ERDC/CHL TR-04-9

Coastal and Hydraulics Laboratory

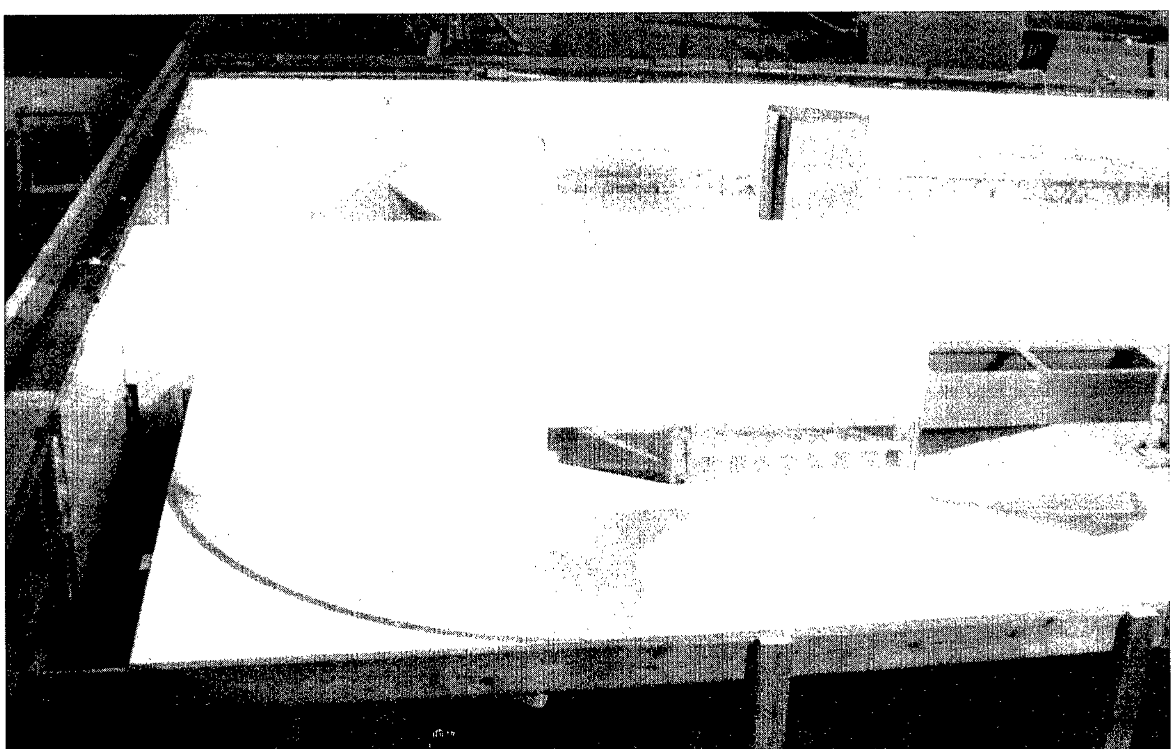
US Army Corps of Engineers®
Engineer Research and Development Center

J. T. Myers Lock Outlet Study, Ohio River

Hydraulic Model Investigation

John E. Hite, Jr.

August 2004



ERDC/CHL TR-04-9
August 2004

J. T. Myers Lock Outlet Study, Ohio River

Hydraulic Model Investigation

John E. Hite, Jr.

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Engineer District, Louisville
Mazzoli Federal Building, 600 Dr. Martin Luther King Place
Louisville, KY 40202

ABSTRACT:

Navigation improvements are planned at J. T. Myers Locks and Dam on the Ohio River main stem. The existing project consists of a navigation dam, a 1,200-ft-long by 110-ft-wide main lock chamber adjacent to a 600-ft-long by 110-ft-wide auxiliary lock chamber. One of the improvements includes developing a 1,200-ft long lock chamber from the existing 600-ft-long lock chamber. The outlet design proposed for the filling and emptying system in the extended lock section was a manifold type diffuser located within the landside guide wall monolith and discharging toward the right (looking downstream) bank. A landside diffuser would help minimize closure of the main lock during construction of the lock extension. A 1:25-scale model was used to evaluate the outlet design. Modifications to the original design were made to improve the hydraulic conditions at the outlet. The vanes in the original design outlet were angled downstream to direct the jets away from the right bank. This design was the type 2 outlet diffuser. A stilling basin with two rows of baffle blocks and an end sill was developed to help dissipate the energy of the outlet discharge and reduce the potential for scour. The banks were also reshaped to direct the outlet flow downstream. The size riprap required to protect the area surrounding the outlet was determined. Hawser forces were also measured on tows moored at various locations in the lower approach with solid and floating guide walls.

Contents

List of Figures

List of Tables

List of Photos

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
miles	1.609347	kilometers
square feet	0.09290304	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms

Preface

The model investigation reported herein was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE) at the request of the U.S. Army Engineer District, Louisville in May 2002. The model experiments were performed during the period Aug 2002 to March 2004 by personnel of the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC) under the general supervision of Mr. Thomas W. Richardson, Director, CHL; Dr. W. D. Martin, Deputy Director, CHL; Mr. Donald C. Wilson, Chief, Navigation Branch, CHL, and Dr. Sandra Knight and Ms. Joan Pope, Technical Directors, CHL.

The experimental program was led by Messrs. J. E. Myrick and J. P. Crutchfield under the supervision of Dr. J. E. Hite, Jr., Leader, Locks Group. Model construction was completed by Messrs. M. A. Simmons, M. L. Bolden (retired), J. E. Gullet, J. A. Lyons, and K. K. Raner of the Model Shop and Mr. C. Burr of the Carpenter Shop, Department of Public Works (DPW), ERDC, under the supervision of Mr. J. Schultz, Chief of the Model Shop, DPW, and Mr. T. M. Beard, Chief of the Carpenter Shop. Data acquisition and remote-control equipment were installed and maintained by Messrs. S. W. Guy and T. E. Nisley, Information Technology Laboratory (ITL), ERDC. Data acquisition software was developed by Dr. B. W. McCleave, ITL. The report was written by Dr. Hite. Mr. M. T. Sanchez performed a peer review of the report.

During the course of the model study, Col. Robert Rowlette, Messrs. Byron McClellan, Boyd McClellan, George Herbig , David Schaaf, Andy Lowe, Greg Werncke, Brian Huston, Ken Lamkin, Jeff Bayers, Bobby Buckman, Jay Davis, Bob Kanzinger, Gene Allsmiller, Robert Gibbs, Daniel Allgeier, Pete Frick, David Hawkins, and Ms. Veronica Rife of U.S. Army Engineer District Louisville; Col. William Bulen, Messrs. Sean Smith, David Conley, Ted Hamb, and Chris Beck of the U.S. Army Engineer District, Huntington; Messrs.Omer Coleman and David Reed of Crounse Corp.; Mr. David K. Smith of Marathon Ashland; Mr. Samuel Dickey of ACBL; Mr. Richard Kern of Midland ENT; Mr. Barney Owens of Ingram Barge Co.; Mr. Joe Vancil of R&W Marine; and Messrs. Chuck Surprenant, Leroy Koch, and Mike Litwin of the U.S. Fish and Wildlife Service visited ERDC to observe model operation, review experiment results, and discuss model results.

Dr. James R. Houston was Director of ERDC, and COL James R. Rowan, EN, was Commander and Executive Director.

1 Introduction

Background

The U.S. Army Engineer District, Louisville, is planning navigation improvements at J. T. Myers Locks and Dam on the Ohio River. These improvements include extending the existing 600-ft[1]-long by 110-ft-wide landside chamber to accommodate a tow consisting of 15 barges, 3 wide by 5 long (each barge 35 ft wide by 195 ft long), and towboat and also modifying the approach walls for better tow entry and exit. Hite and Crutchfield (2004) performed a model study to evaluate the lock filling and emptying system for the lock extension. During this study, evaluation of the lock outlet was initiated but was halted so the U.S. Army Engineer District, Huntington, could use the lock filling and emptying facility to study the filling and emptying system for the Greenup navigation project. The outlet study was continued in another flume, and this report provides the results of that investigation.

Prototype

The existing J. T. Myers Locks and Dam project is located on the Ohio River approximately 846 miles below its head at Pittsburgh, PA, and about 3.5 miles downstream from Uniontown, KY (Figure 1). The locks are on the Indiana side of the river. The current lock system consists of a 110-ft-wide by 1,200-ft-long main lock chamber adjacent to a 110-ft-wide by 600-ft-long auxiliary lock chamber. The filling and emptying system for the 600-ft chamber is the single-culvert bottom-lateral design with six laterals. A view of the existing J. T. Myers Locks and Dam on the Ohio River is shown in Figure 2 along with a schematic of a proposed lock expansion.

Purpose and Scope

The purpose of the investigation was to assist the Louisville District in verifying the landside outlet design and make modifications to the design if necessary to achieve acceptable performance. The landside outlet is preferable over a riverside outlet for lock extension projects since closure of the main lock

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

chamber will be minimized during construction of the outlet. The outlet was evaluated based on flow patterns in the lower approach, tendencies for sediment deposition, and hawser forces on a tow moored in the lower approach.

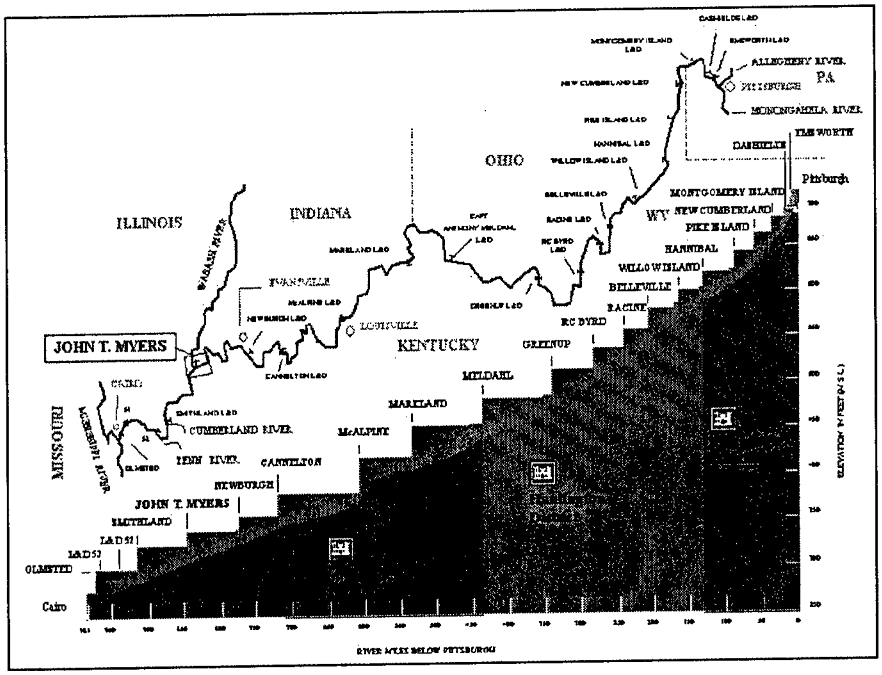


Figure 1. Location map

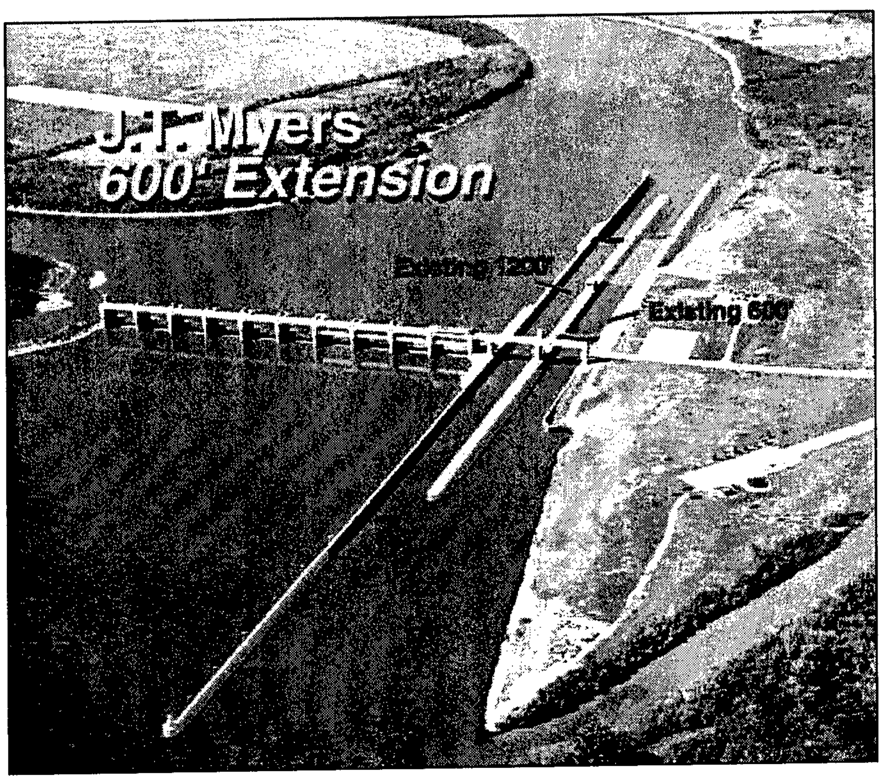


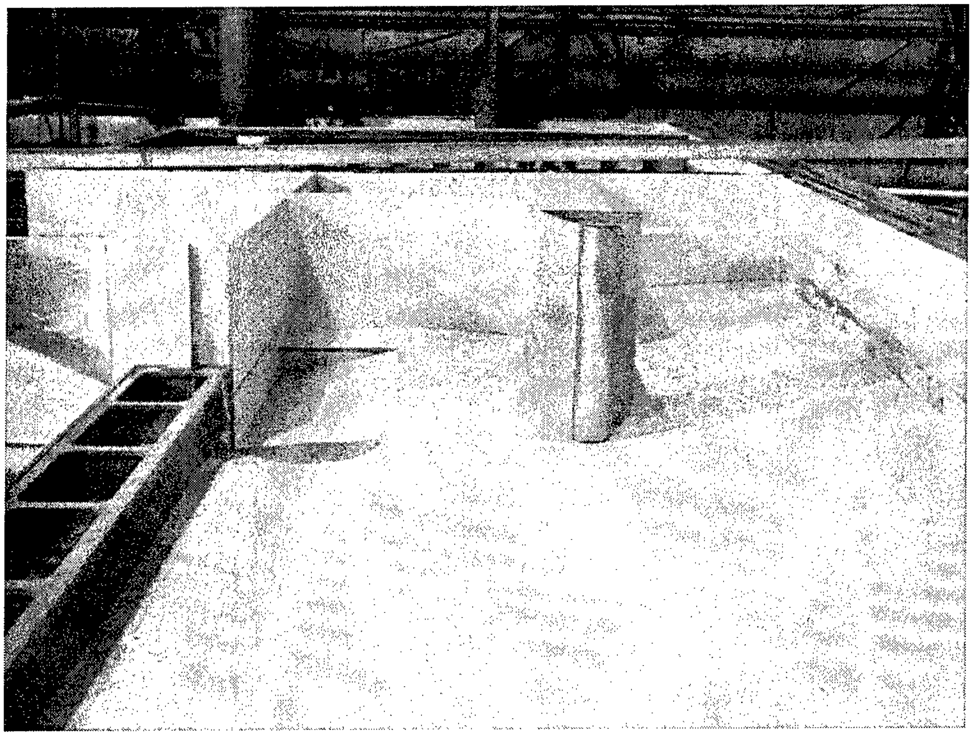
Figure 2. J. T. Myers proposed lock extension looking downstream

2 Physical Model

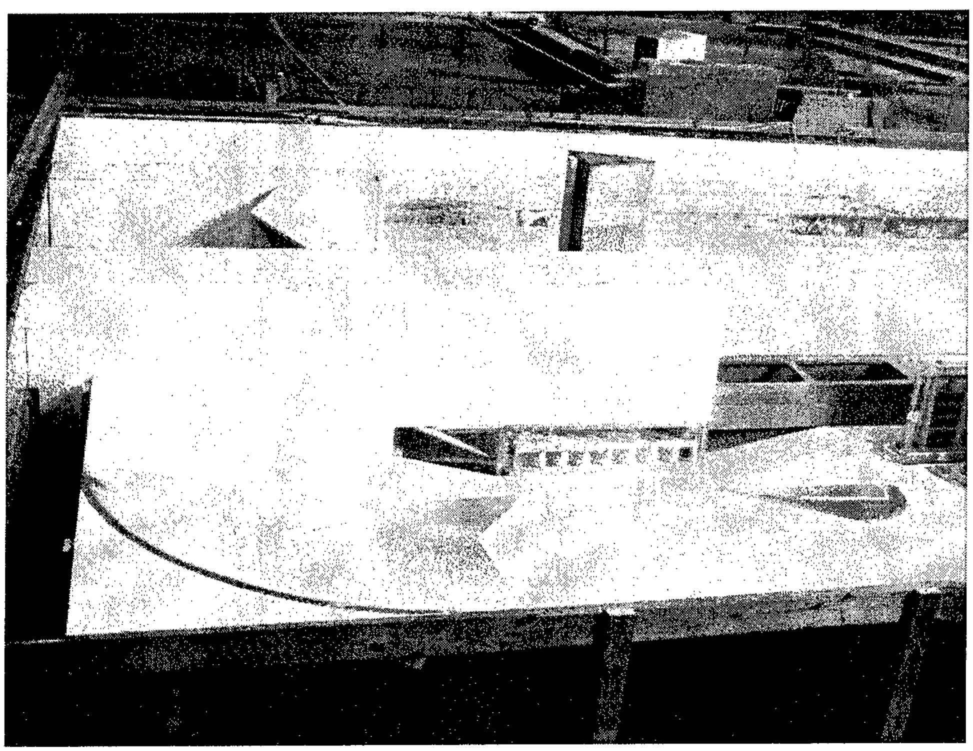
Description

The 1:25-scale model of the landside outlet reproduced a 600-ft-width and 1,500-ft-length of the lower approach beginning at the emptying valve for the downstream filling and emptying system. The model included the reverse tainter valve for emptying, the lock culvert between the emptying valve and outlet, the landside outlet diffuser and portions of the lower approach topography.

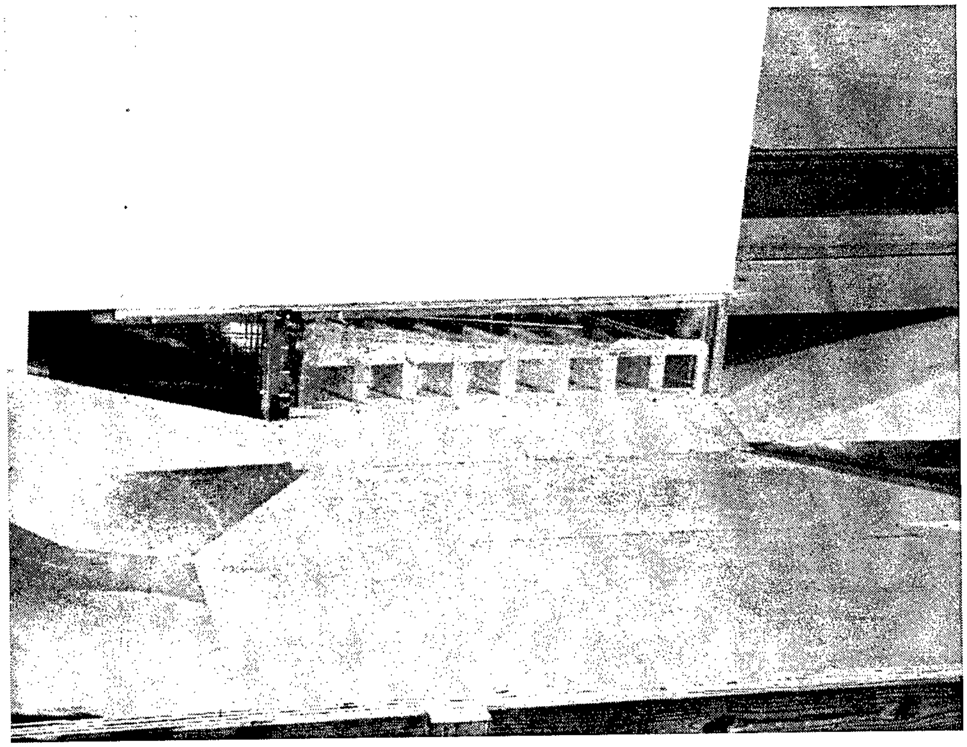
Photographs of the outlet model are shown in Figure 3. To simulate emptying operations in this model, the emptying valve was operated to reproduce the discharge hydrographs for various valve operations. These hydrographs were obtained from the filling and emptying model results. The laterals in the lower half of the chamber discharge back into a landside culvert that connects the landside outlet diffuser. The model layout is shown in Plate 1. Details of the original design diffuser, type 1 design, evaluated by Hite and Crutchfield (2004) are provided in Plates 2 and 3. The type 1 design diffuser was a converging manifold type with eight ports 7-ft high by 4.5-ft wide. The jets from the ports discharged normal to the landside bank. The type 2 design outlet diffuser was the first design evaluated in the outlet model. This design shown in Plate 4 was similar to the type 1 design in size. The vanes within the diffuser were angled downstream to direct the jet flow in this direction.



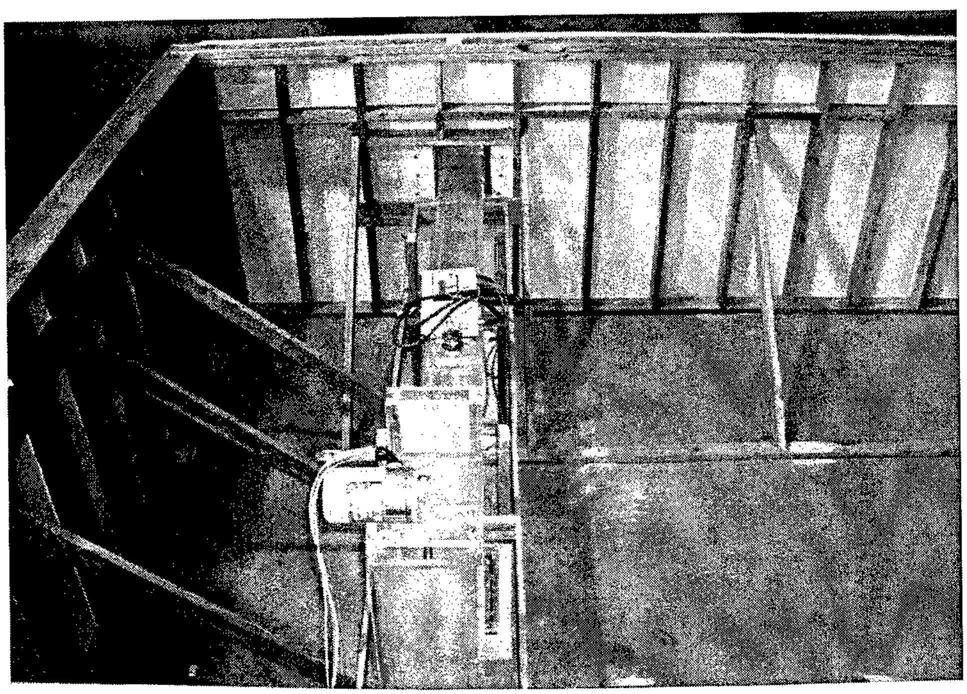
a. View looking upstream of lower approach to locks
Figure 3. 1:25-scale section model of outlet (Sheet 1 of 4)



b. View of outlet area
Figure 3. (Sheet 2 of 4)



c. Close-up view of outlet diffuser
Figure 3. (Sheet 3 of 4)



d. Emptying valve and culvert
Figure 3. (Sheet 4 of 4)

Appurtenances and Instrumentation

Water was supplied to the model through a circulating system. The lower pool was maintained at near constant elevations during the emptying operations using a long horizontal weir at the end of the flume. A constant head skimming weir was used upstream from the outlet diffuser to provide a discharge source. A paddle wheel type flow meter was calibrated in a separate facility to insure proper working condition. The meter was then installed in the culvert upstream from the emptying valve and the relationship between culvert discharge and gate opening was established. Knowing this relationship, the correct emptying hydrographs could be reproduced using the emptying valve. Water-surface elevations inside the lower approach model were determined using point gauges. Dye and confetti were used to study subsurface and surface current directions. Small, near neutrally buoyant, beads were used to help evaluate sediment deposition tendencies.

An automated data acquisition and control program, Lock Control[1] was used to control the valve operation and collect strain gauge data for the hawser force measurements. Four data channels were used, one for control of the emptying valve and three for collecting strain gauge information. The data were usually collected at a sampling rate of 10 Hz.

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 4. 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 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 personal computer.

[1] Written by Dr. Barry W. McCleave, Information Systems Development Division, Information Technology Laboratory, ERDC.

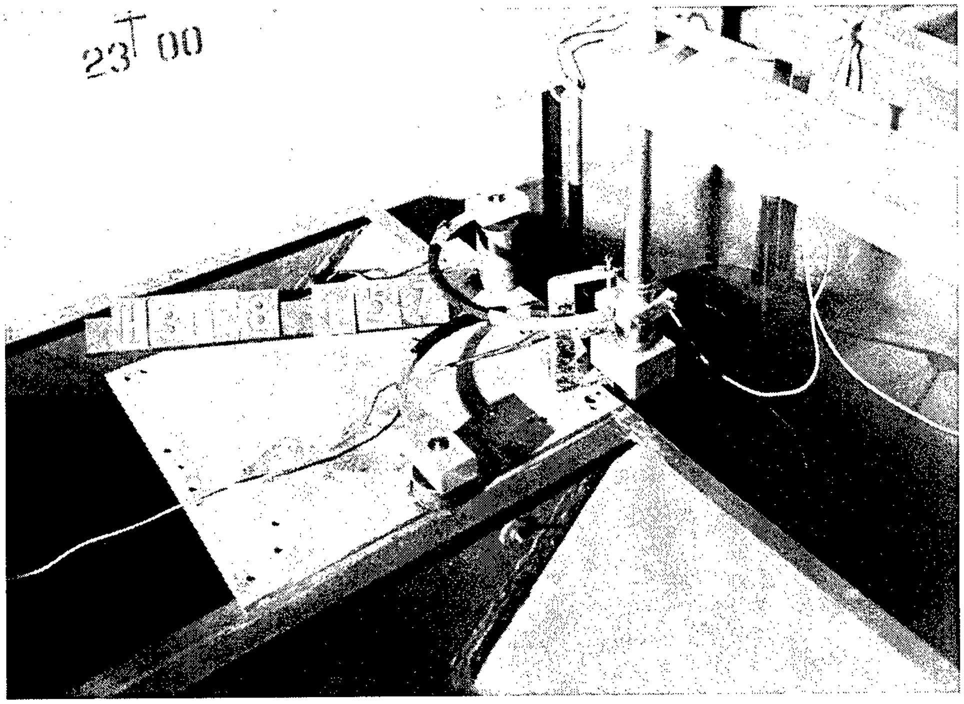


Figure 4. Hawser-pull (force links) measuring device

Similitude Considerations

Kinematic similitude

Kinematic similarity can be used for modeling free-surface flows in which the viscous stresses are negligible. Kinematic similitude requires that the ratio of inertial forces ($\rho V^2 L^2$) to gravitational forces ($\rho g L^3$) in the model are equal to those of the prototype. Here, ρ 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 flow conditions in the lower lock approach included measuring hawser forces on moored barges during emptying operations. These hawser forces are generated primarily by slopes in the water surface.

Dynamic similitude

Modeling of forces is a significant purpose of the laboratory investigation. Appropriate scaling of viscous forces requires the model 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

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

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

Similitude for models

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 (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 model-to-prototype comparisons. Setting the model and prototype Froude numbers equal results in the relations between the dimensions and hydraulic quantities in the following tabulation:

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 lock outlet was based on observation of flow conditions in the vicinity of the outlet, sediment deposition tendencies, energy dissipation achieved by the outlet basin, and hawser forces experienced by tows moored in the lower approach. Experiments were conducted to investigate these conditions and obtain velocity and hawser forces measurements.

3 Model Experiments and Results

Velocities with Type 2 Lower Approach

Experiments with the type 2 lower approach were performed in the filling and emptying model, Hite and Crutchfield (2004). The lower approach was designated type 2 since it was modified from the topography originally placed in the filling and emptying model. No data were collected with the original design topography. The type 2 lower approach was reproduced in the outlet model, Plate 1, and a close-up of the design is shown in Plate 5. Velocity measurements were obtained at selected locations to help evaluate the flow patterns in the vicinity of the outlet area. The measurements were made with an upper pool el[1] of 342 and a lower pool el of 324 (18-ft lift). The upper pool was maintained at el 342 by opening the upper miter gates with the upper filling valves closed and the emptying valves open. This provided the maximum velocities that could occur during an emptying operation.

The velocity measurements obtained with the 18-ft lift are shown in Plate 6. The highest velocity measured was 10.1 ft /sec in the middle of the apron at the diffuser outlet. The dimensions of the apron were 20 ft wide by 84.5 ft long and the invert el was 286. Since this area was subjected to the jet flow discharging from the outlet diffuser during emptying, a concrete structure is recommended. The flow in this area was highly turbulent as seen by a wide range in the velocity magnitudes and directions in Plate 6. The velocity measurements were obtained approximately 1 ft off the bottom.

Due to the configuration of the model (the model cutoff wall just upstream from the diffuser), a concentrated eddy formed on the upstream side of the diffuser from the jets discharging from the upstream ports. The jets discharging from the middle of the diffuser were directed upward and outward at the end of the apron with some of the flow contributing to the eddy on the upstream side and the remaining flow spreading out in a downstream direction. High velocity flow occurred near the water surface at the top of the landside bank line. A velocity of 8.6 ft/sec was measured near the top bank approximately 400 ft downstream from the diffuser. A velocity of 5.5 ft/sec was measured near the top

[1] All elevations (el) cited herein are in feet referenced to the National Geodetic Vertical Datum. To convert feet to meters, multiply number of feet by 0.3048.

bank 800 ft downstream from the diffuser. The velocity of the flow along the bottom at the toe of the landside bank was low (1 to 2 ft/sec).

Type 2 Design Outlet

The outlet diffuser was modified in an effort to distribute more flow along the floating guide wall and direct the flow in a downstream direction. The velocities along the wall near the bottom were around 1 ft/sec and higher velocities were preferred in this area to help reduce sediment deposits. Due to time restraints in the filling and emptying model, the type 2 outlet diffuser and lower approach were installed in another separate flume (Figure 3 and Plate 1) and experiments were continued.

The type 2 design outlet shown in Plate 2 was developed to replace the original design. The ports were angled (45 deg from the bank) in an effort to direct the outlet discharge in a downstream direction. This should help distribute the flow better in the area between the landside floating wall and bank and could also help prevent excessive sediment deposition near the floating wall. The beginning of the floating guide wall was also moved to the end of the outlet diffuser monolith to eliminate the presence of a floating wall over the outlet.

Bottom velocities were obtained with the type 2 design outlet and are shown in Plate 7. The velocities were measured with a steady flow and represented the maximum discharge that occurs during an emptying operation with a 2-min valve. The velocities near the top bank were reduced from those measured with the previous design and were higher near the toe of the bank. This indicated the flow was spreading out better, although there was no significant change in the bottom velocities between the toe of the bank and the floating wall. A fairly strong eddy still occurred upstream from the outlet between top bank and the outlet diffuser monolith wall.

Type 3 Design Outlet

A single row of baffle blocks was placed in the outlet basin to break up the discharging jets and aid in the energy dissipation. The blocks were 4 ft high by 4.5 ft wide with a tapered downstream side. The face of the blocks was located 10 ft from the face of the outlet ports. Bottom velocities measured with this design showed the blocks helped reduce the bottom velocities along the water's edge and also prevented the strong jet flow from reaching the water's edge.

Type 4 Design Outlet

Vertical vanes were placed in the basin to try and provide more flow along the floating guide wall. The vanes began in the basin at el 286 and tapered to el 300. The vanes helped direct more flow into the area between the bank and floating wall. The highest velocities along the bottom were measured where the walls tied into el 300. Surface, middepth and bottom velocities were obtained with this design to determine the depth wise distribution of flow. The velocities shown in Plate 8 indicated the highest velocities measured in the area between the floating wall and the sloping bank, occurred at the toe of the bank. The velocities in the lower approach did not show any large changes with depth.

Type 5 Design Outlet

A single row of baffle blocks was placed in the basin along with the vertical vanes. This design was designated the type 5 design outlet. Velocities measured at the bottom, middepth, and surface (Plate 9) revealed there was a slight reduction in velocity at the bottom and surface where the vanes tied into el 300. The velocities measured at the downstream riverside of the outlet basin were in the upstream direction.

Types 6 and 7 Design Outlet

The last downstream port in the diffuser was modified to direct the discharge from this port downstream. The face of this port, which was previously flush with the outlet monolith, was extended so that the face was pointed downstream to direct more flow parallel to the floating guide wall. Velocities were measured with the modified port and with the vertical vanes (type 6 design outlet shown in Plate 10) and with the vertical vanes and baffle blocks (type 7 design outlet shown in Plate 11). There was a slight increase in the velocities in the middle of the area between the bank and the floating wall with these two designs, however there was a significant increase in the bottom velocity near the floating wall where the basin transitioned to el 300. With the type 6 design outlet, the velocity was 11.2 ft/sec compared to 2.1 ft/sec with the type 4 design outlet. Likewise, the velocity measured at this location with the type 7 design outlet was 11.5 ft/sec compared to 2.1 ft/sec with the type 5 design outlet. These high velocities were not desired in this area.

Type 3 Lower Approach

For many of the designs evaluated, the bottom velocities measured where the basin transitioned to el 300 were higher than desired. The basin size was increased from 20 ft wide by 84.5 ft long to 100 ft wide by 164.5 ft long to allow more space for energy dissipation. The bank was reshaped to accommodate this size basin. Based on the results of navigation experiments performed concurrently in the 1:100-scale navigation model, the length of the floating guide wall was also reduced to 400 ft. These modifications were designated the type 3 design lower approach and are shown in Plate 12.

Type 8 Design Outlet

The outlet design with the type 3 lower approach was designated the type 8 design outlet due to the increased basin size. The bottom velocities were higher than desired (Plate 13), and eddies were observed both upstream and downstream from the outlet diffuser. The jet flow from the outlet tends to run up the slope from el 286 to el 300 at the outer downstream corner of the basin causing higher velocities along the bank and eddies.

Type 9 Design Outlet

Two rows of baffle blocks and a vertical wall were installed in the basin as shown in Plate 14. These modifications were employed to break up the jet flow and confine the energy dissipation to an area closer to the outlet. These modifications reduced the magnitude of the velocities on the bank as well as in the upstream eddy. The size of the upstream eddy was still much larger than desired although the magnitude of the velocities was less than the type 8 design outlet. Velocities measured with the type 9 design outlet are shown in Plate 15.

Type 10 Design Outlet and Type 4 Lower Approach

The bank was modified to reduce the size of the upstream eddy observed with the types 8 and 9 design outlets. This modification, designated the type 4 lower approach, is shown in Plate 16. The outlet was also designated the type 10 design outlet since the shape of the basin was modified. The size of the eddy was reduced and the velocity measurements shown in Plate 17 indicate the magnitude of the highest velocity in the eddy was reduced slightly (from 5.1 to 4.9 ft/sec). Overall, the flow direction was improved with the type 10 design outlet and the type 4 lower approach.

Water-Surface Measurements Near Floating Wall

During the outlet operation, the water surface near the floating wall was observed to rise above the lower pool elevation. Maximum water- surface measurements were made during the emptying operation on each side of the floating wall at 12.5 ft downstream from the outlet monolith and 12.5 ft upstream from the end of the floating wall. These measurements, listed in Table 1, show that the water-surface rises about 0.4 ft above the lower pool elevation at the location near the outlet monolith and 0.3 ft above the lower pool near the end of the floating wall. Time-histories were not obtained.

Table 1
Maximum Water-Surface Elevations, Across Floating Guide Wall, Type 10 Design Outlet, 2-Min Empty Valve, Upper Pool el 342, Lower Pool el 324

Landside	Riverside
12.5 ft Downstream from End of Outlet Monolith	
324.4	324.4 ft NGVD
12.5 ft Upstream from End of Floating Wall	
324.3	324.3 ft NGVD

Scour Experiments

An experiment was performed next to help determine the size stilling basin required to adequately dissipate energy and contain the highly turbulent flow from the outlet. The velocities measured with the type 10 design outlet basin indicated the baffle blocks were working well and no jet type flow was observed in the lower approach. Sand was placed in the model up to el 289 as shown in Plate 18. The area in the vicinity of the basin was observed after three consecutive tests with a 2-min emptying valve and the type 10 design outlet. The main area of scour occurred just downstream from the basin as outlined in the bottom schematic in Plate 18. The test indicated if the area enclosed by the end sill was increased slightly, the scour could probably be reduced.

Types 11 and 12 Design Outlets

The downstream basin wall was aligned the same as the upstream basin wall to form the type 11 design outlet shown in the middle of Plate 18. The vertical end sill was replaced with one having a sloping upstream face. A 2-min emptying valve was run for five consecutive times and the amount of scour from these operations was observed. The extent of the scoured area was reduced from that observed with the type 10 design outlet. The location of the maximum scour depth is shown in Plate 18. The downstream corner of the basin was modified as shown in Plate 18 to form the type 12 design outlet. Again, a 2-min emptying valve was run for five consecutive times and the amount of scour from these operations was observed. The scoured area was larger than the scoured area with the type 11 design outlet. A pocket of scour occurred along the wall where the modification was made. The type 11 design outlet performed better than the type 12 design outlet so this design was placed back in the model for evaluating the size riprap needed in the vicinity of the basin.

Riprap Experiments

Type 1 riprap design

A plan view of the type 1 riprap design is shown in Plate 19. The design was based on a velocity over the end sill of 6 ft/sec and the Hydraulic Design Criteria (HDC) (HQUSACE 1988) for riprap placed in the dry for highly turbulent flow. A d_{50} size stone of 6 in. with a blanket thickness of 18 in. was placed on top of a thin layer of sand and separated using a filter cloth. The limits of the riprap gradation from Engineer Manual 1110-2-1605 (HQUSACE 1987) and the gradation used in the model are shown in Plate 20. The stability of the design was evaluated after three consecutive 2-min emptying valve operations. No movement was detected. The model was then allowed to run steady with the maximum discharge with a 2-min emptying valve for 15-min model time (equivalent to 1 hr and 15-min prototype time). The filter cloth was exposed in the two areas shown in Photo 1. This type of operation is not expected to occur; however, since this size stone was small, additional experiments were performed with a larger gradation.

Photo 1. Exposure of filter cloth after experiments with type 1 riprap

Type 2 riprap design

The type 1 riprap located 15 ft immediately adjacent to the basin was replaced with larger riprap. This plan was designated the type 2 riprap design shown in Plate 21 and the gradation for this design is shown in Plate 22. The d_{50} size stone was 9 in. and the blanket thickness was increased to 2 ft. The model was run steady with the maximum discharge from a 2-min emptying valve operation for 20-min model time (equivalent to 1 hr and 40-min prototype time). After 15 min of operation, slight movement of some of the smaller stones was observed; however, no filter cloth was exposed. This design was considered stable for this type of operation. The eddy upstream from the basin tended to concentrate with steady flow causing higher velocities that would not occur with normal empty operations.

Velocities were measured in the lower approach with the type 11 design outlet and the type 2 riprap design (Plate 23). The lower pool elevation was 324 and the discharge was the maximum that occurs during a 2-min emptying valve operation. The velocities near the bottom between the toe of the bank near the edge of the water surface ranged from 2.6 to 5.1 ft/sec. The velocities measured between the floating wall and toe of the bank were low and were around 1 ft/sec. These velocities were not excessive and the type 2 riprap design should protect the banks in the vicinity of the outlet.

Lower Approach Experiments with Floating Wall

Experiments were performed next to evaluate the conditions in the lower approach with the unsteady flows that occur during lock emptying. Sediment deposition tendencies, flow patterns, velocities, and hawser force measurements were evaluated for various emptying valve operations.

Sediment deposition tendencies

Qualitative tests were performed with small neutrally buoyant beads to observe where they would settle in the lower approach after emptying valve operations. The first experiment was performed with the beads placed within the outlet basin as shown in Photo 2. A 2-min emptying valve operation was performed with upper pool el 342 and lower pool el 324. The model was then slowly drained to avoid disturbing the beads that deposited in the lower approach. Beads were observed on the landside of the floating wall near the upstream end of the wall. The beads did not appear to deposit underneath the floating wall. The position of the beads after the model was drained is shown in Photo 3. Deposition occurred along the toe of the slope at the upstream edge of the riprap protection and in the lower approach between the floating guide wall and the toe of the slope.

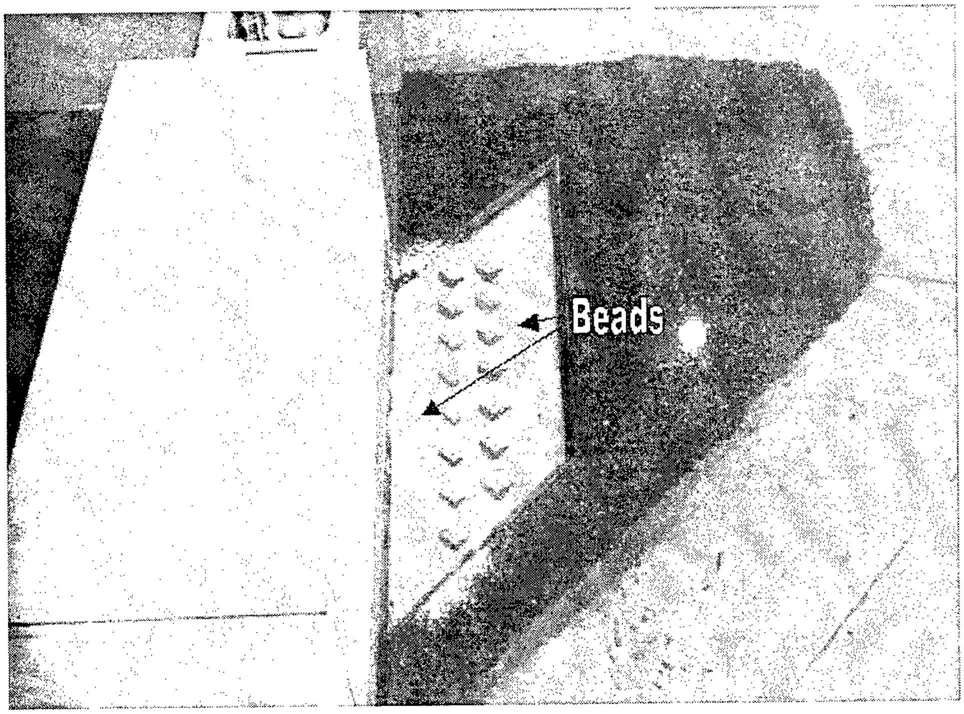


Photo 2. Initial placement of beads for floating wall experiments

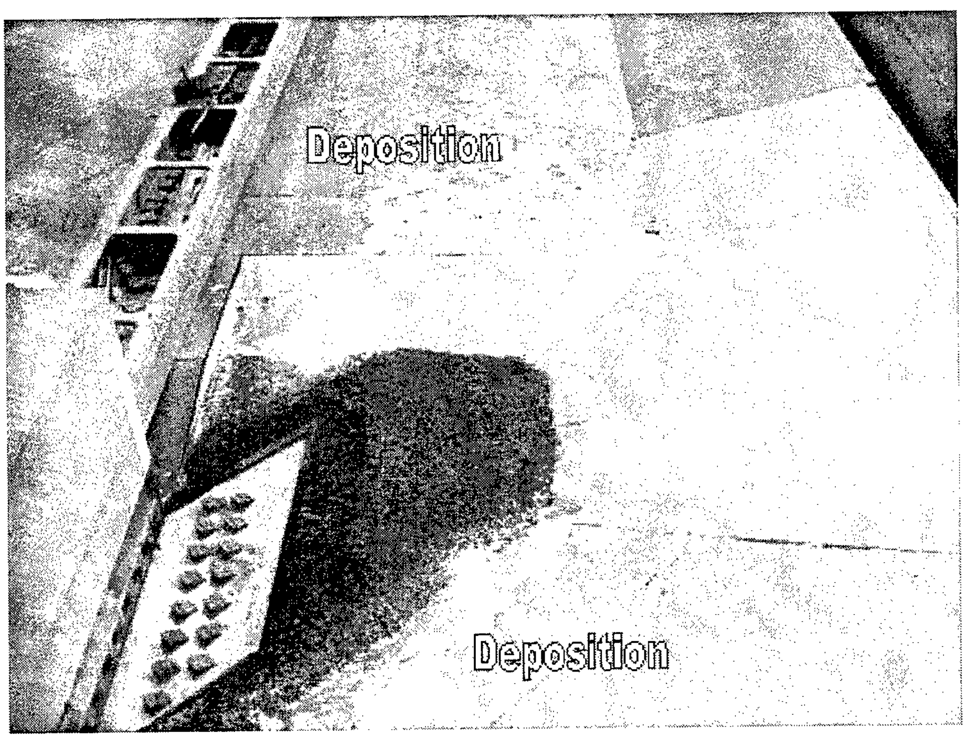


Photo 3. Deposition after initial experiment with floating wall

Another experiment was performed with the beads initially placed in the emptying valve well instead of the basin as shown in Photo 4. Most of the beads deposited in similar locations to the previous experiment as shown in Photo 5.

Since not all the beads were recovered from the initial experiment, the quantity of deposition was reduced. The most likely location for the sediment to deposit near the floating guide wall is shown in Photo 6. This area is adjacent to the vertical wall that exists along the sloping section between the basin (el 286) and the lower approach (el 300). A few beads were observed near the wall at el 300 and more deposition was observed at the base of the vertical transition.

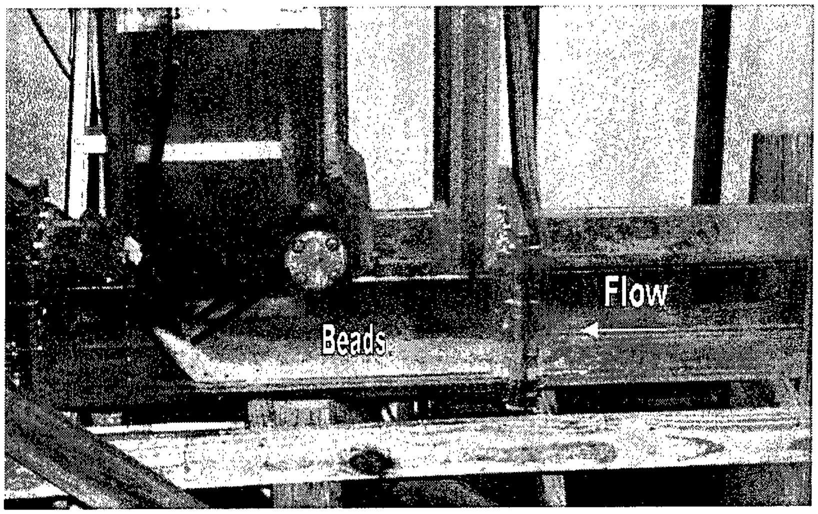


Photo 4. Initial placement of beads in valve well

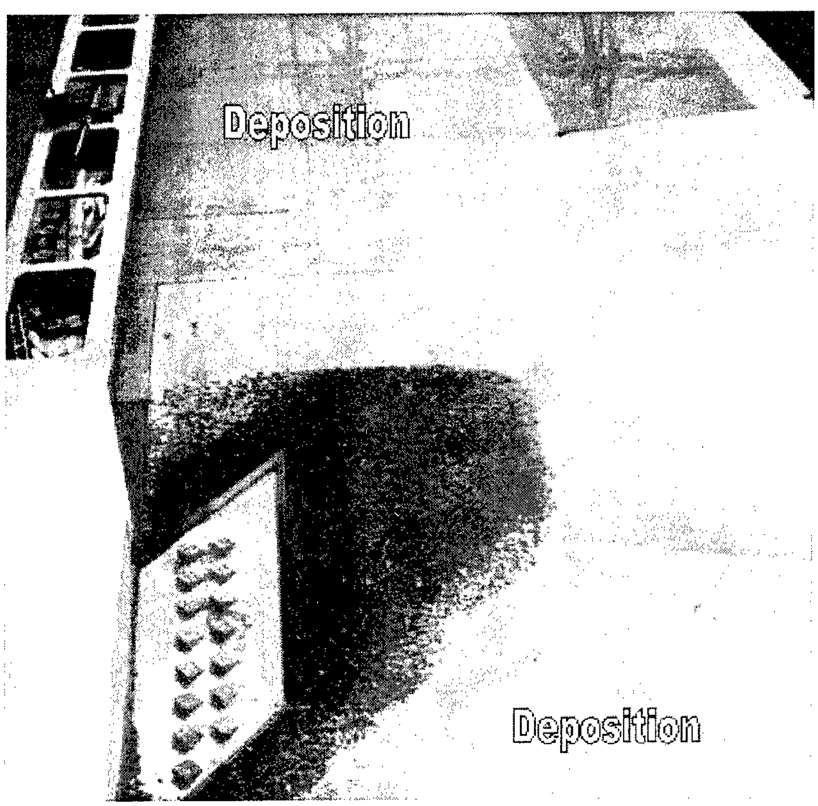


Photo 5. Deposition after initial placement in emptying valve well

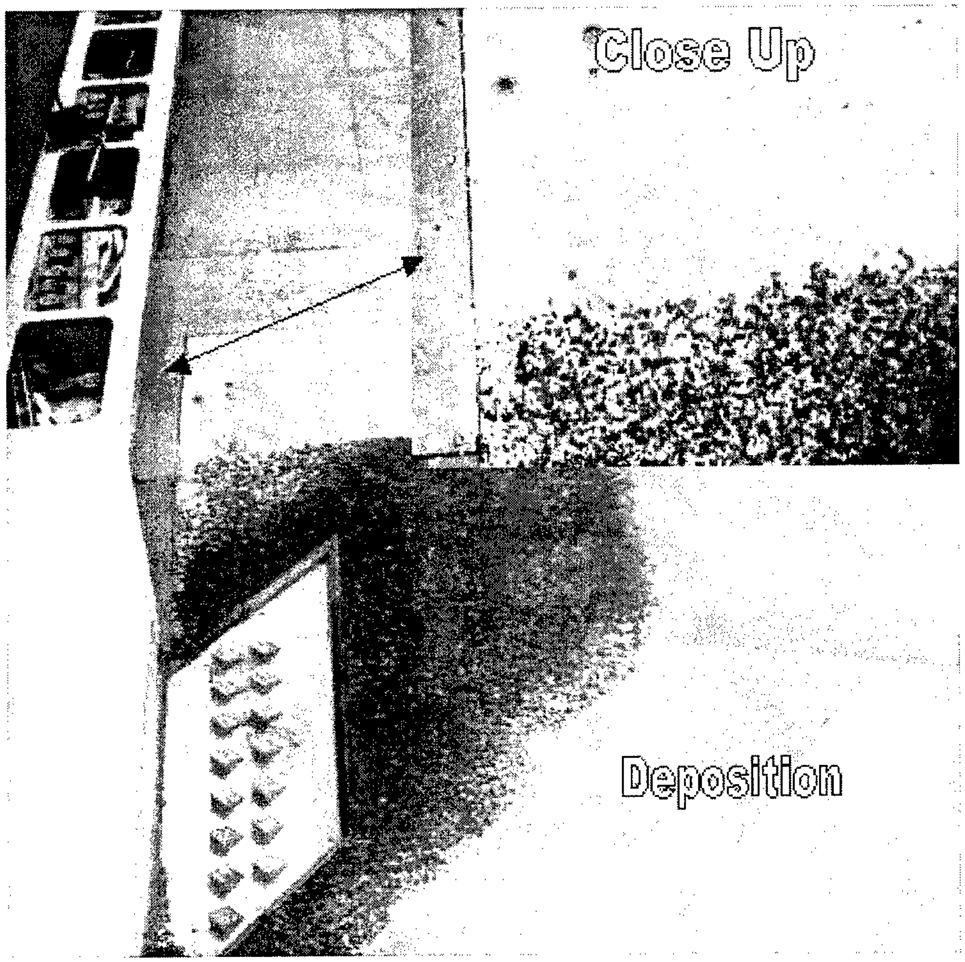


Photo 6. Deposition near floating wall

The beads indicated that deposition of material from the outlet should be expected along the slope just upstream from the upstream edge of the riprap and in the lower approach between the floating wall and the toe of the bank slope as indicated in Photos 3 and 5. Some deposition is likely to occur under the floating guide wall near the upstream end of the wall.

Velocity measurements with unsteady flow

Additional velocity measurements were made in the lower approach during the unsteady conditions that occur during emptying operations. The locations chosen for observation were those where higher velocities were observed during the steady flow releases from the outlet. The measurements were made 1 ft off the bottom and are shown in Plate 24. The values shown are the maximum that occurred during the 2-min emptying valve operation. A maximum velocity of 2.8 ft/sec was measured near the top of the right bank and compares to 4.9 ft/sec measured at this location with steady flow (Plate 23). During the unsteady conditions, the flow does not have time to establish a dominant pattern and therefore the velocities along the bank are not as high. The upstream velocity along the bank shown in Plate 24 is higher than the measurement downstream indicating the presence of the eddy that was also observed during the steady flow measurements. This velocity, 3.9 ft/sec, was lower than the 5 to 6 ft/sec velocities measured with steady flow. These measurements indicate that the type 2 riprap design placed on the banks should remain stable for flow conditions with upper pool el 342, lower pool el 324, and a 2-min emptying valve.

Hawser force experiments

Hawser forces were measured on a 3-wide by 5-long barge arrangement moored at three locations in the lower approach. The upstream end of the barges was located 100 ft downstream from the lower pintle of the landside lock for location 1 and 200 ft downstream from the lower pintle for location 2 (Plate 25). The barges were moored on the river wall as shown in Plate 25 for location 3. The hawser forces were measured using the hawser ring technique described in Hite and Crutchfield (2004). The longitudinal hawser force and both the upstream and downstream transverse forces were measured. Time-histories of these forces were obtained for 1-, 2-, and 5-min valve operations.

Hawser force measurements, location 1. Typical time-histories obtained with a 1-min valve are shown in Plate 26. Transverse hawser forces above 0 are those that would move the barges to the right side of the lower approach (looking downstream) and those hawser forces below 0 are those that would move the barges to the left side of the lower approach. Longitudinal hawser forces above 0 are those that would move the barges upstream and those below 0 would move the barges downstream. The highest force measured was the upstream transverse hawser force toward the right side of the lower approach, the middle time-history in Plate 26, and occurred just after the emptying valve was completely open. The discharge from the outlet diffuser was near maximum just after the valve was completely open. A higher velocity occurred on the landside of the floating guide wall due to the outlet discharge. This caused the water surface on the landside to drop slightly during the initial portion of the emptying operation. The drop in water surface drew the upstream barges toward the floating guide wall. Later in the emptying operation after the valve opened, the velocities on the landside of the floating wall began to reduce, the water surface began to rise, and the upstream barges moved to the left side of the lower approach. About 3 min after the valve operation was begun, the hawser forces were small.

Typical time-histories with 2- and 5-min emptying valve operations are also shown in Plate 26. Similar trends were observed with these valve operations. The upstream transverse forces were the highest measured although all maximum hawser forces were less than 5 tons. A list of the maximum values of the hawser forces measured at location 1 is provided in Table 2 and a plot of the average maximum hawser forces measured for the 1-, 2-, and 5-min emptying valve operations is shown in Plate 27. The plot shows the highest forces measured were the upstream right transverse hawser force.

Table 2
Hawser Force Measurements, Lower Approach, 400-ft Floating Guide Wall, Location 1, 18 ft-Lift, Upper Pool el 342.0, Lower Pool el 324.0

	Hawser Force, tons					
	Longitudinal		US Transverse		DS Transverse	
Valve Time (min)	US	DS	Right	Left	Right	Left
1.0	4.5	-3.3	5.4	-5.3	1.6	-3.2
	4.1	-2.9	5.8	-5.1	1.9	-3.2
	4.2	-3.4	5.6	-5.5	2.2	-3.0
Average	**4.3**	**-3.2**	**5.6**	**-5.3**	**1.9**	**-3.1**
2.0	2.7	-2.8	4.8	-4.5	1.9	-2.3
	2.5	-2.0	4.1	-4.7	1.2	-2.0
	2.2	-2.0	4.4	-4.6	1.0	-1.5
Average	**2.5**	**-2.3**	**4.4**	**-4.6**	**1.4**	**-1.9**
5.0	1.3	-1.6	2.1	-2.6	0.9	-1.2
	1.3	-1.7	1.9	-3.0	0.6	-1.1
	1.4	-1.5	2.1	-2.6	0.5	-1.4
Average	**1.3**	**-1.6**	**2.0**	**-2.7**	**0.7**	**-1.2**

Hawser force measurements, location 2. The upstream end of the barges was moved 100 ft farther downstream and this position was designated location 2. The hawser force measurements were repeated at location 2. Typical time-histories with 1-, 2-, and 5-min valve operations are shown in Plate 28. Table 3 provides the maximum values measured at location 2 and Plate 29 shows a plot of the average maximum hawser forces. The downstream longitudinal hawser forces were the highest forces measured with the barges moored at location 2.

Table 3
Hawser Force Measurements, Lower Approach, 400-ft Floating Guide Wall, Location 2, 18-ft Lift, Upper Pool el 342.0, Lower Pool el 324.0

	Hawser Forces (tons)					
	Longitudinal		US Transverse		DS Transverse	
Valve Time (min)	US	DS	Right	Left	Right	Left
1.0	5.3	-8.5	1.5	-3.5	1.0	-2.3
	5.6	-7.0	1.6	-2.8	1.1	-1.4
	5.6	-7.2	1.3	-2.9	1.2	-1.7
Average	**5.5**	**-7.6**	**1.5**	**-3.1**	**1.1**	**-1.8**
2.0	4.8	-6.0	1.1	-1.9	0.9	
	5.0	-5.6	1.0	-1.8	1.1	-1.3
	5.1	-5.6	1.1	-1.8	0.9	-1.0
Average	**5.0**	**-5.7**	**1.1**	**-1.8**	**1.0**	**-1.1**
5.0	2.2	-3.1	1.6	-2.1	2.9	-0.6
	2.7	-2.8	0.9	-1.5	1.2	-0.8
	2.4	-2.6	0.6	-1.2	0.5	-0.8
Average	**2.4**	**-2.8**	**1.0**	**-1.6**	**1.5**	**-0.8**

Hawser force measurements, location 3. The upstream end of the barges remained the same longitudinal distance from the lower pintle of the landside lock and the entire barge group was placed on the river wall for location 3. The hawser forces were then measured for this location. Typical time-histories with 1-, 2-, and 5-min valve operations are shown in Plate 30. Table 4 provides a list of the maximum values measured and Plate 31 shows a plot of the average maximum hawser forces. The forces were similar in magnitude and direction to those measured at location 2. The downstream longitudinal hawser forces were the highest forces measured at location 3.

Table 4
Hawser Force Measurements, Lower Approach, 400-ft Floating Guide Wall, Location 3, 18-ft Lift, Upper Pool el 342.0, Lower Pool el 324.0

	Hawser Forces (tons)					
	Longitudinal		US Transverse		DS Transverse	
Valve Time (min)	US	DS	Right	Left	Right	Left
1.0	6.0	-6.7	1.4	-2.2	2.0	-2.1
	5.3	-6.3	1.7	-2.5	2.4	-1.8
	5.3	-6.7	1.4	-2.4	1.3	-2.2
Average	**5.5**	**-6.6**	**1.5**	**-2.4**	**1.9**	**-2.0**
2.0	4.8	-4.7	1.2	-1.1	1.8	-1.4
	5.1	-4.5	1.4	-1.1	2.0	-1.1
	5.1	-4.4	0.9	-1.4	1.6	-1.4
Average	**5.0**	**-4.5**	**1.2**	**-1.2**	**1.8**	**-1.3**
5.0	2.7	-2.2	0.8	-0.8	0.9	-0.9
	2.7	-2.4	0.9	-1.3	1.3	-1.9
	2.4	-2.4	0.8	-0.7	0.8	-1.0
Average	**2.6**	**-2.3**	**0.8**	**-0.9**	**1.0**	**-1.3**

Comparison of hawser forces with floating wall, locations 1-3. Comparison of the average maximum hawser forces measured with the type 11 outlet design and the floating guide wall are shown in Plate 32. The highest transverse hawser forces were measured at location 1 and the highest longitudinal hawser forces were measured at location 2. All hawser forces measured were less than 9 tons.

Type 5 Lower Approach

The lower guide wall design was changed from a floating wall to a 400-ft-long solid wall design as shown in Plate 33. This modification was designated the type 5 lower approach. The sediment deposition experiments were repeated with the solid guide wall to qualitatively determine areas of deposition. Velocity and hawser force measurements were also obtained for comparison with the results from the floating guide wall experiments.

Lower Approach Experiments with Solid Wall

Sediment deposition experiments with solid guide wall

The beads were placed within the outlet basin and a 2-min emptying valve operation was performed with an upper pool el of 342 and a lower pool el of 324. The model was then slowly drained to keep the deposited beads from moving. The position of the beads after the model was drained is shown in Photo 7. Deposition occurred in the vicinity of the riprap protection. An eddy formed between the solid guide wall and the bank downstream from the basin. The eddy caused the beads to deposit in the area downstream from the outlet near the guide wall. This eddy was slightly stronger than observed with the floating guide wall. Slightly more material may deposit in this area with the solid wall although most of the sediment deposition will probably result from spillway flows.

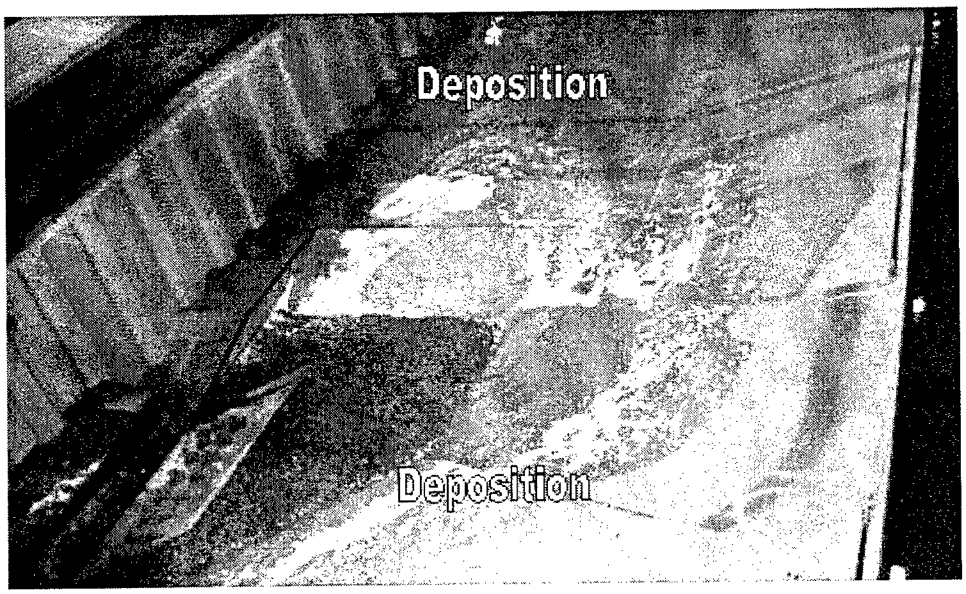


Photo 7. Deposition after initial experiment with solid guide wall

Velocity measurements with unsteady flow and solid guide wall

Velocity measurements were obtained in the lower approach for the 2-min valve operation with the solid guide wall in place. The maximum velocity that occurred at selected locations in the lower approach during an emptying operation with a 2-min valve operation was measured. Plates 34-36 show measurements made 1 ft off the bottom, the middepth, and 1 ft below the surface. The velocities in the lower approach were not excessive; however, the eddy on the landside of the solid guide wall was slightly stronger than observed with the floating guide wall.

Hawser force experiments with solid guide wall

Hawser force measurements with solid guide wall, location 1. Hawser forces were measured for barges moored in the same location as the floating guide wall (Plate 25) and the same emptying valve operations, 1, 2, and 5 min. Typical time-histories with a 1-min valve operation are shown in Plate 37 with the barges moored at location 1. The highest force, 7.3 tons, occurred on the left downstream transverse hawser at about the time the valve was completely open. Time-histories with a 2- and 5-min empty valve are also shown in Plate 37. The maximum hawser forces were less than 5 tons with the 2-min valve and were equal to or less than 2.5 tons with the 5-min valve. Table 5 lists the maximum values measured and Plate 38 provides a plot of the average maximum hawser forces for the solid guide wall with the barges moored at location 1.

Table 5
Hawser Force Measurements, Lower Approach, 400-ft Solid Guide Wall, Location 1, 18-ft Lift, Upper Pool el 342.0, Lower Pool el 324.0

	Hawser Forces (tons)					
	Longitudinal		US Transverse		DS Transverse	
Valve Time (min)	US	DS	Right	Left	Right	Left
1.0	5.7	-5.4	4.4	-4.6	6.5	-7.3
	5.5	-4.8	4.6	-4.8	6.2	-7.3
	5.5	-5.4	5.0	-4.8	6.3	-7.4
Average	**5.6**	**-5.2**	**4.7**	**-4.7**	**6.3**	**-7.3**
2.0	4.2	-4.6	4.0	-3.2	4.8	-4.4
	4.2	-4.3	3.8	-3.1	4.7	-4.2
Average	**4.2**	**-4.5**	**3.9**	**-3.2**	**4.8**	**-4.3**
5.0	1.3	-1.2	1.5	-1.6	2.0	-2.5
	1.1	-0.8	1.2	-1.3	1.6	-1.9
	1.0	-0.7	1.2	-1.2	1.9	-1.9
Average	**1.1**	**-0.9**	**1.3**	**-1.4**	**1.8**	**-2.1**

Hawser force measurements with solid guide wall, location 2. Typical time-histories with a 1-, 2-, and 5-min valve operations are shown in Plate 39 with the barges moored at location 2. The left upstream transverse hawser forces were higher at location 2 than at location 1 and the highest force, 7.0 tons, occurred on the left upstream transverse hawser with the 1-min valve. Table 6 provides the maximum values measured and Plate 40 shows a plot of the average maximum hawser forces for the solid guide wall with the barges moored at location 2.

Table 6
Hawser Force Measurements, Lower Approach, 400-ft Solid Guide Wall, Location 2, 18-ft Lift, Upper Pool el 342.0, Lower Pool el 324.0

	Hawser Forces (tons)					
	Longitudinal		US Transverse		DS Transverse	
Valve Time (min)	US	DS	Right	Left	Right	Left
1.0	4.7	-2.9	6.3	-7.0	4.7	-5.7
	4.6	-3.1	6.4	-7.0	4.6	-5.6
	4.2	-3.2	6.4	-6.9	4.7	-5.7
Average	**4.5**	**-3.1**	**6.4**	**-7.0**	**4.7**	**-5.7**
2.0	3.2	-3.0	4.7	-4.7	3.4	-3.2
	3.3	-2.6	4.6	-4.5	3.1	-3.3
Average	**3.3**	**-2.8**	**4.7**	**-4.6**	**3.3**	**-3.3**
5.0	1.0	-1.1	2.1	-1.8	1.5	-1.5
	0.9	-1.2	1.8	-1.7	1.3	-1.6
	0.9	-1.2	1.8	-1.8	1.3	-1.5
Average	**0.9**	**-1.2**	**1.9**	**-1.8**	**1.4**	**-1.5**

Hawser force measurements with solid guide wall, location 3. Typical time-histories with a 1-, 2-, and 5-min valve operations are shown in Plate 41 with the barges moored at location 3. The longitudinal hawser forces were the largest forces measured at location 3. The highest force, 6.6 tons, occurred on the upstream longitudinal hawser force with the 1-min empty valve operation. Table 7 provides the maximum values measured and Plate 42 shows a plot of the average maximum hawser forces for the solid guide wall with the barges moored at location 3.

Table 7
Hawser Force Measurements, Lower Approach, 400-ft Solid Guide Wall, Location 3, 18-ft Lift, Upper Pool el 342.0, Lower Pool el 324.0

	Hawser Forces (tons)					
	Longitudinal		US Transverse		DS Transverse	
Valve Time (min)	US	DS	Right	Left	Right	Left
1.0	6.6	-5.6	2.6	-2.1	2.7	-2.8
	6.0	-6.5	2.7	-2.1	2.5	-2.6
	6.1	-6.2	2.3	-2.1	2.3	-2.6
Average	**6.2**	**-6.1**	**2.5**	**-2.1**	**2.5**	**-2.7**
2.0	4.8	-4.6	2.7	-1.5	2.5	-1.6
	4.7	-2.4	2.1	-1.7	2.2	-1.5
	4.8	-4.6	2.8	-1.6	2.3	-1.5
Average	**4.8**	**-3.9**	**2.5**	**-1.6**	**2.3**	**-1.5**
5.0	1.1	-1.4	0.7	-0.7	0.8	-0.9
	1.0	-1.2	0.8	-0.7	0.7	-0.9
	1.3	-1.0	0.8	-0.5	1.2	-0.8
Average	**1.1**	**-1.2**	**0.8**	**-0.6**	**0.9**	**-0.9**

Comparison of hawser forces with solid guide wall, locations 1-3

A comparison of the average maximum hawser forces measured at the three locations for the solid guide wall is shown in Plate 43. The transverse hawser forces measured at location 1 with a 1-min empty valve were the largest of the conditions tested. The transverse hawser forces were higher at location 1 and 2 compared to location 3. The location of the barges did not significantly affect the longitudinal hawser forces.

Comparison of Hawser Forces with Floating and Solid Guide Walls

A comparison of the hawser forces measured at location 1 with the floating and solid guide walls is shown in Plate 44. Both the longitudinal and transverse hawser forces were higher with the solid wall for the 1- and 2-min empty valves. The hawser forces were similar with the 5-min empty valve. A comparison of the hawser forces at location 2 (shown in Plate 45) indicates the transverse hawser forces were higher with the solid wall and the longitudinal hawser forces were slightly higher with the floating wall. At location 3 (Plate 46), both the longitudinal and transverse forces were similar for the floating and solid guide wall.

4 Summary and Recommendations

The original design outlet for the lock extension project at J. T. Myers was evaluated and modified slightly to improve the flow patterns in the lower approach during emptying operations. The vanes in the diffuser manifold, type 2 design outlet diffuser (shown in Plate 4), were angled downstream to direct flow away from the right bank and an outlet basin containing two rows of baffle blocks and an end sill was added to improve energy dissipation. A riprap protection design, type 2 riprap design, was developed and is recommended in the vicinity of the outlet basin to prevent scouring of the channel invert. The type 2 riprap gradation was considered adequate for the bed and banks in the vicinity of the outlet. If a larger size gradation is easier to obtain, it will also work. A gradual reduction in size from the larger riprap to natural material is recommended to prevent excessive scour at the termination of the larger riprap.

Several combinations of outlet basin designs and bank geometries were investigated in addition to floating and solid guide walls. The stilling basin for a landside diffuser needs to be effective in energy dissipation to prevent scouring of the bed and banks. The type 11 design outlet which consisted of two rows of baffle blocks 4 ft high by 4.5 ft wide and a 3-ft-high sloping end sill surrounding the basin as shown in Plate 19 is recommended. The blocks and end sill were effective in breaking up the jets discharging from the outlet and preventing any strong concentrated flow in the lower approach during emptying. Other outlet designs evaluated worked satisfactory, but were considered more costly to construct. The bank was also reshaped to help reduce the size of the eddy that formed upstream from the outlet basin during emptying and direct the flow in the downstream direction.

Comparative experiments were performed with a 400-ft-long floating wall and a 400-ft-long solid wall. During emptying operations with the type 11 design outlet, eddies formed just upstream from the outlet and between the guide wall and the right bank. Sediment deposition experiments showed that if sediment is discharged from the outlet, it will likely deposit in the areas where the eddies occur. Slightly more sediment may occur with the solid guide wall since the eddy is stronger with this design. The most likely location for sediment to deposit with the floating wall is near the upstream end near the outlet. Sediment deposition should not be a problem from an outlet performance standpoint. Spillway flows will probably be the source of any sediment deposition problems. The outlet discharge should help keep the area in the vicinity of the outlet clean and tow traffic should help keep excessive sediment from depositing. However, the outlet discharges will probably not be strong enough to sweep all of the sediment out of the area between the guide wall and right bank since this area is so large.

There was not a significant difference in the flow patterns in the lower approach between the floating and solid guide walls. The hawser force experiments indicated the largest difference in the average maximum hawser forces between the floating and solid guide walls occurred with the transverse hawser forces at location 2 although these forces were not considered excessive. Either the floating guide wall or the solid guide wall will function as needed. The recommended design should be based on an economic evaluation.

References

Headquarters, U.S. Army Corps of Engineers. (1987). "Hydraulic design of navigation dams," EM 1110-2-1605, Washington, DC.

Headquarters, U.S. Army Corps of Engineers. (1988). "Hydraulic design criteria," 18th edition, Washington, DC.

Hite, J. E., Jr., and Crutchfield, J. P. (in preparation). "J. T. Myers lock filling and emptying system, Ohio River," Technical Report ERDC/CHL TR-04-X, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

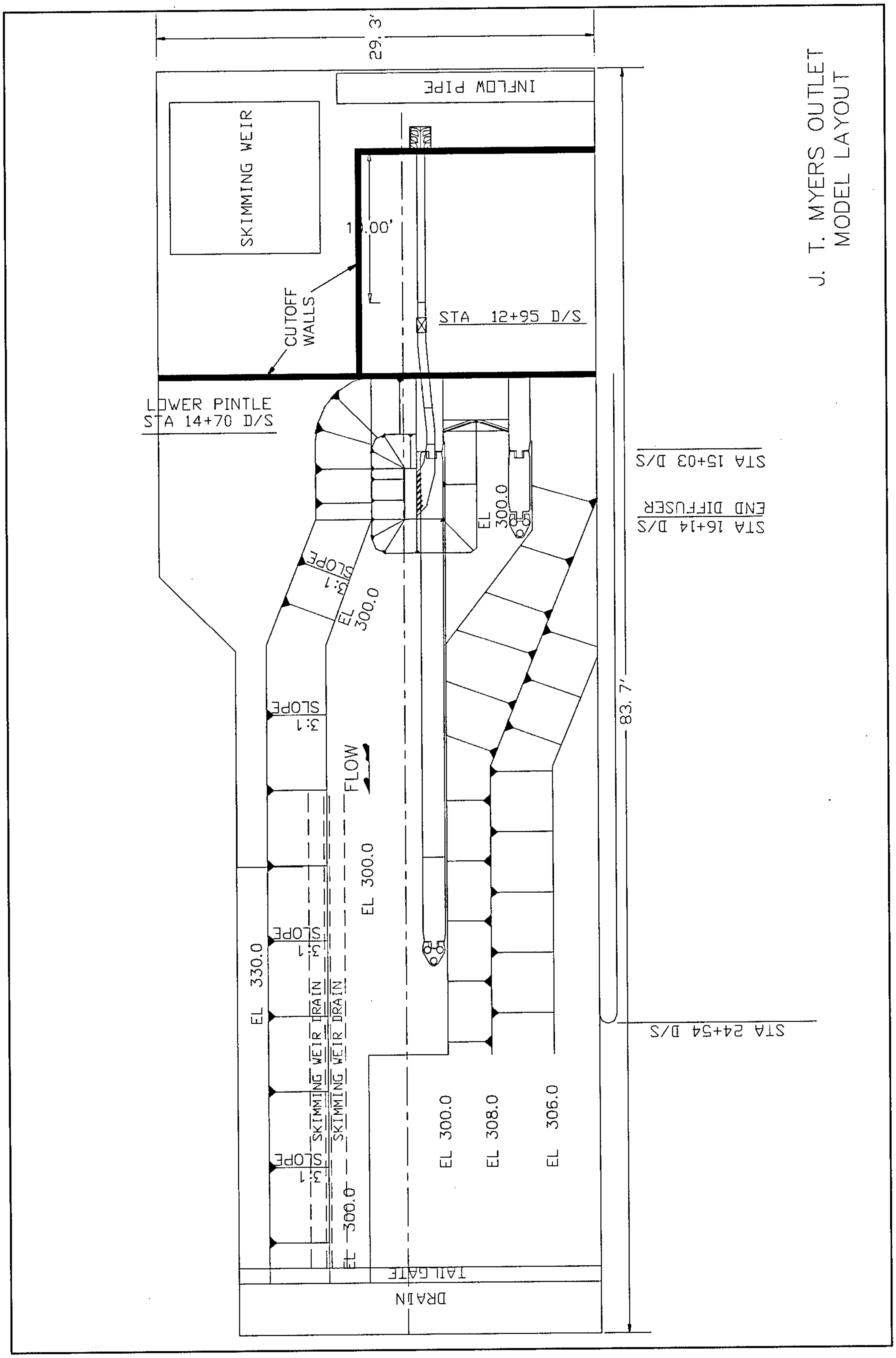

J. T. MYERS OUTLET
MODEL LAYOUT
29.3'
INFLOW PIPE
SKIMMING WEIR
10.00'
CUTOFF WALLS
STA 12+95 D/S
LOWER PINTLE
STA 14+70 D/S
STA 15+03 D/S
END DIFFUSER
STA 16+14 D/S
EL 300.0
SLOPE
3:1
EL 300.0
SLOPE
3:1
FLOW
83.7'
EL 300.0
SLOPE
3:1
EL 330.0
SKIMMING WEIR DRAIN
SKIMMING WEIR DRAIN
STA 24+54 D/S
EL 300.0
EL 308.0
EL 306.0
SLOPE
3:1
EL 300.0
TAILGATE
DRAIN

Plate 1

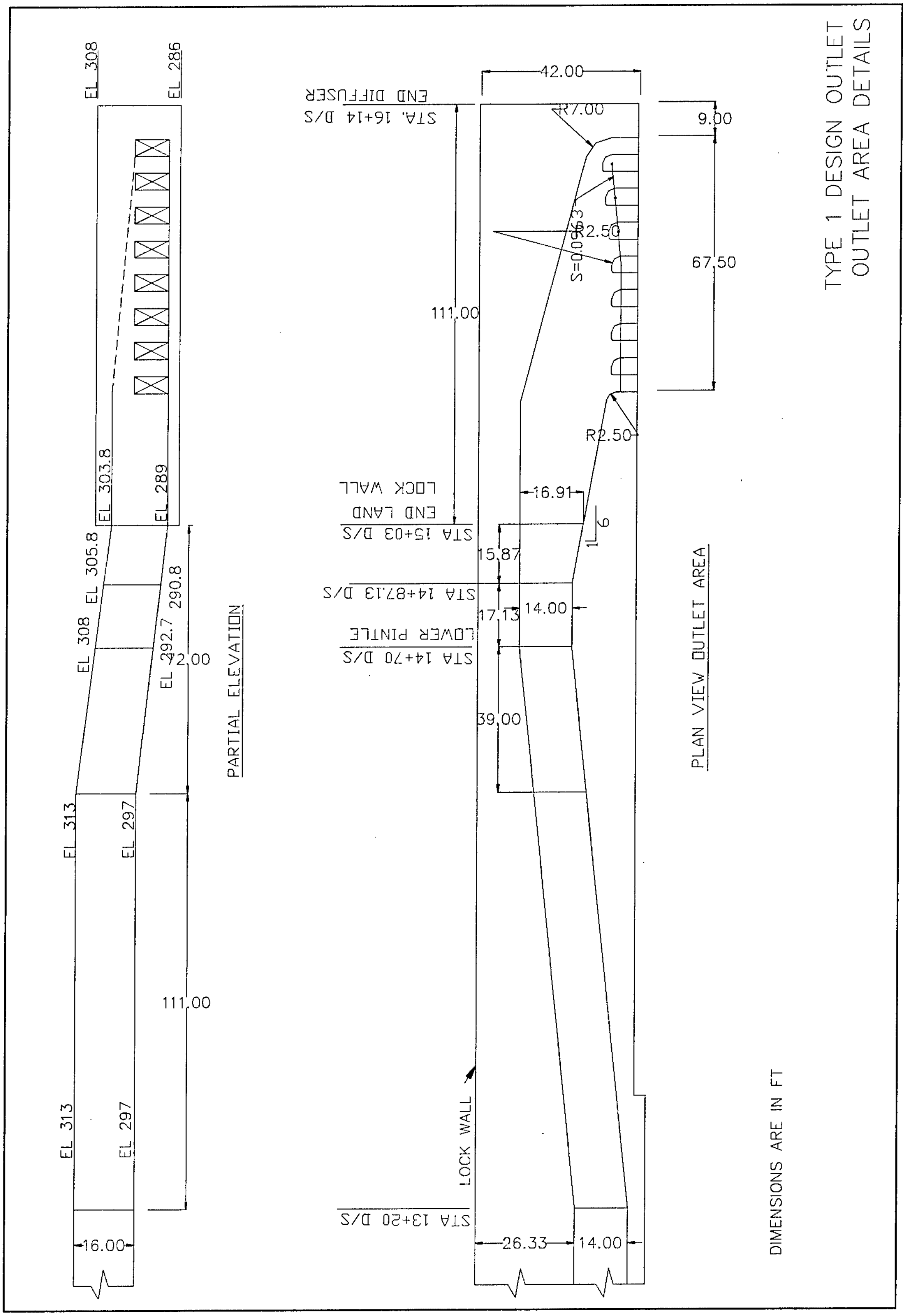
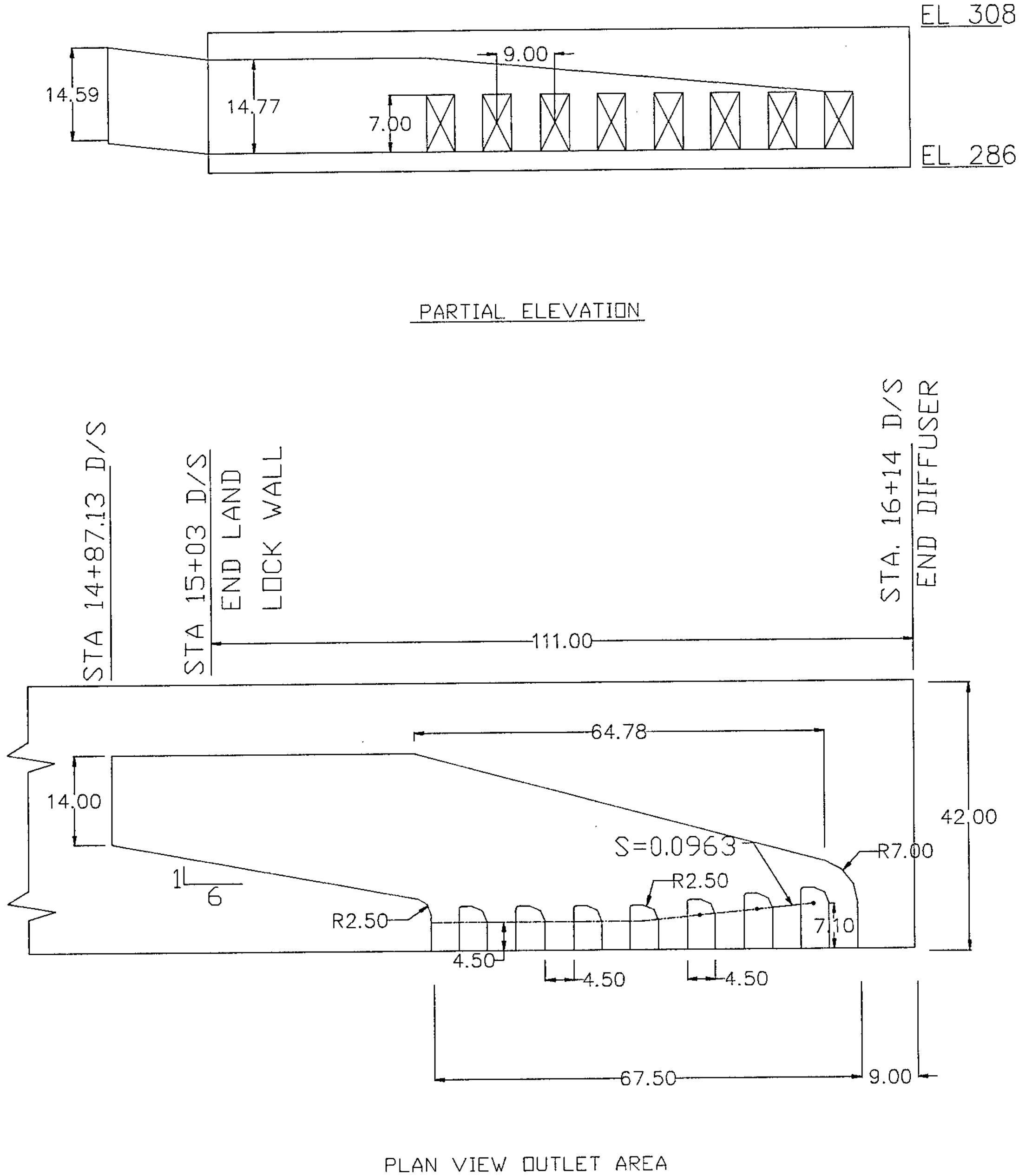
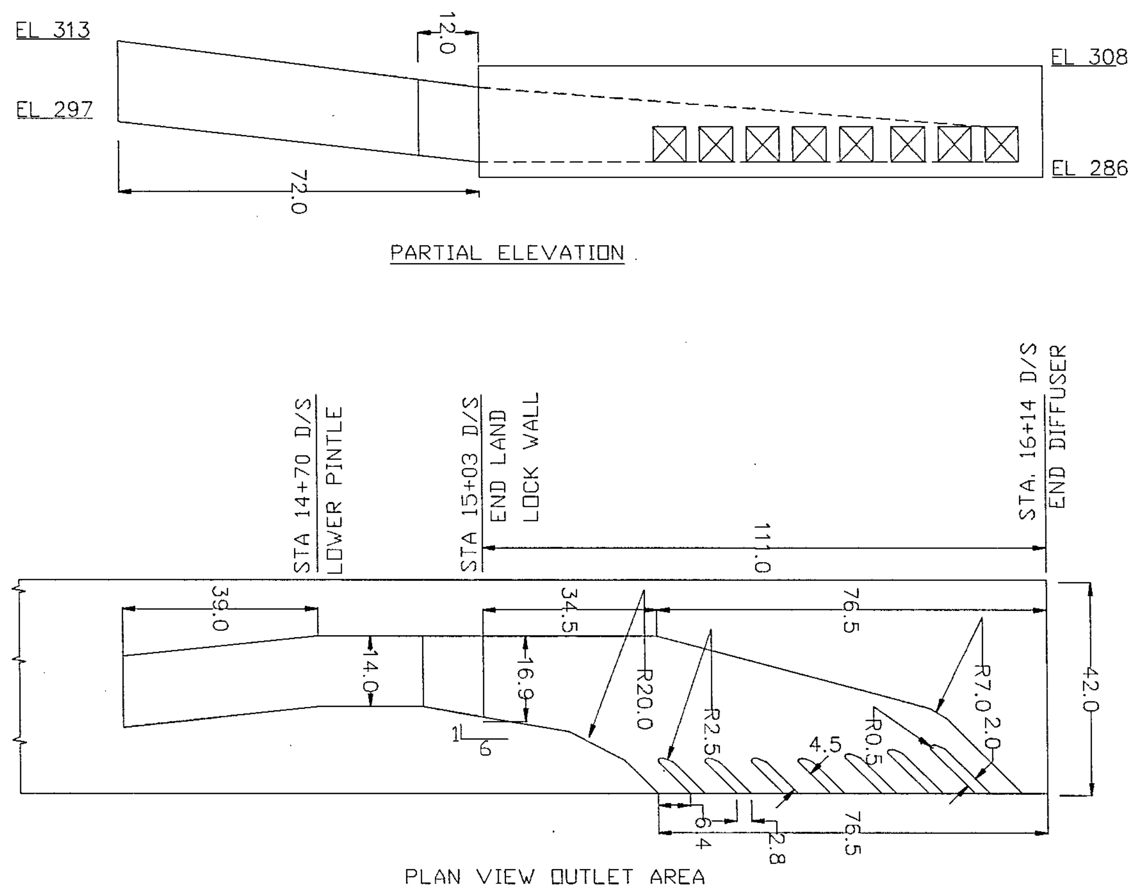

TYPE 1 DESIGN OUTLET
OUTLET AREA DETAILS
PARTIAL ELEVATION
PLAN VIEW OUTLET AREA
DIMENSIONS ARE IN FT
EL 308
EL 286
EL 303.8
EL 289
EL 305.8
EL 290.8
EL 308
EL 292.7
EL 313
EL 297
EL 313
EL 297
72.00
111.00
16.00
42.00
R7.00
9.00
R2.50
S=0.0963
67.50
111.00
R2.50
16.91
1
6
15.87
14.00
17.13
39.00
STA. 16+14 D/S
END DIFFUSER
LOCK WALL
END LAND
STA 15+03 D/S
STA 14+87.13 D/S
LOWER PINTLE
STA 14+70 D/S
LOCK WALL
STA 13+20 D/S
26.33
14.00

Plate 2



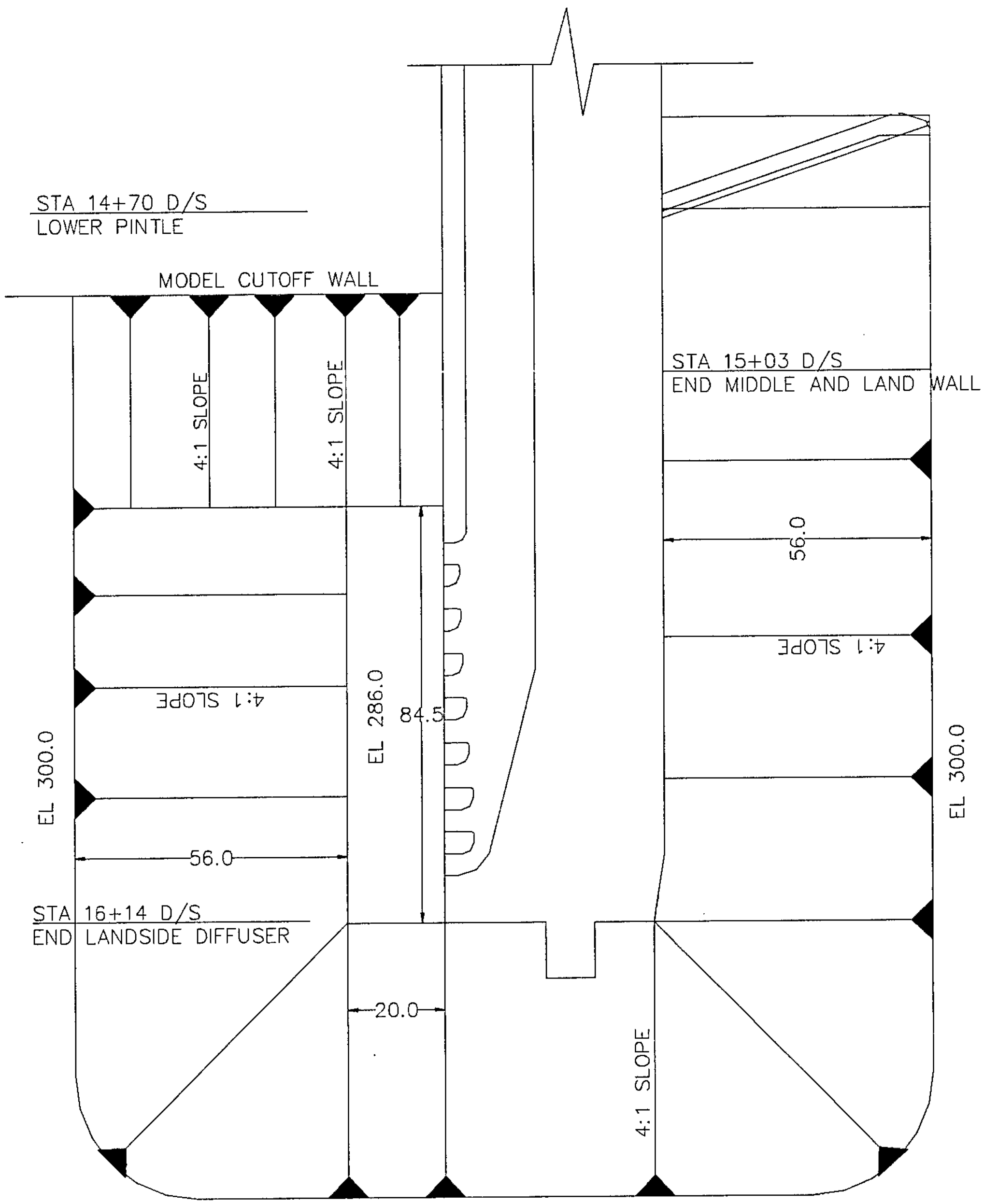
TYPE 1 OUTLET
DIFFUSER DETAILS



DIMENSIONS ARE IN FT

TYPE 2 DESIGN OUTLET DIFFUSER

TYPE 2 LOWER APPROACH
CLOSEUP AROUND OUTLET AREA



DIMENSIONS ARE IN FT

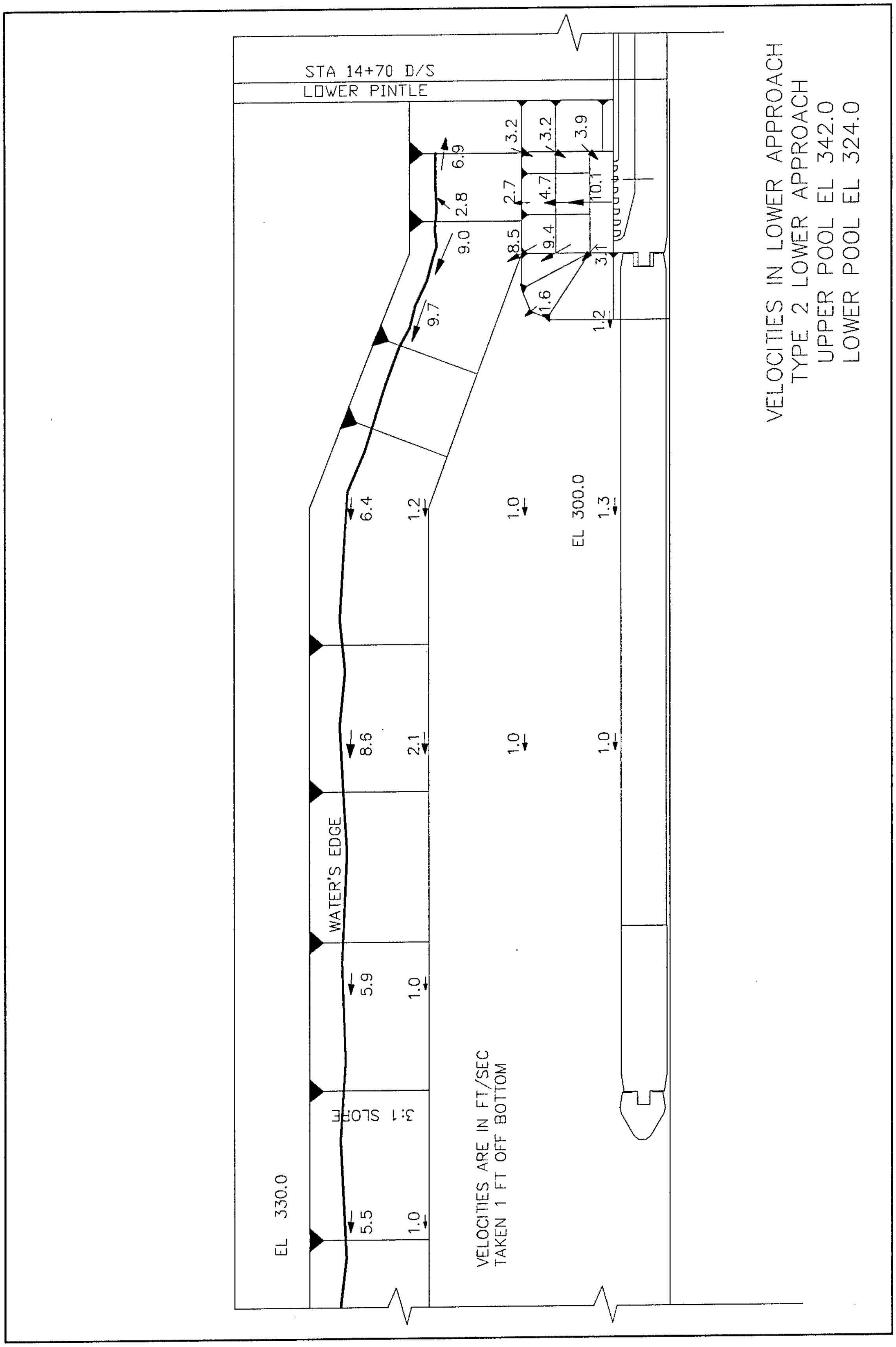
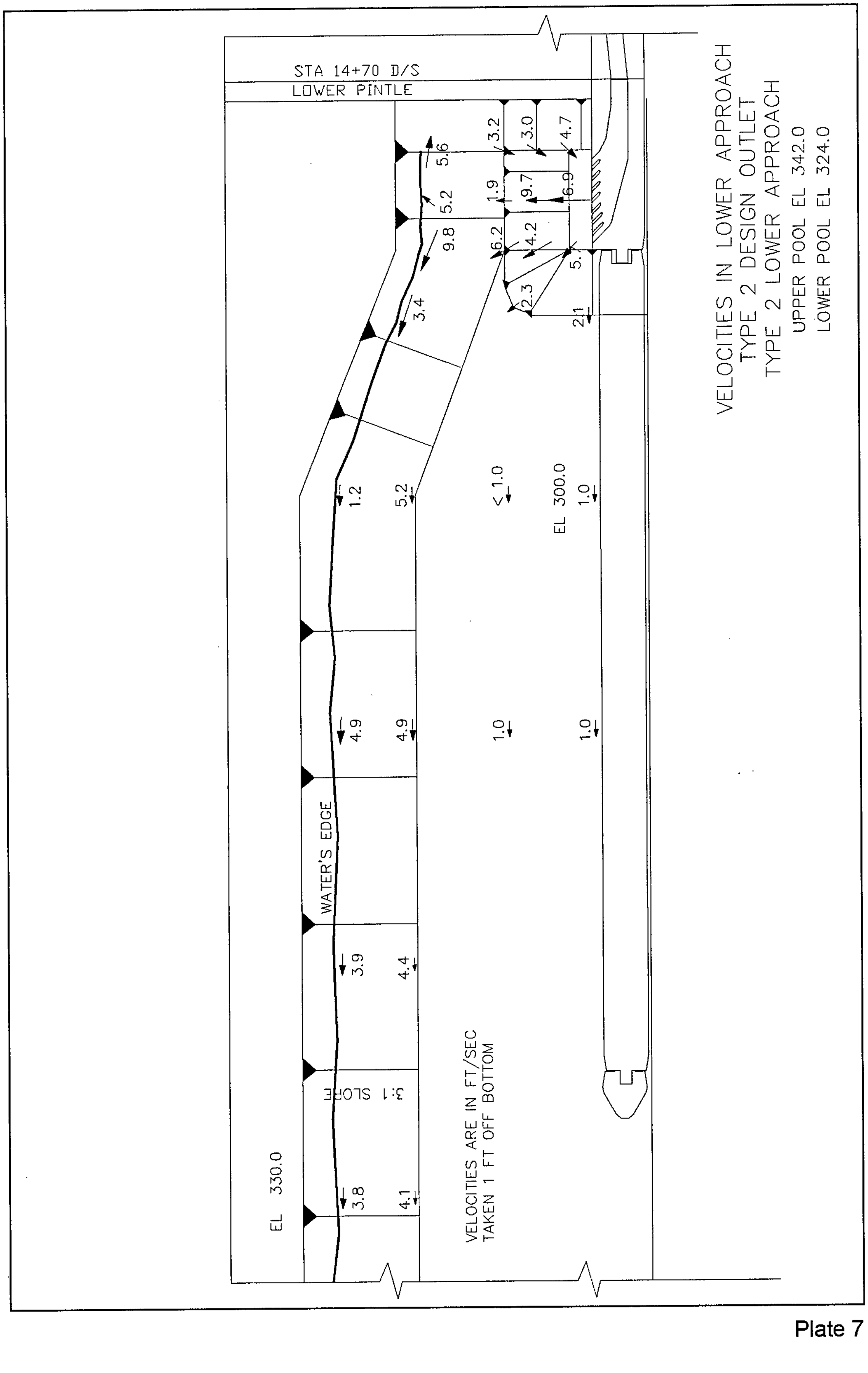

VELOCITIES IN LOWER APPROACH
TYPE 2 LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
STA 14+70 D/S
LOWER PINTLE
WATER'S EDGE
3:1 SLOPE
EL 330.0
EL 300.0
VELOCITIES ARE IN FT/SEC
TAKEN 1 FT OFF BOTTOM
6.9
2.8
9.0
9.7
3.2
3.2
3.9
2.7
4.7
10.1
8.5
9.4
3.1
1.6
1.2
6.4
1.2
1.0
1.3
8.6
2.1
1.0
1.0
5.9
1.0
5.5
1.0

Plate 6


VELOCITIES IN LOWER APPROACH
TYPE 2 DESIGN OUTLET
TYPE 2 LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
STA 14+70 D/S
LOWER PINTLE
WATER'S EDGE
3:1 SLOPE
EL 330.0
EL 300.0
VELOCITIES ARE IN FT/SEC
TAKEN 1 FT OFF BOTTOM
3.2
3.0
4.7
5.6
5.2
1.9
9.7
6.9
9.8
6.2
4.2
2.3
2.1
3.4
1.2
5.2
< 1.0
1.0
4.9
4.9
1.0
1.0
3.9
4.4
3.8
4.1

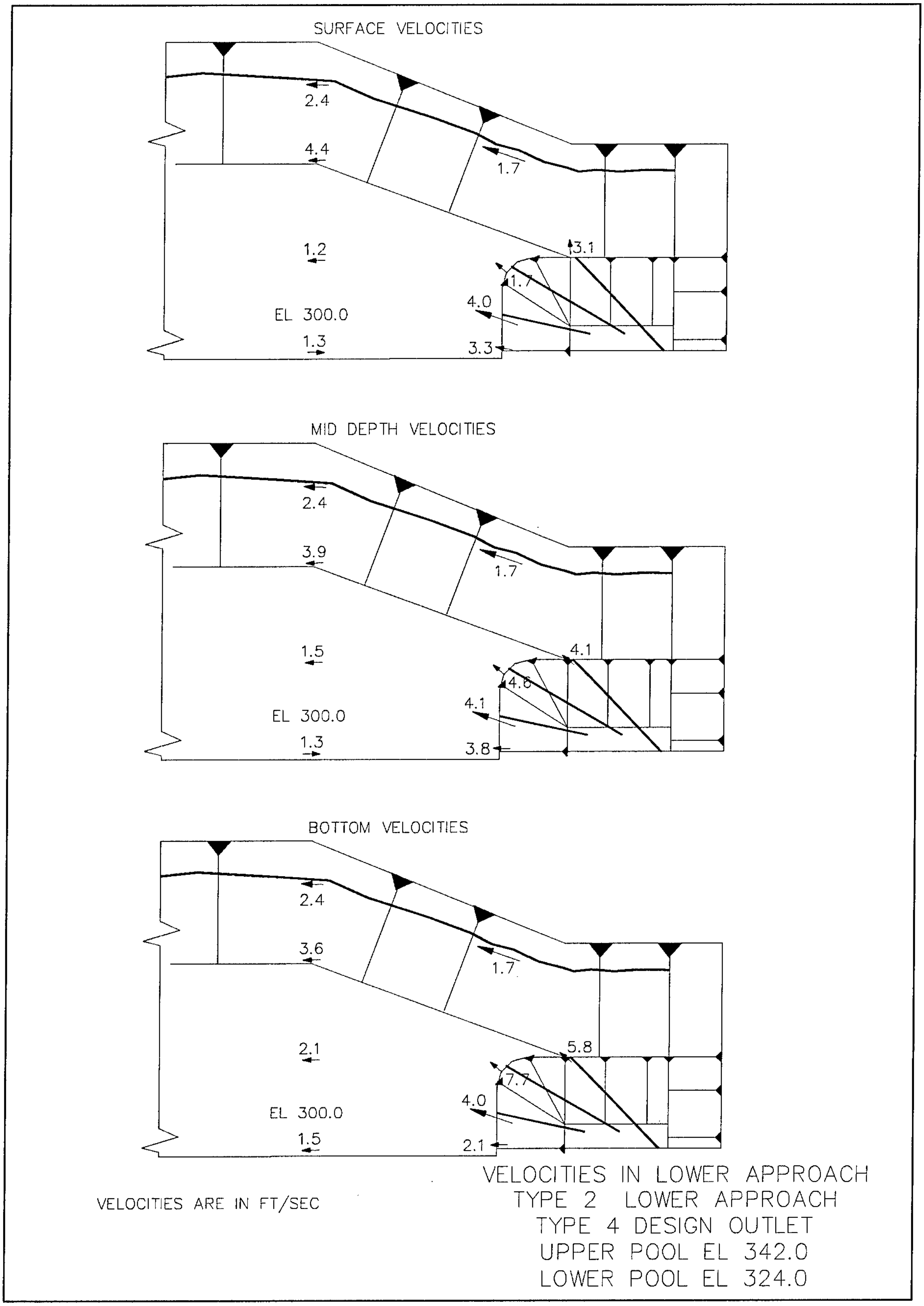
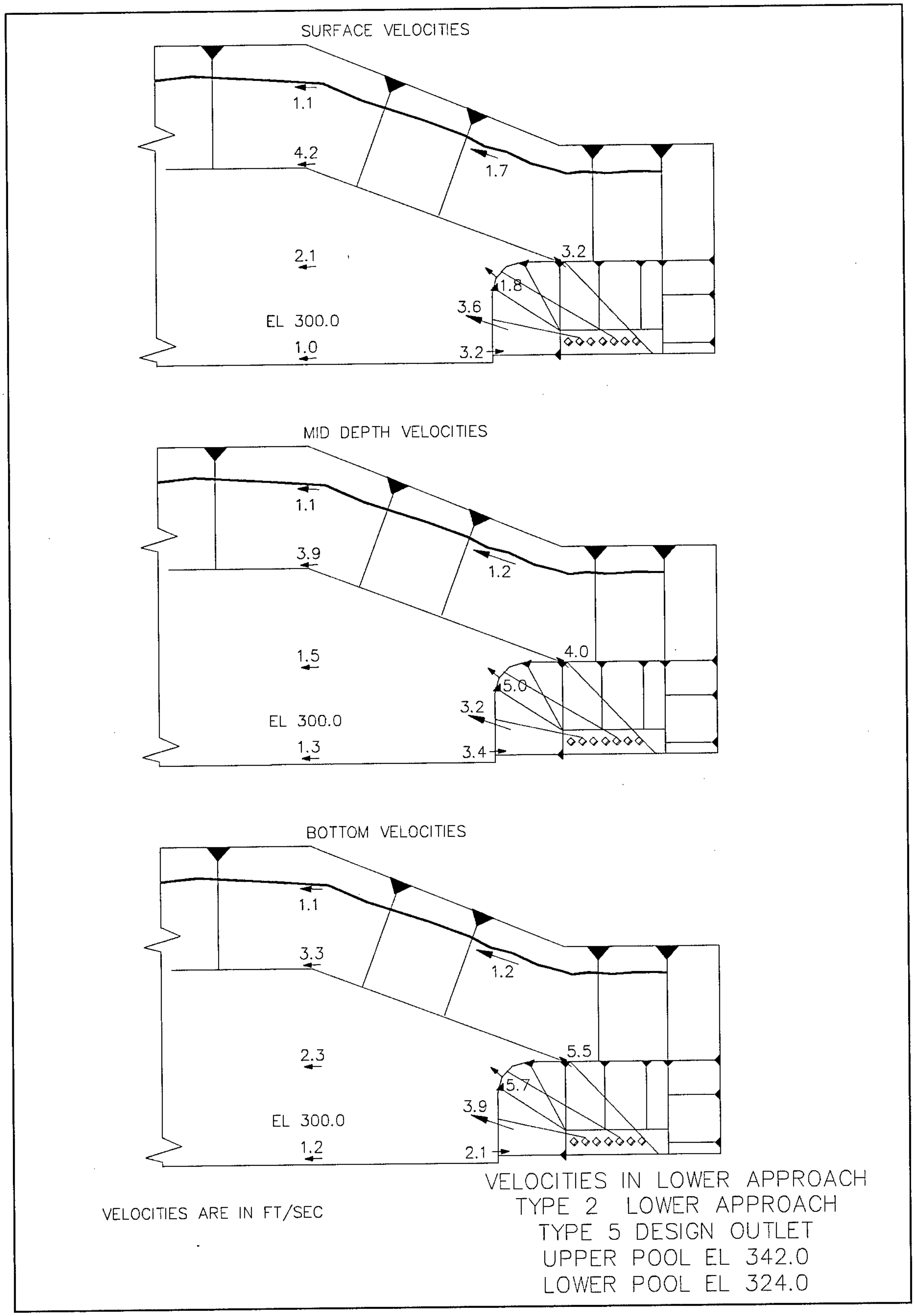
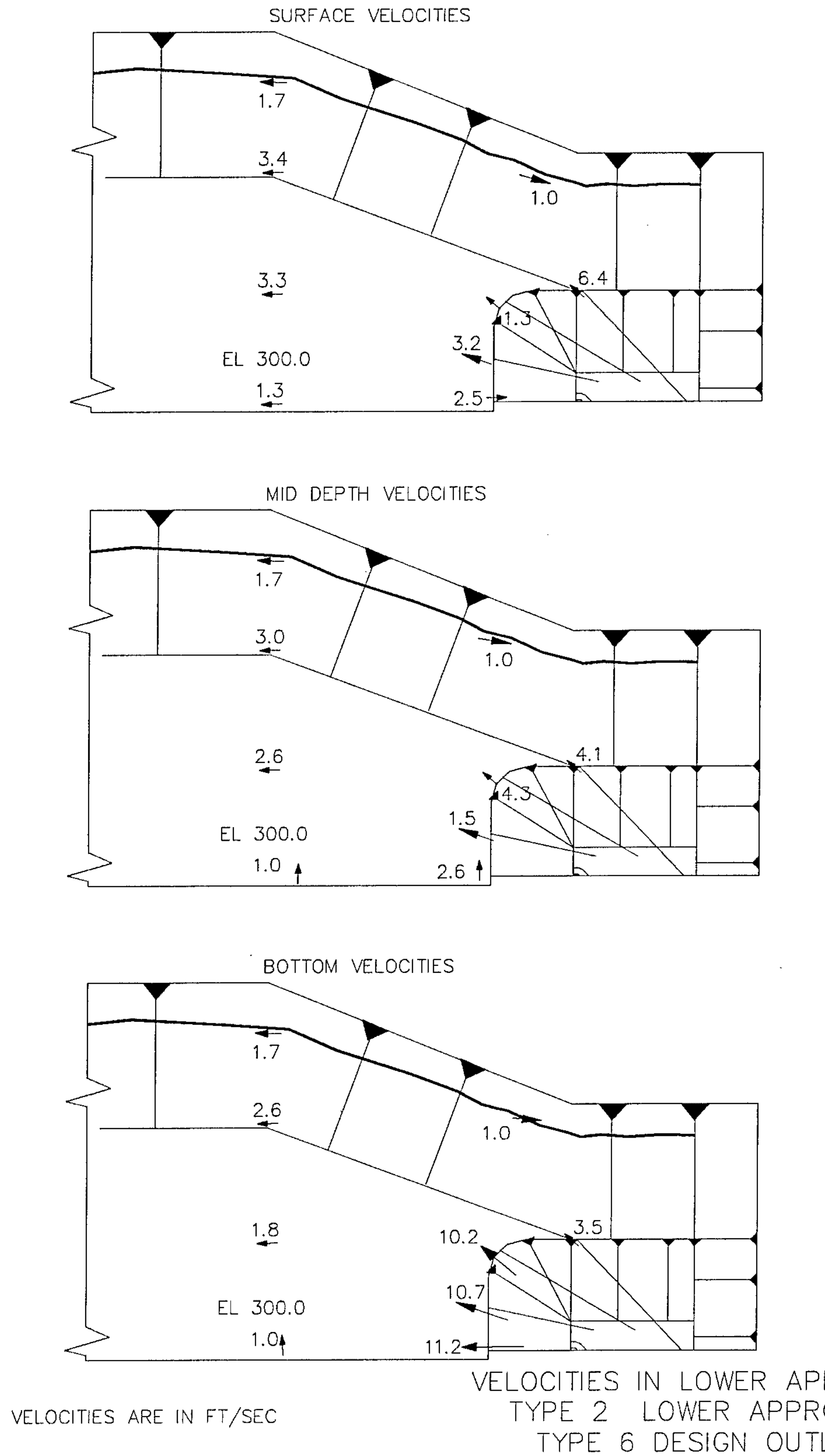
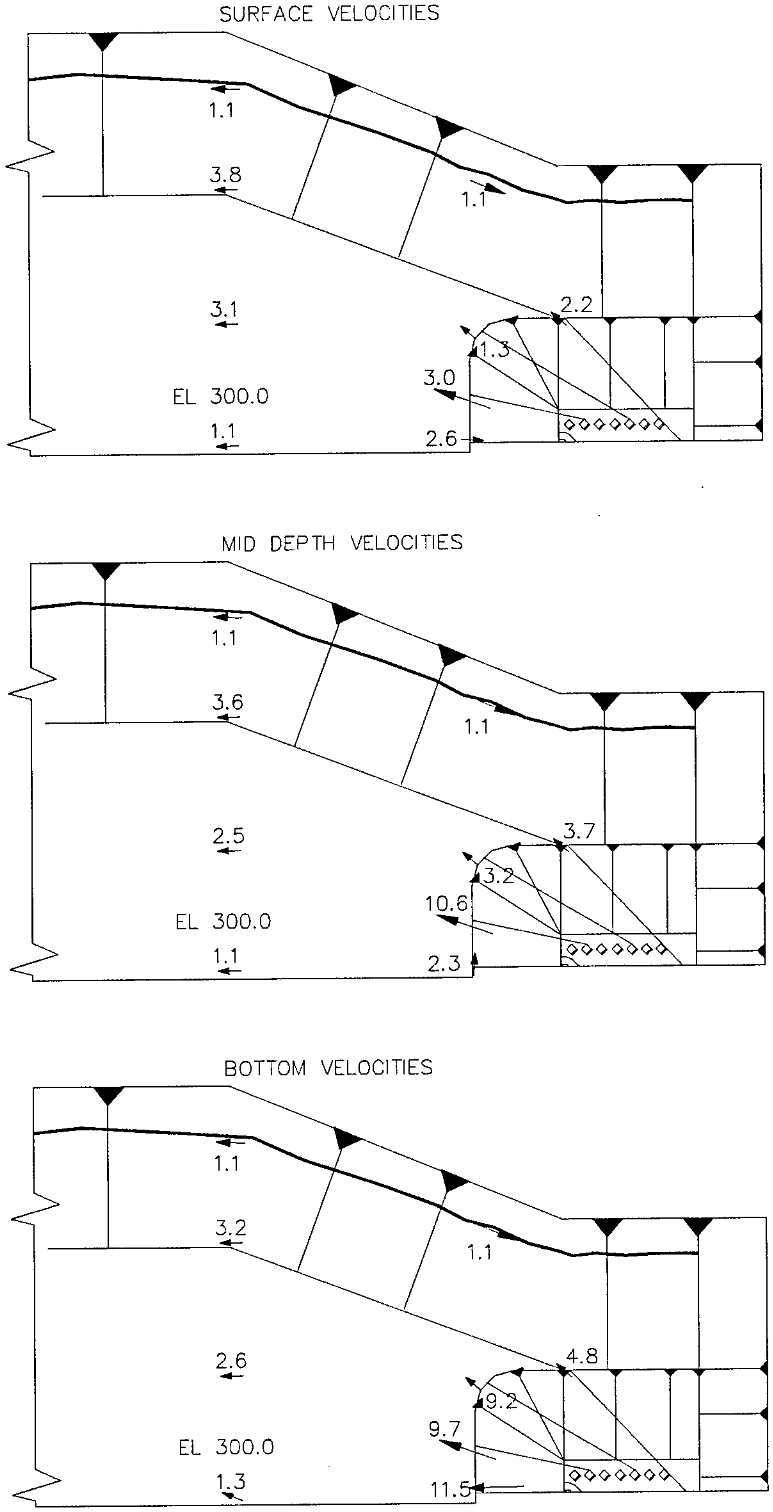

SURFACE VELOCITIES
2.4
4.4
1.7
1.2
3.1
1.7
4.0
EL 300.0
1.3
3.3
MID DEPTH VELOCITIES
2.4
3.9
1.7
1.5
4.1
4.6
4.1
EL 300.0
1.3
3.8
BOTTOM VELOCITIES
2.4
3.6
1.7
2.1
5.8
7.7
4.0
EL 300.0
1.5
2.1
VELOCITIES ARE IN FT/SEC
VELOCITIES IN LOWER APPROACH
TYPE 2 LOWER APPROACH
TYPE 4 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0

Plate 8


SURFACE VELOCITIES
1.1
4.2
1.7
2.1
3.2
1.8
3.6
EL 300.0
1.0
3.2
MID DEPTH VELOCITIES
1.1
3.9
1.2
1.5
4.0
5.0
3.2
EL 300.0
1.3
3.4
BOTTOM VELOCITIES
1.1
3.3
1.2
2.3
5.5
5.7
3.9
EL 300.0
1.2
2.1
VELOCITIES ARE IN FT/SEC
VELOCITIES IN LOWER APPROACH
TYPE 2 LOWER APPROACH
TYPE 5 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0



VELOCITIES IN LOWER APPROACH
TYPE 2 LOWER APPROACH
TYPE 6 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0



VELOCITIES ARE IN FT/SEC

VELOCITIES IN LOWER APPROACH
TYPE 2 LOWER APPROACH
TYPE 7 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0

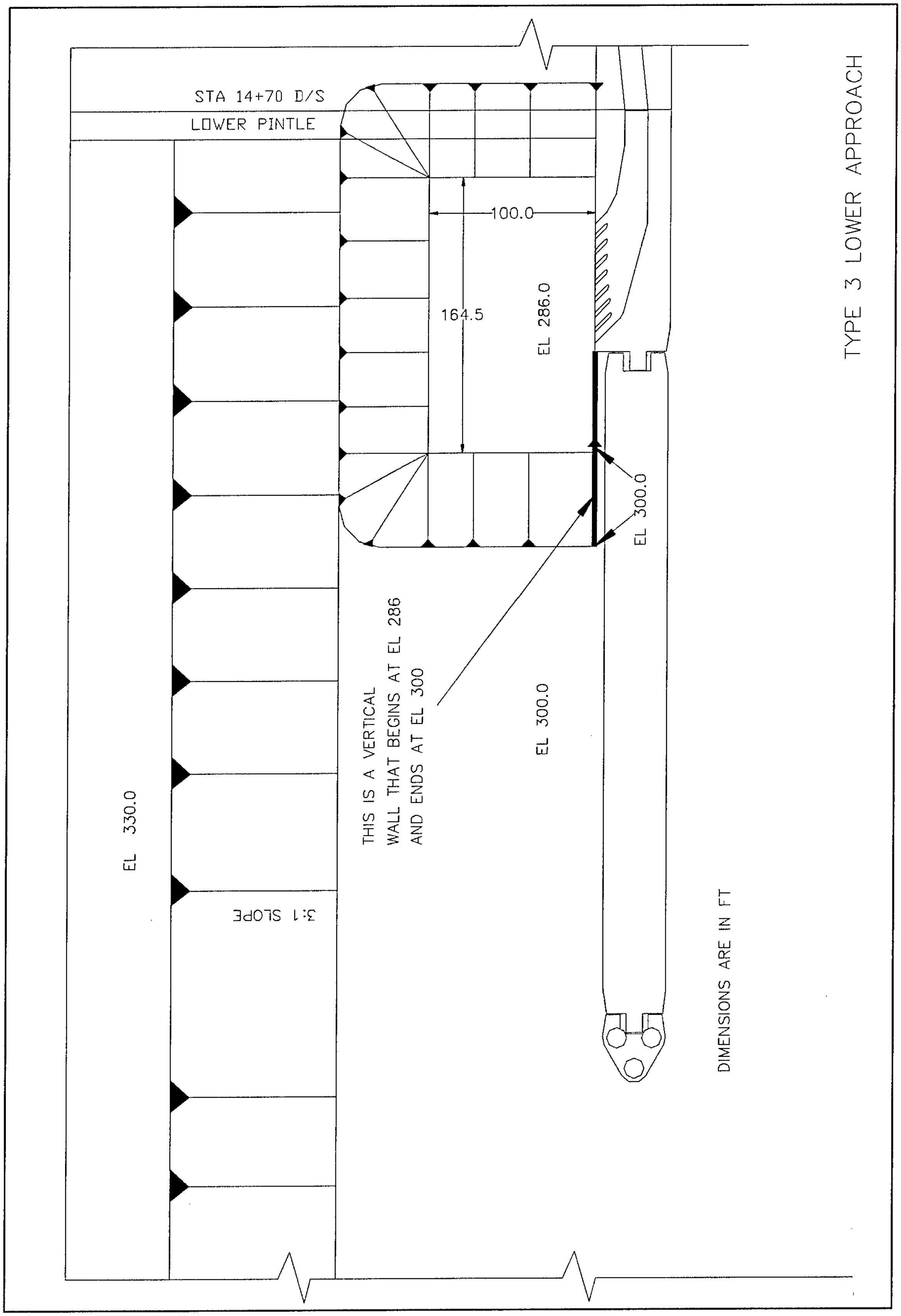
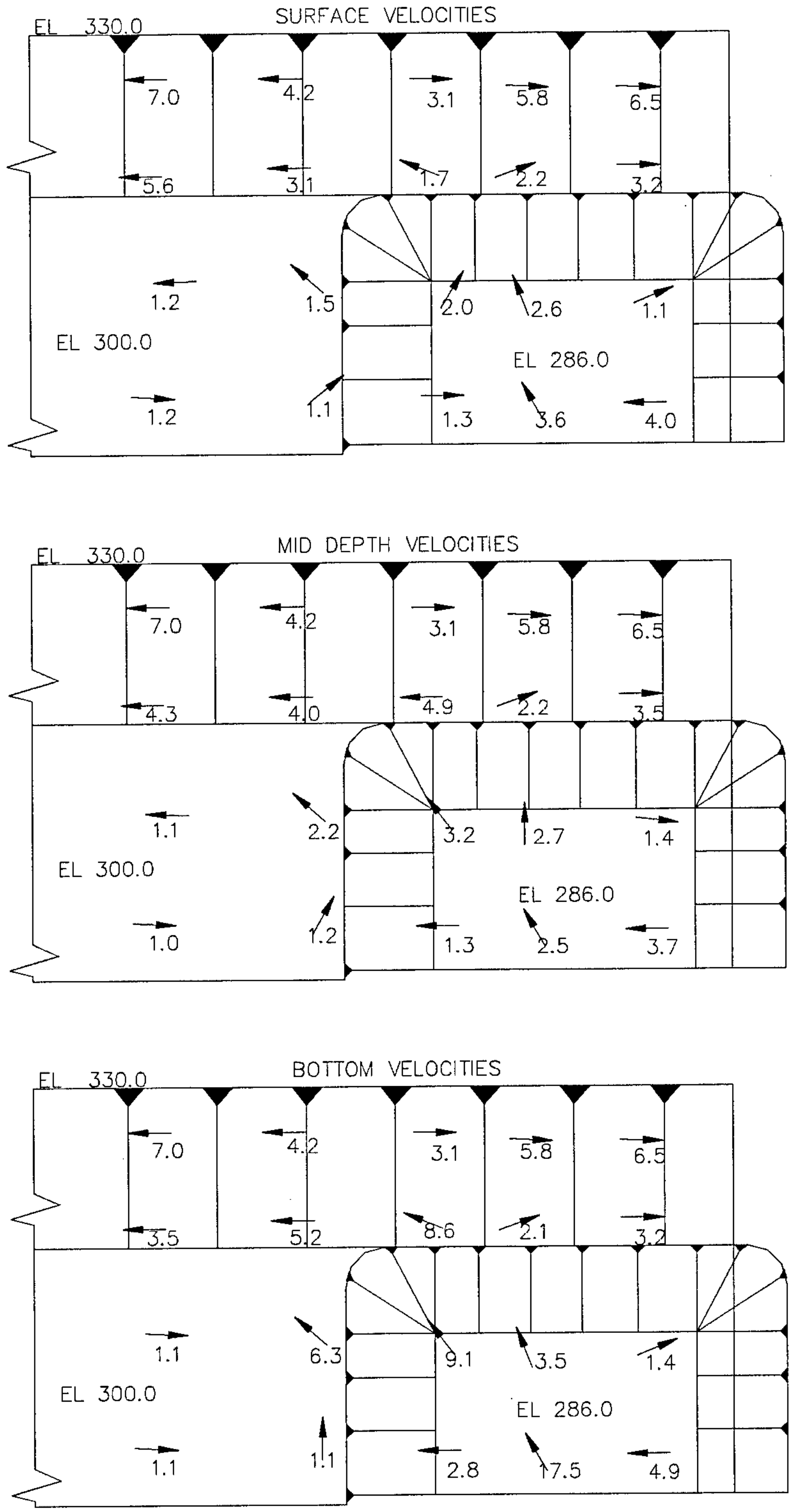
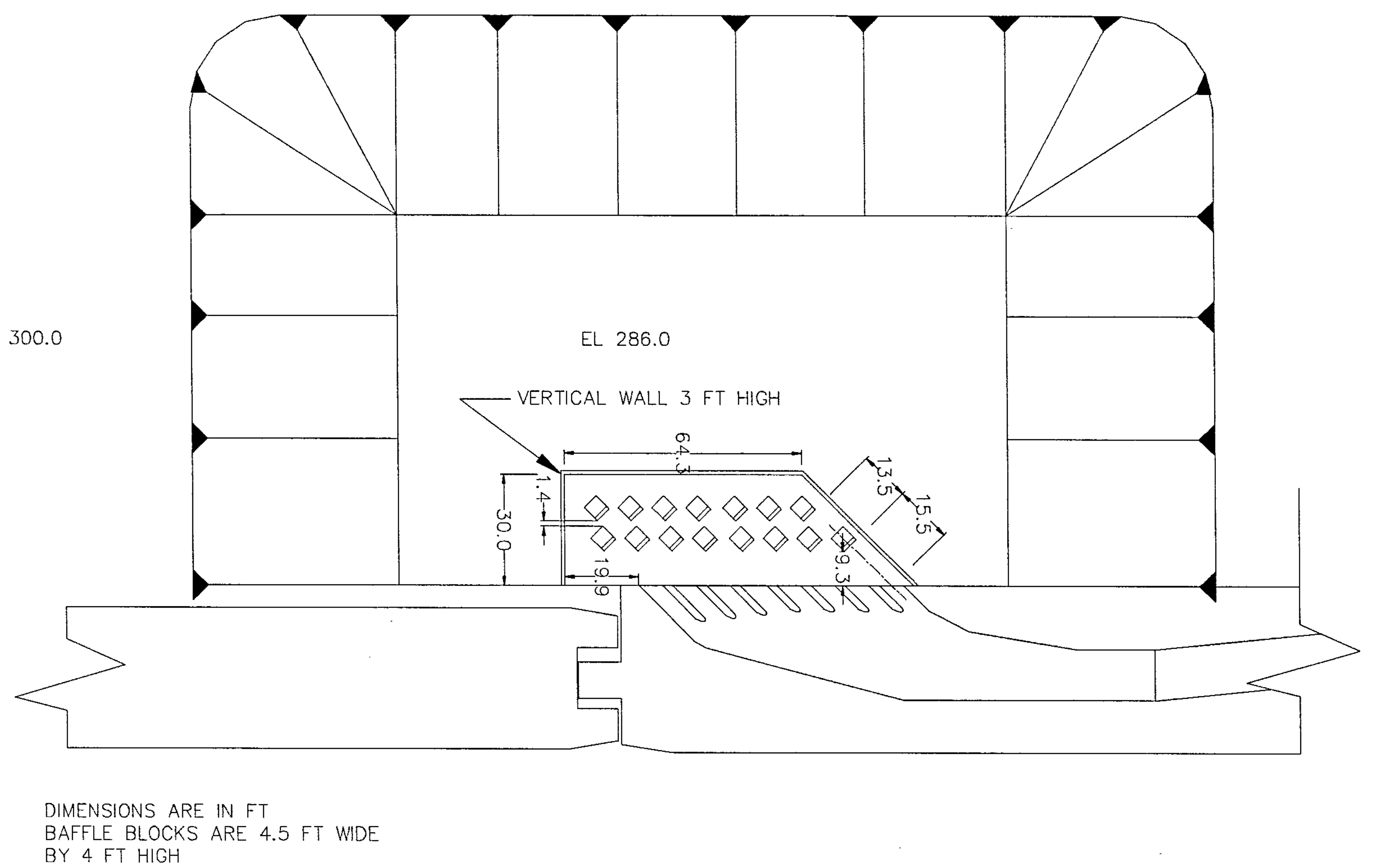

TYPE 3 LOWER APPROACH
STA 14+70 D/S
LOWER PINTLE
100.0
164.5
EL 286.0
EL 300.0
THIS IS A VERTICAL
WALL THAT BEGINS AT EL 286
AND ENDS AT EL 300
EL 300.0
EL 330.0
3:1 SLOPE
DIMENSIONS ARE IN FT

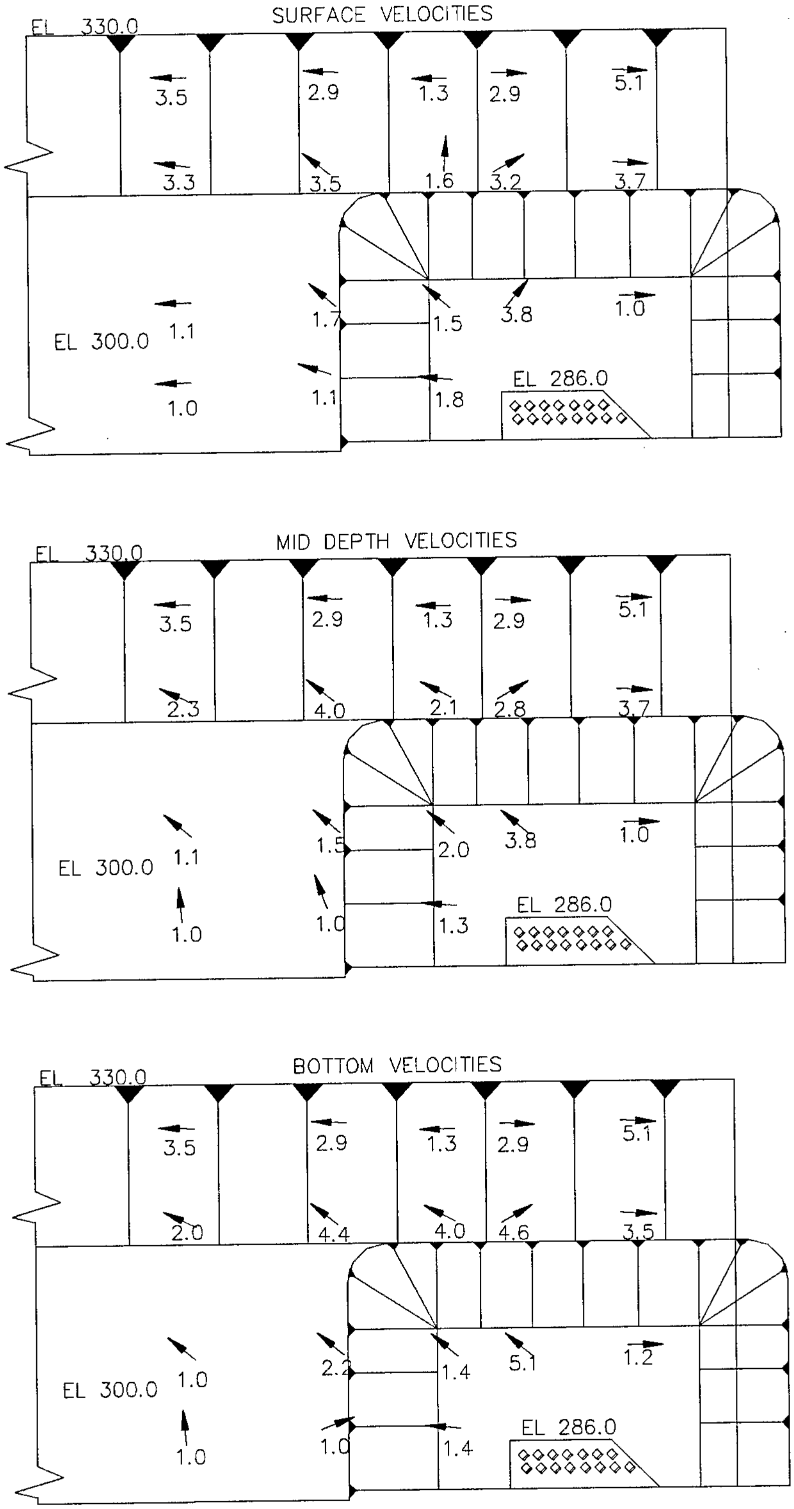
Plate 12



VELOCITIES IN LOWER APPROACH
TYPE 3 LOWER APPROACH
TYPE 8 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0



TYPE 9 DESIGN OUTLET
TYPE 3 LOWER APPROACH



VELOCITIES IN LOWER APPROACH
TYPE 3 LOWER APPROACH
TYPE 9 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0

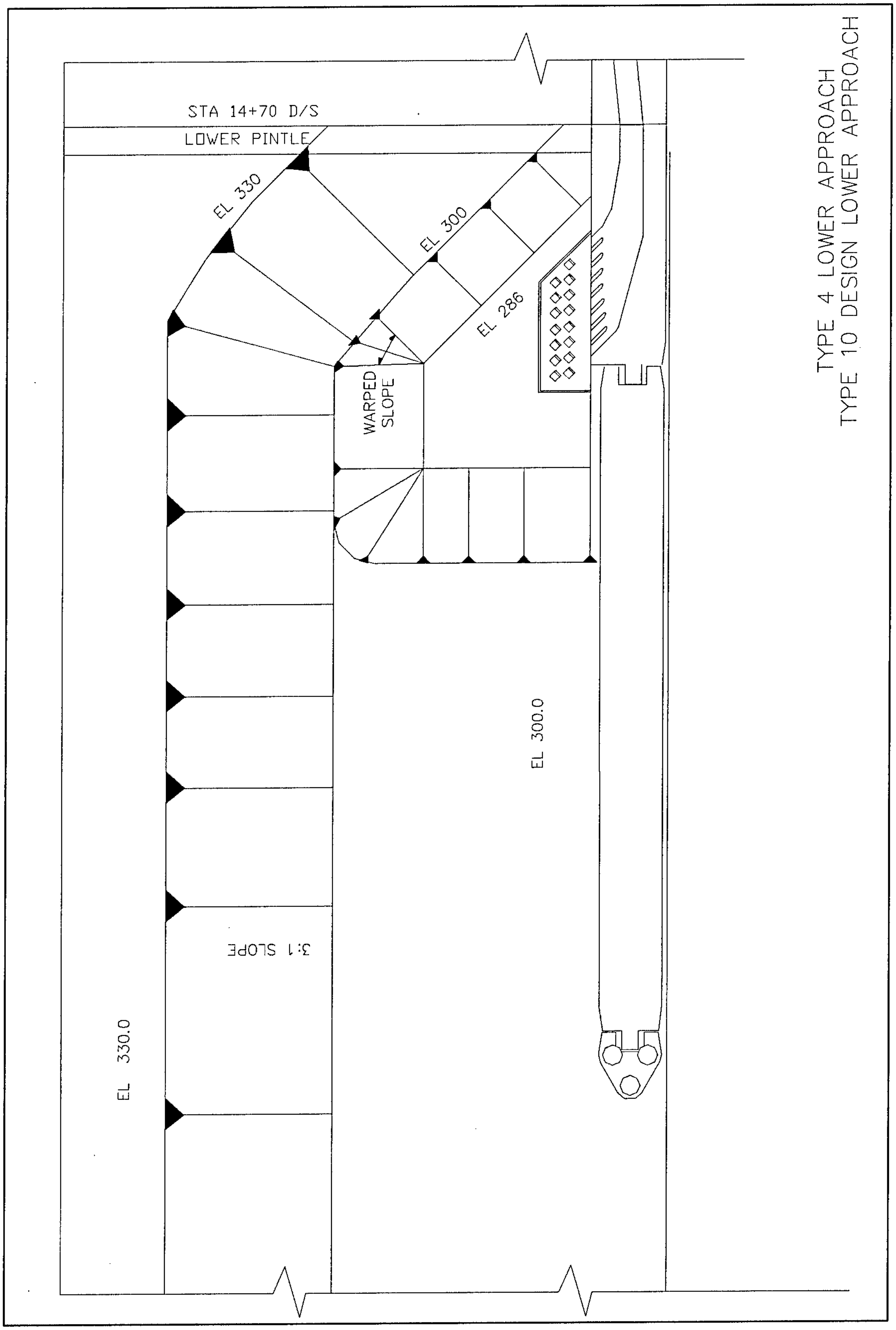
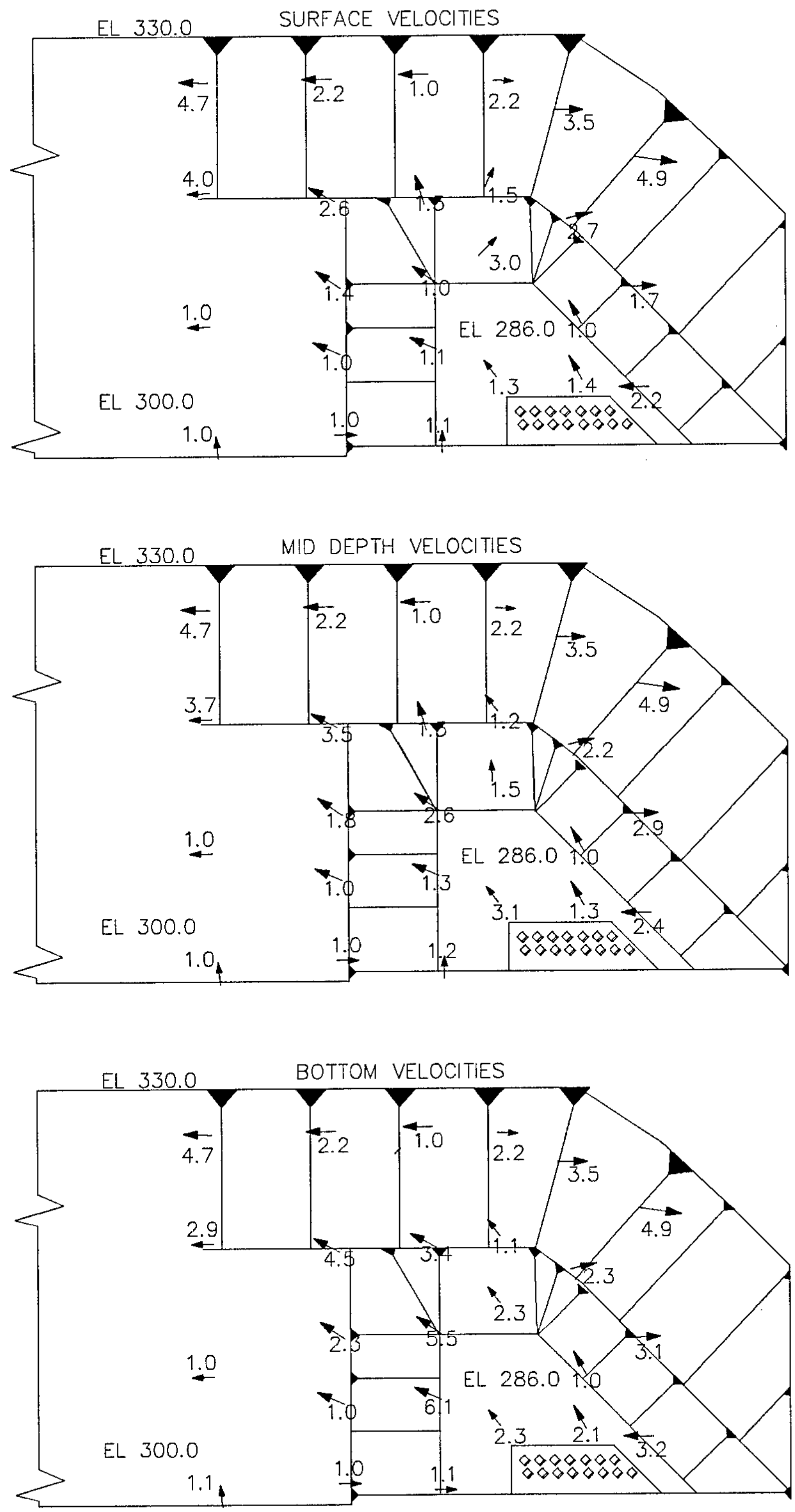
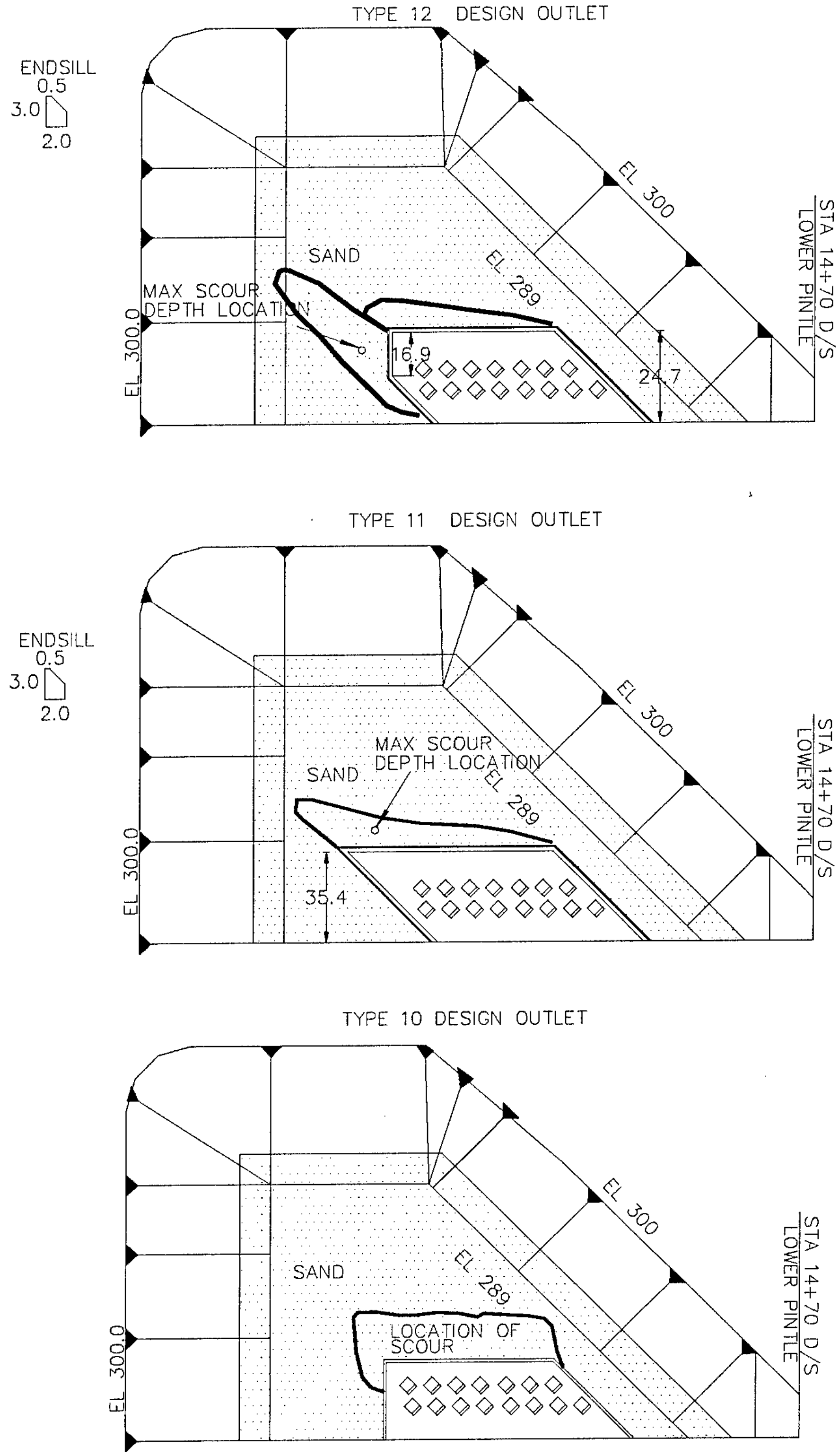

TYPE 4 LOWER APPROACH
TYPE 10 DESIGN LOWER APPROACH
STA 14+70 D/S
LOWER PINTLE
EL 330
EL 300
EL 286
WARPED SLOPE
EL 300.0
EL 330.0
3:1 SLOPE

Plate 16

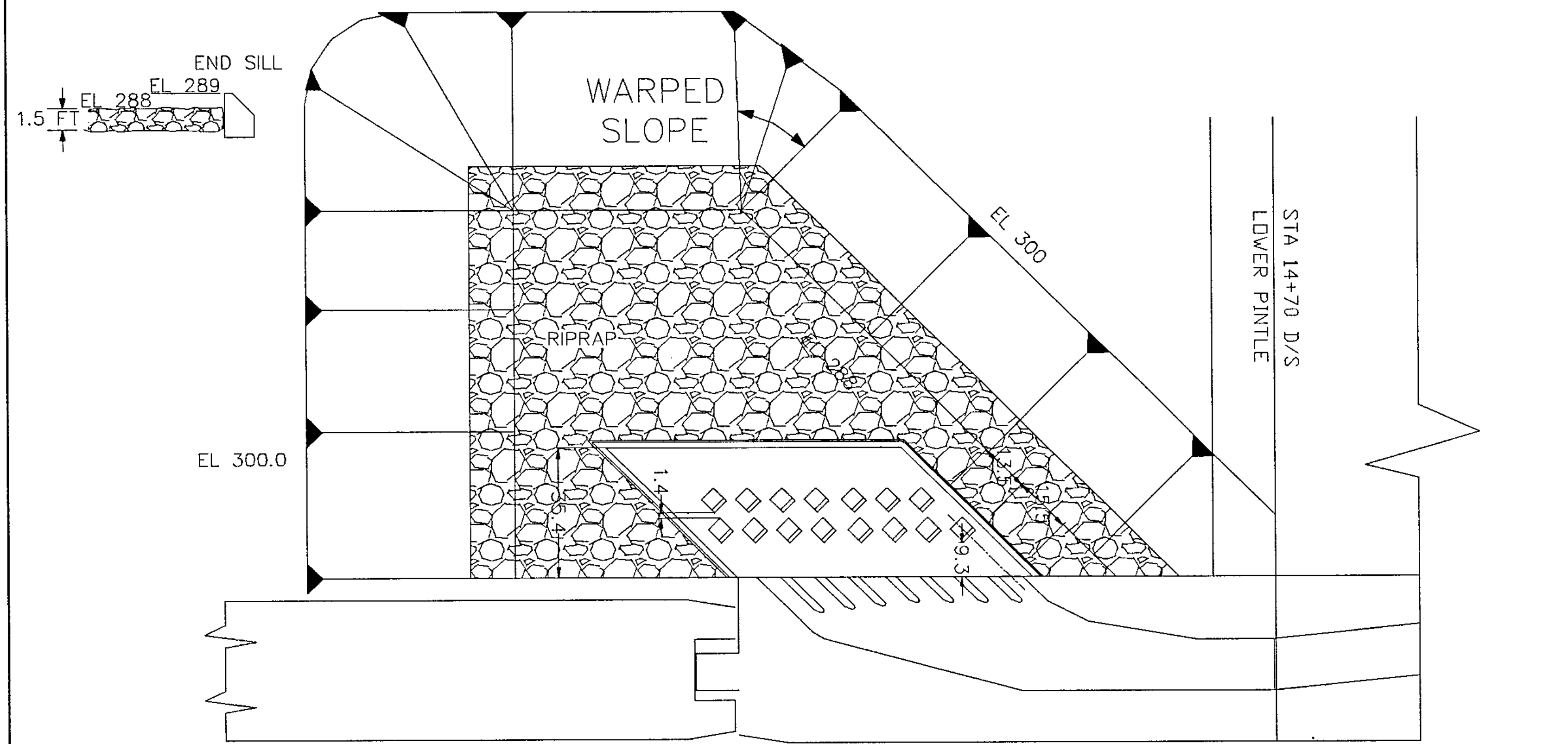


VELOCITIES IN LOWER APPROACH
TYPE 4 LOWER APPROACH
TYPE 10 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0



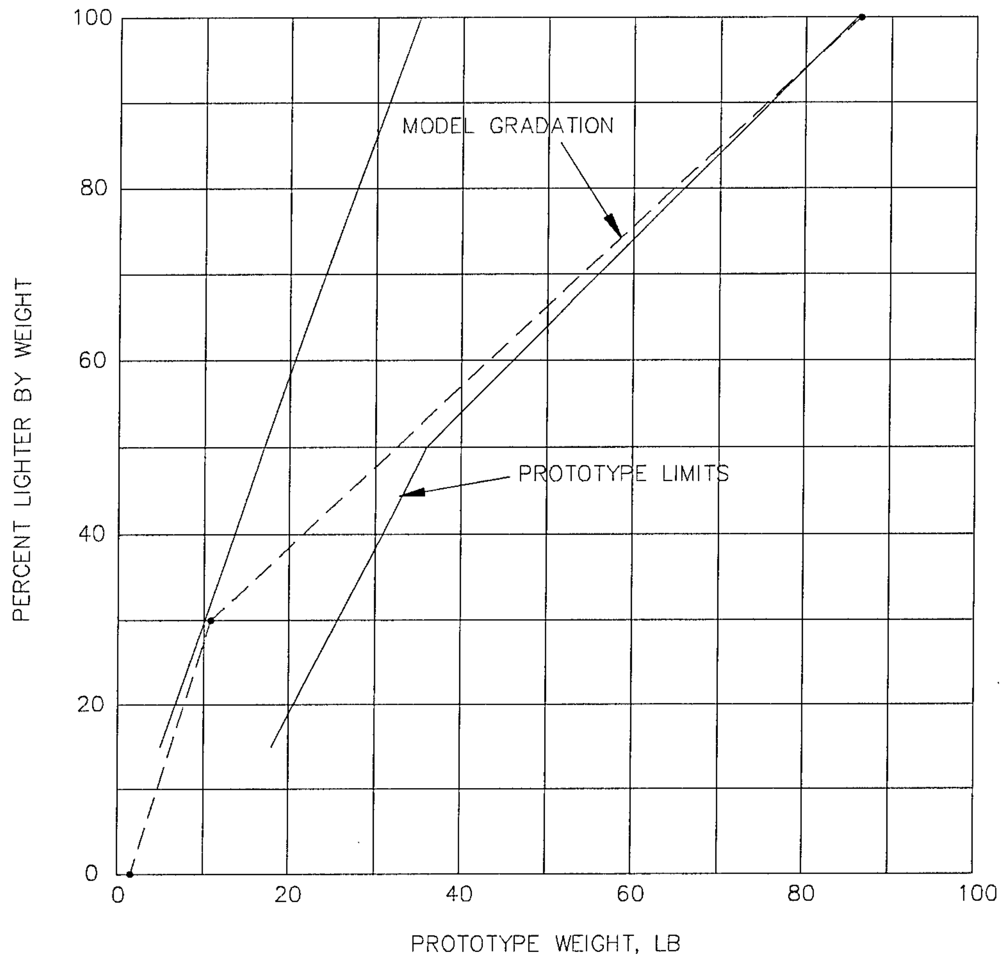
DIMENSIONS ARE IN FT

COMPARISON OF SCOURED AREAS
TYPE 4 LOWER APPROACH
TYPE 10–12 DESIGN OUTLETS



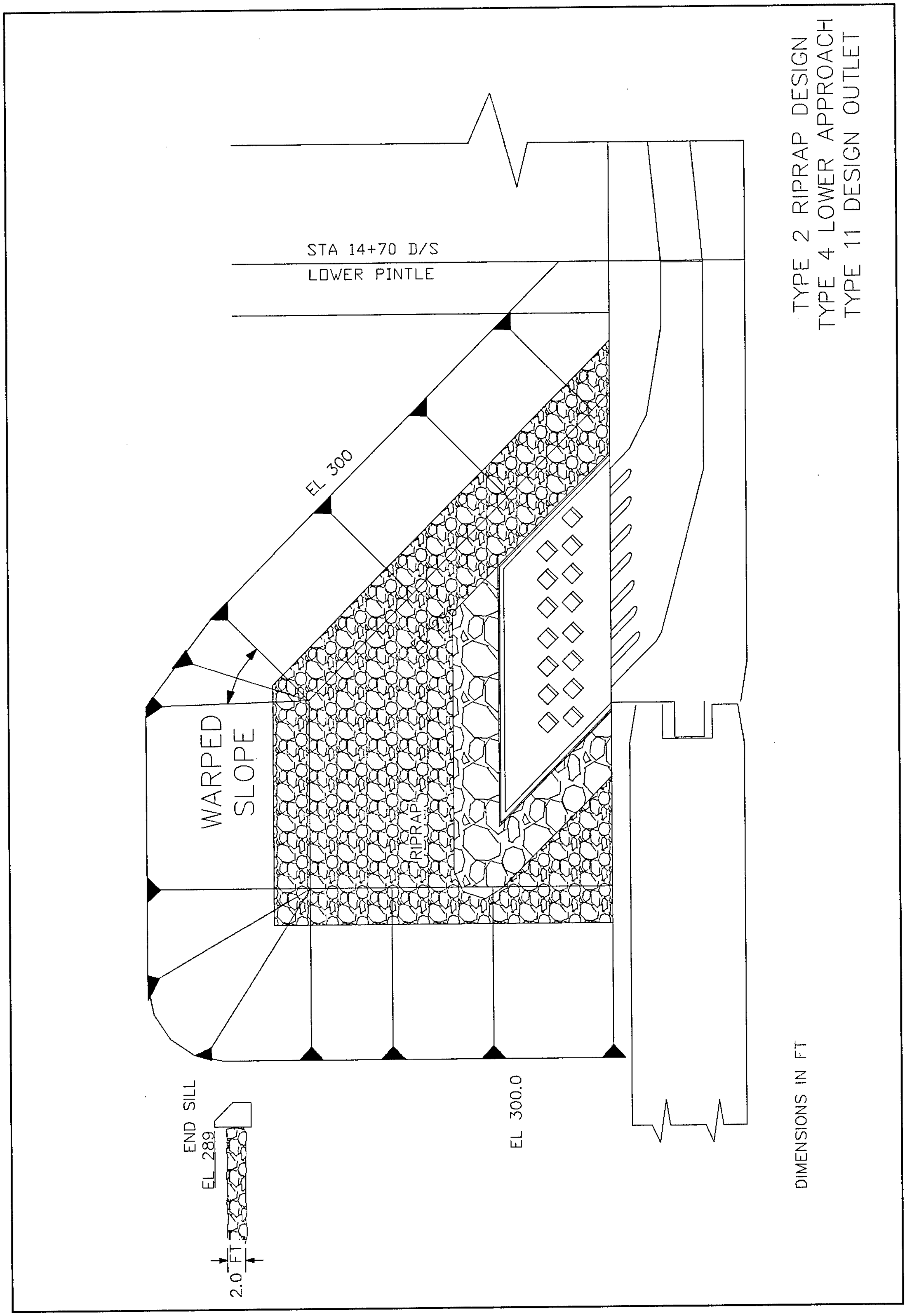
DIMENSIONS IN FT

TYPE 1 RIPRAP DESIGN
TYPE 4 LOWER APPROACH
TYPE 11 DESIGN OUTLET



TYPE 1 RIPRAP GRADATION
BLANKET THICKNESS = 1.5 FT
D_{50} = 0.5 FT

Plate 20


TYPE 2 RIPRAP DESIGN
TYPE 4 LOWER APPROACH
TYPE 11 DESIGN OUTLET
STA 14+70 D/S
LOWER PINTLE
EL 300
WARPED SLOPE
RIPRAP
EL 300.0
END SILL
EL 289
2.0 FT
DIMENSIONS IN FT

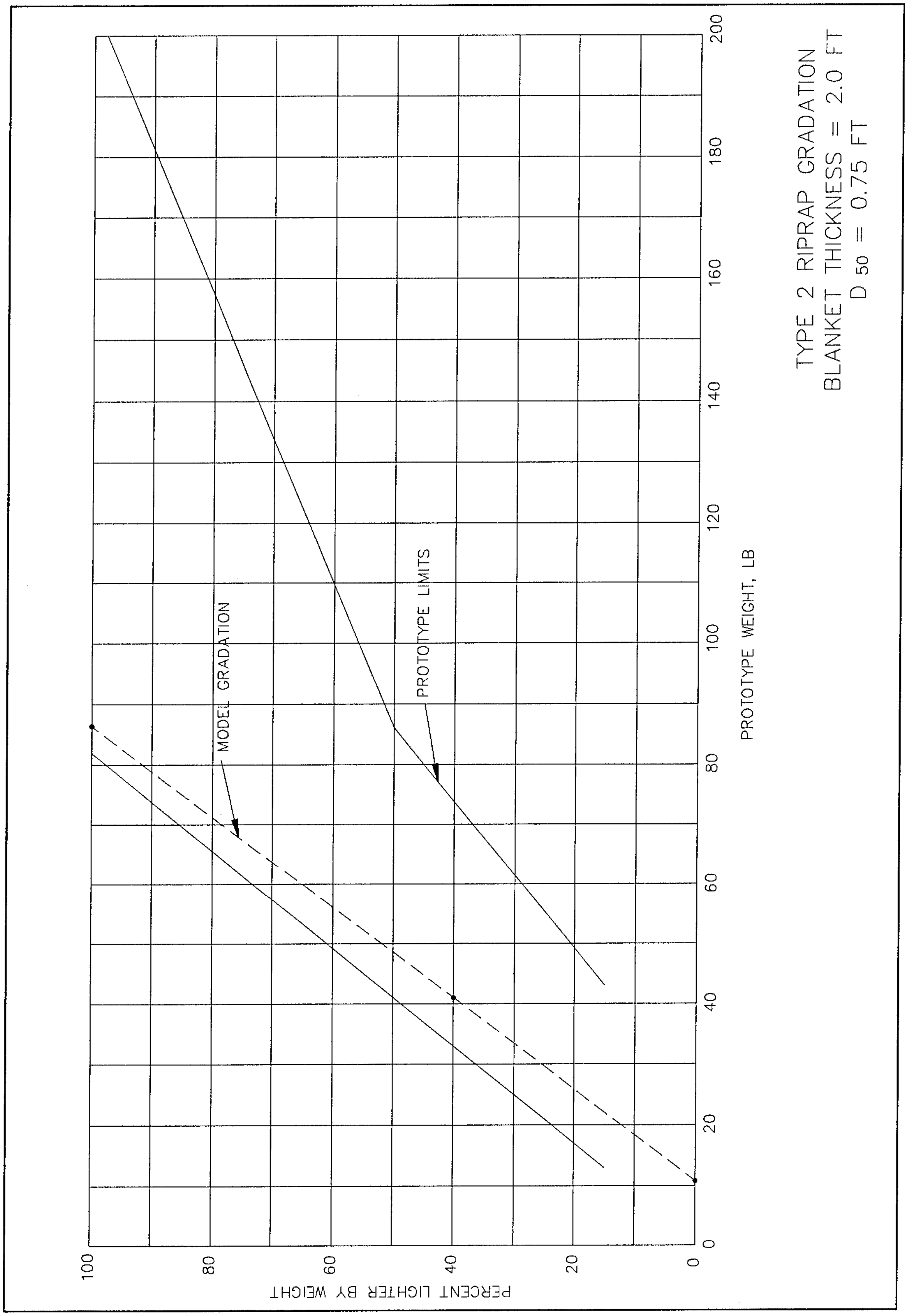
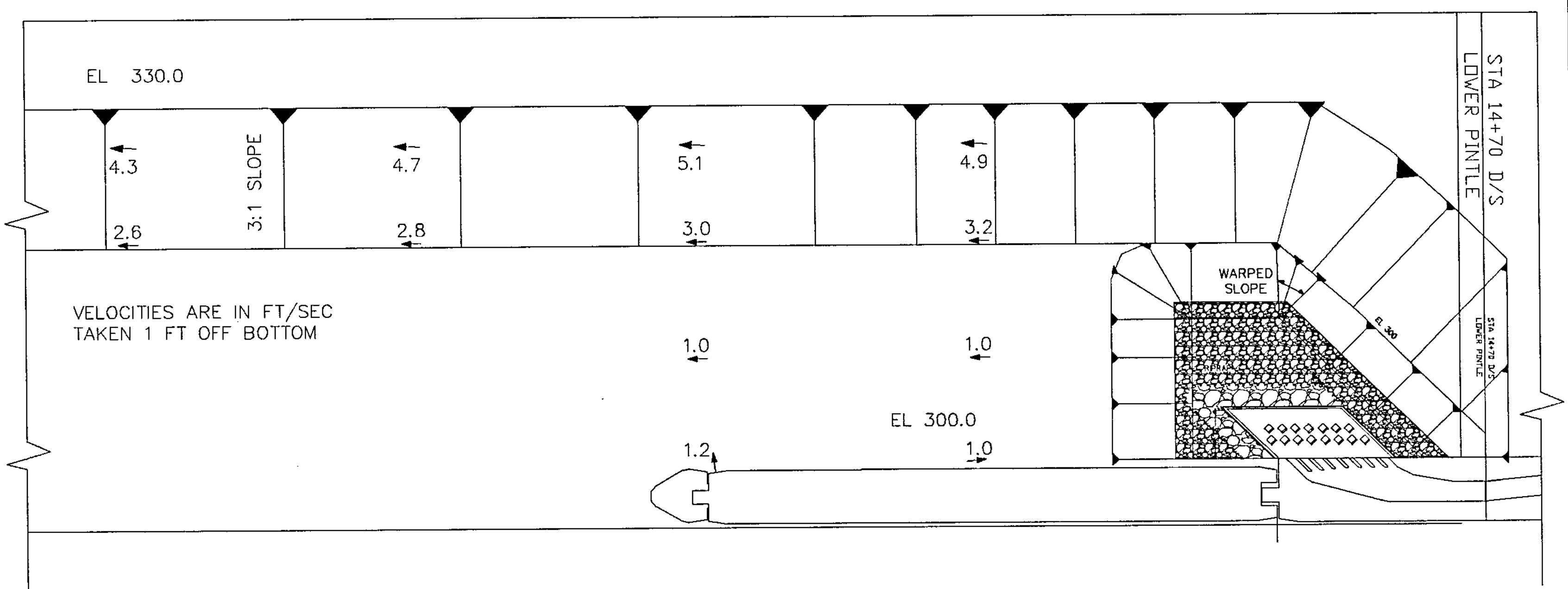
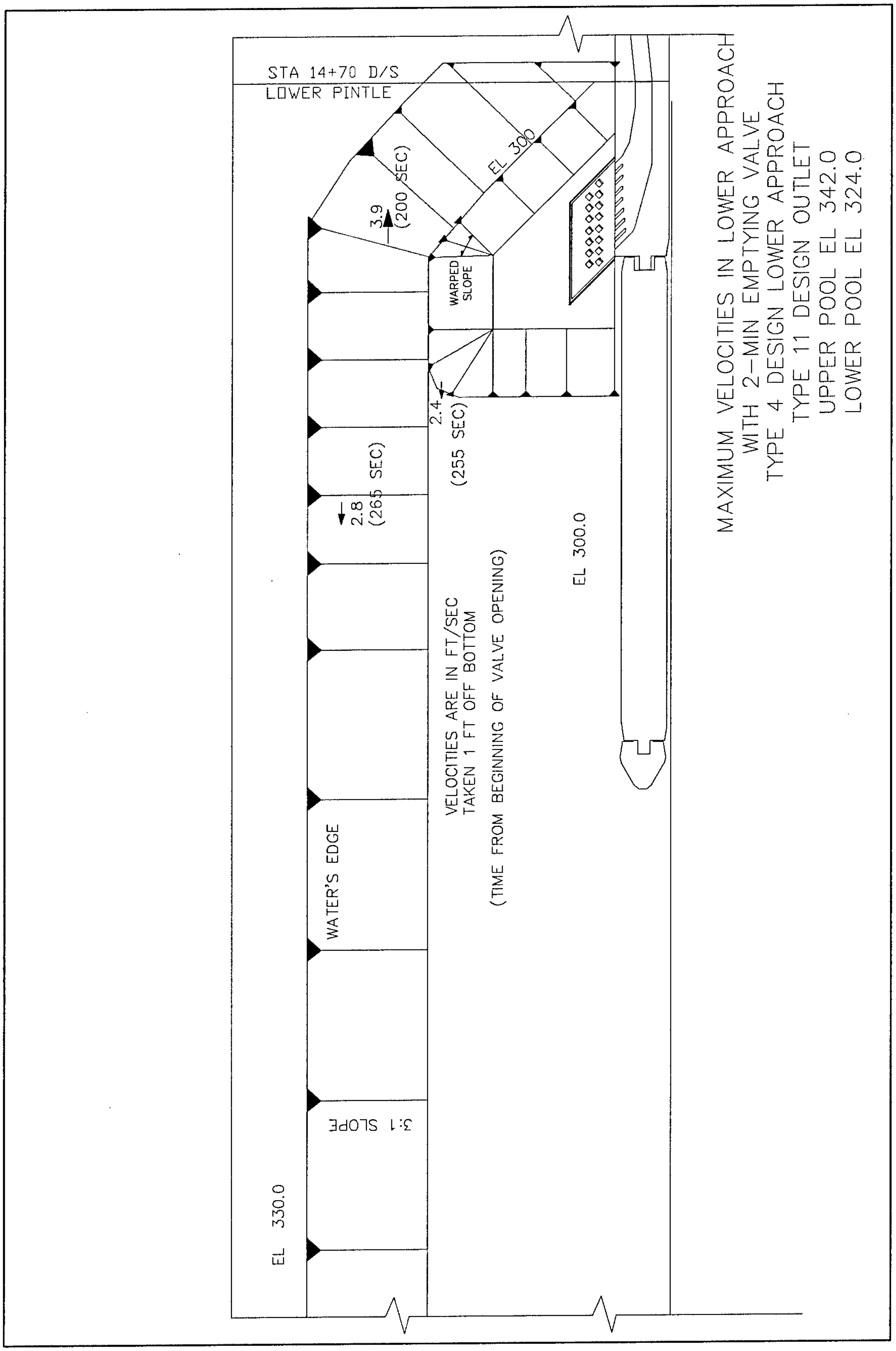

TYPE 2 RIPRAP GRADATION
BLANKET THICKNESS = 2.0 FT
D 50 = 0.75 FT
MODEL GRADATION
PROTOTYPE LIMITS
PROTOTYPE WEIGHT, LB
PERCENT LIGHTER BY WEIGHT
0
20
40
60
80
100
120
140
160
180
200

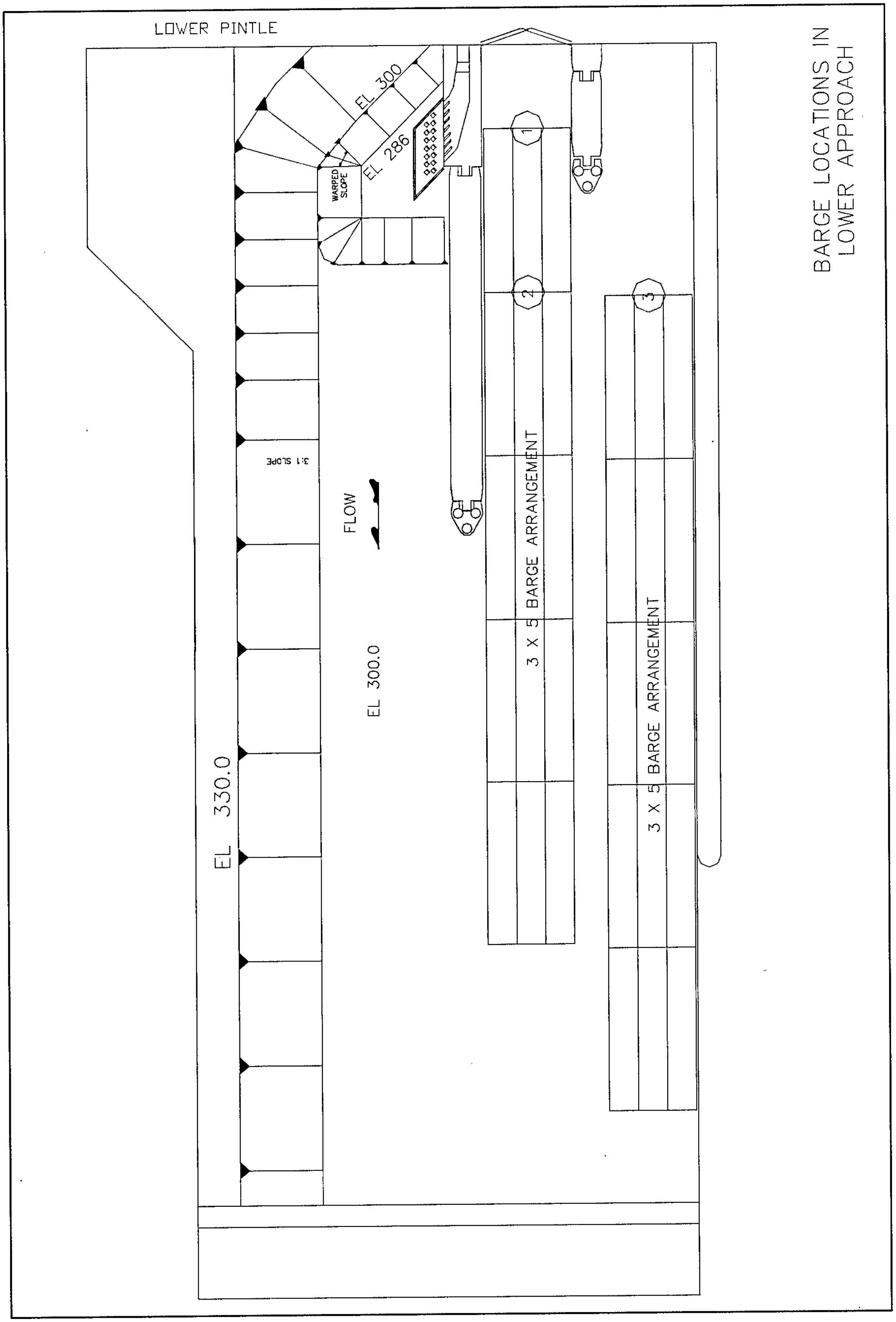
Plate 22

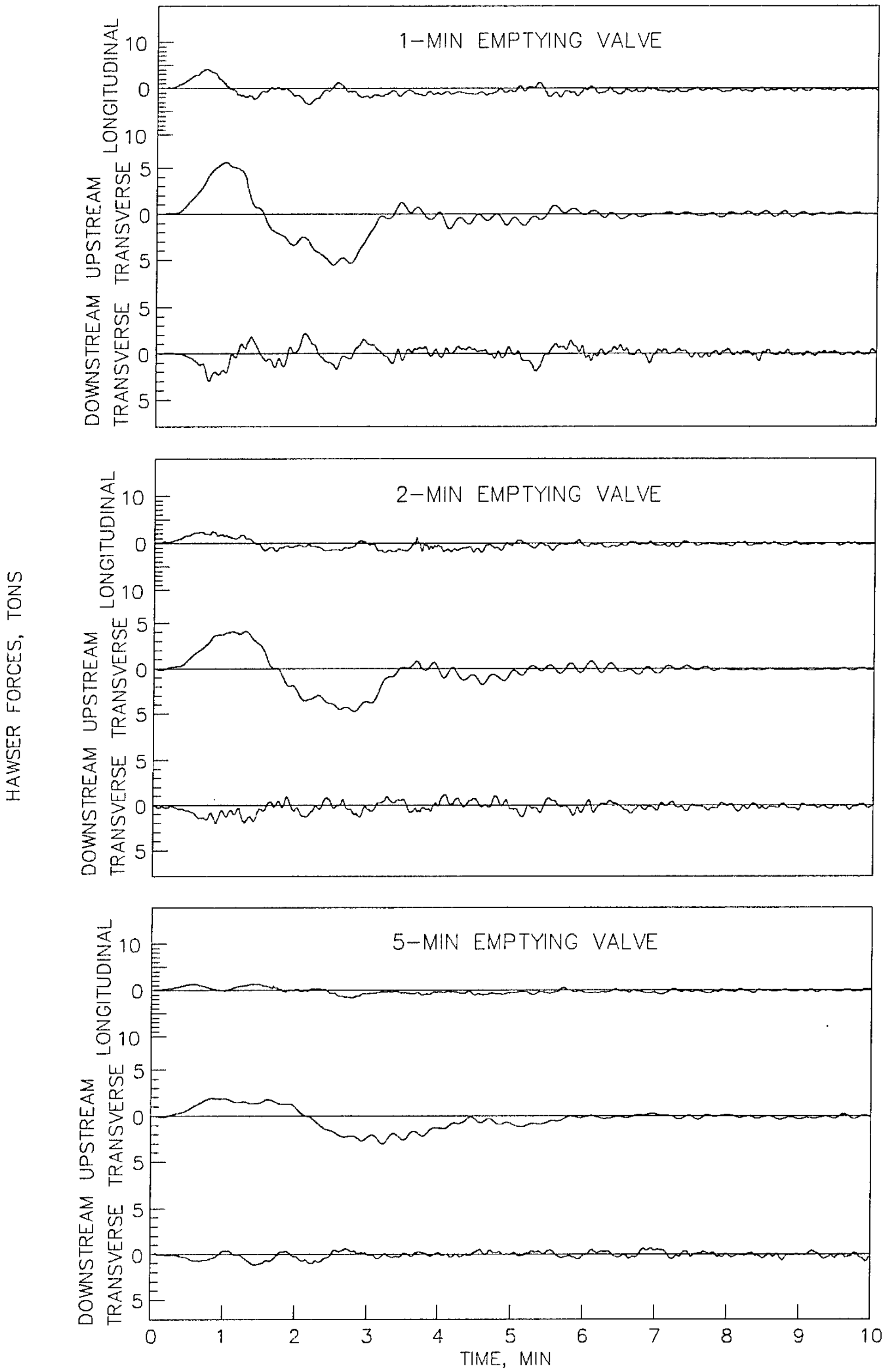


VELOCITIES IN LOWER APPROACH
TYPE 4 LOWER APPROACH
TYPE 11 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0

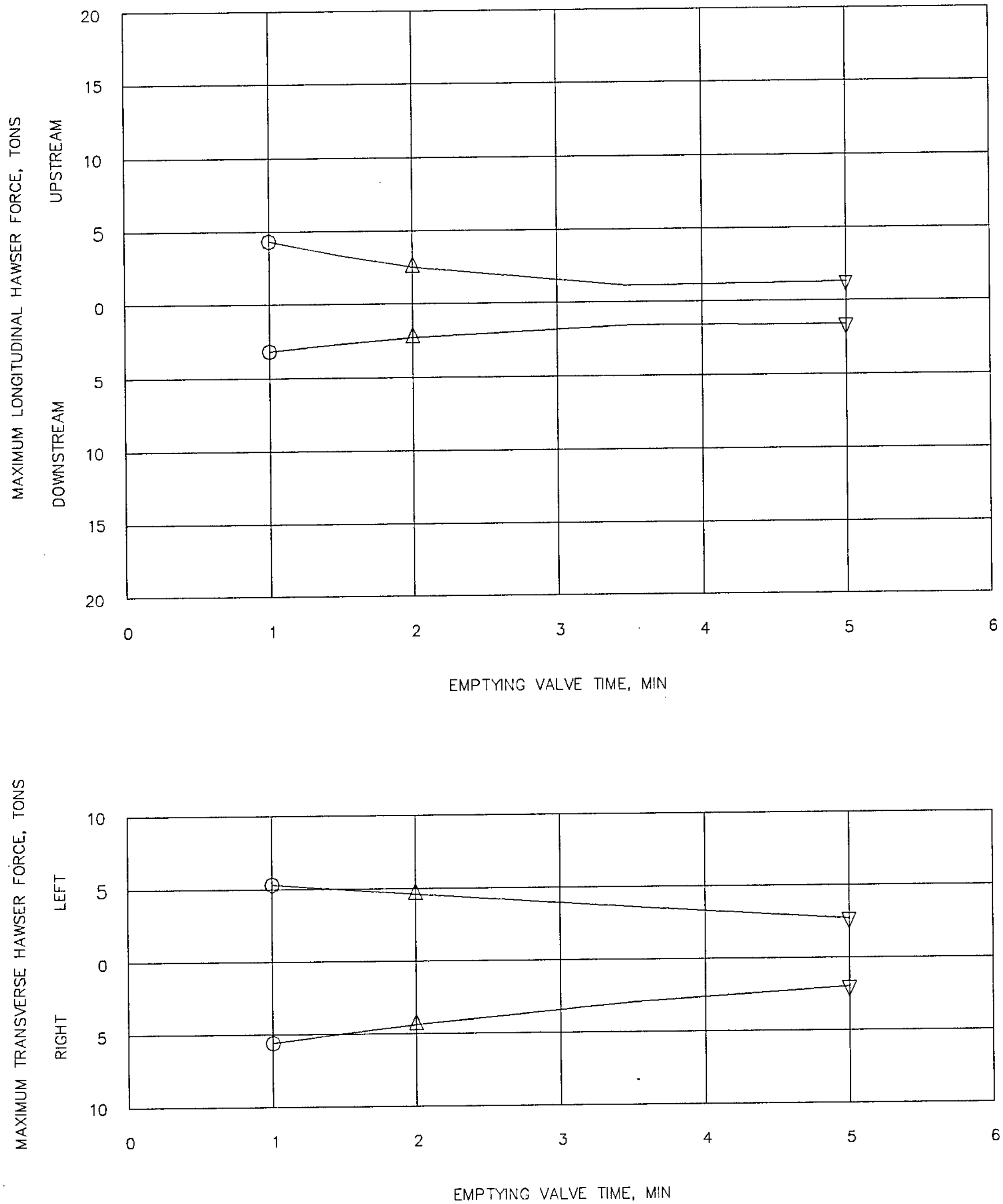


MAXIMUM VELOCITIES IN LOWER APPROACH
WITH 2-MIN EMPTYING VALVE
TYPE 4 DESIGN LOWER APPROACH
TYPE 11 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0
STA 14+70 D/S
LOWER PINTLE
EL 300
3.9
(200 SEC)
WARPED SLOPE
2.4
(255 SEC)
2.8
(265 SEC)
EL 300.0
VELOCITIES ARE IN FT/SEC
TAKEN 1 FT OFF BOTTOM
(TIME FROM BEGINNING OF VALVE OPENING)
WATER'S EDGE
3:1 SLOPE
EL 330.0


BARGE LOCATIONS IN LOWER APPROACH
LOWER PINTLE
EL 300
EL 286
WARPED SLOPE
3:1 SLOPE
FLOW
EL 300.0
EL 330.0
1
2
3
3 X 5 BARGE ARRANGEMENT
3 X 5 BARGE ARRANGEMENT

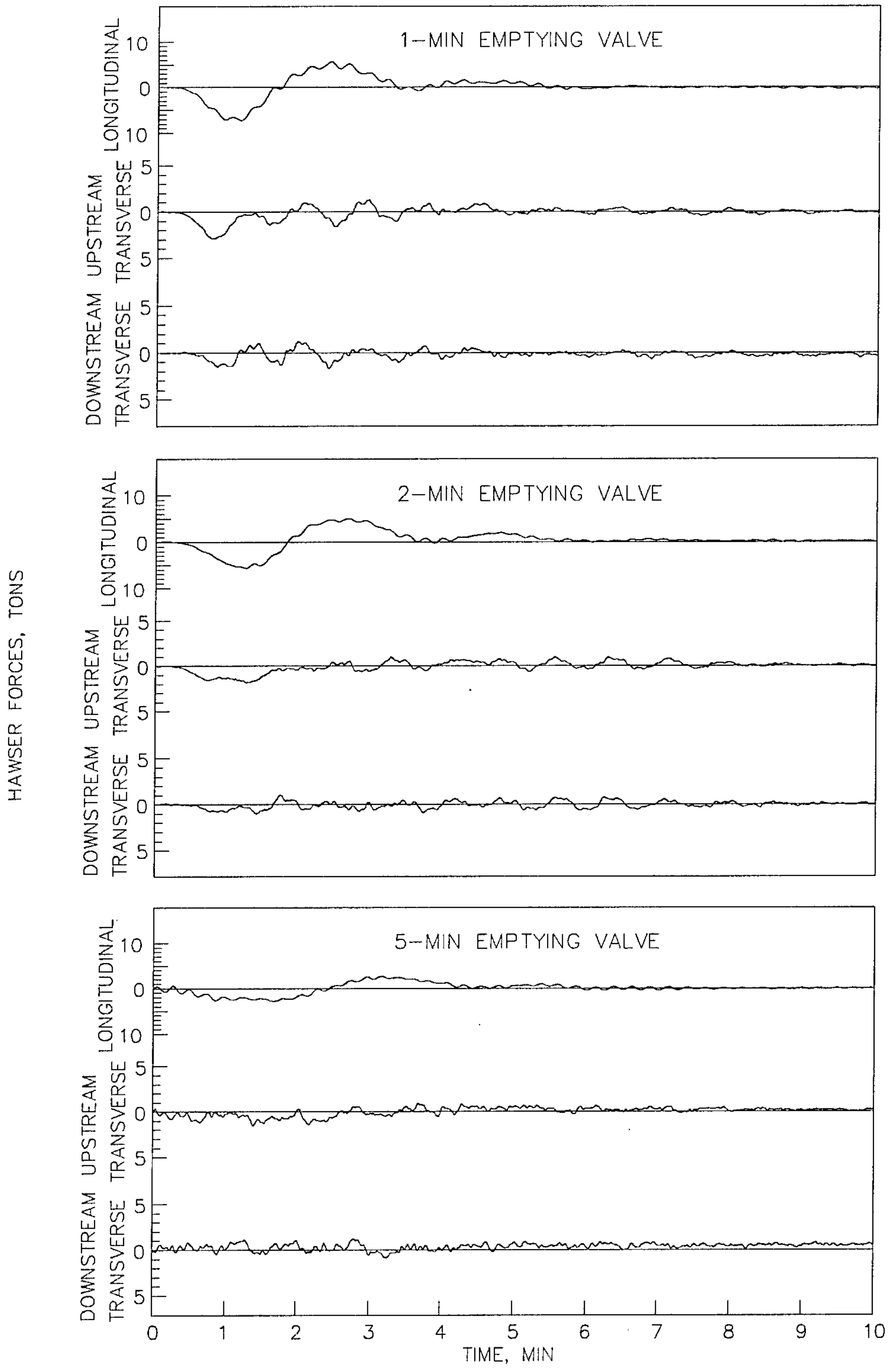


HAWSER FORCES, LOWER APPROACH
BARGE LOCATION 1
400-FT FLOATING GUIDE WALL
LOWER POOL EL 324

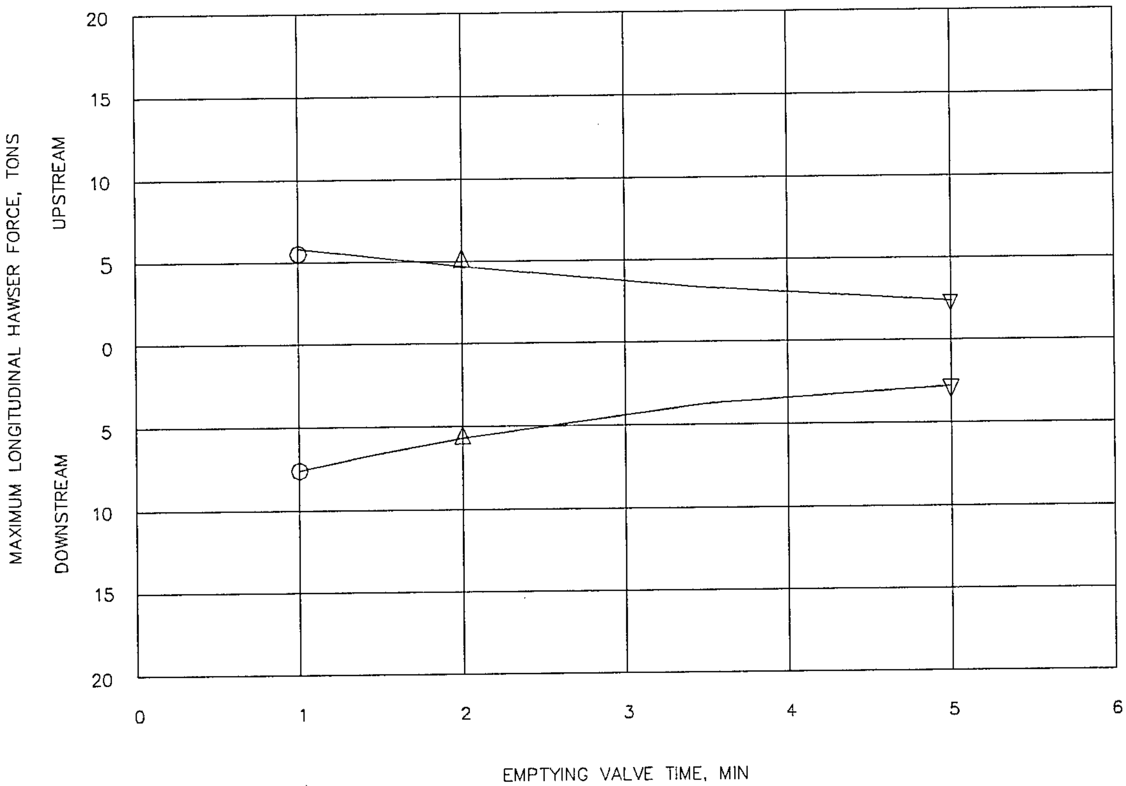


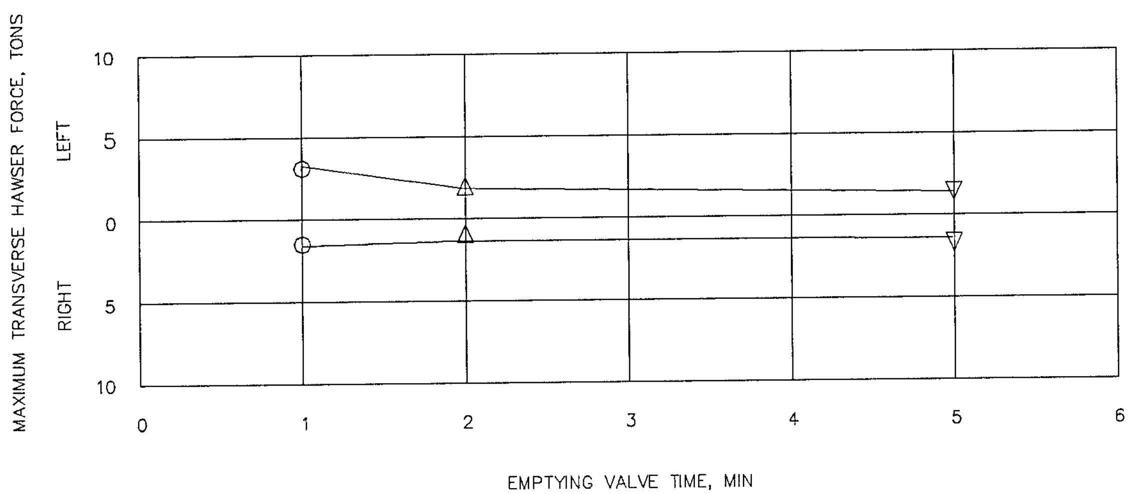
LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5

HAWSER FORCES
DURING EMPTYING
LOWER APPROACH
400-FT FLOATING WALL, LOCATION 1
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT



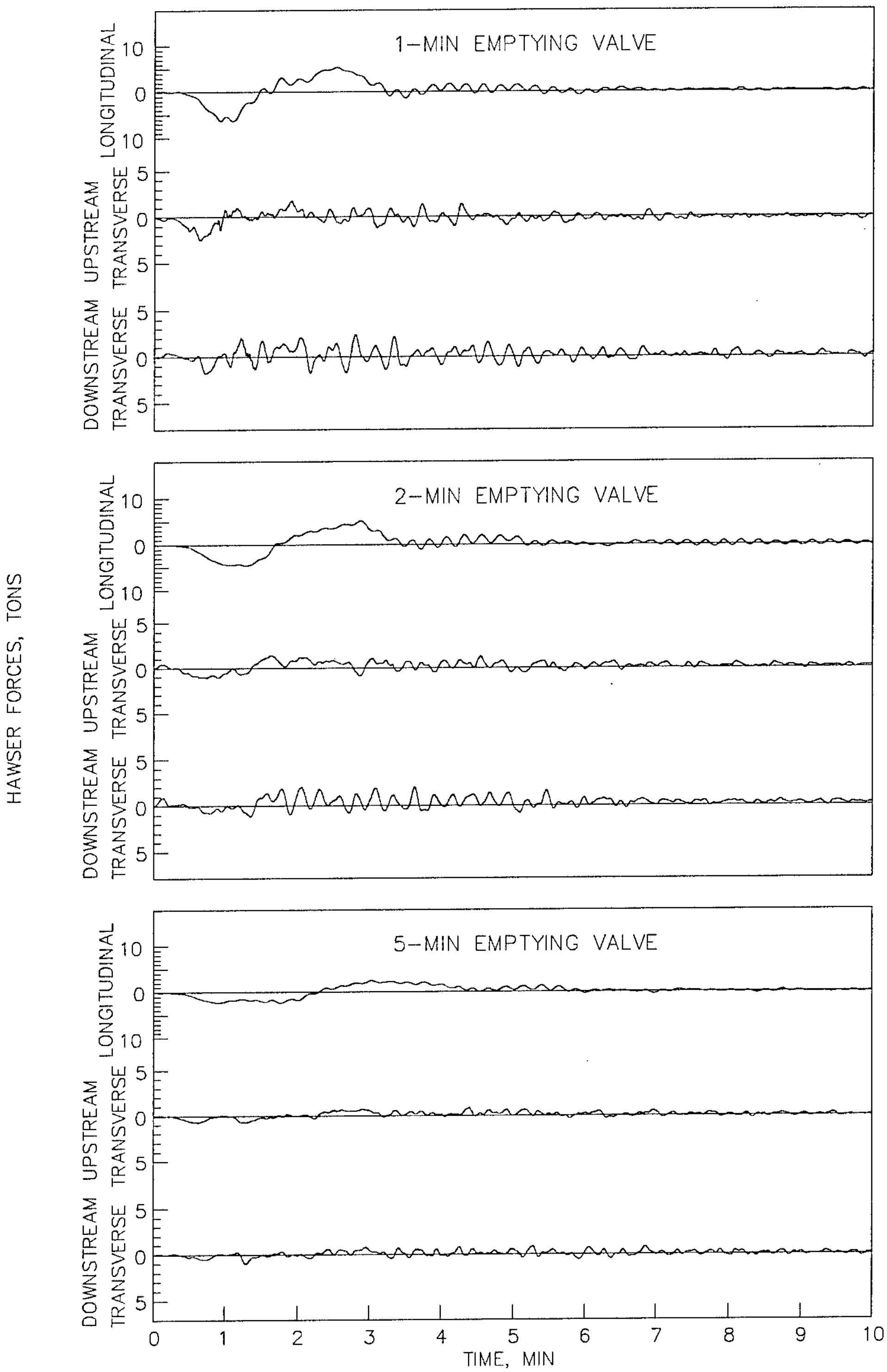
HAWSER FORCES, LOWER APPROACH
BARGE LOCATION 2
400-FT FLOATING GUIDE WALL
LOWER POOL EL 324



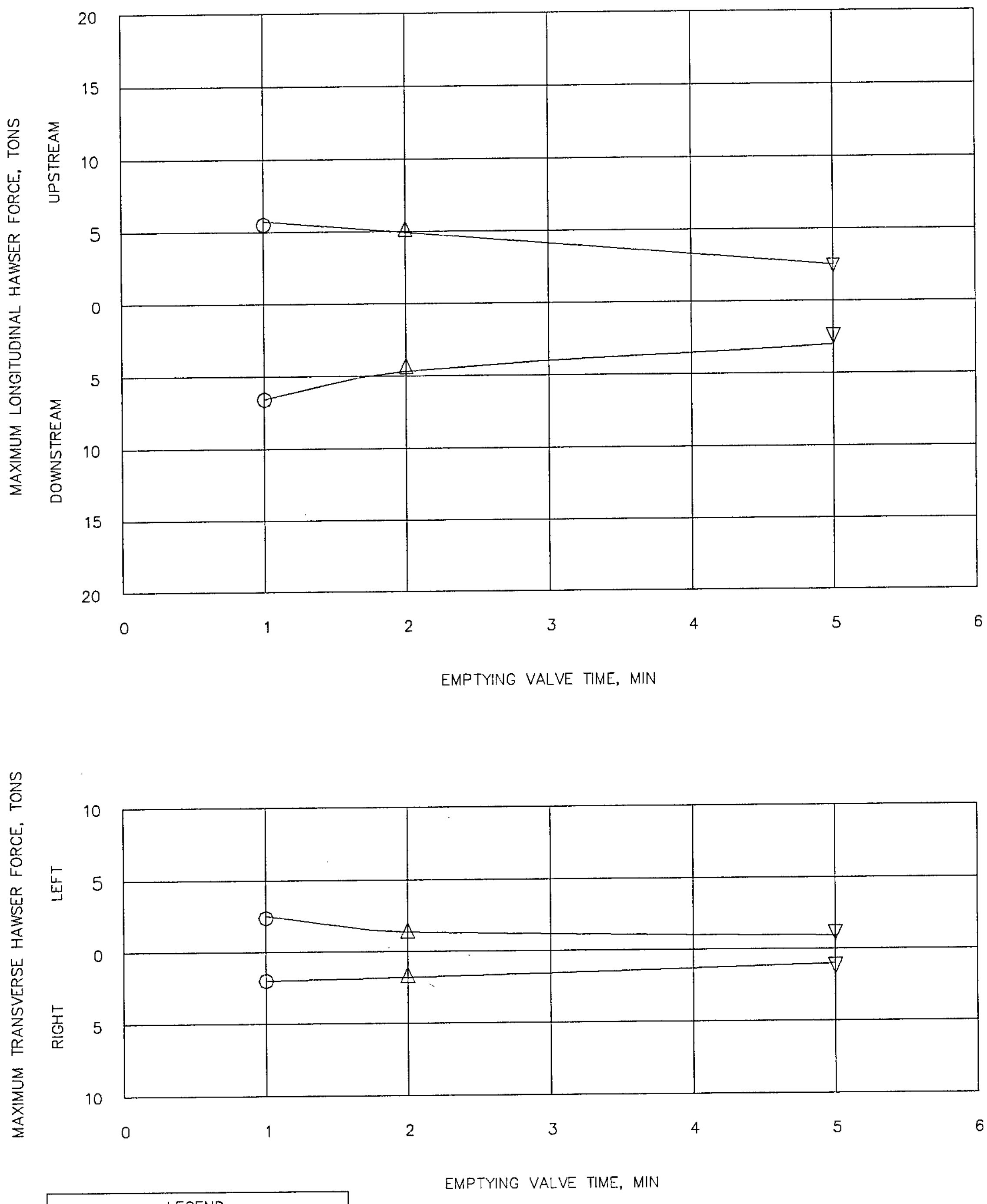


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5

HAWSER FORCES
DURING EMPTYING
LOWER APPROACH
400-FT FLOATING GUIDE WALL, LOCATION 2
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT

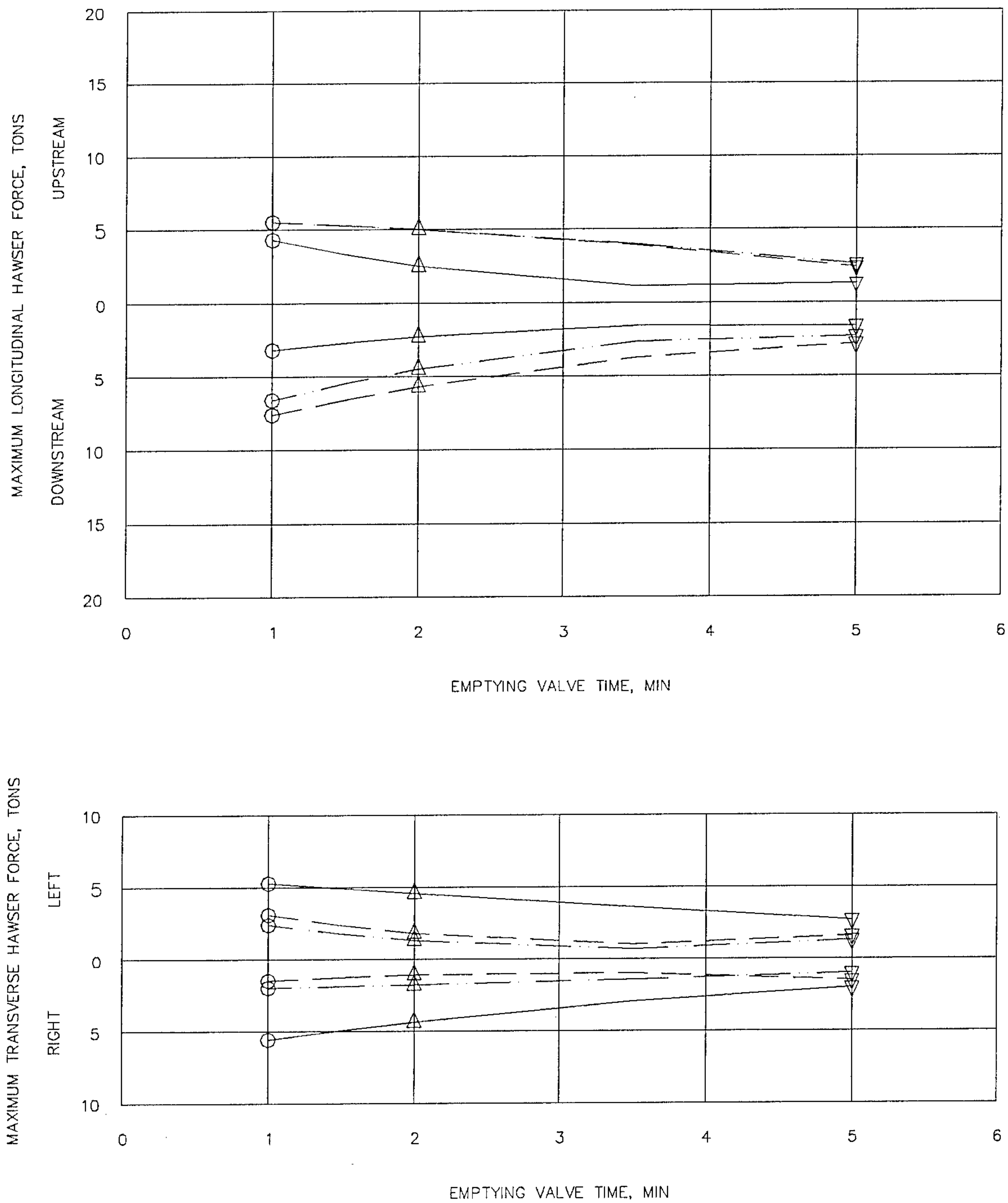


HAWSER FORCES, LOWER APPROACH
BARGE LOCATION 3
400-FT FLOATING GUIDE WALL
LOWER POOL EL 324



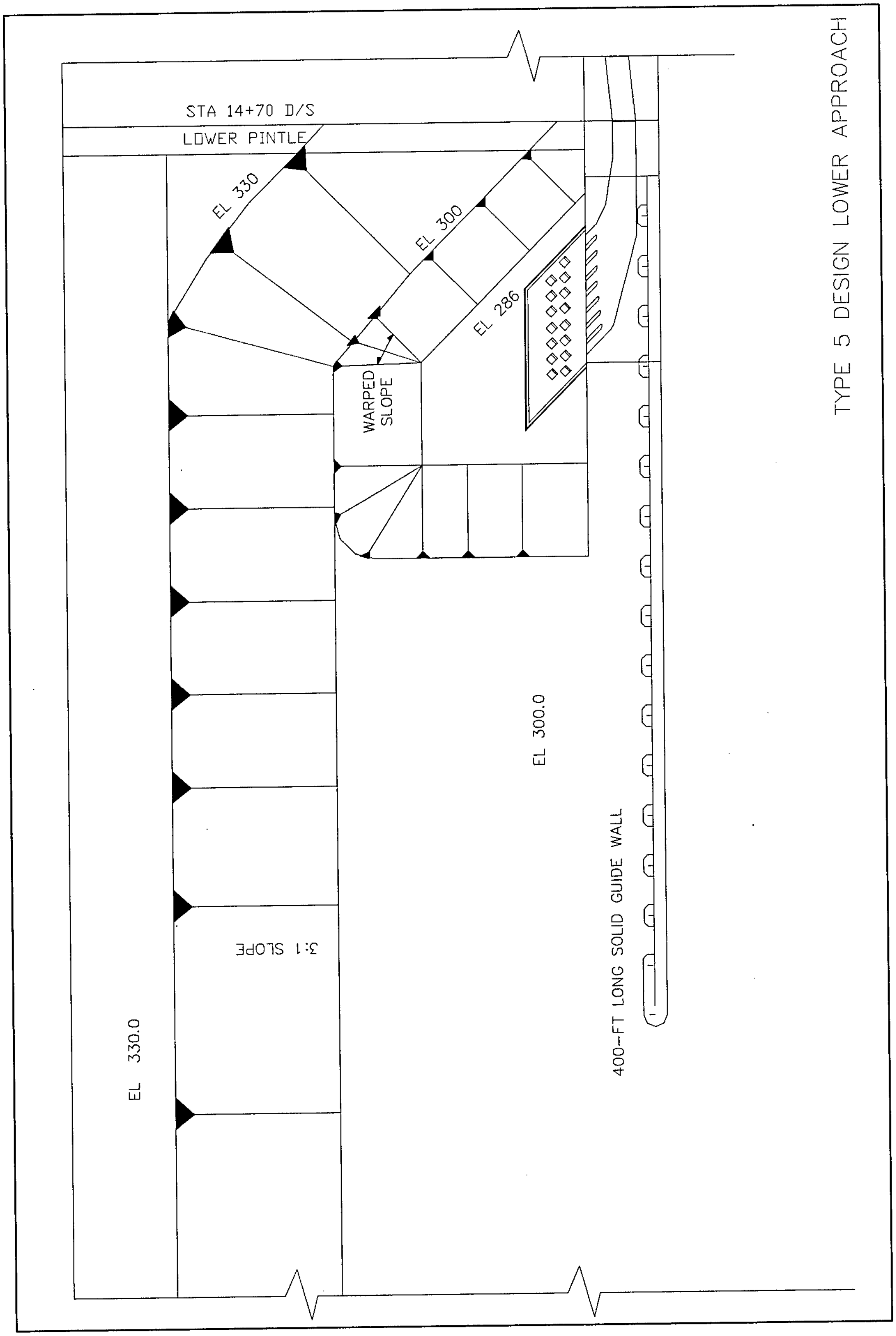
LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5

HAWSER FORCES
DURING EMPTYING
400-FT FLOATING GUIDE WALL, LOCATION 3
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5
LINETYPE	LOCATION
———	1
— —	2
— · —	3

COMPARISON OF
HAWSER FORCES
DURING EMPTYING
400-FT FLOATING GUIDE WALL
LOCATIONS 1,2,&3
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT


TYPE 5 DESIGN LOWER APPROACH
STA 14+70 D/S
LOWER PINTLE
EL 330
EL 300
EL 286
WARPED SLOPE
EL 300.0
400-FT LONG SOLID GUIDE WALL
3:1 SLOPE
EL 330.0

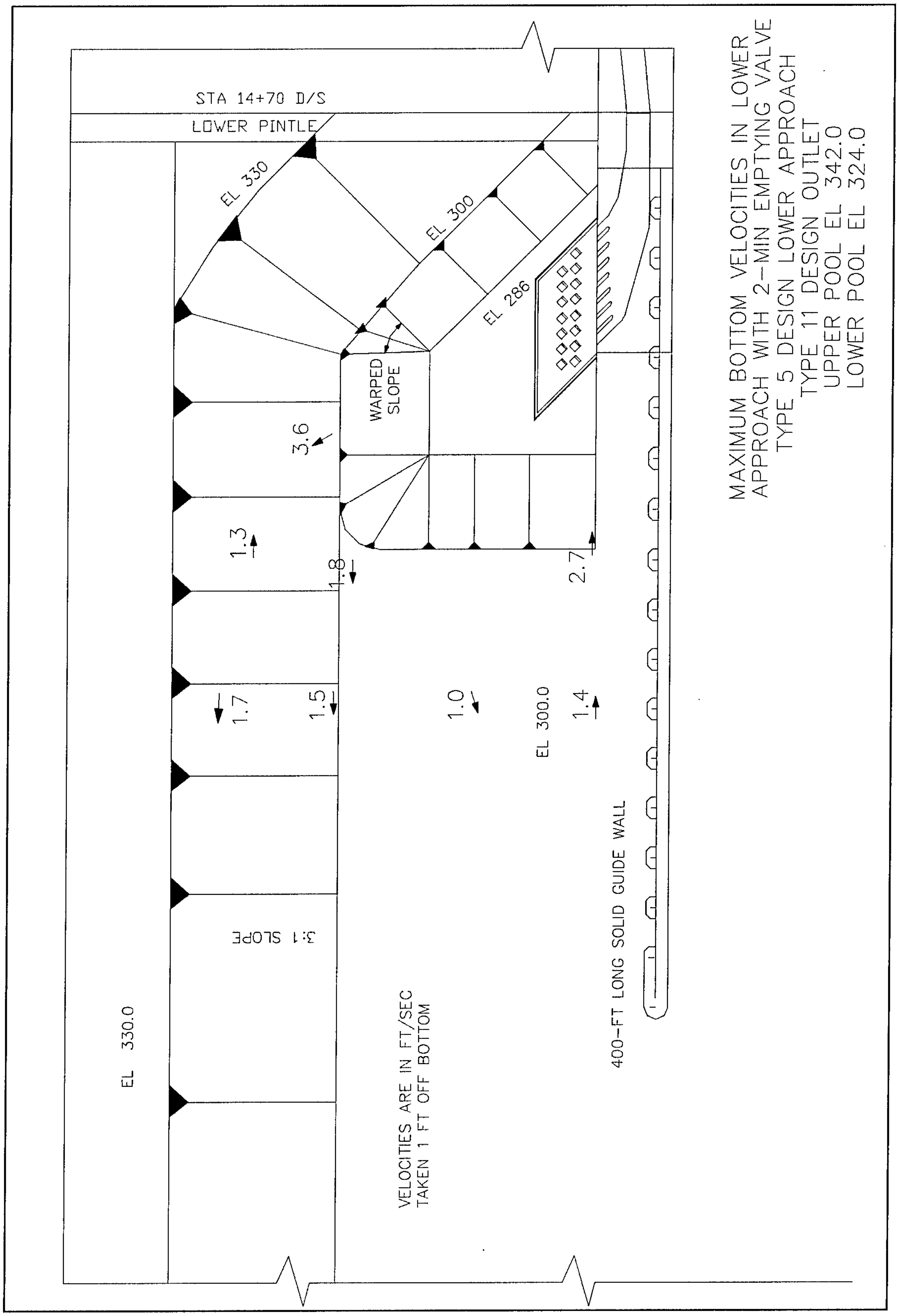
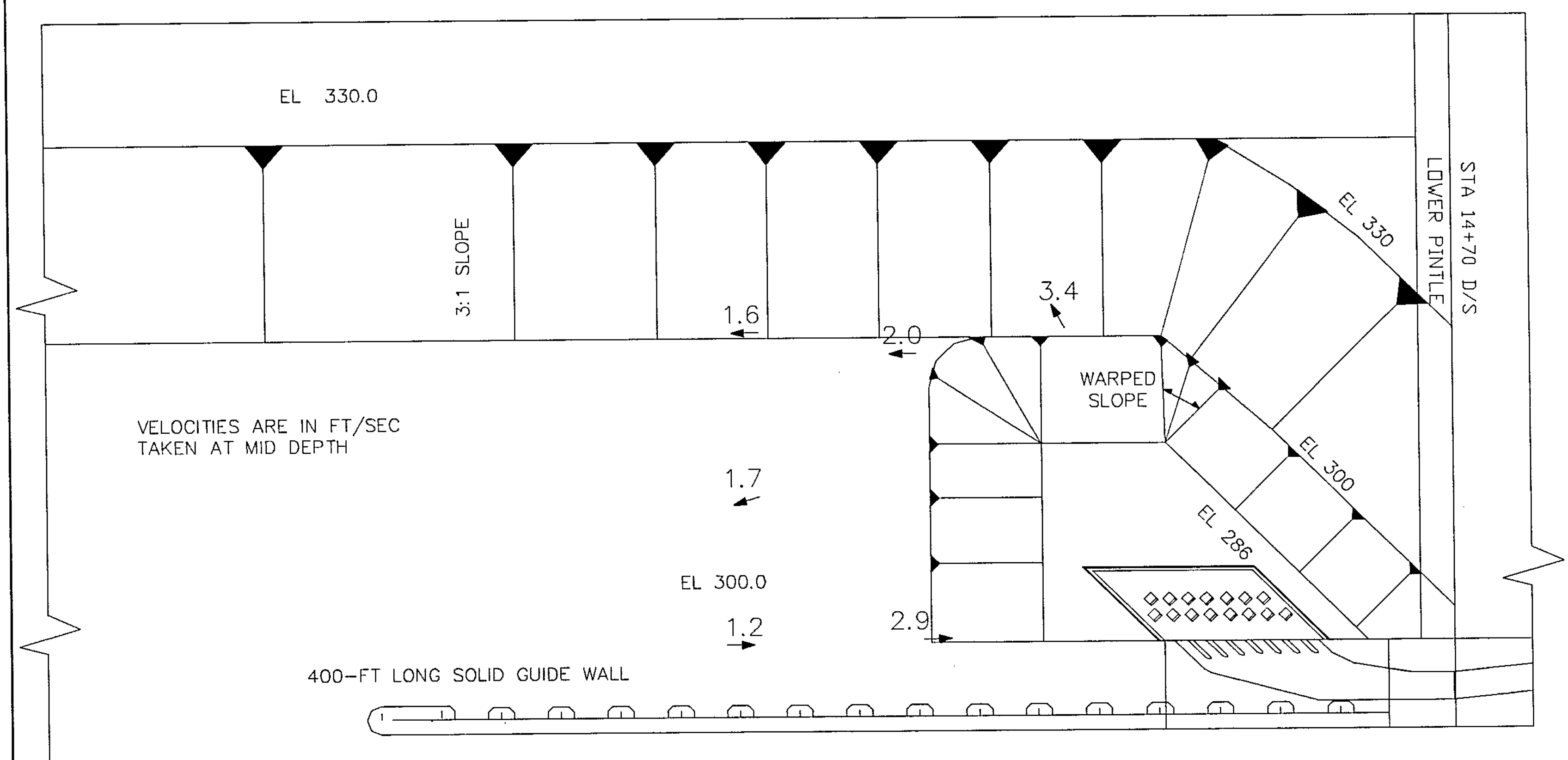

MAXIMUM BOTTOM VELOCITIES IN LOWER
APPROACH WITH 2-MIN EMPTYING VALVE
TYPE 5 DESIGN LOWER APPROACH
TYPE 11 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0
STA 14+70 D/S
LOWER PINTLE
EL 330
EL 300
EL 286
WARPED SLOPE
3.6
1.3
1.8
2.7
1.7
1.5
1.0
EL 300.0
1.4
3:1 SLOPE
EL 330.0
VELOCITIES ARE IN FT/SEC
TAKEN 1 FT OFF BOTTOM
400-FT LONG SOLID GUIDE WALL

Plate 34



MAXIMUM MID DEPTH VELOCITIES IN LOWER APPROACH WITH 2-MIN EMPTYING VALVE
TYPE 5 DESIGN LOWER APPROACH
TYPE 11 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0

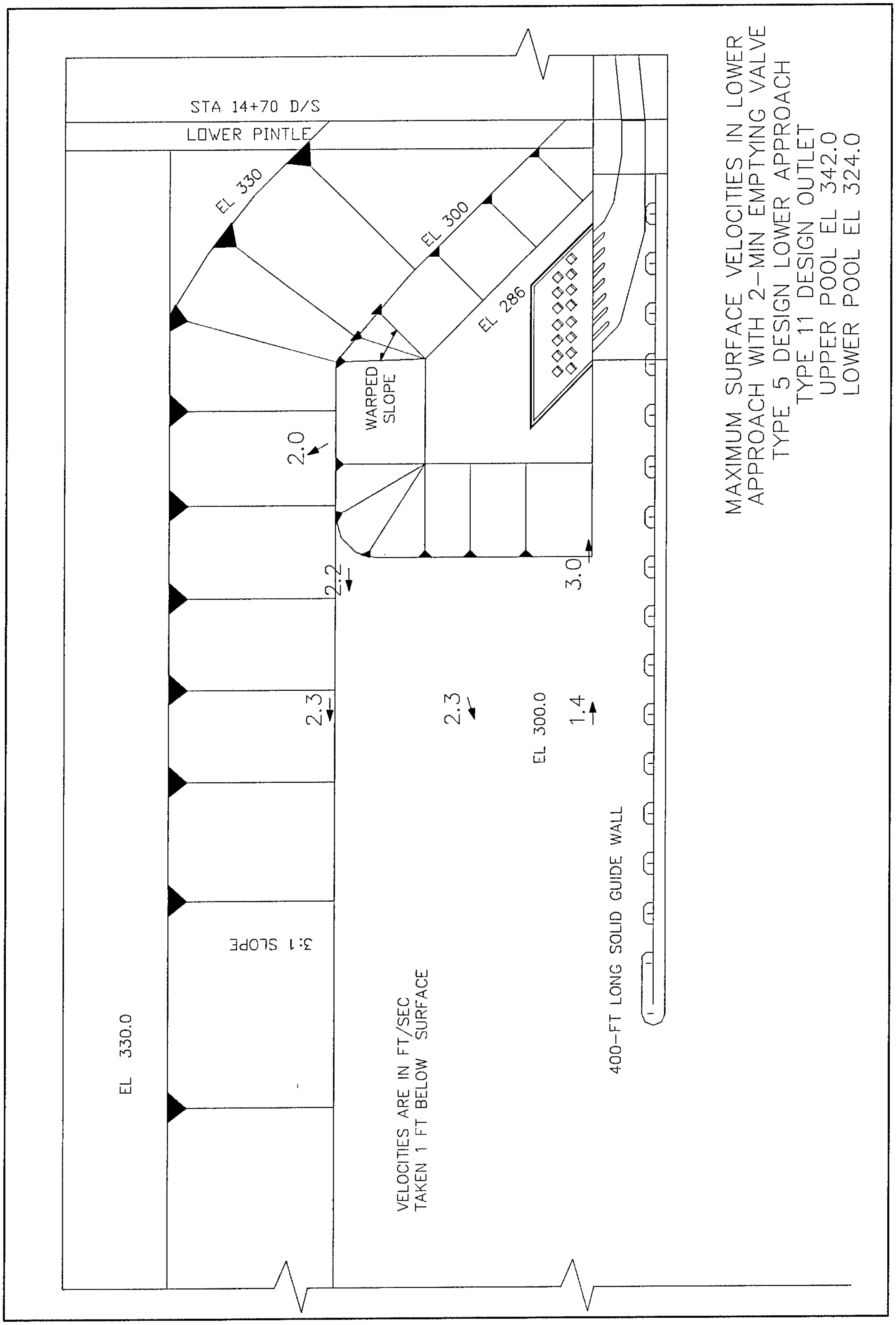
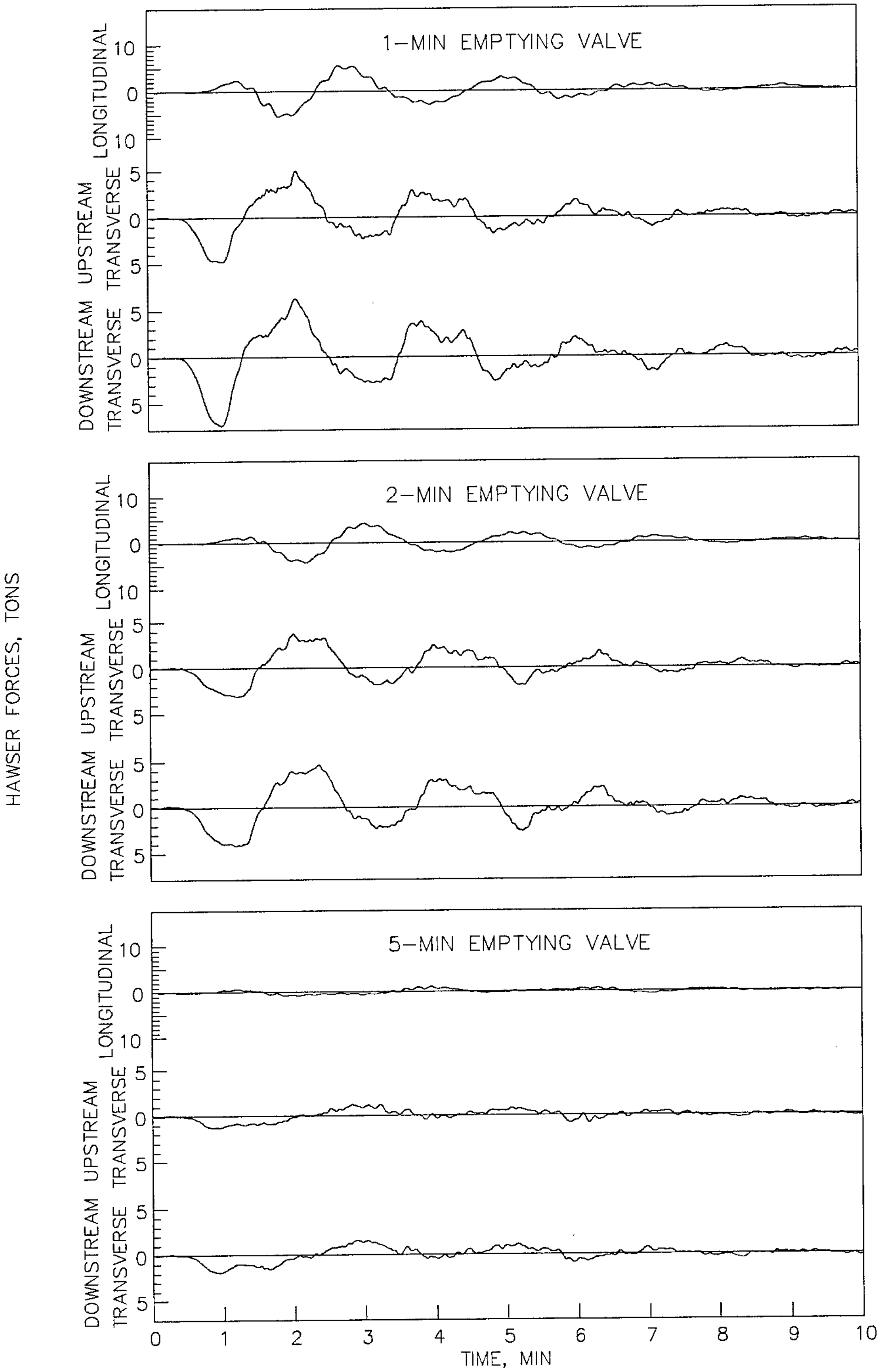
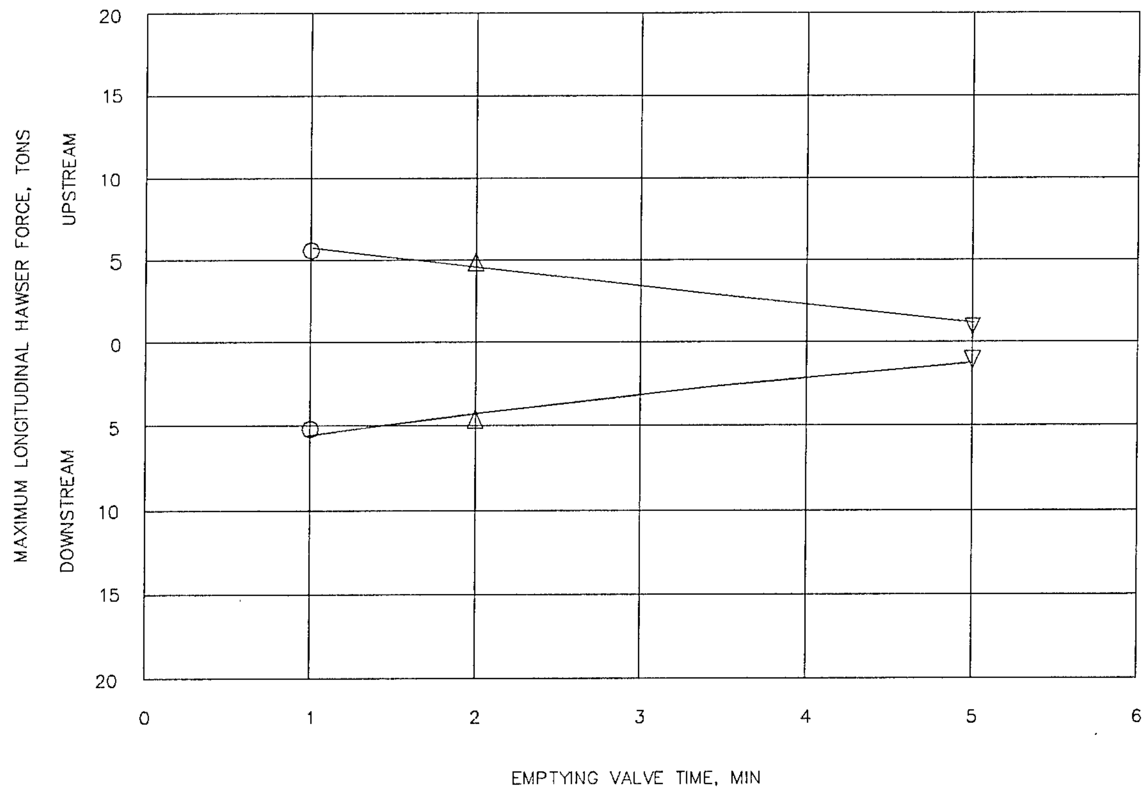
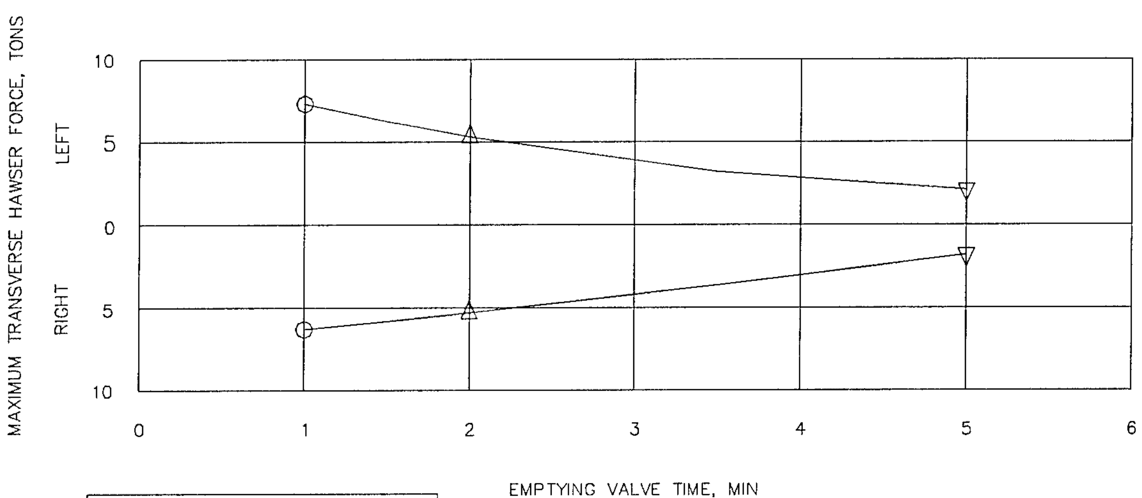

MAXIMUM SURFACE VELOCITIES IN LOWER
APPROACH WITH 2-MIN EMPTYING VALVE
TYPE 5 DESIGN LOWER APPROACH
TYPE 11 DESIGN OUTLET
UPPER POOL EL 342.0
LOWER POOL EL 324.0
STA 14+70 D/S
LOWER PINTLE
EL 330
EL 300
EL 286
WARPED SLOPE
2.0
2.2
3.0
2.3
2.3
1.4
EL 300.0
400-FT LONG SOLID GUIDE WALL
3:1 SLOPE
EL 330.0
VELOCITIES ARE IN FT/SEC
TAKEN 1 FT BELOW SURFACE

Plate 36



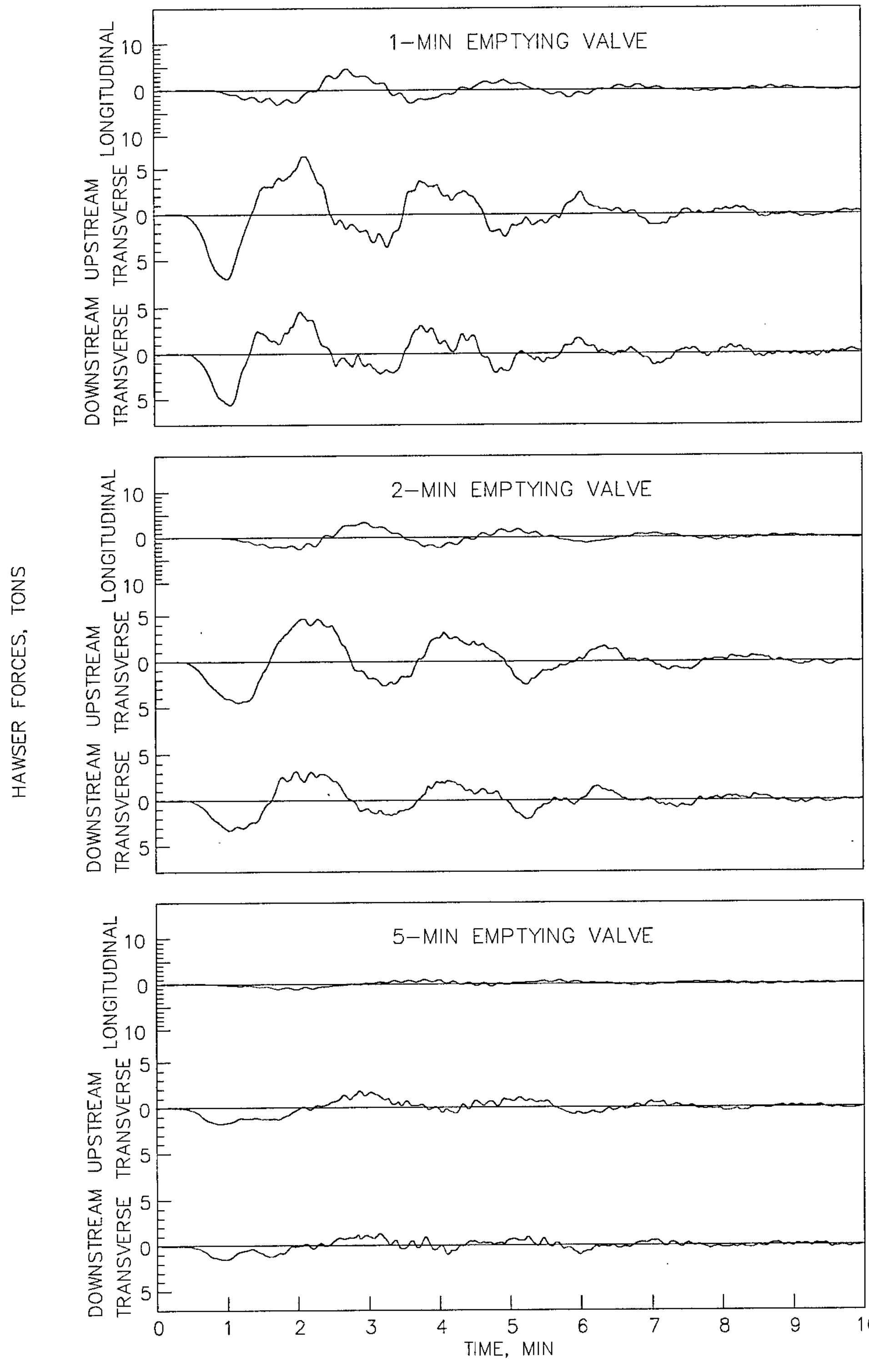
HAWSER FORCES, LOWER APPROACH
BARGE LOCATION 1
400-FT SOLID GUIDE WALL
LOWER POOL EL 324



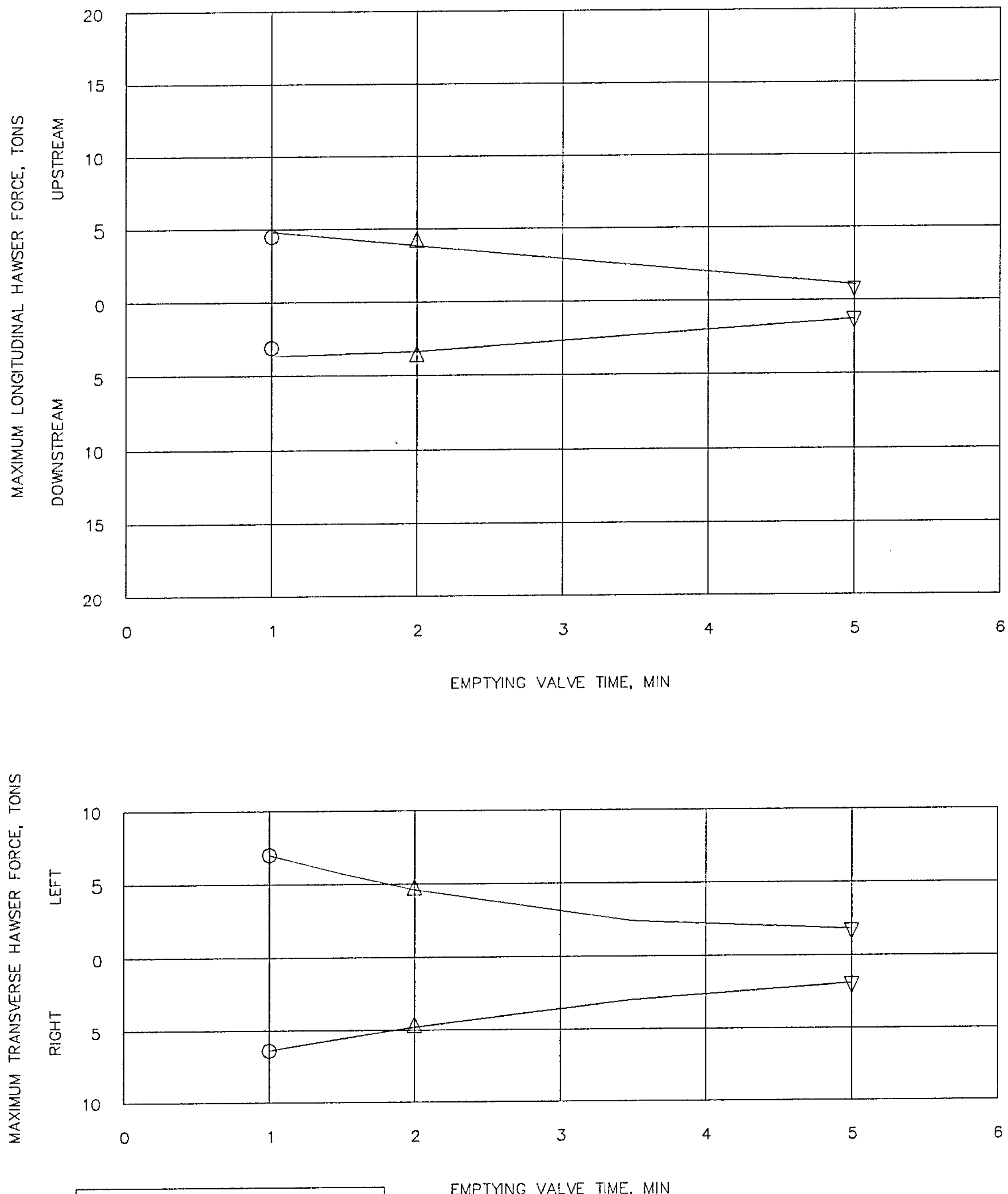


LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5

HAWSER FORCES
DURING EMPTYING
400-FT SOLID GUIDE WALL, LOCATION 1
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT

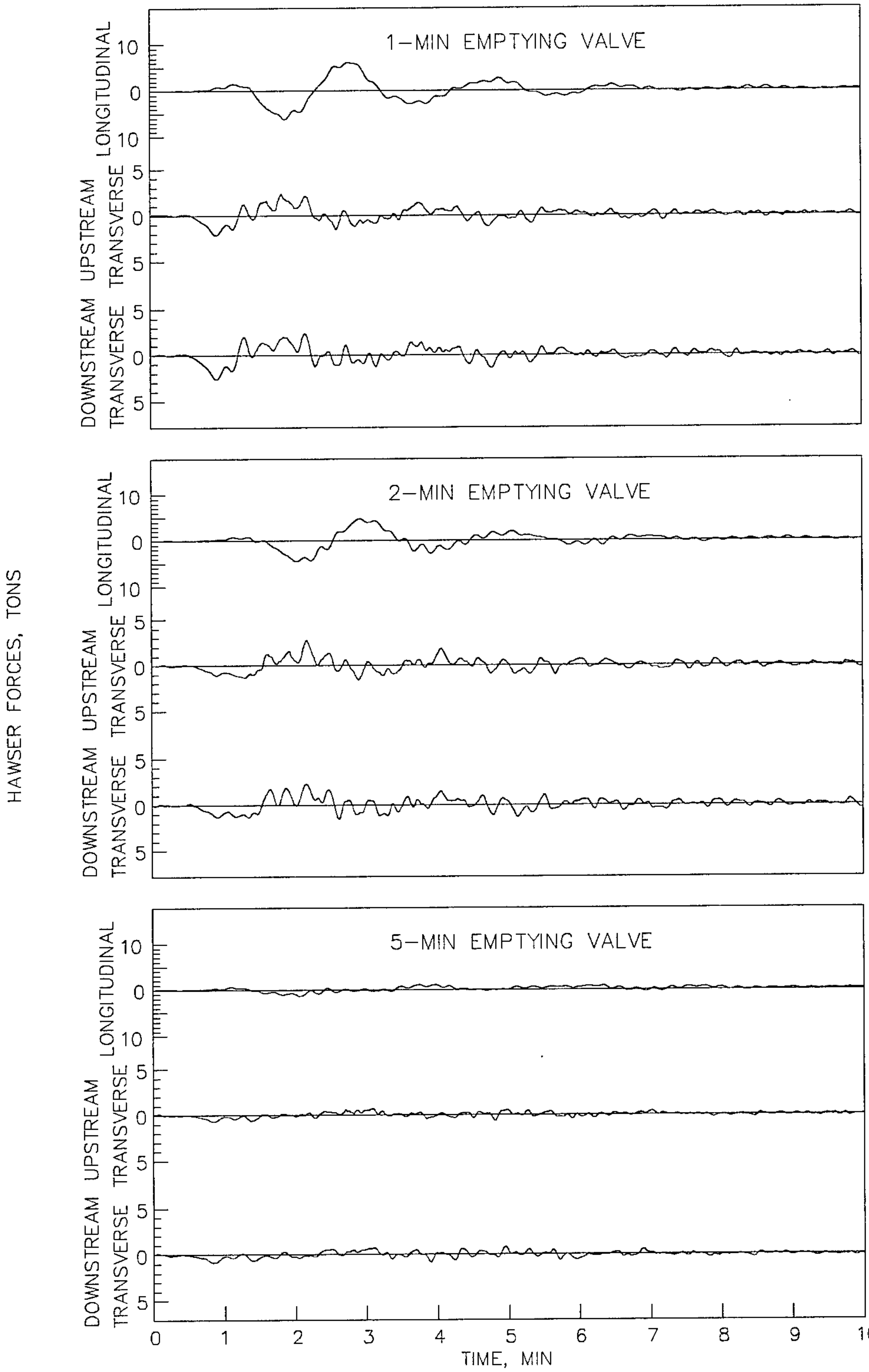


HAWSER FORCES, LOWER APPROACH
BARGE LOCATION 2
400-FT SOLID GUIDE WALL
LOWER POOL EL 324

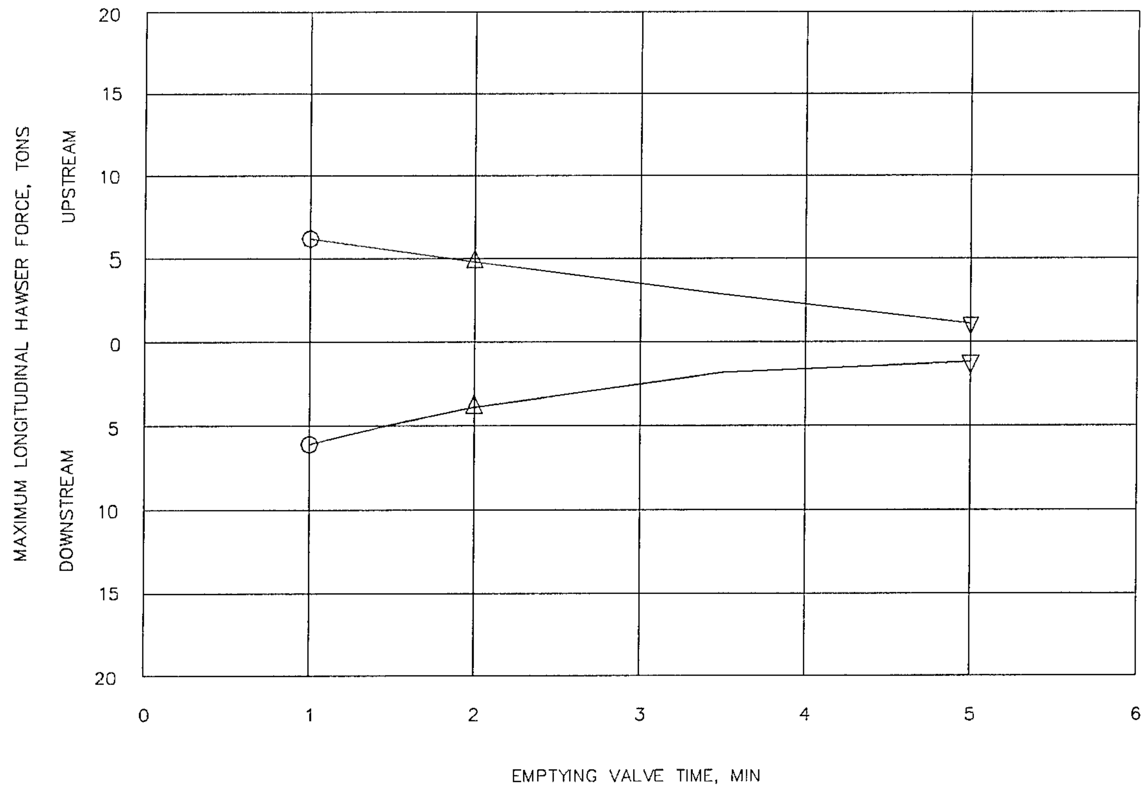


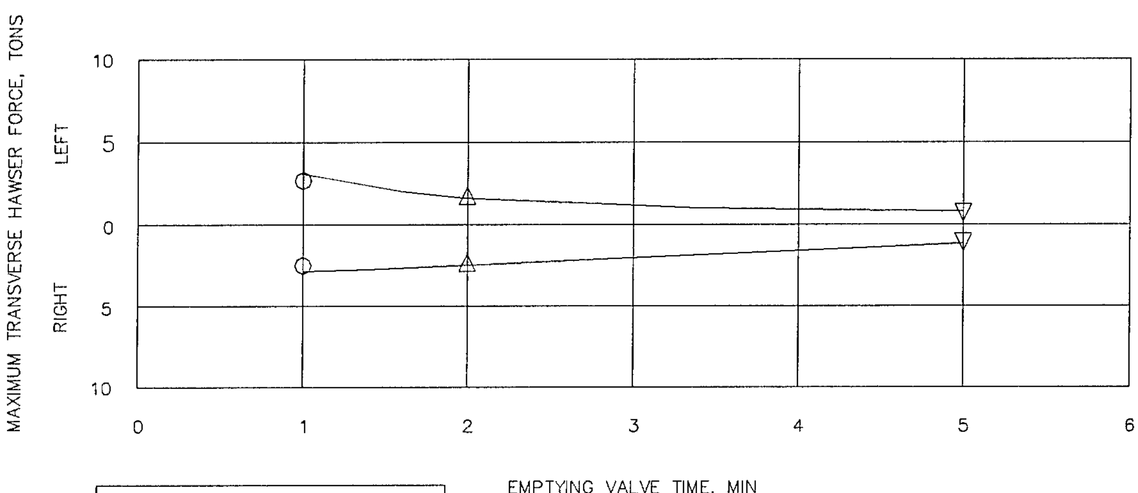
LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5

HAWSER FORCES
DURING EMPTYING
400-FT SOLID GUIDE WALL, LOCATION 2
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT



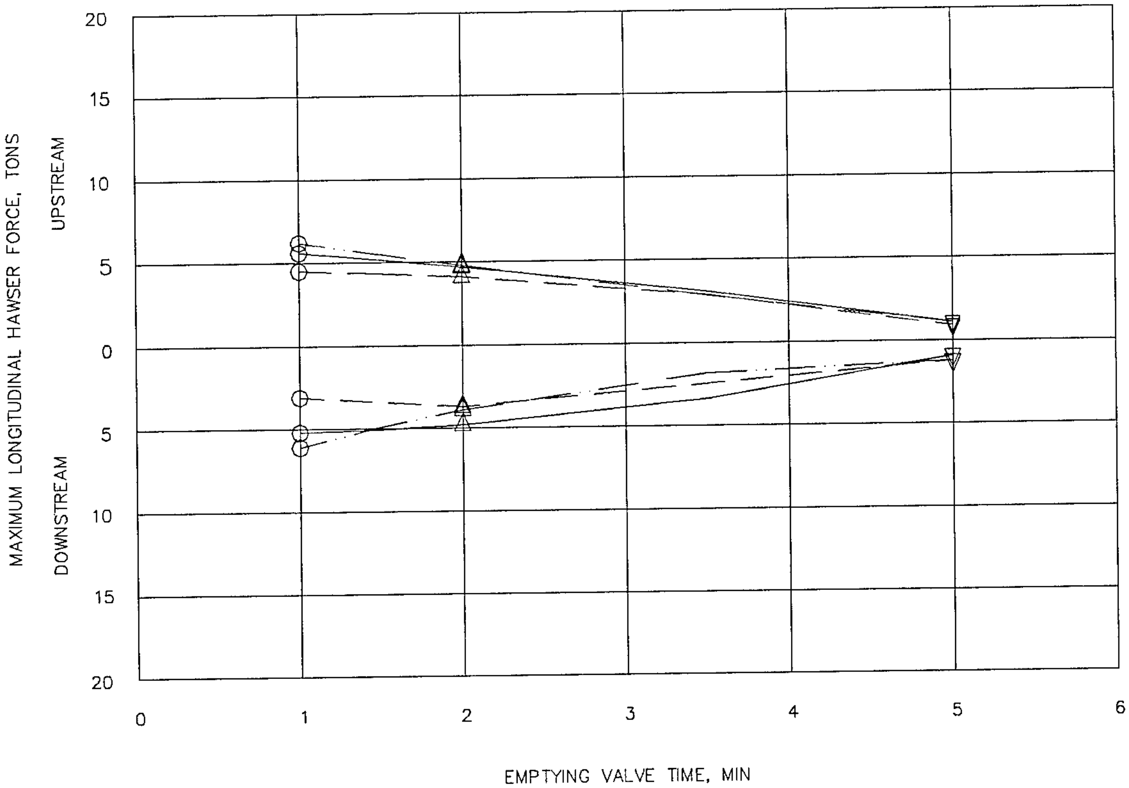
HAWSER FORCES, LOWER APPROACH
BARGE LOCATION 3
400-FT SOLID GUIDE WALL
LOWER POOL EL 324

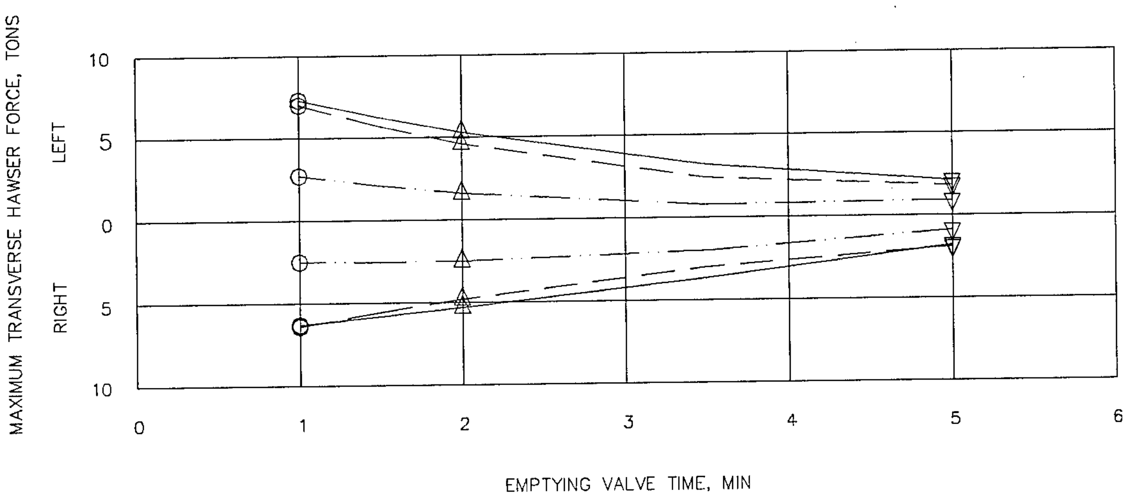




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5

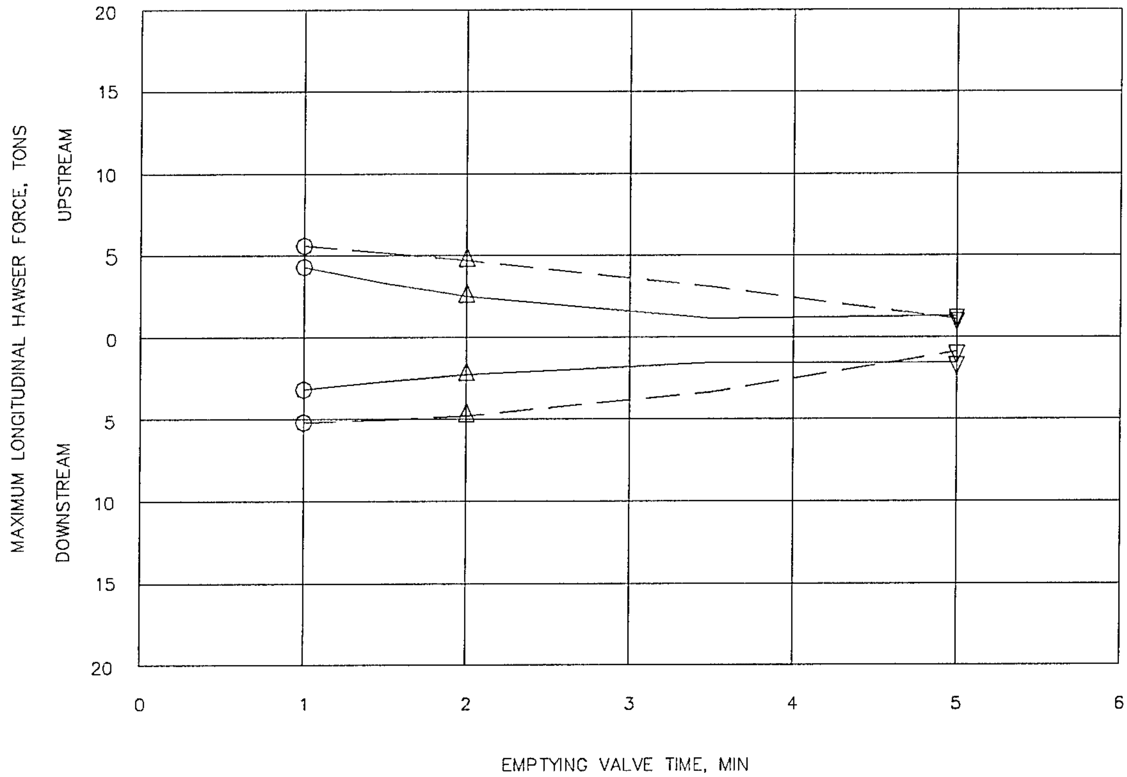
HAWSER FORCES
DURING EMPTYING
400-FT SOLID GUIDE WALL, LOCATION 3
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT

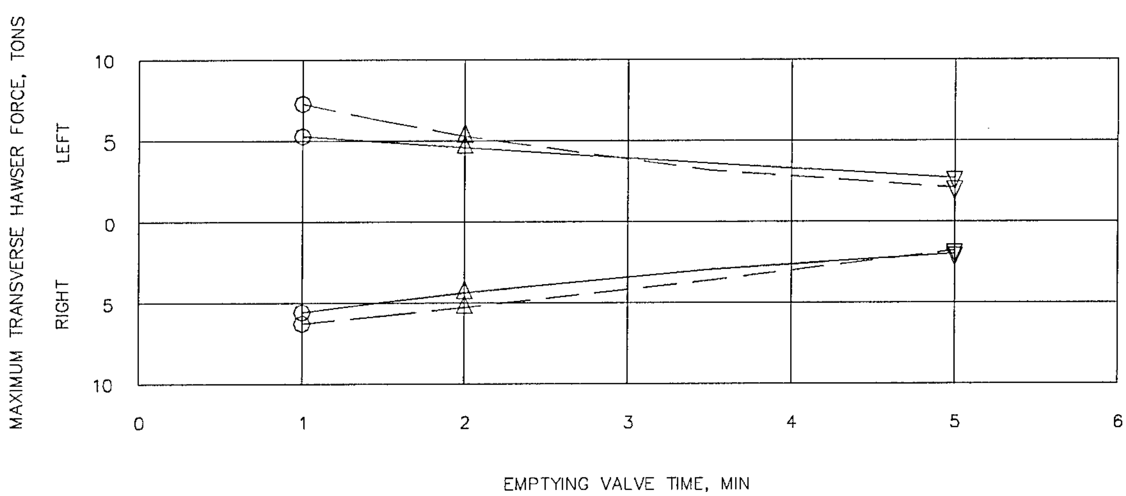




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5
LINETYPE	LOCATION
———	1
— —	2
—·—·—	3

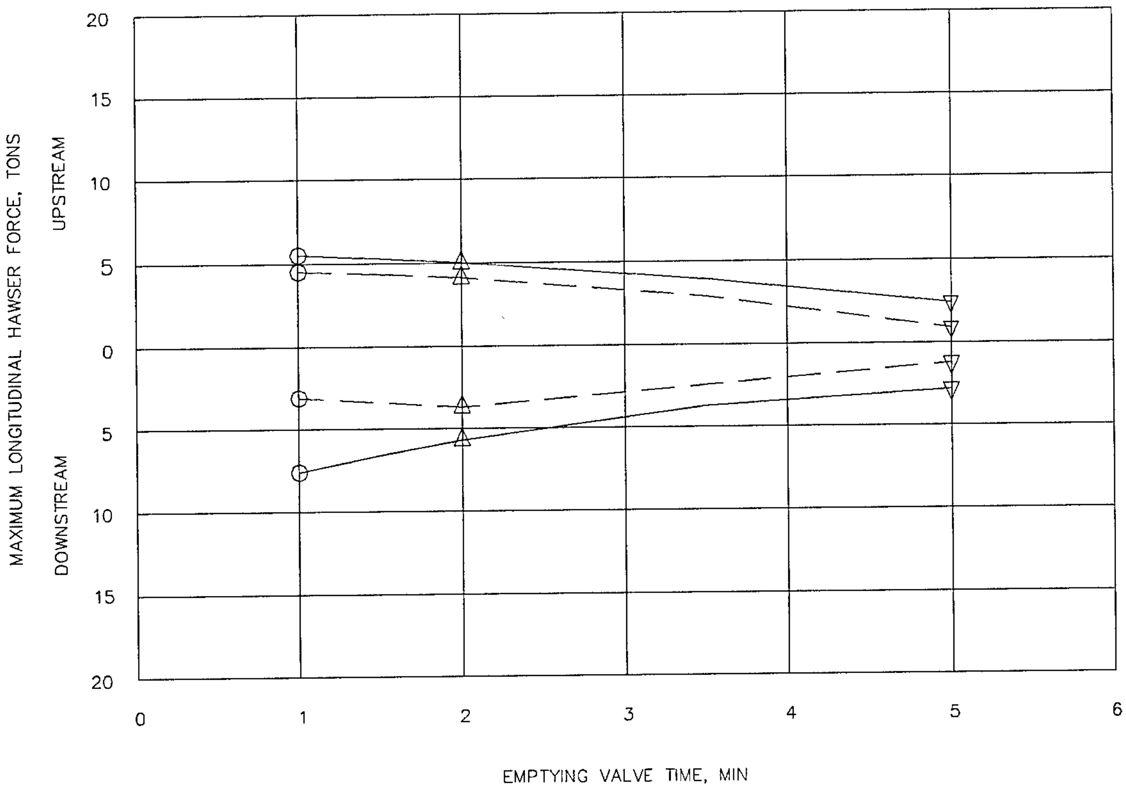
COMPARISON OF
HAWSER FORCES
DURING EMPTYING
400-FT SOLID GUIDE WALL
LOCATIONS 1,2,&3
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT

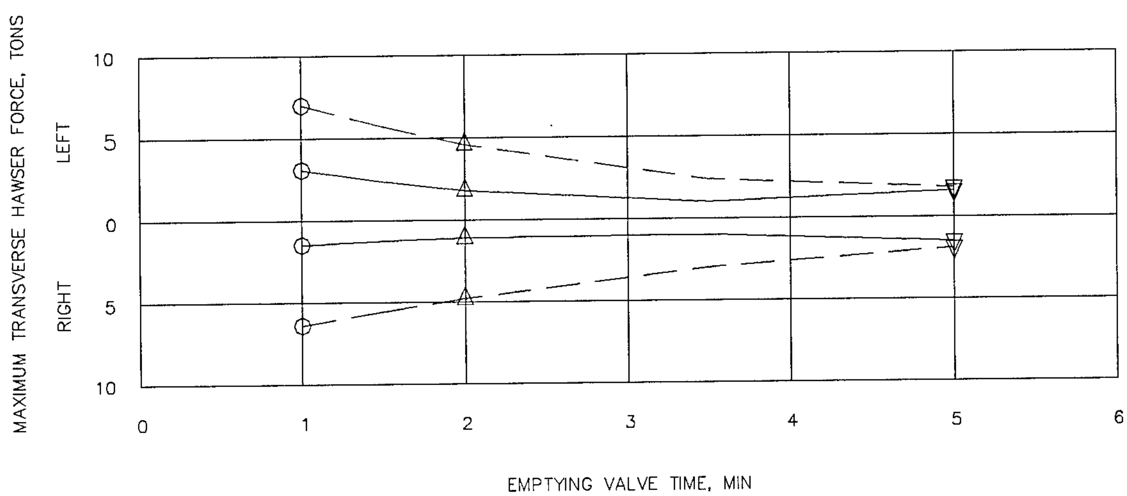




LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5
LINETYPE	TYPE
———	FLOATING GUIDE WALL
— —	SOLID GUIDE WALL

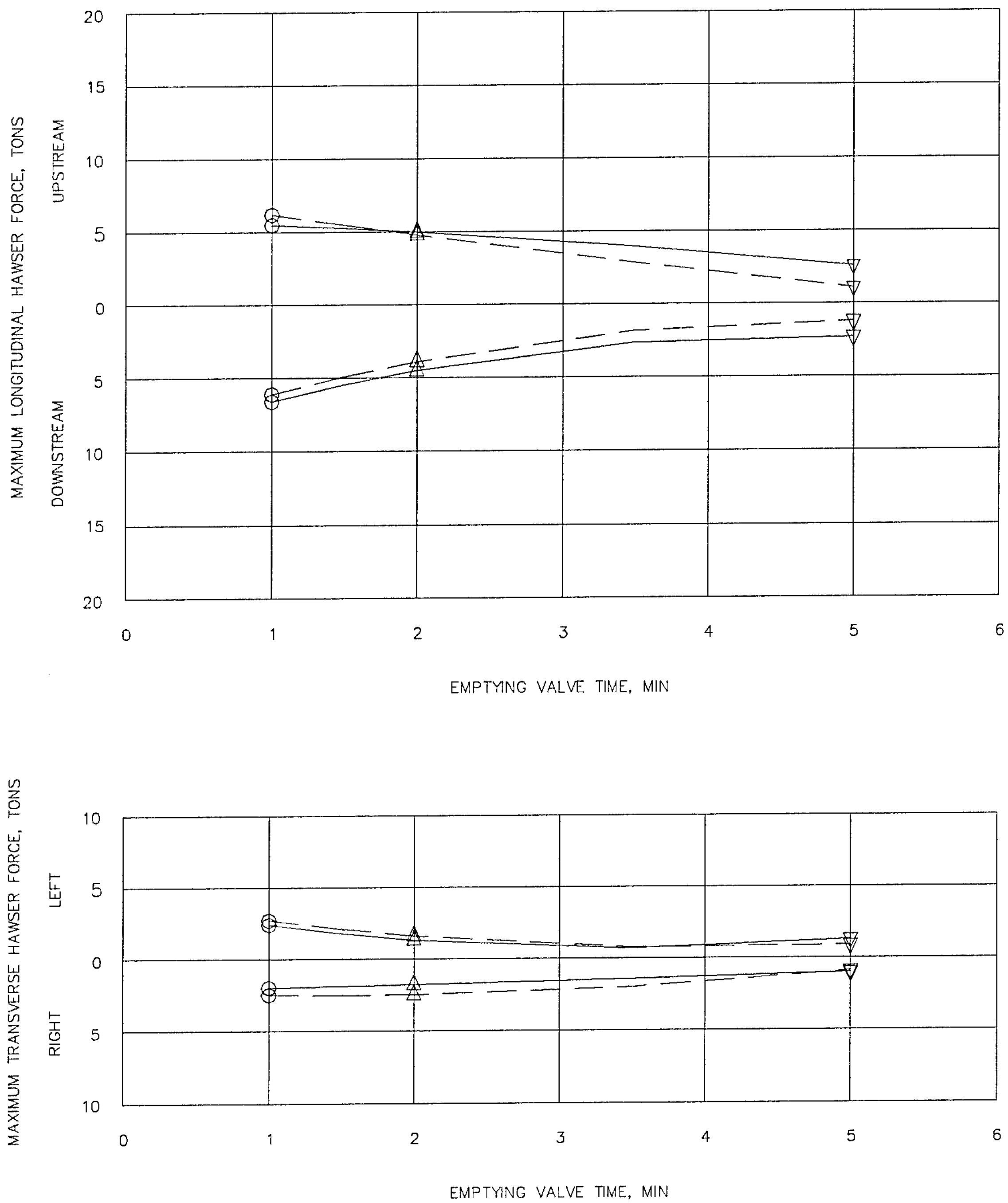
COMPARISON OF
HAWSER FORCES
DURING EMPTYING
LOCATION 1
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT





LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5
LINETYPE	TYPE
———	FLOATING GUIDE WALL
— —	SOLID GUIDE WALL

COMPARISON OF
HAWSER FORCES
DURING EMPTYING
LOCATION 2
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT



LEGEND	
SYMBOL	VALVE SCHEDULE, MIN
○	1
△	2
▽	5
LINETYPE	TYPE
———	FLOATING GUIDE WALL
— —	SOLID GUIDE WALL

COMPARISON OF
HAWSER FORCES
DURING EMPTYING
LOCATION 3
LOWER APPROACH
UPPER POOL EL 342.0
LOWER POOL EL 324.0
18-FT LIFT

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
August 2004

2. REPORT TYPE
Final report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
J. T. Myers Lock Outlet Study, Ohio River; Hydraulic Model Investigation

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
John E. Hite, Jr.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center
Coastal and Hydraulics Laboratory
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CHL TR-04-9

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Louisville
Mazzoli Federal Building, 600 Dr. Martin Luther King Place
Louisville, KY 40202

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Navigation improvements are planned at J. T. Myers Locks and Dam on the Ohio River main stem. The existing project consists of a navigation dam, a 1,200-ft-long by 110-ft-wide main lock chamber adjacent to a 600-ft-long by 110-ft-wide auxiliary lock chamber. One of the improvements includes developing a 1,200-ft-long lock chamber from the existing 600-ft-long lock chamber. The outlet design proposed for the filling and emptying system in the extended lock section was a manifold type diffuser located within the landside guide wall monolith and discharging toward the right (looking downstream) bank. A landside diffuser would help minimize closure of the main lock during construction of the lock extension. A 1:25-scale model was used to evaluate the outlet design. Modifications to the original design were made to improve the hydraulic conditions at the outlet. The vanes in the original design outlet were angled downstream to direct the jets away from the right bank. This design was the type 2 outlet diffuser. A stilling basin with two rows of baffle blocks and an end sill was developed to help dissipate the energy of the outlet discharge and reduce the potential for scour. The banks were also reshaped to direct the outlet flow downstream. The size riprap required to protect the area surrounding the outlet was determined. Hawser forces were also measured on tows moored at various locations in the lower approach with solid and floating guide walls.

15. SUBJECT TERMS
Hawser forces
J. T. Myers navigation project
Lock extension
Ohio River
Outlet diffuser
Riprap design
Stilling basin

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		86	