ERDC/CHL TR-03-3

Coastal and Hydraulics Laboratory

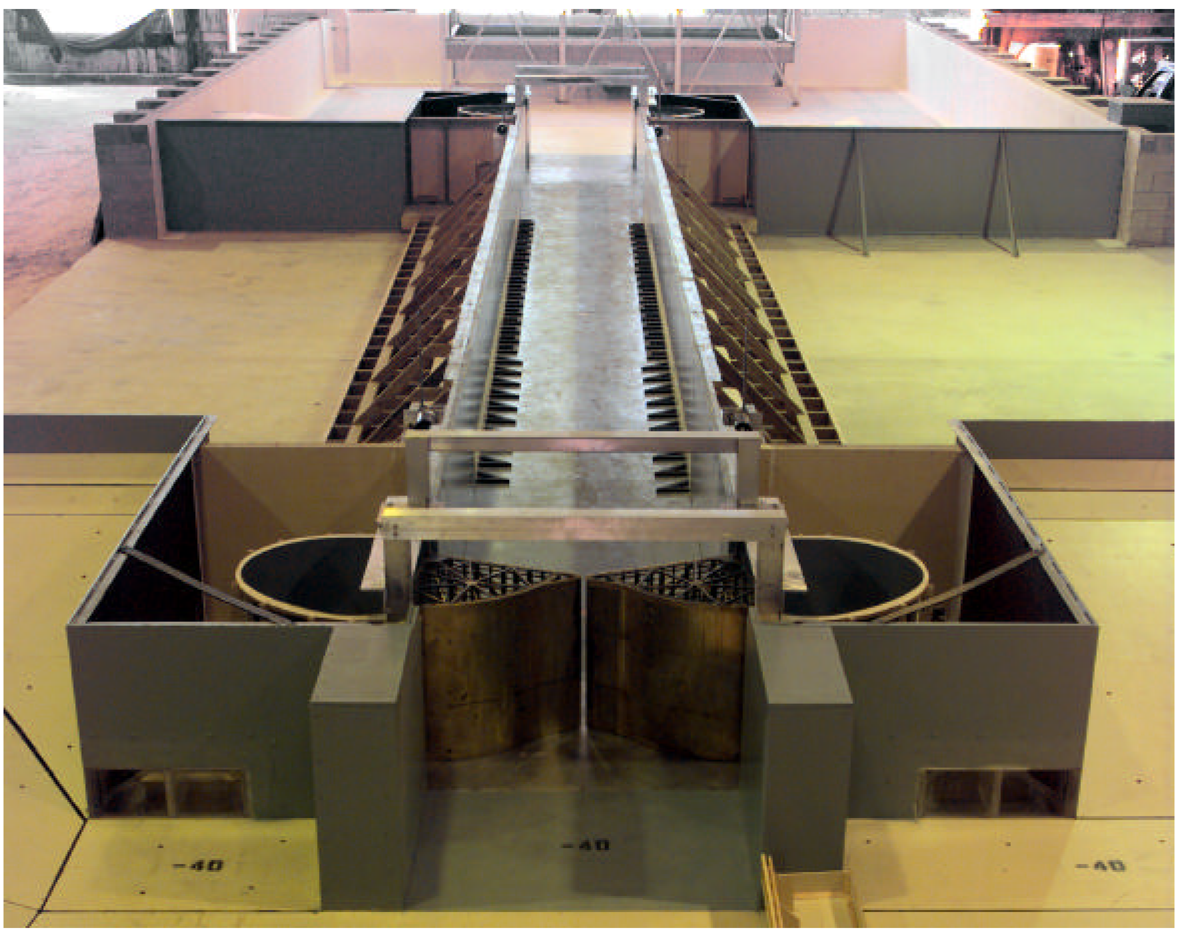
US Army Corps of Engineers®
Engineer Research and Development Center

Inner Harbor Navigation Canal Replacement Lock Filling and Emptying System, Inner Harbor Navigation Canal, New Orleans, Louisiana

Hydraulic Model Investigation

John E. Hite, Jr.

March 2003



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Inner Harbor Navigation Canal Replacement Lock Filling and Emptying System, Inner Harbor Navigation Canal, New Orleans, Louisiana

Hydraulic Model Investigation

by John E. Hite, Jr.

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Final report

Prepared for U.S. Army Engineer District, New Orleans
New Orleans, LA 70118-3651

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
feet-kips	1,355.818	newton-meters
miles	1.609344	kilometers
square feet	0.09290304	square meters
tons (force)	8.896443	kilonewtons
tons (mass)	907.1847	kilograms

Preface

The model investigation reported herein was authorized by Headquarters, U.S. Army Corps of Engineers, at the request of the U. S. Army Engineer District, New Orleans, on 11 April 1997. The model experiments were performed during the period October 1998 to May 2001 by personnel of the Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS, of the U.S. Army Engineer Research and Development Center (ERDC) under the general supervision of Dr. J. R. Houston, former Director, CHL; Mr. T. W. Richardson, Director, CHL; Dr. P. G. Combs, former Chief of the Rivers and Structures Division, CHL; and Dr. S. K. Knight, Chief of the Navigation Branch, CHL.

The experimental program was led by Messrs. J. S. Ashley and J. E. Myrick under the supervision of Dr. J. E. Hite, Jr., Leader, Locks Group, Navigation Branch. Model construction was completed by Messrs. M. A. Simmons, M. L. Bolden, J. E. Gullet, and V. J. Jeffers of the Model Shop, Department of Public Works (DPW), ERDC, under the supervision of Mr. J. Schultz, Chief of the Model Shop. Data acquisition and remote-control equipment were installed and maintained by Messrs. S. W. Guy and T. E. Nisley, Information Technology Laboratory (ITL), Vicksburg, MS, ERDC. Data acquisition software was developed by Dr. B. W. McCleave, ITL. The report was written by Dr. Hite and peer reviewed by Mr. J. E. Sanchez, Locks Group. Ms. Kathy Miller, Navigation Branch, helped in the preparation of the report.

During the course of the model study, Messrs. Don Alette, Arthur Laurent, Vann Stutts, Dennis Strecker, Mark Gonski, Ron Elmer, and Joe Dicharry, New Orleans District, and Messrs. Jim Tuttle, Joe McCormick, Malcolm Dove, and Chuck Shadie of the U.S. Army Engineer Division, Mississippi, visited ERDC to observe model operation, review experiment results, and discuss model results.

At the time of publication of this report Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

1 Introduction

Background

The U.S. Army Corps of Engineers is planning to replace the existing lock at the Inner Harbor Navigation Canal (IHNC) in New Orleans, LA (Figure 1). This lock replacement project is considered critical to the Nation's commerce. The replacement lock is the No. 2 priority project in the Inland Waterway System (IWS) following the Olmsted Navigation Project on the Ohio River, which is currently under construction. The IHNC lock is the busiest in the IWS with an estimated average wait to lock through of 10 hr.

The IHNC is a major navigation artery linking the Mississippi River, Gulf Intracoastal Waterway (GIWW), Mississippi River-Gulf Outlet, and Lake Ponchartrain. The existing 675- by 75-ft[1] lock with a floor elevation[2] of -36 will be replaced with the new larger lock with dimensions of 1,270 ft by 110 ft and a floor el of -40, which will reduce navigation delays to a minimum. The new lock is designed for a maximum lift of 19.6 ft and will be located a short distance north of the existing lock. The area where the lock will be constructed is mostly open water, which will reduce excavation and minimize the impact to land areas.

The Prototype

The existing lock contains a side port filling and emptying system with two sets of miter gates on each end since the project is subject to reverse heads. The canal is about 425 ft wide and 35 ft deep. Flow is minimal just north of the existing lock and consists primarily of lockage flows and tidal flows in the lake. The project is impacted to the south by water levels on the Mississippi River and to the north by tidal influences and surges from the Gulf of Mexico.

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[1] A table of factors for converting non-SI units of measurement to SI (metric) units is found on page vii.
[2] All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

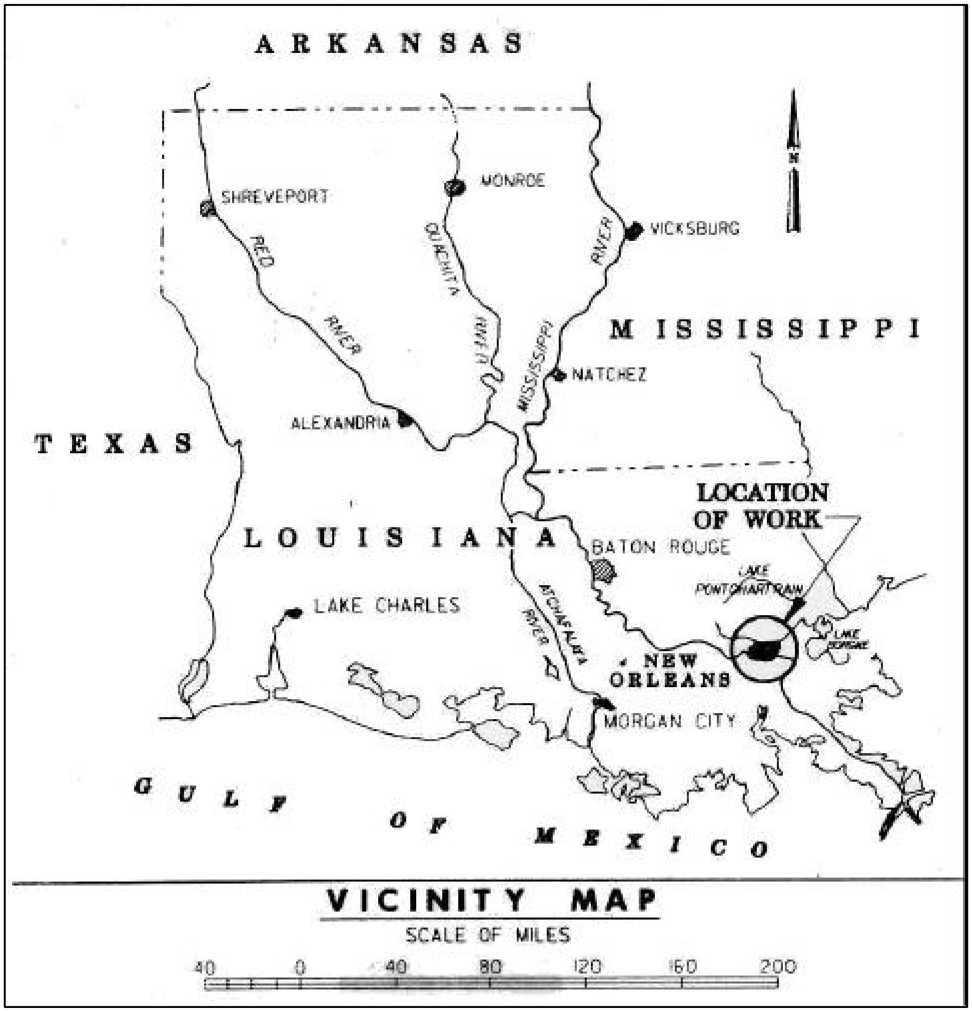


Figure 1. Vicinity map

The replacement lock will serve as the line of protection from Mississippi River floods, and elevations must provide protection to the Mississippi River and Tributaries (MR&T) Project design flow line standards. The MR&T Project design flood flow line at the IHNC lock site is el 17.6. The authorized freeboard is 4.8 ft; therefore, the embankment grade must be el 22.4. To the north, the predominant threat from flooding is a hurricane surge. The project features must therefore provide the level of protection associated with the Lake Ponchartrain and Vicinity Project. Design stages for this project are based on a Standard Project Hurricane producing a stage of el 13.0 at the IHNC lock site. A freeboard of 1.0 ft is added to this design surge level to obtain net embankment grades.

The maximum differential head for hydraulic design purposes is based on the occurrence of a project design flood flow line of el 17.6 on the Mississippi River concurrent with the observed historical minimum el of –2.0 on the north side of the lock. This produces a maximum normal design head of 19.6 ft. The maximum reverse differential head is based on the minimum historical stage of el –1.6 on the Mississippi River at Carrollton, LA, concurrent with the project design hurricane stage of el 13.0. This produces a maximum design reverse head of 14.6 ft.

Purpose and Scope

The initial design proposed for the model investigation was a 1,360-ft-long (pintle to pintle) by 110-ft-wide end filling sector-gated system. This design was designated the Type 1 design. Additional length was added to the standard pintle-to-pintle length for a 1,200-ft lock to allow a buffer area for the end filling system. During the planning for the model investigation, the U.S. Army Engineer District, New Orleans, and the U.S. Army Engineer Research and Development Center (ERDC) decided to incorporate the side port filling and emptying system into the model along with the end filling system. As will be discussed subsequently, the Type 1 design was modified during the study by shortening the chamber and changing the intake and outlet designs. The lock with these modifications was designated the Type 2 design. The objectives of the model investigation were as follows:

a. Determine the filling and emptying times for various valve speeds for lifts up to 19.6 ft.

b. Determine hawser forces on barges and a ship in the chamber for varying operating conditions.

c. Determine intake and outlet performance.

d. Determine pintle torque loads on the sector gates.

e. Make modifications if necessary to improve hydraulic performance.

A laboratory model was used to evaluate the performance of the filling and emptying system. Model studies of lock filling and emptying systems designed for barge traffic have targeted maximum hawser forces of 5 tons as a design objective. System design and operation are optimized such that a full tow at design draft produces hawser forces of 5 tons or less during lock operations at the design pool conditions. This limiting maximum hawser force guidance is provided in paragraph 8-6 of Engineer Manual (EM) 1110-2-2602 (Headquarters, U.S. Army Corps of Engineers (HQUSACE) 1995), paragraph E-2 of EM 1110-2-1604 (HQUSACE 1995), and also in the discussion of permissible filling times in paragraph D-15 of EM 1110-2-1604. Davis (1989) summarizes the findings of physical model studies:

> "In working with models to determine hawser stresses, it must be noted that when a hawser stress of only 5 tons is achieved in a model it does not necessarily follow that the hawser stress on the prototype lock will be no greater than the value measured in the model. On a performance basis it has been found that when the model hawser stress is no greater than 5 tons, the prototype lock will perform very well and no surging or severe turbulence will occur."

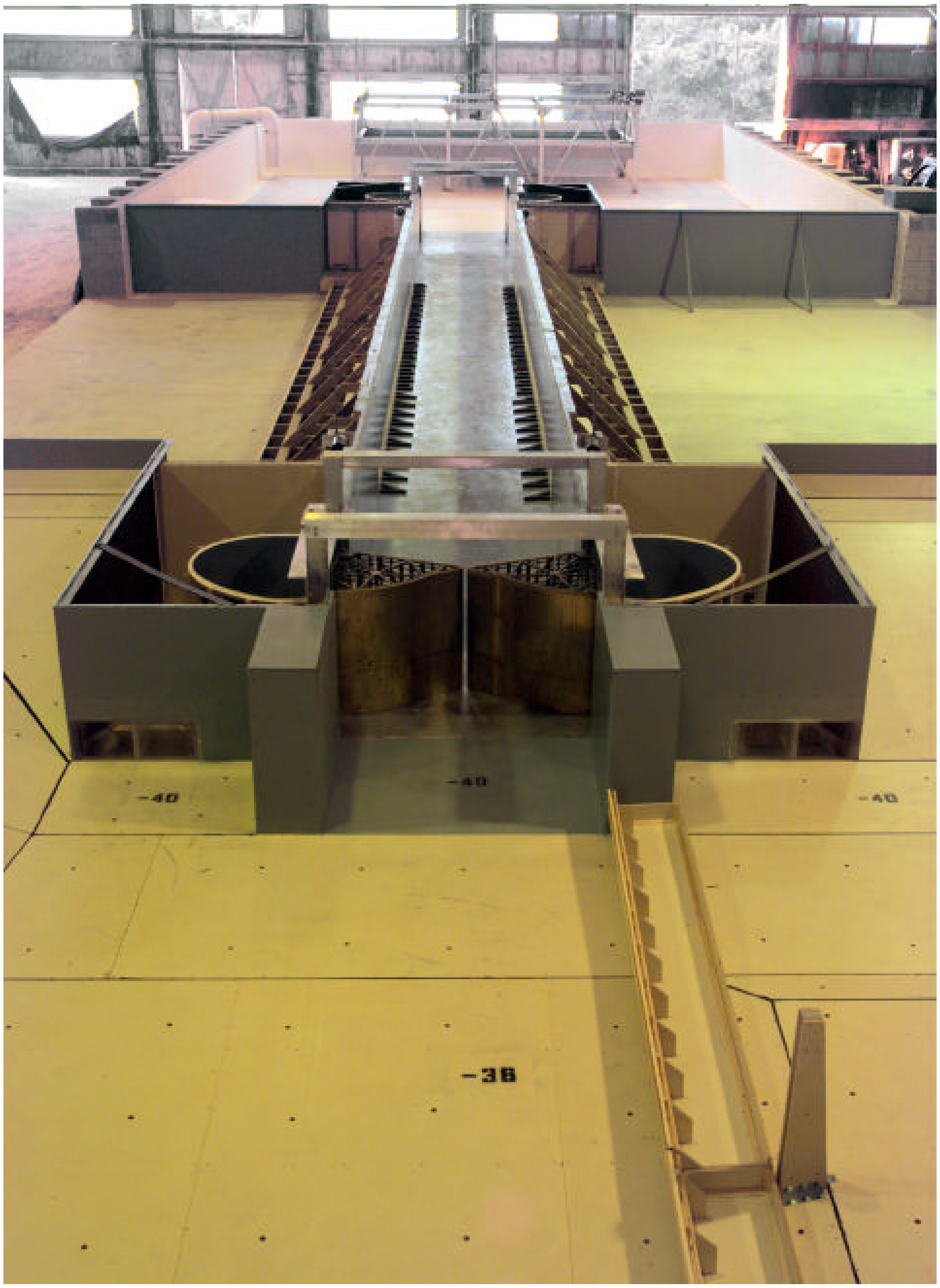
Criteria for hawser forces as stated in EM 1110-2-1604 indicate that for a ship of 50,000 tons, the forces should not exceed 10 tons and for a ship of 170,000 tons, the hawser force should not exceed 25 tons. The ship weight for this study was 85,000 tons, and interpolation of the guidance would give maximum hawser forces not to exceed 15 tons for this size vessel.

2 Physical Model

Description

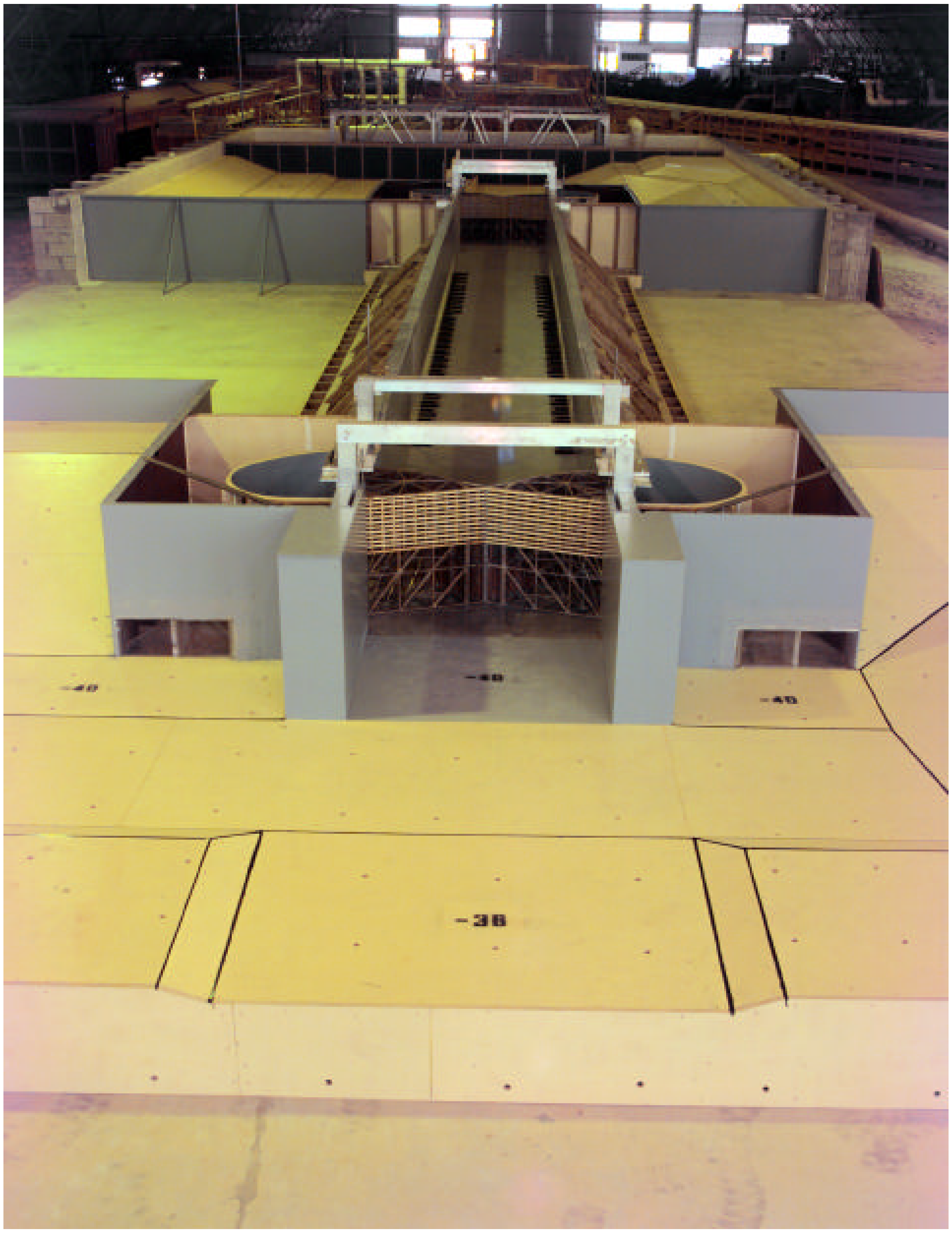
The 1:25-scale model reproduced approximately 800 ft of the upper and lower approaches, the intakes and outlets, the sector gates, and the side port filling and emptying system. The model layout is shown in Plate 1. The model was located in a concrete block flume approximately 150 ft long by 40 ft wide with 4-ft-high walls. Dry-bed views of the model are shown in Figures 2-4. Figure 2a is a view of the model looking from the Mississippi River side toward Lake Pontchartrain. The lock intakes for the side port system can be seen off the sides of the approach walls. The normal head (also referred to as direct head) exists when the Mississippi River stages are higher than the lake stages. Reverse head exists when the lake stages are higher than the river stages. "Looking downstream" in this report refers to river stages higher than lake stages. A view of the model looking from the lakeside toward the river is shown in Figure 2b. The discharge outlets for the side port system are identical to the intakes and can be seen off to the sides of the lower approach walls. A view of one of the four reverse tainter valves is shown in Figure 3. Close-up views of one of the four sector gates are shown in Figure 4. The structural members of the gate were reproduced in detail since force measurements were requested.

Details of the side port filling and emptying system are provided in Plate 2. The design was based on guidance provided in EM 1110-2-1604 (HQUSACE 1995) for a 1,270-ft-long pintle to pintle by 110-ft-wide lock chamber. The rectangular wall culverts were 18.25 ft high by 15 ft wide. The two intakes for the side port system were flush mounted in each sector gate monolith normal to the approach flow. Each intake contained two openings and together provided an area at the face of the intake of 949 ft^2. This gives an intake area to culvert area ratio of 3.47. The two openings transitioned horizontally to the culvert area 48.4 ft downstream from the face of the intake. Each culvert contained 28 ports with triangular baffles on the first 10 upstream ports and rectangular baffles on the last 18 downstream ports. The outlet design was identical in geometry to the intake and was mirrored about the transverse chamber centerline. The sector gate design was patterned after the Algiers lock sector gate developed in the 1951 model investigation (U.S. Army Corps of Engineers 1951).



a. Looking from riverside to lakeside

Figure 2. Dry-bed view of Type 1 (original) design (Continued)



b. Looking from lakeside to riverside

Figure 2. (Concluded)

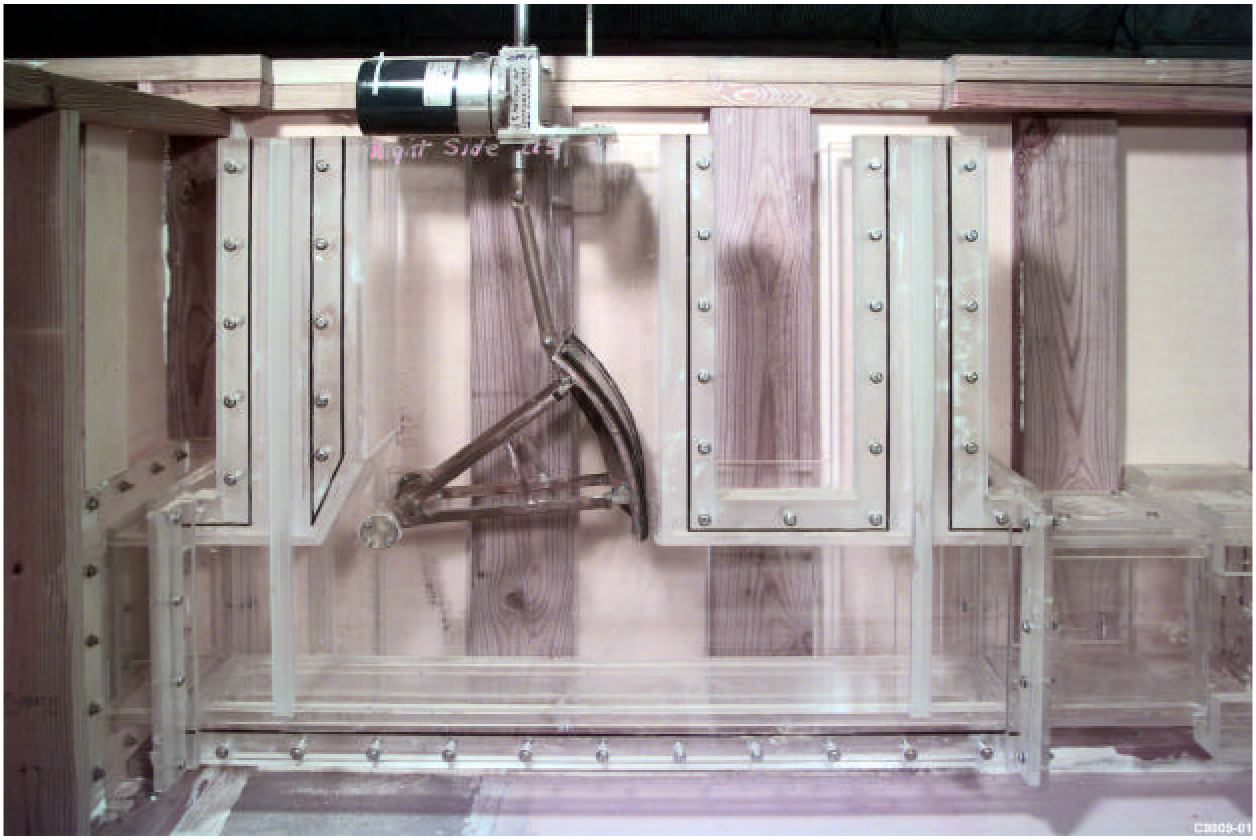
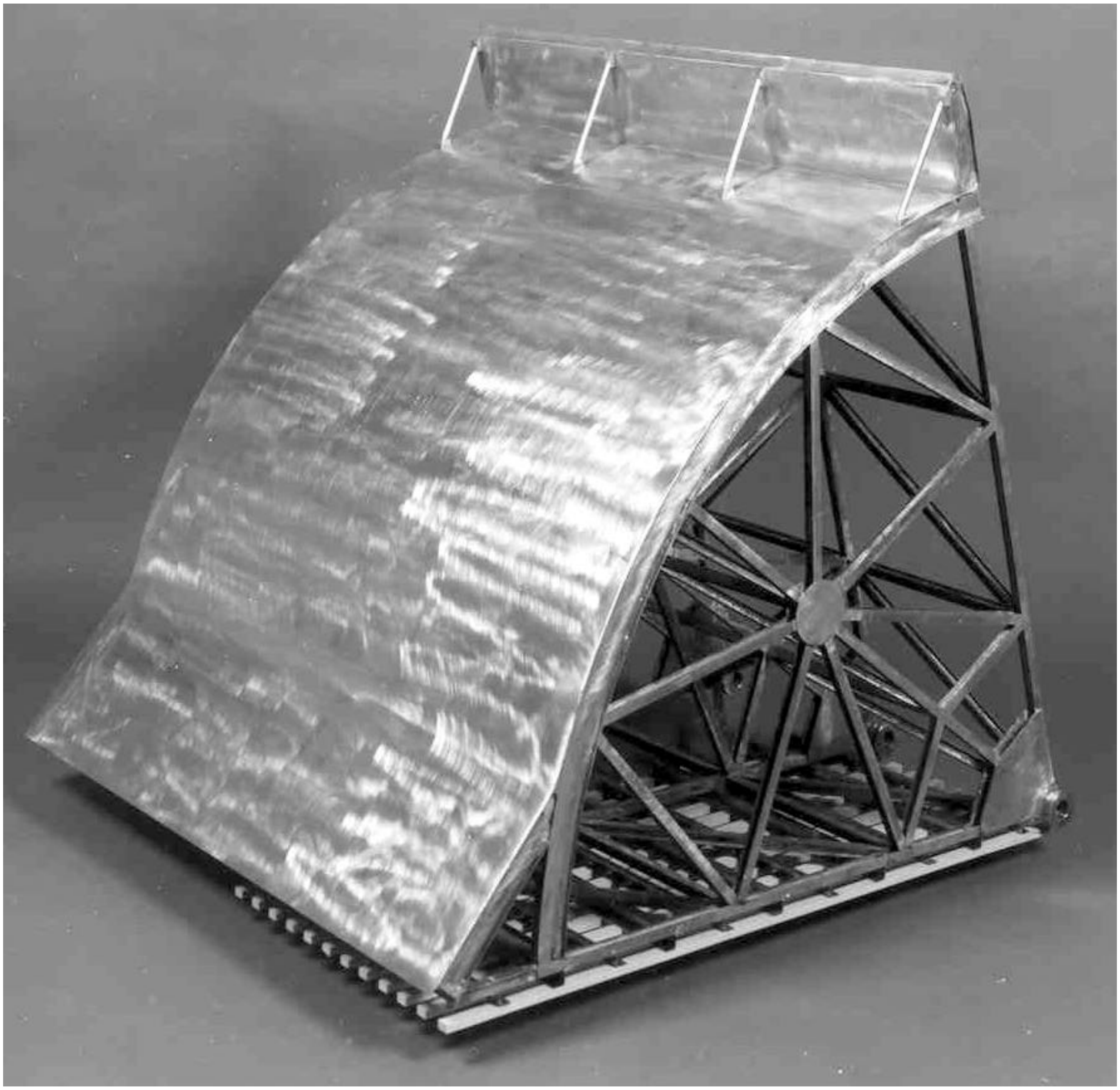
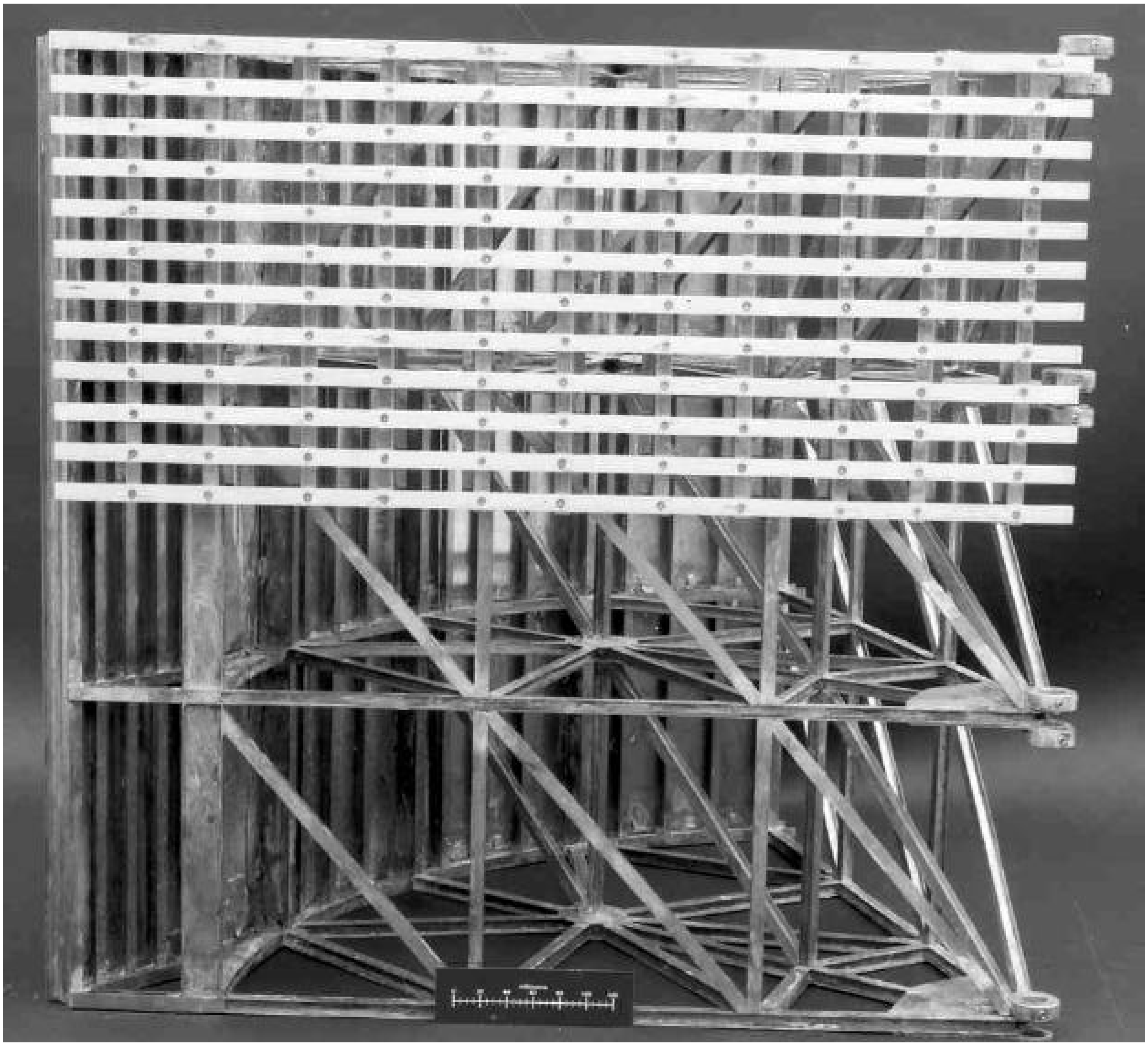


Figure 3. Side view of reverse tainter valve



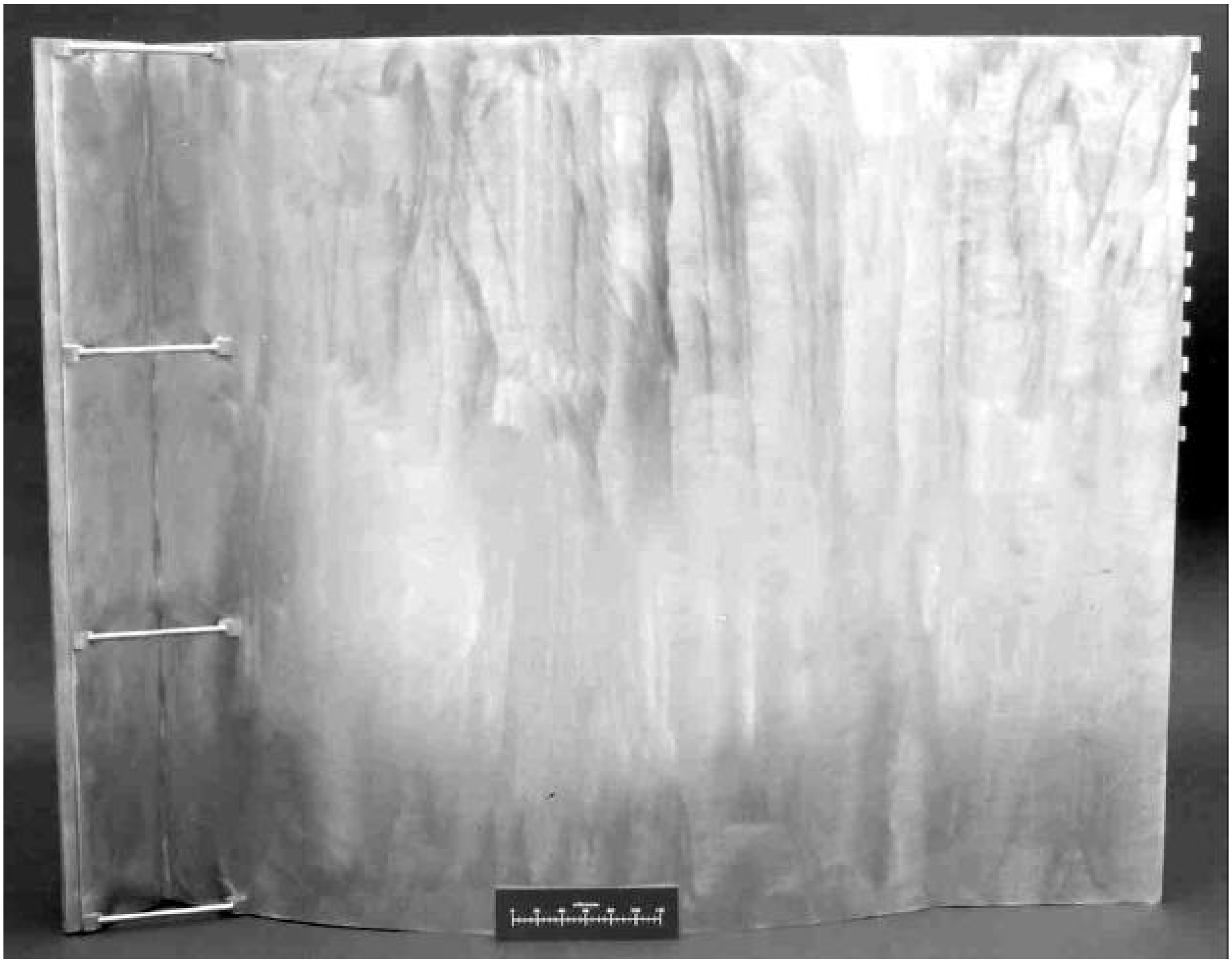
a. View of gate turned on side

Figure 4. 1:25-scale sector gate (Sheet 1 of 3)



b. View looking toward skin plate

Figure 4. (Sheet 2 of 3)



c. View of skin plate

Figure 4. (Sheet 3 of 3)

Appurtenances and Instrumentation

Water was supplied to the model through a circulating system. The upper and lower pools were maintained at near constant elevations during the filling and emptying operations using constant-head skimming weirs in the model headbay and tailbay. During a typical filling operation, excess flow was allowed to drain over the weirs at the beginning of the fill operation and minimal flow over the weir was maintained at the peak discharge, thereby minimizing the drawdown in the upper reservoir. This operation was reversed during lock emptying. Upper and lower pool elevations were set to the desired level by adjusting the skimming weirs and reading piezometers placed in calm areas of the upper and lower pools. Water-surface elevations inside the chamber were determined from electronic pressure cells located in the middle and on each end of the lock chamber. Pressure cells were also used to measure instantaneous pressures in the culvert just downstream of the filling and emptying valves. Histories of the end-to-end water-surface differential were also recorded during filling and emptying operations. Dye and confetti were used to study subsurface and surface current directions. Pressures throughout the systems were measured with piezometers (open-air manometers). Pressures obtained in this manner are considered average pressures because of the reduction in frequency response resulting from the use of nylon tubing.

An automated data acquisition and control program, Lock Control[1], was used to control valve operations and collect pressure and strain gauge data. Thirteen data channels were used, four for control of the filling and emptying valves, six for pressure data, and three for collecting strain gauge information. The data were usually collected at a sampling rate of 50 hz. Some of the hawser force and lock filling and emptying data were collected at 10 hz. These data were then processed using a computer program.[2] The processed data were used to determine lock filling and emptying times, longitudinal and transverse hawser forces, and pressures downstream from the filling and emptying valves.

A hawser-pull (force links) device used for measuring the longitudinal and transverse forces acting on a tow in the lock chamber during filling and emptying operations is shown in Figure 5. Three such devices were used: one measured longitudinal forces and the other two measured transverse forces on the downstream and upstream ends of the tow, respectively. These links were machined from aluminum and had SR-4 strain gauges 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 was engaged to a fixed vertical rod. While connected to the tow, the link was free to move up and down with changes in the water surface in the lock. Any horizontal motion of the tow caused the links to deform and vary the signal, which was recorded with a personal computer (PC) using an analog-to-digital converter. The links were calibrated by inducing deflection with known weights. Instantaneous pressure and strain gauge data were recorded digitally with a PC.

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1 Written by Dr. Barry W. McCleave, Information System Development Division, Information Technology Laboratory, ERDC.
2 Written by Dr. Richard L. Stockstill, Locks Group, Navigation Branch, Coastal and Hydraulics Laboratory, ERDC.

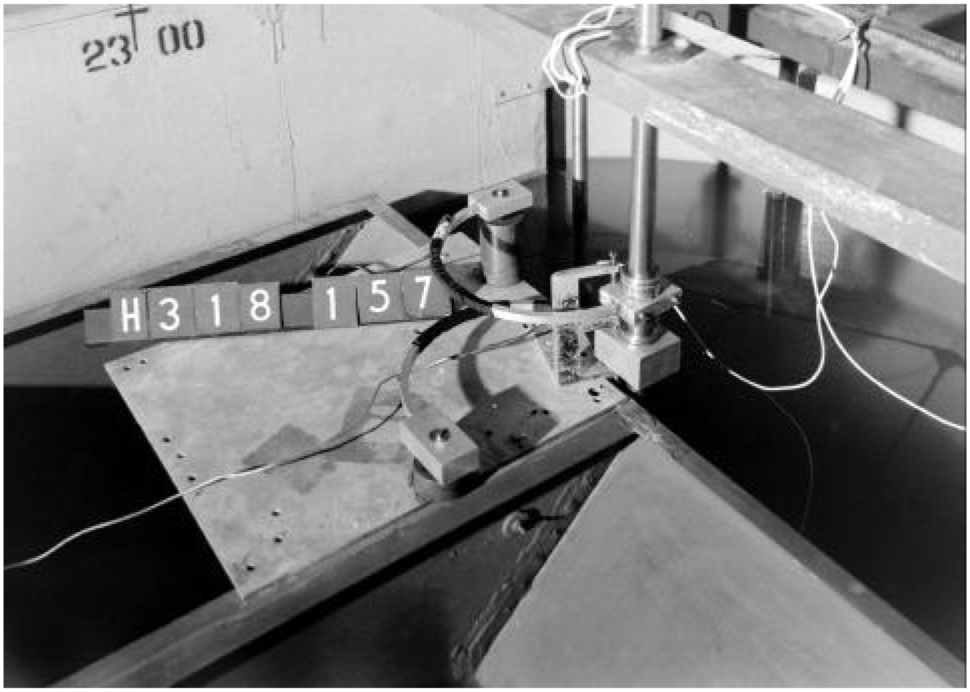

Figure 5. Hawser-pull (force links) measuring device

Similitude Considerations

Kinematic similitude

Kinematic similarity is an appropriate method of modeling free-surface flows in which the viscous stresses are negligible. Kinematic similitude requires that the ratio of inertial forces rV^2L^2 to gravitational forces rgL^3 in the model is equal to that of the prototype. Here, r is the fluid density, V is the fluid velocity, L is a characteristic length, and g is the acceleration due to gravity. This ratio is generally expressed as the Froude number N_F:

$$N_F = \frac{V}{\sqrt{gL}} \tag{1}$$

where L, the characteristic length, is usually taken as the flow depth in open-channel flow.

The Froude number can be viewed in terms of the flow characteristics. Because a surface disturbance travels at celerity of a gravity wave $(gh)^{1/2}$, where h is the flow depth, it is seen that the Froude number describes the ratio of advection speed to the gravity wave celerity. Evaluation of the lock chamber performance concerns primarily modeling of hawser forces on moored barges during filling and emptying operations. These hawser forces are generated primarily by slopes in the lock chamber water surface. The tow bow-to-stern water-surface differentials are the result of long period seiches or oscillations in the lock chamber. Seiching is gravity waves traveling in the longitudinal direction from the upper miter gates to the lower miter gates. Equating Froude numbers in the model and prototype is an appropriate means of modeling the lock chamber.

Dynamic similitude

Modeling of forces is a significant purpose of the laboratory investigation. Appropriate scaling of viscous forces requires the model to be dynamically similar to the prototype. Dynamic similarity is accomplished when the ratios of the inertia forces to viscous forces μVL of the model and prototype are equal. Here, μ is the fluid viscosity. This ratio of inertia to viscous forces is usually expressed as the Reynolds number:

$$N_R = \frac{VL}{n} \tag{2}$$

where ν is the kinematic viscosity of the fluid ($\nu = \mu/r$) and the pipe diameter is usually chosen as the characteristic length L in pressure flow analysis.

Similitude for lock models

Complete similitude in a laboratory model is attained when geometric, kinematic, and dynamic similitudes are satisfied. Physical models of hydraulic structures with both internal flow (pressure flow) and external flow (free surface) typically are scaled using kinematic (Froudian) similitude at a large enough scale so that the viscous effects in the scaled model can be neglected. More than 50 model and 10 prototype studies of lock filling and emptying systems have been investigated (Pickett and Neilson 1988). The majority of these physical model studies used a scale of 1 to 25 (model to prototype). Lock model velocities scaled using kinematic similitude (model Froude number equal to prototype Froude number) in a 1:25-scale model have maximum Reynolds numbers at peak discharges on the order of 10^5, yet the corresponding prototype values are on the order of 10^7. The model Reynolds number is large enough to avoid significant viscous effects.

Boundary friction losses in lock culverts are empirically described using the smooth-pipe curve of the Darcy-Weisbach friction factor where the head loss is expressed as

$$H_f = f \frac{L}{D} \frac{V^2}{2g} \tag{3}$$

where

H_f = head loss due to boundary friction
f = Darcy-Weisbach friction factor
L = culvert length
D = culvert diameter

The Darcy-Weisbach friction factor for turbulent flow in smooth pipes is given in an implicit form (Vennard and Street 1982):

$$\frac{1}{\sqrt{f}} = 2.0 \log\left(N_R \sqrt{f}\right) - 0.8 \qquad (4)$$

Because f decreases with increasing N_R, the model is hydraulically "too rough." The scaled friction losses in the model will be larger than those experienced by the prototype structure. Consequently, the scaled velocities (and discharges) in the model will be less and the scaled pressures within the culverts will be higher than those of the prototype. Low pressures were not a major concern with the IHNC design; however, the lower discharges would in turn result in longer filling and emptying times in the model than the prototype will experience.

Modeling of lock filling and emptying systems is not entirely quantitative. The system is composed of pressure flow conduits and open-channel components. Further complicating matters, the flow is unsteady. Discharges (therefore N_F and N_R) vary from no flow at the beginning of an operation to peak flows within a few minutes and then return to no flow at the end of the cycle. Fortunately though, engineers now have about 50 years of experience in conducting large-scale models and subsequently studying the corresponding prototype performance. This study used a 1:25-scale Froudian model in which the viscous differences were small and could be estimated based on previously reported model-to-prototype comparisons. Setting the model and prototype Froude numbers equal results in the following relations between the dimensions and hydraulic quantities:

Characteristic	**Dimension**[1]	**Scale Relation Model:Prototype**
Length	$L_r = L$	1:25
Pressure	$P_r = L_r$	1:25
Area	$A_r = L_r^{2}$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Time	$T_r = L_r^{1/2}$	1:5
Force	$F_r = L_r^{3}$	1:15,625
[1]Dimensions are in terms of length.		

These relations were used to transfer model data to prototype equivalents and vice versa.

Experimental Procedures

Evaluation of the various elements of the lock system was based on data obtained during typical filling and emptying operations. Performance was based primarily on hawser forces on tows in lockage, roughness of the water surface, pressures, and time required for filling and emptying. Quantification of energy loss coefficients was made using fixed-head (steady-flow) conditions with the culvert valve and/or miter gates fully opened or closed. All values of length, pressure, area, velocity, discharge, time, and force mentioned in the following experiments have been converted to prototype equivalents unless otherwise stated.

3 Model Experiments and Results, Type 1 Design

Pintle Torque Measurements

Initial model experiments were performed to measure the torque on the sector gate pintle for different gate openings. A torque meter was installed in-line in the pintle shaft and the output signal was conditioned, recorded on a PC, and converted to prototype values of torque. The left (looking toward the lake) riverside sector gate was instrumented for these tests. The experiments were performed by setting the gate at the desired gate opening, then setting the river and lake stages, and then recording pintle torque under these steady-state conditions. The pintle torque values determined from these experiments are listed in Table 1. The lakeside stage was maintained at el 1.0 for direct head measurements and the riverside stage was maintained at el 0.0 for reverse head measurements. Plate 3 shows the position of the sector gates for typical gate settings. The gate opening is the distance from gate tip to gate tip normal to the lock center line.

The model did not have the flow capacity to maintain the higher heads using both sector gates for larger gate openings. This was compensated for during the experiments with the larger gate settings by opening only one sector gate and assuming the flow through the opening was symmetrical about the center line of the approach. The symmetrical flow was achieved by blocking the flow at the same upstream station as the instrumented sector as shown in Plate 3. The maximum gate opening obtained using both gates for the 19.6-ft direct head was 12 ft. The maximum gate opening simulated with the 19.6-ft direct head was 24 ft (Plate 3). The maximum gate opening obtained using both gates for the 9-ft direct head was 24 ft, and a 60-ft gate opening was achieved for the 2-ft direct head using both sector gates. The maximum gate opening obtained using both gates for the 9-ft reverse head (herein designated on the plates as 9R) was 44 ft.

The maximum pintle torque measured during these experiments was 7,360 ft-kips and occurred with a 24-ft gate opening for the 19.6-ft direct head. For the pintle torque measurements the sector gate was made as frictionless as possible and no seals were attached to the gates. A plot of pintle torque versus gate opening for the head conditions tested is shown in Plate 4. With a 2-ft direct head, the torque varied from 257 ft-kips with a 2-ft gate opening to 1,139 ft-kips with a 60-ft gate opening. With a 19.6-ft direct head, the pintle torque varied from 1,563 ft-kips at a 2-ft gate opening to 7,360 ft-kips at a 24-ft gate opening. A close-up plot of the torque measurements obtained for gate openings up to 8 ft is shown in Plate 5. This plot indicates a rapid change in torque between 2- and 4-ft gate openings with the 9-ft direct head. This change was probably caused by the distribution and direction of flow between the sector gates and the recesses. For all direct head measurements obtained, the hydraulic forces tended to close the gates. For the 9-ft reverse head measurements, the hydraulic forces tended to close the gate with openings less than 4 ft and open the gates with settings higher than 4 ft. The New Orleans District indicated these measurements were acceptable, and no attempts were made to reduce the forces by modifying the gate shape.

Lock Chamber Velocities

The New Orleans District requested velocity measurements inside the lock chamber with both sector gates in the recessed position. This condition represented an unusual operation or a gate malfunction. Measurements were obtained for a lakeside el of +1.0 and riverside stage el of +2.2, +2.0, and +1.5 at the locations shown in Plate 6. Velocities as high as 7.3 ft/sec were measured in the middle of the chamber with a river stage of el +2.2 and a lakeside stage of el +1.0. The velocity measurements are provided in Plate 6.

Chamber Performance with End Filling and Emptying System

End filling with barges drafted to 11 ft

The first filling and emptying experiments were performed with the sector gate system and a 6-long by 3-wide barge arrangement drafted to 11 ft. Each barge was 195 ft long by 35 ft wide. The sector gate system is also referred to as the end filling and emptying system. The barges were positioned in the chamber as shown in Plate 7. The sector gate speeds were chosen based on those used in the Algiers Lock model study (U.S. Army Corps of Engineers 1951) and in discussions with the New Orleans District. The different gate speeds used are shown in Plate 8. The fastest speed, schedule E, opened the gates to 8.5 ft in 4 min, and the slowest speed, schedule C, opened the gates to 8.5 ft in 36 min. Data were obtained with four different normal lift conditions, 3, 7, 11, and 19.6 ft and a reverse lift of 9 ft. The New Orleans District requested that the initial tests be performed with an 11-ft draft on the barges. Generally three tests for each condition were performed to ensure repeatability. The lakeside stage was maintained at el –2.0 for the normal lift experiments and at el 9.0 for the reverse lift experiments.

End filling with 3-ft lift. Time-histories of data obtained during a typical experiment with a 3-ft lift are shown in Plate 9. The time-history at the top shows the longitudinal hawser forces measured during an end filling operation with gate opening schedule D. Gate schedule D opens the gate to 8.5 ft in 6 min.

The maximum longitudinal hawser force measured in the upstream direction during this experiment was 4.9 tons at about 6.5 min. An upstream hawser force indicates that the barge arrangement wants to move toward the upper sector gates. A downstream hawser force indicates that the barges want to move toward the downstream sector gates. The downstream hawser forces are designated as the negative forces in Plate 9 for clarity. In subsequent discussions of downstream hawser forces, the negative sign will not be shown. The maximum downstream longitudinal hawser force measured was 5.1 tons and occurred at 3 min into the filling operation. The two time-histories below the top one are the upstream and downstream transverse hawser forces, respectively. Right and left refer to the direction, looking downstream, the barges would move if not moored. Transverse hawser forces in the left direction are designated as negative forces. These forces ranged from 1.3 to 1.9 tons and occurred between 4 and 5 min into filling. The next to the last trace at the bottom of the plot is the filling curve. This curve was determined by averaging the water-surface elevations measured using pressure cells located in the middle and both ends of the lock chamber. The curve indicated that the lock reached the riverside el in 6.5 min. The trace at the bottom of the plot is the rate of rise of the water surface in the chamber. The values for rate of rise are on the right side of the plot.

To determine the filling time required to maintain hawser forces of 5 tons or less, experiments were performed with different gate schedules. The average of the maximum forces measured for three experiments (typically) with the same lift and gate schedule was determined and plotted versus the average filling time. The average maximum hawser forces determined for the experiments performed with the 3-ft lift and gate operations A, D, and E are shown in Plate 10. The average maximum values for the hawser forces and the average filling times for the 3-ft lift and gate schedules A, D, and E are listed in Table 2. The data indicated that the filling time required to maintain hawser forces of 5 tons or less was 6.8 min. This filling time would result from a gate operation slightly slower than gate schedule D.

End filling with 7-ft lift. Time-histories of data obtained during a typical experiment with a 7-ft lift and gate schedule B are shown in Plate 11. The maximum longitudinal hawser force measured in the upstream direction during this experiment was 4.8 tons, and the maximum downstream longitudinal hawser force measured was 4.6 tons. The transverse forces ranged from 3.6 to 5.5 tons and occurred between 12 and 14 min into the filling operation, which was near the time of the maximum rate of rise. The average maximum hawser forces determined for the experiments performed with the 7-ft lift and gate operations A, B, and D are shown in Plate 12 and listed in Table 2. To maintain hawser forces of 5 tons or less, the filling time required was 19.3 min. A gate schedule just slower than B would be needed to achieve a filling time of 19.3 min.

End filling with 11-ft lift. Time-histories of data obtained with a 11-ft lift and gate schedule C are shown in Plate 13. The maximum longitudinal hawser force measured in the upstream direction during this experiment was 8.2 tons and the maximum downstream longitudinal hawser force measured was 5.4 tons. The transverse forces ranged from 4.1 to 4.6 tons and occurred between 14 and 17 min into filling. The average maximum hawser forces determined for the experiments performed with the 11-ft lift and gate operations A, B, and C are shown in Plate 14 and listed in Table 2. To maintain hawser forces of 5 tons or less, the filling time was extrapolated from the data and determined to be 30 min. This filling time would require a gate schedule slower than the slowest one evaluated (C).

End filling with 19.6-ft lift. The data obtained with a 19.6-ft lift and gate schedule C are shown in Plate 15. The maximum longitudinal hawser force measured in the upstream direction during this experiment was 11.5 tons, and the maximum downstream longitudinal hawser force measured was 9.0 tons. The transverse forces ranged from 4.6 to 6.8 tons and occurred between 14 and 17 min into filling. The average maximum hawser forces determined for the experiments performed with the 19.6-ft lift and gate operations A, B, and C are shown in Plate 16 and listed in Table 2. Even with the slowest gate schedule, C, the hawser forces were greater than 5 tons. A filling time greater than 35 min would be required to obtain longitudinal forces less than 5 tons.

End filling with 9-ft reverse lift. Experiments were performed for a reverse head condition with the lakeside stage at el 9.0 and the riverside stage at el 0.0. Time-histories of data obtained during a typical experiment performed with a 9-ft lift (reverse head) and gate schedule C are shown in Plate 17. The maximum longitudinal hawser force measured in the upstream direction during this experiment was 4.0 tons, and the maximum downstream longitudinal hawser force measured was 5.9 tons. The transverse forces ranged from 1.8 to 2.7 tons and occurred between 15 and 18 min into filling. The average maximum hawser forces determined for the experiments performed with the 9-ft lift (reverse head) and gate operations A, B, and C are shown in Plate 18. To maintain hawser forces of 5 tons or less, the filling time was 28.3 min. This compares to a filling time of 25 min with normal head conditions and 9-ft lift.

Evaluation of the end filling system with 18 barges drafted to 11 ft for lifts between 3 and 19.6 ft revealed the system was extremely slow. A plot of lift versus filling time to keep hawser forces less than 5 tons is shown in Plate 19. To maintain hawser forces less than 5 tons and filling times less than 8 min, lifts less than 3.5 ft must exist. Once the lift exceeded 11 ft, the hawser forces even with the slowest practical gate schedule were higher than 5 tons.

End filling with barges drafted to 9 ft

The New Orleans District requested experiments to evaluate the end filling system for lifts of 3 and 19.6 ft with the 18 barges drafted to 9 ft. The results of the hawser force experiments with the 3-ft lift are shown in Plate 20 along with the results for the barges drafted to 11 ft. A filling time of 5.9 min or slower was required to maintain hawser forces of 5 tons or less with the 18 barges drafted to 9 ft and 3-ft lifts. This compares to 6.8 min with the 11-ft draft. The results of the hawser force experiments with the 19.6-ft lift are shown in Plate 21 along with the results for the barges drafted to 11 ft. A filling time of about 32 min was required to maintain hawser forces of less than 5 tons.

End filling with 15 barges drafted to 11 ft

The New Orleans District requested experiments with a 3 by 5 barge arrangement placed at selected locations within the lock chamber. The lock chamber with the original design end fill system was designed longer than a conventional 1,270-ft-long (pintle to pintle) lock to allow additional room for energy dissipation with the end fill system. As shown in Plate 7 with the 6 by 3 barge arrangement, the downstream end of the barges was placed at sta 12+58.75, which was 50 ft upstream from the lower sector gate skin plate (the upstream end was at sta 0+88.75). The first experiments with 15 barges and a 7-ft lift were conducted with the downstream end of the barges placed at sta 11+88.75 (120 ft upstream from the sector gate skin plate as shown in Plate 22), which puts the upstream end of the barges at sta 2+13.7. Hawser forces measured with these conditions are shown in Plate 23 on the plot labeled "3 by 5 at 120 ft." The filling time to maintain hawser forces of 5 tons or less was 11.9 min. The upstream end of the barges was then placed at the same location as the upstream end of a 3 by 6 barge arrangement. The results of the hawser force experiments with the barges in this location and the 7-ft lift are also shown in Plate 23 (3 × 5 at 245 ft). The filling time to maintain 5-ton hawser forces or less was just over 19 min. This is the same as the filling time for the 3 by 6 barge arrangement, also shown in Plate 23. The higher hawser forces occurred in the upstream direction. The maximum upstream hawser forces with the 3 by 5 barge arrangement were sensitive to barge location whereas the maximum downstream hawser forces were not sensitive to barge location. The upstream end of the barges on the plots labeled "3 by 5 at 245 ft" and "3 by 6 at 50 ft" in Plate 23 were at the same location in the chamber (sta 0+88.75).

End emptying with barges drafted to 11 ft

End emptying with 3-ft lift. Experiments were conducted to evaluate the performance of the sector gate emptying system. Typical time-histories of the data obtained with the 3-ft lift and gate schedule D are shown in Plate 24. The maximum downstream longitudinal hawser force was 5.0 tons at just over 3 min into emptying, and the maximum upstream longitudinal hawser force was 4.8 tons at about 7 min into emptying. The transverse hawser forces were small (less than or equal to 1 ton). A plot of the average maximum hawser forces measured with gate schedules E, D, and A is shown in Plate 25 and the values are listed in Table 3. The results indicate to maintain 5-ton hawser forces or less will require an emptying time of 7.3 min or longer.

End emptying with 7- and 11-ft normal lifts and 9-ft reverse lift. The average maximum hawser forces measured with normal lifts of 7 and 11 ft and 9-ft reverse lift with gate schedules of A, B, and C are shown in Plate 26 and Table 3. The results indicate that to maintain 5-ton hawser forces or less with a 7-ft lift will require an emptying time of about 20 min. The upstream and downstream longitudinal hawser forces measured with the 7-ft lift were fairly insensitive to the different gate speeds. The upstream longitudinal hawser forces were just under 5 tons for all three gate schedules (A, B, and C), and the downstream longitudinal hawser forces were slightly greater than 5 tons for gate schedules A and B and slightly less than 5 tons for gate schedule C. These results make the determination of a filling time to maintain 5 tons or less difficult since the forces are similar. The maximum longitudinal hawser forces were primarily a result of the seiching in the chamber caused by the gate opening rather than the speed of the sector gate for these three gate schedules and 7-ft lift.

The average maximum hawser forces measured with an 11-ft lift and gate schedules of A, B, and C are shown in Plate 26 and Table 3. With the slowest gate speed tested, the longitudinal hawser forces were still slightly higher than 5 tons, indicating an emptying time near 35 min would probably be required to meet the hawser criteria. The average maximum hawser forces measured with a 9-ft reverse lift and gate schedules of A, B, and C are also shown in Plate 26 and Table 3. The determination of emptying time to maintain 5-ton hawser forces or less was difficult due to the insensitivity of the hawser forces with these gate speeds. The emptying time to maintain hawser forces of 5 tons or less with the 9-ft reverse lift was near 27 min. Results of tests with a 19.6-ft lift conducted with gate schedule C (Table 3) indicated that emptying times to achieve 5 tons were excessive and therefore no further tests were performed.

Emptying times to maintain hawser forces of 5 tons or less for the normal lifts between 3 and 11 ft and the reverse head lift of 9 ft are shown in Plate 27. The emptying times ranged from 7.3 min with a 3-ft lift to over 35 min with an 11-ft lift. These times are extremely slow compared with those of existing 1,270-ft side port locks.

End filling with ship

Experiments were conducted to evaluate the performance of the end filling system with a ship in the lock chamber. The position of the ship during the hawser force experiments is shown in Plate 28. The ship was 760 ft long by 106 ft wide drafted to 36 ft. The shape of the hull approximated that of a tanker. The experiments were performed in the same manner as the barge experiments. The lakeside stage was at el 0.0, and the riverside stage was set according to the lift desired. The minimum lake stage of el –2.0 could not be set since the draft of the ship was 36 ft and the elevation of the top of the port baffles for the side port system was el –38.0. Hawser force data were obtained for lifts of 3, 7, and 11 ft with the varying gate speeds.

End filling with ship and 3-ft lift. Time-histories of data obtained for a 3-ft lift with gate schedule A are shown in Plate 29. The maximum downstream hawser force measured was 15.2 tons at about 7 min into filling, and the maximum upstream hawser force was 7.3 tons and occurred about the time the chamber was full (10.7 min). The transverse forces were small, ranging from 0.3 to 0.6 ton. A plot of the average maximum hawser forces for gate schedules C, B, A, and D is shown in Plate 30, and the values are provided in Table 4. To maintain hawser forces of 15 tons or less, a filling time of 9.4 min was required.

End filling with ship and 7- and 11-ft normal lifts and 9-ft reverse lift. The average maximum hawser forces measured with the 7-ft lift and gate schedules C, B, and A are shown in Plate 30 and Table 4. To maintain hawser forces of 15 tons or less, a filling time of 17.8 min was required. The average maximum hawser forces for gate schedules C, B, and A with an 11-ft lift are also shown in Plate 30 and Table 4. To maintain hawser forces of 15 tons or less with the 11-ft lift, a filling time of 22.5 min was required. The average maximum hawser forces measured with 9-ft reverse head are also included for gate schedules C, B, and A in Plate 30 and Table 4. The upstream longitudinal hawser forces were still greater than 20 tons for the slow gate operation (schedule C). Therefore, to maintain hawser forces of 15 tons or less, a filling time much greater than 25 min would be required. This was not acceptable.

End emptying with ship

Experiments were performed next with the end emptying system with the ship in the chamber. The lakeside stage was at el 0.0, and the riverside stage was set according to the lift desired for normal head conditions. The average maximum hawser forces determined for 3-, 7-, and 11-ft normal lifts and 9-ft reverse lift are shown in Plate 31 for the various gate schedules. The values are provided in Table 5. To maintain hawser forces of 15 tons or less with a 3-ft lift, an emptying time of 10.1 min was required.

The average maximum upstream longitudinal hawser forces measured with a 7-ft lift for all three gate speeds ranged from 17.0 to 17.2 tons and occurred between 0.5 and 1 min into the emptying operation. The movement of the gravity wave formed when the gates were opened caused these forces. With a 7-ft lift and this size chamber and ship, the minimum upstream longitudinal hawser forces to be expected were between 16 and 17 tons with any gate speed. The average maximum hawser forces measured with the 7-ft lift are shown in Plate 31 and listed in Table 5. Upstream longitudinal hawser forces of 15 tons or less were not achieved with the slowest gate speed (schedule C) evaluated.

For all three gate speeds tested with the 11-ft lift, the maximum upstream longitudinal hawser forces measured were 23.6 to 24.0 tons and occurred between 0.5 and 1 min into the emptying operation. As shown in Plate 31 and listed in Table 5, an average maximum upstream longitudinal hawser force of 15 tons or less was not achieved with the slowest gate speed (schedule C) evaluated.

The same tendencies observed with the normal lift were observed with the 9-ft reverse lift. The maximum downstream longitudinal hawser force occurred toward the end of the emptying operation, and the maximum upstream longitudinal hawser force occurred at the beginning of the emptying operation. The magnitudes of the average maximum downstream longitudinal hawser forces were higher than those observed with the 11-ft normal lift. The average maximum upstream longitudinal hawser forces were lower than those measured with the 11-ft lift. To maintain hawser forces of 15 tons or less with the 9-ft reverse lift, an emptying time of 33.7 min was extrapolated from the average maximum downstream longitudinal hawser forces plotted in Plate 31.

The only lift with normal head where the 15-ton limit was achieved for the gate speeds evaluated was the 3-ft lift. With 7- and 11- ft lifts, the hawser forces were greater than 15 tons even with the slowest gate speed. With a 9-ft lift and reverse head, an emptying time of 33.7 min was required to keep hawser forces less than 15 tons.

Chamber Performance with Side Port Filling and Emptying System

Side port filling with barges drafted to 11 ft

Experiments were conducted to evaluate the chamber performance of the side port filling and emptying system with a 6- by 3-barge arrangement drafted to 11 ft. The side port filling and emptying system consisted of two 18.25-ft-high by 15.0-ft-wide culverts, reverse tainter filling and emptying valves, and 28 ports 3.75 ft high by 2.54 ft wide spaced 28 ft apart. The center of the upstream ports began 274.7 ft downstream from the riverside pintle. The ports contained triangular-shaped baffles on the first 10 upstream ports, and the remaining ports contained square baffles to help direct and dissipate the energy of the flow jets as shown in Plate 32.

The system was evaluated by measuring hawser forces during filling and emptying with varying valve speeds. Typical valve speeds ranged from 1 to 12 min. The valve opening curve for the reverse tainter valves is shown in Plate 33 along with the values used for the curve. The barges were located in the chamber in the same manner as with the end filling system (Plate 7).

The average maximum longitudinal hawser forces measured with 1-, 2-, 4-, and 6-min valve operations are shown in Plate 34 and in Table 6. A 3.9-min filling time was required to maintain hawser forces of 5 tons or less with the 3-ft lift. All average maximum transverse hawser forces for this lift were less than 1.1 tons (Table 6). The average maximum longitudinal hawser forces measured for selected valve operations with 7-, 11-, and 19.6-ft normal lifts and a 9-ft reverse lift are also shown in Plate 34 and Table 6. The filling time required to maintain hawser forces of 5 tons or less with a 7-ft lift was 8.4 min. With an 11-ft lift and a 12-min valve operation, the downstream hawser forces were still slightly greater than 5 tons. The data indicated that with the 11-ft lift and 6- by 3-barge group, the maximum downstream longitudinal hawser force was between 5 and 6 tons for all the valve speeds tested. With a 12-min valve speed, the lock filled in just over 13 min. Also with the 19.6-ft lift, the average maximum downstream longitudinal hawser forces were similar for all the valve operations. This force was a result of the gravity wave in the chamber, and with this head a maximum hawser force of 5 tons could not be attained with normal valve operations. Even with a 16-min valve speed and a 19.6-ft lift, the lock filled in 17 min. The filling time required to maintain hawser forces of 5 tons or less with the 9-ft reverse lift was 8.8 min. The average maximum hawser forces measured are shown in Plate 34 and Table 6.

Experiments performed with the side port filling system with 18 barges drafted to 11 ft indicated that for lifts over 7 ft, normal valve operations did not produce hawser forces of 5 tons or less. Even with very slow valve operations, the hawser forces were greater than 5 tons.

Side port emptying with barges drafted to 11 ft

Experiments were performed to evaluate the chamber performance during emptying operations with the side port system. The placement of the barges in the chamber was the same as during filling (Plate 7), and the valve curve used to operate the emptying valves is shown in Plate 33.

The average maximum longitudinal hawser forces measured with the 3-, 7-, 11-, and 19.6-ft lifts and the 9-ft reverse lift are shown in Plate 35 and Table 7. The transverse forces are also included in Table 7. The emptying time required to maintain hawser forces of 5 tons or less with a 3-ft lift was 4.7 min and 8.2 min with a 7-ft lift. With the 11-ft lift, even with a 12-min valve operation, the hawser forces were greater than 5 tons. With the 19.6-ft lift, the hawser forces were still greater than 5 tons with a 16-min valve operation. The emptying time for a 16-min valve and a lift of 19.6 ft was 17.5 min. The filling time required to maintain hawser forces of 5 tons or less with a 9-ft reverse lift was 8.3 min.

Experiments performed with the side port emptying system with 18 barges drafted to 11 ft indicated that for lifts over 7 ft, normal valve operations did not produce hawser forces of 5 tons or less. Even with very slow valve operations, the hawser forces were greater than 5 tons.

Side port filling with ship

Experiments were conducted to evaluate the performance of the side port filling system with the ship in the chamber. The ship was placed in the chamber as shown in Plate 28.

The average maximum longitudinal hawser forces obtained for various valve speeds during filling operations with normal lifts of 3, 7, 11, and 15 ft and a reverse lift of 9 ft are shown in Plate 36 and Table 8. The average maximum transverse hawser forces are also included in Table 8. A filling time of 6.2 min was required to maintain hawser forces of 15 tons or less with the 3-ft lift and 11.5 min was required with the 7-ft lift. For the 11-ft lift, the average maximum downstream longitudinal hawser forces were higher than 15 tons with the 14-min normal valve. Normal valve refers to both culvert valves operating identically. A 15-ft lift instead of the 19.6-ft lift was tested next with the ship due to the large downstream hawser forces measured with the 11-ft lift. With a 16-min normal valve and 15-ft lift, the hawser forces were still higher than 20 tons and the filling time was greater than 16 min. The maximum longitudinal hawser forces measured with the 9-ft reverse lift were also greater than 15 tons. With a 9-ft reverse lift and a 14-min normal valve, the maximum downstream longitudinal hawser forces were higher than 18 tons and the filling time was 12.1 min.

Experiments performed with the side port filling system with the 760-ft ship drafted to 36 ft indicated that for lifts over 7 ft, normal valve operations did not produce hawser forces of 15 tons or less. Even with very slow valve operations, the hawser forces were greater than 15 tons.

Side port emptying with ship

Experiments were conducted to evaluate the performance of the side port emptying system with the ship in the chamber. Time-histories of the hawser forces, water-surface elevation, and rate of rise for a typical experiment with a 3-ft lift and 6-min valve operation are shown in Plate 37. The maximum downstream longitudinal hawser force measured for this experiment was 15.4 tons and occurred around 2 min into emptying. The maximum upstream longitudinal hawser force was 11.3 tons and occurred between 7 and 8 min after the emptying valves were opened. The lock chamber emptied in 6.2 min with this valve speed and lift, indicating that the maximum upstream longitudinal hawser force occurred during underemptying. The term underemptying is used to indicate the period of time when the lock water-surface elevation drops below the lower pool elevation due to the inertia of the flow during the emptying operation. It is similar to overfilling during a filling operation. The transverse hawser forces ranged from 0.8 to 1.2 tons. The average maximum longitudinal hawser forces obtained for the 3-ft lift are shown in Plate 38 and Table 9. Table 9 also includes the average maximum transverse hawser forces. An emptying time of 6.5 min was required to maintain hawser forces of 15 tons or less.

The average maximum longitudinal hawser forces obtained with the 7-ft lift are shown in Plate 38 and Table 9. The average maximum upstream longitudinal hawser force occurred after the emptying valves were opened (during under-emptying). An emptying time of 10.4 min was required to maintain hawser forces of 15 tons or less with the 7-ft lift. With the 11-ft lift and a 14-min normal valve, the maximum downstream longitudinal hawser forces were still higher than 15 tons (Plate 38 and Table 9). This was also the case with a 15-ft normal lift and 9-ft reverse lift. With the 15-ft lift and a 16-min normal valve, the maximum downstream longitudinal hawser forces were still higher than 20 tons. With the 9-ft reverse lift and a 14-min normal valve, the hawser forces were still higher than 15 tons.

Experiments performed with the side port emptying system with the 760-ft ship drafted to 36 ft indicated that for lifts over 7 ft, normal valve operations did not produce hawser forces of 15 tons or less. Even with very slow valve operations, the hawser forces were greater than 15 tons.

Lock Coefficient for the Side Port Filling and Emptying System

A computed lock coefficient can be used as a method to evaluate the efficiency of a filling and emptying system. An equation typically used by the U.S. Army Corps of Engineers to compute the overall lock coefficient C_L is

$$C_L = \frac{2A_L\left(\sqrt{H+d} - \sqrt{d}\right)}{A_c\left(T - kt_v\right)\sqrt{2g}} \qquad (5)$$

where

A_L = area of lock chamber, ft^2
H = initial head, ft
d = overtravel, ft
A_c = area of culverts, ft^2
T = filling time, sec
k = a constant
t_v = valve opening time, sec
g = acceleration due to gravity, ft/sec^2

Davis (1989) gives more information on the development of this equation. The term T - kt_v is the lock filling or emptying time for the hypothetical case of instantaneous valve operation and is determined directly from the curves presented in Plate 39. These curves represent the filling and emptying times determined for varying valve operations and lifts (lakeside stage at el –2.0) with the side port system. The lock coefficients computed from Equation 5 for the side port system are C_L = 0.65 for filling and C_L = 0.63 for emptying. These were computed using the 11-ft lift. The lock coefficient for filling is slightly less than those determined from previous studies of 1,200-ft chambers.

Effects of Increased Submergence with End Filling and Emptying and Side Port Filling and Emptying Systems

A few experiments were performed to determine the effects of increased submergence in the chamber. The submergence, defined as the depth between the lower pool and the floor of the lock chamber, for the previous experiments was 38 ft for the barge experiments and 40 ft for the ship experiments with normal head conditions. The submergence was increased by 5 ft, and chamber performance was evaluated for the end filling and emptying system with a 7-ft lift and 3- and 11-ft lifts with the side port filling and emptying system.

Table 10 compares the filling times to achieve 15-ton hawser forces for the ship and 5-ton hawser forces for the barges for the different submergence conditions with a 7-ft lift. The increased submergence allowed slightly faster filling times for the barges and ship, but did not have any effect on the emptying times.

The increased submergence conditions were also evaluated for the side port system and the ship in the chamber. The filling times for 15-ton hawser forces with the 40- and 45-ft submergence are shown in Table 11. For this range of lifts, the increased submergence resulted in reduced filling times from 2 to 3 min without exceeding the 15-ton hawser force limit. The emptying times for the 40- and 45-ft submergence conditions are also provided in Table 11. A reduction in emptying time was also observed with the increased submergence although not as much as observed for filling operations.

Variable Valve Speed with Side Port System and Barges

Experiments were performed with the side port system to determine the chamber performance with variable-speed valves (VSV) at varying valve speeds. The valve opening curves used with the barges in the chamber are shown in Plate 40. The curves labeled 8- and 12- min valves were the normal valve operations and the curves labeled F8BT, F12BT, E8BT, and E12BT were the curves with varying valve speeds. The valve speeds at the beginning of the opening operation were reduced from the constant speed and then increased slightly to achieve full open at the same time as a constant-speed valve operation.

Filling with VSV F8BT, 11-ft lift

The first variable valve speed operation tested was F8BT, and the lift was 11 ft. The valve was opened to 1.33 ft in 110 sec and then to full open in the remaining 370 sec. Time- histories of the water-surface and longitudinal hawser force data determined for a normal (constant speed) 8-min valve are shown in Plate 41 along with the same data obtained with valve operation F8BT. Both the upstream and downstream longitudinal hawser forces were slightly reduced with the varying valve speed. The transverse forces (which are not shown) showed no significant change. The filling time with valve speed F8BT was 10.6 min compared with 10.8 min with the normal 8-min valve.

Filling with VSV F12BT, 11-ft lift

Valve operation F12BT (Plate 40) was evaluated next with the 11-ft lift. The valve was opened to 0.87 ft in 110 sec and then to full open in the remaining 610 sec. Time-histories of the water-surface and longitudinal hawser force data determined for a normal 12-min valve are shown in Plate 42 along with the same data obtained with valve operation F12BT. Again, both the upstream and downstream longitudinal hawser forces were reduced with the varying valve speed. The filling time with valve speed F12BT was 12.9 min compared with 13.2 min with the normal 12-min valve.

Emptying with VSV E8BT, 11-ft lift

Emptying operations were also performed with varying valve operations with the 11-ft lift. For valve operation E8BT, the valve was opened to 0.72 ft in 60 sec and then to full open in the remaining 420 sec. Time-histories of the water-surface and longitudinal hawser force data determined for a normal 8-min valve and with valve operation E8BT are shown in Plate 43. The maximum upstream longitudinal hawser force was reduced from 5.3 tons to 2.7 tons, and the maximum downstream longitudinal hawser force was reduced from 6.3 tons to 4.0 tons. No significant change in transverse forces was observed. A slight increase in emptying time was observed. The emptying time with valve speed E8BT was 10.6 min compared with 10.4 min with the normal 8-min emptying valve.

Emptying with VSV E12BT, 11-ft lift

Emptying operations with a 12-min variable valve were also performed with the 11-ft lift. For valve operation E12BT, the valve was opened to 0.47 ft in 60 sec and then to full open in the remaining 660 sec. Time-histories of the water-surface and longitudinal hawser force data determined for a normal 12-min valve and with valve operation E12BT are shown in Plate 44. The maximum upstream longitudinal hawser force was reduced from 5.1 tons to 2.1 tons, and the maximum downstream longitudinal hawser force was reduced from 6.0 tons to 3.1 tons. A very slight increase in emptying time was observed. The emptying time with valve speed E12BT was 12.8 min compared with 12.7 min with the normal 12-min emptying valve.

Variable-Speed Valve with Side Port System and Ship

Filling with VSV F8ST, 11-ft lift

Variable valve operations were also performed with the side port system and the ship in the chamber (Plate 45). These varying valves were slower at the beginning of the operation than those used with the barges (Plate 40). For valve operation F8ST with the 11-ft lift, the valve was opened to 2.27 ft in 180 sec and then to full open in the remaining 300 sec. Time-histories of the water-surface and longitudinal hawser force data determined for a normal 8-min valve and an 8-min VSV are shown in Plate 46. The maximum downstream longitudinal hawser force was reduced from 21.7 tons to 16.9 tons; however, the maximum longitudinal upstream hawser force was increased from 9.0 tons to 11.1 tons. The filling time with valve speed F8ST was 10.7 min compared to 10.3 min with the normal 8-min valve.

Filling with VSV F12ST, 11-ft lift

Valve operation F12ST was evaluated next with the ship and 11-ft lift. The valve was opened to 1.55 ft in 190 sec and then to full open in the remaining 530 sec. Plate 47 shows the time-histories of the water-surface and longitudinal hawser force data determined for a normal 12-min valve and a 12-min VSV (F12ST). The maximum downstream longitudinal hawser force was reduced from 18.0 tons to 14.3 tons; however, the maximum longitudinal upstream hawser force was increased from 8.4 tons to 10.0 tons. The transverse forces showed no significant change. The filling time with valve speed F12ST was 13.1 min compared with 12.5 min with the normal 12-min valve.

Emptying with VSV E8ST, 11-ft lift

Emptying operations were also performed with varying valve operations with the ship and 11-ft lift. For VSV E8ST, the valve was opened to 1.22 ft in 100 sec and then to full open in the remaining 380 sec. Time-histories of the water-surface and longitudinal hawser force data determined for a normal 8-min valve and with VSV E8ST are shown in Plate 48. The maximum downstream longitudinal hawser force was reduced significantly from 22.3 tons to 13.2 tons, and the maximum upstream longitudinal hawser force was reduced from 11.5 tons to 10.6 tons. The transverse hawser forces were slightly increased with the variable operation. The emptying time with VSV E8ST was 11.6 min compared with 10.5 min with the normal 8-min emptying valve.

Emptying with VSV E12ST, 11-ft lift

For VSV E12ST, the valve was opened to 0.88 ft in 110 sec and then to full open in the remaining 610 sec. Time-histories of the water-surface and longitudinal hawser force data determined for a normal 12-min valve and with VSV E12ST are shown in Plate 49. The maximum downstream longitudinal hawser force was reduced from 18.6 tons to 12.6 tons, and the maximum upstream longitudinal hawser force was reduced from 10.6 tons to 9.4 tons. The emptying time with VSV E12ST was 13.7 min compared with 12.7 min with the normal 12-min emptying valve.

The experiments performed with the VSV for total valve opening times of 8 and 12 min revealed that reductions in the hawser forces could be achieved with these operations. With side port filling and barges in the chamber, both the upstream and downstream longitudinal hawser forces were reduced as well as the filling time. The maximum transverse hawser forces were not changed noticeably. With side port emptying and barges in the chamber, reductions in the maximum upstream and downstream longitudinal and transverse hawser forces were observed. The emptying times were slightly increased. With side port filling and the ship in the chamber, the maximum downstream longitudinal hawser force was reduced significantly and the maximum upstream longitudinal hawser force was increased slightly. The filling times were slightly increased. With side port emptying and the ship in the chamber, the maximum downstream longitudinal hawser force was reduced significantly and the maximum upstream longitudinal hawser force was also reduced. A slight increase in the maximum transverse forces was observed. The emptying times were increased with the variable 12-min valve operation.

Chamber Performance with Combined Side Port and End Filling and Emptying Systems

A few experiments were performed to determine chamber performance using both the side port and the end filling and emptying systems. The 11-ft lift condition with the ship in the chamber was evaluated since fast and acceptable filling times and hawser forces were not achieved for these conditions with either filling and emptying system. The first experiment was conducted with the side port filling valves opening in 14 min and initiating opening of the end fill sector gates at 6.33 min after the side port valves began opening. The end fill gates were opened to 8 ft at 14 min after filling began and stopped at this opening. Time-histories of the hawser forces and water-surface elevations measured during this experiment are shown in Plate 50. The longitudinal hawser forces were excessive. A maximum downstream longitudinal hawser force of 45.6 tons was measured between 8 and 8.5 min into filling and was caused by the end gates opening. A maximum upstream longitudinal hawser force of 22.3 tons was measured at 12 min, which was after the lock filled. The lock filling time with this operation was 11.7 min. The maximum transverse hawser forces ranged from 2.5 to 3.7 tons and were not affected significantly by the end gates opening.

The second combination of filling with the 11-ft lift consisted of a 14-min valve with the side port filling valves and gate speed C (Plate 8) with the end gates. Results shown in Plate 51 indicate that the maximum longitudinal hawser forces were reduced significantly from those shown in Plate 50; however, the filling time was slower, 14.1 min compared with 11.7 min. This filling time was similar to that determined using the side port system only with a 14-min filling valve. The hawser forces shown in Plate 51 were also similar to those determined using only the side port system with a 14-min valve. The results indicated that operating the end gates with gate speed C and the side port with a 14-min valve was not helpful in reducing filling times.

The next combination of filling with the 11-ft lift consisted of a 14-min valve with the side port filling valves and gate schedule speed B (Plate 8) with the end gates. Results shown in Plate 52 indicated that the maximum longitudinal hawser forces were not any higher than those measured with gate speed C and the filling time was faster, 13.0 min. The maximum longitudinal hawser forces were not excessive and were not significantly higher than those measured with the side port system only with a 14-min filling valve. This filling system combination showed that improvements to the chamber performance could be achieved using both systems to fill the lock. Additional experiments would be required to determine the best combinations needed to achieve 15-ton hawser forces.

Emptying experiments were conducted with the 11-ft lift, side port system with a 14-min emptying valve and various sector gate operations. The best performance was observed with gate speed C (Plate 53). The maximum longitudinal hawser forces were not excessive (but were greater than 15 tons) and were not significantly higher than those measured with the side port system only with a 14-min emptying valve. Again this emptying system combination showed that improvements to the chamber performance could be achieved using both systems to empty the lock.

Additional Pintle Torque Measurements during Gate Movement

Experiments were conducted to measure torque on the sector gate pintle caused by flow through the lock from an accident or mechanical malfunction.

There was concern over the pintle torque caused by flow through the lock chamber if the lower sector gates were in the open position and the upper gates were also inoperable.

Normal head, sector gates open initially, riverside el 1.6, lakeside el 0.5

The initial measurements were performed with all the sector gates in the open position as shown in Plate 54, a riverside stage el of 1.6, and a lakeside stage of el 0.5. Time-histories of the pintle torque, gate position, and water-surface elevations measured with these conditions are shown in Plate 55. This test (TRQ5) was performed by allowing flow through the lock with all the sector gates in the open position for 4 min. The resisting torque of the gate operating machinery as determined by the New Orleans District was 2,760 ft-kips. This resisting torque was simulated in the model with a slip clutch device. A torque greater than this amount was required to move the sector gate. As shown in Plate 55, essentially no torque was caused by the flow during the initial 4 min with the gates in the open position. The left sector gate, which contained the torque meter and slip clutch, was then manually moved from fully open to a gate location 43 ft from the lock center line. This gate position is equivalent to a gate opening of 98 ft with the tip of the gate 12 ft from the lock wall. This is indicated on the time-history by the first arrow on the left pointing to the torque time-history. The sharp spike in torque shows the resisting torque being overcome during manual movement and then dropping back to 500 ft-kips when manually released. The gate remained in this position; the flow did not move the gate. At 11 min, the gate was manually moved to a gate position 32 ft from the lock center line. The torque fluctuated between 400 and 700 ft-kips at this gate position and again was not moved by the flow. The water-surface elevations began to change during this gate position. The riverside began to rise and the lakeside began to drop as shown in Plate 55. The gate was moved to 8.5 ft from the lock center line at 16 min, and when the gate was released, the torque dropped to around zero. Again no continuous movement of the gate was observed. Additional experiments were performed with similar stages (Plates 56 and 57), and similar results were observed.

Normal head, right sector gate closed initially, riverside el 2.45, lakeside el 0

Experiments were then performed with the right (looking downstream) sector gate closed and the left gate open initially. This configuration is also shown in Plate 54. Time-histories from this experiment are shown in Plate 58. The left sector gate remained in the open position for 2.5 min and did not move. The gate was manually moved to a location 50 ft from the lock center line and left in that position until 8 min. The torque fluctuated noticeably in this position with the maximum torque observed just over 2,000 ft-kips. No continuous closure was observed. At 8 min, the gate was manually moved to 43 ft from the lock center line where the torque fluctuated between 500 and 2,500 ft-kips and no continuous closure was observed. At 13 min, when the gate was manually moved to 33 ft from the lock center line, the torque fluctuated between 250 and 2,600 ft-kips. The flow caused the gate to begin to close, and the riverside elevation began to rise. At about 20 min, the gate movement stopped at an opening of 22 ft from the lock center line with the torque still fluctuating. The gate was nudged to 15 ft from the lock center line where the mean torque was reduced and the gate closed very slightly. Another experiment was performed with similar conditions, and similar results were obtained as shown in Plate 59.

Reverse head

A few experiments were performed with reverse head and varying conditions. The gate positions for these experiments are shown in Plate 60. The first experiment was conducted with a lakeside initial el of 0 and a riverside initial el of –1.3. Time-histories measured are shown in Plate 61. The gate was manually restrained and released at time 0. The gate tended to close, and the pintle torque was around 750 ft-kips. At 2.5 min the gate opening was manually increased to 2 ft. The torque recorded was –200 ft-kips, and no continuous movement was observed. The negative torque tended to open the gate (move the gate into the recess). At 7.5 min, the gate opening was manually increased to 5 ft, and the torque was near –300 ft-kips. At 12.5 min the gate was moved to 10 ft, and the torque measured was between –1,000 and –1,200 ft-kips. When the gate was further opened to 25 and 38 ft, the torque dropped below –500 ft-kips. No continuous gate movement was observed during this experiment.

Another experiment was performed with conditions similar to those described previously (Plate 62). For this experiment, the gate was manually restrained from movement between time 0 and 2.5 min and then released. The gate opening remained at 0 ft, and the torque was between 500 and 750 ft-kips. At 5 min, the gate was moved to a 2-ft opening, and the torque dropped to –100 ft-kips. For this experiment, the torque never exceeded –500 ft-kips even with the 30-ft gate opening.

Experiments were performed next with both sector gates closed initially (Plate 60) and varying lakeside and riverside elevations. The time-histories from these experiments are provided in Plates 63-66. The sector gate opposite the instrumented gate remained in the closed position throughout the experiments. Some continuous movement was detected during these experiments; however, no rapid movements were observed.

Summary of Original Design Performance

A major focus of this model investigation was to compare the performance of the end filling and emptying system to that of the side port filling and emptying system for the shallow-draft (11-ft) barges and the deep-draft (36-ft) ship.

A comparison of the filling times to achieve 5-ton hawser forces or less for the end filling and side port systems is shown in Plate 67. The side port system was considerably faster than the end filling system. With lifts over 7 ft and normal head conditions, the 5-ton hawser limit was difficult to achieve with normal valve operations for the side port system. The data points for the side port system with 11- and 19.6-ft lifts are not shown since a 5-ton hawser force was not reached for the valve operations tested. The maximum longitudinal downstream hawser forces measured with the19.6-ft lift and side port system were between 8 and 9 tons for valve operations between 4 and 16 min. The filling time with the end fill system and an 11-ft lift was 28.7 min.

A permissible filling time given in EM 1110-2-1604 (HQUSACE 1995) for a 1,270- by 110-ft side port lock with a 20-ft lift is 7.5 min. This is based on the 5-ton hawser force limit determined from model investigations that used barges drafted to represent 9 ft. The model results shown in Plate 67 are for barges drafted to 11 ft. An equivalent hawser force for a 9-ft-draft barge estimated from the measurements made using an 11-ft-draft barge force could be obtained by multiplying the force by 9/11. For example, if the maximum downstream longitudinal hawser forces shown in Plate 34 for the side port system with an 11-ft lift were multiplied by 9/11, they would all be under 5 tons. The filling times would then be much faster and more comparable to the guidance provided in EM 1110-2-1604. The difference in chamber pintle-to-pintle length between the current study (1,360 ft) and the models used to obtain the guidance in the EM (1,270 ft) also contributes to the longer filling times determined for the IHNC Type 1 design lock.

A comparison of the emptying times determined for the end emptying and side port systems is shown in Plate 68. The side port emptying was much faster than the end emptying. With a 7-ft lift, the side port emptied in 8.2 min compared with 20 min for the end emptying. For lifts between 7 and 19.6 ft with the side port, the maximum downstream longitudinal hawser forces were slightly over 5 tons and are not shown in Plate 68. With the side port and 11-ft lift, maximum hawser forces of just over 5 tons were observed with a filling time of 10.5 min. With the 19.6-ft lift, hawser forces just over 5 tons were observed with a filling time of 17 min for the side port system.

Acceptable filling times determined for the deep-draft ship with the end filling and side port systems are shown in Plate 69. The side port system was faster than the end filling. With the 7-ft lift, the filling time for the side port was 11.5 min compared with 17.8 min for the end filling system.

Emptying times determined to obtain a 15-ton hawser force or less are shown in Plate 70 for the end emptying and side port systems. For lifts higher than 3 ft with the end emptying system and normal head, hawser forces of 15 tons could not be achieved with the gate speeds tested. This indicates this system would be extremely slow for emptying operations. The side port system was faster, but hawser forces of 15 tons or less could not be achieved for the valve operations tested for lifts greater than 7 ft.

Outlet Flow Conditions

The flow conditions observed in the outlet culvert and channel were not favorable with the original design. The flow in the outlet culvert during emptying was concentrated along the outside wall resulting in the flow conditions depicted in Plate 71. More flow discharged from the outside port and caused circulating flow in the outlet channel. The flow concentration was caused by the culvert bend and the abrupt expansion at the beginning of the outlet. The New Orleans District indicated this design should be modified.

4 Model Experiments and Results, Type 2 Design

In an effort to improve the performance of the original design lock, modifications were made to the design. The pintle-to-pintle length of the chamber was reduced from 1,360 ft to 1,270 ft. Initially the longer length of the lock was considered necessary with the end filling and emptying system. Since a decision was made by the New Orleans District to use the side port filling and emptying system, the additional length should not be needed. The intakes and outlet designs were modified in an attempt to reduce the flow separations observed during filling and emptying operations. The layout for the modified lock chamber (Type 2 design) is shown in Plate 72. The details for the Type 2 design intake are shown in Plate 73. The Type 2 design outlet was a mirror image of the Type 2 design intake.

Chamber Performance with Type 2 Design

Experiments were conducted to evaluate the lock chamber performance of the Type 2 design with barges drafted to 11 ft and positioned in the chamber as shown in Plate 74. The side port system was used for these experiments. The lakeside stage was maintained at el –2.0 for all normal lift conditions with barges in the chamber and el 0.0 with the ship in the chamber.

Filling with barges and 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift

The first chamber performance experiments with the Type 2 design were conducted with a 3-ft lift. Time-histories of data obtained during a typical experiment, Test 2, performed with a 3-ft lift and 2-min valve are shown in Plate 75. Generally, three experiments were performed for each condition to ensure repeatability. The top trace shows the longitudinal hawser forces measured during filling with a 2-min valve operation. The maximum longitudinal hawser force measured in the upstream direction during this experiment was 4.0 tons at about 1.5 min. The maximum downstream longitudinal hawser force measured was 4.8 tons at about 1 min into the filling operation. The maximum upstream and downstream transverse hawser forces ranged from 0.8 to 1.1 tons and occurred between 1.5 and 4 min into filling. The curve indicates the lock filled in 3.7 min.

The results from these experiments with the 3-ft lift are listed in Table 12 along with the other lifts evaluated. The average maximum longitudinal hawser forces determined for the experiments performed with the 3-ft lift and valve operations of 1, 2, 4, and 6 min are plotted in Plate 76 versus the filling time. The plot indicates that to maintain hawser forces of 5 tons or less, the filling time required was 3.6 min, which was achieved with a 2-min valve operation. The average maximum transverse hawser forces were less than 1.6 tons for all valve speeds tested.

The average maximum longitudinal hawser forces determined for the experiments performed with normal lifts of 7, 11, and 19.6 ft and a reverse lift of 9 ft are listed in Table 12 and plotted in Plate 76. To maintain hawser forces of 5 tons or less with a 7-ft lift, the filling time required was 5.4 min. The filling times required to maintain hawser forces of 5 tons or less with lifts of 11 and 19.6 ft were 8.0 and 16.0 min, respectively.

Experiments were performed to determine the chamber performance with reverse head conditions. The riverside was set at el 0.0 and the lakeside was set at el 9.0. The average maximum hawser forces determined for the experiments performed with the 9.0-ft reverse lift condition are listed in Table 12 and are plotted in Plate 76. A hawser force of 5 tons was not reached with the slowest valve operation tested (12 min). The average maximum downstream longitudinal hawser forces were similar for valve operations of 8, 10, and 12 min. These results indicate that the initial seiching in the chamber was similar for these valve operations and that a VSV operation was needed to reduce the downstream longitudinal hawser forces. The filling time required to maintain hawser forces of 5.9 tons or less was 8.2 min.

Emptying with barges and 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift

The performance of the Type 2 design system was also evaluated for emptying operations. These experiments were also conducted with 18 barges drafted to 11 ft. The average maximum hawser forces determined for these experiments with the 3-ft lift are listed in Table 13 and are plotted in Plate 77. The emptying time required to maintain hawser forces of 5 tons or less was 4.5 min.

The average maximum hawser forces determined for 7-, 11-, and 19.6-ft normal lifts and the 9-ft reverse lift are provided in Table 13. The average maximum longitudinal hawser forces are plotted in Plate 77. The emptying time required to maintain hawser forces of 5 tons or less with a 7-ft lift was 7.6 min. The emptying time required to maintain hawser forces of 5 tons or less with the 11-ft lift was extrapolated from the data and was determined to be 11.4 min. With a 19.6-ft lift, the emptying time to maintain hawser forces of 5 tons or less was extrapolated from the data and was 16.4 min. For the 9-ft reverse lift condition, the emptying time required to maintain hawser forces of 5 tons or less was 7.3 min.

Summary, Type 2 design side port system with barges

A plot of lift versus filling time to maintain hawser forces of 5 tons or less for lifts up to 19.6 ft and the 9-ft reverse lift is shown in Plate 78. The filling times determined with the original design (Type 1 design) are included for comparison. Faster filling times and hawser forces of 5 tons or less were achieved with the Type 2 design for lifts up to 19.6 ft. With the Type 1 design, hawser forces of 5 tons or less were not reached for lifts greater than 7 ft using very slow valve operations.

A plot of lift versus emptying time to maintain hawser forces of 5 tons or less for lifts up to 19.6 ft and the 9-ft reverse lift is shown in Plate 79. A comparison of the filling times determined with the original design (Type 1 design) is included. Faster emptying times and 5-ton hawser forces were achieved with the Type 2 design for lifts up to 19.6 ft. With the Type 1 design, 5-ton hawser forces were not reached for lifts greater than 7 ft using very slow valve operations.

Filling with ship and 3-, 7-, 11-, 15-, and 19.6-ft normal lifts and 9-ft reverse lift

Experiments were conducted to evaluate the performance of the Type 2 design side port filling system with the ship in the chamber. The ship was placed in the chamber as shown in Plate 80. The average maximum hawser forces determined with the ship in the chamber and the Type 2 design lock are listed in Table 14. The average maximum longitudinal hawser forces are plotted in Plate 81 for normal lifts of 3, 7, 11, 15, and 19.6 ft and a reverse lift of 9 ft. The following filling times were required to maintain hawser forces of 15 tons or less: 4.9 min with a 3-ft lift; 7.2 min with the 7-ft lift; 9.5 min for the 11-ft lift; 11.7 min for the 15-ft lift; and 15.5 min for the 19.6-ft lift. A filling time of 13.4 min (extrapolated from the data shown in Plate 81) was required to maintain hawser forces of 15 tons or less with the 9-ft reverse lift.

Emptying with ship and 3-, 7-, 11-, 15-, and 19.6-ft normal lifts and 9-ft reverse lift

Experiments were also conducted to evaluate the performance of the Type 2 design side port emptying system with the ship in the chamber. The average maximum hawser forces determined for normal lifts of 3, 7, 11, 15, and 19.6 ft and a reverse lift of 9 ft are listed in Table 15. The average maximum longitudinal hawser forces are plotted in Plate 82. The acceptable emptying times to keep maximum hawser forces at 15 tons or less for normal lifts of 3, 7, 11, 15, and 19.6 ft were 6.6, 10.6, 13.0, 14.4, and 15.3 min, respectively. An emptying time of 9.7 min was required to maintain hawser forces of 15 tons or less with the 9-ft reverse lift.

Summary, Type 2 side port system with ship

A plot of lift versus filling time to maintain hawser forces of 15 tons or less for lifts up to 19.6 ft and the 9-ft reverse lift is shown in Plate 83. The filling times determined with the original design (Type 1 design) are provided for comparison. Faster filling times and 15-ton hawser forces were achieved with the Type 2 design for lifts up to 19.6 ft and for the reverse head with 9-ft lift. With the Type 1 design, 15-ton hawser forces were not reached for lifts greater than 7 ft even with very slow valve operations.

Experiments performed with the side port emptying system with the 760-ft ship drafted to 36 ft indicated that a 15-ton hawser force was achieved with all lifts tested. With the Type 1 design this was not accomplished for lifts over 7 ft and very slow valve operations. A plot of lift versus emptying time to maintain hawser forces of 15 tons or less with the Type 2 design and ship is shown in Plate 84.

Variable speed valve with Type 2 Design

Type 1 VSV filling with barges. Experiments were performed to determine the effects of using a VSV with the Type 2 design for filling the lock. Results of the filling and emptying experiments with the normal (constant speed) valve operation revealed that the maximum downstream longitudinal hawser force occurs during the initial portion of the filling cycle. This is due to the amount and distribution of flow entering the chamber in combination with the seiching of the chamber (movement of the gravity wave). Observation of the time-history of the longitudinal hawser forces with a 19.6-ft lift and 8-min normal valve showed that the maximum downstream longitudinal hawser force of 6.6 tons occurred 36.4 sec after filling began. This is very close to the time required for a gravity wave to travel from the lower end of the chamber to the upper end of the chamber with a depth of 38 ft and a chamber length of 1,270 ft.

The VSV operation shown in Plate 85 was tested with a 19.6-ft lift and 18 barges drafted to 11 ft. This valve operation, designated the Type 1 VSV, consisted of a constant speed for the first 2 min to open the valve to 2.5 percent (radial), changing to a constant speed for the next 2 min to open the valve to 37.4 percent, and then changing to a constant speed for the final 2 min to open the valve fully. The filling curve and longitudinal hawser forces determined for this operation are shown in Plate 86 along with the filling curve and longitudinal hawser forces for an 8-min normal valve operation. The maximum upstream and downstream longitudinal hawser forces were reduced with this type valve operation. The maximum downstream longitudinal hawser force was 4.4 tons and occurred between 2 and 3 min into the filling operation. This force was caused by the increase in flow into the chamber after the valve speeds were switched. As mentioned previously with a 19.6-ft lift and normal valve operations, a 16.0-min filling time was required to maintain hawser forces of 5 tons or less. With the VSV operation shown in Plate 85 with a 19.6-ft lift, the filling time was 13.6 min and the maximum downstream longitudinal hawser force was 4.4 tons.

Types 2-4 VSV filling with ship. Experiments similar to those performed with the barges were conducted to determine the effects of using a VSV for filling the lock with a ship in the chamber. The results from the barge experiments indicated that the valve could be opened slightly faster than the curve shown in Plate 85. The VSV shown in Plate 87 was tested with the ship in the chamber for a lift of 11 ft. This valve operation (designated the Type 2 VSV) consisted of using a constant speed for the first 2 min to open the valve to 12.5 percent radially, changing to a constant speed for the next 2 min to open the valve to 37.4 percent, and then changing to a constant speed for the final 2 min to open the valve fully. The maximum downstream longitudinal hawser force measured was -13.2 tons, and the maximum upstream longitudinal hawser force was 15.0 tons as shown in Plate 88. The filling time for this operation was 8.6 min. The chamber performance was considered acceptable for this VSV operation. With a constant-speed valve operation and an 11-ft lift, the filling time required to maintain longitudinal hawser forces of 15 tons or less was 9.5 min. The permissible filling time was faster with the variable speed than the constant-speed valve.

Another experiment was performed with the 11-ft lift and the VSV operation shown in Plate 89. This valve operation (Type 3 VSV) consisted of using a constant speed for the first 2 minutes to open the valve to 12.5 percent and changing to a constant speed for the next 4 min to open the valve to 100 percent. The maximum downstream longitudinal hawser force measured was 13.1 tons, and the maximum upstream longitudinal hawser force was 9.8 tons as shown in Plate 90. The filling time for this operation was 8.0 min. Chamber performance was improved from the previous experiment since the filling time was reduced from 8.6 to 8.0 min and the hawser forces were also reduced. The longitudinal hawser forces measured with Type 3 VSV were less than 15 tons indicating a faster filling time was possible and could be obtained by opening the valve more in the initial portion of the operation.

An experiment with the 11-ft lift and ship using the VSV operation shown in Plate 91 was conducted next. This valve operation (designated the Type 4 VSV) consisted of using a constant speed for the first 2 min to open the valve to 17.5 percent and changing to a constant speed for the next 4 min to open the valve to 100 percent. The valve was opened 5 percent more in the first 2 min than in operations with the Type 3 VSV. The filling valve operations were performed with the Type 4 VSV, which consisted of using a constant speed for the first third of the total valve time ($T_o/T_v = 0.333$) to open the valve to 17.5 percent and changing to a constant speed for the remaining two-thirds of operation to open the valve to 100 percent. The maximum downstream longitudinal hawser force measured was 14.0 tons, and the maximum upstream longitudinal hawser force was 10.0 tons as shown in Plate 92. Chamber performance was improved since the filling time was reduced slightly from the previous experiment.

Additional experiments with Type 2 design and Type 4 VSV

Previous experiments with the Types 1 and 2 design locks showed that improvements in the chamber performance were possible using a VSV instead of a constant-speed valve. A limited number of filling and emptying experiments were performed with the ship and barges in the Type 2 design lock chamber to further evaluate chamber performance with VSV operations.

Filling with Type 4 VSV, ship, and 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift. Because of improvements to performance with the Type 4 VSV, more experiments were conducted. The average maximum of the hawser forces and the filling times determined for normal lifts of 3-, 7-, 11-, and 19.6-ft lifts and a 9-ft reverse lift are shown in Table 16. The average maximum longitudinal hawser forces measured for these lifts are plotted in Plate 93. The filling time required to keep the maximum longitudinal hawser forces at 15 tons or less with the 3-ft lift was 4.2 min. This time was achieved with the Type 4 VSV and a total valve time of 3 min. The filling time required to maintain maximum hawser forces of 15 tons or less with a constant-speed valve for the 3-ft lift and ship with the Type 2 design lock was 4.9 min.

Filling times of 6.2 and 8.0 min were required to maintain hawser forces of 15 tons or less with lifts of 7 and 11 ft, respectively. A filling time greater than the 15.5 min was required for acceptable chamber performance with the 19.6-ft lift. The 15.5-min filling time was determined with the constant-speed valve. The Type 4 VSV was not advantageous with the ship and a 19.6-ft lift. For the 9-ft reverse lift, maximum downstream longitudinal hawser forces of just over 15 tons were achieved with a 12.2-min filling time. Longer valve times gave similar results.

Emptying with Type 11 VSV, ship, and 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift. Experiments were conducted next to evaluate the performance of the Type 2 design lock and VSV operation during emptying with the ship in the chamber. The Type 11 VSV shown in Plate 94 was used for these emptying experiments. Due to the large hawser forces observed in the constant-speed valve experiments during the underemptying at the end of the emptying operation, the valve was stopped at 80 percent open. The 80 percent refers to the radial travel of the gate and is equivalent to a b/B value of 0.733.

The average maximum hawser forces determined for normal lifts of 3, 7, 11, and 19.6 ft and a reverse lift of 9 ft are shown in Table 17. The average maximum longitudinal hawser forces measured with these lifts are plotted in Plate 95. An emptying time of 5.0 min was required to maintain hawser forces of 15 tons or less with the 3-ft lift. Emptying times of 7.8, 9.6, and 12.8 min were required to maintain hawser forces of 15 tons or less with lifts of 7, 11, and 19.6 ft, respectively. An emptying time of 7.1 min was required to maintain hawser forces of 15 tons or less with the 9-ft reverse lift.

Filling with Type 4 VSV, barges, and 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift. Chamber performance was evaluated next during filling with the Type 4 VSV and 18 barges drafted to 11 ft inside the chamber. The average maximum hawser forces determined for the experiments with normal lifts of 3, 7, 11, and 19.6 ft and a reverse lift of 9 ft are provided in Table 18. The average maximum longitudinal hawser forces are plotted in Plate 96. To maintain hawser forces of 5 tons or less with lifts of 3, 7, 11, and 19.6 ft, the filling times required were 3.3, 4.8, 7.0, and 11.6 min, respectively. The filling time required to maintain hawser forces of 5.0 tons or less with a 9-ft reverse lift was 7.2 min.

Emptying with Type 11 VSV, barges, and 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift. The chamber performance of the Type 2 design system with the Type 11 VSV was also evaluated for emptying operations. These experiments were also conducted with 18 barges drafted to 11 ft. The average maximum hawser forces determined for these experiments with the 3-, 7-, 11-, and 19.6-ft normal lifts and a 9-ft reverse lift are listed in Table 19. The average maximum longitudinal hawser forces are plotted in Plate 97. The emptying times required to maintain hawser forces of 5 tons or less with normal lifts of 3, 7, and 11 ft were 4.1, 5.6, and 7.0 min, respectively. The emptying time required to maintain hawser forces of 5 tons or less with a 19.6-ft lift was extrapolated from the data and determined to be 11.0 min. The emptying time required to maintain hawser forces of 5 tons or less with a 9-ft reverse lift was 7.0 min.

Summary, Type 2 design with VSV operations

Results of the experiments with the VSV revealed that acceptable chamber performance was achieved with faster filling and emptying times than was achieved with the constant-speed valve. The only exception was filling with the 19.6-ft lift and the ship in the chamber where the filling times were essentially the same.

A plot of lift versus filling time for 15-ton hawser forces with the ship is shown in Plate 98. With the 11-ft lift, the filling time to maintain hawser forces of 15 tons or less was reduced from 9.5 min with a constant-speed valve to 8.0 min with the Type 4 VSV. The filling times were reduced for all lifts except the 19.6-ft lift. A comparison of the emptying results with the ship is shown in Plate 99. The emptying times were up to 25 percent faster with the Type 11 VSV.

The filling results with the barges and the VSV are shown in Plate 100. Filling was about 10 percent faster with the VSV for lifts up to 11 ft and was determined to be more than 25 percent faster with a lift of 19.6 ft. The emptying results (Plate 101) with the barges and VSV indicated the emptying times were reduced from 10 to 40 percent over those determined with the constant-speed valve depending on the lift. With an 11-ft lift, the emptying time was reduced from 11.4 min with the constant-speed valve to 7.0 min with the VSV. This is a reduction of almost 40 percent.

A significant improvement in chamber performance was observed with the VSV especially during emptying operations. The hawser forces during underemptying with the ship in the chamber were still noticeable although reduced from those with the constant-speed valve.

Lock Coefficient for the Type 2 Design

A lock coefficient was computed from Equation 5 with the Type 2 design. The valve operation curves for the 3-, 7-, 11-, and 19.6-ft normal lifts and 9-ft reverse lift with a constant-speed valve are shown in Plates 102 and 103, respectively. These curves represent the filling and emptying times determined for varying valve operations and lifts with the Type 2 design side port system. The lock coefficients computed from Equation 5 for the Type 2 design side port system were C_L = 0.88 for filling and C_L = 0.77 for emptying. These were computed using the 11-ft lift.

Pressure Measurements with Type 2 Design

Pressures were measured at locations throughout the filling and emptying system during steady flow conditions using piezometers. These measurements were used to quantify loss coefficients for various components of the system. Energy loss through each component is expressed as

$$H_{L_i} = K_i \frac{V^2}{2g} \tag{6}$$

where K_i is the loss coefficient for component i, and V is the culvert velocity, which is one-half of the total discharge divided by a culvert area of 18.25 ft by 15 ft.

The total energy loss coefficient for the original and Type 2 design filling systems K was determined to be 2.3 and 2.0, respectively. Distribution of this sum by lock filling components is listed in the following tabulation:

Component	Loss Coefficient K_l	
	Original Design	**Type 2 Design**
Intakes	0.4	0.2
Upstream culvert	0.2	0.1
Manifold	1.7	1.7

The total energy loss coefficient for the original and Type 2 design emptying systems K was determined to be 2.5 and 1.8, respectively. Distribution of this sum by lock filling components is listed in the following tabulation:

Component	Loss Coefficient K_l	
	Original Design	**Type 2 Design**
Manifold	1.1	1.1
Culvert	0.5	0.2
Outlet	0.9	0.5

The loss coefficients show that the intake and outlet designs with the Type 2 design were improved over the original design.

5 Summary and Conclusions

Evaluation of the proposed filling and emptying system for the IHNC replacement lock provided much information on lock filling and emptying systems to the U.S. Army Corps of Engineers.

The pintle torque results verified that the sector gate and recess designs were satisfactory for a 110-ft-wide lock. These designs were based on the Algiers gate and recess designs for a 75-ft-wide chamber. The New Orleans District indicated the pintle torque measurements were acceptable, and no attempts were made to reduce the forces by modifying the gate shape. The torque measurements made when the resisting torque, which represented the gate operating machinery, was installed indicated the gate would not open or close rapidly with flow through the chamber and with the head conditions evaluated.

Corps lock chamber performance guidance recommends that the end filling and emptying systems should be used for very low lift projects (lifts less than 10 ft). The experiments performed with the original design end filling and emptying system revealed that a lock filling time approaching 20 min was required for a 7-ft lift. A similar time was required for emptying with this lift. These times were determined for 18 barges drafted to 11 ft. Experiments to evaluate barge location in the chamber were conducted with 15 barges drafted to 11 ft. The upstream longitudinal hawser force was lower when the downstream end of the barges was closer to the lower pintle. Experiments with the 106-ft-wide by 760-ft-long ship drafted to 36 ft showed that to achieve acceptable chamber performance with a 7-ft lift, a filling time of 18 min was required. End emptying experiments with the ship revealed that emptying times required to achieve acceptable chamber performance were extremely long. With a 3-ft lift, the acceptable emptying time was greater than 10 min. Acceptable chamber performance was not achieved for normal lifts greater than 7 ft even with very slow gate operations. The performance of the end emptying system was not acceptable with a ship in the chamber.

The experiments conducted with a reverse lift of 9 ft with the barges and end filling system showed that filling times were slower than for the normal lift condition. This was also observed with the ship in the chamber. The emptying time for the reverse lift and end emptying was similar to the normal lift time with barges in the chamber. The end emptying time with the ship in the chamber and the reverse lift could not be compared since acceptable conditions were not achieved with the normal lift.

Experiments with the original design side port system provided performance data with low lifts. The original design chamber was longer than the normal 1,270-ft-long side port system. This extra length was considered necessary for the end filling and emptying system to help energy dissipation. The performance of the original design was slower than desired. Comparison to guidance in the Corps manuals was difficult since this guidance was based on barges drafted to 9 ft and the barges were drafted to 11 ft in these experiments. The slower filling times were due to the longer chamber and intake and outlet designs. The intakes and outlets were not as efficient as a conventional manifold type design.

The New Orleans District decided additional chamber experiments were needed with the side port system and pintle-to-pintle chamber length of 1,270 ft. The intake and outlet design were also changed to help reduce filling and emptying times. These changes were designated the Type 2 design lock. Chamber performance with the type 2 design was improved over the original design side port system. Filling times were reduced and maximum hawser forces of 5 tons or less were obtained with lifts up to 19.6 ft with the barges in the chamber. Faster filling times were also observed with the ship in the chamber. The reverse lift experiments showed that the filling time was slower than the filling time with the same normal lift. During emptying with the barges in the chamber and the reverse lift, the emptying times were faster than for the same lift under normal conditions. The same tendencies were observed with the ship in the chamber although the filling time with a reverse lift of 9 ft was 13.4 min compared to a filling time of 8.3 min with a normal lift of 9 ft. This was more extreme than observed with the barges and the reverse lift (6.7 min normal lift compared to 8.2 min reverse lift).

Evaluation of the Type 2 design lock based on hawser forces measured inside the chamber showed that the maximum downstream and upstream longitudinal hawser forces occurred during the initial portion (1 to 2 min) of the filling operation. These values were reduced using slower valve times at the expense of slowing down the filling operation. The same conditions were observed with the barges in the chamber during emptying operations. With the ship in the chamber, the maximum upstream and downstream longitudinal hawser forces also were measured in the early portion of the filling operation. During emptying with the ship in the chamber, the maximum downstream longitudinal hawser force occurred in the early portion of the emptying operation. The maximum upstream longitudinal hawser force occurred at the end of the emptying operation during underemptying.

A VSV operation was tested to try to reduce the hawser forces. The logic was to slow the valves initially and reduce the hawser forces early in the filling or emptying operation, then speed the valve up to minimize the overall filling or emptying time. Of the VSV operations tested for filling, the Type 4 VSV was most effective in reducing the hawser forces early in the operation. This valve operation consisted of using a constant speed for the first one-third of the total time to open the valve to 17.5 percent and changing to a constant speed for the final two-thirds of operation to open the valve to 100 percent.

The Type 11 VSV was the most effective of the VSVs tested during emptying experiments. This operation consisted of a constant speed to open the valve to 17.5 percent in the first one-third of the total time and then opening the valve using a constant speed to 80 percent in the final two-thirds of total time. The 80 percent was the radial travel of the gate and was equivalent to a *b/B* value of 0.733. This operation reduced the high hawser forces in the initial portion of the operation and eliminated the high upstream hawser forces during the underemptying with the ship in the chamber.

The Type 2 design lock with the Type 4 VSV during filling operations and Type 11 VSV during emptying operations provided the best hydraulic performance of the designs tested. The filling and emptying times were acceptable and the flow conditions at the intake and outlet were satisfactory. No strong vortices were observed in the upper approach during filling with the 19.6-ft head (largest discharge) and Type 2 design intake, and flow discharging from the outlet spread uniformly into the outlet channel with the Type 2 design outlet. The outlet design was a mirror image of the intake design shown in Plate 73.

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Table 1
Pintle Torque Measurements, ft-kips

Gate Opening, ft	9-ft Direct Head	9-ft Reverse Head	19.6-ft Direct Head	2-ft Direct Head
2	558	911	1742	257
4	1784	736	1963	400
6	1866	-499	2342	310
8	1947	-1733	2721	221
10	2113	-2815	3770	247
12	2279	-3896	4818	273
14	2292	-4436	5266	329
16	2305	-4976	5714	384
18	2334	-5217	6162	415
20	2363	-5457	6561	446
22	2497	-5546	6961	446
24	2630	-5653	7360	446
26	2786	-5718		477
28	2942	-5783		508
30	3099	-5827		546
32	3255	-5871		583
34	3412	-5903		619
36	3568	-5934		654
38	3911	-5931		734
40	4254	-5928		814
42	4598	-5923		858
44	4941	-5918		902
46	5284	-5966		951
48	5627	-6015		999
50		-6063		1048
52		-6112		1097
54		-6160		1131
56		-6208		1165
58		-6257		1152
60		-6305		1139
62		-6354		
64		-6402		
66		-6450		
68		-6499		
70		-6547		
72		-6595		
74		-6644		
76		-6692		
78		-6741		
80		-6789		

Note: Direct Head - Lakeside El = +1.0
Reverse Head - Riverside El = 0.0

Table 2
Filling Characteristics, Original Design, End Filling System, 18 Barges with 11-ft Draft

Lift, ft	Gate Schedule	Average Maximum Hawser Forces, tons						Filling Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	E	9.8	-5.8	2.0	-0.8	1.5	-1.3	5.1
	D	5.5	-5.0	1.9	-1.2	1.8	-1.6	6.4
	A	2.8	-2.9	1.6	-1.0	1.8	-1.8	10.1
7.0	D	19.7	-8.2	5.5	-4.2	5.7	-4.7	7.8
	A	12.4	-5.5	4.3	-4.0	4.3	-4.2	11.7
	B	5.4	-4.6	3.6	-3.7	3.1	-3.8	18.9
11.0	A	19.9	-6.0	6.3	-7.7	7.1	-7.0	12.4
	B	11.2	-5.2	3.8	-5.0	5.5	-4.1	19.9
	C	8.4	-6.1	4.3	-4.1	4.8	-4.4	26.3
19.6	A	37.1	-10.0	8.1	-11.9	7.9	-9.1	15.0
	B	19.4	-11.6	6.4	-8.8	6.8	-6.5	21.6
	C	14.8	-8.5	5.7	-9.1	8.4	-7.4	28.4
9-Reverse	A	12.4	-5.7	2.2	-2.0	6.1	-2.1	13.2
	B	8.7	-4.7	1.2	-1.8	2.1	-1.8	19.9
	C	6.2	-4.4	2.0	-2.1	1.9	-2.7	25.6

Table 3
Emptying Characteristics, Original Design, End Emptying System, 18 Barges with 11-ft Draft

Lift, ft	Gate Schedule	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	E	6.9	-8.5	1.0	-0.9	0.9	-1.0	6.1
	D	4.9	-5.0	0.9	-1.0	1.0	-1.1	7.3
	A	2.9	-3.0	0.7	-1.0	0.9	-0.9	10.0
7.0	A	4.5	-5.9	1.5	-1.6	1.4	-1.5	12.9
	B	4.6	-5.4	1.4	-1.5	1.7	-1.5	20.0
	C	4.5	-4.9	0.8	-1.4	1.2	-1.2	25.5
11.0	A	7.3	-7.6	2.5	-2.4	1.6	-1.7	14.1
	B	6.8	-6.9	2.4	-2.9	2.6	-2.8	20.9
	C	6.9	-6.3	1.3	-2.1	1.4	-1.6	26.7
19.6	C	12.1	-11.1	4.8	-3.9	3.8	-4.1	32.1
9-Reverse	A	6.1	-4.4	1.0	-2.0	1.7	-1.3	13.9
	B	5.7	-3.9	1.4	-1.7	1.7	-1.7	22.5
	C	4.8	-2.3	1.4	-2.2	2.0	-1.7	30.7

Table 4
Filling Characteristics, Original Design, End Filling System, 760- x 106- x 36-ft Ship

Lift, ft	Gate Schedule	Average Maximum Hawser Forces, tons						Filling Time min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	D	16.8	-31.0	1.0	-0.6	0.6	-0.6	6.7
	A	7.5	-14.6	0.8	-0.2	0.3	-0.5	10.7
	B	4.6	-8.4	0.7	-0.4	0.3	-0.6	17.8
7.0	A	12.2	-24.5	1.2	-1.4	0.4	-1.0	12.1
	B	7.2	-13.3	0.9	-0.9	0.5	-0.8	19.5
	C	7.9	-8.6	0.9	-0.4	0.5	-0.8	25.5
11.0	A	18.1	-31.9	1.3	-3.9	0.8	-3.0	13.0
	B	10.4	-18.4	1.2	-2.7	0.9	-1.3	21.0
	C	10.3	-11.3	1.0	-1.5	0.7	-1.0	28.4
9-Reverse	A	27.9	-13.8	1.9	-3.2	1.1	-6.3	12.9
	B	22.8	-7.5	0.6	-1.5	1.4	-2.6	19.7
	C	22.4	-7.2	0.5	-1.6	1.0	-1.7	25.7

Table 5
Emptying Characteristics, Original Design, End Emptying System, 760- x 106- x 36-ft Ship

Lift, ft	Gate Schedule	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	D	16.8	-31.6	1.2	-1.1	1.6	-0.7	6.9
	A	11.0	-12.7	0.6	-0.7	1.1	-0.7	10.6
	B	10.5	-7.4	0.4	-0.8	0.8	-0.6	16.5
7.0	A	17.1	-25.6	1.9	-0.8	3.4	-0.7	12.4
	B	17.0	-12.4	0.9	-1.2	1.8	-0.7	19.1
	C	17.2	-11.1	0.6	-1.5	1.3	-0.8	25.0
11.0	A	23.8	-40.1	3.0	-0.7	5.8	-1.1	13.4
	B	23.6	-18.8	1.6	-1.3	3.3	-0.9	20.3
	C	24.0	-15.8	1.0	-1.3	2.2	-1.1	26.2
9-Reverse	A	7.7	-45.1	1.1	-1.3	0.7	-2.4	14.4
	B	7.5	-25.8	1.1	-0.7	0.6	-1.7	22.9
	C	6.3	-18.2	1.2	-0.3	0.7	-1.3	30.5

Table 6
Filling Characteristics, Original Design, Side Port System, 18 Barges with 11-ft Draft

Lift, ft	Gate Operation min	Average Maximum Hawser Forces, tons						Filling Time min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	1.0	6.5	-6.2	1.1	-0.7	1.1	-0.9	3.5
	2.0	4.1	-4.5	0.9	-0.8	1.1	-1.1	4.0
	4.0	2.9	-3.8	1.0	-0.5	0.9	-1.2	5.2
	6.0	2.9	-3.9	0.9	-0.4	0.8	-0.9	6.3
7.0	4.0	4.8	-5.5	1.6	-0.9	1.2	-1.8	6.7
	6.0	4.5	-5.3	1.2	-0.8	1.3	-0.9	7.8
	8.0	3.9	-4.8	1.0	-0.6	0.9	-0.7	9.1
	10.0	3.2	-4.6	1.1	-0.6	0.9	-0.7	10.4
11.0	4.0	5.6	-6.3	1.9	-1.6	1.6	-2.1	8.9
	8.0	5.2	-6.1	1.3	-0.8	1.4	-1.2	10.7
	10.0	4.3	-6.0	1.1	-0.7	1.0	-1.4	12.0
	12.0	4.8	-6.2	1.1	-0.6	1.0	-1.0	13.2
19.6	4.0	9.0	-9.1	3.1	-1.8	1.9	-2.9	11.5
	8.0	7.5	-8.9	1.9	-1.3	1.7	-1.4	13.3
	12.0	6.4	-8.9	1.3	-1.1	1.3	-1.4	15.2
	16.0	6.9	-9.0	1.9	-1.3	1.6	-1.8	17.0
9-Reverse	4.0	6.8	-7.2	2.5	-1.7	2.0	-2.2	7.3
	8.0	4.6	-4.6	1.8	-1.1	1.5	-1.7	9.1
	10.0	4.1	-4.8	1.7	-1.1	1.7	-1.9	10.3
	12.0	4.2	-4.2	1.4	-0.8	1.2	-1.2	11.1

Table 7
Emptying Characteristics, Original Design, Side Port System, 18 Barges with 11-ft Draft

Lift, ft	Gate Operation min	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	1.0	8.6	-8.7	1.4	-1.4	1.3	-1.4	3.6
	2.0	5.2	-6.1	1.1	-1.4	1.4	-1.1	4.1
	4.0	3.2	-4.2	1.0	-1.3	1.6	-1.1	5.2
	6.0	3.1	-3.1	1.1	-1.1	1.3	-1.2	6.2
7.0	4.0	5.0	-6.0	1.4	-1.7	1.7	-1.6	6.7
	6.0	3.8	-5.1	1.2	-1.4	1.6	-1.5	7.8
	8.0	4.0	-4.6	1.3	-1.6	1.5	-1.4	8.9
	10.0	3.6	-4.7	0.9	-1.1	1.4	-0.9	10.0
11.0	4.0	6.5	-7.6	1.7	-2.3	2.2	-2.0	10.4
	8.0	5.4	-7.0	1.0	-1.6	1.8	-1.8	10.4
	10.0	4.8	-6.4	1.1	-1.4	1.6	-1.5	11.6
	12.0	4.9	-6.4	1.2	-1.4	1.7	-1.4	12.7
19.6	4.0	5.7	-7.2	2.8	-3.3	3.3	-3.1	11.3
	8.0	5.0	-6.0	2.2	-2.8	2.5	-2.7	13.3
	12.0	4.2	-5.5	1.4	-2.0	2.0	-2.0	15.2
	16.0	4.0	-5.4	1.2	-1.9	1.9	-1.4	17.5
9-Reverse	4.0	5.2	-4.9	1.1	-1.5	1.8	-1.5	7.6
	8.0	4.6	-3.3	1.0	-1.6	1.5	-1.3	9.8
	10.0	4.5	-3.2	1.2	-1.4	1.6	-1.5	10.9
	12.0	4.6	-3.0	1.1	-1.5	1.6	-1.4	12.0

Table 8
Filling Characteristics, Original Design, Side Port System, 760-ft Ship with 36-ft Draft

Lift, ft	Gate Operation min	Average Maximum Hawser Forces, tons						Filling Time min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	2.0	22.8	-26.5	1.5	-1.5	1.2	-1.5	3.8
	4.0	11.1	-18.5	1.3	-1.1	0.9	-1.2	5.0
	6.0	6.4	-15.2	1.4	-0.7	1.0	-1.1	6.1
	8.0	5.7	-12.9	1.4	-0.6	1.0	-1.1	7.2
7.0	8.0	7.0	-18.5	1.7	-1.6	1.4	-1.7	8.8
	10.0	6.2	-16.1	1.3	-1.3	1.2	-1.5	10.0
	12.0	6.5	-15.3	1.2	-1.2	1.0	-1.3	11.1
	14.0	6.3	-14.3	1.1	-0.9	0.8	-1.1	12.5
11.0	8.0	9.0	-21.8	2.0	-2.7	1.7	-2.3	10.3
	10.0	8.6	-19.6	1.7	-2.3	1.7	-2.3	11.5
	12.0	8.4	-18.1	1.7	-1.6	1.5	-2.0	12.6
	14.0	8.7	-17.4	1.2	-1.4	1.2	-1.5	14.1
15.0	10.0	11.3	-22.5	1.8	-2.5	2.0	-2.7	12.7
	12.0	11.7	-21.4	1.6	-2.0	1.8	-2.3	13.7
	14.0	11.8	-20.3	1.3	-1.9	1.8	-2.4	14.9
	16.0	11.6	-20.3	1.5	-1.6	1.7	-2.3	16.2
9-Reverse	8.0	11.9	-26.2	1.5	-3.0	2.8	-2.1	8.8
	10.0	8.6	-22.5	1.6	-2.9	2.2	-2.4	10.1
	12.0	8.2	-20.3	1.3	-2.0	1.7	-1.6	11.1
	14.0	7.7	-18.6	1.5	-2.0	1.2	-1.5	12.1

Table 9
Emptying Characteristics, Original Design, Side Port System, 760-ft Ship with 36-ft Draft

Lift, ft	Gate Operation min	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	2.0	15.0	30.0	6.0	-1.7	3.9	-1.6	4.1
	4.0	15.4	-20.4	3.9	-0.9	2.6	-0.7	5.1
	6.0	11.8	-15.8	0.8	-0.9	2.6	-0.7	6.2
	8.0	9.4	-12.8	0.7	-1.0	1.3	-0.9	7.2
7.0	8.0	13.4	-17.1	2.7	-1.3	2.3	-1.2	9.0
	10.0	12.1	-15.4	1.2	-1.4	1.6	-1.2	10.1
	12.0	9.4	-13.9	1.0	-1.1	1.5	-1.0	11.2
	14.0	8.1	-13.1	0.9	-1.0	1.2	-0.8	12.3
11.0	8.0	11.5	-21.9	1.5	-1.4	1.9	-1.2	10.6
	10.0	11.6	-19.9	1.5	-1.3	1.9	-1.2	11.6
	12.0	10.6	-18.5	1.3	-1.4	1.6	-1.2	12.8
	14.0	9.4	-17.8	1.0	-1.2	1.4	-1.2	14.0
15.0	10.0	14.0	-24.2	1.4	-1.3	1.9	-1.5	13.3
	12.0	12.7	-22.3	1.2	-1.0	1.8	-1.2	14.2
	14.0	11.9	-21.4	1.2	-1.1	1.6	-1.4	15.6
	16.0	12.0	-21.1	1.1	-1.3	1.4	-1.2	17.1
9-Reverse	8.0	8.7	-17.7	0.9	-1.2	1.3	-2.0	9.8
	10.0	11.8	-18.1	0.9	-0.9	1.2	-2.0	10.4
	12.0	9.1	-16.7	1.1	-0.9	1.2	-2.0	11.3
	14.0	8.8	-15.8	1.1	-0.9	1.0	-1.9	12.4

Table 10
Effects of Increased Submergence, Original Design, End Filling and Emptying System, 7-ft Lift

Operation	Submergence, ft	Riverside El	Lakeside El	Operation Time for Acceptable Hawser Forces, min
Barges				
Filling	38	5.0	-2.0	19.3
	43	10.0	3.0	16.8
Emptying	38	5.0	-2.0	20 to 25
	43	10.0	3.0	20 to 25
Ship				
Filling	40	7.0	0.0	17.8
	45	12.0	5.0	13.4
Emptying	40	7.0	0.0	_[1]
	45	12.0	5.0	_[1]

[1] 15-ton hawser forces were not achieved.

Table 11
Effects of Increased Submergence, Side Port Filling and Emptying System, Original Design, 760-ft Ship with 36-ft Draft

Operation	Submergence, ft	Riverside El	Lakeside El	Operation Time for Acceptable Hawser Forces, min
3-ft Lift				
Filling	40	3.0	0.0	6.2
	45	8.0	5.0	4.3
Emptying	40	3.0	0.0	6.5
	45	8.0	5.0	5.3
7-ft Lift				
Filling	40	7.0	0.0	11.5
	45	12.0	5.0	8.3
Emptying	40	7.0	0.0	10.4
	45	12.0	5.0	9.2
11-ft Lift				
Filling	40	11.0	0.0	_[1]
	45	16.0	5.0	12.7
Emptying	40	11.0	0.0	_[1]
	45	16.0	5.0	12.9

[1] 15-ton hawser forces were not achieved.

Table 12
Filling Characteristics, Type 2 Design, 18 Barges with 11-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons: Longitudinal Upstream	Longitudinal Downstream	Upstream Transverse Right	Upstream Transverse Left	Downstream Transverse Right	Downstream Transverse Left	Filling Time min
3.0	1.0	7.4	-7.2	1.5	-1.1	1.6	-1.3	3.2
	2.0	4.3	-4.7	0.9	-0.7	0.9	-0.8	3.8
	4.0	2.2	-3.1	0.9	-0.5	0.9	-0.8	4.9
	6.0	2.1	-2.8	0.9	-0.6	0.9	-0.9	6.1
7.0	1.0	11.1	-10.1	1.1	-1.0	0.7	-0.9	4.5
	2.0	5.7	-6.6	1.1	-0.8	0.6	-0.7	5.1
	4.0	3.3	-4.7	1.2	-1.1	1.2	-1.2	5.7
	6.0	2.4	-3.9	1.6	-1.0	1.5	-2.3	6.9
	8.0	1.9	-3.4	1.9	-1.6	1.3	-1.9	8.2
	10.0	2.1	-3.4	2.0	-0.5	0.4	-1.9	9.4
11.0	2.0	7.9	-8.3	1.2	-1.1	0.9	-1.0	6.9
	4.0	4.3	-5.7	1.0	-1.0	0.8	-0.8	7.7
	6.0	3.4	-5.1	0.9	-0.5	0.6	-0.8	8.6
	8.0	3.3	-4.7	1.3	-0.7	0.9	-1.3	9.6
	10.0	2.4	-4.0	1.0	-0.5	0.5	-1.0	10.9
19.6	8.0	4.7	-6.4	1.3	-0.9	1.0	-1.4	12.0
	12.0	3.4	-5.7	1.6	-0.9	1.2	-1.3	14.1
	16.0	3.7	-5.0	1.0	-0.7	0.9	-0.9	16.2
9-Reverse	4.0	-7.7	7.0	1.3	-0.9	0.9	-1.9	6.1
	8.0	-6.0	4.6	1.2	-0.4	0.6	-1.1	8.2
	10.0	-5.8	4.0	1.3	-0.6	0.7	-1.4	9.4
	12.0	-5.9	4.3	1.1	-0.6	0.6	-1.2	10.5

Table 13
Emptying Characteristics, Type 2 Design, 18 Barges with 11-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	1.0	8.0	-9.4	0.5	-0.5	0.5	-0.3	3.5
	2.0	5.3	-6.5	0.6	-0.4	0.6	-0.4	4.0
	4.0	3.6	-4.5	0.7	-0.4	0.6	-0.5	5.1
	6.0	2.3	-3.9	0.5	-0.3	0.3	-0.3	6.0
7.0	1.0	12.0	-14.0	1.2	-1.4	0.8	-0.9	4.4
	2.0	8.7	-9.6	1.5	-1.0	0.9	-0.9	5.0
	4.0	4.1	-6.4	0.6	-0.7	0.8	-0.6	6.0
	6.0	3.7	-5.6	0.6	-0.6	0.7	-0.7	7.0
	8.0	3.9	-5.1	1.6	-1.8	1.0	-1.8	8.2
	10.0	4.2	-4.9	1.6	-1.8	0.5	-1.9	9.1
11.0	2.0	10.0	-11.4	0.6	-1.1	0.7	-0.6	6.4
	4.0	5.4	-7.7	0.6	-0.8	0.7	-0.1	7.5
	6.0	4.8	-6.9	0.6	-0.8	1.0	-0.8	8.5
	8.0	4.5	-6.6	0.8	-1.0	1.0	-0.9	9.4
	10.0	4.4	-6.1	0.6	-0.7	0.9	-0.6	10.6
	12.0	4.4	-6.0	0.7	-0.6	0.8	-0.7	11.8
19.6	6.0	5.2	-8.3	0.5	-1.2	0.8	-0.8	10.4
	8.0	5.1	-7.7	0.6	-1.0	0.9	-0.7	11.9
	12.0	4.3	-7.1	0.9	-0.8	0.9	-0.6	14.2
	16.0	3.4	-5.3	0.7	-0.8	0.8	-0.8	16.0
9-Reverse	4.0	-5.2	4.3	-0.6	0.7	-1.1	0.5	6.9
	8.0	-4.1	3.2	-0.8	0.5	-1.0	0.6	9.0
	10.0	-3.5	2.8	-0.7	0.7	-1.0	0.7	10.2
	12.0	-3.4	2.8	-0.6	0.6	-0.8	0.6	11.5

Table 14
Filling Characteristics, Type 2 Design, 760-ft Ship with 36-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Filling Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	2.0	22.0	-23.4	1.5	-0.8	0.7	-1.5	4.0
	4.0	11.6	-14.6	1.1	-0.5	0.9	-1.1	5.0
	7.0	7.3	-9.6	1.3	-0.6	1.1	-1.2	7.0
7.0	4.0	12.3	-20.7	1.7	-1.0	1.2	-1.8	5.5
	7.0	7.5	-14.6	1.1	-1.0	1.4	-1.2	7.3
	8.0	5.7	-13.3	1.3	-1.0	1.5	-1.3	8.0
11.0	7.0	8.6	-16.5	1.4	-1.2	1.7	-1.6	8.2
	8.0	7.8	-15.8	1.5	-1.3	1.8	-1.5	9.0
	10.0	6.6	-14.3	1.5	-1.4	2.0	-1.6	10.0
15.0	10.0	7.8	-15.5	1.7	-1.6	2.1	-1.8	10.6
	12.0	7.4	-15.1	1.5	-1.8	2.1	-1.8	11.6
	14.0	8.2	-14.1	1.4	-1.8	1.8	-1.7	12.8
19.6	10.0	9.1	-17.7	1.9	-2.1	2.6	-2.3	12..8
	12.0	8.8	-16.3	1.9	-2.4	2.6	-2.4	13.5
	14.0	9.5	-16.0	1.8	-2.0	2.2	-2.1	14.5
	16.0	10.2	-15.7	1.8	-2.1	2.0	-2.2	15.5
9-Reverse	8.0	5.6	-26.0	2.2	-2.2	2.3	-2.0	7.7
	12.0	5.3	-20.4	2.1	-1.9	2.2	-1.6	9.6
	14.0	5.5	-19.1	1.6	-1.6	1.9	-1.4	10.4

Table 15
Emptying Characteristics, Type 2 Design, 760-ft Ship with 36-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	2.0	18.8	-27.8	0.9	-0.8	0.5	-1.0	3.9
	4.0	15.4	-19.9	0.9	-0.8	0.8	-0.9	5.1
	7.0	12.4	-14.5	1.1	-0.9	0.9	-1.2	7.0
7.0	4.0	21.2	-25.7	1.5	-1.1	0.8	-1.5	5.9
	7.0	18.8	-18.6	1.3	-1.1	1.1	-1.4	7.6
	8.0	17.5	-18.5	1.4	-1.0	1.1	-1.3	8.0
	10.0	14.8	-17.6	1.1	-0.9	1.1	-0.9	9.0
	12.0	12.8	-17.0	1.1	-1.0	1.0	-1.0	9.9
11.0	7.0	18.3	-21.2	1.6	-1.0	0.9	-1.6	8.6
	8.0	19.5	-20.9	1.3	-1.2	1.0	-1.6	9.1
	10.0	18.1	-18.9	1.2	-1.0	1.1	-1.3	10.2
	14.0	-17.2	13.5	1.2	-0.9	0.9	-1.2	12.3
15.0	10.0	19.4	-18.9	1.3	-1.5	1.0	-1.6	11.0
	12.0	17.3	-18.7	1.5	-1.1	1.1	-1.5	12.0
	14.0	15.0	-16.7	1.3	-1.1	1.0	-1.4	13.0
	16.0	9.5	-15.8	1.3	-1.3	0.9	-1.6	14.3
19.6	10.0	17.3	-18.3	1.8	-1.1	1.1	-1.8	12.3
	12.0	16.6	-16.8	1.7	-1.1	0.9	-1.7	13.3
	14.0	15.9	-15.3	1.5	-0.8	0.8	-1.7	14.4
	16.0	14.4	-15.1	1.5	-0.8	0.8	-1.6	15.4
9-Reverse	8.0	10.9	-18.5	2.0	-1.4	1.2	-2.0	7.9
	12.0	9.4	-15.0	1.0	-0.9	0.9	-1.0	9.7
	14.0	8.5	-14.3	0.9	-0.8	0.8	-1.1	10.5

Table 16
Filling Characteristics, Type 2 Design, Type 4 VSV, 760-ft Ship with 36-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Filling Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	3.0	14.1	-15.3	0.9	-0.8	0.8	-1.3	4.2
	4.0	12.3	-11.2	0.8	-0.7	0.8	-1.0	4.6
7.0	3.0	20.4	-20.6	2.0	-1.3	1.3	-2.9	5.5
	4.0	14.5	-14.9	1.4	-1.1	1.4	-1.7	6.2
11.0	4.0	14.6	-17.3	2.9	-2.5	2.4	-3.3	7.0
	6.0	9.4	-14.8	1.6	-2.0	2.1	-1.6	8.2
19.6	12.0	11.9	-16.7	2.3	-2.2	1.9	-1.8	15.0
	14.0	10.6	-16.0	1.9	-2.2	2.0	-1.6	16.0
	16.0	11.7	-16.5	1.7	-2.3	2.0	-1.4	17.4
9-Reverse	12.0	7.4	-16.3	2.4	-1.2	1.2	-2.1	11.5
	14.0	6.7	-15.7	1.3	-1.2	1.5	-1.3	12.2
	16.0	7.8	-16.4	1.1	-1.8	1.5	-1.5	13.2

Table 17
Emptying Characteristics, Type 2 Design, Type 11 VSV, 760-ft Ship with 36-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	3.0	12.7	-15.9	1.0	-1.1	1.0	-1.2	4.9
	4.0	12.4	-10.3	1.1	-2.1	1.0	-2.2	5.5
7.0	3.0	13.0	-20.6	1.4	-1.4	1.3	-1.6	6.8
	4.0	13.5	-14.6	1.5	-1.3	1.1	-1.5	8.0
11.0	4.0	11.1	-17.2	1.5	-1.4	1.2	-1.6	8.4
	6.0	11.8	-15.2	1.6	-1.2	1.2	-1.5	9.6
19.6	6.0	10.1	-15.6	1.7	1	1	-1.5	12.4
	8.0	10.0	-14.1	1.8	-0.9	0.9	-1.9	13.6
	10.0	9.7	-13.0	1.7	-0.7	1.1	-1.5	14.7
	12.0	10.0	-12.2	1.6	-0.9	1.1	-1.4	16.0
9-Reverse	3.0	8.9	-16.8	0.8	-0.9	1.3	-0.9	6.7
	4.0	9.5	-13.8	0.8	-1.2	1.4	-1.0	7.3
	6.0	9.4	-12.5	0.9	-0.8	1.0	-0.9	9.0
	8.0	14.0	-12.0	0.9	-5.2	0.9	-0.8	9.7
	12.0	8.0	-10.7	0.7	-0.9	0.8	-0.6	11.9

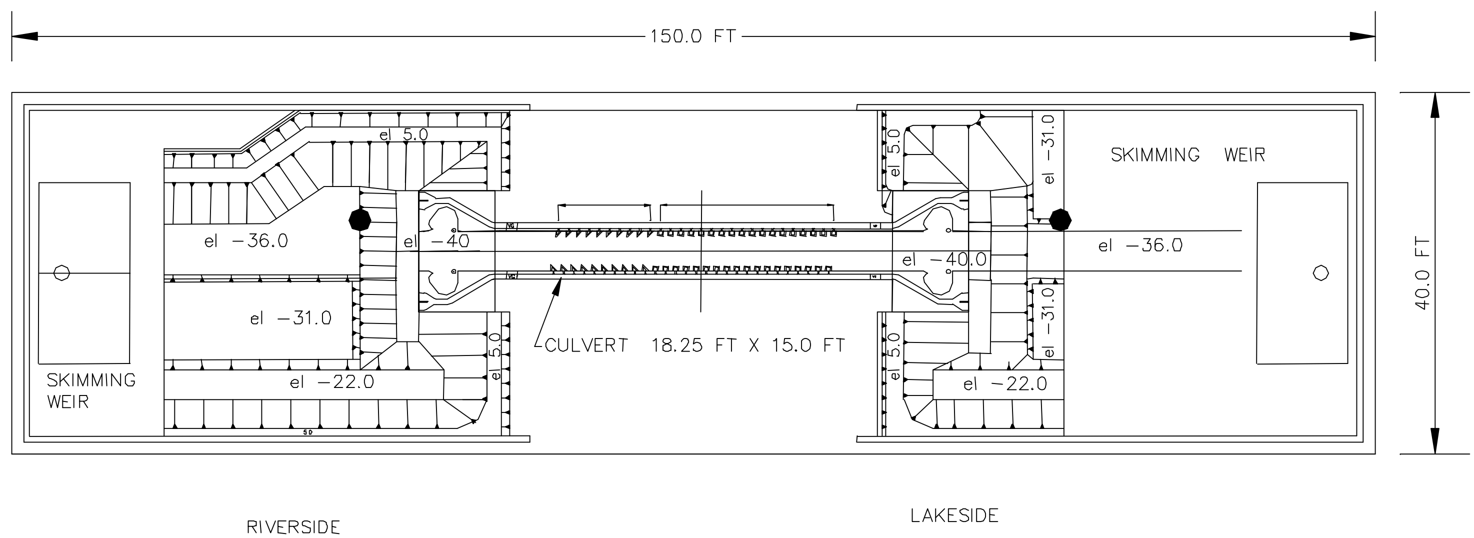
Table 18
Filling Characteristics, Type 2 Design, Type 4 VSV, 18 Barges with 11-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Filling Time min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	1.0	7.4	-5.4	0.3	-0.6	0.5	-0.3	3.3
	2.0	2.7	-3.5	0.3	-0.5	0.4	-0.3	3.9
7.0	1.0	12.5	-8.3	0.6	-0.8	0.4	-0.5	4.3
	2.0	5.2	-5.0	0.6	-0.5	0.6	-0.5	4.8
	4.0	3.4	-4.1	0.5	-0.4	0.4	-0.5	5.7
11.0	2.0	5.4	-6.2	1.1	-0.8	0.8	-0.7	6.3
	4.0	3.8	-5.1	0.8	-0.5	0.6	-0.6	7.5
19.6	8.0	5.3	-6.2	1.1	-0.7	0.8	-0.8	10.5
	10.0	4.4	-4.7	0.8	-0.6	0.6	-0.6	12.0
9-Reverse	4.0	5.3	-5.4	1.0	-0.4	1.2	-0.4	6.9
	6.0	3.0	-3.9	0.7	-0.4	0.8	-0.4	7.9

Table 19
Emptying Characteristics, Type 2 Design, Type 11 VSV, 18 Barges with 11-ft Draft

Lift, ft	Valve Operation min	Average Maximum Hawser Forces, tons						Emptying Time, min
		Longitudinal		Upstream Transverse		Downstream Transverse		
		Upstream	Downstream	Right	Left	Right	Left	
3.0	1.0	6.1	-5.4	0.4	-0.9	0.6	-0.6	3.9
	2.0	3.1	-3.0	0.4	-0.7	0.6	-0.4	4.5
7.0	1.0	7.9	-8.0	0.7	-0.7	0.5	-0.5	5.2
	2.0	3.4	-4.0	0.8	-0.8	0.8	-0.6	5.8
	4.0	2.9	-3.6	0.6	-0.4	0.3	-0.5	6.8
11.0	1.0	7.2	-9.0	0.9	-0.8	0.6	-0.6	6.5
	2.0	4.3	-4.2	0.7	-0.8	0.7	-0.6	7.1
19.6	6.0	2.9	-4.3	0.4	-1.1	0.5	-0.4	12.1
	10.0	2.8	-3.4	0.4	-0.7	0.6	-0.2	14.2
9-Reverse	2.0	4.7	-5.8	0.8	-0.7	0.6	-0.6	6.4
	4.0	3.5	-4.6	1.1	-0.8	1.5	-1.1	7.4

FILLING AND EMPTYING PORTS HAVE
10 TRIANGULAR DEFLECTORS @ 28 FT C TO C RIVERSIDE AND
18 SQUARE DEFLECTORS @ 28 FT C TO C LAKESIDE



NOTE: All elevations (el) are in feet referenced to the National Geodetic Vertical Datum NGVD)

INNER HARBOR NAVIGATION CANAL LOCK
MODEL LAYOUT

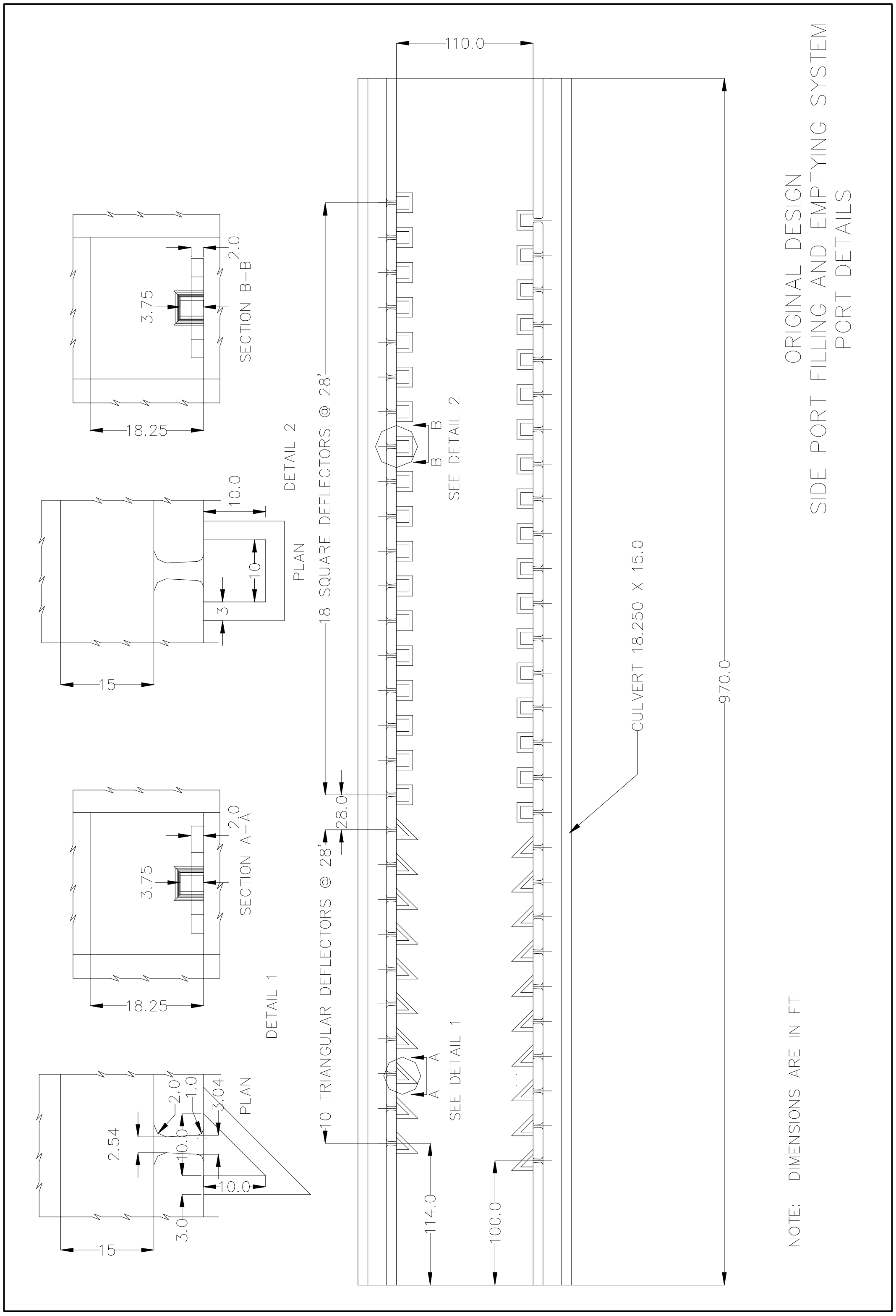
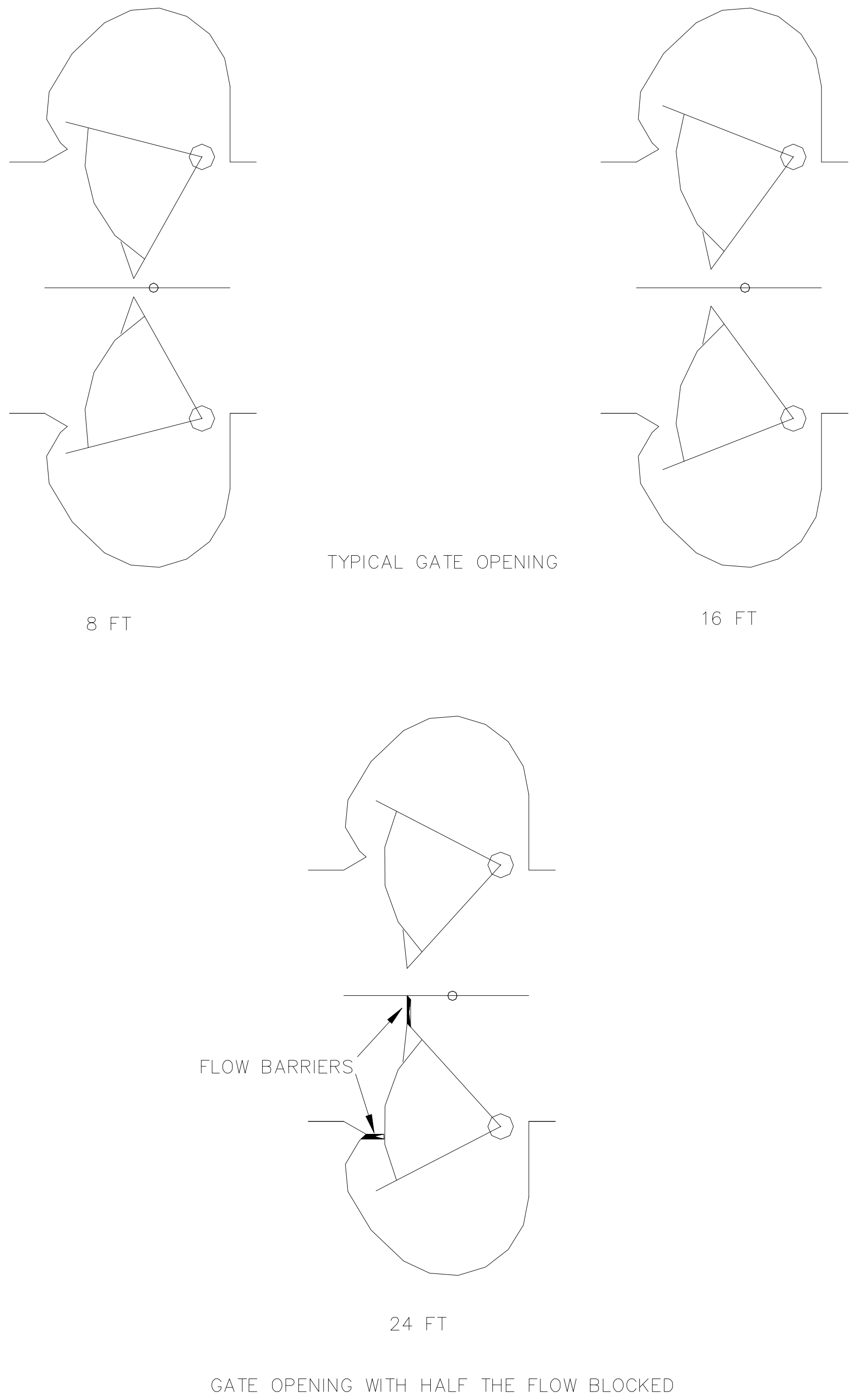
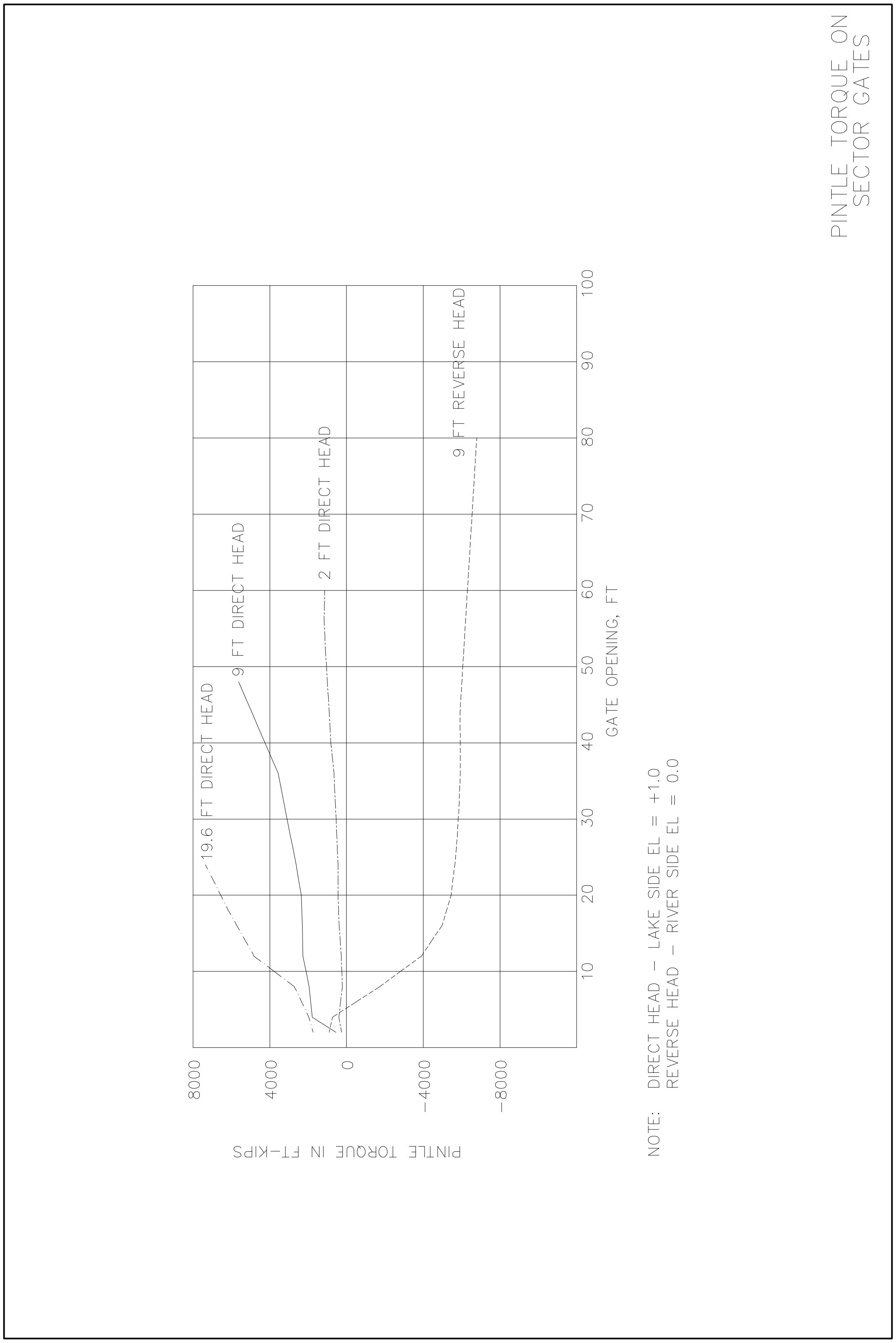
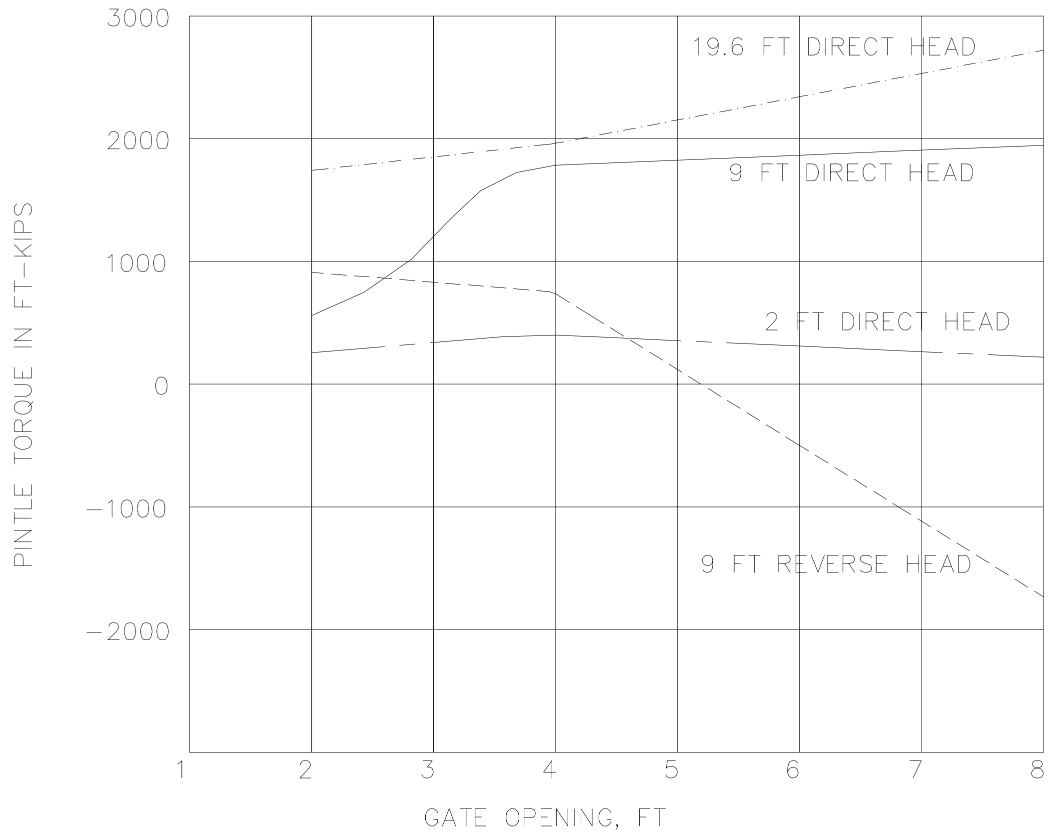

ORIGINAL DESIGN
SIDE PORT FILLING AND EMPTYING SYSTEM
PORT DETAILS
NOTE: DIMENSIONS ARE IN FT
110.0
970.0
CULVERT 18.250 X 15.0
18 SQUARE DEFLECTORS @ 28'
10 TRIANGULAR DEFLECTORS @ 28'
28.0
114.0
100.0
SEE DETAIL 1
SEE DETAIL 2
A
A
B
B
DETAIL 1
DETAIL 2
PLAN
PLAN
SECTION A-A
SECTION B-B
18.25
18.25
15
15
3.75
3.75
2.0
2.0
2.0
10.0
10.0
10.0
10
3
2.54
1.0
3.04
3.0

Plate 2



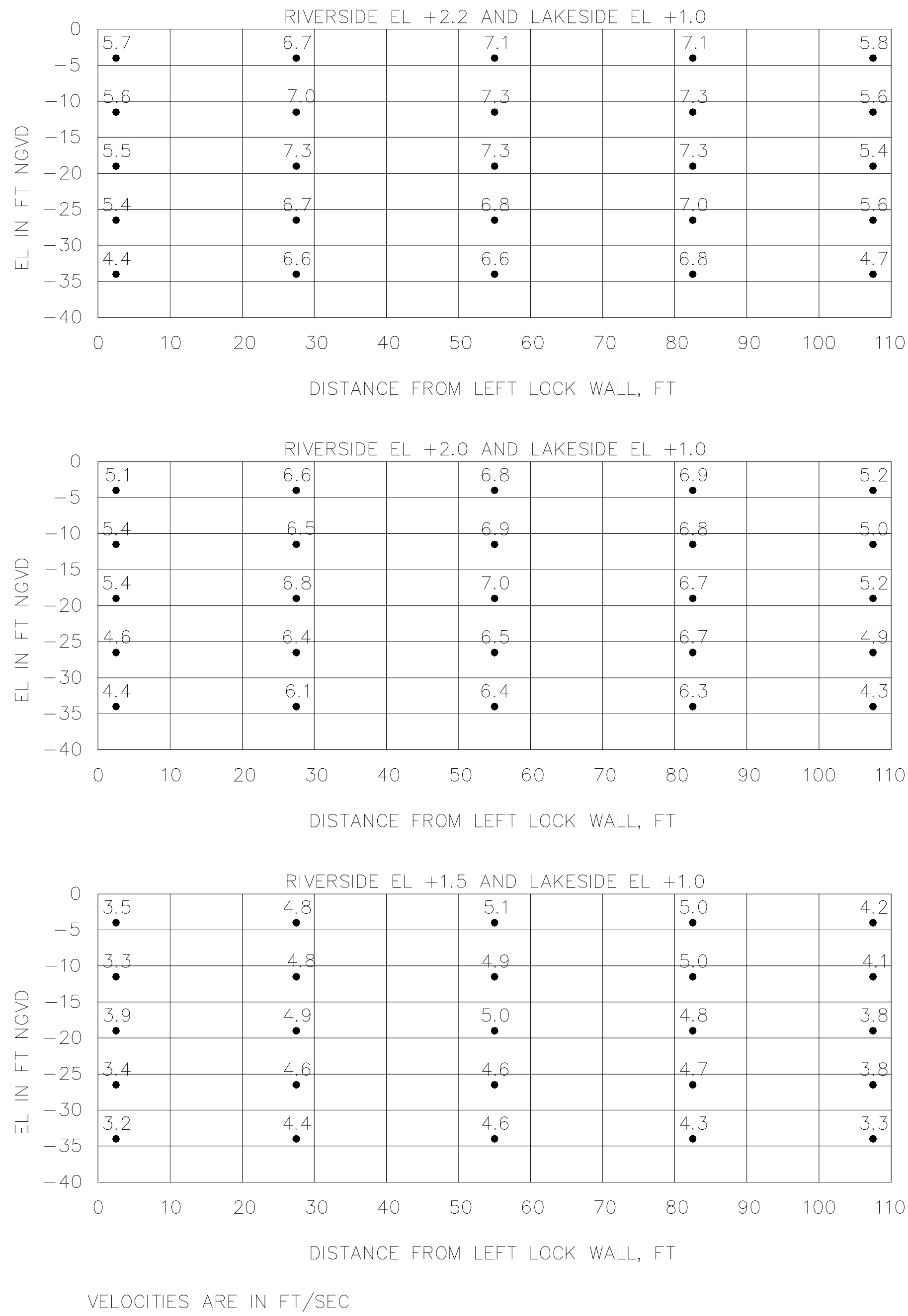
SECTOR GATE OPENINGS


PINTLE TORQUE ON
SECTOR GATES
PINTLE TORQUE IN FT-KIPS
8000
4000
0
-4000
-8000
10
20
30
40
50
60
70
80
90
100
GATE OPENING, FT
19.6 FT DIRECT HEAD
9 FT DIRECT HEAD
2 FT DIRECT HEAD
9 FT REVERSE HEAD
NOTE: DIRECT HEAD - LAKE SIDE EL = +1.0
REVERSE HEAD - RIVER SIDE EL = 0.0



NOTE: DIRECT HEAD − LAKE SIDE EL = +1.0
REVERSE HEAD − RIVER SIDE EL = 0.0

PINTLE TORQUE ON
SECTOR GATES
FOR GATE OPENINGS
UP TO 8 FT



VELOCITIES INSIDE LOCK CHAMBER

ORIGINAL DESIGN

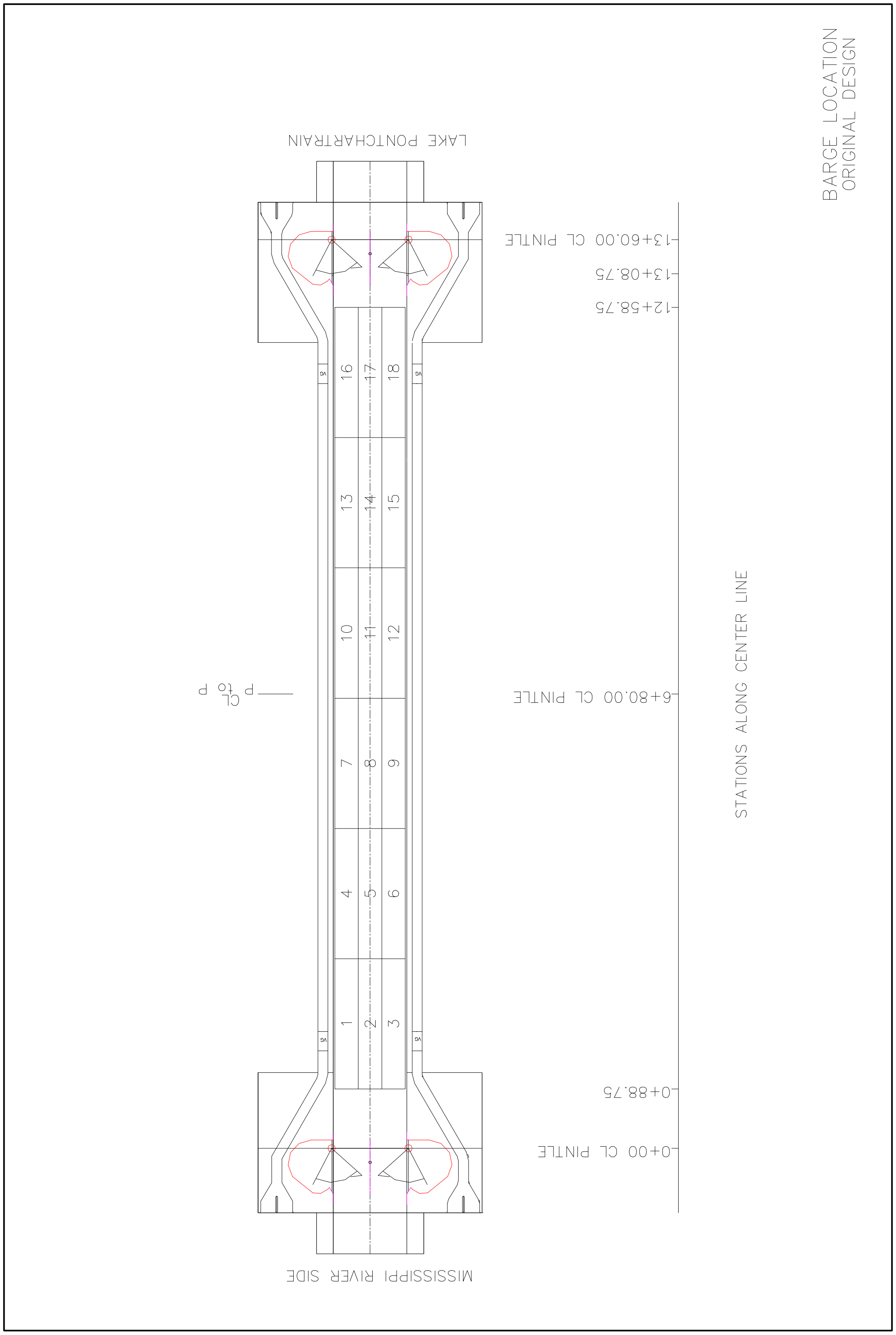

BARGE LOCATION
ORIGINAL DESIGN
LAKE PONTCHARTRAIN
MISSISSIPPI RIVER SIDE
STATIONS ALONG CENTER LINE
13+60.00 CL PINTLE
13+08.75
12+58.75
6+80.00 CL PINTLE
0+88.75
0+00 CL PINTLE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Plate 7

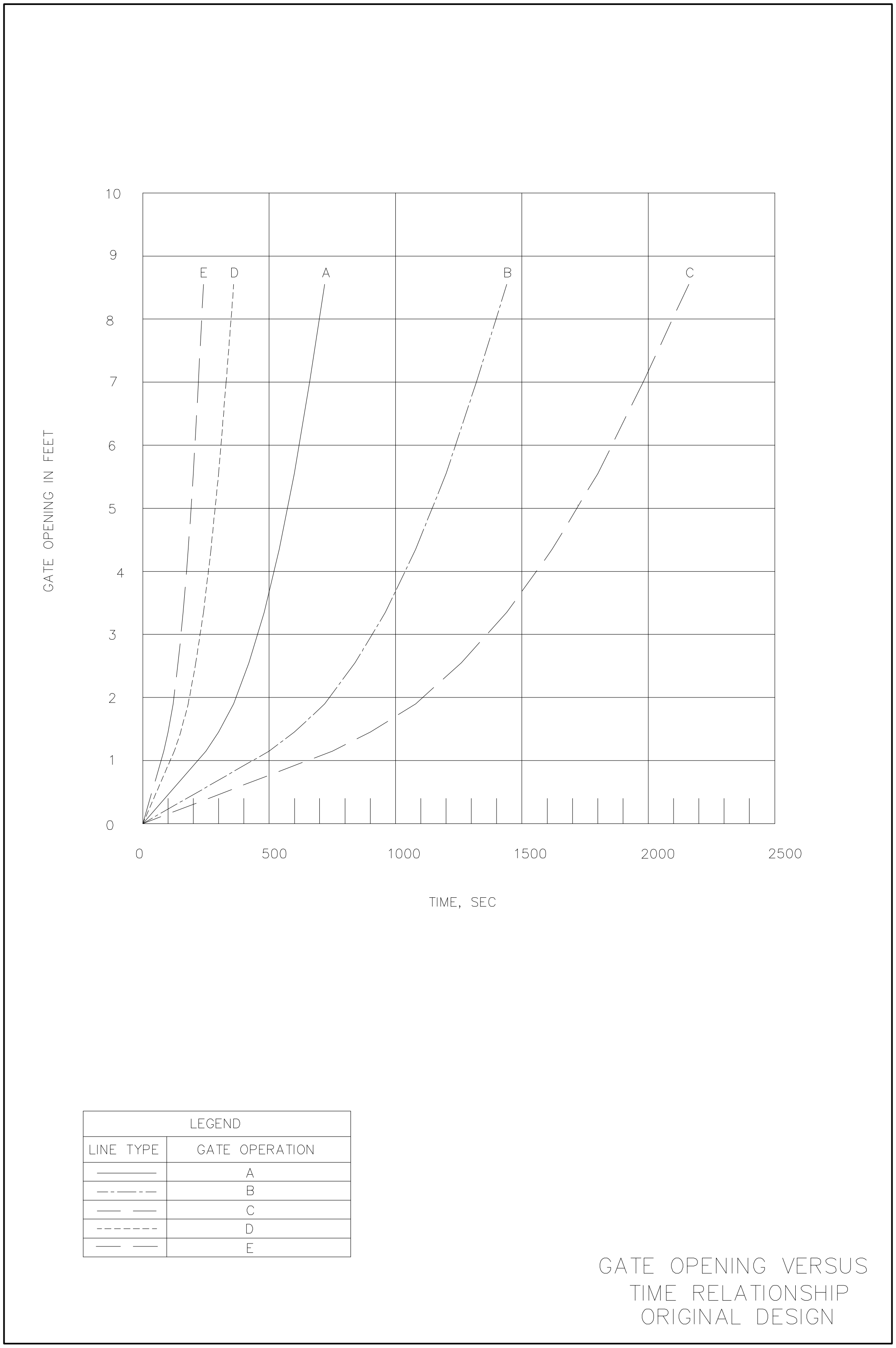
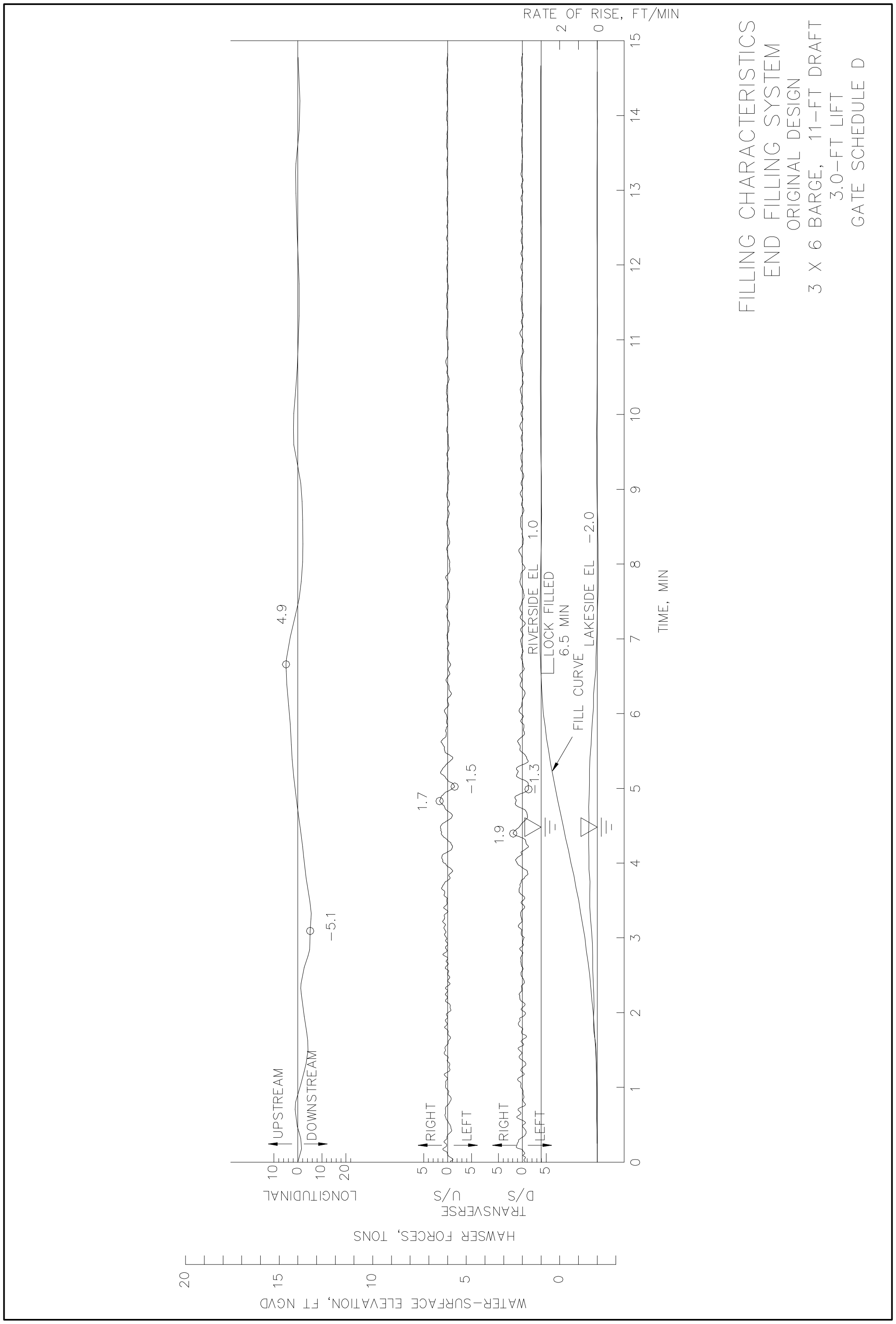
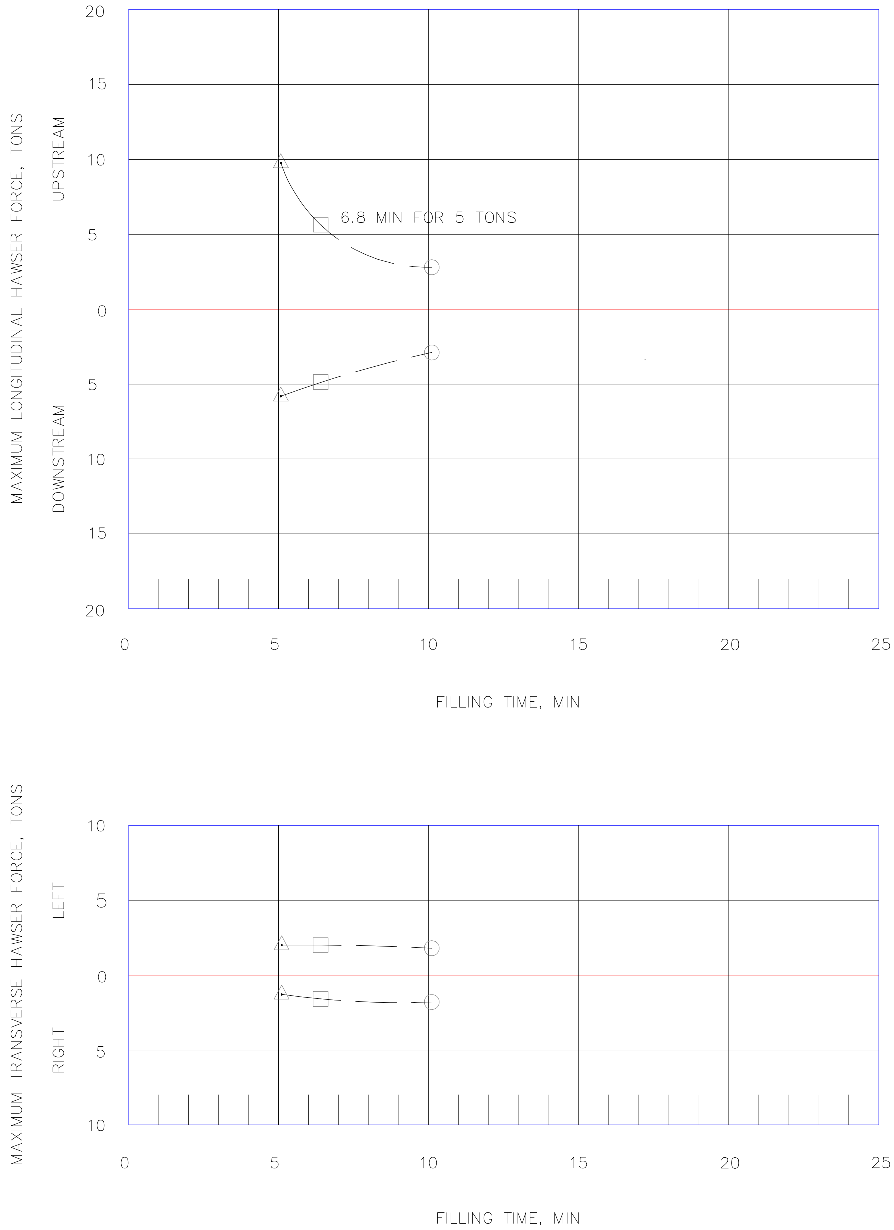

GATE OPENING IN FEET
TIME, SEC
0
500
1000
1500
2000
2500
1
2
3
4
5
6
7
8
9
10
A
B
C
D
E
LEGEND
LINE TYPE
GATE OPERATION
A
B
C
D
E
GATE OPENING VERSUS
TIME RELATIONSHIP
ORIGINAL DESIGN

Plate 8

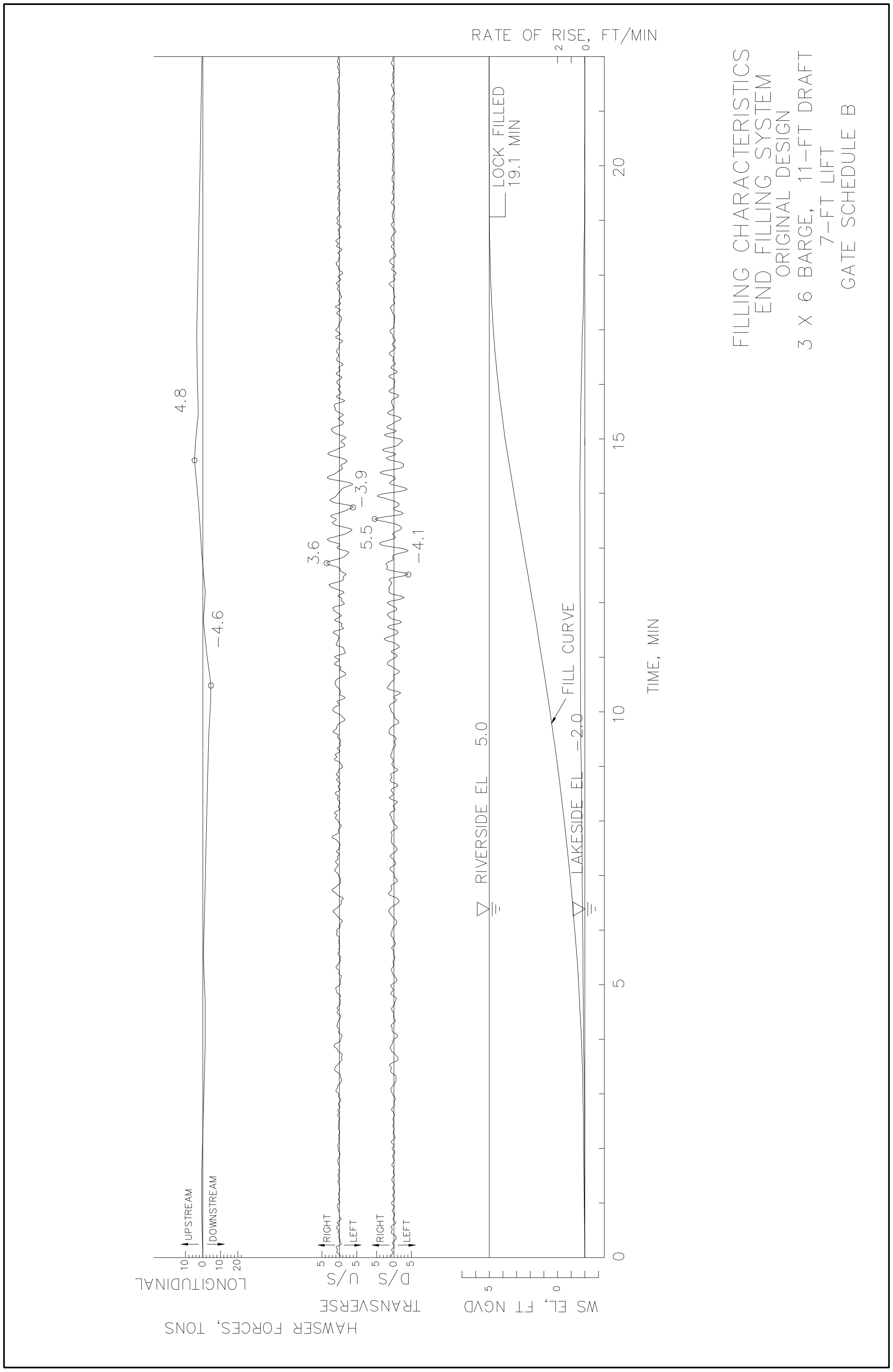

FILLING CHARACTERISTICS
END FILLING SYSTEM
ORIGINAL DESIGN
3 X 6 BARGE, 11-FT DRAFT
3.0-FT LIFT
GATE SCHEDULE D
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
RIVERSIDE EL 1.0
LAKESIDE EL -2.0
LOCK FILLED
6.5 MIN
FILL CURVE
4.9
-5.1
1.7
-1.5
1.9
-1.3

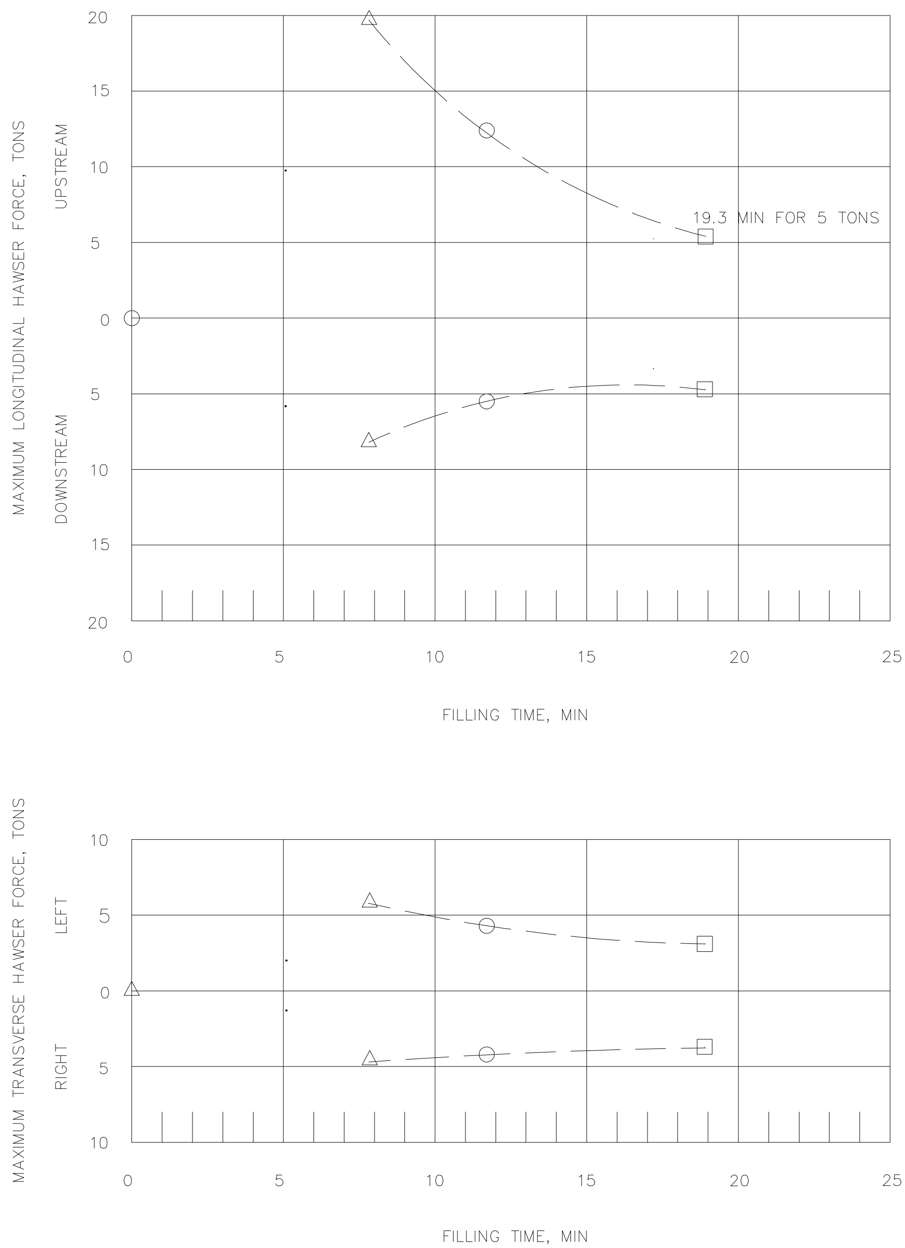


LEGEND	
SYMBOL	GATE OPERATION
○	A
□	D
△	E

HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
3.0–FT LIFT
18 BARGES WITH 11–FT DRAFT

Plate 10

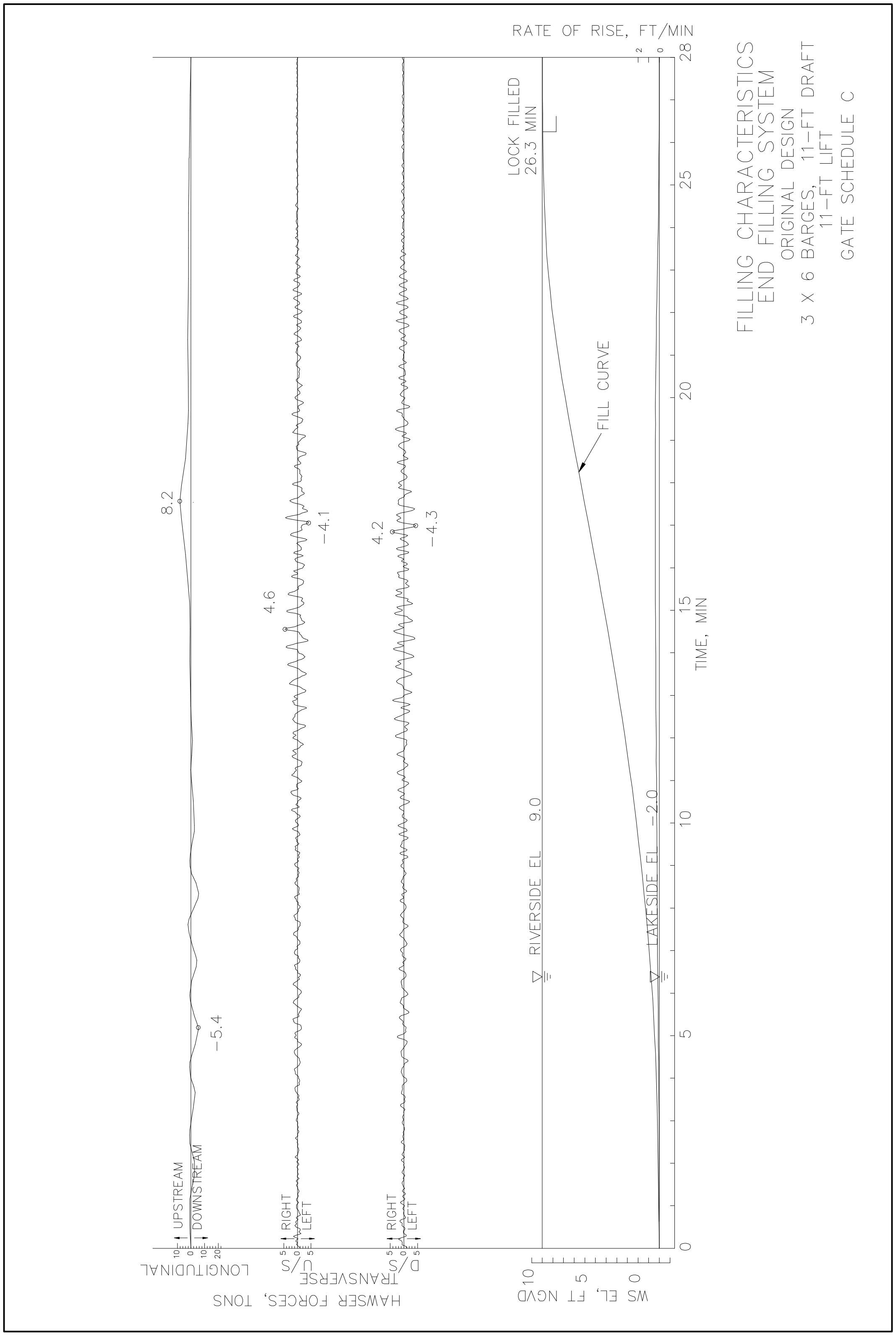

FILLING CHARACTERISTICS
END FILLING SYSTEM
ORIGINAL DESIGN
3 X 6 BARGE, 11-FT DRAFT
7-FT LIFT
GATE SCHEDULE B
RATE OF RISE, FT/MIN
LOCK FILLED
19.1 MIN
FILL CURVE
RIVERSIDE EL 5.0
LAKESIDE EL -2.0
TIME, MIN
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
WS EL, FT NGVD
4.8
-4.6
3.6
-3.9
5.5
-4.1

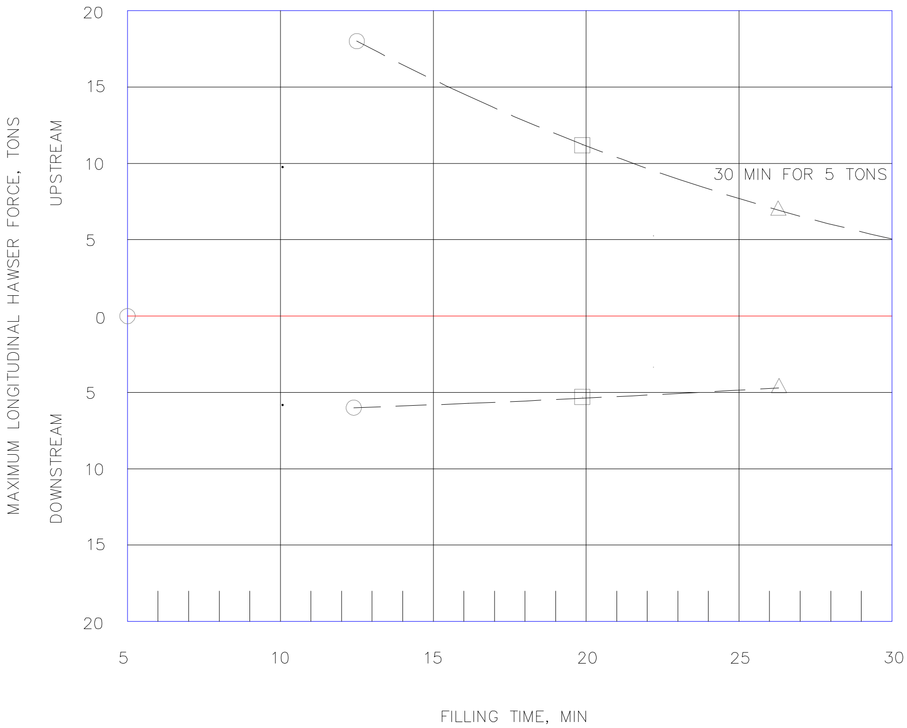


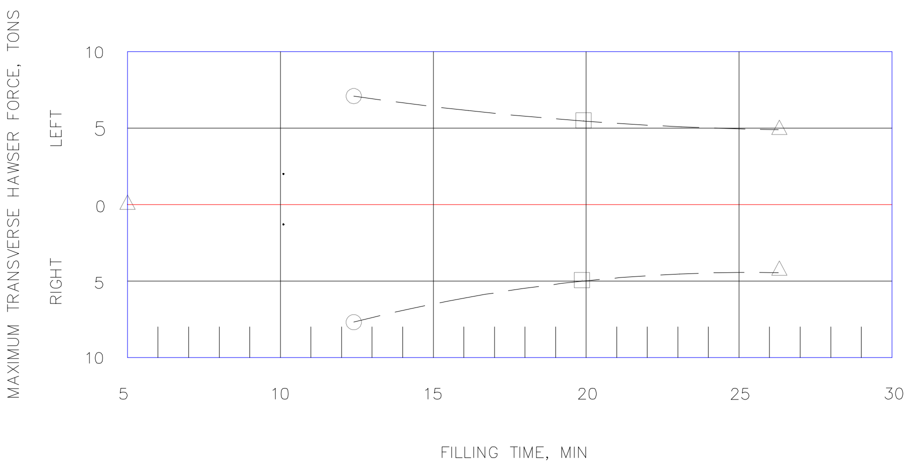
LEGEND	
SYMBOL	GATE OPERATION
○	A
□	B
△	D

HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
7.0-FT LIFT
18 BARGES WITH 11-FT DRAFT

Plate 12

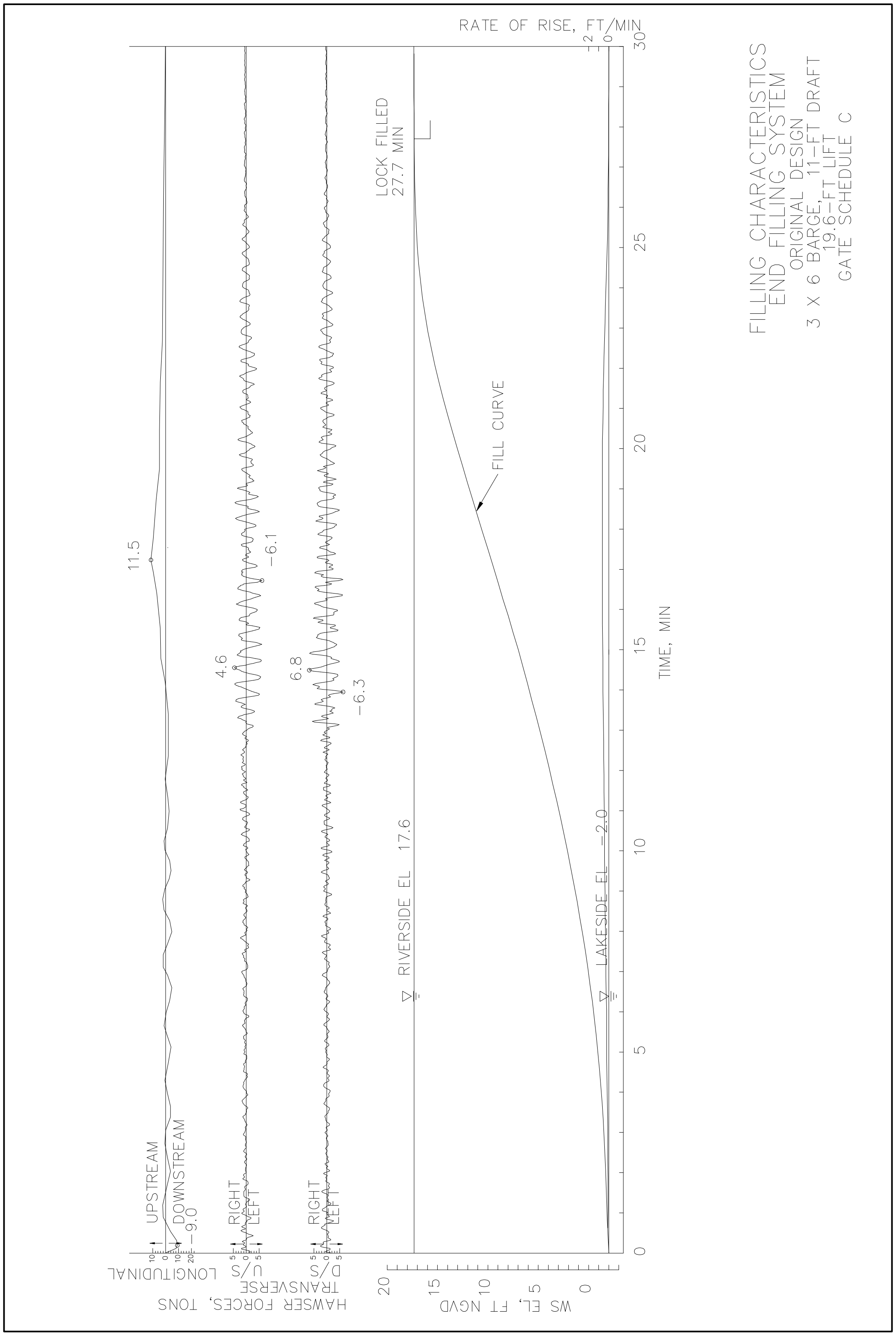

FILLING CHARACTERISTICS
END FILLING SYSTEM
ORIGINAL DESIGN
3 X 6 BARGES, 11-FT DRAFT
11-FT LIFT
GATE SCHEDULE C
RATE OF RISE, FT/MIN
TIME, MIN
HAWSER FORCES, TONS
LONGITUDINAL
UPSTREAM
DOWNSTREAM
TRANSVERSE
U/S
D/S
RIGHT
LEFT
WS EL, FT NGVD
LOCK FILLED
26.3 MIN
FILL CURVE
RIVERSIDE EL 9.0
LAKESIDE EL -2.0
8.2
-5.4
4.6
-4.1
4.2
-4.3

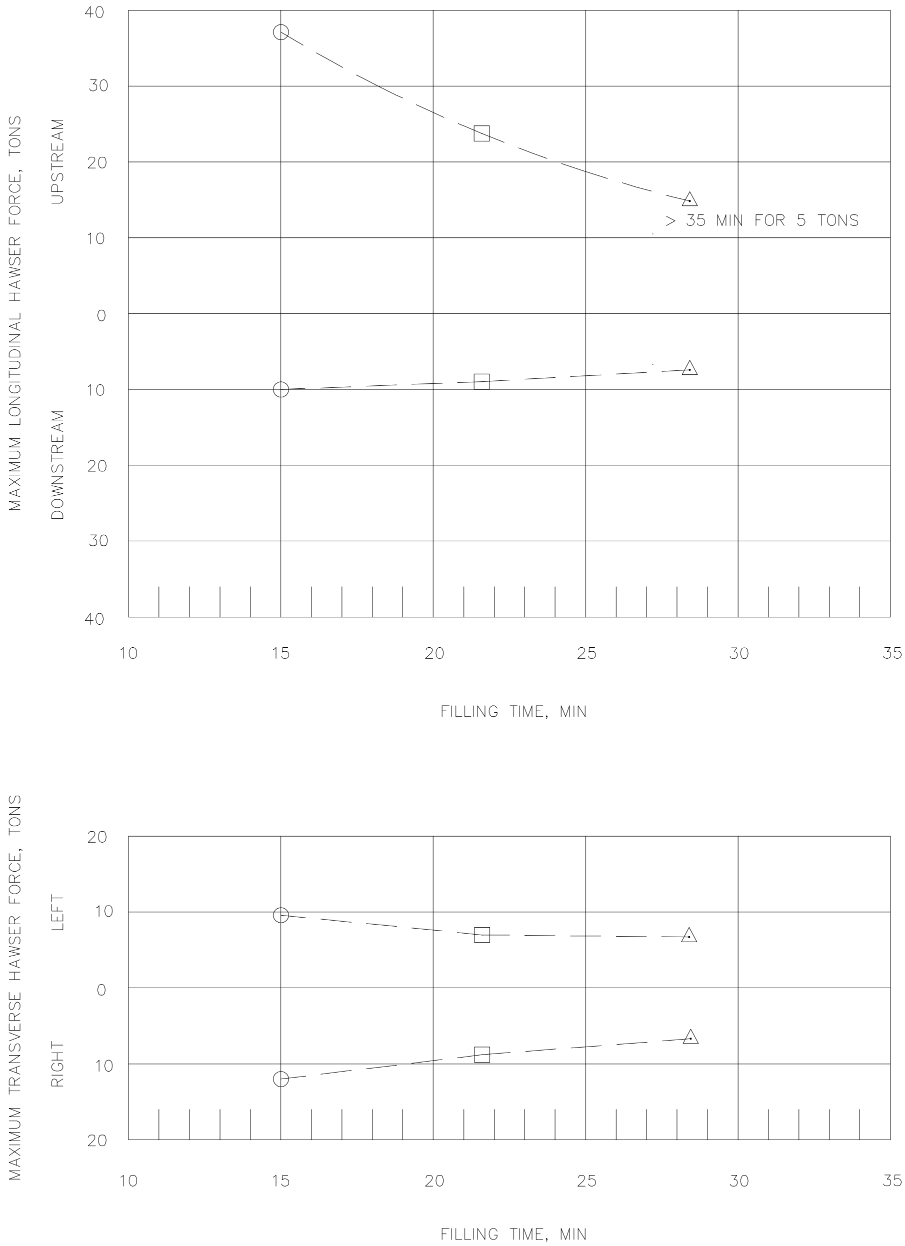




LEGEND	
SYMBOL	GATE OPERATION
○	A
□	B
△	C

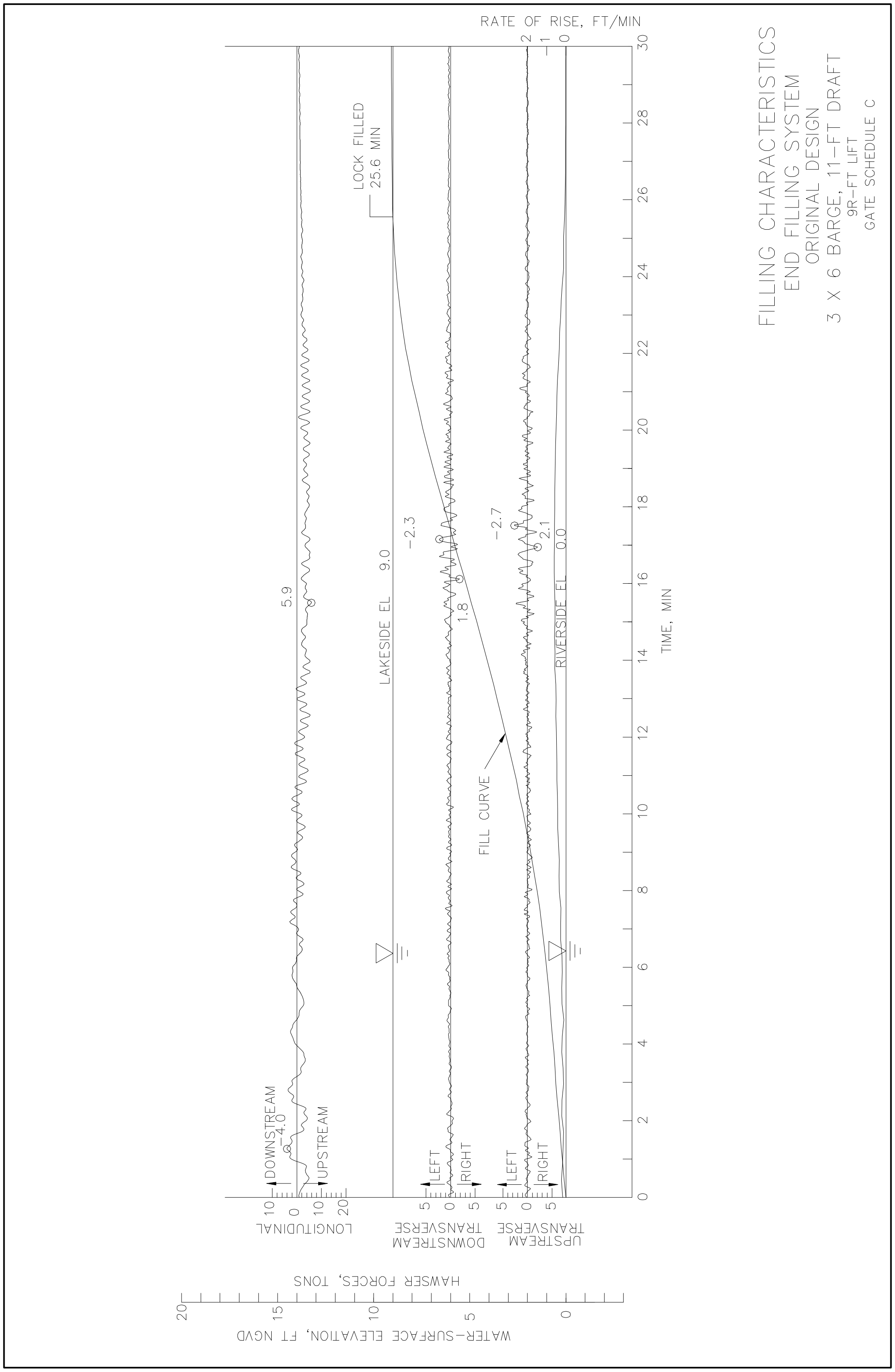
HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
11.0-FT LIFT
18 BARGES WITH 11-FT DRAFT

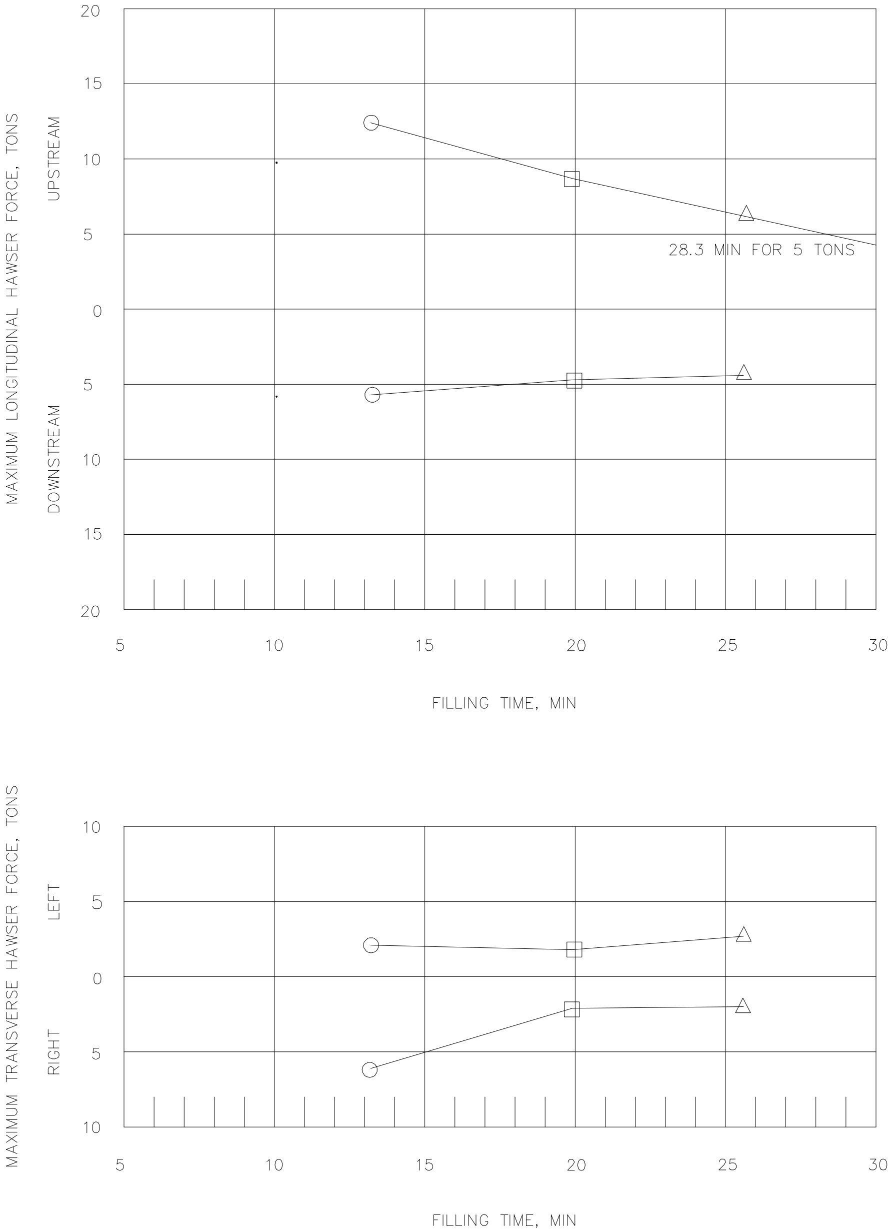

FILLING CHARACTERISTICS
END FILLING SYSTEM
ORIGINAL DESIGN
3 X 6 BARGE, 11-FT DRAFT
19.6-FT LIFT
GATE SCHEDULE C
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
RIGHT
LEFT
-9.0
11.5
4.6
-6.1
6.8
-6.3
RIVERSIDE EL 17.6
LAKESIDE EL -2.0
FILL CURVE
LOCK FILLED
27.7 MIN
WS EL, FT NGVD
RATE OF RISE, FT/MIN
TIME, MIN
0
5
10
15
20
25
30



LEGEND	
SYMBOL	GATE OPERATION
○	A
□	B
△	C

HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
19.6-FT LIFT
18 BARGES WITH 11-FT DRAFT

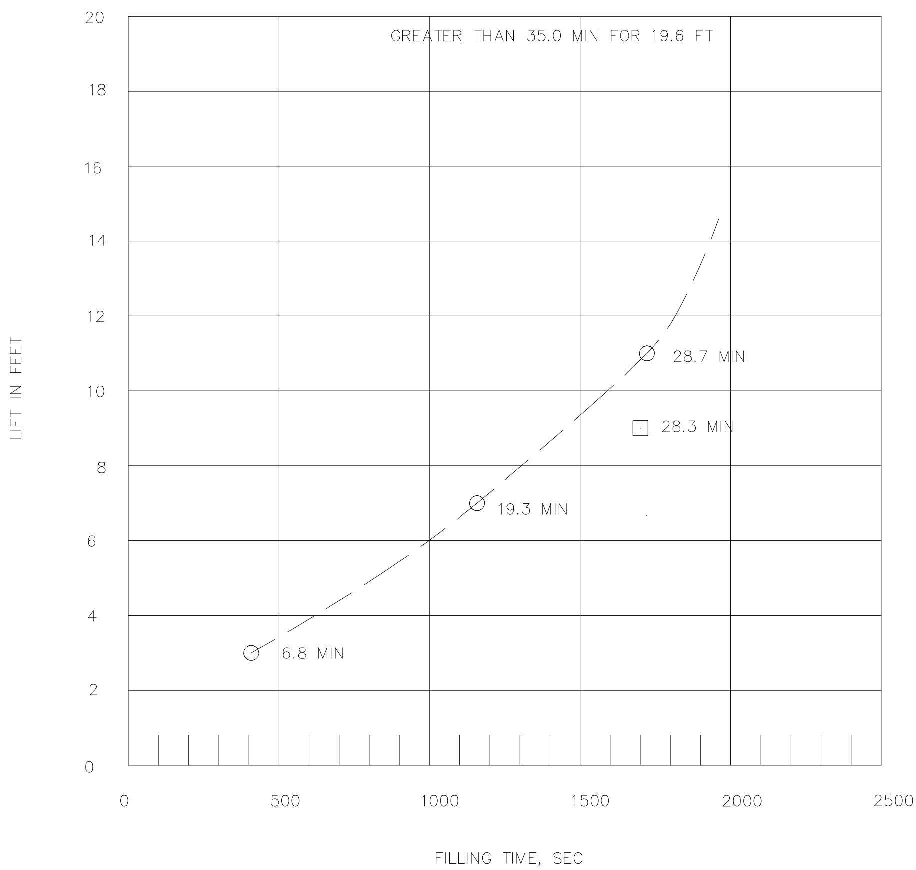

FILLING CHARACTERISTICS
END FILLING SYSTEM
ORIGINAL DESIGN
3 X 6 BARGE, 11-FT DRAFT
9R-FT LIFT
GATE SCHEDULE C
RATE OF RISE, FT/MIN
LOCK FILLED
25.6 MIN
LAKESIDE EL 9.0
RIVERSIDE EL 0.0
FILL CURVE
TIME, MIN
DOWNSTREAM
UPSTREAM
LEFT
RIGHT
LONGITUDINAL
DOWNSTREAM TRANSVERSE
UPSTREAM TRANSVERSE
HAWSER FORCES, TONS
WATER-SURFACE ELEVATION, FT NGVD
-4.0
5.9
-2.3
1.8
-2.7
2.1



LEGEND	
SYMBOL	GATE OPERATION
○	A
□	B
△	C

fh9Refb

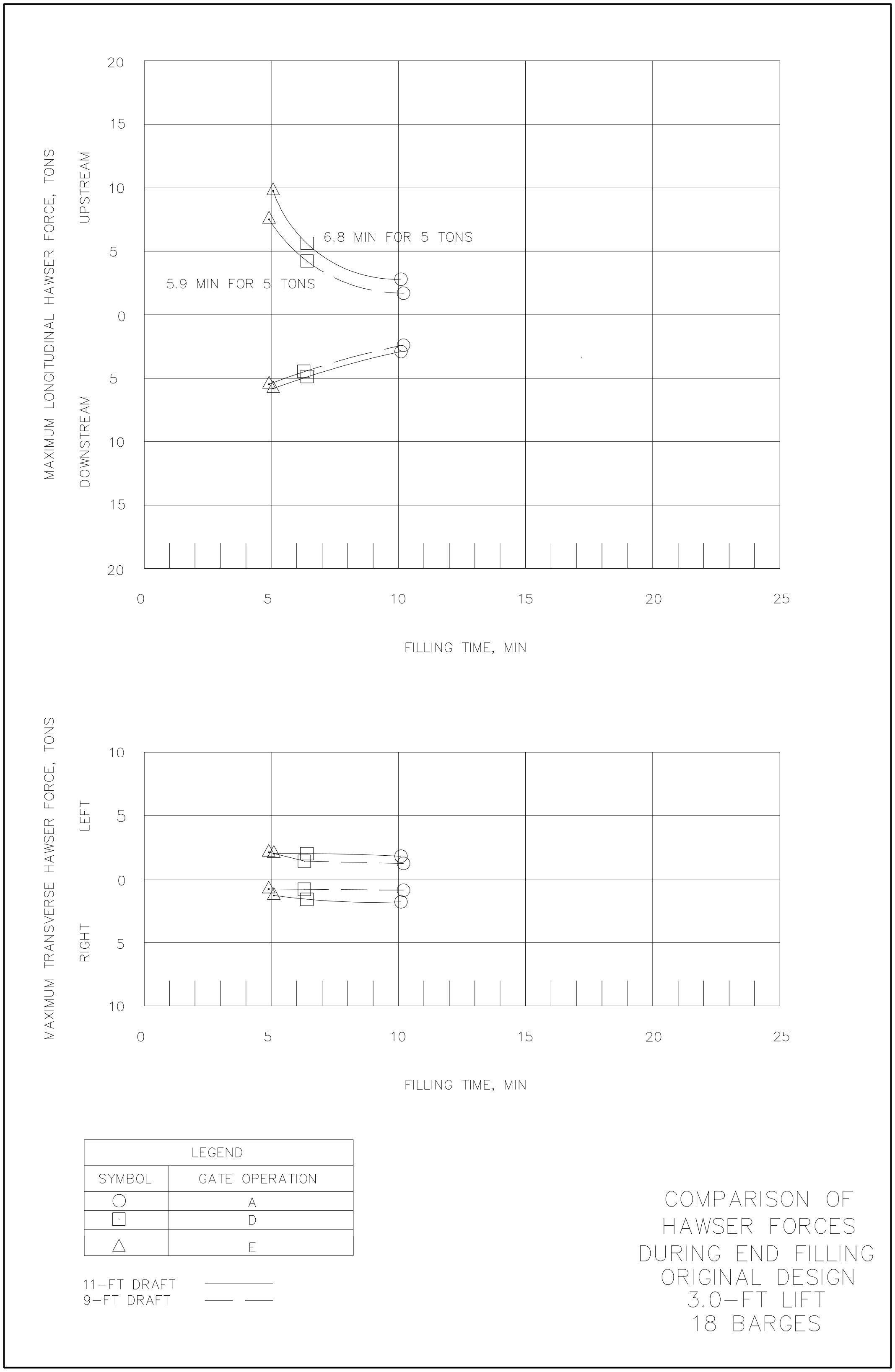
HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
9.0-FT REVERSE LIFT
18 BARGES WITH 11.0-FT DRAFT

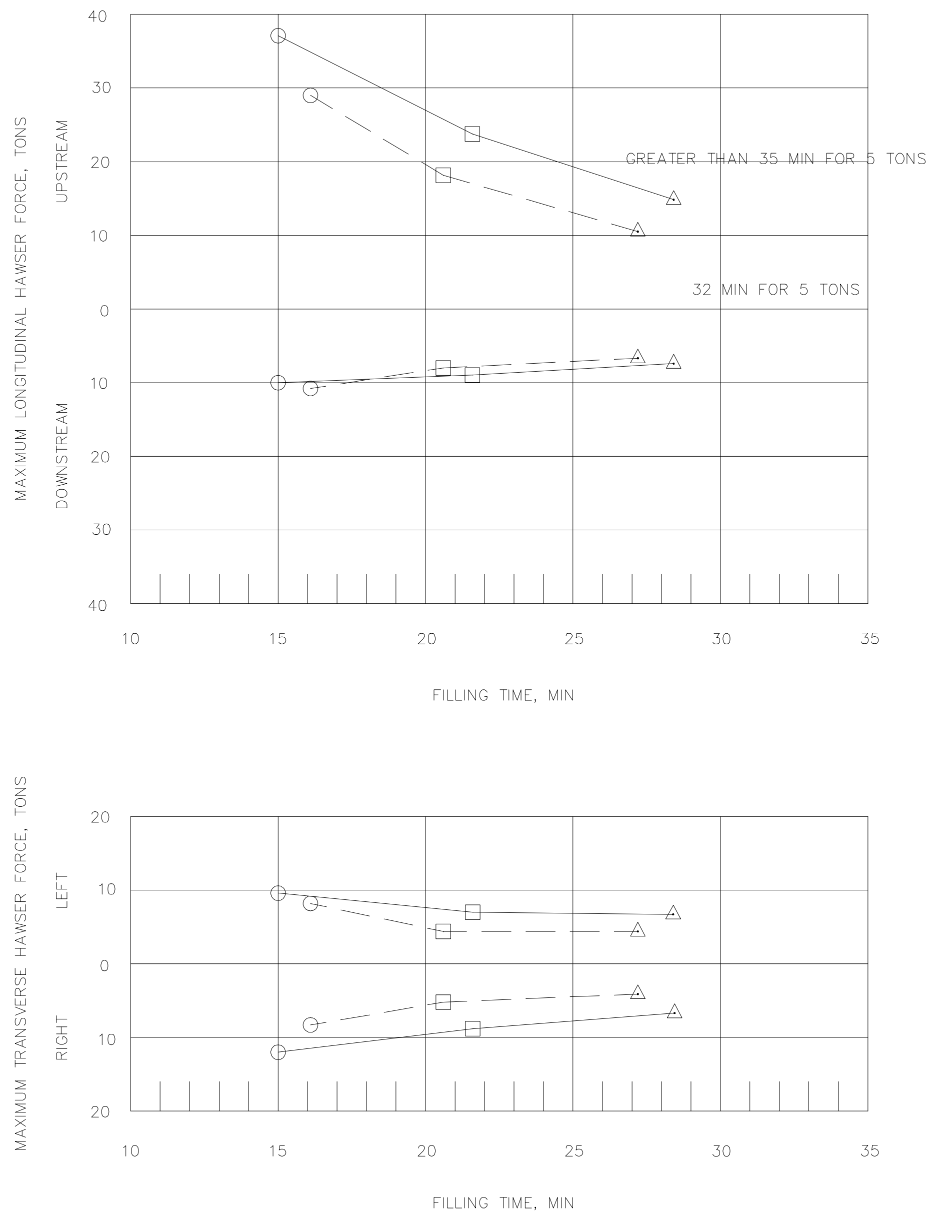


NOTE: LAKESIDE EL = −2.0 FT

○ NORMAL HEAD
□ REVERSE HEAD

FILLING TIMES FOR
5–TON HAWSER FORCE LIMIT
LIFTS = 3, 7, 9, 11, AND 19.6 FT
END FILLING SYSTEM
18 BARGES, 11–FT DRAFT

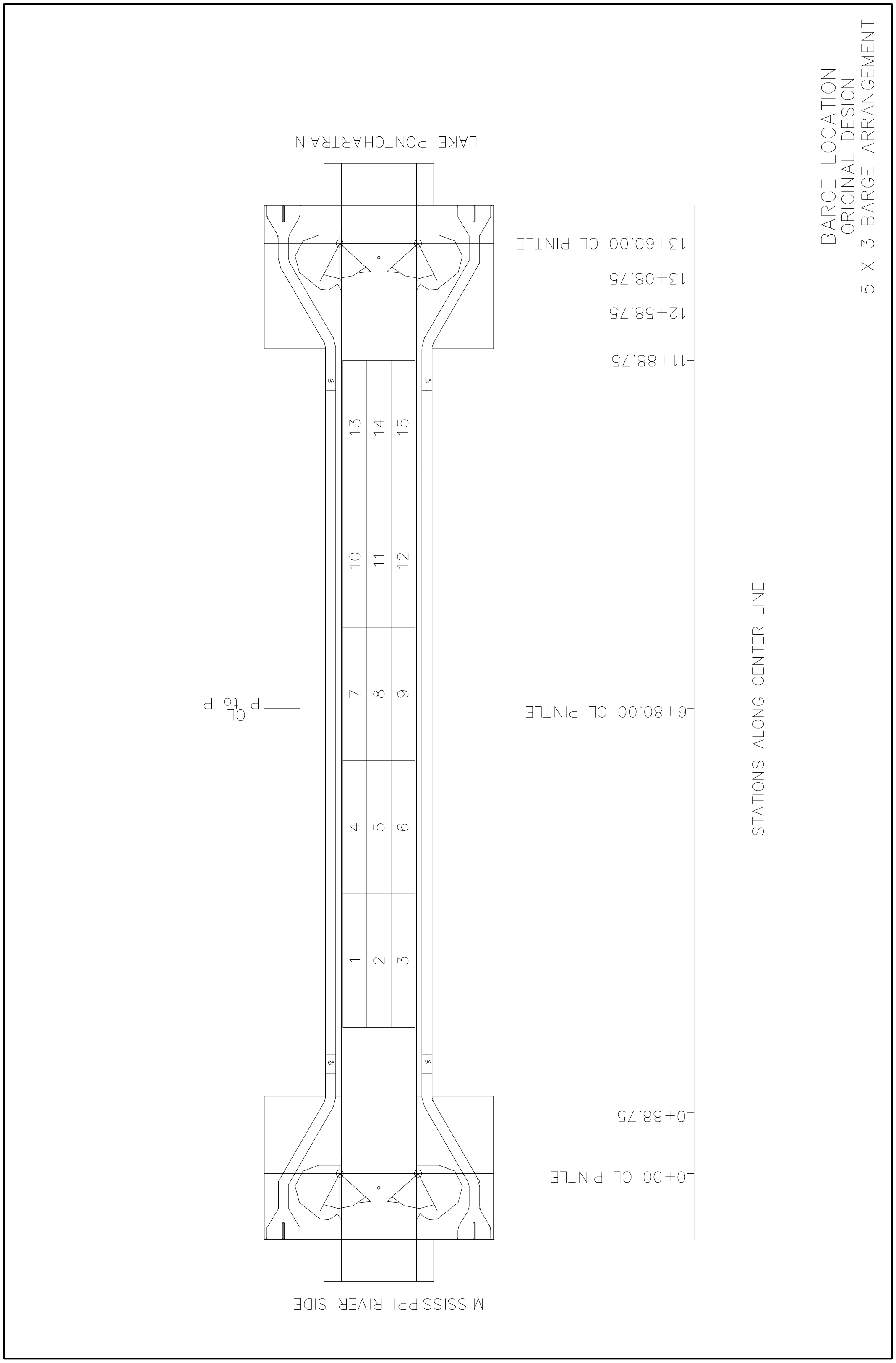

MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
20
15
10
5
0
5
10
15
20
6.8 MIN FOR 5 TONS
5.9 MIN FOR 5 TONS
0
5
10
15
20
25
FILLING TIME, MIN
MAXIMUM TRANSVERSE HAWSER FORCE, TONS
LEFT
RIGHT
10
5
0
5
10
0
5
10
15
20
25
FILLING TIME, MIN
LEGEND
SYMBOL
GATE OPERATION
A
D
E
11-FT DRAFT
9-FT DRAFT
COMPARISON OF
HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
3.0-FT LIFT
18 BARGES



LEGEND	
SYMBOL	GATE OPERATION
○	A
□	D
△	E

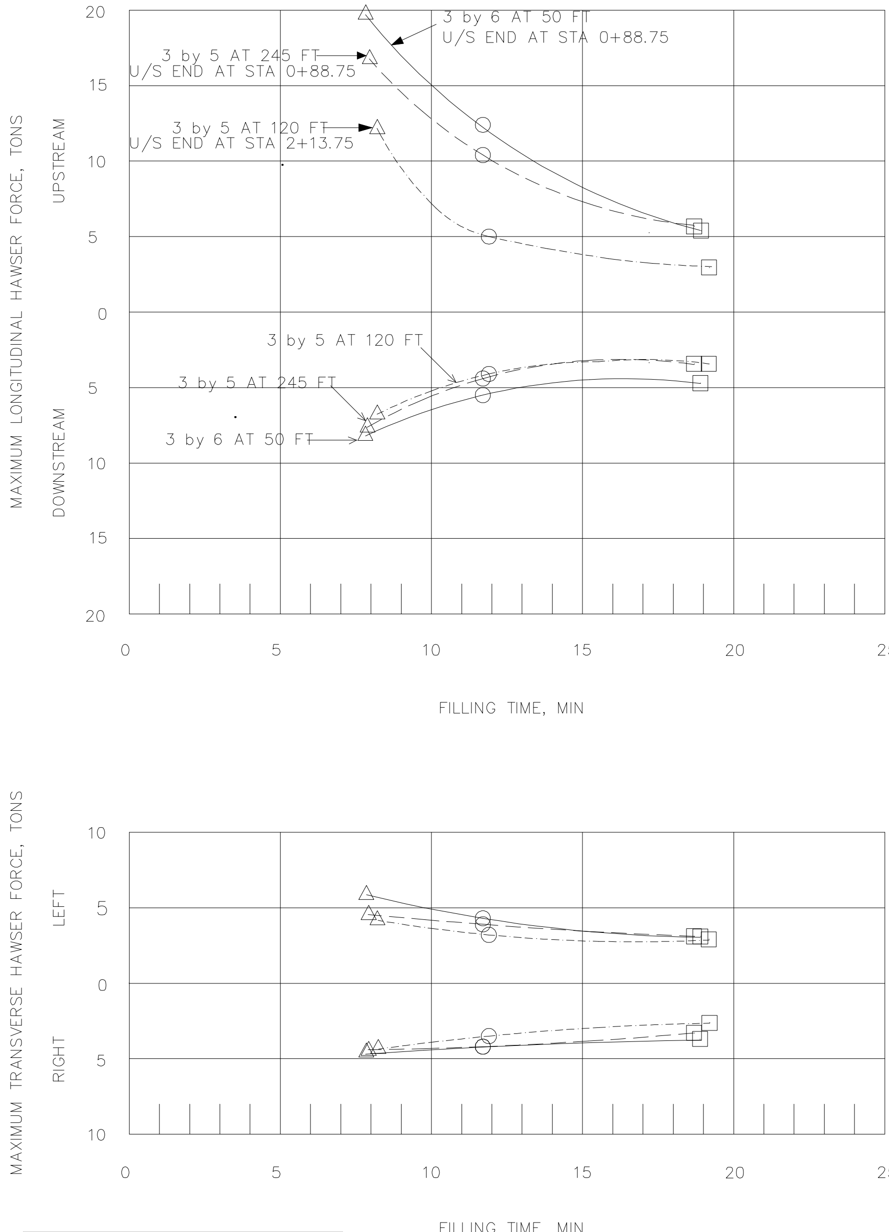
11-FT DRAFT ————
9-FT DRAFT —— ——

COMPARISON OF
HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
19.6-FT LIFT
18 BARGES



BARGE LOCATION
ORIGINAL DESIGN
5 X 3 BARGE ARRANGEMENT
LAKE PONTCHARTRAIN
13+60.00 CL PINTLE
13+08.75
12+58.75
11+88.75
6+80.00 CL PINTLE
0+88.75
0+00 CL PINTLE
STATIONS ALONG CENTER LINE
CL P to P
MISSISSIPPI RIVER SIDE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Plate 22



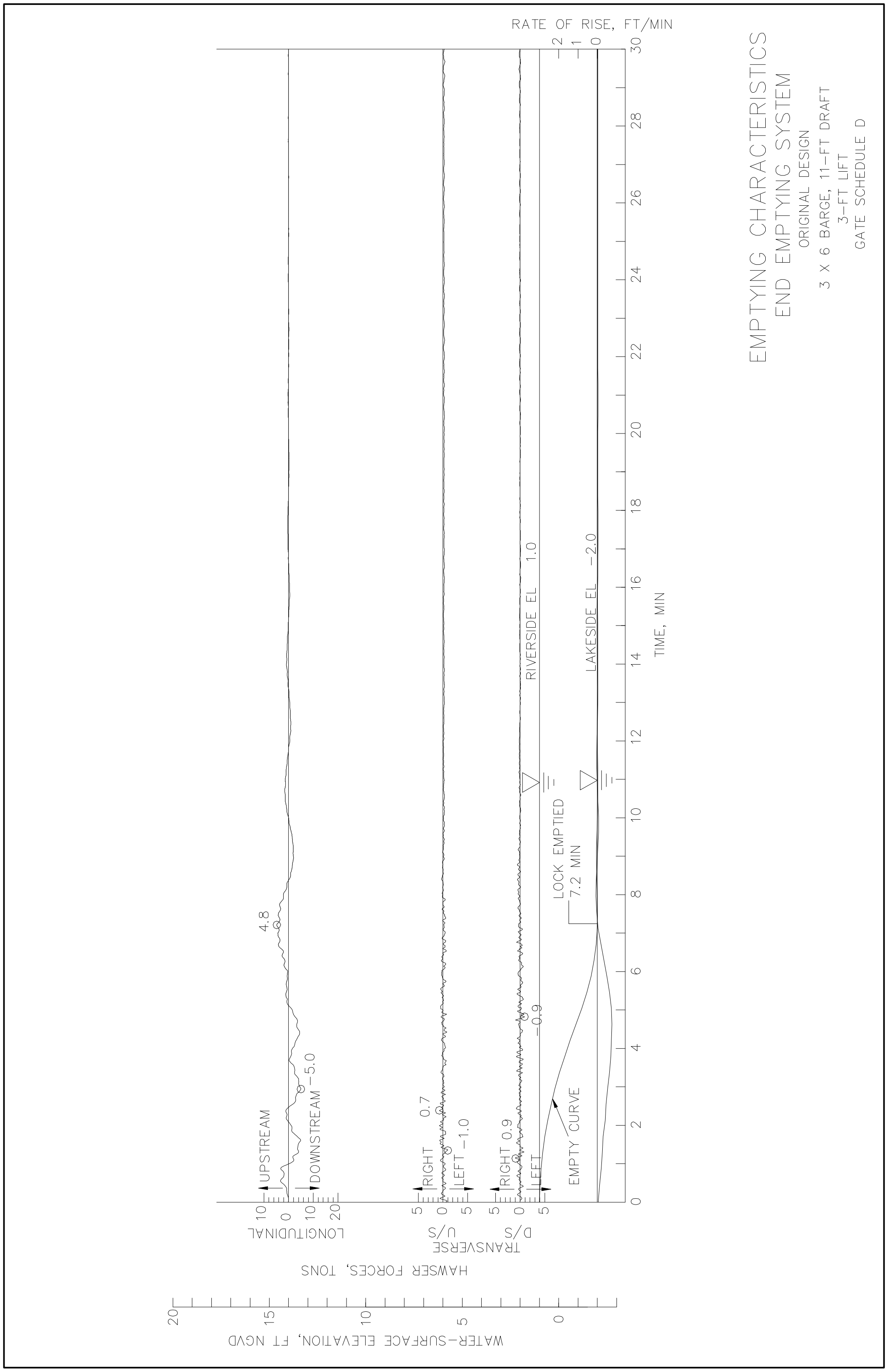
LEGEND	
SYMBOL	GATE OPERATION
△	D
○	A
□	B

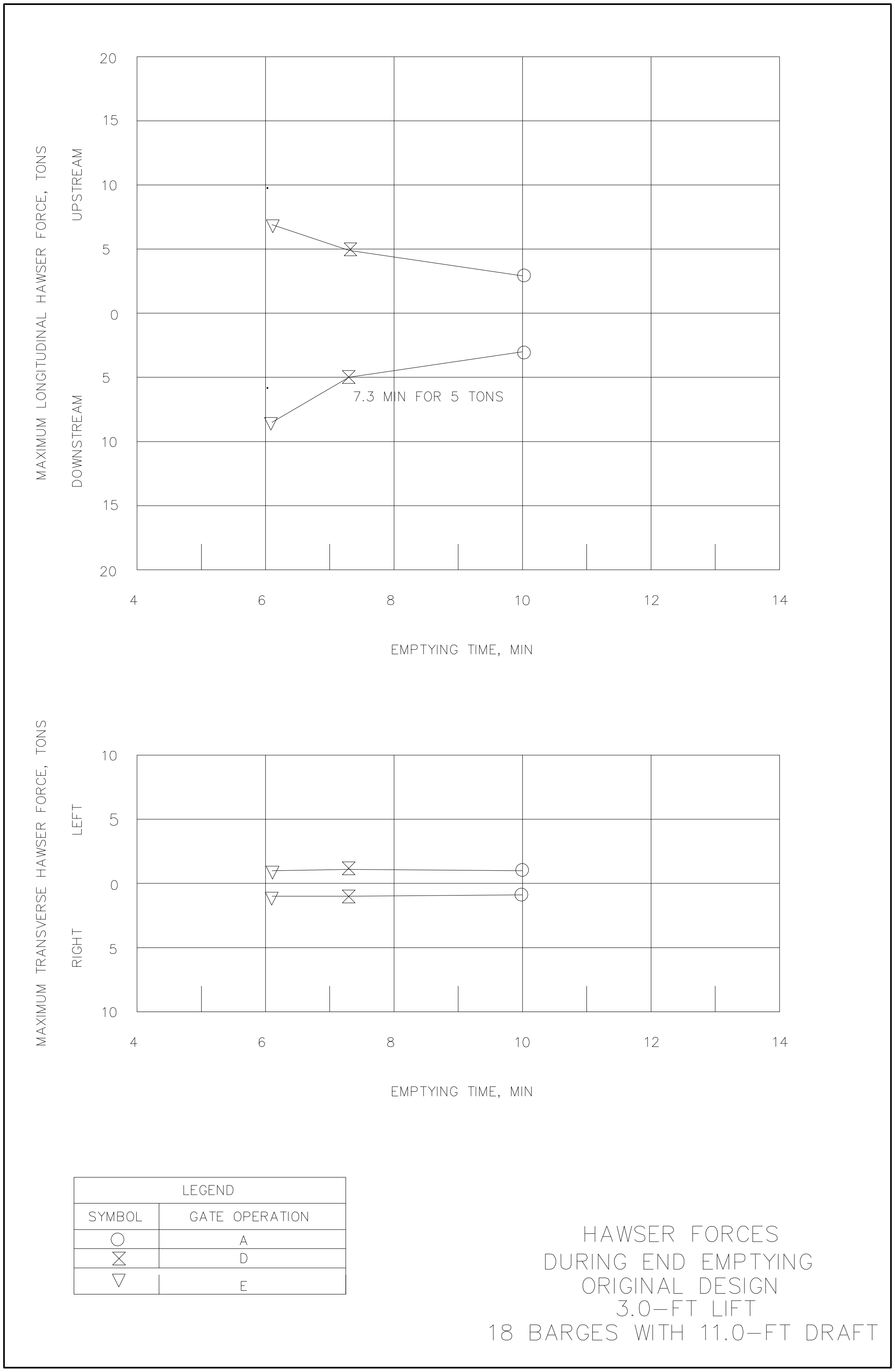
3 x 6 AT STA 0+88.75 ————————

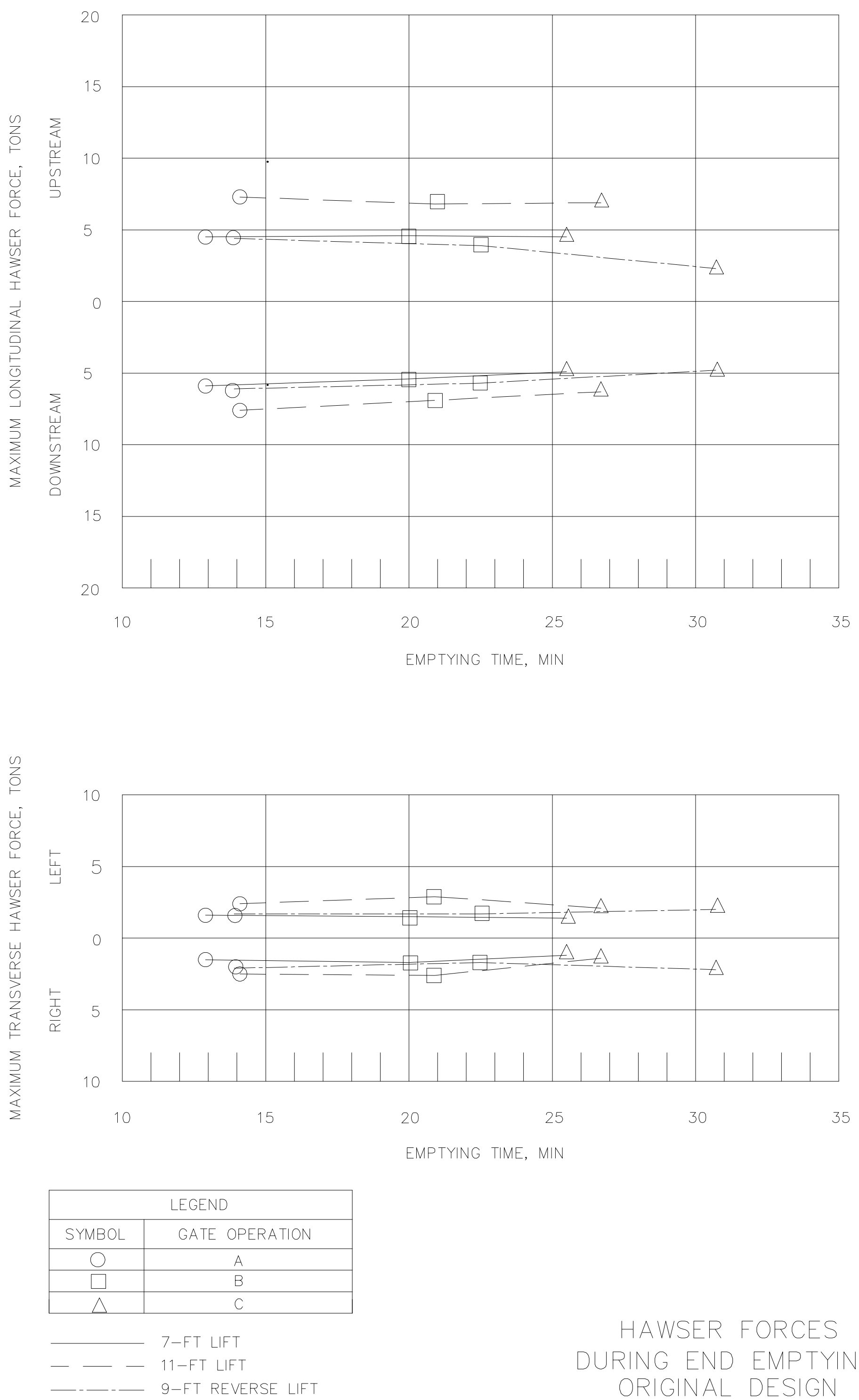
3 x 5 AT STA 0+88.75 – – – – – –

3 x 5 AT STA 2+13.75 –·–·–·–·–·–

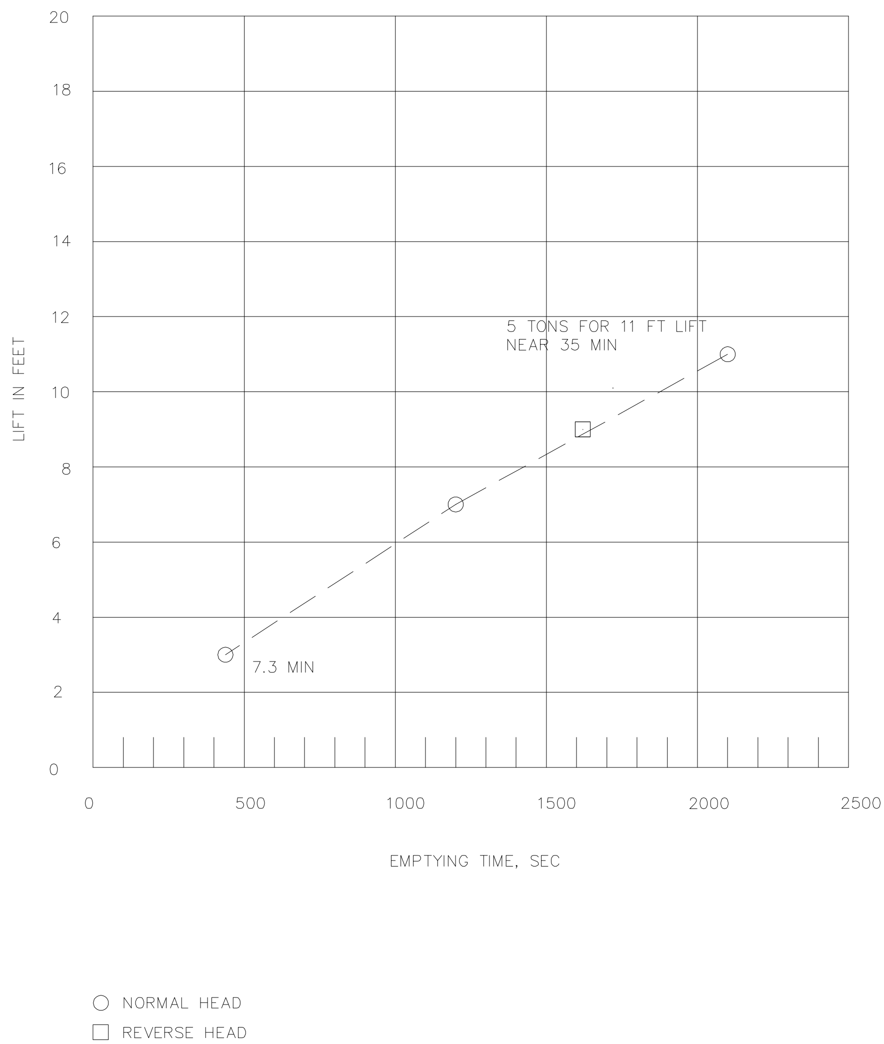
HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
7.0–FT LIFT
15 AND 18 BARGES WITH 11–FT DRAFT


EMPTYING CHARACTERISTICS
END EMPTYING SYSTEM
ORIGINAL DESIGN
3 X 6 BARGE, 11-FT DRAFT
3-FT LIFT
GATE SCHEDULE D
RATE OF RISE, FT/MIN
TIME, MIN
RIVERSIDE EL 1.0
LAKESIDE EL -2.0
LOCK EMPTIED
7.2 MIN
EMPTY CURVE
UPSTREAM
DOWNSTREAM
LONGITUDINAL
RIGHT
LEFT
U/S
D/S
TRANSVERSE
HAWSER FORCES, TONS
WATER-SURFACE ELEVATION, FT NGVD
4.8
-5.0
0.7
-1.0
0.9
-0.9


MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
20
15
10
5
0
5
10
15
20
4
6
8
10
12
14
7.3 MIN FOR 5 TONS
EMPTYING TIME, MIN
MAXIMUM TRANSVERSE HAWSER FORCE, TONS
LEFT
RIGHT
10
5
0
5
10
4
6
8
10
12
14
EMPTYING TIME, MIN
LEGEND
SYMBOL
GATE OPERATION
A
D
E
HAWSER FORCES
DURING END EMPTYING
ORIGINAL DESIGN
3.0–FT LIFT
18 BARGES WITH 11.0–FT DRAFT



HAWSER FORCES
DURING END EMPTYING
ORIGINAL DESIGN
7.0–, 11.0–, AND 9R– FT LIFTS
18 BARGES WITH 11.0–FT DRAFT



EMPTYING TIMES FOR
5-TON HAWSER FORCE LIMIT
LIFTS = 3, 7, 11, AND 9R FT
END EMPTYING SYSTEM
ORIGINAL DESIGN
18 BARGES, 11-FT DRAFT

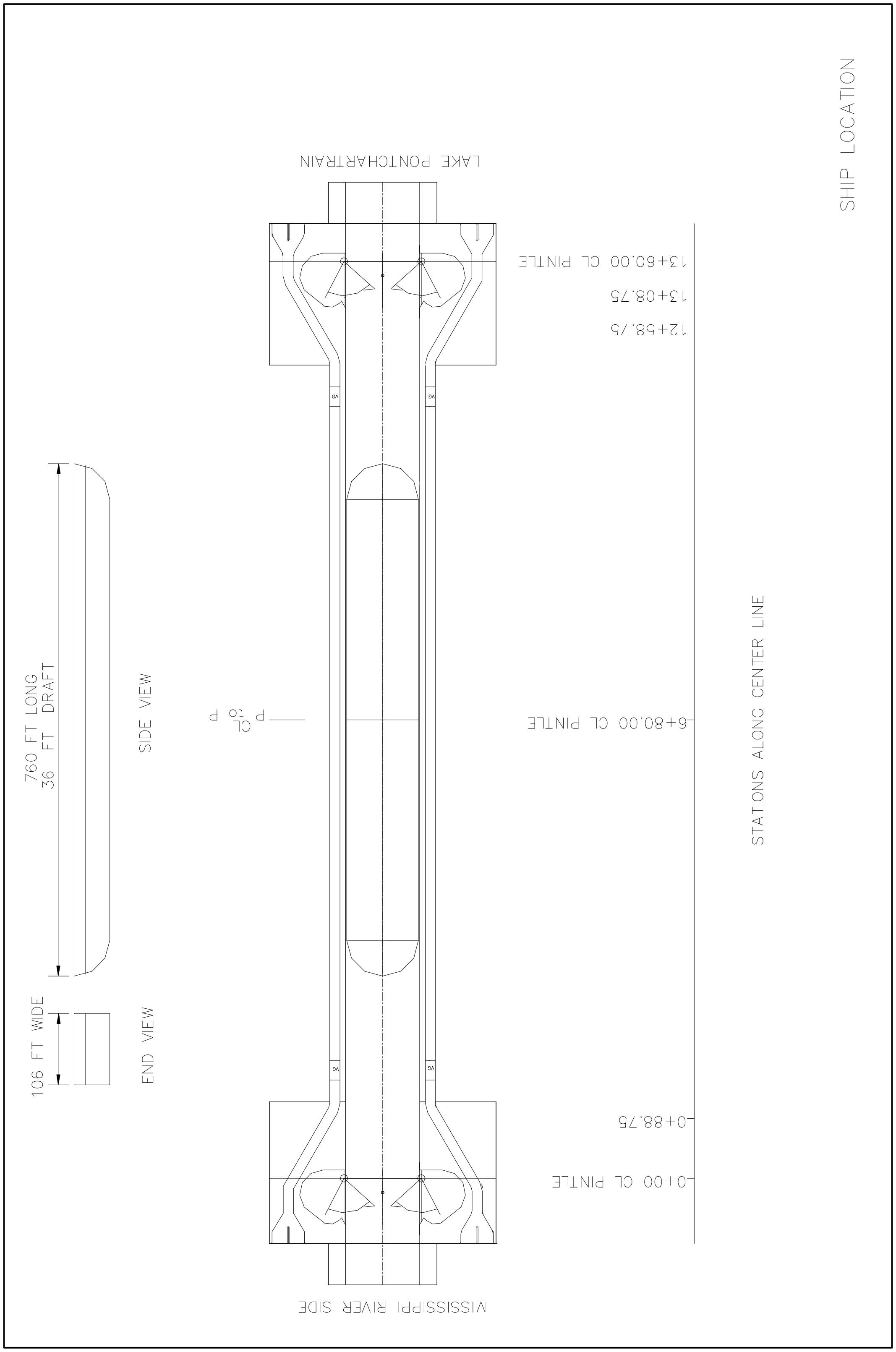
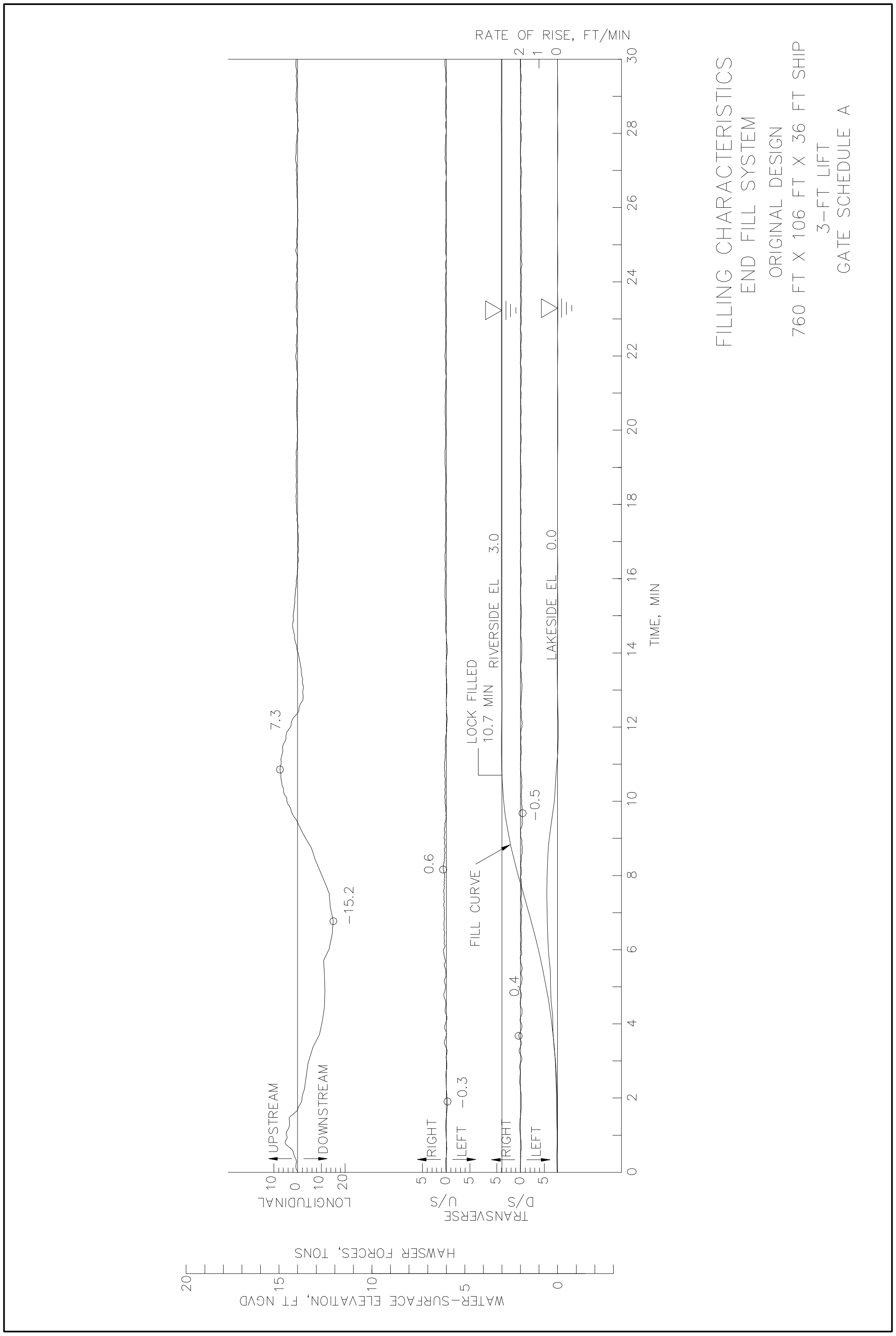
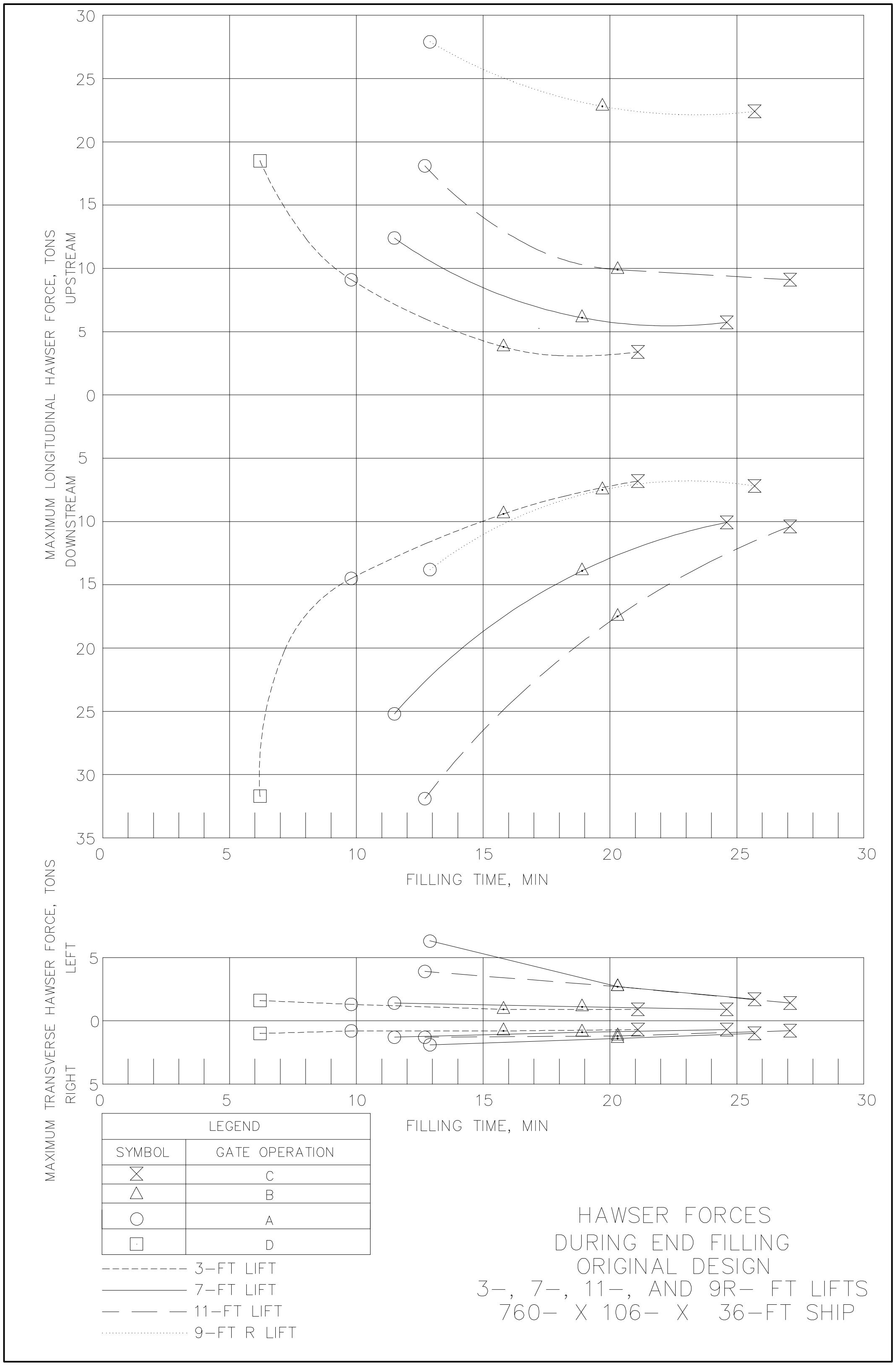
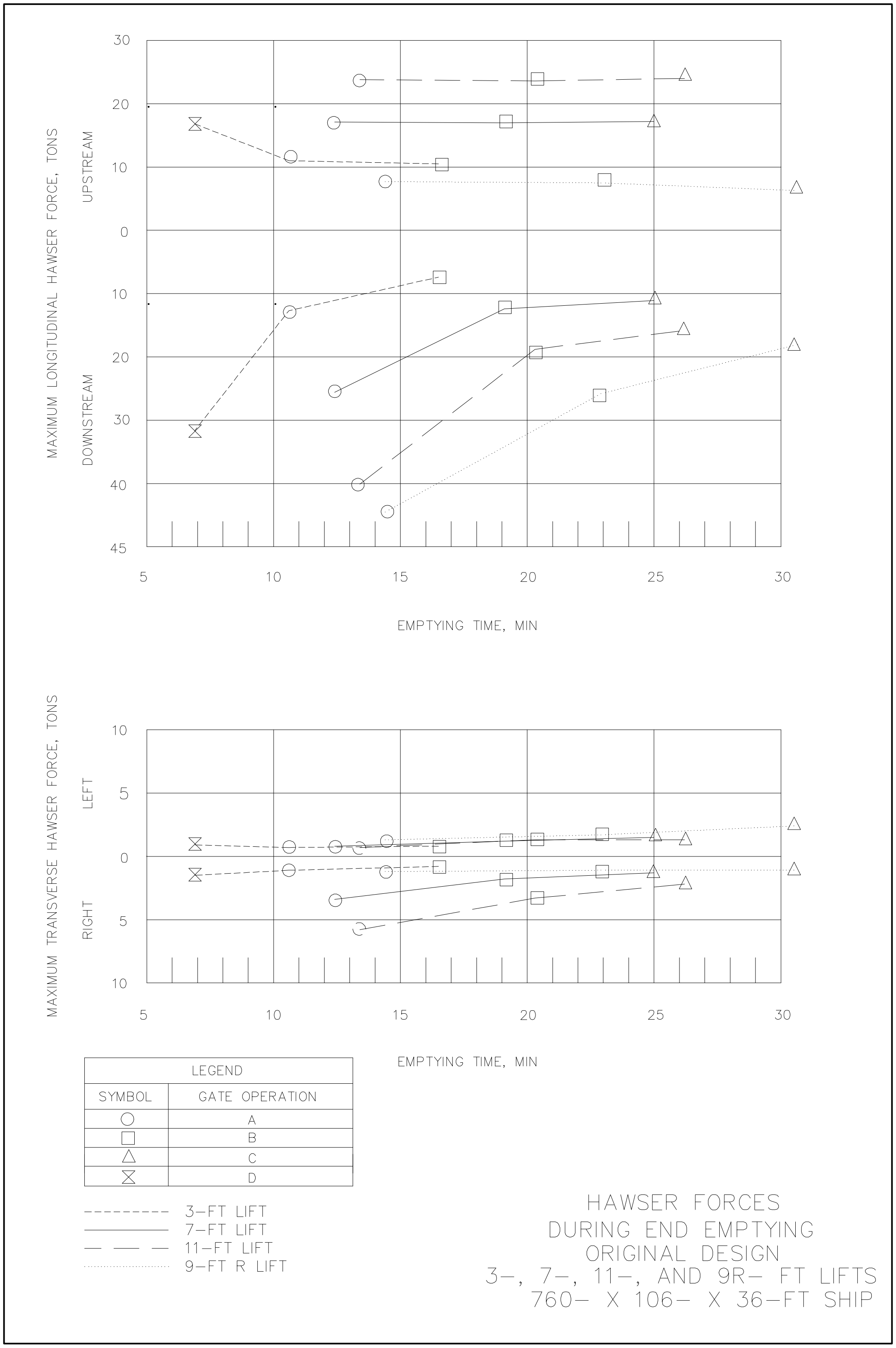

SHIP LOCATION
LAKE PONTCHARTRAIN
MISSISSIPPI RIVER SIDE
13+60.00 CL PINTLE
13+08.75
12+58.75
6+80.00 CL PINTLE
0+88.75
0+00 CL PINTLE
STATIONS ALONG CENTER LINE
CL to P
760 FT LONG
36 FT DRAFT
SIDE VIEW
106 FT WIDE
END VIEW

Plate 28


FILLING CHARACTERISTICS
END FILL SYSTEM
ORIGINAL DESIGN
760 FT X 106 FT X 36 FT SHIP
3-FT LIFT
GATE SCHEDULE A
RATE OF RISE, FT/MIN
TIME, MIN
LOCK FILLED
10.7 MIN
RIVERSIDE EL 3.0
LAKESIDE EL 0.0
FILL CURVE
UPSTREAM
DOWNSTREAM
LONGITUDINAL
RIGHT
LEFT
U/S
D/S
TRANSVERSE
HAWSER FORCES, TONS
WATER-SURFACE ELEVATION, FT NGVD
7.3
-15.2
0.6
-0.3
0.4
-0.5



MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
30
25
20
15
10
5
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
FILLING TIME, MIN
MAXIMUM TRANSVERSE HAWSER FORCE, TONS
LEFT
RIGHT
5
0
5
0
5
10
15
20
25
30
FILLING TIME, MIN
LEGEND
SYMBOL
GATE OPERATION
C
B
A
D
3-FT LIFT
7-FT LIFT
11-FT LIFT
9-FT R LIFT
HAWSER FORCES
DURING END FILLING
ORIGINAL DESIGN
3-, 7-, 11-, AND 9R- FT LIFTS
760- X 106- X 36-FT SHIP


30
20
10
0
10
20
30
40
45
UPSTREAM
DOWNSTREAM
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
5
10
15
20
25
30
EMPTYING TIME, MIN
10
5
0
5
10
LEFT
RIGHT
MAXIMUM TRANSVERSE HAWSER FORCE, TONS
5
10
15
20
25
30
EMPTYING TIME, MIN
LEGEND
SYMBOL
GATE OPERATION
A
B
C
D
3–FT LIFT
7–FT LIFT
11–FT LIFT
9–FT R LIFT
HAWSER FORCES
DURING END EMPTYING
ORIGINAL DESIGN
3–, 7–, 11–, AND 9R– FT LIFTS
760– X 106– X 36–FT SHIP

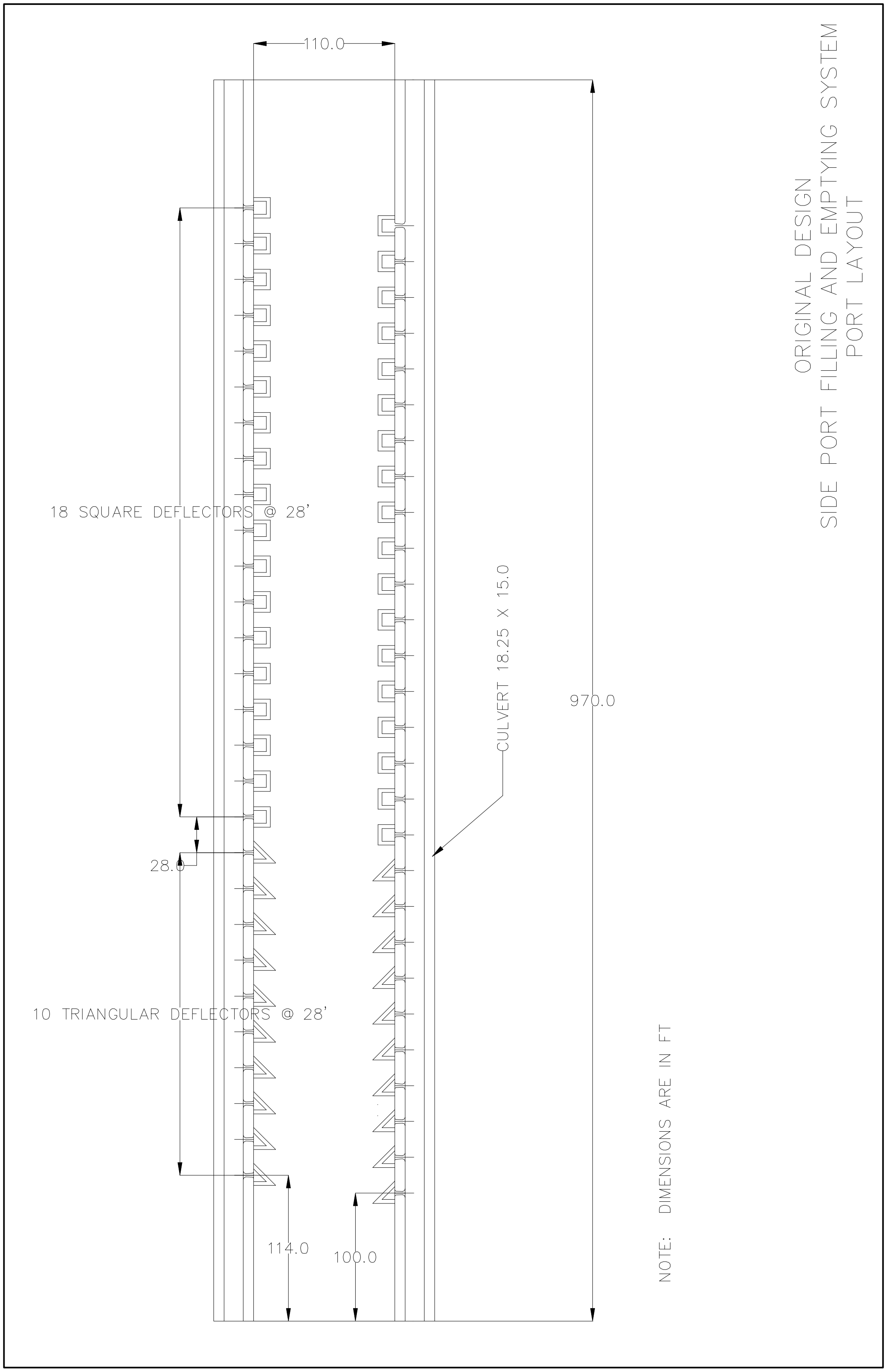
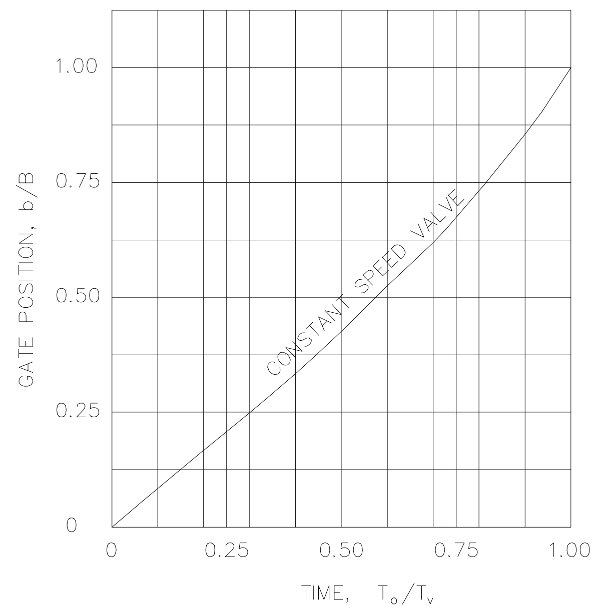

ORIGINAL DESIGN
SIDE PORT FILLING AND EMPTYING SYSTEM
PORT LAYOUT
110.0
18 SQUARE DEFLECTORS @ 28'
28.0
10 TRIANGULAR DEFLECTORS @ 28'
CULVERT 18.25 X 15.0
970.0
114.0
100.0
NOTE: DIMENSIONS ARE IN FT

Plate 32



T_o = TIME SINCE OPENING BEGAN

T_v = TIME TO OPEN FULL OR STOP

B = 18.25 FT

b = VERTICAL DIST. FROM LIP TO FLOOR

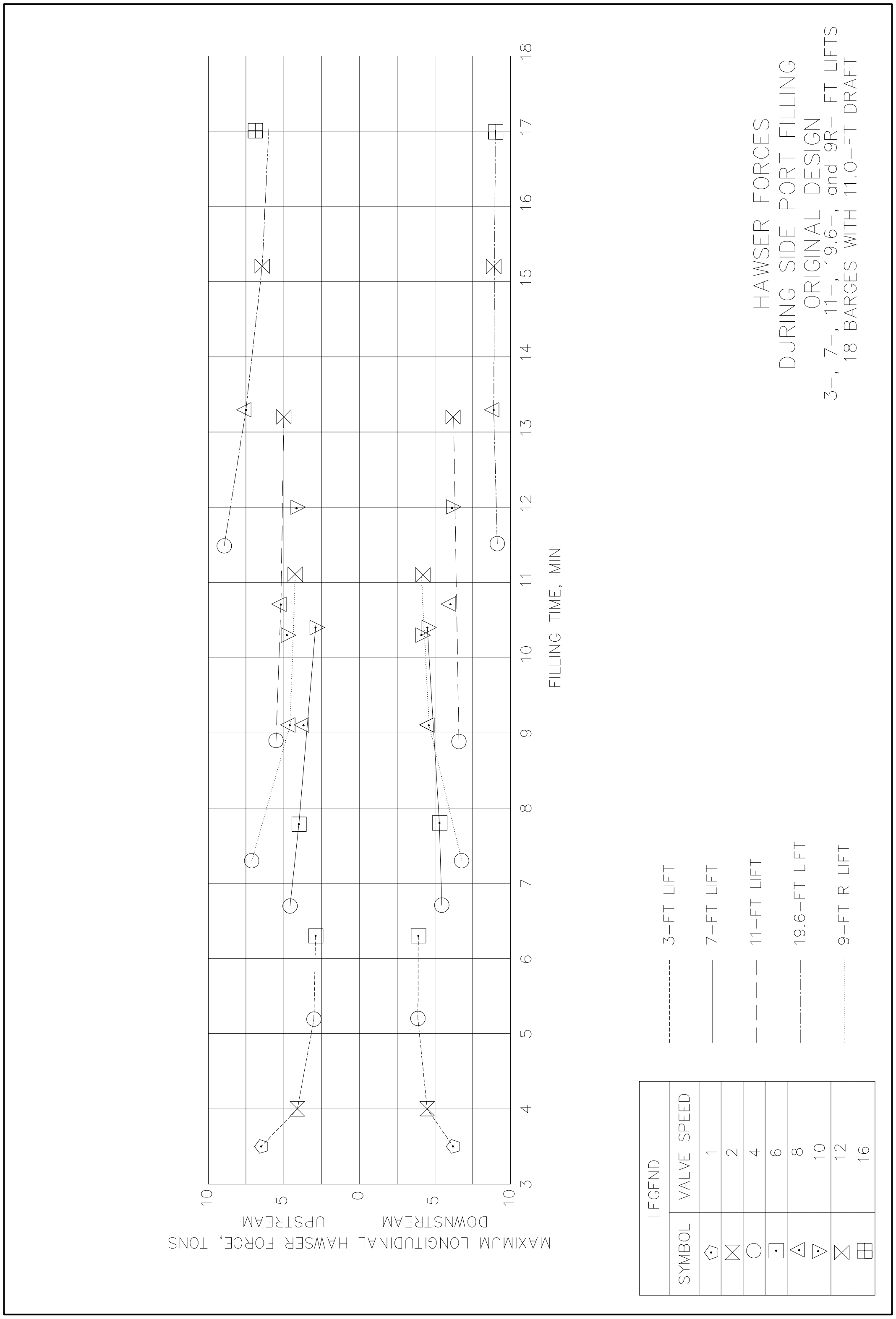
ORIGINAL VALVE CURVE
(CONSTANT SPEED)

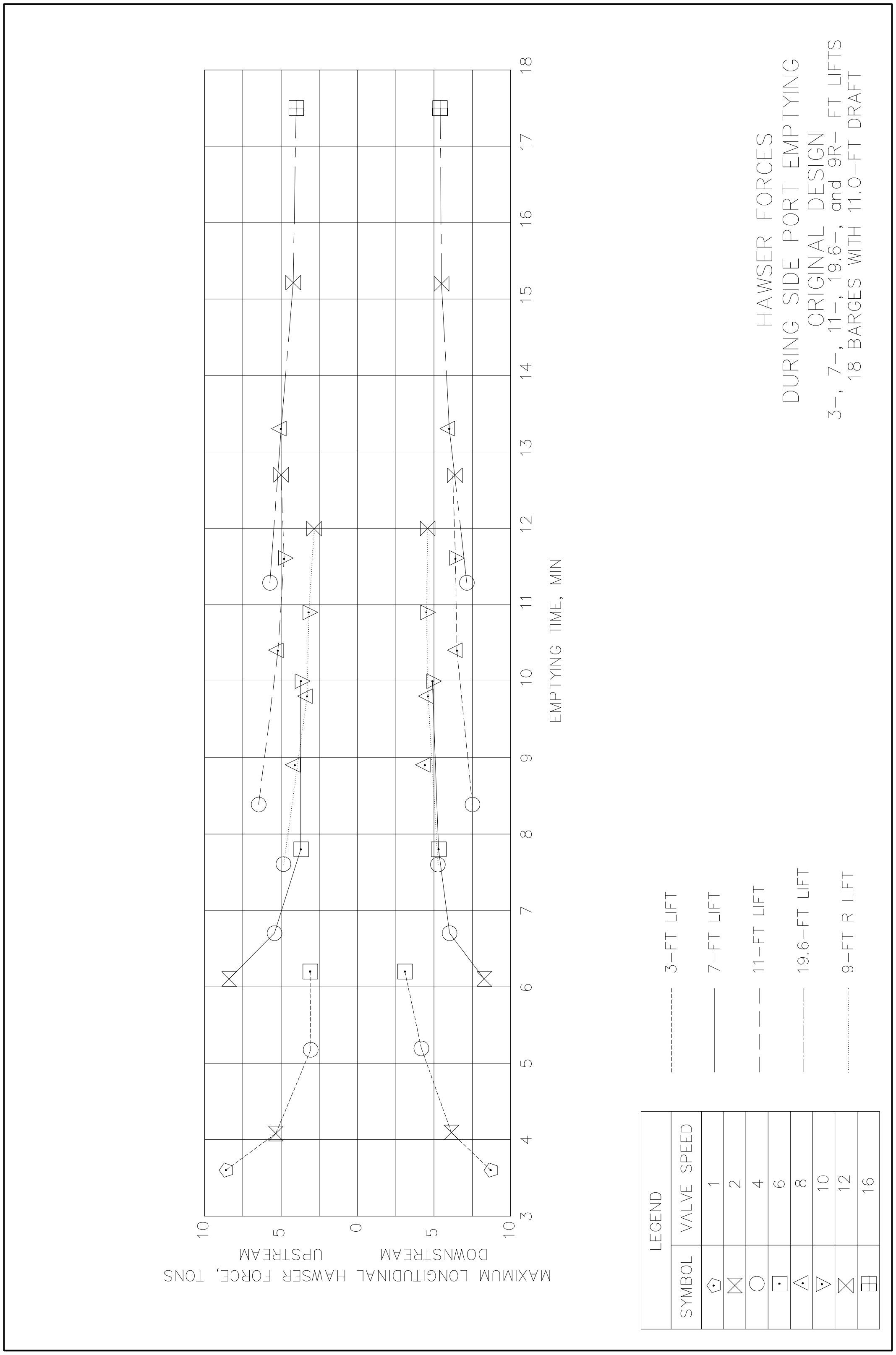
b/B	T_o/T_v
0	0
0.084	0.10
0.167	0.20
0.249	0.30
0.334	0.40
0.426	0.50
0.525	0.60
0.619	0.70
0.732	0.80
0.855	0.90
1.000	1.00

GATE POSITION DATA

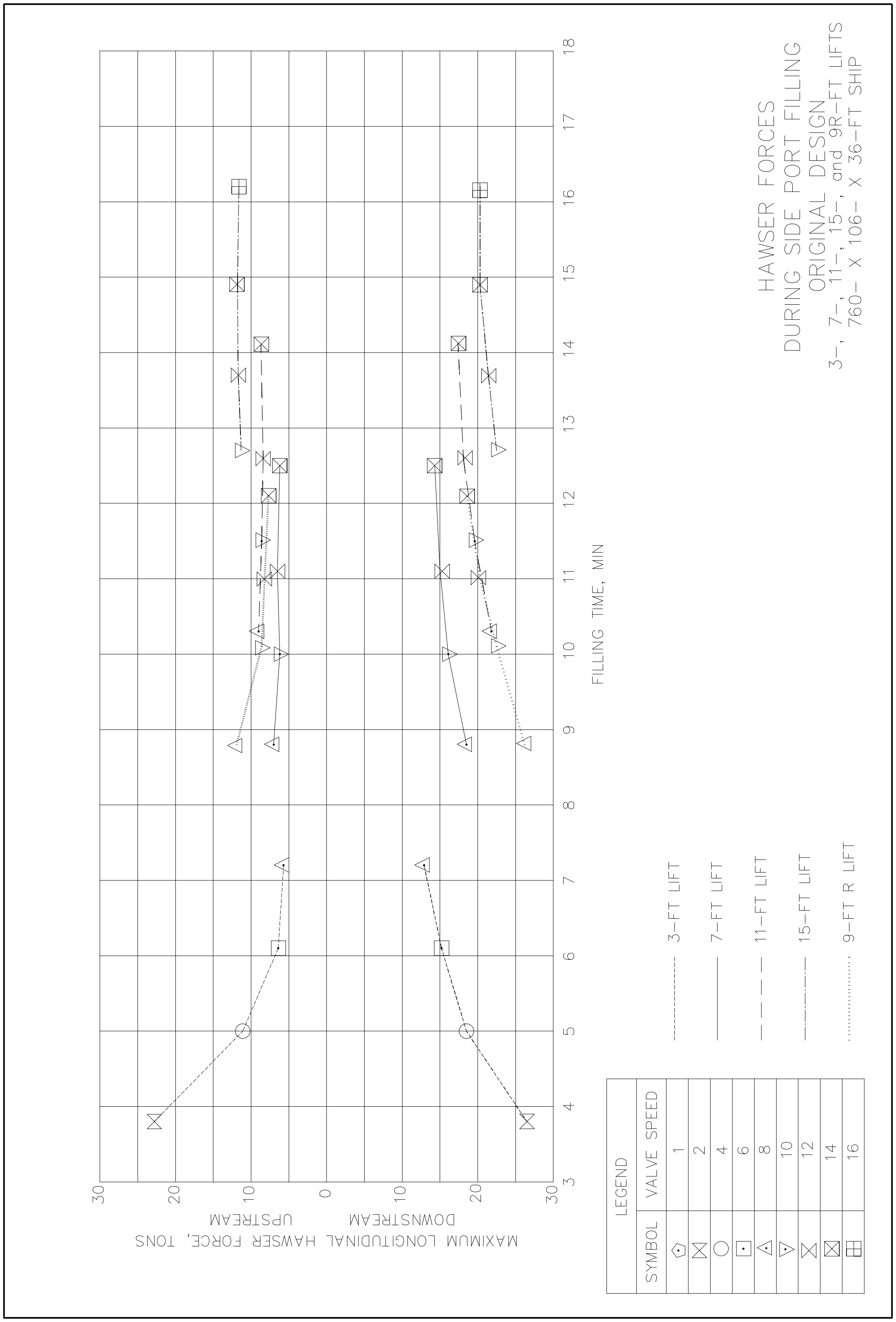
b	% Open (Radially)
0	0
1.525	10
3.050	20
4.550	30
6.100	40
7.775	50
9.575	60
11.300	70
13.375	80
15.600	90
18.250	100

CONSTANT-SPEED VALVE CURVE


HAWSER FORCES
DURING SIDE PORT FILLING
ORIGINAL DESIGN
3-, 7-, 11-, 19.6-, and 9R- FT LIFTS
18 BARGES WITH 11.0-FT DRAFT
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
10
5
0
5
10
FILLING TIME, MIN
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
3-FT LIFT
7-FT LIFT
11-FT LIFT
19.6-FT LIFT
9-FT R LIFT
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
8
10
12
16

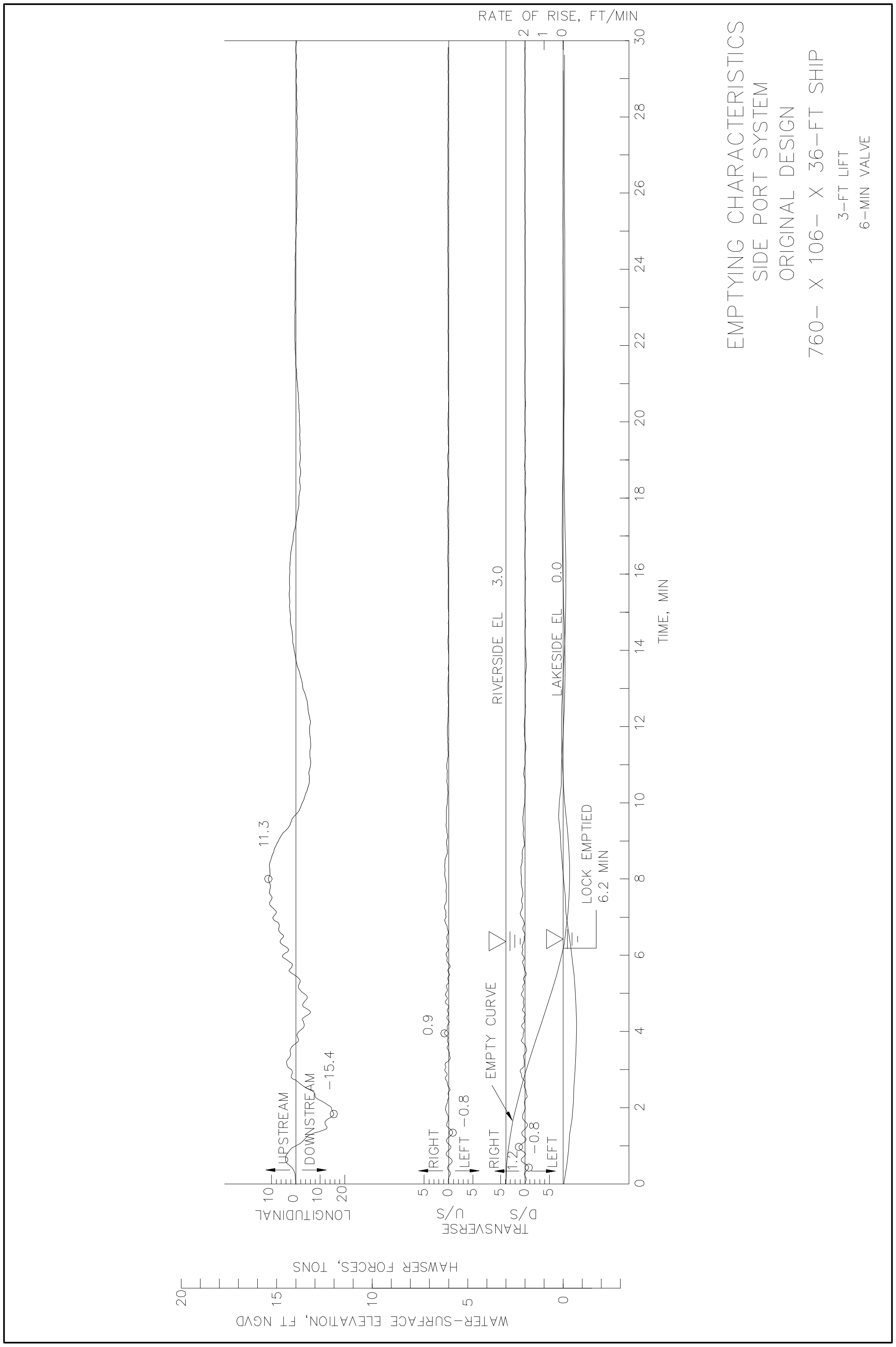


HAWSER FORCES
DURING SIDE PORT EMPTYING
ORIGINAL DESIGN
3-, 7-, 11-, 19.6-, and 9R- FT LIFTS
18 BARGES WITH 11.0-FT DRAFT
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
EMPTYING TIME, MIN
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
8
10
12
16
3-FT LIFT
7-FT LIFT
11-FT LIFT
19.6-FT LIFT
9-FT R LIFT



HAWSER FORCES
DURING SIDE PORT FILLING
ORIGINAL DESIGN
3–, 7–, 11–, 15–, and 9R–FT LIFTS
760– X 106– X 36–FT SHIP
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
FILLING TIME, MIN
3–FT LIFT
7–FT LIFT
11–FT LIFT
15–FT LIFT
9–FT R LIFT
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
8
10
12
14
16

Plate 36


EMPTYING CHARACTERISTICS
SIDE PORT SYSTEM
ORIGINAL DESIGN
760- X 106- X 36-FT SHIP
3-FT LIFT
6-MIN VALVE
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
11.3
-15.4
0.9
-0.8
1.2
EMPTY CURVE
RIVERSIDE EL 3.0
LAKESIDE EL 0.0
LOCK EMPTIED
6.2 MIN

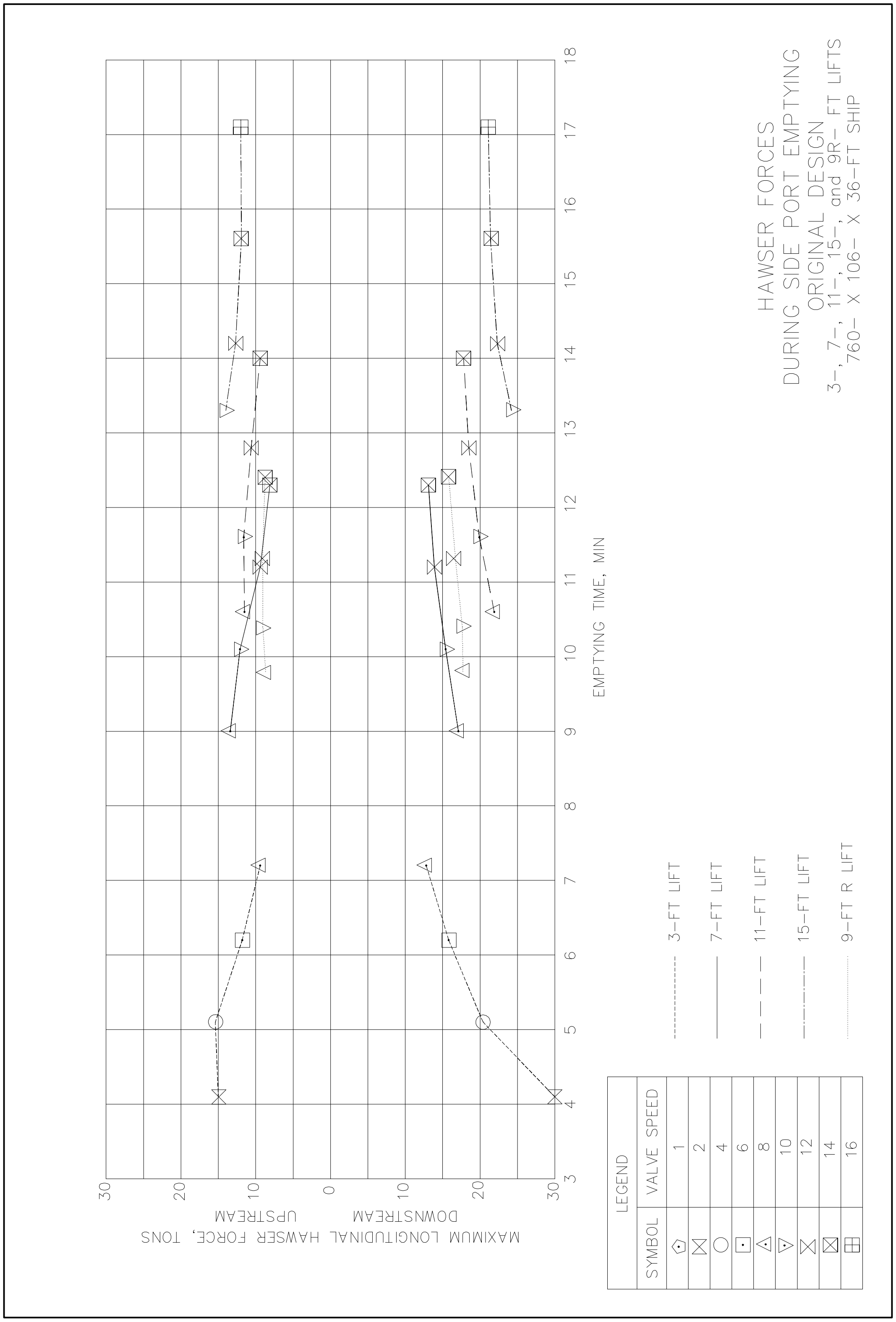
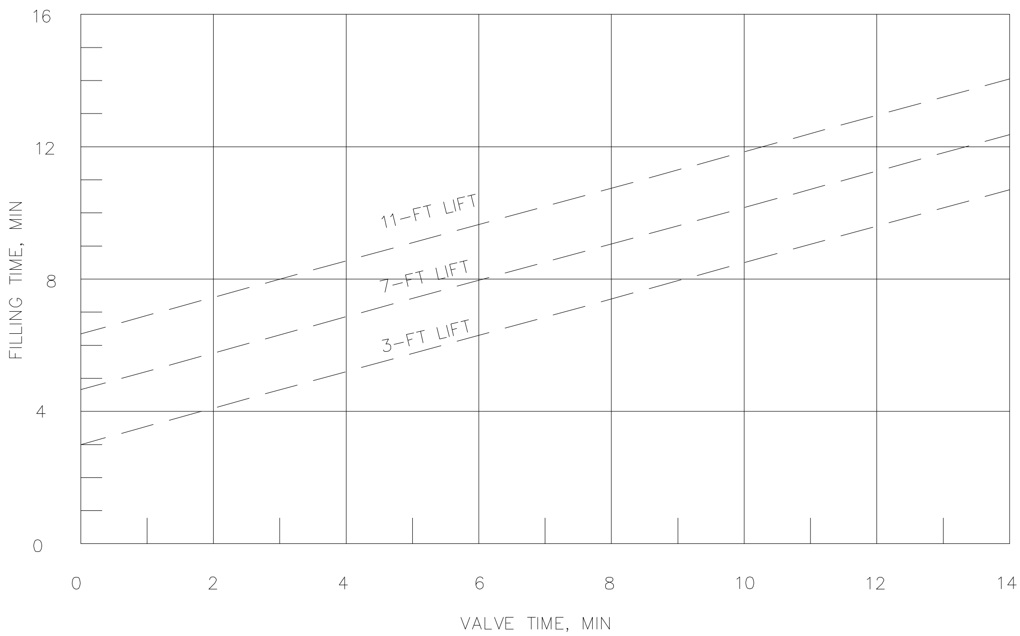
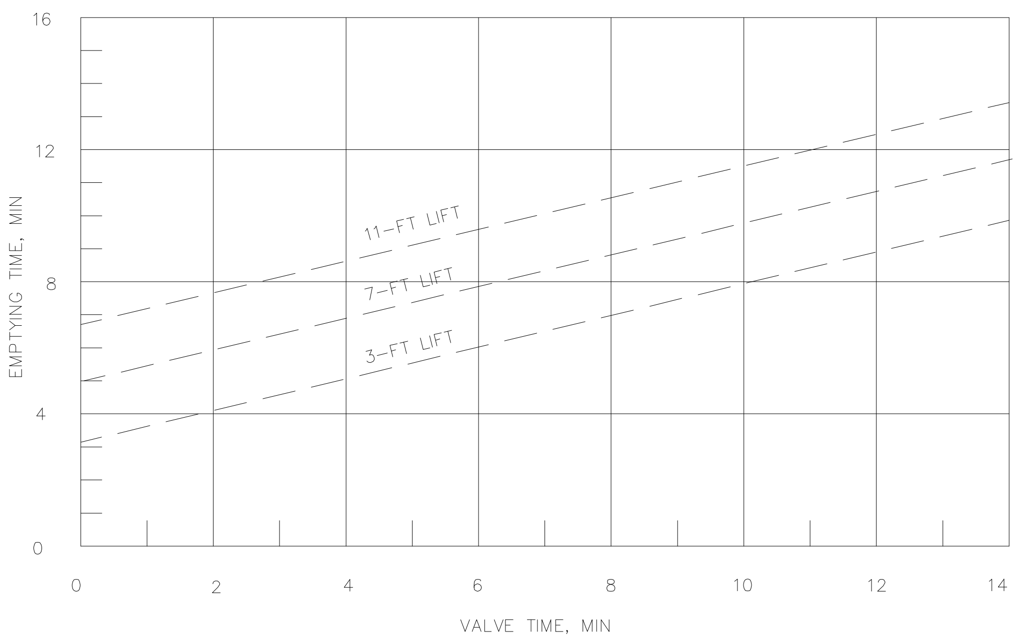
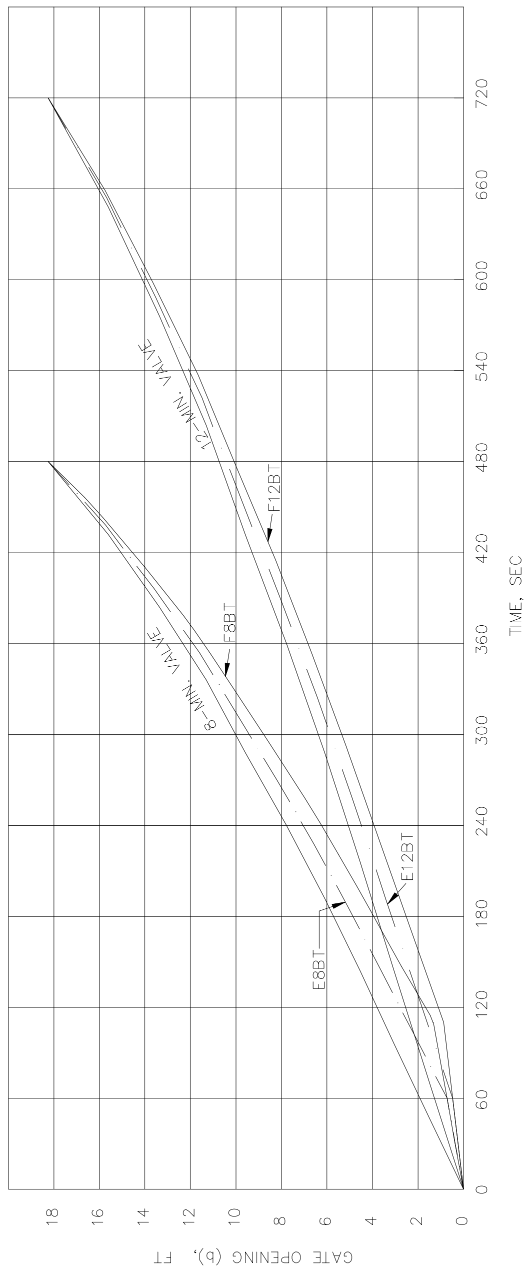

HAWSER FORCES
DURING SIDE PORT EMPTYING
ORIGINAL DESIGN
3-, 7-, 11-, 15-, and 9R- FT LIFTS
760- X 106- X 36-FT SHIP
EMPTYING TIME, MIN
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
8
10
12
14
16
3-FT LIFT
7-FT LIFT
11-FT LIFT
15-FT LIFT
9-FT R LIFT

Plate 38

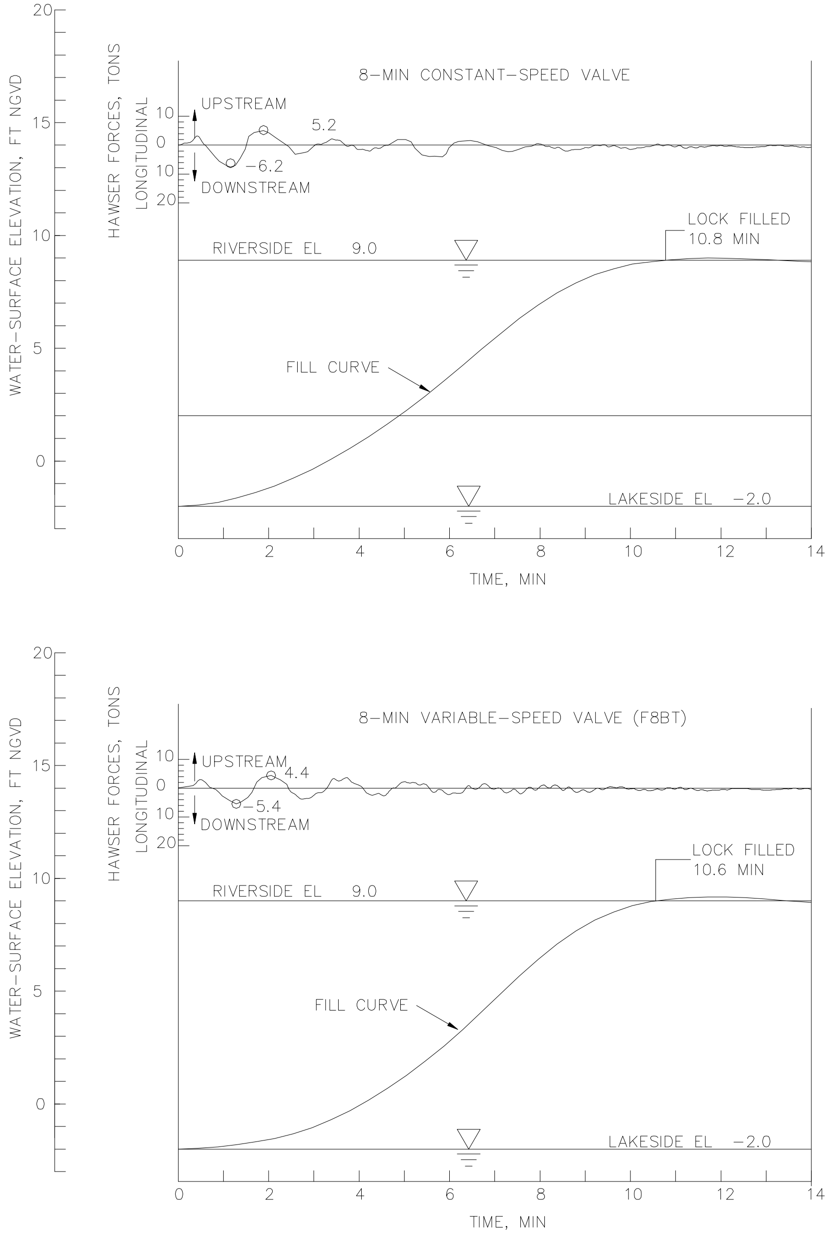




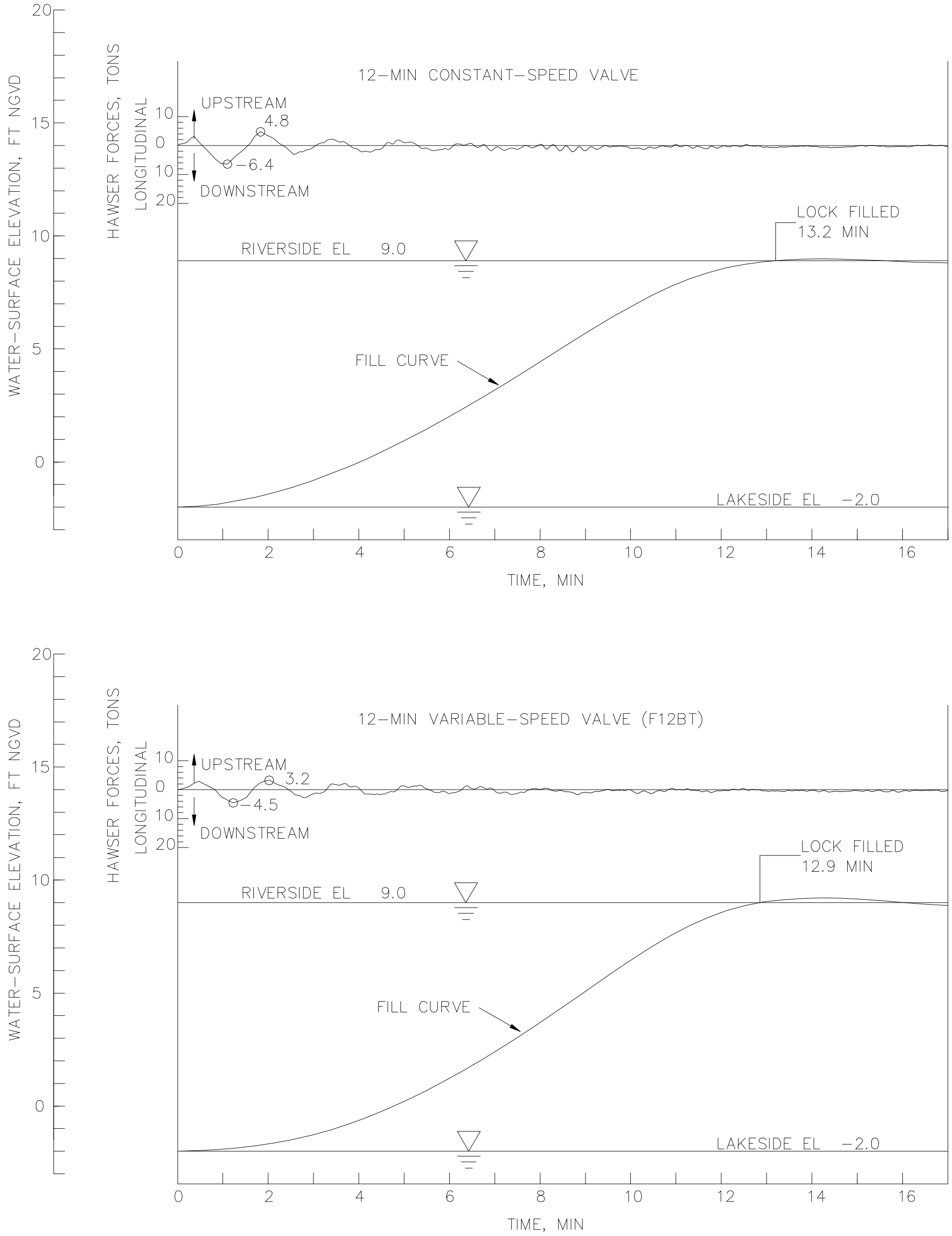
OPERATION TIMES FOR
LIFTS = 3, 7, AND 11 FT
SIDE PORT SYSTEM
ORIGINAL DESIGN



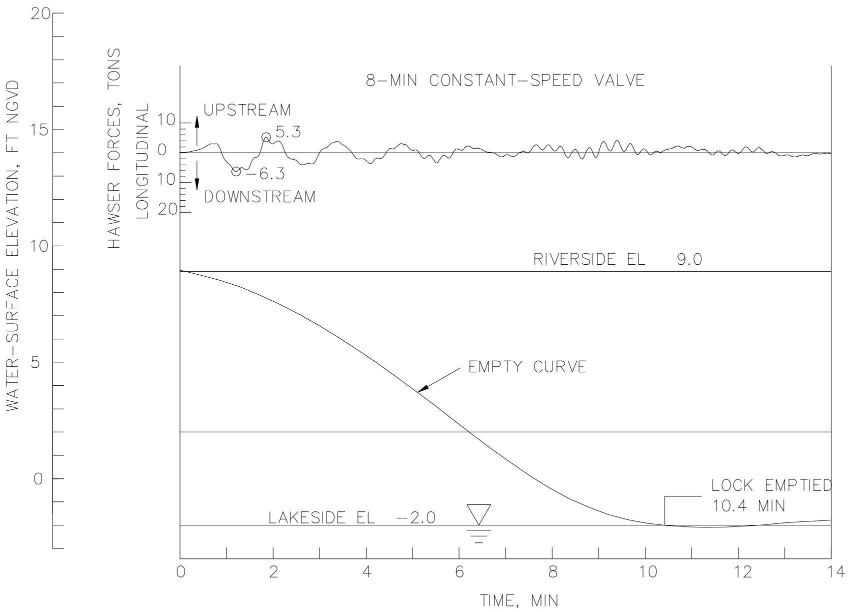
VALVE OPENING CURVES
SIDE PORT WITH BARGES
ORIGINAL DESIGN

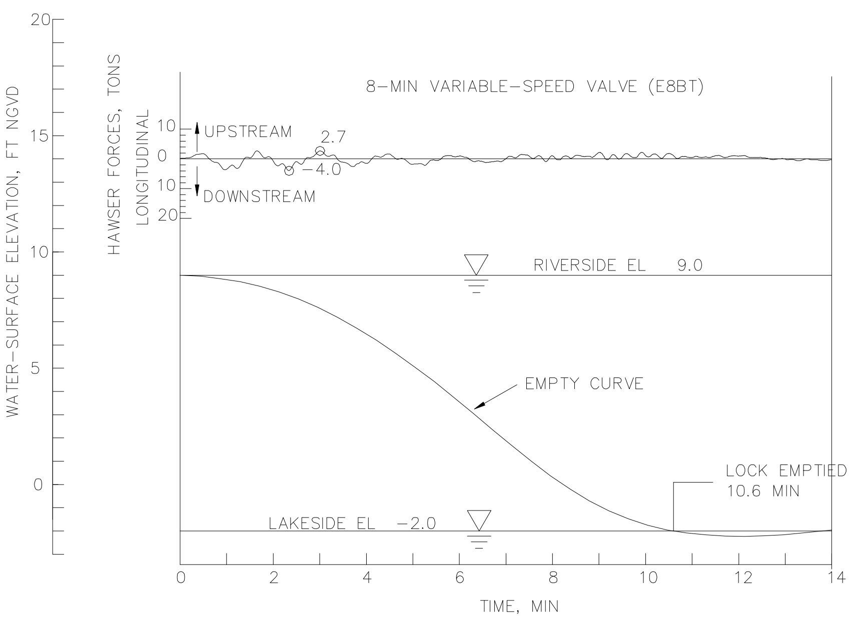


COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING FILLING
ORIGINAL DESIGN
8-MIN CONSTANT AND VARIABLE-SPEED VALVES
3 X 6 BARGE, 11-FT DRAFT
11-FT LIFT

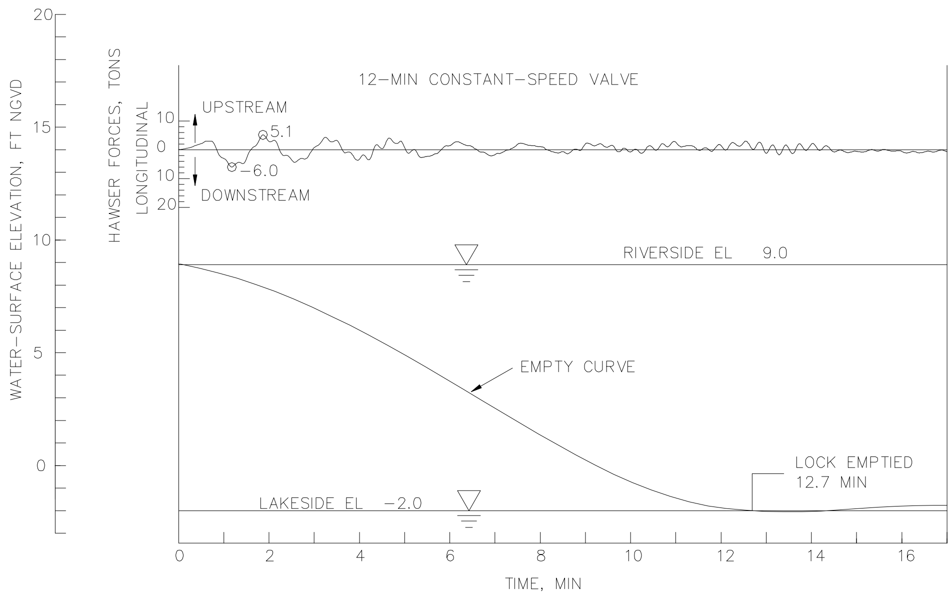


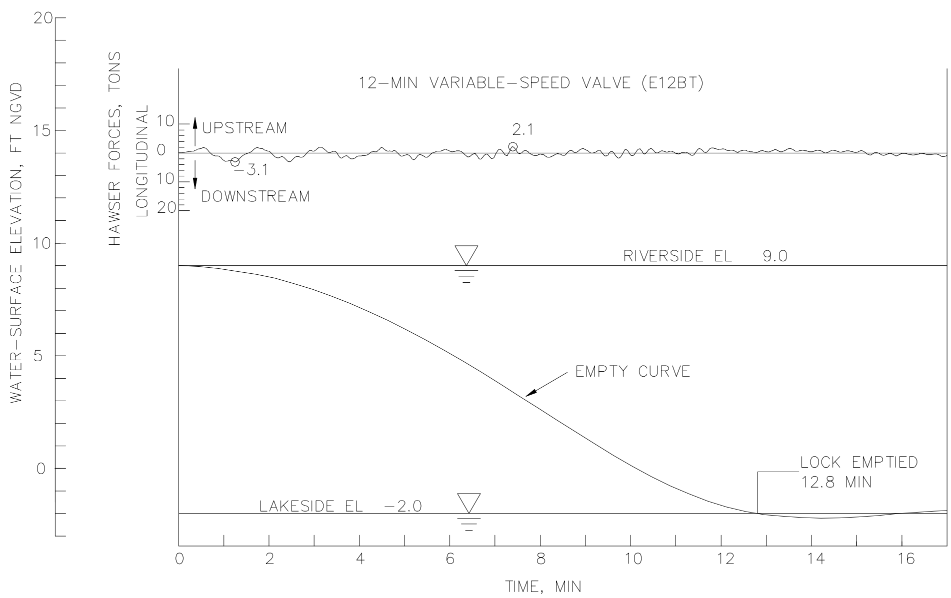
COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING FILLING
ORIGINAL DESIGN
12-MIN CONSTANT AND VARIABLE-SPEED VALVES
3 X 6 BARGE, 11-FT DRAFT
11-FT LIFT



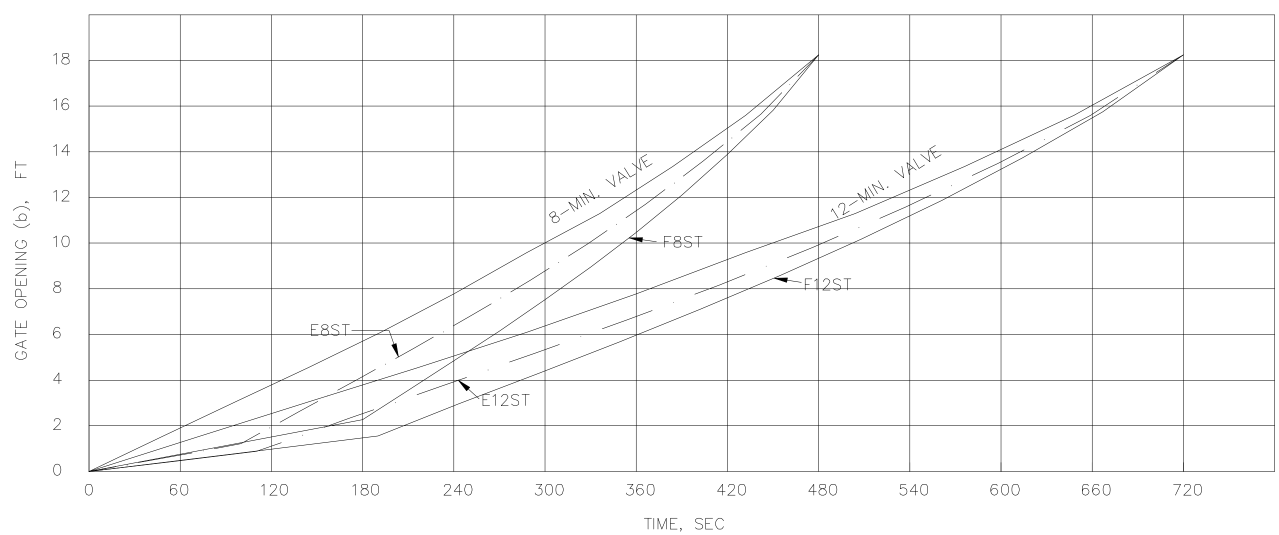


COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING EMPTYING
ORIGINAL DESIGN
8-MIN CONSTANT AND VARIABLE-SPEED VALVES
3 X 6 BARGE, 11-FT DRAFT
11-FT LIFT

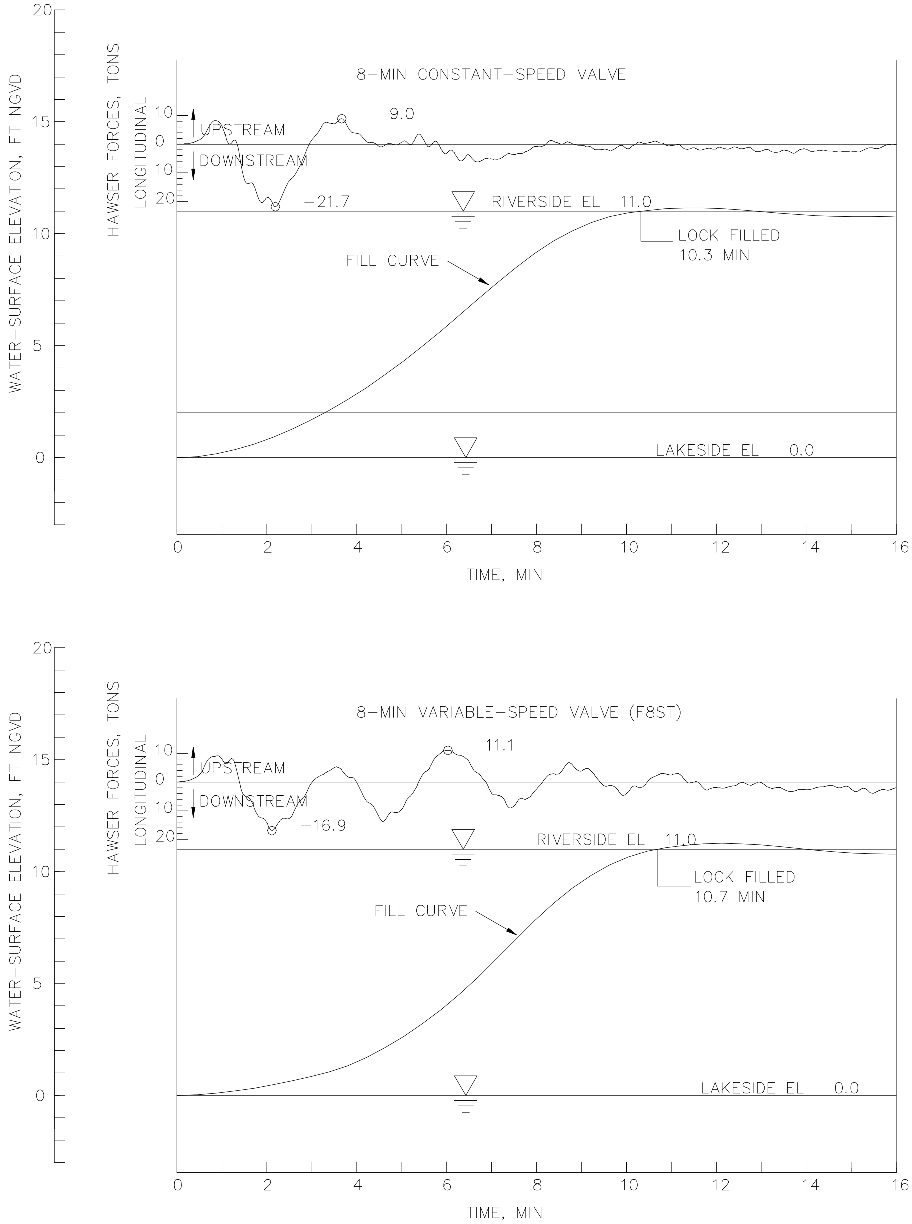




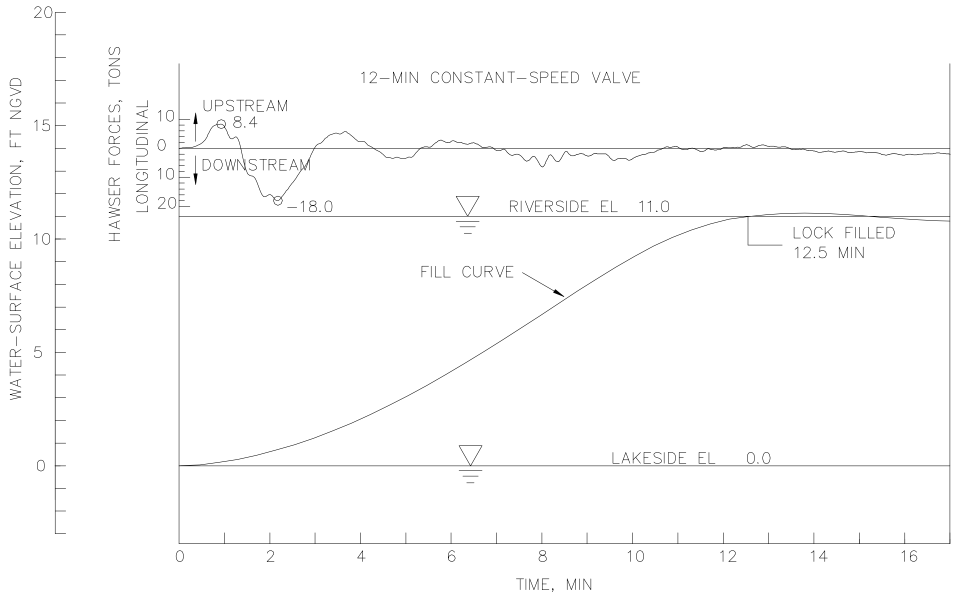
COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING EMPTYING
ORIGINAL DESIGN
12-MIN CONSTANT AND VARIABLE-SPEED VALVES
3 X 6 BARGE, 11-FT DRAFT
11-FT LIFT

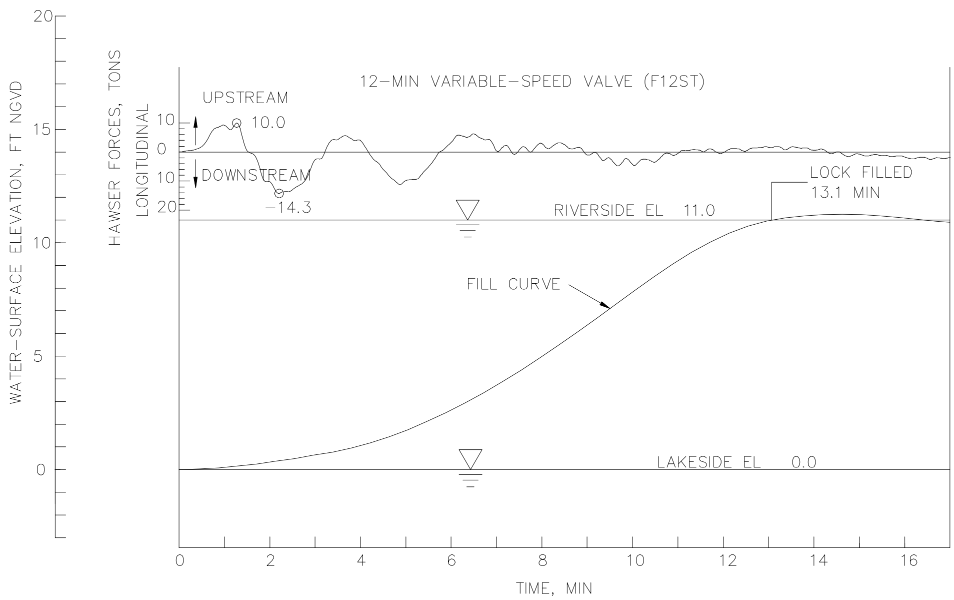


VALVE OPENING CURVES
SIDE PORT WITH SHIP
ORIGINAL DESIGN

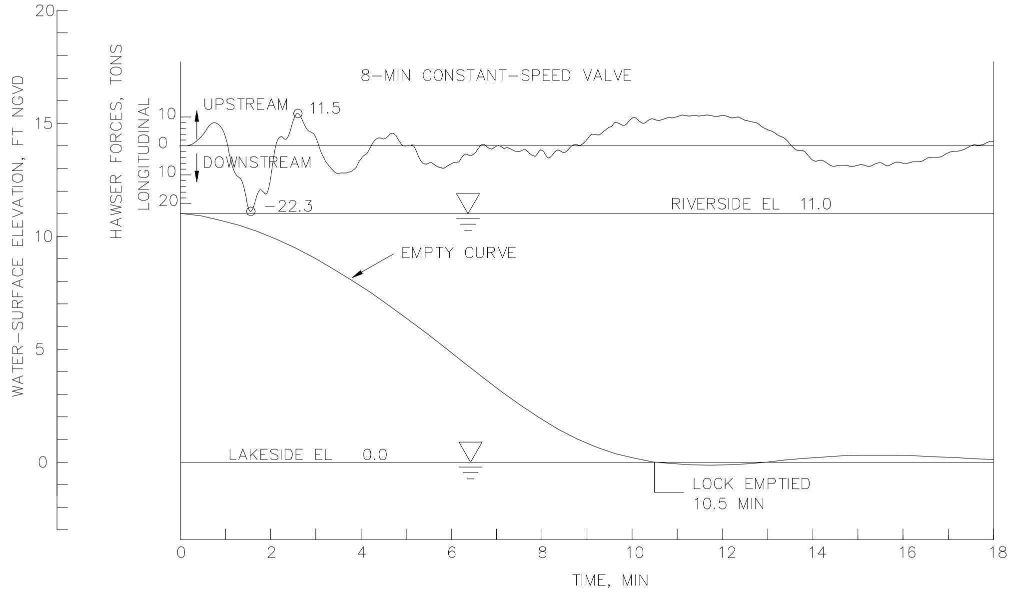


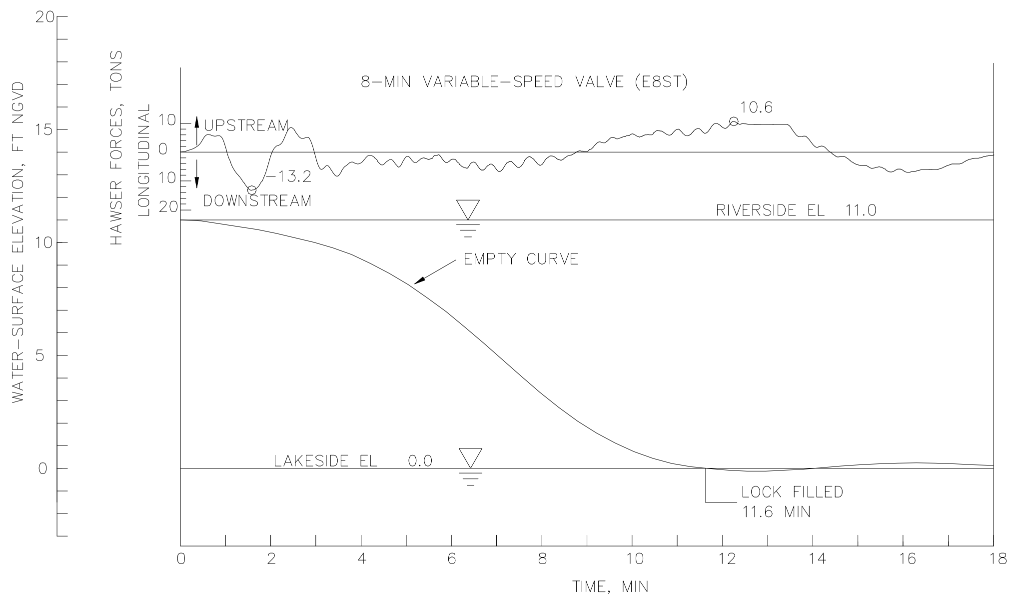
COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING FILLING
ORIGINAL DESIGN
8-MIN CONSTANT AND VARIABLE-SPEED VALVES
760- X 106- X 36-FT SHIP
11-FT LIFT



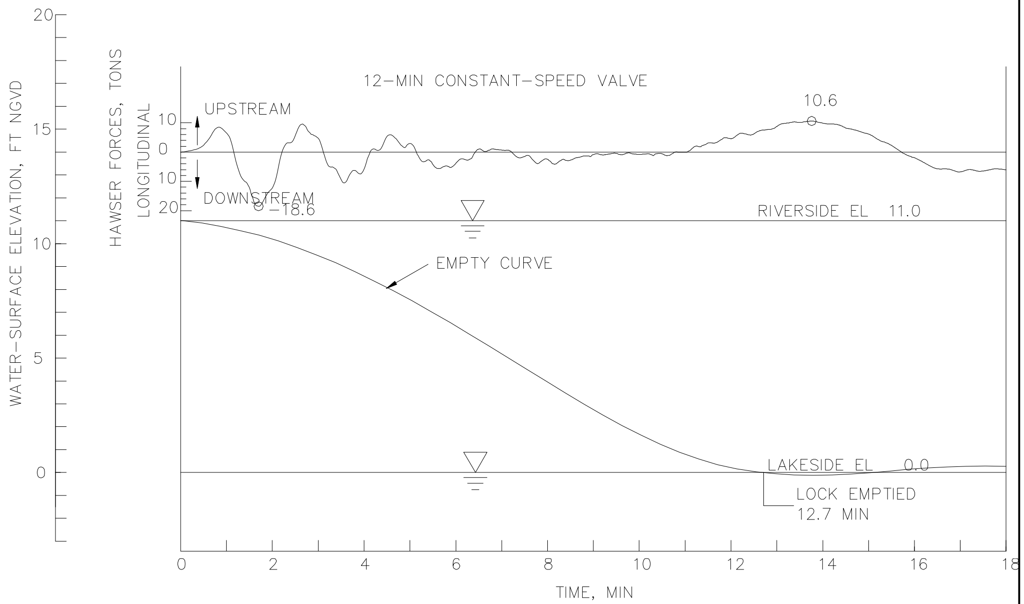


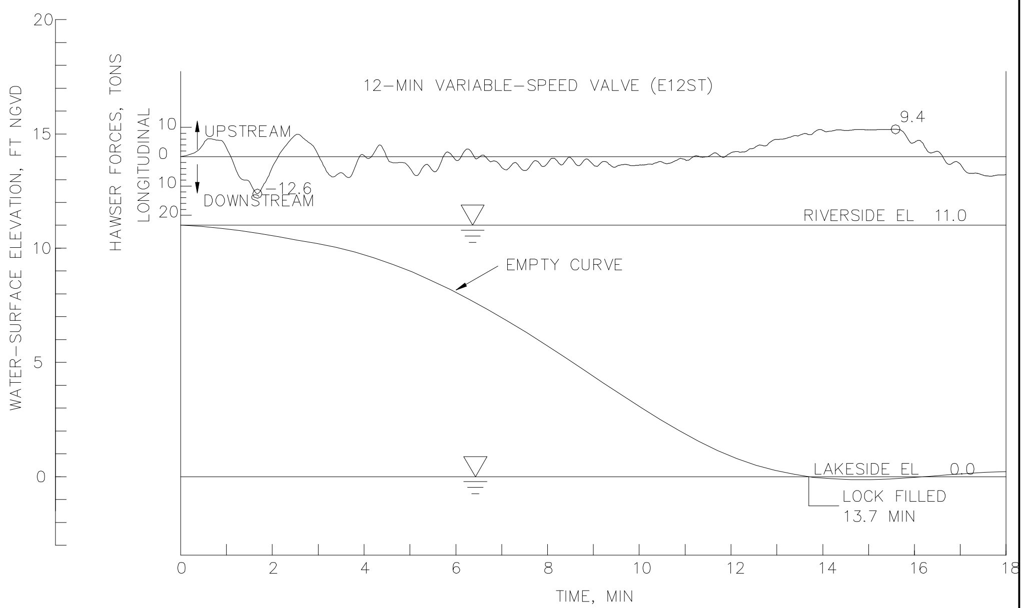
COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING FILLING
ORIGINAL DESIGN
12-MIN CONSTANT AND VARIABLE-SPEED VALVES
760- X 106- X 36-FT SHIP
11-FT LIFT





COMPARISON OF CHAMBER PERFORMANCE
SIDE PORT SYSTEM
DURING EMPTYING
ORIGINAL DESIGN
8-MIN CONSTANT AND VARIABLE-SPEED VALVES
760- x 106- x 36-FT SHIP
11-FT LIFT





COMPARISON OF CHAMBER PERFORMANCE
DURING EMPTYING
SIDE PORT SYSTEM
ORIGINAL DESIGN
12-MIN CONSTANT AND VARIABLE-SPEED VALVES
760- X 106- X 36-FT SHIP
11-FT LIFT

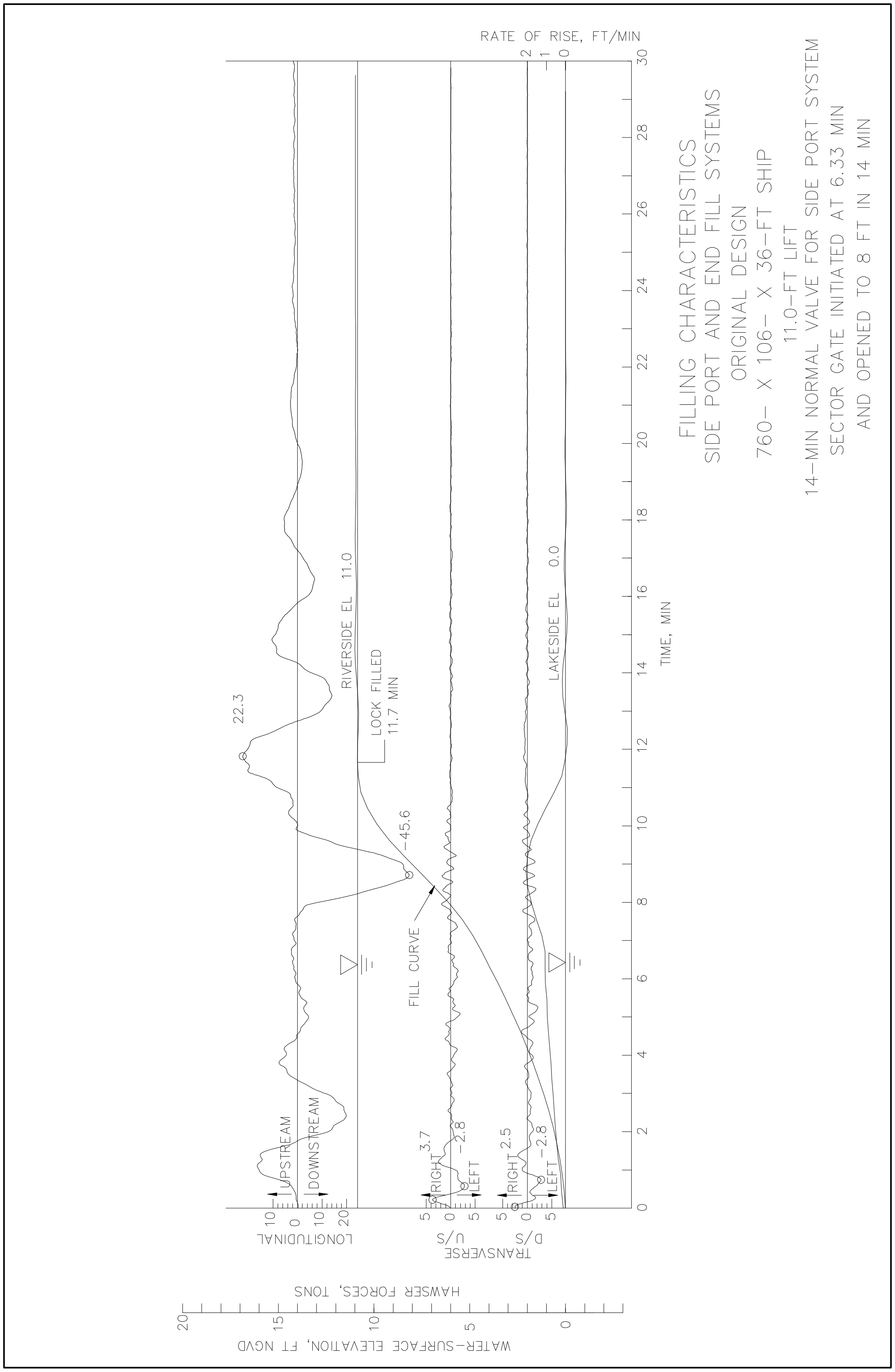
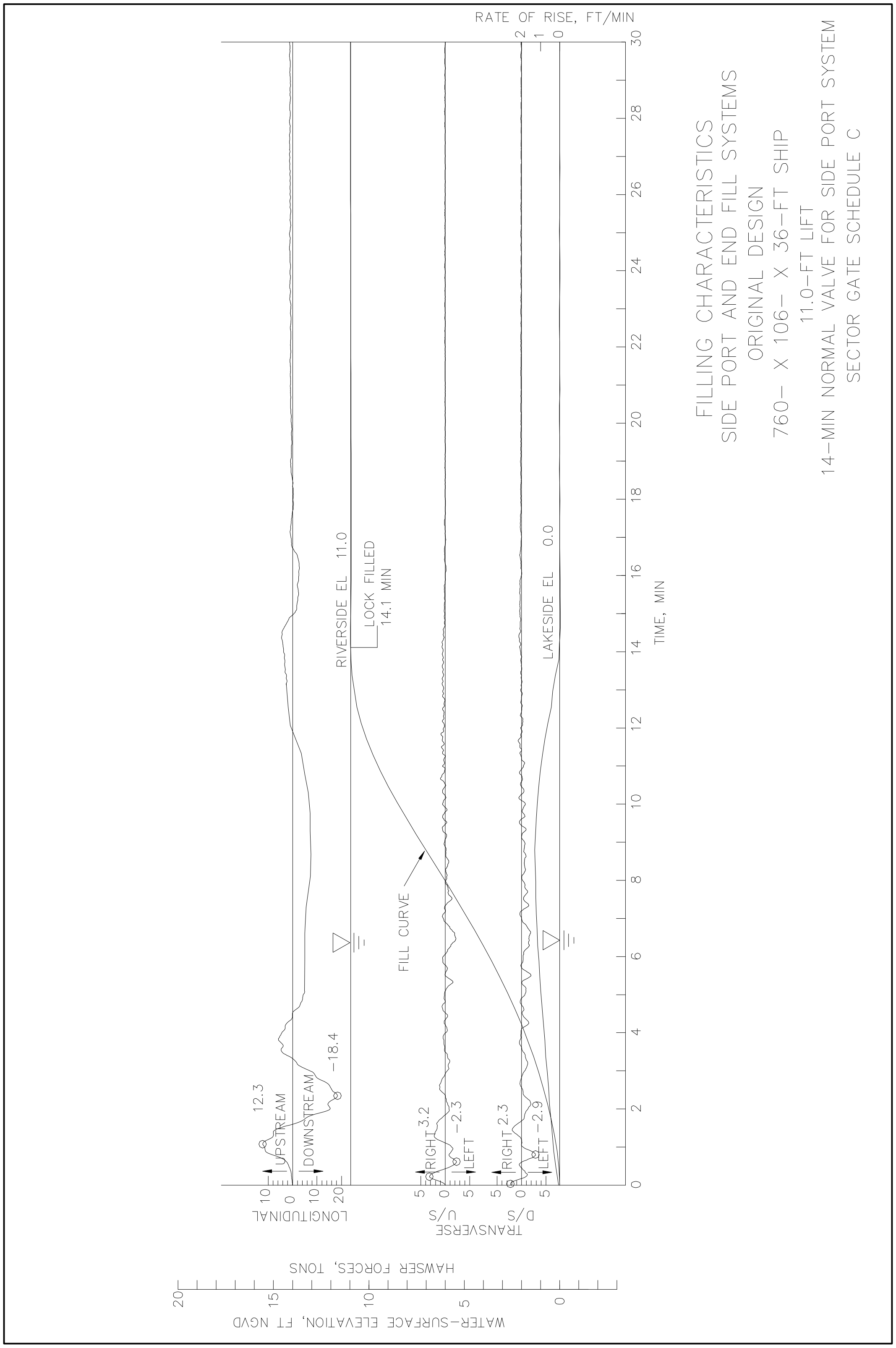
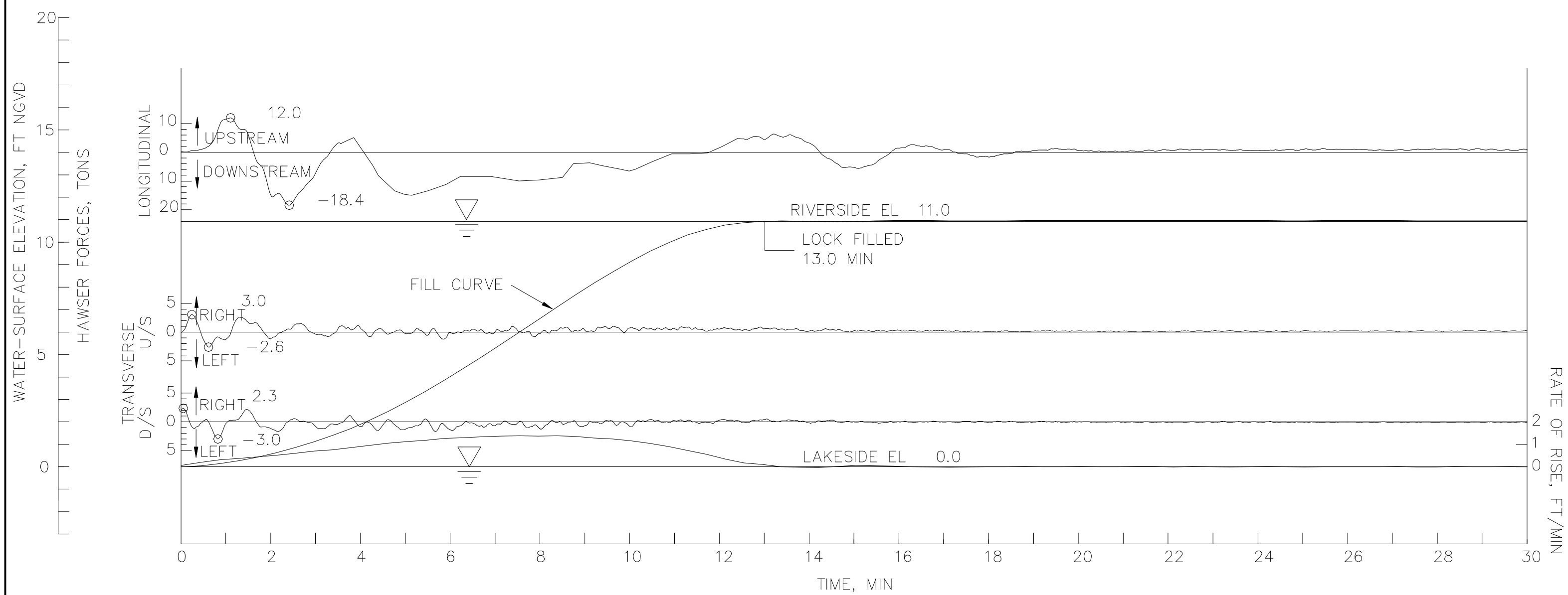
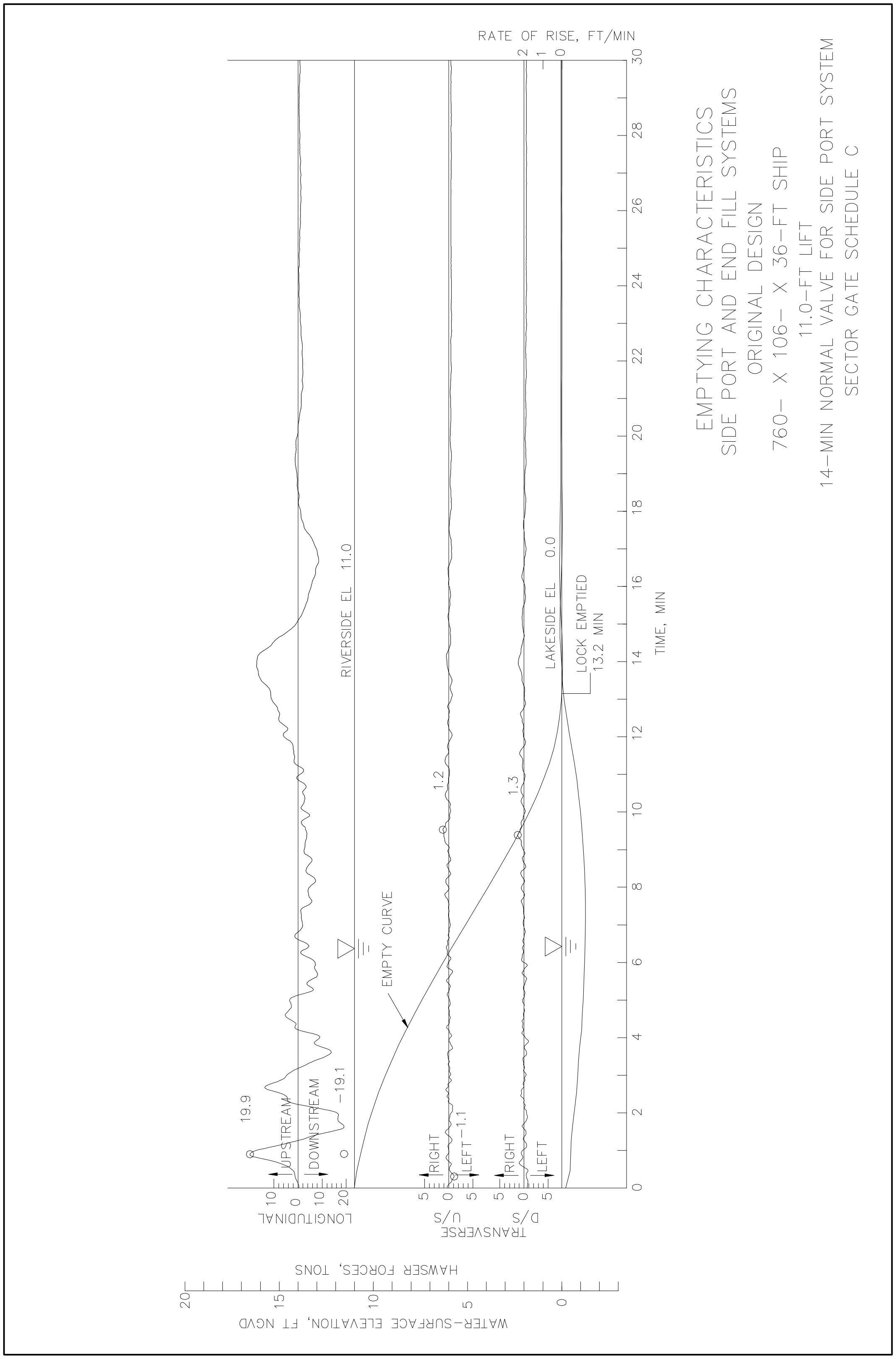

FILLING CHARACTERISTICS
SIDE PORT AND END FILL SYSTEMS
ORIGINAL DESIGN
760- X 106- X 36-FT SHIP
11.0-FT LIFT
14-MIN NORMAL VALVE FOR SIDE PORT SYSTEM
SECTOR GATE INITIATED AT 6.33 MIN
AND OPENED TO 8 FT IN 14 MIN
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
RIVERSIDE EL 11.0
LAKESIDE EL 0.0
LOCK FILLED
11.7 MIN
FILL CURVE
22.3
-45.6
3.7
-2.8
2.5
-2.8

Plate 50

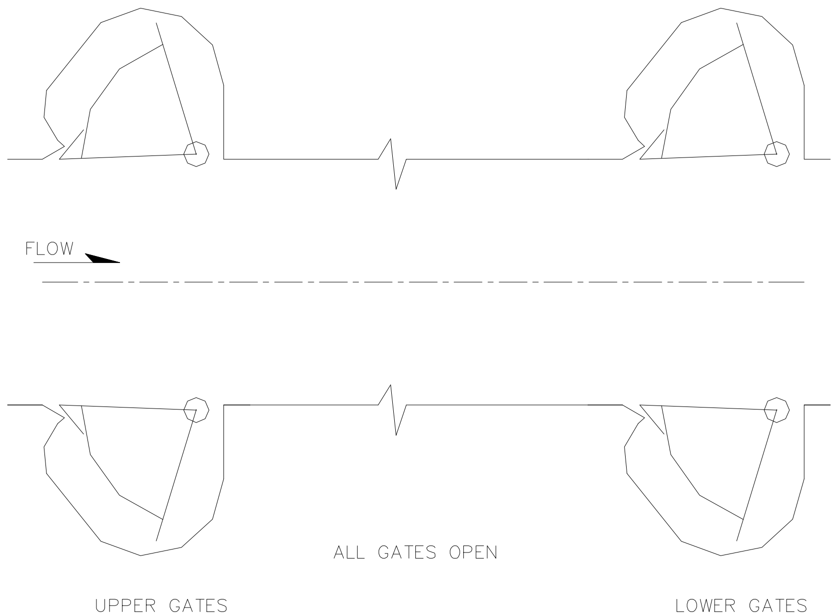

FILLING CHARACTERISTICS
SIDE PORT AND END FILL SYSTEMS
ORIGINAL DESIGN
760- X 106- X 36-FT SHIP
11.0-FT LIFT
14-MIN NORMAL VALVE FOR SIDE PORT SYSTEM
SECTOR GATE SCHEDULE C
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
12.3
-18.4
3.2
-2.3
2.3
-2.9
FILL CURVE
RIVERSIDE EL 11.0
LOCK FILLED
14.1 MIN
LAKESIDE EL 0.0

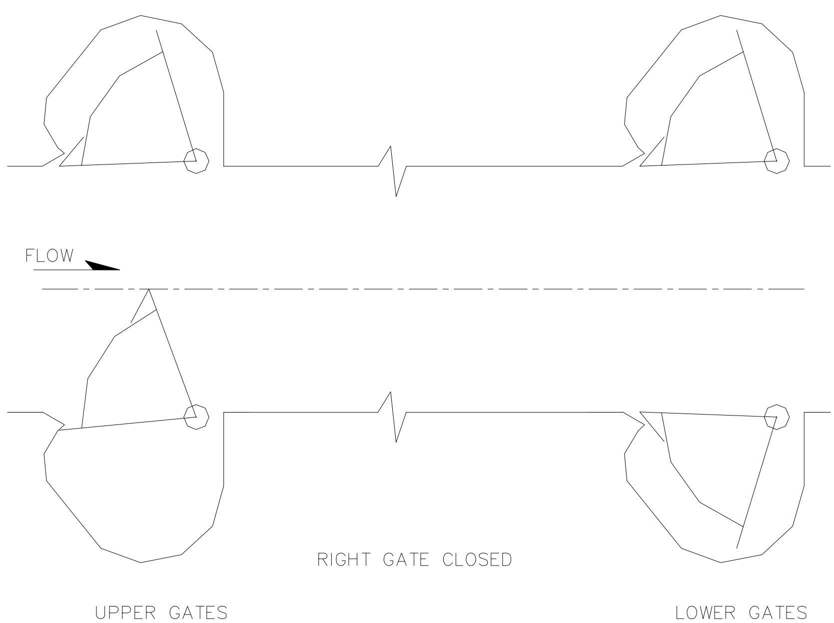


FILLING CHARACTERISTICS
SIDE PORT AND END FILL SYSTEMS
ORIGINAL DESIGN
760- X 106- X 36-FT SHIP
11.0-FT LIFT
14-MIN NORMAL VALVE FOR SIDE PORT SYSTEM
SECTOR GATE SCHEDULE B

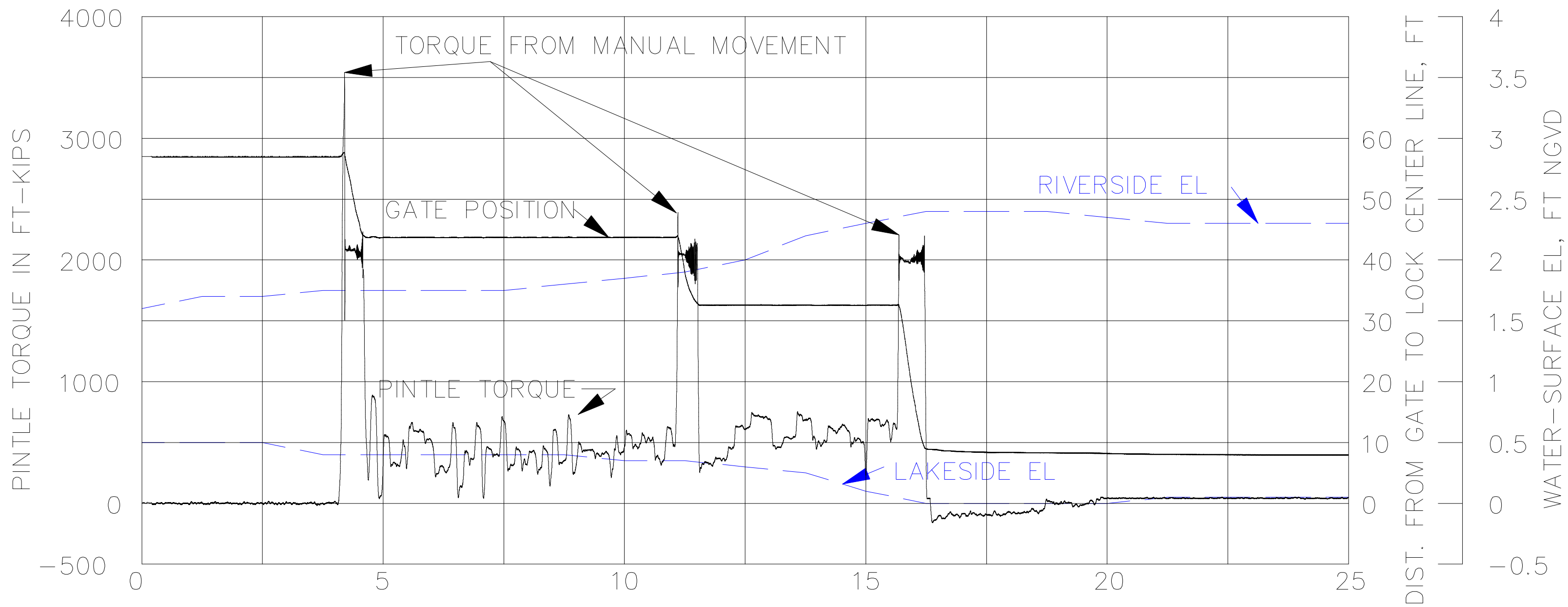


EMPTYING CHARACTERISTICS
SIDE PORT AND END FILL SYSTEMS
ORIGINAL DESIGN
760- X 106- X 36-FT SHIP
11.0-FT LIFT
14-MIN NORMAL VALVE FOR SIDE PORT SYSTEM
SECTOR GATE SCHEDULE C
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
19.9
-19.1
-1.1
1.2
1.3
RIVERSIDE EL 11.0
LAKESIDE EL 0.0
EMPTY CURVE
LOCK EMPTIED
13.2 MIN
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30



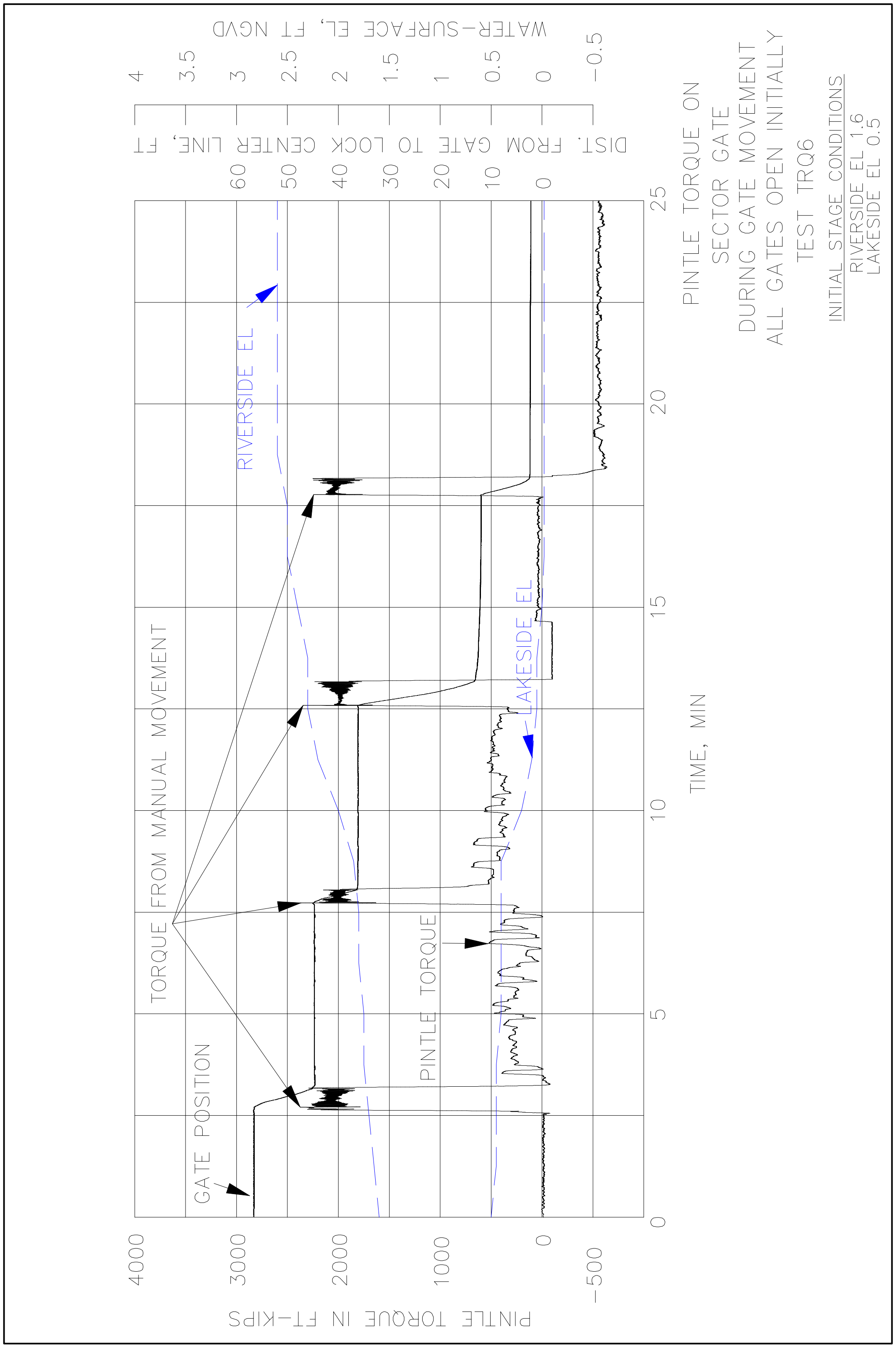


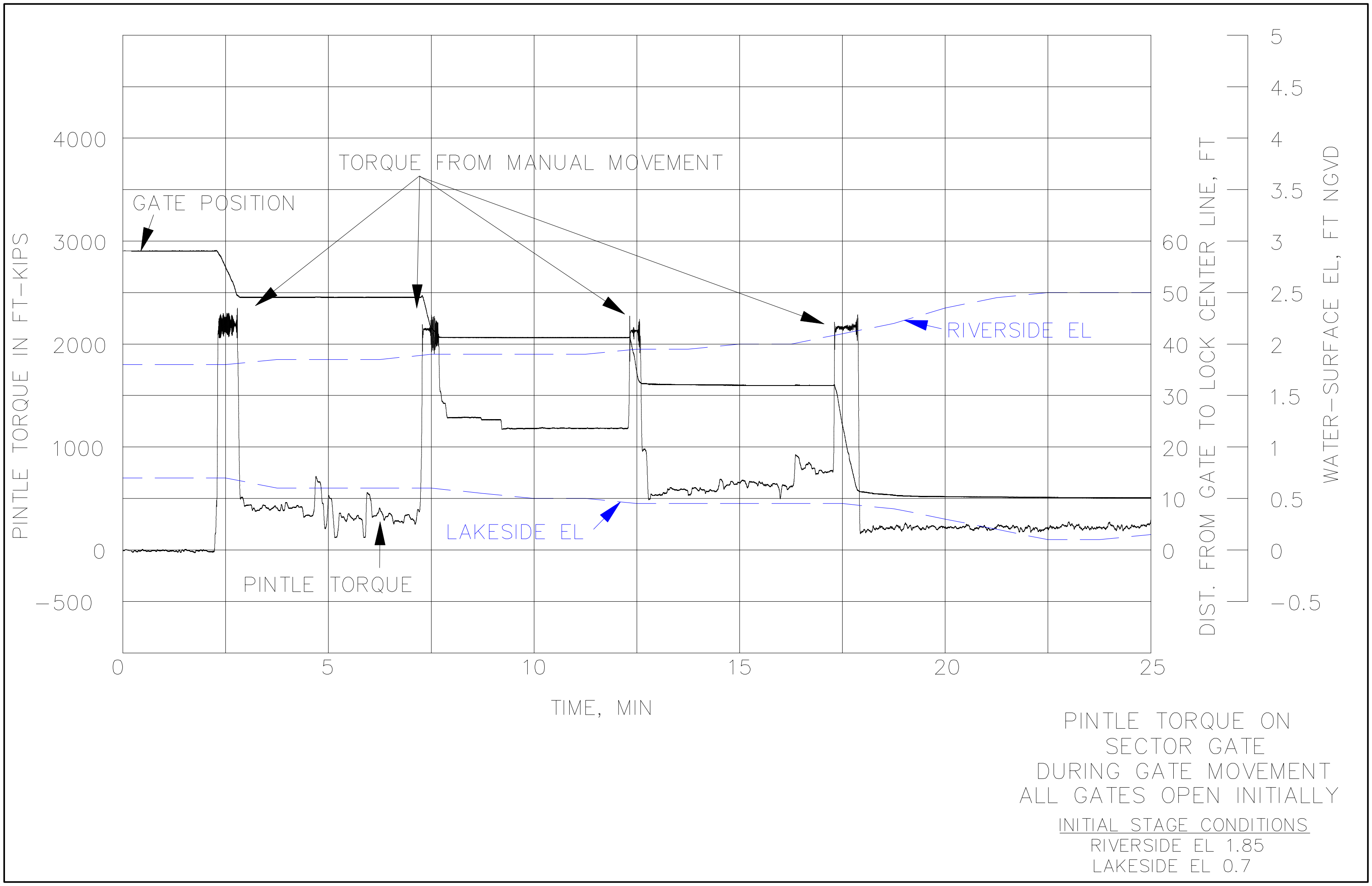
INITIAL SECTOR GATE OPENINGS
DURING PINTLE TORQUE TESTS
WITH NORMAL HEAD



PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
ALL GATES OPEN INITIALLY
TEST TRQ5

INITIAL STAGE CONDITIONS
RIVERSIDE EL 1.6
LAKESIDE EL 0.5


PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
ALL GATES OPEN INITIALLY
TEST TRQ6
INITIAL STAGE CONDITIONS
RIVERSIDE EL 1.6
LAKESIDE EL 0.5
PINTLE TORQUE IN FT-KIPS
TIME, MIN
DIST. FROM GATE TO LOCK CENTER LINE, FT
WATER-SURFACE EL, FT NGVD
GATE POSITION
PINTLE TORQUE
TORQUE FROM MANUAL MOVEMENT
RIVERSIDE EL
LAKESIDE EL
4000
3000
2000
1000
0
-500
0
5
10
15
20
25
60
50
40
30
20
10
0
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5


PINTLE TORQUE IN FT-KIPS
4000
3000
2000
1000
0
−500
TIME, MIN
0
5
10
15
20
25
DIST. FROM GATE TO LOCK CENTER LINE, FT
60
50
40
30
20
10
0
WATER-SURFACE EL, FT NGVD
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
−0.5
TORQUE FROM MANUAL MOVEMENT
GATE POSITION
PINTLE TORQUE
RIVERSIDE EL
LAKESIDE EL
PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
ALL GATES OPEN INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL 1.85
LAKESIDE EL 0.7

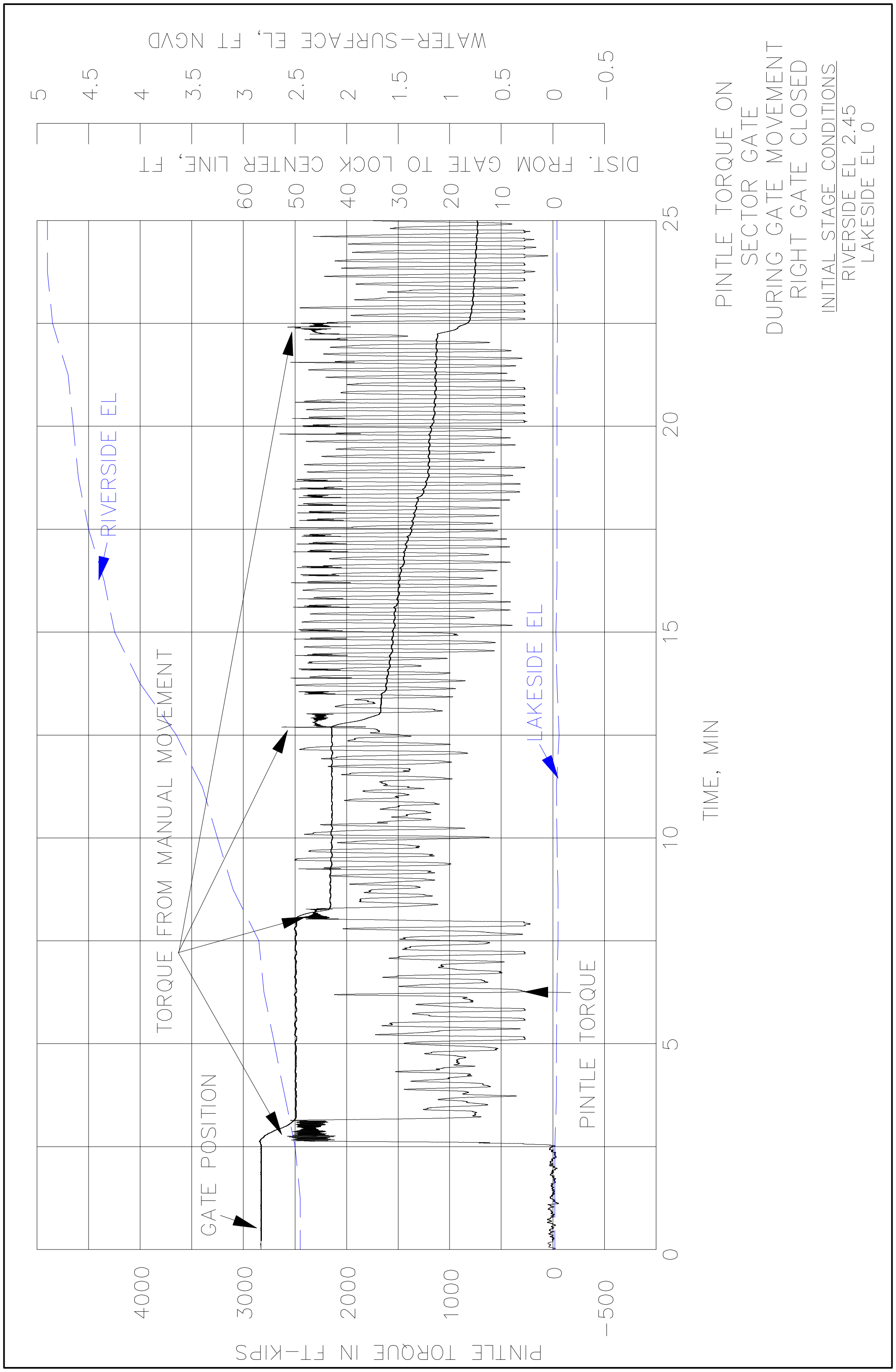
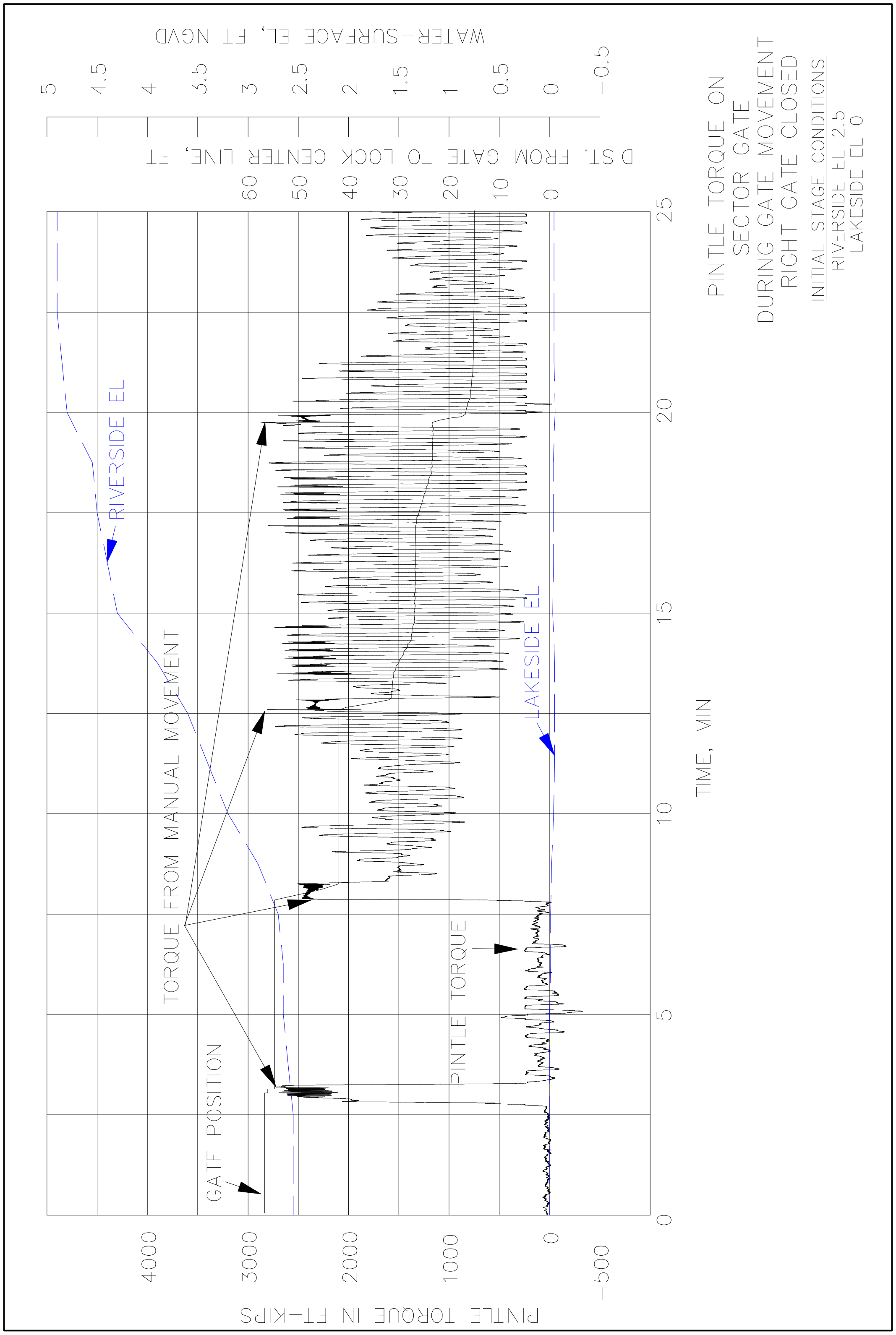
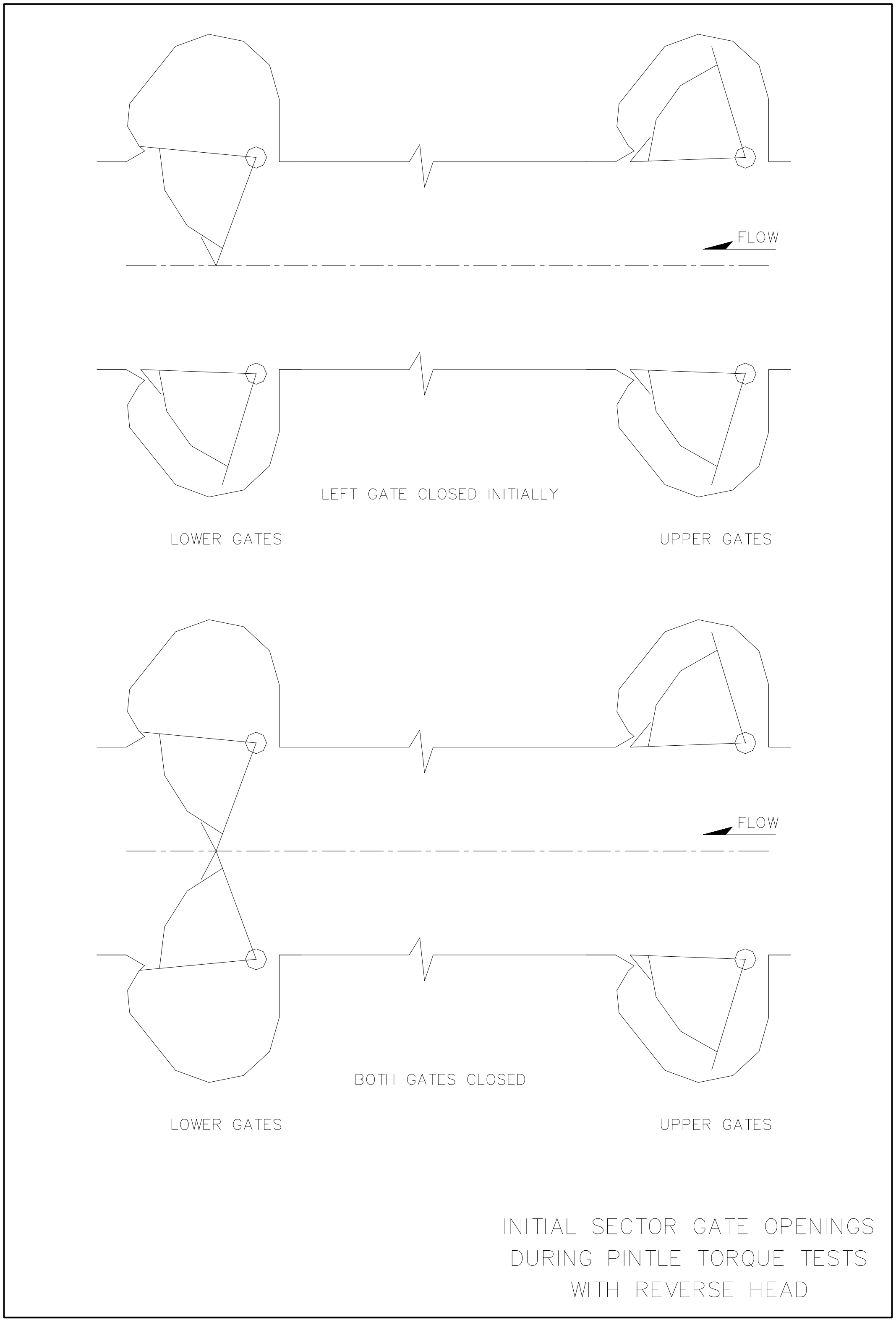

PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
RIGHT GATE CLOSED
INITIAL STAGE CONDITIONS
RIVERSIDE EL 2.45
LAKESIDE EL 0
WATER-SURFACE EL, FT NGVD
DIST. FROM GATE TO LOCK CENTER LINE, FT
PINTLE TORQUE IN FT-KIPS
TIME, MIN
RIVERSIDE EL
LAKESIDE EL
TORQUE FROM MANUAL MOVEMENT
GATE POSITION
PINTLE TORQUE
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
60
50
40
30
20
10
0
4000
3000
2000
1000
0
-500
0
5
10
15
20
25

Plate 58


PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
RIGHT GATE CLOSED
INITIAL STAGE CONDITIONS
RIVERSIDE EL 2.5
LAKESIDE EL 0
WATER-SURFACE EL, FT NGVD
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
DIST. FROM GATE TO LOCK CENTER LINE, FT
60
50
40
30
20
10
0
PINTLE TORQUE IN FT-KIPS
4000
3000
2000
1000
0
-500
TIME, MIN
0
5
10
15
20
25
RIVERSIDE EL
LAKESIDE EL
TORQUE FROM MANUAL MOVEMENT
PINTLE TORQUE
GATE POSITION


FLOW
LEFT GATE CLOSED INITIALLY
LOWER GATES
UPPER GATES
FLOW
BOTH GATES CLOSED
LOWER GATES
UPPER GATES
INITIAL SECTOR GATE OPENINGS
DURING PINTLE TORQUE TESTS
WITH REVERSE HEAD

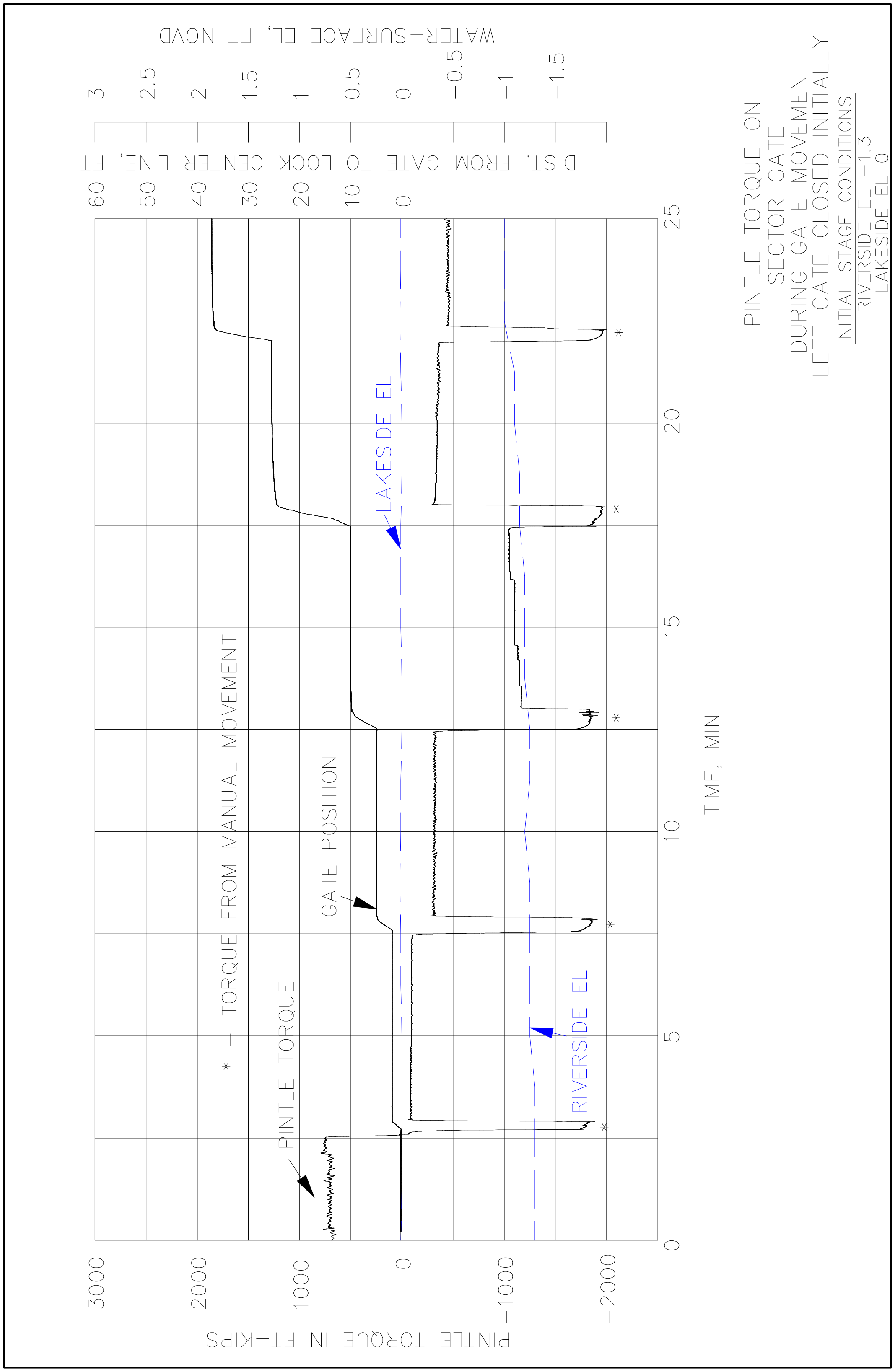

PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
LEFT GATE CLOSED INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL -1.3
LAKESIDE EL 0
PINTLE TORQUE IN FT-KIPS
DIST. FROM GATE TO LOCK CENTER LINE, FT
WATER-SURFACE EL, FT NGVD
TIME, MIN
* - TORQUE FROM MANUAL MOVEMENT
PINTLE TORQUE
GATE POSITION
LAKESIDE EL
RIVERSIDE EL

Plate 61

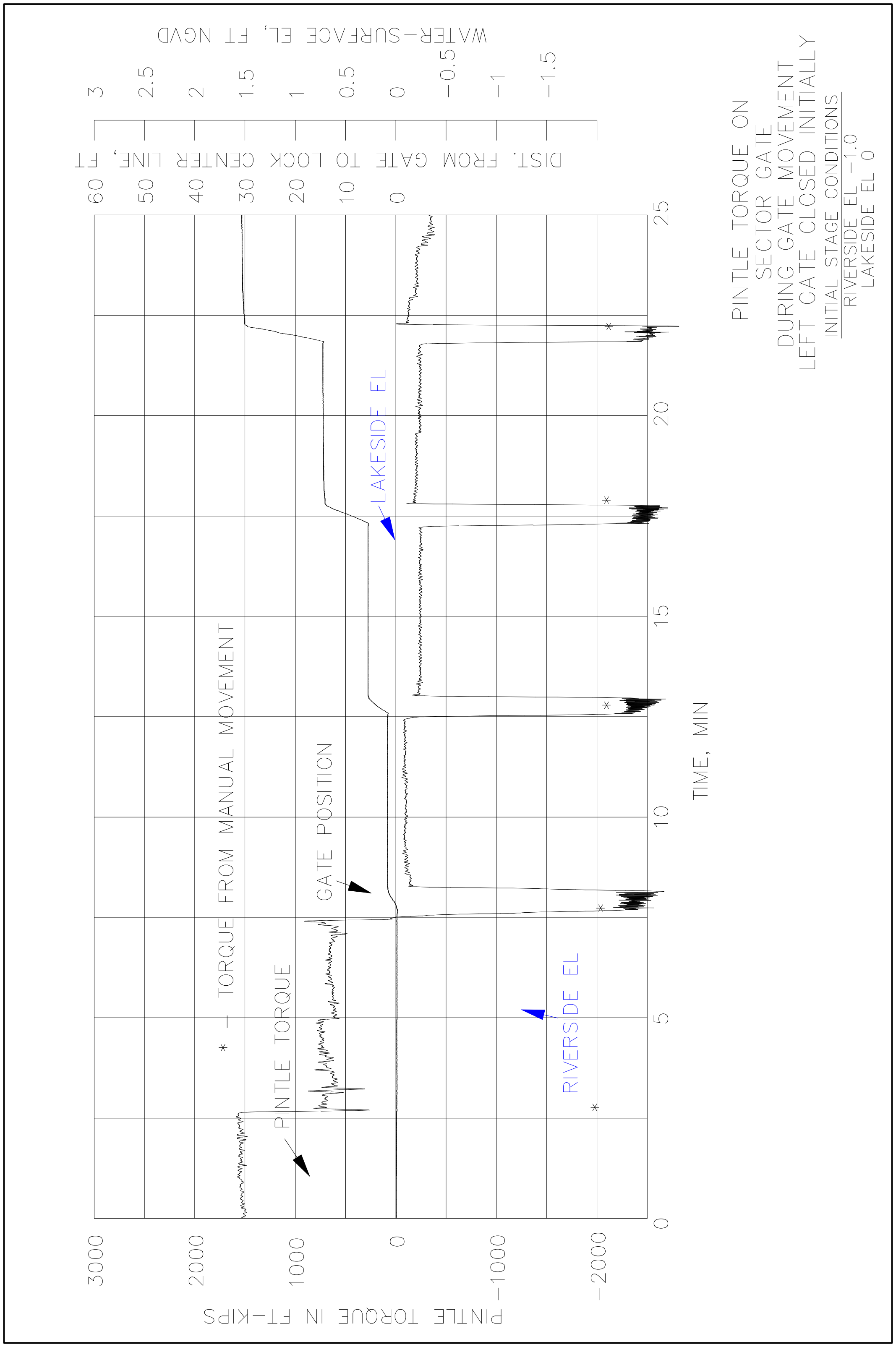
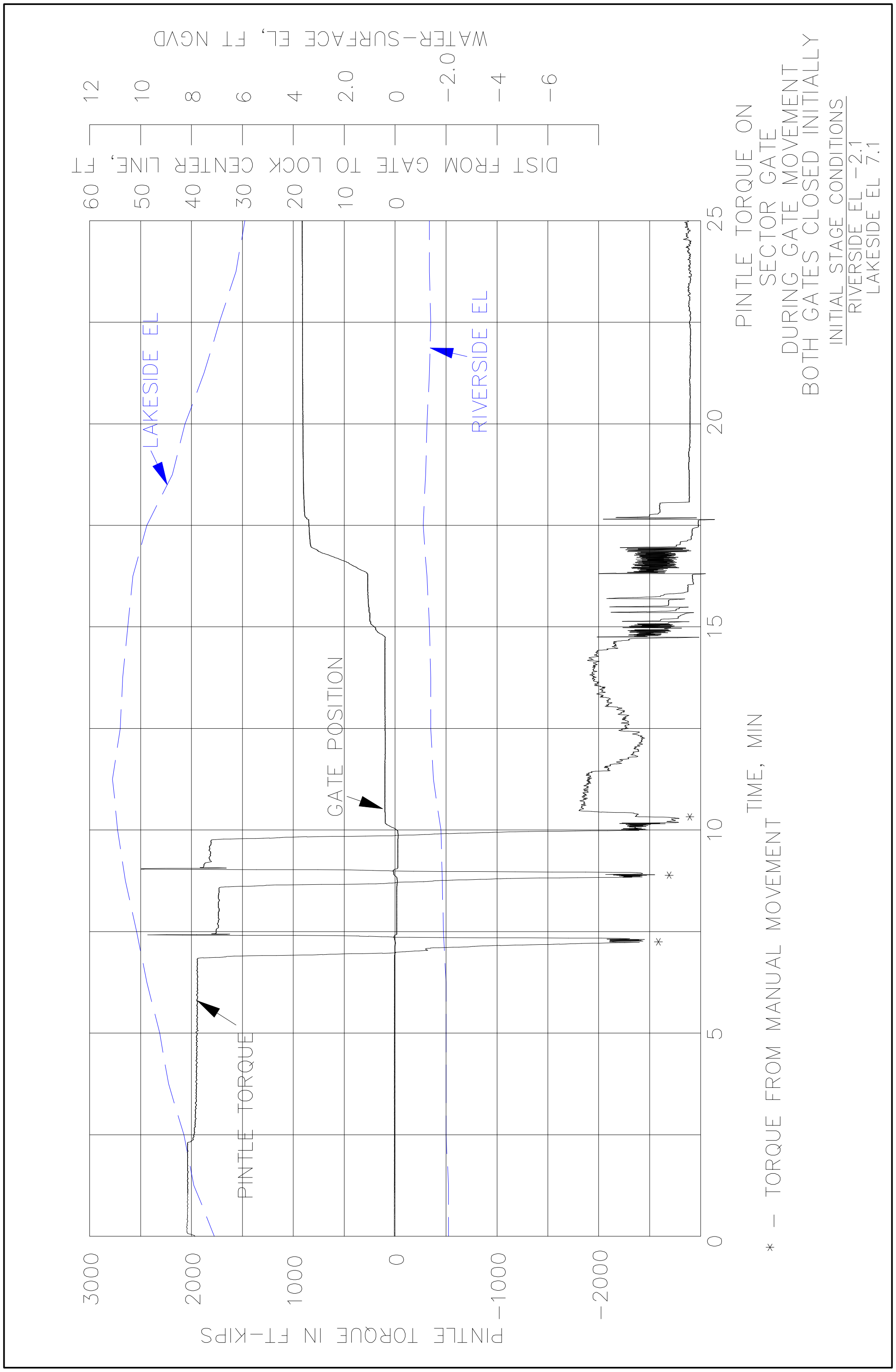

PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
LEFT GATE CLOSED INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL -1.0
LAKESIDE EL 0
PINTLE TORQUE IN FT-KIPS
3000
2000
1000
0
-1000
-2000
TIME, MIN
0
5
10
15
20
25
DIST. FROM GATE TO LOCK CENTER LINE, FT
60
50
40
30
20
10
0
WATER-SURFACE EL, FT NGVD
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
* - TORQUE FROM MANUAL MOVEMENT
PINTLE TORQUE
GATE POSITION
LAKESIDE EL
RIVERSIDE EL

Plate 62


PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
BOTH GATES CLOSED INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL -2.1
LAKESIDE EL 7.1
PINTLE TORQUE IN FT-KIPS
DIST FROM GATE TO LOCK CENTER LINE, FT
WATER-SURFACE EL, FT NGVD
TIME, MIN
* - TORQUE FROM MANUAL MOVEMENT
LAKESIDE EL
RIVERSIDE EL
GATE POSITION
PINTLE TORQUE

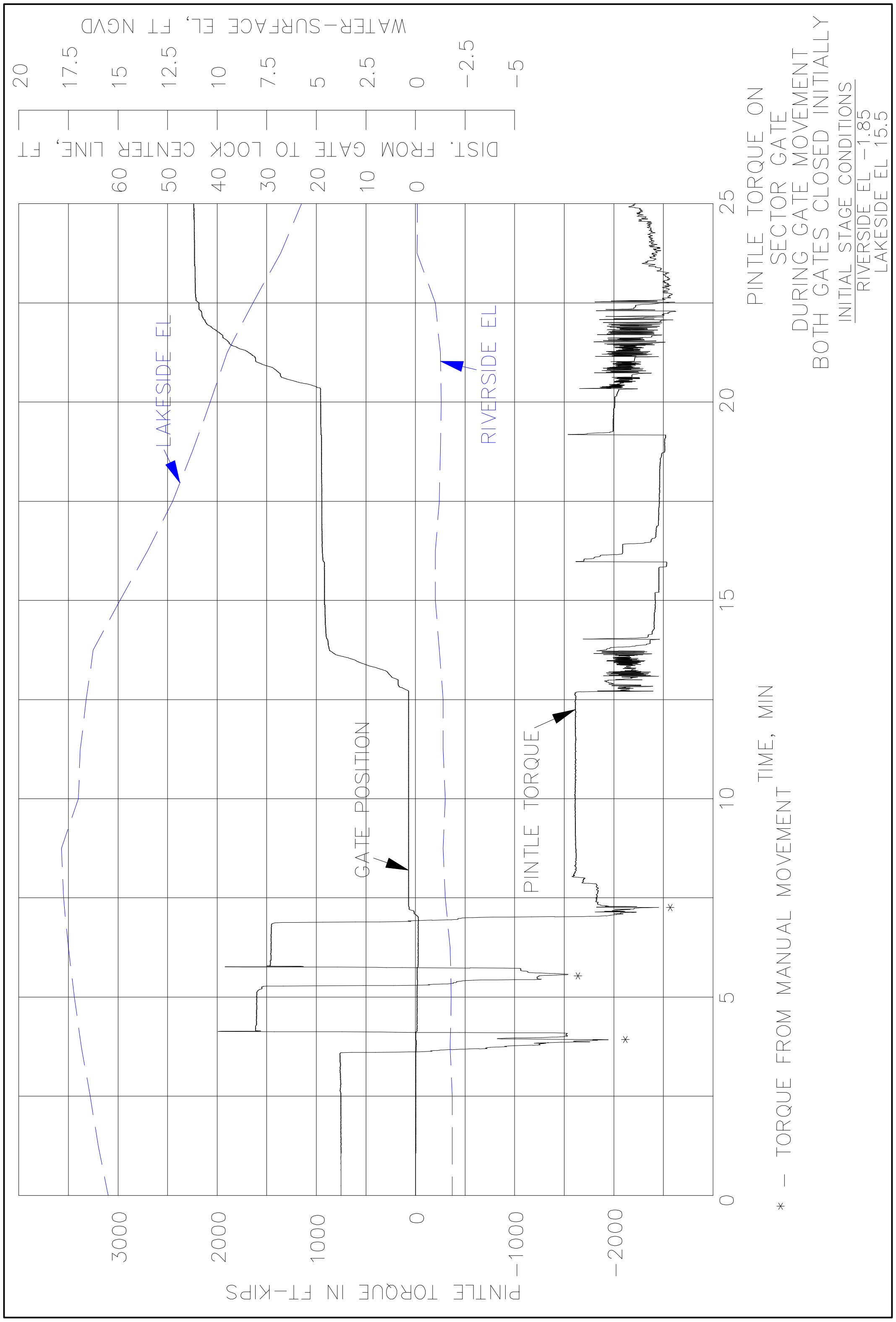
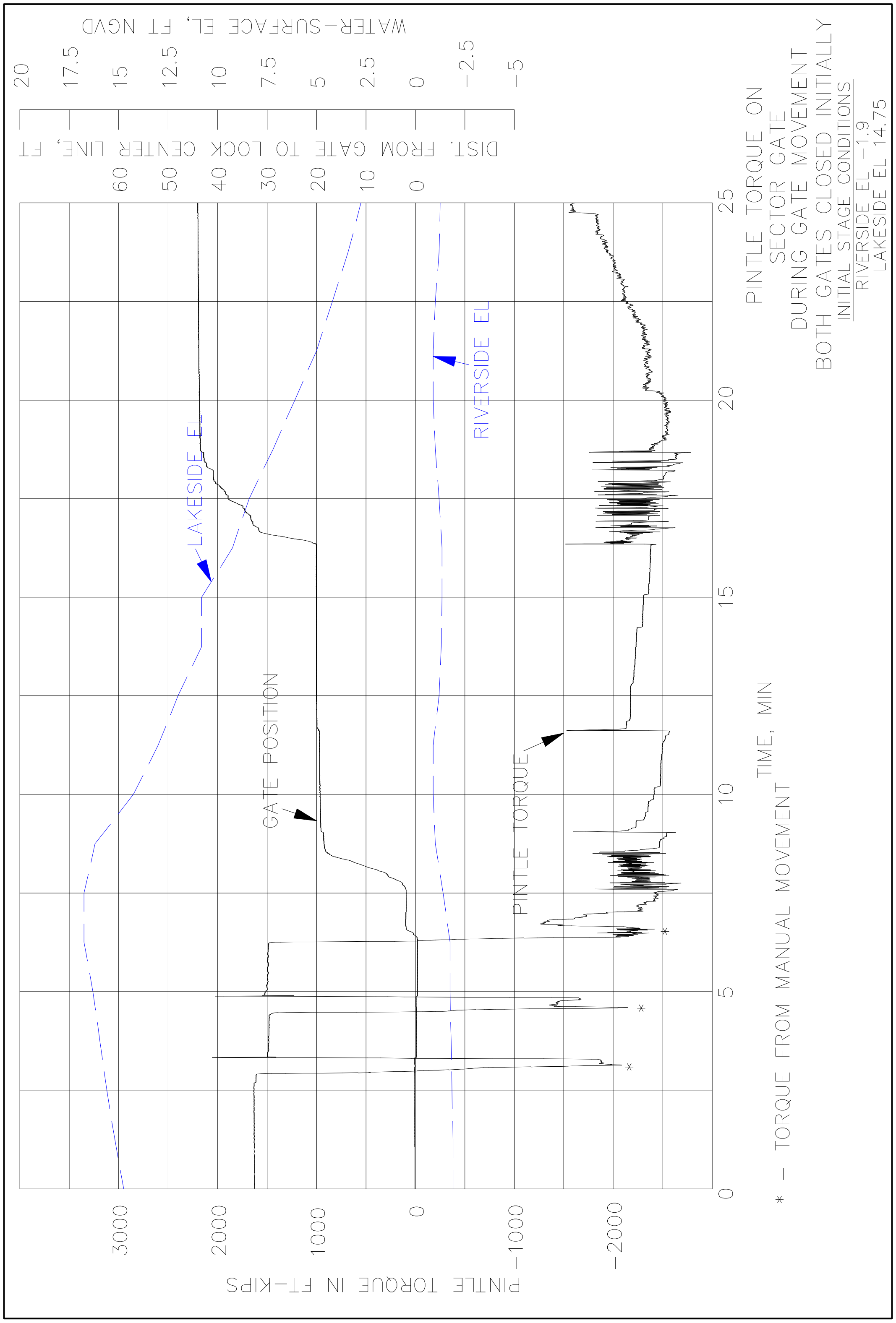

PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
BOTH GATES CLOSED INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL -1.85
LAKESIDE EL 15.5
WATER-SURFACE EL, FT NGVD
20 17.5 15 12.5 10 7.5 5 2.5 0 -2.5 -5
DIST. FROM GATE TO LOCK CENTER LINE, FT
60 50 40 30 20 10 0
PINTLE TORQUE IN FT-KIPS
3000 2000 1000 0 -1000 -2000
TIME, MIN
0 5 10 15 20 25
LAKESIDE EL
RIVERSIDE EL
GATE POSITION
PINTLE TORQUE
* - TORQUE FROM MANUAL MOVEMENT

Plate 64



PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
BOTH GATES CLOSED INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL -1.9
LAKESIDE EL 14.75
WATER-SURFACE EL, FT NGVD
20
17.5
15
12.5
10
7.5
5
2.5
0
-2.5
-5
DIST. FROM GATE TO LOCK CENTER LINE, FT
60
50
40
30
20
10
0
PINTLE TORQUE IN FT-KIPS
3000
2000
1000
0
-1000
-2000
TIME, MIN
0
5
10
15
20
25
LAKESIDE EL
RIVERSIDE EL
GATE POSITION
PINTLE TORQUE
*
* - TORQUE FROM MANUAL MOVEMENT

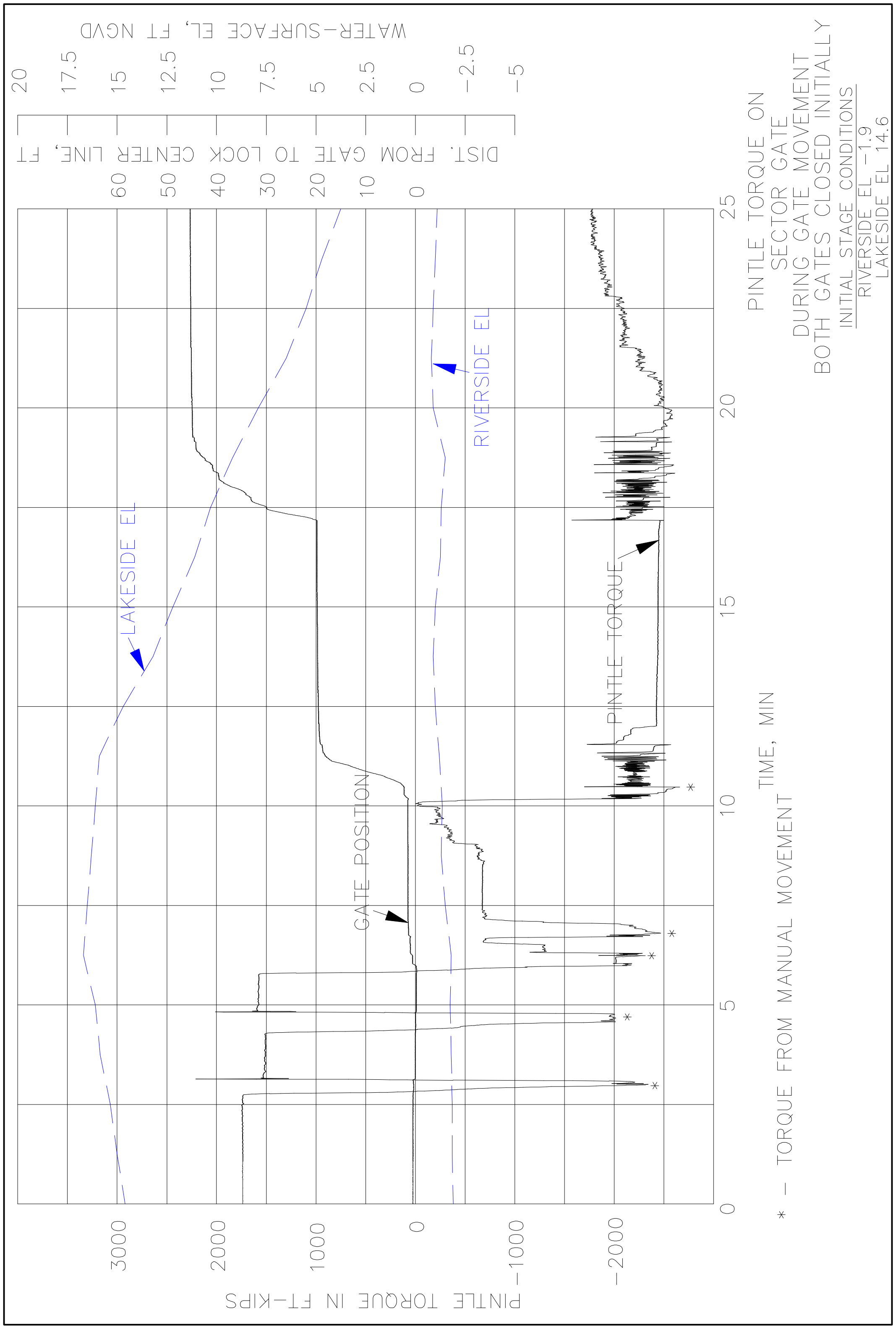
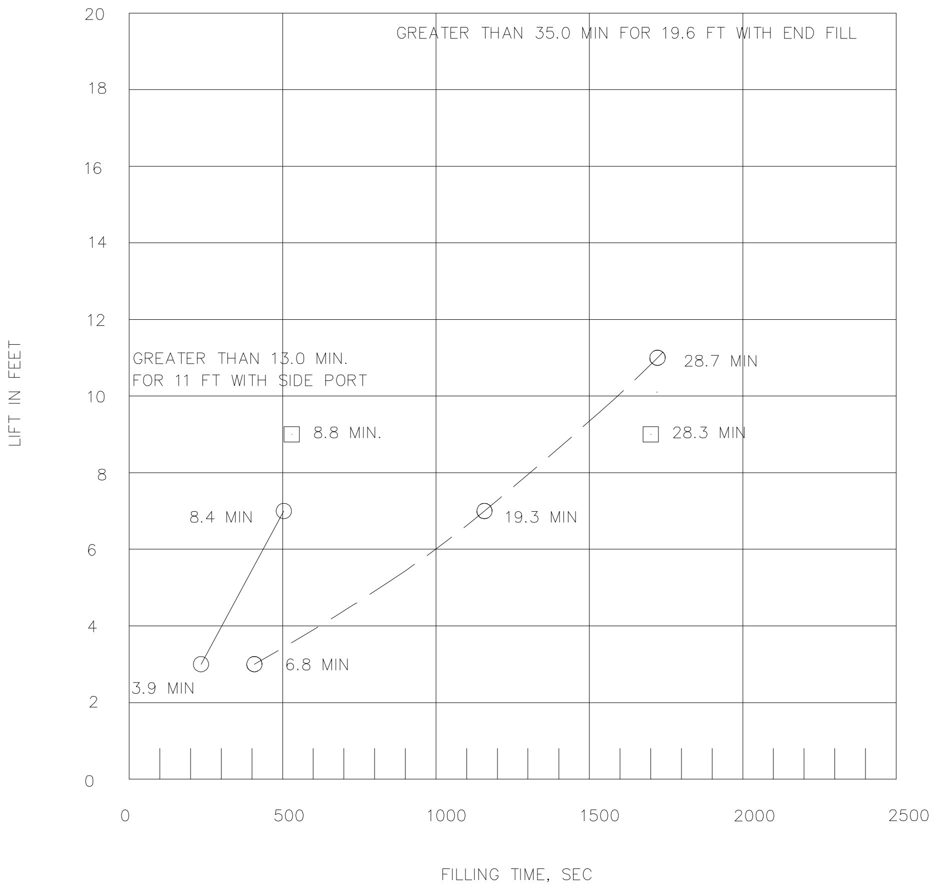

PINTLE TORQUE ON
SECTOR GATE
DURING GATE MOVEMENT
BOTH GATES CLOSED INITIALLY
INITIAL STAGE CONDITIONS
RIVERSIDE EL -1.9
LAKESIDE EL 14.6
WATER-SURFACE EL, FT NGVD
20
17.5
15
12.5
10
7.5
5
2.5
0
-2.5
-5
DIST. FROM GATE TO LOCK CENTER LINE, FT
60
50
40
30
20
10
0
PINTLE TORQUE IN FT-KIPS
3000
2000
1000
0
-1000
-2000
TIME, MIN
0
5
10
15
20
25
LAKESIDE EL
RIVERSIDE EL
GATE POSITION
PINTLE TORQUE
* - TORQUE FROM MANUAL MOVEMENT

Plate 66

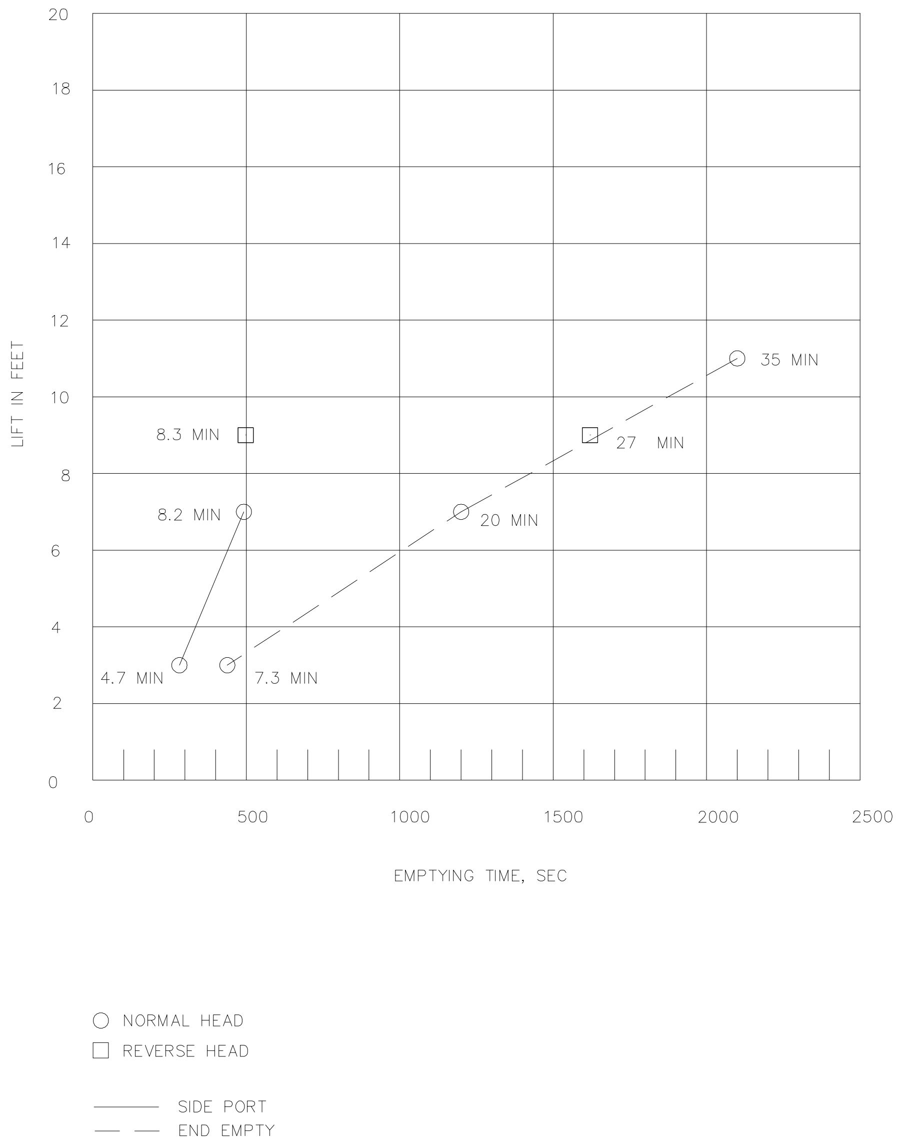


NOTE: LAKESIDE EL = −2.0 FT

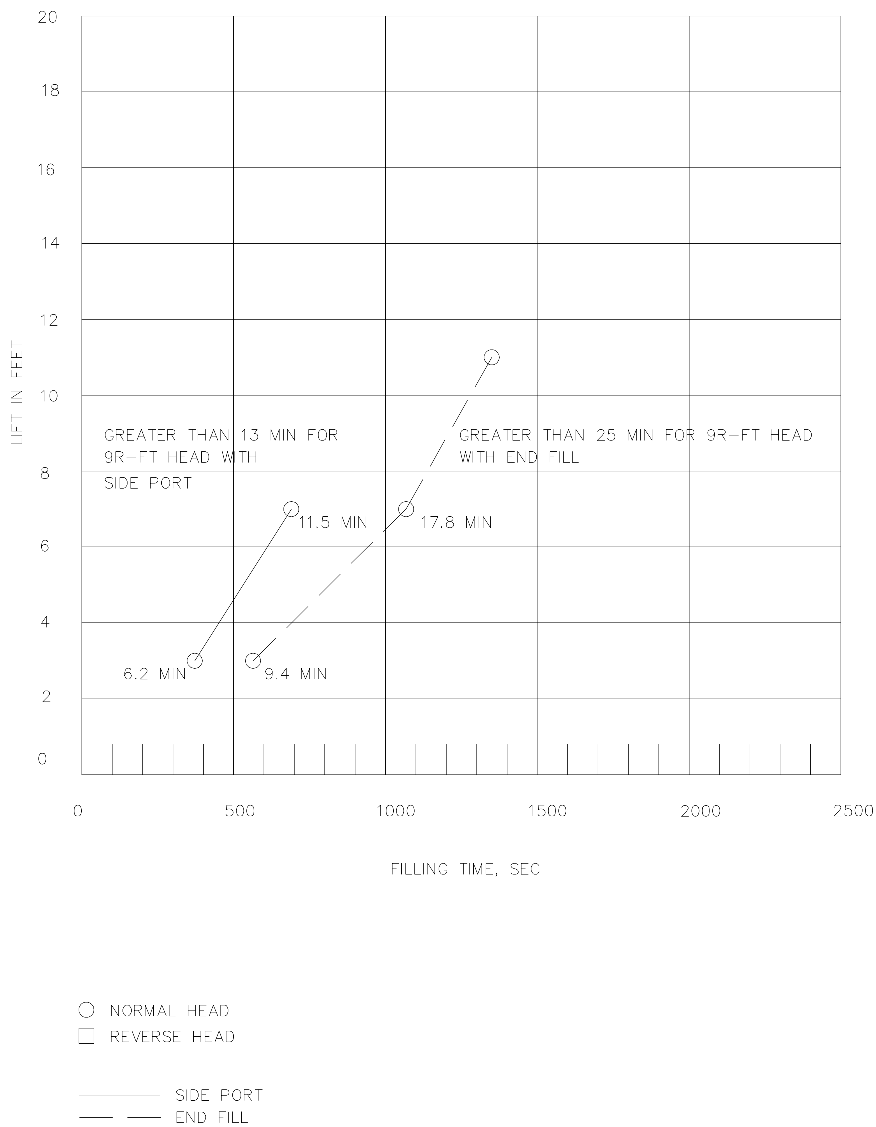
○ NORMAL HEAD
□ REVERSE HEAD

——— SIDE PORT
— — END FILL

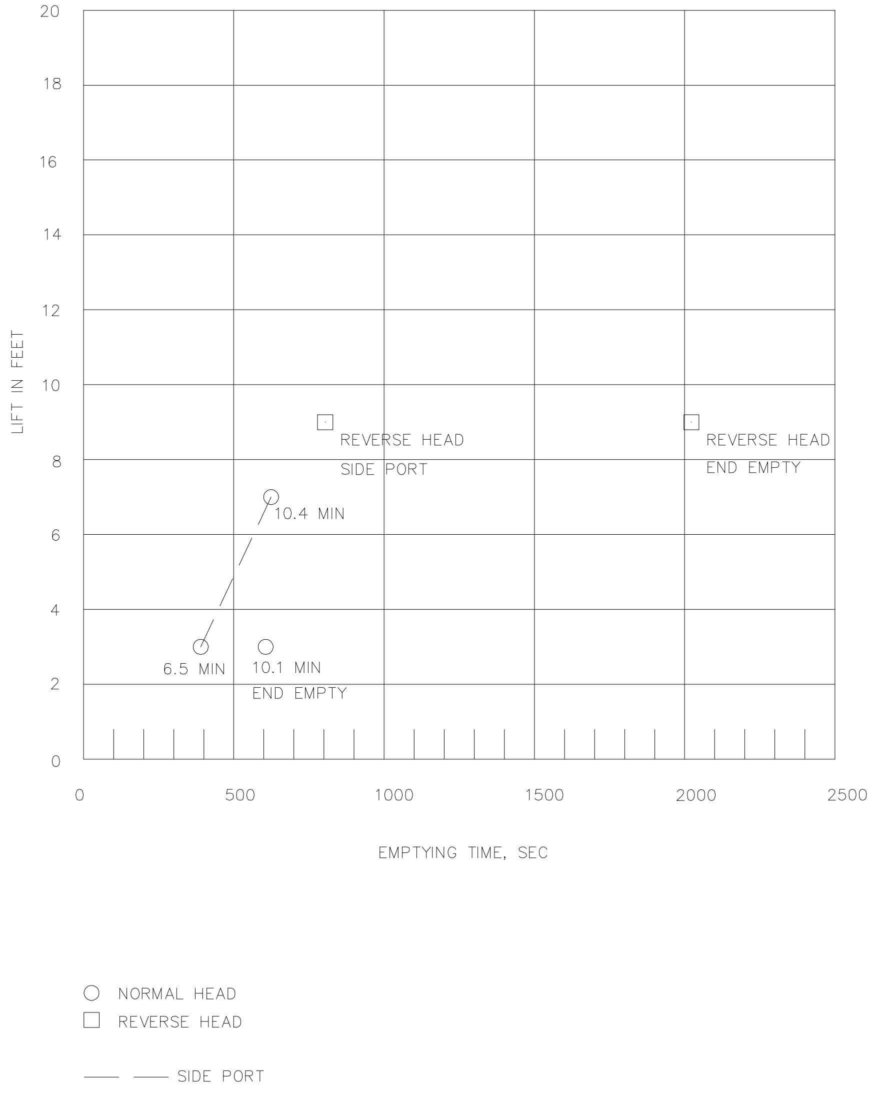
COMPARISON OF FILLING TIMES FOR
5–TON HAWSER FORCE LIMIT
END FILLING AND
SIDE PORT SYSTEMS
ORIGINAL DESIGNS
18 BARGES, 11–FT DRAFT



COMPARISON OF EMPTYING TIMES FOR
5–TON HAWSER FORCE LIMIT
END EMPTYING AND
SIDE PORT SYSTEMS
ORIGINAL DESIGNS
18 BARGES, 11–FT DRAFT

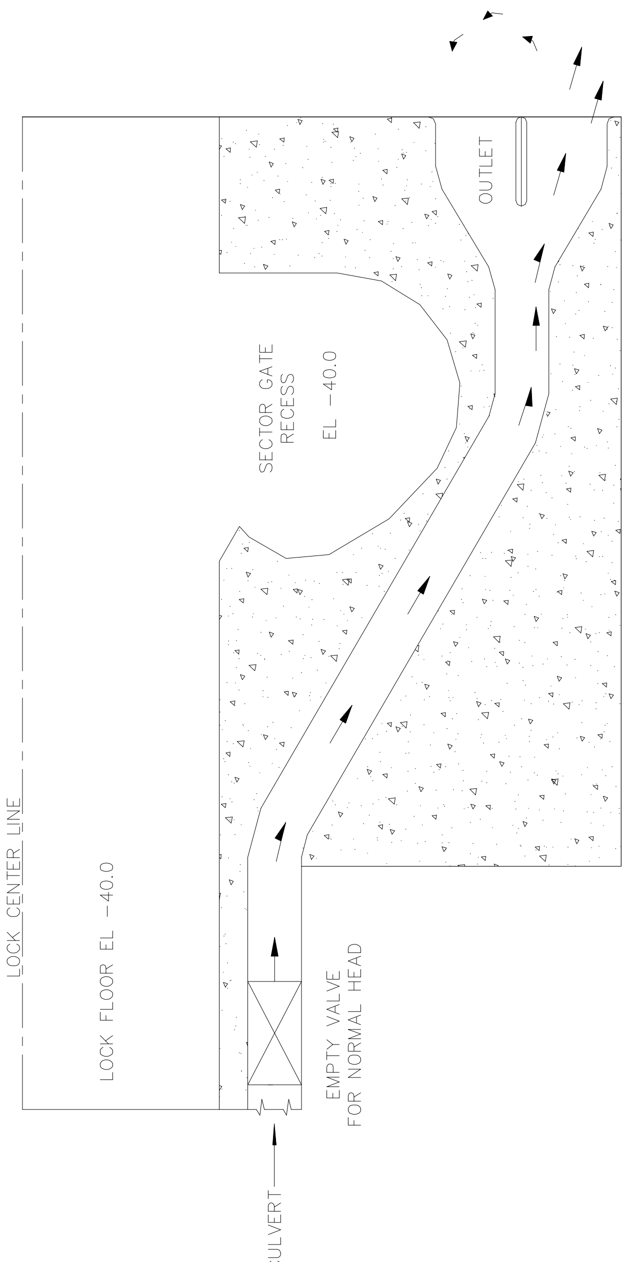


COMPARISON OF FILLING TIMES FOR
15–TON HAWSER FORCE LIMIT
END FILLING AND
SIDE PORT SYSTEMS
ORIGINAL DESIGNS
760– X 106– X 36–FT SHIP



COMPARISON OF EMPTYING TIMES FOR 15-TON HAWSER FORCE LIMIT

END EMPTYING AND SIDE PORT SYSTEMS ORIGINAL DESIGNS 760- X 106- X 36-FT SHIP



FLOW CONDITIONS
DURING EMPTYING
TYPE 1 DESIGN OUTLET

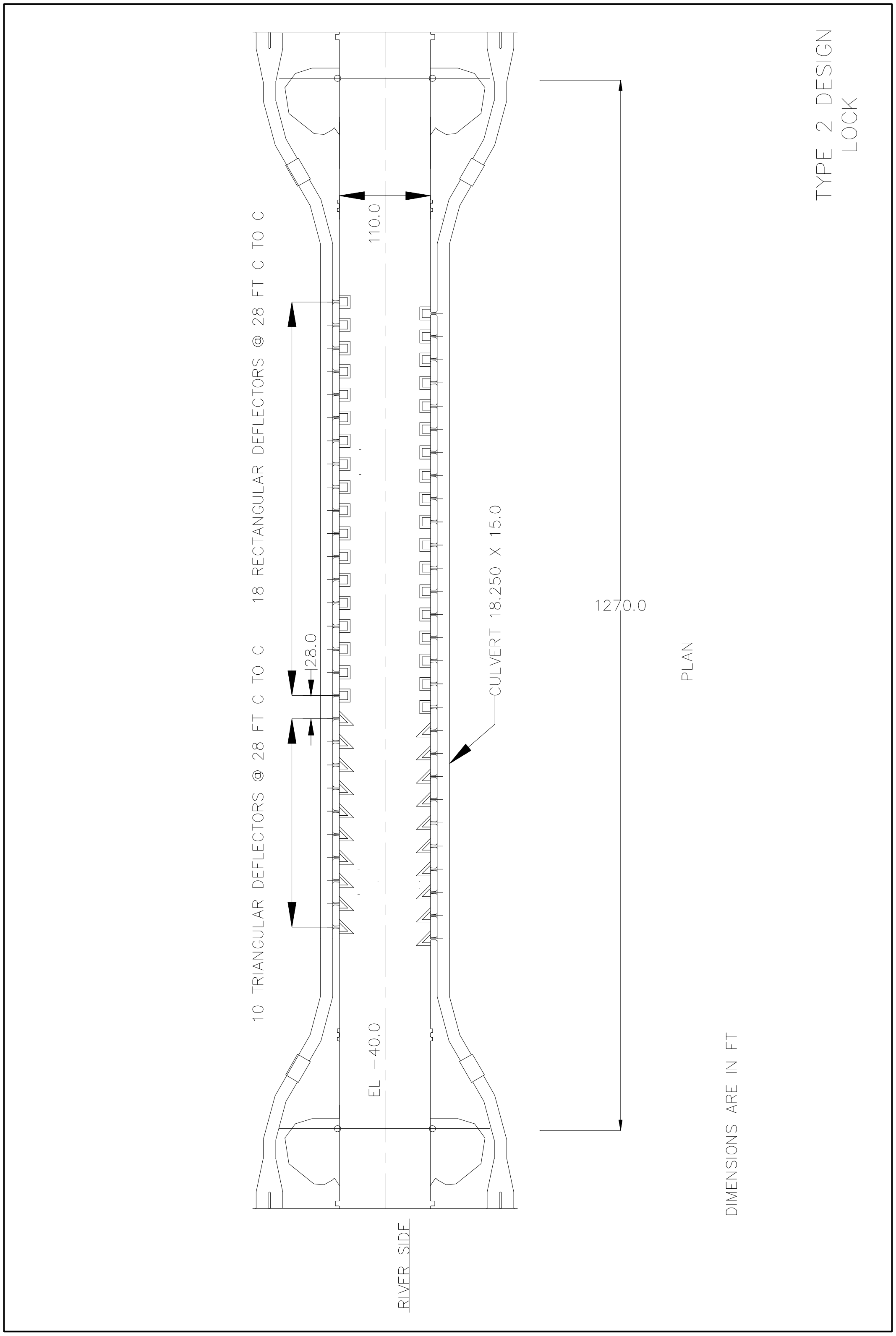
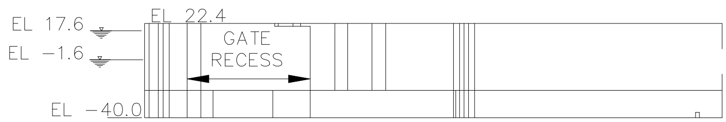
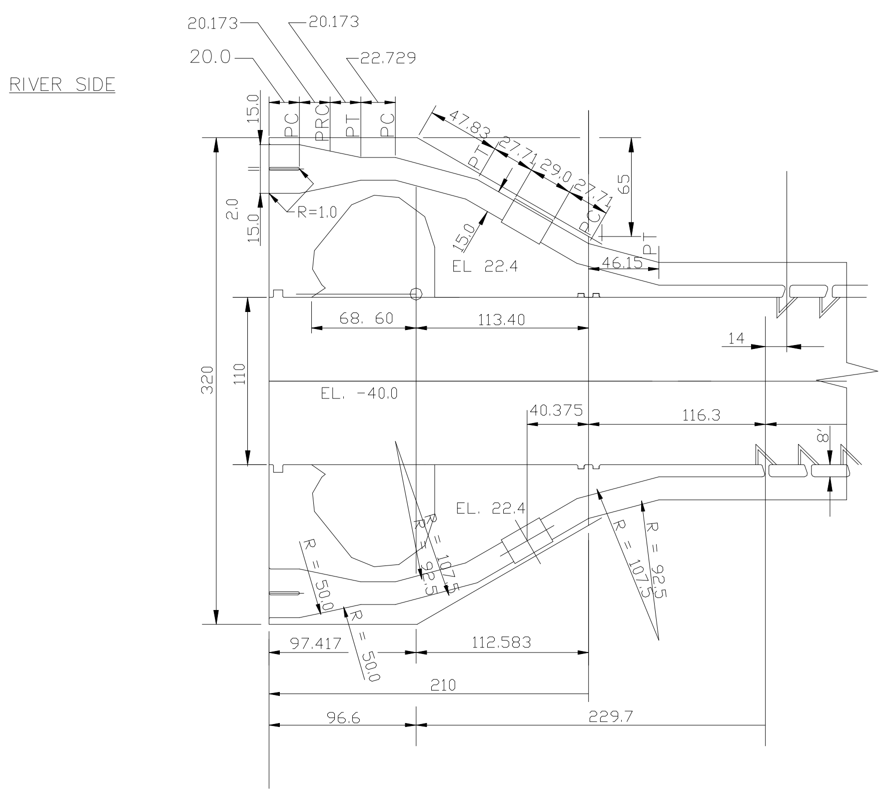

TYPE 2 DESIGN
LOCK
110.0
18 RECTANGULAR DEFLECTORS @ 28 FT C TO C
10 TRIANGULAR DEFLECTORS @ 28 FT C TO C
28.0
CULVERT 18.250 X 15.0
1270.0
PLAN
EL -40.0
DIMENSIONS ARE IN FT
RIVER SIDE

Plate 72



ELEVATION



PLAN

DIMENSIONS ARE IN FT

DETAILS
TYPE 2 DESIGN INTAKE

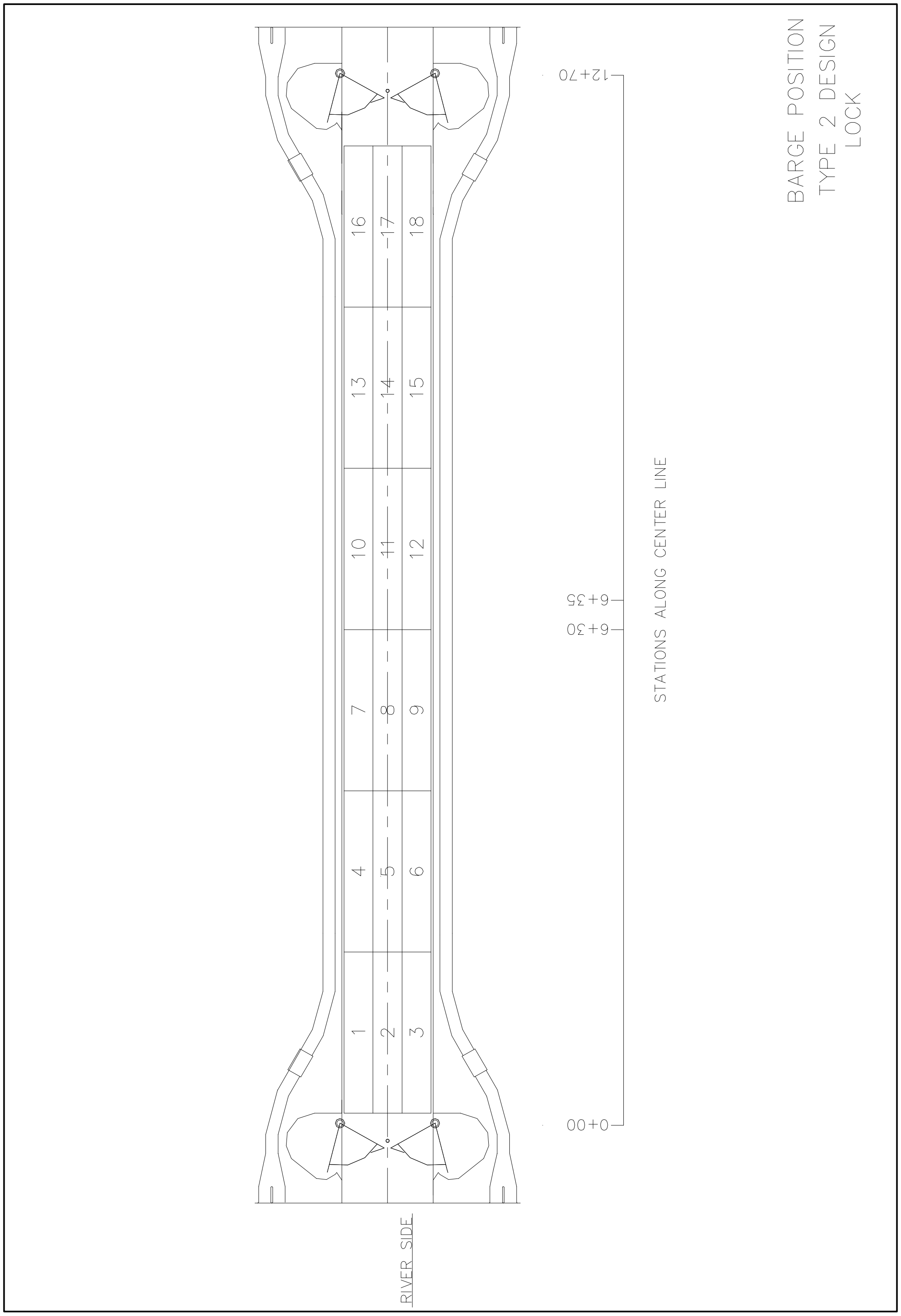
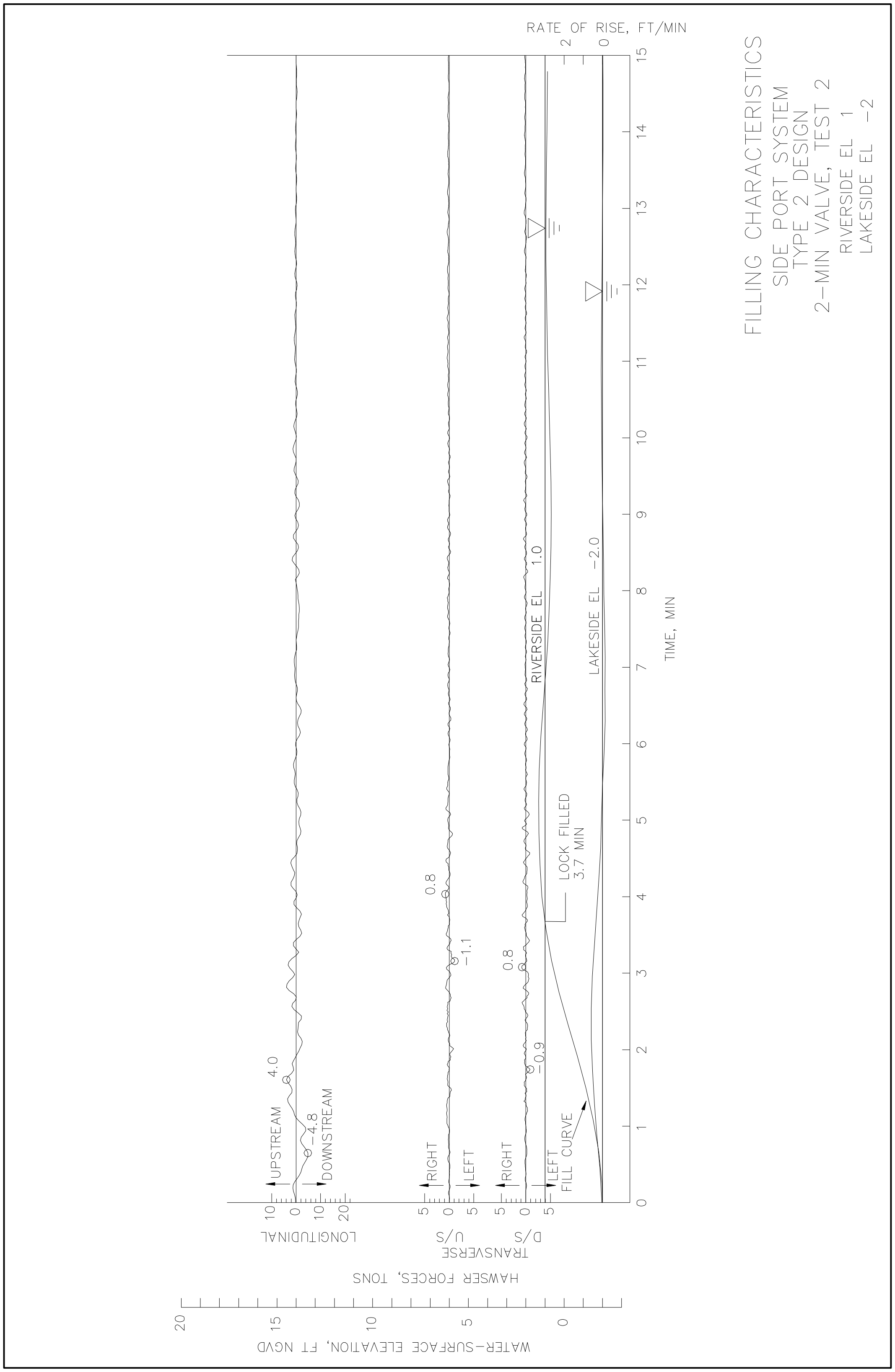
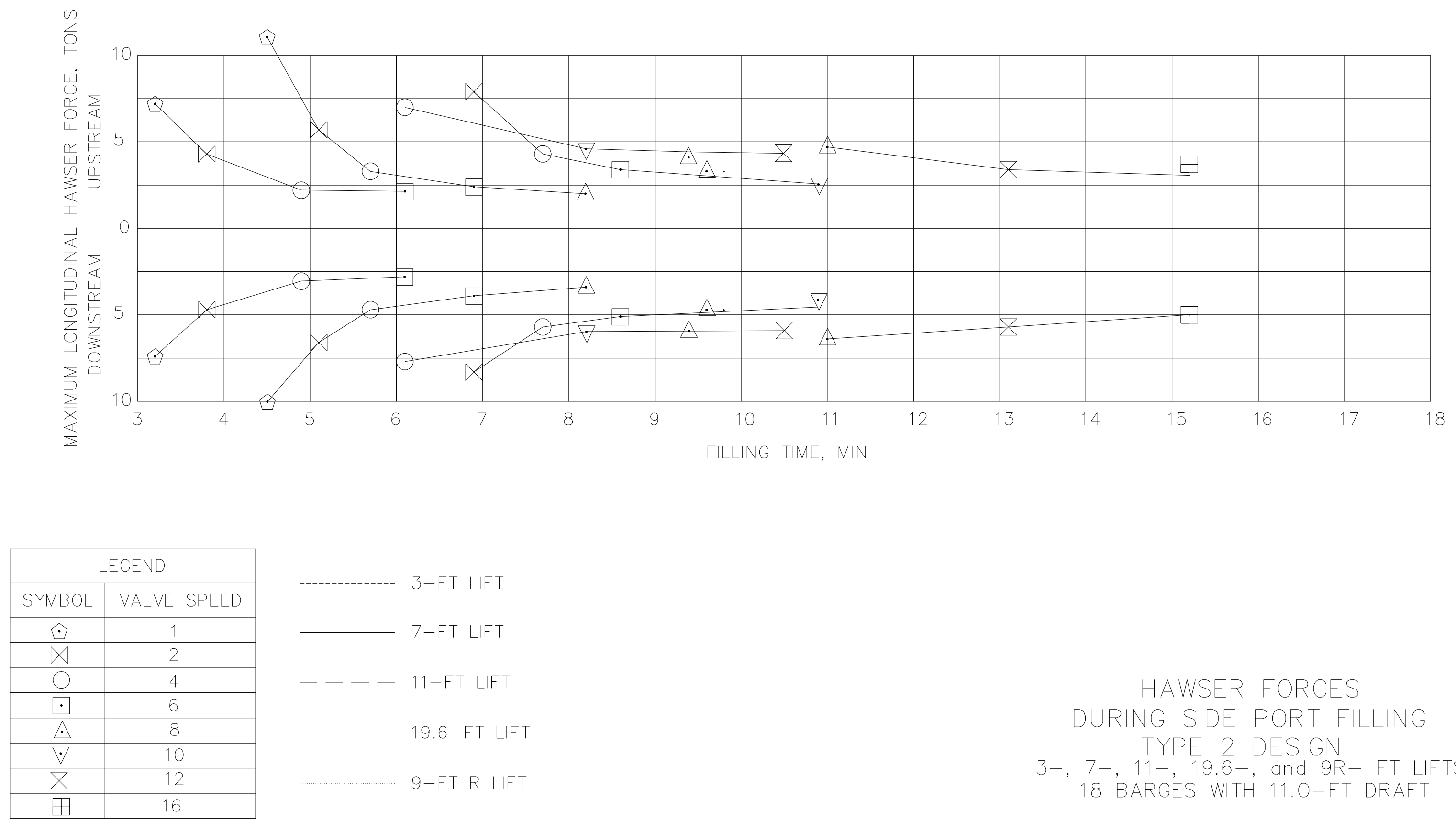
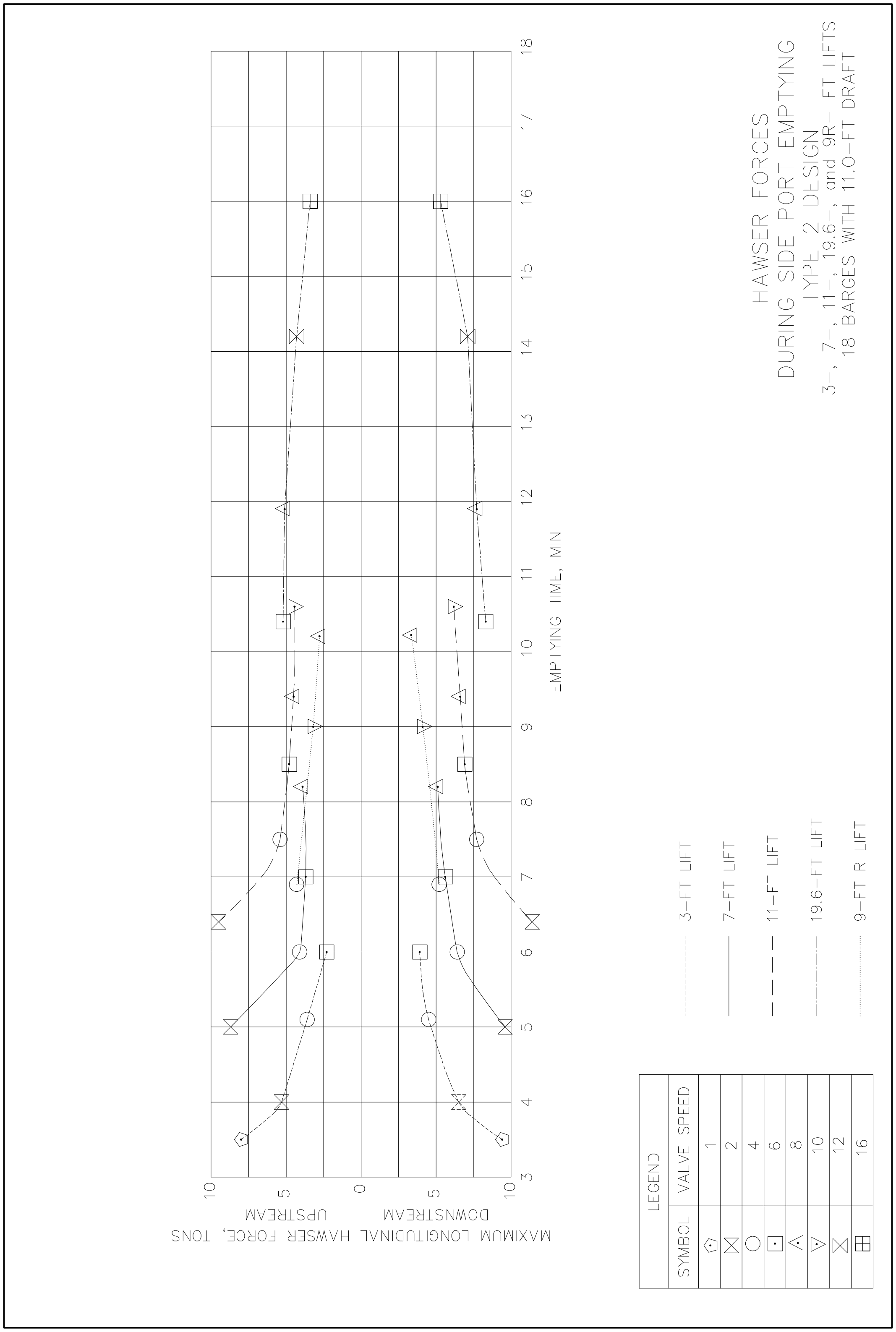

BARGE POSITION
TYPE 2 DESIGN
LOCK
STATIONS ALONG CENTER LINE
12+70
6+35
6+30
0+00
RIVER SIDE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

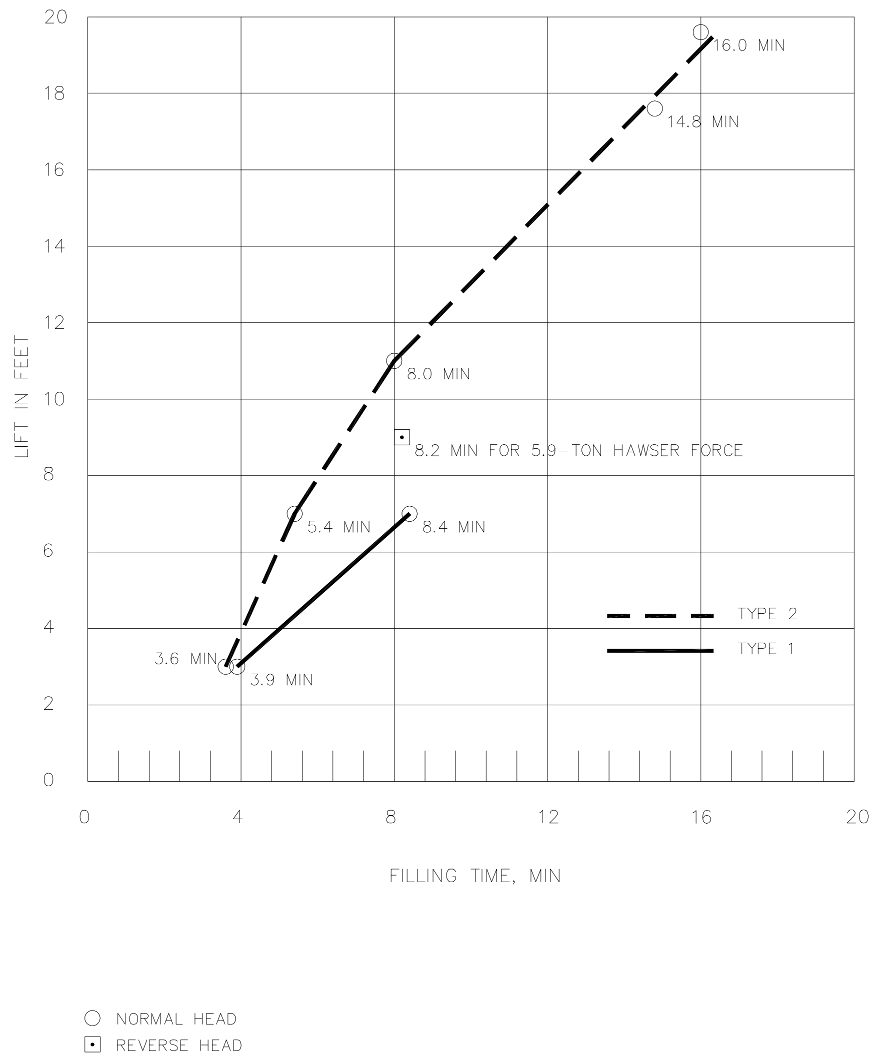
Plate 74


FILLING CHARACTERISTICS
SIDE PORT SYSTEM
TYPE 2 DESIGN
2-MIN VALVE, TEST 2
RIVERSIDE EL 1
LAKESIDE EL -2
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
FILL CURVE
LOCK FILLED
3.7 MIN
RIVERSIDE EL 1.0
LAKESIDE EL -2.0
4.0
-4.8
0.8
-1.1
-0.9

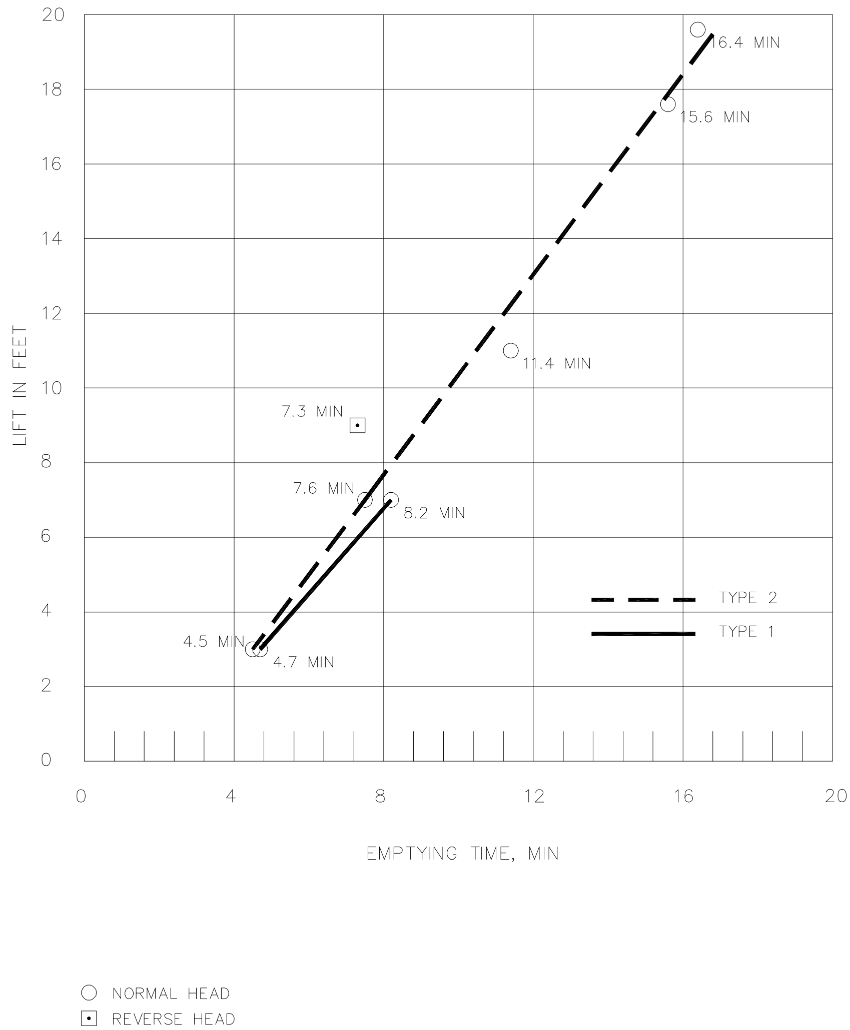


HAWSER FORCES
DURING SIDE PORT FILLING
TYPE 2 DESIGN
3–, 7–, 11–, 19.6–, and 9R– FT LIFTS
18 BARGES WITH 11.0–FT DRAFT

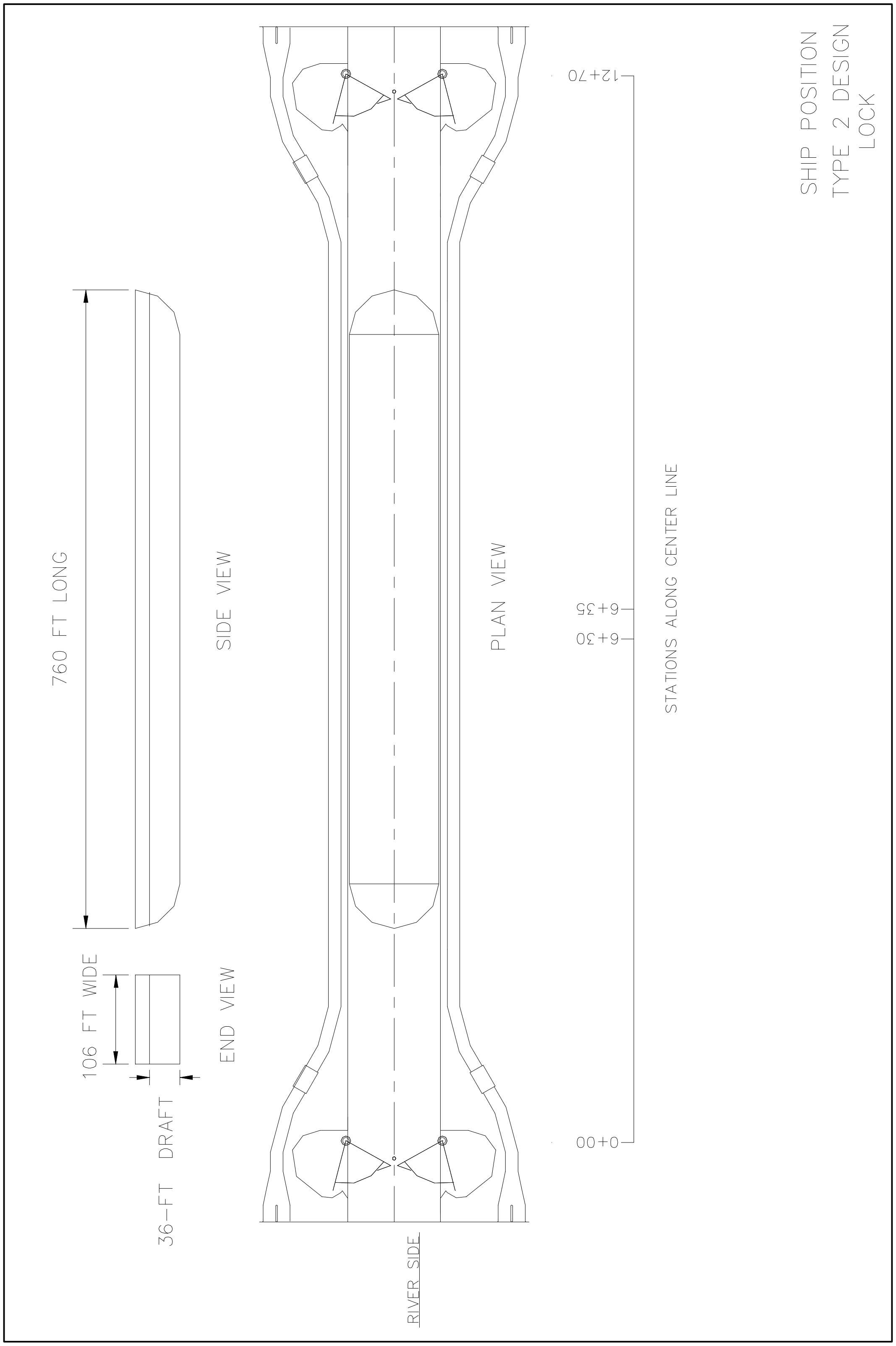

HAWSER FORCES
DURING SIDE PORT EMPTYING
TYPE 2 DESIGN
3-, 7-, 11-, 19.6-, and 9R- FT LIFTS
, 18 BARGES WITH 11.0-FT DRAFT
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
EMPTYING TIME, MIN
3-FT LIFT
7-FT LIFT
11-FT LIFT
19.6-FT LIFT
9-FT R LIFT
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
8
10
12
16



COMPARISON OF
FILLING TIMES FOR
5–TON HAWSER FORCE LIMIT
TYPE 1 AND 2 DESIGNS
SIDE PORT FILLING SYSTEM
18 BARGES, 11–FT DRAFT

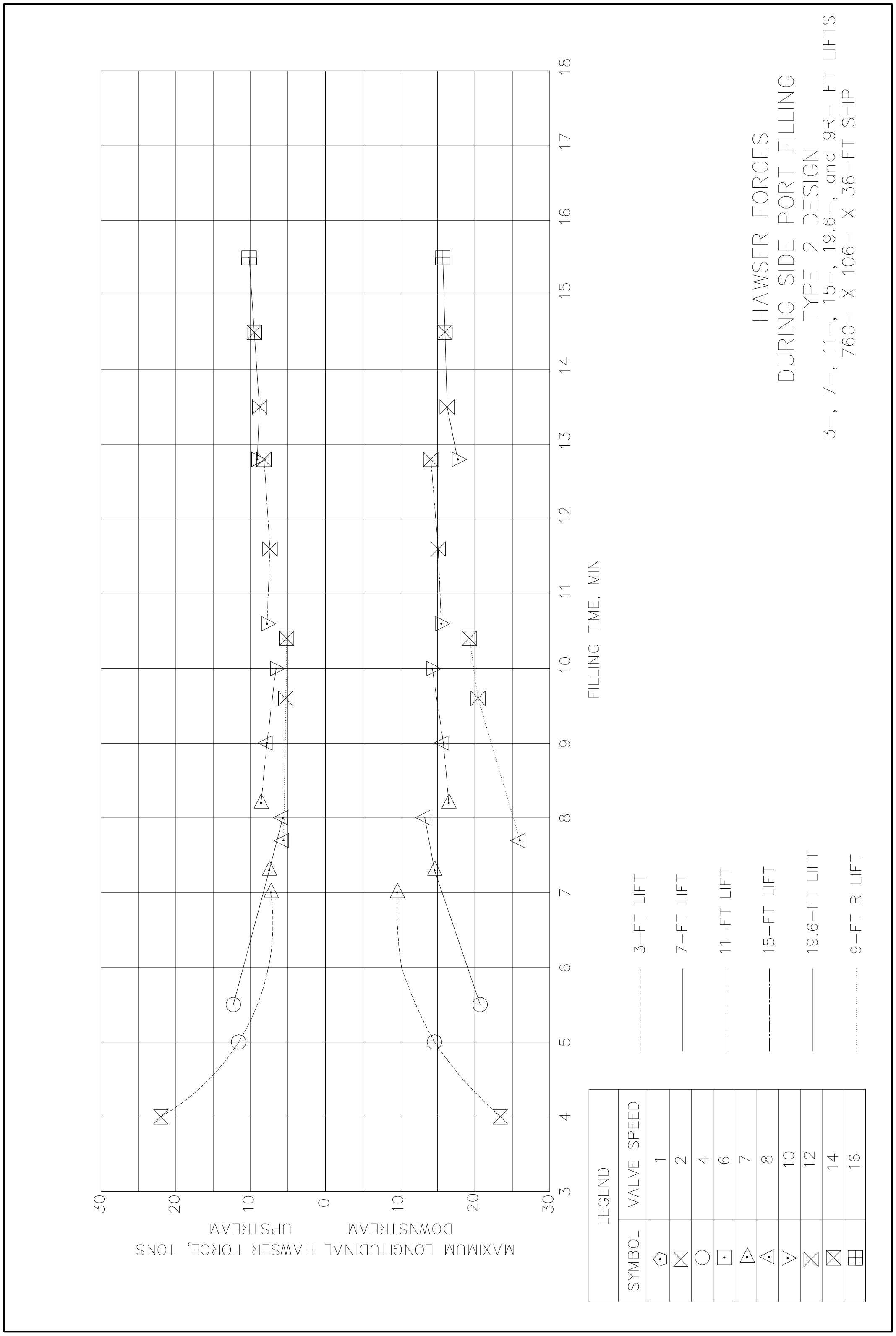


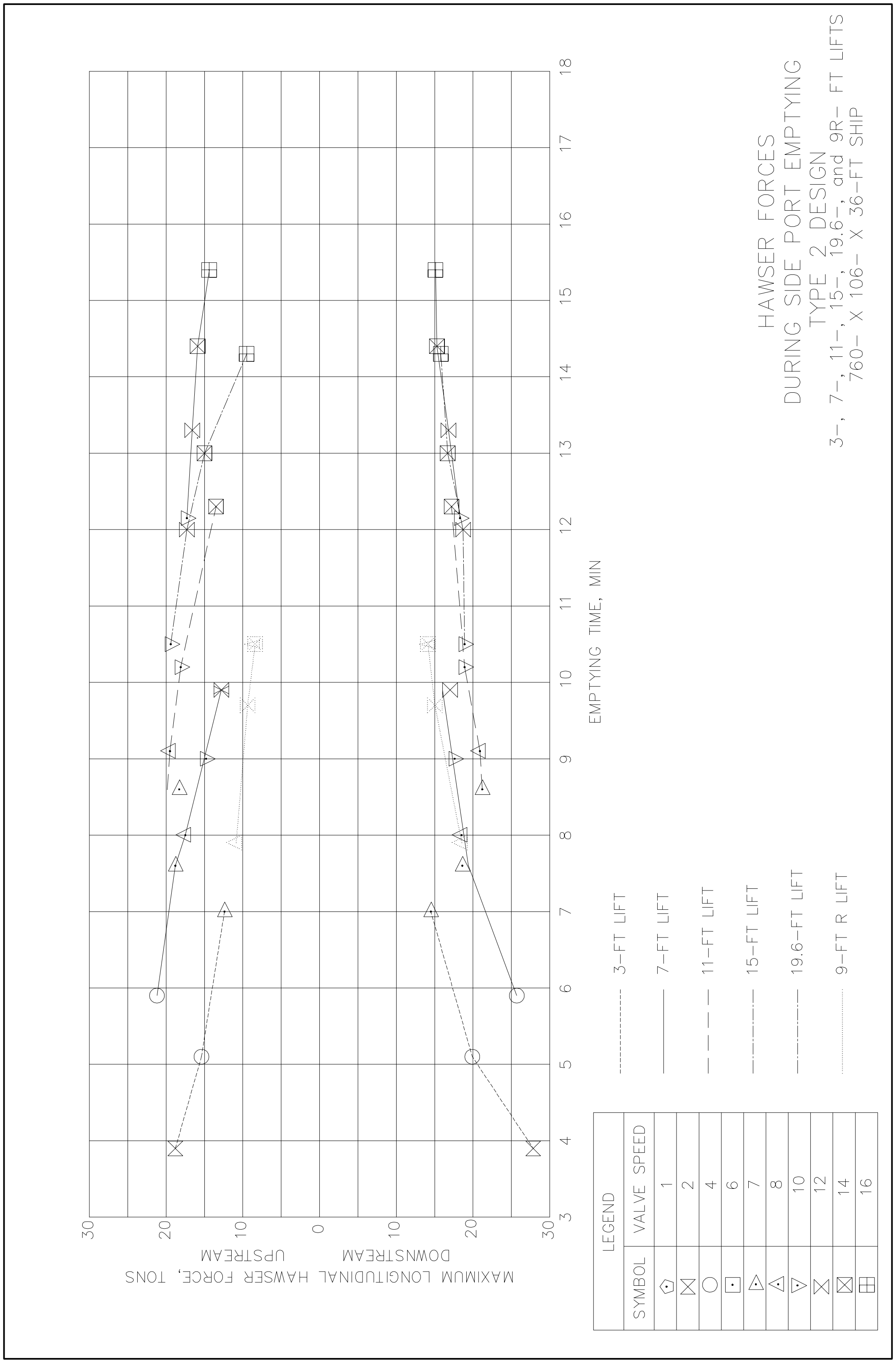
COMPARISON OF
EMPTYING TIMES FOR
5–TON HAWSER FORCE LIMIT
TYPE 1 AND 2 DESIGNS
SIDE PORT FILLING SYSTEM
18 BARGES, 11–FT DRAFT

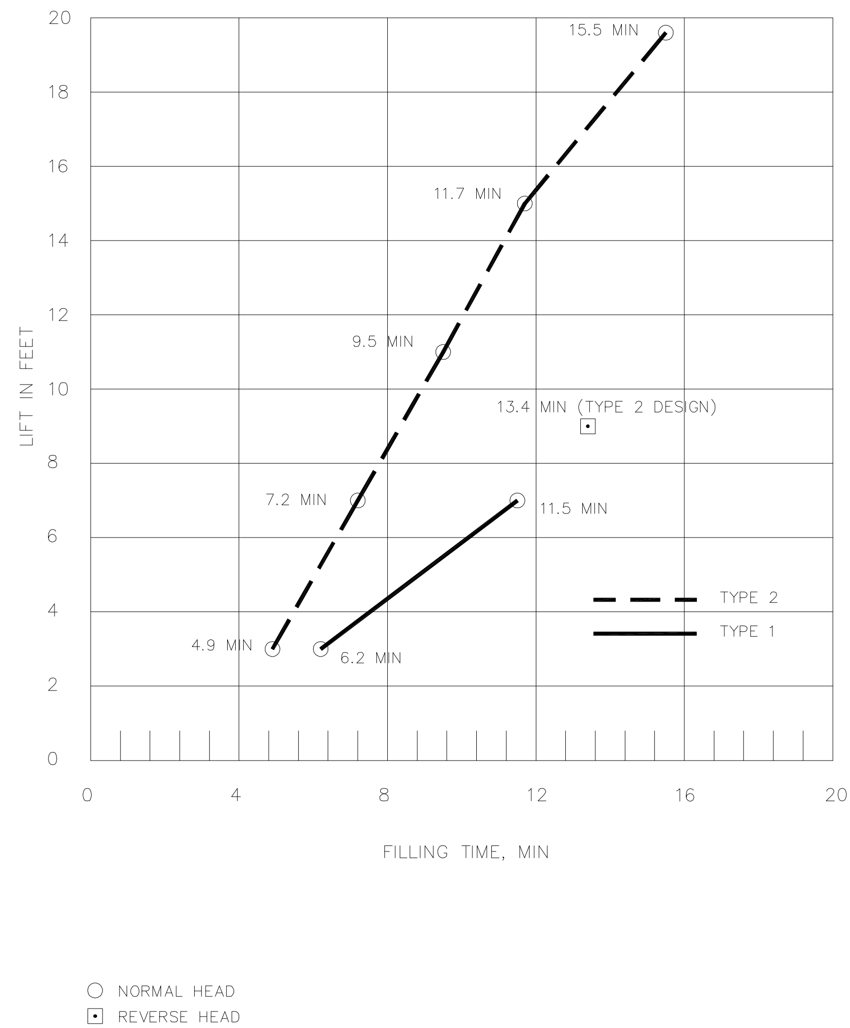


SHIP POSITION
TYPE 2 DESIGN
LOCK
760 FT LONG
SIDE VIEW
106 FT WIDE
END VIEW
36-FT DRAFT
PLAN VIEW
12+70
6+35
6+30
0+00
STATIONS ALONG CENTER LINE
RIVER SIDE

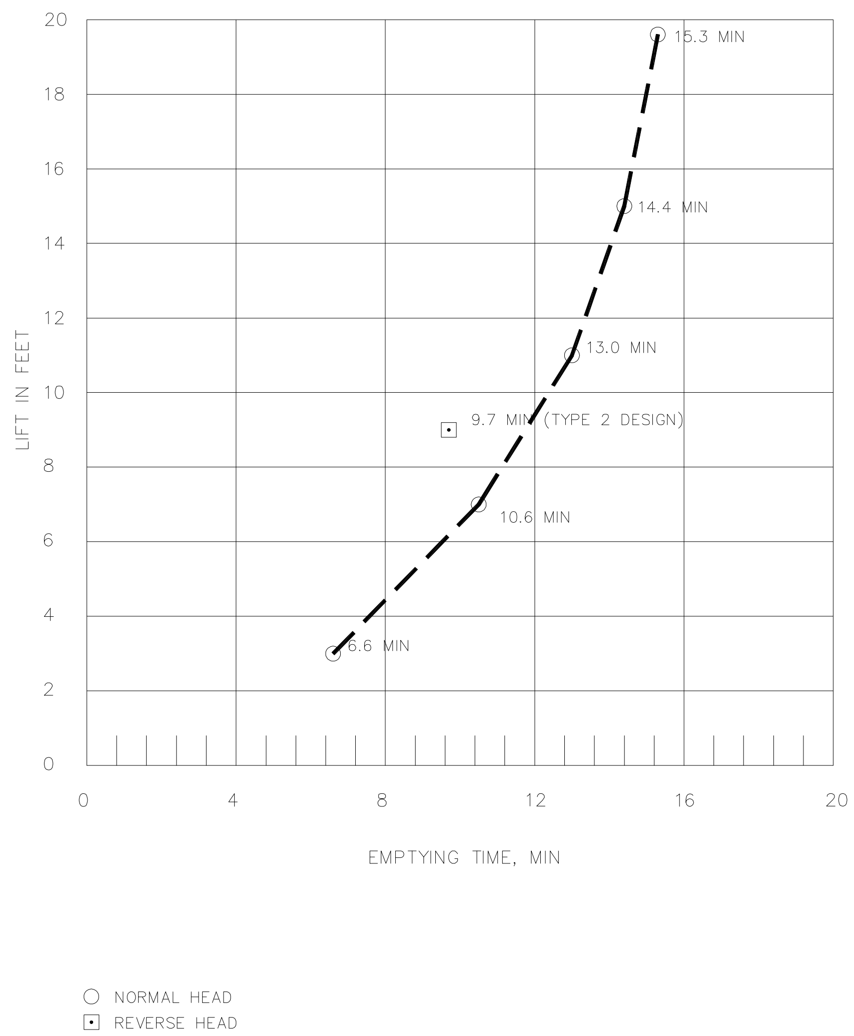
Plate 80


HAWSER FORCES
DURING SIDE PORT FILLING
TYPE 2 DESIGN
3-, 7-, 11-, 15-, 19.6-, and 9R- FT LIFTS
760- X 106- X 36-FT SHIP
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
FILLING TIME, MIN
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
7
8
10
12
14
16
3-FT LIFT
7-FT LIFT
11-FT LIFT
15-FT LIFT
19.6-FT LIFT
9-FT R LIFT

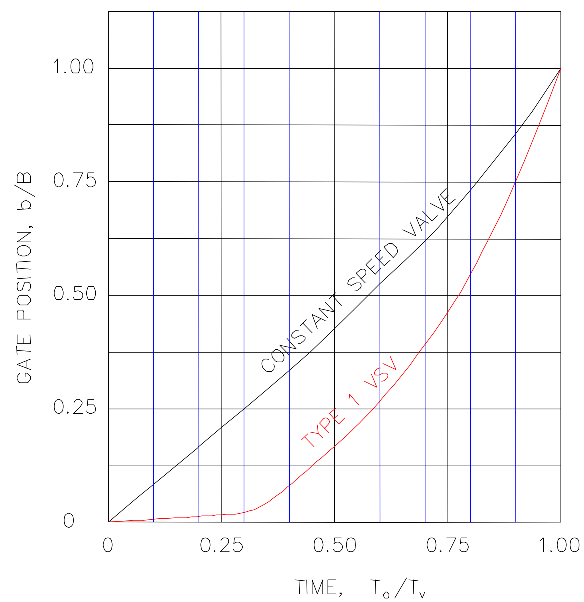

HAWSER FORCES
DURING SIDE PORT EMPTYING
TYPE 2 DESIGN
3-, 7-, 11-, 15-, 19.6-, and 9R- FT LIFTS
760- X 106- X 36-FT SHIP
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
30 20 10 0 10 20 30
EMPTYING TIME, MIN
3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
3-FT LIFT
7-FT LIFT
11-FT LIFT
15-FT LIFT
19.6-FT LIFT
9-FT R LIFT
LEGEND
SYMBOL
VALVE SPEED
1
2
4
6
7
8
10
12
14
16



COMPARISON OF
FILLING TIMES FOR
15–TON HAWSER FORCE LIMIT
TYPE 1 AND 2 DESIGNS
SIDE PORT FILLING SYSTEM
760–FT x 106–FT x 36–FT SHIP



COMPARISON OF
EMPTYING TIMES FOR
15-TON HAWSER FORCE LIMIT
TYPE 2 DESIGN
SIDE PORT FILLING SYSTEM
760-FT X 106-FT X 36-FT SHIP



T_o = TIME SINCE OPENING BEGAN

T_v = TIME TO OPEN FULL OR STOP

B = 18.25 FT

b = VERTICAL DIST. FROM LIP TO FLOOR

ORIGINAL VALVE CURVE
(CONSTANT SPEED)

b/B	T_o/T_v
0	0
0.084	0.10
0.167	0.20
0.249	0.30
0.334	0.40
0.426	0.50
0.525	0.60
0.619	0.70
0.732	0.80
0.855	0.90
1.000	1.00

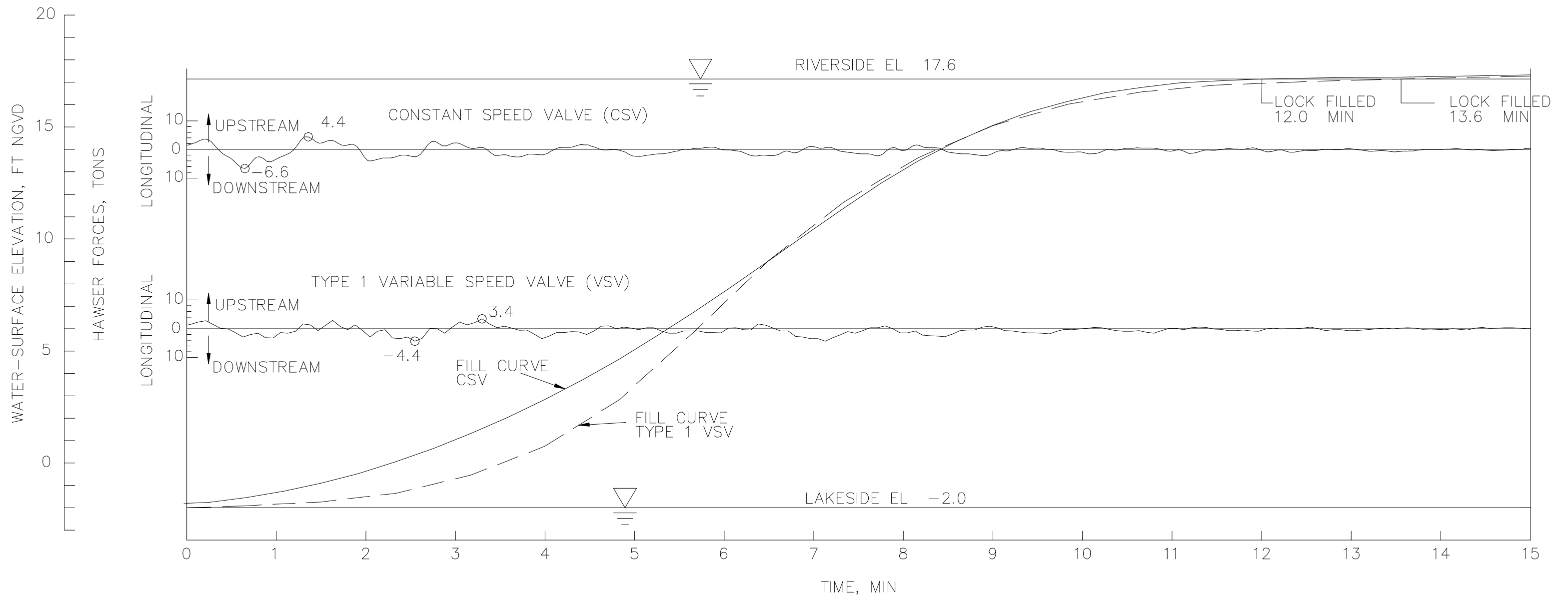
TYPE 1 VSV

b/B	T_o/T_v
0	0
0.006	0.10
0.013	0.20
0.022	0.30
0.080	0.40
0.167	0.50
0.266	0.60
0.394	0.70
0.545	0.80
0.753	0.90
1.000	1.00

GATE POSITION DATA

b	% Open (Radially)
0	0
1.525	10
3.050	20
4.550	30
6.100	40
7.775	50
9.575	60
11.300	70
13.375	80
15.600	90
18.250	100

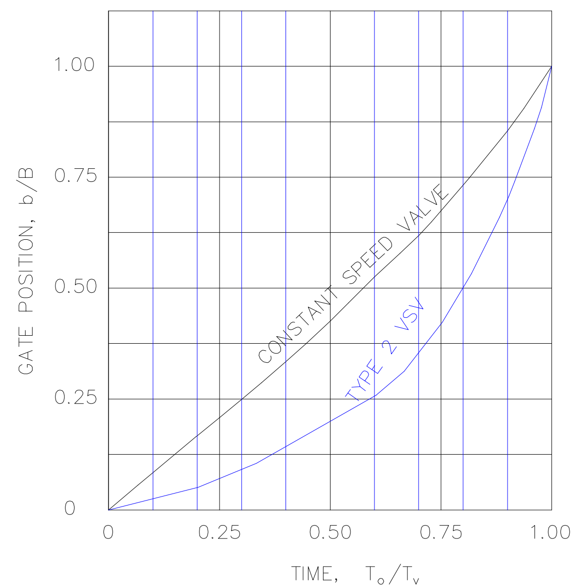
TYPE 1 VSV
VALVE CURVE



CONSTANT SPEED VALVE (CSV) - 8 MIN NORMAL VALVE

VARIABLE SPEED VALVE (VSV) - 2 MIN TO 2.5 % OPEN, 2 MIN TO 37.4 % OPEN, AND 2 MIN TO 100% OPEN

COMPARISON OF
FILLING CHARACTERISTICS
SIDE PORT SYSTEM
TYPE 2 DESIGN
CSV AND VSV OPERATIONS
19.6-FT LIFT
RIVERSIDE EL 17.6
LAKESIDE EL -2



T_o = TIME SINCE OPENING BEGAN

T_v = TIME TO OPEN FULL OR STOP

B = 18.25 FT

b = VERTICAL DIST. FROM LIP TO FLOOR

ORIGINAL VALVE CURVE
(CONSTANT SPEED)

b/B	T_o/T_v
0	0
0.084	0.10
0.167	0.20
0.249	0.30
0.334	0.40
0.426	0.50
0.525	0.60
0.619	0.70
0.732	0.80
0.855	0.90
1.000	1.00

TYPE 2 VSV

b/B	T_o/T_v
0	0
0.022	0.10
0.050	0.20
0.088	0.30
0.140	0.40
0.196	0.50
0.259	0.60
0.352	0.70
0.500	0.80
0.699	0.90
1.000	1.00

GATE POSITION DATA

b	% Open (Radially)
0	0
1.525	10
3.050	20
4.550	30
6.100	40
7.775	50
9.575	60
11.300	70
13.375	80
15.600	90
18.250	100

TYPE 2 VSV
VALVE CURVE

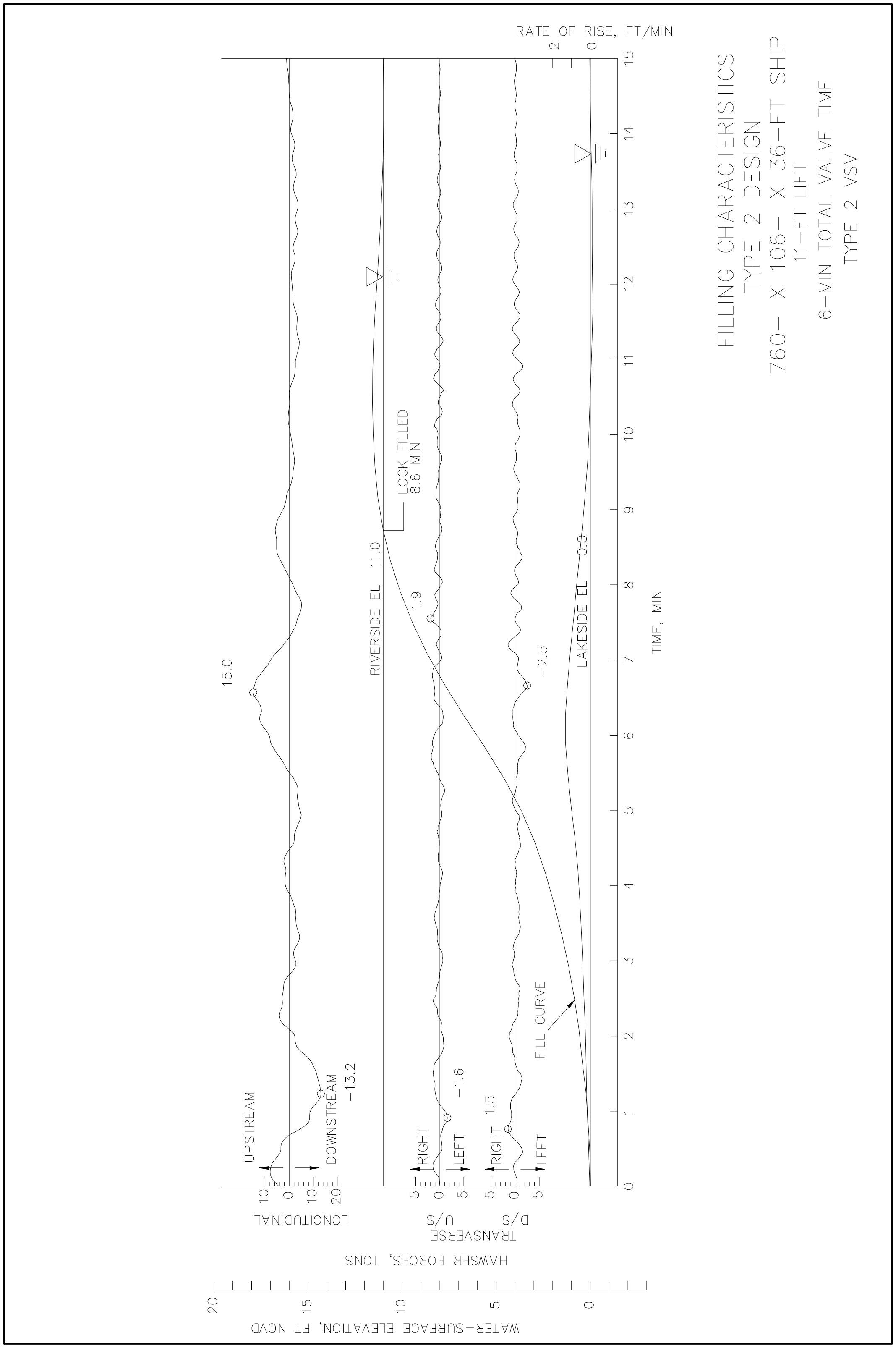
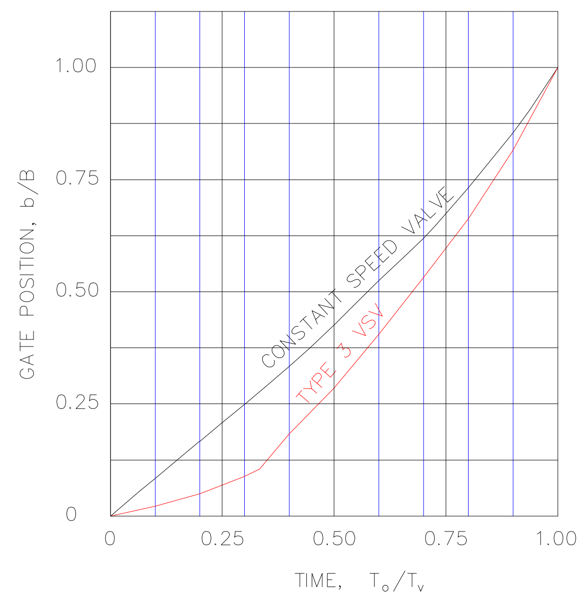

FILLING CHARACTERISTICS
TYPE 2 DESIGN
760- X 106- X 36-FT SHIP
11-FT LIFT
6-MIN TOTAL VALVE TIME
TYPE 2 VSV
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
RIVERSIDE EL 11.0
LAKESIDE EL 0.0
LOCK FILLED
8.6 MIN
FILL CURVE
15.0
-13.2
1.9
-1.6
1.5
-2.5

Plate 88



T_o = TIME SINCE OPENING BEGAN

T_v = TIME TO OPEN FULL OR STOP

B = 18.25 FT

b = VERTICAL DIST. FROM LIP TO FLOOR

ORIGINAL VALVE CURVE
(CONSTANT SPEED)

b/B	T_o/T_v
0	0
0.084	0.10
0.167	0.20
0.249	0.30
0.334	0.40
0.426	0.50
0.525	0.60
0.619	0.70
0.732	0.80
0.855	0.90
1.000	1.00

TYPE 3 VSV

b/B	T_o/T_v
0	0
0.022	0.10
0.050	0.20
0.088	0.30
0.183	0.40
0.285	0.50
0.405	0.60
0.532	0.70
0.663	0.80
0.816	0.90
1.000	1.00

GATE POSITION DATA

b	% Open (Radially)
0	0
1.525	10
3.050	20
4.550	30
6.100	40
7.775	50
9.575	60
11.300	70
13.375	80
15.600	90
18.250	100

TYPE 3 VSV
VALVE CURVE

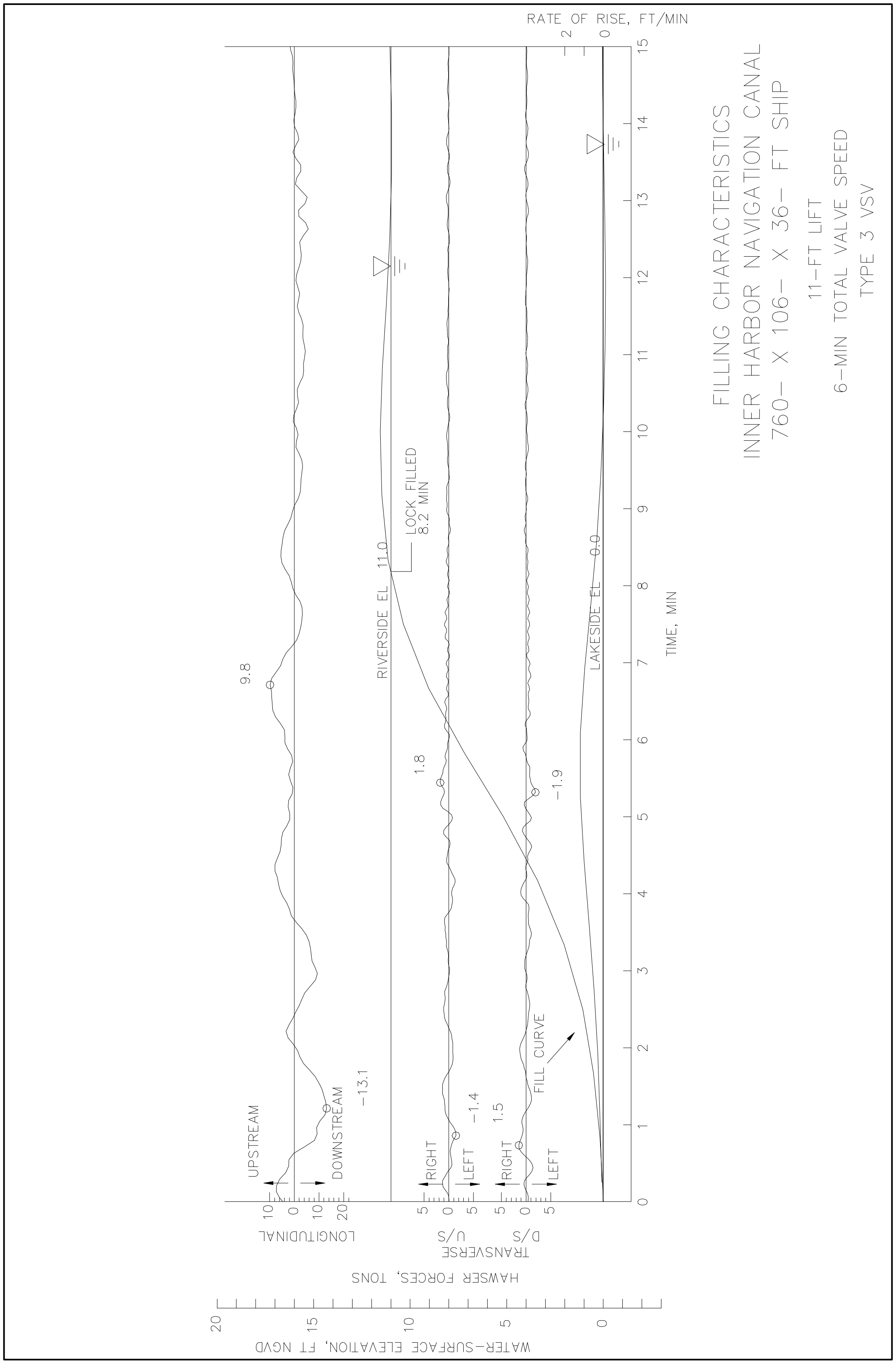
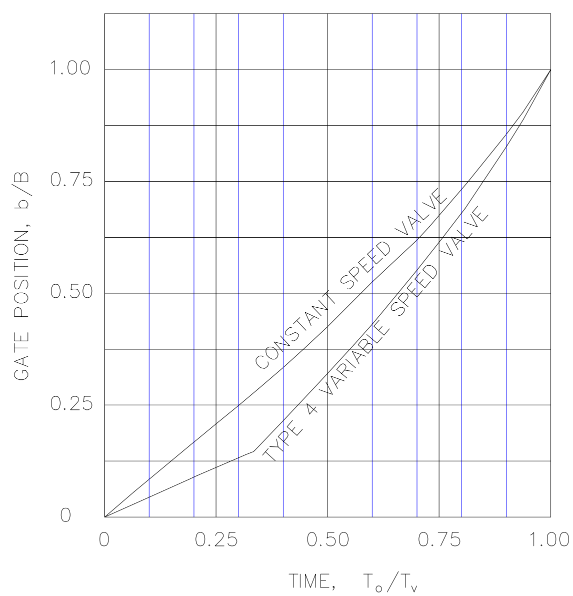

FILLING CHARACTERISTICS
INNER HARBOR NAVIGATION CANAL
760- X 106- X 36- FT SHIP
11-FT LIFT
6-MIN TOTAL VALVE SPEED
TYPE 3 VSV
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
RIVERSIDE EL 11.0
LAKESIDE EL 0.0
LOCK FILLED
8.2 MIN
FILL CURVE
9.8
-13.1
1.8
-1.4
1.5
-1.9

Plate 90



T_o = TIME SINCE OPENING BEGAN

T_v = TIME TO OPEN FULL OR STOP

B = 18.25 FT

b = VERTICAL DIST. FROM LIP TO FLOOR

ORIGINAL VALVE CURVE
(CONSTANT SPEED)

b/B	T_o/T_v
0	0
0.084	0.10
0.167	0.20
0.249	0.30
0.334	0.40
0.426	0.50
0.525	0.60
0.619	0.70
0.732	0.80
0.855	0.90
1.000	1.00

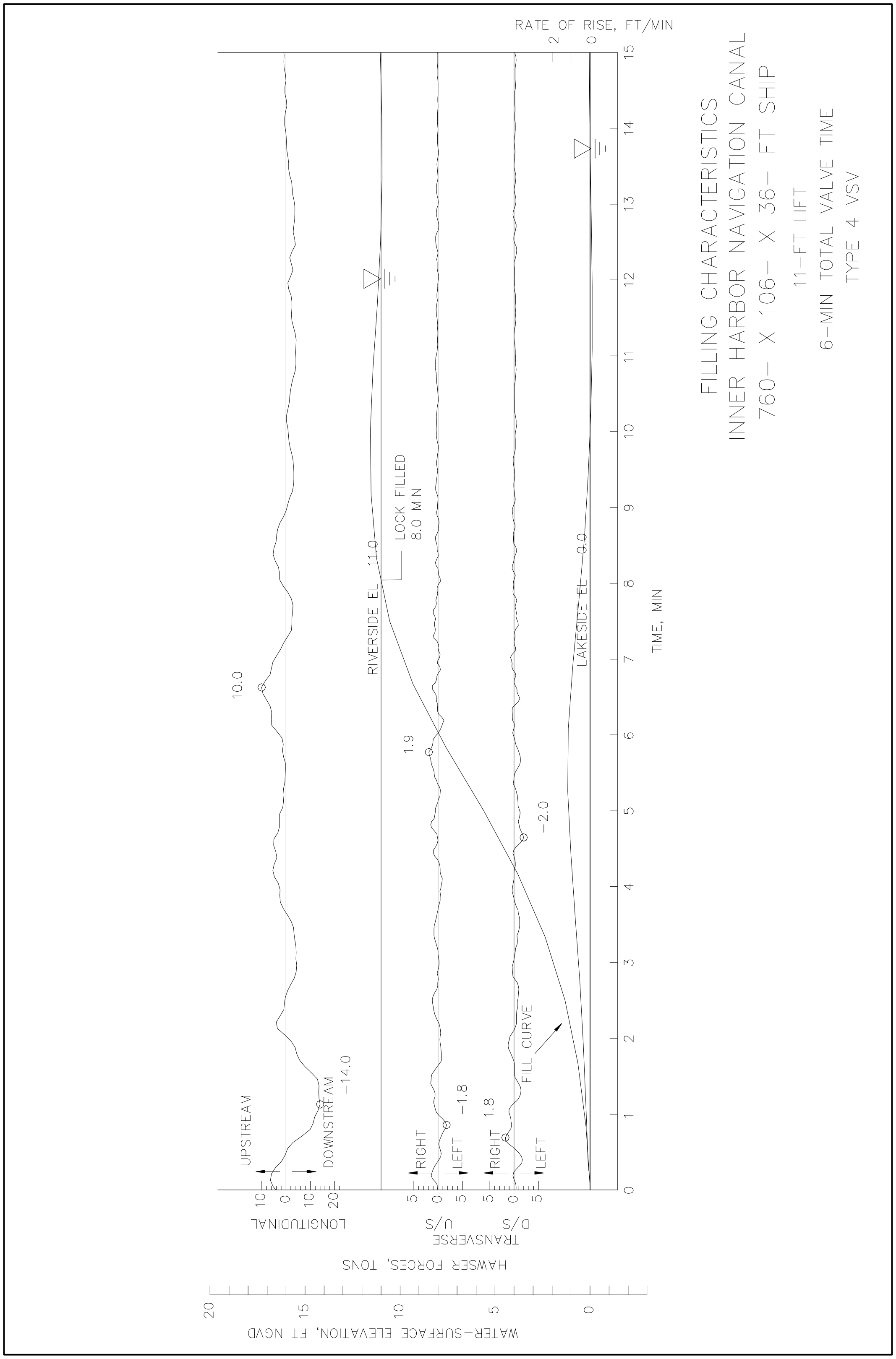
TYPE 4 VSV

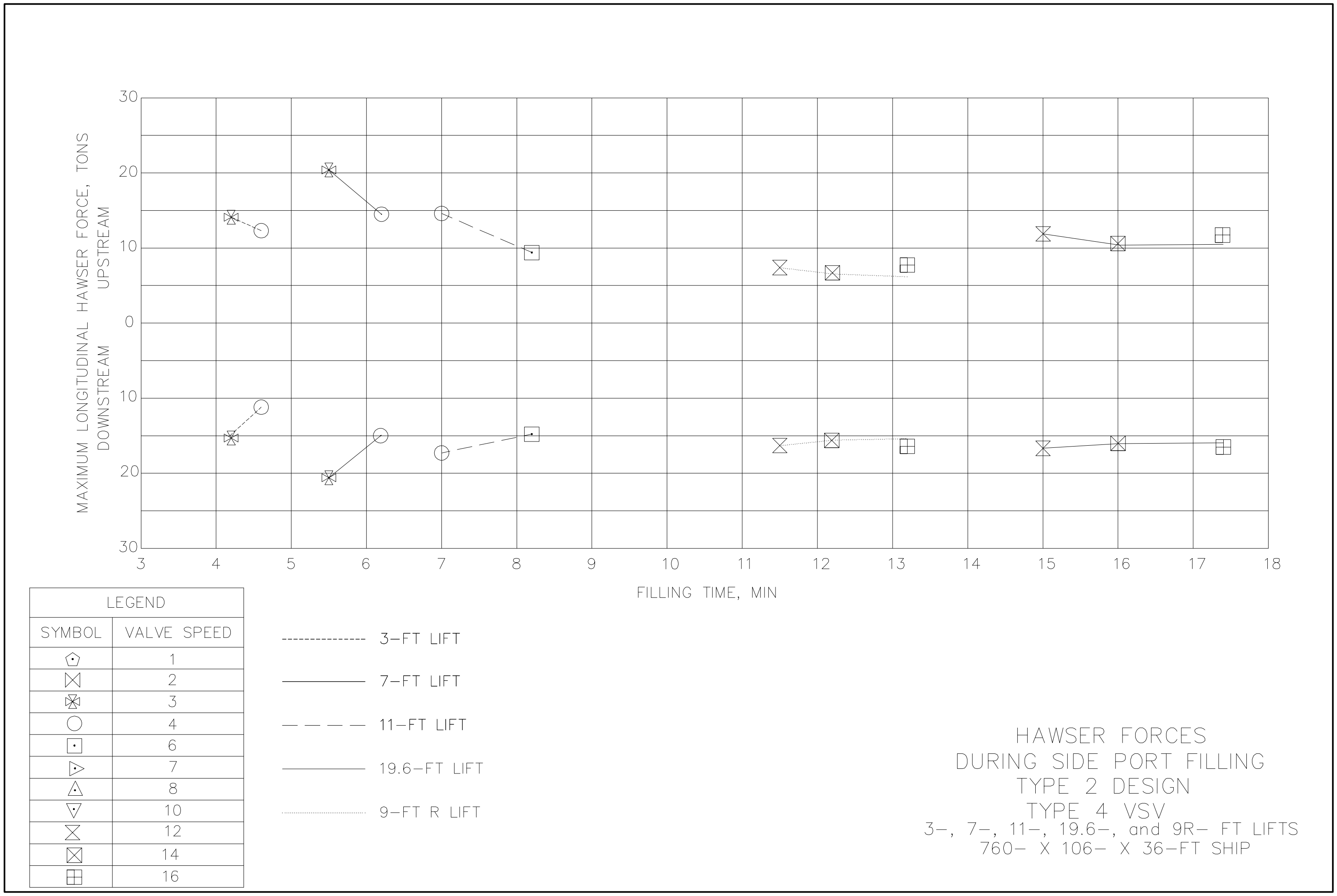
b/B	T_o/T_v
0	0
0.044	0.10
0.089	0.20
0.132	0.30
0.215	0.40
0.321	0.50
0.431	0.60
0.552	0.70
0.679	0.80
0.827	0.90
1.000	1.00

GATE POSITION DATA

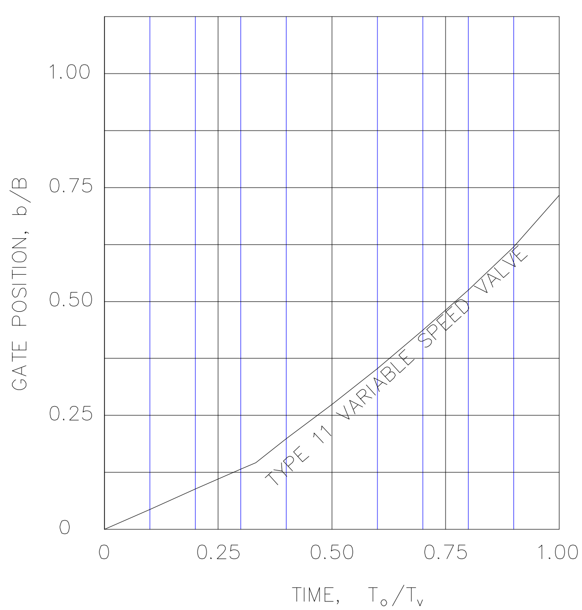
b	% Open (Radially)
0	0
1.525	10
3.050	20
4.550	30
6.100	40
7.775	50
9.575	60
11.300	70
13.375	80
15.600	90
18.250	100

TYPE 4 VSV
VALVE CURVE


FILLING CHARACTERISTICS
INNER HARBOR NAVIGATION CANAL
760- X 106- X 36- FT SHIP
11-FT LIFT
6-MIN TOTAL VALVE TIME
TYPE 4 VSV
RATE OF RISE, FT/MIN
TIME, MIN
WATER-SURFACE ELEVATION, FT NGVD
HAWSER FORCES, TONS
LONGITUDINAL
TRANSVERSE
U/S
D/S
UPSTREAM
DOWNSTREAM
RIGHT
LEFT
RIVERSIDE EL 11.0
LAKESIDE EL 0.0
LOCK FILLED
8.0 MIN
FILL CURVE
10.0
-14.0
1.9
-1.8
1.8
-2.0



MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
30
20
10
0
10
20
30
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
FILLING TIME, MIN
LEGEND
SYMBOL
VALVE SPEED
1
2
3
4
6
7
8
10
12
14
16
3-FT LIFT
7-FT LIFT
11-FT LIFT
19.6-FT LIFT
9-FT R LIFT
HAWSER FORCES
DURING SIDE PORT FILLING
TYPE 2 DESIGN
TYPE 4 VSV
3-, 7-, 11-, 19.6-, and 9R- FT LIFTS
760- X 106- X 36-FT SHIP



T_o = TIME SINCE OPENING BEGAN

T_v = TIME TO OPEN FULL OR STOP

B = 18.25 FT
b = VERTICAL DIST. FROM LIP TO FLOOR

ORIGINAL VALVE CURVE
(CONSTANT SPEED)

b/B	T_o/T_v
0	0
0.084	0.10
0.167	0.20
0.249	0.30
0.334	0.40
0.426	0.50
0.525	0.60
0.619	0.70
0.732	0.80
0.855	0.90
1.000	1.00

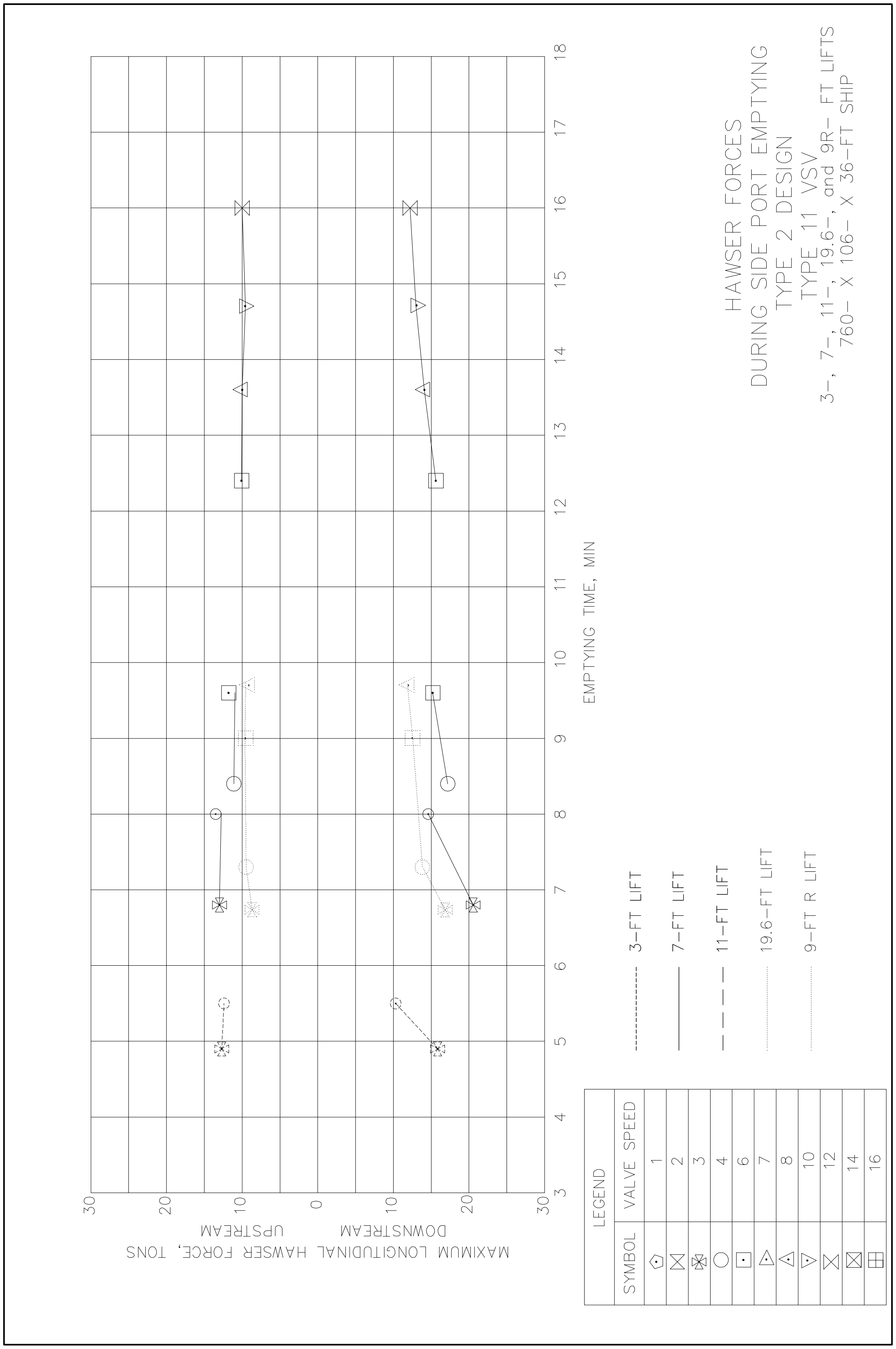
TYPE 11 VSV

b/B	T_o/T_v
0	0
0.044	0.10
0.089	0.20
0.132	0.30
0.199	0.40
0.274	0.50
0.353	0.60
0.437	0.70
0.525	0.80
0.620	0.90
0.7333	1.00

GATE POSITION DATA

b	% Open (Radially)
0	0
1.525	10
3.050	20
4.550	30
6.100	40
7.775	50
9.575	60
11.300	70
13.375	80
15.600	90
18.250	100

TYPE 11 VSV
VALVE CURVE


HAWSER FORCES
DURING SIDE PORT EMPTYING
TYPE 2 DESIGN
TYPE 11 VSV
3-, 7-, 11-, 19.6-, and 9R- FT LIFTS
760- X 106- X 36-FT SHIP
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
30
20
10
0
10
20
30
EMPTYING TIME, MIN
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
3-FT LIFT
7-FT LIFT
11-FT LIFT
19.6-FT LIFT
9-FT R LIFT
LEGEND
SYMBOL
VALVE SPEED
1
2
3
4
6
7
8
10
12
14
16

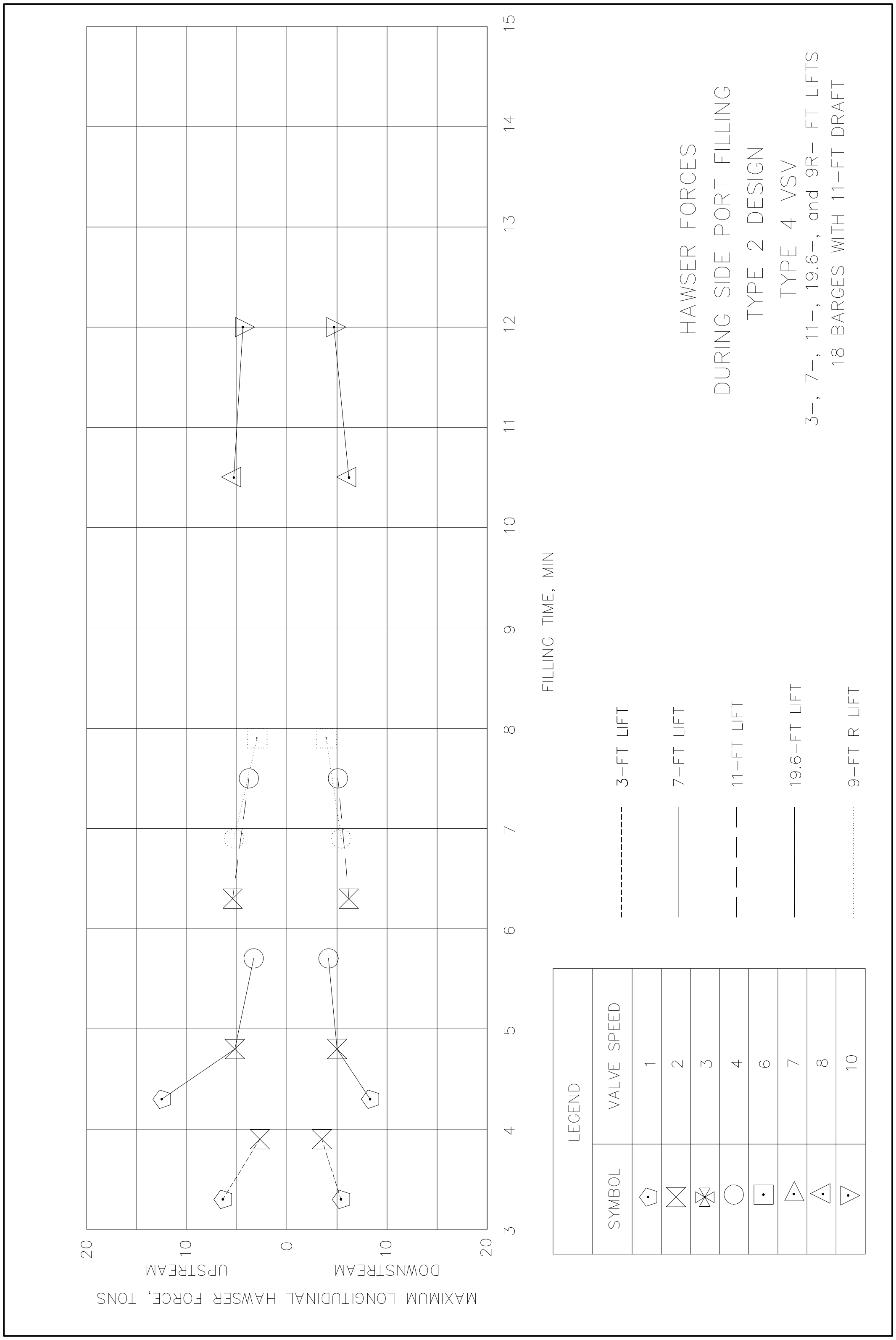
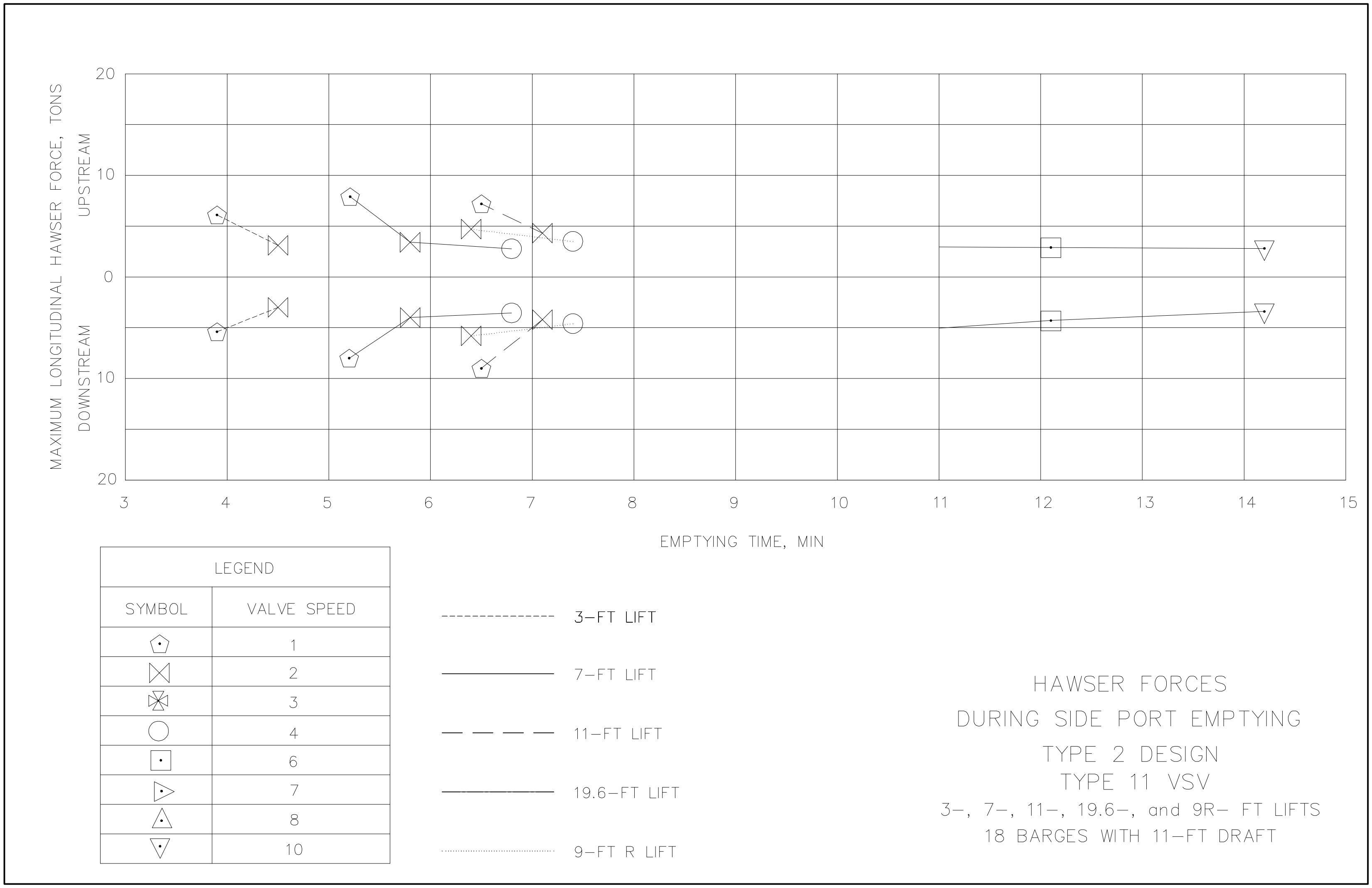
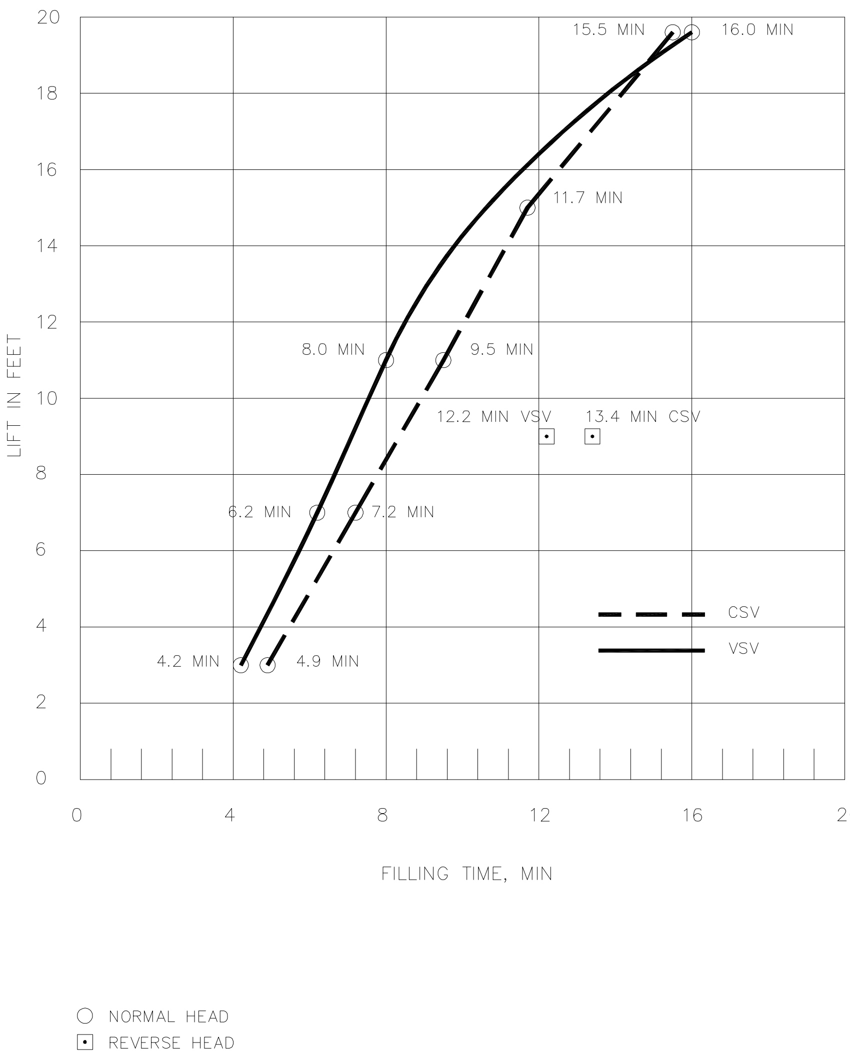
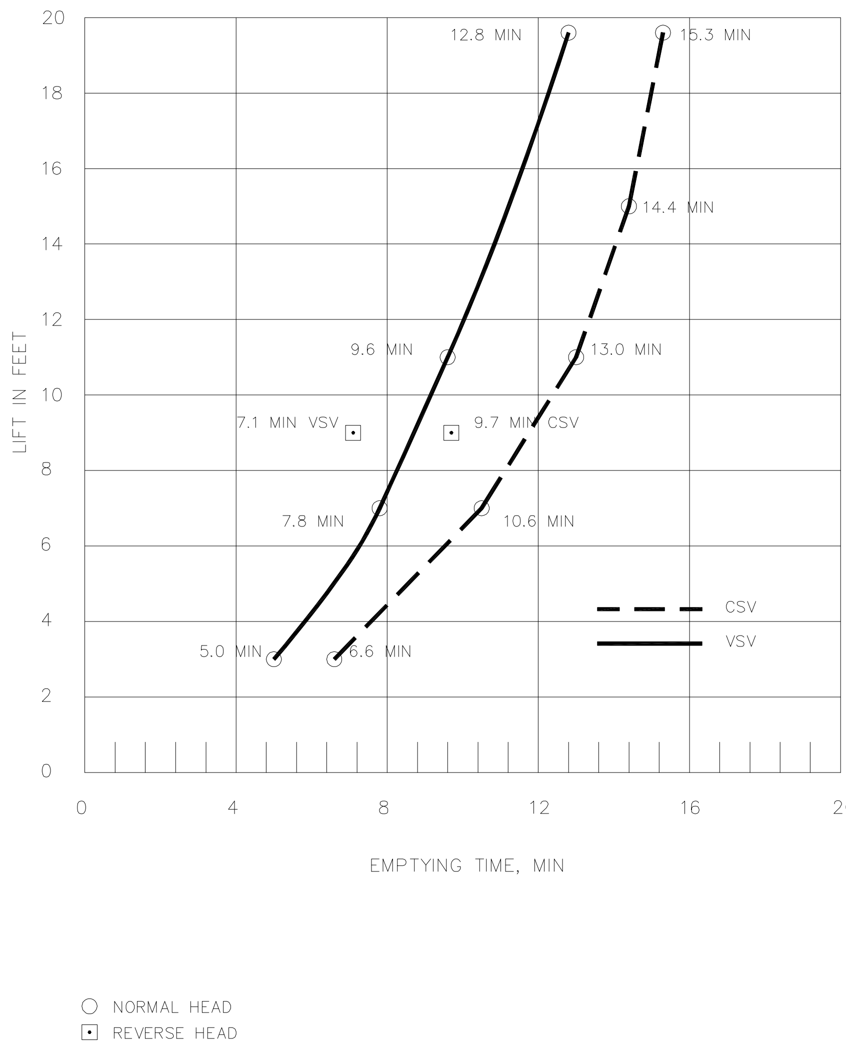

HAWSER FORCES
DURING SIDE PORT FILLING
TYPE 2 DESIGN
TYPE 4 VSV
3–, 7–, 11–, 19.6–, and 9R– FT LIFTS
18 BARGES WITH 11–FT DRAFT
MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
FILLING TIME, MIN
20
10
0
10
20
3
4
5
6
7
8
9
10
11
12
13
14
15
LEGEND
SYMBOL
VALVE SPEED
1
2
3
4
6
7
8
10
3–FT LIFT
7–FT LIFT
11–FT LIFT
19.6–FT LIFT
9–FT R LIFT

Plate 96

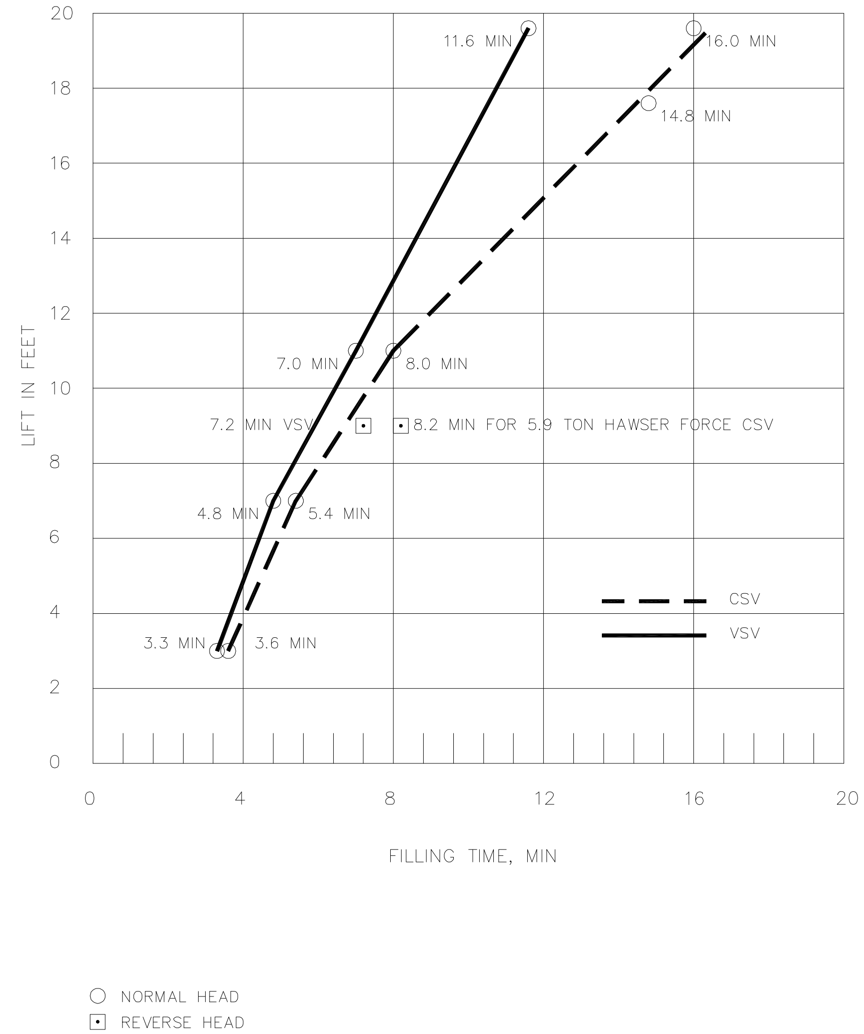

MAXIMUM LONGITUDINAL HAWSER FORCE, TONS
UPSTREAM
DOWNSTREAM
20
10
0
10
20
3
4
5
6
7
8
9
10
11
12
13
14
15
EMPTYING TIME, MIN
LEGEND
SYMBOL
VALVE SPEED
1
2
3
4
6
7
8
10
3–FT LIFT
7–FT LIFT
11–FT LIFT
19.6–FT LIFT
9–FT R LIFT
HAWSER FORCES
DURING SIDE PORT EMPTYING
TYPE 2 DESIGN
TYPE 11 VSV
3–, 7–, 11–, 19.6–, and 9R– FT LIFTS
18 BARGES WITH 11–FT DRAFT



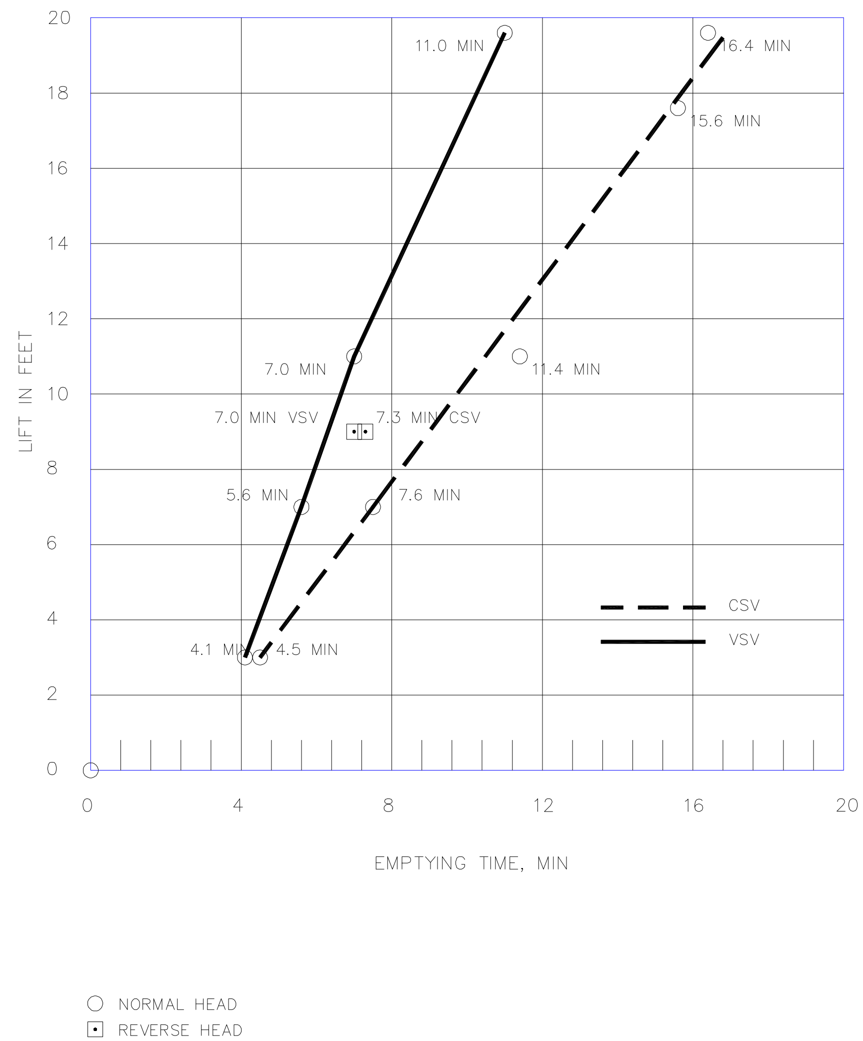
FILLING TIMES FOR
15–TON HAWSER FORCE LIMIT
TYPE 2 DESIGN
CONSTANT– AND VARIABLE–
SPEED VALVES
760– x 106– x 36–FT SHIP



EMPTYING TIMES FOR
15-TON HAWSER FORCE LIMIT
TYPE 2 DESIGN
CONSTANT- AND VARIABLE-
SPEED VALVES
760- X 106- X 36-FT SHIP



FILLING TIMES FOR
5–TON HAWSER FORCE LIMIT
TYPE 2 DESIGN
CONSTANT– AND VARIABLE–
SPEED VALVES
18 BARGES, 11–FT DRAFT



EMPTYING TIMES FOR
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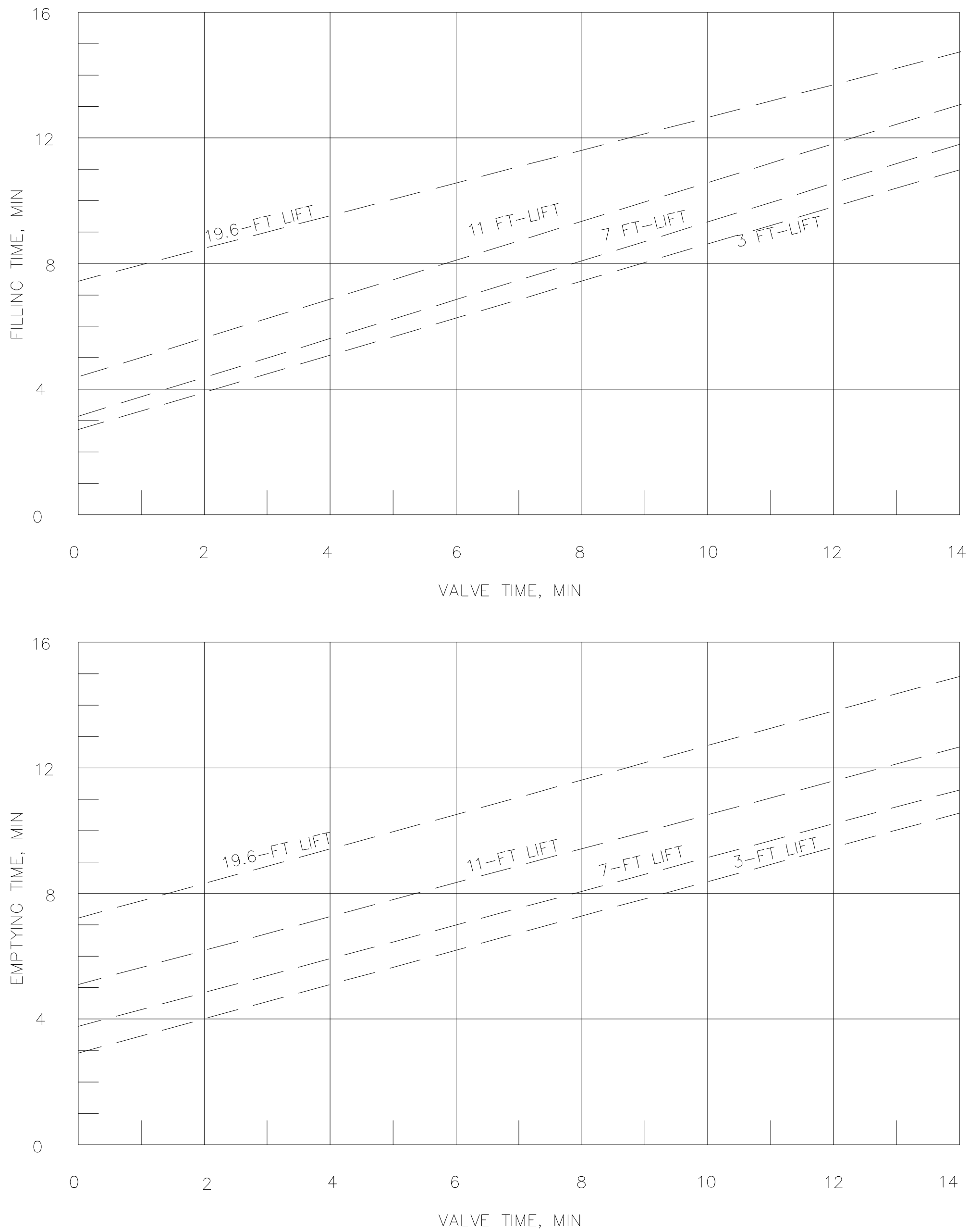
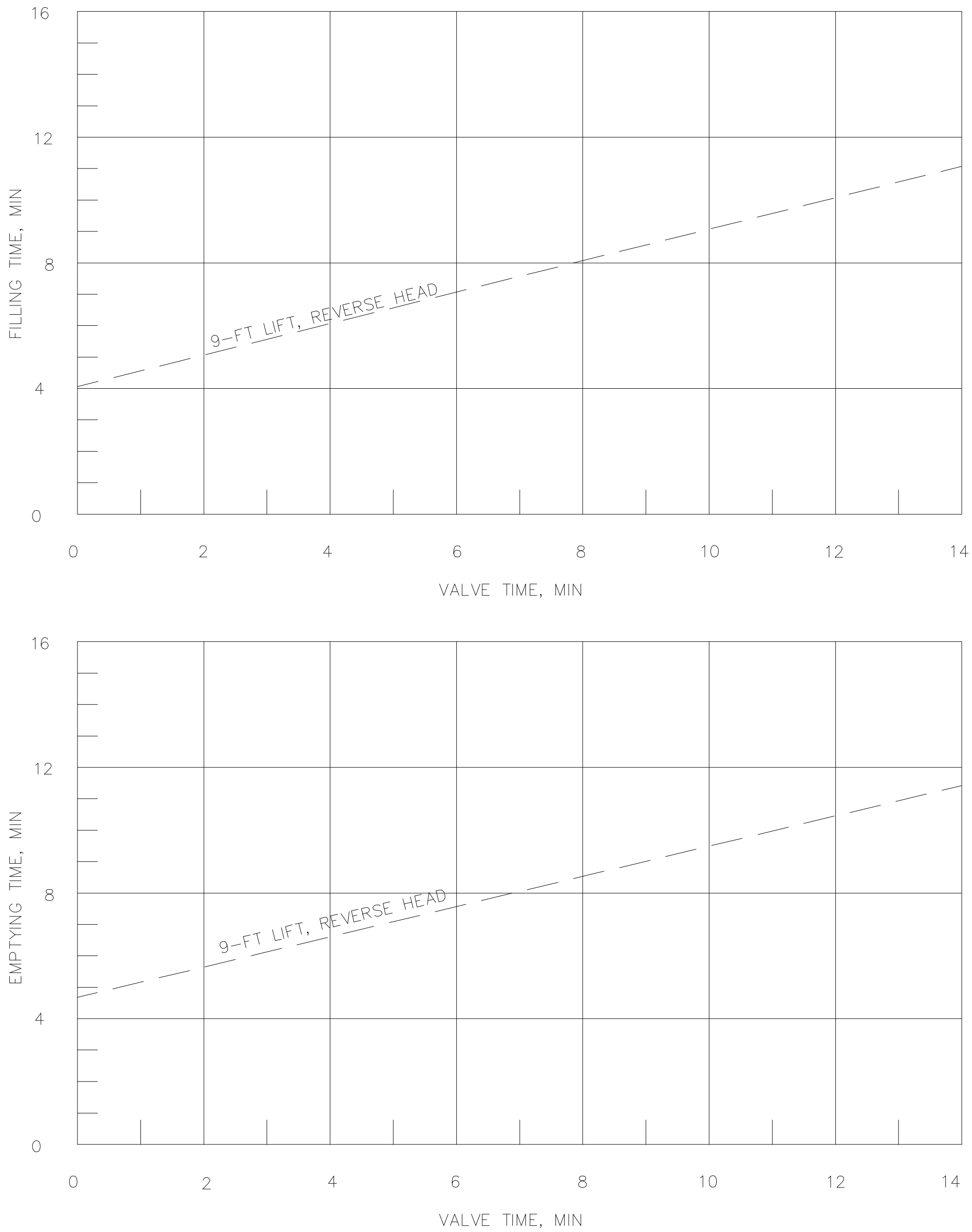
TYPE 2 DESIGN
CONSTANT– AND VARIABLE–
SPEED VALVES
18 BARGES, 11–FT DRAFT



OPERATION TIMES FOR
LIFTS = 3, 7, 11, AND 19.6 FT
TYPE 2 DESIGN
CONSTANT-SPEED VALVE



OPERATION TIMES FOR
9-FT REVERSE LIFT
TYPE 2 DESIGN
CONSTANT-SPEED VALVE

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14. ABSTRACT
A replacement lock is planned for the Inner Harbor Navigation Canal (IHNC) Lock in New Orleans, LA. The existing 675-ft-long by 75-ft-wide lock with a floor elevation of -36 ft referred to the National Geodetic Vertical Datum (NGVD) will be replaced with a 1,200-ft-long by 110-ft-wide lock with a floor elevation of -40 ft NGVD. The design lift for the new lock is 19.6 ft, and it will handle both deep- and shallow-draft vessels. A 1:25-scale physical model study of the proposed design was performed to verify the hydraulic design. The initial design consisted of an end filling and emptying system with sector gates. The sector gates were selected because of the reverse lift conditions that occasionally occur at the project. Guidance for this type design and lift for a deep-draft vessel was essentially nonexistent. There was concern that the end filling system might be too slow to maintain safe filling operations for this lift. A side port system was selected as the alternate system to evaluate during the study. The initial end filling and emptying system design proposed was 1,360 ft long from pintle to pintle and allowed for additional lengths at the ends of the chamber for energy dissipation. Both filling and emptying systems were evaluated with this length of lock. Normal lift conditions between 3 and 19.6 ft and a reverse lift of 9 ft were evaluated for selected valve operations. Excessive filling times were determined for the end filling and emptying system with shallow-draft vessels. With a deep-draft vessel and the end filling and emptying system, the accepted hawser force criteria could not be met with lifts greater than 3 ft even with extremely slow gate opening operations. The side port system was faster (Continued)

15. SUBJECT TERMS

Deep-draft vessels	Hawser forces	Lock replacement
End filling and emptying system	Inner Harbor Navigation Canal	Side port filling and emptying system
	Lock design	Variable speed valve operations

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14. ABSTRACT (continued)

and the hydraulic conditions were more desirable. The side port system was chosen for further evaluation and the pintle-to-pintle lock length was reduced to a more conventional 1,270 ft (Type 2 design lock). The Type 2 design lock performed satisfactorily for the project conditions for both shallow- and deep-draft vessels. A variable-speed valve operation was used to speed up the locking operations and improve the hydraulic conditions in the chamber.