The swift moving river, the brilliant tropic foliage, and the towering cliffs, all tend to belie the Isthmian poet Gilbert’s lines that:

"Beyond the Chagres River
'Tis said (the story’s old),
Are paths that lead to mountains
Of purest virgin gold;

But 'tis my firm conviction,
Whate'er the tales they tell,
That beyond the Chagres River,
All paths lead straight to hell."

The Chagres has two principal branches, one (the larger), known as the Pequeni, rising in the San Blas mountains, very close to the Atlantic coast, and the other the Indio River. Between Bas Obispo and Gatun, it has 26 branches, the largest of which are the Gatun and Trinidad rivers. In the dry season these tributaries may be regarded as negligible, but during the rainy months they, like the main river, become tropic torrents, with a volume not to be ignored. However, such floods or freshets, which are of frequent occurrence in the rainy season, would have but slight apparent effect on the lake, for it would take the greatest known flood of the Chagres nine hours to raise the level of the lake one foot. The smallest run-off of water in the basin during the past 22 years, as
measured at Gatun, was that of the fiscal year 1912, which was about 132 billion cubic feet. In 1910, the run-off was 360 billion cubic feet, or a sufficient quantity to fill the lake one and a half times.

The rainy season is from May to December, and during that time showers are of frequent occurrence. The average yearly rainfall on the Atlantic coast at Cristobal during 40 years of record, has been about 118 inches and at Porto Bello during four years’ record, about 149 inches; at Culebra, during 20 years of record, about 83 inches, and at Ancon on the Pacific coast during a period of 13 years, about 66 inches. The maximum rainfall for 24 hours was 10.86 inches; for one hour 5.86 inches, and for three minutes, 2.46 inches.

**DAMS ON THE PACIFIC SIDE**

Pedro Miguel and Miraflores locks occupy the ancient valley of the Rio Grande. Here it was necessary to construct two small earth dams, one on the west side of Pedro Miguel lock, about 1,700 feet long and 105 feet high at its crest; and the other, west of Miraflores locks, about 2,700 feet long, and 70 feet high at its crest. The Miraflores barrier consists of earth and rock toes, with an impervious core fill, and dams the Cocoli River, forming Cocoli Lake, now a part of Panama’s water supply system. To the east, both Pedro Miguel and Miraflores locks approach close to the hills, so it was only necessary to join locks and hills by concrete walls.

**THE LOCKS**

Under the original plans, the flight of two locks at Miraflores was to have been located at Sosa Hill near the Pacific entrance. The change was made upon the recommendation of the Isthmian Canal Commission, approved on December 20, 1907, by the President, because suitable lock and dam foundations could not be found. In addition, the site at Miraflores is six miles

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*[Image of the concrete operations at Gatun locks required modern handling machinery. These are the unloading cableways at Gatun docks. Rock and sand are picked up from the barges by clamshell buckets and conveyed to storage piles.*]
Sand bins and unloading cranes at Balboa. Sand for the concrete used in the Pedro Miguel and Miraflores locks was obtained from Punta Chame, about 25 miles along the Pacific coast from Balboa. It was towed to Balboa in barges, lifted into the bins by the unloading cranes and when needed was dumped from the bins into cars and hauled to the lock storage piles.

Ancon rock crusher plant and quarry, between Panama City and Balboa, where the crushed rock was obtained for the concrete used in the Pacific locks. The side of the hill has been literally eaten away to secure the large amount of rock required.
A general view of the main concrete mixing plant at Gatun Locks, which houses a battery of eight 2-cubic yard mixers. Rock and sand were carried to the mixers by an electric railroad running underground to a point beneath the storage piles. The finished product was carried to the lock site by a surface electric railroad.

A closer view of the same plant, which has produced as high as 3,434 cubic yards of concrete in a day of 12 hours, working 6-hour shifts.
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 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\( \frac{1}{2} \) 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\( \frac{1}{2} \) 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

![Sunday scene on south approach wall at Gatun Locks. In order to finish a piece of work within a given time, it was frequently necessary to work the men the full seven days.](image-url)
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 10 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

To guard against accident, the gates at the entrances 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.
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

Method of constructing the 18-foot side wall culverts. Collapsible steel forms were used and after the concrete had set, were taken down in sections.
The handling equipment used at Pedro Miguel and Mirafloros 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 Miraflores Locks. With the completion of the heavy masonry work at Pedro Miguel, the cranes were moved to Miraflores 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.
These 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.