EMERGENCY GATE PERFORMANCE
MC ALPINE LOCK, OHIO RIVER, KENTUCKY

Hydraulic Prototype Tests

MISCELLANEOUS PAPER NO. 2-622

February 1964

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

$0.50

TA7
W34m
no. 2-622
c. 2

4213492

EMERGENCY GATE PERFORMANCE
MC ALPINE LOCK, OHIO RIVER, KENTUCKY

Hydraulic Prototype Tests

MISCELLANEOUS PAPER NO. 2-622

February 1964

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

TA7
W34m
no. 2-622
Cop. 2

PREFACE

The prototype tests of the downstream leaf of the emergency gate, McAlpine Locks and Dam, were authorized in correspondence from the U. S. Army Engineer District, Louisville, to the U. S. Army Engineer Waterways Experiment Station (WES), dated 24 May 1961. The tests were conducted on 19 August and 30 October 1961. Some of the work also was conducted under the Corps of Engineers Civil Works Investigation 805, "Hydraulic Prototype Tests." The WES is responsible for coordinating the hydraulic prototype test program, and consequently was requested to assist in these tests.

Instrumentation and personnel for conducting the electronic measurements were furnished by the WES. These personnel included Messrs. E. B. Pickett, C. J. Huval, and L. M. Duke. Velocity measurements, staff-gage observations, and photographs were made by Louisville District personnel. Special acknowledgment is made to Mr. A. K. Boyle, Resident Engineer at McAlpine Locks, and the several project personnel who assisted in the tests. Mr. Steve Rauh was in charge of the test operation for the general contractor, Hardaway Contracting Company. He and his co-workers installed and removed much of the test equipment and were most helpful at all times.

Test observers were sent from the Office, Chief of Engineers; Ohio River Division; Louisville District; and the WES. A total of about 43 observers were present for one or both of the test series in August and October. The test schedules were coordinated principally with Messrs. A. J. Moors, Ohio River Division, and S. F. Farmer, Louisville District.

This investigation was conducted under the supervision of Mr. E. P. Fortson, Jr., Chief, Hydraulics Division, and Mr. F. B. Campbell, Chief, Hydraulics Analysis Branch. This report was prepared by Mr. C. J. Huval

39912

under the general supervision of Mr. E. B. Pickett, Chief, Prototype Section.

Director of the WES during the tests and preparation of this report was Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

SUMMARY

Tests were conducted on the downstream leaf of the two-leaf, vertical-lift emergency gate to determine whether the gate would perform satisfactorily under flowing-water conditions approximating an emergency. The test operation used to simulate an emergency consisted of lowering the downstream leaf to the full-down position and then raising it to the initial damming position with the lock-emptying valves fully open and the downstream miter gate closed. Measurements included gate position, gate hoist loads, gate vibration, and water-surface elevations during the test operation; flow conditions in the lock were also observed. The initial test sequence was interrupted by the failure of the latching device for one of the upper-miter-gate leaves. The latches were strengthened, and a second test sequence was successfully completed.

Results of the tests indicated stable gate operation under relatively severe flow conditions. Gate vibration was very low with no tendency to increase, indicating no elastic resonance with any fluctuating hydraulic load. Good agreement was found between prototype observations and results of a model study of the gate. Gate hoist loads were somewhat higher in the prototype than in the model, with the variation being attributed to differences in gate construction or higher seal and reaction-roller friction in the prototype.

EMERGENCY GATE PERFORMANCE

McALPINE LOCK, OHIO RIVER, KENTUCKY

Hydraulic Prototype Tests

PART I: INTRODUCTION

Features of the Project

1. The McAlpine Locks and Dam project is located on the Ohio River at Louisville, Kentucky (see fig. 1). The project was known as Locks and Dam No. 41 and Louisville Locks and Dam prior to 24 May 1960, when the name was officially changed to the present designation. The project is part of the comprehensive plan for replacement and modernization of navigation structures on the Ohio River. As part of the modernization program, the existing dam will be replaced with a fixed weir section and nine tainter gates for flow control. The 37-ft-lift lock structures, located on the south (Kentucky) shore of the river, consist of three parallel lock

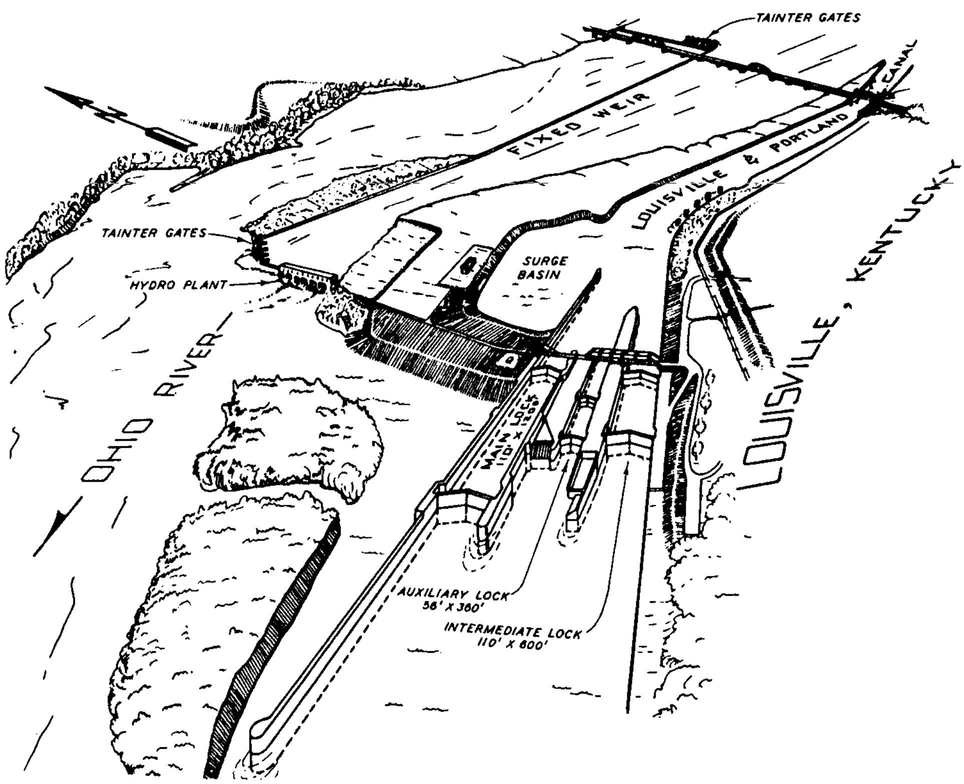


Fig. 1. Project layout

chambers. The main (newly constructed) lock has nominal dimensions of 110 by 1200 ft, the intermediate lock is 110 by 600 ft, and the auxiliary, smaller lock is 56 by 360 ft. The navigation gates of the main lock are of the horizontally framed miter type, and both upstream and downstream gates are 70 ft high. The lock is filled and emptied through floor laterals extending from longitudinal culverts in the lock wall. The river or north wall culvert serves the upstream laterals, and the land or south wall culvert the downstream laterals. A general plan and sections of the main lock are shown in plate 1.

Emergency Gate

Background

2. A two-leaf, vertical-lift emergency gate (see fig. 2) was

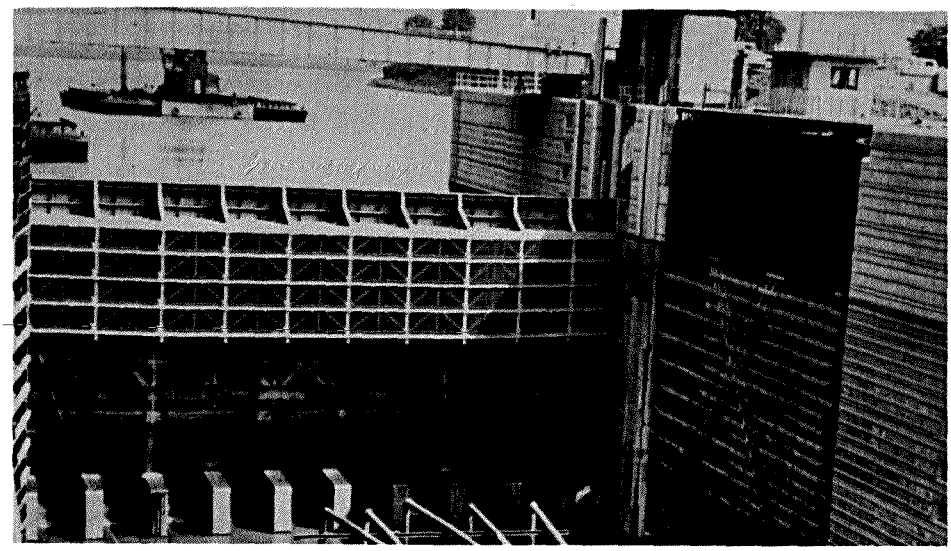


Fig. 2. Two-leaf emergency gate and bascule bridge at upstream end of lock; upstream leaf in lowered position; downstream leaf in partially raised position

provided in the new lock structure, primarily to preserve the upper pool in the event of an accident to the miter gates. This facility permits relatively rapid closure of the lock compared to stoplog-type bulkheads. The provision of gates as emergency closure structures for navigation locks is unusual in inland river waterways. However, similar gates have been built for the Greenup and Markland Locks and are planned for the Cannelton Locks, all on the Ohio River. The Greenup emergency-gate design was investigated in a model study* to determine the vertical forces acting on the downstream leaf of the gate and to correct any unsatisfactory conditions. After study of nine gate types, a satisfactory crest shape was developed to give minimum downpull without causing uncontrollable uplift of the gate. The 1- by 3-ft triangular crest of this gate is shaped to direct the overflow nappe beyond the downstream edge of the top girder flange at higher flows and counteract unstable conditions and high uplift from a back roller under the nappe. Later model studies** were also made of the McAlpine emergency gate, the design of which was based on the Greenup gate design.

Description

3. Both leaves of the emergency gate are normally stored in a submerged position, resting on concrete pedestals just downstream of a concrete sill. Plate 2 shows pertinent details of the McAlpine emergency gate. The gate is located a short distance upstream of the upper miter gate and spans the lock completely. Both leaves of the gate were built of horizontally framed structural-steel weldments. The downstream leaf consists essentially of five main, horizontal plate girders with an upstream skin plate and downstream grating screens which allow aeration and entry of water on the downstream side. The main-girder web plates contain several 6- and 3-in.-diameter drain holes totaling about 11.1 sq ft of area. All girders of the downstream leaf have vertical girder-flange projections which extend 3 in. above the web plate on the downstream flange. Rubber seals are provided on each of the leaves.

4. Each leaf of the gate is suspended by wire ropes with multipart reeving on each side, and is raised and lowered by a single electrically driven hoist. The hoist arrangement is shown in plate 2. Only the downstream leaf is raised through flowing water; it effects a closure up to an elevation about 6 ft above normal upper pool elevation 420.† The downstream leaf has six 3-ft-diameter rollers mounted on each end. When used in conjunction with the upstream leaf, the downstream leaf can be raised to

---

* U. S. Army Engineer Waterways Experiment Station, CE, Emergency Gate, Greenup Locks, Ohio River, Kentucky; Hydraulic Model Investigation, Technical Report No. 2-527 (Vicksburg, Miss., October 1959).

** Model study results not yet published.

† All elevations herein are in feet referred to mean sea level.

a crest elevation of 443, the top of the lock wall, for closure. Trash screens and bulkhead panels are used to cover the gate recesses on each side of the lock and protect the gate sheaves and lifting wire rope from debris and damage by tows. These panels fit into guides in the lock walls and ride up and down on top of the gate leaves.

Uses for gate

5. Operation of the emergency gate with water flowing over its crest would be required for the following purposes:

a. To prevent loss of pool in event of accidental damage to one or both sets of miter gates from direct tow impact or other causes. Operating heads would be maximum under this condition.

b. To furnish additional waterway for floodflows. For this condition, both leaves of the emergency gate would first be raised, then both sets of miter gates would be opened, and lastly the emergency gate would be lowered. The operating head would be nominal for this condition.

c. To skim drift or ice from above the lock chamber. This is similar to condition b, except that the emergency gate would be lowered only a short distance, held there, and again raised when the drift had passed. The operating head for this function would be in the range of 5 to 6 ft maximum.

d. To provide the necessary flow to periodically scour the downstream lock approach. Operating heads would be substantial for this function.

Purpose and Scope of Tests

6. Model test results had indicated that uplift could not be entirely eliminated on the downstream leaf of the Greenup emergency gate. Because of the possibility of vibration resonance with some fluctuating hydraulic load, it was decided to investigate the performance of the prototype gate. Construction schedules resulted in the McAlpine emergency gate being the first of the type originally developed for the Greenup Lock to be available for testing. Accordingly, the construction contract for the new McAlpine main lock included performance tests of the emergency gate to determine the acceptability of the gate when operated under flowing-water conditions approximating those of an emergency.

7. The upstream leaf of the emergency gate remained in the lowered

position during the tests, and measurements were made on the downstream (moving) leaf only. Electronic measurements on the gate included vibration, gate position, and hoist-cable load. Hydraulic measurements included records of water levels in the upper pool, lower pool, and at two locations in the lock chamber, and velocities immediately upstream of the emergency gate. The hoist-cable load was analyzed to determine sheave and sliding-seal friction. The degree of conformity between the performances of the model and prototype gates was also investigated.

Test Series

8. The tests were begun on 19 August 1961. For the testing operation both leaves of the upper miter gate were opened and latched into their recesses. During the first test in flowing water, the miter-gate latches failed on the north, upstream miter-gate leaf. Failure occurred when the gate crest was about 3-1/2 ft above the sill (18 min after start of gate lowering). The gate swung out into the flow and reached fully mitered position in 5 to 10 sec (about 10 times normal gate speed), and was held there by the miter-gate sill and the operating linkage. The emergency gate was stopped, the lock-emptying valves were closed, and the lock quickly filled to pool level. Later inspection of the south miter-gate latches revealed that failure of these latches was also imminent. Therefore, testing was suspended until the upstream part of the lock could be dewatered, the upstream miter gate inspected, and latches repaired and strengthened. The tests were resumed on 30 October, and the strengthened latches were able to resist the unusually high hydraulic forces generated by emergency gate operation.

PART II: TEST EQUIPMENT

Electronic Instrumentation

9. The instrumentation for the tests furnished by the Waterways Experiment Station (WES) included dynamometers, accelerometers, linear-displacement gages, and amplifying and recording equipment. Figs. 3 and 4

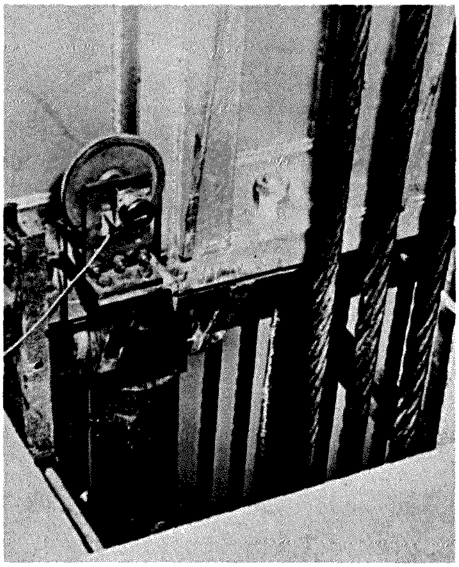


Fig. 3. Drive wheel of float tape and 360-deg potentiometer to measure gate position. Dynamometer in fall line is visible below potentiometer bracket

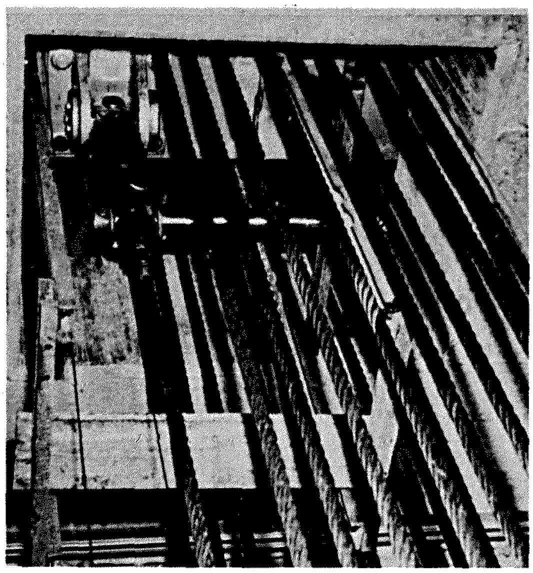


Fig. 4. Dynamometer assembly in fall line of wire rope reeving. Note anchored horizontal bar through clevis to prevent rotation of threaded connection

show a dynamometer and a displacement gage at one of the fall lines. A Baldwin 50,000-lb-capacity dynamometer* was installed at the dead end of the hoist cables at each end of the gate leaf to measure hoist loads (see plate 2). The dynamometer assemblies were inserted between the end of the hoist rope and its anchor which is connected to the bottom of the hoist-sheave beam. Special clevis and eye adapters for the dynamometers were made to fit the rope and anchor fittings. A heavy bar was inserted through the fall-line clevis and anchored to prevent rotation of the

* Mention of trade products or companies does not imply recommendation or indorsement.

threaded dynamometer connections by the twisted cable under varying loads.

10. Four Statham 5-g-capacity* accelerometers in waterproof boxes were fastened to heavy structural members inside the gate leaf, as shown in plate 2, to measure vertical vibration at each end and at the center of the gate as well as upstream-downstream vibration at the center. Protective conduits were provided for the lead cables inside the gate and were extended well above the water surface at the end of the gate. The gate was raised partially out of the water for installation of the accelerometers.

11. The linear-displacement gages were assembled using standard perforated float tape and 18-in.-circumference drive wheels for stage recorders (see fig. 3). These instruments were used to indicate gate position as the gate moved and any transverse slope of the gate. The tapes were connected to the tops of vertical pipes welded to the ends of the gate, and the wheel brackets were fastened to the top hoist-sheave supporting beams. A 360-deg potentiometer was attached to each drive-wheel shaft, and each 18-in. change in gate position caused the recorder trace to make a full pass across the chart. Dynamometers and accelerometers were calibrated prior to the tests; position indicators were calibrated using the known 18-in. displacement per revolution and the known gate elevation with the gate resting on the gate sill. Direct measurements of the gate-crest elevation also were made with the gate resting on the sill and in the damming position.

12. Signals from the two dynamometers, four accelerometers, and two potentiometers were amplified with Consolidated Electrodynamics Corporation (CEC) type 1-118 amplifiers. A CEC type 5-116 light-beam oscillograph was used in the August tests to record the signals. In the October tests, a CEC type 5-114 light-beam oscillograph was used. A cam-actuated, 1-sec timer was added for the October tests to give accurate values of elapsed time. However, the instrumentation for the October tests did not differ significantly from that for the tests in August.

Other Instrumentation

13. The upper pool elevation was measured by a temporary recording

* g = acceleration due to gravity = 386 in. per sec^2.

gage located on the upstream end of the pier between the auxiliary lock and the intermediate lock (see plate 1). The tailwater elevation was measured by a temporary recording gage placed about 20 ft downstream of the lower miter gate in the north-lock-wall ladder recess. A permanent staff gage in the north lock wall about 70 ft downstream of the lower miter gate was also used to measure tailwater elevation. Two temporary staff gages were placed in the lock chamber, one just below the upper miter gate and the other just above the lower miter gate (see plate 1), and the lock water-surface elevation was read from them with binoculars. During the August tests, a temporary recording gage was connected to a floating mooring bit located in the downstream end of the lock chamber, but was later removed as explained in paragraph 44.

14. Surges and waves in the lock chamber during the August tests caused large water-surface fluctuations, making the further use of a mechanical stage-recording gage unfeasible. Velocity measurements were made from the middle of the upstream side of the bascule bridge, approximately 50 ft upstream from the emergency gate (see fig. 2), by means of two current meters which were lowered to 0.2 and 0.8 of the initial depth and left there during the test. Photographic records of flow over the gate and other test phenomena were made with still and motion-picture cameras.

PART III: TEST PROCEDURES

15. The test procedure used to simulate an emergency condition in which the emergency gate would operate in flowing water was as follows:

a. At the start of testing, the downstream leaf of the emergency gate was in the damming position (gate crest slightly above the upper pool), and the lock-filling valves and lower miter gate were closed. The upstream leaf of the emergency gate was in the stored position resting on the sill pedestals, and it remained in that position. The lock-emptying valves and the upper miter gate were fully open and the water level inside the lock chamber was initially at lower pool level.

b. In the test, the downstream emergency-gate leaf was fully lowered until it rested on the gate sill, and then raised to its original damming position. Three full cycles of this procedure were required for acceptance of the gate, and were successfully completed in the test operation.

16. Prior to the flowing-water tests, several complete raising and lowering cycles were made in still water with the upper miter gate closed. The purposes of these tests were to evaluate sheave friction and to check the electronic recording system. During the flowing-water test operations, traffic through the other two locks was suspended and special safety precautions were observed to ensure protection against any unusual flow conditions. Interconnected phones were used for communcation between the various measuring points, and to ensure simultaneous starting of the measurements at all points.

17. The electronic instrumentation recorded continuously during all tests, beginning a few minutes prior to movement of the gate in both raising and lowering. While the gate was at the full-down position (on the sill), a few minutes were used to change oscillograph chart magazines.

18. The three complete test cycles were made on 30 October 1961. Essentially the same procedure was used in the August tests as in the October tests. However, the gate-slot trash screens were not installed at the time of the August test, but were in place for the October test sequences.

19. The upper pool at the beginning of test operations was at about elevation 420 (normal pool) for both the August and October tests. However, the pool elevation dropped about 2 ft below normal during gate lowering and

rose to about 1 ft above normal during gate raising. The lower pool was near normal (383), being 384.7 at the start of the August test and 384.2 for the first test in October. A slight rise of less than 1 ft occurred during the October test operations.

20. While the lower pool did not fluctuate significantly during the test operation, the lock-chamber water-surface level varied an appreciable amount. Plate 4 shows the variation during one of the test sequences. The lock water level at the start of gate lowering was about 385 and increased during the test operation to a maximum of 414. In the gate positions at which model studies indicated maximum uplift to occur (2 to 5 ft above sill), the prototype head differential was about 5 ft during gate raising and approximately 18 ft during gate lowering. Model studies of this gate showed maximum uplift forces occurring usually at low heads, and maximum downpull at high heads across the gate. Thus, the head differentials in the prototype test operation probably produced the highest gate uplift, as well as downpull forces, that could occur.

PART IV: ANALYSIS OF TEST RESULTS, AND DISCUSSION

Stillwater Tests

Sheave-friction analysis

21. An analysis was made of forces acting on the downstream-leaf emergency-gate hoist in order to determine from the dynamometer measurements the total load on the hoist. Fig. 5 shows the forces acting on the hoist. The effect of sheave and cable friction on the dynamometer measurements is assumed to be principally concentrated in the 17 sheaves of the fixed- and gate-sheave assemblies at each end of the gate.

22. When the downstream leaf is raised in still water, sheave friction will cause the tension in the dynamometer-equipped fall line (T_{18}) to be smaller than the line T_1 which goes to the hoist drum. Conversely, when the gate is lowered the tension in T_{18} will be greater than that in T_1. Without sheave friction the total load would be evenly distributed among the sheaves and cables. The effects of hydrodynamic forces, side-seal friction, and reaction-roller friction are assumed to be negligible because of the slow gate speed and zero head differential across the gate for stillwater operation. The ratio of tensions in the fall line in raising and lowering gives an indication of the sheave and cable friction.

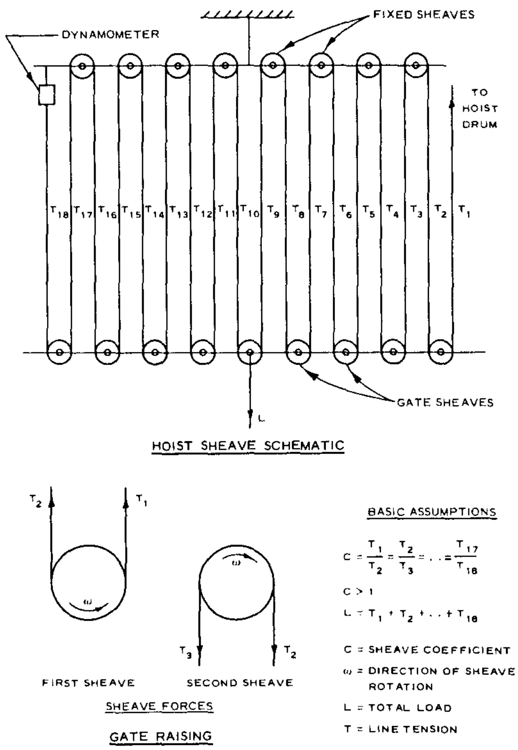


Fig. 5. Hoist forces

23. The analysis procedure for sheave and cable friction is shown in fig. 5. The results are derived in detail below for the gate-raising operation. Forces on each side of an individual sheave were assumed to be proportional to each other, i.e.

$$\frac{T_1}{T_2} = \frac{T_2}{T_3} = \cdot \cdot \cdot = \frac{T_{17}}{T_{18}} = C$$

where C (the sheave coefficient) is greater than 1. The ratio of forces in the second sheave

$$\frac{T_2}{T_3} = C$$

gives

$$T_3 = \frac{T_2}{C} = \frac{1}{C} \cdot \frac{T_1}{C} = \frac{T_1}{C^2}$$

or

$$\frac{T_3}{T_1} = \frac{1}{C^2}$$

Similarly, for 17 sheaves the ratio is

$$\frac{T_{18}}{T_1} = \frac{1}{C^{17}}$$

The total load L will be the sum of the cable tensions,

$$L = T_1 + T_2 + T_3 + \cdot \cdot \cdot + T_{18}$$

or

$$L = \frac{T_1}{C^0} + \frac{T_1}{C^1} + \frac{T_1}{C^2} + \cdot \cdot \cdot + \frac{T_1}{C^{17}}$$

therefore

$$\frac{L}{T_1} = \frac{1}{C^0} + \frac{1}{C^1} + \frac{1}{C^2} + \cdot \cdot \cdot + \frac{1}{C^{17}} = \sum_{n=1}^{n=18} \frac{1}{C^{n-1}}$$

This geometric series can be evaluated as

$$\frac{L}{T_1} = \sum_{n=1}^{n=18} \frac{1}{C^{n-1}} = \frac{C^{18} - 1}{C^{17}\,(C - 1)}$$

consequently

$$\frac{T_1}{L} = \frac{C^{17}\,(C - 1)}{C^{18} - 1}$$

By means of the previously derived ratio

$$\frac{T_{18}}{T_1} = \frac{1}{C^{17}}$$

the ratio of tension in the fall line to the total load can be computed as

$$\frac{T_{18}}{L} = \frac{C - 1}{C^{18} - 1}$$

A similar analysis for the gate-lowering operation will give the following results:

$$\frac{T_{18}}{T_1} = C^{17}$$

$$\frac{T_{18}}{L} = \frac{C^{17}\,(C - 1)}{C^{18} - 1}$$

$$\frac{T_1}{L} = \frac{C - 1}{C^{18} - 1}$$

The ratio of T_{18}/L for raising and lowering gives

$$\frac{T_{18}\ (\text{raising})}{T_{18}\ (\text{lowering})} = \frac{1}{C^{17}}$$

<u>Gate loads</u>

24. Dynamometer loads were scaled from the oscillograph records for the third stillwater test made on 28 October. Individual measurements

were very close to the following averages of the load readings:

Gate End	Gate Movement	Avg T_{18} kips
North	Lowering	17.6
North	Raising	9.3
South	Lowering	16.5
South	Raising	9.0

The differences between the north and south ends may have been due to uneven gate-weight distribution or sheave friction. These values were used in computing sheave friction by the procedures shown in the preceding paragraph. The resulting coefficient C for sheave and cable friction is 1.0362 for the south end and 1.0382 for the north end of the gate.

25. The total load (L) when the gate is being lowered (ℓ) or raised (r) can be computed by using the north (N) and south (S) end dynamometer measurements and the following equations:

$$\text{Lowering:}\quad L_\ell = \left[\frac{T_{18}}{\dfrac{C^{17}(C-1)}{C^{18}-1}}\right]_N + \left[\frac{T_{18}}{\dfrac{C^{17}(C-1)}{C^{18}-1}}\right]_S = \frac{T_{18\ N\ell}}{0.0748} + \frac{T_{18\ S\ell}}{0.0738}$$

$$\text{Raising:}\quad L_r = \left[\frac{T_{18}}{\dfrac{C-1}{C^{18}-1}}\right]_N + \left[\frac{T_{18}}{\dfrac{C-1}{C^{18}-1}}\right]_S = \frac{T_{18\ Nr}}{0.0395} + \frac{T_{18\ Sr}}{0.0403}$$

The total load in stillwater gate operation is essentially the submerged gate weight (W_s) and can be computed for the gate-lowering operation as

$$W_s = \frac{17{,}600}{0.0748} + \frac{16{,}500}{0.0738} = 459 \text{ kips}$$

26. The dry weight of the gate can also be computed by noting that

$$W_d = \frac{W_s}{1 + \dfrac{\gamma_w}{\gamma_s}}$$

where

W_d = dry weight of gate, kips

γ_w = unit weight of water = 62.4 lb per cu ft

γ_s = unit weight of steel = 490 lb per cu ft

The computed dry weight of 527 kips is very close to the 531 kips used for design, and the agreement between these two values helps to substantiate the method of computing total gate loads by using the dynamometer-measured fall-line tensions.

Hoist efficiency

27. A value used to describe the effect of sheave friction is the hoist efficiency E , which is derived as follows:

$$E = \frac{1}{n} \cdot \frac{L}{T_{max}}$$

where

n = number of cables

L = total load

T_{max} = maximum cable tension

For the 18 hoist cables of the McAlpine gate, the efficiency is related to the sheave coefficient by

$$E = \frac{1}{18} \cdot \frac{(C^{18} - 1)}{C^{17}\ (C - 1)}$$

From the test results, efficiencies of 75.3 and 74.3 percent were computed for the south and north end hoists, respectively. The fixed sheaves in the hoist system have roller bearings, and the gate sheaves have lubricated bronze bearings. The maximum cable tension is assumed to be limited to the tension occurring in the 18 cables of the gate hoist. Higher tension would be obtained at the hoist drums due to friction in the several idler and deflection sheaves (see plate 2).

Gate vibration

28. Records of starting and stopping transients indicated smooth operation with very low acceleration. Very low vertical vibration occurred during the gate-raising operation in still water, the maximum being about 0.0025 g at 11.7 cps (one-half of peak-to-peak readings). This maximum vibration produced a vertical gate displacement of ± 0.0002 in. from the

mean position. Generally the north and south accelerometers were in phase when any vibration occurred. From a gate position of 4 ft to about 15 ft above the sill, no significant vibrations occurred. Negligible vertical and horizontal vibration was indicated by the two accelerometers located at the center of the gate.

29. Discernible vibration in gate lowering in still water occurred only for gate positions higher than about 14 ft above the sill. Maximum acceleration was about 0.006 g at 1.4 cps, giving a displacement of ± 0.03 in. Frequencies of gate vibration were generally 1.4 and 3.0 cps or superpositions of those frequencies. A study of the oscillograms indicated that the lower frequency was associated with vertical motion and the higher frequency with rocking motion. This was determined from the phase differences among the three accelerometers measuring vertical vibration. Horizontal vibrations were very low throughout the gate lowering.

Natural frequency

30. The natural frequency of the gate in air was computed by means of formulas given in standard texts on vibration analysis.* The gate was assumed to be a single-degree-of-freedom system that might vibrate vertically on the 36-part hoist or rock about the gate center of rotation on the two 18-part hoists. The dry weight of the gate (531 kips) and a modulus of elasticity of 11.2×10^6 psi for the new wire rope were used to determine the following natural frequencies:

Gate Height Above Sill ft	Natural Frequency, cps	
	Vertical Motion	Rocking Motion
0	2.7	4.8
10	2.9	5.2
20	3.2	5.7

The tabulated values show little variation of natural frequency with gate height. The effect of submergence cannot be readily determined due to the varying degrees of submergence during the flowing-water tests.

31. It is believed that the observed 1.4- and 3.0-cps frequencies may be the natural frequencies of the gate, since they were the most

* C. R. Freberg and E. N. Kemler, Elements of Mechanical Vibration, John Wiley and Sons, Inc. (New York, N. Y., 1949).

predominant frequencies in the stillwater test oscillograms. The approximate 50 percent difference between the computed and observed frequencies is attributed to the mass of water that is accelerated as the gate vibrates.

Cable motion

32. Operation of the gate under stillwater conditions appeared to be relatively smooth. However, the hoist cables were observed to have a jerky motion of about 2 cps. The closer the individual cables were to the fall line across the hoist, the smaller the motion. This behavior had occurred when the gates were installed, but operation became smoother as the cable stretch was equalized with successive operations. It is believed that the jerky motion of the hoist cables is due to "slipping-sticking" action of the hoist sheaves resulting from the very low rotational speeds involved. Motion of the hoist drum was relatively smooth.

Flowing-Water Tests

33. Essentially the same procedure was used in the three tests made with flow over the gate, and the data did not differ significantly in magnitudes or patterns between tests. The third test sequence will be used for detailed analysis because the best oscillogram was obtained and most of the photographs were taken during this test. Emergency-gate dynamometer and gate-height data recorded during this test are shown in table 1. Water-surface elevations recorded during the three tests are given in table 2, supplementary hydraulic data in table 3, and gate hoist power measurements in table 4. Plate 3 presents part of a test oscillogram.

Gate loads

34. The north dynamometer generally measured higher loads than the south dynamometer up to a maximum value of 2 kips. The peak dynamometer load occurred during gate lowering when the gate was about 15 ft above the sill. Peak dynamometer loads in lowering were slightly lower in the October tests (30 kips) than in the August tests (31.5 kips). The August test data showed no significant effect on the gate load as a result of a miter-gate latch failure (see paragraph 8). Maximum dynamometer load fluctuations of about ±2500 lb occurred between the 2- and 3-ft gate positions while the gate was being lowered.

35. In both the August and October tests, the north end of the gate

was about 0.1 ft lower than the south end during gate lowering. Approximately the same difference was observed during gate raising, although a maximum difference of 0.2 ft occurred. Precise level measurements made with the gate stopped in the damming position indicated a higher gate level at the north end by about 0.04 ft. Average gate speeds were 0.77 ft per min in raising and 0.82 ft per min in lowering.

36. From the data in table 1, values of total load were computed using the equations given in paragraph 25. The results are shown in plate 4. No attempt was made to eliminate sliding and reaction-roller friction because of variations in flow conditions in raising and lowering. These variations were caused by the differences in lock water levels as shown in plate 4. The plotted total loads for gate raising and lowering include the varying effects of submerged or dry gate weight, hydraulic forces, and seal and reaction-roller friction, but not hoist-sheave friction. Also plotted are data obtained in a model study* of the McAlpine emergency gate. Prototype peak total forces were about 900 kips in gate raising and about 800 kips in gate lowering. Model results obtained with a stationary gate indicated about 760 kips peak total force. Since seal and reaction-roller friction forces in the prototype act to increase the hoist load in raising the gate leaf and to decrease it in lowering, the prototype average peak load of 850 kips should be more directly comparable to the stationary model gate loads. The higher prototype results may be due to higher seal and reaction-roller friction or difference in prototype construction from that tested in the model. The model tests of the adopted design were made without the 3-in. girder-flange projections which were included in the prototype. The variation in lock water-surface elevation shown in plate 4 may also have contributed to the differences in the model and prototype results.

37. At gate crest heights more than 15 ft above the sill, the lock levels were below the gate and the difference in gate raising and gate lowering loads should be principally due to the effect of seal sliding and reaction-roller friction. The data indicate little deviation from an average difference of 210 kips for gate positions between 16.5 and 18.5 ft. However, the upper pool levels generally were about 1 ft higher at the end

---

* Report of model study not yet published.

of the test cycles (gate raising completed) than at the beginning (gate lowering started). The higher pool would cause increased hydrostatic pressures and the friction force would be correspondingly higher. Assuming the gate crest at 17 ft above the sill and initial and final pool elevations of 420 and 421, respectively, the corresponding hydrostatic loads on the 17- by 110-ft area would be 1008 and 1205 kips. The resulting seal and roller-friction factor would be about 0.095.

38. Peak uplift occurred during gate lowering at a gate position about 3 ft above the sill. This compares favorably with model results, as shown in plate 4. At this gate position the lock water level was about elevation 401 which gave a head across the gate of about 18 ft. This result agrees with the model results which indicated maximum uplift forces with the lock water level approximately at the sill elevation.

Gate vibration

39. Vibrations during the starting and stopping transients were very low in magnitude and indicated smooth gate operation. Vibrations during the flowing-water tests were also low in magnitude and did not indicate gate instability by a tendency to increase. Generally, the random nature of the vibrations increased as the flow over the gate increased. A pattern of vertical vibrations similar to that noted for the stillwater test was observed in gate lowering from 19 to 14 ft above the sill. In this case the rocking motion was 5.6 cps when the north and south accelerometers were out of phase with each other. Maximum measured vertical acceleration was about 0.025 g, giving a displacement of ± 0.008 in. This occurred when the gate was between 19 and 17 ft above the sill. Accelerations of about 0.025 g at 2.8 cps were measured when the north and south accelerometers were in phase, giving displacements of ± 0.025 in. This pattern occurred at a gate height of about 16.5 ft, but decreased in magnitude as the gate was lowered further. At a gate height of 15.5 ft, the previous pattern with a frequency of 2.8 cps was again observed. As the flow over the gate increased, higher frequency components of the vibration increased greatly, making it difficult to distinguish the more important lower frequencies.

40. At a gate height of about 16.3 ft, the horizontal accelerometer amplitude increased to a maximum of about 0.03 g at 6.8 cps, which would produce a displacement of ± 0.006 in. This vibration became small at gate

heights of about 15.5 ft. Starting at a gate height of 14 ft, the horizontal accelerometer again indicated a strong periodicity at a frequency of 3.2 cps. The maximum measured acceleration was 0.035 g, which would produce a displacement of ± 0.033 in. This pattern of horizontal vibration persisted until the gate reached a height of about 12 ft, when it decreased in amplitude and the periodicities became increasingly masked by higher frequency components.

41. No significant, sustained periodicities in gate vibration were discerned as the gate was lowered from about 12 ft. Starting at about 6 ft, a mild shock phenomenon was recorded by the accelerometer measuring vertical vibration at the gate center. This occurred at irregular intervals to about 2 ft. Maximum vibration due to this phenomenon was about 0.10 g at high frequencies of about 70 cps. Shocks of this type also were indicated by the accelerometer measuring horizontal vibration, but they were much smaller in magnitude. None of the other measuring devices indicated similar effects. No clear periodicities could be discerned on the accelerometer records. However, at gate positions of maximum uplift (about 2 to 3 ft) the displacement gages indicated fluctuations up to about ± 0.1 in. from the average. Plate 3 shows a part of the test oscillogram at a gate position near maximum uplift.

42. At the beginning of gate raising, vibrations were very low in magnitude and were of high frequency. At a gate height of about 2 ft, accelerations increased to about 0.05 g at frequencies of 60 cps. At 5 ft, vibration again decreased to smaller magnitudes. Significant vibrations did not occur again until the gate was at about 7 ft, when vertical vibration at the center of the gate was about 0.005 g at a frequency of 1.6 cps. This would cause a displacement of about ± 0.02 in. However, only about 10 cycles of sustained vibration occurred. From 7 to 9 ft, vibrations were low in magnitude and no sustained periodicity was observed. From 9 to 12 ft, a mild shock phenomenon was observed in the accelerometer measuring vertical vibration at the gate center. Magnitudes of acceleration were about the same as observed in gate lowering when similar shocks were noted. Gate vibration for the rest of the raising operation was similar in pattern to that during the lowering operation. As observed in gate lowering, periodicities were more distinct as the flow over the gate decreased.

Amplitudes of vibration were of the same order of magnitude as those of the gate-lowering operation.

Visual Observations of Flow Conditions

Gate lowering

43. Some leakage was noted with the downstream leaf in the damming position prior to beginning test operation with a head differential of about 36 ft. There was no seal between the upstream and downstream leaves. As flow began over the gate crest, the overflow nappe struck the web of the top girder, then proceeded over the 3-in. flange offset and into the lock chamber. Fig. 6 shows flow conditions at the beginning of overflow. The

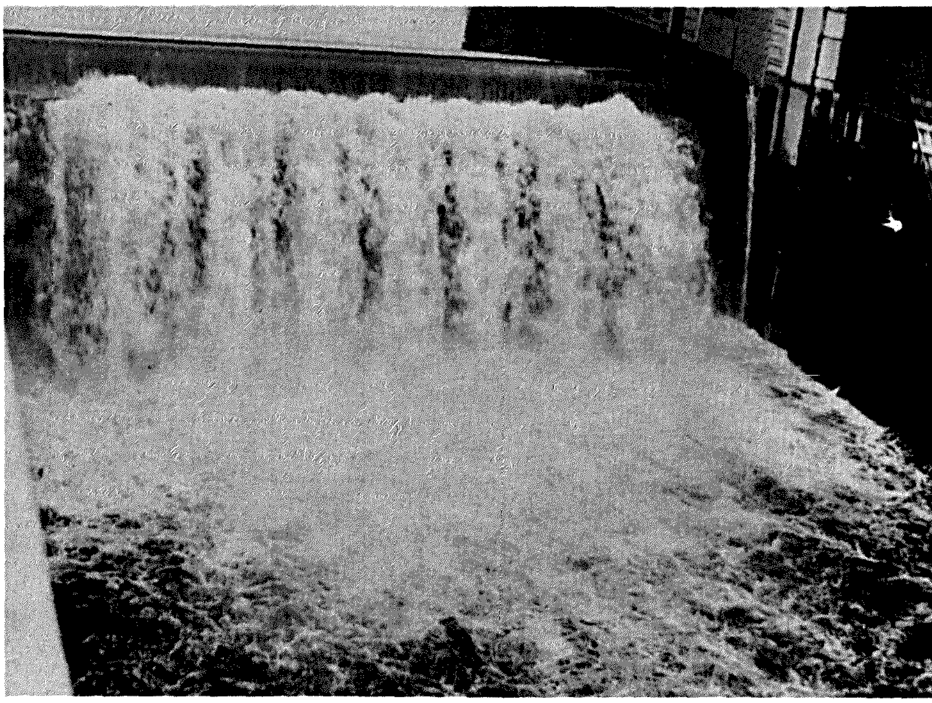


Fig. 6. Flow over gate during gate lowering. Gate crest about 16 ft above sill. Maximum downpull occurred at this condition

girder drain holes were probably not sufficient to drain all of the overflow. As the gate was further lowered and the overflow increased, the overflow nappe began to clear the girder top, progressing from the ends, where the girder is tapered, toward the gate center. When the gate crest was about 13 ft above the sill, the overflow nappe appeared to have cleared the downstream edge of the top girder flange. The overflow at this stage

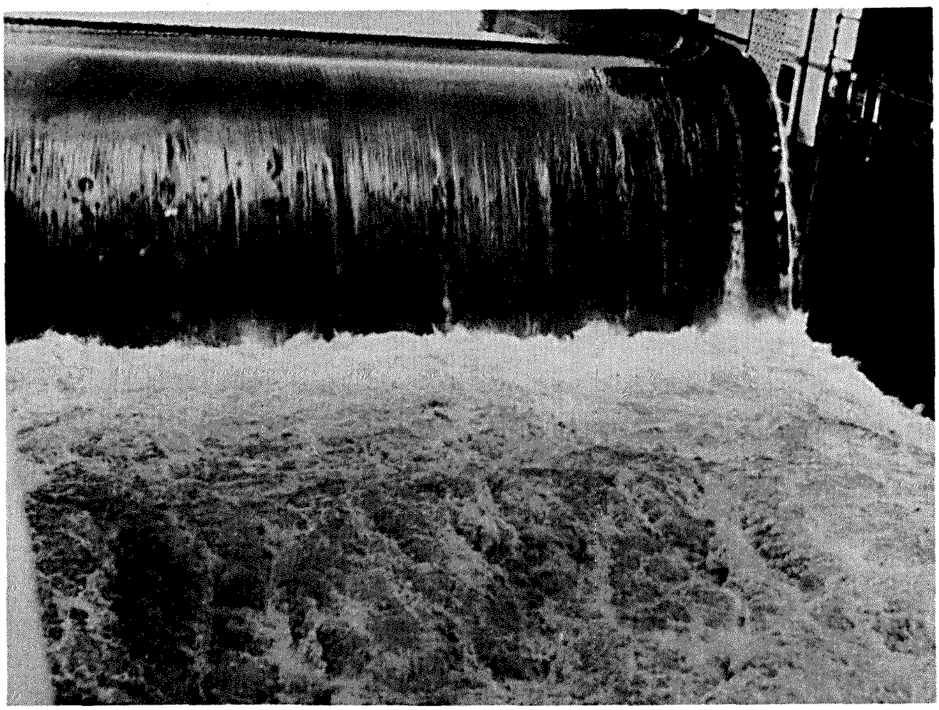


Fig. 7. Flow over gate during gate lowering. Gate crest about 12 ft above sill

is shown in fig. 7. As the gate was lowered further, the overflow nappe was less discernible as the lock water surface rose.

44. Flow into the lock chamber at the beginning of gate lowering was much like a frayed, vertically dropping jet. Turbulence was restricted to a short distance downstream of the gate. As overflow increased, a rough hydraulic jump formed downstream of the plunging jet, starting when the gate crest was about 11 ft above the sill. The jump extended downstream to the upstream miter-gate pintles. As the lock water level increased, flow into the lock approached a drowned hydraulic jump with a plunging jet (see fig. 8), producing a violent condition. When the gate crest was about 3 ft above the sill, the entire lock chamber was covered with choppy waves (see fig. 9). Waves up to 5 ft in height were measured during the August tests by means of a temporary recording gage attached to a floating mooring bit located in the downstream end of the lock chamber. This gage, however, had to be disconnected from the mooring bit about midway through the tests in order to prevent the rapid vertical oscillations of the bit from damaging the recorder. These surface waves in the lock chamber abated somewhat as

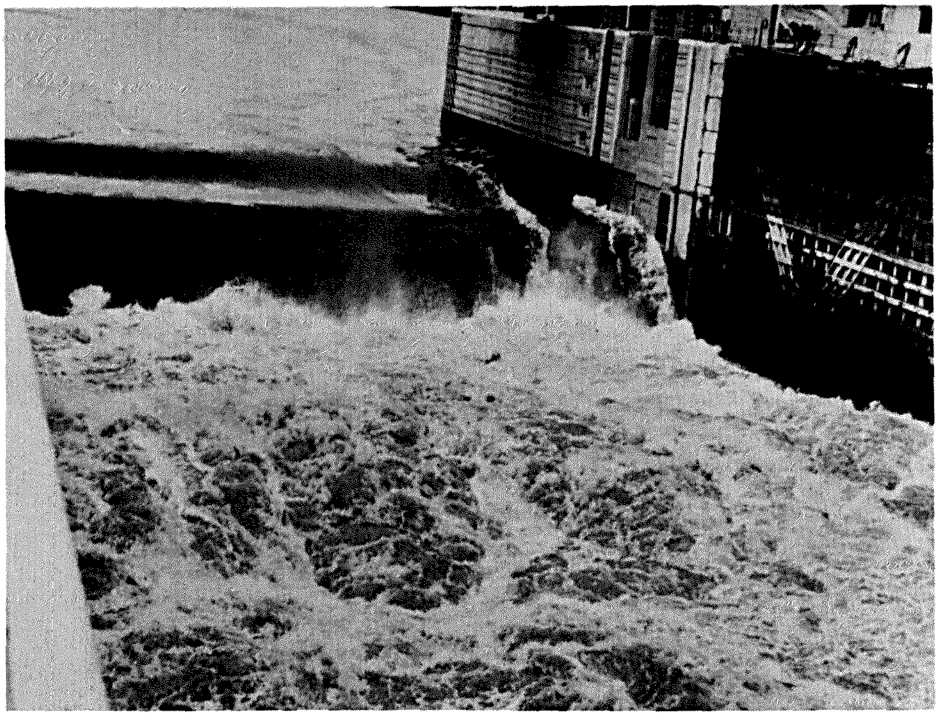


Fig. 8. Flow over gate during gate lowering. Gate crest about 3-1/2 ft above sill. Maximum uplift occurred at this condition. Note separation along guide wall at right

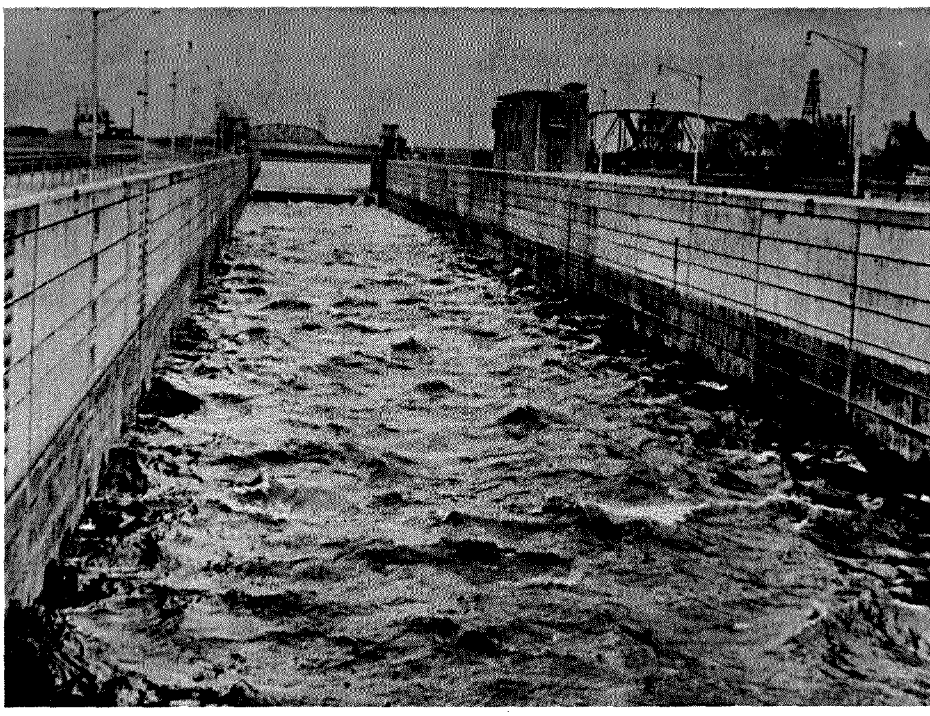


Fig. 9. Flow in lock chamber while gate was being lowered. Gate crest about 3 ft above sill. Wave heights up to about 5 ft

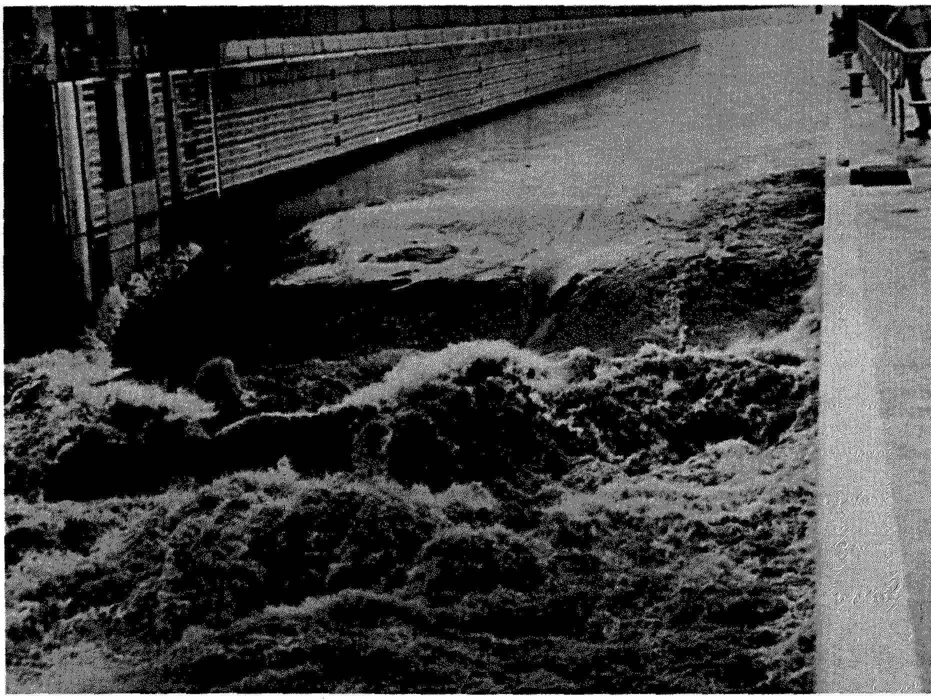


Fig. 10. Flow over gate at full-down position. Gate crest at sill. Note separation along guide wall at right

the gate was further lowered. When the gate reached full-down position (crest at elevation 402), a wavy type of surface disturbance was observed. This undular type of hydraulic jump maintained a relatively steady position downstream of the gate. Fig. 10 shows flow conditions with the gate at full-down position.

45. As the flow over the gate increased, flow separation around the upstream south guide wall increased in severity and size. At the gate full-down position, the zone extended to about one-half the lock width (see figs. 7 and 10).

Gate raising

46. Flow conditions appeared to be smoother for gate raising than for gate lowering, especially for gate positions of 8 ft and less (compare figs. 8 and 11). This was probably due to the lock water surface being several feet higher during the gate raising as compared to gate lowering at equal gate positions. As the lock water level decreased, flow conditions appeared similar to gate lowering conditions.

Other observations

47. In the August tests without the trash screens, turbulence in the

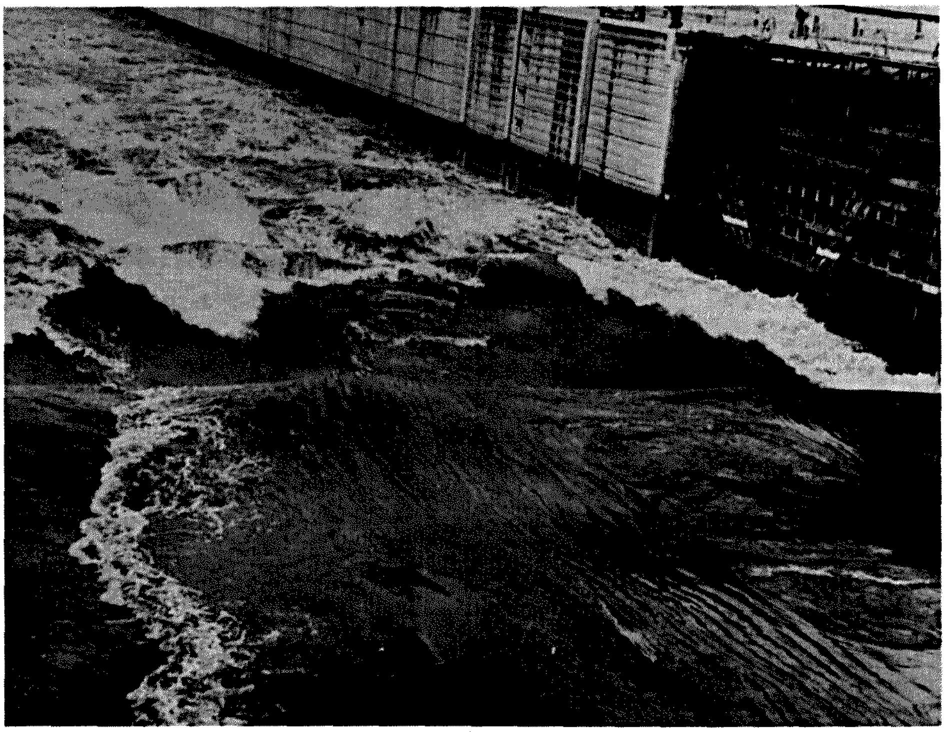


Fig. 11. Flow over gate during gate raising. Gate crest about 2-1/2 ft above sill

emergency gate slots appeared severe. The trash screens were in place for the October tests and little turbulence was noted, although jets of water spurted into the slots through the ~~holes in the trash screens~~. No vibration of the gate could be detected by visual observations of the gate and position-indicator tapes. The jerky hoist-cable motion observed during the stillwater tests persisted for the flowing-water test. After the August test series, the chamber floor was dewatered between the miter- and emergency-gate sills. Some loose rock had accumulated between the pedestals under the upstream leaf, and minor erosion of the rock floor had occurred.

Lock overfilling surges

48. After completion of the third test cycle, the emergency gate was raised a few feet above the minimum damming position, the emptying valves were closed, and the filling valves were opened wide. Filling time was not measured, but appeared to be rapid. No turbulence was observed in the lock chamber. A minor vortex appeared for a time at the south entrance manifold. After the chamber was filled, the following succession of concurrent stages

39912

was noted in the chamber and in the pool just above the gate: 421.0 in chamber, and 419.3 in pool; 421.4 in chamber, and 419.7 in pool; and 421.0 in chamber, and 419.7 in pool. The maximum upstream head on the gate was thus about 1.7 ft. From the standpoint of overfilling surges, the operation differed considerably from normal lock filling. The preceding emergency gate tests had induced extensive surging in the lock approaches, producing an upper pool at elevation 419.3 at time of maximum head differential. The upper pool during normal lock filling seldom drops below about elevation 419.8, causing a maximum reverse head differential of about 1.2 ft. These tests also differed from normal operation in that there was a slightly larger volume of chamber to be filled between the miter gates and emergency gate and also small additional inflow from leakage between the two leaves of the emergency gate.

PART V: CONCLUSIONS

49. From the analyses of the test results, the following conclusions are believed warranted:

- a. Stability of the prototype emergency gate against uplift forces was very good at all operating conditions. Maximum recorded vibration was of very low magnitude, producing about 0.1-in. vertical displacement. No elastic resonance with any fluctuating hydraulic load was observed.
- b. Observations of prototype flow conditions indicated close agreement with model results. Flow hit the emergency-gate top girder at low heads, and a roller formed in the lock at higher heads.
- c. Total loads on the emergency gate hoist were somewhat higher in the prototype than in the model; the difference may have been due to differences in model and prototype construction or higher seal and reaction-roller friction in the prototype. A maximum total load of about 850 kips (average of peak loads in raising and lowering) was measured on the prototype emergency gate as compared with 760 kips measured in the stationary model. A peak load of about 900 kips was measured in raising.
- d. Loads at each end of the emergency gate were nearly equal during the test operations; the north end of the gate was about 0.1 ft lower than the south end. Gate speeds averaged about 0.77 ft per min in raising and about 0.82 ft per min in lowering.
- e. Performance of the McAlpine lock emergency gate under flowing-water conditions was considered satisfactory.

Table 1

Flowing-Water Tests

Emergency Gate Loads and Position

	October Test 3								August Test			
	Gate Raising				Gate Lowering				Gate Lowering			
	Gate Height ft		Dynamometer Measurements kips		Gate Height ft		Dynamometer Measurements kips		Gate Height ft		Dynamometer Measurements kips	
Time min:sec*	North End	South End	North End	South End	North End	South End	North End	South End	North End	South End	North End	South End
0:00	0.00	0.00	0.0	0.0	18.92	18.99	13.3	12.0	18.39	18.51	13.3	13.8
1:00	0.49	0.63	11.0	10.0	18.09	18.16	20.2	19.3	17.56	17.65	21.8	21.3
2:00	1.29	1.40	11.0	10.0	17.20	17.30	23.0	21.8	16.67	16.79	26.9	26.3
3:00	2.07	2.13	11.0	9.5	16.35	16.43	27.0	26.4	15.86	15.94	29.7	29.1
4:00	2.87	2.99	10.5	9.5	15.50	15.59	29.5	28.4	15.03	15.13	31.8	31.3
5:00	3.73	3.78	10.5	9.3	14.66	14.75	29.9	29.5	14.19	14.28	31.6	31.3
6:00	4.44	4.56	10.5	9.5	13.83	13.91	28.7	28.2	13.38	13.49	30.4	30.6
7:00	5.22	5.35	10.5	9.5	13.00	13.09	27.5	27.0	12.56	12.67	26.4	26.2
8:00	6.01	6.13	10.5	9.5	12.17	12.26	23.9	23.5	11.76	11.87	25.3	25.2
9:00	6.79	6.91	10.7	9.1	11.36	11.45	23.6	22.8	10.93	11.04	25.5	25.2
10:00	7.58	7.71	10.3	9.2	10.54	10.64	23.4	21.5	10.13	10.24	25.5	24.0
11:00	8.36	8.47	12.0	11.0	9.71	9.80	22.4	20.6	9.28	9.43	24.6	23.0
12:00	9.12	9.23	14.5	12.8	8.88	8.98	21.6	19.9	8.53	8.63	24.1	23.0
13:00	9.87	9.98	15.0	13.0	8.05	8.16	22.0	20.0	7.69	7.82	24.1	23.2
14:00	10.62	10.74	16.5	14.7	7.23	7.32	22.0	21.2	6.89	6.99	24.2	24.0
15:00	11.42	11.52	14.0	13.0	6.38	6.49	21.8	22.0	6.05	6.09	23.2	22.8
16:00	12.20	12.31	13.8	12.5	5.56	5.66	22.1	21.7	5.27	5.23	23.2	22.8
17:00	12.97	13.08	14.5	12.9	4.73	4.82	21.9	21.4	4.46	4.45	23.4	23.2
18:00	13.70	13.86	14.5	13.0	3.99	3.88	21.6	21.3	3.67	3.63	18.0	18.8
18:20	---	---	--	--	---	---	--	--	3.38	3.36	17.6	19.8
18:30	---	---	--	--	---	---	--	--	3.41	3.37	14.3	17.4
19:00	14.46	14.59	17.5	16.0	3.19	3.08	17.5	16.8	3.41	3.37	13.8	15.9
20:00	15.21	15.35	18.5	16.8	2.35	2.24	20.0	19.5	3.41	3.37	12.9	13.7
21:00	15.95	16.11	18.8	17.1	1.50	1.39	20.6	20.6	3.41	3.37	12.7	12.9
22:00	16.72	16.84	18.5	16.7	0.67	0.56	21.0	20.8	3.41	3.37	13.3	12.7
23:00	17.42	17.64	16.2	15.5	---	---	--	--	3.41	3.37	13.6	12.5
23:05	---	---	--	--	0.00	0.00	0.0	0.0				
24:00	18.62	18.42	15.0	14.2								
24:45	19.25	19.03	13.5	12.5								

* After start of gate movement.

Table 2

Flowing-Water Tests

Water-Surface Elevations

Time min:sec*	Test 1 Upper Pool	Test 1 Upper End Lock Chamber	Test 1 Lower End Lock Chamber	Test 1 Lower Pool	Test 2 Upper Pool	Test 2 Upper End Lock Chamber	Test 2 Lower End Lock Chamber	Test 2 Lower Pool	Test 3** Upper End Lock Chamber
					Gate Lowering				
0:00	---	---	---	---	---	385.0	---	---	---
0:40	419.7	384.0	---	---	---	---	---	---	---
1:00	419.4	384.8	384.9	384.2	---	---	---	---	---
1:20	---	---	---	---	420.8	385.0	384.9	384.7	---
1:30	---	---	---	---	---	---	---	---	385.0
2:00	419.3	385.0	384.9	384.4	420.8	385.0	384.9	384.7	---
3:00	419.3	385.0	385.2	384.4	420.8	385.0	385.2	384.7	385.0
4:00	419.2	385.5	385.3	384.5	420.8	385.5	385.5	384.7	385.5
5:00	419.1	385.5	385.6	384.6	420.8	386.0-	385.8	384.8	385.5
6:00	418.9	386.0	385.9	384.6	420.8	386.0	386.2	384.8	386.0
7:00	418.7	387.0	386.6	384.6	420.9	386.5	386.7	384.8	386.0
8:00	418.6	387.0	387.2	384.6	420.8	387.0	387.3	384.8	386.5
9:00	418.5	388.0	387.8	384.5	420.7	388.0	387.9	384.9	387.0
10:00	418.4	389.0	388.5	384.5	420.6	388.5	388.6	384.9	388.0
11:00	418.4	390.0	389.5	384.5	420.5	390.0	389.5	384.8	388.0
12:00	418.3	391.0	390.5	384.5	420.4	391.0	390.6	384.9	390.0
13:00	418.3	392.5	391.6	384.5	420.3	392.0	391.8	384.9	391.0
14:00	418.2	394.0	393.1	384.6	420.2	394.0	393.1	384.9	393.0
15:00	418.2	396.0	394.9	384.6	420.0	394.0	394.9	385.0	394.0
16:00	418.2	398.0	397.0	384.5	419.8	396.0	396.4	385.0	394.0
17:00	418.2	399.0	398.5	384.6	419.6	398.0	398.1	384.9	397.0
18:00	418.2	401.0	401.0	384.6	419.3	399.0+	400.2	384.8	399.0
19:00	418.2	404.0	403.6	384.6	419.1	402.0	402.0	384.8	401.0
20:00	418.3	406.0	406.4	384.6	418.9	404.0	404.0	384.8	404.0
21:00	418.3	407.0	407.6	384.7	418.7	405.0	406.0	384.8	406.0
22:00	418.4	409.0	408.8	384.6	418.6	407.0	407.6	384.9	407.0
23:00	---	---	---	---	418.6	409.0	408.8	385.0	407.5
23:05	---	---	---	---	---	---	---	---	407.5
					Gate Raising				
23:20	418.6	409.0+	410.4	384.7	---	---	---	---	---
24:00	418.7	410.0	411.8	384.7	---	---	---	---	---
24:55	---	---	---	---	---	---	---	---	407.5
25:00	418.8	412.0	412.6	384.7	---	---	---	---	---
25:55	---	---	---	---	418.6	409.0	411.9	385.0	---
26:00	418.9	411.0	413.0	384.8	---	---	---	---	410.0
27:00	419.1	412.0	413.3	384.7	418.7	411.0	412.7	385.0	411.0
28:00	419.2	412.5	413.5	384.8	418.8	411.0	413.1	385.0	412.0
29:00	419.4	412.0	413.6	384.8	418.8	412.0	413.6	385.1	412.0-
30:00	419.5	411.0+	413.2	384.8	418.9	412.0	414.1	385.0	412.0
31:00	419.7	410.0	412.4	384.8	419.0	411.0	413.8	385.0	412.0
32:00	419.8	410.0	411.2	384.8	419.1	411.0	412.9	385.0	411.0
33:00	419.9	409.0-	410.3	384.8	419.2	411.0	412.0	385.0	410.0
34:00	420.1	407.5	408.5	384.8	419.5	410.0	410.8	385.0	409.0
35:00	420.2	405.0	407.2	384.8	419.7	409.0	409.8	385.0	408.5
36:00	420.3	403.5	405.4	384.8	419.8	408.0	408.4	385.0	407.0
37:00	420.4	402.0	403.4	384.8	420.0	406.5	407.2	385.1	406.0-
38:00	420.5	399.5	401.6	384.8	420.1	405.0	405.4	385.1	404.0
39:00	420.5	397.0	399.3	384.9	420.3	403.0	403.4	385.1	402.0
40:00	420.6	395.0	397.2	384.9	420.4	401.0	401.4	385.2	400.0
41:00	420.6	393.0	395.0	385.0	420.6	399.0-	398.9	385.1	397.0
42:00	420.6	391.0	392.8	385.0	420.7	396.0	397.0	385.2	395.0
43:00	420.7	389.0	391.0	385.0	420.9	394.0	394.4	385.1	393.0
44:00	420.7	388.0	388.9	385.0	421.1	392.0	392.7	385.2	391.0
45:00	420.6	386.0	387.5	385.0	421.2	390.0	390.3	385.1	389.0
46:00	420.5	385.5	386.3	384.9	421.3	388.0	388.4	385.2	387.0
47:00	420.5	384.5	385.5	384.8	421.4	387.0	387.1	385.2	386.0
47:15	420.5	384.5	384.8	384.8	---	---	---	---	---
48:00	---	---	---	---	421.5	386.0	386.0	385.2	385.0
49:00	---	---	---	---	421.6	385.0	385.2	385.2	385.0
49:05	---	---	---	---	---	---	---	---	385.0
49:55	---	---	---	---	421.7	385.0	384.8	385.0	---

Note: Locations of gages shown in plate 1.
* After start of gate lowering.
** Limited data obtained for test 3.

Table 3

Flowing-Water Tests

Supplementary Hydraulic Data

Time min:sec*	Test 1: Flow at Bridge** Average Measured Velocity fps	Test 1: Flow at Bridge** Computed Surface El† msl	Test 1: Computed Discharge Inflow†† cfs	Test 1: Computed Discharge Outflow‡ cfs	Test 2: Flow at Bridge Average Measured Velocity fps	Test 2: Flow at Bridge Computed Surface El‡‡ msl	Test 2: Computed Discharge Inflow†† cfs	Test 2: Computed Discharge Outflow‡ cfs
				Gate Lowering				
0:00	--	---	---	---	--	---	---	---
1:00	--	---	---	---	--	---	---	---
2:00	--	---	---	2,805	--	---	---	1,940
3:00	--	---	---	3,130	--	---	---	2,800
4:00	2.2	419.1	4,000	3,315	0.8	---	3,500	3,320
5:00	2.4	419.0	4,700	3,745	1.2	---	4,300	3,820
6:00	2.6	418.9	5,400	4,480	1.6	---	5,000	4,480
7:00	2.9	418.8	6,200	5,310	2.0	---	5,700	5,180
8:00	3.3	418.5	7,000	6,005	2.4	---	6,500	5,820
9:00	3.8	418.4	7,900	6,690	2.9	---	7,400	6,420
10:00	4.5	418.2	8,900	7,420	3.4	---	8,400	7,170
11:00	5.3	418.0	10,100	8,215	4.0	---	9,400	7,980
12:00	6.2	417.8	11,700	9,000	4.6	---	10,600	8,820
13:00	7.1	417.5	13,300	9,805	5.2	---	11,800	9,650
14:00	7.9	417.3	14,800	10,740	5.8	---	13,200	10,550
15:00	8.7	417.0	16,200	11,830	6.7	---	14,600	11,440
16:00	9.8	416.7	17,700	12,745	7.9	---	16,200	12,300
17:00	11.1	416.3	19,200	13,650	9.5	---	18,100	13,270
18:00	12.7	415.7	20,300	14,760	11.3	---	19,500	14,170
19:00	13.7	415.3	21,000	15,855	12.7	---	20,200	14,600
20:00	14.2	415.2	21,400	16,630	13.4	---	20,600	15,060
21:00	14.4	415.1	21,500	17,075	13.6	---	20,900	16,120
22:00	14.2	415.2	21,600	17,550	13.3	---	21,000	16,950
23:00	--	---	---	---	13.2	---	21,000	17,420
				Gate Raising				
23:20	13.8	415.5	21,300	18,055	--	---	---	---
24:00	13.1	416.0	20,800	18,425	--	---	---	---
25:00	12.2	416.4	20,100	18,600	--	---	---	---
25:55	--	---	---	---	13.4	---	21,000	18,360
26:00	11.2	416.8	19,100	18,715	--	---	---	---
27:00	10.4	417.3	17,900	18,790	13.4	---	20,800	18,560
28:00	9.5	417.7	17,000	18,810	13.3	---	20,600	18,680
29:00	8.7	418.1	16,400	18,765	13.1	---	20,200	18,840
30:00	8.4	418.4	15,900	18,585	12.4	---	19,400	18,890
31:00	8.0	418.7	15,100	18,255	10.5	---	17,600	18,700
32:00	7.4	418.8	14,000	17,900	9.2	---	16,500	18,410
33:00	6.7	419.1	12,900	17,430	8.4	---	15,900	18,060
34:00	6.0	419.4	11,500	16,870	8.0	---	15,300	17,680
35:00	5.2	419.7	10,100	16,300	7.7	---	14,400	17,250
36:00	4.3	419.9	8,800	15,555	7.0	---	13,200	16,760
37:00	3.6	420.2	7,700	14,765	6.3	---	12,000	16,160
38:00	3.1	420.3	6,600	13,885	5.7	---	10,900	15,410
39:00	2.7	420.4	5,700	12,840	5.1	---	9,900	14,600
40:00	2.2	420.5	4,800	11,705	4.4	---	8,800	13,620
41:00	1.6	420.6	3,900	10,470	3.7	---	7,900	12,540
42:00	1.2	420.6	3,100	9,220	3.1	---	6,900	11,360
43:00	0.9	420.6	2,300	7,765	2.7	---	6,000	10,160
44:00	0.7	420.7	1,500	6,235	2.4	---	5,000	8,810
45:00	0.6	420.6	1,500	4,850	2.0	---	4,000	7,140
46:00	0.4	420.6	1,100	3,530	1.8	---	3,000	5,540
47:00	--	420.5	---	2,555	--	---	---	3,970
47:15	--	420.5	---	1,575	--	---	---	---
48:00	--	---	---	---	--	---	---	1,570

* After start of gate lowering.

** Upstream side of bridge, about 50 ft upstream from emergency gate.

† From pool elevation and velocity of approach.

†† From average of the computed discharge at bridge and the difference between chamber rate-of-rise and outflow.

‡ From conduit outlet rating.

‡‡ Omitted because of effects of large pretest surge.

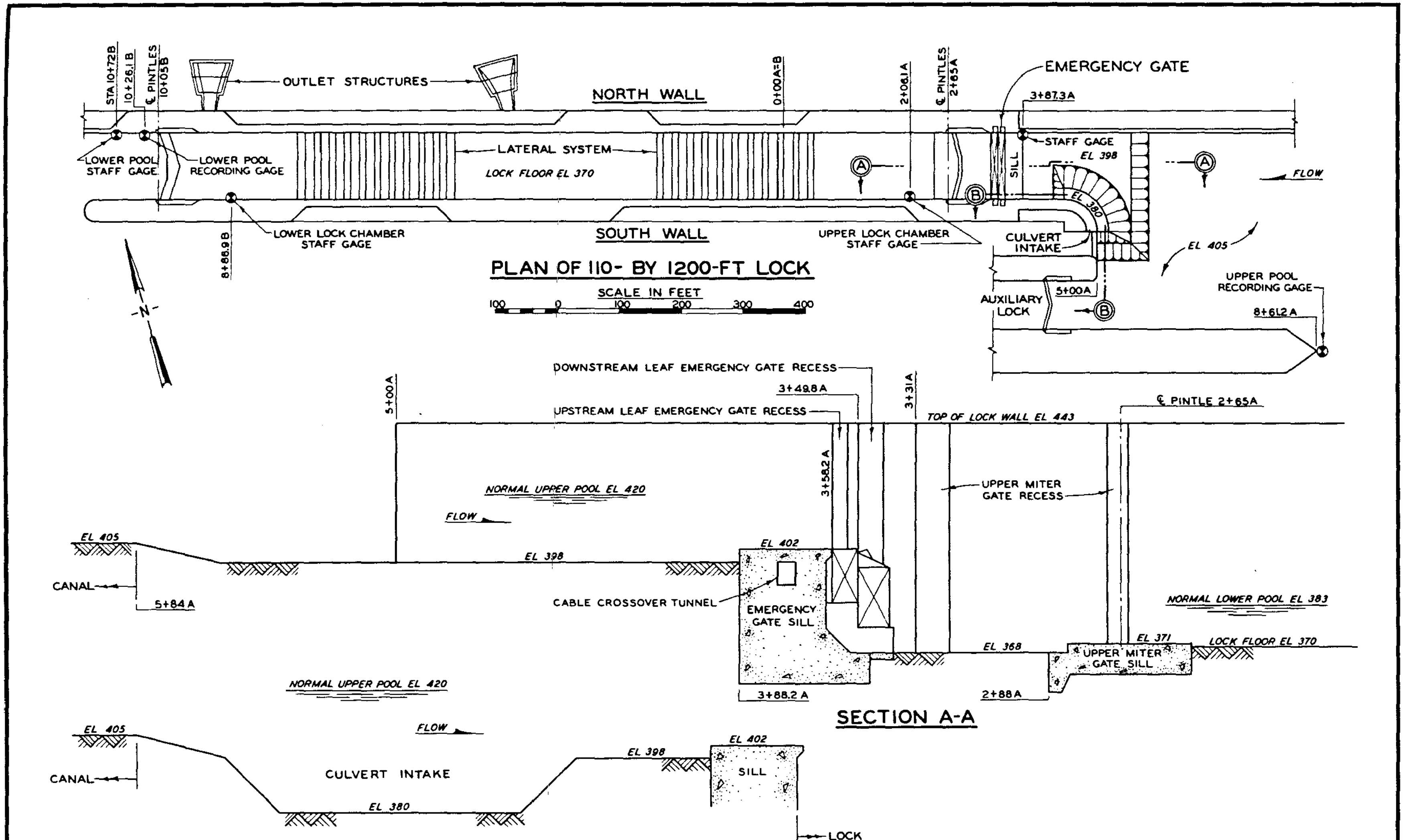
Table 4

Flowing-Water Tests

Gate Hoist Power Measurements

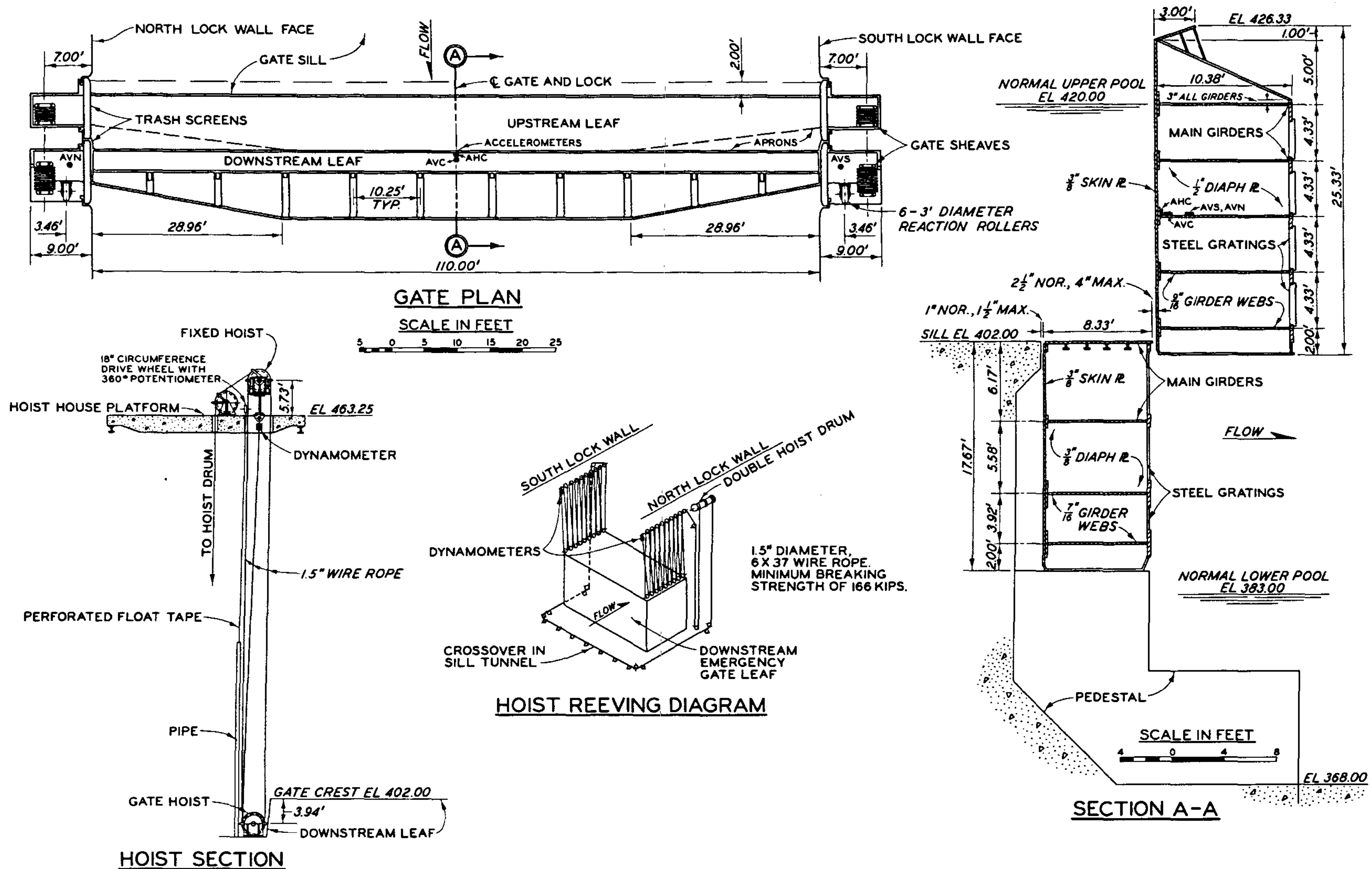
Time min:sec*	Volts	Amps	Power Factor %	Power kw	Motor Speed rpm
		Test 1, Gate Lowering			
0:00	472	22.5	--	--	--
		Test 1, Gate Raising			
25:00	462	32.5	66.4	17.4	--
35:00	462	33.0	72.0	21.9	--
36:00	462	37.0	74.0	22.5	--
38:00	462	38.0	75.2	24.0	--
39:00	462	36.0	73.5	22.1	--
42:00	462	41.0	77.8	27.3	--
44:00	462	43.0	78.5	27.5	--
45:00	462	44.0	79.0	28.8	--
47:00	462	39.0	76.2	23.1	--
47:15	462	37.5	74.2	22.5	--
		Test 2, Gate Lowering			
3:00	471	19.0	80 lead	--	1226
11:00	471	23.0	80 lead	--	1215
21:00	473	22.5	80 lead	--	1222
		Test 2, Gate Raising			
28:00	464	32.0	68.0	17.8	1167
35:00	462	32.0	66.0	15.9	1158
38:00	461	36.0	74.0	22.5	1151
43:00	459	36.0	74.0	22.4	1148
45:00	458	42.0	78.0	27.5	1152
47:00	458	43.0	79.0	27.5	1158
49:00	459	43.0	78.0	25.5	1158
		Test 3, Gate Lowering			
3:00	475	23.0	80 lead	--	1218
12:00	475	23.0	80 lead	--	1222
19:00	475	22.5	80 lead	--	1211
		Test 3, Gate Raising			
26:00	465	37.0	68.0	17.8	1158
34:00	465	31.0	67.0	17.9	1148
37:00	462	36.0	74.0	22.8	1140
41:00	463	36.0	74.0	21.3	1138
44:00	464	42.0	78.0	26.3	1126
46:00	465	43.5	79.0	28.8	1130
49:00	469	38.0	65.0	25.0	--

* After start of gate lowering.

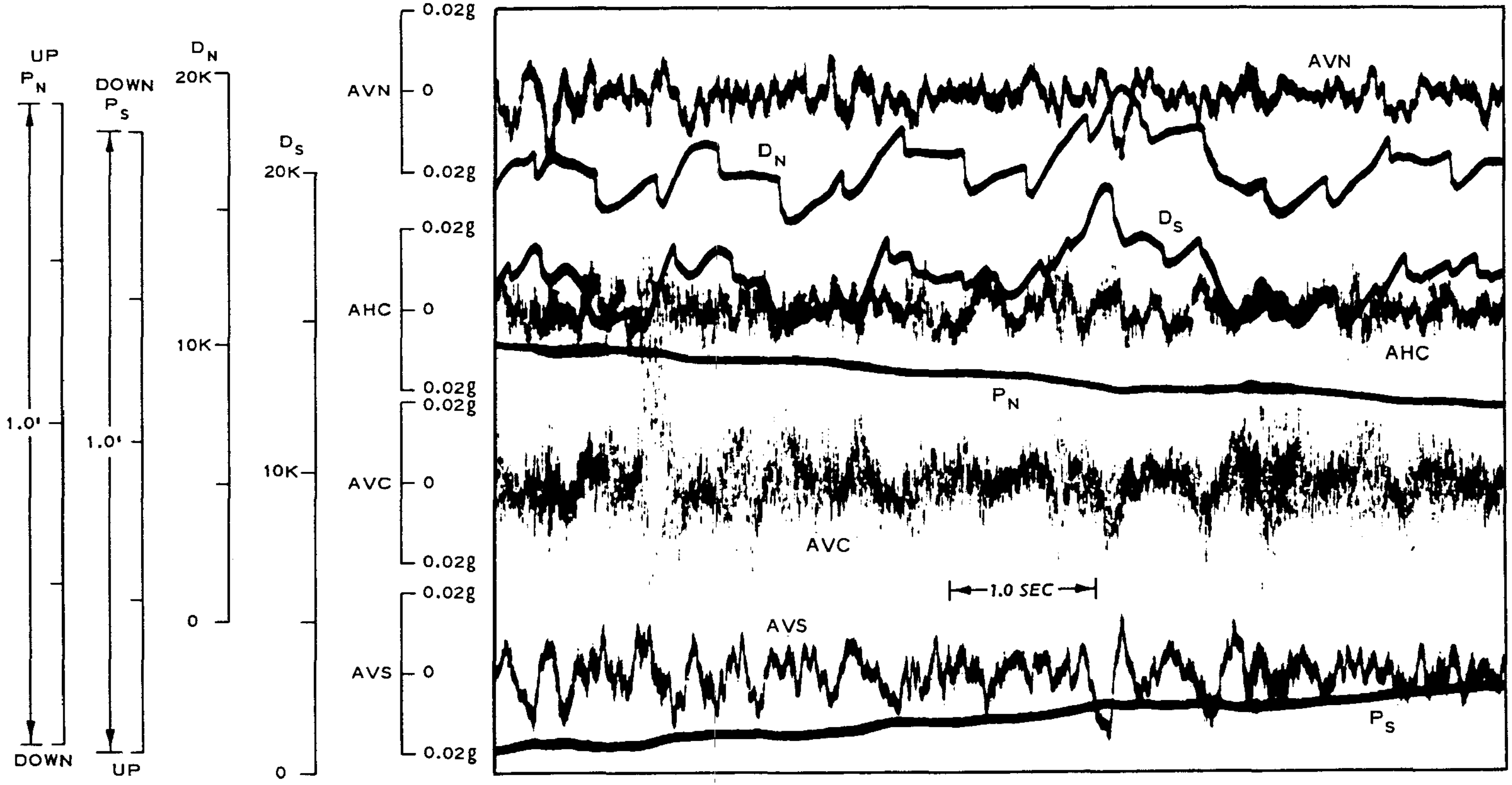


MAIN LOCK
PLAN AND SECTIONS

PLATE 1



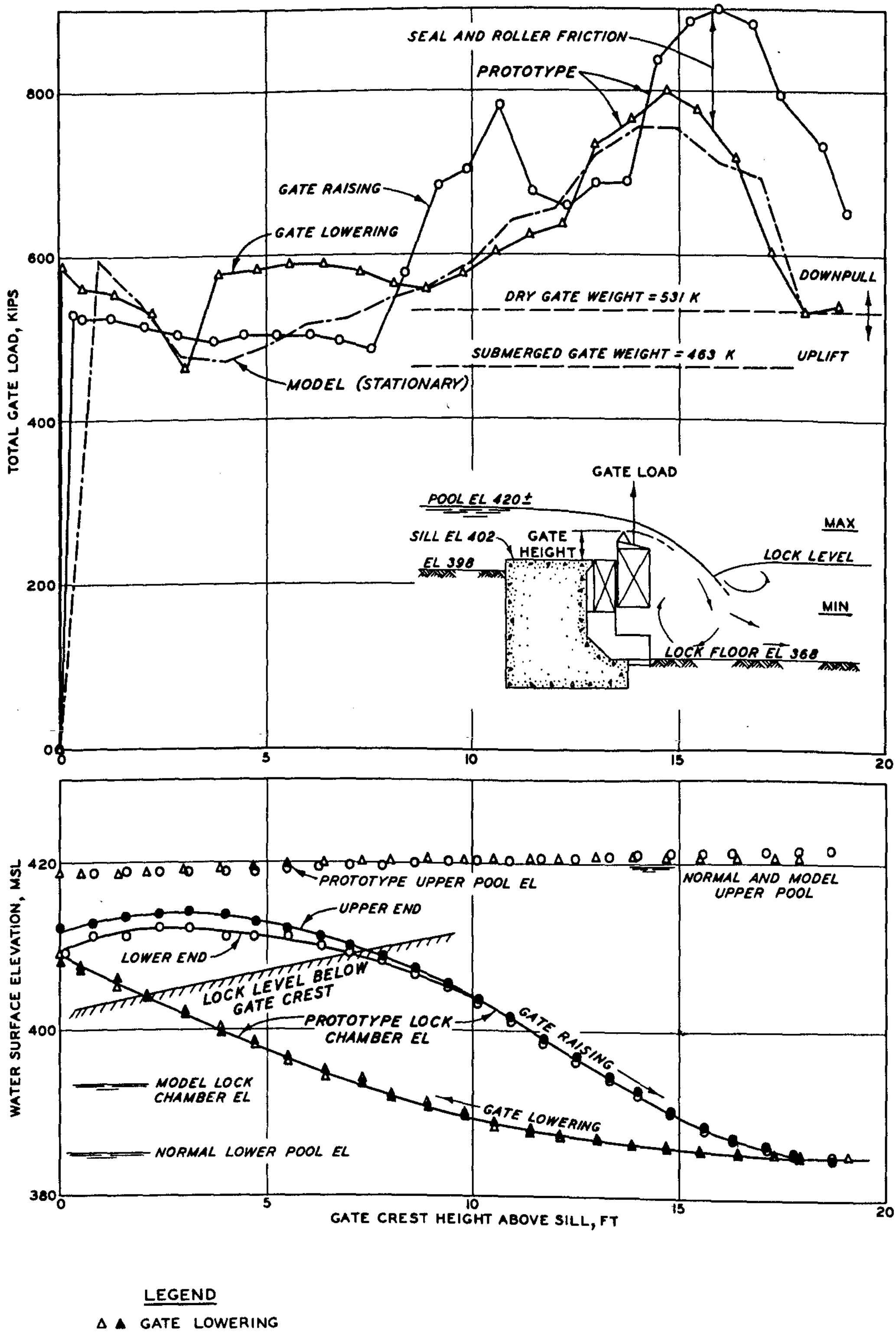
EMERGENCY GATE



AVN, ETC. — ACCELEROMETERS (SEE PLATE 2 FOR LOCATIONS)
P_N, P_S — POSITION INDICATORS, NORTH AND SOUTH ENDS
D_N, D_S — DYNAMOMETERS, NORTH AND SOUTH ENDS

TEST OSCILLOGRAM

GATE LOWERING
3 FT ABOVE SILL



EMERGENCY GATE LOADS AND LOCK LEVELS