CHAPTER XXIV

CULEBRA CUT

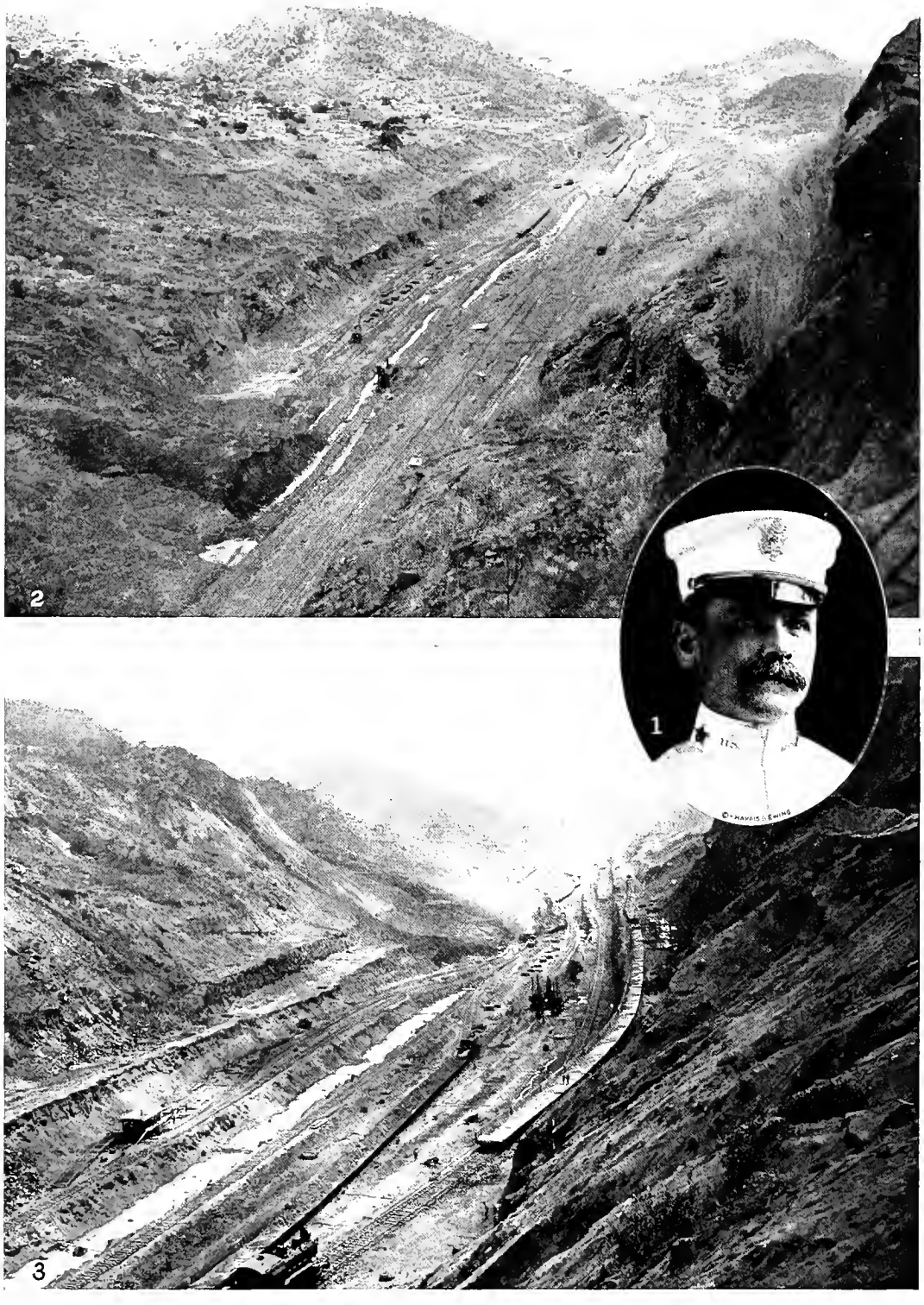
DIVORCING MOUNTAINS AND WEDDING OCEANS—FORTUNATE THAT CONGRESS DID NOT FORESEE DIFFICULTIES ENCOUNTERED—THE WORLD'S ONLY ARTIFICIAL CAÑON—BATTLING WITH THE SLIDES—A WONDERFUL SCENE—PRESSING FORWARD AT TOP SPEED—THE USE OF DYNAMITE—SHOVELING UP THE SPOIL—HAULING IT TO THE DUMPS—THE LIDGERWOOD EQUIPMENT—A HUNDRED AND ONE INVENTIONS—THE NAOS ISLAND BREAKWATER—TROUBLES IN THE RAINY SEASON—TWO FARMS GOING INTO THE CANAL—UNCANNY TRICKS BY SLIDES—A MISTAKEN BOARD OF CONSULTING ENGINEERS.

THE engineers at Panama have been able figuratively to wed the oceans only by literally divorcing the mountains. From the Arctic to the Antarctic there stretches a vast and lofty mountain chain, dividing the East from the West on two continents. The task that confronted the American engineers was that of cutting through the weakest of the links of this chain of mountains. When it was proposed to build the Panama Canal there were those who believed it possible to cut down the backbone of the Cordilleras until the waters of the oceans could sweep through unhindered to a depth which even at low tide would carry the largest steamship afloat. There were others who held that a more feasible plan would be to lift up the waters, so that they could meet and mingle, not above the mountain tops, but at least a part of the way above the sea. The latter idea prevailed, and to the fact that it did prevail the American people owe their triumph at Panama.

In all the world of work there is perhaps no better example of the wisdom of the Infinite in withholding from man a knowledge of the future; for if the American people had known of the tremendous difficulties that lay before them in their work of severing the link that united two continental mountain systems into one chain, it is doubtful if that work would ever have been undertaken. If some prophet, speaking with foreknowledge, and not without honor in his own country, had come to the Congress of the United States in 1902, stating to that body that it would cost $10,000,000 a mile to dig Culebra Cut at its present level, and that it would require the excavation of over 100,000,000 cubic yards of material, there would have been no Culebra Cut and no Panama Canal to-day.

There now stretches through the backbone of the intercontinental divide a cañon cut by human beings, the only one on the earth. Nine miles long, with an average depth of 120 feet, with a bottom width of 300 feet, and with a top width which reaches at places to a third of a mile, this marvelous cañon presents at once an inspiring and awesome aspect, revealing both man's audacity and nature's grim resistance to his efforts. On either side of the gorge rises a majestic peak, standing as sentinels guarding the passage from the Atlantic to the Pacific. But now, where once they were bound together with chains of primeval rock, they are separated by the arm of a lake, the largest yet created by human cunning. Where once the Chagres river encountered immense barriers which turned it about and forced it to flow into the Atlantic, now it comes down into that wide lake, whose waters may be made to flow either into the Atlantic or the Pacific, at the touch of a button.

To accomplish this wonderful work, the American canal army was called upon to



1. The late Col. D. D. Gaillard, the genius of Culebra Cut.
2. View from Cucaracha slide looking toward Pedro Miguel, whose locks appear in the background.
3. View from Contractor's Hill, looking past Cucaracha slide.

1. Upheaval in the bottom of Culebra Cut.
2. View of the basalt formations at Gold Hill, in Culebra Cut.

go to lengths unprecedented in the history of engineering. A thousand and one unforeseen difficulties arose. Nature interposed her powerful self between the canal engineer and his purpose, and seemed to take almost fiendish delight in a defensive warfare against his labors. She manœuvered her forces with consummate cunning, in a way best designed to strike terror to the hearts of those against whom she was defending that mountain pass. Now she sent down slides which threatened to disrupt the whole system of excavation in the cut; now these slides became quiescent, as if to lull the engineer into a false security; now they made a feint, threatening dire results, but stopping short of actual conflict; now they came in the dead of night, spreading chaos in every direction; now they seemed to raise the white flag of surrender, allowing the dikes of basalt to peep out as a message to the engineers that the slides could move no further because they were tied by these dikes to the very core of the earth; and then they would destroy the hopes which these dikes aroused by shearing them off as if they were but pipe stems, and flowing, unrestrained, into the cut.

But through all their trials and tribulations, through all their delays and repulses, the canal engineers led their forces onward, checking the slides and retrieving every inch of lost ground, until Nature herself lay exhausted at their feet and accorded them the triumph for which they had struggled so long and so persistently.

As we look back over the story of Culebra Cut we are struck by the constantly rising limit of the amount of material to be excavated. A few months before Colonel Goethals took charge at Panama, the amount of material which it was thought would have to be removed was less than 54,000,000 cubic yards. As we survey the completed project we find that there has been removed more than 100,000,000 cubic yards; that the cut has been dug at an outlay of nearly $10,000,000 a mile, and that the heaviest miles have cost as much as $15,000,000; that the slides added some 30,000,000 cubic yards of material, to say nothing of the unforeseen difficulties which they brought into the cut with them. We find that there has been taken out almost as much material to make a lock level cut as was estimated for the sea-level cut. We find that there was taken out of Culebra Cut to bring it to the stage of completion as much material as it was estimated would have to be removed to complete the canal from the Atlantic to the Pacific.

Whether the cut was viewed from the hills above, or from the bottom of the ditch below, it presented, during the construction period, a strange admixture of awesome proportions and apparently chaotic conditions; but what seemed to be chaos and confusion was in fact order and system. Hundreds of well drills, tripod drills, and hand drills ate their way down through the rock, preparing the holes in which were to be planted the tons of dynamite used to provide the daily spoil for the forty-odd steam shovels that consumed the vitals of the cut. Dozens of dirt trains moved to and fro, as they took the spoil from the shovels and carried it to the dumps, which were an average of some twelve miles distant. Necessarily there was order and system when the daily stint was that of loading and hauling away 160 trainloads of material from a cut nine miles long.

The work moved forward at a pace unprecedented in the annals of engineering. In the nine-mile section in a single twelve-month there was removed a total of 16,586,000 cubic yards of material. Six thousand men labored within this short stretch, preparing for the blasts, handling shovels and the dirt trains, and shifting the tracks as the work moved forward. At eleven o'clock in the forenoon and at five in the afternoon the cut was temporarily deserted; and then there came the thunderous blasts that tore loose the rock and provided the next four hours' supply of food for the steam shovels.

Dynamite was used in enormous quantities. No mind can conceive of the tremendous force of 60,000,000 pounds of high powdered dynamite, the amount used by the engineers in tearing asunder Gold Hill from Contractor's Hill. Were the holes that were drilled in preparing for the work of the dynamite put end to end, they would more than reach through the earth itself, at the equator. Great batteries of the largest well drills, lined up in rows, drove down through the solid rock, to an average of twenty-four feet in depth; a whole company of tripod drills hammered their noisy way down into the adamant; while here and there gangs of negroes, swinging heavy sledges to the rhythm of some folk lore song, drove the steel hand drills inch by inch into the rock. In the case of the wells a small amount of dynamite was sent to the bottom and exploded in order to "spring" the hole. Then hundreds of pounds of explosives were put down into these wells, tamped home, and connected with wires bearing high-power current from the electric light plants. The turning of a switch made the earth shake and shattered the embedded rock. More than 600 holes were fired daily. In addition to these there were small "toe" blasts and many "doby" blasts. The handling of dynamite is never free from dangers, but the Culebra Cut work was so well ordered under the rules formulated by the chief engineer, that only eight men were killed in the handling of 19,000,000 pounds of explosives. In the early years of the work blasts were set off by simple dry batteries, but it was found that this frequently resulted in a failure to explode the charge, with constant danger of premature or unexpected explosions. The substitution of the other method insured the explosion of every charge. The largest single blasts at Panama were set off in a series of holes containing 52,000 pounds of dynamite. The most serious accident that ever occurred was at Bas Obispo, December 12, 1908, when 44,000 pounds of dynamite exploded prematurely, at the moment when the last load was being tamped home. Great care had to be exercised in preventing premature explosions. The action of warm moist air on the iron pyrites sometimes heated the material, causing a blast to go off while being tamped home. To overcome this, a stream of water was played into the hole before the dynamite was put down.

After the blasts had been fired, the steam shovels appeared. Some of them could pick up eight tons of material at a mouthful and take a new mouthful every three minutes. One ninety-five-ton Bucyrus shovel handled 543,000 cubic yards of material in one year. The record for a month was 86,844 cubic yards. The average output per shovel ran up from 500 yards a day in 1905 to more than double that amount in 1912. There were forty-three shovels at work at the height of activities in Culebra Cut. To handle the spoil that could be loaded upon the trains required the services of 140 locomotives and 3,700 cars. In a single year the shovels loaded 1,119,000 carloads of material, and 75 trains were constantly going in and out of the big ditch. When the work reached the climax there was a train in or out nearly every minute of the working day.

The bulk of the spoil was hauled away on Lidgerwood flat cars. Each car held about nineteen cubic yards of spoil, and they were run in twenty-one-car trains. The cars were boarded upon one side only, and steel sheets were hinged from the floor of one car to the floor of the one ahead, so as to give, to all intents and purposes, a solid car floor for the entire length of the train. When a train was loaded, it was pulled out of the cut and hauled to the dumps. Here a huge plow, reposing on a car that had been unloaded previously, was attached to the train at one end, while a car carrying a large steam windlass was attached to the other end. A cable the size of a man's wrist was stretched from the windlass to the plow. When the train was in position for

unloading, the windlass began to turn, pulling the plow along on the floor of the cars until they were unloaded. Then the car on which the plow finally rested and the one on which the windlass rested were cut out of the train, and it was hauled back empty.

The heavy cable that pulled the plow over the floor of the train was stretched in an ingenious way. There was a frame built across the track like those which support the warning ropes at overhead bridges and tunnels. The train to be unloaded ran through this frame, switched in the car containing the windlass, and attached the end of the cable to the frame. As the train moved back, the cable was stretched along the length of the train, and was ready to be attached to the plow as soon as the car carrying it was attached to the train. All this indicates that there was considerable switching in placing the cars containing the windlass and the plow into the train and cutting them out again. There was; but the men who did it became so adept that there was comparatively little delay.

After the plow had removed the dirt from the cars and the empty train had started back for another load, another engine came along with another sort of plow. This plow ran along the track and pushed the dirt down the bank. It was followed, in turn, by a track shifter, which lifted the track over bodily to the new position that the widened bank made possible. And thus the work went forward. Every operation that could be performed by machinery was taken out of the hands of the laborers. Each of these inventions made it possible for one man to do the work of dozens. Each car gave up its load in a half minute; the spreader forced a trainload of rock and earth down the bank in ten minutes; and the track shifters always had the track moved over by the time the next train was ready to discharge its burden.

From time to time many improvements were made in these different devices. As originally constructed the floors of the Lidgerwood cars extended the same distance over the wheels on both sides. This did not permit a proper centering of the load, necessitating its being placed too much on the boarded side, which resulted in an excessive wear and tear on the wheels of one side of the car. An apron was therefore built on the other side of the car, which extended the floor a foot or more over the wheels. This permitted the load to be centered, and at the same time permitted the plow to throw the material further away from the track. It also gave the car a nineteen-yard capacity where it formerly had a sixteen-yard capacity.

The cables at first were likely to break when the plow struck an obstruction, such as a large stone or a broken car-floor; a weak link, with a breaking-point just a little weaker than that of the cable, overcome the difficulty. Couplers sometimes became worn or broken under hard usage, causing the parting of a train at times when it was desirable that such things should not happen; a master mechanic invented a kind of "bridle" that saved the day here. The plows sometimes caught the edge of the side board at the end of a car; a bullnose piece of iron was devised, which steered the plow away from the side boards. Some fifty-odd improvements were made on the spreaders alone.

In addition to the Lidgerwood equipment for hauling away the spoil, a large number of Western Dump Cars, dumped by compressed air, and a number of ordinary cars, dumped by hand, were used. At the height of the work 333 trainloads of material were handled by the Central Division in a single day, the bulk of them coming from Culebra Cut.

The disposal of the spoil was a serious problem. Over a hundred million cubic yards of material had to be hauled away and dumped. With a part of it the engineers converted an island into a peninsula, three and a quarter miles out in the Pacific Ocean. This peninsula is the Naos Island

Breakwater, which serves the double purpose of providing communication between the mainland and the Pacific fortifications, and preventing the cross currents of Panama Bay from filling up the end of the canal with silt. With another part of the spoil they converted nearly 500 acres of the Pacific Ocean into a town site and a military reservation. With still another part of it they made a parade ground. But still scores of millions of cubic yards of this débris had to be hauled out and dumped in the jungle. In one of these big waste dumps 17,000,000 cubic yards of material were disposed of.

The Naos Island Breakwater was the most troublesome work on the isthmus. At one spot it settled 125 feet. In not a single foot of its more than three miles of length is the original trestle to be found under the tracks it was meant to support. It sank down and shifted to the side, at some places as much as 300 feet from the spot where it was put down.

Disposition of the spoil in the wet season was difficult. Imagine a dump covering perhaps 1,000 acres, and with tracks over its several terraces. Then picture a rainfall twice as heavy as that which occurs in the United States, dashing down and converting this great dump of freshly excavated material into a sea of mud. Then fancy the dirt trains running through that sea of mud, with the track sinking three or four feet, and shifting to one side or the other. Then watch the trainmen working and toiling to extricate their trains. That is what might have been seen hundreds, if not thousands, of times at Panama. But through it all, and in spite of it all, the trains kept running and disposing of the spoil, for when the trains stopped, all other work ceased.

We now come to the slides; and no man who ever saw them working their way into Culebra Cut can fail to see in them the handwriting on the wall—the handwriting that says that no sea-level canal shall ever be built at Panama. Bringing into Culebra Cut more than 250 acres of land, buildings, and all; driving downward 30,000,000 cubic yards of material which ought never to have come into the cut; imposing upon the canal engineers not only the task of removing all this extra material, but multiplying the difficulties under which the material which belonged in the cut was removed,—the slides were Nature's heavy artillery, indeed, in repelling the invasion of man.

They were absolutely unforeseen. No one dreamed that material would move into Culebra Cut in quantities vast enough to load a train of cars reaching half way round the earth, and requiring the equivalent of a string of locomotives 700 miles long to haul it away. Nor did any one foresee that the cut would be choked up repeatedly, now disrupting one-half of the entire transportation system, now disrupting the other half. A total of 200 miles of railroad track was covered up, destroyed, or dislocated in a single year by these slides. The very bottom of the cut itself was upraised sometimes as much as 18 feet, as if to recover the ground lost by the operation of the steam shovels and the dirt trains.

It was more than the mere digging of a ditch that Colonel Goethals had to encounter when seventy-five acres of the town of Culebra broke away and moved foot by foot into the canal; carrying hotels and club houses with them until these buildings were removed. Cucaracha slide carried into the cut many millions of cubic yards of material, bottling up the channel, and sending its "toe" sixty-odd feet up the other side. It was fight, fight, fight, now with dynamite, now with steam shovels, now with hydraulic excavators, and now with dredges. The campaign finally resolved itself into one of inviting the slides to do their worst, and then meeting them as they came. Some of them, like Cucaracha, were mere masses of material slipping by force of gravity into the channel; others, like the West Culebra slide, were breaks. If a cut is dug deep enough, even side walls of granite

1. Slides which carried 230 acres of earth into the canal.
2. Steam shovel caught in a slide.

finally will break at the bottom, causing the material above to press down and into the cut. This is what happened at West Culebra. The material at the bottom broke, and the material above forced its way down, and like water poured into a U tube, rose up on the other side—the other side in this case being the bottom of the canal.

Sometimes these breaks played uncanny tricks. At one place a steam shovel, track and all, was picked up and carried half way across Culebra Cut, where it was left unharmed. At another place, where three tracks were close together, the one nearest the bank sank down several feet, and the one farthest from the bank rose up correspondingly, while the middle one was not disturbed. One slide kept a gradual motion, moving down just as fast as the steam shovel worked, so that the shovel was able to make 103 trips across the "toe" of the slide without shifting its track an inch.

Cucaracha, with its fifty acres or more of sliding material, was first in the field, having paid the French a visit that drove them from that part of the Culebra Cut. Again in 1905 it came down, and once more in 1907. Intermittently it has been in motion ever since. At one time it broke so far back that the rear part sloped away from the canal. Then a hydraulic jet, with a nozzle pressure of eighty pounds to the inch, was turned on the materials that drained away from the cut, and they were sluiced back into another valley.

The actual delay in the completion of Culebra Cut because of the slides cannot be ascertained accurately. If the slides had not involved any other difficulty than that of removing them the delay would have been twenty-two months. But when we reckon all the hindrances to the other work, it is probable that the total delay involved is not less than two and a half years. In other words, but for the slides, Colonel Goethals and his lieutenants would have completed Culebra Cut by the first of January, 1912; they would have removed the 70,000,000 cubic yards of material, other than the slides, in five years, although the board of consulting engineers said it would require eight years to remove 54,000,000 cubic yards; and they would have removed the larger amount with forty steam shovels, although the board of consulting engineers estimated that it would require 100 steam shovels to remove the smaller amount.

The board of consulting engineers, in fact, went astray in dealing with Culebra Cut. Serious results would have followed the adoption of their recommendations. They reported that a sea-level Culebra Cut would require the excavation of only 110,000,000 cubic yards of material; it has taken almost that much work to build the lock-level cut. It would probably require the removal of another 100,000,000 cubic yards to bring the present cut down to sea level.

Those engineers in the majority report ridiculed the idea of encountering any serious difficulties in Culebra Cut; they said its banks would stand up with an average slope of three feet rise on two feet back; yet at some places there is only one foot rise to ten feet back. They said a hundred shovels could be operated in Culebra Cut; the highest number operated was forty-three. They said handling the slides was only a question of drainage; and yet the worst ones occurred in the dry season.

The American people probably owe it to Mr. Roosevelt that their enterprise at Panama did not fail as ingloriously as the French project. If he had not possessed the moral courage to change his own mind, and to come out against such a powerful majority as that on his board of consulting engineers, the country would be awaking to the discovery that a sea-level canal is an impossibility—so far as pocketbooks and patience go—instead of putting the finishing touches on the lock canal. Meanwhile there would have been expended some $50,000,000 in digging a sea-level ditch from Gatun to Gamboa; some $8,000,000 on a masonry dam at Gamboa, and as much more on tidal locks at Sosa Hill—only to find that none of these expenditures would have been of value in building a lock canal.

CHAPTER XXV

BUILDING THE DAMS

MAKING A LAKE OUT OF A RIVER—THE CHAGRES VALLEY AS A PLACE FOR A LOCK CANAL—THE DIMENSIONS OF GATUN DAM—HOW THE "TOES" OF THE DAM WERE BUILT—MAKING A CORE OF NATURAL LIQUID CEMENT—THE GATUN SPILLWAY—HOW IT IS OPERATED—THE MOODY CHAGRES—FACILITIES FOR TAKING CARE OF TWO RIVERS LIKE IT—DRIVING A HYDRO-ELECTRIC PLANT—FIRST SUGGESTION OF GATUN AS A DAM SITE—JOHN F. STEVENS FAVORED IT—OBJECTION TO A LOCK CANAL ON ACCOUNT OF GATUN DAM—SEVILLE CONDUCTS THE EXPERIMENTS WHICH DETERMINE THE CHARACTER OF THE STRUCTURE—A DAM THAT BURST WHERE THERE WAS NO DAM—PRESIDENT-ELECT TAFT AND HIS CONSULTING ENGINEERS VISIT GATUN—GATUN DAM A HAPPY SURPRISE—THE DAM AT PEDRO MIGUEL—THE WORKS AT MIRAFLORES—THE ABANDONED SOSA HILL LAKE.

THE construction of the Panama Canal required the construction of three dams, two on the Pacific side and one on the Atlantic side. The dam at Gatun is so huge in its proportions, and was for years the subject of so much controversy, that it eclipses the two dams on the Pacific side. The vastness of its proportions can scarcely be conceived. It is really nothing more or less than a hill thrown across the Chagres valley, so as to impound the waters of the Chagres River, converting them into a lake with an area of 164 square miles, and with a shore line of 1,016 miles. The Chagres River drains a watershed of 1,320 square miles. The average rainfall on this watershed approximates 100 inches annually. It is the mission of the Gatun Dam to impound enough of this water in the lake to carry the commerce of the world across the continental divide, and to provide lockage water for putting the ships through the locks at the two sides of the isthmus. The dam impounds 183,000,000,000 cubic feet of water, or practically as much as the Chagres River brings down in an average year.

The valley of the Chagres was framed by the hand of Nature in such a way as to fit admirably into the plans of the canal engineers for a lock canal across the isthmus, with the Atlantic locks at Gatun. In the upper and middle reaches of the valley, after the river strikes the line of the canal, the hills which border it are far flung. As you approach Gatun, coming down the valley, they swing in toward the canal on both sides, and at that point are only a mile and a half apart. Midway across this valley there was a small hill with a foundation of rock. The problem was simply one of building a dam between the hills at the two sides of the valley, utilizing the small hill in the middle of the valley as a site for the spillway, through which the surplus waters in the lake should be passed over the dam and down into the sea. The dam which was built is a mile and a half long, half a mile wide at the base, 300 feet wide at the water line, and 100 feet wide at its crest. It is 105 feet high, making the crest twenty feet higher than the normal surface of the water in the lake. The dam contains 22,000,000 cubic yards of material. Its total weight approximates 30,000,000 tons. It covers 288 acres of ground, and contains enough earth and rock to build a fence eighteen inches thick and three feet high around the earth at the equator; or a wall around the State of Ohio ten feet high by twelve feet wide.

In the construction of the dam two parallel ridges of stone 1,200 feet apart were

first thrown across the Chagres valley. The height of these ridges ranged from thirty feet on the down-stream side to sixty feet on the up-stream side. Between these ridges, which were technically known as "toes," there was built up a dam of earth. The central portion of this earth-dam is known as the hydraulic core. Huge dredges were put to work breaking loose the soft natural cement of the valley below the dam and pumping it into the great pond maintained on the surface of the dam as it rose upward. The material carried in suspension in the water was allowed to settle, and then the water was drawn off and sent back for another load of liquid silt. In this way there was built across the valley, in the heart of the dam, a wall of natural cement 850 feet wide at the base and as high as the dam itself.

After the dam was built to its desired height, the entire up-stream side was armored with stone. Wherever the wave action is strong, huge boulders weighing many tons are planted on the face of the dam, to break the force of the waters. Although the dam impounds the largest artificial lake in the world, its bulk is so great that sixty-three pounds of material would have to be pushed aside for every pound of pressure that can be brought against the dam.

The spillway by which the surplus waters brought down by the Chagres into Gatun lake are passed to the sea is a most interesting structure. It consists of a large semi-circular masonry dam built on the small hill in the middle of the valley, with the arc jutting up into the lake. On the crest of this dam were set thirteen piers and two abutments, making fourteen openings, each of which is forty-five feet wide and twenty feet high. Huge gates close these openings, moving up and down on roller bearings. They weigh forty-two tons each, and are operated by electricity. The water is permitted to pass through these openings, and the torrents thus created are made to converge at the bottom of the spillway, so that their fury is neutralized as they rush together. In addition to this, there are huge steel-faced baffle piers erected near the bottom of the spillway apron, which further arrest the maddened waters as they make their sixty-foot plunge from the surface of the lake to the surface of the river channel below. The spillway is so constructed that whenever the water flows deeper than six feet it adheres to the apron of the spillway instead of rushing over and making a perpendicular descent.

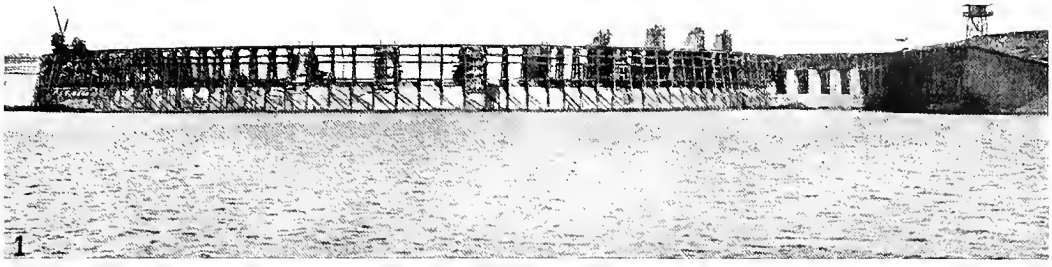
The Chagres River is one of the moodiest streams in the world. Now it flows along as a peaceful, lazy little tropical river not over two feet deep, moving sleepily on its journey to the sea. A day later it may become a wild, raging torrent, forty feet deep, madly hastening on toward the sea. Once there was nothing to oppose its moods, and it swept out to sea like a tidal wave. But to-day the mouth of the Chagres, properly speaking, is no longer at the Caribbean Sea; it is some thirty miles inland, at Gamboa. What once was the valley of the Chagres between Gamboa and Gatun is now Gatun Lake, and the Chagres flows into it at Gamboa instead of flowing into the Atlantic Ocean at Fort Lorenzo. Now the river may rage, coming down from its upper watershed with as great a flood as it has ever been known to carry, but the lake into which it flows is so extensive that angry torrents of the Chagres are swallowed up and scarcely disturb the placid surface. When the lake reaches eighty-seven feet, the spillway has a capacity of 145,000 cubic feet per second, which is 17,000 cubic feet more than the Chagres has ever carried. In addition to this the big culverts in the locks can dispose of 50,000 cubic feet per second. At ninety-two feet the capacity of the spillway and locks becomes 262,000 cubic feet per second, which would take care of two Chagres rivers instead of one. During the rainy season observers of the Chagres are placed above Gamboa, who telephone the stages of the river to the operators at Gatun. There is no danger that the operators at Gatun will ever be caught

napping for a period of two days while the Chagres is on a rampage, and inasmuch as the capacity of the spillway, even at the normal lake level, is greater than the water-carrying capacity of the Chagres at its flood stage, the Chagres has been robbed of all its terrors. It has been transformed from a menace to the canal into a burden-bearer of commerce. Not only will it bear the burden of maintaining the level of the lake in the thirty-five miles stretch from Gatun to Pedro Miguel, but it will also be called upon to furnish the water which will drive the turbines of the hydro-electric plant at Gatun spillway, where the power for operating the locks, operating the terminal facilities, and lighting the Canal Zone settlements will be generated. Furnishing the water for the middle thirty-seven mile stretch of the canal, for the locks, and for the hydro-electric plant, the Chagres River has been made the major factor of the great trans-isthmian highway. It has become the friend of the lock canal, where it would have been the foe of a sea-level canal.

The first suggestion of Gatun as a proper site for the locks on the Atlantic isthmus was made in 1879 by Godin de Lepinay, who was chief engineer of bridges and roads in France. He tried to induce de Lesseps to give real consideration to engineering figures on his proposition to build a lock-type canal, but de Lesseps dodged the issue. De Lepinay then wrote his own report, setting forth objections to a sea-level canal, and presenting the advantages of a lock canal at Gatun. That report has been proved a very far-seeing one by experience at Panama. The reasoning he employed against a sea-level canal, and that which he urged in favor of a lock canal, is amply vindicated by facts ascertained in the actual construction of the highway. When the Walker Commission took up the matter, they followed de Lesseps's plan for a dam at Bohio. The first chief engineer of the present canal, John F. Wallace, took little interest in investigations at Gatun, because he advocated a sea-level canal. It was the second chief engineer, John F. Stevens, who recommended the site at Gatun, and upon his careful investigations the decision to build the dam and locks there was reached. One of the principal objections urged to a lock canal was that a stable dam could not be built at Gatun. How little this objection was justified is shown by the success that attended the construction of Gatun Dam.

The fight against a lock canal was kept up even after that type had been authorized by Congress, and those who opposed the lock canal centered their attack upon Gatun Dam. They declared that underground rivers flowed beneath the valley of the Chagres, and that there was no hope of building there a dam which would impound the waters of Gatun Lake. Colonel Goethals, as soon as he took charge, determined to ascertain just what the situation was beneath the surface of the valley. He called to his aid Caleb M. Seville, one of the foremost earth-dam experts of the world, who had been in charge of the work on the Wachusetts Dam in Massachusetts. They honeycombed the site of Gatun Dam with borings, and sank test pits here and there, so that they could go down and see with their own eyes the various strata of the proposed foundation of the dam. Never was the site of any structure explored more thoroughly than was the site of Gatun Dam. They found that the alleged rivers beneath the valley of the Chagres had no existence except in the imagination of those who opposed the building of a dam at Gatun. After they had satisfied themselves as to the site, they next took up the work of determining the properties of the materials with which the dam was to be constructed. They modeled experimental dams drawn to scale, and brought varying water pressures against them. They filled huge steel cylinders with the material they proposed to put into the dam, and exerted a water pressure upon it equal to a head of water twice that of Gatun Lake; and

1. Brig. Gen. William L. Sibert, builder of Gatun Dam.
2. Pipe line dredge pumping silt to crest of dam making natural cement core.
3. Lake side of dam, riprapped to prevent destructive wave action.



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1. The lake side of Gatun spillway dam.
2. The water after passing over the spillway.
3. Down-stream side of the spillway dam.

the trace of seepage through three feet of this material was nothing but perfectly clear water. It was obvious that if three feet of the material was impervious under such a pressure, there could be no question about the 800 feet of it to be used in the dam.

When the stone in one of the "toes" of the dam sank in 1908, a sensational dispatch was sent to a New Orleans newspaper stating that the dam had given way. This report was spread broadcast, and it so stirred the nation—for the people had not stopped to think that there was as yet no dam at Gatun to give way—that President Roosevelt asked President-elect Taft to go to Panama to investigate the situation. The net result of this investigation was that the engineers who accompanied Mr. Taft—Messrs. F. P. Stearns, Arthur P. Davis, Henry A. Allen, James D. Schuyler, John R. Freeman, and Allen Hazen—decided that the dam was being built with a greater margin of safety than even the utmost precaution required. They reported that the crest of the dam should be cut down thirty feet, and that there was no necessity for driving interlocking sheet piling across the valley as a precaution against imaginary underground rivers.

The completed Gatun Dam has proven a happy surprise. It has shown itself to be water-tight beyond all engineering demands; it has become such a part and parcel of the topography of the Gatun region that it seems to be nothing more than a hill of very gentle slope, thrown by the hand of Nature across the valley at Gatun. Nature has adopted it as a part of her own work, having covered it with a dense cover of jungle growth which relieves it of every indication of artificiality.

At Pedro Miguel the valley to be closed up was half a mile wide. Here a very small dam, thrown from the locks to the hills on the west, acts as a cork for the Gatun Lake bottle, of which Culebra Cut is the neck. At Miraflores there are two small dams. The construction of the west dam is similar to that at Gatun, and runs almost parallel with the locks. This was made necessary in order to control a small river during the period of lock construction at Miraflores. More than a dozen of these small rivers were haltered and led about by the canal diggers during the work of completing the canal. Some of them were forced to change their beds several times before they were finally permitted to resume an age-long repose.

At the outset of the work at Panama it was intended to create a large lake at the Pacific end of the canal, by throwing dams across depressions between Ancon Hill, Sosa Hill, and the hills to the west of the canal. It was found, however, that instead of costing $4,000,000, dams at these points would cost $11,000,000. Furthermore, locks and dams at Sosa Hill would have been exposed to an enemy's fire from Panama Bay, while Miraflores is out of the range of hostile guns. These considerations led to the abandonment of the projected lake, and the digging of a sea-level canal from the Pacific to Miraflores followed.

CHAPTER XXVI

THE STORY OF THE LOCKS

THE FUNCTION OF THE PANAMA LOCKS—THEIR DIMENSIONS—THE WATER CULVERTS—THE LOCK GATES—HOW THE GATE LEAVES ARE MOVED—PRECAUTIONS AGAINST ACCIDENT IN THEIR MOVEMENTS—MAKING THE GATE CONTACT WATERTIGHT—SAFEGUARDING THE OPERATIONS OF THE LOCKS—HUGE FENDER CHAINS—AUTOMATIC PUMPS—TOWING LOCOMOTIVES—EXTRA SAFETY GATES—THE EMERGENCY DAM—ACCIDENT AT THE SOO LOCKS—ELIMINATING THE PERSONAL EQUATION—LITTLE GATES AND BIG GATES—GREAT USE OF CONCRETE—CABLEWAYS AND ELECTRIC RAILROADS—MIXING CONCRETE AND WIGWAGGING IT INTO POSITION—USING CRANES ON THE PACIFIC SIDE.

THE great locks at Panama through which ships are lifted up from the sea to Gatun Lake and back down to the sea again, after a thirty-seven-mile sail through fresh water, constitute a vast and wonderful engineering work. Their total cost approximates $60,000,000. With their approach walls, their aggregate length is nearly two miles. There are three steps on each side of the isthmus by which ships are lifted up 85 feet on the one side and let down 85 feet on the other. Each of these steps has two lock chambers, making parallel shipways through the locks. The side walls vary from 45 to 50 feet wide at the floor of the locks, and at a point 24⅓ feet above the floor they begin to step in 6-foot steps until they are 8 feet wide at the top. The total width of the locks between the two side walls is 280 feet. In the middle of the locks, and running parallel with the side walls, is a center wall, which divides the locks into two chambers. This wall is 60 feet wide all the way up. At a point 42½ feet above the floor of the lock the solid construction ceases, and a U-shaped opening runs the entire length of the wall. This serves to provide three long tunnels, the full length of the center wall, one above the other. The lowest of these tunnels is used for drainage purposes; the middle one is used for the conduits through which the electric cables are run; the upper tunnel is used as a passageway from one piece of operating machinery to another.

Running lengthwise through the side and center walls are three large water tunnels, or culverts, eighteen feet in diameter—large enough to accommodate a modern passenger train. These huge culverts are used to carry the water down from the lake into the several locks. From these tunnels extend a series of cross culverts which pass under the floor of the locks. There are fourteen of these cross culverts in each lock chamber. Seven of them open from the side culvert and seven from the center wall culvert. These cross culverts are large enough for the passage of a two-horse team. Through each one of them there are five openings into the floor of the lock chamber itself, making seventy in all in the bottom of each lock chamber. These holes are so large that a sugar barrel could pass through each one without difficulty. The passage of water through the culverts is controlled by a large number of valves. In the large wall culverts, these valves consist of two huge gates, each 8 by 18 feet, which slide up and down in frames after the manner of a window. Each of these gates weighs ten tons, and must be able to hold in check a head of sixty feet of water. The gates which control the passage of the water from the wall culverts to the cross culverts have ordinary cylindrical valves. They are so

arranged that each one may be opened or closed independently, or they may be opened or closed in series.

The gates which separate the several chambers of a flight of locks are of enormous size, ranging from 47 to 82 feet high, and are 7 feet thick. They are built in two leaves to each gate, each of these leaves being 65 feet wide. The weight of the leaves varies from 390 tons to 730 tons, depending upon the height of the leaf. They are swung to the walls of the lock chamber in such a way that when they are closed they extend across the lock in the shape of a flattened V, with the apex pointing in the direction from which the pressure comes. The lower sill of each gate leaf weighs approximately eighteen tons. The gates are built up of structural steel, and are covered with large riveted steel plates, just as the hull of a ship is covered. Each of these gate leaves is hung on huge pintles anchored to the walls of the lock. The hinges that are hung on them weigh 36,752 pounds each. They were made to stand a strain of 40,000 pounds before stretching, and 70,000 pounds before breaking. Under an actual test it was found that they were able to stand a strain of 3,300,000 pounds before breaking.

The movement of a gate leaf is accomplished through a huge connecting rod, one end of which is attached to the leaf about midway between the wall and the other end of the leaf; the other end is attached to a huge master wheel which lies flat on the top of the lock wall. This master wheel weighs 34,000 pounds and turns on a huge center pin which is keyed in a heavy casting, anchored securely to the concrete. The casting and the center pin weigh 13,000 pounds. The rim of the great master wheel is so heavy that its weight would break the spokes, and so it is supported in four places by rollers. One-half of this rim is cog geared. Through these it is revolved by an electric motor which drives a train of gears and pinions. These turn the rim of the wheel, which moves the connecting rod to the gate, causing the gate to open or close in two minutes. The action is just the reverse of the action of the connecting rod on the driving wheel of a locomotive. If the reader can picture a locomotive suspended in the air, and the driving wheel moved by power applied to the rim, the resulting movement of the connecting rod with the piston will represent in general outline the method by which the gate leaves are moved back and forth. The motor is remotely controlled by an operator stationed in the controlling house near the lower end of the upper locks, a simple pull of a small switch being sufficient either to close or open a 700-ton gate.

Elaborate precautions have been taken against accidents to the gate leaves. It is easy to see that this huge connecting rod, driven by the powerful master wheel, pushing the gate shut or pulling it open, would cause great damage in case the gate struck an obstruction, unless some method were devised to stop the machinery automatically. Such a method was devised and is in operation. At the gate end of the connecting rod there are two large nests of springs, one of which comes into play when the gate is being opened, and the other when the gate is being closed. These springs will bear a pressure of 60,000 pounds before compressing in the slightest degree, and a pressure of 134,000 pounds before breaking. In case a gate leaf is being closed, and a serious obstruction is encountered, one nest of springs will be compressed. When they reach a certain degree of compression a lever is automatically thrown which cuts off the electric power from the master wheel and stops it instantly. The opposite nest of springs acts in the same way when the gate strikes an obstruction on being opened.

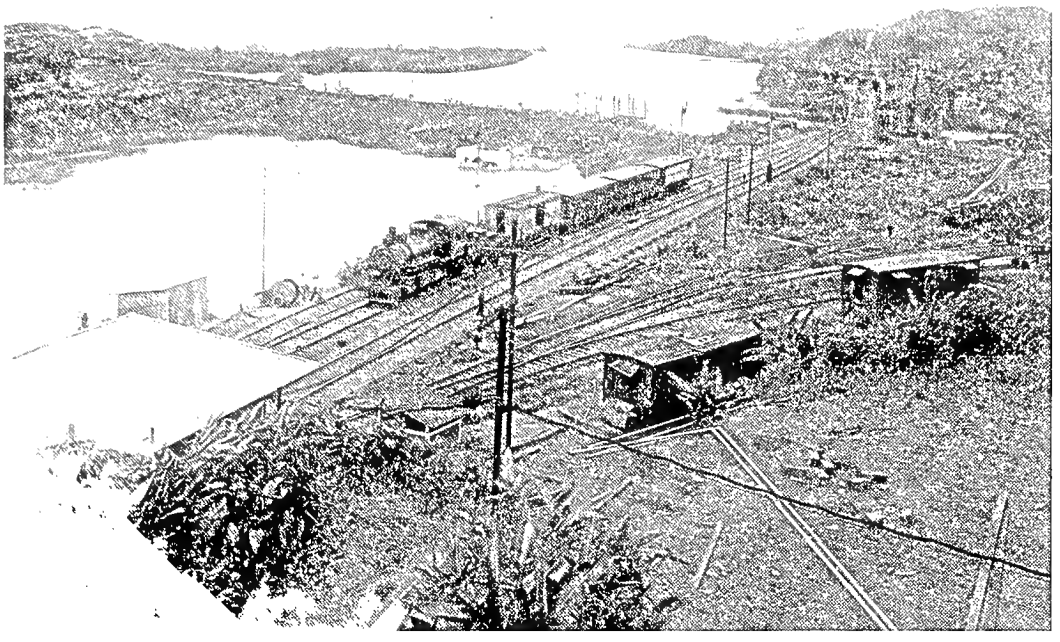
The connecting rods and master wheels are so arranged that the greatest power is exerted when the most of it is needed. As a gate leaf is swung open it must force out the water in the V-shaped space between it and the lock wall, so that most power is needed just at that time. When

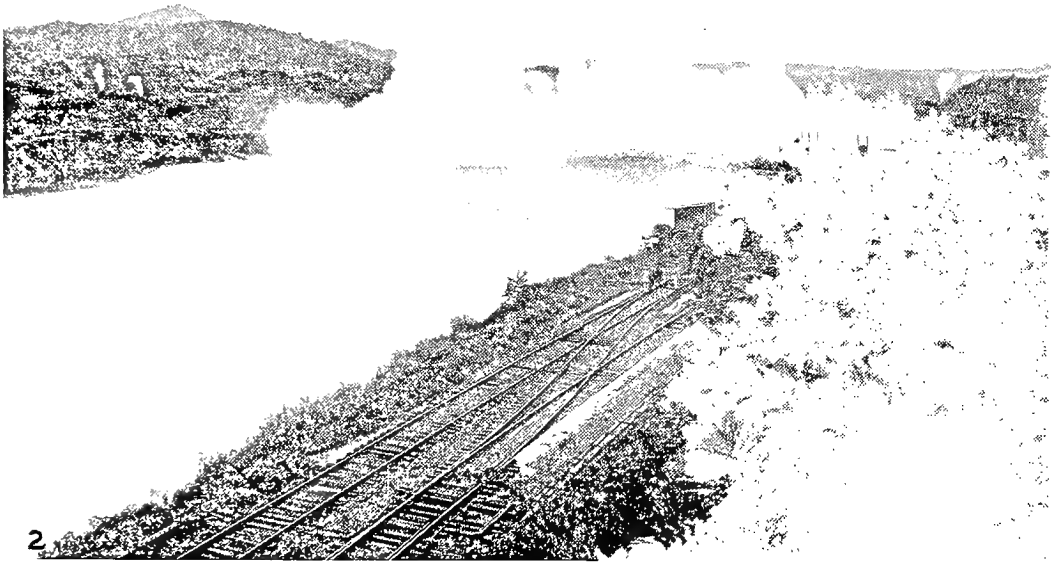
a gate swings back against its recess in the wall the angle of the connecting rod is such as to give it great leverage but slow motion. The same wise provision has been made for holding the gate in position when closed. At this point the connecting rod is practically on a dead center, so that any pressure that may be exerted on it does not tend to revolve the master wheel.

It may be imagined that without many sealing devices there would be openings between the gate leaves and between the gates, walls, and floors that would leave them anything but water tight. One of the devices in use is known as a miter-forcing machine. This consists of a mechanism placed on the end of one gate leaf, which reaches out and takes hold of an engaging part on the end of the opposite leaf, when the gates are in the act of closing. It forces the two leaves together and holds them in rigid contact so long as the gates are shut. In opening the gates it is necessary first to release this miter-forcing machine. On the floor of the lock is placed a heavy timber which comes in contact with very heavy rubber flaps four inches wide, on the bottom of the gate, thus making a perfect seal.

Around no other canal locks in the world have so many safeguards been thrown. In the first place, across the locks ahead of each gate, a huge chain, whose links are fashioned out of three-inch iron, is swung in such a way that any ship not stopping in due time will ram its nose into the chain and will be checked by it before any damage can be done. This chain will stop within 70 feet a 10,000-ton ship moving at the rate of five knots an hour. Each of these protective chains has a great hydraulic paying-out arrangement at either end, which is imbedded in the lock walls. The chain begins to pay out when the pressure reaches 100 tons. It will not break under a pressure of less than 262 tons. Each chain is 428 feet long, and its two ends are attached to big plungers in cylinders imbedded in the lock walls. There is a broad surface of water under each plunger from which small valves open up when a pressure of 750 pounds to the square inch is brought against them. The harder the pressure, the greater the amount of water let out and the greater the resulting speed of the paying-out apparatus. The chain pays out four feet for each foot of movement of the piston. The hydraulic arrangement of the chains practically makes them vast water buffers against the progress of the ship. The paying-out process is rapid enough to prevent any undue strain on the fender chains, and yet slow enough to stop the ship before it can do any harm. There are twenty-four of these fender chains across the locks, and their normal position is one of readiness to stop any ship which approaches the lock gates when it is not under thorough control. These chains are raised and lowered in about one minute. As there is always danger that a paying-out mechanism may be flooded, a unique automatic pump has been installed. A flood valve is in position always ready to turn on an electric switch, which starts the pump the minute the paying-out mechanism is threatened with such an overflow of water. As soon as the water is pumped out, the switch is turned back by the same automatic process, and the pump stopped.

It has been demonstrated that the majority of accidents in the operation of locks are caused by ships passing through them under their own power. A single misunderstood order or a single moment of hesitation in executing an order passed from the lock operator to the man in the engine room may result in disastrous consequences, and has so resulted upon many occasions in various locks. At Panama no ship will be allowed to pass through the locks under its own power. All vessels are required to come up to the guide walls, where they are taken in tow by electric towing engines. There are engines on each of the two walls of a lock chamber, and with ordinary ships





1. Dike at Gamboa which kept the water of the Chagres River out of Culebra Cut during the construction period. Well drills at work preparing for blasting.
2. Blowing up Gamboa dike.

the floor of the bridge. Every precaution has been taken to make these dams efficient. The bridges are swung by electricity, and limit switches make certain that they will stop in exactly the right position. Electrically operated machinery drives the wedges which hold the bridge firmly in position. The emergency dams were made by the American Bridge Company, and each one had to be thoroughly tried out before it was accepted. It takes only a few minutes to swing the bridge across the channel, and not much longer to close up the channel with the steel-plated dam which swings down from the floor of the bridge to the floor of the locks. While all of the machinery of the emergency dams is operated by electricity, provision is made for their operation by hand in the event that they are needed in an emergency when no electric current is available. That these dams give efficient results is shown by experience at the Soo Canal. There a ship rammed the gates and started the waters flowing through the locks with destructive force. The emergency dam had been so long out of use that it could be operated only by hand. Yet with this difficulty, the Soo lock operators were able to check the flow of water in a very little while.

Every precaution has been taken to eliminate the personal equation in the operation of the locks at Panama. The man who operates a set of locks occupies a control house on the center wall of the upper flight of locks, thus giving him an unobstructed view of the whole series of locks with which he must deal. Further than this, he has a little model of the locks, and every result of his manipulation of the levers and switches stands out before him on the model in his office. When he opens the mighty gates of the locks, he also opens the gates of the little lock model; when he operates the valves in the water supply culverts, he also operates the valves of his little model. In this way he is able at all times to know exactly what he has been doing. Further than this, he cannot make a wrong movement even if he should be careless. His system of levers and buttons is an interlocking one, and he simply cannot do the wrong thing. For instance, he cannot let the water through the large culverts until the gates which are to control this water have first been set into position. Likewise, he cannot operate the gates until he has first set the fender chains in their proper position. In this way practically every chance of accident from carelessness is eliminated.

Having seen now what the locks are, let us return and look at them in the process of construction. In building them enough concrete was used to build a row of houses reaching from Chicago to St. Louis. Upward of five million barrels were used in constructing the locks, spillways, and dams. The stone for the locks on the Atlantic side was brought from Porto Bello; that used on the Pacific side was quarried at Ancon Hill. Two different types of material handling machines were used. On the Atlantic side the concrete was handled by huge Lidgerwood cableways. The towers of these cableways were 85 feet high, and they were set on the banks of the canal so that the cableways would span the set of locks. The cables consisted of two and a half inch lock steel wire. They were guaranteed to carry six tons at a trip and to make twenty trips an hour. Each cableway was guaranteed for a life of 60,000 trips.

A circular electric railroad connected the storage piles of sand, stone, and cement with the concrete mixing machinery. The material in the storage piles had been brought to Gatun in barges, the sand from Nombre de Dios, the stone from Porto Bello, and the cement from the docks at Colon. The sand and stone supply was unloaded upon the storage piles by cableways like those used in handling the concrete in building the locks. It was taken from these piles and loaded upon the little cars of the circular railway, in exactly the right proportions. Then the cars were sent on their way to the concrete mixers, which could deliver a mixed charge or receive an unmixed one without stopping. The

little cars on the circular railway ran without motormen. They had automatic governors that held them to a constant speed up hill and down, and when going down hill their motors were reversed into generators, thus making them furnish, in part, the current that lifted some other car over the incline.

After the concrete mixers had finished rolling around the stone, sand, cement, and water in their busy maws, they dumped the mixture out in big buckets mounted on little electric trains operated by a motorman on a third rail track. Each little train carried two buckets. One of them would pull up to the concrete mixers, receive its two bucketfuls of concrete, nearly six tons of it to the bucket, and then hasten away to a point under a Lidgerwood cableway. Here would come down out of the air two empty buckets, which would be set on the cars beside the two full ones. A little wigwagging served to place them properly, and then a little more wigwagging, and the full buckets were caught up into the air to the steel cableway where they struck a carrier that carried them across to the desired position over the locks. Here they were emptied and returned to be delivered to the next train that came along, in exchange for two other buckets filled with concrete.

On the Pacific side cranes were used in lieu of cableways, and dinkey steam locomotives instead of electric railways. One crane carried the materials to the concrete mixers, which turned over the concrete to the little trains, just as at Gatun. They conveyed it to the other crane, which lifted it up to the desired position, where it was dumped.