OPERATING FORCES ON MITER-TYPE LOCK GATES

TECHNICAL REPORT NO. 2-651

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
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ARMY-MRC VICKSBURG, MISS.

PREFACE

Investigation of the operating forces on miter-type lock gates was authorized by the Office, Chief of Engineers, on 6 January 1948, as part of the Civil Works Investigation Program (CW 300). General plans for the investigation were formulated during a conference held at the Waterways Experiment Station on 25 February 1949. Represented at this conference were the Office, Chief of Engineers, the Waterways Experiment Station, and several of the Division and District offices which at that time were concerned with lock operating problems.

All tests were conducted at the Waterways Experiment Station under the general direction of and in cooperation with engineers of the Office, Chief of Engineers. Mr. G. D. Smith of that office visited the test facilities on several occasions and his guidance was particularly helpful.

Personnel of the Hydraulics Division, Waterways Experiment Station, actively engaged in the study included Messrs. A. H. Barnes, J. L. Grace, Jr., J. D. Harms, and E. S. Melsheimer under the general supervision of Messrs. T. E. Murphy, F. R. Brown, and E. P. Fortson, Jr. This report was prepared by Messrs. Grace, Murphy, and Brown.

Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors of the Waterways Experiment Station during the conduct of this study and the preparation of this report. Mr. J. B. Tiffany was Technical Director.

CONTENTS

SUMMARY

Tests to determine operating forces on miter-type lock gates were conducted in a 5.5-ft-wide, 66.5-ft-long, 4.25-ft-deep flume equipped with a single set of miter gate leaves located approximately in the center of the flume. Three linkages, with different kinematics of the operating machinery, were studied: modified Ohio River, Panama, and Ohio River. For each linkage, tests were conducted at gate submergences of 1 to 4 ft and at operating times of 10.1 to 40.2 sec. The effects of chamber length, bottom clearance of gates, presence of barges in the lock chamber, and nonsynchronous operation of the gate leaves also were investigated.

Peak hydraulic resistance to operation of the miter gate was observed as the leaves entered and left the mitered (closed) position with the maximum resistance occurring as the leaves entered the mitered position. (Peak torques were actually observed as the leaves left the recesses (began closing) with the Ohio River and modified Ohio River linkages, but these torques were created by sudden application of loads to the rigid model linkages and thus were not considered representative of those of prototype gates which are equipped with shock absorbers.) The modified Ohio River and Panama linkages resulted in peak resistances in terms of torque at the pintles which were approximately equal and about 40 percent less than the peak torques obtained with the Ohio River linkage.

Other general findings were:

- a. An increase in submergence of the gate leaves or speed of operation resulted in increased hydraulic resistance.
- b. Hydraulic resistance increased as the bottom clearance of the gate leaves was decreased.
- c. Hydraulic resistance decreased as the length of the lock chamber was increased.
- d. Nonsynchronous operation of the gate leaves resulted in a slight reduction in peak torque.
- e. Limited tests conducted with barges in the lock chamber showed no appreciable effect of a tow in the chamber on torque values.
- f. Although only limited field test data are available, the peak torques observed on prototype miter gates utilizing

the modified Ohio River linkage compare favorably with those observed on the model gates.

g. Peak torques observed in model tests of the Panama linkage by the Special Engineering Division of the Panama Canal (see Appendix A) occurred during the opening cycle whereas peak torques were observed during the closing cycle in the WES model tests. However, the maximum torque value predicted from the WES tests on the basis of average angular velocity of gate travel, for equal submergence and operating time, compares favorably with that predicted from the Panama Canal tests.

OPERATING FORCES ON MITER-TYPE LOCK GATES

PART I: INTRODUCTION

The Problem

1. The miter-type gate is the most frequently employed type of lock gate. It consists of a pair of symmetrical leaves which when open fit into recesses in the lock walls, and when closed seal against sills in the lock bottom and bear against each other at the center line of the lock. Each gate leaf is swung about a vertical axis. The operating machinery for miter gates usually consists of a large gear wheel and a sector arm revolving in a horizontal plane. This wheel is connected to the gate leaf by a strut, one end of the strut being joined to the sector arm fastened to the large wheel and the other end to a pin on the gate leaf. The large gear wheel is usually driven either by an electric motor located in a recess in the lock wall or by a hydraulically operated cylinder arrangement. The latter method is used when the locks are subject to flooding by high river stages.

2. Miter gates are not suitable for operation under other than essentially balanced conditions, that is, the lock chamber must be filled or emptied by means of a culvert system prior to operation of the gate leaves. Thus the water level on each side of the gate is equalized, or nearly so, before movement of the gate leaves is undertaken. The forces to be overcome by the gate-operating machinery are friction, wind loads, surges, hydraulic drag forces, and head differentials created by the leaves moving through the water.

3. Friction and wind loads can only be estimated, but are generally small in comparison with the hydraulic loads. Although it would appear that evaluation of operating forces caused by hydraulic drag and head differential could be made through tests on existing lock gates, in practice it has been found difficult to make accurate load measurements in the field; furthermore, it is not possible to vary field operating conditions such as gate speed and gate submergence (height of water on gate). In view of the difficulties enumerated above, only limited use has been

made of prototype test data. In 1941 and 1942, the Special Engineering Division, Panama Canal, made considerable use of model tests in connection with the design of the Third Lock Project. The report on these tests is included herein as Appendix A. An article on the Panama Canal miter gate model study has also been published.*

Purpose and Scope of Investigation

4. The purpose of the study reported herein was to investigate by means of model tests the force required to move miter-type lock gates throughout the opening and closing cycles under a wide range of conditions. Variables to be investigated included (a) kinematics of operating machinery, (b) submerged depth of gate, (c) operating time, (d) chamber length, (e) bottom clearance under gate, (f) the presence of barges in the chamber, and (g) nonsynchronous operation of the gate leaves.

5. Evaluation of the effects of the variables outlined in paragraph 4 on miter gate operation was accomplished for three types of linkages: the modified Ohio River type, the Panama type, and the Ohio River type. The principal difference between the three linkages is the angularity of the connecting strut and sector arm at the extremities of gate travel. The modified Ohio River linkage has angularity between the strut and sector arms at open position only, the Panama linkage has no angularity at either the open or closed position, and the Ohio River linkage has angularity at both the open and closed positions. The Panama linkage is usually driven by an electric motor, whereas hydraulic cylinders are the driving mechanism for miter gates with the modified Ohio River or Ohio River linkages.

6. The kinematics of the operating cycle are such that the elimination of all angularity between the strut and sector arm (Panama linkage) reduces the velocity of gate movement near the limits of gate travel for uniform rate of movement (constant travel) of the operating machinery. This in turn reduces the peak loads on the operating machinery. However, this reduction cannot be obtained at each end of the operating cycle unless

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* Maurice N. Amster, "Hydraulic model investigation of miter gate operation." Proceedings, American Society of Civil Engineers, vol 70, No. 3 (New York, N. Y., March 1944), pp 303-319.

the sector arm is raised above the large gear wheel to permit passage over the central axis. The raising of the sector arm creates an eccentric load on the system which some designers desire to avoid.

Test Facilities

Flume and miter gate

7. The test facilities consisted of a wooden flume 66.5 ft long, 5.5 ft wide, and 4.25 ft deep (fig. 1), with a single set of 4.5-ft-high miter gate leaves, located approximately in the center of the flume, dividing the flume into 31.5-ft-long upstream, and 30.0-ft-long downstream chambers. Provisions were made for varying the clearance under the gate and lock chamber length. The gate was constructed of sheet metal and 1/4-in.-thick steel plate attached to 2-in.-diameter-pipe pintles. A skin plate was fastened to the upstream face of the gate only. The gate leaves were supported on ball bearings packed with grease to minimize frictional resistance. The gate and gate recesses, shown in detail in fig. 2, approximated those of Chain of Rocks Lock, Mississippi River.

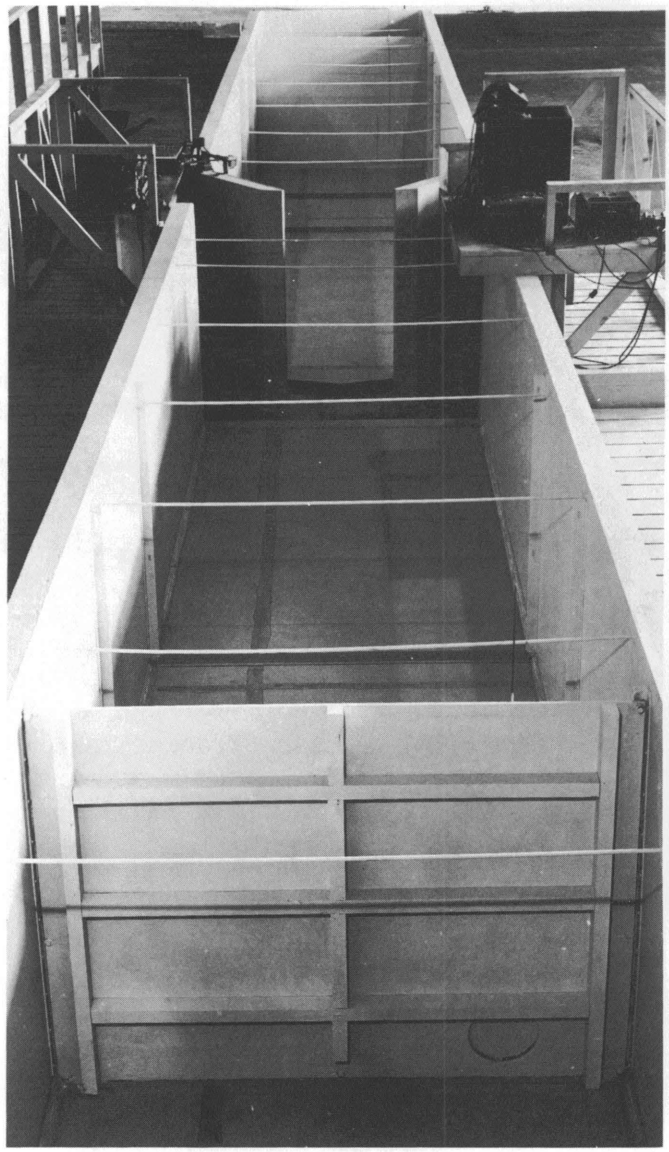

Fig. 1. Model lock chamber

Method of operating gate

8. The gate leaves were operated hydraulically. The hydraulic circuit (fig. 3) consisted of a rotary pump driven by a 1.5-hp, a-c motor, two 2-in.-diameter, double-acting pistons connected in series with

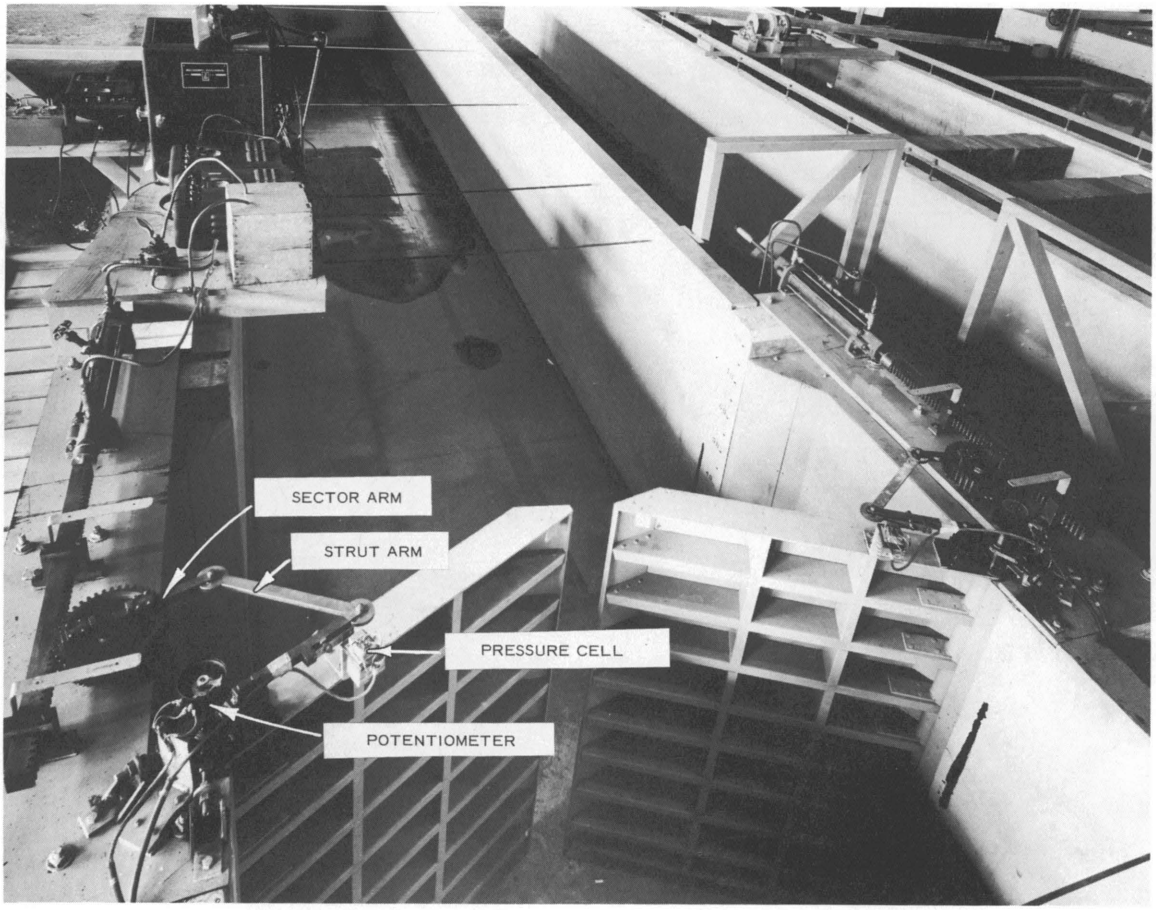

Fig. 2. Details of downstream face of miter gate, linkage, and measuring equipment

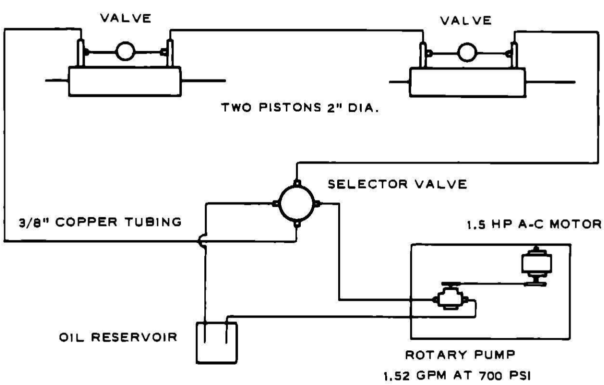

Fig. 3. Schematic of hydraulic operating equipment

3/8-in.-diameter copper tubing, and a source of hydraulic brake fluid. An operating pressure of 700 psi was used to produce constant piston travel and, consequently, a minimum deviation between the theoretical and recorded instantaneous gate position. A rack fastened to each piston rod engaged a large gear whose resulting rotary motion transmitted the force required for movement of each gate leaf by means of the linkage (fig. 2). Speed control was obtained by means of a throttle valve located between the selector valve and the hydraulic cylinders.

Instrumentation

Torque measurement

9. The deflection of a 3/4-in.-square steel beam, 12 in. in length, was used to determine the torque produced by the hydraulic forces acting to resist movement of a gate leaf. Fastened to the side of the 3/4-in. beam was a thin steel cantilever to which a Statham cell, an electrical resistance-type strain gage, was attached (figs. 2 and 4). This cantilever not only afforded protection to the strain gage, which had a maximum deflection of 0.0015 in. but also provided an easy means of recording the range of expected hydraulic forces with the same Statham cell. The cell, in conjunction with a d-c amplifier, served to convert the deflection of the beams to movement of a pen on the recording tape of a six-channel oscillograph (fig. 5). The beams were calibrated by fixing the gate leaf,

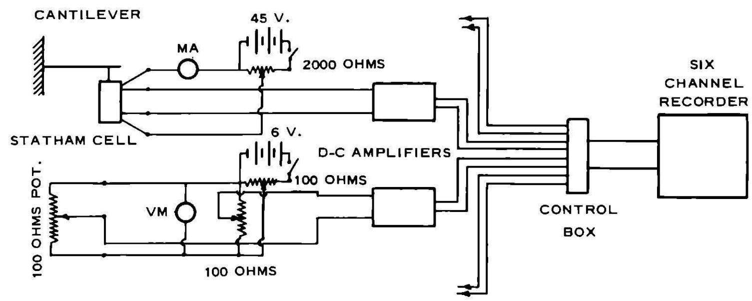

Fig. 4. Schematic of electrical measuring equipment

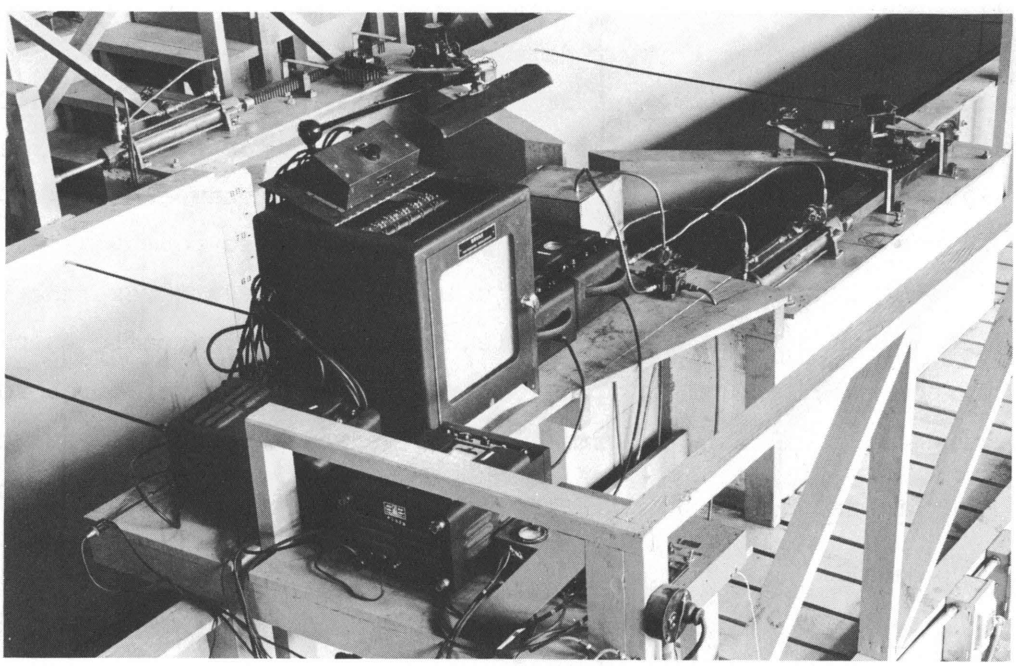

Fig. 5. Recording equipment

applying known loads in a direction perpendicular to and in the horizontal plane of the beams, and noting the recorded amplitude on the oscillograph. Thus the force recorded on the gate leaf during any test was always the component acting at right angles to the gate rather than the direct force exerted by the strut arm. As a check on the measurement of the hydraulic forces, measuring apparatus was installed on each gate leaf.

Gate position indicator

10. A linear potentiometer, with its rotating arm connected to the center of the gate leaf's rotating shaft and its resistance element fixed (see fig. 2), was employed as part of a Wheatstone bridge circuit to determine the instantaneous gate position, that is, to continuously record the gate's position so that it would be known for any instant of the operating time. The signal from this circuit was fed to a d-c amplifier and the six-channel oscillograph. The position indicator circuit was calibrated by swinging the gate leaf through known angles and noting the recorded amplitude on the oscillograph. Again, provision was made for recording the instantaneous position of both leaves.

Scale Relations

11. Basic data and test results are presented in terms of model dimensions purposely in order that data can be applied to a variety of prototype locks similar in nature yet different in terms of actual dimensions. The test facility was essentially a 1:20-scale model of a 110-ft-wide by 85-ft-high lock in which the upstream and downstream chamber lengths were equal and were varied from 300 to 600 ft. The accepted equations of hydraulic similitude, based on Froude's law, can be used to express mathematical relations between the geometric, kinematic, and dynamic characteristics of the model and prototype. General and specific relations for transference of model data to prototype equivalents are as follows:

Dimension	Ratio	Scale Relations
Length	L_r	1:20
Time	$t_r = L_r^{1/2}$	1:4.472

(Continued)

Dimension	Ratio	Scale Relations
Velocity	$V_r = L_r^{1/2}$	1:4.472
Force	$F_r = L_r^3$	1:8,000
Torque	$T_r = L_r^4$	1:160,000

12. In the application of the model data to lock widths other than 110 ft, it is suggested that the length ratio be determined on the basis of relative gate-leaf lengths.

Test Procedure

13. Before tests of each linkage were begun, several trial openings and closings of the miter gate leaves were made without water in the lock to determine both the inertial force imparted to the gate leaves to start movement and the friction forces that might be encountered. In the final analysis of the test data, the forces measured in operation of the gate in the dry were subtracted from the total forces recorded in the tests to give the true hydraulic force encountered. This procedure was believed permissible since, in the prototype, shock absorber springs are usually located at the junction of the strut arm and the gate to reduce inertial forces.

14. Prior to each test, the linkage and physical dimensions of the gate and lock chamber were adjusted to the desired conditions. Then the operating speed of the gate leaves was adjusted by the throttle valve between the selector valve and the hydraulic pistons, and the water level in the lock was adjusted to the desired amount of gate submergence. The water in the lock was allowed to stand until it became calm to eliminate any residual wave action, and testing was then undertaken.

PART II: TESTS AND RESULTS

Initial Test Series

15. An initial series of tests was conducted on the Ohio River linkage for a number of conditions. These tests were reported in Advance Reports 1 and 2, prepared for limited distribution by the Waterways Experiment Station, and in a paper presented at the 7th meeting of the National Conference on Industrial Hydraulics, Chicago, Illinois, 1951.* The detailed results of these initial tests are not included herein because of the large difference between the recorded and calculated (theoretical) gate positions for constant travel of the hydraulic-driven piston.

16. In the series of tests reported in the following paragraphs (the second series), a rotary pump larger than the one used in the initial tests was provided to reduce the difference between the theoretical and recorded instantaneous gate positions to a minimum, so that the torque values measured over the entire operating cycle would be more nearly correct for uniform movement of the hydraulic piston.

Modified Ohio River Linkage

Kinematics

17. The modified Ohio River linkage has angularity between the strut and sector arms at the recess or open position and no angularity at the mitered or closed position. Kinematics of the operating cycle, and gate and recess details are shown in fig. 6.

Forces measured during gate operation

18. Typical oscillographs of the closing and opening cycles with the gate operating in the dry and at a 4-ft submergence are shown in fig. 7. In each instance the sudden acceleration of a gate leaf from zero velocity to the operating velocity resulted in a large indicated torque. Also, at the end of the opening cycle, after the gate reached the recess position,

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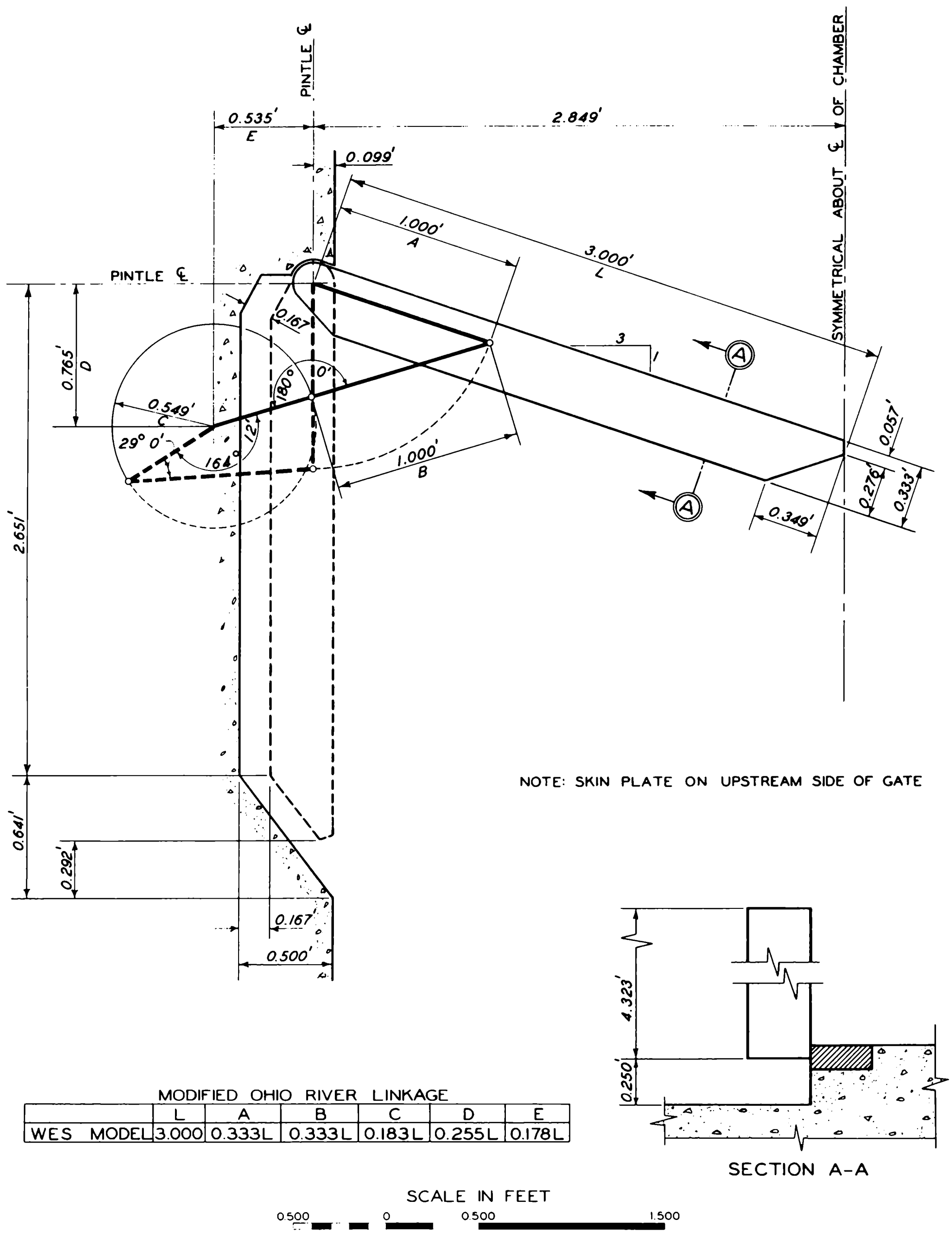
* Frederick R. Brown, Operating Forces on Miter-Type Lock Gates, 1951.



MODIFIED OHIO RIVER LINKAGE

	L	A	B	C	D	E
WES MODEL	3.000	0.333L	0.333L	0.183L	0.255L	0.178L

Fig. 6. Kinematics of operating cycle and gate and recess detail, modified Ohio River linkage

there was a sudden drop in torque followed by vibrations due to sudden stoppage of gate movement, after which torque values were recorded with maximum amplitudes nearly as large as those obtained when the gate reached the mitered position. These large values of torque observed when starting and stopping movement of the rigid model linkage were not considered representative of the torques on miter gates equipped with shock absorbers.

19. It is believed also that because of the impact characteristic

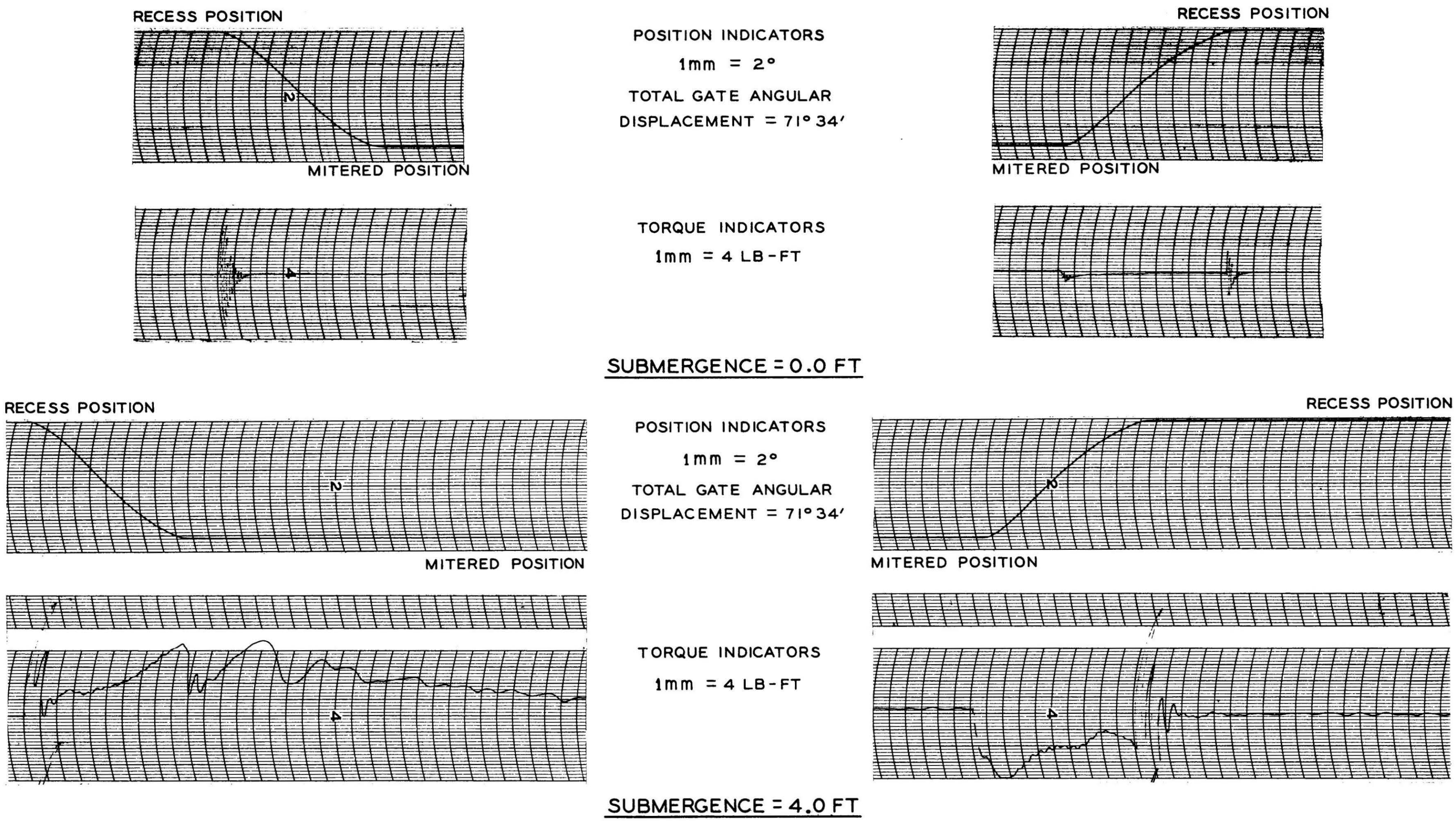


Fig. 7. Typical oscillograph record, modified Ohio River linkage, operating time 10.1 sec, chamber lengths 25 ft

of the applied force to overcome the inertia of the gate leaf, the measuring cantilever was caused to deflect more than it would have for a similar but steady force. Prototype gates are provided with shock absorbers to reduce these large impact loads. For this reason, the torque at the beginning of the closing cycle and end of the opening cycle was determined as the ordinate of the point of intersection of a curve extended from the portion of the oscillograph record free of vibrations through the averaged values of the vibrations. Unusual loads were not evident as the gate left or entered the mitered position; this was attributed to the favorable position of the linkage.

20. Deviation between the theoretical gate position, based on constant piston travel, and the recorded instantaneous gate position is shown in fig. 8. This deviation was within ±3 percent of the calculated position for the maximum and minimum submergences and all operating times. The longer the time of operation, the less the deviation between observed and calculated gate position.

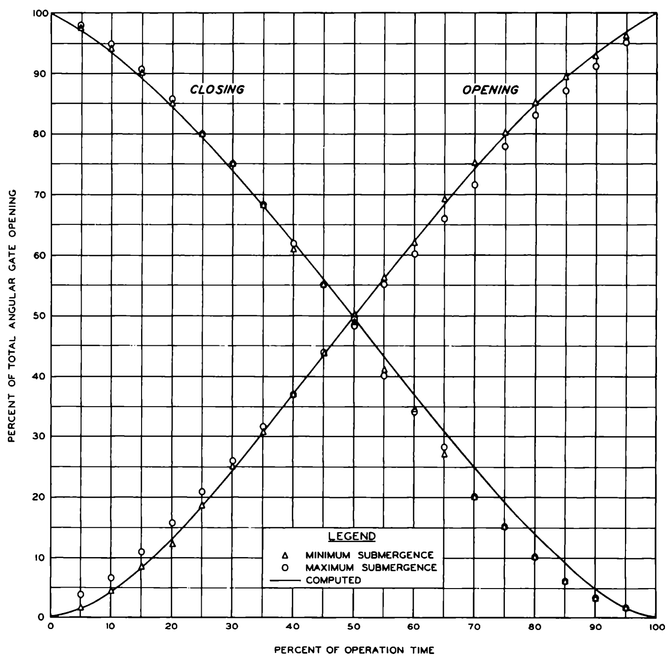
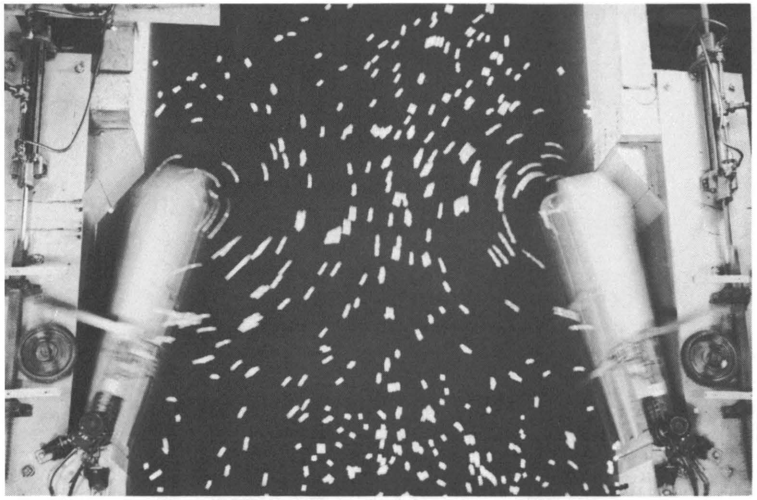


Fig. 8. Deviation between theoretical and recorded instantaneous gate position

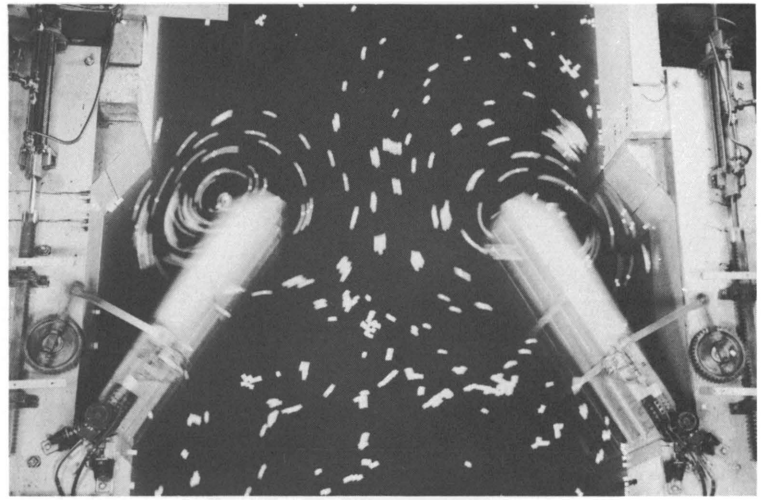
21. Eddy conditions set up by movement of the gate leaves are shown in fig. 9. Closure of the gate created eddies on the side opposite the direction of gate travel and displaced a volume of water in the lock chamber, i.e. the water surface was raised on the side in the direction of gate travel and lowered on the other side. This head differential, though slight, was sufficient to account for an appreciable part of the total load.

Effect of submergence

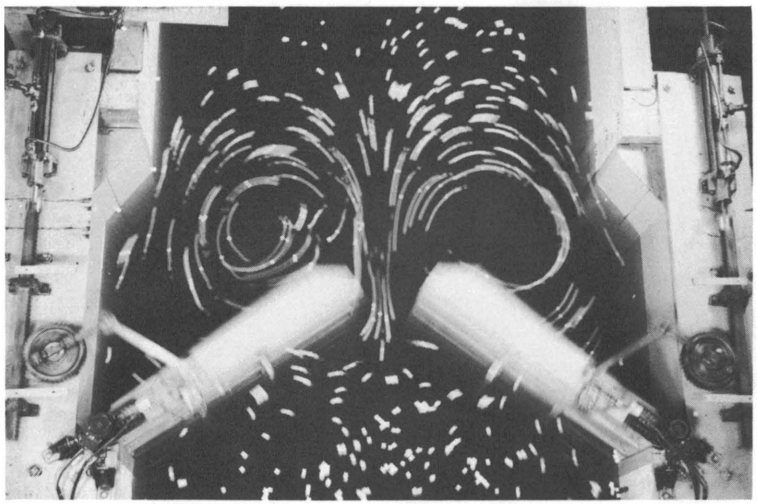
22. With the physical dimensions of the test facilities (such as bottom clearance of gate, shape of gate and gate recesses, and length of chamber) remaining constant, tests were made at submergences from 1 to 4 ft in increments of 0.5 ft for gate-operating times of 10.1 sec and



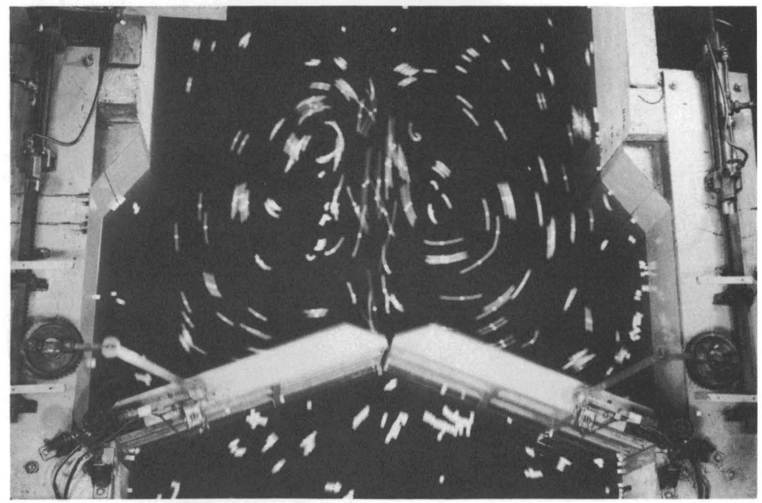
a. 1/4 closed



b. 1/2 closed



c. 3/4 closed



d. Closed

Fig. 9. Flow pattern with gates closing; exposure time, 2 sec

13.4 to 40.2 sec in increments of 6.7 sec.

23. Torque curves plotted from an average of the measured instantaneous torques on each gate leaf are presented in plates 1-6. Close agreement between the results of measurements on the individual leaves was obtained. The short-duration, high torque values at the beginning of the closing cycle are considered to have been caused primarily by the sudden application of the load. The peak values observed as the gate leaves entered or left the mitered position are believed representative of maximum torque values which will occur in the prototype.

24. Plots of the maximum torque, recorded near the mitered position for both the closing and opening cycles, as a function of submergence of the gate leaves are shown in plate 7. It appears from these plots that the maximum torque recorded as the gate leaves entered the mitered position varied as the 1.9 power of the submergence; the maximum torque recorded as the gate leaves left the mitered position varied as the 2.2 power of the submergence.

Effect of operating time

25. A comparison of plates 1-6 also shows the effect of gate operating time on the maximum torque value. Plots of maximum torque as a function of the operating time (plate 7) indicate that the maximum torque decreased as the 1.1 power of the operating time for the closing cycle, and as the 1.5 power for the opening cycle. The maximum torque value recorded during the closing cycle was slightly greater than that recorded during the opening cycle.

Effect of chamber length

26. Tests to study the effect of length of lock chamber on hydraulic forces on miter gates were made by varying the length of chamber on each side of the gate from 15 to 30 ft in increments of 5 ft. These tests were made at submergences from 2.5 to 4.0 ft in increments of 0.5 ft, for operating times of 10.1 sec and of 13.4 to 40.2 sec in increments of 6.7 sec.

27. Torque curves plotted from an average of the measured instantaneous forces on each gate leaf for chamber lengths of 15, 20, and 30 ft are presented in plates 8-25. The effects of submergence and operating time on the maximum torque of the 15-, 20-, and 30-ft chamber lengths are presented

in plates 26, 27, and 28, respectively; plate 7 shows similar data for a chamber length of 25 ft. The maximum torque values observed for the various submergences, chamber lengths, and operating times also are plotted in plates 29 and 30. Analysis of these data indicates that all three variables influence the value of torque. In general, for a particular operating time, the maximum torque decreased as the chamber length increased. It also appears that as the length of operating time was increased, the length of lock chamber had less effect on torque values.

28. Attention is invited to the fact that the data on lock length may not be directly applicable to single-lift prototype structures. The waves created upstream and downstream by the movement of the pair of gate leaves would be reflected in only one of the chambers; the wave in the other chamber would be dissipated in the long reach upstream or downstream from the lock. The wave generated in the test flume by the initial movement of the gate in practically every instance could travel to the end of the chamber and return to the gate before it was closed. The effect of this wave on the maximum torque recorded as the gate leaves entered the mitered position in the closing cycle was dependent on the direction of travel of the reflected wave, and both an increase and a decrease in torque were observed. Wave movement away from the closing gate leaves produced reduced torques as the leaves entered the mitered position but later upon its return and reflection upon the closed gate, torque values were observed that were nearly as large as those recorded when wave movement was opposite the direction of gate travel and the wave impinged upon the gate leaves as they entered the mitered position. It should be remembered that the test linkage was rather rigid, whereas the prototype linkage has shock absorbers. For this reason, it is expected that the effect of reflected waves will be less in the prototype. The actual displacement of water in the chamber also is a contributing force as mentioned in paragraph 21. The maximum torque for the opening cycle was recorded immediately after the gate left the mitered position, while it was not affected by wave action or by displacement of water in the test facilities.

Effect of presence of barges in lock chamber

29. Tests to study the effect of barges in the lock chamber on

hydraulic forces on miter gates were made by placing four barges abreast at distances of 1.25, 2.50, 3.75, and 4.00 ft from the gate pintles on the downstream side. These barges (1.35 ft wide, 4.5 ft long, and 0.75 ft high) occupied 98 percent of the entire width of the chamber, and were at a draft of 0.45 ft. For each location of the barges, tests were conducted at gate submergences from 1.0 to 4.0 ft in increments of 1.0 ft, for operating times of 10.1 sec and 13.4 to 40.2 sec in increments of 6.7 sec.

30. Data on the maximum torques observed as the leaves approached the mitered position of the closing cycle, with and without barges located downstream from the gate, are presented in table 1 and are graphically compared in fig. 10. These data indicate that the barges had negligible effect on hydraulic forces.

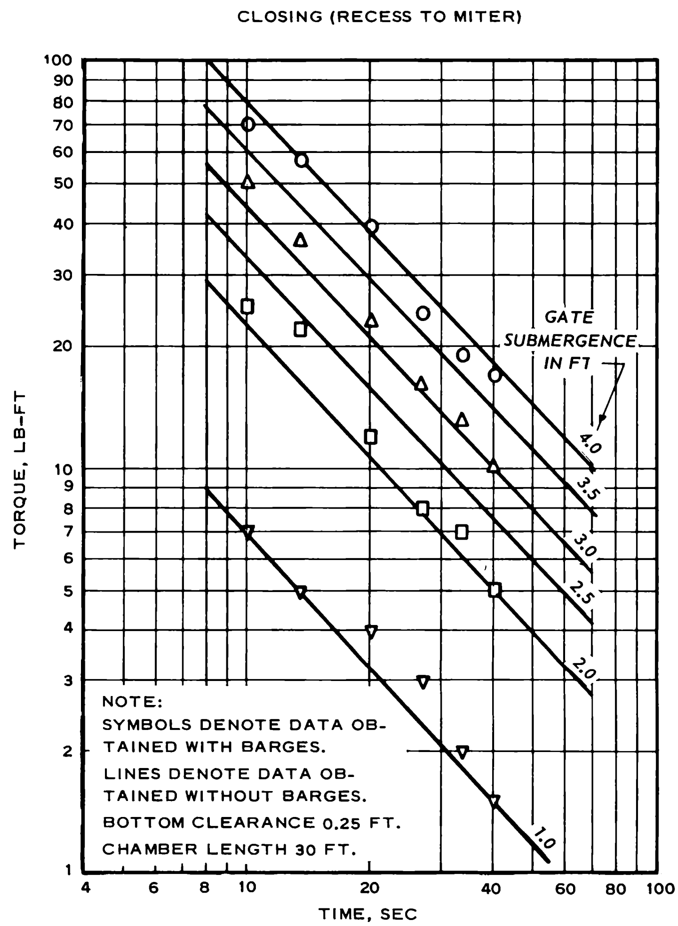


Fig. 10. Effect of barges on maximum torque, modified Ohio River linkage

Effect of nonsynchronous operation of gate leaves

31. Since it is difficult to secure synchronous operation of the gate leaves in the prototype, hydraulic forces were recorded on both model gate leaves while one lagged 1.1, 2.2, 3.4, or 4.5 sec behind the other. Some data were also obtained for single-leaf operation. The results of these tests, plotted in plates 31 and 32, reveal that forces on the leading leaf were slightly less than those recorded for synchronous operation. Hydraulic forces on the lagging gate leaf were greater during most of the closing cycle and less during the opening cycle than similar forces recorded for synchronous operation of the

gate leaves. This reversal in torque values in the opening and closing cycle is attributed to the shape of the gate lip and the different flow characteristics between the gate leaves during the two cycles. For single-leaf operation, hydraulic forces were reduced considerably.

Effect of gate bottom clearance

32. No tests were conducted in the second series of tests (see paragraph 16) for various gate clearances; however, in the initial series, tests were conducted wherein the bottom clearance under the gate was varied from 1/4 to 3 in. These tests revealed an increase in torque values as the bottom clearance decreased, regardless of the length of operating time. Data from these tests, taken where the deviation of the recorded and computed instantaneous gate position was a minimum (±3 percent), are presented in plate 33 and indicate the percentage increase in torque for various bottom clearances relative to the torque observed with a 3.0-in. bottom clearance. These data can be used to adjust the observed torque values determined for a bottom clearance of 3.0 in.

Panama Linkage

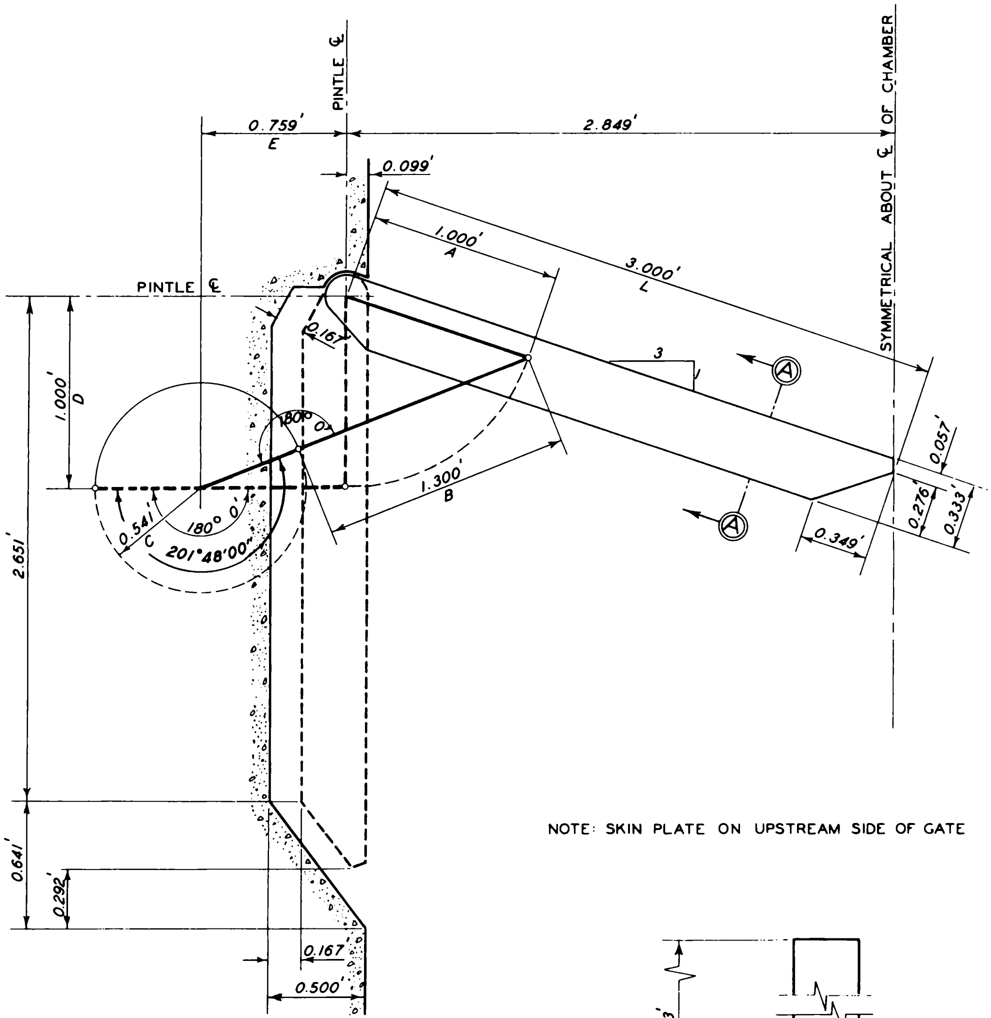
Kinematics

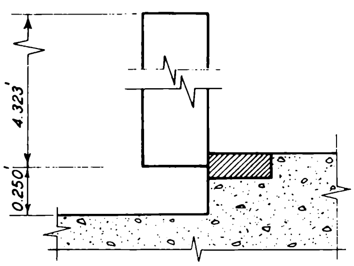
33. Kinematics of the operating cycle for the Panama linkage are shown in fig. 11. This linkage has no angularity between the strut and sector arms at either the open or closed positions of the gate.

Forces measured during gate operation

34. Typical oscillographs of the closing and opening cycles, with the gate operating in the dry and at a 4-ft submergence, are shown in fig. 12. The favorable position of the linkage at each end of the operating cycle resulted in no unusual impact loads either at the beginning or end of an operation.

35. Deviation between the theoretical gate position, based on constant piston travel, and the recorded instantaneous gate position was





SECTION A-A

PANAMA TYPE LINKAGE

	L	A	B	C	D	E
WES MODEL	3.000	0.333L	0.433L	0.180L	0.333L	0.253L

SCALE IN FEET

0.500 0 0.500 1.500

Fig. 11. Kinematics of operating cycle and gate and recess detail, Panama linkage

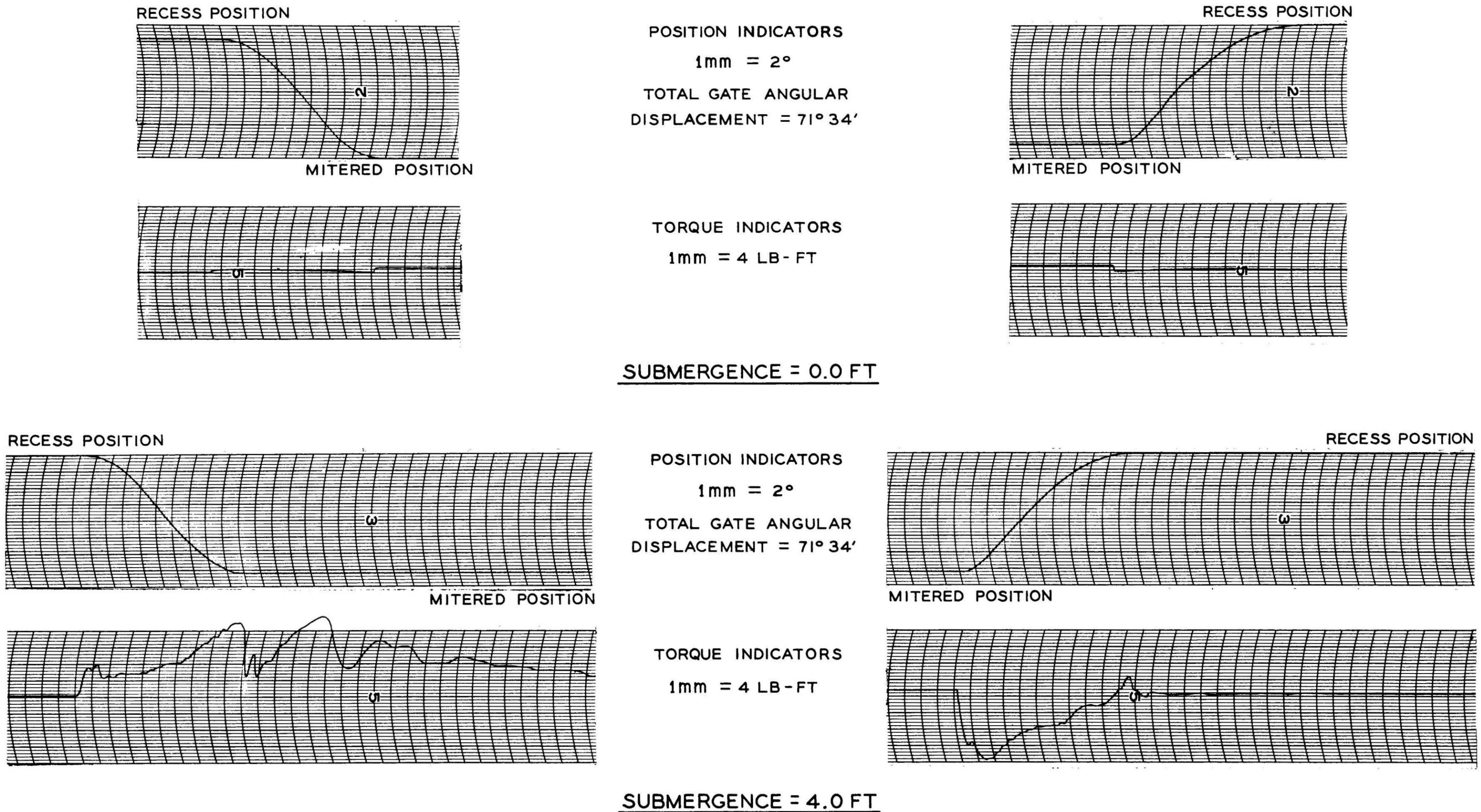


Fig. 12. Typical oscillograph record, Panama linkage, operating time 10.1 sec, chamber lengths 25 ft

less than ±3 percent for maximum and minimum submergences and all operating times (fig. 13).

36. Although (as mentioned in paragraph 6) the driving force for the Panama linkage is usually an electric motor, all tests reported herein were made with the hydraulic cylinder. Efforts were made to utilize an electric motor with known torque-slip characteristics so as to reproduce full-scale operating conditions as nearly as possible, but torque-slip characteristics could not be maintained from test to test with any of the several motors tried.

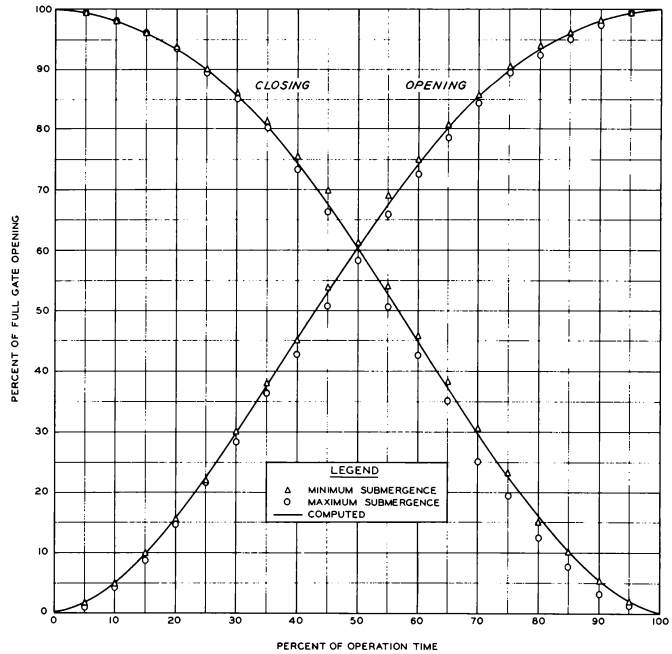


Fig. 13. Deviation between theoretical and recorded instantaneous gate position

Effect of submergence

37. Curves plotted from an average of the measured instantaneous torques on each gate leaf are presented in plates 34-39. Results obtained on the individual leaves were in close agreement. In all tests, the peak torque was obtained before the gate entered and after it left the mitered position. Plots of the maximum torque, recorded near the mitered position for both the closing and opening cycles, as a function of submergence of the gate leaves are shown in plate 40. It appears from these plots that the maximum torque recorded as the gate leaves entered the mitered position varied as the 1.5 power of the submergence; the maximum torque recorded as the gate leaves left the mitered position varied as the 1.7 power of the submergence.

Effect of operating time

38. The torque curves in plates 34-39 also show the effect of the gate-operating time on the maximum torque value. The plots of maximum torque as a function of speed of operation (plate 40) indicate that the maximum torque decreased as the 1.1 power of the operating time for the closing cycle, and as the 1.3 power for the opening cycle.

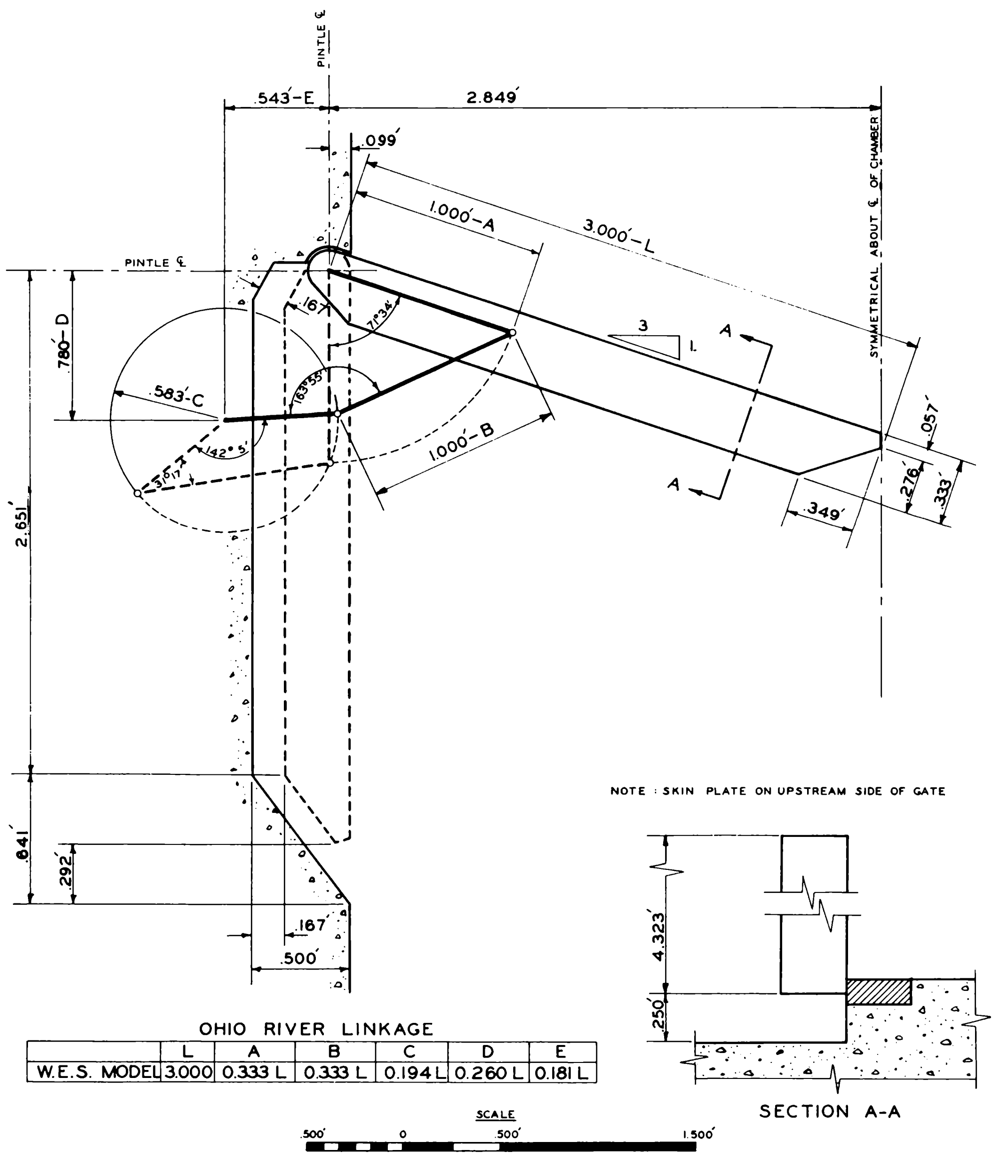
Bottom clearance

39. For conditions of gate bottom clearances of other than 3 in., it is suggested that the relations for modified Ohio River linkage, listed in paragraph 32, be used.

Ohio River Linkage

Kinematics

40. The Ohio River linkage has angularity between the strut and sector arms at both the open and closed positions (fig. 14).



OHIO RIVER LINKAGE

	L	A	B	C	D	E
W.E.S. MODEL	3.000	0.333 L	0.333 L	0.194 L	0.260 L	0.181 L

Fig. 14. Kinematics of operating cycle and gate and recess detail, Ohio River linkage

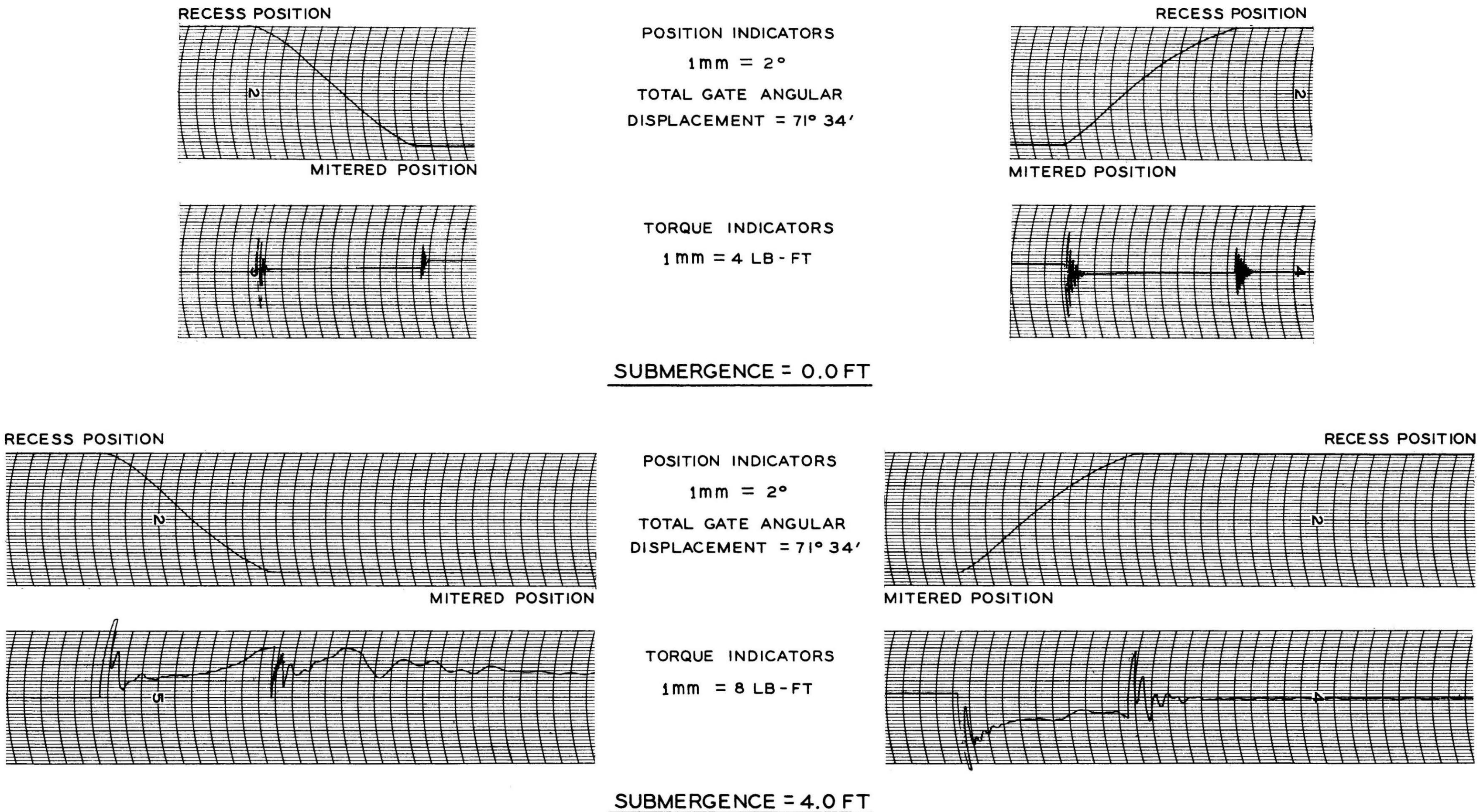


Fig. 15. Typical oscillograph record, Ohio River linkage, operating time 10.1 sec, chamber lengths 25 ft

Forces measured during gate operation

41. Typical oscillographs of the closing and opening cycles with the gate operating in the dry and at a 4-ft submergence are shown in fig. 15. Note that at each end of both the closing and opening cycles there was a series of vibrations due to sudden starting and stopping of the gate leaves. Since prototype gates are equipped with shock absorbers to reduce these impact loads, the torque at each end of an operating cycle was determined as the ordinate of the point of intersection of a curve extended from the portion of the oscillograph record free of vibrations through the averaged values of the vibrations.

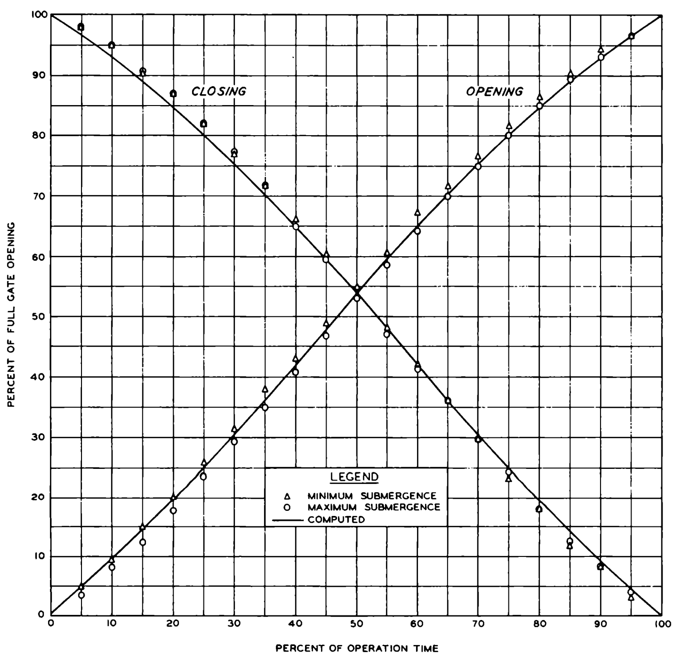


Fig. 16. Deviation between theoretical and recorded instantaneous gate position

42. Deviation between the theoretical gate position, based on constant piston travel, and the recorded instantaneous gate position is shown in fig. 16, and was within ±3 percent for the maximum and minimum submergences and all operating times.

Effect of submergence

43. Torque curves plotted from an average of the measured instantaneous torques on each gate leaf are shown in plates 41-46. Again, the short-duration, high torque values at the start of the closing cycle are believed to have been caused primarily by impact, and the peak values observed near the mitered position are considered to represent the maximum torque which will occur at a prototype installation. Plots of the maximum torque, recorded near the mitered position for both the closing and opening cycles, as a function of submergence of the gate leaves are shown in plate 47. These plots indicate that the maximum torque recorded as the gate leaves entered the mitered position varied as the 1.5 power of the submergence; the maximum torque recorded as the gate leaves left the mitered position varied as the 2.1 power of the submergence.

Effect of operating time

44. The torque curves plotted in plates 41-46 also show the effect of the gate-operating time on the value of the maximum torque. The plots of maximum torque as a function of operating time (plate 47) indicate that the maximum torque decreased as the 1.0 power of the operating time for both the opening and closing cycles.

Effect of gate bottom clearance

45. For conditions of gate clearances at the bottom of other than 3 in., the procedure outlined in paragraph 32 should be used.

PART III: DISCUSSION

Loads on Operating Machinery

46. The fact that peak hydraulic resistance to operation of the miter gate occurred as the leaves entered the mitered position suggests that head differential on the two sides of a gate leaf is the primary cause of loads on the operating machinery. If drag forces were the predominating influence, it would be expected that the peak load would occur simultaneously with the maximum rate of angular movement, which for all linkages tested happened when the gate was about 45 percent open. Also, if inertial forces were major factors, the torque should have been greatest as the leaves moved away from the mitered position and were accelerating, while the reverse was found to be true.

47. In the test facilities, no attempt was made to simulate the effect of operation of the filling or emptying culverts on the hydraulic resistance to the operation of the miter gate. Because of the transient nature of the water-level differences acting on the gate leaves, there is considerable doubt that the open culverts would have a measurable effect on the peak forces. In this connection, reference is made to discussion of ASCE Paper No. 2257 by Maurice N. Amster.* In any case, the miter gate machinery would have to be designed to operate the gates under the most adverse conditions, that is, with the culvert valves closed.

48. Surges, from any cause, in the lock chamber or lock approach also could have an appreciable effect in either increasing or decreasing loads, depending on the direction of the surge. In the model study surges which were initiated by movement of the gate leaves and traveled to the ends of the lock chambers and back to the gate during closing operations, are believed to have caused the considerable scattering of data obtained during the series of tests concerned with chamber lengths. Thus, although the trend in these tests was for loads on the operating machinery to decrease as the chamber length increased, certain combinations of chamber

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* Maurice N. Amster, "Hydraulic model investigation of miter gate operation." Paper No. 2257, <u>Transactions, American Society of Civil Engineers,</u> vol 72, No. 2, Part 3 (New York, N. Y., 1945), pp 1297-1326.

lengths, water depths, and operating speeds could result in either quite favorable or extremely adverse loads during the closing cycle.

49. Occasionally, surges caused by overtravel of water in the culvert system during filling of a lock chamber combine with drawdown in the upper lock approach channel to create a differential head tending to open the upper gate; on some locks, this head has been estimated to be from 1 to 2 ft. These transient forces do not affect the power requirements of the miter gate operating machinery, but they do require consideration in the design of the machinery elements.

Prototype Tests

50. In prototype tests it is most difficult to obtain the same degree of control as in model tests; thus only limited field test data are available for comparison with the results presented herein. The Waterways Experiment Station has cooperated with the U. S. Army Engineer Districts at Mobile, Ala., and Nashville, Tenn., in prototype tests on the miter gates of locks at Demopolis, Ala., and Cheatham, Tenn., which utilize the modified Ohio River linkage. Although final analysis of the data has not been completed, the maximum torques observed during the simultaneous closing of the prototype gates were compared with those predicted using the model results reported herein. Prototype and equivalent model dimensions are given in table 2.

51. The model torque value, shown in plate 28 for a 2.45-ft submergence and operating time of 26 sec, was changed to the Demopolis Lock prototype equivalent, and based on data in plate 33, was multiplied by 1.20 to approximate the value for a prototype clearance under the gate of 2.93 ft rather than 5 ft (clearance simulated in model). The WES model tests indicate a peak torque during the closing cycle of 2.4×10^6 lb-ft, that measured in the Demopolis test. Similarly, the model torque value for a submergence of 1.35 ft and an operating time of 20.4 sec when changed to the Cheatham Lock prototype equivalent and multiplied by 1.20 to approximate the value for a bottom clearance of 3 ft rather than 5 ft predicted a torque of 5.8×10^6 lb-ft. The maximum torque observed in closing the Cheatham gate was 3.9×10^6 lb-ft.

52. The bypass valves on the hydraulic operating cylinders of the Demopolis and Cheatham gates were set for pressures of 850 and 750 psi, respectively. The maximum recorded pressure in the cylinder during the Demopolis test was 810 psi, and thus good agreement would be expected between model and prototype torque values. However, in the Cheatham tests, the pressure in the cylinder exceeded the bypass pressure of 750 psi. The Cheatham data are being analyzed to determine the instantaneous rate of gate travel, and it is suspected that these data will show that the rate of gate travel decreased considerably when the bypass valve opened. The deviation between the theoretical gate position, based on constant piston travel, and the recorded instantaneous gate position in the model was within ±3 percent for all operating conditions. Therefore, it appears reasonable that the maximum torque observed in closing the Cheatham Lock miter gates under the aforementioned conditions would be less than that predicted based on the model results reported herein.

Comparison of WES and Panama Canal Test Results

53. In the series of model tests conducted by the Special Engineering Division of the Panama Canal (see Appendix A) the 1:25-scale model gate tested for the Third Locks utilized the Panama linkage, but differed from the WES test gate in certain proportions. Table 3 lists model and equivalent prototype dimensions of the Panama Canal test gate. Also tabulated are dimensions of the WES test gate and the Third Locks prototype equivalent, based on consideration of the length of a gate leaf as the governing dimension. Thus, the WES test gate which had a 3-ft-long leaf is considered as a 3/85- or 1:28.33-scale model of the proposed Third Locks gate which had an 85-ft-long leaf.

54. Maximum torque values, shown in plate 40 for a 3-ft submergence, were changed to Third Locks prototype equivalents and, based on data in plate 33, were multiplied by 1.20 to approximate values for a prototype clearance under the gate of 2 ft rather than 7 ft. The maximum torque values predicted from the WES tests are compared with those observed in the Panama Canal tests on the basis of average angular velocity of gate travel in fig. 17. Note that no attempt has been made to adjust for differences

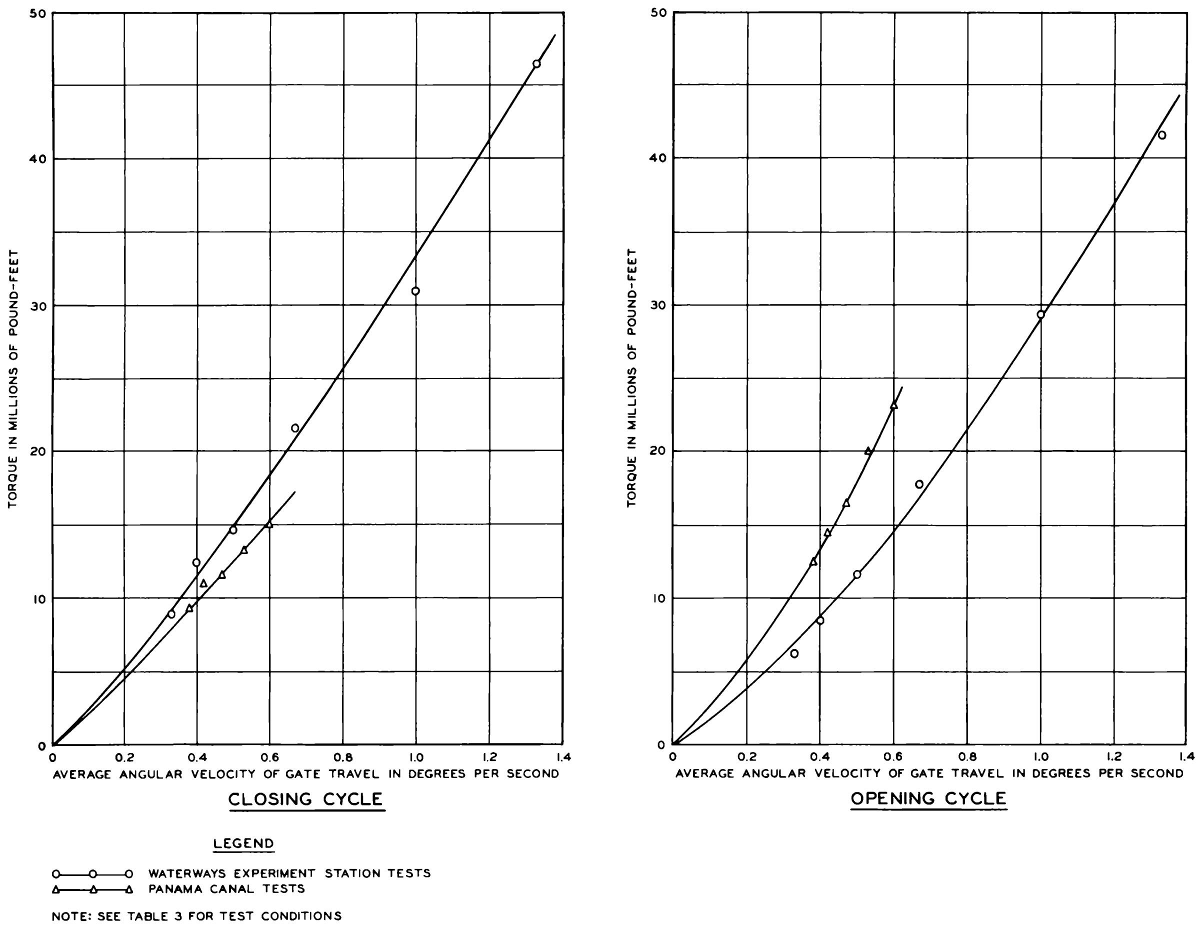


Fig. 17. Predicted maximum torque on operating machinery of miter gates for proposed Third Locks, Panama Canal

in chamber lengths since insufficient data are available on which to base such an adjustment. The WES tests indicate peak torques greater than those of the Panama Canal tests during the closing cycle, and lesser torques during the opening cycle. The Panama tests indicated opening-cycle torques greater than those recorded for the closing cycle in the WES tests. The general shapes of the torque curves from the two models are quite similar for both the opening and closing cycles. It is not known whether the differences in maximum torques are due to inequalities in chamber lengths, dimensions of the linkages, miter angles, or types of operating equipment.

55. Better correlation is obtained by comparing the maximum torques in terms of the Third Locks prototype equivalents on the basis of equal submergence and operating time. For a submergence of 82.5 ft and an

operating time of 105 sec, the WES model data predict that maximum torques of 22×10^6 and 18×10^6 lb-ft would occur during the closing and opening cycles, respectively. The Panama Canal tests indicate that maximum torques of 15×10^6 and 23×10^6 lb-ft would occur during the closing and opening cycles, respectively. However, operating machinery designed from the two series of tests would have been essentially the same.

Summary of Results

56. The results of the study may be summarized as follows:

a. Peak hydraulic resistance to operation of the miter gate was observed as the leaves entered and left the mitered (closed) position with the maximum resistance occurring as the leaves entered the mitered position.

b. The modified Ohio River and Panama linkages resulted in peak resistances in terms of torques at the pintles which were approximately equal and about 40 percent less than the peak torques obtained with the Ohio River linkage.

c. An increase in submergence of the gate leaves or speed of operation resulted in increased hydraulic resistance.

d. Hydraulic resistance increased as the bottom clearance of the gate leaves was decreased.

e. Hydraulic resistance decreased as the length of the lock chamber was increased.

f. Nonsynchronous operation of the gate leaves resulted in a slight reduction in peak torque.

g. Limited tests conducted with barges in the lock chamber showed no appreciable effect of a tow in the chamber on torque values.

h. Although only limited field test data are available, the peak torques observed on prototype miter gates utilizing the modified Ohio River linkage compare favorably with those observed on the model gates.

i. Peak torques observed in model tests of the Panama linkage by the Special Engineering Division of the Panama Canal (see Appendix A) occurred during the opening cycle whereas peak torques were observed during the closing cycle in the WES model tests. However, the maximum torque value predicted from the WES tests on the basis of average angular velocity of gate travel for equal submergence and operating time compares favorably with that predicted from the Panama Canal tests.

Table 1

Maximum Torques Observed Near Mitered Position of Gate Closing Cycle with and Without Barges* in Lock Chamber

Chamber Width, 5.5 ft
Chamber Length, 30 ft

Modified Ohio River Linkage
Gate Bottom Clearance, 3.0 ft

Gate Submergence ft	Operating Time sec	Maximum Torque, ft-lb, with Barges as Indicated Below Pintle 1.25 ft	2.5 ft	3.75 ft	4.0 ft	Avg Torque ft-lb with Barges	Torque ft-lb Without Barges
1.0	10.1	9	6	5	7	7	7**
	13.4	5	3	5	7	5	
	20.1	4	2	4	4	4	
	26.8	3	1.5	3	2	3	2**
	33.5	2.5	1.5	2	2	2	
	40.2	2	1.0	1.5	1	1.5	1.5**
2.0	10.1	31	28	27	15	25	23**
	13.4	23	22	22	22	22	
	20.1	13	12	9	15	12	
	26.8	7	7	10	6	8	8**
	33.5	6	7	7	7	7	
	40.2	6	4	5	5	5	5**
3.0	10.1	62	50	45	46	50	45
	13.4	36	35	37	38	36	33
	20.1	22	23	24	22	23	22
	26.8	14	16	18	15	16	13
	33.5	12	13	14	13	13	13
	40.2	12	11	9	8	10	9
4.0	10.1	76	69	68	68	70	78
	13.4	60	59	60	50	57	65
	20.1	37	44	27	46	39	37
	26.8	24	31	21	22	24	28
	33.5	17	20	21	19	19	22
	40.2	18	17	18	17	17	19

* Four 1.35-ft-wide, 4.5-ft-long, and 0.75-ft-high barges used in tests.
** Value estimated from plate 28.

Table 2

Dimensions and Test Conditions

Demopolis Lock, Cheatham Lock, and Waterways Experiment Station Test Gates

Dimensions* and Test Conditions	Demopolis Lock			Cheatham Lock		
	WES Model	Scale Ratio	Prototype	WES Model	Scale Ratio	Prototype
L , ft (leaf length)	3.000	$L_r = \frac{3}{60}$ or 1:20	60	3.000	$L_r = \frac{3}{60}$ or 1:20	60
A , ft	1.000	L_r	20	1.000	--	18.67
B , ft	1.000	--	19.5	1.000	--	18.58
C , ft	0.549	--	11.67	0.549	--	10.0
D , ft	0.765	--	15.58	0.765	--	15.5
E , ft	0.535	--	10.58	0.535	--	9.67
α	201°48'09"	--	145°49'04"	201°48'09"	--	184°48'35"
Miter angle	1:3	--	1:3	1:3	--	1:3
Lock width, ft	5.5	L_r	110	5.5	L_r	110
Chamber length, ft	30	L_r	600	30	--	800
Clearance under gate, ft	0.25	--	2.93	0.25	--	3.0
Submergence, ft	2.45	L_r	49.0	1.35	L_r	27.0
Operating time, sec	26.0	$L_r^{1/2}$	116	20.4	$L_r^{1/2}$	91

* See fig. 6.

Table 3

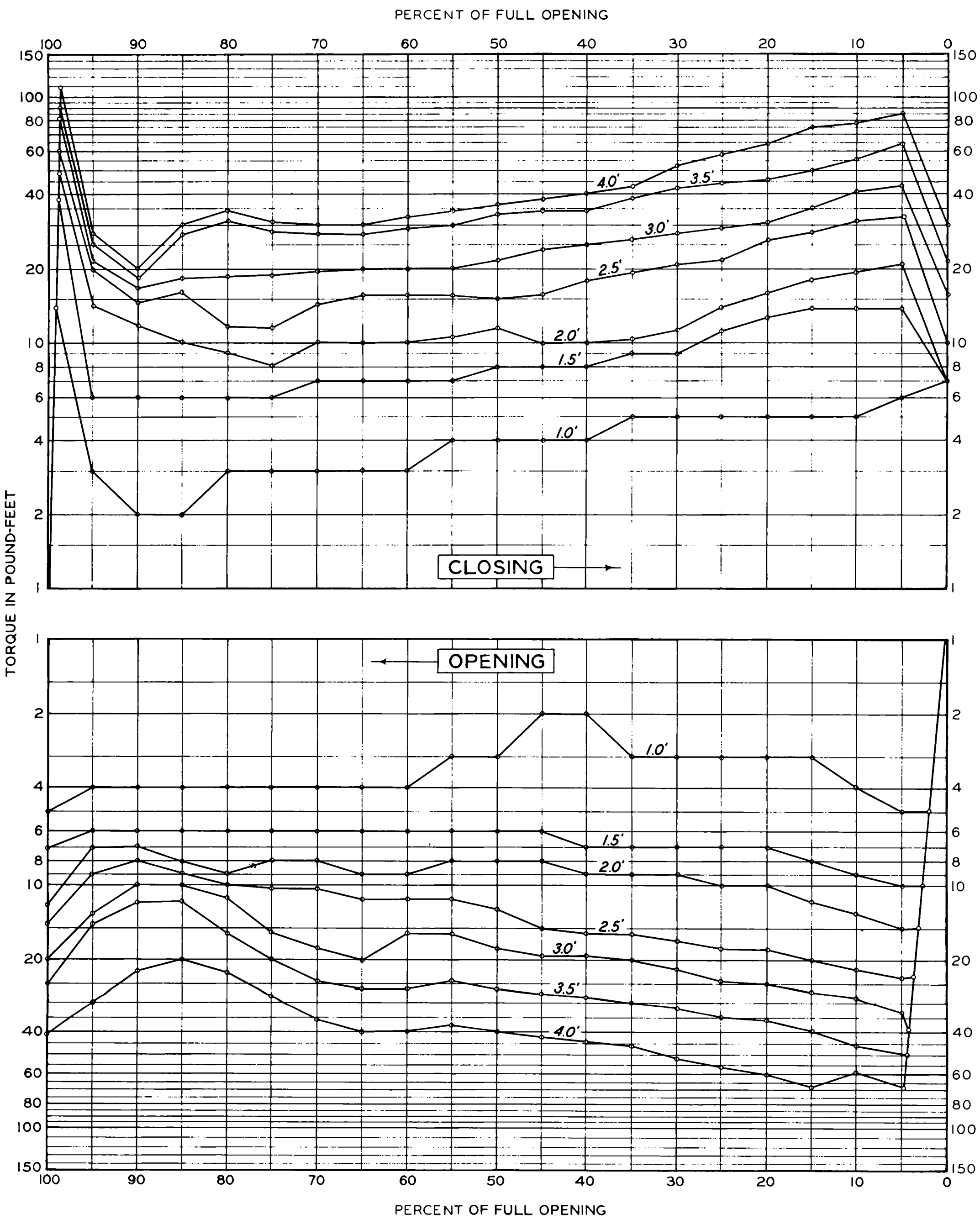
Dimensions and Test Conditions

Panama Canal and Waterways Experiment Station Test Gates

Dimensions* and Test Conditions	Panama Canal			Waterways Experiment Station		
	Model	Scale Ratio	Prototype	Model	Scale Ratio	Prototype
L, ft (leaf length)	3.400	$L_r = \frac{3.4}{85}$ or 1:25	85.0	3.000	$L_r = \frac{3}{85}$ or 1:28.33	85.0
A, ft	1.075	L_r	26.9	1.000	L_r	28.3
B, ft	1.386	L_r	34.6	1.300	L_r	36.8
C, ft	0.569	L_r	14.2	0.541	L_r	15.3
D, ft	1.040	L_r	26.0	1.000	L_r	28.3
E, ft	1.160	L_r	29.0	0.759	L_r	21.5
α	187°52'31"	--	187°52'31"	201°48'09"	--	201°48'09"
Miter angle	1:2	--	1:2	1:3	--	1:3
Lock width, ft	5.6	L_r	140.0	5.5	L_r	155.8
Upstream chamber length, ft	44.2	L_r	1105.0	25.0	L_r	708.0
Downstream chamber length, ft	8.0	L_r	200.0	25.0	L_r	708.0
Clearance under gate, ft	0.08	L_r	2.0	0.25	L_r	7.1**
Submergence, ft	3.3	L_r	82.5	3.0	L_r	85.0
Operating time, sec	21.0	$L_r^{1/2}$	105.0	20.1	$L_r^{1/2}$	107.0

* See fig. 11.

** Torque values plotted in fig. 17 were multiplied by 1.20 in order to correct for difference in clearance under gate. Factor of 1.20 determined from consideration of data in paragraph 32.

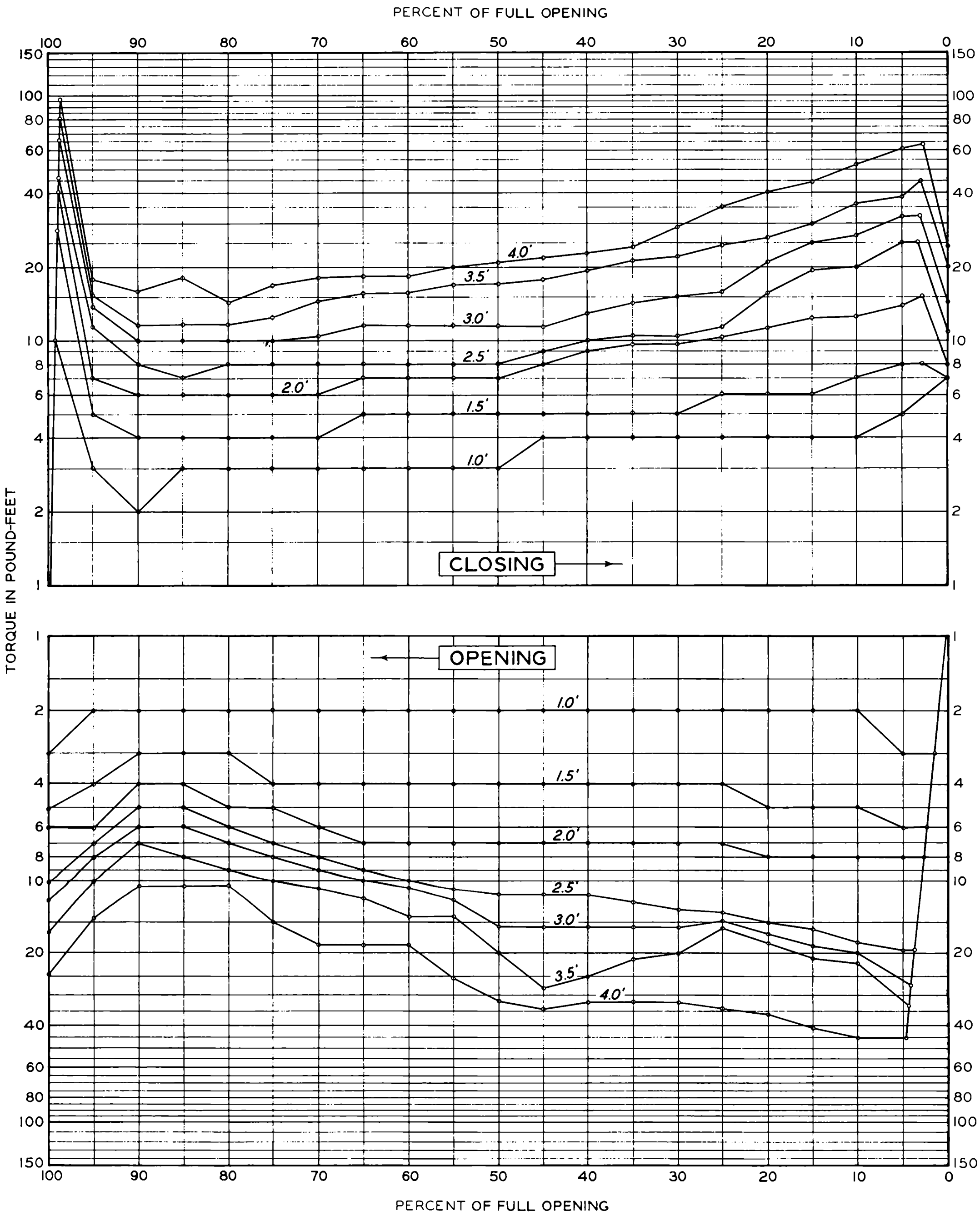


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 10.1 SECONDS
CHAMBER LENGTHS 25 FEET



SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

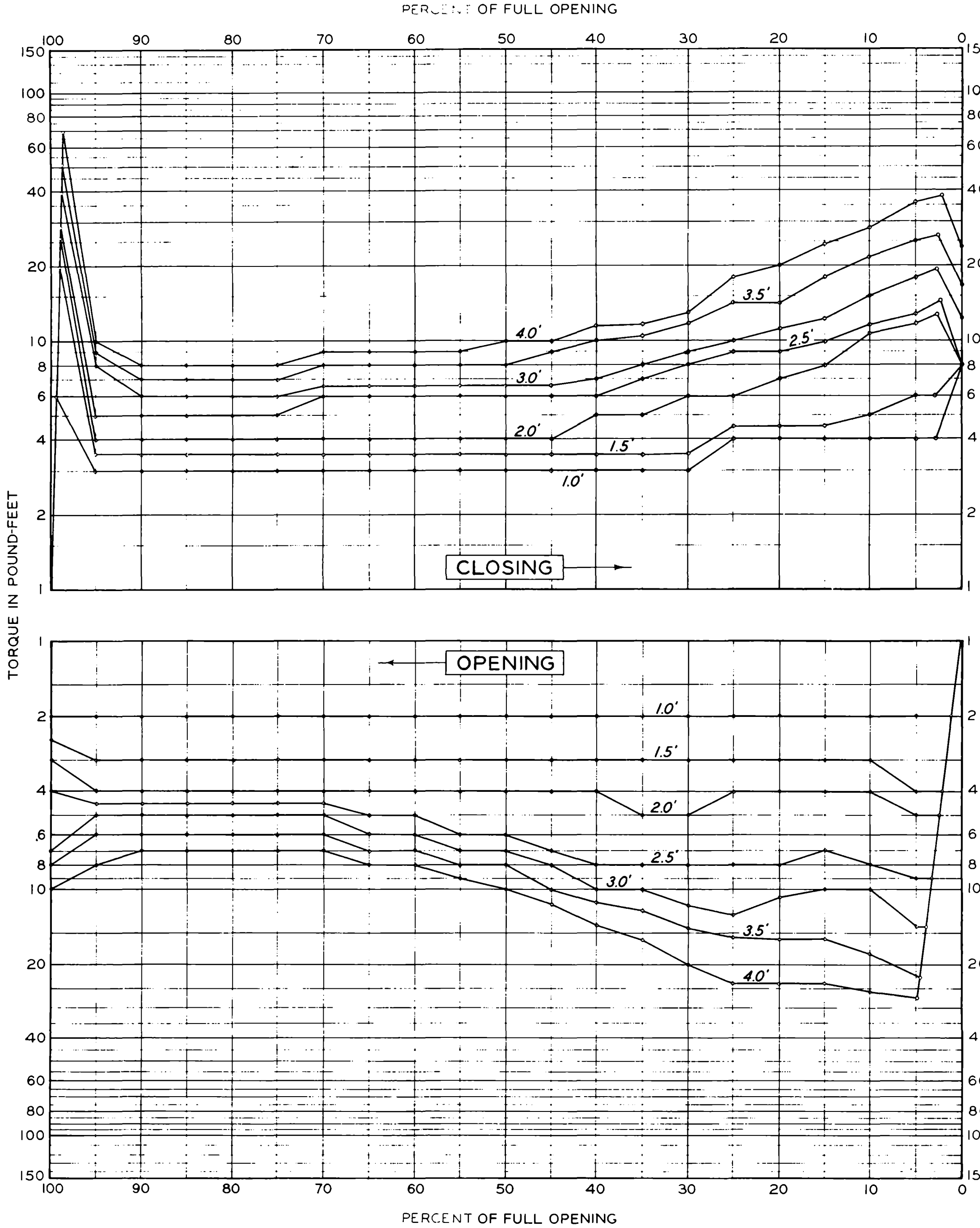
MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 13.4 SECONDS

CHAMBER LENGTHS 25 FEET

PLATE 2



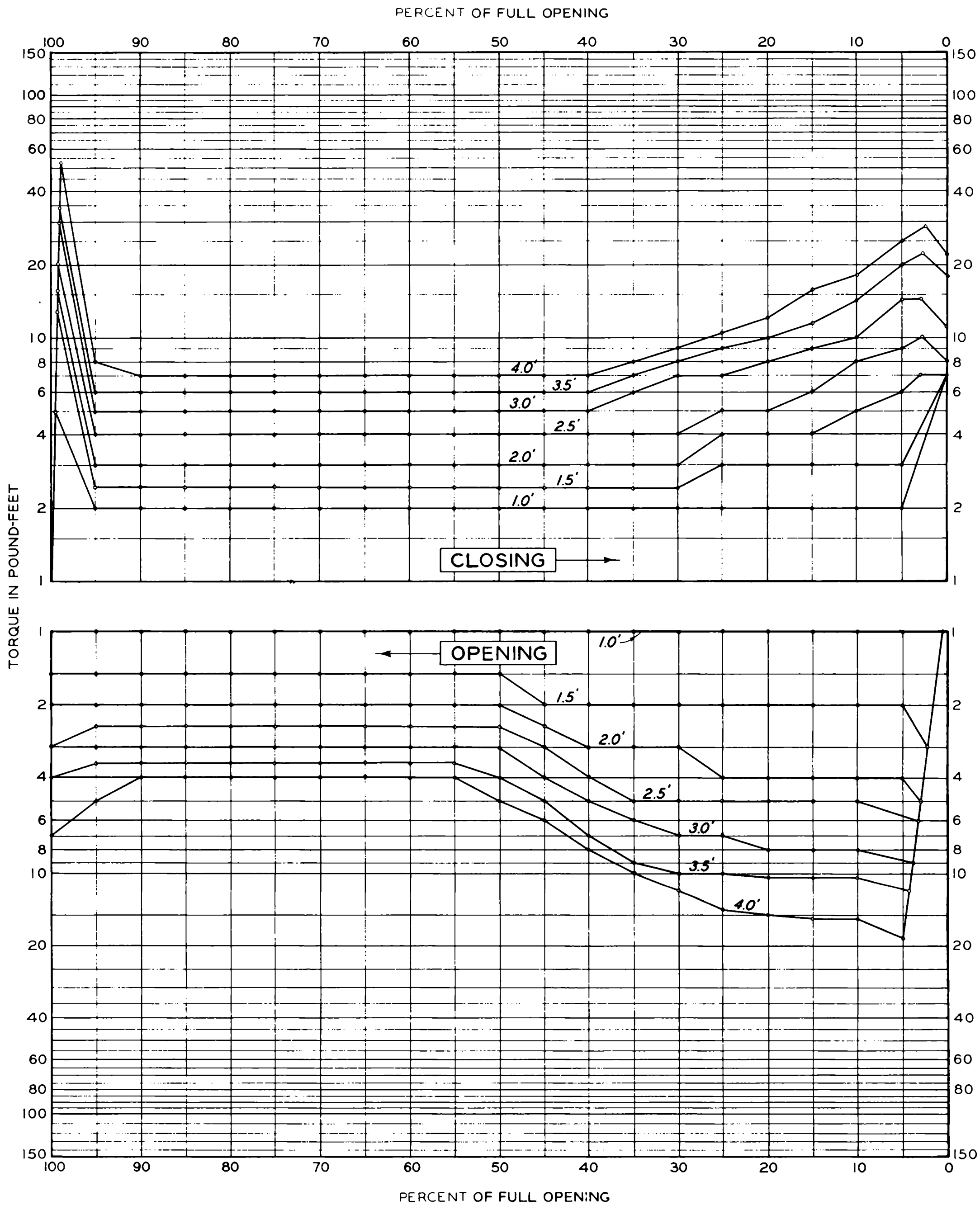
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0 25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 20.1 SECONDS

CHAMBER LENGTHS 25 FEET



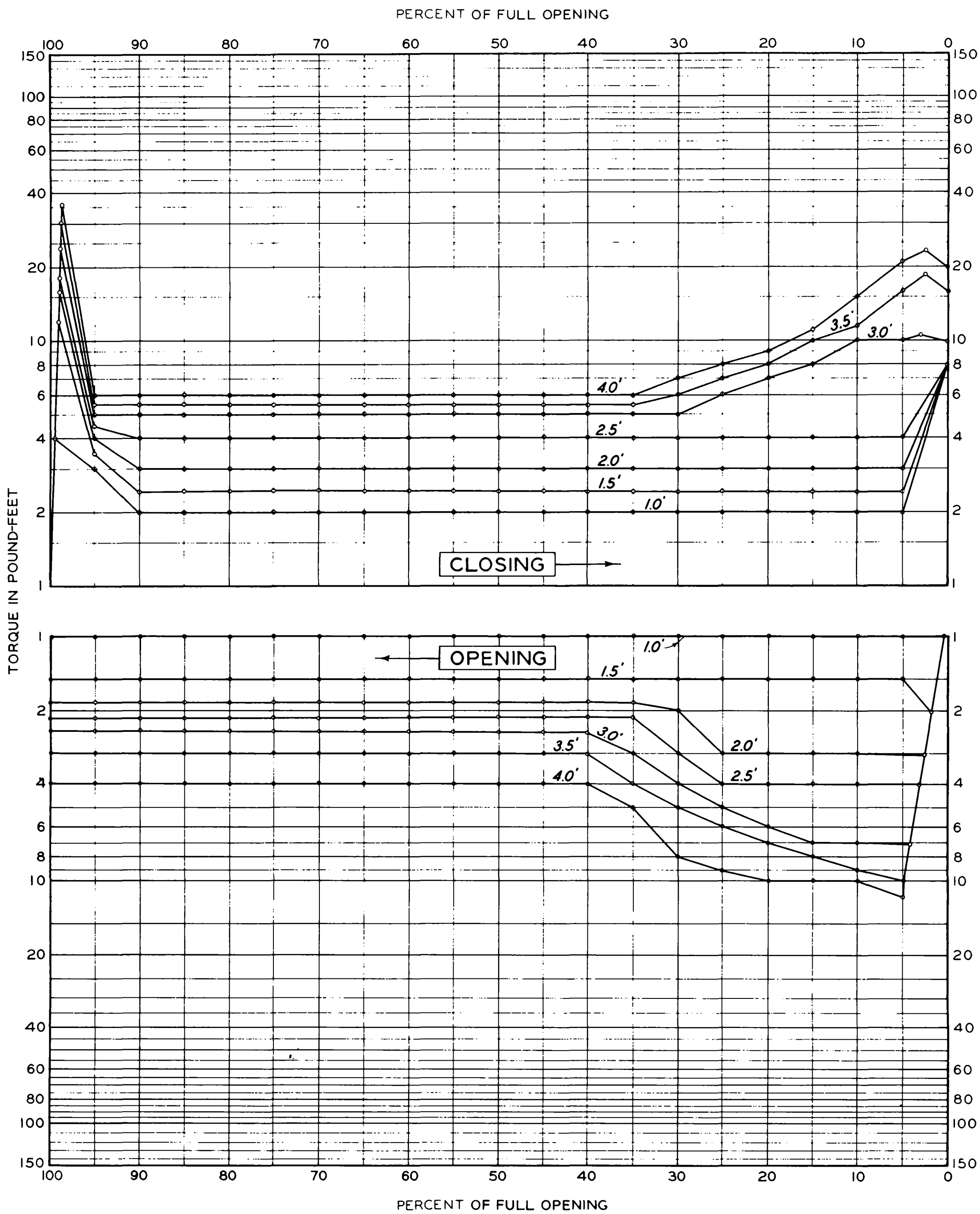
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 26.8 SECONDS

CHAMBER LENGTHS 25 FEET



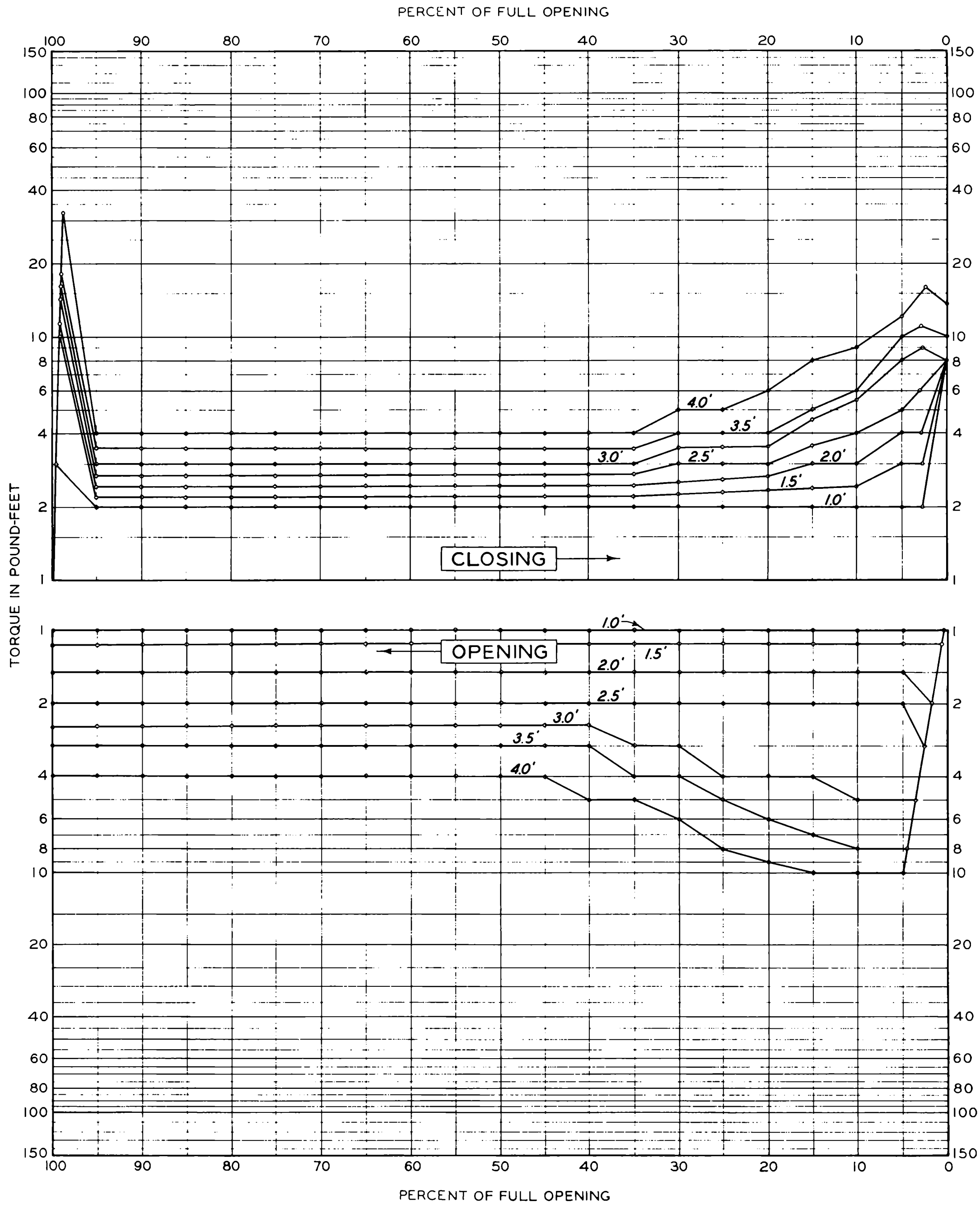
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 33.5 SECONDS

CHAMBER LENGTHS 25 FEET

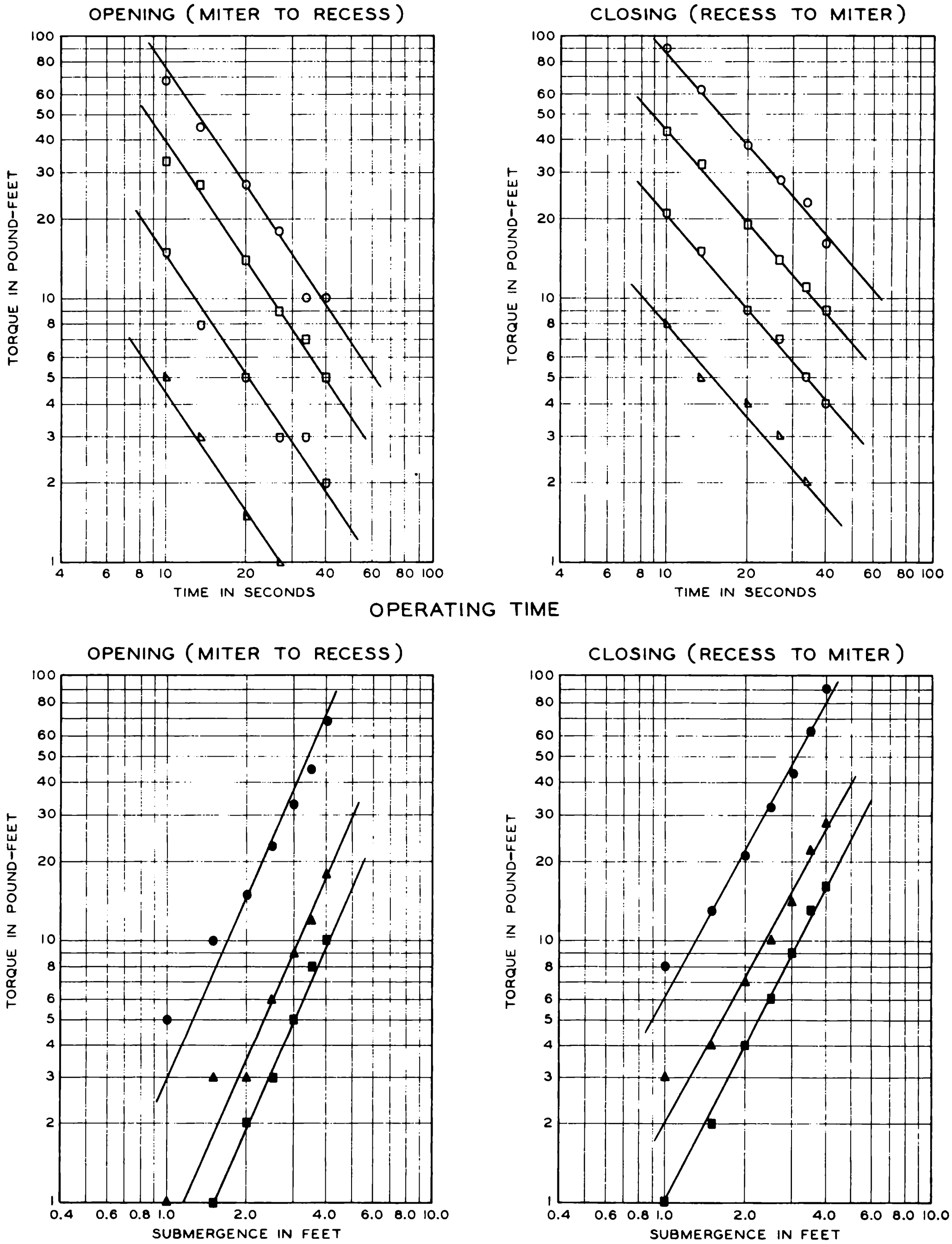


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 40.2 SECONDS
CHAMBER LENGTHS 25 FEET



NOTE: BOTTOM CLEARANCE 0.25 FT

LEGEND

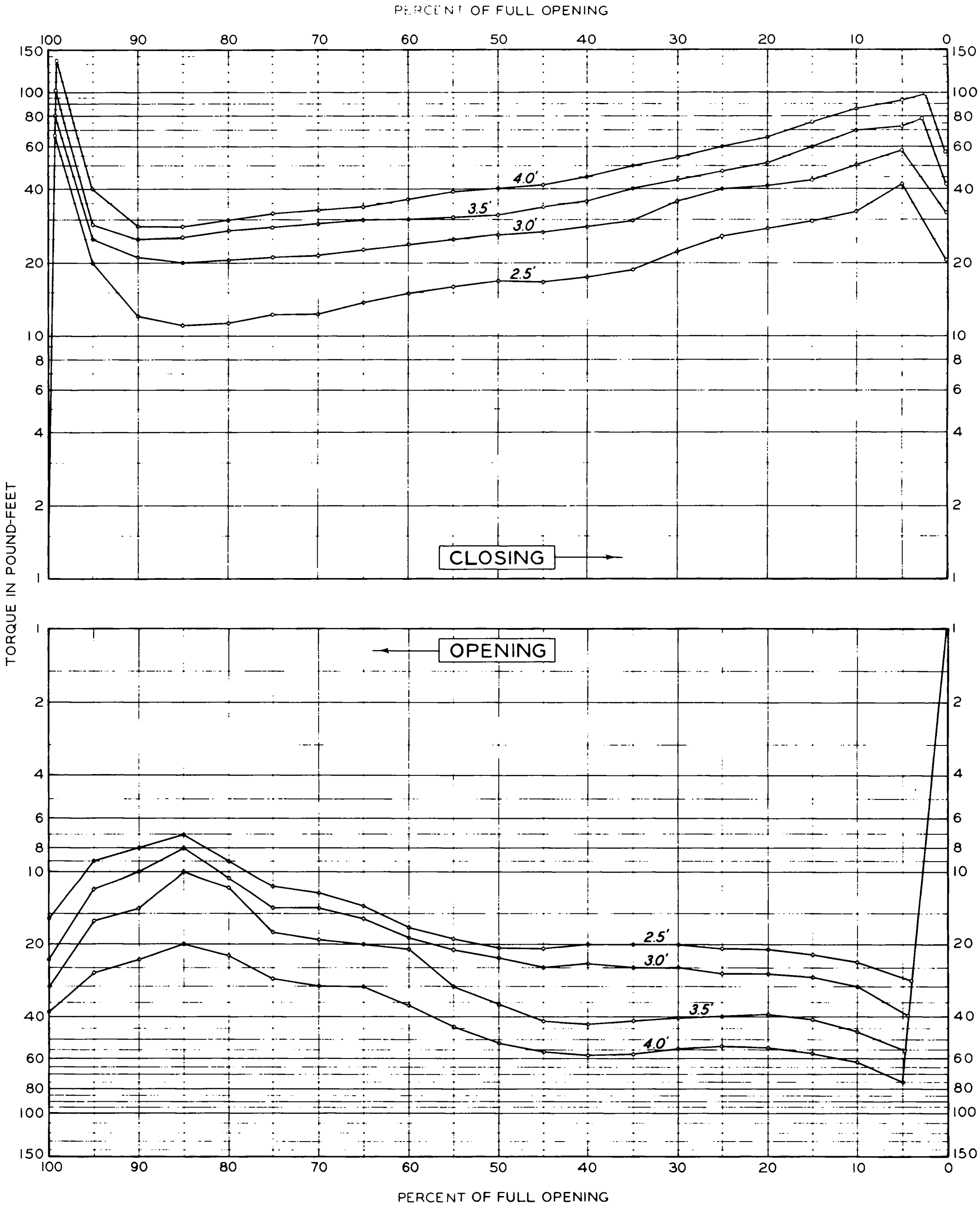
TIME OF OPERATION
- SUBMERGENCE 4.0 FT
- SUBMERGENCE 3.0 FT
- SUBMERGENCE 2.0 FT
- SUBMERGENCE 1.0 FT

SUBMERGENCE
- OPERATING TIME 10.1 SEC
- OPERATING TIME 26.8 SEC
- OPERATING TIME 40.2 SEC

MODIFIED OHIO RIVER LINKAGE

EFFECTS OF OPERATING TIME AND SUBMERGENCE ON MAXIMUM TORQUE

CHAMBER LENGTHS 25 FEET



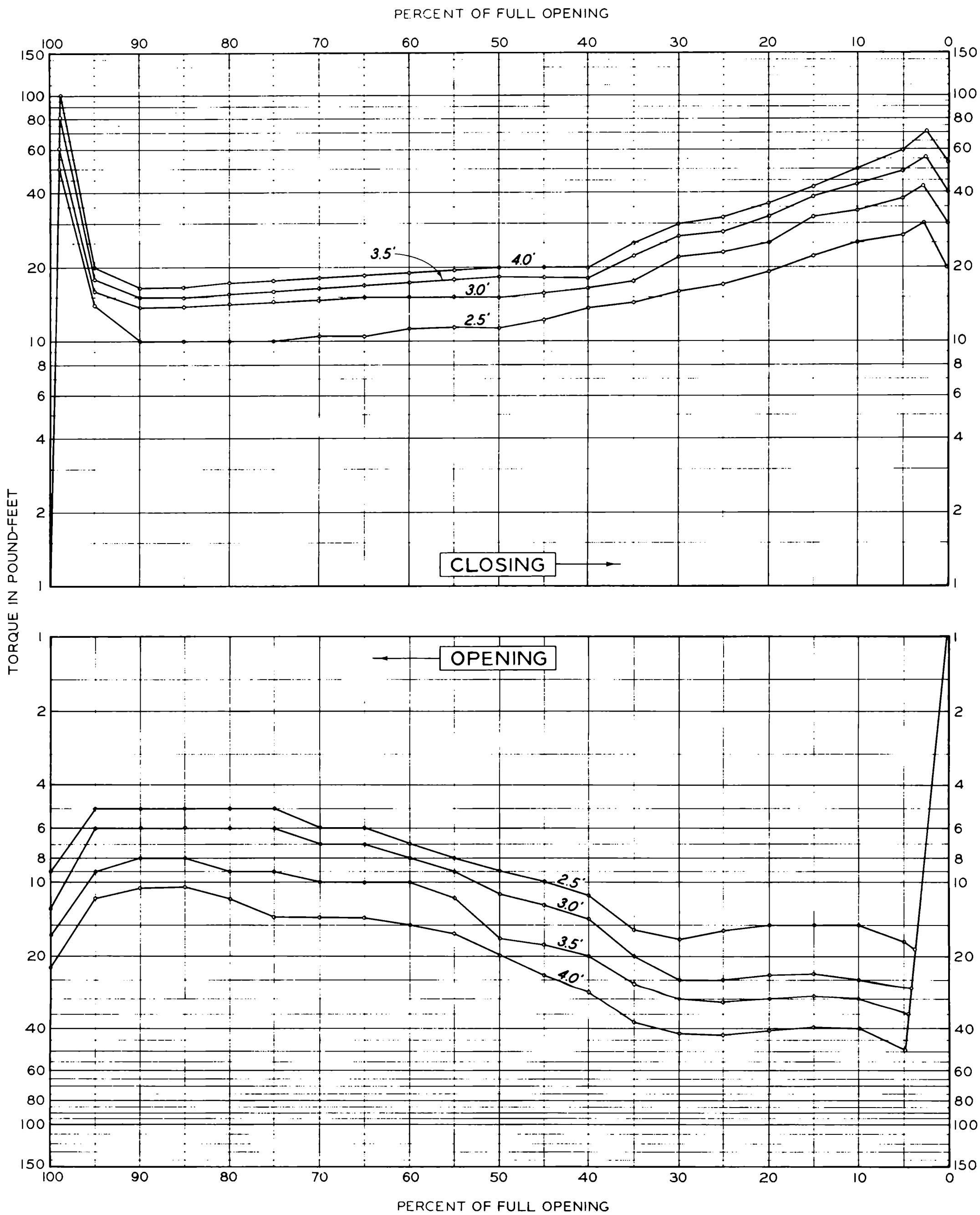
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 10.1 SECONDS

CHAMBER LENGTHS 15 FEET

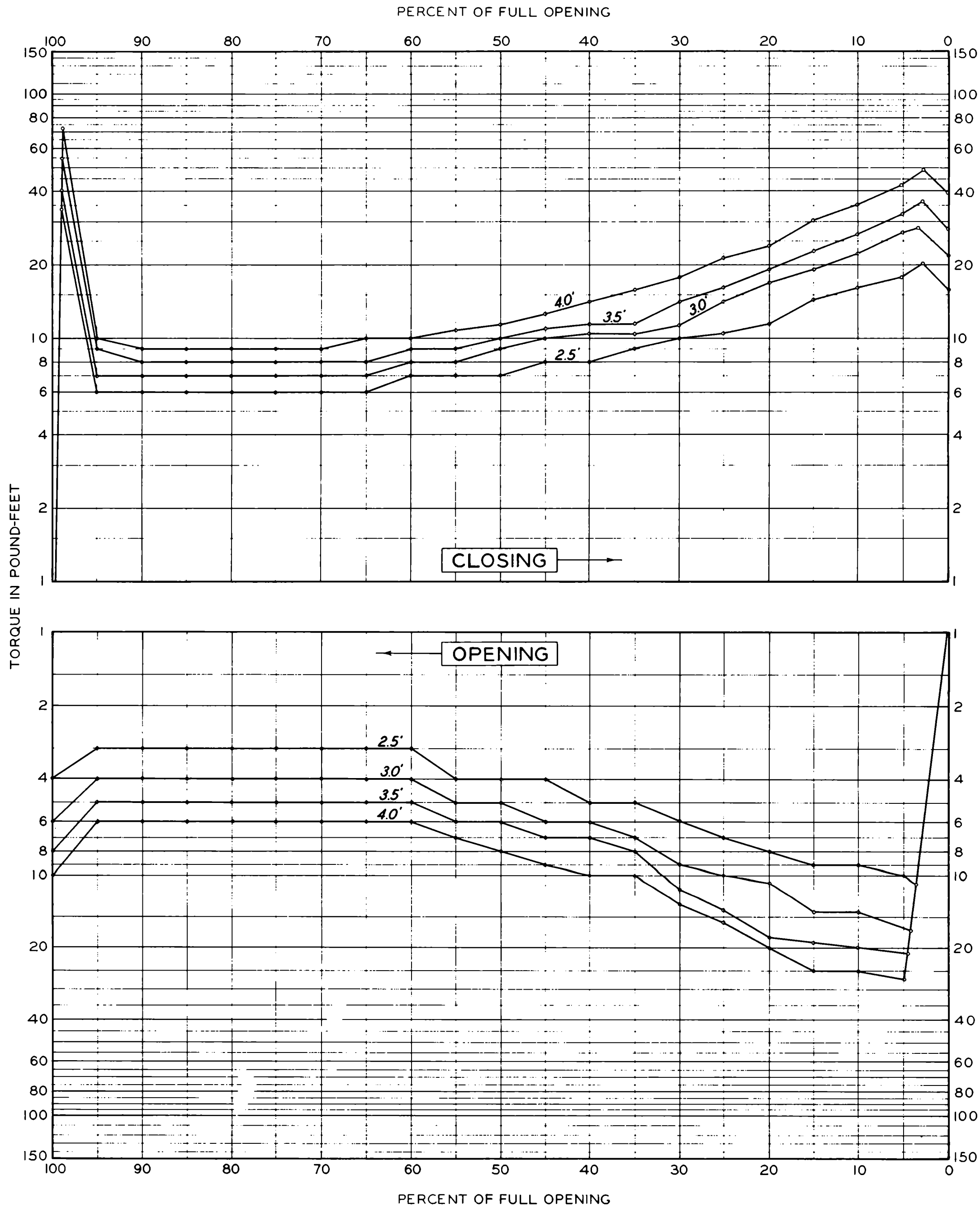


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 13.4 SECONDS
CHAMBER LENGTHS 15 FEET

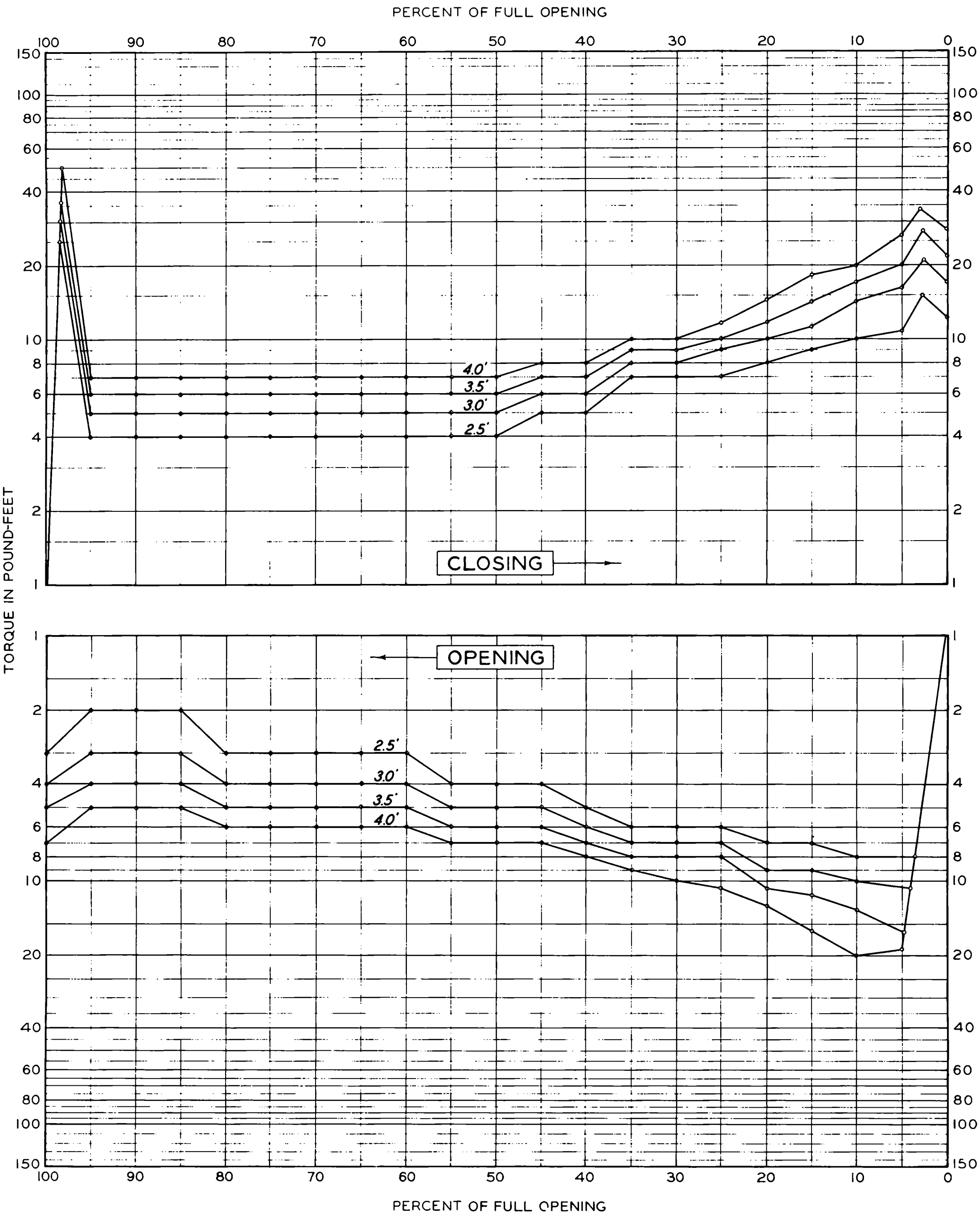


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 20.1 SECONDS
CHAMBER LENGTHS 15 FEET



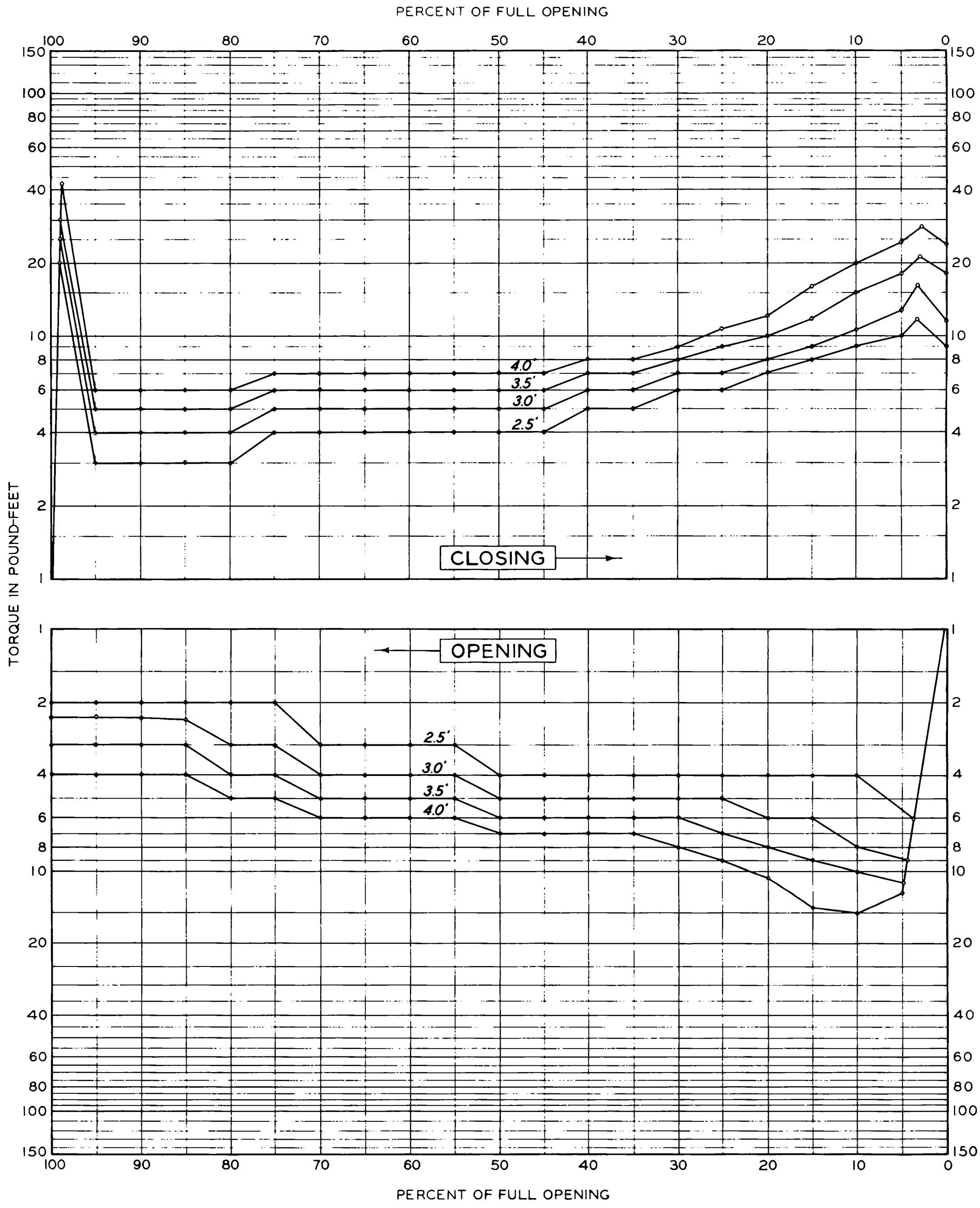
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 26.8 SECONDS

CHAMBER LENGTHS 15 FEET

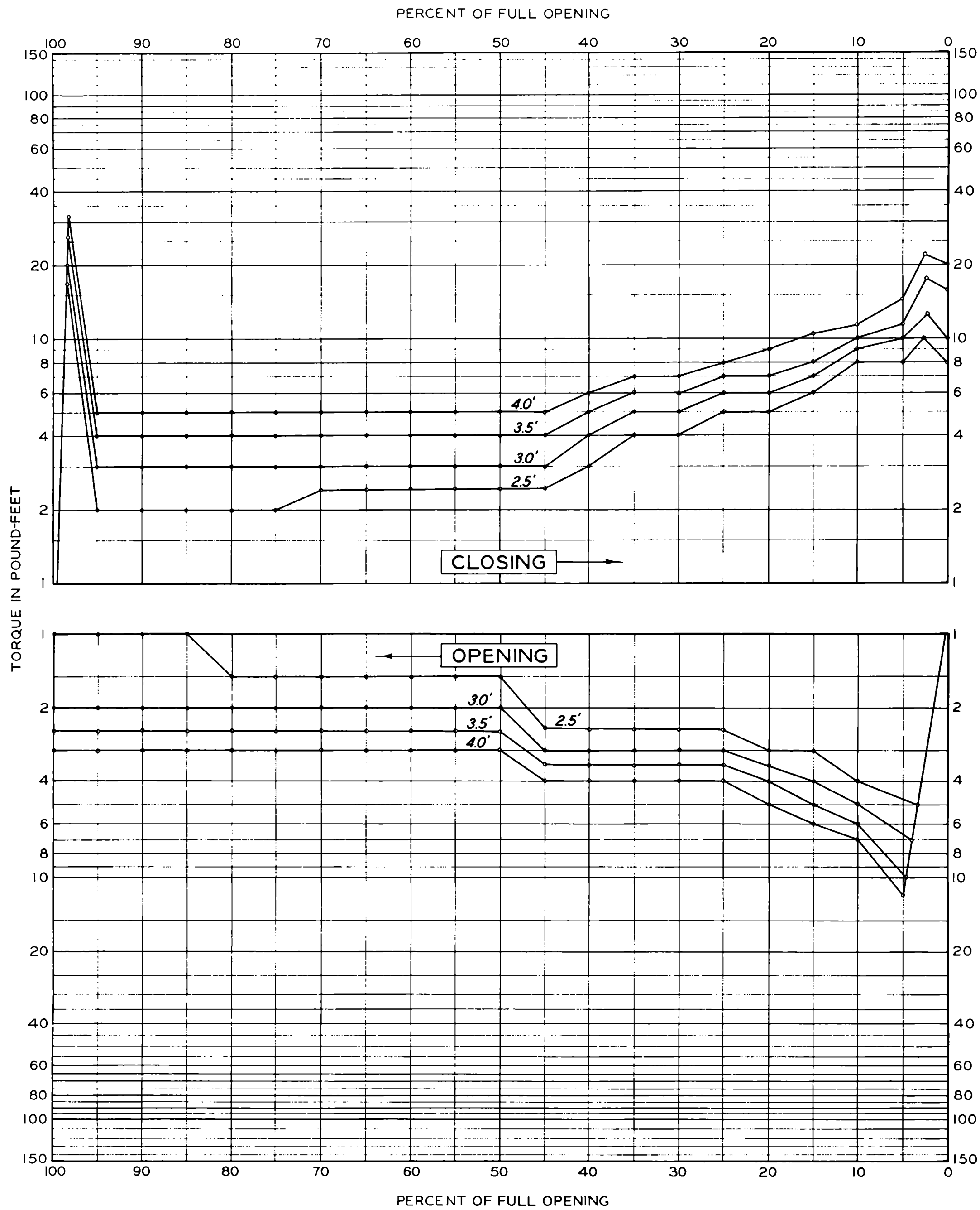


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 33.5 SECONDS
CHAMBER LENGTHS 15 FEET

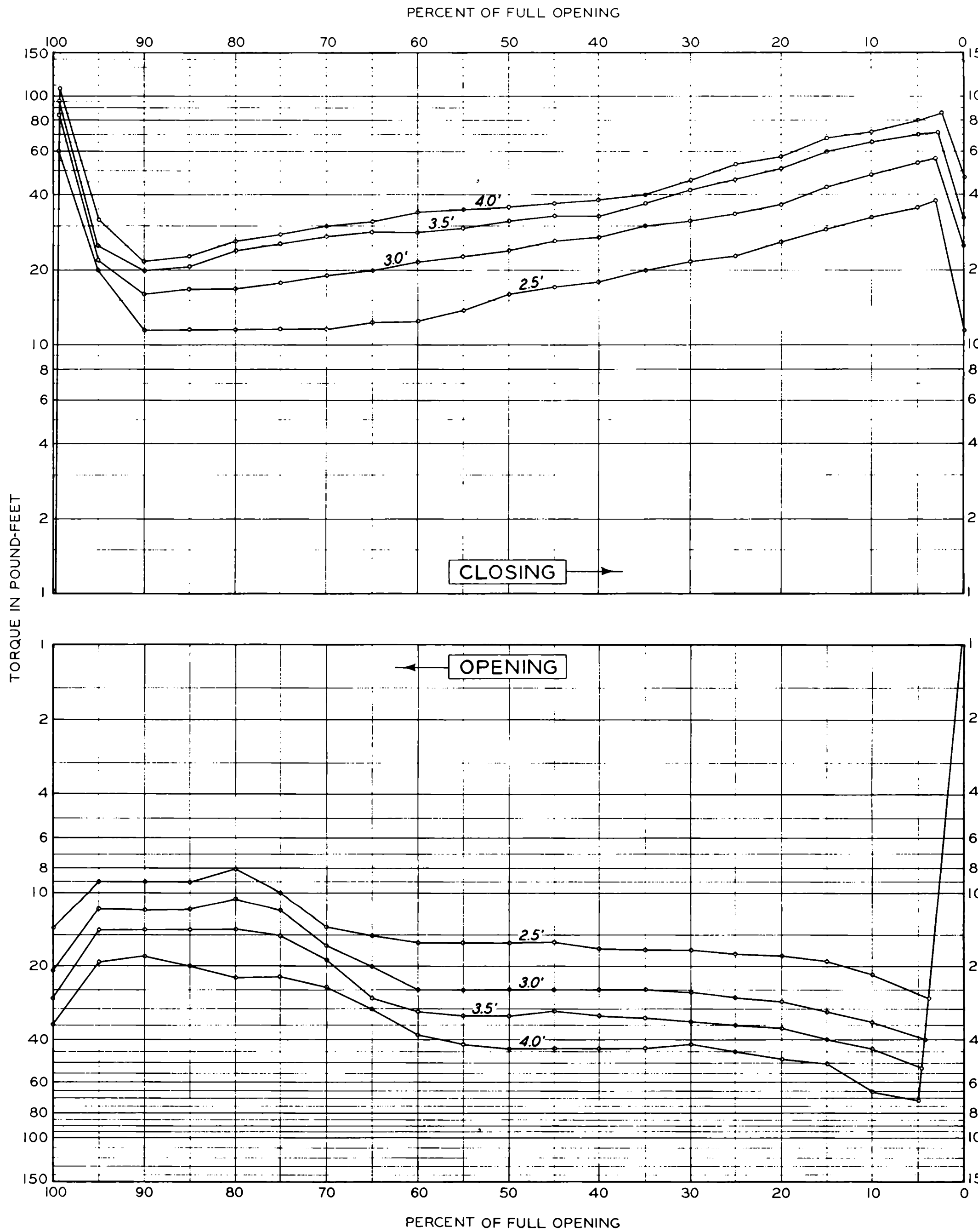


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 40.2 SECONDS
CHAMBER LENGTHS 15 FEET



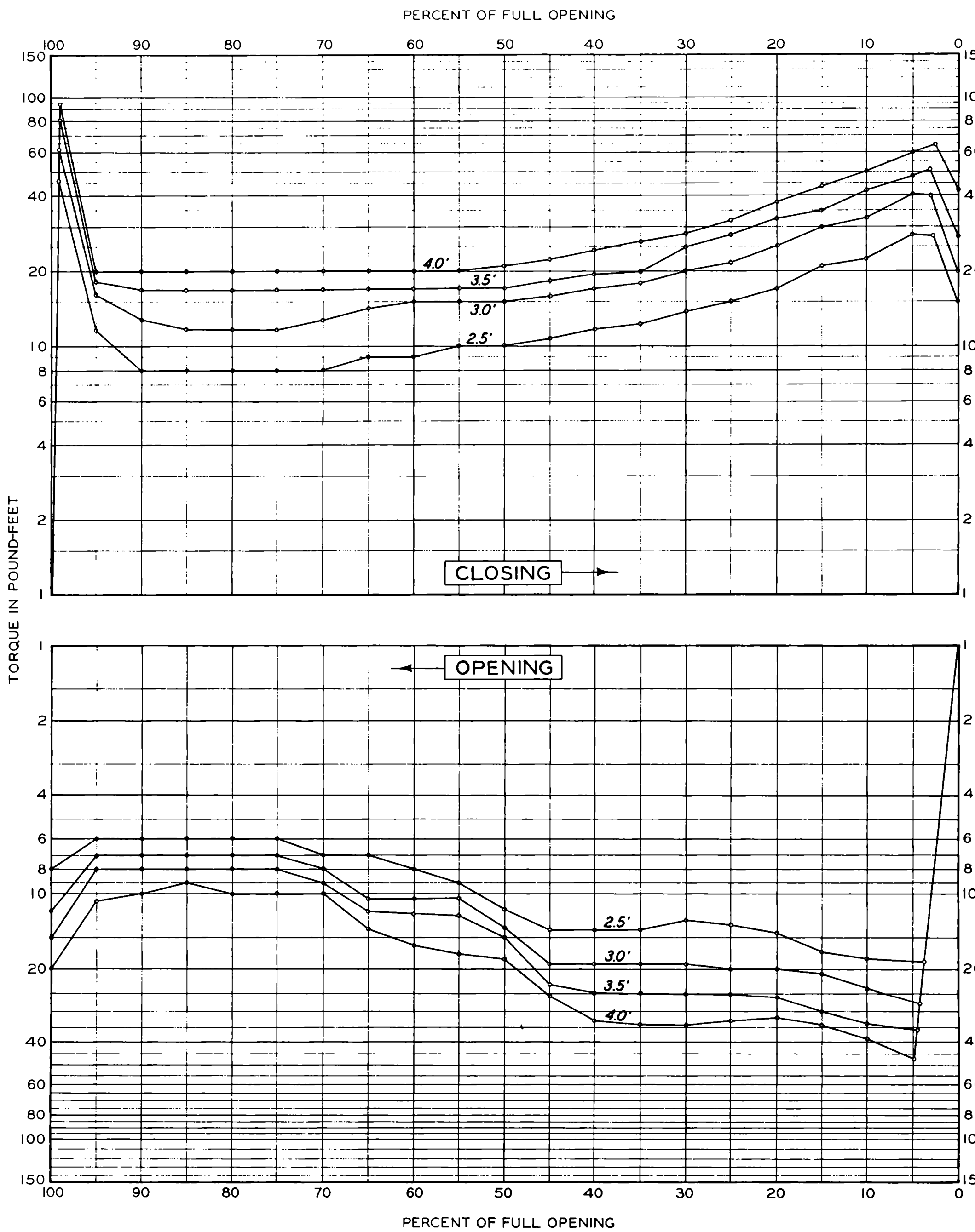
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 10.1 SECONDS

CHAMBER LENGTHS 20 FEET

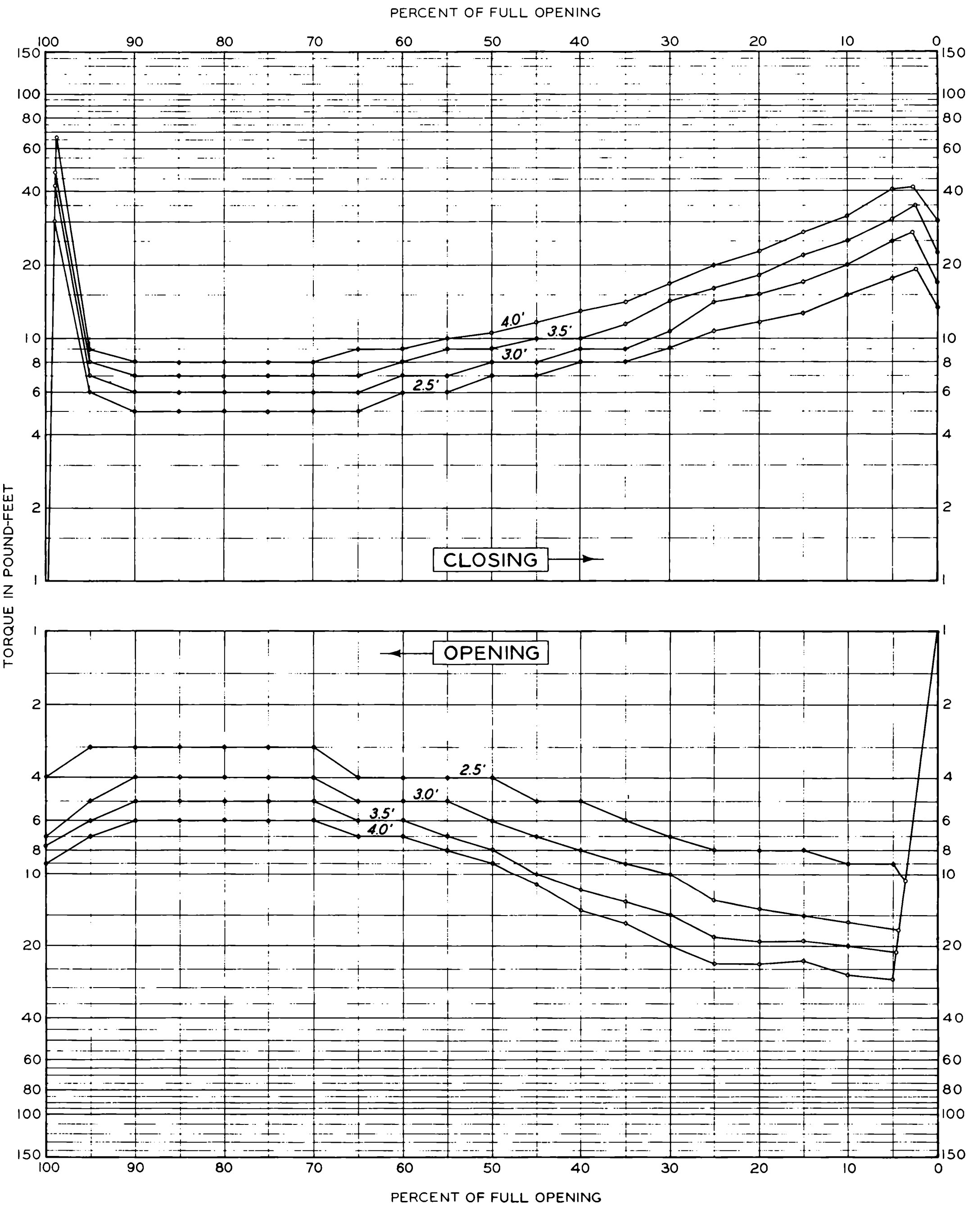


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 13.4 SECONDS
CHAMBER LENGTHS 20 FEET

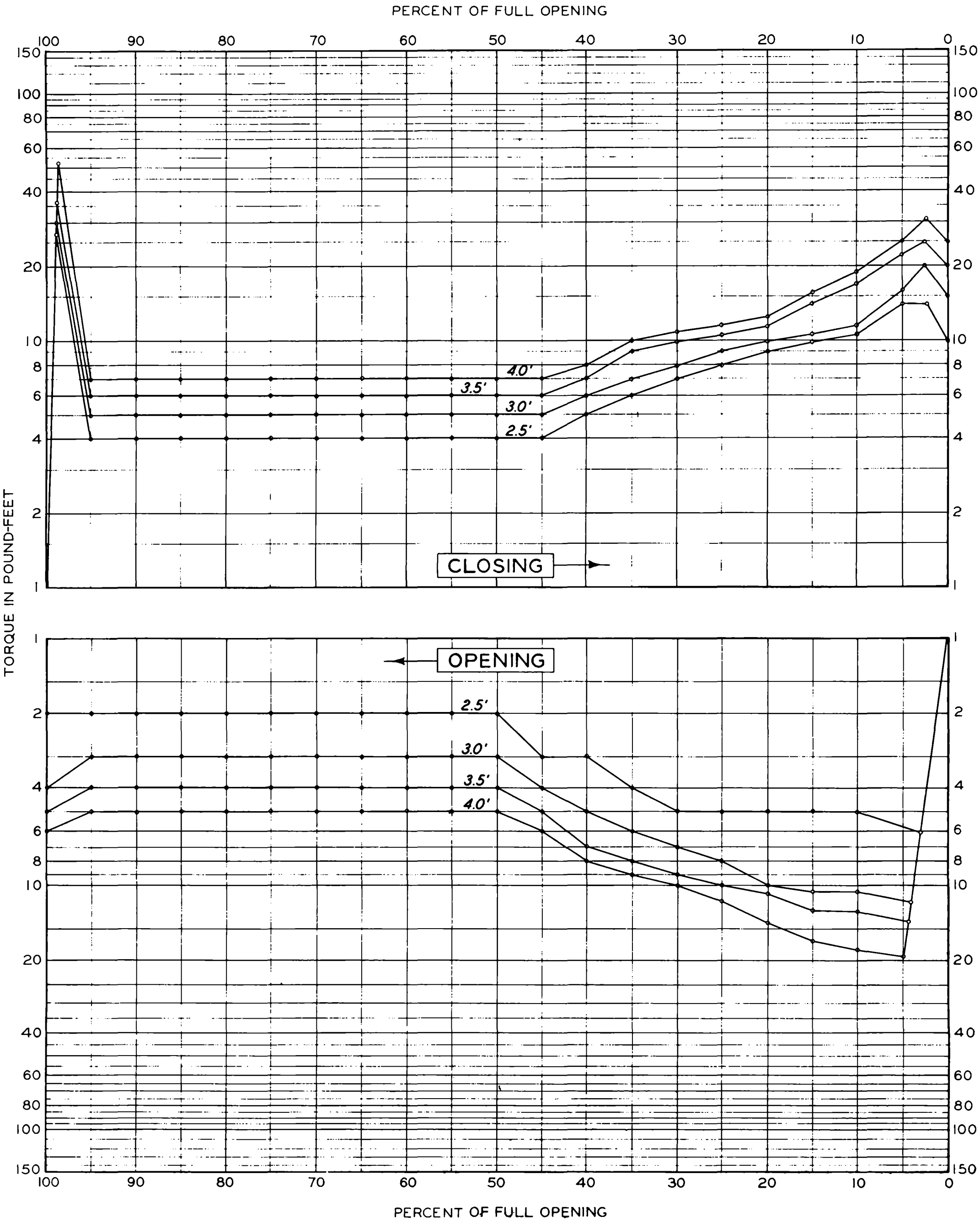


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 20.1 SECONDS
CHAMBER LENGTHS 20 FEET

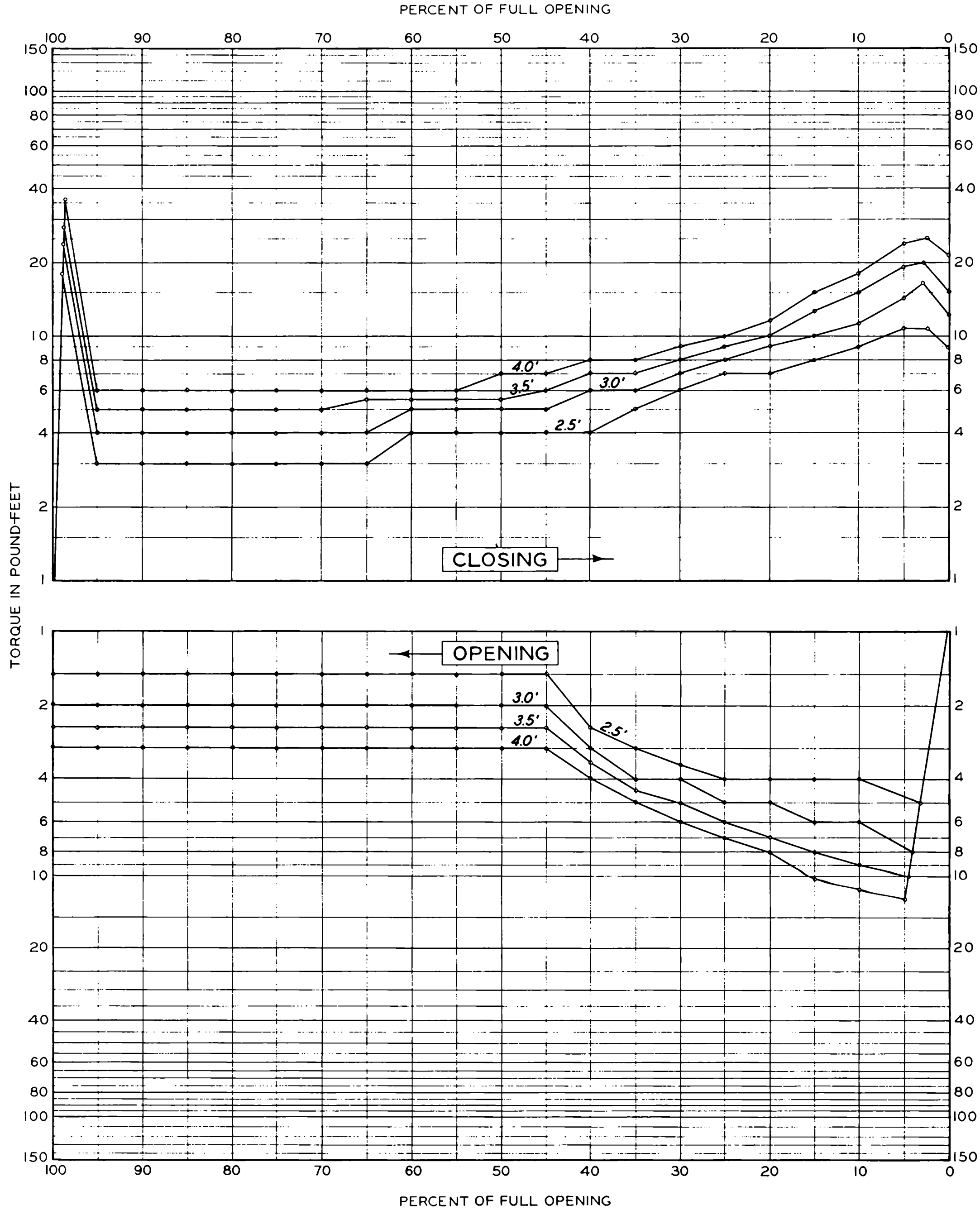


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 26.8 SECONDS
CHAMBER LENGTHS 20 FEET

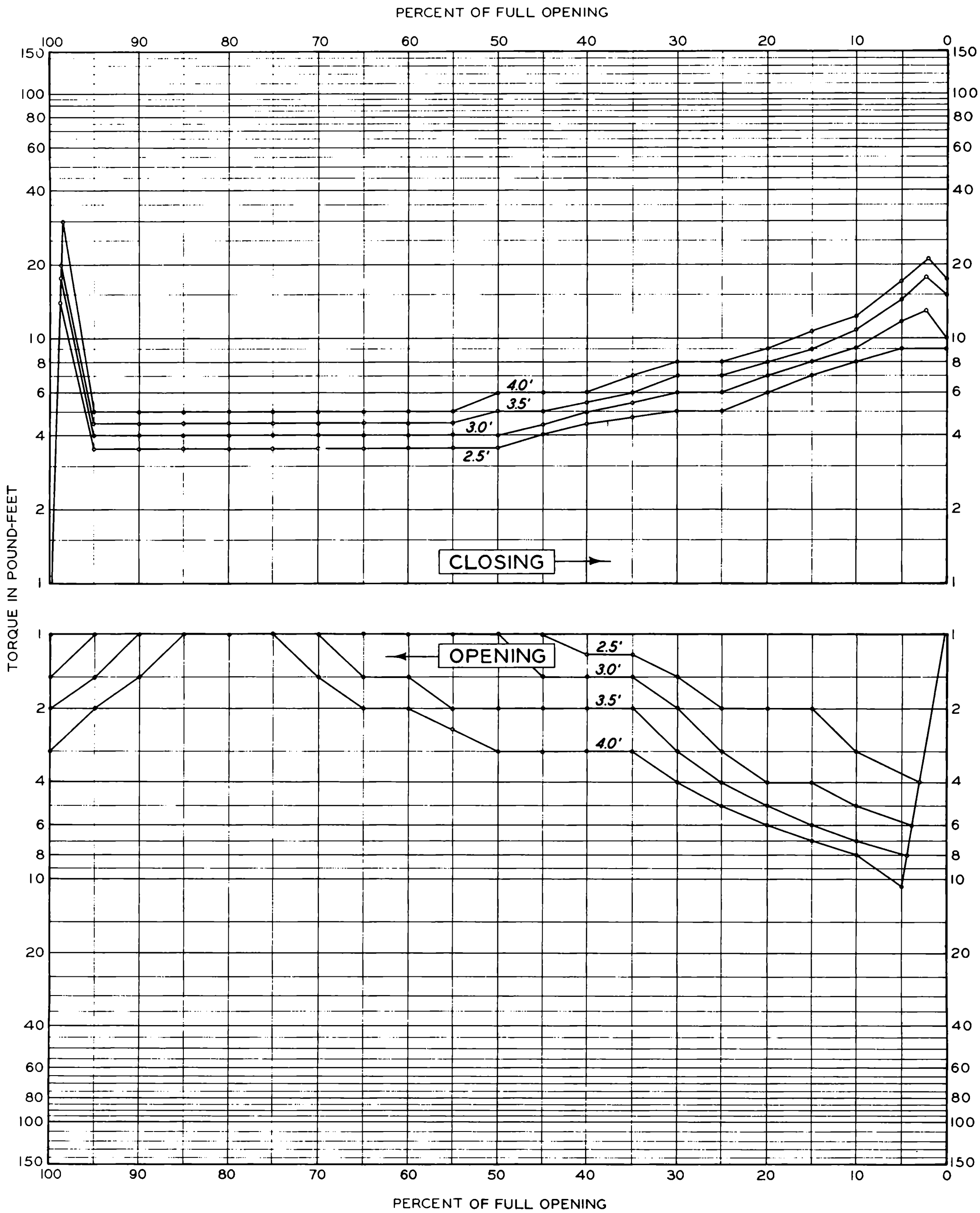


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 33.5 SECONDS
CHAMBER LENGTHS 20 FEET

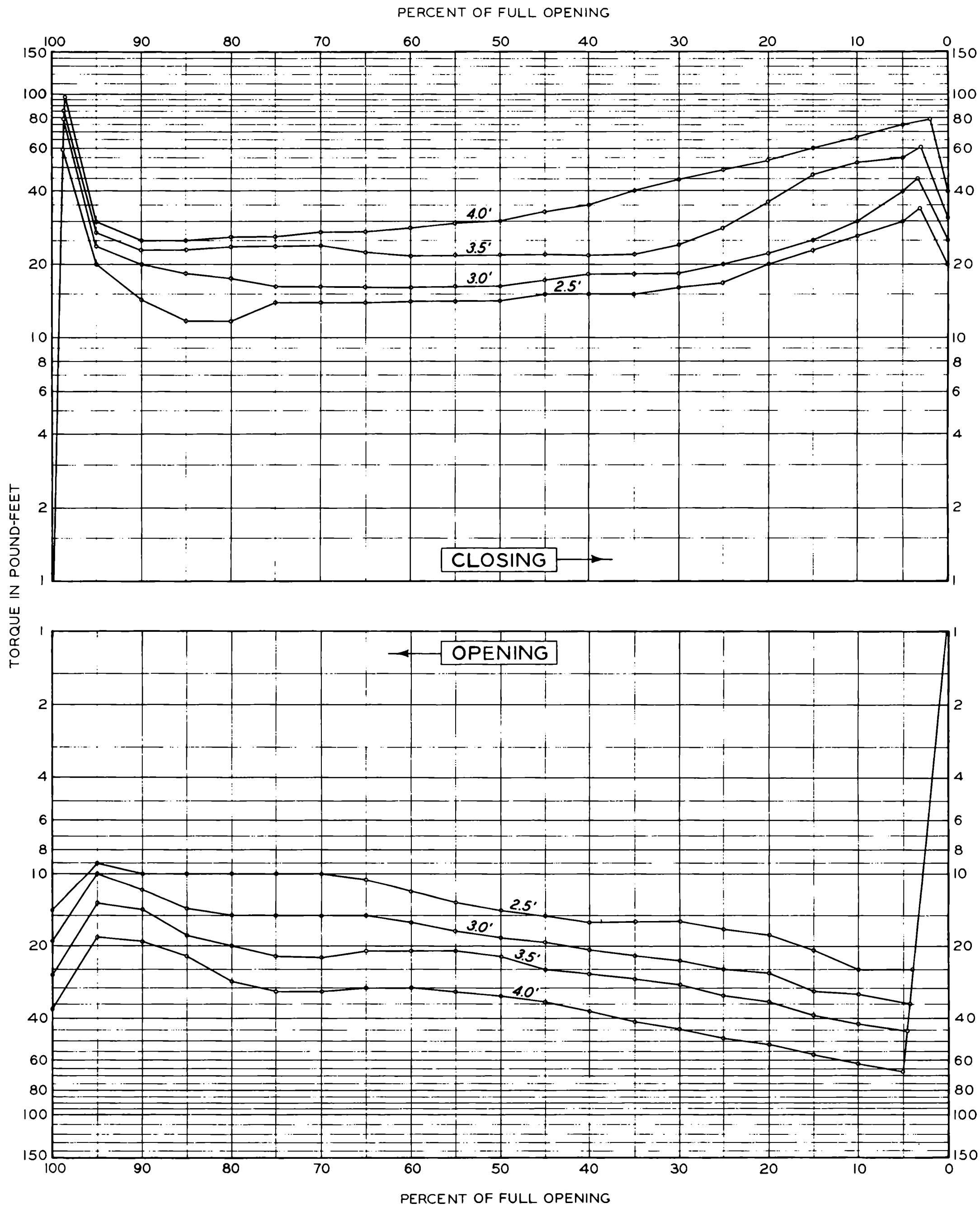


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 40.2 SECONDS
CHAMBER LENGTHS 20 FEET

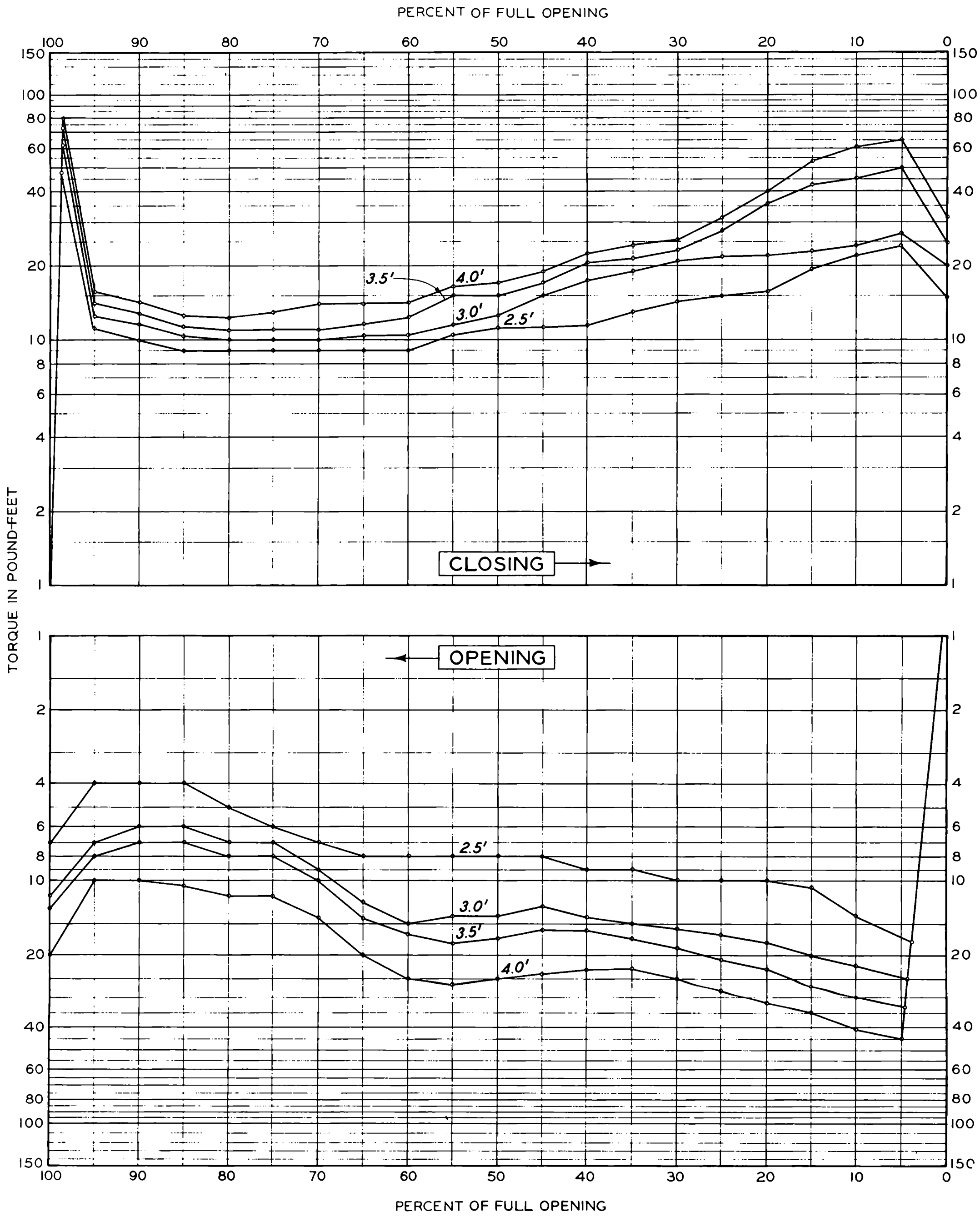


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 10.1 SECONDS
CHAMBER LENGTHS 30 FEET

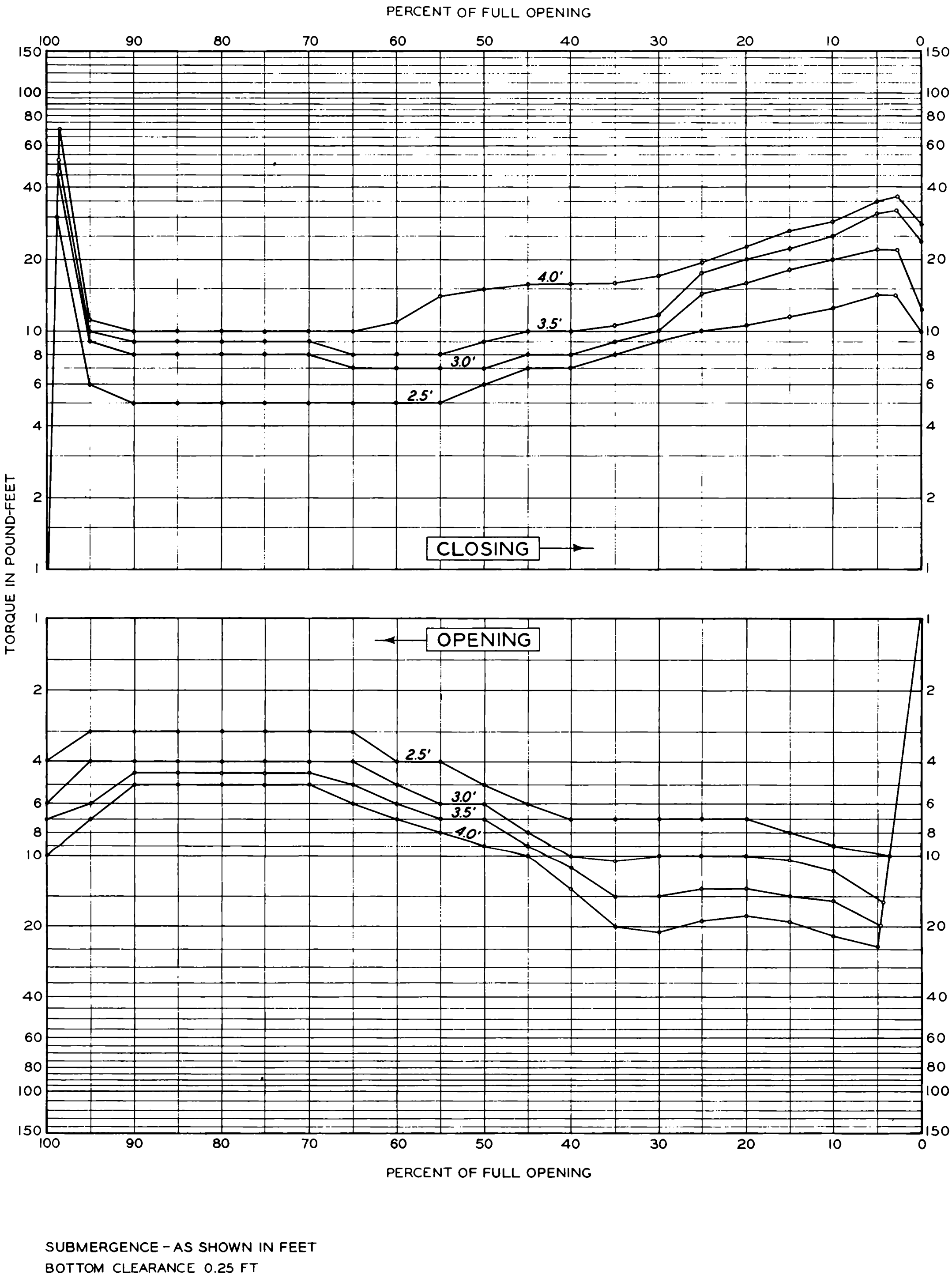


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 13.4 SECONDS
CHAMBER LENGTHS 30 FEET

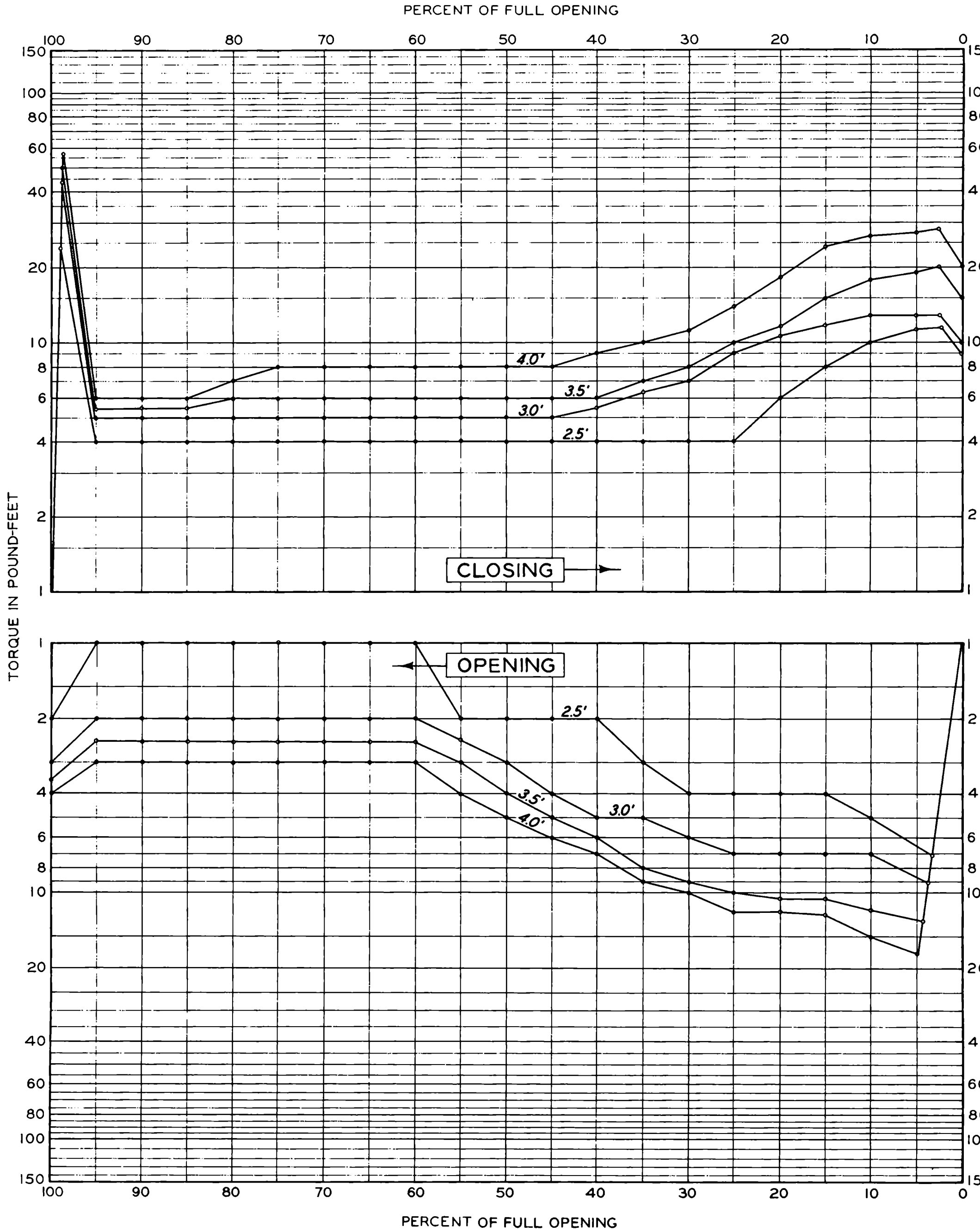


MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 20.1 SECONDS

CHAMBER LENGTHS 30 FEET



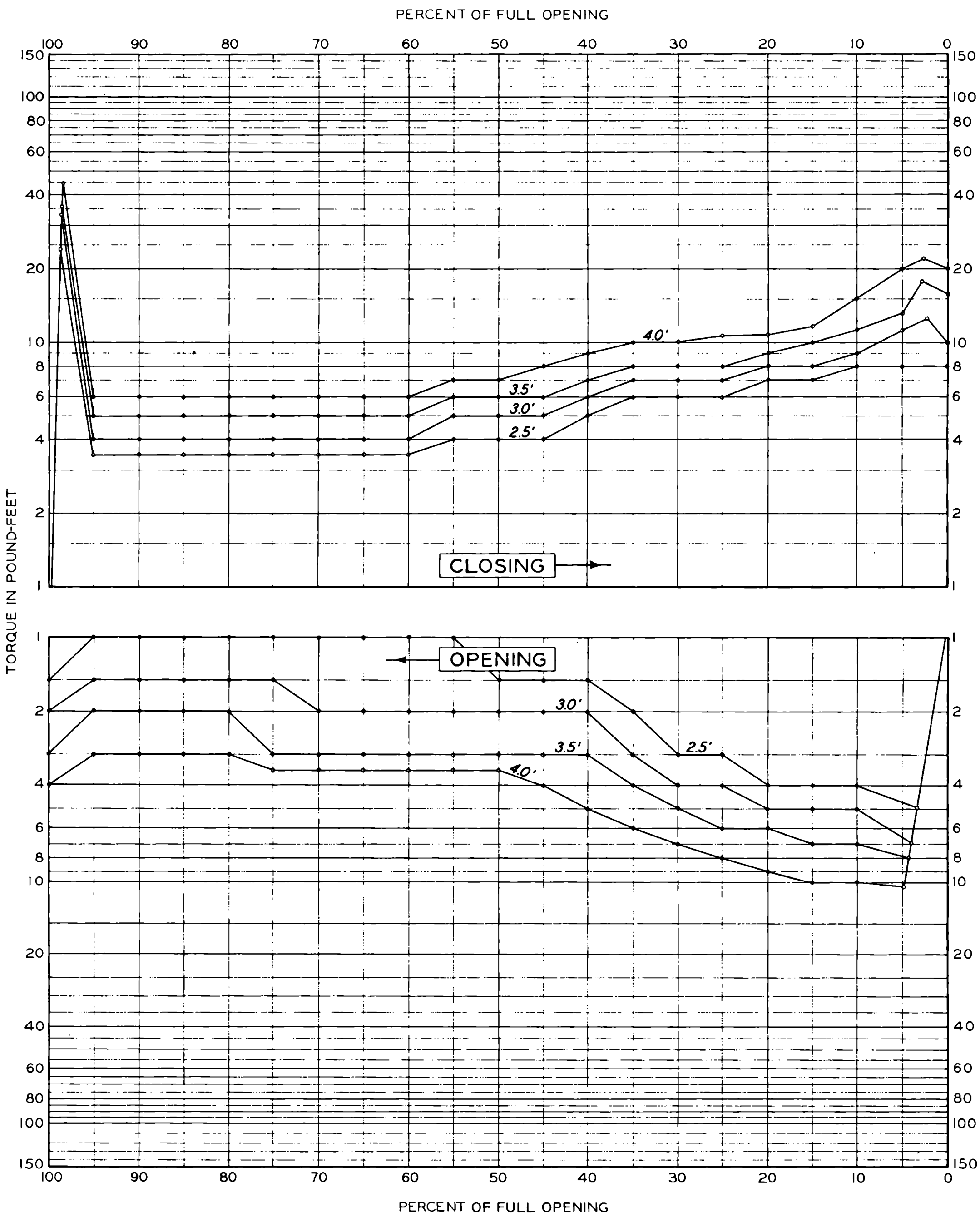
SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 26.8 SECONDS

CHAMBER LENGTHS 30 FEET

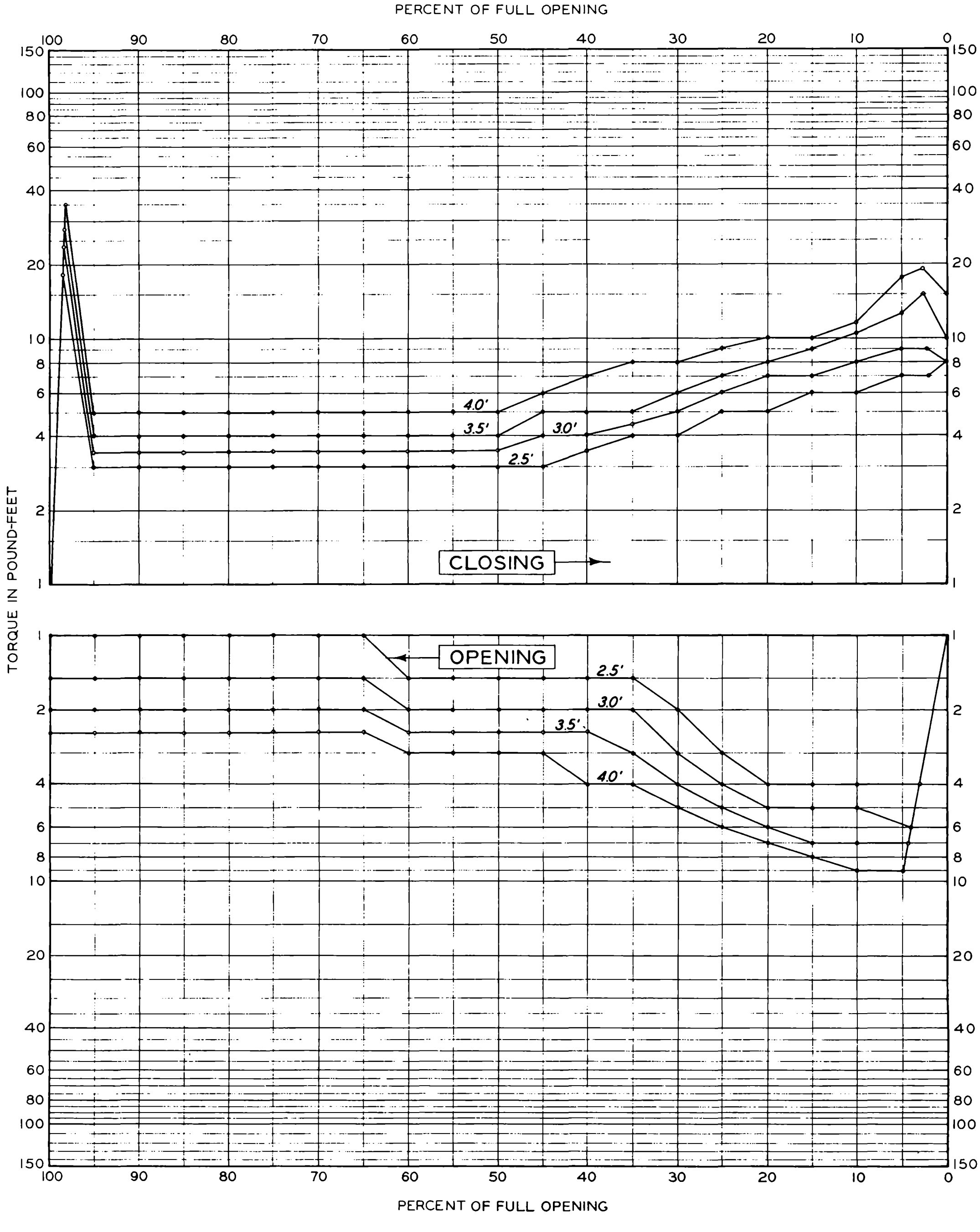


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 33.5 SECONDS
CHAMBER LENGTHS 30 FEET

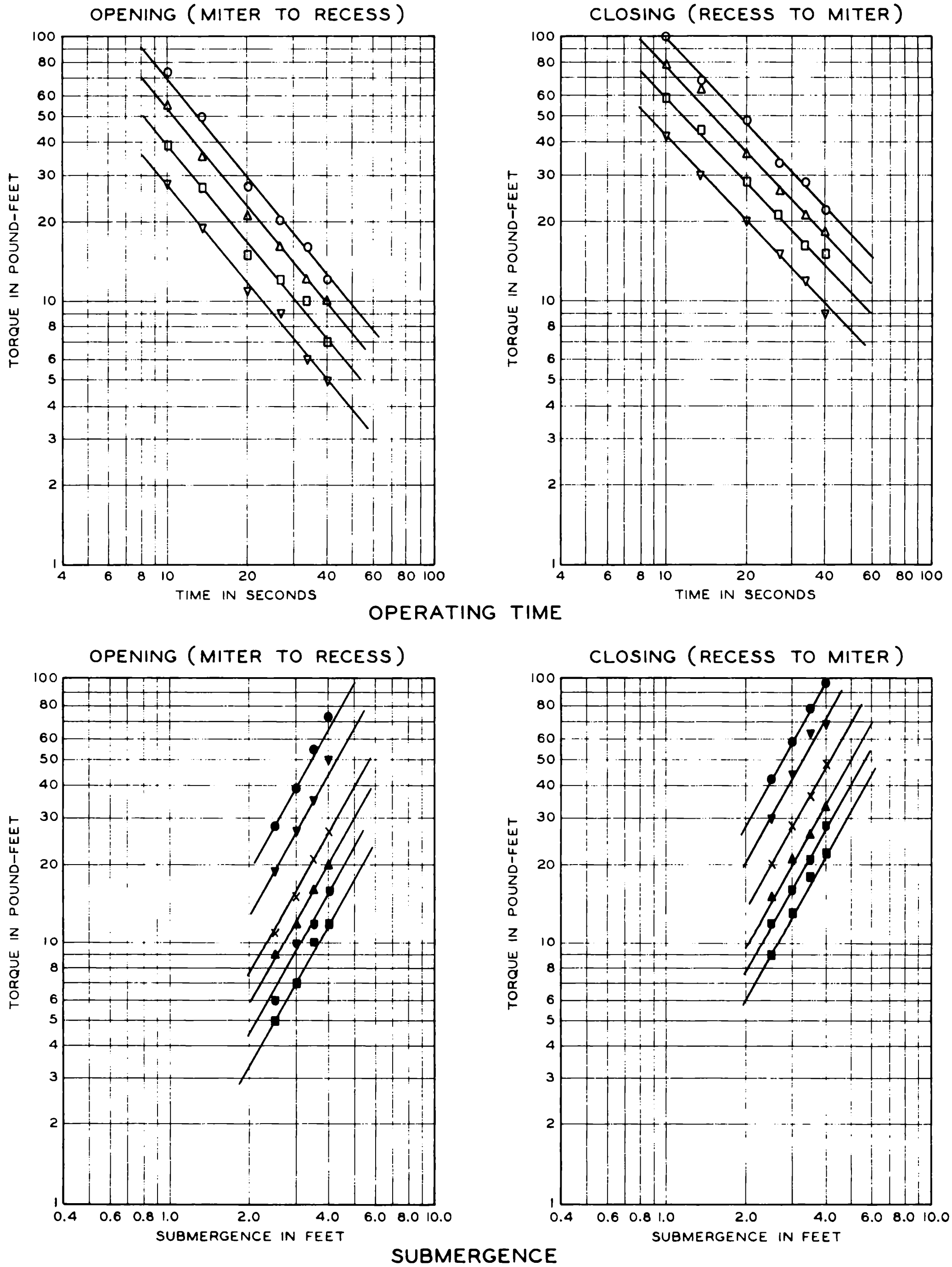


SUBMERGENCE - AS SHOWN IN FEET
BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 40.2 SECONDS
CHAMBER LENGTHS 30 FEET



LEGEND

TIME OF OPERATION

- ○——○ SUBMERGENCE 4.0 FT
- △——△ SUBMERGENCE 3.5 FT
- □——□ SUBMERGENCE 3.0 FT
- ▽——▽ SUBMERGENCE 2.5 FT

SUBMERGENCE

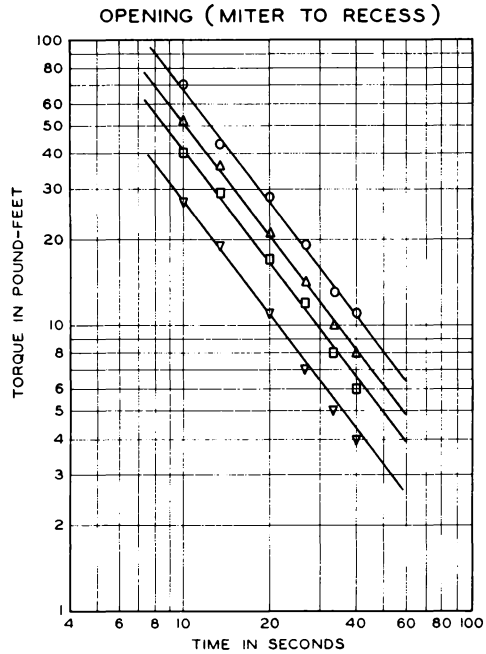
- ●——● OPERATING TIME 10.1 SEC
- ▼——▼ OPERATING TIME 13.4 SEC
- ×——× OPERATING TIME 20.1 SEC
- ▲——▲ OPERATING TIME 26.8 SEC
- ●——● OPERATING TIME 33.5 SEC
- ■——■ OPERATING TIME 40.2 SEC

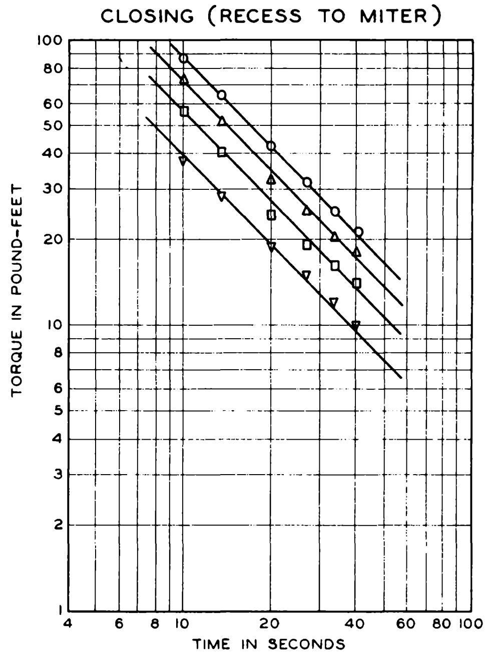
NOTE: BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

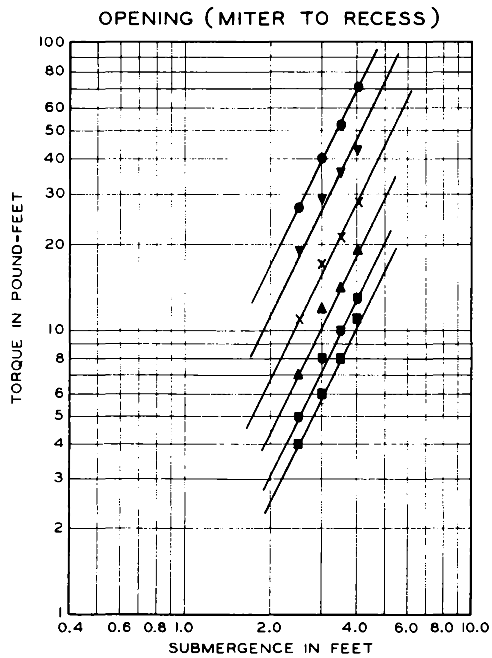
EFFECTS OF OPERATING TIME AND SUBMERGENCE ON MAXIMUM TORQUE

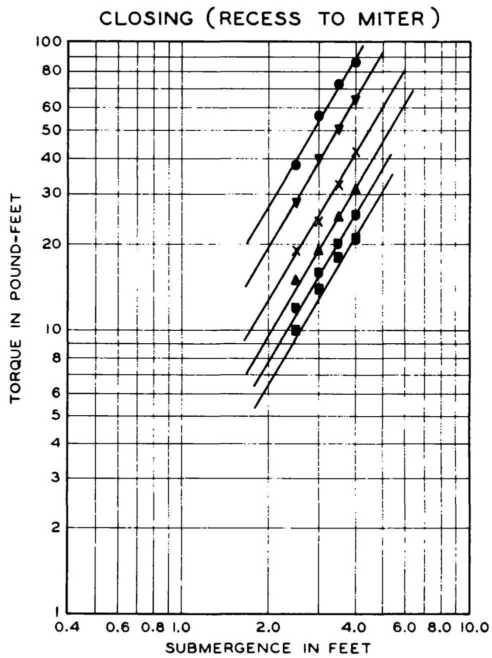
CHAMBER LENGTHS 15 FEET





OPERATING TIME





SUBMERGENCE

LEGEND

TIME OF OPERATION
- ○———○ SUBMERGENCE 4.0 FT
- △———△ SUBMERGENCE 3.5 FT
- □———□ SUBMERGENCE 3.0 FT
- ▽———▽ SUBMERGENCE 2.5 FT

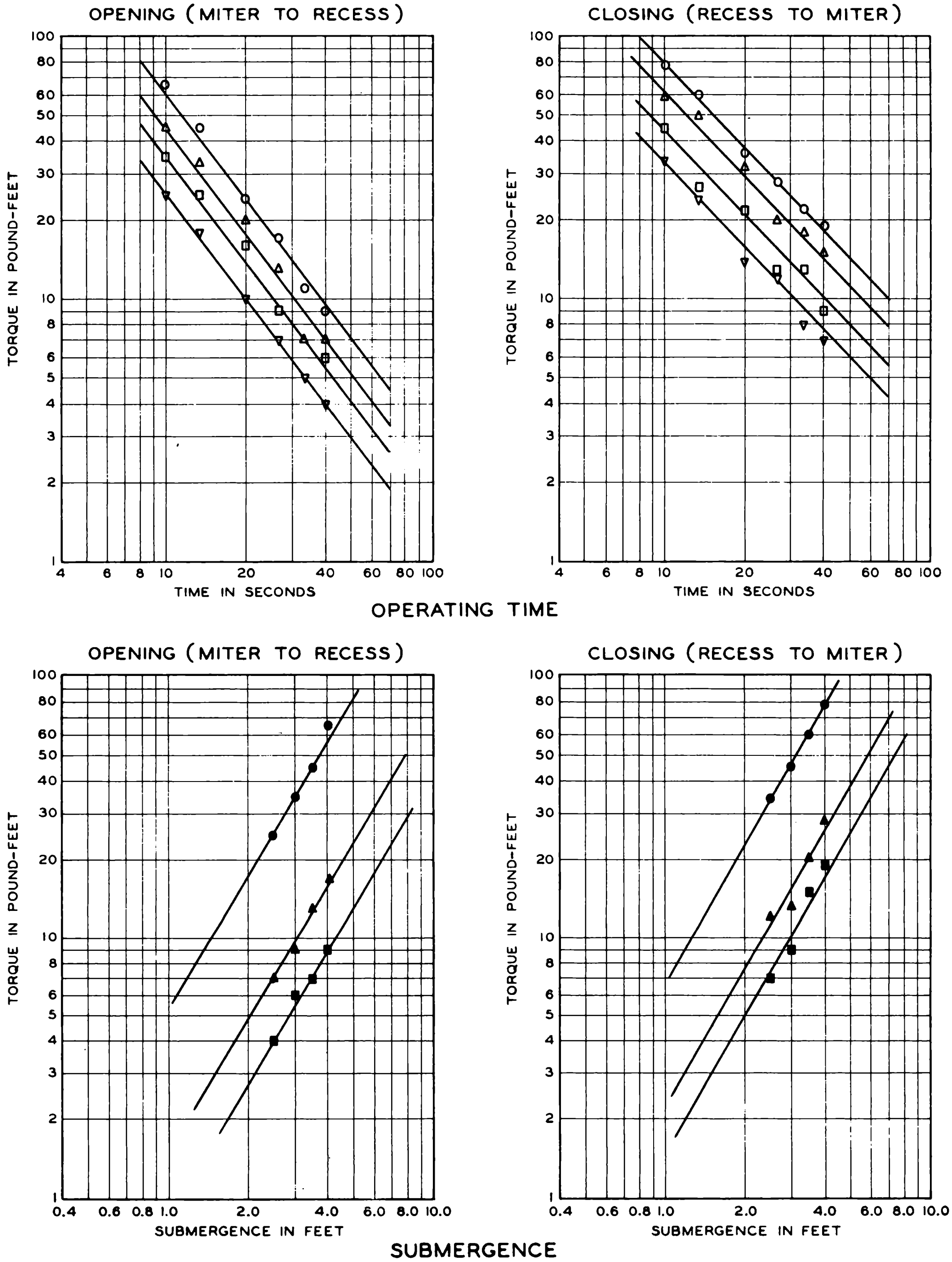
SUBMERGENCE
- ●———● OPERATING TIME 10.1 SEC
- ▼———▼ OPERATING TIME 13.4 SEC
- ✕———✕ OPERATING TIME 20.1 SEC
- ▲———▲ OPERATING TIME 26.8 SEC
- ⬢———⬢ OPERATING TIME 33.5 SEC
- ■———■ OPERATING TIME 40.2 SEC

NOTE: BOTTOM CLEARANCE 0.25 FT

MODIFIED OHIO RIVER LINKAGE

EFFECTS OF OPERATING TIME AND SUBMERGENCE ON MAXIMUM TORQUE

CHAMBER LENGTHS 20 FEET



NOTE: BOTTOM CLEARANCE 0.25 FT

LEGEND

TIME OF OPERATION

- ○———○ SUBMERGENCE 4.0 FT
- △———△ SUBMERGENCE 3.5 FT
- □———□ SUBMERGENCE 3.0 FT
- ▽———▽ SUBMERGENCE 2.5 FT

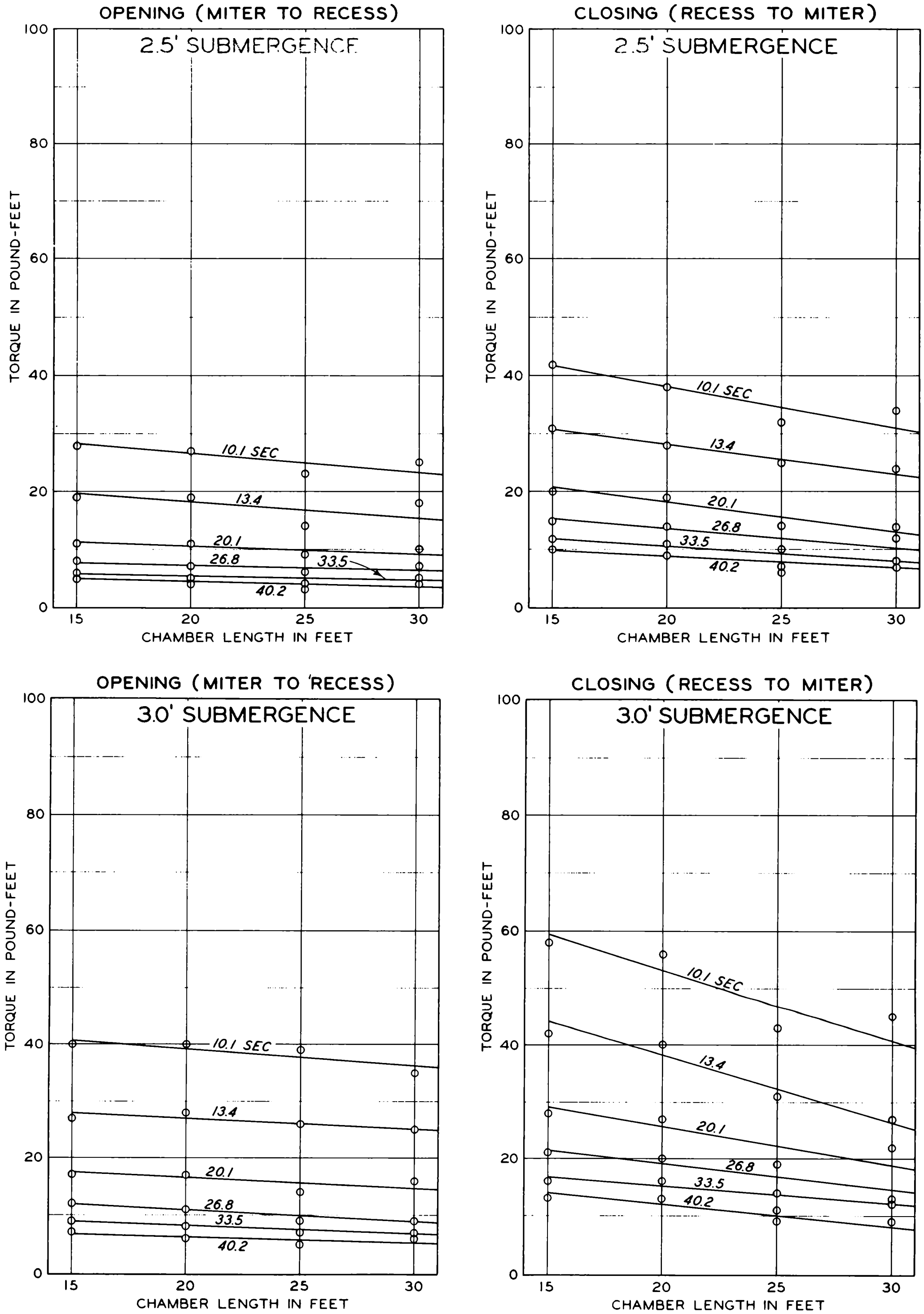
SUBMERGENCE

- ●———● OPERATING TIME 10.1 SEC
- ▲———▲ OPERATING TIME 26.8 SEC
- ■———■ OPERATING TIME 40.2 SEC

MODIFIED OHIO RIVER LINKAGE

EFFECTS OF OPERATING TIME AND SUBMERGENCE ON MAXIMUM TORQUE

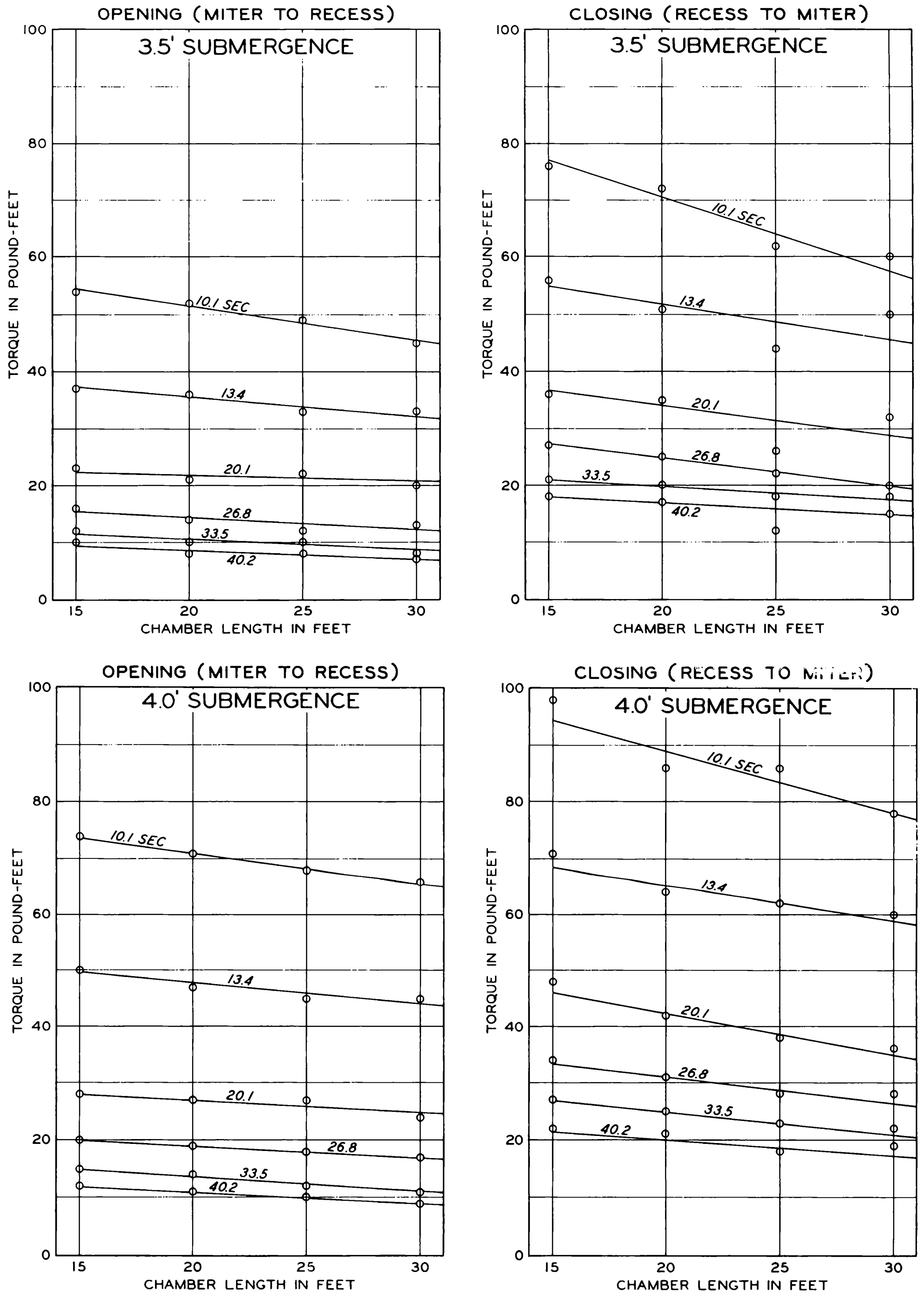
CHAMBER LENGTHS 30 FEET



MODIFIED OHIO RIVER LINKAGE

EFFECT OF CHAMBER LENGTHS ON MAXIMUM TORQUE

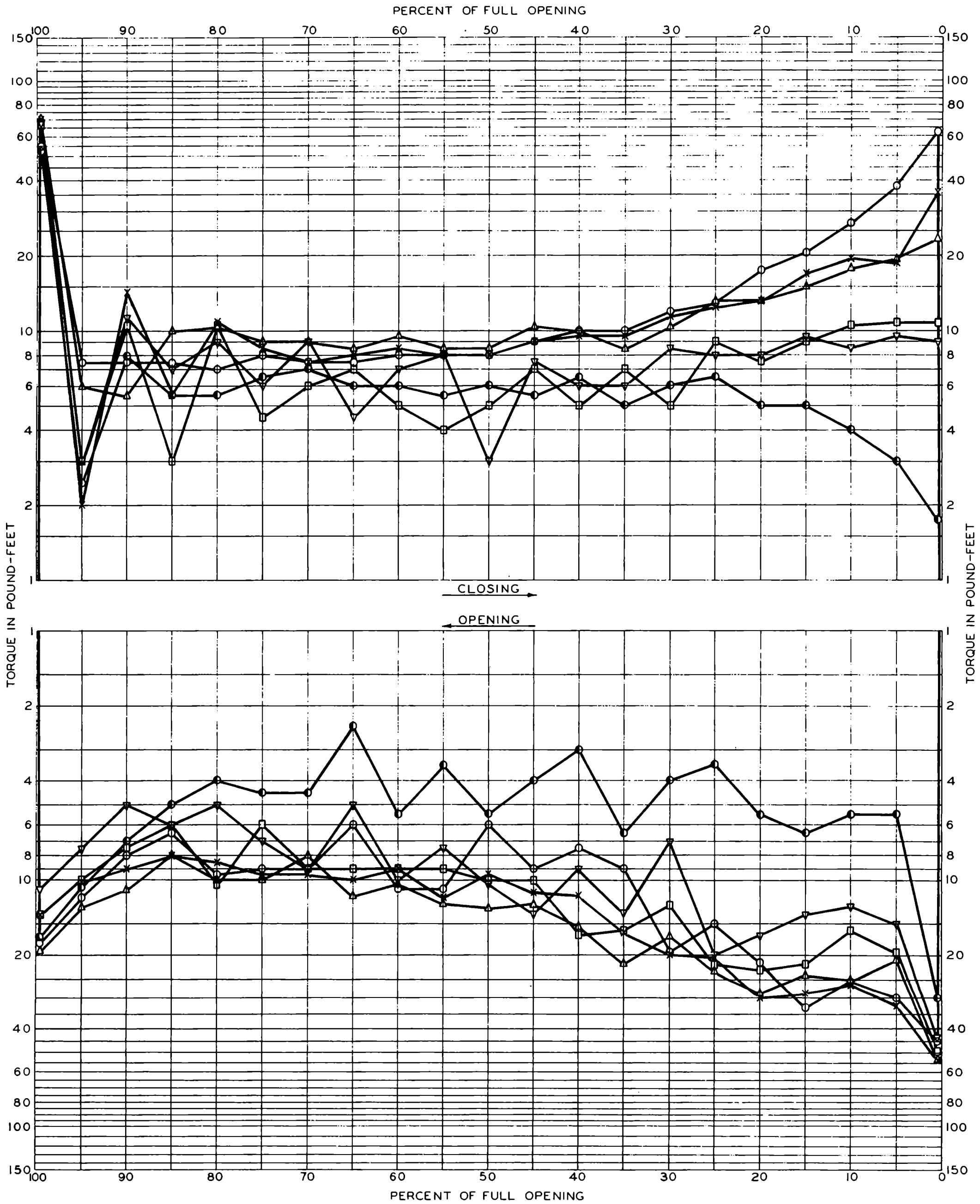
SUBMERGENCE 2.5 AND 3.0 FEET



MODIFIED OHIO RIVER LINKAGE

EFFECT OF CHAMBER LENGTHS ON MAXIMUM TORQUE

SUBMERGENCE 3.5 AND 4.0 FEET



TEST CONDITIONS

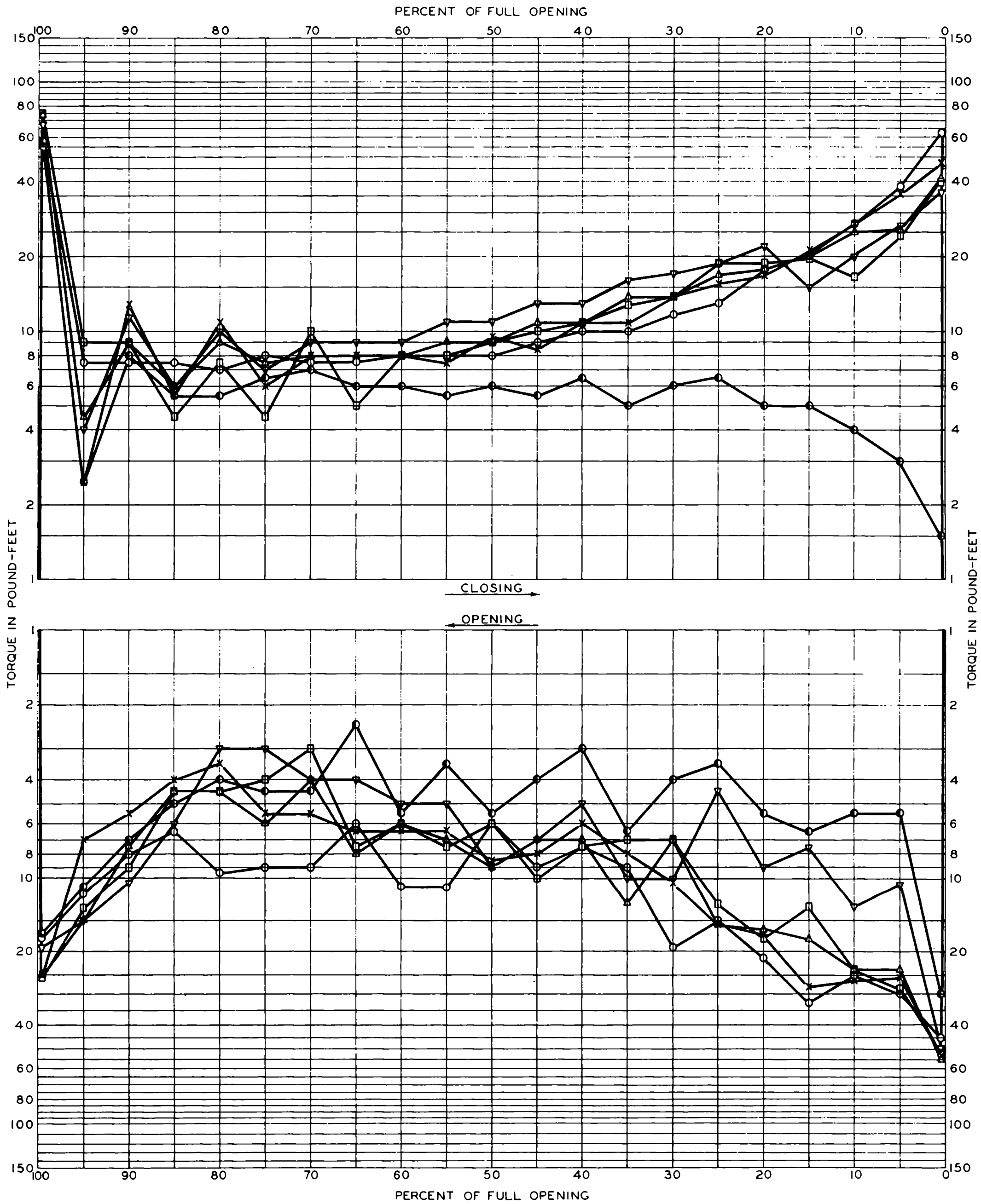
SUBMERGENCE	4.0 FEET
CHAMBER LENGTHS	25.0 FEET
BOTTOM CLEARANCE	3.0 INCHES
OPERATING TIME	20.1 SECONDS
OHIO RIVER LINKAGE	

LEGEND

- SYNCHRONOUS OPERATION
- 1.1 SECONDS
- 2.2 SECONDS
- 3.4 SECONDS
- 4.5 SECONDS
- SINGLE-LEAF OPERATION

EFFECT OF NONSYNCHRONOUS OPERATION ON INSTANTANEOUS TORQUE

LEADING LEAF



TEST CONDITIONS

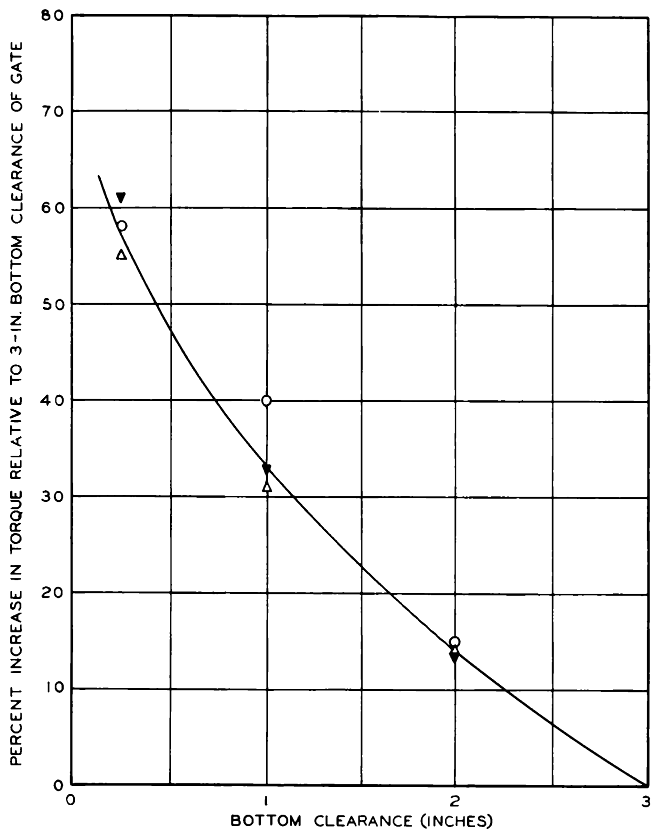
SUBMERGENCE	4.0 FEET
CHAMBER LENGTHS	25.0 FEET
BOTTOM CLEARANCE	3.0 INCHES
OPERATING TIME	20.1 SECONDS
OHIO RIVER LINKAGE	

LEGEND

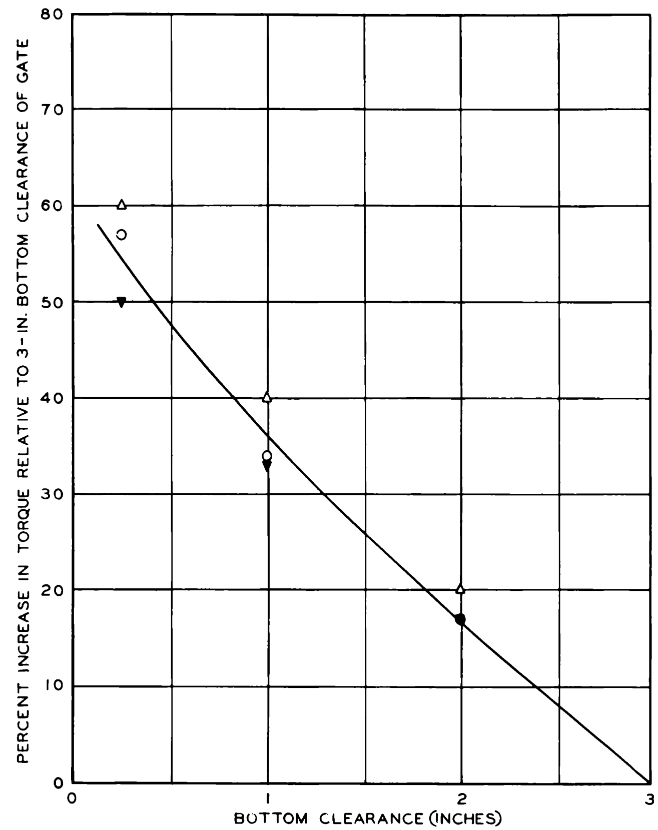
- SYNCHRONOUS OPERATION
- 1.1 SECONDS
- 2.2 SECONDS
- 3.4 SECONDS
- 4.5 SECONDS
- SINGLE-LEAF OPERATION

EFFECT OF NONSYNCHRONOUS OPERATION ON INSTANTANEOUS TORQUE

LAGGING LEAF



OPENING CYCLE

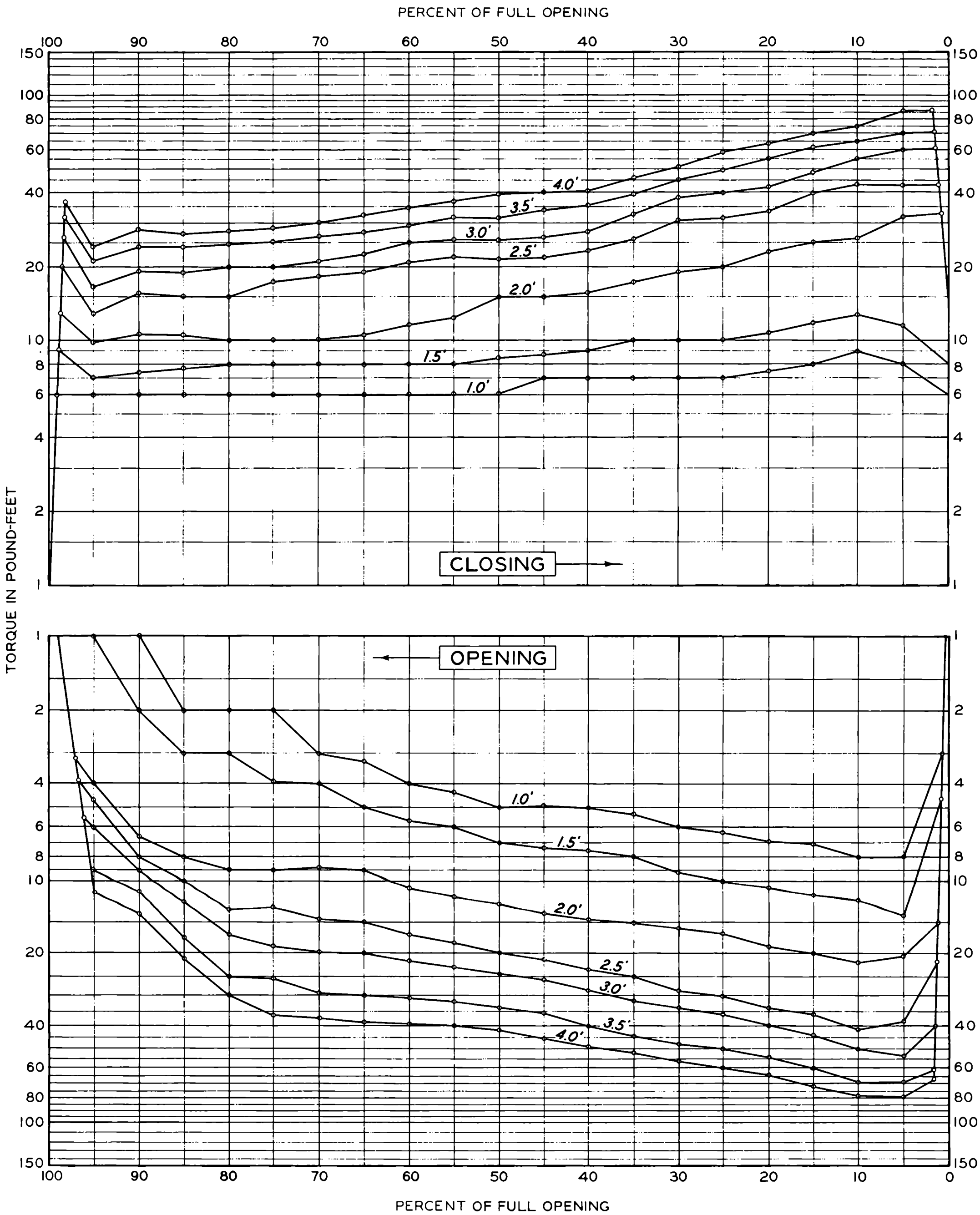


CLOSING CYCLE

SYMBOL	OPERATING TIME SEC	TORQUE, LB-FT (3-IN. BOTTOM CLEARANCE) OPENING CYCLE	CLOSING CYCLE
○	13.4	40	35
△	20.1	29	20
▼	26.8	18	12

RELATIVE EFFECT OF GATE BOTTOM CLEARANCE ON TORQUE

4.0-FT SUBMERGENCE

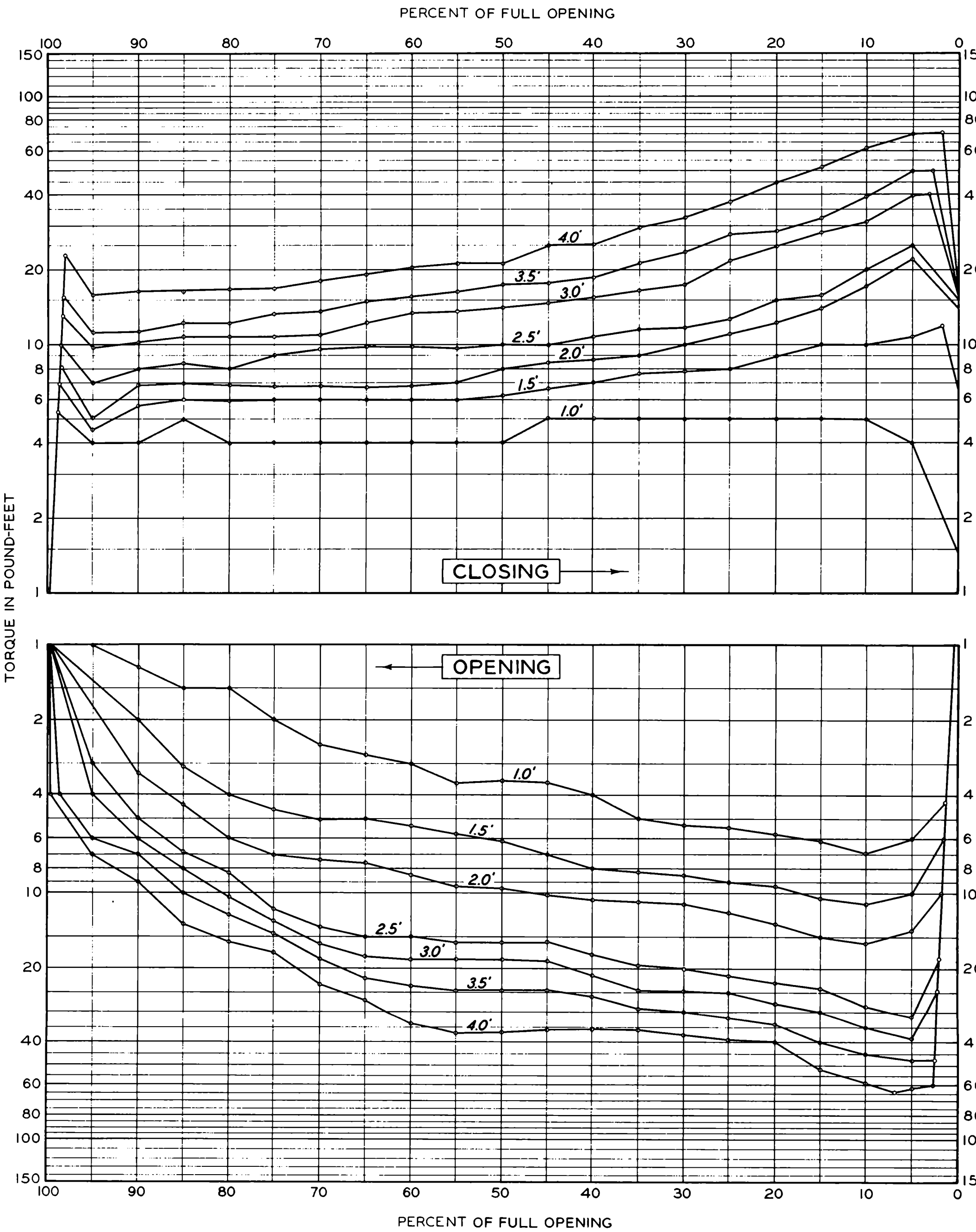


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

PANAMA LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 10.1 SECONDS

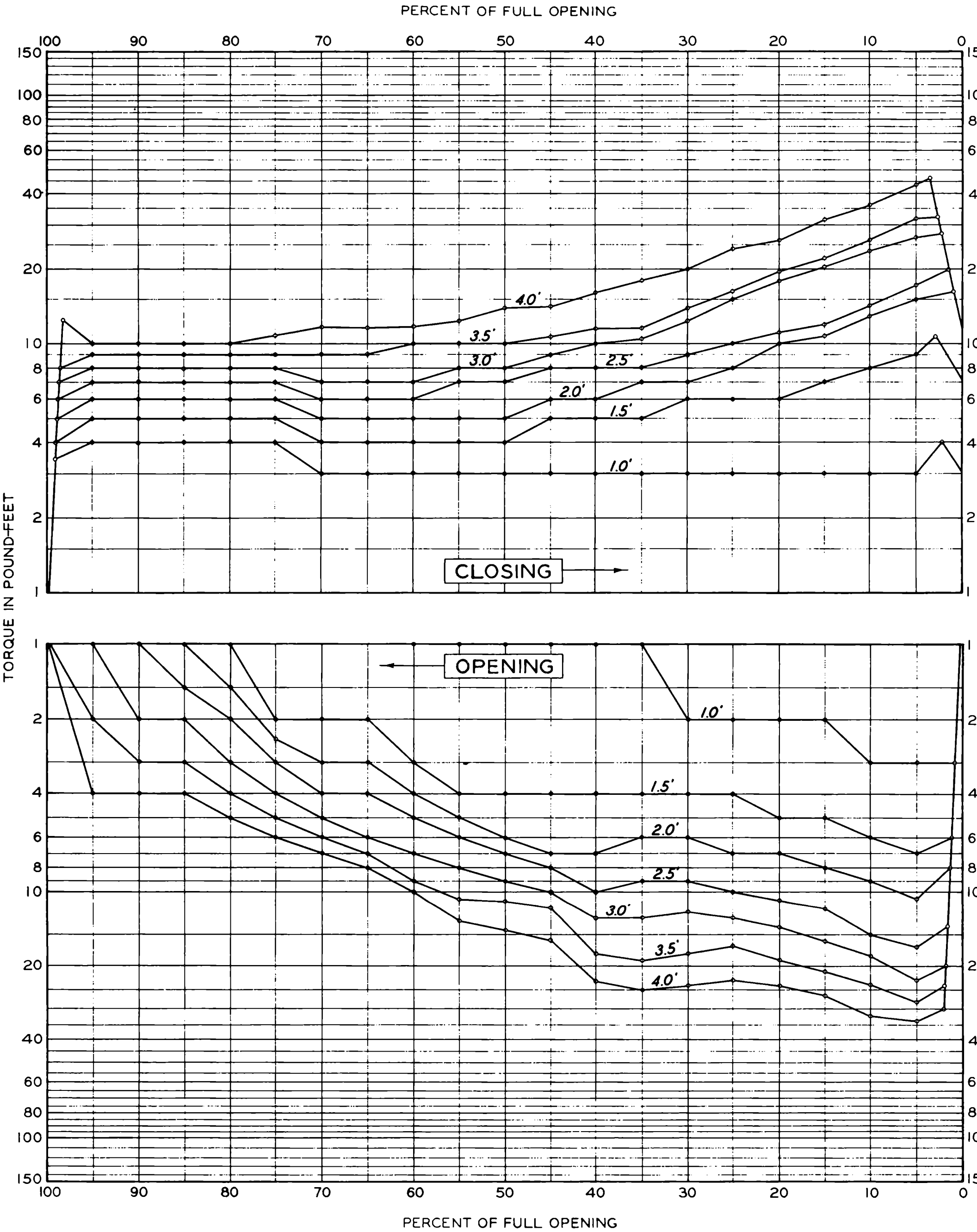


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

PANAMA LINKAGE

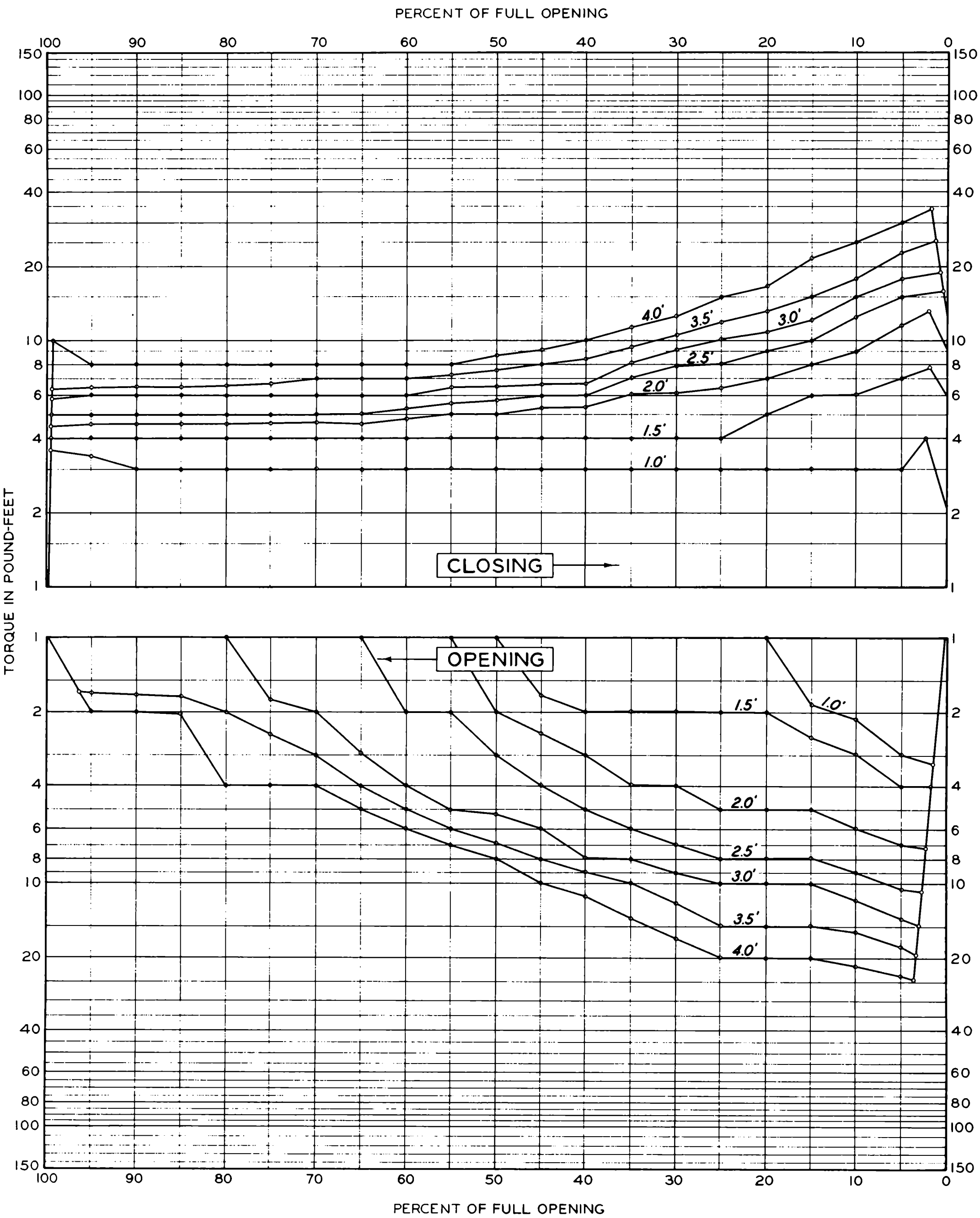
EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 13.4 SECONDS



SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

PANAMA LINKAGE
EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE
OPERATING TIME 20.1 SECONDS

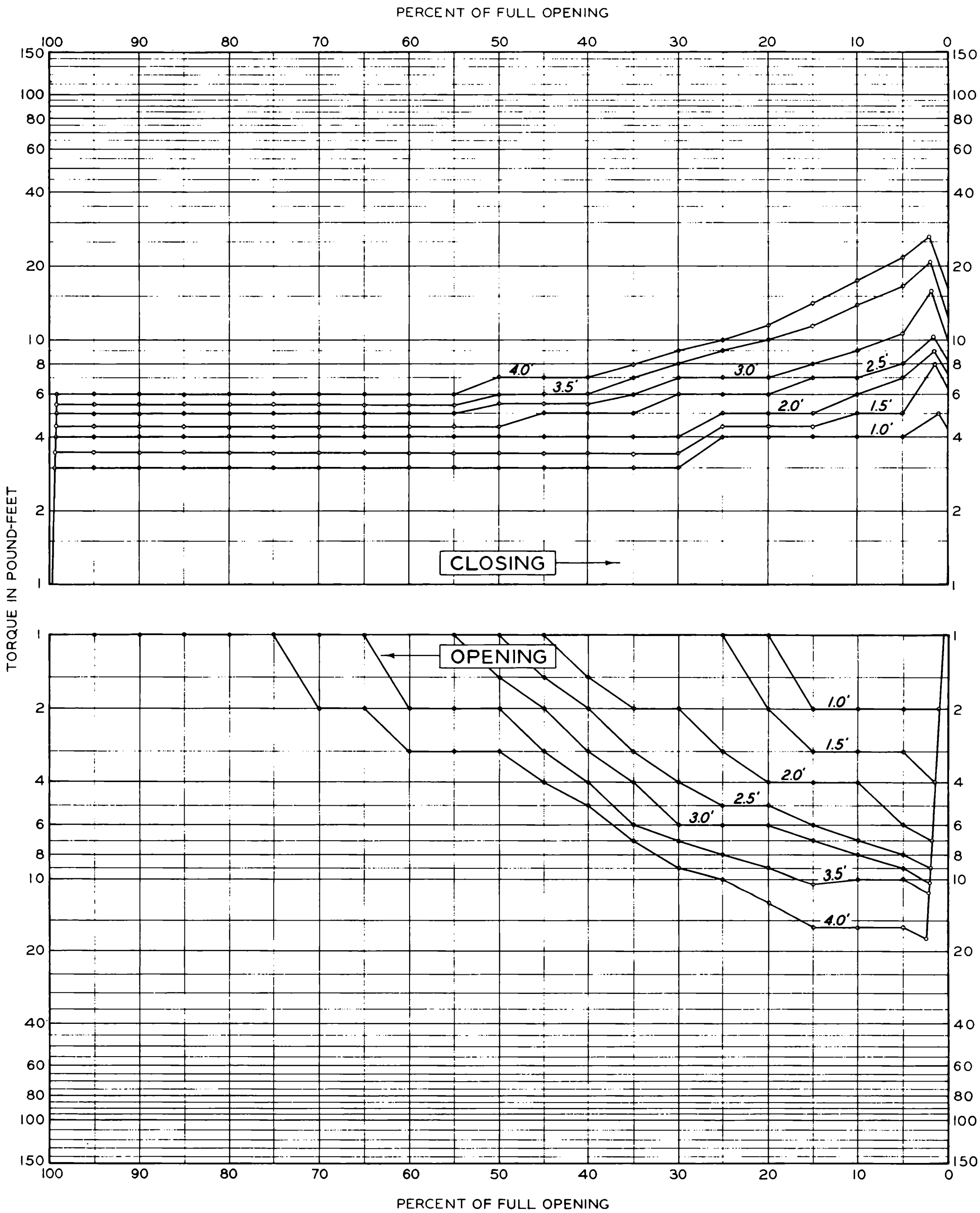


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

PANAMA LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 26.8 SECONDS

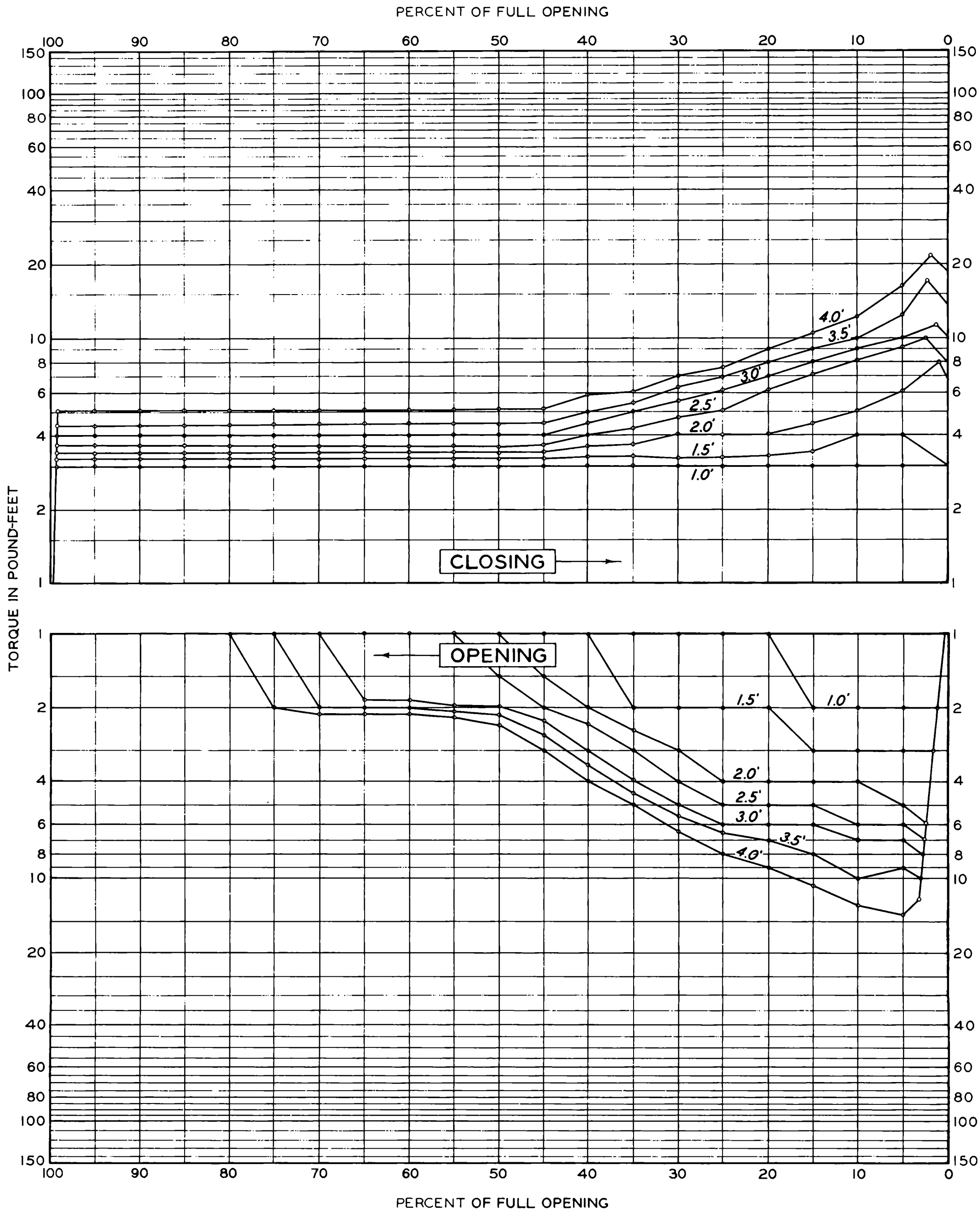


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

PANAMA LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 33.5 SECONDS

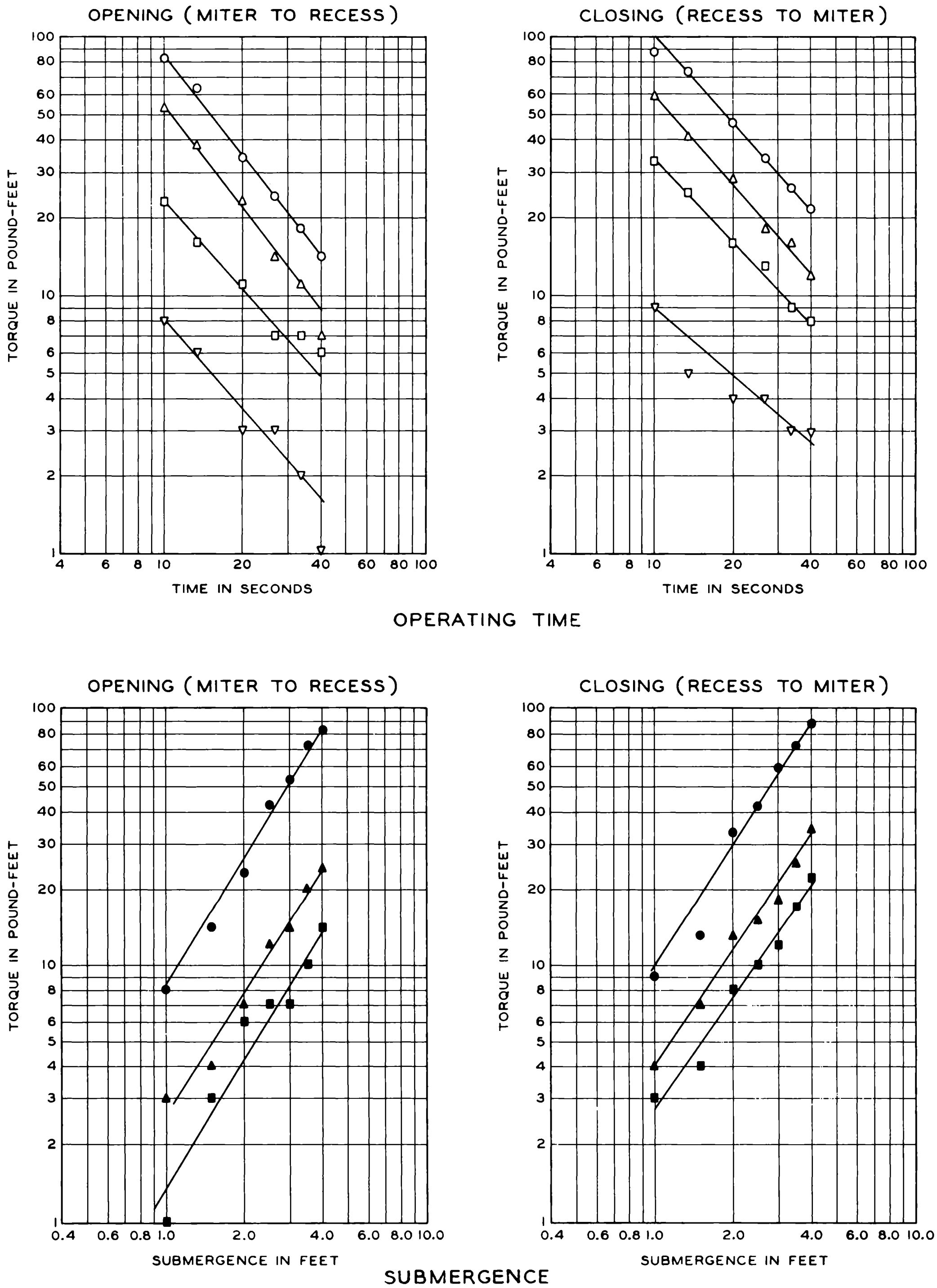


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

PANAMA LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 40.2 SECONDS



NOTE: BOTTOM CLEARANCE 0.25 FT

LEGEND

TIME OF OPERATION

- ○——○ SUBMERGENCE 4.0 FT
- △——△ SUBMERGENCE 3.0 FT
- □——□ SUBMERGENCE 2.0 FT
- ▽——▽ SUBMERGENCE 1.0 FT

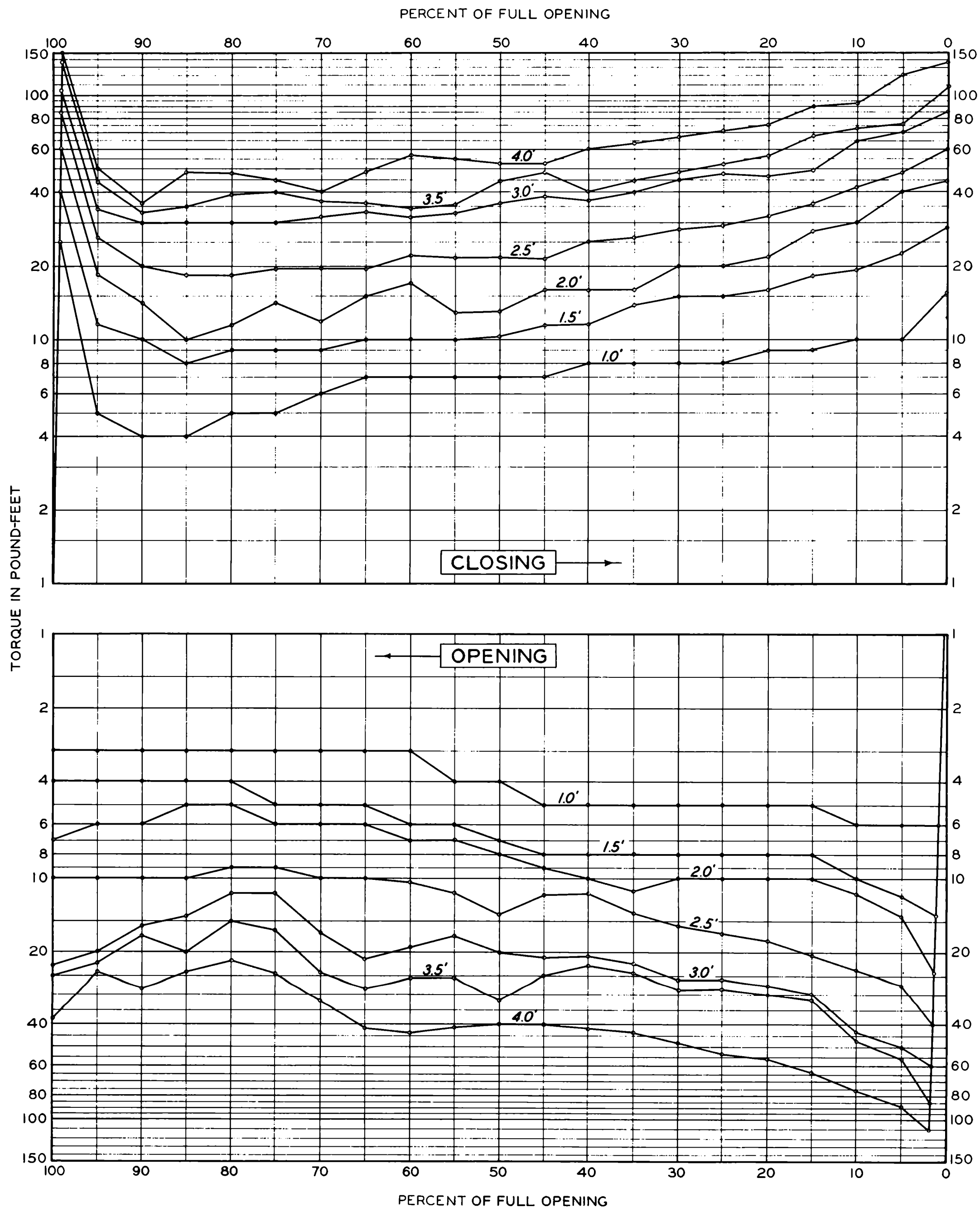
SUBMERGENCE

- ●——● OPERATING TIME 10.1 SEC
- ▲——▲ OPERATING TIME 26.8 SEC
- ■——■ OPERATING TIME 40.2 SEC

PANAMA LINKAGE

EFFECTS OF OPERATING TIME AND SUBMERGENCE ON MAXIMUM TORQUE

CHAMBER LENGTHS 25 FT

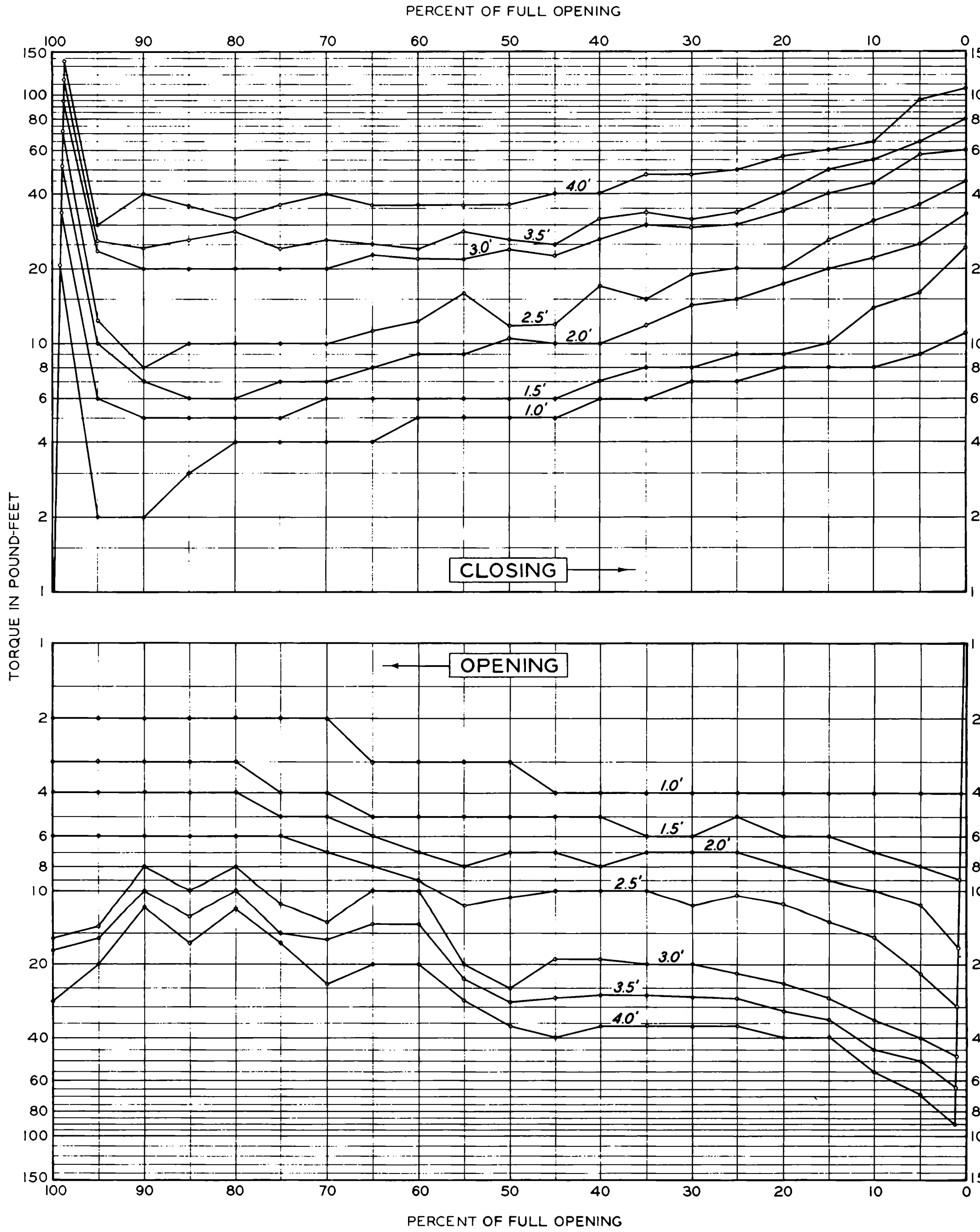


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 10.1 SECONDS

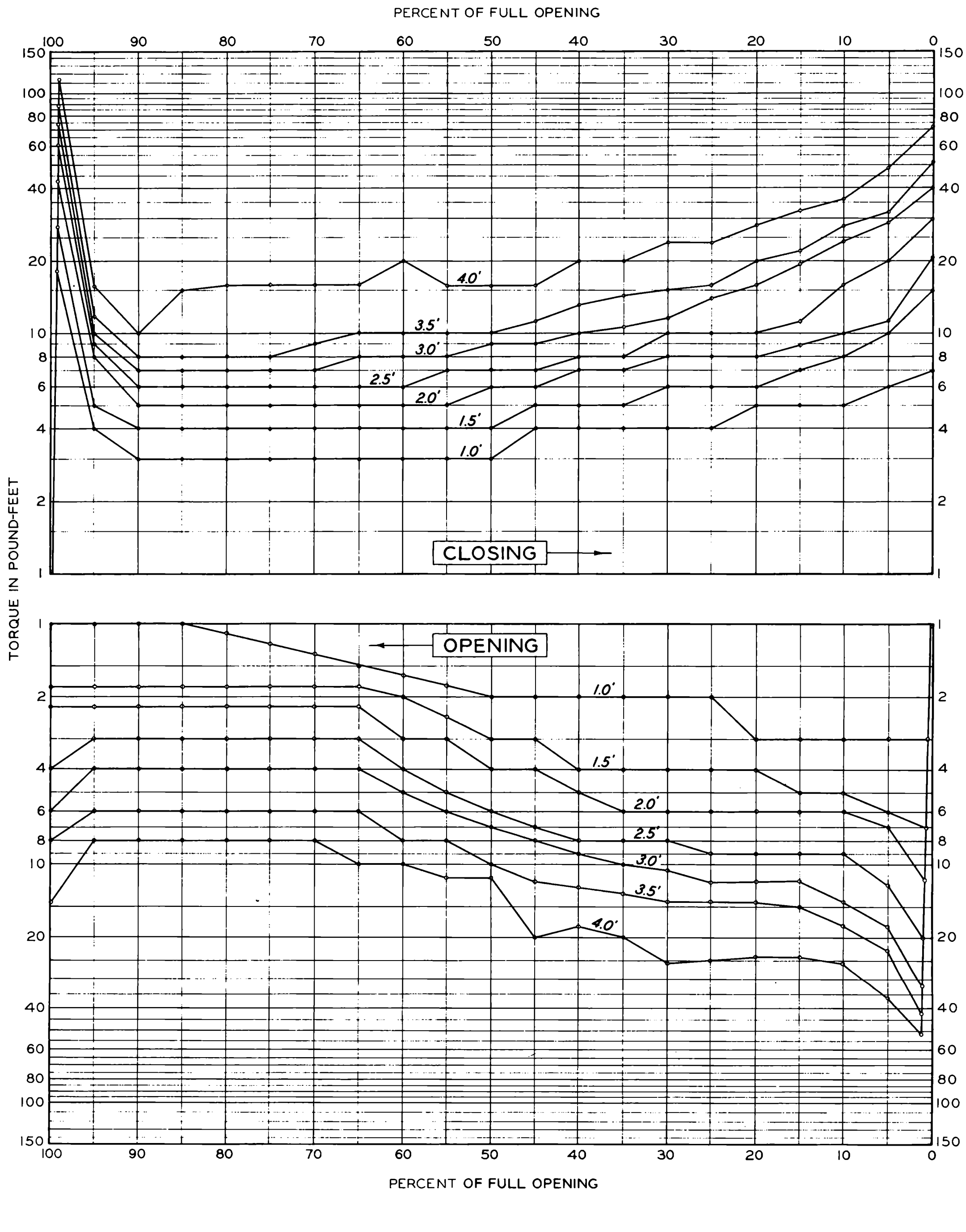


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 13.4 SECONDS

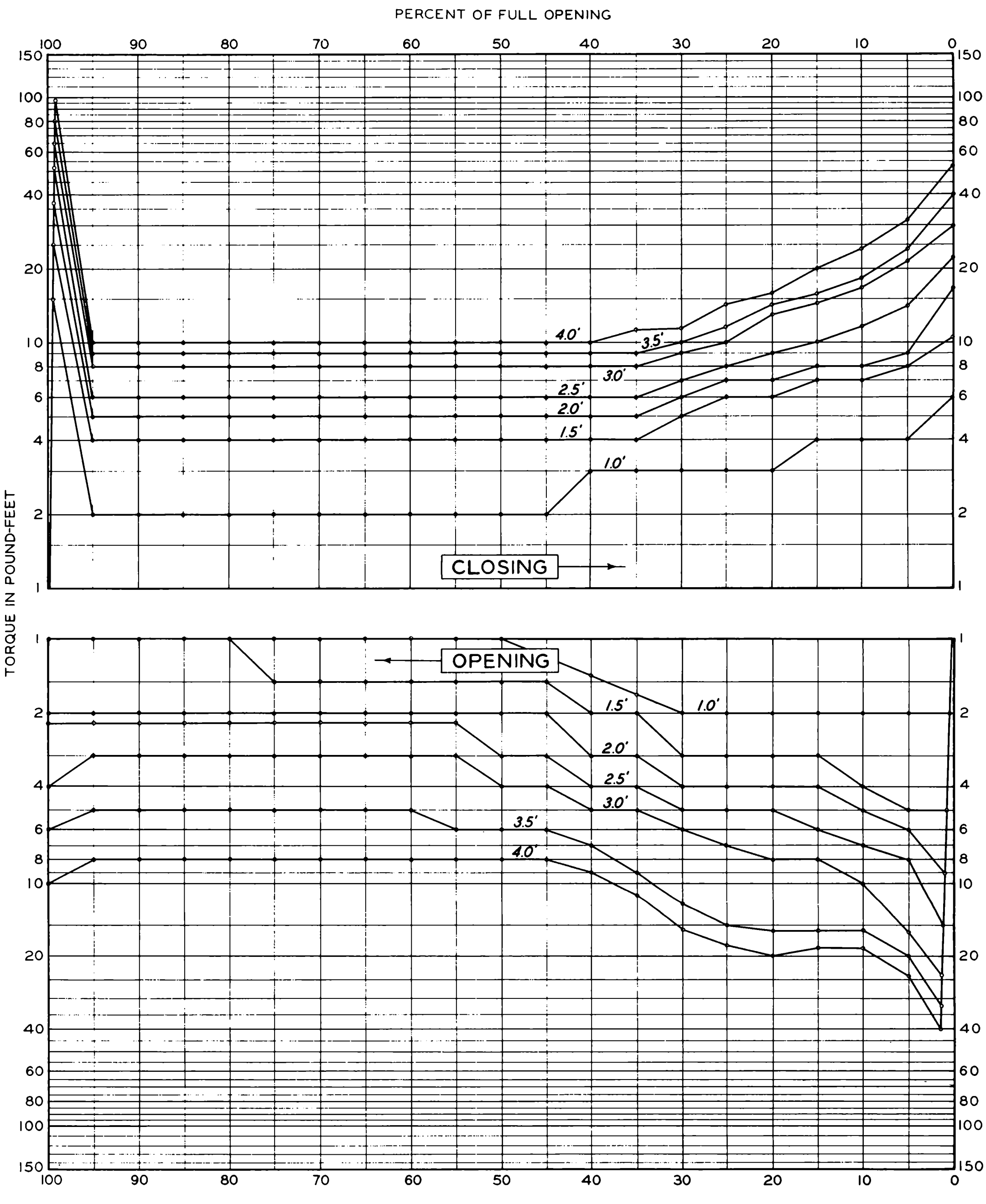


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 20.1 SECONDS

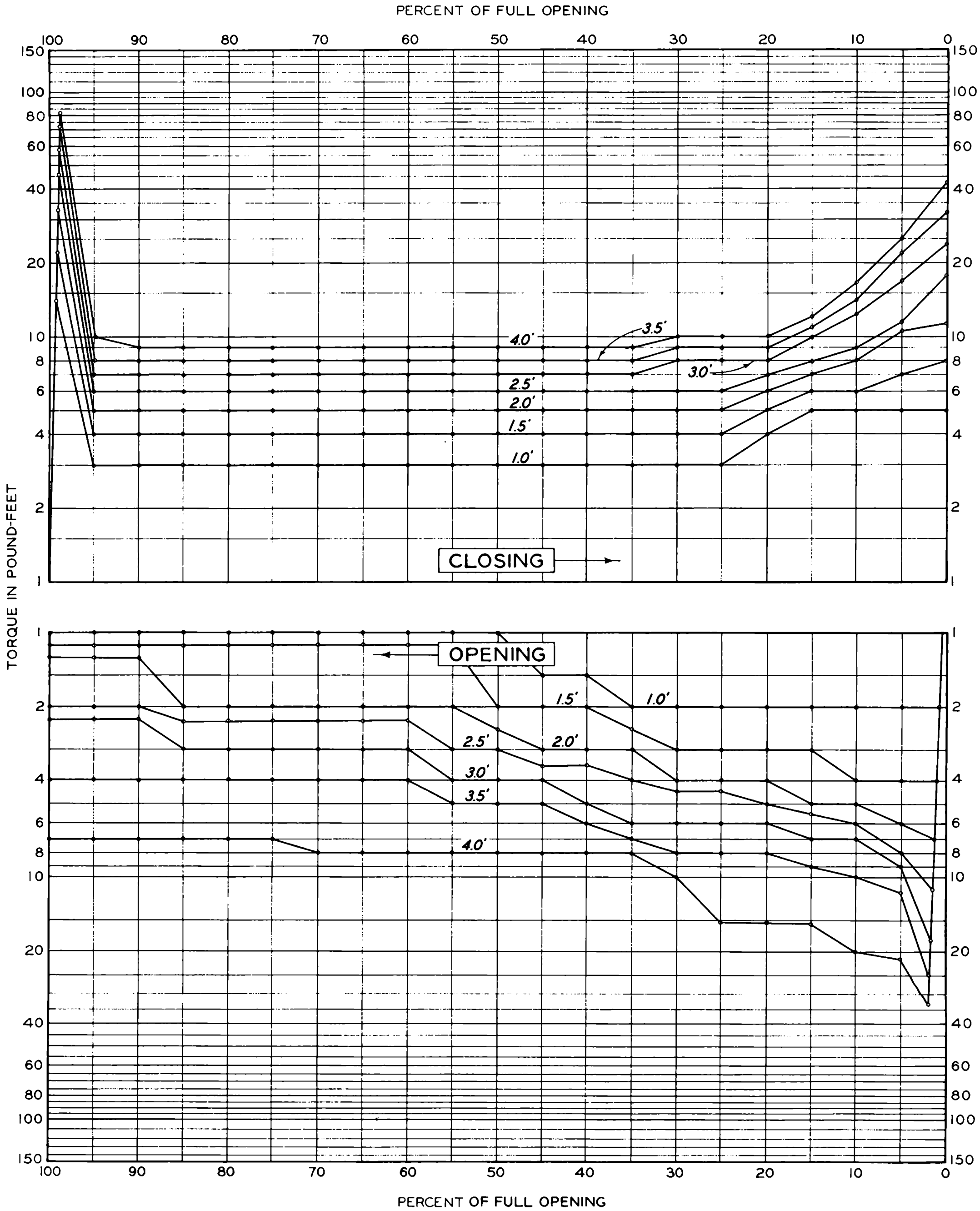


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 26.8 SECONDS

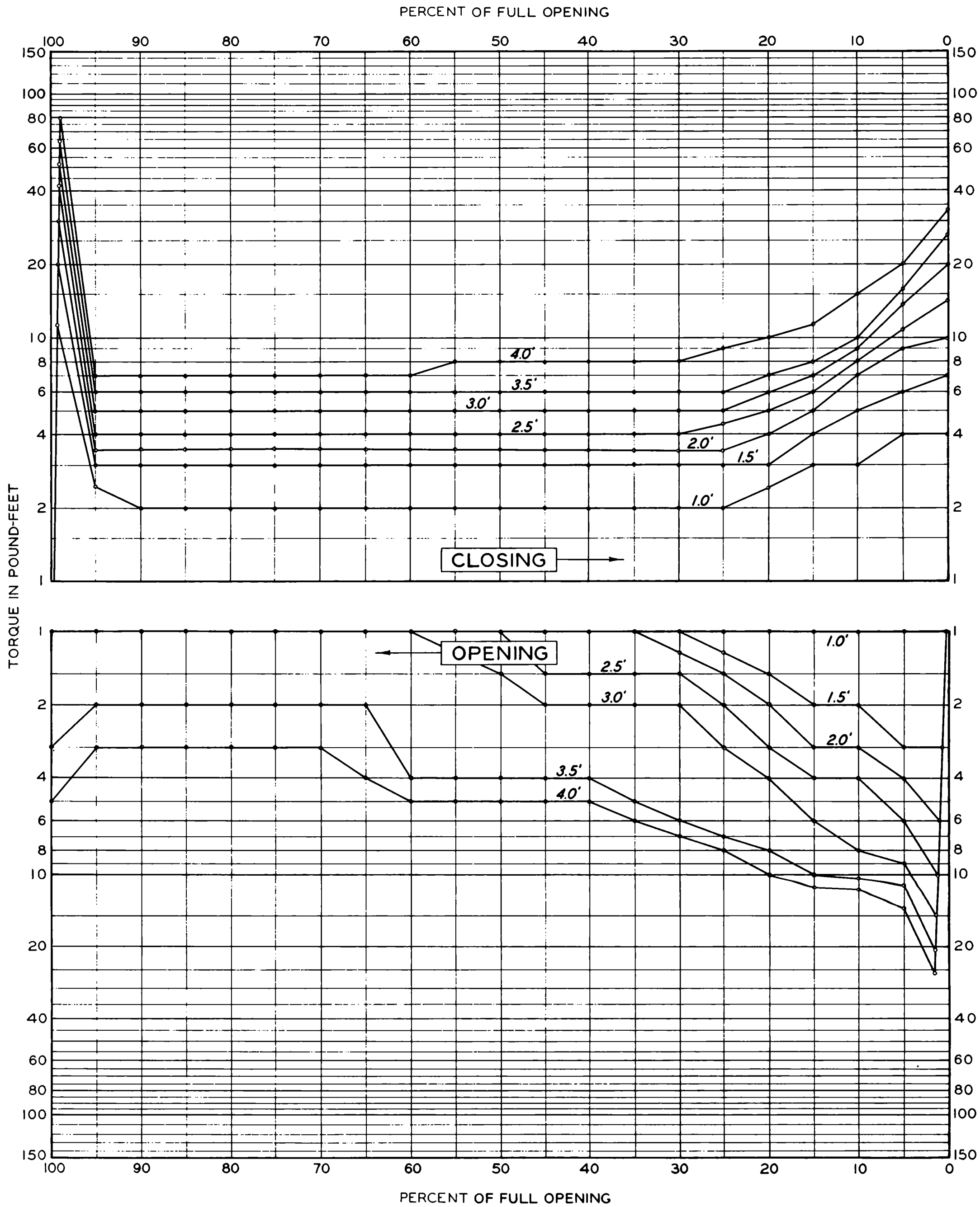


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 33.5 SECONDS

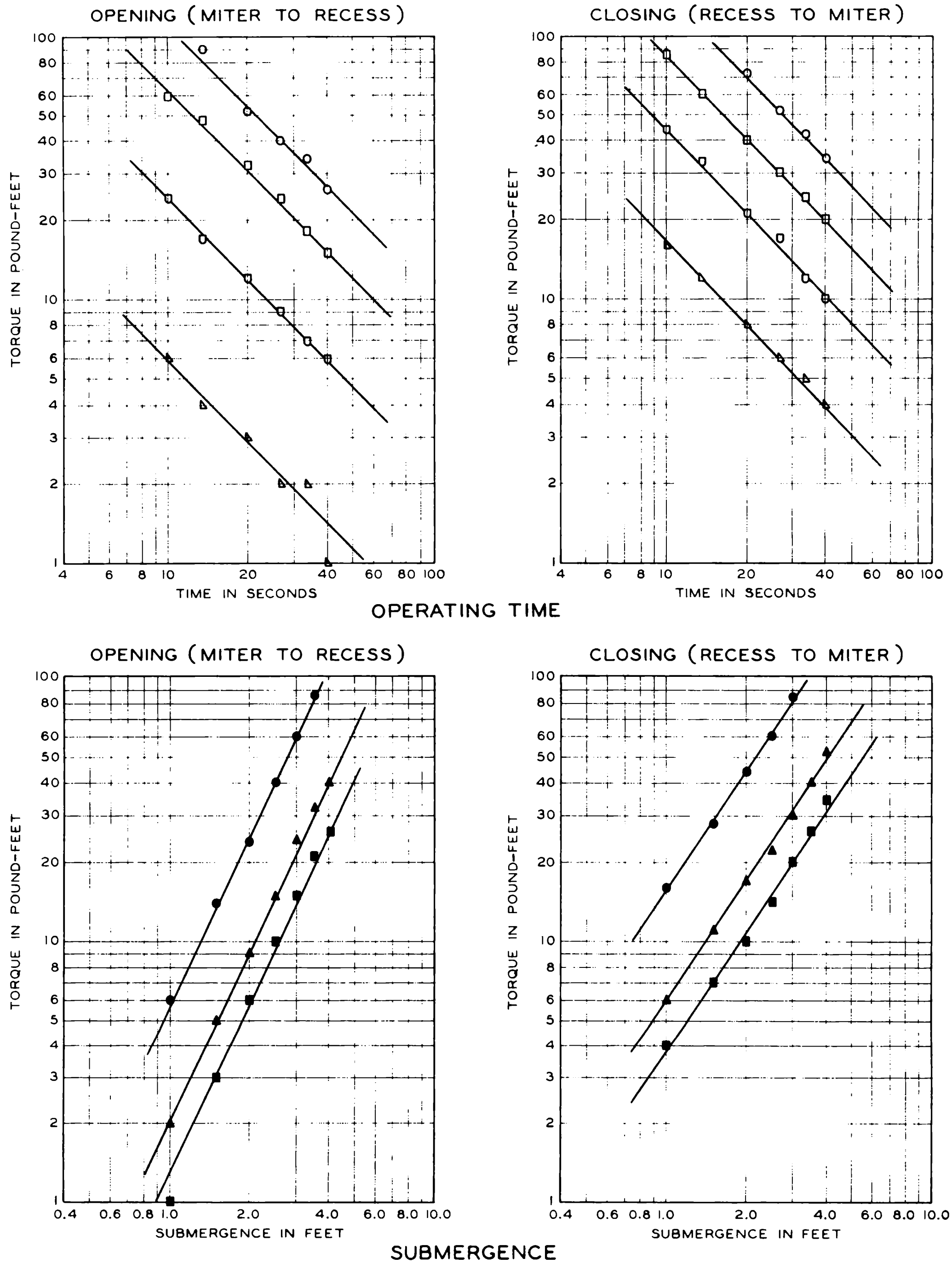


SUBMERGENCE - AS SHOWN IN FEET
CHAMBER LENGTH
UPSTREAM - 25 FT
DOWNSTREAM - 25 FT
BOTTOM CLEARANCE 0.25 FT

OHIO RIVER LINKAGE

EFFECT OF SUBMERGENCE ON INSTANTANEOUS TORQUE

OPERATING TIME 40.2 SECONDS



NOTE: BOTTOM CLEARANCE 0.25 FT

LEGEND

TIME OF OPERATION
- ○—○ SUBMERGENCE 4.0 FT
- □—□ SUBMERGENCE 3.0 FT
- SUBMERGENCE 2.0 FT
- △—△ SUBMERGENCE 1.0 FT

SUBMERGENCE
- ●—● OPERATING TIME 10.1 SEC
- ▲—▲ OPERATING TIME 26.8 SEC
- ■—■ OPERATING TIME 40.2 SEC

OHIO RIVER LINKAGE

EFFECTS OF OPERATING TIME AND SUBMERGENCE ON MAXIMUM TORQUE

CHAMBER LENGTHS 25 FEET

APPENDIX A

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
HYDRAULIC SECTION

HYDRAULIC MODEL INVESTIGATION OF MITER GATE OPERATION

By

Maurice N. Amster
Assistant Engineer

Diablo Heights, C. Z.
May 1942

CONTENTS

HYDRAULIC MODEL INVESTIGATION OF MITER GATE OPERATION

SYNOPSIS

This report presents (1) the results of hydraulic tests conducted on a model of the service miter gate designed for the Third Locks of the Panama Canal, and (2) the results of verification tests conducted on a model of a miter gate of the existing locks. The scale ratios, model to prototype, were: 1 to 25 for the Third Locks tests; 1 to 18.813 for the verification tests.

The investigation of the Third Locks gate included variation, over suitable ranges, of the following functions:

(a) Operating speed
(b) Submerged depth
(c) Chamber lengths
(d) Weight of leaves
(e) Nonsynchronous operation of leaves

The results of the tests on the gate of the existing locks were compared with data obtained from electric power input tests on a prototype gate.

All data are given in the form of curves showing the relationship between angular position of a gate leaf relative to the lock wall and instantaneous torque acting on the leaf.

INTRODUCTION

1. A survey of existing literature on the operating characteristics of lock miter gates failed to disclose data upon which the design of the operating mechanism for the proposed Third Locks gates could reliably be based. The Third Locks gates are to be larger than any constructed in the past, and the meager data available could be applied only by dubious extrapolation. It was decided, therefore, to conduct model tests to obtain better information about the forces to be expected in the operation of the Third Locks gates.

Editor's Note: The original edition of this report contained seven photographs. However, it was not possible to obtain legible reproductions of these photographs for inclusion in this report; consequently, the photographs have been omitted together with references thereto.

AUTHORITY

2. The study was authorized by the Governor, May 8, 1941, in the sixth indorsement to a memorandum from the Mechanical and Electrical Engineer to the Hydraulic Engineer, dated April 12, 1941.

THE MODELS

Gate Bays and Lock Chambers

3. The gate bays, with upstream and downstream lock chambers, were reproduced in a 70-foot rectangular concrete flume. The flume layout without gate-bay details is shown in Figure 1.

4. Details of a typical Third Locks gate bay are shown in Figure 2. Some of the Third Locks gate bays will have removable gate sills built over the floor-level sill of Figure 2. These removable sills, which extend 25 to 30 feet above the lock floor, will serve until possible conversion to a sea-level canal. The floor-level sill was chosen for the Third Locks tests because it offers greater resistance to flow under the gate during operation, and thus represents the most adverse operating condition. The location of the gate bay in the 1 to 25 scale model flume permitted simulation of a 1,105-foot length of chamber upstream and a 200-foot length of chamber downstream from the gate. In this respect, it corresponded with the bay of Gate 3 of Gatun Third Locks and represented the most adverse end-boundary conditions. Variation of chamber length was effected by the use of movable bulkheads.

5. The removable wood lining, shown in Figure 1, provided for converting the model to existing-lock dimensions without changing the locations of the model gate pintle bearings. This arrangement resulted in a scale ratio of 1 to 18.813 for the verification tests.

6. Both models were geometrically similar to their respective prototypes; that is, the linear dimensions varied as the scale ratios. The ratio of operating times, prototype to model, was made equal to the square root of the scale ratio in accordance with Froude's Law. Correspondingly, the torques observed on the model were multiplied by the fourth power of the scale ratio. The effects of viscosity were neglected.

7. The prototype data were derived from tests on Leaf 108 of the intermediate gate of the upper east chamber at Miraflores Locks. Details of the gate bay of Leaves 108 and 109 are shown in Figure 3.

Gate Leaves

8. Dimensions of prototype gate leaves are shown in Figures 2 and 3. The model gate leaves were constructed of angle-iron frameworks faced with galvanized sheet metal. Holes in the top and bottom faces permitted water to flow in or out of the leaves freely during changes of the water-surface elevation in the flume.

9. No effort was made to simulate prototype weights. Comparative weights are given in Table I. As is shown later, the accelerations are so small that weight is a minor factor for which allowance can be made by calculation.

TABLE I

	Model		Prototype
	Weight in pounds	Equivalent in Prototype tons	Weight in tons
Verification			
Leaf in air	73	243	720
Water in leaf at 73.16-foot submerged depth	287	955	470
Total	360	1198	1190
Third Locks			
Leaf in air	60	475	730
Water in leaf at 82.5-foot submerged depth	195	1525	628
Total	255	2000	1358

Gate Operation

10. The gates of the Third Locks and of the existing locks are to be operated by the same type of mechanism; namely, strut and bull wheel. The dimensions are given in Figure 4.

11. Details of the mechanism which simulated the kinematics of prototype operation are shown in Figure 5. Two vertical-shaft speed reducers corresponded to the prototype bull wheels. Power was furnished by an electric motor operating a vari-speed pulley arrangement which served as the

control of the operating speed of the gate. It was established by numerous trials that for a fixed vari-speed pulley setting, the duration of the operating cycle varied less than 0.2 second, model time, other conditions remaining unchanged.

12. In order to concentrate and simplify the model mechanism, the speed reducers were located 180 degrees from the corresponding positions of the prototype bull wheels (compare Figures 4 and 5). Instead of being connected directly to the model leaf, the model strut was connected to an arm keyed to an alloy-steel shaft which transmitted the driving torque to the leaf.

Torque Measurement

13. The lower section of the alloy-steel drive shaft was turned to a diameter of 0.6 inches, and the driving torque was derived as a function of the angle of twist produced in this section during operation. Details of the measuring apparatus are shown in Figure 6. Dial gages graduated in thousanths of an inch indicated the relative movement between the arm on which they were mounted and an arm bolted to a hollow cylinder keyed to the lower end of the torsion section of the drive shaft. The latter arm was extended to indicate the angular position of the leaf on a curved scale. A large number of simultaneous values of leaf angle and dial gage reading was obtained during an operating cycle with a motion-picture camera attached to the drive shaft above the gages. The use of two opposing dial gages produced positive readings for both operating directions.

14. The torsion section of the drive shaft was calibrated by fixing the arm carrying the dial gages, applying known forces to the gate leaf, and observing the resultant gage readings. The results indicated the expected straight-line relationship.

TESTING PROCEDURE

Third Locks Tests

15. The following conditions were chosen as a basis for comparative study:

Operating time:	2 minutes (tentatively selected)
Submergence:	82.5 feet (probable maximum)

Upstream chamber length: 1,105 feet (Gate 3 to Gate 4, Gatun Locks)
Downstream chamber length: 200 feet (Gate 3 to Gate 2, Gatun Locks)

Operation under these base conditions was repeated for each series of tests.

16. To determine the effect of operating speed, a series of tests was conducted in which the operating time was varied from 1.75 to 2.75 minutes in 1/4-minute increments.

17. A submergence range from 45 to 82.5 feet was tested.

18. The effect of upstream and downstream boundaries was studied by operating with various combinations of upstream and downstream chamber lengths.

19. To ascertain whether the weight of the gate leaves was an appreciable factor, tests were conducted with a 50-pound weight placed on top of each leaf, approximately over the center of gravity.

20. The effect of delayed starting of one of the leaves was studied by disengaging and engaging the flexible couplings (Figure 5) to produce lead or lag in the operation of the test leaf. The operating speed was not changed in these tests, each leaf completing its movement in 2 minutes. Leads and lags of 5, 10, 15, and 20 seconds were tested, as well as the extreme case--single-leaf operation.

Verification Tests

21. In the electric power input tests that were made on the existing Miraflores gate, the upstream and downstream boundaries were at distances of 358.5 and 650.0 feet, respectively, from the test gate. In the model-verification tests, various combinations of chamber lengths were tested to obtain the effect of chamber length over a wide range. Opening and closing operations at a submergence of 73.16 feet were tested with synchronous operation and with single-leaf operation.

TEST RESULTS

General

22. In all gate operations, peak torque was reached in the vicinity of the mitered position.

23. Peak torque values of opening operations were always greater than those of closing operations conducted under identical conditions.

Third Locks Tests

24. Figures 7 and 8 show the results of runs made at various times under base conditions. It is noted that the extreme deviation from average is about 1,500,000 foot-pounds or 8.1 per cent in the opening operation and only 500,000 foot-pounds or 3.8 per cent in the closing operation.

25. Figures 9 and 10 show the effect of speed variation over the entire operating cycle, and Figure 11 shows the relationship between operating speed and peak torque. The points of Figure 11 are plotted logarithmically in Figure 12, resulting in a straight-line graph in which peak torque is a monomial exponential function of the operating speed.

26. The effect of change of submerged depth on the torque curve is shown in Figures 13 and 14, and the relationship between submerged depth and peak torque is shown in Figure 15. Figure 16 is a logarithmic plotting of the points in the opening curve of Figure 15. As in the speed tests, the peak torque appears to be a monomial exponential function of the submerged depth within the test range. The closing curve of Figure 15 was not plotted logarithmically because of the irregularity of the points.

27. Figures 17 and 18 show the result of varying the upstream chamber length while maintaining a constant downstream chamber length. No appreciable effect is indicated for upstream chamber lengths greater than 625 feet.

28. The curves of Figures 19 and 20 indicate that the effect of a 20 per cent increase in leaf weight was not sufficient to be revealed in the model tests. This could be expected from a consideration of the small value of angular acceleration of the leaves. Computed in prototype terms for the peak-torque position in the opening operation:

Angular acceleration = 0.00056 radians per second per second
(at leaf angle of 54 degrees)

Moment of inertia about pintle axis = 306,000,000 slug-feet^2

Driving torque necessary to accelerate leaf = 306,000,000 $\times$ 0.00056
= 171,000 foot-pounds

The peak torque values obtained in the tests ranged from 17,000,000 to 20,000,000 foot-pounds. Thus the inertial component is only about one percent of the total.

29. Figures 21, 22, 23, and 24 show the reduction in peak torque produced by lag and lead of the test leaf with respect to the opposite leaf. (The curve for synchronous operation is included in each of these figures for comparison.) Comparisons of Figure 21 with Figure 23 and of Figure 22 with Figure 24 reveal that in both opening and closing operations the leaf farther from the mitered position requires the greater peak torque. Thus the larger operating torque is required for the leading leaf in the opening operation and for the lagging leaf in the closing operation. (See Figures 21 and 24.) In each of these two cases, the peak torque occurs farther from the mitered position as the lead or lag is increased. All four figures indicate that the effectiveness in the reduction of peak torque is greatest for a lead or lag of about 15 or 20 seconds and diminishes rapidly with greater delays. This agrees very well with experience in the operation of the existing gates.

Verification Tests

30. Figure 25 shows the results of operation with three different chamber lengths (upstream and downstream equal). The torque seems to vary nearly in inverse proportion to the total chamber length. The tests with 470.3-foot chambers produced closest agreement with prototype test data, but in all of the model tests the torque peaks occurred much farther from the mitered position than in the prototype tests.

31. Figure 26 shows the results of tests in which the lengths of the chambers upstream and downstream from the gate were varied, the sum of the lengths remaining approximately constant. The indications are that the torque curve depends, within limits, only on the sum of the chamber lengths.

32. Figure 27 compares the results of four types of single-leaf operation with the prototype curves. The verification agrees more favorably than for synchronous operation, but the torque values occur in a much lower range.

33. There are several factors that may be considered to account for the disparity between model results and prototype results. The principal factor is the difference in characteristics of model and prototype motors.

The model motor had negligible slip; the slip of the prototype motors is high. Consequently the prototype gates almost come to a stop at the position of maximum resistance. The slow movement tends to reduce the peak torque. Another important factor is the use of individual operating motors for the prototype leaves. Even when the motors are started simultaneously in the prototype, the leaves do not reach their final positions at the same time. Observations have established a time difference as high as 10 seconds for the test gate. The nonsynchronous operation in the Third Locks tests (Figures 21 through 24) shows: (1) that this time difference could produce a considerable part of the difference in peak torque value, and (2) that if the prototype test leaf was lagging in its opening movement and leading in its closing movement, the disagreement with regard to position of the torque peaks would be partly explained.

34. Motion pictures showing the operating mechanism and the currents during the operating cycle are on file at the Hydraulic Laboratory.

CONCLUSIONS

General

35. Peak hydraulic resistance to the operation of lock miter gates occurred in the early part of the opening operation. Therefore peak motor load can be minimized by employing operating kinematics involving low speed in this part of the cycle.

36. The peak torque was approximately a monomial exponential function of operating speed and submerged depth.

37. The peak torque was approximately in inverse proportion to the total chamber length upstream and downstream from the miter gate; however, with a relatively short chamber on one side of the gate, the length of the longer chamber affected the torque curve only within a limited range.

38. The weight of the leaves was a negligible factor because the angular acceleration of the leaves was too low to produce inertial forces significant in comparison with the forces of hydraulic resistance.

Application of Data

39. The data obtained from the model tests are believed to provide a reasonably accurate basis for determining the maximum forces required for

operation of the Third Locks gates. However, any slip occurring in the prototype motors or couplings would tend to reduce the operating forces.

40. Possibly the data could be applied to other miter gates operated on the same kinematic cycle by correlation of scalar ratios with the functional relationships derived for ranges of operating speed and submerged depth.

41. The applicability of model data to operation of miter gates using a different kinematic cycle depends on the degree of departure. No general conclusion as to this use of the data is possible.

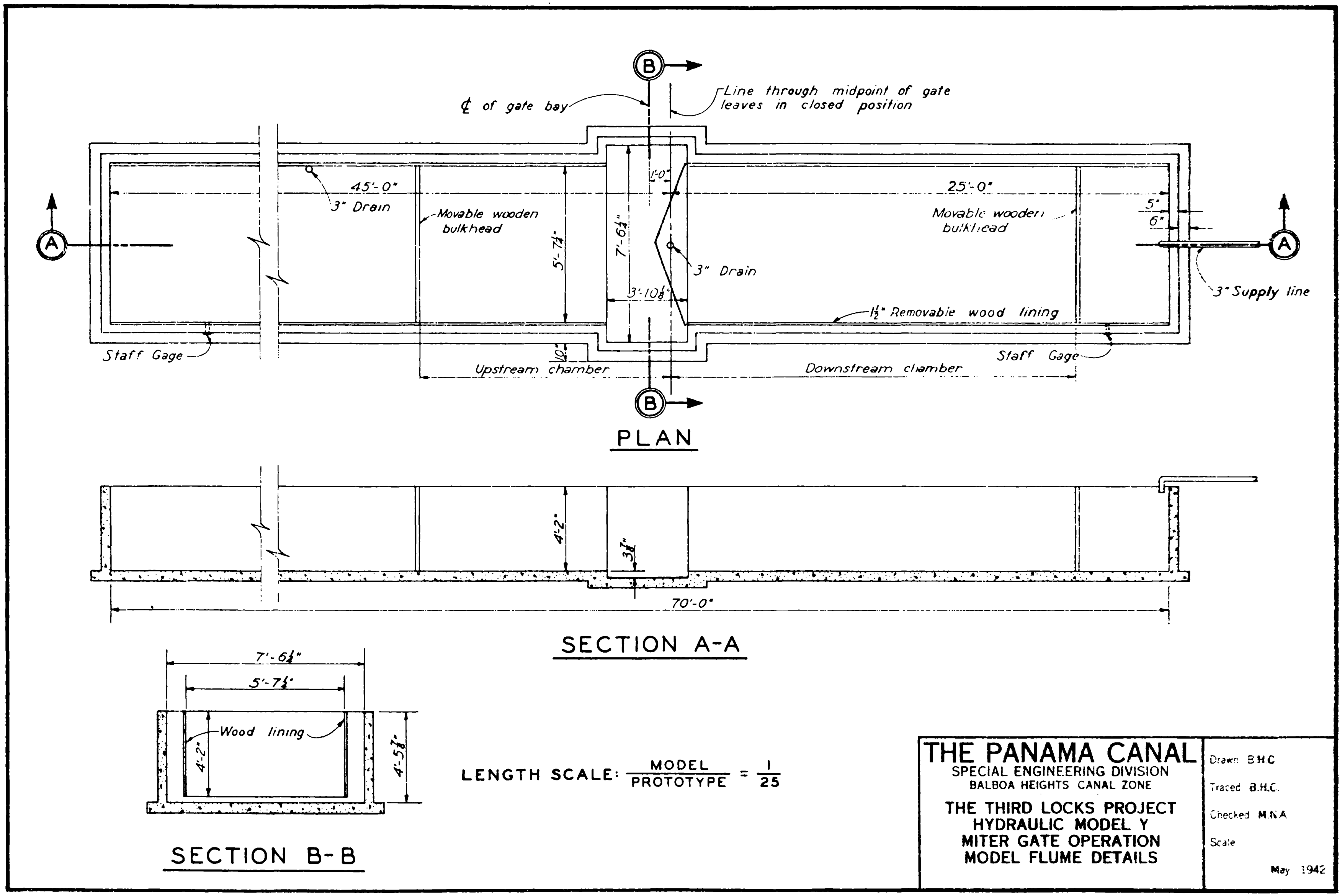
PERSONNEL

42. The gate-operating mechanism was designed by G. D. Smith, Engineer, Mechanical-Electrical Section. The model study was conducted by the Hydraulic Laboratory personnel under the direction of F. W. Edwards, Senior Hydraulic Engineer, and later E. Soucek, Senior Hydraulic Engineer. The laboratory was under the supervision of F. S. Witzigman, Associate Engineer, and later M. J. Webster, Engineer. Maurice N. Amster, Assistant Engineer, was in charge of the studies.

Prepared: ____________________
MAURICE N. AMSTER
Assistant Engineer

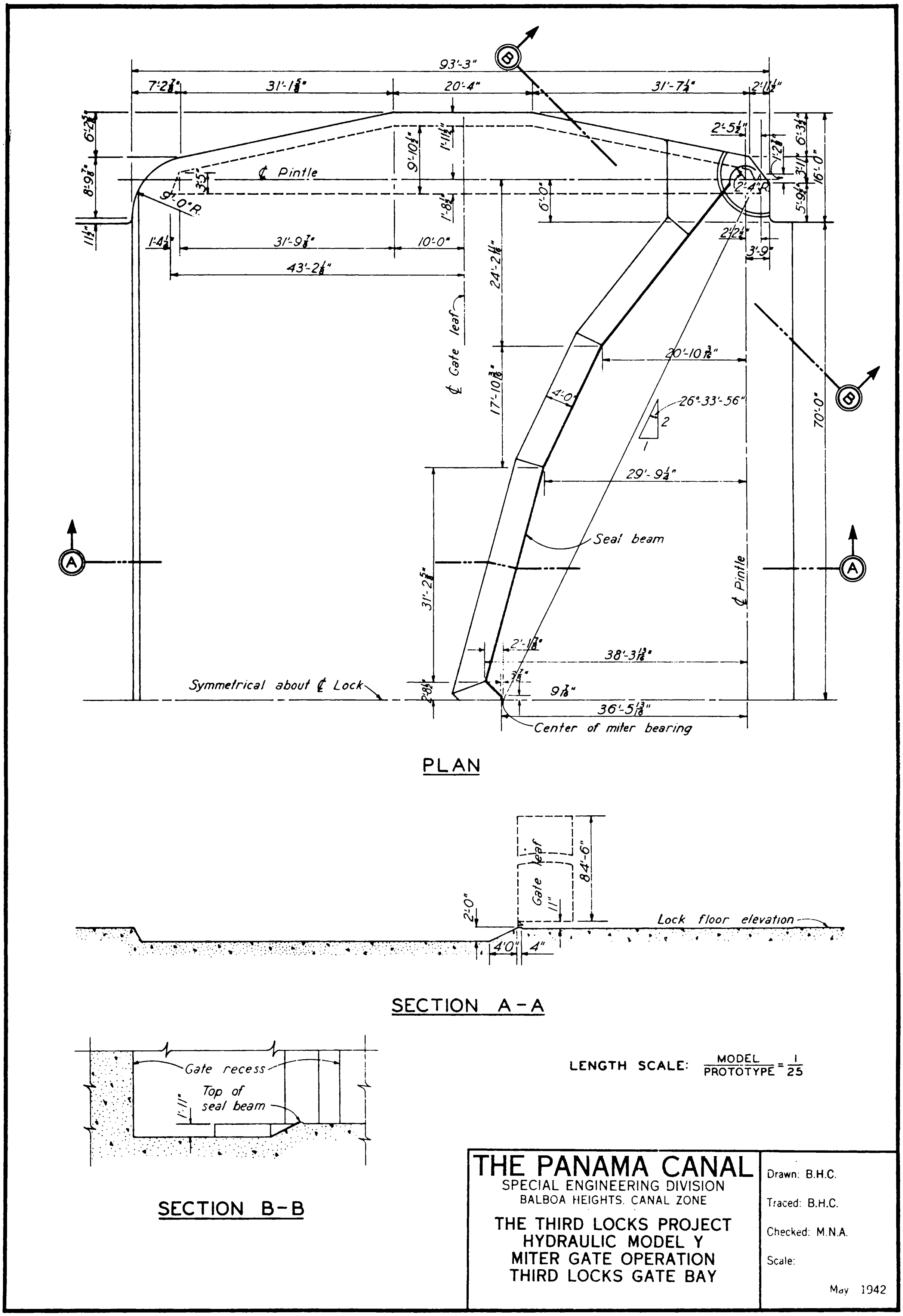
Submitted: ____________________
E. SOUCEK
Senior Hydraulic Engineer

ILLUSTRATIONS



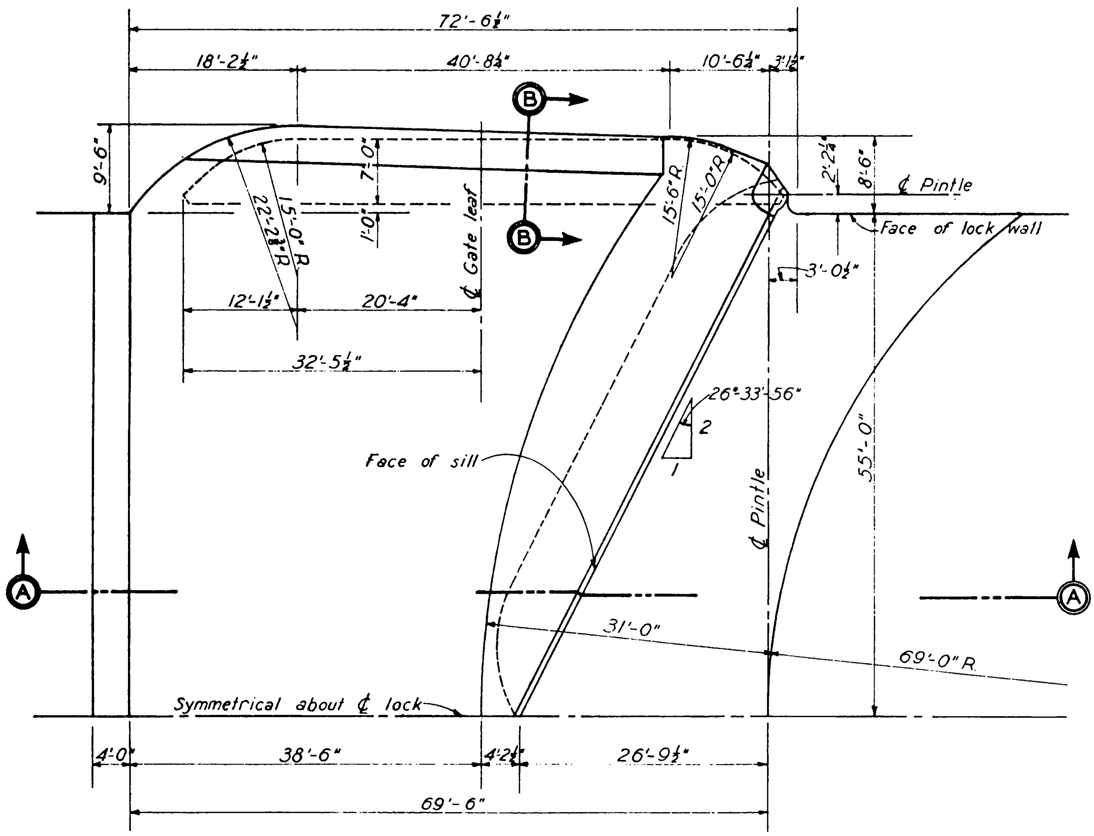
℄ of gate bay
Line through midpoint of gate leaves in closed position
45'-0"
3" Drain
Movable wooden bulkhead
5'-7½"
7'-6½"
1'-0"
3'-10⅛"
3" Drain
25'-0"
Movable wooden bulkhead
5"
6"
3" Supply line
1½" Removable wood lining
Staff Gage
Staff Gage
Upstream chamber
Downstream chamber
PLAN
4'-2"
3⅞"
70'-0"
SECTION A-A
7'-6½"
5'-7½"
Wood lining
4'-2"
4'-5⅞"
SECTION B-B
LENGTH SCALE: MODEL / PROTOTYPE = 1 / 25
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
MODEL FLUME DETAILS
Drawn B.H.C
Traced B.H.C.
Checked M.N.A
Scale
May 1942

FIGURE 1

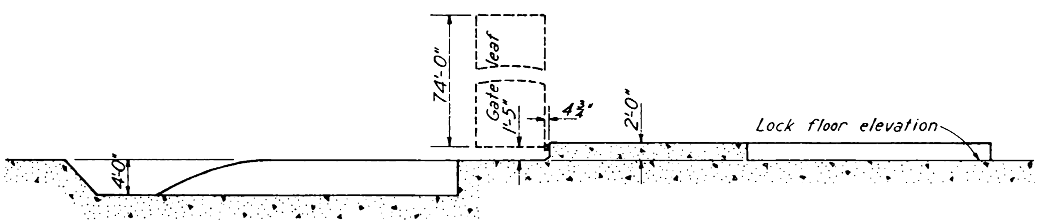


93'-3"
7'-2⅞"
31'-1⅝"
20'-4"
31'-7¼"
2'-0½"
2'-5½"
6'-2⅜"
8'-9⅞"
1'-1½"
9'-10½"
1'-8½"
3'-5"
℄ Pintle
9'-0" R
6'-0"
16'-0"
70'-0"
1'-4½"
31'-9⅞"
10'-0"
43'-2⅛"
24'-2⅞"
℄ Gate leaf
17'-10⅜"
20'-10⅜"
4'-0"
26°-33'-56"
29'-9¼"
Seal beam
31'-2⅝"
℄ Pintle
2'-1⅞"
38'-3⅞"
Symmetrical about ℄ Lock
9⅞"
36'-5⅞"
Center of miter bearing
PLAN
Gate leaf
84'-6"
2'-0"
11"
Lock floor elevation
4'-0"
4"
SECTION A-A
Gate recess
Top of seal beam
1'-11"
SECTION B-B
LENGTH SCALE: MODEL / PROTOTYPE = 1/25
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS GATE BAY
Drawn: B.H.C.
Traced: B.H.C.
Checked: M.N.A.
Scale:
May 1942

FIGURE 2

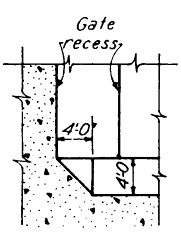


PLAN



SECTION A-A

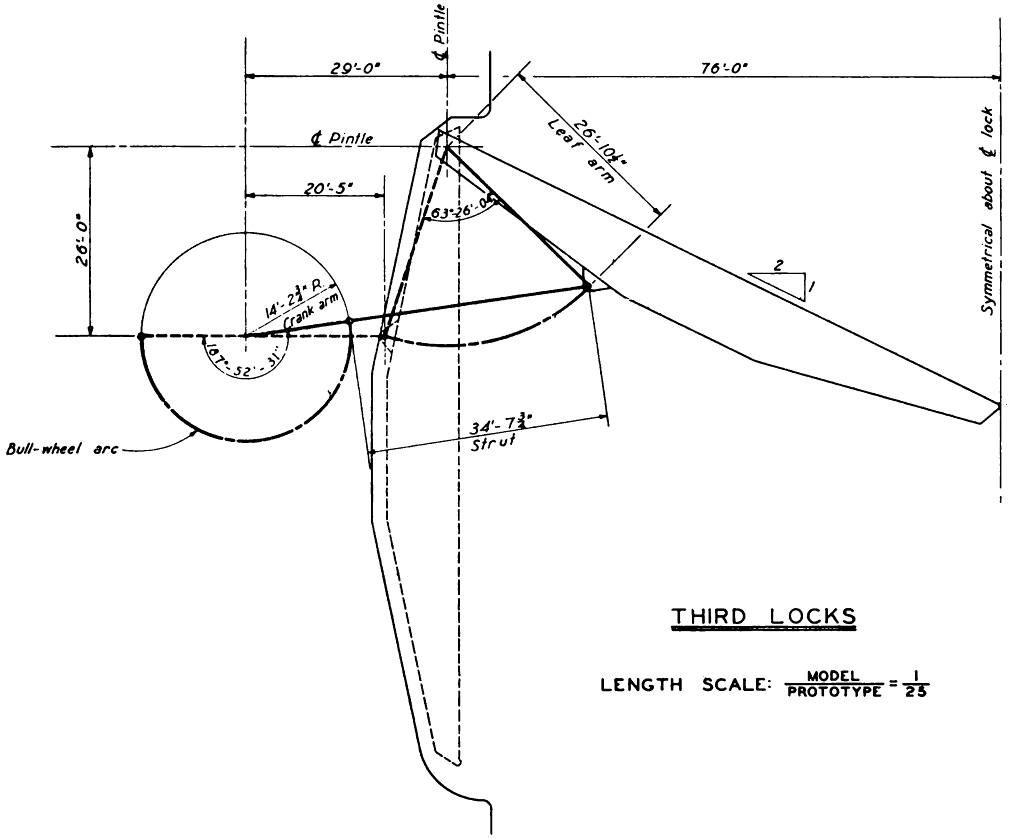
LENGTH SCALE: $\frac{\text{MODEL}}{\text{PROTOTYPE}} = \frac{1}{18.813}$



SECTION B-B

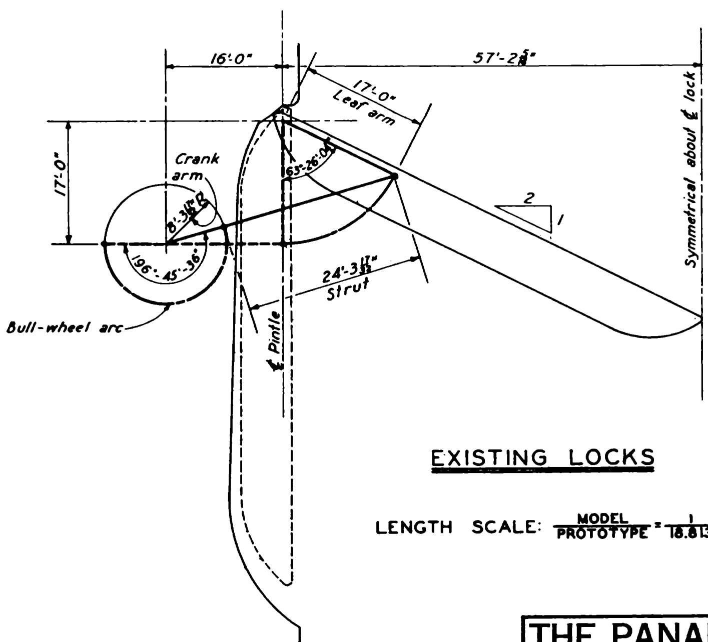
THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS, CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION EXISTING LOCKS GATE BAY	Drawn: M.N.A. Traced: B.H.C. Checked: M.N.A. Scale: May 1942

FIGURE 3



THIRD LOCKS

LENGTH SCALE: $\frac{\text{MODEL}}{\text{PROTOTYPE}} = \frac{1}{25}$

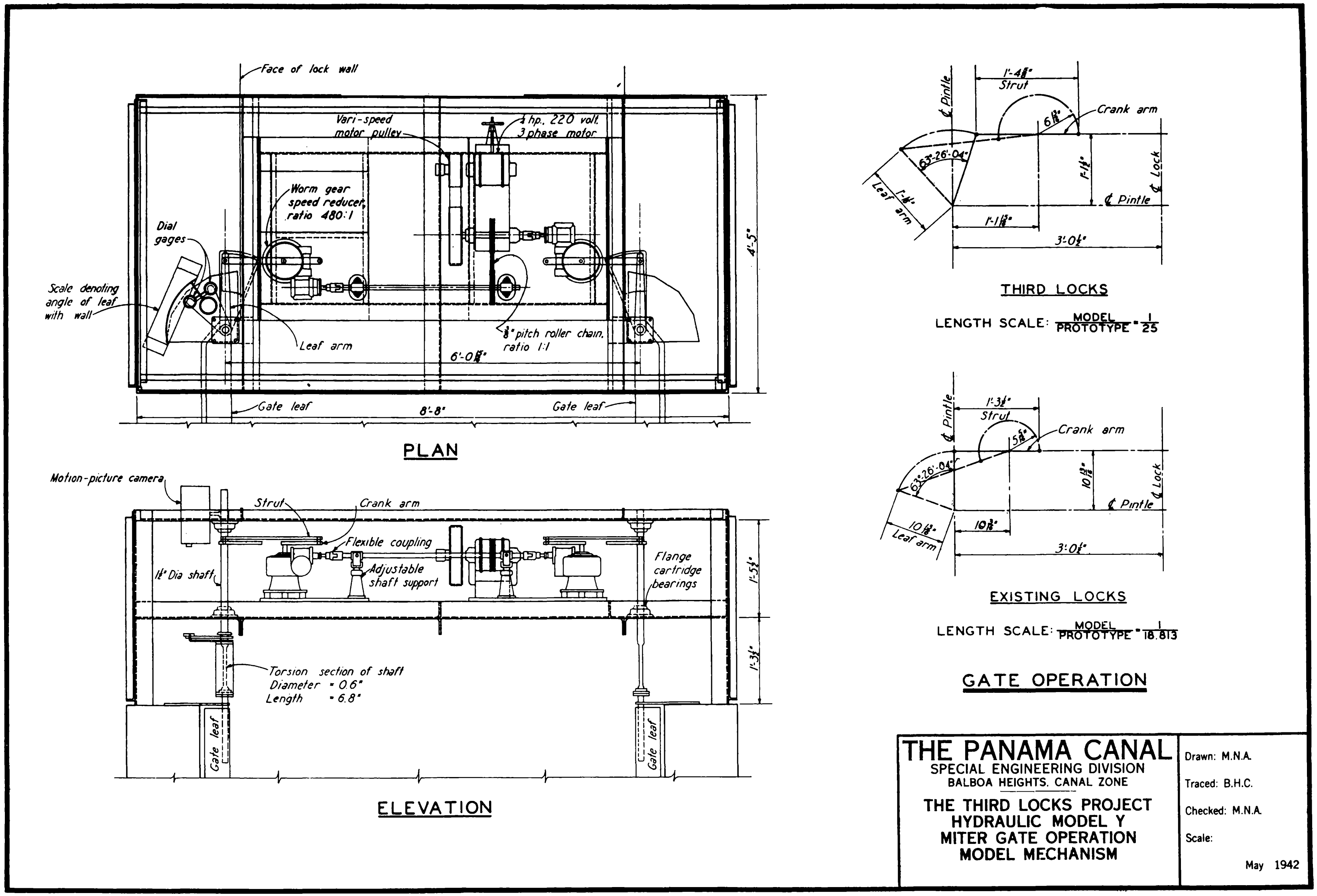


EXISTING LOCKS

LENGTH SCALE: $\frac{\text{MODEL}}{\text{PROTOTYPE}} = \frac{1}{18.813}$

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS. CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION PROTOTYPE MECHANISM	Drawn: M.N.A. Traced: B.H.C. Checked: M.N.A. Scale: May 1942

FIGURE 4



Face of lock wall
Vari-speed motor pulley
¼ hp., 220 volt, 3 phase motor
Worm gear speed reducer, ratio 480:1
Dial gages
Scale denoting angle of leaf with wall
Leaf arm
⅜" pitch roller chain, ratio 1:1
6'-0⅝"
4'-5"
Gate leaf
8'-8"
Gate leaf
PLAN
Motion-picture camera
Strut
Crank arm
Flexible coupling
Adjustable shaft support
1¼" Dia shaft
Flange cartridge bearings
1'-5½"
1'-3½"
Torsion section of shaft
Diameter = 0.6"
Length = 6.8"
Gate leaf
Gate leaf
ELEVATION
Strut
Crank arm
℄ Pintle
℄ Lock
℄ Pintle
Leaf arm
63°-26'-04"
THIRD LOCKS
LENGTH SCALE: MODEL / PROTOTYPE = 1/25
EXISTING LOCKS
LENGTH SCALE: MODEL / PROTOTYPE = 1/18.813
3'-0½"
GATE OPERATION
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
MODEL MECHANISM
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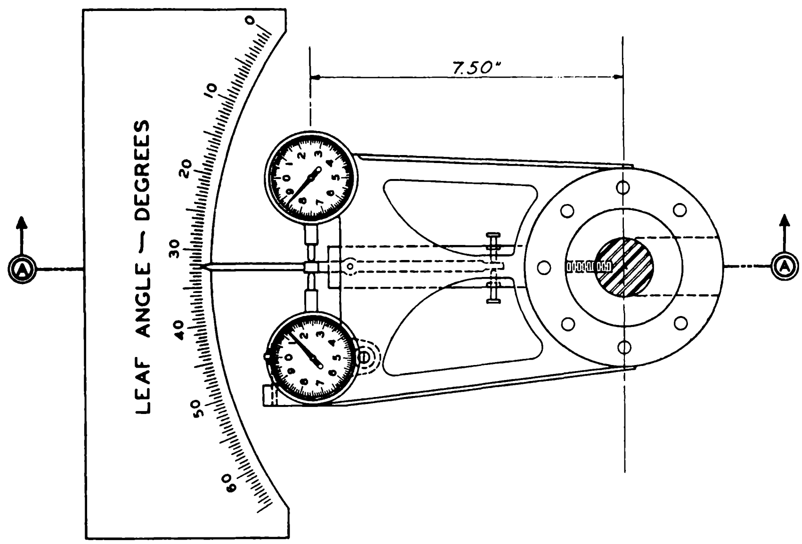
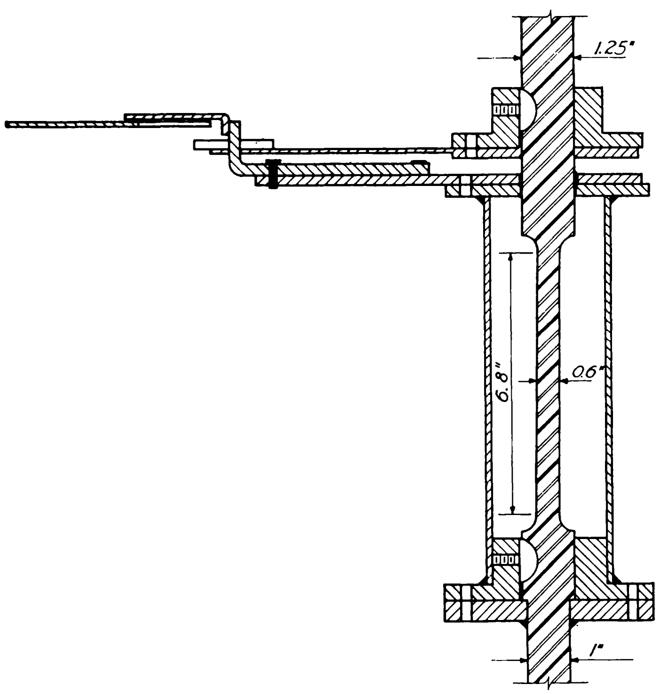
Traced: B.H.C.
Checked: M.N.A.
Scale:
May 1942

FIGURE 5



PLAN



SECTION A-A

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS. CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
DETAILS OF
TORQUE MEASUREMENT

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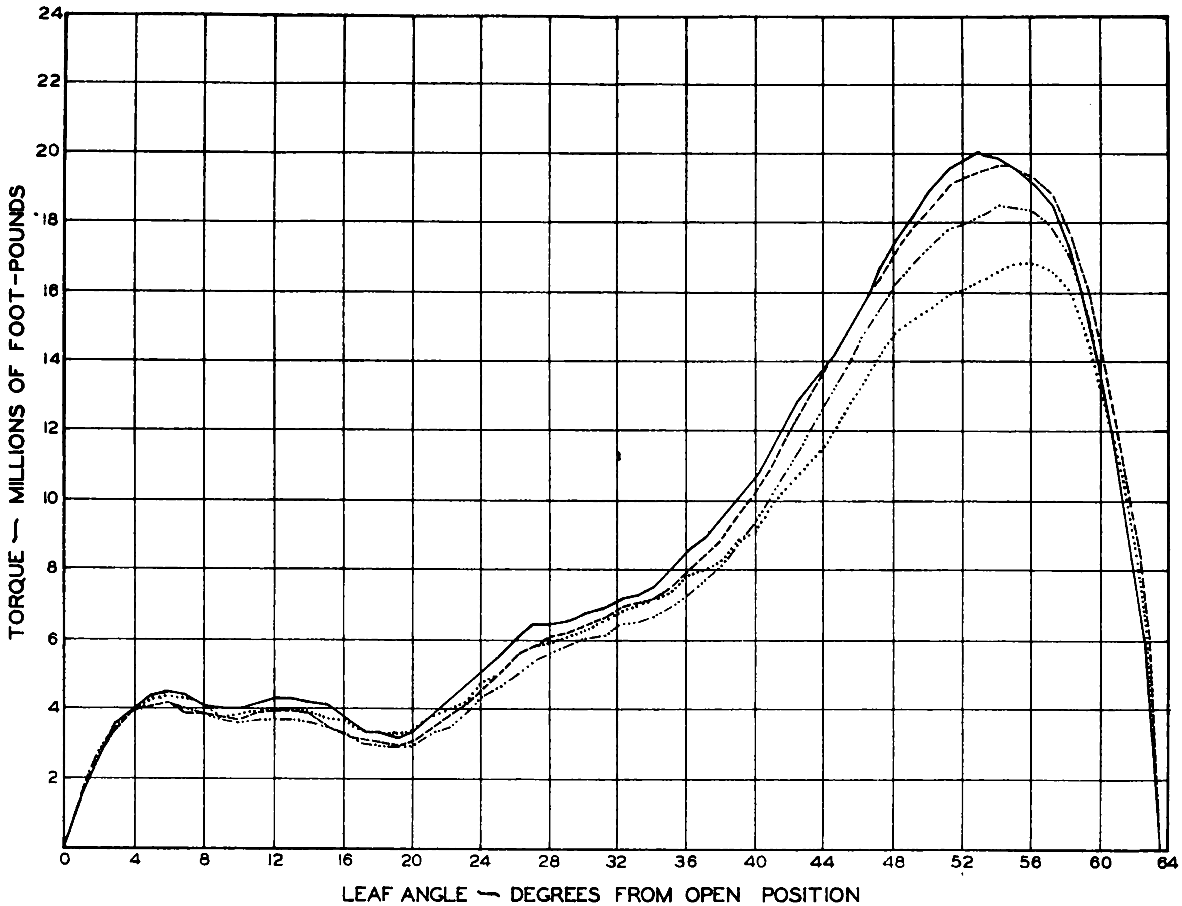
May 1942

FIGURE 6



OPENING OPERATION ←

BASE CONDITIONS

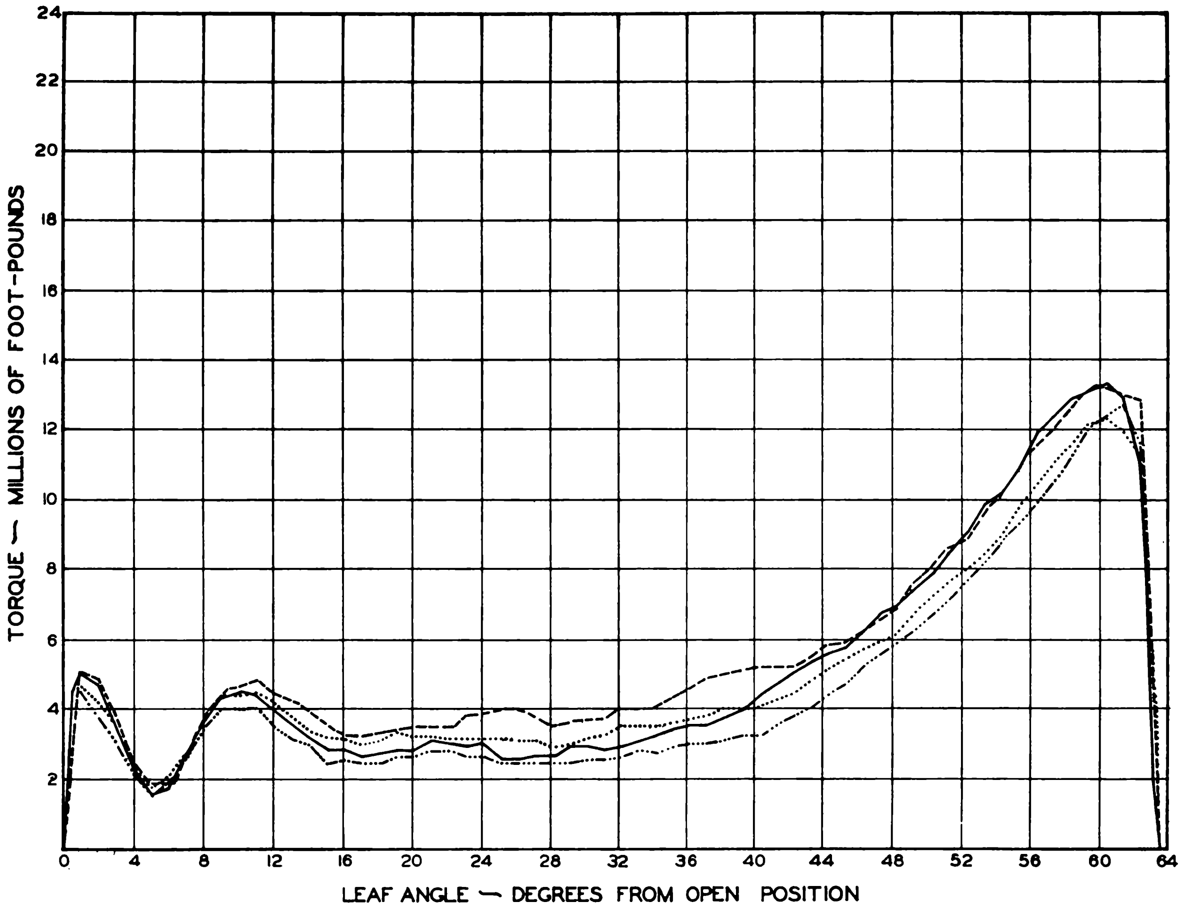
OPERATING TIME: 2 MINUTES
SUBMERGENCE: 82.5 FEET
CHAMBER LENGTHS:
UPSTREAM: 1105 FEET
DOWNSTREAM: 200 FEET

NOTE:
CURVES SHOW VARIATION OF RESULTS OBTAINED UNDER IDENTICAL OPERATING CONDITIONS.

THE PANAMA CANAL	
SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS. CANAL ZONE	Drawn: M.N.A.
THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Traced: B.H.C. Checked: M.N.A. May 1942

FIGURE 7

FIGURE 8



CLOSING OPERATION →

BASE CONDITIONS

OPERATING TIME: 2 MINUTES
SUBMERGENCE: 82.5 FEET
CHAMBER LENGTHS:
UPSTREAM: 1105 FEET
DOWNSTREAM: 200 FEET

NOTE:
CURVES SHOW VARIATION OF RESULTS OBTAINED UNDER IDENTICAL OPERATING CONDITIONS.

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

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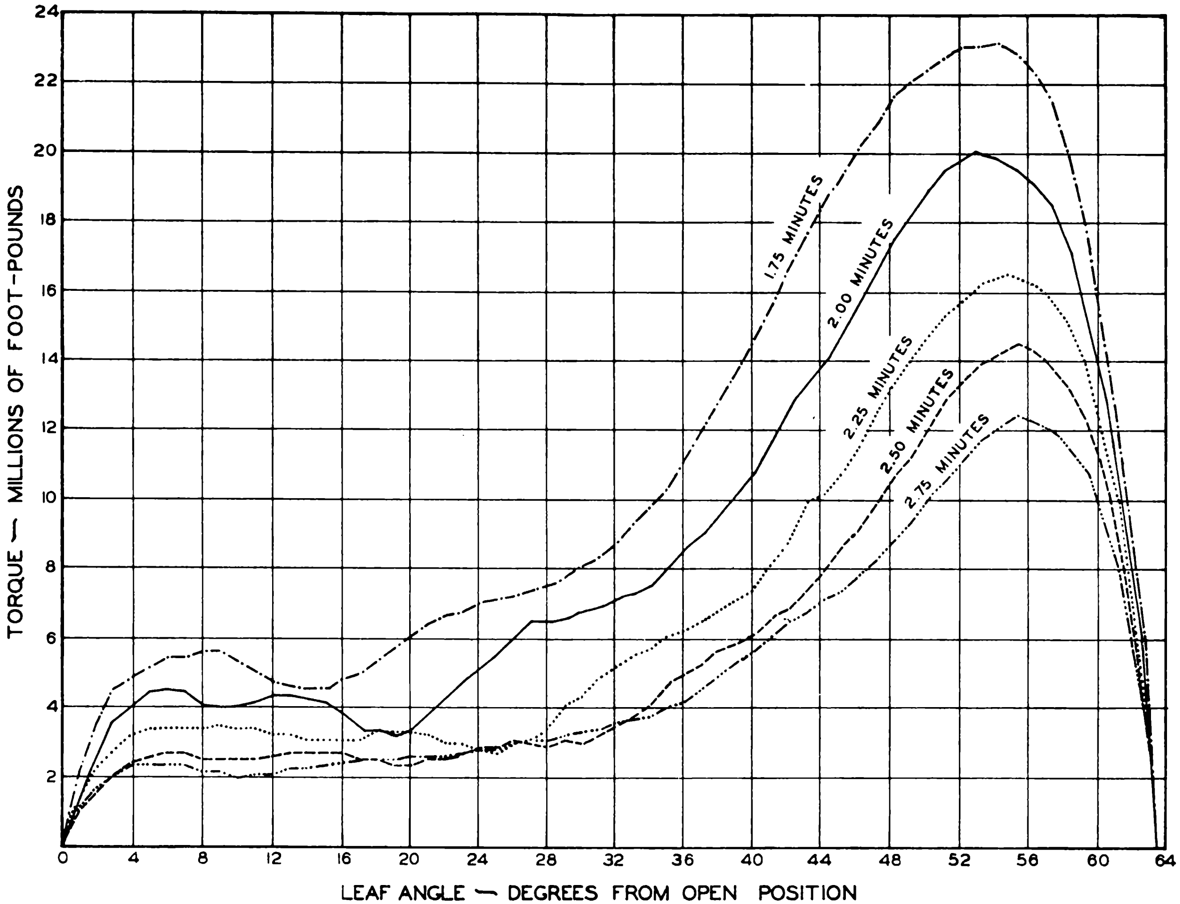
May 1942



OPENING OPERATION ←

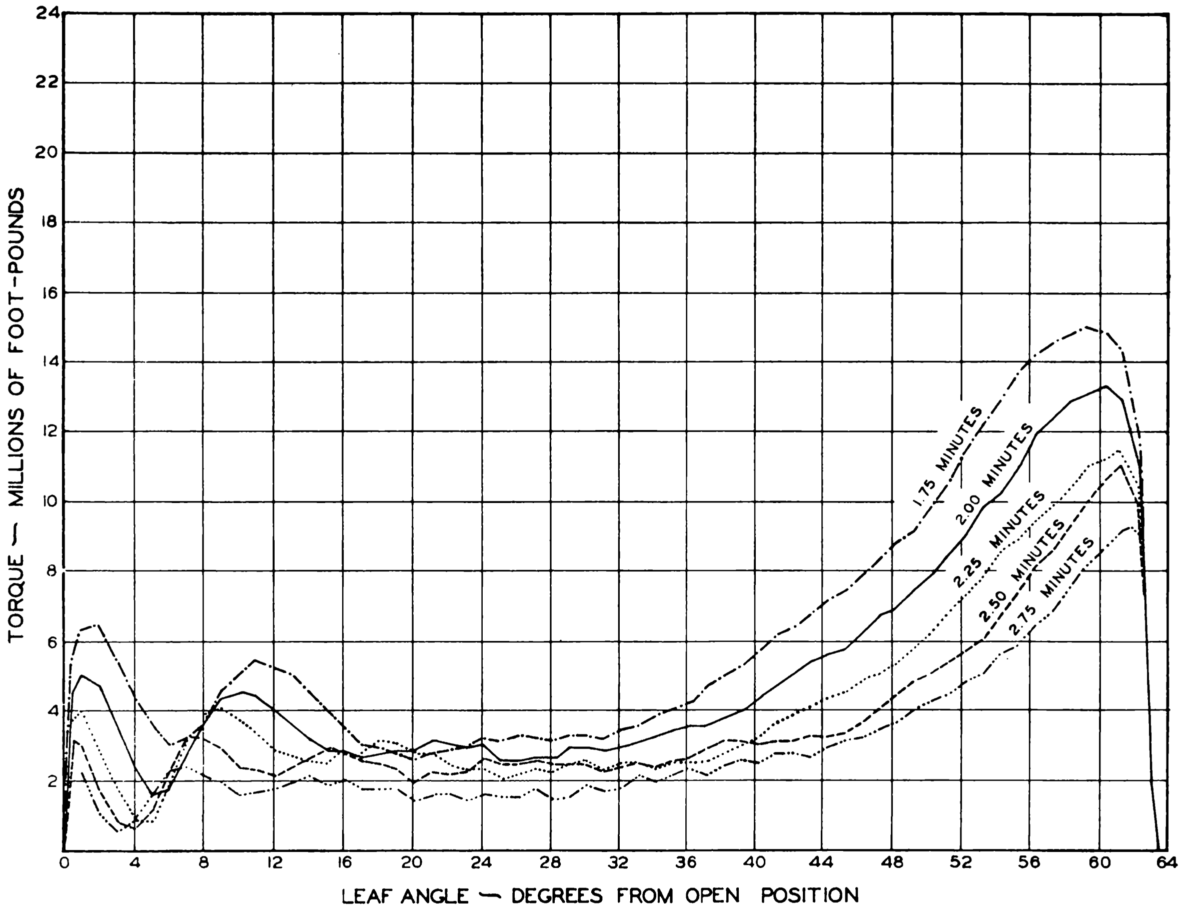
VARIATION OF OPERATING SPEED

OPERATING TIME: AS INDICATED
SUBMERGENCE: 82.5 FEET
CHAMBER LENGTHS:
UPSTREAM: 1105 FEET
DOWNSTREAM: 200 FEET

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS, CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn M.N.A. Traced B.H.C. Checked M.N.A. May 1942

FIGURE 9

FIGURE 10



CLOSING OPERATION →

VARIATION OF OPERATING SPEED

OPERATING TIME:	AS INDICATED
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
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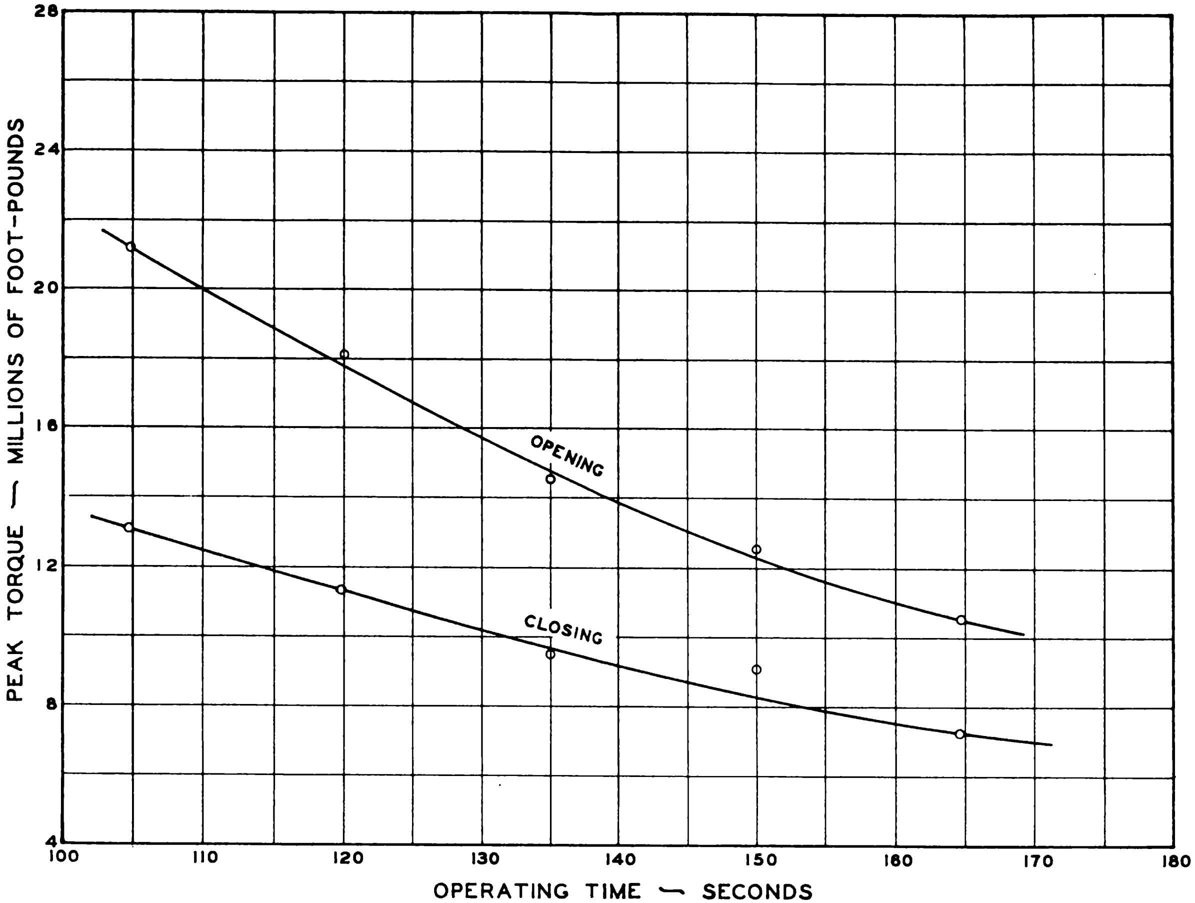
May 1942



VARIATION OF OPERATING SPEED

SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
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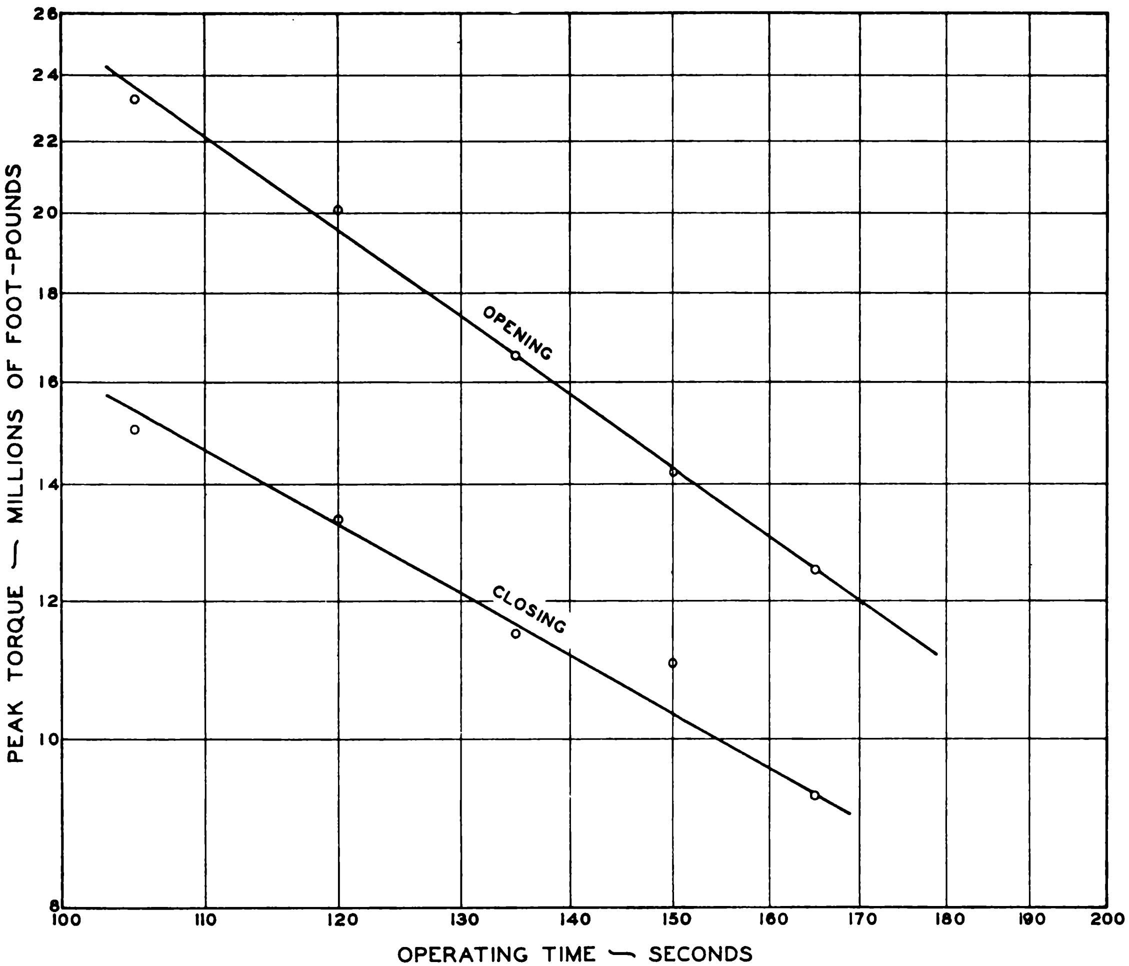
May 1942

FIGURE 11

FIGURE 12



VARIATION OF OPERATING SPEED

SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

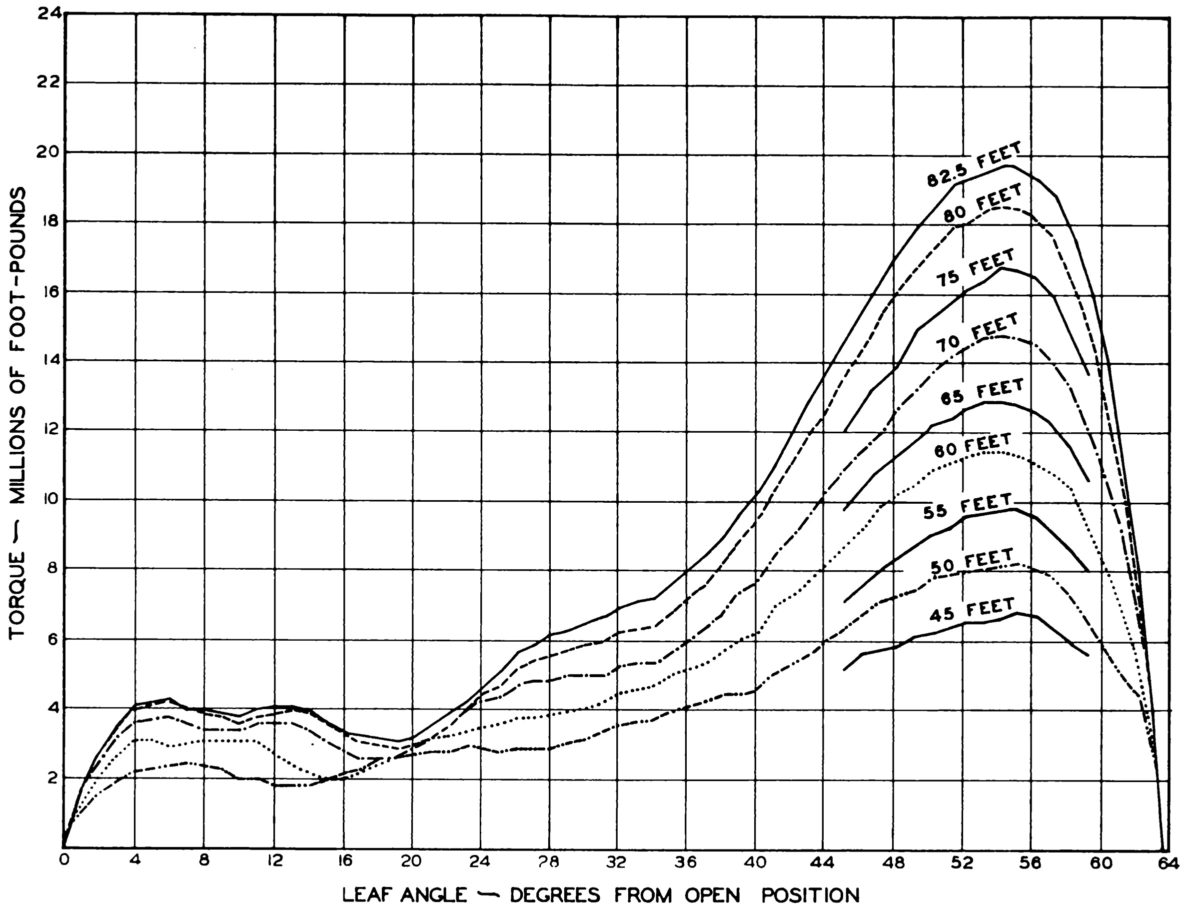
EQUATIONS

OPENING: $P = 16,560 \quad T^{-1.41}$

CLOSING: $P = 2,818 \quad T^{-1.12}$

P = PEAK TORQUE IN MILLIONS OF FOOT-POUNDS
T = OPERATING TIME IN SECONDS

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS, CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn M.N.A. Traced B.H.C. Checked M.N.A. May 1942



VARIATION OF SUBMERGENCE

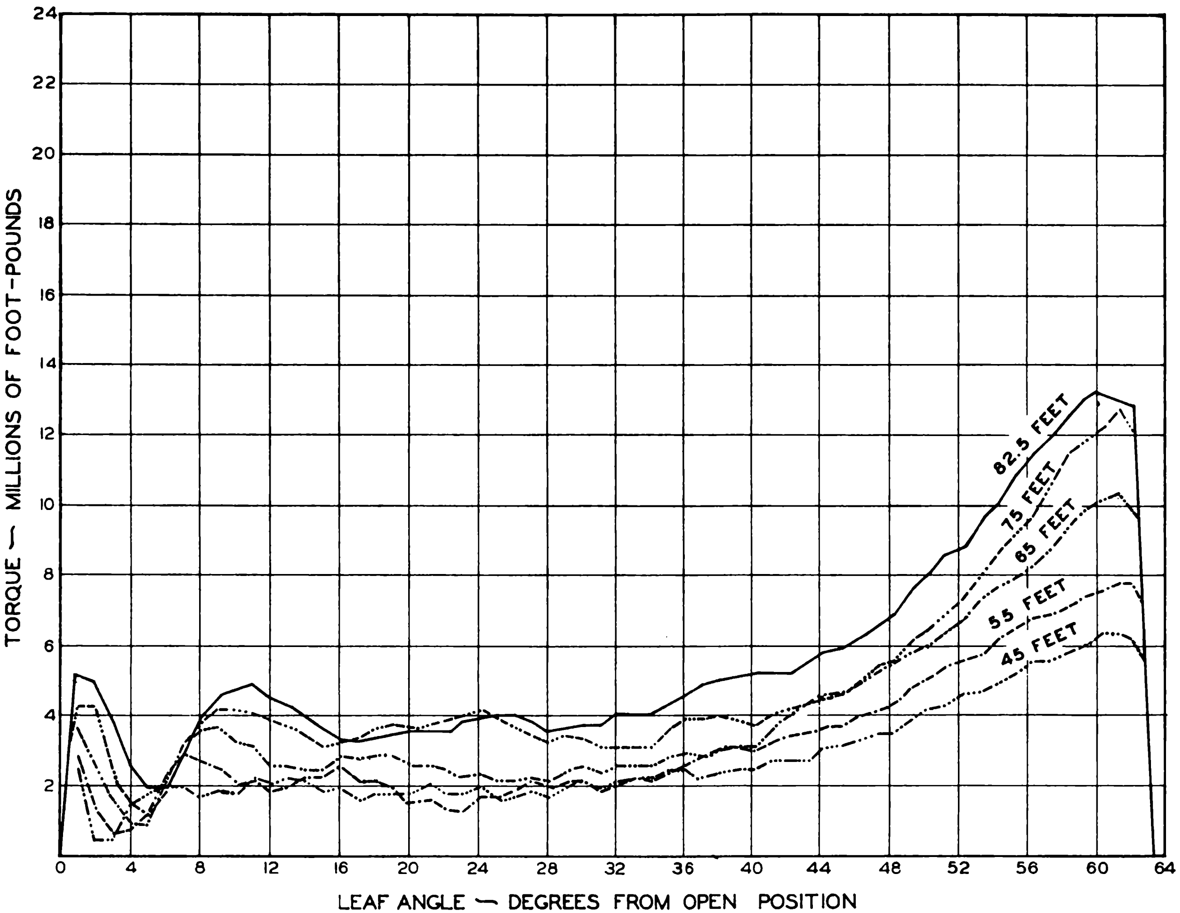
OPERATING TIME:	2 MINUTES
SUBMERGENCE:	AS INDICATED
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

OPENING OPERATION ←

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS, CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn. M.N.A. Traced: B.H.C. Checked: M.N.A. May 1942

FIGURE 13

FIGURE 14



VARIATION OF SUBMERGENCE

OPERATING TIME:	2 MINUTES
SUBMERGENCE:	AS INDICATED
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

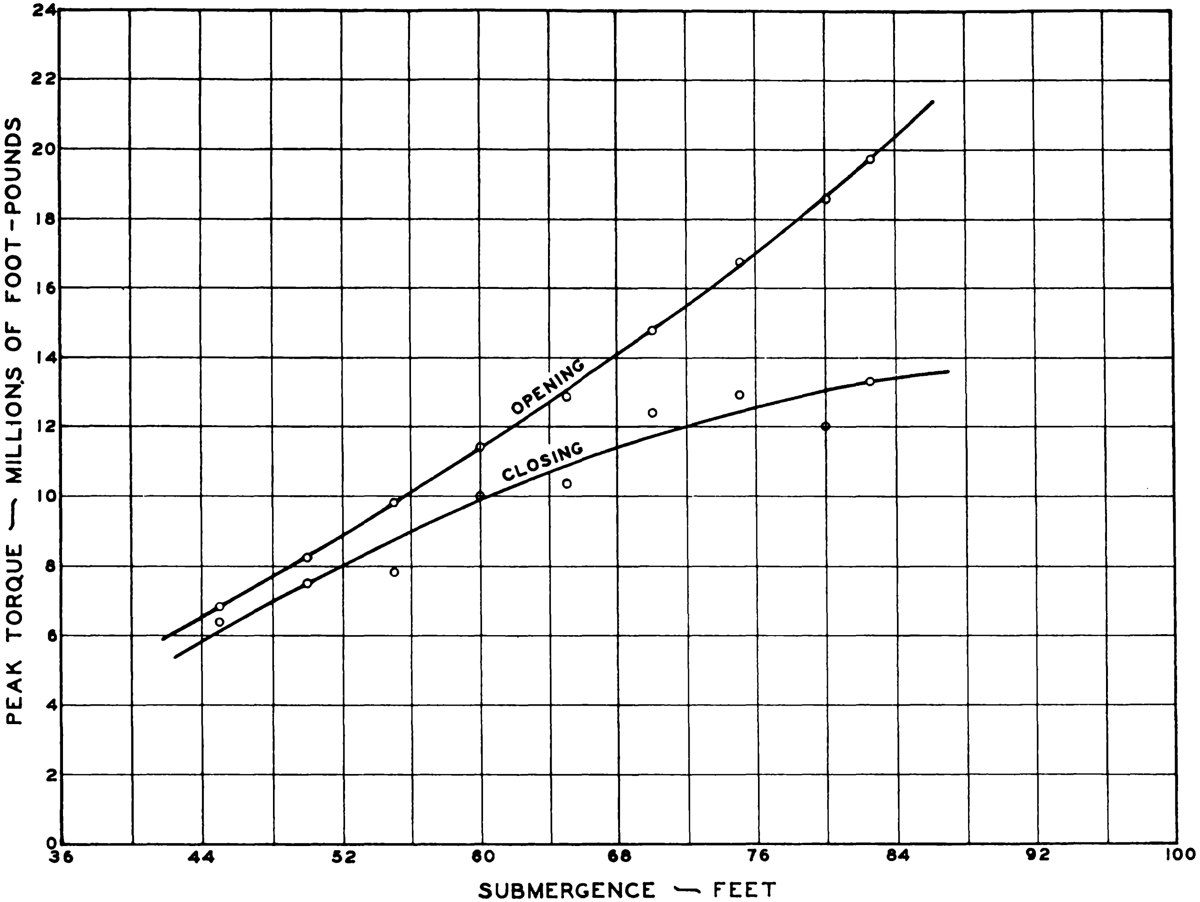
CLOSING OPERATION →

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
Traced: B.H.C.
Checked: M.N.A.

May 1942



VARIATION OF SUBMERGENCE

OPERATING TIME:	2 MINUTES
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

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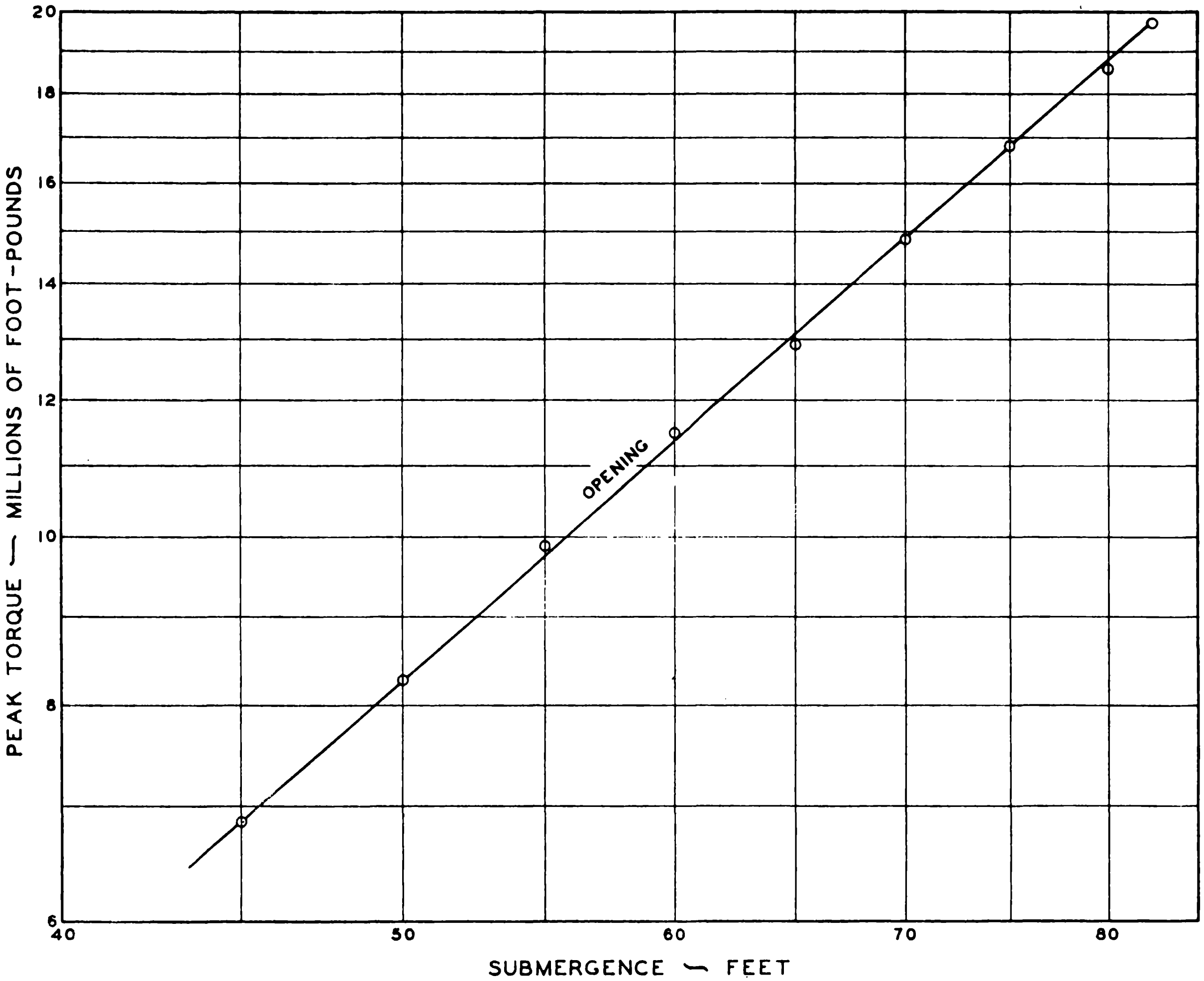
May 1942

FIGURE 15

FIGURE 16



VARIATION OF SUBMERGENCE

OPERATING TIME: 2 MINUTES

CHAMBER LENGTHS:

UPSTREAM: 1105 FEET

DOWNSTREAM: 200 FEET

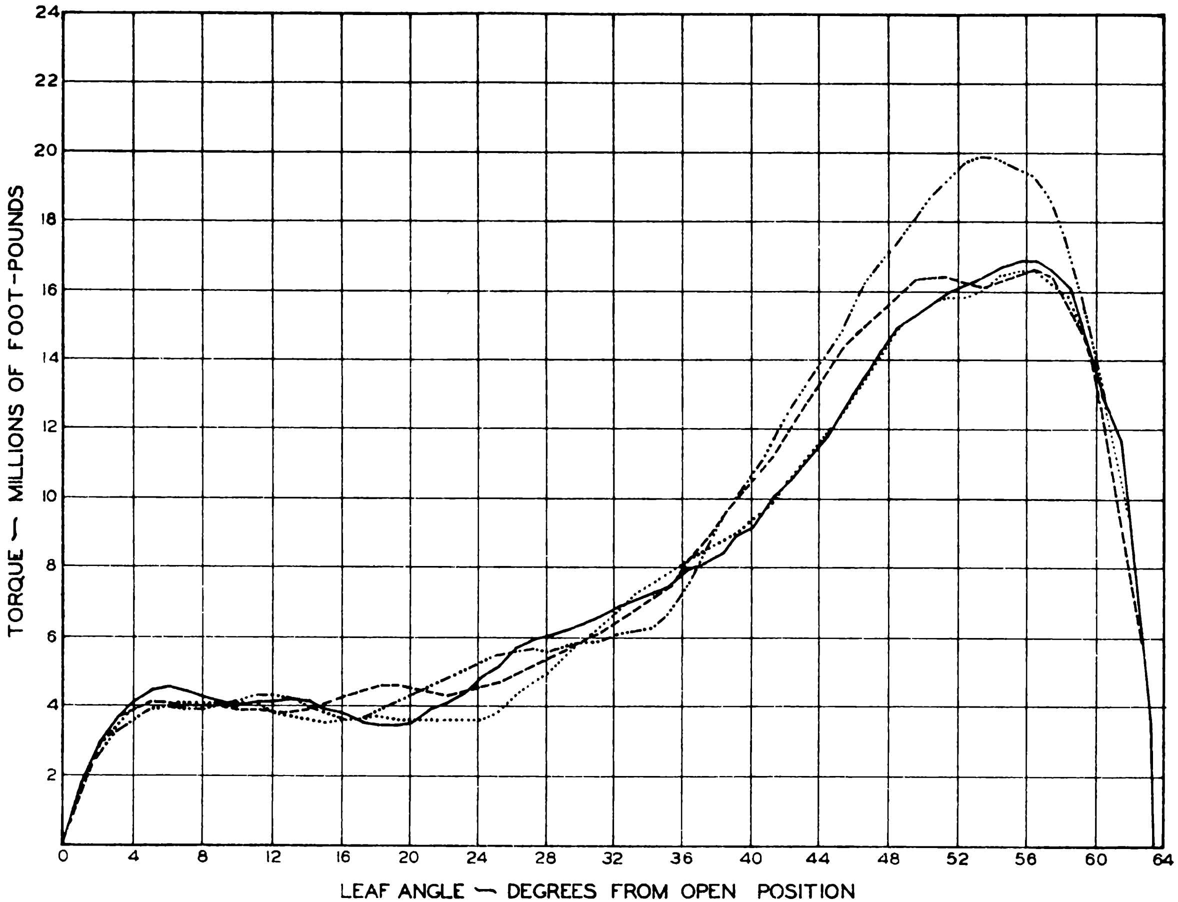
EQUATION

$$P = 0.0087\ S^{1.75}$$

P = PEAK TORQUE IN MILLIONS OF FOOT-POUNDS

S = SUBMERGENCE IN FEET

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS, CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn: M.N.A Traced: B.H.C. Checked: M.N.A. May 1942



VARIATION OF CHAMBER LENGTH

OPERATING TIME: 2 MINUTES
SUBMERGENCE: 82.5 FEET
CHAMBER LENGTHS:
DOWNSTREAM: 200 FEET
UPSTREAM:
——— 1105 FEET
900 FEET
- - - - 625 FEET
-···-··· 300 FEET

OPENING OPERATION ←

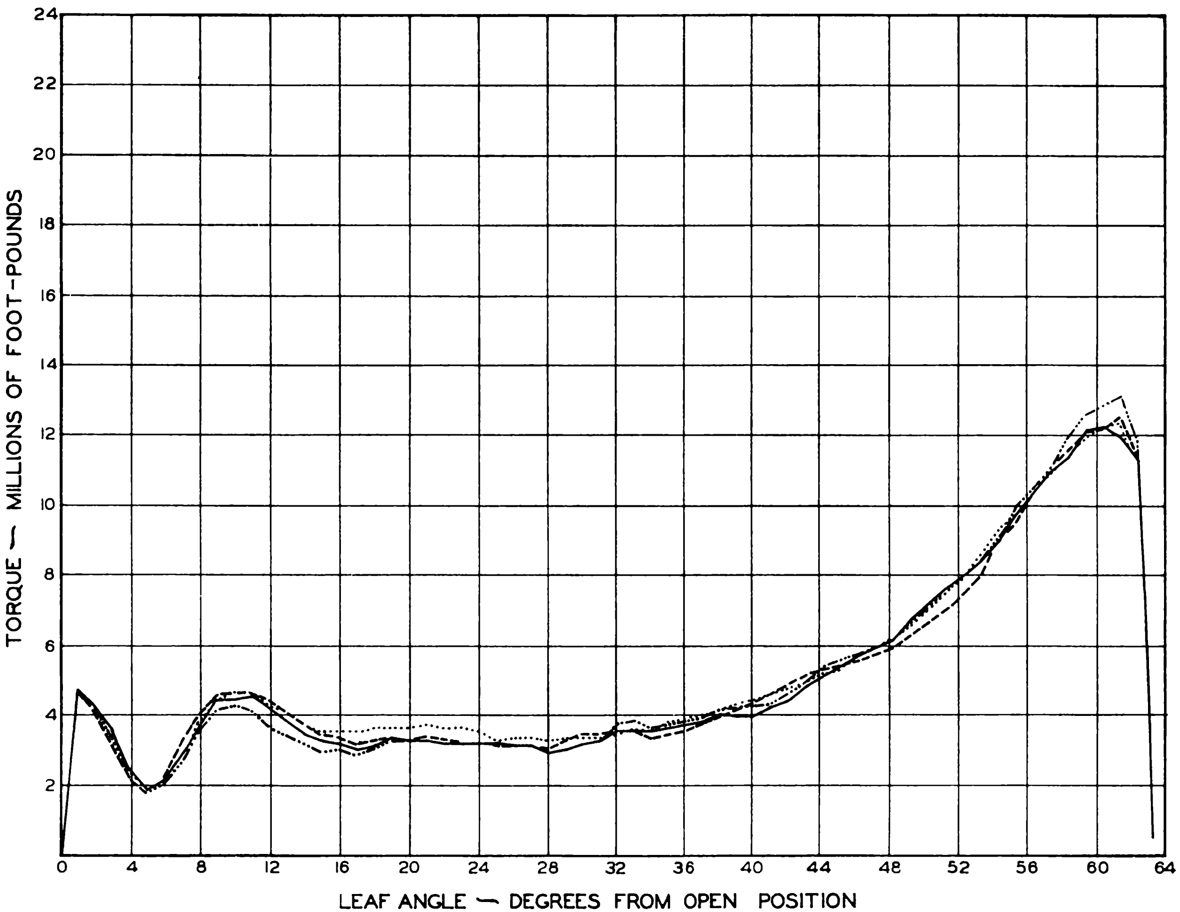
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A
Traced: B.H.C.
Checked: M.N.A.
May 1942

FIGURE 17

FIGURE 18



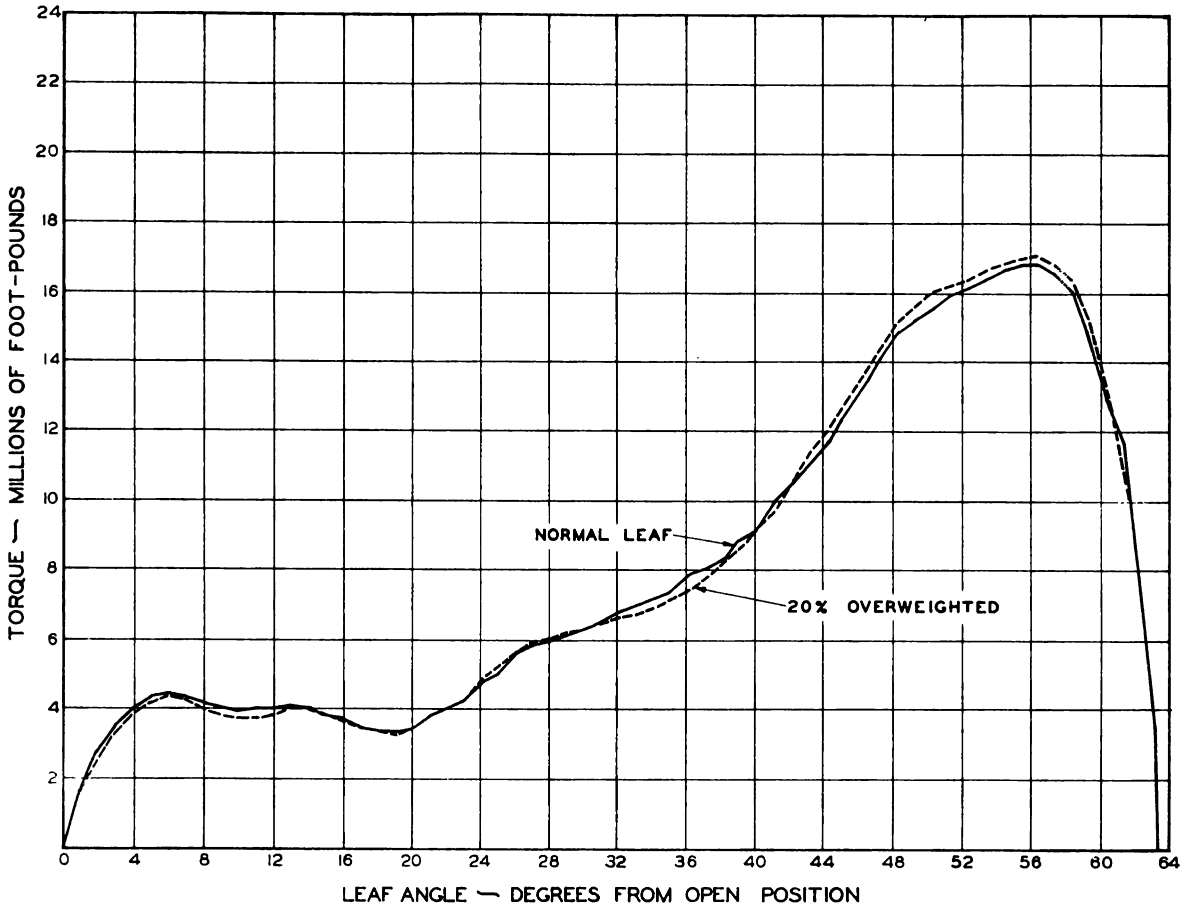
VARIATION OF CHAMBER LENGTH

OPERATING TIME: 2 MINUTES
SUBMERGENCE: 82.5 FEET
CHAMBER LENGTHS:
DOWNSTREAM: 200 FEET
UPSTREAM:
——— 1105 FEET
········ 900 FEET
– – – – 625 FEET
–··–·· 300 FEET

CLOSING OPERATION

→

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS. CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn. M.N.A. Traced: B.H.C. Checked: M.N.A May 1942



VARIATION OF WEIGHT OF LEAF

OPERATING TIME:	2 MINUTES
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

OPENING OPERATION ←

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

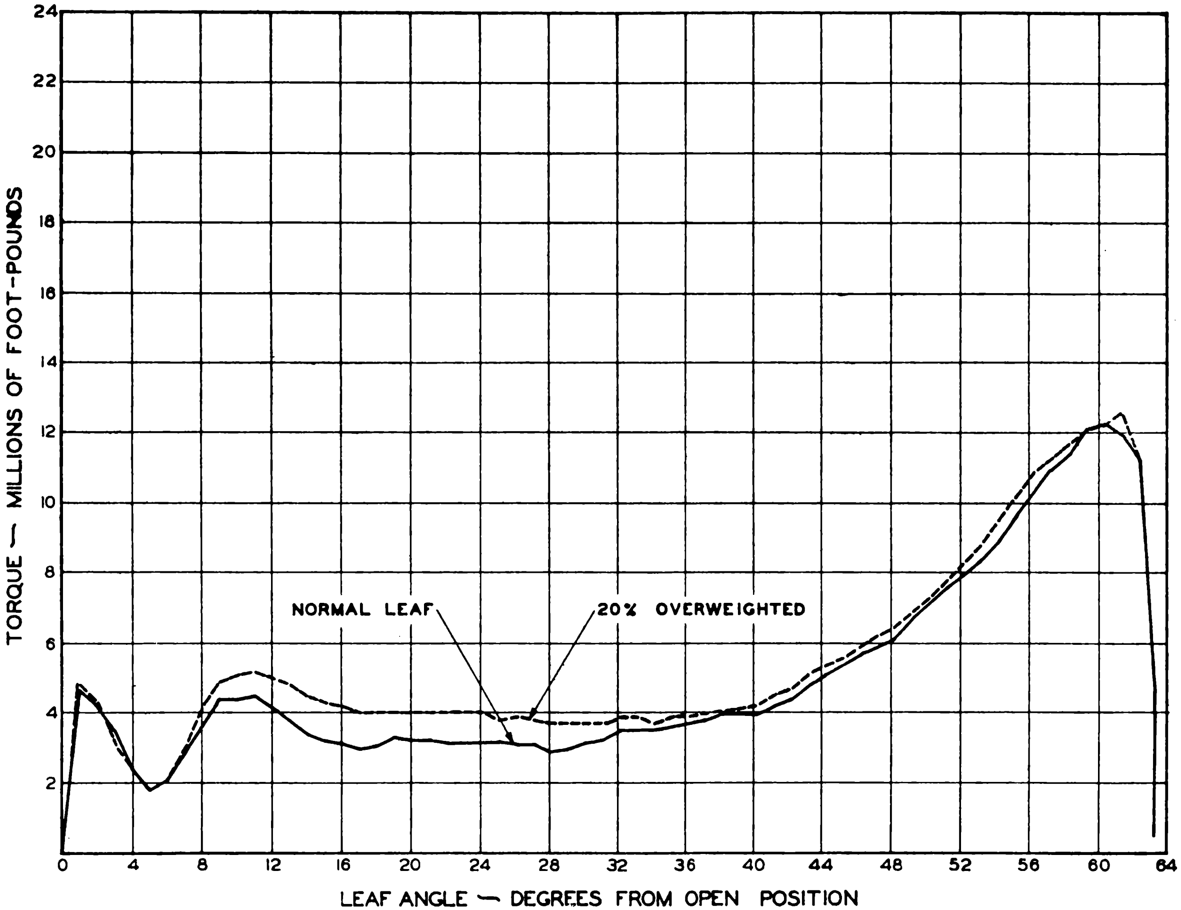
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
Traced: B.H.C.
Checked: M.N.A.
May 1942

FIGURE 19

FIGURE 20

VARIATION OF WEIGHT OF LEAF



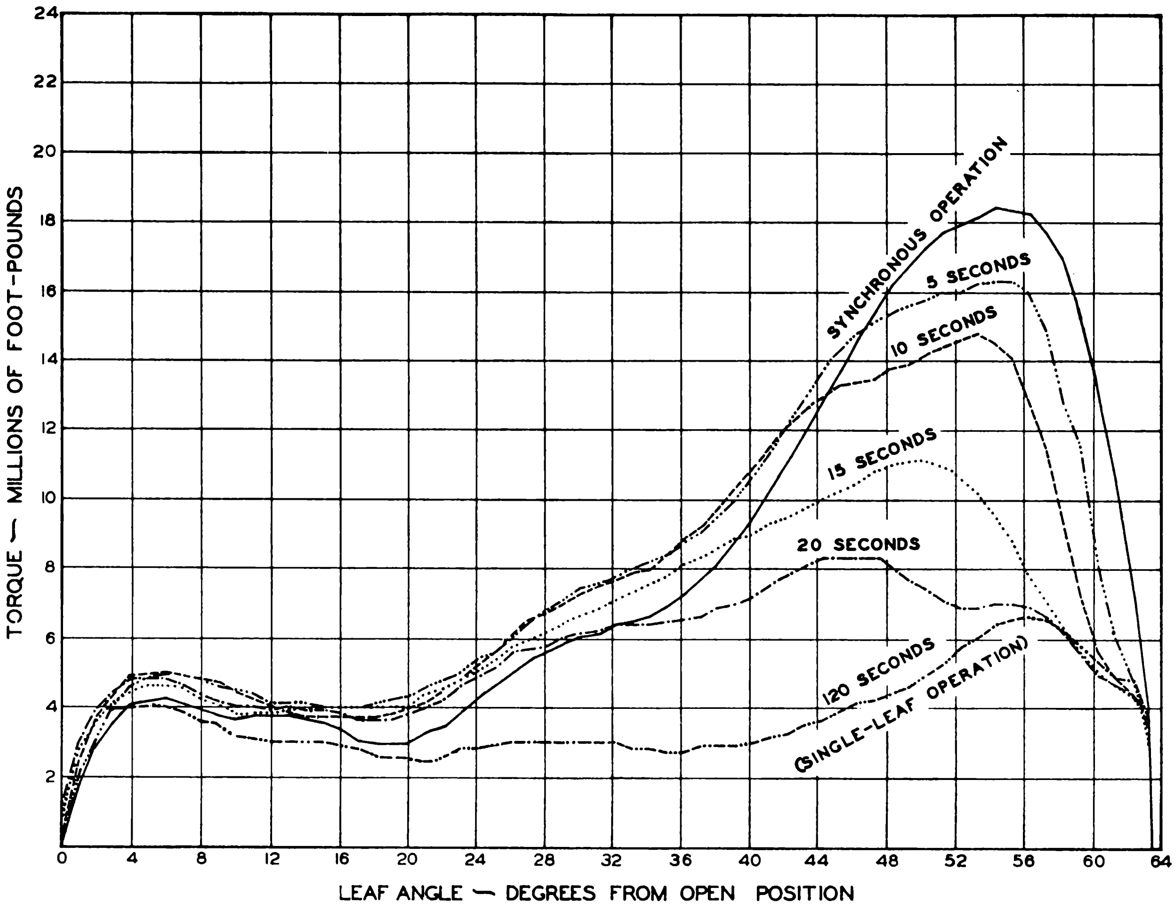
OPERATING TIME:	2 MINUTES
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET

CLOSING OPERATION →

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS. CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
Traced: B.H.C.
Checked: M.N.A.
May 1942



NONSYNCHRONOUS OPERATION

LEADING LEAF

OPERATING TIME:	2 MINUTES
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET
LEAD TIME:	AS INDICATED

OPENING OPERATION
←

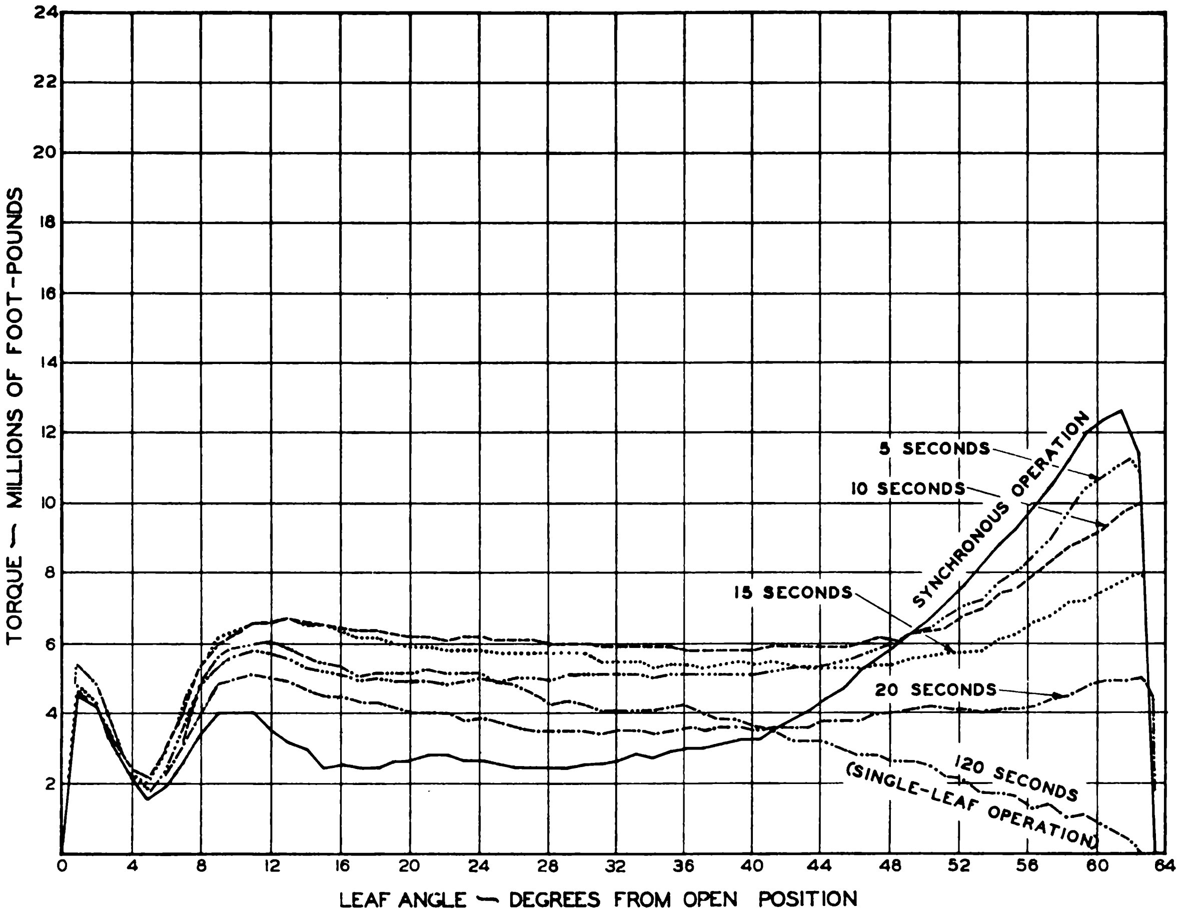
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS. CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
Traced: B.H.C.
Checked: M.N.A.
May 1942

FIGURE 21

FIGURE 22



NONSYNCHRONOUS OPERATION

LEADING LEAF

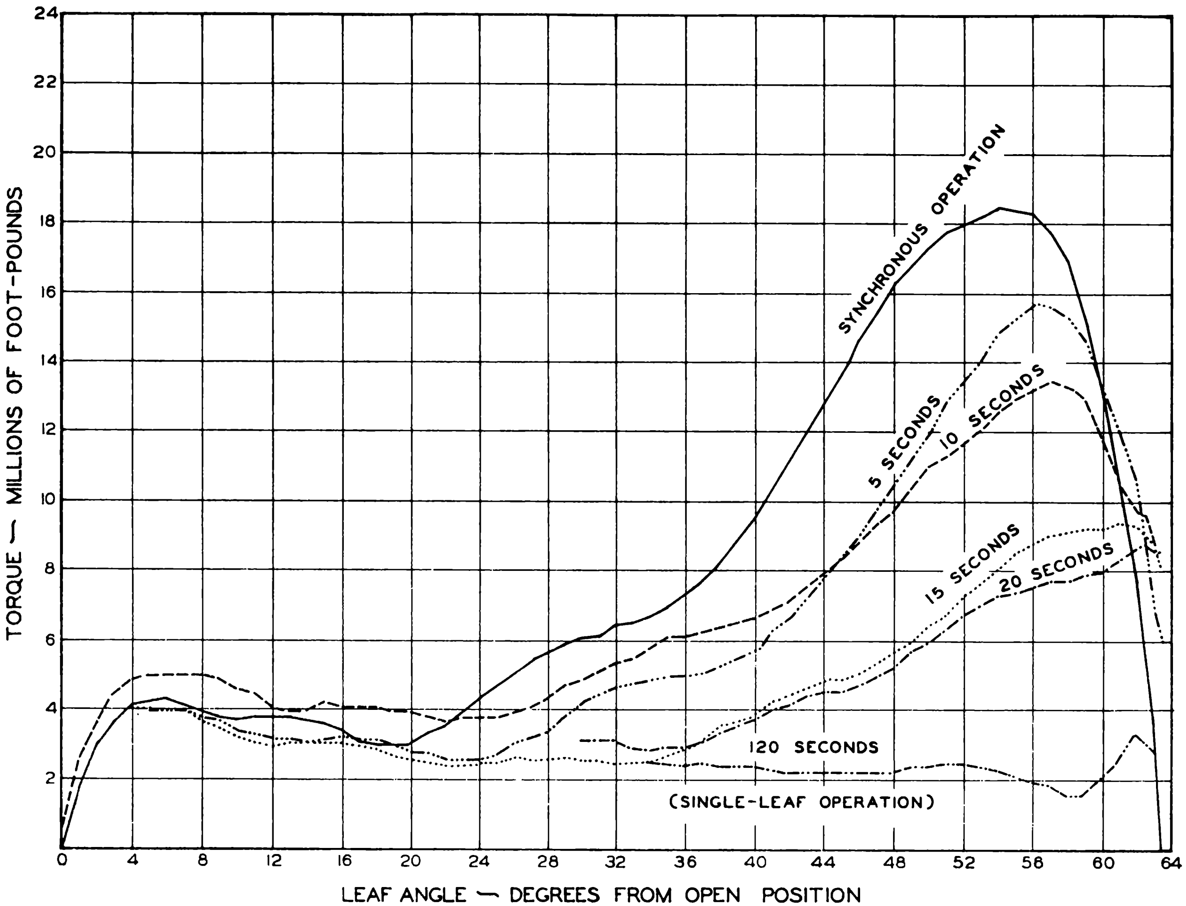
OPERATING TIME:	2 MINUTES
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET
LEAD TIME:	AS INDICATED

CLOSING OPERATION →

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
THIRD LOCKS TEST CURVES

Drawn: M.N.A.
Traced: B.H.C.
Checked: M.N.A.
May 1942



OPENING OPERATION ←

NONSYNCHRONOUS OPERATION

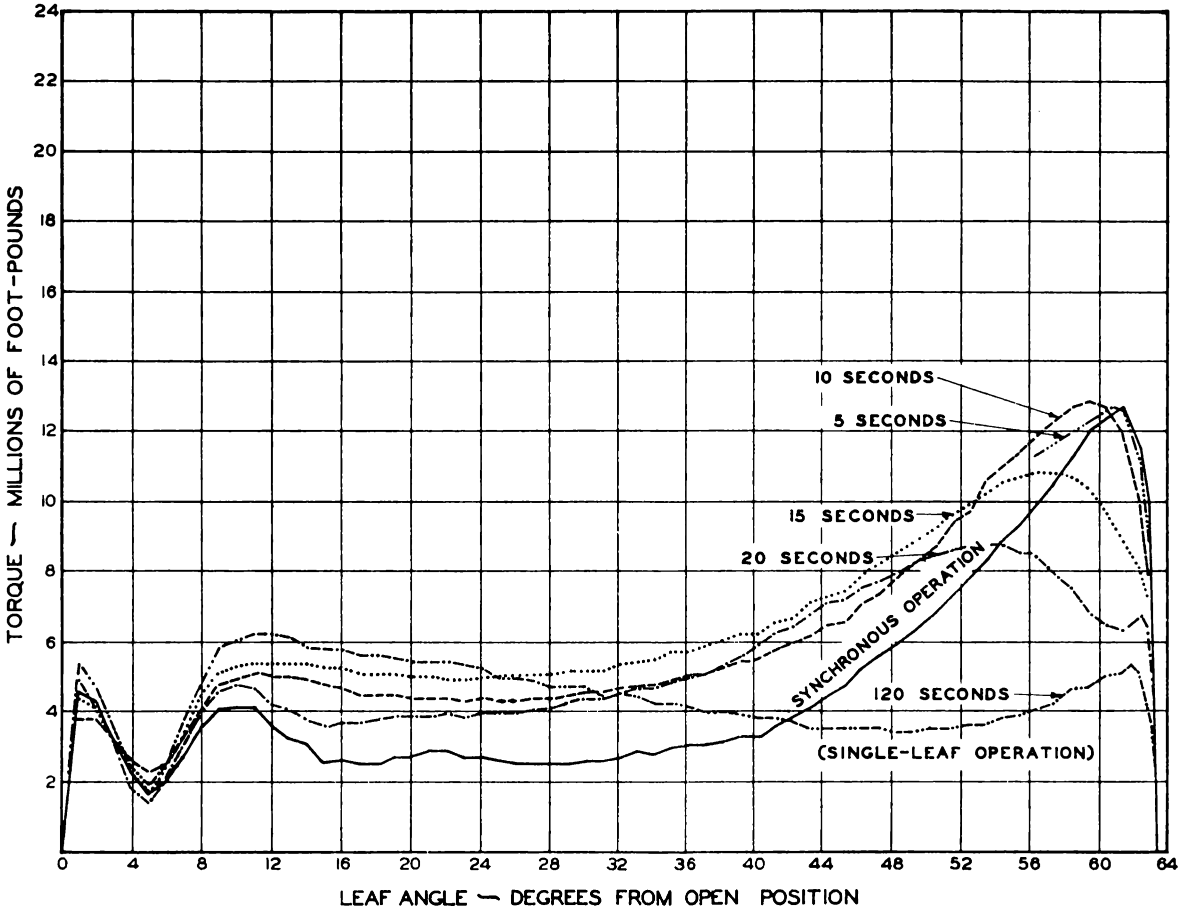
LAGGING LEAF

OPERATING TIME:	2 MINUTES
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET
LAG TIME:	AS INDICATED

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS. CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn. M.N.A. Traced. B.H.C. Checked. M.N A. May 1942

FIGURE 23

FIGURE 24



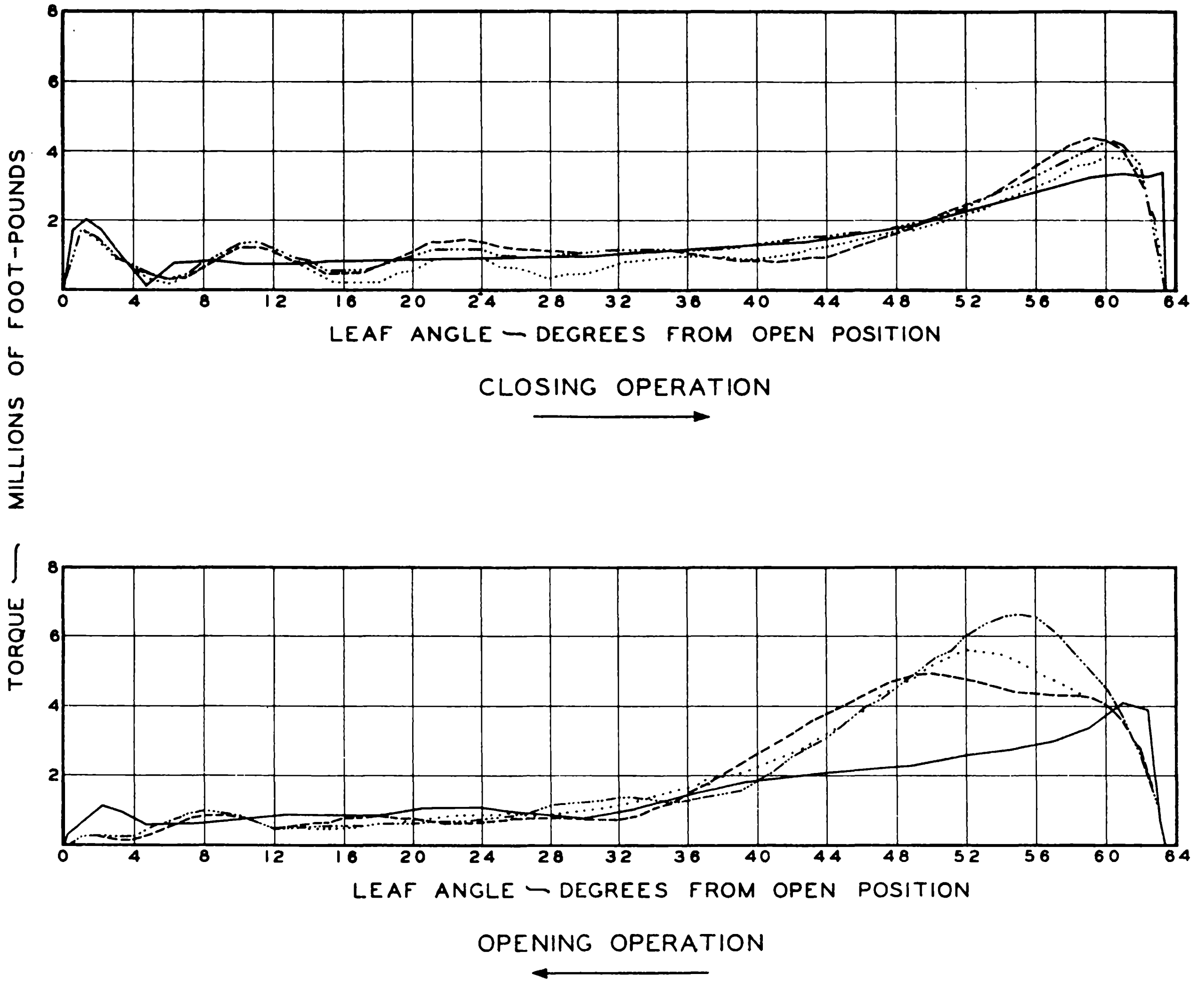
CLOSING OPERATION →

NONSYNCHRONOUS OPERATION

LAGGING LEAF

OPERATING TIME:	2 MINUTES
SUBMERGENCE:	82.5 FEET
CHAMBER LENGTHS:	
UPSTREAM:	1105 FEET
DOWNSTREAM:	200 FEET
LAG TIME:	AS INDICATED

THE PANAMA CANAL SPECIAL ENGINEERING DIVISION BALBOA HEIGHTS. CANAL ZONE THE THIRD LOCKS PROJECT HYDRAULIC MODEL Y MITER GATE OPERATION THIRD LOCKS TEST CURVES	Drawn. M.N.A. Traced: B.H.C. Checked: M.N.A. May 1942



VARIATION OF CHAMBER LENGTHS

SUBMERGENCE: 73.16 FEET

OPERATING TIME:

OPENING: 126.2 SECONDS

CLOSING: 121.5 SECONDS

CHAMBER LENGTHS:

	UPSTREAM	DOWNSTREAM
———	358.5 FEET	650.0 FEET
-··-···	225.8 FEET	225.8 FEET
·······	338.6 FEET	338.6 FEET
----	470.3 FEET	470.3 FEET

NOTE:

SOLID LINES REPRESENT RESULTS OF PROTOTYPE POWER-INPUT TESTS. OTHER LINES REPRESENT RESULTS OF MODEL TESTS.

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

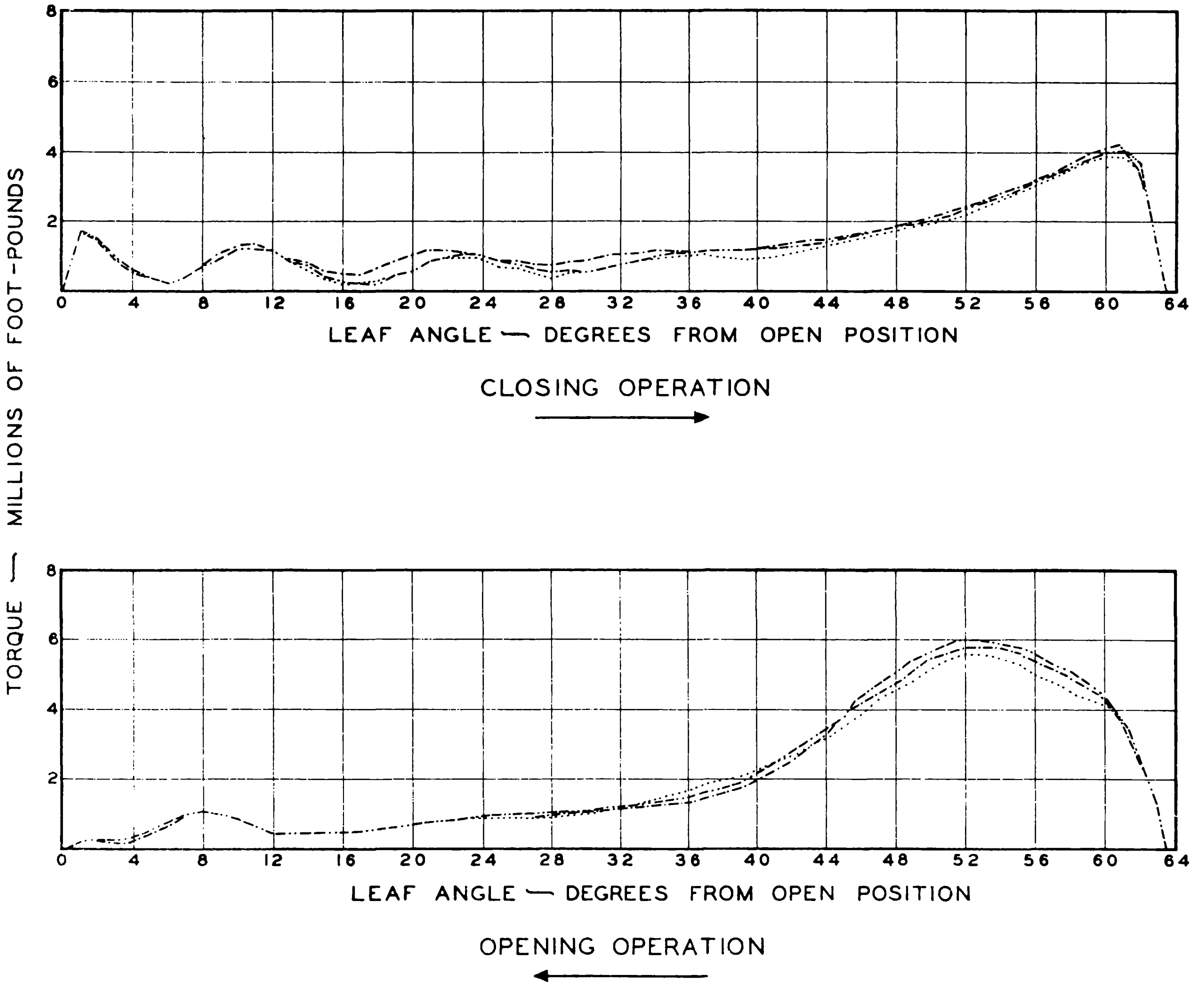
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
EXISTING LOCKS TEST CURVES

Drawn M.N.A.
Traced B.H.C.
Checked M.N.A.

May 1942

FIGURE 25

FIGURE 26



VARIATION OF CHAMBER LENGTHS

SUBMERGENCE: 73.16 FEET

OPERATING TIME:

OPENING: 126.2 SECONDS

CLOSING: 121.5 SECONDS

CHAMBER LENGTHS:

	UPSTREAM	DOWNSTREAM
—·—·—	225.8 FEET	470.3 FEET
—··—··—	470.3 FEET	225.8 FEET
·······	338.6 FEET	338.6 FEET

THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

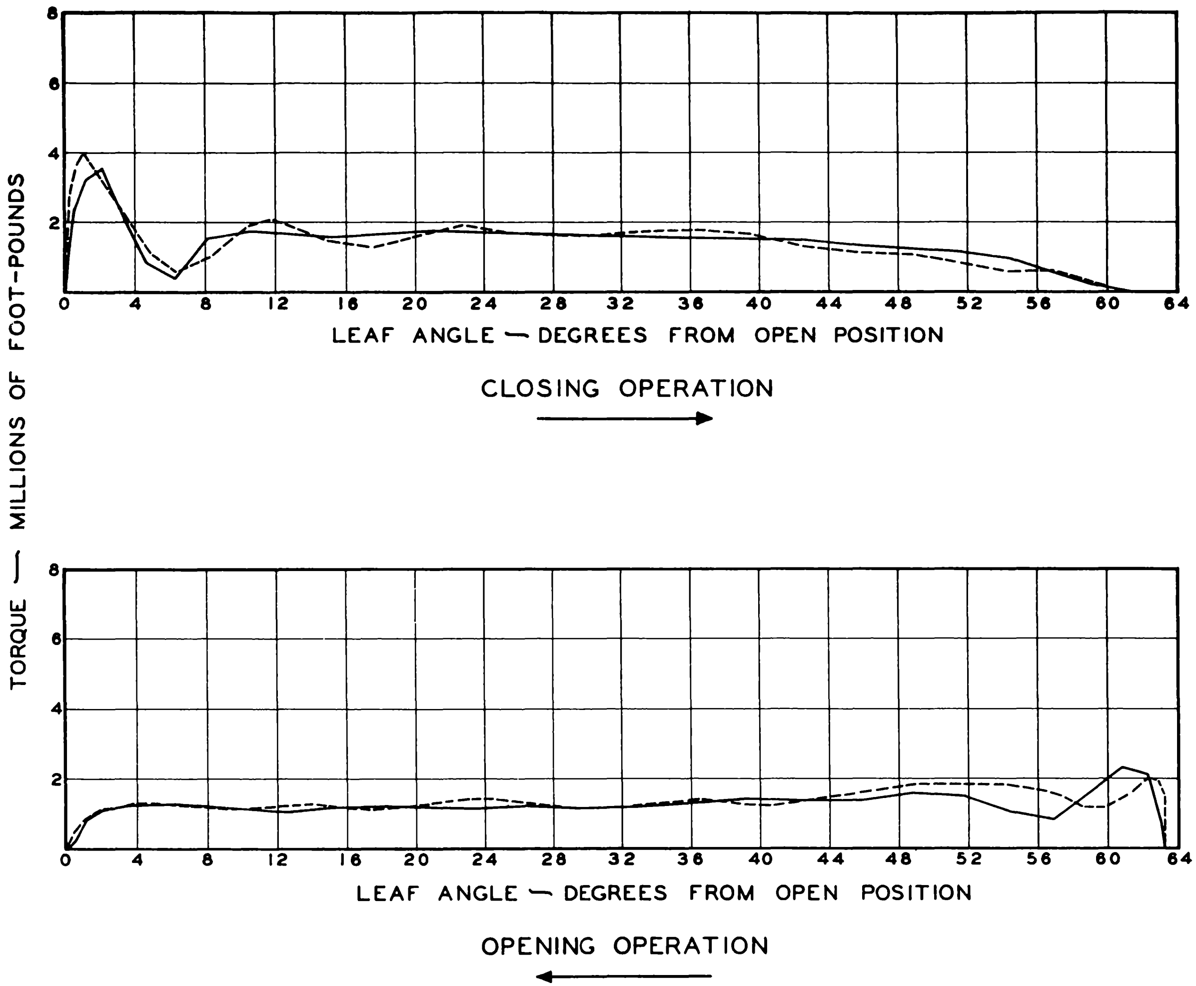
THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
EXISTING LOCKS TEST CURVES

Drawn M.N.A.

Traced B.H.C.

Checked M.N.A.

May 1942



SINGLE-LEAF OPERATION

ONE LEAF OPEN

SUBMERGENCE: 73.16 FEET

OPERATING TIME:

OPENING: 111.7 SECONDS

CLOSING: 112.1 SECONDS

CHAMBER LENGTHS:

	UPSTREAM	DOWNSTREAM
———	358.5 FEET	650.0 FEET
- - - -	470.3 FEET	470.3 FEET

NOTE:

SOLID LINES REPRESENT RESULTS OF PROTOTYPE POWER-INPUT TESTS. DASHED LINES REPRESENT RESULTS OF MODEL TESTS.

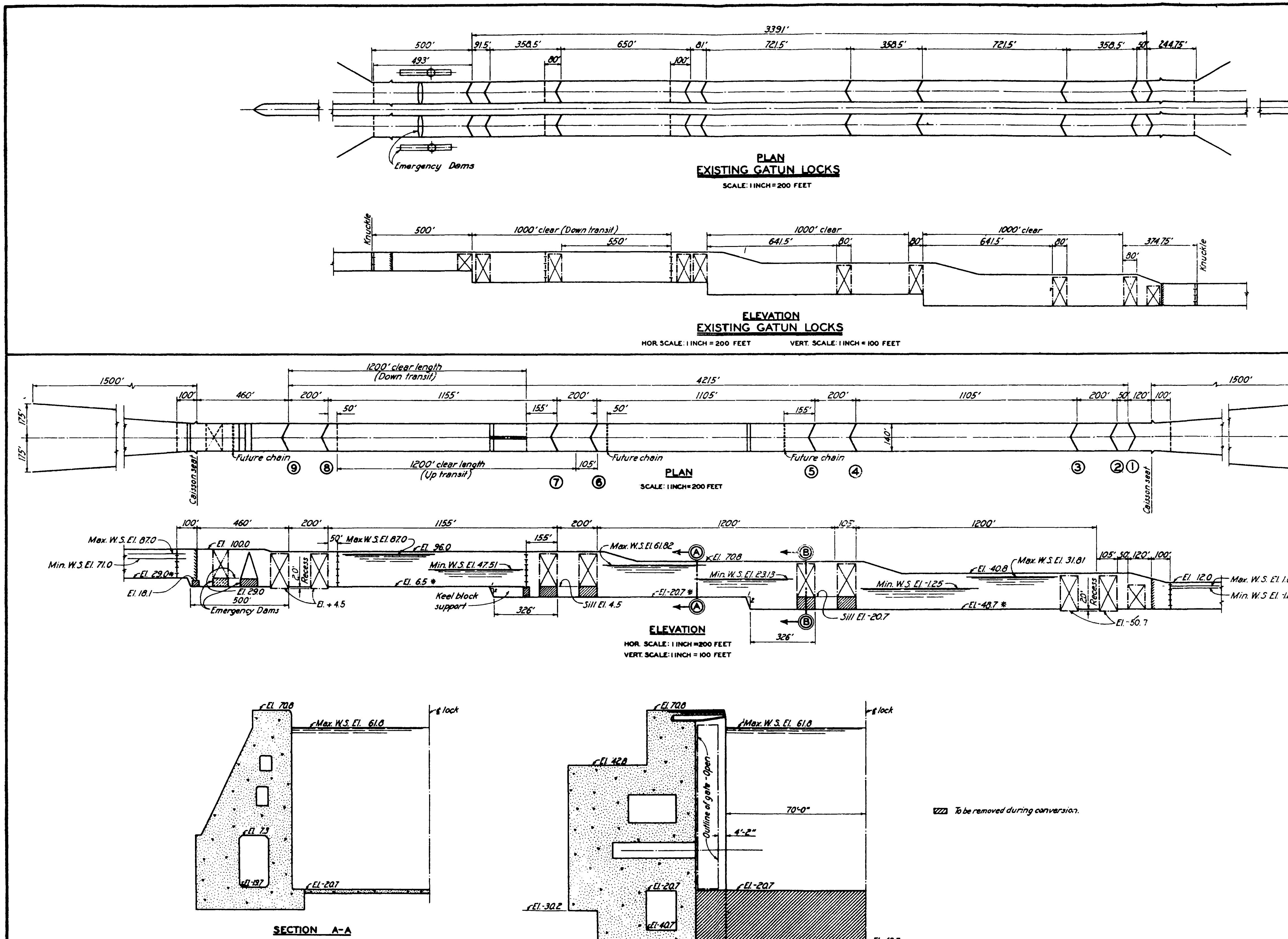
THE PANAMA CANAL
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
HYDRAULIC MODEL Y
MITER GATE OPERATION
EXISTING LOCKS TEST CURVES

Drawn: M.N.A.
Traced: B.H.C.
Checked: M.N.A.

May 1942

FIGURE 27



NOTE:
* Controlling maximum elevations.

No.	Revision	Date	Checked / Submitted	Reviewed	Recomm. / Approved	Change Order No.
1	Elevation ℄ strut deleted	8-2-41				

THE PANAMA CANAL
DEPARTMENT OF OPERATION AND MAINTENANCE
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
NEW GATUN LOCKS
PROPOSED GATE ARRANGEMENT

SCALE: AS SHOWN JULY 1941

Designed. Drawn K.R.B. Traced: A.O.A. Checked:

SUBMITTED: REVIEWED:

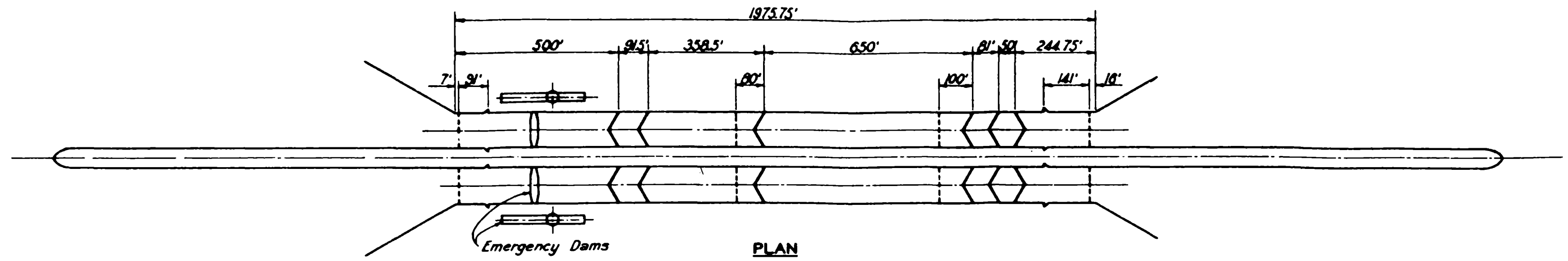
Designing Engineer

REVIEWED: APPROVED:

Supervising Engineer

(TO ACCOMPANY MEMORANDUM DATED JULY 23, 1941 FOR ENGINEER OF MAINTENANCE)
(APPROVED BY GOVERNOR JULY 28, 1941)

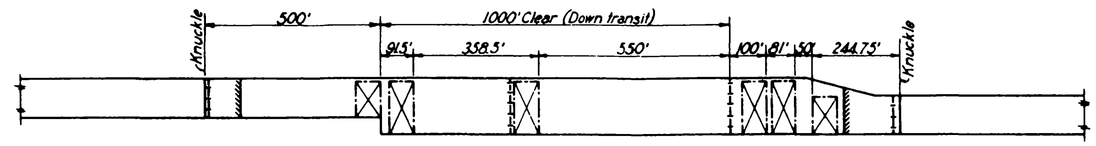
SK 1720-14 R1



PLAN

EXISTING PEDRO MIGUEL LOCKS

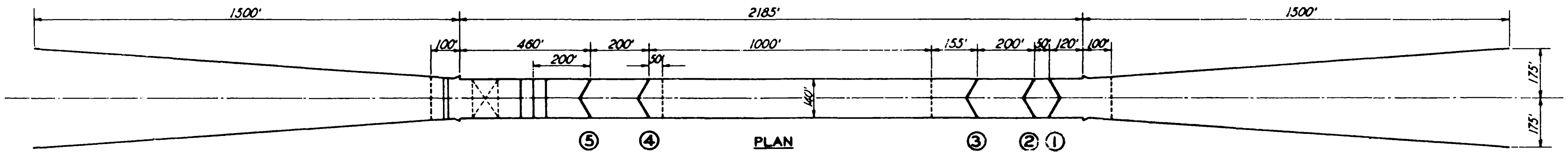
SCALE: 1 INCH = 200 FEET



ELEVATION

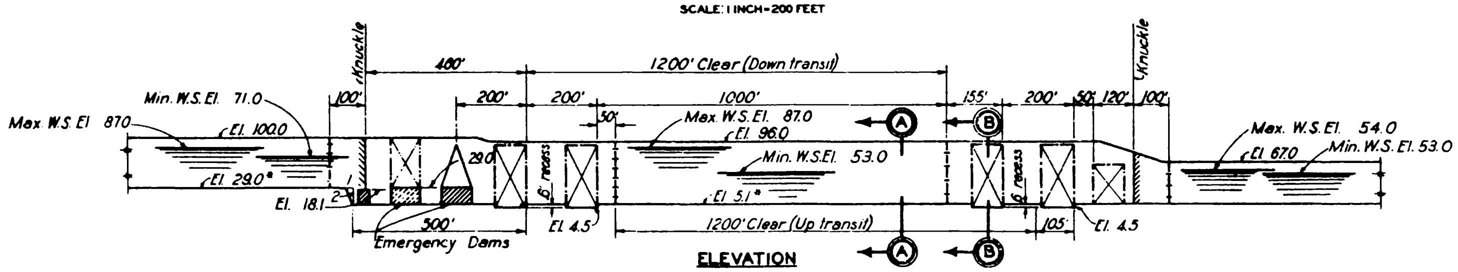
EXISTING PEDRO MIGUEL LOCKS

HOR. SCALE: 1 INCH = 200 FEET
VERT. SCALE: 1 INCH = 100 FEET



PLAN

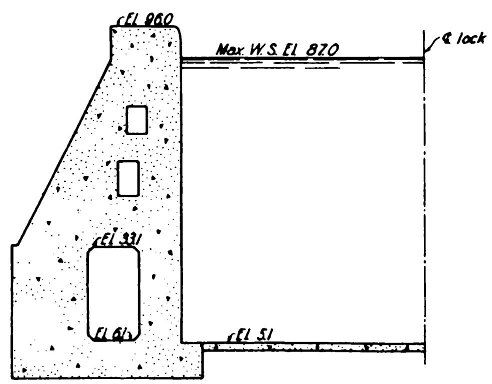
SCALE: 1 INCH = 200 FEET



ELEVATION

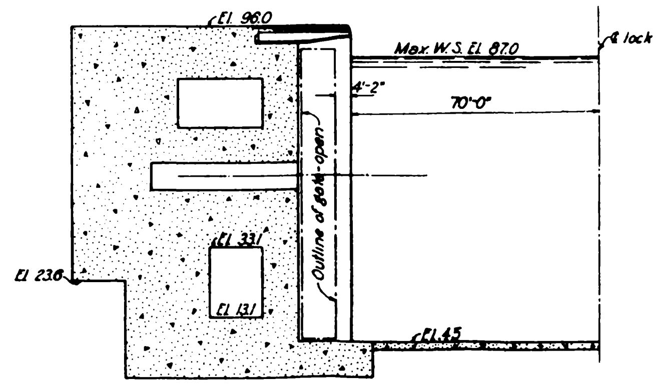
HOR. SCALE: 1 INCH = 200 FEET
VERT. SCALE: 1 INCH = 100 FEET

NOTE:
* Controlling maximum elevation.



SECTION A-A

SCALE: 1 INCH = 20 FEET



SECTION B-B

SCALE: 1 INCH = 20 FEET

PREPARED UNDER SUPERVISION OF:

NO.	REVISION	DATE
1	Elevation & strut deleted	8-2-41

THE PANAMA CANAL
DEPARTMENT OF OPERATION AND MAINTENANCE
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
NEW PEDRO MIGUEL LOCK
PROPOSED GATE ARRANGEMENT

SCALE: AS SHOWN — JULY 1941

Designed: — Drawn: K.R.B. — Traced: C.S.F. — Checked:

SUBMITTED: — REVIEWED:

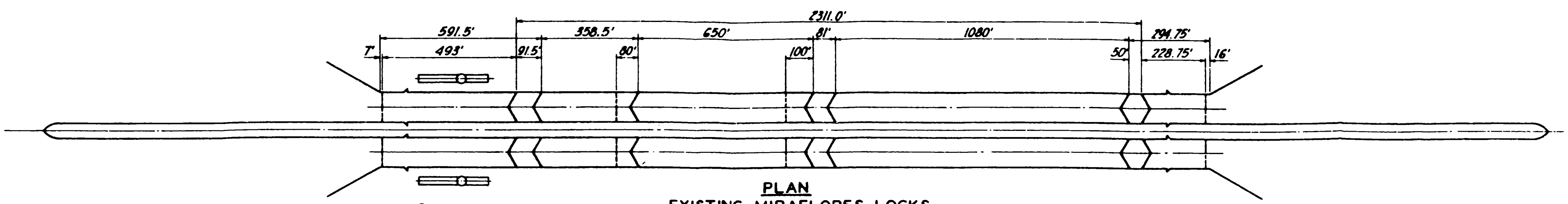
Designing Engineer

REVIEWED: — APPROVED:

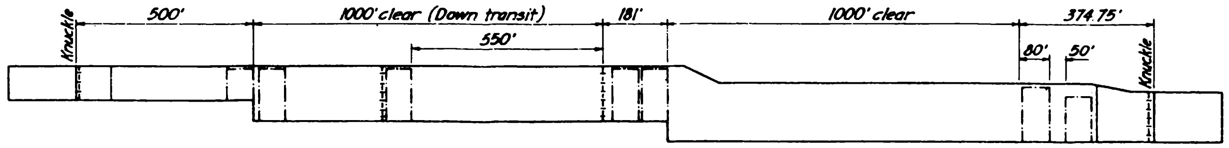
Supervising Engineer

(TO ACCOMPANY MEMORANDUM DATED JULY 23, 1941 FOR ENGINEER OF MAINTENANCE)
(APPROVED BY GOVERNOR JULY 29, 1941)

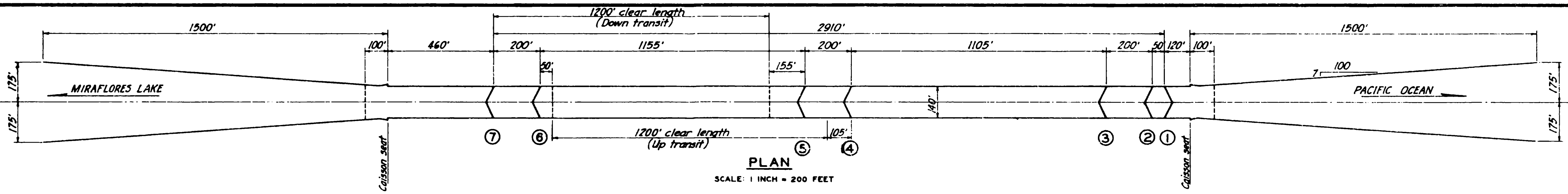
SK 1721-4 R 1



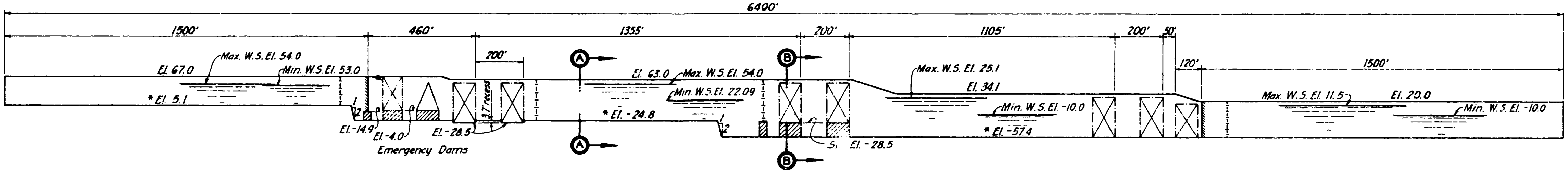
PLAN
EXISTING MIRAFLORES LOCKS
SCALE: 1 INCH = 200 FEET



ELEVATION
EXISTING MIRAFLORES LOCKS
HOR. SCALE: 1 INCH = 200 FEET
VERT. SCALE: 1 INCH = 100 FEET

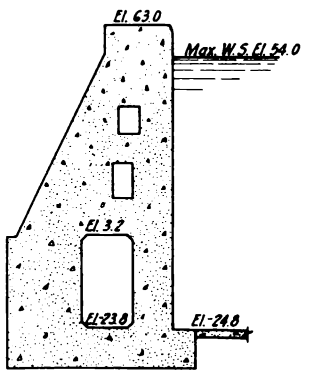


PLAN
SCALE: 1 INCH = 200 FEET

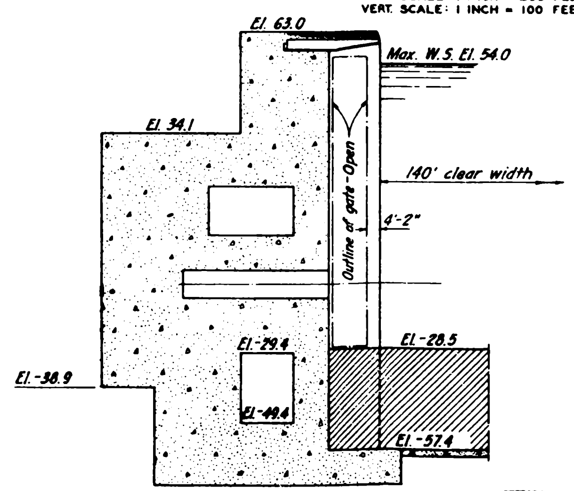


ELEVATION
HOR. SCALE: 1 INCH = 200 FEET
VERT. SCALE: 1 INCH = 100 FEET

NOTE:
* Controlling maximum elevation.



SECTION A-A
SCALE: 1 INCH = 20 FEET



SECTION B-B
SCALE: 1 INCH = 20 FEET

PREPARED UNDER SUPERVISION OF:
C. E. Pohl .... Engineer, Civil
W. E. Johnson .... Prin. Engineer, Civil
J. E. Reeves .... Asst. Designing Engineer

NO.	REVISION	DATE	CHECKED / SUBMITTED	REVIEWED	RECOMM. / APPROVED	CHANGE ORDER NO.
1.	Elevations at strut and machine room deleted	8-2-41				

(TO ACCOMPANY MEMORANDUM DATED JULY 23, 1941 FOR ENGINEER OF MAINTENANCE)
(APPROVED BY GOVERNOR JULY 29, 1941)

THE PANAMA CANAL
DEPARTMENT OF OPERATION AND MAINTENANCE
SPECIAL ENGINEERING DIVISION
BALBOA HEIGHTS, CANAL ZONE

THE THIRD LOCKS PROJECT
NEW MIRAFLORES LOCKS
PROPOSED GATE ARRANGEMENT

SCALE: AS SHOWN — JULY 1941

Designed: — Drawn: C.E.W. — Traced: G.A.R. — Checked:

SUBMITTED: — REVIEWED:

Designing Engineer

REVIEWED: — APPROVED:

Supervising Engineer

SK 1722-3 R1