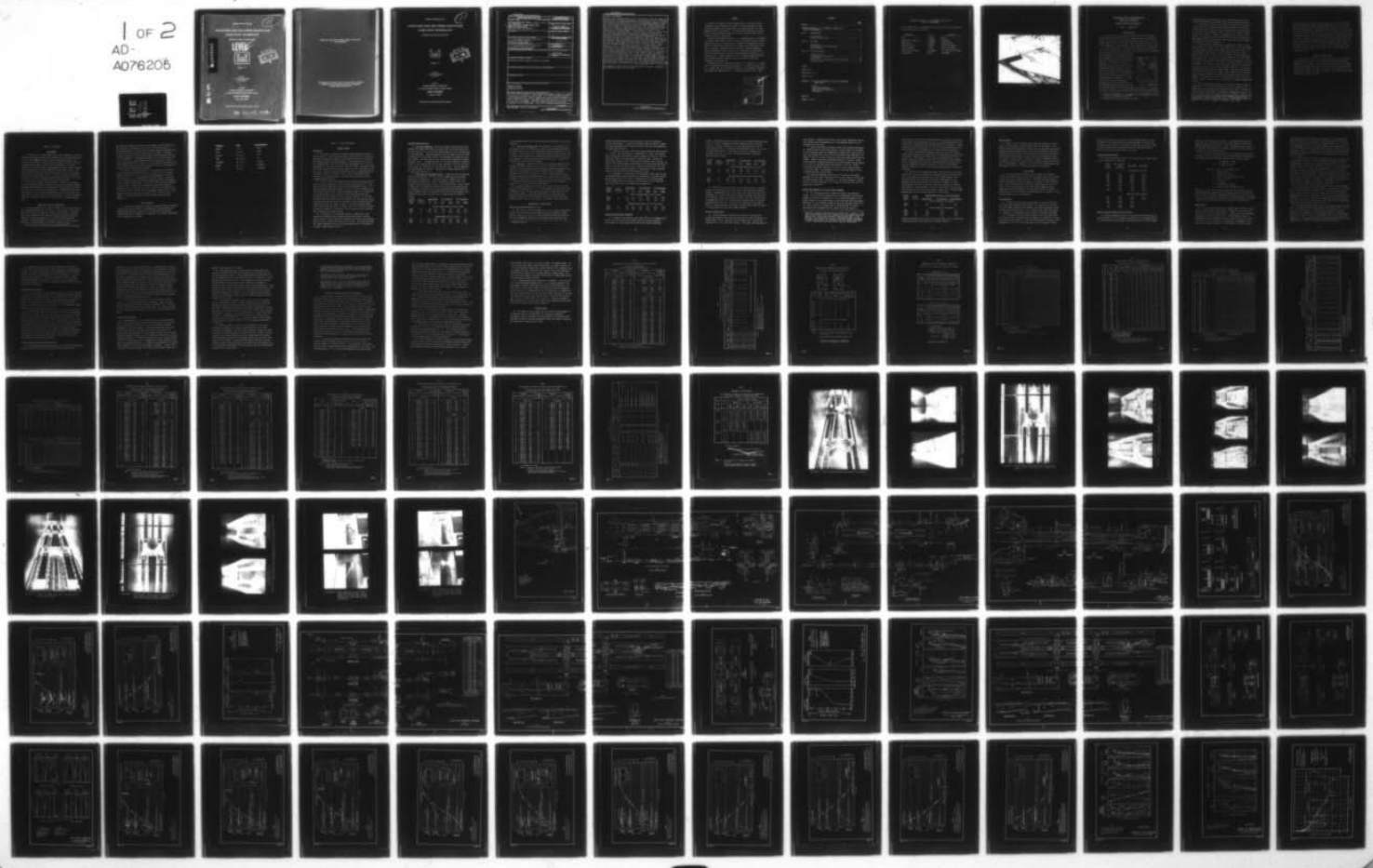
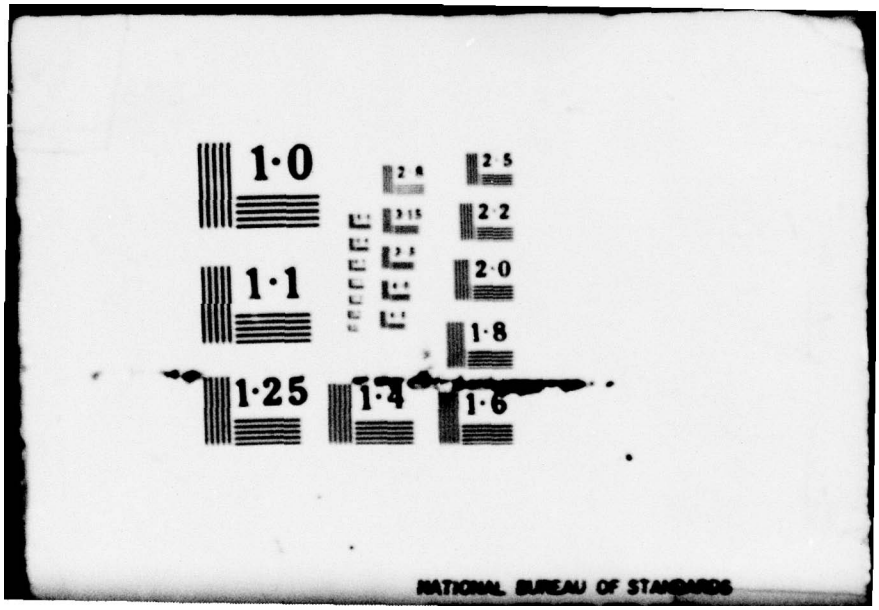
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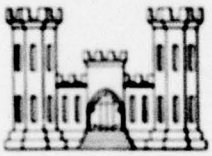
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Lower Granite navigation lock is designed for maximum, average, and minimum lifts of 105, 100, and 87 ft, respectively. The filling and emptying systems are dynamically balanced hydraulic systems that include a unique arrangement of eight longitudinal floor culverts symmetrically placed around the center of the 86- by 675-ft lock chamber. Portions of the forebay and tailrace, two adjacent spillway bays, and elements of the lock chamber and hydraulic system were reproduced in a 1:25-scale model. Tests of the proposed system indicated that

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turbulence and longitudinal hawser forces on barge tows in the lock chamber were excessive with a 4.0-min valve schedule at the design head of 105 ft. Pressures on the culvert roofs downstream from the filling valves were satisfactory when both valves were operated. With one valve, the minimum instantaneous pressure was -19 ft of water. Revised ports and baffles along the walls and over the ports were developed to reduce turbulence in the lock. Average maximum hawser forces of 6.2 tons on an eight-barge, 9-ft-draft tow and 9.9 tons on a four-barge tow in the original design lock were reduced to 1.4 and 1.7 tons, respectively, in the final design. A filling time of 9.8 min was obtained with a 1.11-min valve period and still maintained acceptable flow conditions, pressures, and hawser forces. Conditions were satisfactory when the lock was emptied in 11.5 min with two 1.03-min valves and an eight-barge tow. Air entraining vortexes over the intake manifolds should not occur unless the left filling valve only is used when the initial head is 105 ft and flow in adjacent spillway bays is more than 6,000 cfs per bay or when the initial head is 87 ft and spillway flow is slightly less than 4,000 cfs per bay. The 12-ft-wide culverts increased in height from 14 ft near the filling valves to 22 ft in a distance of 76 ft. A low average pressure of -5 ft on the culvert roofs downstream from the filling valves was desired to provide a continuous flow of air through the air vents and to prevent pressure reversals that might cause objectionable noises during filling. Low average pressures of 6, -6, and -11 ft of water were measured when the right culvert transition was moved downstream 25, 57, and 76 ft, respectively (two 1.11-min valves, initial head 105 ft). Pressures were within the range of cavitation when a single (right) valve was tested with the original culvert roof transition. (During testing the model air vents and culvert bulkhead slots were filled with water and sealed to prevent air intrusion and relief of low pressures.) The adopted transitions are 55 ft downstream from the original position, four 12-in.-diam air vents were used, and 16-ft-long steel culvert liners were installed downstream from the filling valves.

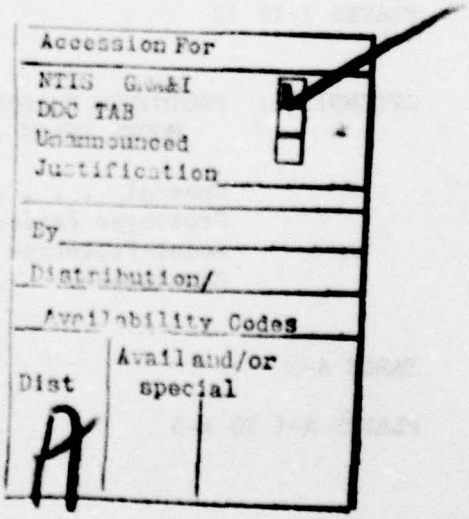
Tests made with the prototype lock were duplicated in the model. Essentially good agreement between the two occurred.

PREFACE

Authority for hydraulic model investigations of the Lower Granite navigation lock was granted by the Office, Chief of Engineers, in the fourth indorsement, dated 8 April 1965, to a request by the U. S. Army Engineer District, Walla Walla. The studies were conducted at the North Pacific Division Hydraulic Laboratory during the period October 1966 to November 1970 and in March 1976.

During the investigations Messrs. G. C. Richardson and J. D. McMichael of the Walla Walla District and H. A. Smith of the North Pacific Division made frequent trips to the Laboratory to observe flow conditions in the model, to discuss test results, and to correlate the results with design work in progress. Representatives of the Office, Chief of Engineers, Waterways Experiment Station, North Pacific Division, and Walla Walla District attended several conferences and demonstrations relative to the navigation lock. Design engineers of the St. Lawrence Seaway Authority also visited the model; progress reports on the test results were forwarded to that Authority.

The model study was conducted by Messrs. R. L. Johnson, A. G. Nissila, and G. D. Bocksler and supervised by Messrs. H. P. Theus, Director, and A. J. Chanda, Chief of the Hydraulics Branch, of the Hydraulic Laboratory. This report was compiled by Mr. L. Z. Perkins and edited by Mr. Theus.



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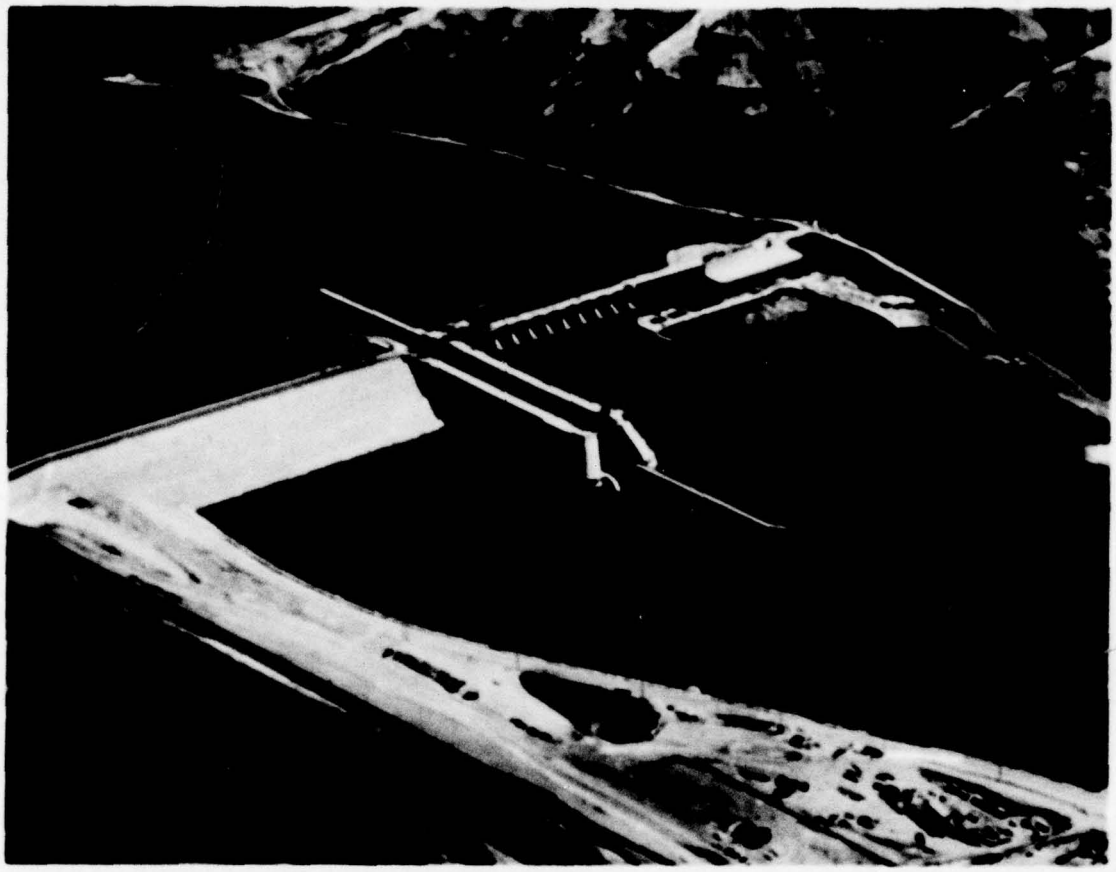
TABLE A-A

PLATES A-1 TO A-5

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

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

Multiply	By	To Obtain
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square feet	0.092903	square meters
feet per second	0.3048	meters per second
feet per minute	0.3048	meters per minute
cubic feet per second	0.0283168	cubic meters per second
tons (short)	907.185	kilograms



Lower Granite Dam

NAVIGATION LOCK FOR LOWER GRANITE DAM
SNAKE RIVER, WASHINGTON
Hydraulic Model Investigations

PART I: INTRODUCTION

The Prototype

1. Lower Granite Lock and Dam is on the Snake River 107.5 miles upstream from the confluence with the Columbia River, 37.2 miles above Little Goose Dam, and 21.8 miles below Lewiston, Idaho.* Fig. 1 is a vicinity map of the area. The project was constructed by the U. S. Army Corps of Engineers for flood control, power, navigation, and other uses.

2. Salient features of the project, shown on plate 1, include the spillway and stilling basin, powerhouse and excavated tailrace, navigation lock and approaches, facilities to collect and pass migratory fish upstream over the dam, embankments, and concrete nonoverflow sections. The navigation lock with clear dimensions of 86 by 675 ft (plate 2) is designed for a maximum lift of 105 ft from minimum tailwater at elev 633 to normal pool at elev 738.** Normal and minimum lifts are 100 and 87 ft. The minimum lift results from lowering the pool 6 ft at a river discharge of 300,000 cfs to prevent overtopping of levels at Lewiston. Minimum clearance over the sills is 15 ft. The submersible upstream tainter gate has an effective height of 23 ft, and the ends are recessed 2.5 ft into the lock walls to protect the hoisting cables from injury by passing vessels.

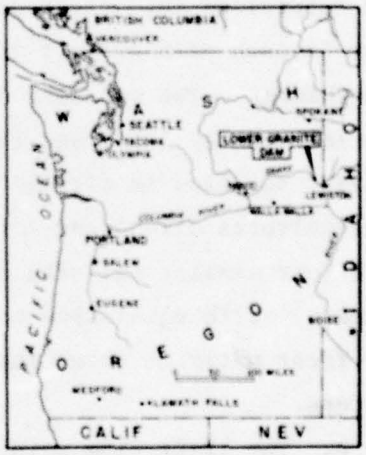


Fig. 1. Vicinity map.

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

** Elevations are in feet above mean sea level.

The downstream miter gate consists of two 112.5-ft-high, horizontally-framed, all-welded leaves that span 92.67 ft between abutment bearings.

3. Initial plans for the lock included a conventional split-lateral filling system with intakes in the upstream guide walls, longitudinal culverts and reverse tainter valves in the lock walls, and an excavated outlet basin for each emptying culvert. Plans for the intakes and main conduits were retained. However, a longitudinal floor culvert system similar in principle to that for Millers Ferry Lock* was developed as an improvement over the split-lateral system, and an outlet basin common to both emptying culverts was adopted.

4. The new design, sometimes called a dynamically balanced system, admits water to the center of the lock chamber where it is divided equally to a large number of ports placed symetrically on the lock floor. The ports discharge simultaneously to minimize turbulence and to obtain uniform distribution of flow in the lock chamber. At Lower Granite the main culverts enter the center of the lock chamber and are then divided and subdivided into eight smaller longitudinal culverts (plates 2 and 3). Flow in each main culvert is divided by a horizontal splitter as it enters the chamber. The top half of the divided right culvert turns upstream on the lock center line, and the bottom half goes downstream. In the left culvert the flow is divided in reverse manner. Each set of superimposed half-culverts discharges into a common central chamber that is separated into four smaller culverts at about the one-quarter points of the lock chamber. With equal flow to the first pair of ports in each sub-culvert, the first water to enter the lock is discharged in a balanced symmetrical pattern.

5. The 12-ft-wide main culverts of the original design increased in height from 14 ft at the filling valves to 22 ft in a distance of 76 ft downstream to provide satisfactory pressures at the valves. Changes that resulted from the model study are described in paragraphs 52 and 57. At

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* J. H. Ables, Jr. and M. B. Boyd, "Filling and Emptying Systems, Millers Ferry and Jones Bluff Locks, Alabama River, Alabama; Hydraulic Model Investigation," Technical Report No. 2-718, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi (March 1966).

the horizontal splitters each culvert became two 12- by 10-ft sections that discharged into a chamber that divided into four 5- by 12-ft sub-culverts. Each sub-culvert contained six pairs of ports. The size of ports was selected on the basis that the area of ports in each sub-culvert should not exceed 85 to 90 percent of the culvert area and that the ratio of total port area to valve area should be similar to that at other high-lift locks. Ratios of 1.11 to 1.23 have been used successfully at Ice Harbor, John Day, Lower Monumental, and Little Goose Locks. Ninety-six ports, each 2.00 by 2.16 ft in size, were selected initially. This provided a ratio of 1.24 and was 86.5 percent of the sub-culvert area. Later the ports were made 1.25 ft wide by 3.46 ft high, but the area remained the same.

Purpose of Model Study

6. The primary purposes of the model study were to investigate the hydraulic characteristics of the proposed new design and to develop improvements if required. Specific information was desired concerning filling and emptying times for different valve speeds and initial heads, direction and extent of movement of free barge tows, hawser pulls on barges moored in the lock chamber, pressures in the culverts, and vortex action at the intake manifolds.

PART II: THE MODEL

Description

7. Portions of the forebay and tailrace and all elements of the lock chamber and hydraulic system were reproduced in a 1:25-scale model (plate 4). The lock chamber was constructed of waterproofed plywood. The intakes, main culverts, central distribution system, and bifurcations to the manifolds were made of clear plastic (photograph 1) to obtain stability of structural shapes, approximate the correct surface roughness, and allow observation of dye injected into the hydraulic system. The eight longitudinal culverts were made with plastic floors, cast plastic walls and ports, and plywood roofs. The outlet culverts and downstream outlet structures that reproduced the preliminary design with an outlet on each side of the lock were used throughout the model study.

8. The reverse tainter valves were made of plastic with aluminum structural members and were fitted with rubber seals to prevent leakage. Each valve was connected by a rod and bridle to a gear-driven cam plate. The gear drive for each valve was powered by a reversible electric motor. Limit switches on the cam plates automatically shut off the motors when fully open or closed valve positions were reached. Provision was made for uniform and staggered operation of the valves and for variable opening time.

Appurtenances and Instrumentation

9. Water was supplied to the model through a recirculating system in which discharges were measured by means of orifice meters. The forebay and tailbay contained troughs that acted as overflow weirs to maintain relatively constant pool and tailwater elevations during filling and emptying. Vertical adjustments of the overflow troughs permitted simulation of desired heads on the hydraulic system. Dye and confetti were used to study subsurface and surface current directions.

10. Water-surface elevations upstream and downstream from the lock

were measured by means of electronic point gages in stilling wells that were connected to piezometers in the floor of the model (plate 4). Differential pressure cells were used to measure variations between water-surface elevations at opposite ends of the lock chamber. Pressures throughout the hydraulic system were measured with piezometers connected to water manometers. Flush-mounted pressure cells were installed in the roof of each culvert just downstream from the filling valve. During pressure measurements the air vents and the bulkhead slots downstream from the valves were filled with water and sealed to prevent air entering the culverts and relieving negative pressures.

11. Hawser force data and drifts of free barge tows were observed with sheet metal barges that were each 40 ft wide by 135 ft long and loaded to drafts of 9 or 14 ft, which were displacements of 1,380 and 2,225 tons (plate 5). Longitudinal and transverse hawser forces that acted on barge tows during filling and emptying operations were measured by semi-circular aluminum links to which SR-4 strain gages were cemented. Three were used: one measured longitudinal forces and two measured transverse forces at the ends of the tow. One end of the link was pin-connected to the tow, and the other end engaged a fixed vertical rod and was free to move up and down as the water rose or fell in the lock chamber. Force link and pressure cell data were recorded oscillographically.

Scale Relations

12. The accepted equations of hydraulic similitude based on Froudian relations were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. *General relations for transference* of model data to prototype equivalents, or vice versa, were as follows:

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

PART III: TESTS AND RESULTS

Original Design

Description

13. The layout of the plan A (original design) hydraulic system is shown on plate 4. Flow entered the right filling culvert from inside the upstream lock approach through an intake manifold with four 8-ft-wide by 30-ft-high openings that were submerged 52 ft by minimum pool elev 732. The downstream end of the right intake was approximately 141 ft from the upstream toe of the upper sill block. The left intake, positioned to draw water from outside the lock approach channel, was 43 ft upstream from the sill block. Vertical transitions downstream from the intakes reduced the 12-ft-wide culverts to a height of 14 ft, 30.29 ft upstream from the trunnions of the filling valves. The valve inverts were 41 ft below minimum tailwater elev 633.

14. Air vents, which were manifolds with transverse openings with an area of 3.9 sq ft connected to four vent pipes with an area of 3.4 sq ft, were located just downstream from the filling and emptying valves. The culverts increased in height from 14 ft to 22 ft in 76 ft downstream from the filling valves and 140 ft farther downstream lowered 1 ft through 50-ft-long transitions. Both culverts turned 90 degrees and entered a transverse dividing section centered at station 76+06.00. A 2-ft-thick horizontal partition centered at elev 602 split the flow from each culvert into upper and lower portions that continued through 90 degree bends and transition sections into eight 5-ft-wide, 12-ft-high longitudinal sub-culverts with walls and roofs 2 ft thick. Each of the culverts contained six pairs of opposite, 2.0-ft-wide by 2.16-ft-high ports with sides and tops rounded by 1.0-ft-radius curves.

15. In emptying, flow re-entered the ports, passed back to the transverse dividing section, and moved downstream through 22-ft-high outlet culverts, 34.9-ft-long roof transitions, 14-ft-high tainter valves, and 12- by 14-ft culverts with inverts at elev 592. (As noted previously, the combined emptying system of the adopted design was not reproduced in the model; compare plates 3 and 4.)

Hydraulic Characteristics

16. Filling and Emptying. Filling and emptying characteristics were measured for normal (two valves) and single (left) valve operations with an initial head of 105 ft and valve opening times of 4.0 min (filling) and 2.0 min (emptying). Times were measured from the instant the valves began to open until the lock water surface first equalled the forebay and tailwater levels. Filling curves for two- and one-valve operations are shown on plates 6 and 7. The emptying curve for two-valve operation is shown on plate 8. The average times (of five runs) required to fill the lock were 12.1 min with two valves and 17.7 min with one valve. The lock emptied in 12.6 min through both culverts. Overtravel for normal operation was 1.2 ft; undertravel was 0.6 ft.

17. Flow Conditions and Hawser Forces. Although filling and emptying times were satisfactory, flow into the lock chamber was more turbulent than desired (photograph 2). Typical patterns of hawser forces on an eight-barge tow (position I, plate 5) are shown on plates 6 and 7 for filling with an initial head of 105 ft and 4.0-min valves. Typical values of hawser forces are peaks of relatively rapid load fluctuations and do not represent a sustained force of that magnitude against the barge tows. Typical maximum forces in a representative filling run and maximum forces obtained in five repeat runs with four- and eight-barge tows were as follows:

Filling Valves Used	Barge Position	Longitudinal		U/S Transverse		D/S Transverse	
		U/S	D/S	Left	Right	Left	Right
		Typical Maximum Hawser Forces in Tons					
Both	I	4.8	5.2	3.1	4.4	3.9	5.5
Both	IV	10.4	0.9	3.5	4.6	3.5	4.5
Left	I	2.2	6.3	7.8	0.0	4.9	0.3
		Maximum Hawser Forces in Tons					
Both	I	6.2	8.0	5.6	4.9	6.2	5.9
Both	IV	11.7	3.9	4.6	5.2	4.9	5.9
Left	I	4.4	6.3	7.8	0.5	6.4	0.5

Typical maximum hawser forces during emptying were between 0.4 and 0.6 ton (plate 8).

18. Drift of Free Barge Tows. The movements of an unmoored tow of four barges in the lock chamber were observed during normal filling with an initial head of 105 ft. The barges were placed at position II, III, or IV (plate 5) before each test. Although the barges drifted as much as 50 ft while the lock filled, they always moved toward the center of the lock from upstream or downstream starting positions (plate 9). Therefore, a free barge tow would not harm the gates.

19. Pressures. Pressures in the lock culverts were measured at the piezometer locations shown on plates 10 and 11. With both culverts in operation, the average minimum and instantaneous minimum pressures* on the culvert roof downstream from the left filling valve at piezometer (pressure cell) L-4 were 15 and 10 ft of water, respectively (plate 6). Average and instantaneous minimum pressures of -10 and -19 ft occurred at piezometer L-4 when only the left culvert was used to fill the lock (plate 7). Pressures downstream from the emptying valves were not observed because of the continuous aeration that existed.

20. Pressures measured with steady flow through fully-open filling valves and the maximum head of 72.5 ft that existed when the valves first became fully open during filling operations with initial head of 105 ft are listed in table A. During the measurements the emptying valves remained closed, and the downstream gate was raised to maintain water-surface elev 665.5 in the lock chamber. All pressures were satisfactory.

Development of Final Design

Plan A Ports and Baffle Plans I to III

21. The jets from the lock chamber ports of the original design were observed by dye injected into the manifolds and the behavior of small pieces of yarn held in the flow. Those observations indicated that the jets were incompletely baffled by the adjacent walls because the jets

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* Defined on table P.

turned slightly downstream from the direction of flow in individual culverts (photograph 3). The need for baffles along the walls to improve the energy dissipation and reduce deflection of the jets both downstream and upward was indicated.

22. Details of the first three baffle plans tested are shown on plate 12. In plan I the A baffle was 6 ft high and B 5 ft high. All baffles were 2-ft deep with the interior nitches centered on the ports. The 5-ft walls were found to be high enough to contain the jets. The plan II baffles were similar to plan I except that all baffles were 5 ft high. In plan III the interior baffles were shifted 2.5 ft and the end baffles were moved 5 ft in the direction of flow to improve interception of the jets. Plan III also had triangular-shaped roof extensions to reduce upwelling along the vertical face of the downstream sill block.

23. Comparison of photograph 4 with photograph 2 shows that the plan III baffles greatly reduced upwelling and turbulence at the water surface during normal filling of the lock. Consequently, the following hawser forces obtained with 4-min valves and initial head of 105 ft were much lower than those without the baffles (see paragraph 17).

Filling Valves Used	Barge Position	Longitudinal		U/S Transverse		D/S Transverse	
		U/S	D/S	Left	Right	Left	Right
		Typical Maximum Hawser Forces in Tons					
Both	I	1.7	1.2	1.9	0.6	1.3	0.6
Both	IV	2.8	0.8	1.5	1.4	1.0	1.6
Left	I	1.5	2.9	1.8	0.9	2.4	0.9
		Maximum Hawser Forces in Tons (Five Runs)					
Both	I	2.1	1.7	1.9	1.7	1.8	1.0
Both	IV	3.2	0.9	2.1	1.7	2.1	1.6
Left	I	2.3	2.9	2.3	0.9	2.4	1.2

Plan B Ports and Plan III Baffles

24. To improve the direction of the jets from the lock chamber ports, the 2.0- by 2.16-ft ports with rounded sides and top were changed to 1.25-ft-wide by 3.46-ft-high plan B ports with 90 degree downstream

corners. The plan B ports were installed in the original manifolds having walls 2 ft thick. Preliminary tests were made with plan III baffles (plate 12), 4.0-min filling valves, 2.0-min emptying valves, and an initial head of 105 ft. Filling time decreased from 12.1 to 11.7 min for two valves and from 17.7 to 17.3 min for one valve. Emptying time decreased from 12.6 to 12.1 min. The following hawser forces were obtained during filling:

Filling Valves Used	Barge Position	Longitudinal		U/S Transverse		D/S Transverse	
		U/S	D/S	Left	Right	Left	Right
		Typical Maximum Hawser Forces in Tons					
Both	I	2.6	1.0	0.6	1.3	1.2	1.3
Both	IV	2.8	0.8	0.9	1.7	1.5	1.3
Left	I	2.6	2.0	1.6	1.0	1.3	0.5
		Maximum Hawser Forces in Tons (Five Runs)					
Both	I	3.0	1.3	1.6	1.7	1.7	1.3
Both	IV	3.6	0.9	1.0	2.6	2.0	1.6
Left	I	3.8	2.9	2.6	1.4	2.5	0.7

25. The plan B ports were more efficient than the ports of original design, and turbulence and upwelling over the manifolds were increased slightly. Maximum hawser forces were higher than those with plan A ports (paragraph 23). Studies made with an unmoored four-barge tow located in the downstream, center, and upstream portions of the lock indicated that the maximum drift of 95 ft occurred when the barge tow was in the downstream position (plate 13). Drift was 44 ft upstream from the center position. Barges initially placed near the gates moved toward the center of the lock where they would not damage the gates.

Effects of Valve Speed

26. A study was made to determine the effects of filling valve opening times faster than 4.0 min with plan B ports, plan III baffles, an initial head of 105 ft, and eight- and four-barge tows. Actual valve times were 0.55, 1.11, 2.09, and 4.00 min. Five repeat runs were made for

each condition. Pressures on the roof of the culvert downstream from the left filling valve were measured with a flush-mounted pressure cell at piezometer L-4 (plate 10).

27. Surface turbulence increased as valve time decreased (photograph 5). Hawser forces for two-valve operation, filling times, and pressures for the conditions tested are summarized in tables B and C and on plate 14. With valve speeds faster than 4.0 min during single-valve operations, air drawn into the left culvert through the valve well erupted inside the lock chamber. Hawser forces were not measured when that occurred.* Hawser forces generally increased gradually as the valve opening time was reduced to 1.11 min but increased sharply when reduced to 0.55 min. Hawser forces were acceptable (less than 5.1 tons) for valve opening times of 1.11 min and longer. The maximum force of 8.5 tons was measured with a four-barge tow and 0.55-min valves.

28. Pressures downstream from the left filling valve were above atmospheric for two-valve operations and for a valve time of 0.55 min when one valve was used (table C and plate 14). The lowest pressure occurred with the 2.09-min valve speed (8 ft of water for two-valve and -29 ft for single-valve operations).

Plan B Lock Chamber, Plan C Ports, Plan V Baffles

29. The following structural changes were made in the hydraulic system: (a) the vertical upstream face of the downstream sill block was changed to a slope of 45 degrees; (b) 1.5-ft fillets were added to the inside corners of all culverts except in the valve wells and longitudinal manifolds; (c) the thickness of manifold walls was increased from 2 ft to 3 ft (plan C ports); (d) sloped roofs in curved sections of culvert bifurcations were eliminated and the culvert invert was lowered to

* Turbulence created by entrained air in a model is not to scale. In the model, large pockets of air are released in the lock chamber where they rapidly rise to the surface and burst creating turbulence. In the prototype, air entering the culverts is entrained as small bubbles in the high velocity flow. Upon release in the lock chamber they appear to have a cushioning effect rather than creating a disturbance.

elev 601.0; and (e) the floor between manifolds was lowered to elev 596.5. In the model, only the sloping sill block, 3-ft-thick manifold walls, and fillets in the central culverts were added (plan B lock chamber). Fillets in other areas and items (d) and (e) were not revised because they would have little effect on performance of the hydraulic system (plate 15).

30. Plan V baffles were developed for use with the plan B lock to reduce surface turbulence and free barge drift that had occurred with plan III baffles. Respacing the dividers near the downstream ends of the baffles (plate 16) reduced the barge drift, particularyly with 4.00-min valves. The maximum drift was 38 ft upstream from the downstream end of the lock chamber with two-valve operation. With the 1.11-min-valve schedule, barge drift of 85 ft away from the upstream gate occurred with two-valves.

31. The plan B lock chamber with plan C ports and plan V baffles was tested with 1.11-min and 4.00-min valve opening times, an initial head of 105 ft, and eight- and four-barge tows. With 4.00-min valves, flow conditions at the water surface were excellent (photograph 6), and although upwelling increased when the valves were opened in 1.11 min, turbulence was less than it was with plan B ports and plan III baffles (photograph 5). Filling times of 11.3, 16.9, 9.6, and 15.2 min occurred with two and one 4.00- and 1.11-min valves, respectively. As shown below, maximum hawser forces on barge tows were 3.7 tons or less.

Filling Valves Used	Barge Position	Maximum Hawser Forces in Tons (Five Runs)		
		Longitudinal	U/S Transverse	D/S Transverse
		Valves Opened in 1.11 Minutes		
Both	I	3.2	3.2	2.7
Both	IV	3.7	2.2	2.1
		Valves Opened in 4.00 Minutes		
Both	I	2.0	1.2	1.3
Both	IV	3.0	2.4	1.6
Left	I	3.4	1.5	1.9
Left	IV	3.6	2.1	1.8

Pressures downstream from the left filling valve were 1 to 6 ft lower than they were with plan B ports and plan III baffles (table C).

Plan VI Baffles

32. Tests of plan V baffles had indicated that opening the filling valves in 1.11 instead of 4.00 min would reduce filling times 1.7 min without causing large increases in hawser forces or decreases in pressures downstream from the filling valves. The plan VI baffles were devised to partially dissipate the port jets that were reflected back to the sides of the manifolds from the walls, central culverts, and tee-baffles during filling with 1.11-min valves. Continuous 2-ft-wide overhanging roofs on the manifolds restricted the discharge and caused horizontal flow from the ends of the manifolds. Overhangs 7 ft long with 7-ft spaces between them (photograph 7 and plate 17) were selected as the final design.

Final Design

33. The final design included the plan A intakes, longitudinal culverts, and outlets (plate 4), plan B lock chamber (plate 15), and plan C ports with plan VI baffles (plate 17). More than the usual amount of data were obtained to provide information for design of future high-lift locks. Tests were made with filling valve opening times of 0.55, 1.11, 2.07, 4.00, 6.40, and 8.00 min, 1.03- and 2.00-min emptying valves, single- and two-valve operations, initial heads of 105, 100, and 87 ft, barge positions I to VII (plate 5), and barge drafts of 9 and 14 ft. Five runs were made for each test condition.

Flow Conditions

34. As shown by dye patterns in photograph 8, jets from the plan C ports were almost normal to the manifolds. The smooth water surface in the lock chamber indicated that turbulence was almost nonexistent during filling with both valves with 1.11- or 4.00-min valve times (photograph 9). Comparison of photographs 9 and 2 shows the improvement developed.

35. The absence of objectionable currents in the lock chamber was also shown by drift studies made with an unmoored four-barge tow in three starting positions (plate 18). With two filling valves in operation, the maximum drift of 51 ft for any barge position and the maximum average

drift for all positions occurred with a valve opening time of 0.55 min. The amount of drift decreased as valve time increased. With one valve, the greatest drift (60 ft) occurred with a valve time of 1.11 min. With two minor exceptions the barges drifted away from the gates when the initial positions were near the ends of the lock.

Filling and Emptying Times

36. Filling and emptying times for all heads and valve opening times that were studied were as follows:

Initial Head in Feet	Valve Opening Time in Minutes	Two Valves	One Valve
		Filling Time in Minutes	
105	0.55	9.4	15.0
105	1.11	9.8	15.5
105	2.07	10.4	16.1
105	4.00	11.5	17.2
105	6.40	12.9	18.7
105	8.00	13.8	19.8
100	1.11	9.6	15.0
100	4.00	11.2	16.8
87	1.11	9.0	14.0
87	4.00	10.6	15.9
		Emptying Time in Minutes	
105	1.03	11.5	19.8
105	2.00	12.2	20.6
100	1.03	11.3	
100	2.00	12.0	
87	1.03	10.6	
87	2.00	11.2	

Rates of Rise and Overall Lock Coefficients

37. Filling and emptying curves for selected valve opening times and the design head of 105 ft are shown on plates 19 to 28. Maximum rates of rise and discharge were determined from large-scale plots of the steepest

portion of each filling curve (table D). The maximum discharges with fully open valves were used later to set model inflows for tests with steady flow through the hydraulic system. The maximum rates of rise of 20.5 fpm with two valves and 13.3 fpm with one valve occurred with the 0.55-min valve time and 105-ft head.

38. Overall lock coefficients based on filling times for one- and two-culvert operation and valve opening times between 0.55 and 4.00 min were computed with the following equation and are listed in table D.

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

where A_L = area of lock chamber, sq ft

H = initial head, ft

d = measured overtravel, ft

A_C = area of culverts at valves, sq ft

T = filling time, sec

K = a constant

t_v = valve opening time, sec

g = acceleration of gravity, ft/sec^2

The term $T - Kt_v$ is the lock filling time for the hypothetical case of instantaneous valve opening and can be obtained directly from the test data. The coefficients for the maximum head ranged from 0.778 (1.11-min valves) to 0.772 (4.00-min valves) with two valve operations. The highest coefficient with single valve operation was 0.987 (1.11-min valve).

Hawser Forces

39. Lock filling times and typical maximum hawser forces are shown in table E; average forces and the range of forces that occurred in five repeat runs are listed in tables F and G. Similar data for the emptying operation are listed in tables H and I. Typical hawser forces for representative test conditions are shown on plates 19 to 24 for filling and plates 25 to 28 for emptying. As mentioned in paragraph 17, the hawser forces shown on plates 19 to 28 are peaks of relatively rapid

fluctuations that do not represent a sustained force of that magnitude against the barge tows. Lock filling times and pressures at the valves for one- and two-valve operations with opening times of 0.55 to 8.00 min and maximum hawser forces for two-valve operations and opening times of 0.55 to 4.00 min with four and eight barges loaded to a draft of 9 ft are summarized on plate 29. Hawser forces for operation of one filling valve with opening times of 0.55 to 4.00 min at an initial head of 105 ft are shown on plate 30.

40. Normal two-valve operations (maximum head, 1.11 min valves) with an eight-barge tow with 9-ft draft produced very satisfactory average maximum hawser forces of 2.3 tons during filling (table F). Similar conditions with 1.03-min valves produced forces of 0.5 ton during emptying (table I). With four barges in the downstream end of the lock chamber (position IV, plate 5), the maximum forces in any run were 4.8 tons (filling) and 1.0 ton (emptying). Delaying the opening of a filling valve 30 and 60 sec caused only minor variations in filling times and hawser forces (tables E, F, and G); therefore, synchronization of the valves will not be required. However, an interlock or other device should be installed to insure that both valves are in operation.

41. Use of a filling valve opening time of 1.11 min was recommended for two-valve operations. The filling time of 9.8 min for the 105-ft head was 1.7 min less than with 4.00-min valves. Maximum individual hawser forces for any position of 9-ft-draft barges were less than the design maximum force of 5 tons. Although the overall average of longitudinal and transverse forces was 3.7 tons or less, individual maximum longitudinal forces of 6.1 and 7.6 tons were measured when eight- and four-barge tows, respectively, were loaded to a draft of 14 ft.

42. Filling times and hawser forces increased when a single valve was used. The overall average maximum hawser force increased from 1.7 to 3.3 tons with a valve time of 1.11 min and eight barges with 9-ft draft (table F). The maximum forces for individual runs with the same barges were 8.4, 6.6, and 3.4 tons for valve times of 0.55, 1.11, and 4.00 min, respectively. No data were observed with single-valve operations and four barge tows with 0.55-min valve time or barge draft of 14 ft.

43. Hawser forces during emptying were always less than during filling. The faster valve time of 1.03 min resulted in a maximum hawser force of 1.8 tons with single-valve (left) operation and an eight-barge tow with 9-ft draft. The maximum force with two valves was 1.0 ton and occurred with four barges. For similar conditions but with 2.00-min valves, maximum hawser forces were 1.4 tons and 1.0 ton, respectively. The largest individual force was 3.5 tons with a single 2.00-min valve and eight 14-ft-draft barges.

Pressures at Filling Valve

44. Positive pressures existed downstream from the left filling valve for all two-valve operations (plate 29). Instantaneous minimum pressures ranged from 6 ft of water with 2.07- and 4.00-min valves to 23 ft when the valves opened in 0.55 min. Average minimum pressures were slightly higher. The pressure graphs on plates 19 to 22 show the average of pressure fluctuations for typical test runs and the instantaneous minimum pressures that occurred during those runs.

45. During single-valve operation negative pressures existed downstream from the valve (plates 23, 29, and 31). With valve opening times of 2.07 min and faster, pressures downstream from a wide-open valve were so low that air entered the model culvert through the valve well. The lowest pressures, -19 ft average and -26 ft instantaneous, occurred when the left valve opened in 2.07 min. The 0.55-min valve opened so rapidly that maximum velocities and minimum negative pressures did not occur until after the valve was fully open. The duration of negative pressures increased with valve time (plate 31). Because of its short low-pressure period, the 1.11-min valve schedule appears more desirable for single-valve operation of the filling system than a longer period that has approximately the same minimum pressures.

Pressures With Steady Flow Through Culverts

46. Pressures were measured with steady flows through the filling and emptying culverts so that losses in the hydraulic system could be

determined for use in design computations. The pressures were obtained with discharges and water-surface elevations that existed when the filling or emptying valves reached full opening during operation with an initial head of 105 ft. Flow conditions for filling valve opening times of 1.11 and 4.00 min, emptying valve opening time of 1.03 min, and single- and two-valve operations were reproduced. During filling tests, the emptying valves remained closed, the filling valve or valves were fully open, and flow was released under the downstream lock gate to maintain desired discharges and water-surface elevations in the lock chamber. During emptying tests, the filling valves were closed, the emptying valve or valves were fully open, the upstream gate was removed, sufficient water to maintain desired lock water-surface elevations flowed over the upstream sill, and tailwater was held at elev 633.

47. All pressures were satisfactory for the conditions studied (tables J to L, filling; tables M and N, emptying). Since the model culverts downstream from station 73+10.50 (piezometer ring F, plate 10) differed from the adopted prototype design (plate 3), energy grade lines in the prototype emptying culvert will vary from those indicated by the model.

Vortex Action at Intakes

48. The possibility of vortex formation over the intake manifolds (plate 3) was investigated during normal filling operations at initial heads of 87 and 105 ft (pool elev 732 and 738, minimum and maximum submergences of the lock intakes). Observations were made with single- and two-valve operations and simulated spillway flows through two adjacent spillway bays (plate 4). The discharge capability of the model limited the adjacent spillway flow to 4,000 cfs per bay when both filling valves were operated. A "vortex" was defined as a cone of swirling water at least 2 ft deep with a core or filament that extended downward into an intake port (observed with dye). A "dimple" was a depression in the water surface between 0.5 and 2.0 ft deep without a filament. A "swirl" was a concentrated circular movement of the water surface, and an "eddy" was a

general circular motion of the water.

49. Flow conditions, type of vortex action, starting time, and duration of the most noticeable vortex action that occurred during the tests are listed in table 0. Vortex phenomena usually lasted from 2 to 13 min and ended when the lock was within 10 to 20 ft of being full. Actual vortexes lasted from 3 to 9 min. Swirls, dimples, and vortexes formed intermittently in successive test runs. There was no tendency for vortexes to form over the right intake because the wall adjacent to it was smooth and flow to it was not affected by flow through the spillway. Flow around the sharp vertical corners of the left intake structure created favorable conditions for vortexes to form. Although dimples and swirls existed, air entraining vortexes occurred only when the lock was filled through the left culvert.

50. The intensity of maximum vortex action over the left intake is shown in photographs 10 and 11. Because submergence of the intake was reduced, vortex action was most intense with an initial head of 87 ft. The slower 4.00-min valve schedule and the longer filling period provided more head on the intakes during the last portion of the filling operation and extended the duration of conditions under which vortexes were likely to develop. The maximum conditions (87-ft head, left valve opened in 4.00 min, 4,000 cfs through each of two adjacent spillway bays) produced a 6-ft-diam vortex with air-filled cone 4 ft in diameter (photograph 11 and table 0).

51. Hydraulic models can predict the possibility of vortexes at prototype lock intakes if the usual tranquil approach flow at these structures is reproduced. The rock-filled baffle that is shown on plate 4 was used to reduce trubulence in the model forebay. However, the short distance (12 ft) between the baffle and the intake might have allowed minor disturbances created by flow through the baffle to increase vortex action over the intake. Although available model inflow did not allow studies of normal filling operations to be made at an initial head of 105 ft with spillway flows greater than 4,000 cfs per bay, the following were indicated by the vortex study:

a. Air entraining vortexes are not likely to occur during normal filling of the lock through both valves, if one valve is used when the spillway is closed, and if the right valve and spillway are used simultaneously.

b. Vortexes may occur if the left valve only is used when the initial head is 105 ft and flow in adjacent bays of the spillway is more than 6,000 cfs per bay.

c. Vortexes will occur if the left valve only is used when the initial head is 87 ft and flow in adjacent spillway bays is slightly less than 4,000 cfs per bay. Increasing the valve opening time of 4.00 min will increase the duration and intensity of vortex action.

Revision of Filling Culvert Roof Transitions

52. Loud pounding or booming noises accompanied by large and rapid pressure reversals have occurred at the filling valves of several high-lift locks on the Columbia and Snake Rivers. These noises are thought to result from the collapse of large vapor cavities that form in the cores of vortexes shed from the valve lips. The formation and collapse of the cavities are thought to be the cause of the pressure changes. Observations at these projects have indicated that the introduction of sufficient air into the culverts prevents or cushions the collapse of the cavities and eliminates the noises and large pressure reversals. It was thought that this could be accomplished at Lower Granite by modifying the vertical transitions located immediately downstream from the filling valves to obtain a low average pressure of approximately -5 ft of water for the design conditions of normal two-valve operations with 1.11-min valve opening period and an initial head of 105 ft. Low average pressure is defined as the low point of a line drawn through the average of the pressure fluctuations measured by a pressure cell and recorded oscillographically.

53. As originally designed and reproduced in the lock model, the filling culverts increased in height from 14 ft to 22 ft in 76 ft (stations 79+05.00 to 78+28.00, plate 4). The beginning of the transitions were 1.65 ft downstream from the downstream face of the valves. Low average pressures of 15 ft of water were measured on the right culvert

roof at station 78+99.70 with a flush-mounted pressure cell during filling with an initial head of 105 ft and 1.11-min valves (plate 32). With the transition in the right culvert moved 76 ft downstream the low average pressure at station 78+99.70 was -11 ft. Increasing the valve opening time to 4.00 or 6.40 min had no significant effect on low average pressures when both valves were operated. Average pressures in the right culvert were negative between valve openings of 4.5 to 9.8 ft, 4.3 to 9.4 ft, and 4.0 to 8.4 ft with valve times of 1.11, 4.00, and 6.40 min, respectively, which indicated that air would be drawn through the air vents as the valves opened through those ranges. The pressures were measured with the air vents closed.

54. When the air vents were open, air was drawn into the right culvert with both one- and two-valve operations. Air was drawn into the left culvert having the original design transition with single-valve operation only. Visual observations indicated that violent flow conditions existed at the valves when air first entered the culverts. The mixing of air and water was extremely turbulent until a pocket of air or a hydraulic jump (with single valve) formed.

55. Use of only the right valve produced very low instantaneous pressures of -44, -74, and -58 ft of water in that culvert with valve opening times of 1.11, 4.00, and 6.40 min, respectively. Although negative pressures of this magnitude are not possible in the prototype, they indicate that cavitation would occur and that moving the transitions 76 ft downstream was not desirable for single-valve operation.

56. Tests made in the right culvert with the transition moved back to station 78+79.70 (25.23 ft downstream from its original position) produced a low average pressure of 6 ft. A line drawn through the available data points indicated that the desired low average pressure of -5 ft should occur if the transition were moved about 57 ft downstream from the original position to station 78+48.00.

57. With the transition at station 78+48.00, the low average pressure at station 78+99.70 was -6 ft and the instantaneous minimum pressure was -10 ft when both filling valves opened in 1.11 min (table P). Single-valve operation resulted in a low average pressure of -32 ft in the

revised right culvert and -3 in the left culvert of original design. The -6-ft pressure was slightly lower than desired. To obtain a pressure of -5 ft the transitions should be at station 78+50.00, 55 ft downstream from the original position. With the final location of the valve trunnions at station 79+27.13 (moved 1.0 ft upstream from the original design), the roof slope should begin at station 78+51.00 (56.67 ft downstream from the valve) and end at station 77+75.00.

58. Although placing the transition 57 ft instead of 76 ft from the valve increased minimum pressures about 5 ft, pressures remained in the range where cavitation would result from use of one filling valve. For this reason, the prototype culverts were lined with corrosion-resistant steel for about 16 ft downstream from the filling valves. In addition to two 12-in.-diam air vents in the top of each culvert two vents of the same size were placed at elev 598.5 and elev 603.5 in each side of the prototype culverts to aerate flow off the valve lip. Provision was made to measure pressures in the prototype culverts with piezometers and pressure cells in the culvert roofs at station 78+97.79.

Prototype Tests

59. Tests made on the prototype lock to evaluate the performance of the balanced hydraulic system design are discussed in Appendix A. Included are tests to determine the effectiveness of the revised culvert transition presented above and supplemental model tests made to duplicate the conditions of those prototype tests.

TABLE A

AVERAGE PRESSURES WITH STEADY FLOW THROUGH FULLY OPEN FILLING VALVES

Plan A Lock (Original Design)
Pool Elev 738.0, Lock Water-Surface Elev 665.5

Piezometer			Average Pressure in Feet of Water	Piezometer			Average Pressure in Feet of Water
Number	Station	Elevation		Number	Station	Elevation	
Right Culvert				Left Culvert			
1	81+71.23	678.0	56.9	1	80+72.10	680.0	47.4
2	81+65.08	680.0	54.5	2	79+40.42	606.0	81.3
3	81+65.08	650.0	84.6	3	78+99.70	606.5	79.3
4	81+65.08	678.0	56.2	5	78+24.00	614.0	93.6
5	81+63.95	678.0	57.0				
6	81+62.65	680.0	53.1	6	76+44.00	591.0	104.0
7	81+62.65	650.0	83.5	7	76+20.00	608.0	82.8
8	81+61.27	678.0	52.0	8	75+92.00	608.0	100.2
9	81+57.72	678.0	51.6	9	75+68.00	591.0	117.8
10	81+51.92	678.0	54.6	10	72+43.12	606.0	27.0
11	81+50.96	680.0	50.3				
12	81+50.96	650.0	80.3	Lock Chamber			
13	81+49.92	678.0	47.2				
14	81+46.46	678.0	48.4	1	75+92.00	596.0	92.0
15	81+39.36	678.0	50.1	2	75+92.00	608.0	77.4
16	81+39.27	678.0	52.2	3	76+20.00	608.0	78.8
17	81+38.75	680.0	48.3	4	76+20.00	596.0	92.8
18	81+38.75	650.0	80.0	5	77+62.32	597.7	98.7
19	81+38.15	678.0	45.9	6	77+62.32	597.7	97.7
20	81+36.59	678.0	45.1	7	77+77.75	606.1	71.2
21	79+40.42	606.0	82.0	8	77+79.75	606.8	72.1
22	79+06.44	606.5	64.6	9	77+77.75	607.4	73.4
23	79+05.96	606.3	64.7	10	77+85.00	605.5	69.9
24	78+99.70	606.5	80.7	11	77+99.75	606.8	73.1
25	78+95.00	607.0	83.0	12	78+26.50	602.0	83.1
26	78+90.00	607.5	84.8	13	78+40.50	602.0	88.1
27	78+85.00	608.0	86.2	14	78+54.50	602.0	92.9
28	78+40.00	612.8	92.1	15	78+68.50	602.0	96.1
29	76+20.00	608.0	81.9	16	78+82.50	602.0	98.8
30	76+20.00	596.0	95.2	17	78+96.50	602.0	99.1
31	75+92.00	608.0	99.9	18	77+35.50	602.0	84.7
32	75+92.00	596.0	110.9	19	74+76.50	602.0	83.3
33	72+91.26	599.0	109.0	20	73+85.50	602.0	85.1
34	72+43.12	593.0	40.0	A	76+06.00	608.0	88.8
35	72+43.12	606.0	27.0	B	76+06.00	596.0	102.9
36	71+65.25	605.0	28.0	C	75+70.50	608.0	89.9
A	80+72.10	665.0	61.9	D	75+70.50	596.0	102.8
B	79+40.42	599.0	89.3	E	74+76.50	608.0	78.3
C	78+24.00	603.0	104.5	F	74+76.50	608.0	78.9
D	76+44.00	603.0	102.3	G	73+85.50	608.0	79.9
E	73+50.40	603.0	105.1	H	73+85.50	608.0	79.4
F	73+10.50	599.0	109.1	I	76+41.50	608.0	88.7
G	72+73.50	599.0	109.1	J	76+41.50	596.0	101.2
				K	77+35.50	608.0	78.9
				L	77+35.50	608.0	79.5
				M	78+26.50	608.0	78.0
				N	78+26.50	608.0	80.3

NOTES: 1. Details of lock are shown on plate 4.

2. Piezometer locations are shown on plates 10 and 11.

TABLE B

FILLING TIME AND HAWSER FORCES DURING FILLING OPERATION

Plan A Lock, Plan B Ports, Plan III Baffles, Initial Head 105 Feet

Valves Used	Valve Time in Minutes	Filling Time in Minutes	Barge Position	Average Maximum Hawser Forces in Tons							Maximum Hawser Forces in Tons		
				Longitudinal		U/S Transverse		D/S Transverse		Overall Average	Longitudinal	Transverse	
				Upstream	Downstream	Left	Right	Left	Right		(see note 3)	Upstream	Downstream
Both	0.55	9.81	I	4.2	2.2	2.1	3.9	2.7	3.6	3.1	5.6	5.5 Rt	5.3 Rt
Both	1.11	10.15	I	2.8	1.9	2.1	2.4	2.1	2.1	2.2	4.0	2.9 Rt	2.7 Lt
Both	2.09	10.71	I	2.8	1.0	1.4	2.6	2.1	2.0	2.0	3.9	3.3 Rt	2.9 Lt
Both	4.00	11.74	I	2.5	0.9	1.0	1.5	1.3	0.9	1.3	3.0	1.7 Rt	1.7 Lt
Both	0.55	9.81	IV	5.6	3.2	2.6	3.2	3.4	2.4	3.4	8.5	3.7 Rt	3.9 Lt
Both	1.11	10.15	IV	3.7	1.7	1.7	3.2	3.7	3.0	2.8	5.1	4.5 Rt	4.5 Lt
Both	2.09	10.71	IV	3.1	1.4	1.6	3.3	2.1	1.8	2.2	4.0	4.3 Rt	2.8 Lt
Both	4.00	11.74	IV	3.1	0.7	0.9	1.8	1.7	1.3	1.7	3.6	2.6 Rt	2.0 Lt
Left	0.55	15.10	I										
Left	1.11	15.46	I	Hawser forces not measured because of air drawn into culvert.									
Left	2.09	16.10	I										
Left	4.00	17.30	I	2.6	2.2	1.7	1.0	1.8	0.6	1.6	3.8	2.6 Lt	2.5 Lt

NOTES: 1. Details of lock are shown on plates 4 and 10 to 12.

2. Barge positions are shown on plate 5.

3. Maximum longitudinal hawser forces were directed upstream.

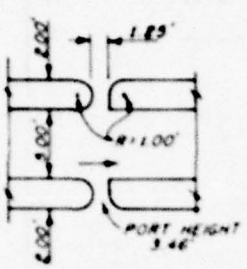
4. Data obtained from five duplicate runs.

TABLE B

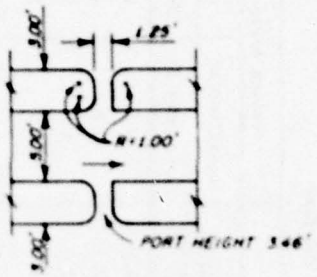
TABLE C

MINIMUM PRESSURES DOWNSTREAM FROM LEFT FILLING VALVE

Lock Plans A and B; Initial Head 105 Feet



PLAN B PORT



PLAN C PORT

Valves Used	Valve Time in Min	Number of Runs	Minimum Pressures in Feet of Water	
			Average	Instantaneous
Plan A Lock, Plan B Ports, Plan III Baffles				
Both	0.55	5	26	23
Both	1.11	5	12	9
Both	2.09	5	10	8
Both	4.00	5	12	7
Left	0.55	2	14	10
Left	1.11	5	- 9	-14
Left	2.09	3	-21	-29
Left	4.00	5	-11	-22
Plan B Lock, Plan C Ports, Plan V Baffles				
Both	1.11	5	11	6
Both	4.00	5	12	8
Left	1.11	5	-12	-20
Left	4.00	5	-13	-26

NOTES:
1. Details of lock plans A and B are shown on plates 4, 10, and 15.
2. Port and baffles plans are shown on plates 12 and 16.
3. Pressures were measured with a flush-mounted pressure cell at piezometer L-4 (plate 10).

TABLE D

MAXIMUM RATES OF RISE AND OVERALL LOCK COEFFICIENTS

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)

Maximum Rates of Rise

Valve Time in Minutes	One Valve Operating			Both Valves Operating		
	Initial Head in Feet			Initial Head in Feet		
	105	100	87	105	100	87
	Rise of Lock Water Surface in FPM					
0.55	13.3	--	--	20.5	--	--
1.11	13.2	12.6	11.7	20.0[1]	19.7[2]	18.4[3]
2.07	12.9	--	--	18.6	--	--
4.00	12.2	11.6	10.7	17.8	17.1	15.6
6.40	11.5	--	--	15.2	--	--
8.00	10.8	--	--	14.1	--	--

Overall Lock Coefficients[4]

Valve Time in Minutes	One Valve Operating			Both Valves Operating		
	Initial Head in Feet			Initial Head in Feet		
	105	100	87	105	100	87
0.55	0.982	--	--	0.772	--	--
1.11	0.987	0.993	0.997	0.778	0.767	0.761
2.07	0.982	--	--	0.778	--	--
4.00	0.976	0.987	0.991	0.772	0.767	0.761

-- No data obtained.

[1] Maximum filling discharge 20,600 cfs.

[2] Maximum filling discharge 20,400 cfs.

[3] Maximum filling discharge 19,100 cfs.

[4] Coefficient $C_L = \frac{2A_L}{A_c\sqrt{2g}} \frac{(\sqrt{H+d} - \sqrt{d})}{(T - Kt_v)}$

Terms defined in paragraph 38.

TABLE E

FILLING TIMES AND TYPICAL MAXIMUM HAWSER FORCES

Plan B Lock, Plan C Force, Plan VI Baffles (Final Design)

Initial Head in Feet	Valves Used	Valve Time in Minutes	Filling Time in Minutes	Barge Position	Barge Draft in Feet	Typical Maximum Hawser Forces in Tons and Times of Occurence in Minutes											
						Longitudinal				Upstream Transverse				Downstream Transverse			
						Upstream		Downstream		Left		Right		Left		Right	
						Force	Time	Force	Time	Force	Time	Force	Time	Force	Time	Force	Time
87 (a)	Both	1.11	9.0	I	9	1.3	3.6	1.4	1.2	1.0	1.3	1.3	1.7	0.9	2.1	0.8	1.6
87	Left	1.11	14.0	I	9	3.2	1.7	2.9	1.4	1.6	2.2	2.0	1.7	1.3	1.5	0.8	1.6
87	Both	1.11	9.0	IV	9	2.2	2.7	1.6	3.0	1.5	2.4	1.1	2.1	1.2	3.0	1.3	1.9
87	Left	1.11	14.0	IV	9	2.4	1.7	2.4	2.1	1.9	2.1	1.3	1.8	1.3	3.0	0.6	2.7
87	Both	4.00	10.6	I	9	1.0	5.5	1.3	5.9	0.9	5.9	0.8	3.6	0.8	3.8	0.5	3.3
87	Left	4.00	15.9	I	9	1.7	6.7	2.6	5.4	1.3	5.4	1.1	6.2	0.8	6.0	0.4	4.9
87	Both	4.00	10.6	IV	9	1.5	4.4	1.3	4.3	0.6	3.9	0.5	3.5	0.7	3.0	1.1	3.7
87	Left	4.00	15.9	IV	9	1.9	4.7	1.9	5.0	0.9	5.0	0.4	4.9	0.8	4.7	0.9	6.4
100 (b)	Both	1.11	9.6	I	9	2.0	1.7	1.8	1.3	2.1	2.2	1.0	2.3	1.3	2.1	1.5	2.0
100	Left	1.11	15.0	I	9	4.7	1.7	4.3	2.3	3.4	3.1	2.2	1.7	2.1	2.0	0.8	2.5
100	Both	1.11	9.6	IV	9	2.5	1.9	2.1	3.2	1.7	1.0	1.7	2.8	1.8	1.8	1.4	1.9
100	Left	1.11	15.0	IV	9	3.8	1.8	3.2	1.4	2.6	1.4	1.8	1.8	1.5	3.6	1.0	2.0
100	Both	4.00	11.2	I	9	1.5	5.0	1.9	4.8	0.9	4.0	0.6	4.0	0.8	4.1	0.5	4.2
100	Left	4.00	16.8	I	9	2..	5.7	2.5	4.2	1.5	5.5	0.9	5.7	1.4	4.4	0.6	4.0
100	Both	4.00	11.2	IV	9	1.8	5.5	1.6	5.4	0.7	5.5	0.8	5.0	0.6	5.5	1.1	5.4
100	Left	4.00	16.8	IV	9	2.1	4.3	2.5	4.8	1.2	4.8	1.0	3.5	0.9	4.2	0.9	6.0
105 (c)	Both	0.55	9.4	I	9	3.6	1.1	3.4	0.9	3.1	1.5	2.3	1.4	2.3	1.3	2.7	1.4
105	Left	0.55	15.0	I	9	6.4	1.4	7.0	0.9	3.1	1.7	2.9	1.1	2.8	1.5	2.0	1.1
105	Both	0.55	9.4	IV	9	3.3	1.0	2.5	0.6	2.8	0.9	2.2	0.8	2.5	0.9	2.3	0.7
105	Both	1.11	9.8	I	9	2.2	1.7	2.0	1.3	1.0	2.5	0.5	3.1	2.4	1.7	1.6	2.1
105	Left	1.11	15.5	I	9	4.8	1.9	4.8	1.4	3.9	2.0	2.9	2.5	3.2	2.1	1.7	1.4
105	Right	1.11	15.5	I	9	3.8	2.8	4.3	2.4	1.4	2.4	2.9	2.8	0.8	2.6	1.7	1.1
105	Both	1.11	9.8	II	9	2.3	1.6	2.4	1.3	1.5	1.5	1.7	2.3	1.6	1.2	2.0	2.8
105	Both	1.11	9.8	III	9	2.3	2.8	3.4	1.8	2.2	1.5	2.1	1.6	2.5	1.5	1.9	1.6
105	Both	1.11	9.8	IV	9	3.7	1.6	2.7	1.3	2.8	1.5	1.5	1.6	1.9	1.2	1.3	1.8
105	Left	1.11	15.5	IV	9	1.3	1.9	1.1	1.9	2.3	1.6	2.6	2.0	1.6	1.9	3.3	2.6
105	Both*	1.11	10.0	IV	9	3.3	2.6	2.6	3.7	1.9	1.9	1.5	1.6	2.6	1.1	1.8	1.6
105	Both**	1.11	10.2	IV	9	5.0	2.3	5.0	1.5	2.6	2.2	1.5	1.8	2.3	2.1	1.7	1.6
105	Both	1.11	9.8	V	9	1.3	2.6	1.1	1.9	2.3	1.8	2.6	2.0	1.6	1.9	3.3	1.8
105	Both	1.11	9.8	VI	9	1.3	1.5	1.2	1.1	1.2	2.6	1.5	1.9	2.0	1.5	1.8	1.1
105	Both	1.11	9.6	VII	9	1.7	2.9	2.3	3.7	1.7	1.7	2.6	1.3	1.8	2.8	2.3	2.2
105	Both	1.11	9.6	I	14	4.7	1.8	3.5	0.9	4.3	0.9	2.9	1.9	3.5	1.7	2.8	1.9
105	Both	1.11	9.8	II	14	4.2	1.7	5.0	1.2	2.6	1.1	2.6	1.4	3.0	1.2	2.4	1.3
105	Both	1.11	9.8	III	14	2.9	2.1	4.9	1.2	4..	1.1	2.0	1.8	3.4	1.6	4.2	1.0
105	Both	1.11	9.8	IV	14	4.0	1.4	3.0	2.0	2.5	1.2	1.8	1.4	3.4	1.5	1.5	1.3
105	Both	1.11	9.8	V	14	1.4	4.3	2.8	1.3	1.4	2.6	4.4	1.3	0.9	4.4	5.2	1.7
105	Both	1.11	9.8	VI	14	1.4	1.7	2.0	1.3	2.4	1.2	1.8	1.8	2.3	1.5	2.2	1.8
105	Both	1.11	9.6	VII	14	2.4	1.6	1.8	1.0	1.7	2.0	3.8	1.2	1.7	1.8	4.1	1.9
105	Both	2.07	10.4	I	9	2.2	3.4	1.8	1.6	1.0	2.9	0.8	1.9	1.8	1.8	1.0	4.0
105	Left	2.07	16.1	I	9	4.7	3.4	4.3	3.0	2.7	1.0	1.0	2.8	2.3	2.1	1.2	2.5
105	Both	2.07	10.4	IV	9	2.7	3.4	2.4	3.5	1.0	..1	1.0	2.2	1.7	2.3	1.9	2.9
105	Both	4.00	11.5	I	9	1.3	3.4	1.3	5.7	0.5	3.2	0.9	3.4	0.8	2.7	0.8	4.6
105	Left	4.00	17.2	I	9	3.0	4.5	2.4	6.7	1.9	4.1	0.8	4.5	1.4	4.1	0.8	2.8
105	Both	4.00	11.5	II	9	2.1	4.1	1.4	3.6	1.4	4.2	0.9	3.8	1.4	5.9	1.0	3.8
105	Both	4.00	11.5	III	9	1.3	5.6	1.1	4.7	1.5	3.9	0.7	3.0	1.0	3.7	1.0	3.3
105	Both	4.00	11.5	IV	9	1.6	4.5	1.5	4.6	1.0	2.9	0.9	3.3	0.6	2.5	1.2	3.9
105	Left	4.00	17.2	IV	9	2.8	4.2	4.7	4.0	1.1	4.7	0.8	3.6	1.4	3.7	0.7	2.9
105	Both*	4.00	11.8	IV	9	1.7	4.4	1.6	6.0	0.8	5.3	0.9	4.4	0.6	5.0	1.1	5.0
105	Both**	4.00	12.0	IV	9	1.4	4.3	1.3	5.8	1.0	5.3	0.6	4.1	1.3	4.0	1.0	4.4

(a) Pool elev 732, tailwater elev 645.
(b) Pool elev 738, tailwater elev 638.
(c) Pool elev 738, tailwater elev 633.

* Right valve delayed 30 seconds.
** Right valve delayed 60 seconds.

NOTES: 1. Details of final design are shown on plates 13 and 17.

2. Times were measured from start of valve opening.

3. Average maximum hawser forces and the range of maximum hawser forces are shown in tables F and G.

TABLE F

AVERAGE MAXIMUM HAWSER FORCES DURING FILLING OPERATION (FIVE RUNS)

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)

Initial Head in Feet	Valves Used	Valve Time in Minutes	Barge Position	Barge Draft in Feet	Hawser Forces in Tons						
					Longitudinal		U/S Transverse		D/S Transverse		Overall Average
					U/S	D/S	Left	Right	Left	Right	
87 (a)	Both	1.11	I	9	1.3	1.4	0.9	0.9	0.7	0.9	1.0
87	Left	1.11	I	9	3.6	3.5	1.7	1.7	1.2	0.8	2.1
87	Both	1.11	IV	9	2.2	1.8	1.5	1.0	1.1	1.1	1.4
87	Left	1.11	IV	9	2.5	2.6	1.8	1.5	1.3	0.8	1.7
87	Both	4.00	I	9	0.9	1.4	0.8	0.8	0.7	0.5	0.9
87	Left	4.00	I	9	1.7	2.4	1.3	1.2	0.9	0.4	1.3
87	Both	4.00	IV	9	1.4	1.4	0.7	0.5	0.6	1.0	0.9
87	Left	4.00	IV	9	2.1	1.7	1.0	0.4	0.8	0.9	1.1
100 (b)	Both	1.11	I	9	1.7	1.6	1.8	0.9	1.5	1.2	1.5
100	Left	1.11	I	9	4.5	4.5	3.0	2.1	1.8	0.9	2.8
100	Both	1.11	IV	9	2.5	2.0	2.0	1.9	1.5	1.4	1.9
100	Left	1.11	IV	9	3.4	3.0	2.5	1.8	1.6	0.9	2.2
100	Both	4.00	I	9	1.4	1.6	0.7	0.7	0.7	0.7	1.0
100	Left	4.00	I	9	2.4	2.3	1.4	1.0	1.2	0.7	1.5
100	Both	4.00	IV	9	2.0	1.6	0.8	0.8	0.7	1.2	1.2
100	Left	4.00	IV	9	2.3	2.3	1.2	0.8	0.9	0.9	1.4
105 (c)	Both	0.55	I	9	3.7	3.5	3.5	2.6	2.9	2.6	3.1
105	Left	0.55	I	9	6.5	7.6	3.9	2.3	2.7	1.4	4.1
105	Both	0.55	IV	9	3.7	2.7	2.6	2.1	2.5	1.7	2.6
105	Both	1.11	I	9	2.3	2.0	1.5	0.9	2.0	1.3	1.7
105	Left	1.11	I	9	5.2	5.0	3.6	2.3	1.9	1.6	3.3
105	Right	1.11	I	9	3.6	4.3	1.5	2.7	1.1	2.5	2.6
105	Both	1.11	II	9	2.7	2.4	1.5	2.0	1.9	1.9	2.1
105	Both	1.11	III	9	2.5	3.4	2.1	1.8	2.1	2.1	2.3
105	Both	1.11	IV	9	3.6	2.5	2.3	1.7	2.1	1.7	2.3
105	Left	1.11	IV	9	3.7	3.5	3.4	1.8	2.2	1.4	2.7
105	Both*	1.11	IV	9	3.5	2.1	1.9	1.6	2.5	1.6	2.2
105	Both**	1.11	IV	9	5.1	3.1	2.3	1.4	2.4	1.9	2.7
105	Both	1.11	V	9	1.2	1.1	1.9	2.3	1.8	2.8	1.8
105	Both	1.11	VI	9	2.4	2.3	2.5	1.6	1.9	2.2	1.6
105	Both	1.11	VII	9	1.7	1.1	1.2	2.5	1.7	2.3	1.7
105	Both	1.11	I	14	4.3	3.1	3.8	3.4	3.5	2.1	3.4
105	Both	1.11	II	14	4.1	3.1	2.2	2.8	3.3	2.5	3.0
105	Both	1.11	III	14	3.5	3.3	4.0	2.1	3.6	3.9	3.7
105	Both	1.11	IV	14	6.1	3.7	2.6	2.3	2.9	1.9	3.2
105	Both	1.11	V	14	1.7	2.7	1.8	3.6	1.4	4.6	2.6
105	Both	1.11	VI	14	1.6	1.7	2.0	1.8	2.3	2.6	2.0
105	Both	1.11	VII	14	2.2	2.0	2.5	4.3	2.0	4.4	2.9
105	Both	2.07	I	9	1.8	1.7	0.9	0.6	1.6	0.9	1.2
105	Left	2.07	I	9	4.9	4.3	2.4	1.1	1.9	1.1	2.6
105	Both	2.07	IV	9	2.6	2.1	1.0	0.9	1.5	1.6	1.6
105	Both	4.00	I	9	1.2	1.3	0.8	0.9	0.9	0.9	1.0
105	Left	4.00	I	9	2.6	2.5	1.9	1.0	1.6	1.0	1.7
105	Both	4.00	II	9	1.9	1.6	0.9	0.8	1.2	0.9	1.2
105	Both	4.00	III	9	1.3	1.3	1.4	0.8	1.0	0.9	1.1
105	Both	4.00	IV	9	1.7	1.2	1.1	1.0	0.8	1.2	1.2
105	Left	4.00	IV	9	2.9	1.9	1.1	0.7	1.1	0.9	1.4
105	Both*	4.00	IV	9	1.7	1.3	0.9	0.9	0.7	1.1	1.1
105	Both**	4.00	IV	9	1.8	1.4	1.1	0.7	1.1	1.1	1.2

(a) Pool elev 732, tailwater elev 645.
(b) Pool elev 738, tailwater elev 638.
(c) Pool elev 738, tailwater elev 633.
* Right valve delayed 30 seconds.
** Right valve delayed 60 seconds.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Filling times and typical maximum hawser forces are shown in table E.

3. The range of maximum hawser forces is shown in table G.

TABLE G

RANGE OF MAXIMUM HAWSER FORCES DURING FILLING OPERATION (FIVE RUNS)

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)

Initial Head in Feet	Valves Used	Valve Time in Minutes	Barge Position	Barge Draft in Feet	Hawser Forces in Tons											
					Longitudinal				Upstream Transverse				Downstream Transverse			
					Upstream		Downstream		Left		Right		Left		Right	
					Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
87 (a)	Both	1.11	I	9	1.0	1.9	1.0	1.7	0.5	1.1	0.6	1.3	0.4	0.9	0.6	1.2
87	Left	1.11	I	9	2.4	5.9	2.4	5.3	1.4	2.0	1.0	2.1	1.1	1.3	0.4	1.3
87	Both	1.11	IV	9	1.7	2.6	1.6	2.0	1.1	2.2	0.5	1.5	0.7	1.3	0.8	1.3
87	Left	1.11	IV	9	2.1	2.8	2.1	4.1	1.4	2.5	1.2	1.9	1.0	1.8	0.6	1.3
87	Both	4.00	I	9	0.7	1.0	1.0	1.7	0.6	0.9	0.5	0.9	0.5	0.9	0.4	0.5
87	Left	4.00	I	9	0.9	2.5	1.9	2.7	0.9	1.7	0.9	1.6	0.8	0.9	0.5	0.7
87	Both	4.00	IV	9	1.1	1.8	1.1	1.9	0.6	0.9	0.5	0.6	0.4	0.7	0.9	1.1
87	Left	4.00	IV	9	1.8	2.7	1.4	2.1	0.8	1.1	0.4	0.5	0.4	1.0	0.7	1.0
100 (b)	Both	1.11	I	9	1.4	2.0	1.1	1.8	1.1	2.4	0.6	1.1	1.2	2.0	0.9	1.5
100	Left	1.11	I	9	3.7	5.2	3.8	5.2	2.7	3.4	1.1	2.6	1.5	2.1	0.6	1.3
100	Both	1.11	IV	9	2.3	2.7	2.6	2.6	1.4	3.1	1.5	2.5	1.2	1.8	1.2	1.5
100	Left	1.11	IV	9	2.2	4.0	2.5	3.2	2.3	2.7	1.2	2.4	1.4	1.7	0.7	1.0
100	Both	4.00	I	9	1.1	1.9	1.4	1.9	0.3	1.0	0.6	1.0	0.5	0.9	0.5	0.9
100	Left	4.00	I	9	1.3	3.5	1.4	3.1	1.2	1.7	0.6	2.3	1.0	1.4	0.4	1.1
100	Both	4.00	IV	9	1.4	3.0	1.2	2.1	0.6	1.0	0.6	0.9	0.5	1.1	1.0	1.4
100	Left	4.00	IV	9	1.8	3.1	2.0	2.7	0.9	1.5	0.6	1.0	0.8	1.1	0.7	1.1
105 (c)	Both	0.55	I	9	2.4	4.8	2.6	4.6	2.5	4.3	1.7	3.3	2.3	3.4	1.9	3.6
105	Left	0.55	I	9	4.8	8.0	4.9	8.4	3.1	4.7	1.6	2.9	2.4	3.0	1.0	2.0
105	Both	0.55	IV	9	3.0	4.2	2.5	3.6	2.0	3.2	1.7	2.6	2.0	2.9	1.1	2.3
105	Both	1.11	I	9	2.1	2.6	1.4	2.7	0.7	2.3	0.4	1.5	1.4	2.4	0.5	1.6
105	Left	1.11	I	9	4.6	6.5	4.3	6.6	3.1	4.1	1.3	2.9	1.6	2.2	1.5	1.7
105	Right	1.11	I	9	3.0	4.9	3.8	5.1	1.1	1.9	2.0	3.1	0.7	1.5	1.7	3.1
105	Both	1.11	II	9	2.1	3.5	1.6	3.1	1.0	2.1	1.7	2.4	1.1	2.6	1.4	2.0
105	Both	1.11	III	9	1.4	3.4	2.7	4.3	1.9	2.6	1.5	2.6	1.4	2.8	1.7	3.0
105	Both	1.11	IV	9	2.9	4.8	2.3	2.7	2.5	3.1	2.4	2.9	1.7	2.5	2.3	2.1
105	Left	1.11	IV	9	3.1	4.5	2.5	4.7	2.8	3.7	1.3	2.8	1.3	2.5	1.1	1.7
105	Both*	1.11	IV	9	2.9	4.2	3.2	2.6	1.5	2.5	1.1	2.0	1.7	3.0	1.2	2.4
105	Both**	1.11	IV	9	4.7	5.5	2.0	3.5	2.0	2.6	0.8	2.5	1.5	3.1	1.0	3.1
105	Both	1.11	V	9	1.1	1.5	0.8	1.4	1.1	2.9	1.3	2.8	1.5	2.3	2.2	3.3
105	Both	1.11	VI	9	1.0	1.9	1.2	1.5	1.2	1.9	1.5	2.1	1.6	2.4	1.8	2.7
105	Both	1.11	VII	9	1.2	2.1	0.9	1.3	0.9	1.7	2.1	2.9	1.0	2.3	1.6	3.0
105	Both	1.11	I	14	3.1	6.1	2.4	3.6	3.0	4.3	1.7	4.9	3.3	3.9	1.0	2.9
105	Both	1.11	II	14	3.7	4.4	2.7	3.7	1.7	2.6	1.9	4.6	2.9	4.0	1.8	3.1
105	Both	1.11	III	14	2.8	4.6	4.9	5.8	3.1	4.9	1.0	3.5	2.7	4.8	2.9	5.1
105	Both	1.11	IV	14	4.7	7.6	2.6	5.6	1.8	3.9	1.7	5.0	1.7	4.1	1.5	2.4
105	Both	1.11	V	14	1.0	2.2	1.9	4.1	1.0	2.6	2.2	5.1	0.9	2.5	3.7	5.2
105	Both	1.11	VI	14	1.3	2.2	0.9	2.2	1.5	2.7	1.3	3.0	1.7	2.7	2.1	3.4
105	Both	1.11	VII	14	1.9	2.4	1.3	3.2	1.7	3.9	3.8	4.7	1.6	2.3	3.8	5.8
105	Both	2.07	I	9	1.1	2.2	1.4	1.9	0.7	1.0	0.5	0.8	1.4	1.8	0.6	1.2
105	Left	2.07	I	9	4.4	5.4	3.6	4.7	2.0	2.7	0.4	1.4	1.5	2.3	0.9	1.2
105	Both	2.07	IV	9	2.1	2.9	1.5	2.4	0.4	1.2	0.9	1.0	1.0	1.7	1.0	2.0
105	Both	4.00	I	9	0.8	1.8	1.2	1.4	0.5	1.4	0.8	1.0	0.5	1.1	0.8	1.1
105	Left	4.00	I	9	2.1	7.0	1.7	3.6	1.5	2.4	0.9	1.4	1.2	1.9	0.8	1.2
105	Both	4.00	II	9	1.2	2.7	1.2	1.9	0.5	1.4	0.7	1.0	0.9	1.4	0.8	1.1
105	Both	4.00	III	9	1.2	1.4	0.9	1.8	1.0	1.8	0.7	0.9	0.9	1.1	0.8	1.1
105	Both	4.00	IV	9	1.4	2.1	1.0	1.5	0.7	1.4	0.8	1.7	0.6	1.1	1.0	1.4
105	Left	4.00	IV	9	2.3	3.8	1.5	2.5	1.0	1.2	0.5	1.0	0.9	1.4	0.7	1.3
105	Both*	4.00	IV	9	1.3	2.1	0.9	1.8	0.8	1.2	0.6	1.0	0.6	0.9	0.8	1.4
105	Both**	4.00	IV	9	1.3	2.7	1.2	1.8	0.9	1.4	0.6	1.0	0.8	1.3	1.0	1.2

(a) Pool elev 732, tailwater elev 645.
(b) Pool elev 738, tailwater elev 638.
(c) Pool elev 738, tailwater elev 633.

* Right valve delayed 30 seconds.
** Right valve delayed 60 seconds.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Filling times and typical maximum hawser forces are shown in table E.

3. Average maximum hawser forces are shown in table F.

TABLE H

EMPTYING TIMES AND TYPICAL MAXIMUM HAWSER FORCES

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)

Initial Head in Feet	Valves Used	Valve Time in Minutes	Emptying Time in Minutes	Barge Position	Barge Draft in Feet	Typical Maximum Hawser Forces in Tons and Times of Occurrence in Minutes											
						Longitudinal				Upstream Transverse				Downstream Transverse			
						Upstream		Downstream		Left		Right		Left		Right	
						Force	Time	Force	Time	Force	Time	Force	Time	Force	Time	Force	Time
87 (a)	Both	1.03	10.6	I	9	0.3	3.8	0.4	2.4	0.3	1.9	0.2	1.8	0.3	2.2	0.2	0.7
87	Both	2.00	11.2	I	9	0.6	3.4	0.8	3.2	0.3	3.2	0.4	3.5	0.3	3.3	0.4	3.4
100 (b)	Both	1.03	11.3	I	9	0.5	1.5	0.5	4.7	0.4	4.2	0.2	1.5	0.4	3.7	0.2	4.8
100	Both	2.00	12.0	I	9	0.5	4.2	0.7	4.2	0.5	4.3	0.3	8.8	0.2	3.9	0.3	2.2
105 (c)	Both	1.03	11.5	I	9	0.5	1.5	0.4	3.5	0.4	3.0	0.2	1.9	0.4	2.0	0.1	0.5
105	Both	1.03	11.5	IV	9	0.1	0.6	0.8	5.8	0.5	5.9	0.1	0.9	0.2	1.9	0.1	5.0
105	Left	1.03	19.8	I	9	1.2	3.0	0.9	4.6	0.5	2.3	0.5	3.0	0.4	4.7	0.2	5.6
105	Left	1.03	19.8	IV	9	0.5	2.5	0.8	4.0	0.5	5.9	0.1	1.7	0.2	3.5	0.3	2.5
105	Both	1.03	11.5	I	14	0.6	2.7	0.5	2.9	0.8	2.9	0.7	2.7	0.3	2.7	0.6	2.5
105	Both	1.03	11.5	IV	14	0.9	6.9	0.8	1.9	0.7	1.9	0.5	5.8	0.5	4.6	0.3	5.9
105	Left	1.03	19.8	I	14	1.4	1.9	1.9	2.1	1.4	2.1	1.2	3.9	1.1	4.4	0.8	3.1
105	Left	1.03	19.8	IV	14	1.4	3.3	1.3	3.5	1.1	4.8	0.4	3.3	0.5	1.6	0.3	4.8
105	Both	2.00	12.2	I	9	0.5	4.4	0.6	2.6	0.5	2.6	0.3	3.8	0.1	4.2	0.4	2.8
105	Both	2.00	12.2	IV	9	0.3	1.8	0.7	2.7	0.5	2.8	0.1	1.2	0.3	4.2	0.3	1.9
105	Left	2.00	20.6	I	9	1.1	6.7	1.4	6.8	0.5	6.9	0.7	6.7	0.5	3.4	0.6	3.5
105	Left	2.00	20.6	IV	9	0.7	3.6	0.6	4.7	0.6	4.2	0.3	3.6	0.4	2.7	0.3	4.3
105	Both	2.00	12.2	I	14	0.6	5.1	0.7	5.3	0.4	5.3	0.4	5.1	0.3	4.1	0.5	3.9
105	Both	2.00	12.2	IV	14	1.1	6.2	1.3	4.8	0.8	4.3	0.3	4.5	0.4	6.2	0.5	5.8
105	Left	2.00	20.6	I	14	1.7	5.8	1.5	4.2	0.9	6.7	1.0	5.8	0.7	4.3	0.8	4.1
105	Left	2.00	20.6	IV	14	1.4	6.7	2.0	5.5	1.0	6.5	0.4	6.7	0.6	6.1	0.6	5.9

(a) Pool elev 732, tailwater elev 645.
(b) Pool elev 738, tailwater elev 638.
(c) Pool elev 738, tailwater elev 633.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Time listed under hawser forces was measured from start of valve opening.

3. Average maximum hawser forces and the range of maximum hawser forces are shown in table I.

TABLE H

TABLE I

AVERAGE AND RANGE OF MAXIMUM MOOVER FORCES DURING EMPTYING OPERATION (FIVE RUNS)

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)

Initial Head in Feet	Valves Used	Valve Time in Minutes	Barge Position	Barge Draft in Feet	Average Maximum Moover Forces in Tons						
					Longitudinal		Upstream Transverse		Downstream Transverse		Overall Average
					Upstream	Downstream	Left	Right	Left	Right	
87 (a)	Both	1.03	I	9	0.3	0.5	0.3	0.2	0.3	0.2	0.3
87	Both	2.00	I	9	0.4	0.7	0.4	0.4	0.3	0.3	0.4
100 (b)	Both	1.03	I	9	0.4	0.4	0.3	0.1	0.3	0.1	0.3
100	Both	2.00	I	9	0.5	0.8	0.5	0.3	0.1	0.4	0.4
105 (c)	Both	1.03	I	9	0.3	0.4	0.3	0.2	0.4	0.1	0.4
105	Both	1.03	IV	9	0.1	0.8	0.5	0.1	0.2	0.2	0.3
105	Left	1.03	I	9	1.4	1.1	0.6	0.6	0.4	0.2	0.7
105	Left	1.03	IV	9	0.5	0.8	0.5	0.1	0.3	0.3	0.4
105	Both	1.03	I	14	0.6	0.7	0.7	0.7	0.4	0.6	0.6
105	Both	1.03	IV	14	0.9	0.8	0.7	0.4	0.3	0.3	0.6
105	Left	1.03	I	14	1.4	1.7	1.4	1.2	0.9	0.7	1.2
105	Left	1.03	IV	14	1.3	1.4	1.2	0.4	0.6	0.5	0.9
105	Both	2.00	I	9	0.5	0.7	0.5	0.4	0.2	0.4	0.5
105	Both	2.00	IV	9	0.4	0.7	0.5	0.2	0.3	0.4	0.4
105	Left	2.00	I	9	1.1	1.2	0.5	0.6	0.4	0.4	0.7
105	Left	2.00	IV	9	0.6	0.6	0.5	0.3	0.3	0.4	0.5
105	Both	2.00	I	14	0.6	0.7	0.6	0.4	0.3	0.5	0.5
105	Both	2.00	IV	14	0.7	1.0	0.6	0.3	0.4	0.3	0.6
105	Left	2.00	I	14	2.0	2.0	1.1	1.2	0.7	0.8	1.3
105	Left	2.00	IV	14	1.1	1.8	0.9	0.4	0.6	0.5	0.9

Initial Head in Feet	Valves Used	Valve Time in Minutes	Barge Position	Barge Draft in Feet	Range of Maximum Moover Forces in Tons									
					Longitudinal				Upstream Transverse				Downstream Transverse			
					Upstream		Downstream		Left		Right		Left		Right	
					Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
87 (a)	Both	1.03	I	9	0.3	0.4	0.4	0.7	0.2	0.5	0.1	0.2	0.2	0.4	0.1	0.2
87	Both	2.00	I	9	0.2	0.6	0.5	0.9	0.3	0.4	0.1	0.6	0.2	0.4	0.1	0.5
100 (b)	Both	1.03	I	9	0.3	0.5	0.2	0.5	0.2	0.4	0.1	0.2	0.1	0.4	0.1	0.2
100	Both	2.00	I	9	0.4	0.6	0.6	1.1	0.4	0.6	0.2	0.4	0.1	0.2	0.3	0.5
105 (c)	Both	1.03	I	9	0.3	0.6	0.4	0.6	0.4	0.6	0.1	0.3	0.3	0.5	0.1	0.2
105	Both	1.03	IV	9	0.1	0.2	0.7	1.0	0.4	0.5	0.1	0.1	0.2	0.3	0.1	0.2
105	Left	1.03	I	9	1.0	1.8	0.8	1.4	0.5	0.8	0.5	0.8	0.4	0.5	0.2	0.3
105	Left	1.03	IV	9	0.4	0.6	0.5	1.1	0.2	0.8	0.1	0.1	0.2	0.4	0.2	0.3
105	Both	1.03	I	14	0.6	1.0	0.6	1.0	0.5	0.9	0.4	1.1	0.3	0.6	0.5	0.6
105	Both	1.03	IV	14	0.4	1.4	0.6	1.0	0.4	0.9	0.2	0.5	0.4	0.5	0.1	0.4
105	Left	1.03	I	14	1.1	1.9	1.4	1.9	1.3	1.7	0.8	1.7	0.8	1.1	0.6	0.8
105	Left	1.03	IV	14	1.0	2.0	1.2	1.8	1.0	1.5	0.9	0.5	0.5	0.8	0.3	0.9
105	Both	2.00	I	9	0.4	0.6	0.5	0.9	0.5	0.6	0.5	0.7	0.1	0.3	0.2	0.5
105	Both	2.00	IV	9	0.3	0.5	0.5	1.0	0.6	0.5	0.1	0.6	0.2	0.6	0.3	0.5
105	Left	2.00	I	9	0.9	1.3	1.0	1.6	0.5	0.6	0.6	0.7	0.3	0.5	0.2	0.6
105	Left	2.00	IV	9	0.5	0.7	0.5	0.7	0.5	0.6	0.3	0.3	0.3	0.6	0.3	0.6
105	Both	2.00	I	14	0.6	1.1	0.6	1.1	0.6	0.8	0.6	0.6	0.2	0.5	0.6	0.5
105	Both	2.00	IV	14	0.6	1.1	0.5	1.3	0.6	0.8	0.3	0.6	0.3	0.6	0.3	0.5
105	Left	2.00	I	14	1.6	3.2	1.6	3.5	0.8	1.7	0.8	2.2	0.6	1.2	0.5	1.5
105	Left	2.00	IV	14	0.6	1.6	1.2	2.3	0.6	1.0	0.2	0.6	0.6	0.9	0.3	0.8

(a) Pool elev 732, tailwater elev 645.
(b) Pool elev 738, tailwater elev 638.
(c) Pool elev 738, tailwater elev 633.

NOTES: 1. Details of final design are shown on plates 13 and 17.

2. Emptying times and typical maximum moover forces are shown in table H.

TABLE I

TABLE J

AVERAGE PRESSURES WITH STEADY FLOW THROUGH FULLY OPEN FILLING VALVES

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)
Pool Elev 738.0, Lock Water-Surface Elev 641.9

Piezometer			Average Pressure in Feet of Water	Piezometer			Average Pressure in Feet of Water
Number	Station	Elevation		Number	Station	Elevation	
Right Culvert				Left Culvert			
1	81+71.23	678.0	53.9	1	80+72.10	680.0	40.9
2	81+65.08	680.0	51.9	2	79+40.42	606.0	53.3
3	81+65.08	650.0	82.4	3	78+99.70	606.5	50.6
4	81+65.08	678.0	53.8	5	78+24.00	614.0	77.5
5	81+63.95	678.0	54.8	6	76+44.00	591.0	76.3
6	81+62.65	680.0	50.2	7	76+20.00	608.0	57.8
7	81+62.65	650.0	80.0	8	75+92.00	608.0	85.2
8	81+61.27	678.0	46.2	9	75+68.00	591.0	102.4
9	81+57.72	678.0	46.5	10	72+43.12	606.0	27.0
10	81+51.92	678.0	50.9				
11	81+50.96	680.0	45.3	Lock Chamber			
12	81+50.96	650.0	75.7				
13	81+49.92	678.0	39.9	1	75+92.00	596.0	46.7
14	81+46.46	678.0	41.6	2	75+92.00	608.0	48.7
15	81+39.36	678.0	43.8	3	76+20.00	608.0	51.8
16	81+39.27	678.0	46.9	4	76+20.00	596.0	67.0
17	81+38.75	680.0	42.2	5	77+62.32	597.7	72.0
18	81+38.75	650.0	71.8	6	77+62.32	597.7	74.2
19	81+38.15	678.0	--	7	77+77.75	606.1	39.9
20	81+36.59	678.0	36.5	8	77+79.75	606.8	42.5
21	79+40.42	606.0	53.3	9	77+77.75	607.4	44.5
22	79+06.44	606.5	40.6	10	77+85.00	605.5	37.4
23	79+05.96	606.3	43.0	11	77+99.75	606.8	43.7
24	78+99.70	606.5	52.9	12	78+26.50	602.0	52.4
25	78+95.00	607.0	56.7	13	78+40.50	602.0	62.3
26	78+90.00	607.5	59.8	14	78+54.50	602.0	70.7
27	78+85.00	608.0	62.5	15	78+68.50	602.0	75.8
28	78+40.00	612.8	74.5	16	78+82.50	602.0	78.4
29	76+20.00	608.0	55.6	17	78+96.50	602.0	79.8
30	76+20.00	596.0	70.5	18	77+35.50	602.0	57.8
31	75+92.00	608.0	83.8	19	74+76.50	602.0	55.2
32	75+92.00	596.0	95.2	20	73+85.50	602.0	52.2
33	72+91.26	599.0	93.5	A	76+06.00	608.0	66.9
34	72+43.12	593.0	40.0	B	76+06.00	596.0	81.7
35	72+43.12	606.0	27.0	C	75+70.50	608.0	66.9
36	71+65.25	605.0	28.0	D	75+70.50	596.0	79.9
A	80+72.10	665.0	55.7	E	74+76.02	608.0	48.8
B	79+40.42	599.0	61.2	F	74+76.02	608.0	50.8
C	78+24.00	603.0	88.1	G	73+85.98	608.0	47.2
D	76+44.00	603.0	84.8	H	73+85.98	608.0	47.8
E	73+50.40	603.0	89.6	I	76+41.50	608.0	66.6
F	73+10.50	599.0	93.6	J	76+41.50	596.0	78.5
G	72+73.50	599.0	93.6	K	77+35.98	608.0	51.9
				L	77+35.98	608.0	51.2
				M	78+26.02	608.0	47.1
				N	78+26.02	608.0	48.7

-- Piezometer inoperative.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Piezometer locations are shown on plate 15.

3. Lock water-surface elevation obtained from filling curve for initial head of 105 ft and valve time of 1.11 min.

TABLE K

AVERAGE PRESSURES WITH STEADY FLOW THROUGH FULLY OPEN FILLING VALVES

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)
Pool Elev 738.0, Lock Water-Surface Elev 664.8

Piezometer			Average Pressure in Feet of Water	Piezometer			Average Pressure in Feet of Water
Number	Station	Elevation		Number	Station	Elevation	
Right Culvert				Left Culvert			
1	81+71.23	678.0	55.9	1	80+72.10	680.0	44.8
2	81+65.08	680.0	54.2	2	79+40.42	606.0	73.1
3	81+65.08	650.0	84.4	3	78+99.70	606.5	71.0
4	81+65.08	678.0	55.9	5	78+24.00	614.0	89.3
5	81+63.95	678.0	56.5	6	76+44.00	591.0	109.0
6	81+62.65	680.0	51.9	7	76+20.00	608.0	75.9
7	81+62.65	650.0	82.5	8	75+92.00	608.0	96.2
8	81+61.27	678.0	50.4	9	75+68.00	591.0	113.5
9	81+57.72	678.0	50.3	10	72+43.12	606.0	27.0
10	81+51.92	678.0	53.6				
11	81+50.96	680.0	48.9	Lock Chamber			
12	81+50.96	650.0	79.2				
13	81+49.92	678.0	45.8				
14	81+46.46	678.0	46.7	1	75+92.00	596.0	69.3
15	81+39.36	678.0	47.1	2	75+92.00	608.0	69.2
16	81+39.27	678.0	50.7	3	76+20.00	608.0	71.1
17	81+38.75	680.0	46.8	4	76+20.00	596.0	85.6
18	81+38.75	650.0	67.1	5	77+62.32	597.7	89.1
19	81+38.15	678.0	--	6	77+62.32	597.7	90.5
20	81+36.59	678.0	42.7	7	77+77.75	606.1	62.4
21	79+40.42	606.0	72.9	8	77+79.75	606.8	64.2
22	79+06.44	606.5	66.3	9	77+77.75	607.4	66.1
23	79+05.96	606.3	66.5	10	77+85.00	605.5	60.9
24	78+99.70	606.5	72.8	11	77+99.75	606.8	65.2
25	78+95.00	607.0	75.3	12	78+26.50	602.0	72.8
26	78+90.00	607.5	77.6	13	78+40.50	602.0	80.2
27	78+85.00	608.0	79.3	14	78+54.50	602.0	86.5
28	78+40.00	612.8	87.4	15	78+68.50	602.0	90.4
29	76+20.00	608.0	74.3	16	78+82.50	602.0	92.0
30	76+20.00	596.0	88.2	17	78+96.50	602.0	92.9
31	75+92.00	608.0	95.3	18	77+35.50	602.0	77.2
32	75+92.00	596.0	106.8	19	74+76.50	602.0	75.5
33	72+91.26	599.0	105.0	20	73+85.50	602.0	73.3
34	72+43.12	593.0	40.0	A	76+06.00	608.0	82.4
35	72+43.12	606.0	27.0	B	76+06.00	596.0	96.5
36	71+65.25	605.0	28.0	C	75+70.50	608.0	82.7
A	80+72.10	665.0	60.3	D	75+70.50	596.0	95.2
B	79+40.42	599.0	80.8	E	74+76.02	608.0	69.2
C	78+24.00	603.0	99.8	F	74+76.02	608.0	70.5
D	76+44.00	603.0	97.4	G	73+85.98	608.0	67.9
E	73+50.40	603.0	100.9	H	73+85.98	608.0	68.4
F	73+10.50	599.0	104.9	I	76+41.50	608.0	82.0
G	72+73.50	599.0	104.9	J	76+41.50	596.0	94.2
				K	77+35.98	608.0	71.1
				L	77+35.98	608.0	70.8
				M	78+26.02	608.0	67.4
				N	78+26.02	608.0	68.3

-- Piezometer inoperative.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Piezometer locations are shown on plate 15.

3. Lock water-surface elevation obtained from filling curve for initial head of 105 ft and valve time of 4.0 min.

TABLE L

AVERAGE PRESSURES WITH STEADY FLOW THROUGH FULLY OPEN RIGHT FILLING VALVE

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)
Pool Elev 738.0, Lock Water-Surface Elevs 638.2 and 652.4

Piezometer			Lock Water-Surface Elev		Piezometer			Lock Water-Surface Elev	
			638.2	652.4				638.2	652.4
Number	Station	Elevation	Average Pressure in Feet of Water		Number	Station	Elevation	Average Pressure in Feet of Water	
Right Culvert					Lock Chamber				
1	81+71.23	678.0	51.4	51.9	1	75+92.00	596.0	42.6	56.9
2	81+65.08	680.0	48.6	49.3	2	75+92.00	608.0	24.8	37.2
3	81+65.08	650.0	78.9	79.7	3	76+20.00	608.0	10.5	19.8
4	81+65.08	678.0	49.4	50.2	4	76+20.00	596.0	36.8	49.2
5	81+63.95	678.0	51.7	52.1	5	77+62.32	597.7	50.5	62.8
6	81+62.65	680.0	46.2	47.0	6	77+62.32	597.7	61.1	70.5
7	81+62.65	650.0	75.4	76.4	7	77+77.75	606.1	40.7	49.0
8	81+61.27	678.0	40.1	41.8	8	77+79.75	606.8	40.9	49.2
9	81+57.72	678.0	40.1	41.2	9	77+77.75	607.4	40.8	49.4
10	81+51.92	678.0	45.9	47.1	10	77+85.00	605.5	42.0	49.2
11	81+50.96	680.0	38.8	39.9	11	77+99.75	606.8	41.4	49.1
12	81+50.96	650.0	69.2	70.4	12	78+26.50	602.0	46.4	55.2
13	81+49.92	678.0	29.0	31.0	13	78+40.50	602.0	44.7	57.3
14	81+46.46	678.0	31.9	33.9	14	78+54.50	602.0	42.0	58.0
15	81+39.36	678.0	34.5	36.7	15	78+68.50	602.0	41.1	58.2
16	81+39.27	678.0	39.9	41.4	16	78+82.50	602.0	41.8	57.0
17	81+38.75	680.0	34.9	35.8	17	78+96.50	602.0	45.5	59.0
18	81+38.75	650.0	63.2	63.0	18	77+35.50	602.0	47.2	56.4
19	81+38.15	678.0	--	--	19	76+76.50	602.0	37.2	55.7
20	81+36.59	678.0	24.2	26.9	20	73+85.50	602.0	41.5	54.8
21	79+40.42	606.0	12.9	21.6	A	76+06.00	608.0	31.2	41.2
22	79+06.44	606.5	0.3*	3.4	B	76+06.00	596.0	45.2	57.0
23	79+05.96	606.3	4.7*	4.7	C	75+70.50	608.0	26.2	36.8
24	78+99.70	606.5	1.1*	21.0	D	75+70.50	596.0	39.3	51.6
25	78+95.00	607.0	5.3*	26.3	E	74+76.02	608.0	36.0	49.2
26	78+90.00	607.5	13.5*	31.1	F	74+76.02	608.0	41.6	53.8
27	78+85.00	608.0	22.0*	34.8	G	73+85.98	608.0	35.6	48.8
28	78+40.00	612.8	44.6*	53.2	H	73+85.98	608.0	39.8	51.8
29	76+20.00	608.0	15.5*	24.5	I	76+41.50	608.0	24.5	37.3
30	76+20.00	596.0	28.9	41.0	J	76+41.50	596.0	35.8	48.7
31	75+92.00	608.0	55.9	64.9	K	77+35.98	608.0	41.1	50.0
32	75+92.00	596.0	69.2	76.5	L	77+35.98	608.0	42.5	54.4
33	72+91.26	599.0	67.3	75.3	M	78+26.02	608.0	40.3	49.2
34	72+43.12	593.0	40.0	40.0	N	78+26.02	608.0	43.9	53.3
35	72+43.12	606.0	27.0	27.0					
36	71+65.25	605.0	28.0	28.0					
A	80+72.10	665.0	46.0	48.2					
B	79+40.42	599.0	20.9	29.0					
C	78+24.00	603.0	59.8	68.9					
D	76+44.00	603.0	56.0	64.3					
E	73+50.40	603.0	63.3	71.3					
F	73+10.50	599.0	67.3	75.3					
G	72+73.50	599.0	67.3	75.3					

-- Piezometer inoperative.
* Air was drawn into piezometers from valve well. Piezometers were flushed and data obtained before air returned.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Piezometer locations are shown on plate 15.

3. Lock water surfaces obtained from filling curves for initial head of 105 ft and valve time of 1.11 min (638.2) and 4.00 min (652.4), respectively.

TABLE M

AVERAGE PRESSURES WITH STEADY FLOW THROUGH FULLY OPEN EMPTYING VALVES

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)
Lock Water-Surface Elev 731.5, Tailwater Elev 633.0

Piezometer			Average Pressure in Feet of Water	Piezometer			Average Pressure in Feet of Water
Number	Station	Elevation		Number	Station	Elevation	
Right Culvert				Left Culvert			
1	81+71.23	678.0	61.2	1	80+72.10	680.0	59.2
2	81+65.08	680.0	59.2	2	79+40.42	606.0	133.2
3	81+65.08	650.0	89.2	3	78+99.70	606.5	71.0
4	81+65.08	678.0	61.2	5	78+24.00	614.0	62.9
5	81+63.95	678.0	61.2	6	76+44.00	591.0	85.5
6	81+62.65	680.0	59.2	7	76+20.00	608.0	65.1
7	81+62.65	650.0	89.2	8	75+92.00	608.0	42.5
8	81+61.27	678.0	61.2	9	75+68.00	591.0	69.0
9	81+57.72	678.0	61.2	10	72+43.12	606.0	12.5
10	81+51.92	678.0	61.2				
11	81+50.96	680.0	59.2	Lock Chamber			
12	81+50.96	650.0	89.2				
13	81+49.92	678.0	61.2				
14	81+46.46	678.0	61.2	1	75+92.00	596.0	135.8
15	81+39.36	678.0	61.2	2	75+92.00	608.0	45.2
16	81+39.27	678.0	61.2	3	76+20.00	608.0	51.8
17	81+38.75	680.0	59.2	4	76+20.00	596.0	63.0
18	81+38.75	650.0	89.2	5	77+62.32	597.7	78.1
19	81+38.15	678.0	--	6	77+62.32	597.7	78.7
20	81+36.59	678.0	61.2	7	77+77.75	606.1	59.9
21	79+40.42	606.0	133.2	8	77+79.75	606.8	61.0
22	79+06.44	606.5	70.9	9	77+77.75	607.4	60.2
23	79+05.96	606.3	71.1	10	77+85.00	605.5	55.3
24	78+99.70	606.5	70.9	11	77+99.75	606.8	66.4
25	78+95.00	607.0	70.4	12	78+26.50	602.0	76.2
26	78+90.00	607.5	69.9	13	78+40.50	602.0	92.5
27	78+85.00	608.0	69.4	14	78+54.50	602.0	103.6
28	78+40.00	612.8	64.6	15	78+68.50	602.0	110.3
29	76+20.00	608.0	67.9	16	78+82.50	602.0	110.8
30	76+20.00	596.0	78.3	17	78+96.50	602.0	113.9
31	75+92.00	608.0	42.7	18	77+35.50	602.0	78.8
32	75+92.00	596.0	57.8	19	74+76.50	602.0	74.5
33	72+91.26	599.0	14.5	20	73+85.50	602.0	72.0
34	72+43.12	593.0	25.0	A	76+06.00	608.0	60.4
35	72+43.12	606.0	15.9	B	76+06.00	596.0	65.1
36	71+65.25	605.0	26.0	C	75+70.50	608.0	62.4
A	80+72.10	665.0	74.1	D	75+70.50	596.0	75.1
B	79+40.42	599.0	140.2	E	74+76.02	608.0	69.5
C	78+24.00	603.0	74.3	F	74+76.02	608.0	69.1
D	76+44.00	603.0	74.5	G	73+85.98	608.0	66.4
E	73+50.40	603.0	56.8	H	73+85.98	608.0	68.5
F	73+10.50	599.0	31.0	I	76+41.50	608.0	67.5
G	72+73.50	599.0	27.5	J	76+41.50	596.0	78.6
				K	77+35.98	608.0	73.9
				L	77+35.98	608.0	74.3
				M	78+26.02	608.0	71.8
				N	78+26.02	608.0	71.9

-- Piezometer inoperative.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Piezometer locations are shown on plate 15.

3. Lock water surface obtained from emptying curve for initial head of 105 ft and valve time of 1.03 min.

TABLE N

AVERAGE PRESSURES WITH STEADY FLOW THROUGH FULLY OPEN RIGHT EMPTYING VALVE

Plan B Lock, Plan C Ports, Plan VI Baffles (Final Design)
Lock Water-Surface Elev 734.9, Tailwater Elev 633.0

Piezometer			Average Pressure in Feet of Water	Piezometer			Average Pressure in Feet of Water
Number	Station	Elevation		Number	Station	Elevation	
Right Culvert				Lock Chamber			
1	81+71.23	678.0	59.0	1	75+92.00	596.0	139.1
2	81+65.08	680.0	57.0	2	75+92.00	608.0	110.4
3	81+65.08	650.0	87.0	3	76+20.00	608.0	63.8
4	81+65.08	678.0	59.0	4	76+20.00	596.0	122.3
5	81+63.95	678.0	59.0	5	77+62.32	597.7	119.2
6	81+62.65	680.0	57.0	6	77+62.32	597.7	119.7
7	81+62.65	650.0	87.0	7	77+77.75	606.1	104.3
8	81+61.27	678.0	59.0	8	77+79.75	606.8	104.4
9	81+57.72	678.0	59.0	9	77+77.75	607.4	103.5
10	81+51.92	678.0	59.0	10	77+85.00	605.5	102.8
11	81+50.96	680.0	57.0	11	77+99.75	606.8	106.5
12	81+50.96	650.0	87.0	12	78+26.50	602.0	113.3
13	81+49.92	678.0	59.0	13	78+40.50	602.0	118.8
14	81+46.46	678.0	59.0	14	78+54.50	602.0	123.0
15	81+39.36	678.0	59.0	15	78+68.50	602.0	125.2
16	81+39.27	678.0	59.0	16	78+82.50	602.0	123.0
17	81+38.75	680.0	57.0	17	78+96.50	602.0	126.2
18	81+38.75	650.0	87.0	18	77+35.50	602.0	114.2
19	81+38.15	678.0	--	19	74+76.50	602.0	114.3
20	81+36.59	678.0	59.0	20	73+85.50	602.0	115.0
21	79+40.42	606.0	131.0	A	76+06.00	608.0	75.0
22	79+06.44	606.5	88.5	B	76+06.00	596.0	76.9
23	79+05.96	606.3	88.7	C	75+70.50	608.0	109.5
24	78+99.70	606.5	88.5	D	75+70.50	596.0	108.1
25	78+95.00	607.0	88.0	E	74+76.02	608.0	109.5
26	78+90.00	607.5	87.5	F	74+76.02	608.0	109.5
27	78+85.00	608.0	87.0	G	73+85.98	608.0	108.8
28	78+40.00	612.8	82.2	H	73+85.98	608.0	109.2
29	76+20.00	608.0	82.2	I	76+41.50	608.0	98.0
30	76+20.00	596.0	93.8	J	76+41.50	596.0	120.8
31	75+92.00	608.0	49.5	K	77+35.98	608.0	108.2
32	75+92.00	596.0	66.5	L	77+35.98	608.0	108.2
33	72+91.26	599.0	4.8	M	78+26.02	608.0	107.2
34	72+43.12	593.0	16.3	N	78+26.02	608.0	107.2
35	72+43.12	606.0	12.5				
36	71+65.25	605.0	28.1				
A	80+72.10	665.0	72.0				
B	79+40.42	599.0	138.0				
C	78+24.00	603.0	92.0				
D	76+44.00	603.0	91.2				
E	73+50.40	603.0	66.0				
F	73+10.50	599.0	29.2				
G	72+73.50	599.0	24.5				

-- Piezometer out of order.

NOTES: 1. Details of final design are shown on plates 15 and 17.

2. Piezometer locations are shown on plate 15.

3. Lock water surface obtained from emptying curve for initial head of 105 ft and valve time of 1.03 min.

TABLE O

VORTEX FORMATION OVER INTAKE MANIFOLDS

Pool Elev	Initial Head in Feet	Valves Used	Valve Time in Minutes	Filling Time in Minutes	Maximum Inflow in CFS	Spillway Flow in CFS		Intake	Phenomenon			Remarks
						Bay 1	Bay 2		Description[1]	Starting Time in Minutes[2]	Duration in Minutes	
738	105	Left	1.11	15.5	13,600	-	-	Left	Dimple	2.0	13.4	Maximum diameter 2 ft.
		Right				-	-	Right	Swirl	11.9	3.6	
		Left				6,000[3]	6,000[3]	Left	Vortex	9.7	3.8	Maximum diameter 3 to 4 ft; no air entrained.
		Right				6,000	6,000	Right	Swirl	10.7	4.8	
732	87	Left	1.11	14.0	12,300	-	-	Left	Dimple	2.9	11.1	Maximum diameter 2 ft.
		Right				-	-	Right	Swirl	11.5	2.7	
		Left				4,000[3]	4,000[3]	Left	Vortex	6.9	5.8	Maximum diameter 6 ft; 3-ft air tail.
		Right				4,000	4,000	Right	Swirl	11.1	2.9	
738	105	Left	4.00	17.2	12,600	-	-	Left	Dimple	5.1	10.4	Maximum diamter 1 ft.
		Left				4,000[3]	4,000[3]	Left	Vortex	13.8	3.5	Maximum diameter 4 ft; no air entrained.
		Right				4,000	4,000	Right	Swirl	10.8	1.8	
732	87	Left	4.00	15.9	11,100	-	-	Left	Dimple	3.9	12.0	Maximum diameter 3 ft.
		Left				4,000[3]	4,000[3]	Left	Vortex	6.9	9.0	Maximum diameter 6 ft; 4-ft air tail.
		Right				4,000	4,000	Right	Swirl	11.4	4.4	
738	105	Both	1.11	9.8	20,600	-	-	Left	Dimple	6.4	3.4	Maximum diameter 1 ft.
						-	-	Right	Eddy	1.1	8.7	Continuous eddy above intake.
		Both				4,000[4]	4,000[4]	Left	Dimple	3.9	6.0	Maximum diameter 2 ft.
						4,000[4]	4,000[4]	Right	Eddy	0.5	9.3	Continuous eddy above intake.
732	87	Both	1.11	9.0	19,100	-	-	Left	Dimple	5.3	1.2	Maximum diameter 1 ft.
						-	-	Right	Eddy	1.1	7.9	Continuous eddy above intake.
		Both				4,000[4]	4,000[4]	Left	Dimple	4.1	4.7	Maximum diameter 4 ft.
						4,000[4]	4,000[4]	Right	Eddy	0.5	9.3	Continuous eddy above intake.
738	105	Both	4.00	11.5	18,500	4,000[4]	4,000[4]	Left	Dimple	3.4	6.4	Maximum diameter 2 ft.
						4,000[4]	4,000[4]	Right	Eddy	2.0	9.5	Continuous eddy above intake.
732	87	Both	4.00	10.6	16,200	4,000[4]	4,000[4]	Left	Dimple	3.4	7.2	Maximum diameter 4 ft.
						4,000[4]	4,000[4]	Right	Swirl	9.4	1.2	

[1] Vortex - A depression more than 2 ft deep with filament (dye trace) that extended to intake.
Dimple - Depression from 0.5 to 2 ft deep without filament.
Swirl - Concentrated clockwise motion of surface flow.
Eddy - General counter-clockwise motion of surface flow.

[2] Time from instant filling valve or valves began to open.

[3] Minimum discharge to create a vortex.

[4] Maximum spillway flow available in model when lock filled with both valves.

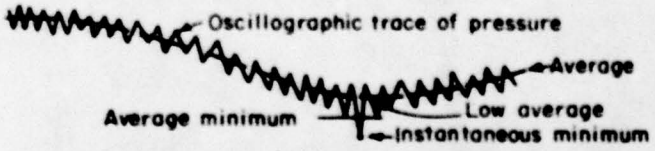
TABLE P

PRESSURES AT FILLING VALVES

Roof Transition in Right Culvert Moved 57 Feet Downstream
Valve Time 1.11 Minutes; Initial Head 105 Feet

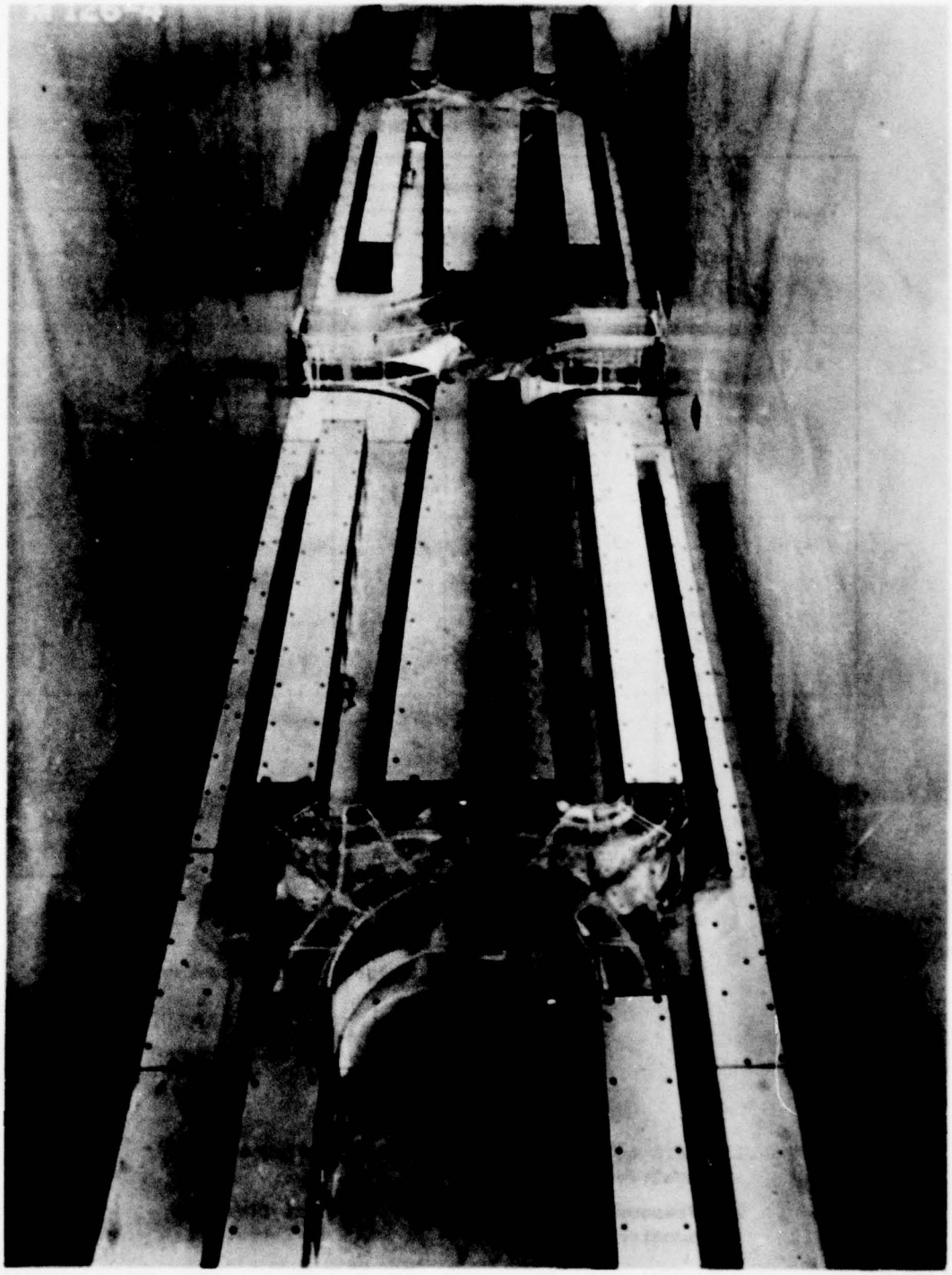
Valves Used	Run No.	Pressure in Feet of Water[1]					
		Right Valve			Left Valve		
		Avg Min	Inst Min	Low Avg	Avg Min	Inst Min	Low Avg
Both	1	- 6.5	- 7.5	- 4.5	13.5	12.0	16.0
	2	- 9.0	-10.5	- 7.0	13.5	11.0	15.0
	3	- 6.5	- 8.5	- 5.5	12.5	10.0	15.0
	4	- 9.5	-11.5	- 7.0	13.0	11.5	15.0
	5	- 7.5	-10.0	- 5.5	13.0	11.5	15.0
	Avg	- 8.0	-10.0	- 6.0	13.0	11.0	15.0
Right	1	-37.0	-42.5	-34.5			
	2	-33.5	-37.0	-30.5			
	3	-36.5	-38.5	-33.0			
	4	-34.5	-37.0	-31.5			
	5	-36.0	-39.5	-33.0			
	Avg	-35.0	-39.0	-32.0			
Left	1				- 7.5	-12.5	- 4.5
	2				- 5.5	- 9.5	- 2.5
	3				- 5.5	- 8.5	- 2.5
	4				- 6.0	- 9.0	- 2.5
	5				- 8.0	-12.0	- 3.0
	Avg				- 6.0	-10.0	- 3.0

[1] Definition sketch.



NOTES: 1. Left culvert roof transition in original position.

2. Pressures were measured by means of flush-mounted pressure cells at station 78+99.70.



Photograph 1. Plan A (original design) lock chamber and manifolds.



Looking upstream

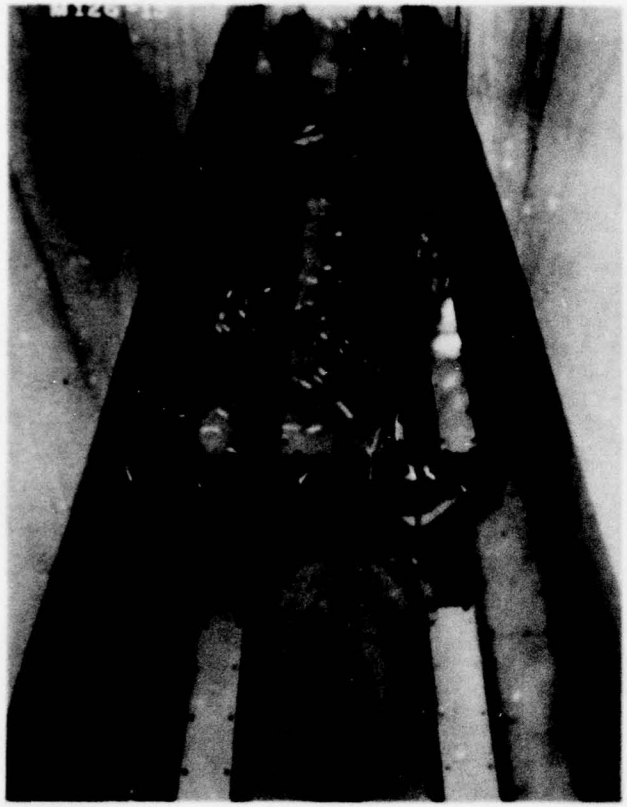


Looking downstream

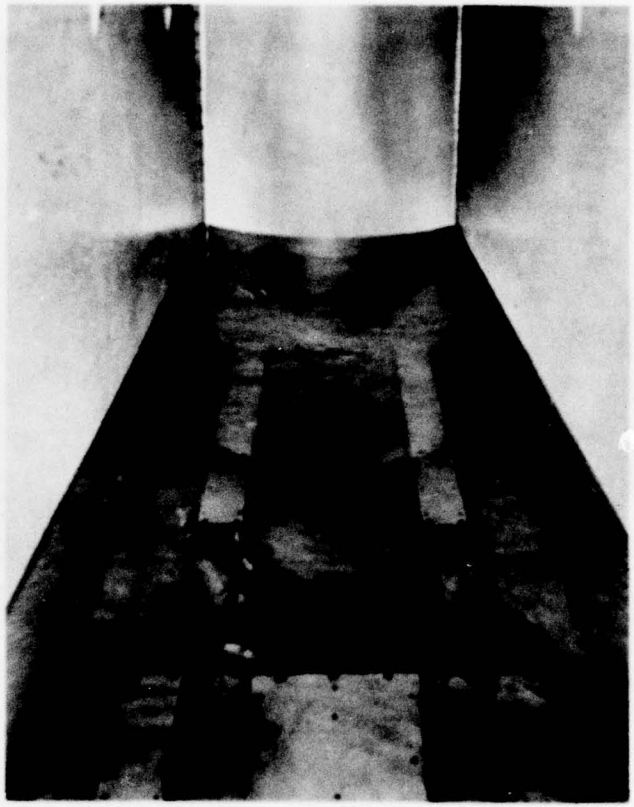
Photograph 2. Flow patterns and surface turbulence in downstream portion of plan A lock chamber; initial head 105 ft, valve opening 14 ft.



Photograph 3. Flow from ports in downstream half of plan A lock chamber. Steady flow, head 105 ft, filling valves open 4 ft.

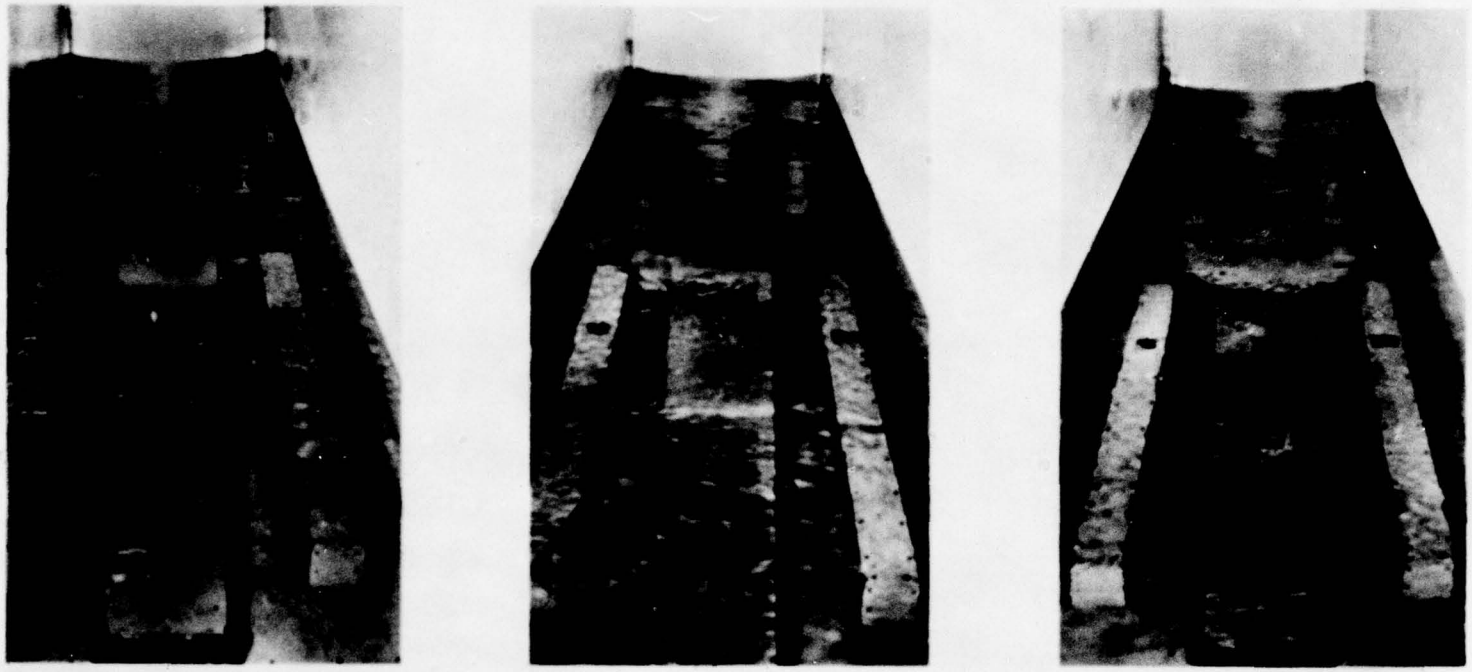


Looking upstream



Looking downstream

Photograph 4. Flow patterns and surface turbulence in downstream portion of plan A lock chamber with plan III baffles; initial head 105 ft, valve opening 14 ft.

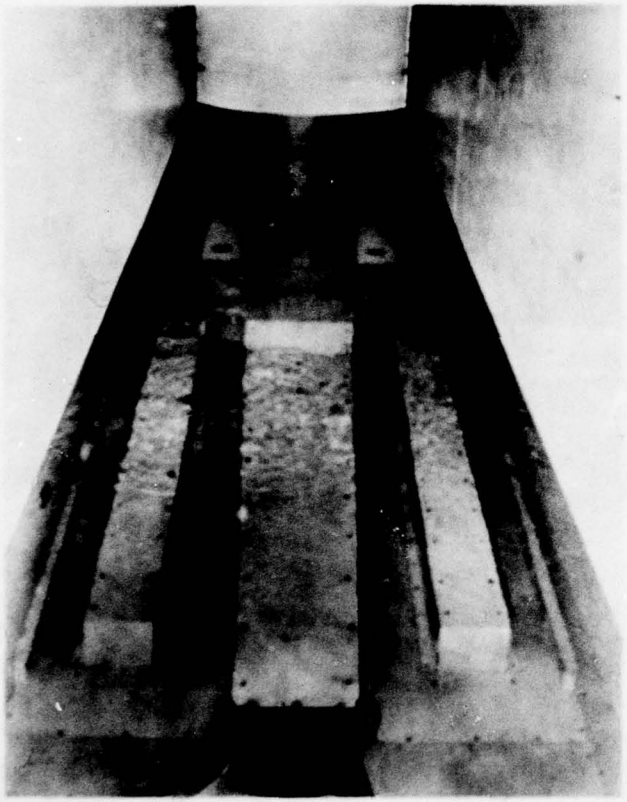


0.55-min valve,
water-surface elev 640

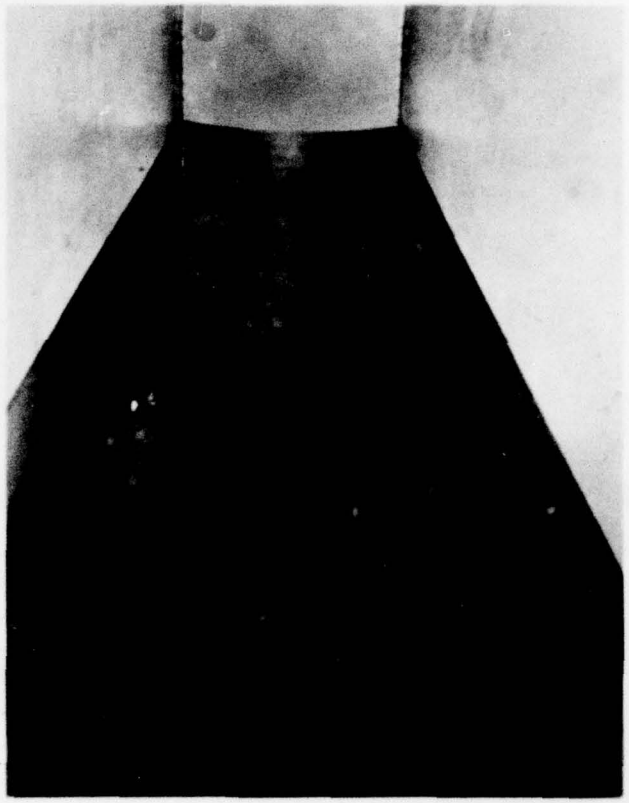
1.11-min valve,
water-surface elev 650

2.09-min valve,
water-surface elev 655

Photograph 5. Effect of valve opening schedule on maximum turbulence over downstream manifolds in plan A lock chamber with plan III baffles; initial head 105 ft.

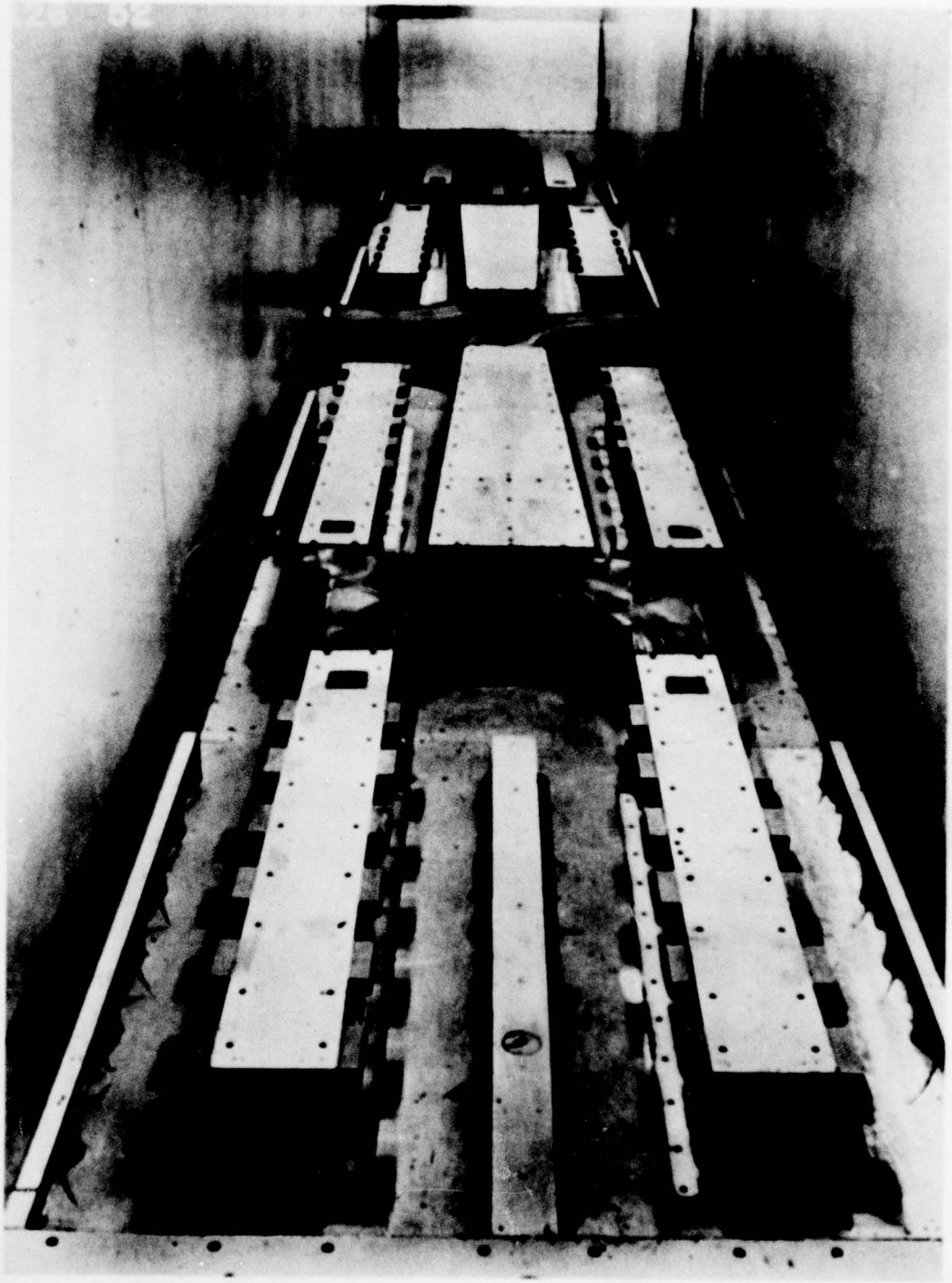


1.11-min valve,
water-surface elev 640.8

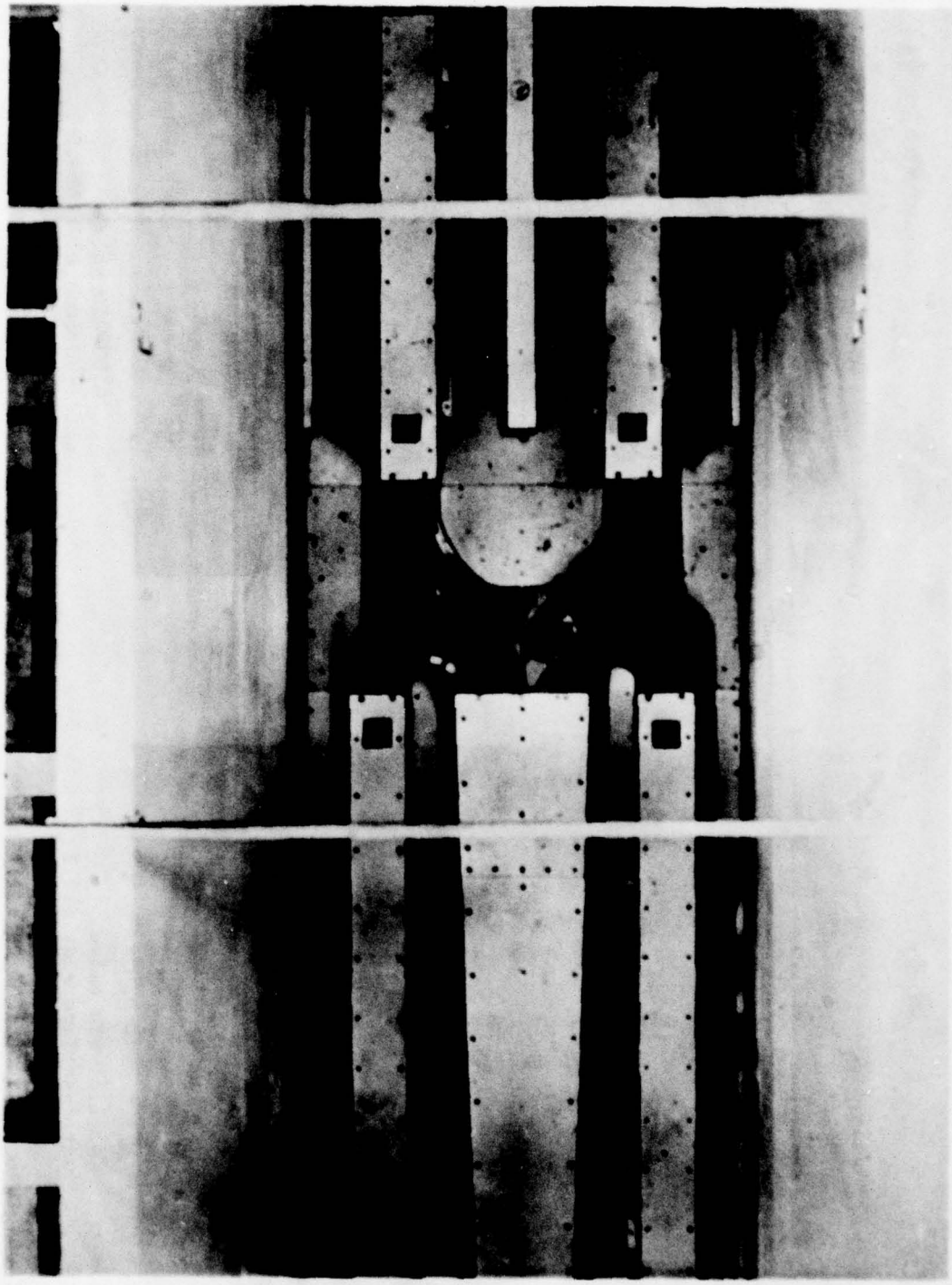


4.00-min valve,
water-surface elev 664.5

Photograph 6. Effect of valve opening schedule on maximum turbulence over downstream manifolds in plan B lock chamber with plan C ports and plan V baffles; initial head 105 ft.



Photograph 7. Plan B lock chamber with plan C ports and plan VI baffles (final design).



Photograph 8. Flow from plan C ports in plan B lock chamber with plan VI baffles (final design); 1.11-min valve, single-valve operation, initial head 105 ft.

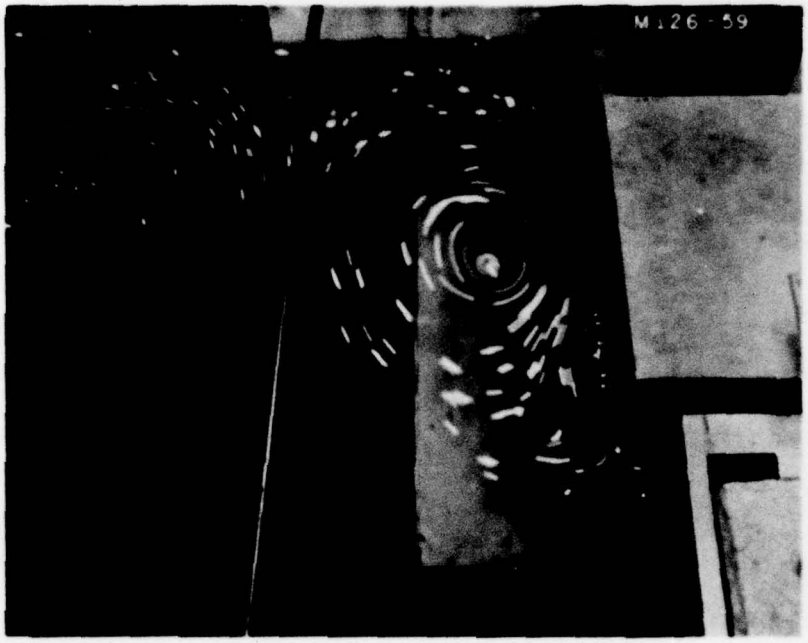


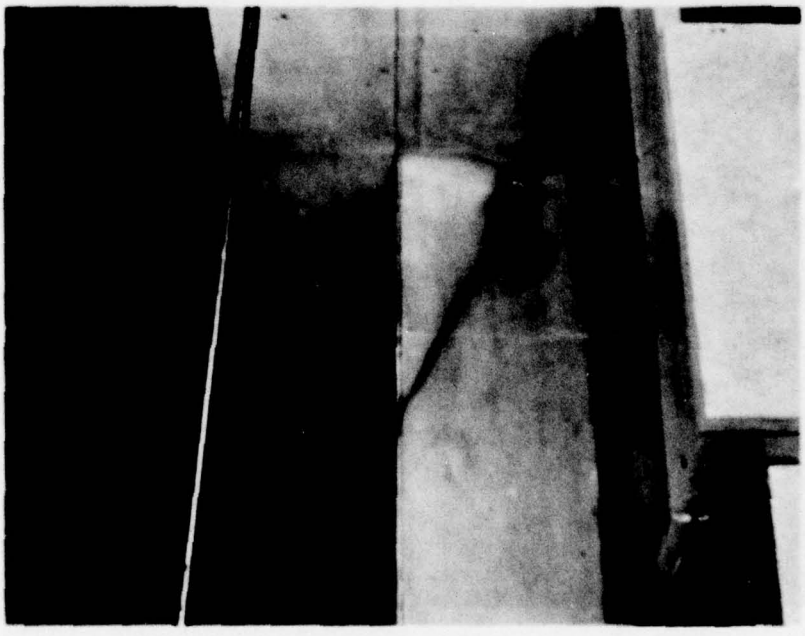
1.11-min valve,
water-surface elev 640.8



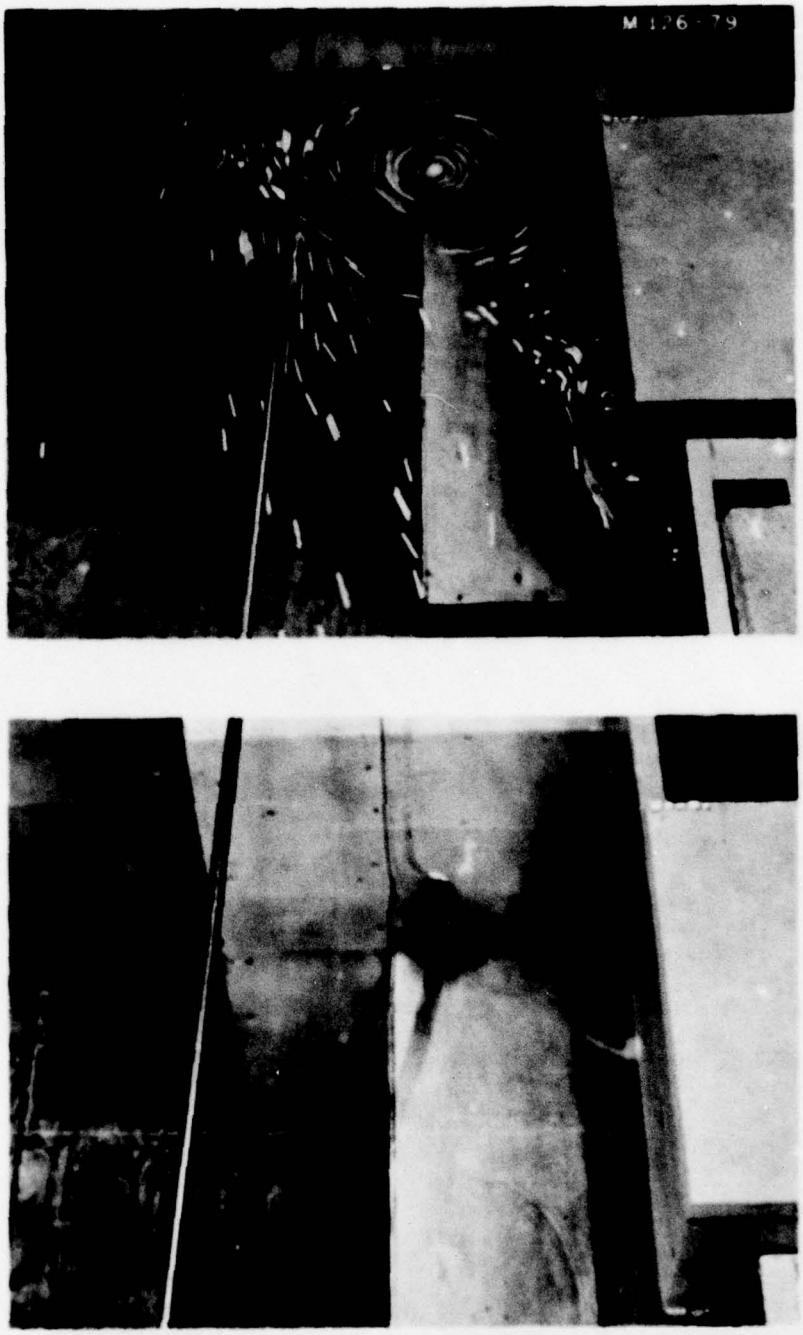
4.00-min valve,
water-surface elev 664.5

Photograph 9. Surface flow patterns over downstream manifolds in plan B lock chamber with plan C ports and plan VI baffles (final design); initial head 105 ft.

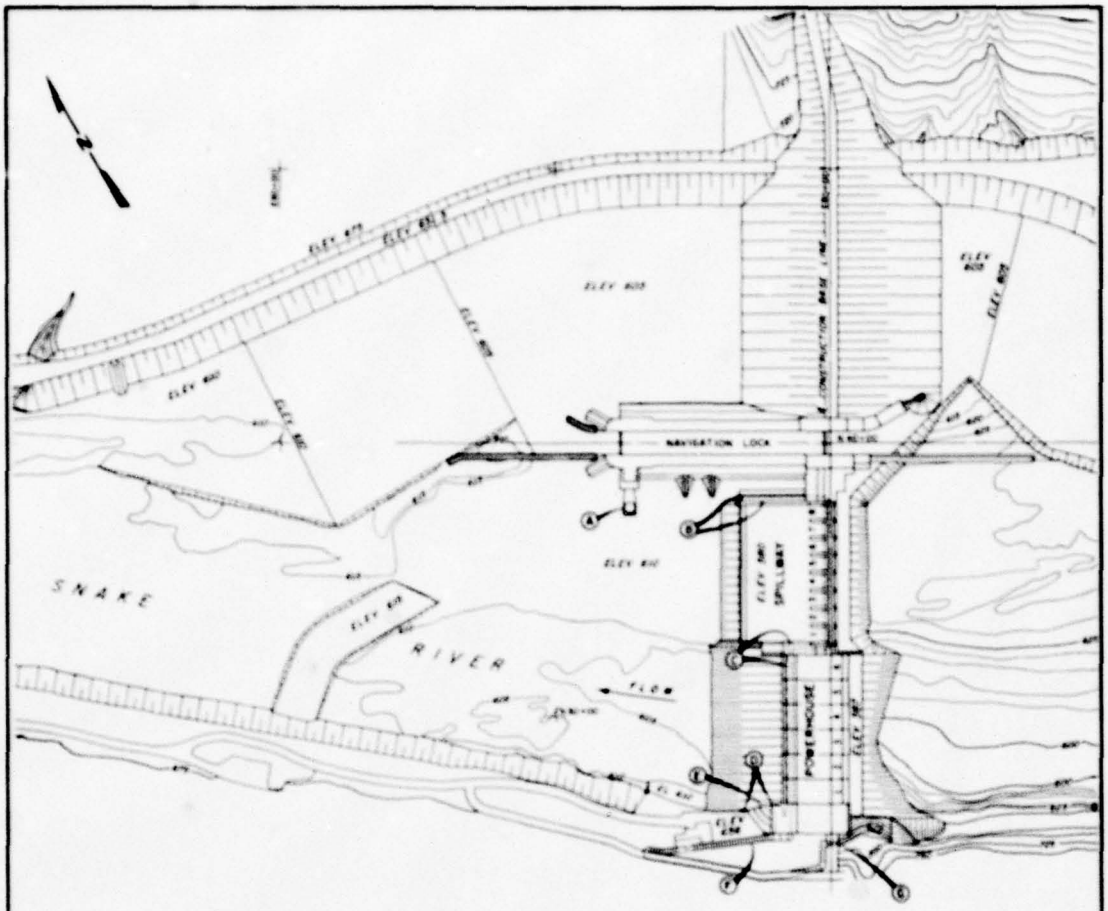




Photograph 10. Vortex formation over left intake. Right filling valve closed, initial head 87 ft, 1.11-min valve schedule, spillway bays 1 and 2 passing 4,000 cfs per bay.



Photograph 11. Vortex formation over left intake. Right filling valve closed, initial head 87 ft, 4.00-min valve schedule, spillway bays 1 and 2 passing 4,000 cfs per bay.



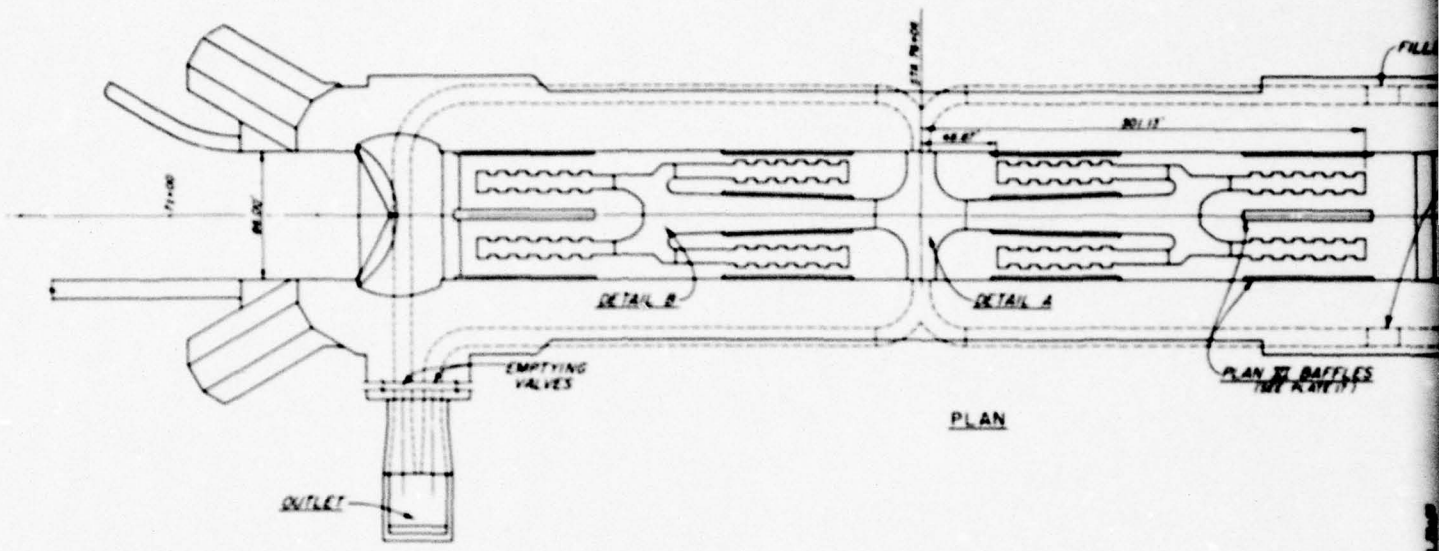
SCALE

LEGEND

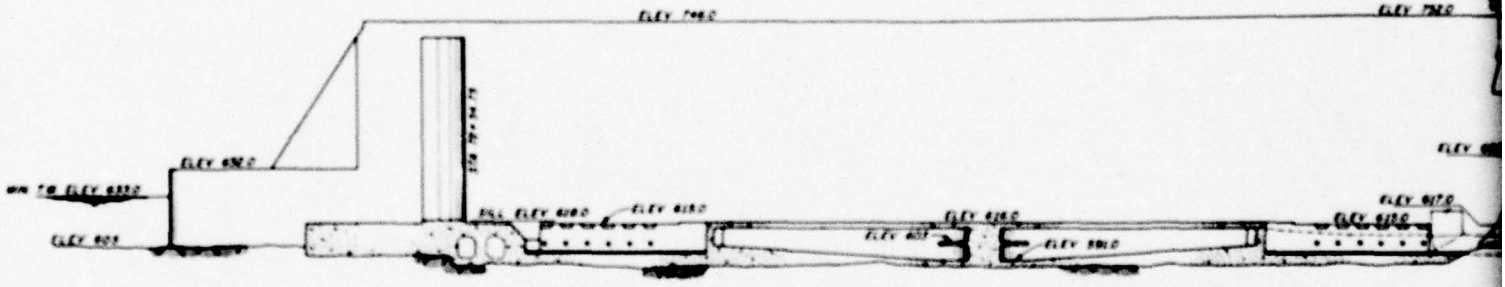
- (A) LOCK OUTLET
- (B) NORTH FISHWAY ENTRANCES
- (C) FISHWAY ENTRANCES
- (D) SOUTH FISHWAY ENTRANCES
- (E) PUMP HOUSE INTAKE
- (F) FISH LADDER
- (G) FISH EXIT

PROJECT LAYOUT

PLATE 1

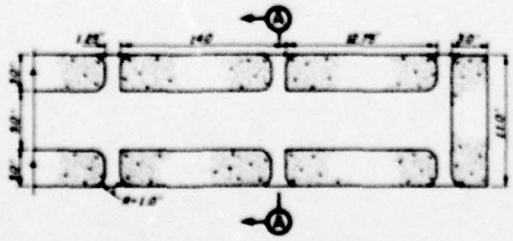


PLAN

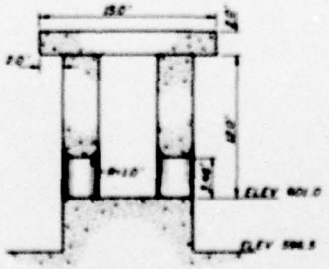


SECTION ALONG CENTER LINE OF LOCK

SCALE



TYPICAL SECTION OF MANIFOLD

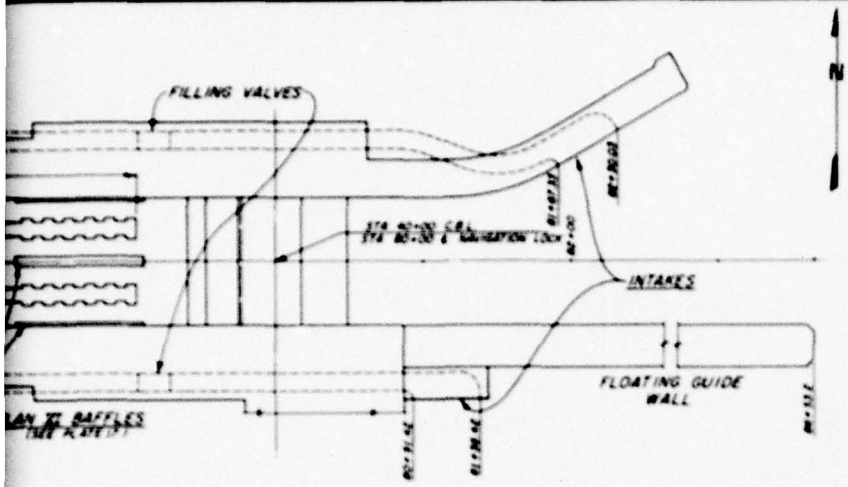


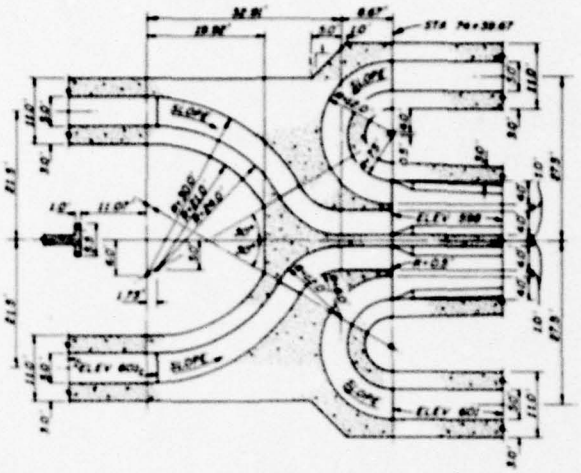
SECTION A-A



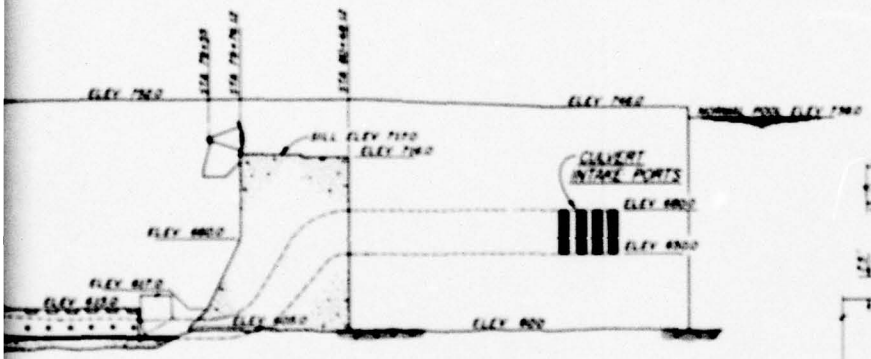
SECTION AL

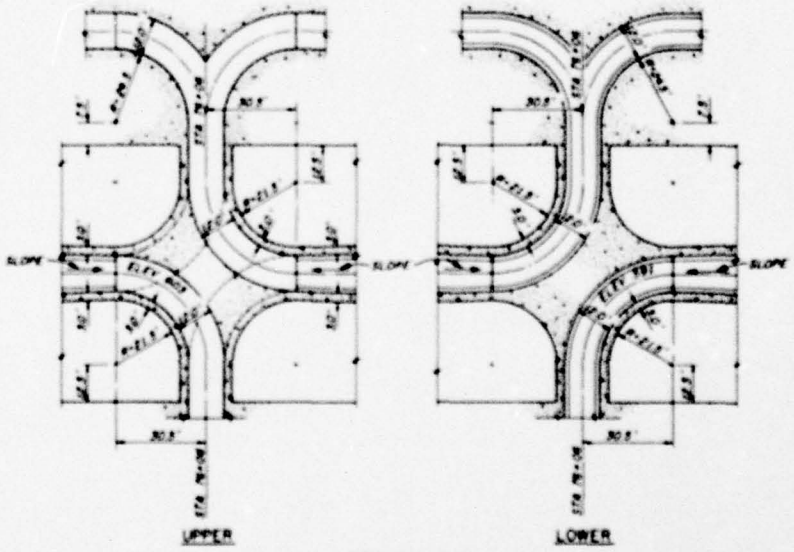
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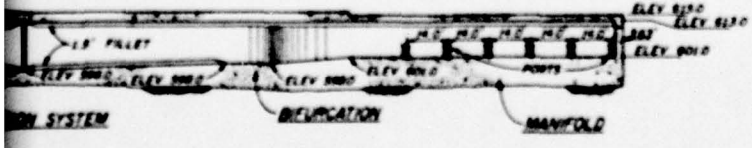
DETAIL B
BIFURCATION





UPPER LOWER

DETAIL A

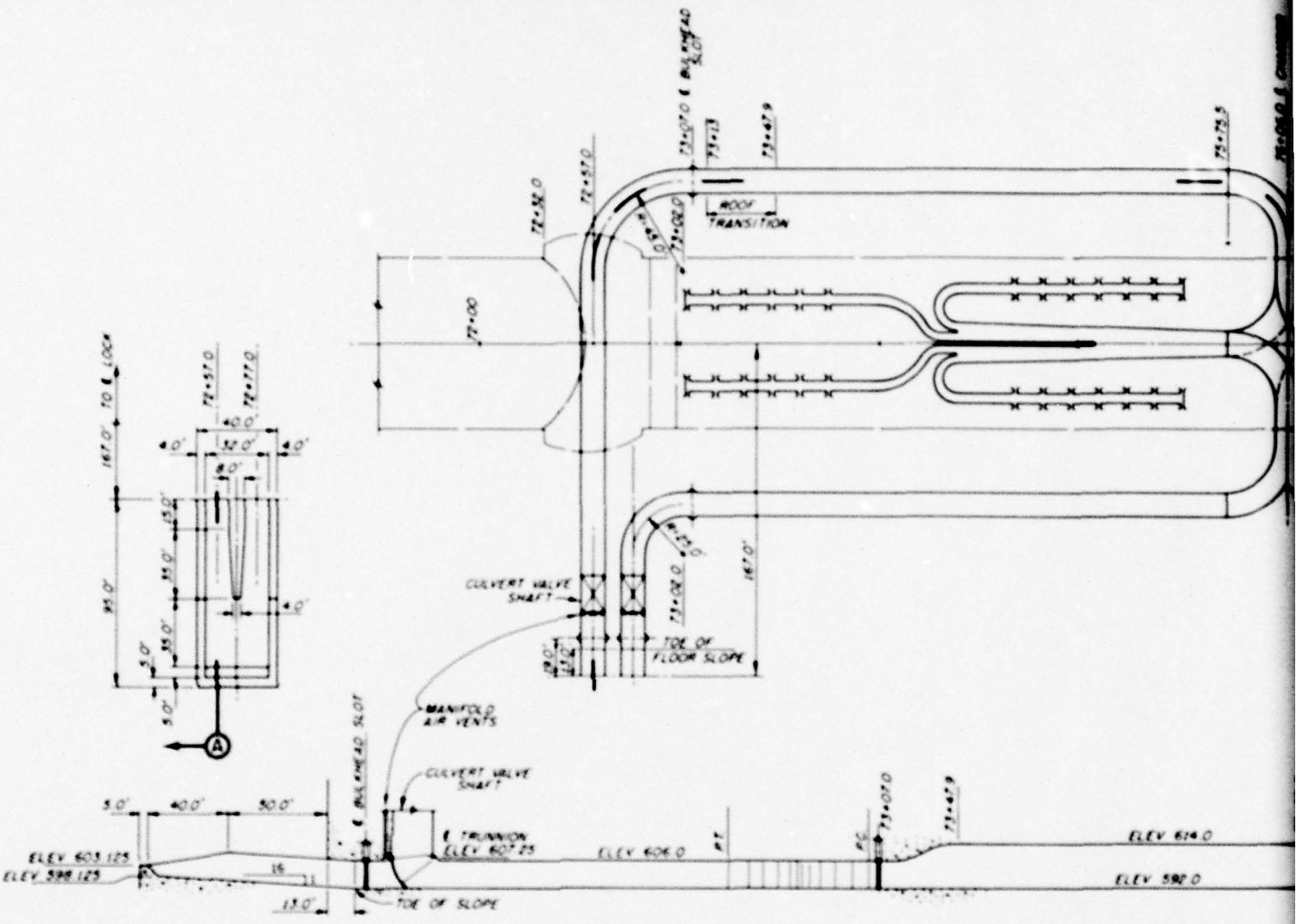


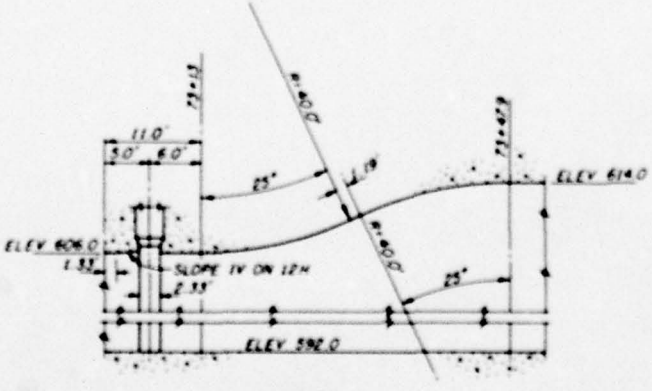
SECTION ALONG FLOW LINE

SCALE

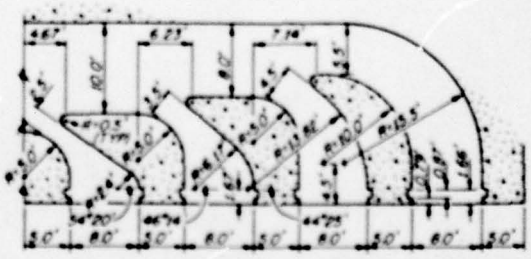
NAVIGATION LOCK
PLAN AND SECTIONS
FINAL DESIGN

PLATE 2



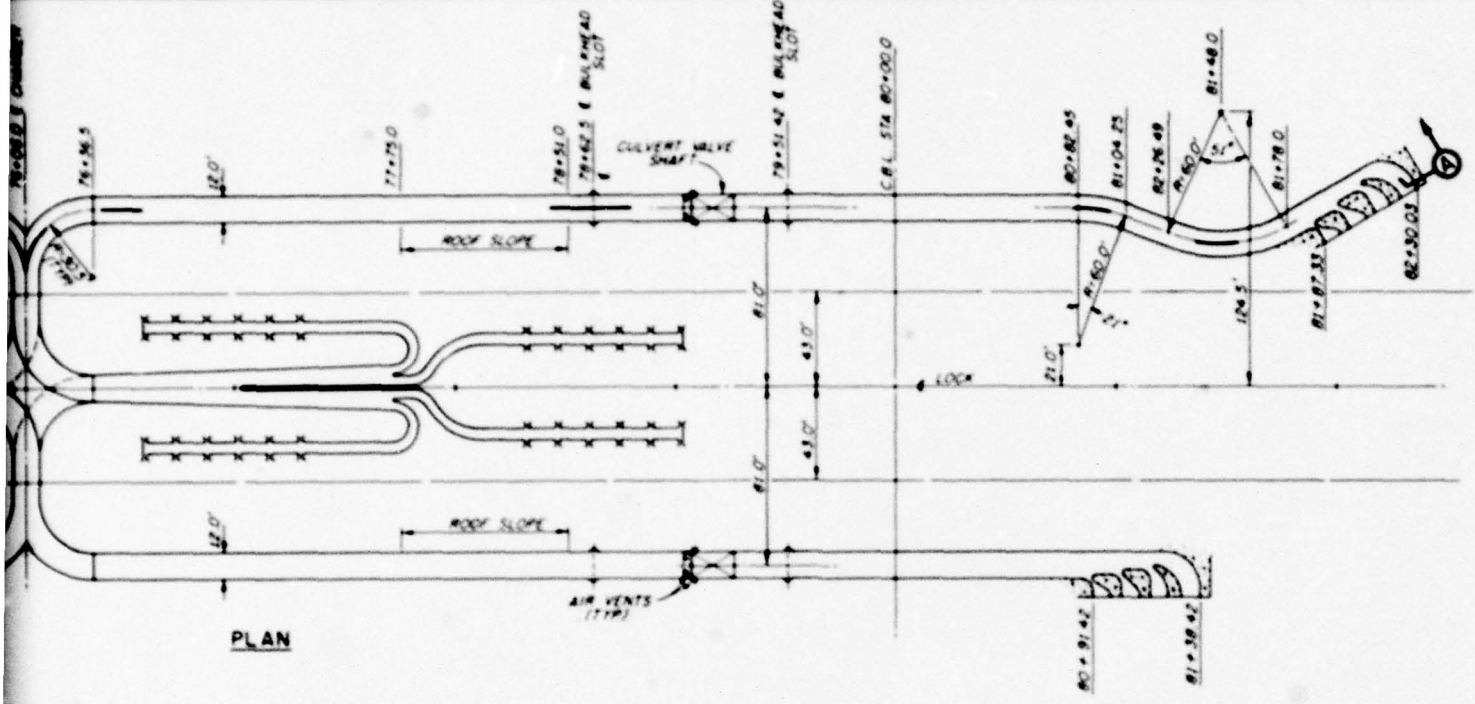


ROOF TRANSITION
STA 73+13.0 TO 73+47.9

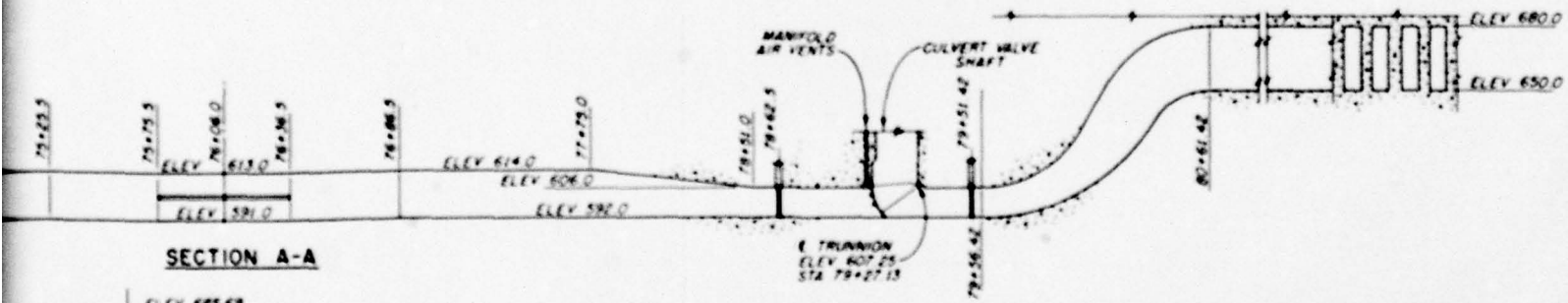


INTAKE PORTS
(TYPICAL)

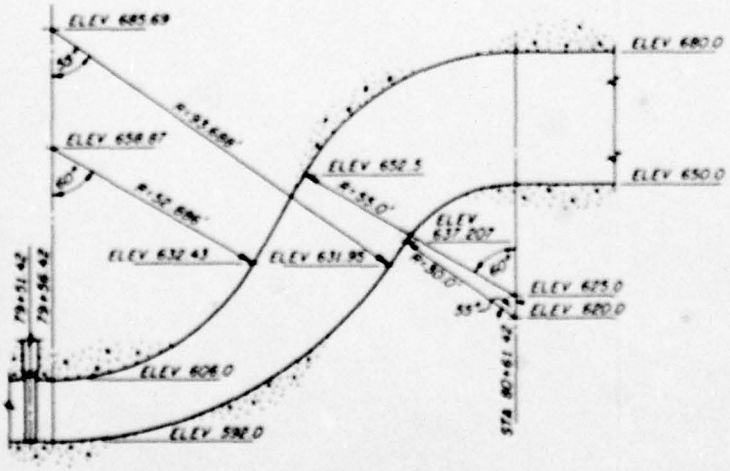
1



PLAN



SECTION A-A



CULVERT TRANSITION

STA 79+56.42 TO 80+61.42

LOCK HYDRAULIC SYSTEM

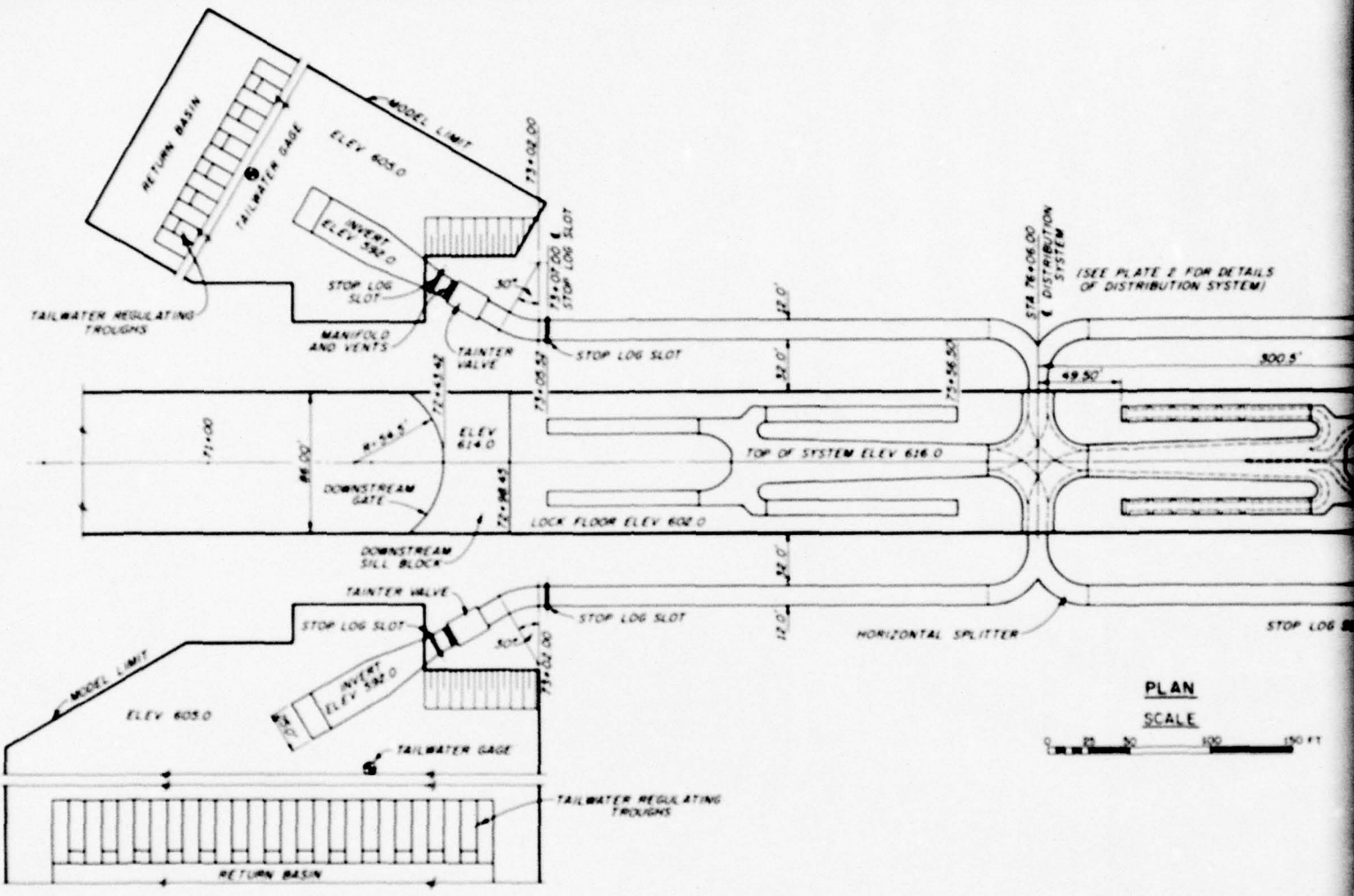
CULVERT LAYOUT AND DETAIL

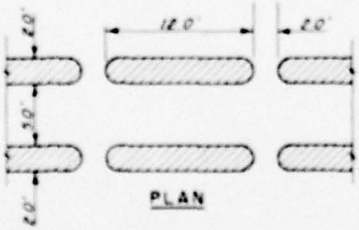
(AS CONSTRUCTED)

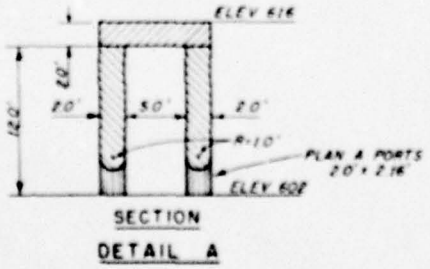
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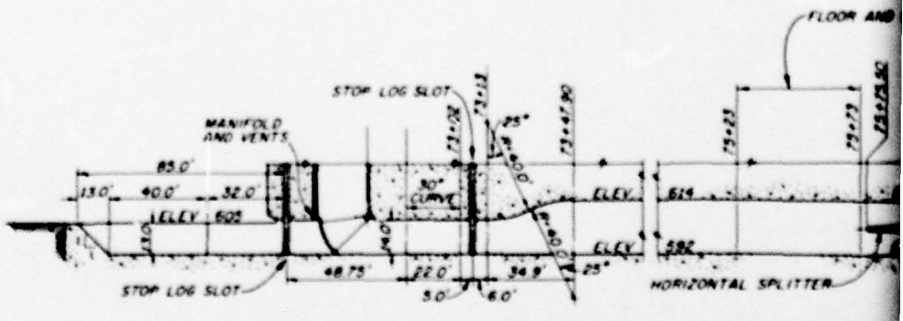
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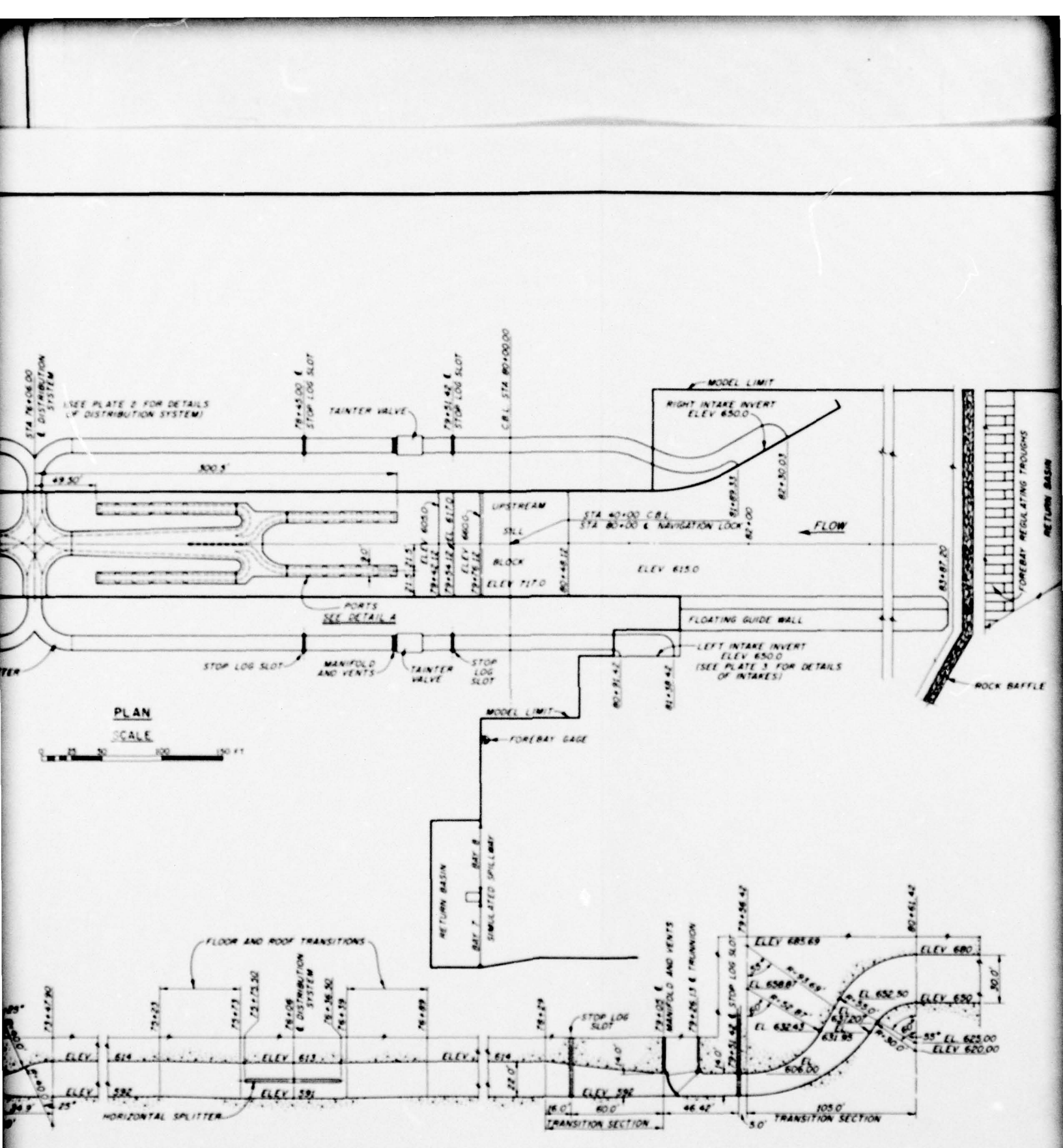
PL


RETURN BASIN
TAILWATER GAGE
MODEL LIMIT
ELEV 605.0
INVERT ELEV 592.0
STOP LOG SLOT
TAILWATER REGULATING TROUGHS
MANIFOLD AND VENTS
TAINTER VALVE
STOP LOG SLOT
DOWNSTREAM GATE
DOWNSTREAM SILL BLOCK
LOCK FLOOR ELEV 602.0
TOP OF SYSTEM ELEV 616.0
STA 76+06.00 DISTRIBUTION SYSTEM
(SEE PLATE 2 FOR DETAILS OF DISTRIBUTION SYSTEM)
HORIZONTAL SPLITTER
PLAN
SCALE


PLAN


ELEV 616
ELEV 602
PLAN A PORTS 2.0 x 2.16
SECTION
DETAIL A

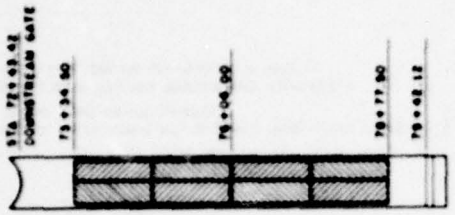

STOP LOG SLOT
MANIFOLD AND VENTS
50' CURVE
HORIZONTAL SPLITTER
SECTION



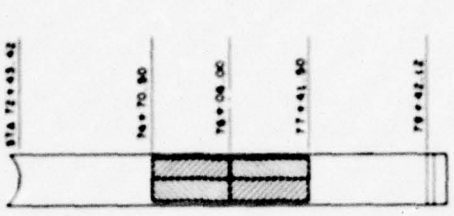
SECTION ALONG CENTER LINE OF RIGHT WALL CULVERT

MODEL LAYOUT

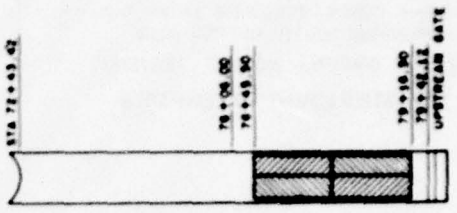
PLAN A HYDRAULIC SYSTEM
(ORIGINAL DESIGN)



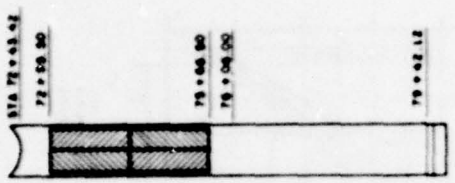
POSITION I



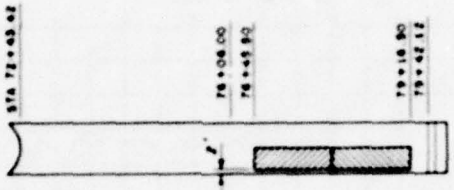
POSITION II



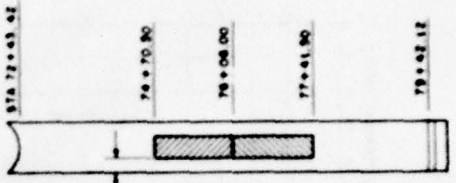
POSITION III



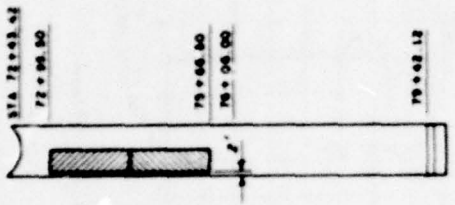
POSITION IV



POSITION V



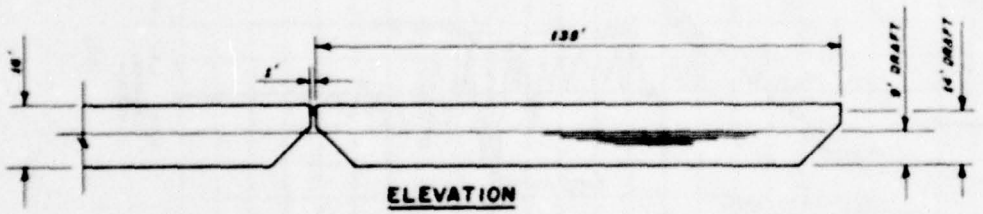
POSITION VI



POSITION VII

NOTES

1. STATION 76+06.00 IS CENTER LINE OF CENTRAL DISTRIBUTION SYSTEM (PLATES 2 TO 4).
2. BARGE DISPLACEMENT 1380 TONS EACH WITH 9 FT DRAFT, 2225 TONS EACH WITH 14 FT DRAFT.



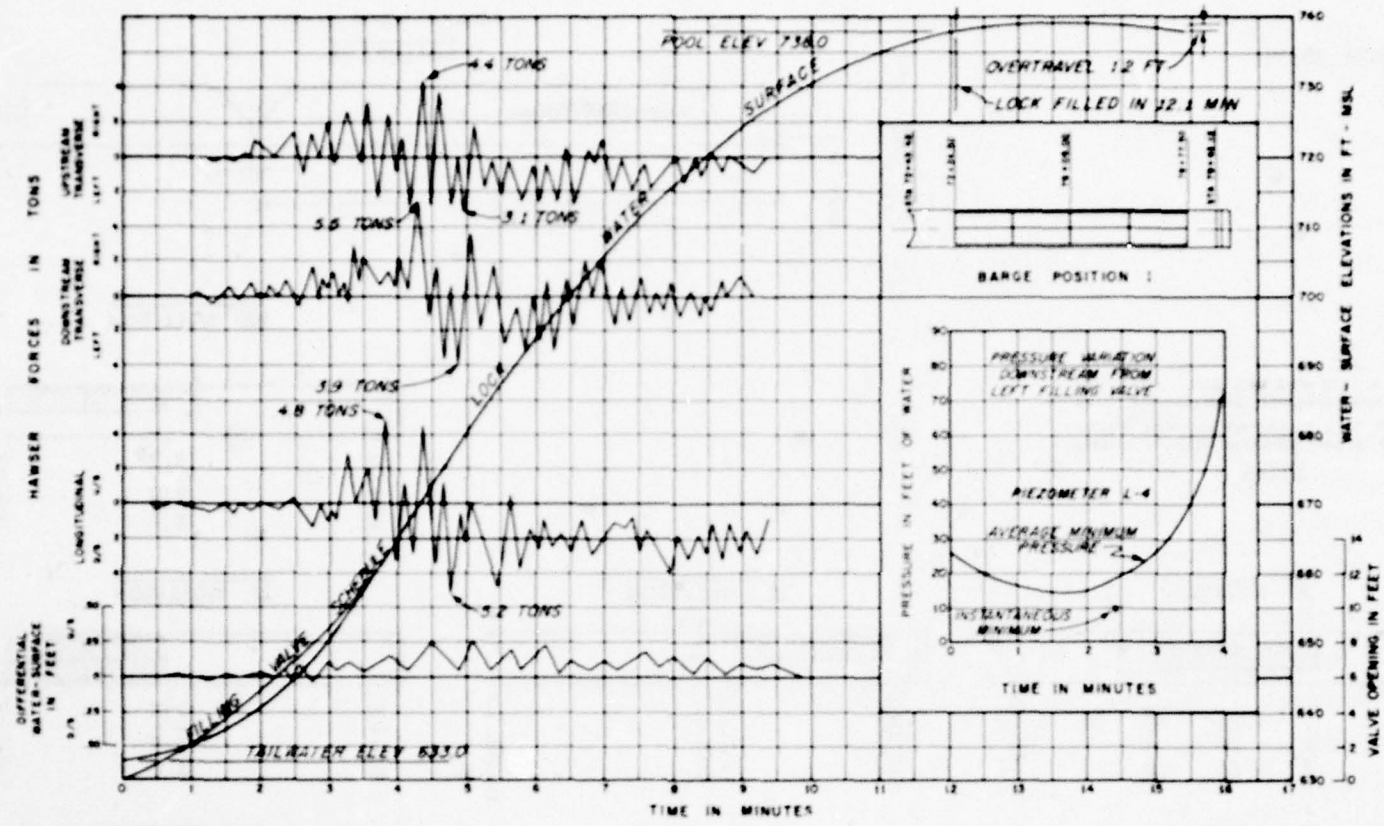
ELEVATION

40-FT WIDE BARGES

BARGE POSITIONS

PLATE 5

PLATE 6



NOTES

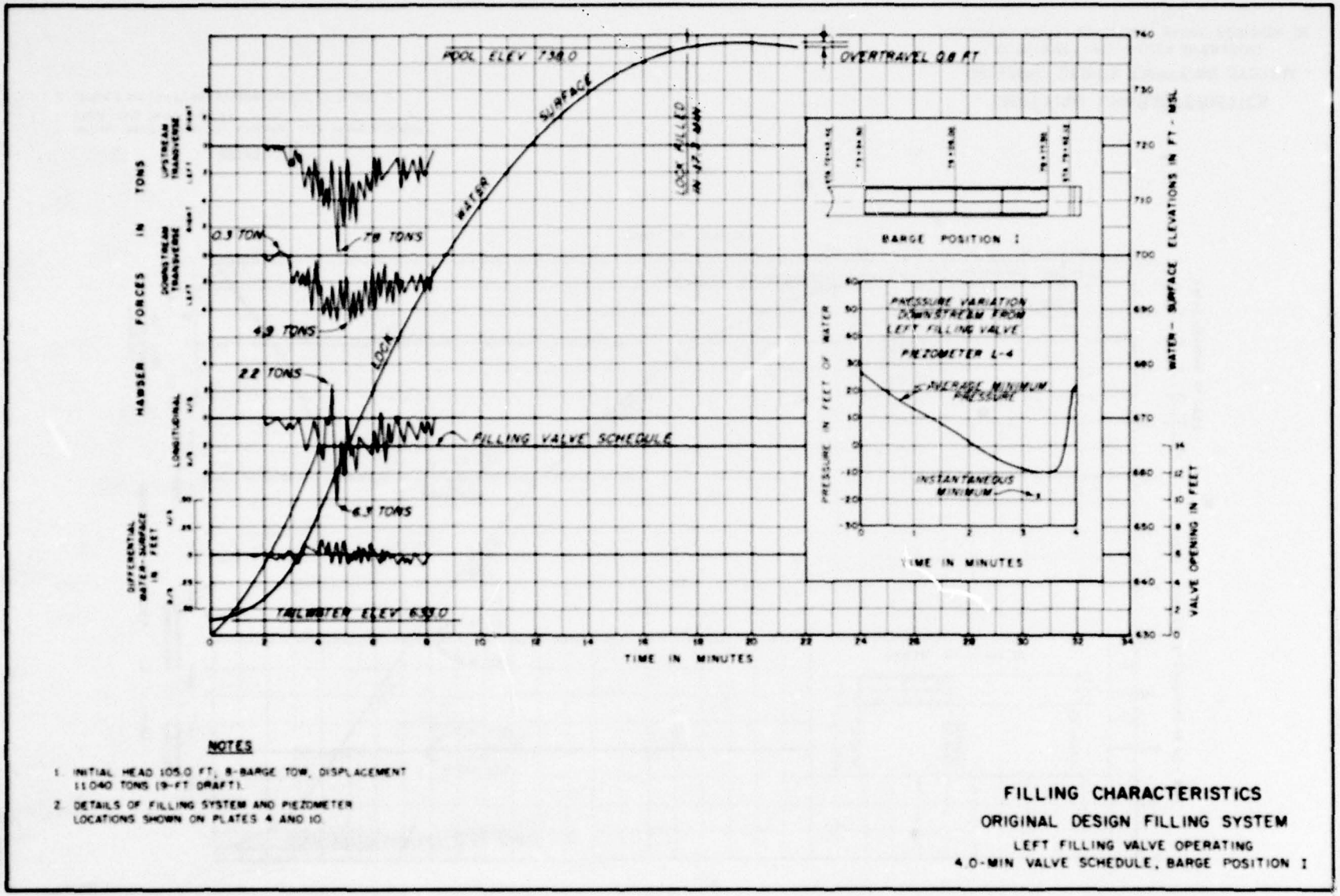
1. INITIAL HEAD 105.0 FT, 8-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 4 AND 10.

FILLING CHARACTERISTICS

ORIGINAL DESIGN FILLING SYSTEM

BOTH FILLING VALVES OPERATING

4.0-MIN VALVE SCHEDULE, BARGE POSITION I



NOTES

1. INITIAL HEAD 105.0 FT, 8-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 4 AND 10.

PLATE 7

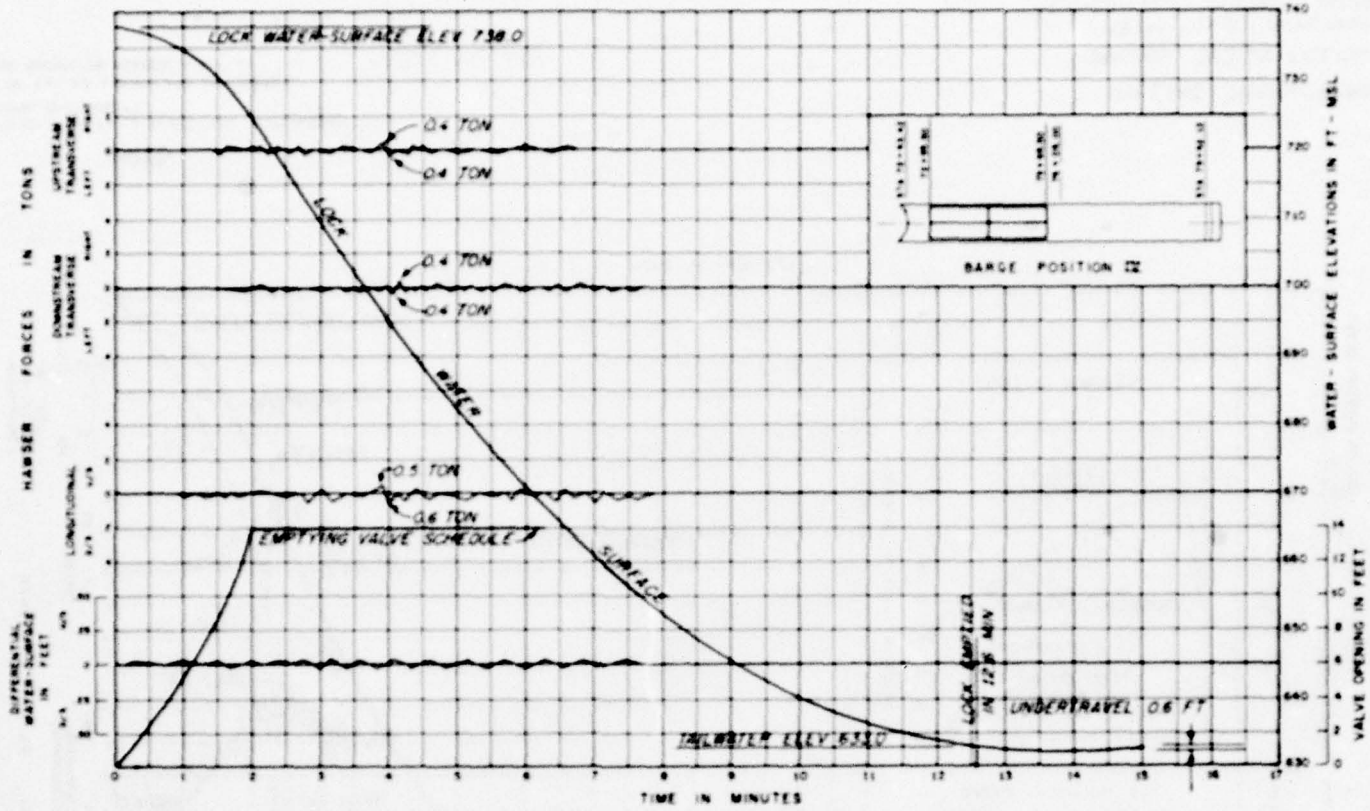
FILLING CHARACTERISTICS

ORIGINAL DESIGN FILLING SYSTEM

LEFT FILLING VALVE OPERATING

4.0-MIN VALVE SCHEDULE, BARGE POSITION I

PLATE 8



NOTES

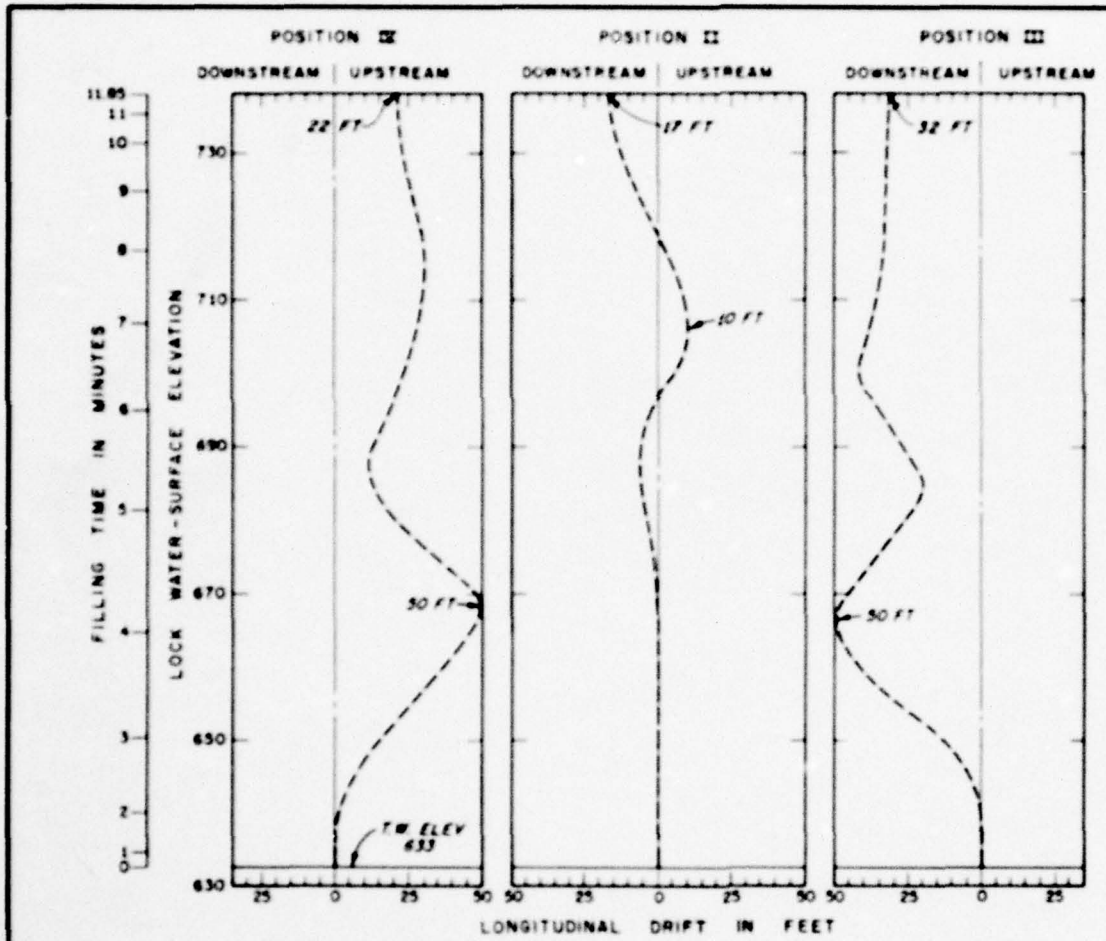
1. INITIAL HEAD 105.0 FT, 4-BARGE TOW, DISPLACEMENT 5520 TONS (9-FT DRAFT).
2. DETAILS OF EMPTYING SYSTEM SHOWN ON PLATE 4.

EMPTYING CHARACTERISTICS

ORIGINAL DESIGN EMPTYING SYSTEM

BOTH EMPTYING VALVES OPERATING

2.0-MIN VALVE SCHEDULE, BARGE POSITION II



NOTES

1. LOCK DETAILS SHOWN ON PLATE 4.
2. BARGE POSITIONS SHOWN ON PLATE 5.

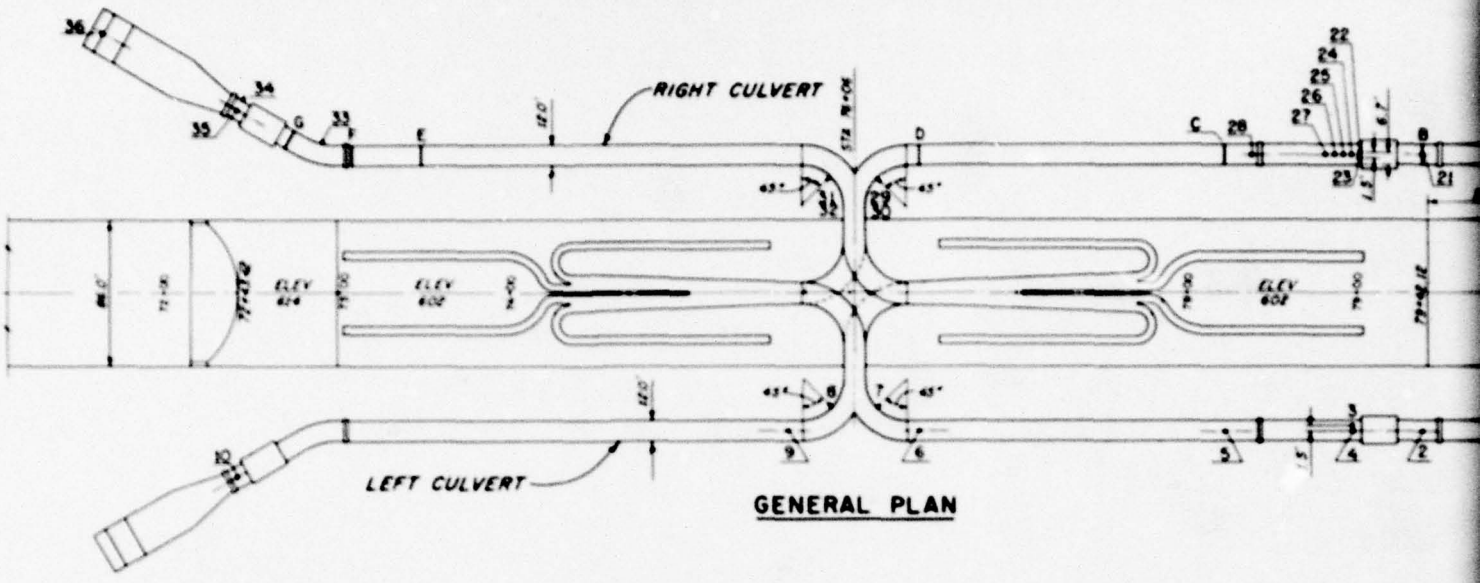
OPERATING CONDITIONS

POOL ELEVATION 738
TAILWATER ELEVATION 633
TWO-VALVE OPERATION WITH 4-MINUTE VALVE SCHEDULE
BARGE DRAFT 9 FT

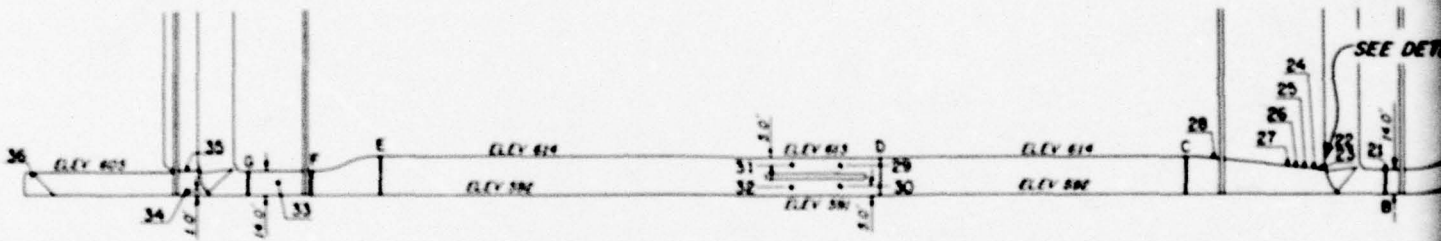
DRIFT OF FREE 4-BARGE TOWS

PLAN A LOCK AND MANIFOLDS
(ORIGINAL DESIGN)

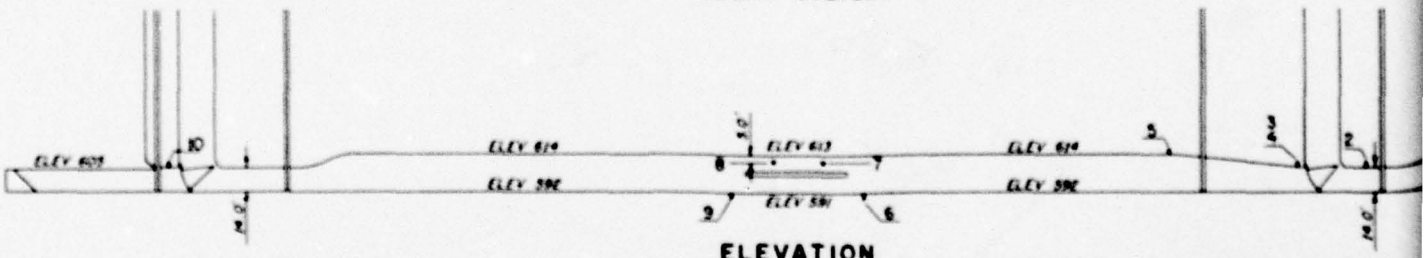
PLATE 9



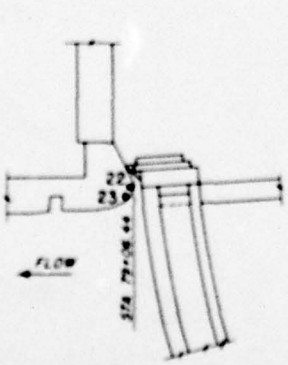
GENERAL PLAN



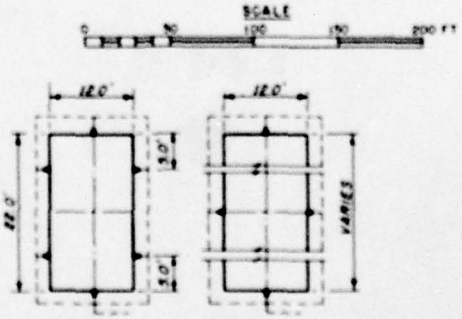
ELEVATION
RIGHT CULVERT



ELEVATION
LEFT CULVERT

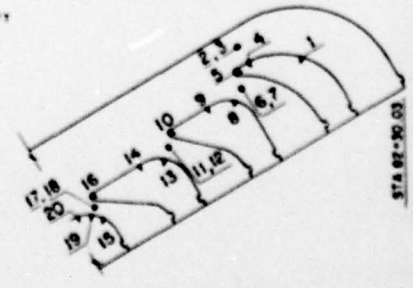


DETAIL A

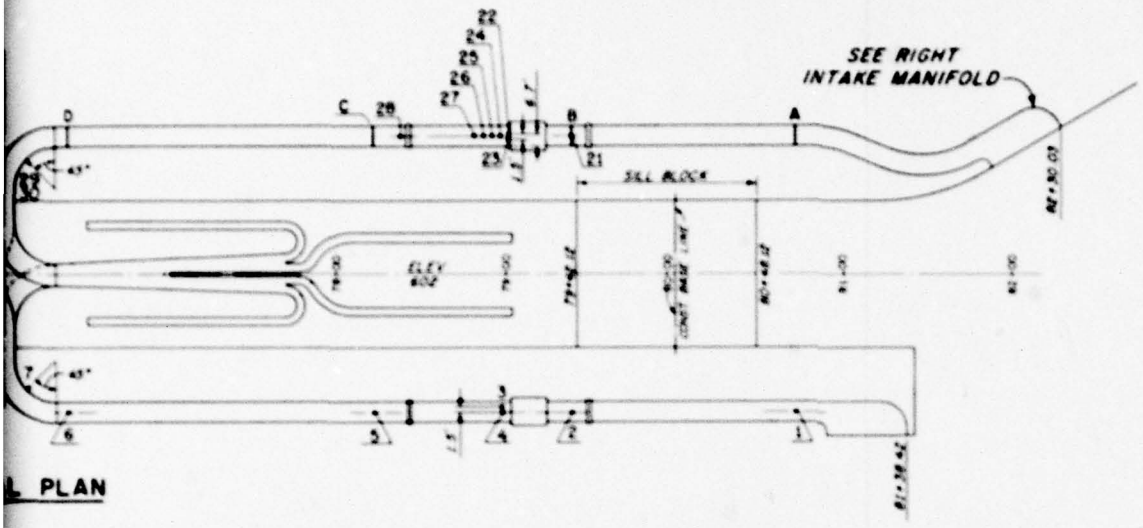


RING D

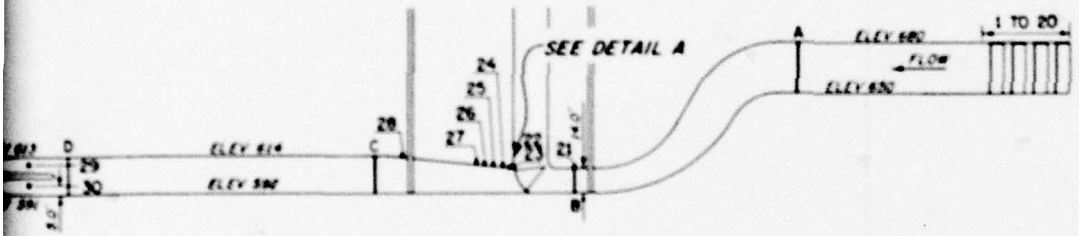
RINGS
A,B,C,E,F,G
(TYPICAL)



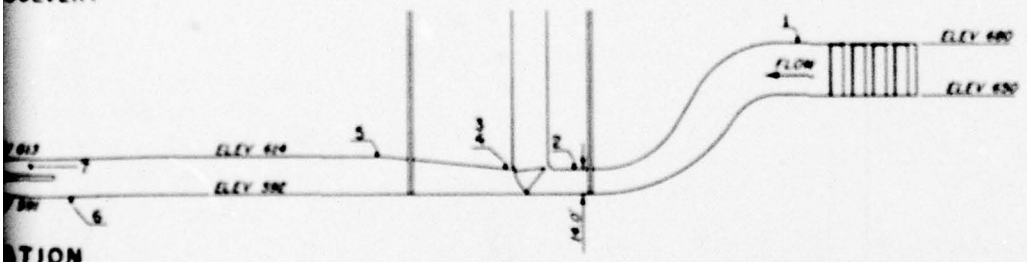
PLAN
RIGHT INTAKE MANIFOLD



L PLAN



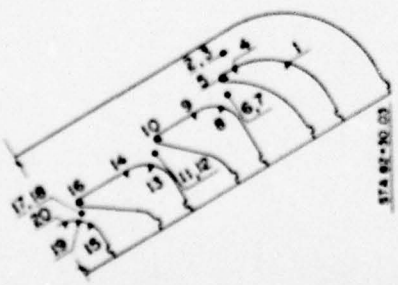
ATION
CULVERT



ATION
ULVERT



BS
E,F,G
EAL)



PLAN
RIGHT INTAKE MANIFOLD

PIEZOMETER LOCATIONS

NUMBER	LOCK STATION	ELEVATION	ORIFICE TYPE *
	RIGHT CULVERT		
1	81+71.23	678.0	STD
2	81+65.08	680.0	"
3	81+65.08	650.0	"
4	81+65.08	678.0	"
5	81+63.95	678.0	"
6	81+62.65	680.0	"
7	81+62.65	650.0	"
8	81+61.27	678.0	"
9	81+57.72	678.0	"
10	81+51.92	678.0	"
11	81+50.96	680.0	"
12	81+50.96	650.0	"
13	81+49.92	678.0	"
14	81+46.46	678.0	"
15	81+39.36	678.0	"
16	81+39.27	678.0	"
17	81+38.75	680.0	"
18	81+38.75	650.0	"
19	81+38.15	678.0	"
20	81+36.59	678.0	"
21	79+40.42	606.0	FA
22	79+06.44	606.5	STD
23	79+03.96	606.3	"
24	78+99.70	606.5	STD,FW CELL
25	78+95.00	607.0	STD
26	78+90.00	607.5	"
27	78+85.00	608.0	"
28	78+40.00	612.8	"
29	76+20.00	608.0	"
30	76+20.00	596.0	"
31	75+92.00	608.0	"
32	75+92.00	596.0	"
33	72+91.26	599.0	"
34	72+43.12	593.0	FA
35	72+43.12	606.0	FA
36	71+65.25	605.0	STD
A	80+72.10	665.0	RING
B	79+40.42	598.0	"
C	79+24.00	603.0	"
D	76+44.00	603.0	"
E	73+50.40	603.0	"
F	73+10.80	599.0	"
G	72+73.80	599.0	"
	LEFT CULVERT		
1	80+72.10	680.0	STD
2	79+40.42	606.0	"
3	78+99.70	606.5	FA
4	78+99.70	606.5	FW CELL
5	78+24.00	614.0	STD
6	76+44.00	591.0	"
7	76+20.00	608.0	"
8	75+92.00	608.0	"
9	75+68.00	591.0	"
10	72+43.12	606.0	"

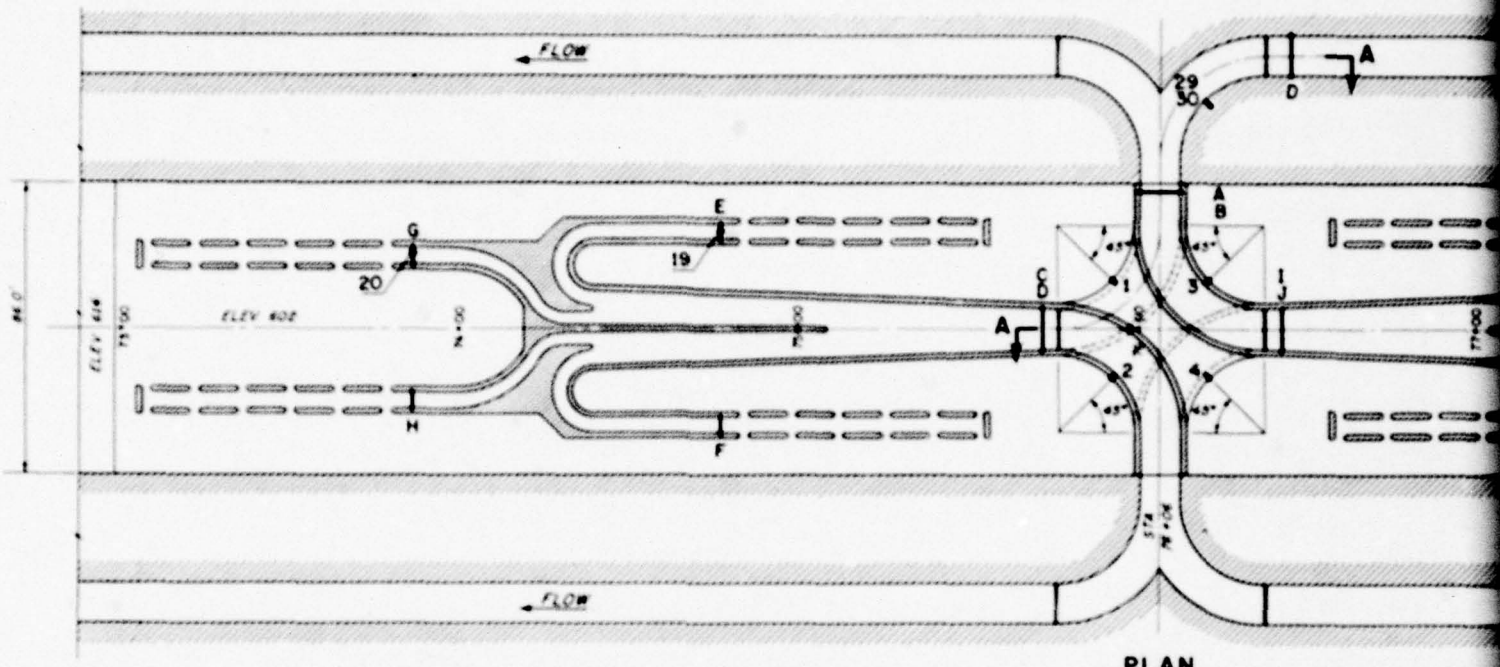
* STD = STANDARD $\frac{1}{4}$" DIAMETER OPENING
FA = FAST ACTING $\frac{1}{8}$" DIAMETER OPENING
RING = SEVERAL STANDARD PIEZOMETERS INTERCONNECTED
FW CELL = FLUSH MOUNTED PRESSURE CELL

NOTES

1. CULVERT AND MANIFOLD DETAILS SHOWN ON PLATES 2 TO 4.
2. PRESSURE CELL INSTALLED AT PIEZOMETER 24 FOR FINAL TEST ONLY.

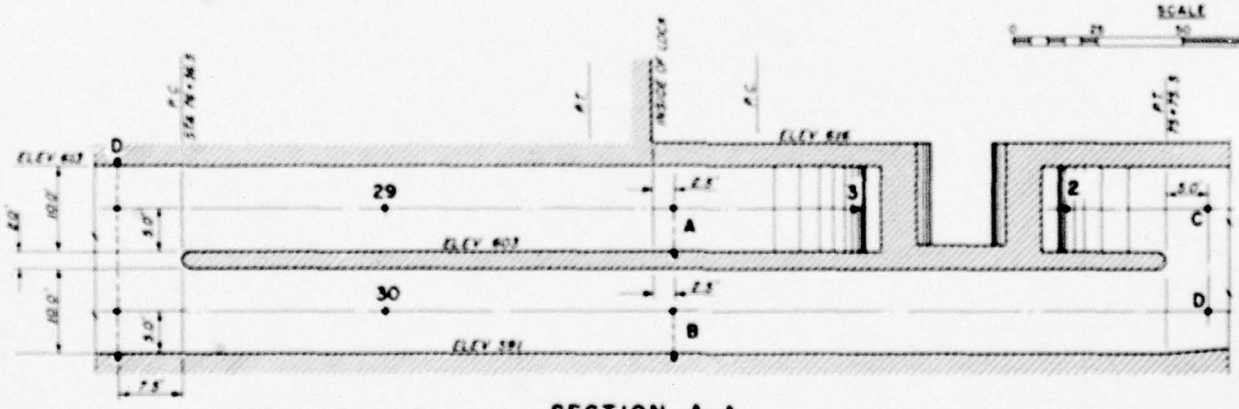
DETAILS AND PIEZOMETER LOCATIONS

PLAN A
WALL CULVERTS

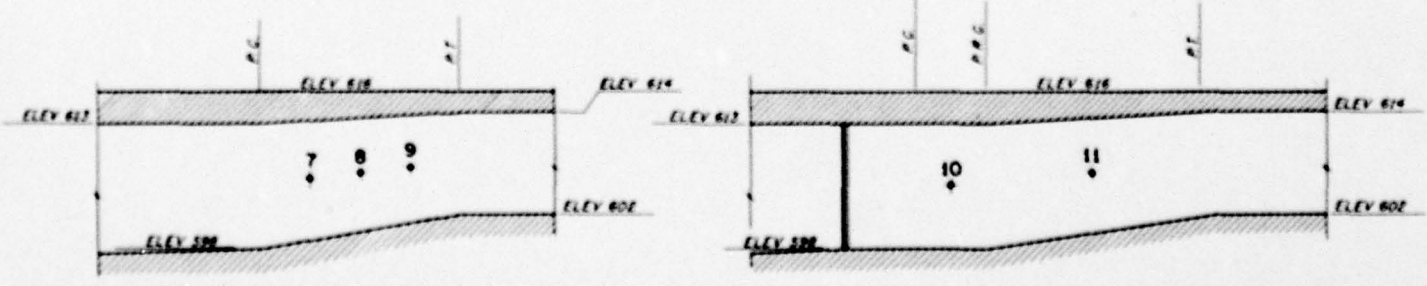


PLAN

SCALE



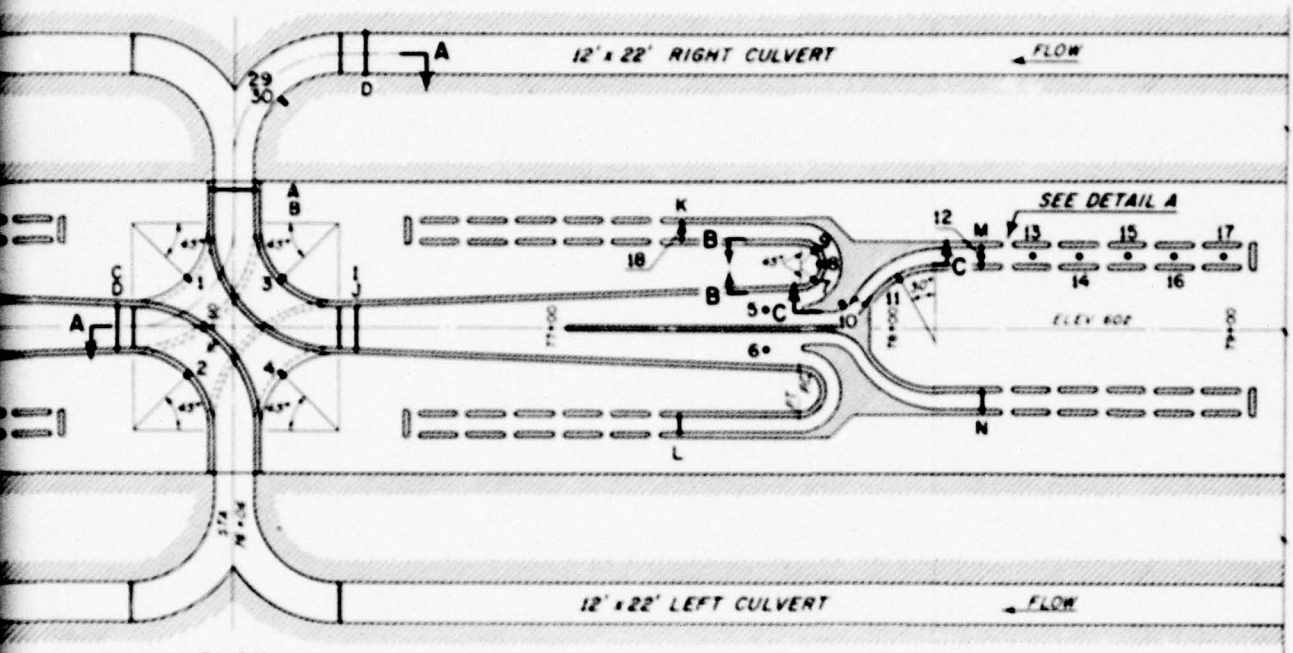
SECTION A-A



SECTION B-B

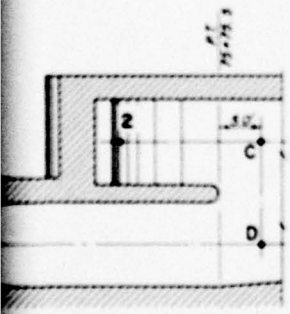
SECTION C-C

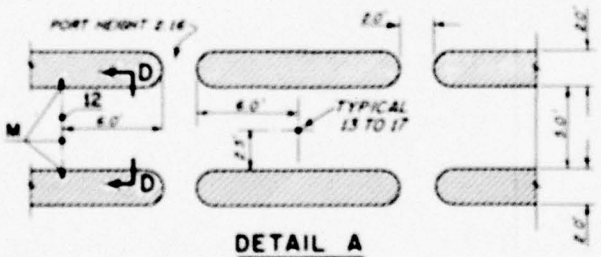
SCALE



PLAN

SCALE





DETAIL A

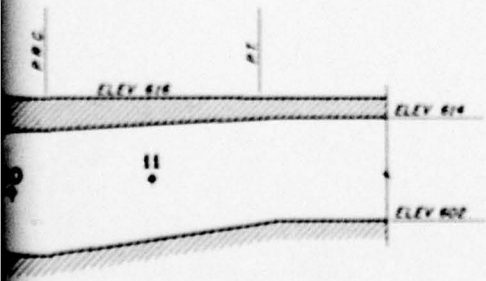
SCALE

PIEZOMETER LOCATIONS			
NUMBER	LOCK STATION	ELEVATION	ORIFICE TYPE
1	75+92.00	594.0	STD
2	75+92.00	608.0	"
3	76+20.00	608.0	"
4	76+20.00	594.0	"
5	77+62.32	597.7	"
6	77+62.32	597.7	"
7	77+77.75	606.1	"
8	77+79.75	606.8	"
9	77+77.75	607.4	"
10	77+85.00	605.5	"
11	77+99.75	606.8	"
12	78+26.50	602.0	FA
13	78+40.50	602.0	STD
14	78+54.50	602.0	"
15	78+68.50	602.0	"
16	78+82.50	602.0	"
17	78+96.50	602.0	"
18	77+35.50	602.0	FA
19	74+76.50	602.0	"
20	73+85.50	602.0	"
A	76+08.00	608.0	RING
B	76+08.00	594.0	"
C	75+70.50	608.0	"
D	75+70.50	594.0	"
E	74+78.50	608.0	"
F	74+78.50	608.0	"
G	73+85.50	608.0	"
H	73+85.50	608.0	"
I	76+41.50	608.0	"
J	76+41.50	594.0	"
K	77+35.50	608.0	"
L	77+35.50	608.0	"
M	78+26.50	608.0	"
N	78+26.50	608.0	"

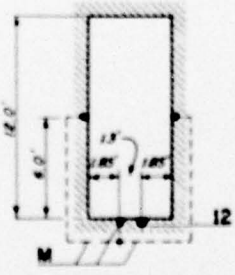
* STD - STANDARD $\frac{1}{4}$" DIAMETER OPENING
FA - FAST ACTING $\frac{1}{4}$" DIAMETER OPENING
RING - SEVERAL STANDARD PIEZOMETERS INTERCONNECTED

NOTE

DETAILS OF DISTRIBUTION SYSTEM SHOWN ON PLATES 2 TO 4



ECTION C-C



SECTION D-D

(TYPICAL)

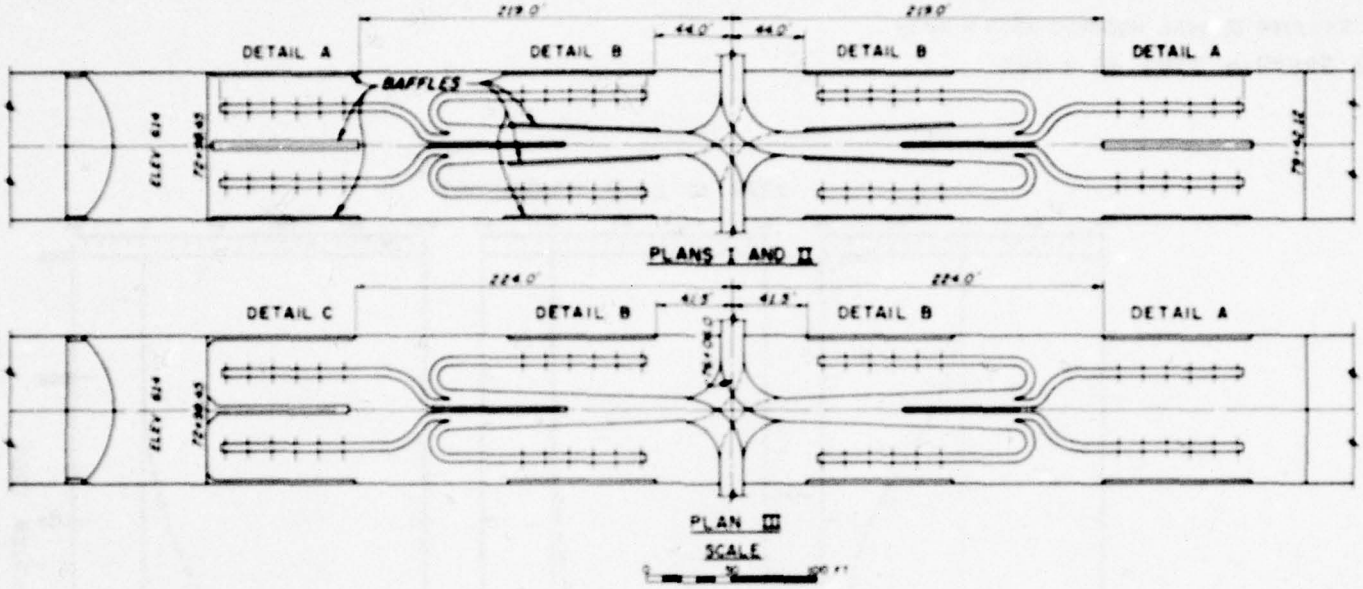
G & 20, E & 19

K & 18, M & 12

DETAILS AND PIEZOMETER LOCATIONS

PLAN A

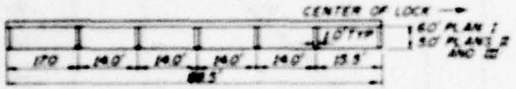
DISTRIBUTION AND MANIFOLD SYSTEMS



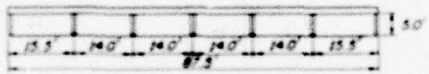
PLANS I AND II

PLAN III

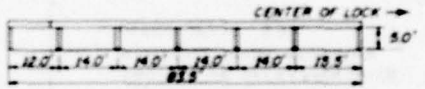
SCALE



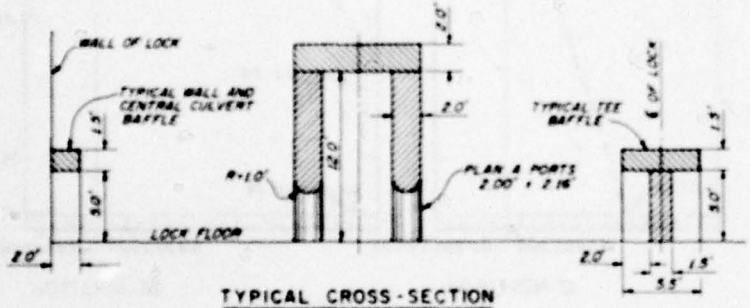
DETAIL A



DETAIL B



DETAIL C

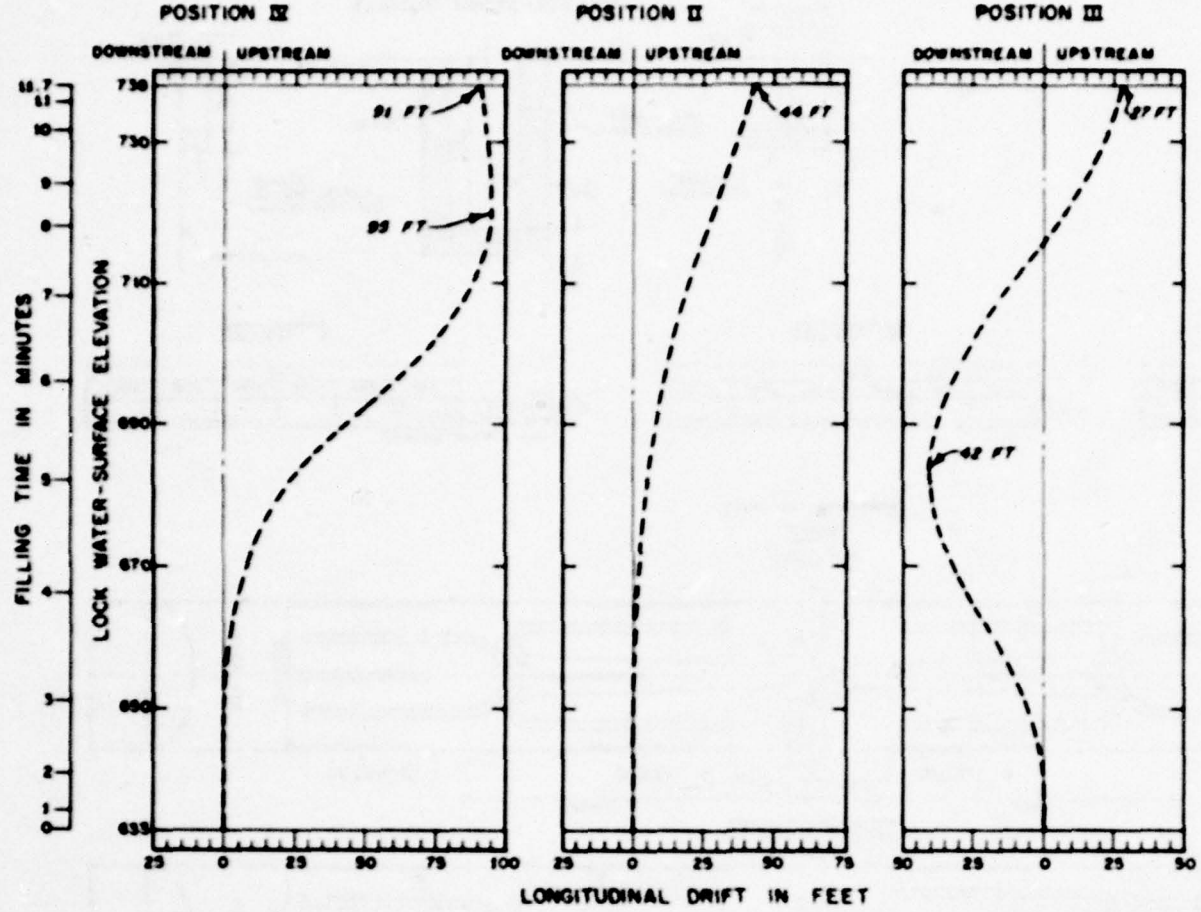


TYPICAL CROSS-SECTION

BAFFLE PLANS I TO III

PLATE 12

PLATE 13



NOTES

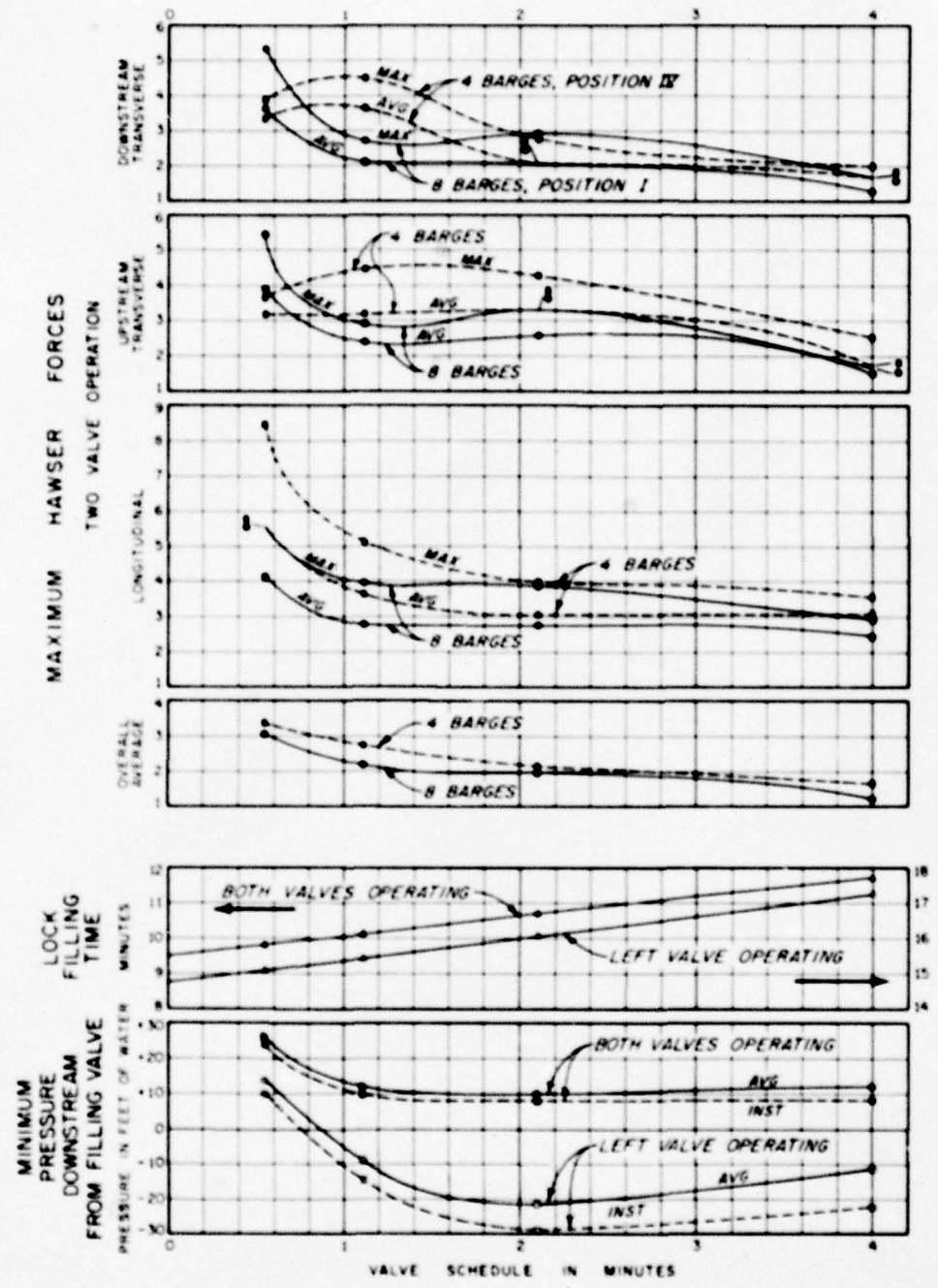
1. BARGE POSITIONS SHOWN ON PLATE 5.
2. LOCK CHAMBER DETAILS SHOWN ON PLATE 4.
3. BAFFLE AND PORT DETAILS SHOWN ON PLATE 12.

OPERATING CONDITIONS

FOREBAY ELEVATION 738
TAILWATER ELEVATION 633
TWO-VALVE OPERATION WITH 4-MINUTE VALVE SCHEDULE
BARGE DRAFT 9 FT

DRIFT OF FREE 4-BARGE TOWS

PLAN A LOCK CHAMBER, TYPE III BAFFLES, PLAN B PORTS



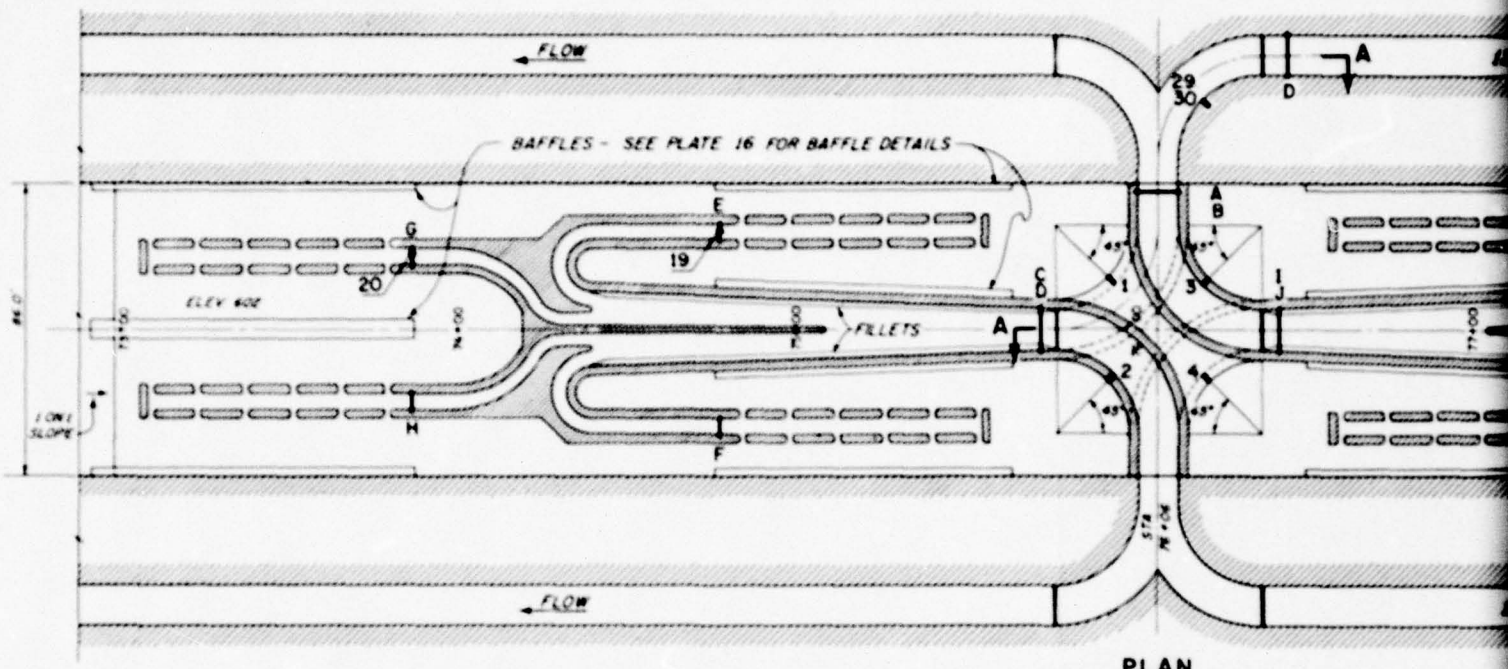
NOTES

1. DATA OBTAINED FROM TWO TO FIVE RUNS WITH EACH VALVE SCHEDULE AND 105-FT INITIAL HEAD.
2. PRESSURE DOWNSTREAM FROM FILLING VALVE OBTAINED WITH FLUSH MOUNTED PRESSURE CELL (PIEZOMETER L-4, PLATE 10).
3. BARGE POSITIONS SHOWN ON PLATE 5.
4. BARGE DRAFT 9 FT.

EFFECT OF FILLING VALVE SCHEDULE

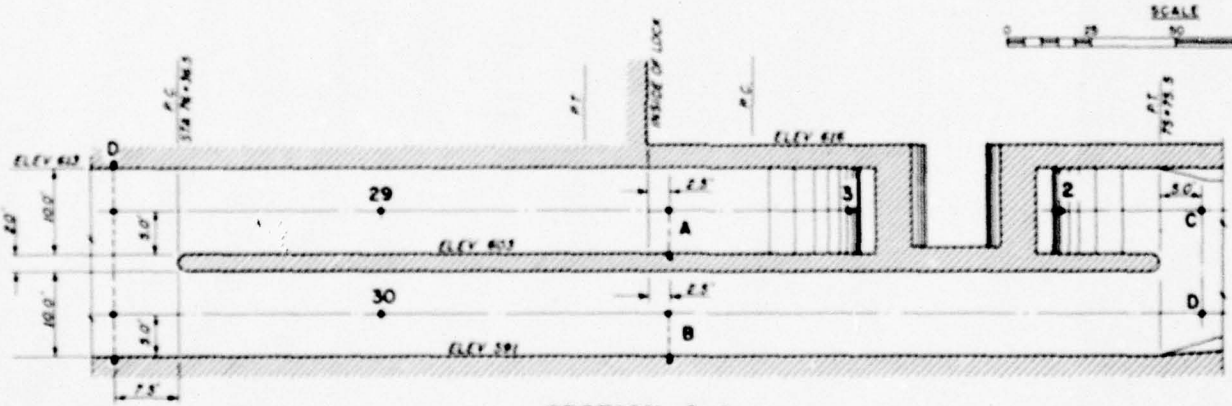
PLAN A LOCK, TYPE III BAFFLES
PLAN B PORTS

PLATE 14

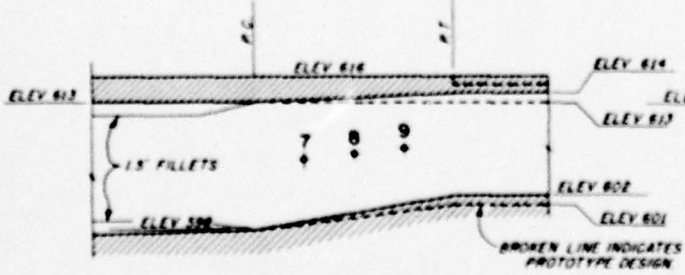


PLAN

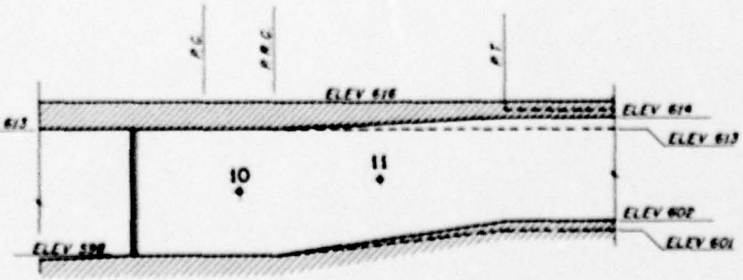
SCALE



SECTION A-A

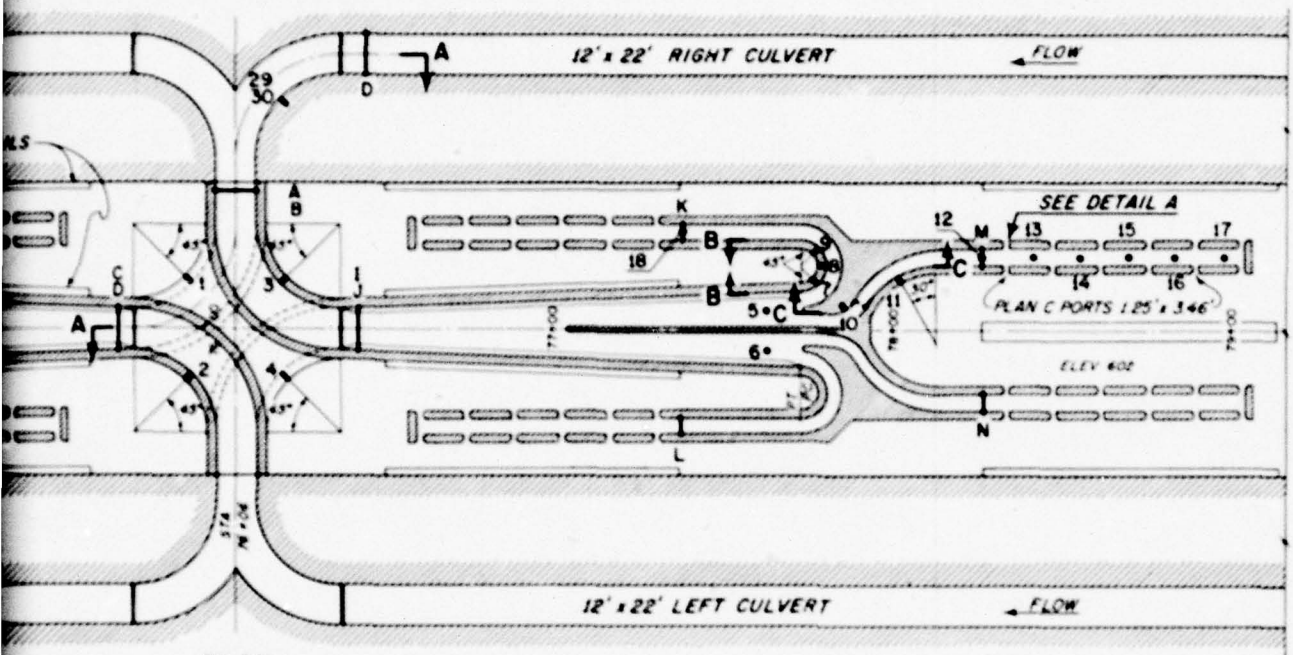


SECTION B-B



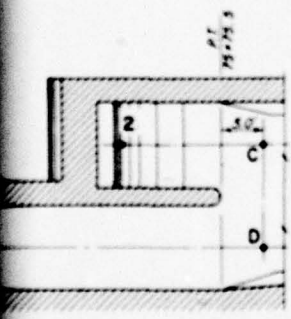
SECTION C-C

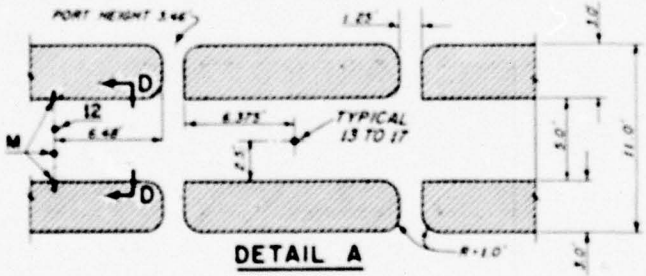
SCALE



PLAN

SCALE



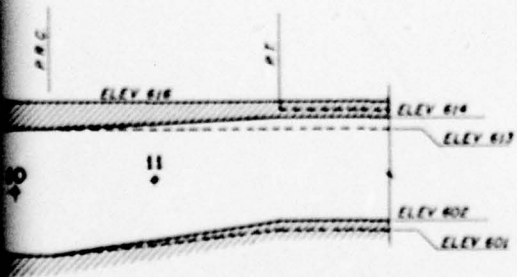


DETAIL A

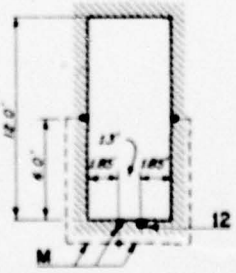
SCALE

PIEZOMETER LOCATIONS			
NUMBER	LOCK STATION	ELEVATION	ORIFICE TYPE
1	75+92.00	596.0	STD
2	75+92.00	608.0	"
3	76+20.00	608.0	"
4	76+20.00	596.0	"
5	77+62.32	597.7	"
6	77+62.32	597.7	"
7	77+77.75	606.1	"
8	77+79.75	606.8	"
9	77+77.75	607.4	"
10	77+85.00	605.5	"
11	77+99.75	606.8	"
12	78+26.50	602.0	FA
13	78+40.50	602.0	STD
14	78+54.50	602.0	"
15	78+68.50	602.0	"
16	78+82.50	602.0	"
17	78+96.50	602.0	"
18	77+35.50	602.0	FA
19	74+76.50	602.0	"
20	73+85.50	602.0	"
A	76+08.00	608.0	RING
B	76+08.00	596.0	"
C	75+70.50	608.0	"
D	75+70.50	596.0	"
E	74+76.02	608.0	"
F	74+76.02	608.0	"
G	73+85.98	608.0	"
H	73+85.98	608.0	"
I	76+41.50	608.0	"
J	76+41.50	596.0	"
K	77+35.98	608.0	"
L	77+35.98	608.0	"
M	78+26.02	608.0	"
N	78+26.02	608.0	"

* STD = STANDARD $\frac{1}{4}$" DIAMETER OPENING
FA = FAST ACTING $\frac{1}{8}$" DIAMETER OPENING
RING = SEVERAL STANDARD PIEZOMETERS INTERCONNECTED



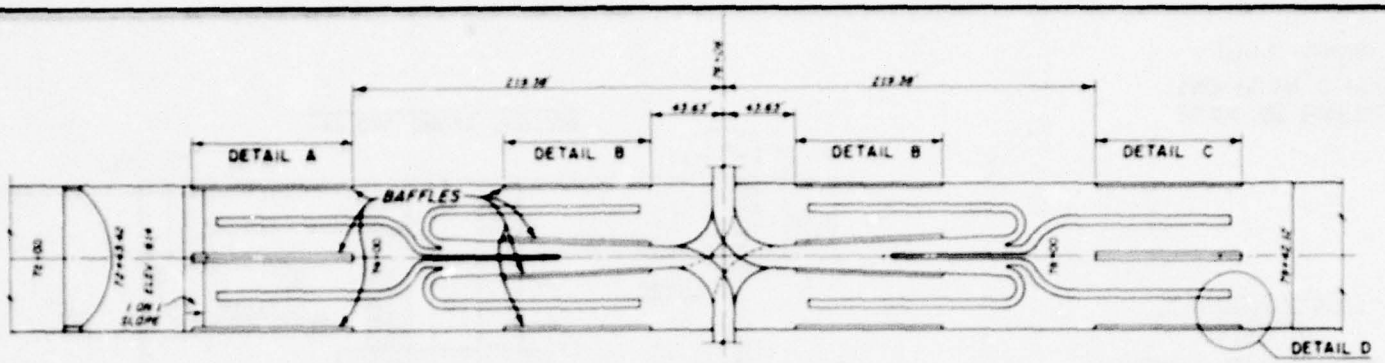
SECTION C-C



SECTION D-D
(TYPICAL)
G & 20, E & 19
K & 18, M & 12

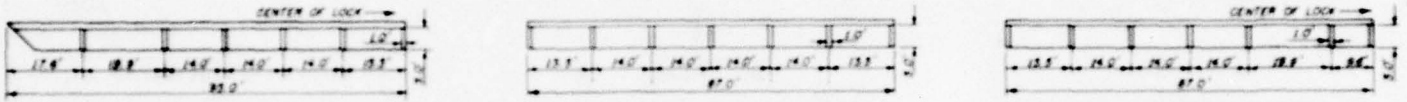
DETAILS AND PIEZOMETER LOCATIONS

PLAN B DISTRIBUTION SYSTEM



PLAN

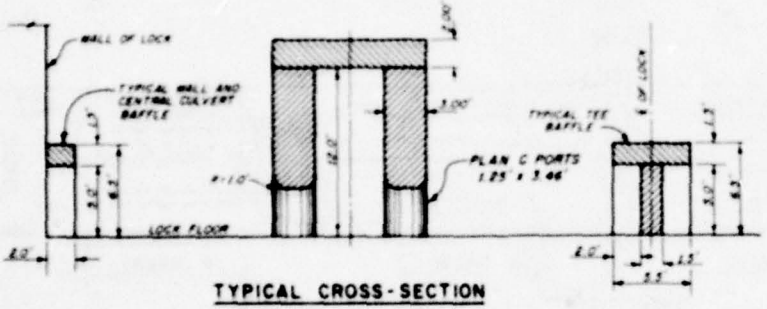
SCALE



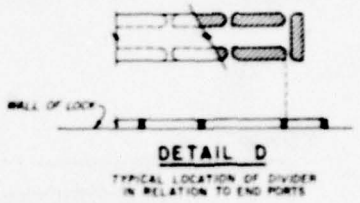
DETAIL A

DETAIL B

DETAIL C



TYPICAL CROSS-SECTION



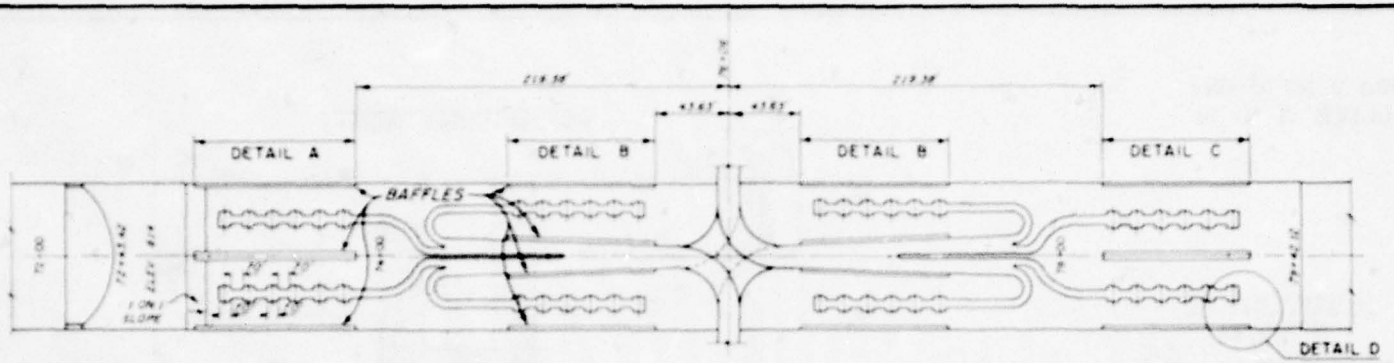
DETAIL D

TYPICAL LOCATION OF DIVIDER IN RELATION TO END PORTS

PLAN ∇ BAFFLES AND PLAN C PORTS

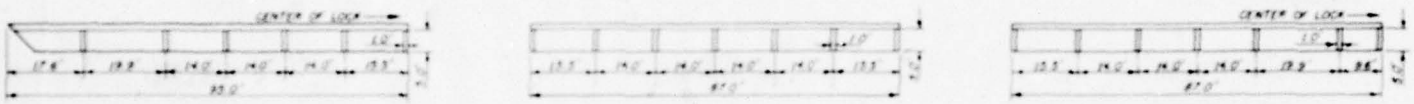
PLATE 16

PLATE 17



PLAN

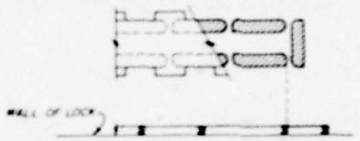
SCALE



DETAIL A

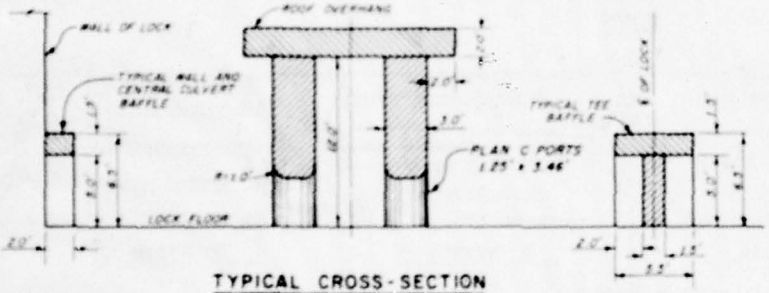
DETAIL B

DETAIL C



DETAIL D

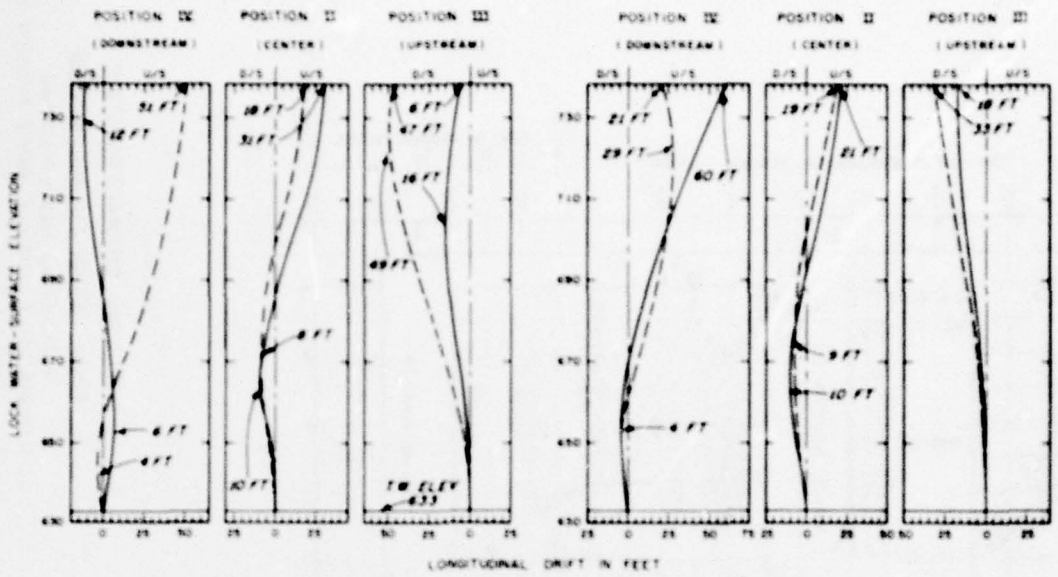
TYPICAL LOCATION OF DIVIDER IN RELATION TO END PORTS



TYPICAL CROSS-SECTION

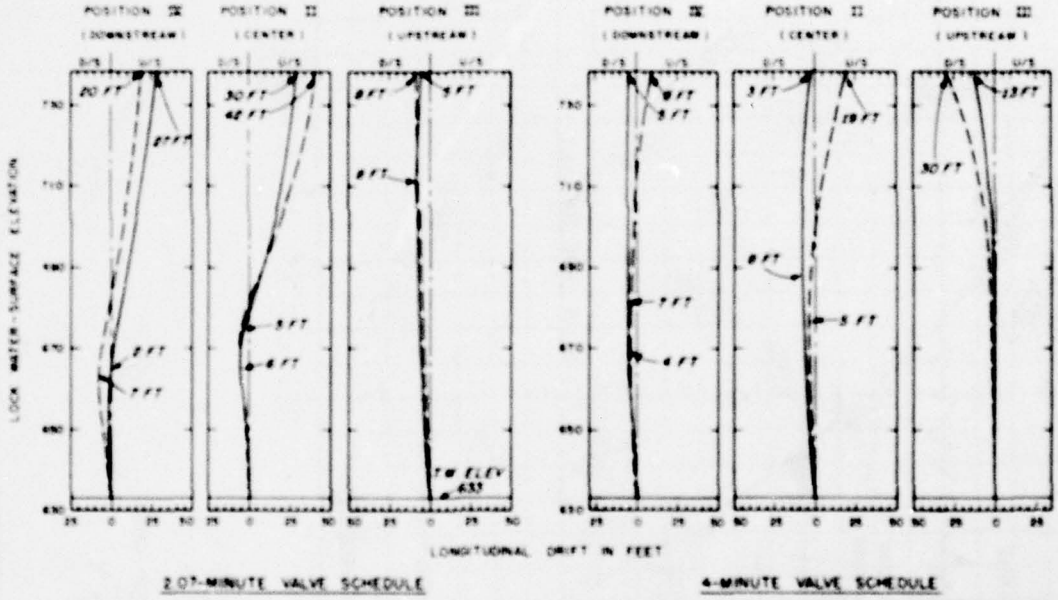
PLAN VI BAFFLES AND PLAN C PORTS

(FINAL DESIGN)



0.55-MINUTE VALVE SCHEDULE

1.11-MINUTE VALVE SCHEDULE



2.07-MINUTE VALVE SCHEDULE

4-MINUTE VALVE SCHEDULE

LEGEND

——— SINGLE VALVE OPERATION
– – – TWO VALVE OPERATION

OPERATING CONDITIONS

POOL ELEVATION 730
TAILWATER ELEVATION 633
BARGE DRAFT 9 FT

NOTES

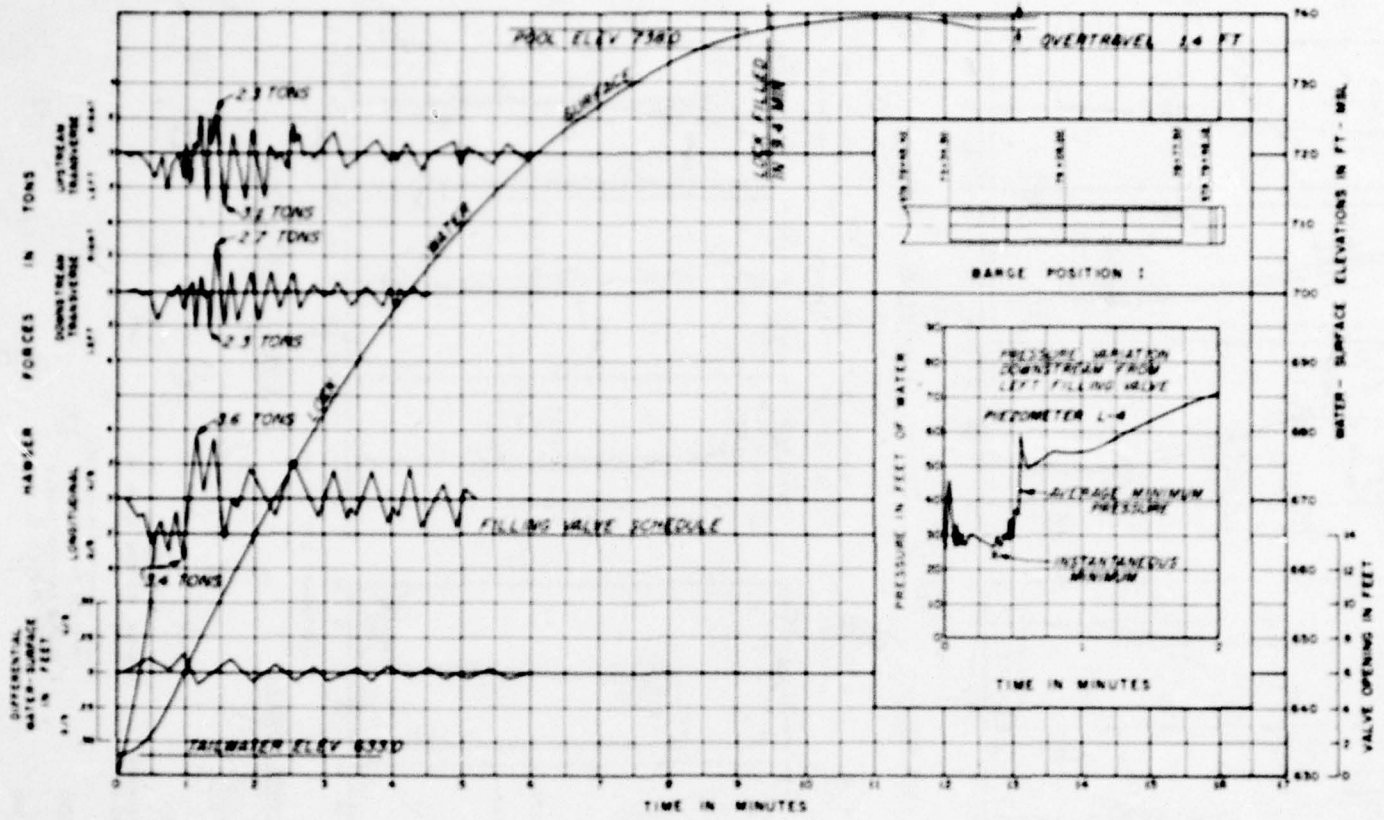
1. BARGE POSITIONS SHOWN ON PLATE 5.
2. LOCK CHAMBER DETAILS SHOWN ON PLATE 15.
3. BAFFLE AND PORT DETAILS SHOWN ON PLATE 17.

DRIFT OF FREE 4-BARGE TOWS

PLAN B LOCK CHAMBER
PLAN VI BAFFLES, PLAN C PORTS

(FINAL DESIGN)

PLATE 19



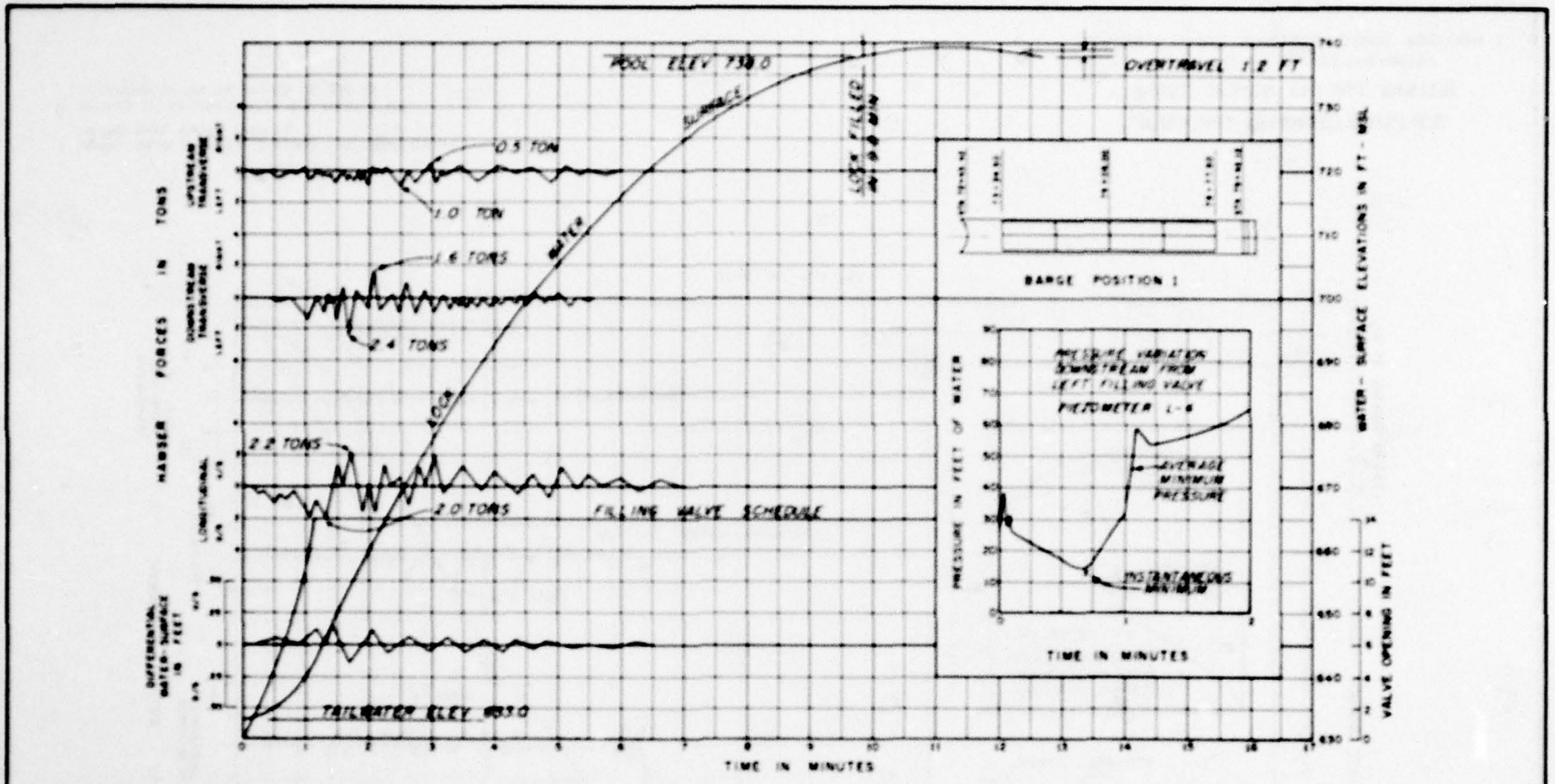
NOTES

1. INITIAL HEAD 105.0 FT, 9-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 15 AND 17.

FILLING CHARACTERISTICS

FINAL DESIGN FILLING SYSTEM

BOTH FILLING VALVES OPERATING
0.55-MIN VALVE SCHEDULE, BARGE POSITION I



NOTES

1. INITIAL HEAD 105.0 FT, 9-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 15 AND 17.

FILLING CHARACTERISTICS

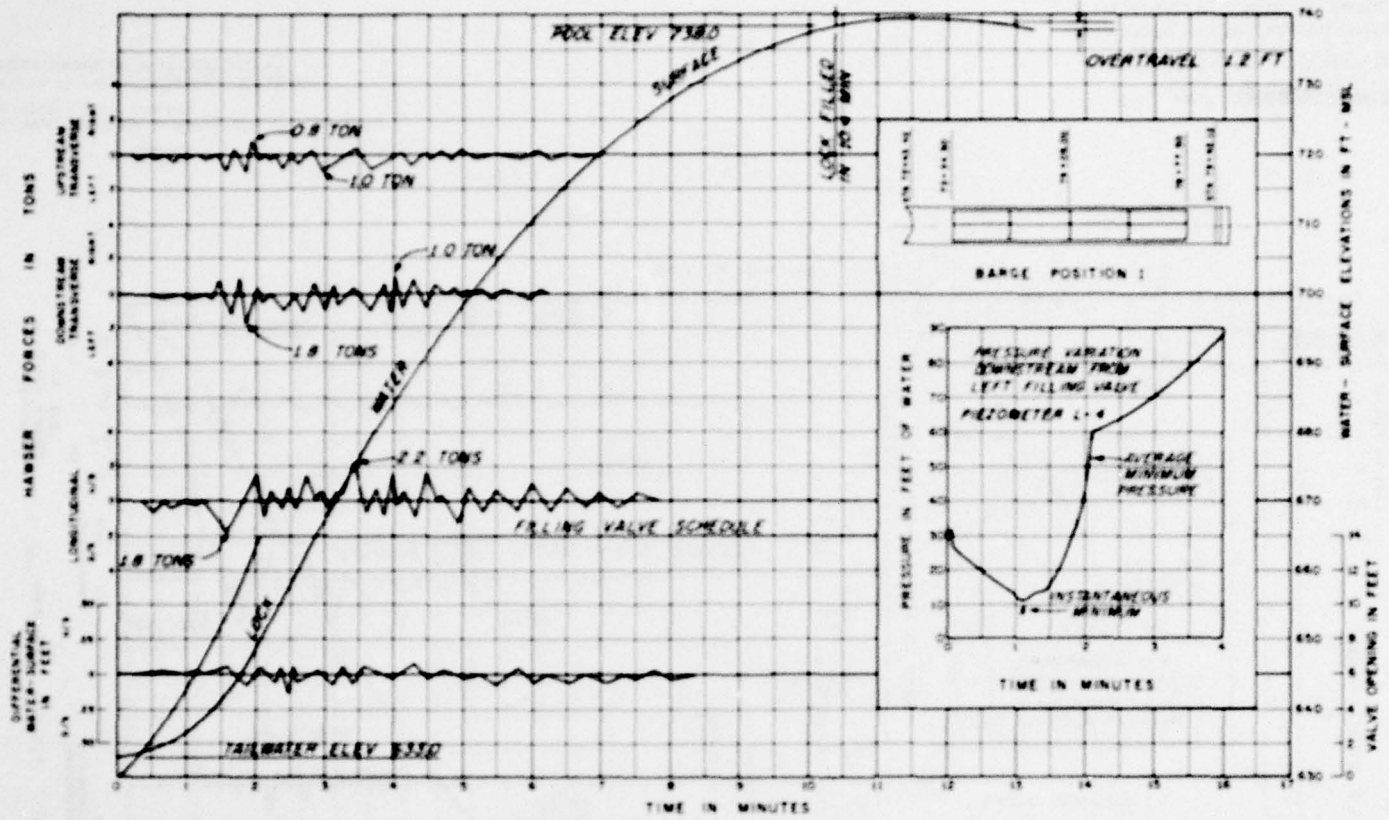
FINAL DESIGN FILLING SYSTEM

BOTH FILLING VALVES OPERATING

1 11-MIN VALVE SCHEDULE, BARGE POSITION 1

PLATE 20

PLATE 21



NOTES

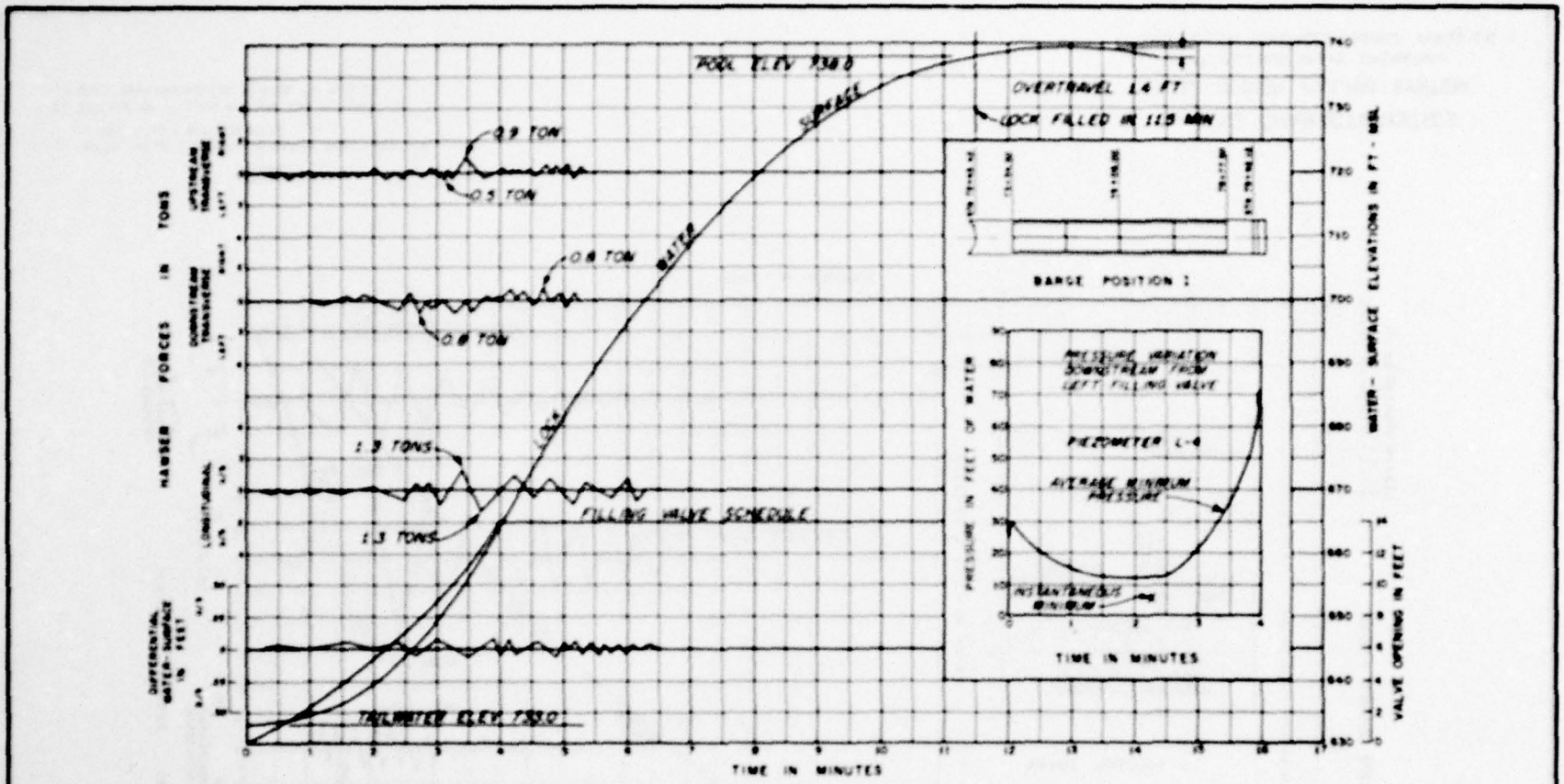
1. INITIAL HEAD 105.0 FT, 8-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 15 AND 17.

FILLING CHARACTERISTICS

FINAL DESIGN FILLING SYSTEM

BOTH FILLING VALVES OPERATING

2.07-MIN VALVE SCHEDULE, BARGE POSITION I



NOTES

1. INITIAL HEAD 105.0 FT, 8-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 15 AND 17.

FILLING CHARACTERISTICS

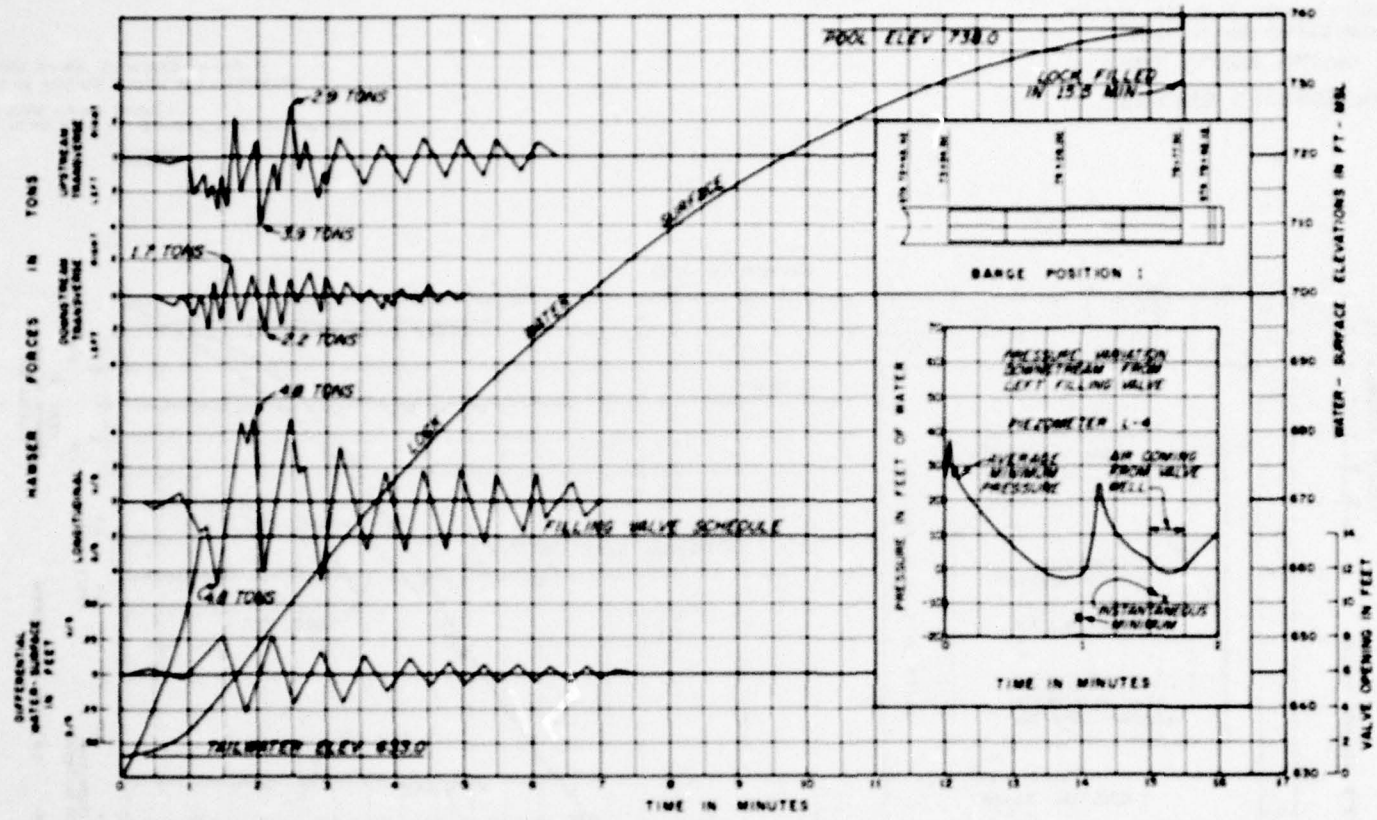
FINAL DESIGN FILLING SYSTEM

BOTH FILLING VALVES OPERATING

4.0-MIN VALVE SCHEDULE, BARGE POSITION I

PLATE 22

PLATE 23



NOTES

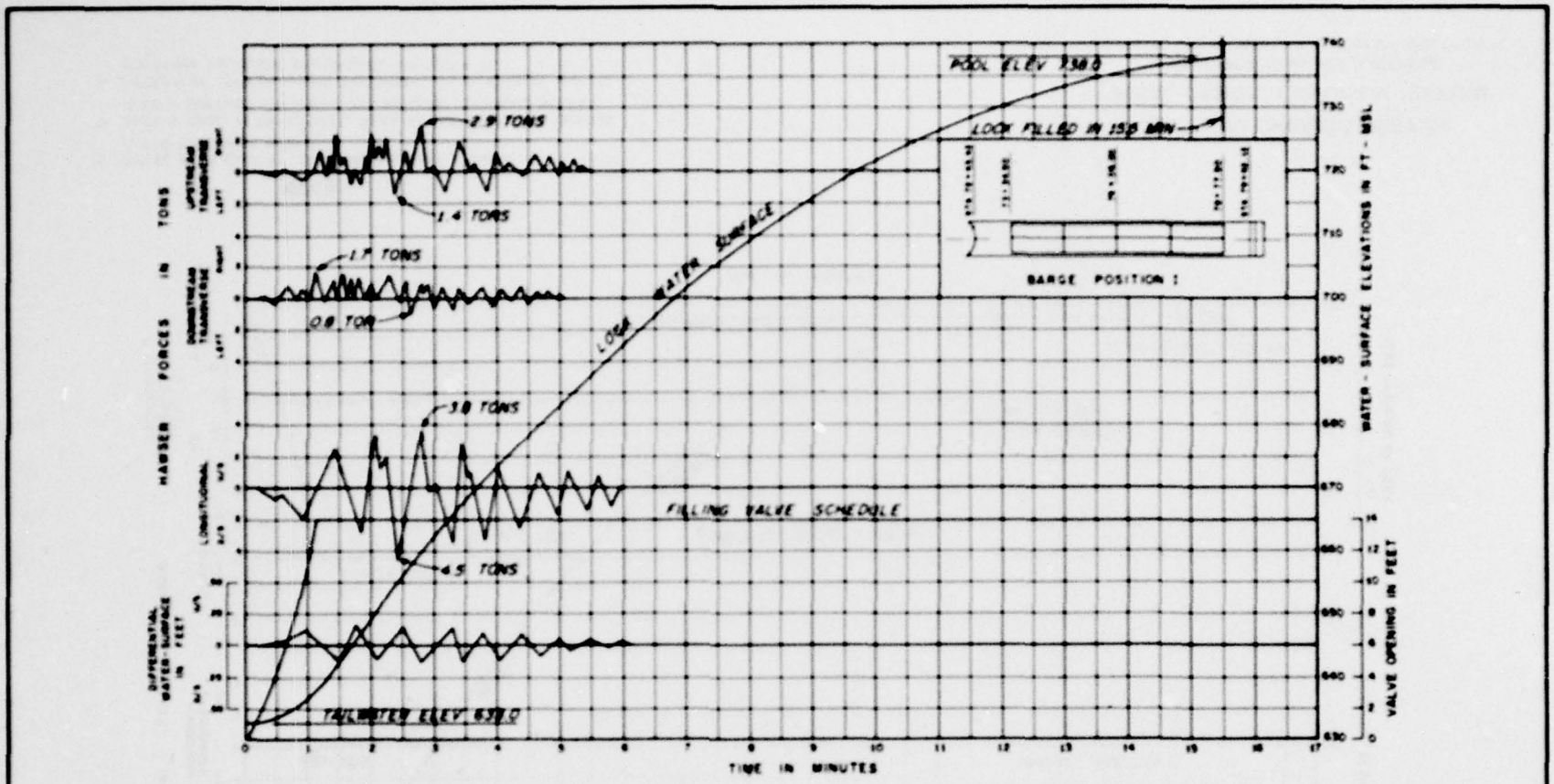
1. INITIAL HEAD 105.0 FT, 8-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 15 AND 17.

FILLING CHARACTERISTICS

FINAL DESIGN FILLING SYSTEM

LEFT FILLING VALVE OPERATING

1.11-MIN VALVE SCHEDULE, BARGE POSITION I



NOTES

1. INITIAL HEAD 105.0 FT, 8-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. DETAILS OF FILLING SYSTEM AND PIEZOMETER LOCATIONS SHOWN ON PLATES 15 AND 17.

FILLING CHARACTERISTICS

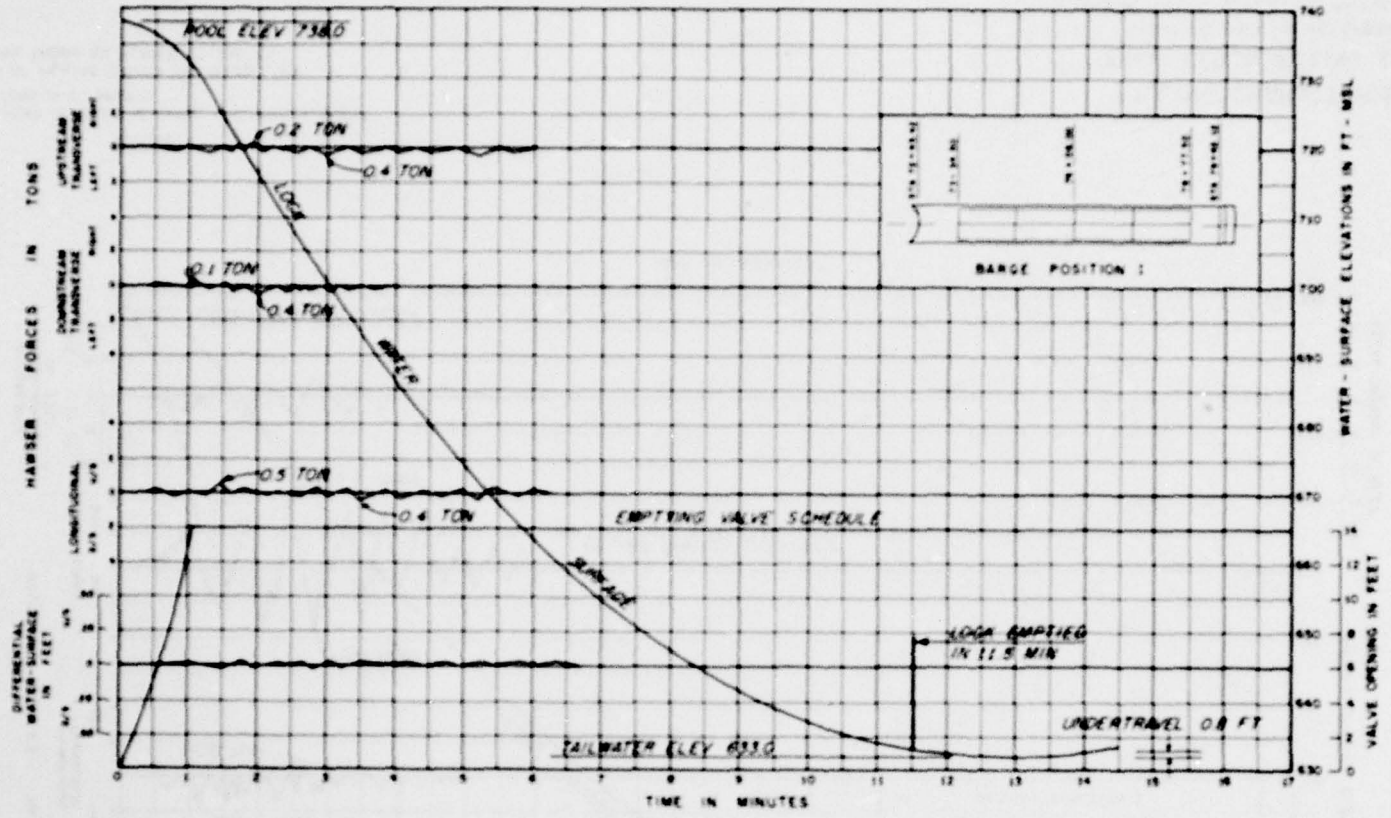
FINAL DESIGN FILLING SYSTEM

RIGHT FILLING VALVE OPERATING

1.11-MIN VALVE SCHEDULE, BARGE POSITION I

PLATE 24

PLATE 29



NOTES

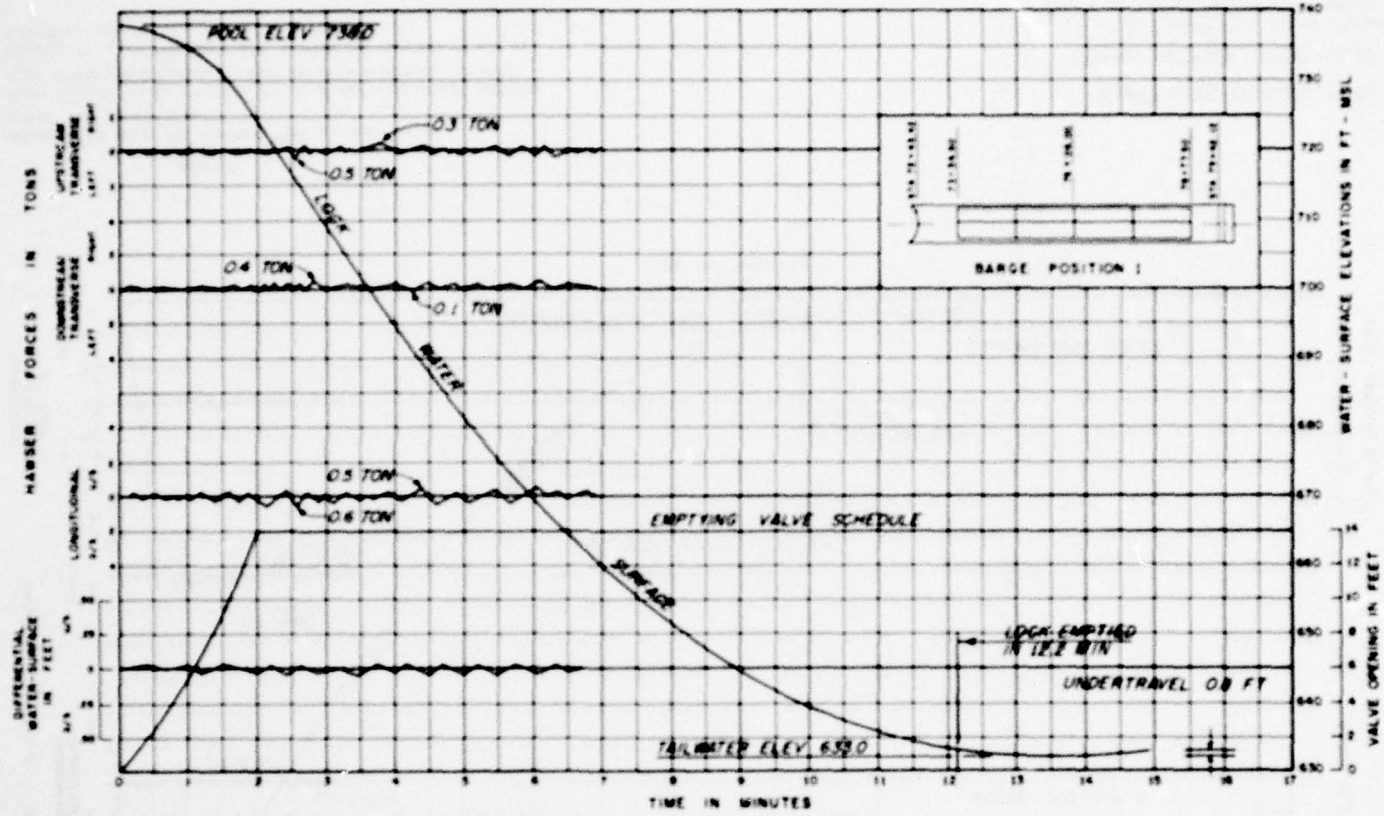
1. INITIAL HEAD 105.0 FT, 9 BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. PLAN B LOCK, PLAN C PORTS, PLAN B BAFFLES (FINAL DESIGN) PLAN A EMPTYING CULVERTS AND OUTLETS (ORIGINAL DESIGN).
3. DETAILS OF LOCK CHAMBER ARE SHOWN ON PLATES 15 AND 17, EMPTYING CULVERTS ARE SHOWN ON PLATE 4.

EMPTYING CHARACTERISTICS

FINAL DESIGN HYDRAULIC SYSTEM

BOTH EMPTYING VALVES OPERATING

1.03-MIN VALVE SCHEDULE, BARGE POSITION I



NOTES

1. INITIAL HEAD 105.0 FT, 9-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. PLAN B LOCK, PLAN C PORTS, PLAN 22 BAFFLES (FINAL DESIGN), PLAN A EMPTYING CULVERTS AND OUTLETS (ORIGINAL DESIGN).
3. DETAILS OF LOCK CHAMBER ARE SHOWN ON PLATES 15 AND 17, EMPTYING CULVERTS ARE SHOWN ON PLATE 4.

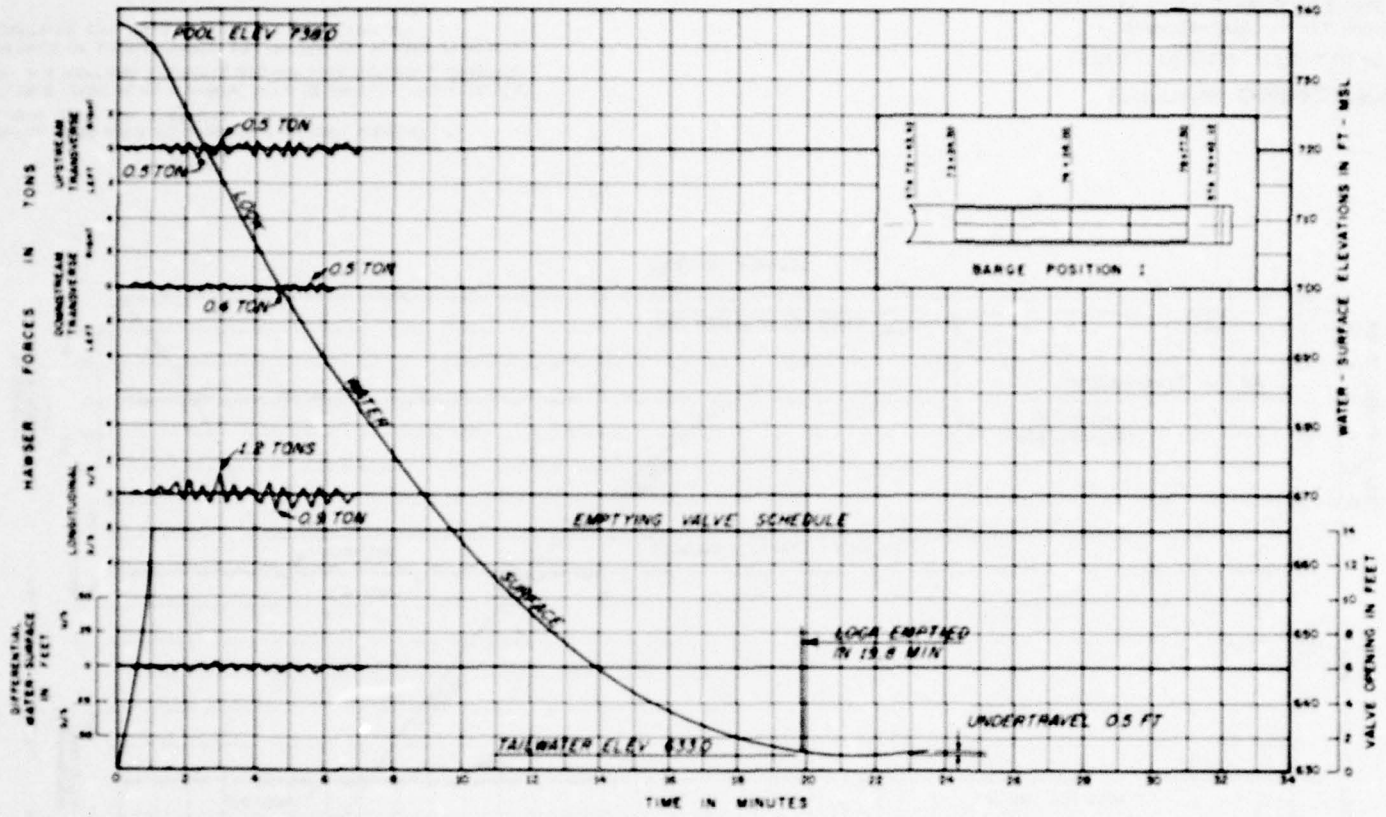
EMPTYING CHARACTERISTICS

FINAL DESIGN HYDRAULIC SYSTEM

BOTH EMPTYING VALVES OPERATING
2.00-MIN VALVE SCHEDULE, BARGE POSITION I

PLATE 26

PLATE 27



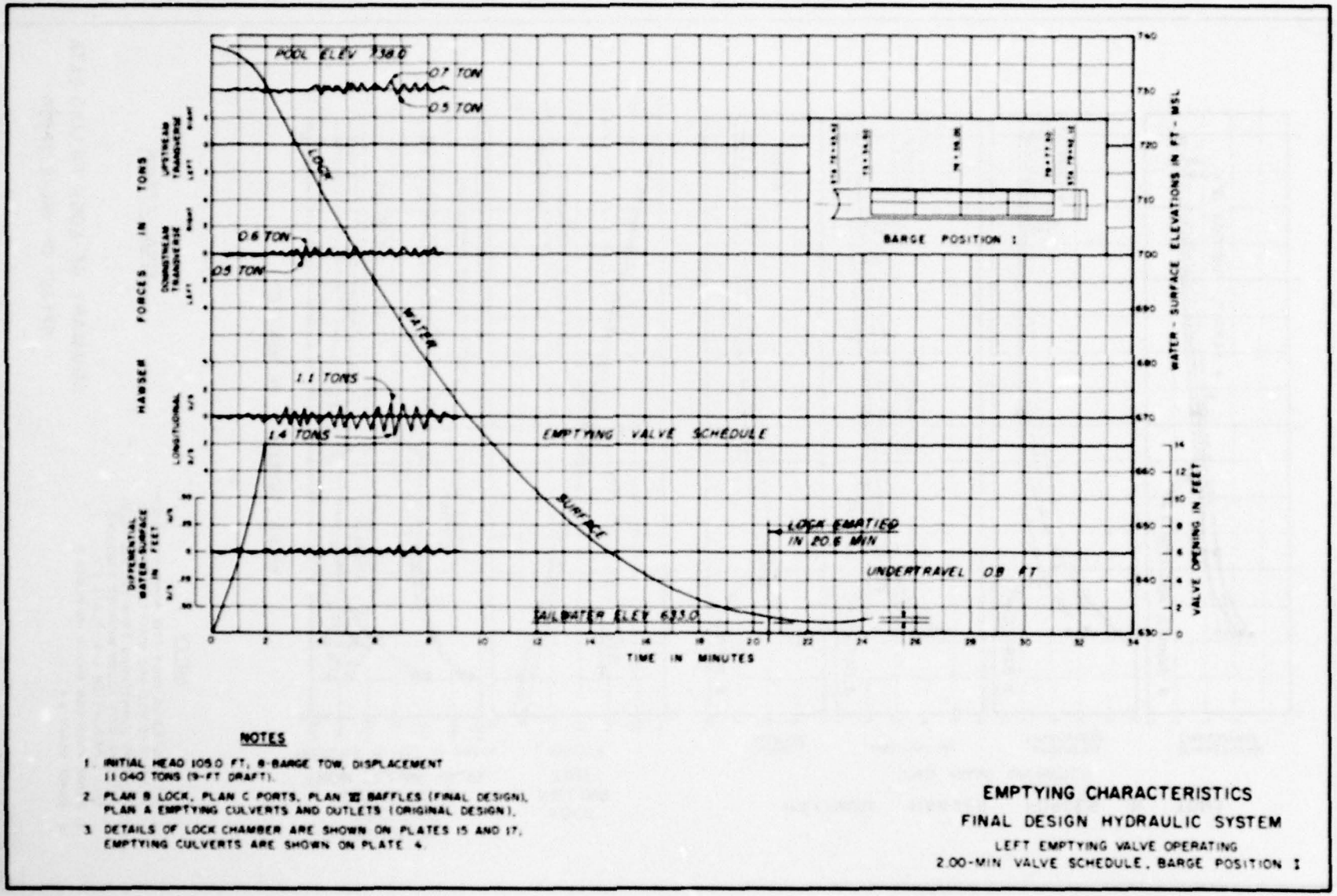
NOTES

1. INITIAL HEAD 105.0 FT, 9-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. PLAN B LOCK, PLAN C PORTS, PLAN III BAFFLES (FINAL DESIGN), PLAN A EMPTYING CULVERTS AND OUTLETS (ORIGINAL DESIGN).
3. DETAILS OF LOCK CHAMBER ARE SHOWN ON PLATES 15 AND 17. EMPTYING CULVERTS ARE SHOWN ON PLATE 4.

EMPTYING CHARACTERISTICS

FINAL DESIGN HYDRAULIC SYSTEM

LEFT EMPTYING VALVE OPERATING
1.03-MIN VALVE SCHEDULE, BARGE POSITION I



NOTES

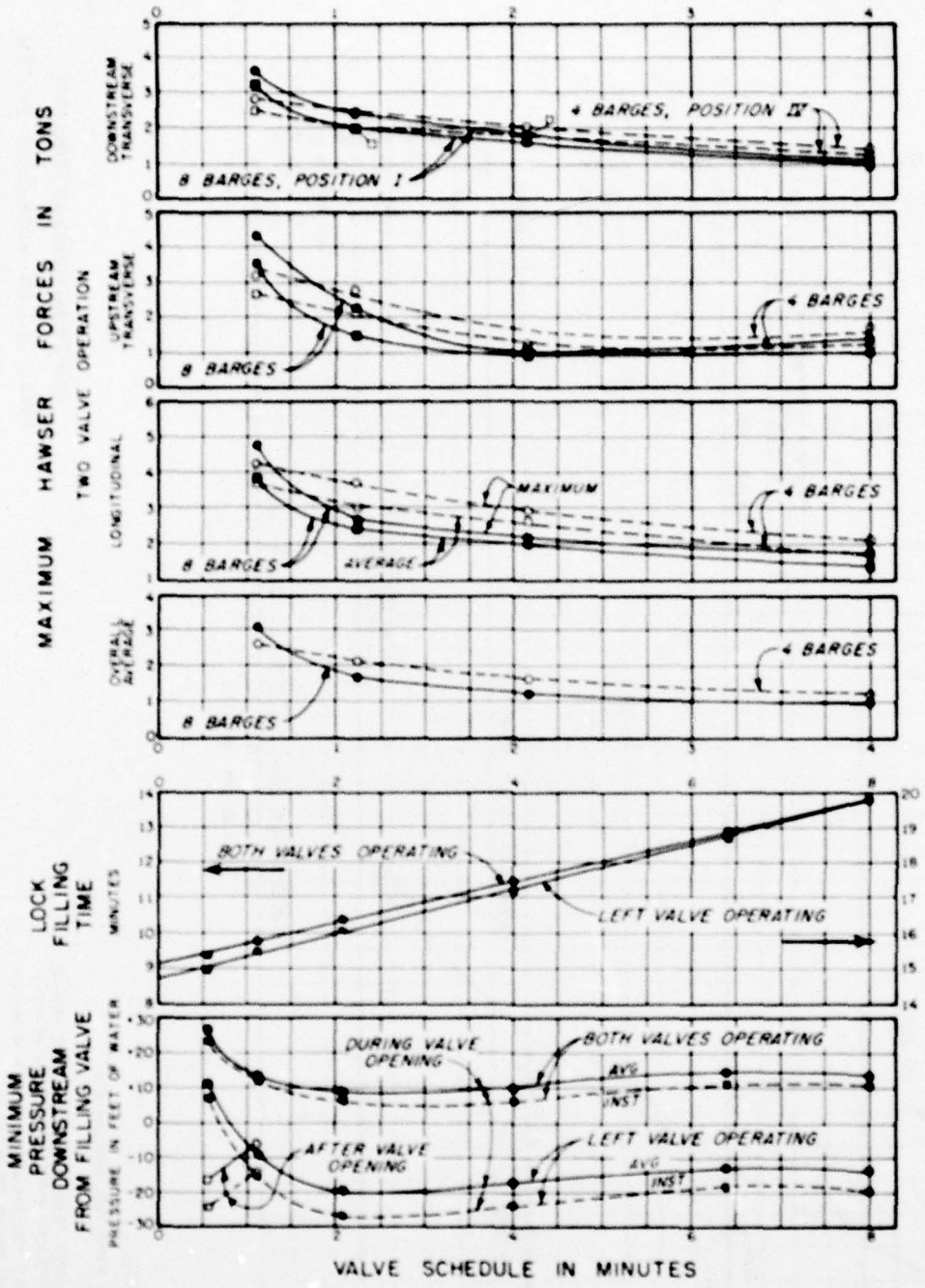
1. INITIAL HEAD 105.0 FT, 9-BARGE TOW, DISPLACEMENT 11,040 TONS (9-FT DRAFT).
2. PLAN B LOCK, PLAN C PORTS, PLAN III BAFFLES (FINAL DESIGN), PLAN A EMPTYING CULVERTS AND OUTLETS (ORIGINAL DESIGN).
3. DETAILS OF LOCK CHAMBER ARE SHOWN ON PLATES 15 AND 17. EMPTYING CULVERTS ARE SHOWN ON PLATE 4.

EMPTYING CHARACTERISTICS

FINAL DESIGN HYDRAULIC SYSTEM

LEFT EMPTYING VALVE OPERATING
2.00-MIN VALVE SCHEDULE, BARGE POSITION I

PLATE 28



NOTES

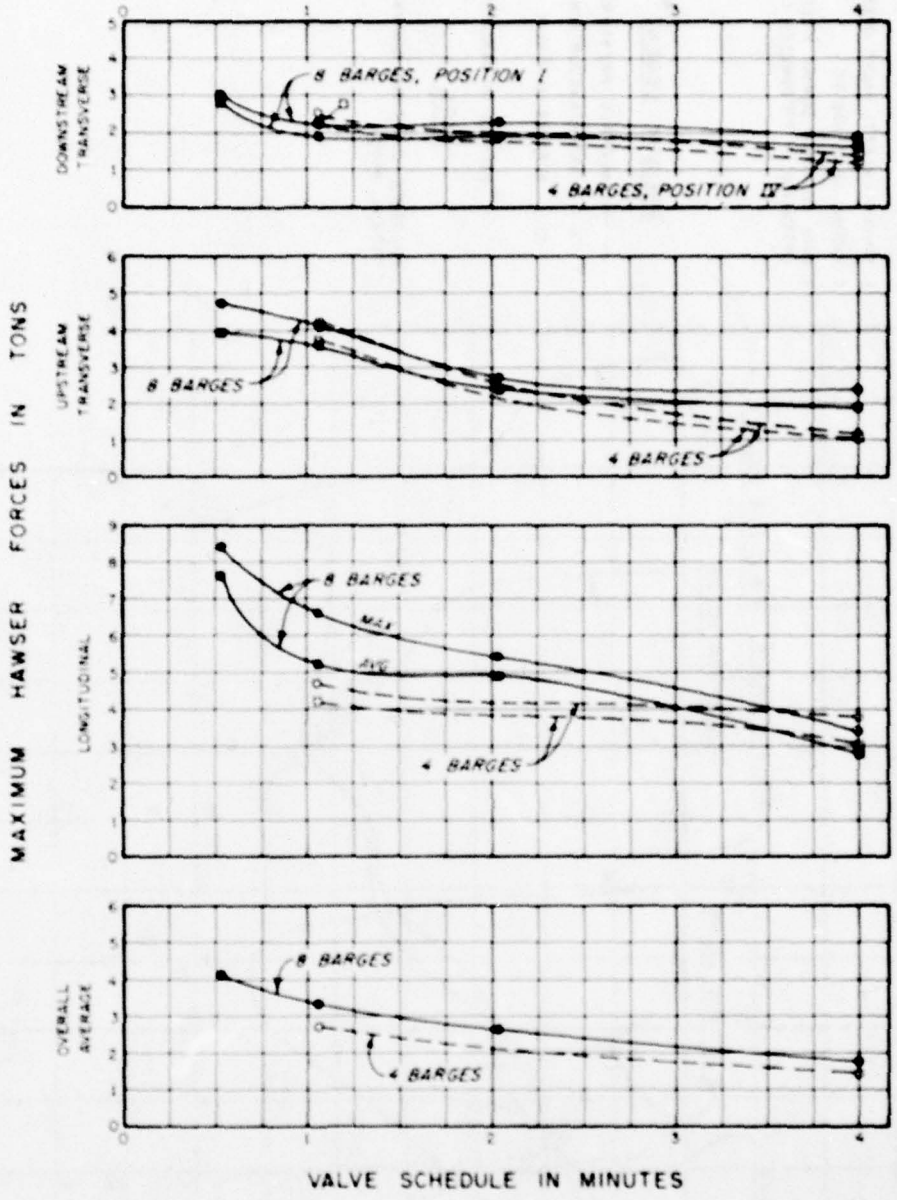
1. DATA OBTAINED FROM FIVE RUNS WITH EACH VALVE SCHEDULE AND 105-FT INITIAL HEAD.
2. PRESSURE DOWNSTREAM FROM FILLING VALVE OBTAINED WITH FLUSH MOUNTED PRESSURE CELL (PIEZOMETER L-4, PLATE 10).
3. BARGE POSITIONS SHOWN ON PLATE 5.
4. BARGE DRAFT 9 FT.

FINAL DESIGN

SUMMARY OF LOCK FILLING DATA

EFFECT OF VALVE SPEED

PLATE 29



NOTES

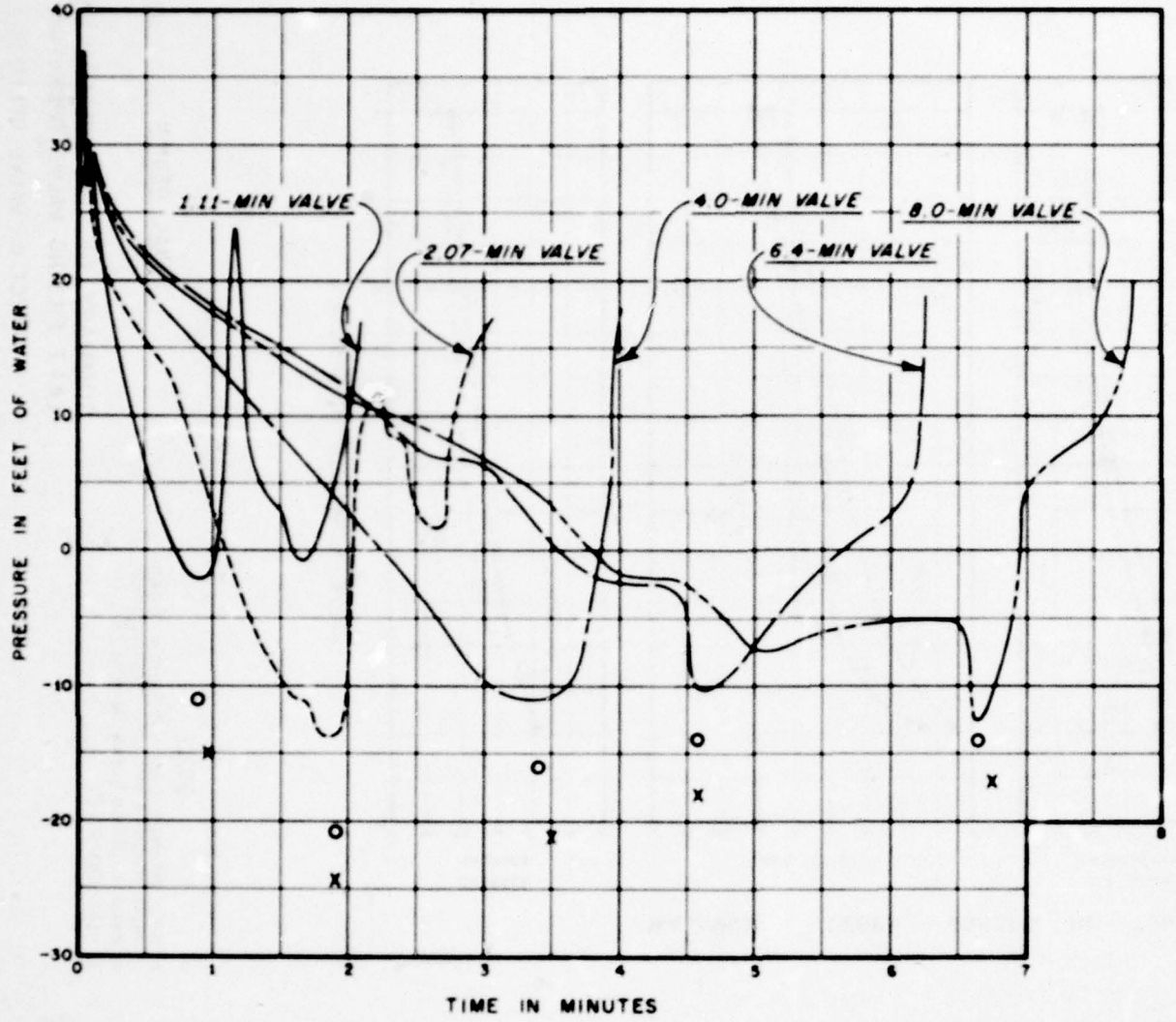
1. DATA OBTAINED FROM FIVE RUNS WITH EACH VALVE SCHEDULE AND 105 FT INITIAL HEAD.
2. BARGE POSITIONS SHOWN ON PLATE 5.
3. BARGE DRAFT 9 FT.

FINAL DESIGN

SUMMARY OF HAWSER FORCES
LEFT FILLING VALVE OPERATING
EFFECT OF VALVE SPEED

PLATE 30

PLATE 31



OPERATING CONDITIONS

1. SINGLE - (LEFT) VALVE OPERATION
2. INITIAL HEAD 105 FT
3. DATA OBTAINED DURING FILLING OPERATION AT PIEZOMETER L-4

PRESSURE LEGEND*

— — AVERAGE PRESSURE

X INSTANTANEOUS MINIMUM

O AVERAGE MINIMUM

*DEFINED ON TABLE P

NOTE

PRESSURE VARIATIONS SHOWN FOR TYPICAL RUNS

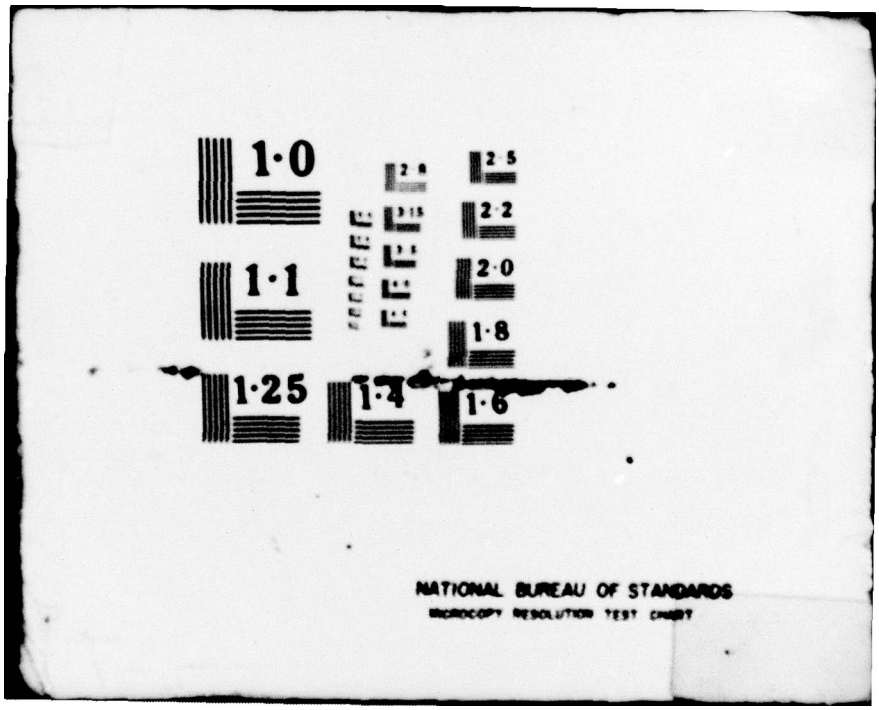
PRESSURE VARIATION AT FILLING VALVE

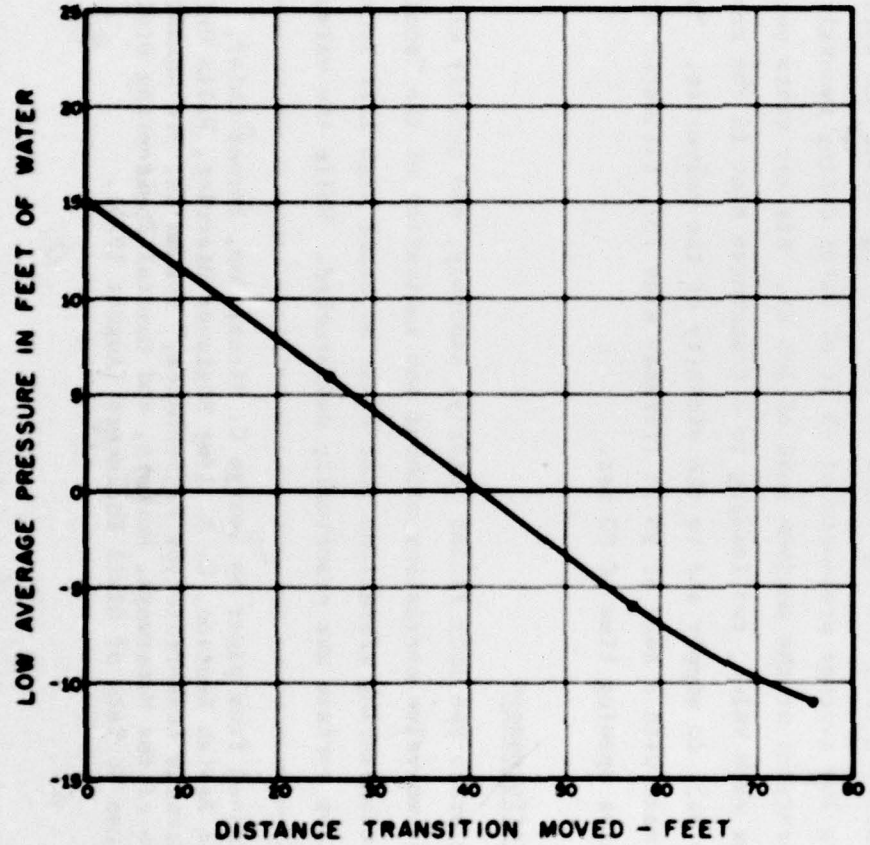
AD-A076 205 ARMY ENGINEER DIV NORTH PACIFIC BONNEVILLE OREG DIV --ETC F/G 13/13
NAVIGATION LOCK FOR LOWER GRANITE DAM, SNAKE RIVER, WASHINGTON.--ETC(U)
SEP 79
UNCLASSIFIED TR-126-1 NL

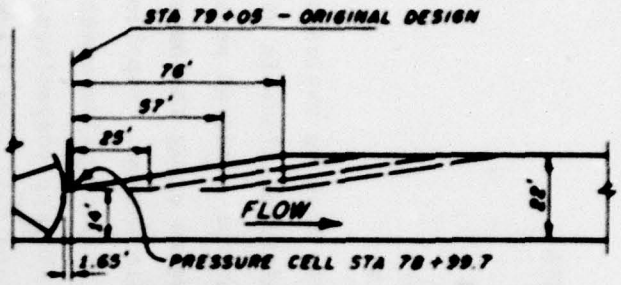
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1·25
2·5
2·2
2·0
1·8
1·6
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART





ROOF TRANSITION POSITIONS

NOTES

1. PRESSURES OBTAINED WITH FLUSH MOUNTED PRESSURE CELL.
2. PLOTTED POINTS ARE AVERAGES OF 5 RUNS.
3. TESTS MADE IN RIGHT CULVERT.

EFFECT OF ROOF TRANSITION ON PRESSURE AT FILLING VALVE

1.11-MIN VALVE SCHEDULE

TWO-VALVE OPERATION, 105-FT INITIAL HEAD

PLATE 35

APPENDIX A
PROTOTYPE PERFORMANCE TESTS
AND
SUPPLEMENTAL MODEL TESTS

General

1. Prototype tests were made at Lower Granite lock to evaluate the effectiveness of the revised filling culvert roof transitions in eliminating the sonic disturbances and vibrations that had occurred at some Columbia-Snake River locks. Tests also were made to study the overall performance of this dynamically balanced hydraulic system. Supplemental model tests were made to duplicate the head and filling valve opening period of the prototype tests to obtain model-prototype comparison.

2. The adopted culvert roof transitions (plate A-1) were located 56.4 ft downstream from the top seals of the filling valves and were based on obtaining low average pressures of -5 ft of water during two-valve filling operations at the maximum head of 105 ft. Six air vents were provided for each valve, two leading to a transverse slot in the roof and two in each wall to supply air to the vicinity of the valve lip. The tests were made with a head of 99 ft (forebay elev 737, tailwater elev 638) and valve opening time of 80 sec.

Prototype Performance*

3. The prototype lock filled quickly, smoothly, and quietly with both single- and two-valve operations without any indication of the "sonic booms" or accompanying vibrations that occur at other high lift locks. The lock water surface was practically undisturbed. While the valves were

---

* Data obtained from paper by George C. Richardson, former Chief, Hydraulic Design Section, U. S. Army Engineer District, Walla Walla, "Lower Granite Lock-Prototype Performance," Volume II, 3rd Annual Symposium of the Waterways, Harbors, and Coastal Engineering Division of American Society of Civil Engineers (August 1976).

being opened, air entering the vents was audible. The air entrainment ceased before the aerated water appeared in the lock chamber. The entrained air gradually disappeared as the lock filled. Debris floating on the water surface slowly drifted around and gradually moved toward the center of the lock chamber, indicating that there was no tendency for tows to be moved toward the lock gates.

4. Tests were made to determine the minimum number of air vents required to maintain acceptable negative pressures on the culvert roofs and to preclude the formation of sonic disturbances. The results were:

EFFECT OF AIR VENTS ON ROOF PRESSURES
DOWNSTREAM FROM FILLING VALVE

Number of Vents Open	Two-Valve Operation		Single-Valve Operation	
	Minimum Pressures in Feet of Water			
	Average	Instantaneous	Average	Instantaneous
6	- 4	- 9	- 4	- 8
4	- 2	-10	- 4	- 8
2	- 3	- 7	-11	-12
1	- 4	- 9	-10	-13
0	-11	-25	-14	-20

From the above, it is apparent that venting is required to eliminate unacceptable negative pressures but that the number of vents used is not critical, particularly with two-valve operation. The average and instantaneous negative pressures with single-valve operation and vents closed were minimized by air that entered through the valve shaft as the valve became about half open. Closing of vents did not cause the sonic disturbances to develop. It is possible that venting occurred through the bulkhead slots located downstream from the valves and upstream from the beginning of the roof transitions (plate 3).

5. Although the aerated water surface in the lock chamber with multiple vents in use did not appear objectionable, it is possible that

the roughened surface might adversely affect small boat operation. Therefore, one vent supplying the transverse slot across the top of each culvert was selected for normal use. The vents installed in the side walls to aerate the flow off the valve lip were not required.

6. An additional test was made with reduced head on the lock filling system. This was accomplished by commencing to fill the lock with the lock water surface raised 10 ft to elev 648. The total head during this test was 85 ft, an extreme condition that would only occur as the river discharge approached the standard project flood.

7. The additional 10 ft of culvert submergence and 14 ft of head reduction adversely affected the culvert pressures. With both valves operating and the vents closed, the average minimum pressure was +10 ft, the minimum instantaneous pressure was -6 ft, and the "sonic boom" phenomenon developed. Opening a vent did not produce any perceptible air entrainment or effect any improvement.

8. With single-valve operation and the vents closed, the average minimum pressure fell to -20 ft, and a very slight thumping noise occurred at 40-45 sec. With a vent open, the minimum average pressure was raised to -9 ft, air was drawn through the vent for about 30 sec, and the thumping was eliminated. The period of venting was so short that the entrained air was not visible on the water surface.

Model-Prototype Comparison

9. The prototype filling time for two-valve operation with a head of 99 ft was 8.1 min. The corresponding model time was 9.7 min. Single-valve filling times were 13.1 min, prototype, and 16.2 min, model. Emptying time with two valves were 9.7 min, prototype, and 11.4 min, (interpolated) model. The improved hydraulic efficiency of the prototype lock, as indicated by the reduced filling and emptying time, was anitcipated. The model hydraulic system was constructed of acrylic plastic, which is considered to be the smoothest workable material available for this purpose. However, at the model scale of 1:25 the acrylic plastic is too rough to duplicate the smooth water passages of

the prototype. For economic reasons and the ease of operation, the reduced efficiency of 1:25-scale lock models is accepted.*

10. The maximum discharge in the prototype was estimated to be 20,500 cfs, based on the maximum rate of rise of the lock water surface. The maximum model discharge was 19,800 cfs (interpolated) when filling through both valves. With the increased prototype discharges, pressures on the culvert roofs downstream from the valves were lower than indicated by the model. Model pressures are listed in table A-A, and comparisons of model and prototype pressures for typical test conditions are shown on plates A-2 to A-5. While filling with two valves and the vents closed (plate A-2), the model and prototype pressures were similar for the first 30 sec. As the valves continued to open, the average prototype pressures dropped about 11 ft below the model pressures (0 ft to -11 ft). With one valve and the vents closed (plate A-3), pressures were almost identical for the first 50 sec at which time the prototype flow became aerated through the lowered water surface in the valve shaft while the model pressure continued to drop to a low of -20 ft. In the model the bulkhead slots were sealed. With two valves and the vents open (plate A-4), correlation was good for the first 60 sec. With one valve vented (plate A-5), correlation was again good until the flow became aerated in both model and prototype at about 50 sec. (i.e., open channel flow with hydraulic jump in culvert)

Conclusions

11. The prototype tests verified the model predictions that Lower Granite lock is of superior design, based on the following:

a. Sonic disturbances and accompanying structural vibrations have been eliminated.

b. The lock fills quickly and smoothly with either one or both valves operating.

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* For acrylic plastic to duplicate the 'n' value of smooth concrete, a 1:16-scale model would be required. At this scale, the model would be 56 percent larger and require three times the discharge of the 1:25-scale model.

c. One air vent at each valve eliminates low pressures without causing objectionable water surface disturbance.

d. No adverse currents exist that could force a free tow into a lock gate.

e. Compared to other locks of similar lift, this design offers faster lockage times, reduced hawser forces, elimination of hazards caused by unsynchronized filling valves or emergency use of a single valve, and greater uniformity of filling conditions.

12. Essentially, good agreement exists between the model and prototype test results.

TABLE A-A

AVERAGE PRESSURES DOWNSTREAM FROM
RIGHT FILLING VALVE OF MODEL

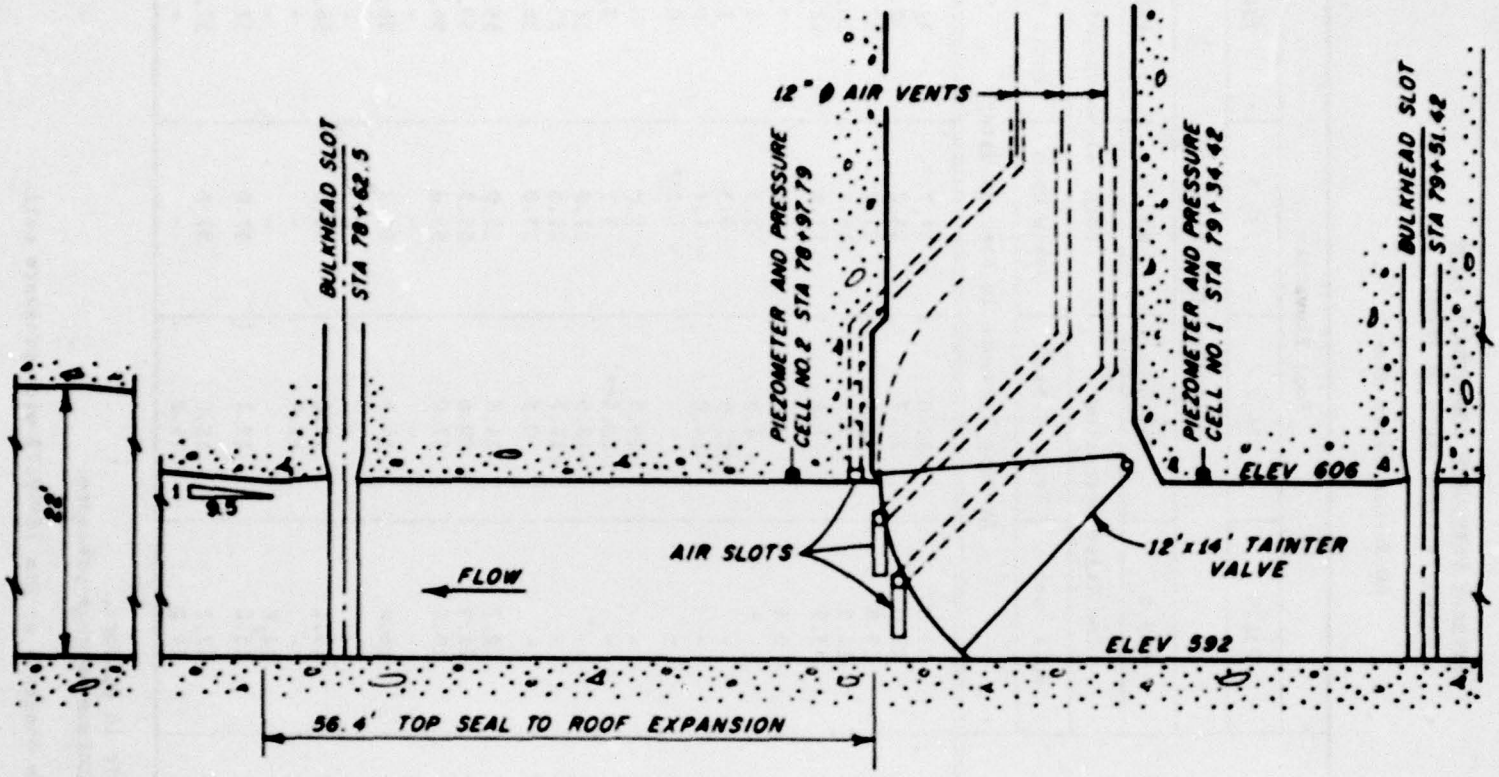
80-Second Valve Time

Valve Opening in Feet	Time in Seconds	Pool Elevation			
		736.5	736.2	736.5	736.2
		Tailwater Elevation			
		639.0	638.0	637.7	638.1
		One Valve Operating		Both Valves Operating	
		Vents Open	Vents Closed	Vents Open	Vents Closed
		Average Pressure in Feet of Water			
0	0	33.0	32.0	31.7	32.1
1	8.5	28.0	27.7	28.2	28.2
2	16.9	19.8	20.6	21.9	22.0
3	24.6	12.5	13.9	16.3	16.7
4	31.5	5.9	7.6	11.6	11.7
5	37.7	- 0.4	1.5	7.4	7.4
6	43.7	- *	- 4.9	3.5	4.0
7	49.4	-	-11.0	0.3	1.6
8	54.9	-	-16.0	- 1.4	0.3
-	57.0	-	-	- 1.8**	0.2**
9	60.3	-	-19.2	- 1.0	0.8
10	65.2	-	-20.4**	3.2	3.5
11	69.8	-	-18.9	11.0	11.5
12	73.8	-	-12.7	21.5	23.5
13	77.2	-	0.5	35.0	38.3
14	80.3	26.2	24.5	55.0	55.3
14	85.0	22.9	20.6	55.3	55.7
14	90.0	19.6	17.0	55.8	56.0
14	91.5	-	-	-	-
14	95.0	16.8	14.3	56.2	56.4
14	96.3	-	-	-	-
14	100.0	15.1	13.0	56.8	56.9
14	102.0	-	12.9	-	-
14	103.0	14.8	-	-	-
14	105.0	15.0	13.1	57.0	57.2
14	110.0	17.2	15.0	57.6	57.8
14	115.0	21.2	19.2	-	-

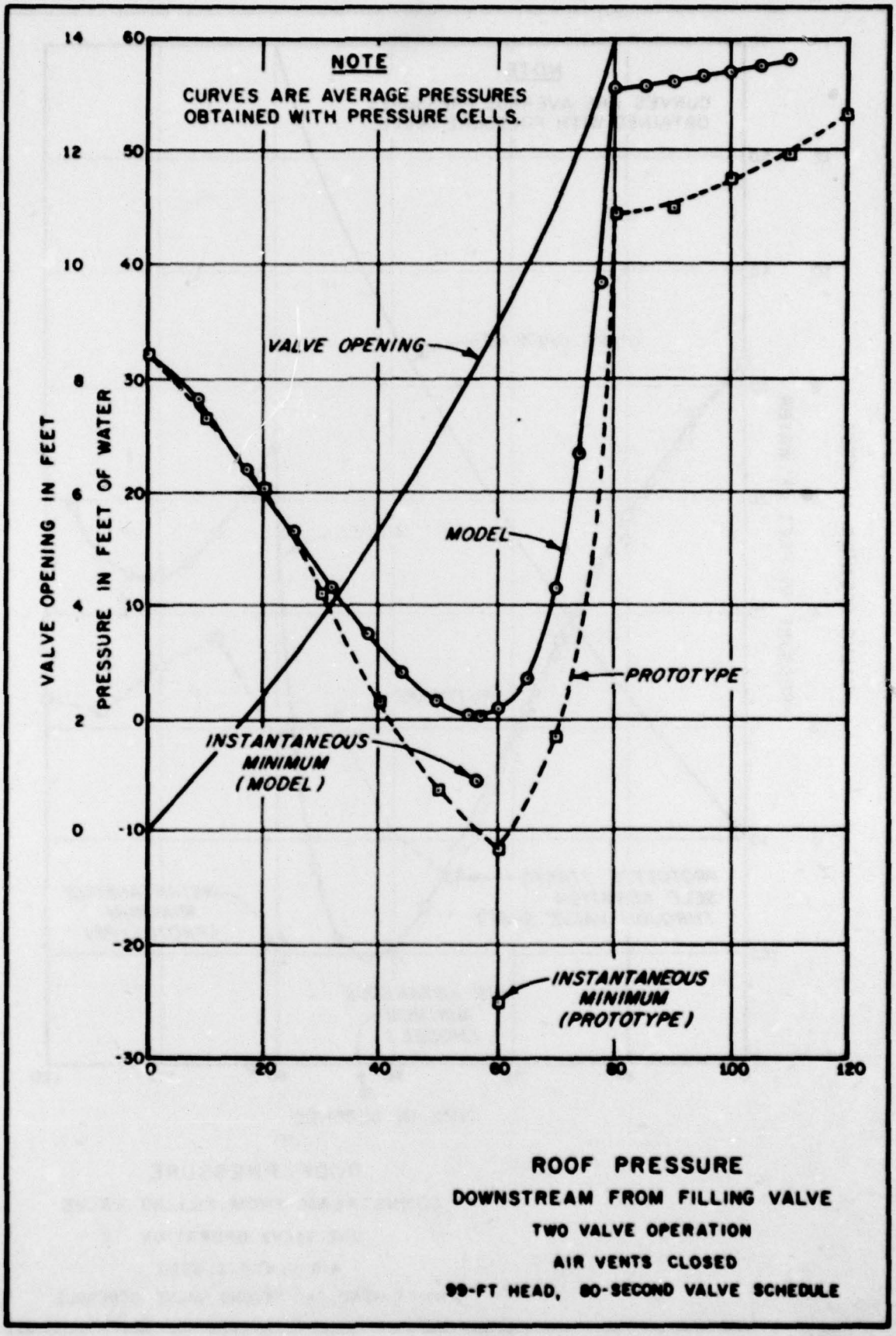
* Air in culvert.
** Minimum average pressure.

NOTE: Pressures observed at sta 78+99.70 with pressure cell.

PLATE A-1



CULVERT ROOF TRANSITION
AND
AIR VENT LOCATIONS



ROOF PRESSURE

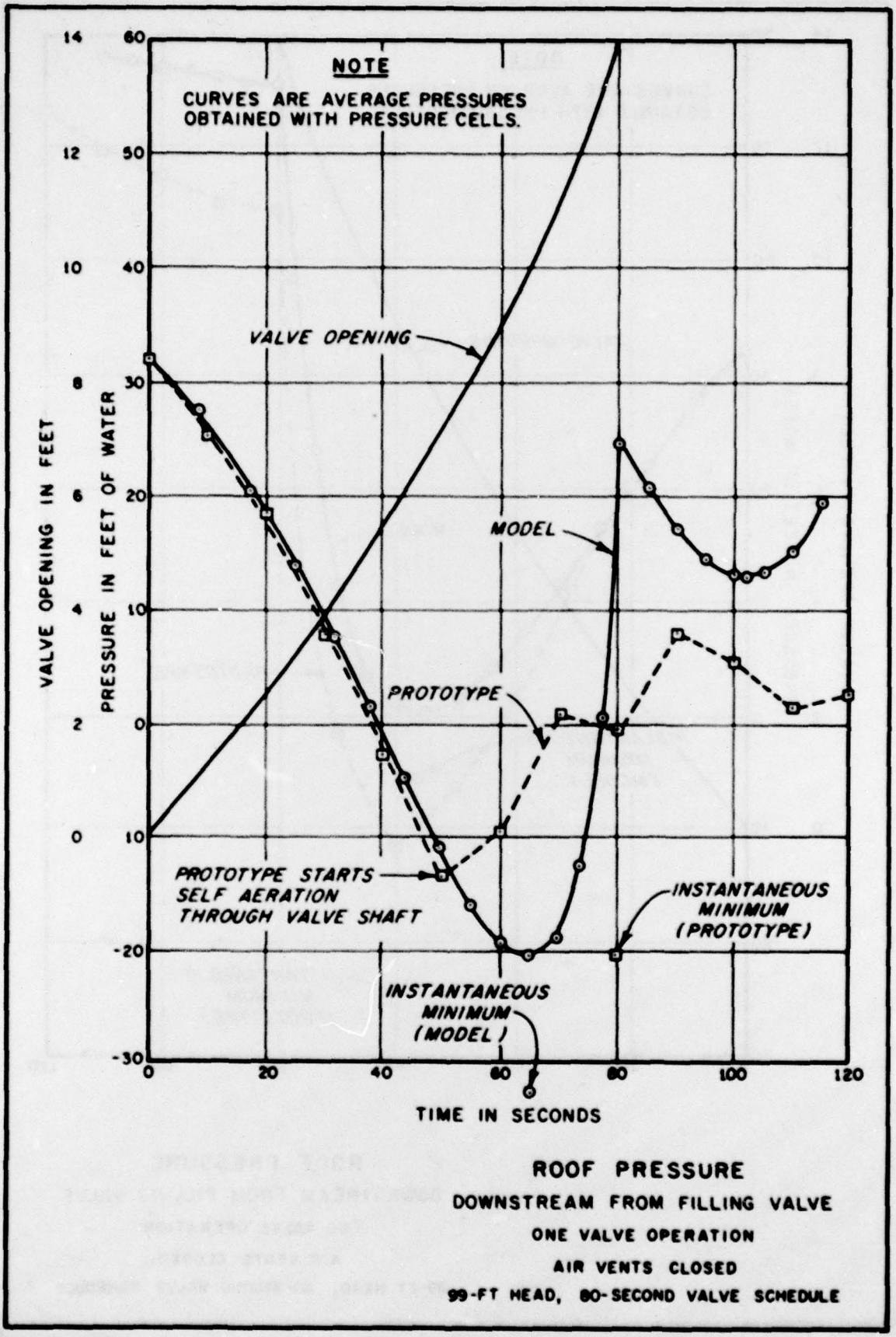
DOWNSTREAM FROM FILLING VALVE

TWO VALVE OPERATION

AIR VENTS CLOSED

99-FT HEAD, 60-SECOND VALVE SCHEDULE

PLATE A-2



ROOF PRESSURE

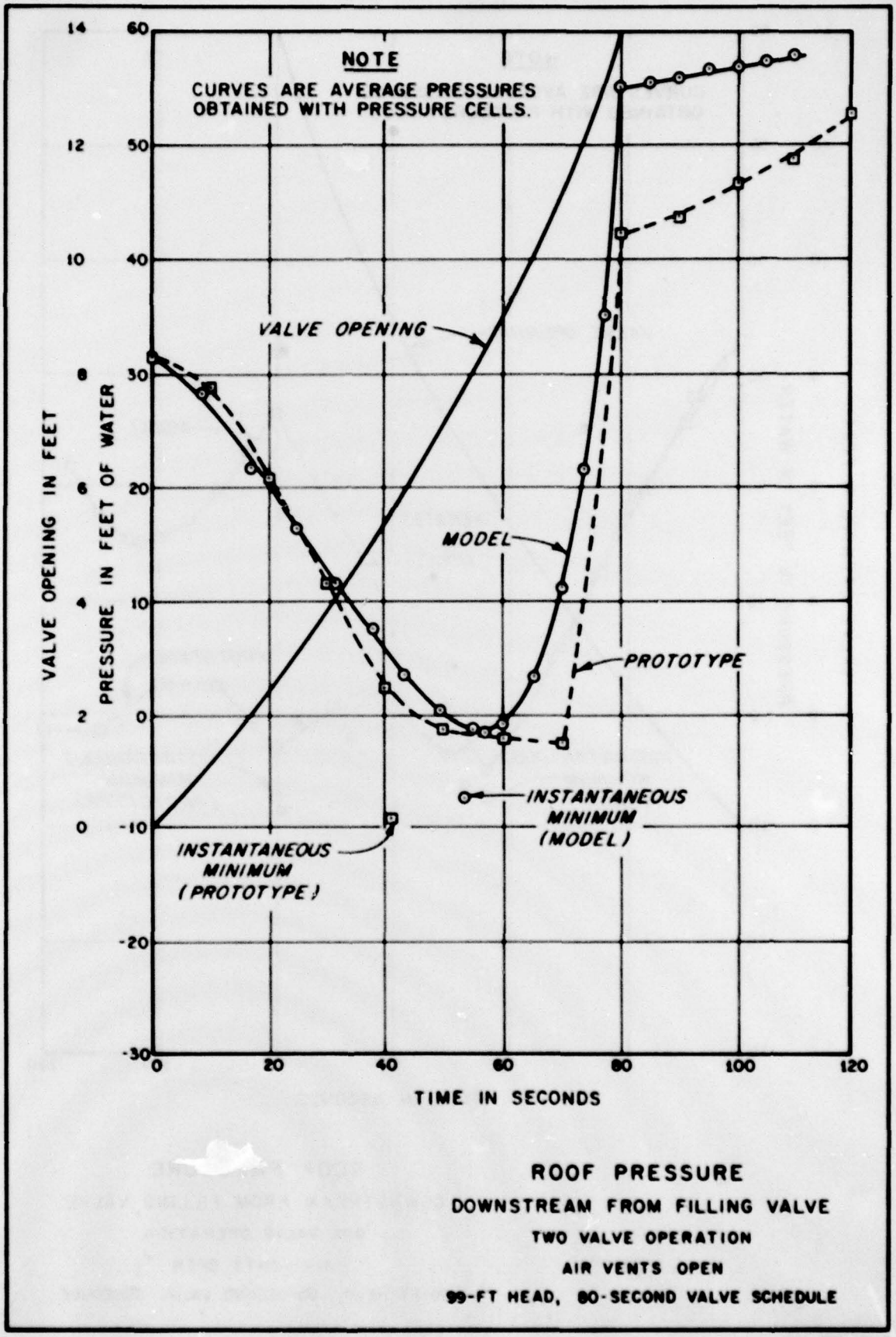
DOWNSTREAM FROM FILLING VALVE

ONE VALVE OPERATION

AIR VENTS CLOSED

99-FT HEAD, 80-SECOND VALVE SCHEDULE

PLATE A-3



ROOF PRESSURE

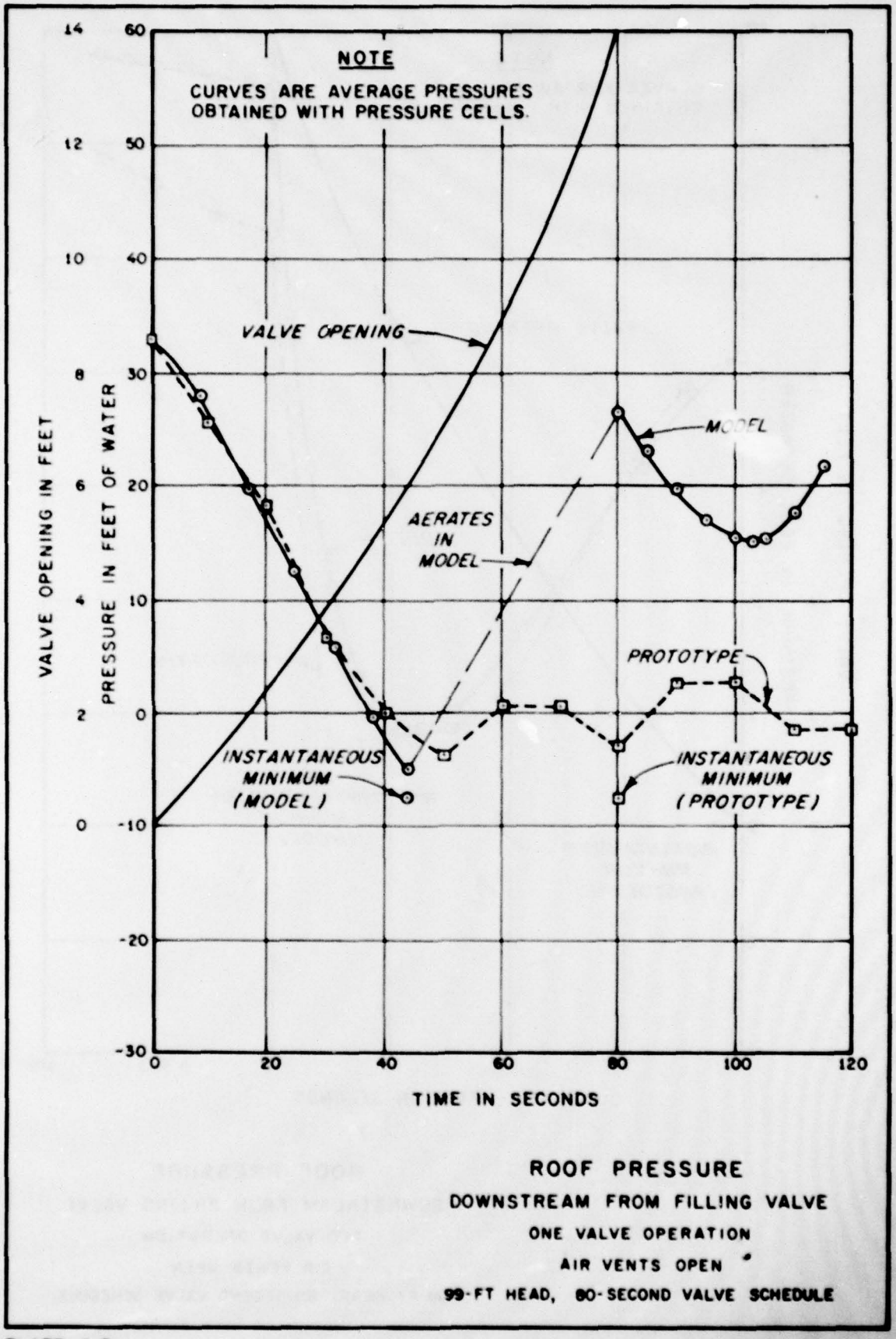
DOWNSTREAM FROM FILLING VALVE

TWO VALVE OPERATION

AIR VENTS OPEN

99-FT HEAD, 80-SECOND VALVE SCHEDULE

PLATE A-4



ROOF PRESSURE

DOWNSTREAM FROM FILLING VALVE

ONE VALVE OPERATION

AIR VENTS OPEN

99-FT HEAD, 60-SECOND VALVE SCHEDULE

PLATE A-5