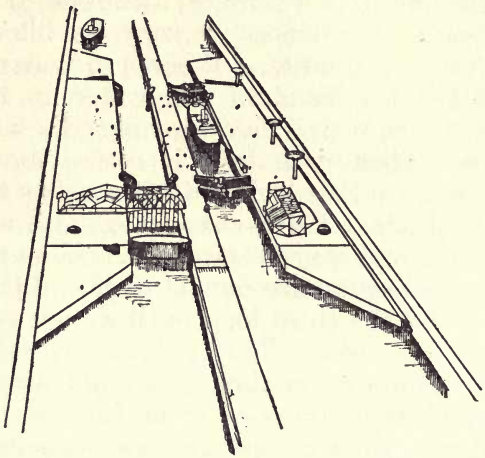
very good idea of how a lock looks may be gathered from the accompanying bird's-eye view of the model of Pedro Miguel Lock.

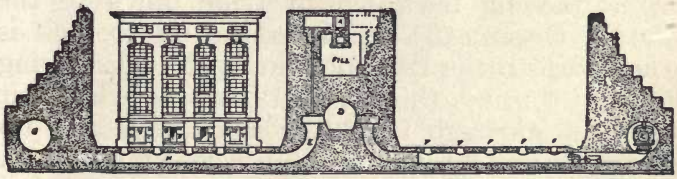


FROM A MODEL OF PEDRO MIGUEL LOCK

It will be seen that there are two of them side by side — twin locks, they are called, making them like a double-track railway. The lock on the right is nearly filled for an upward passage. The ship will be seen in it, held in position by the four towing engines, which appear only as tiny specks hitched to hawsers from the stem and stern. Behind the ship are the downstream gates. They were first opened to admit the ship, and then closed to impound the water that flows up through the bottom of the lock. Ahead are the upstream gates, closed also until the water in the lock is brought up to the level of the water in the lake. Then the gates will be opened, the big

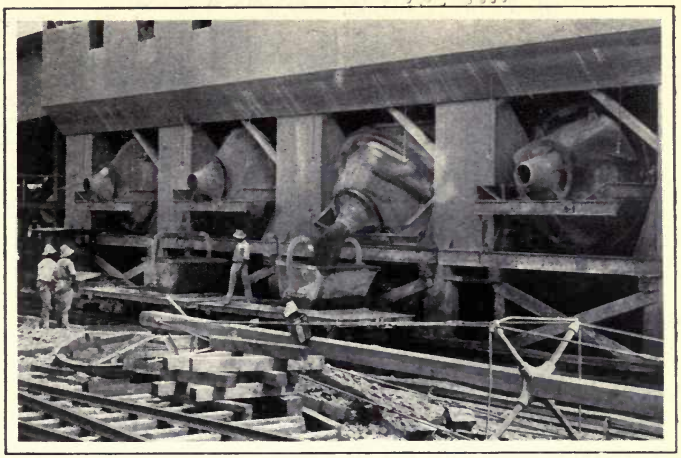
chain fender will be dropped down, and the ship will be towed out into the lake and turned loose. On the side wall of the right lock there is a big bridge set on a pivot so that it can be swung around across the lock and girders let down from it to serve as a foundation upon which to lay a steel dam if anything happens to the locks or gates. On the other lock the bridge has been swung into position, and the steel girders let down. Great steel sheets will be let down on live roller bearings on these girders, and when all are in place they will form a watertight dam of steel. Between this bridge and the reader is a huge floating tank of steel, which may be used to dam all the water out of the locks when that is desired.

Referring to the next figure we see a cross section of the twin locks. The side walls are from 45 to 50 feet thick at the floor. At a point $24\frac{1}{3}$ feet above the floor they begin to narrow by a series of 6-foot steps until they are 8 feet wide at the top. The middle wall is 60 feet wide all the way up, although at a point $42\frac{1}{2}$ feet above the lock floor room is made for a filling of earth and for a three-story tunnel, the top story being used as a passageway for the operators, the second story as a conduit for electric wires, and the lower story as a drainage system.

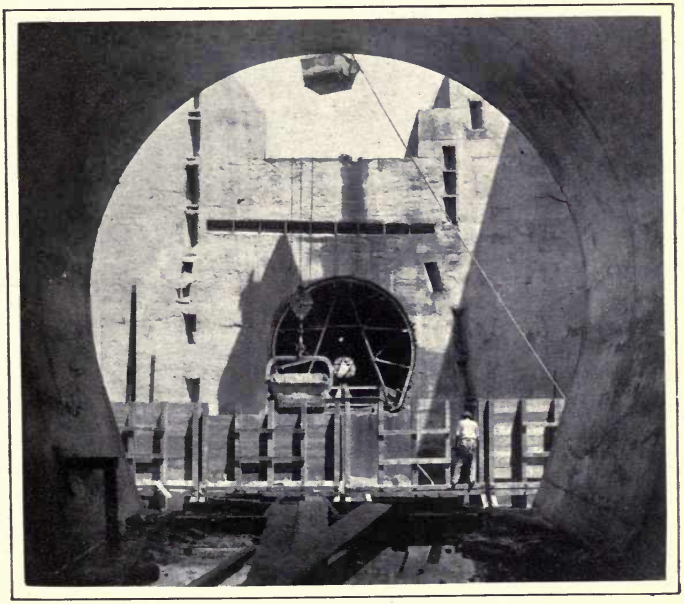


A CROSS-SECTION OF LOCKS, GIVING AN IDEA OF THEIR SIZE

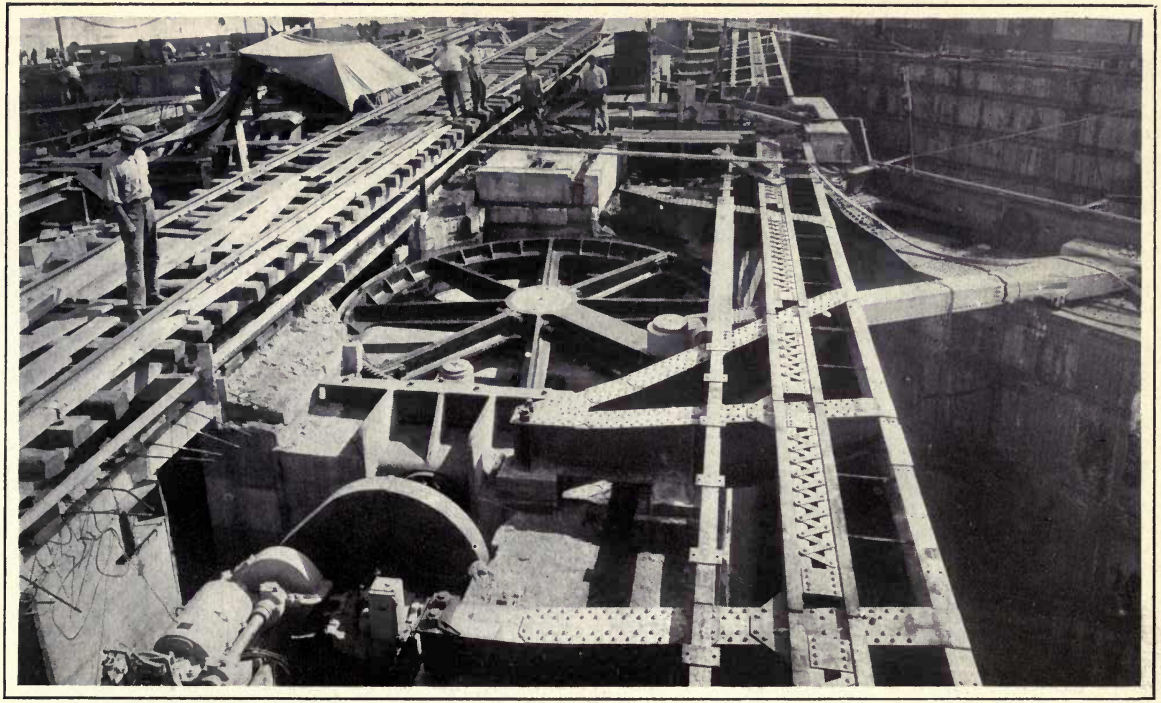
In this figure D and G are the big 18-foot cul-



CONCRETE MIXERS, GATUN



A CENTER WALL CULVERT, GATUN LOCKS



THE MACHINERY FOR MOVING A LOCK GATE

it, the valves are closed against the water in the lake, the ones permitting the escape of this water into the lock below are opened, and it continues to flow out of the upper lock into the lower one until the water in the two has the same level. Then the gates between the two locks are opened, the ship is towed into the second one and the operation is repeated for the last lock in the same way.

The gates of the locks are an interesting feature. Their total weight is about 58,000 tons. There are 46 of them, each having two leaves. Their weight varies from 300 to 600 tons per leaf, dependent upon the varying height of the different gates. The lowest ones are 47 feet high and the highest ones 82 feet, their height depending upon the place where they are used. Some of these are known as intermediate gates, and are used for short ships, when it is desired to economize on both water and time. They divide each lock chamber into two smaller chambers of 350 and 550 feet, respectively. Perhaps 90 per cent of all the ships that pass Panama will not need to use the full length lock — 1,000 feet. Duplicate gates will always be kept on the ground as a precaution against accident. Each leaf is 65 feet wide and 7 feet thick. The heaviest single piece of steel in each one of them is the lower sill, weighing 18 tons. It requires 6,000,000 rivets to put them together. In the lower part of each gate is a huge tank. When it is desired that the gate shall have buoyancy, as when operating it, this tank will be filled with air. When closed it is filled with water. The gates are opened and closed by a

huge arm, or strut, one end of which is connected to the gate and the other to a huge wheel in the manner of the connecting rod to the driver of a locomotive. Leakage through the space between the gate and the miter sill on the floor of the lock is prevented by a seal which consists of heavy timbers with flaps of rubber 4 inches wide and half an inch thick. A special sealing device brings the edges of the two leaves of a gate together and holds them firmly while the gates are closed.

Remembering that these gates are nothing more than Brobdingnagian double doors which close in the shape of a flattened V, it follows that they must have hinges. And these hinges are worth going miles to see. That part which fastens to the wall of the lock weighs 36,752 pounds in the case of the operating gates, and 38,476 pounds in the protection gates. These latter are placed in pairs with the operating gates at all danger points — so that if one set of gates are rammed down, another pair will still be in position. The part of the hinge attached to the gate was made according to specifications which required that it should stand a strain of 40,000 pounds before stretching at all, and 70,000 pounds before breaking. Put into a huge testing machine, it actually stood a strain of 3,300,000 pounds before breaking — seven times as great as any stress it will ever be called upon to bear. The gates are all painted a lead gray, to match the ships of the American Navy. Those which come into contact with sea water will be treated with a barnacle-proof preparation.

Now that we have described the locks, we may go back and see them in course of construction.

The first task was getting the lock building plant designed and built. At Gatun the plant consisted of a series of immense cableways, an electric railroad, and enormous concrete mixers. Great towers were erected on either side of the area excavated for the locks, with giant cables connecting them. These towers were 85 feet high, and were mounted on tracks like steam shovels, so that they could be moved forward as the work progressed. The cables connecting them were of $2\frac{1}{2}$-inch lock steel wire covered with interlocking strands. They were guaranteed to carry 6 tons at a trip, 20 trips an hour, and to carry 60,000 loads before giving way. They actually did better than the specifications called for as far as endurance was concerned.

The sand for making the concrete for Gatun came from Nombre de Dios (Spanish for Name of God), and the gravel from Porto Bello. The sand and gravel were towed in great barges, first through the old French Canal, and later through the Atlantic entrance of the present canal. Great clamshell buckets on the Lidgerwood cableways would swoop down upon the barges, get 2 cubic yards of material at a mouthful, lift it up to the cable, carry it across to the storage piles and there dump it. In this way more than 2,000,000 wagon loads of sand and gravel were handled.

A special equipment was required to haul the sand, gravel, and cement from the storage piles to the concrete mixers. There were two circular railroads of 24-inch gauge, carrying little electric cars that ran without motormen. Each car was stopped, started, or reversed by a switch attached

to the car. Their speed never varied more than 10 per cent whether they were going empty or loaded, up hill or down. When a car was going down hill its motor was reversed into a generator so that it helped make electricity to pull some other car up the hill. The cars ran into a little tunnel, where each was given its proper load of one part cement, three parts sand, and six parts gravel — 2 cubic yards, in all — and was then hurried on to the big concrete mixers. These were so arranged in a series that it was not necessary to stop them to receive the sand, gravel, and cement, or to dump out the concrete.

On the emptying sides of the concrete mixers there were other little electric railway tracks. Here there were little trains of a motor and two cars each, with a motorman. The train, with two big 2-cubic-yard buckets, drew up alongside two concrete mixers. Without stopping their endless revolutions the mixers tilted and poured out their contents into the two buckets, 2 yards in each. Then the little train hurried away, stopping under a great cable. Across from above the lock walls came two empty buckets, carried on pulleys on the cableway. When they reached a point over the train they descended and were set on the cars, behind the full buckets. The full buckets were then attached to the lifting hooks, and were carried up to the cable and then across to the lock walls, where they were dumped and the concrete spread out by a force of men. Meanwhile the train hustled off with its two empty buckets, ready to be loaded again.

On the Pacific side the concrete handling plant

was somewhat different. Instead of cableways there were great cantilever cranes built of structural steel. Some of these were in the shape of a giant T, while others looked like two T's fastened together. Here the clamshell dippers were run out on the arms of the cranes to the storage piles, where they picked up their loads of material. This was put in hoppers large enough to store material for 10 cubic yards. The sand and stone then passed through measuring hoppers and to the mixers with cement and water added. After it was mixed it was dumped into big buckets on little cars drawn by baby steam locomotives, which looked like overgrown toy engines. These little fellows reminded one of a lot of busy bees as they dashed about here and there with their loads of concrete, choo-chooing as majestically as the great dirt train engines which passed back and forth hard by. The cranes would take their filled buckets and leave empty ones in exchange, and this was kept up day in and day out until the locks were completed. When the plant was removed from Pedro Miguel to Miraflores, a large part of the concrete was handled directly from the mixers to the walls by the cranes without the intermediary locomotive service.

The cost of the construction of the locks was estimated in 1908 at upward of $57,000,000. But economy in the handling of the material and efficiency on the part of the lock builders cut the actual cost far below that figure. On the Atlantic side about a dollar was saved on every yard of concrete laid — about $2,000,000. On the Pacific side more than twice as much was saved.

Before the locks could be built it became necessary to excavate down to bed rock. This required the removal of nearly 5,000,000 cubic yards of material at Gatun. Then extensive tests were made to make certain that the floor of the locks could be anchored safely to the rock. These tests demonstrated that by using the old steel rails that were left on the Isthmus by the French, the concrete and rock could be tied together so firmly as to defy the ravages of water and time. A huge apron of concrete was built out into Gatun Lake from the upper locks at that place, effectively preventing any water from getting between the rocks and the concrete lying upon them.

# CHAPTER V

## THE LOCK MACHINERY

ONE of the problems that had to be solved before the Panama Canal could be presented to the American people as a finished waterway, was that of equipping it with adequate and dependable machinery for its operation. Panama canals are not built every year, so it was not a matter of ordering equipment from stock; everything had to be invented and designed for the particular requirement it was necessary to meet. And the first and foremost requirement was safety. When we look over the canal machinery we see that word "safety" written in every bolt, in every wheel, in every casting, in every machine. We see it in the devices designed for protection and in those designed for operation as well. We see it in the giant chain that will stop a vessel before it can ram a gate; we see it in the great cantilever pivot bridges that support the emergency dams; we see it in the double lock gates at all exposed points; we see it in the electric towing apparatus, in the limit switches that will automatically stop a machine when the operator is not attending to his business, in the friction clutches that will slip before the breaking point is reached. Safety, safety, safety, the word is written everywhere.

The first thing a ship encounters when it approaches the locks is the giant chain stretched across its path. That chain is made of links of 3 inches in diameter. When in normal position it is stretched across the locks, and the vessel which does not stop as soon as it should will ram its nose into the chain. There is a hydraulic paying-out arrangement at both ends of the chain, and when the pressure against it reaches a hundred gross tons the chain will begin to pay out and gradually bring the offending vessel to a stop. After a ship strikes the chain its momentum will be gradually reduced, its energy being absorbed by the chain mechanism. While the pressure at which the chain will begin to yield is fixed at 100 gross tons, the pressure required to break it is 262 tons. Thus the actual stress it can bear is two and a half times what it will be called upon to meet. The mechanism by which the paying-out of the chain is accomplished is exceedingly ingenious. The principle is practically the reverse of that of a hydraulic jack. The two ends of the 428-foot chain are attached to big plungers in the two walls of the locks. These plungers fit in large cylinders, which contain broad surfaces of water. They are connected with very small openings, which are kept closed until a pressure of 750 pounds to the square inch is exerted against them. By means of a resistance valve these openings are then made available, the water shooting out as through a nozzle under high pressure. This permits the chain plunger to rise gradually, while keeping the tension at 750 pounds to the inch, and the paying-out of the chain proceeds accord-

ingly. Of course not all ships will strike the chain at the same speed, and in some cases the paying-out process will have to be more rapid than in others. This is provided for by the automatic enlargement of the hole through which the water is discharged, the size of the hole again becoming smaller as the tension of the chain decreases. This chain fender will stop the *Olympic* with full load, when going a mile and a half an hour, bringing it to a dead standstill within 70 feet, or it will stop an ordinary 10,000-ton ship in the same distance even if it have a speed of 5 miles. The function of the resistance valve is to prevent the chain from beginning to pay out until the stress against it goes up to 100 tons, and to regulate the paying-out so as to keep it constant at that point, so long as there is necessity for paying-out. Any pressure of less than a hundred tons will not put the paying-out mechanism into operation.

When a ship is to be put through the locks the chain will be let down into great grooves in the floor of the lock. There is a fixed plunger operating within a cylinder, which, in turn, operates within another cylinder, the resulting movement, by a system of pulleys, being made to pay out or pull in 4 feet of chain for every foot the plunger travels. The chain must be raised or lowered in one minute, and always will have to be lowered to permit the passage of a ship. The fender machines are situated in pits in the lock walls. These pits are likely to get filled with water from drippings, leakages, wave action, and drainage, so they are protected with automatic pumps. Float valves are lifted when the water rises in the

pits. This automatically moves the switch controlling an electric motor, which starts a pump to working whenever the water gets within 1 inch of the top of the sump beneath the floor of the pit. Twenty-four of these chain fenders are required for the protection of the locks, and each requires two such tension machines.

No ship will be allowed to go through the canal except under the control of a canal pilot. He will certainly bring it to a stop at the approach wall. But if he does not, there is the chain fender. There is not a chance in a thousand for a collision with it, and not a chance in a hundred thousand that the ship will not be stopped when there is such a collision.

But if the pilot should fail to stop the ship, and it should collide with the fender chain, and then if the fender chain should fail to stop it, there would be the double gates at the head of the lock. There is not one chance in a hundred that a ship, checked as it inevitably would be by the fender chain, could ram down the first, or safety gate. But if it did, there would still be another set of gates some 70 feet away. The chances here might be one in a hundred of the second set being rammed down. From all this it will be seen that the chances of the second pair of gates being rammed is so remote as to be almost without the realm of possibility. But suppose all these precautions should fail, and suddenly the way should be opened for the water of Gatun Lake to rush through the locks at the destructive speed of 20 miles an hour? Even that day has been provided against by the construction of the big emergency dams. The

emergency dams, like the fender chains, are designed only for protection, and have no other use in the operation of the locks. There will be six of these dams, one across each of the head locks at Gatun, Pedro Miguel, and Miraflores.

These emergency dams will be mounted on pivots on the side walls of the locks about 200 feet above the upper gates. When not in use they will rest on the side wall and parallel with it. When in use they will be swung across the locks, by electric machinery or by hand, and there rigidly wedged in. It will require two minutes to get them in position by electricity and 30 minutes by hand. There is a motor for driving the wedges which will hold the dam securely in position, and limit switches to prevent the dams being moved too far.

When a bridge is put into position across the lock, a series of wicket girders which are attached to the upstream side of the floor of the bridge are let down into the water, the connection between the bridge and one end of each girder being made by an elbow joint. The other end goes down into the water, its motion being controlled by a cable attached some distance from the free end of the girder and paid out or drawn in over an electrically operated drum. This free end passes down until it engages a big iron casting embedded in the concrete of the lock floor. This makes a sort of inclined railway at an angle of about 30 degrees from the perpendicular, over which huge steel plates are let down into the water. There are six of these girders, and they are all made of the finest nickel steel. When they are all in position, a row of six plates are let down, and they make the

stream going through the locks several feet shallower. Then another row of plates is let down on these, and the stream becomes that much shallower. Another row of plates is added, and then another, until there is a solid sheet of steel plates resting on the six girders, and they make a complete steel dam which effectively arrests the mad impulse of the water in Gatun Lake to rush down into the sea. The plates are moved up and down by electrical machinery, and are mounted on roller-bearing wheels, so that the tremendous friction caused by their being pressed against the girders by the great force of the water may be overcome. That the emergency dams will be effective is shown by the experience at the "Soo" locks, on the canal connecting Lakes Superior and Huron. There, a vessel operating under its own power, rammed a lock gate. Although the emergency dam had grown so rusty by disuse that it could be operated only by hand, it was swung across the lock and effectively fulfilled its mission of checking the maddened flow of the water.

Another protective device for the locks is the big caisson gates that will be floated across the head and tail bays when it is desired to remove all the water from the locks for the purpose of permitting the lower guard gates to be examined, cleaned, painted, or repaired, and for allowing the sills of the emergency dams to be examined in the dry. The caisson gates are 112½ feet long, 36 feet beam, and have a light draft of 32 feet and a heavy draft of 61 feet. When one is floated into position to close the lock, water will be admitted to make it sink to the proper depth. Then its

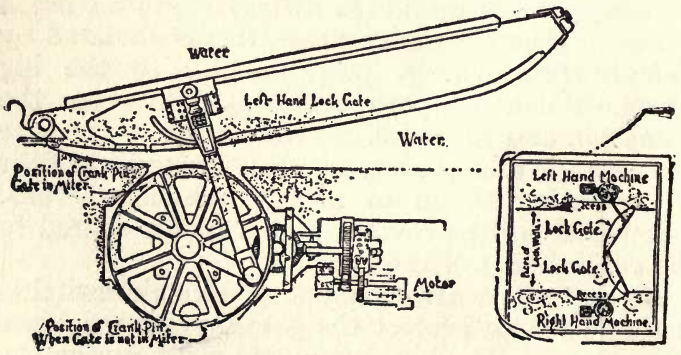
large centrifugal pumps, driven by electric motors, will pump the water out of the lock. When the work on the lock is completed these pumps will pump the water out of the caisson itself until it becomes buoyant enough to resume its light draft, after which it will be floated away.

The machinery for opening and closing the lock gates called for unusual care in its designing. The existing types of gate-operating machinery were all studied, and it was found that none of them could be depended on to prove satisfactory, so special machines had to be designed.

A great wheel, resembling a drive wheel of a locomotive, except that a little over half of the rim is cog-geared, is mounted in a horizontal position on a big plate, planted firmly in the concrete of the wall and bolted there with huge bolts 11 feet long and $2\frac{1}{4}$ inches in diameter. This plate weighs over 13,000 pounds, and the wheel, cast in two pieces, weighs 34,000 pounds. As the weight of the rim of the wheel on the eight spokes probably would tax their strength too much when the wheel is under stress, this is obviated by four bearing wheels, perpendicular to the big wheel, which support the rim. Between the crank pin and the point of attachment on the gate leaf there is a long arm, or strut, designed to bear an operating strain of nearly a hundred tons. The wheel will be revolved by a motor geared to the cogged part of the rim.

An ingenious arrangement of electric switches is that used to protect the gate-moving machines from harm. The big connecting rod between the master wheel and the gate leaf is attached to the

gate leaf by a nest of springs capable of sustaining a pressure of 184,000 pounds, in addition to the fixed pressure of 60,000 pounds. Should any obstruction interfere with the closing of the gate and threaten a dangerous pressure on the connecting rod, the springs, as soon as they reach their full compression, establish an electrical contact and thus stop the motor. Likewise, should any obstruction come against the gate as the connecting rod is pulling it open, the springs again permit the establishment of an electrical contact and stop the motor. All of these precautions are entirely independent of and supplemental to the limit switches, which cut off the power from the gate-moving machine should the strain reach the danger line. These big machines move the huge gate leaves without the slightest noise or vibration. Such a machine is required for each of the 92 leaves used in the 46 gates with which the locks are equipped. The operator can open or close one of these big gates in two minutes.




ONE OF THE 92 GATE-LEAF MASTER WHEELS