THE PANAMA CANAL

Frederic J. Haskin

The 5 Points of Authority in this Book

★ **1.** All of the chapters in this book pertaining to the actual construction of the Canal were read and corrected by Colonel George W. Goethals, Chairman and Chief Engineer of the Isthmian Canal Commission.

★ **2.** All of the illustrations were made from photographs taken by Mr. Ernest Hallen, the official photographer of the Commission.

★ **3.** The book contains the beautiful, colored Bird's-eye View of the Canal Zone, made under the direction of the National Geographic Society, as well as the black-and-white official map of the Canal.

★ **4.** The extensive index was prepared by Mr. G. Thomas Ritchie, of the staff of the Library of Congress.

★ **5.** The final proofs were revised by Mr. Howard E. Sherman, of the Government Printing Office, to conform with the typographical style of the United States Government.

"The American Government,"

by the same author, was read by millions of Americans, and still holds the record as the world's best seller among all works of its kind.

THE PANAMA CANAL

BY

FREDERIC J. HASKIN

AUTHOR OF "THE AMERICAN GOVERNMENT," ETC.

Illustrated from photographs taken by
ERNEST HALLEN
Official Photographer of the Isthmian Canal Commission

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PREFACE

THE primary purpose of this book is to tell the layman the story of the Panama Canal. It is written, therefore, in the simplest manner possible, considering the technical character of the great engineering feat itself, and the involved complexities of the diplomatic history attaching to its inception and undertaking. The temptation to turn aside into the pleasant paths of the romantic history of ancient Panama has been resisted; there is no attempt to dispose of political problems that incidentally concern the canal; in short, the book is confined to the story of the canal itself, and the things that are directly and vitally connected with it.

Colonel Goethals was good enough to read and correct the chapters relating to the construction of the canal, and, when shown a list of the chapters proposed, he asked that the one headed "The Man at the Helm" be omitted. The author felt that to bow to his wishes in that matter would be to fail to tell the whole story of the canal, and so Colonel Goethals did not read that chapter.

Every American is proud of the great national achievement at Panama. If, in the case of the individual, this book is able to supplement that pride by an ample fund of knowledge and information, its object and purpose will have been attained.

ACKNOWLEDGMENTS

THE grateful acknowledgments of the author are due to Mr. William Joseph Showalter for his valuable aid in gathering and preparing the material for this book. Acknowledgments are also due to Colonel George W. Goethals, chairman and chief engineer of the Isthmian Canal Commission, for reading and correcting those chapters in the book pertaining to the engineering phases of the work; to Mr. Ernest Hallen, the official photographer of the Commission, for the photographs with which the book is illustrated; to Mr. Gilbert H. Grosvenor, editor of the *National Geographic Magazine*, for permission to use the bird's-eye view map of the canal; to Mr. G. Thomas Ritchie, of the Library of Congress, for assistance in preparing the index; and to Mr. Howard E. Sherman, of the Government Printing Office, for revising the proofs to conform with the typographical style of the United States Government.

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The Panama Canal

"I have read the chapters in 'The Panama Canal' dealing with the engineering features of the Canal and have found them an accurate and dependable account of the undertaking."

GEO. W. GOETHALS.

THE PANAMA CANAL

CHAPTER I

THE LAND DIVIDED — THE WORLD UNITED

THE Panama Canal is a waterway connecting the Atlantic and Pacific Oceans, cut through the narrow neck of land connecting the continents of North and South America. It is the solution of the problem of international commerce that became acute in 1452 when the Eastern Roman Empire fell before the assaults of the Turks, and the land routes to India were closed to Western and Christian Europe.

Forty years after the Crescent supplanted the Cross on the dome of St. Sophia in Constantinople, Columbus set sail to seek a western route to the Indies. He did not find it, but it was his fortune to set foot on the Isthmus of Panama, where, more than four centuries later, the goal of his ambition was to be achieved; not by discovery, but by virtue of the strength and wealth of a new nation of which he did not dream, although its existence is due to his own intrepid courage.

Columbus died not knowing that he had multiplied the world by two, and many voyagers after him also vainly sought the longed-for western pas-

sage. Magellan sought it thousands of leagues to the southward in the cold and stormy seas that encircle the Antarctic Continent. Scores of mariners sought it to the northward, but only one, Amundsen, in the twentieth century, was able to take a ship through the frozen passages of the American north seas.

Down the western coast of the new continent from the eternal ice of Alaska through the Tropics to the southern snows of Tierra del Fuego, the mighty Cordilleras stretch a mountain barrier thousands and thousands and thousands of miles.

Where that mountain chain is narrowest, and where its peaks are lowest, ships may now go through the Panama Canal. The canal is cut through the narrowest part of the Isthmus but one, and through the Culebra Mountain, the lowest pass but one, in all that longest, mightiest range of mountains. There is a lower place in Nicaragua, and a narrower place on the Isthmus east of the canal, but the engineers agreed that the route from Colon on the Atlantic to Panama on the Pacific through Culebra Mountain was the most practicable.

The canal is 50 miles long. Fifteen miles of it is level with the oceans, the rest is higher. Ships are lifted up in giant locks, three steps, to sail for more than 30 miles across the continental divide, 85 feet above the surface of the ocean, then let down by three other locks to sea level again. The channel is 300 feet wide at its narrowest place, and the locks which form the two gigantic water stairways are capable of lifting and lowering the largest ships now afloat. A great part of the

higher level of the canal is the largest artificial lake in the world, made by impounding the waters of the Chagres River, thus filling with water the lower levels of the section. Another part of the higher level is Culebra Cut, the channel cut through the backbone of the continent.

Almost before Columbus died plans were made for cutting such a channel. With the beginning of the nineteenth century and the introduction of steam navigation, the demand for the canal began to be insistent.

Many plans were made, but it remained for the French, on New Year's Day of 1880, actually to begin the work. They failed, but not before they had accomplished much toward the reduction of Culebra Cut. They expended between 1880 and 1904 no less than $300,000,000 in their ill-fated efforts.

In 1904 the United States of America undertook the task. In a decade it was completed and the Americans had spent, all told, $375,000,000 in the project.

Because the Atlantic lies east and the Pacific west of the United States, one is likely to imagine the canal as a huge ditch cut straight across a neck of land from east to west. But it must be remembered that South America lies eastward from North America, and that the Isthmus connecting the two has its axis east and west. The canal, therefore, is cut from the Atlantic southeastward to the Pacific. It lies directly south of Pittsburgh, Pa., and it brings Peru and Chile closer to New York than California and Oregon. The first 7 miles of the canal, beginning at the

the city of Panama is the capital. Cristobal and Balboa, although immediately contiguous to Colon and Panama, are American towns under the American flag.

The Canal Zone historically and commercially has a record of interest and importance longer and more continuous than any other part of the New World. Columbus himself founded a settlement here at Nombre de Dios; Balboa here discovered the Pacific Ocean; across this narrow neck was transported the spoil of the devastated Empire of the Incas; here were the ports of call for the Spanish gold-carrying galleons; and here centered the activities of the pirates and buccaneers that were wont to prey on the commerce of the Spanish Main.

Over this route, on the shoulders of slaves and the back of mules, were transported the wares in trade of Spain with its colonies not only on the west coasts of the Americas, but with the Philippines.

Not far from Colon was the site of the colony of New Caledonia, the disastrous undertaking of the Scotchman, Patterson, who founded the Bank of England, to duplicate in America the enormous financial success of the East India Company in Asia.

Here in the ancient city of Panama in the early part of the nineteenth century assembled the first Pan American conference that gave life to the Monroe doctrine and ended the era of European colonization in America.

Here was built with infinite labor and terrific toll of life the first railroad connecting the Atlantic

and the Pacific Oceans — a railroad less than 50 miles in length, but with perhaps the most interesting story in the annals of railroading.

Across this barrier in '49 clambered the American argonauts, seeking the newly discovered golden fleeces of California.

This was the theater of the failure of Count de Lesseps, the most stupendous financial fiasco in the history of the world.

And this, now, is the site of the most expensive and most successful engineering project ever undertaken by human beings.

It cost the French $300,000,000 to fail at Panama where the Americans, at the expenditure of $375,000,000, succeeded. And, of the excavation done by the French, only $30,000,000 worth was available for the purpose of the Americans. That the Americans succeeded where the French had failed is not to be assigned to the superiority of the American over the French nation. The reasons are to be sought, rather, in the underlying purposes of the two undertakings, and in the scientific and engineering progress made in the double decade intervening between the time when the French failure became apparent and the Americans began their work.

In the first place, the French undertook to build the canal as a money-making proposition. People in every grade of social and industrial life in France contributed from their surpluses and from their hard-earned savings money to buy shares in the canal company in the hope that it would yield a fabulously rich return. Estimates of the costs of the undertaking, made by the engineers, were

arbitrarily cut down by financiers, with the result that repeated calls were made for more money and the shareholders soon found to their dismay that they must contribute more and yet more before they could hope for any return whatever. From the beginning to the end, the French Canal Company was concerned more with problems of promotion and finance than with engineering and excavation. As a natural result of this spirit at the head of the undertaking the whole course of the project was marred by an orgy of graft and corruption such as never had been known. Every bit of work was let out by contract, and the contractors uniformly paid corrupt tribute to high officers in the company. No watch was set on expenditures; everything bought for the canal was bought at prices too high; everything it had to sell was practically given away.

In the next place, the French were pitiably at the mercy of the diseases of the Tropics. The science of preventive medicine had not been sufficiently developed to enable the French to know that mosquitoes and filth were enemies that must be conquered and controlled before it would be possible successfully to attack the land barrier. Yellow fever and malaria killed engineers and common laborers alike. The very hospitals, which the French provided for the care of the sick, were turned into centers of infection for yellow fever, because the beds were set in pans of water which served as ideal breeding places for the death-bearing stegomyia.

In this atmosphere of lavish extravagance caused by the financial corruption, and in the continual

fear of quick and awful death, the morals of the French force were broken; there was no determined spirit of conquest; interest centered in champagne and women; the canal was neglected.

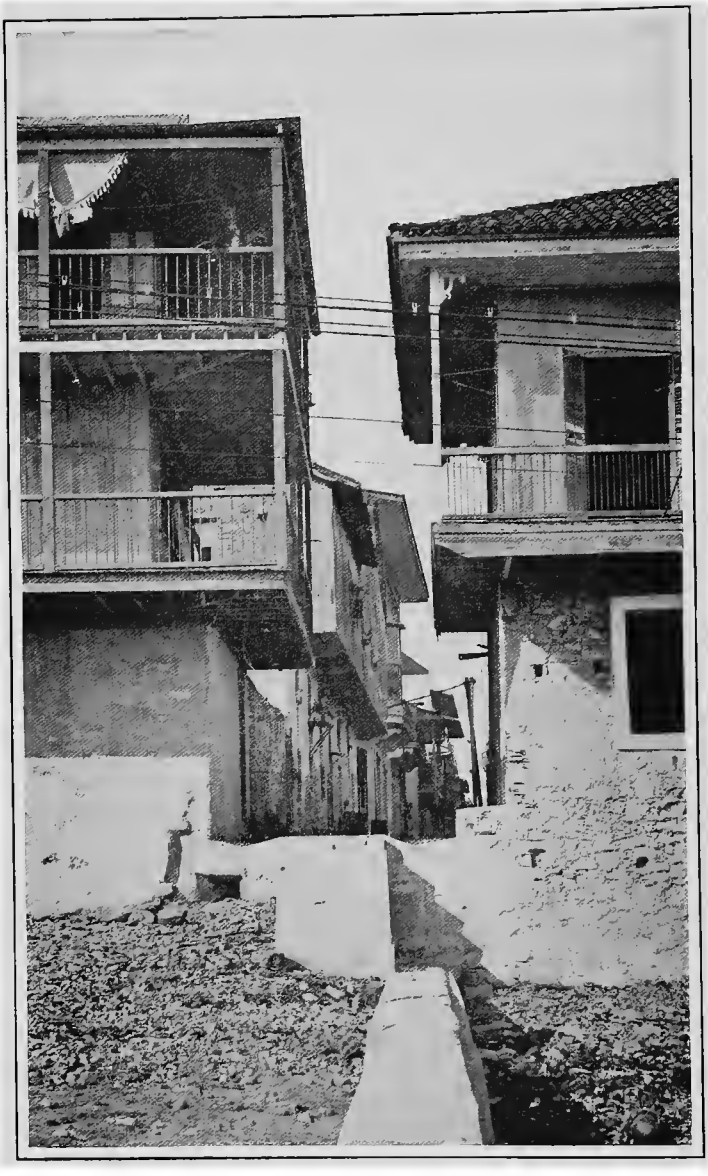
Yet, in spite of this waste, this corruption of money and morals, much of the work done by the French was of permanent value to the Americans; and without the lessons learned from their bitter experience it would have been impossible for the Americans or any other people to have completed the canal so quickly and so cheaply.

The Americans brought to the task another spirit. The canal was to be constructed not in the hope of making money, but, rather, as a great national and popular undertaking, designed to bring the two coasts of the great Republic in closer communication for purposes of commerce and defense.

The early estimates made by the American engineers were far too low, but the French experience had taught the United States to expect such an outcome. Indeed, it is doubtful if anybody believed that the first estimates would not be doubled or quadrupled before the canal was finished.

The journey of the U. S. S. *Oregon* around the Horn from Pacific waters to the theater of the War with Spain in the Caribbean, in 1898, impressed upon the American public the necessity of building the canal as a measure of national defense. Commercial interests long had been convinced of its necessity as a factor in both national and international trade, and, when it was realized that the *Oregon* would have saved 8,000 miles if there

Chairman and Chief Engineer



A STREET IN THE CITY OF PANAMA

had been a canal at Panama, the American mind was made up. It determined that the canal should be built, whatever the cost.

From the very first there was never any question that the necessary money would be forthcoming. It is a fact unprecedented in all parliamentary history that all of the appropriations necessary for the construction and completion of the Isthmian waterway were made by Congress without a word of serious protest.

During the same War with Spain that convinced the United States that the canal must be built, a long forward step was taken in the science of medicine as concerned with the prevention and control of tropical diseases. The theory that yellow fever was transmitted by mosquitoes had been proved by a Cuban physician, Dr. Carlos Finley, a score of years earlier. An Englishman, Sir Patrick Manson, had first shown that disease might be transmitted by the bites of insects, and another Englishman, Maj. Roland Ross, had shown that malaria was conveyed by mosquitoes. It remained, however, for American army surgeons to demonstrate, as they did in Cuba, that yellow fever was transmissible only by mosquitoes of the stegomyia variety and by no other means whatsoever.

With this knowledge in their possession the Americans were able to do what the French were not — to control the chief enemy of mankind in torrid climes. In the first years of the work the public, and Congress, reflecting its views, were not sufficiently convinced of the efficacy of the new scientific discoveries to afford the means for put-

ting them into effect. The Isthmian Canal Commission refused to honor requisitions for wire screens, believing that they were demanded to add to the comfort and luxury of quarters on the Zone, rather than for protection against disease. But the outbreak of yellow fever in 1905 was the occasion for furnishing the Sanitary Department, under Col. W. C. Gorgas, with the necessary funds, and thus provided, he speedily and completely stamped out the epidemic. From that time on, no one questioned the part that sanitation played in the success of the project. The cities of Panama and Colon were cleaned up as never were tropical cities cleaned before. All the time, every day, men fought mosquitoes that the workers in the ditch might not be struck down at their labors.

The Americans, too, made mistakes. In the beginning they attempted to build the canal under the direction of a commission with headquarters in Washington. This commission, at long distance and by methods hopelessly involved in red tape, sought to direct the activities of the engineer in charge on the Isthmus. The public also was impatient with the long time required for preparation and insistently demanded that "the dirt begin to fly."

The work was begun in 1904. It proceeded so slowly that two years later the chairman of the Isthmian Canal Commission asserted that it must be let out to a private contractor, this being, in his opinion, the only way possible to escape the toils of governmental red tape. The then chief engineer, the second man who had held that position while fretting under these methods, was opposed

to the contract system. Bids were asked for, however, but all of them were rejected.

Fortunately, Congress from the beginning had left the President a practically free hand in directing the course of the project. Mr. Roosevelt reorganized the commission, made Col. George W. Goethals, an Army engineer, chairman of the commission and chief engineer of the canal. The constitution of the commission was so changed as to leave all the power in the hands of the chairman and to lay all of the responsibility upon his shoulders.

It was a master stroke of policy, and the event proved the choice of the man to be admirable in every way. From the day the Army engineers took charge there was never any more delay, never any halt in progress, and the only difficulties encountered were those of resistant Nature (such as the slides in Culebra Cut) and those of misinformed public opinion (such as the absurd criticism of the Gatun Dam).

The Americans, too, in the early stages of the work were hampered by reason of the fact that the final decision as to whether to build a sea-level canal or a lock canal was so long delayed by the conflicting views of the partisans of each type in Congress, in the executive branches of the Government, and among the engineers. This problem, too, was solved by Mr. Roosevelt. He boldly set aside the opinion of the majority of the engineers who had been called in consultation on the problem, and directed the construction of a lock canal. The wisdom of this decision has been so overwhelmingly demonstrated that the con-

troversy that once raged so furiously now seems to have been but a tiny tempest in an insignificant teapot.

One other feature of the course of events under the American régime at Panama must be considered. Graft and corruption had ruined the French; the Americans were determined that whether they succeeded or not, there should be no scandal. This, indeed, in part explains why there was so much apparently useless circumlocution in the early stages of the project. Congress, the President, the engineers, all who were in responsible position, were determined that there should be no graft. There was none.

Not only were the Americans determined that the money voted for the canal should be honestly and economically expended, but they were determined, also, that the workers on the canal should be well paid and well cared for. To this end they paid not only higher wages than were current at home for the same work, but they effectively shielded the workers from the exactions and extortions of Latin and Oriental merchants by establishing a commissary through which the employees were furnished wholesome food at reasonable prices — prices lower, indeed, than those prevailing at home.

As a result of these things the spirit of the Americans on the Canal Zone, from the chairman and chief engineer down to the actual diggers, was that of a determination to lay the barrier low, and to complete the job well within the limit of time and at the lowest possible cost. In this spirit all Americans should rejoice, for it is the

highest expression of the nearest approach we have made to the ideals upon which the Fathers founded our Republic.

It is impossible to leave out of the reckoning, in telling the story of the canal, the checkered history of the diplomatic engagements on the part of the United States, that have served both to help and to hinder the undertaking. What is now the Republic of Panama has been, for the greater part of the time since continental Latin America threw off the yoke of Spain, a part of that Republic having its capital at Bogota, now under the name of Colombia, sometimes under the name of New Granada, sometimes a part of a federation including Venezuela and Ecuador. The United States, by virtue of the Monroe doctrine, always asserted a vague and undefined interest in the local affairs of the Isthmus. This was translated into a concrete interest when, in 1846, a treaty was made, covering the construction of the railroad across the Isthmus, the United States engaging always to keep the transit free and open. Great Britain, by virtue of small territorial holdings in Central America and of larger claims there, also had a concrete interest, which was acknowledged by the United States, in the Clayton-Bulwer treaty of 1850, under which a projected canal should be neutral under the guarantee of the Governments of the United States and Great Britain.

For years the United States was inclined to favor a canal cut through Nicaragua, rather than one at Panama, and, after 1898, when the American nation had made up its mind to build a canal some-

where, the partisans of the Panama and Nicaragua routes waged a bitter controversy.

Congress finally decided the issue by giving the President authority to construct a canal at Panama, with the proviso that should he be unable to negotiate a satisfactory treaty with Colombia, which then owned the Isthmus, he should proceed to construct the canal through Nicaragua. Under this threat of having the scepter of commercial power depart forever from Panama, Colombia negotiated a treaty, known as the Hay-Herran treaty, giving the United States the right to construct the canal. This treaty, however, failed of ratification by the Colombian Congress, with the connivance of the very Colombian President who had negotiated it.

But President Roosevelt was most unwilling to accept the alternative given him by Congress — that of undertaking the canal at Nicaragua — and this unwillingness, to say the least, encouraged a revolution in Panama. This revolution separated the Isthmus from the Republic of Colombia, and set up the new Republic of Panama. As a matter of fact, Panama had had but the slenderest relations with the Bogota Government, had been for years in the past an independent State, had never ceased to assert its own sovereignty, and had been, indeed, the theater of innumerable revolutions.

The part the United States played in encouraging this revolution, the fact that the United States authorities prevented the transit of Colombian troops over the Panama Railway, and that American marines were landed at the time, has led to

no end of hostile criticism, not to speak of the still pending and unsettled claims made by Colombia against the United States. Mr. Roosevelt himself, years after the event and in a moment of frankness, declared: "I took Panama, and left Congress to debate it later."

Whatever may be the final outcome of our controversy with Colombia, it may be confidently predicted that history will justify the coup d' état on the theory that Panama was the best possible site for the interoceanic canal, and that the rupture of relations between the territory of the Isthmus and the Colombian Republic was the best possible solution of a confused and tangled problem.

These diplomatic entanglements, however, as the canal is completed, leave two international disputes unsettled — the one with Colombia about the genesis of the canal undertaking, and the other with Great Britain about the terms of its operation.

Congress, in its wisdom, saw fit to exempt American vessels engaged exclusively in coastwise trade — that is to say, in trade solely between ports of the United States — from payment of tolls in transit through the canal. This exemption was protested by Great Britain on the ground that the Hay-Pauncefote treaty, which took the place of the Clayton-Bulwer treaty, provided that the canal should be open to all nations on exact and equal terms. The future holds the termination of both these disputes.

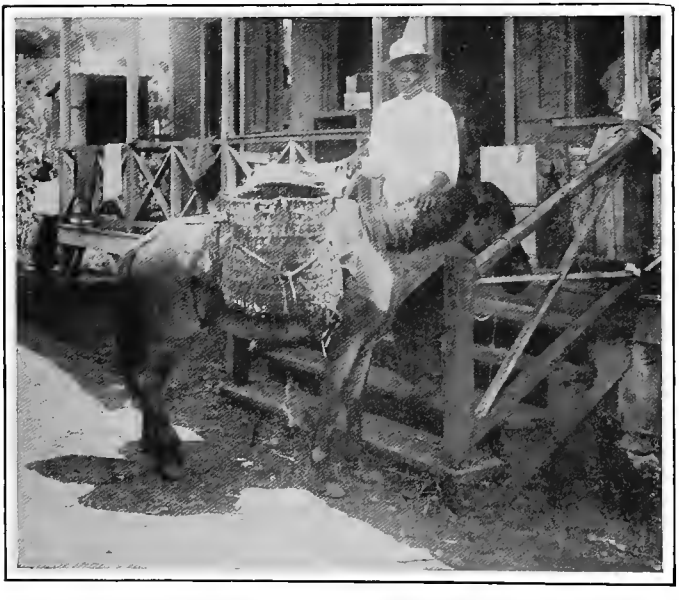
Congress, that never begrudged an appropriation, indulged in many disputes concerning the

building and operation of the canal. First, there was the controversy as to site, between Nicaragua and Panama. Next, came the question as to whether the canal should be at sea level or of a lock type. Then there was the question of tolls, and the exemption of American coastwise traffic. But, perhaps the most acrimonious debates were on the question as to whether or not the canal should be fortified. Those who favored fortification won their victory, and the canal was made, from a military standpoint, a very Gibraltar for the American defense of, and control over, the Caribbean. That this was inevitable was assured by two facts: One that the trip of the *Oregon* in 1898 crystallized public sentiment in favor of constructing the canal; and the other that the canal itself was wrought by Army engineers under the direction of Colonel Goethals. Colonel Goethals never for a moment considered the possibility that Congress would vote against fortifications, and the whole undertaking was carried forward on that basis.

If the military idea, the notion of its necessity as a feature of the national defense, was the determining factor in initiating the canal project, it remains a fact that its chief use will be commercial, and that its money return, whether small or large, nearly all will be derived from tolls assessed upon merchant vessels passing through it.

The question of the probable traffic the canal will be called upon to handle was studied as perhaps no other world-wide problem of transportation ever was. Prof. Emory R. Johnson was the student of this phase of the question from

VENDERS IN THE STREETS OF PANAMA



A NATIVE BOY MARKETING

the beginning to the end. He estimates that the canal in the first few years of its operation will have a traffic of 10,000,000 tons of shipping each year, and that by 1975 this will have increased to 80,000,000 tons, the full capacity of the canal in its present form. Provision has been made against this contingency by the engineers who have so constructed the canal that a third set of locks at each end may be constructed at a cost of about $25,000,000, and these will be sufficient almost to double the present ultimate capacity, and to take care of a larger volume of traffic than now can be foreseen.

Americans are interested, first of all, in what the canal will do for their own domestic trade. It brings Seattle 7,800 miles nearer to New York; San Francisco, 8,800 miles nearer to New Orleans; Honolulu 6,600 miles nearer to New York than by the Strait of Magellan. Such saving in distance for water-borne freight works a great economy, and inevitably must have a tremendous effect upon transcontinental American commerce.

In foreign commerce, also, some of the distances saved are tremendous. For instance, Guayaquil, in Ecuador, is 7,400 miles nearer to New York by the canal than by the Strait of Magellan; Yokohama is nearly 4,000 miles nearer to New York by Panama than by Suez; and Melbourne is 1,300 miles closer to Liverpool by Panama than by either Suez or the Cape of Good Hope. Curiously enough, the distance from Manila to New York, by way of Suez and Panama, is almost the same, the difference in favor of Panama being only 41 miles out of a total of 11,548 miles. The

difference in distance from Hongkong to New York by the two canals is even less, being only 18 miles, this slight advantage favoring Suez.

But it is not by measure of distances that the effect of the canal on international commerce may be measured. It spells the development of the all but untouched western coast of South America and Mexico. It means a tremendous up-building of foreign commerce in our own Mississippi Valley and Gulf States. It means an unprecedented commercial and industrial awakening in the States of our Pacific coast and the Provinces of Western Canada.

While it was not projected as a money-making proposition, it will pay for its maintenance and a slight return upon the money invested from the beginning, and in a score of years will be not only self-supporting, but will yield a sufficient income to provide for the amortization of its capital in a hundred years.

The story of how this titanic work was undertaken, of how it progressed, and of how it was crowned with success, is a story without a parallel in the annals of man. The canal itself, as Ambassador Bryce has said, is the greatest liberty man has ever taken with nature.

Its digging was a steady and progressive victory over sullen and resistant nature. The ditch through Culebra Mountain was eaten out by huge steam shovels of such mechanical perfection that they seemed almost to be alive, almost to know what they were doing. The rocks and earth they bit out of the mountain side were carried away by trains operating in a system of

such skill that it is the admiration of all the transportation world, for the problem of disposing of the excavated material was even greater than that of taking it out.

The control of the torrential Chagres River by the Gatun Dam, changing the river from the chief menace of the canal to its essential and salient feature, was no less an undertaking. And, long after Gatun Dam and Culebra Cut cease to be marvels, long after the Panama Canal becomes as much a matter of course as the Suez Canal, men still will be thrilled and impressed by the wonderful machinery of the locks — those great water stairways, operated by machinery as ingenious as gigantic, and holding in check with their mighty gates such floods as never elsewhere have been impounded.

It is a wonderful story that this book is undertaking to tell. There will be much in it of engineering feats and accomplishments, because its subject is the greatest of all engineering accomplishments. There will be much in it of the things that were done at Panama during the period of construction, for never were such things done before. There will be much in it of the history of how and why the American Government came to undertake the work, for nothing is of greater importance. There will be something in it of the future, looking with conservatism and care as far ahead as may be, to outline what the completion of this canal will mean not only for the people of the United States, but for the people of all the world.

Much that might be written of the romantic

history of the Isthmian territory — tales of discoverers and conquistadores, wild tales of pirates and buccaneers, serio-comic narratives of intrigue and revolution — is left out of this book, because, while it is interesting, it now belongs to that antiquity which boasts of many, many books; and this volume is to tell not of Panama, but of the Panama Canal — on the threshold of its story, fitted by a noble birth for a noble destiny.

CHAPTER II

GREATEST ENGINEERING PROJECT

THE Panama Canal is the greatest engineering project of all history. There is more than the patriotic prejudice of a people proud of their own achievements behind this assertion. Men of all nations concede it without question, and felicitate the United States upon the remarkable success with which it has been carried out. So distinguished an authority as the Rt. Hon. James Bryce, late British ambassador to Washington, and a man not less famous in the world of letters than successful in the field of diplomacy, declared before the National Geographic Society that not only is the Panama Canal the greatest undertaking of the past or the present but that even the future seems destined never to offer any land-dividing, world-uniting project comparable to it in magnitude or consequence.

We are told that the excavations total 232,000,000 cubic yards; that the Gatun Dam contains 21,000,000 cubic yards of material; and that the locks and spillways required the laying of some 4,500,000 cubic yards of concrete. But if one is to realize the meaning of this he must get out of the realm of cubic yards and into the region of concrete comparisons. Every one is familiar with the size and shape of the Washington Monu-

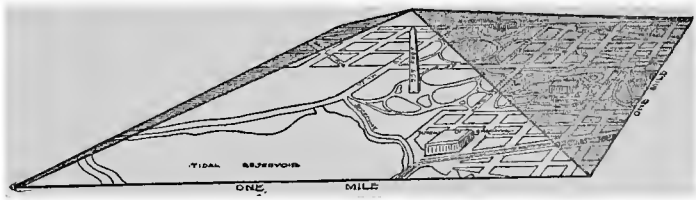
ment. With its base of 55 feet square and its height of 555 feet, it is one of the most imposing of all the hand reared structures of the earth. Yet the material excavated from the big waterway at Panama represents 5,840 such solid-built shafts. Placed in a row with base touching base they would traverse the entire Isthmus and reach 10 miles beyond deep water in the two oceans at Panama. Placed in a square with base touching base they would cover an area of 475 acres. If all the material were placed in one solid shaft with a base as large as the average city block, it would tower nearly 100,000 feet in the air.

Another illustration of the magnitude of the quantity of material excavated at Panama may be had from a comparison with the pyramid of Cheops, of which noble pile some one has said that "All things fear Time, but Time fears only Cheops." We are told that it required a hundred thousand men 10 years to make ready for the building of that great structure, and 20 years more to build it. There were times at Panama when, in 26 working days, more material was removed from the canal than was required to build Cheops, and from first to last the Americans removed material enough to build sixty-odd pyramids such as Cheops. Were it all placed in one such structure, with a base as large as that of Cheops, the apex would tower higher into the sky than the loftiest mountain on the face of the earth.

Still another way of arriving at a true conception of the work of digging the big waterway is to consider that enough material had to be removed by the Americans to make a tunnel

through the earth at the equator more than 12 feet square.

But perhaps the comparison that will best illustrate the immensity of the task of digging the ditch is that of the big Lidgerwood dirt car,



A GRAPHIC REPRESENTATION OF THE MATERIAL HANDLED AT PANAMA

on which so much of the spoil has been hauled away. Each car holds about 20 cubic yards of dirt, and 21 cars make a train. The material removed from the canal would fill a string of these cars reaching about three and a half times around the earth, and it would take a string of Panama Railroad engines reaching almost from New York to Honolulu to move them.

Yet all these comparisons have taken account of the excavations only. The construction of the Panama Canal represents much besides digging a ditch, for there were some immense structures to erect. Principal among these, so far as magnitude is concerned, was the Gatun Dam, that big ridge of earth a mile and a half long, half a mile thick at the base, and 105 feet high. It contains some 21,000,000 cubic yards of material, enough to build more than 500 solid shafts like the Washington Monument. Then there was the dam at Pedro Miguel — "Peter Magill,"

as the irreverent boys of Panama christened it — and another at Miraflores, each of them small in comparison with the great embankment at Gatun, but together containing as much material as 70 solid shafts like our Washington Monument.

Besides these structures there still remain the locks and spillways, with their four and a half million cubic yards of concrete and their hundreds and thousands of tons of steel.

With all these astonishing comparisons in mind, is it strange that the digging of the Panama Canal is the world's greatest engineering project? Are they not enough to stamp it as the greatest single achievement in human history? Yet even they, pregnant of meaning as they are, fail to reveal the full and true proportions of the work of our illustrious army of canal diggers. They tell nothing of the difficulties which were overcome — difficulties before which the bravest spirit might have quailed.

When the engineers laid out the present project, they calculated that 103,000,000 cubic yards of material would have to be excavated, and predicted that the canal diggers would remove that much in nine years. Since that time the amount of material to be taken out has increased from one cause or another until it now stands at more than double the original estimate. At one time there was an increase for widening the Culebra Cut by 50 per cent. At another time there was an increase to take care of the 225 acres of slides that were pouring into the big ditch like glaciers. At still another time there was an increase for the creation of a small lake between the locks at

Pedro Miguel and Miraflores. At yet another time it was found that the Chagres River and the currents of the Atlantic and the Pacific Oceans were depositing large quantities of silt and mud in the canal, and this again raised the total amount of material to be excavated. But none of these unforeseen obstacles and additional burdens dismayed the engineers. They simply attacked their problem with renewed zeal and quickened energy, with the result that they excavated in seven years of actual operations more than twice as much material as they were expected to excavate in nine years. In other words, the material to be removed was increased 125 per cent and yet the canal was opened at least 12 months ahead of the time predicted.

How this unprecedented efficiency was developed forms in itself a remarkable story of achievement. The engineers met with insistent demands that they "make the dirt fly." The people had seen many months of preparation, but they had no patience with that; they wanted to see the ditch begin to deepen. It was a critical stage in the history of the project. If the dirt should fail to fly public sentiment would turn away from the canal.

So John F. Stevens addressed himself to making it fly. Before he left he had brought the monthly output almost up to the million yard mark. When that mark was passed the President of the United States, on behalf of himself and the nation, sent a congratulatory message to the canal army. Many people asserted that it was nothing but a burst of speed; but the canal diggers squared

themselves for a still higher record. They forced up the mark to two million a month, and straightway used that as a rallying point from which to charge the heights three million. Once again the standard was raised; "four million" became the slogan. Wherever that slogan was flashed upon a Y. M. C. A. stereoptican screen there was cheering — cheering that expressed a determined purpose. Finally, when March, 1909, came around all hands went to work with set jaws, and for the only time in the history of the world there was excavated on a single project, 4,000,000 cubic yards of material in one month.

With the dirt moving, came the question of the cost of making it fly. By eliminating a bit of lost motion here and taking up a bit of waste there, even with the price of skilled labor fully 50 per cent higher on the Isthmus than in the States, unit costs were sent down to surprisingly low levels. For instance, in 1908 it was costing $11\frac{1}{2}$ cents a cubic yard to operate a steam shovel; in 1911 this had been forced down to $8\frac{7}{8}$ cents a yard. In 1908 more than $18\frac{1}{2}$ cents were expended to haul a cubic yard of spoil 8 miles; in 1911 a cubic yard was hauled 12 miles for a little more than $15\frac{1}{5}$ cents.

Some of the efficiency results were astonishing. To illustrate: One would think that the working power of a ton of dynamite would be as great at one time as another; and yet the average ton of dynamite in 1911 did just twice as much work as in 1908. No less than $50,000 a month was saved by shaking out cement bags.

It was this wonderful efficiency that enabled

the United States to build the canal for $375,000,000 when without it the cost might have reached $600,000,000. In 1908, after the army had been going at regulation double-quick for a year, a board was appointed to estimate just how much material would have to be taken out, and how much it would cost. That board estimated that the project as then planned would require the excavation of 135,000,000 cubic yards of material, and that the total cost of the canal as then contemplated would be $375,000,000. Also it was estimated that the canal would be completed by January 1, 1915. After that time the amount of material to be excavated was increased by 97,000,000 cubic yards, and yet so great was the efficiency developed that the savings effected permitted that great excess of material to be removed without the additional expense of a single penny above the estimates of 1908, and in less time than was forecast.

Although the difficulties that beset the canal diggers were such as engineers never before encountered, they were met and brushed aside, and all the world's engineering records were smashed into smithereens. It required 20 years to build the Suez Canal, through a comparatively dry and sandy region. When the work at Panama was at its height the United States was excavating the equivalent of a Suez Canal every 15 months. Likewise it required many years to complete the Manchester Ship Canal between Liverpool and Manchester, a distance of 35 miles. This canal cost so much more than was estimated that money was raised for its completion only with the greatest

difficulty. Yet at Panama the Americans dug four duplicates of the Manchester Ship Canal in five years. All of this was done in spite of the fact that they had to work in a moist, hot, enervating climate where for nine months in a year the air seems filled with moisture to the point of saturation, and where, for more than half the length of the great ditch, the annual rainfall often amounts to as much as 10 feet — all of this falling in the nine months of the wet season.

A few comparisons outside of the construction itself will serve to illustrate the tremendous proportions of the work. Paper money was not handled at all in paying off the canal army. It took three days to pay off the force with American gold and Panaman silver. When pay day was over there had been given into the hands of the Americans, and thrown into the hats of the Spaniards and West Indian negroes, 1,600 pounds of gold and 24 tons of silver. When it is remembered that this performance was repeated every month for seven years, one may imagine the enormous outlay of money for labor.

The commissary also illustrates the magnitude of the work. Five million loaves of bread, a hundred thousand pounds of cheese, more than 9,000,000 pounds of meat, half a million pounds of poultry, more than a thousand carloads of ice, more than a million pounds of onions, half a million pounds of butter — these are some of the items handled in a single year.

Wherever one turns he finds things which furnish collateral evidence of the magnitude of the work. The Sanitary Department used each year

150,000 gallons of mosquito oil, distributed thousands of pounds of quinine, cut and burned millions of square yards of brush, and spent half a million dollars for hospital maintenance.

No other great engineering project has allowed such a remarkable "margin of safety" — the engineering term for doing things better than they need to be done. The engineers who dug the canal took nothing for granted. No rule of physics was so plain or so obvious as to escape actual physical proof before its acceptance, when such proof was possible. No one who knows how the engineers approached the subject, how they resolved every doubt on the side of safety, and how they kept so far away from the danger line as actually to make their precaution seem excessive can doubt that the Panama Canal will go down in history as the most thorough as well as the most extensive piece of engineering in the world.

CHAPTER III

GATUN DAM

THE key to the whole Panama Canal is Gatun Dam, that great mass of earth that impounds the waters of the Chagres River, makes of the central portion of the canal a great navigable lake with its surface 85 feet above the level of the sea, and, in short, renders practicable the operation of a lock type of canal across the Isthmus.

Around no other structure in the history of engineering did the fires of controversy rage so furiously and so persistently as they raged for several years around Gatun Dam. It was attacked on this side and that; its foundations were pronounced bad and its superstructure not watertight. Doubt as to the stability of such a structure led some of the members of the Board of Consulting Engineers to recommend a sea-level canal. Further examination of the site and experimentation with the materials of which it was proposed to construct it, showed the engineers that it was safe as to site and satisfactory as to superstructure. The country had about accepted their conclusions, when, in the fall of 1908, there was a very heavy rain on the Isthmus, and some stone which had been deposited on the soil on the upstream toe of the dam, sank out of sight — just as the engineers

expected it to do. A story thereupon was sent to the States announcing that the Gatun Dam had given way and that the Chagres River was rushing unrestrained through it to the sea. The public never stopped to recall that the dam was not yet there to give way, or to inquire exactly what had happened, and a wave of public distrust swept over the country.

To make absolutely certain that everything was all right, and to restore the confidence of the people in the big project, President Roosevelt selected the best board of engineers he could find and sent them to the Isthmus in company with President-elect Taft to see exactly what was the situation at Gatun.

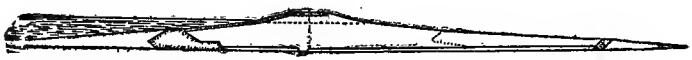
They examined the site, they examined the material, they examined the evidence in Colonel Goethal's hands. When they got through they announced that they had only one serious criticism to make of the dam as proposed. "It is not necessary to tie a horse with a log chain to make sure he can not break away," observed one of them, "a smaller chain would serve just as well." And so they recommended that the crest of the dam be lowered from 135 feet to 115 feet. Still later this was cut to 105 feet. They found that the underground river whose existence was urged by all who opposed a lock canal, flowed nowhere save in the fertile valleys of imagination. The engineers had known this a long time, but out of deference to the doubters they had decided to drive a lot of interlocking sheet piling across the Chagres Valley. "What's the use trying to stop a river that does not exist?" queried the engineers, and so the sheet piling was omitted.

As a matter of fact, Gatun Dam proved the happiest surprise of the whole waterway. In every particular it more than fulfilled the most optimistic prophecies of the engineers. They said that what little seepage there would be would not hurt anything; the dam answered by showing no seepage at all. They said that the hydraulic core would be practically impervious; it proved absolutely so. Where it was once believed that Gatun Dam would be the hardest task on the Isthmus it proved to be the easiest. Culebra Cut exchanged places with it in that regard.

Gatun Dam contains nearly 22,000,000 cubic yards of material. Assuming that it takes two horses to pull a cubic yard of material it would require twice as many horses as there are in the United States to move the dam were it put on wheels. Loaded into ordinary two-horse dirt wagons it would make a procession of them some 80,000 miles long. The dam is a mile and a half long, a half mile thick at the base, 300 feet thick at the water line, and 100 feet thick at the crest. Its height is 105 feet.

Yet in spite of its vast dimensions it is the most inconspicuous object in the landscape. Grown over with dense tropical vegetation it looks little more conspicuous than a gradual rise in the surface of the earth. Passengers passing Gatun on the Panama Railroad scarcely recognize the dam as such when they see it, so gradual are its slopes. An excellent idea of the gentle incline of the dam may be had by referring to the accompanying figure, which shows the outlines of a cross section of the dam.

The materials of which it is constructed are also shown there. Starting on the upstream side there is a section made of solid material from Culebra Cut. Beyond this is the upstream toe of the dam, which is made of the best rock in the

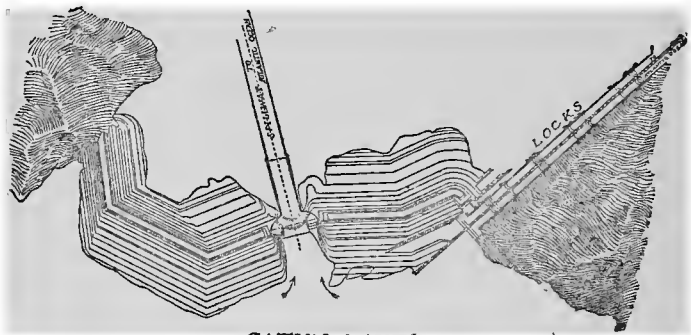


A CROSS-SECTION OF THE GATUN DAM

Culebra Cut. After this comes the hydraulic fill. This material is a mixture of sand and clay which, when it dries out thoroughly, is compact and absolutely impervious to water. It was secured from the river channel and pumped with great 20-inch centrifugal pumps into the central portion of the dam, where a veritable pond was formed; the heavier materials settled to the bottom, forming layer after layer of the core, while the lighter particles, together with the water, passed off through drain pipes. In this way the water was not only the hod carrier of the dam construction, but the stone mason as well. Where there was the tiniest open space, even between two grains of sand, the water found it and slipped in as many small particles as were necessary to stop it up.

Above the hydraulic fill on the upstream side is a layer of solid material, while that part of the face of the dam exposed to wave action is covered with heavy rock. The same is true of the crest. On the downstream half of the dam there is approximately 400 feet of hydraulic fill, then 400 feet of solid fill, then a 30-foot toe, and then ordinary excavated material.

The Chagres Valley is a wide one until it reaches Gatun. Here it narrows down to a mile and a half. It is across this valley that the Gatun Dam is thrown in opposition to the seaward journey of the Chagres waters. At the halfway point across the valley there was a little hill almost entirely of solid rock. It happened to be planted exactly at the place the engineers needed it. Here they could erect their spillway for the control of the water in the lake above.



PLAN OF THE GATUN DAM AND LOCKS

The regulation of the water level in Gatun Lake is no small task, for the Chagres is one of the world's moodiest streams. At times it is a peaceful, leisurely stream of some 2 feet in depth, while at other times it becomes a wild, roaring, torrential river of magnificent proportions. Sometimes it reaches such high stages that it sends a million gallons of water to the sea between the ticks of a clock.

In controlling the Chagres, the engineers again

took what on any private work would have been regarded as absurd precaution. In the first place, Gatun Lake will be so big that the Chagres can break every record it heretofore has set, both for momentary high water and for sustained high water, and still, with no water being let out of the lake, it can continue to flow that way for a day and a half without disturbing things at all. It could flow for two days before any serious damage could be done. Thus the canal force might be off duty for some 45 hours, with the outlet closed, before any really serious damage could be done by the rampage of the river.

But of course no one supposes that it would be humanly possible that two such contingencies as the highest water ever known, and everybody asleep at their posts for two days, could happen together. When the water in the lake reached its normal level of 87 feet the spillway gates would be opened, and, if necessary, it would begin to discharge 145,000 feet of water a second. This is 17,000 feet more than the record for sustained flow heretofore set by the Chagres. But if it were found that even this was inadequate the culverts in the locks could be brought into play, and with them the full discharge would be brought up to 194,000 feet a second, or 57,000 more than the Chagres has ever brought down. But suppose even this would not suffice to take care of the floods of the Chagres? The spillway is so arranged that as the level of the water in the lake rises the discharging capacity increases. With the spillway open, even if the Chagres were to double its record for continued high water, it would take

many days to bring the lake level up to the danger point — 92 feet. When it reached that height the spillway would have a capacity of 222,000 feet, which, with the aid of the big lock culverts, would bring the total discharge up to 262,000 feet a second — only 12,000 cubic feet less than double the highest known flow of the Chagres.

But this is only characteristic of what one sees everywhere. Whether it be in making a spillway that would accommodate two rivers like the Chagres instead of one, or in building dams with 63 pounds of weight for every pound of pressure against it, or yet in building lock gates which will bear several times the maximum weight that can ever be brought against them, the work at Panama was done with the intent to provide against every possible contingency.

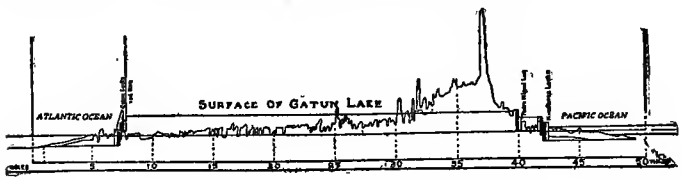
The spillway through which the surplus waters of Gatun Lake will be let down to the sea level, is a large semicircular concrete dam structure with the outside curve upstream and the inside curve downstream. Projecting above the dam are 13 piers and 2 abutments, which divide it into 14 openings, each of them 45 feet wide. These openings are closed by huge steel gates, 45 feet wide, 20 feet high, and weighing 42 tons each. They are mounted on roller bearings, suspended from above, and are operated by electricity. They work in huge frames just as a window slides up and down in its frame. Each gate is independent of the others, and the amount of water permitted to go over the spillway dam thus can be regulated at will.

When a huge volume of water like a million

gallons a second is to be let down a distance of about 60 feet, it may be imagined that unless some means are found to hold it back and let it descend easily, by the time it would reach the bottom it would be transformed into a thousand furies of energy. Therefore, the spillway dam has been made semicircular, with the outside lines pointing up into the lake and the inside lines downstream, so that as the water runs through the openings it will converge all the currents and cause them to collide on the apron below. This largely overcomes the madness of the water. But still further to neutralize its force and to make it harmless as it flows on its downward course, there are two rows of baffle piers on the apron of the spillway. They are about 10 feet high and are built of reinforced concrete, with huge cast-iron blocks upon their upstream faces. When the water gets through them it has been tamed and robbed of all its dangerous force. The spillway is so constructed that when the water flowing over it becomes more than 6 feet deep it adheres to the downstream face of the dam as it glides down, instead of rushing out and falling perpendicularly.

The locks are situated against the high hills at the east side of the valley, after which comes the east wing of the dam, then the spillway, then the west wing of the dam, which terminates on the side of the low mountain that skirts the western side of the valley. With the hills bordering the valley and the dam across it, the engineers have been able to inclose a gigantic reservoir which has a superficial surface of 164 square miles. It is irregular in shape and might remind one of a

pressed chrysanthemum, the flower representing the lake and the stem Culebra Cut. The surface of the water in this lake is normally 85 feet higher than the surface of the water seaward from Gatun and Miraflores. The lake is entirely fresh water supplied by the Chagres River. The accompanying figure shows the profile of the canal.



A PROFILE SECTION OF THE CANAL

The Chagres River approaches the canal at approximately right angles at Gamboa, some 21 miles above Gatun. The lake will be so large that the river currents will all be absorbed, the water backing far up into the Chagres, the river depositing its silt before it reaches the canal proper.

With the currents thus checked, the Chagres will lose all power to interfere with the navigation of the canal, although upon the bosom of its water will travel for a distance of 35 miles all the ships that pass through the big waterway from Gatun to Miraflores. This fresh water will serve a useful purpose besides carrying ships over the backbone of the continent. Barnacles lose their clinging power in fresh water, and when a ship passes up through the locks from sea level to lake level and from salt water to fresh, the barnacles that have clung to the sides and bottom of the vessel through many a thousand mile of "sky-hooting through

the brine" will have their grip broken and they will drop off helplessly and fall to the bed of the lake, which, in the course of years, will become barnacle-paved. How many times in dry-dock this will save can only be surmised, but the ship that goes through the canal regularly will not have much bother with barnacles.

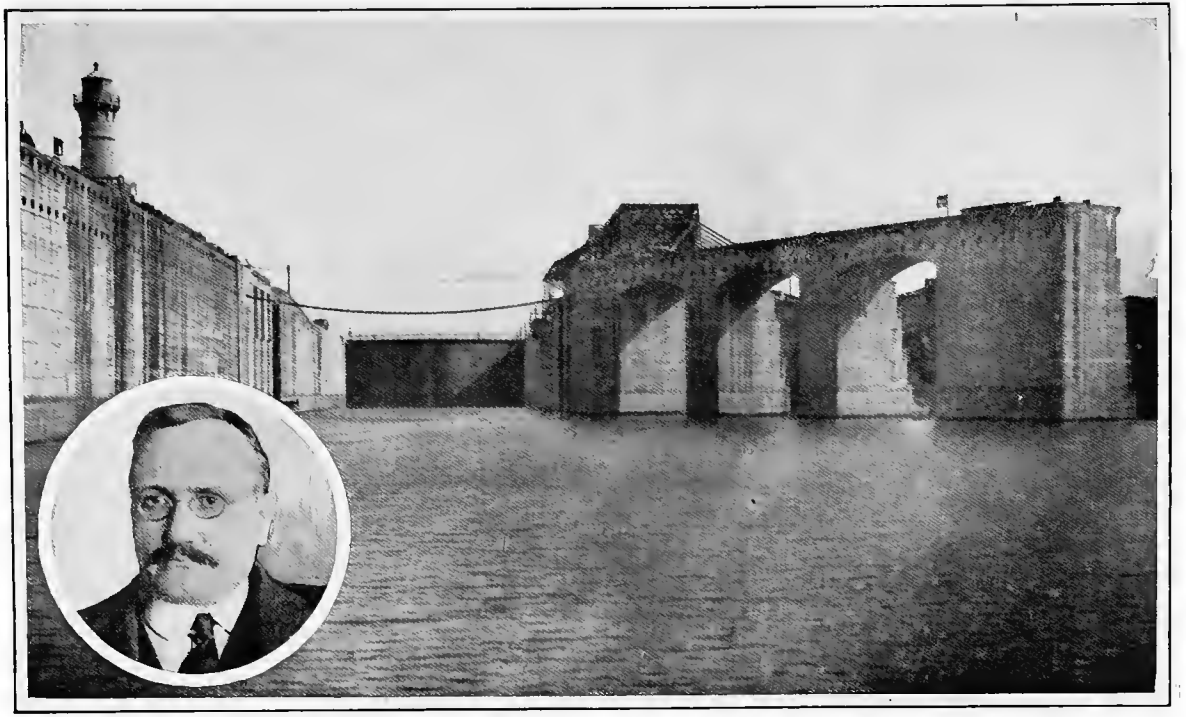
The engineer who worked out the details of the engineering examination of the dam in 1908 was Caleb M. Saville, who had had experience on some of the greatest dams in the world. In the first place, the whole foundation was honeycombed with test borings, and several shafts were sunk so that the engineers could go down and see for themselves exactly what was the nature of the material below. There are some problems in engineering where a decision is so close between safety and danger that none but an engineer can decide them. But Gatun Dam could speak for itself and in the layman's tongue.

After investigating the site and getting such conclusive evidence that the proverbial wayfaring man might understand it the engineers next conducted a series of experiments to determine whether or not the material of which they proposed to build the dam would be watertight. They wanted to make sure whether enough water would seep through to carry any of the dam material along with it. The maximum normal depth of the water is 85 feet. The material it would have to seep through is nearly a half mile thick. In order to determine how the water would behave they took some 3 feet of the material and put it in a strong iron cylinder with water

above it and subjected it to a pressure equivalent to a head of 185 feet of water. Only an occasional drop came through. If only an occasional drop of clear water gets through 3 feet of material under a pressure of 185 feet of water, it does not require a great engineer to determine that there will not be any seepage through more than a thousand feet of the same material under a head of only 85 feet.

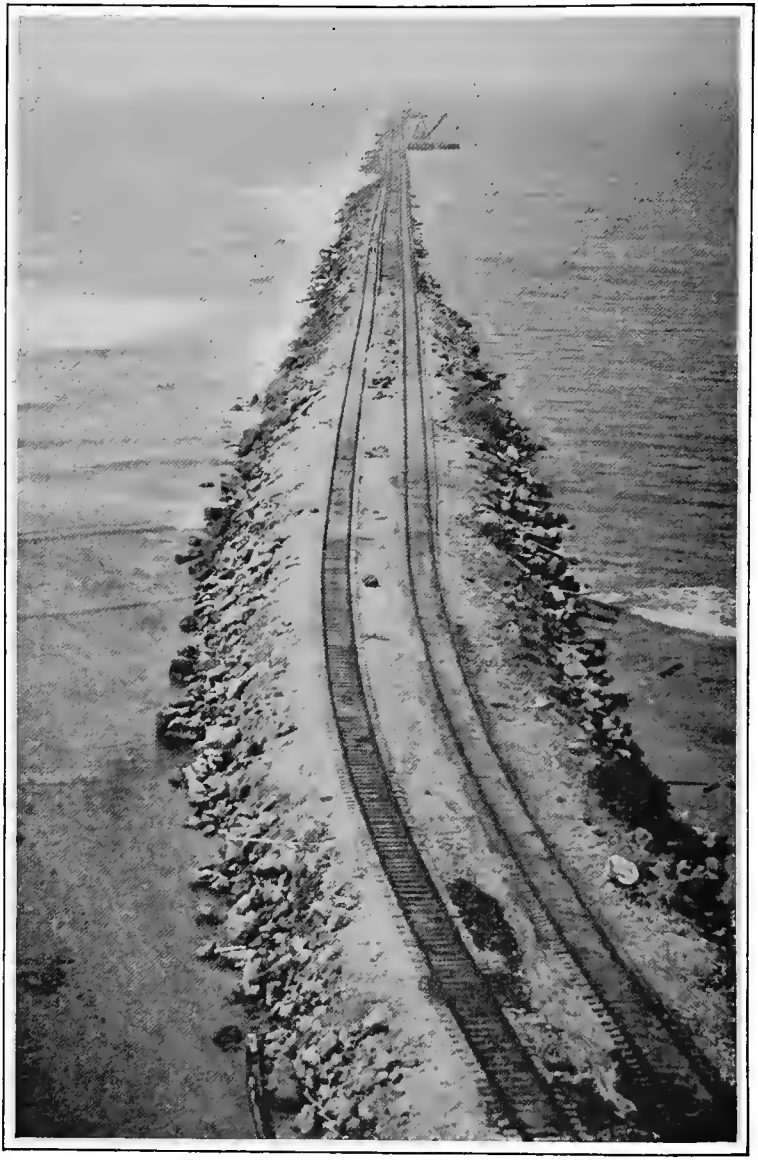
And that is only a sample of their seeking after the truth. When they had gone thus far it was then decided to build a little dam a few yards long identical in cross section with Gatun Dam. It was built on the scale of an inch to the foot, by the identical processes with which it was intended to build the big dam. The result only added confirmation to the other experiments. With a proportionate head of water against it, it behaved exactly as they had concluded the big dam would when completed. Every engineer who has read Saville's report pronounces it a masterpiece of engineering investigation. It proved conclusively that the site of the dam is stable, and the dam itself impervious to seepage. The engineers who visited the Isthmus at the time with President-elect Taft unanimously agreed that those investigations removed every trace of doubt.

The Gatun Dam covers about 288 acres. The material in it weighs nearly 30,000,000 tons. The pressure of the highest part of the dam on the foundations beneath amounts to many tons per square foot. The old bugaboo about earthquakes throwing it down is a danger that exists only in the minds of those who see ghosts. Some of the



LIEUT. COL. W. L. SIBERT

THE UPPER LOCKS AT GATUN



TORO POINT BREAKWATER

biggest earth dams in the world are located in California. The Contra Costa Water Company's dam at San Leandro is 120 feet high and not nearly so immense in its proportions as Gatun Dam, yet it weathered the San Francisco earthquake without difficulty. In Panama City there is an old flat arch that once was a part of a church. It looks as though one might throw it down with a golf stick, and yet it has stood there for several centuries. As a matter of fact, Panama is out of the line of earthquakes and volcanoes, but even if shocks much worse than those at San Francisco were to come, there is no reason to fear for the safety of the big structure.

The lack of knowledge of some of those who in years past criticized the Gatun Dam was illustrated by an amusing incident that occurred at a senatorial hearing on the Isthmus. Philander C. Knox, afterwards Secretary of State, was then a Senator and a member of the committee which went to the Isthmus. Another Senator in the party had grave doubts about the stability of Gatun Dam, and asked Colonel Goethals to explain how a dam could hold in check such an immense body of water. Colonel Goethals, in his usual lucid way, explained that it was because of that well-known principle of physics that the outward pressure of water is determined by its depth and not by its volume — that a column of water 10 feet high and a foot thick would have just as much outward pressure as a lake 200 square miles in extent and 10 feet deep. Still unconvinced, the Senator pressed his examination further. At this juncture Senator Knox, who is a

past master at the art of answering a question with a question, interposed, and asked his colleague: "Senator, if your theory holds good, how is it that the dikes of Holland hold in check the Atlantic Ocean?"

CHAPTER IV

THE LOCKS

SHIPS that pass Panama way will climb up and down a titanic marine stairway, three steps up into Gatun Lake and three steps down again. These steps are the 12 huge locks in which will center the operating features of the Isthmian waterway. The building of these locks represents the greatest use of concrete ever undertaken. The amount used would be sufficient to build of concrete a row of six-room houses, reaching from New York to Norfolk, via Philadelphia, Baltimore, Washington and Richmond — houses enough to provide homes for a population as large as that of Indianapolis.

The total length of the locks and their accessories, including the guide walls, approximates 2 miles. The length of the six locks through which a ship passes on its voyage from one ocean to the other is a little less than 7,000 feet.

If one who has never seen a lock canal is to get a proper idea of what part the locks play in the Panama Canal, he must follow attentively while we make an imaginary journey through the canal on a ship that has just come down from New York. Approaching the Atlantic entrance from the north, we pass the end of the great man-made peninsula, jutting out 11,000 feet into the bay known as

Toro Point Breakwater. It was built to protect the entrance of the canal, the harbor, and anchorages from the violent storms that sweep down from the north over that region. Omitting our stops for the payment of tolls, the securing of supplies, etc., we steam directly in through a great ditch 500 feet wide and 41 feet deep, which simply permits the ocean to come inland 7 miles to Gatun. When we arrive there we find that our chance to go farther is at an end unless we have some means of getting up into the beautiful lake whose surface is 85 feet above us. Here is where the locks come to our rescue. They will not only give us one lift, but three.

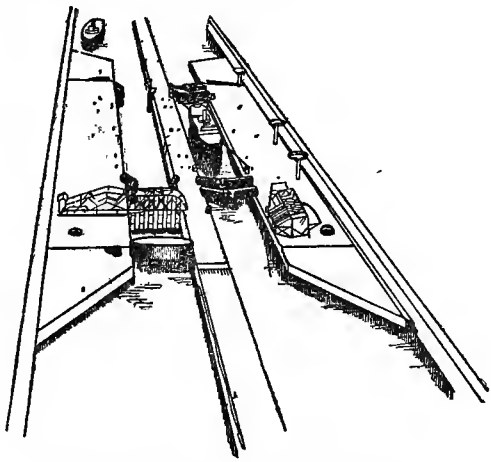
When we approach the locks we find a great central pier jutting out into the sea-level channel. If our navigating officers know their duty they will run up alongside of this guide wall and tie up to it. If they do not they will run the ship's nose into a giant chain, with links made of 3-inch iron, that is guaranteed to bring a 1,000-ton ship, going at the rate of 5 knots per hour, to a dead standstill in 70 feet. When we are once safely alongside the guide wall, four quiet, but powerful locomotives, run by electricity, come out and take charge of our ship. Two of them get before it to pull us forward, and two behind it to hold us back. Then the great chain, which effectively would have barred us from going into the locks under our own steam, or from colliding with the lock gates, is let down and we begin to move into the first lock.

Starting at the sea-level channel, the first, second, and third gates are opened and our ship

towed into the first lock. Then the second and third gates are closed again, and the lock filled with water, by gravity, raising the ship at the rate of about 2 feet a minute, although, if there is a great rush of business, it may be filled at the rate of 3 feet a minute. When the water in this lock reaches the level of the water in the lock above, gates four and five are opened, and we are towed in. Then gate four is closed again, and water is let into this lock until it reaches the level of the third one. Gates six, seven, and eight are next opened, and we are towed into the upper lock. Gates six and seven are now closed, and the water allowed to fill the third lock until we are up to the level of Gatun Lake. Then gates nine and ten are opened, the emergency dam is swung from athwart the channel, if it happens to be in that position, the fender chain like the one encountered when we entered the first lock, and like the ones which protect gates seven and eight, is let down, the towing engines turn us loose, and we resume our journey, with 32 miles of clear sailing, until we reach Pedro Miguel. Here, by a reverse process, we are dropped down $30\frac{1}{3}$ feet. Then we go on to Miraflores, a mile and a half away, where we are lifted down $54\frac{2}{3}$ feet in two more lifts. This brings us back to sea level again, where we meet the waters of the Pacific, and steam out upon it through a channel 500 feet wide and 8 miles long.

Having learned something of the part the locks play in getting us across the Isthmus, by helping us up out of one ocean into Gatun Lake and then dropping down into the other ocean, it will be interesting to note something of the mechanism. A

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

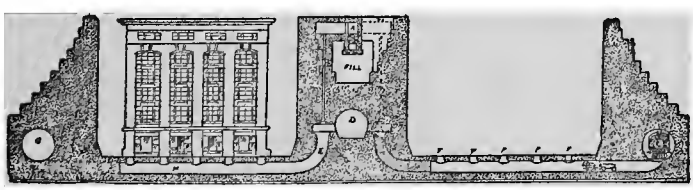


FROM A MODEL OF PEDRO MIGUEL LOCK

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

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

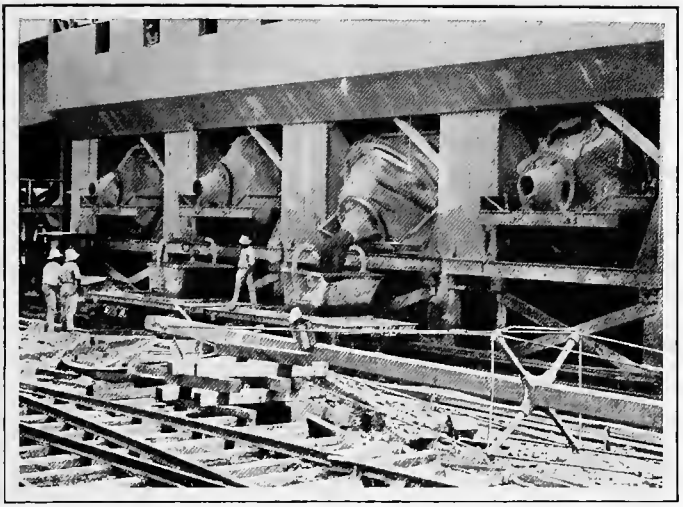
Referring to the next figure we see a cross section of the twin locks. The side walls are from 45 to 50 feet thick at the floor. At a point 24⅓ feet above the floor they begin to narrow by a series of 6-foot steps until they are 8 feet wide at the top. The middle wall is 60 feet wide all the way up, although at a point 42½ feet above the lock floor room is made for a filling of earth and for a three-story tunnel, the top story being used as a passageway for the operators, the second story as a conduit for electric wires, and the lower story as a drainage system.



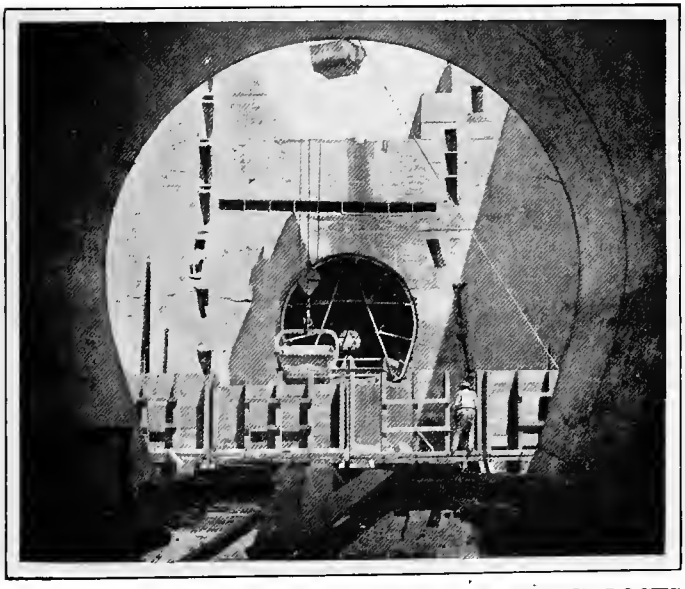
A CROSS-SECTION OF LOCKS, GIVING AN IDEA OF THEIR SIZE

In this figure D and G are the big 18-foot culverts through which water is admitted from the lake to the locks. Each of these three big culverts, which are nearly 7,000 feet long, is large enough to accommodate a modern express train, and is about the size of the Pennsylvania tubes under the Hudson and East Rivers. H represents the culverts extending across the lock from the big ones. Each of them is big enough to accommodate a two-horse wagon, and there are 14 in each lock. Every alternate one leads from the side wall culvert and the others from the center wall culvert. F represents the wells that lead up through the floor into the lock, each larger in diameter than a sugar barrel in girth. There are five wells on each cross culvert, or 70 in the floor of each lock.

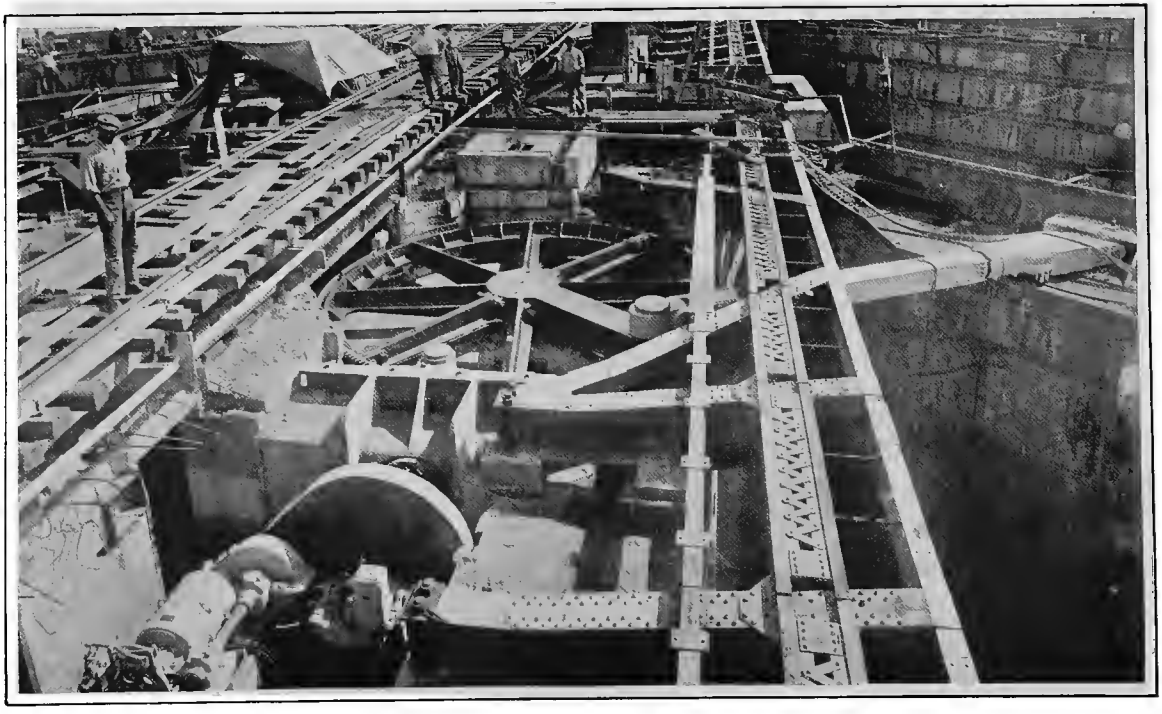
The flow of the water into the locks and out again is controlled by great valves. The ones which control the great wall tunnels or culverts are called Stoney Gate valves, and operate something like giant windows in frames. They are mounted on roller bearings to make them work without friction. The others are ordinary cylindrical valves, but, having to close a culvert large enough to permit a two-horse team to be driven through it, they must be of great size. When a ship is passing from Gatun Lake down to the Atlantic Ocean, the water in the upper lock is brought up to the level of that in the lake, being admitted through the big wall culverts, whence it passes out through the 14 cross culverts and up into the locks through the 70 wells in the floor. Then the ship is towed in, the gates are shut behind



CONCRETE MIXERS, GATUN.



A CENTER WALL CULVERT, GATUN LOCKS



THE MACHINERY FOR MOVING A LOCK GATE

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

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

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

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

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

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

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

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

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

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

On the Pacific side the concrete handling plant

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

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

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

CHAPTER V

THE LOCK MACHINERY

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

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

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

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

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

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

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

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

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

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

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

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

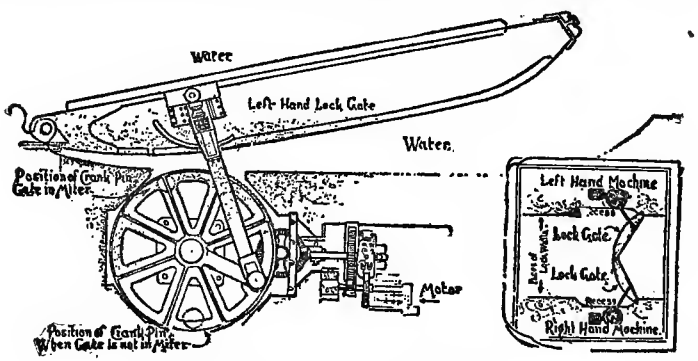
large centrifugal pumps, driven by electric motors, will pump the water out of the lock. When the work on the lock is completed these pumps will pump the water out of the caisson itself until it becomes buoyant enough to resume its light draft, after which it will be floated away.

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

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

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

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



ONE OF THE 92 GATE-LEAF MASTER WHEELS

The control of the water in the culverts of the locks is taken care of by an ingeniously designed series of valves. The big wall culverts, 18 feet in diameter, are divided into two sections at the points where the valves are installed, by the construction of a perpendicular pier. This makes two openings 8 by 18 feet. The big gates of steel are placed in frames to close these openings just as a window sash is placed in its frame. They are mounted on roller bearings, so as to overcome the friction caused by the pressure of water against the valve gates. They must be mounted so that there is not more than a fourth of an inch play in any direction. The big wall culvert gates will weigh about 10 tons each, and must be capable of operating under a head of more than 60 feet of water. They will be raised and lowered by electricity.

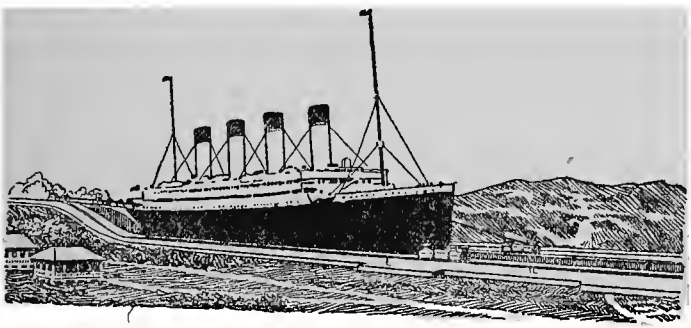
The electric locomotives which will be used to tow ships through the locks are one of the interesting features of the equipment. There will be 40 of them on the 3 sets of locks. The average ship will require four of them, two at the bow and two at the stern, to draw it through the locks. They will run on tracks on the lock walls, and will have two sets of wheels. One set will be cogged, and will be used when the locomotives are engaged in towing. The other set will be pressed into service when they are running light. When a vessel is in one lock waiting for the water to be equalized with that in the next one and the gates opened to permit passage, the forward locomotives will run free up the incline to the lock wall above, paying out hawser as they go. When they get

to the next higher level they are ready to exert their maximum pull. Each locomotive consists of three parts: two motors hitched together, and the tandem may be operated from either end. The third part is a big winding drum around which the great hawsers are wound. This towing windlass permits the line to be paid out or pulled in and the distance between the ship and the locomotives varied at will. The locomotive may thus exert its pull or relax it while standing still on the track, a provision especially valuable in bringing ships to rest. In the main, however, the pull of the locomotive is exercised by its running on the semi-suppressed rack track anchored in the coping of the lock walls. Each flight of locks will be provided with two towing tracks, one on the side and one on the center wall. Each wall will be equipped with a return track of ordinary rails, so that when a set of locomotives has finished towing a ship through the locks they can be switched over from these tracks and hustled back for another job. When they reach the inclines from one lock to the next above the rack track will be pressed into service again until they reach the next level stretch.

Here again one meets the familiar safeguard against accident. Some engineer of one of these towing locomotives might sometime overload it, so the power of doing so has been taken out of his hands. On the windlass or drum that holds the towing hawser there is a friction coupling. If the engineer should attempt to overload his engine, or if for any other reason there should suddenly come upon the locomotive a greater strain than it could bear, or upon the track, or upon the hawser,

the friction clutch would let loose at its appointed tension of 25,000 pounds, and all danger would be averted.

When the locomotives are towing a ship from the walls it is natural that there should be a side pull on the hawser. This is overcome by wheels that run against the side of the track and are mounted horizontally. All of the towing tracks extend out on the approach walls of the locks so that the locomotives can get out far enough to take charge of a ship before it gets close enough to do the locks any damage.



A *Mauretania* IN THE LOCKS

From the foregoing it will be seen that a great deal of electric current will be required in the operation of the locks. This will be generated at a big station at Gatun, with a smaller one at Miraflores, and they will be connected. The overflow water will be used for generating the required current, and in addition to the operation of the lock machinery it will operate the spillway gates, furnish the necessary lighting current, and

eventually it may furnish the power for an electrified Panama Railroad.

In passing a ship through the canal it will be necessary to open and close 23 lock gates, of an aggregate weight of more than 25,000 tons, to lower and raise 12 fender chains, each weighing 24,000 pounds, and to shut and open dozens of great valves, each of which weighs tons. All these operations at each set of locks will be controlled by one man, at a central switchboard. In addition to these operations there is the towing apparatus. The arrangement at Gatun is typical; there 4 fender chains must be operated, 6 pairs of miter gates, and 46 valves. In all not less than 98 motors will be set in motion twice, and sometimes this number may be increased to 143. Some of them are more than half a mile away from the operator, and half of them are nearly a quarter of a mile away.

The operator in his control house will be high enough to have an uninterrupted view of the whole flight of locks over which he has command. His control board will consist of a representation of the locks his switches control. On his model he will see the rise and fall of the fender chains as he operates them, the movement of the big lock gates as they swing open or shut, the opening and closing of the valves which regulate the water in the culverts, and the rise and fall of the water in the locks.

A system of interlocked levers will prevent him from doing the wrong thing in handling his switches. Before he can open the valves at one end of a lock he must close those at the other end.

Before he can open the lock gates, the valves in the culverts must be set so that no harm can result. Before he can start to open a lock gate, he must first have released the miter-forcing machine that latches the gates. Before he can close the gates protected by a fender chain, he must first have thrown the switch to bring the fender chain back to its protecting position, and he can not throw the switch to lower the chain until he first has provided for the opening of the gate it protects. All of this interlocking system makes it next to impossible to err, and taking into consideration the additional safeguard of limit switches, which automatically cut off the power when anything goes wrong, it will be seen that the personal equation is all but removed from the situation.