Manual on lock valves

American society of civil engineers. Waterways division. Committee on lock valves.

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MANUAL
ON
LOCK VALVES

COMPILED BY THE

COMMITTEE ON LOCK VALVES
WATERWAYS DIVISION
AMERICAN SOCIETY OF CIVIL ENGINEERS

HEADQUARTERS OF THE SOCIETY
33 WEST 39TH ST. 1930 NEW YORK, N.Y.

FOREWORD

At a meeting of the Executive Committee of the Waterways Division held in Philadelphia, Pa., October 8, 1926, a Committee on Lock Valves was authorized for the purpose of preparing a Manual on the subject.

The Committee was formally appointed on December 4, 1926, with the following personnel: M. G. Barnes, *Chairman,* W. J. Barden, L. D. Cornish, Malcolm Elliott, Henry Goldmark, C. I. Grimm, Fred Hendershot, H. F. Hodges,* W. H. McAlpine, Montgomery Meigs, L. C. Sabin, A. W. Sargent, J. L. Savage, E. H. Schulz, and Walter M. Smith, of the Society membership; and C. M. Wellons and C. A. D. Young, Affiliates, of the Waterways Division.

Mr. Barnes served as Chairman of this Committee until April 12, 1927, when he was forced to resign on account of ill health and the pressure of official duties. The vacancy caused by Mr. Barnes' resignation was filled by Mr. Sabin, who has since acted as Chairman.

The personnel of the original Committee otherwise has remained unchanged except for the addition of a few new members. The present Committee is constituted as follows: L. C. Sabin, *Chairman,* W. J. Barden, L. D. Cornish, Lynn L. Davis, Isaac DeYoung, Malcolm Elliott, Henry Goldmark, C. I. Grimm, Fred Hendershot, H. F. Hodges, W. H. McAlpine, Montgomery Meigs, A. W. Sargent, J. L. Savage, E. H. Schulz, Walter M. Smith, and Frank E. Sterns, of the Society membership; and C. M. Wellons and C. A. D Young, Affiliates, of the Waterways Division.

The Technical Procedure Committee has defined a manual as "an orderly presentation of facts on a particular subject supplemented by an analysis of the limitations and application of these facts." Among the forms which such a manual may take, the one which appears to best fit the subject of Lock Valves is to make it an "exposition of the many forms of single type of structure, each successful but differing in their adaptability."

Types of lock valves have not in general become standardized. Much less has the type to be used in a certain situation become well established. Each set of conditions has its own requirements and these differ so widely as to call for a detailed study in almost every case. Only where a number of locks are to be constructed on a single waterway with practically uniform conditions as to building foundations and character of traffic to be accommodated is it possible to adopt a single type which will be the best solution for the general situation.

Accordingly, the plan adopted in preparing the present Manual was to have individual members of the Committee prepare separate monographs descriptive of particular installations with which they are familiar and to supplement the descriptive matter as far as practicable by comments on the efficiency obtained and the difficulties and defects so far as these were developed.

* General Hodges died September 24, 1929.

SUMMARY

Following this plan the Committee has received monographs describing the valves and culvert systems installed at:

(1) The New York State Barge Canal (page 7).
(2) The Lake Washington Ship Canal, Seattle, Wash. (page 12).
(3) The Locks of the Division of Waterways, State of Illinois (page 17).
(4) The Black Rock Lock, Buffalo, N. Y. (page 23).
(5) The St. Marys Falls Canal, Michigan (page 31).
(6) The Harbor Lock at Chemulpo, Korea, and the Lock at New Orleans, La. (page 46).
(7) The Locks on the Ohio River (page 52).
(8) The Panama Canal (page 54).
(9) The Locks on the Monongahela River (page 72).
(10) The Wilson Lock, and Lock No. 1, Tennessee River (page 77).
(11) The Lock at Keokuk, Iowa (page 84).
(12) The Welland Ship Canal, Dominion of Canada (page 94).

After correspondence with the authors, designed to bring about a certain degree of uniformity in the presentation of the data, in order to facilitate comparison of the results obtained, the additional information was incorporated in the original papers, and, as thus extended, these are printed as Appendices under the names of the authors.

Valves.—The installations described are all of reasonably recent construction, and it is noticeable that, except for one instance, they include, for regular operation, no examples of valves in the lock-gates, a device which was commonly used in small locks forty or fifty years ago. Even in the one instance cited, *viz.,* the Black Rock Lock, the valves in the gates were added years after the lock was opened, in order to hasten operation under the changed demands of navigation. (Appendix 4, p. 27).

Valves are provided, however, in the gates in several locks not mentioned in the monographs, particularly in some of the locks on the Monongahela and Ohio Rivers; also provision is made in the plating for the later installation of valves in the gates of some other locks on the Allegheny. The purpose of such valves, however, is now usually confined to the equalizing of the levels in case of bad leakage in the culvert valves or for flushing ice or dêbris from the chambers or lower approach.

In all the installations, except the St. Marys Falls Canal and the Ohio River Locks, the main filling culverts are placed lengthwise in the walls, the distribution into the lock chamber being made (*a*) through ports opening horizontally at or near the floor level, in ten instances; and (*b*) through lateral culverts under the lock floor, opening vertically through ports directing the flow upward, in two instances. In most of these cases the main wall culverts connect the upper and lower pools, and are used for both filling and emptying the lock. In the case of the Chemulpo Lock (Appendix 6) and of Lock No. 8 on the Welland Ship Canal (Appendix 12), the emptying culverts are distinct from the filling culverts.

At the St. Marys Falls Canal (Appendix 5) the main filling culverts are under the lock floor and communicate with the chamber through ports opening vertically and directing the flow upward. The emptying culverts are distinct from the filling culverts, draw from a well near the lower end of the lock, and pass out under the miter walls of the lower gates.

The typical Ohio River Lock (Appendix 7) is filled and emptied through short ports opening through the river wall at right angles to its length. The filling ports are above the dam, the emptying ports below.

There are three installations using Stoney valves (Appendix 2, Lake Washington; Appendix 4, Black Rock; and Appendix 8, Panama); four using cylindrical valves (Appendix 2, Lake Washington; Appendix 8, Panama; Appendix 10, Wilson; and Appendix 11, Keokuk); three using wagon body valves (Appendix 1, New York State Barge Canal; Appendix 3, Illinois; and Appendix 6, New Orleans); four using butterfly valves (Appendix 4, Black Rock; Appendix 5, St. Marys River; Appendix 7, Ohio; and Appendix 9, Monongahela); one using spool valves (Appendix 10, Wilson); one using sliding gate valves (Appendix 6, Chemulpo); and one using Taintor valves (Appendix 12, Welland).

Efficiency.—In the case of the Keokuk Locks (Appendix 11), the Chemulpo Lock (Appendix 6), the locks of the Illinois State Waterway (Appendix 3), and the Welland Ship Canal Locks (Appendix 12), data for determining the hydraulic efficiency of the systems are lacking. In the others an estimate can be formed of greater or less accuracy. It appears from these estimates that the efficiency depends upon many elements beside the valves themselves. Broadly speaking, the ratio of the sectional area of the culverts to the horizontal area of the chamber to be filled is the most influential feature. With a satisfactorily large culvert area good results may be obtained with any of the usual types of valves under ordinary heads, with the qualification that the upright cylindrical valve, and probably any type which cramps the flow through the culvert in the same manner, gives generally a smaller value of the coefficient of flow than do the other types considered, which open the culvert more directly in line with the flow of the water. Nevertheless, the cylindrical type has found wide application, and is especially suited to cases where the pressure may come from either direction.

The formula commonly used in calculating the coefficient of flow will be found on page 65 of Appendix 8, Panama. When this formula, as it stands, is rigidly applied, the resulting value of the coefficient of flow does not in all cases give a correct measure of the effect which the valves and culverts have on the efficiency of the system. Some consideration must be given to the circumstances of each example; thus, the opening of the valves may take an appreciable time, during which the full area of the culvert is not open to flow; the sudden draft on the pool above the chamber may cause a drop in the level of the water above, or the flow from the chamber may raise the level locally below the outlets, in both cases diminishing the head (Appendix 5, St. Marys, page 36; Appendix 8, Panama, page 66); if there be a large volume of water in the culverts, it may take an appreciable time to start the flow after the valve begins to open, in which case a corresponding extension of flow beyond the point of equalization of levels has been observed in some instances (Appendix 8, Panama, page 66); the value to be taken for the culvert area in the formula may or may not be its smallest cross-section, it having been observed that a reduction in sectional area of part of the culvert between two portions of larger area does not necessarily reduce the flow correspondingly (Appendix 3, Illinois Waterway, page 18; Appendix 8, Panama, page 67); a difference in density of the waters joined may prevent actual equalization of levels (Appendix 2, Lake Washington, page 14; Appendix 8, Panama, page 67).

In endeavoring to calculate the values of the coefficient given in Table 1, the data are in most cases insufficient to permit suitable consideration to be given to all the elements which enter. In the cases of the Panama Canal and of the St. Marys Falls Canal allowance has been made for the time of opening the valves, and, in the latter instance, the drop in the forebay has also been taken into account. In the other cases the formula has been applied to the data given in the monographs as to lift, time, culvert area, etc., and the results, while giving a measure of the practical efficiency of the system, are merely approximate indications of the influence of the valves and culverts, as distinct from other causes.

Surges.—Practically, the time in which the lock should be filled or emptied is sometimes determined, not by the valve and culvert capacity, but by the necessity of keeping the surface of the water in the lock and approaches sufficiently quiet for the safety of the vessels using the waterway (Appendix 5, St. Marys, page 35; Appendix 8, Panama, page 71). So far as the lock chamber is concerned this applies principally to the operation of filling, when the disturbance due to the flow takes place in the chamber. With side culverts, even when the distribution into the chamber is made from many ports, it is usually found that there is a cross slope in the surface downward toward the wall through which the culvert in use enters (Appendix 8, Panama, page 67; Appendix 11, Keokuk, page 89), tending to hold the vessel against that wall. When both side culverts are used simultaneously, two cross slopes result with a valley lengthwise along the middle line tending to center the vessel in the lock. At St. Marys Falls Canal, where the filling is through culverts under the floor, there seems to be no lateral slope.

With both wall and floor culverts a slope lengthwise of the lock may sometimes be noted (Appendix 2, Lake Washington, page 14; Appendix 3, Illinois, page 17; Appendix 5, St. Marys, page 36). With large locks and vessels this slope is not of great importance, and may change in direction during the filling, by wave action or otherwise. Efforts have been made to arrange and multiply the ports admitting the water, in such manner as to distribute the flow uniformly throughout the length of the chamber. In some cases it has been found that the down-stream ports tend to discharge more than those nearer the filling valve, after steady flow in the culverts has been established (Appendix 3, Illinois Waterway, page 17; Appendix 5, St. Marys, page 36; Appendix 6, New Orleans, page 51).

In emptying the lock, the surface of the water in the chamber is usually quiet enough, even when the culverts draw from a single point in the length of the lock (Appendix 5, St. Marys, page 35). It appears that the designer's attention may safely be directed to securing a quiet and satisfactorily rapid filling, and that any arrangement of ports which will accomplish this will not cause disturbance in the lock when emptying. Any such disturbance is to be

TABLE 1.—TABULAR SUMMARY—LOCKS AND VALVES.

Lock.	Culverts.	Area, in square feet. Chamber.	Culverts.	Laterals.	Ports.	Head. in feet.	Time, in seconds.	Coefficient of flow.	Valves.
New York Barge Canal	Both sides	15 300	126	......	Variable	23 to 41.5	240	0.72	Wagon body
Lake Washington	Both sides	67 000	217	......	448	18.0	450	0.73	Stoney
Lake Washington, small lock	Both sides	4 500	48	......	92	18.0	210	0.48	Cylindrical
Illinois State Waterway	Both sides	74 910	226	......	352	42.0	......	......	Wagon body
Black Rock	Both sides	46 300	56.5	......	67	5.0	840	0.54	Stoney
Black Rock, modified	Added valves in gates	46 800	110.2	......	67	5.0	360	0.66	Stoney and butterfly
St. Marys Falls	Under floor	114 500	528	......	1 064	19.1	420	0.75	Butterfly
Chemulpo	Both sides	25 800	90	......	114	Variable	......	......	Wagon body
New Orleans	Both sides	46 000	128	......	320	16	420	0.83	Sliding
Ohio River	Ports in river wall	74 000	......	......	260	6.2	270	0.66	Butterfly
Panama, 900 ft., single	Both sides	123 000	510	861	1 285	28.0	460	0.79	Stoney and cylindrical
Panama, 900 ft., single	One side	123 000	255	......	1 285	33.0	840	0.88	Stoney
Panama, equalizing two upper locks	Both sides	{ 123 000 / 121 000 }	510	......	1 285	60.0	380	0.61	Stoney and cylindrical
Panama, equalizing Miraflores	One side	121 000	255	......	1 285	39.3	570	0.72	Stoney
Monongahela River, No. 7	Both sides	22 650	240	......	432	15.0	210	0.51	Butterfly
Wilson Lock	Both sides	About 20 000	126	......	180	44.5	720	0.37	Spool
Wilson Lock, modified	Both sides	About 20 000	63	......	180	44.5	720	0.74	Cylindrical
Tennessee River, No. 1	Both sides	About 20 000	126	.....	180	16.0	480	0.83	Spool
Keokuk	One wall	44 400	133	226	396	41.0	......	......	Cylindrical
Welland Ship Canal, No. 2	Both sides	69 000	420	......	600	46.5	......	......	Taintor

found in the tail-bay, and means may be taken to provide against injurious effect.

It may be desirable to operate the valves at less than their maximum capacity, in order to avoid disturbance in the lock or approaches, even at the cost of increased time (Appendix 5, St. Marys, page 36; Appendix 10, Wilson, page 83). On the other hand, when the circumstances of the installation are such that no dangerous disturbance is thereby created, the valve and culvert system may be so proportioned as to permit an extreme rapidity of filling, as in the case of the smaller Lake Washington Lock (Appendix 2, page 14) and Locks Nos. 7 and 8, Monongahela River (Appendix 9, page 73).

Results of Experience.—It appears from the monographs that, in most instances, experience in service has justified confidence in the designs adopted. Nevertheless, some defects have developed. At the Wilson Lock the spool valves failed to give satisfaction under high head (Appendix 10, Wilson, page 80); but at Dam No. 1, Tennessee River, they function well under the moderate head of 16 ft. (Appendix 10, Wilson, page 83); the type of cylinder valve which is used in the Panama Canal (Appendix 8, page 70) under a head reaching 60 ft., has given satisfaction there and at the Lake Washington Canal (Appendix 2, page 16). In both these installations the dome of the valve is built into the concrete of the wall above it, and cannot be lifted. At Keokuk similar valves, free at the top, were wrecked, apparently by water-hammer from within; but the expedient of ventilating the interior removed this danger (Appendix 11, page 88). Both at Panama and at Keokuk a number of the valve stems parted at the couplings after some years of service, during which corrosion of the screw-threads had taken place, and in both cases welding was resorted to as a cure (Appendix 8, page 70; Appendix 11, page 92).

On account of the high lifts which may be expected in the future, especially in case of locks built in connection with power dams, it may be found desirable to use valves resembling those which have been successful under extremely high heads at certain installations of the United States Bureau of Reclamation, and which are described in a report* by J. M. Gaylord and J. L. Savage, M. Am. Soc. C. E. The Committee knows of no locks in which such valves have yet been adopted. The head under which the Stoney valves in the lock flights of the Panama Canal function in service may reach 60 to 65 ft., and they must remain tight under heads of about 85 ft. The cylindical valves there and at the Wilson Lock also function satisfactorily under high heads. Lock valves of types now in use are, therefore, adequate for the severest conditions to be found at existing locks; but it seems possible that the limit of lift has not yet been reached. Other types of valves designed especially for high heads should not be overlooked.

The interesting example of a siphon lock on the New York Barge Canal described in Appendix 1, page 9, is well worthy of study.

The foregoing summary of the several papers appearing as Appendices has been submitted to the members of the Committee and includes, in general, the individual comments and suggestions received. This summary with its appendices is presented as the final report of the Committee on Lock Valves.

* "High-Pressure Reservoir Outlets," U. S. Govt. Printing Office, 1923.

APPENDIX 1

LOCK VALVES OF NEW YORK STATE BARGE CANAL

BY THOMAS F. FARRELL, ESQ.*

Culvert System.—The locks on the improved Canal System are 45 ft. wide by 310 ft.† in useful length and vary in normal lift between 6 ft. at Erie Locks Nos. 25 and 26, at May's Point and Clyde, to 40.5 ft. at Erie Lock No. 17, at Little Falls. Filling and emptying is accomplished through a culvert in each side wall, extending from above the upper to below the lower gates and controlled by two valves, one near each end.

The culverts are connected to the lock by ports that open into the chamber at the bottom of the lock walls. These culverts vary in size, the dimensions being 5 by 7 ft. for locks of 12-ft. lift, or less; 6 by 8 ft., or less, between 12 and 23 ft. and 7 by 9 ft., when the lift is 23 ft., or more. Connected with the 5 by 7-ft. culverts are ports varying in size and number but equal for each side of the lock chamber, while the number is increased with the 6 by 8-ft. culverts and still further increased, both in size and number, for the 7 by 9-ft. culverts. The ports have been made by embedding cast-iron pipes in the concrete and by leaving rectangular openings in the walls, the rectangular openings being the later method which so far has proved quite satisfactory. The area of the opening may vary from 7½ to 14 sq. ft., the idea of the design being to provide for filling and emptying locks of all sizes in the same time.

The average time required to fill or empty any of the locks varies slightly due to differences in head, size of ports, and the speed with which the valves are operated, but in general the time for emptying or filling a lock is approximately 4 min. if the valves are opened as quickly as possible. The surface of the water during the filling and the emptying is reasonably quiet, but with the higher-lift locks there is a dangerous eddy just above the locks at the upper tunnel entrance during the filling, and likewise a dangerous boil in the lower approach during the emptying. It is considered unsafe for a boat to be tied up or operated within 100 ft. of the lock during these operations.

Wagon-Body Valves.—In making preliminary studies of the advantages of various available types of valves consideration was given to simplicity of construction, reliability and ease of operation, and facility of repairs and maintenance. The design adopted is a four-wheel valve with tapered side seats. It is simple and rugged (Fig. 1). In from ten to fifteen years' use the equipment has given efficient service with little annoyance other than routine repairs of broken chains, replacement of worn parts, and other minor items.

Immediately below the valve wells the culverts are provided with cast-iron linings varying from 6 to 12 ft. in length. These linings are embedded in the concrete of the lock walls and support tapered cast-steel seats against which adjustable bronze strips on the valve bodies make contact as the valves are closed.

* Commr. of Canals and Waterways, State of New York, Albany, N. Y.

† 339 ft., between hollow quoins.

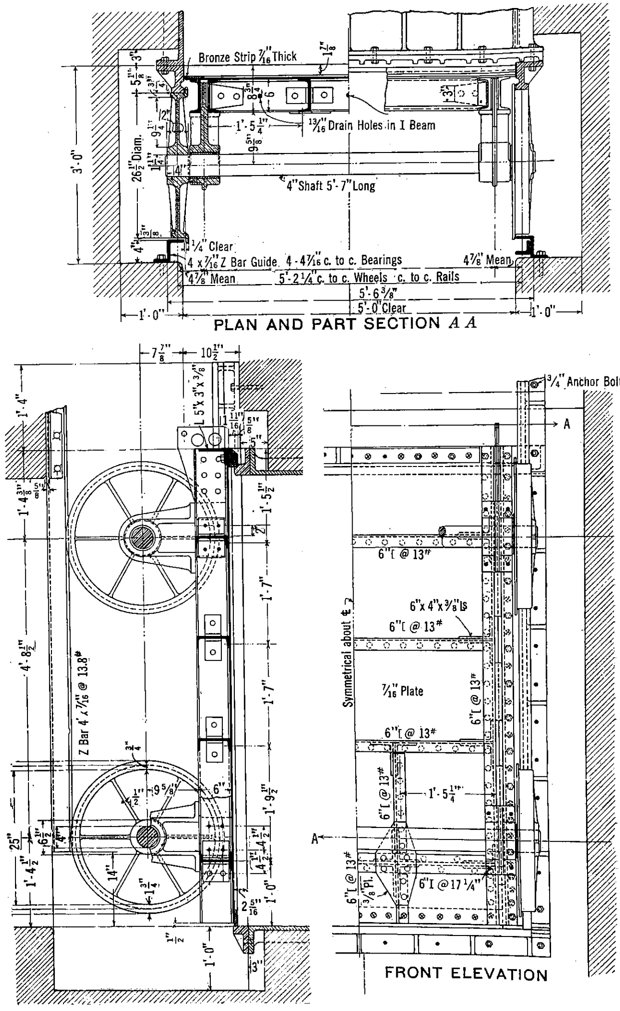

Fig. 1.—New York State Barge Canal: Details of Wagon-Body Valves at Upper and Lower Ends of Lock.

Large wheels and rugged axles so support these valve bodies that water pressure is always carried from them to journal boxes, thence to axles, to wheels, and to cast-steel tracks integral with the side seats, previously mentioned. Consequently, these valves are opened under full head with comparative ease due to substitution of rolling friction for the sliding friction at the seats inherent with the ordinary type of sluice-gates.

Clear openings of valves are 35, 48, and 63 sq. ft. The bodies are light because they are constructed of rolled steel plates, channels, and I-beams. The power demand is a minimum because each valve is balanced by cast-iron sectional counterweights.

Travel is vertical and weights and valves are restrained by steel guides and tracks composed of Z-bars and angles. The culvert linings in the later locks were provided in lengths of less than 2 ft. to serve solely as valve-seat supports. Danger from erosion of concrete culverts was believed to be so slight as to justify this considerable saving in cast-iron linings that at first were deemed necessary.

Erection.—The construction procedure was to install culvert linings or valve-seat supports at the time the lock walls were constructed. Seats, valves, and guides were provided under later contracts and still later ones supplied the operating machines, motors, wiring, and control devices.

The first equipment contract awarded provided machines for thirty-two valves. Small motors (about 2 h.p.) with high-speed gears are housed in watertight cast-iron boxes placed in recesses below the top of the lock walls. Slow-speed gears actuate the cup-wheels and two wrought-iron chains that support the valves and weights.

Under equipment contracts subsequently made there were provided about 176 machines of heavier design, having 3-h.p., or 7-h.p., motors placed in cabinets above the top of the lock walls. Certain locks along the Mohawk River were equipped with concrete, two-story cabins, with motors and control placed well above expected flood waters.

By removing the supporting head-frame with cup-wheels, shafts, etc., it is possible to hoist a valve to the surface for inspection, painting, or repairs, or even to replace it with a spare of like size.

Operation.—Operating stands at convenient locations provide master switch-control and indicator lights to show open, closed, and intermediate positions of the valves. Limit switches cut off the power at each end of travel. The speed of travel is about 6 ft. per min.

Emergency hand operation is provided by "walk around" operating levers and bevel gearing with jaw clutches in a manner commonly adapted for hand operation of swing bridges.

Siphon Lock.—A siphon lock (Fig. 2) is located in the City of Oswego, the only one of this type on the New York State Barge Canal and also the first to be built in this country. The general design of the culverts, 5 by 7 ft. in sectional area, is similar to that of a lock of ordinary type, except that at the upper and lower ends the culverts are curved up so as to form necks, or crowns, which rise a little above the highest water level and which, at the

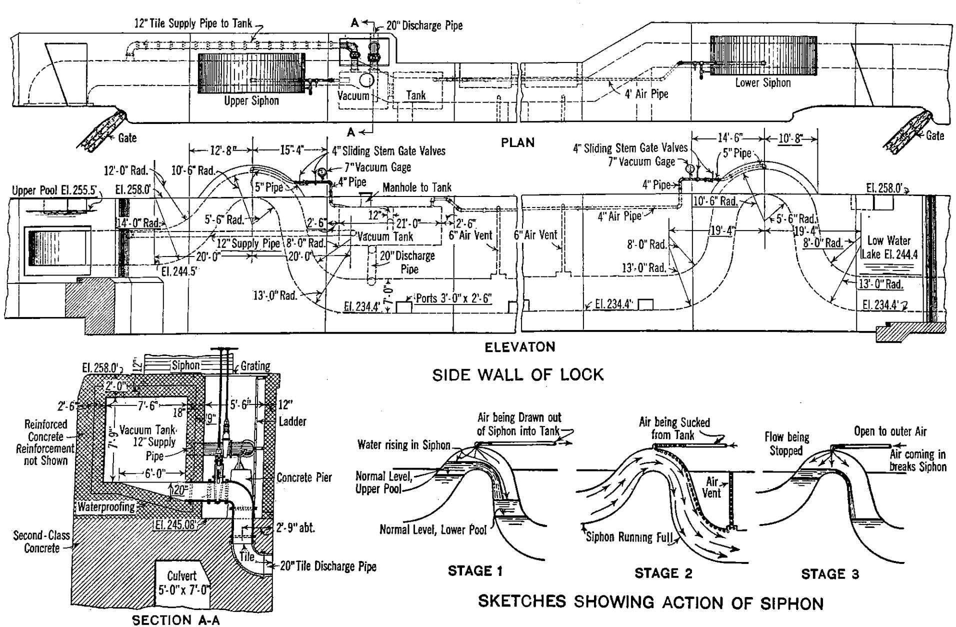

FIG. 2.—NEW YORK STATE BARGE CANAL: DETAILS OF SIPHON LOCK AT OSWEGO, N. Y.

same time, are shut off from all communication with the outer air, except through the operating pipes. At the crown of the siphon the sectional area is reduced to 5 by 5 ft.

The flow of water is started in the siphons by means of vacuum tanks (Fig. 2), one being built in each wall near the upper end, and communicating through pipes with the upper and lower levels and with both siphons in the same wall, and being shut off from all other communication with the outer air. To perform an operation the tank is first filled with water; then the intake valve is closed and the outlet opened. There results a body of water suspended by its weight but tending to escape into the lower pool, thus producing the necessary vacuum. On opening the air-valve, air from the siphon rushes into the vacuum and water begins flowing over the crest in the neck. Using both siphons the lock chamber can be filled in from 4½ to 5 min. with a head of 11.1 ft., and it can be emptied in from 5½ to 6 min. It has been found that the draft of the siphon is such that soon after the flow has started the direction of the air movement is reversed and the vacuum is restored in the tank. Thus, the operating power is self-renewing and, except for air leakage, lockages can be conducted by merely manipulating the 4-in. air-valves.

The ports in the valve tunnels correspond with other installations and although the operating time for this lock is slightly longer than for the others, in general it has been quite satisfactory and the repairs to valve equipment have been practically negligible. It is necessary to safeguard the piping from freezing.

APPENDIX 2

LAKE WASHINGTON SHIP CANAL LOCK VALVES

By W. J. Barden* and A. W. Sargent,† Members, Am. Soc. C. E.

1.—General Problem.—The Lake Washington Ship Canal, lying entirely within the City of Seattle, connects the fresh-water lakes, Washington and Union, with Puget Sound. It extends from Puget Sound through Shilshole Bay, Salmon Bay, and Lake Union to deep water in Lake Washington, a distance of approximately 8 miles, and has added to the commodious salt-water harbor of Elliott Bay a fresh-water harbor of approximately 25 000 acres, with a shore line of 100 miles. The tidal range extends to the locks about 1¼ miles; the extreme tidal range is 19 ft.

The double lock and fixed dam with movable crest are located at the Narrows at the westerly end of Salmon Bay, and hold the waters of Salmon Bay and the lakes 25 ft. above extreme low tide in Puget Sound with an allowable variation of 1 ft. above and 1 ft. below this plane.

The dredged channel from Puget Sound to the locks is 300 ft. wide, and 34 ft. deep at mean lower low water. From the locks to Lake Union the channel is 100 ft. wide and 36 ft. deep. From the easterly end of Lake Union to deep water in Lake Washington the channel is 100 ft. wide and 25 ft. deep. The large lock is 80 ft. wide, 825 ft. long, and will accommodate vessels of maximum draft of 36 ft. The small lock is 30 ft. wide, 150 ft. long, with a depth of 16 ft. over the upper sill. Table 2 gives the principal features of the locks. The sections of the locks and dam in Fig. 3, show the general relations.

TABLE 2.—Principal Features of Lake Washington Ship Canal Locks.

Item.	Large lock.	Small lock.
Clear width of chamber, in feet	80	30
Maximum available length, in feet	760	128
Maximum lift, in feet	26	26
Depth on upper miter-sill at low water in upper pool, in feet	36	16
Depth on intermediate sill at mean lower low water, in feet	29	...
Depth on lower miter-sill at mean lower low water, in feet	29	16

The large lock is designed to accommodate the largest commercial ships on the Pacific Coast. It is not probable that ships of immense size will have occasion to enter this Canal as it differs from the Panama and Sault Ste. Marie Canals, through which vessels must pass to reach other ports. At Seattle, the largest vessels afloat can be accommodated in the salt-water harbor of Elliott Bay without passing through the Canal.

The small lock, alongside and south of the large lock, is designed to accommodate with a minimum of delay, the large number of launches, tug-boats, and small craft continually passing in and out of the Canal.

* Col., Corps of Engrs., U. S. A., New York, N. Y.
† Civ. Engr., U. S. Engr. Office, Seattle, Wash.

The traffic in the Canal consists mostly of floated logs, lumber, sand and gravel, fuel oil, coal, and other commodities carried on barges.

During 1927, 16 427 vessels passed through the large lock and 22 657 through the small lock. The large lock-gates and valves were operated 10 321 times, and those of the small lock, 21 865 times. The net registered tonnage through the large lock was 2 340 962 and through the small lock 369 066. In all, 2 384 000 short tons of freight, including floated logs, passed through the large lock.

The locks are in continuous operation except about one week during the year when each lock is closed for general repairs.

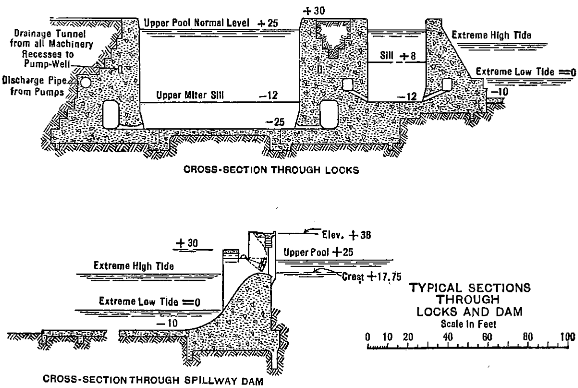

FIG. 3.—SECTIONS THROUGH LOCKS AND DAMS, LAKE WASHINGTON SHIP CANAL.

2.—Elements Affecting Type, Size, and Location of Valves, Etc.—The large lock chamber, 825 ft. long, is divided into two chambers by an intermediate gate, the lower chamber being 375 ft. long and the upper one, 450 ft. long. The small lock chamber is 150 ft. long and 30 ft. wide. The locks and dam are constructed of concrete on a bed of hard impervious clay; the walls in general are in sections, 30 ft. long, and in courses, 5 ft. thick, constructed with broad base and toe, 10 ft. wide. The floor of the large lock is 3 ft. thick and is designed merely as a pavement, to prevent scour in the lock. The culverts in both locks are in the side walls, with laterals extending into the chamber at the floor level. The ends of the culverts are between the service-gates and the guard-gates, and all gates and valves are accessible when the lock is unwatered, except the exterior surfaces of the guard-gates.

The culverts of the large lock are 8½ ft. wide and 14 ft. high, with corners rounded to a radius of 3.5 ft. The intake ends are increased in size to 16 ft. in width and 14 ft. in height, and the discharge ends are 10 ft. wide and 16 ft. high. Both ends turn at an angle of 90° horizontally into the lock. The bottom of the culverts are at the floor level, except at the discharge end, where they are raised 5 ft. The ports are 4 ft. wide and 2 ft. high, except four in each chamber which are 2 ft. wide and 6 ft. high, to allow easy access to the culverts when the lock is unwatered. There are twenty-four entering the upper chamber, with intervals of 28 ft., and twenty-eight in the lower chamber, with intervals of 20 ft. between centers.

The small lock culverts are 5.5 ft. in diameter at the valves, gradually changing in shape below the upper valves to 6 ft. high and 4.5 ft. wide, with corners rounded to a radius of 18 in., and changing in shape below the lower valves to 6 ft. high and 5.5 ft. wide. The discharge and intake ends of the culverts are increased considerably in size, and a liberal increase in area is provided around all the valves. There are twelve ports, each 3 ft. wide by 2 ft. high, and two ports, 2 ft. wide by 5 ft. high, extending into the lock chamber, one-half from each main culvert.

The time of filling and emptying the large lock is 7½ min., from 18-ft. head to zero, and 3½ min. for the small lock. Zero is considered the elevation which the water in the lock reaches when the gate is ready to be opened. The water on the two sides of the gate never equalizes, due to the difference in density of salt and fresh water, the remaining head being from 3 to 5 in., and as soon as the water appears to cease rising the gate is pulled open under this head. There is considerable leakage in the valves at the small lock and the new valve seats probably retard the flow, but it was expected that upon renewal of the water-seals later, the time of filling would be reduced to about 3 min. It is important that the locks be filled and emptied without appreciable surge, and the only indication of surge is in the large lock after it has been practically filled, when there is a slight up-stream current, but not sufficient to affect ships. Small leaks are not of great importance. Since practically all freight traffic and all but the smaller vessels must be passed through the large lock, it is very important that it be kept in continuous operation. All gates and valves are electrically operated, the power for operation, repairs, etc., being furnished by a local company.

3.—Description of Installation.—The valves of the large lock are of the Stoney gate type, composed of vertical I-beams connected by cross-beams and all sheathed with buckled plate. Water-seals are provided at the sides and top. The valves are equipped with roller trains running between two tracks; one fastened to the down-stream face of the vertical I-beam and one to the concrete in the valve recess. The valve stem and the roller train stems pass through a water-tight bulkhead which closes the bottom of the machinery recess, the upper end of the valve stem being attached by pin to a cross-head made up of steel I-beams.

The cross-head is raised and lowered by two vertical screws revolving in nuts. The screws are supported at the upper end on roller thrust bearings and are driven, through gears, by an induction motor provided with solenoid brake. A limit switch governs the extreme travel of the valve. Steel springs are provided in the two ends of the cross-head so that the cross-head nuts may travel 5 in. against the spring after the valve has reached its seat, stopping the motor without shock. The valve motor is controlled by an automatic starting compensator with no voltage release, and a drum-reversing switch in connection with the limit switch.

The valve stems are of triple-strength steel pipe accurately finished to dimensions and fitted at the ends with cast-steel connections. The cross-head nuts are of bronze, and the screws of forged steel. The coil springs are of vanadium steel, designed to carry a load of 5 250 lb., on a compression of 7 in.

The rollers in the roller train are of tool steel turned and finished to exactly the same diameter, and tempered. They are bronze bushed; the side-bars are rolled steel with cast-iron separators.

The valves of the small lock are of the cylindrical type, made of cast-iron, each section being in two pieces and bolted together. Cast-steel guides are provided for holding the valve in position. The valve seat is cast iron. Sole leather water-seals are provided around the upper edge. The valves are 6 ft. in diameter, covering a circular opening in the culvert 5½ ft. in diameter. The valves are raised and lowered by means of screws actuated by bevel gears operated by an induction motor. The weight of the valve is supported on roller bearings. The motor is equipped with a solenoid brake which stops the motor when the power is shut off, and is controlled by a solenoid-operated contactor with drum-reversing switch and limiting switch.

4.—Experience Gained in Operation.—The Stoney gate valves were originally equipped with racks and pinions for raising and lowering the roller trains. A rack on the gate meshes with two pinions on each side of the roller train, which, in turn, mesh with racks attached to the roller track fastened to the lock wall. They were of vanadium steel with accurately cut teeth bushed with a composition of zinc and tin. A water-seal of spring steel was attached to the up-stream face at the sides of the valves. The rollers of the train were bushed with zinc and tin alloy, and the pins shouldered at the inner side of the bars making it necessary to removed one side-bar to replace a pin on a roller.

The rack and pinion arrangement operated satisfactorily for a time, but caused considerable trouble after the parts began to wear, the principal difficulty being improper meshing, due partly to wear in the bushings, and partly to bark or other foreign material being caught between the racks and pinions, bending the pins. In order to make repairs it was necessary to remove the valve, but it could not be replaced with the roller train satisfactorily without unwatering the lock.

In the present arrangement each roller train has a stem passing through a stuffing-box in the water-tight bulkhead, a chain being attached at the upper end, which, in turn, passes over sheaves; the other end is fastened to the cross-head on the valve, raising the roller train with the valve, but at half speed. With this arrangement a damaged roller train can be removed and a new one placed at low tide by removing the stuffing-box in the bulkhead. A valve can also be removed and replaced by removing the entire bulkhead. This arrangement has been very satisfactory.

The spring steel water-seals on the valves are easily broken, and they have been replaced by heavy rubber belting with a steel contact strip fastened on the outer edge. This usually gives good service for from one to three years.

The composition bushings in the rollers were apparently too soft and deteriorated rapidly. Bronze is now used. An experiment is now to be made with the roller trains constructed without bushings in the rollers; the same style side-bars will be used, but the pins will be without shoulders and one can be replaced at any time without removing a side-bar. They will pass through sleeves made of cold rolled steel shafting cut to exactly the same length, taking the place of the shoulders on the pins for holding the side-bars in position. The rollers without bushings will turn on the sleeves.

The valves are coated with bituminous solution and enamel, which usually lasts about four years, when the valves are hoisted to the top of the lock wall for general repairs and painting.

After eleven years' service it was found necessary, on account of wear, to replace the roller-train tracks at the upper valves. They wore down at the rate of 0.05 in. per year and to compensate for the wear on the tracks, the size of the rollers was increased every two or three years, from the original diameter of 4 in. to a maximum diameter of 5 in. When the new tracks were replaced in 1928 the 4-in. rollers were again installed.

A roller-train track usually requires some repairs to pins, nuts, etc., every year. The rollers give very good service for about three years, when they become quite badly pitted and the bushings badly worn. They are then removed and new trains installed. When making up the new tracks with 4-in. rollers, the worn-out 5-in sizes are again put into service by turning them down to the smaller diameter.

The cylindrical valves of the small lock have given very satisfactory service; the guides and water-seals have been replaced from time to time; the valve seats were badly worn after six years' service and new seats were made and fastened to the original castings without removing them. One valve which had been in service eleven years was worn entirely through where it was in contact with the guides, and was replaced with a new valve. An additional valve has been made for replacement in 1930, with removable parts both for the valve and the guides where they are in contact. This will no doubt increase the life of the valve indefinitely, as the worn parts can easily be replaced. A collar which was attached to the valve stem above the valve as a safety device to prevent the valve from being broken by coming in contact with the top of the recess, in case a limit switch failed, was removed and a similar device fastened in the valve machine in the machinery recess. In its original position the collar prevented the removal of the stem for repairs, except when the lock was unwatered, but now the valve stem can be removed at any time, with the assistance of a diver.

APPENDIX 3

THE ILLINOIS WATERWAY: VALVES FOR FILLING AND EMPTYING SYSTEM

By L. D. Cornish,* M. Am. Soc. C. E.

The principal requirements of lock filling-and-emptying systems, due regard being given to economy, are that they shall permit equalization of levels in a reasonable time, will not create dangerous water disturbance in the locks or approaches, and will not allow excessive waste through leakage.

Distribution of Inflow.—The systems at the Soo and the Panama Canal locks are conspicuous examples of attempts to secure a uniform distribution of flow into the lock chamber and that at Panama is notable as to outflow also. The Soo locks have large longitudinal filling culverts under the floor with small vertical outlets into the chambers. Both the filling and emptying systems of the Panama locks consist of large longitudinal culverts in the lock walls with transverse or lateral culverts leading therefrom under the floor. The Soo and Panama systems are considered objectionable for shallow-draft canals and flat-bottom boats and barges as used on the Mississippi River and its tributaries. Vertical jets create a greater disturbance in shallow water and may cause violent movements of boats and fleets of barges which cannot be foreseen and provided for. That these disturbances occur is constantly shown in the operation of the Keokuk lock on the Mississippi, the filling system of which is similar to that at Panama, with only the side culvert in use.

Until recent years, the correct design of a lock-filling system has been a disputed question among canal engineers, owing to the lack of experimental data. In the Panama locks the openings into the lock chamber were as evenly spaced as the plans permitted, but tests under operating conditions show conclusively that the flow into or out of the lock chambers is not uniform. After steady flow has been established, the maximum discharge in both cases is from the openings nearest the lower end of the chamber, and the minimum discharge is from the up-stream openings. Such a condition of flow induces a current and drift of boats toward the upper gates when filling and toward the lower gates when emptying, which might be troublesome for fleets of barges. It has caused no trouble at Panama, where the towing locomotives hold the ships without difficulty.

The Panama tests developed data which permit of a close approximation of the number and size of openings required and their relative discharge capacity. Using these data it was found for the Illinois Waterway locks that, for each main culvert having an area of 113 sq. ft., ten openings, each having an area of 17.5 sq. ft., would develop the capacity of the main culvert and that the six up-stream openings or ports had approximately the same capacity as the four down-stream ports. Therefore, six ports were located above, and four

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below, the transverse axis of the lock. The distance between the two ports nearest this axis is 115 ft. With this arrangement the drift from each group will be approximately equal in intensity and, when filling, will be toward the center of the lock, thus automatically centering the vessel in the lock chamber so that it will not drift toward the miter gates. When emptying a chamber the drift will be away from the center, but with large boats or fleets of barges the drift effort from the two groups will tend to neutralize each other. Furthermore, a good distribution in emptying is not so essential because the violent water disturbances are due to the dissipation of the energy of the flowing water, and when emptying a lock this dissipation of energy takes place in the culverts and tail-bay and not in the lock chamber as is the case when filling.

Culverts and Valves.—The culverts are controlled by lift-gates at each end of the locks. The culverts draw from the upper pool through intakes enlarged to 201 sq. ft. at the entrance. Screens are provided at the intakes to prevent drift from entering the culverts. The horizontal area of the lock chamber is 74 910 sq. ft.

In determining the size of valves for the locks of this waterway advantage was taken of the Venturi principle which is common practice for water supply systems. The culverts are 12 ft. in diameter (113 sq. ft. in area), whereas the valve openings are 81 sq. ft., or 71½% of culvert area. Similar valves in the gate-house of the Ashokan Reservoir of the New York City water supply system when tested developed an average discharge coefficient of 1.15 for greater velocities than will occur in these locks.

Using a coefficient of 0.83 for culverts and 1.15 for valves in the lock, the filling-time formula indicates, for Illinois Waterway locks, that the time lost by the use of small valves will be about 3 sec. per lockage. The flare between the valve opening and circular culvert section for these locks is 3 degrees and 20 minutes.

The valves for controlling the filling and emptying system of the locks will be of the vertical lift-gate type. The maximum head to which these valves will be subjected varies from 42 to 16 ft., according to the location of the locks, but as there would be little or no economy in modifying the structural members, one design has been adopted for all locks.

Roller-Bearing Wheels.—The valves as adopted are of the wagon-body type and the only new feature of their design is the use of roller-bearing wheels, as shown on Fig. 4. Ordinary journal-bearing wheels produce high friction loads, and lubrication under water is so impracticable that it is seldom attempted. Stoney trains of live rollers are theoretically ideal as regards friction, but are mechanically troublesome to operate.

Roller-bearing wheels possess practically all the advantages and none of the objectionable features of journal-bearing wheels or live rollers, and the development in the science of their manufacture permitted their use for these valves, as the maximum load per wheel is about 27 000 lb., which is within the safe limit of load guaranteed by the manufacturers of Hyatt roller bearings. The section of wheel shown in Fig. 4 indicates the use of Hyatt roller bearings, this type being preferred on account of the flexibility of the Hyatt helical roller. These bearings will be lubricated and preserved from the oxidizing effect of water as the rollers will run in grease, and the design is such that the grease cannot escape except with considerable difficulty and can be easily renewed.

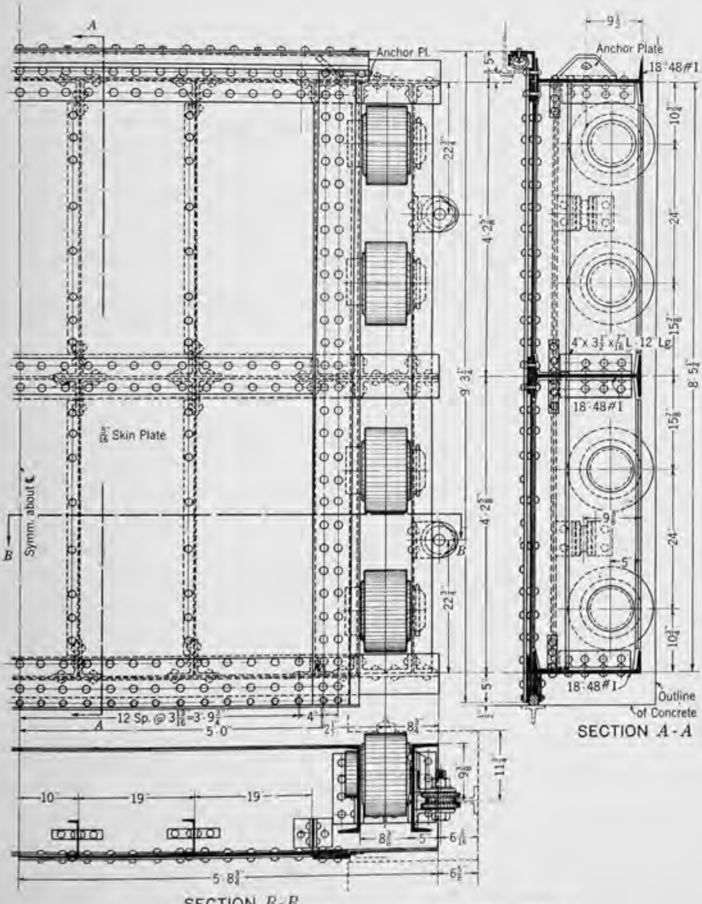

FIG. 4.—ILLINOIS WATERWAY: CULVERT VALVE GATE ASSEMBLY.

Valve Details.—Each valve is approximately 10 by 11½ ft. and will close an opening 9 ft. square. The valves are built up of three horizontal, 18-in., 55-lb. I-beams. The down-stream bottom flange of the lower beam is cut off and holes are provided through the web—the object being to facilitate the flow of water and operation of the gate under high heads. With this design of the bottom girder a vacuum will not be formed by the fast-flowing water when the gate is open only a few inches. The skin is placed on the up-stream face of the gate and consists of buckle-plates which will be under tension. The valves will be raised by chains connected to the operating machinery. A vibratory or chattering motion of the valves is limited to ¼ in. laterally by the clearance of the side rollers attached to the gate and to the same amount up stream by the clearance between metal parts of the gate and valve chamber.

The bottom water-seal will consist of a 1¼ by 1½-in. strip of rubber attached to the gate which will bear on a T-bar when the gate is closed. The side seals will be made by the contact of beveled edges of steel plates on the gate and attached to the masonry of the valve chamber. The top seal will be made by the contact of rubberized fabric hose attached to the gate and one leg of an inverted T-bar attached to the masonry.

Based on actual tests of the rising-stem valves of the Panama Canal locks, it is expected that the leakage of these valves under a 41-ft. head will not exceed 0.5 cu. ft. per sec.

APPENDIX 3 (A)

ILLINOIS WATERWAY: OPERATING MACHINERY FOR LOCK VALVES

By A. S. Grossberg,* Esq.

The valves on the Illinois Waterway are designed to be lifted by means of a single chain winding on a motor-driven chain drum (Fig. 5). Its dead weight is intended to seat the valve in the lowering operation.

The valve well extends through the concrete lock wall, with a niche left at the top to receive a chain sheave. This sheave acts as an idler to transfer the pull horizontally, through a cast-iron hawse pipe and a concrete groove, to a machinery pit below the lock wall, and at a distance of about 12 ft. from the valve well.

Originally, it was intended that all the drive machinery, including the motor and the limit switch, was to be set in this machinery pit below the lock-wall surface. It was found upon investigating the locks at other places where the machinery is partly, or entirely, below the lock-wall surface, that much trouble is encountered on account of dampness, hoar frost, and ice forming on the machined surfaces, and rapidly deteriorating the windings of the motors and starters. Of course, no such condition has been encountered in the Panama locks, where the machinery placed below the lock-wall surface has given no trouble, because it is not subject to such conditions.

For the foregoing reason, the machinery pits are utilized only for the chain drums and train gear of the operating machinery; and it has been decided to set the motors and limit switches above the lock wall, and to inclose them with sheet metal housings.

The chain passes over the idler sheave, through the hawse pipe and concrete groove, into the machinery pit, where it wraps around the chain drum (Fig. 5). This chain drum has been standardized for the deepest valve well (at Lockport), with enough wrappings of the chain to lift the valve beyond the full open position, and up to the idler chain sheave in the niche at the top of the valve well.

In case it is desired to remove the valve body from the valve well, the chain sheave can be unbolted and lifted out from the top of the lock wall, by a block and tackle and a temporary derrick.

The chain drum is keyed to the drum shaft, which is actuated by a spur-gear transmission to a worm-gear drive (with a reduction of 50 to 1). The vertical-worm shaft passes through the machinery pit roof-slab, and has mounted upon it above the lock wall two sets of miter gears. The lower set of miter gears transmits the travel to a motor drive shaft, and the upper set, to a hand windlass.

The motor rotates at 900 rev. per min. and is provided with a back-gear shaft. The total gear ratio from the motor to the chain-drum shaft is such

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that the vertical travel of 9 ft. to fully open or close the valve is performed in 1 min.

The motor shaft is direct-connected by a flexible coupling to an electric limit switch. The limit switch is designed to break the circuit and cut off the current to the motor at the closed and fully-opened position of the valve. (When desired to lift the valve out of its well, the limit switch can be disconnected electrically and made inoperative.) The limit switch is of the six-circuit type with cam contactors which can give three indicating positions of the valve in its vertical travel from fully closed to fully opened position.

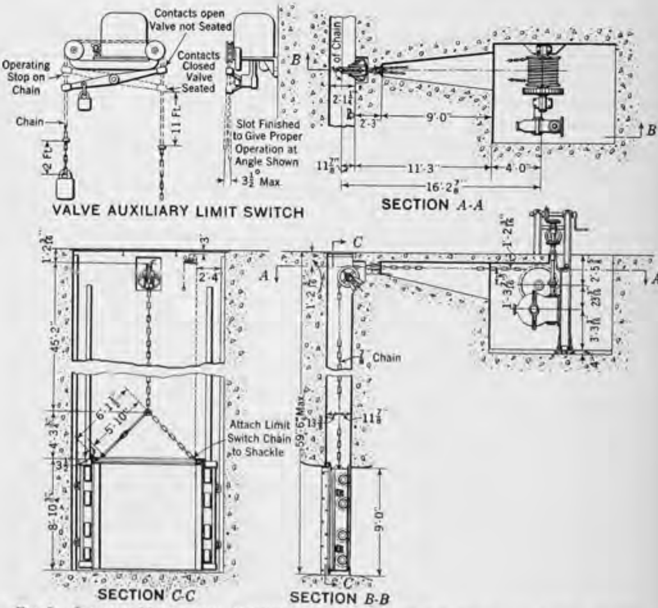

Fig. 5.—Illinois Waterway: Machinery and Methods for Operating Lock Valves.

In addition to the integral motor limit switch described, an auxiliary limit switch is provided to indicate the fully closed position. This is operated by the valve direct (Fig. 5). It has a set of contacts operated by a chain attached to the valve at one end and counterweighted at the other end. The chain and contacts are capable of being adjusted, so that the contacts are open at all times except when the valve is completely closed. When the valve is completely closed, the contacts are closed, which lights up an indicating lamp on the control stand. Until this indication is made, the operator knows that the valve has not been completely seated.

APPENDIX 4

LOCK VALVES, BLACK ROCK LOCK, BUFFALO, NEW YORK

By Lynn L. Davis,* M. Am. Soc. C. E.

Description of Waterway.—The Black Rock Canal is a slack-water channel around the rapids at the head of the Niagara River, extending from the head of the river at the foot of Lake Erie, down the east side, to the foot of Squaw Island, a distance of about 3.4 miles. The canal is separated from the river by the Bird Island Pier and Squaw Island, the pier and a dike along the east side of the Island forming the dam that maintains the canal at lake level.

The Federal project in Niagara River that preceded this waterway consisted of a 14-ft. channel cut through the rock reef at the head of the river and through the east branch to the northerly boundary of North Tonawanda, N. Y. This channel was ample for the old type of small lake vessels that were used in the lumber traffic, which previous to 1902 constituted most of the business on the river, but it was not suitable for the larger type of vessels used in the ore and grain traffic. When the problem of providing a waterway suitable for these larger vessels was presented, it was decided to abandon the old project and build a canal around the swift rapids at the head of the river. The principal reasons for this decision were the fact that cutting a wider and deeper channel through the reef would materially lower the level of Lakes Erie, Huron, and Michigan, and the impracticability of navigating the larger type of lake vessels in such a current with safety.

The Black Rock Canal follows the route of the old Erie Canal, which was built by the State of New York and opened to traffic in 1825. The portion of the old canal, of the Black Rock Harbor, and of the contiguous structures needed for the new canal was ceded to the United States by the State of New York in 1905, with the understanding that the Federal Government would build a canal and lock capable of accommodating the largest type of lake freight vessel.

The canal is 200 ft. wide on the straight reaches and from 240 to 300 ft. wide on the curves and angles. The project depth is 21 ft. at low-water datum, which is about 1.6 ft. below the mean lake level as determined by observations since 1860. The actual controlling depth is only about 19 ft., due to the lowering of the zero of the Buffalo gauge 0.35 ft. after the first three canal contracts were let; to a provision in the first contract whereby solid rock found at a depth of 20 ft. was not to be excavated; and to the fact that it is found to be impossible to maintain a rock-cut channel to within less than 2 ft. of the solid rock bottom, because of the presence of loose pieces of rock which are rolled or turned up by the current or suction of passing vessels.

Entrance into the river at the down-stream end of the canal is through the Black Rock Lock (Fig. 6), near the foot of Squaw Island, in what was

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originally a branch of the Niagara River. The lock is 650 ft. long between gates, 70 ft. wide, and 22 ft. deep over sills, and is capable of passing vessels 625 ft. long and of 68-ft. beam. There is an intermediate set of gates dividing the 650-ft. chamber into two chambers, one 400 ft. long and the other 250 ft. long. These gates were provided to accommodate the large amount of local and Barge Canal traffic. The average lift of the lock is 5.2 ft. The guard-gates are of steel similar in construction to the lock-gates. The upper guard-gate is equipped with swinging machinery and has two 30-in. filling conduits, thereby making provision for passing exceptionally long vessels. This increases the available length for deep-draft vessels about 40 ft., or to a total length of 665 ft., and for light-draft vessels, 55 ft., or for a total length of 680 ft. At present there are only two vessels on the Great Lakes too long to lock through the regular lock chamber, and it is believed that vessels of this length would not be suited to the Niagara River traffic on account of the difficulty of handling them with safety in the current.

Traffic Planned For.—The tonnage passing through the waterway at the time the canal project was adopted was approximately 1 500 000, about one-third of which was Barge Canal traffic. In 1927, the total traffic passing through the waterway had increased to 3 852 412 tons, about 40% of which was Barge Canal traffic. The increase has been comparatively uniform and present indications are that it is likely to increase to two or three times its present volume.

Size of Vessels.—As stated hereinbefore, the lock was designed to pass the largest lake freighter, which at that time was about 600 ft. in length. It was also designed to be safe for the large amount of small motor-boat traffic then using the river. This latter consideration determined the size of the filling conduits in order that the resulting agitation in the lock chamber would not be great enough to capsize the smallest motor-boat or canoe. Since that time the automobile has almost entirely displaced the motor-boat on the river until now very few boats of this type are using the waterway.

Navigation Season.—The navigation season for lake vessels usually extends from about April 15 to December 10, that for Barge Canal traffic from May 1 to December 1, and local traffic starts as soon as ice conditions will permit and often extends into January. The policy adopted on the canal is to operate as long as ice conditions will permit without damage to lock-gates or machinery, if the traffic demands it. During open winters vessels are locked through every month of the year.

Character of Foundations.—The lock walls are founded on solid limestone rock which is found from 34 to 43 ft. below river level. The approach walls are of concrete superstructure on timber cribs founded on a small stone base deposited in a dredged trench. The natural material of the bottom is largely sand, mixed with more or less mud and silt.

Materials Available for Construction.—The lock walls were built of concrete and the gate quoins of granite. Clean gravel containing the required quantity of sand was found in the Niagara River within two miles of the site of the work. It was possible to pump this mixture of sand and gravel from

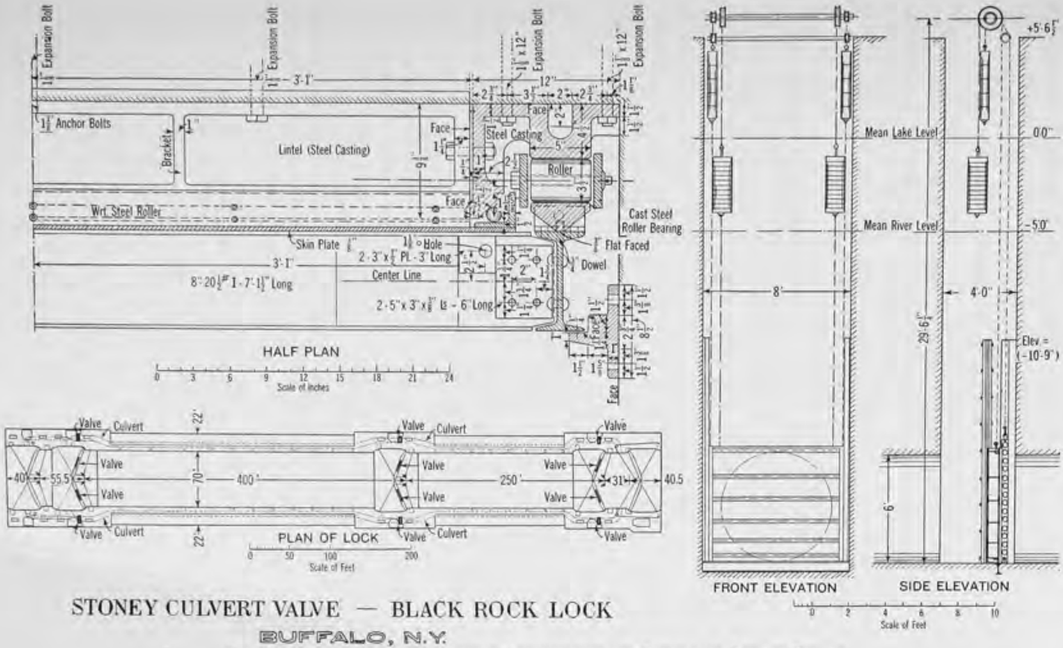

FIG. 6.—BLACK ROCK LOCK: GENERAL ARRANGEMENT AND DETAILS OF CULVERT VALVES.

the river, so that the sand content would not vary more than 5% from the required amount. When the variation was greater than this, correction was made by adding sand or gravel. Variations of less than 5% were allowed, additional cement being added when the sand was in excess, in order to insure mortar of the required strength.

Considerable wear of the lock-chamber side of the lock walls is evident after 15 years of use, which shows that the concrete mixture of 1:3:6 specified for this work was too lean for a structure subjected to as much wear and shock as a lock wall. There has been no appreciable settlement of the lock walls. The approach walls have settled from 6 in. to 1 ft. A settlement of about 6 in. was expected and planned for.

Elements Affecting the Type, Size, and Location of Valves and Culverts.—As already noted, the size of the filling and emptying culverts was affected by the large amount of small motor and pleasure boat traffic using the waterway at the time it was designed. Since there was no need to conserve the water used for lockages it was deemed unnecessary to provide for a floor in the lock chambers. This, of course, made it necessary to place the conduits in the lock walls. Since there was only one lock in the waterway it was necessary to keep this in continuous operation in order not to block navigation. The main river can be used for light-draft vessels, but the current is too swift for lake vessels to pass up, and the depth is not sufficient for them when loaded. Electric power could have been generated by a power plant at the lock, as the supply of water is inexhaustible, but this was considered inadvisable and uneconomical in view of the fact that Niagara Falls power was available at a low cost at all times. Duplicate power feeder lines connect Buffalo with the generating station at the Falls, and very little trouble has been had during the fifteen years the lock has been in operation.

Culverts.—The culverts consist of two 6-ft., steel, riveted pipes, one in each wall, moulded into the concrete. The intake and discharge ends of these conduits enter the lock chamber between the lock-gates and the guard-gates. Branch pipes 18 in. in diameter connect each main conduit with the lock chamber, eleven in each wall to the 400-ft. chamber and eight in each wall to the 250-ft. chamber. The valves for controlling the flow through the conduits are in wells, 4 ft. wide by 8 ft. long, extending from the top of the lock wall to the bottom of the conduit, one well in each wall opposite each lock-gate.

In order to provide for the use of the upper guard-gates for locking extra long vessels as hereinbefore described, two 30-in. conduits were installed, one in each wall, extending from the up-stream end of the 6-ft. conduit around the upper guard-gate. They are equipped with standard cast-iron, 30-in. gate valves, operated by hand.

Valves.—The valves for the 6-ft. conduit are the Stoney culvert type (Fig. 6), operated by 5-h.p. motors and counterweighted chain drive, all operating machinery being at the top of the lock wall. The valve-gates are built of structural steel, the movable leaf being 7 ft. 6 in. wide by 6 ft. 4 in. high, and are in a well 4 ft. wide by 8 ft. long. The guides and frame for the gates are of structural steel except the sill, which is an 8-in. I-beam set in the floor of the well with its top flush with the surface of the concrete and even with the bottom of the conduit. The general plan and arrangement are shown on Fig. 6.

Roller bearings are inserted between the gate and the cast-steel frame at each side, to overcome friction and to make it possible to operate the gate with a chain drive when the full water pressure is against it. The rollers for each side are held in a frame and operated by a chain drive geared to give one-half the speed of the moving gate.

To prevent excessive leakage through the valves, 1¼-in., round, caulking rods were inserted in a V-shaped groove between the valve-gate and the cast-steel frame and lintel, as shown on Fig. 6. The water pressure would force these rods into the groove tightly, so that very little leakage would take place. The results secured by the rods were satisfactory, but it was found that the constant vibration of the rod wore holes through the supporting member of the frame, and the rods fell out, obstructing the valve guides so that the valves could not be closed until they were removed. This required the services of a diver and was very hazardous on account of the smallness of the well and the presence of rods, chains, etc. As there was no need to conserve the water and the amount of leakage was not sufficient to affect the time of lockage materially, the rods were removed.

The valves are operated by a 5-h.p. motor in a shallow well or depression in the top of the lock-wall. These motors were originally equipped with limit devices that were supposed to stop the gates accurately at the fully closed and open positions. These never proved successful as they were not equipped with brakes and the momentum of the valve would carry it beyond the desired point. The friction seemed to be different under different conditions, thereby making it impossible to anticipate the over-run of the valve after the power was cut off. The limit devices were removed and the operator was required to stop the valve at the proper point. Indicators are furnished so that the position is evident to the operator and also for some distance along the lock wall.

The effort to reduce the surge in the chamber to a minimum to protect the small pleasure boats was entirely successful, as it was so slight that a properly handled canoe was safe in any place in the chamber or at the point of discharge below the lock. The time of filling or emptying the different chambers for a lift of 5 ft. was as follows:

650-ft. chamber (entire lock)	14 min.
400-ft. chamber	12 min.
250-ft. chamber	10 min.

As traffic in the canal increased, this excessive time of filling or emptying the lock was the cause of considerable delay. This delay became serious whenever several vessels were waiting for lockage in one direction. It was decided, therefore, that some improvement must be made whereby this time could be cut at least in half, or in less than half if it could be done without excessive surge. The most desirable method would have been the enlargement of the existing culverts, as this would have distributed the excess water and caused the minimum of surge. This method would have been very difficult and expensive and was discarded at least until other methods had been proved ineffective. It was finally decided that the least expensive method that would give results would be the installation of valves in the lock-gates, and it was believed that valves of moderate size would greatly expedite the time without causing excessive surge. Butterfly valves were installed, four in each of the three lock-gates near the bottom of the gate.

Butterfly Valves in Lock-Gates.—The lock-gates (Fig. 7) are of the horizontal girder, single-skin type with vertical stiffener plates between girders, spaced at intervals of about 7 ft. 10 in., thereby making open pockets on the girder side of the gates, about 7 ft. 10 in. long, from 3 ft. to 3½ ft. high, and 4 ft. horizontal depth in the central portion of the gate. Two butterfly valves were installed in each gate leaf, one each side of the middle of the gate between the second and third girder from the bottom.

The valves are of cast steel, the movable leaf being 7 ft. 3 in. long by 2 ft. 5½ in. wide, set in a cast-steel frame with clear opening of 7 ft. by 2 ft. 3½ in. through it. The valve leaf is 4½ in. thick, so when it is wide open the clear width of opening through the frame is reduced to 1 ft. 11 in. The valve frames are riveted and bolted to the web-plates of the girders and vertical stiffeners near the middle of the pocket, as shown on Fig. 7. The skin plates of the lock-gate are cut out in the pockets where the valves are installed, making an opening through that plate of 7 ft. 3 in. by 2 ft. 3 in., or considerably larger than the clear opening through the valve.

The original plans for these valves provided for a lining in the pockets giving a smooth passage or throat for the flow of the water, to prevent disturbance and to insure the best efficiency possible for the size of the opening. The cost of this lining was found to be excessive and was eliminated with the idea that some cheaper lining would be devised if found necessary at some later time. The reduction of time effected by the installation far exceeded the estimate, therefore the addition of a lining will not be necessary.

The valves are operated by an electric motor (Fig. 7), on the top girder of the gate, one motor for the two valves in each gate leaf. The motor turns a long shaft through a worm and chain of reducing gears, which is connected by cranks with rods attached at the bottom ends with the movable leaf of the valve. The throw of the crank is just sufficient to open or close the valves, thereby making it impossible to injure or break the gate by closing too hard. The motors are equipped with a limit device which stops the gate at the open and closed positions; however, if this device fails to operate no harm is done, as the valve continues to open and close until the motor is stopped.

The operation of these butterfly valves and the results obtained have proved very satisfactory. The surge created is less than was anticipated, probably due to the fact that the valves are about 18 ft. below the lower water level, thereby giving room for a considerable diffusion of the incoming jet of water before it reaches the surface. The time of filling and emptying the lock chambers has been reduced as follows:

650-ft. chamber (entire lock).....	from 14 min.	to 6 min.
400 " "	" 12 "	" 4 "
250 " "	" 10 "	" 3 "

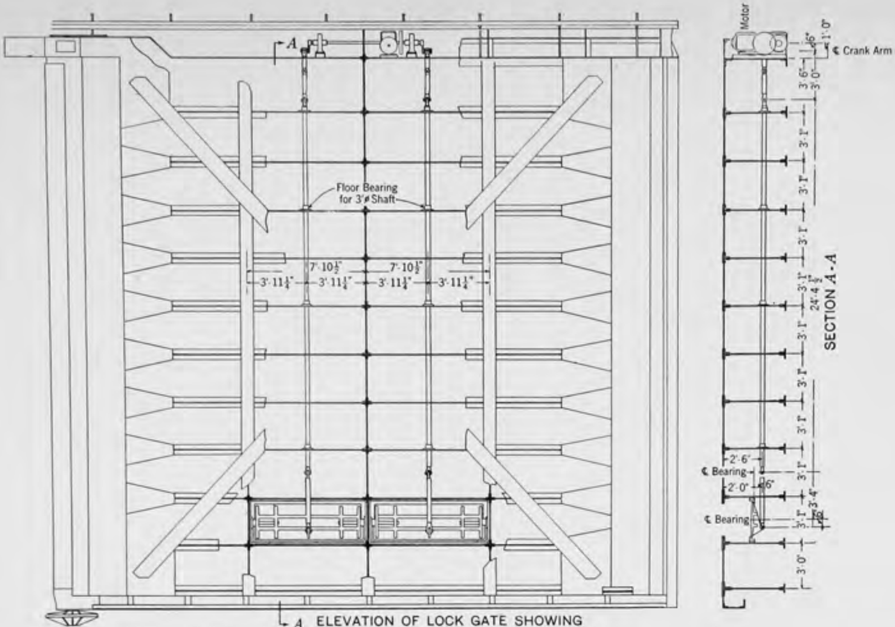

Fig. 7.—Black Rock Canal: Details of Valves in Gate Structures.

The time now consumed is only 43, 33⅓, and 30%, respectively, of the former time. The delays at the lock have been materially reduced, much to the satisfaction of the vessel-men using the waterway.

Conclusions.—The original conduit and valve system has proved satisfactory except in size. If the conduits had had about three times their present capacity, possibly with an increase in the number of discharge and intake branches, the system would have proved satisfactory in every respect. The use of riveted steel pipe is not recommended, as it is believed that better results could be obtained with collapsible steel forms. With such forms, rounding the entrance to the main and branch conduits would be easier, and this rounding would undoubtedly materially increase the capacity of the conduits.

The valves have given very little trouble. The use of the 1¼-in. packing rods could have been continued by reinforcing the supporting members at the bottom of the recess, but this was considered unnecessary, as there was no need of conserving water. With greater head against the valves it is believed that a positive worm-gear drive for the valve would be preferable to the chain drive. With a head of about 20 ft. against the valves, it is very difficult to raise them and they cannot be lowered against the flow resulting from that head.

The butterfly valves installed in the gates have been successful as an auxiliary system, but are not recommended as an original installation. This type of valve has many advantages over the Stoney culvert type, as it is practically balanced and requires very little power to operate. It can be made more nearly water-tight, and from this experience should be used in preference to the other type wherever possible.

APPENDIX 5

LOCK VALVES OF THE ST. MARYS FALLS CANAL

By Isaac DeYoung,* M. Am. Soc. C. E.

Waterway and Traffic

The St. Marys River, lying between the Upper Peninsula of Michigan and the Province of Ontario, Canada, is the connecting strait between Lake Superior and Lake Huron, the shortest navigable route being about 62 miles in length. At Sault Ste. Marie there is a rapid with fall of about 20 ft. in a distance of ¾ mile. The St. Marys Falls Canal, on the American side of the rapids, is provided with four locks and the Sault Ste. Marie Canal, on the Canadian side, has a single lock. All vessels bound to, or from, Lake Superior must pass one of these locks. This monograph relates to the locks of the St. Marys Falls Canal on the American side.

During the 74 years the canal has been in commission the yearly traffic to and from Lake Superior has increased from 14 503 in 1855 to 92 623 017 net tons in 1929—the maximum record. The record for maximum freight passing the canal in a single day was 752 645 net tons, which occurred on September 6, 1926, the total number of vessel passages on that day being 131. The maximum record of vessel passages in a single day was 161, which occurred on July 5, 1917. The average daily tonnage passing the canals during 1929 was about 376 512, and it is not unusual for the daily traffic to exceed 500 000 tons. In recent years the valuation of freight carried in a single season has exceeded $1 000 000 000. The canal is open to traffic about 8 months during the year.

In designing a lock to pass vessels from one level to another, the size of sluices or valve openings required depends upon the size of the lock chamber, the difference in level, and the period of time in which it is desirable to fill or empty the lock. The size of lock chamber is determined by the character of vessels and volume of traffic, but the time allowable for a single operation depends on the number of lockages that must be made within a given period.

Rock is ideal for the foundation of a lock and is the material found at St. Marys Falls Canal. A lock built on other than solid rock, requires broader bases for its support than one on the firmer foundation. The wider walls, having greater cross-sectional areas, permit the construction of large passages within the walls without any great additional cost. In the narrower walls, built on rock foundations, the designer is more or less limited in planning the filling passages and the problem suggests building them under the lock. A study of side culverts was made in designing the Davis Lock, and this method proved more expensive. It is concluded that for locks built on soft bottom, requiring walls with broad bases, side culverts would be

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economical, but with rock bottom, culverts under the floor are preferable. The relative time required to fill a lock through side or bottom culverts depends on the size of passages, disposition of openings, length of curvature, and, so far as rapidity of filling is concerned, either method might be used. In a paper by the late H. F. Hodges, M. Am. Soc. C. E., on "Action of Water in Locks of Panama Canal,"* it is shown that excellent results may be obtained with side culverts as regards rapidity of filling. The coefficients of flow are about 0.85, whereas in the Davis Lock they are about 0.75, as described by L. C. Sabin, M. Am. Soc. C. E., in a paper entitled, "Filling and Emptying the Third (Davis) Lock at St. Marys Falls Canal."†

Where a dam across a river starts near the river wall of a lock, an ideal arrangement for filling and emptying small locks seems to be obtainable by having the culverts extend directly through the river wall. However, the number of valves required, the possible distribution of flow into the chamber, and the question of possible slope in the river from the upper gates to the dam, and from the dam to the lower gates, would have to be carefully considered.

Dimensions of Vessels

In 1904, only one lake vessel of 500 ft. length used the canal. In 1928, there were 199 vessels using the canal having lengths of 500 ft., or more, and of this number there were 74 with lengths of 600 ft., or more, the largest lake freighter being 633 ft. long by 70-ft. beam. Vessels of this class have a carrying capacity of 10 000 tons, or more. The largest single cargo carried during 1928 was 16 650 net tons, which is the maximum cargo of record. The number of individual registered vessels using the canal and locks during 1928 was 739, and the total number of passages was 19 286, an average of 85 vessels per day.

The volume of traffic is such that at times the lockage facilities are taxed to the utmost. Because of the congested traffic it was desirable, in the design of the new locks, to provide for filling and emptying the lock as quickly as it would be safe to raise or lower a vessel.

General Plan of Locks

There are four locks at St. Marys Falls Canal (Fig. 8), all in usable condition. The Weitzel Lock, completed in 1881, designed principally by the late Alfred Noble, Past-President, Am. Soc. C. E., under the direction of the Corps of Engineers, U. S. Army, is 515 ft. long between operating gates by 80 ft. wide, narrowing to 60 ft. at the gates. The Poe Lock, completed in 1896, is 800 ft. long between operating gates by 100 ft. wide. The Davis and Fourth Locks, completed in 1914 and 1919, respectively, each have a length of 1 350 ft. between service gates and a width of 80 ft. The Weitzel Lock has not been in use since 1918, owing to increase in size of lake vessels and to insufficient draft.

* *Professional Memoirs*, U. S. Corps of Engrs., January–February, 1915.
† *Loc. cit.*, March–April, 1917.

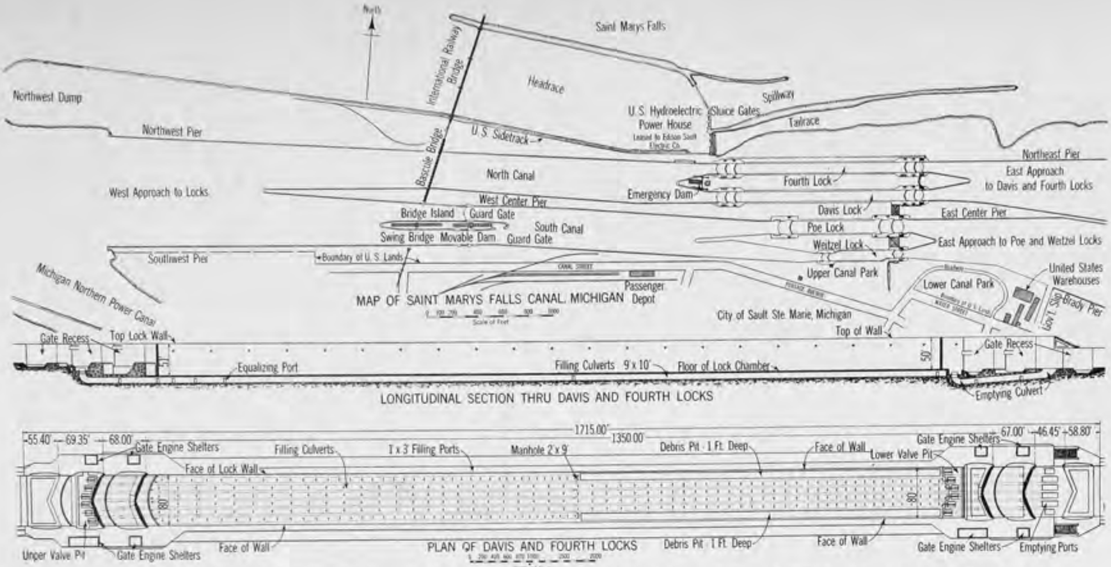


Fig. 8.—St. Marys Falls Canal: General Arrangement of All Locks, Together with Details of the Largest Units.

In addition to these four American locks there is also a lock on the Canadian side of the river having a length of 900 ft. between gates and a width of about 60 ft.

The Weitzel and Poe Locks are of similar construction, having cut limestone masonry with timber-lined floors and culverts. The Davis and Fourth Locks are built of reinforced concrete masonry throughout.

Culverts and Ports

General.—The filling and emptying culverts of all these locks are under the floors of the chambers. All the culvert valves are of the butterfly type, and operated by hydraulic power, each valve being operated by a separate single-stroke engine. The axes of the valves of the Poe and Weitzel Locks are transverse to the locks, and those of the Davis and Fourth Locks are longitudinal with the locks. There are two filling and two emptying valves in the Weitzel Lock, and six valves each for filling and emptying in all the other locks. The sizes of valves and culverts of each of the locks are given in Table 3.

TABLE 3.—Data on Locks at St. Marys Falls Canal.

Lock.	Valve Opening.		Culverts.			Ports.	
	Dimensions.	Clear opening area, in square feet.	No.	Size.	Area.	No.	Total area, in square feet.
Weitzel.	9 ft. 11¼ in. by 7 ft. 10½ in.	65	2	8 ft. by 8 ft.	64	58	174
Poe	7 " 11 " by 9 " 11 "	68	6	8 " by 8 "	64	214	642
Davis	12 " 0¼ " by 9 " 0¼ "	89.4	6	9 " by 10 "	88.07	324	1 064
Fourth	12 " 0¼ " by 9 " 0¼ "	89.4	16	9 " by 10 "	88.07	328	1 086

As stated, the culverts of the Weitzel and Poe Locks are timber lined. Two rows of rods, 1¼ in. in diameter, spaced 18 in., pass through the culverts, being fox-wedged into the rock bottom, and extending through the floor of the lock. The culverts of the Davis and Fourth Locks are anchored into the rock with the bulb rods which pass through the concrete walls, giving the culverts a clear and unobstructed opening.

In general, it may be said that in locks in service the usual ratio of the horizontal cross-section, or area of the lock chamber, to the cross-sectional area of the valve and culvert openings is between 200 and 300, although there are some cases where this ratio is outside these limits, values as low as 140 and as high as 370 being found.

Sizes and Areas.—In the Weitzel Lock there are two filling culverts, 8 by 8 ft. in section, extending the length of the lock. The ratio of the lock area to the culvert area is 295. Each culvert has twenty-nine ports, 3 sq. ft. in area, to communicate with the chamber and having a combined cross-sectional area of 174 sq. ft. Each port is made up of three openings of 6 by 24 in.

The filling and emptying culverts of the Poe Lock are 8 by 8 ft. in size, arranged in pairs. The outside filling culverts extend about one-half the upper length of the chamber, or about 350 ft. each, having thirty-five ports to communicate with the lock chamber, each having an area of opening of 3 sq. ft. The four inner filling culverts are about 685 ft. long, extending the full length of the lock to the bulkhead just above the emptying well. The middle pair have thirty-six ports each, equally spaced the full length of the lock, but the intermediate pair have no openings in the upper half, but thirty-six ports each in the lower half, the spacing between ports being one-half that of the other long pair. There are, therefore, 214 filling ports having a combined area of 642 sq. ft. As in the Weitzel Lock each port is composed of three openings 6 by 24 in. in size. The ratio of the horizontal lock area to the culvert area is about 212.

In the Davis and Fourth Locks, the general plans of which are shown in Fig. 8, there are also six filling and six emptying culverts, each having dimensions of 9 by 10 ft., with rounded corners, and a cross-sectional area of 88.07 sq. ft. As in the Poe Lock the outer filling culverts extend under the upper half of the lock and have a length of 675 ft. The four inner culverts extend under the entire length of the lock, and are about 1 370 ft. long. The outside culverts are made shorter to save expense, and, as the valves in these culverts are opened after the head is somewhat reduced, the inflow is made adequate by placing the ports closer together. Each outer culvert has forty ports, and each of the four inner culverts is provided with fifty-nine 1 by 3-ft. ports. Each outer culvert in both these locks has also a large manhole at the lower end, 2 by 9 ft. in size. The four inner culverts of the Davis Lock also have manholes of this size at the lower end, but in the Fourth Lock these manholes are 2 by 3½ ft. In addition, in the Davis Lock there are two 2 by 2-ft. manholes at the upper end in the middle pair of culverts, but in the Fourth Lock there are similar manholes at the upper end for each of the six culverts. There is, therefore, a total of 1 064 sq. ft. of port area in the Davis Lock and 1 036 sq. ft. in the Fourth Lock. The spacing of the 1 by 3-ft. ports diminishes from the upper to the lower end of the chamber, the distance between ports at the upper end of the chamber being twice that at the lower end. The purpose of such spacing is to distribute the flow in the chamber area uniformly and to reduce the longitudinal current as much as possible.

Relative Areas and Volumes.—The length of these two locks (Davis and Fourth) is 1 350 ft. (Fig. 8). This is the distance between the inner operating gates. There are two pairs of operating gates at each end of the lock—spaced 69 ft. between centers at the upper end and 67 ft. at the lower end—which are always used in every lockage as a safety measure. The volume of water between the lower pair is always moved in each lockage, making a length of chamber of 1 417 ft. The ratio of the horizontal area of water moved in the lock chamber in a lockage to the cross-sectional area of the culverts is 217.

Considering the Davis Lock as a whole, the ratio of total port area to the horizontal cross-section of volume of water moved in each lockage is

0.0093. Similarly, for the Fourth Lock this figure is 0.00905. For the upper half of the Davis Lock, based on 1 417-ft. length, there are one hundred and eighty-four 1 by 3-ft. ports, two 2 by 9-ft. ports, and two 2 by 2-ft. ports, a combined area of 596 sq. ft. In the lower half there are one hundred and thirty-two 1 by 3-ft. ports and four 2 by 9-ft. ports, having a total area of 468 sq. ft. In the Fourth Lock there are in the upper half one hundred and eighty-four 1 by 3-ft. ports, two 2 by 9-ft. ports, and six 2 by 2-ft. ports; a combined area of 612 sq. ft. In the lower half, there are one hundred and thirty-two 1 by 3-ft. ports, and four 2 by 3½-ft. ports, a total area of 424 sq. ft. The ratio for the upper portion of port area to horizontal area of the Davis Lock is $\frac{596}{56\ 800} = 0.105$, and the ratio for the lower half is $\frac{468}{57\ 700} = 0.0081$. The similar ratios for the Fourth Lock are 0.0108 for the upper, and 0.0074 for the lower, end. The filling port area of the lower half of the lock is 78½% of the upper half in the Davis Lock, and 69% in the Fourth Lock.

Filling Rates.—As the valves of the outside culverts are not opened in practice during the early part of the filling, the port area in the lower half of the lock is greater than in the upper half, before the outside culvert valves are opened, that is, while a high head prevails, although this result is modified to some extent by the large communicating passages, or equalizing ports, between the adjacent culverts. In filling the lock the flow begins to show first at the upper end, where the water momentarily rises faster than at the lower; but the surface becomes nearly level in the first minute. The lower end is then higher for about 1 min. Thereafter, the level fluctuates back and forth, the difference being about 1 ft., gradually reducing until the chamber is filled. The slight reduction in port area in the lower half, and the small increase in the upper half of the Fourth Lock, as compared with the Davis Lock, is considered to give somewhat better results in preventing the extreme fluctuations. However, with the plan of operation in use, the variations of water level in these locks do not ordinarily cause any appreciable amount of surge of the vessels.

If the six valves at the upper end are suddenly opened to fill the lock, the level in the canal immediately above the lock will drop 2 ft., while the level in the lock is rising 3 ft., so that the head on the valves is decreased 5 ft. within 1 min. after the valves are opened. A little later the level rises in the chamber and continues to rise slowly until the lock is full, so that the head is continuously less than it would have been had the level of the upper pool not been affected.

In actual practice the valves are opened gradually. A four-way operating valve is placed in the operator's house on the lock wall, and so connected with piping as to operate the valve engines in pairs, there being three operating valves at each end of the lock. The valves to the central culverts are opened first, and those on the outside culverts after the filling has progressed sufficiently, and under reduced head, so as to prevent surge.

If the six culvert valves were opened simultaneously the lock could be filled in about 6 min., but in actual practice about 10 or 11 min. are consumed.

According to the law of flow through a submerged orifice under a falling head the lock is three-quarters filled or emptied in one-half the time required to equalize the levels completely. That is, for a constant area of submerged opening, and constant levels of the upper and lower pools, the average rate of flow throughout the first half of the time required to equalize is three times the average rate of the last half of the time. The last foot or so is equalized very slowly. It is evident that the area of opening of valve and culvert should be ample, so that the time consumed in the latter stages of filling or emptying will be reduced to a minimum, although it will be found inadvisable to open all the valves at the high head.

Plan of Operation.—The schedule adopted with the latest locks built at St. Marys Falls Canal is, first to open the central pair of valves very slowly, consuming about 2 min. in the operation. After a lapse of 3 min. the intermediate pair are opened slowly and then the outside pair 3 min. later. It is noted that the area of opening is gradually increased under a reducing head. Under this method the maximum rate of rise in the chamber is about 3½ ft. per min. The tendency to surge under this schedule is so small that the stress on mooring lines is very slight.

The several culverts communicate with the adjacent ones by large openings through the vertical walls separating them, these openings being about 28 sq. ft. in cross-section. Each outer or short culvert communicates with the adjoininig one through six of these openings, and the four longer culverts communicate one with another through seven openings. The effect of this is to distribute the flow throughout all the culverts, although all the valves may not be open, thus giving better distribution of flow as well as relieving the horizontal pressure on the culvert walls.

In the emptying culverts there is no attempt at distribution. All the water is drawn from the valve well just above the two pairs of lower gates, and flows through the culverts under the miter walls, discharging into the lower pool. As the valves are operated, this results in a mean velocity of about 2¾ ft. per sec. as a maximum in a vertical cross-section of the lock chamber, near the lower end, gradually reducing toward the middle of the lock. There is no difficulty in holding a vessel in position with this velocity, the only inconvenience being that in case the bow is so close to the lower gate as to be over the whirl that forms over the valve pit, the bow is sometimes drawn away from the lock wall.

Valve Details

Limitations in Design.—As far as known, the two latest locks at the Sault are the longest locks in the world. With the culverts under the lock floor, and of large dimensions, it is practically necessary for each valve unit to be complete in itself. As to design, a valve operated direct from machines on the lock wall through shafting, rocker arms, etc., involves complicated parts of large dimensions. With culverts in the lock walls, the mechanism can be placed directly overhead and the designer is not so limited as to the type of valve to be selected. A butterfly valve is simple and rugged, has few working parts, and these can be made so strong that the chances for accidental damage are remote.

There has been no delay to operation on any of the Sault locks on account of valve trouble since 1898, and this was due to a leak in the pressure piping of the Poe Lock. Prior to this, a delay was caused in the Weitzel Lock, owing to a broken trunnion. The trunnions of the Weitzel Lock are made of cast iron and are cast hollow. It may be noted that such parts or machines of this nature should not be made of cast iron, although cast metal may be used for the main part of the valve. The fluid used in the pressure system is hydraulic oil, which has these qualities, that it is a good lubricant, is free from acids, and remains liquid at 2° Fahr. In former years it was customary to use water in the pressure system during the summer months and change to oil in the freezing time of the year. In recent years oil has been used during the entire season. The loss of oil from leakage, etc., when oil is used throughout the season, has been about 5 bbl. per lock per season. The cost of this oil is from 14 to 17 cents per gal.

The gates used in the regulating works to control the level of Lake Superior at the head of St. Marys Rapids are of the Stoney type. These gates are hand-operated through a train of gears. In the construction of this type of gate many moving parts are involved and the leakage is considerable in the local examples.

Valves are usually constructed of structural steel, cast steel, or cast iron. Castings ordinarily resist corrosion much better than structural steel. In localities where steel rusts rapidly preference should be given to cast metal, if possible, to prevent rust. In the latest locks at the Sault the valve frames are practically entirely of steel. The valves themselves are 74½% cast steel. The parts of the engines are about 90% castings—mostly cast iron.

With these considerations and data at hand the valves may be properly proportioned, placed, and designed, giving due consideration to the method and speed of operation.

Sizes.—The Poe Lock, built in 1887 to 1896, 800 ft. long by 100 ft. wide, the largest one then in use, could be filled in about 8 or 9 min. with about 1 sq. ft. of culvert area to each 212 sq. ft. of horizontal cross-section of lock chamber. The Davis and Fourth Locks being about 600 ft. longer and 20 ft. narrower, it was anticipated that more difficulty would be experienced in distributing the water entering the lock so as not to cause the vessel to surge in the lock chamber, and that on this account it might not be practicable to allow the new lock to fill as rapidly as the Poe. As stated, the two new locks have 1 sq. ft. of culvert area to each 217 sq. ft. of horizontal lock area.

In the Weitzel Lock, 515 ft. long by 80 ft. wide, built from 1870 to 1881, the valves are 7 ft. 10½ in. by 9 ft. 11¼ in., with axes on the longer dimension, and have net openings of 65 sq. ft. The two culverts each have a net section of 64 sq. ft. The axes of the two valves are at right angles to the lock axis. The engines are suspended overhead in the valve pit and are connected to the valve body by a cast crank bracket. The construction in the main is similar to that of the Poe Lock.

The valves of the Poe Lock, having rectangular dimensions of 7 ft. 11 in. by 9 ft. 11 in., with axes on the shorter dimension, each have a clear opening of 68 sq. ft. against a cross-sectional culvert area of 64 sq. ft. The valves of the Davis and Fourth Locks, having rectangular dimensions, 9 ft. 0¼ in. by 12 ft. 0¼ in., with axes on the longer dimension, each have a clear opening of 89.4 sq. ft., with a corresponding culvert cross-sectional area of 88.07 sq. ft.

Structural Features.—In the Poe Lock the valves and valve frames are of structural steel with forged steel trunnions and cast-steel housings with bronze bushings. The axes of the valves are at right angles with the lock axis. The engines are suspended overhead in the valve pit and connected to a crank bracket riveted to the valve body. The trunnion bearings are 11 in. in diameter and 10½ in. long. To provide for ease of repairs in case of wear of the trunnions, steel trunnion bands, or collars, ½ in. thick, are shrunk on to the bearing ends, which can be removed and renewed in place without the removal of the valves. Phosphor bronze bearings are provided in the bearing boxes. Fig. 9 shows the general construction and location of the valves with respect to the culverts.

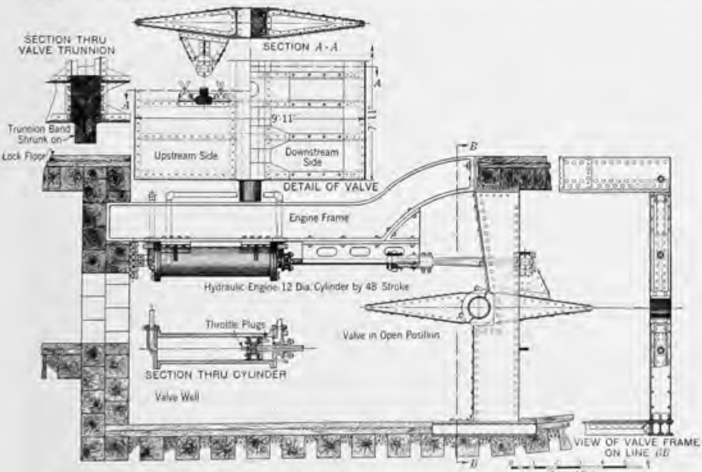


FIG. 9.—ST. MARYS FALLS CANAL, POE LOCK: DETAILS OF HYDRAULIC VALVE AND OPERATING ENGINE.

The valves of the Davis and Fourth Locks are made of a cast-steel skeleton, having a cast central barrel to which are bolted cast triangular frames. Cast-steel trunnions are taper fitted and keyed into the ends of the barrel. On one end the trunnion is extended and fitted with a cast-steel crank, through which the valve is operated. The valve body is covered on both sides with ½-in. steel plates. The trunnion bearings are 12¼ in. in diameter and 10 in. long. As in the Poe Lock, steel trunnion bands, ½ in. thick, are shrunk on to the axles, which can be easily renewed in case of wear. Phosphor bronze was originally provided for the bearings, but has been gradually replaced in part by manganese bronze having a high ultimate strength and yield point.

The valve frames (Fig. 10) are of cast steel and have flanges 12 in. wide which extend into the masonry of the culvert. The valve trunnion centers are 12 in. above the floor of the valve well, so that in overhauling and repair work the parts are above any water or débris that may be on the well floor. The frame is cast in four parts, and bolted together at finished flanged joints. The inner edge of the frame is finished to a rectangular shape having a clearance between the valve and frame of ⅛ in. The leakage through this opening has never been measured, and it is believed that it cannot be determined with any degree of accuracy. Based on theoretical computation, the leakage through one valve may reach 11 cu. ft. per sec. under maximum head, resulting in an average velocity in the culvert of ⅛ ft. per sec. and producing a velocity head of 0.0002 ft. The leakage is not perceptible in the operations. The valve frame was completely assembled before it was placed on its concrete foundation. The weight of each frame is nearly 6 tons. The weight of the valve is about 7½ tons. Figs. 10 and 11 are views taken during the progress of erection of these valves.

Engines.—In all the locks each valve is operated by a separate submerged engine directly attached to the valve (Figs. 11 and 12). The engines are straight line, cylinder, hydraulic-operated, with cross-head connected to the valve through a connecting rod and a crank bracket on the valve blade in the Weitzel and Poe Locks and through a bell-crank in the Davis and Fourth Locks. The cylinders of the Weitzel Lock engines are 15 in. in diameter by 48-in. stroke. The cylinders of the Poe, Davis, and Fourth Locks are 12 in. in diameter and have 48-in. stroke.

The piston travel of the engines in the Weitzel and Poe Locks at the ends of the stroke is regulated by a bronze throttle plug, rigidly attached to the piston, which moves into the opening of the cylinder through which the fluid passes, practically closing the passage (Fig. 9). In the original installation of the Davis Lock the throttling was effected by an elongated inlet, reducing to a narrow slot at the ends. This was fairly effective, but it did not entirely prevent the piston from coming against the cylinder head, as some of the fluid would pass around the piston packing and cause leakage around the cylinder flanges, thus breaking the bolts fastening the heads to the cylinder. In the Fourth Lock a new throttling means was devised, and since has been adopted in the Davis Lock, in which a sliding throttling plug (Fig. 12) was introduced into the piston which moves into the cylinder-head opening at the ends of the strokes, completely shutting off the passage of the fluid. This has worked very effectively.

The hydraulic pressure for operating the Weitzel and Poe Locks is produced directly by hydraulic turbines and in the Davis and Fourth Locks with electricity generated by water power, by which the hydraulic pressure is produced with pressure pumps through accumulators on the lock walls and connected by piping to the engines.

Criticism of Details

Maintenance and Repair.—Although the valve trunnion bearings are considered to be of ample dimensions, especially in the Davis and Fourth Locks,

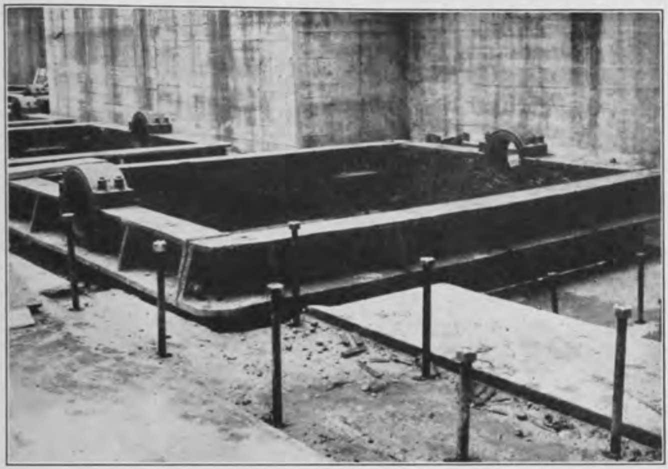


FIG. 10.—ST. MARYS FALLS CANAL: CAST-STEEL VALVE FRAME, DAVIS AND FOURTH LOCKS.

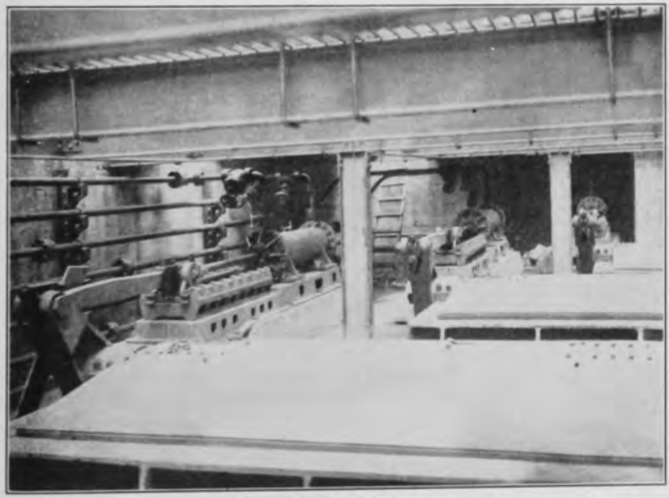


FIG. 11.—ST. MARYS FALLS CANAL: UPPER VALVE PIT, FOURTH LOCK, JUNE 18, 1919.

under ordinary mechanical working conditions, it is considered that, in view of the fact that they must operate for a long period without attention, the working results would be better were they provided with greater bearing areas. During the closed season, when the machinery is being overhauled and repaired, the bronze bushings and shrunk-on collars at times require renewal on account of scoring. The trunnion bands require renewal after about 10 years' use, and the bronze bushings last about 5 years. With larger bearings, reducing the unit pressure, less frequent renewals might be sufficient. Also, if the collars were made of nickel steel, and the bushings of manganese bronze, the length of service would be increased. The term, manganese bronze, is frequently applied to what is a manganese brass. Bronze is a much better alloy than brass, and a manganese brass should not be used. These journals are lubricated only during the closed season, when the machinery is overhauled. More frequent lubrication would produce longer use of the bearings.

A troublesome experience in the scoring of the Davis Lock gate pintles has been corrected by lubrication, the lubricant being forced to the bearing as desired. Before this gate pintle was lubricated the methods used at other locations were investigated. As far as could be learned lubrication had not been provided on any other important locks.

This provision, as well as making the pintles of nickel steel and the bushing cups of Parson's manganese bronze, has proved to be very effective, and these parts are due for a long period of use without examination and repair.

Pressure System.—To operate the valve engines, hydraulic pressures of 130 lb. per sq. in. in the Weitzel Lock, 200 lb. in the Poe Lock, and 285 lb. in the Davis and Fourth Locks, are used. The cylinders of the Weitzel Lock engines are 15 in. in diameter and those in the other lock engines, 12 in. in diameter. High working pressures are objectionable on piping joints and on the entire mechanical equipment. The higher pressures cause leakage of the working fluid (which is oil in the Sault Locks) through the glands and moving parts. The pressure pumps also are working under a heavy strain. Working pressures of about 150 lb. per sq. in., if possible, are desired. To obtain this result the cylinders of the engines should be of greater diameter, thus making it possible to reduce the working pressure and, with the greater diameter of the cylinder flanges, to increase the number of cylinder-head bolts, which is very essential in preventing leakage.

As shown in Fig. 12, in the Davis and Fourth Locks the pressure fluid as it enters the cylinder must pass through the cylinder head on account of the throttling device which operates through the head. It is important that the piping be attached to the cylinder and not to the head, because it is desirable not to disturb the pipe connections to the engine in case of repairs. The inlet to the cylinder is thus designed so that the pressure fluid passes through a return passage in the end of the cylinder.

Piston Position.—There is another feature worthy of note in the design of the valve engine, which, however, does not affect its operation. When the engine is in its idle position, that is, when the valve is closed, which is ordinarily the position when the lock is not operated, the piston rod should be

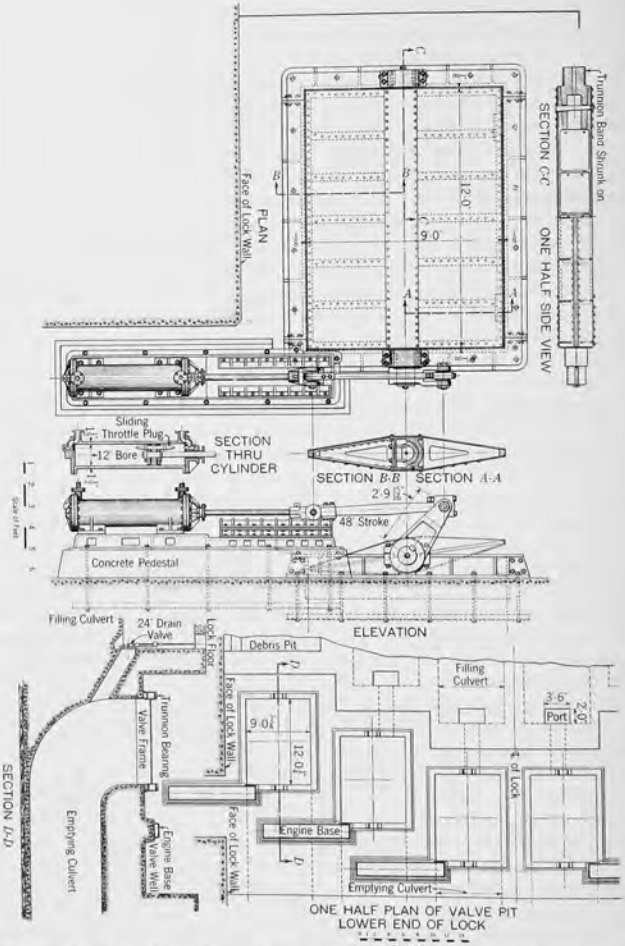


FIG. 12.—ST. MARYS FALLS CANAL, DAVIS AND FOURTH LOCKS: GENERAL ARRANGEMENT AND DETAILED SECTIONS OF VALVES AND OPERATING MECHANISM.

in the cylinder. This position can be obtained by the proper placing of the crank. It will be readily understood that in this position the piston rod will not be subject to the lodgment of débris nor liable to corrosion. This condition obtains in the Weitzel and Poe Locks, but not in the Davis and Fourth Locks.

The piston head should be made of generous length, to provide greater bearing area and to relieve the leather cups of excessive wear.

Conclusion

The type of lock valve and method of operation as adopted at St. Marys Falls Canal, which type has been in use since 1881, has given very satisfactory service, with infrequent interruption.

APPENDIX 6

LOCK VALVES AT CHEMULPO, KOREA, AND NEW ORLEANS, LOUISIANA

BY HENRY GOLDMARK,* M. AM. SOC. C. E.

TIDAL LOCK AT CHEMULPO, KOREA

General Description.—The six valves used in this lock are of the type known as "wagon-body" valves, which roll on four large wheels secured to the main casting. This form has been used extensively on Canadian canals and also in the United States, and was adopted for the large dry dock at Panama.

The work consists of an inclosed basin, the so-called Jinsen Dock, in which vessels are moored, and a tidal lock connecting the dock with the outer harbor. The dock is about 700 ft. wide and 1 500 ft. long. A minimum depth of 27.5 ft. is maintained at all times. When the tide falls below this normal dock level, the gates are closed and vessels locked in and out. The lock has a clear width of 60 ft., a length of 424 ft. between gates, and a depth of 48 ft. The walls are of mass concrete with heavy floors 10 to 15 ft. thick, reinforced with steel rails.

The filling system consists of a longitudinal culvert 6 ft. wide and 7½ ft. high in each side wall, with six horizontal 3 by 4-ft. outlets, the bottoms of which are 7 ft. above the lock floor. The culverts for emptying the lock are of the same size as the filling culverts, and discharge through outlets in the lower gate recesses. There are six valves in all, which are in the main culverts, four being in daily operation, and the other two, at the ocean end, being utilized only when the lock is to be pumped out.

The steel lock-gates are of the mitering type with air chambers, and, like the valves, are operated by electric motors. Four capstans, also driven by electricity, assist in the handling of vessels.

The general plan of the valves at the upper end of the lock and the machinery for raising and lowering them is given in Fig. 13. The double valves at the lower end have a common operating mechanism with a single motor.

Valves and Frames.—Wagon-body valves, for openings of moderate size, are simpler and cheaper than Stoney valves with loose trains of small rollers, and move quite as freely. They have generally been built of structural steel, although cast iron was preferred for the Jinsen Dock in order to reduce the corrosion in salt water. Careful workmanship is necessary to insure an equal distribution of the hydrostatic load over the wheels, and their chilled treads should be ground accurately to size.

The design adopted for the fixed frames in the walls (Fig. 14) was the result of careful study and is believed to have special merits. Much trouble has been experienced with large valves in setting the frames correctly in the concrete, especially when the side castings are not rigidly connected. In

* Cons. Engr., New York, N. Y.

many cases the main frame does not extend above the culvert opening, and small guide-rails are used for the upper part of the gate travel, which it is almost impossible to set accurately. In some large locks recently built the great care required in placing the fixed frames interfered seriously with rapid and economical concreting. Nevertheless, it was afterward necessary to go to heavy expense in correcting errors in setting.

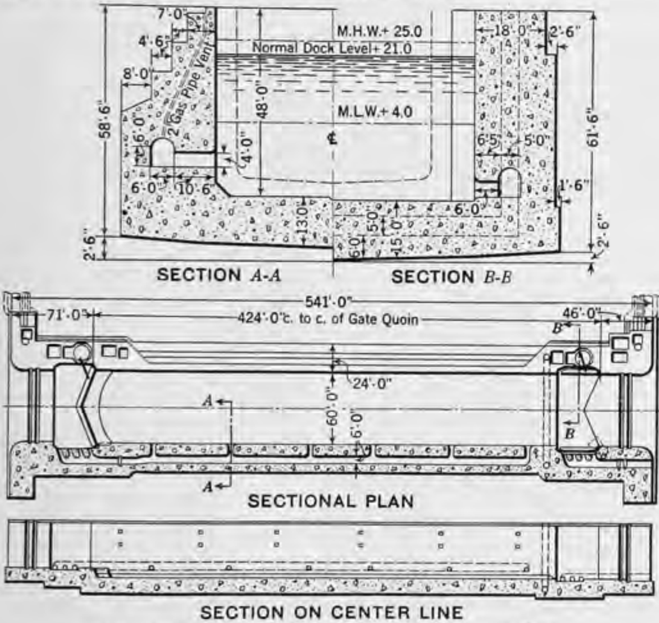


FIG. 13.—TIDAL LOCK AT CHEMULPO, KOREA, GENERAL PLAN.

The frames here adopted are made long enough to guide the valves through their whole stroke (Fig. 14), and have heavy cross-pieces at top and bottom. These maintain the correct distance between the side pieces and permit the entire frame to be handled as a unit. Even if it should be slightly out of plumb, the valve would work properly, as the stem has a flexible connection at the top. All the frames were assembled in the shop in order to guard against errors. The joint between the valve and frame is made tight at the sides and top by rubber seals and at the bottom by a strip of babbitt metal on which the valve rests.

Mechanical Operation.—The valve is raised and lowered by a stem made of 6-in. double extra-heavy pipe, which is fastened to a pin at the bottom and screwed at the top into a cross-head nut of phosphor bronze. The latter is moved up and down by a revolving screw and comes to rest against springs at the top and bottom. It is guided by steel bars riveted to a suspended structural frame. There is a roller thrust bearing to resist the downward force, while the small upward reaction is taken by a shoulder in the casting. The screw is driven from the motor shaft by a gear-and-pinion reduction and two bevel gears. The small gears, motors, and other electrical equipment are in a separate machinery room, the horizontal shaft passing through a stuffing-box in the dividing wall so as to exclude water from the machinery (Fig. 14).

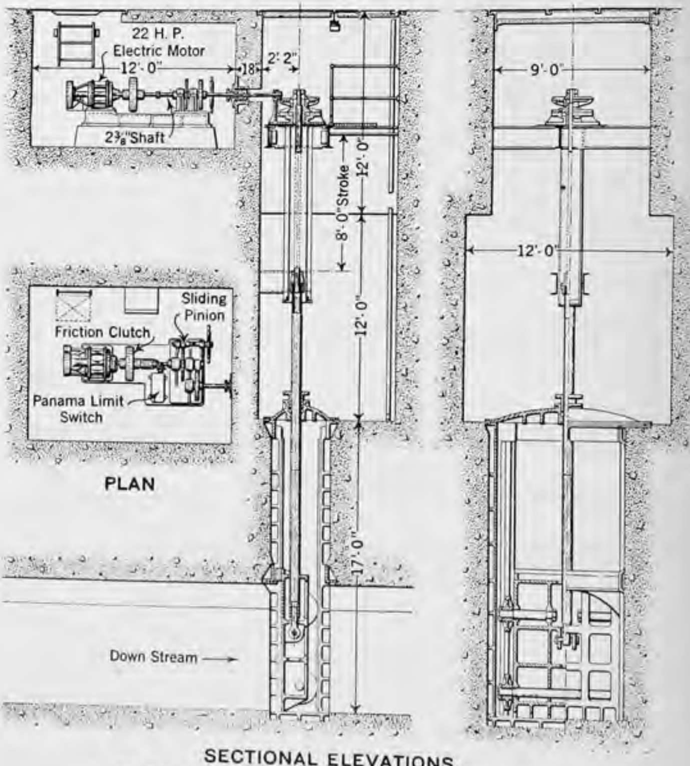


FIG. 14.—CHEMULPO LOCK: DETAILS OF VALVES AND MECHANISM.

The valves are electrically operated. The three-phase alternating current at 60 cycles and 220 volts is furnished by a central power house, which also serves other installations. All the sluice motors are normally operated from a small central control house at the middle of the lock wall, but each motor can also be controlled from a switchboard in its own machinery room. The main control switchboard is on the second floor of the control house, from which all parts of the lock are visible to the operator. All power and control cables are cambric-insulated and lead-sheathed, and drawn through iron conduits embedded in the concrete close to the top of the lock wall.

Motors.—The motors are started and stopped by contactor panels in the several machinery rooms. There are two double-pole contactors for each motor (one for opening and the other for closing the gate), which carry the main current. Ordinarily, the motors are started by the operator in the control house, and stopped by a limit switch connected to the motor shaft when the valve has reached the end of its travel. Indicators are installed both in the individual machinery rooms and the control house. There is a set of three lights for each machine. Red and blue lights indicate the open and closed positions, respectively; the white lights show when a valve is in motion.

All the motors for the valve operation are interchangeable, being standard 22-h.p. motors, with a synchronous speed of 720 rev. per min. They are of the squirrel-cage form, designed for intermittent service, entirely inclosed and fitted with solenoid brakes mounted on extensions of the motor shaft. As a safety provision against overloading the sluice-valve motors, there are mechanical friction cut-off couplings attached to the motor shafts.

All parts of the machinery were built in the United States, from detailed plans prepared by the writer. The valves have proved satisfactory in operation.

Lock in Inner Navigation Canal, New Orleans, La.

Hydraulic Features.—This canal, completed in 1922, is about 5 miles long and connects the Mississippi River in the lowest part of the City of New Orleans with a tidal inlet known as Lake Pontchartrain.

The purpose of this canal is primarily to give opportunity for the construction of docks along the sides of the canal with a constant depth of water and also to give access to a similar system of docks to be built along the shores of Lake Pontchartrain. The docks along the banks of the Mississippi, previously the only place where vessels could be moored, are undesirable because of the great variation in depth of water at different stages of the river. The canal may ultimately serve as the entrance to a dredged channel through Lake Pontchartrain and the adjacent waters, giving shorter and better access to the Gulf than is offered by the Lower Mississippi at present.

As the water level in the river is usually higher than in the lake, the maximum difference being about 19 ft. (although for short periods the lake level is as much as 3 ft. above the river), it was necessary to install a lock for navigation. This lock has a usable length of 600 ft., a clear width of 75 ft., and a depth of water of 30 ft. on the sills.

Culverts and Valves.—The character of the soil made it necessary that the weight resting on it should be as light as possible. Reinforced concrete, therefore, was used, with light walls and a heavy floor connecting them.

The filling system consists of a culvert in each of the side walls, which are widened for this purpose at the level of the bottom of the lock chamber, with side outlets into the chamber at frequent intervals.

The valves have a clear opening of 8 by 8 ft. and are of a simple sliding type, with bronze bearings such as are common in smaller valves of this kind.

Although with this type of valve the friction is higher than in valves fitted with some form of rollers or wheels, the greater simplicity of construction was believed to compensate for the moderate increase required in the power for opening and closing the gates.

The valve proper consists of a ribbed casting, which is lifted by means of a stem attached to its central point. A bulkhead casting surrounds the opening on all sides. A series of hooks fastened to the valve hold the valve disk close to the bulkhead when the valve is closed. Water-tightness is secured by a narrow bearing strip of bronze in the disk resting against a similar strip on all sides of the bulkhead casting. Special arrangements were made by additional castings back of the bulkhead, which were bolted to the concrete when it was poured, so that the adjustment of the bulkhead could be accurately and quickly made during the erection of the valves.

Lifting Mechanism.—The stem for lifting the valve passes through a stuffing-box and extends to a platform near the top of the lock wall. A system of springs on the lower part of this stem guards against an excessive impact when the valve disk reaches the bottom.

The valves are electrically operated with a simple system of gearing. The motors are normally operated by remote control from a central control house on the top of the lock wall. A control board in this house represents in miniature all the different lock-gates and valves, with levers for operating each piece of machinery. The different gates and valves on the model board move simultaneously with the full-sized pieces of mechanism, so that the operator knows at all times exactly the position of the different gates, etc.

This mechanism is also quite fully interlocked, so that it is impossible to open the several gates and valves in the wrong sequence. This somewhat complicated and expensive mechanism is believed to be justified by greater safety in operation and a reduction in the operating force.

Various Details.—The valves are designed to withstand a maximum face pressure of 45-ft. head, or a back pressure of 32-ft. head. The motors are 52-h.p., 440-volt, three-phase, 60-cycle. The time of opening or closing is 40 or 45 sec.—a rather high speed which made it desirable to insert the system of springs in the stem which has been mentioned. Provision for hand operation is also made.

In designing the valves and machinery a coefficient of friction of 0.35 was assumed, this corresponding to actual tests on many United States Government works. This coefficient corresponds to a pressure on the bronze strips of 300 lb. per sq. in.

The approximate weights of the valves are as follows:

	Pounds.
Sluice-gate proper	16 150
Bulkhead	2 525
Wall-casting surrounding bulkhead with anchor-bolts	3 025
Stem	4 800
Stand	1 925
Total	28 425

Operation.—The operation of these valves has been entirely satisfactory. The valves were manufactured by the Coffin Valve Company, of Boston, Mass., following mainly its standard practice. The design of the valve system as a whole, however, of the bulkhead castings and the outer castings to which they are attached, of the arrangement of the spring buffer and details of the operating machine, as well as of modifications in the disk, were worked out in the writer's office and all parts of the valve were subject to his approval.

With reference to the results of experience with this installation, the following information has been supplied by Samuel Young, M. Am. Soc. C. E., Chief Engineer of the Board of Commissioners of the Port of New Orleans:

"At stages of the river only a few feet above lake level the time required for filling or emptying the lock is about 5½ min. When the difference between river level and lake level is as much as 12 to 18 ft., the time required for filling or emptying is about 7 min. We find no leakage in valves.

"The surface of the water in the lock is reasonably quiet during operation under normal conditions. No slope is noticeable either lengthwise or transversely. At times, when equipment on one side has been out of order, it has been necessary to fill the lock-chamber from one side only. At such times we have noticed a slight transverse movement of large ships in the lock. This trouble has been cured by throttling the valve which was in operation while the other was closed for repairs.

"There are 15 ports opening from the culverts on each side. These ports are 2 ft. 8 in. wide by 4 ft. 0 in. high.

"In order to insure a reasonable and uniform discharge through these ports into the lock-chamber throughout its length, we found it necessary to throttle the ports nearer the north or lake end by means of baffle-boards. We used dressed pine boards 3 in. by 6 in. by 3 ft. 6 in. long, set horizontally across the opening and spaced 6 in. center to center. The edge of the top board was set 1 in. above the top of the port opening. On the first 5 openings from the north end on both sides 4 boards were set; on the next 3 openings 3 boards, and on the next 2 openings two boards were set. On the remaining 5 ports no boards were provided. This adjustment gave satisfactory filling conditions and has never been changed from the beginning."

APPENDIX 7

VALVES OF OHIO RIVER LOW-LIFT MOVABLE DAMS

By C. I. Grimm,* M. Am. Soc. C. E.

Arrangement.—The locks for the Ohio River movable dams are 600 ft. long, 110 ft. wide in useful dimensions (Fig. 15), and, with the exception of the one at Louisville Falls, have low lifts ranging from 6 to 12 ft. Without consideration of the filling and emptying system it is desirable that the axis of the movable dam be at the center of the lock. This feature and the low lift permit of the very simple valve system that is in use at all these low-lift locks which are filled and emptied by numerous openings through and at right angles to the river wall. In the later designs there are seventeen of these openings above the dam and the same number below, each having a net area of 15.25 sq. ft., or a combined area for either filling or emptying of 260 sq. ft. The average time for either operation is 5 min.

Butterfly Valves.—The valves are of the butterfly type, mounted on a vertical axis which extends to a pit in the top of the wall in which the operating mechanism is located. The valve is rotated through an angle of approximately 75° by means of a sector at the top of the stem, engaged by a rack which is moved forward or back by the piston of a small hydraulic cylinder jack. These jacks are connected to common pipe lines, the pressure in which is reversed and regulated from a central point. Any valve, or several of them, may be cut out from the system and kept closed if not operating properly, without materially impairing the efficiency of the system. Fig. 15 shows the features that have been described, as well as some further details.

Improvements.—While the general arrangement of valves and operating mechanism is the same at all locks, the construction of which has extended over a period of forty years, a number of changes in design have been made as a result of experience. Those changes have been made with a view toward reducing breakage and facilitating repairs and replacements. The replacement of broken valve stems has frequently been necessary, and, occasionally, sectors have been broken.

In the first design the stems extended through the valve blades which were of cast iron and were connected to them by means of pins through the blades and stems. This design was soon modified by substituting structural steel blades to which the stem was connected at the top, thus making it easier to connect and disconnect stems and reducing the probability of breaking valve blades. At first, the jacks were actuated by compressed air which, due to its expansive property, caused valves to slam when necessary to build up a high pressure to start them. The substitution of hydraulic pressure reduced breakage.

In the early designs, the stems extended from the valves to the top of the walls through a small well only large enough to admit the stem, and in order

* Asst. Engr., U. S. Engr. Dept., Cincinnati, Ohio.

to remove it or a valve it was necessary for a diver to disconnect them at the lower end of the stem. This arrangement was modified subsequently by providing a large rectangular well over the lock-valves through which the entire

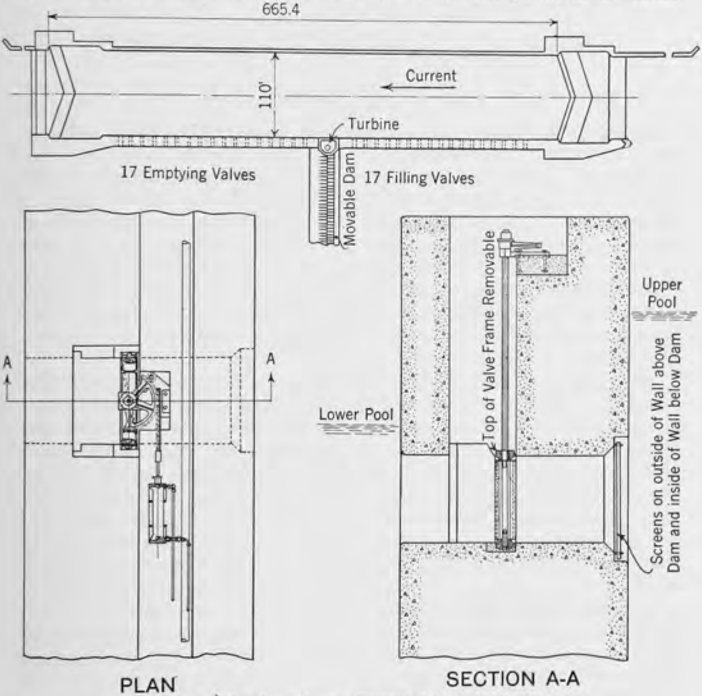


FIG. 15.—OHIO RIVER: TYPICAL LOCK AND VALVES.

valve can be removed without the aid of a diver. The details of this feature, which is regarded as important in valve design, are shown on Fig. 15.

APPENDIX 8

VALVES USED IN THE LOCKS OF THE PANAMA CANAL

By H. F. Hodges* and L. D. Cornish,† Members, Am. Soc. C. E.

General Problem

Locks.—The locks of the Panama Canal are planned to pass the largest sea-going vessels. They have a depth over the sills of 40 ft. in salt water, or 41⅔ ft. in fresh water, a width of 110 ft., a usable length of 1 000 ft., and lifts which may run from 25 to 35 ft., approximately, with different stages of the summit level and the tide. They are six in number, three in a flight at Gatun, to move vessels between the Caribbean Sea and Gatun Lake, a mean total lift of about 85 ft.; one single lock at Pedro Miguel, overcoming the difference in level of Gatun Lake above and Miraflores Lake below, a lift normally of 30⅓ ft.; and a flight of two locks at Miraflores, passing vessels between Miraflores Lake and the Pacific Ocean level, a lift which may vary between 34⅔ and 54⅔ ft.

The lock chambers are divided by intermediate gates, except at lower Miraflores Lock, and chambers with lengths of 1 000 ft., 900 ft., 550 ft., and 350 ft. may be used. The areas in plan of the 1 000-ft. and 900-ft. locks are, respectively, 134 000 and 123 000 sq. ft. Such areas and lifts cause an expenditure which may reach 7 500 000 cu. ft. of water for each through passage, when the large locks are used. The navigation season lasts all the year, which is climatically divided into a wet season of eight to nine months, when there is a superabundance of water, and a dry season covering the remainder of the year when there may be no rainfall at all. For the operation of the canal electric power generated at the Gatun Spillway is conveniently available.

Filling Time.—Estimates of the water supply for the canal indicated the possibility that that element might be the first to limit its capacity during the dry season, and made the saving of water one of the ruling considerations in the design of the locks and dams.

In designing the filling and emptying system the aim was to secure one which, with due economy in construction, would permit equalization in a reasonable time, would not create dangerous disturbance in the locks or approaches, and would not allow excessive leakage. Economy made it desirable not to go too far below the floor level. The other conditions required unobstructed admission and discharge, communicating channels of large capacity, a reasonably uniform distribution of the flow over the horizontal area of the lock, and reasonably tight valves.

To fill or to empty the large lock in 15 min. was thought to be satisfactory in point of time. As the prism of lift may reach, say, 4 500 000 cu. ft., this condition would necessitate a discharge opening of 300 or 400 sq. ft. under

* Maj.-Gen., U. S. A. (*Retired*), Lake Forest, Ill.; General Hodges died September 24, 1929.

† Chf. Engr., Div. of Waterways, State of Illinois, Chicago, Ill.

ordinary heads. Such a stream could not be passed through the gates, and a system of culverts was indicated.

Structural Features.—In order to insure continuous operation, which is of the highest importance, the locks were planned with twin chambers separated by a middle wall.

The side walls of the locks are 40 to 50 ft. thick at the base, and the middle wall, which may take the thrust from either direction of the full head on one side with a dry lock-pit on the other, is 60 ft. thick,* except at the gate chambers. The height varies from 78⅓ ft. to 83 ft., and all the walls rest on good foundations. The thickness of the side walls is ample to allow a culvert of adequate size. The middle wall will contain one such culvert, but not two. It was not thought advisable to increase its thickness sufficiently to admit two culverts, since that would have exceeded greatly the requirements for stability, with very serious additional expense.

For uniformity of distribution of flow into the lock, it was thought desirable to preserve the possibility of admitting or discharging water from both sides, although it was not believed that this would be necessary in all cases.

Culverts and Valves.—The system finally adopted comprises three main culverts, each 255 sq. ft. in sectional area, one in each lock-wall, running the full length of the lock flight and connecting the upper and lower pools, being controlled by valves at each lift. These main culverts communicate with the lock chamber through lateral culverts at right angles to the lock walls, running under the lock floor, with a number of openings in the roof. The culvert in each side wall is connected by twelve laterals† with the adjoining chamber only. The middle-wall culvert is connected with both chambers by ten laterals on each side. It follows that the laterals from the middle-wall culverts must have individual valves, in order that communication may be established or closed with either chamber at will; while the laterals from the side-wall culverts need no individual valves.

The variations in area of the waterway through which the flow takes place are shown diagrammatically on Fig. 16. All edges are rounded, to eliminate contraction. The valves which operate the main culverts work under heads which may reach 80 to 85 ft. and are always on the same side. Those which operate the middle-wall laterals are exposed to a maximum head of about 60 ft., which may come from either side. The main valves above each lift wall and at the lower end of each flight are installed in duplicate, as insurance against accident. The guard-valves provide the duplicate set at the head of each flight. A typical location of the valves is shown on Fig. 16.

Description of Installations

Rising Stem Valves.—The choice of type for the main valves was influenced by the local conditions that the leakage must be small, that operation under high head must be reasonably easy, and that the valve must be capable of use in large sizes. The well-known Stoney valve was chosen, a gate-valve in which

* It is 66 ft. at the floor level, owing to a batter given to the lower 9 ft. of both faces of the wall.

† Including the T-culvert regulating the space between the safety and the lower gates.

the body moves vertically on frames of live rollers against which it is pressed by the operating head. There are 134 of these valves in the three lock flights, all alike in structural features. Eighteen of them, which operate the culvert intakes and are called guard-valves, are counterweighted and connected with the operating machinery by chains. The remainder, 116 in number, have stiff rising stems connected to the middle of the bodies and passing into the machinery chambers above through stuffing-boxes in water-tight bulkheads. The stems are of steel pipe about 6¾ in. in inside diameter and finished to 8 in. in outside diameter.

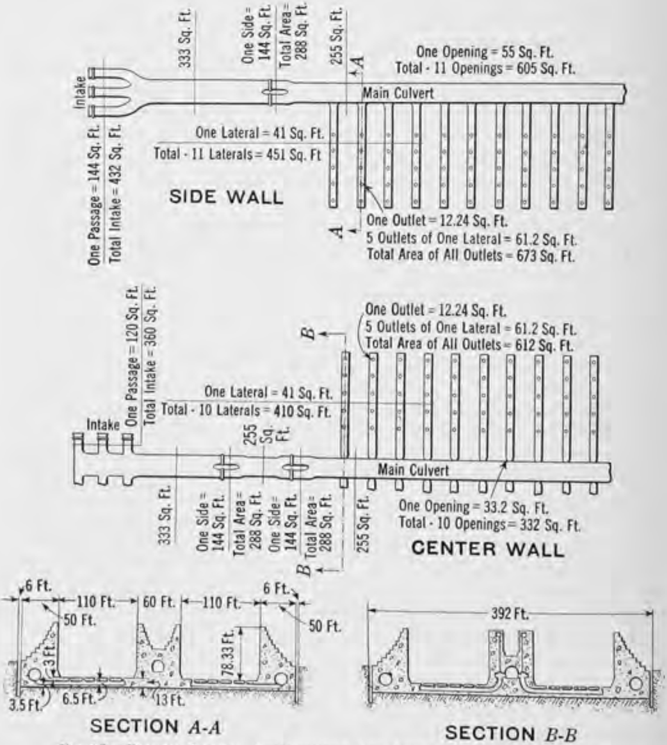
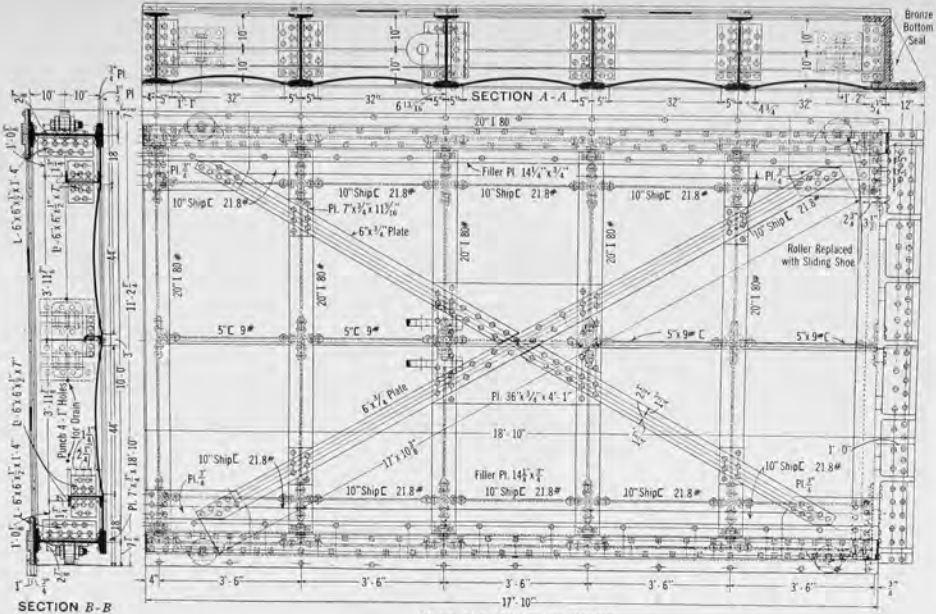


FIG. 16.—PANAMA LOCKS; ARRANGEMENT AND AREAS OF CULVERT SYSTEMS.

Each rising stem valve is built of steel I-beams sheathed with buckled plates, with the convexity down stream. The construction is shown on Figs. 17, 18, and 19. The lower member (Fig. 19) is a steel casting fashioned to



REAR ELEVATION OF VALVE

FIG. 17.—PANAMA CANAL: RISING STEM GATE VALVES; REAR ELEVATION AND SECTIONS.

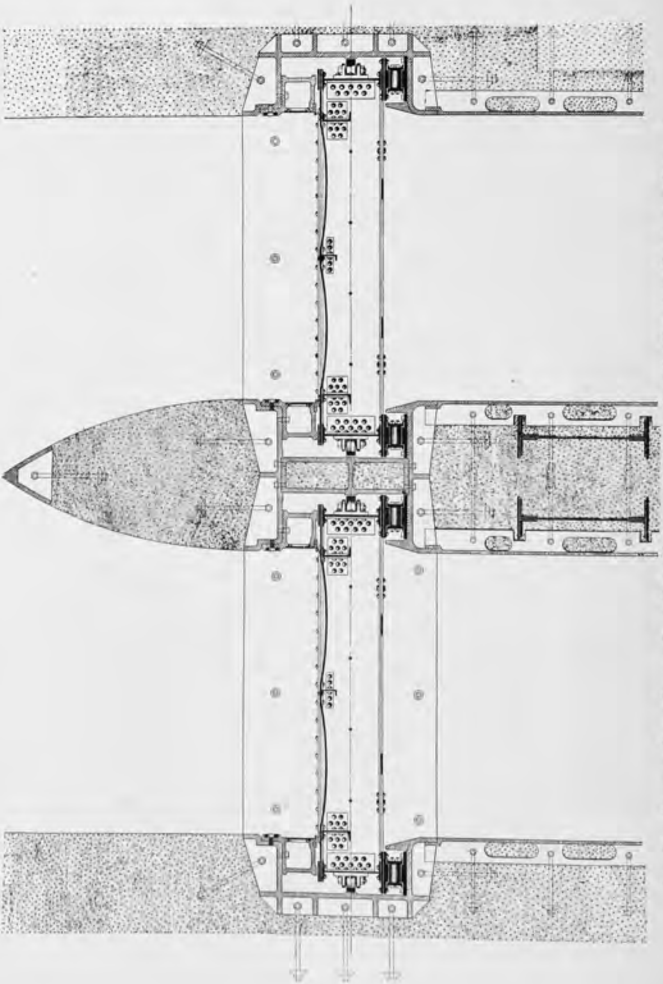


Fig. 18.—Panama Canal Rising Stem Gate Valve: Horizontal Section Through Valve and Chamber.

make contact with a sill in the culvert floor. The horizontal leg of the casting is pierced with seven holes. The purpose of these holes and of the shape of the casting is to facilitate the flow of water under the valve when the seal is broken under high heads. Difficulty in starting gate-valves under head has been noted elsewhere, and attributed to the formation of a vacuum under the bottom of the valve. No such difficulty has been found in operating these valves on the Panama Canal. Each valve body, exclusive of the stem and roller trains, weighs about 21 600 lb.

At the valve chamber the main culvert is split in two by a central pier, on each side of which one valve is installed. This pier, as well as the culvert walls and roof, is armed with castings to minimize erosion, to form a frame for the valve when closed, to support tracks for the live rollers, and, at the same time, to limit to very small amounts the possible motion of the valve horizontally. As originally installed, the limit was ¼ in. Side rollers made the contact and were intended to reduce friction, in case of lateral motion. Actually, they have been replaced by sliding contact pieces, as they were found to become fixed by rust and to develop flats. The throat of the opening which each valve closes is 8 ft. wide and 18 ft. high.

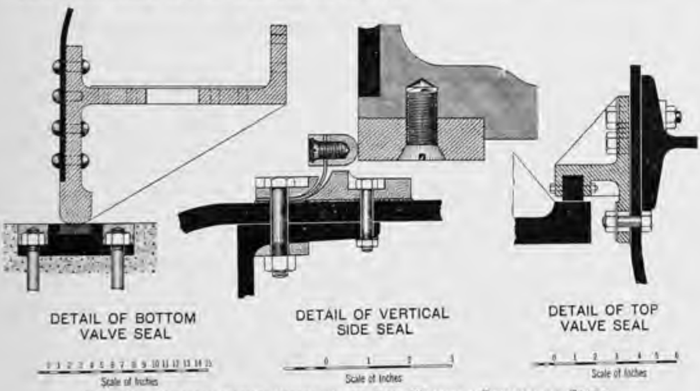


Fig. 19.—Panama Canal Rising Stem Gate Valves: Details of Seals.

A noteworthy feature of the valve is the side seal, a new device designed expressly to meet this case. It consists of a thin phosphor-bronze spring (Fig. 19) bent to an arc and having attached to it a bronze rod with pointed edge which makes contact with a strip affixed to the wall casting. The spring is attached to the up-stream surface of the valve between two bronze straps, having faces of such curvature that the spring cannot be deflected excessively by the water pressure. The joint between the spring parts and the face of the valve is made tight by a canvas gasket soaked in red lead and oil. The spring is installed under initial stress sufficient to keep the point of the seal pressed against the wall strip. The water pressure tends to press it still more firmly into contact. The device has proved satisfactory in service. The wall strip against which the pointed edge of the side seal spring presses was originally made of steel. This was found to corrode and erode seriously in use, and was finally replaced with a strip of bronze.

The bottom seal (Fig. 19) is made by the lower edge of the casting resting on a seat in the floor of the valve chamber. Originally, this seat was of babbitt metal. Corrosion resulted, pitting the lower surface of the casting, which had to be machined. The babbitt metal has since been replaced by a sill of greenheart and a manganese bronze strip fastened at the bottom of the gate to form contact. Since the greenheart sill has been found to be attacked by teredos, it was planned to return to babbitt metal at the next overhaul of the Pacific Locks.

The top seal (Fig. 19) is of rubber fixed in the lower surface of a casting extending the full width of the valve, made fast to the upper surface at the top horizontal member and projecting up-stream. When the valve is lowered this rubber strip rests on the upper surface of a casting bolted to the top member of the frame inclosing the valve opening, and, when properly adjusted, makes a tight joint.

Writing in November, 1926, H. Burgess, Col., Corps of Engineers, U. S. A., M. Am. Soc. C. E., then Engineer of Maintenance of the Panama Canal, stated that:

"(*a*) Repairs and replacements to the roller trains, guide rollers and sealing devices have been necessary at every overhaul* period. There is no effective way of lubricating parts subject to friction when such parts are beneath the water. Rapid wear is inevitable. It was found advisable to provide 36 valves as spares, in addition to the 116 valves in use. These valves are reconditioned between overhaul periods for replacing a like number which have been in use. In this way the time of tying up a lock for repairs is greatly reduced.

"(*b*) The valves bear on live roller trains. These trains, which consist of steel rollers, guide-bars, and bearing surfaces wear rapidly and require truing up every four years.

"(*c*) Pitting and corrosion have been observed in the portions of the stems of these valves between the valves and stuffing-boxes. The affected parts are being repaired, after being thoroughly cleaned, by depositing metal in the parts by the oxy-acetylene process, thus restoring the stems to their original outlines."

Cylindrical Valves.—The lateral culverts which connect the middle-wall culvert with the chambers on either side, are closed by individual valves. Inasmuch as the water in the chamber from which the culvert is cut off by the valve may be higher or lower than that in the culvert, these valves must be able to resist pressure from either direction. At the same time they must fulfill the same conditions as the main valves as to reasonable water-tightness and ease of operating under high heads.

The cylindrical valve, a type which has been much used in the United States as the main valves of small locks, was selected to meet the situation. In this type, as applied on the Panama Canal (see Fig. 20),† a movable vertical cylinder, the lower edge of which when resting on the valve seat

* The locks are now overhauled every four years.

† This drawing shows the valves with certain improvements dictated by experience. The original design is shown in *Transactions*, International Eng. Cong., 1915, Vol. II, Panama Canal, p. 84.

makes the seal, may be lifted or lowered inside another fixed cylinder. This second cylinder, the upper surface of which is closed against the entrance of the water in the main culvert, is raised on pedestals above the valve seat to a distance equal to the height of the movable cylinder. The movement of the valve cylinder takes place between the pedestals, which act as guides and serve to prevent rotation or undue lateral motion. The upper portion of the fixed cylinder is prolonged upward to fit into a dome-shaped casting built into the masonry. Inasmuch as the water pressure acts normally to the surface of the cylinder when the valve is under head, it does not affect the force required to raise the valve, which is opposed only by the friction and the weight of the moving parts. The valve operates as easily under high heads as under low.

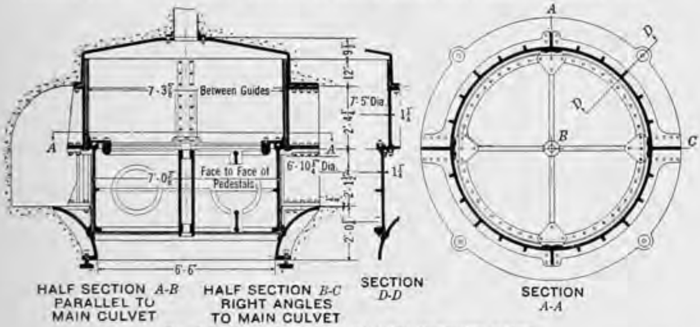


FIG. 20.—PANAMA CANAL: 78-INCH CYLINDER VALVE.

The vertical valve stem, to the bottom of which the movable cylinder is attached, rises to the operating chamber near the top of the lock wall through a casing with a stuffing-box at the upper end. This casing is provided at the top with a vent pipe and check-valve, which prevents water from entering the operating chamber and at the same time allows air to enter the casing and prevent the formation of a vacuum. As originally installed, the valve seat and the dome were of cast iron. The moving and fixed cylinder and the pedestals were of cast steel in about one-third of the valves and of semi-steel in the remainder. The valve stem is of galvanized steel pipe and the stem casing of lap-welded galvanized pipe. The gaskets which pack the joint between the fixed and movable cylinders against reversible pressure were originally rings of leather which became hard and stiff in service and for which rings of rubber have since been substituted. The throat of the culverts closed by these valves is circular and 33.2 sq. ft. in cross-section.

These valves have been in use since 1914. Writing in November, 1926, the Engineer of Maintenance of the Panama Canal, stated that:

"(a) There are 120 cylindrical valves used for controlling the flow of water in the lateral culverts which lead from the center wall culvert. These were originally made of a cast seat, a movable valve cylinder, and a fixed housing or body. Erosion of the seat took place to such an extent that bronze liners are being installed. It is anticipated that the installation will be completed on the seats in 1927.

"(*b*) The valves and bodies are also wearing at the vertical guideways to a serious extent. The guide grooves were machined out of the integral castings of the valve and body and there is no way in which new guide faces can be cut or built up. To overcome this condition, new valves and bodies are being designed having all wearing and bearing surfaces provided with bronze parts which are bolted in place. These parts may easily be removed for refacing or for replacing, if required. The replacement program contemplates commencing the installation at Gatun Locks in 1927, and completing the installation at Gatun Locks in 1931. That is, a part of them will be installed during each two overhaul periods occurring in 1927 and 1931. The installations at both Pedro Miguel and Miraflores Locks will be made in 1929.

"(*c*) During twelve years' operation approximately 18 out of the 120 valves in service broke away from their stems. One of these failures was due to the nut working off the lower end of the stem. The other failures were due to corrosion of the threads in the couplings that join the sections of the stems together; the threads stripped, allowing the stems to pull apart. These failures are being eliminated by welding the ends of the couplings to the stems."

Operating Machinery.—The moving parts of the valves are operated by machinery placed in chambers in the lock walls below the coping level. The operating chambers of the rising stem and cylindrical valves are in part below the level which the water may attain outside the wall, and would be flooded unless sealed against inflow.

The machinery of all the valves is electrically operated, the current being drawn from the generating station at Gatun Spillway. It has been described at length in a paper* by Edward Schildhauer, M. Am. Soc. C. E. A brief description only will be given here.

Rising Stem Valve Machinery.—The rising stem valves (Fig. 21) are operated by a cross-head, to the middle point of which the upper end of the valve stem is pinned. The cross-head is raised and lowered by two vertical screws which pass through non-revolving nuts near its extremities, these nuts being pivoted in the cross-head to permit slight motion and thus to allow for variation in the wear of the nuts and screws. The weight of the valve is carried by the screws in suspension.

The machinery chamber is separated from the lower part of the valve well by a water-tight bulkhead (Fig. 21), through stuffing-boxes in which pass the valve stem and two rods to which the roller trains are fastened and which are raised by chains passing around sheaves at the free ends of the rods. One end of each chain is fast to the masonry above the rod, the other to the cross-head, and two idler pulleys are interposed to bring the chain in line with the forces acting on it. Thus, the roller trains are constrained to move at one-half the speed of the valve body, this being their natural rate when the valve is moving while pressed against them. The valve well, bulkhead, machinery room, and machinery are so designed that the valve itself may be lifted out freely to the top of the lock wall for examination and repair. This requires the removal of only the chain sheaves, valve stem, roller-train rods, and bulkhead.

As the depth of the culverts below the coping is not the same in all cases, valve stems of different lengths are needed. Otherwise, the installation is identical at all rising stem valves.

* *Transactions*, International Eng. Cong., 1915, Vol. II, Panama Canal.

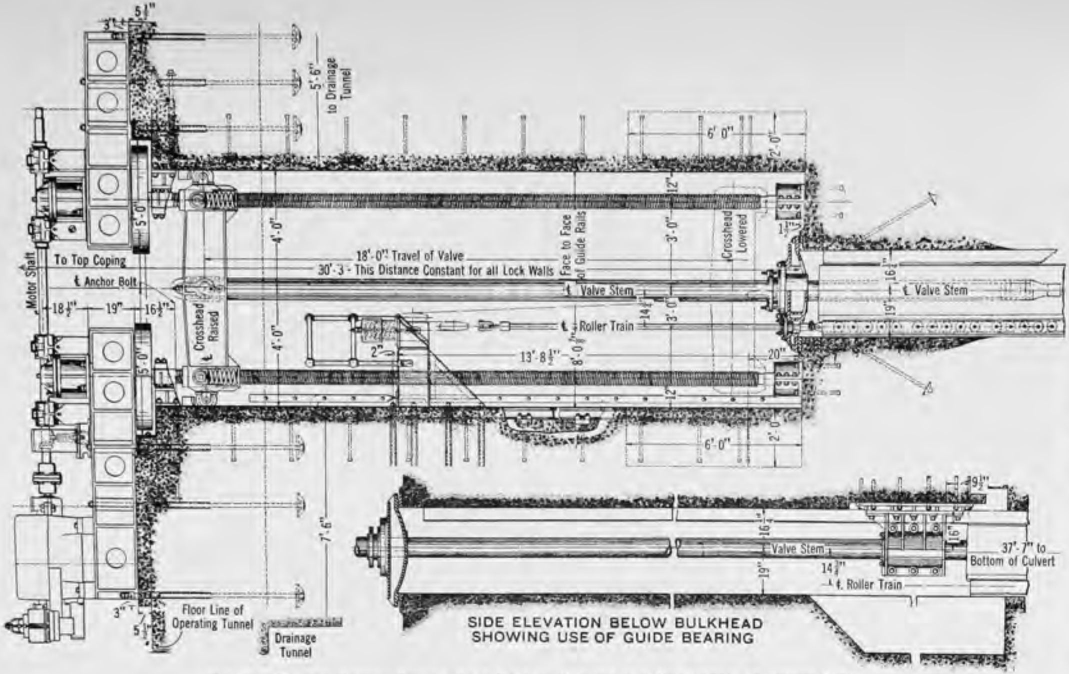


FIG. 21.—PANAMA CANAL: STONEY GATE VALVES, DETAILS AND MECHANISM OF RISING STEM.

The screws which move the cross-head are turned by a 50-h.p. motor through miter and spur gear. The length of the motion is 18 ft., and the time 1 min. The power is shut off automatically at the end of the stroke, a sufficient over-travel being permitted to insure that the motor will stop before anything is injured.

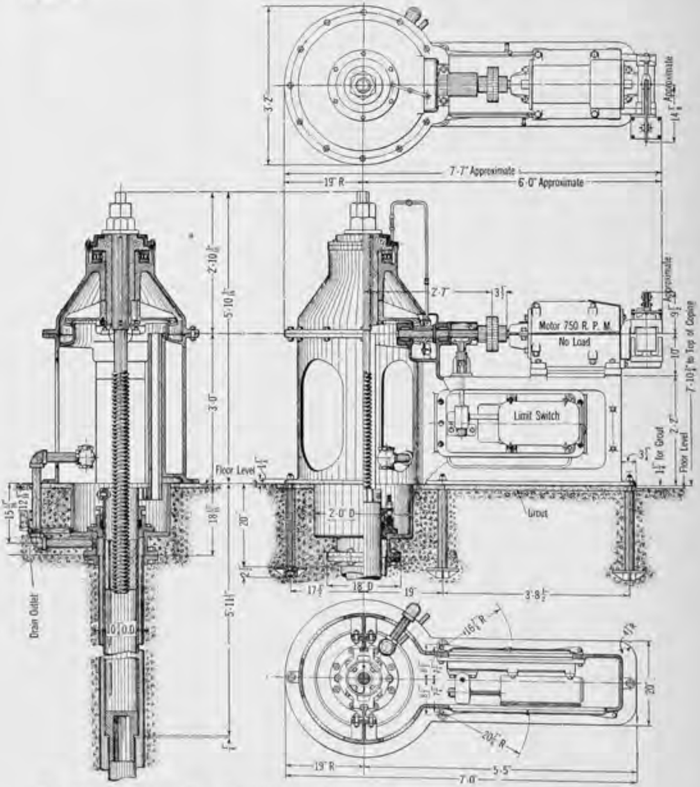


FIG. 22.—PANAMA CANAL CYLINDRICAL VALVES: ASSEMBLY AND DETAILS OF OPERATING MACHINERY.

Cylindrical Valve Machinery.—The stem of the cylindrical valve (Fig. 22) is plugged at its top and extended by a sleeve which passes through a stuffing-box sealing the top of the casing. This sleeve is also closed near the top by a fixed nut through which passes the vertical screw of the machine. When this screw is turned by its motor, through suitable gearing, the valve stem and valve rise or fall. The portion of the sleeve between the nut and the plug closing the top of the valve stem proper serves as an oil reservoir. When the valve is raised the screw enters this reservoir, forcing its own volume of oil out through a hole in the nut into the part of the sleeve above the nut. When the valve is lowered this oil flows back again. The weight of all the moving parts hangs from a roller thrust-bearing at the top of the screw.

The stroke of the valve is 3 ft. and the time, 10 sec. The motor is cut off by a limit switch at the end of the stroke. The screw is allowed to rise through the roller bearing when the valve reaches its seat on the down stroke, thus guarding against severe shock and giving the motor a chance to stop. A bulkheaded entrance from the lock chamber to the middle wall culvert permits removal and replacement of any part of a valve during overhaul periods.

Guard-Valve Machines.—At the location of the guard-valves, which close the culvert intakes of the side walls, the head-room is insufficient for a rising stem connection with the machinery. The adopted machine consists of a heavy chain, one end of which is fastened to the valve and the other to a counterweight. The intermediate part of the chain is led over a pulley and a pocket wheel driven by a motor through worm and spur gear. The roller trains are raised by separate chains and are held to the required rate of motion in the same manner as in the case of the rising stem valves, except that the moving end of the chain is attached to the counterweight instead of the cross-head.

Leakage.—The leakage through the rising stem valves is not excessive, the sealing devices giving good results. In July and August, 1914, seven tests among ten different valves under a 52-ft. head, measured to the center of the valve, gave an average leakage of 1.23 cu. ft. per sec. per gate. The leakage through a cylindrical valve is also reasonably small. Under a 60-ft. head it was experimentally determined to be 0.10 cu. ft. per sec. In both cases the leakage undoubtedly increases with use and with the passage of time since the last overhaul, but at the worst it is not excessive. The total leakage from the summit level through the valves and gates at Pedro Miguel and Gatun and through the Gatun Spillway was found by measurement in 1914 to be 14.57 cu. ft. per sec. An allowance of 275 cu. ft. per sec. was made for this item in the preliminary investigation of the adequacy of the water supply.

Discharge Through Culverts

Theoretical Time.—The efficiency of the culvert system is influenced favorably by the large quantity of water which it contains and which must be set in motion in each operation. The formula* ordinarily used for the time of filling and emptying a single-lift lock is,

$$t = \frac{2\,A}{C\,F\sqrt{2\,g}}\left(\sqrt{h_1} - \sqrt{h_2}\right) \qquad (1)$$

in which, A is the horizontal area of the lock chamber; F, the cross-sectional area of the opening through which the water flows; C, a coefficient dependent upon the culvert and valve conditions; h_1 and h_2, the initial and final heads,

* For equalization of two consecutive locks, of areas, A and A', in a flight, the expression, $\frac{A\,A'}{A + A'}$, is to be substituted for A in Equation (1).

respectively; and t, the time, in seconds. In planning the system, the value of C was assumed as 0.65, but this was supposed to cover all the losses or gains in efficiency in the system, that is, all the elements which would cause the actual time of filling or emptying to differ from the time which would result if the water in the smallest section of the connecting channel should flow at each instant with the velocity due to the head then existing. Actually the value assumed has been more than realized.

Practical Tests.—Observations made in 1914 showed that to fill the Pedro Miguel single-lift, 900-ft. lock from Elevation 50.9 in Miraflores Lake to Elevation 84.8 through the side culvert alone, took 14 min., using both valves. In Equation (1), A, for the 900-ft. lock, is 123 000 sq. ft., and A, for the most restricted section of the channel of flow, namely, the culvert itself, is 255 sq. ft. One minute of the whole time is taken up in raising the valve, during which time the valve opening increases from zero to 288 sq. ft., and the water in the lock rises to Elevation 51.7. Therefore, the full section of 255 sq. ft. is available for about 13 min. and 7 sec. Taking the value of t as this interval, the value of H as $84.8 - 51.7 = 33.1$, and that of h as $84.8 - 84.8 = 0$, C becomes 0.88. If the entire time after the first movement of the valve be reckoned, disregarding the fact that the full area of the culvert is not available for 53 sec. after that movement, a value of C of 0.83 will result.

It is to be noted that the large volume of water in the culvert does not respond instantly to the motion of the valve, which takes 1 min. to open. Steady flow is not established for about 1½ min. The water in the forebay drops several inches and recovers slowly during the remainder of the filling. When the water level inside the lock rises above the somewhat lowered level of the forebay, the upper gates crack open from the back pressure. The flow in the culvert, however, continues. The water surface in the lock rises even above the original level in the forebay. The time, t, which is taken at the instant of equalization with that original level, is about 1 min. longer than the interval measured to the instant when the gates crack open. This cracking really ends the operation of filling, since it is taken as the signal for setting the gate-opening gear in motion.

Similar phenomena, indicating over-travel of the water in the culverts, are to be noted in filling or emptying all the locks of the canal.

Hydraulic Coefficients.—The value of C for emptying the Pedro Miguel Lock, using the side culvert only, is somewhat less favorable, being 0.804, when both valves are used and allowance is made for the time consumed in raising them.

The value of C for the middle wall culvert only is much less, being about 0.587, as determined at Upper Gatun Lock. It should be remembered that in the middle wall, the water passes through Stoney valves as well as cylindrical valves. All the loss is not to be attributed to the latter; but they undoubtedly cramp the flow.

For the combination of side wall and middle wall culverts observations indicate the total time consumed and the value of C about as follows, at normal pool levels:

To fill an upper lock, or the Pedro Miguel Lock . . $t = 7$ to 8 min.; $C = 0.78$
To equalize consecutive locks in flight . . . . $t = 6.5$ to 7 min.; $C = 0.60$
To empty lower lock to sea . . . . $t = 7.5$ to 8.5 min.; $C = 0.69$
To empty Pedro Miguel Lock . . . . $t = 7.5$ to 8 min.; $C = 0.79$

The values of C have been corrected for the time used in raising the valves.

Peculiarities of Flow.—When the side wall culvert alone is used the corresponding times become, respectively, about 13.5 min., 8.5 to 12.5 min., 14 to 17.5 min., and 15 min. The greater time required in emptying the lower lock to the sea is doubtless due in part to the form given to the side culvert outlet, which, for reasons* connected with the difference in the densities of the waters separated by the lowest gates, was turned upward to discharge through an opening in a horizontal plane, whereas in the Pedro Miguel Lock, the culvert outlet is in a vertical plane and the discharge direct and unimpeded.

It should also be remembered that, when the lower lock is emptied to the sea, actual equalization of levels does not take place until the lower gates are opened, there being still a residual head of a few inches on the inside, or fresh-water side, of the gate leaves when the heavier salt water on the outside forces them apart, at which instant the gate-opening machinery is started by the operator. This tends to make the time of emptying dependent in a small degree on the relative salinity of the two waters, which is not constant.

When the chamber is filled through the side culvert using only one valve, the most contracted section of the waterway is at the valve and measures 144 sq. ft. The observed time of filling the Pedro Miguel Lock through one side-wall valve was 18 min., from Elevation 51.5 to Elevation 84.8. It took 1 min. to raise the valve, during which time the water rose from Elevation 51.5 to Elevation 53.0. Applying these corrections and substituting in Equation (1), a value of $C = 1.177$ results, indicating that after the valve had been fully raised the water flowed through the most contracted section of the culvert with a velocity greater than that due to the head. This conclusion was confirmed by experiment at Gatun, where a value of $C = 1.272$ resulted. Undoubtedly, the contraction of the culvert at the valve, lying between larger sections above and below, produces in part the effect of a compound mouthpiece, or Venturi meter, in increasing the velocity at the throat. It seems admissible to take advantage of this principle in designing large culvert systems.

It should be kept in mind that these values of C cover all losses or gains due to the nature of the channel through which the water flows from one level to the other, whether they be attributable to the valve chambers, to skin friction, to changes in direction, to dynamic head, or to other elements.

Lateral Shifting of Ships.—The distribution of flow from the lateral culvert over the horizontal area of the lock chamber is not entirely uniform, the ports in the laterals which are farthest from the main culvert discharging more than the nearer ones. The velocity of flow in the laterals evidently carries the stream past the nearer ports without giving them their full share of the discharge. When only one main culvert is used in the locking operations, a surface slope results, tending to draw a vessel toward the wall in which that culvert lies. The Engineer of Maintenance of the Panama Canal writes, under date of January 24, 1928, that,

* See, *Transactions,* International Eng. Cong., 1915, Vol. II, Panama Canal, p. 30.

"Experience at the locks shows that when a heavy ship is to be locked up by means of side wall culvert alone, there is some difficulty in holding it from the side wall. The ship is usually spotted nearer the center wall to begin with and held to the center wall with locomotive cables and manila rope lines."

The tendency is noticeable particularly when filling the lowest locks of the Gatun and Miraflores flights, perhaps because of the blanket of denser water through which the fresher water of the inflow has to force its way. When both culverts are used, no difficulty is found in holding a vessel in the middle of the chamber; while in down-lockages, whether made with one or with both culverts, the surface of the water is placid and the vessel shows no tendency to drift toward either wall. Consequently, up- lockages are given the preference for two-culvert operation, when a choice must be made. For an extended discussion of these and other phenomena resulting from the culvert system, reference is made to papers* by Mr. R. H. Whitehead, and others.

True Equation of Flow.—In Mr. Whitehead's paper a very interesting discussion of the true equation of flow is made, in which the beneficial effect of dynamic head is taken into account, and values of the coefficient of flow under different conditions are deduced after that effect has been applied. These values are less than the values of C previously given and are undoubtedly more accurate as measuring the losses due to culverts and valves, when the gain due to the dynamic head is separately applied; but they are not the coefficient which was assumed as 0.65 in planning the system, since that coefficient was supposed to cover all elements working to change the time of flow from that which would result under perfect hydraulic conditions.

The writers believe that, except possibly in very simple cases of openings in walls or gates, or of very short culverts combined with such, a coefficient based only on the smallest area of the connecting channel and found experimentally for one installation can not be relied upon with confidence in designing a different one, even though the valves used be the same. Such a coefficient, proved to be correct in one place, may well serve as an indication of probabilities in another; but culvert conditions as to plan, length, size, and shape of intakes and outlets, curvature, lining, and volume contained, all play a part in determining the hydraulic efficiency of any system. Even a difference in density of the waters connected may have its influence. There is much room for judgment in estimating the comparative effect of all these factors before adopting for a new design the results of experience elsewhere.

Subsidiary Valves.—In addition to the valves hereinbefore described, certain others are used in the auxiliary culverts which regulate the space between double gates and at the upper and lower ends of the middle wall culvert to confine the draft and flow of water to the proper side of the wall, but these are not of a nature requiring description here.

Experience in Operation

M. L. Walker, M. Am. Soc. C. E., the Governor of The Panama Canal, writing in December, 1927, gives the following information as to the performance of the valves after about thirteen years' service.

* *Transactions*, International Eng. Cong., 1915, Vol. II, "The Panama Canal."

1.—Rising Stem (Stoney Gate) Valves

(*a*).—*General.*—The type of valve as originally designed is well suited to its requirements. The duplicate sets as originally installed have been carefully maintained at all points.

(*b*).—The only criticism of the operation of the center wall culvert (not a criticism of the valves themselves) is that there were not two culverts, one for each lock chamber. This would have dispensed with all cylindrical valves and required an additional set of rising stem valves for the additional culvert, and probably some additional valves for cross-spilling from a chamber on one side to a chamber on the other side of the center wall. The particular advantage of this extra culvert would occur at overhaul periods when the one chamber in operation could be filled from two culverts, center and side, whereas at present it can only be filled from one side wall culvert.

(*c*).—*Roller Trains.*—Every three or four years it is necessary to rebuild the roller trains and guide-bars, and to dress down the tracks for the rollers. No improvement in general design has yet been devised. The combined action of corrosion and erosion rapidly removes the smooth finish of rollers and track. The spools or trunnions on the ends of the rollers where they fit into the guide-bars also corrode and erode so that the correct fit and, consequently, the correct alignment is soon destroyed. Experiments have been made with a view to obtaining non-corrosive material for rollers, tracks, and guide-bars, but the materials are so costly that it is probable that the additional life would not save the increased first cost. An improvement which has been definitely adopted is to make the tracks in two parts, a permanent base and a detachable wearing face. New wearing faces are made up and tapped for screws. Another improvement to the guide-bars has been the change from the channel section to a flat bar section 1 in. thick which gives added wearing surface to the roller trunnion bearings.

(*d*).—*Lateral Guides.*—The lateral guide roller was found to be corroded to its bearing so that it failed to rotate. As a result of this a sliding guide shoe has been adopted.

(*e*).—*Side Seals.*—The general design of these seals has proved very satisfactory. Troubles developed due to the fastenings coming loose. The screws have come out at times, but this has been remedied by greater care in installing them. It was necessary to increase the diameter of the bolts.

(*f*).—*Bottom Seals.*—Due to roughening of the bottom of the valve where it makes contact on closing, a manganese bronze bar has been fastened on with screws.

(*g*).—*Corrosion.*—Corrosion with evidences of electrolytic action is generally found on steel parts which are in the path of currents of water. Contact parts when made of manganese bronze show practically no deterioration. Tobin bronze screws and bolts give excellent results. Frequently, nuts and heads of bolts when exposed to currents of water without protective coatings are badly corroded.

(*h*).—*Protection Against Corrosion.*—It is the general practice to coat all submerged steel and iron work with bituminous enamel, applied hot. A number of other protective coatings have been tried, but none was as successful as bituminous enamel. Difficulty has been experienced in getting perfect protection due to the dampness and water in the culverts even when drained. Manganese bronze needs no protection.

2.—Cylindrical Valves

(*a*).—*General.*—The valves, as a type, have performed their functions in a satisfactory manner. The design has been considerably changed in detail as will be shown in the following.

(*b*).—*Failures.*—After several years' operation the valves began to come apart from their stems. The cause was due to corrosion of the threads at the couplings. Several valves were found to be cracked, the cause probably being due to dropping from the stems when raised.

(*c*).—*Seats.*—The lower contact surfaces became so badly corroded that it was necessary to install bronze seats and to machine off the lower edge of the valves. Later, when new valves were built, they were equipped with bronze rings on the bottom edges.

(*d*).—*Pedestals.*—When wear in the vertical guides became pronounced a new type of pedestal was developed, with detachable bronze face and slotted holes in the top and bottom to permit adjustment.

(*e*).—*Valve Stems.*—Due to loosening of stems at joints new stems were made with features to prevent this. The stem finally adopted is made of the same stock, but provided with extra heavy joints welded outside the threaded area.

(*f*).—*New Valves.*—The design was made to fit the space occupied by the old valves. The flanges, ribs, and wall thickness were increased. The side guides and bottom seat were provided with detachable bronze liners secured with bronze bolts. The top guide was given greater bearing area. The outer seal retainer was flanged down so as to restrain the valve from chattering when it is raised.

(*g*).—*Protection.*—All iron and steel work is coated with hot bituminous enamel during overhaul.

3.—General Policy in Design

(*a*).—It has been found advantageous to make all contact and wearing surfaces detachable so that they may be quickly removed at overhaul. Contact and sliding surfaces are generally made as large as practicable.

(*b*).—Sliding surfces, underwater, as well as the lower bearing surfaces of valves, are generally made with bronze faces.

(*c*).—Templates and drill jigs are used for spacing holes for repair parts so all are interchangeable.

(*d*).—Manganese bronze is generally used for the liners. Tobin bronze is used for bolts and screws which secure the bronze parts. Semi-steel is used in preference to cast iron for valve parts.

(*e*).—Bituminous enamel is the most durable protective coating for iron or steel under water.

(*f*).—Efforts are made to prevent chattering of valves when open, as mentioned in Paragraph 2 (*f*).

4.—Hydraulic Tests of Lock Culverts

There have been no special hydraulic tests of the lock culverts since those made by Testing Engineer R. H. Whitehead in 1913. The details of those tests, discussion thereon, coefficients of flow, and other data in connection therewith, have been admirably set forth in Mr. Whitehead's paper on "Hydraulics of the Locks of the Panama Canal".* In this paper Mr. Whitehead makes certain recommendations for better hydraulic distribution by tapering the culvert walls; he also suggests the value of a different connection between main and lateral culverts. The inside-of-lock surges mentioned by Mr. Whitehead of course still exist; in fact, the back pressure opening of the lower lock-gate leaves is used as the signal by the operator for opening the gates.

5.—Surges

As far as the writers have been able to ascertain, there are no injurious surges in the culverts.† On opening valves, under considerable head, when the lock is connected to a long narrow channel, a 1-ft. to 3-ft. surge in Gaillard Cut obtains at almost every draft of water at Pedro Miguel Locks. This surge is a factor in causing sheers in the handling of shipping in the Cut. A detailed illustrated paper on these surges, taken from official sources, has been published by Messrs. H. G. Cornthwaite and R. Z. Kirkpatrick.‡ They may be prevented by drawing water from a reservoir through a culvert and valves, lateral to the locks. This plan is proposed for Pedro Miguel. Protection against surging, based on the experience at the Panama Canal, is not necessary when the lock opens out on a broad body of water, such as exists at the south end of Gatun Locks and the north end of Miraflores.

6.—Leakages—Valves and Gates

The condition of leakages of both the valves and the gates on the Panama Canal locks has been very satisfactory. These leakages were experimentally determined in 1913 for both the valves and the gates, but not for the valves alone, which are believed to contribute the smaller share of the total. The values determined at that time were as follows:

Gatun	5.9	cu. ft. per sec.
Pedro Miguel	5.0	"
Miraflores	5.3	"

The original estimate by the members of the Board of Consulting Engineers of 1906 allowed 275 cu. ft. per sec. for lock and spillway leakage losses from Gatun Lake. The experimental check of the leakages made in 1913 has not been possible since. However, by occasional measuring of the changes of levels in the lock chambers during non-operating hours, some approximations on the leakages are made from time to time. As might be expected, the leakage coefficients show little higher values than when the seals and fixed irons and sills were new. Moreover, they show higher values before the lock overhaul periods than afterward.

* *Transactions*, International Eng. Congress, 1915, Vol. II, pp. 165–234.

† The rising stem valves have been closed repeatedly, when the water in the culvert was flowing under high head, without evidence of surging or water hammer.

‡ *The Military Engineer*, January–February, 1920.

APPENDIX 9

LOCK VALVES USED IN LOCKS ON THE MONONGAHELA RIVER

By Charles M. Wellons,* Esq.

Older Locks.—Locks Nos. 1, 2, 4, 5, and 6, Monongahela River, consist of two parallel chambers with a clear length of 360 ft. and a width of 56 ft. The normal lift varies from 8 to 15 ft. Lock No. 3 has one chamber 720 by 56 ft., and one, 360 by 56 ft. Locks Nos. 7 and 8 are single chambers, 360 ft. in clear length (400 ft. between pintle centers) and 56 ft. wide, with a lift of 15 ft.

The older locks, Nos. 1 to 6, present a variety of filling and emptying arrangements, the general plan being to place a culvert in each wall at the gates, with the intake immediately above the gate recess and the outlet immediately below. The total sectional area of the filling or emptying culverts is about 112 sq. ft. for each chamber. The arrangement results in a considerable local disturbance. A high rate of filling is not attempted and the effect is not serious enough to hamper navigation. In some cases cylindrical valves are used and in others, butterfly valves.

The cylindrical valves have given very satisfactory service except for defects in the design of minor parts. They are, however, not suitable for obtaining the maximum culvert area in a wall of given width when used with low or medium lifts.

The older butterfly valves are generally rectangular, 8 ft. high and 7 ft. wide, operating on the vertical axis. The frames are cast iron embedded in the concrete. Most of the blades are of cast iron in one piece. Some of the older blades were of structural steel plate stiffened by channels and angles. These valves have been the source of considerable trouble both from corrosion and breakage.

The 720-ft. lock at No. 3 has 54-in. circular butterfly valves and a filling and emptying system somewhat similar to that used on the Ohio River, except that filling is effected from a culvert behind the land wall, while the emptying culverts pass directly through the lower half of the middle wall into the lower approach of the 360-ft. lock.

Later Installations.—Locks Nos. 7 and 8 (Fig. 23) are identical in design and typical of the newer construction in which a large culvert area is used to decrease the time of filling and emptying in order to increase the capacity of the lock. A longitudinal culvert, 12 ft. high by 10 ft. wide, with curved ceiling, is placed in each wall and each culvert has a filling valve near the upper gate and an emptying valve near the lower gate. The valves are of the rectangular butterfly type, operating on the horizontal axis and are 12 ft. high by 10 ft. wide. The structure of the valve reduces the culvert area by about 15 per cent.

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For filling, each culvert draws water through ten openings distributed along the upper approach (Fig. 23). In emptying, each culvert discharges through twelve openings similarly distributed along the lower approach. The throat of each of these ports is 4 by 4 ft. with rounded edges, and the discharge end is flared to 5 by 5 ft. Each main culvert communicates with the lock through eighteen ports with throats, 3 by 4 ft. in area, with rounded edges and flared discharge. All ports are placed at or close to the bottom of the lock and approaches, and draw or discharge horizontally below the hulls of passing vessels.

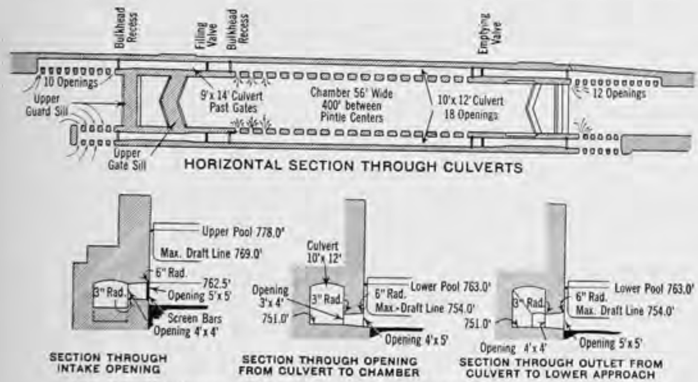

FIG. 23.—MONONGAHELA RIVER: TYPICAL ARRANGEMENTS OF LOCK CULVERTS.

The filling time at these locks is $3\frac{1}{2}$ min. for a head of 15 ft. The water in the chambers is exceptionally quiet and, what is equally important on the river, there is no severe disturbance in the approaches. These effects were given primary consideration in the design of the locks. The arrangement of the intakes and outlets causes the water to be broken up into a large number of small vortices; and no great local disturbances, such as are noticeable at some of the older locks when being filled rapidly, are present.

The leakage through one of these valves, which may be assumed as due to an opening averaging $\frac{1}{8}$ in. wide around the perimeter, is of no practical importance.

Valve Design.—The valve (Fig. 24) is designed to resist the maximum possible head due to surge. The maximum surge effect occurs when the valve is closed, with the water running in the culvert, and is limited by the openings from the top of the wall to the culvert immediately up stream and down stream from the valve. These openings provide for a static head to oppose the velocity head and the maximum possible static head acting on the valve is assumed to be the distance from the axis of the valve to the top of the wall.

The blade is constructed of structural steel. Resistance to bending in the direction of the axis is provided by a box girder approximately 18 in. square and built up of plates and angles. The steel axle castings are fitted into the ends of this girder. Resistance to bending in the direction perpendicular to the axis is provided by the skin plates and steel-plate diaphragms. The construction of the valve is shown in Fig. 24.

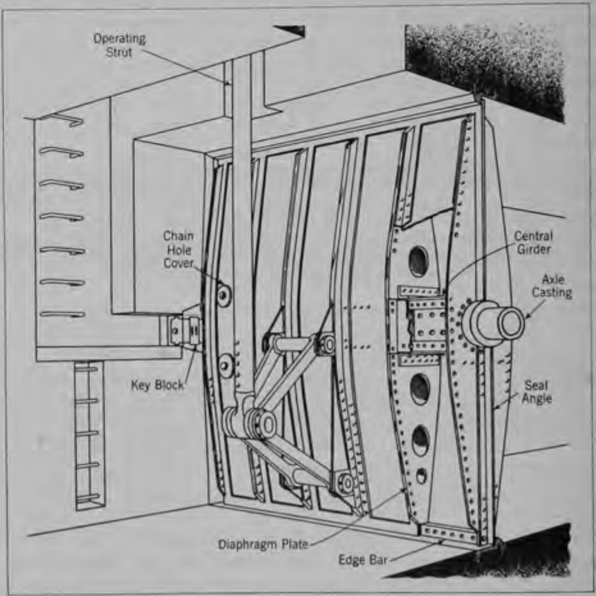

FIG. 24.—MONONGAHELA RIVER: TYPICAL LARGE STRUCTURAL STEEL BUTTERFLY VALVE.

The frames are of cast iron embedded in the concrete forming the sides, floor, and roof of the culvert. The top and bottom frame castings are each a single piece and are bolted at the ends to the side frames. The side frames are each made up of three pieces bolted together. The middle piece of the side frame carries the bearing and is designed to receive the whole axle load and to distribute this load on an area of concrete that is adequate to sustain it. The axle is supported on the back or down-stream side by a removable bronze bearing and is secured on the front or up-stream side by a cast-iron bearing block and key (Fig. 24).

Operation and Maintenance.—A blade can be removed, replaced, or repaired without interfering with the operation of the lock, except for the reduction in the speed of filling and emptying due to one culvert being out of service. A bulkhead recess extending to the top of the lock wall is provided above and below each valve for the purpose of unwatering the section of culvert at the valve. The open shaft at the valve is large enough to permit hoisting the blade from the culvert.

These valves are operated by hydraulic cylinders. The cylinder is horizontal and located in a recess on the top of the wall. The motion is transmitted through a rocker arm to a vertical operating strut connected to the operating connection on the blade (Fig. 24). The cylinder has a bore of 15 in., a stroke of 67 in., and operates with oil at 250 lb. pressure. The normal time of operation from closed to open position, or the reverse, is 1 min. The operating strut is fitted with a spring arranged to be compressed when the valve is closed and to limit the downward force on the strut to approximately 10 000 lb. When opening, the force is transmitted directly through the strut without acting on the spring.

The outstanding features of the large structural steel butterfly valves are simplicity and ruggedness. They have few working parts and these are so heavy that the chances for accidental damages are remote. Since all parts are relatively heavy, the rate of corrosion is lower than in the case of a number of small valves having an equal area.

The cost of a 12 by 10-ft. structural steel butterfly valve, as described, with its operating machinery, is approximately $4 000, or about $33 per sq. ft. of area.

Torque for Operating Butterfly Valves.—The torque required to open a butterfly valve operating against a head varies from a relatively small amount at the start to a maximum at about 10° from the open position. For the purposes of design it is usually only necessary to know the maximum torque

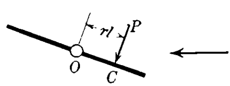

FIG. 25.

that will be required, and this may be determined from comparison with the torque required to operate valves in service, if the proper factors of similarity are applied.

Referring to Fig. 25,

Let M = maximum moment required to operate valve.
w = width of valve blade in direction of axis.
l = length of valve blade in direction perpendicular to axis.
A = area of valve blade = wl.
P = total pressure acting on blade due to reaction of water at angle of maximum torque.
p = average unit pressure acting on blade = $\frac{P}{A}$.
v = average velocity of water in culvert.
r = coefficient for distance from axis to center on pressure, $\frac{O-C}{l}$.

n = coefficient for reaction of water on blade at angle of maximum torque $= \frac{p}{v^2}$.

k = constant of culvert efficiency.

H = effective head acting on the water in the culvert to produce the velocity, v.

g = acceleration due to gravity.

It is assumed that:

(1) Reaction on the blade is proportional to v^2.

(2) Reaction on the blade is proportional to the area of the blade.

(3) That r has a fixed value for all blades at the angle of maximum torque and is independent of v.

(4) That n has a fixed value for the angle of maximum torque for all velocity heads.

The pressure acting on the blade at the angle of maximum torque is $P = p\ A$. Furthermore, $p = n\ v^2$, $v = k\sqrt{2\ g\ h}$, and $v^2 = k^2\ 2\ g\ h$; therefore, $p = 2\ n\ k^2\ g\ h$, and $P = 2\ n\ k^2\ g\ h\ A$. The moment arm of this force is $(0 - C) = r\ l$. The moment of torque is, therefore,

$$M = P\ r\ l = 2\ n\ k^2\ g\ h\ A\ r\ l = 2\ n\ g\ r\ k^2\ H\ A\ l.$$

The factors, 2, n, g, and r, are constant values and may be grouped as a single constant, C. Then, $M = C\ k^2\ H\ A\ l$.

For rectangular blades, $M = Ck^2Hwl^2$. For circular blades, let R = the radius of the blade and D = the diameter of the blade. Then, for an elementary section, $d\ M = C\ k^2\ H\ l^2\ d\ w$, and $\left(\frac{l}{2}\right)^2 = R^2 - w^2$

Then,

$$M = 2\ C\ k^2\ H \int_0^R l^2\ d\ w = 2\ C\ k^2\ H \left[\int_0^R 4\ (R^2 - w^2)\ \right] d\ w$$

$$= 8\ C\ k^2\ H \left[R^2\ w - \frac{w^3}{3}\right]_0^R = \frac{16\ C\ k^2\ H\ R^3}{3} = \frac{2}{3}\ C\ k^2\ H\ D^3$$

The value of C determined by tests on a 10 by 12-ft. valve at Lock No. 6, Monongahela River, is 0.114; when, M is in inch-pounds, k is 0.60; H is in feet, and w and l are in inches. Tests on a 54-in. circular butterfly valve at Emsworth Lock on the Ohio River gave a value for C of 0.115.

For general use a value of 0.12 is recommended. The torque thus obtained is that required to overcome the reaction of the water and additional allowance must be made for friction in the bearings and operating mechanism. Tests at Lock No. 6, Monongahela River, showed that the friction was 20% of the total power required to operate the valve and at Emsworth it was 21 per cent.

APPENDIX 10

LOCK VALVES, WILSON DAM AND DAM NO. 1, TENNESSEE RIVER, FLORENCE, ALABAMA

C. A. D. Young,* M. Am. Soc. C. E.

Tennessee River and Its Dams.—Wilson Dam in the Tennessee River, 2½ miles above Florence, Ala., is primarily a power dam authorized by Congress to be built to furnish power for the production of nitrates as part of a war-preparedness program.

Lock and Dam No. 1, at Florence, is strictly a navigation structure and was built to provide a navigable channel over the shoals between Florence and Wilson Dam.

The Holston River, which rises in Southwest Virginia, and the French Broad River, rising in Southwest North Carolina, join a few miles above Knoxville in East Tennessee to form the Tennessee River. The Tennessee River flows southwesterly into Alabama, westerly across Northern Alabama, thence northerly across Tennessee and Kentucky to join the Ohio at Paducah, Ky., 46.5 miles above the junction of the Ohio and the Mississippi Rivers.

The Tennessee River has an average flow at Wilson Dam of 54 000 cu. ft. per sec., with a maximum of 446 000 and a minimum of 8 000 cu. ft. per sec. It has been partly improved under various projects by open channel work and by locks and dams from its mouth to Knoxville, a distance of 645 miles, but continuous all-year navigation has not been obtained, except from Paducah to Florence, in which stretch a least depth of 4 ft. is available at extreme low water. Navigation is possible to Chattanooga for boats drawing 3.5 ft. for an average of about 80% of the time.

Lock Structures.—The present traffic is very limited. However, the project under which Wilson Dam and Dam No. 1 were built provides for a 9-ft. depth and the sills for Wilson Dam were so placed that the limiting depth is 9.5 ft., as is also the upper sill of Lock No. 1. The lower sill at Lock No. 1 was placed at such an elevation as would provide 6 ft. at extreme low water under present conditions. When the channel below Dam No. 1 is improved for a 9-ft. depth it must be done by raising the water surface either by low navigation dams or by a high combined power navigation dam. When this is accomplished, there will be 9.5 ft. over the lower sill of Lock No. 1. The upper sill of Wilson Lock is 12 ft. below the normal pool level.

The elevation of the pool above Wilson Dam is 89 ft. above the pool provided by Dam No. 1, and the lock therefore was made in two lifts of 44.5 ft. each. The upper pool is held at constant level by regulating gates on the crest of the dam, although a draw-down of 2.5 ft. is possible at times. Dam No. 1 has a lift of but 16 ft. at extreme low water.

The lock chambers (Fig. 26) are all of approximately the same size, 60 ft. in width by about 300 ft. usable length, or about 350 ft. between gate quoins

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of the lower locks. The Tennessee River towboat is about 140 ft. in length by 38 ft. wide, with 4-ft. draft. The barges which it is anticipated will be used are 120 ft. long by 26 ft. wide. Each lock will accommodate four barges, or two barges and a towboat, so that it will be necessary to break a six-barge tow but once. The navigation season is 365 days in the year.

The same general design for culverts and valves was used for Lock No. 1 as for Wilson Lock except for some changes which are believed to be in the nature of improvements, and these are described later.

Governing Factors, Wilson Lock.—The Muscle Shoals section of the river in which Wilson Dam is located, is 4 200 ft. wide with precipitous limestone bluffs on either side extending approximately 150 ft. above the bed of the river. The lock is at the north end of the dam and built partly in the limestone bluff. The upper gates are just below the line of the dam. The foundation of both the dam and the lock is on limestone bed-rock.

The concrete aggregate used in the construction was graded river gravel and sand obtained from gravel-bars about eight miles down stream from the dam.

The lock chambers were excavated partly from the solid rock. The lock walls are 15 ft. thick between the gates and 23 ft. thick at the gates (Fig. 26). The speed of filling was fixed at about 8 min. for each lock of the flight. As the towboats have a very slight free-board, from 6 in. to 1 ft., turbulence in filling is very objectionable and for the same reason surge is to be avoided as much as possible.

In the low-water season every drop of water has value as potential power, so that leakage is of considerable importance, consequently both in the gate and valve design great precautions were taken to reduce leakage to a minimum. Electric power is available, but for operation of the lock machinery this is converted into compressed air at 90 lb. pressure.

Description of Spool Valves.—The culverts, one in either wall, are 7 by 9 ft. in section and twelve outlets, 2.5 by 3 ft., are provided from each culvert into each lock chamber. Each culvert was provided with three vertical relief pipes, 6 in. in diameter, leading from the top of the culvert and opening into the lock chamber 3 ft. below the top of the wall. The lower and outer end of the culvert ports is 1.5 ft. above the lock floor. The inner end is level with the bottom of the culvert and 2.5 ft. above the lock floor. Since the upper and lower pools are practically constant, the difference of level being 89 ft., the heads at commencement of operation are the same in both locks, or 44.5 ft. This may vary by only a few tenths of a foot.

The valves as originally designed (Fig. 27) consisted of a cast-steel spool about 6 ft. high by 2½ ft. in diameter at the center and flaring to about 7 ft. at either end. This spool worked vertically in a cast-iron casing, seating at top and bottom on this casing. The valve spool had a vertical travel of 2 ft. 9 in., and when seated the water surrounded the spool and the pressure was equalized. When the spool was raised the water dropped down through a vertical shaft and also flowed upward and down outside the casing, entering the shaft below.

The seal consisted of removable bronze bearings on the spool and the casing and these were machined very carefully at the shop and were ground to a perfect fit during the installation.

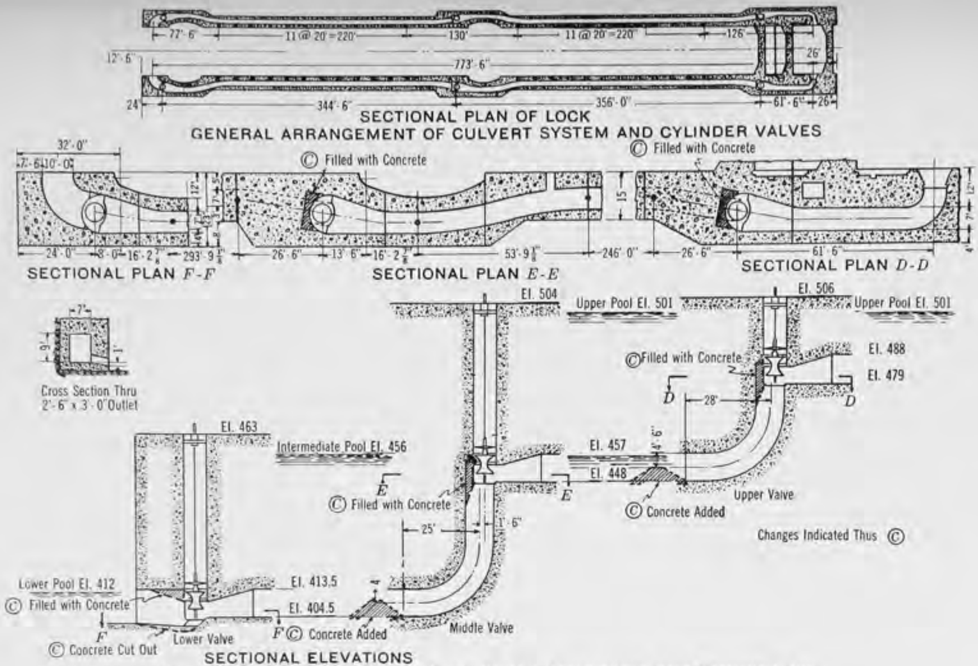

Fig. 26.—Tennessee River, Wilson Lock: General Arrangement, with Horizontal and Vertical Sections Through Culverts.

A piston working in an air cylinder, 20 in. in inside diameter, provided the power for raising the valve spool and opening the valve. This was to have been operated from a tower at the upper end of the upper lock and a very elaborate system of control piping was provided in the original plans. It was decided later that, owing to the necessary dependence on automatic signals to indicate the operations of machinery, it would be safer to operate from points close to the machines. A compressor in the lower part of the tower furnishes air for operating the valves and the gate engines.

Difficulty in Operation.—The first test operation went off very well, but the next time the valves were operated they gave trouble, and this grew worse until a valve casing was wrecked.

The cause of the trouble was twofold. It will be noted from Fig. 27 that the upper flange of the valve is larger in diameter than the lower, with about 14% greater area. This would cause an upward pressure of about 5 000 lb. on the middle valve and one considerably greater, perhaps twice as great, on the lower valve, when the valve is but very slightly open. When the seal is perfectly tight as it was at the first operation, the weight of the valve is sufficient to hold it closed so that no difficulty in operating was experienced; but with a very slight leak the upward pressure becomes so great as to lift the valve, and that was the trouble experienced with the lower valves.

As the difference in pool level decreased the lifting effect on the valve decreased until at 16 ft. difference in pool levels, the weight of the valve was sufficient to close it. Tests were made to determine what weight on the valve was necessary to overcome this effect, and it was found that an added weight of 2 000 lb. allowed an increase of head of only 1 ft.

Effect of Vacuum.—When flow has started, the water dropping down the vertical shaft at the upper and intermediate valves creates a partial vacuum so that the downward pressure on the valve is very great.

It was impossible to raise the middle valves more than 8 in., when starting to empty the upper lock due to this vacuum, but as the operation progressed the valve gradually came up until with a difference of about 20 ft. in pool level the valve was fully open. Necessary lockages were made by holding the lower valves closed by props and operating the middle valve as indicated, until one of the middle valve casings was wrecked. The valves were raised to the 8-in. limit and the air was left on the piston. For some reason the vacuum was broken momentarily during one operation; the valve came up and was caught and dogged by one of the workmen. When the vacuum was again restored, the valve was forced down on the casing and that part of the casing not embedded in the concrete was broken away. The 1⅝-in. steel rod connecting the valve with the piston was stretched 16½ in. in about 39 ft., indicating a downward pressure on the valve of at least 60 000 lb. The reduction of section was practically uniform for the whole length.

Before this happened, however, a diaphragm was built in the shaft above the valve at both the upper and middle valves, and made as nearly air-tight as possible. A vacuum gauge was installed and readings were taken. It was found that operating under full head a vacuum of 7 in. was produced at the

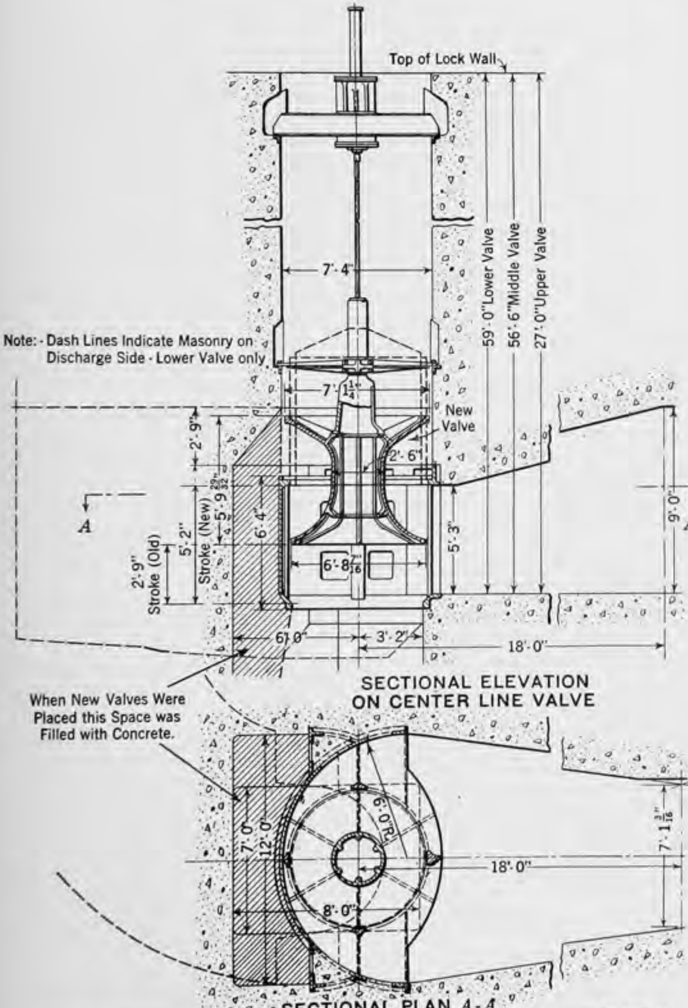

Fig. 27.—Tennessee River, Wilson Lock: General Assembly, Cylinder Valve as Originally Designed and Installed.

upper valve. The maximum reading obtained on the middle valve was 23 in. when the diaphragm collapsed.

The maximum effect is had when emptying the upper lock. At the begining of this operation there is a difference in pool level of 89 ft. At a difference of about 20 ft. in pool level the vacuum is not great enough to cause trouble.

Water was thrown from the 6-in. relief pipes to the opposite wall of the lock. This was in a solid stream, at the beginning of the flow, but changed to spray and, finally, to air only as the water in the pipe was exhausted. The action was intermittent and first from one pipe and then the other.

This was overcome by turning the pipes to the back of the wall and connecting them to a header which discharges at the lower end of the lock.

New Cylindrical Valves.—After wrecking the valve casing it was decided to design and install a new valve and casing on the order of the cylindrical valves in successful use on the Panama Locks. This valve was made of about the same over-all dimensions as the old valve, but cylindrical in place of the spool shape. The passageway which allowed the water to flow downward back of the casing was concreted so that all the water passes downward into the shaft leading to the outlet culvert.

The valve was made heavier than the original; this made a larger cylinder necessary, and the stroke was increased to 5 ft. 2 in. At the same time this valve was changed to operate by oil. A closed tank was placed in the well containing the lifting cylinder. This contains enough oil to operate the valve, and pressure is obtained by admitting compressed air to the tank above the oil, forcing the oil into the lifting cylinder. This was arranged for operation by an air-valve on top of the lock wall and in close proximity to the valve.

Constrictions for Culverts.—It was thought that part of the trouble was caused by the water getting away through the shaft and lower culvert faster than it came to it through the upper culvert, so that there was not a solid stream flowing from the upper to the lower pool.

To obviate this, the passage through the valve was reduced by concreting the passage back of the valve casing and the culvert below the valve was partly closed, all as shown on Figs. 26 and 27.

The area of the culvert was contracted below the valve to 50% of its original section. This had no effect on the time of filling the lock, and since these changes were made the lock has been in successful operation.

Operation, Wilson Lock.—As at first constructed, the time of filling the lock, from the best information available, was 12 min. As at present constructed, the time of filling the upper lock is 12 min. and the time of equalizing the water level in the upper and lower locks is 12 min. The time required to empty the lower lock is 15 min. This is with valves wide open. As operated in service, the time required to fill the upper lock is 14¾ min. and to equalize the level in the upper and lower locks, 17 min. The time required to empty the lower lock is 15 min.

It has been found that the turbulence with both filling valves wide open is dangerous to river craft having shallow draft and small free-board. It is, therefore, the practice to open first the valve on the side to which the boat is moored about 18 in. When the water has risen about 6 ft., the same valve is raised to about the half-open position and the opposite valve is raised 18 in. When the water has risen an additional 6 ft., the first valve is fully opened and the opposite valve half opened. When the water has risen an additional 6 ft., the second valve is opened full. This operation takes about 7 min.

The water flows out of the culvert port across to the opposite wall, up to the surface and back across the lock, and by operating by this method the current tends to keep the boat up against the wall to which it is moored.

If the boats were provided with sufficient lines they could put out enough hawsers to the wall-hooks provided, and could shift without letting go entirely, as the water rises. Then it would be safe to open both valves full at the start; but as traffic is very light and the difference in time is small, this change is not considered worth while.

Lock No. 1 Installation.—At Dam No. 1, the culvert ports are 1.5 ft. above the lock floor at the outer end and 3.0 ft. above the floor at the inner end. The actual time of filling or emptying is 8 min. at 16-ft. head. The operating head varies from 0 to 16 ft. In filling at any head the water in the lock is so quiet that even the smaller boats are not disturbed.

The valves and culverts at Lock No. 1 are the same as the original at Wilson Lock, and have operated successfully since their installation. One important difference, of course, is that the vertical shaft below the valve is very much shorter than at Wilson Lock, the extreme low-water lift of the lock being only 16 ft. as compared to the 44.5 ft. at Wilson Lock. One change, while it does not affect the operation of the valve, is believed to be of importance, that is, the provision for stopping off any one valve so it could be unwatered for repairs without closing the lock.

The operation of the valves is by a hydraulic cylinder mounted above the valve as at Wilson Lock. The oil under pressure is furnished by a triplex pressure pump located on a mound on which are also the operators' homes. While electric power is available, hydraulic operation was selected because the lock is subject to overflow. In December, 1926, the water was 5 ft. above the top of the lock wall.

The pump is driven by a 3-phase motor which is geared to the pump and is started and stopped by an automatic switch. The accumulator consists of a steel air-tight tank into which the oil is forced against air pressure. The cylinder holds sufficient oil to start the operation of the lock machinery, and as soon as the pressure in the tank drops below a fixed limit, the pump is started and completes the operation.

It is apparent from this experience that these valves will work successfully where the head is not more than 20 to 25 ft. and, possibly, with great care in the design of the water passages so that they will be full of water at all points and under all conditions, they would work successfully with greater heads.

APPENDIX 11

LOCK VALVES OF THE MISSISSIPPI RIVER LOCK AT KEOKUK, IOWA

By M. Meigs,* M. Am. Soc. C. E.

Type of Lock and Equipment.—The writer having been inspector on the work during the construction of the power plant at Keokuk, Iowa, and having had charge of the operation of the lock for thirteen years, seems to be in a position to point out some valuable lessons learned during that time.

The valves were not of an untried design but their methods of operation and the arrangement were in some ways unique.

In 1913 the Mississippi River Power Company finished its great power plant at the foot of Des Moines Rapids. It was built with great rapidity, considering the magnitude of the work. H. L. Cooper, M. Am. Soc. C. E., was the Superintending Engineer on the construction and prepared the plans for the hydraulic work which were submitted for approval to Charles Keller, Major, Corps of Engineers, U. S. A., M. Am. Soc. C. E., in charge of the Rock Island District, and through him to the Chief of Engineers, U. S. A., and to the writer who was on the ground.

The permit from Congress for this work was contingent on replacing the old Des Moines Rapids Canal with three small locks, 350 by 80 ft., by a single large lock, 111 by 400 ft., with a lift of 41 ft. at extreme low water; also the replacement of a dry dock at the old canal with its shops, storehouses, and power to operate them.

Since the old dry dock used pneumatic tools extensively and as air would be required for operating the new gates of the lock and dry dock, it was arranged for the Power Company to furnish a power plant. This consisted of a 400-h.p. turbine attached to suitable air compressors in a separate plant, which furnished the air for handling the valves of the lock. The valves specified by the Chief of Engineers were identical with those at Panama, except the method of operation by air. Had they been operated by electricity trouble might not have developed, as operating by air introduced new problems.

The lock had some new and unusual features. For instance, filling and emptying is accomplished by a single straight steel penstock embedded in the foot of the east, or river, wall of the lock (Fig. 28.) This penstock at the upper end is 13 ft. in diameter and tapers to 8 ft. at the lower end.

Filling Valves

Description.—There are four filling valves situated vertically above the penstock (Fig. 28), with four vertical steel conduits, 7 ft. in diameter, reaching upward to the valves. They are buried in massive concrete that forms a floor on which the valves sit (Fig. 29). Each valve consists of a cast-steel drum about 3 ft. high with a massive cover which rests on four pedestals or legs

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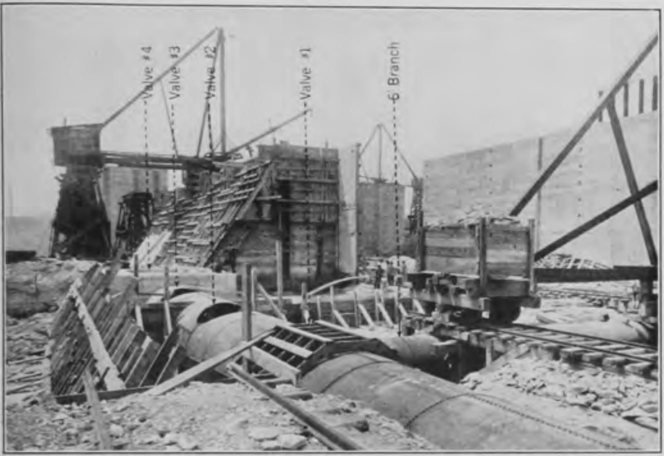

FIG. 28.—KEOKUK LOCK: DISCHARGE VALVE SEATS ON MAIN TUNNEL.

FIG. 29.—KEOKUK LOCK: INLET VALVES IN PLACE.

arranged around the upper end of the 7-ft. conduit. Inside this drum is a sliding cylinder which closes the opening under the drum when let down and opens it to the passage of water when drawn up (Fig. 30). The sliding cylinder has a spider or set of four spokes that unite in a hub in the center with a 3-in. hole for the operating stem.

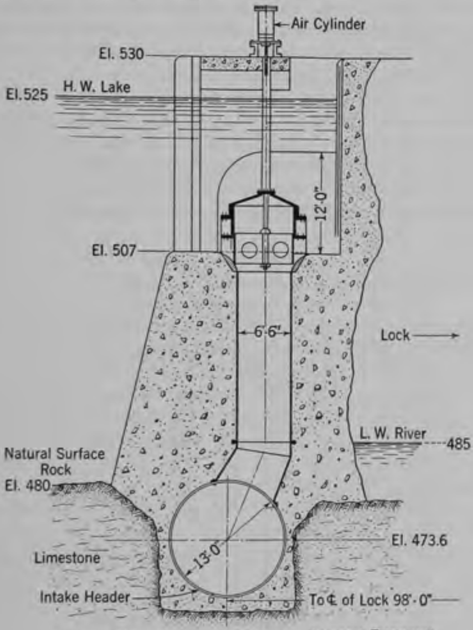

Fig. 30.—Keokuk Lock: Vertical Section Through Inlet Valves.

The stem is of 6-in. pipe the upper end of which terminates in a piston 15 in. in diameter working in a vertical cylinder on the upper or top wall of the lock. Pipes 1¼ in. in diameter connect to each end of the operating cylinder and unite in the operating house near-by in a single valve for operating all four valves together. An ingenious contrivance to prevent surging and knocking consists of check valves placed where the air pipes enter the operating cylinder. Each valve is perforated by a small hole about ⅜ in. in diameter so that when air is admitted for a power stroke the valve lifts and offers no obstacle to the air. When, however, the air is exhausted it has to pass through the ⅜-in. hole which insures slow and easy motion. This device has proved very satisfactory and has given no trouble. It takes the place of a "cataract" with oil or water in a separate cylinder.

Difficulty in Operation.—A few days after the lock was opened to navigation the operator reported that when he raised the valve to fill the lock, a heavy concussion was felt underground and he heard water splashing. On examining the valves he found some displacement and cracking of the concrete under the operating cylinder. Nothing further happened, however. A few days later, the concussion was again heard at another valve, accompanied by splashing of water and slightly cracked concrete. The same thing happened in succession to all four valves. Although something serious had occurred, the valves continued to function as well as at first.

It was apparent that there was violent surging in these valves and many arguments arose regarding the cause of the trouble and means of preventing it. Finally, the writer made a small model of glass tubing (Fig. 31). In this model the system could be filled with water and the upper end of any tube opened by the wire attached to the rubber valve. When air was introduced into any tube, lowering the column of water in that tube, if any other tube was opened

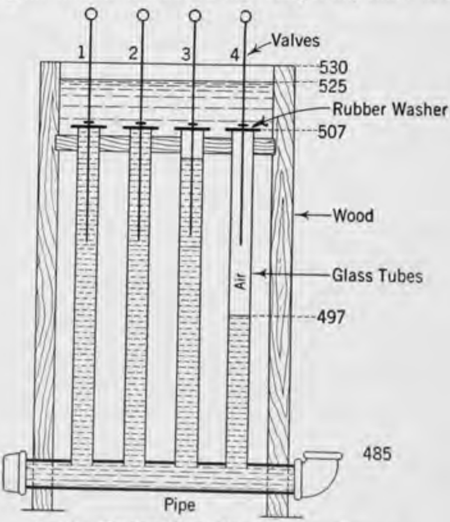

FIG. 31.—KEOKUK LOCK: EXPERIMENTAL MODEL TO SHOW SURGING IN PIPES.

the column of water in the partly filled tube would oscillate. From Fig. 31 it will be seen that when the water fills the tube and the valve itself, it is supported only by the vacuum due to the height of the column of water above low water, namely, 28 ft. This is so near the maximum height that may be attained by vacuum it was evident that at times all the valves and conduits were only partly filled with water. Had the operation been by electrically driven screws operating simultaneously, the hammering probably would never have occurred. The cylinders being all on one pipe and operated by the same throttle, did not work exactly together so that the water danced up and down in all tubes containing air.

For example, suppose Pipe and Valve No. 4, in Fig. 31, to be filled about half-way, or 12 ft. above low water, the weight would be about 17 tons, which is balanced by the vacuum in the pipe. The column of water in Valve No. 3, being 41 ft. high, would weigh 48 tons. Now, suddenly, raise Valve No. 3 and release 48 tons of weight downward; the effect is to shove the water column in Valve No. 4 upward, creating sufficient shock to cause great damage when arrested. The cure was to vent the top of the valves to air and destroy the vacuum. This done, no more hammering occurred.

Remedying Trouble.—At the close of the season of navigation the filling valves were unwatered and examined. All four legs on three valves were broken at the smallest section, close to the top. One valve had only three broken legs. It so happened the fractures were such that when the top was lifted it returned into place exactly, and thus the valves continued to operate although broken. Computed from the area of fractured metal and the 7 ft. diameter of the valve there must have been a pressure of 200 lb. per sq. in. inside the valve, before the legs broke.

Some experiments were made to determine how air got into the pipes. The valves were so far beneath the surface of the water that, when filling, no whirls or eddies could be seen. The water rushing in through a grating in front to keep out drift was examined and fine bubbles were noted alongside the vertical bars. On making experiments it was found that a velocity of 1 ft. per sec. in the water would entrain and suck down these very fine bubbles. Water, under a vacuum, gives up air so it was clear that the valves, given time enough for the bubbles to gather, were never clear of air. When the conditions were right the hammering took place destructively. Since the vent pipes were placed, it is easy to distinguish the dancing up and down of the four columns of water by the blowing and sucking of the vent pipes, but as filling starts with the conduits empty, no damage now occurs.

Discharge Valves

Arrangement.—The discharge valves are placed in line with the filling valves on top of the main penstock or tunnel with only a very short connection between (Fig. 32). Unlike the filling valves the water enters from below and introduces different conditions of flow. Coming from both directions and making a short turn vertically the water is then, in the valve itself, turned horizontally into the river at the low-water level. The tunnel or penstock serves both for filling the lock and emptying it. The water flows from the tunnel through eight branches 6 ft. in diameter at right angles to the tunnel, and each branch has seven 3-ft. openings that discharge vertically into the lock chamber. The whole system is buried in the lock floor. Arranged as it is, the water enters and leaves by the same course.

This arrangement of the lock has worth-while consequences. The water flowing into the filling valves is away from the lock entrance and tends to keep drift out of the lock. When filling the lock, it is also found that the entering water streams are fastest on the far side, causing a return current that holds a boat quiet against the side where the water enters and prevents the boat from straining and possible breakage of moorings. This procedure would not do for ships which need be kept in the middle and away from the walls, as at Panama, but on a river and for river boats with no gear projecting over the sides, it is ideal. The tunnel where the discharge valves sit is 12 ft. in diameter. As with the filling valves, the maximum head is 41 ft. between low water in the river and lake level above the dam.

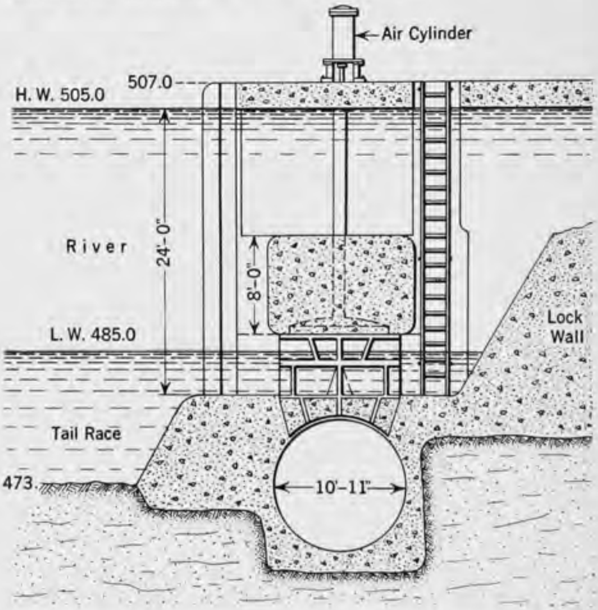

FIG. 32.—KEOKUK LOCK: DISCHARGE VALVE AND ITS RELATION TO OTHER PARTS OF SYSTEM.

Damage in Service.—The short turns in the valve give rise to considerable drumming and vibration when opened because the current is turbulent. It strikes the sides of the spider of the movable cylinder in a way not discoverable in the filling valves. Owing to this drumming and the construction of the valve stems, serious consequences followed after about three years of use. One day when the lock was being emptied and when the valves were lifted, a heavy concussion occurred. The water went out a little faster than usual and when the lock water was level with the river considerable leakage to one valve was noted. On filling the lock this leak showed up strongly at the discharge opening of the No. 4 valve, and the stem, when raised, showed that it was not lifting the movable cylinder. A diver reported that the nut on the end of the stem had worked off and allowed the valve to close suddenly and that a large piece of the cylinder had been blown out. It was impossible to unwater the valve in the middle of the season as the whole lock would have to be unwatered and remain closed until repairs were made, since there was no means of equalizing the levels to permit operating the upper gate which is a floating pontoon, 110 ft. long and drawing 11 ft. of water.

Accordingly, temporary repairs were made by the diver. Needles bolted to a ring of channel iron were used to shut off the water (Fig. 33). These repairs enabled the lock to be used. At different times similar breaks have occurred in these valves which are dealt with chronologically for the value of the lesson they teach.

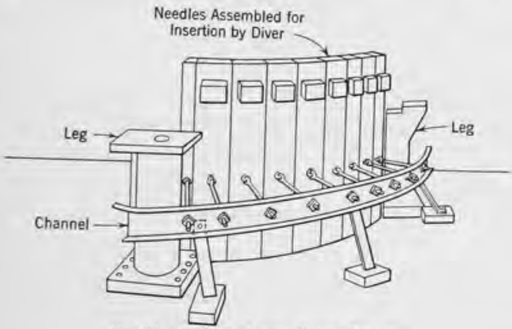

FIG. 33.—KEOKUK LOCK: VALVE REPAIRS.

CHRONOLOGY OF VALVE TROUBLES

As stated previously, the valves were put in use in August, 1913. For two years only two stoppages occurred, and these by drift getting caught in the valves, but no real trouble ensued.

On May 11, 1915, Valve No. 2 dropped, and, on May 17, Valve No. 4. Both occurrences were marked by heavy concussions that shook the lock. A diver reported that the stems of the valves were pulled apart. Valve No. 4 was broken, a large piece of the sliding drum being broken out. The broken valve was shut off by needles applied inside and fastened to a channel iron curved to fit the outside of the legs of the valve (see Fig. 33). Valve No. 2 seemed not to have suffered. On removing the stems of Valves Nos. 1, 2, and 3, all were found to be so corroded in the threads that they would stand little strain. Moreover, the sleeve connection of bronze used to unite two sections of the 6-in. pipe that formed most of the stem (Fig. 34), had corroded the neighboring metal. They should have had a lump of zinc bolted to the steel in the vicinity of the joint as is usual in under-water work. Rivets were put through all these joints and the stems replaced. Only three valves, however, were now in use.

In 1916 no trouble was recorded. On July 15, 1917, Valve No. 3 was found to be leaking badly. A diver discovered 3 ft. of the sliding drum broken out and gone. This valve was blocked off the same as No. 4. It was also found that No. 4 had lost its needles, cut off by the pressure from the concussion in closing Valve No. 3. The 4 by 6-in. needles were cut off as with a knife, and this valve had to be bulk-headed anew, using 6 by 8-in. timbers. With two valves gone the operation of the lock was very slow from August 29 to September 24, when Valve No. 2 swelled and could not be used. From then to November 12, the lock was operated with one valve, and 1½ hours were required to lock a boat through instead of 12 min. with all valves in use.

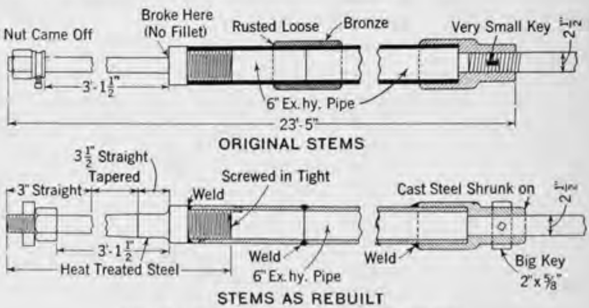

FIG. 34.—KEOKUK LOCK; VALVE STEM REPAIRS.

On November 12, 1917, at the close of the season, the unwatering of the lock was started. It was unfortunately at the height of preparations for the World War and no one could be found to undertake any outside work. Moreover, the patterns had been destroyed in a shop fire, so it was resolved to see what could be done by patching.

The diver was employed to find the broken pieces of the valve, some being found in the tunnel and some in the river at a distance from the lock. All the pieces were finally collected, fitted with two rolled steel plates the shape of the inside of the valve, and applied in pieces 12 in. wide.

The stems were overhauled, the bronze sleeves discarded, and acetylene welding was substituted for riveting. One valve had lost the lower end where it passed through the spider and a new piece was screwed into the pipe and then welded.

In 1918 and 1919 only minor troubles were experienced from drift in the valves.

On July 3, 1920, the 3-in. stem of Valve No. 2 broke off at the lower end where it entered the spider. This break was repaired by a new stem screwed into the 6-in. pipe and welded.

On August 31, 1920, Valve No. 3 dropped, and the broken stem was repaired.

On May 31, 1921, Valve No. 2 again dropped. The diver found the nut off the lower end. Evidence showed that the nut, placed on the end of the pipe when it was repaired in 1920, had not been made secure by the set-screw furnished for the purpose, and it had gradually rattled off. The valves had worn, and drummed when opening. The lock was now operated with three valves to the end of the season.

Permanent Repairs.—In November, 1921, at the close of operations, the war being over it was decided to make thorough repairs. All the sliding drums were replaced new. All pedestals or legs were replaced and made so that they could be easily removed. Welded joints and keys were used instead of screw-joints (Fig. 34). The lower stems were renewed with heat-treated steel. These pieces had to be screwed into the end of the pipe, but were welded on the outside with a liberal surplus of metal. The stem was also enlarged to 3½ in. at the top where it entered the spider and tapered to 3 in. at the lower end as before. A nut was used on the lower end and below it a deep key was inserted sufficiently large to do all the work, should the nut unscrew.

This work was done during the winter of 1921-22, and the lock put into service again.

From January, 1922, to April, 1928, the valves have operated without any trouble or breakages.

Desirable Details for Valves.—Four lessons may be learned by these experiences:

1.—Do not use screwed joints under water for end pull.
2.—Do not use bronze in contact with steel or iron under water without fastening a piece of zinc to the steel in the neighborhood of the joint.
3.—Use welded joints wherever possible.
4.—Use keys instead of screw-joints and fit a keeper to the keys as they may rattle out when unstrained.

The difficulties with these valves were not due to their form, but to the imperfect stem construction. In the writer's opinion the valves are among the best designed. They are balanced and operate easily. They are difficult to clear of drift in some cases without the use of a diver. They are at their best with the water going downward through them where compression is on the outside.

For use with reversed flow, with pressure on the inside, they are also excellent if they are kept from surging. In this case the stems are the dangerous factor, and no trouble or expense should be spared to make them so strong and so constructed that they can be left for long periods without examination, a treatment they are sure to receive. Particularly in northern latitudes, where winter repairs may be necessary, with freezing and draining troubles to encounter, such valves call for the best of workmanship and design.

Finally, the cylindrical valve seems to have the following advantages over sliding or hinged valves:

(*a*) There are no journals or bronze bearings to wear out and be replaced.
(*b*) Being of cast iron they need no painting as they rust very slowly under water.
(*c*) They are balanced against water pressure, and if the moving parts are counterpoised, they may be operated with hand power even in large sizes. They can be trusted for long periods without any attention or danger, provided the stems are made to resist corrosion at joints (especially when the pressure is on the inside of the valve) and surging is prevented.

APPENDIX 12

THE LOCK VALVES OF THE WELLAND SHIP CANAL

By Frank E. Sterns,* M. Am. Soc. C. E.

General Description.—The Welland Ship Canal is being built by the Government of Canada to provide better facilities for navigation between Lake Ontario and Lake Erie than are afforded by the present Welland Canal which now carries the whole of the traffic between the two lakes. For 10 miles of its total 25 miles in length the Welland Ship Canal is formed by widening and deepening portions of the long summit level of the present waterway. The remaining 15 miles of its length are in new locations adopted to improve the alignment and to enable the new locks to be built without interfering with navigation through the present canal.

The water level of Lake Ontario varies between Elevations 242.5 and 249.0 above mean sea level, and the low and high-water levels of Lake Erie are at Elevations 568.0 and 580.0, respectively, above the same datum. In the Welland Ship Canal the total lift of 325.5 ft. between the low-water levels of the two lakes will be made in seven locks, each of approximately 46.5-ft. lift.

On the line followed by the canal the ground slopes gently up from Lake Ontario for a few miles and then rises steeply at the Niagara Escarpment to an elevation above the water level of Lake Erie. This profile places the seven high-lift locks all within 7 miles of Lake Ontario. Locks Nos. 1, 2, and 3 are located at intervals of from 2 to 3 miles on the gentle slope below the Escarpment. Locks Nos. 4, 5, 6, and 7 overcome the rise at the Escarpment, Locks Nos. 4, 5, and 6 being in flight and Lock No. 7, ½ mile above the flight.

In order that the flight locks may handle traffic in both directions not less rapidly than the other locks, twin flights side by side are provided so that down-bound ships may be locked through one flight while up-bound ships are passing through the other.

About a mile above Lock No. 7 a guard-gate is located, beyond which the summit level of the canal extends for 15 miles to Humberstone, Ont., where it is separated from the Lake Erie entrance by a guard-lock, No. 8. The summit level will be maintained at or near the low-water level of Lake Erie and the lift of the guard-lock will vary with the lake level, being normally about 3 or 4 ft.

As a special safety measure Lock No. 6 at the head of the flight locks will be equipped with duplicate gates. The area of its lockage prism therefore will be greater than that of either of the two locks in flight below it, which have not this feature. For this reason the lift of each of the locks, Nos. 4 and 5, is 47.9 ft., 1.4 ft. greater than the average lift of 46.5 ft., while the lift of Lock No. 6 is only 43.7 ft.

* Designing Engr., Welland Ship Canal, St. Catharines, Ont., Canada.

Lock No. 1 has a lift of 46.5 ft. when Lake Ontario is at its low-water level, but a somewhat smaller lift at other times. The remaining locks have each a lift of 46.5 ft.

The guard-lock, having only a small lift, is made of exceptional length to expedite traffic by enabling two or more of the smaller ships to lock through it at the same time. Its usable length is 1 355 ft. The high-lift locks have a usable length of 820 ft., or 859 ft. between pintle centers. All locks are 80 ft. wide and have a depth of 30 ft. of water over the gate sill platforms, although the reaches of the canal are being excavated at present only to depths varying from 25 to 27 ft. The waterway therefore will be navigable by ships considerably larger than the largest now in service on the Great Lakes and by the largest ocean-going ships which, for many years to come, could economically be placed in regular service through it, should Lake Ontario be made accessible by large ships from the ocean.

Traffic.—Vessels up to 261 ft. in length by 45-ft. beam by 14-ft. draft can pass through the locks of the present Welland Canal, and the majority of the vessels using the waterway during recent years have been of approximately this maximum size. The navigation season opens about April 15 and closes around December 15. The periods of heaviest traffic usually occur toward the close and at the beginning of the navigation season, due to the movement of grain from the West toward the Atlantic seaboard. Table 4 shows the traffic carried by the canal during the years 1914 to 1927, inclusive.

TABLE 4.—Traffic on Welland Canal.

Year.	Total number of vessels passed through canal.	Total net tons of freight carried.
1914	3 513	3 860 969
1915	2 782	3 061 012
1916	2 609	2 544 964
1917	2 881	2 490 542
1918	2 914	2 174 298
1919	3 004	2 170 779
1920	2 902	2 276 072
1921	3 707	3 076 966
1922	3 799	3 891 419
1923	4 102	3 755 912
1924	4 761	5 037 412
1925	5 108	5 640 298
1926	4 724	5 214 514
1927	6 211	7 247 459

Lock Foundations.—All the locks of the Welland Ship Canal are founded on rock. At the lower levels the rock is the red Medina shale. Above the Medina shale are strata of grey sandstone, mottled red and grey sandstone, and limestone and grey shale, above which the rock is limestone. Locks Nos. 1 to 4 are founded on the Medina shale. Locks Nos. 5 and 6 are in the sandstones. The excavation for Lock No. 7 passed through the upper strata of limestone into a thick bed of grey shale. Lock No. 8 is entirely in limestone.

The rock surface at Lock No. 1 is 3 or 4 ft. above the level of the lock floor. At Locks Nos. 2 and 3 the rock surface is from 15 to 20 ft. below the lock floors, so that the lock walls have to be carried down below the floor level.

At Locks Nos. 4, 6, and 7 the rock surface varies from 23 to 55 ft. above the floor level, while at Locks Nos. 5 and 8 it is near the coping level of the locks.

Rate of Filling.—In view of the heavy traffic which the canal is expected to carry it is important to have the locks filled and emptied rapidly in order to enable a large number of lockages to be made per day. Accordingly, the culvert system of the locks was designed to enable filling in approximately 8 min. with the valves opened gradually so as to give a maximum rate of filling of 8 ft. per min. While this rate of filling is considerably greater than has been used heretofore in other locks, so far as the writer knows, it is believed that by distributing the inflow over the entire length of the lock it can be safely used and will produce no objectionably strong tendency for the ship to surge in the lock.

Size of Culverts.—The locks will be filled and emptied through culverts formed in the walls. Except in Lock No. 8 the culverts run the full length of the lock and communicate with the chambers through numerous small lateral culverts placed just above the floors and distributed uniformly from end to end of the lock, which is filled and emptied through the same culverts.

The cross-sectional area of the main culvert in the side walls of the high-lift locks is 210 sq. ft., and 180 sq. ft. in the side walls of Lock No. 8. Two culverts are formed in the center wall of the flight locks, one for each lock chamber upon either side of it. The cross-sectional area of each of these culverts is 180 sq. ft.

The side-wall culverts in Locks Nos. 1, 2, 3, and 4 are 14 ft. wide by 16½ ft. high with semi-circular tops. In Locks Nos. 5, 6, and 7 where the side walls are narrower, being built, for a considerable portion of their height, against vertical faces of solid rock, the side-wall culverts are 9 ft. wide by 24½ ft. high, with semi-circular tops. The center wall culverts in the flight locks are 12 ft. wide by 16½ ft. high and also have semi-circular tops. At the valves, however, the culverts in all locks are of rectangular section, 15 ft. high, and subdivided into two valve chambers each 6 ft. or 7 ft. wide as required to suit the area of the two different sizes of culverts. All changes in the direction or shape of the culverts are made with easy curves and transitions.

Arrangement of Culverts.—Fig. 35 shows the general arrangement of the culvert system of Lock No. 2, a similar arrangement being used in the other single locks with the exception of Lock No. 8. Water for filling the lock will be drawn from behind the east lock wall through four intake valves. Two of these valves control the flow into the filling culvert in the east lock wall and the other two serve a culvert which passes under the lock floor to the filling culvert in the west lock wall. Each of these culverts extends the full length of the lock to an outfall into the lower entrance below the lower gate, the discharge from each culvert being controlled by a pair of discharge valves placed near its lower end. Twenty-five lateral culverts, 3 ft. wide by 4 ft. high, lead from each main culvert at intervals of 30 ft.

In the case of the twin locks, No. 6, the main culverts at the east side of the east lock and the west side of the west lock are supplied with water drawn from behind the east side wall of the east lock through four valves arranged similarly to the intake valves of the single locks, the flow through two of the

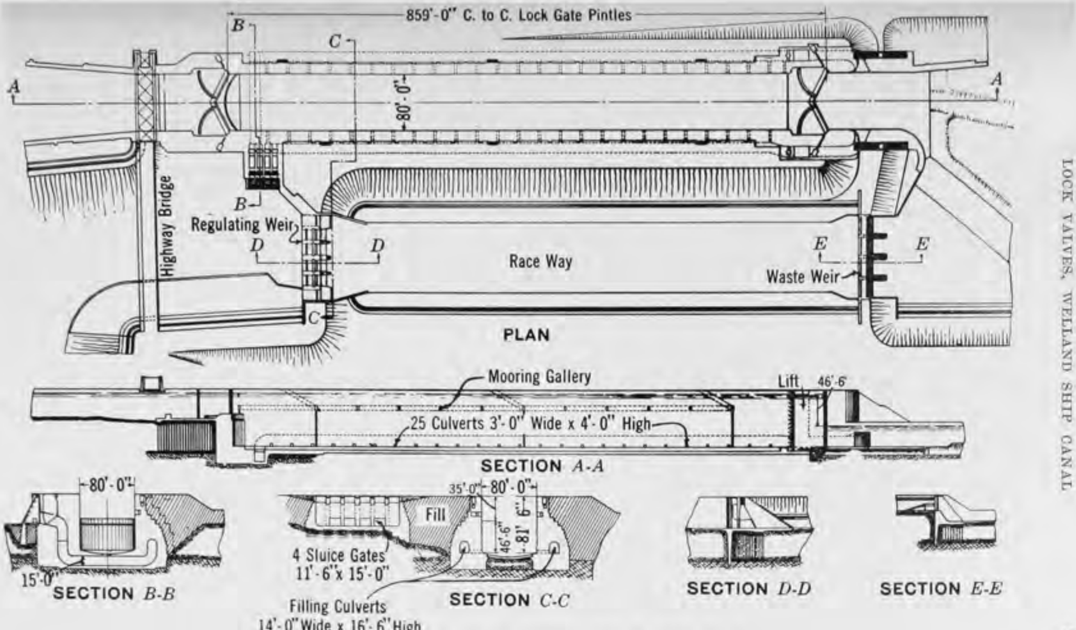

FIG. 35.—WELLAND SHIP CANAL: GENERAL PLAN OF LOCK NO. 2.

valves being carried under the floors of both locks to the far side of the west lock. The main culverts in the center wall draw their water supply from the forebays of the locks, two intake valves being provided in each culvert. The four main filling culverts extend from the head of Locks No. 6 to the foot of Locks No. 4 where they discharge into the lower entrances of the locks. At the lower end of each of the three locks each filling culvert is provided with a pair of discharge valves.

The lateral culverts in the flight locks are 3 by 4 ft. in cross-section and spaced at 30 ft. center to center, as in the single locks.

At Lock No. 8 where the lift is small, a simpler arrangement of filling and emptying culverts is used. There are two filling culverts, one in each side wall, extending from an intake in the forebay of the lock to a distance of only 171 ft. below the upper service gate, and two discharge culverts extending from a distance of 250 ft. above the lower guard-gate to outlets into the lower entrance of the lock. Each filling and emptying culvert communicates with the lock chamber through twelve lateral culverts, 4 ft. wide by 5 ft. high. Each main culvert is provided with a pair of valves placed side by side. Under a head of 4 ft. the maximum rate of filling the lock will be 1.8 ft. per min. and the time required to complete a lift of 4 ft. will be 4½ min.

Duplicate gates will be provided at the upper and lower ends of Locks Nos. 7 and 8, as well as in the twin locks, No. 6, as noted. The space between the lower service gate and the lower guard-gate in these locks will be filled and emptied with the lock chamber in normal operation and to feed it two lateral culverts, each 33 sq. ft. in area, are provided, one leading from each of the main filling culverts. These culverts are equipped with hand-operated sliding-gate valves by means of which they can be closed when necessary or throttled as required to cause the part of the lock chamber which they serve to fill and empty properly with reference to the remainder of the chamber.

The space between the two upper gates of these locks will normally be held at upper pool level, being placed in communication with the forebay of the lock through a 4 by 4-ft. culvert formed in one of the lock walls. A hand-operated sliding gate valve is provided for closing this culvert when desired.

Types of Valves.—The principal conditions governing the choice of the type of valve to be used are the following: When the canal is operating at its full capacity the valves will have to be opened and closed about 10 000 times per season.

The discharge valves will be subjected to a normal head of 46.5 ft. in most of the locks and a head of 77.9 ft. in Locks Nos. 5 and 6.

With two valves serving each main culvert the required effective area of each valve opening is 90 sq. ft. for the valves in Lock No. 8 and in the center wall of the flight locks, and 105 sq. ft. for all other valves.

On account of the heavy traffic which the canal will carry and its importance as a link in the Great Lakes System, an interruption of navigation through it would entail serious losses to shipping interests. The lock valves, as well as other essential items of the lock equipment, should be therefore thoroughly reliable in service.

In order to avoid any loss of time in filling and emptying the locks and to conserve the water supply, leakage at the valves should be reduced to a negligible quantity without the use of complicated sealing devices which might impair the reliability of the valves.

After a thorough investigation of the relative advantages of the various types of valves available, the Taintor type was found to meet all the conditions of the case most satisfactorily, and was adopted. The Taintor valve was considered to be preferable to the Stoney valve on account of the frequency of operation required, which would produce rapid wearing of the Stoney rollers and treads, involving troublesome and expensive maintenance. Cylindrical valves of the necessary size would require larger valve chambers than could be provided conveniently. Furthermore, they could not have been used as discharge valves without either placing them upon a horizontal axis, or using crooked and complicated water passages.

The Taintor type was preferred to the butterfly type on account of the unbalanced forces exerted upon the latter, when partly open, by the water flowing at high velocities through it, and on account of the rather unsatisfactory details involved in the construction of butterfly valves of the required size for the high head to be carried.

Construction of Valves.—As far as possible the valves for the different locks have been made alike and interchangeable so that, if found advantageous, spare units could be kept on hand to enable a damaged valve to be quickly replaced. Valves of two different sizes, 7 by 15 ft. and 6 by 15 ft., are required, however, on account of the two different sizes of culverts used. Also, the valves 6 ft. wide in Lock No. 8 and in the center wall at the head of the twin locks, No. 6, will be operated by means of wire ropes directly connected to them instead of through operating struts as used for all other valves. This entails some slight differences in the construction of these valves which, as they can therefore never be used in locations where they would be subjected to heads greater than 42 ft., are of lighter construction than the other valves. All valves of each of these three different kinds, however, are made identical and interchangeable and suitable for the maximum head obtaining in any location in which they could be used. For convenience the valves 7 and 6 ft. wide with operating strut connections will be referred to hereinafter as Type A and Type B valves, respectively, and the valves 6 ft. wide with wire rope connections as Type C valves.

The details of the construction of Type A valve are shown in Fig. 36. It consists of a face plate of rolled steel, 3 in. narrower than the nominal width of the valve, bent to a radius of 20 ft. The face plate is supported by a curved plate girder near each side with cross-beams of rolled I and channel sections framed between them. Each curved girder is connected to a hinge bearing by three or, in the case of Type C valves, two radial arms or struts, thoroughly stiffened in both directions by steel angle bracing between the struts.

Hinges.—Each hinge bearing consists of two steel hub castings bolted one at each side of the central gusset-plate to which the radial arms are riveted. The bolts connecting the hub castings to the gusset-plates are made a tight driving fit and the pin-hole through the hub is bored and bushed after the hub castings have been firmly bolted in place. After the entire valve has been assembled and adjusted, with all shop rivets driven and all field connections fully bolted up, using from one to four accurately fitted bolts in each field connection, the bushings of both hinge bearings are accurately bored in one operation, truly parallel to the finished lower edge of the face plate.

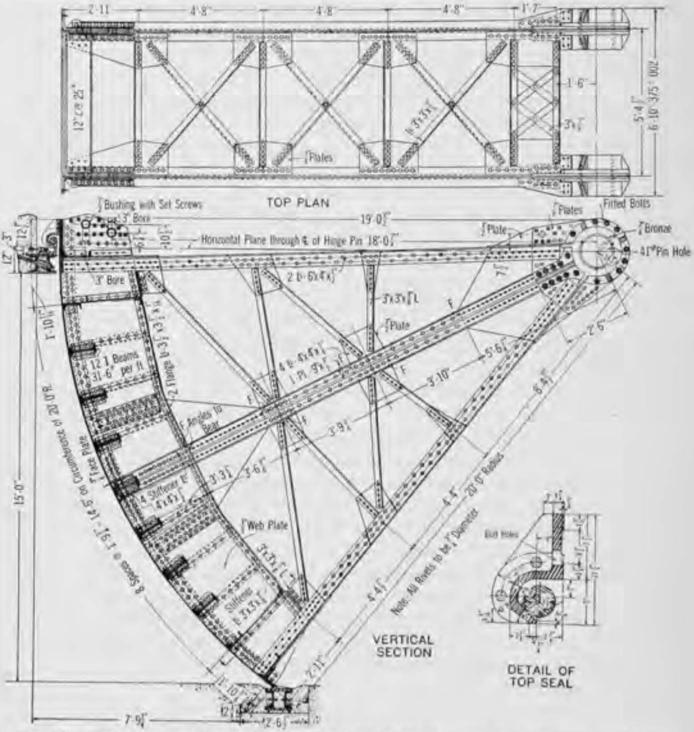

FIG. 36.—WELLAND SHIP CANAL: DETAILS OF 7 BY 15-FT. TAINTOR GATE VALVES FOR LOCKS.

Each valve turns upon two fixed hinge pins, 14 in. in diameter, each mounted in a separate steel hinge casting. The hinge castings are bolted to a heavy structural steel box girder embedded in and anchored to the masonry of the lock-wall. The hinge castings and pins of all valves are alike and interchangeable. To facilitate the proper setting of new hinge castings to replace any broken in service, there are provided, between the hinge castings and the box girders, base castings having accurately finished surfaces in two planes at right angles to each other, which fit corresponding finished surfaces on the hinge castings. The pin-holes in the hinge castings are bronze bushed to prevent the pins from rusting in place and being difficult to withdraw. The pins are held in place and prevented from rotating in the hinge castings by large bronze cotter pins. The maximum pressure on the hinge bearings will be 1 100 lb. per sq. in. Lubrication is provided for by holes drilled in the fixed hinge pins to which pipes will be led from a convenient point.

Seals.—Simplicity and reliability were the governing considerations in the design of the valve seals.

Water-tightness along the bottom of the valve is secured by the close contact of the planed lower edge of the valve face plate with a finished seat on a steel sill casting riveted to a structural steel sill embedded in the masonry.

The seals at each side of the valve consist of a steel rail embedded in the masonry and a steel angle bolted through slotted holes to the valve, both, of course, being bent to suit the curve of the valve. The head of the rail projects ¼ in. from the face of the concrete wall of the valve chamber and is planed to a true surface after bending. Rails having grooved heads are used to form a labyrinth seal. The rails are set about 0.03 in. wider apart at the top of the valve than at the bottom. The face of the seal angle on the valve which meets the rail-head is also planed after bending and when the valve is set in place the angles are adjusted to make contact with the rail-heads.

To provide for slight variations in the height of the valve due to temperature changes, wear at the bottom seal, etc., the seal at the top is not rigid but consists of a circular sealing rod 3½ in. in diameter which is held loosely in the trough of the steel seal casting bolted to the face of the valve (Fig. 36). When the valve is closed the sealing rod lies in contact with both the planed top of a rib on the lintel casting and the planed seat on the seal casting and is held in tight contact with these surfaces by the water pressure. The lintel casting is bolted to a structural steel lintel embedded in and anchored to the masonry.

The sill, side sealing rails, and lintel of the valve are erected in recesses left for them in the masonry. They are adjusted accurately to their proper positions with reference to the valve hinges by gauges carried on a steel frame swung on the hinges, and the recesses are then filled with mortar.

Counterweights.—In order to reduce the load on the valve-operating machines and to enable them to operate easily in opening as well as in closing the valves, counterweights are provided and connected to the valves by chains passing over sheaves arranged as shown on Fig. 37. The torques exerted upon the valve by gravity and by the tension of the counterweight chain vary somewhat in different positions, but the counterweight is so proportioned that there will always be a small resultant torque tending to close the valve.

Operating Mechanism.—The valves will be operated by electrically driven machines supported at the coping level of the lock walls upon structural steel girders spanning the valve pits. To suit the different conditions to be met in the various locations, three different methods are used for transmitting power from the operating machines to the valves.

For intake valves of Type A the power is transmitted through a structural steel strut (Fig. 37), to the upper portion of which is bolted a rack which meshes with the operating pinion on the machine, while the lower end of the strut carries a cross-head having pin connections to the ends of the two girders at the sides of the valve.

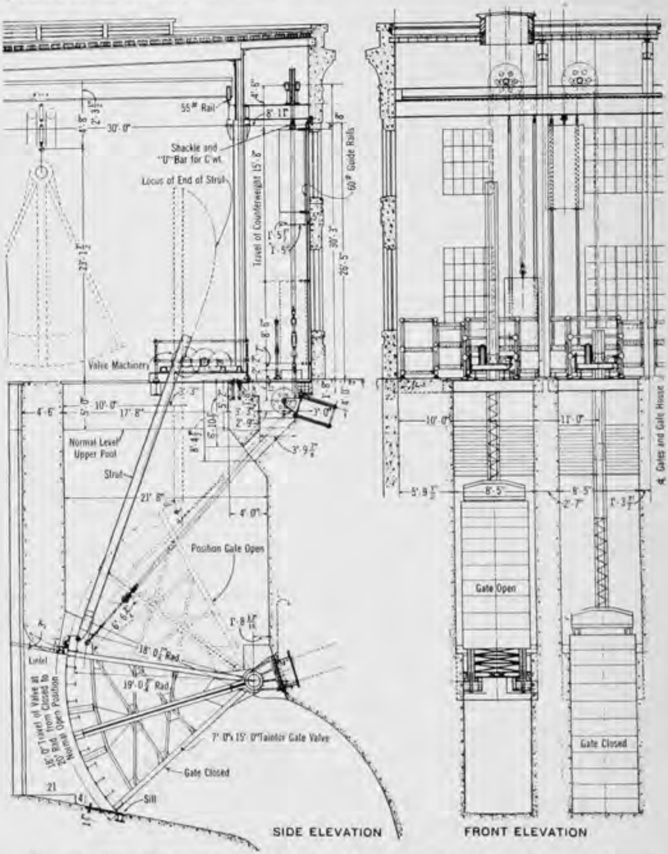

FIG. 37.—WELLAND SHIP CANAL: GENERAL ARRANGEMENT OF TAINTOR INTAKE VALVES AND OPERATING MACHINERY.

In the case of discharge valves of Types A and B, the bottom of the valve pit is 81.5 ft., or 82.9 ft., below the coping level so that an arrangement similar to that used for the intake valves would involve the use of a strut of impractical length. Accordingly, an operating strut 34 ft. 4 in. in length is connected to the valve as described, its upper end being supported and guided by a structural steel radius frame hinged to the wall of the valve pit. The use of a second strut to connect the top of the first to the operating machine would have been satisfactory except that it would have required a machinery house of an otherwise unnecessary and undesirable height to clear the top of the strut in the open position of the valve. Wire rope connections, therefore, were adopted between the operating machine and the top of the operating strut.

For the valves of Type C the same operating machine with wire operating ropes is used for the same reason. Here, however, the distance from the machine to the valve is too small to permit of the use of an operating strut and the operating ropes are connected directly to the valve itself. This arrangement requires a narrow gap to be left in the top seal of the valve to enable the ropes to pass through it and lie against the face plate of the valve. The leakage at this point however will be small, especially as the head on these valves is never very great.

Operating Machines.—The operating machines are designed to exert a maximum force of 20 000 lb. upon the operating strut or rope in opening or closing the valve. The operating force is limited to this maximum value by means of a slip friction built into the spur gear mounted upon the main shaft which carries the operating pinion or drum. The general arrangement of the machine for rack connection to the strut consists simply of a train of spur gearing between the electric motor and the operating pinion. In the machine for wire rope operation a somewhat greater total gear ratio is required and a worm gear reduction from the motor is used.

Each operating machine is provided with a geared limit switch by which the current is cut off and the solenoid brake set to stop the motor when the valve reaches either end of its travel. The motor is a 550-volt, squirrel-cage, induction type of 13 nominal h. p. The control panel of the motor is equipped with overload protection and no voltage release. The overload relay is of the inverse time type and is adjusted to carry, for only a short time, the overload produced by the torque at which the friction will slip. Therefore, should the valve meet with any obstruction in its travel which would cause the friction to slip, the overload relay would soon trip and stop the motor. The valves are operated under remote control from the lock-control desk.

Machinery Houses.—The water level in the valve pits will rise and fall during the operation of the locks, displacing large volumes of air. To permit the passage of the air the flooring over the valve pits is of open steel grating and large ventilating louvres are provided in the roofs of the valve houses. The building over the intake valves of each of the high-lift locks is high enough to enable the valves to be lifted out of their pits inside the building by a hand-operated traveling crane provided for the purpose. The houses over the other valves are quite low and have a large opening in their roofs with a removable steel cover. When the cover is removed the valves may be hoisted out of the valve pit.