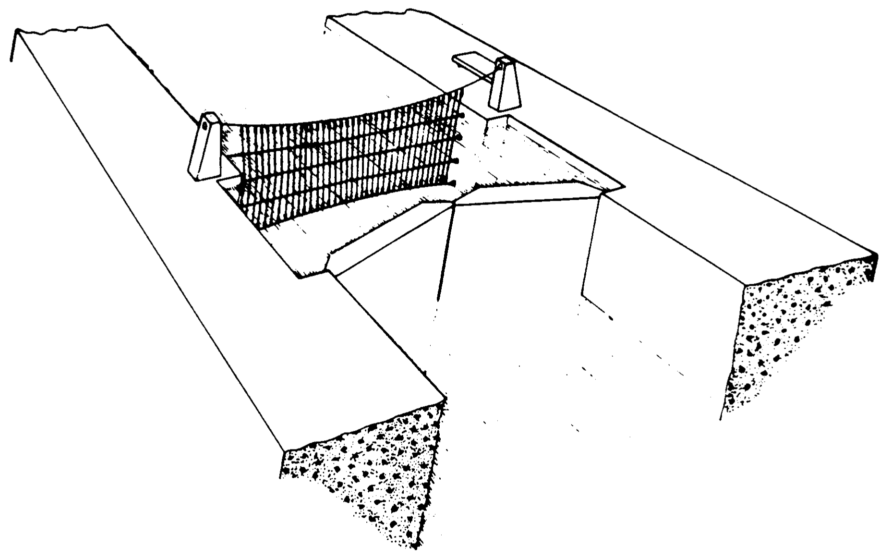
REMR TECHNICAL NOTE HY-N-1.4

INTERIM GUIDANCE ON LOCK GATE BARRIER SYSTEMS



PURPOSE: To provide a review of protective devices currently used or proposed for the protection of lock gates from vessel impact and to present a summary of pertinent data relative to the design constituents of these barriers.

BACKGROUND: Devices for the protection of lock gates from vessel impact have been proposed or are in use on a number of locks throughout the world. The design constituents of protective systems or barriers vary according to the functional needs and physical limitations at site-specific locations. Justification for the barriers at these projects was primarily based on the need to eliminate costly expenditures related to repair and downtime resulting from vessel impact on the gates. In some instances the barriers were justified on the basis of decreasing lockage time by increasing permissible entrance speeds.

DISCUSSION: There are two major types of protective systems for lock gates: (a) protection provided on the gates directly and (b) protection applied independently of the gate and its operating machinery. The latter, which will be referred to as a barrier, is the subject of this technical note. In Ref a, Sadovenko recommends a classification system that breaks down the components of a protective barrier and that should be considered in a review of currently available designs. This type of breakdown is vital for the comparison of available barriers and for previewing the decisions that need to be made in the selection of a suitable barrier.

Sadovenko classifies protective barrier systems according to function, location, transformation of energy, structure or shape, method of moving barrier from vessel passage, installation relative to pool elevation, and energy design criteria.

Protective barrier systems function in one of two ways: normal or emergency operation. They can be located upstream of upstream gates, downstream of upstream gates, upstream of downstream gates, or downstream of downstream gates. Methods for transforming energy include deformation (rigid support to lock wall), gravitational (counterweights), frictional, hydraulic/pneumohydraulic, or mechanical and electrical. The shape of the barrier can be rigid (horizontal beam), flexible cable or chain, flexible but shaped other than cable or chain, or bumper/fender type. Methods for removing the barrier out of vessel passage include dropping it below the vessel, raising it above the vessel, having it swing or rotate, or having it function as a drawbridge. The barrier can be stationary, floating, or power-operated. Energy design criteria include the speed and mass of the vessel, the angle of entry, and the shape of the vessel.

Unless the barrier system is capable of being activated on short notice, the operation of the barrier has to take place during all lockages. Emergency closure gates that allow for dewatering and repair after the fact are provided on many locks. The barriers described herein are to be used during normal operation as a preventative means to minimize the need for repairs.

The predominant location of protective barriers is on the upstream side of the downstream gates. It is at this location that the most catastrophic accidents occur from the loss of control of a downbound vessel. This fact does not preclude the use of barriers at other locations as well.

The means by which the energy produced by the vessel can be dissipated can be accomplished by several mechanisms, mostly related to the operating equipment which supports the barrier structure itself. That is, the transformation of energy of the approaching vessel can be dissipated by deformation of the structure itself in the case of a rigid support, by a counterweight system that restrains the movement of the barrier, by frictional components such as springs or pistons, by hydraulic or pneumohydraulic cylinders, or by mechanical gearing processes. The most frequently used or recommended designs use some type of hydraulic shock absorbers.

The actual structural component that is contacted by the approach vessel can be one of several shapes. One type of barrier that could be used is a rigid beam (concrete or steel). Ref b has an example of a rigid beam elastically fixed at both ends with some type of braking absorbers in the lock walls. The most commonly used barrier, a flexible cable or chain, is strictly effective on vessels with a V-shaped bow such as a ship. Another possibility is a flexible barrier shaped in the form of a net. A device such as this would likely be more suitable for push tows. Finally, a model study for the St. Lawrence Seaway proposed a fendering system with retractable wheel fenders placed along the length of the lock chamber.

Depending upon the location of the barrier in the lock and the lift from upstream to downstream, some type of mechanism may be required to remove the barrier from the path of the vessel after impact. An exception to this requirement would be a high-lift lock in which the barrier is located in the chamber just upstream of the downstream lock gates. In this situation a barrier could be fixed in a stationary position during fill and the vessel could pass below the structure during the empty cycle. If clearance height is not available, the barrier could be lowered below the vessel, raised by a pulley system above the vessel, or swung into position by a rotating arm or draw-bridge.

Another consideration in the design of the barrier is to determine if, because of variable pool elevations, there is a need to reposition the barrier elevation for better contact with the approach vessel. In the case of a relatively fixed pool elevation, a stationary elevation for the barrier is suitable; otherwise, the barrier should be capable of floating with the pool elevation or be equipped with operating machinery that can winch the barrier into position.

Finally, the most intensive portion of the design is in the determination of the force that will be applied to the system. The design criteria would require a representative estimate of the size (mass) and speed of the entering vessels on the respective lock system. Ref a and c imply or state that once a maximum vessel mass has been established, this mass should be increased by 10 to 15 percent to account for the translatory wave which precedes the vessel entering the lock. Other considerations are the shape of the bow, the approaching angle of entry, and the contact point with the barrier.

DATA SUMMARY: The tables provided present the locks in which barriers are in use or for which they have been proposed. It is likely that this is an incomplete listing; yet, this listing should show that the concept of barrier protection is not a new one. Table 1 describes the elements of the protection systems that have been designed or are in use. Table 2 is a list of locks, their dimensional characteristics, the type of barrier used or proposed for these locks, and pertinent comments and design criteria where available. Finally, the figures give an overview of representative type barriers.

CONCLUSIONS: It should be apparent from the tables and figures presented that the types of barriers now in use are diverse in scope and design. Each has been constructed for a specific purpose and by a rather specific set of criteria. The majority of the barriers have been designed for the arrest of ships rather than tows with barges; however, some general guidelines that could be applicable to barrier designs on Corps locks do exist.

RECOMMENDATIONS: The results of the REMR work unit will provide guidance on predicting impact forces from variable size tows and chambers and will include the effects of the attached mass of the water to its effect on the total force acting on the barrier. Guidance as to the appropriate shapes of barriers suitable for the various shaped bows of vessels commonly found on the US waterways will also be provided. In the interim, consideration should be given to the variables described in the discussion, the guidance offered in Ref b, and the following recommendations:

a. Expected vessel mass should be increased by 10 to 15 percent.

b. A hydraulic or pneumohydraulic braking system should be used.

c. Retrofit aspects of the barrier should be considered in the selection of the operating mechanisms.

d. The deformable bar concept used in Ref d should be avoided because of possible operational drawbacks in the continuous replacement of broken rods.

e. A net or several parallel cables should be used in the selection of the shape of the barrier.

f. A rigidly supported or rigid barrier should be avoided because of excessive loading on the lock monoliths and damaging effects on the vessels.

g. The barrier(s) should be located to deter the most frequent and costly accidents.

h. The economic benefits of increased permissible velocities should be considered in designing the barrier.

REFERENCES: a. Sadovenko, V. V. 1970. "Study of the Work of Protective Barrages in Front of Navigation Lock Gates," Master's thesis, Leningrad Institute of Water Transport, (translated from Russian).

b. Permanent International Association of Navigation Congresses (PIANC). 1987. Final Report of the International Commission for the Study of Locks, pp 254-265.

c. Kozak, G. I. 1979 (Nov). "Design of Protective Devices for Navigation-Lock Gates, Employing Hydraulic Shock Dampers," Hydrotechnical Construction, (English translation of Gidrotekhicheskoe Stroitel'stve), No. 11, pp 1100-1108.

d. Cabelka, Jaroslav, Cabelka, Jan, Podzimek, J., and Zaruba, J. 1977. "Modern Equipment of Locks Raising the Traffic Capacity and Security of Navigation on Inland Waterways in Czechoslovakia," Proceedings of the 24th International Navigation Congress, PIANC, Leningrad, Section 1, Subject 1, pp 57-74.

e. Roehle, D., Adolf, I., and Fruhwirt, K. 1977. "Measures Against Damage to Locks and Ships and Measures During Winter Operation on the Austrian Danube," Proceedings of the 24th International Navigation Congress, PIANC, Leningrad, Section 1, Subject 1, pp 7-20.

f. Shestakov, A. S. 1973. "Theoretical and Experimental Research into the Operation of Safety Systems to Protect the Gates of Navigational Locks from Vessel Collisions," Author's Abstract for Masters of Technical Sciences thesis, Leningrad Institute of Water Transport, (translated from Russian).

g. Headquarters, US Army Corps of Engineers. 1954 (Oct). "Navigation Lock and Dam Design, Lock Masonry," Engineer Manual EM 1110-2-2602, Washington, DC.

h. Sadovenko, V. V. 1968. "Design of Safety Barriers in Locks," Rechnoy Transport (in Russian), Moscow, No. 5, pp 32-33.

i. Jackson, J. P., Thomson, A., and Murrer, E. W. 1978 (Sep). "A Ship Arrester System for the Protection of Lock Gates," Proceedings of the 5th International Fluid Power Symposium, British Hydraulic Research Association, Durham, England, No. E3, pp 33-62.

j. US Army Engineer District, Nashville. 1977. "Bay Springs Lock and Dam, Appendix IX, Lock Gate Study," Design Memorandum No. N-12, Nashville, TN.

k. __________. 1978. "Bay Springs Lock and Dam, Rope System Impact Barrier Study," Nashville, TN.

l. Gabriel, P., Cabelka, J., Dolezal, L., Podzimek, J., and Trejtnar, K. 1981. "Means of Increasing the Capacity and Safety of Navigation on the Labe Waterway," Proceedings of the 25th International Navigation Congress, PIANC, Edinburgh, Section 1, Vol 2, pp 233-248.

m. Gelencser, G. J. 1977. "Improving the Effective Capacity of a Navigation System," Proceedings of the 24th International Navigation Congress, PIANC, Leningrad, Section 1, Subject 1, pp 21-40.

n. Hausser, R., and Beaudry, J. P. 1969 (Apr). Welland Canal Lock No. 7, Model Study of the S.A.M. Project, LHL-509, Lasalle Hydraulic Laboratory Ltd.

Table 1

Description of Available Barriers

1. Flexible cable or chain, one rigid support, hydraulic absorber, retractable boom. This barrier consists of a cable placed at a fixed elevation across the width of the lock chamber. Typically, it has one end of the cable rigidly affixed to the chamber wall, and the energy is absorbed by means of a hydraulic or pneumohydraulic cylinder located in the other lock wall. The barrier can be removed from the vessel path by means of a boom arm that lowers to catch the cable and either raises to an upright position or swings horizontally to the side of the chamber. See Figure 1 (Ref b, c, e, f, and g).

2. Flexible cable or chain, counterweight system, friction, or other-than-hydraulic braking system. This barrier is a variation of the type 1 design and basically was the forerunner to the hydraulic absorption type. An example would be a cable that absorbs the impact by a pulley system which has weights attached to it. The barrier may or not be capable of being retracted from the path of the vessel (Ref a and h).

3. Flexible cable, hydraulic shock absorbers both walls. This barrier, a unique variation of the type 1 barrier, has an arrester system in which the pistons on either wall act as modules. Figure 2 shows the system on Eastham Lock in which the pistons are placed vertically to minimize the amount of area used on the lock walls (Ref i).

4. Flexible net or dual cables. The rope-and-cable system barrier designed but not implemented for the Bay Springs Lock (Ref j and k) consists of a net made of horizontal and vertical three-strand nylon ropes supported by two steel cables. The ropes are connected at their intersections to force interaction so that the entire rope system will function as a unit in resisting barge impact. The nylon net rope system is supported at the top and bottom by cables that are anchored into the lock wall and into the concrete pylons.

Another design similar to this is presented in Ref b. The barrier consists of a set of parallel cables supported by floating fence post elements and four cables on each side. The impact is absorbed elastically by the cable system and by winches with friction brakes at the outer end of each cable. The corresponding inner end is fixed in the chamber wall. See Figure 3.

5. Dynamic bar. This barrier has lock-in grooves supported by the lock wall. The barrier itself has sacrificial elements that are intended to break or deform upon impact. The principal element of the deformable rod is a bundle of mild-steel reinforcing bars that plastically elongate to brake the approaching vessel. The bars are fixed in the supporting caisson and attached to anchorage blocks at both ends. After each impact of a vessel on the rod, the supporting tube as well as the rod bars are replaced by new ones. The barrier can be raised above the vessel path by a pulley system. (In Ref d, the following patent was given for this barrier: CS patent Nr 157568 of April 15, 1975.) See Figure 4 (Ref d and 1).

(Continued)

Table 1 (Concluded)

6. Rigid beam with hydraulic mechanism in lock wall. A rigid beam could be used as a barrier. The beam described in the manual of the Permanent International Association of Navigation Congress (PIANC) (Ref b) was elastically fixed at both ends and could be removed from the vessel path by means of a hoist or swing device. In the Bay Springs study (Ref j and k), rigid barriers made of steel or concrete were contemplated also. However, because these barriers were designed to transfer all loads to the lock walls, they were determined to be impractical.

7. Ship Alignment and Mooring System (SAM). Floating pneumatic wheel fenders in recesses of the lock walls were studied in a 1:48 scale model of the Welland Canal Lock No. 7. These fenders consist of vertical axis wheels mounted on a horizontally pivoting arm that, when extended, protrude into the lock chamber to apply a braking force to the incoming vessels. The floating wheels, designed to remain 3 ft above the waterline, are controlled by actuating mechanisms that position the wheel and apply a pressure to the vessel (Ref m and n).

8. Breaking wings. This barrier, developed in Italy, has two pivoted but independent crank arms that project across the width of the lock with a gap between their ends. The arms rotate into the vessel path, and the energy is transformed to hydraulic brake cylinders. See Figure 5 (Ref b).

9. Shock absorbing swing beams. A rigid beam swings into the path of the vessel, and the kinetic energy is absorbed by means of a hydraulic cylinder. See Figure 6 (Ref b).

Table 2

Summary Lock Data and Barrier Information

Lock Name	Location: Waterway	Location: Country	Chamber Dimensions, ft: Length	Chamber Dimensions, ft: Width	Chamber Dimensions, ft: Lift	Lock Gates[1]	Barrier Type[2]	Design Criteria[3]	Comments
Altenworth	Danube River	Austria	754.6	78.7	55.8	U.S. Vertical D.S. Miter*	1	NA	This same barrier on 11 other locks on the Mosel River
Ottensheim-Wilhering	Danube River	Austria	754.6	78.7	40.4	U.S. Vertical D.S. Miter*	1	NA	between Koblenz and Palzem. See Figure 1.
Lehmen	Mosel River	Germany (R.F.A.)	NA	39.4	NA	NA	1	NA	First lock in this waterway system to use this type.
No. 7 (and others)	Welland Canal	Canada	810 appr.	80	50 appr.	NA	7, 2	NA	Type 7 is proposed. Type 2 is common to locks on Welland Canal.
	Panama Canal	Panama Canal Zone	1,090	110	30	variable	1	NA	
	Elbe-Vltava Waterway	Czechoslovakia	278.9	39.4 to 72.2	18	U.S. Miter* D.S. Miter	5	1.10E+06 ft-lb to 2.20E+06 ft-lb wt. = 1,650 tons v = 3.28 fps (Note 4)	50 installations on other locks in system. See Figure 4.
Eastham	Manchester Ship Canal	England	NA	80	NA	NA		1.71E+07 ft-lb wt. = 22,000 tons v = 5 fps	Unique because of vertical placement of hydraulic pistons. See Figure 2.
Uelzen	Elbe-Setten Kanal	Germany (R.F.A.)	623.4	39.4	78.7	U.S. Submersible D.S. Vertical	9	3.69E+05 ft-lb to 7.38E+05 ft-lb	Swing beams (Ref b). See Figure 6.

(Continued)

NOTES: NA = not available.

1. An asterisk (*) denotes gate which barrier protects, if known.
2. See Table 1 for description of barrier types.
3. Three basic quantities are stated: kinetic energy (ft-lb), weight of the vessel (tons), and approach speed of the vessel (fps).
4. Calculated kinetic energy from 1,650 tons at 3.28 fps produces 5.50E+05 ft-lb. Data were taken from two sources--Ref d and 1.
5. Shestakov (Ref e) recommended that barriers be used on all locks greater than 39.4 ft wide. He also suggested that the following design criteria be used for various size locks:

   475.7 ft × 59.1 ft--7,440 tons at 3.28 to 3.94 fps
   885.9 ft × 59.1 ft--7,440 tons at 4.92 fps
   951.5 ft × 98.4 ft--barge train, 20,930 tons at 4.92 fps; ship - 7,440 tons at 8.2 fps

Table 2 (Concluded)

Lock Name	Location		Chamber Dimensions, ft			Lock Gates[1]	Barrier Type[2]	Design Criteria[3]	Comments
	Waterway	Country	Length	Width	Lift				
Leerstetten	Main-Donau Kanal	Germany (R.F.A.)	623.4	39.4	81.2	U.S. Submersible D.S. Vertical	9	3.69E+05 ft-lb to 7.38E+05 ft-lb	
Avanconca di-Cremona	Canal Milano-Cremona-Po	Italy	360.9	39.4	13.1	U.S. Bottom hinged, D.S. Miter	8	1.23E+05 ft-lb	Breaking wings, reference b. See Figure 5.
Wijk bij Duurstede	Amsterdam-Rhine	Netherlands	938.4	78.7	27.6	U.S. Vertical D.S. Vertical	4	9.11E+06 ft-lb wt. = 12,100 tons v = 4.9 to 5.6 fps	This design data, reference b and reference e. Suitable for barge train See Figure 3.
	Zeeland Canal		NA	NA	NA	NA	1	2.65E+07 ft-lb wt. = 30,800 tons v = 5.3 fps	Found in Ref e. Some type of flexible barrier with shock absorber.
Poe Lock (Mcarthur, Davis, and Sabin)	St. Marys River	U.S.A.	1,200	110	22	D.S. Miter*	1	EM 1110-2-2602, reference 12	Wire rope fender with retractable boom. Commonly found on St. Lawrence Seaway.
Bay Springs	Tenn-Tom Waterway	U.S.A.	600	110	84	U.S. Miter* D.S. Miter*	4, 6	6.68E+05 ft-lb wt. = 8,000 tons v = 1.64 fps	Several alternatives were proposed, but none were constructed.
Kiev Lock	Dnepr-bug River	U.S.S.R.	488.9	59.1	37.7	U.S. Submersible D.S. Miter*	1 or 3	2.39E+06 ft-lb wt. = 7,160 tons v = 3.28 fps	Proposed design by Ref a for Kiev and Kanev Locks. See note 5 for Shestakov's recommendations.
Kanev Lock	Dnepr-bug River	U.S.S.R.	885.9	59.1	34.5	U.S. Submersible D.S. Miter*	1 or 3	2.39E+06 ft-lb wt. = 7,160 tons v = 3.28 fps	
Kuybyshev	Dnepr-bug River	U.S.S.R.	NA	NA	NA	NA	2	2.89E+05 ft-lb wt. = 4,820 tons	First lock in system to have barrier. Actual design criteria.
Zaporozhye	Dnepr-bug River	U.S.S.R.	951.4	59.1	128.6	U.S. Submersible D.S. Miter*	2	5.78E+05 ft-lb wt. = 4,820 tons v = 2 fps	Actual design criteria.

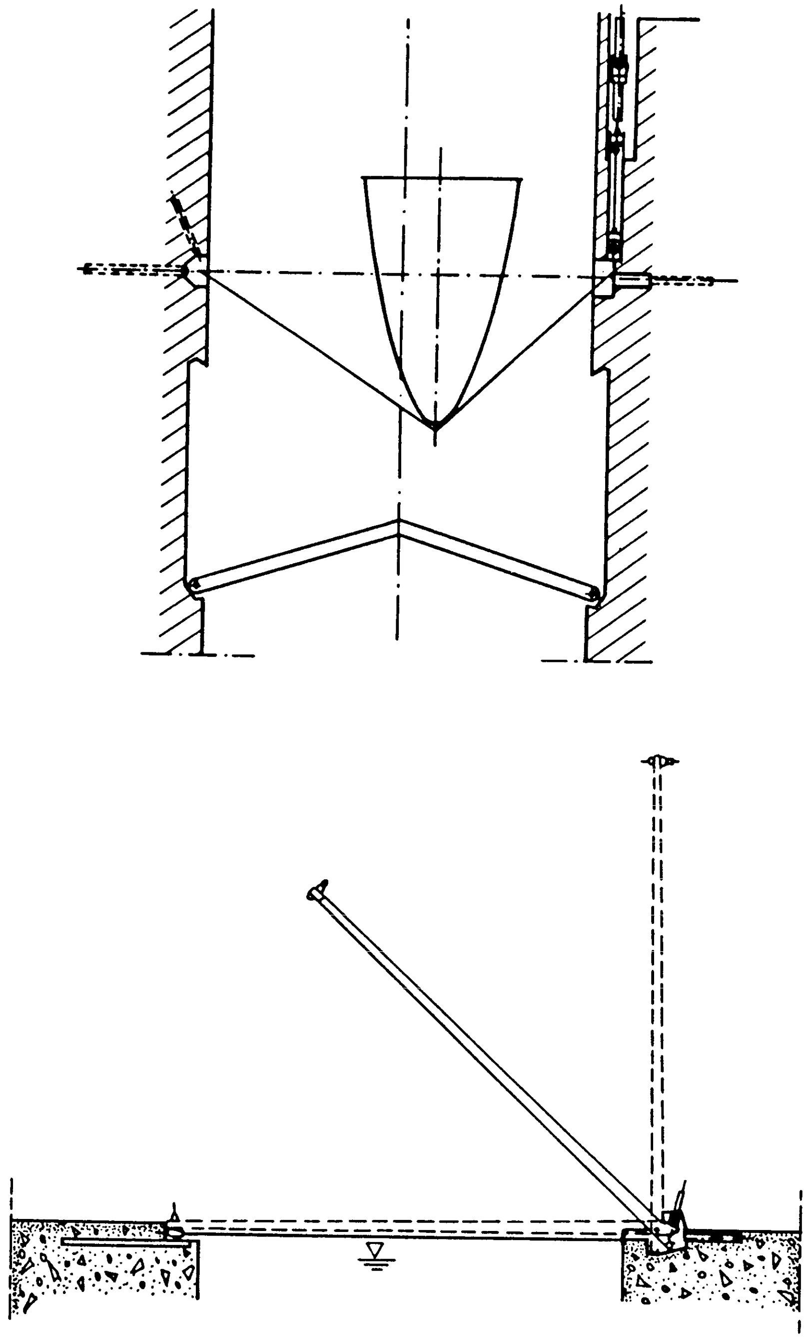


Figure 1. Cable restraining device (Ref b, p 262, Figure 49)

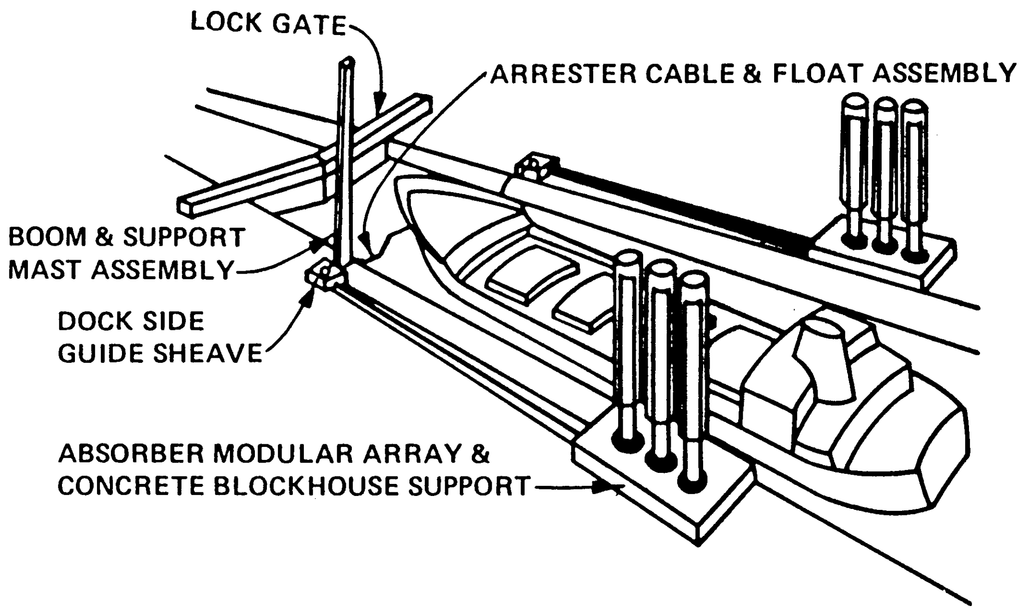


Figure 2. Ship arrester system
(Ref i, p E3-40, Figure 1)

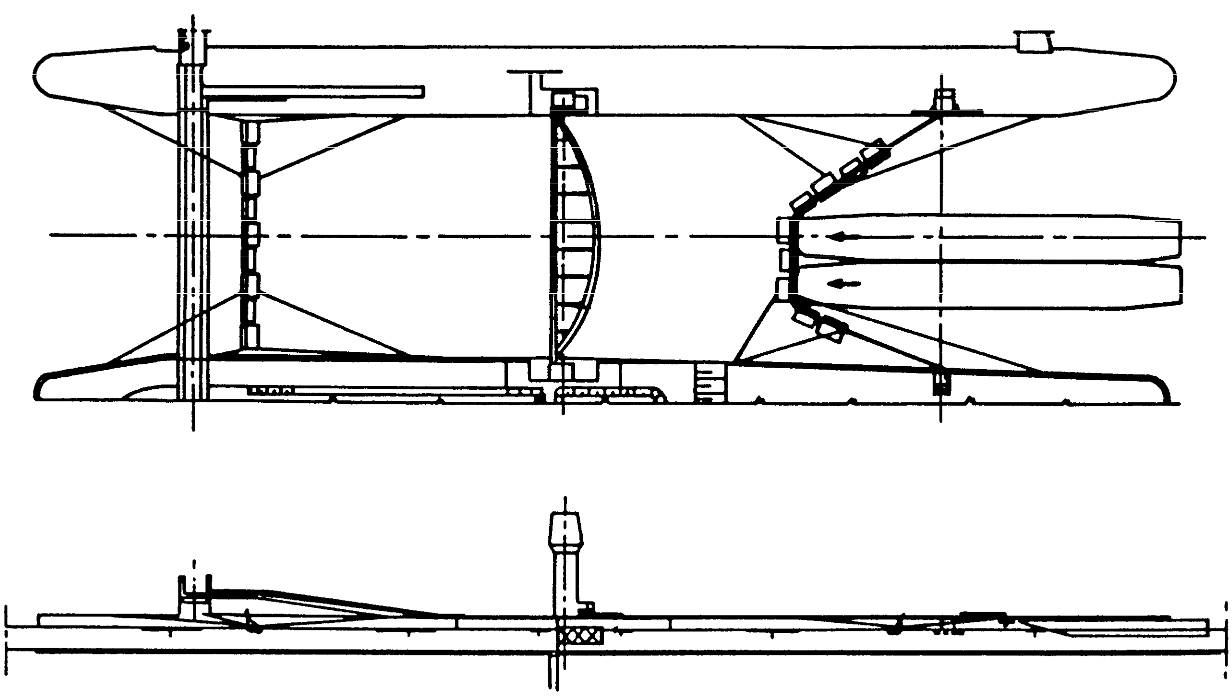


Figure 3. Protection net (Ref b, p 265, Figure 52)

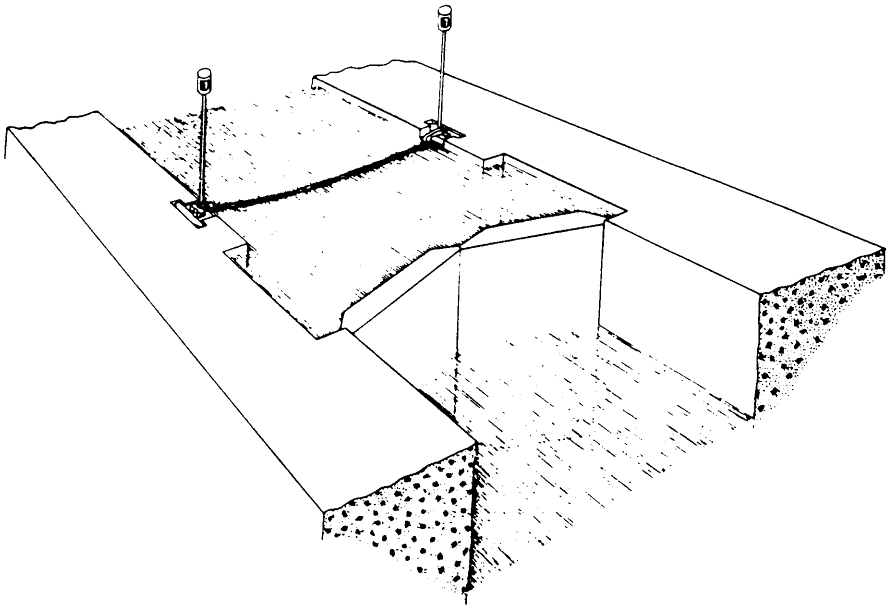


Figure 4. Dynamic bar (patented concept from Ref d and 1)

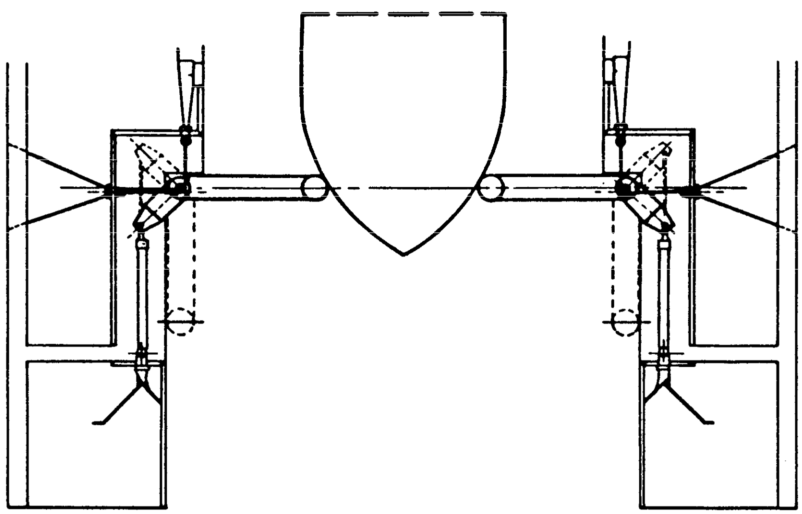


Figure 5. Breaking wings (Ref b, p 264, Figure 51)