vessels, but the hydraulic apparatus finally selected was considered to have advantages over all other forms.

In each of the twenty-four fenders built at Panama, there are three cylinders of the plunger type, the upper of which is suspended from beams spanning the machine pit while the bottom plunger rests directly on the concrete. The intermediate cylinder is movable, and slides on the inner surface of the upper and the outer surface of the lower cylinder. The chain passes through a hawse-pipe casting of steel, secured to a heavy anchorage, and is connected to the moving cylinder by a system of grooved sheaves. The pull of the chain when stopping a vessel is transferred to the anchors embedded in the concrete.

The lowering and raising of the chain is brought about by pumping water under pressure into the bottom and top cylinders respectively. The maximum stroke is 21 ft. 3 ins. and the multiplication given by the sheaves is four-fold, so that the chain pays out 85 ft. from each wall, a length which is sufficient for the deepest lock and also provides ample stopping power in emergency operation.

The chains were made from wrought iron bars 3 ins. in diameter and have links 10 ins. wide and 17 ins. long. The sections spanning the lock chamber have standard Navy stud links, while open links are used for the part that passes around the sheaves. Considerable difficulty was met with in obtaining chains of proper strength, especially the open links which have rarely been made of so large a size. The specified breaking strength was 500,000 lbs. for the studded and 450,000 lbs. for the open links, but all shots of chain were subjected to proof tests of 300,000 lbs. and 250,000 lbs. respectively.

In order to start the cylinder on either the upward or downward stroke, it is necessary to start the centrifugal pump and also to reverse the position of the operating valve which controls the direction of the flow. The latter is of the double piston type and operated by a small electric motor. Both the pump and valve motors are normally started from the central control house, from which all the gate and valve machines in the lock flight are controlled, but local control is also provided for.

The cylinder is brought to rest at each end of the stroke by a limit switch which stops the pump automatically, and it also starts the same whenever leakage has caused the cylinder to move up or down a predetermined distance from its end position.

The maximum pressure in the cylinders is from 100 to 150 lbs. per square inch, the higher pressure being required in lowering the chain as the heavy intermediate cylinder has to be lifted in this case. The high pressure prevails in the upper cylinder when raising and the lower cylinder when lowering the chain.

The pump has two stages, the first being of the volute, the second of the turbine type, a somewhat novel arrangement, which has proved entirely satisfactory. The pump has a 6-in. suction and 5-in. discharge pipe and is operated at 460 r.p.m. by a 70-h.p., 250-volt, 25-cycle induction motor. The lowering or raising of the chain is done in a satisfactory manner, the chain dropping into a pit in the floor so as to offer no obstruction to the passage of vessels.

Emergency Operation

As the sole function of the fender is the checking of vessels, the device for maintaining a heavy tension on the chain, as it pays out, after being struck, is the most vital part of the entire apparatus.

It consists of a pair of resistance or relief valves. When the chain is struck by a vessel, there is a tendency for the moving cylinder to rise, so that the water pressure in the piping increases rapidly. The resistance valves must permit the water to escape, as soon as the pressure reaches a point corresponding to a suitable working tension in the chain links and then keep the pressure as nearly constant as possible. As a rule it will be necessary, in order to accomplish this result, for the opening in the valves to vary slightly as the chain pays out. Their movement must, of course, be reliable and they must close promptly when the strain on the chain is entirely relieved.

It should be noted that the travel of the chain is resisted not only by the hydraulic resistance to the motion of the cylinder but also by the weight of the cylinder and other moving parts, by the friction of the chain at the hawse-pipe casting, as well as by frictional resistance in the machinery itself. It proved entirely feasible to measure these supplemental forces accurately. They proved about equal in amount to the internal hydraulic resistance, making it necessary to set the valves which control the pressure in the cylinder for a much lower pressure than originally contemplated.

With the chain in its normal operating condition across the top of the lock, all gate and check valves are closed, so that the resistance valves provide the only means by which the pressure can be relieved.

In view of the importance of the subject, various types of valves that seemed suitable for the purpose were carefully studied and three different designs were finally selected for detailed tests. The tests were very carefully made, with delicate apparatus, so that they may be called laboratory experiments on a large scale. There were three series of tests:—

(1) Preliminary tests on the three valves at a large pumping plant in the United States, which provided water under high pressure.

(2) Tests made on the first fender machine erected in Gatun Lock, the chain being put into tension by a large winding engine.

(3) Actual working tests of one of the Gatun fenders in stopping large vessels.

Tests in Stopping Vessels

The first two tests gave a reasonable assurance that the fenders would function properly in stopping vessels. Twenty-two of the fenders were therefore built, practically identical in plan, while two others (in the lower approach to Miraflores Lock) differ only in having two chains stretched across the lock at different levels, to provide for the great difference (22 ft.) between high and low tides in the Pacific. Their machinery is absolutely identical with that in the other fenders, the high and low level chains being alternately connected and detached, as the tide changes.

It was, of course, desirable to make an actual test of the fenders in checking a vessel in the lock. In October and November, 1915, after the writer had left the Isthmus, a number of such tests were therefore made by a board appointed by the governor of the canal. They proved of great interest and value especially as the vessels were of considerable size. Two ships were used, the "Allianca," having at the time a displacement of 4,221 tons, and moving at speeds varying from 1.23 to 3.38 miles per hour, and the "Cristobal," with a displacement of 18,000 tons and speeds as high as 2.45 miles per hour.

The resistance valves were set to open at 360 lbs. per square inch in most of the tests, and the propellers of the vessels were stopped in every case before the chain was struck. Indicators were connected to the piping system