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MODIFICATIONS TO FILLING AND EMPTYING SYSTEM OF LOCK NO. 1, MISSISSIPPI RIVER MINNEAPOLIS, MINNESOTA

Hydraulic Model Investigation

by

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Final Report

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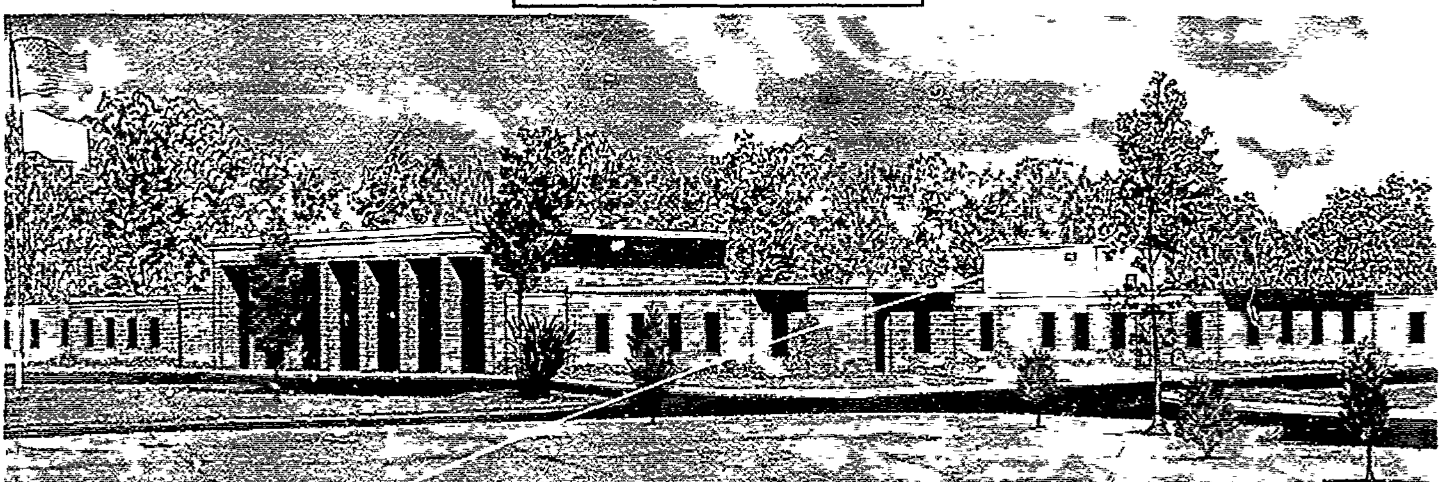

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The existing locks at Locks and Dam No. 1 were constructed between 1929 and 1932. Problems have been experienced with accumulation of ice and debris at the intakes, air entrapment in the culverts of the filling and emptying system, excessive turbulence in the lock chamber during filling, and hazardous conditions downstream from the locks during emptying operations. Also, the stoney gates used for control of filling and emptying, the miter gates, and miter gate operating machinery are in bad condition.

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20. ABSTRACT (Continued).

> Various elements of the filling and emptying system were developed in a 1:25-scale hydraulic model for use in rehabilitating the locks. Both the landward and riverward locks were investigated and recommended design and modifications were furnished to accomplish rehabilitation of both locks although only the landward lock will be completely rehabilitated. Major modifications to the locks will include constructing new intake manifolds, lowering the roof of the filling and emptying culverts and changing their shape, constructing new sidewall ports, replacing the stoney gates with tainter valves, and constructing new culvert outlets.

With the rehabilitated system, the lock could be filled in 10.2 min and emptied in 10.6 min with a 4-min valve time and a 37.8-ft lift.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army (OCE), on 23 June 1975 at the request of the U. S. Army Engineer District, St. Paul (NCS).

The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period of July 1976 to February 1978 under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the direct supervision of Mr. G. A. Pickering, Chief of the Locks and Conduits Branch. The engineer in immediate charge of the model was Mr. J. H. Ables, Jr., assisted by Messrs. J. V. Hines, D. B. Murray, and C. L. Dent. This report was prepared by Mr. Ables.

During the course of this study, Messrs. S. P. Powell, Bruce McCartney, and H. Keith Snyder of OCE; J. F. Ordenez of the North Central Division; R. B. Fletcher, Joe Schultz, Grant Westall, Stuart V. Dobberpuhl, Chuck Spitzack, Alfred H. Mathews, John Plump, Stan Kumpula, Glen S. Bengtson, and Richard Pomerleau of NCS, and representatives of the Harza Engineering Co. visited WES to discuss test results and correlate these results with design work being accomplished concurrently.

Directors of WES during the conduct of the studies and the preparation and publication of this report were COL G. H. Hilt, CE, COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
feet per second per second	0.3048	metres per second per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
tons (force)	8896.444	newtons
tons (2000 lb, mass)	907.185	kilograms

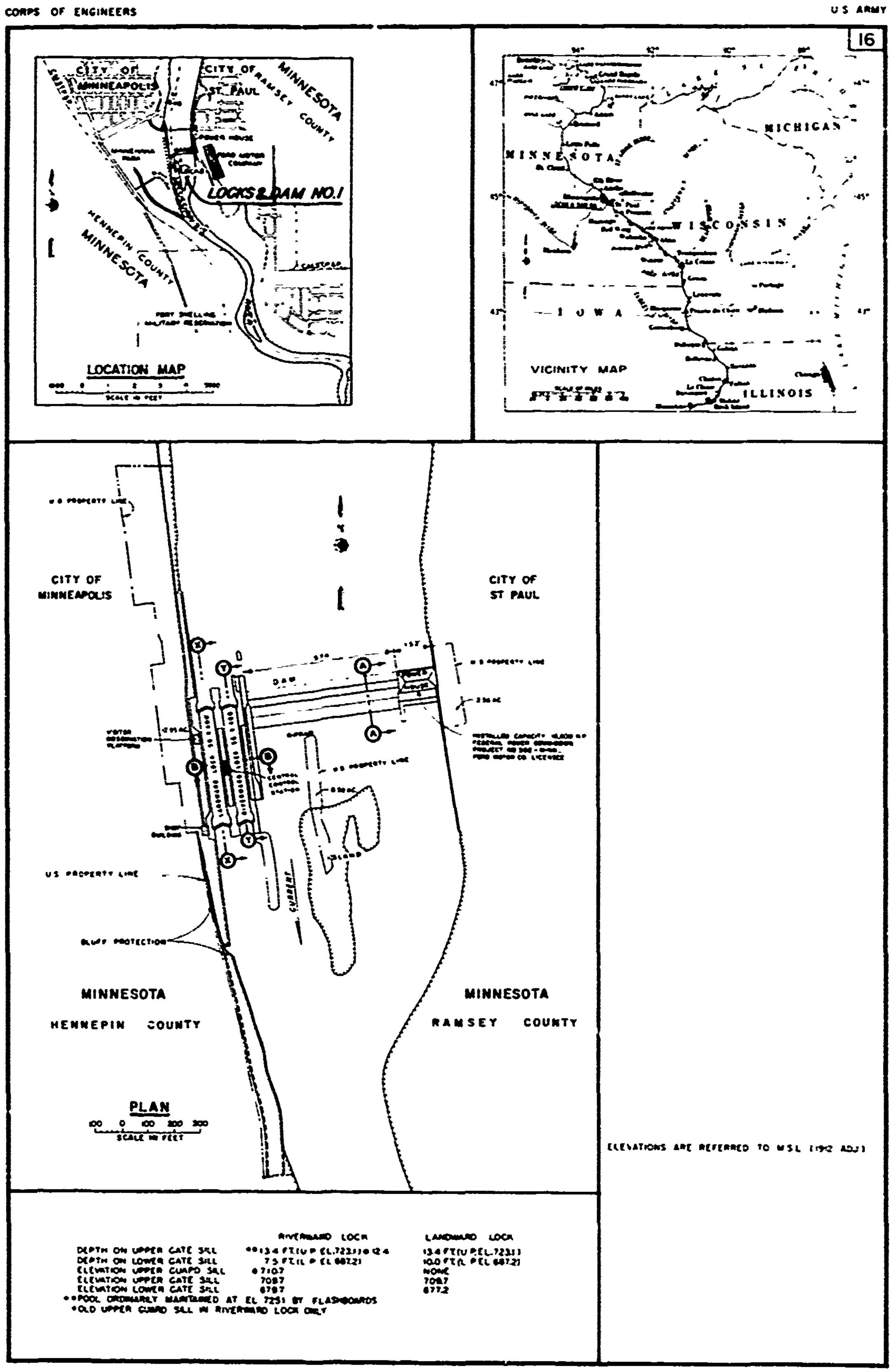

Figure 1. Locks and Dam No. 1

MODIFICATIONS TO FILLING AND EMPTYING SYSTEM OF LOCK NO. 1
MISSISSIPPI RIVER, MINNEAPOLIS, MINNESOTA

Hydraulic Model Investigation

PART I: INTRODUCTION

Present Situation

1. Locks and Dam No. 1 is located at Mississippi River mile 847.6 above the mouth of the Ohio River between the cities of St. Paul and Minneapolis, Minnesota (Figure 1). The project has been included in the Lock and Dam Replacement Program for a number of years. Early reports considered replacement of the entire lock and dam structure. In the interim period, several rehabilitation contracts have restored various components of this structure. Alternatives for rehabilitation of the lock filling and emptying system are now being investigated.* Rehabilitation is defined as any work necessary to extend the life of the structure 40 years without increasing the depth, width, or length of the locks.

General Description and History of Prototype Structures

2. The original structure was completed and placed in operation in 1917 and included a 152-ft-long** hydroplant adjacent to the left bank, a 574-ft-long dam surmounted by 2-ft-high automatic release flashboards and eight sluiceways (of which only three sluice gates are operated and maintained at the present time), and an 80- by 360-ft navigation lock. In 1929 the lock failed, cutting off all barge traffic to

* U. S. Army Engineer District, St. Paul, "Study of Alternatives for Rehabilitation of Lock and Dam No. 1, Mississippi River, Minneapolis, Minnesota," Vols I and II, Apr 1976, St. Paul, Minn.

** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

Minneapolis. To ensure against a future interruption to barge traffic, it was decided to build twin 56- by 400-ft locks at this site. The first lock (riverward lock) was completed in 1930 and the second lock (landward lock) was placed in operation in 1932. A plan and sections of the lock structures are shown in Plates 1-6.

Dam

3. The dam is a concrete structure and for the greater part is supported on an alluvial fill consisting primarily of sand, gravel, and limestone slabs; a portion of the dam and apron, however, is supported on timber piling. Along the upstream face of the dam is a steel-sheet piling cutoff wall; there is also a row of steel sheet piling along the toe of the apron as a preventive measure against scour. The crest and the downstream face have been resurfaced (1949-1953). A major portion of the apron has been replaced and a baffle wall was constructed on the apron to induce a hydraulic jump to overcome serious scour below the dam; this work was completed in 1953. In 1952 the dam was stabilized by placing sand fill in the interior to reduce the possibility of failure by sliding. Three of the eight sluice gates in the dam were rehabilitated and hydraulic machinery to operate them was installed in 1954. Under present pool conditions, the dam maintains a normal head of about 38.0 ft during the navigation season and about 36.0 ft during the winter season. In general, the dam is in good condition.

Riverward lock

4. The present riverward lock was built in 1929 and 1930 to replace the original lock which failed on 19 August 1929. The plan was to provide a structure suitable for 9-ft draft navigation based on the design pool level for Lock and Dam No. 2 which was then under construction. However, due to probable seepage damages, local interests obtained a court order limiting the elevation to which the pool could be raised to 685.7.* Later, in 1934, the court approved the raising of the pool to el 687.2, 1.9 ft less than its designed height. As a result,

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* All elevations (el) cited herein are in feet referred to mean sea level (msl).

there is a depth of only 7.5 ft over the lower sill at flat pool (zero flow) or about 8.0 ft at normal tailwater elevation; hence, the lock has had little use except for an occasional locking of pleasure boats, empty barges, or shallow-draft towboats. The stability of the lock walls, the poor condition of the operating machinery, and the lack of guide walls which makes approaches difficult have also been factors in limiting the use of the riverward lock. Actually in building the riverward lock, the landward wall thereof was constructed of adequate width with two emptying and filling tunnels to serve as the intermediate wall of the twin locks when the second lock was constructed.

Landward lock

5. The present landward lock was built in 1931-1932 as a safeguard to maintain river traffic to and from Minneapolis. As a result of the failure of the original lock, Minneapolis was without barge line service for over a year; and it was determined that a recurrence should be avoided if at all possible. The downstream sill of this lock has a top elevation of 677.2 providing a depth of flat lower pool of 10.0 ft or about 10.8 ft at normal tailwater elevation; hence, the landward lock handles practically all traffic through this facility.

Hydroelectric plant

6. The hydroelectric plant, located at the east end of the dam, and flashboards on the crest of the dam are maintained by the Ford Motor Company.

River Characteristics

7. Lower pool elevation at the site is controlled by Dam No. 2 near Hastings, Minn., and it is also influenced by discharges from the Minnesota River. During the period of 1951-1972, the average tailwater elevation was about 690.0 and the minimum elevation was as low as 686.2. The highest water level downstream of the dam was recorded at 719.0 on 17 April 1965.

8. Upper pool elevation at the site is controlled by the overflow dam and by discharges through the low-level sluices and through the Ford

power plant. During the navigation season, when flashboards on top of the dam are at a raised position, the headwater is kept normally at 725.0. The flashboards on the dam contain shear pins which fail due to ice pressure or high spring flows. During the winter months the water surface in the upper pool will thus be lowered to approximately el 723.0. The highest headwater elevation ever recorded, 734.5, occurred on 17 April 1965.

Major Hydraulic Problems at Existing Locks

9. Four major hydraulic problems exist at Locks and Dam No. 1:

a. Debris at intakes. The intake manifolds for the locks (Plates 2, 5, and 6) are located in the miter gate recesses. During filling, vortices form over the intakes and attract ice and floating debris into the gate recesses. This obstructs complete opening of the miter gates until the debris is removed. Lockages are delayed and under some conditions normal removal of debris can be hazardous.

b. Air entrapment. The crown of the 9.5-ft-diam filling and emptying culverts is at el 690.7 (Plates 3 and 4), 3.5 ft above normal lower pool elevation 687.2. Prior to filling, a layer of air is therefore resident in the level portion of the culverts and also in the sloping portions downstream of the filling valves (Plates 5 and 6). When the filling valves are opened, the inrushing water compresses the air in the culverts and causes pulsating pressures on the downstream valves. Damage occurs to the roller train rollers and guide plates. Loud noises can be heard and vibrations of the lock walls can be felt. Air also enters the culverts through the upper bulkhead slots immediately downstream of the filling valves. There is a venting system in current use, but it is inadequate.

c. Lock chamber turbulence. When the lock chamber is being filled, jets issuing from the adjacent culvert-filling ports flow directly across the lock chamber and meet, causing excessive turbulence. This undesirable condition is further intensified by the size of the 10 ports (3 ft wide by 4 ft high) that are spaced 26 ft on centers in each wall. This results in an undesirable culvert-to-port-area ratio of 1:1.69. The insufficient submergence of the ports (2 ft above the port roof) permits entrapment and entrainment of air in the culvert which when passed into the lock chamber creates a highly turbulent condition.

Some air and entrained water is expelled through the vents. Manipulation of the culvert valves by the lockmaster to lessen turbulence and reduce hawser forces on barge tows significantly increases lock filling time. When pleasure craft or small boats are locked, they must be moored near the miter gate sill where turbulence is less hazardous.

d. Downstream conditions. During emptying operations, the discharge from the culverts in the intermediate wall flows directly into the approach channel (Plate 2). This discharge is not dissipated and generates large waves; consequently, small boats must remain more than 400 ft downstream to avoid being swamped. The landward culvert discharges through a manifold immediately downstream of the miter gate, and discharge from the river-wall culvert is turned 90 deg and directed toward a nearby island. These flows could endanger people or pleasure craft located in the area.

10. The various hydraulic problems associated with the existing locks, as discussed in paragraph 9, were studied under contract by Mr. M. E. Nelson (NCS consultant). Results of his study, including a description of the problems and proposed solutions and modifications to the existing filling and emptying system to improve its operation and to reduce hazards to navigation, were presented in a report entitled "Hydraulic Problems and Recommended Solutions at Locks and Dam No. 1, Mississippi River." These recommendations were reviewed, and with suggestions by engineers of OCE, NCD, NCS, and WES,* the elements of the existing lock systems to be modified are as follows:

a. Construct new intake manifolds (Plate 7) upstream of the miter gate recesses to reduce the tendency for floating debris to interfere with opening of the miter gates. The intake should remove vortex problems and improve efficiency of the filling system.

b. Relocate the filling valves to the lower culvert level with invert el 681.2 (later changed to el 678.7). Air entrainment and surges will be reduced by this modification (Plates 8 and 9).

c. Replace the present stoney filling and emptying valves

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* OCE, Office, Chief of Engineers; NCD, U. S. Army Engineer Division, North Central; NCS, U. S. Army Engineer District, St. Paul; and WES, U. S. Army Engineer Waterways Experiment Station.

with new reverse tainter valves (Plates 8 and 9), vertical-lift gates, or butterfly valves.

d. Lower the existing 9.5-ft-diam culverts at invert el 681.2 to invert el 678.7 and change to 9.5-ft-wide by 7.5-ft-high rectangular culverts, in order to exclude or reduce air in the culvert crowns at normal tailwater el 687.2 (Plates 9 and 10).

e. Lower the ports in the lock walls to discharge flush with the lock chamber floor and increase submergence of the jets emerging from the ports during the filling cycle. Design the ports for a more optimum culvert-to-port-area ratio and stagger the ports in opposing lock walls (Plates 8 and 9).

f. Consider elimination of the existing venting system by improvements suggested above (subparagraphs a-d).

g. Provide energy dissipation in the lower lock approach by constructing bottom interlaced laterals downstream of each lock chamber (Plates 10 and 11). Consider alternate proposals for discharges from the river-wall culvert (Plate 12).

Purpose of Model Investigation

11. It was recognized that the improvements to the hydraulic filling and emptying system listed in paragraph 10 constituted significant departures from the existing design. Since assurance was necessary that the proposed structurally feasible modifications would result in the acceptable performance they were intended to provide, a model study of the modified system was required to confirm the hydraulic adequacy of the modified filling and emptying system.

PART II: THE MODEL

Description

12. The 1:25-scale lock model reproduced approximately 600 ft of the upstream approach, the entire landward filling and emptying system including intakes, culvert tainter valves in longitudinal wall culverts, the interlaced outlet, and about 500 ft of downstream approach (Figures 2-7 and Plate 13). The riverward lock intake and outlets were blocked out to permit initial tests of the landward lock modifications. Upon completion of the landward lock modification tests, the downstream topography and emptying system for the riverward lock were installed and the modifications for the riverward lock were developed. The lock approach topography was molded in concrete. The lock chamber was constructed of plywood and the intakes, longitudinal wall culverts, and sidewall port manifolds and outlets were reproduced in plastic. The culvert valves were constructed of sheet metal and fitted with rubber seals to prevent leakage. Six sheet-metal barges, each simulating a length of 120 ft and a width of 25 ft (Plate 14), were loaded with weights to reproduce the desired drafts of 9.0 ft on the landward lock and 6.5 ft on the riverward lock.

Appurtenances and Instrumentation

13. Water was supplied to the model through a circulating system. Both the headbay and tailbay of the model contained skimming weirs that maintained essentially constant upper and lower pools during filling and emptying operations. Vertical adjustments of the skimming weirs permitted simulation of any desired upper and lower pool elevations. Dye and confetti were used to study surface and subsurface current directions. Pressure cells were used to measure instantaneous pressures at selected locations in the culvert system.

14. The instrumentation and control system provided for operation of the culvert reverse tainter valves and later slide valves (Figures 3

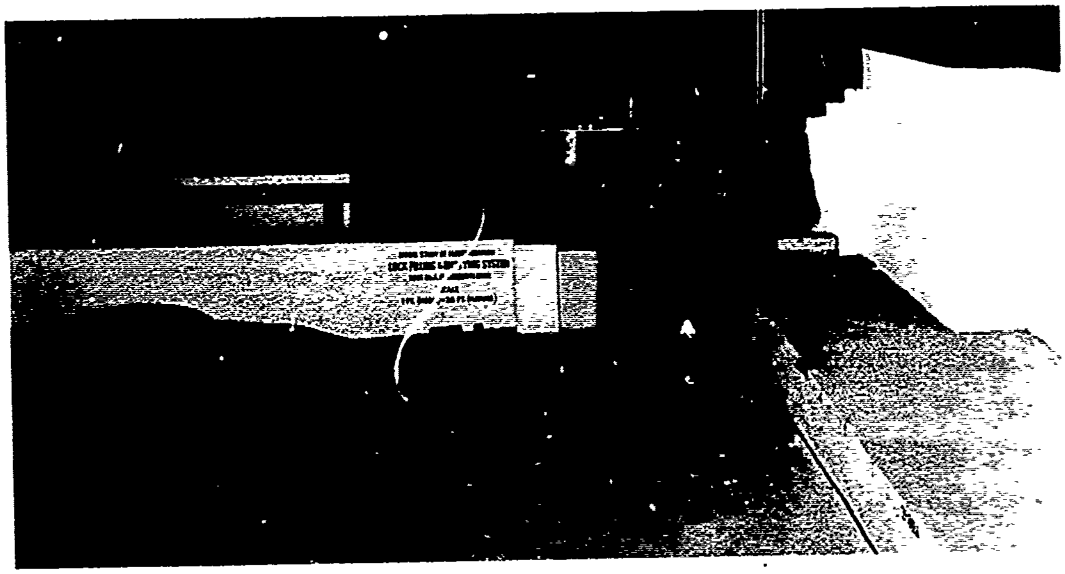


Figure 2. General view of model looking downstream

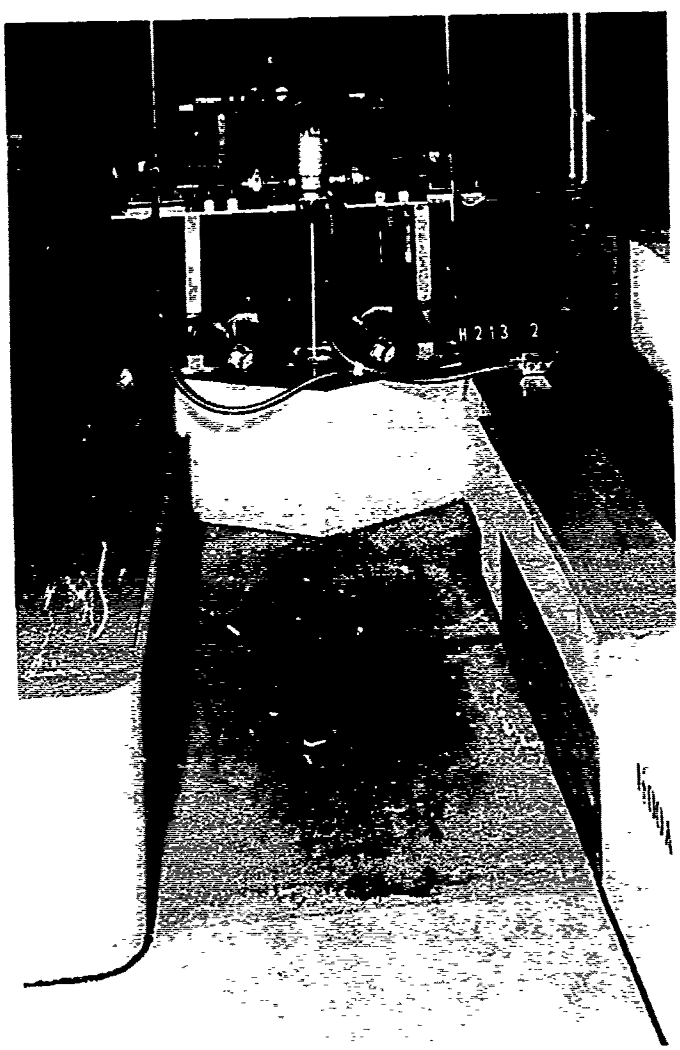
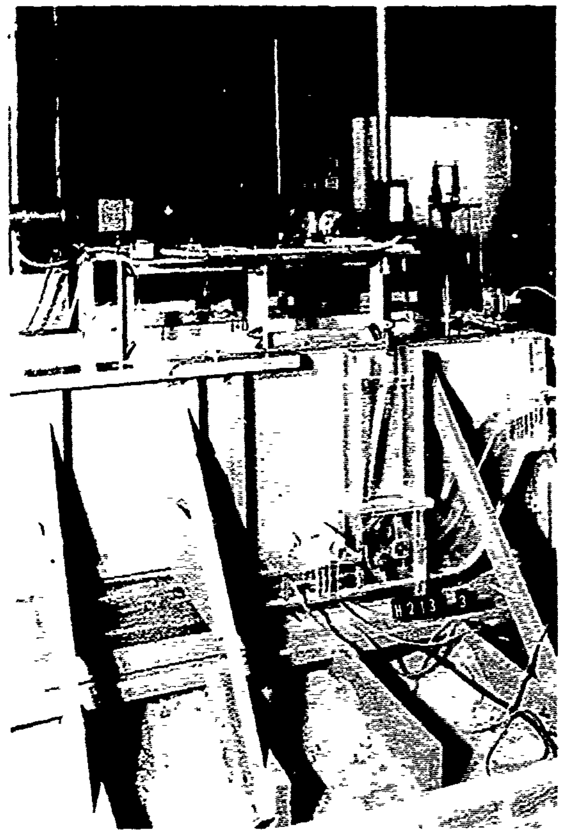


Figure 3. Close-up of landwall lock intake manifold, miter gates, and culvert valve drive equipment

Figure 4. Valve drive equipment



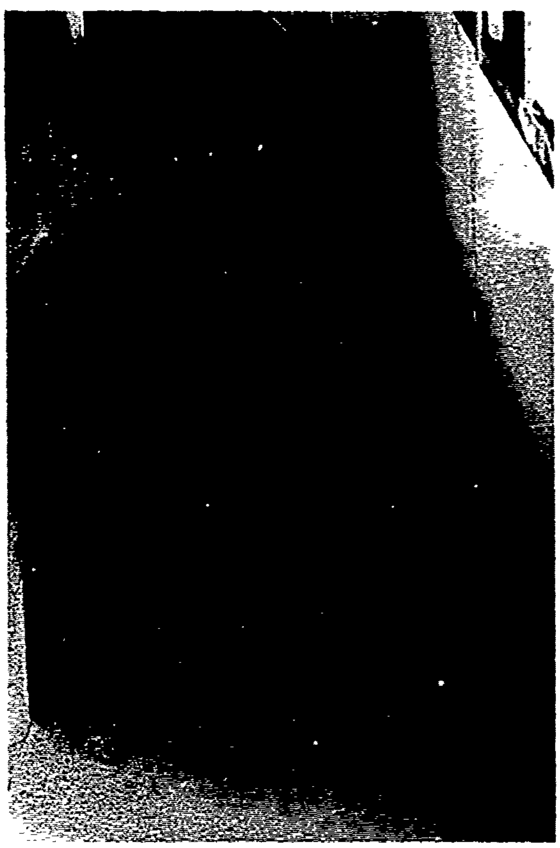


Figure 5. Chamber and sidewall port manifold

Figure 6. Close-up of outlet for landwall lock

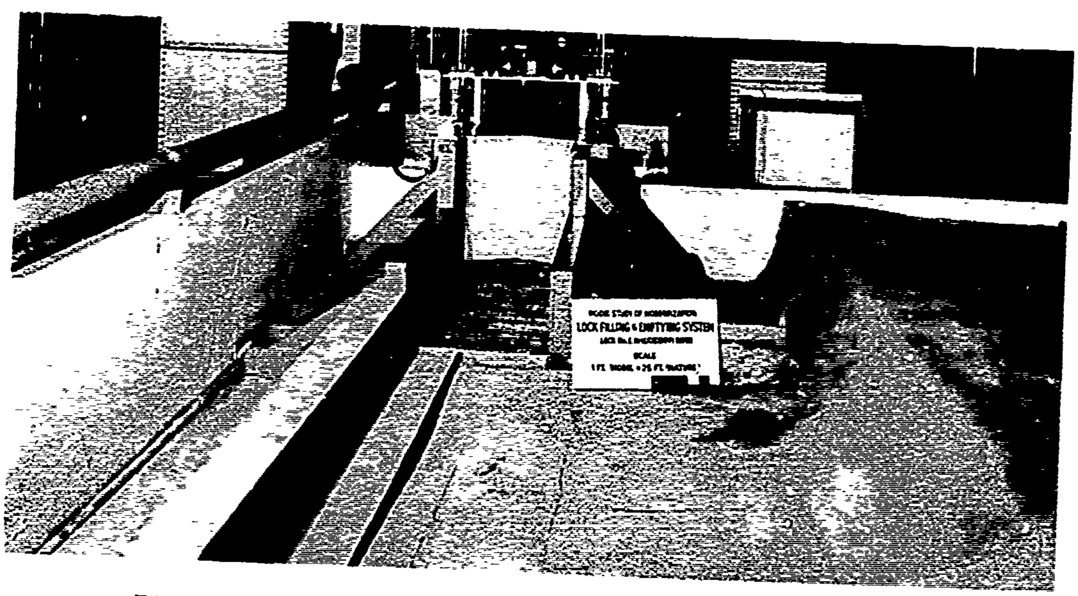


Figure 7. Outlet and lower approach for landwall lock

and 4) were simulated by means of a programmable d-c motor. The position of the valve opening was indicated by a linear potentiometer. The command signal plot was drawn to carefully control the valve position as a function of time. The control system was further enhanced by introducing two electromagnetic clutches to provide for both normal (dual) and single culvert valve control. The lock water surface was monitored by means of a commercial water level probe.

15. A hawser-pull (force links) device used for measuring the longitudinal and transverse forces acting on the upstream and downstream ends of a tow in the lock chamber during filling and emptying operations is shown in Figure 8. These links were machined from aluminum and had SR-4 strain gages cemented to the inner and outer edges. When the device was mounted on the tow, one end of the link was pin-connected to the tow while the other end engaged a fixed vertical rod and was free to move up and down with changes in the water-surface elevation in the locks. Any horizontal motion of the tow caused the links to deform and

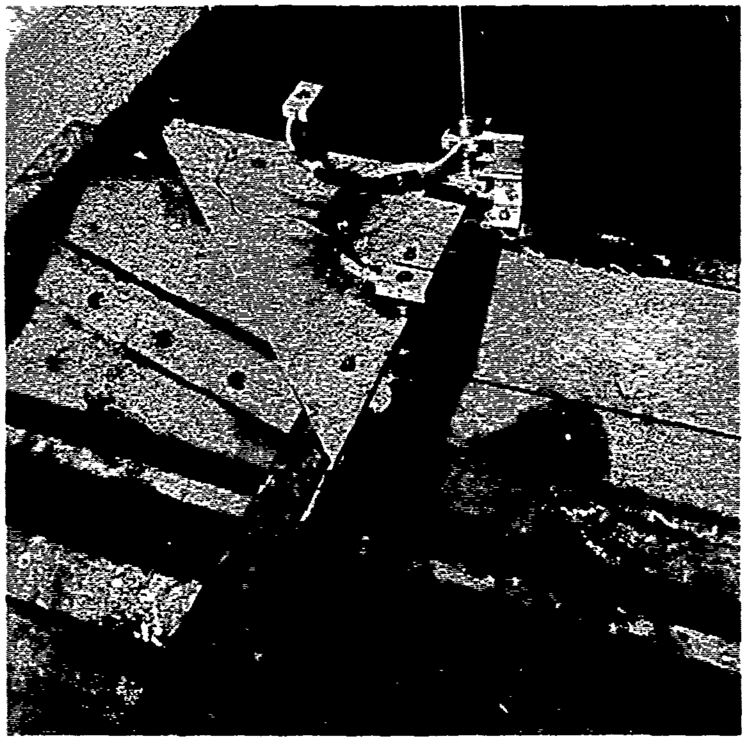


Figure 8. Hawser force links

vary the signal to a recorder. The links were calibrated by inducing deflection with known weights.

16. Data were recorded graphically on a commercial recorder. The sensing elements (mechanical-to-electrical conversion devices) located at various points on the model were connected by shielded cables to amplifiers where the outputs were stepped up to the level required for graphical recording.

Scale Relations

17. The accepted equations of hydraulic similitude, based upon the Froudian relations, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. General relations for transference of model data to prototype equivalents are presented in the following tabulation.

Dimension	Ratio	Model Scale Relations Lock	Gate
Length	$L_r = L$	1:25	1:10
Area	$A_r = L_r^2$	1:625	1:100
Velocity	$V_r = L_r^{1/2}$	1:5	1:3.162
Time	$T_r = L_r^{1/2}$	1:5	1:3.162
Discharge	$Q_r = L_r^{5/2}$	1:3,125	1:316.23
Weight	$W_r = L_r^3$	1:15,625	1:1,000
Force	$F_r = L_r^3$	1:15,625	1:1,000

PART III: TESTS AND RESULTS

Test Procedure

18. Evaluation of the various elements of the filling and emptying systems shown in Table 1 was based on data obtained during general filling and emptying operations with a 37.8-ft head differential (upper pool el 725.0 and lower pool el 687.2) and submergences of 11 ft in the landward lock and 8.5 ft in the riverward locks, which had chamber invert elevations of 676.2 and 678.7, respectively. Performance was primarily based on flow conditions and distribution at the intakes, at the outlets, and in approaches to the lock; turbulence and hawser forces measured on tows moored in the lock chamber; pressure measurements throughout the system and particularly below the filling and emptying culvert valves and/or slide gates; and filling and emptying times. In determination of flow distribution in portions of the system, and in some studies of approach and exit conditions, fixed heads and steady-flow conditions were maintained with the culvert valves and/or miter gates fully or partially open. For steady-flow tests, water-surface elevations within the lock chamber were set in accordance with conditions expected at a given instant of time from filling and emptying curves recorded for particular valve or slide gate opening schedules.

Landward Lock Filling and Emptying System

Type 1 (original) system

19. The type 1 design filling and emptying system shown in Plates 15-17 was designed to utilize as much of the existing culvert and culvert alignments as possible with the lock chamber and sills unchanged. Modifications were made to the intermediate wall nose, intakes, culverts, sidewall port manifold, interlaced lateral outlets, and filling and emptying valves. The shape of the culvert was changed from round to rectangular and the invert was lowered as much as existing structural and foundation considerations would permit. Primary elements of the

system consisted of six-port, sidewall intake manifolds entering 8-ft-wide by 10-ft-high culverts in each wall at invert el 708.7. The culvert then dropped 30 ft to el 678.7 while transitioning to an 8-ft-wide by 7.5-ft-high section at the reverse-mounted culvert tainter valves. From the valves, the culvert transitioned to a 9.5-ft-wide by 7.5-ft-high section for the sidewall port manifold that consisted of 19 ports in each culvert, spaced 13 ft on centers and staggered in each wall, with individual port throats 1.5 ft wide by 2.3 ft high. This resulted in a culvert-to-port-area ratio of 0.92. An 8-ft-wide by 7.5-ft-high transition connected the chamber manifold to reverse tainter emptying valves, and the culverts emptied through three interlaced lateral outlets from the two wall culverts downstream of the lower miter gates.

20. Upstream approach and type 1 intake manifold. During preliminary observations the 5-ft radius installed on the intermediate wall nose intake (Plate 15) was found to be too short and inadequate as swirls, vortices, and an air-entraining vortex formed at port 1. The 5-ft radius was increased to 12.5 ft which extended the nose 7.5 ft farther upstream to sta 0+96 (type 2 nose, Plate 18). Surface current patterns in the upstream approach area and in the intermediate vicinity of the type 1 intakes with the type 2 intermediate wall nose were recorded by means of 5-sec-sequence (exposure) Photos 1a-1f during a typical 4-min valve filling operation. The culvert valve operating schedule is shown in Plate 19. These photographs were recorded prior to and at 2, 4, 6, 8, and 10 min after the start of a 4-min valve filling operation. The surface currents at 8 and 10 min have reversed with movement away from the intakes and toward the river approach. Swirls will occur in the prototype, but vortex or air-entraining vortex problems will not result. Similar observations with the upper pool lowered 2 ft to el 723.0 resulted in no perceptible difference in surface currents as they appeared in Photos 1a-1f. During the navigation season, the headwater is kept normally at el 725.0. The flashboards on the dam contain shear pins which fail due to ice pressures or high spring flows. During the winter months the water surface in the upper pool will thus

be lowered to approximately el 723.0. Submergence* over the intake roof at el 713.7 is 11.3 ft with normal upper pool 725.0, and 9.3 ft with upper pool at el 723.0.

21. Velocities at the wall face of the type 1 intake ports were measured under steady-flow conditions, and these velocities and resulting flow distribution are plotted in Plate 20. Flow was divided with 50.9 percent through the intermediate wall intake and 49.1 percent through the land wall intake, and distribution across the manifold was considered to be satisfactory. Steady-flow pressures in and throughout the filling system are shown in Table 2. Piezometer locations are indicated in Plate 21. The type 1 intake and type 2 intermediate wall nose in Plates 15 and 18 were recommended for inclusion in the landward lock rehabilitation.

22. Pressures at the filling and emptying culvert valves. Subatmospheric pressures were observed with pressure cells installed on the roof of the culvert (el 686.2) downstream of the filling and emptying valves at sta 0+95.45 and 4+21.87B (Plates 21 and 22). The bulkhead slots upstream and downstream of the filling valves were sealed at the roof of the culvert during these measurements to prevent the drawing of large amounts of air into the filling system unnecessarily. Relief of the subatmospheric pressure conditions by means of controlled air venting will be discussed later. The bulkhead slots upstream and downstream of the emptying valves were not sealed and controlled air venting will also be needed to relieve low pressure conditions.

23. Turbulence in the lock chamber and hawser forces on tows moored in the chamber with type 1 sidewall port manifold. During filling operations turbulence in the lock chamber was considered to be excessive with the type 1 system. The sidewall port manifold with sloping ports (Plate 16) 7.25 ft long on the land wall and 5.08 ft long on the intermediate wall directed the jets downward, from the culvert invert at el 678.7 to the chamber invert 2.5 ft lower at el 676.2, in

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* Submergence is the difference in elevation between the lower pool and the lock chamber floor.

such a manner that flow spread hand-fan-shaped fashion and the opposing jets met near the center of the lock chamber and rolled back toward the lock walls. Figure 9 shows this type of action, flow from manifold ports 10 to 3 1 min after beginning of a 4-min valve filling operation. Sequence Photos 2a-2f show confetti movement (5-sec exposure) on the lock chamber water surface during a similar filling operation. Foundation problems in the existing lock necessitated the 2.5-ft difference in culvert and chamber invert elevations. This required sloping of the ports negated to some degree the optimum design of the manifold with respect to culvert and port throat-area ratio and port spacing and staggering in opposite walls.

24. Hawser forces were measured during filling and emptying with a 6-barge tow at 9-ft draft (4,844-ton displacement) with the upstream end of the tow at sta 0+65 B. Hawser forces versus lock filling and emptying times are shown in Plate 23. Similar data for the same head

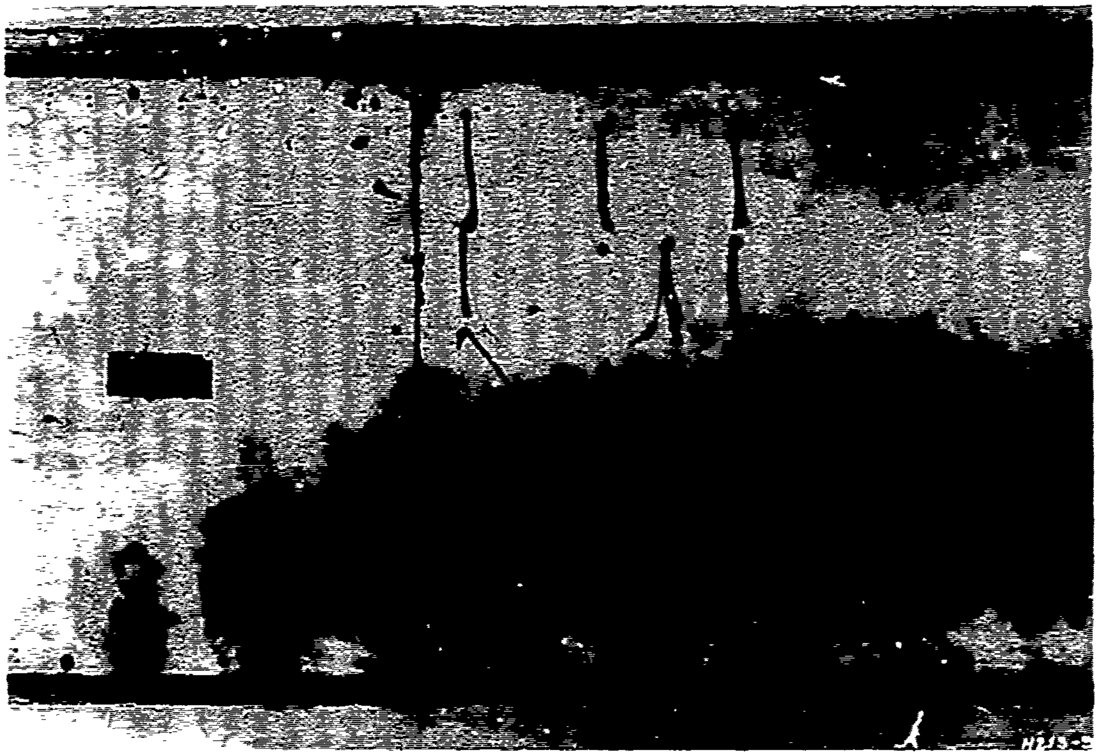

Figure 9. Path of jets from intermediate wall after beginning of filling operation, type 1 (original) design

differential and 2 ft higher upper and lower pools are also indicated in Plate 23. Although hawser forces did not exceed the 5-ton criterion for barge tows, turbulence described in paragraph 23 was most unsatisfactory, particularly for small craft; and it was obvious that further development of the sidewall port manifold would be necessary.

25. Type 1 outlets and lower approach. Details of the type 1 outlets and lower approach are shown in Plates 10 and 17 and Figures 6 and 7. Velocities recorded at the face of the outlet lateral ports and the resulting flow distribution under steady-flow conditions are plotted in Plate 24. Flow was divided with 49.6 percent through the land wall laterals and 50.4 percent through the intermediate wall laterals. Steady-flow pressures observed in the emptying system are shown in Table 3. Piezometer locations are shown in Plate 21. Figure 10 shows flow conditions at the outlet with maximum discharge for a normal head and 4-min valve time. Velocities and flow distribution at the type 1 outlets and flow conditions in the lower approach were satisfactory. These outlets are recommended for use in rehabilitation of the landward lock.

26. Overall lock coefficients. The culvert valve schedule in Plate 19 for valve times of 2, 4, 6, and 8 min resulted in filling and emptying times shown in Plate 25. Overall lock coefficients (C_L), based on these data, were computed by the equation

$$C_L = \frac{2A_L\left(\sqrt{H + d} - \sqrt{d}\right)}{A_c\left(T - Kt_v\right)\sqrt{2g}}$$

where

A_L = area of lock chamber, sq ft
H = initial head, ft
d = measured overfill or undertravel, ft
A_c = area of culvert, sq ft
T = filling or emptying time, sec
K = a constant
t_v = valve time, sec
g = acceleration due to gravity, ft/sec^2

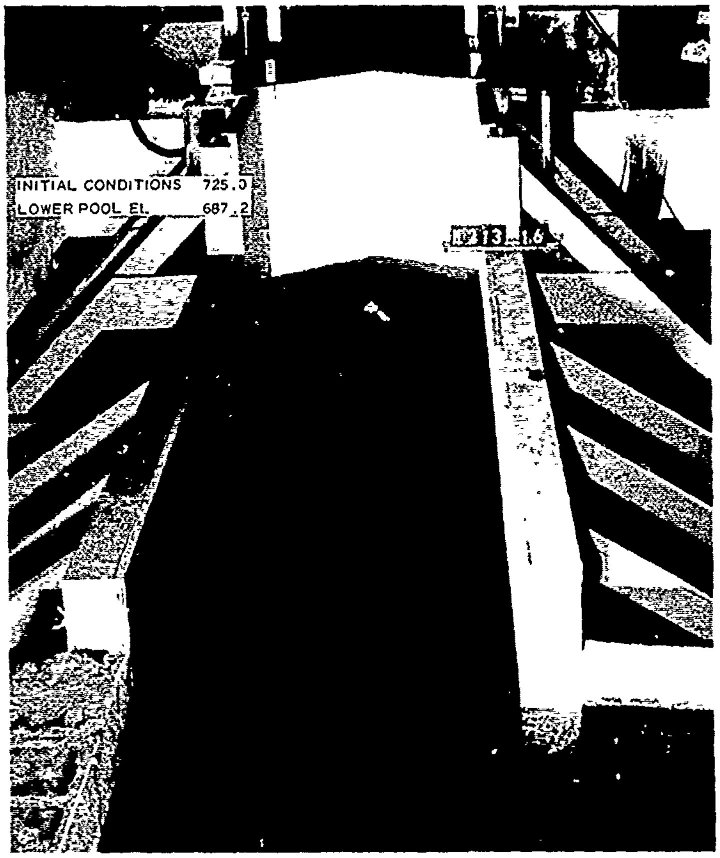

Figure 10. Flow conditions during peak discharge at type 1 (original) design outlet, 4-min valve time

The term $T - Kt_v$ is lock filling or emptying time for the hypothetical case of instantaneous valve opening as is obtained directly from the curves plotted in Plate 25. Computed overall lock coefficients for the type 1 (original) system were 0.59 for filling and 0.57 for emptying.

Alternate systems

27. The original sidewall port manifold required additional modification and testing. For optimum performance the wall culverts, ports, and lock chamber would have a common invert el 671.7, which is 15.5 ft below lower pool el 687.2. This would provide 6.5-ft clearance for dissipation of port jet energy beneath a 9-ft draft tow. Due to foundation and structural problems, instead of 15.5-ft submergence over the lock floor there was a minimum submergence of only 11 ft and 2-ft

clearance beneath a 9-ft draft tow. Also, because of foundation and structural problems, the ports were sloped downward 2.5 ft from the invert of the culvert to the chamber invert. Thus, the jets were forced into the invert and dissipated in the hand-fan-shaped fashion in this area, reflected upward toward the center line of the chamber, and rolled back toward the wall from which flow entered, which generated subsurface and surface turbulence in the lock chamber. Tests were conducted with various deflector walls and trenches in an effort to reduce the high degree of turbulence observed with the type 1 system. Tests were also conducted with the wall culvert, port, and chamber floor at a common invert elevation to determine what effect this would have on turbulence and hawser forces. All of the sidewall port modifications were tested with other elements of the systems unchanged from the type 1 system.

28. Type 2 sidewall port manifold and system. Port deflectors 1 to 2 ft high and 3 ft long (Plate 26) were tested in an effort to reduce the spreading of the sloping port jets and turbulence in the chamber. The type 4 deflector (4 ft long and 1 ft high) was the most satisfactory and was selected as an element of the type 2 sidewall port manifold and system. Figure 11 shows the path of the jets issuing from the intermediate wall ports 10 to 3 1 min after beginning of a 4-min valve opening. A considerable reduction in jet spread and control of flow across the lock is apparent when the type 1 manifold jets in Figure 9 are compared with the type 2 manifold jets in Figure 11. Sequence photographs of confetti movement on the chamber water surface with a 4-min valve time are presented in Photos 3a-3f. The deflectors significantly improved turbulence in the chamber as can be seen by comparing Photos 2a-2f (type 1) with Photos 3a-3f (type 2). The type 4 deflectors in the type 2 system were 1 ft high and with only 1-ft minimum clearance between the deflector and a 9-ft draft tow, problems could be encountered during entering or exiting as well as during emptying operations due to squat* of the towboat and tow, and undertravel at the end of emptying

* Squat is the settling of a towboat or tow at a deeper draft in the available submergence in the lock chamber due to the increased power applied to move or slow a tow within the confines of a lock chamber.

Figure 11. Path of jets from intermediate wall after beginning of filling operation, type 2 sidewall port manifold design

operations. In the model tests, the 1-ft clearance between the top of the deflector and bottom of a 9-ft draft tow was adequate during emptying undertravel; however, the practicality of this small amount of clearance was considered marginal for tows entering and exiting the lock chamber.

29. Comparison of filling and emptying times for types 1 and 2 systems with normal and single (right) culvert operations are shown in Plate 25. Maximum longitudinal hawser force data on a 6-barge tow at 9-ft draft are compared in Plate 27.

30. Type 3 sidewall port manifold and system. Since the use of deflector walls in type 2 sidewall port manifold and system was not a feasible or practical solution to the control of jet flow from the sidewall port manifold, the manifold port jets were investigated with various lengths of 1- and 2-ft-deep trenches in the floor of the lock chamber immediately in front of each port (Plate 28). The 0.75-ft-radius

curves at the side of the portals adjacent to the chamber were removed so that the ports entered the chamber and trench at a 2.10-ft width on the land wall side and 1.88-ft width on the intermediate wall side. The invert slope of each port was extended past the chamber and port wall face into the trench at the invert depth being investigated. In addition to the types 1-8 trenches shown in Plate 28, performance was observed with sloped as well as square ends in the trenches. Turbulence in the lock chamber was less with the type 8 trench in front of the sidewall port manifolds. This trench was 1 ft deep at invert el 675.2 and 28 ft long to the center line of the lock chamber. The type 1 manifold modified to include the type 8 trenches was designated the type 3 manifold and system. The port jet tends to follow the trenches as shown in Figure 12, a photograph of the jets discharging from intermediate wall ports 10 to 3 (left to right or top to bottom of the figure) 1 min after the start of a 4-min valve opening. Sequence photographs of

Figure 12. Path of jets from intermediate wall after beginning of filling operation; type 3 sidewall port manifold design

confetti on the chamber water surface are presented in Photos 4a-4f. These photographs show that the turbulence was most satisfactory. The Photos 4a-4f sequence can be compared with similar Photos 2a-2f for type 1 and Photos 3a-3f for type 2 manifolds and systems.

31. Type 4 sidewall port manifold system. Since the riverward lock design had the wall culvert, ports, and chamber invert at a common invert elevation of 676.2, it was decided to make comparative tests of this system after the model was revised to simulate the riverward lock. This was accomplished by raising upper and lower pool elevations 2.5 ft and maintaining initial submergence of 11 ft in the chamber and a 37.8-ft head as in previous tests of types 1 to 3 manifolds and systems. The culvert roof was submerged 3.5 ft instead of 1 ft in tests of types 1 to 3 systems; this was designated the type 4 system (Table 1).

32. Observance of turbulence in the lock chamber during filling and emptying indicated good distribution of flow throughout the chamber. A photograph of the path of jets from the intermediate wall ports 10 to 3 (left to right or top to bottom of photograph) obtained 1 min after the 4-min valve began to open is shown in Figure 13. The dye jets and strings on the lock chamber floor indicate the existence of well-directed flow with a minimum of disturbance in the area when the flow from the staggered ports intermingled. There was sufficient rubbing of the jets and accompanying energy dissipation to prevent the jets from reaching the opposite wall with excessive energy of strength to induce adverse upwelling along the wall. Sequence photographs of confetti movements on the water surface during filling with a 4-min valve time are shown in Photos 5a-5f.

33. Maximum hawser forces versus filling and emptying times for 6- and 2-barge tows at 9-ft draft are plotted in Plate 29. Hawser forces did not exceed the 5-ton criterion for barge tows with valve times between 2 to 8 min. Similar data for single (right) culvert operations are plotted in Plate 30.

34. Minimum pressure gradient elevations (ft msl) versus filling and emptying times with normal and single (right) culvert operations are plotted in Plate 31. The shaded data were recorded with upper and lower

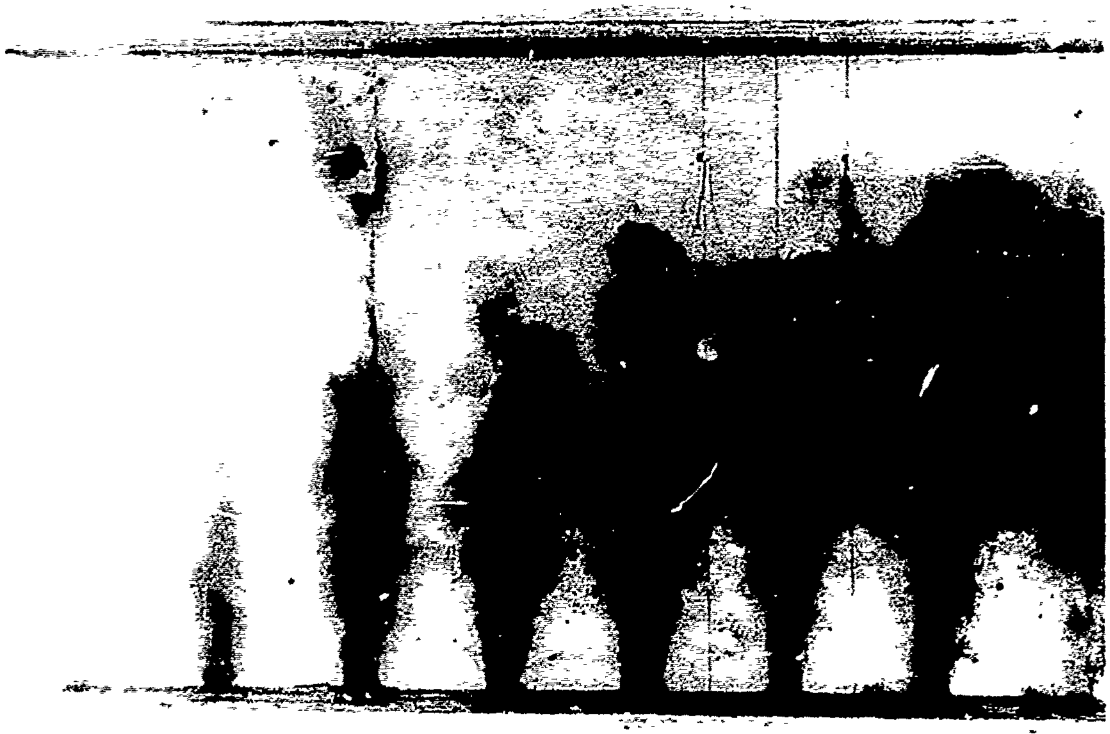

Figure 13. Path of jets from intermediate wall after beginning of filling operation; type 4 sidewall port manifold design. Chamber floor invert el 678.7, upper pool el 727.5, lower pool el 689.7, 11-ft submergence

pools raised 2.5 ft above normal (unshaded) conditions. The shaded data reflect 11-ft initial submergence over the chamber floor and 3.5-ft initial submergence over the roof of the culvert. The unshaded data are for 8.5-ft initial submergence over the chamber floor and 1.0-ft initial submergence over the roof of the culvert.

Recommended (type 3) systems

35. The type 3 (recommended) filling and emptying system (Table 1) for the landward lock site consisted of the following elements.

- a. Type 2 intermediate wall nose (Plate 18).
- b. Type 1 intake manifold (Plate 15).
- c. Culvert reverse tainter valves (Plates 9, 15, and 17). Subsequent test of slide gates in the 1:25-scale model for the riverward lock site and in a 1:10-scale model (for the purpose of studying hoist loads) indicated

satisfactory performance. However, the sponsor preferred the reverse-mounted culvert tainter valves due to the proven success with this type of valve experienced over long periods of lock operations at other Corps of Engineer navigation locks. It was recommended that vertically framed tainter valves developed during model tests of the Holt Lock* for the U. S. Army Engineer District, Mobile, be adopted for Lock No. 1 modifications.

d. Type 3 sidewall port manifold.

e. Type 1 discharge outlets (Plate 17).

36. Comparisons of filling and emptying times for filling and emptying systems types 1-4 for normal and single valve operations are plotted in Plate 32. Maximum hawser forces measured on a 6-barge tow at 9-ft draft are plotted in Plate 33. These plots reveal very small differences in filling and emptying times and hawser forces. However, the water-surface turbulence was considered to be more satisfactory for types 3 and 4 systems (compare Photos 4a-4f and 5a-5f). The type 3 system appears to be the most feasible and economic because the type 4 system, as developed in model tests for the landward lock, requires lowering the culvert manifolds 2.5 ft from invert el 678.7 to el 676.2.

37. Average pressures throughout the type 3 system during filling and emptying operations are listed in Tables 4 and 5. Piezometer locations are shown in Plate 21. Subatmospheric pressures were recorded on the roof of the culvert downstream of the filling and emptying valves by means of pressure cells installed at sta 0+95.45B and 4+21.87B. Minimum pressure gradient elevations (ft msl) versus filling and emptying times for 2-, 4-, 6-, and 8-min valve times are plotted in Plate 34. The bulkhead slots upstream and downstream of the filling valves were sealed at the roof of the culvert. The bulkhead slots upstream and downstream of the emptying valves were not sealed. Similar data for single (right) culvert valve operations are plotted in Plate 34. Single 12-in.-diam air vents should be flush-mounted at all valves on the roof of the

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* T. E. Murphy and J. H. Ables, Jr., "Lock Filling and Emptying System, Holt Lock and Dam, Warrior River, Alabama; Hydraulic Model Investigation," Technical Report No. 2-698, Nov 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

culvert about 3.5 ft (one-half the culvert height) downstream of the reverse tainter valve to prevent the potential for structural damage due to cavitation. Control valves (which can be locked after setting) should be installed on the air vents at the top of the lock wall to provide for a controlled admission of air in the prototype. At the time the modifications to the existing lock are placed in operation, hydraulic design personnel of NCS and WES should assist in determining the vent valve control settings that will preclude cavitation without an excessive amount of air and additional turbulence in the lock chamber. This has been done successfully at several locks and experience has shown that satisfactory performance can be obtained within a range of settings. The vent valves should then be locked at the desired position to prevent accidental changing of the setting. Additional information on design of culvert valve vents is given in paragraphs 2-5 of EM 1110-2-1610, 15 August 1975, "Hydraulic Design of Lock Culvert Valves."

38. Maximum hawser forces versus filling and emptying times measured with 6- and 2-barge tows at 9-ft drafts are plotted in Plate 35. Hawser forces did not exceed the 5-ton criterion for barge tows at valve times of 2, 4, 6, and 8 min. Similar data for single (right) culvert valve operations are shown in Plate 36. The high transverse hawser forces acting on the tow toward the right wall, which contains the filling culvert, are to be expected since the model tow was moored at the center line of the lock chamber and full force is allowed to develop in this direction. A tow moored at floating mooring bits in the right wall would rise vertically with the tow securely snubbed in position without any difficulty.

39. Delayed valve operations were considered prior to initiation of model testing and several delayed valve operations were investigated using the kinematics of a 4-min valve schedule and introducing a 2-min delay in opening at 1.5, 1.75, and 2.0 min, and then continuing until the valve reaches the fully open position in 6 min. Hawser forces and minimum pressures on the culvert roof downstream of the valves are plotted in Plate 37. Delayed valve operations require slightly longer to fill and empty with no significant advantages in hawser forces or

minimum pressures at the valves. In addition, prototype valve operating equipment would be more complicated.

40. The type 3 filling and emptying system should be operated with either a 4- or 2-min valve schedule as shown in Plate 19. Filling and emptying times are shown in Plate 32. Computed overall lock coefficients for the type 3 (recommended) system were 0.57 for filling and 0.54 for emptying.

Riverward Lock Filling and Emptying System

41. The riverward lock, as a result of existing conditions, has only 8.5 ft of submergence over the chamber floor and 1 ft of cover over the roof of the culverts. A normal head of 37.8 ft and normal upper and lower pools of 725.0 and 687.2, respectively, were reproduced in all riverward lock tests. Barge tow draft, because of the available 8.5-ft submergence, was limited to 6.5 ft in all riverward lock tests.

Type 4 system

42. Riverward lock tests were initiated with the recommended elements of the type 4 system for the landward lock, and the sidewall port manifold (Figure 14, Plate 38), culvert, ports, and chamber at invert el 678.7 (type 4, Table 1). Turbulence on the lock chamber water surface is indicated in sequence Photos 6a-6f. The degree of turbulence was considered to be satisfactory. Plots showing filling and emptying characteristics with a 6.5-ft-draft tow and pressures downstream of the reverse tainter valves are presented in Plates 30-32 and 39. A request was made by the sponsor to measure hawser forces on a single line of three barges aligned end to end, as well as on a full 6-barge tow for normal and single (right) culvert operations. These data are shown in Plates 40 and 41. The type 4 system, with only 8.5-ft minimum submergence over the lock floor, performed satisfactorily with tows loaded to 6.5-ft draft. Average pressures throughout the type 4 system with 4-min valve schedule are listed in Tables 6 and 7. Piezometer locations are shown in Plate 21. Filling culvert piezometers A-E were added on the invert of the right wall culvert drop section upstream of the filling

Figure 14. Sidewall port manifold prior to installation

valve, and piezometers C' and C" also were added in the same vicinity on the roof of the culvert immediately downstream of the bulkhead at sta 0+37B. Average pressure conditions throughout the system were found to be satisfactory. Minimum culvert roof pressures downstream of the culvert valves are shown in Plate 31.

Type 5 system

43. The reverse tainter control valves installed in the wall culverts for all model tests of the types 1-4 systems were replaced with slide gates in the type 5 system. The slide gate and gate slot design are shown in Plates 42 and 43. The type 5 system is shown schematically with piezometer locations in Plate 44. The slide gates for filling operations were essentially in the same position as the lower lip of the tainter valves in this closed position. However, the emptying slide gates were located approximately 78 ft farther downstream than the tainter valves in order to possibly utilize the existing prototype

stoney valve slots. Except for the installation of slide gates, the type 5 system was identical with the type 4 system.

44. Plate 19 shows the proposed constant-speed gate schedule used in all slide gate operations. Filling and emptying times versus valve times are presented in Plate 45. Average pressures throughout the system with a 4-min valve time are listed in Tables 8 and 9. Minimum pressures recorded with pressure cells on the culvert roof immediately downstream of the slide gates during normal and single (right) culvert operations are plotted in Plate 46. Table 10 is a tabulation of visual observations of minimum water-surface levels in the bulkhead slots immediately upstream of the filling and emptying gates during 2-, 4-, 6-, and 8-min normal and single gate operations. During emptying operation, the bulkhead water level dropped to the culvert roof at el 686.2. Although no air entered the emptying culvert from the slot, the condition is marginal; and air could be expected to enter the culvert in the more efficient prototype structure. Thus, provisions to seal the bulkhead slots upstream as well as downstream of the emptying valve and downstream of the filling valve should be provided if the slide gates are adopted for modification of the riverward lock system.

45. Maximum hawser forces during filling and emptying operations with normal and single (right) gate operations were measured with 6- and 2-barge tows at 6.5-ft draft (Plates 47 and 48). The hawser forces were considered to be satisfactory. The comment regarding transverse hawser forces on single gate filling operation in paragraph 38 is pertinent to all sidewall port filling systems.

46. The type 5 system was more efficient than the systems with the reverse tainter valves. Normal filling and emptying operations required about 1 min less time, and there was a reduction of about 2 min during single culvert filling and emptying operations. The type 5 system (Table 1) performed satisfactorily in all respects for a system with a minimum of 8.5-ft submergence in the chamber at lower pool and barge tow draft limited to 6.5 ft.

Type 6 system

47. The filling system in the type 6 system was identical with

the type 5 system. Thus, no additional filling tests were conducted with this system. The type 6 emptying system (Table 1) included a three-lateral outlet positioned left of the intermediate wall culvert in the lower riverward lock approach for the right culvert (type 2 design, Plate 49) and a four-port outlet (type 3, Plate 12) for the left culvert. These outlets are shown in Figure 15. The riverward outlet discharged into a 45-ft-wide channel with invert elevation of 677.0, and this channel was positioned behind the high topography adjacent to the left guard wall downstream of the lock as shown in Plate 50. The dashed lines at the lower left end of the riverward outlet channel in Plate 50 indicate a transition from invert el 677.0 to existing topography to permit smooth outlet flow into the river. Both slide gates for the type 6 emptying system were moved 95.5 ft upstream, from sta 4+94B in the type 5 system to sta 3+98.50B in the type 6 system, as shown in Plate 49.

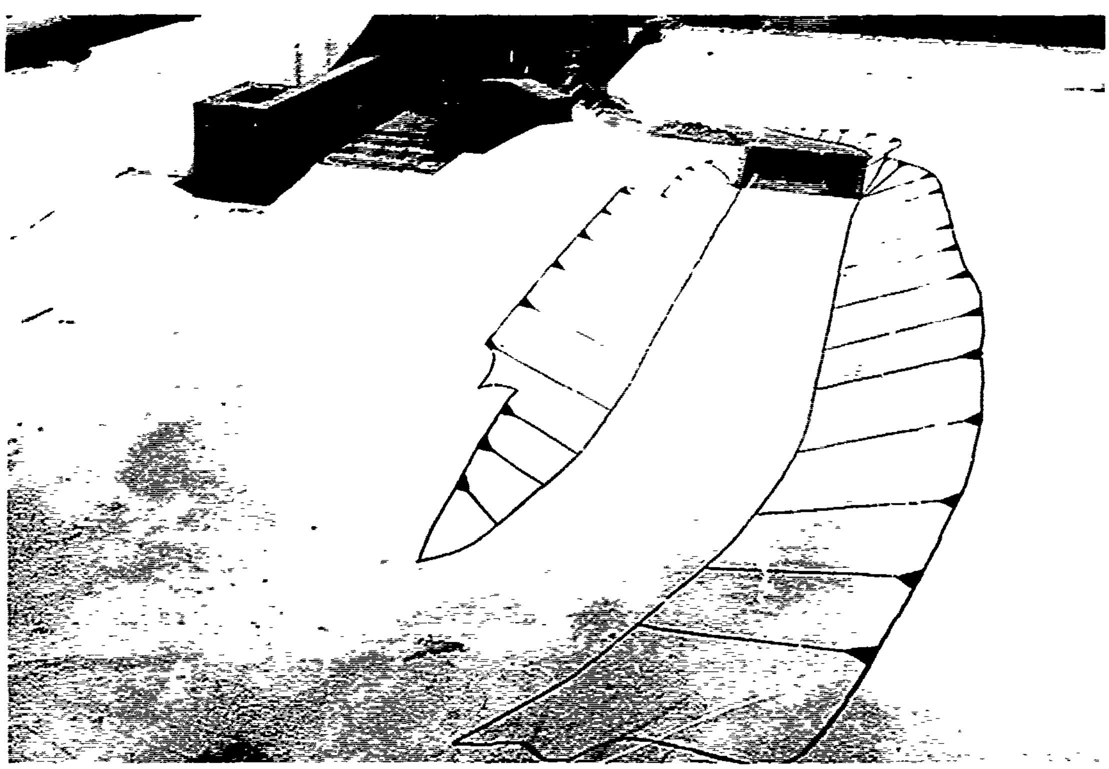

Figure 15. General view of lower approach to type 6 filling and emptying system with types 2 and 3 outlets for riverward lock installed

Photos 7a-7c show 4-min slide gate operations with peak discharge conditions for normal (Photo 7a), single (right, Photo 7b), and single (left, Photo 7c) culvert operations. There appeared to be no problem in the lower approach area during any of the operations. The turbulence in the lower approach was confined to the immediate vicinity above and adjacent to the laterals with slightly greater flow near the first ports in each lateral. This was not considered to be a problem since tows or small craft are not permitted in this area prior to completion of an emptying operation.

48. Velocities measured at the face of the types 2 and 3 outlets and the resulting flow distribution under steady-flow conditions are shown in Plates 51 and 52. The distribution of flow was 43.2 percent through the right outlet and 56.8 percent through the left outlet. In the right culvert outlet, laterals 1 and 2 each passed slightly more than a third of the right culvert total flow and lateral 3 carried slightly less than a third of the flow. In the riverward outlet, port 1 carried about 21 percent while ports 2-4 passed the balance of left culvert flow in near equal amounts. Flow in the outlets was considered to be satisfactory. Steady-flow pressures in the type 6 emptying system are listed in Table 11. Piezometer locations are shown in Plates 44 and 53. Average pressures throughout the type 6 emptying system with 4-min valve times are shown in Tables 12-14. Plate 54 is a plot of minimum pressures measured with a pressure cell mounted flush with the culvert roof 5 ft downstream of the emptying gate (Plate 53). The bulkhead slots downstream of the slide gates were sealed at the culvert roof. Table 15 is a record of visual observations of the water level in the bulkhead slots located 10 ft upstream of the slide gates during emptying operations. For all gate-operating schedules the water level reached the roof of the culvert. No air was admitted at the slot into the right (intermediate) culvert for normal or single gate operations; however, air was entrained through the slot into the left (riverward) culvert flow for some normal and single gate operations (Table 15). Since the prototype lock is expected to be about 10 percent more efficient than the 1:25-scale model, air can be expected to enter the prototype culvert

through the bulkhead slots 10 ft upstream of the slide gate. The air entrainment will occur after or near full gate opening and minimum pressures downstream of the slide gates will have already occurred. Therefore, provisions should be provided in the prototype to seal the bulkhead slots upstream and downstream of the slide gates near the culvert roof, and a controlled 12-in.-diam air vent should be positioned on the center line of the roof about 3.5 ft downstream of the slide gate. The controls should be located at the top of the lock wall to permit control adjustment and locking by representatives of NCS and WES prior to opening the lock system should the type 6 emptying system be adopted for modernization of the riverward lock at Lock No. 1.

49. Maximum hawser forces on 6- and 2-barge tows at 6.5-ft draft versus emptying times are plotted in Plate 55. Hawser forces did not exceed 3 tons. Plate 56 is a plot of emptying times versus slide gate times and these plots were used in computing overall lock coefficients of 0.59 for normal emptying, 0.52 for single (right) culvert emptying, and 0.61 for single (left) culvert emptying. The equation for these computations is shown in paragraph 26.

Recommendations

50. All of the filling and emptying systems tested for the riverward lock performed satisfactorily and any of these systems would be adequate for rehabilitating the existing lock. Little difference could be detected in the hydraulic performance of the lock when either tainter valves or slide gates were used to control filling and emptying. If tainter valves are used, they should be the vertically framed type referenced in paragraph 35. A 4-min opening schedule as shown in Plate 19 is recommended. Controlled air vents (12-in. diam) will be required at each valve as described in paragraph 37.

51. Either the type 1 interlaced lateral outlet (Plate 17) or the separated types 2 and 3 outlets (Plates 49 and 12) performed satisfactorily. The types 2 and 3 outlets were designed to remove a portion of emptying discharge away from the lower approach of the riverward lock, particularly since the landward lock empties in an adjacent area. However, under normal circumstances, it is very unlikely that the

lockmaster would allow simultaneous emptying operations of the locks, even if both locks were operable and active.

1:10-Scale Model Slide Gate Tests

52. As a part of the preliminary design studies for Lock No. 1, the sponsor requested model tests to determine hoist loads on a proposed slide gate design (Plates 42 and 43), which was under consideration for control of the filling and emptying operations. Slide gates performed satisfactorily in 1:25-scale model tests of the types 5 and 6 filling and emptying systems as discussed in paragraphs 43-48. The alternate proposal of slide gates in lieu of tainter valves was under consideration because of relative estimated cost and related service factors. After completion of the 1:25-scale model test, a 1:10-scale model of the slide gate and a single culvert was constructed (Figures 16 and 17) to determine pressures near the gate and hoist loads on the gate. Figure 18 shows the model test gate which simulated a prototype gate with a dry weight of 4,209 lb and a submerged weight of 1,814 lb.

53. The slide gate was built as shown in Plates 42 and 43, with seals removed from the gate and stainless steel bearings added outside and downstream in the slot area to minimize friction so that only hydraulic loads would be measured. The slide gate was positioned at various gate openings, and a range of discharges were passed through the culvert with the energy gradient immediately upstream of the gate maintained at approximately 46.3 ft (el 725.0) above the culvert invert (el 678.7). The energy gradient was maintained by means of a control gate at the end of the culvert, approximately 142 ft downstream of the slide gate. Details of the gate slot are shown in Plate 43. Plots of the loads listed in Table 16 permit identification of hoist loads for any slide gate operating schedule with appropriate discharges.

54. Hoist loads on the slide gate were measured by means of a force cell mounted as an integral part of the operating strut immediately above the gate pickup point (Figure 17). The force cell output signal was transmitted through a flexible cable, amplified, and recorded

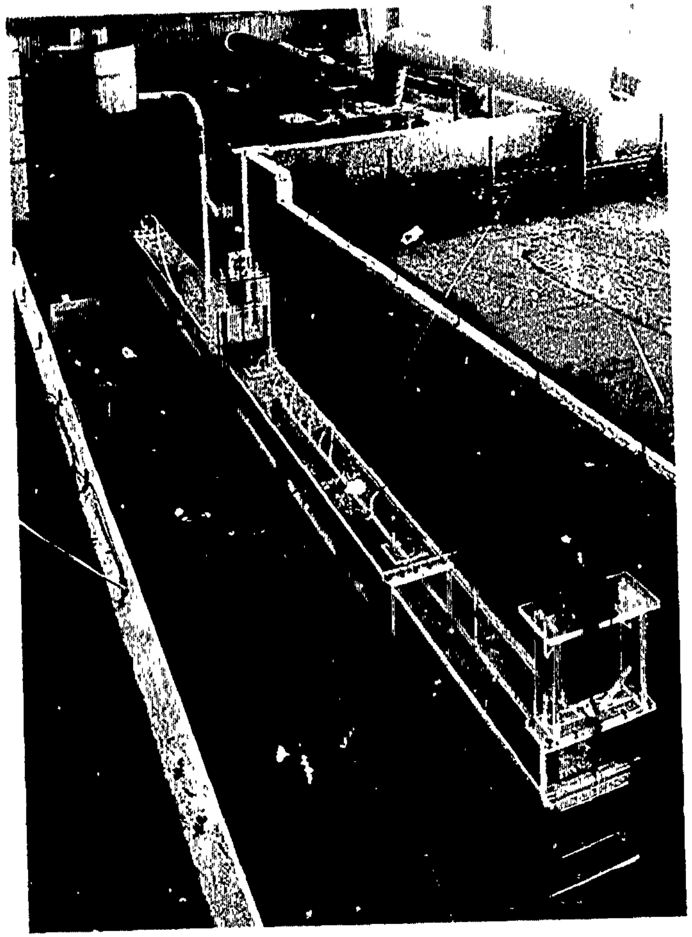

Figure 16. Model control gate, culvert and test section, and headbay tank. Culvert extends 175 ft upstream and 142 ft downstream of slide gate slot

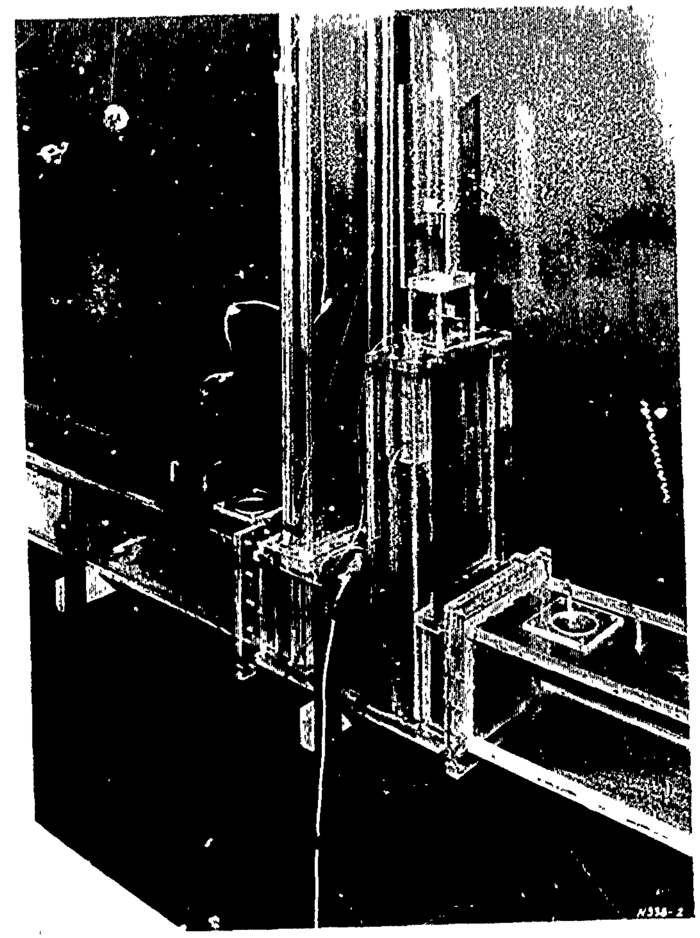

Figure 17. Model test gate installed in test section bulkhead slot

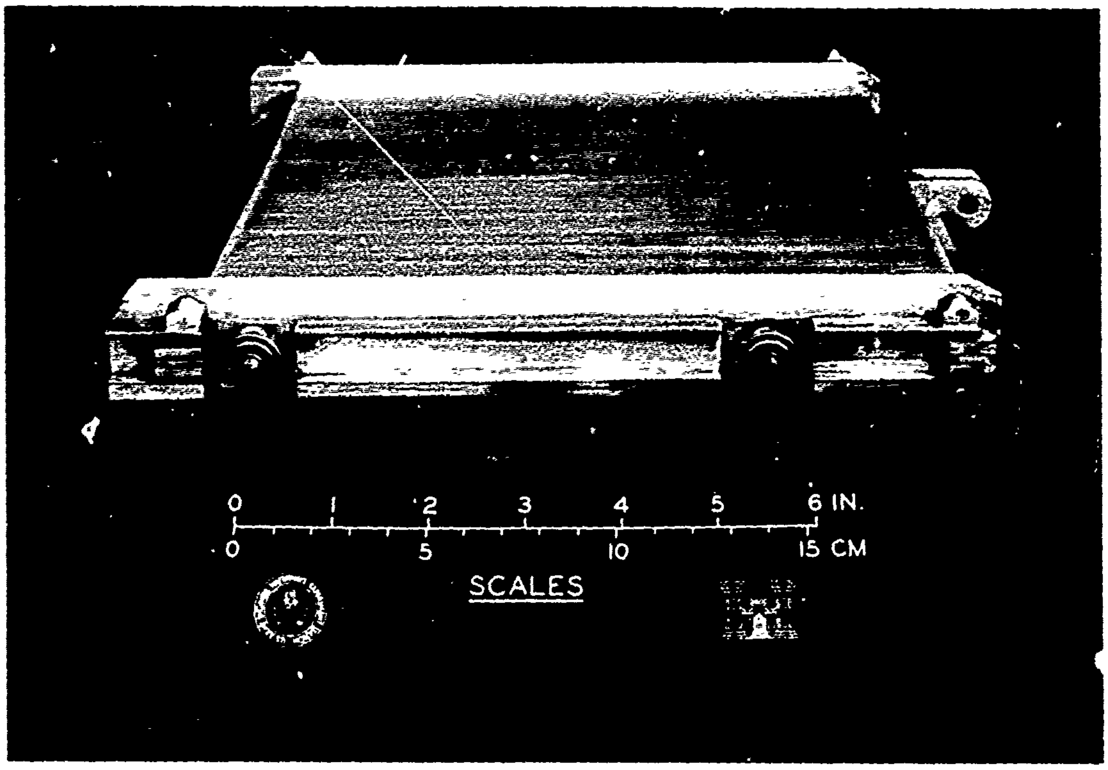

Figure 18. Side view of type 1 (original) slide gate; submerged weight 1,814 lb, dry weight 4,209 lb

on a direct-writing recorder. The operating strut was aligned so that the force along the vertical axis was the only significant component. The electrical cable was attached so that it did not contribute lateral forces on the strut or project into the flow stream.

55. Hoist loads on the slide gate to be expected during normal 4-min gate operation simulating the type 5 filling and emptying cycle are plotted in Plates 57 and 58. Similar hoist loads for the type 6 emptying system for a 4-min valve schedule and normal, single (right) and single (left) culvert operations are plotted in Plates 59-61. The discharge curves in Plates 57-61 were computed from filling and emptying data recorded on the 1:25-scale comprehensive model in which the type 5 and 6 filling and emptying systems were reproduced. Under steady-state conditions, no problems with respect to pressure were observed.

56. A very thorough report was drafted on the subject "Filling and Emptying Valves for Lock No. 1, Mississippi River," by representatives

of the NCS. The report included sections concerned with:

a. Existing conditions

b. Preliminary investigation

c. Hydraulic model study

d. Site inspections

e. Cost comparisons

Conclusions of the report stated: "There is not enough research or experience to indicate whether or not slide gates will perform satisfactorily as filling and emptying gates at Locks and Dam No. 1. On the other hand, tainter valves have been used successfully at numerous Corps of Engineers locks. Reverse tainter valves meet the highest quality of engineering for new or rehabilitated locks. The additional cost for installation of reverse tainter valves is less than 2 percent of the total project cost, which is well within reason for valves of proven performance, minimum required maintenance, and highest quality. Therefore the St. Paul District has recommended that reverse tainter valves be installed in landward locks to replace the existing stoney gate valves during the rehabilitation of Locks and Dam No. 1."

PART IV: DISCUSSION AND RECOMMENDATIONS

57. The existing locks at Locks and Dam No. 1 were constructed between 1929 and 1932. Problems have been experienced with accumulation of ice and debris at the intakes, air entrapment in the culverts of the filling and emptying system, excessive turbulence in the lock chamber during filling, and hazardous conditions downstream from the locks during emptying operations. Also, the stoney gates used for control of filling and emptying, the miter gates, and miter gate operating machinery are in bad condition. Initial investigations and studies indicated that both the landward and riverward locks should be completely rehabilitated. However, later studies recommended that the landward lock be completely rehabilitated and the riverward lock be only partially rehabilitated. Although the riverward lock will not be rehabilitated in the near future, model tests were conducted for both the landward and riverward locks, since those tests had been initiated before the decision was made not to rehabilitate the riverward lock. Also, results of these tests can be used if rehabilitation of the riverward locks becomes feasible in the future.

58. Items that were concerned with improving the hydraulic conditions at the landward lock and recommended from model tests are as follows:

- a. The radius of the nose of the intermediate wall will be increased from 5 ft to 12.5 ft to eliminate vortex tendencies in the upstream approach area.
- b. A new six-port culvert intake manifold will be constructed.
- c. Lowering the existing 9.5-ft-diam culvert invert el 681.2 to invert el 678.7 and changing the culvert shape to 9.5 ft wide by 7.5 ft high resulted in a 1-ft submergence of the culvert roof instead of a 3.5-ft depth of air at the culvert crown at normal lower pool el 687.2.
- d. New sidewall ports 1.5 ft wide by 2.3 ft high will be constructed from the modified 9.5-ft-wide by 7.5-ft-high wall culverts. There will be 19 ports in each culvert spaced 13 ft on centers and staggered in each wall. Because the invert of the culverts is higher than the lock chamber floor, the ports will slope downward. This

slope will extend into the 1-ft-deep trenches in front of each port. The trenches that extend to the center of the lock chamber and terminate vertically are 2.1 ft wide for the land wall ports and 1.88 ft wide for the intermediate wall ports. The difference in width of the trenches is necessary because the port sides expand horizontally on a 1-on-20 slope and the two walls have different thicknesses.

<u>e</u>. A new culvert outlet will be constructed with interlaced laterals in the lower approach area.

<u>f</u>. New reverse tainter filling and emptying valves will be installed. These valves should be designed in accordance with the vertically framed tainter valves developed during model tests of the Holt Lock and should be scheduled to open in 4 min.

<u>g</u>. Twelve-inch-diam air vents will be installed on the center line of the culvert roof about 3.5 ft downstream of the filling and emptying valves. The vents should extend upward to the top of the lock walls and be provided with a control valve which can be locked when set. After the rehabilitation is completed the vents should be adjusted to admit just enough air to preclude cavitation in the low pressure area immediately downstream from the valves without permitting an excessive amount of air and resulting turbulence in the lock chamber. These items were elements of the type 3 system recommended for the landward lock.

59. Rehabilitation of the landward lock as recommended in the type 3 filling and emptying system and operating the culvert tainter valves as recommended will result in a reliable design with satisfactory prototype performance. For normal 37.8-ft head conditions and imposed limitations of 11-ft submergence over the chamber floor and only 1-ft submergence over the sidewall culvert roof at minimum lower pool, the lock can be filled in about 10.2 min or emptied in 10.6 min with a 4-min valve time. In fact, due to differences in friction losses, the prototype lock can be expected to fill or empty about 10 percent faster than the model lock. Longitudinal and transverse hawser forces will be well within the 5-ton limiting criterion for any size tow loaded up to the allowable 9-ft draft. Turbulence in the lock chamber is considered satisfactory and safe for large tows as well as small craft, primarily because of the addition of the trenches in chamber floor at each of the

sidewall ports. There is no indication of any vortex problem in the upstream approach area in the vicinity of the intakes. Flow conditions in the upstream and downstream approaches are good and flow distribution at the intakes and outlets is satisfactory.

60. Since much has been said about the submergence limitations of 11.0 ft, the question of what is the desired submergence in a 56-ft-wide lock with a sidewall port manifold system will be discussed. The greater the submergence, the faster is the permissible filling time. However, in many cases each foot is quite costly and the designer needs to know the minimum submergence at which satisfactory operation can be expected. Data from various width locks indicate that jets from ports expand in an upward direction at the same rate as they expand horizontally. Thus, a clear space between the bottom of the vessel equal to one half the port spacing is required to prevent direct action of the port jets against the bottom of the vessel. In a 56-ft-wide lock designed for 9-ft draft, a submergence of 15.5 ft should be provided (9-ft draft of tow plus 6.5 ft clear under the tow, one half of the 13-ft port spacing). If a greater submergence under the tow is provided, permissible filling times will be shorter; but an increase in clear space under the tow of 100 percent will allow a decrease in permissible filling time of only 10 percent. On the other hand, a decrease in the suggested clear space under the tow of only 20 percent will require a 20 percent increase in permissible filling time. For the case of the landward lock, there was a 69 percent reduction in this desired clearance. This was compensated for, to some degree, by the sloping ports. However, without the port face, port invert extension, and trenches in the chamber floor or some other geometry changes, an acceptable degree of turbulence would have been impossible to obtain. This would have imposed significantly longer filling times for the landward lock. A more thorough treatment of the state of the art and design information on sidewall port lock design is presented in WES Miscellaneous Paper H-75-7.* The total

* T. E. Murphy, "Lock Design, Sidewall Port Filling and Emptying System," Miscellaneous Paper H-75-7, Jul 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

culvert and port throat-area ratio, number, spacing, and longitudinal position of the sidewall port manifold in the chamber were based on these design criteria.

61. The invert of the riverward lock chamber is 2.5 ft higher than the landward lock. As a result there is 8.5 ft of submergence in the lock at minimum lower pool and 1 ft of submergence over the culvert roof. Thus, the barge draft must be reduced to 6.5 ft leaving 2 ft of clearance between the barge tow and chamber invert.

62. The same culvert intake design and culvert modifications, including valves and air vents, recommended for the landward lock were recommended for the riverward lock. Since the culverts, ports, and lock chamber were at the same elevation, the sloping ports and chamber trenches were not necessary for the riverward lock; however, the port size, number, and spacing were the same.

63. The culvert outlet with interlaced laterals in the lower approach used in the landward lock would also be satisfactory for the riverward lock. However, if it is desirable to remove a portion of the emptying discharge away from the lower approach of the lock, the separate outlets developed during the model studies could be used.

64. The slide gates investigated in the 1:25-scale model performed satisfactorily with 2- or 4-min valve times. Hoist loads measured in the 1:10-scale model with the slide gate were satisfactory. Little difference in the hydraulic performance of the lock was detected when either tainter valves or slide gates were used. For reasons stated earlier in this report, the culvert tainter valves will be utilized in the landward lock rehabilitation; and the existing stoney valves removed from the existing landward lock will be used as spare gates and for parts to maintain the existing stoney gates for operating the riverward lock where only minimal rehabilitation is planned.

65. With regard to the minimal rehabilitation of the existing riverward lock and the extremely poor operating characteristics and conditions that will of necessity remain, it is suggested that once final plans are prepared, a review be made of possible improvements which might be accomplished at a minimum cost to improve existing conditions.

One such improvement would be to seal the bulkhead slots upstream of the existing stoney valves that presently (in 1976 observations) are one source of air which could be eliminated. There may be other improvements that could be recognized and corrected by economical means.

66. Generalized tests* were made with the type 6 filling and emptying system for lifts of 30 and 40 ft and submergences of 8.5, 11, 13, and 15 ft over the lock floor. A 6-barge tow at 6.5-ft draft with the upstream end of the tow at sta 0+65 was used to measure hawser forces during filling and emptying with 1-, 2-, and 4-min valve times. Plate 62 is a plot of filling times for 3-, 4-, and 5-ton hawser force limits indicating the effect of submergence and head variations. The filling and emptying times for normal slide gate operation for 30- and 40-ft lifts are also plotted in Plate 62. Hawser forces during all generalized emptying tests were about 3 tons.

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* Funded by CWIS Work Unit No. 31076 "Improved Criteria for Lock Design."

Table 1

Systems Tested and Elements of Systems as Developed

System Type	Filling and Emptying Controls: Filling	Station	Emptying	Station	Sidewall Port Manifold: Type	No. of Ports	Invert: Culvert el	Invert: Chamber el	Sidewall Port Deflectors: Type	Height ft	Length ft	Sidewall Port Radius Removed	Trenches Recessed in Floor: Type	Width ft	Length ft	Depth ft	Outlets Type
Landward Lock																	
Intermediate Wall Nose Type 2 (Recommended)																	
1	Reverse tainter valves	0+94.95B	Reverse tainter valves	4+17.87B	1 (Recommended)	19	678.7	676.2	None			No	None				
2					1 (Recommended)				4 (Recommended)	1.0	4.0	Yes	None				1 (Recommended)
3 (Recommended)					1 (Recommended)				None			Yes	8 (Recommended)	[illegible].1 Landwall 1.88 Intermediate wall	8	1.0	
4					2			678.7	None			No	None				
Riverward Lock																	
Intermediate Wall Nose Type 2 (Recommended)																	
4	Reverse tainter valves	0+94.95B	Reverse tainter valves	4+17.87B	2 (Recommended)	19	678.7	678.7	None			No	None				1 (Recommended)
5	Slide gate	0+85.00B	Slide gate	4+92.00B													2 (Recommended)
6	Slide gate	0+85.00B	Slide gate	3+98.50B													[illegible] (Recommended)

Table 2

Steady-Flow Pressures in Type 1 (Original) Design Filling System

Landward Lock

	Piezometer			
No.	Station	Elevation	Reading	Pressure
	Right Wall Culvert			
	Intake to Filling Valve			
1	0+75.50A	708.7	722.5	13.8
2	0+70.40A		721.5	12.8
3	0+65.25A		719.3	10.6
4	0+62.20A		717.5	8.8
5	0+57.00A		716.1	7.4
6	0+53.90A		715.0	6.3
7	0+48.50A		720.3	11.6
8	0+45.80A		718.1	9.4
9	0+40.50A		716.3	7.6
10	0+37.50A		714.8	6.1
11	0+33.88A		713.8	5.1
12	0+18.50A	708.7 B	713.6	4.9
13		713.7 L	713.5	-0.2
14		718.7 T	714.0	-4.7
15		713.7 R	713.5	-0.2
16	0+44.30B	701.7	712.0	10.3
17	0+46.80B	697.7	712.5	14.8
18	0+72.33B	686.2	706.2	20.0
	Filling Valve			
19	0+91.45B	686.2	706.5	20.3
20	1+04.95B	686.2	706.0	19.8
21	1+09.95B	678.70 B	706.3	27.6
22		682.25 L	706.2	23.95
23		686.20 T	705.7	19.5
24		682.25 R	706.0	23.75
	Sidewall Port Manifold			
1A	1+32.58B	682.45	706.8	24.35
2A	2+09.58B		709.7	27.25
3A	3+00.08B		711.6	29.15
4A	3+73.98B		712.0	29.55

	Piezometer			
No.	Station	Elevation	Reading	Pressure
	Intermediate Wall Culvert			
	Ring Downstream of Intake			
25	0+18.50A	708.7 B	713.9	5.2
26		713.7 L	713.8	0.1
27		718.7 T	714.3	-4.4
28		713.7 R	714.0	0.3
	Ring Downstream of V[illegible]e			
29	1+10.58B	678.7 B	706.9	28.2
30		682.25 L		24.35
31		686.2 T		20.4
32		682.25 R		24.35

Note: Pressures are in prototype feet of water. Test conditions: steady-flow discharge, 2868 cfs; upper pool el, 725.0; lock chamber el, 704.5; filling valves open; upper miter gates closed; emptying valves closed; lower miter gates open.

Table 3

Steady-Flow Pressures in Type 1 (Original) Design Emptying System

Landward Lock

No.	Station	Piezometer Elevation	Piezometer Reading	Pressure
		Right Wall Culvert		
Ring Downstream of Filling Valve				
21	1+09.95B	678.7 B	705.7	27.0
22	↓	682.45 L	705.7	23.25
23	↓	686.2 T	706.1	19.9
24	↓	682.45 R	705.7	23.25
Sidewall Port Manifold				
1B	1+32.58B	680.95	705.5	24.55
2B	2+09.58B	↓	705.0	24.05
3B	3+00.08B	↓	701.2	20.25
4B	3+73.98B	↓	695.0	14.05
Emptying Valve				
1	4+17.87B	686.2	AIR	--
2	4+25.87B	↓	691.0	4.8
3	4+30.87B	↓	690.5	4.3
4	4+35.87B	↓	688.5	2.3
5	4+40.87B	↓	689.5	3.3
6	4+45.87B	↓	688.0	1.8
7	4+50.87B		688.5	2.3
8	4+70.87B	687.7	688.3	9.6
9	↓	682.45	BAD	--
10	↓	686.2	688.3	2.1
11	↓	682.45	688.3	5.85
Outlet				
1	5+15.12B	677.82	680.7	2.88
2	5+18.00B	677.2	690.3	13.1
3	↓	676.2	688.6	12.4
4	↓	670.2	686.1	15.9
5	↓	↓	688.0	17.8
6	↓	↓	688.3	18.1
7	↓		689.0	18.8
8	5+34.00B	686.2	AIR	--
9	5+50.00B	670.2	687.1	16.9
10	5+50.00B	670.2	688.6	18.4
		Right Wall Culvert		
Outlet (Continued)				
11	5+50.00B	670.2	689.2	19.0
12	5+50.00B	670.2	690.2	19.0
13	5+66.00B	686.2	AIR	
14	5+78.00B	677.82	684.8	6.98
15	5+82.00B	677.2	691.3	14.1
16	↓	676.2	690.5	14.3
17	↓	670.2	686.9	16.7
18	↓	↓	686.4	16.2
19	↓	↓	688.1	17.9
20			689.2	19.0
		Intermediate Culvert		
Ring Downstream of Filling Valve				
29	1+10.58B	678.7 B	705.2	26.5
30	↓	682.45 L	705.2	22.75
31	↓	686.2 T	705.1	18.9
32	↓	682.45 R	705.2	22.75
Ring Downstream of Emptying Valve				
21	4+70.50B	678.7	688.5	9.8
22	↓	682.45	BAD	--
23	↓	686.2	688.5	2.3
24	↓	682.45	688.6	6.15

Note: Pressures are in prototype feet of water. Test conditions: steady-flow discharge, 2888 cfs; lock chamber el, 711.2; lower pool el, 687.2; filling valves closed; upper miter gates open; emptying valves open full; lower miter gates closed.

Table 4

Average Piezometer Readings During Filling Operation, Type 3 System, 37.5-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T = 30* LC = 687.5**	T = 60 LC = 688.0	T = 90 LC = 689.3	T = 120 LC = 691.1	T = 150 LC = 693.5	T = 180 LC = 696.5	T = 210 LC = 700.0	T = 240 LC = 703.5	T = 270 LC = 706.6	T = 300 LC = 709.4	T = 330 LC = 712.1	T = 360 LC = 714.3	T = 420 LC = 718.3	T = 480 LC = 721.5	T = 540 LC = 723.4	T = 600 LC = 724.7
Right Wall Culvert																		
Intake to Filling Valve																		
1	0+75.50A	706.7	724.9	724.8	724.1	724.0	723.3	722.4	721.7	721.5	721.9	722.3	722.6	723.2	723.5	724.2	724.5	724.7
2	0+70.40A			724.6	724.0	723.4	722.3	722.0	720.2	720.4	721.1	721.9	722.1	722.6	723.6	724.1	724.6	724.7
3	0+65.25A			724.5	724.0	723.0	721.3	719.4	719.0	718.1	718.9	720.0	720.5	721.3	722.8	723.7	724.4	724.7
4	0+62.20A			724.4	723.7	722.3	720.3	717.5	715.9	716.1	717.4	718.6	719.5	720.5	722.3	723.5	724.3	724.8
5	0+57.00A			724.4	723.6	722.1	719.4	716.9	714.7	714.3	715.5	717.2	718.5	719.5	721.7	723.2	724.2	724.7
6	0+53.90A			724.3	723.2	721.3	718.4	715.2	712.8	713.1	715.0	716.5	718.0	719.1	721.6	723.1	724.1	724.7
7	0+48.50A			724.6	724.0	723.0	721.4	719.6	718.6	718.9	719.8	720.9	721.0	722.8	723.0	723.9	724.5	724.8
8	0+45.80A			724.5	723.8	722.5	720.5	718.1	716.7	716.8	718.0	719.2	719.9	720.7	722.4	723.6	724.4	724.7
9	0+40.50A			724.4	723.3	721.6	719.0	716.6	714.5	714.7	715.9	717.8	718.7	719.5	721.8	723.3	724.1	724.6
10	0+37.50A		724.8	724.2	723.0	720.9	717.9	714.4	713.9	712.8	714.5	716.3	717.7	718.8	721.5	723.0	724.1	724.7
11	0+33.88A		724.8	724.2	723.0	720.9	717.8	714.0	711.7	711.9	713.8	715.7	717.0	718.4	721.0	722.9	724.0	
12	0+18.50A	706.7 B	724.8	724.2	723.1	721.0	717.8	714.1	711.5	711.5	713.4	715.4	716.9	718.2	720.9	722.8	724.0	
13	0+18.50A	713.7 L	724.7	724.1	722.9	720.3	717.1	713.4	711.0	711.7	713.8	715.7	717.2	718.4	721.1	722.5	724.1	
14	0+18.50A	718.7 T	724.8	724.2	723.1	721.1	718.0	714.6	712.0	712.1	713.9	715.9	717.3	718.5	721.1	722.9	724.0	
15	0+18.50A	713.7 T	724.7	724.1	722.9	720.7	717.5	713.7	711.4	711.5	713.6	715.5	717.1	718.2	721.0	722.8	724.0	
16	0+44.30B	701.7	724.3	723.6	722.0	719.3	715.5	711.4	709.1	709.9	712.4	714.4	716.0	717.4	720.5	722.5	723.9	
17	0+46.80B	697.7	724.4	723.8	722.3	719.9	718.4	712.4	705.9	710.3	712.6	714.7	716.3	717.8	720.6	722.7	724.0	724.8
18	0+72.33B	686.2	724.1	723.3	721.3	717.8	712.5	706.7	703.9	701.8	706.9	710.0	712.4	714.5	718.7	721.8	723.7	[illegible]
Culvert Invert at Drop																		
A	0+30.00B	708.7	724.3	723.6	722.3	720.0	716.4	712.7	710.4	711.9	713.3	715.3	716.8	718.2	720.9	722.8	724.0	
B	0+35.00B	708.7		723.5	722.1	719.3	715.3	711.0	708.5	709.4	711.8	714.2	715.9	717.4	720.5	722.6	723.9	
C	0+37.00B	708.7		723.4	721.8	718.5	713.7	708.6	705.6	706.6	709.5	712.1	714.1	716.0	719.7	722.2	723.9	
D	0+39.50B	707.8		723.4	721.7	718.1	712.7	706.8	703.4	704.5	707.6	710.9	713.3	715.3	719.4	722.2	723.8	
E	0+41.25B	705.7		723.4	721.7	715.6	714.2	709.9	707.3	708.3	710.9	713.1	715.0	716.6	719.9	722.3	723.8	
Filling Valve																		
19	0+91.45B	686.2	686.1	683.1	679.9	677.4	676.9	682.1	689.4	702.2	706.4	709.4	711.8	713.9	715.2	721.1	723.2	724.4
20	1+04.95B	686.2	685.2	681.9	678.3	676.7	678.1	687.5	699.5	703.5	706.8	709.8	712.1	714.4	718.6	721.4	723.4	724.5
21	1+09.95B	678.7 B	686.4	683.3	680.3	680.0	682.2	689.2	697.6	702.8	706.2	709.2	711.6	713.8	718.1	721.1	723.2	724.4
22	1+09.95B	682.25B	685.6	682.6	679.4	680.0	683.7	692.8	699.5	703.9	707.0	709.9	712.5	714.5	718.6	721.5	723.5	724.5
23	1+09.95B	686.2 T	686.2	682.3	679.0	679.3	682.6	691.0	698.9	703.0	706.3	709.4	711.9	714.1	718.4	721.3	723.4	724.4
24	1+09.95B	682.25B	686.8	684.7	679.7	679.8	682.7	689.9	698.4	703.1	706.4	709.4	711.9	714.0	718.2	721.4	723.4	724.6
Sidewall Port Manifold																		
1A	1+32.58B	682.45	687.1	687.6	688.1	689.3	692.5	696.2	700.4	704.1	707.4	710.2	712.5	714.5	718.6	721.5	723.4	
2A	2+09.58B		687.0	687.7	689.0	691.4	694.9	698.9	703.5	707.0	709.5	712.1	714.1	715.9	719.3	721.9	723.6	
3A	3+00.08B		687.0	687.5	688.8	691.5	695.3	700.2	705.1	706.6	711.1	713.1	714.9	716.6	719.7	722.0	723.7	
4A	3+73.96B		687.0	687.7	689.2	692.1	696.4	701.5	706.6	709.8	712.1	714.1	715.8	719.4	720.2	722.3	723.8	724.8
Intermediate Wall Culvert																		
Ring Downstream of Intake																		
25	0+18.50A	706.7 B	724.7	724.1	723.1	721.2	718.3	715.1	712.6	712.4	714.1	716.1	717.4	718.5	721.1	722.9	724.0	724.7
26	0+18.50A	713.7 L	724.6	724.0	723.0	721.0	718.0	714.5	712.3	712.3	714.2	716.1	717.5	718.6	721.2	722.9		724.7
27	0+18.50A	718.7 T	724.7	724.1	723.1	721.3	718.4	715.4	712.9	712.9	714.8	716.4	717.5	718.9	721.4	723.0		
28	0+18.50A	713.7 R	724.8	724.1	723.2	721.3	718.3	715.1	712.6	712.5	714.1	715.9	717.3	718.5	721.1	722.9		
Ring Downstream of Valve																		
29	1+10.58B	618.7 B	656.8	683.5	681.6	681.9	684.9	691.6	699.6	704.4	707.2	710.6	712.9	715.0	718.9	721.6	723.4	
30	1+10.58B	682.25L	636.6		681.5	681.8	685.0	692.2	699.3	704.0	707.4	710.3	712.6	714.8	718.8	721.7	723.5	
31	1+10.58B	686.2 T	666.6		680.8	681.1	684.8	692.1	700.2	704.3	707.6	710.5	712.8	714.9	718.8	721.7	723.5	724.5
32	1+10.58B	682.25R	656.7		682.0	681.6	685.1	692.0	699.6	704.2	707.6	710.5	712.8	714.9	718.9	721.6	723.0	724.7

Note: Lock filled in 10.2 min with 4-min valve. The bulkhead slots upstream and downstream of the filling valves were sealed at the roof of the culvert.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 5

Average Piezometer Readings During Emptying Operation, Type 3 System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T = 30* LC = 724.?**	T = 60 LC = 724.2	T = 90 LC = 723.4	T = 120 LC = 722.1	T = 150 LC = 720.0	T = 180 LC = 717.1	T = 210 LC = 714.2	T = 240 LC = 711.2	T = 270 LC = 707.9	T = 300 LC = 704.9	T = 330 LC = 702.1	T = 360 LC = 699.2	T = 420 LC = 695.2	T = 480 LC = 691.7	T = 540 LC = 689.3	T = 600 LC = 687.6
Right Wall Culvert																		
Sidewall Port Manifold																		
1R	1+32.58R	680.95	724.8	724.2	722.7	720.4	716.9	713.1	708.8	704.8	702.0	699.8	697.8	695.8	692.6	690.0	688.2	687.0
2R	2+09.58R			724.0	722.6	720.0	716.7	712.5	707.1	704.2	701.5	699.4	697.5	695.6	692.3	689.9	688.1	
3R	3+00.00R			723.8	721.8	718.8	714.2	709.4	704.1	700.3	698.3	695.7	695.0	694.6	691.1	689.3	688.0	
4R	3+73.98R			723.3	720.7	716.9	710.9	704.8	699.7	694.7	693.2	692.1	691.3	690.6	689.3	688.3	687.5	
Emptying Valve																		
1	4+17.87R	686.2	685.3	681.7	677.[illegible]	674.0	671.3	67[illegible]	676.1	681.6	686.3	686.4	686.6	686.3	686.3	686.[illegible]	686.6	
2	4+25.87R		684.7	681.1	676.7	673.2	670.7	671.8	679.3	688.3	688.1	687.9	687.9	687.7	687.5	687.3	687.[illegible]	
3	4+30.87R		685.0	681.5	677.1	673.7	672.3	676.1	684.6	688.1	688.0	687.8	687.8	687.7	687.5	687.3	687.1	
4	4+35.87R		686.0	682.0	677.8	676.3	676.1	680.8	686.7	688.0	687.9	687.7	687.7	687.6	687.4	687.3	687.1	
5	4+40.87R		687.0	683.3	680.3	679.3	680.0	684.0	687.3	688.0	687.8	687.7	687.6	687.4	687.3	687.2	687.0	
6	4+45.87R		687.4	685.0	683.2	682.0	681.5	685.9	687.7	688.0	687.7	687.7	687.6	687.4		687.2		
7	4+50.87R		687.4	686.6	685.0	684.4	685.3	686.8	687.7	687.8	687.5	687.6	687.6	687.3		687.[illegible]		
8	4+70.37R	678.7 B	687.3	687.6	687.3	687.4	687.1	687.6	687.7	687.7	687.5	687.5	687.4			687.[illegible]		
9	4+70.87R	682.45L																
10	4+73.87R	686.2 T	687.4	687.3	687.6	687.6	687.7	687.8	687.8	687.7	687.4	687.4	687.5					
11	4+70.87R	682.45R	687.5	687.0	687.5	687.6	687.3	687.7	687.7	687.7	687.4	687.4	687.5					
Outlet																		
1	5+19.12R	677.82	687.[illegible]	687.1	686.6	685.8	683.7	682.5	680.8	680.9	681.8	682.8	683.[illegible]	684.2	685.1	686.8	686.5	
2	5+18.00R	677.2		687.3	687.7	688.3	689.0	689.4	689.8	689.9	689.8	689.3	688.7	688.5	688.0	687.7	687.3	687.1
3	5+18.00R	676.2		687.3	687.7	688.1	688.7	688.9	689.0	688.5	688.8	688.2	688.0	687.8	687.8	687.4	687.2	687.0
4	5+18.00R	670.2		687.2	687.1	687.1	686.8	686.5	686.9	685.8	686.0	684.2	686.5	686.5	686.8	686.9	687.1	
5	5+18.00R			687.3	687.3	687.5	687.7	687.8	687.8	687.8	687.7	687.7	687.5	687.4	687.1	687.3	687.0	
6	5+18.00R			687.3	687.3	687.6	687.8	688.0	688.0	688.1	688.0	687.8	687.6	687.4	687.4	687.3	687.0	
7	5+19.00R			687.3	687.4	687.7	688.3	688.7	688.8	688.7	688.6	687.2	688.0	687.8	687.6	687.4	687.0	
8	5+34.00R	686.2		687.5	688.0	688.7	689.6	690.3	690.9	691.0	690.5	690.0	688.6	689.3	688.3	688.0	687.3	687.1
9	5+50.00R	670.2	687.2	687.3	687.3	687.4	687.4	687.3	687.1	687.2	68[illegible].1	687.3	687.3	687.1	687.1	687.1	687.0	687.0
10	5+50.00R			687.3	687.3	687.6	687.9	688.0	688.1	689.3	688.1	688.0	687.8	687.6	687.5	687.3	687.1	687.0
11	5+50.00R			687.3	687.3	687.8	688.1	688.6	688.7	689.0	688.6	688.3	688.1	688.0	687.6	687.4	687.2	686.9
12	5+50.00R			687.4	687.6	688.1	688.7	689.3	689.6	690.0	690.0	689.3	689.0	688.5	688.0	687.6	687.3	687.1
13	5+66.00R	686.2		687.5	688.0	689.3	690.6	691.7	692.8	692.8	692.3	691.5	690.8	690.8	689.3	688.3	687.8	687.2
14	5+78.00R	677.82	687.3	687.3	687.0	686.9	686.5	685.2	691.4	685.5	683.9	684.5	685.2	685.7	686.4	686.6	686.8	686.9
15	5+82.00R	677.2	687.3	687	687.9	688.7	689.7	690.7	690.5	691.0	690.6	690.1	688.7	689.3	688.3	687.9	687.3	687.2
16	5+82.00R	676.2	687.3	687.	687.8	688.3	688.1	690.0	686.9	690.0	689.8	689.7	689.3	689.0	688.0	687.7	687.3	687.1
17	5+82.00R	670.2	687.2	687.2	687.2	687.3	687.1	686.8	687.7	686.8	686.8	687.8	687.0	687.0	687.0	687.0	687.1	
18	5+82.00R		687.2		687.3	687.4	687.5	687.6	687.7	687.5	687.4	687.3	687.6	687.3	687.4	687.2	687.1	
19	5+82.00R		687.2		687.3	687.5	687.8	688.2	688.3	688.1	688.0	687.8	687.7	687.6	687.5	687.5	687.1	
20	5+82.00R		687.4		687.4	687.7	688.3	689.0	689.3	689.1	687.4	688.7	688.5	688.3	687.8	687.3	687.3	
Intermediate Wall Culvert																		
Ring Downstream of Emptying Valve																		
21	4+70.50R	678.7 B	687.4	687.3	687.4	688.3	688.5		688.2	689.0	688.5	688.3	688.2		688.1	687.8	687.1	686.8
22	4+70.50R	682.45L		687.5	687.6	688.6	688.5											
23	4+70.50R	686.2 T		687.6	687.6	688.6	688.8											
24	4+70.50R	682.45R																

Note: Lock empties in 10.2 min with 4-min valve. The bulkheads of emptying valves were open.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 5

Average Piezometer Readings During Filling Operation, Type 4 System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T = 30* LC = 687.7**	T = 60 LC = 588.2	T = 90 LC = 689.5	T = 120 LC = 691.2	T = 150 LC = 693.[illegible]	T = 180 LC = 696.2	T = 210 LC = 699.8	T = 240 LC = 703.3	T = 270 LC = 707.1	T = 300 LC = 710.4	T = 330 LC = 713.3	T = 360 LC = 715.9	T = 420 LC = 719.4	T = 480 LC = 722.2	T = 540 LC = 724.2	T = 600 LC = 725.1
Right Wall Culvert																		
Intake to Filling Valve																		
1	0+75.50A	708.7	724.9	724.8	724.6	724.1	723.5	722.8	722.1	721.7	721.9	722.3	722.9	723.3	724.0	724.5	724.8	725.1
2	0+70.40A			724.6	724.3	723.5	722.3	721.5	720.5	720.4	721.2	721.7	722.5	723.1	723.8	724.3	724.9	
3	0+65.25A			724.5	724.1	723.0	721.4	719.7	718.2	718.1	719.0	720.1	721.1	721.9	723.1	724.2	724.7	
4	0+62.20A			724.4	723.5	722.2	721.1	717.7	715.7	[illegible]6.0	717.1	718.4	719.7	721.0	722.6	724.0	724.7	
5	0+57.00A			724.4	723.4	721.7	719.3	716.9	714.7	[illegible]	715.7	717.2	718.3	720.2	722.1	723.6	724.5	
6	0+53.90A		724.8	724.2	723.1	721.0	718.0	[illegible]	713.1	713.1	714.7	716.7	778.3	719.9	722.1	723.5	724.6	
7	0+48.50A		724.9	724.6	723.9	723.1	721.6	720.2	719.3	719.3	719.9	721.6	721.7	722.4	723.4	724.3	724.8	
8	0+45.80A		724.9	724.6	723.7	722.9	721.3	719.2	717.1	716.7	717.[illegible]	718.6	719.9	721.0	722.7	723.7	724.3	725.0
9	0+40.50A		724.8	724.5	723.4	721.8	719.4	717.2	715.1	714.4	715.7	717.2	718.8	720.1	723.1	723.5	724.5	725.0
10	0+37.50A		724.8	724.2	723.1	720.8	717.7	715.0	712.4	712.4	714.0	716.2	718.0	719.5	721.7	723.4	724.5	725.0
11	0+33.88A		724.8		723.1	720.8	719.1	717.3	713.1	712.2	712.9	714.7	716.6	718.3	720.9	722.9	724.2	724.8
12	0+18.50A	708.7 B	724.7		723.1	720.9	717.9	715.8	711.9	711.4	713.1	[illegible]	717.1	718.7	721.3	723.2	724.5	725.1
13	0+18.50A	713.7 L	724.7		722.8	720.5	717.4	714.1	711.4	711.3	713.2	[illegible]	717.2	719.0	721.4	723.3	724.5	725.1
14	0+18.50A	718.7 T	724.7		723.2	721.2	718.2	715.5	715.1	715.2	716.0	717.1	718.0	718.8	720.4	721.9	723.1	724.7
15	0+18.50A	713.7 R	724.5		723.0	721.5	718.9	716.0	713.9	711.7	712.5	714.3	716.1	718.0	720.7	722.8	724.[illegible]	724.8
16	0+44.30B	701.7	724.4	724.1	722.2	720.3	717.1	713.2	710.1	709.2	711.0	713.3	715.7	717.6	720.6	722.7	724.2	725.0
17	0+46.80B	697.7	724.3	724.0	722.5	720.2	716.9	713.2	710.4	710.0	711.9	714.2	716.2	718.1	721.0	723.1	724.4	725.1
18	0+72.33B	686.2	724.1	723.4	721.2	716.5	712.4	707.2	702.7	702.7	706.1	709.5	712.3	715.2	719.3	722.3	724.2	725.1
Culvert Invert at Drop																		
A	0+30.00B	708.7	724.3	723.7	722.3	719.9	716.7	713.2	710.7	710.8	712.9	715.2	717.0	718.7	721.5	723.3	724.6	721.1
B	0+3[illegible].00B	708.7		723.6	722.1	719.2	715.6	711.7	710.7	709.1	711.5	713.7	716.0	718.0	721.0	723.2	724.5	725.1
C	0+[illegible].00B	708.7		723.5	721.6	718.2	713.8	709.2	705.3	705.7	708.7	711.6	714.2	716.6	720.1	722.7	724.3	
C	0+37.00B	718.7		723.4	722.6	720.5	717.7	715.0	713.9	713.1	714.9	716.7	716.4	719.8	722.0	723.6	724.7	
C	0+37.00B	718.7		723.6	723.0	720.6	71[illegible].0	715.2	713.2	713.4	715.1	717.0	718.3	719.9	722.0	723.4	724.7	
D	0+39.50B	707.8		723.7	721.7	717.8	712.7	707.5	703.1	703.8	706.0	709.2	712.4	715.2	719.5	722.5	724.2	
E	0+41.25B	705.7		723.5	721.8	[illegible]	715.0	710.9	707.7	707.8	71[illegible].4	713.0	713.4	71[illegible].4	720.6	722.9	724.4	
Filling Valve																		
19	0+91.45B	686.2	685.2	682.0	679.0	676.6	676.5	679.9	687.7	701.1	706.2	70[illegible].6	712.3	715.2	719.3	722.2	724.1	725.0
20	1+04.95B	686.2	684.7	681.7	678.9	677.3	679.5	685.0	697.6	702.3	706.1	709.5	712.3	715.2	719.3	722.2	724.1	725.1
21	1+09.95B	678.7 B	684.7	681.6	680.5	680.0	683.6	689.4	698.1	702.7	706.4	709.7	712.5	715.3	719.4	722.3	724.1	724.9
22	1+09.95D	682.25B	684.4	681.5	681.0	679.7	68[illegible]	690.1	698.3	702.8	706.5	709.8	712.6	715.4	719.4	722.1	724.2	725.1
23	1+09.95B	686.2 T	684.2	681.4	680.1	679.4	683.6	690.1	698.6	702.3	705.9	709.5	712.4	715.2	719.4	721.3	724.2	725.1
24	1+09.95B	682.25B	685.9	682.7	681.0	680.0	68[illegible].7	688.0	696.5	701.4	705.4	708.8	711.8	714.5	718.7	721.7	723.7	724.9
Sidewall Port Manifold																		
1A	1+32.58B	682.45	687.5	687.6	687.8	689.7	692.9	696.2	700.7	704.5	707.9	711.0	71[illegible].5	716.1	719.8	722.4	724.2	725.0
2A	2+09.58B		687.5	683.2	690.0	692.6	695.7	699.4	703.8	707.4	71[illegible].2	713.0	715.1	717.3	720.6	722.8	724.3	725.0
3A	3+00.08B		686.3	688.2	690.1	693.1	696.7	701.1	706.3	709.4	712.1	714.4	716.4	718.2	721.0	722.9	724.4	725.1
4A	3+73.98B		686.3	688.3	690.3	693.4	697.2	702.9	707.3	710.1	712.7	715.1	716.8	718.6	721.2	723.1	724.6	725.2
Intermediate Wall Culvert																		
Ring Downstream of Intake																		
25	0+18.50A	708.7 B	724.8	724.1	722.9	720.6	717.7	714.6	711.8	711.7	713.7	715.7	717.4	719.1	721.7	723.4	724.6	725.1
26	0+18.50A	713.7 L	724.7		723.0	720.7	717.7	714.3	711.7	711.5	713.2	715.5	717.2	718.9	721.6	723.3	724.5	
27	0+18.50A	718.7 T	724.7		723.0	720.7	718.0	714.9	712.3	712.2	713.9	716.0	717.7	719.4	721.7	723.4	724.6	
28	0+18.50A	713.7 R	724.7		723.2	721.0	718.2	715.0	712.2	711.6	713.1	715.3	717.2	718.8	721.5	721.2	724.5	
Ring Downstream of Valve																		
29	1+10.58B	678.7 B	684.6	682.8	681.6	682.0	684.7	690.7	698.6	703.1	706.7	710.2	713.0	715.7	719.7	722.4	724.2	
30	1+10.58B	682.25L	685.0	683.0	681.2	681.7	684.2	689.0	697.7	702.1	705.9	709.4	712.4	715.2	719.4	722.2		
31	1+10.58B	686.2 T	684.7	682.7	680.7	681.3	684.6	691.0	699.1	702.8	706.4	710.0	712.7	715.5	719.4	722.3		
32	1+10.58B	682.25R	684.3	682.9	681.6	682.2	685.2	690.7	69[illegible].3	702.8	706.5	710.0	712.8	715.3	719.5	722.4		

Note. Lock filled in 9.8 min with 4-min valve. The bulkhead slots upstream and downstream of the filling valves were sealed at the roof of the culvert.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 7

Average Piezometer Readings During Emptying Operation, Type 4 System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water						
No.	Station	Elevation	T = 30* LC = 724.9**	T = 60 LC = 724.4	T = 90 LC = 723.3	T = 120 LC = 721.7	T = 150 LC = 719.7	T = 180 LC = 716.8	T = 210 LC = 713.5
Right Wall Culvert Sidewall Port Manifold									
1B	1+32.58B	680.95	724.9	724.2	722.4	720.0	716.4	712.0	707.4
2B	2+09.58B		725.0	724.2	722.6	720.1	716.7	712.2	707.7
3B	3+00.08B		724.7	723.7	721.4	718.6	715.2	709.2	704.3
4B	3+73.98B		724.6	723.2	720.2	716.7	713.1	704.6	699.2
Emptying Valve									
1	4+17.87B	686.2	685.2	680.8	675.9	672.5	670.6	672.0	677.2
2	4+25.87B		684.9	680.3	675.2	672.0	670.1	673.4	685.3
3	4+30.87B		685.2	680.3	675.8	673.1	672.9	680.5	687.7
4	4+35.87B		686.6	681.0	677.2	675.6	678.2	685.4	688.2
5	4+40.87B		687.2	682.7	680.0	679.2	682.7	687.0	688.3
6	4+45.87B		687.2	685.1	682.6	682.2	685.2	687.6	688.3
7	4+50.87B		687.3	686.7	685.1	685.2	686.3	687.7	688.2
8	4+70.87B	678.7 B	687.3	687.5	687.4	687.4	687.3	687.8	687.7
9	4+70.87B	682.45L							
10	4+70.87B	686.2 T	687.4	687.5	687.6	687.7	688.0	688.0	687.9
11	4+70.87B	682.45R	687.4	687.6	687.5	687.6	687.9	688.0	688.0
Outlet									
1	5+15.12B	677.82	687.2	687.2	686.3	685.3	683.2	681.2	677.0
2	5+18.00B	677.2		687.8	688.1	688.6	688.3	690.1	690.5
3	5+18.00B	676.2		687.8	688.0	688.4	689.0	689.2	689.9
4	5+18.00B	670.2		687.4	687.2	687.3	686.9	686.4	686.2
5	5+18.00B			687.5	687.5	687.7	687.9	688.1	688.2
6	5+18.00B		687.3	687.5	687.5	687.8	688.2	688.2	688.5
7	5+18.00B			687.5	687.8	688.1	688.5	689.0	689.5
8	5+34.00B	686.2		687.8	687.3	688.8	689.8	690.7	691.2
9	5+50.00B	670.2		687.5	687.4	687.6	687.6	687.5	687.5
10	5+50.00B				687.6	687.9	638.3	688.6	688.8
11	5+50.00B				687.7	688.1	688.6	689.1	689.2
12	5+50.00B				687.9	688.5	689.2	690.0	690.3
13	5+66.00B	686.2		687.8	687.4	688.9	690.2	691.7	692.2
14	5+78.00B	677.82		687.5	687.2	686.7	685.2	685.9	684.9
15	5+82.00B	677.2	687.0	687.3	687.8	688.5	689.6	690.9	690.3
16	5+82.00B	676.2	687.3	687.7	687.2	688.7	689.5	690.5	689.2
17	5+82.00B	670.2		687.5	687.5	687.5	687.5	687.2	686.9
18	5+82.00B				687.5	687.6	687.8	687.2	687.6
19	5+82.00B				687.6	687.7	688.1	683.3	688.3
20	5+82.00B				687.8	688.2	688.8	689.4	689.5
Intermediate Wall Culvert Ring Downstream of Emptying Valve									
21	4+70.50B	678.7 B	687.5	687.8	687.7	687.8	688.4	688.4	688.4
22	4+70.50B	682.45L			687.7	687.9		688.5	688.5
23	4+70.50B	686.2 T			687.8	687.9		688.6	688.6
24	4+70.50B	682.45R							

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water								
No.	Station	Elevation	T = 240 LC = 709.7	T = 270 LC = 706.1	T = 300 LC = 702.7	T = 330 LC = 700.0	T = 360 LC = 697.2	T = 420 LC = 693.1	T = 480 LC = 689.8	T = 540 LC = 688.0	T = 600 LC = 6[illegible].9
Right Wall Culvert Sidewall Port Manifold											
1B	1+32.58B	680.95	703.6	700.6	698.4	696.2	694.2	691.3	688.9	687.5	6.7
2B	2+09.58B		703.7	700.5	[illegible].5	695.9	694.3	691.4	689.1	687.6	6.9
3B	3+00.08B		701.7	698.2	696.4	694.7	693.1	690.6	688.5	687.4	686.9
4B	3+73.98B		695.6	693.9	692.9	691.7	690.7	689.1	688.0	687.2	686.9
Emptying Valve											
1	4+17.87B	686.2	686.1	687.3	687.3	687.3	687.2	687.2	687.0	686.9	686.8
2	4+25.87B		688.3	688.0	687.9	687.8	687.6	684.4	687.2	687.1	687.0
3	4+30.87B		688.2	687.9	687.8	687.7	687.7	687.4		687.2	686.9
4	4+35.87B		688.2	687.8	687.7	687.7	687.6				686.9
5	4+40.87B		688.1	687.8	687.7	687.7	687.6				687.0
6	4+45.87B		688.1	687.7	687.7	687.6	687.5				687.0
7	4+50.87B		687.8	687.5	687.5	687.4	687.4				687.1
8	4+70.87B	678.7 B	687.5	687.3	687.2	687.2	687.3				
9	4+70.87B	682.45L									
10	4+70.87B	686.2 T	687.6	687.3	687.5	687.4	687.4				
11	4+70.87B	682.45R	687.6	687.4	687.4	687.4	687.4				
Outlet											
1	5+15.12B	677.82	678.1	680.7	681.3	682.4	684.0	685.3	686.3	686.9	687.2
2	5+18.00B	677.2	690.7	690.3	689.8	689.3	688.8	688.3	687.8	687.4	
3	5+18.00B	676.2	689.5	689.1	688.8	688.4	688.2	687.9	687.6	687.3	
4	5+18.00B	670.2	686.1	686.3	686.3	686.5	686.7	687.0	687.2	687.2	
5	5+18.00B		688.1	687.9	687.8	687.8	687.6	687.5	687.4	687.3	
6	5+18.00B		688.5	688.2	688.2	687.9	687.8	686.6	687.4	687.3	
7	5+18.00B		689.3	688.8	688.7	688.4	688.2	687.8	687.5	687.3	
8	5+34.00B	686.2	691.3	690.7	690.3	689.7	689.3	688.4	687.8	687.5	
9	5+50.00B	670.2	687.6	687.5	687.5	687.5	687.5	687.4	637.3	687.3	
10	5+50.00B		688.6	688.2	688.3	688.2	687.9	687.6	687.4		
11	5+50.00B		689.1	688.8	688.5	688.3	688.1	687.8	687.5		
12	5+50.00B		690.0	689.6	689.2	688.9	688.5	688.1	687.6		
13	5+66.00B	686.2	692.8	692.6	692.2	691.6	690.8	689.4	688.5	687.9	687.5
14	5+78.00B	677.82	684.4	684.3	685.1	686.1	686.1	686.6	687.1	687.2	687.2
15	5+82.00B	677.2	691.4	690.7	690.2	689.6	689.1	688.3	687.6	687.2	687.0
16	5+82.00B	676.2	690.8	690.3	689.8	689.3	689.0	688.3	687.7	687.2	687.3
17	5+82.00B	670.2	687.1	686.8	687.0	687.1	687.2	687.2	687.2	687.3	687.2
18	5+82.00B		687.6	687.5	687.5	687.5	687.4	687.3	687.3	687.3	687.2
19	5+82.00B		688.5	688.1	688.1	687.8	687.8	688.6	687.3	687.3	687.2
20	5+82.00B		689.7	689.3	689.0	688.7	688.4	687.9	687.5	687.4	687.3
Intermediate Wall Culvert Ring Downstream of Emptying Valve											
21	4+70.50B	678.7 B	688.1	688.8	687.8	687.7	687.6	687.5	687.3	687.2	687.1
22	4+70.50B	682.45L	688.2		687.8	687.8					
23	4+70.50B	686.2 T	688.2		687.9	687.8					
24	4+70.50B	682.45R									

Note: Lock empties in 9.9 min with 4-min valve. The bulkheads at emptying valves open.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 8

Average Piezometer Readings During Filling Operation, Type 5 (with Slide Gates) System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T = 30* LC = 687.7**	T = 60 LC = 688.6	T = 90 LC = 690.1	T = 120 LC = 692.4	T = 150 LC = 695.3	T = 180 LC = 698.5	T = 210 LC = 702.0	T = 240 LC = 705.6	T = 270 LC = 709.1	T = 300 LC = 711.9	T = 330 LC = 714.6	T = 360 LC = 717.1	T = 420 LC = 720.9	T = 480 LC = 723.8	T = 540 LC = 725.4	T = 600 LC = 726.1
Right Wall Culvert																		
Intake To Filling Valve																		
1	0+75.50A	708.7	724.8	724.5	724.0	722.2	722.8	722.0	721.9	722.0	722.5	723.2	723.4	723.9	724.2	724.8	725.0	725.0
2	0+70.40A		724.8	724.2	723.5	722.8	721.8	721.0	720.5	721.0	721.6	722.5	723.0	723.4	724.1	724.7		725.0
3	0+62.20A		724.9	724.1	723.2	721.8	720.3	718.9	718.3	718.6	719.6	720.8	721.6	722.2	723.5	724.5		725.0
4	0+53.90A		725.0	724.0	722.7	720.9	719.0	717.3	716.5	717.0	718.2	719.5	720.7	721.7	723.2	724.4		725.1
5	0+45.80A		725.0	724.0	722.4	720.3	718.2	716.0	715.0	715.5	717.0	718.4	719.8	721.0	723.0	724.2	724.9	
6	0+37.70A		724.6	723.5	721.8	719.4	717.0	714.9	714.0	714.5	716.2	718.0	719.8	720.9	722.8	724.1	724.0	
7	0+65.25A		724.9	724.2	723.2	721.9	720.9	719.7	719.2	719.9	720.8	721.5	722.1	722.9	723.9	724.7	725.0	
8	0+57.00A		724.8	724.0	722.6	720.9	719.2	717.9	718.5	717.8	718.9	720.0	720.9	722.0	723.5	724.5	725.0	
9	0+48.50A		724.6	723.6	722.0	719.8	718.0	716.2	715.0	716.9	717.6	719.0	720.1	721.1	723.0	724.3	724.9	
10	0+40.50A		724.5	723.3	721.3	718.7	716.2	714.0	713.5	713.9	716.0	717.5	719.7	720.6	722.5	724.3	724.0	725.2
11	0+30.90A		724.5	723.2	721.1	718.4	715.8	713.4	712.6	713.5	715.4	717.4	719.0	720.5		724.1	724.0	
12	0+18.50A	708.7 B	724.4	723.0	720.9	718.1	715.6	713.0	712.4	713.1	715.3	717.3	718.9	720.4		724.1	725.0	
13	0+18.50A	713.7 L	724.5	723.1	721.0	718.1	715.4	713.0	712.3	713.0	715.2	717.2	718.8	720.4		724.2		
14	0+18.50A	718.7 T	724.6	723.2	721.2	718.5	716.0	713.6	713.0	713.8	715.8	717.6	719.1	720.6	722.6	724.2		
15	0+18.50A	713.7 R	724.5	723.1	721.0	718.2	715.5	713.0	712.3	713.1	715.1	717.1	718.8	720.3	722.5	724.2		
16	0+44.30B	702.03	724.4	722.8	720.3	717.3	714.4	711.5	710.7	711.5	714.0	716.1	718.0	719.7	722.1	724.0		
17	0+46.80B	697.78	724.3	722.7	720.3	717.4	714.6	712.0	711.2	712.2	714.5	716.6	718.2	720.0	722.4	724.1		
18	0+72.33B	686.31	724.1	722.2	719.2	715.5	711.4	707.0	705.3	706.0	708.8	712.2	715.0	717.3	720.9	723.5	724.8	725.0
18-A	0+77.00B	686.2	724.0	722.0	719.0	715.1	711.1	707.4	706.0	707.0	710.2	713.2	715.6	718.0	721.1	723.8	725.0	
Culvert Invert Drop																		
A	0+30.00B	708.7	724.2	722.8	720.5	717.7	715.0	712.5	711.7	712.6	715.0	717.0	718.7	720.2	722.4	724.1	725.0	
B	0+35.00B	708.7	724.2	722.6	720.0	716.9	713.5	710.8	710.0	711.0	713.5	716.0	718.0	719.7	722.1	724.0		
C	0+37.00B	708.7	724.1	722.2	719.1	715.5	711.5	708.2	707.2	708.4	711.5	714.2	716.5	718.5	722.6	723.9		
C' TE	0+37.00B	718.7	724.4	723.0	721.0	718.6	716.5	714.3	714.0	714.8	716.6	718.2	719.8	721.0	723.0	724.3		
C T LT	0+37.00B	718.7	724.4	723.2	721.2	718.9	716.7	714.6	714.2	715.0	716.9	718.3	719.9	721.0	723.0	724.3		
D	0+39.50B	708.17	724.1	722.1	718.6	714.2	709.7	705.8	704.6	706.0	709.5	712.8	715.3	717.8	721.4	723.9		
E	0+41.25B	708.08	724.1	722.2	719.5	716.0	712.9	709.8	709.1	710.3	713.0	715.4	717.3	719.1	722.9	724.0		
Filling Valve																		
19	0+87.00B	686.2	683.5	679.2	676.3	676.2	679.5	686.0	694.0	706.2	709.6	712.8	715.3	717.7	721.0	723.6		
20	0+95.00B	686.2	683.2	678.5	675.5	675.5	679.0	687.6	701.2	706.1	709.5	712.7	715.2	717.7				
21	1+00.00B	678.7 B	683.4	679.5	676.9	678.0	688.2	693.0	701.7	706.4	709.7	712.8	715.2	717.6			724.9	
22	1+00.00B	682.45L	683.2	679.0	676.8	677.8	683.5	693.2	702.0	706.5	709.8	712.9	715.4	717.8			725.0	
23	1+00.00B	686.2 T	683.5	679.2	676.0	676.6	682.0	692.5	701.9	705.7	709.0	712.3	715.0	717.4		723.5	724.9	
24	1+00.00B	682.45R	683.6	679.5	676.8	677.0	682.1	692.6	701.2	705.8	709.2	712.4		717.5		723.6		
25	1+05.00B	686.2	683.8	679.6	677.6	687.0	688.6	697.0	702.5	705.9	709.1	712.4		717.6		723.5		
26	1+10.00B	686.2	684.0	681.0	681.2	685.0	691.2	697.6	702.0	705.6	709.0	712.3		717.4		723.6		
Sidewall Port Manifold																		
1A	1+32.58B	682.5	687.8	688.4	690.7	693.2	696.4	701.0	705.0	708.4	711.5	714.2	716.5	718.3	721.4	723.7		725.1
2A	2+09.08B		687.9	689.4	692.0	695.1	699.0	703.5	707.2	710.6	713.1	715.5	717.3	719.0	721.7	723.8		
3A	3+00.08B		687.5	689.1	691.8	695.4	700.0	705.0	708.9	712.0	714.5	716.5	718.1	719.8	722.1	723.9	725.0	
4A	3+73.98B		687.5	689.2	692.1	696.0	700.6	705.7	709.5	712.5	715.0	717.0	718.6	720.1	722.4	724.0		
5A	4+05.50B		687.6	689.1	692.0	695.7	700.4	705.5	709.3	712.4	714.9	717.0	718.5	720.0	722.3	724.0		
Intermediate Wall Culvert																		
Ring Downstream of Intake																		
27	0+18.50B	708.7 B	724.5	722.7	720.4	717.5	715.0	712.6	712.2	713.5	715.5	717.4	718.9	720.4	722.6	724.1		
28	0+18.50B	713.7 L		722.6	720.2	717.3	714.5	712.2	712.0	713.0	715.3	717.1	718.9	720.3	722.6	724.1		
29	0+18.50B	718.7 T		723.4	721.4	718.5	715.9	713.1	712.2	712.8	714.7	716.8	718.3	720.0	722.2	723.9		
30	0+18.50B	713.7 R		722.8	720.4	717.5	714.7	712.2	711.9	713.0	715.3	717.1	718.8	720.3	722.6	724.1		
Ring Downstream of Filling Valve																		
31	1+00.00B	678.7 B	683.8	680.2	678.1	678.8	684.8	694.5	702.2	706.5	709.8	713.0	715.4	717.9	721.2	723.8		725.0
32	1+00.00B	682.45B	682.7	678.2	676.7	677.2	683.8	695.0	701.9	705.8	709.3	712.5	715.1	717.7	721.1			
33	1+00.00B	686.2 T	682.8	678.3	675.8	678.9	683.2	695.0	702.0	705.6	709.2	712.5	715.1	717.6	721.0			
34	1+00.00B	682.45L																

Note: Lock filled in 8.7 min with 4-min valve (constant speed gate opening). The bulkhead slots upstream and downstream of the filling valves were sealed at the roof of the culvert.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 9

Average Piezometer Readings During Emptying Operation, Type 5 (with Slide Gates) System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T = 30* LC = 724.7**	T = 60 LC = 724.0	T = 90 LC = 722.6	T = 120 LC = 720.4	T = 150 LC = 718.1	T = 180 LC = 715.1	T = 210 LC = 711.9	T = 240 LC = 708.3	T = 270 LC = 705.1	T = 300 LC = 702.0	T = 330 LC = 699.0	T = 360 LC = 696.5	T = 420 LC = 694.2	T = 480 LC = 689.1	T = 540 LC = 687.2	T = 600 LC = 686.0
Right Wall Culvert																		
Sidewall Port Manifold																		
1B	1+32.58B	680.95	725.0	723.5	721.5	718.5	713.8	710.3	705.1	702.3	699.5	697.0	694.9	693.0	690.2	688.3	687.0	686.8
2B	2+09.08B		725.0	723.5	721.4	718.3	713.3	709.8	704.8	702.0	699.3	696.8	694.8	693.0	690.1	688.3		686.9
3B	3+00.08B		724.8	723.0	720.4	718.0	711.5	707.7	702.3	699.8	697.3	695.2	693.5	692.0	689.7	688.1		686.9
4B	3+73.98B		724.4	722.0	718.8	714.4	707.5	702.8	696.8	694.5	693.0	691.8	690.8	689.9	688.7	687.6		686.9
5B	4+05.50B		724.2	721.5	717.6	712.5	704.3	699.0	692.4	690.0	669.1	688.8	688.1	687.9	686.2	686.8	686.3	686.3
Culvert Slide Gate																		
1	4+65.50B	678.7 B	724.2	721.8	718.0	713.0	704.5	698.8	691.5	688.8	687.7	687.4	687.2	687.2	686.2	687.1	687.0	687.0
2	4+65.50B	682.45L																
3	4+65.50B	686.2 T	724.1	721.4	717.7	712.5	703.9	698.3	691.2	688.7	687.9	687.8	687.6	687.7	686.3	687.2		
4	4+65.50B	682.45R	724.0	721.0	717.0	711.7	703.0	697.4	690.5	688.3	687.8	687.8	687.6	687.7	686.3	687.2		
5	4+94.00B	686.2	685.2	781.9	680.2	679.0	677.9	677.4	680.0	687.0	687.0	687.1	687.1	687.2	686.1	687.1		
6	5+01.75B		685.0	781.0	680.0	679.0	678.0	679.8	687.0	687.2	687.0	687.0	687.1	687.2	686.2	687.1		
7	5+06.75B		684.2	780.1	680.3	680.2	682.5	686.5	685.2	685.0	685.2	685.7	686.0	686.8	686.8	687.0		
8	5+11.75B		684.7	782.1	682.7	684.6	687.5	688.5	688.0	687.7	687.5	687.5	687.3	687.5	686.2	687.2		
Outlet																		
1	5+14.10B	677.82	687.0	686.5	686.8	687.1	687.4	687.2	684.2	682.0	682.0	682.8	684.0	685.0	686.0	686.7		
2	5+18.00B	677.2		686.5	686.8	687.0	687.9	688.4	691.2	691.0	690.1	689.6	689.0	688.8	688.0	687.5	687.1	
3	5+18.00B	676.2		687.0	686.9	687.7	687.2	688.5	689.0	689.1	688.8	688.7	688.1	688.0	687.5	687.3	687.0	
4	5+18.00B	670.2		687.0	686.9	687.8	687.0	687.8	687.0	687.7	686.6	686.7	686.8	687.0	687.0	687.1		
5	5+18.00B		687.2	687.1	687.3		687.0	688.0	688.0	688.0	687.8	687.7	687.6	687.5	687.3	687.1		
6	5+18.00B		687.2	687.2	687.3		688.0	688.1	688.2	688.2	688.0	687.9	687.8	687.6	687.3	687.1		
7	5+18.00B		687.2	687.3	687.4		688.0	688.2	688.8	688.9	688.6	688.5	688.0	687.9	687.5	687.2		
8	5+34.00B	678.7	687.4	688.4	690.7	691.0	692.0	692.6	691.8	691.5	690.6	689.9	689.3	689.0	688.0	687.6		
9	5+50.00B	670.2	687.5	687.3	687.2	687.0	687.0	696.0	687.6	687.5	687.5	687.3	687.2	687.3	687.2	687.1		
10	5+50.00B			687.5	687.5	688.0	688.0	687.2	688.5	688.5	688.2	688.0	687.8	687.7	687.4	687.1		
11	5+50.00B			687.7	687.9	688.5	689.0	689.1	689.4	689.2	688.9	688.5	688.2	688.0	687.6	687.2		
12	5+50.00B			687.6	688.4	689.3	690.0	690.2	690.2	690.0	689.5	689.1	688.8	688.2	687.9	687.4	687.1	
13	5+66.00B	678.7	687.6	689.9	692.2	694.0	695.5	696.0	695.2	694.0	692.5	691.3	690.7	689.8	689.5	687.7	687.2	
14	5+78.10B	677.82	687.6	686.8	685.5	684.5	683.8	683.0	685.8	684.5	685.0	685.3	685.5	686.3	687.6	687.0	687.0	
15	5+82.00B	677.2	687.8	689.5	691.3	692.3	693.5	693.8	692.3	691.5	690.7	689.9	689.8	688.8	689.0	687.7	687.2	
16	5+82.00B	676.2	687.7	689.0	690.2	691.3	692.3	692.5	691.0	690.5	690.0	689.5	689.1	688.3	688.9	687.5	687.1	
17	5+82.00B	670.2	687.5	687.5	687.0	686.7	686.5	686.5	686.4	686.5	686.7	686.8	687.0	687.0	687.0	687.0	687.0	
18	5+82.00B			687.5	687.5	687.6	687.5	687.6	687.5	687.5	687.3	687.2	687.3	687.3	687.2	687.2	687.0	
19	5+82.00B			687.8	688.0	688.3	688.5	688.7	688.5	688.4	688.0	687.9	687.7	687.6	688.3	687.2	687.0	
20	5+82.00B			688.2	689.2	689.8	690.4	690.5	690.0	689.7	689.2	688.9	688.5	688.1	687.7	687.3	687.2	
Intermediate Wall Culvert																		
Ring Downstream of																		
Sidewall Port Manifold																		
21	4+65.50	678.7 B	724.0	720.8	716.3	710.0	701.0	695.5	689.5	687.4	687.4	687.2	687.2	687.2	687.2	687.2	687.0	
22	4+65.50	682.45L	723.9	720.5	716.0	708.5	700.5	695.2	689.1	687.3	687.4	687.2	687.2	687.2	687.2	687.1	687.0	
23	4+65.50	686.2 T	723.9	720.7	716.2	710.5	701.8	696.5	690.4	688.8	688.5	688.2	688.2	688.1	688.0	688.0	687.7	687.7
24	4+65.50	682.45R																

Note: Lock empties in 9.0 min with 4-min valve (constant speed gate opening). The bulkhead [illegible]

* T denotes time (in prototype [illegible]

Table 10

Visual Observations of Water Surface in Bulkhead Slots

Immediately Upstream of Slide Gates During

Filling and Emptying Operations

Type 5 System

Slide Gate Operation	Valve Time, V_t min	Upstream Bulkhead Slot Water-Surface El ft, msl	Upstream Bulkhead Slot Time of Occurrence min*
Normal Filling			
	2	701.0	2.2
	4	706.0	3.8
	6	710.0	5.2
	8	712.0	6.0
Normal Emptying			
	2	686.2**	2.0
	4	686.2**	3.4
	6	686.2**	5.1
	8	686.2**	7.0
Single (Right) Culvert Filling			
	2	695.0	1.5
	4	697.2	4.1
	6	702.5	6.2
	8	705.0	7.3
Single (Right) Culvert Emptying			
	2	686.2**	1.9
	4	686.2**	3.2
	6	686.2**	5.4
	8	686.2**	7.1

Note: Initial conditions 37.8-ft head (upper pool el 725.0, lower pool el 687.2). Slide gates open at constant speed. Bulkhead slots downstream of slide gates sealed at roof of culvert.

* Time after slide gates begin opening.

** Roof of culverts at el 686.2

Table 11

Steady-Flow Pressures in Type 6 Design Emptying System

Riverwood Lock

Intermediate Wall (Right Culvert)

Piezometer No.	Piezometer Station	Piezometer Elevation	msl Reading	Pressure
Sidewall Port Manifold				
1B	1+32.58	680.95	701.8	20.85
2B	2+09.08		701.6	20.65
3B	3+00.08		699.4	18.45
4B	3+73.98		694.5	13.45
Culvert Slide Gate				
1	3+91.50	686.2	690.1	3.9
2	4+00.50	686.2	690.0	3.8
3	4+08.50	686.2	689.8	3.6
4	4+13.50	687.7 B	691.5	12.8
5	4+13.50	682.45 R	689.7	7.25
6	4+13.50	686.2 T		3.5
7	4+18.50	686.2		3.5
8	4+23.50	686.2		3.5
9	4+65.50	678.7 B	688.7	10.0
10	4+65.50	686.2 T	688.7	2.5
Outlet				
1	5+11.50	678.7	687.5	8.8
2	5+11.50	686.2	687.9	1.7
3	5+25.20	677.9	678.8	0.9
4	5+29.00	677.2	689.7	12.5
5		674.1	690.2	16.1
6		672.2	686.2	14.0
7			687.7	15.2
8			688.3	16.1
9			689.0	16.8
10	5+57.20	677.9	687.5	9.6
11	5+61.00	677.2	689.8	12.6
12		674.1	689.8	15.7
13		672.2	687.0	14.8
14			687.5	15.3
15			688.1	15.9
16			688.5	16.3

Riverward Wall (Left Culvert)

Piezometer No.	Piezometer Station	Piezometer Elevation	msl Reading	Pressure
Sidewall Port Manifold				
1C	1+32.58	680.95	701.2	20.25
2C	2+09.08		701.0	20.05
3C	3+00.08		697.5	16.55
4C	3+73.98		691.5	10.55
Culvert Slide Gate				
1	4+13.50	678.7 B	685.5	6.80
2	4+13.50	682.45 L	685.5	3.05
3	4+13.50	686.2 T	685.0	-1.2
4	4+65.5	678.7 B	683.7	5.0
5	4+65.5	686.2 T	683.7	-2.5
Outlet				
1	4+94.00	678.7 B	684.8	6.1
2	4+94.00	686.2 T	684.7	-1.5
3	4+94.00	675.5 B	684.4	8.9
4	4+89.25	678.2 R	684.3	6.1
5	4+94.00	682.97 T	684.0	1.03
6	4+98.75	678.2 L	684.3	6.1
7	4+95.90	675.0	686.7	11.7
8	5+04.40		687.2	12.2
9	5+01.60		685.8	10.8
10	4+98.80		685.4	10.4
11	4+95.60		686.0	11.0
12	4+95.00		686.7	11.7
13	4+94.10		686.7	11.7

Note: Pressures are in prototype feet of water. Test conditions: steady-flow discharge, 2970 cfs; lock chamber el, 707.2; lower pool el, 687.2; filling slide gate closed; upper miter gates open; emptying slide gates open; lower miter gate closed.

Table 12

Average Piezometer Readings During Normal Slide Gate Emptying Operations, Type 6 System, 37.8-ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Riverward Lock

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water															
No.	Station	Elevation	T = 30* LC = 724.7**	T = 60 LC = 724.2	T = 90 LC = 723.0	T = 120 LC = 721.0	T = 150 LC = 718.8	T = 180 LC = 715.7	T = 210 LC = 712.7	T = 240 LC = 709.2	T = 270 LC = 705.9	T = 300 LC = 702.9	T = 330 LC = 799.2	T = 360 LC = 797.2	T = 420 LC = 692.9	T = 480 LC = 690.0	T = 540 LC = 688.0	T = 600 LC = 686.7
Intermediate Wall (Right)																		
Sidewall Port Manifold																		
1B	1+32.58B	680.95	725.0	723.7	721.3	718.0	714.2	709.7	705.5	701.8	698.8	696.4	694.5	692.8	689.9	687.9	687.0	[illegible]
2B	2+09.08B		724.9	723.5	721.0	717.5	713.7	709.1	704.9	701.4	698.5	696.2	694.4	692.7	689.8	687.9	687.0	687.0
3B	3+00.08B		724.8	723.1	720.2	716.3	712.1	707.2	703.0	699.6	696.9	694.9	693.4	692.0	689.5	687.3	687.1	
4B	3+73.98B		724.4	722.0	718.0	713.0	707.8	702.3	697.8	694.9	693.1	691.8	690.9	690.0	689.6	687.5	587.1	
Culvert Slide Gate																		
1	3+91.50B	686.2	724.6	722.2	717.8	712.1	706.0	699.1	693.8	690.6	689.3	688.9	688.7	688.4	687.9	687.4	687.1	
2	4+00.50B	686.2	685.0	679.2	675.0	673.0	673.0	675.8	680.4	689.1	689.0	688.8	688.5	688.3	687.8	687.3	687.0	
3	4+08.50B	686.2	684.8	679.2	674.5	678.8	673.0	678.6	687.5	689.5	689.0	688.7	688.3	688.2	687.7	687.2	687.0	
4	4+13.50B	678.7 B	687.7	688.0	689.0	689.5	690.2	691.3	691.7	691.4	691.0	689.9	689.5	689.0	688.2	687.6	687.4	687.1
5	4+13.50B	682.45R	684.3	679.0	675.1	675.0	677.7	685.4	689.4	689.6	688.9	688.5	688.4	688.2	687.8	687.3	687.1	687.0
6	4+13.50B	686.2 T	684.1	679.5	675.5	675.0	678.6	685.7	689.1	689.7	689.0	688.6	688.5	688.2	687.8			
7	4+18.50B	686.2	684.2	679.6	677.0	678.7	687.0	688.5	689.5	689.5	688.8	688.5	688.3	688.1	687.7			
8	4+23.50B	686.2	685.0	681.1	680.5	682.8	687.0	688.9	689.5	689.4	688.7	688.4	688.3	688.0	687.7			
9	4+65.50B	678.7 B	678.8	688.2	688.5	688.7	688.5	688.6	688.6	688.6	688.0	687.9	687.9	687.8	687.6		687.2	
10	4+65.50B	686.2 T	687.8	688.2	688.5	688.8	688.7	688.8	688.8	688.7	688.0	687.8	687.9	687.9	687.6	687.4	687.2	
Outlet																		
1	5+11.50B	678.7	687.7	688.0	688.1	688.0	687.8	687.5	687.4	687.4	687.0	687.0	687.3	687.5	687.5	687.4	687.3	687.1
2	5+11.50B	686.2	687.7	688.0	688.2	588.2	688.0	687.9	687.7	687.9	687.5	687.5	687.6	687.6	687.6	687.4	687.2	687.1
3	5+23.20B	677.9	687.5	687.0	685.1	683.2	681.1	678.0	677.5	679.0	679.1	681.0	682.2	684.0	685.8	686.9	687.2	687.1
4	5+29.00B	677.2	684.2	679.2	675.5	675.0	677.7	684.3	688.4	689.5	688.8	688.5	688.5	688.2	687.8	687.4	687.1	687.0
5	5+29.00B	674.1	687.7	688.0	688.9	689.2	690.0	691.5	692.3	691.5	691.1	690.3	689.8	689.2	688.3	687.7	687.4	687.2
6	5+29.00B	672.2	687.6	687.5	687.1	686.6	686.1	685.7	685.9	686.0	686.0	686.2	686.6	686.9	687.1	687.4	687.4	
7	5+29.00B		687.5	687.7	687.7	687.8	687.9	687.8	687.8	687.8	687.6	687.5	687.7	687.7	687.5	687.4	687.4	
8	5+29.00B		687.5	687.8	687.8	688.0	688.2	688.4	688.3	688.3	688.0	687.8	687.9	687.9	687.6	687.4	687.3	
9	5+29.00B		687.5	687.8	688.0	688.5	688.8	689.1	689.1	689.0	688.7	688.3	688.5	688.0	687.7	687.5	687.4	687.3
10	5+57.20B	677.9	687.6	687.7	687.2	687.0	686.4	685.7	686.4	688.1	686.5	686.3	687.8	687.4	687.5	687.5	687.3	687.2
11	5+61.00B	677.2	687.6	688.1	688.8	689.3	689.3	689.8	689.8	688.7	689.3	688.9	688.9	688.5	687.8	687.6		
12	5+61.00B	674.1	687.6	688.2	688.8	689.4	689.2	690.1	689.8	688.5	689.2	688.1	688.7	688.5	687.8	687.5		
13	5+61.00B	672.2	687.5	687.5	687.4	687.4	687.1	686.9	686.8	687.3	687.0	686.9	687.2	687.4	687.3	687.3		
14	5+61.00B			687.6	687.6	687.5	687.5	687.4	687.3	687.4	687.3	687.4	687.4	687.5	687.4	687.4		
15	5+61.00B			687.6	687.7	688.0	688.0	688.1	687.9	687.9	687.7	687.8	687.8	687.6	687.5	687.4		
16	5+61.00B			687.6	688.0	688.2	688.4	688.7	688.8	688.5	688.4	688.2	688.0	688.0	687.6	687.5	687.4	
River Wall (Left)																		
Sidewall Port Manifold																		
1C	1+27.58B	680.95	724.6	723.3	720.7	717.1	713.0	708.5	704.2	700.6	698.2	696.1	694.2	692.5	689.7	687.9	686.9	686.7
2C	2+02.58B		724.6	723.3	720.7	717.1	713.0	708.6	704.3	701.0	698.3	696.3	694.5	692.5	689.7	687.9		
3C	2+93.58B		724.5	722.6	719.5	715.3	710.4	705.5	700.8	697.5	695.5	693.8	692.5	691.0	689.0	687.7		
4C	3+73.98B		724.1	721.8	717.8	712.4	706.2	700.1	694.9	691.7	690.7	690.0	689.3	688.7	687.8	687.3		
Culvert Slide Gate																		
1	4+13.50B	678.7 B	684.5	678.3	673.7	678.1	673.0	679.5	683.8	684.9	685.2	685.4	685.8	686.0	686.5	686.8	686.8	687.0
2	4+13.50B	682.45L	684.5	678.2	673.5	671.7	672.7	680.3	684.0	685.0	685.1	685.3	685.7	686.0	686.5		686.9	
3	4+13.50B	686.2 T	684.7	678.1	673.3	671.2	672.2	680.3	683.8	683.9	684.2	684.7	685.2	685.6	686.4			
4	4+65.50B	678.7 B	688.0	688.0	687.7	686.8	685.7	684.7	683.2	683.0	688.7	684.5	685.1	685.5	686.4			
5	4+65.50B	686.2 T	687.9	688.0	687.7	687.0	686.0	684.8	683.4	683.1	688.7	684.6	685.0	685.4	686.3	686.7		
Outlet																		
1	4+94.00B	678.7 B	687.8	687.9	687.5	687.0	686.0	684.9	684.5	684.5	684.8	685.2	685.8	686.0	686.6	686.9	687.0	
2	4+94.00B	686.2 T	687.8	688.0	687.6	687.0	686.2	685.3	684.5	684.3	684.6	685.0	685.6	685.9	686.4	686.9	697.0	
3	4+94.00B	675.5 B	687.6	687.5	687.3	686.7	685.8	684.9	684.0	683.8	684.0	684.6	685.1	685.8	686.4	686.9	687.0	
4	4+89.25B	678.2 R	687.7	687.7	687.4	686.6	685.7	684.8	684.0	684.0	684.4	685.0	685.5	685.9	686.5	687.0		687.1
5	4+94.00B	682.97T	697.8	687.7	687.2	686.4	685.5	684.7	683.9	683.9	684.4	685.0	685.6	685.9	686.6	687.0		
6	4+98.75B	678.2 L	687.8	687.8	687.4	686.6	685.8	684.9	684.2	684.0	684.5	685.0	685.6	685.9	686.6	687.0		
7	4+95.70B	675.0	687.6	687.7	687.7	687.5	687.2	685.9	686.7	686.5	686.6	686.8	686.8	686.9	687.0	687.1	687.1	
8	5+04.40B		687.4	687.6	687.6	687.4	687.3	689.3	687.1	687.1	687.0	687.1	687.2	687.2	687.3	687.3	687.2	687.2
9	5+01.60B		687.3	687.5	687.2	687.0	686.5	686.2	685.9	685.7	686.0	686.1	686.3	686.6	686.9	687.1	687.1	687.1
10	4+98.80B		687.3	687.5	687.3	687.0	686.2	685.4	685.2	685.1	685.4	685.7	686.0	686.3	686.8	687.1		
11	4+95.60B		687.3	687.5	687.4	687.0	686.8	686.2	686.0	685.9	686.1	686.2	686.5	686.5	686.8	687.1		
12	4+95.00B		687.4	687.6	687.6	687.5	687.3	686.9	686.7	686.5	686.6	686.8	686.9	687.0	687.1	687.2		
13	4+94.10B		687.3	687.5	687.6	687.5	687.3	686.9	686.8	686.6	686.8	686.8	686.9	687.0	687.1	687.2		687.2

Note: Lock filled in 9.6 min with 4-min valve. The bulkhead slots downstream of the emptying slide gates were sealed at the roof of the culvert.

* T denotes time (in prototype seconds) after beginning of valve movement.

** LC denotes elevation of water surface in lock chamber.

Table 13

Average Piezometer Readings During Single (Right) Culvert Slide Gate Emptying Operation, Type 6 System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Riverward Lock

Average Piezometer Readings in Prototype Feet of Water

No.	Station	Elevation	T = 30* LC = 724.7**	T = 60 LC = 724.4	T = 90 LC = 723.9	T = 120 LC = 723.2	T = 150 LC = 721.9	T = 180 LC = 720.6	T = 210 LC = 719.0	T = 240 LC = 717.3	T = 270 LC = 715.2
Intermediate Wall (Right)											
Sidewall Port Manifold											
1B	1+32.58B	680.9	725.0	724.1	722.4	719.9	716.9	713.5	710.5	707.9	706.1
2B	2+09.08B	↓	724.9	724.0	722.2	719.5	716.5	713.0	710.0	707.5	705.7
3B	3+00.08B	↓	724.8	723.5	721.2	718.2	714.5	710.5	707.2	704.5	703.0
4B	3+73.98B	↓	724.4	722.7	719.1	714.7	709.8	704.6	700.6	697.8	696.8
Culvert Slide Gate											
1	3+91.50B	686.2	724.5	722.7	718.8	713.7	707.4	700.6	695.1	691.3	690.3
2	4+00.50B	686.2	684.6	679.4	674.0	671.4	670.9	678.4	678.1	689.5	689.8
3	4+08.50B	686.2	684.5	679.3	673.8	670.8	670.9	676.4	687.6	690.2	689.6
4	4+13.50B	678.7 B	687.5	688.0	688.7	689.8	690.3	691.9	692.8	692.8	692.7
5	4+13.50B	682.45R	685.0	679.1	674.2	672.4	676.6	684.9	689.4	690.0	689.5
6	4+13.50B	686.2 T	683.8	679.2	674.5	672.6	677.7	685.0	689.1	690.1	689.6
7	4+18.50B	686.2	683.5	679.8	675.6	677.0	683.8	688.0	689.7	689.9	689.4
8	4+23.50B	686.2	683.9	680.8	678.6	682.6	685.9	688.9	689.7	689.8	689.2
9	4+65.50B	678.7 B	687.7	688.0	688.0	688.2	688.5	688.3	688.4	688.4	688.0
10	4+65.50B	686.2 T	687.8	688.0	688.2	688.5	683.8	688.8	688.9	688.6	688.1
Outlet											
1	5+11.50B	678.7	687.5	687.8	687.8	687.8	687.4	686.9	685.8	686.5	686.2
2	5+11.50B	686.2	687.6	687.8	687.9	688.0	687.8	687.5	687.4	687.1	687.0
3	5+23.20B	677.9	687.3	686.5	684.5	682.2	679.8	674.5	673.6	673.9	673.0
4	5+29.00B	677.2	684.0	679.4	674.3	673.0	676.8	680.1	688.4	689.9	689.4
5	5+29.00B	674.1	687.5	687.0	688.6	689.3	690.0	691.7	693.2	692.9	692.9
6	5+29.00B	672.2	687.3	687.3	686.8	686.2	685.8	684.9	685.0	684.9	684.9
7	5+29.00B	↓	↓	687.4	687.5	687.5	687.3	687.5	687.6	687.5	687.5
8	5+29.00B	↓	↓	687.5	687.7	687.8	688.0	688.2	688.3	688.2	688.2
9	5+29.00B	↓	↓	687.5	687.8	688.2	688.6	689.0	689.2	689.3	689.0
10	5+57.20B	677.9	↓	687.4	687.1	687.3	685.3	684.2	686.6	687.4	687.5
11	5+61.00B	677.2	687.4	687.8	688.5	689.0	690.3	690.6	690.0	689.6	689.8
12	5+61.00B	674.1	687.5	687.9	685.7	689.1	690.3	691.1	689.8	690.3	689.8
13	5+61.00B	672.2	687.2	687.3	687.1	687.1	686.5	686.4	686.4	686.4	686.1
14	5+61.00B	↓	687.3	687.4	687.3	687.3	687.0	686.8	687.0	687.0	686.8
15	5+61.00B	↓	687.3	687.5	687.6	687.7	687.7	687.8	687.7	687.7	687.4
16	5+61.00B	↓	687.3	687.5	687.7	688.0	688.5	688.9	688.8	688.7	688.5

No.	Station	Elevation	T = 300 LC = 713.8	T = 360 LC = 710.5	T = 420 LC = 707.2	T = 480 LC = 704.1	T = 600 LC = 699.0	T = 720 LC = 695.0	T = 840 LC = 691.7	T = 960 LC = 689.5	T = 1080 LC = 687.8
Intermediate Wall (Right)											
Sidewall Port Manifold											
1B	1+32.58B	680.9	704.5	702.3	699.8	697.5	693.6	690.8	688.8	687.5	687.0
2B	2+09.08B	↓	704.3	702.1	699.5	697.3	693.5	690.7	688.8	687.5	687.1
3B	3+00.08B	↓	701.8	699.8	697.7	695.7	692.7	690.2	688.5	687.5	687.0
4B	3+73.98B	↓	696.2	695.0	693.5	692.5	690.5	689.0	688.0	687.4	687.1
Culvert Slide Gate											
1	3+91.50B	686.2	690.2	689.9	689.5	689.1	688.5	688.0	687.5	687.3	687.1
2	4+00.50B	686.2	689.7	689.5	689.1	688.9	688.5	687.9	687.4	687.3	687.0
3	4+08.50B	686.2	689.5	689.3	689.0	688.8	688.2	687.8	687.4	687.0	687.0
4	4+13.50B	678.7 B	692.3	691.2	691.0	690.0	689.0	688.3	687.7	687.3	687.2
5	4+13.50B	682.45R	689.4	689.4	689.0	688.8	688.3	687.8	687.5	↓	687.1
6	4+13.50B	686.2 T	689.6	689.5	689.2	688.8	688.3	687.8	↓	↓	687.1
7	4+18.50B	686.2	689.4	689.2	689.0	688.7	688.2	687.7	↓	↓	687.1
8	4+23.50B	686.2	689.2	689.0	688.8	688.6	688.1	687.7	↓	↓	687.0
9	4+65.50B	678.7 B	688.2	688.2	688.0	688.0	687.8	687.6	687.4	↓	687.1
10	4+65.50B	686.2 T	688.3	688.3	688.1	688.0	687.8	687.6	687.5	↓	687.1
Outlet											
1	5+11.50B	678.7	686.6	686.8	687.0	687.1	687.3	687.4	687.3	↓	687.1
2	5+11.50B	686.2	687.4	687.4	687.4	687.7	687.4	687.4	687.4	↓	687.2
3	5+23.20B	677.9	674.7	677.0	[illegible]	680.7	683.3	685.3	686.4	↓	687.2
4	5+29.00B	677.2	689.4	689.4	689.0	688.8	688.3	687.8	687.6	↓	687.1
5	5+29.00B	674.1	698.7	691.8	691.0	690.1	689.1	688.4	687.8	↓	687.2
6	5+29.00B	672.2	685.2	685.6	685.7	686.0	686.5	686.9	687.0	↓	687.2
7	5+29.00B	↓	687.4	687.4	687.5	687.4	687.5	687.4	687.3	↓	687.1
8	5+29.00B	↓	688.1	688.0	687.9	687.8	687.7	687.6	687.3	↓	687.1
9	5+29.00B	↓	688.0	688.7	688.5	688.3	687.9	687.7	687.4	↓	687.2
10	5+57.20B	677.9	687.7	688.5	687.7	687.7	687.6	687.5	687.3	↓	↓
11	5+61.00B	677.2	689.6	689.6	688.6	687.8	688.5	687.9	687.5	↓	↓
12	5+61.00B	674.1	689.5	689.2	688.4	687.8	688.4	687.8	687.5	↓	↓
13	5+61.00B	672.2	686.8	686.4	686.8	686.7	687.0	687.2	687.2	↓	↓
14	5+61.00B	↓	687.0	686.9	687.0	687.0	687.2	687.3	687.2	↓	↓
15	5+61.00B	↓	687.5	687.4	687.5	687.4	687.5	687.4	687.3	↓	↓
16	5+61.00B	↓	688.5	688.0	688.0	688.0	687.1	687.5	687.4	↓	↓

Note: Lock filled in [illegible] min with 4-min valve. The bulkhead slots downstream of the emptying slide gates were sealed at the roof of the culvert.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 14

Average Piezometer Readings During Single (Left) Culvert Slide Gate Emptying Operation, Type 6 System, 37.8-Ft Head

Upper Pool El 725.0, Lower Pool El 687.2

Riverward Lock

Piezometer Locations			Average Piezometer Readings in Prototype Feet of Water																
No.	Station	Elevation	T = 30* LC = 724.5**	T = 60 LC = 724.0	T = 90 LC = 723.0	T = 120 LC = 721.7	T = 150 LC = 720.0	T = 180 LC = 718.1	T = 210 LC = 716.2	T = 240 LC = 714.1	T = 270 LC = 711.9	T = 300 LC = 709.9	T = 360 LC = 706.1	T = 420 LC = 702.3	T = 480 LC = 699.8	T = 600 LC = 695.0	T = 720 LC = 690.2	T = 840 LC = 688.6	T = 960 LC = 687.1
River Wall (Left)																			
Sidewall Port Manifold																			
1C	1+27.58B	680.95	724.7	723.8	722.0	719.5	716.1	712.6	709.3	706.4	704.5	703.0	700.3	697.7	695.5	691.7	689.1	687.5	687.0
2C	2+02.58B		724.7	723.8	721.8	719.5	716.1	712.8	709.6	706.6	704.9	703.5	700.5	697.8	695.6	691.8	689.3	687.5	
3C	2+93.58B		724.5	723.3	720.7	717.5	713.2	709.1	705.0	702.0	700.4	699.2	697.0	695.1	693.5	690.5	688.5	687.5	
4C	3+73.98B		724.2	722.5	719.0	714.3	708.5	702.8	696.4	693.7	692.6	690.4	691.3	690.5	689.8	688.5	687.7	687.3	
Culvert Slide Gate																			
1	4+13.50B	678.7 B	684.0	678.9	673.4	670.6	671.0	677.1	681.6	683.7	683.8	684.2	684.7	685.2	685.7	686.4	686.8	687.0	
2	4+13.50B	682.45L	684.0	678.8	673.4	670.0	670.8	677.1	682.1	683.5	683.7	684.1	684.6	685.1	685.6	686.4	686.8		
3	4+13.50B	686.2 T	684.1	678.7	672.9	669.9	670.5	677.6	682.1	682.1	682.4	682.9	683.5	684.4	685.2	686.2	686.7		
4	4+65.50B	678.7 B	687.8	687.9	687.3	686.6	685.6	684.4	682.0	681.2	681.5	682.2	682.8	683.8	684.7	686.2	686.6		
5	4+65.50B	686.2 T	687.7	687.8	687.4	686.7	685.6	684.3	682.5	681.4	681.5	682.2	682.9	683.9	684.8	[illegible]	686.5	686.0	
Outlet																			
1	4+94.00B	678.7 B	687.7	687.7	687.2	686.6	685.5	684.5	683.8	682.9	683.2	683.2	684.1	685.0	685.5	686.5	686.8	687.0	
2	4+94.00B	686.2 T	687.7	687.8	687.5	686.9	686.0	684.8	683.7	682.8	682.7	683.2	683.9	684.7	685.2	686.2	686.8		
3	4+94.00B	675.5 B	687.5	687.5	687.0	686.3	685.4	684.3	682.8	682.2	682.2	682.6	683.2	684.1	684.8	686.0	686.7		
4	4+89.25B	678.2 R	687.6	687.6	687.2	686.4	685.4	684.2	682.9	682.2	682.4	682.8	683.7	684.5	685.2	686.2	686.8		
5	4+94.00B	682.97T	687.6	687.6	687.0	686.2	685.1	683.9	682.7	682.1	682.5	683.0	683.8	684.5	685.2	686.3	686.7		
6	4+98.75B	678.2 L	687.6	687.6	687.2	686.4	685.5	684.4	683.0	682.2	682.4	684.3	683.7	684.5	685.2	686.2	686.7		
7	4+95.90B	675.0	687.4	687.5	687.4	687.2	687.0	686.7	686.2	685.8	686.0	686.0	686.2	686.5	686.7	686.9	687.0	687.1	
8	5+04.40B		687.3	687.4	687.3	687.2	687.0	687.0	686.8	686.4	686.5	686.5	686.7	686.9	687.0	687.1	687.1	687.2	687.2
9	5+01.60B			687.3	687.1	686.8	686.4	685.9	685.4	684.9	685.2	685.4	685.6	685.8	686.3	686.8	687.0	687.1	
10	4+98.80B			687.3	687.0	686.5	685.8	684.9	684.5	684.1	684.3	684.6	685.1	685.5	686.0	686.6	687.0	687.1	
11	4+95.62B			687.4	687.1	686.9	686.5	685.9	685.5	685.1	685.2	685.4	685.7	685.9	686.2	686.8	687.0	687.1	
12	4+95.00B		687.4	687.5	687.5	687.2	687.0	686.5	686.2	686.0	686.0	686.1	686.3	686.5	686.8	687.0	687.1	687.2	
13	4+94.10B		687.4	687.5	687.5	687.2	687.0	686.5	686.3	686.1	686.0	686.2	686.4	686.5	686.8	687.0	687.1	687.2	

Note: Lock filled in 15.2 min with 4-min valve. The bulkhead slots downstream of the emptying slide gates were sealed at the roof of the culvert.
* T denotes time (in prototype seconds) after beginning of valve movement.
** LC denotes elevation of water surface in lock chamber.

Table 15

Visual Observations of Water Surface in Bulkhead Slots Immediately Upstream of Slide Gates During Emptying Operations

Type 6 System

Emptying Operation	Valve Time, V_t min	Minimum Water-Surface El ft msl	Time of Occurrence min*	Remarks
Normal (Both Culverts)				
Right	2	686.2**	1.3	
	4	↓	4.1	
	6	↓	7.7	
	8	↓	11.6	
Left	2	↓	2.1	Air is entrained
	4	↓	3.8	
	6	↓	10.6	
	8	↓	11.6	
Single (Right) Culvert				
	2	↓	11.7	
	4	↓	11.7	
	6	↓	11.7	
	8	↓	12.5	
Single (Left) Culvert				
	2	↓	2.0	Severe air entrained 3 min til 5 min
	4	↓	4.0	Air is entrained for 2 min til 6 min
	6	↓	5.8	Air is entrained for 1.2 min til 7 min
	8	↓	7.5	

Note: Initial conditions 37.8-ft head (upper pool el 725.0, lower pool el 687.2). Slide gates open at constant speed. Bulkhead slots downstream of slide gates sealed at roof of culvert.

* Time after slide gate begins opening.

** Roof of culverts at el 686.2.

Table 16

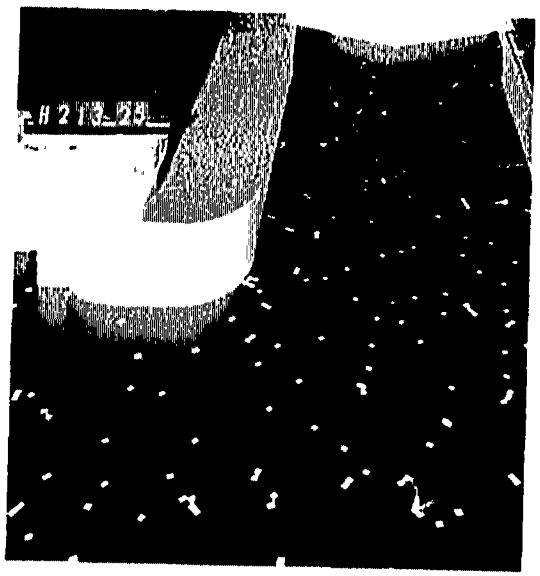
1:10-Scale Model Tests, Lock No. 1 Slide Gate

Hoist Loads, Type 1 (Original) Slide Gate

Slide Gate Open Percent	Slide Gate Open Feet	Culvert Discharge, cfs	Total Hoist Load, Kips Low	Total Hoist Load, Kips Observed Average	Total Hoist Load, Kips High
10	0.75	100	2.6	2.7	2.8
		150	3.0	3.1	3.2
		200	3.4	3.5	3.6
		250	3.8	3.9	4.0
		300	4.3	4.4	4.6
20	1.50	200	2.6	2.7	2.8
		300	4.0	4.1	4.2
		400	5.3	5.5	5.6
		500	6.5	6.9	7.1
30	2.25	350	2.9	3.1	3.2
		500	4.7	4.9	5.1
		650	6.4	6.7	7.1
		700	7.2	7.5	7.9
40	3.00	500	3.5	3.7	3.9
		650	5.1	5.0	5.6
		800	6.9	7.2	7.5
		950	7.7	8.1	8.6
		1100	8.3	8.8	9.3
50	3.75	750	4.2	4.4	4.7
		900	6.0	6.5	6.9
		1050	7.2	7.2	8.1
		1200	8.1	8.8	9.4
		1350	9.0	9.6	10.2
60	4.50	900	4.3	4.6	5.1
		1050	5.4	5.9	6.5
		1200	6.2	6.9	7.6
		1350	7.0	7.7	8.3
		1500	7.5	8.2	9.1
70	5.25	1050	3.5	3.9	4.5
		1200	4.1	4.7	5.4
		1400	4.9	5.6	6.4
		1500	5.2	6.0	6.9
		1600	5.8	6.6	7.4
80	6.00	1100	2.1	2.4	2.8
		1250	2.5	2.9	3.4
		1400	2.8	3.3	4.0
		1550	3.1	3.9	4.5
		1700	3.3	4.3	5.0
90	6.75	1300	0.8	1.1	1.3
		1400	1.4	1.7	2.1
		1500	1.7	2.0	2.4
		1600	1.8	2.1	2.5
		1800	1.8	2.2	2.6
100	7.50	1300	0.8	1.1	1.4
		1400	1.4	1.7	2.1
		1500	1.6	2.0	2.4
		1600	1.9	2.2	2.5
		1700	1.9	2.2	2.6

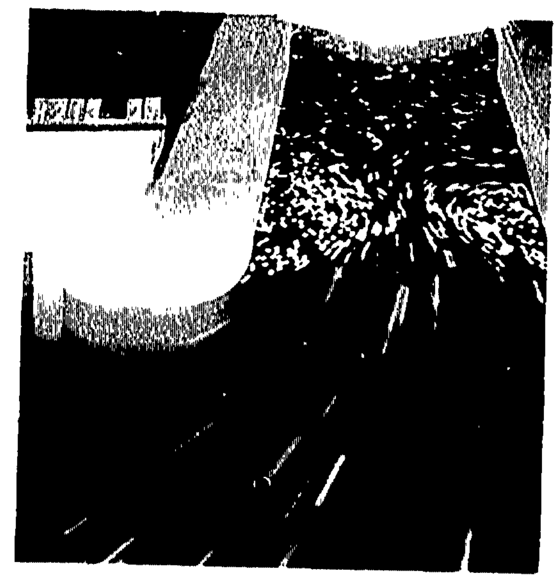
Note: Energy elevation immediately upstream from culvert slide gate was maintained at approximately 46.3 ft (el 725.0) above the culvert invert (el 678.7). Submerged weight of gate is 1,814 lb (1.814 kips). Dry weight of gate is 4,209 lb (4.209 kips). Culvert 8 ft wide by 7.5 ft high.

PHOTOGRAPHS



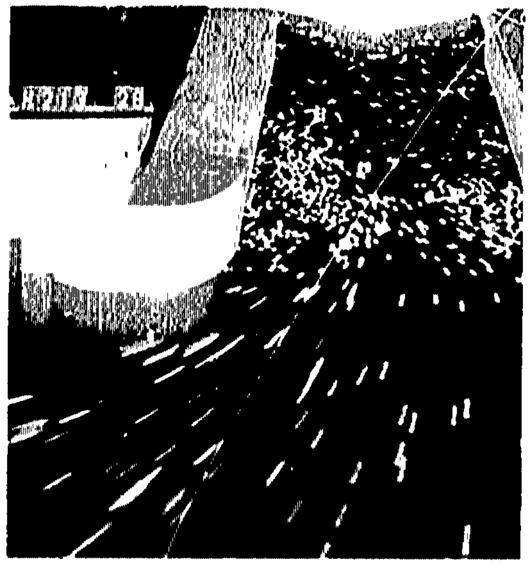
a. Before filling started

b. 2 min after filling started



c. 4 min after filling started

Photo 1. Surface currents in approach during filling operation with type 1 (original) intake and approach, type 2 intermediate wall pier nose, 4-min valve time; upper pool el 725.0, lock chamber el 687.2 (sheet 1 of 2)



d. 6 min aft‹ filling started

e. 8 min after filling started

f. 10 min after filling started

Photo 1. (sheet 2 of 2)

a. Before filling started

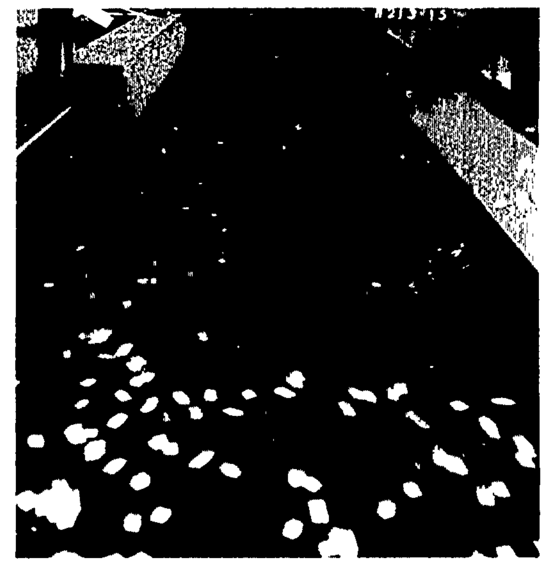
b. 2 min after filling started

c. 4 min after filling started

Photo 2. Surface currents in lock chamber during filling operation with type 1 (original) design, 4-min valve time, 11-ft submergence; upper pool el 725.0, lower chamber el 687.2 (sheet 1 of 2)

d. 6 min after filling started

e. 8 min after filling started

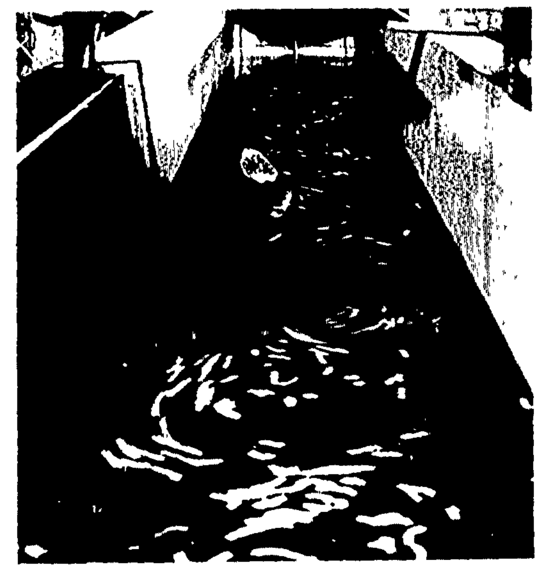


f. 10 min after filling started

Photo 2. (sheet 2 of 2)

a. Before filling started

b. 2 min after filling started



c. 8 min after filling started

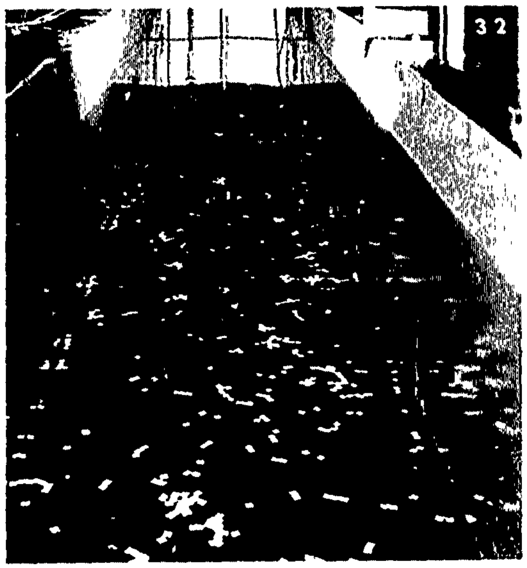
Photo 3. Surface currents in lock chamber during filling operation with type 2 sidewall port manifold design, 4-min valve time, 11-ft submergence; upper pool el 725.0, lower chamber el 687.2 (sheet 1 of 2)

d. 6 min after filling started

e. 8 min after filling started

f. 10 min after filling started

Photo 3. (sheet 2 of 2)



a. Before filling started

b. 2 min after filling started

c. 4 min after filling started

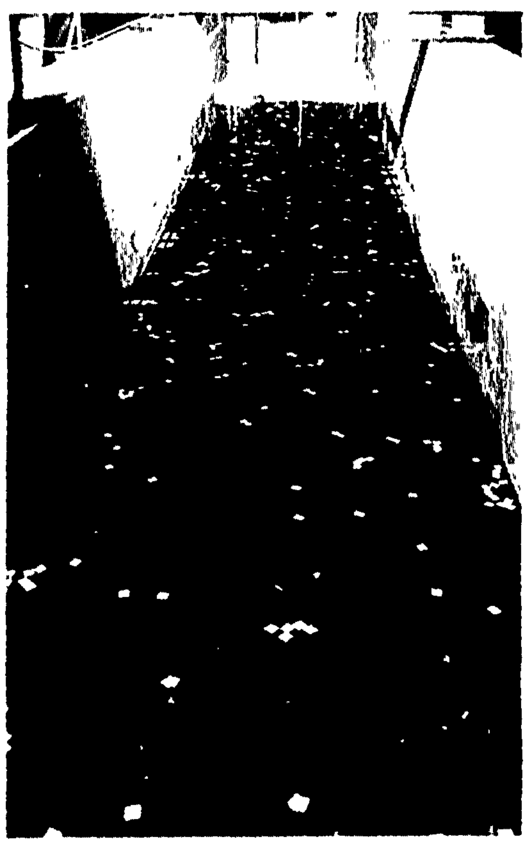
Photo 4. Surface currents in lock chamber during filling operation with type 3 sidewall port manifold design, 4-min valve time, 11-ft submergence; upper pool el 725.0, lower pool el 687.2 (sheet 1 of 2)

d. 6 min after filling started

e. 8 min after filling started

f. 10 min after filling started

Photo 4. (sheet 2 of 2)

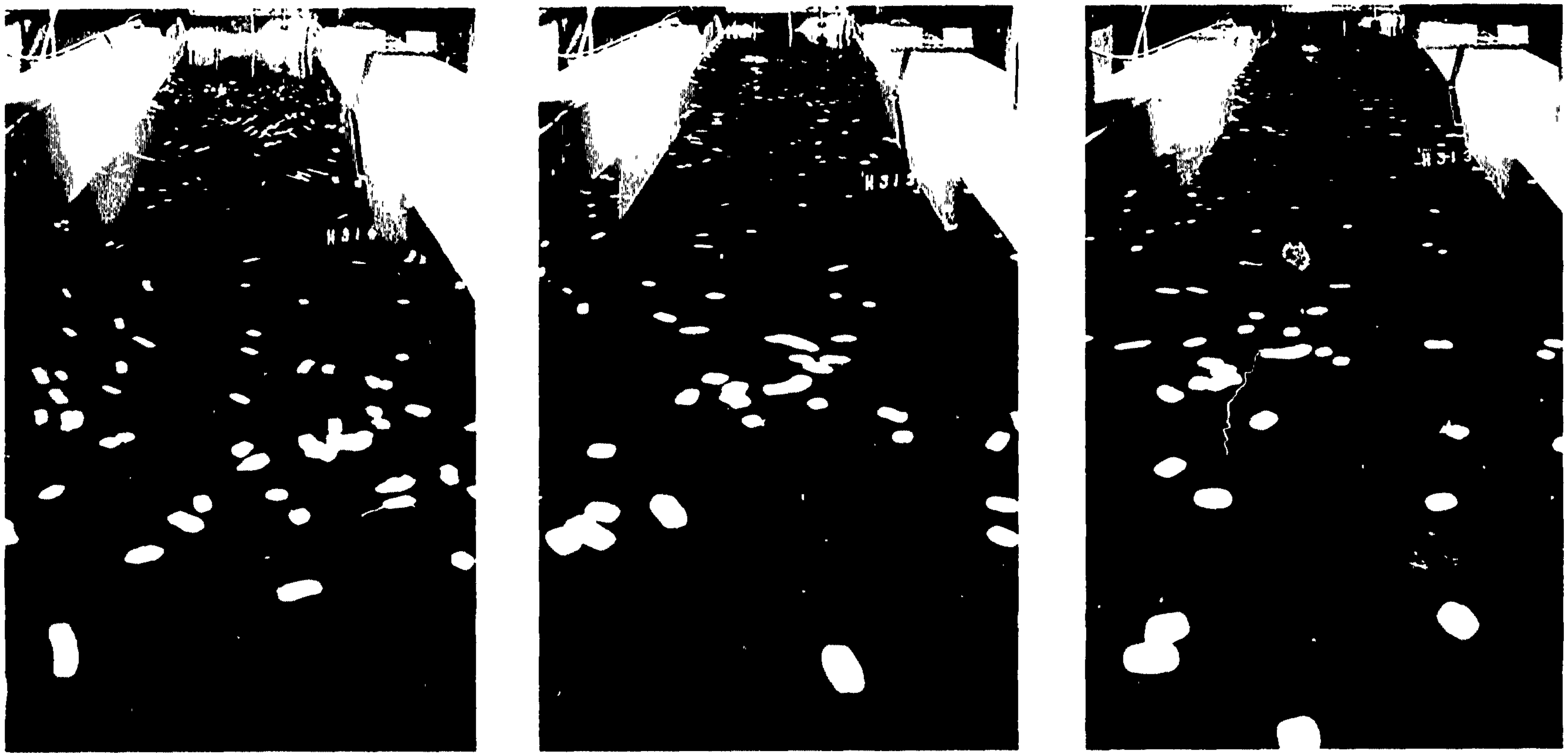


a. Before filling started

b. 2 min after filling started

c. 4 min after filling started

Photo 5. Surface currents in lock chamber during filling operation with type 4 sidewall port manifold design, 4-min valve time, 11-ft submergence; upper pool el 727.5, lower pool el 689.7 (sheet 1 of 2)

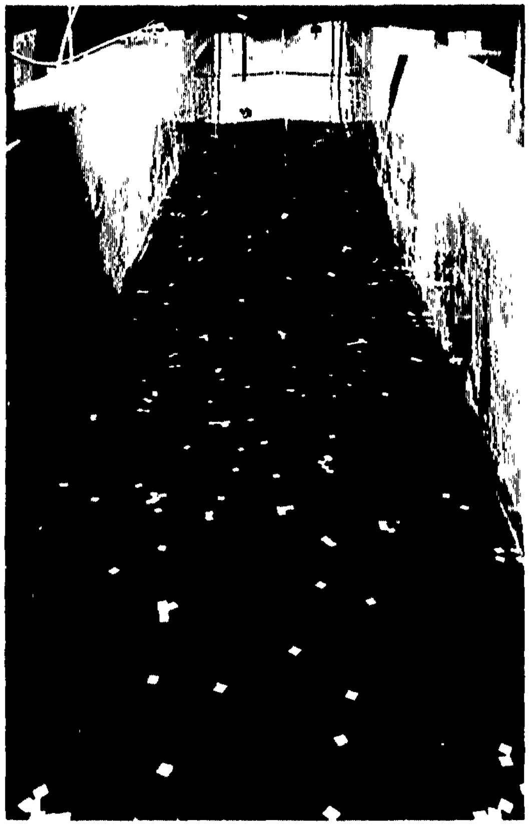


d. 6 min after filling started

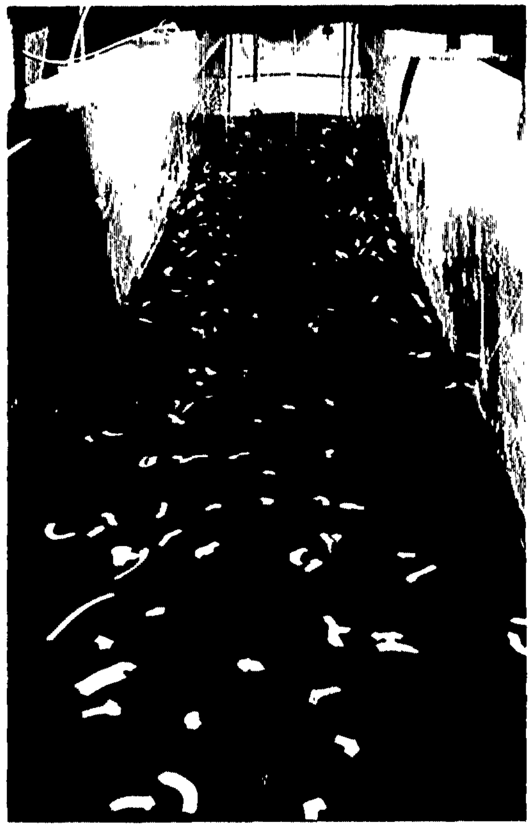
e. 8 min after filling started

f. 10 min after filling started

Photo 5. (sheet 2 of 2)



a. Before filling started



b. 2 min after filling started

c. 4 min after filling started

Photo 6. Surface currents in lock chamber during filling operation with type 4 sidewall port manifold design, 5-min valve time, 8.5-ft submergence, riverward lock conditions; upper pool el 725.0, lower pool el 687.2 (sheet 1 of 2)

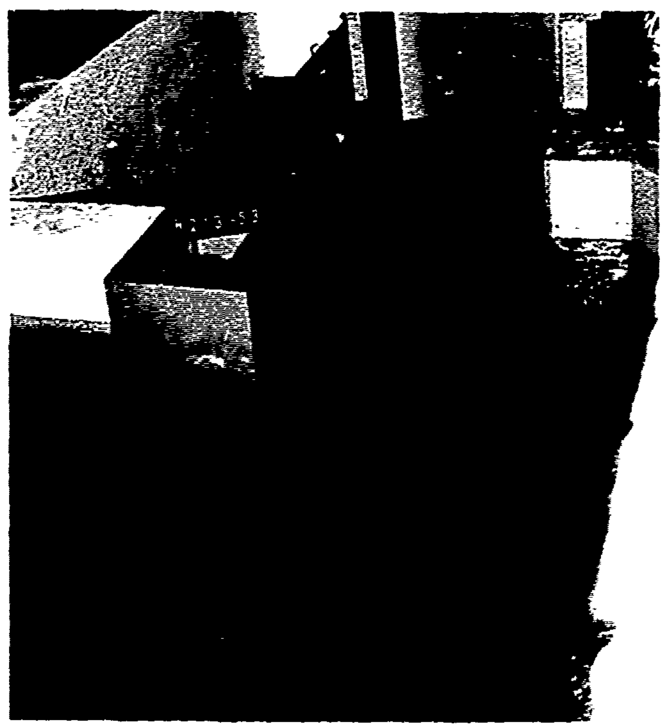
d. 6 min after filling started

e. 8 min after filling started

f. 10 min after filling started

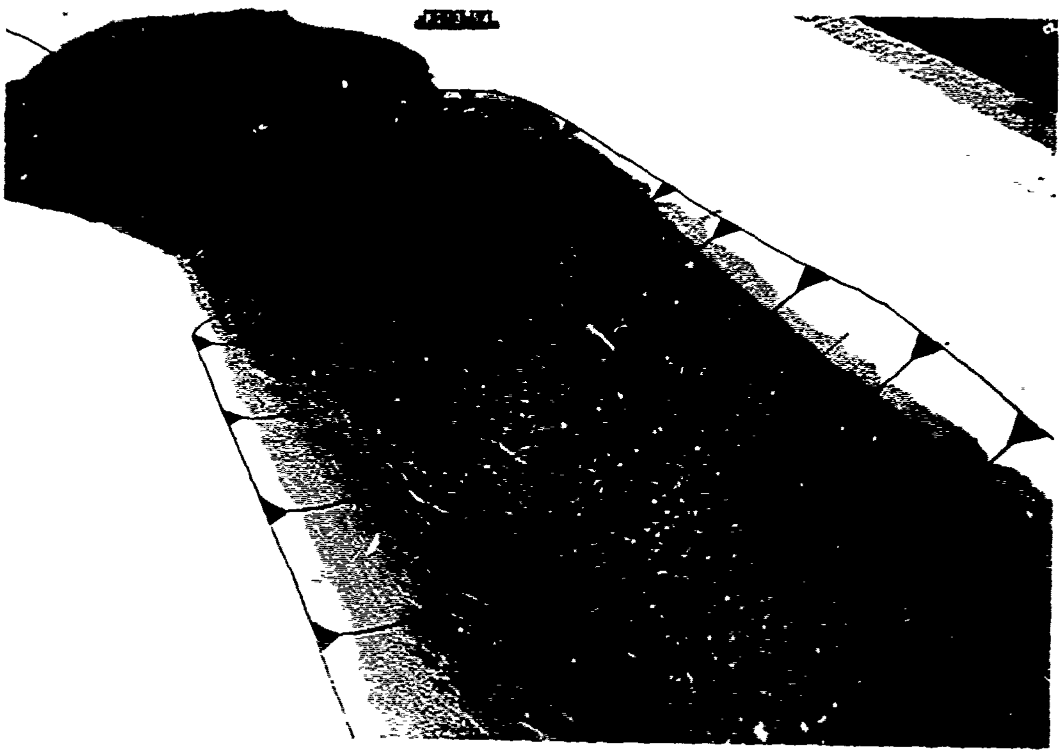
Photo 6. (sheet 2 of 2)

a. Normal culvert operation



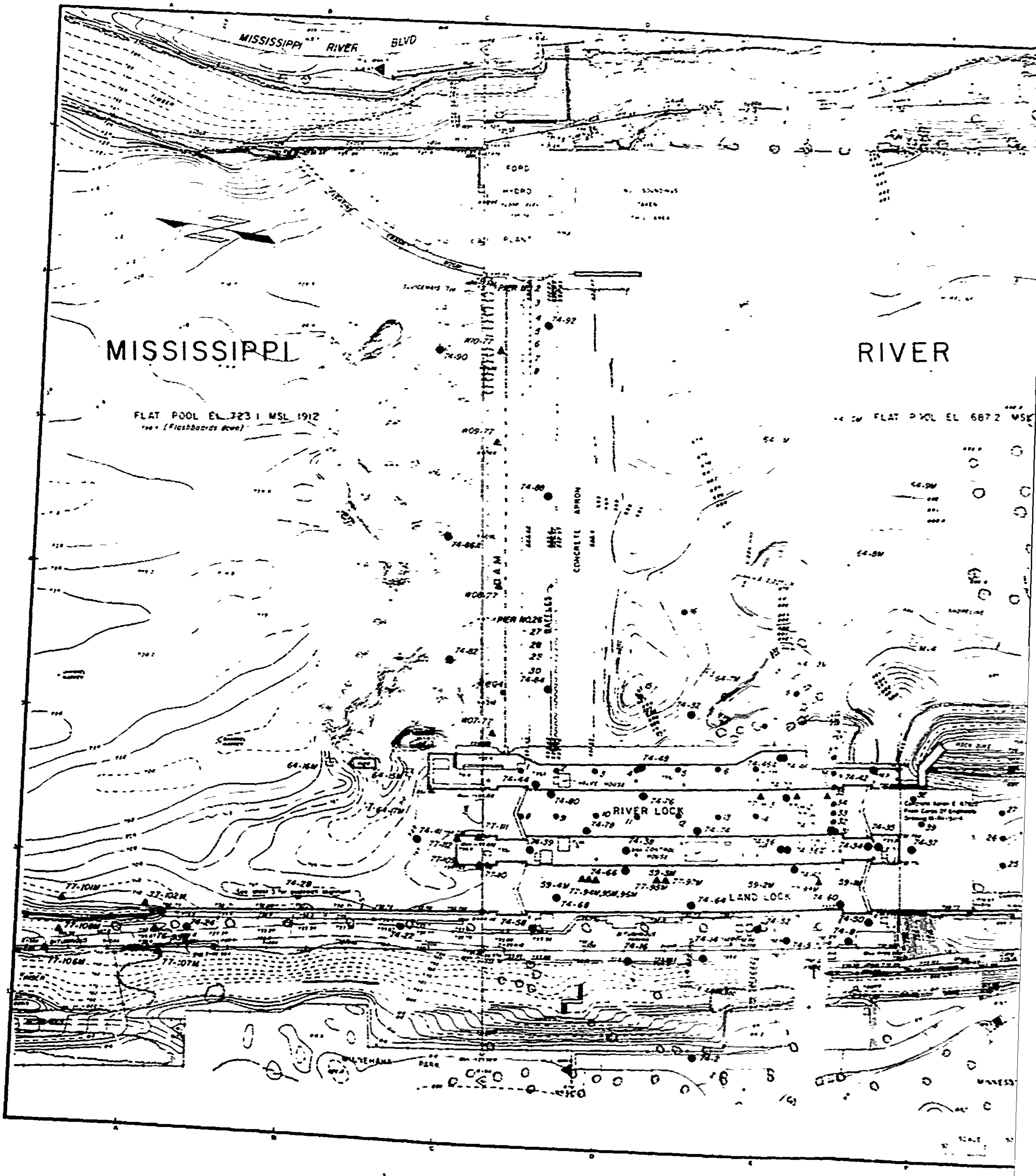
b. Single (right) culvert operation

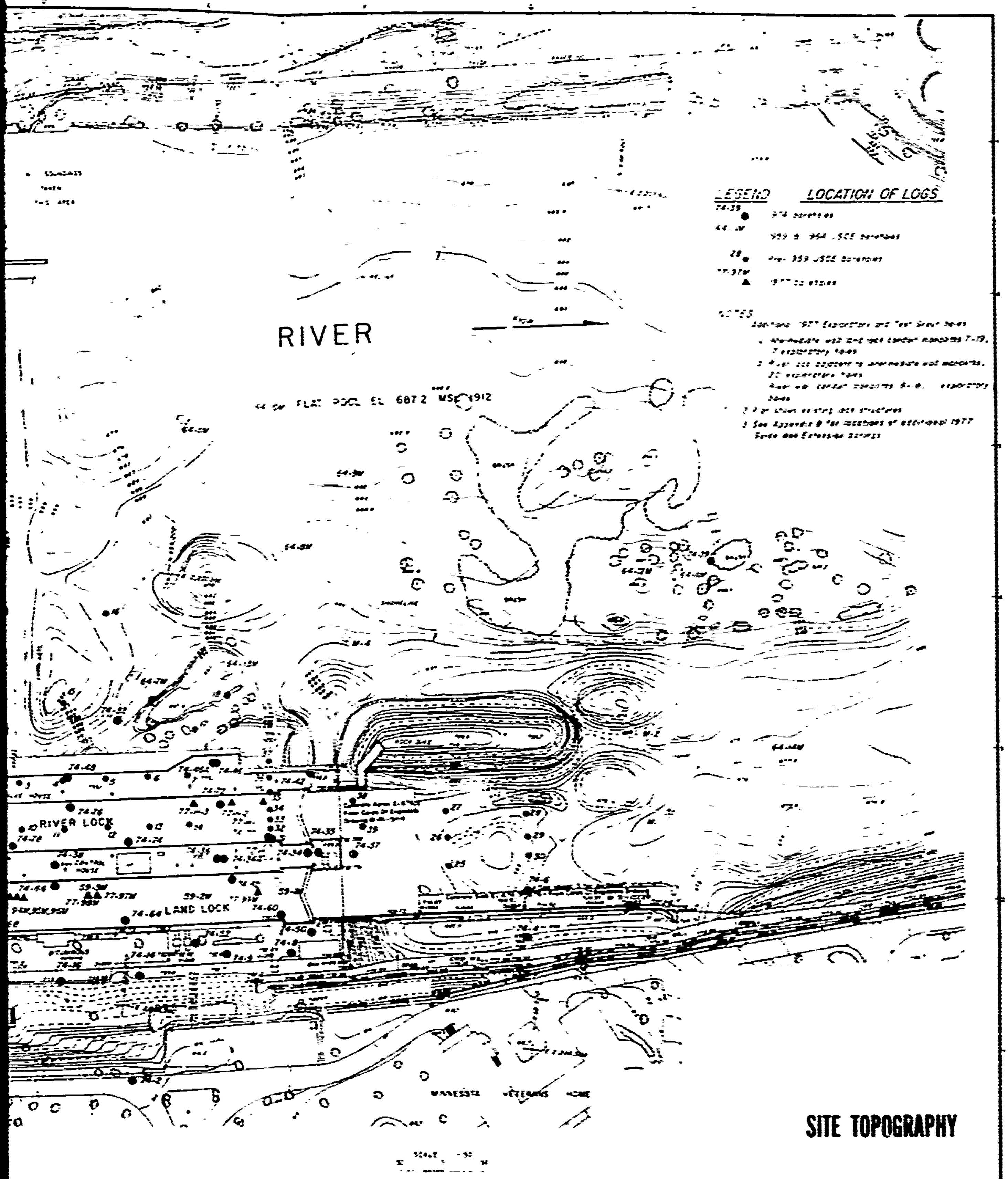
Photo 7. Flow conditions during peak discharge with type 2 outlets for riverward lock installed, 4-min valve; initial lock chamber el 725.0, lower pool el 687.2 (sheet 1 of 2)



c. Single (left) culvert operation

Photo 7. (sheet 2 of 2)

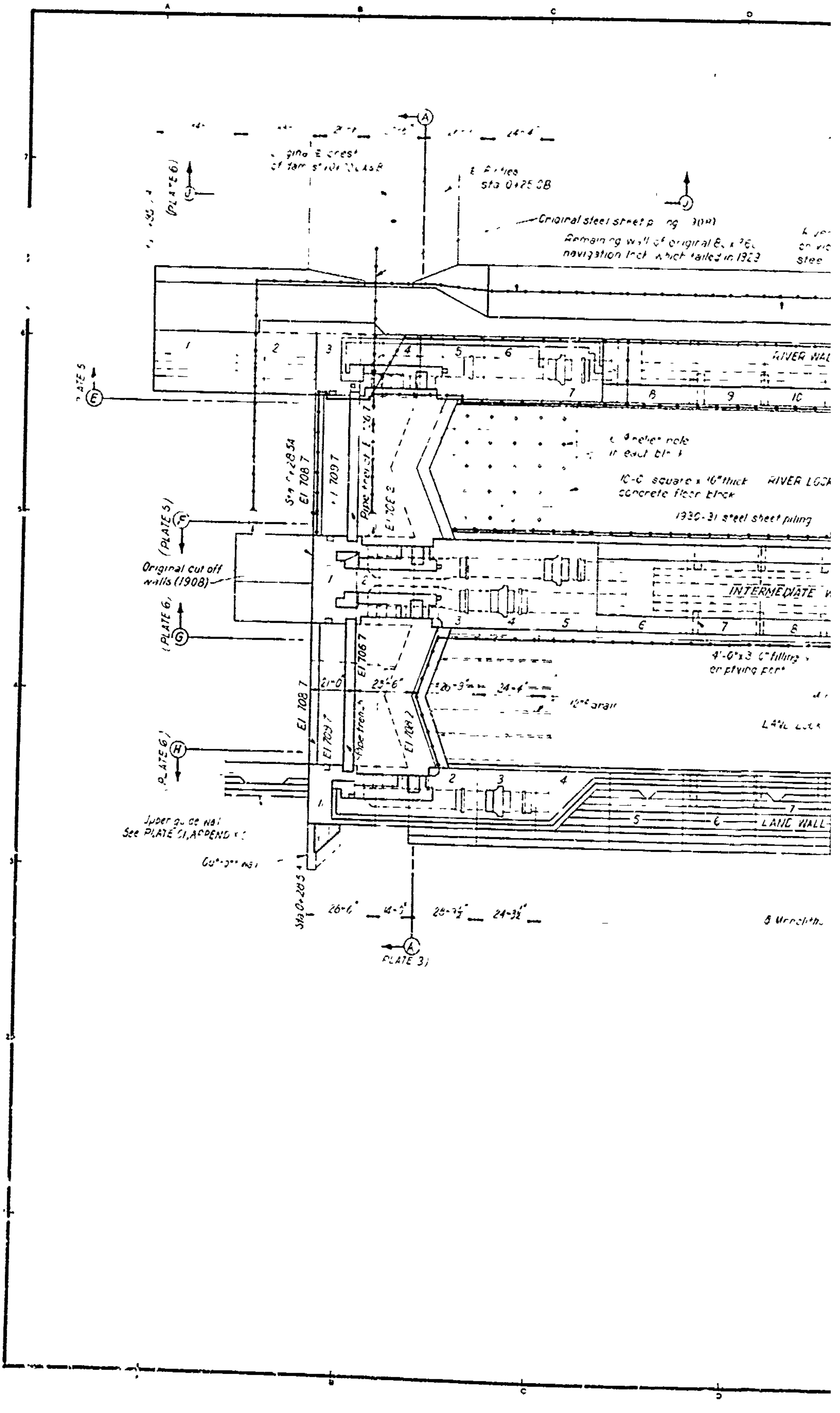

MISSISSIPPI RIVER BLVD
FORD
HYDRO
MISSISSIPPI
RIVER
FLAT POOL EL. 723.1 MSL 1912
CONCRETE APRON
DAM
RIVER LOCK
LAND LOCK

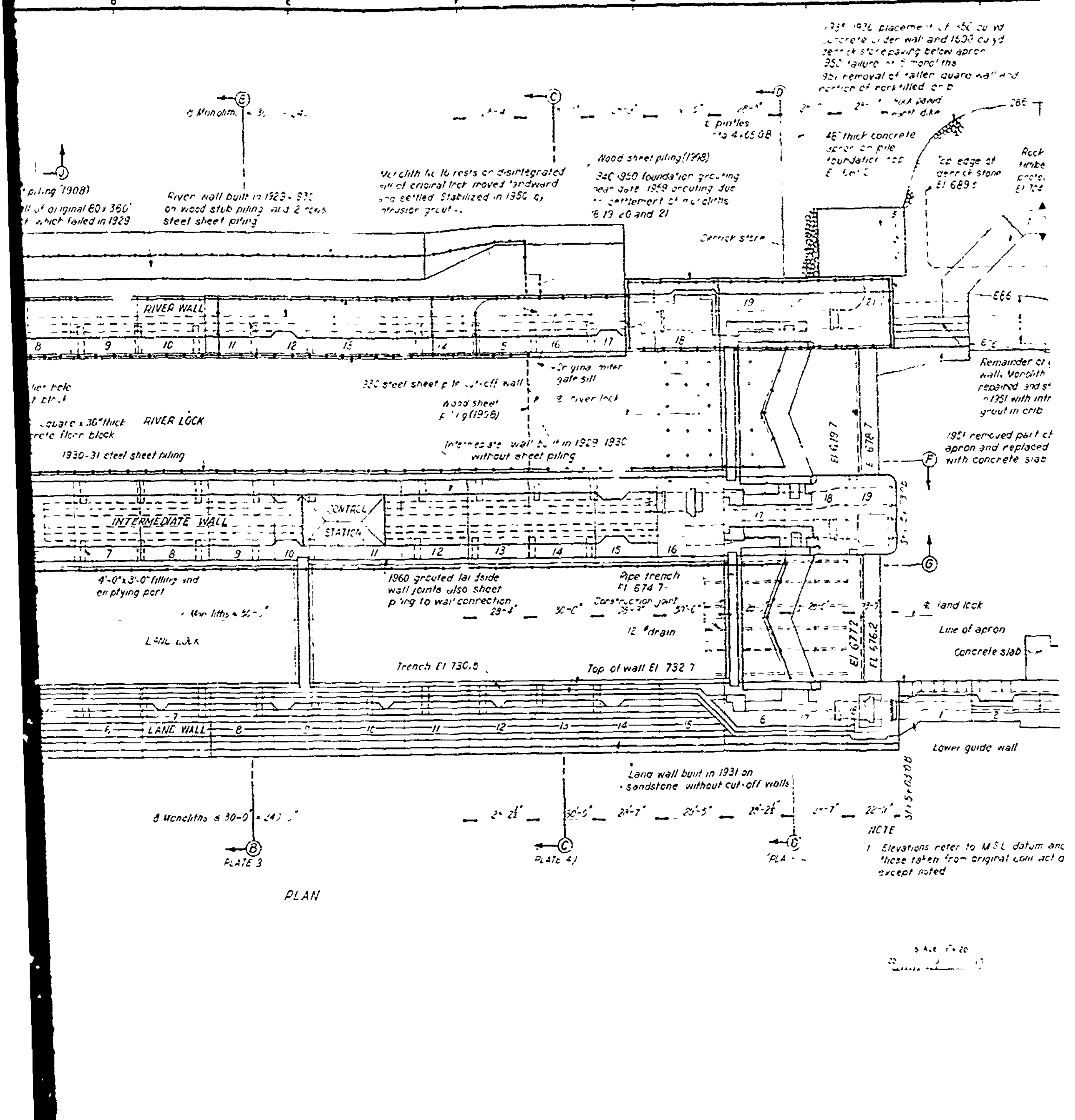


SITE TOPOGRAPHY

PLATE 1

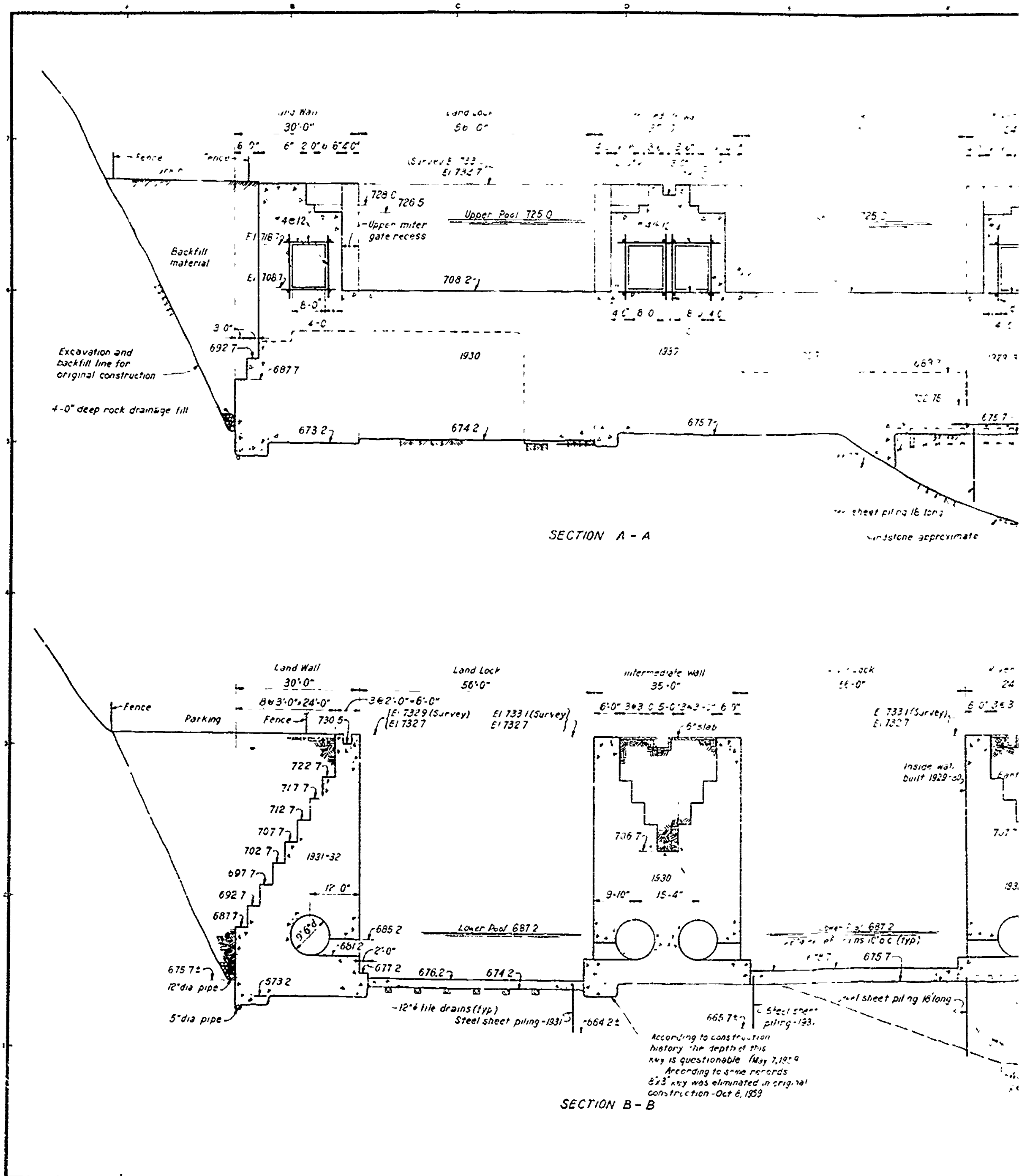
2


Original steel sheet piling
Remaining wall of original navigation lock which failed in 1929
RIVER WALL
RIVER LOCK
1930-31 steel sheet piling
Original cut off walls (1908)
INTERMEDIATE
LAND WALL
(PLATE 5)
(PLATE 6)
PLATE 3)
Pipe trench
El 708.7
El 709.7
El 706.7
10'-0" square x 16" thick concrete floor block
4'-0"x3'-0" filling or pivting post
Upper guide wall See PLATE 51, APPEND
Sta 0+28.5
26'-6"
24'-4"
21'-0"
25'-6"

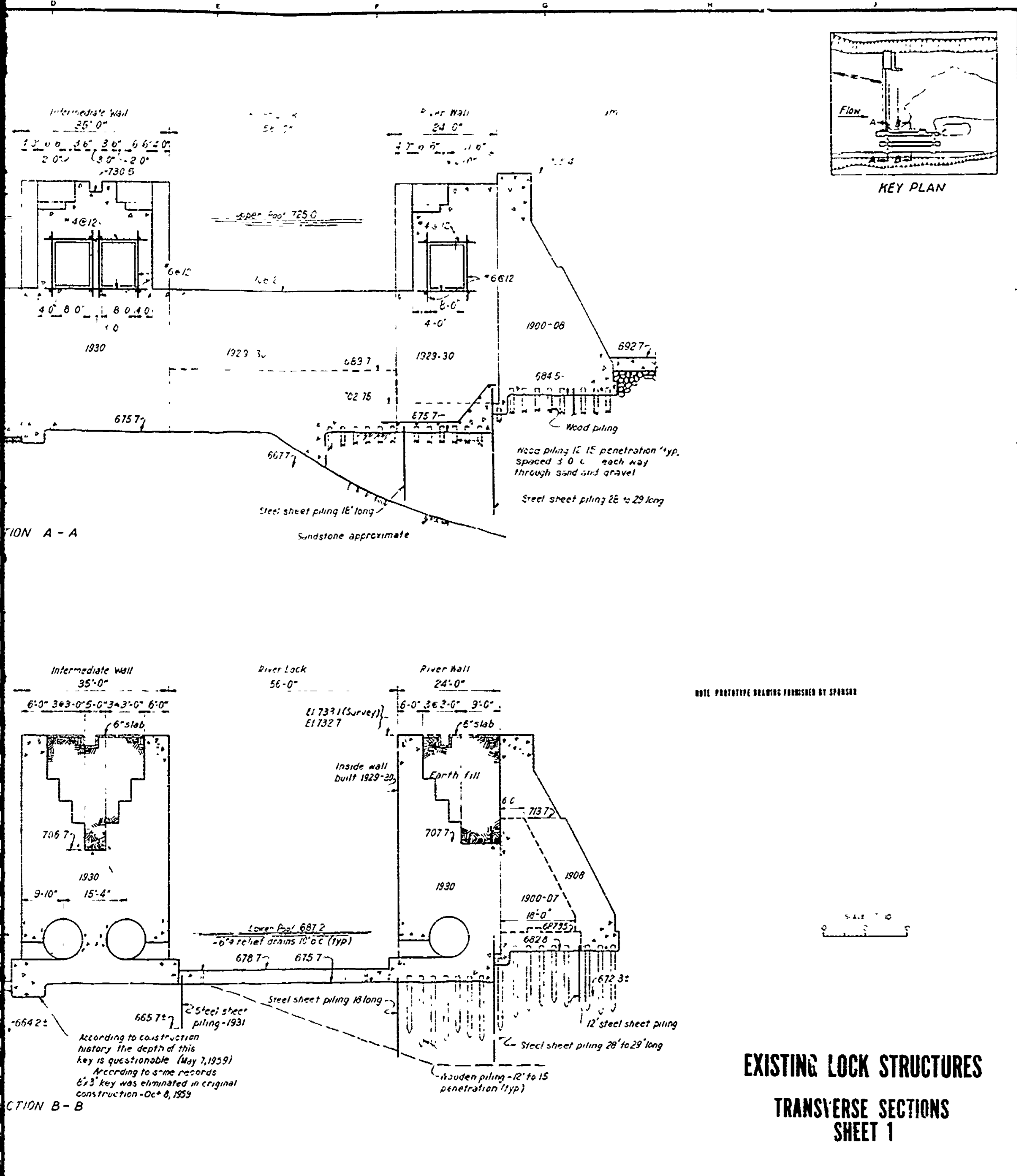


EXISTING LOCK STRUCTU

PLAN



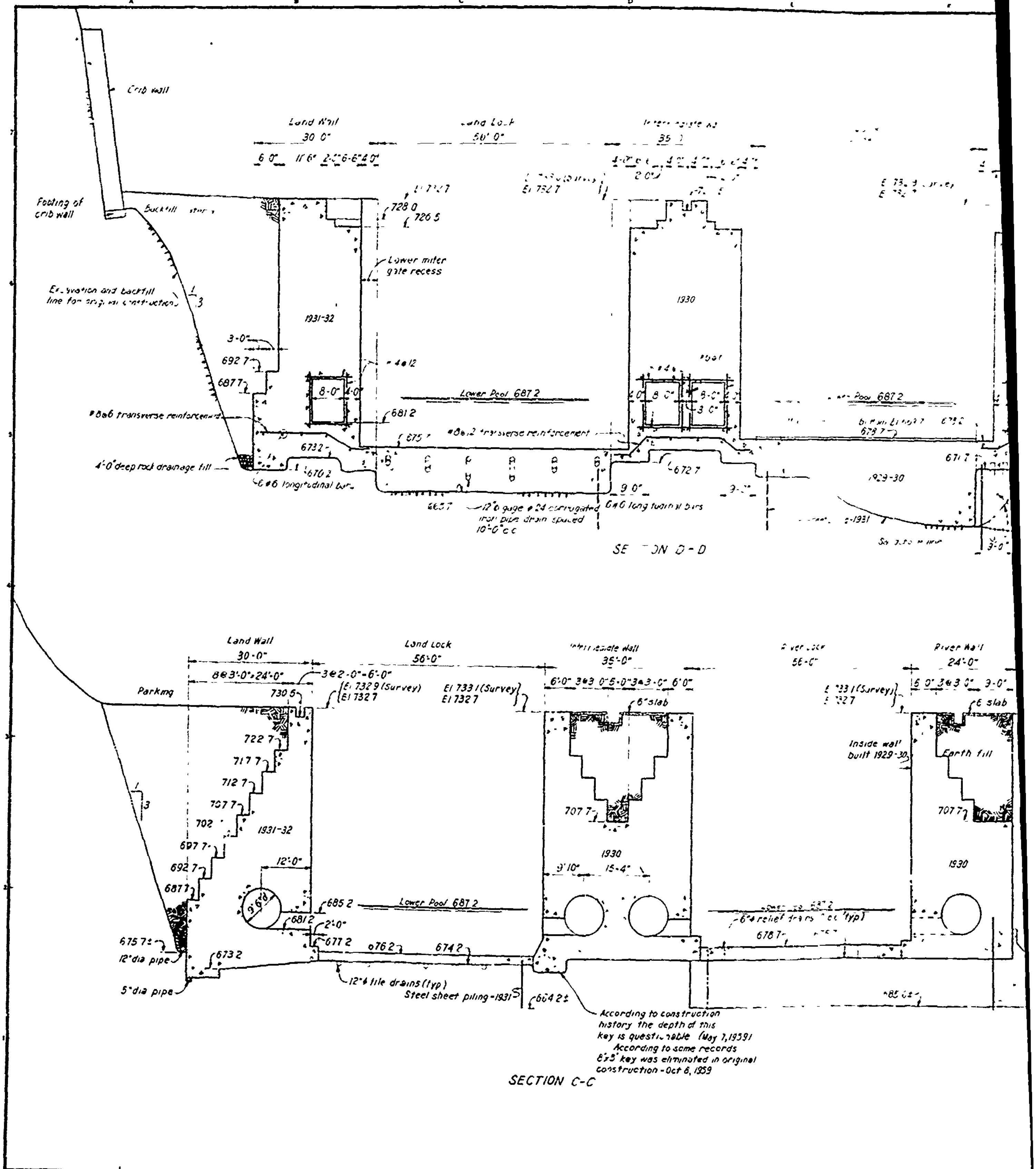
SECTION A - A
Land Wall
30'-0"
Land Lock
56'-0"
Fence
Upper Pool 725.0
Upper miter gate recess
Backfill material
Excavation and backfill line for original construction
4'-0" deep rock drainage fill
1930
sheet piling 16' long
sandstone approximate
SECTION B - B
Land Wall
30'-0"
Land Lock
56'-0"
Intermediate Wall
35'-0"
Fence
Parking
El 732.9 (Survey)
El 732.7
El 733.1 (Survey)
El 732.7
6" slab
1931-32
1930
Lower Pool 687.2
Inside wall built 1929-30
12" dia pipe
5" dia pipe
12" tile drains (typ)
Steel sheet piling-1931
Steel sheet piling-1931
sheet piling 18' long
According to construction history the depth of this key is questionable (May 7, 1959)
According to some records 6'x3' key was eliminated in original construction - Oct 8, 1959



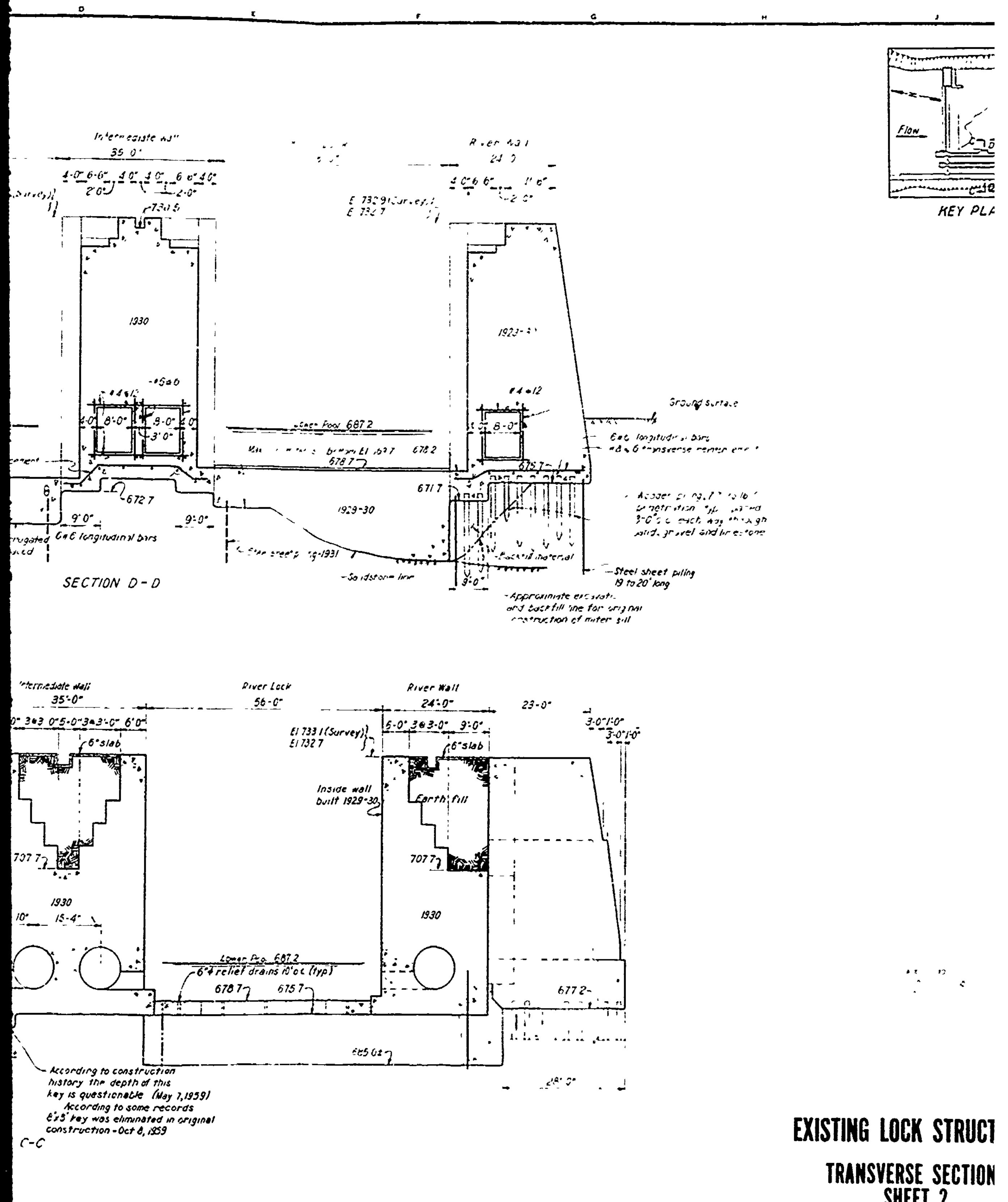
EXISTING LOCK STRUCTURES

TRANSVERSE SECTIONS
SHEET 1

PLATE 3

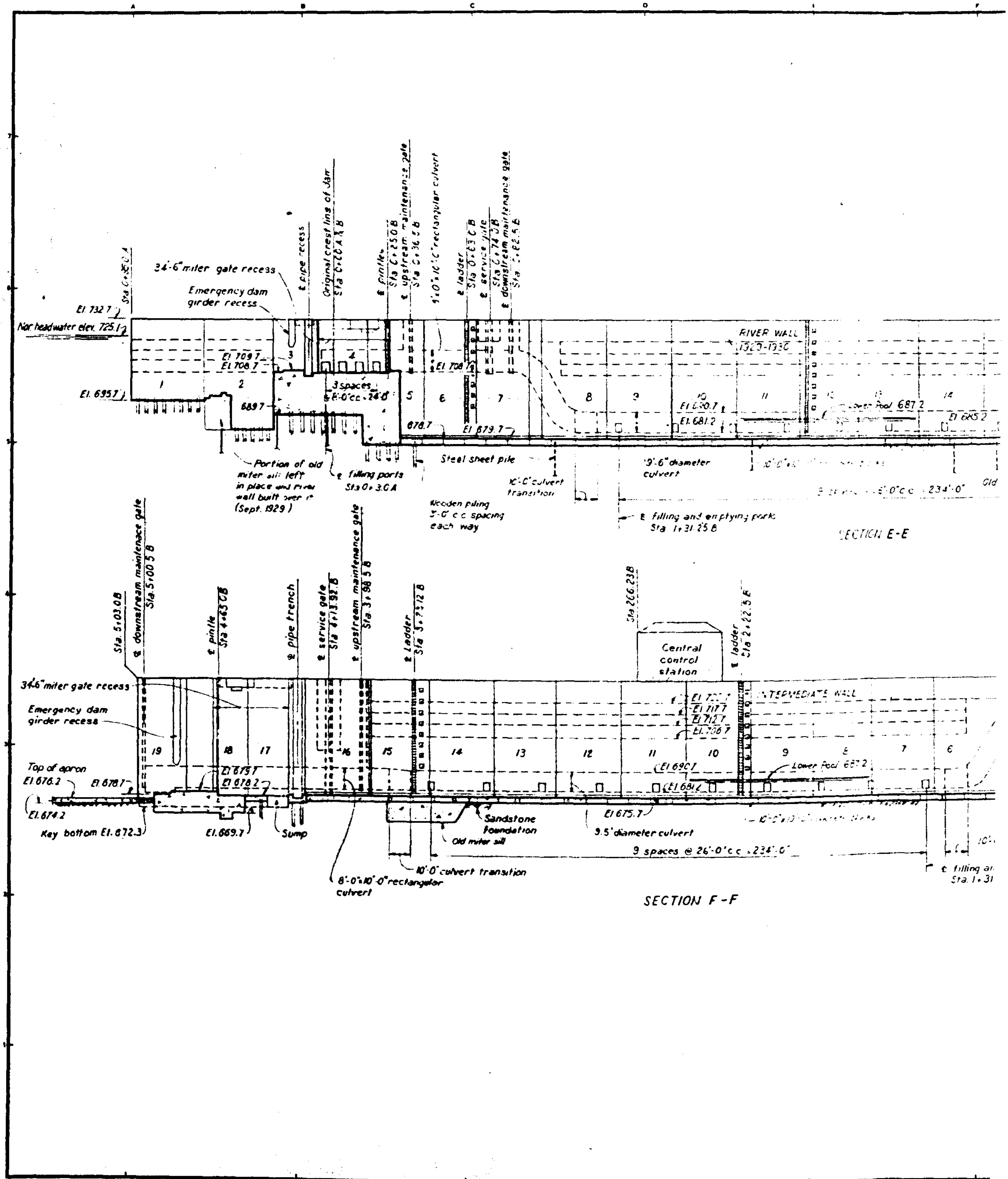


Crib wall
Footing of crib wall
Land Wall
30'0"
56'0"
Lower miter gate recess
Excavation and backfill line for original construction
1931-32
1930
3-0"
692 7
687 7
8-0"
Lower Pool 687 2
Pool 687 2
#8a6 transverse reinforcement
4'-0" deep rock drainage fill
6 #6 longitudinal bars
681 2
673 2
670 2
672 7
12" φ gage # 24 corrugated iron pipe drain spaced 10'-0" c c
6 #6 longitudinal bars
1929-30
Land Wall
30'-0"
8@3'-0"=24'-0"
3@2'-0"=6'-0"
Land Lock
56'-0"
El 732 9 (Survey)
El 732 7
El 733 1 (Survey)
El 732 7
35'-0"
6'-0" 3@3 0" 5'-0" 3@3'-0" 6'-0"
6" slab
River Wall
24'-0"
Parking
730 5
722 7
717 7
712 7
707 7
702
697 7
692 7
687 7
1931-32
12'-0"
685 2
Lower Pool 687 2
681 2
2'-0"
677 2
676 2
674 2
673 2
675 7±
12" dia pipe
5" dia pipe
12" φ tile drains (typ)
Steel sheet piling-1931
664 2±
707 7
1930
9'10"
15'-4"
6" φ relief drains (typ)
Inside wall built 1929-30
Earth fill
According to construction history the depth of this key is questionable (May 7, 1959)
According to some records 6'x5' key was eliminated in original construction - Oct 6, 1959
SECTION C-C

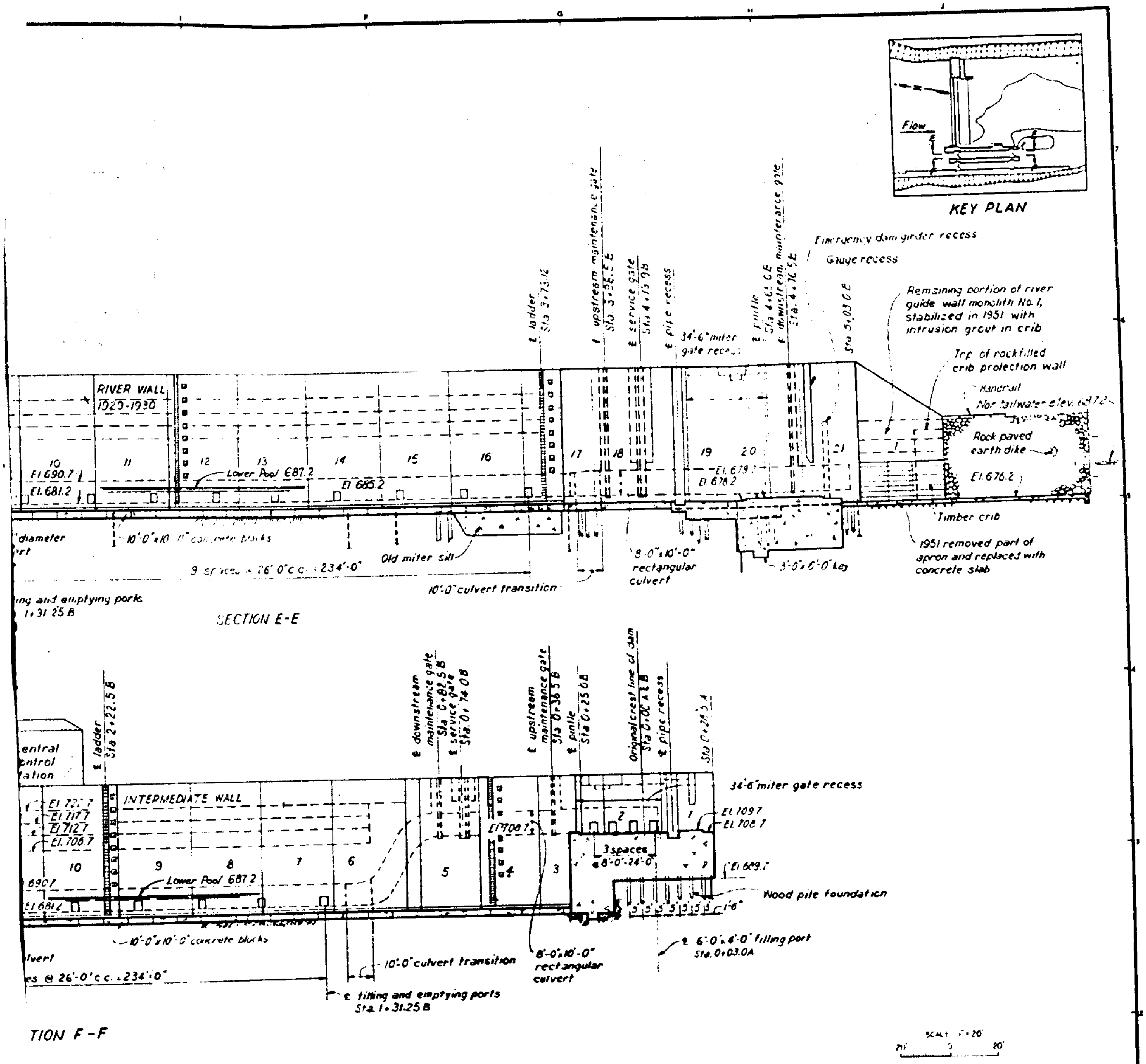


EXISTING LOCK STRUCT

TRANSVERSE SECTION
SHEET 2



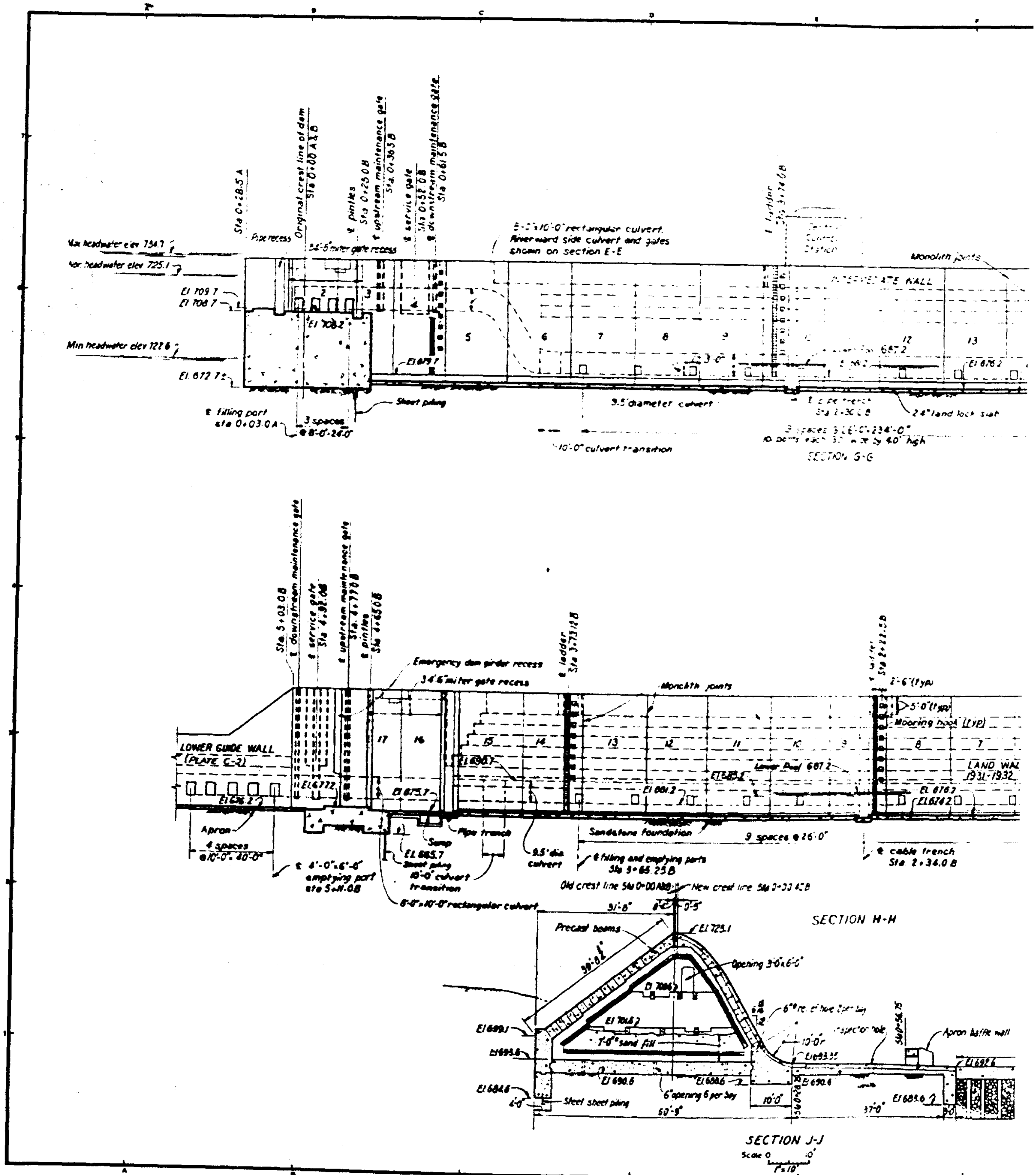
34'-6" miter gate recess
Emergency dam girder recess
Nor. headwater elev. 725.1
El. 732.7
El. 695.7
El. 709.7
El. 708.7
3 spaces @ 8'-0" c.c. = 24'-0"
689.7
678.7
El. 679.7
RIVER WALL
Lower Pool 687.2
Portion of old miter sill left in place and river wall built over it (Sept. 1929)
℄ filling ports Sta. 0+3.0 A
Steel sheet pile
10'-0" culvert transition
Wooden piling 3'-0" c.c. spacing each way
9'-6" diameter culvert
℄ Filling and emptying ports Sta. 1+31.25 B
SECTION E-E
℄ downstream maintenance gate Sta. 5+00.5 B
Sta. 5+03.0 B
℄ pintle Sta. 4+63.0 B
℄ pipe trench
℄ service gate
℄ upstream maintenance gate
℄ Ladder
Sta. 2.66.23 B
Central control station
℄ ladder
INTERMEDIATE WALL
El. 717.7
El. 712.7
El. 708.7
El. 690.7
El. 681.2
Lower Pool 687.2
Top of apron El. 676.2
El. 678.7
El. 679.7
El. 678.2
El. 674.2
Key bottom El. 672.3
El. 669.7
Sump
Sandstone foundation
Old miter sill
El. 675.7
9.5' diameter culvert
9 spaces @ 26'-0" c.c. = 234'-0"
10'-0" culvert transition
8'-0"x10'-0" rectangular culvert
SECTION F-F



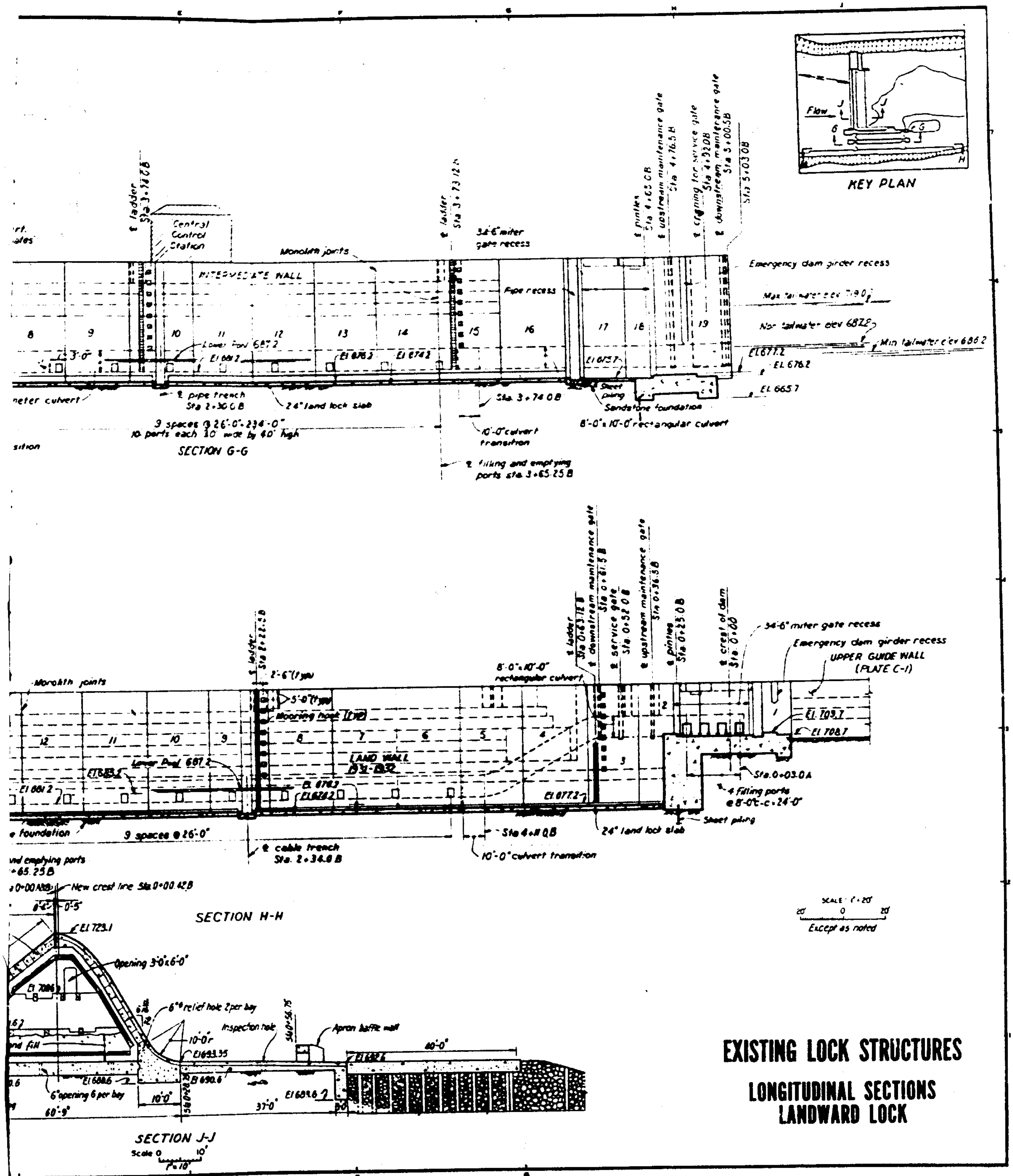
EXISTING LOCK STRUCTURES

LONGITUDINAL SECTIONS RIVERWARD LOCK

2

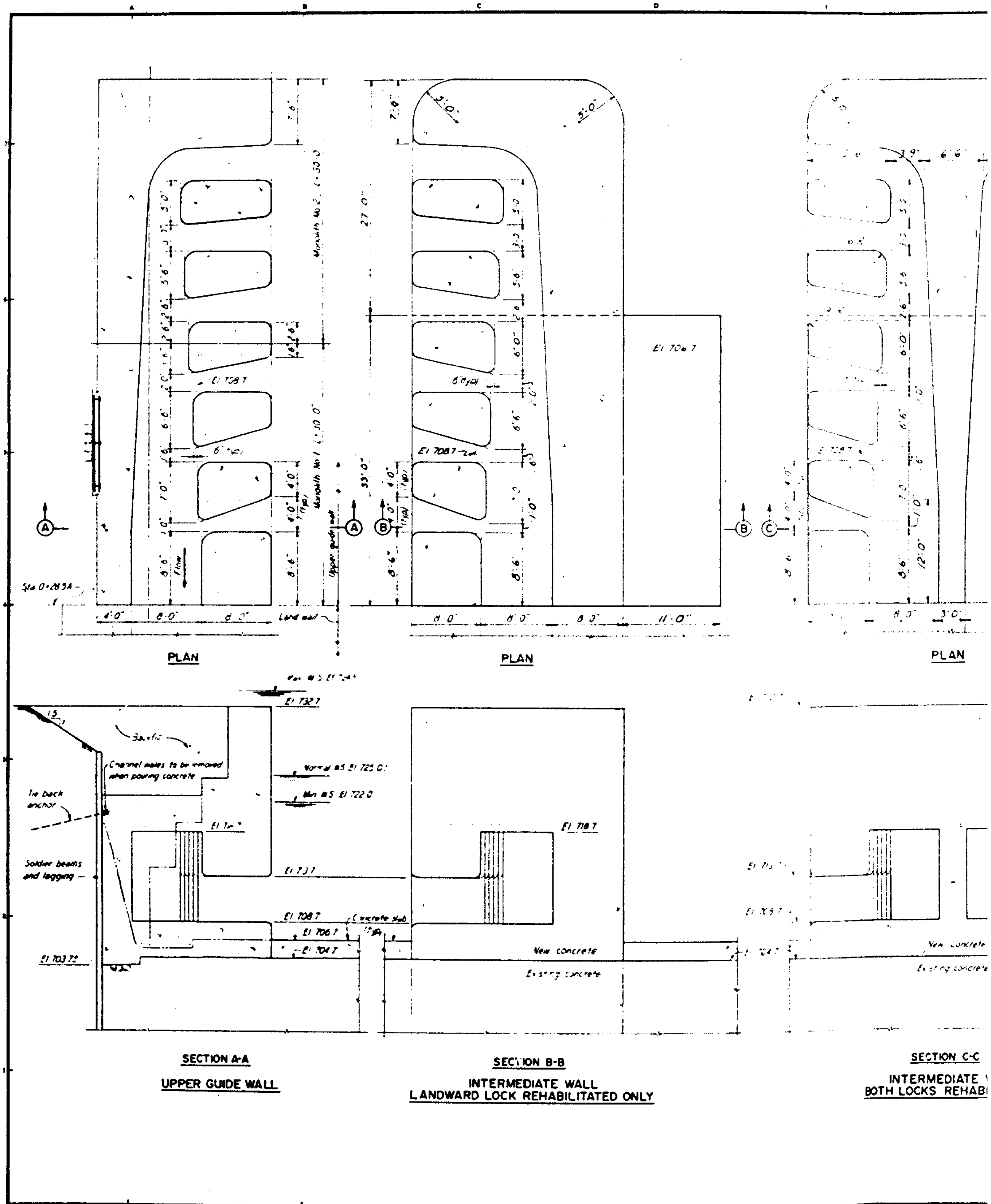


Max headwater elev 734.7
Nor headwater elev 725.1
Min headwater elev 722.6
El 709.7
El 708.7
El 708.2
El 672.7
El 679.7
Sta 0+28.5 A
Pipe recess
Original crest line of dam Sta 0+00 A & B
34'-6" miter gate recess
℄ pintles Sta 0+25.0 B
℄ upstream maintenance gate Sta 0+36.3 B
℄ service gate Sta 0+58.0 B
℄ downstream maintenance gate Sta 0+61.5 B
8'-0"x10'-0" rectangular culvert. Riverward side culvert and gates shown on section E-E
Monolith joints
INTERMEDIATE WALL
Lower Pool 687.2
Sheet piling
9.5' diameter culvert
10'-0" culvert transition
℄ filling port sta 0+03.0 A
3 spaces @ 8'-0"=24'-0"
℄ pipe trench Sta 2+30.0 B
24" land lock slab
10 ports each 3.0' wide by 4.0' high
SECTION G-G
Sta 5+03.0 B ℄ downstream maintenance gate
℄ service gate Sta 4+98.0 B
℄ upstream maintenance gate Sta 4+77.0 B
℄ pintles Sta 4+65.0 B
Emergency dam girder recess
34'-6" miter gate recess
℄ ladder Sta 3+73.2 B
Monolith joints
℄ ladder Sta 2+22.5 B
2'-6" (typ)
5'-0" (typ)
Mooring hook (typ)
LOWER GUIDE WALL (PLATE C-2)
LAND WALL 1931-1932
Lower Pool 687.2
El 690.7
El 677.2
El 675.7
El 676.2
El 681.2
El 685.5
El 676.2
El 674.2
Apron
4 spaces @ 10'-0"=40'-0"
℄ 4'-0"x6'-6" emptying port sta 5+11.0 B
Sump
Pipe trench
EL 665.7
Sheet piling
10'-0" culvert transition
9.5' dia culvert
℄ filling and emptying ports Sta 3+65.25 B
Sandstone foundation
9 spaces @ 26'-0"
℄ cable trench Sta. 2+34.0 B
8'-0"x10'-0" rectangular culvert
SECTION H-H
Old crest line Sta 0+00 A & B
New crest line Sta 0+33.42 B
31'-8"
0'-5"
El 725.1
Precast beams
Opening 3'-0"x6'-0"
El 708.2
El 701.2
7'-0" sand fill
El 699.1
El 695.6
El 690.6
El 688.6
6" opening 6 per bay
El 684.6
4'-0"
Steel sheet piling
60'-9"
10'-0"
Inspector hole
El 693.35
El 690.6
Apron baffle wall
El 689.6
37'-0"
SECTION J-J
Scale 0 10'
1"=10'

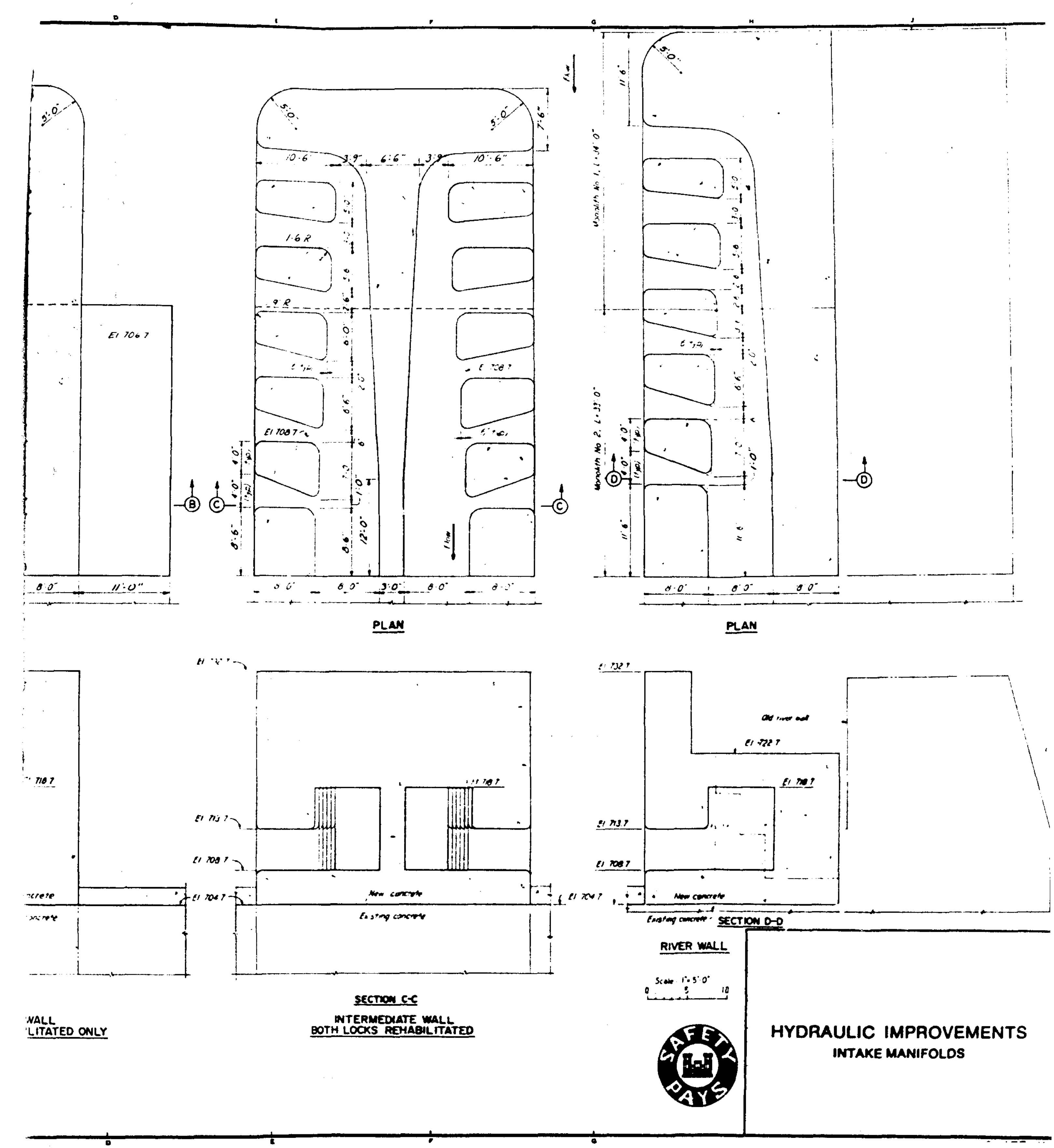


EXISTING LOCK STRUCTURES

LONGITUDINAL SECTIONS LANDWARD LOCK



PLAN
PLAN
PLAN
Monolith No 2
Monolith No 1
Upper guide wall
Land wall
Flow
Sta 0+28.5A
El 708.7
El 706.7
6" (typ)
El 708.7
SECTION A-A
UPPER GUIDE WALL
SECTION B-B
INTERMEDIATE WALL
LANDWARD LOCK REHABILITATED ONLY
SECTION C-C
INTERMEDIATE
BOTH LOCKS REHABI
Backfill
Channel wales to be removed when pouring concrete
Tie back anchor
Soldier beams and lagging
Normal WS El 725.0
Min WS El 722.0
El 732.7
El 718.7
El 713.7
El 708.7
El 706.7
El 704.7
El 703.7±
Concrete slab
New concrete
Existing concrete

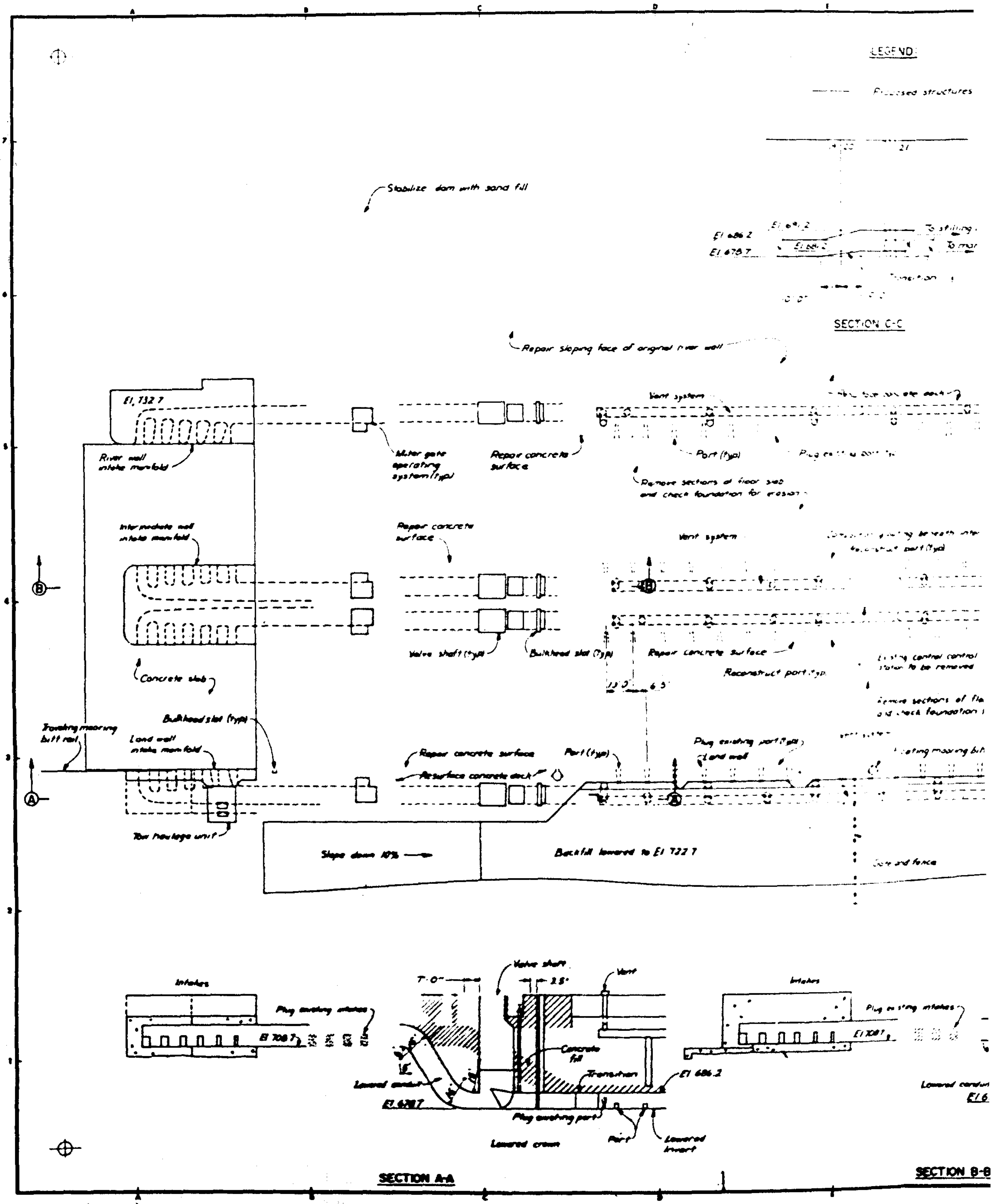


HYDRAULIC IMPROVEMENTS

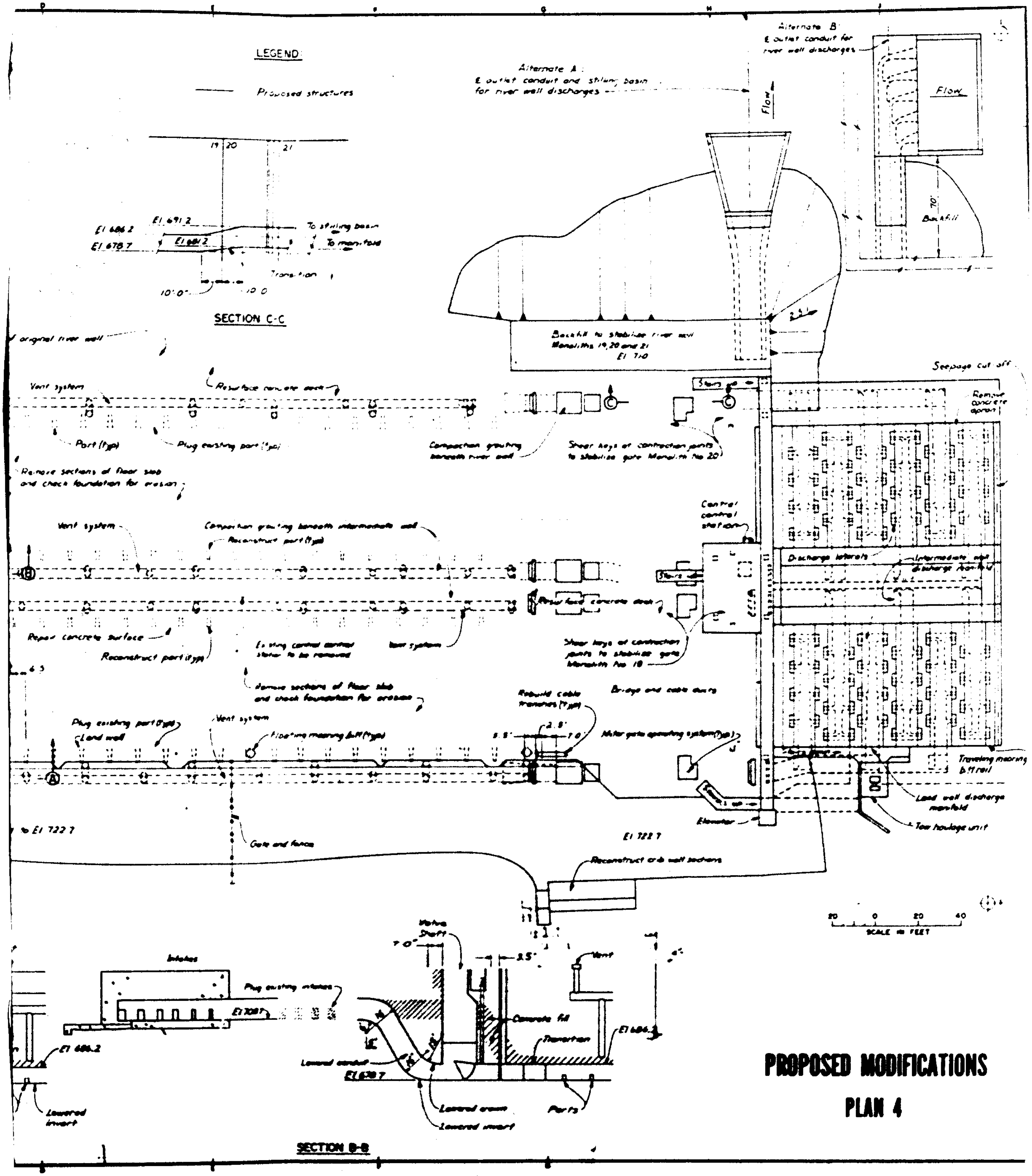
INTAKE MANIFOLDS

PLATE 7

2



LEGEND
Proposed structures
SECTION C-C
Stabilize dam with sand fill
Repair sloping face of original river wall
El. 732.7
River wall intake manifold
Miter gate operating system (typ)
Repair concrete surface
Vent system
Port (typ)
Remove sections of floor slab and check foundation for erosion
Intermediate wall intake manifold
Repair concrete surface
Vent system
Valve shaft (typ)
Bulkhead slot (Typ)
Repair concrete surface
Reconstruct port typ.
Concrete slab
Bulkhead slot (typ)
Traveling mooring bitt rail
Land wall intake manifold
Repair concrete surface
Resurface concrete deck
Port (typ)
Plug existing port (typ)
Land wall
Tow haulage unit
Slope down 10%
Backfill lowered to El 722.7
Intakes
Plug existing intakes
El 708.7
Valve shaft
Vent
Concrete fill
Transition
El 686.2
Lowered conduit
El 678.7
Plug existing port
Lowered crown
Port
Lowered invert
SECTION A-A
SECTION B-B

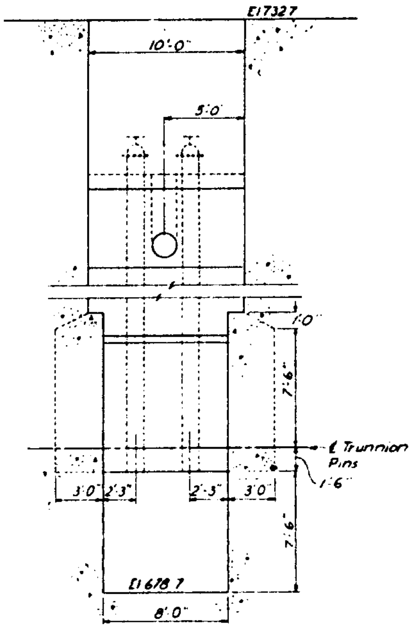


PROPOSED MODIFICATIONS

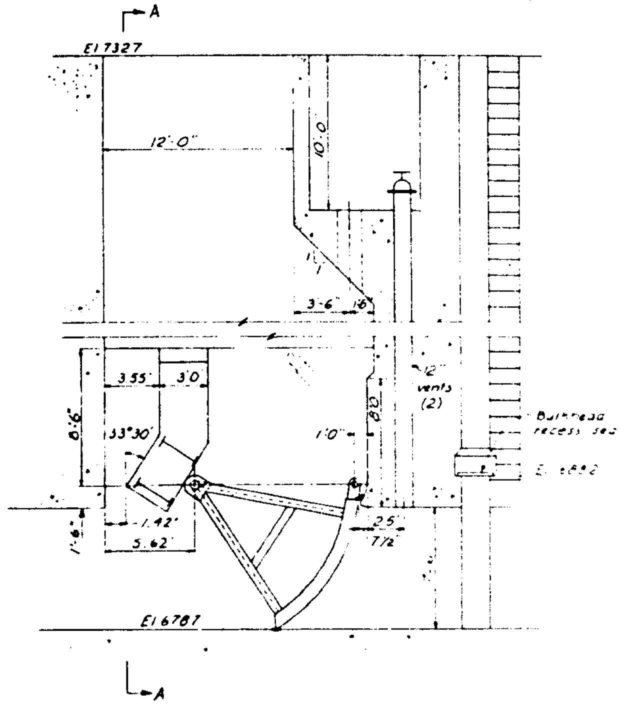
PLAN 4

PLATE

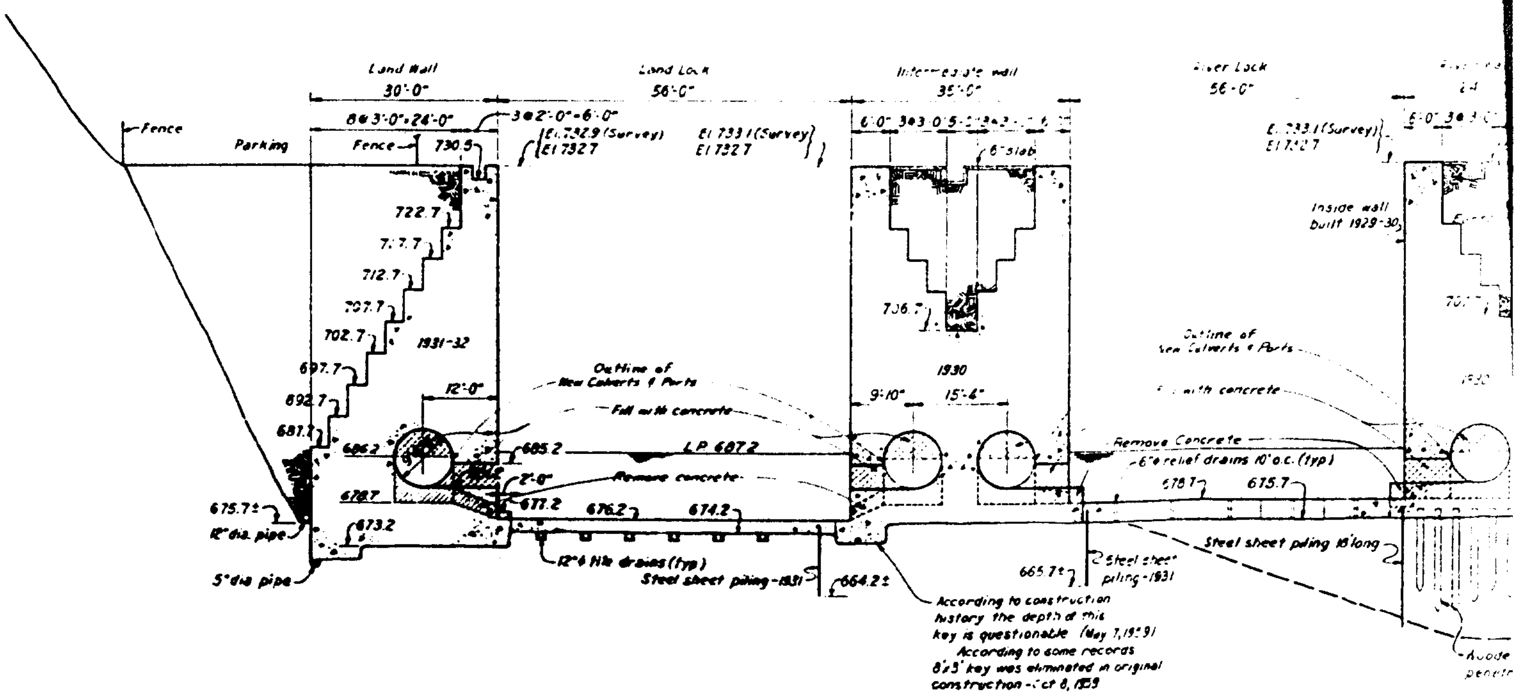
2



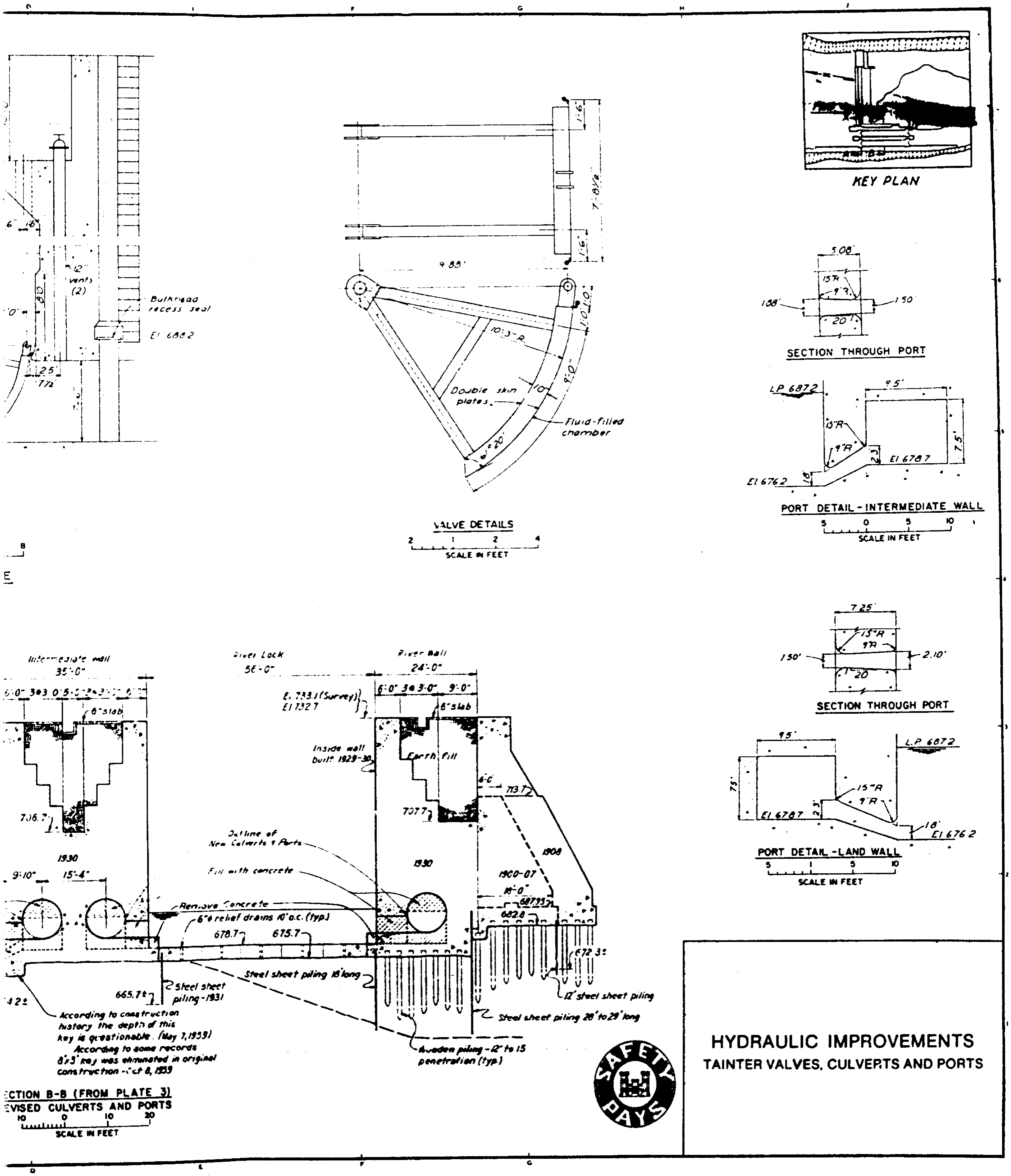
SECTION A-A
VALVE OMITTED
4 0 4 8
SCALE IN FEET



SIDE VIEW
4 0 4 8
SCALE IN FEET
TAINTER VALVE

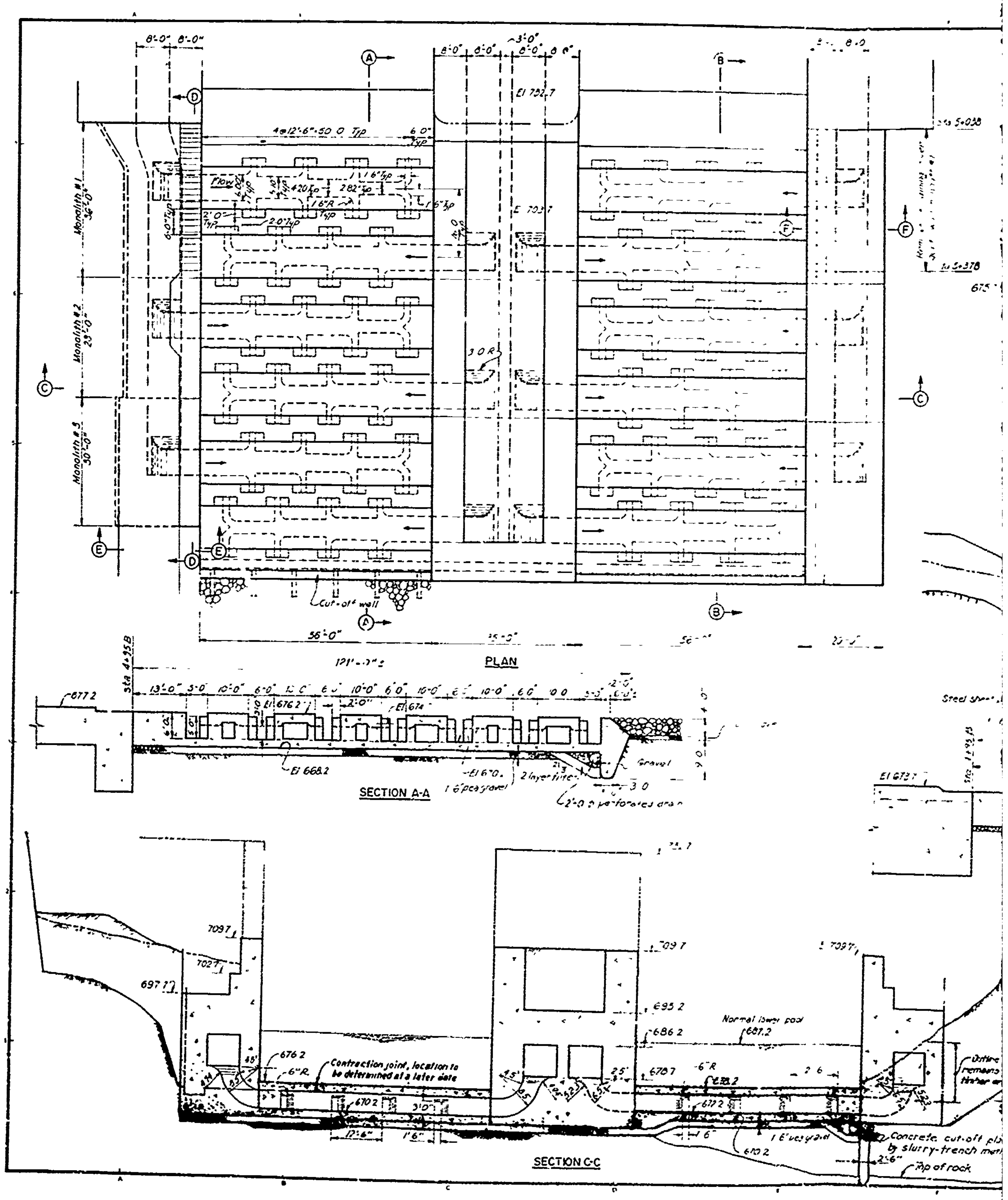


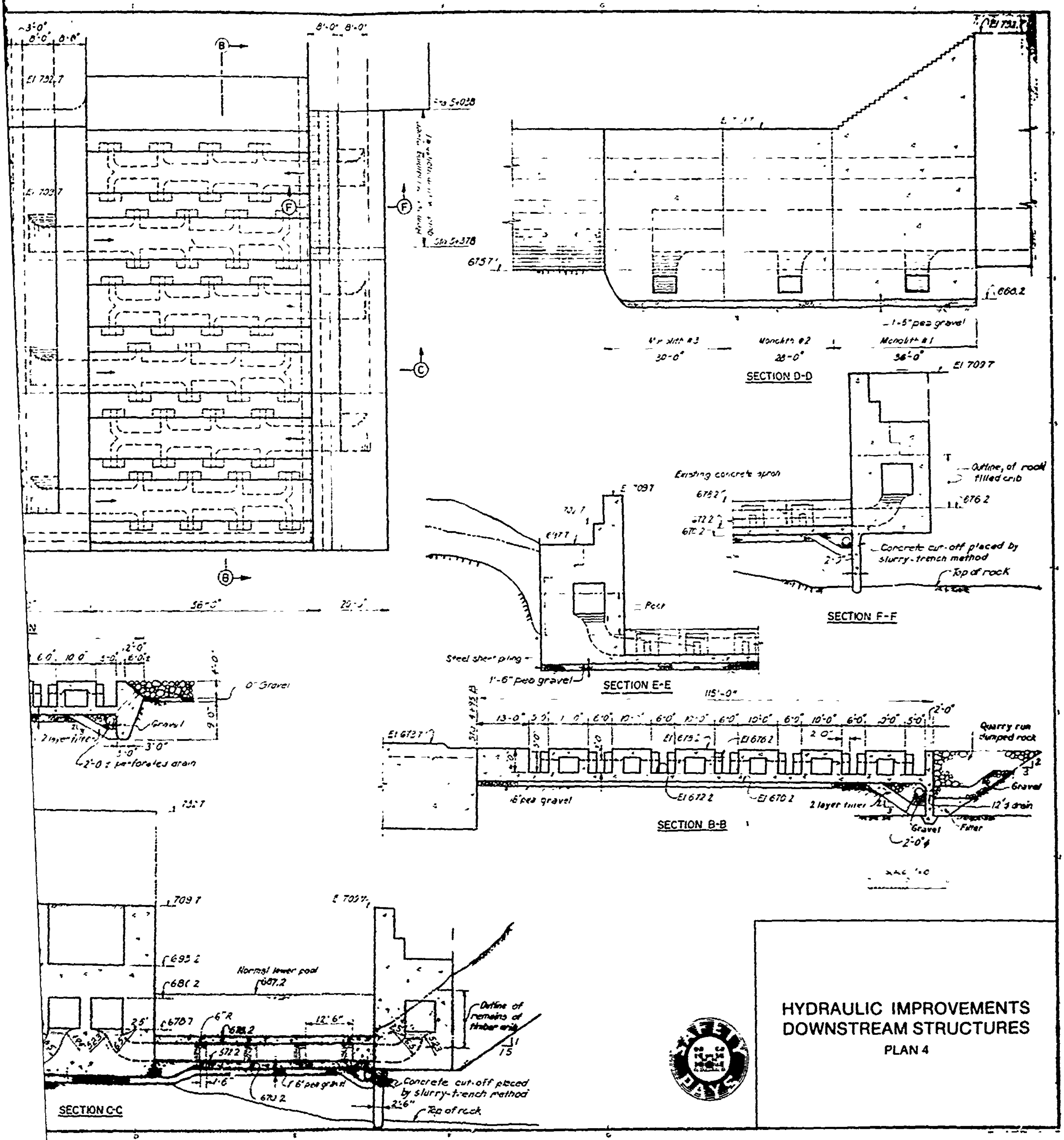
SECTION B-B (FROM PLATE 3)
REVISED CULVERTS AND PORTS
10 0 10 20
SCALE IN FEET



HYDRAULIC IMPROVEMENTS

TAINTER VALVES, CULVERTS AND PORTS

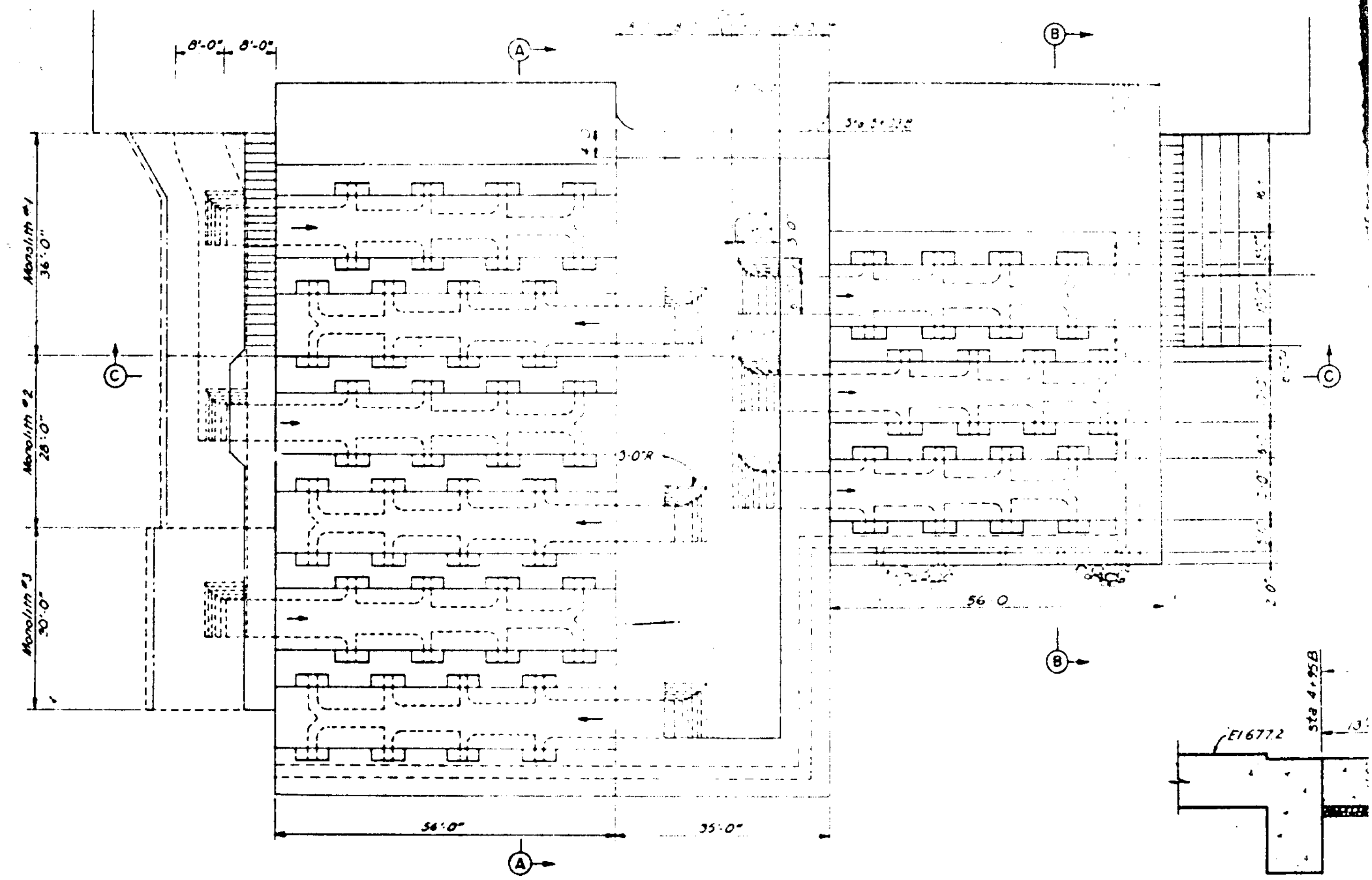

PLAN
SECTION A-A
SECTION C-C
Monolith #1 36'-0"
Monolith #2 29'-0"
Monolith #3 30'-0"
Flow
Cut-off wall
56'-0"
El 668.2
Gravel
1 6" pea gravel
2 layer filter
Contraction joint, location to be determined at a later date
Normal lower pool 687.2
Concrete cut-off
by slurry-trench
Top of rock



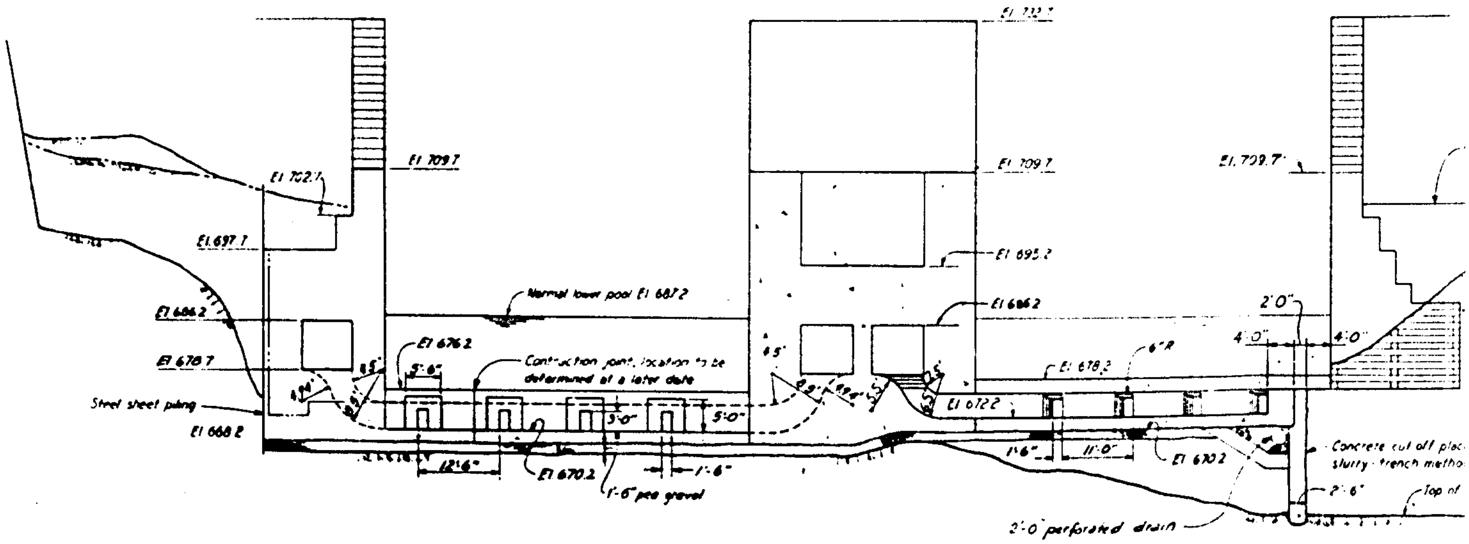
HYDRAULIC IMPROVEMENTS
DOWNSTREAM STRUCTURES
PLAN 4

PLATE 10

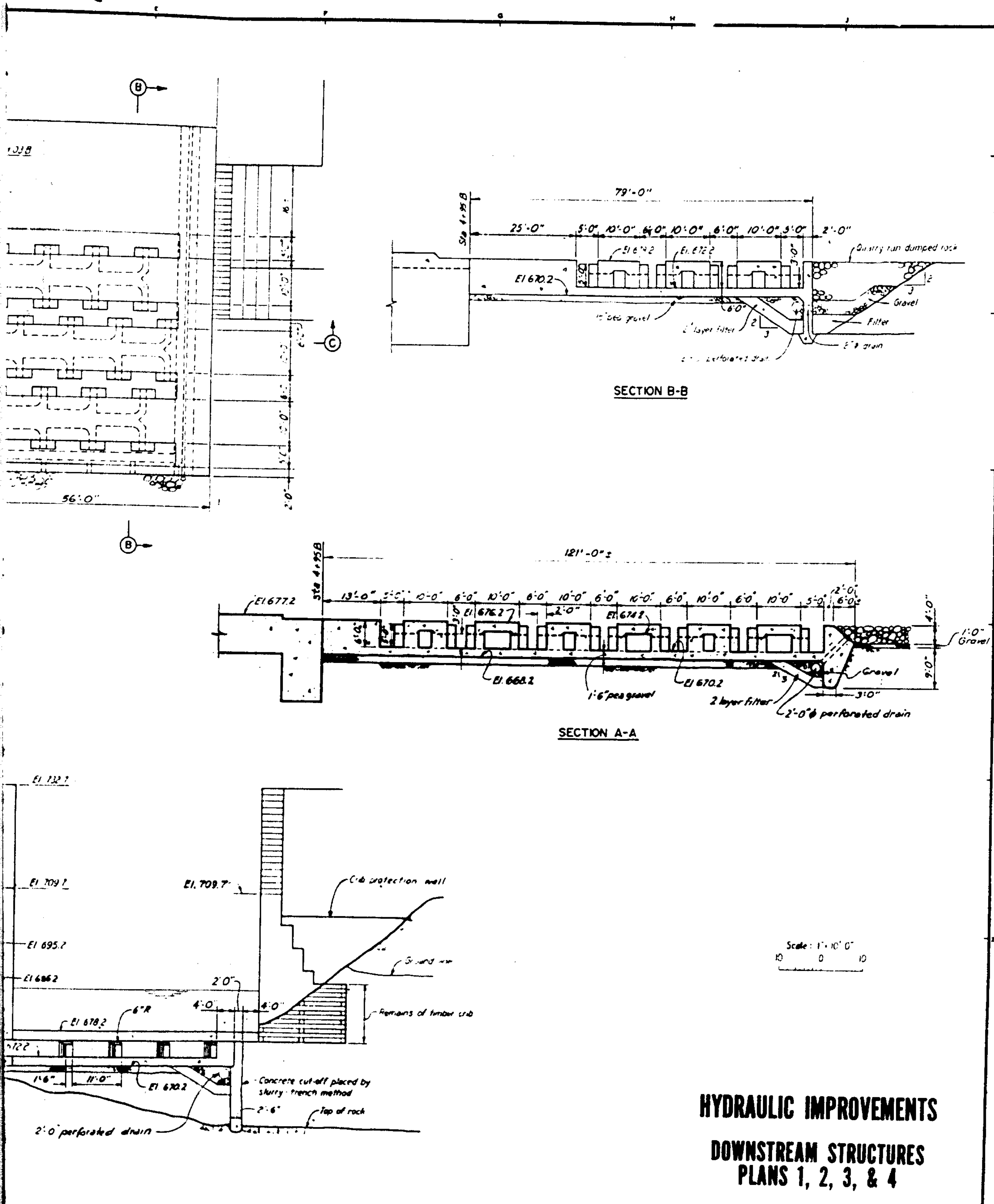
2



PLAN



SECTION C-C

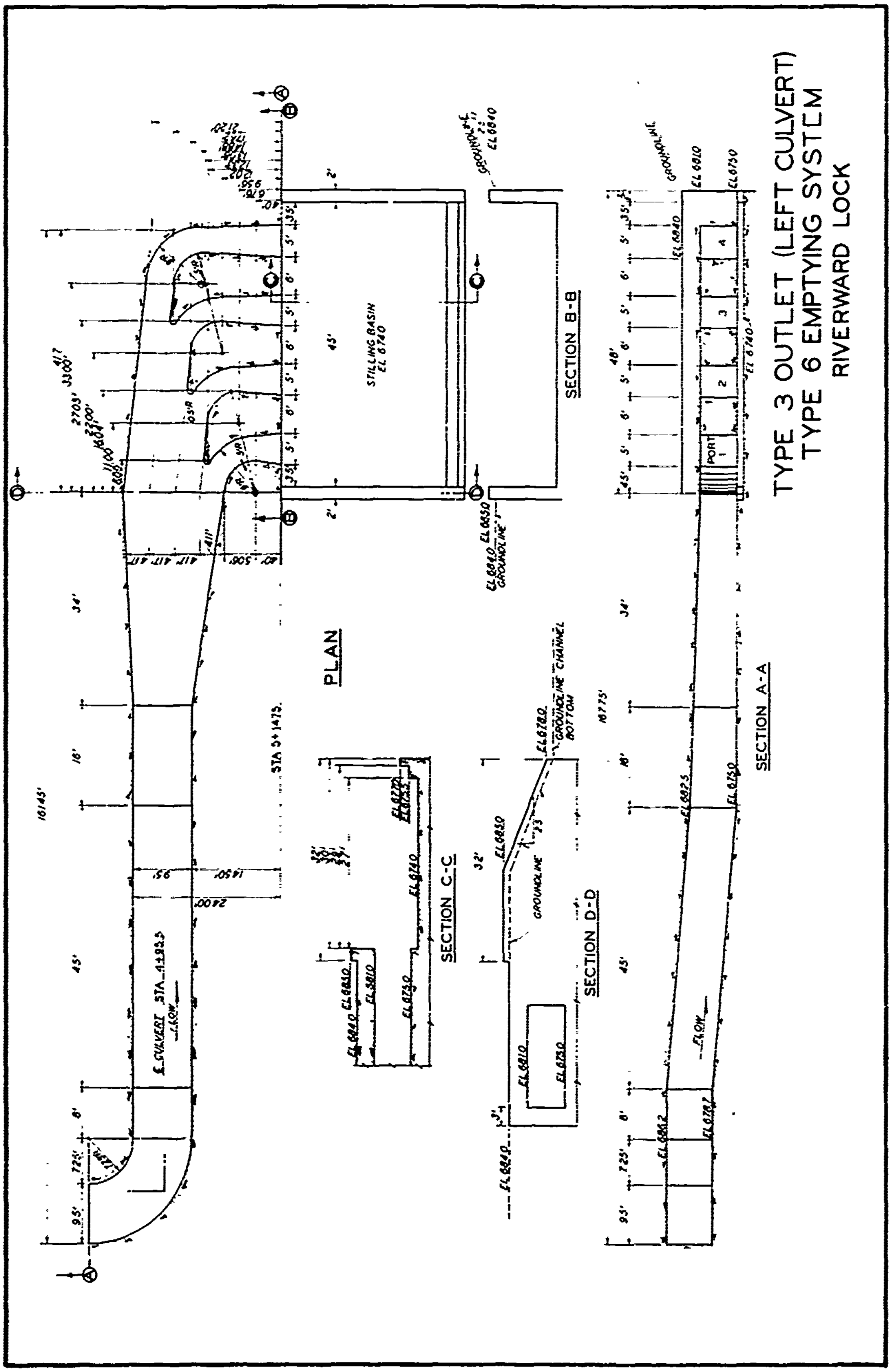


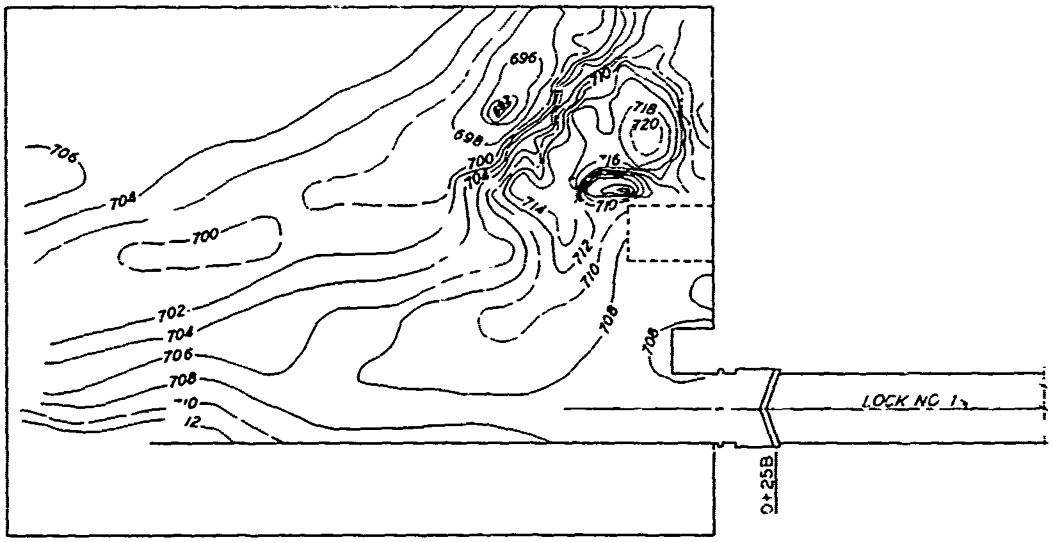
HYDRAULIC IMPROVEMENTS

DOWNSTREAM STRUCTURES
PLANS 1, 2, 3, & 4

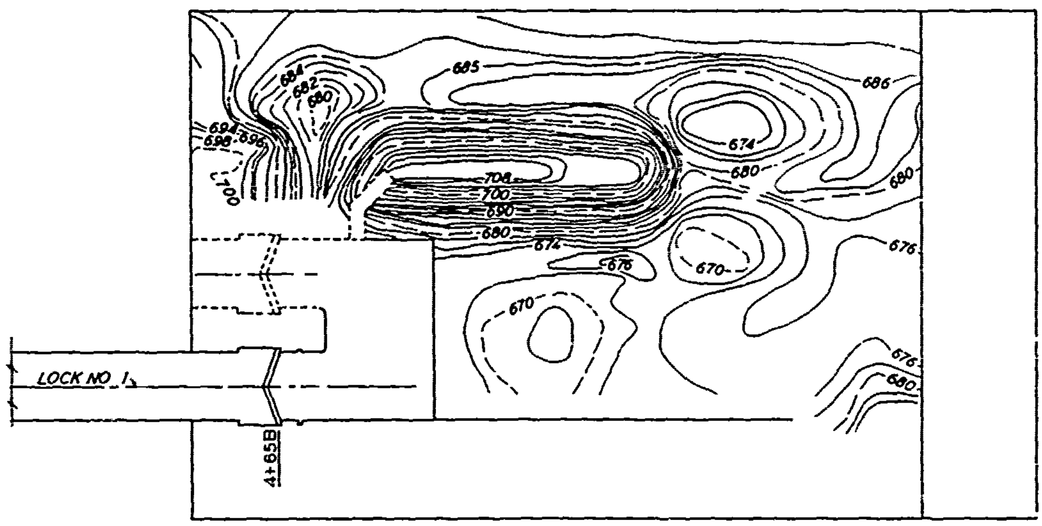
PLATE 11

2


TYPE 3 OUTLET (LEFT CULVERT)
TYPE 6 EMPTYING SYSTEM
RIVERWARD LOCK
PLAN
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
STILLING BASIN
EL 674.0
PORT 1
STA 5+14.75
GROUNDLINE
FLOW



UPSTREAM PLAN



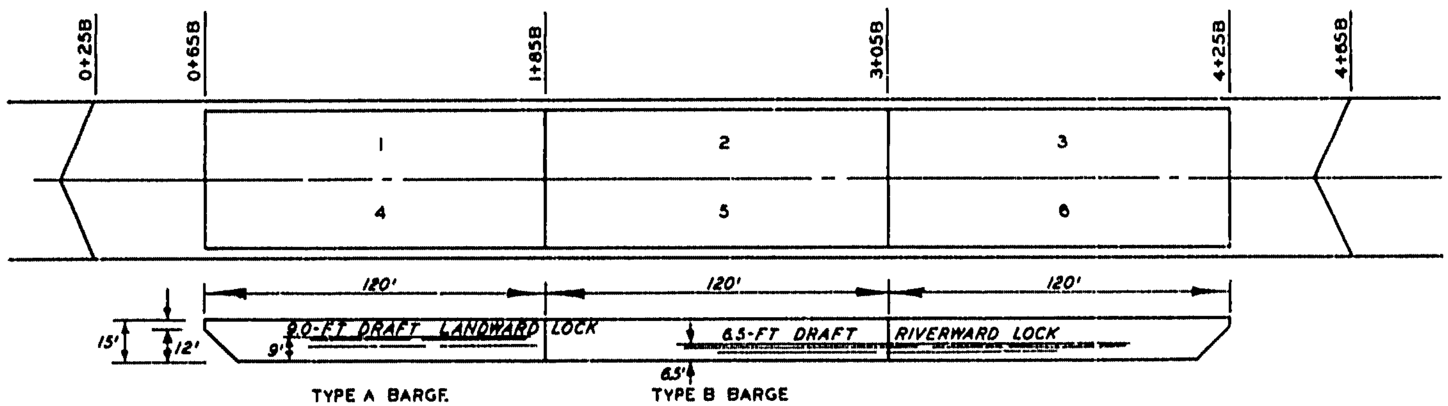
DOWNSTREAM PLAN

NOTE: FOR RIVERWARD LOCK TEST THE DOWNSTREAM TOPOGRAPHY WAS SHIFTED AS SHOWN IN PLATE 50.

SCALE

50 0 50 100 150FT

LANDWARD LOCK
TOPOGRAPHY



NO. OF BARGES	BARGE TYPES A	BARGE TYPES B	DISPLACEMENT, TONS 9-FT DRAFT	DISPLACEMENT, TONS 6.5-FT DRAFT
6(1-6)	4	2	4844	3472
3(1-3)	2	1	2422	1736
2(1&4)	2		1580	1128

DETAILS OF BARGES AND BARGE TOWS

LANDWARD LOCK TOW DRAFT 9.0 FT
RIVERWARD LOCK TOW DRAFT 6.5 FT

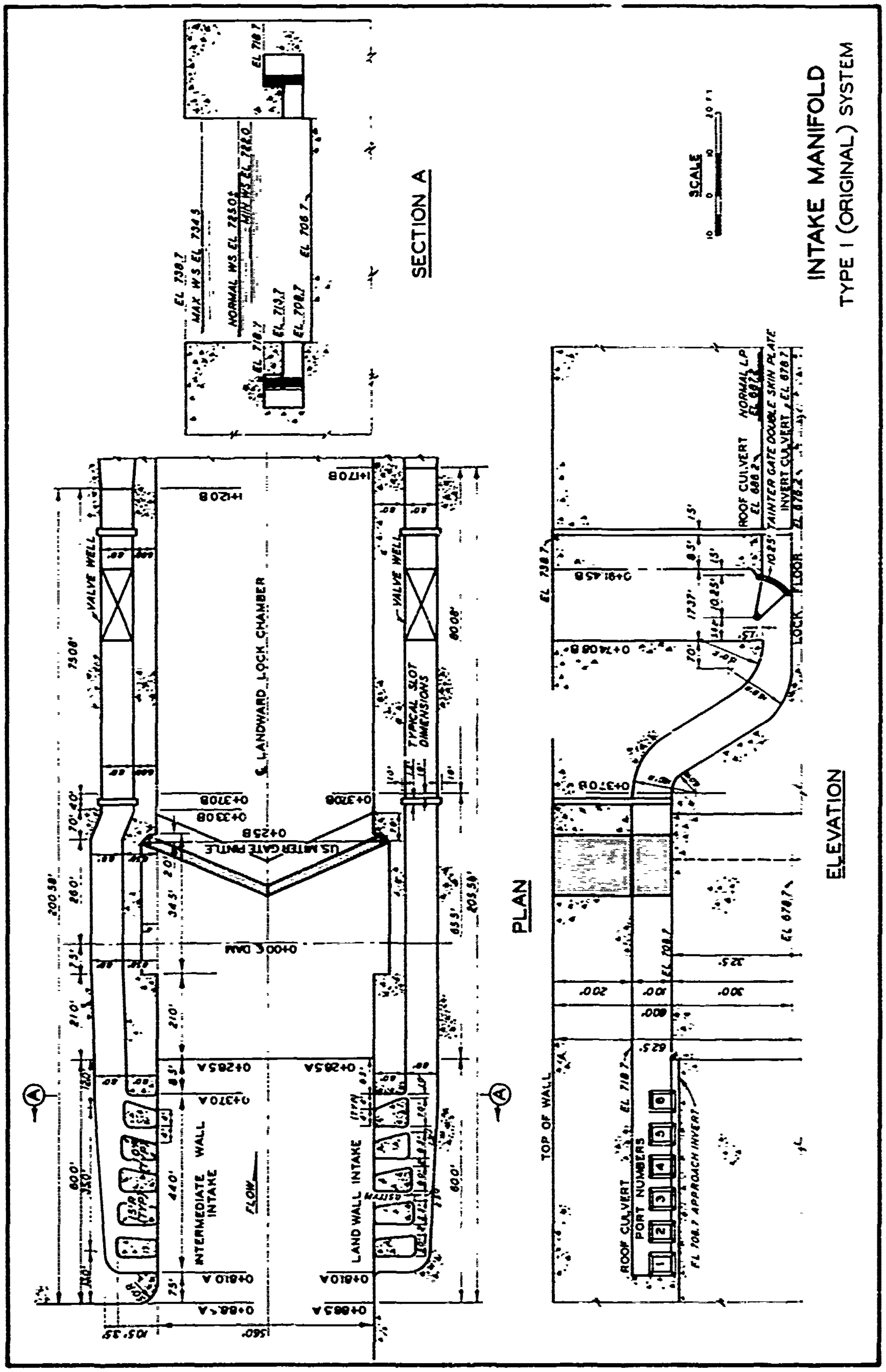

INTAKE MANIFOLD
TYPE 1 (ORIGINAL) SYSTEM
SECTION A
PLAN
ELEVATION
SCALE
LANDWARD LOCK CHAMBER
VALVE WELL
TYPICAL SLOT DIMENSIONS
U.S. MITER GATE PINTLE
INTERMEDIATE WALL INTAKE
LAND WALL INTAKE
FLOW
TOP OF WALL
ROOF CULVERT
PORT NUMBERS
EL 708.7 APPROACH INVERT
ROOF CULVERT EL 688.2
NORMAL L.P. EL 697.2
TAINTER GATE DOUBLE SKIN PLATE
INVERT CULVERT EL 678.7
LOCK FLOOR
MAX W.S. EL 734.5
NORMAL W.S. EL 725.0
MIN W.S. EL 722.0
0+00 DAM

PLATE 15

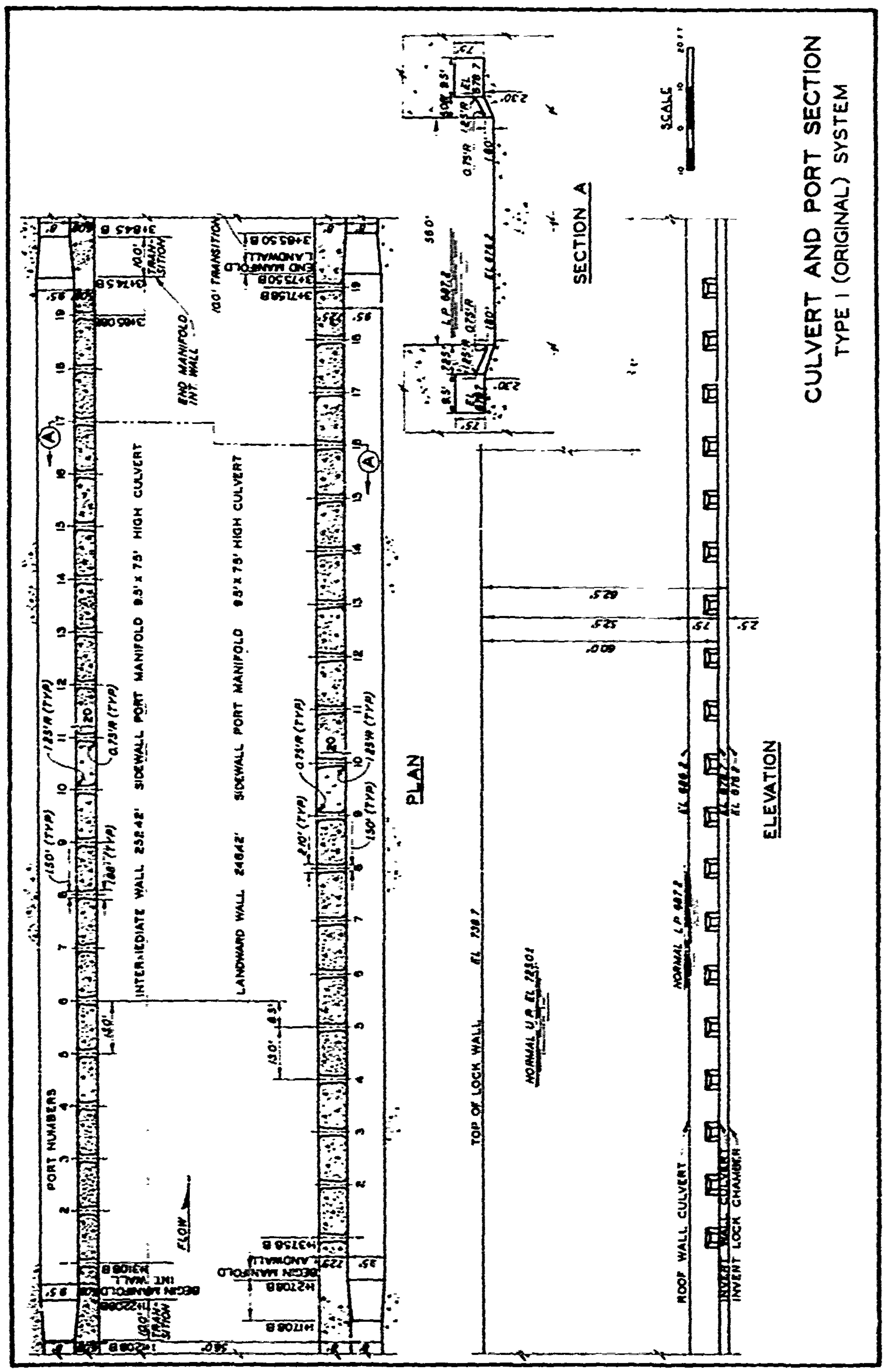

CULVERT AND PORT SECTION
TYPE I (ORIGINAL) SYSTEM
PLAN
SECTION A
ELEVATION
SCALE
PORT NUMBERS
FLOW
INTERMEDIATE WALL 252.42' SIDEWALL PORT MANIFOLD 9.5' x 7.5' HIGH CULVERT
LANDWARD WALL 246.42' SIDEWALL PORT MANIFOLD 9.5' x 7.5' HIGH CULVERT
END MANIFOLD INT WALL
100' TRANSITION
END MANIFOLD LANDWALL
BEGIN MANIFOLD LANDWALL
BEGIN MANIFOLD INT. WALL
TOP OF LOCK WALL EL 739.7
NORMAL U.P. EL 728.0
NORMAL L.P. 687.8
ROOF WALL CULVERT
INVERT WALL CULVERT
INVERT LOCK CHAMBER

PLATE 16

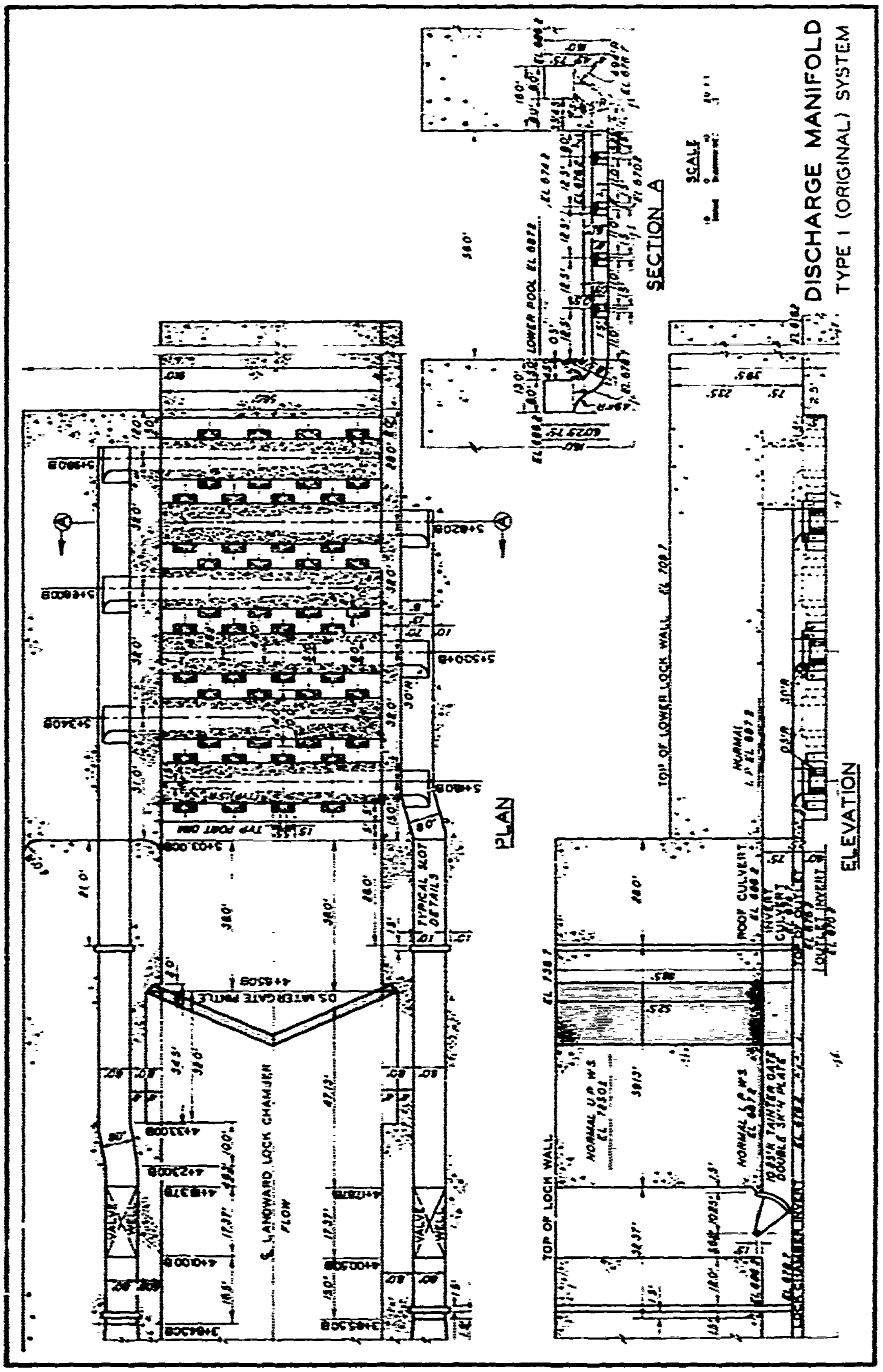
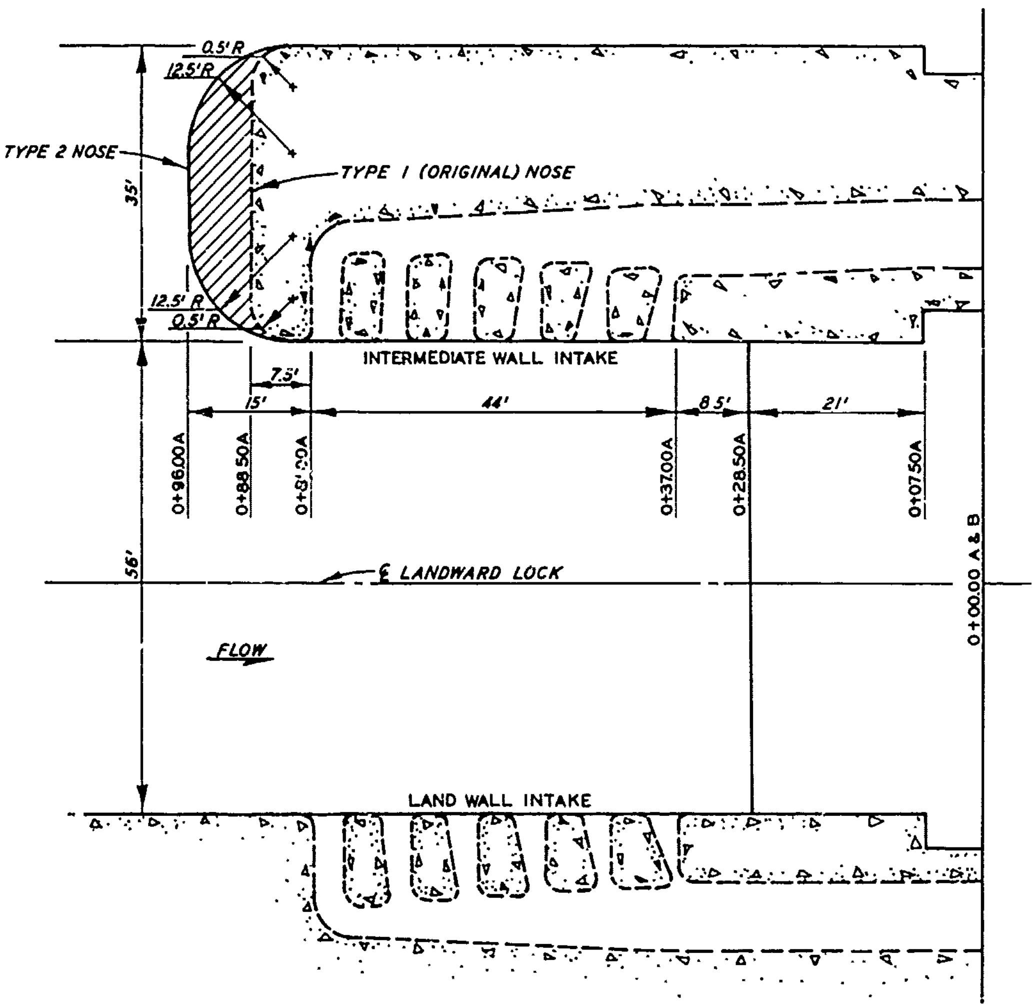
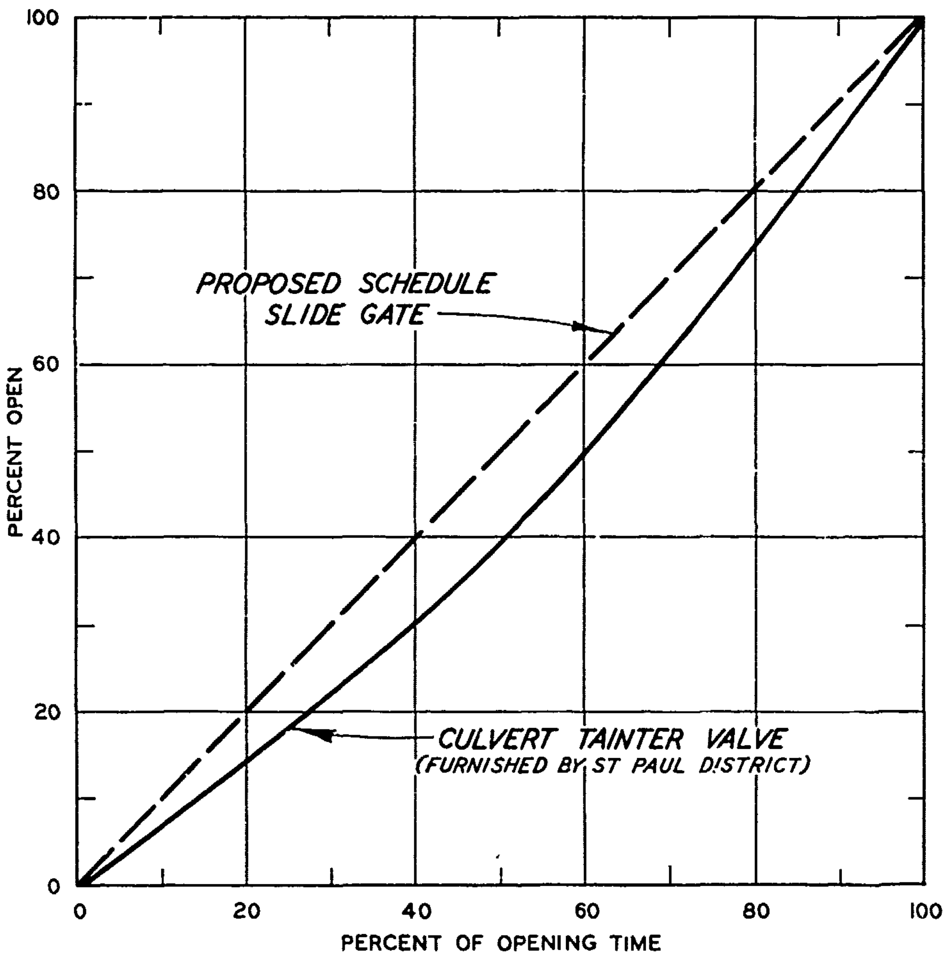

PLAN
ELEVATION
SECTION A
SCALE
TOP OF LOCK WALL
TOP OF LOWER LOCK WALL
LANDWARD LOCK CHAMBER
FLOW
VALVE WELL
TYPICAL SLOT DETAILS
LOWER POOL EL 687.2
DISCHARGE MANIFOLD
TYPE 1 (ORIGINAL) SYSTEM

PLATE 17

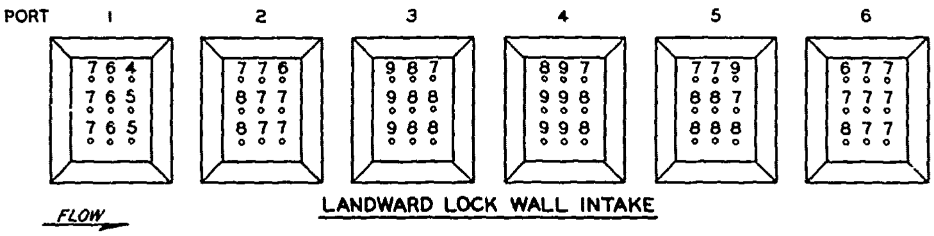


PLAN

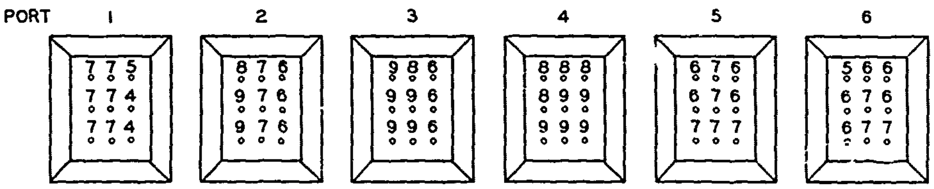
TYPE 2 INTERMEDIATE WALL NOSE
AT TYPE 1 (ORIGINAL) INTAKE



CULVERT TAINTER VALVE
VERSUS SLIDE GATE
OPENING SCHEDULE

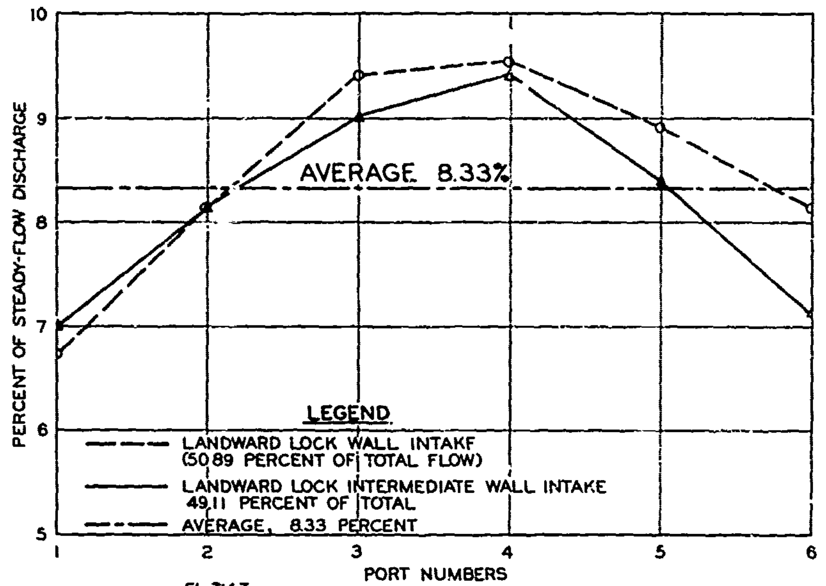


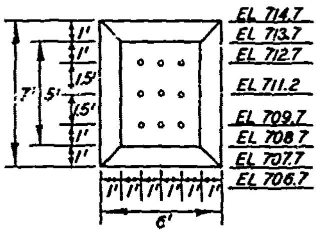
LANDWARD LOCK WALL INTAKE



LANDWARD LOCK INTERMEDIATE WALL INTAKE

VELOCITIES AT PORT FACE





FLOW DISTRIBUTION

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND AND ARE MEASURED AT WALL FACE OF INTAKE MANIFOLDS.

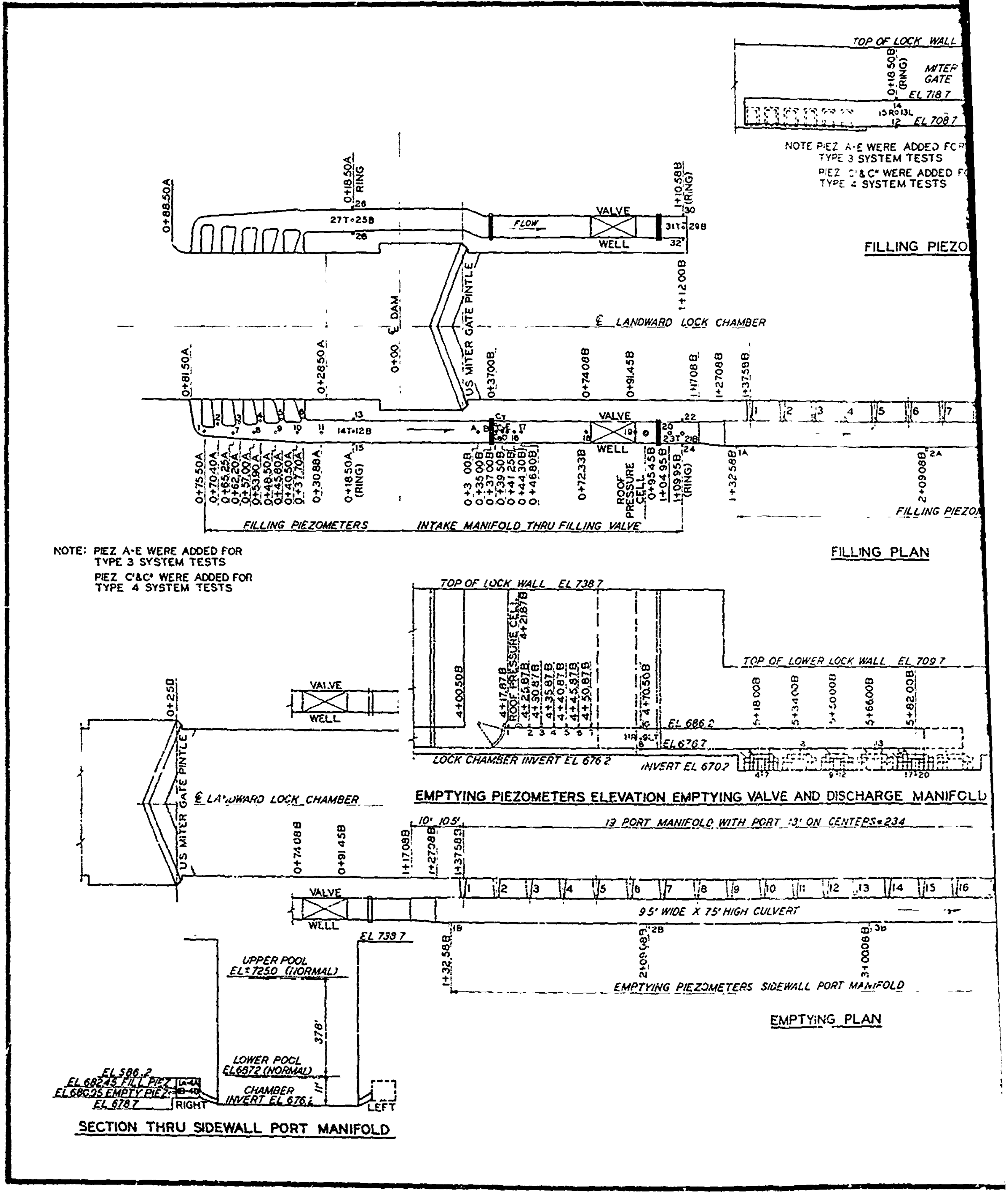
TEST CONDITIONS

TOTAL DISCHARGE 2868 CFS
UPPER POOL EL 725.0
LOCK CHAMBER EL 704.5
FILLING VALVES OPEN FULL
UPPER MITER GATES CLOSED
EMPTYING VALVES CLOSED
LOWER MITER GATES OPEN

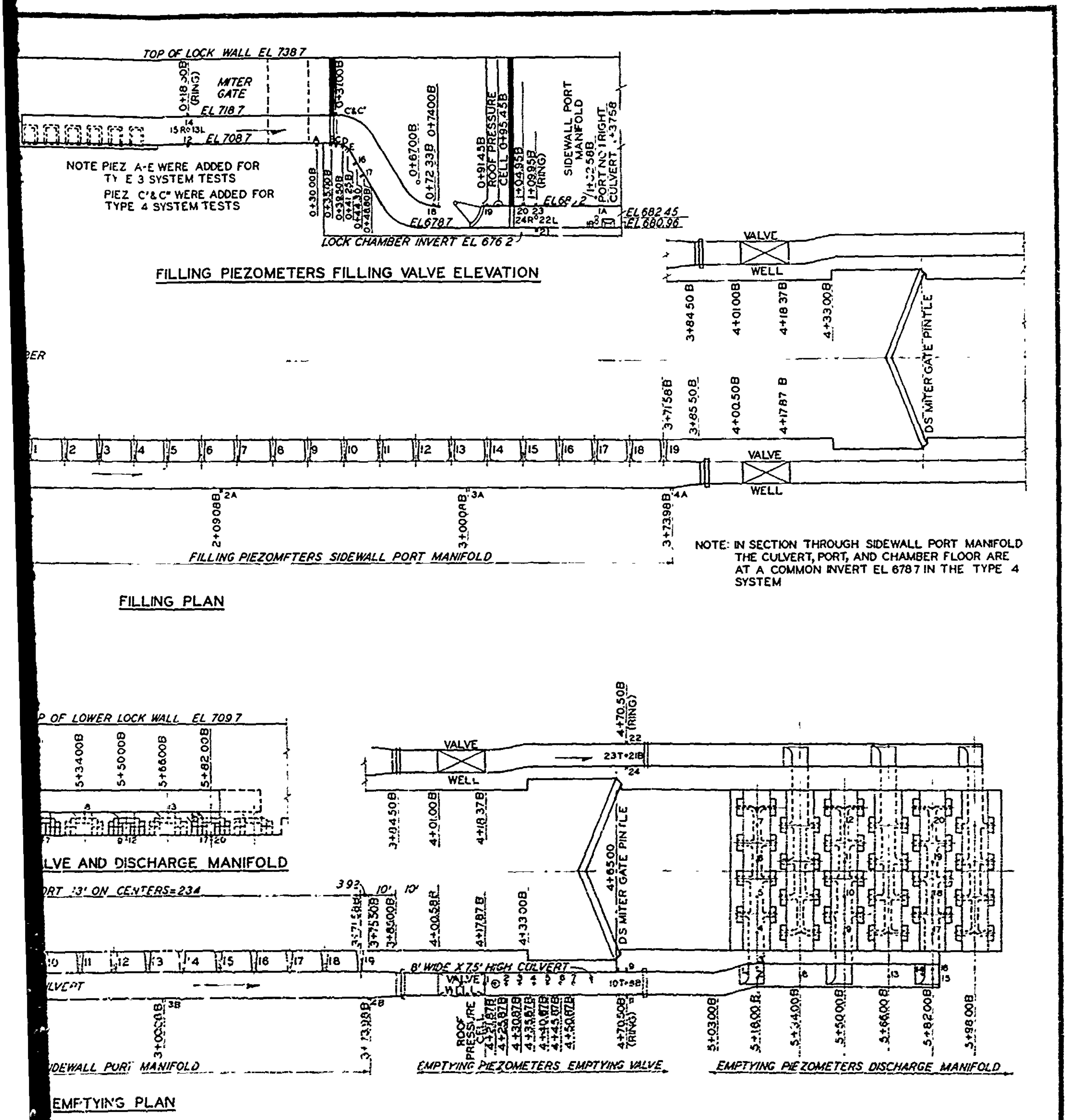
INTAKE MANIFOLD VELOCITIES AND FLOW DISTRIBUTION

TYPE I (ORIGINAL) SYSTEM

STEADY-FLOW CONDITION

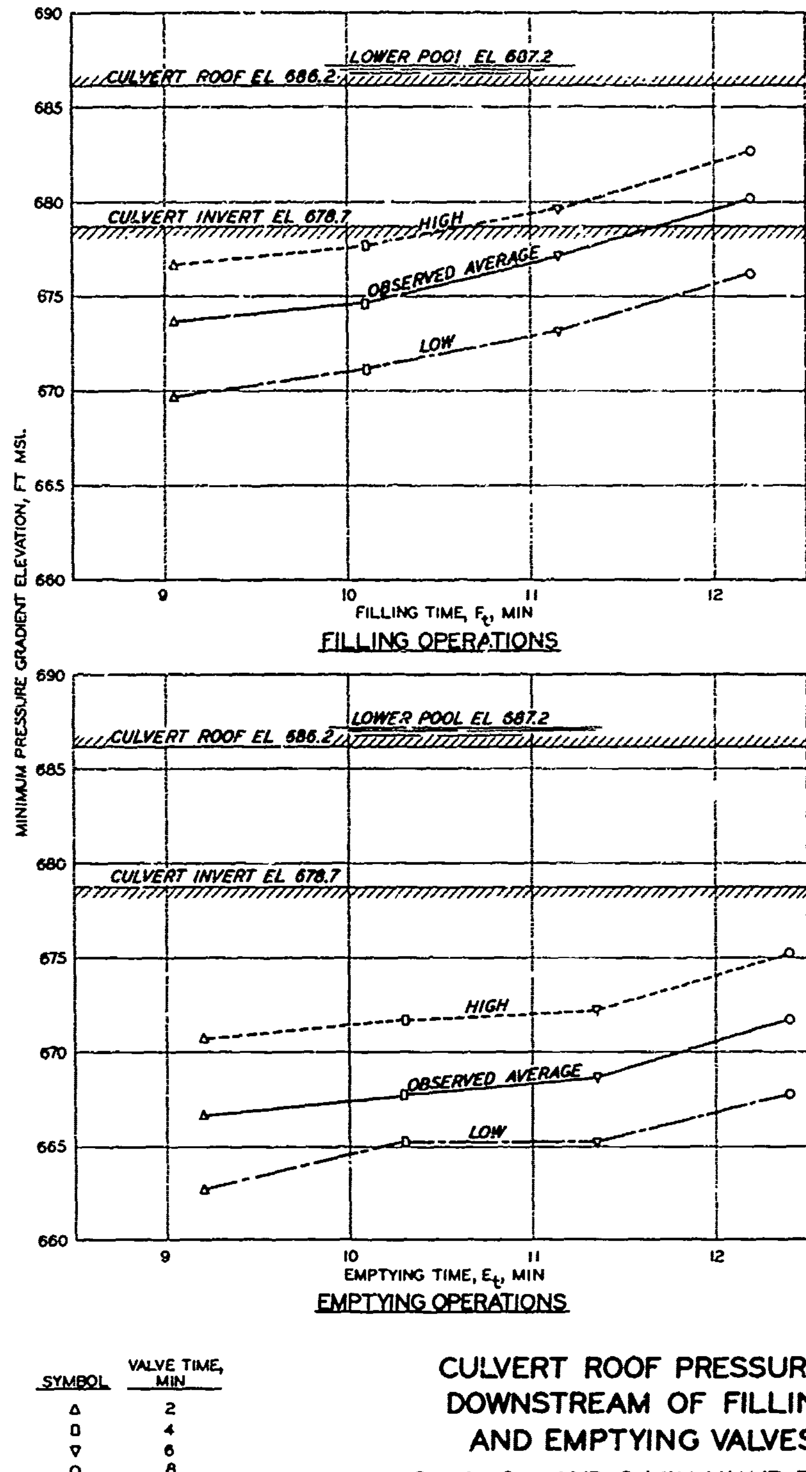


TOP OF LOCK WALL
MITER GATE
EL 718.7
EL 708.7
NOTE PIEZ A-E WERE ADDED FOR TYPE 3 SYSTEM TESTS
PIEZ C'&C" WERE ADDED FOR TYPE 4 SYSTEM TESTS
FILLING PIEZO
FLOW
VALVE
WELL
US MITER GATE PINTLE
℄ DAM
℄ LANDWARD LOCK CHAMBER
ROOF PRESSURE CELL
FILLING PIEZOMETERS
INTAKE MANIFOLD THRU FILLING VALVE
FILLING PLAN
NOTE: PIEZ A-E WERE ADDED FOR TYPE 3 SYSTEM TESTS
PIEZ C'&C" WERE ADDED FOR TYPE 4 SYSTEM TESTS
TOP OF LOCK WALL EL 738.7
TOP OF LOWER LOCK WALL EL 709.7
EL 686.2
EL 676.7
LOCK CHAMBER INVERT EL 676.2
INVERT EL 670.7
EMPTYING PIEZOMETERS ELEVATION EMPTYING VALVE AND DISCHARGE MANIFOLD
13 PORT MANIFOLD WITH PORT 13' ON CENTERS=234
9.5' WIDE X 7.5' HIGH CULVERT
EMPTYING PIEZOMETERS SIDEWALL PORT MANIFOLD
EMPTYING PLAN
EL 738.7
UPPER POOL EL±725.0 (NORMAL)
LOWER POOL EL687.2 (NORMAL)
CHAMBER INVERT EL 676.2
EL 686.2
EL 682.45 FILL PIEZ
EL 680.05 EMPTY PIEZ
EL 678.7
RIGHT
LEFT
SECTION THRU SIDEWALL PORT MANIFOLD



PIEZOMETER LOCATIONS
TYPES I (ORIGINAL) AND
2-4 SYSTEMS

2

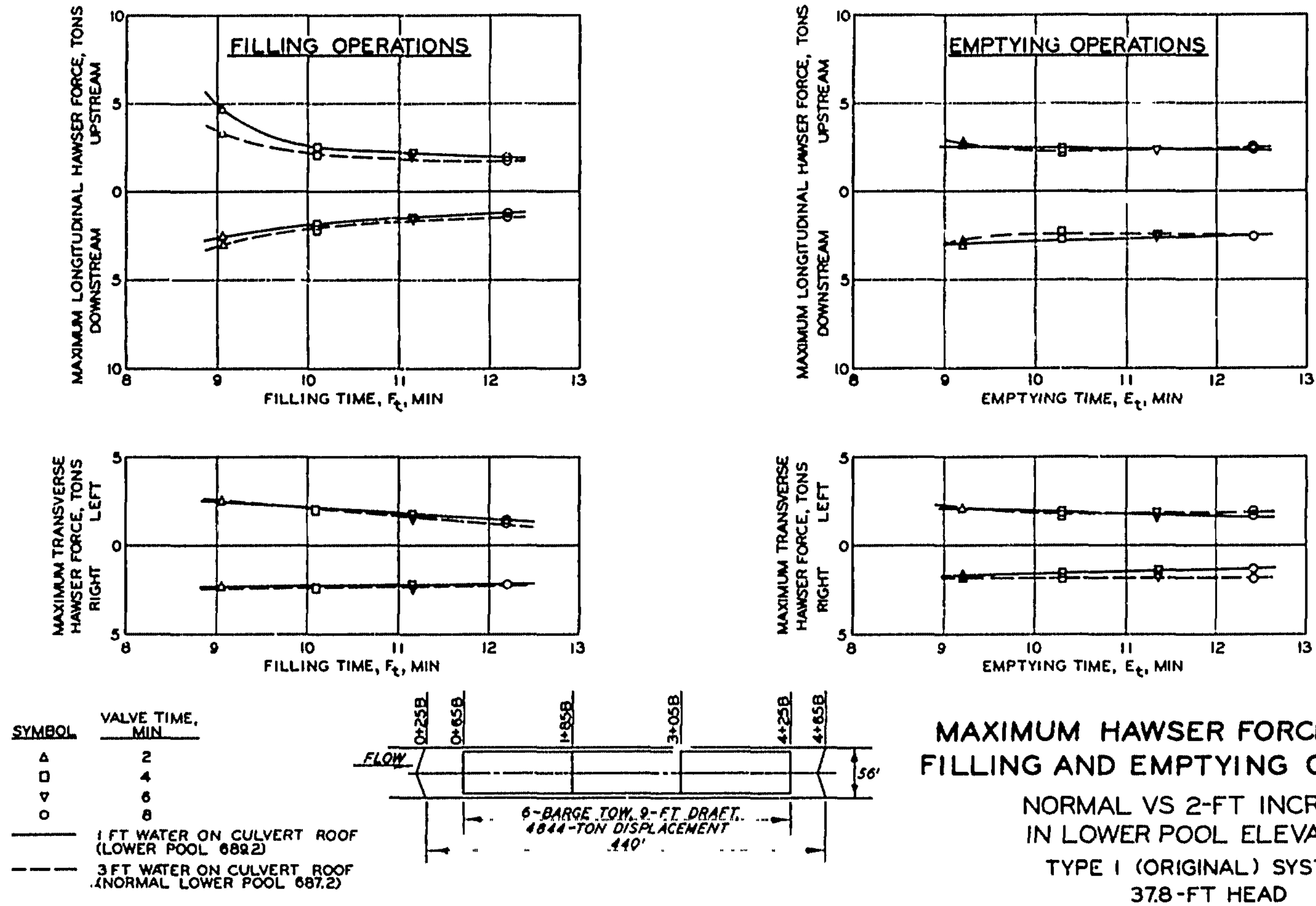


CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES

2-, 4-, 6-, AND 8-MIN VALVE TIMES

TYPE I (ORIGINAL) SYSTEM

37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)
LANDWARD LOCK



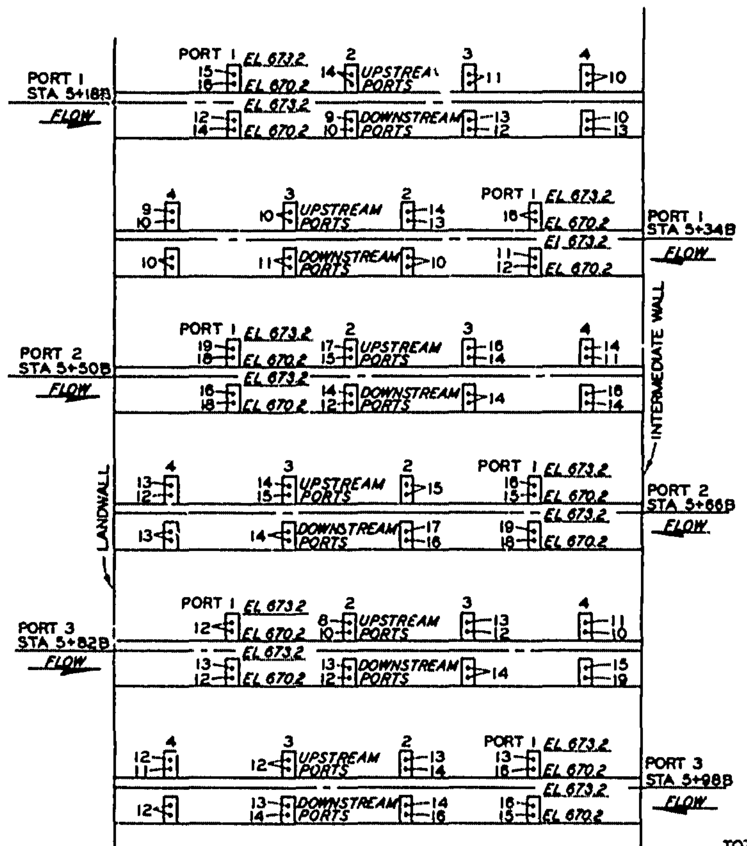
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

NORMAL VS 2-FT INCREASE IN LOWER POOL ELEVATION

TYPE I (ORIGINAL) SYSTEM

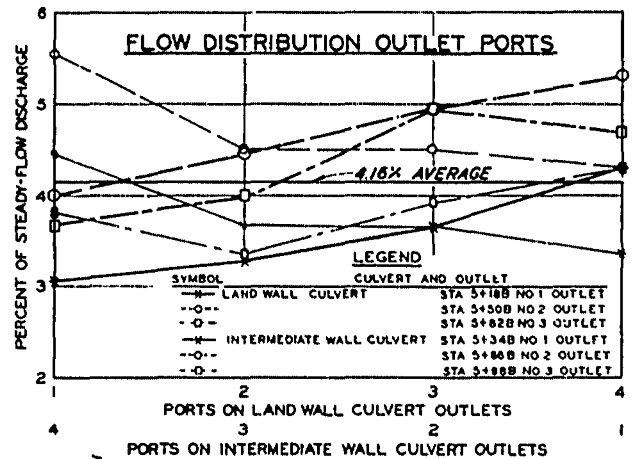
37.8-FT HEAD

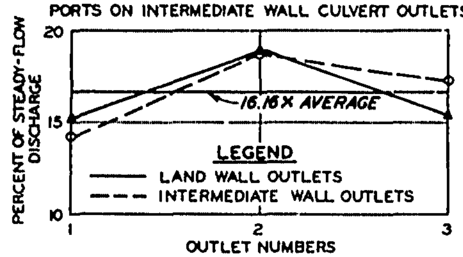
LANDWARD LOCK



VELOCITIES AT PORT FACE

NOTE VELOCITIES ARE IN PROTOTYPE FEET PER SECOND AND ARE MEASURED AT WALL FACE OF OUTLET PORTS





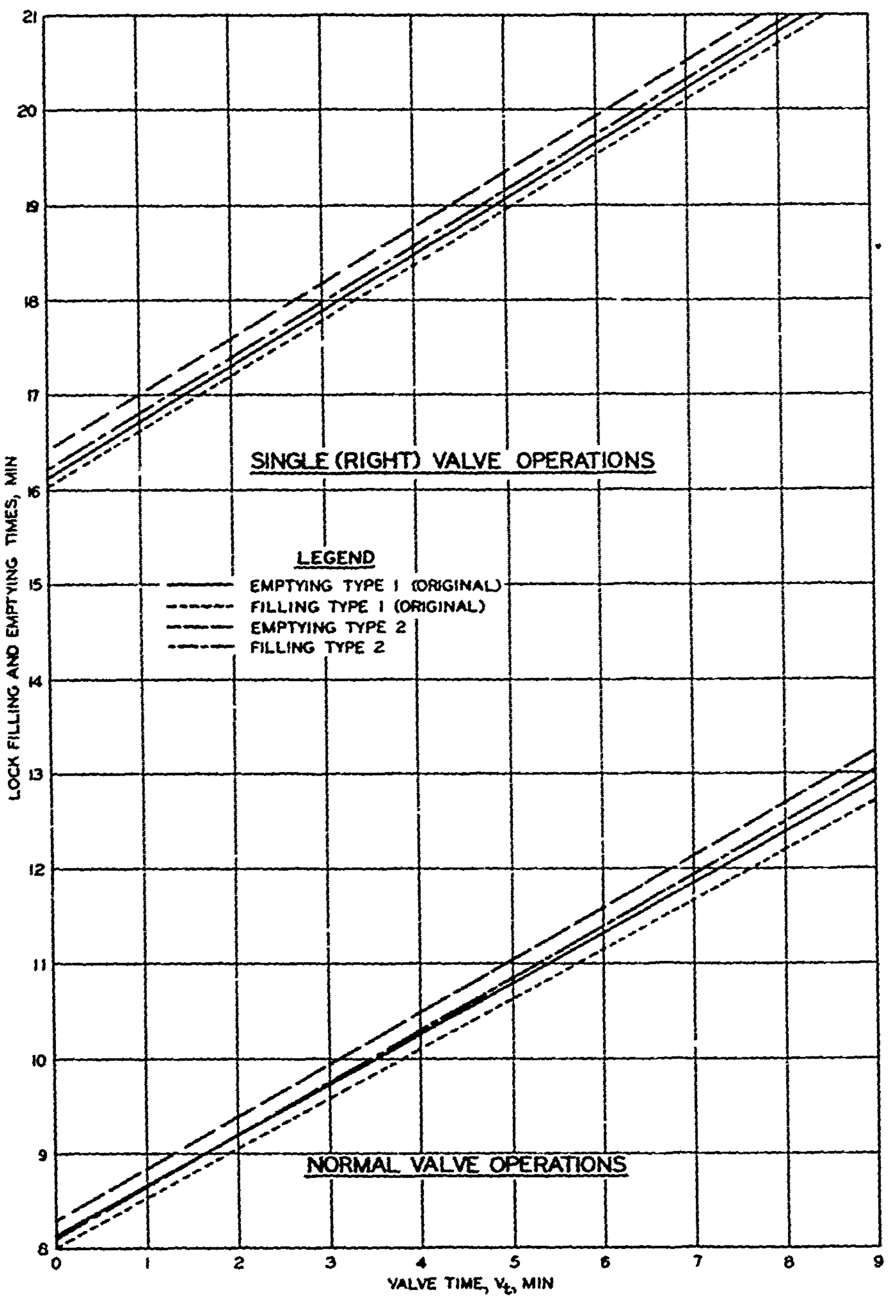
OUTLET FLOW DISTRIBUTION
LAND WALL VS INTERMEDIATE WALL

TEST CONDITIONS

TOTAL DISCHARGE	2888 CFS
LOCK CHAMBER EL	711.2
LOWER POOL EL	678.2

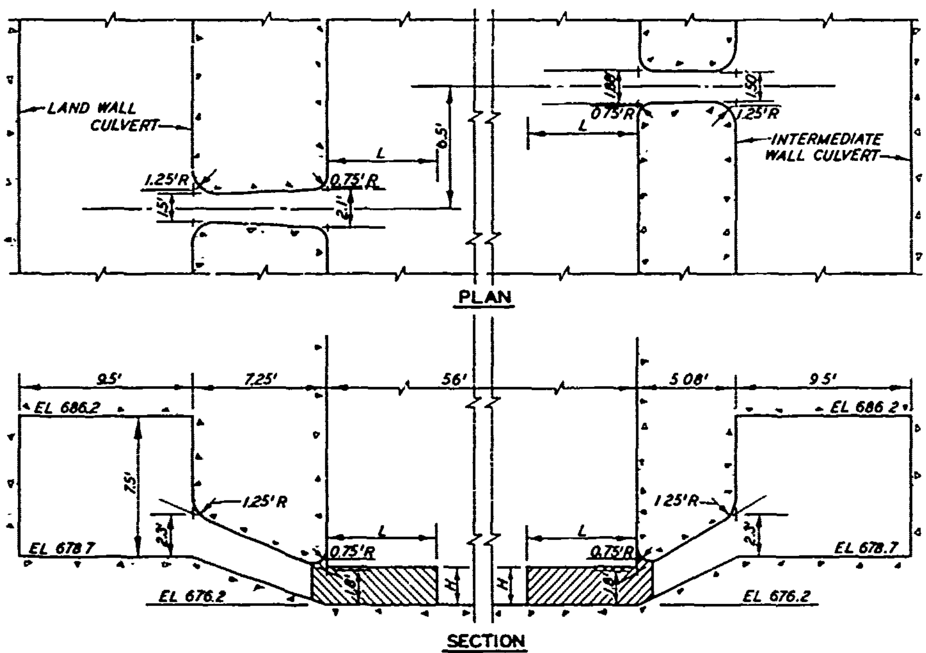
FILLING VALVES CLOSED
UPPER MITER GATES OPEN
EMPTYING VALVES OPEN FULL
LOWER MITER GATES CLOSED

OUTLET VELOCITIES AND FLOW DISTRIBUTION
TYPE 1 (ORIGINAL) SYSTEM
STEADY-FLOW CONDITION
LANDWARD LOCK



LOCK FILLING AND EMPTYING TIMES
TYPE 1 (ORIGINAL) VS TYPE 2 SYSTEMS
LANDWARD LOCK
37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)

PLATE 25



PORT DEFLECTORS

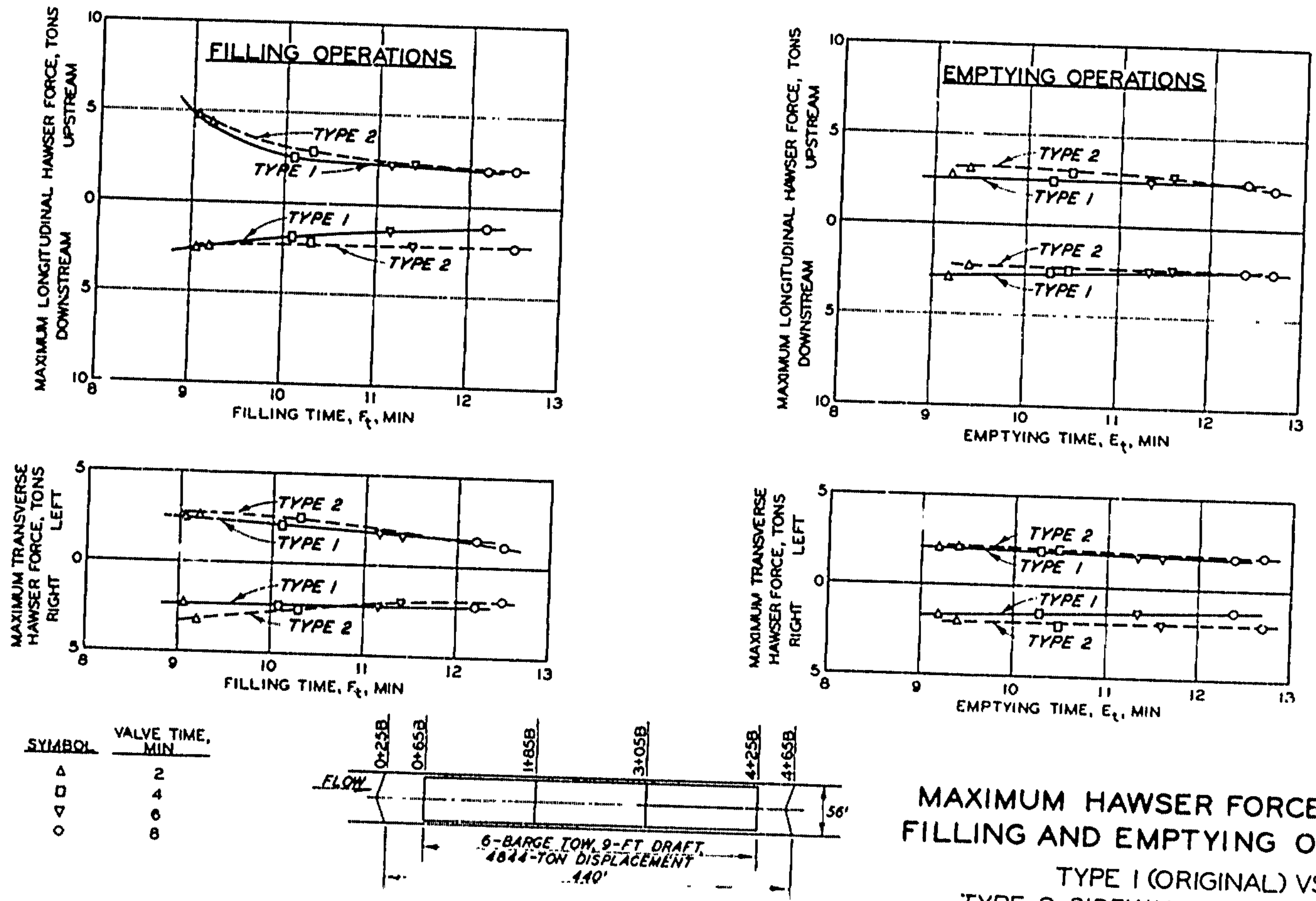
TYPE	DIMENSIONS, FT LENGTH, L	HEIGHT, H
1	6	2
2	4	2
3	3	2
4	4	1

NOTE: VISUAL OBSERVATIONS OF TURBULENCE AND INITIAL PORT JET PATTERNS WERE MADE WITH THE TYPE 1 (ORIGINAL) PORT AND MANIFOLD ARRANGEMENT AND PORT DEFLECTORS TYPES 1-4 INSTALLED.

THE TYPE 1 (ORIGINAL) PORT AND MANIFOLD DESIGN WITH TYPE 4 PORT DEFLECTORS WAS DESIGNATED TYPE 2 SIDEWALL PORT MANIFOLD ARRANGEMENT

DETAILS OF TYPE 1 (ORIGINAL) PORTS AND PORT DEFLECTORS TYPES 1-4

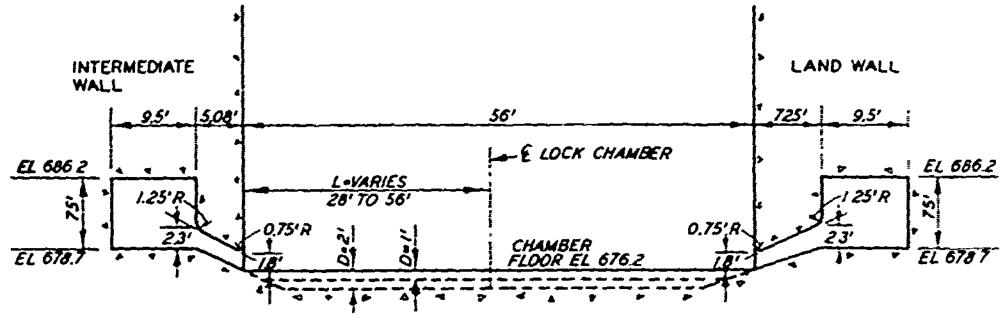
LANDWARD LOCK



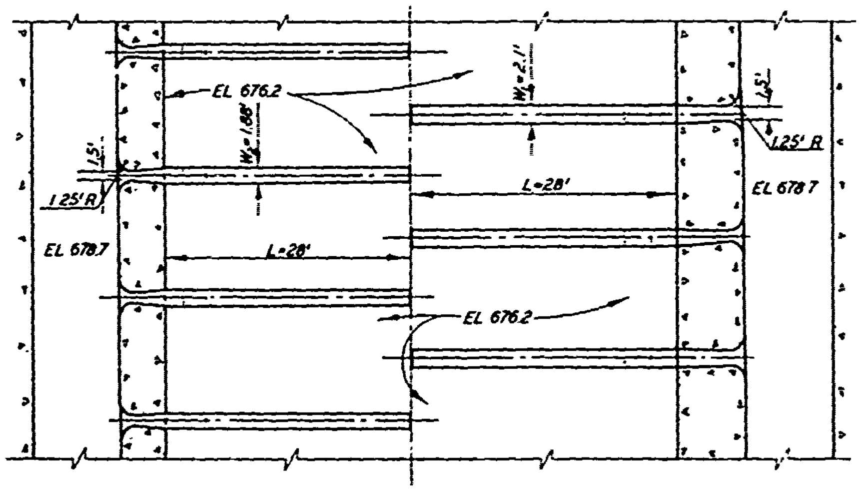
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

TYPE 1 (ORIGINAL) VS
TYPE 2 SIDEWALL PORT SYSTEMS

37.8-FT HEAD
LANDWARD LOCK



ELEVATION



PLAN

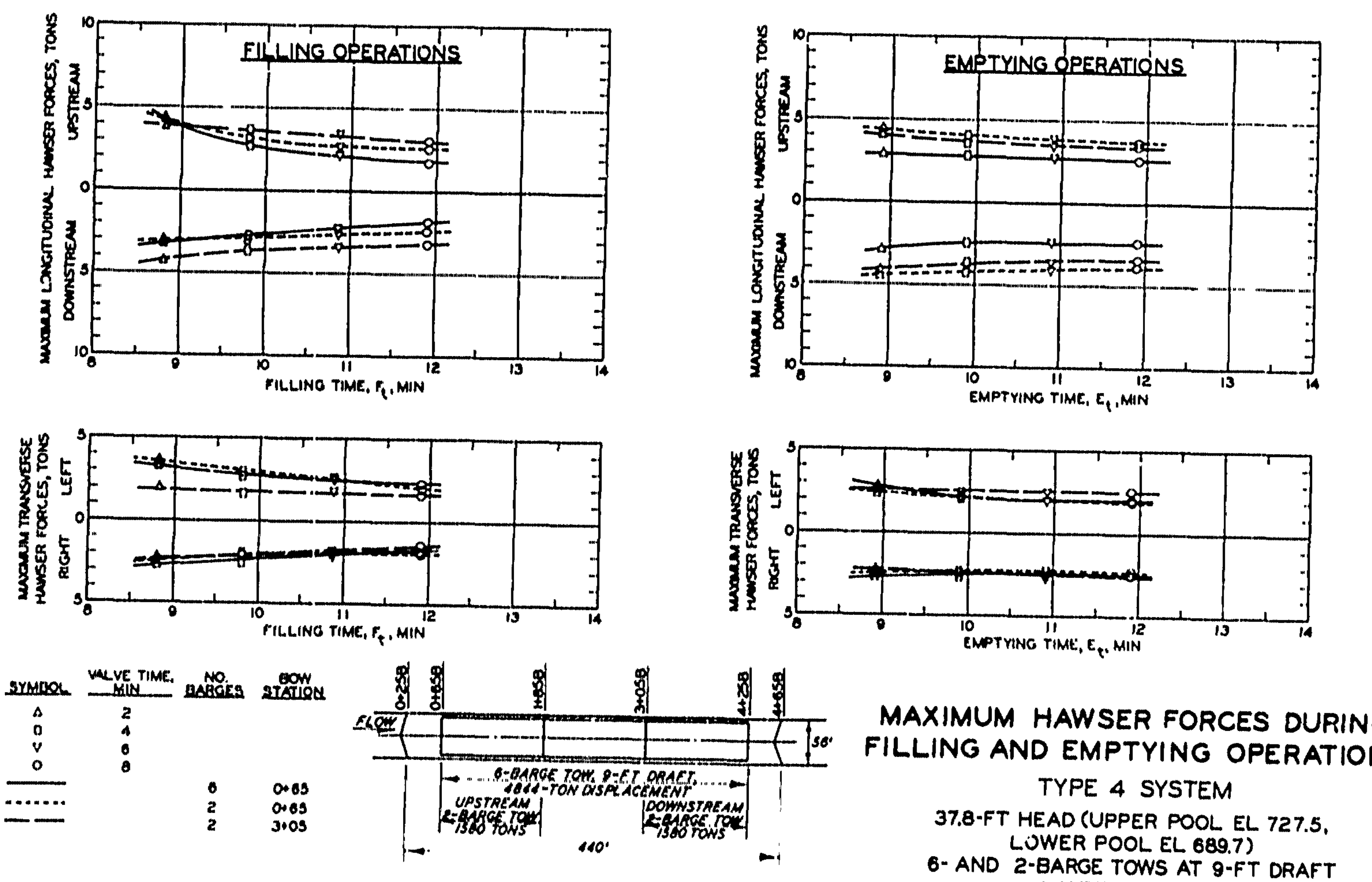
TYPE TRENCH IN FRONT PORTS	DIMENSIONS OF TRENCHES, FT: DEPTH, D	LENGTH, L	LAND WALL PORT AND TRENCH,* W_1	INTERMEDIATE WALL PORT AND TRENCH,* W_2
1	2	56	2.1	1.88
2	2	42	2.1	1.88
3	2	35	2.1	1.88
4	2	28	2.1	1.88
5	1	56	2.1	1.88
6	1	42	2.1	1.88
7	1	35	2.1	1.88
8†	1	28	2.1	1.88

*AT PORTAL (WITH 0.75'-RADIUS SIDE PORTAL REMOVED)
†RECOMMENDED

NOTE: SLOPE OF PORT INVERT EXTENDS INTO CHAMBER TO DEPTH OF TRENCH.

TRENCHES TYPES 1-8

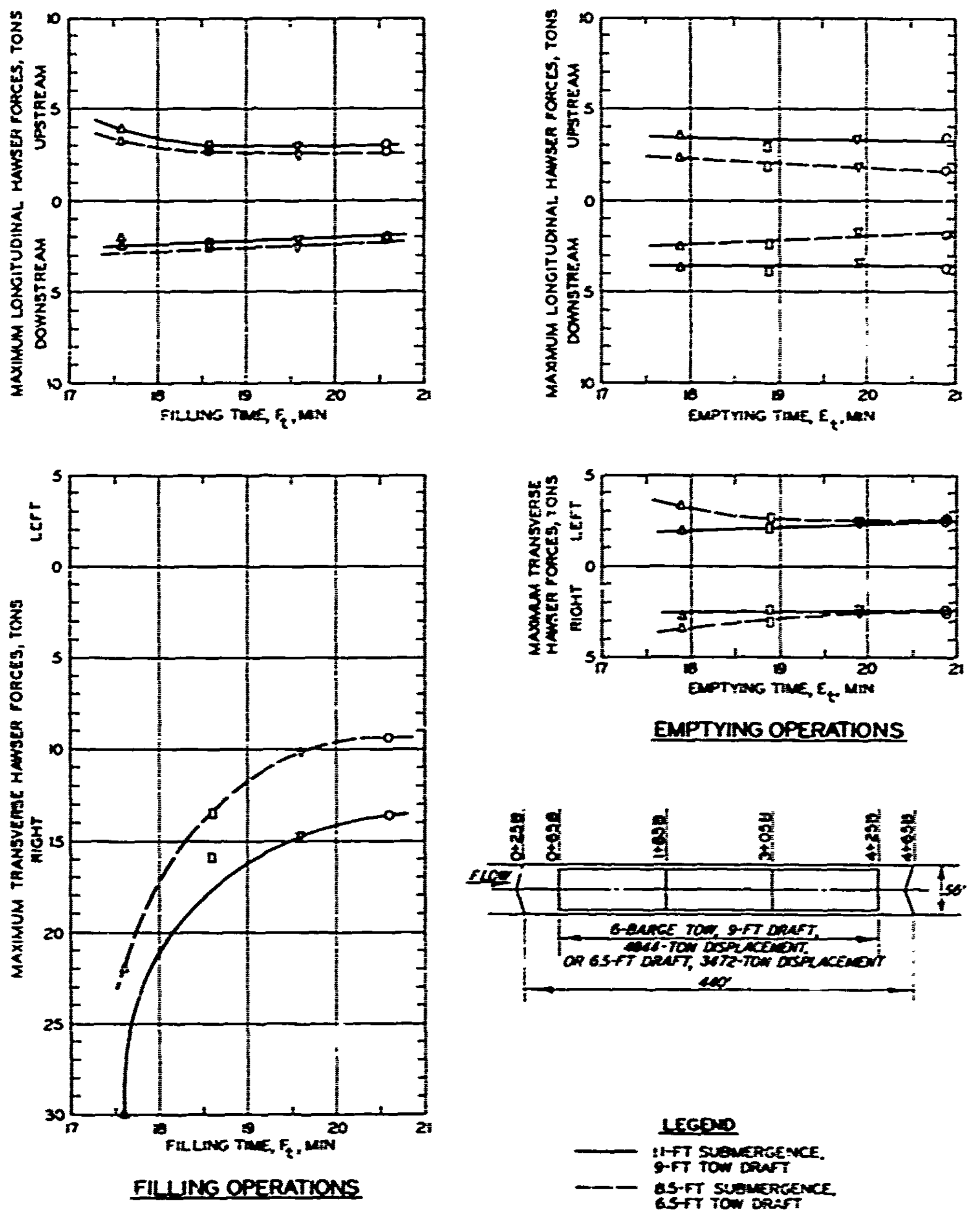
POSITIONED IN CHAMBER FLOOR IMMEDIATELY IN FRONT OF SIDEWALL PORT MANIFOLD



MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

TYPE 4 SYSTEM

37.8-FT HEAD (UPPER POOL EL 727.5, LOWER POOL EL 689.7)
6- AND 2-BARGE TOWS AT 9-FT DRAFT
LANDWARD LOCK



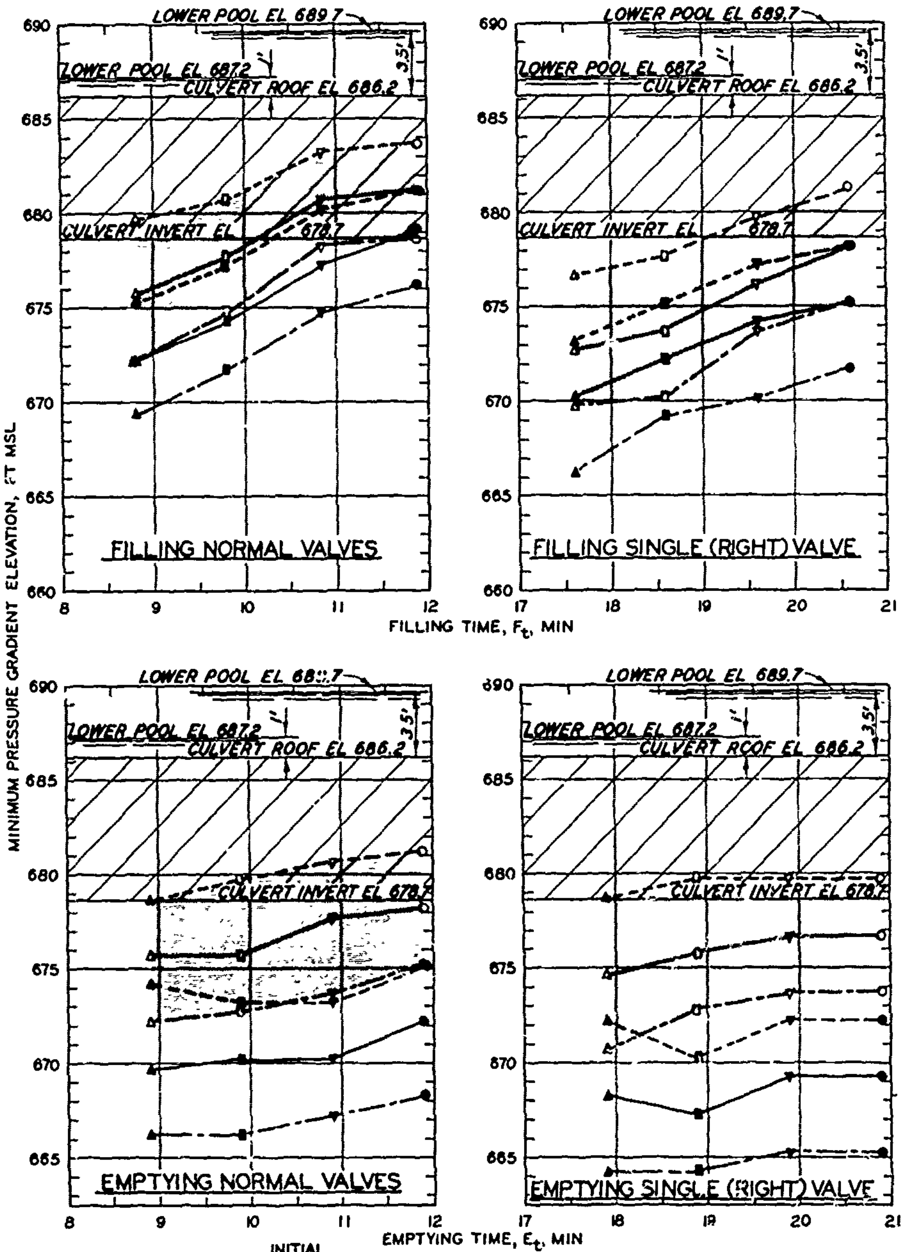
SYMBOL	VALVE TIME MIN
Δ	2
□	4
∇	6
O	8

MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

SINGLE (RIGHT) VALVE
TIMES 2, 4, 6, AND 8 MIN

TYPE 4 SYSTEM

37.8-FT HEAD, 8.5-FT SUBMERGENCE, 6.5-FT DRAFT
VERSUS
37.8-FT HEAD, 11.0-FT SUBMERGENCE, 9-FT DRAFT



SYMBOL	VALVE TIME MIN	INITIAL CULVERT ROOF SUBMERGENCE, FT
△	2	3.5
□	4	
▽	6	
○	8	
▲	2	10
■	4	
▼	6	
●	8	

LEGEND

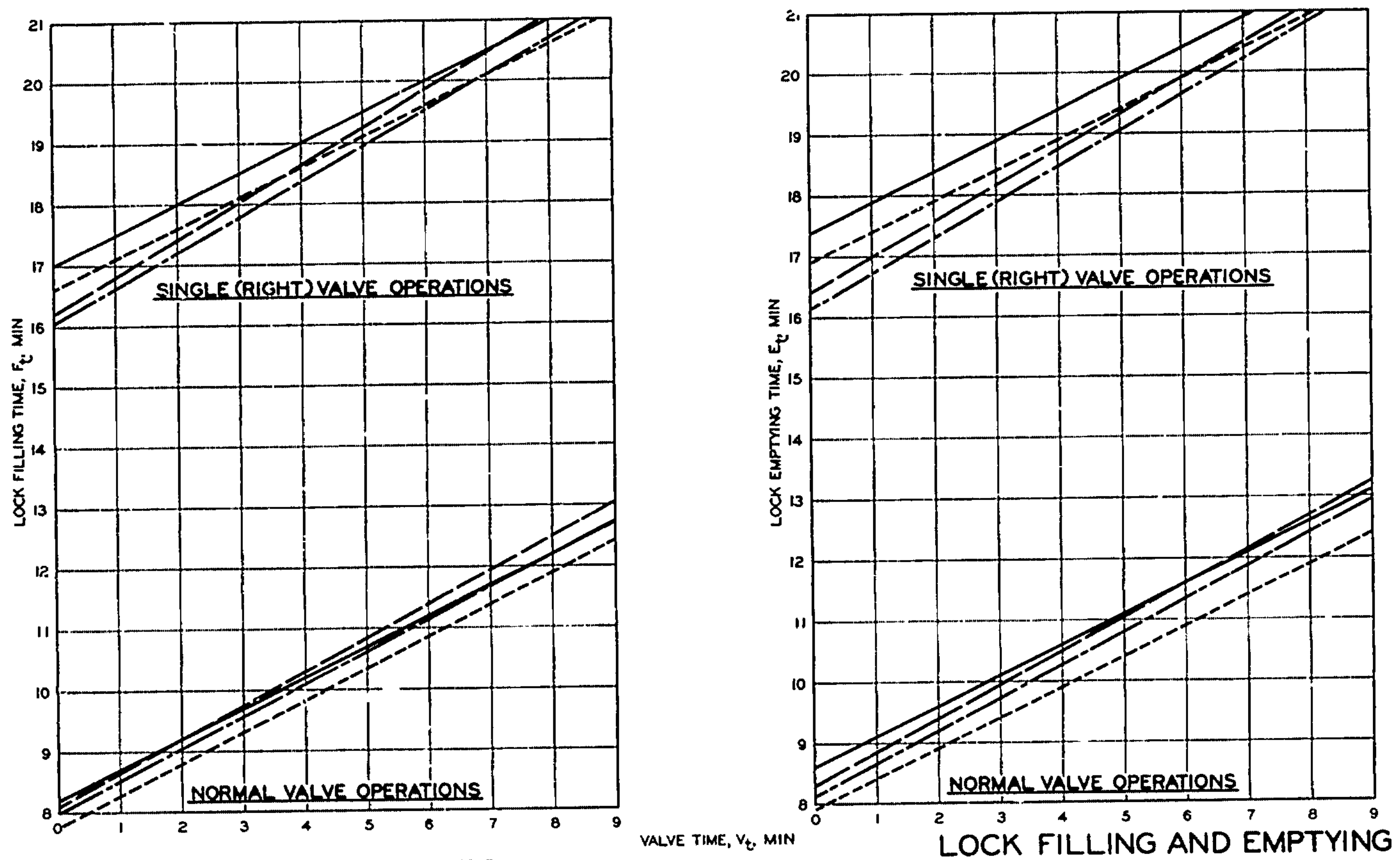
- ——— OBSERVED AVERAGE
- – – – HIGH
- –·–·– LOW

CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES

NORMAL AND SINGLE (RIGHT) VALVE OPERATIONS

TYPE 4 SYSTEM

11-FT SUBMERGENCE, LOWER POOL EL 689.7
8.5-FT SUBMERGENCE, LOWER POOL EL 687.2
37.8-FT HEAD



NOTE. 11-FT SUBMERGENCE, OR MINIMUM LOWER POOL ABOVE LOCK CHAMBER FLOOR DURING THESE TESTS. THUS FOR TYPE 4 SIDEWALL PORT MANIFOLD DESIGN 11 WAS NECESSARY TO ADD 2.5 FT ADDITIONAL DEPTH TO UPPER AND LOWER POOLS

LEGEND

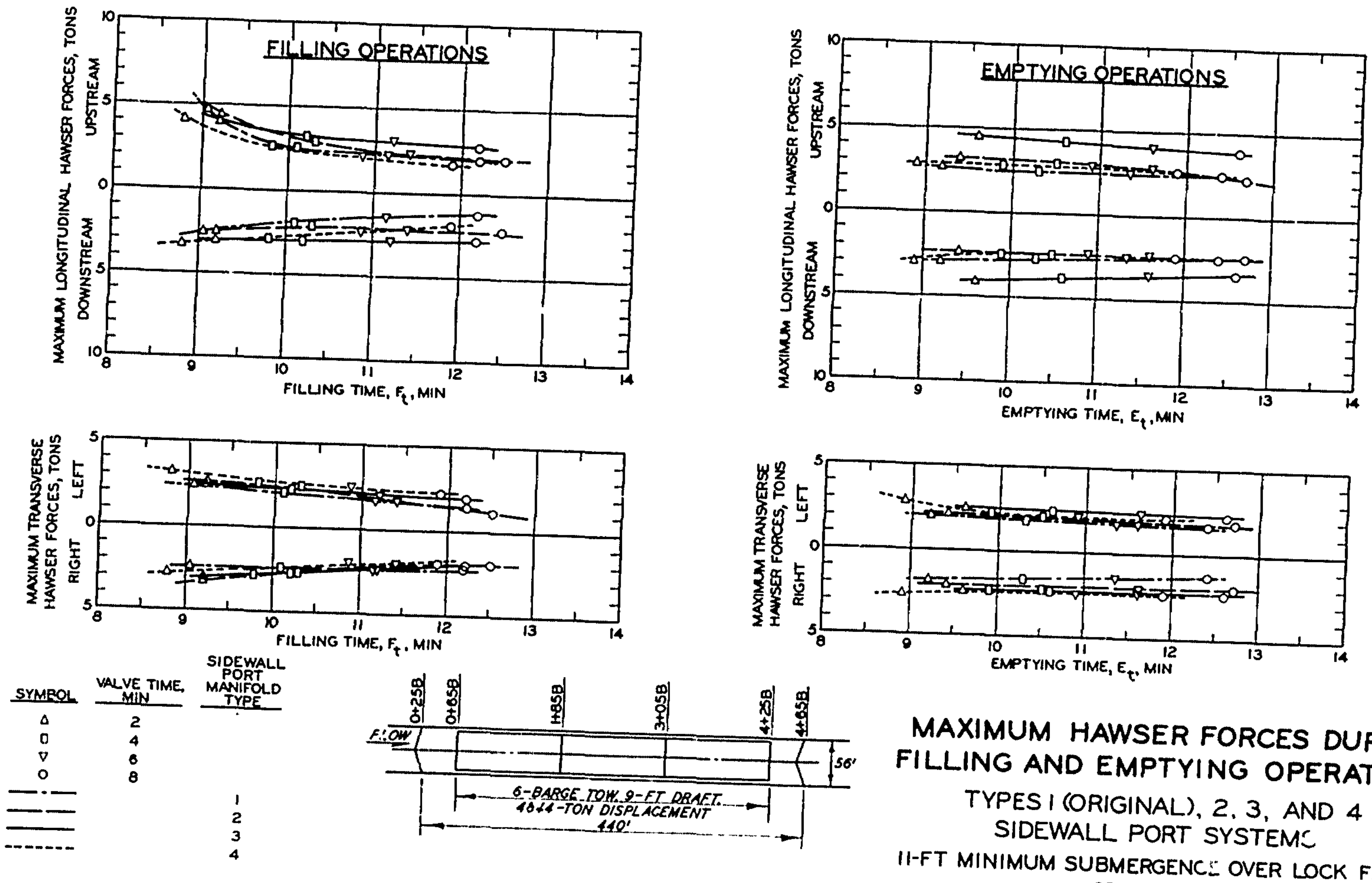
TYPE 1
TYPE 2
TYPE 3
TYPE 4

LOCK FILLING AND EMPTYING TIME VS VALVE TIME

TYPES 1 (ORIGINAL), 2, 3, AND 4 SYSTEMS

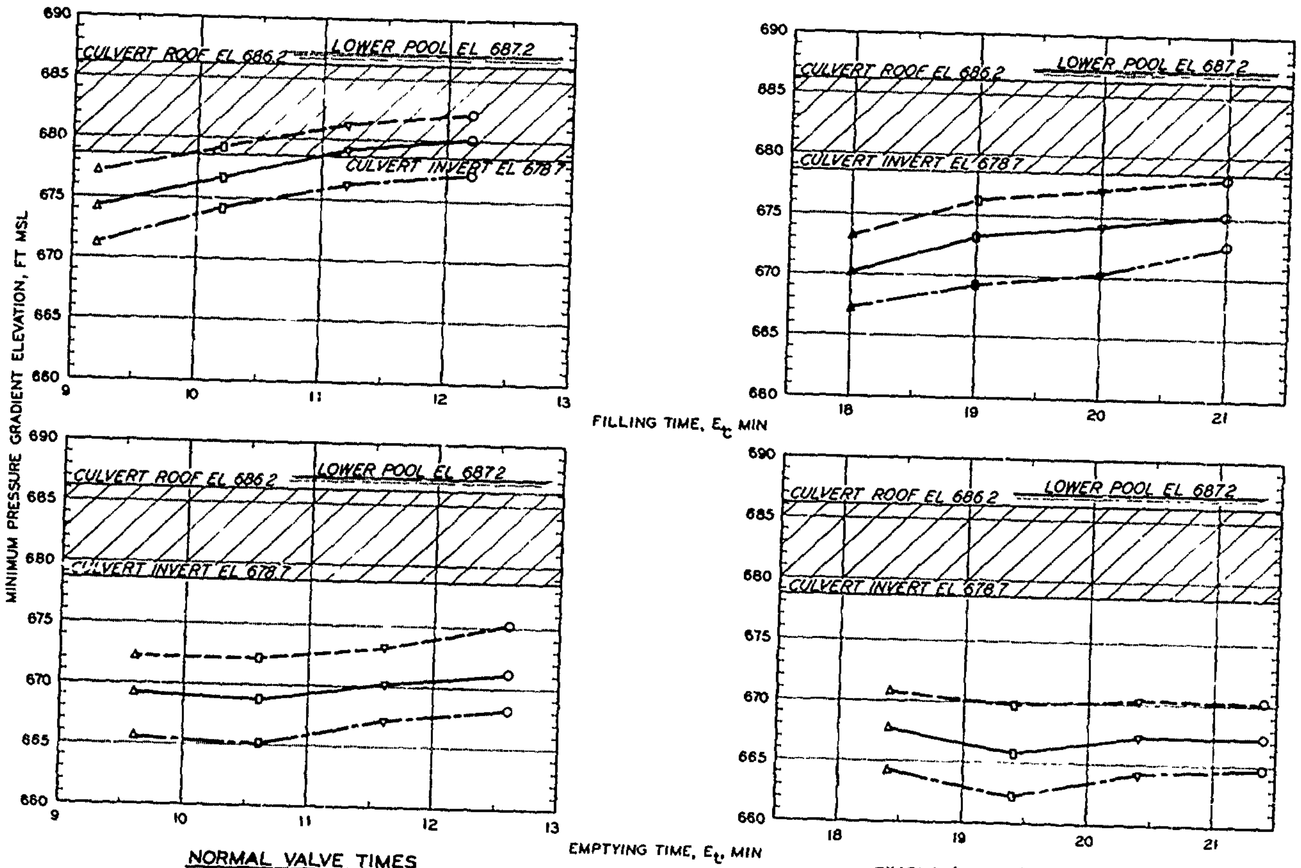
LANDWARD LOCK

37.8-FT HEAD



MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

TYPES I (ORIGINAL), 2, 3, AND 4
SIDEWALL PORT SYSTEMS
11-FT MINIMUM SUBMERGENCE OVER LOCK FLOOR
37.8-FT HEAD
LANDWARD LOCK



SYMBOL	VALVE TIME, MIN
△	2
□	4
▽	6
○	8

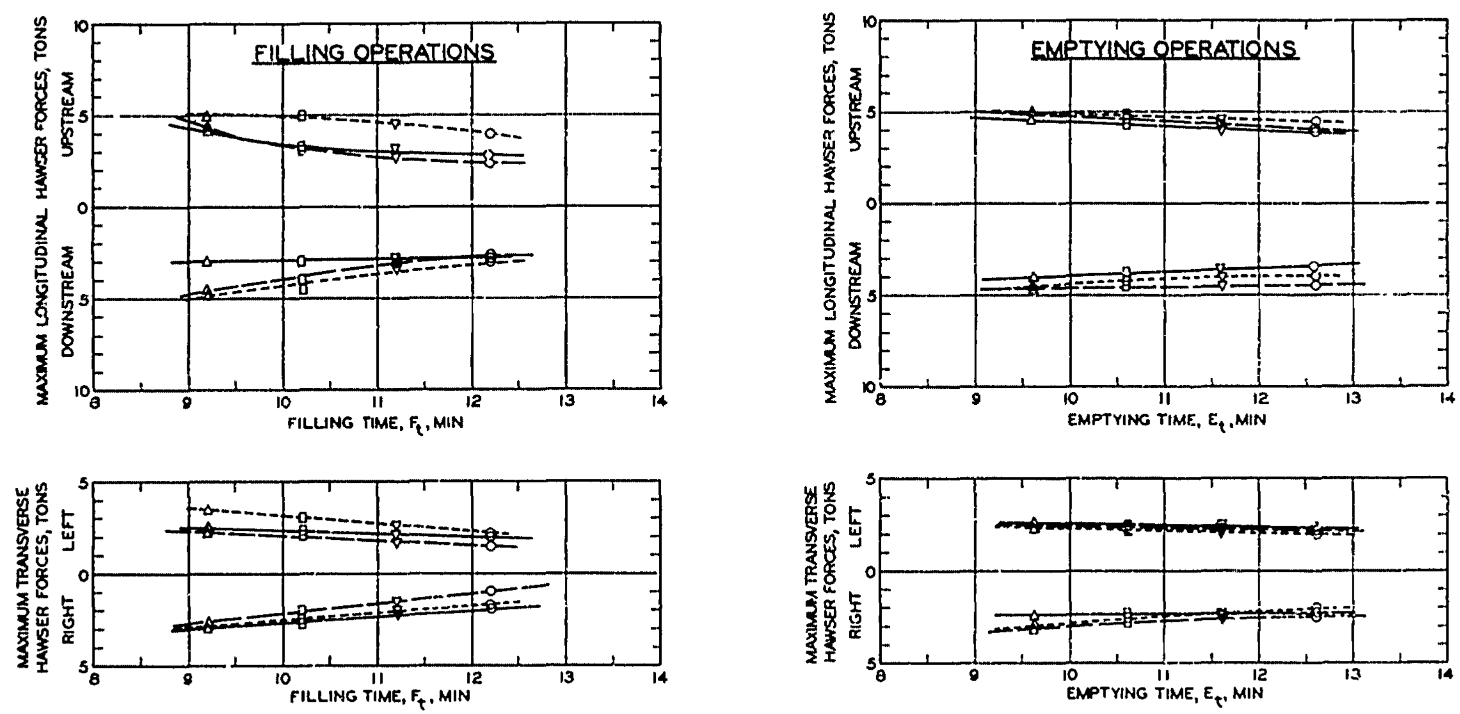
LEGEND

- ——— OBSERVED AVERAGE
- – – – HIGH
- –·–·– LOW

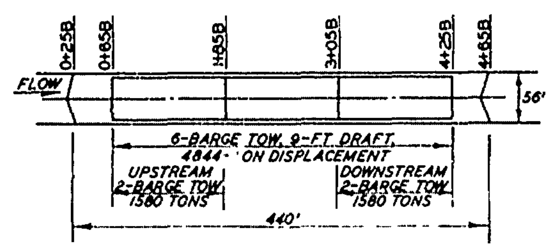
CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES

TYPE 3 SYSTEM

37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)



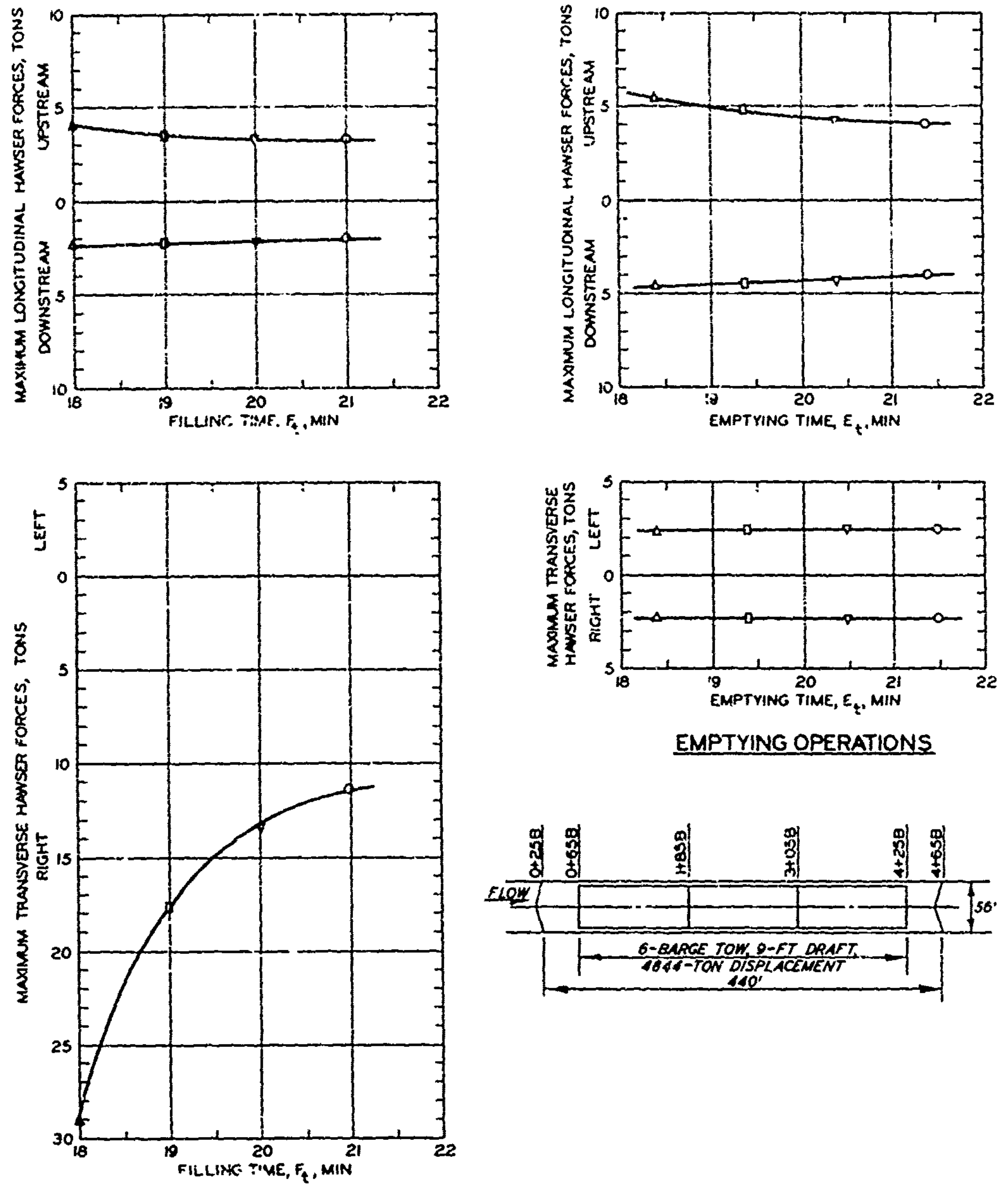
SYMBOL	VALVE TIME, MIN	NO. BARGES	BOW STATION
△	2		
□	4		
▽	6		
○	8		
———		6	0+65
- - - - -		2	0+65
— — —		2	3+05



MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

TYPE 3 SYSTEM

37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)
6- AND 2-BARGE TOWS AT 9-FT DRAFT
LANDWARD LOCK



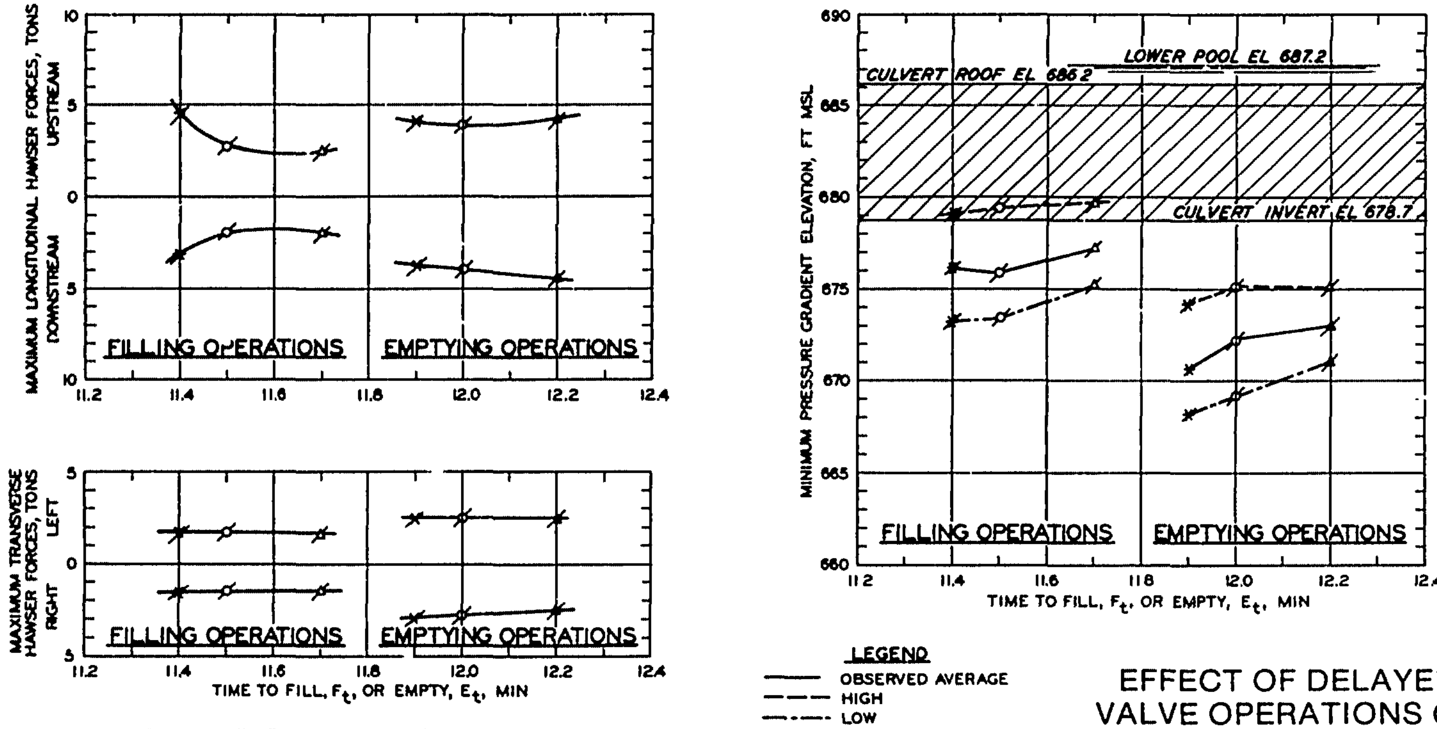
FILLING OPERATIONS

SYMBOL	VALVE TIME MIN
△	2
□	4
▽	6
○	8

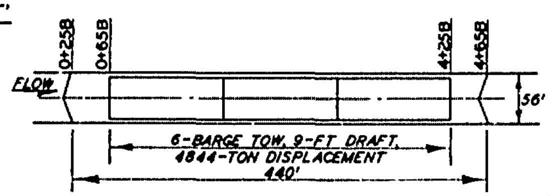
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

SINGLE (RIGHT) VALVE
TIMES 2, 4, 6, AND 8 MIN

TYPE 3 SYSTEM
37.8-FT HEAD (UPPER POOL EL 725.0,
LOWER POOL EL 687.2)
6-BARGE TOW AT 9-FT DRAFT
LANDWARD LOCK



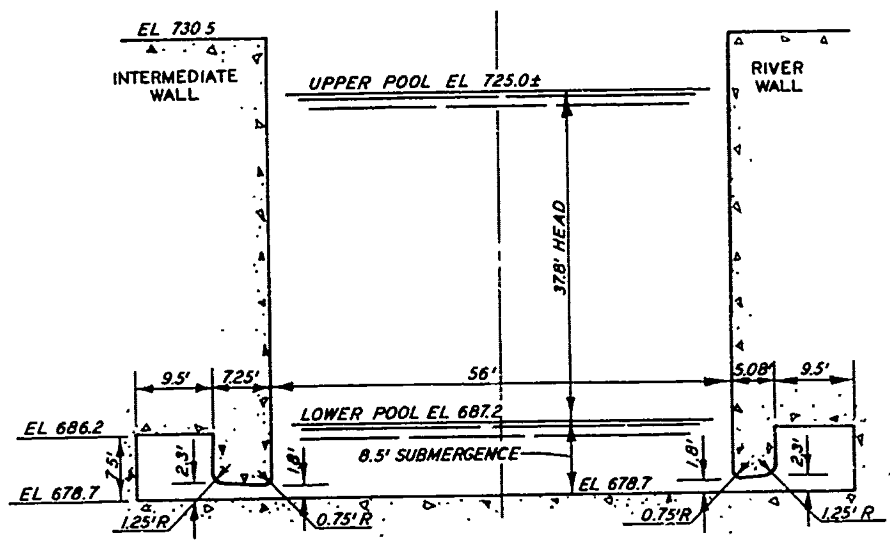
SYMBOL	VALVE OPENING, MIN	VALVE HOLDS POSITION, MIN	VALVE OPENS TO FULL, MIN
	2.0	2.0	2.0
	1.75	2.0	2.25
	1.50	2.0	2.50



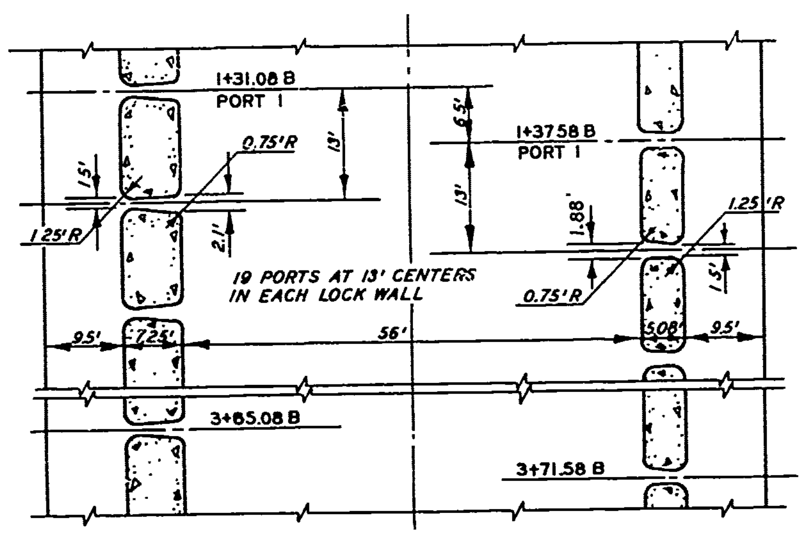
EFFECT OF DELAYED VALVE OPERATIONS ON MAXIMUM HAWSER FORCES FULL TOW AND CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING VALVES

TYPE 3 SYSTEM

37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)
LANDWARD LOCK



ELEVATION



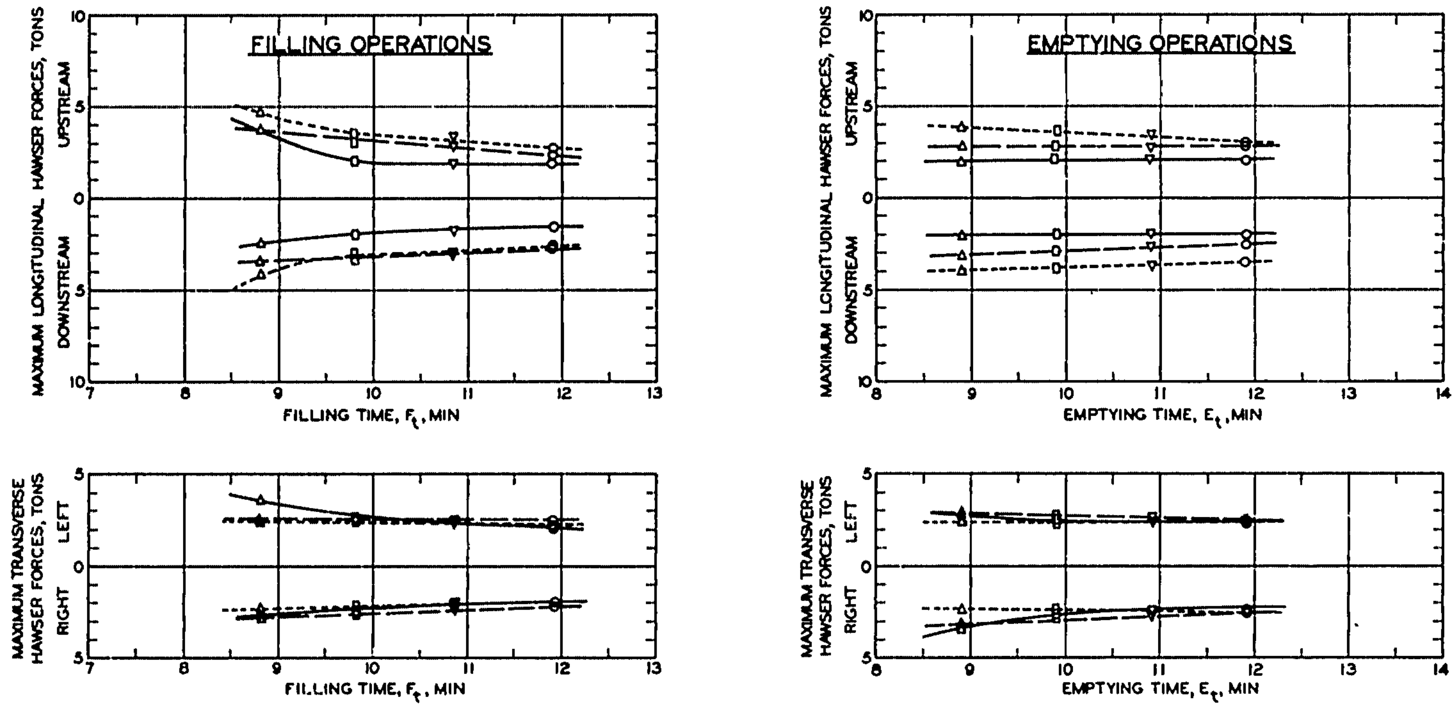
PLAN

NOTE: IN ORDER TO UTILIZE THE LANDWARD LOCK FLUME FOR RIVERWARD LOCK TEST A MIRROR IMAGE OF THE CULVERT AND PORT SECTION WAS MODELED AS SHOWN.

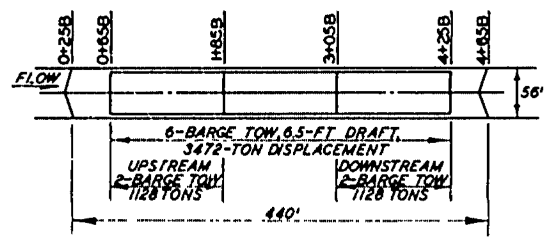
CULVERT AND PORT SECTION
TYPE 2

FILLING AND EMPTYING SYSTEMS TYPES 4-6

RIVERWARD LOCK



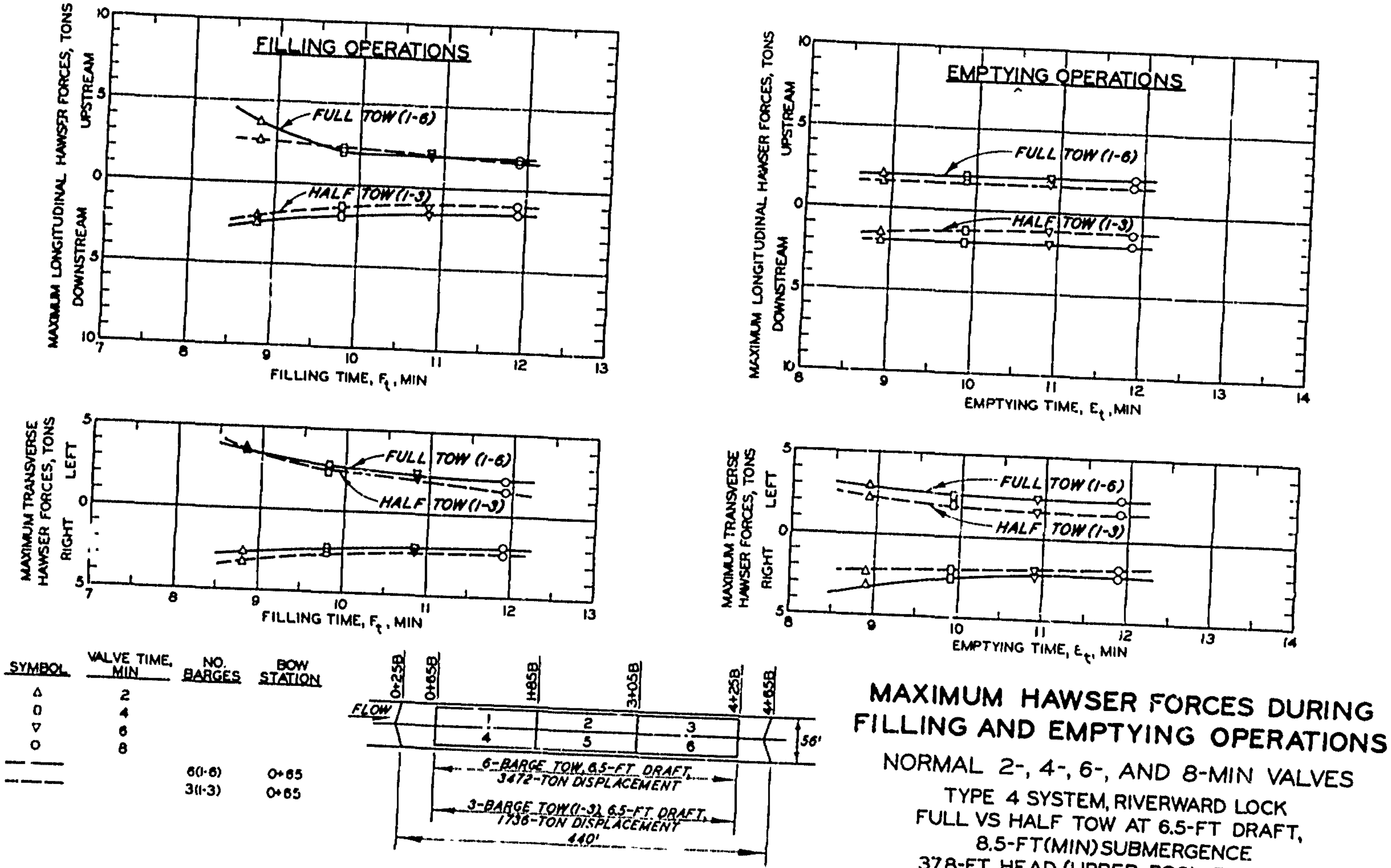
SYMBOL	VALVE TIME, MIN	NO BARGES	BOW STATION
△	2		
□	4		
▽	6		
○	8		
——— (solid)		6	0+65
- - - - (dotted)		2	0+65
— — (dashed)		2	3+05



MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

TYPE 4 SYSTEM

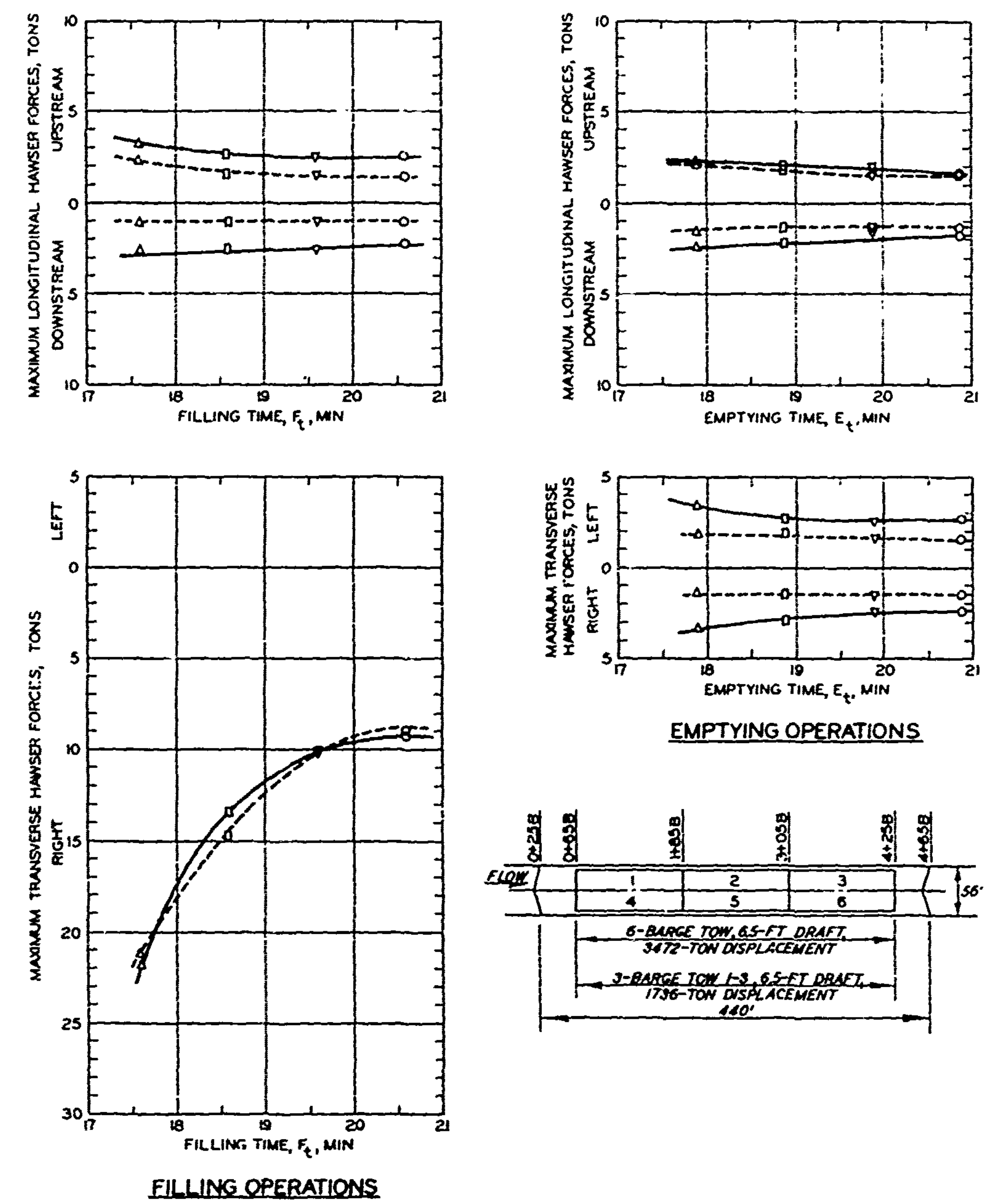
37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)
6- AND 2-BARGE TOWS AT 6.5-FT DRAFT
RIVERWARD LOCK



MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

NORMAL 2-, 4-, 6-, AND 8-MIN VALVES

TYPE 4 SYSTEM, RIVERWARD LOCK
FULL VS HALF TOW AT 6.5-FT DRAFT,
8.5-FT (MIN) SUBMERGENCE
37.8-FT HEAD (UPPER POOL EL 725.0,
LOWER POOL EL 687.2)

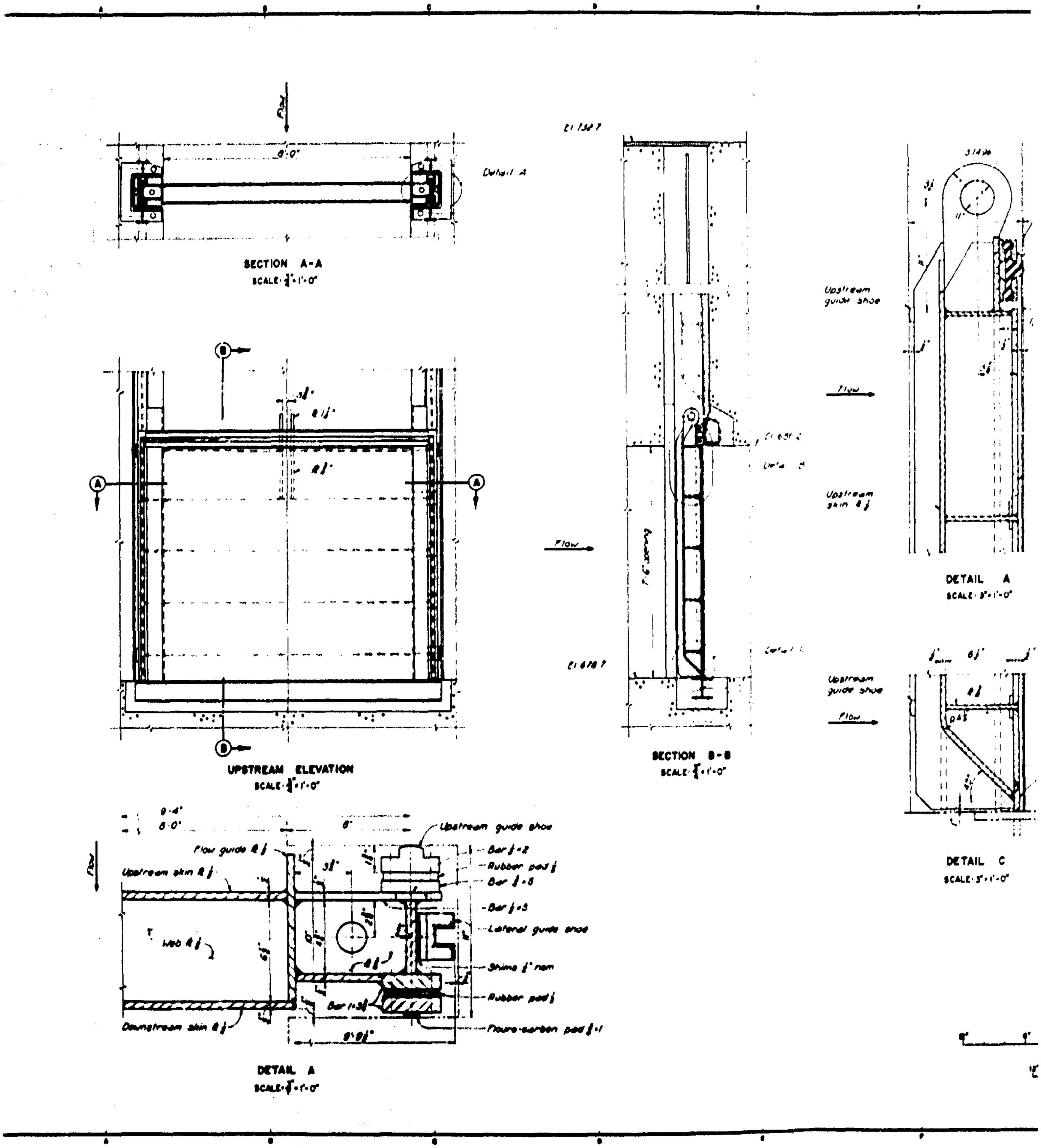


SYMBOL	VALVE TIME, MIN	NO. BARGES	BOW STATION
△	2		
□	4		
▽	6		
○	8		
——— FULL TOW		6(1-6)	0+65
– – – HALF TOW		3(1-3)	0+65

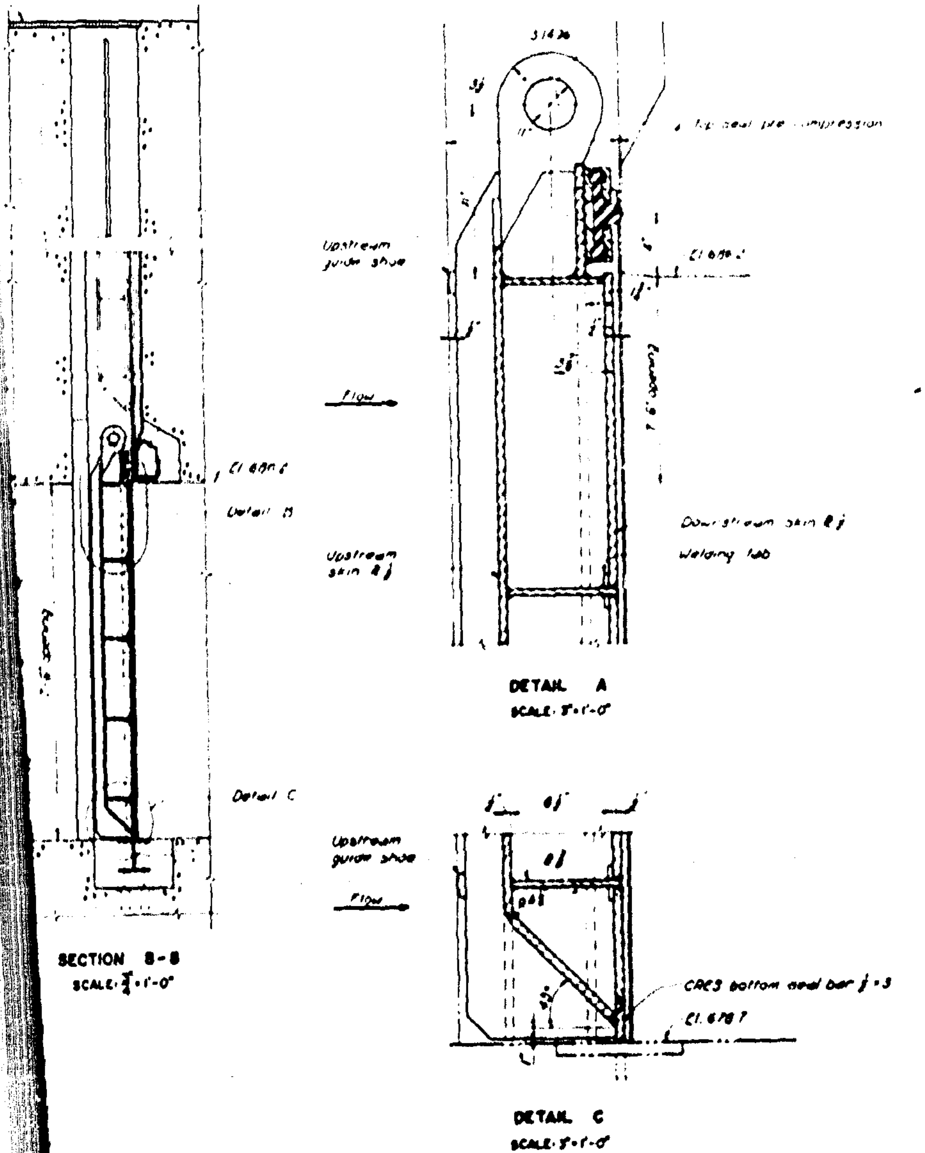
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

SINGLE (RIGHT) VALVE
TIMES 2, 4, 6, AND 8 MIN

TYPE 4 SYSTEM, RIVERWARD LOCK
FULL VS HALF TOW AT 6.5-FT DRAFT
8.5-FT(MIN) SUBMERGENCE
37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)



Flow
Detail A
SECTION A-A
UPSTREAM ELEVATION
SECTION B-B
Flow
DETAIL A
Upstream guide shoe
Upstream skin Pl
DETAIL C
Upstream guide shoe
Flow guide Pl
Upstream skin Pl
Web Pl
Downstream skin Pl
Rubber pad
Lateral guide shoe
Shims
Rubber pad
DETAIL A



General Notes
Gate to be welded air-tight and to be filled with inert gas.
Est. gate wt. = 4400 lb.

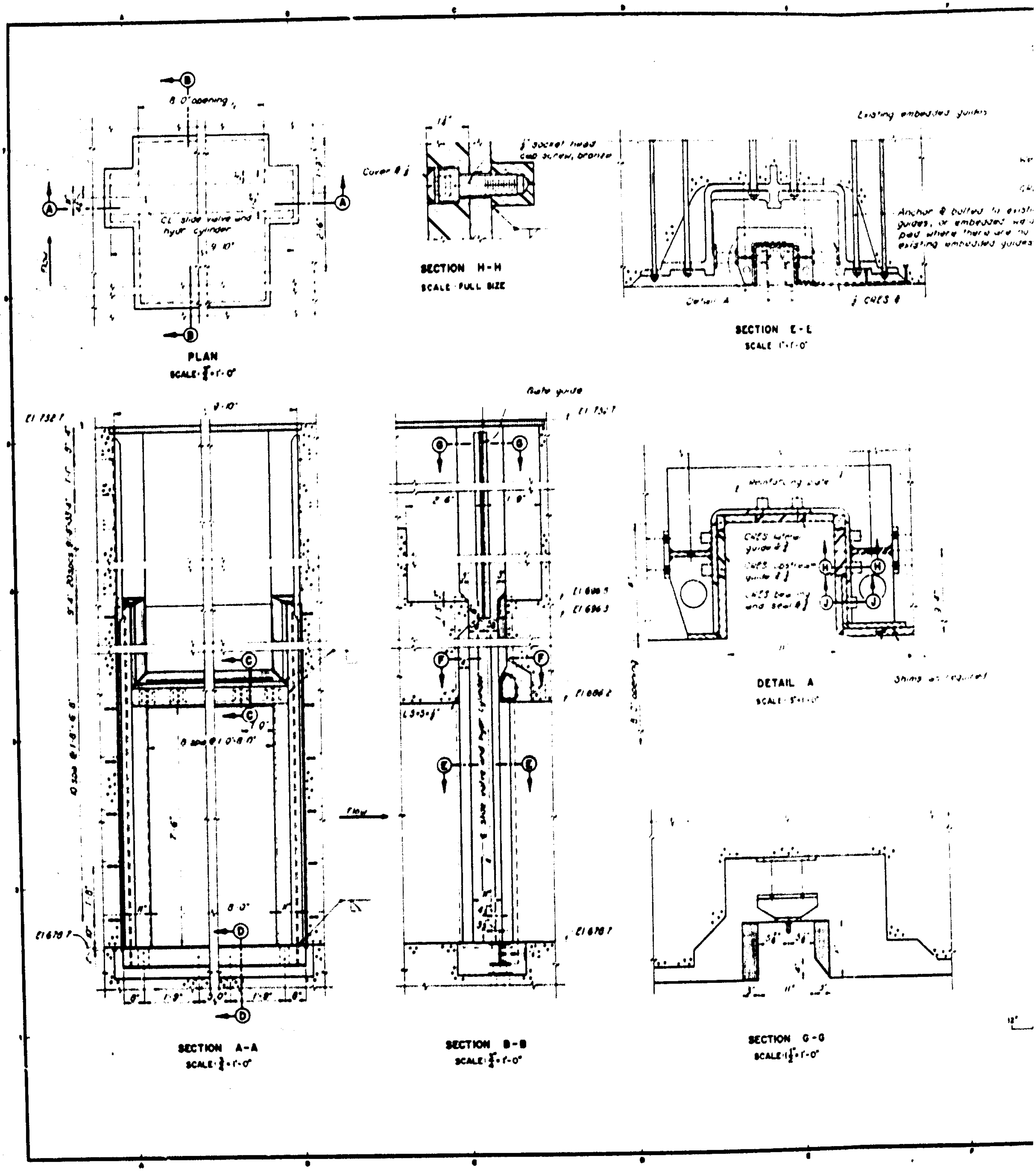
SAFETY PAYS

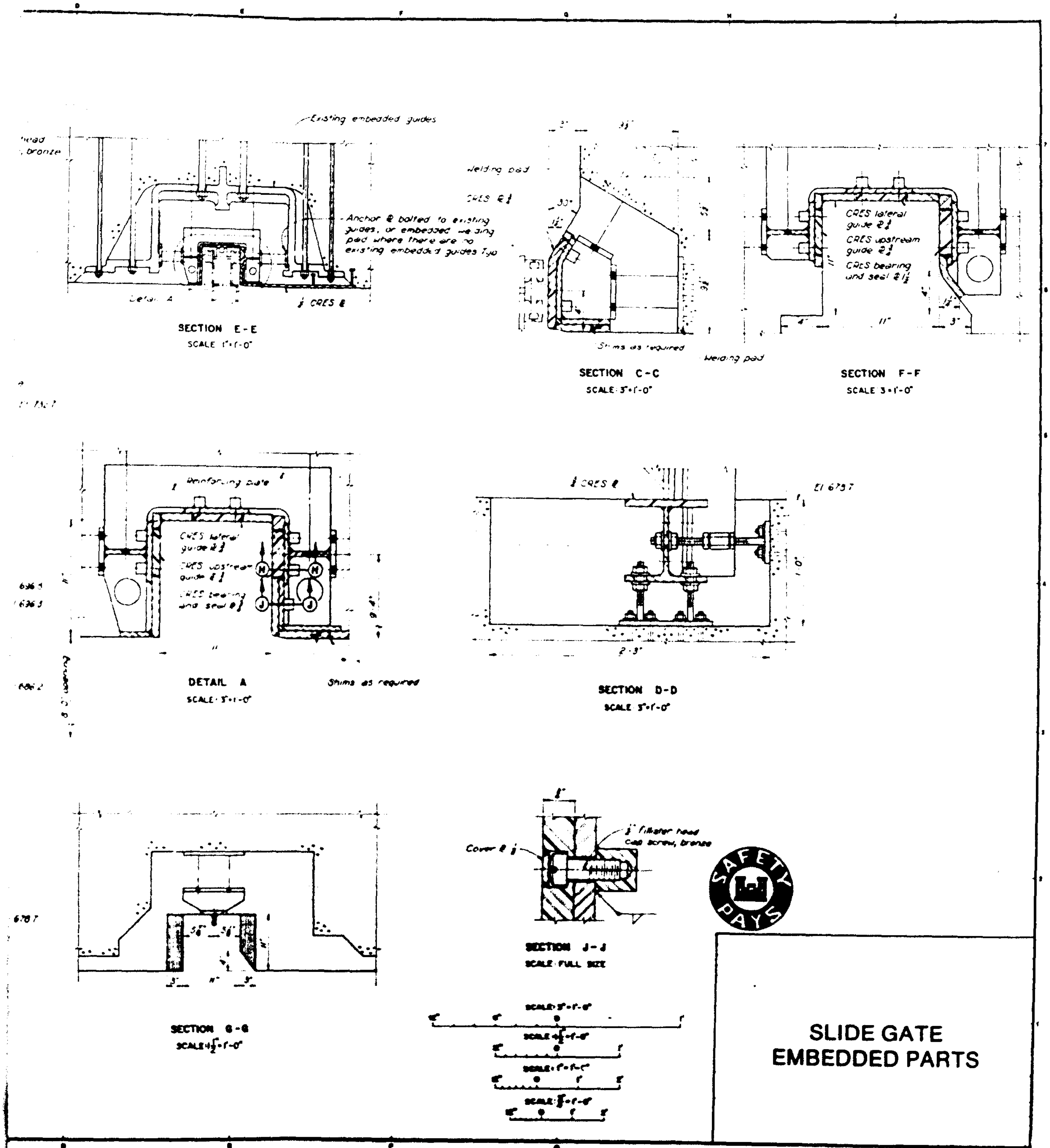
SCALE: 3" = 1'-0"

SCALE: ⅜" = 1'-0"

SCALE: ⅜" = 1'-0"

SLIDE GATE

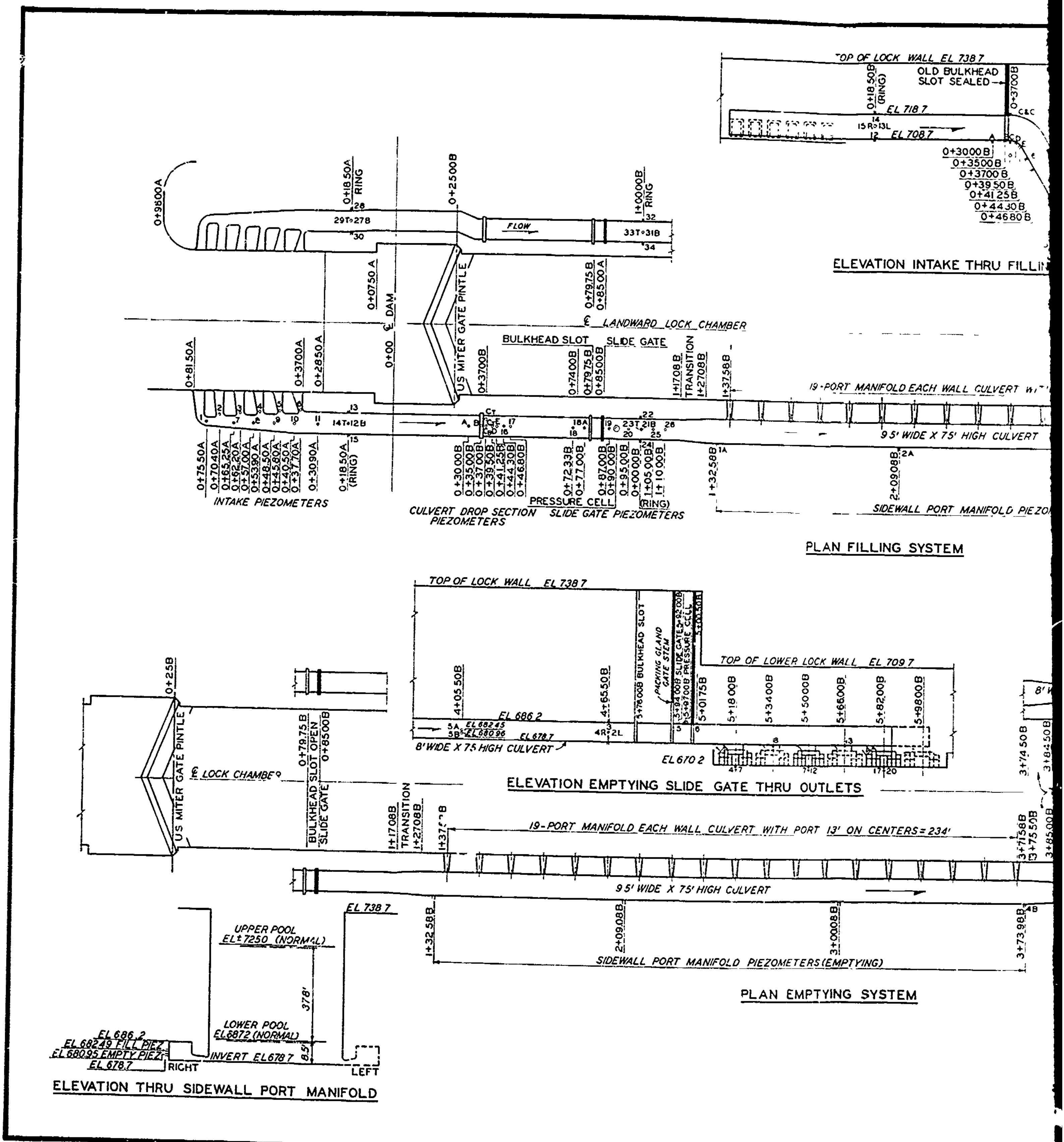

PLAN
SCALE: 3/8" = 1'-0"
SECTION H-H
SCALE: FULL SIZE
SECTION E-E
SCALE: 1" = 1'-0"
SECTION A-A
SCALE: 3/8" = 1'-0"
SECTION B-B
SCALE: 3/8" = 1'-0"
DETAIL A
SCALE: 3" = 1'-0"
SECTION G-G
SCALE: 1 1/2" = 1'-0"
Existing embedded guides
Flow



SAFETY PAYS

SLIDE GATE
EMBEDDED PARTS

PLATE 43



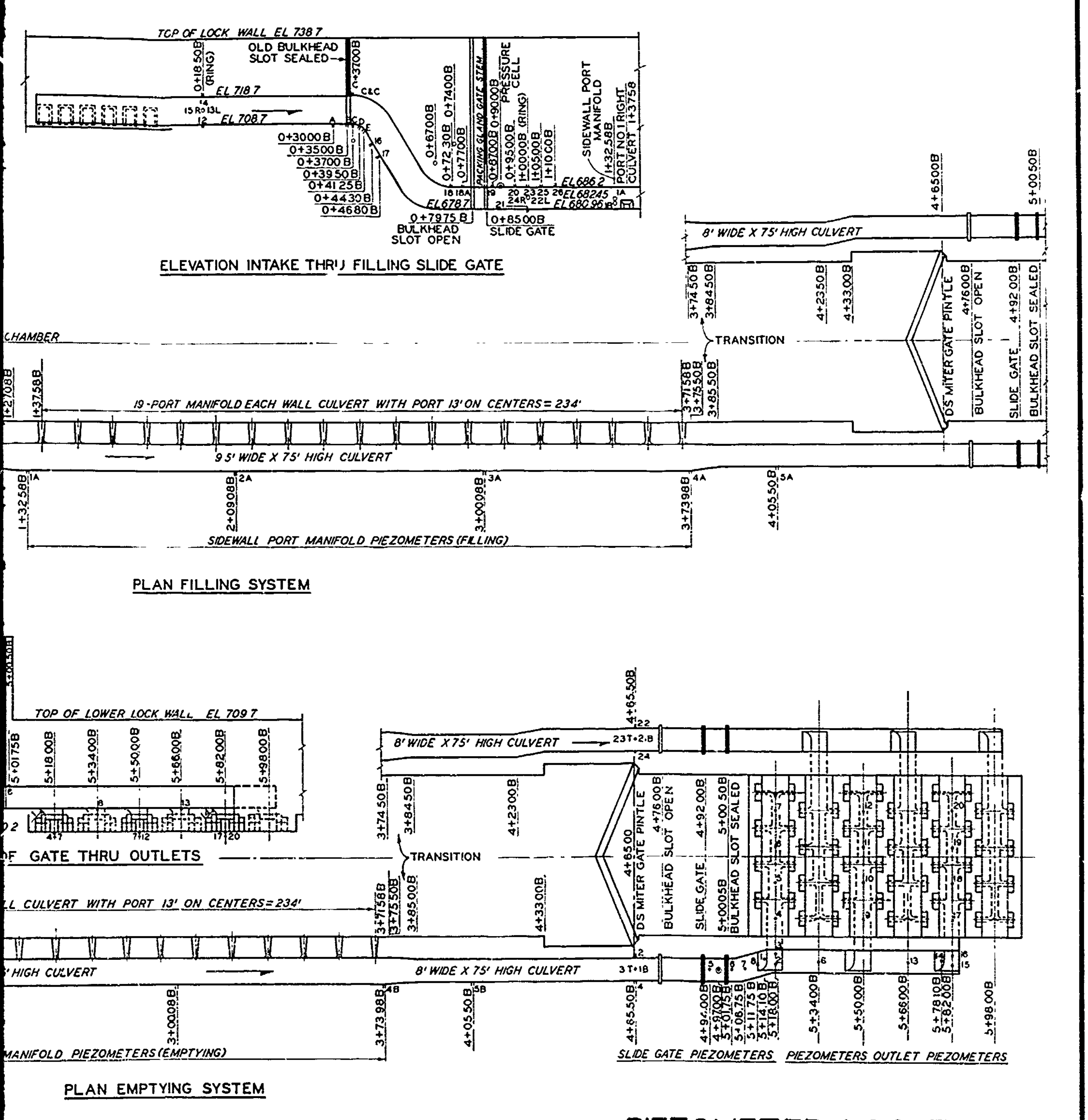
ELEVATION INTAKE THRU FILLING

PLAN FILLING SYSTEM

ELEVATION EMPTYING SLIDE GATE THRU OUTLETS

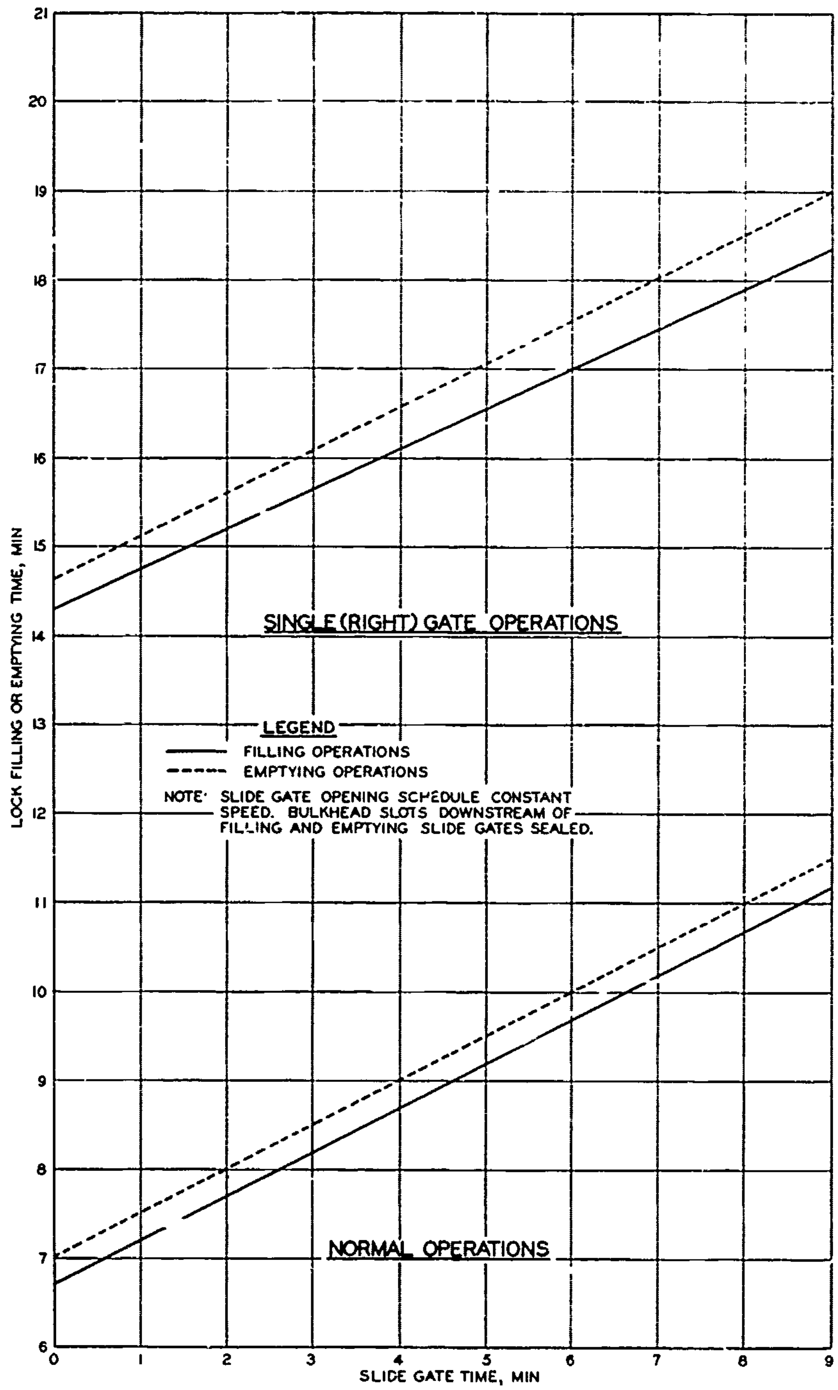
PLAN EMPTYING SYSTEM

ELEVATION THRU SIDEWALL PORT MANIFOLD



PIEZOMETER LOCATIONS
TYPE 5 SYSTEM WITH
CULVERT SLIDE GATES

2

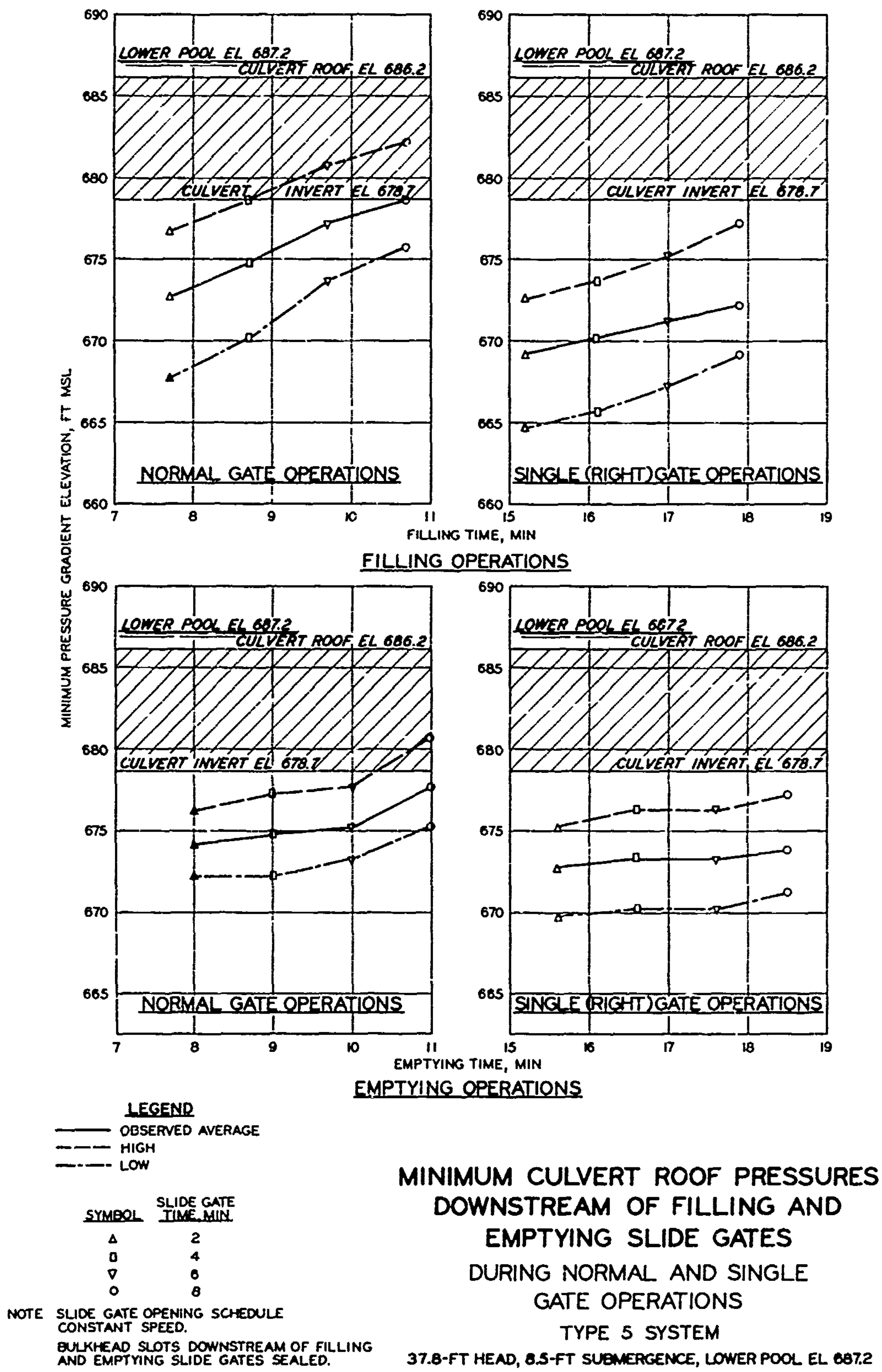


LOCK FILLING AND EMPTYING TIMES VS SLIDE GATE TIME

NORMAL AND SINGLE (RIGHT) GATE OPERATIONS

TYPE 5 SYSTEM

378-FT HEAD, 8.5-FT SUBMERGENCE, LOWER POOL EL 687.2

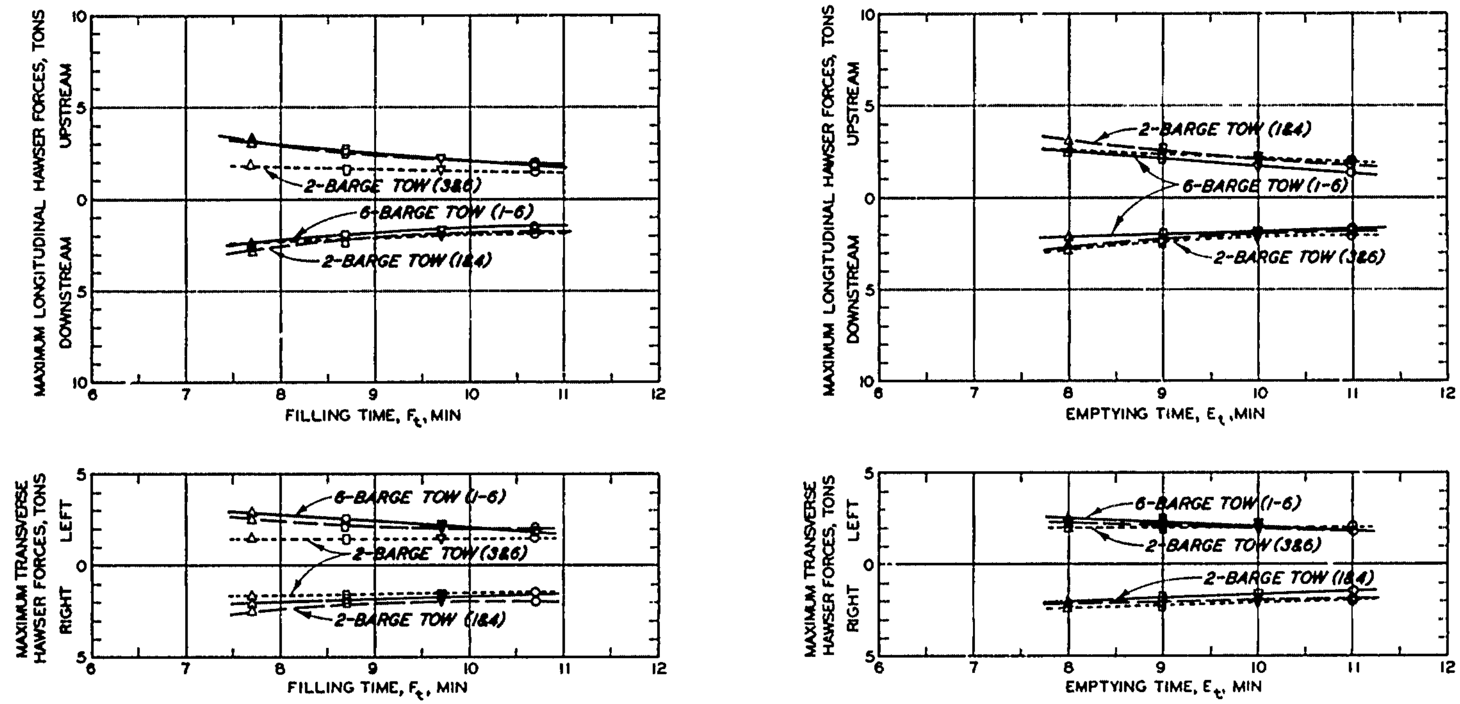


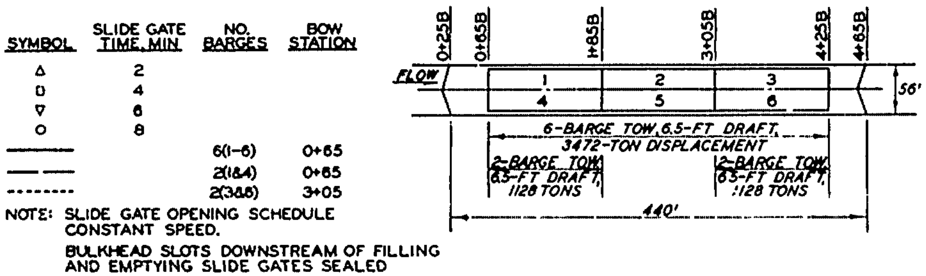
MINIMUM CULVERT ROOF PRESSURES DOWNSTREAM OF FILLING AND EMPTYING SLIDE GATES

DURING NORMAL AND SINGLE GATE OPERATIONS

TYPE 5 SYSTEM

37.8-FT HEAD, 8.5-FT SUBMERGENCE, LOWER POOL EL 687.2





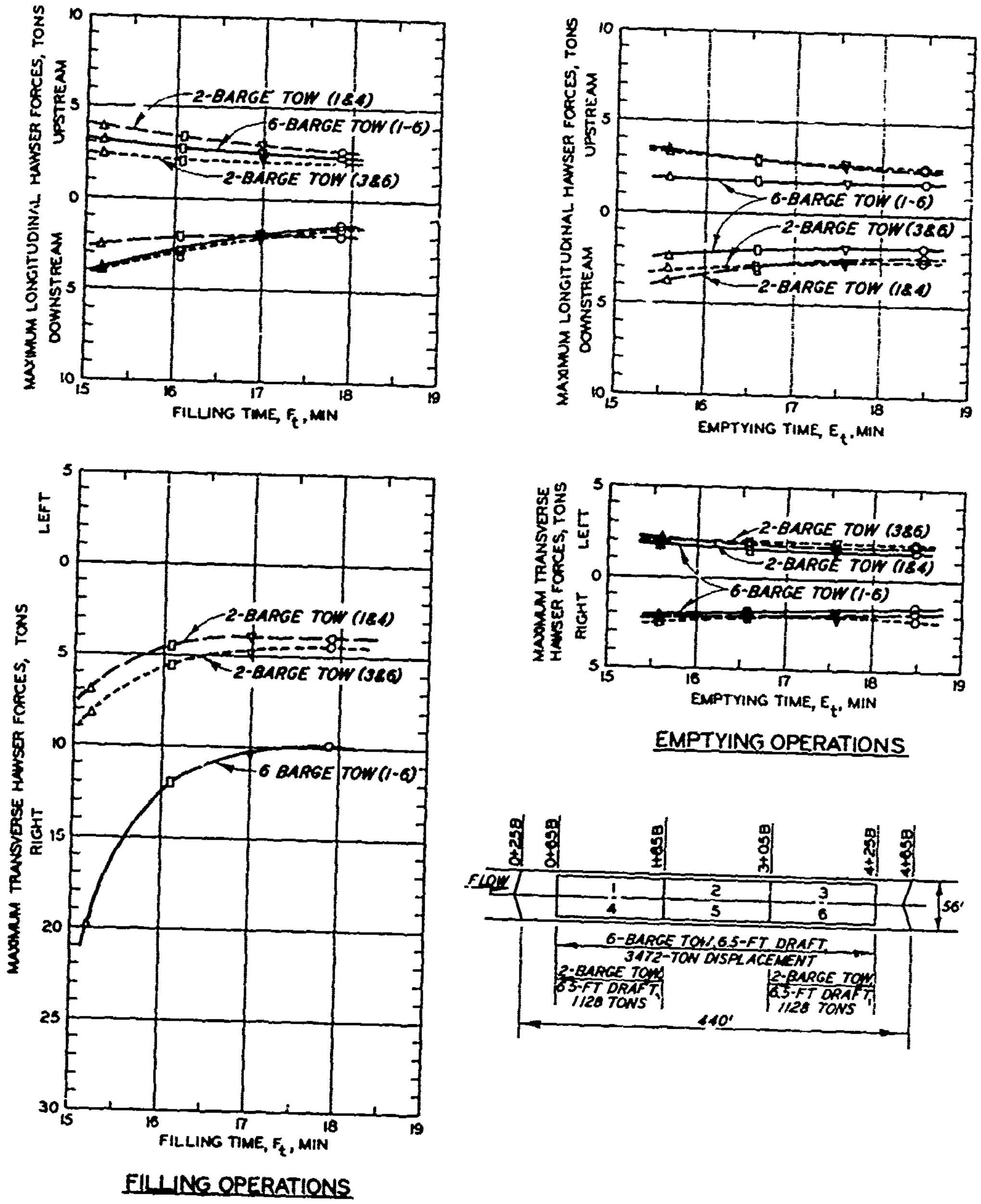
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

NORMAL 2-, 4-, 6-, AND 8-MIN
SLIDE GATE OPERATIONS

TYPE 5 SYSTEM

8.5-FT SUBMERGENCE, LOWER POOL EL 687.2

37.8-FT HEAD

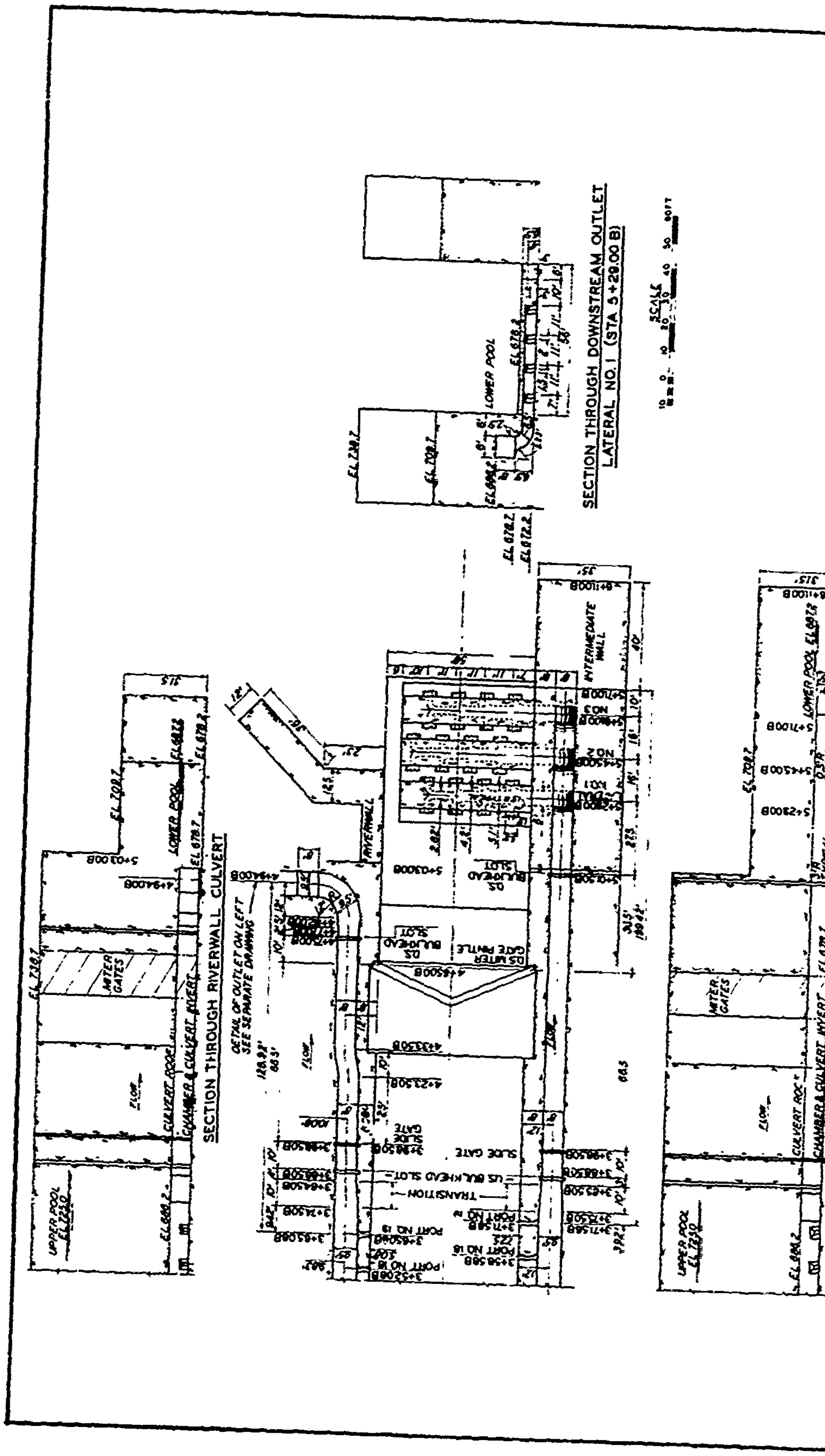


SYMBOL	SLIDE GATE TIME, MIN	NO. BARGES	BOW STATION
△	2		
□	4		
▽	6		
○	8		
———		6(1-6)	0+65
— — —		2(1&4)	0+25
--------		2(3&6)	3+05

NOTE: SLIDE GATE OPENING SCHEDULE CONSTANT SPEED.
BULKHEAD SLOTS DOWNSTREAM OF FILLING AND EMPTYING SLIDE GATES SEALED.

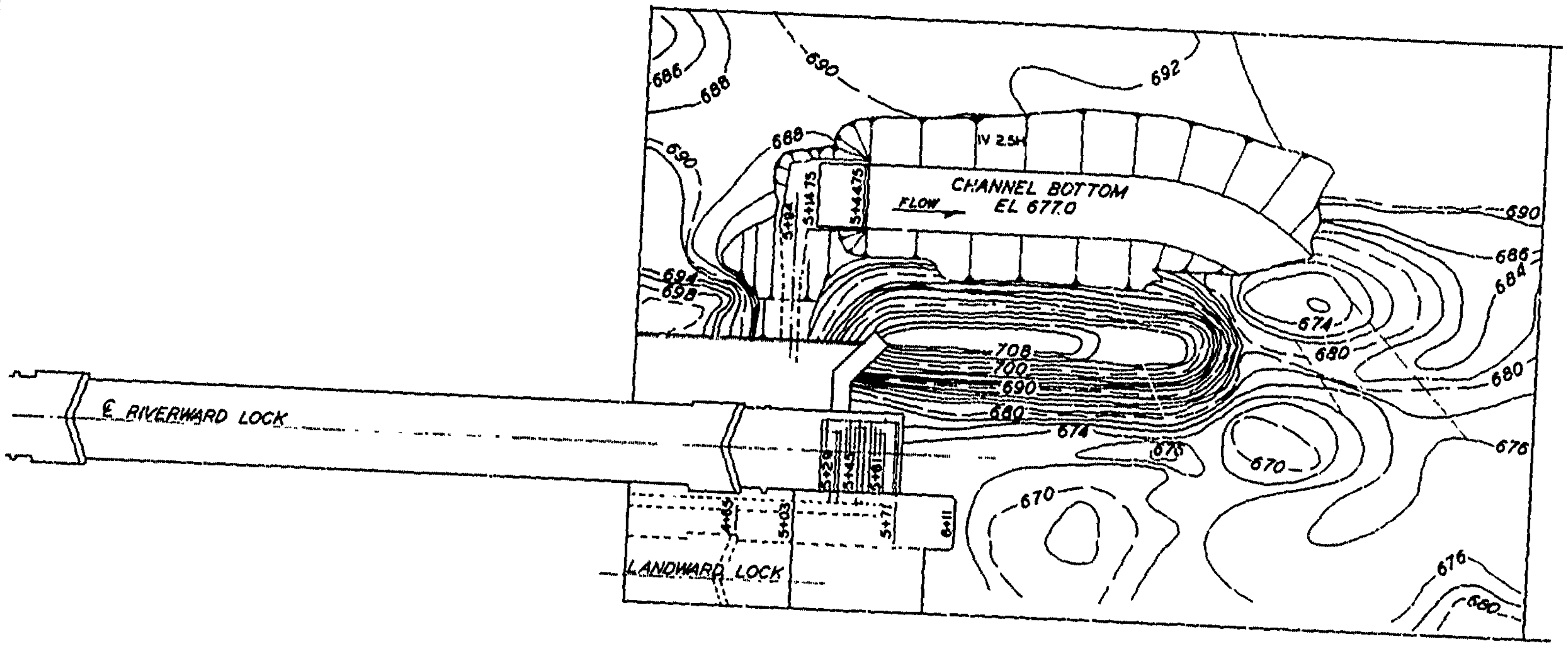
MAXIMUM HAWSER FORCES DURING FILLING AND EMPTYING OPERATIONS

SINGLE (RIGHT) SLIDE
GATE 2, 4, 6, AND 8 MIN
TYPE 5 SYSTEM
8.5-FT SUBMERGENCE, LOWER POOL EL 687.2
37.8-FT HEAD



TYPE 2 OUTLET (RIGHT CULVERT)
TYPE 6 EMPTYING SYSTEM
RIVERWARD LOCK

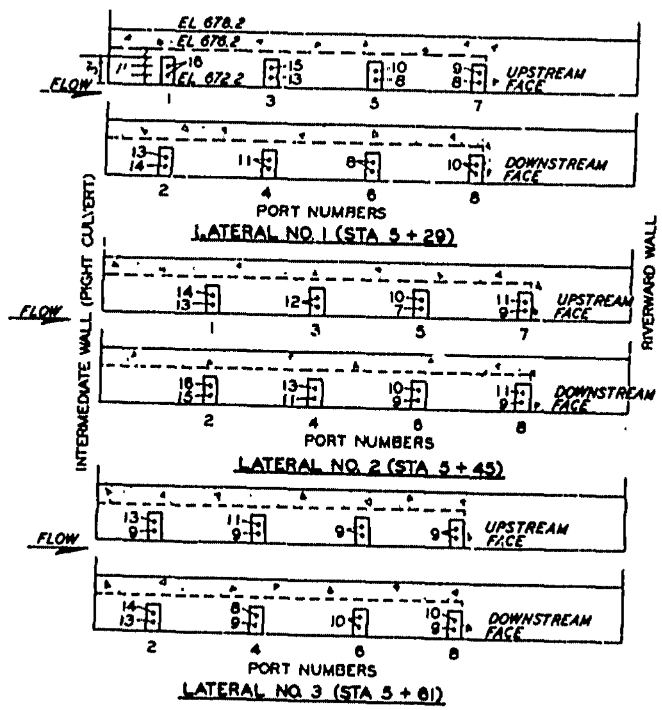
PLATE 49



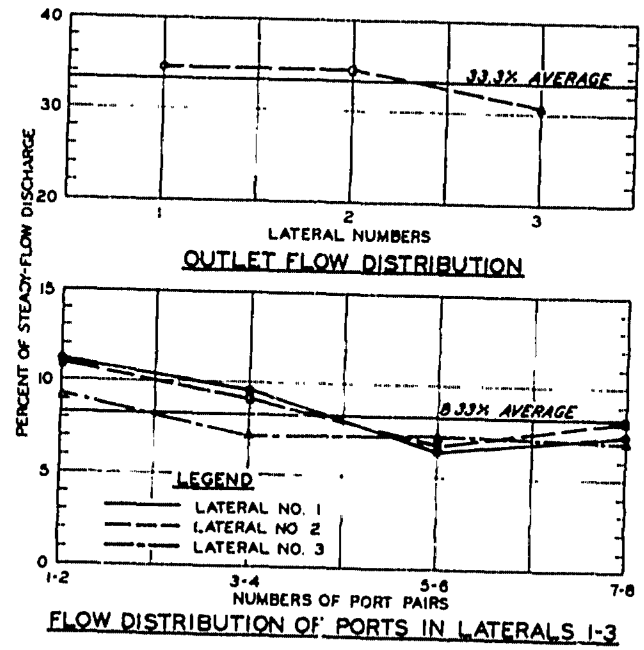
PLAN

SCALE
25 0 25 50 75 100 FT

TAILBAY TOPOGRAPHY
TYPE 6 EMPTYING SYSTEM
RIVERWARD LOCK



VELOCITY DISTRIBUTION AT LATERAL PORT WALL FACE
RIGHT CULVERT, INTERMEDIATE WALL
RIVERWARD LOCK



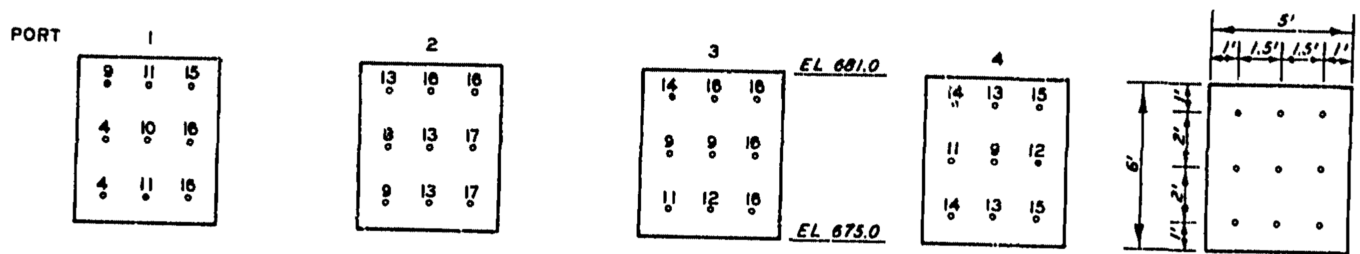
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND AND ARE MEASURED AT WALL FACE OF PORTS.

TEST CONDITIONS

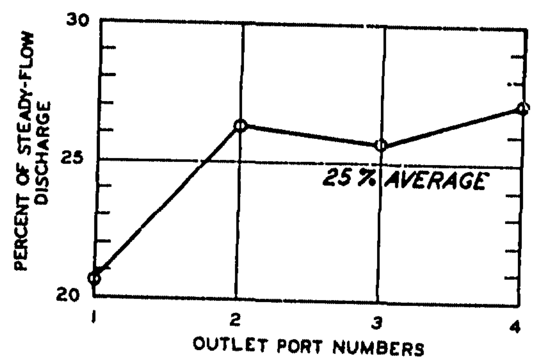
TOTAL DISCHARGE (PEAK STEADY FROM 4-MIN NORMAL)	2965 CFS
PERCENT DISCHARGE INTERMEDIATE (RIGHT WALL) OUTLET	43.2
PERCENT DISCHARGE RIVERWARD LOCK WALL OUTLET	56.8
LOCK CHAMBER EL	707.2
LOWER POOL EL	687.2

FILLING VALVES AND LOWER MITER GATES CLOSED
EMPTYING VALVES AND UPPER MITER GATES OPEN

OUTLET VELOCITIES AND FLOW DISTRIBUTION
TYPE 2 DESIGN
INTERMEDIATE WALL OUTLET
STEADY-FLOW DISCHARGE
RIVERWARD LOCK



VELOCITY DISTRIBUTION AT OUTLET PORT WALL FACE
LEFT CULVERT, RIVERWARD LOCK



OUTLET FLOW DISTRIBUTION

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND AND ARE MEASURED AT WALL FACE OF PORTS

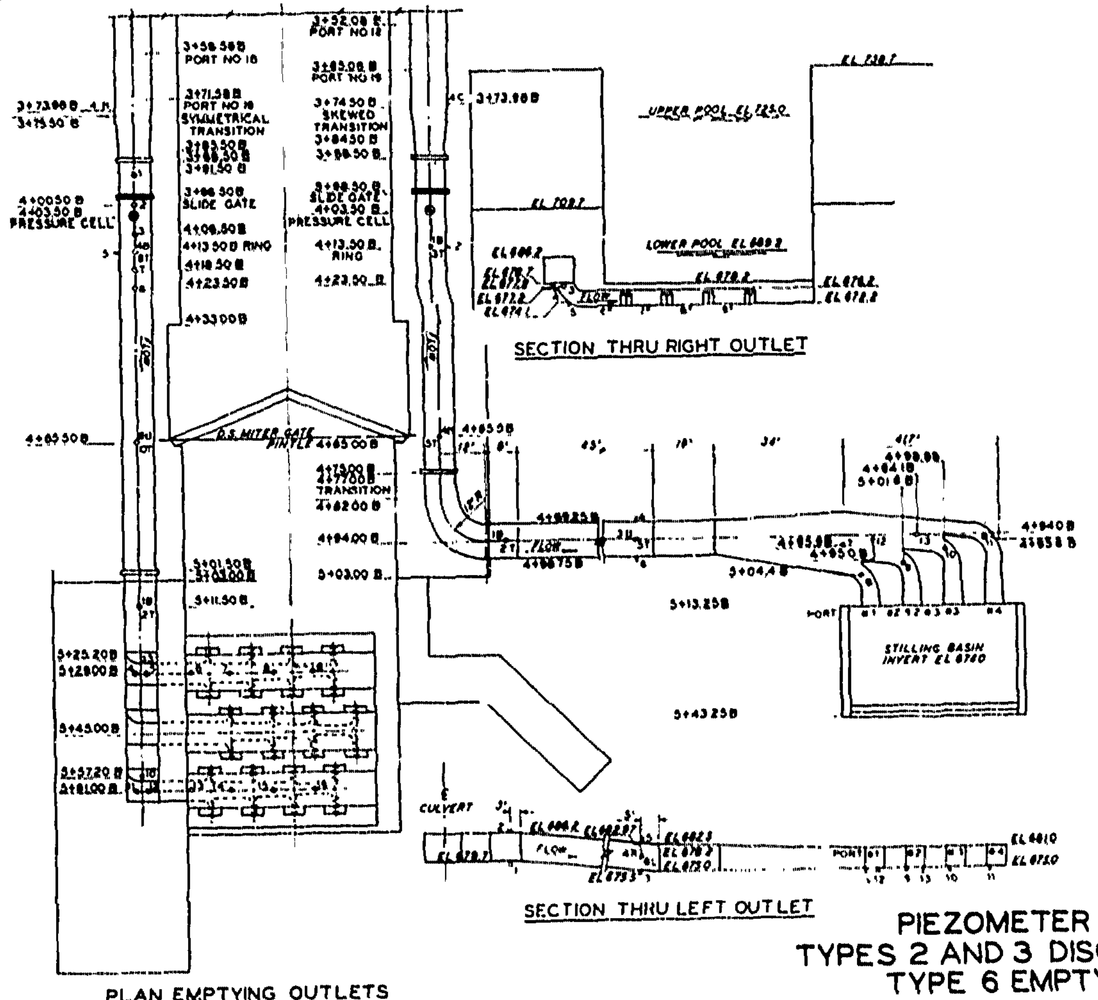
TEST CONDITIONS

TOTAL DISCHARGE (PEAK STEADY FROM 4 MIN NORMAL)	2985 CFS
PERCENT DISCHARGE INTERMEDIATE WALL OUTLET	4[illegible].2
PERCENT DISCHARGE RIVERWARD LOCK WALL OUTLET	56.8
LOCK CHAMBER EL	707.2
LOWER POOL EL	687.2
FILLING VALVES AND LOWER MITER GATES CLOSED	
EMPTYING VALVES AND UPPER MITER GATES OPEN	

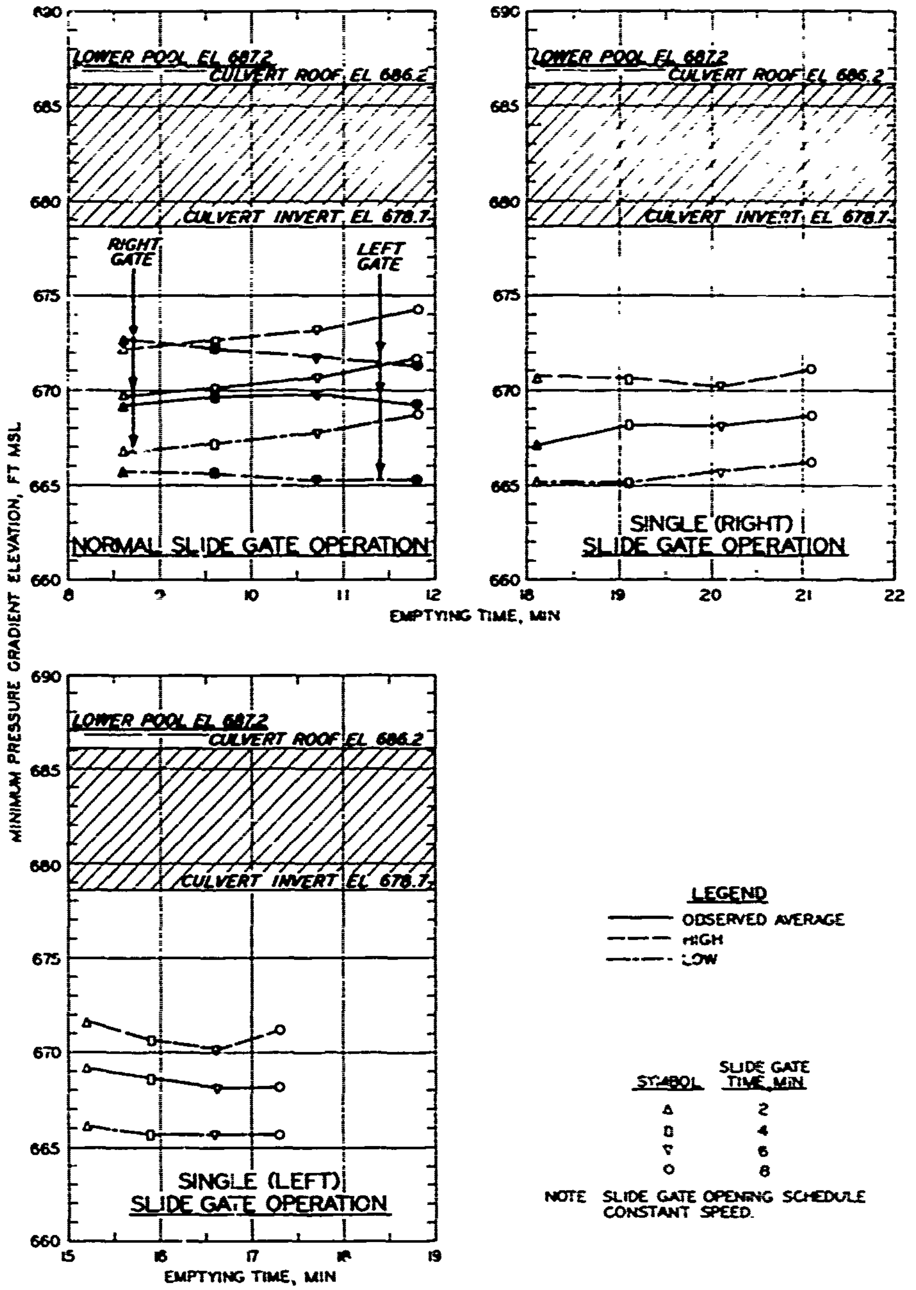
OUTLET VELOCITIES AND FLOW DISTRIBUTION

TYPE 3 DESIGN, RIVERWARD WALL OUTLET

STEADY-FLOW DISCHARGE
RIVERWARD LOCK



PIEZOMETER LOCATIONS
TYPES 2 AND 3 DISCHARGE OUTLETS
TYPE 6 EMPTYING SYSTEM
RIVERWARD LOCK

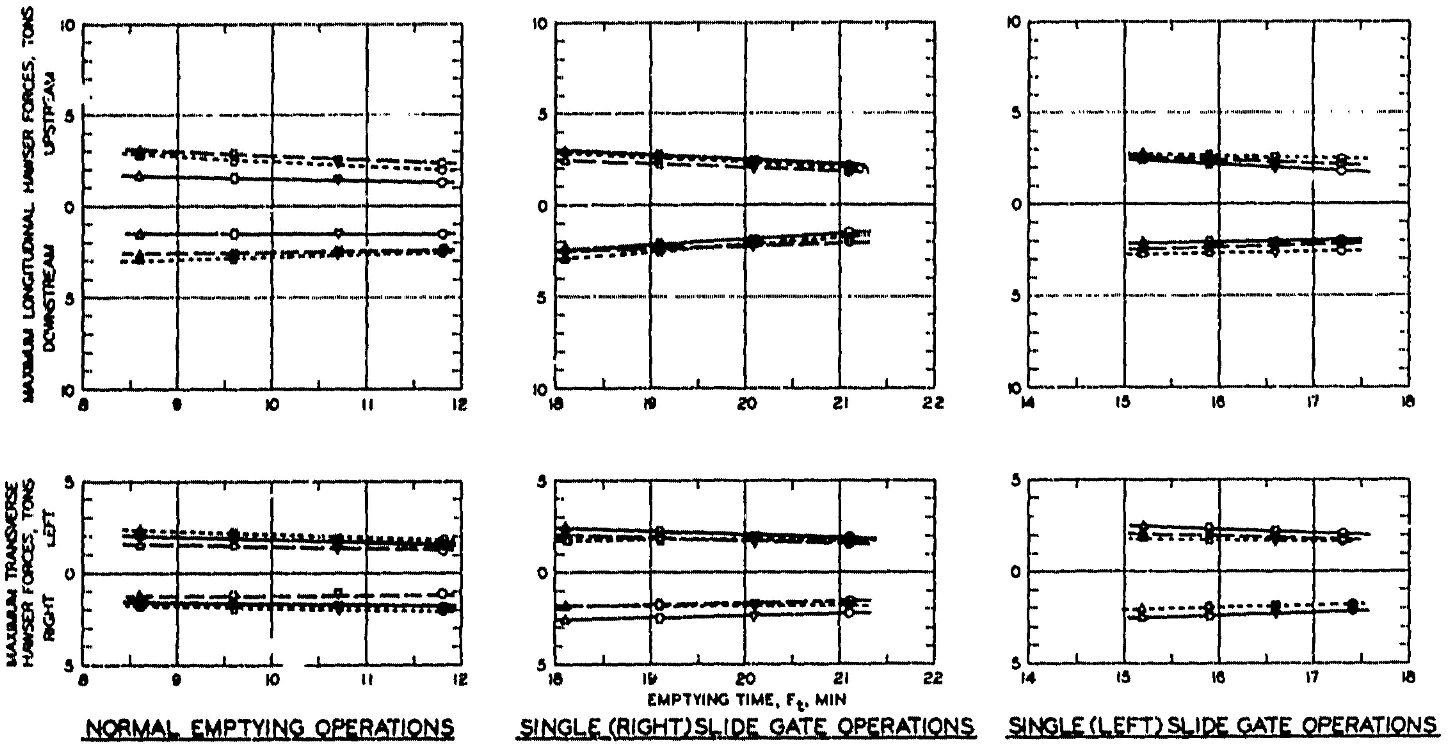


MINIMUM CULVERT ROOF PRESSURES DOWNSTREAM OF EMPTYING SLIDE GATE

DURING NORMAL AND SINGLE (RIGHT AND LEFT) GATE OPERATION

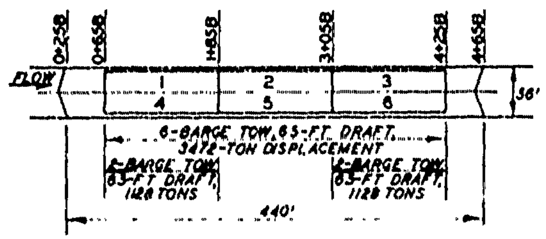
TYPE 6 SYSTEM

37.8-FT HEAD (UPPER POOL EL 725.0, LOWER POOL EL 687.2)
RIVERWARD LOCK



SYMBOL	SLIDE GATE TIME, MIN	NO. BARGES	BOW STATION
△	2		
□	4		
▽	6		
○	8		
———		6(1-6)	0+65
— —		2(1&4)	0+65
········		2(3&6)	3+05

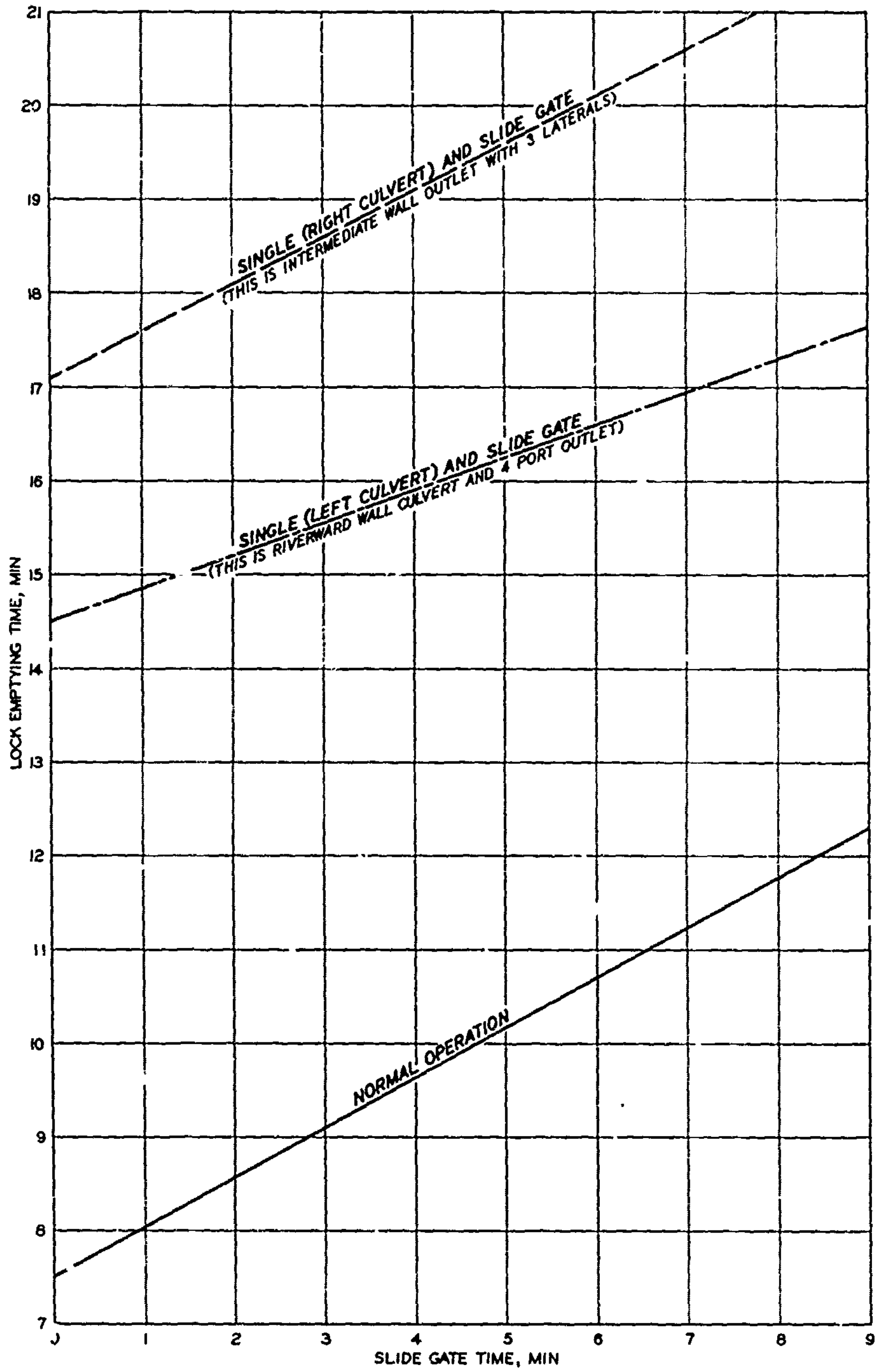
NOTE: SLIDE GATE OPENING SCHEDULE CONSTANT SPEED
BULKHEAD SLOTS DOWNSTREAM OF FILLING AND EMPTYING SLIDE GATES SEALED.



MAXIMUM HAWSER FORCES DURING NORMAL AND SINGLE SLIDE GATE EMPTYING OPERATION AT 2, 4, 6, AND 8 MIN

TYPE 6 SYSTEM

8.5-FT SUBMERGENCE, LOWER POOL EL 687.2
37.8-FT HEAD



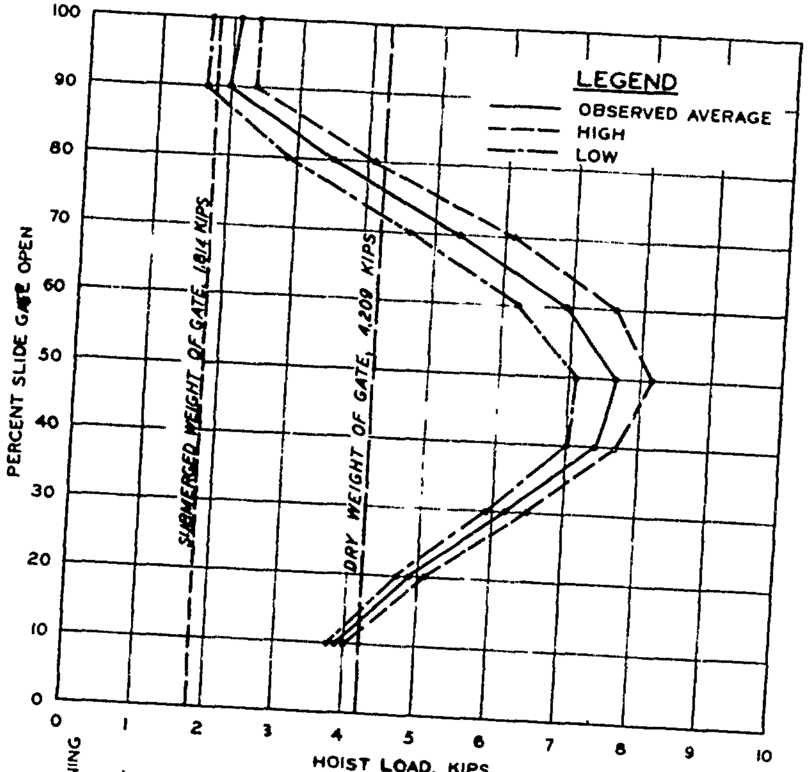
NOTE SLIDE GATE OPENING SCHEDULE CONSTANT SPEED. BULKHEAD SLOTS DOWNSTREAM OF EMPTYING SLIDE GATES SEALED.

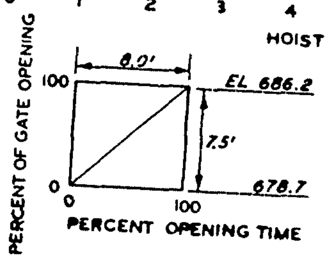
EMPTYING TIME VS
SLIDE GATE OPENING TIME

NORMAL AND SINGLE (RIGHT AND LEFT)
GATE OPERATIONS

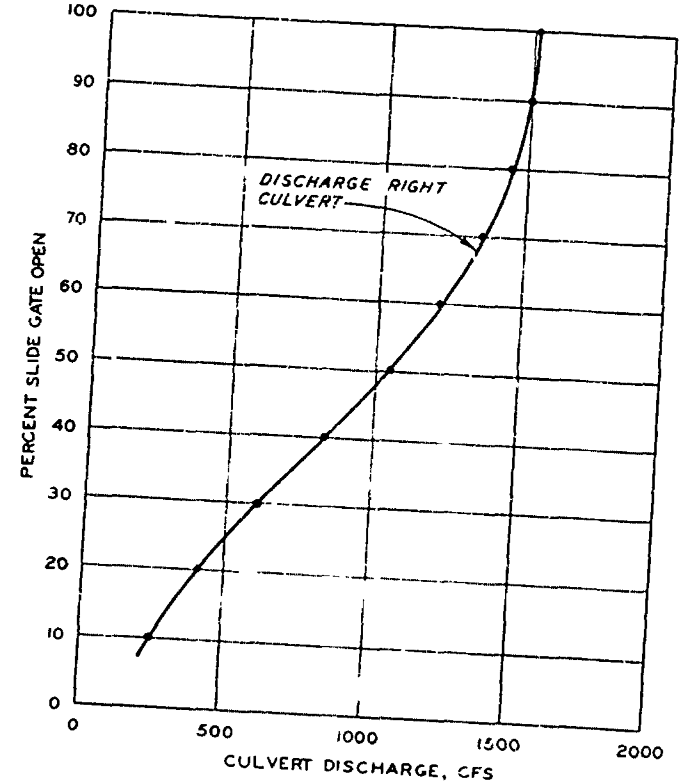
TYPE 6 SYSTEM

38.5-FT HEAD, 8.5-FT SUBMERGENCE, LOWER POOL EL 687.2
RIVERWARD LOCK

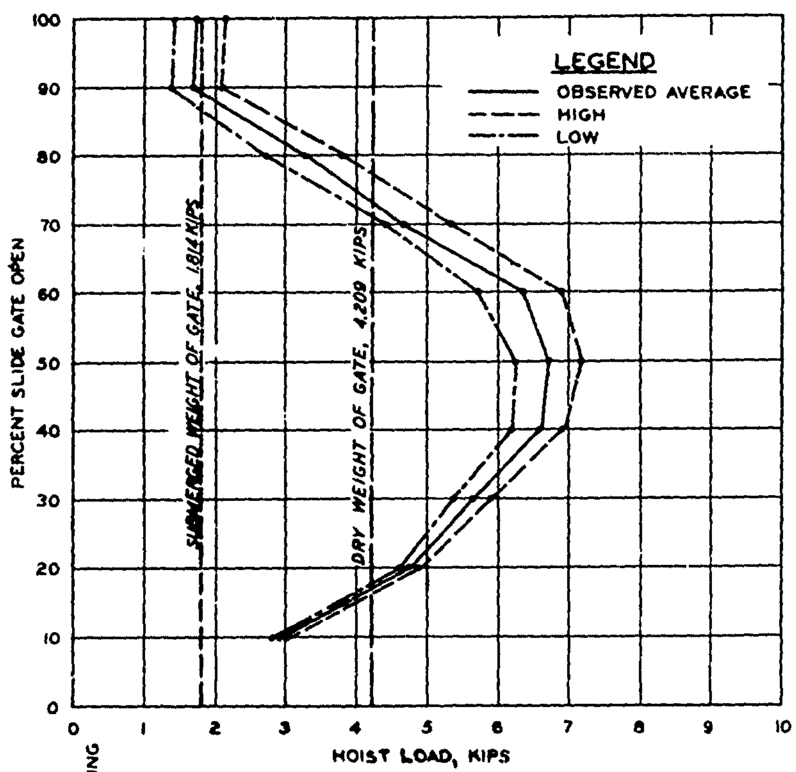


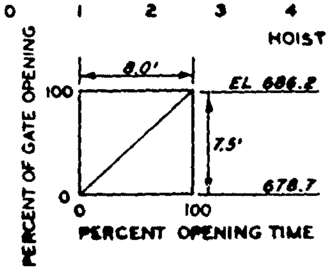


SLIDE GATE OPENING SCHEDULE

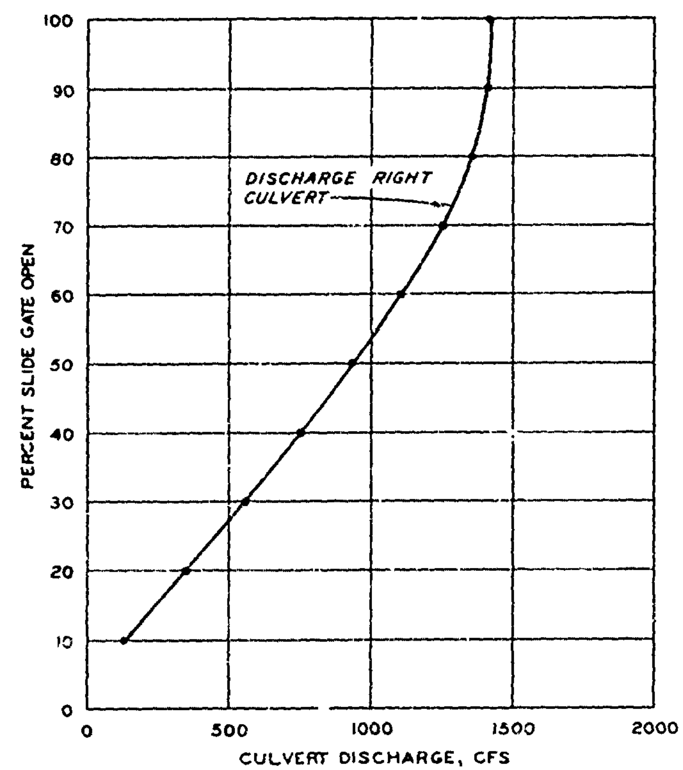


HOIST LOADS
TYPE I (ORIGINAL) SLIDE GATE
NORMAL OPERATION, 4-MIN GATE SCHEDULE
TYPE 5 FILLING SYSTEM



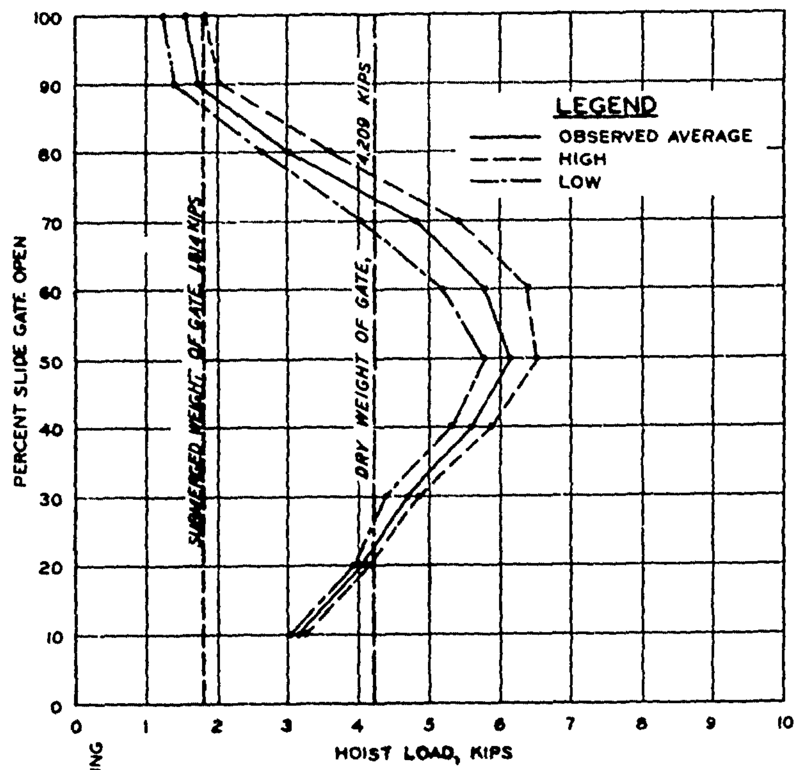


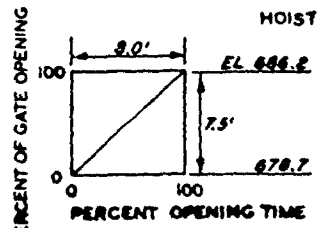
SLIDE GATE OPENING SCHEDULE



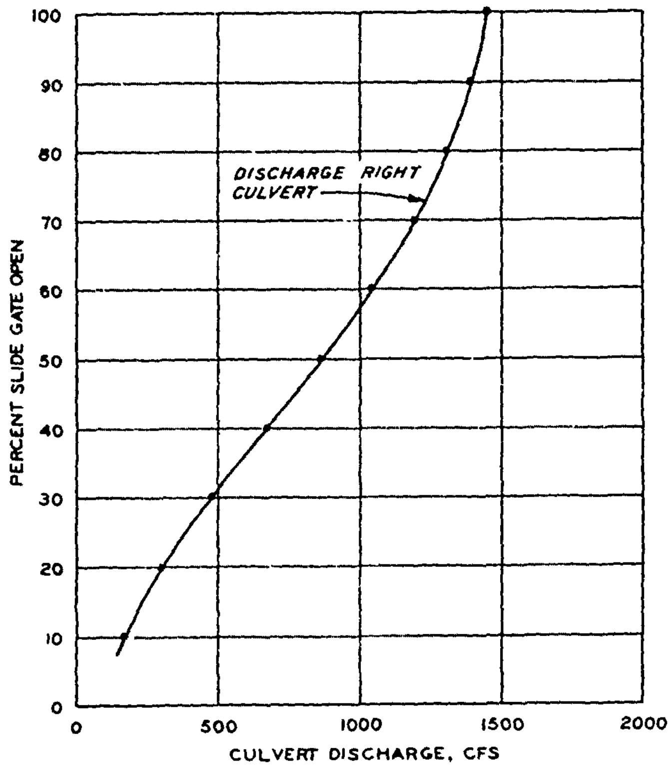
HOIST LOADS
TYPE I (ORIGINAL) SLIDE GATE

NORMAL OPERATION, 4-MIN GATE SCHEDULE
TYPE 5 EMPTYING SYSTEM

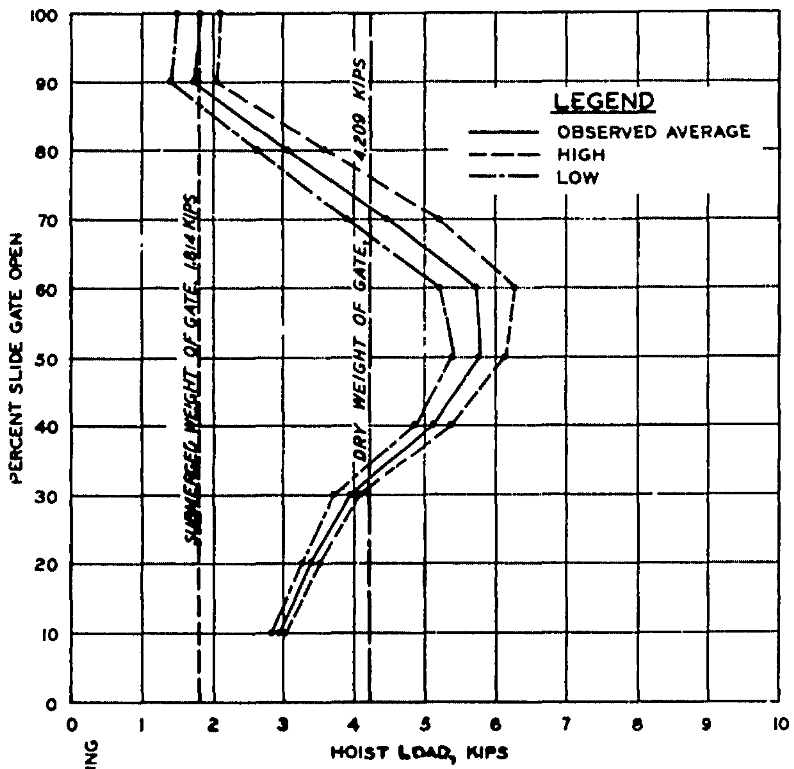


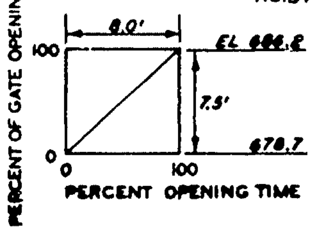


SLIDE GATE OPENING SCHEDULE

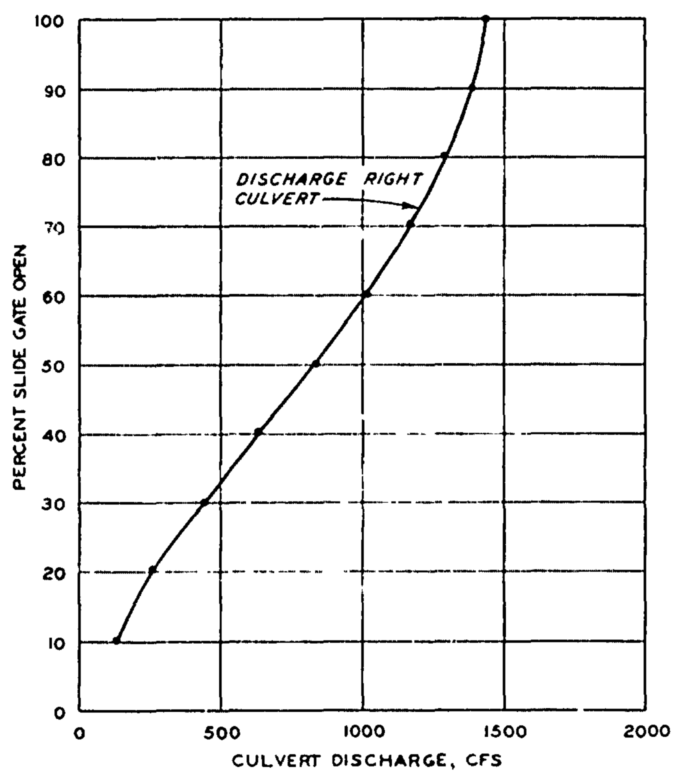


HOIST LOADS
TYPE I (ORIGINAL) SLIDE GATE
NORMAL OPERATION, 4-MIN GATE SCHEDULE
TYPE 6 EMPTYING SYSTEM



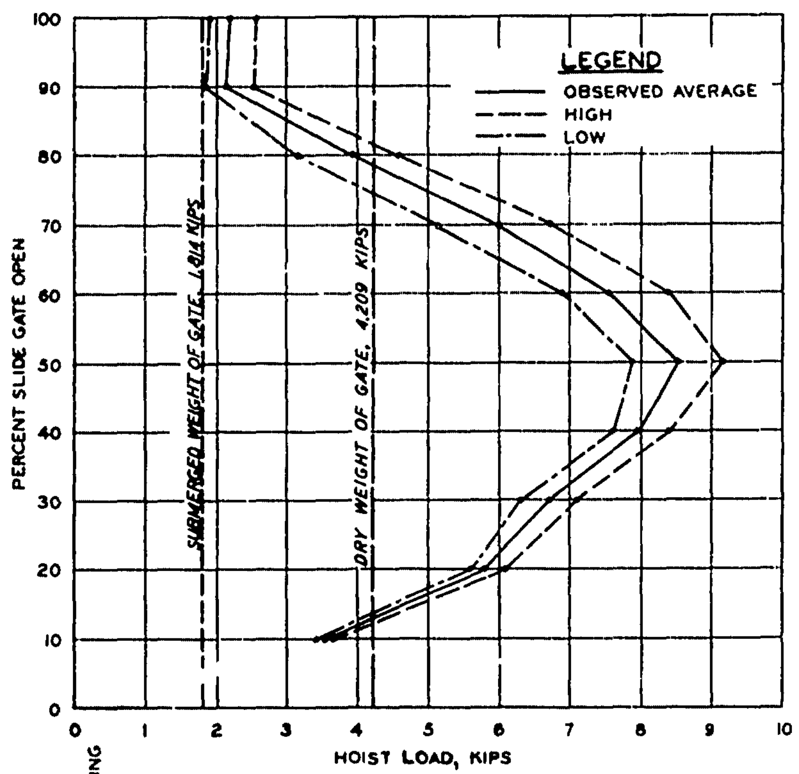


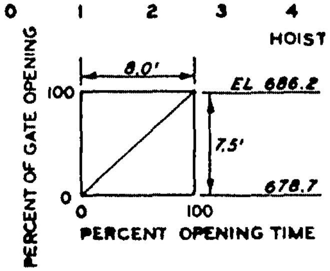
SLIDE GATE OPENING SCHEDULE



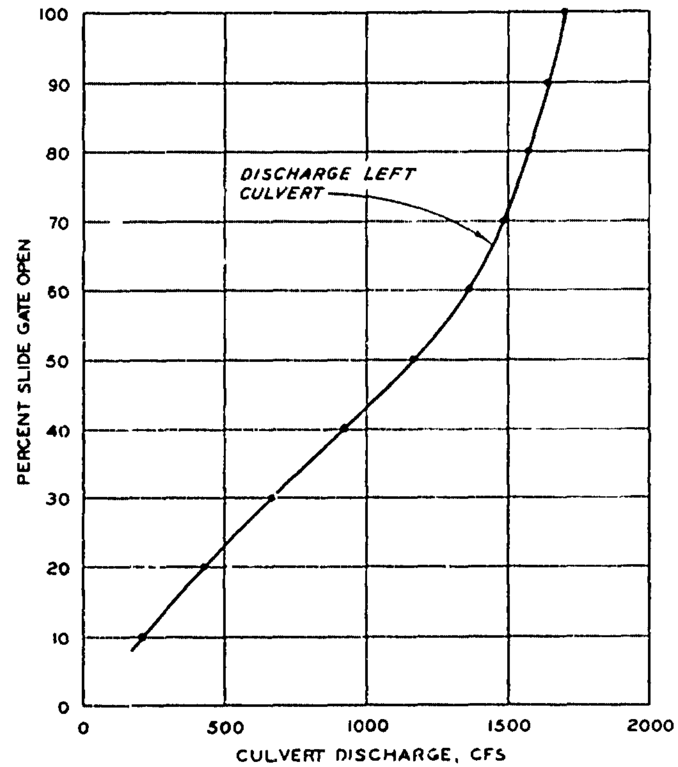
HOIST LOADS
TYPE I (ORIGINAL) SLIDE GATE

SINGLE (RIGHT) 4-MIN GATE OPERATION
TYPE 6 EMPTYING SYSTEM

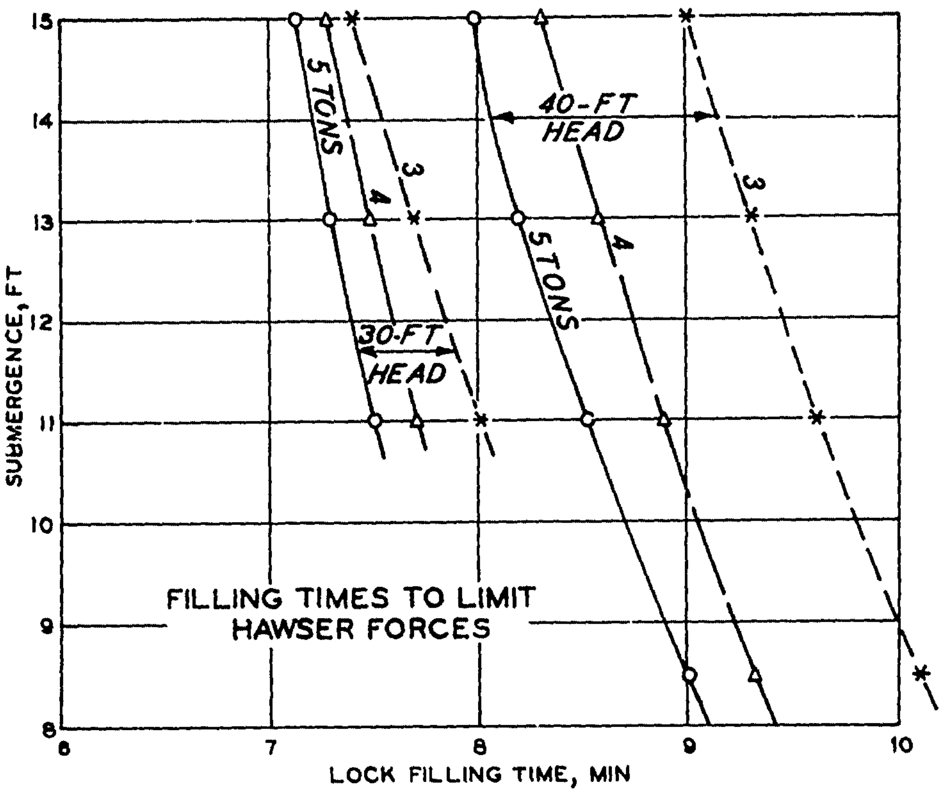


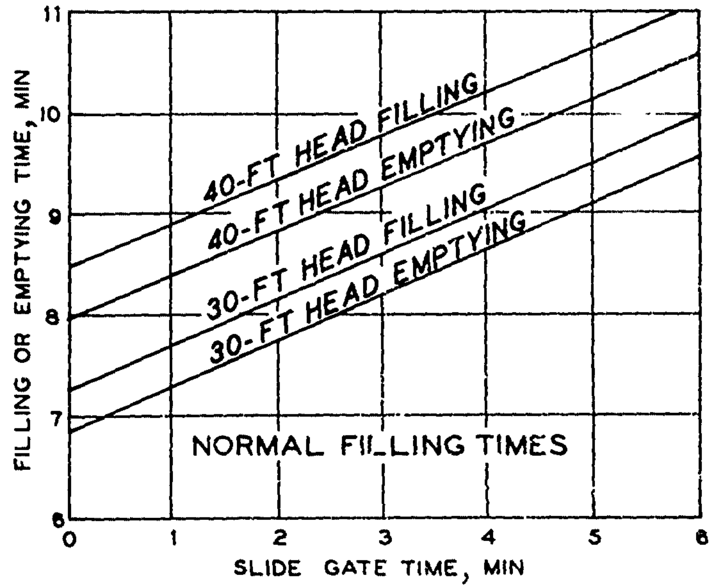


SLIDE GATE OPENING SCHEDULE



HOIST LOADS
TYPE I (ORIGINAL) SLIDE GATE
SINGLE (LEFT) 4-MIN GATE SCHEDULE
TYPE 6 EMPTYING SYSTEM





NOTE: SUBMERGENCE IS THE DIFFERENCE IN ELEVATION BETWEEN THE LOWER POOL AND THE LOCK CHAMBER FLOOR AT EL 678.7.

HAWSER FORCES WERE MEASURED ON A 6-BARGE TOW AT 6.5-FT DRAFT (3472 TONS DISPLACEMENT) MOORED WITH UPSTREAM END OF TOW AT STA 0+65

THESE TESTS WERE FUNDED BY CWIS WORK UNIT NO. 31076 "IMPROVED CRITERIA FOR LOCK DESIGN."

FILLING TIME REQUIRED TO LIMIT HAWSER FORCES TO 3, 4, AND 5 TONS WITH INITIAL SUBMERGENCE OVER LOCK FLOOR 8,5, 11, 13, AND 15 FT
TYPE 6 SYSTEM

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Ables, Jackson H
Modifications to filling and emptying system of Lock No. 1, Mississippi River, Minneapolis, Minnesota; hydraulic model investigation / by Jackson H. Ables, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
44, [31] p., [39] leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-79-21)
Prepared for U. S. Army Engineer District, St. Paul, St. Paul, Minnesota.

1. Hydraulic models. 2. Lock and Dam No. 1, Mississippi River. 3. Lock filling and emptying systems. 4. Locks (Waterways). 5. Mississippi River. I. United States. Army. Corps of Engineers. St. Paul District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-79-21.
TA7.W34 no.HL-79-21