CHAPTER VII

CULEBRA CUT—ONE-FOURTH OF ITS ENTIRE EXCAVATION DUE TO SLIDES AND BREAKS

Everything was in readiness for vigorous and effective work when the new commission took charge in April, 1907. The preparatory stage of the work had come to an end, and the period of active construction had begun. A large part of the plant ordered by Mr. Wallace and Mr. Stevens, including about sixty powerful steam-shovels, was at hand; the tracks of the transportation system planned by Mr. Stevens were in place, and modern spoil cars, trackshifters, unloaders, and spreaders were already in use. A working force steadily growing in numbers and efficiency had been assembled.

The chief point of attack was, of course, the Culebra Cut, then, as always, the most formidable obstacle to be fought and overcome. How much more formidable it really was than had been suspected was soon to be revealed.

No part of the canal more completely confounded the preliminary estimates of some of the highest engineering authorities in the United States and Europe than the slides and breaks in the banks of the canal prism through Culebra Cut. The International Board of
Consulting Engineers, in 1906, after a thorough study of the question by a special committee, placed the probable total amount at 500,000 cubic yards. The minority report of the same board placed the total amount of Culebra Cut excavation for an 85-foot level canal at 53,800,000 cubic yards, and the majority report estimated the amount necessary at the same point for a sea-level canal with a depth of 40 feet at 110,-000,000 cubic yards. In 1908 the canal commission, in a revised estimate, placed the total Cut excavation at about 78,000,000 cubic yards. In 1910 it increased it to 84,000,000; in 1911 to 89,000,000; in 1912 to nearly 94,000,000; and in 1913 to about 100,000,000. The increase was due partially to widening the bottom width of the channel in the Cut from 200 to 300 feet, authorized by President Roosevelt in 1908, an increase of about 13,000,000 cubic yards, and other enlargements of the original plan, but mainly to breaks and slides.

A careful study of the geological structure of the Cut had been made in 1898 by two eminent French engineers, Philippe Zürcher and Marcel Bertrans, the latter a professor of geology in the National High School of Mines at Paris, and in their report they declared, in referring to slides:

The question of these cavings-in was formerly a cause of great anxiety, but that cause no longer exists. That of Cucaracha was partly due to want of care in the method of constructing the embankments, and it was easily stopped by comparatively simple works of drainage. . . . There are no caving belts to fear, ex-
cept the clays of the upper part which are already almost entirely excavated, and if any special precautions are to be taken against cavings-in, it would only be for the small extent of about 1 kilometer (0.62 mile) where the slope of the clay is toward the Cut.

Professor William H. Burr, who was a member of the International Board of Consulting Engineers, and was a strenuous advocate of the sea-level as opposed to the lock-level type of canal, said in his testimony before the Senate Committee on Interoceanic Canals, in March, 1906, in regard to slides in the Cut:

All that is necessary to remedy such a condition is simply to excavate the clay or to drain it to keep the water out. It is not a new problem. It is no formidable feature of the work. It is simply to be treated down on the Isthmus as it would be treated here. There would be no slipping of the clay in the vicinity of the Culebra Cut if it is drained, as it may be, or if portions of it, where it may readily be treated in that way, are excavated. It is not a material difficulty; it is not an obstacle to the construction of a sea-level canal. It simply means drainage and excavation; that is all. I might say that I speak, perhaps, with undue emphasis on this point, because I have been over every foot of that ground myself, and in view of my previous experience with slipping clay, I speak not from hearsay or opinion but actual observation over many years.

These opinions were based mainly upon what is known as the Cucaracha slide, on the east bank of the canal, just south of Gold Hill, which is the highest point of the Culebra Cut. This first began to move
in 1887, during the most active period of French operations, and I am assured by persons who were on the isthmus at the time that it caused a feeling among the French engineers that very nearly approached consternation, they seeing in it a most formidable obstacle to the sea-level canal which they were engaged in constructing. Be that as it may, the French engineers at once ceased operations in that vicinity and never resumed them. In consequence the slide was quiescent during the remaining period of French work. Scarcely had the Americans begun excavation there in 1905 when the slide began to move again in the first wet season, and to resume movement in the succeeding wet season. On October 4, 1907, after a period of very heavy rains, it started afresh in the night. Without warning, it shot almost completely across the canal prism, overwhelming two steam-shovels in its course, covering all the dirt-train railway tracks, and for ten days maintained a glacier-like movement of fourteen feet each twenty-four hours. During that time it filled the canal prism and piled up a mass of material thirty feet in height on the west bank. Nearly half a million cubic yards of material were thrown into the canal prism by this movement, and the operation of dirt trains through this part of the Cut was delayed for about a month. In January, 1913, during the dry season, it again became active, carrying about 2,500,000 cubic yards more into the Cut, blocking all tracks in the bottom of the canal, and bringing the total slide excavation at this point up to about 7,000,000 cubic yards.
The Cucaracha slide was the largest of those classed as normal or gravity slides. These occurred where there was a top layer of porous material resting upon a sloping surface of rock or other harder material. The water of heavy rains, sinking through the overlying porous material, caused a muddy, slippery zone to form between that and the harder material below, sending the entire top layer, of a thickness varying from ten to forty feet, into the canal prism. Slides of another type, involving a very much greater amount of excavation, are classed by geologists as structural break or deformation slides. These were due to unstable geological rock formations, steepness and height of slopes, and effects of blasting. As excavation advanced, and lateral support was removed from the high banks in the deepest portions of Culebra Cut, the underlying layer of rock of poor quality and soft material, unable to sustain the enormous weight above it, was crushed and forced laterally into the prism of the canal, causing a heaving of the bottom to a height varying from 15 to 30 feet, and a shearing and settling of the slopes. The most formidable slides of this character occurred during the dry season, and were in no way due to saturation by rainfall. They were completely unforeseen by any of the engineers who had studied conditions in the Culebra Cut before active operations were begun by Americans. The two most serious occurred on opposite sides of the canal, one north of Gold Hill, and the other in front of the village of Culebra. That on the west bank covered an area of 75 acres, involved the removal of about 10,000,000
cubic yards of material, and invaded the site of the village to such an extent that a large number of its buildings had to be removed or demolished. That on the east bank covered an area of 50 acres and involved the removal of about 7,000,000 cubic yards of material. Together these two slides widened the top width of the canal at this point from 840 to about 2,000 feet.

There were at various times during canal construction 22 slides of different kinds, covering an area aggregating 220 acres, and compelling an excavation of about 25,000,000 cubic yards, or about one-fourth of the excavation required for the Culebra Cut. In addition to the extra work required for removal of this material, the interruption of work and general annoyance caused by the slides must be taken into account. Colonel Gaillard, the division engineer in charge of the work in Culebra Cut, estimated the amount of railway track that was destroyed by them within 8.8 miles of the Cut at fully 200 miles, and that they delayed the completion of the excavation in the Cut by at least a year and a half. This delay did not affect the date of canal completion, however, because that depended upon the concrete and gate work in the locks. In spite of the addition of the 25,000,000 cubic yards of slide excavation, the Culebra Cut was ready for use when the condition of the lock work allowed the water to be turned in.

In regard to the method used in the treatment of slides, Colonel Gaillard’s views, published in November, 1912,* are those of an expert and of the first value:

*Scientific American, Nov. 9, 1912.
Innumerable plans for treating the slides have been suggested by interested and patriotic citizens throughout the country, but not one of them has proven practicable. The only successful method of treating the slides or breaks, once the material is in motion, is to dig it out and haul it away until the slide comes to rest upon reaching the angle of repose for the particular material then in motion. This angle of repose varies much in different localities, depending upon the character of the material composing the slide, the angle of inclination of the strata and the angles of the numerous dikes, faults, seams, etc. At the Cucaracha slide the angle of repose corresponds to a slope a little steeper than one vertical to five horizontal, while on the west bank of the Cut at the town of Culebra, the material is still moving slightly on a slope of about one vertical to five horizontal.

In one or two slides which have developed in the Cut, the surface on which the material was sliding had a slope of one vertical to ten horizontal, and in the case of another slide on the west bank of the canal, north of the village of Culebra, the moving material, which consisted of stratified rock, was moving en masse, at the rate of three feet in twenty-four hours, on a lignite layer about six inches thick, which had a slope of about one vertical to seven horizontal and was underlaid by layers of sedimentary rock, which did not move. A rather remarkable thing about this last slide was that, like two or three other slides, it developed in the dry season and moved at a faster rate during the four months when there was no rain than it has done since the rains have come.

The writer is aware that there is a very general impression that slides are due solely to saturation by rainfall, or underground water, of the material which is in motion, and while this is to a great extent correct
for the slides like the one at Cucaracha, yet there have been three large slides, involving in all nearly two million cubic yards of material, which developed during the dry season and were composed wholly of material so dry that when loaded on the trains, the cars were almost hidden during the windy season by clouds of dust. One of these slides was moving on a surface which had a slope of one vertical to six horizontal, and its rate of advance was about two and one-half feet per day for several months. A steam shovel made one hundred and three cuts across the toe of this slide with the position of the loading track unchanged.

But while the slides were an annoyance and added heavily to the task in hand, they were of great value in demonstrating the utter impossibility of constructing a sea-level canal across the isthmus, thus vindicating the wisdom of the minority members of the International Consulting Board and the foresight of President Roosevelt, Secretary Taft, and the first canal commission in favoring and securing the adoption of the lock plan. A sea-level canal would cost billions of money, in all probability would never be completed, and if completed, could not be kept open for navigation. This is virtually the universal opinion among engineers today.

The work in Culebra Cut was under the direction of W. E. Dauchy as division engineer from November, 1904, till July, 1906. He was appointed by Mr. Wallace, and retained by Mr. Stevens until the latter date. He was succeeded by D. W. Bolich, who retained the position of division engineer after the Goethals administration came in, on April 1, 1907, acting under Colonel
D. D. Gaillard as head of the Department of Excavation and Dredging. He retained the position till May, 1908, when he resigned and was succeeded by L. K. Rourke. On July 1, 1908, a new organization was created, consisting of three divisions—Atlantic, Central, and Pacific, and Colonel Gaillard was made division engineer of the Central Division which included Culebra Cut. L. K. Rourke was made assistant division engineer, retaining that position till June 1, 1910, when he resigned to accept the position of superintendent of streets in Boston, Mass. He was the author of the organization for work in the Culebra Cut which was continued in operation with remarkable success till the completion of the task. On his retirement the position of assistant division engineer was abolished, and Colonel Gaillard assumed personally its duties.
CHAPTER VIII

THE WONDERFUL CULEBRA CUT

The special wonder of the canal, its spectacular show-piece, was and still is the Culebra Cut. Those who see it first from the decks of passing ships, however, can form only a very inadequate conception of its appearance during the final years of construction, when the fight of man against Nature was at its height, Nature striking back in a quick succession of terrific blows. Then, indeed, it was one of the world's wonders, and by no means the least. Nothing else in the work was comparable to it, for this alone was destructive, while the other great features were constructive, the mere piling up of great masses of earth and concrete in accordance with well-established rules and without serious obstruction or opposition. Experience and trained ability were necessary for the proper accomplishment of these tasks, and their unprecedented magnitude made them interesting, but there was little in them to arouse enthusiasm or that could be called inspiring.

With the struggle in the Cut, it was quite another matter. Here the problems were new and strange. As John Hay once said of one of the most turbulent of the South American countries, the isthmus was a "land of the fantastic and the unexpected." No one
could say when the sun went down at night what the condition of the Cut would be when the sun arose the next morning. The work of months and years might be blotted out by an avalanche of earth or the toppling over of a small mountain of rock.

It was a task to try men's souls, and it was one also to kindle in them a joy of combat which no repulse could chill and a buoyant faith in ultimate victory which nothing could shake.

From all quarters of the globe came engineers and others engaged in construction operations to view the struggle. They came in doubt often as to the outcome, but they went away with all doubt removed. What had given them confidence was a close view of a working organization the like of which, for efficiency, perfection of detail, precision, and smoothness of operation, unity of spirit and enthusiasm, they confessed frankly never to have seen before. For an organization of that character, they said, no obstacle was insurmountable. They were not surprised, after witnessing this wonderful human machine at work, that slide after slide went into the Cut without causing the faintest shadow of uneasiness to any one concerned, and without delaying the final completion of the task. A distinguished American engineer, who himself had directed some of the largest construction enterprises in the country, after watching the organization in operation, wrote of it to a friend: "I have never seen its superior—such perfect co-ordination and such energetic prosecution at every point, all under absolute control. It is something that everyone from the chief
down is entitled to the greatest credit for and in which everyone can justly take the greatest pride. I went to the Isthmus with my mind made up to be impressed, but the actualities exceeded my anticipations."

The spectacle exceeded all anticipations, for nowhere else on earth was there to be found a display of human activity on so large a scale and with so marvellous a setting. It was this combination which added the final touch of the extraordinary to the picture. To stand at the southern end of the Cut, between the towering, majestic hills of the Great Divide, was an experience which few who had ever had it could easily forget. On either side were the grim, forbidding, perpendicular walls of rock, and in the steadily widening and deepening chasm between—the first man-made canyon of the world—a swarming mass of men and rushing railway trains, monster-like machines, all working with ceaseless activity, all animated seemingly by human intelligence, without confusion or conflict anywhere. Throughout the eight miles of the Cut the scene varied only in the setting. The rock walls gave place here and there to the ragged sloping banks of rock and earth left by the great slides, covering many acres and reaching far back into the hills, but the ceaseless human activity prevailed everywhere. Everybody knew what he was to do and was doing it, apparently without verbal orders and without getting in the way of anybody else. It was organization reduced to a science—the endless-chain system of activity in perfect operation.

Instead of detracting from the spectacular or pictur-
esque effects of the natural setting of the work, the slides enhanced them by adding a distinct touch of awe, possibly of terror. They revealed more clearly than ever the tremendous difficulties of the task and the magnitude of the victory which was being achieved in surmounting them.

The effect of a trip through the Cut while the work was in full progress was the same on all visitors—amazement coupled with admiration. Tourists from the United States emerged invariably in a glow of patriotic enthusiasm, with an irrepressible desire to remove their hats and cheer for the American flag—to let the "eagle scream." Those from other lands, especially if they were engineers, and there were many of these from all the leading countries of the world, were scarcely less enthusiastic, and were astonished at the magnitude of the task and unstinted in expressions of admiration for the manner in which it was being accomplished. I have seen many of these during my six years' connection with the work, but not one who did not declare it to be the finest exhibition of engineering organization and execution that he had ever witnessed. Generally, the more the observer knew of engineering and construction work, the higher and warmer was his appreciation.

What most impressed all observers, next to the organization, not merely of the Cut, but of the entire work, was the loyalty and enthusiasm of the force. An eminent visitor from Japan was especially struck by this, being apparently much surprised at its manifestation. "What are your impressions?" he was asked at the
Culebra Cut, looking north from La Pita, showing close view of rock break in east bank, October 9, 1912.
close of a careful inspection of all parts of the work, extending over a period of several days. “Is the work as great as you anticipated?” “Oh, very much greater,” he replied; “it is stupendous, magnificent, colossal! No nation but the great, rich American nation could build this canal. Japan has much to learn from you.”

What he saw on every hand as he moved about was not so much the wealth, resources, and power displayed in the task, but the spirit of the nation itself as revealed in the zeal and enthusiasm of the men who were doing the work. In the creation and development of this spirit the struggle in the Cut was the most powerful factor.
CHAPTER IX

CHANGES IN CANAL PLANS — LARGERLOCKSAND WIDER CHANNEL—ESTIMATES OF TOTAL COST

During 1907 work was prosecuted with such vigor at all points along the line of the canal that a grand total of 15,765,290 cubic yards of excavation was accomplished. In March the million cubic-yard limit was reached for the first time and passed. There was a decrease in May and June, due partly to the rainy season and partly to temporary trouble with steam-shovel operators over the question of wages, but in August a total of 1,274,000 cubic yards was reached, an achievement which called from President Roosevelt a congratulatory message by cable to Colonel Goethals. There was a large increase in September, October, and November, and in December the 2,000,000 mark was reached and passed in a total of 2,200,000 cubic yards, making the grand total for the year 15,765,290, or an average of over 1,300,000 a month. This was more than double the amount excavated during the preceding three years, which had aggregated less than 7,000,000 cubic yards.

Changes in the plan of the canal were made in 1908 which added about $18,500,000 to the cost of construction. On January 15 President Roosevelt approved
a resolution of the Isthmian Canal Commission increasing the width of the locks of the canal from 100 to 110 feet, in accordance with an opinion of the General Board of the navy that such an increase was desirable. This added about $5,500,000 to the cost of construction. On October 23 the President authorized the enlargement of the bottom width of the canal, throughout four and a half miles of the deepest part of the Culebra Cut, from 200 to 300 feet, making 300 feet the minimum width at any point in the entire canal. This enlargement required about 13,000,000 cubic yards of additional excavation, and entailed an extra expense of about $13,000,000. Under the original plan this section of the canal had a bottom width of 200 feet. This and other changes in the original plan, all in the direction of enlargement, had increased the total excavation, estimated by the authors of the project at 103,796,000 cubic yards, to 174,667,000, or by more than two-thirds. After these changes had been made the total cost of the canal, including the $40,000,000 paid to the French canal company and the $10,000,000 paid to the Republic of Panama, was estimated by the Isthmian Canal Commission at $375,201,000. This estimate was announced to the House Committee on Appropriations by the chief engineer, Colonel Goethals, at Washington, on February 15, 1909, and was embodied in the annual report of the commission for that year.

So far as excavation was concerned, 1908 was the "record year" in canal construction. During that year the plant, or working equipment, reached its
maximum. There were in service 101 steam-shovels, about 300 locomotives, about 4,000 dirt or spoil cars of various kinds, 46 car unloaders or ploughs, 25 spreaders, and 10 trackshifters. The railroad trackage had been increased from 74 miles in 1904 to 160 miles, with 50 miles of main track and 35 miles of double track on the Panama Railroad line, all equipped with new and heavy rails. The efficiency of the working force, through experience, had more than doubled during the previous two years. Because of familiarity with climatic conditions, nearly as much work was accomplished during each of the eight or nine months of the rainy season as during those of the dry season. As a result, the total excavation of 1908 exceeded 37,000,000 cubic yards, and the average for each month of the year, wet or dry, was about 3,090,000 cubic yards. The highest total for a single month in 1908 was that of March, which was 3,487,287 cubic yards. This was surpassed in March, 1909, when for the first and only time during canal construction the four-million mark was reached, with a total of 4,062,632 cubic yards.

This was the record-mark in excavation. The monthly totals began to drop after that date, for the reason that in several localities the work had been completed and the field of operation had been narrowed. From that time forward excavation ceased to be the primary and became the secondary element in canal work, the construction of locks and dams passing into the first position. The excavation of 1909, consequently, while exceeding 35,000,000, fell 2,000,000 below that of 1908. The grand total for the
Old village of Gatun from dam site, November, 1906.

Canal Channel, looking south from San Pablo to Caimito. Width of channel, 800 feet; surface of water, 55 feet above sea-level. October, 1912.
two years exceeded 72,000,000 cubic yards, making the average each month for that period 3,000,000 cubic yards. In 1910 and 1911 the total exceeded 31,000,000 cubic yards, the monthly average being over 2,600,000 cubic yards, and in 1912 it exceeded 30,000,000. The grand total for the five years of greatest activity, 1908, 1909, 1910, 1911, and 1912, exceeded 165,500,000 cubic yards, an average of over 2,750,000 cubic yards a month, comprising more than 75 per cent of the excavation of the entire canal.
CHAPTER X

GATUN DAM AND LOCKS—FIRST SUGGESTION OF THE SITE—ITS NATURAL ADVANTAGES—HUMOROUS AND OTHER ASSAULTS

Credit for the first suggestion of Gatun as the site for a great dam belongs to Godin de Lépinay, chief engineer of bridges and roads, who was one of the French delegates to the Lesseps International Congress at Paris, in 1879. This able and far-seeing engineer was one of the foremost of the opponents in that congress of the Lesseps project for a sea-level canal across the isthmus. He was a member of the committee on technique in the congress which had charge of technical questions relating to the proposed canal, including physical conditions, cost of construction, operation, and maintenance, and facility and security of operation. He made repeated efforts to obtain from Lesseps and his sea-level advocates satisfactory estimates on these points, but could get only the vaguest guesses. Having had personal experience in directing work in the tropics—being, in fact, the only French engineer in the congress with such experience—M. de Lépinay made estimates of his own in regard to the costs of a sea-level canal, and reached the conclusion that they were so great as to be prohibitive. He prepared a
In support of this, plan he advanced arguments which were virtually identical with those used successfully a quarter of a century later by the advocates of the present canal.

He contended that a lock canal could be constructed for at least 500,000,000 francs ($100,000,000) less than a sea-level canal; could be constructed in much shorter time, and at less cost of human life; would be easier and quicker in navigation; and would make the Chagres River not a menace as a canal at sea-level would, but an ally and aid to navigation.

M. de Lepinay's paper made a strong impression on the congress, but Lesseps would not consider it or permit it to be put to a vote. Its author's views had such weight, however, with the committee on technique that when the final vote on the Lesseps project was taken only nineteen of its forty-two members voted ay, while five voted no, fourteen were absent, and four declined to vote. The Gatun suggestion had evidently attracted attention in the United States, for in 1880 it was advanced by Ashbel Welch, an American engineer, in a paper before the American Society of Civil Engineers, and again by C. D. Ward before the same society in 1904. It was not included in the lock-canal project adopted by Lesseps and the new Panama Canal company in 1887, when he was compelled to abandon his sea-level plan, for that project included one dam at Bohio and another at Bas Obispo, on the Atlantic side, with a
double flight of two locks at each point, and duplicate single locks at Paraiso, Pedro Miguel, and Mirafloros, on the Pacific side, with a summit elevation of about one hundred feet above sea-level. The Isthmian Canal Commission of 1899–1901, generally known as the Walker commission, after its chairman, Rear-Admiral John G. Walker, U. S. N., followed the suggestion of the new Panama Canal company and recommended Bohio as the site for a dam. Just how much consideration, if any, this commission gave to the Gatun site does not appear from its report, for there is no mention of it; merely a statement that "no location suitable for a dam exists on the Chagres River below Bohio." The Walker commission plan included two double locks at Bohio, a lake with a summit level of ninety feet, two double locks at Pedro Miguel and one at Mirafloros.

When the first commission that was appointed to construct a canal at Panama began its work, in 1904, it was proceeding under the authority of the Spooner Act of 1902, which provided merely for the construction of a "canal of sufficient capacity and depth as shall afford convenient passage for vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated." No specific type of canal was designated, but the general expectation was that the lock type would be adopted. Operations were begun with that type in view, and the engineers in charge showed that they had the Gatun site in mind by making surveys and soundings at that point as well as at Bohio. These had been under way for some weeks when the first chief engineer, Mr. Wallace, took charge
Gatun Upper Locks. The foot-bridge across the Upper Guard gates, January 14, 1913.
on July 1, 1904. He continued the work during the eleven months of his administration, but he had in the meantime reached the conclusion that a sea-level canal was preferable to one with locks and took little interest in the investigations and did not make them sufficiently thorough to be decisive. Mr. Stevens, who succeeded him in July, 1905, was impressed on his first careful study of the field by the superior advantages of the Gatun site, and had such additional borings made as convinced him of its suitableness. He recommended it earnestly both to the canal commission and to the International Board of Consulting Engineers when that body visited the isthmus, in 1905. Its adoption by the minority members of that board in the plan of canal recommended by them and approved subsequently by Congress was due largely to his advocacy.

No part of the canal project was more furiously or more ignorantly assailed and none has been more ludicrously misunderstood than the Gatun Dam. The majority of visitors from the United States and elsewhere, who passed in great swarms over the isthmus during the final years of construction, expected to see a structure of masonry towering more or less straight into the air for a distance of several hundred feet. What they did see was a low-lying ridge, which did not look in the least like a dam, but more like the sloping bank of a pond or river. James Bryce, the distinguished English author, traveller, and diplomatist, who visited the isthmus in September, 1910, spoke of the canal project as the "most gigantic effort yet made by man on this planet to improve upon Nature." No
part of that project is an improvement more in harmony with Nature's work than the erection of this dam at the extreme southern point in the valley of the Chagres where the encircling hills most nearly approach each other. If Nature had intended to place a great lake among the hills of the isthmus at Panama, she would have put a barrier across the valley at this point. It converts the valley of the Chagres into a huge reservoir which impounds all the water that flows into it, not only from the Chagres River, which is the principal source of supply, but from many other smaller streams. It is not only as solid as the everlasting hills, but more scientifically constructed than they are, more pains, if one may say so without irreverence, having been taken in its making. That it will hold water has been demonstrated to the satisfaction of everybody whose opinion has value. Tropical growth is covering it with a thick mantle of green, and all signs of construction are disappearing from view.

The visitor stands on its summit and asks: "Where is the dam?" If he recalls the fierce and persistent assault which was made upon both the site and the method of construction, an assault which endured for three years and attracted the attention of the whole world, he will wonder what inspired it. It was an assault as unreasoning as it was venomous. No weapon was too contemptible or too ridiculous to be used, and no ally too unworthy to be welcomed. Engineers who had advocated the sea-level plan threw aside professional etiquette and even professional pride, and sometimes openly, but oftener anonymously, gave
the color of expert knowledge to gross and shameless misrepresentation. Foreign engineers, some of whom had been connected with the Lesseps failure, were given front rank in the onslaught, and their views commanded unlimited space in portions of the American press, in ludicrous disregard of the obvious fact that if there were in the world persons whom it behooved to keep silent, they were those who had attempted to perform the task in hand and had failed. Every man with a canal plan of his own, or with an invention he wished to have adopted for canal work; every contractor whose bid had been rejected by the canal commission—all these were sure of a hearing in this chorus of misrepresentation and defamation.

No rumor was too ridiculous to be credited. An unconscious humorist, eager for journalistic fame, sent to an American newspaper a report that a great underground lake had been discovered under the Gatun Dam—and the newspapers published it, without hint of a grin! This feat excited the ambition of a rival, who was an equally unconscious humorist, and he, when an insignificant slump in one of the toes of the as yet unbuilt Gatun Dam occurred, cabled to New York and the world that the dam had “sunk.” These two grotesque “yarns”—underground lake and sinking dam—coming one after the other upon a public that had been educated to uneasiness by the persistent assault on the Gatun site, were accepted at their face value. They spread instantly, not only throughout the United States, but over Europe, carrying everywhere with them doubt about the canal project.
So wide-spread was the uneasiness created, that President Roosevelt in January, 1909, requested Secretary Taft to go to the isthmus for a personal inspection and appointed to go with him a special commission,* composed of seven of the country's most eminent civil engineers with instructions to make a thorough investigation and "report especially upon the feasibility and safety of the Gatun Dam project." Secretary Taft, accompanied by Mrs. Taft and the seven engineers, arrived on the isthmus on January 29 and remained till February 7. This was Mr. Taft's fifth visit as Secretary of War. He made two visits subsequently as President, in 1910 and 1912, being again accompanied on the latter by Mrs. Taft. As was his invariable custom in all his visits, he devoted nearly every hour of the day, in company on this occasion with the engineers of the special commission, to a thorough inspection of all parts of the work, and gave up the evenings to receptions and meetings of employees at which he made addresses. In his address in 1909 he warmly praised the manner and spirit in which the work was being carried forward and predicted certain and brilliant success. On his way back to Washington, in an informal speech at Meriden, Miss., he said:

I do not care whether you are Democrats or Republicans, you want the work done, and when the army engineers who are doing this work are giving all their time to the carrying out of this work, you are not men to go back on them or to believe every idle story that

Special Commission of Civil Engineers, January, 1909.

Top row, left to right: Colonel Goethals, James D. Schuyler, Isham Randolph, John R. Freeman.
Bottom row, left to right: President Taft, Frederic P. Stearns, Allen Hazen, Henry A. Allen, Arthur P. Davis.
comes from the mouth of some politician who is seeking to make himself prominent, or to give himself the advertisement of a little unfounded sensational statement.

That work is being done honestly. I know what I am talking about. The Canal will be built, and all the windy opposition that comes merely from a desire to exalt and exploit the man who makes himself responsible will not obstruct it.

On February 16, the engineers made an elaborate report to the President in which they declared unanimously that a full study of the subject had left no doubt in their minds "as to the safe, tight, and durable quality of the Gatun Dam," and that they were satisfied that "the dams and locks, the lock gates, and all other engineering structures involved in the lock-canal project are feasible and safe, and that they can be depended upon to perform with certainty their respective functions."

In sending the report to Congress, on February 17, President Roosevelt said: "This report not only determines definitely the type of canal, but makes it evident that hereafter attack on the type—the lock type—is in reality merely attack upon the policy of building any canal at all."

Shortly before Secretary Taft and the engineers had gone to the isthmus, Mr. John F. Stevens, the predecessor of Colonel Goethals as chief engineer, published a letter * in which he expressed the opinion that the attack on the Gatun Dam was in the interest of the rejected Nicaraguan project, adding:

* Engineering News, December 31, 1908.
The question of the advisability of building an Interoceanic Canal has nothing whatever to do with the matter. The people have decided they want the canal and they are ready to pay for it. The choice of its location has been wisely made, and the work properly planned. It is in competent hands, and is being executed with a rapidity that surprises even its friends. And the thing to do is to extend to Colonel Goethals and his assistants all the encouragement and moral help possible, which the importance of the work demands. And the engineering world will have every reason to be proud of the result when it is an accomplished fact.

The publication of the report and the plain and truthful characterizations by the President, Secretary Taft, and Mr. Stevens of the real motives of the prolonged assault upon the canal work put an end to the agitation. A few feeble and spasmodic efforts were made subsequently to revive it; but these, too, ceased in August, 1909, when Congress authorized for canal construction a bond issue of $290,569,000, in addition to previous issues, bringing the total up to the $375,000,000 estimated as necessary for constructing the canal.

As the visitor to the isthmus to-day stands at Gatun and looks over the locks and the low-lying dam he cannot fail to wonder, if he is familiar with this long and venomous assault, what it was all about. The dam fits so completely and so unobtrusively into the natural conformation of the region that it does not seem to be at all artificial, or the work of man. It is so low and flat, so broad and solid, and so apparently a part of the
everlasting hills themselves, that it seems incredible that intelligent men should ever have raised the question of its stability and efficiency. Like the great lake whose waters it holds so surely in place, it looks for all the world as if it had been there from the dawn of time. So strong is this impression that soon after the lake was formed an ingenuous foreign visitor, who had not grasped in its entirety the plan of the canal, remarked to an engineer who was showing him about Gatun: "You were extremely fortunate, you know, to have this large body of water here!" Another visitor, with equally keen powers of observation, after having been taken over the Gatun Dam in a motor-car running on railway tracks, a proceeding consuming nearly an hour's time, and after having been told that the dam contained 21,000,000 cubic yards of material, asked his guide: "Is this a permanent or merely a temporary structure?" Still a third of this joyous class of visitors, whose advent on the isthmus contributed a welcome note of gayety to its sometimes monotonous life, after looking at the spillway of the dam, a concrete-lined channel 285 feet wide and 1,200 feet long, through which water was rushing furiously, asked thoughtfully: "Where are you going to put the roof?"

In the interest of historic truth it should be recorded that the site of the locks at Gatun was assailed as furiously and persistently as that of the dam. It was said to be composed in part of sand and gravel, to be permeable to water, and to be unsatisfactory in general. To quiet any misgivings that might be raised by these assertions, President Roosevelt, in the spring of 1907,
requested three of the highest engineering authorities on lock and dam construction in the United States—Alfred Noble, Frederic P. Stearns, and John R. Freeman—to visit the isthmus and make a personal examination of the Gatun and other sites. They went to the isthmus in April with Secretary Taft, and, by means of test pits which had been dug for the purpose, inspected the various sites, reporting on May 2 that they found that “all of the locks will rest upon rock of such a character as should furnish a safe and stable foundation.” To-day the lock walls are in place and furnish to the eye an aspect of solidity and stability equal to that of the dam. They are mere continuations upward of the natural rock upon which they stand, and are as immovable and as indestructible. There has been no sign of settling, or of leakage, or of percolation beneath or around them. Like the dam, they have confounded the direful predictions of the prophets of evil and silenced them forever.

It is impossible to convey in words anything approaching an adequate conception of the picture which the series of locks, with their massive, towering walls and their equipment of colossal gates, presents. It defies description, as it does the camera, even in its wonderful modern development, and can be portrayed only by the inspired pencil of a Pennell. It is stupendous, prodigious, overwhelming; even these adjectives are inadequate. As I stood on the walls with a distinguished engineer, who had been a strenuous advocate of a sea-level canal, I asked him if he could conceive of a safer place in which to put a great ship
than inside one of the locks, and he replied without hesitation that he could not. They will be the brilliant spots in the illuminated canal, with their great clusters of electric lamps, high up on shapely concrete columns, flooding every portion of the vast structures with noon-day brightness, making them the shining centres and symbols of what Joseph Pennell calls the greatest of the world's Wonders of Work.

After the locks were completed and the huge gates, weighing from four hundred to seven hundred tons each, were being erected, the final, despairing wail of the assailants of the lock canal was emitted. Two of the gates had been finished and the test of the ability of the new machinery for opening and closing them was about to be made. A short time earlier, that indefatigable, but invariably anonymous and polyonymous personage, known indifferently as "an American engineer" or "an eminent engineer," who was very familiar in the newspapers of the United States during the early period of construction, emerged into view with the startling information that a stupendous disaster was about to occur on the isthmus. He declared that he had returned recently from a thorough inspection of the canal work and knew what he was talking about. The Gatun Dam was all right, and the slides in Culebra Cut could be disposed of easily, but a far greater peril was hanging over the project and was to be found in a totally unsuspected quarter—namely, in the huge lock gates. When the attempt was made to move these, he predicted, a truly awful catastrophe would follow, for they would move only to fall in a mass of ruins—mere
junk or "scrap." With this portentous warning ringing in his ears, Colonel H. F. Hodges, the author and supervising architect of the gates, proceeded, without visible perturbation, to Gatun one morning in May, 1912, and in the presence of other canal officials "bowdaciously," as Uncle Remus would say, turned the small switch which started the operating machinery of a gate. As the great wheel in the wall began to revolve, a leaf of the massive gate moved slowly from the wall beside which it hung, and without noise or vibration, and with perfect steadiness, swung into position at the opening of the lock. The journey was made in one minute and forty-eight seconds, twelve seconds less than was required in the specifications under which it had been constructed. Colonel Hodges pulled the switch again, and the return journey was made in the same manner and time. Since then other gates have been swung in other locks with like success and there has been no "crash," save in the reputation of the prophet who, like all his kind, concealed his identity at the moment of supreme inspiration.

The work at Gatun was under the direction of Colonel William L. Sibert during the entire period of construction. Previous to his arrival the work done had been nearly or quite all preparatory, and in this A. B. Nichols, in charge of surveys and explorations, and F. B. Maltby and William Gerig, division engineers in the Stevens organization, had been the chief agents. Mr. Maltby resigned in August, 1907. Mr. Gerig remained as division engineer of the Gatun Dam division till June 30, 1908, when he resigned. Under a new organ-
Gatun Locks, looking toward the Atlantic, June 1, 1913. Electric-light poles partially constructed. Range lighthouse at the left.
ization which went into effect on July 1, 1908, Colonel Sibert became the division engineer of the Atlantic division, which included all work at Gatun and the Atlantic entrance to the canal. Major Chester Harding, U.S.A., who had been division engineer of the Gatun Locks division, was appointed assistant division engineer. He retained that position till February 27, 1913, when he resigned to accept the position of engineer member of the board of commissioners of the District of Columbia. Others associated with Colonel Sibert in the work were Major Edgar Jadwin, Major J. C. Jervey, Captain G. M. Hoffman, Captain Horton W. Stickle, Captain W. S. Ross, and Lieutenant-Colonel William V. Judson, all of the United States army. Of these, Major Jervey and Captain Hoffman were engaged in the work during the entire period of construction, and the others for a portion of that period, with the exception of Lieutenant-Colonel Judson, who was added to the division force in place of Colonel Harding in March, 1913, after the work was nearly completed.

Full charge of all the designing work of the canal was vested by Colonel Goethals in Colonel H. F. Hodges when the latter became a member of the canal commission in July, 1908. Previous to that date, as general purchasing officer of the commission and chief of the Washington office, Colonel Hodges had been in charge of the designs for the lock gates. Colonel Goethals had desired to have him appointed to the commission when it was reorganized in 1907, but he could not be relieved from the position which he held at that time—principal assistant to the chief of engineers at
Washington. He was considered by Colonel Goethals to be the army engineer best fitted by ability and experience to supervise the designing work. He had been an assistant under General O. M. Poe, when the latter was constructing the Poe lock in the Sault Ste. Marie Canal, and had designed the steel gates for it. Colonel Goethals authorizes this estimate of his services:

He took over the designing work for the Panama Canal at a time when definite plans had to be adopted and the work carried to completion: Comprised in that work were designs for the dams, locks, gates, spillways, valves, operating machinery, hydro-electric station, and aids to navigation. He was placed in charge subsequently of the erection of gates and the installation of valves and operating machinery. Charged with the solution of the most important engineering problems of the canal, it can be said of him truthfully that the canal could not have been built without him.
CHAPTER XI

LOCKS AND DAMS ON THE PACIFIC SIDE—THE TASK MUCH SIMPLER THAN THAT AT GATUN

It is a curious fact that the most vulnerable feature of the original plan for an eighty-five-foot level canal was assailed scarcely at all by the opponents of the project. They directed their assault upon the Gatun site, paying little or no heed to the fact that at the Pacific end a site for two great dams and a double flight of two locks had been selected which had far more questionable features. Work had only begun at this site when it was demonstrated that no suitable foundations for the proposed dams could be secured save at much larger expense than had been estimated. Then, too, the locks, if erected on the site proposed, would extend out into Panama Bay and be exposed to bombardment from an enemy's ships.

Secretary Taft, on February 19, 1906, in his letter to President Roosevelt transmitting the reports of the International Consulting Board, had recommended the adoption of the lock plan except so far as it related to the dam and locks at the Pacific end. On this point he said:

The great objection to the locks at Sosa Hill is the possibility of their destruction by the fire from an
enemy's ships. If, as has been suggested to me by officers of this Department entitled to speak with authority on military subjects, these locks may be located against and behind Sosa Hill in such a way as to use the hill as a protection against such fire, then economy would lead to the retention of this lake. The lake would be useful to commerce as a means for relieving any possible congestion in the canal should the traffic be very great and would give, in case of need, a place for concentrating or sheltering the fleet. If, however, Sosa Hill will not afford a site with such protection, then it seems to me wiser to place the locks at Miraflores.

John F. Stevens, the second chief engineer, had expressed similar views. In giving his formal approval to the plan, on January 26, 1906, he said:

As regards the plan and alignment of the canal at the Pacific end, I am still inclined to my former expressed opinion that, on account of the military and sanitary features, the location of all the locks at Miraflores and Pedro Miguel, instead of part of them at La Boca, with the necessary dam at the same place, will be found more satisfactory; but as the latter plan will cost about $6,000,000 less to construct than the former one, I am ready to waive my views in favor of the latter plan, although simply on account of the difference in the estimated cost.

Work had been in progress only a few months on the toes of one of the dams when it was discovered, through the shifting and sinking of the trestles from which spoil from Culebra Cut was being dumped, that the material overlying the rock foundations was composed mainly of
Spillway Dam. Regulation gates in position between the piers, June 1, 1913.

Emergency dam swung across entrance of Gatun Lock, June 1, 1913.
The wicket girders will drop from the portions of the dam overhanging the water.
unctuous blue clay, without grit, possessing little supporting power, instead of a stiff clay, as indicated on the profiles of the original borings. The depth of rock below the surface varied from ten to seventy feet. A new estimate of the cost of constructing stable dams there, based upon additional borings, placed it at $11,574,000, or more than double the original estimate of $4,314,000. In view of all this a further examination was made of the canal route from Pedro Miguel to the Pacific to ascertain if more suitable foundations for locks and dams could be found. These resulted in showing that there existed satisfactory foundations for one lock at Pedro Miguel and for two at Miraflores, a point about a mile and a third nearer to the Pacific. The locks themselves would constitute a portion of the necessary dams, and as they would lie behind high hills and be from three to four miles inland, they would be protected against possibility of distant bombardment from the sea and be less exposed to gunboat or torpedo attack. This superior military position was of itself a very powerful reason for the change. The new project would eliminate the proposed large lake on the Pacific side, as it provided only for a small lake about a mile square between Pedro Miguel and Miraflores, and would entail a cost of about eight million dollars less than the original one.

Colonel Goethals submitted the proposed change, with the unanimous recommendation of the commission, to President Roosevelt on December 9, 1907, and the President approved it on December 20. As amended, the plan provided for a double lock, with a lift of
30\frac{3}{4} \text{ feet, at Pedro Miguel, two double locks in flight, with a combined lift of } 54\frac{3}{4} \text{ feet at Miraflores, and from there to deep water in the Pacific, a distance of } 8.31 \text{ miles, a channel } 500 \text{ feet in width and } 45 \text{ feet deep below mean sea-level.}

The change of plan delayed somewhat the beginning of work on the Pacific side. There was much less clearing required than at Gatun, and this was begun early in January, 1908, and active excavation for the locks, both at Pedro Miguel and Miraflores, began soon afterward. Both sites lie in the valley of the Rio Grande, which is about half a mile wide at Pedro Miguel and about two-thirds of a mile wide at Miraflores, with hills on both sides. Between the hills and the walls of the upper locks at both places dams were erected forming a complete barrier to the water, that at Pedro Miguel maintaining the water-level of Gatun Lake, and that at Miraflores the level of the intermediate or Miraflores Lake. The natural level of the valley in which this lake lies was so near to that of the bottom of the canal prism that only about one million cubic yards of excavation was necessary for the channel through it.

The lock site at Miraflores was crossed from the west by the Cocoli River, a tributary of the Rio Grande. It is quite a formidable stream in times of heavy rains. In order to divert it from the lock site during the period of construction, and to have the use of its waters afterward in the Miraflores Lake, the dam on the west side, constructed in the same manner as that at Gatun, was run on a line nearly parallel to the axis of the locks.
Pedro Miguel Locks, January 25, 1912.

Gatun Upper Locks.
South entrance to east chamber.
Surface of lake, 48 feet above sea-level.

March 15, 1913.
from the head of them to Cocoli Hill, a distance of two thousand three hundred feet. By this means the river was made to enter the Miraflores Lake site at its upper end, flowing through it and out through a diversion channel on the east side of the locks. When the lock work was finished this channel was closed with a concrete dam, extending from the lock walls to the hills. In the dam a spillway allows the surplus water of the lake to escape and be used to supply power to the electric plant near by.

The work at Pedro Miguel and Miraflores was under the direction of Sidney B. Williamson, division engineer of the Pacific division, from its beginning till December, 1912, when he resigned to accept the offer of an important position from an English contracting firm with headquarters in London. He had been in the canal service since May, 1907; was the only civilian in charge of one of the three great divisions of canal work, and in the estimation of Colonel Goethals, who had asked him to enter the service, had no superior in the engineering force. At the time of his resignation the work at Pedro Miguel and Miraflores was nearly completed. His position was abolished, and the chief engineer, Colonel Goethals, took personal charge of the Pacific division.
CHAPTER XII

SANITATION OF THE Isthmus — SCIENTIFIC DISCOVERIES WHICH MADE IT POSSIBLE — MARTYRDOM OF LAZEAR

Something very like a marvel has been accomplished at Panama. A veritable valley of death has been converted into a land of health and comfort. So complete is the transformation that astonished observers have declared, with mild and not unjustifiable exaggeration, that the "foremost pest-hole of the earth has become a health-resort." If it be not in the full sense of the term a health-resort, that part of the Isthmus of Panama which is under American control is to-day as healthful a place of abode as most civilized communities anywhere, and far more so than many of them.

But while the transformation that has been wrought is marvellous, and takes rank easily as the supreme achievement in sanitation, not only of the century, but of the ages, there is nothing miraculous about it. It surpasses all previous efforts in the same field in magnitude, but not in effectiveness, simply because it was the first work on a large scale undertaken in the illuminating light of a discovery that, as by a flash of lightning, wrought a complete revolution in existing methods of tropical sanitation. Old things passed
away and all became new in those methods when in 1900 surgeons and soldiers of the army of the United States, at the risk of their lives, proved that yellow fever, the supreme terror of the tropics, was not a contagious or a filth disease, but was transmitted from one human being to another solely by a mosquito of a particular type, the *stegomyia*. It was this conviction of the *stegomyia* mosquito of high crimes and misdemeanors against the human race which lifted medical science out of the bog of blind, groping experimentation in tropical sanitation to the firm ground of exact knowledge. The sanitation of the isthmus became a mere matter of intelligent administration, and the sanitation of the isthmus made possible the construction of the Panama Canal, for without the light afforded by this discovery yellow fever could not have been banished from the isthmus, and its periodic outbreaks would have made it impossible to maintain an adequate working force of Americans. It is to the heroic men who risked their lives in the experiments which resulted in this discovery, and above all others to the martyr who both risked and lost his, that highest honors should be paid in celebrating the completion of the canal. The story of their deeds, one of the most inspiring in human annals, is entitled to first rank in the history of the canal, and especially of the sanitation of the isthmus.

When the Americans took possession of the isthmus in 1904 they began the task of converting it into a healthful place of abode and work, in the light not only of the yellow-fever transmission discovery, but of an-
other, only secondary in importance, which had been made in 1898, that malaria was transmitted in like manner from person to person by a mosquito of a different type, the *anopheles*. The details of these discoveries are so imperatively necessary to a proper comprehension of the work that has been done on the isthmus that they are set forth here in advance of the account of the work itself, considering first the yellow-fever discovery because of its superior importance.

The theory that yellow fever was transmitted from one person to another solely by means of a mosquito was advanced speculatively as early as 1847, but it was first set forth positively by Doctor Carlos J. Finlay, of Havana, in a paper published in 1881. Doctor Finlay made several experiments to test the truth of the theory, but they were not successful because he used for inoculation mosquitoes that had bitten yellow-fever patients only from two to five days earlier, whereas later experiments proved that the mosquito is harmless until twelve days or longer after the biting.

During the occupation of Cuba by the United States army in 1900 yellow fever became epidemic in Havana, and in spite of the use of all known methods for warding it off there were nearly 1,600 cases and 231 deaths among American officers and men. It was made evident to the army surgeons who were on duty there that existing methods of fighting the disease were well-nigh powerless to check its spread. They knew neither its cause nor its means of transmission. They stood by the death-beds of its victims, to quote one of them, "in utter perplexity and wonder." Doctor George
M. Sternberg, Surgeon-General of the United States Army, considering the presence of the disease as affording opportunity for testing various theories that had been advanced in regard to it, appointed four army surgeons, specially fitted for the task—Walter Reed, James Carroll, Jesse W. Lazear, and Aristides Agramonte—a board to conduct a series of experiments with a view to ascertaining the causation and method of transmission of the disease from one person to another.

The board began its experiments in June, 1900, and continued them into February, 1901. It first made thorough tests of the theory of bacterial transmission and proved it to be unfounded. It then turned its attention to the theory of mosquito transmission and decided to subject that to a series of experiments. In order to do this, human life must be put in jeopardy, for only human beings could be used for the experiments. One member of the board, Doctor Agramonte, was immune. The other three were not. These were unwilling to assume the responsibility of asking others to risk their lives unless they first risked their own, and accordingly they agreed to make the first experiments upon themselves.

To realize the complete devotion to duty and the high courage of this resolve it should be borne in mind that these men were physicians who had been close observers and students of the disease for many years and were familiar with its deadly character. They made their resolve without proclamation of any sort, without publicity or the desire of it.

The duty of breeding and infecting mosquitoes for
the tests was assigned to Doctor Lazear because of his special knowledge of mosquito work. Before the mosquitoes were ready for the tests Doctor Reed was summoned to Washington on urgent official duty and was prevented from entering the experiments. Doctor Carroll was first bitten, and suffered a very severe attack of yellow fever from which he recovered, but for a time his life hung in the balance. Subsequently Doctor Lazear, while in a yellow-fever hospital, collecting blood from the patients for study, saw a mosquito settle on the back of his hand. He allowed it to remain there, calmly studying its operations till it had satisfied its hunger. Five days later he came down with an attack of the disease “in its most terrible form,” from which he died. These cases had demonstrated so conclusively that the disease was transmitted by mosquitoes that when Doctor Reed returned from Washington his friends persuaded him not to submit himself to infection, on the ground that it was a foolish and unnecessary risk for him at his age. He decided to conduct a series of more elaborate experiments for the purpose of establishing beyond dispute the truth of the new theory, and to demonstrate that not only was yellow fever transmitted by the mosquito, but by the mosquito alone.

In an address which he delivered in April, 1901, describing the results of the army board’s experiments, Doctor Reed paid this affectionate tribute to Lazear:

Before proceeding to the discussion of this subject, it is fitting that I should pay brief tribute to the memory of a former member of this faculty, the late Dr.
Jesse W. Lazear, United States Army. I can hardly trust myself to speak of my late colleague, since the mention of his name brings back such scenes of anxiety and depression as one recalls only with pain. Along with these sad memories, however, come other recollections of a manly and fearless devotion to duty such as I have never seen equalled. In the discharge of the latter, Doctor Lazear seemed absolutely tireless and quite oblivious of self. Filled with an earnest enthusiasm for the advancement of his profession and for the cause of science, he let no opportunity pass unimproved. Although the evening might find him discouraged over the difficult problem at hand, with the morning’s return he again took up the task full of eagerness and hope. During a service of less than one year in Cuba he won the good will and respect of his brother officers and the affection of his immediate associates. Almost at the beginning of what promised to be a life full of usefulness and good works he was suddenly stricken, and, dying, added one more name to that imperishable roll of honor to which none others belong than martyrs to the cause of humanity.

Tests had been made on nine volunteers before the infection of Doctors Carroll and Lazear, but had been without results because mosquitoes had been used too soon after biting yellow-fever patients. It was made plain by the cases of Carroll and Lazear that the infected mosquito did not become harmful till a considerable period had elapsed after biting. To establish the length of this period, and also the length of the period which must elapse after the patient has been stricken before the disease can be conveyed to the mosquito for transmission, Doctor Reed instituted a sec-
ond series of experiments in a camp established near Quemados, Cuba, and named after Lazear. General Leonard Wood, who was then military governor of Cuba, gave all possible assistance in the matter, and to encourage volunteers for the tests offered a reward of two hundred dollars for such service.

It should be remembered that this call for volunteers was issued soon after the death of Lazear, and at a time when it was common knowledge in the army that yellow fever had been given both to him and to Carroll through the bites of mosquitoes. Notwithstanding this, records Major Walter D. McCaw, of the Medical Corps of the United States army, “to the everlasting glory of the American soldier, volunteers from the army offered themselves for experiment in plenty and with the utmost fearlessness.”

The first to present themselves were two young soldiers from Ohio, John R. Kissinger and John J. Moran. Doctor Reed talked the matter over with them, explaining fully the danger and suffering involved, and stating the money consideration offered by General Wood. Both young men declared that they were prepared to undergo the experiment, but only on condition that they should receive no pecuniary reward. When he heard this declaration, Doctor Reed touched his hat with profound respect, saying: “Gentlemen, I salute you!”

How well his respect was merited was shown a few days later when the two young soldiers faced the tests. Kissinger on three successive occasions was taken, clad only in a nightshirt, into a room where mos-
1. Dr. Robert P. Cooke, U. S. A.
2. Dr. Walter Reed, U. S. A.
3. Dr. Carlos J. Finlay.
5. Dr. James Carroll, U. S. A.
7. Dr. Jesse W. Lazear, U. S. A.

Heroes of the yellow-fever tests.
quitoes known to be infected were confined, and lying down, remained there quietly while they bit him. On the third day, according to Major Reed's account, "we concentrated our insects upon him, selecting five of our most promising mosquitoes for the purpose," and he was infected with the fever, from which he recovered. About the same date, a room was prepared and made hospitable by the presence of fifteen infected mosquitoes. What happened in that inviting room is thus described by Major Reed:

At noon on the same day, five minutes after the mosquitoes had been placed therein, a plucky Ohio boy, Moran by name, clad only in his nightshirt, and fresh from a bath, entered the room containing the mosquitoes, where he lay down for a period of thirty minutes. Within two minutes from Moran's entrance he was being bitten about the face and hands by the insects that had promptly settled down upon him. Seven in all bit him at this visit. At 4.30 p.m., the same day, he again entered and remained twenty minutes, during which time five others bit him. The following day at 4.30 p.m., he again entered and remained fifteen minutes, during which time three insects bit him, making the number fifteen that had fed at these three visits. On Christmas morning, at 11 a.m., this brave lad was stricken with yellow fever, and had a sharp attack, which he bore without a murmur.

Moran, like Kissinger, recovered. Well might Major Reed say of the two heroes: "In my judgment this exhibition of moral courage has never been surpassed in the annals of the army of the United States." He
might have added with perfect truth, "or anywhere else." The subsequent history of the two men will be referred to later in this narrative.

There were in all twenty-two persons who submitted to the tests, thirteen of them American soldiers, and most of them accepted pecuniary reward.

Into the tests to demonstrate that yellow fever was not a contagious disease, seven persons entered, Doctor Robert P. Cooke, acting assistant surgeon of the army, and six privates of the hospital corps. The courage shown by these men was equalled only by that of the men who had undergone the other tests. A small building with a single room, fourteen by twenty feet, was erected and carefully guarded against the entrance of mosquitoes. Its temperature was maintained at about seventy-six degrees, with a sufficient amount of humidity. It was supplied with a large quantity of bed clothing, wearing apparel, and night clothing taken from the beds and persons of patients who had died of yellow fever. For twenty consecutive nights Doctor Cooke and his men went into this room, handled, wore, and slept in the contaminated clothing, although the stench was so offensive as to be almost unbearable. They emerged from the ordeal in perfect health, proving beyond possibility of dispute that the disease was not contagious and that the mosquito was the sole method of transmission. Let any one who wishes to comprehend fully the courage required for this service ask himself if he possesses it.

Like Lazear and Carroll and the brave American soldiers who underwent the first tests, Doctor Cooke
and his associates were acting solely in the interest of humanity, were risking their lives for their fellow-men. On a tablet erected to the memory of Lazear in Johns Hopkins Hospital, at Baltimore, there is this inscription, written by President Eliot of Harvard University:

WITH MORE THAN THE COURAGE AND THE
DEVOTION OF THE SOLDIER HE RISKED AND
LOST HIS LIFE TO SHOW HOW A FEARFUL
PESTILENCE IS COMMUNICATED AND HOW
ITS RAVAGES MAY BE PREVENTED.

Surely it can be said of all the men who entered the two series of tests that they showed "more than the courage and the devotion of the soldier," for there were lacking the excitement of the battle-field, the inspiring and sustaining presence of thousands of companions, and the hope of martial glory. Unwitnessed and alone they went into the presence of death itself, remaining there for hours and days and weeks, inviting it, without thought of renown or lasting remembrance. We may well be proud that they were Americans, that we belong to a race capable of such lofty heroism. But like Lazear, who was also American, and like Carroll, who was of English birth, they belong to no country, but to the human race. Their deeds are the common heritage and the common glory of all mankind.

In order to make complete the record of experiments—in Cuba, it should be added that Doctor John Guiteras, of Havana, began in February, 1891, a series of tests for the purpose of ascertaining whether or not yellow
fever could be propagated in a controllable form by means of infected mosquitoes, thus securing immunization as is done by the use of vaccination in the case of smallpox. He infected eight persons with mosquitoes, three of whom died, including an American nurse, Miss Clara B. Maas, of Orange, N. J., who volunteered herself for the experiment. This result was so unfavorable to the theory of controllable propagation that further experiments in that field were abandoned, but the additional tests had afforded complete confirmation of the truth of the mosquito theory of transmission.

The discovery that malaria is not due to miasma or to poisonous air of any sort, but is transmitted from one person to another by a mosquito of the *anopheles* variety, was made by Major Ronald Ross, a surgeon of the British army, formerly in the India service and now connected with the Liverpool School of Tropical Medicine. He had been a careful student of the problem for several years, when in a series of experiments in 1898 he succeeded in infecting birds with malaria from the bites of mosquitoes. Later in the same year and in 1899, three Italian physicians, A. Bignami, G. Bastianelli, and B. Grassi, applying the methods of Ross, succeeded in infecting human beings. Major Ross and the same physicians had proved in previous experiments that men could not be infected with malaria with air or water brought from malarious localities.

Not only were these discoveries known several years before the task of sanitation was begun on the isthmus, but practical application had demonstrated the com-
Here the experiments with the yellow-fever mosquito were first carried out and the transmission of the disease by this means proved.

Building where the experiments were made which proved that yellow-fever is not transmitted by means of infected clothing (fomites).

Camp Lazear.
PERIOD OF CONSTRUCTION 233

plete effectiveness of the new theories. The board of army surgeons that had conducted the experiments in Cuba drew up a set of regulations for the application of the new methods of fighting yellow fever in Havana, and these were put in force on February 15, 1901, by order of General Leonard Wood, and under the direction of Surgeon Major W. C. Gorgas, at that time chief sanitary officer of the city. The main features of the new methods were the segregation of all yellow fever patients behind wire screens and the fumigation of all infected houses. Success was immediate and convincing. Within three months yellow fever was banished from Havana, and for a period of fifty-four days the city was free of the disease. Subsequently there was an outbreak of it in the town of Santiago de las Vegas, a suburb of Havana, whence it was brought into the city, but strict and prompt application of the new methods in both places stamped it out within six weeks, and in the autumn of 1901, the period in which for many years the annual epidemic of yellow fever had been at its height, there was not a single case in Havana. There have been sporadic cases of it since from time to time, but those have been controlled easily and there has been no infection.

Application of suppression methods against the malaria mosquito, in accordance with the discovery of Doctor Ross, was made in Havana during the same period and with striking success. In 1900 the number of deaths from malaria in the city had been 325. In 1901, the year in which malaria mosquito work was begun, the number of deaths was reduced to 151, in
1902 to 77, and in 1903 to 45, which has been about the average annual rate since.

Immediately following the discovery of Major Ross, application of the new method of suppressing malaria was made in various parts of the world, notably in Egypt. The most striking success was that achieved under the personal direction of Major Ross, acting for the Suez Canal Company, at Ismailia. This is a town of 10,000 inhabitants on Lake Timsah, in Egypt, a small sea-water lake through which the Suez Canal passes. Originally a healthful town, it had become, through the formation of shallow marshes, defective drainage, and lack of sewerage, a hotbed of mosquitoes and of malaria. Nearly 2,000 cases were treated each year, and in 1901 there were nearly 2,500. By strict application of the new methods the disease was stamped out completely in three years, and the town has remained free from it since. The original outlay for the work was about ten thousand dollars, and the annual expenditure is about five thousand dollars. Similar results were achieved subsequently at Port Said.

Like all revolutionary discoveries, those of mosquito transmission were received with quite general incredulity, and even in the medical profession scepticism was by no means unusual. The most striking case of it was that of Colonel W. C. Gorgas, the man who was destined to win world-wide fame in applying the new methods. He was present in Cuba when the yellow fever experiments were made, and was a close witness of them; yet even after they had been concluded, and
Major Reed had declared the results in a paper which he read before the Pan-American Medical Congress at Havana, in February, 1901, Colonel Gorgas was still incredulous. Nothing but the success of the new methods which he himself had applied in Havana sufficed to remove his doubts, for in an official report of that work which he made to General Wood, under date of July 12, 1902, he said of Major Reed's paper of the previous year:

This idea was so new and so entirely contrary to all former theories on the subject, and apparently to all former experience, that the paper was received with scant belief. I myself had seen the work, and was convinced that the mosquito could convey yellow fever, but I was hardly prepared to believe that it was the only way, or even the ordinary way of conveying the disease . . .

I had very little hope of accomplishing much (in Havana); it seemed to me that even if the mosquito did convey yellow fever, he could not be gotten rid of, and, apparently, from all past experience, the mosquito was not the only way, or even the principal way, of conveying the disease; but, as he evidently could convey the disease, it was our duty to take precaution in this direction.

His conclusion, in view of his unexpected success, was that "the stegomyia mosquito is the only method of transmitting yellow fever—a fact proved by the army commission." In an address that he made three years later, before the Pan-American Medical Congress, at Panama, he said:
In time Reed’s Army Board came along and made the astounding discovery that the mosquito alone conveyed yellow fever, and that dirt and filth had very little, if anything, to do with the question. My good friend, Dr. Finlay, some twenty years before had advanced this same theory, and during the twenty years preceding our occupation of the island had written and advocated the theory continuously. I had often heard him expound his views on the subject, but, like the Cuban woman, I smiled in a superior way at the “crazy Cuban doctor.”

“The world requires,” says Major Ross in the preface to his most interesting and valuable book,* “The Prevention of Malaria,” “at least ten years to understand a new idea, however important or simple it may be. The mosquito theorem of malaria was at first ridiculed, and its application to the saving of human life treated with neglect, jealousy, and opposition.” The same thing could be said of the mosquito theorem of yellow fever. In fact, when the American occupation of the isthmus began in 1904, comparatively few people in the United States were aware that the two discoveries had been made, and still fewer realized their inestimable value in the task of building the canal. It is a safe assertion that when the sanitation of the isthmus had been accomplished the general belief throughout the world was that the methods so successfully applied had been originated by those in charge of the work. It could not be said that the martyr Lazear and his heroic associates were forgotten; their deeds had never been known. It required the startling effect

of a great success to awaken the world to a just sense of the priceless debt of gratitude that the human race owes to these modest, self-effacing surgeons and soldiers of the American army. To them belongs all the credit without division or diminution, for, as President Eliot, with that aptness of phrase of which he is so enviable a master, has said, they not only showed "how a fearful pestilence is communicated," but "how its ravages may be prevented." The showing was so clear that the sanitation of the isthmus or any other part of the tropics or of the world became a mere matter of intelligent administration.
CHAPTER XIII

ACTIVE WORK UNDER COLONEL GORGAS AND THE DEPARTMENT OF MUNICIPAL ENGINEERING—FINAL OUTBREAK AND ROUT OF YELLOW FEVER

President Roosevelt, who was fully aware of the value of the discoveries described in the preceding chapter, instructed the first canal commission to give special attention to sanitation, and to secure the best medical experts attainable for this purpose, saying further, in a letter to the Secretary of War, that “it is the belief of those who have noted the successful results secured by our army in Cuba in the obliteration of yellow fever in that island, that it is entirely feasible to banish the diseases that have heretofore caused most mortality on the isthmus.” By unanimous consent, Colonel William C. Gorgas was the expert best fitted to take charge of the work. His close association with the army surgeons who had made the discoveries, and had formulated the new methods of applying them, gave him the practical experience necessary for intelligent administration. He had only to adopt on the isthmus the plans of the successful campaign in Cuba to win a second and more brilliant triumph.

Yellow fever was the special curse of the isthmus. Dread of that was the paramount obstacle in the way of canal construction. Malaria in its most deadly form, Chagres fever, was a scarcely less venomous foe
to health, but it excited far less fear. If yellow fever could be banished the canal could be built, in spite of malaria and all other tropical ills. The "astounding discovery" had shown, with a clearness that amounted to a revelation, that existing methods of fighting yellow fever were only so much wasted energy, and that the sure and only way to check and suppress it was to restrict the activity of the mosquitoes, and, so far as possible, suppress them.

Colonel Gorgas, who was familiar with the work of Major Ross in Ismailia and elsewhere, invited him to visit the isthmus, when the work of sanitation began in the summer of 1904, in order to have the benefit of his advice and suggestions, and the invitation was accepted, Major Ross making the visit as the guest of the canal commission. The work was begun, therefore, under most favorable conditions, with exact knowledge of what to do and with expert ability to guide in doing it. There was still another and scarcely less valuable aid to the task. Under the treaty with Panama the United States had sovereign power for health purposes not only in the Canal Zone, but in the cities of Colon and Panama, and could enforce all necessary regulations.

When the work began the whole isthmus was literally a mosquito paradise, with well-nigh ideal conditions for propagation and infection. The temperature being tropical, and scarcely varying at all the year round, allowed constant breeding, for which opportunities and facilities were virtually universal. During nine months of the year the innumerable stagnant pools of fresh water left by the almost constant rains afforded
the most favorable breeding-places possible for the malaria mosquito. In the dry season, there being no water-supply for cities and towns, the rain was stored in tanks and receptacles of various kinds, which made equally favorable breeding-places for the yellow fever mosquito. From one end of the Canal Zone to the other, a fifty-mile strip ten miles in width, tropical undergrowth flourished virtually undisturbed. Microscopical examination of the blood of the inhabitants showed that fully seventy per cent of the ten thousand or twelve thousand of them had the malarial parasite circulating in their blood. The malarial mosquito thus had a perpetual feeding-ground from which to obtain the seeds of infection. When a case of yellow fever occurred, the *stegomyia* was at hand, propagaded often at the very bedside of the victim, to obtain and convey the infection.

The work of the American sanitary officers was thus clearly marked out for them. They must restrict the activities of the mosquitoes and, so far as possible, suppress them. The first needs were a water-supply and sewer system for the cities and towns, for until these were furnished existing methods of storing water could not be abolished. While these were being supplied houses could be screened and their inmates protected against infection.

Plans were adopted by the first commission almost immediately after its appointment for the construction of reservoirs to supply the cities of Panama and Colon with water, and later similar plans were adopted for all labor centres along the line of the canal. At the same time plans were adopted for a system of
sewers for the cities and the paving or resurfacing of their streets. This work, which was begun in the first six months of American occupation, was separate from the strictly sanitary work, and was performed by the Division of Municipal Engineering, which was under the general Department of Construction and Engineering, of which the chief engineer was the head. It was in existence till August 1, 1908, when, its work having been completed, it was abolished. During the four years of its activity it expended nearly $6,000,000, of which about $2,250,000 was for water-works, sewers, and pavements in the cities of Panama and Colon, and about $3,500,000 was for work in the Canal Zone. Subsequent expenditures in Colon and Panama brought the total cost of improvements made in them by the commission up to nearly $3,500,000. All of this, in accordance with the treaty between the United States and Panama, will be paid back to the United States, through water and sewerage rates, within a period of fifty years, at the expiration of which the system of water-works and sewers within city limits will revert to the cities, and the use of water will be free to their inhabitants, with the exception of a sufficient water rate necessary for maintenance and operation.

Through these expenditures pure water was supplied to the cities of Panama and Colon and all settlements in the Canal Zone, the cities were converted from hot-beds of disease, without water-supply or decent pavements or sewers, into the best-paved, best-watered, and best-sewered cities in Central or South America.

Moving side by side with the work of the Division of Municipal Engineering, though separate and distinct
from it, was the work of the Sanitary Department. The new methods of fighting disease, which had been shown to be effective by the mosquito tests in Cuba, were put into operation. Repairs and additions were made to the hospitals acquired from the French at Ancon and Colon, and emergency hospitals and sick-camps were established along the line of the canal.

The supreme test of the mosquito theory as applied to yellow fever came in 1905. When the Americans took possession of the Canal Zone in 1904 there were a few scattered cases of yellow fever, but as this was the usual condition between periodic epidemics of the disease, little concern was felt. In January, 1905, however, there was an increase in cases to 19, among whom there were 7 employes of the commission and Panama Railroad Company. Eight died, among them a canal employe. There were 14 cases in February, 11 in March, and 9 in April, and of these 18 were employes, 6 of whom died.

The 7 cases in April were among employes in the French administration building, which had become the headquarters of the commission in Panama, where about 300 Americans were engaged. When 3 of them died a panic arose among Americans on the isthmus, and all steamers outward bound were laden to the full capacity with frightened employes. An increase of the number of cases in May to 33, including 22 employes, 3 of whom died, and a further increase in June to 62, including 34 employes, 6 of whom died, added to the panic, and nothing except lack of sailing accommodations prevented the scattering of the entire force. In July the number of cases began to decline,
showing that the progress of the disease had been checked, and a further decline in August partially restored confidence. By the first of September the disease was shown to be under control, and in December the last case was registered and there was no death. There had been among employes of the commission and Panama Railroad employes 133 cases and 35 deaths. As this epidemic was the last of its kind on the isthmus, the full record of it is given:

**STATISTICS OF THE LAST YELLOW-FEVER EPIDEMIC ON THE Isthmus, 1904–5**

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<tr>
<th>MONTH</th>
<th>TOTAL Cases</th>
<th>TOTAL Deaths</th>
<th>EMPLOYES CASES</th>
<th>EMPLOYES DEATHS</th>
<th>PLACE OF ORIGIN PANAMA</th>
<th>PLACE OF ORIGIN COLON</th>
<th>PLACE OF ORIGIN CANAL GROVE</th>
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<td>35</td>
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In applying the new methods of fighting the disease, Colonel Gorgas had the hearty co-operation and earnest support of Charles E. Magoon, who, as member of the second Isthmian Canal Commission, which had succeeded the first commission on April 3, 1905, was governor of the Canal Zone when the yellow-fever epidemic began to gain headway. Governor Magoon, immediately upon his arrival on the isthmus on May 24, assured Colonel Gorgas that the entire resources of the commission and the government of the Canal Zone were available for the work of stamping out yellow fever on the isthmus. Under the joint labors of these two officials the cities of Panama and Colon were fumigated house by house, the towns of the Canal Zone were divided into districts for the extermination of mosquitoes, medical inspectors were appointed to make daily house-to-house canvasses and to report all suspected cases, and all such were taken at once, willingly or unwillingly, to the hospitals and segregated.

At the same time that these vigorous measures were being applied a rigid quarantine, which had been established at the outset of American occupation, was maintained against all infected ports, preventing the introduction of disease from outside.

Since December, 1905, there has been no case of yellow fever on the isthmus which has originated there. There have been sporadic cases from time to time, but invariably of persons who have brought the disease from outside the isthmus. In each instance the victim has been segregated and there has been no infection.