US Army Corps
of Engineers

TECHNICAL REPORT HL-87-15

# LIFT GATE FOR LOCKPORT LOCK ILLINOIS WATERWAY

## Hydraulic Model Investigation

by

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

The guard lift gate for the Lockport Lock will be equipped to operate during emergency closure of the lock chamber. This will involve operation under dynamic heads. A 1:24-scale section model of the lock chamber, guard and service gate sills, the guard gate, approach area, and lock chamber was used to study magnitude and frequency of the hydraulic forces acting on the lifting cables and the flow conditions over the gate. Tests indicated that the hydraulic load increased as the exposed gate height increased until the exposed gate height became approximately equal to 60 percent of the pool height. At this point, the hydraulic loads peaked and began to decrease with increasing exposed gate heights. This hydraulic model investigation yielded hydraulic loads less than the calculated hydraulic loads provided by the US Army Engineer District, Rock Island. Although some gate vibrations were indicated, they were random and small compared to the magnitude of the total load.

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# PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, US Army, on 15 August 1983 at the request of the US Army Engineer District, Rock Island (NCR).

The study was conducted during the period August 1983 to February 1984 in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES), under the direct supervision of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs, HL, respectively, and under the general supervision of Messrs. J. L. Grace, Jr., Chief, Hydraulic Structures Division, and N. R. Oswalt, Chief, Spillways and Channels Branch. The project engineer for the model study was Mrs. D. R. Cooper, assisted by Messrs. B. P. Fletcher, E. L. Jefferson, R. Bryant, Jr., and T. L. Kirkpatrick, all of the Spillways and Channels Branch, and R. H. Floyd, S. Bell, and L. B. Smithhart, Instrumentation Services Division, WES. The gate was constructed by Mr. R. L. Blackwell, Engineering and Construction Services Division, WES. This report was edited by Mrs. Nancy Johnson, Information Products Division, under the Inter-Personnel Agreement Act.

During the course of the investigation, Messrs. D. McCully, R. Beach, J. A. Aidala, and J. Bartek, NCR, visited WES to discuss the program and results of model tests, observe the model in operation, and correlate these results with design studies.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

CONTENTS

# CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

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

| Multiply | By | To Obtain |
|---|---|---|
| cubic feet | 0.2831685 | cubic metres |
| degrees (angle) | 0.01745329 | radians |
| feet | 0.3048 | metres |
| inches | 25.4 | millimetres |
| miles (US statute) | 1.609347 | kilometres |
| pounds (force) | 4.448222 | newtons |
| pounds (mass) | 0.4535924 | kilograms |
| pounds (mass) per cubic foot | 27.6799 | grams per cubic centimetre |
| square feet | 0.0929304 | square metres |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |

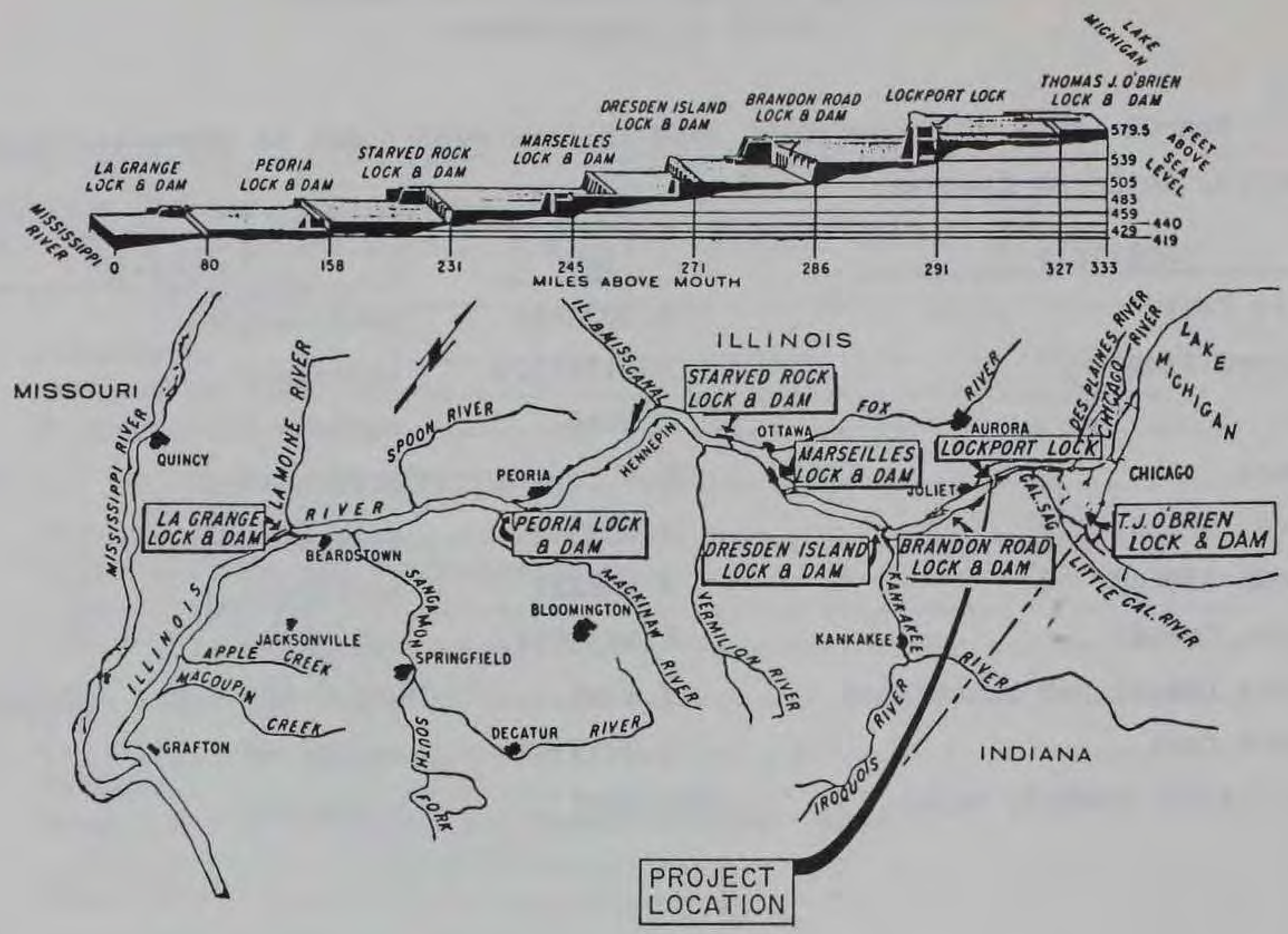


Figure 1. Vicinity map

Figure 2. Lockport Lock lift gate

# LIFT GATE FOR LOCKPORT LOCK

# ILLINOIS WATERWAY

## Hydraulic Model Investigation

## PART I: INTRODUCTION

### Prototype

1. Lockport Lock is located at river mile 291 on the Illinois Waterway, immediately west of the city of Lockport, Illinois (Figure 1). The lock is 600 ft* long by 110 ft wide and has a lift of 39 ft. The lock walls and sills are constructed of concrete masonry. Two submersible vertical lift gates, a guard gate and a service gate, are provided at the upper end of the lock. In addition, a shutter gate was located in the forebay upstream of the guard gate. The purpose of the shutter gate was to restrict flow of water through the lock during an emergency so that the guard gate could be raised into place. However, the shutter gate was removed in August 1984. The lower gates are of the miter type. Plate 1 presents the general layout and typical sections of the lock.

2. The two submersible-type lift gates are submerged on the downstream side of the sills when the gates are in the open position. The service gate is approximately 70 ft downstream of the guard gate. The two gates are identical in construction except that the guard gate is equipped with butterfly-type filling valves that are necessary for the guard gate to function as an alternate to the service gate. The gates, consisting of four horizontal trusses, are horizontally framed. The horizontal trusses are framed into a vertical truss at each end. The skin plate is on the upstream side of the gate. The gates are operated by machinery located on overhead bridges carried by steel towers mounted on the lock walls (Figure 2). The weight of the gates is balanced by concrete counterweights suspended inside the framework of the towers. The gates are not provided with bearing rollers and thus cannot be operated under the flow of water. In the event an accident should occur

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* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 3.

requiring closing of the gate under head, the gate could not be closed under the present system.

3. Both gates are in excellent condition. The lift towers are also in good condition. The chains for lifting the service and guard gates are a continuing and costly maintenance problem and will be replaced with cables.

## Purpose of Model Study

4. The existing guard gate with its present lifting mechanism (electrically powered sprocket driving the lift chain of the counterweights) cannot be closed against a head of flowing water. The analysis of the new guard gate and service gate lifting mechanisms by the Rock Island District was presented in Design Memorandum No. 1* and Design Memorandum No. 2.** The model testing program was undertaken for the following reasons:

- a. To substantiate the theoretical analysis presented in Design Memorandum No. 2.
- b. To determine the lifting loads required to permit closing of the gate against a head of flowing water.
- c. To observe flow conditions over the gate.
- d. To determine the magnitude of the hydraulic forces and frequency of vibrations acting on the lifting cables with various gate openings and flow rates.

## Presentation of Data

5. In the presentation of test results, the data are not provided in the order in which the tests were conducted. Instead, as each element of the gate and the gate lifting mechanism is considered, all tests conducted thereon are discussed. All model data are presented in terms of prototype equivalents. All tests are discussed in Part III.

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* US Army Engineer District, Rock Island. 1982 (May). "General Design Memorandum, Illinois Waterway, Lockport Lock Major Rehabilitation," Design Memorandum No. 1, Rock Island, Ill.

** ________ . 1983 (Jul). "Lift Gate Machinery Modifications; Illinois Waterway, Lockport Lock Major Rehabilitation," Design Memorandum No. 2, Rock Island, Ill.

## PART II: MODEL AND TEST PROCEDURE

### Description

6. The 1:24-scale model at the US Army Engineer Waterways Experiment Station (WES) (Figure 3) reproduced the 110-ft-wide lock chamber, the guard and service gate sills, a 300-ft-long section upstream of the lock chamber, and 400 ft of the lock chamber. The model gate was constructed of brass and simulated a prototype weighing 400,500 lb (dry weight). The trusses, skin plate, and walkway were reproduced to scale, and three roller bearings were attached at each end of the model gate to minimize friction in the gate slots (Figure 4). Model tests indicated that the friction forces were insignificant compared to the water loads on the gate.

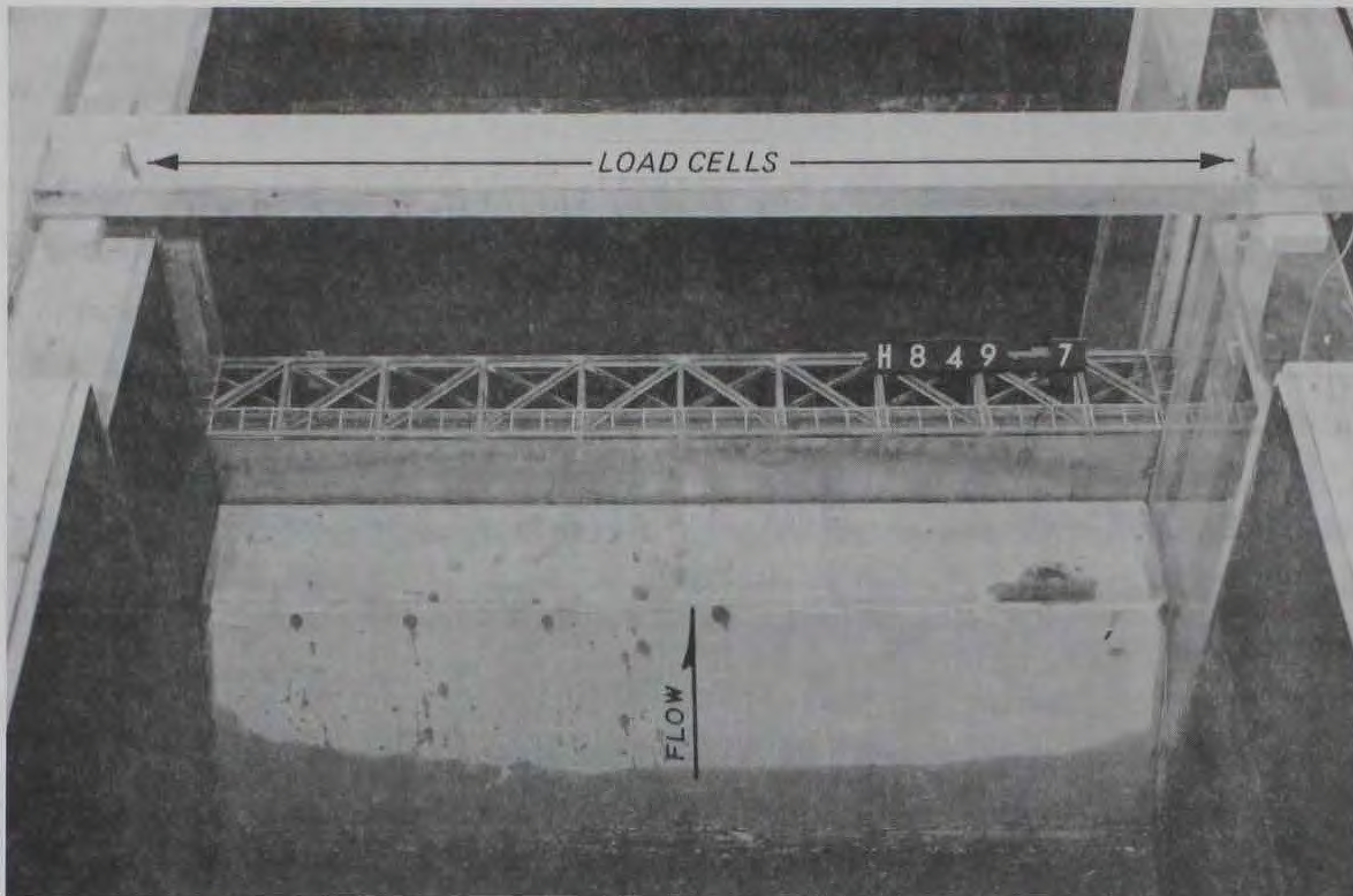
7. The lock chamber was constructed of plywood, and the gate slots were fabricated of transparent plastic to allow observation of flow conditions in and around the gate slots. The gate lifting mechanism consisted of a cable at each end of the gate attached to load cells bolted into an aluminum channel that was suspended across the model (Figure 3 and Plate 2). Each model cable was sized to reproduce the elastic properties of the eight prototype cables proposed for each end of the gate.

### Appurtenances and Instrumentation

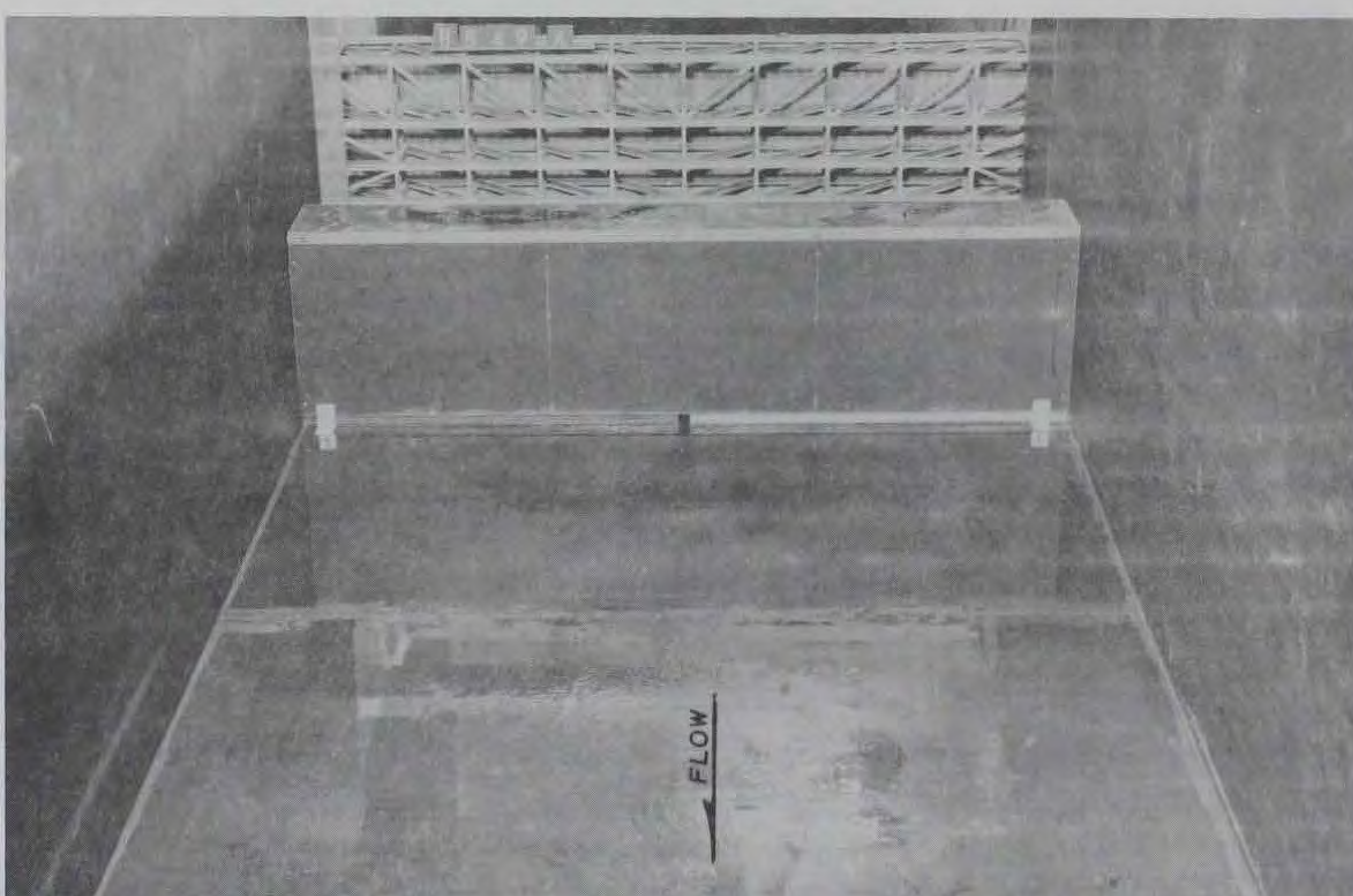
8. Water used in the operation of the model was supplied by pumps, and discharges were measured by means of venturi meters. Steel rails set to grade provided reference planes for measuring devices. Water-surface elevations were obtained with point gages. Load cells and an oscillograph recorder were used to measure and record the magnitude and frequency of the total forces acting on each end of the gate. Chart speed used during testing was 1 ips.

### Scale Relations

9. The accepted equations of hydraulic similitude, based upon the Froudian relations, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. General relations for transference of model data to prototype equivalents are presented in the following tabulation:

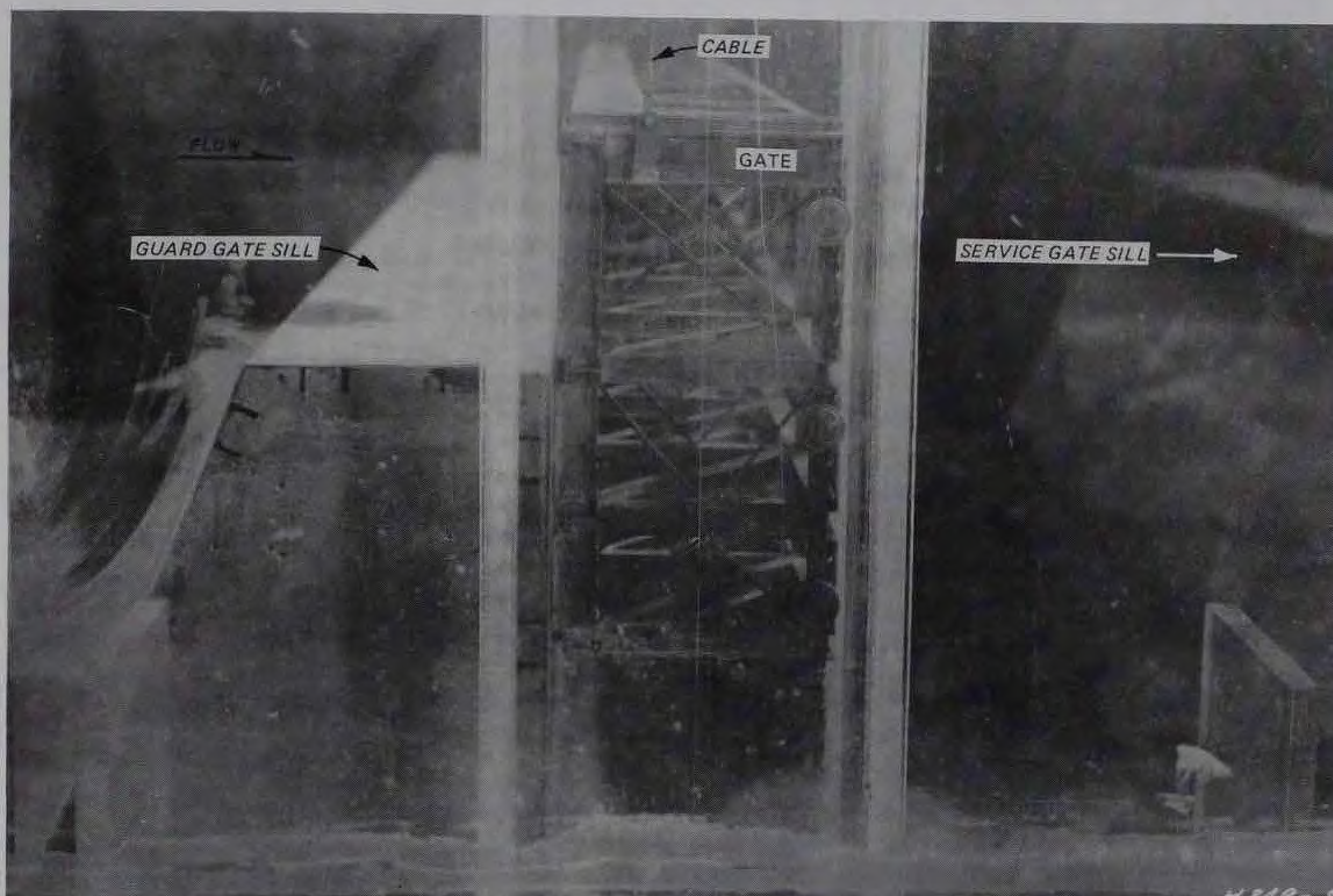



a. Looking downstream




b. Looking upstream

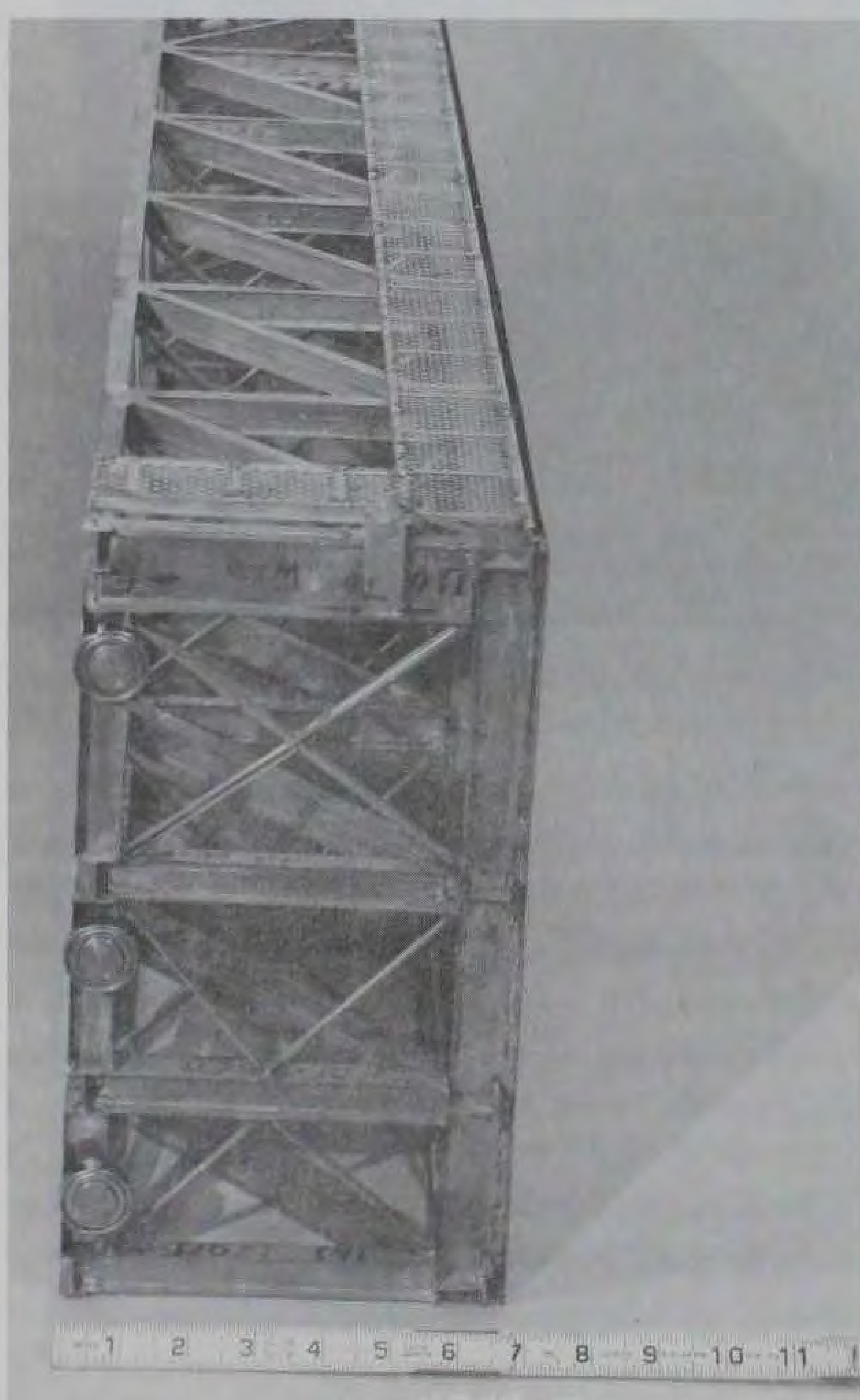
Figure 3. 1:24-scale Lockport Lock lift gate model (Continued)




c. Profile of breach

Figure 3. (Concluded)

a. Upstream and plan views




b. End view

Figure 4. 1:24-scale model of guard gate

| Dimension | Ratio | Scale Relation |
|---|---|---|
| Length | $L_r = L$ | 1:24 |
| Area | $A_r = L_r^2$ | 1:576 |
| Velocity | $V_r = L_r^{1/2}$ | 1:4.899 |
| Time | $T_r = L_r^{1/2}$ | 1:4.899 |
| Discharge | $Q_r = L_r^{5/2}$ | 1:2,821.81 |
| Weight | $W_r = L_r^3$ | 1:13,824 |
| Force | $F_r = L_r^3$ | 1:13,824 |

## Test Procedure

10. Tests were conducted in the model to measure loadings on the gate, to observe flow conditions over the gate, and to determine the magnitude and frequency of the hydraulic forces acting on the lifting cables with various gate openings and flow rates. In measuring the forces on the gate, pool elevations were held constant while the exposed gate height was varied. Tests were conducted to measure total head on the guard gate sill for discharges up to 30,000 cfs. Tests were also conducted to develop an equation for flow over the guard gate for any head on the gate and exposed gate height above the sill.

11. Test procedures were generally the same for all tests and consisted of the following:

- a. Record test number, date, data recorder, and test conditions.
- b. Calibrate load cells.
- c. Raise gate to test position and allow upper and lower pools to stabilize.
- d. Record hoisting cable loads on the oscillograph.
- e. Record upper and lower pool elevations and other test conditions.
- f. Check load cell calibrations.

## Guard Gate Sill

12. Tests were conducted to measure the total head on the guard gate sill for discharges up to 30,000 cfs. The water-surface elevation was measured using a point gage located 70 ft upstream of the guard gate sill while the gate was submerged. The velocity head of the approach flow in the section model was added to the water-surface elevation to determine the total head or energy representative of the upper pool in the prototype. An example calculation is presented and variables are defined in Plate 3. Rating curves of the breach due to the guard gate and the service gate sills (Plate 3) are presented in Plates 4 and 5. Data used to plot the curves in Plates 4 and 5 are presented in Table 1. A rating curve calculated by Rock Island District* is also shown in Plate 4.

## Cables

13. Each model cable was sized to reproduce the elastic properties of the eight prototype cables proposed for each end of the gate. Tests were conducted to ensure that natural frequencies of the model cables would not influence the hydraulic force measurements. Natural frequency readings were recorded on the oscillograph for exposed gate heights of 0 and 3-18 ft in 1-ft increments. The natural frequency of the model cables ranged from 20 Hz (unsubmerged) to 25 Hz (submerged). A comparison of the natural dynamic response of the model with the exciting hydraulic forces (2-4 Hz) indicated that the forces measured in the model would not be significantly affected by the natural frequency or damping characteristics of the model and related instrumentation. The gate hoisting cables were not subjected to a significant dynamic loading (less than 1.0 percent of total load measured and at a random frequency). Therefore, only maximum loads are tabulated in the tables and shown on the plots. A typical oscillograph record of natural frequency measurement is shown in Plate 6.

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* US Army Engineer District, Rock Island. 1983 (Jul). "Lift Gate Machinery Modifications; Illinois Waterway, Lockport Lock Major Rehabilitation," Design Memorandum No. 2, Rock Island, Ill.

14. The water load $F_W$ (Plate 3) acting on the gate and hoist cables was obtained by the following equation:

$$F_W = F_T - F_S \quad (1)$$

where

$F_W$ = maximum force due to water passing over gate (water load), lb

$F_T$ = maximum total force measured in model cables, lb

$F_S$ = dry weight of gate minus weight of volume of water displaced by gate, lb

15. Model tests for upper pools with elevations 10, 16, 18, and 25 ft above the guard gate sill were conducted for exposed gate heights of 0 and 3 through 18 ft. The first phase of testing was run with gate heights fixed. The second phase of testing was run while the gate was lifted at a rate of 2 fpm.

16. Each test with upper pool conditions fixed in the first phase of testing was repeated. The gate was raised to a given height and the pool was allowed to stabilize. The load cells were zeroed. The load (force) was measured and recorded on the oscillograph (Plate 7).

17. The gate was raised at a rate of 2 fpm in the second phase of testing and the forces recorded on the oscillograph concurrently. The pools were held constant while the gate was manually being lifted.

18. The water load increased as the exposed gate height $d_r$ increased until $d_r$ became approximately equal to 60 percent of the pool height. At this point, the hydraulic loads peaked and decreased with increasing exposed gate heights (Plates 8-11). Data used to plot the curves in Plates 8-11 are presented in Tables 2-5. A maximum load of 73,400 lb occurred at $d_r = 6$ ft for the first phase and 70,300 lb at $d_r = 6$ ft for the second phase of testing with a 10-ft pool (Plate 8). The maximum loads increased to 133,900 lb at $d_r = 9$ ft during the first phase and 134,000 lb at $d_r = 9$ ft during the second phase of tests with a 16-ft pool (Plate 9). A maximum of 163,600 lb at $d_r = 10$ ft for the first phase and 164,000 lb at $d_r = 10$ ft for the second phase of testing resulted with an 18-ft pool (Plate 10). Increasing the pool to 25 ft increased the maximum load of the first phase of testing to 322,900 lb at $d_r = 15$ ft and the maximum load of the second phase of testing to 319,400 lb at $d_r = 15$ ft (Plate 11). At the peak load condition, the water cascaded through the gate members rather than forming a definable nappe.

## Comparison of Computed and Measured Water Loads Acting on the Hoist Cables

19. The water load $F_W$ was calculated by Rock Island District to be approximately equal to the weight of water acting over the cross-sectional area of the top truss of the gate (see Figure 5).

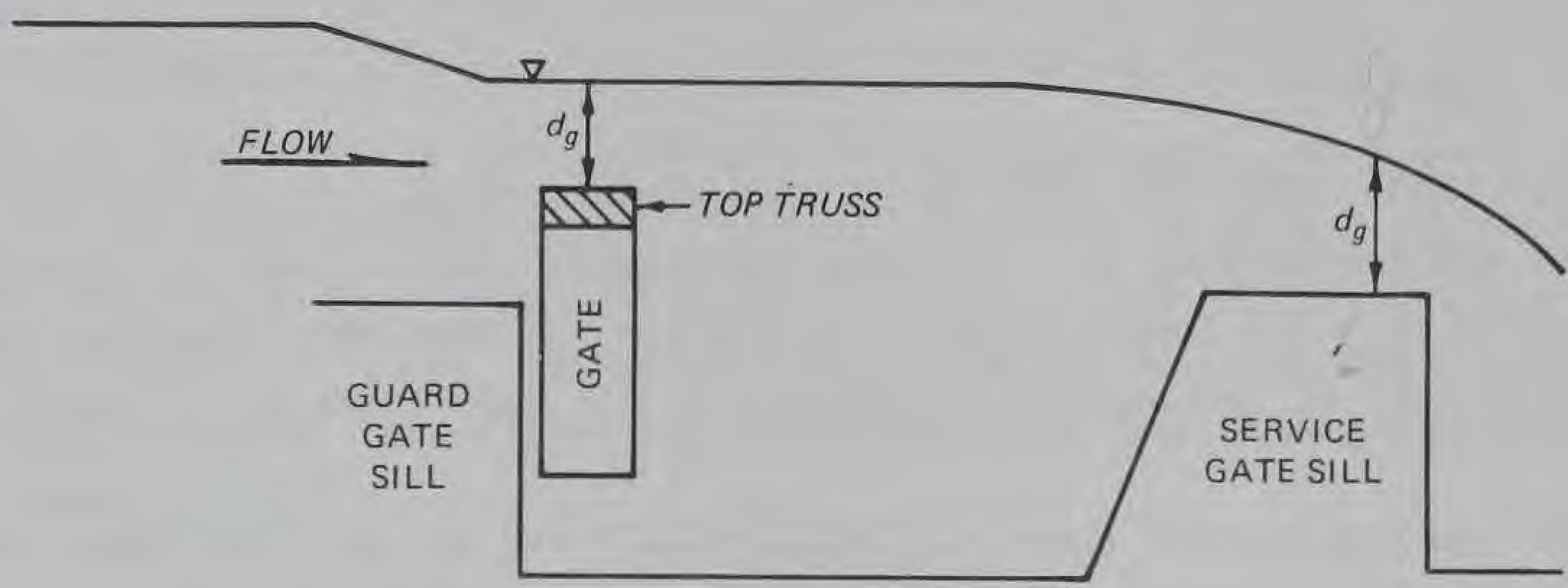


Figure 5. Water-surface profile used for calculating $F_W$

The equation used was

$$F_W = d_g \gamma A_T \gamma \quad (2)$$

where

$d_g$ = depth of water relative to top of gate, ft

$\gamma$ = specific weight of water, 62.4 pcf

$A_T$ = cross-sectional area of top truss, ft

20. In the model, the members composing the top truss were simulated and water cascaded through the gate members as shown in Figure 6 and Photos 1-3.

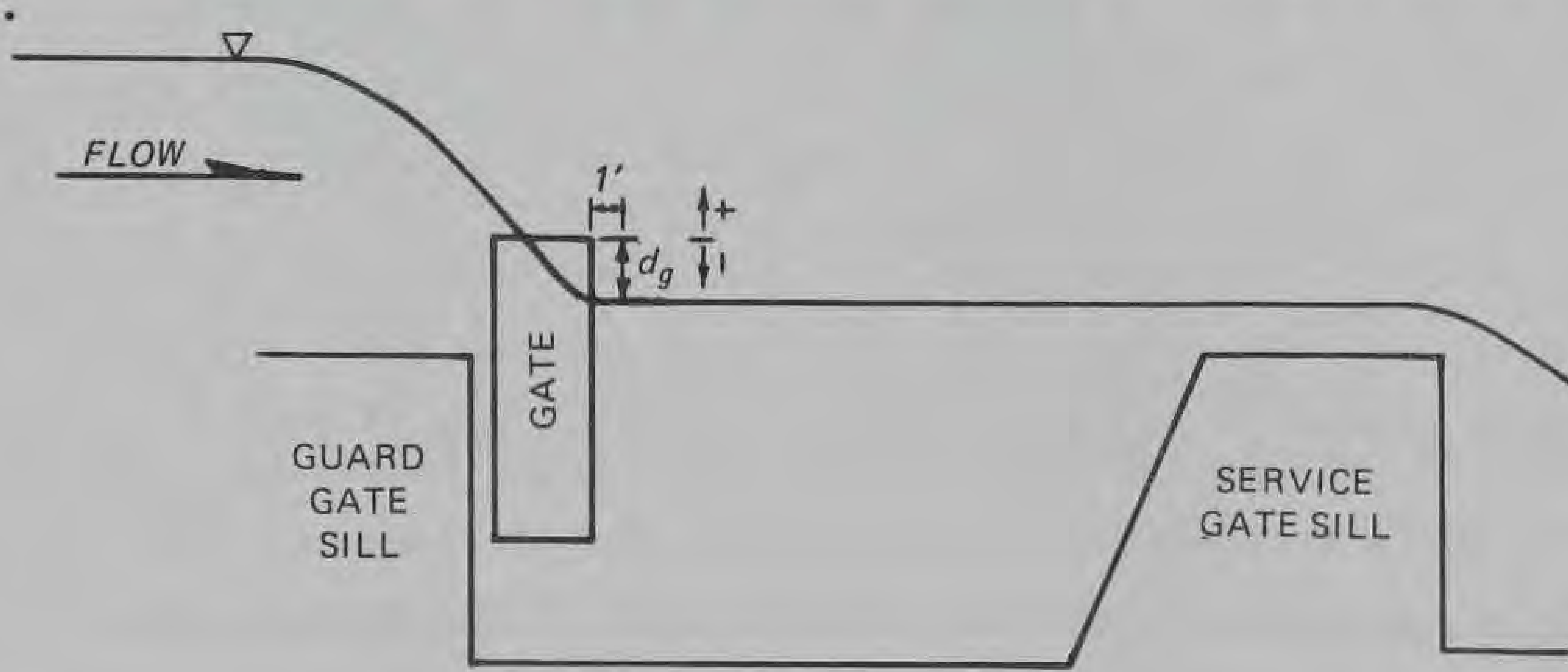


Figure 6. Typical water-surface profile observed in the model

21. A comparison of $d_g$ assumed by Rock Island District and $d_g$ measured at WES indicated that the WES $d_g$ value was less than the Rock Island District $d_g$ value. Also, the maximum WES $F_W$ values were about 28 percent less than the Rock Island District calculated $F_W$ values.

## Guard Gate

22. Tests were conducted to develop an equation for flow over the gate for any head on the gate and gate height above the sill. Discharge versus head on the gate for various depths of pool above the sill was plotted (Plate 12). Data used to plot the curves on Plate 12 are presented in Table 6. The following equation was obtained and may be used to calculate the discharge for free uncontrolled flow over the gate:

$$Q = 3.49LH_g^{1.5} \tag{3}$$

where

$Q$ = discharge over the gate, cfs

$L$ = width of the gate, 110 ft

$H_g$ = distance from the upper pool to the top of the gate, ft

## PART IV: CONCLUSIONS

23. The hydraulic model investigation of the Lockport Lock lift gate yielded hydraulic loads about 28 percent less than the calculated hydraulic loads provided by the Rock Island District. The measured depth of the gate under water, $d_g$ (Plate 3), was less than that assumed by the Rock Island District in Design Memorandum No. 2.* The difference in $d_g$ measured in the model and $d_g$ used in the calculations may have caused the discrepancy between measured and calculated loads.

24. The water loads on the lifting cable increased from 73,400 lb with 10 ft of head on the gate sill to 322,900 lb with 25 ft of head on the gate sill. The lifting loads required to permit closing of the gate against a head of flowing water are dependent upon two variables: the amount of head on the gate sill $H_T$ and the exposed height of the gate above the gate sill $d_r$.

25. Discharge coefficients were determined for computing the discharge through the structure with the lift gate in the lowered position, $d_r = 0$, and with the gate in various raised positions. The discharge coefficient was considerably lower with the gate lowered (2.86) than with the gate raised (3.49). This was attributed to the change in shape of the control weir with the gate lowered (guard gate sill shape) and with the gate raised (gate shape).

26. Although there was some gate vibration as indicated on the oscillograph record (Plate 7), the vibrations were random and small compared to the magnitude of the load.

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* US Army Engineer District, Rock Island. 1983 (Jul). "Lift Gate Machinery Modifications, Illinois Waterway, Lockport Lock Major Rehabilitation," Design Memorandum No. 2, Rock Island, Ill.

Table 1

Calibration Data, Lockport Lock Lift Gate

| Discharge cfs | Water-Surface el* | $\bar{V}$, fps | $\bar{V}^2/2g$ | $\bar{V}^2/2g$ + Water-Surface El | $H_T$, ft |
|---|---|---|---|---|---|
| 0 | 558.00 | 0.00 | 0.00 | 558.00 | 0.00 |
| 5,000 | 564.29 | 1.29 | 0.026 | 564.32 | 6.32 |
| 7,500 | 566.42 | 1.82 | 0.052 | 566.47 | 8.47 |
| 10,000 | 568.10 | 2.33 | 0.084 | 568.19 | 10.19 |
| 12,500 | 569.64 | 2.80 | 0.121 | 569.76 | 11.76 |
| 15,000 | 571.37 | 3.22 | 0.161 | 571.53 | 13.53 |
| 17,500 | 572.57 | 3.65 | 0.207 | 572.78 | 14.78 |
| 20,000 | 573.79 | 4.06 | 0.256 | 574.05 | 16.05 |
| 22,500 | 574.75 | 4.47 | 0.310 | 575.06 | 17.06 |
| 25,000 | 575.90 | 4.85 | 0.365 | 576.27 | 18.27 |
| 27,500 | 576.77 | 5.23 | 0.425 | 577.20 | 19.20 |
| 30,000 | 577.44 | 5.63 | 0.492 | 577.93 | 19.93 |


ELEV ℄ LOCK

* All elevations cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

Table 2

Hoist Cable Loads

Y = 10 ft

| | Phase I Testing | | | | | | | | Phase II Testing | | | Calculated by Rock Island District | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | | | Test 2 | | | | | | | | | |
| $d_r$ ft | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $F_T$ lb | $F_S$ lb | $F_W$ lb | $d_g$ ft | $F_T$ lb | $F_W$ lb |
| 0 | 5.8 | 349,600 | 347,400 | 2,200 | 5.8 | 347,500 | 347,400 | 100 | 352,500 | 347,400 | 5,100 | -- | 322,248 | 0 |
| 3 | 3.0 | 373,100 | 347,400 | 25,700 | 2.8 | 366,100 | 347,400 | 18,700 | 373,300 | 347,400 | 25,900 | 5.0 | 322,248 | 0 |
| 4 | 2.0 | 369,800 | 347,400 | 22,400 | 1.8 | 373,000 | 347,400 | 25,600 | 383,300 | 347,400 | 35,900 | 4.2 | 322,171 | 0 |
| 5 | -0.2 | 404,100 | 347,900 | 56,200 | 0 | 403,900 | 347,400 | 56,500 | 404,400 | 347,400 | 57,000 | 3.4 | 437,586 | 103,534 |
| 6 | -1.9 | 421,200 | 351,900 | 69,300 | -1.7 | 424,500 | 351,100 | 73,400 | 418,200 | 347,900 | 70,300 | 2.7 | 419,816 | 82,218 |
| 7 | -4.6 | 410,800 | 356,900 | 53,900 | -4.4 | 410,800 | 356,400 | 54,400 | 418,200 | 356,900 | 61,300 | 2.0 | 400,729 | 60,902 |
| 8 | -6.1 | 407,400 | 359,900 | 47,500 | -5.9 | 410,800 | 359,400 | 51,400 | 411,300 | 359,900 | 51,400 | 1.3 | 381,618 | 39,587 |
| 9 | -7.8 | 400,600 | 363,400 | 37,200 | -7.6 | 397,000 | 362,900 | 34,100 | 401,300 | 363,400 | 37,900 | 0.7 | 365,227 | 21,316 |
| 10 | -9.5 | 367,900 | 367,900 | 0 | -9.3 | 366,400 | 366,400 | 0 | 367,900 | 367,900 | 0 | 0 | 345,297 | 0 |

Note: See Plate 3 for definition of terms.

Table 3

Hoist Cable Loads

Y = 16 ft*

| | Phase I Testing | | | | | | | | Phase II Testing | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | | | Test 2 | | | | | | |
| $d_r$ ft | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $F_T$ lb | $F_S$ lb | $F_W$ lb |
| 0 | 12.5 | 365,500 | 347,400 | 18,200 | 11.3 | 369,500 | 347,400 | 22,100 | 362,900 | 347,400 | 15,500 |
| 3 | 6.4 | 400,600 | 347,400 | 53,200 | 6.4 | 393,600 | 347,400 | 46,200 | 400,900 | 347,400 | 53,500 |
| 5 | 4.2 | 431,700 | 347,400 | 84,300 | -- | -- | -- | -- | 428,600 | 347,400 | 81,200 |
| 6 | 4.1 | 431,700 | 347,400 | 84,300 | 3.4 | 435,000 | 347,400 | 87,600 | 432,000 | 347,400 | 84,600 |
| 7 | 2.8 | 435,000 | 347,400 | 87,600 | 2.6 | 428,100 | 347,400 | 80,700 | 445,800 | 347,400 | 98,400 |
| 8 | 1.1 | 459,500 | 347,400 | 112,100 | 0.9 | 469,500 | 347,400 | 122,100 | 473,500 | 347,400 | 126,100 |
| 9 | -0.8 | 477,100 | 348,900 | 128,200 | -1.1 | 483,300 | 349,400 | 133,900 | 483,800 | 349,400 | 134,400 |
| 10 | -- | -- | -- | -- | -4.2 | 472,900 | 355,900 | 117,000 | 475,300 | 355,900 | 119,400 |
| 11 | -- | -- | -- | -- | -5.5 | 469,500 | 358,400 | 111,100 | 470,200 | 358,400 | 111,800 |
| 12 | -7.0 | 449,100 | 361,900 | 87,200 | -7.2 | 435,000 | 362,400 | 72,600 | 466,800 | 362,400 | 104,400 |
| 15 | -10.2 | 431,700 | 368,400 | 63,300 | -10.2 | 442,000 | 368,400 | 73,600 | 449,400 | 368,400 | 81,000 |
| 16 | -11.2 | 370,400 | 370,400 | 0 | -11.2 | 370,400 | 370,400 | 0 | 370,400 | 370,400 | 0 |

Note: See Plate 3 for definition of terms.
* No calculated loads.

Table 4

Hoist Cable Loads

Y = 18 ft

| | Phase I Testing | | | | | | | | | | | Calculated by Rock Island District | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | | | Test 2 | | | | Phase II Testing | | | | | |
| $d_r$ ft | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $F_T$ lb | $F_S$ lb | $F_W$ lb | $d_g$ ft | $F_T$ lb | $F_W$ lb |
| 0 | 12.5 | 369,800 | 347,400 | 22,400 | 10.3 | 373,000 | 347,400 | 25,600 | 375,400 | 347,400 | 28,000 | -- | -- | -- |
| 3 | 6.4 | 421,200 | 347,400 | 73,800 | 5.6 | 424,700 | 347,400 | 77,300 | 428,500 | 347,400 | 81,100 | 11.0 | 329,117 | 0 |
| 4 | 5.4 | 428,000 | 347,400 | 80,600 | -- | -- | -- | -- | 449,300 | 347,400 | 101,900 | 10.1 | 328,801 | 0 |
| 5 | 3.2 | 428,000 | 347,400 | 80,600 | -- | -- | -- | -- | 442,400 | 347,400 | 95,000 | 9.3 | 328,356 | 0 |
| 6 | 0.9 | 438,200 | 347,400 | 90,800 | 0.9 | 448,900 | 347,400 | 101,500 | 445,800 | 347,400 | 98,400 | 8.5 | 328,105 | 0 |
| 7 | -0.1 | 451,900 | 347,700 | 104,200 | -- | -- | -- | -- | 456,200 | 347,700 | 108,500 | 7.7 | 327,965 | 0 |
| 8 | -1.1 | 445,100 | 349,900 | 95,200 | -- | -- | -- | -- | 470,000 | 349,900 | 120,100 | 7.0 | 569,262 | 213,158 |
| 9 | -1.3 | 452,000 | 350,400 | 101,600 | -1.3 | 476,500 | 350,400 | 126,100 | 483,800 | 350,400 | 133,400 | 6.2 | 549,672 | 188,797 |
| 10 | -- | -- | -- | -- | -1.8 | 514,500 | 350,900 | 163,600 | 514,900 | 350,900 | 164,000 | 5.5 | 532,488 | 167,482 |
| 11 | -- | -- | -- | -- | -3.3 | 500,700 | 353,900 | 146,800 | 508,400 | 343,900 | 154,500 | 4.8 | 515,005 | 146,166 |
| 12 | -4.6 | 489,600 | 356,900 | 132,700 | -5.0 | 490,300 | 357,400 | 132,900 | 508,000 | 357,400 | 150,600 | 4.1 | 502,647 | 124,850 |
| 13 | -- | -- | -- | -- | -7.2 | 486,900 | 362,400 | 124,500 | -- | -- | -- | 3.4 | 484,429 | 103,534 |
| 14 | -- | -- | -- | -- | -9.7 | 459,100 | 367,400 | 91,700 | -- | -- | -- | 2.7 | 465,905 | 82,218 |
| 15 | -11.2 | 480,000 | 370,400 | 109,600 | -11.6 | 479,800 | 373,900 | 105,900 | 480,400 | 373,900 | 106,500 | 2.0 | 446,950 | 60,902 |
| 16 | -- | -- | -- | -- | -13.4 | 466,000 | 374,900 | 91,100 | -- | -- | -- | 1.3 | 427,477 | 39,587 |
| 17 | -- | -- | -- | -- | -14.9 | 452,500 | 375,900 | 77,600 | -- | -- | -- | 0.67 | 409,685 | 20,402 |
| 18 | -17.8 | 383,400 | 383,400 | 0 | -15.8 | 379,900 | 379,900 | 0 | 383,400 | 383,400 | 0 | 0 | 390,165 | 0 |

Note: See Plate 3 for definition of terms.

Table 5

Hoist Cable Loads

Y = 25 ft*

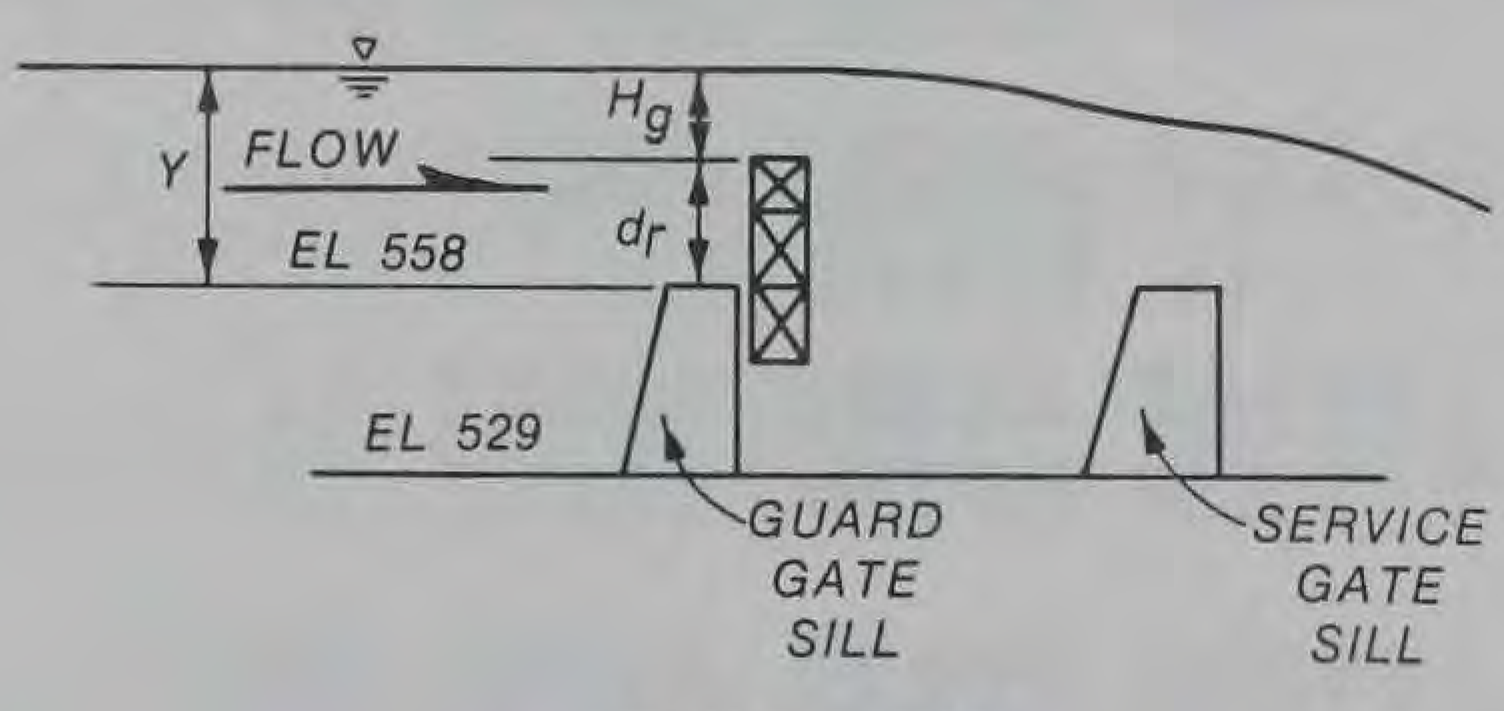
| | Phase I Testing | | | | | | | | Phase II Testing | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Test 1 | | | | Test 2 | | | | | | |
| $d_r$ ft | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $d_g$ ft | $F_T$ lb | $F_S$ lb | $F_W$ lb | $F_T$ lb | $F_S$ lb | $F_W$ lb |
| 0 | 10.6 | 400,900 | 347,400 | 53,500 | 10.6 | 432,000 | 347,400 | 84,600 | 435,500 | 347,400 | 88,100 |
| 3 | 6.6 | 473,500 | 347,400 | 126,100 | 6.6 | 442,400 | 347,400 | 95,000 | 459,700 | 347,400 | 112,300 |
| 4 | 4.8 | 480,400 | 347,400 | 133,000 | 4.8 | 463,100 | 347,400 | 115,700 | 476,900 | 347,400 | 129,500 |
| 5 | 3.4 | 497,700 | 347,400 | 150,300 | 3.4 | 487,300 | 347,400 | 139,900 | 504,600 | 347,400 | 157,200 |
| 6 | 1.9 | 501,100 | 347,400 | 153,700 | 1.9 | 515,000 | 347,400 | 167,600 | 525,300 | 347,400 | 177,900 |
| 7 | -0.5 | 525,300 | 348,400 | 176,900 | -1.2 | 532,200 | 349,900 | 182,300 | 532,200 | 349,900 | 182,300 |
| 8 | -2.2 | 542,600 | 352,400 | 190,200 | -2.2 | 532,200 | 352,400 | 179,800 | 535,700 | 352,400 | 183,300 |
| 9 | -4.4 | 546,100 | 356,900 | 189,200 | -4.4 | 546,100 | 356,900 | 189,200 | 549,500 | 356,900 | 192,600 |
| 10 | -4.8 | 525,300 | 357,400 | 167,900 | -4.8 | 528,800 | 357,400 | 171,400 | 546,100 | 357,400 | 188,700 |
| 11 | -5.0 | 539,100 | 357,900 | 181,200 | -5.0 | 549,500 | 357,900 | 191,600 | 532,200 | 357,900 | 174,300 |
| 12 | -5.0 | 573,700 | 357,900 | 215,800 | -5.0 | 570,200 | 357,900 | 212,300 | 570,200 | 357,900 | 212,300 |
| 13 | -5.0 | 642,800 | 357,900 | 284,900 | -5.0 | 653,200 | 357,900 | 295,300 | 591,000 | 357,900 | 233,100 |
| 14 | -6.6 | 656,600 | 360,900 | 295,700 | -6.3 | 677,400 | 360,400 | 317,000 | 670,500 | 360,900 | 309,600 |
| 15 | -8.5 | 684,300 | 364,900 | 319,400 | -8.5 | 687,800 | 364,900 | 322,900 | 684,300 | 364,900 | 319,400 |
| 16 | -9.0 | 684,300 | 365,900 | 318,400 | -9.7 | 684,300 | 367,400 | 316,900 | 667,000 | 367,400 | 299,600 |
| 17 | -11.2 | 677,400 | 370,400 | 307,000 | -11.2 | 687,800 | 370,400 | 317,400 | 670,464 | 370,400 | 300,064 |
| 18 | -12.2 | 615,200 | 372,400 | 242,800 | -12.2 | 601,300 | 372,400 | 228,900 | 591,000 | 372,400 | 218,600 |

Note: See Plate 3 for definition of terms.

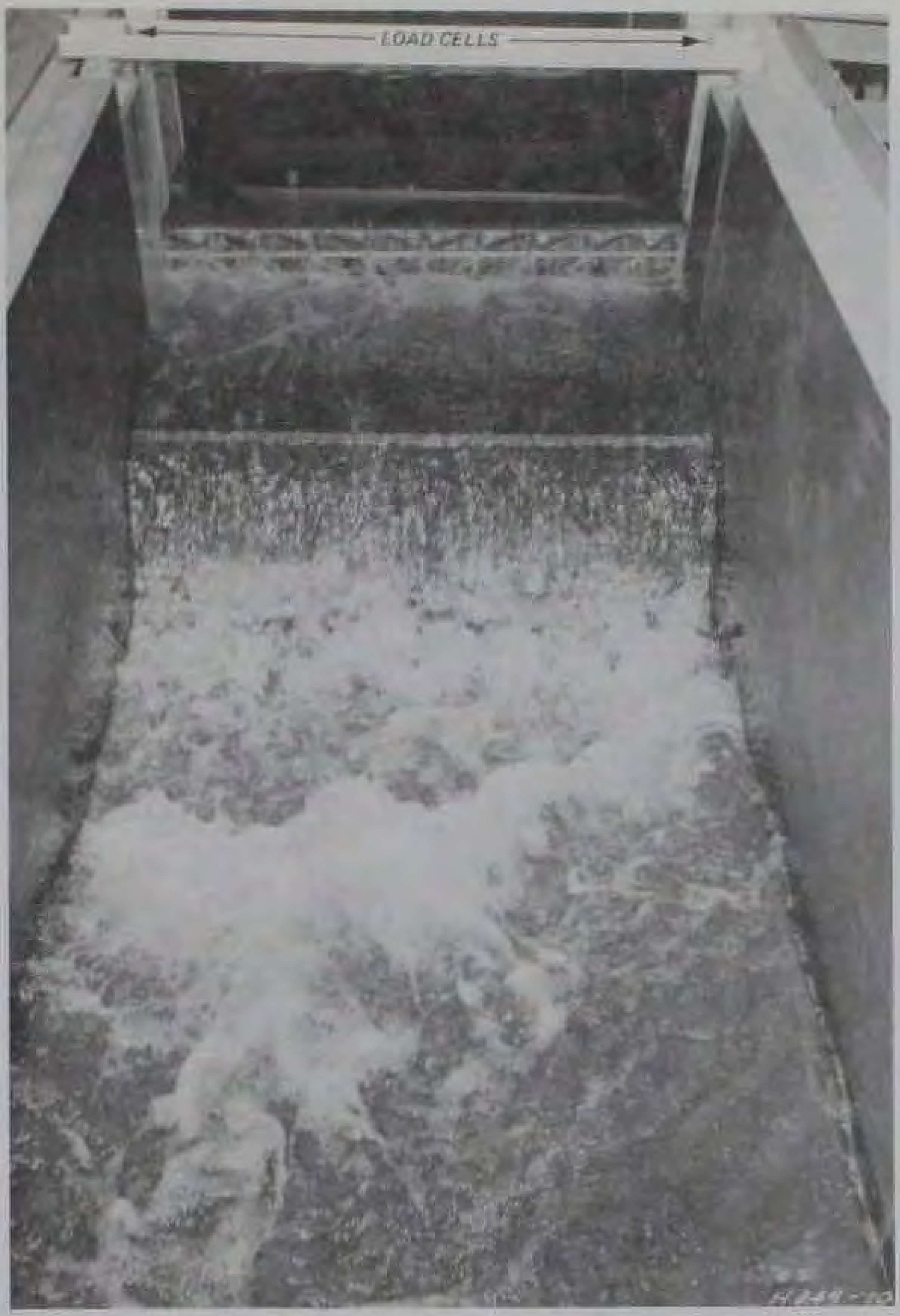
* No calculated loads.

Table 6
Discharge Data, Model Study of Lockport Lock Liftgate

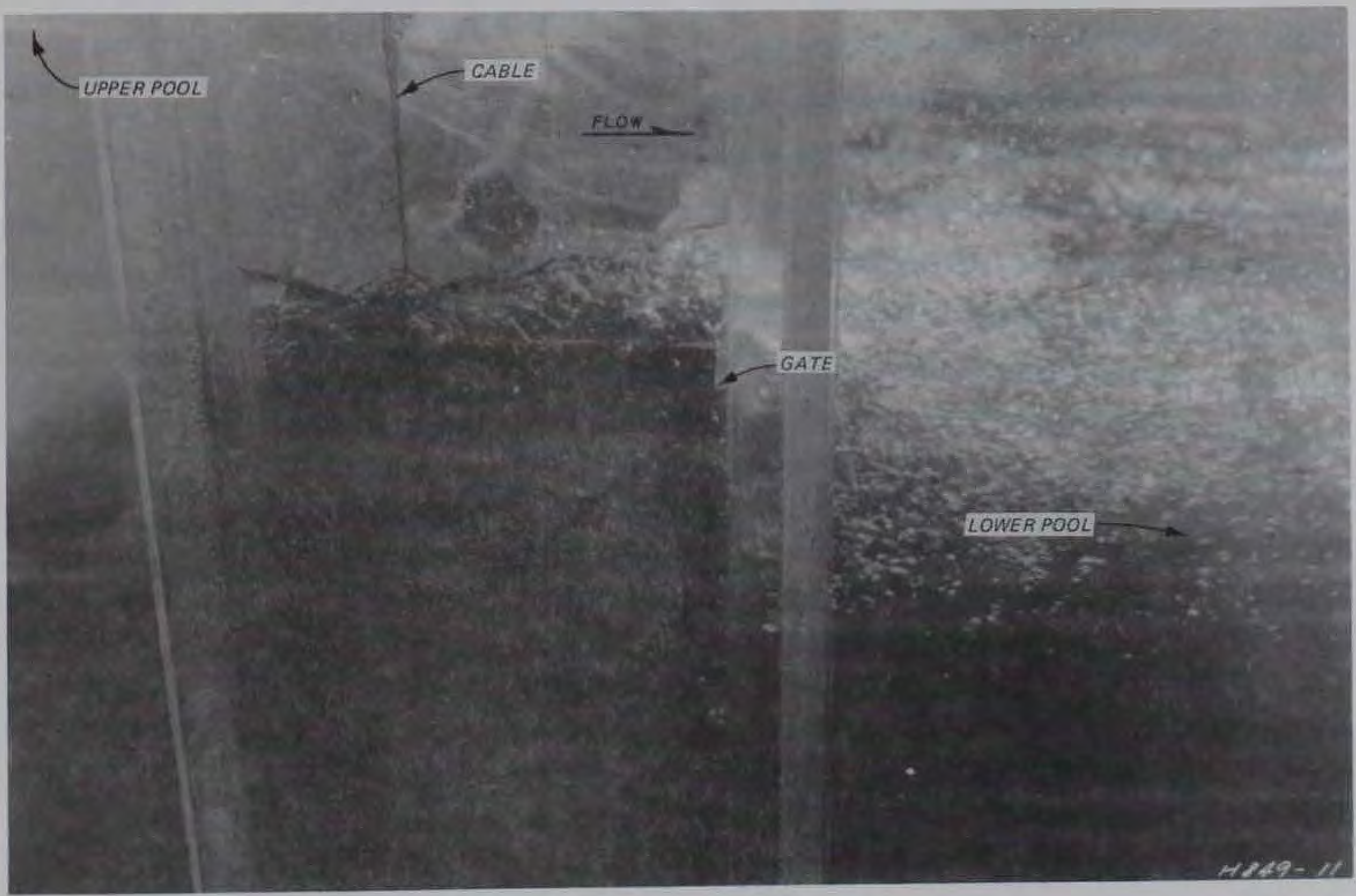
| | Y = 10 ft | | Y = 16 ft | | Y = 18 ft | | Y = 25 ft | |
|---|---|---|---|---|---|---|---|---|
| $d_r$, ft | $H_g$, ft | Q, cfs | $H_g$, ft | Q, cfs | $H_g$, ft | Q, cfs | $H_g$, ft | Q, cfs |
| 3 | 7 | 6,600 | 13 | 16,700 | 15 | 20,900 | 22 | 38,900 |
| 4 | 6 | 4,700 | -- | -- | 14 | 18,900 | 21 | 36,200 |
| 5 | 5 | 3,700 | 11 | 12,500 | 13 | 16,800 | 20 | 34,100 |
| 6 | 4 | 3,000 | 10 | 11,500 | 12 | 15,200 | 19 | 31,600 |
| 7 | 3 | 1,600 | 9 | 9,500 | 11 | 13,400 | 18 | 29,200 |
| 8 | 2 | 1,100 | 8 | 8,600 | 10 | 12,200 | 17 | 26,900 |
| 9 | -- | -- | 7 | 7,000 | 9 | 9,300 | 16 | 25,000 |
| 10 | -- | -- | 6 | 5,300 | 8 | 7,900 | 15 | 21,100 |
| 11 | -- | -- | 5 | 5,000 | 7 | 6,800 | 14 | 20,700 |
| 12 | -- | -- | 4 | 4,600 | 6 | 5,500 | 13 | 19,800 |
| 13 | -- | -- | -- | -- | 5 | 4,400 | 12 | 17,700 |
| 14 | -- | -- | -- | -- | 4 | 3,200 | 11 | 15,700 |
| 15 | -- | -- | -- | -- | -- | -- | 10 | 12,800 |
| 16 | -- | -- | -- | -- | -- | -- | 9 | 12,200 |
| 17 | -- | -- | -- | -- | -- | -- | 8 | 10,800 |
| 18 | -- | -- | -- | -- | -- | -- | 7 | 7,300 |




ELEV ℄ LOCK




a. Downstream view




b. Side view

Photo 1. Unit discharge 57 cfs/ft, $d_r$ = 12.0 ft, pool el 576 ft (NGVD), tailwater el 539 ft (NGVD)

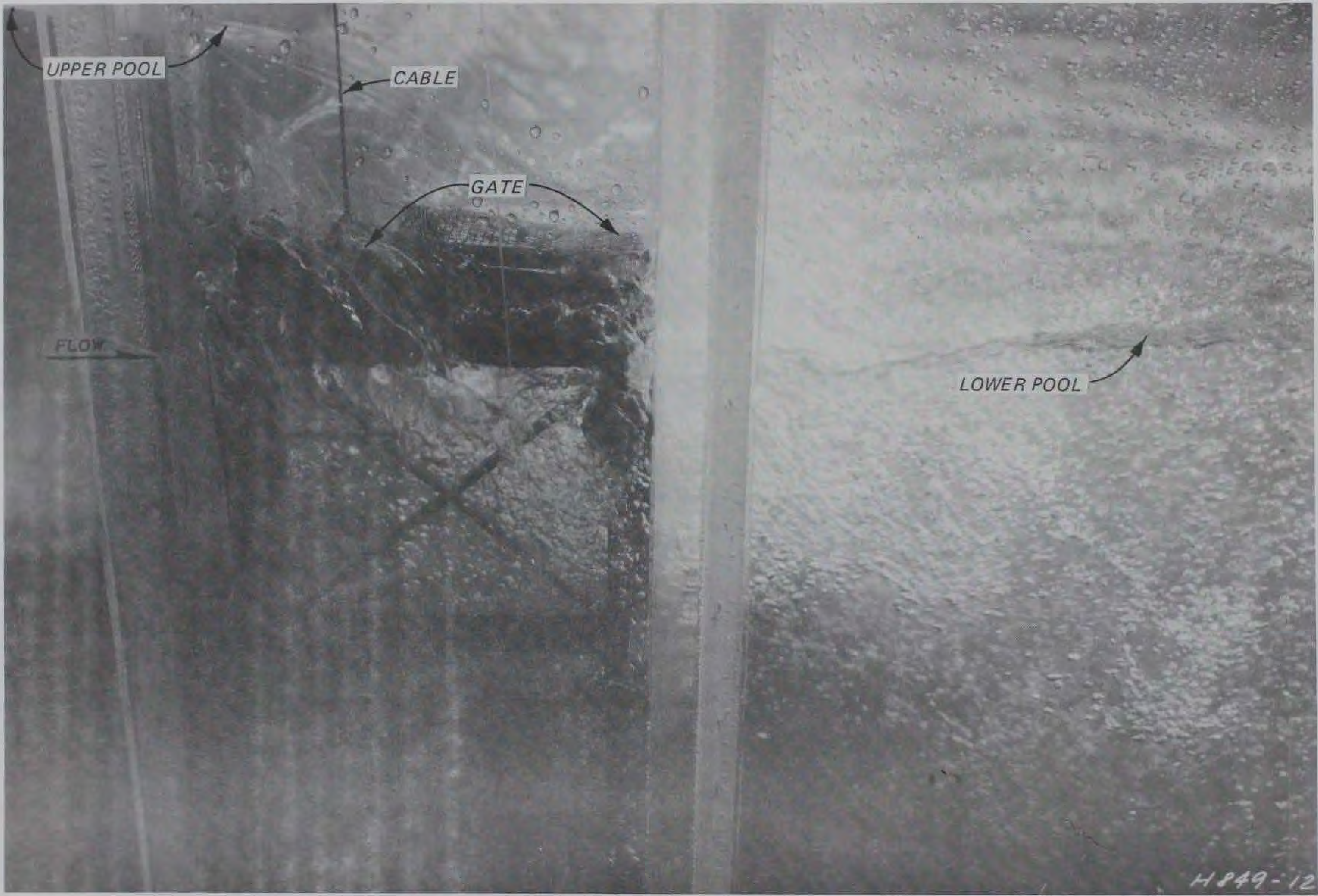



Photo 2. Unit discharge 64 cfs/ft, $d_r$ = 9.0 ft, pool el 574 ft (NGVD), tailwater el 539 ft (NGVD)

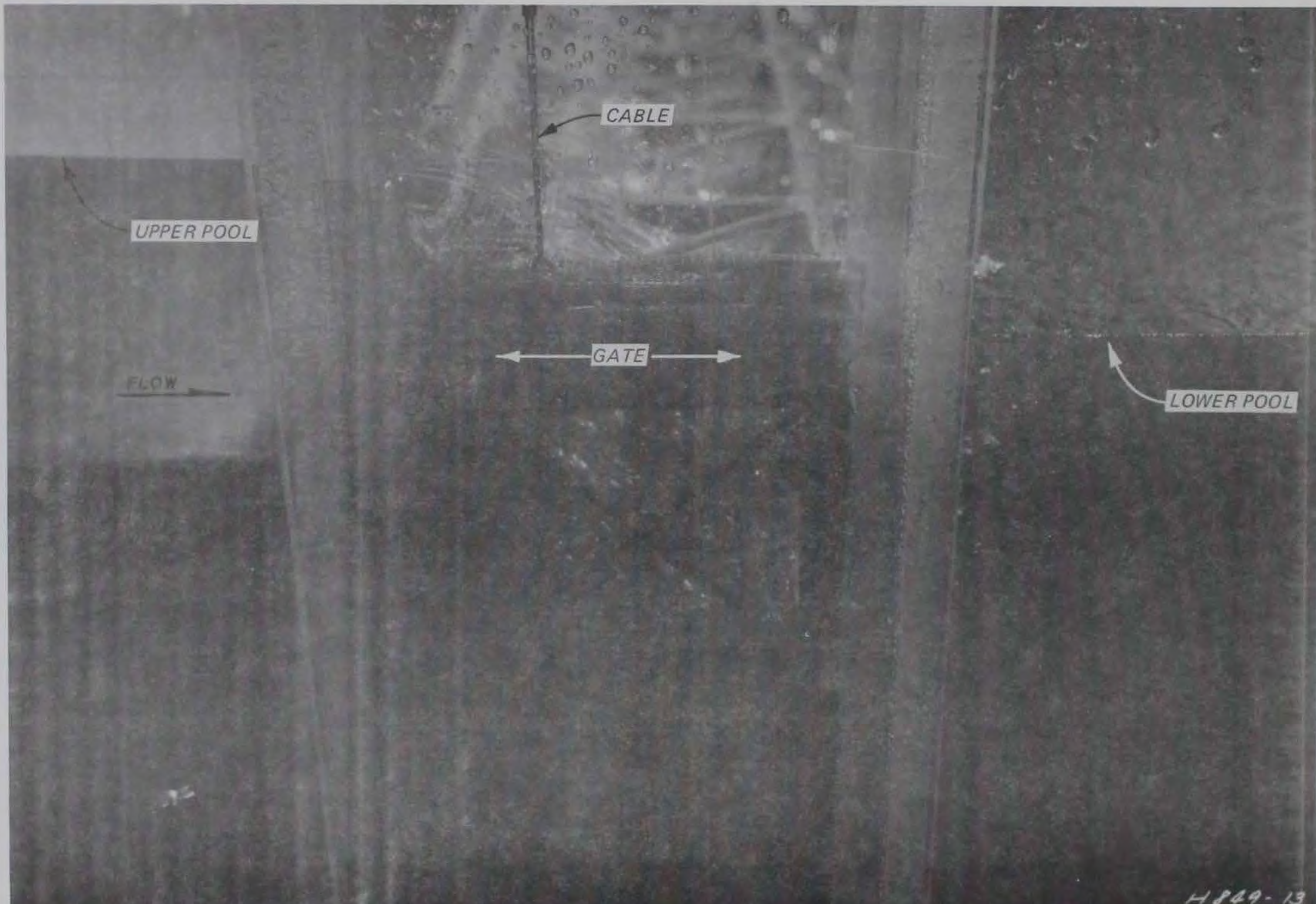
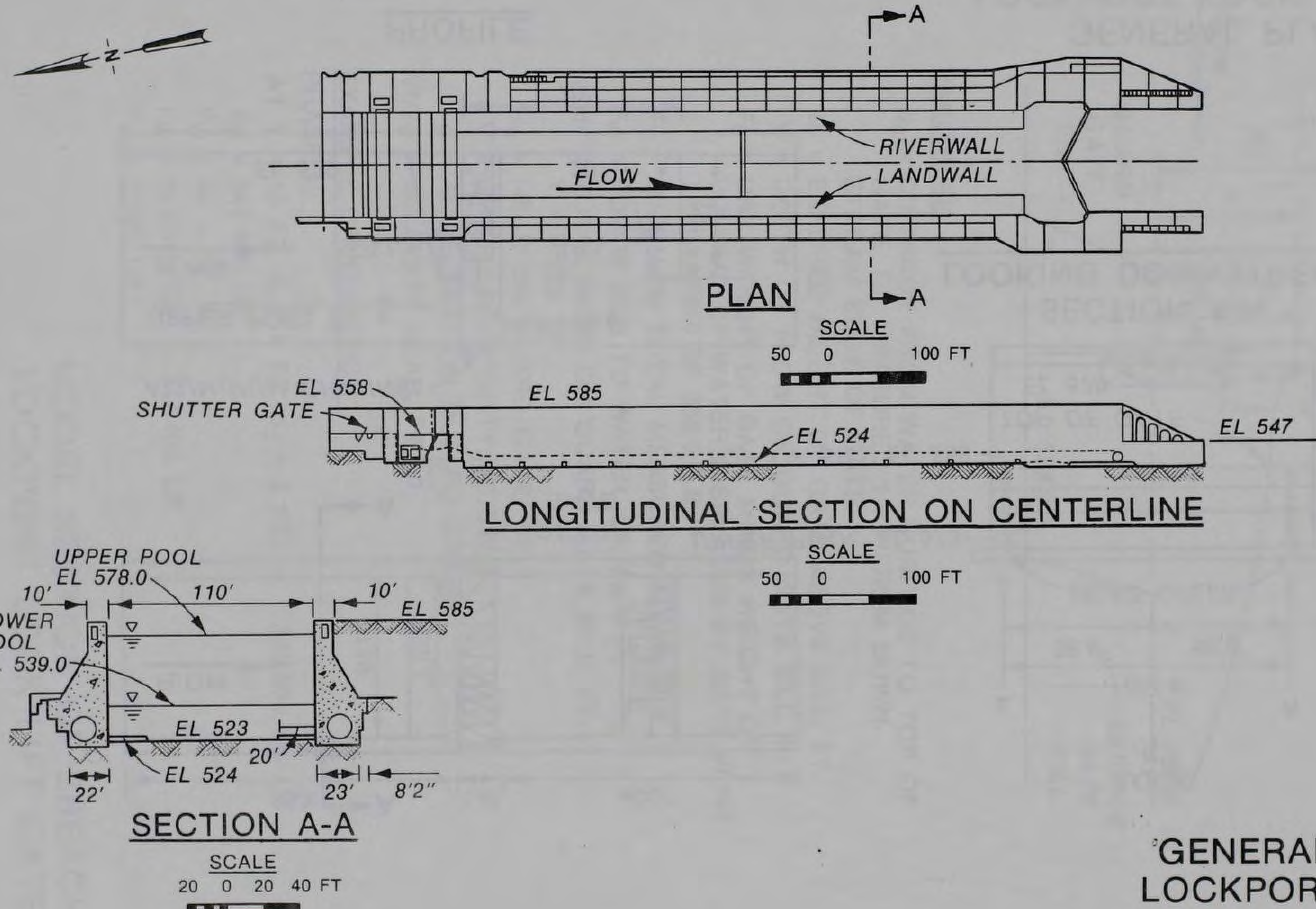
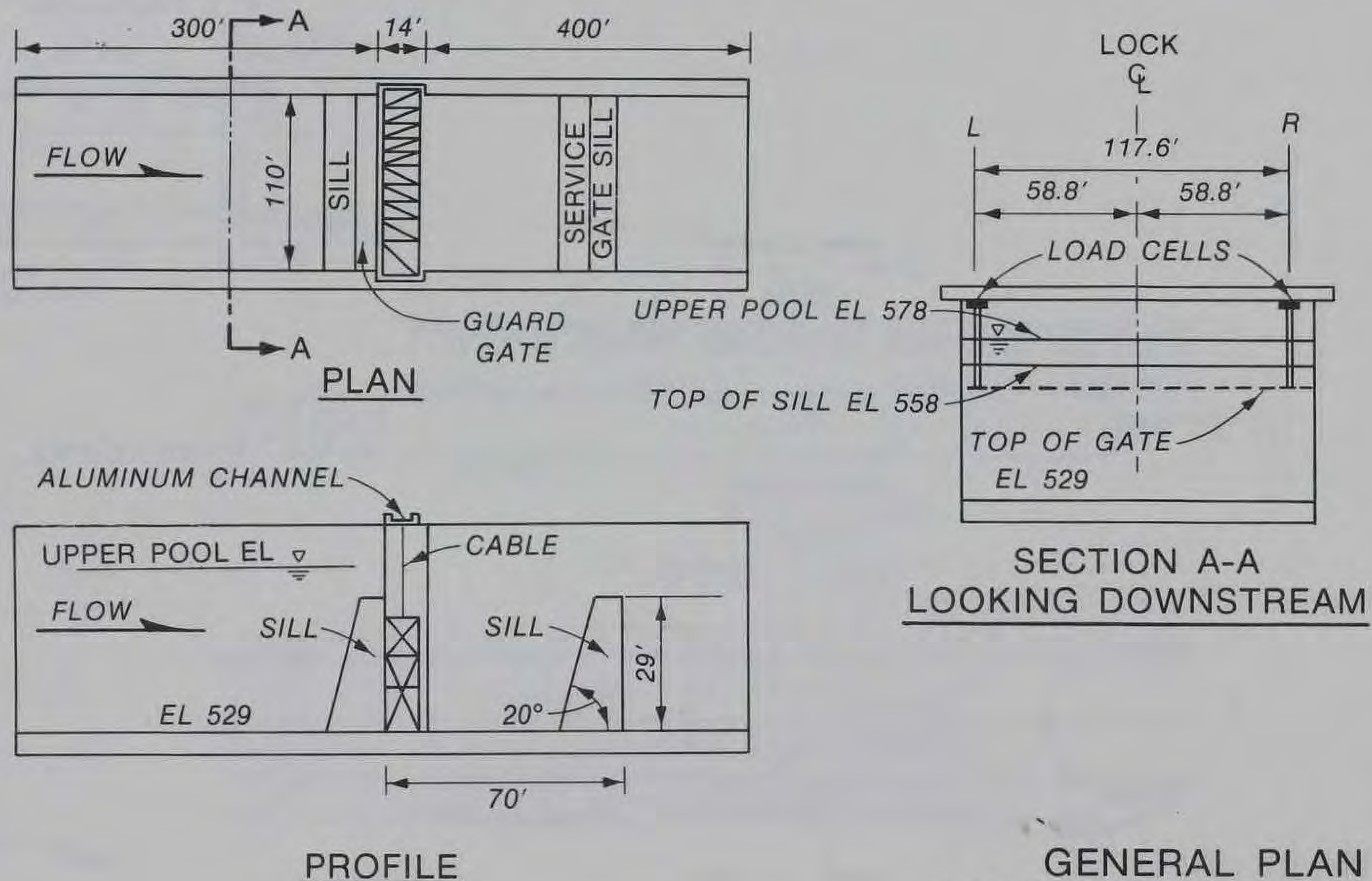



Photo 3. Unit discharge 27 cfs/ft, $d_r$ = 6.0 ft, pool el 568 ft (NGVD), tailwater el 539 ft (NGVD)

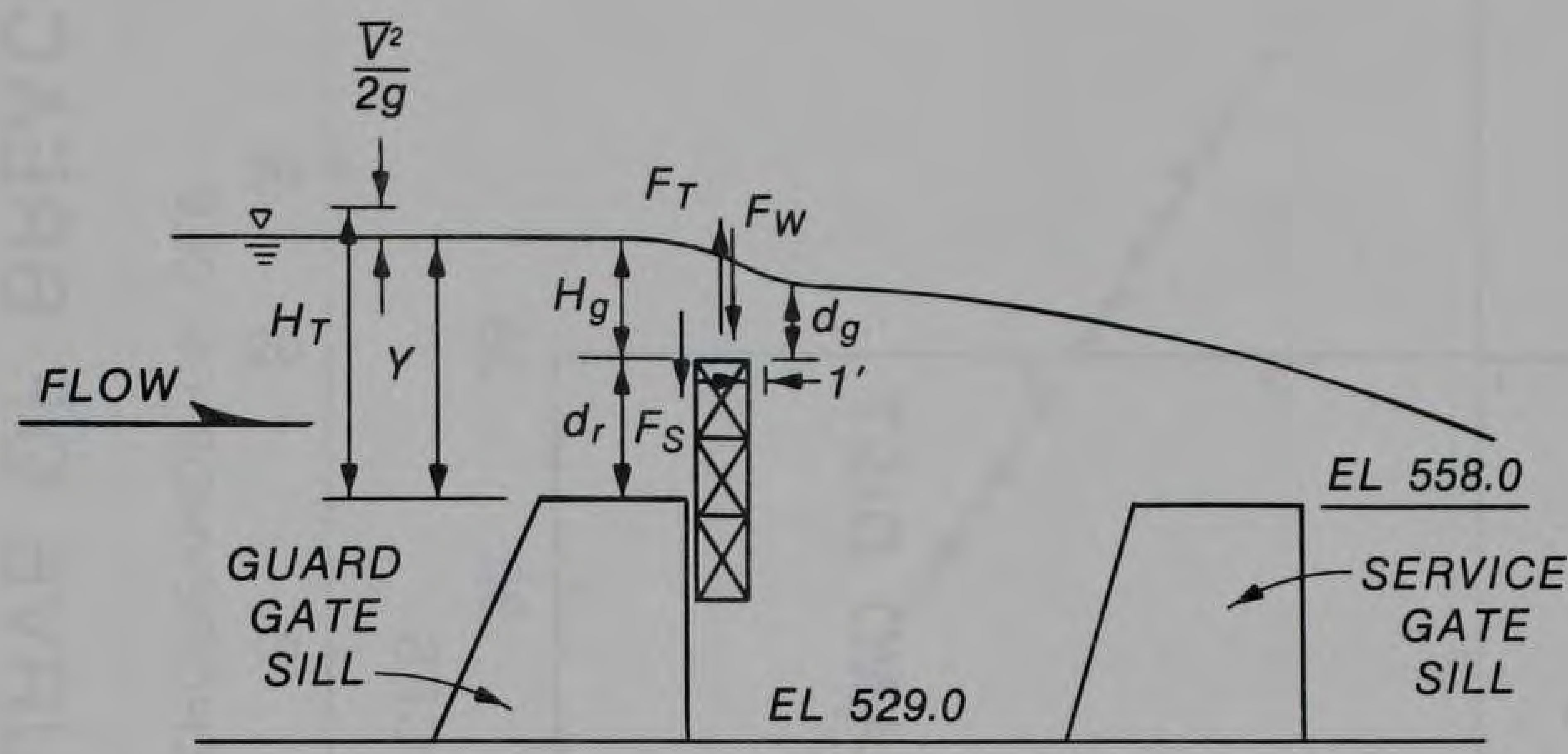



GENERAL PLAN
LOCKPORT LOCK




ALL DIMENSIONS ARE IN PROTOTYPE.

GENERAL PLAN
LOCKPORT LOCK MODEL




VARIABLES

$d_g$ = DISTANCE FROM WATER SURFACE TO TOP OF GATE, FT, MEASURED 1 FT FROM DOWN-STREAM EDGE OF GATE.

$d_r$ = EXPOSED HEIGHT OF GATE ABOVE SILL, FT.

Y = DEPTH OF FLOW ON GUARD GATE SILL, FT.

$F_S$ = DRY WEIGHT OF GATE MINUS WEIGHT OF VOLUME OF WATER DISPLACED BY GATE WITH TAILWATER OF 558.0, LB.

$F_T$ = MAXIMUM TOTAL MEASURED FORCE, LB.

$F_W$ = FORCE DUE TO WATER, LB, $F_W = F_T - F_S$.

$H_T$ = TOTAL HEAD ON GUARD GATE SILL, FT. $Y + \overline{V}^2/2g$.

$H_g$ = HEAD ON GUARD GATE, FT.

$\overline{V}$ = AVERAGE VELOCITY, FT/SEC.

g = ACCELERATION DUE TO GRAVITY, FT/SEC$^2$.

$\overline{V}^2/2g$ = VELOCITY HEAD, FT.

EXAMPLE CALCULATION

PHASE 1:

AT Y = 10 FT, $d_r$ = 4 FT, $d_g$ = 2 FT, $F_T$ = 349,600 LB

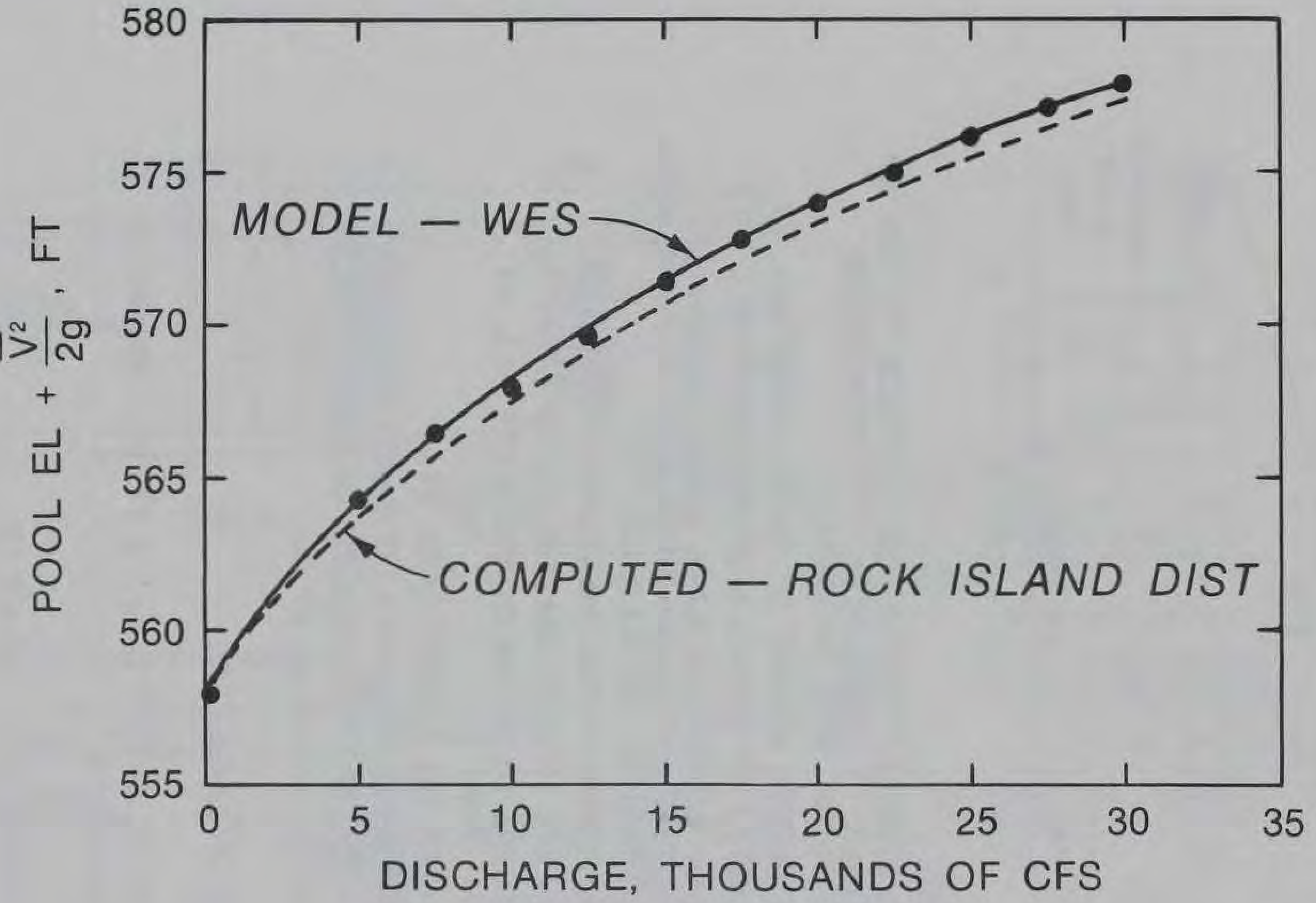
$F_S$ = 347,400 LB

$F_W = F_T - F_S$

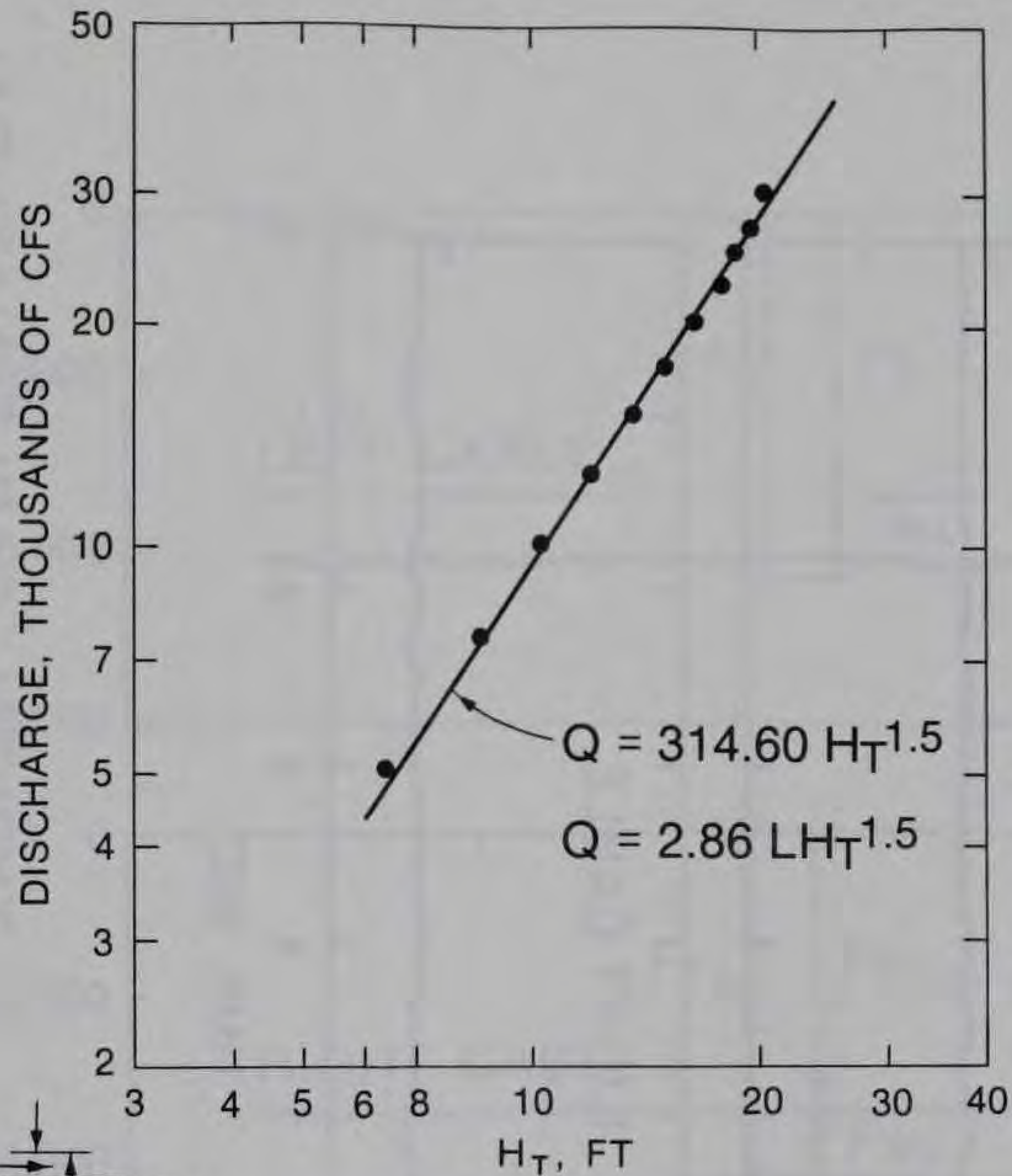
$F_W$ = 349,600 LB - 347,400 LB

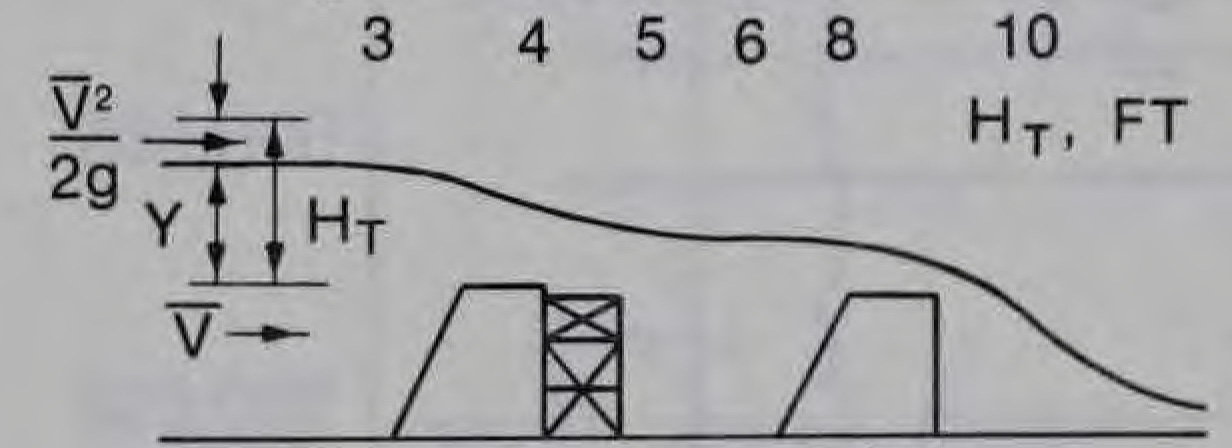
$F_W$ = 2,200 LB

MODEL SECTION OF BREACH
LOCKPORT LOCK LIFT GATE




RATING CURVE OF BREACH




ELEV ℄ LOCK

<u>BASIC EQUATION</u>

$H_T = Y + \overline{V}^2/2g$

WHERE:

$H_T$ = TOTAL HEAD ON GUARD GATE SILL, FT

$Y$ = DEPTH OF FLOW ON GUARD GATE SILL, FT

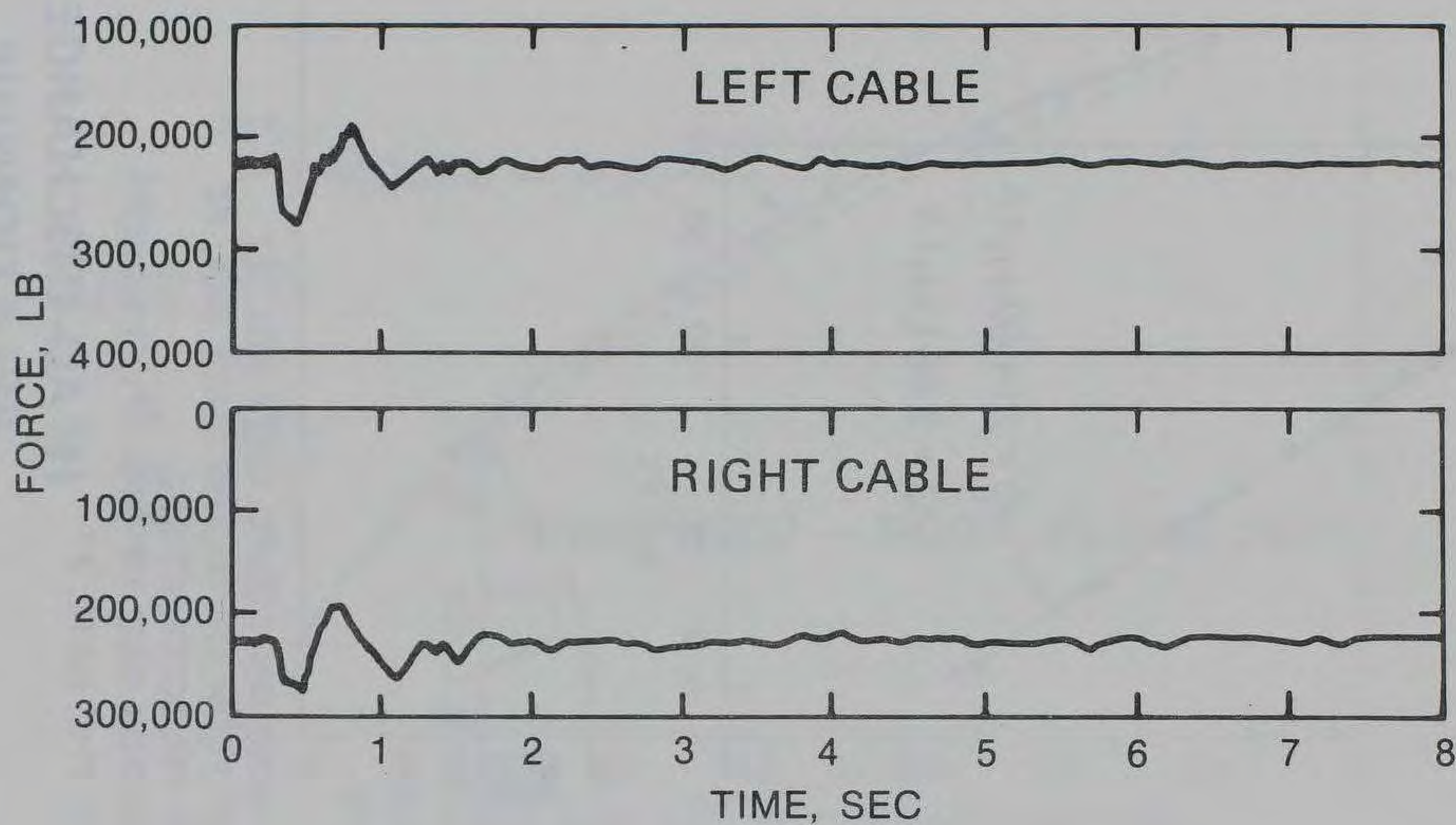
$\overline{V}$ = AVERAGE VELOCITY, FT/SEC

$g$ = ACCELERATION DUE TO GRAVITY, FT/SEC$^2$

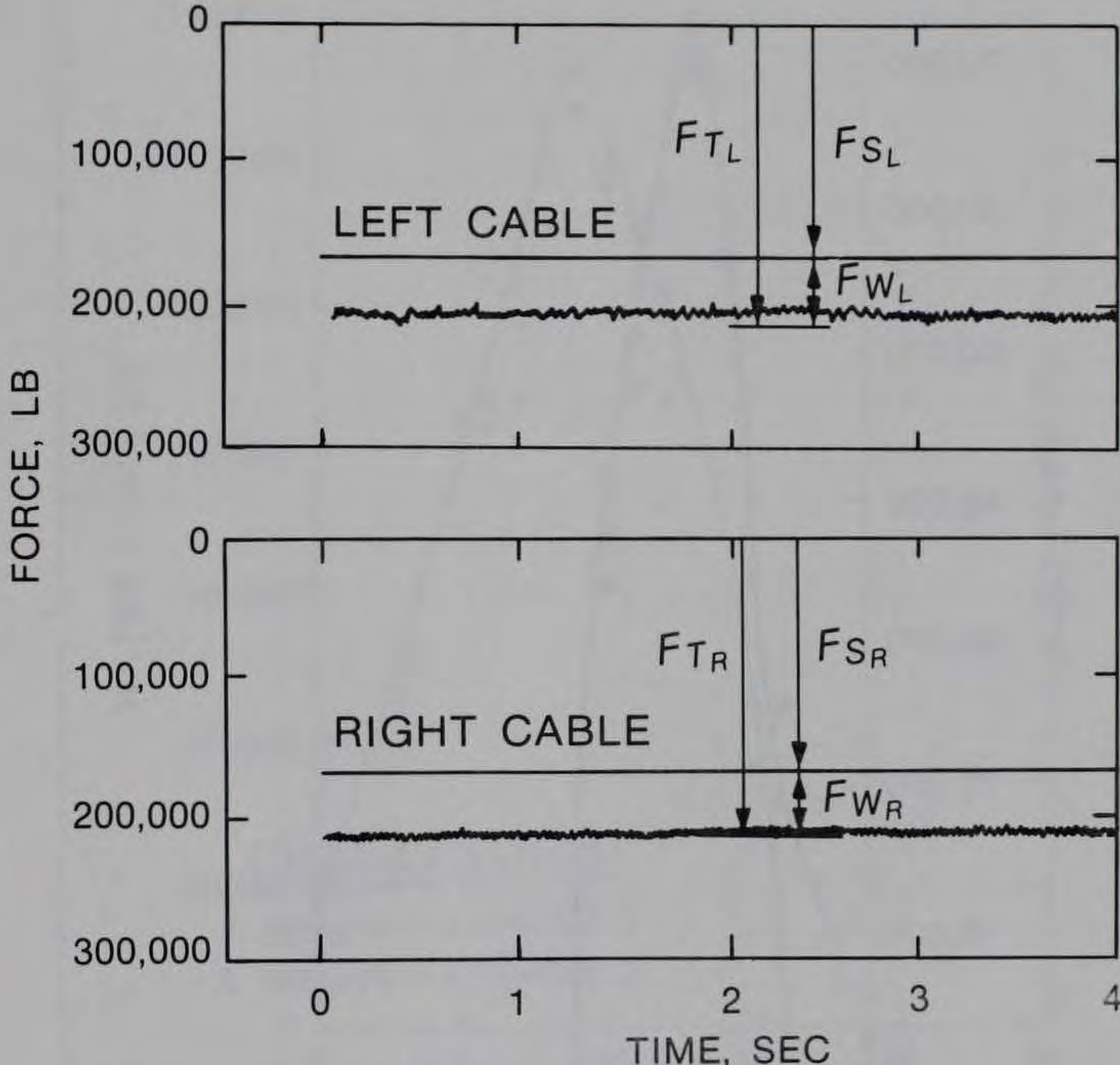
$L$ = WIDTH OF THE GATE, FT

**HEAD-DISCHARGE RELATIONSHIP**

**$d_r = 0$**




TYPICAL CABLE NATURAL FREQUENCIES




$F_T = F_{T_L} + F_{T_R}$

$F_S = F_{S_L} + F_{S_R}$

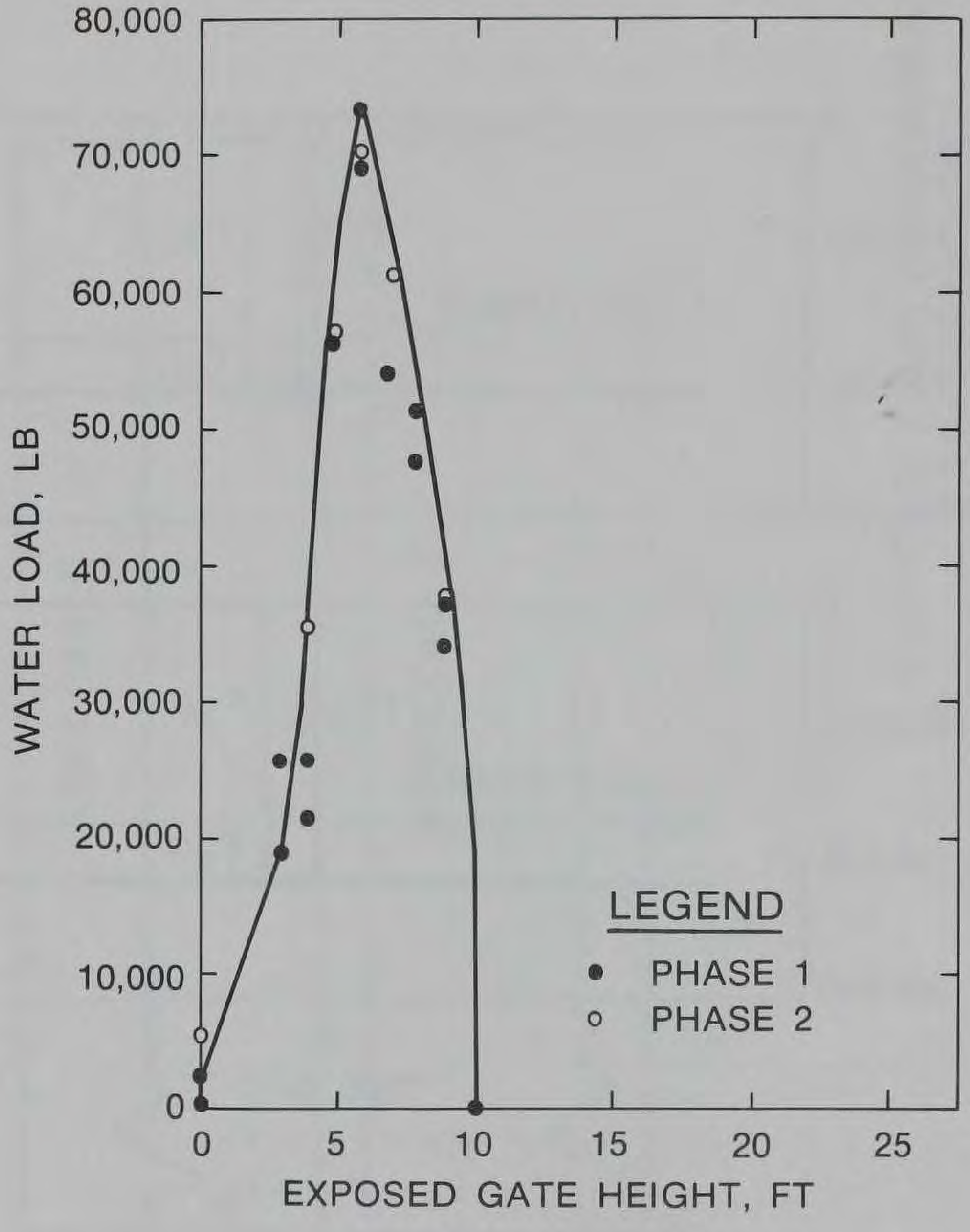
$F_W = F_{W_L} + F_{W_R}$

## TYPICAL CABLE

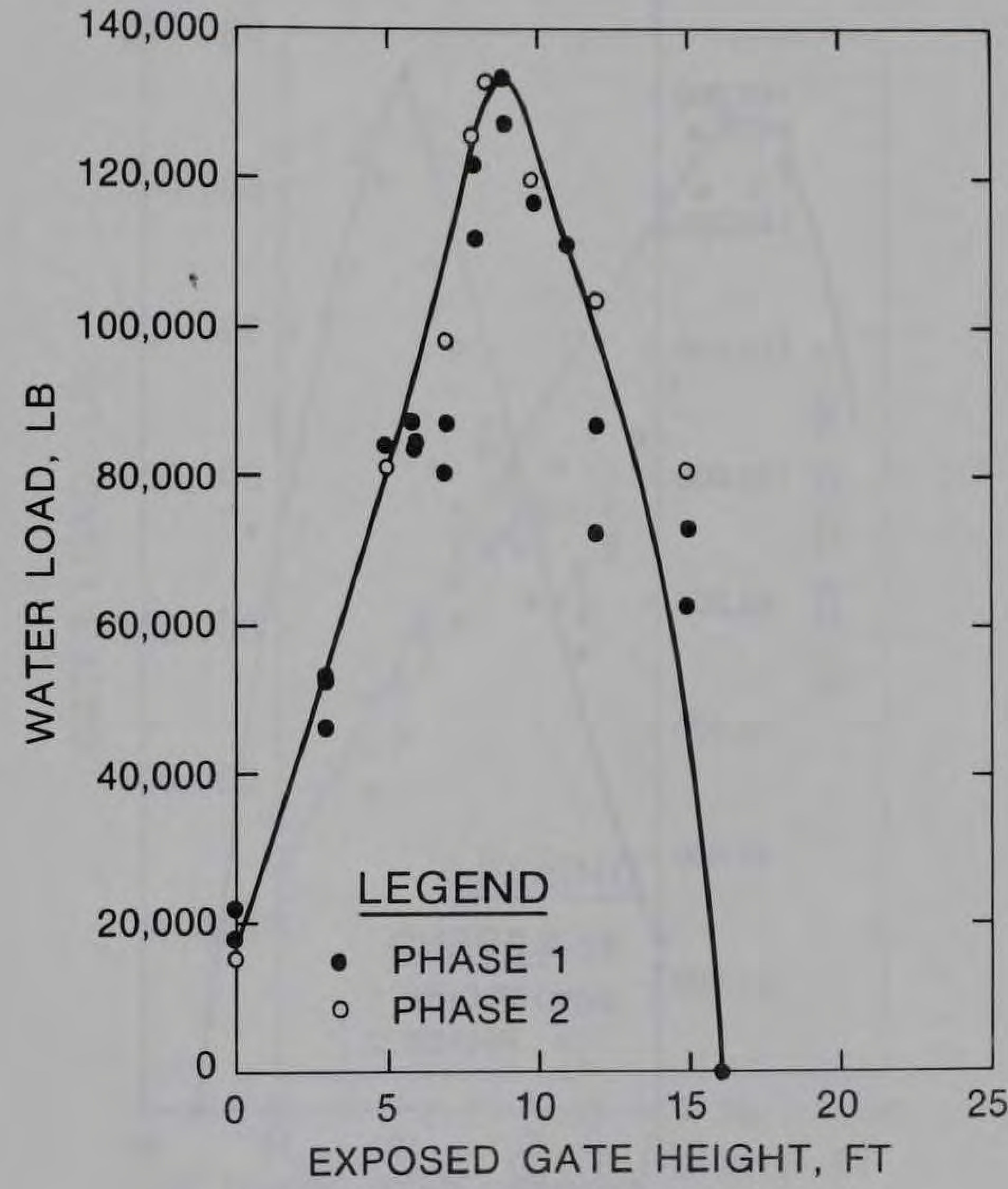
FORCE MEASUREMENT

$Y = 18$ FT

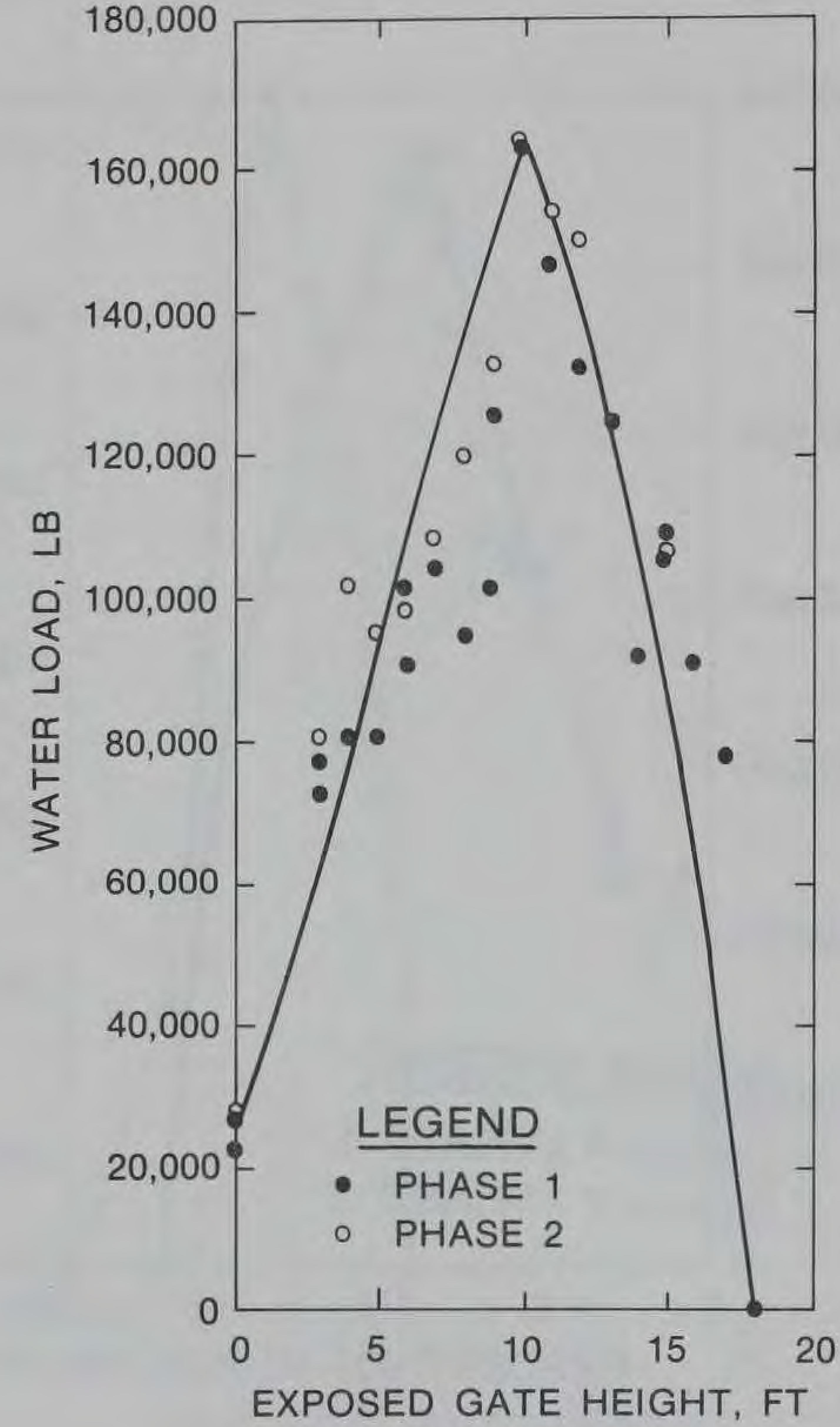
$d_r = 3$ FT



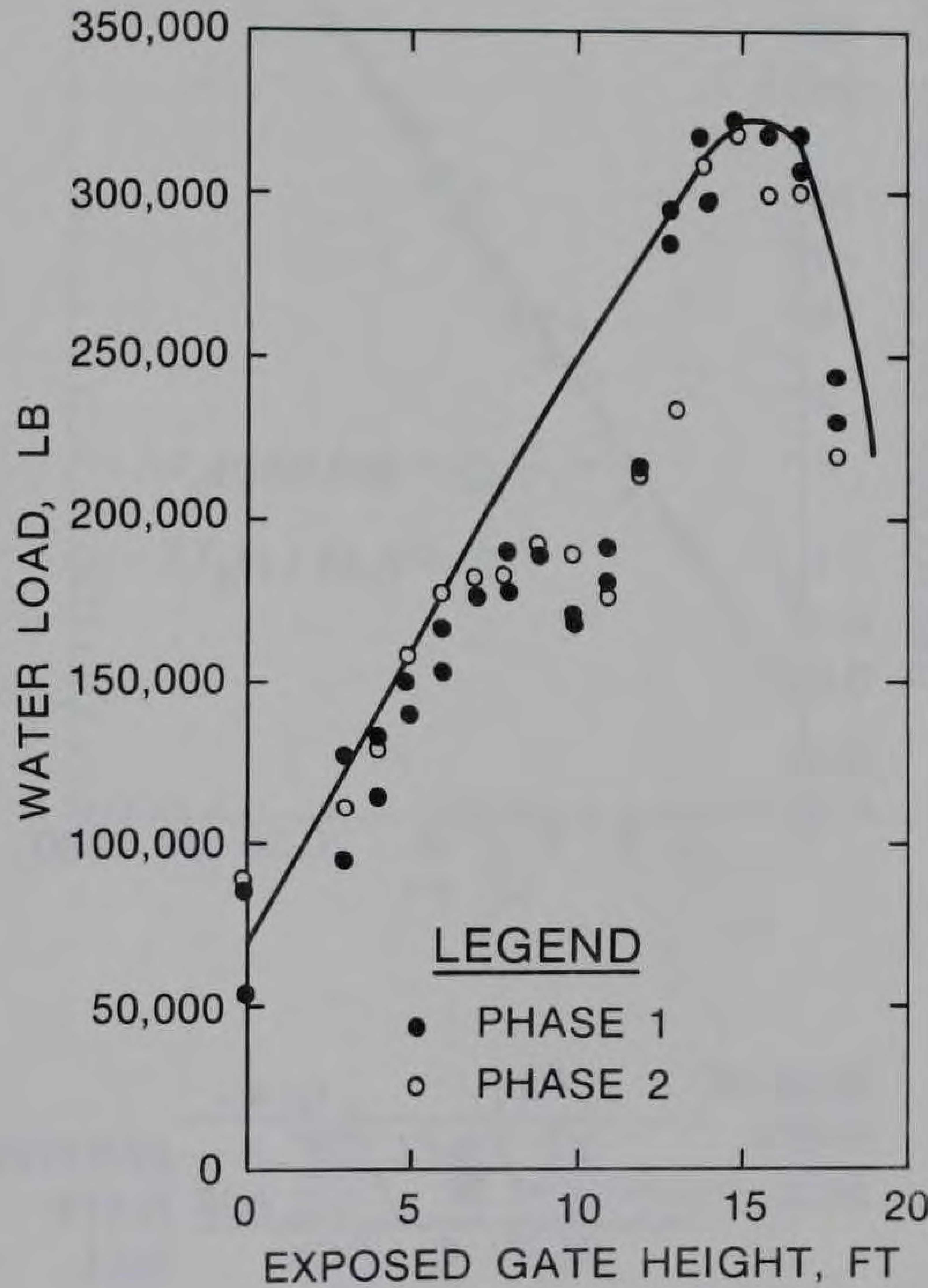

WATER LOAD
VERSUS
EXPOSED GATE HEIGHT
Y = 10 FT



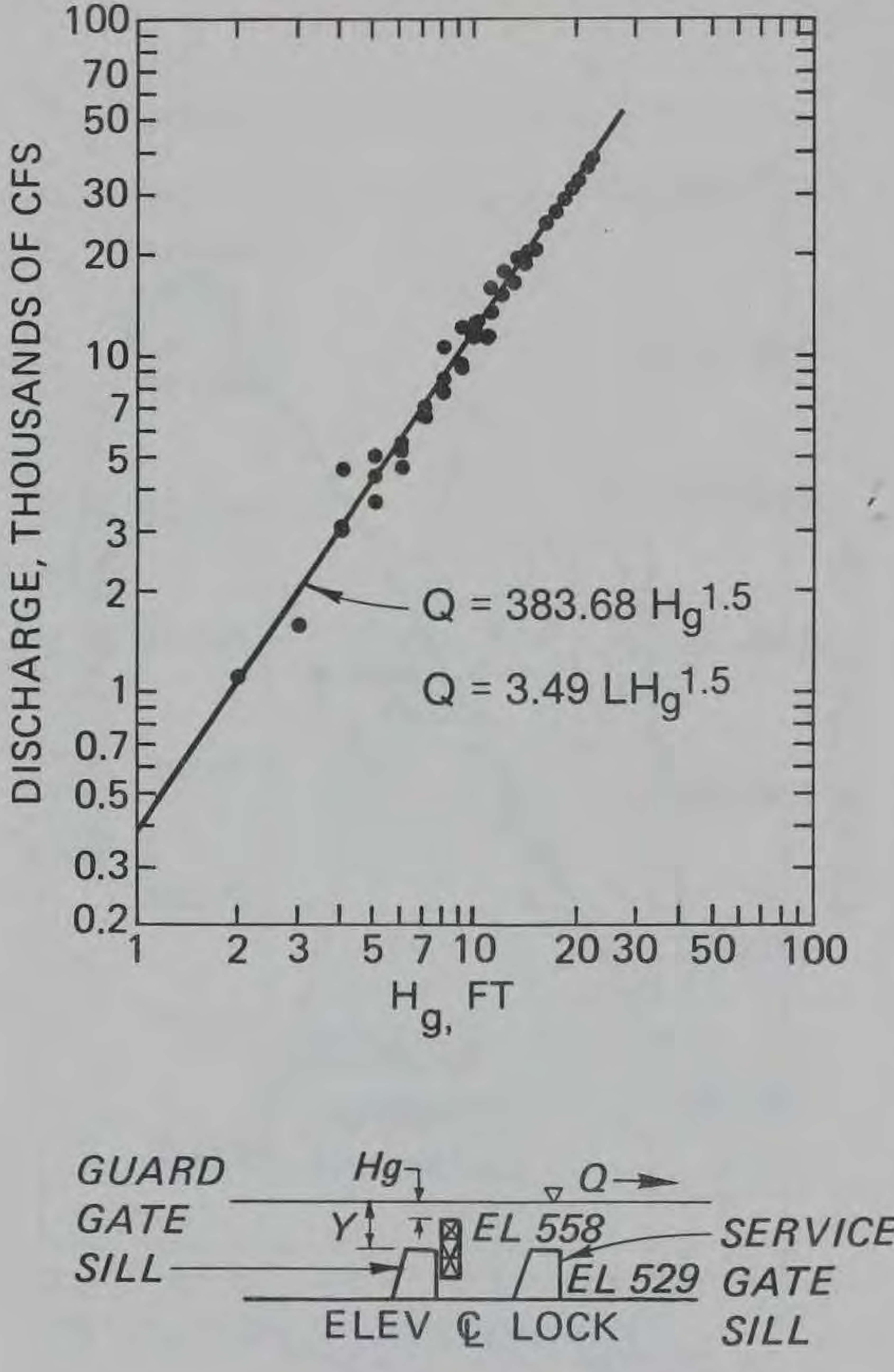

WATER LOAD
VERSUS
EXPOSED GATE HEIGHT
Y = 16 FT




WATER LOAD
VERSUS
EXPOSED GATE HEIGHT
Y = 18 FT




WATER LOAD
VERSUS
EXPOSED GATE HEIGHT
Y = 25 FT




**HEAD - DISCHARGE RELATIONSHIP**

**$d_r$ = 3 FT THRU 18 FT**