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Hydrodynamic Forces on Reverse Tainter Valves; Hydraulic Model Investigation

by Richard L. Stockstill, E. Allen Hammack, David S. Smith, Jane M. Vaughan, and Keith Green

BACKGROUND: The repair and/or replacement of lock culvert valves is an issue that many US Army Corps of Engineers (USACE) offices are facing, partly because many of the navigation locks have reached or exceeded their design life. Reverse tainter valves are the most common valve type found on navigation locks constructed by the USACE (Pickett and Neilson 1988; Headquarters, USACE 1975). Many existing reverse tainter valves are of double-skin-plate construction, but several projects are in the process of replacing these valves with new valves of a vertically framed, single-skin design because they are easier to inspect and repair.

The geometric and hydraulic parameters describing a reverse tainter valve are shown in Figure 1. Lock culvert flow is controlled by rotating the valve about the trunnion axis. The valve position is listed as the valve opening ratio b/B, where b is the distance from the valve lip to the culvert floor, and B is the culvert height at the valve.

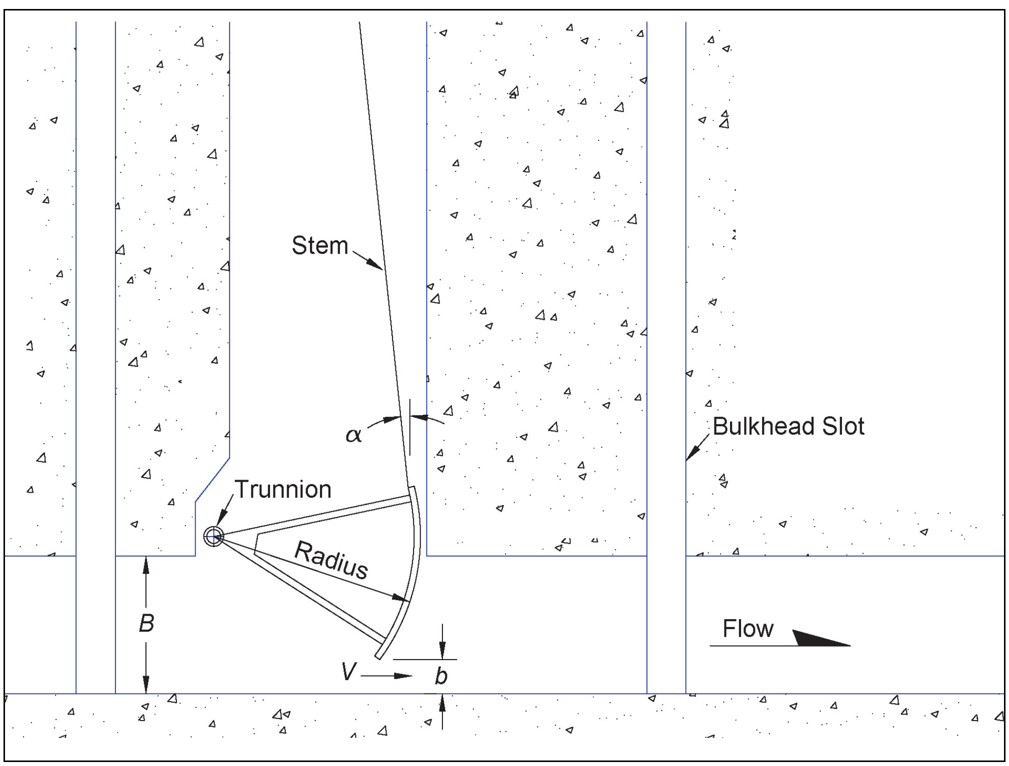


Figure 1. Reverse tainter valve parameters.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **DEC 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Hydrodynamic Forces on Reverse Tainter Valves; Hydraulic Model Investigation**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army Engineer Research and Development Center,Vicksburg,MS, 39180-**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

This technical note presents laboratory data of loads on vertical-frame and double-skin-plate valve designs. The objective is to identify differences in hoist forces for these two reverse tainter valve designs. A physical model was instrumented with a load cell to measure valve hoist loads. Comparison is made between the hoist forces acting on a vertical-frame and a double-skin-plate valve given the same head and discharge.

PHYSICAL MODELING FACILITY: Completion of a physical model study of the culvert valves of the Eisenhower and Snell Locks, St. Lawrence Seaway (Stockstill et al., in preparation), provided an opportunity to study the differences between vertical-frame and double-skin-plate valve designs. The lock valves were modeled at a 1:15 scale in a test facility (Figure 2) that reproduced the valve, valve well, bulkhead slots, and approximately five culvert heights upstream and twelve culvert heights downstream of the valve. The upper pool was represented with a pressure tank, and the culvert pressure was regulated with a slide gate located near the end of the culvert. The valves were made of brass, and the valve well, bulkhead slots, and culvert were constructed of transparent plastic to permit flow observation. Water was supplied to the model through a circulating system in which discharge was measured using a standard orifice meter in the supply line upstream of the model.

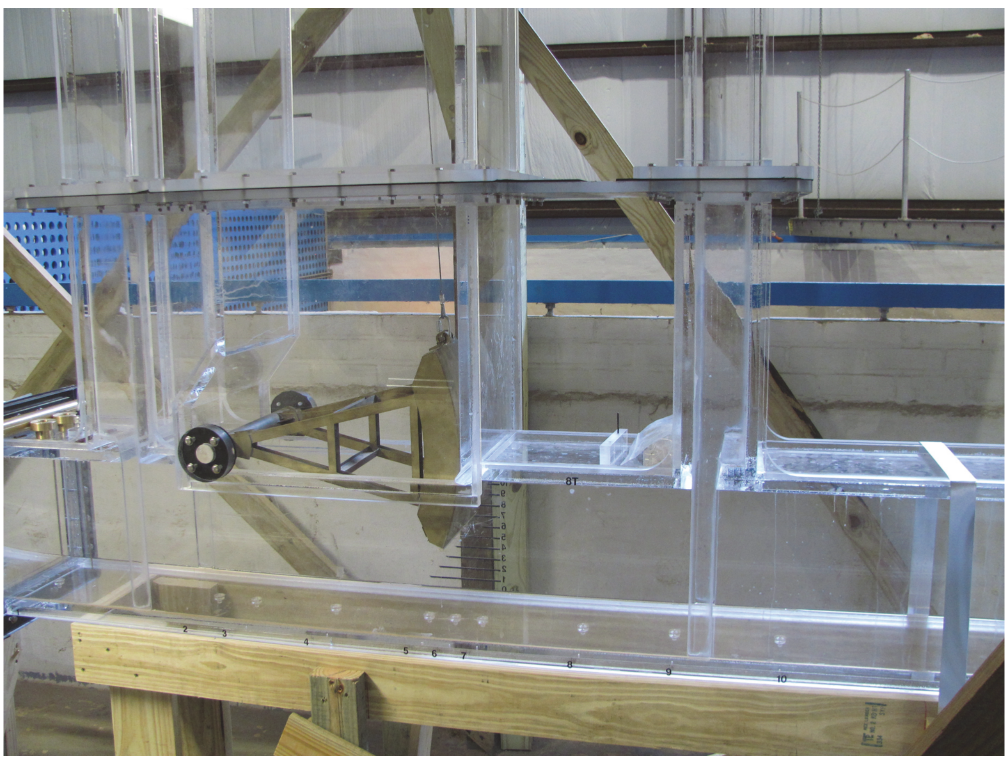
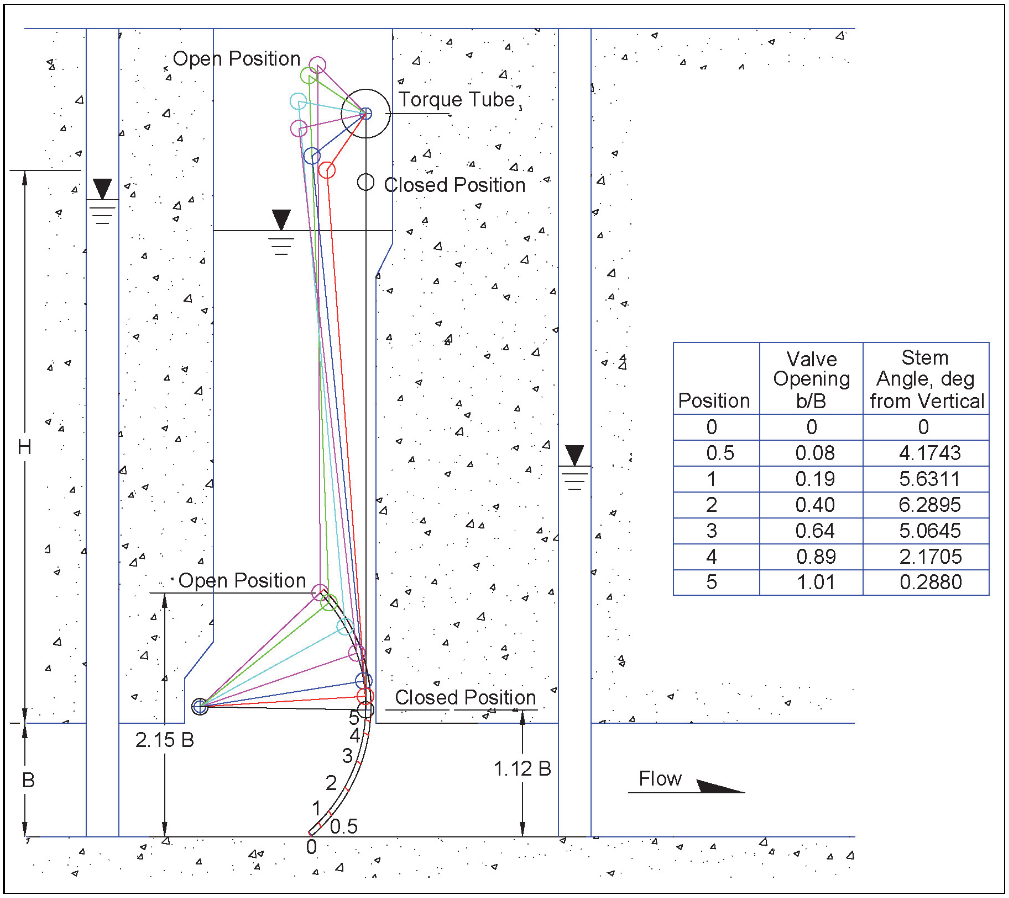


Figure 2. Physical model of lock culvert valve.

Dynamic forces on the valve stem (hoist loads) were measured with a commercial load cell mounted as an integral section of the stem. Experiments were conducted under steady-flow conditions with the valve at fixed positions. The details of the valve and stem positions for various valve openings are shown in Figure 3. Steady-flow tests simulated the conditions occurring at a particular instance during a lock operation. Each flow setup represented a head/discharge condition expected to occur during normal operations. The discharge varied such that the velocity under the valve ranged from 41 to 47 fps and averaged approximately 45 fps, which is typical for a 50 ft lift (Headquarters, USACE 1975). Each experiment maintained the energy grade line upstream of the valve, H in Figure 3, at approximately 82 ft above the culvert floor.



Position	Valve Opening b/B	Stem Angle, deg from Vertical
0	0	0
0.5	0.08	4.1743
1	0.19	5.6311
2	0.40	6.2895
3	0.64	5.0645
4	0.89	2.1705
5	1.01	0.2880

Figure 3. Reverse tainter valve stem angles.

MODEL EXPERIMENTS: The first set of experiments measured the weight and hoist forces for the vertical-frame valve shown in Figures 4 and 5. Hoist-load data obtained in the model of the vertical-frame valve are presented in Table 1 and Figure 6 as force per unit width of valve. The hydraulic forces, the difference in the hoist load and dry valve load, are plotted in Figure 7. Where hoist-load values are greater than the load due to the valve's dry hoist load, hydraulic forces were acting to close the valve; where they are less, hydraulic forces were acting to open the valve. These conditions are referred to as *downpull* and *uplift,* respectively. The largest hydraulic loads were 0.44 kips per ft of valve width at a valve opening ratio b/B of 0.40 and 0.31 kips per ft of valve width at a valve opening ratio of 0.64.

Experiments were then conducted to measure the hoist loads on a double-skin-plate valve with the same flow conditions that the vertical-frame valve was tested. The double-skin-plate valve had its structural members wrapped in plate steel, which was understood to provide a streamlined body (Headquarters, USACE 1975). The double-skin-plate valve's radius and stem positions were identical to that of the vertical-frame valve.

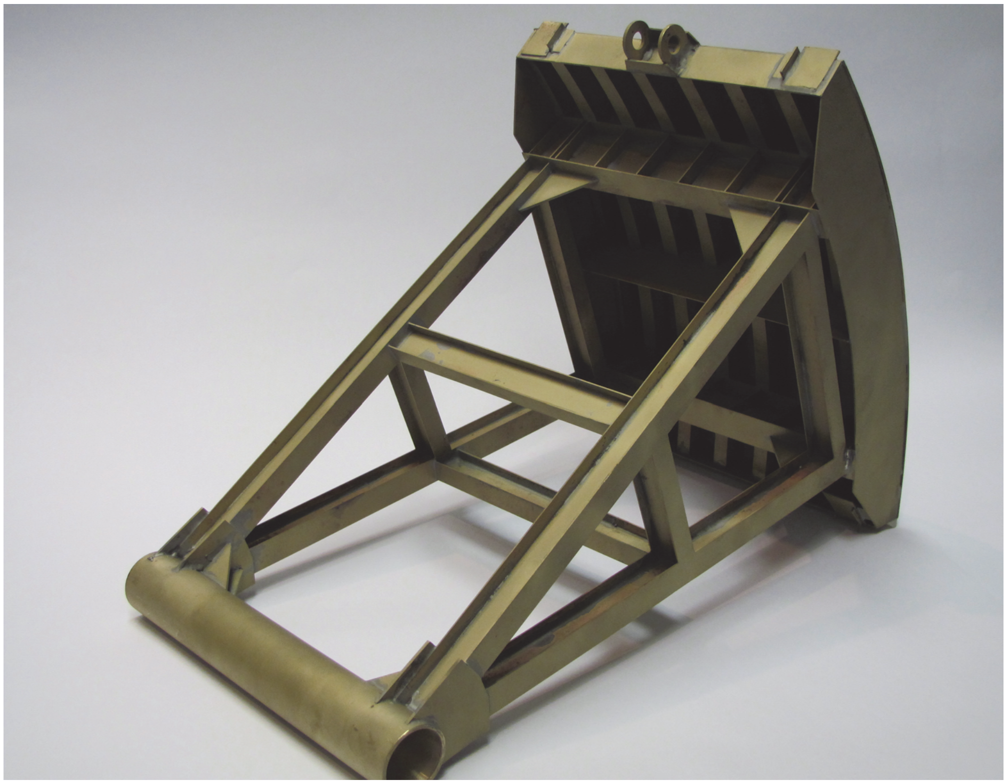


Figure 4. Vertical-frame reverse tainter valve.

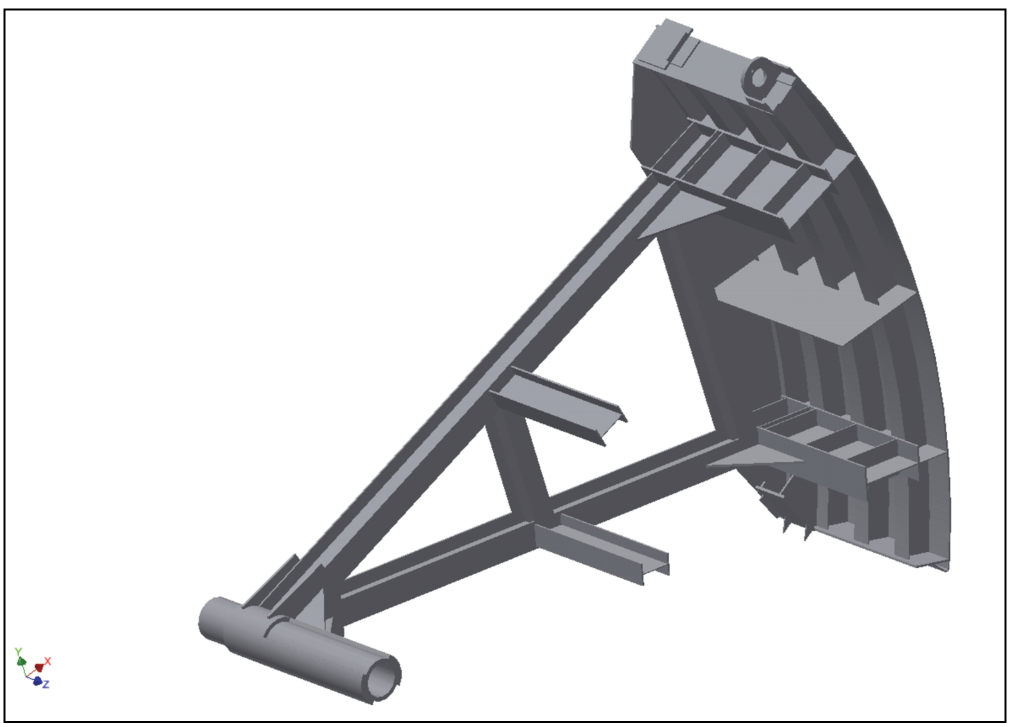


Figure 5. Half-section view of the vertical-frame valve.

Table 1. Hoist loads, vertical-frame valve.

b/B	Culvert Velocity, cfs	Hoist Load, kips per ft of Valve Width			
		Dry Valve	Hydrodynamic		
			Minimum	Maximum	Observed Average
0.09	43.8	2.50	2.07	2.13	2.09
0.19	41.0	2.56	2.54	2.65	2.59
0.40	40.8	2.69	3.01	3.28	3.13
0.64	44.2	2.86	2.87	3.45	3.17
0.89	47.3	3.15	1.94	3.26	2.64
1.01	40.2	3.35	1.98	3.13	2.61

Table 2. Hoist loads, double-skin-plate valve.

b/B	Culvert Velocity, cfs	Hoist Load, kips per ft of Valve Width			
		Dry Valve	Hydrodynamic		
			Minimum	Maximum	Observed Average
0.09	43.8	3.60	2.52	2.57	2.54
0.19	41.0	3.70	2.78	2.86	2.82
0.40	40.8	3.88	3.31	3.51	3.40
0.64	44.2	4.13	3.28	3.66	3.45
0.89	47.3	4.53	2.93	3.55	3.24
1.01	40.2	4.82	2.99	3.54	3.29

The double-skin-plate valve model was constructed as close as possible to the prototype valve, including the internal structural members that are not visible once the valve is complete. The framing members of the double-skin-plate valve are shown in the half-section view in Figure 8. A photograph of the finished model valve is provided in Figure 9.

Hoist loads with the double-skin-plate valve are plotted in Figure 6. Small holes were placed in the valve's skin plate along the outside edges so that water filled the interior once it was submerged. The double-skin-plate valve was significantly heavier than the vertical-framed design previously described. The load data provided in Figure 6 show that the double-skin-plate dry valve hoist loads varied from 2.54 kips per ft of valve width at a valve opening ratio *b/B* of 0.09 to 3.45 kips per ft of valve width at the full open position.

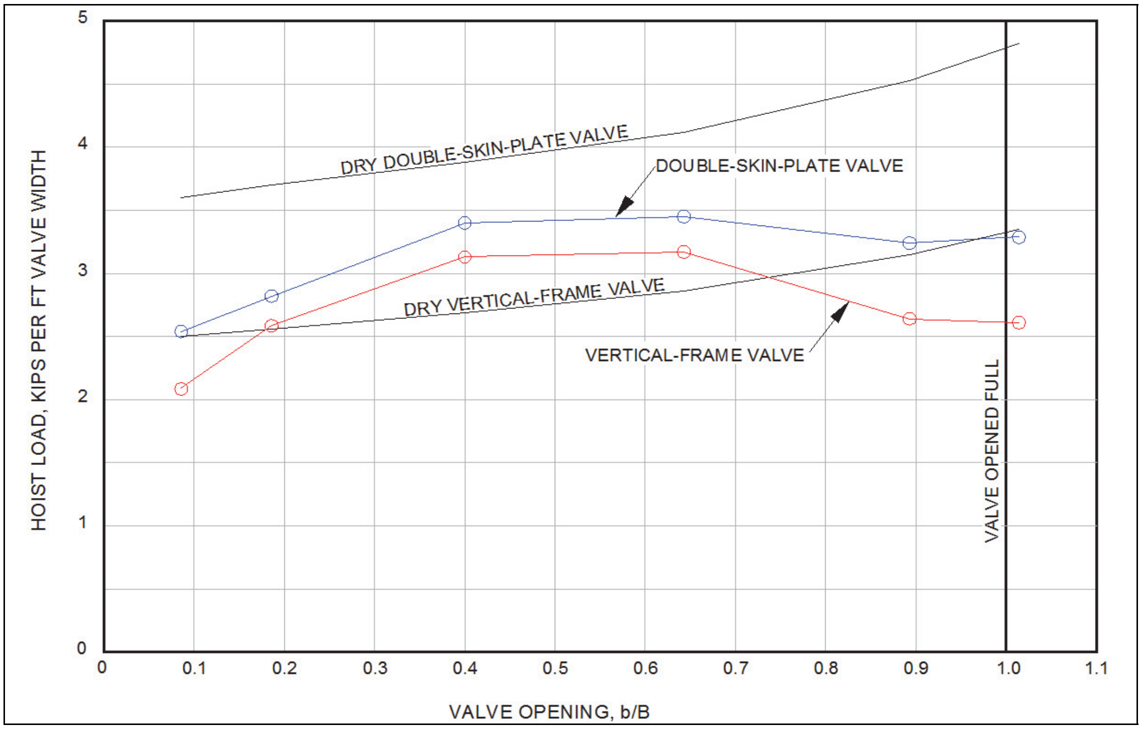


Figure 6. Hoist loads for vertical-frame and double-skin-plate valves.

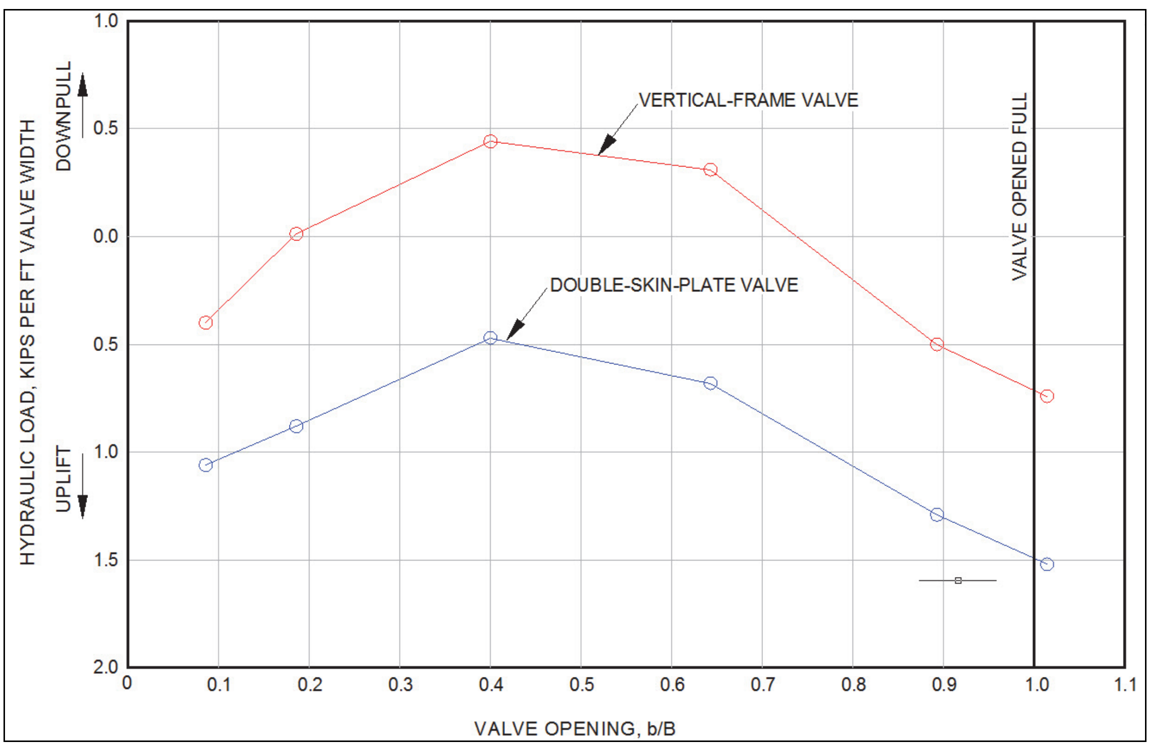


Figure 7. Hydraulic loads for vertical-frame and double-skin-plate valves.

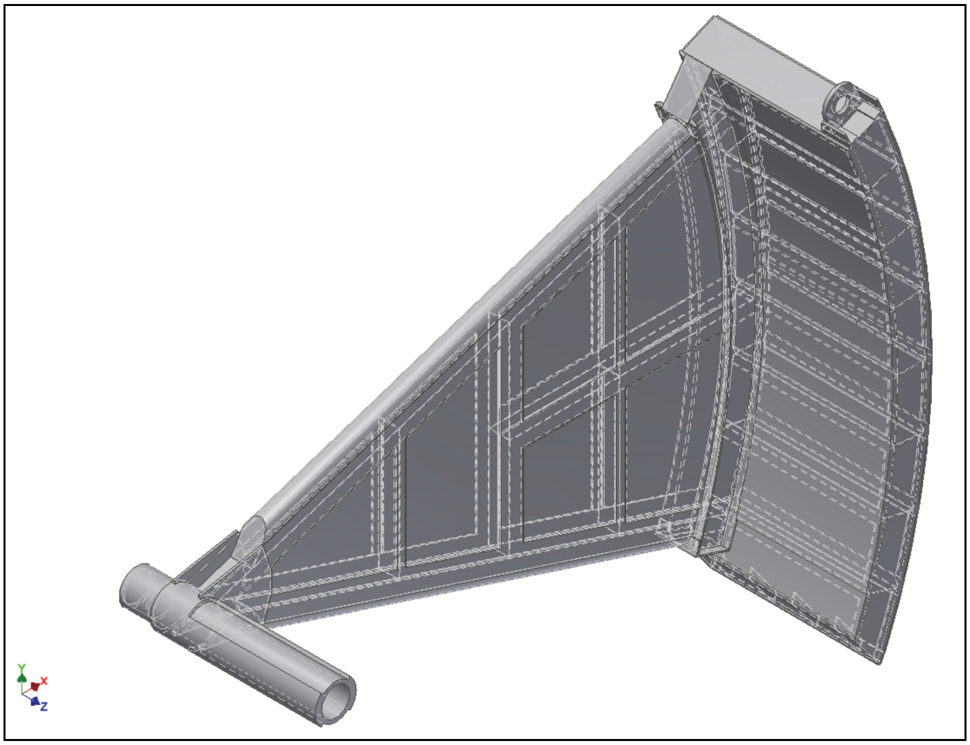


Figure 8. Half-section view of double-skin plate valve; the hidden lines show the internal framing members.

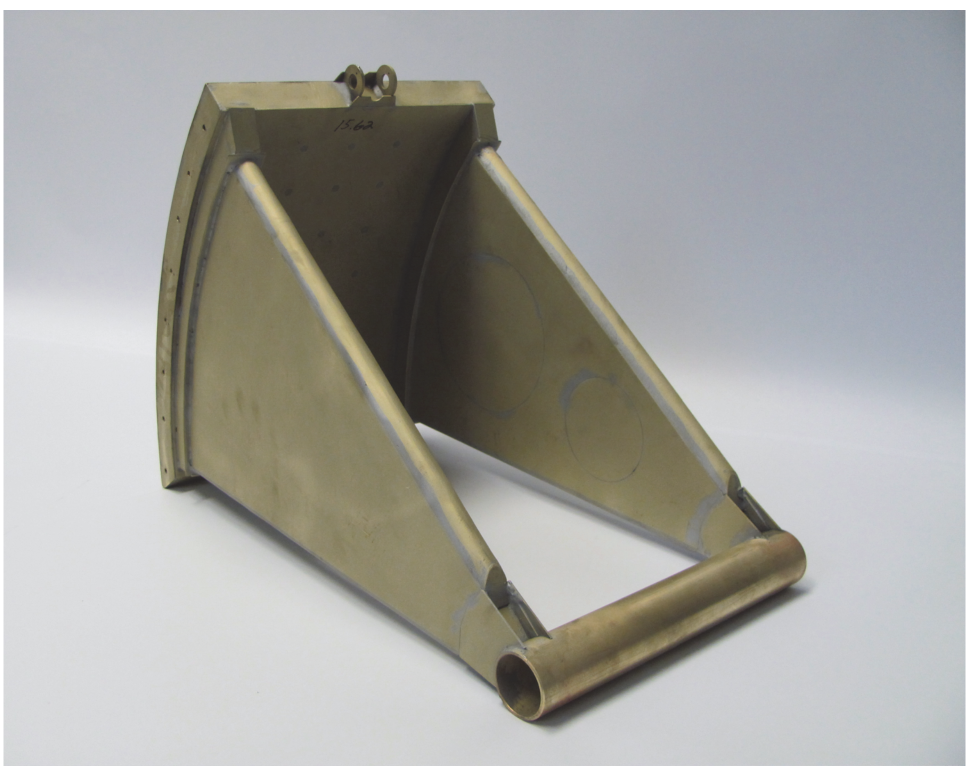


Figure 9. Double-skin-plate reverse tainter valve.

SUMMARY: Reverse tainter valves have been used almost exclusively in the United States to control the filling and emptying of navigation locks. Locks having lifts greater than approximately 30 ft use the vertical-frame or double-skin-plate valve design. Data from a hydraulic model were used to study the differences between vertical-frame and double-skin-plate designs. The lock valves were modeled in a 1:15-scale test facility that reproduced the valve, valve well, bulkhead slots, and the culvert upstream and downstream of the valve. The physical model was instrumented with a load cell to measure valve hoist loads. Comparison was made between the hoist forces acting on a vertical-frame and a double-skin-plate valve. The uplift forces were much larger with the double-skin-plate valve design, but not large enough to overcome the dry weight differences between the two valve designs. The hoist loads for the vertical-frame valve design were less than those required to lift the double-skin-plate valve design.

ADDITIONAL INFORMATION: This CHETN is a product of the Repair and Replacement Guidance for Lock Culvert Valves work unit of the Navigation Structures Research Program being conducted at the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Questions about this technical note can be addressed to Dr. Richard L. Stockstill (601-634-4251; e-mail: Richard.L.Stockstill@usace.army.mil). For information about the Monitoring Completed Navigation Projects – Navigation Structures Research Program, contact the Program Manager, Charles E. Wiggins at 601-634-2471, e-mail: Charles.E.Wiggins@usace.army.mil. This technical note should be cited as follows:

> Stockstill, R. L., E. A. Hammack, D. S. Smith, J. M. Vaughan, and K. Green. 2013. *Hydrodynamic forces on reverse tainter valves; hydraulic model investigation*. ERDC/CHL CHETN-IX-33. Vicksburg, MS: US Army Engineer Research and Development Center. http://chl.erdc.usace.army.mil/chetn

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Stockstill, R. L., E. A. Hammack, D. S. Smith, J. M. Vaughan, and K. Green. In preparation. *Hydraulic evaluation of culvert valves at Eisenhower and Snell Locks, St. Lawrence Seaway*. Vicksburg, MS: US Army Engineer Research and Development Center.