inland behind hills which will effectively protect them from the fire of a hostile fleet. The locks under the original plans were to have a usable length of 900 feet, width of 95 feet, and a depth over the gate sills of 41 3/4 feet. These dimensions were increased on January 15, 1908, in compliance with the wishes of the Navy Department, to a usable length of 1,000 feet and a width of 110 feet in order to allow the passage of larger battleships at that time contemplated. The height of the lock walls is about the same as that of a six-story building. The largest of the present-day ships, the Imperator, 919 feet long, can be locked through the canal. However, most of the ships that will use the Isthmian trade route, or

Eight of these cableways, four on each bank, were used to place the concrete in the lock walls. They consisted of steel towers, 85 feet high, operating on their own tracks, and supported cables, which carried the concrete buckets back and forth.

that are likely to use it for many years to come, are less than 600 feet long. In fact, 95 per cent. of the vessels navigating the high seas are less than 600 feet long. For this reason, each lock is divided by intermediate gates into two chambers 400 and 600 feet long, respectively. This does not mean that the full length of 1,000 feet cannot be used if necessary, but with this division a saving in both water and time can be made in the locking of small ships.

There are six double locks in the Canal, three flights of twin locks on each side of the Isthmus to lift ships from sea level to the lake level, and vice versa. They are made in pairs, in order that ships can be locked both up and down at the same time, and, in case of accident to one set, there will be no delay to traffic as the duplicate flight can be used. The usable dimensions of all are the same. Each lock is a concrete chamber with steel mitering gates at each end, and with the gates closed, ships are raised and lowered by simply admitting or withdrawing water. The side walls are 45 to 50 feet wide at the surface of the floor.
This view shows the dumping of concrete at Gatun Locks. Every move of the bucket is at the will of the man stationed in the cableway tower, who, in dumping, follows the signals of the man supervising the operation. As fast as the concrete is deposited, men, standing knee deep in the mixture, spread it out evenly.
perpendicular to the face, and narrow from a point 24 1/2 feet above the floor until they are eight feet wide at the top. The center walls are 60 feet wide, approximately 81 feet high, and each face is vertical. In the six pairs of locks there have been placed approximately 4,500,000 cubic yards of concrete, requiring about the same number of barrels of cement.

In the center wall of each set of locks, 42 1/2 feet above the floor, there is a space 19 feet wide at the bottom and 44 feet wide at the top in which there is a tunnel divided into three galleries. The lowest gallery is for drainage; the middle, for the wires for the electric current to operate the lock machinery installed in the center wall, and the upper is a passageway for the operators. To fill and empty the locks there are culverts extending the entire length of the center and side walls. These culverts are 18 feet in diameter and are large enough to permit the passage of a railroad train. From these large culverts there are several smaller culverts, 33 to 44 square feet in area, which extend laterally under the floor of the locks and open into them through wells. These smaller culverts would permit of the passage of a two-horse cart. The water is conveyed from the lake level through the large culverts, and thence through the small lateral culverts to the lock chamber, thus insuring an even distribution of the water over the entire area of the chamber. This reduces the disturbance when the lock is being filled or emptied, so that ships are lifted or lowered without undergoing any strain or violent pitching. The flow of water through the culverts is controlled by valves. The large culvert in the center wall communicates with the chamber of each of the twin locks, so that water may be passed from one lock to the other of the pair, thereby effecting a saving. The average time required to fill and empty a lock is about 15 minutes, and the time
The beginning of concrete work at Gatun Locks. Laying the floor and installing the lateral culverts. The circular holes in the floor are to admit the water to the locks, and to empty them. The floor varies in thickness from 13 to 20 feet of solid concrete, according to the character of material underlying it, and is anchored by steel rail to a depth of 19 feet.

Installing the cylindrical valves for the control of the flow of water in and out of the locks. The water control system of the locks consists of rising stem or Stony gate valves, and cylindrical valves. The rising stem valves govern the flow of water in the side wall culverts, and the cylindrical valves govern the flow of water in the center wall culverts.
of passage of a vessel through the entire canal ranges from 10 to 12 hours, according to the size of the ship, and the rate of speed at which it can travel.

The lock gates are of the miter type, built of steel frame covered with steel plate, 65 feet long and from 47 to 82 feet high, according to their position in the locks. In all there are 41 gates of two leaves each. These gates weigh from 390 to 730 tons each, and, in order to reduce this weight as much as possible from the bearings and hinges upon which they swing, they are divided horizontally into two separate compartments. The lower compartment is watertight, sufficiently buoyant to practically float in the water. The upper half, however, has an opening and, as the water rises in the chamber it flows into the upper half and adds sufficiently to the weight of the gate to offset the increased pressure of the water in the lock chamber.

The machinery for opening and closing the gates, operated by electricity, was invented by Mr. Edward Schildhauer, Electrical and Mechanical Engineer of the canal commission. It consists of a large “bull” wheel, mounted in a horizontal position on the lock wall, to the rim of which is fastened a steel strut or arm; this arm is also attached to the top of each gate leaf. The wheel rotates through an arc of 197 degrees, and closes or opens the gate leaf, according to the direction in which it is turned. This operation can be performed in two minutes, and it is similar to the action of a person who reaches out an arm to open or close a door.

GUARDS AGAINST ACCIDENTS

In case, the gates at the entrance to all the locks and at the lower end of the upper lock in each flight are placed in pairs, thus eliminating the chances of a ship ramming the gate which is holding back the water of the level above. These guard gates miter outward to give them added power to resist any blow which might be given to them. They are also available for use in case the gates proper become damaged, or for any reason cannot be operated.

Steel forms in position for side and center wall construction. They are made of sheet steel, carried on movable towers and operated on tracks. Each tower and form weighs almost four and one-half million pounds.
THE LAND DIVIDED — THE WORLD UNITED

Ships will not be allowed to enter the locks under their own steam, but will be towed through by electric locomotives operating on the lock walls. A ship about to enter the locks will first come to a standstill alongside the approach walls where the towing locomotives, two on each wall, two forward and two aft, can attach their lines. Before the ship can enter a lock chamber it encounters a fender chain which has been placed on the upstream side of all the gates of the upper locks, and in front of the guard gates at the lower end of each flight of locks, to prevent the gates from being rammed by a ship separated from the towing locomotives, or approaching the gates under its own steam. In operation the chain is stretched across the lock chamber from the top of the opposing walls; when it is desired to allow a ship to pass, the chain is lowered into a groove in the lock floor, and is raised again after the ship passes. It is worked by a hydraulically operated system of cylinders, and is capable of bringing to a stop a 10,000-ton ship, running at four knots an hour, within 73 feet, which is less than the distance between the chain and the gate.

In case these precautions to prevent accident to the gates fail, or in case it should be necessary to make repairs which would necessitate the shutting off of all water from the lake levels, an emergency dam of the movable type has been placed above each flight of locks. This dam is a steel truss bridge of the cantilever type, pivoted on the side wall of the lock approach. When not in use it rests upon the side wall parallel to the channel. When required for use it is
The handling equipment used at Pedro Miguel and Miraflores locks was entirely different from that at Gatun. At Pedro Miguel, Berm cranes, containing the mixing machinery, were stationed at the head of the lock, with arms extending on either side, from which grab buckets were lowered to pick up sand and rock, as the case might be.

The finished product was carried by these trains into the lock chambers. Many of the old French locomotives were repaired and used for this work.
The Chamber cranes, shown here, lifted the buckets of cement from the train and transported them to the point desired. The method of dumping by the Chamber cranes is very similar to that of the Gatun cableways, the operation being controlled by a man stationed in the cage on the trolley arm. These cranes operated on tracks, were self-propelling, and were used to advantage also in handling heavy pieces of lock machinery.

Berm cranes at Miraflures Locks. With the completion of the heavy masonry work at Pedro Miguel, the cranes were moved to Miraflures Locks. The mixing cranes were slightly modified, and were stationed on the banks of the locks, instead of at the head, dumping directly into the side walls, while the chamber cranes were used solely for center wall construction. This method eliminated the necessity of concrete carrying trains to a large extent.
swung across the channel, with its end resting on the center wall of the lock. A series of wicket girders hinged to it are then lowered with their ends resting in pockets embedded in the lock floor. The action of these girders might be compared to the dropping of the tines on a sulky rake, with the exception that the girders are hung on individual pivots. After these girders have been lowered into place, they afford runways for gates which are let down one at a time, closing the space between them. The first row of plates lowered close the channel to a height of 10 feet; another series of panels lowered brings this height to 20 feet, and so on until the channel is completely closed. With the main flow of water checked, the remainder, due to the clearance between the plates, is checked by driving steel pipes between the sides of the adjacent panels.

When it is desired to gain access in the dry to the sills of these emergency dams, or to repair the lower guard gates of the locks, and the gates of the spillway dam, floating caisson gates of the molded ship type are available. When their use is required they are towed into position in the forebay of the upper lock, above the emergency dam, or between the piers of the spillway, and sunk. They are equipped with electric motor driven pumps for the purpose of pumping out the caissons and for unwatering the locks.

The gates, fender chains, emergency dams, towing locomotives, and culvert valves are operated by electricity, and all but the towing locomotives will be controlled by operators stationed in a control house on the center wall from which all parts of the locks can be seen. These houses are equipped with a double control board duplicated to conform to the duplication in locks. It contains a representation, part model and part diagrammatic of the flight of locks controlled by the respective series of switches. As the operator throws the switches he can see before him, in model or diagram, the progress of the fender chains, the movement of the gates, the opening and closing of the gate

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**CROSS SECTION OF LOCK CHAMBERS AND WALLS OF LOCKS**

- A—Passageway for operators.
- B—Gallery for electric wires.
- C—Drainage gallery.
- D—Culvert in center walls.
- E—These culverts run under the lock floor and alternate with those from side walls.
- F—Walls opening from lateral culverts into lock chamber.
- G—Culverts in sidewalls.
- H—Lateral culverts.
The upper picture shows the intakes in the walls where water is let in and out of the culverts. The center picture gives a view of Gatun locks under construction. In the lower picture the square concrete building in the distance is the control house from which all of the lock operating machinery will be manipulated.
valves, and the rise and fall of the water in the lock chambers. The system is interlocking so that certain motors can not be started in a certain direction until other motors are operated in a proper manner.

HOW THE LOCKS WERE BUILT

One of the most interesting sights to the canal visitor during the time construction work was in progress on the locks was the working of the concrete mixers and the cableways and cranes, now dismantled, which carried the material to the point where it was to be poured.

At Gatun locks, where 2,043,763 cubic yards of concrete were placed, the assembling and the distribution of the material was done by means of industrial
The upper picture shows a view looking north from Miraflores Locks. Pedro Miguel Lock in the distance, site of Miraflores Lake in between. Spillway to the right, temporary bridge for the gate contractors to the left of picture. The center picture shows a view looking south from the same lock, Ancon Hill in the distance. The lower picture presents a busy scene at the locks when the gates were under construction.
electric railways and overhead cableways. From the docks in Cristobal, the cement was carried in barges up the old French canal, which had been deepened for the purpose, to a cement storage dock at Gatun. Rock quarried and crushed at Porto Bello, about 17 miles east of Colon, and sand dredged at Nombre de Dios, about 35 miles east of Colon, was towed in barges to Gatun docks. This material was unloaded by overhead cableways, upon which grab buckets were hung, and carried to storage piles. The material was then assembled in the mixers by cars operated under the cement shed and under the sand and rock storage piles. Another electric railway carried the buckets of concrete to the bank above the lock sites. At this point the full buckets were lifted from the cars by cableways stretched across the lock site and lowered into the lock chamber where desired. There were eight of the cableways arranged in pairs,

The lock walls as a whole give the visitor an idea of massive construction only. The arched sections, shown in the picture, connecting the main walls with the wing and guide walls, effect a saving in concrete and also give a symmetrical touch to the structures.

each pair stretching from a steel tower 85 feet high to a similar tower on the opposite side of the locks, a distance of 800 feet. These towers were placed on trucks on which they could be moved along tracks parallel to the locks to the point desired. Besides the concrete, the cableways also handled heavy construction material, such as steel forms and lumber. Their capacity was six tons each, and the greatest lift 170 feet for a distance of 670 feet.

For the locks at the Pacific end a distinctly different system was employed. Placement at Pedro Miguel was made by means of four cantilever cranes, two resting on tracks on the floor of each lock chamber, and two berm cranes equipped with two 2-cubic yard mixers in the upper forebay. Each of the chamber cranes was 95 feet high with cantilever arms, which extended to both sides from the center. Placement in the approach and wing walls was made by means of
A general view of Gatun Locks as they appeared October 1, 1912. All heavy masonry work, with the exception of the north approach wall was completed, and this view gives an idea of their magnitude. Each lock contains two parallel chambers separated by a center wall. The side walls are 45 to 50 feet wide at the floor level, and narrow to a width of 8 feet at the top. The middle wall is 60 feet wide and 81 feet high.
View inside the lower lock, west chamber, Miraflores Locks. The lock chambers are the largest concrete troughs in the world, having usable dimensions of 1,000 feet in length and 110 feet in width, and at the present time will accommodate the largest ships afloat. A striking comparison is obtained by looking at the man standing on the lock floor.
derricks, which lifted the buckets from concrete trains which ran between the
mixer and chamber cranes.

When the heavy masonry work at Pedro Miguel was finished the chamber
kranes were transferred to Miraflores, and operated in the same manner.
The berm cranes were modified in order that they might be operated on the
sides of the locks, instead of at the head.

The crushed stone for the concrete of both Pedro Miguel and Miraflores
locks was supplied by rail from a large quarry and crusher plant on the west
side of Ancon hill near Panama. Sand was dredged at Punta Chame, on Pana-
ma Bay, 23 miles west of Panama. It was hauled in barges to Balboa and there
unloaded by special machinery and hauled by rail to the storage piles at the
locks.

MAKING THE DIRT FLY

The work of excavation in the canal prism was divided into two classes,
“wet” and “dry,” that taken out by means of dredges, and that by steam
shovels, respectively. The wet excavation, up to October 5, 1913, when water
was admitted into Culebra Cut, was practically confined to the sea level

Section of the north guide wall at Gatun Locks under construction. This was one of the most
difficult pieces of masonry work in the whole job. The greater part of its length of 1,000 feet
rests upon piles driven to solid rock. To the right is seen the east wing wall of the locks.

approaches to the Canal, that at the Atlantic entrance seven miles to the locks
at Gatun, and that at the Pacific entrance 8½ miles to the locks at Miraflores.
The largest part of the excavation, however, was accomplished by steam
shovels in Culebra Cut prior to the letting in of the water of Gatun Lake and in
the Chagres section. There remained on September 1, about 9,153,000 cubic
yards of spoil in Culebra Cut, out of a total of 95,869,000 cubic yards. The
total excavation, “wet” and “dry” for the entire canal, as originally estimated
by the minority members of the Board of Consulting Engineers, was 103,795,000
cubic yards, in addition to the amount excavated by the French companies,
Entrance to Gatun Locks from the lake. Gatun Dam on the left and approach wall in the foreground. Approach walls 1,000 feet long, have been built at each end of all the locks, and as the name indicates, they serve as a guide to ships coming up the approach channel. Ships must come to a stop at these walls, until the locomotives which tow them through the locks make fast their lines.

View of the upper gates at Miraflores Locks under construction. The first of these is completed and partly swung open to full view giving an idea of their thickness. The gates are operated by electricity and may be opened or closed in one minute and 47 seconds.
who accomplished 29,708,000 cubic yards useful under the present plans. This estimate has been increased several times on account of changes in the canal plans, to silting in the canal entrances and in the Chagres section, to slides in Culebra Cut, for the terminals at both entrances, and for the dry docks at Balboa. The last estimate made on July 1, 1913, places the grand total at 232,333,000 cubic yards, considerably more than double the amount originally estimated. When the canal is entirely completed, the excavated material would make a line of 63 pyramids, each equal in size to the Great Pyramid of Egypt.

DREDGING

Most of the work in the Atlantic entrance, about 53,167,000 cubic yards, was accomplished by two elevator dredges left by the French, and overhauled by the Americans, a dipper dredge of American make, and a sea-going 20-inch suction dredge, also made in the United States. Where the channel ran inside the shore line two small hills were dug out by steam shovels to a depth of 41 feet, and the remainder then accomplished by the dredges.

In the Pacific entrance about 61,489,000 cubic yards was accomplished by two elevator dredges of the Belgian type and two Scotch elevator dredges left by the French and overhauled by the Americans, a modern elevator dredge built in Scotland in 1911, and a sea-going 20-inch suction dredge. This latter dredge was floated into Culebra Cut in October, 1913, and is now at work taking out the remaining spoil in that section. In the Pacific entrance a large quantity of rock was encountered which was too hard for the dredges to handle.

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Completed sills from the lock gates. These sills, built of steel and concrete, form foundations on which the gates rest.
The gates under construction at Pedro Miguel. The lock gates, 46 in number, two leaves to each gate, constitute one of the spectacular features of Canal construction. They are 7 feet thick, from 47 to 82 feet high, and each leaf or half gate weighs from 300 to 700 tons. They are built up of great horizontal girders weighing from 12 to 18 tons each, with vertical frame work in between, sheathed with steel plates on each side.

Near view of the massive lock gates showing riveting gang on scaffold. The lower part of each gate is an air chamber, so that in using it, the gate is buoyed up by the surrounding water, reducing the weight on its hinges, and making it easier to move. To overcome the lifting effect when the lock chamber is full of water, the upper half has openings on the up-stream side which allows it to automatically fill or empty, thus equalizing the weight.
To break up this material, in addition to subaqueous blasting, a Lohnitz subaqueous rock breaker was used.

CUTTING THROUGH THE DIVIDE

The part of the canal on which the most work has been done, and which was the last to be completed, is Culebra Cut, the 9-mile section through the continental divide. Work has been nearly continuous in this section since the French started operations in 1882. It is also one of the most important and interesting portions of the Canal project on account of the deep cutting necessary, and the difficulties encountered on account of slides and the disposal of spoil. When the Americans took over the work in May, 1904, they found the French engaged in taking out just sufficient material to hold their concession. This

they were doing with a few obsolete side excavators, served by small Deauville dump cars and Belgian engines.

Work was continued with the equipment left by the French until it could be gradually replaced with modern steam shovels, cars and engines. The first steam shovel was placed in operation on November 11, 1904, and the last of the French excavators was discontinued on June 16, 1905. On August 1, 1905, there were 11 steam shovels at work, but they were greatly handicapped in their output as they were served by old French cars operated on lines which, as Chief Engineer Stevens said: “By the utmost stretch of the imagination could not be called railroad tracks.” Work was practically stopped until proper preparations could be made for handling the spoil and effecting an organization which would obtain the greatest possible results from the use of modern methods of
This illustrates the size to which even the smaller features of gate construction attain, as well as the care taken in their manufacture. This steel yoke, made of vanadium, is used to connect the tops of the gates with the anchors in the walls. It weighs 14,000 pounds, and was subjected to a stress of 3,300,000 pounds before it broke.

The operating mechanism of a lock gate. The wheel is a bull wheel, which, in operating, turns through an arc, giving the connecting rod the movement of an arm in opening and shutting a door. It is 19 feet in diameter, and weighs over 35,000 pounds.
excavation. Tracks were properly laid, a proper transportation system inaugurated, and proper dumping places located before the work was resumed on a large scale in 1907. In that year 9,177,130 cubic yards were taken out, and from that time to when the maximum of 16,596,891 cubic yards was reached in 1911, there was a steady increase in the amount of material excavated as new

Side view of emergency dam on east wall at Gatun Locks. In case an accident occurred to the gates, allowing a free passage of water from the 85-foot lake level, to the sea level, the dam would be swung across the lock chamber and a series of wicket girders hinged to it would be lowered with their ends resting in pockets in the lock floor. Steel gates would then be let down, one at a time, which would close the lock chamber and check the flow of water.

equipment was installed. Trains of flat and dump cars, 20 to a train, drawn by 100-ton locomotives carried the spoil to be used in the dam at Gatun, the breakwater at the Pacific entrance, fills, or to dumps where it was merely wasted. As the Cut neared completion, the work became concentrated in a short section at Culebra where the deepest cutting, 272 feet, was necessary, and the number of steam shovels had to be gradually reduced.

To prevent the flooding of the Cut, the canal channel was paralleled on each side from Gold Hill north to Bas Obispo, a distance of five miles, by small canals or diversions, which carried into the Chagres River the water from streams that otherwise would have flowed into the Cut and interrupted the work. To prevent the water in Gatun Lake from backing up into the cut the earthen dike which was blown up on October 10, 1913, was built. To the south of Gold Hill the water which would have flooded the Cut was carried off by the Rio Grande and an old French diversion channel. Rain water that collected in the Cut flowed north and south. At Gamboa, on the north, it was pumped through the dike, and at Pedro Miguel, to the south, it drained off through the lock wall culverts.

All steam shovel work in the Cut was discontinued on September 15, and between that date, and October 5, 1913, when water was admitted, all equipment and other material, including over 36 miles of construction track, was removed. At that time there were about 30 steam shovels at work. The following table of material excavated in the Cut and for the whole canal, indicates the period of preparatory work, the time when the highest point of effi-
Section of lock wall showing the rack rail over which the towing locomotives travel.

Towing locomotive in operation at Gatun Locks. These machines are designed to tow vessels through the locks. There will be two locomotives ahead towing, and two astern to retard the vessel's progress if required. In towing, they will not move faster than two miles an hour, but a second or return track, permits them to go back at greater speed.