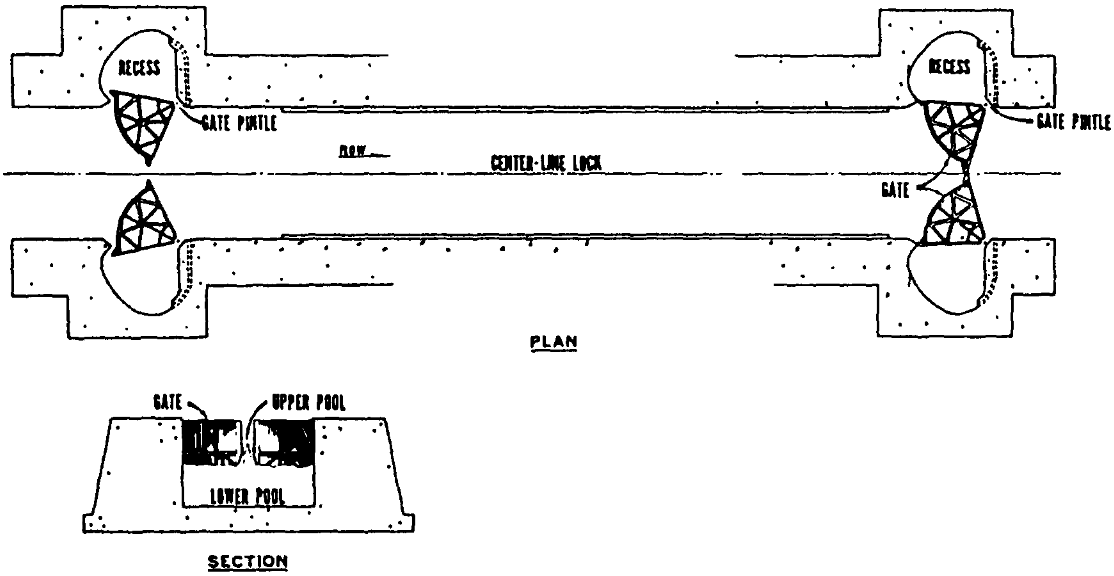

Figure 4. Sector Gate
(Source : U. S. Army Corps of Engineers, EM 1110-2-1604, 1995)

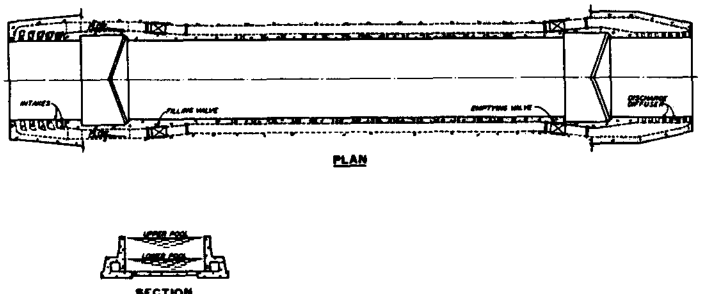

Figure 5. Sidewall Port
(Source : U. S. Army Corps of Engineers, EM 1110-2-1604, 1995)

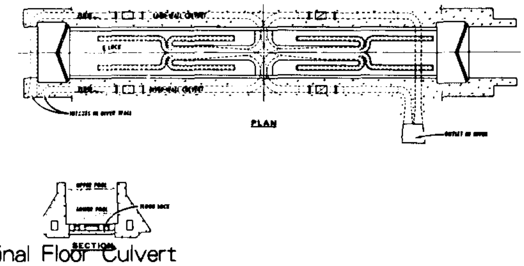

Figure 6. Logitudinal Floor Culvert
(Source : U. S. Army Corps of Engineers, EM 1110-2-1604, 1995)

A lock with reversing heads could use a sector gate, submerged vertical lift, rolling gate or rising sector gate. However, the miter gate would not be appropriate because it resists hydraulic loads from only one direction.

An end filling lock would use a vertical axis sector gate or a rising sector gate because these gates would provide symmetrical flow into the chamber which minimizes turbulence.

CASE HISTORY, NEW BONNEVILLE LOCK

A case history is provided below for the recently constructed Bonneville replacement lock. This case history is taken from McCartney and others(in preparation).

Description : The new lock at the Bonneville Dam project is located on the Columbia River about 40 miles east of Portland, Oregon. The lock dimensions match the 7 upstream locks on the 450 mile long Columbia-Snake River navigation system. This lock replaces the original (1938) which was the first lock on the system with chamber dimensions of 76 feet wide and 500 feet long.

Pertinent Data :

-Lock useable length:	675 feet
-Lock width:	86 feet
-Maximum lift:	70 feet
-Design tow:	84 feet wide, 660 feet long, 14 foot draft.

Lock Filling System :

The filling system is a bottom longitudinal type with four discharge conduits in the chamber (tuning fork configuration).

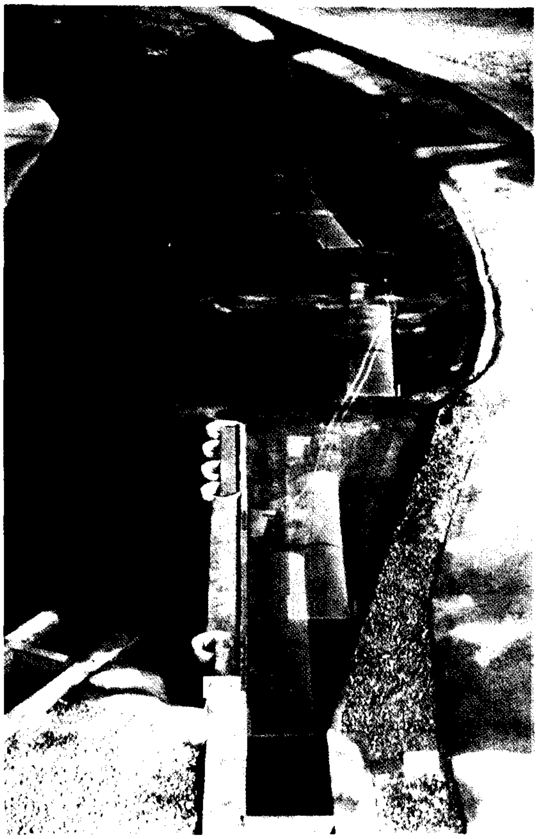

Photo 1. Bonneville Lock, Model of downbound tow in upper approach.

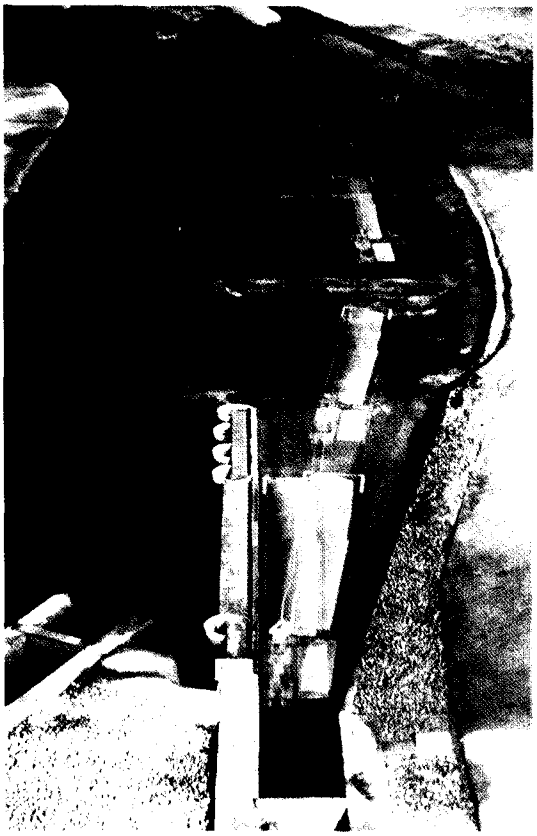

Photo 2. Bonneville Lock, Model of upbound tow in upper approach.

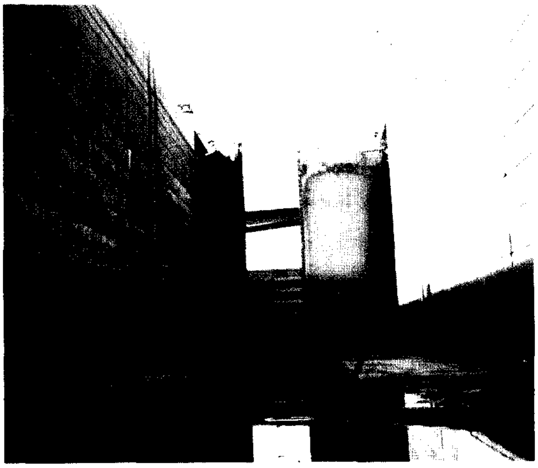

Photo 3. Bonneville Lock, Inside Lock chamber lookibg upstream.

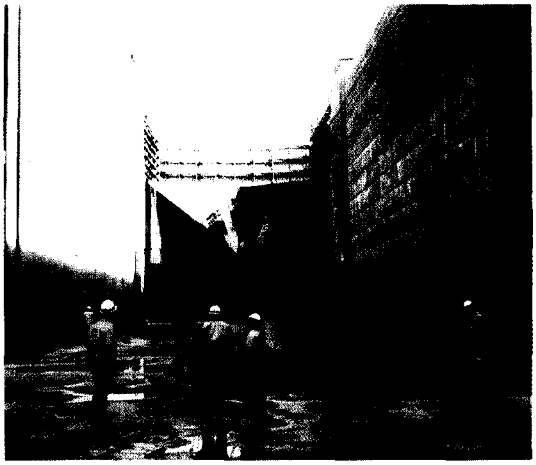

Photo 4. Bonneville Lock, Inside Lock chamber looking downstream.

The filling conduits between the filling valves and discharge conduits are mined through rock on each side of the chamber. Fill and empty times are between 8 and 12 minutes.

Construction Chronology:

-Relocate 1/2 mile of railroad track
July 1986 Aug 1987
-Initial lock excavation 1 mill cy of rock
July 1987 July 1988
-Upstream Guardwall and Prehistoric
-Landslide Stabilization
April 1988 April 1989
-Lock Construction
Sept 1988 March 1993
-Open to Traffic
March 1993

Project cost: $330 million US including design cost

Models Used for Design:

-General Navigation, 1 to 80 scale
-Lock fill and empty, 1 to 25 scale

Unique Features:

-Upstream approach currents up to six ft/sec. Powerhouse flows create high velocities in the confined channels shared with the lock.

-A series of upstream submerged groins were used to reduce velocities in the lock approach. Groin dimensions and location were determined in the general navigation model.

-Upstream guardwall (land side wall) also was used to stabilize a prehistoric landslide zone. Tendons were used to tie wall into good rock in hillside.

-Upstream guidewall was made up of floating pontoons connected to sheet pile cells. One 400 foot long pontoon was not fixed to cells but allowed to float in slots in the cells. The floating pontoon was needed to reduce currents under the pontoon which would pin the tow to the wall at low pools. This tow pinning problem was discovered in model testing.

-Lock was located in a large rock formation. This allowed the walls to be attached to rock with rock bolts. The fill and empty conduits are mined through the rock instead of being located in a gravity wall section.

Project Performance:

The lock has operated as designed with no accidents. The tow boat operators are very pleased with the ease and speed of lock transit.

APPENDIX Ⅰ. REFERENCES

McCartney, B. L. 1986, "Inland Waterway Navigation Project Design," Journal of Waterway, Port, Coastal, and Ocean Engineering, ASCE, Vol. 112 No. 6.

"Hydraulic Design of Navigation Locks," 1995, EM 1110-2-1604, U.S. Army Corps of Engineers.

"Layout and Design of Shallow-Draft Waterway," 1980, EM 1110-2-1611, U.S. Army Corps of Engineers.

McCartney, B. L., George, J., Lee, B. K., Lindgren, M., and Neilson, F. "Inland Navigation; Locks, Dams and Channels," Manual and Reports on Engineering Practice. ASCE. (in preparation)

Photo 5. Bonneville Lock, Prototype view of upper approach near end of construction.

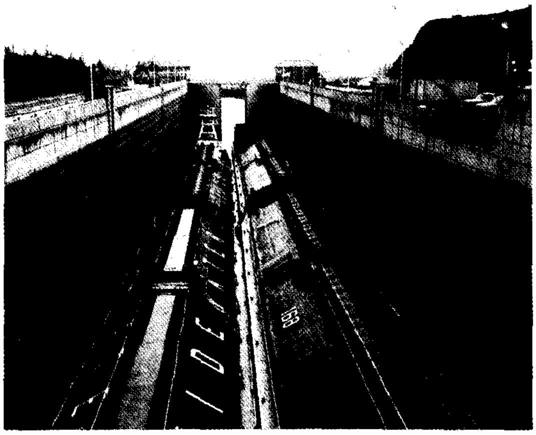

Photo 6. Bonneville Lock, Tow in Lock chamber looking downstream.

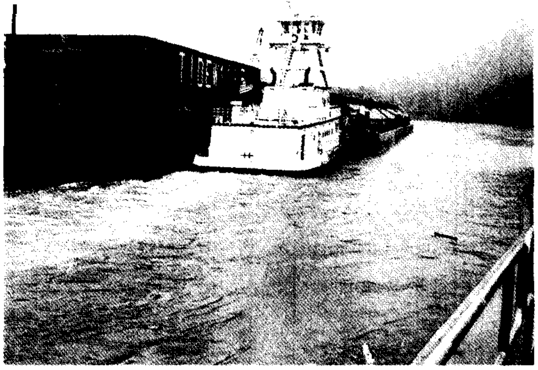

Photo 7. Bonneville Lock, Tow headed upstream.