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Coastal and Hydraulics Laboratory

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Hydraulic Evaluation of Whitten Lock Filling and Emptying System, Tennessee-Tombigbee Waterway, Mississippi

Richard L. Stockstill

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Hydraulic Evaluation of Whitten Lock Filling and Emptying System, Tennessee-Tombigbee Waterway, Mississippi

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Final report

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Preface

The numerical modeling and hydraulic analysis presented in this report were performed under the sponsorship of the U.S. Army Engineer District, Mobile. The Mobile District authorized this study on 1 December 2001.

This work was conducted in the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC) during the period December 2001 to February 2002 under the direction of Mr. Thomas W. Richardson, Director, CHL; and Mr. Donald C. Wilson, Chief, Navigation Branch, CHL.

Simulation runs and analyzes of results were conducted by Dr. Richard L. Stockstill of the Navigation Branch. Dr. Stockstill wrote the report.

Acknowledgment is made to the personnel of the Mobile District, especially Mr. Harry Stone, Lock Master of Whitten Lock; Mr. Rick Saucer, Chief, Navigation Section; and Mr. Sidney M. Bufkin, Hydraulic Design, for their assistance in this investigation.

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

1 Introduction

Project Features

Whitten Lock and Dam is the uppermost navigation structure on the Tennessee-Tombigbee Waterway and is located at river mile 412 (Figure 1). The lock, which was initially named Bay Springs Lock, was officially opened to navigation in May 1985. The lock chamber is nominally 180 m (600 ft) long (pintle to pintle) by 33.5 m (110 ft) wide. Whitten Lake has a normal summer pool of el 414.[1] The downstream canal has a 91.4-m (300-ft) base width and a depth of 4 m (13 ft) with the normal water surface of el 330 provided by the Montgomery Lock and Dam located 8.4 km (5.2 miles) downstream. At normal upper and lower pools, the lock has a lift of 25.6 m (84 ft). The filling and emptying system is a bottom longitudinal floor culvert system commonly referred to as an "H" system. Details of the filling and emptying system are provided in Figure 2.

The culvert system consists of 10-port intake manifolds on either lock wall from which the flow transitions to 4.26-m by 4.26-m (14-ft by 14-ft) culverts in each wall. Reverse tainter valves are used to control both the filling and emptying flow in these main culverts. Dual 0.305-m- (12-in.-) diam ducts are provided to introduce air downstream of each filling and emptying valve. The crossover culvert vertically splits the flow with a horizontal splitter plate in each main culvert, thus dividing the flow into each half of the chamber. The flow is then split horizontally to feed two longitudinal filling and emptying manifolds in each half of the chamber. These longitudinal manifolds each have 12 pairs of 1.07-m- (3.5-ft-) tall by 0.46-m- (1.5-ft-) wide ports. Each main culvert of the emptying system terminates

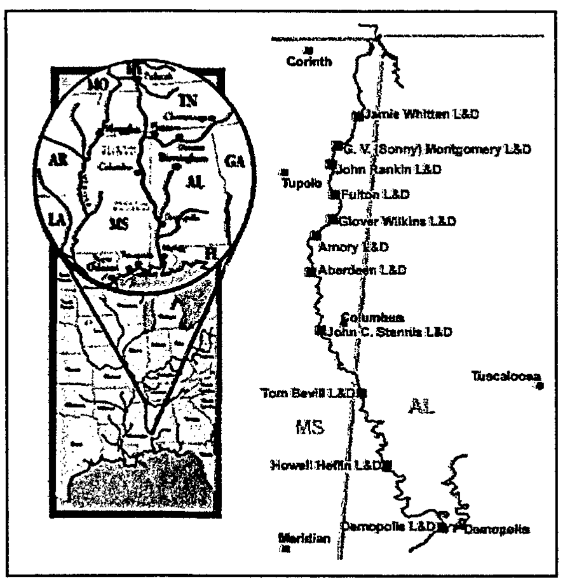

Figure 1. Location map for Whitten Lock, Tennessee-Tombigbee Waterway

[1] All elevations (el) cited are in feet referred to the National Geodetic Vertical Datum (NGVD).

at a lateral manifold. These manifolds each have 8 pairs of 1.83-m- (6-ft-) tall by 0.91-m- (3-ft-) wide ports.

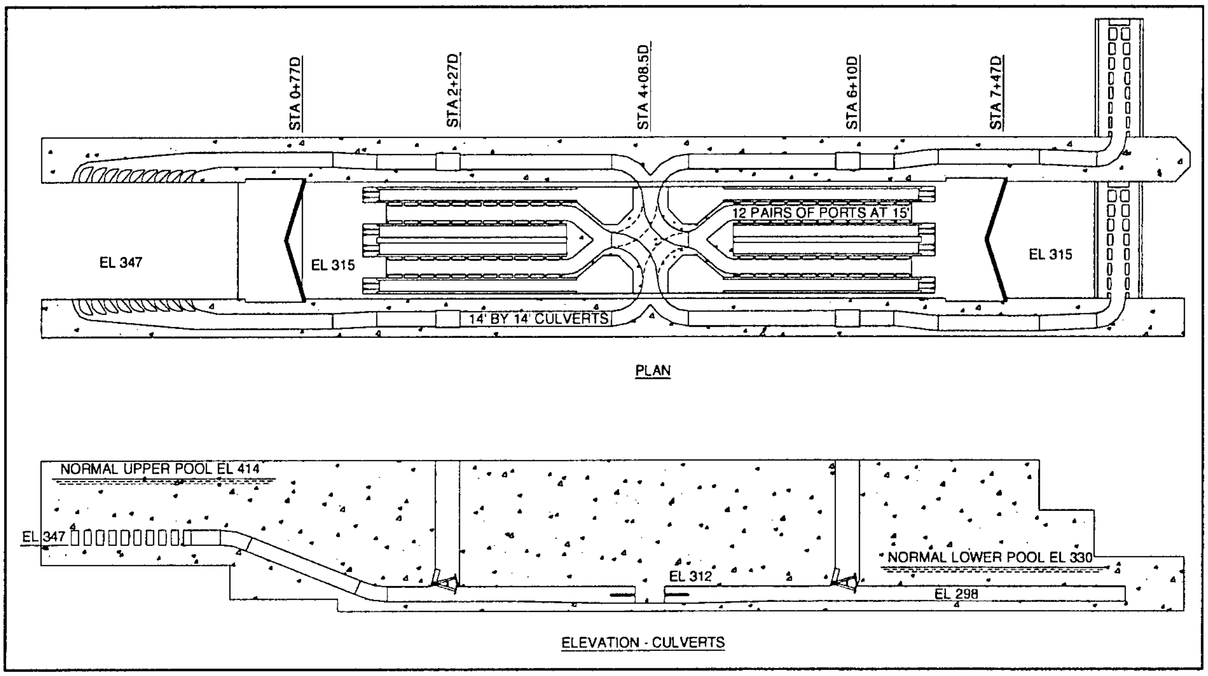

Figure 2. Plan and profile of Whitten Lock

Problem

A hydraulic evaluation of the culvert system was considered necessary because the lock structure has experienced significant damage over the past years on the roof of the crossover where the right culvert enters the lock chamber (Figure 3). The concrete roof has eroded several centimeters deep for a distance of 6 m (20 ft) or so towards the center of the lock. This area has experienced damage before and was repaired in 1996 and again in 2001.

A section of the roof of the top portion of the left culvert is also eroded, but not nearly as much as the comparable location on the right side. An area of concrete about one-quarter of a square meter and several centimeters deep on the roof about a meter downstream from the construction joint was eroded.

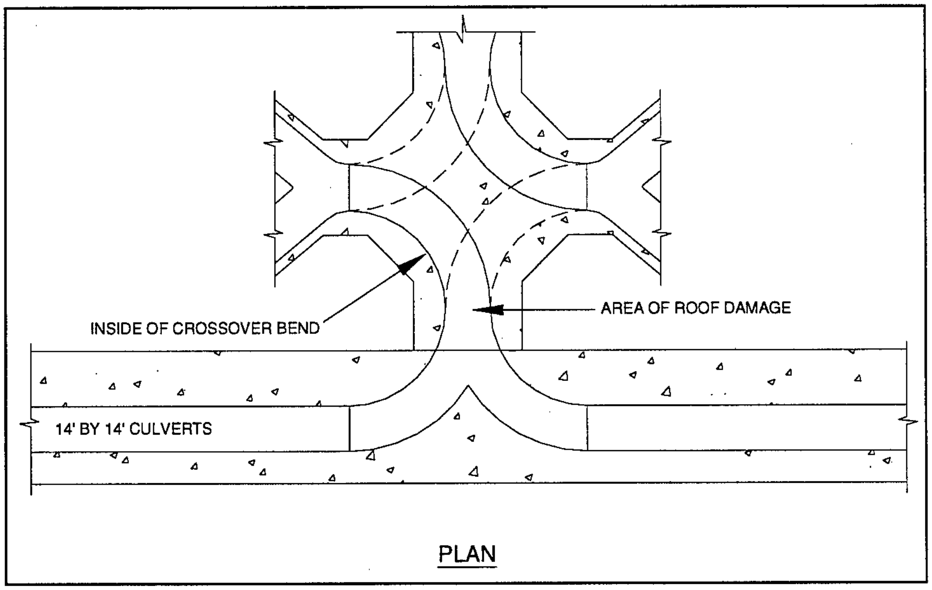

Figure 3. Detail of right crossover culvert

Purpose and Scope

The purpose of this study was to determine if the existing hydraulic conditions are significantly different from those anticipated during the design process and if these hydraulic conditions are causing the damage to the crossover roof. This process involved first discussing operations with Mobile District personnel and then evaluating the pressures and velocities in the troubled area where the concrete has failed and also in other sensitive areas of the filling and emptying system such as just downstream of the valves. There was concern that adverse conditions (pressures) are occurring near the damaged area on the top portion of right crossover. A numerical evaluation of the filling and emptying system was performed using the LOCKSIM computational model. The LOCKSIM model, once validated for the Whitten Lock, was used to evaluate culvert pressures for lock operations of interest including normal- (dual) valve and single-valve filling and emptying operations and partial filling operations.

Previous Investigations

Prior hydraulic model study

A 1:25-scale lock model study was reported by Ables (1978). The model reproduced approximately 210 m (700 ft) of the upstream approach; the entire filling and emptying system, including the upper guide and guard walls, intakes, tainter valves and culverts, floor culvert system, outlets, the lock chamber, and lower guide and guard walls; and about 180 m (600 ft) of the downstream approach. Piezometers were placed at points throughout the filling and emptying system culverts. The piezometers, which provide average pressures, were read during lock operations. Pressure cells were used to measure instantaneous pressures at selected locations in the culvert system and to record water surface in the lock chamber. The model study provided pressure data and lock filling and emptying times for various valve operations. Particular emphasis was given to valve operations and the resulting pressures in the culvert immediately downstream.

Prior field study

McGee (1989) conducted a field investigation to determine the operating characteristics and hydraulic efficiency of the lock. Particular attention was given to evaluating important design factors such as the cavitation parameter and the effects of venting and submergence of the valves. Pressure transducers were used to measure the water-surface elevation in the upper pool, the lock chamber, the lower pool, and the left filling and emptying valve wells. Transducers were also mounted on the left culvert roof to measure the piezometric head downstream of the filling and emptying valves. Movement of any operating reverse tainter valve (filling or emptying) was monitored with angular potentiometers.

Approach

The filling and emptying system of Whitten Lock was evaluated using the one-dimensional unsteady flow model LOCKSIM (Schohl 1999). Details of the filling and emptying system are provided in Figure 2. The approach taken was to construct a model of the Whitten Lock system and then investigate hydraulic conditions with various operational schemes for both filling and emptying. The idea was to minimize the differential pressure at the culvert roof in the crossover area while maintaining acceptable hydraulic conditions throughout the remainder of the culvert system. The differential pressure is the internal pressure exerted on the soffit of the culvert roof less the hydrostatic pressure exerted on the culvert top produced by water in the lock chamber.

2 Model Validation

Model Description

This study's principal objective was to construct a model of the Whitten Lock system and then investigate the hydraulic conditions associated with various operational schemes. A schematic showing the nodes and components of the LOCKSIM model is provided in Figure 4. The Whitten Lock model is similar to the Bay Springs Lock model provided in the LOCKSIM user's manual (Schohl 1999). Coefficients were adjusted so the model better reproduced field data provided by McGee (1989).

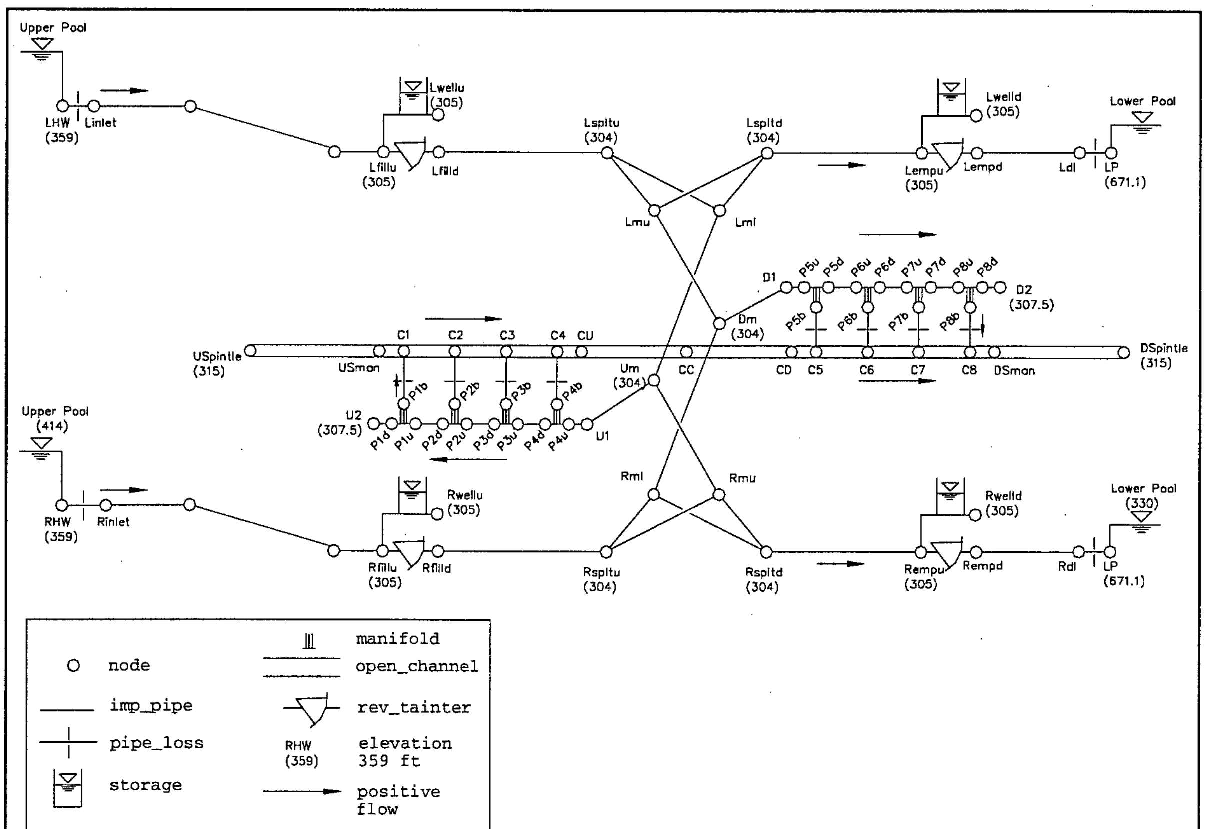

Figure 4. Schematic of LOCKSIM model (modified from Schohl 1999)

The numerical flow model LOCKSIM serves as an evaluation tool for lock filling and emptying system designs. LOCKSIM couples the unsteady pressure-flow equations, which are applicable to the conduits within the system, with the free-surface equations describing the approach reservoirs, valve wells, and lock chamber. The model computes pressures and flow distributions throughout a lock system. LOCKSIM simulates closed-conduit components such as culverts, reverse tainter valves, pipe losses, tees, and manifolds. Free-surface components include prismatic open channels, riverine channels, and water storage components (which can represent reverse tainter valve wells). Individual components from these lists are connected together at nodes, where they share a common piezometric head.

Discharge and piezometric head in the pipe and free-surface channel components are computed by numerically solving partial differential equations for one-dimensional unsteady flow. The water storage component is governed by an ordinary differential equation describing conservation of mass. The relationships between discharge and piezometric head difference for valves, check valves, and pipe losses are described by algebraic energy equations. The position of a valve is prescribed as a function of simulation time using tabulated data. Functions are also used for tee and manifold components, which simulate combining and dividing flow, to describe the variation of the branch headloss coefficients with the ratios of the individual branch discharges to the combined discharge. Available time-varying numerical results include pressure, hydraulic gradeline elevation, and discharge at all computational points. The stage, velocity, depth, top width, and channel area are provided at each computational point within the free-surface components, and the velocity, shear stress, and vapor cavity volume are given for each computational point within the closed-conduit components. The minimum pressures and cavitation indices in the wakes of reverse tainter valves are also computed.

The numerical model reproduced the entire filling and emptying system including the intakes, filling and emptying valves and valve wells, culverts, filling and emptying manifolds, lock chamber, and outlets. Energy loss coefficients for several components of the culvert system were gathered from the limited set of published lock data. Loss coefficients for the intakes and port outlets were adjusted on the filling system. The emptying system included adjustment of loss coefficients for the ports when acting as intakes and the lock outlet manifolds so that the model reproduced the previously published field data.

Field Data

Filling Test FE1 and emptying Test FE4 in McGee (1989) were used to determine energy loss coefficients on the components. LOCKSIM computes head losses for flow through components in the form

$$H_{L_i} = K_i \frac{V_i^2}{2g} \qquad (1)$$

where

H_L = headloss
K = loss coefficient
V = velocity
g = gravitational acceleration
i = a particular component

Loss coefficients for many hydraulic components are well established and are readily available in the literature (e.g., Miller 1990). However, lock culvert system components are often unique to a particular project, and the loss coefficients have not been determined. This study validated the LOCKSIM model using field data (one set for the filling system and one set for the emptying system) to refine loss coefficient values. These coefficients were then used in modeling existing operational conditions and to investigate alternative valve operation strategies.

Model Parameters

Numerical model parameters such as the time-step and the implicit weighting factor used in Preissmann's scheme (Schohl 1999) were selected based on previous LOCKSIM studies (e.g. Schohl 1999; Stockstill, Fagerburg, and Waller 2001). Lock filling and emptying simulations employed a time-step of 2.0 sec, and an implicit weighting factor of 0.55 provided sufficient stability.

The contraction coefficient C_c is a parameter used by LOCKSIM to calculate the piezometric head at the culvert soffit immediately downstream of the filling and emptying valves and the cavitation index σ (discussed further in Chapter 4) for the low-pressure region downstream of the valves. Published data quantifying the contraction coefficient shows considerable scatter (Engineer Manual 1110-2-1610; Headquarters, U.S. Army Corps of Engineers 1975). The coefficient of contraction for flow downstream of the valves was

$$C_c = 2.291\left(\frac{b}{B}\right)^4 - 6.286\left(\frac{b}{B}\right)^3 + 6.263\left(\frac{b}{B}\right)^2 - 2.297\left(\frac{b}{B}\right) + 0.923 \qquad (2)$$

where

b = valve opening
B = culvert height at the valve

This relation describing C_c in terms of the relative valve opening provides the best fit of the prototype filling data of pressures downstream of the valve presented in McGee (1989). The C_c for a reverse tainter valve is very sensitive to the shape of the bottom edge of the valve. There is no universal description of C_c's for reverse tainter valves. However, the values used for this study are believed to be adequate for estimating the lowest pressures at partial gate openings.

Determination of Loss Coefficients

Loss coefficients for many hydraulic components are well established and are readily available in the literature (e.g., Miller 1990; U.S. Army Corps of Engineers). However, hydraulic structures, in particular lock culvert systems, are composed of geometrically complicated components. Since these components are often unique to a particular project, the energy loss coefficients associated with them have not been documented. Field measurements are then used to quantify coefficients for unique lock components.

Filling system

Model loss coefficients were refined for the filling system components using the field data reported as Test FE1. Test FE1 documented pressures downstream of the filling valves and the water surface in the valve wells and lock chamber with an upper pool elevation of 412.3 and lower pool elevation of 329.3. The valve opening versus time curve for the reverse tainter valves on the Whitten Lock is presented in Figure 5 where *t* is the actual time and *tv* is the valve time. Figure 6 defines the valve opening *b/B* ratio. During Test FE1, the valve opened in 219 sec (Figure 7). Particular emphasis was the determination of appropriate loss coefficient values for the intakes and the lock chamber port outlets. The field data was used to establish the values of these loss coefficients. These model results are compared with those observed in the field in Figures 8-10. Figure 8 is the lock-filling curve on which the water-surface elevation is plotted against time. The lock filled in 10.4 min. The temporal variation of the water surface within the filling valve well is provided in Figure 9. The maximum drawdown in the well was to el 370. The piezometric head in the culvert downstream of the filling valve is shown in Figure 10. The lowest pressure observed in the field was el 305.3, whereas the model computed a minimum elevation of 301.3. The lowest pressures occur at 110 sec when the valve is about 35 percent open. The model reproduces the field data quite well except for the pressures downstream of the filling valve when the pressure is lowest. The model is conservative since its predictions are lower than field measurements.

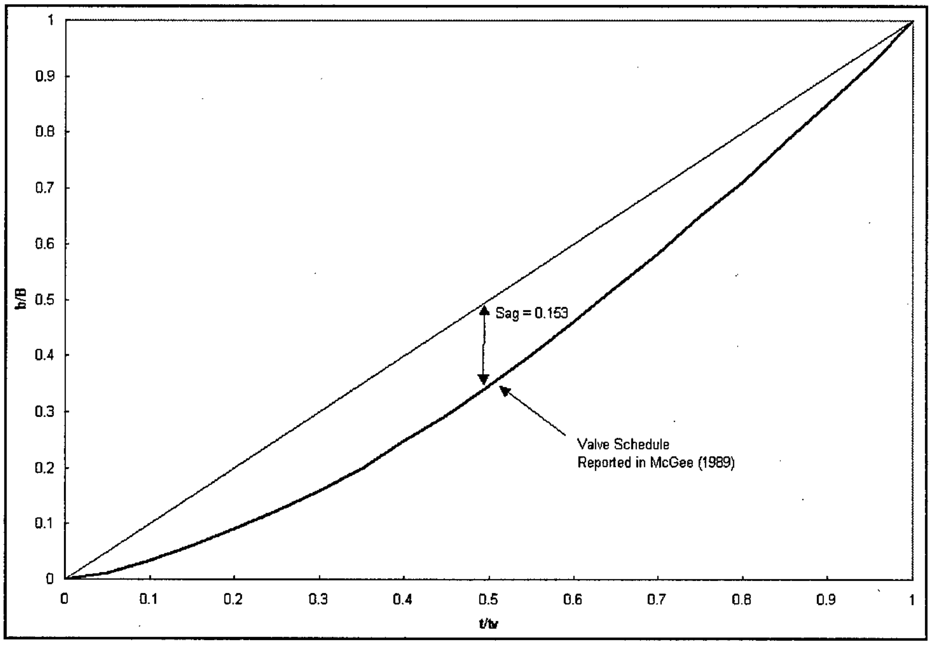

Figure 5. Reverse tainter valve curve

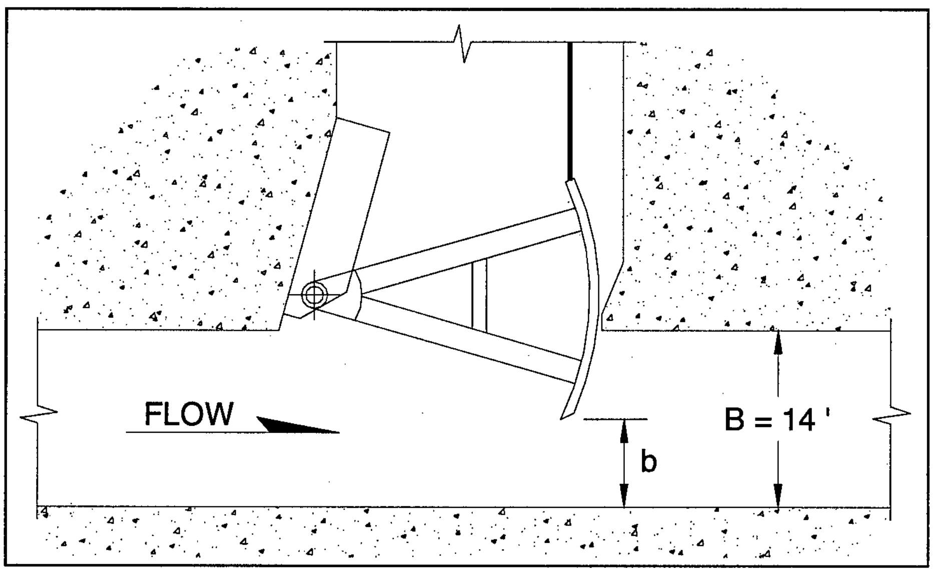

Figure 6. Definition of valve parameters

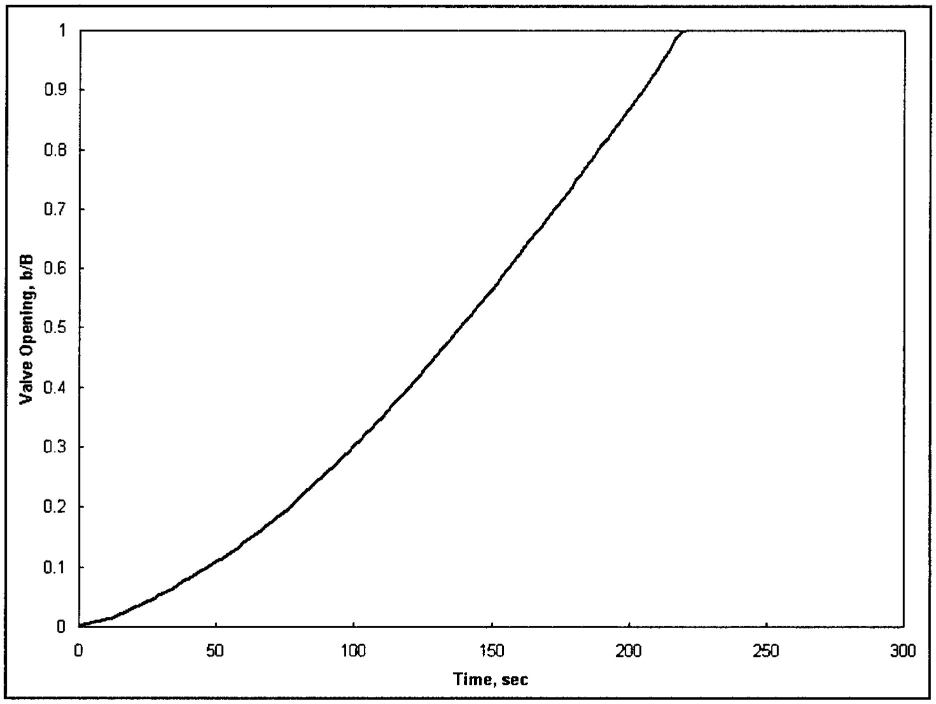

Figure 7. Test FE1 valve schedule, operation of filling valves, 219-sec valve time

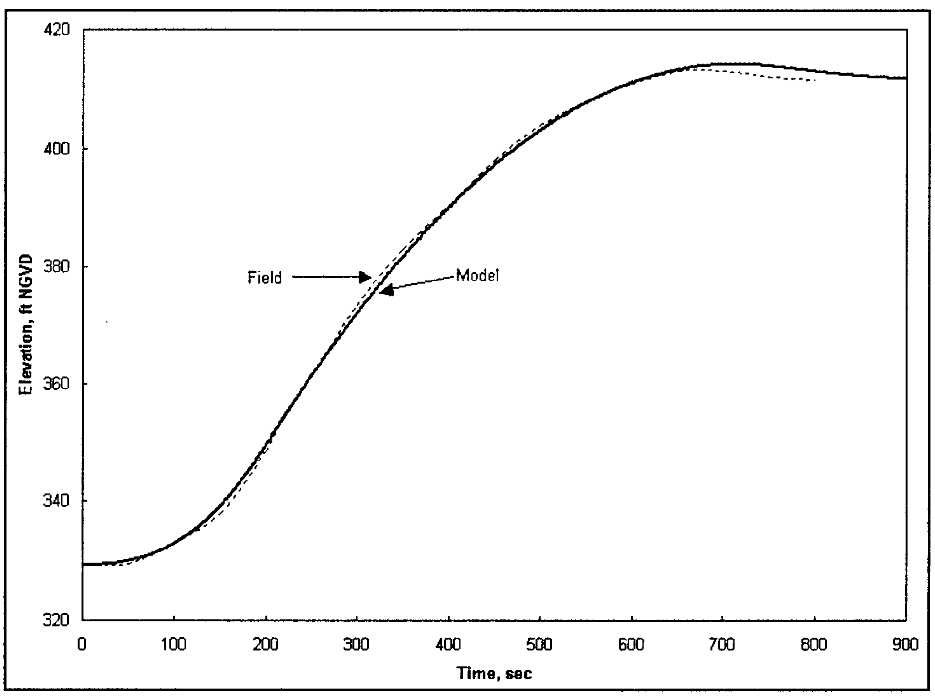

Figure 8. Lock chamber water surface during filling, 219-sec valve time, upper pool el 412.3, lower pool el 329.3

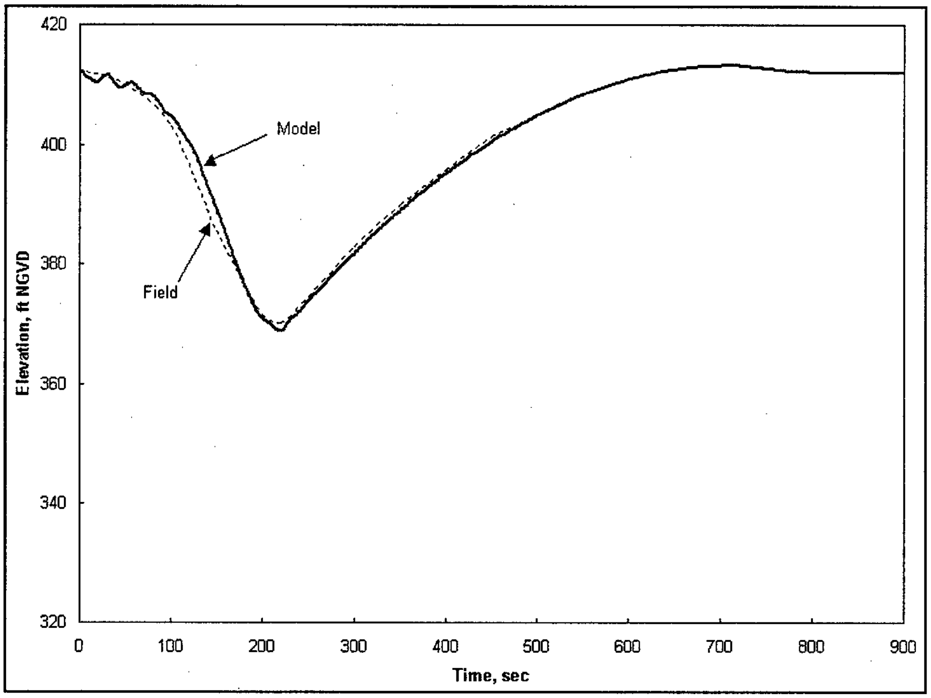

Figure 9. Valve well water surface during filling, 219-sec valve time, upper pool el 412.3, lower pool el 329.3

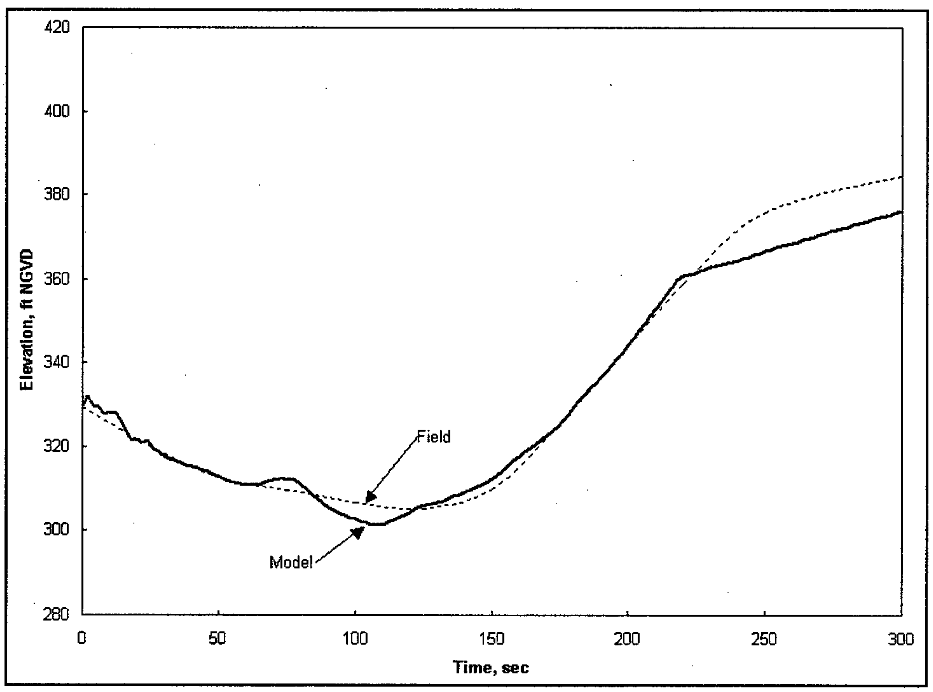

Figure 10. Pressure head downstream of valve during filling, 219-sec valve time, upper pool el 412.3, lower pool el 329.3

Emptying system

The emptying system was validated with the data of Test FE4. The pool conditions for this test were upper pool el 412.1 and lower pool el 330.4. The valve operated in 205 sec. The valve schedule for this normal-valve emptying operation is presented in Figure 11. These runs were used to quantify loss coefficients for the ports acting as intakes and the lateral outlet manifolds. The emptying system model results are provided in Figures 12-14. The emptying curve on Figure 12 shows that the lock emptied in 11.8 min. The computed emptying curve matched the field data well. The drawdown of the water surface within the emptying valve well is shown on Figure 13. The time variation of the well's water surface reduces significantly at 220 sec. Figure 14 provides a time-history of the pressure head downstream of the emptying valve. The lowest pressure measured was el 308.5, whereas the lowest elevation computed by the model was el 306.7. The lowest pressures downstream of the valve occur when the valve is 50 to 70 percent open. The model is conservative in estimation of pressure downstream of the valve. The model with the loss coefficients determined from the field data for filling and emptying was considered adequate for the present study.

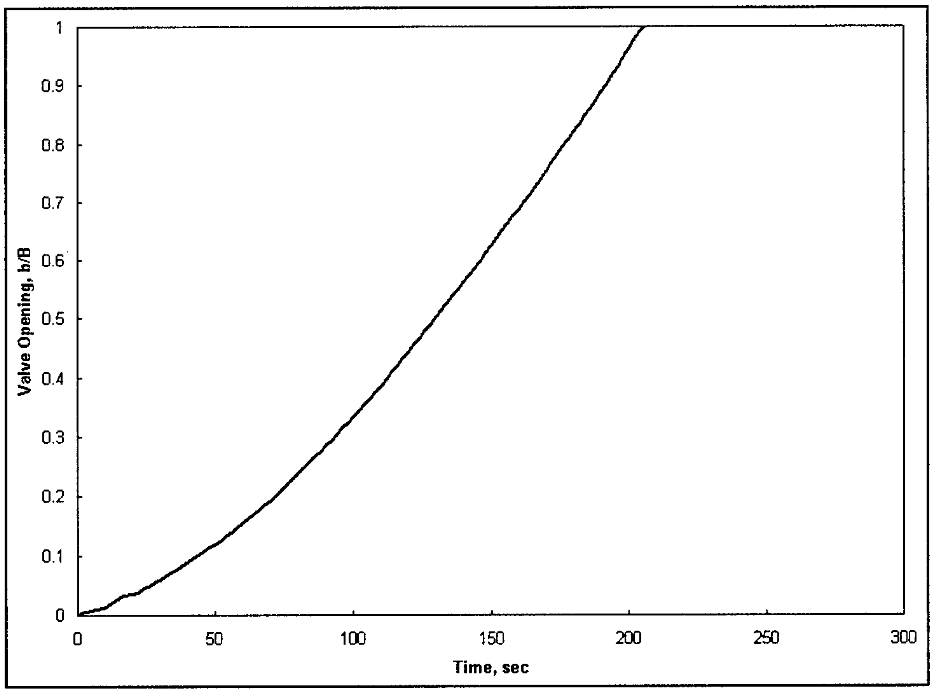

Figure 11. Test FE4 valve schedule, operation of emptying valves, 205-sec valve time

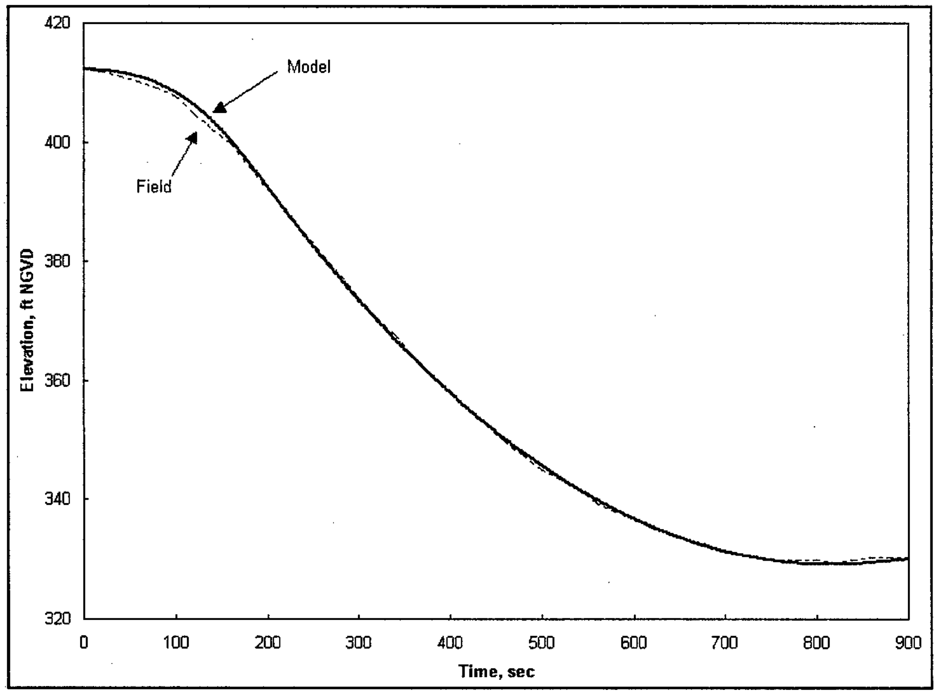

Figure 12. Lock chamber water surface during emptying, 205-sec valve time, upper pool el 412.1, lower pool el 330.4

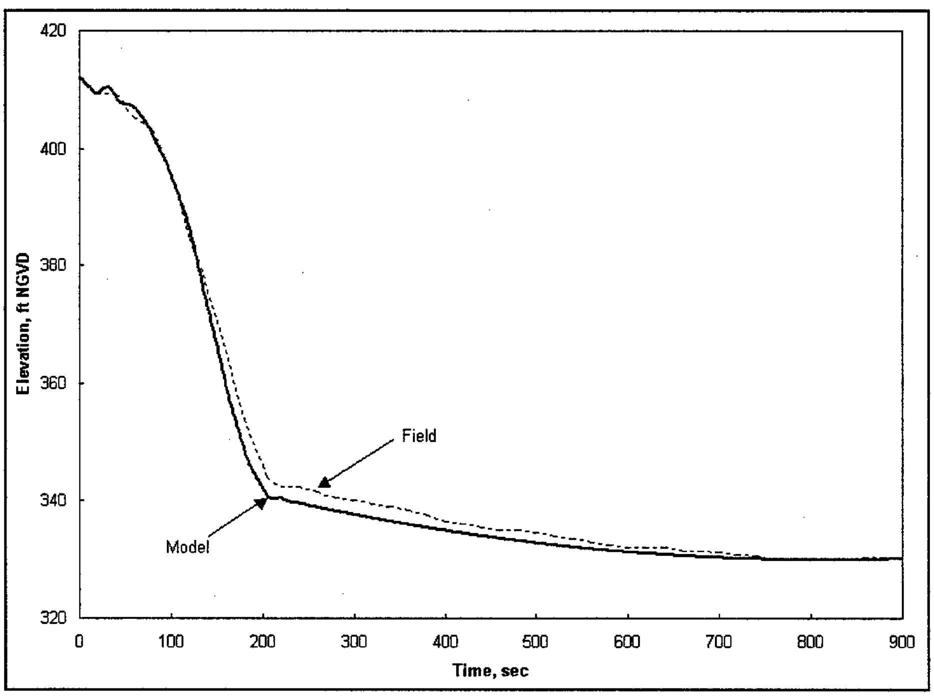

Figure 13. Valve well water surface during filling, 205-sec valve time, upper pool el 412.1, lower pool el 330.4

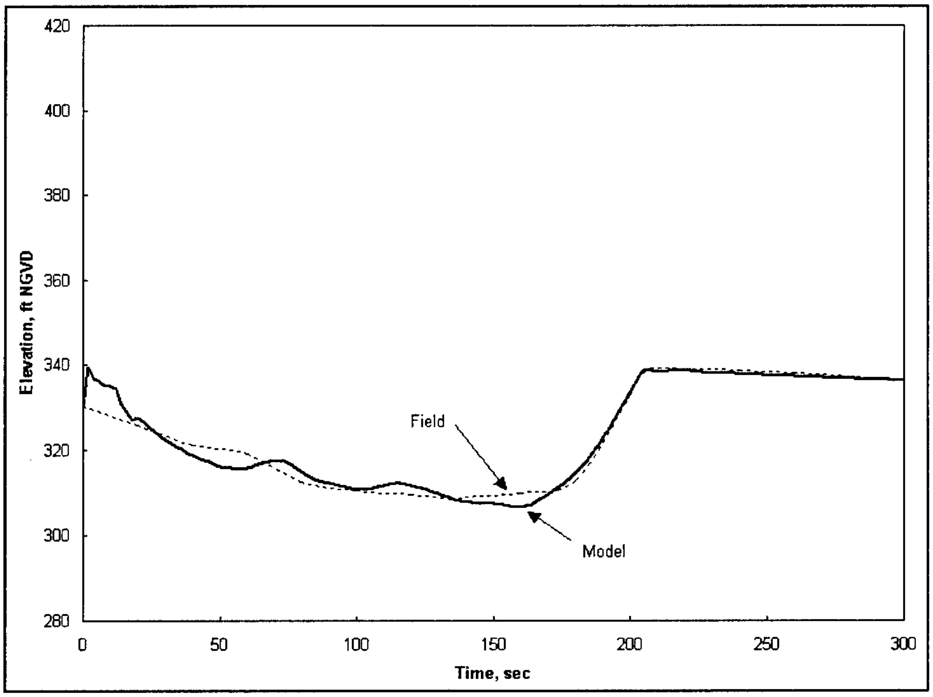

Figure 14. Pressure head downstream of valve during filling, 205-sec valve time, upper pool el 412.1, lower pool el 330.4

3 Existing Operations

Present Valve Timings

Operation conditions presently used at the project were modeled to evaluate the existing hydraulic conditions throughout the system. The design lift of 25.6 m (84 ft) (upper pool el 414 and lower pool el 330) was simulated. The valve operation times of 135 sec (2:15) for both the filling and emptying valves were supplied by operation personnel. Both normal- and single-valve filling and emptying operations were modeled.

Model Results

The results of these calculations are shown on the time-history plots in Figures 15-19. Pressures are a minimum on the inside of the crossover bends where velocities are a maximum. Estimations of the pressures on the inside wall are determined from the cross-sectional average velocity and pressure within the crossover culvert (U.S. Army Corps of Engineers).

$$h_{p_i} = h_p - C_p \frac{V^2}{2g} \tag{3}$$

where

h_{pi} = pressure head on the inside of the bend
h_p = cross-sectional average pressure head
C_p = pressure drop parameter
V = cross-sectional average velocity
g = gravitational acceleration

The bend pressure coefficient is a function of the culvert's radius of curvature R and culvert half-width c.

$$C_p = \left[\frac{2}{\left(\frac{R}{c} - 1\right) \ln \left(\frac{\frac{R}{c}+1}{\frac{R}{c}-1} \right)} \right]^2 - 1 \qquad (4)$$

The C_p value for the culvert bends found on the Whitten Lock crossover is 0.48. So, the pressure head difference between the cross-sectional average and that on the inside of the bend is about half (0.48) of the average velocity head in the culvert.

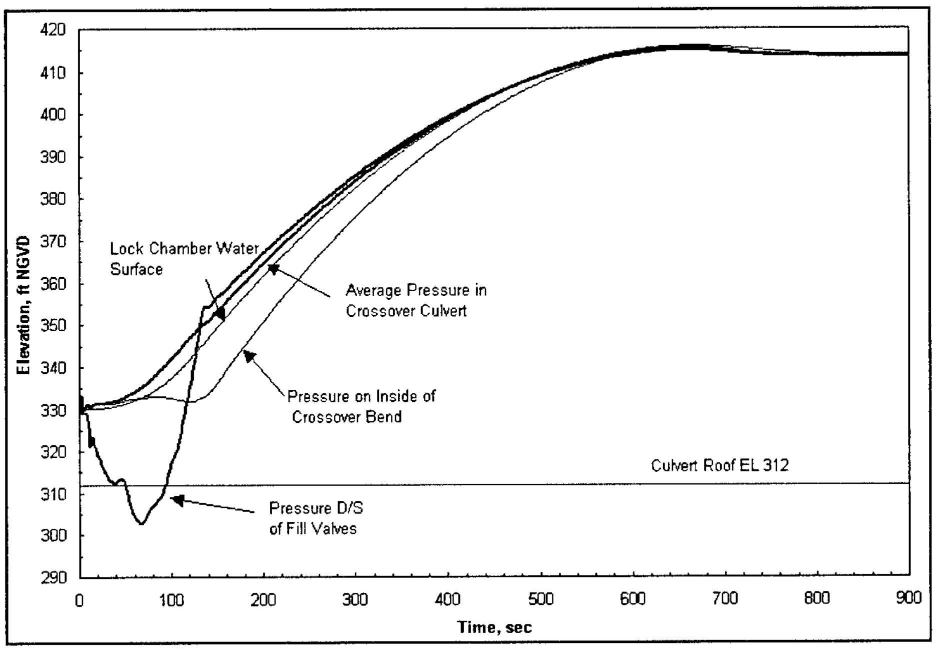

Figure 15. Pressure head in the culverts during normal-valve filling, 135-sec valve time, upper pool el 414, lower pool el 330

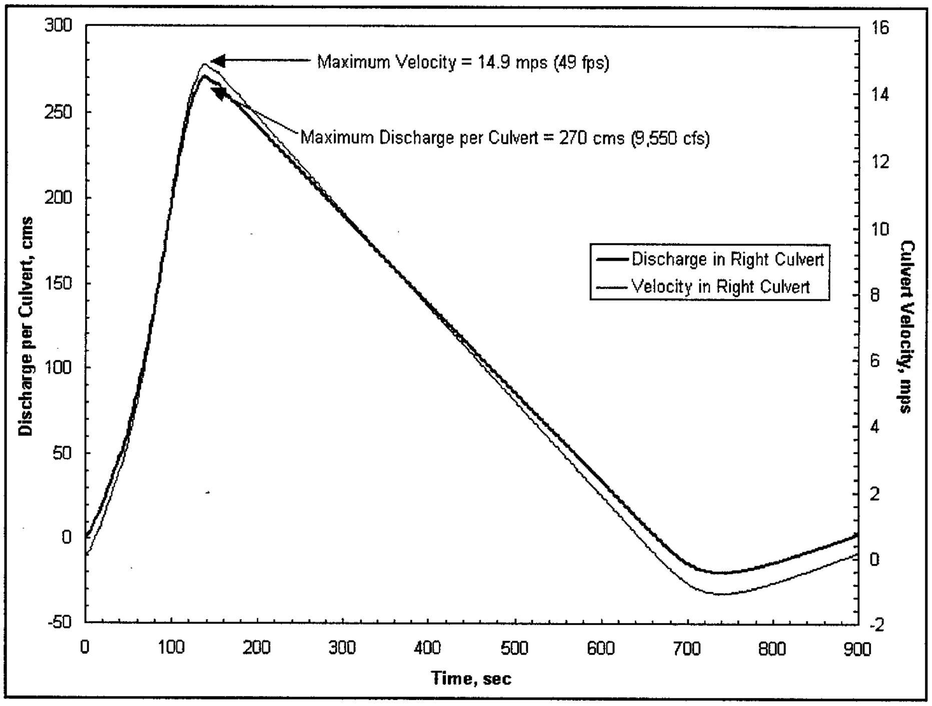

Figure 16. Culvert discharge and velocity during normal-valve filling, 135-sec valve time, upper pool el 414, lower pool el 330

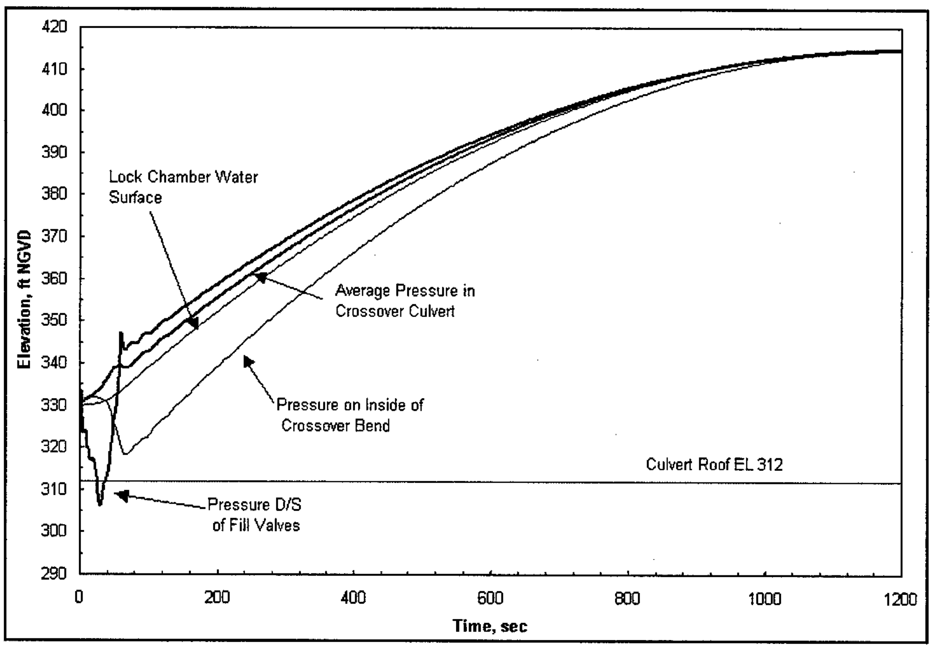

Figure 17. Pressure head in the culverts during single-valve filling, 135-sec valve time, upper pool el 414, lower pool el 330

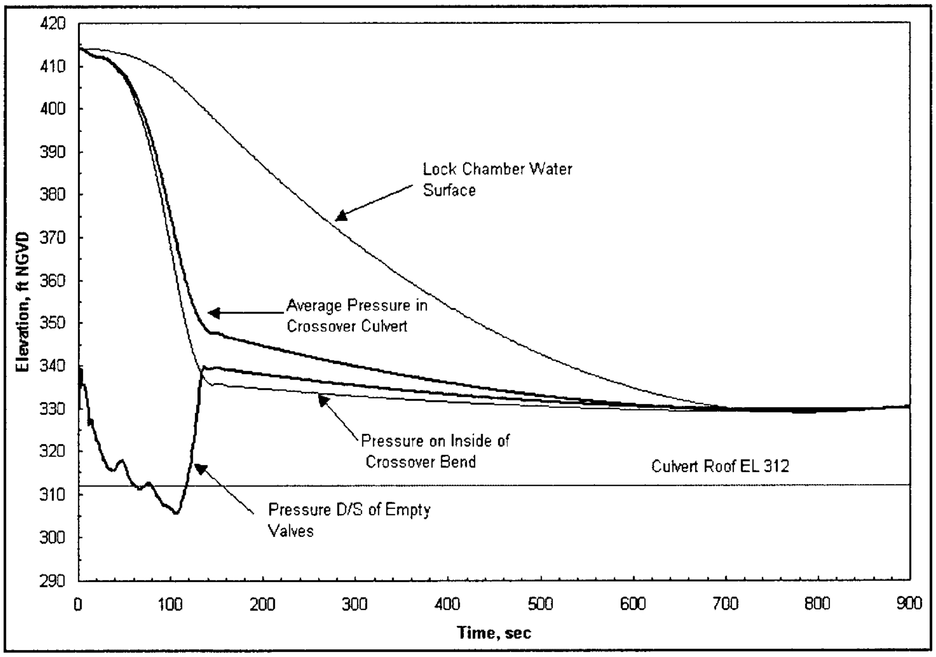

Figure 18. Pressure head in the culverts during normal-valve emptying, 135-sec valve time, upper pool el 414, lower pool el 330

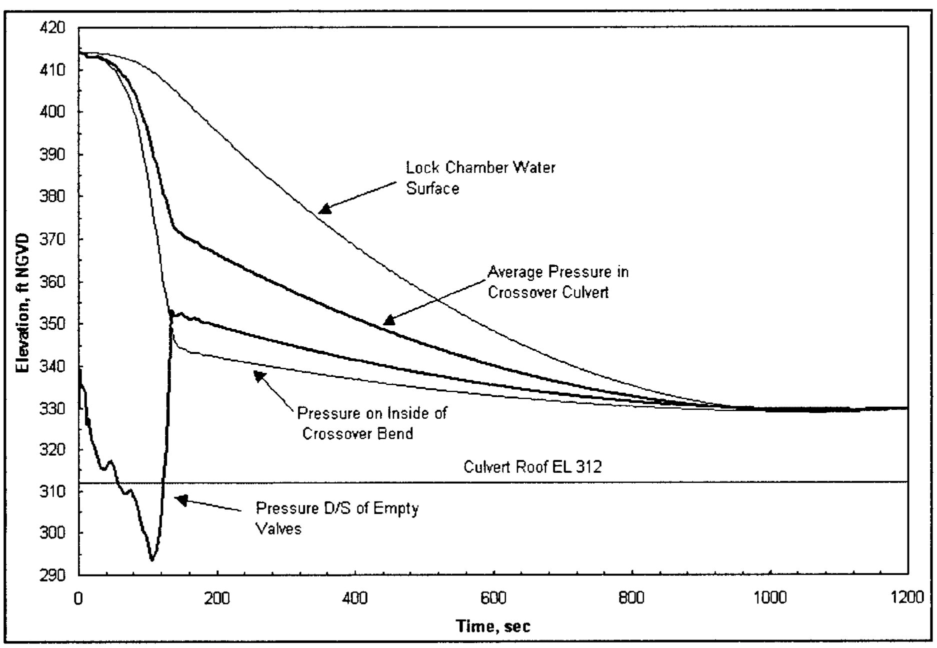

Figure 19. Pressure head in the culverts during single-valve emptying, 135-sec valve time, upper pool el 414, lower pool el 330

Partial Filling

Additional simulations were made to compute the conditions when the filling valves were opened and then immediately shut at the 135-sec rate for opening and a 140-sec rate for closing (valve schedule 1, Figure 20). Project personnel provided these valve operation timings and are the measured timings currently used. Also, the model was run with the filling valve opening 50 percent in 85 sec and then closing (valve schedule 2, Figure 20). Valve operations such as these are used at the project from time-to-time to partially fill the lock chamber. The lock chamber is partially filled to better insulate the lower miter gates located at the south end of the structure from solar heating. Sun exposure on these extremely tall gates results in thermal expansion of the gates, which sometimes makes opening and/or mitering of the gates difficult. Partial filling of the chamber provides sufficient insulation to prevent adverse expansion of the gates during hot weather.

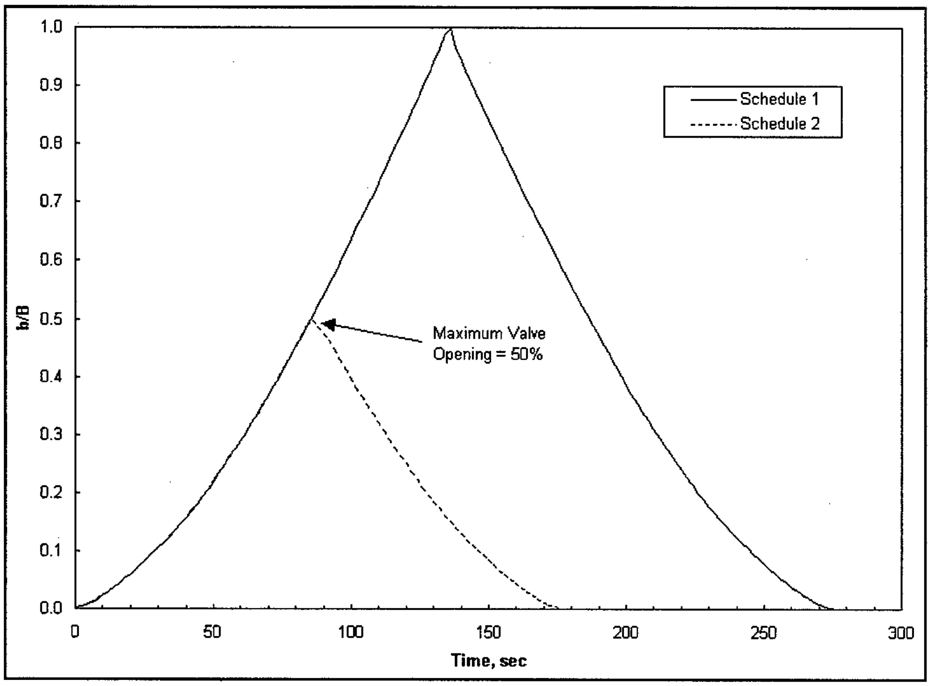

Figure 20. Valve schedules for partial filling operations

Results of the partial filling operations mentioned above are shown in Figures 21 and 22. Valve schedule 1 results in the lock chamber water surface rising to el 361.4 and valve schedule 2 fills the lock to el 340.7. No adverse pressures were computed during these partial-filling tests, although closing the valve while there is flow in the culvert does produce low pressures downstream of the valve. Differential pressures in the crossover culvert (area of concern) were no larger than those observed during normal filling operations.

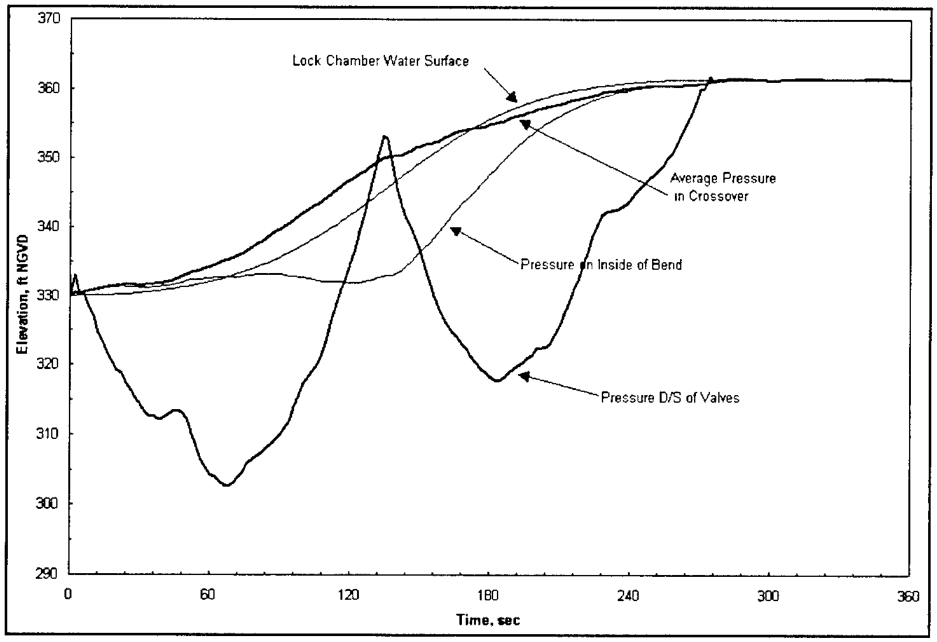

Figure 21. Pressure head in the culverts during partial filling, valve schedule 1, upper pool el 414, lower pool el 330

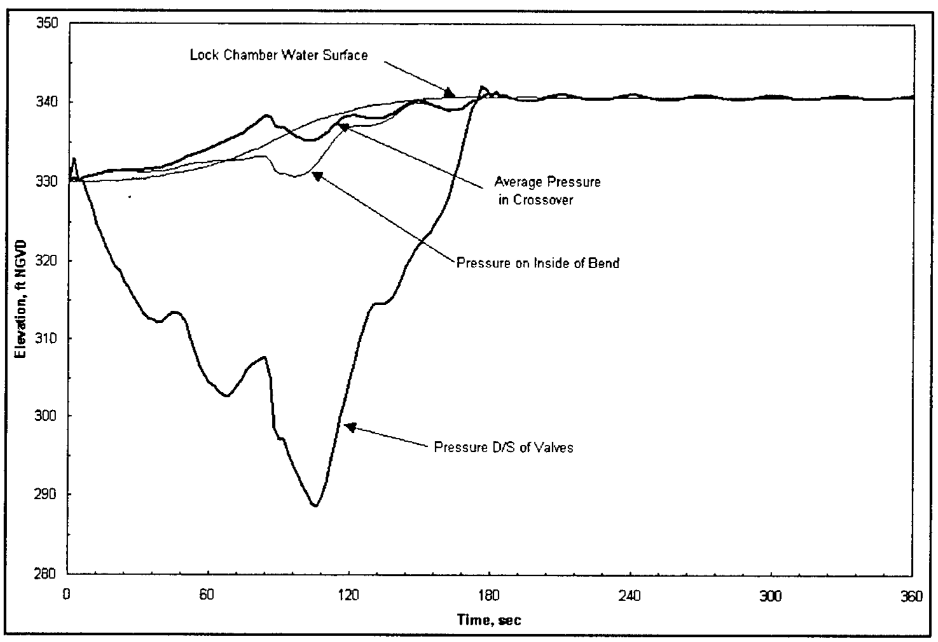

Figure 22. Pressure head in the culverts during partial filling, valve schedule 2, upper pool el 414, lower pool el 330

Three-Dimensional Model

To further investigate the flow field inside the culverts, a three-dimensional (3D) flow model (Adaptive Hydraulics model, ADH (Stockstill and Berger 2000)) of the right filling culvert and crossover culverts was constructed. The idea was to use the 3D model results as a flow visualization aid. The 3D finite element mesh is depicted in Figure 23. The mesh had 8251 nodes and 34765 elements, which is rather coarse for the related size of the structure modeled, but the resolution was believed to be adequate for visualization purposes. Peak flow conditions (at t = 138 sec) during normal-valve filling (138 sec into filling operation) were extracted from the LOCKSIM results and imposed as boundary conditions to the 3D model. Velocity contours on horizontal planes sliced through the upper crossover culvert are provided in Figures 24 and 25. Figure 24 is a plane immediately below the culvert roof, and Figure 25 is a plane passing through the center of the upper crossover culvert. The distribution of pressure across the upper culvert is shown on the contour plots provided in Figures 26 and 27. Figure 26 is a plane at the culvert roof, and Figure 27 is a plane located at the center of the culvert. These plots are the pressure head relative to the culvert roof el 312. The pressure contours show significantly lower pressures on the inside of the bend and higher pressures on the outer wall of the bend. The highest pressures are at the stagnation point that is formed on the outer wall just downstream of the culvert bend of the emptying system. The pressure distribution across the culvert suggests that if cavitation led to the concrete failure, it would have most likely have occurred on the inside wall rather than in the center of the culvert roof.

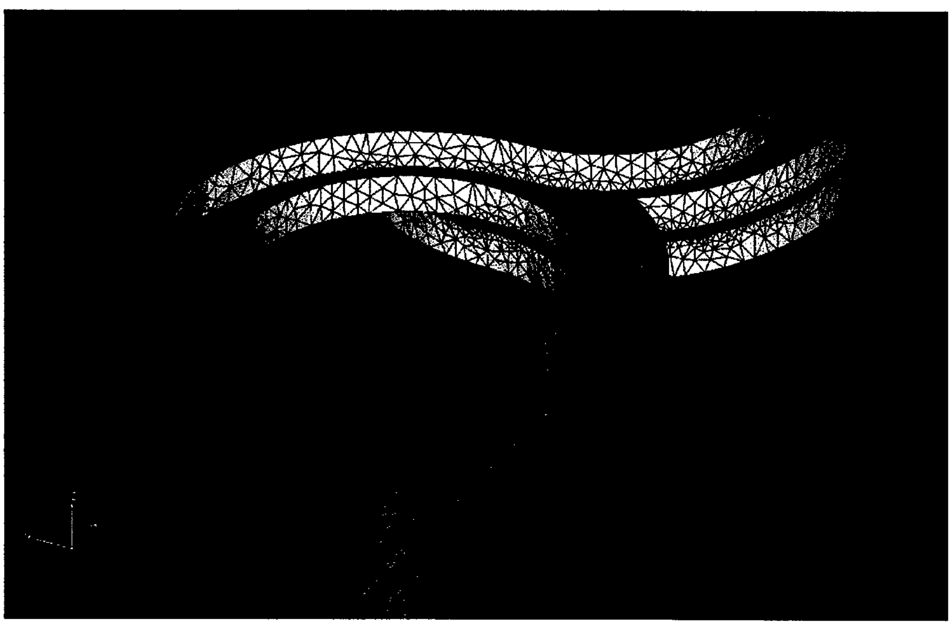

Figure 23. Surface mesh of 3D flow model of crossover area

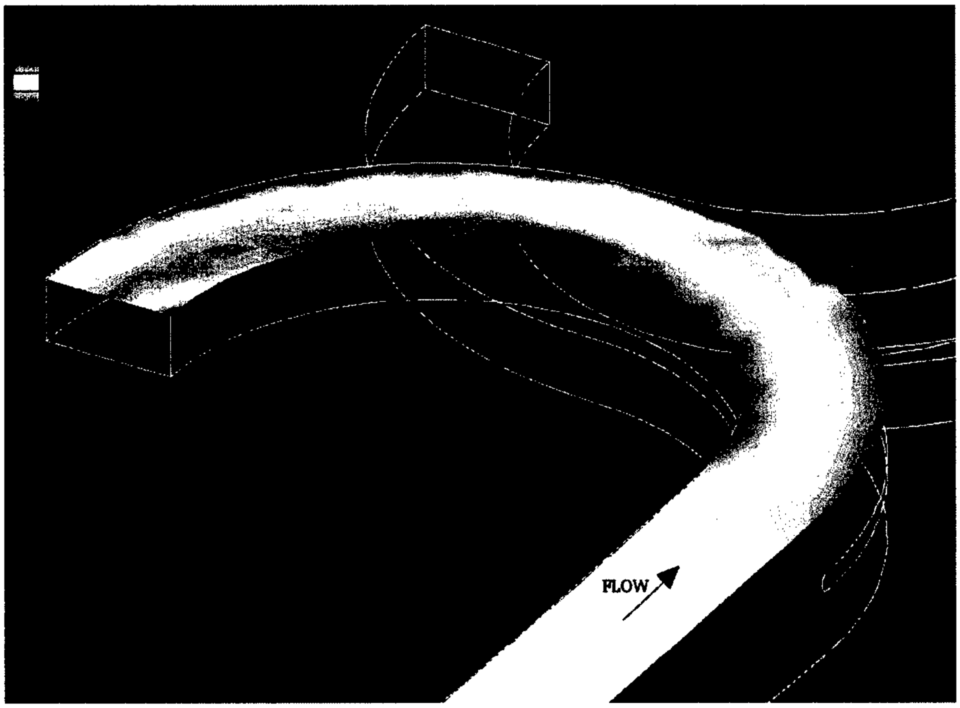

Figure 24. Velocity contours on a horizontal plane at the culvert roof

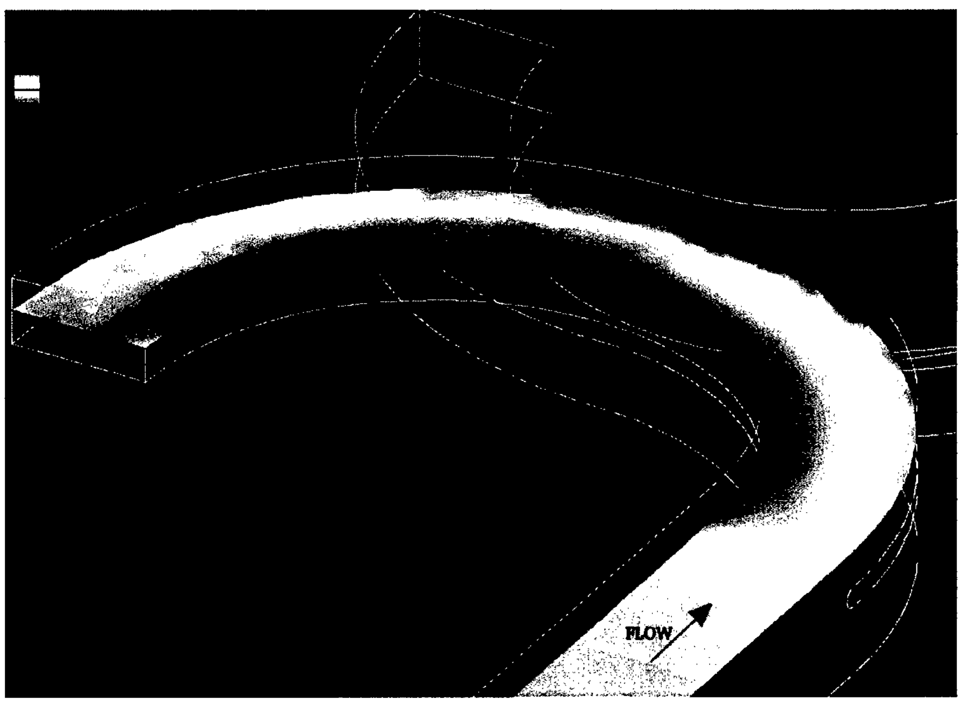

Figure 25. Velocity contours on a horizontal plane at mid-height of the top culvert

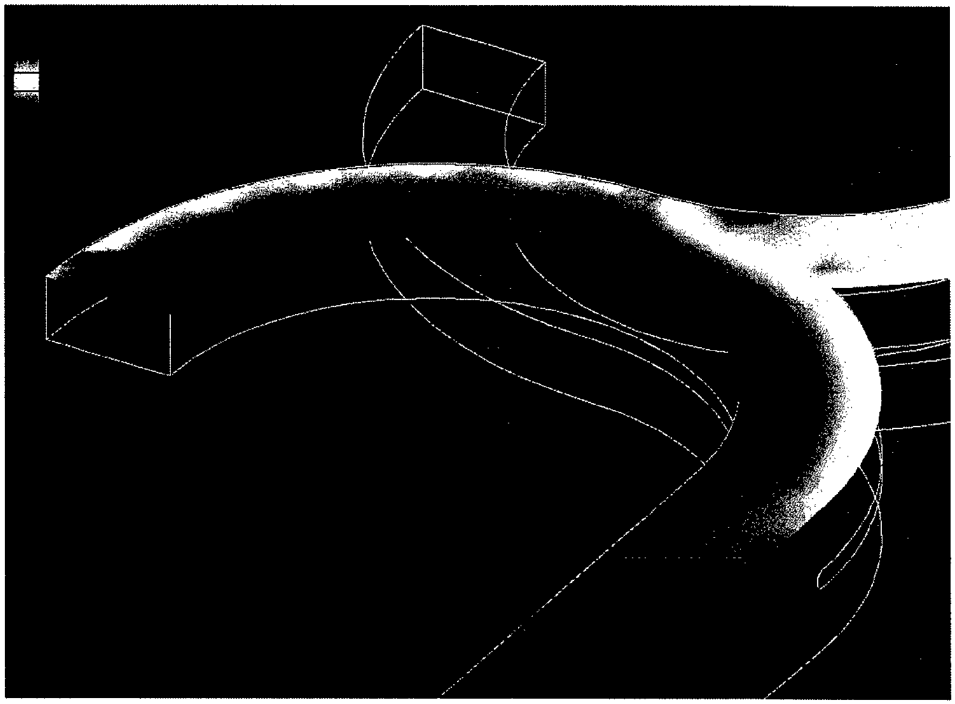

Figure 26. Pressure head contours on a horizontal plane at the culvert roof

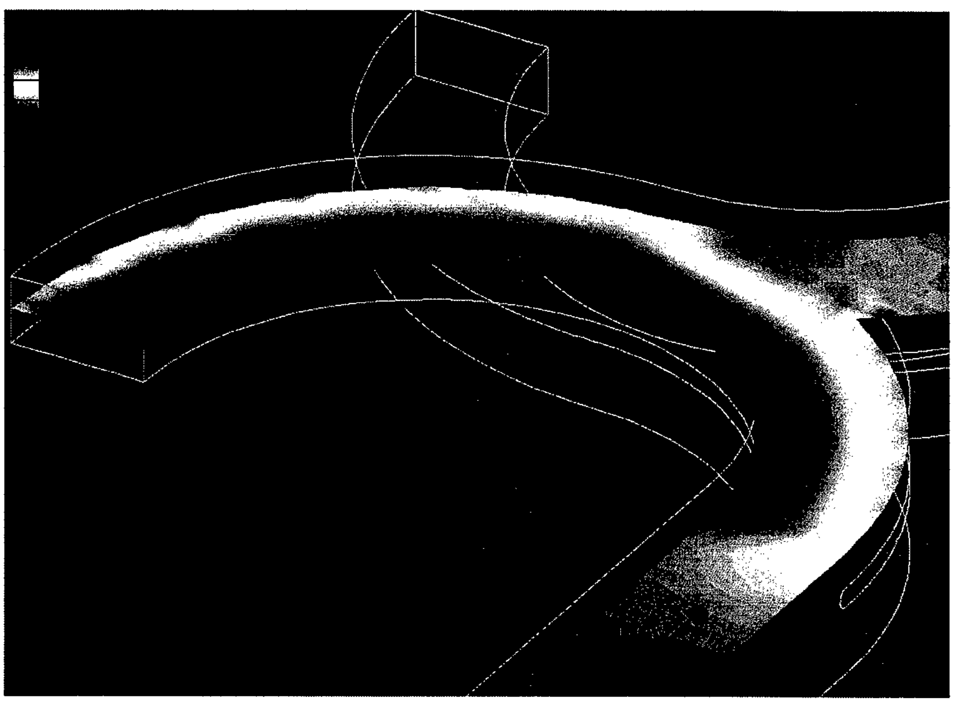

Figure 27. Pressure head contours on a horizontal plane at mid-height of top culvert

4 Operation Optimization

Strategy

The next phase of this study was to determine if an alternate valve operation strategy could be developed that would provide optimum flow conditions at the area of interest (described below) while ensuring acceptable conditions throughout the filling and emptying system. This was accomplished using the optimization techniques provided in the commercial software package iSIGHT (Engineous Software, Inc. 1999). This evaluation involved linking the LOCKSIM model of Whitten Lock with iSIGHT. The optimization routine was developed to automatically change the valve time in the LOCKSIM input file, execute the LOCKSIM program, read the flow solution, and compute optimization parameters. The parameters were chosen to be the lowest pressure downstream of the valve computed during the locking operation, maximum differences in pressure within the crossover culvert and the lock chamber water surface during operation, and the time required to fill (or empty) the lock. Minimum pressures downstream of the valve were maximized, the maximum differences in pressures on the roof of the crossover culvert were minimized, and the operation time was minimized.

The Whitten Lock culvert system was designed to carry flow at a design head of 25.6 m (84 ft) with average culvert velocities near 15.2 mps (50 fps). This high-velocity flow requires smooth, flat surfaces to avoid cavitation damage. Displacement of a patch of the culvert roof results in a boundary that has a roughened surface and an offset away from the flow. Cavitation can then occur in the flow due to the turbulence generated by the boundary roughness and due to the large shear layer eddies which form downstream of the offset (Falvey 1990).

Results

Given the set of optimization objectives, the optimization scheme drives these parameters toward zero by adjusting the valve time. Constraints were added that the valve time could vary only between 60 and 480 sec. More than 500 LOCKSIM runs were completed in an automatic fashion for both normal- and single-valve filling and emptying operations (four models at more than 500 runs each).

Operation rates of both the filling and the emptying valves were varied. The pool conditions selected for this operation optimization were an upper pool elevation of 126.2 m (414 ft) and a lower pool elevation of 100.6 m (330 ft). The results of these optimization runs are provided on the plots of computed minimum pressure downstream of the valves and the pressure on the crossover roof for filling and emptying in Figures 28 and 29, respectively. The optimization scheme always pointed to the fastest valve time as being the best alternative (60-sec valve). Ables (1978) points out that a 1-min valve time maximizes the minimum pressure downstream of the valves, but Ables goes on to recommend using a 2-min valve for emptying to ensure the pressures are low enough to draw air into the culverts. The current model results suggest that the valve schedule that is presently used at the project (2-min 15-sec filling and emptying valve opening time) is acceptable. These valve timings ensure adequate air is drawn into the culvert to cushion the cavitation implosions and therefore should be retained as operation procedure.

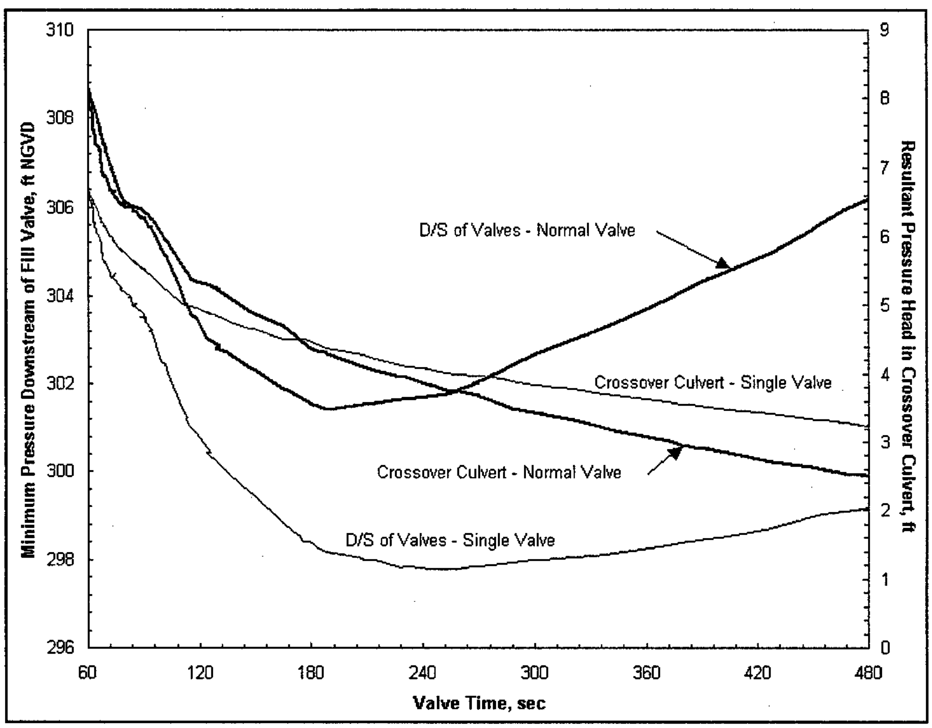

Figure 28. Effect of valve time on culvert pressure head during filling, upper pool el 414, lower pool el 330

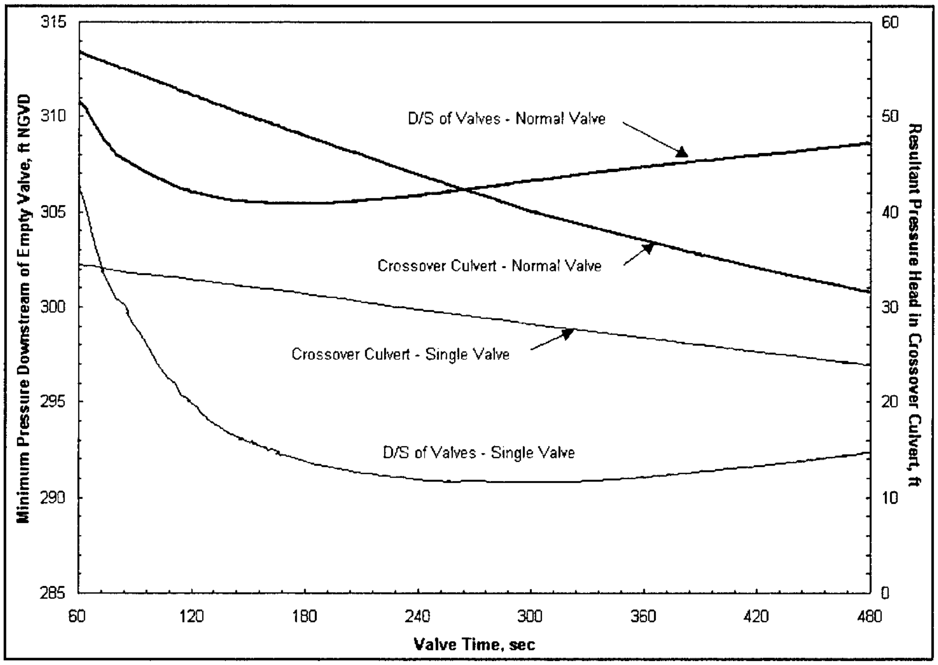

Figure 29. Effect of valve time on culvert pressure head during emptying, upper pool el 414, lower pool el 330

5 Summary and Conclusions

This evaluation of the Whitten Lock has determined that the hydraulic conditions within the filling and emptying system for the normal operations indicated by the Mobile District are not much different than what was anticipated during design. The high-lift lock experiences peak average velocities near 15.2 mps (50 fps). The differential pressure across the culvert roof at the area of concern is larger for longer valve times during filling, and actually reduces as valve times are increased during emptying. There is not a significant difference in the resultant pressure in the crossover for normal- or single-valve during filling operations. However, the normal valve produces a much larger resultant than a single valve during emptying. This differential pressure would produce the bending moments on the roof. The LOCKSIM model shows that the prototype experiences a maximum differential of 15.8 m (52 ft) across the culvert roof during a 2-min normal-valve emptying operation. The physical model study (Ables 1978) reported differences of about 17.7 m (58 ft) in this area under these same operating conditions. This leads to the conclusion that the hydraulic conditions in the existing project are similar to those expected during the design phase. Emptying the lock using a single-valve operation reduces the surge in the channel downstream of the lock. The results of this study show that the resultant pressure at the problem area during single-valve emptying is acceptable, but the pressures downstream of the emptying valve are excessively low. The air vent seems to be capable of supplying the volume of air demanded during these moments of low pressures. This statement is based on the fact that no structural damage below the emptying valves was noted during the last project inspection although single-valve emptying operations have been used often.

References

Ables, J. H. (1978). "Filling and emptying system for Bay Springs Lock, Tennessee-Tombigbee Waterway, Mississippi, Hydraulic model investigation," Technical Report HL-78-19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Engineous Software, Inc. (1999). *iSIGHT developer's guide.* version 5.0.

Falvey, H. T. (1990). "Cavitation in chutes and spillways," *Engineering Monograph No. 42*, Bureau of Reclamation, Denver, CO.

Headquarters, U.S. Army Corps of Engineers. (1975). "Hydraulic design of lock culvert valves," EM 1110-2-1610, Washington, DC.

McGee, R. G. (1989). "Prototype evaluation of Bay Springs Lock, Tennessee-Tombigbee Waterway, Mississippi," Technical Report HL-89-15, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Miller, D. S. (1990). *Internal flow systems.* 2nd ed., Gulf Publishing Co., Houston, TX.

Schohl, G. A. (1999). "User's manual for LOCKSIM: Hydraulic simulation of navigation lock filling and emptying systems," Contract Report CHL-99-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Stockstill, R. L., and Berger, R. C. (2000). "Simulation of flow in hydraulic structures using ADH," Coastal and Hydraulics Engineering Technical Notes, *http://chl.wes.army.mil/library/publications*, section IX-4, pp 1-7, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Stockstill, R. L., Fagerburg, T. L., and Waller, T. N. (2001). "Pool lowering at Lock and Dam 1 using the lock filling and emptying system, Mississippi River, Minnesota," ERDC/CHL TR-01-8, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

U.S. Army Corps of Engineers. "Hydraulic design criteria," prepared for Headquarters, U.S. Army Corps of Engineers, by U.S. Army Engineer Research and Development Center, Waterways Experiment Station, Vicksburg, MS, issued serially since 1952.

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14. ABSTRACT
A hydraulic analysis of the Whitten Lock filling and emptying system was performed. Evaluation of the culvert system was considered necessary because the lock structure has experienced damage over the past years on the roof of the crossover culvert. The purpose of this study was to determine whether or not the hydraulic conditions were significantly different from those anticipated during the design process and whether or not these hydraulic conditions were causing the damage to the crossover roof. A numerical model study of the lock provided peak velocities and pressure differences throughout the filling and emptying system. The numerical model results indicated that the hydraulic conditions were not significantly different from those observed in the hydraulic model study conducted during the project's design phase. The current study also investigated the hydraulic consequences of various filling and emptying valve operations.

15. SUBJECT TERMS

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