TECHNICAL REPORT NO. 2-778

MODERNIZATION OF FILLING AND EMPTYING SYSTEM, EXISTING MC ALPINE LOCK (OLD NO. 41), OHIO RIVER LOUISVILLE, KENTUCKY

Hydraulic Model Investigation

by

J. H. Ables, Jr.
T. E. Murphy

May 1967

Sponsored by

U. S. Army Engineer District
Louisville

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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FOREWORD

Model investigation of the existing 600- by 110-ft McAlpine Lock was authorized by the Office, Chief of Engineers on 17 November 1959 at the request of U. S. Army Engineer District, Louisville. The study was accomplished in the Hydraulics Division of the Waterways Experiment Station (WES) during the period January 1960 to January 1961.

The investigation was conducted under the general supervision of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. F. R. Brown, Chief of the Hydrodynamics Branch, and under the direct supervision of Mr. T. E. Murphy, Chief of the Structures Section. The engineer in immediate charge of the model was Mr. J. H. Ables, Jr., assisted by Messrs. Tasso Schmidgall and H. H. Allen. This report was prepared by Messrs. Ables and Murphy.

During the course of the investigation Messrs. C. L. Cowan and A. I. Gulden of the Louisville District, Messrs. A. J. Moors and W. H. Browne of the Ohio River Division, and Mr. J. P. Davis of the Office, Chief of Engineers visited WES to discuss model results and the structural feasibility of proposed modifications.

Directors of WES during the testing program were COL Edmund H. Lang, CE, and COL Alex G. Sutton, Jr., CE. Director during preparation of this report was COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimeters
feet	0.3048	meters
miles	1.609344	kilometers
tons	907.185	kilograms
cubic feet per second	0.028317	cubic meters per second
feet per minute	0.3048	meters per minute

SUMMARY

Tests were conducted on a 1:25-scale model of the filling and emptying systems of the existing 600- by 110-ft lock of the McAlpine project. These tests were concerned with whether structurally feasible modifications of the systems would result in decreased turbulence and hawser stresses and thus permit faster filling and emptying of the lock.

Tests demonstrated that major improvement in performance of the filling and emptying system would result from connecting the filling and emptying culverts and plugging certain of the ports in the existing filling system.

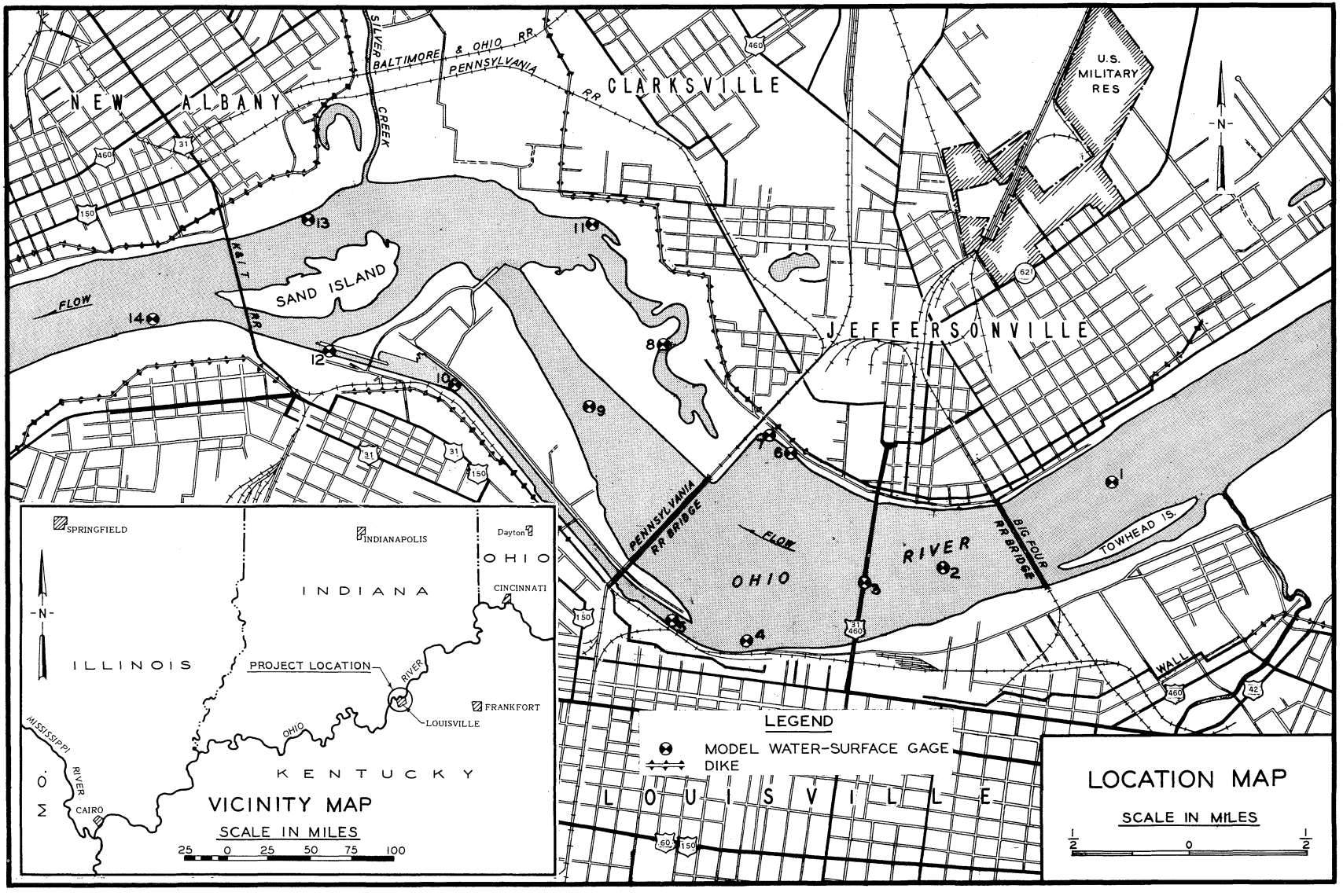

Fig. 1. Vicinity and location maps

MODERNIZATION OF FILLING AND EMPTYING SYSTEM EXISTING McALPINE LOCK (OLD NO. 41) OHIO RIVER, LOUISVILLE, KENTUCKY

Hydraulic Model Investigation

PART I: INTRODUCTION

The McAlpine Project

Location

1. The McAlpine Locks and Dam project is located on the Ohio River 604.5 miles* downstream from Pittsburgh, Pennsylvania, at the northwestern end of Louisville, Kentucky (fig. 1), in the section known as Portland. The pool created by these structures extends approximately 75 miles to the Markland Locks and Dam near Warsaw, Kentucky.

Description

2. The natural waterfall at the McAlpine site made necessary the first navigation structure in the Ohio River. The first project, which included a 3-flight lock, was completed in 1830. Various improvements and alterations were made from time to time until a combined navigation and hydroelectric development was completed in 1930. This project consisted of a navigable dam, the Louisville Portland Canal, a main lock, and an auxiliary lock. The dam is the longest and highest navigable dam on the Ohio River. With crest elevation at 420.0,** it provided slack water with a project depth of 9 ft between Louisville and Dam No. 39 at Markland, Indiana. The navigation locks at the lower end of the canal, with a normal lift of 37 ft and a maximum lift of 42 ft, were the highest lift locks on the Ohio River. The existing (old main) lock, placed in operation in 1921, is 110 ft wide by 600 ft long; the auxiliary lock, placed in operation in 1930, is 56 ft wide by 360 ft long.

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

** Elevations are in feet referred to mean sea level.

3. In 1954 modernization of the navigation facilities at Louisville was undertaken, and by 1962 a new lock, 110 by 1200 ft, was in operation. The modernization plan included reconstruction and widening of the upper lock entrance canal, installation of a surge basin in this canal, and provision of a nonnavigable, gate-controlled dam in place of the Boule weir and Chanoine wicket dam. Further, it was contemplated that the existing 110- by 600-ft lock would be maintained and used as an auxiliary lock. The new dam will consist of nine tainter gates, four near the powerhouse and five just above the Pennsylvania Railroad bridge, and a fixed weir with crest at elevation 422.0 at the four downstream gates, incrementally raised to a crest elevation of 423.0 at the five upstream gates. Final plans for reconstruction of the dam were based on separate model tests.*

Existing 110- by 600-ft Lock

Description

4. The existing lock has separate side port filling and emptying systems, with the ports for the filling system confined to the upstream half of the chamber and the ports for the emptying system in the downstream half of the chamber.

5. The filling system (plate 1) includes intake manifolds located in each lock wall within the upstream miter gate recesses, and 12.7-ft-diameter culverts. Flow through the culverts is regulated by Stoney-type, vertical-lift valves. At the filling ports the inverts of the longitudinal culverts are at elevation 389.8, about 6.8 ft above the normal lower pool, elevation 383.0. Ten filling ports, spaced 28 ft on centers, slope down from the longitudinal culverts and discharge into the chamber with their inverts at elevation 373.0, 2 ft above the chamber floor. Three 12-in.-diameter vents in each filling culvert provide escape routes for the air in the culverts.

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* U. S. Army Engineer Waterways Experiment Station, CE, Navigation Conditions at McAlpine Locks and Dam, Ohio River; Hydraulic Model Investigation, by J. J. Franco and C. D. McKellar, Jr., Technical Report No. 2-749 (Vicksburg, Miss., November 1966).

6. The 12.7-ft-diameter emptying culverts (plate 2) and the 10 ports in each wall which feed these culverts have inverts at elevation 372.0. Flow is regulated by Stoney-type, vertical-lift valves and discharges through wall manifolds into the lower lock approach.

Present operation

7. Although in its present condition the lock can be filled in 16 to 18 min, in practice the filling valves are opened at a very slow rate with the result that filling time is 20 to 25 min. Faster filling creates excessive hawser stresses on tows moored in the lock chamber and dangerous turbulence in the upstream half of the lock chamber. Also, in the past, fast filling created excessive surges in the canal, but this has been alleviated by widening of the canal and installation of the surge basin.

Purpose of Model Study

8. The purpose of the model study was to determine whether structurally feasible modification of the filling and emptying systems would result in decreased turbulence and hawser stresses and thus permit faster filling of the lock.

PART II: THE MODEL

Description

9. The model (plate 3) of the existing McAlpine Lock, constructed to a scale of 1:25, reproduced 600 ft of upstream lock approach, the lock chamber, all elements of the filling and emptying systems, and 1200 ft of the downstream approach. In the initial construction, certain provisions were made for testing proposed modifications. These provisions included installation of connecting culverts between the longitudinal filling and emptying culverts. Gates were installed in these connecting culverts to permit testing with the filling and emptying systems separate or combined. The lock chamber and approach area were constructed of plywood and concrete (fig. 2). The intake manifolds, culverts, ports, and discharge manifolds were constructed of transparent plastic (fig. 3). The connecting culverts between the filling and emptying culverts were molded of fiber glass. The culvert valves were constructed of plastic and fitted with rubber seals to prevent leakage; the valves were raised or lowered automatically at predetermined rates.

Appurtenances and Instrumentation

10. Water was supplied to the model through a recirculating system in which discharge was measured by means of metering devices in the supply lines. The headbay and tailbay of the lock model each contained a skimming weir that maintained constant upper and lower pools during filling and emptying operations. Vertical adjustment of the skimming weirs permitted simulation of any desired pool elevation. Pitot tubes were used to determine the velocity of flow; dye and confetti were used to show subsurface and surface current directions. Pressures throughout the filling and emptying systems were measured with piezometers. Pressure cells were used to record the level of the water surface in the lock chamber.

11. By means of the linear motion of a gear-rack-driven cam plate,

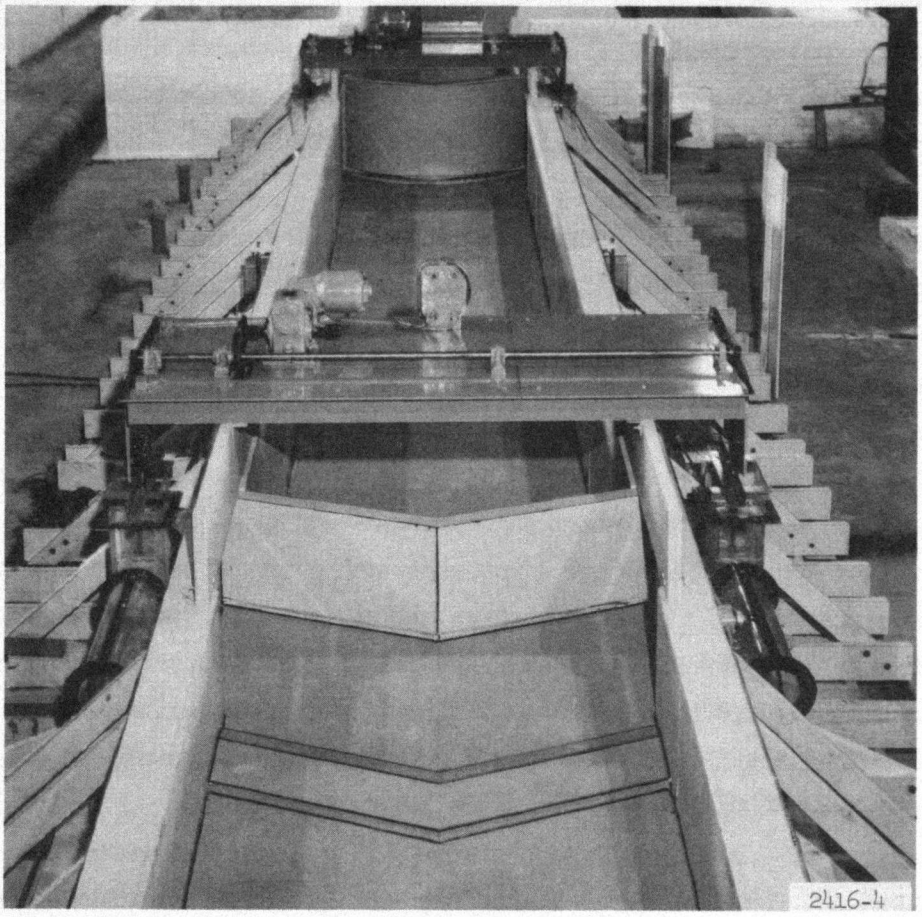


Fig. 2. The 1:25-scale lock model

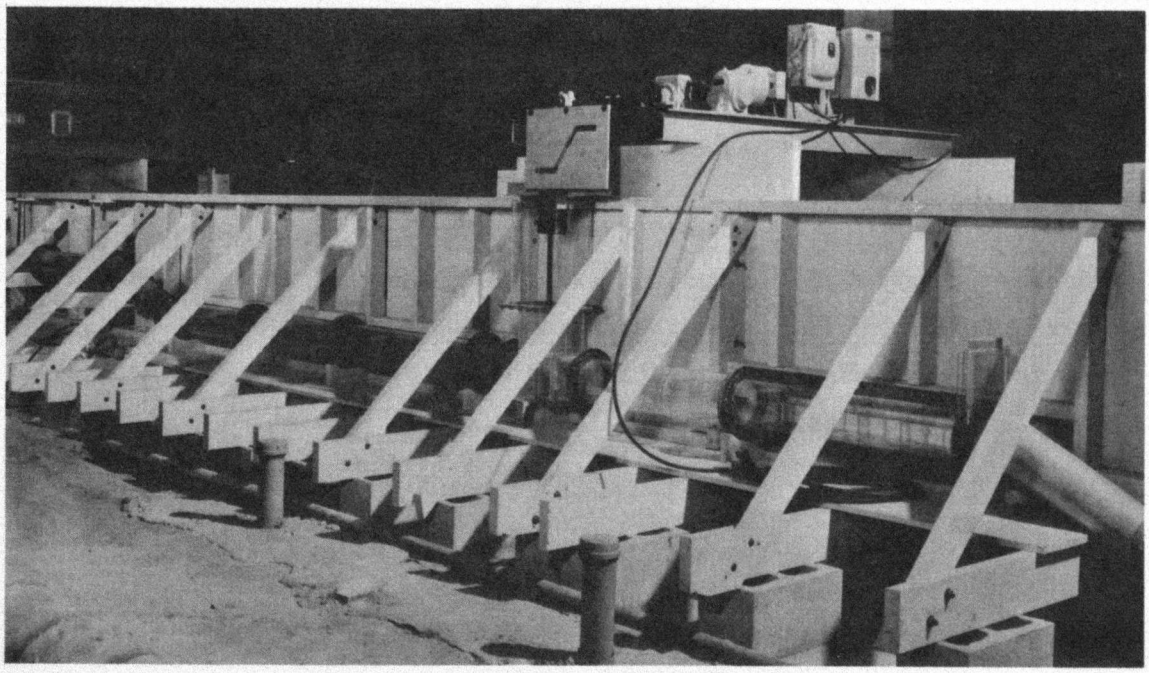


Fig. 3. Transparent plastic culverts

the culvert valve drive mechanism accurately controlled the rate at which the Stoney valves opened. The gear drive was powered by a reversible motor. Limit switches, mounted on the gear-rack guide, automatically shut off the valve drivers when either the fully open or fully closed position of the valve was reached.

12. A hawser pull (force link) device for determining the transverse and longitudinal forces acting on a barge tow in the lock chamber during filling and emptying operations is shown in photograph 4. Three such devices were used: one to measure longitudinal stresses, and the other two to measure transverse stresses on each end of the tow. These links were machined from aluminum, and had SR-4 strain gages cemented to the inner and outer edges. When the devices were mounted on the barge tow, one end of the link was pin-connected to the barge while the other end engaged a fixed vertical rod and was free to move up and down with changes in water-surface elevation in the lock. Any motion of the tow caused the links to deform and vary the signal to a recorder. The links were calibrated by inducing deflections of the links with known weights. The majority of the tests were conducted with a 6-barge tow at 9-ft draft (plate 4) with a total displacement of 12,000 tons.

13. All data were recorded graphically on a commercial six-channel, direct-writing recorder. The sensing elements (mechanical-to-electrical conversion devices), located at various points on the model, were connected by shielded cables to amplifiers which stepped up the outputs to levels required for graphical recording.

Scale Relations

14. 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, or vice versa, are presented in the following tabulation.

Dimension	Ratio	Scale Relations
Length	$L_r = L$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Time	$T_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Force	$F_r = L_r^3$	1:15,625

Test Procedure

15. Tests were conducted in the model to observe flow conditions in the upstream approach, to determine flow distribution in the intake and outlet manifolds, to obtain pressures throughout the system, to observe turbulence in the lock chambers, to measure hawser stresses on tows in the chamber, and to determine filling and emptying times. In the determination of flow distribution and pressure conditions, and in some studies of approach flow, fixed-head (steady-flow) conditions were used with the culvert valves fully or partially opened. For steady-flow tests, water-surface elevations and discharges were set from filling or emptying curves to correspond to selected flow conditions.

Prototype Performance Data

16. Certain aspects of prototype performance were observed by personnel concerned with the model tests. Other prototype performance data were taken from Prototype Lock Hydraulics Tests to Verify Model Experiments, Hydraulic Laboratory Report No. 46, St. Paul District, October 1941.

PART III: TESTS AND RESULTS

Existing Conditions

Turbulence

17. In the model a small vortex formed in each miter gate recess immediately over the upstream intake port (photograph 1). These vortexes were excellent reproductions in size, position, and duration of vortexes noted in the prototype; however, they were not considered to be of any consequence.

18. Flow in the filling culvert, which was above tailwater level, was extremely turbulent and considerable air was entrained in the model (photograph 2); but, no doubt, much more air was entrained in the prototype.

19. Water-surface turbulence in the model lock chamber during a filling operation is shown in photograph 3. This turbulence is considered excessive and certainly would make it unsafe for small craft to tie up in the upstream end of the lock chamber. In the prototype, the entrained air made the water white which tended to give the impression that prototype turbulence was more severe than that in the model.

Stages

20. In the model stages in the lock chamber with respect to time from the beginning of valve operation were recorded for valve times of 1, 2, and 4 min. Similar observations had been made in the prototype. Filling times for both model and prototype are tabulated below:

Filling Tests

Date	Valve Time min:sec	Upper Pool El	Lower Pool El	Lift ft	Filling Time min:sec
		Model			
1960-61	1:00	420.0	383.0	37.0	15:42
1960-61	2:00	420.0	383.0	37.0	16:12
1960-61	4:00	420.0	383.0	37.0	16:48

(Continued)

Filling Tests

Date	Valve Time min:sec	Upper Pool El	Lower Pool El	Lift ft	Filling Time min:sec
		Prototype			
Aug 1928	2:50	420.3	387.0	33.3	19:00
Oct 1928	2:10	419.9	384.0	35.9	17:10
Aug 1938	0:54	420.8	385.1	35.7	18:20
July 1953	2:29	420.1	383.8	36.3	21:50
Aug 1960	4:51	419.7	383.2	36.5	21:30

Filling curves derived from two tests in the model and two tests in the prototype and rate-of-rise curves are plotted in plate 5. Similar curves for emptying and rate of fall are plotted in plate 6.

21. In general, the model filled and emptied slightly faster than did the prototype; usually the opposite is true. The reasons for the large discrepancies between the filling times obtained in the model and those obtained in the prototype, and between the two prototype observations are unknown. Study of rate-of-rise curves indicates that the maximum difference in rate of rise between model and prototype occurs when the lock is about 80 percent full. Thus, it does not appear that air entrainment during the early stages of the filling cycle is a major cause of the differences in filling times. In some of the prototype tests, the filling time might have been influenced by surges in the canal. Also, obstructions of varying extent occur at the trash racks of the intake manifold and are removed periodically.

Hawser stresses

22. Typical plots of data recorded during a filling operation with a 2-min valve time are included in plate 7. Pertinent data for other valve times and for an emptying operation are listed in table 1. Although the high longitudinal hawser stresses were considered the most dangerous, concern also was expressed at the rather high transverse hawser stresses. Since with the lower pool at elevation 383.0 the bottom of a barge at 9-ft draft extends about 2 ft below the top of the chamber ports, it was felt that the impact of flow from the ports against the side of a barge could cause serious displacement of the barge. Basic model data revealed that the high transverse hawser stresses were of short duration with the

direction of the pull alternating. Thus, the data indicate that these stresses are a result of turbulence rather than of a sustained differential. To observe transverse movement of a tow, demonstration tests were made with two 244-ft-long by 34-ft-wide barges loaded to 9-ft draft in tandem in the lock chamber. Tests were started with the tow alongside the left wall (normal tie-up procedure in the prototype) and in the center of the lock chamber. For all tests the tow either remained against the left wall or at the beginning of the filling cycle moved from the center of the chamber to a wall and remained there throughout the filling cycle. Thus, it was concluded that the relatively high transverse hawser stresses measured with the model tow held in the center of the chamber would not create a problem in the prototype.

23. In developing a design and operating program for a new lock, hawser stresses in the model in excess of 5 tons usually are considered unacceptable. Thus, the high longitudinal hawser stresses together with the extreme turbulence make it obvious why experience has shown that the lock should not be filled in less than 20 to 25 min.

Pressures

24. Locations of piezometers installed in the model are shown in plate 8 and pressures for steady flows through the filling and emptying systems are listed in tables 2 and 3.

Individual Elements

Sidewall ports

25. It was evident that decreased hawser stresses during filling would require distribution of flow over the entire lock chamber rather than over only the upstream half. Therefore, the filling and emptying lock chamber manifolds were connected by sections of culvert, details of which are shown in plate 9. With the manifolds connected, tests were made with 29 combinations of the 20 ports in each culvert discharging (plates 10-13).

26. With 20 instead of 10 ports discharging, filling time for a 2-min valve time was decreased only from 16.2 to 14.7 min and emptying

time was decreased only from 14.6 to 13.9 min. However, flow was better distributed in the lock chamber, turbulence was decreased, and hawser stresses were reduced. Pertinent data from filling tests are listed in table 4 and from emptying tests in table 5.

27. All data considered, the types 16, 25, and 28 port arrangements resulted in the most favorable conditions. Hawser stresses during filling were measured for these port arrangements with 1- and 4-min valve times in addition to the 2-min valve time used in tests of all port arrangements. At all valve times the maximum upstream and downstream hawser stresses were about equal with the type 16 port arrangement, but not with the types 25 and 28 arrangements (plate 14). Also, turbulence in the upstream portion of the lock chamber was most favorable with the type 16 port arrangement.

28. For reasons stated above, it is recommended that modification of the lock include connecting the filling and emptying culverts and plugging of certain of the upstream ports in order to reproduce the type 16 port arrangement. Water-surface turbulence in the upstream end of the lock chamber during a filling operation is shown in photograph 4. Typical plots of data recorded during a filling operation with a 2-min valve time are included in plate 15. Maximum hawser stresses for various tows are plotted in plate 16. Pressures are listed in tables 2 and 3 and piezometer locations are shown in plate 8.

Intakes

29. Measurement of flow into the 6-port intake manifold revealed that instead of each port carrying about 16.7 percent of the total flow, only about 12.5 percent entered the upstream port while about 25 percent entered the downstream port. It was considered that enlargement of the total port area and streamlining of the flow passages probably would result in a reduction in filling time. Within space limitations imposed by the existing prototype structures, a 3-port intake manifold (plate 17) was designed, fabricated, and installed in the model. Distribution of flow into the intake was excellent (plate 18); however, with either intake a filling time of about 16 min was required in order to maintain hawser stresses at reasonable values (plate 19).

Valves

30. Major alterations of the prototype valves were not considered feasible. No model tests were concerned with valve modifications.

Vents

31. Three 12-in.-diameter vents are installed in the roof of each filling culvert to discharge air during a filling operation. In the model, four additional 36-in.-diameter vents were installed for this purpose. The locations of existing and proposed vents and test data are shown in plate 20. Tests were made with various combinations of the vents open. The additional vents had a negligible effect on turbulence, filling time, and longitudinal hawser stresses. With all vents closed, filling time was increased from 15.0 to 18.3 min.

Outlets

32. Distribution of flow from the six ports of the discharge manifold is shown in plate 21. Attempts to improve this distribution were not considered warranted.

33. An emptying test was made with the left culvert discharging through the existing manifold and flow from the right culvert diverted outside of the lower approach. Undesirable eddy conditions were set up in the lower approach and no further attempts were made to improve conditions in the lower approach.

PART IV: DISCUSSION AND RECOMMENDATIONS

34. The model tests demonstrated that a major improvement in performance of the existing 110- by 600-ft McAlpine Lock would result from connecting the filling and emptying culverts and plugging ports 1, 2, 3, 5, 7, and 9 in each filling culvert (type 16 port arrangement, plate 11). This will permit the lock to be filled in about 16 min with maximum longitudinal hawser stresses of about 8 tons. Under existing conditions, maximum longitudinal hawser stresses of 28 tons result from a 16-min filling time. Usually operation requirements are set so that hawser stresses will not exceed 5 tons, but based on experience, it is suggested that the Louisville District consider waiving this requirement in the present case. Of course, if difficulties develop, a slower valve time would result in a longer filling time but reduced hawser stresses.

35. Transverse hawser stresses should not be a problem, as tests demonstrated that a free tow would be held against the lock wall.

36. Improvement of the intake manifold would permit faster filling times than are possible with the existing system. However, a filling time of 16 min still would be required to maintain maximum hawser stresses at 8 tons. Advantages can be gained by use of the type 2 intake (plate 17) only if maximum hawser stresses greater than 8 tons are permitted.

37. An increase in the number or size of vents for discharging air from the filling culvert had a negligible effect on performance.

38. It is not feasible to empty the right culvert outside of the lower approach as flow from only the left culvert will cause an undesirable eddy in the lower approach.

Table 1

Filling and Emptying Characteristics, Existing System

37-ft Lift (Upper Pool El 420.0, Lower Pool El 383.0)

Valve Time min	Filling or Emptying Time min	Maximum Hawser Stresses											
		Longitudinal				Upstream Transverse				Downstream Transverse			
		Upstream		Downstream		Left		Right		Left		Right	
		Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min
						Filling							
1	15.7	5.1	2.1	43.0	1.2	5.3	2.2	7.2	1.0	3.2	2.2	3.1	0.7
2	16.2	0.0	--	28.2	1.3	5.9	2.4	6.3	1.0	2.7	2.1	4.0	3.7
4	16.8	0.0	--	15.6	1.2	5.9	2.4	6.3	2.2	3.1	2.0	3.8	1.9
						Emptying							
2	14.6	1.6	2.8	4.1	0.6	2.5	13.8	2.4	13.6	1.5	13.1	1.6	13.2

Note: Time listed under hawser stresses is time of occurrence after beginning of movement of culvert valves. 6-barge tow at 9-ft draft positioned 85 ft from upstream miter gate pintles.

Table 2

Pressures Under Steady-Flow Conditions Through Filling System

Types 1 and 16 Port Arrangements

Upper Pool El 420.0, Discharge 4500 cfs

Piezometer No.	Piezometer Zero ft msl	Station	Type 1 Port Arrangement: Piezometer Reading ft msl	Type 1 Port Arrangement: Pressure ft of Water	Type 16 Port Arrangement: Piezometer Reading ft msl	Type 16 Port Arrangement: Pressure ft of Water
Lock chamber water surface			390.05		398.0	
			Group "A" Intake Manifold			
1	400.0	3+80.29A	417.4	17.4	417.3	17.3
2	400.0	3+72.29A	416.6	16.6	416.4	16.4
3	400.0	3+63.71A	416.7	16.7	416.7	16.7
4	400.0	3+46.45A	415.6	15.6	415.6	15.6
5	400.0	3+37.87A	414.8	14.8	414.8	14.8
6	400.0	3+29.29A	409.7	9.7	409.4	9.4
7	403.1	3+76.29A	418.2	15.1	418.1	15.0
8	403.1	3+67.71A	418.1	15.0	418.0	14.9
9	403.1	3+59.13A	417.3	14.2	417.3	14.2
10	403.1	3+41.87A	415.3	12.2	415.1	12.0
11	403.1	3+33.29A	413.4	10.3	413.4	10.3
12T	409.5	3+13.00A	409.1	-0.4	409.0	-0.5
12B	396.8	3+13.00A	408.9	12.1	408.7	11.9
			Group "B" Filling Valve			
1B	396.8	3+08.00A	408.9	12.1	408.9	12.1
2B	396.8	3+06.00A	408.9	12.1	408.9	12.1
3B	396.8	3+04.00A	408.9	12.1	408.9	12.1
4B	396.8	3+02.00A	408.7	11.9	408.7	11.9
5B	396.8	3+00.00A	408.5	11.7	408.5	11.7
6B	396.8	2+98.00A	408.2	11.4	408.2	11.4
7B	396.8	2+96.00A	408.0	11.2	408.0	11.2
8B	396.8	2+94.00A	407.2	10.4	407.2	10.4
9B	396.8	2+92.00A	406.7	9.9	406.7	9.9
			Group "C" Filling Culvert			
1	389.8	2+37.00A	395.7	5.9	398.4	8.6
2	389.8	2+09.00A	395.8	6.0	398.2	8.4
3	389.8	1+81.00A	395.4	5.6	398.2	8.4
4	389.8	1+53.00A	395.2	5.4	398.3	8.5
5	389.8	1+25.00A	394.0	4.2	397.9	8.1

(Continued)

Table 2 (Concluded)

Piezometer			Type 1 Port Arrangement		Type 16 Port Arrangement	
No.	Zero ft msl	Station	Piezometer Reading ft msl	Pressure ft of Water	Piezometer Reading ft msl	Pressure ft of Water
			Group "C" Filling Culvert (Continued)			
6	389.8	0+97.00A	397.0	7.2	398.4	8.6
7	389.8	0+69.00A	400.8	11.0	398.0	8.2
8	389.8	0+41.00A	401.6	11.8	398.2	8.4
			Group "D" Emptying Culvert			
1	372.0	0+60.50B			398.0	26.0
2	372.0	0+83.50B			398.0	26.0
3	372.0	1+06.50B			399.5	27.5
4	372.0	1+29.50B			401.0	29.0
5	372.0	1+52.50B			401.8	29.8
6	372.0	1+75.50B			402.2	30.2
7	372.0	1+98.50B			402.5	30.5
8	372.0	2+21.50B			402.8	30.8
9	372.0	2+44.50B			403.0	31.0
10T	384.7	3+03.00B			403.0	18.3
10B	372.0	3+03.00B			403.0	31.0

Table 3

Pressures Under Steady-Flow Conditions Through Emptying System

Types 1 and 16 Port Arrangements

Lower Pool El 383.0, Discharge 6500 cfs

Piezometer No.	Piezometer Zero ft msl	Piezometer Station	Type 1 Port Arrangement: Piezometer Reading ft msl	Type 1 Port Arrangement: Pressure ft of Water	Type 16 Port Arrangement: Piezometer Reading ft msl	Type 16 Port Arrangement: Pressure ft of Water
Lock chamber water surface			418.7		415.0	
			Group "C" Filling Culvert			
1	389.8	2+37.00A			413.9	24.1
2	389.8	2+09.00A			413.9	24.1
3	389.8	1+81.00A			413.9	24.1
4	389.8	1+53.00A			413.9	24.1
5	389.8	1+25.00A			413.9	24.1
6	389.8	0+97.00A			413.9	24.1
7	389.8	0+69.00A			413.8	24.0
8	389.8	0+41.00A			413.8	24.0
			Group "D" Emptying Culvert			
1	372.0	0+60.50B	414.1	42.1	413.4	41.4
2	372.0	0+83.50B	414.9	42.9	413.3	41.3
3	372.0	1+06.50B	414.6	42.6	412.8	40.8
4	372.0	1+29.50B	414.6	42.6	412.1	40.1
5	372.0	1+52.50B	413.4	41.4	411.2	39.2
6	372.0	1+75.50B	412.7	40.7	410.3	38.3
7	372.0	1+98.50B	410.6	38.6	408.4	36.4
8	372.0	2+21.50B	408.6	36.6	405.9	33.9
9	372.0	2+44.50B	405.7	33.7	402.7	30.7
10T	384.7	3+03.00B	396.0	11.3	396.3	11.6
10B	372.0	3+03.00B	399.3	27.3	398.3	26.3
			Group "E" Emptying Valve			
1T	384.7	3+08.72B	398.8	14.1	396.9	12.2
2T	384.7	3+10.72B	398.9	14.2	397.3	12.6
3T	384.7	3+12.72B	398.3	13.6	397.1	12.4
4T	384.7	3+14.72B	398.4	13.7	397.2	12.5
5T	384.7	3+16.72B				
6T	384.7	3+18.72B	398.4	13.7	397.3	12.6
7T	384.7	3+20.72B	398.4	13.7	397.3	12.6
8T	384.7	3+22.72B	397.8	13.1	396.7	12.0

(Continued)

Table 3 (Concluded)

Piezometer No.	Piezometer Zero ft msl	Station	Type 1 Port Arrangement Piezometer Reading ft msl	Type 1 Port Arrangement Pressure ft of Water	Type 16 Port Arrangement Piezometer Reading ft msl	Type 16 Port Arrangement Pressure ft of Water
		Group "E" Emptying Valve (Continued)				
9T	384.7	3+24.72B	397.6	12.9	396.3	11.6
10T	384.7	3+26.72B				
11T	384.7	3+28.72B	396.5	11.8	394.7	10.0
12T	384.7	3+30.72B				
13T	384.7	3+32.72B	396.2	11.5	395.1	10.4
14T	384.7	3+34.72B				
15T	384.7	3+36.72B	396.5	11.8	395.1	10.4
1B	372.0	3+08.72B	398.9	26.9	398.7	26.7
2B	372.0	3+10.72B	398.9	26.9	397.5	25.5
3B	372.0	3+12.72B	399.0	27.0	397.5	25.5
4B	372.0	3+14.72B	398.9	26.9	397.3	25.3
5B	372.0	3+16.72B	399.3	27.3	398.0	26.0
6B	372.0	3+18.72B	398.5	26.5	396.7	24.7
7B	372.0	3+20.72B	398.5	26.5	396.7	24.7
8B	372.0	3+22.72B	398.0	26.0	396.5	24.5
		Group "F" Discharge Manifold				
1	378.4	3+71.00B	395.5	17.1	394.3	15.9
2	378.4	3+96.00B	396.7	18.3	395.7	17.3
3	378.4	4+08.50B	399.3	20.9	398.4	20.0
4	378.4	4+21.00B	400.7	22.3	400.5	22.1
5	378.4	4+33.50B	401.5	23.1	401.7	23.3
6	378.4	4+46.00B	399.0	20.6	402.4	24.0
7	372.0	3+89.63B	386.5	14.5	386.4	14.4
8	372.0	4+02.13	382.3	10.3	381.6	9.6
9	372.0	4+14.63B	380.8	8.8	380.5	8.5
10	372.0	4+27.13B	380.8	8.8	380.7	8.7
11	372.0	4+39.63B	380.3	8.3	379.5	7.5
12	372.0	4+52.13B	382.5	10.5	381.0	9.0

Table 4

Filling Characteristics, Types 1-30 Port Arrangements

2-min Valve Time

37-ft Lift (Upper Pool El 420.0, Lower Pool El 383.0)

Port Arrangement Type	Filling Time min	Maximum Hawser Stresses											
		Longitudinal				Upstream Transverse				Downstream Transverse			
		Upstream		Downstream		Left		Right		Left		Right	
		Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min
1 (Existing)	16.2	0.0	--	28.2	1.3	5.9	2.4	6.3	1.0	2.7	2.1	4.0	3.7
2	14.7	5.5	5.1	29.0	1.4	8.8	1.3	5.9	1.7	5.7	1.3	4.4	1.2
3	14.7	3.9	5.3	29.3	1.1	8.0	1.8	10.0	1.4	4.6	1.4	2.9	1.2
4	14.7	5.0	5.4	27.2	1.2	7.9	1.2	13.4	2.0	3.1	1.8	5.5	1.6
5	14.7	7.0	3.1	19.2	1.1	7.1	1.5	11.9	2.0	3.8	1.5	6.0	1.7
6	14.9	14.7	2.5	14.7	1.0	12.0	1.4	8.9	1.6	4.9	2.0	5.0	1.1
7	15.1	21.7	2.3	17.2	1.0	6.5	1.9	6.6	1.4	4.8	1.3	2.6	1.4
8	15.2	25.6	2.1	16.1	2.8	11.0	1.0	7.9	3.3	4.7	1.5	3.2	1.1
9	15.3	23.0	2.0	15.2	3.0	13.8	2.1	12.4	3.5	5.0	1.6	4.0	4.4
10	15.2	24.2	2.0	7.8	2.7	12.5	1.0	13.6	3.4	2.7	0.7	7.9	2.1
11	15.4	13.3	2.2	15.5	1.1	9.0	0.7	9.5	1.6	5.5	2.3	4.5	0.9
12	15.2	13.3	2.0	10.5	0.7	6.8	2.9	11.0	1.5	4.1	1.7	3.8	1.8
13	15.2	9.0	1.8	13.3	1.0	17.0	1.3	11.8	1.1	7.4	1.3	6.8	1.1
14	15.2	15.5	1.9	11.3	1.1	9.3	1.5	12.0	1.2	4.9	3.9	5.9	4.0
15	15.0	13.3	2.0	11.1	1.0	7.4	1.3	9.3	1.2	4.0	1.6	3.5	0.7
16	15.0	11.7	1.8	12.5	1.0	8.8	3.1	11.6	1.8	4.1	1.5	4.7	1.3
17	15.0	10.5	2.4	22.4	1.1	10.3	1.5	12.6	1.4	3.4	1.1	4.8	1.2
18	15.0	7.2	5.4	17.5	1.0	9.3	1.5	9.8	2.4	7.6	2.1	5.6	1.6
19	15.1	8.4	2.4	17.5	1.0	4.7	3.4	14.7	1.1	3.0	1.0	3.9	1.1
20	15.0	9.1	2.0	14.4	1.0	9.0	1.0	7.6	3.2	4.0	1.8	3.0	5.8
21	15.1	21.1	1.8	10.5	1.2	8.8	1.7	13.8	2.0	5.3	1.1	6.1	1.6
22	14.9	10.5	2.9	17.2	1.1	10.4	0.8	9.1	2.2	4.9	1.1	5.5	2.2
23	14.8	5.0	3.8	14.4	1.1	9.8	1.6	11.8	1.1	4.3	1.6	3.0	1.4
24	14.8	6.4	1.7	16.2	1.2	8.0	1.1	11.1	1.0	4.0	2.0	4.5	0.8
25	15.0	10.9	1.7	10.9	0.9	8.2	2.4	12.7	1.1	4.2	1.2	4.9	1.1
26	14.9	12.0	2.4	11.6	0.5	10.1	1.3	12.4	1.8	6.0	1.9	4.1	1.5
27	15.0	3.1	2.1	18.0	1.3	8.8	1.1	12.6	1.6	3.1	1.1	4.1	1.5
28	15.0	6.1	5.3	12.0	0.8	9.3	1.0	9.8	1.8	4.3	1.3	4.2	1.6
29	14.9	5.5	5.1	25.0	1.1	10.5	1.8	7.1	2.2	4.7	2.1	3.1	1.2
30	15.0	4.4	5.2	20.3	1.0	7.1	3.6	7.7	3.5	4.2	1.1	3.5	1.6

Note: Time listed under hawser stresses is time of occurrence after beginning of movement of culvert valves. 6-barge tow at 9-ft draft positioned 85 ft from upstream miter gate pintles.

Table 5

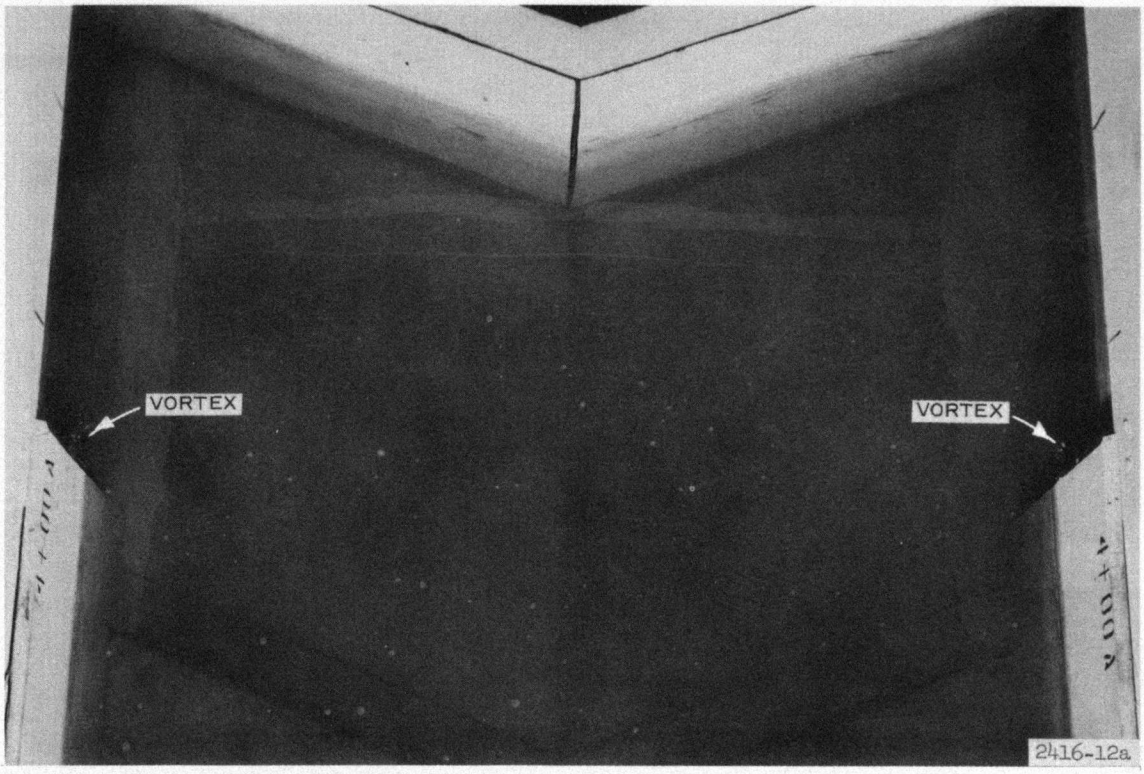
Emptying Characteristics, Types 1-30 Port Arrangements

2-min Valve Time

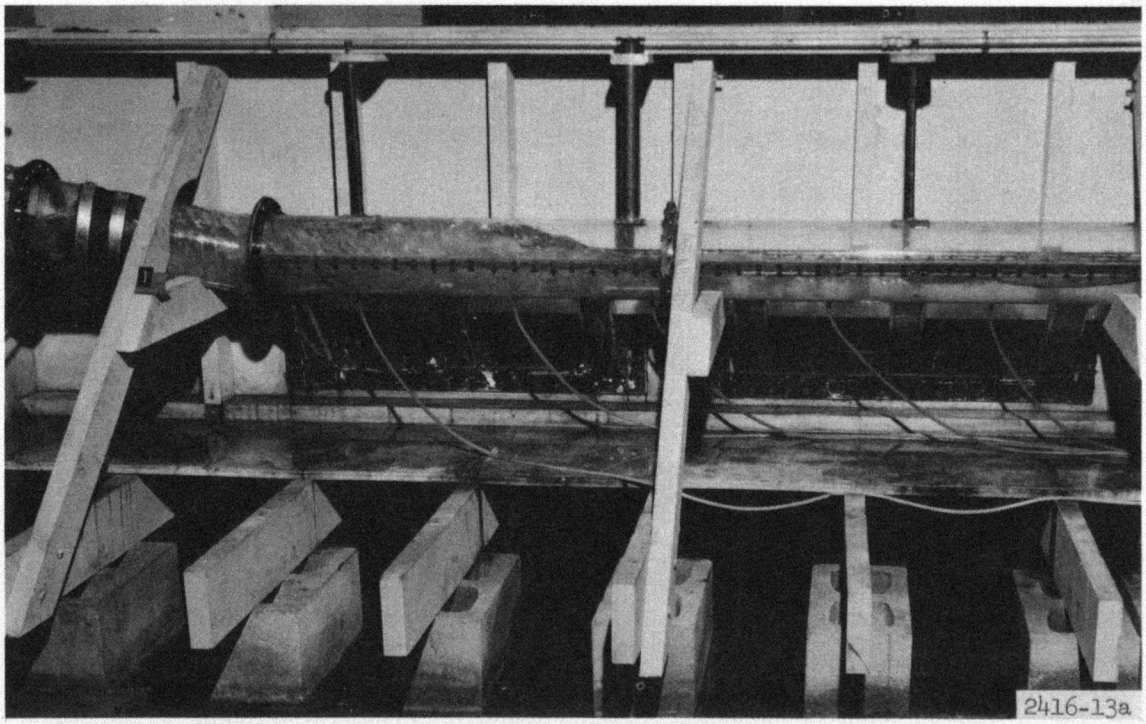
37-ft Lift (Upper Pool El 420.0, Lower Pool El 383.0)

Port Arrangement Type	Emptying Time min	Maximum Hawser Stresses											
		Longitudinal				Upstream Transverse				Downstream Transverse			
		Upstream		Downstream		Left		Right		Left		Right	
		Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min	Pull tons	Time min
1 (Existing)	14.6	1.6	2.8	4.1	0.6	2.5	13.8	2.4	13.6	1.5	13.1	1.6	13.2
2	13.9	2.2	5.3	3.8	0.6	0.8	12.0	0.9	12.6	0.7	5.0	0.5	5.2
3	13.9	1.3	2.0	3.8	0.4	1.2	11.9	0.8	9.3	0.4	11.6	0.6	11.5
4	13.9	1.5	1.3	3.8	0.4	1.2	6.2	0.8	5.4	0.7	7.4	0.8	6.0
5	13.9	0.9	2.0	4.1	0.4	1.2	7.4	0.8	7.3	0.7	12.2	0.6	7.3
6	13.9	0.9	3.6	4.1	0.4	1.2	10.0	1.2	10.1	0.6	8.0	0.5	6.8
7	13.9	1.0	2.0	4.0	0.4	1.0	7.9	0.7	9.7	0.7	9.4	0.6	8.2
8	13.9	0.7	2.0	4.1	0.3	0.9	10.4	1.0	4.7	0.5	10.4	0.6	5.0
9	13.9	1.0	2.8	5.0	0.4	0.7	5.7	0.9	7.3	0.5	6.4	0.6	5.5
10	14.1	1.3	2.0	4.7	0.4	1.1	7.6	0.7	7.2	0.6	5.1	0.6	7.7
11	13.9	1.5	0.6	4.1	0.3	1.0	8.4	0.8	8.6	0.6	9.6	0.6	8.8
12	14.7	0.9	2.0	3.0	0.4	1.0	10.2	1.2	8.8	0.6	8.9	0.8	9.5
13	14.8	0.9	2.7	3.2	0.3	1.1	10.6	1.4	10.2	0.9	10.3	1.0	10.2
14	14.8	0.9	2.7	3.8	0.4	1.2	5.1	1.0	11.2	0.4	11.0	0.6	3.0
15	14.3	0.7	2.0	4.0	0.4	1.0	11.7	1.0	11.4	0.6	11.2	0.6	6.8
16	13.9	1.4	3.3	4.1	0.3	1.0	6.2	1.1	8.4	0.6	5.2	0.6	7.6
17	14.0	1.5	3.4	4.0	0.4	1.4	7.2	0.9	7.5	0.5	10.1	0.5	11.7
18	14.0	1.1	1.2	4.4	0.4	1.1	6.9	0.9	6.8	0.5	5.4	0.6	6.1
19	14.0	1.0	1.3	3.8	0.4	1.2	9.8	0.9	6.8	0.6	7.6	0.6	3.3
20	14.0	0.9	2.0	4.0	0.3	0.9	9.2	1.1	3.0	6.0	2.8	0.7	2.9
21	14.0	1.0	2.8	3.8	0.4	0.9	4.5	0.5	1.5	0.4	6.9	0.6	5.4
22	13.9	1.3	1.2	4.0	0.3	1.1	6.9	0.7	6.8	0.6	9.4	0.5	2.3
23	13.9	1.4	2.0	4.1	0.4	1.6	7.0	1.2	4.4	0.6	2.6	0.6	5.8
24	14.1	1.5	1.3	4.1	0.4	1.2	7.5	0.9	7.4	0.6	5.2	0.6	7.4
25	14.1	1.3	1.3	4.1	1.0	1.2	7.5	1.2	7.6	0.5	7.6	0.5	7.5
26	14.2	1.6	2.0	3.9	0.4	1.0	8.6	0.8	8.8	0.4	7.3	0.5	7.2
27	14.1	0.8	2.0	4.0	0.4	1.4	7.7	1.4	8.5	0.6	5.2	7.8	2.0
28	14.1	1.6	3.4	3.9	0.3	0.9	6.3	1.0	6.2	0.6	4.8	0.4	3.4
29	14.1	1.7	1.3	4.1	0.4	1.4	5.5	1.0	5.1	0.7	5.1	0.8	5.1
30	13.9	1.3	1.3	4.5	0.3	1.0	5.4	1.0	5.3	0.7	5.5	0.8	5.4

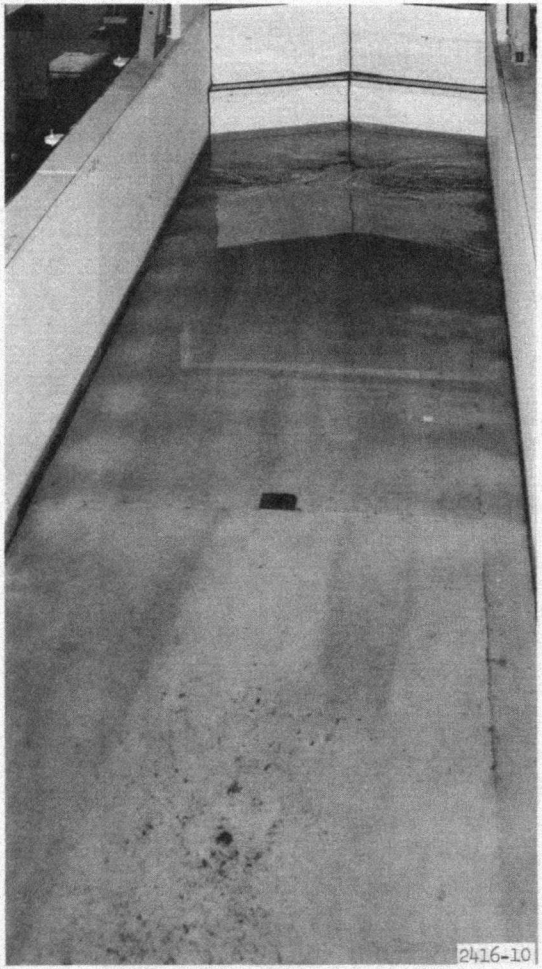
Note: Time listed under hawser stresses is time of occurrence after beginning of movement of culvert valves. 6-barge tow at 9-ft draft positioned 85 ft from upstream miter gate pintles.



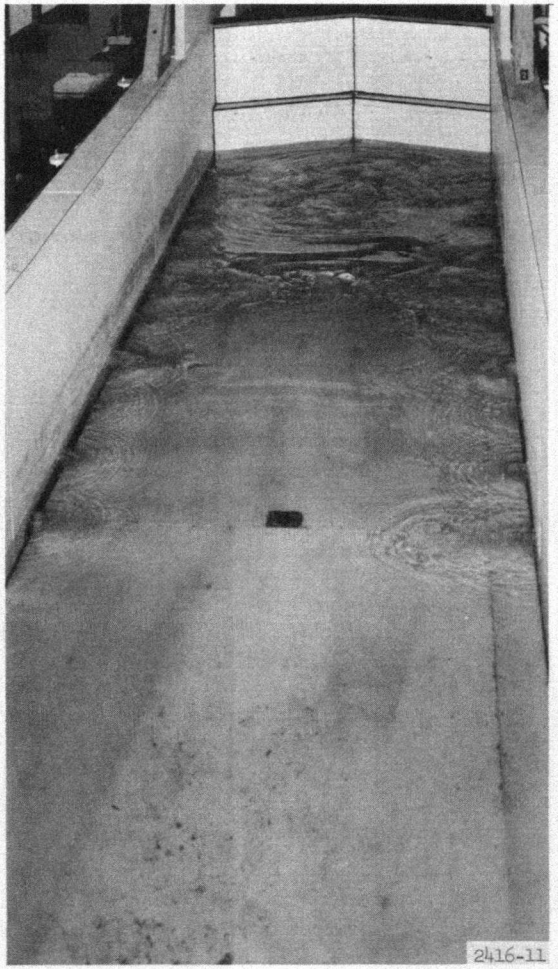
Photograph 1. Vortexes over upstream intake ports in miter gate recesses



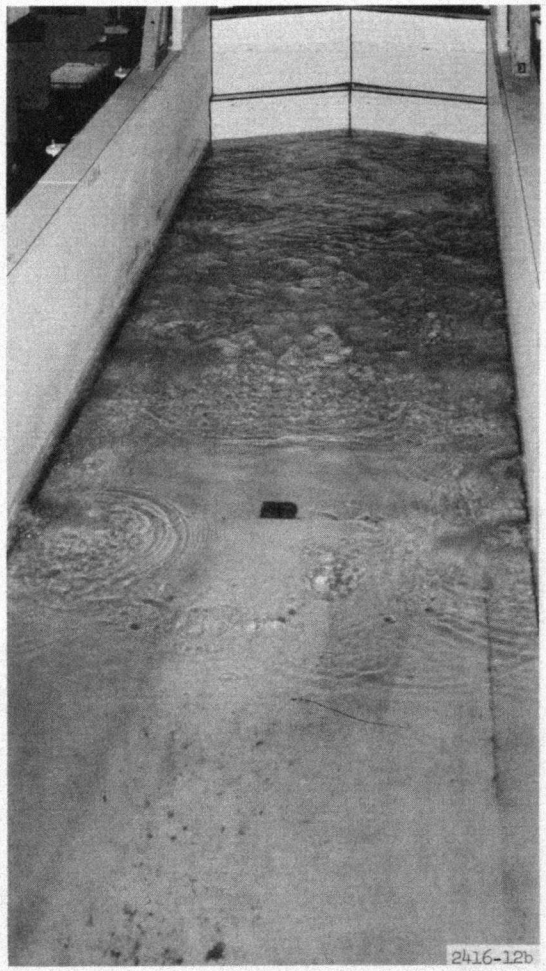
Photograph 2. Air and turbulence in filling culvert



0.33 min after filling started

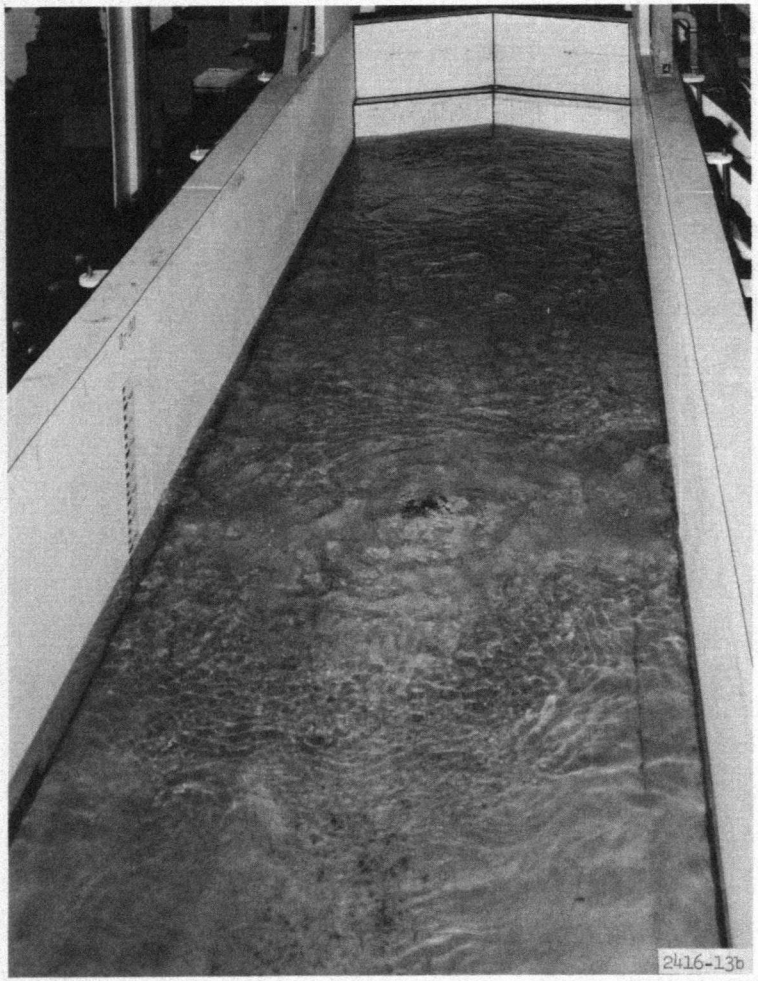


0.66 min after filling started

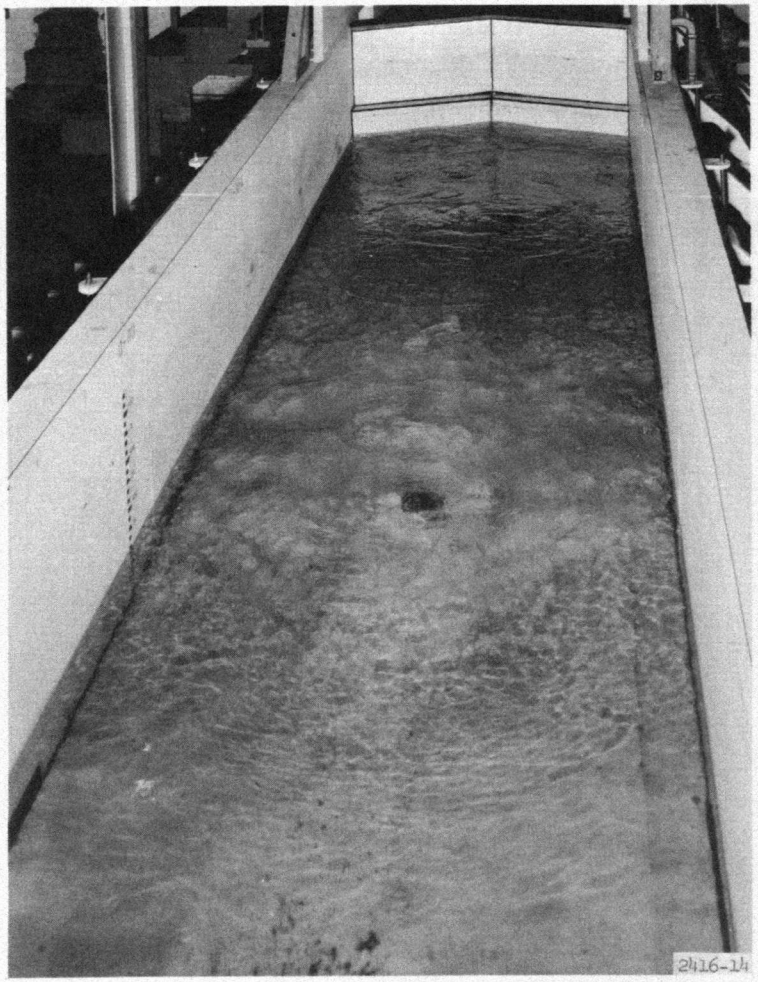


1.00 min after filling started

Photograph 3. Surface turbulence in upstream end of lock chamber during filling operations; existing conditions. Upper pool el 420.0; lower pool el 383.0; valve time 1 min (sheet 1 of 2)

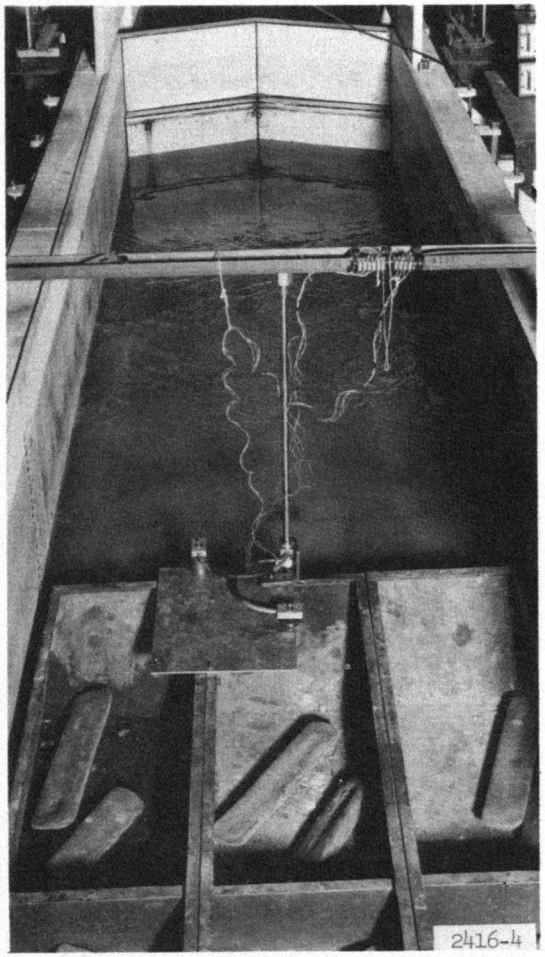


2.00 min after filling started

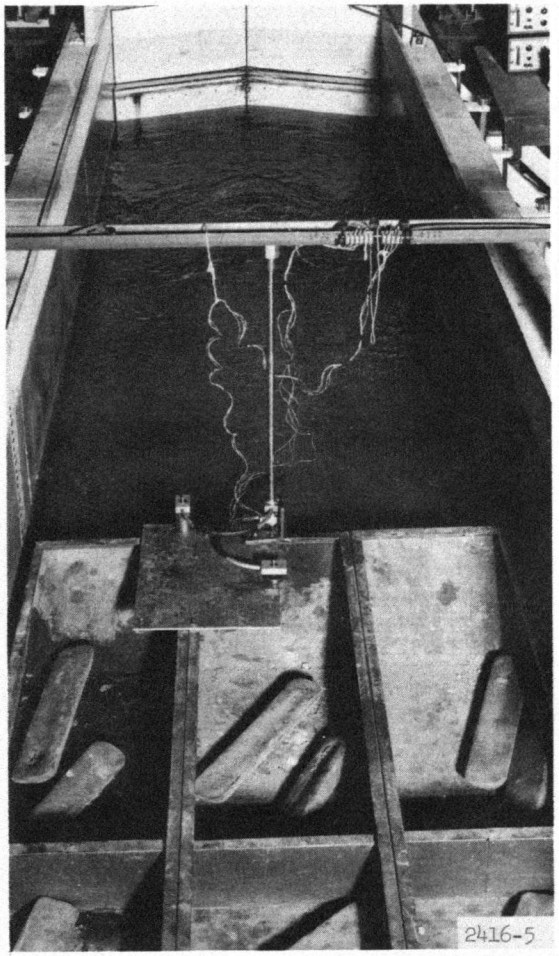


3.00 min after filling started

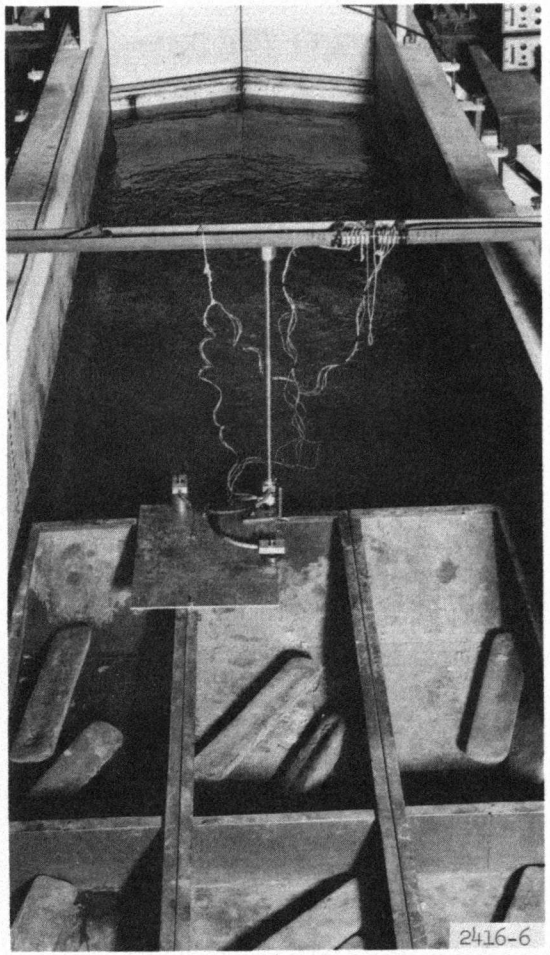
Photograph 3. (Sheet 2 of 2)



1 min after filling started

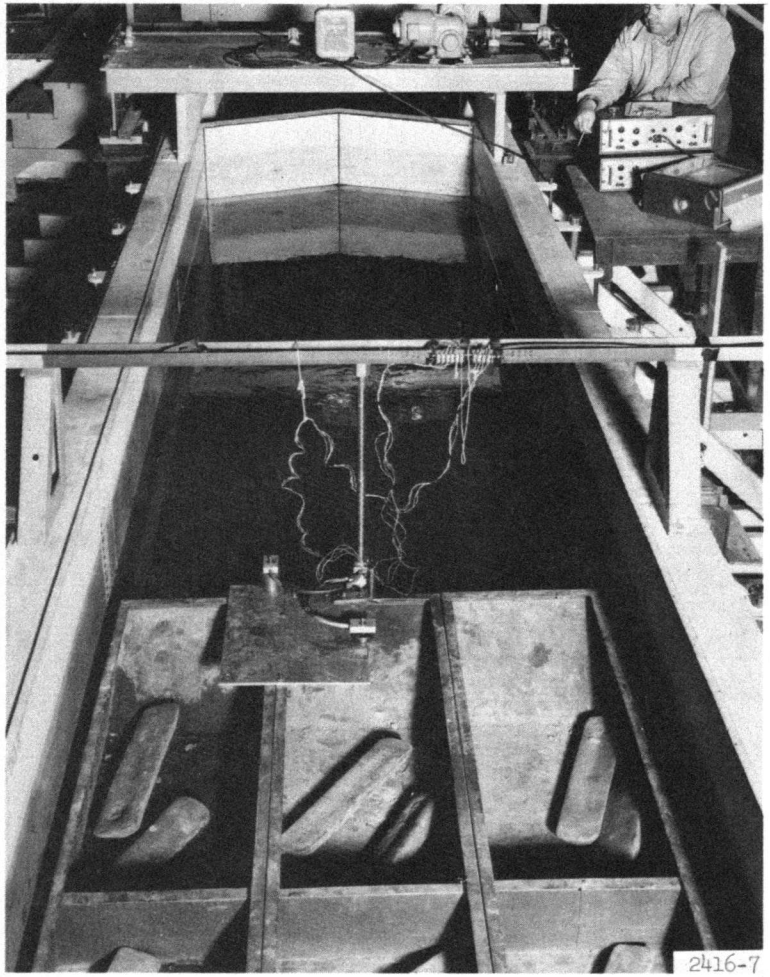


2 min after filling started

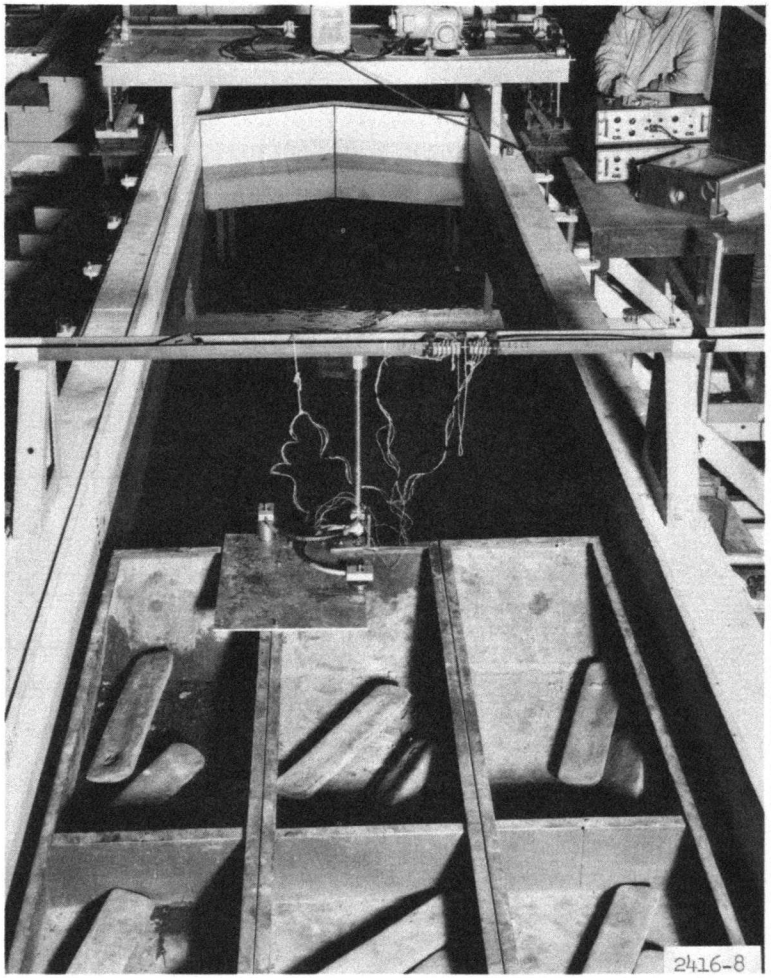


5 min after filling started

Photograph 4. Surface turbulence in upstream end of lock chamber during filling operations, type 16 port arrangement. Upper pool el 420.0; lower pool el 383.0; valve time 4 min. (Loaded barges in foreground) (sheet 1 of 2)

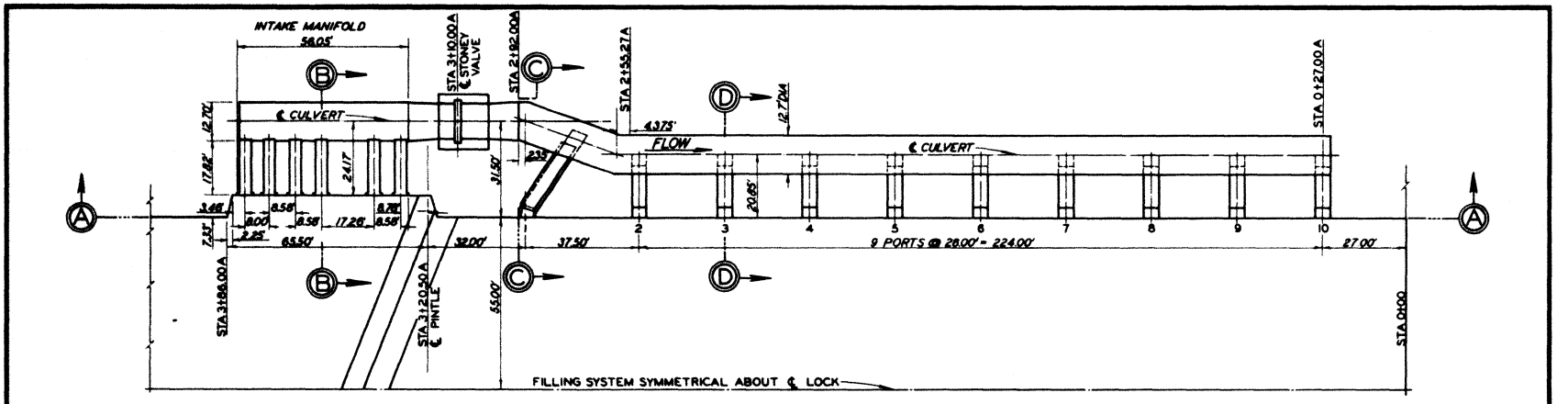


8.00 min after filling started



12.00 min after filling started

Photograph 4. (Sheet 2 of 2)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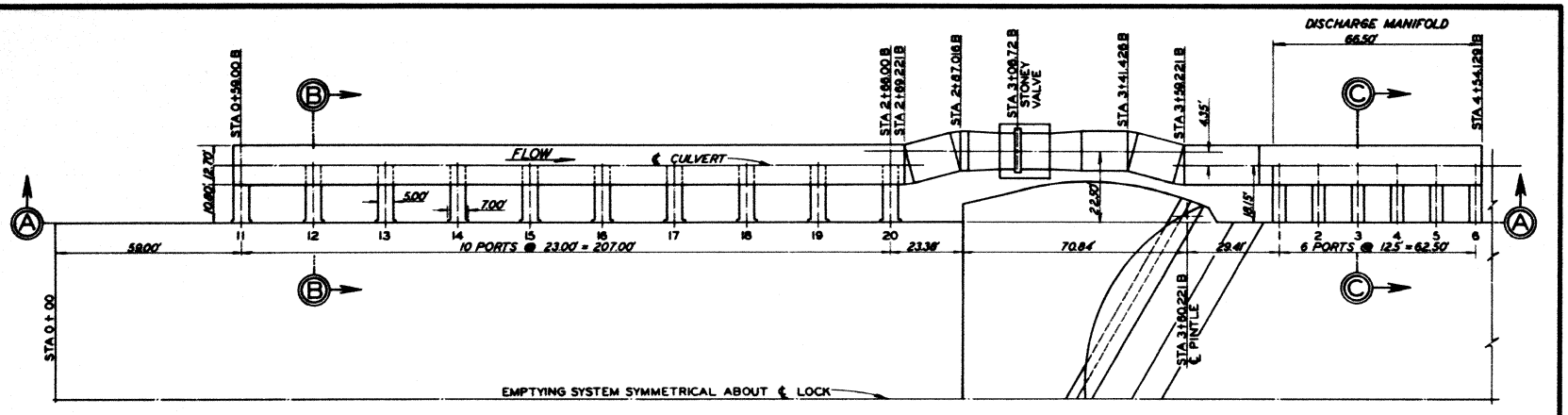
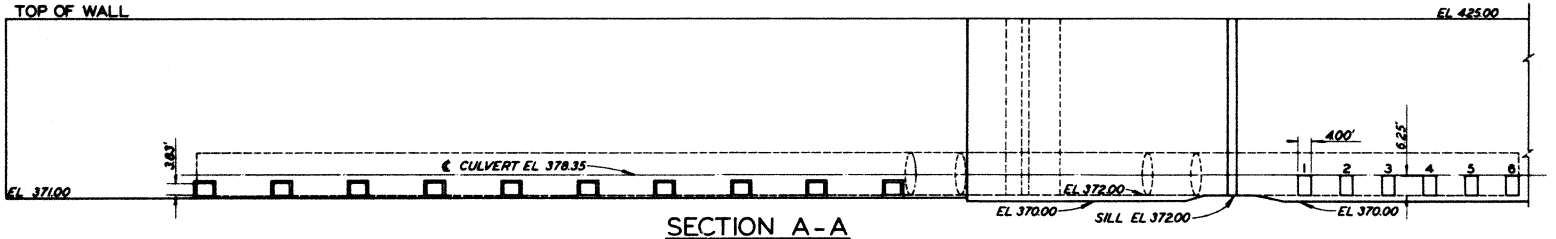
58.05'
STA 3+10.00 A
℄ STONEY VALVE
STA 2+92.00A
STA 2+55.27A
STA 0+27.00A
℄ CULVERT
FLOW
4.375'
12.704'
12.70'
17.88'
24.17'
31.50'
23.5'
20.85'
3.48'
8.00'
8.58'
8.58'
17.26'
8.58'
2.25'
65.50'
32.00'
37.50'
9 PORTS @ 28.00' = 224.00'
27.00'
STA 3+88.00A
STA 3+20.50A
℄ PINTLE
55.00'
STA 0+00
FILLING SYSTEM SYMMETRICAL ABOUT ℄ LOCK
HALF PLAN
TOP OF WALL
EL 425.00
℄ CULVERT EL 403.125
SILL EL 401.00
℄ CULVERT EL 396.125
4.00'
EL 399.00
6.25'
EL 371.00
5.00'
3.83'
EL 373.00
SECTION A-A
DIA 12.7'
24.17'
6.25'
EL 403.125
SECTION B-B
DIA 12.7'
20.85'
EL 396.125
3.125'
3.5'
1.95'
23.125'
44°-08'
3.25'
SECTION D-D
12.75'
30.00'
11°-30'
25°-30'
32.88'
10.65'
20.85'
EL 403.125
EL 396.125
7.0'
SECTION C-C AND PROJECTION
NOTE ALL DIMENSIONS ARE IN PROTOTYPE UNITS
INTAKE MANIFOLD AND CULVERT FILLING SECTION
TYPE I (EXISTING) DESIGN
SCALE
25 0 25 50 75 100 FT
PLATE I

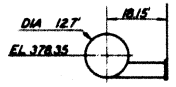
PLATE 2



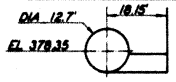
HALF PLAN



SECTION A-A



SECTION B-B



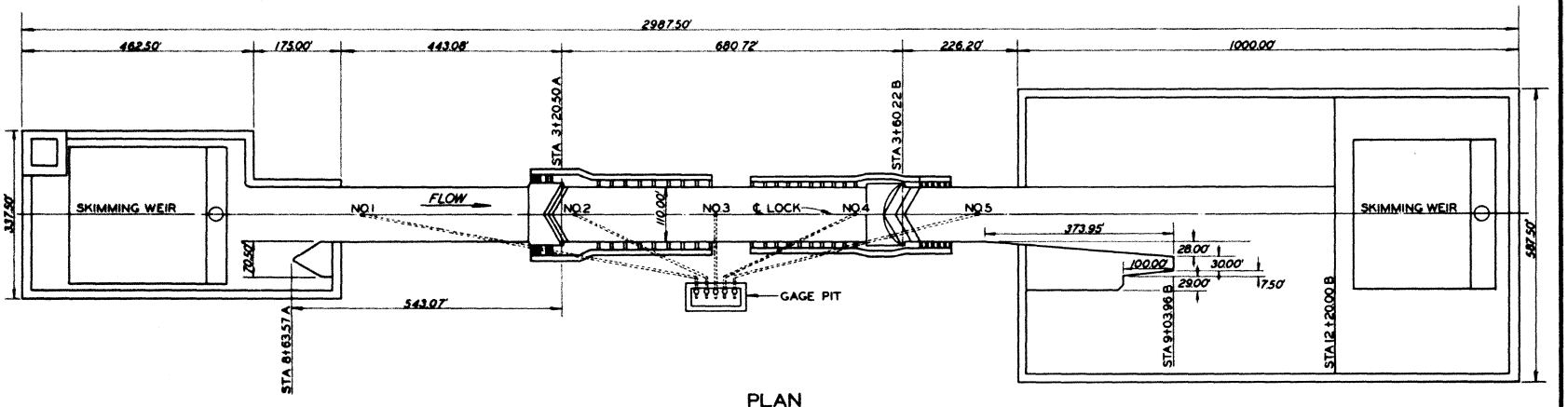
SECTION C-C

NOTE. ALL DIMENSIONS ARE IN PROTOTYPE UNITS.

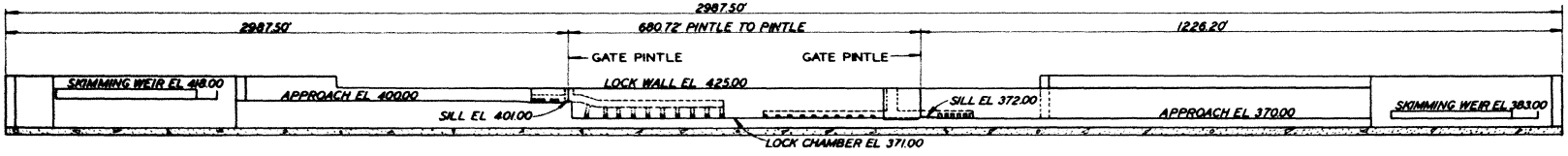
CULVERT EMPTYING SECTION AND DISCHARGE MANIFOLD

TYPE I (EXISTING) DESIGN

SCALE



PLAN



ELEVATION AT FACE OF LOCK WALL

GAGE IDENTIFICATION	
GAGE NO	UNIT MEASURED
1	WATER SURFACE UPSTREAM POOL SIDE
2-4	WATER SURFACE SLOPE LOCK CHAMBER
3	WATER SURFACE LOCK CHAMBER (FILLING OR EMPTYING CURVE)
5	WATER SURFACE DOWNSTREAM POOL SIDE

NOTE: ALL DIMENSIONS ARE IN PROTOTYPE UNITS

MODEL LAYOUT

SCALES

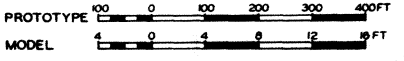
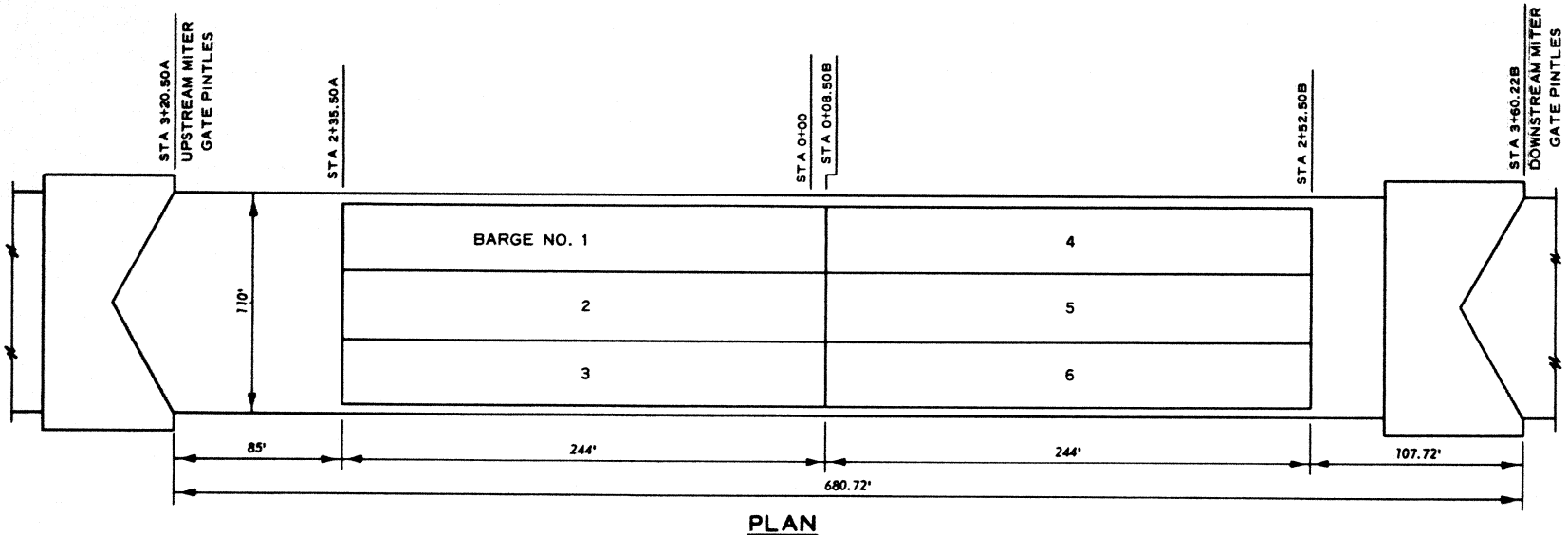
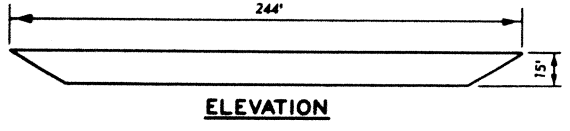


PLATE 3

PLATE 4

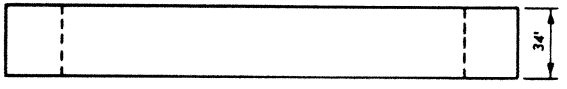


PLAN



ELEVATION

END VIEW

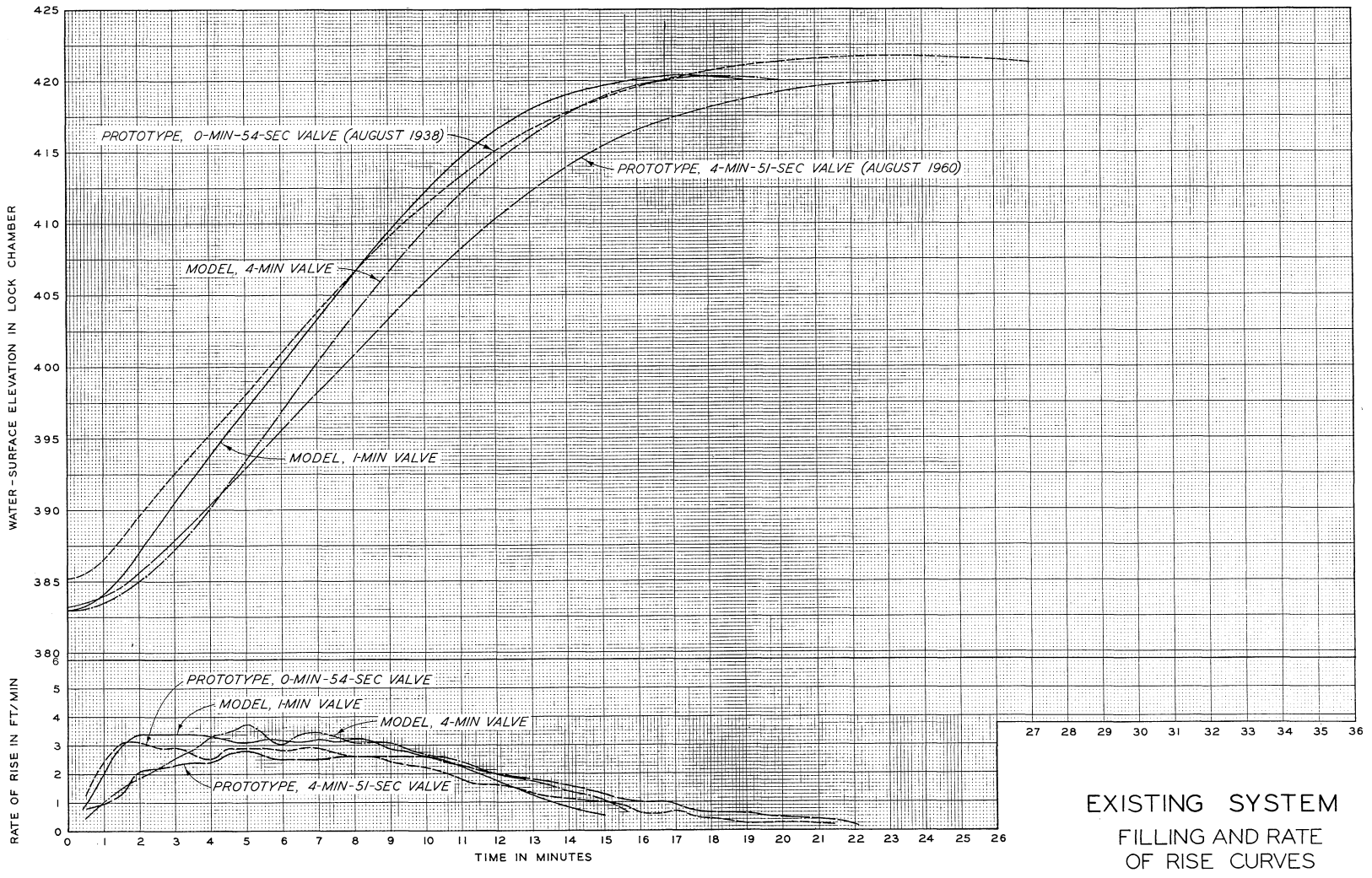


PLAN

BARGE DETAILS

NUMBER BARGES IN TOW	DISPLACEMENT – TONS 9-FT DRAFT
1	2,000
3	6,000
6	12,000

BARGE DETAILS AND TOW ARRANGEMENTS

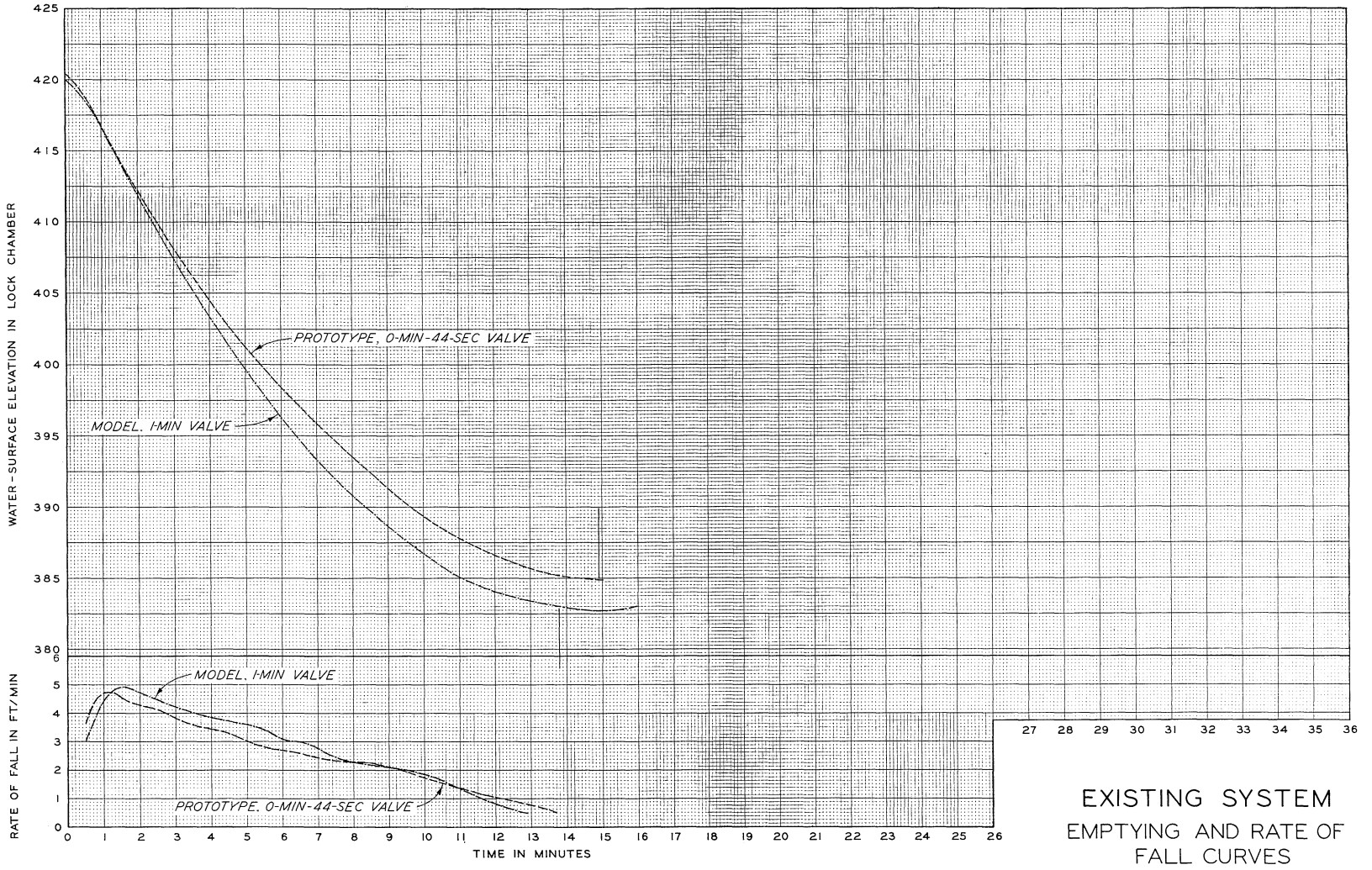


EXISTING SYSTEM

FILLING AND RATE OF RISE CURVES PROTOTYPE AND MODEL

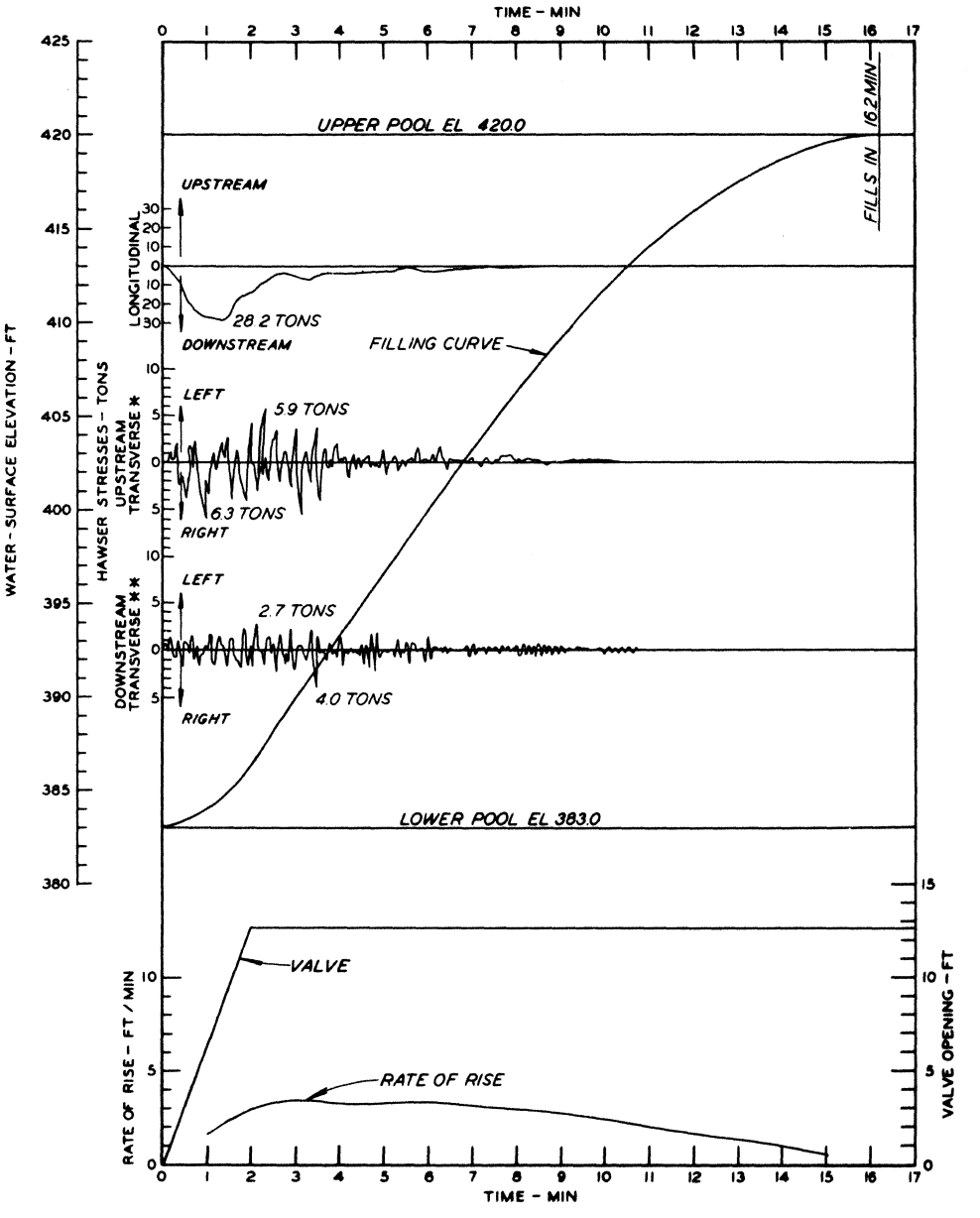
PLATE 5

PLATE 6



EXISTING SYSTEM

EMPTYING AND RATE OF FALL CURVES PROTOTYPE AND MODEL



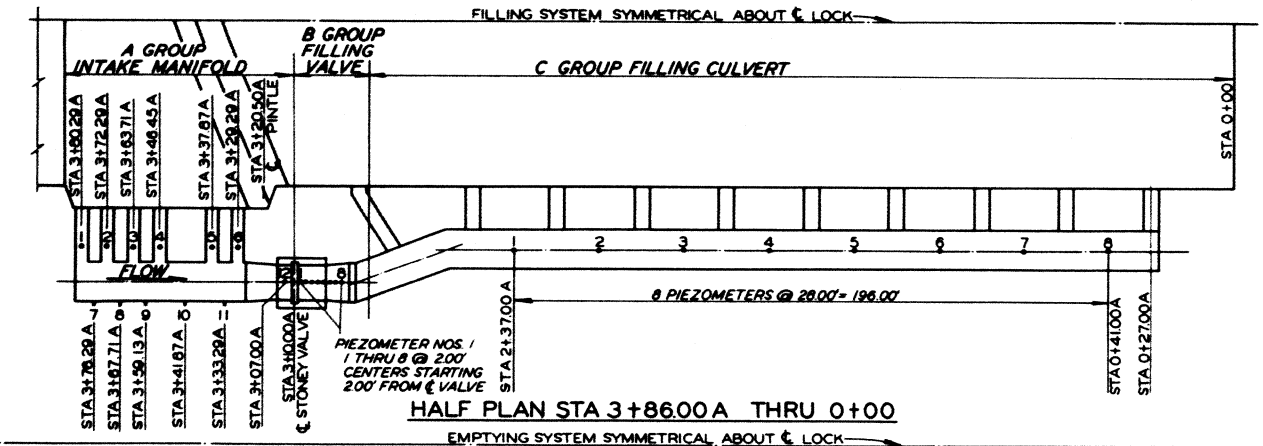
NOTE. 2-MIN VALVE SCHEDULE
6-BARGE TOW AT 9-FT DRAFT
POSITIONED 85 FT FROM UPSTREAM-END
MITER GATE PINTLE.

* MEASURED ON UPSTREAM END OF TOW
** MEASURED ON DOWNSTREAM END OF TOW

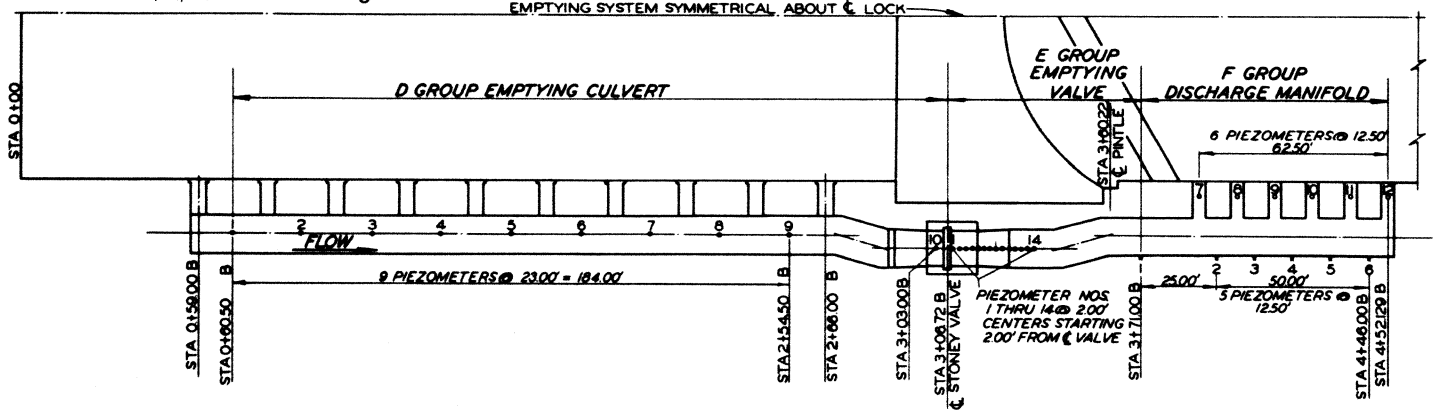
FILLING CHARACTERISTICS
EXISTING SYSTEM

PLATE 7

PLATE 8



HALF PLAN STA 3+86.00 A THRU 0+00



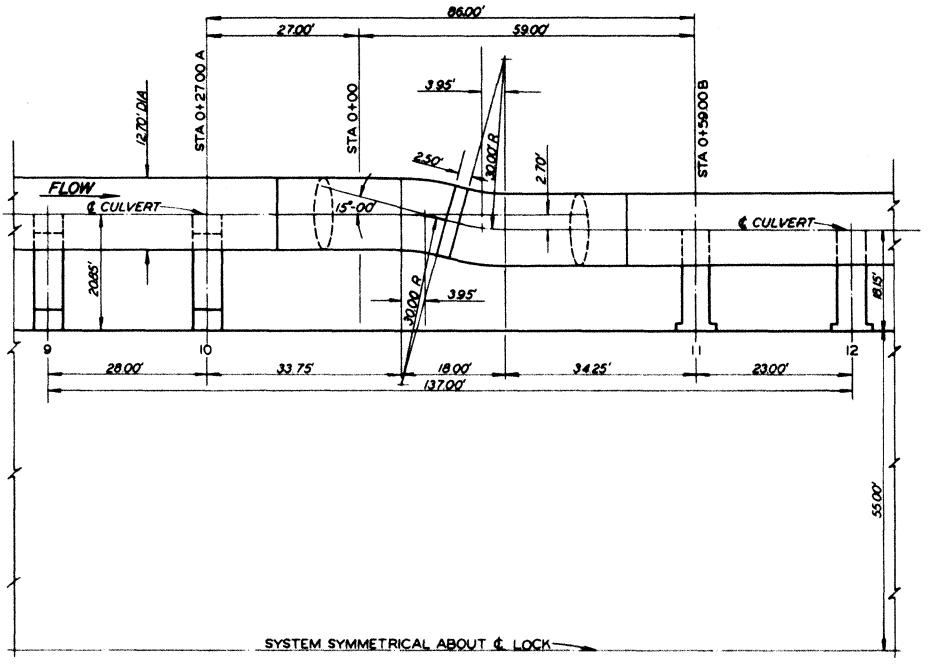
HALF PLAN STA 0+00 THRU 4+54.129 B

PIEZOMETER LOCATIONS

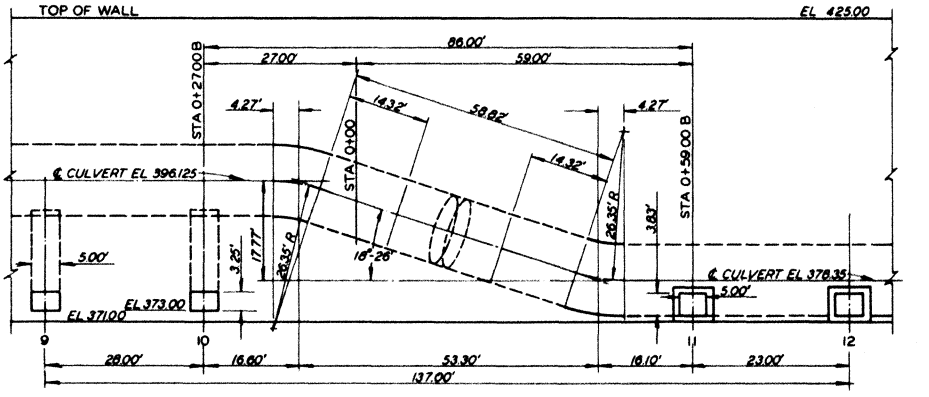
RIGHT HALF OF FILLING AND EMPTYING SYSTEMS

TYPE I (EXISTING) DESIGN

SCALE



PLAN



ELEVATION AT FACE OF LOCK WALL

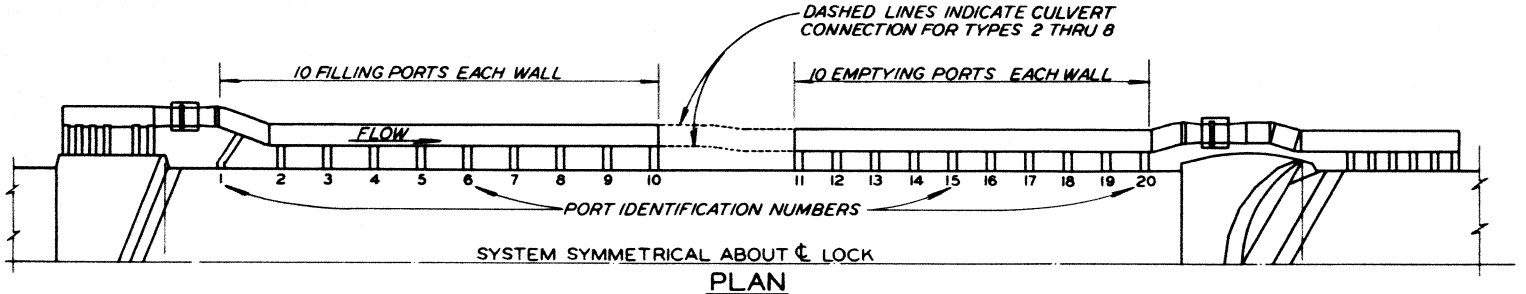
NOTE ALL DIMENSIONS ARE IN PROTOTYPE UNITS

CONNECTION OF UPPER AND LOWER CULVERTS

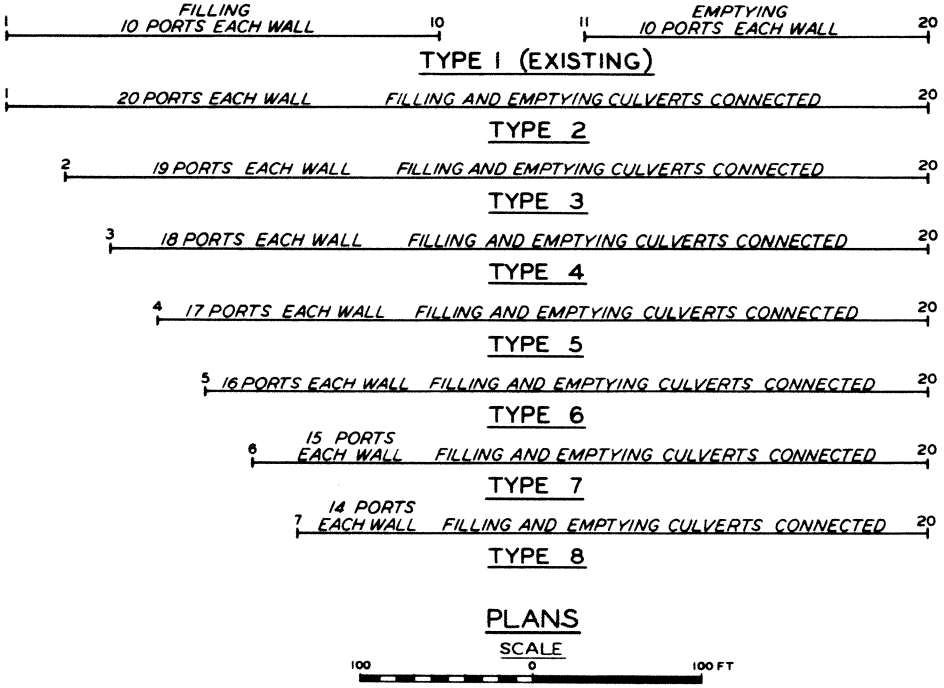
SCALE

25 0 25 50 FT

PLATE 10

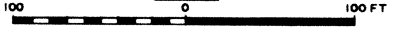


PLAN



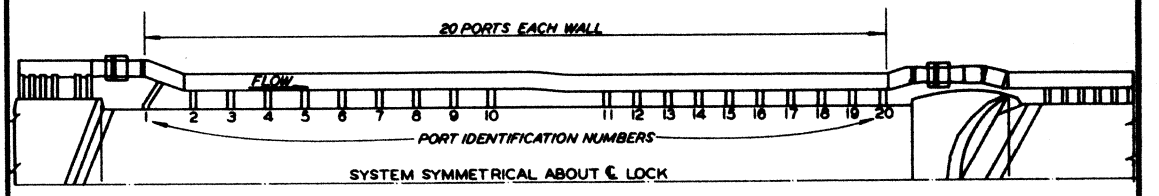
PLANS

SCALE

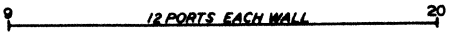


PORT ARRANGEMENTS

TYPES 1-8

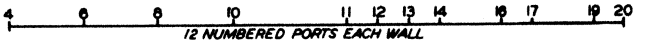


TYPE 9



TYPE 10

TYPE 11



TYPE 12

TYPE 13

TYPE 14

TYPE 15

TYPE 16

PLAN

PORT ARRANGEMENTS

TYPES 9 - 16

SCALE

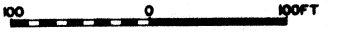
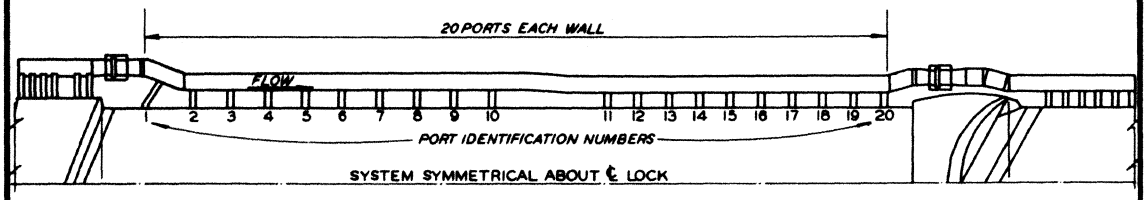
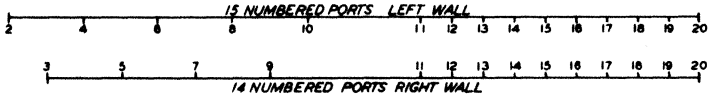


PLATE 11

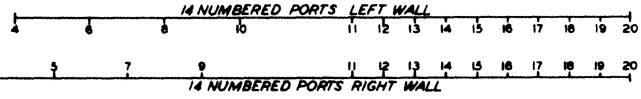


TYPE 17

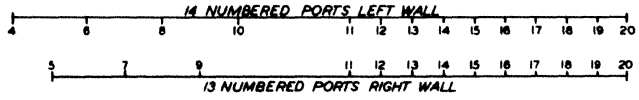
TYPE 18



TYPE 19



TYPE 20



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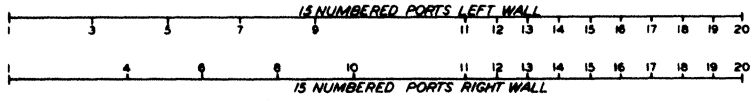


TYPE 22

TYPE 23

PORT ARRANGEMENTS

TYPES 17-23

SCALE

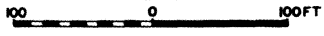
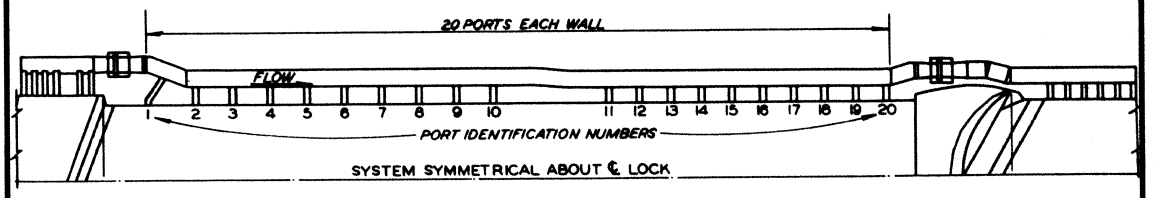


PLATE 12



TYPE 24

TYPE 25

TYPE 26

TYPE 27

TYPE 28

TYPE 29

TYPE 30

PLAN

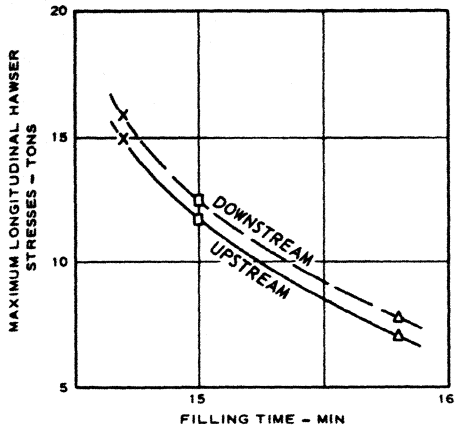
PORT ARRANGEMENTS

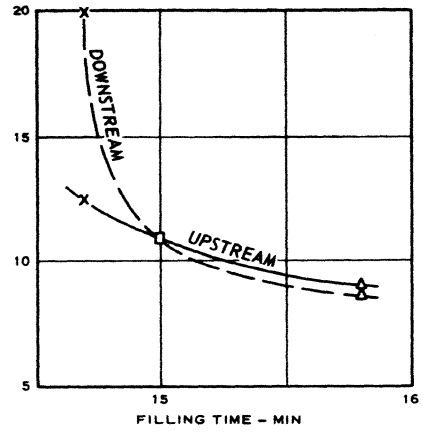
TYPES 24-30

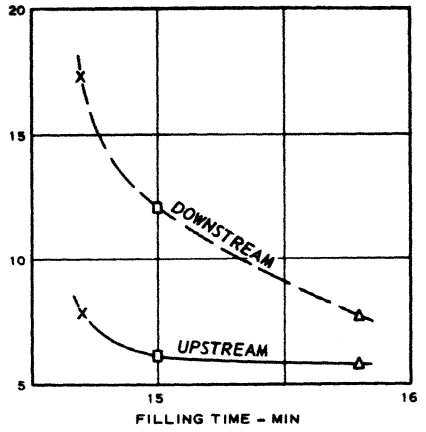
SCALE

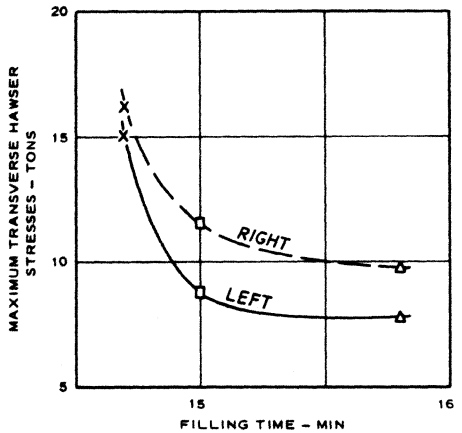
PLATE 13

PLATE 14

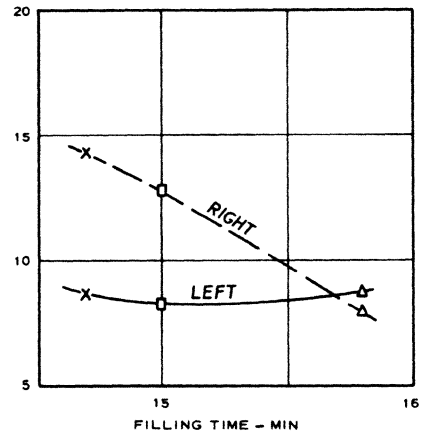




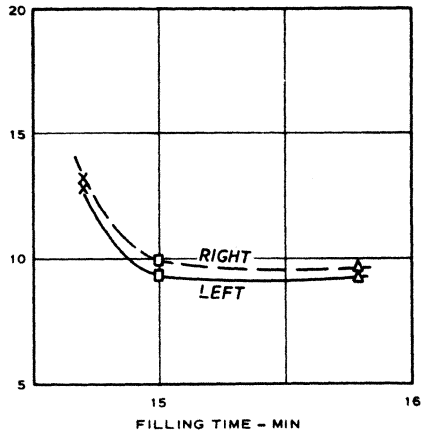




TYPE 16



TYPE 25



TYPE 28

PORT ARRANGEMENTS

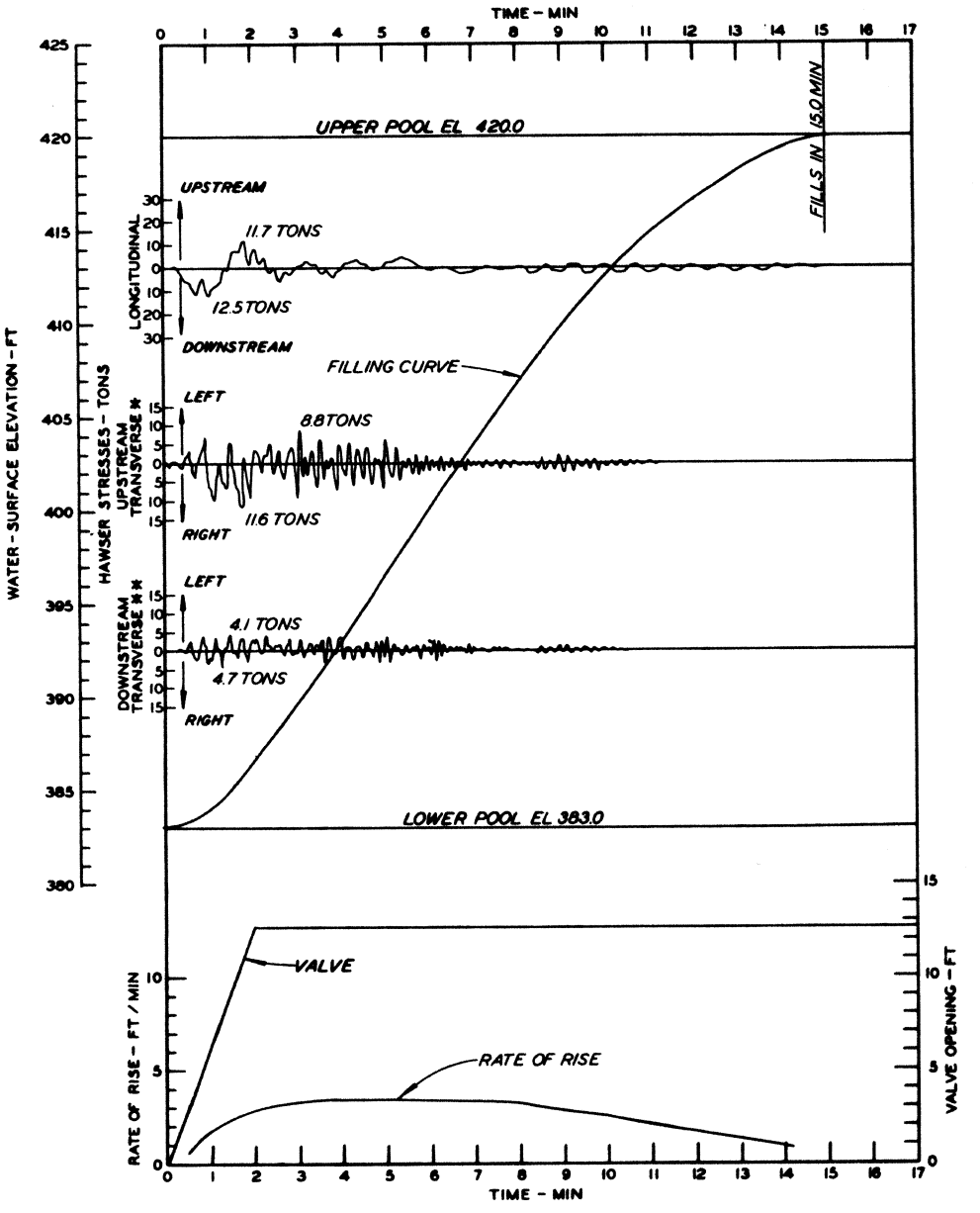
NOTE: 37-FT HEAD (UPPER POOL ELEVATION 420.0 AND LOWER POOL ELEVATION 383.0).
6-BARGE TOW AT 9-FT DRAFT POSITIONED 85 FT FROM UPSTREAM MITER GATE PINTLES.

LEGEND

SYMBOL	VALVE SCHEDULE – MIN
X	1
□	2
△	4

FILLING CHARACTERISTICS

PORT ARRANGEMENTS
TYPES 16, 25, AND 28

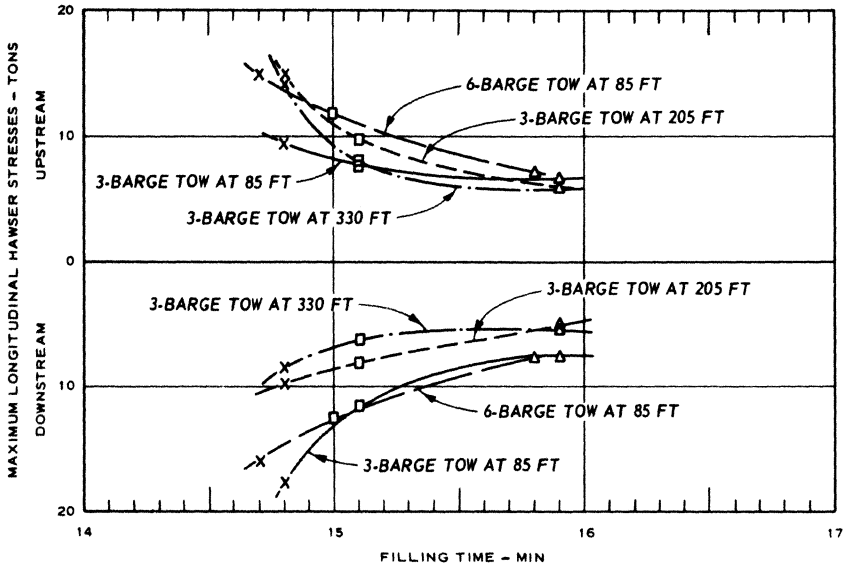


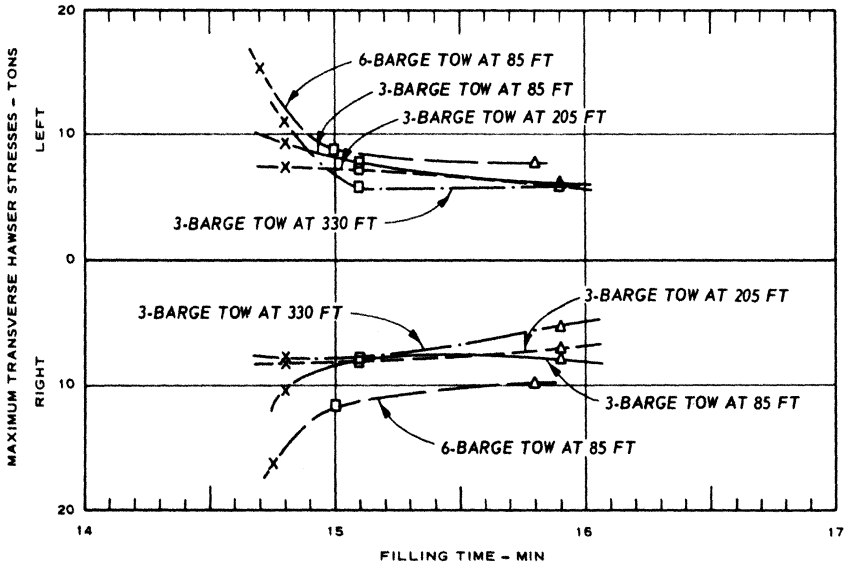
NOTE. 2-MIN VALVE SCHEDULE
6-BARGE TOW AT 9-FT DRAFT
POSITIONED 85 FT FROM UPSTREAM-END MITER GATE PINTLE.

* MEASURED ON UPSTREAM END OF TOW.
** MEASURED ON DOWNSTREAM END OF TOW.

FILLING CHARACTERISTICS
TYPE 16 PORT ARRANGEMENT

PLATE 15





LEGEND

SYMBOL	VALVE SCHEDULE - MIN
X	1
□	2
Δ	4

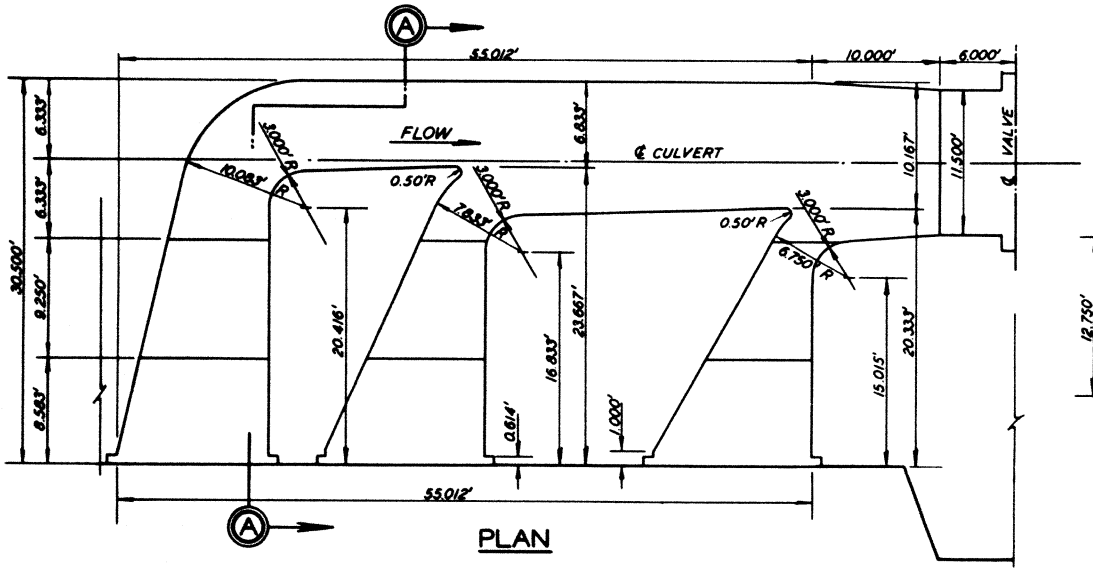
NOTE: 37-FT HEAD (UPPER POOL ELEVATION 420.0 AND LOWER POOL ELEVATION 383.0).

3- AND 6-BARGE TOWS AT 9-FT DRAFT POSITIONED BELOW UPSTREAM MITER GATE PINTLES AS INDICATED.

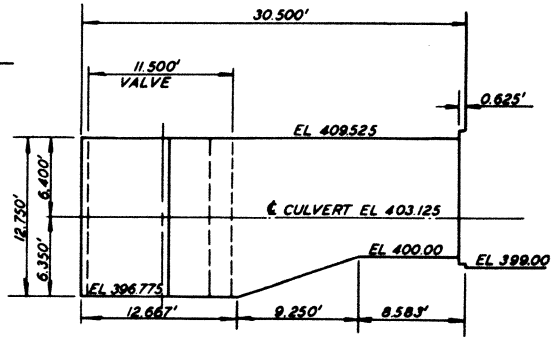
FILLING CHARACTERISTICS

TYPE 16 PORT ARRANGEMENT
3 AND 6 BARGE TOWS

PLATE 16

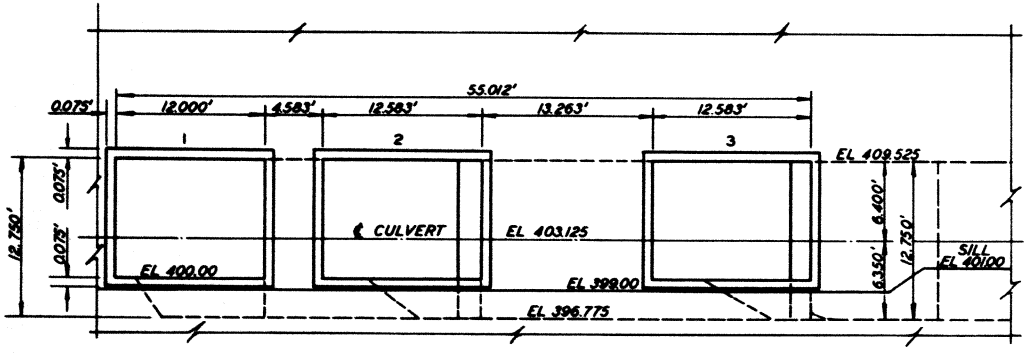


PLAN



SECTION A-A

NOTE: ALL DIMENSIONS ARE IN PROTOTYPE UNITS.



ELEVATION AT WALL FACE

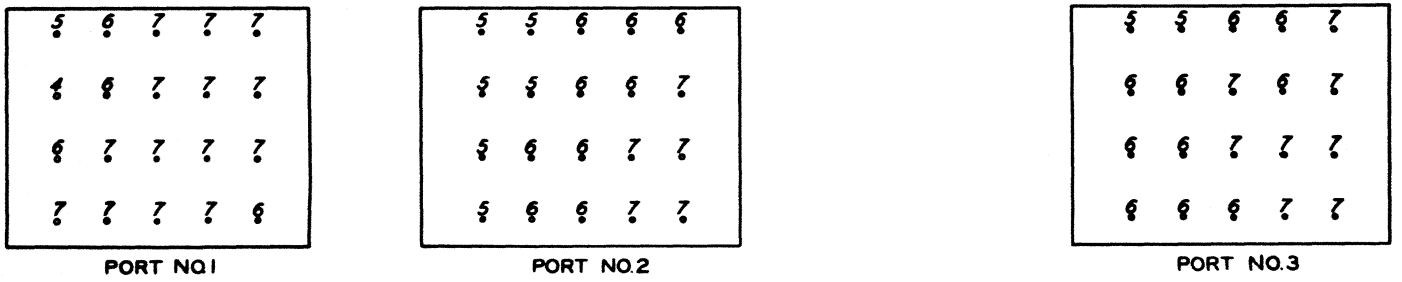
INTAKE MANIFOLD
TYPE 2 DESIGN

SCALE

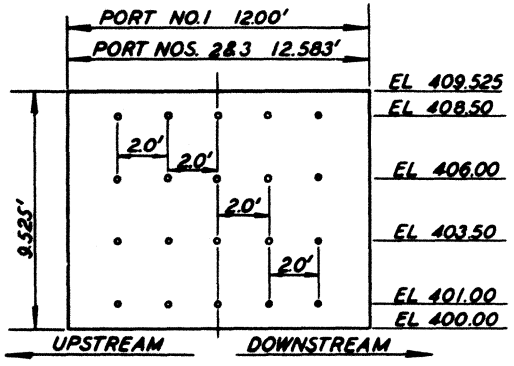
10 0 10 20FT

PLATE 17

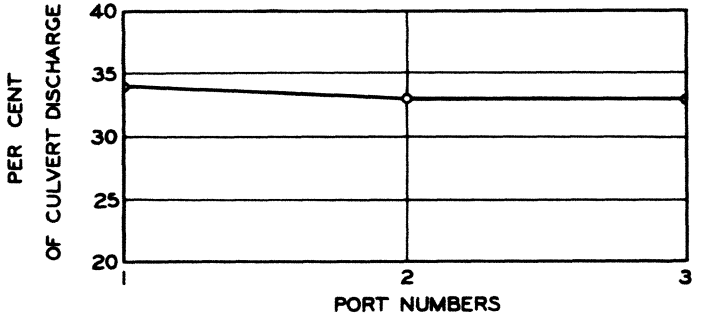
PLATE 18



VELOCITY DISTRIBUTION



LOCATION OF PORT
VELOCITY MEASUREMENT

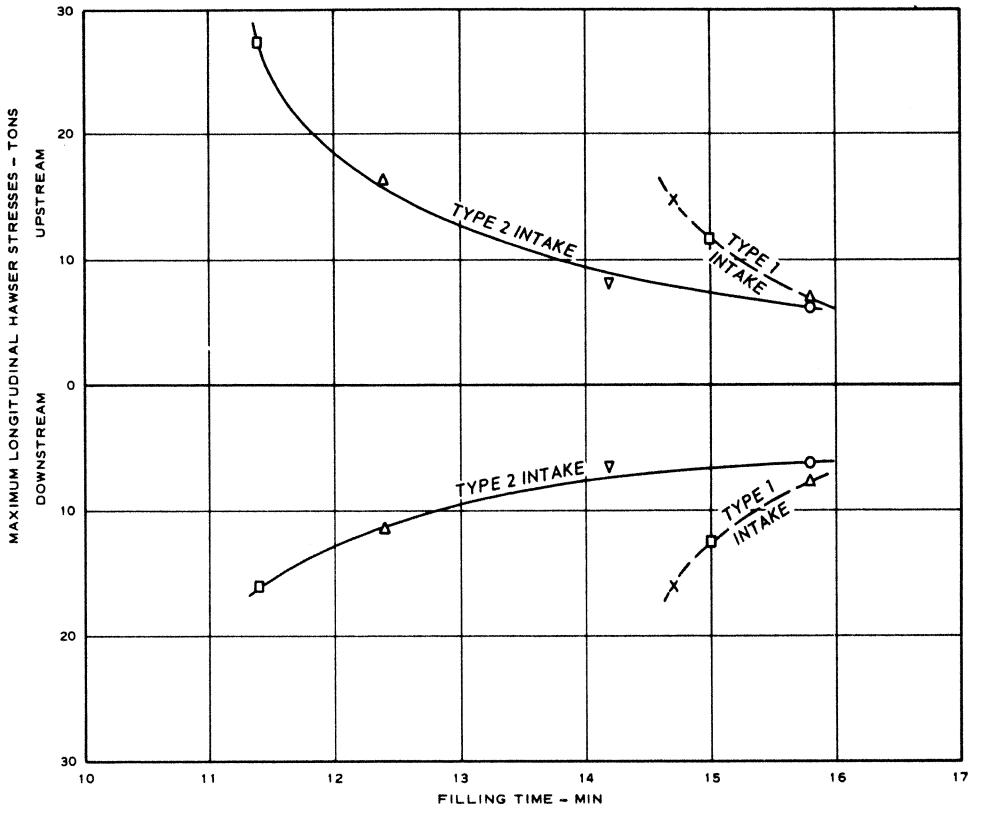


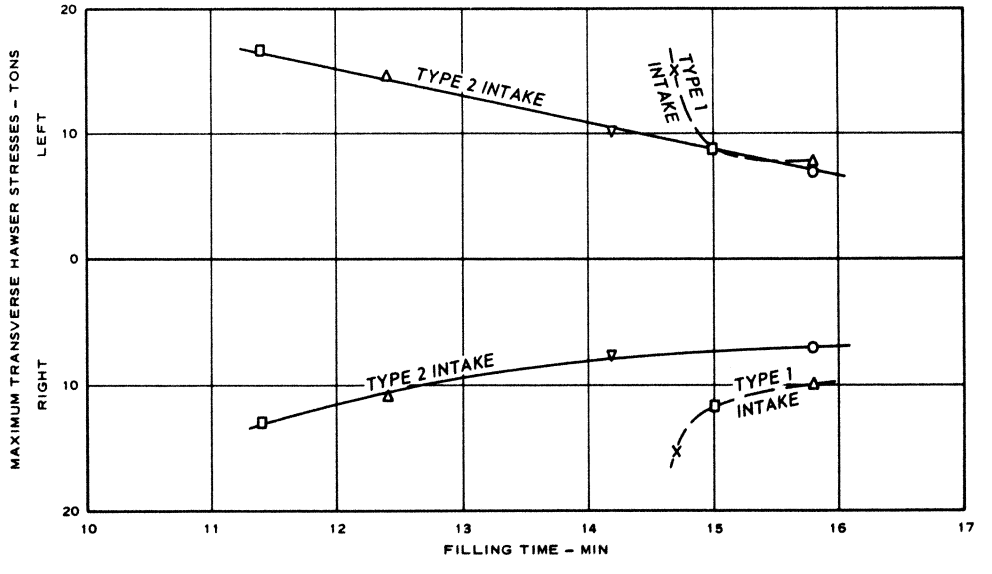
FLOW DISTRIBUTION

NOTE: ALL VALUES ARE IN PROTOTYPE UNITS.
A POOL ELEVATION OF 420 WAS MAINTAINED WITH UPPER MITER GATES AND LOWER CULVERT VALVES CLOSED, AND UPPER CULVERT VALVES AND LOWER MITER GATES OPEN FULL.
DISCHARGE 3000 CFS PER CULVERT.

INTAKE MANIFOLD FLOW DISTRIBUTION

TYPE 2 DESIGN





LEGEND

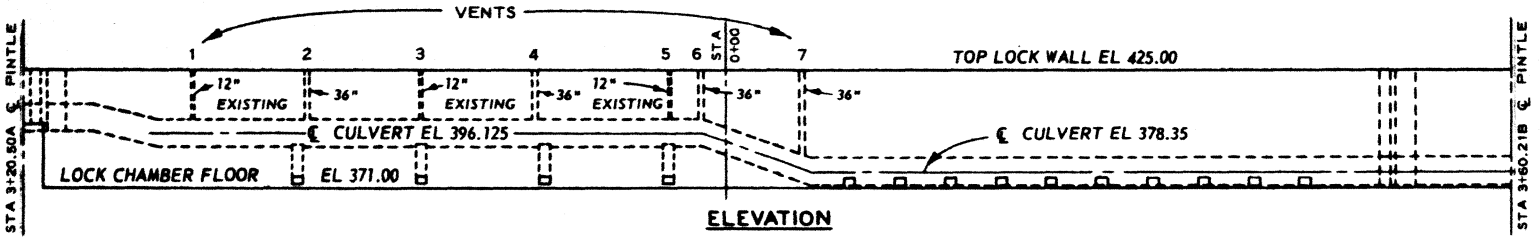
SYMBOL	VALVE SCHEDULE – MIN
X	1
□	2
Δ	4
∇	8
O	12

NOTE: 37-FT HEAD (UPPER POOL ELEVATION 420.0 AND LOWER POOL ELEVATION 383.0).
6-BARGE TOW AT 9-FT DRAFT POSITIONED 85-FT FROM UPSTREAM MITER GATE PINTLES.

FILLING CHARACTERISTICS
TYPE 16 PORT ARRANGEMENT
TYPE 1 VS TYPE 2 INTAKE MANIFOLD

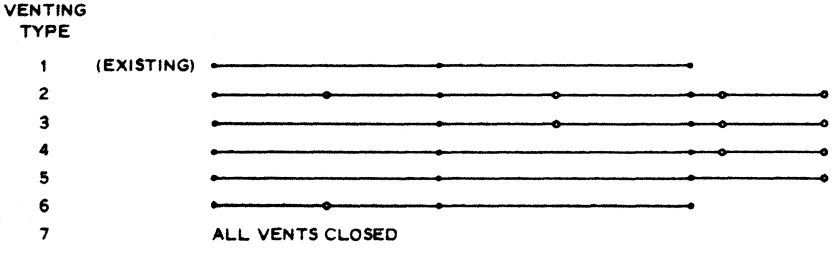
PLATE 19

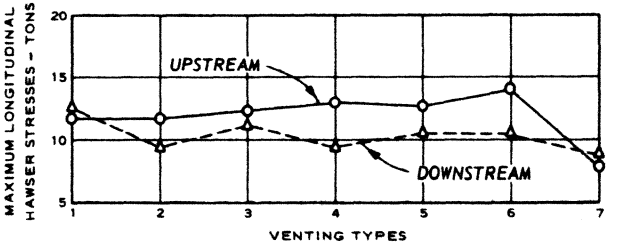
PLATE 20



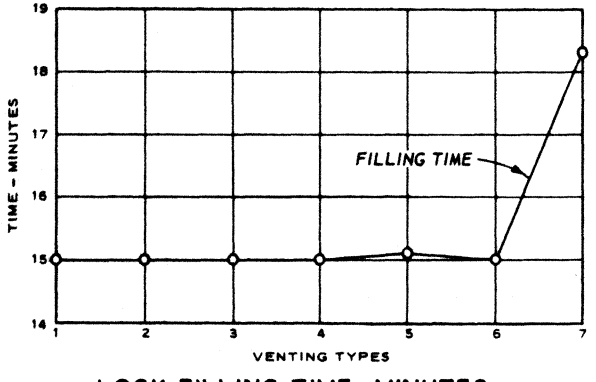
ELEVATION

TYPE 16 PORT ARRANGEMENT WITH POSSIBLE VENTING TESTED

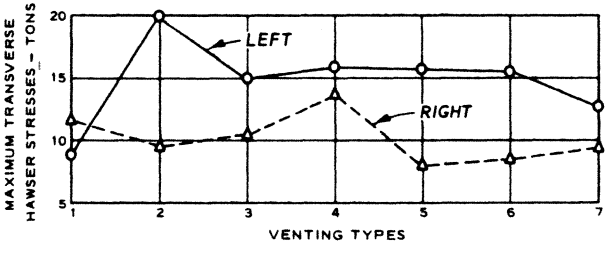




MAXIMUM LONGITUDINAL HAWSER STRESSES-TONS



LOCK FILLING TIME-MINUTES



MAXIMUM TRANSVERSE HAWSER STRESSES-TONS

NOTE: 37-FT HEAD (UPPER POOL ELEVATION 420.0 AND LOWER POOL ELEVATION 383.0).

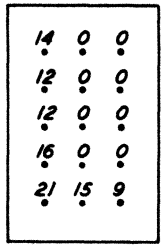
6-BARGE TOW AT 9-FT DRAFT POSITIONED 85 FT FROM UPSTREAM MITER GATE PINTLES.

TYPE 1 INTAKE MANIFOLDS.

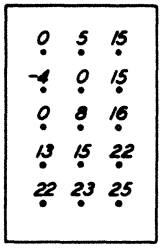
2-MIN VALVE SCHEDULE.

FILLING CHARACTERISTICS

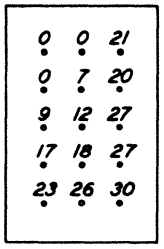
TYPE 16 PORT ARRANGEMENT VENTING TYPES 1-7



PORT NO. 1



PORT NO. 2



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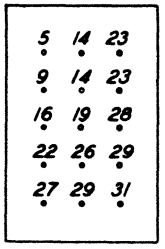

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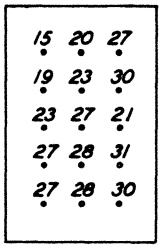
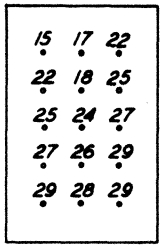
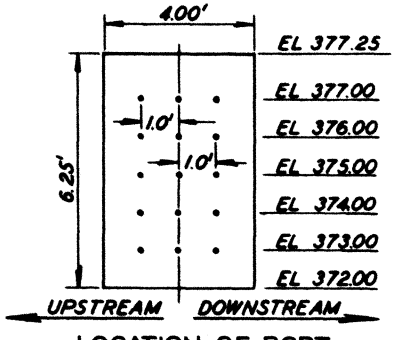


PORT NO. 5

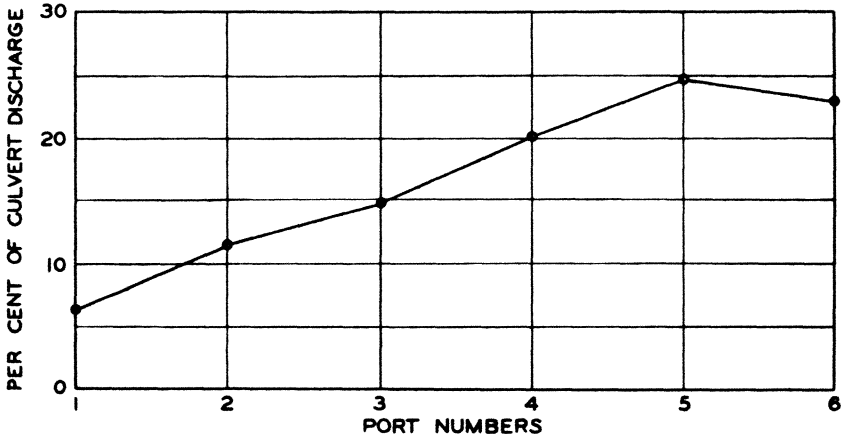


PORT NO. 6

VELOCITY DISTRIBUTION



LOCATION OF PORT
VELOCITY MEASUREMENT



FLOW DISTRIBUTION

NOTE: ALL VALUES ARE IN PROTOTYPE UNITS.
A LOWER POOL ELEVATION OF 383 WAS MAINTAINED WITH UPPER MITER GATES OPEN, LOWER MITER GATES CLOSED, AND EMPTYING VALVES OPEN FULL. A LOCK CHAMBER WATER SURFACE OF ELEVATION 415.0 OBTAINED.
DISCHARGE 3250 CFS PER CULVERT.

DISCHARGE MANIFOLD
FLOW DISTRIBUTION
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PLATE 21

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(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Miss.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
MODERNIZATION OF FILLING AND EMPTYING SYSTEM, EXISTING McALPINE LOCK (OLD NO. 41), OHIO RIVER, LOUISVILLE, KENTUCKY; Hydraulic Model Investigation

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final report

5. AUTHOR(S) *(First name, middle initial, last name)*
Jackson H. Ables, Jr.
Thomas E. Murphy

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1967	52	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	Technical Report No. 2-778
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Engineer District Louisville, Kentucky

13. ABSTRACT

Tests were conducted on a 1:25-scale model of the filling and emptying systems of the existing 600- by 110-ft lock of the McAlpine project. These tests were concerned with whether structurally feasible modifications of the systems would result in decreased turbulence and hawser stresses and thus permit faster filling and emptying of the lock .

Tests demonstrated that major improvement in performance of the filling and emptying system would result from connecting the filling and emptying culverts and plugging certain of the ports in the existing filling system.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hydraulic models Locks -- Filling and emptying systems McAlpine Locks and Dam						