THE CONSTRUCTION OF THE PANAMA CANAL

WILLIAM L. SIBERT
AND
JOHN F. STEVENS

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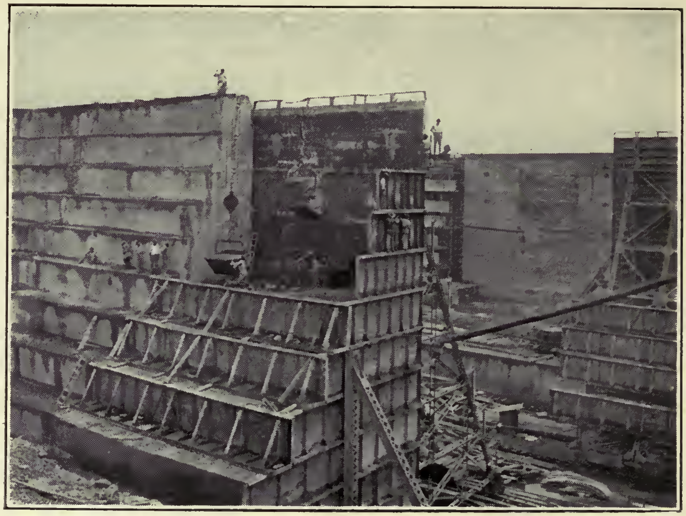

Close View of Steel Forms, Gatun Locks.

Starting to Fill the Gatun Locks for the First Time.

THE CONSTRUCTION OF THE PANAMA CANAL

BY

WILLIAM L. SIBERT

Brigadier General, U. S. A., formerly Member of the Isthmian Canal Commission and in charge of the building of the Gatun Locks and Dam and of the channel from Gatun to the Atlantic Ocean

AND

JOHN F. STEVENS

formerly Chief Engineer and Member of the Isthmian Canal Commission

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PREFACE

While the authors of this book are in general accord as to its entire contents, Mr. John F. Stevens wrote and is responsible for Chapters II to VI, inclusive. These chapters cover the operations in connection with building the Canal prior to the spring of 1907, often referred to as the "Preparatory Period."

The introductory chapter and Chapters VII to XX, inclusive, descriptive of the work after the spring of 1907, often referred to as the "Construction Period," were written by William L. Sibert.

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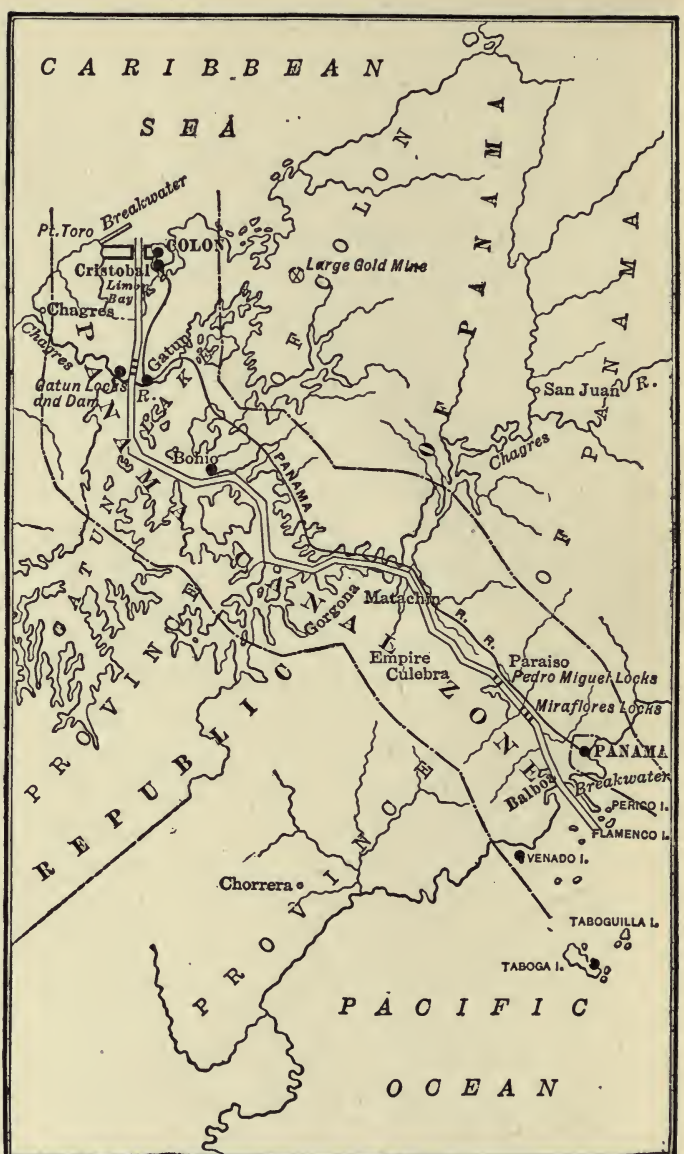

CARIBBEAN SEA
Pt. Toro Breakwater
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Large Gold Mine
PROVINCE OF COLON
PROVINCE OF PANAMA
GATUN LAKE
Bohio
PANAMA R. R.
Matachin
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Chagres
Chorrera
REPUBLIC OF PANAMA
PROVINCE OF PANAMA
PACIFIC OCEAN

THE CONSTRUCTION OF THE PANAMA CANAL

CHAPTER I

INTRODUCTION

The Panama Canal, probably the greatest material contribution of any nation to the world's commerce, was constructed by the President of the United States through a commission of seven men, under authority granted by the Congress of the United States.

The first Commission was appointed under this authority March 3, 1904, and was constituted as follows: John G. Walker, rear-admiral, U. S. Navy; George W. Davis, major-general (retired), U. S. Army; William Barclay Parsons, C. E., New York City; William H. Burr, C. E., New York City; Benjamin M. Harrod, C. E., New Orleans, Louisiana; Carl E. Grunsky, C. E., San Francisco, California; Frank J. Hecker, Detroit, Michigan.

The personnel of the second Commission, nominated March 4, 1905, was as follows: Theodore P. Shonts, chairman; Charles E. Magoon, member and governor of the Canal Zone; John F. Wallace, member and chief engineer; Rear-Admiral Mordecai T. Endicott, U. S. Navy; Brigadier-General Peter C. Hains, U. S. Army (retired); Colonel Oswald H. Ernst, Corps of Engineers, U. S. Army.

John F. Wallace was appointed chief engineer of the first Commission and served in that capacity from June 1, 1904, to June 28, 1905.

During Mr. Wallace's term of office no decision had been made as to type of canal, and his service was largely in making investigations with a view to determining this question. Mr. Wallace resigned his position in June, 1905, and John F. Stevens was appointed chief engineer.

Mr. Stevens, in addition to his position as chief engineer, was made a member of the Commission in July, 1906.

Appreciating, whatever the type of canal finally adopted, that a large amount of excavation would be necessary, Mr. Stevens commenced to plan and procure the necessary plant and to create a needed organization for such excavation. He also made a thorough study of the rail transportation problems and solved them by rebuilding and double-tracking the Panama Railroad and providing the necessary rolling stock. Notwithstanding the fact that it was not until June 29, 1906, that a decision was made as to the type of canal, by the spring of 1907 he had created a working organization, procured an excavation plant, and had commenced to prosecute rapidly that part of the work.

In the development of the working plans for the great excavation problem, prominent parts were taken by such men as John G. Sullivan, W. E. Dauchy, F. B. Maltby, William Gerig, D. W. Bolick, W. G. Comber, Geo. D. Brooke, J. G. Holcombe, A. L. Robinson, A. B. Nichols, and William G. Bierd.

As soon as the type of canal was determined a force for designing the locks and dams was organized under Joseph Ripley. Upon Mr. Ripley's promotion to assistant chief engineer, his former assistant, M. G. Barnes, was placed in charge of the designing force.

In connection with the procuring of material, disbursing of funds, and the housing and feeding of the men, prominent parts were taken by Jackson Smith, R. E. Wood, Edward J. Williams, David W. Ross, William G. Tubby, William M. Belding, and P. O. Wright, Jr.

The term of Mr. Stevens, as chief engineer, can truly be said to have covered the preparatory period of the work. Mr. Stevens resigned April 1, 1907.

In March, 1907, the President reorganized the Isthmian Canal Commission, appointing Major

George W. Goethals, Corps of Engineers, as chairman and chief engineer, and Colonel W. C. Gorgas, Medical Department, U. S. Army; Major D. D. Gaillard, Corps of Engineers, U. S. Army; Major William L. Sibert, Corps of Engineers, U. S. Army; H. H. Rousseau, civil engineer, U. S. Navy; Senator J. C. S. Blackburn, and Jackson Smith, members of the Commission. All members were to reside on the Isthmus and assist in the prosecution of the work.

Jackson Smith resigned in July, 1908, and Major H. F. Hodges, Corps of Engineers, U. S. Army, was appointed to fill the vacancy. Jackson Smith had, under Mr. Stevens, been largely responsible for the adopted system of housing and feeding the canal employees.

Senator J. C. S. Blackburn resigned December 4, 1909, and Maurice H. Thatcher, of Kentucky, was appointed April 12, 1910, in his place. Mr. Thatcher resigned in August, 1913, and Richard L. Metcalf served in his place until April 1, 1914, on which date, in pursuance of an Act of Congress, the Isthmian Canal Commission was abolished. The Canal was essentially finished and the organization of an operating force was necessary.

The period covered by the service of this last Commission was the construction period of the canal.

Major George W. Goethals, who was soon promoted to the rank of Colonel, was the chief engineer and chief executive officer of the Commission during this entire period.

The duties of the Commission during this period were defined in the following extract from an executive order signed by President Roosevelt on January 6, 1908:

The Commission, under the supervision of the Secretary of War and subject to the approval of the President, is charged with the general duty of the adoption of plans for the construction and maintenance of the canal; with the employment and the fixing of the compensation of engineers or other persons necessary for the proper and expeditious prosecution of said work; with the making of all contracts for the construction of the canal or any of its needful accessories; with the duty of making to the President annually, or at such other periods as may be required either by law or the order of the President, full and complete reports of all their actings and doings and of all moneys received and expended in the construction of said work and in the performance of their duties in connection therewith; and with the duty of advising and assisting the Chairman in the execution of the work of canal construction, with the government and sanitation of the Canal Zone and with all matters of sanitation in the cities of Panama and Colon and the harbors thereof, and with the purchase and delivery of supplies, machinery and necessary plant.

The members, in addition to service on the Commission, were assigned the following duties:

Colonel W. C. Gorgas was placed in charge of sanitation, hospitals, and all quarantine work.

Major (afterwards Lieutenant-Colonel) D. D. Gaillard was in charge of all excavation, both steam-shovel work and dredging, until June 30, 1908.

Major (afterwards Lieutenant-Colonel) William L. Sibert was in charge of design and construction of all locks, dams, and regulating works until June 30, 1908.

H. H. Rousseau, civil engineer, U. S. Navy, was in charge of municipal engineering and of the Mechanical Division until June 30, 1908.

J. C. S. Blackburn was in charge of civil administration until he resigned, which duties were assumed in turn by M. H. Thatcher and Richard L. Metcalf.

Civil administration comprised all the ordinary functions of civil government, such as courts, schools, police, taxation, mails, fire protection, etc.

When Major (later Colonel) H. F. Hodges reported for duty as member of the Commission, a redistribution of the duties of the engineers was made.

Colonel H. F. Hodges, as assistant chief engineer, was placed in charge of the design of the locks, dams, regulating works, and accessories; of the design and construction of aids to navigation; the inspection of the manufacture and erection, by contract or otherwise, of the lock gates, operating machinery, valves, emergency dams, and fender chains.

Major William L. Sibert was placed in charge of the Atlantic Division, which comprised the construction of the Gatun Locks and Dam, the excavation of the seven miles of canal from Gatun to the Atlantic Ocean, the construction of the breakwaters in Colon Harbor, and of the municipal engineering within the limits of the division.

Major D. D. Gaillard was placed in charge of the Central Division, which embraced all steam-shovel excavation from Gatun to Pedro Miguel, including the difficult excavation through the Continental Divide at Culebra. Municipal engineering in his division was also a part of his duty.

H. H. Rousseau, civil engineer, U. S. Navy, was assigned to duty as assistant to the Chief Engineer, retaining supervision over shops and terminal construction, including the dry docks and permanent shops.

S. B. Williamson, a civil engineer, was placed in charge of the Pacific Division. This work comprised the construction of the Pedro Miguel and Miraflores Locks and Dams, the excavation of the Canal from Miraflores to the Pacific Ocean, and the municipal engineering in his division.

Under Colonel H. F. Hodges, the following civil engineers were at the head of important subdivisions of design: Henry H. Goldmark, design and installation of lock gates; Edward Schildhauer, electrical and mechanical design and installation; L. D. Cornish, general lock and masonry design; E. C. Sherman, spillway design, and T. B. Monnicke, emergency dams.

Under Lieutenant-Colonel D. D. Gaillard, the following served as division engineers: L. K. Rourke, D. W. Bolich, William Gerig and W. G. Comber; and A. S. Zinn as resident engineer.

Under Lieutenant-Colonel William L. Sibert, Lieutenant-Colonel Chester Harding served as assistant division engineer; Majors Edgar Jadwin, James P. Jervey, and George M. Hoffman served as resident engineers, and Captain Horton W. Stickle as assistant engineer. Mr. George W. Wells served as designing engineer for the division.

Under S. B. Williamson, J. M. G. Watt served as assistant division engineer; W. B. Corse, H. O. Cole, and Frank Cotton as resident engineers, and James Macfarland as superintendent of dredging.

Under H. H. Rousseau, U. S. Navy, J. G. Holcombe served as division engineer; George D. Brooke as superintendent of motive power and machinery; A. L. Robinson as superintendent of mechanical division; P. O. Wright, Jr., as architect; Major T. C. Dickson as inspector of shops, and A. B. Nichols, as office engineer.

Colonel (afterwards Brigadier-General) C. A. Devol, assisted by Captain R. E. Wood, was charged with housing the employees and procuring all material during the construction period.

Lieutenant-Colonel Eugene T. Wilson was charged with feeding the employees and operating the supply stores.

E. J. Williams continued as disbursing officer practically through the construction period and was one of the few officials that served through both the construction and preparatory periods.

Lieutenant George R. Goethals, son of the Chairman and Chief Engineer, was charged with the construction of the fortifications at both ends of the Canal.

All of the engineer members of the Commission in charge of work during the construction period lived to see a completed canal, except Lieutenant-Colonel D. D. Gaillard, who died December 5, 1913, just as his work—the great Culebra Cut—was essentially finished. He was lying unconscious in a hospital at Baltimore the day that the dyke at Gamboa was destroyed—the last barrier that held the waters of Gatun Lake out of Culebra Cut. The destruction of this barrier allowed the waters impounded by the dam on the Atlantic side of the Isthmus to connect with the Pacific Ocean through the locks on that slope.

A West Point classmate has, in the following lines, fittingly expressed the spirit of the services rendered by Colonel Gaillard:

To lay down one's life upon the field of battle in voluntary service of fatherland has been considered in all ages the loftiest expression of patriotism, if not of heroism itself. To fall as Gaillard has fallen—is it any less true heroism? Any less self-sacrifice upon the altar of country? Not amid the din of armed conflict, nerved by the frenzy of an hour or a day, but at the end of long years of patient, exacting work, of terrific responsibility, the tragic end has come. But it is just as much a direct result of the struggle itself as if it were the work of a hostile bullet, and the exalted standard of duty which his career exemplified will command the increasing admiration of men as long as his work in the Isthmian hills endures.

We grieve that he could not have remained to enjoy the fruits of his well-earned fame. But there is compensation in the thought that to him was reserved the higher privilege of laying down his lifework just as it was crowned with success. Like Wolfe on the Plains of Abraham, he has been called with the plaudits of victory ringing in his ears. Whatever may come to others, his record is secure.

STATUS OF WORK AS LEFT BY THE FRENCH

The status of the Canal work at the time it was transferred to the United States differed but little from that in which the first French Company left it in 1889. The new French Company took charge in 1894 and did but little construction work.

The French companies made extensive surveys and plans which were excellently recorded and proved to be of great use. Their value to the United States was estimated in 1911 at $2,000,000. They also erected many buildings, shops, hospitals, etc., but had confined their operations along the Canal practically to excavation, except for the construction of a small dry dock near Colon, and some docks for the discharge of material and machinery for use in building the Canal.

A large amount of material had been excavated in the nine-mile cut through the continental divide and much of it deposited on the low ground in close proximity to the Canal. The deepest cutting was about 165 feet below the original surface and this surface was 333 feet above sea-level. In the sea-level sections of the project last adopted by the French much excavation had been done.

A navigable channel along the Canal line had been excavated from Cristobal to Bohio, at which latter point a dam was to have been built across the Chagres Valley. On the Pacific side a channel had been excavated from La Boca (Balboa) to deep water in the Pacific and considerable work done on channel from La Boca to Miraflores, where the first lock on that side was to have been built.

None of the work on the Atlantic side formed a part of the project carried out by the Americans and was of no value except as an aid during construction. Practically all of the rock, sand, and cement for the locks and spillway at Gatun, as well as a large part of the supplies for dam construction at that place, were transported on the old French canal from Cristobal to Gatun. This channel is still open and may be of use in connection with terminal developments for military or naval needs. That part of the old French canal between Gatun and Bohio is of course covered by Gatun Lake.

Practically all the channel excavation from Balboa to Miraflores was useful, but only a small part of that from Balboa to deep water in the Pacific was utilized, the location of this part of the Canal having been changed.

On the Atlantic side, in addition to channel excavation, the French had dug twenty miles of diversion channel on the east side of the Canal and thirteen on the west side. The west diversion was of some use in transporting supplies for the dam at Gatun, and the east diversion was utilized as a reserve to the Colon water supply.

A total amount of about 80,000,000 cubic yards had been excavated by the French along the line of the Canal, but a large portion of this had been dumped so close to the Canal that it had to be moved again in excavating the enlarged section adopted by the Americans.

A committee, appointed in 1911, estimated that the useful excavation made by the French amounted to 30,000,000 cubic yards. The value of the first 30,000,000 cubic yards should, however, not be measured by later excavation costs. Pioneer work is exceedingly expensive, but the experience gained should be of great value difficult to fix. It may find expression in methods to avoid as well as methods to copy. This committee gives this useful excavation the value of $25,389,240.

Immense quantities of material and machinery were found distributed along the entire line. The book value of this was about $29,000,000; but although much of it was housed and in good condition, it was of little value because it was obsolete. Splendid workmanship was shown on these machines and good material was used in their construction. They were good appliances of their date, but had to give way to more recent mechanical developments.

The French left 2,148 buildings of which 1,536 were utilized after repair. The estimated value of these buildings was over $2,000,000. Six machine shops, containing a considerable quantity of usable tools, were left. These were put into service and were of great assistance in forming a nucleus for the development of larger shops as needed. Their value was estimated at over $2,000,000.

The committee before mentioned estimated the total value of the construction, property, etc., acquired from the French, at $42,800,000, which is a conservative figure, without taking into consideration the value of the French experience.

PREPARATORY PERIOD: 1904 TO MARCH, 1907

CHAPTER II

SEA-LEVEL VERSUS LOCK TYPE OF CANAL

The Act of Congress which authorized the President to proceed with the construction of the Canal, placed almost unlimited power in his hands as to details of route, type and size, the chief limiting clause, which, it may be noted, left much to his judgment, reading as follows: The Canal "shall be of sufficient capacity and depth as shall afford convenient passage for the vessels of the largest tonnage and greatest draft now in use, and such as may be reasonably anticipated."

In order to obtain the advantage of the best engineering advice upon the many problems involved, the President appointed a board of consulting engineers, the members being eminent in their profession, both American and European. The Board of Consulting Engineers consisted of General George W. Davis, chairman, and Alfred Noble, William Barclay Parsons, William H. Burr, General Henry L. Abbot, Frederic P. Stearns, Joseph Ripley, Herman Schussler, Isham Randolph—all Americans; and William Henry Hunter, nominated by the British Government; Eugen Tincauzer by the German Government; Adolph Guérard by the French Government; J. W. Welcker by the Government of The Netherlands, and E. Quellennec, consulting engineer of the Suez Canal.

By executive order dated June 24, 1905, the President directed that this board should convene in Washington on September 1, 1905, for the purpose of considering various proposed plans for the construction of a canal across the Isthmus of Panama between Cristobal and La Boca and to make a report.

At the meeting held on September 1, the Isthmian Canal Commission submitted to the Board plans, maps and data in four parts:

Part I. Report Comité Technique dated November 16, 1898, with map scale of 1 to 5000.

Part II. Report American Commission dated November 16, 1901.

Part III. Data for "sea-level" scheme.

Part IV. Pamphlet, plans by Lindon W. Bates, and plans by P. Bunau-Varilla.

The opinion of the Board was solicited as to the best plan to be followed in the completion of the Panama Canal within reasonable limits of cost and time; the option of the Board was not to be based alone upon the plans submitted but upon any variation of them, or upon any entirely different plan which might suggest itself to the Board.

The Board received no plans originating with the Commission and because of requirements of the act of Congress respecting dimensions and capacity of the Canal preventing the adoption of plans of former commissions, the Board was obliged to act as a creative body as well as a consulting board.

The committee on the sea-level canal was appointed September 16, and consisted of Chairman Davis and members Guérard, Burr, and Hunter.

The lock-canal committee appointed October 12, consisted of Chairman Davis, and members Stearns, Tincauzer, and Ripley. Both committees were increased by the addition of two members on October 30; the "sea-level" committee by members Parsons and Quellennec, and the lock-canal by members Noble and Abbot. The committee on unit prices for purpose of estimate consisted of members Parsons, Welcker and Randolph.

Thirty regular stated meetings were held by the Board lasting from six to eight hours each and stenographic notes were taken of all discussions.

The Board made an inspection of the Wachusett Reservoir at Clinton, Massachusetts, on September 27, and on the following day sailed on the steamer *Panama* for the Isthmus.

During the eight days' stay on the Isthmus, the

Board accompanied the Canal commissioners in making a careful inspection of the entire route of the Canal, paying particular attention to sites for locks and dams and to localities where extensive slides had already taken place.

The numerous cores taken by diamond drills all along the line of the Canal were examined and carefully studied.

Hearings were given to Chief Engineer John F. Stevens and several of his assistants for the purpose of obtaining their views and desired information as to many particulars.

Every day during the trip to and from the Isthmus was spent by all the members of the Board in committee work or attending regular sessions of the Board.

Returning to Washington, the Board continued work on the sea-level and lock-canal plans and estimates and at the regular sessions discussed the details of each feature of the various Canal problems. Hearings were also given to former Chief Engineer John F. Wallace on November 3, and to the presentation of proposed projects by Lindon W. Bates, and those proposed by P. Bunau-Varilla.

The plans for the sea-level canal, but more particularly those for the lock canal required extensive calculations and study as the structures had to be designed in sufficient detail for assured safety and to conform within reasonable limits as to quantities. A force of six computers and draftsmen were assigned to the Board, but in order to expedite the work it was necessary for all members of the Board to make many computations themselves.

Early in November, plans for the sea-level and those for the lock canals were so far progressed that a thorough discussion was had of the advantages and disadvantages of each. While the location of the old French canal was generally followed across the Isthmus, the approaches in Limon Bay and in Panama Bay were materially changed, and the general curvature alignment was entirely eliminated and canal laid out on tangents with a widening at the inner angle of each intersection of adjacent courses.

For a lock canal the committee submitted for consideration four variants:

No. 1. Summit elevation 85 feet with three locks in flight at Gatun, one lock at Pedro Miguel and two locks at Sosa.

No. 2. Elevation 85. Three Locks at Gatun, two at Pedro Miguel and one at Miraflores.

No. 3. Elevation 60. Two locks at Gatun, one at Pedro Miguel and one at Miraflores.

No. 4. Elevation 60. One lock at Gatun, one at Bohio, one at Pedro Miguel and one at Miraflores, and with the last plan (No. 4) a dam at Alhajuela.

The Board voted as to type of canal to be recommended on November 18, and by a majority of 8 to 5, decided in favor of the sea-level canal.

With the exception of Mr. Quellennec, who remained until December 5, the European members on November 5, left Washington for New York to take steamer for home.

The American members at once proceeded to prepare a report including plans, maps and estimates. Chairman Davis and members Noble and Burr were appointed a committee to supervise the preparation of the report.

The minority members, Noble, Abbot, Stearns, Ripley and Randolph, in accordance with the request of the President for minority reports, if there should be a difference of opinion between the members of the Consulting Board, proceeded to prepare a minority report, with recommendation for a lock canal with summit level at elevation 85.

As parts of the majority report were prepared, they were discussed at regular meetings by all the members and agreement reached as to subject-matter and wording. After the completion of this majority report, it was taken to Europe by Chairman Davis. A meeting of the European members was held in Brussels January 9 and 10, and after revising this report as to wording, it was signed by those present.

During January the minority report was prepared, Alfred Noble editing the written statements prepared by the different members of the minority on the parts assigned to each, and finally, two meetings were held at which careful revision of the report was made jointly by all members.

The majority report included a history of the Isthmian Canal projects, reference text and the maps accompanying the report; physical characteristics, climate, sanitation and hygiene work done and present conditions and new field work, various projects hitherto proposed; control of the Chagres River, dams, alignment and estimates of cost and time.

The minority report included the following subjects:

1. The lock-canal project recommended
    - (a) Colon entrance
    - (b) The Gatun Dam
        - i. Stability of an earth dam
        - ii. Regulating works
        - iii. Reduction in cost
    - (c) Water supply of the Canal
    - (d) The summit level
    - (e) Lake Sosa
    - (f) Channel in Panama Bay
    - (g) Dimensions and cost
2. Comparison with the Board's lock-canal project

3. Comparison with the Board's sea-level canal project
4. Relative time for completion of sea-level and 85-foot projects
5. Relative time of transit
6. Capacity for traffic of the two projects
7. Safety of locks and other structures
8. Relative safety of ships in the two types of Canal
9. Land damages
10. Relocation of the Panama Railroad
11. Estimated cost for project recommended
12. Cost of maintenance and operation
13. Safety of dams
14. Conclusions and recommendations

The report was submitted to the Secretary of War on February 5. The recommendations of the minority members were indorsed by all members of the Isthmian Canal Commission, with the exception of Admiral M. T. Endicott, who voted in favor of the sea-level canal.

On June 25, 1906, Congress adopted for construction the lock canal as recommended by the minority members of the Board.

As representing the views of the members of the Commission, with the exception above noted, the following extract from a report made to the Commission, by its Chief Engineer, of date January 26, 1906, will be of interest:

The sum of my conclusions is, therefore, that, all things considered, the lock or high-level canal is preferable to the sea-level type, so-called, for the following reasons:

It will provide a safe and quicker passage for ships, and, therefore, will be of great capacity.

It will provide beyond question, the best solution of the vital problem of how safely to care for the flood-waters of the Chagres and other streams.

Provision is made for enlarging its capacity to almost any extent at very much less expense of time and money than can be provided for by any sea-level plan.

Its cost of operation, maintenance, and fixed charges will be very much less than any sea-level canal.

The time and cost of its construction will not be more than one-half that of a canal of the sea-level type.

The element of time might become, in case of war, actual or threatened, one of such importance that measured, not by years but by months or even days, the entire cost of the Canal would seem trivial in comparison.

Finally, even at the same cost in time and money for each type, I would favor the adoption of the high-level lock-canal plan in preference to that of the proposed sea-level canal.

I, therefore, recommend the adoption of the plan for an eighty-five-foot summit-level lock canal, as set forth in the minority report of the Consulting Board of Engineers.

Very respectfully,

John F. Stevens, *Chief Engineer.*

This report received the approval of all members of the Commission except one.

The arguments which were urged pro and con, by the advocates of the two types, would fill hundreds of pages. As the lock type—the one adopted—is described in detail elsewhere in this volume, a brief description of the sea-level type, as reported favorably by the majority of the Consulting Board, will be given here.

The channel was to begin at the 41-foot contour in Limon Bay, on the Atlantic side, about 5,000 feet north of a line between Toro and Manzanillo lights, the two lights which mark the approach to the Bay. The entrance was to be protected by two diverting jetties, with a width of opening of 1,000 feet. Thence the channel, 500 feet wide at the bottom and 40 feet deep, was to run in a straight line to Mindi, where the land canal proper was to begin, protected by a parallel jetty on the west and by Manzanilla Island on the east.

The land canal was designed with a depth of 40 feet, and a width of 150 feet at the bottom, in earth, with such side slopes as the nature of the ground might permit. In rock the section was to have widths of 200 and 208 feet, at the bottom and top respectively.

At La Boca (now Balboa) the Pacific end, the Canal was to be protected by a tidal lock placed between Ancon and Sosa hills. Such a lock was necessary as there is a difference of about twenty feet between the tides of the Atlantic and Pacific oceans at the Isthmus of Panama, those of the latter being much higher than the former.

It was thought that this difference in tides in such a narrow channel, would produce currents that would make navigation by large vessels hazardous, if not impracticable.

Beyond the tidal lock, there was to be a straight channel projecting into the Bay of Panama, 300 feet in bottom width, 3¾ miles long, to be 45-foot contour.

At Gamboa, the north end of Culebra Cut, and the point where the Chagres River, making a right-angled turn to the north, first strikes the line of the Canal, was to be erected an immense dam, either of masonry or earth, or both combined, 180 feet in height. The object of this dam was to control the flood-waters of the river, which have reached the enormous volume of 65,000 cubic feet per second during the past forty years. This dam would have formed a lake, some 30 miles in area, with a maximum depth of 170 feet. It was to be provided with regulating sluices, so that the flood-waters could be drawn off gradually, in only such volumes that (as estimated) would not interfere with the navigation of the Canal, and still be sufficient in amount to prevent any overflow of the dam proper.

In addition to the Chagres, there are more than thirty other streams, large and small, the waters of which would have discharged directly into the Canal. Regulation of the floods of these streams was to be provided for in various ways, mostly by masonry spillways or steps, designed to break the fall of the water immediately before its entrance into the Canal.

When any canal is built solely for purposes of navigation, it follows that marked points of differences which affect navigation, are to be most seriously considered in balancing the merits of different types. This was eminently true at Panama; but there were also other very important considerations there, which a failure to properly appreciate, would have resulted in serious consequences, and might have proved fatal to the success of the whole project.

As planned, the sea-level canal was to be only 150 feet in width, for 20½ miles; 200 feet for the same distance; 300 to 350 feet for 8 miles; and 500 feet for 10 miles. Or, for nearly one-half of its length it was to be only 150 feet in width, and for five-sixths, not over 200 feet. The alignment through this narrow channel was tortuous, and for long distances the lower part of the section would have been through submerged rock, a state of affairs constituting an absolute menace to safe navigation.

Contrasted with these features, are those of the lock type, which was adopted: for a distance of nearly 20 miles, a minimum width of 1,000 feet; for 16 miles 500 to 800 feet; and excluding the locks the remaining 9 miles of 300 feet, with infinitely better alignment, Lake Gatun alone furnishing miles of easy, long stretches of navigation, where a fair rate of speed can be maintained for almost any class of vessel.

Men experienced in navigation have expressed the opinion that it would have been extremely hazardous, if not impracticable, to have driven a ship of any large size through the sea-level channel, as designed. A certain rate of speed must be maintained to provide for steerage, and at such necessary speeds, the danger of colliding with the banks would have been very imminent. Bearing this fact in mind, with the knowledge that these banks would have been of rough, and in many cases, of jagged rocks and the whole situation complicated with cross-currents formed by the flood-waters of the many streams, the proposition seemed one of more than doubtful value.

The momentum of even a 20,000-ton ship at the low speed of five miles per hour, striking such rocks, would have torn out every plate which was in contact. The consequences of disabling and possibly sinking a ship in a narrow channel, can be readily appreciated. It would have been serious enough in time of peace; in time of war, it might have decided the whole issue at stake for the nation.

It has been argued that similar calamities can occur in the locks of the type constructed. It is possible, but the chances are so extremely remote as to be practically negligible. In the locks the ships would move at slow speed, not under their own power, but towed by locomotives on shore, handled by men especially trained for the purpose, along lock walls perfectly smooth, and through still water. This problem is entirely different from the one which would have been encountered in such a sea-level canal as was proposed.

The well-planned and well-wrought-out precautions that have been installed to provide safety at the lock gates, would seem to insure sufficiently that no danger should be apprehended at those points. It should be remembered that these locks are in duplicate, and that the disabling of one set does not mean the closing of the Canal.

As far as the protection of the locks in war time is concerned, the same problem would have arisen, no matter what type had been chosen; either type is vulnerable and could be put out of commission, if not held by force. A lock was considered an essential feature of the proposed sea-level type, and that was to be located within easy short-distance range of comparatively small battleship guns.

The question as to what effect probable slides in Culebra Cut would have on any canal was given some consideration in discussions, but such effect was not foreseen to its full extent, as is evidenced from the developments which have already taken place.

These slides are serious enough, in the case of the present type of canal, and what they would have been in case of the sea-level, with a depth of eighty-five feet more, can somewhat be imagined. They are occurring along the very deepest part of the cut, and no one realized the extent to which they would occur. While a quick remedy may be found, so far none has been proposed that is publicly known. The only one being in operation at the present time is to let the slides come down, removing the material by dredging as fast as possible. Even by this method, it has so far been impracticable to maintain either the full normal width or depth of the Canal. This condition would have been largely aggravated by the greater depth of the sea-level type. Bad as the situation is, it would have been very much worse had the lower-level type been adopted.

Undoubtedly engineering skill could have planned and built the Gamboa Dam so that, excepting through some extraordinary convulsion of nature, it would have been more than reasonably safe from destruction and consequent disaster to a sea-level canal. But the fact that there was such an immense body of water, with an elevation of 170 feet above the Canal level, subjected to the tremendous floods which prevail in the Chagres River, and less than a mile from the line of navigation, would naturally cause a feeling of apprehension as to what might happen.

The argument can of course be advanced that a similar criticism can be made in regard to the Gatun Dam, as planned and built, probably the most important feature of the lock type. Such a criticism is a just one, to a certain extent. But the depth of water against the Gatun Dam is, and never can be, more than one-half that what it would have been at Gamboa—a difference of thirty-six pounds per square inch in favor of Gatun.

As far as the effect of earthquakes is concerned, the Gatun Dam, built entirely of earth, of such tremendous proportions, represents, it is believed, the very best construction that the skill and experience of centuries has evolved to prevent, or at least to minimize, the effect of shocks. Such would not have been the result at either place had a masonry, or a combination of masonry and earth, structure been built. It might have been practicable to have made the Gamboa Dam entirely of earth, but no decision was ever reached on this very important point.

The matter of an ample water supply for any high-level lock type of canal was given grave consideration. The average yearly rainfall does not vary greatly on the Isthmus, and in computing the amount of water available for lockages, 80 per cent. of the amount which has prevailed as an average during the three dryest months on record was taken as a safe assumption. This net amount is the normal discharge into the high-level from its tributary watershed. To this was added the amount that could be obtained by raising the level of Gatun Lake only one foot above normal, at the end of the wet season; and also that which would be produced by drawing the lake down three feet below its normal level.

After allowing for evaporation, leakage at gates, infiltration, power for gates, lighting, etc., there remains ample water under the assumed conditions for twenty-six lockings per day, or, based upon passing only a single ship of 3,000 tons at each lockage, a yearly capacity of 28,500,000 tons. With ships of 5,000 tons each, there would be a yearly capacity of 47,500,000 tons. But as there is room in the locks to handle two or more small ships, such theoretical possible tonnage as indicated above can be largely increased in practice. The lock walls were, however, built two feet higher than originally contemplated, which would permit a greater allowable oscillation in the lake-level and increase the number of lockages.

Should the tonnage passing the Canal ever increase beyond the present water supply, the amount can be largely increased by the construction of a reservoir dam at Alhajuela, a few miles up the Chagres River, where a most perfect natural site for a dam on rock foundations exists. A description of the water supply for the lock type has been given for the reason that, as the sea-level type would provide an unlimited supply, the fact that the lock type is amply provided also, is very germane to the discussion.

The character of the foundation of the Gatun locks and dam was the subject of a long-drawn-out and somewhat heated controversy. The people who were responsible for the adoption of the lock type, were early satisfied as to its stability and permanence. But in deference to continual clamor, raised by the advocates of the sea-level type, further and more exhaustive tests were made, after the work of construction was well under way. The result of these later tests fully confirmed the previous judgment, and nothing occurring during construction or since has raised any doubts as to its correctness. As far as the foundations are concerned, the works should stand as long as do the surrounding hills.

The time of passage through the Canal is a very important matter. There are many factors which affect this time, and in making practical comparisons between the two types under discussion, the balance is strikingly in favor of the lock type.

In such a sea-level canal as proposed, it would have been necessary for one of two ships of medium or large size, about to meet, to stop and make fast to mooring posts while the other passed at reduced speed. This is done in the Suez Canal, regular mooring places being supplied, excepting through sections where the canal is in rock, where no meetings are allowed. Such a procedure produces certain delays, which would have become more and more serious as traffic increased. The narrow, tortuous channel, with its cross-currents and frequent stoppages, would have entailed delays at least equal to those caused by the locks of the present Canal.

A theoretical calculation was early made as to the comparative time which would be required for passage by two types of vessels: one, 540 feet in length, 60-feet beam, drawing 32 feet of water—result by sea-level, at the rate of 20 ships per day, time required $10\frac{1}{2}$ hours; by lock, $9\frac{7}{10}$ hours; one of type 700 feet in length, 75-feet beam, drawing 37 feet of water—result, by sea-level, at the rate of same number of ships per day, time required $14\frac{3}{10}$ hours; by lock, $10\frac{8}{10}$ hours, speed in every case being at 5 miles per hour.

As a matter of fact, ships have already been passed through the Canal in eight hours, and it is entirely probable that this time may be materially shortened when speed conditions are more fully understood, and the operating force is more experienced.

It is also a fair assumption that in the case of the sea-level canal, ships arriving at terminals late in the day, and desiring passage, would have had to lay up until morning of the succeeding day, as it is not believed that it would be practicable to navigate such a channel by night. Cases of this kind probably would have been the exception, but it is certain many would have occurred. The cost of such delays in each individual case would have been a burden, and in a year's aggregate, would have capitalized to many millions of dollars. All such delay and expense can be obviated in the type as built.

With regard to relative capacity, it has been shown conclusively that the lock type can handle for years to come all the traffic which the most optimistic forecast will justify, and that when, if ever, the time comes that it cannot, it will be entirely practicable to rebuild the Canal, to one of a *true* sea-level type, and carry on traffic coincidently with such reconstruction. And by so doing the enormous additional cost entailed will be borne by future generations, and not by the present, as should be the case.

But while it has been shown by the discussion so far conducted, that the advantages of the lock type far outweighed those of such a sea-level type as was recommended, there remains the question of comparative cost and time of completion of the two types.

In this, as in all others, the preponderance of what may safely be termed facts is very largely in favor of the lock type.

All estimates as to the cost of any project which are made in advance of actual construction are merely intelligent guesses, based upon the most reliable data that technical knowledge and experience afford. Generally such data are available, and fairly accurate forecasts can and should be made, in ordinary cases.

But the Panama Canal was no ordinary case. Its very magnitude; its complexity of details; the unknown elements entering into it; the discouraging results which had been achieved by previous attempts at construction, all made up an extremely uncertain proposition.

Added to all these were the factors of climate, sanitation, inferior labor, distance from base of supplies, and it must be added, up to a certain time, failure to evolve a practical working organization, all making up a mass of uncertainties, out of which no man or class of men could be certain of deducing more than a rough guess. This statement may be questioned by some eminent engineers, but it was a fact nevertheless.

As is often the case, even where conditions are altogether better in every respect, and data are available, the estimates as made for both lock and sea-level types were too low, as has been proven by the actual construction of the present Canal. It should be said, however, in reference to this that important changes, involving increases in cost amounting to many millions of dollars, were made in the details of the Canal, some of which, without doubt, added to its value, while others, possibly, did not.

But admitting this increase over the estimate in the cost of the lock type, it is a fact which cannot be successfully questioned, that a much heavier increase would inevitably have been entailed had the sea-level type been chosen.

Experience is a great teacher, and it is safe to say that there is not a man whose word would carry weight, who was actively connected with the building of the Canal, from 1905 to 1914, but who will go on record that in his opinion a sea-level canal, even of the very unsatisfactory type proposed, would have cost probably double the amount that has been expended upon the lock type.

It is the consensus of opinion among the best-informed men, for the reasons set forth in the report of the Chief Engineer of the Commission, under date of January 26, 1906, already quoted, that the selection of the 85-feet lock type for the Canal was eminently wise, and that such wisdom will become more and more apparent as time goes on.

It will be remembered that reference to a sea-level type, of the kind proposed, has been made several times. As far as value is concerned, if a real sea-level canal of a width sufficient to assure open, free navigation, could have been built within a reasonable limit of time, and with a permissible amount of money, then the problem would have been simplified, and the decision would undoubtedly have been different. While the skill and resources of the United States are ample, these resources could not have been drawn upon with the consent of our people through Congress for such enormous amounts as the construction of the so-called "Straits of Panama" would have entailed.

CHAPTER III

THE RECONSTRUCTION OF THE PANAMA RAILROAD

The importance of the Panama Railroad as a necessary adjunct in the construction of the Canal, under whatever type of canal might be adopted, was early and clearly recognized by the United States Government, and its control and ownership were taken over by the Government before any construction work was undertaken, or even planned. Lying immediately along the line of the proposed canal, it afforded the only practicable machine for handling the commercial business, which, for more than fifty years, had been passing over its rails. This business was to be very largely augmented by the great traffic, in the shape of material and supplies required in canal construction. It was also called upon to handle the millions of cubic yards of waste, rock, and earth from the Culebra Cut.

In passing through the backbone of the Cordilleras, the construction of the Canal required the excavation of a mass of material of over one hundred millions of cubic yards, nine miles in length, and of a maximum depth of 360 feet at its highest point. As comparatively little of the immense bulk of this cutting could be disposed of adjacent to it, by far the greater part had to be handled long distances north and south, into the Gatun Dam, into the works at Balboa (the southern terminal of the Canal and of the railroad), and into spoil or waste banks, wherever they could be most advantageously and economically located. Thus the Panama Railroad was an absolute necessity in the carrying-out of the work of canal construction, and well has it proved its worth.

Originally built as a single track of five-foot gauge, it had been fairly well maintained during more than fifty years of its existence, as far as track conditions went, but it was sadly lacking in many other important features. With but a single track, practically no sidings or station buildings, a worn-out telegraph line, no terminals worthy the name, and with motive power and rolling stock obsolete years before, it presented a problem which had to be grappled with and solved without loss of time. Traffic, both commercial and that pertaining to the Canal, was about at a standstill in the summer of 1905. Thousands of tons of freight were piled in cars, on docks and in warehouses, some of which had lain from three to eighteen months in the hands of the railway company, and in many cases, even the shipping papers and records of this freight were lost.

Owing to the long delay in deciding upon the type of the canal, whether sea-level or lock, it was impossible at the beginning of construction, to rebuild the railroad upon its final definite location. If the former type for the canal were chosen, then, comparatively few of the fifty miles of the railroad needed to be relocated. If the latter, then some forty miles must be relocated and built at a safe working height about the 85-foot level of the proposed Gatun Lake, and of the waters of the completed canal through Culebra Cut. As the necessities of the case admitted of no delay, it was decided to double-track, and otherwise improve and add to the existing facilities of the road, upon its then present location, and later to rebuild it upon its final location, when the necessary data for such action should become available.

This explanation of the situation which confronted the engineers in 1905, will make clear the fact that the rebuilding of the Panama Railroad involved two entirely distinct problems: one to place the road in proper shape to handle ordinary current traffic, and the construction of the Canal proper, and the other, to rebuild it for future needs of the years to come, after the completion of the great waterway.

The work of rejuvenation, or rebuilding the railroad—the solution of the first problem—was begun promptly during the summer of 1905, and was vigorously pressed through 1905 and 1906. Embankments and excavations were widened; bridges and culverts renewed and rebuilt to proper width for double track; an entire new telegraph line, using old rails for poles, was erected, and new sidings and yards of capacity, sufficient, and properly planned to take care of not only the immense, but great variety, of business to be cared for—such variety introducing complications which are seldom met with in the ordinary course of railway operations.

Large amounts of new and heavy rail were laid, ties by the shipload were brought in, miles of old and new track were ballasted, new stations and other accessories were installed, and a complete set of new shops, provided with modern machinery, especially designed for the rapid and economical repair of locomotives and cars, were constructed. Orders were placed for the necessary motive power and equipment, which were received and placed in service within a reasonable length of time, considering the distance of the work from the base of supplies, and the necessity of conducting a great part of the negotiations by cable.

The only delay that was encountered, other than the minor ones arising from the constantly increasing traffic to be handled while the reconstruction and improvement were being carried on, came from the apparent ignorance or the failure of the contracting car company to understand, or to provide for the existing conditions. The necessary cars were built in the United States, and shipped "knocked down," to be erected at Colon by the car company. This delay was largely overcome by the railroad company taking prompt action, by supplying labor, plant and supervision necessary to complete the contract.

New and large modern docks, warehouses and coaling plants were constructed at Colon and Balboa, of capacity ample to receive and transfer economically the very many varieties of materials, supplies and equipment, coal, etc., from ship to rail, and well-arranged terminals were built at both Atlantic and Pacific ports. During all of this time, the work of classifying, sorting out and finally disposing of, as far as possible, the vast amount of freight, which had by reason of inefficient service been allowed to accumulate, was successfully carried out. As portions of this freight were found to belong to consignees, at almost every port from San Diego, California, to Antofagasta, Chile, it can perhaps be realized how intricate and serious the problem really was.

The personnel of the working force of the railroad was thoroughly reorganized from manager to foreman. New and experienced men of all grades of railway service were brought from the

United States and modern systems of accounting and storekeeping were installed, so that the Panama Railroad can truthfully be said to have then become what it imperatively had to be—a proper machine to undertake the great work, which was so suddenly thrust upon it.

As an example of the various unique situations which had to be met promptly and without failure, may be mentioned one, which from its importance, showed strikingly the readiness and versatility of the railroad management to meet all crises.

The city of Colon had for years been supplied with water by a small and wholly inefficient plant belonging to the railroad company. Like much of the property of the company, this plant had been allowed to deteriorate, until it had arrived at a condition where the drinking and culinary requirements of the people of Colon were barely provided for, to say nothing of their protection from dangers of fire, or their ordinary hygienic necessities.

A new, modern system was being constructed, but it was not humanly possible to complete this plant until late in the season of 1906. During the long, unusually dry summer of that year, the old system began to show symptoms of a total collapse, the serious consequences of which, largely aggravated by the rapid increase in population, would have been, unless prevented by extraordinary efforts, nothing less than a disastrous calamity.

The railroad company had a few old tanks mounted on cars, which could be utilized as water carriers, but these were of altogether too small capacity to meet the exigency. It had, however, just received a few refrigerator cars, which were calked and coopered up until they were practically watertight. These cars were put into special service as water-trains, and by dint of unremitting supervision, night and day, the company managed to haul from its distant tanks out on the line, sufficient water to take care of the emergency until the new plant went into operation. Thus the situation was saved.

As an important part of the duties of the railroad company was the purchase, transportation and distribution of all the food supplies, not only for its own employees, but for the entire force employed in Canal construction—an aggregate of fifty thousand persons—unusual facilities were necessary to enable it to carry on this work successfully, remembering always that it was two thousand miles from the base of supplies, and in a tropical climate. The Panama Steamship Company was the property of the railway company, and was managed by its officials and formed the link between Colon and New York, from which port nearly all food supplies were shipped.

Meats, vegetables, eggs, milk, and similar supplies all had to be forwarded from producers in the United States, to ultimate consumers on the Isthmus, under refrigeration. Suitable plants for such purpose were installed on the ships of the company, and all such supplies were landed into Colon, in as perfect condition as the day they left the United States. But this part of the work was the easiest to successfully accomplish. The care and the proper distribution of the perishable food after its arrival on the Isthmus, in a tropical, humid climate, where, night and day, the mercury ranged from 80° to 95°, presented a problem requiring careful thought and thorough preparation.

Coincident with the renovation and improvement of the railroad proper, as a transportation machine, during 1905 and 1906, the company planned and built on the docks at Colon, a large, thoroughly modern, concrete refrigeration and ice-making plant, into which all supplies were handled directly from the plants on the ships, without contact with the outer air, three separate gradations of temperature being provided to care properly for every variety of food. At this plant each and every parcel, no matter how small, required for morning delivery, by the thousands of employees of the Canal, or railroad company, was separated, packed and forwarded by special train of refrigeration cars across the width of the

Isthmus. So perfectly were the plans of the railroad conceived, that the last of such food supplies were delivered at Panama and Bàlboa, at the Pacific end of the works, not later than nine o'clock each morning.

In connection with this plant, the railroad company installed a modern bakery, capable of producing forty thousand loaves of bread, large quantities of pastry, etc., each day; also, a thoroughly up-to-date laundry, which, in addition to caring for the work of more than forty hotels and eating-houses, handled a vast amount of necessary work for private parties, at reasonable charges. The installation of immense commissary store buildings required a stock of over half a million dollars in value, of every conceivable kind and character.

This general description has been given of these accessories, as their installation was properly a part of the necessary rejuvenation and improvements of the railroad, without which its work could not have been done, and without such work the Canal construction could not have been carried out. And all of these features of the reconstructed railroad were planned and carried out in 1905 and 1906. The phantom railroad, which existed early in 1905, unable to conduct properly its ordinary commercial business, had been at the beginning of 1907 transformed physically and otherwise, into a modern, high-class, smoothly running transportation machine, and capable of meeting the extraordinary demands made upon it. In amount and complicated variety of service required probably no similar undertaking can be found in the annals of the railway world.

As originally built, the Panama Railroad from Colon, its Atlantic terminal, on its way to the Pacific followed the low-lying swamps of the lower Chagres River Valley, reaching the northern foot of the Cordilleras, at a point called Gamboa, at which point, the Chagres River, coming from its source among the mountains far to the east, makes an abrupt turn to the north and northeast on its way to the Atlantic. From this point, the line of the railroad climbed by comparatively easy grades, up and across the summit, through practically the lowest point, dropping down to the level of the swamps on the west side of the Cordilleras, at a point just south of Pedro Miguel. The entire distance through the mountain range was about ten miles. For the greater part of this distance, the railroad did not conflict with the line or elevation of the Canal. The retention of this piece of the railroad, as a part of the main line, would have forced a crossing of the Canal by a bridge in the Culebra Cut, a proposition to be avoided, if practicable to do so.

The adoption of the lock type of canal, with the dam and locks at Gatun, distant some seven miles from Colon, together with the locks at or near Pedro Miguel, at the south end of Culebra Cut, created Gatun Lake. This lake in connection with Culebra Cut, formed a body of water some thirty-two miles in length, and would have submerged miles of the track of the railroad, to depths ranging from forty to seventy-five feet. In addition to this, several miles at each end of the lake, approaching Gatun from the north, and Pedro Miguel from the south, had to be relocated and rebuilt on proper gradients, to overcome the height of the lake waters, and to place the permanent railroad at a safe working elevation above them.

All these conditions meant that a low-lying line of railroad, encountering no serious or expensive obstacles in its construction, must be replaced for many miles by a new high-level line, which must find supporting ground, as far as practicable, along the lower slopes and spurs of the Cordilleras, through which countless lateral streams, large and small, found their way to discharge into the Chagres River, the great drainage sewer of the entire district. The fact that both the Atlantic and Pacific terminal cities of the railroad—Colon and Panama—were located on the east side of the Canal, made it at once obvious that the new railroad must follow, for its entire length, the same side, to avoid any crossing of the Canal itself.

Accordingly, with the then known conditions of the problem, the preliminary surveys for the new line were begun in 1906, and continued during that year and through the early part of 1907, when a trial location was completed. Actual work of construction upon small sections was then commenced, leaving the details over the greater part of the line to be worked out, as far as standards and consequent cost were concerned. In consideration of these governing features, the pertinent question of the future use and consequent value of the new line became of the utmost importance.

The then Chief Engineer of the Canal Commission, whose duty it was to decide upon the character of the line, held the belief that once the Canal was put into operation, aside from local passenger travel, supplemented to a small extent by tourists, the business that the road might do would be extremely light. Consequently, only such minimum amounts should be expended upon its construction as would result in a road good enough to handle such comparatively unimportant traffic. Whether these views were held by the parties succeeding him or not, the new line has been built, being completed in May, 1912, after about five years of actual construction work, at a cost of $9,000,000 or at an average of about $200,000 per mile of single track.

It is but fair to say, in explanation of this high cost, that it was originally intended to locate the line through the mountains, along the berme or flat space, left below the upper slope of the Culebra Cut. The development of the slides along this portion to the cut, however, necessitated the abandonment of this route.

This resulted in a location of the line back from the cut for several miles, through a heavy mountain country, increasing the cost of this particular section, it is said, some $1,200,000 over what it would have been if laid through the cut proper. Without any intention to criticize adversely the expenditure incurred, it is a question if several millions could not have been saved, and a road amply sufficient in character have resulted. The cost of any road built across the Isthmus, and under the conditions forced by natural and artificial obstacles, would have been extremely heavy, and the suggestion here made is, that possibly the road as completed is of a higher class and consequent cost, than the circumstances of the case called for.

All the business that the Panama Railroad is handling today—January, 1915—is its passenger- and local freight-train traffic for Isthmian points. And, as it was recently announced, unofficially, that the railroad would operate its ships through the Canal, the probability is that, to avoid rehandling, the greater part of the latter business will be diverted from the railroad.

A part of the old main line of the railroad, lying west of Culebra Cut, has been retained, being connected with the new main line by a pontoon swing-bridge across the Canal, near the south end of the cut. Movements should be infrequent over this piece of track as it is operated simply as a branch. Possibly, it may be abandoned entirely in the future, as the necessity for its retention may disappear.

Generally speaking, the floors of the valleys, which the line had to cross by high embankments in order to maintain the requisite elevation above the waters of the Canal, were composed of soft clay and vegetable matter of varying thicknesses. Before reaching a solid foundation, such blankets of treacherous material proved of insufficient strength to carry such embankments, necessitating the placing of large extra amounts of material, before the roadbed could be brought to, and held to, its proper elevation. One of these embankments contained 5,000,000 cubic yards of material. The cuttings are, as a rule, heavy, and taken altogether, it must be conceded that the new line, while involving no extraordinary technical engineering features, presented problems requiring infinite patience in execution and large amounts in expenditure.

There were no radical departures in methods of construction, from those which obtain in carrying out similar pieces of railway work in the United States. Wherever possible, machinery developed and provided for the construction of the Canal, was utilized to its fullest extent in prosecution of the work. This machinery, and in fact, all of the plant, was of a type representing the latest and most scientific development which human skill, supplemented by practically unlimited financial resources, has up to this date yet produced. Manual labor-saving inventions, such as steam-shovels, work-trains, rapid unloaders, track-shifters, and the numberless devices which could be economically used, were supplied to any extent that seemed advisable, and were an absolute necessity. The amount of material the work called for, could not have been completed without the aid of such plant, in double the length of time that was actually expended upon it.

As the railroad company could draw at will upon the enormous working force assembled for the building of the Canal, which force could at all times be renewed and supplemented by fresh supplies, the labor situation was easy to handle, and the problem of keeping it up to maximum requirements was a comparatively simple proposition. All the labor camps for men of all grades and races were under the watchful supervision and strict regulations of the very efficient Sanitary Department of the Canal Zone. The policing, housing, and feeding arrangements were taken care of under the same general arrangements that obtained along the line of the Canal itself; arrangements that, in scientific planning and fidelity of execution, probably were never equaled in the history of the world, as the results so eloquently testify.

While the terminal facilities at Colon at the Atlantic end, and at Balboa at the Pacific end, installed in 1905 and 1906 to meet the necessities arising from the first problem, as before described, have been utilized as far as possible in the development of the final plant, they have been added to and modified largely to make them suitable for future needs, as far as such needs can be foreseen. Shipping docks, warehouses, coal handling plants, dry docks, and the many facilities needed as accessories to the physical road itself and to the steamship lines, have been constructed, and are of a first-class permanent nature. Machinery to provide for efficient and economical handling of all classes of freight has been installed, and in such matters the road is up to date. Considering its comparatively short length, it is probably in a class by itself.

As far as the entire new plant is concerned, it is built on very high standards. A private report recently made by a first-class railroad man, who was not connected with its construction, says: "It is absolutely the neatest up-to-date little railroad I have ever seen." Laid with heavy rail, well supplied with ties and with the best of modern track fastenings, thoroughly ballasted, it should be easily and cheaply maintained. It is equipped with automatic signals over its entire length, and its operation should be conducted with economy and efficiency. The only blemish on the fair picture is the more than doubt which can be entertained, that it will not have sufficient traffic to justify its creation, at the high standards and at the expense which its construction has entailed.

During the fifty years and more while the property was under private ownership, and during the construction of the Canal, the headquarters of the company were maintained at Colon, the real estate of which city was owned by the railway company. But since the completion of the new line, the headquarters have been moved to the new Administration Building of the Canal Government, at Balboa Heights, adjoining the Pacific terminal of the Canal, and the residences of the principal operating officers established nearby—a much pleasanter and probably a healthier location than the former one.

Before the completion of the locks at Pedro

Miguel, and the final closing of the Gatun Dam, the rails of the old road and all movable property of value on its line, were taken away, and the rising waters of Lake Gatun soon covered its roadbed, to remain forever submerged, or as long as the locks and dams shall exist, until the story of the great works and the memories of the men who planned and executed them will have become more of a legendary than of a historical character.

CHAPTER IV

PROSECUTION OF THE WORK

The first great work to be undertaken on the Isthmus by the Americans after their accession to all the rights of the French Company early in 1904 was that of sanitation. An organization was created to handle this overshadowing problem, the solution of which was necessary as a foundation for the successful prosecution of the work of canal building. Hand in hand with sanitation should have gone active measures looking to preparation along all lines for the systematic operations of construction, and to some extent progress was made in that direction. But the uncertain and dilatory methods—they can hardly be called policies—which were pursued by the first Commission, precluded the achievement of any great results.

While it was true that, owing to the absolute uncertainty which existed as to the type of canal to be built, no ultimate working plans could be adopted, still it was obvious that in any case there were certain important features of the problem which could be grappled with at once. The treaty which the United States made with the new

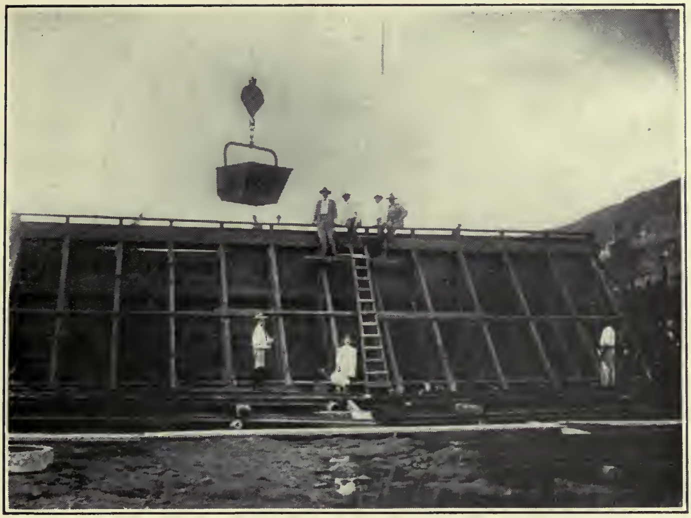
Republic of Panama excluded from the Canal Zone the cities of Colon and Panama. The power to exercise sanitary and quarantine control over these cities was given to the United States in December, 1904.

This provided the authority necessary for the Engineering Department to undertake the work of street-paving, sewer and water-supply construction necessary to change these pestholes into places where life would be reasonably safe. The engineers, therefore, prepared plans for the work in the two cities. Locations for gravity supplies of water were selected, material was ordered and the construction of reservoirs and pipe lines was undertaken early in 1905. Considerable progress had been made on the water supply for Panama by the middle of that year. Orders for large amounts of paving materials had been placed in the United States, and altogether fairly good progress had been made at that time for the city of Panama, but little at Colon.

After July of that year plans for the rapid improvement of both cities were vigorously pushed. The organization of the Division of Municipal Engineering was enlarged and perfected and the work moved along with satisfactory speed and results. Concurrent with these operations, the similar task of providing safe water supplies, sewerage and other adjuncts of the many new towns and camps, which were being established to care for the rapidly increasing force, was being accomplished. Quarries were opened, supplied with plant, and operated to provide the necessary material for the street-making. As material became available, the working force of the division was increased, and by the summer of 1906 the more important parts of all this work were completed and the Sanitary Department was placed on a secure basis.

All this time the very necessary reconstruction of the decrepit Panama Railroad was going forward, as previously described, and in 1907 the railroad had been placed in shape to handle creditably the vast and complicated traffic forced upon it.

The work which the French carried on was confined almost wholly to dredging and excavation in Culebra Cut, and the number of cubic yards they handled seemed great. But in regard to the dredging necessary for the new Canal, nothing of much value could be done with it until the type was decided and plans to conform to it could be formulated. A few of the old dredges were raised, repaired and put at work, deepening and improving the existing channels approaching the docks at Cristobal and La Boca (now Balboa). This work was done principally to facilitate and make safe the then current traffic and not primarily for permanent Canal construction. When the



First Bucket of Concrete, Gatun Locks.

The Crossing of the Amercian and French Canals at Mindi.

final plans for the Canal were completed, it was found that a part of this dredging work was of value, as it had been carried out along the line finally adopted from deep water to the locks.

Mention has been repeatedly made as to the necessity, which was to a great extent ignored by the first Commission, for thorough and comprehensive preparation. While the type of Canal was yet undecided and in a way all plans for permanent work were nebulous, still there was a vast amount of it which was perfectly apparent must be done, whatever type was chosen. And the delay in planning and pushing such work is open to fair criticism. It is easy in almost any experience to look back and see where better judgment could have been exercised, but in this case it is perfectly clear that the better part of a year was lost by indecision or lack of appreciation.

As before remarked, the amount of work that the French had accomplished in Culebra Cut was quite impressive; practically it was of much less value than a superficial judgment would indicate. The many changes in plans which had occurred during the time of French occupation, and the fact that all work that had been done since the De Lesseps failure had been desultory in character, carried on merely to keep the concession alive, precluded any intelligent results. As a consequence the American engineers found simply a big gash in the hills, a part of which they knew they could utilize, a part which they knew they could not, and some of it at least that they could not even guess at. But it was early known by them that only by the use of steam-shovels and railroad trains could the cut be removed. Therefore, the correct procedure would have been to have shaped up such parts of the cut as were reasonably sure to become a portion of the great work.

The intelligence and experience of the American engineer have taught him that the essential factor of rapid and economical steam-shovel operations, when material must be conveyed long distances, lies in a practical track arrangement. Not only must adequate facilities be provided for loading cars, but also as perfect a system of tracks for their transportation must be installed as the conditions will permit. This was especially true at Culebra Cut, owing to its immensity and peculiar location through the backbone of a mountain range. But in deference to what may be termed the clamor of ignorance, the Commission decided that "dirt must fly," and without proper plant—excepting a few modern shovels—and in the utter absence of any intelligent, comprehensive plan, work was begun and carried along in an expensive and unsatisfactory manner until August 1, 1905. At that time all this desultory work of excavation was stopped, and the entire force in the cut was started in making preparations for the real task, the execution of which had so far baffled every effort.

Confidently relying on his grounded belief that the 85-foot lock type would be selected, the Chief Engineer then laid his plans accordingly, but always with the idea in mind that, should the sea-level be chosen, these plans with little modification would apply to it also.

An explanation of the general features of such plans has been made elsewhere. As large a force as could be gotten together and as much material as could be collected were devoted to the work. With the arrival of proper plant of all kinds and material in abundance, progress was steady and continuous. Only a comparatively short time had elapsed when it became possible not only to go on with preparation, but to place a number of shovels actually on the real work itself; so that, when final decision in favor of the lock type was made at the end of June, 1906, not only was the greater part of the plant installed and the organization effected, but a very appreciable amount of material had been removed.

But far more satisfactory was the actual demonstration that had been made, that the plans as evolved and carried out were a success, even beyond expectation. Even with the limiting factor of the Gatun dam and locks in mind, the Chief Engineer was able to assure the Washington officials and representatives of the press in 1906 that the Canal could be completed in 1914 and formally opened January 1, 1915. This was not mere guesswork, but a judgment made after careful calculation. How far his prediction came true, the events of the last year will indicate. After the decision of the type was made, things moved faster and faster in the cut and elsewhere. As the latter work developed, room was made for more shovels and trains, forces were constantly increased, until at the beginning of 1907, it can truly be said that the operations were in full swing. Nothing but a convulsion of nature, or a stoppage of appropriations could delay completion in the time named.

Pending decision as to the type of canal, tentative plans and close surveys had been made of the lock sites, which, under the proposed lock type, would be built. Immediately the decision was made, no time was lost in amplifying such plans so that construction could proceed. Vigorous measures were taken to provide housing and feeding arrangements for the large forces, which the work on the dam and locks at Gatun, as well as the locks at Pedro Miguel and Sosa, would necessitate. This required little time, as provision for quick action had been foreseen and arranged in advance.

The site of the proposed dam at Gatun was cleared. Spur tracks leading from the main line of the railroad were arranged for along the base of the proposed dam. These tracks would enable rock waste to be hauled from Culebra Cut to form an integral part of the dam. Steam-shovels, with necessary complement of railway trains and other plant, were installed at Gatun, and the work of excavation for the lock foundations and spillway of the dam was begun and pushed with vigor. Similar plant was placed at work at Pedro Miguel, so that by the end of 1906, the actual task of building these great works was well under way.

As already described, the crushed rock and sand for the masonry of Gatun locks and dam were brought by water from a point on the coast about twenty miles east of Colon. To enable this to be done, the old French canal, or what remained of it, between Gatun and Limon Bay (Colon), was dredged and extended to the site of the proposed works at Gatun. This made it practicable for tugs and barges to make delivery of material immediately at the works and simplified the handling of it. Work was carried on on the proposed dam at Sosa Hill (Balboa) until, by a change of plans hereafter described, these operations were discontinued.

Dredging at both ends of the Canal was pushed with all available plant, utilizing as much of the old material as practicable, and all of the new was put into commission on arrival.

The inauguration of active construction of these immense works called for the planning and building of many auxiliary plants of a variety and character impossible to enumerate. Some of them were of a magnitude and complexity to justify them as being worthy of extended notice. They were accessories to the greater operations and were carried out with all the minuteness of detail possible to provide. And as far as human foresight could predict, all plant necessary for future operations was placed under order for the quickest practicable delivery. From all that has been said, it may be clearly seen that the work of thorough preparation along all lines of activity was in every sense of the word the one great and overshadowing imperative necessity during the first two years of American occupation. That the work of preparation was well accomplished, the rapid progress attained and the successful completion of the gigantic task abundantly testify.

In considering the length of time required to build the Canal, it may be of interest to discuss somewhat the probable effect of systematic night work. This policy was under serious consideration by the management early in 1907, but no decision had been reached by it when the change of management took place on April 1, that year. The two governing factors in point of time, the works at Gatun and the Culebra Cut, would have required the employment of several thousand more of skilled and common laborers, but with no material increase in general supervision or plant.

One consideration to be taken into account was the mosquito problem. These pests were always more numerous and active during the night hours. However, the success of the Sanitary Department in reducing materially their numbers practically eliminated that handicap.

Considering the entire cost of the Canal, and including all payments made in connection with it, the interest charge on the grand total is not far from one million dollars per month. Conservatively speaking, one week's interest would have paid for all the cost to secure and provide housing and feeding for the extra laborers. By dividing to a greater extent the orders for the material and equipment needed for the locks, and possibly paying a moderate increase in price, the delivery of such material and equipment could undoubtedly have been much hastened.

The situation of, and the conditions which existed at each of these great pieces of work, were such that night work could have been successfully carried on. Taking the time lost in the early stages of the American occupation, together with what might have been gained by employing night shifts, it is believed that the Canal could have been completed in at least two years less time than was the case; more than this even, had the decision as to the type not been so long delayed. In any case, had the management of early 1907 continued in charge, the policy of night work would undoubtedly have been inaugurated.

CHAPTER V

DEVELOPMENT OF WORKING PLANS

DESIGNING AND ACQUISITION OF PLANT

In a description that may be given covering the general features of plans and plant, it will be understood that it covers engineering features only. The coördinate factors, which at the same time were as necessary as engineering to the successful prosecution of the work of the canal building, such as sanitary and governmental functions, are not included. The details embraced under the term of engineering are not merely such as usually pertain to the profession from a technical standpoint, but also those varied and numerous requisites, which the unique conditions of the Panama Canal presented.

It may be of interest to allude briefly to the first nebulous plan for a canal through the Isthmus of Panama. This was probably in 1879, when De Lesseps forced the "Congress" in Paris to vote in favor of a sea-level canal. The advice of experienced engineers against this plan was rejected. A sea-level canal it was to be, and with a loud flourish of trumpets so-called preparations were hurried to open the work.

One of the first steps taken by the company which was organized was the purchase of the Panama Railroad in 1882. Finally, without intelligent, adequate preparation, work was begun and carried on, until the state of the company's finances made it apparent even to De Lesseps that the construction of a sea-level canal was beyond its power.

So in 1887 the company changed its plans from a sea-level to one of a lock type, but nothing but a series of misfortunes pursued it. And after several modifications, all tending to lessen the cost of the Canal under the new plans, work was stopped entirely, and the company broke with a crash that attracted world-wide attention.

During the period which then elapsed up to the time of the American ownership, a new company, which had taken over the franchise after three years of study by a commission of experienced engineers, adopted a plan for a lock-type canal. A very limited amount of work was carried on under it, without, however, providing any intelligent solution of the most important problem involved, viz., the control of the flood-waters of the Chagres River.

The above résumé is given to enable the reader to gain a faint idea of how small value was the general information which the Americans came into possession of in 1904. In matters of technique, the French were past masters in engineering on the Isthmus, and they collected as the results of their surveys a vast volume of detailed data, mostly in the form of maps, plans and profiles, many of which were utilized, but only to extract necessary information.

When the American engineers took charge of the work of planning and building the Panama Canal, they were entering *terra incognita.* They met problems of a magnitude and complexity that had set at naught the efforts of their predecessors.

Taken as a whole, the work of the French was of much value, and their labors and superb courage in the face of great obstacles should be justly appreciated. But the fact remains that not to them, but to the American engineers, is due the credit of solving so successfully the many and intricate problems which were encountered in carrying out the great work.

As a general description has heretofore been given of the methods and discussions, out of which came the decision of the United States Government to build a lock-level canal, nothing more need be said in regard to that phase of the situation. But the length of time which elapsed between the date when the Canal Zone and our rights were acquired and the date when the type was chosen

—from May, 1904, to June, 1906, more than two years—rendered the formation of any definite plans for construction an absolute impossibility.

Owing to unfortunate defects in organization, a large part of this time was practically wasted. The necessity for thorough preparation for the carrying-out of the great work under whatever type was selected did not seemingly impress the Commission. Thus the engineers were hampered in their efforts, and, while some work of real value was accomplished meanwhile, it was not until well into the year 1905 that even preliminary plans began to take intelligent shape.

While the line of the proposed Canal, as laid out by the American engineers, followed generally that of the French, especially through the backbone of the Cordilleras, it differed from it in some important particulars, notably at the termini at both the Atlantic and Pacific Oceans. A line securing much more tangent and much less curvature was projected and laid out on the ground. Cross-sections were taken to develop the conditions, to fix approximately the amount and character of the required work and, incidentally, to check the French data. Hundreds of miles of levels were taken, and finally, after much adjustment made necessary to meet properly all conditions, particularly at Culebra Cut, a definite location was established for the center line of the

Canal, one that would have required little or no change, whatever type of canal was chosen.

Many considerations were weighed carefully in fixing the details of such location. Primarily to reduce quantities to the lowest practicable limit, it was necessary to follow the lowest ground. This was complicated to some extent by the necessity of utilizing the work of the French Company as far as practicable, with respect for the known slides and for those that the future might develop.

In addition to all this work, a vast amount of surveying was carried on at many different points to secure data for the proper location of towns and camps for various needs of the Sanitary Department and for many other purposes. All such data had to be secured as original matter, using whatever of value the French had left to supplement and check the new work.

Besides the work of all these field surveys, the Engineering Department was making tests of the strata and character of the material, not only along the line of the Canal, but particularly at the site of the proposed Gatun dams and the various lock sites. The whole question of the practicability of the lock-type plan depended upon successfully establishing the safe and permanent character of the foundations for these works. An absolutely perfect knowledge of details was essential in order to make proper plans for them.

Once the necessary data were secured and the lock type approved, then a special force of experienced designers was organized, and the real work of designing the dam and locks was begun in August, 1906. This important matter was placed in charge of a capable engineer, one who had long experience in both construction and operation of the largest locks then in existence.

Steady and intensive studies of the many intricate problems involved were rapidly and systematically carried on, and in March, 1907, all the essential features of this vital problem had been successfully worked out. As illustrating the multiplicity of detail involved in these studies, mention may be made that they covered designs of stoney gates, culverts, valves, sections of lock walls, piers, miter wall, side walls, floor sills, rolling gates, miter gates, interlocking pin devices, operating bridges and machinery, and the action of sea water on concrete and construction plant.

Conferences were held with different manufacturers of steel structural material, in order to adapt the plans as far as practicable to standard shapes. Consideration was also given to numerous devices submitted by various parties usually ignorant of the subjects, and these projects were courteously dissected and set aside.

While the essential features, as originally designed, were adhered to in carrying out the work, some changes were made in details, some of which involved a heavy increase in cost of construction without any apparent benefit. One very important change, that of roller instead of miter gates, was ordered in opposition to the judgment of the designing engineers. Such a change was clearly not advisable and would have added some thirteen millions of dollars to the cost of the locks. The order for this change was afterwards rescinded, and the gates were built according to the original plans of the designing engineers, modified for increased width.

The conception and the preparation of plans for the endless variety of work involved, for docks, warehouses, shops, both to care for marine and land plant, dry docks and marine railways, for sewerage, paving and water supply, went on rapidly. The reconstruction of the Panama Railroad required careful consideration as to details, which were all successfully worked out. The planning of all of these works was intrusted to the care of the particular department which was charged with their execution, all being under the direction of the Engineering Department.

Passing over the plans developed for the securing and caring for the vast force of employees, which will be treated elsewhere, last, but not least, was the solution of the overshadowing problem of taking out the Culebra Cut.

The truly stupendous proportions of this cut have been described, as well as its topographical features. The French Company early recognized that it was the *pièce de résistance,* and most of its energies were devoted to its removal. While the amount in cubic yards which they accomplished sounds quite impressive, it was really of much less value than it seemed, owing to the impracticable way in which the work was done and the shape in which it was left.

As in all such problems, a deluge of plans as to just how to handle the cut, complete in every way excepting the quite important one of practical common-sense, was showered upon the Chief Engineer. One genius proposed to wash the entire cut into the oceans by forcing water from a plant on Panama Bay; another, to erect a big compressed air plant at Culebra and blow all the material through pipes out to sea. Still another, equally as brilliant, wanted to drive a double-track railway tunnel, at grade, clear through the entire length—nine miles—and haul all the material above out in cars. The matter was serious enough, but such schemes provided plenty of amusement to afford relaxation.

The problem was simply one of transportation, and the successful solving of it depended entirely on the devising of the correct method. The cut lay directly through a mountain range with precipitous slopes and side valleys of very small areas. As a natural corollary, the spoil must be loaded onto some conveyor that would take it to the spoil banks and works, distant from ten to thirty miles. This conveyor could only be that of railroad trains, loaded in the cut and handled over the Panama Railroad to their destination.

The reconstruction and double-tracking of the railroad provided the means of handling these loaded and empty trains, once they were upon its rails. This was the simplest part of the proposition. The real problem to be solved was to devise such a system of trackage in the cut itself, as would permit the maximum number of immense steam-shovels to be operated with the least possible interference with each other.

After careful study, and as the result of long experience in heavy construction and complicated transportation, the Chief Engineer outlined such a system of work tracks for the cut itself and at the spoil banks, together with the necessary connections with the main tracks of the Panama Railroad. In conjunction with the engineers directly in charge of the cut, the details were steadily worked out, and every track thereafter laid was made to conform to the general plan. Under this system the shovels were enabled to work one above the other on horizontal benches, and the trains were so made up and handled that the shovels could be kept in actual operation to a large percentage of the total time.

Thus the two fundamental results necessary to success were obtained: rapid execution of work at the lowest possible cost. That success was achieved to a marked degree is admitted by everyone, not merely the men connected with the work, but by experienced engineers and contractors, who have visited or studied the operations. And no one has been more emphatic in words of approval than the Army engineers, who took over this elaborate and yet simple installation, which was developed and in running order early in 1907.

The development of plans may be seen to have been in the nature of a gradual evolution, rather than that of any sort of inspiration. This was forced by conditions, natural and artificial, the significance of which had to be properly grasped before decisions could intelligently be made. It was in every way a case of "being sure and then going ahead." There was no time for long-drawn-out experiments. It is possible that now, in the light of nine years of experience, improvements could be effected in some minor details, but on the whole, and especially as regards the greater problems, it is believed that no changes, radical in character, could have been made that would have achieved a more satisfactory result.

The great amount and variety of plant which came to us as the result of our purchase of all the French rights and property, was of a character and complexity to defy description. While much of it was of standard European design of the period, some parts could only be classed as freaks.

Apparently every crank who possessed influence was allowed to exploit his notions in the furnishing of machines to the company, the intended use of which, to this day, one American chief engineer, at least, has not been able to fathom.

Our engineers and contractors have evolved machinery for handling construction work, such as was necessary for the building of the Canal, far in advance of other nations. Without this machinery, the time of the completion of this work would have been postponed for years.

Particularly is this true of steam-shovels, which in heavy land excavations are the greatest time and labor savers that genius has yet produced.

In referring to the French plant, as being the "design of the period" in Europe, it is but just to say that while it was insufficient in principle and magnitude for the task it attempted, for thoroughness of detail and character of material it was unsurpassed. But for practical purposes, as far as the American engineers were concerned, most of it could economically only be consigned to the scrap heap. Some exceptions there were, which will be noted later, but as a general rule the above statement is correct.

During the life of the first Isthmus Canal Commission, or up to the summer of 1905, some of the necessary plant for land work had been supplied, notably a few steam-shovels and accessory machinery. Also, a limited number of locomotives for the railroad had been delivered, and some freight cars put under order. Small plant for street, sewer, and water-works construction had arrived and was being used. But for the great aggregate and variety of work involved in the larger problems of canal construction, practically nothing had been provided, or even planned. It was a blank page of equipment which confronted the engineers at that time, and probably it was best that such was the case.

It was well known by the Engineering Department long before the type of the Canal had been decided, that regardless of type, there would be millions of cubic yards of waste to remove from Culebra Cut, and from other parts of the work. Acting on this sure knowledge, and also on the fact that the plans heretofore explained for the removal of the cut, were the best that could be conceived, no time was lost in preparing for their execution. All types of machinery adapted for the work were carefully considered. The details of many that were of proper type were gone over minutely, and plans and specifications for strengthening, enlarging their capacity, and perfecting them in the highest degree, were wrought out.

Orders were placed for large numbers of steam-shovels, locomotives, cars, rapid unloaders, power drills, stone-crushers, etc. Heavy rail, ties, lumber, hardware, and the thousands of different articles which then could be foreseen would be necessary, were requisitioned. Much of all of this plant was needed in the work of preparation, and the natural delay in its delivery somewhat handicapped the progress.

Some land work was done by utilizing a small part of the best of the old French equipment, but the amount of such work was negligible. In point of economy, it would probably have been wiser to have done nothing with it, excepting from the fact that the necessary work of preparation might be delayed.

Much of this new plant began to arrive long before the type of the Canal was decided, and was promptly set up at the shops of the Commission, and put at work. It was found that when the lock type was chosen, there was not a single item of the millions of dollars' worth of this plant, but what was perfectly adapted to the purposes of its construction.

Not until it was known what type of canal was to be built, could much marine plant be planned or ordered.

Other than tugs and similar light craft, the great bulk of this plant consisted of dredges of several types and capacities. Plans and specifications for these dredges and their accessories were made by the engineers on the Isthmus, and a sufficient number to carry on the work properly were placed on order. Some were really seagoing vessels, which were built in the Atlantic states, manned by crews selected from the staff of the Panama Steamship Company. They went under their own steam to Colon, and in one case, around Cape Horn to Panama. In amount and low cost of output, the performance of these dredges has never been equaled.

The superintendent of motive power, through his department, was made responsible for the design and satisfactory operation of all mechanical features of the land plant, and was in charge of all land shops. These shops were planned, built, and the necessary machinery installed during the years of 1905 and 1906.

The great number of steam-shovels made it necessary to provide a shop especially designed for their erection and maintenance, as they came to the Isthmus "knocked down" or in pieces. An elaborate shop for the maintenance of the engines employed in the cut proper, was erected at one point, and smaller ones elsewhere to avoid loss of time and delay in the operation of the shovels. Engine houses, coaling and water facilities, and a complete system of telephones connecting every part of the work were installed. In short, nothing was neglected that the skill and experience of the Engineering Department could suggest, to provide the most complete plant that could be devised.

The distance of operations from the points of supplies, and the absolute necessity of depending upon its own resources, forced the Department not only to provide a plant as complete in every respect as human ingenuity could plan, but one which should be made up of the very best materials that could be made in the shops of the United States. All plant and material were bought on competitive bids, although in some cases, factors of better values and time of delivery influenced the selection.

As the greater part of Culebra Cut was rock, hard and soft, it was necessary to drill and blast nearly all of its entire bulk. The drilling was carried on largely by power drills, operated by compressed air, and as there were hundreds of these drills in operation simultaneously, the power required was enormous. To provide this power three large air-compressing plants were planned and built at about equi-distant points along the cut, and a supply pipe, nine miles in length, was laid down, from which compressed air was led to reach separate unit of drills, wherever located.

In addition to these air drills, a large number of gravity drills, mounted upon wheels, were provided for the work in isolated places, where it was not convenient to convey air. The entire drilling plant worked well, and without such an installation, neither the steam-shovels nor trains could have done the magnificent work they did until the entire cut was taken out and disposed of.

The construction of the various locks, and of certain features of the Gatun Dam, required the making and placing of millions of cubic yards of concrete masonry, aggregating the greatest amount ever employed in any engineering project. This called for plant not only of great size and capacity, but of special design, fitted to handle material in quantities which before were thought to be impossible in point of time. As no rock of a suitable character could be found within practicable transportation distance from Gatun, a location for a large quarry was selected on the coast, some twenty miles from Colon. Arrangements for its use were made with the Panamanian Government, whose property it was.

A complete crushing plant, probably the largest single one ever erected, was planned and built there. From this point, crushed rock, and sand which was found in the same vicinity, were conveyed by tugs and barges directly to the works at Gatun. The selection of this site for the crushing plant was largely influenced by the fact, that while first-class rock could be obtained at Balboa, the Pacific end of the Canal, it was deemed wise to divert from the Panama Railroad the enormous traffic which its movement would have entailed.

An elaborate plant was planned and supervised in its erection by the Engineering Department at Gatun, to unload material from the barges; to mix, transport and place it directly in the bottom, walls and other parts of the locks. In many ways this plant possessed some new and unique features which were largely experimental, but the record of its operation showed that in amount of output in point of time, it was never equaled or even approximated.

The construction of the Gatun dam and locks was really the limiting feature, in point of time, of the completion of the Canal. The enormous size of these works, compressed into a comparatively small area of operations, rendered the installation of a plant of the largest capacity that could be operated, a prime necessity. The plans and specifications for all this machinery were made, and everything was ready to ask for tenders for its manufacture and delivery early in 1907.

The locks at Pedro Miguel and Miraflores, being segregated in location, could be built in much less time than those at Gatun. A crushing plant was erected near Balboa, where first-class rock was available, the latter point from which material was hauled by rail to the locks. Suitable mixing and erecting plants were installed at these locks, which were very successful in operation, both in point of time and unit costs. These plants were planned and installed in 1908, after the changes in the location of these locks had been decided upon, and which are described elsewhere.

Reference has been made to the use of the old French plant. In carrying out some of the smaller items of the land work, such as operations of small rock crushers, in the handling of materials required for construction of various plants, and in and around the shops, a limited amount of portable cars and track was used to advantage. Many old boilers and engines were repaired and fitted up and made to perform excellent service; some few of which may be called hand tools, were found to be of service, but most of these were obsolete.

The engineers were able to make good use of some of the smaller types of the old dredges. One type in particular, a purely European development, was found to be of much value. These machines were practically wrecks and some of them had lain for years, sunken beneath the waters at the two ends of the Canal. As the use of cheap steel had not become the practice at the time of their creation, they were built of a superior class of iron—a much better metal to withstand the ravages of time and sea water.

These dredges, after having been raised and rebuilt at the marine shops, together with their self-propelling steam barges, served a very useful purpose, and at very satisfactory unit costs. An appreciable amount of work was accomplished by their use, pending the delivery of modern large-sized equipment. It was also found practicable to utilize a few old tugs and launches by renovating them, although the cost of this work would not have justified the expenditure, had not the necessities of the case admitted of no delay.

For the great work in Culebra Cut, the transportation problem, there were required drills, steam-shovels, locomotives, cars, power unloaders, spreaders, track-shifters, besides the many various kinds of smaller tools. The ordinary standard air drills were used in large numbers, as well as those of the gravity type. As is the case in nearly all small plants, duplicates in the whole, and of most of their parts, were kept in stock to avoid delays.

Steam-shovels were generally of two classes, of the same type, but differing in size and capacity. Taking the best type of shovel made in the United

States as standard, plans and specifications were changed to perfect the machines to the utmost possible limit. Strength and speed in operation were the objects sought to be attained. Steel replaced cast iron, parts liable to breakage were enlarged, with a result that a machine in every way superior to any in existence was produced. Some one hundred of these machines were required in the construction of the Canal. And to the fact that the skill of American engineers and artisans had been able to produce them, can be credited to a very great extent, the quick and economical execution of the work, and even that it was possible to do it at all.

There was nothing special required in the proper type of locomotives to serve the shovels. Unusual vigilance was exercised that every part should be of the best material, and according to the most improved practice. Owing to the limited area in which excavation was carried on, so-called heavy tonnage trains could not be handled. The locomotives were therefore designed to move a fair load over tracks which, while of heavy construction, were yet not main line in character. Owing to the great density of the traffic, the locomotives were of necessity of a type that could make comparatively fast time over the tracks of the Panama Railroad. The problem of design was complicated by the fact that they must be, not only switch, but good road engines also, a requirement that only a practical railroad man can appreciate. They served their purpose admirably, and probably could not be much improved upon at this day.

The question of a proper type of cars was a harder one. Ordinarily some approved form of self-dumping type would have been used exclusively, especially had the greater bulk of the cut been of earth instead of rock. It was necessary, in point of time and economy, to load and unload this rock in as large masses as practicable, and to avoid breaking up by hand, into the smaller sizes that dumping cars could handle.

Where dumping cars could be used with economy, they were installed and worked satisfactorily. But the greater portion of the cut was handled on ordinary flat-cars of the largest size and strength. They were made much wider than the standard in ordinary use, and consequently, of increased capacity. As an illustration of the unique conditions met, and the service given, on one occasion a rock, blasted from one of the levels of the cut, containing fifteen cubic yards and weighing some thirty-four tons, was loaded by one of the large shovels onto a car, and safely carried several miles and deposited in the waste bank.

At these dumps, or waste banks, the material was unloaded entirely from one side of the car by rapid power unloaders. The unloader was simply a huge plow, operated by a winding engine, mounted on a car of its own, and provided with a heavy steel cable, extending the length of the train. Then this material was spread, or thrown off down the bank by a machine looking much like a one-sided snowplow pushed by a locomotive. After two or three of such operations, the track was moved its entire length to the edge of the bank, as nearly as safety would permit, and the same operations resumed.

In the moving of the track, there was used a remarkable machine invented by the manager of the Panama Railroad, which, in its idea and application, was an entirely new expedient in construction work. A technical description is not needed here, but it suffices to say that, by its use, an ordinary train crew of five men and a locomotive, with half a dozen laborers, did the equivalent amount of work that before its introduction required about two hundred laborers, and in much less time.

This brief description of the methods by which the enormous amount of waste from Culebra Cut was handled, is given for two reasons: partly, because of the magnitude of the operations, as marking them as of a class by themselves; but, mainly, because it is necessary to understand clearly that the introduction of every device that could do away with common labor, was very imperative. Under any ordinary labor conditions, such a policy would be a true economic necessity, but on the Isthmus these conditions were many times magnified. The low efficiency of this labor, while it increased appreciably up to a certain point as time went on, was a severe enough handicap, even with the aid of such machines. What it would have been without them, or with an inferior plant, only those who were directly in charge of operations can realize; the Canal would have cost fourfold what it did, and its time of completion no man could have safely predicted. To the skill and broad conception of the requirements shown by American engineers, backed by the great resources of the United States, may be ascribed the successful completion of the gigantic task.

It would require many pages to properly detail every class of plant that was needed and provided for the execution of the work in all of its manifold ramifications. The same careful consideration was given to the task of providing not only the best of everything, but in such ample quantities as to preclude serious delay. The greater bulk of all plant was on the Isthmus and at work, early in 1907, and the remainder was supplied in such time and amounts as needed. No chapter of the history of the building of the Canal reflects greater credit than that of the story of equipment.

CHAPTER VI

THE HOUSING AND FEEDING OF THE FORCE

The employment of the thousands of men necessary for the construction of the Panama Canal, under the conditions imposed and in a tropical climate, made imperative the provision of quarters not only ample in capacity, but also of such a character as to comply in every respect with modern sanitary requirements. During the French occupation and operations on the Isthmus, the company which was organized by De Lesseps, beginning in 1883, built large numbers of houses located at various points where required. These buildings were of the same general class, all being of wooden construction, and of a very suitable character to house the large force employed, as far as the necessities for health and comfort were then known.

During the long period which elapsed from the date of the failure and cessation of the work of the company, and its resumption by the Americans (some seventeen years) these buildings had deteriorated largely in usefulness. The destructive action of the elements, very rapid in the tropics, and the ravages of the ants, had rendered practically the great majority of the whole number unfit for human habitation. Only comparatively few buildings had been occupied and maintained during these years. The material necessary for the restoration of a limited number was provided and such repairs as were imperative for temporary occupancy were made without delay.

It will be obvious that the construction and fitting-up of proper quarters for an ultimate force of fifty thousand men of various ranks, races and individualities, involved a large and systematic program. To insure success, it meant that not only must a comprehensive plan looking to final results be definitely adopted, but also that an organization fully capable of its execution must be provided. The strict and very necessary regulations governing living conditions, which were promulgated and enforced to the letter by the Sanitary Department, added greatly to the time, cost and general complexity of the problem. Requirements which had become recognized as standard by the custom of years, were no longer guiding or limiting factors. The Americans took up this work on the same comprehensive and thorough lines which marked their methods in each and every direction.

Without the knowledge of the importance of modern sanitation, naturally the French quarters lacked about everything that we now know is absolutely essential, not only to comfort, but even to safety of life itself in the tropics. Their houses were generally placed well above the ground, supported usually by small piers of concrete masonry. This plan may have been adopted for reasons of ventilation, but more likely to avoid the destructive voracity of a species of ants, which will soon eat any kind of common timber in contact with the ground. The buildings offered eating and sleeping accommodations and very little else. Some of the better class were provided with cesspools, but as a rule only crude latrines were provided. Any provision for bathing was confined wholly to quarters occupied by employees ranking well above common laborers. There was no defense against mosquitoes, as the importance of such precaution was then unknown. Probably in many individual cases, some casual protection was employed, but it was entirely optional.

Under American management, as far as the hygienic needs of the employees were concerned, the orders and rules of the Sanitary Department were paramount. While the Engineering Department made the plans and constructed the buildings, in all matters affecting health conditions, it acted under the orders of the Sanitary Department. That the rules and requirements of that department were wise and farseeing is evidenced beyond question by the great success which attended them, and which enabled the Canal to be built.

The selection of proper sites for new towns or camps was carefully considered. Convenient access to the work was, of course, a prime necessity, but the selection of a location was governed also by its natural features. Ample space without crowding, and perfect drainage, not only by sewers, but by surface drains as well, must be assured. The cardinal principle of elimination of malaria with its different forms of fevers, depended upon the abolition of the germ-carrying mosquito. This could only be accomplished by the utter absence of standing water, which served as breeding-places. This requirement was at times very perplexing in a climate where the yearly precipitation was so constant and so enormous.

Definite rules, based upon scientific research and conclusions, fixed arbitrarily the amount, not only of floor space, but also of the number of cubic feet per hour of fresh air that must be allotted as a minimum to each individual. The proportion of bathing accommodations to the number using them was fixed, as was also that of the other proper sanitary arrangements. Provision was required not only for ample lounging and sitting-rooms, but for the drying of clothes—a very necessary function in that wet climate.

Under the Engineering Department the Division of Building Construction was created which was given the work of planning and building all houses of whatever nature, necessary for the task of Canal construction. An efficient corps of trained architects formed an essential part of its staff. A practical builder of long experience was placed in charge, and he was held responsible for the rapid and economical erection of all buildings.

Standard plans were made, covering every variety of structure, of which two general classes were established—bachelor and married men's quarters—the number and capacity of the former largely predominating. These classes were segregated to as great an extent as practicable.

The great numbers of men necessarily employed in comparatively small areas of operation rendered necessary the condensation of these quarters into settlements or towns of greater or less size, according to circumstances. The housing of the great numbers of bachelor negro laborers resulted in the evolution of standard barracks, all furnished with proper accommodations, strictly in accordance with the rules laid down by the Sanitary Department. Fitted with ample bathing and other sanitary arrangements, all thoroughly screened, drained and sewered, they were veritable palaces as compared with the houses to which they had been accustomed. Small but well-designed quarters, generally in groups of two or four each under one roof, were built for laborers with families. These houses were provided with independent cooking accommodations.

All laborers' quarters were furnished ready for occupancy, and were as complete with regard to comfort and health as close supervision could make them. Owing to the natural indolence of these people, many of whom would only labor enough to secure daily bread, a rule was made that a certain minimum number of hours must be worked each week, to entitle them to the occupancy of Commission quarters and privileges. This rule worked well and tended to drive out the undesirable class, and promoted in a marked degree the efficiency of the whole.

The housing of the white employees presented a vastly more complicated problem. After serious consideration, a plan was evolved under which the relative size and character of the quarters for each and every class was fixed by a somewhat arbitrary standard. Taking the minimum requirements as defined by the Sanitary Department as a basis, the accommodation furnished to each class was worked out on the scale of wages or salaries, as far as practicable. The square foot was taken as the unit, and quarters of different types were planned and built to conform to multiples of such unit, keeping the numbers of such types to as low a limit as possible.

This method gave very satisfactory results, and was pursued not only in the assignment of the houses, but also in their furnishings and fittings. The rule applied to married and bachelor quarters alike, and was adhered to without favor or discrimination. It established a standard that was easily understood by everybody, and systematized a rather complicated proposition. It also proved a strong incentive to encourage individual ambition. A promotion in rank meant not only a better wage, but more commodious living accommodations, and a certain rise in the social scale. Distinctive social lines were drawn on the Isthmus, as sharply as they are elsewhere, particularly after the advent of a large number of families. It was a frequent and amusing occurrence to have the wife of some employee come to headquarters and enter complaint that Mrs. So-and-so, whose husband was drawing a salary only equal to that of her husband's, had an extra rocking-chair, or something of the sort. Such troubles were easily adjusted, but without a system life would have been a burden to the management. It was a truly paternal government the Chief Engineer was called upon to administer.

The system as described, under which quarters were assigned, was adhered to in the case of subordinates and minor officials, including as many as was practicable or politic. Houses of special design were provided for the higher officials of all departments, in accordance with their needs and importance. While the wishes and tastes of the intended occupants were consulted and complied with, when expressed within reasonable limits, the final decision of all such matters rested with the Chief Engineer. Generally speaking, no trouble was experienced in handling such affairs, although some heart-burnings were occasioned by the necessary clipping of exuberant ambition.

The quarters for all employees, of every race and class, from Chief Engineer to laborer, were completely furnished and provided free of rent to their occupants. All were built on sanitary lines as laid down, and provided with the requirements of modern life, particularly those made necessary by reason of the tropical climate with its usual peculiar diseases. One unique feature was especially noticeable. Every aperture was provided with metal screens, and in most cases in the white quarters, the beds were screened also, although the latter was not obligatory. This feature was an essential part of the campaign against mosquitoes, to prevent malaria and other typical diseases.

The most rigid daily inspection of all quarters, from the highest to the lowest, was maintained by the Sanitary Department. No one was exempted, and no excuses prevailed in cases of neglect of rules and regulations. The Chief Engineer was several times formally warned that holes as large as a lead pencil had been found in the screens of his veranda. It was almost a perfect system, and eternal vigilance was the price of health and life itself.

After the completion of all quarters by the Division of Building Construction, they were turned over to the Division of Labor and Quarters, which had charge of their furnishing and fitting-up, ready for occupancy. This division made all assignments in accordance with established rules, and was also held responsible for the continuance of such rules, and for the care of all property. No exchange of either quarters or furniture could be made excepting with its consent, and all supervision was subject to the approval or disapproval of the Chief Engineer.

The very active labors of the Division of Building Construction continued through 1905 and 1906, and reached its culmination in 1907, at which time the demands for quarters were fully met, and thereafter, the force of builders gradually decreased. As may be inferred from the general description given, very large investments were made by the Commission in providing housing for the great army of the employees. While the tropical climate and sanitary requirements made larger expenditures necessary than ordinarily would have been the case, the fact that all these buildings could only be regarded as temporary, complicated the problem. With a certain maximum use of not to exceed ten years for 90 per cent. of them, the most rigid economy was necessary in their construction. These difficult conditions were well met and overcome. Health and comfort were the matters of first consideration, and all else was subordinate to them.

Houses of all classes were of the same general style of construction. The material in every case was either of pine lumber brought from our Gulf states, or fir from the northwest Pacific ports. Owing to the immense amount of such lumber used on the Isthmus, it was brought in by shiploads. In less than two years, a total of eighty-five millions of feet board measure was consumed in various buildings and other improvements, including all lumber used by the Panama Railroad except cross-ties. The payrolls of the Division of Building Construction carried an average of more than four thousand names throughout the same period.

The houses were of the two-story type, of two or four apartment capacity. They were designed to afford the maximum of air space and ventilation. They were placed well above the ground, to promote coolness and to protect from the ravages of ants. All doors and windows were thoroughly screened; also all porches or verandas, the latter generally being used as sitting- or lounging-room, and the most popular one in the house. Shower baths of the most modern type were installed in every apartment, and all sanitary arrangements were of the best that our experts have produced. The interior finish of all houses was generally of planed lumber, painted white, no plaster being used on account of the dampness of the climate. Roofs were of metal, which answered admirably every purpose for the length of time the buildings were required.

Of all the buildings turned over to us by the French, about two-thirds, or some fifteen hundred of all classes, were rebuilt and made to conform to requirements. They were of much value, especially in the saving of time. The assembling of the force of skilled laborers was delayed somewhat by the lack of necessary quarters, especially as it was advantageous to employ men with families, as far as possible. However, early in 1907, sufficient quarters had been provided to care for all men needed up to that time, and thereafter only such additional houses were built as the natural increase and changes in the force demanded, as new work was opened up, or existing work was brought to a finish.

FEEDING THE FORCE

In any study of the problem of properly feeding a mixed force exceeding fifty thousand people on the canal work, it must be remembered that the Isthmus and adjacent countries produce little of food supplies, especially for the force of white employees. Practically all of such supplies could come only from the United States.

For some years the Panama Railroad had maintained a small commissary, through which its employees could obtain necessary food. But to a great extent such supplies were obtained from local stores, operated by private parties, where prices were generally high, and quality and quantity uncertain.

After due consideration it was decided to continue the commissary arrangement of the railroad, enlarging its functions to cover the employees of the Canal Commission. Contracts were made with wholesale dealers in Chicago, for all fresh meats, prices being fixed on the varying daily market scale. The five ships of the Panama Steamship Company were fitted with refrigeration facilities and a sufficient number of refrigerator cars were added to the equipment of the railroad.

It soon became apparent that not only food, but supplies of all kinds must be provided through the commissary. The building was rebuilt and enlarged into an extensive and general department store, capable of carrying a heavy stock of every line of merchandise.

During this period, an extensive and thoroughly modern refrigerator plant, provided with three grades of temperature, was built on the docks at Cristobal—the Zone port at Colon. An ice-making machine, a bakery, and laundry were included in this plant.

So perfect were the arrangements, that from the time fresh meats were loaded on shipboard at New York, they never came into contact with the outside air until delivered to the consumer. In addition to the handling of fresh meats by refrigeration, the same system was employed in supplying all varieties of perishable food—the list of which in a tropical climate was formidable. After the plan had been well established and its successful working demonstrated, the demand for increased varieties was met. In addition to all kinds of vegetables, dressed fowls, eggs, butter, milk, and even fresh strawberries, were successfully handled. At first, most of the fish supply was sent from the United States, but later, arrangements were made to secure from local parties ample quantities of the finest food fishes in the world.

The commissary and refrigeration plant, being both located at Cristobal, made the concentration of supervision comparatively an easy matter. At first, all orders for supplies were filled from the main commissary, but later, branches were established in every important settlement of employees, where orders were taken and filled.

The method of distribution was very complete and successful. A supply train of refrigerator cars, filled with ice, cold storage and other supplies, loaded at the big plant, left Cristobal early every morning, stopping and distributing these stores, at every station along the line of the Panama Railroad. Here they were immediately taken by employees of the Division of Labor and Quarters to the hotels, mess-houses, and individual dwellings of the employees. By this method, all supplies needed for that day were in the hands of the consumer not later than nine o'clock every morning, thus securing the indispensable results sought to be obtained.

Food ample in quantity, variety and character, was provided promptly, and with the least possible effort on the part of the employees. A simple system of coupons was installed, and books were issued to employees only, for cash, in varying denominations from one cent to five and ten dollars. These coupons were good for their face value, for food supplies, or for any kind of merchandise at the main commissary, or any of its branches. The organization and smooth working of the commissaries, under the Division of Labor and Quarters, was one of the best features of the American administration.

While all these plans were being formulated and perfected, the Commission, probably having little faith in their success, awarded a contract to a private party to furnish meals to employees. Such a contract involved the turning-over to him of practically all of the elaborate supply arrangements that had been made, including the large number of hotels and mess-houses that had been built and put into successful operation. And the prices fixed in the contract were to be much higher than those which had been demonstrated were necessary, and which had already been established. A vigorous protest against such a contract was made by the Chief Engineer, with the result that it was cancelled. If carried out, it would have resulted in disaffection and trouble throughout the entire organization, and in large unwarranted profits to the contractor at the expense of the employees.

Thus, the policy of the Commission of feeding and supplying the material wants of its great force of employees was continued. And so perfect were the arrangements, and such care and business ability were displayed, that the cost of living on the Isthmus was materially less than for the same standards in the United States. The

Commission was able to effect this result by cutting out the usual profits of all middlemen, and the only advance that was made over first cost and transportation, was enough to cover handling and amortization of cost of plants. For example, the Chief Engineer, who paid the same prices as everybody else, had daily on his table, the very best cuts of fresh meats, in superb condition, at materially lower cost than he paid in Chicago—not five miles from the slaughtering pens—for the same quality.

The same results were obtained in a greater or less degree all through the long list of goods supplied by the Commissary. On such as might be called luxuries, a larger advance in price was made than on the necessities. But the aim from the first was to furnish all supplies just as near actual cost as possible. As methods improved, and experience showed that it could be done, prices were reduced from time to time. Weekly lists were issued, giving the current prices of all necessities, and attention called to all changes. The "increased cost of living" was never an issue on the Isthmus, and no such advances in the price of supplies were ever made, as were in effect in the United States during the same period. A careful study and close analysis of the reasons why the Commission was able to carry out its policies so successfully, might throw a flood of light onto a problem which has been for some years a burning issue with the American people.

Hotels were built and put into operation in the various towns along the line of the Canal. These were for the accommodation of the bachelor members of the force, who were provided with quarters nearby, as previously described. At these hotels the price of each meal was fixed, in 1905, at thirty cents—which price was maintained until the close of the work, although the quality was improved. In no section of the United States, excepting possibly rural communities, could a meal of as good a character be obtained for less than fifty cents. Ample in quantity and of as great a variety as possible, they presented a forcible illustration of results that can be secured by vigilant supervision. For the laborers, both negro and Spanish, mess-houses of a character to meet the needs of each class were established at convenient points. Three meals each day, suitable to their needs and habits, properly cooked and served, were furnished at the rate of forty cents per day for the Spanish, and twenty-seven cents for the negroes.

When the progress of the work had arrived at a point where it became interesting, and particularly when the sanitary provisions had assured comparative safety for visitors, the flow of tourists became a factor to be reckoned with. Besides the large number of people who came singly or in small parties, delegations of representative business men from various commercial bodies in the United States, Congressional committees, Washington officials, etc., began to visit the Isthmus. At that time there was not a hotel or accommodations there suitable to their wants, and provision for their comfort became imperative. Therefore, the Commission erected and put into operation a large hotel, on a commanding and beautiful site, overlooking the city and Bay of Panama. This was provided with modern conveniences, and thrown open to all guests who chose to avail themselves of its privileges. After the usual time of experiment, it proved valuable in supplying a seriously felt want, and has been operated continually and successfully since the autumn of 1906, and is still the leading hotel on the Isthmus.

Taken altogether, the policy adopted by the Commission of housing, caring for, and feeding its great army of employees by and through the organization of its Engineering Department was a marked success. It not only created a state of contentment, but it also proved a financial benefit to the employees that no other system could have done. And wherever else the policy of extreme paternalism may be questioned, it was without doubt the correct one for the canal construction.

CHAPTER VII

THE ASSEMBLAGE AND MANAGEMENT OF THE FORCE

The construction of the Panama Canal called together the largest number of men that were ever employed at one time on any modern or medieval peaceful enterprise. It is possible that much larger numbers were engaged on works executed in ancient times, like the building of cities, irrigation systems, and the Pyramids of Egypt, but of this we can only theorize. The problem to be solved by the Engineer of the Canal from 1904 to the completion of the work was not only large, but very intricate.

When the Americans took over the control of the project, they inherited from the French a force of about seven hundred men. This force was not only incompetent, but was altogether too small to be regarded as even a nucleus about which to rally an organization. It consisted of negroes from the islands of the Caribbean Sea, who, from their well-known indolent habits, engendered by the lassitude of a tropical climate, were not a sufficient potential factor to depend upon. In numbers, with proper living and sanitary conditions, they could be counted as a supply from which to draw by far the greatest percentage of laborers needed, but in other ways they were woefully deficient.

From the white man's point of view, their wants are primitive, and their efforts to supply them hardly go beyond the aim of securing food enough to ward off starvation. Such an incentive as ambition to lift themselves to a higher grade of civilization is unknown to most of them. The only real competition that ever threatened their absolute domination of the labor market on the Isthmus was the introduction of Chinese by the French. As this was a failure, the situation was intensified.

As the necessities of the case admitted of little delay, efforts were at once made by the first American Commission to augment the force largely, with the result that early in 1905 there were assembled some seven thousand of these blacks, enough numerically to have made an effective start in preparatory work had not a lack of definite plans and a faulty organization prevented the achievement of the best results.

While the delay in the decision as to the type of the canal to be built somewhat handicapped the solution of the labor problem, it was at once apparent to the engineers that, whatever type was adopted, many thousand more laborers would be needed. Steps were at once taken to secure not only such increase as fast as practicable, but also to improve the efficiency of each individual unit. To accomplish the former result, competent agents were established in the greater and most populous of the British and French islands. At first their efforts were largely nullified by the unfavorable impression which prevailed, not only in the islands, but throughout the world, of living and sanitary conditions on the Isthmus. But with the prompt and steady improvements which were made in these conditions, the inflow of these laborers increased to a gratifying extent.

But their efficiency showed no improvement, owing primarily to causes which have been stated, and serious consideration of ways and means to effect progress along this line became imperative. An ill-advised attempt had been made by the first commission to awaken their ambition by segregating the mass into two classes, distinguished by a difference in rate of pay. Owing largely to the small numbers of the force, this plan worked as an absolute detriment rather than as a benefit, as, coupled with a weak organization, it simply resulted in a wild scramble by the heads of the various departments, all seeking to fill their own gangs by offering the higher wage; so that in 1905 it was found that the outcome was a direct and unwarranted increase in the wages of nearly all of the force, with no improvement whatever in their effectiveness. This plan was at once abandoned, and all of such labor was placed on the lower wage basis.

As more knowledge was gained of the methods and habits of these negroes, the engineers became impressed with the belief that a part, at least, of their non-efficiency arose from lack of proper nourishment; in other words, that they were not getting proper food in sufficient and regular amounts to give them strength for continuous work. Up to this time they had been allowed to get their food supplies when and wherever they would or could. The natural result was exactly what might have been expected with such large bodies of men. They did not get enough, nor of the proper kind, owing partly to lack of supply, and partly to their own inherent indolence.

As a first experiment, the plan was tried of furnishing them at cost prices with uncooked food of such character as they and their ancestors had been accustomed to for generations. Supply depots were established at convenient points and placed in charge of men conversant with their needs and peculiarities. For a while it seemed that success might attend the effort, but experience soon showed that good resulted only in individual instances and that on the mass it had little effect. In many cases their natural hereditary laziness led them to secure only such food as they could eat raw, to avoid the labor of cooking.

After a trial lasting long enough to establish the fact of the failure of the plan, a new one was evolved and put into operation. Mess-houses were installed along the line at proper intervals, and well-cooked food of the character suited to their wants was supplied to them. The use of such food was made obligatory, the cost of it being placed as low as possible, and deduction to cover the same made from their wages. A very marked improvement in their working efficiency was soon apparent, and the success attending this plan was such as to justify its continuance to the end of the work. Men with families living at home, where the necessary cooking could be done, were exempted from the rule, as generally such men were fairly well fed.

Mention has been made of the very apparent idea which these people had conceived that they controlled the only available source of labor which could successfully work in the tropics. This idea had assumed such an importance that they openly boasted that the Canal could never be built without their exclusive employment. They are a childlike race, easy to handle, but, as in the case of the average child, sometimes a practical object lesson is far more effective than moral suasion and results in lasting benefit.

The Chief Engineer speedily came to the conclusion that the prevailing clannishness must be broken up, or a partial failure at least of his hopes and plans could only be expected. To effect the needed change in the morale of the negroes, a sufficient number of laborers of other races and of different characteristics had to be secured and placed on the work, and if possible the net value of the new labor had to be greater than theirs. Several plans were considered, most of which were rejected as impracticable. Suggestion was made that large numbers of our Southern negroes would fill the want, particularly as their adaptability to warm climates was assured. But even if their value as units had been established, which under the conditions was considered as doubtful, the result of the withdrawal of an effective number from our Southern industries would have precluded such a step.

The Chief Engineer, from his experience and observation in our Pacific states, had become well aware of the value of the Chinese as laborers, notably those coming from the Cantonese provinces. On his request, the matter of securing them in large numbers was taken up through Washington.

But the customary outcry that is raised in the

United States against the employment of Chinese made itself heard with its usual violence. It was learned, also, that the attitude of the then Chinese government was not altogether favorable to the project. The tragic history of those unfortunate people of that race who were brought to the Isthmus by the French was too fresh in the minds of the rulers of China. In view of the fact that we had at that time hardly convinced the majority of our own people, as evidenced by the opinion of a large proportion of our press, that our sanitary reforms were a success and that life on the Isthmus was as safe as in any average country, we can hardly censure the Chinese for their skepticism. For these and other reasons, the matter was dropped, after having been carried to the point of receiving several bids for supplying such labor.

It is difficult to harmonize the objections of our own people with the fact that the majority of the millions paid out for labor went to people of an alien race, not one of whom ever did, and probably never will, become either a citizen or resident of the United States, and whose place in the scale of civilization ranks very much lower than that of a people to whom the world owes many of its most valuable inventions. The millions so spent would have returned a much greater value to us through the superiority of the Chinese as laborers. But once the adverse decision was made, there seemed nothing more to be said, and a study was made of other possible sources of supply.

The attention of the Chief Engineer was called to the past employment of Spanish laborers on various public and private works in Cuba. Investigation was quickly made, and with a result sufficiently encouraging that steps were at once taken to test the truth of the favorable reports by actual experiment. A competent man, one somewhat versed in Spanish law and an excellent linguist, was sent to Spain, endowed with fairly full powers to act. He soon discovered that the people of Spain who controlled affairs objected to large numbers of its laborers leaving for any other country and most especially for a place with the record of Panama. Therefore, to avoid possible complications, the result of which might have been disagreeable, he left Spain and established an office in Paris.

From this point, with the coöperation of some of the transatlantic lines of steamships, which were interested as passenger carriers, he was able to secure large shipments of picked men from the Biscayan provinces of Spain. After a fair trial of these men as laborers, the results were so encouraging that some eight thousand were brought to the work, and nearly that number remained until its completion. They were paid a wage equivalent to twice that of the negroes and were, on the whole, worth relatively three times as much. The requirements in the housing and sanitation of a less number, with an equal total efficiency, was a distinct advantage, also.

The effect of the introduction of this force was quickly apparent. Not only did it add to the number of laborers, but it did exactly what was expected in changing the self-confidence of the negroes. From an amusing but embarrassing attitude of self-complacency, they soon exhibited the aspect of men who were afraid of losing their jobs, and their value increased accordingly. While in some ways the efficiency of the Spaniards did not hold up to the standard first developed, their introduction was a marked success. At one time apprehensions were aroused that the force might be seriously depleted by the efforts of officials of certain South American countries to entice them away from the Canal work by inducements of higher wages and other promises. Prompt action through our State Department obviated almost entirely that source of anxiety and they proved an excellent investment from every point of view.

While the assemblage and manipulation of the common labor was going on, the securing and organization of skilled labor of all classes was being vigorously pushed. The clerical force was put under United States Civil Service rules, which action was of great assistance. But on the recommendation of the Chief Engineer, the skilled workmen, as well as the subordinate officials, were exempted from the rules, and these men were hired on their records as practical artisans and operatives. Proofs of character and physical fitness were required in a general way. For some months the task of securing the requisite force and keeping its ranks full looked hopeless. The bad name the Isthmus had received, the influence exerted by thoughtless newspapers and the correspondence and interviews of former employees, who had been weeded out for uselessness, were severe handicaps. Gradually these and other drawbacks were overcome, and the supply of labor became ample and the quality steadily improved.

Agencies, with personal representatives—men of practical knowledge of the various kinds of trades—were established in cities of the United States, centers of manufacturing and railway activities. A liberal scale of wages was established, which, together with certain emoluments, such as free rent, medical and hospital service, vacations amounting to 11½ per cent. of each year, with pay, and nominal rates of transportation from ports of the United States, resulted in an advance of from 60 to 70 per cent. over the standard remuneration at home.

The advent of many families from the United States soon established pleasant social relations in every town. Church privileges of different denominations were provided. First-class schools, thoroughly up-to-date, with experienced teachers from "home," were established, which were free to all, white and black.

Club houses were built and fitted with the usual accessories for amusement and recreation. A large, first-class band was organized from talent among the employees, who were paid for their services, and whose instruments were provided by the Commission.

Among so many young men there naturally were scores of fine baseball players. Several clubs were organized, and baseball tournaments became a leading feature of the recreation of leisure hours. And the quality of game that was exhibited would compare very favorably with that of some of our professionals. Home and social life, with the certainty of continuous employment at very remunerative wages for a term of years, produced a state of content and happiness that went far toward assuring the success of the work. As is now well known, the great majority of the Canal workers, of every race and color, rank and class, regretted sincerely when their la-

The Pedro Miguel Lock.

Towing Locomotive, Gatun Locks.

bors there were ended by the completion of the enterprise.

The establishment of an eight-hour law was early ordered, and all work was governed by it. A grave question has always existed as to the wisdom of this regulation. From a financial point of view, it was not economical, and most of the force would have preferred a slight increase in wages with longer hours. In most cases, such a plan would have been a benefit to the morale of the organization. It was not so much of a problem to look after the welfare of the men during working hours as it was during their hours of leisure. However, the situation settled down into a normal state and conditions became satisfactory. It would have been a difficult task to have found on the face of the globe a community of fifty thousand or more persons, coming from practically everywhere, employees and nonemployees, where law and order was so universally obeyed and respected.

There were four departments represented on the Canal work: the Sanitary, Purchasing and Supply, Auditing and Pay, and the Engineering departments. The Engineering Department was very much the largest, not only in the numbers employed, but in the extent and variety of work which it planned and supervised. Excepting the purely technical work of the other departments, it planned and executed every item of the many details, large and small, that were involved in the project. All labor required for the special use of the other departments was furnished by it, and a high degree of coöperation existed between all departments.

The organization of the Engineering Department was framed along lines of simplicity and effectiveness. A successful organization must be based on two cardinal principles: the location of authority, and the fixing of responsibility. General principles, plans and suggestions only were given to guide the heads of divisions, and they were expected to work out the details. These were subject to review by the Chief Engineer, and approved, disapproved, or amended, as seemed proper. In every case, the Division head was held responsible for the correct and economical working-out of the plans, and he was given whatever was necessary, in forces, plant and material, to carry out the work.

Under the Engineering Department were the Divisions of Motive Power and Equipment, of Building Construction, Labor and Quarters, Municipal Engineering, Meteorology and River Hydraulics and the three divisions having direct charge of the construction along the line of the Canal prism and its accessories, such as locks and dams.

Reporting to the Chief Engineer, each division engineer was supreme on his division, and all orders from the head office went through him to subordinates. The divisional organizations were made up on the same general plan. There was no conflict of authority. Every man's duty, from division engineer down to foreman of the smallest gang of laborers, was clearly defined. He knew that he had but one superior to look to for orders, who would hold him to strict account for results.

Weekly meetings of the heads of all departments and division engineers, including an officer of the Panama Railroad, were held at the office of the Chief Engineer. At such meetings a general discussion was held covering all work in progress or planned to come up in the immediate future. Wherever such work or plans did not seem to be for the best interests of all departments, modifications were made to effect such a result. This secured the utmost coöperation of all departments and in a very practical manner taught each official that, while his particular line of work was important, it was but a part of a great system, to the success of which each must contribute. Under this arrangement perfect teamwork became the rule; the department worked as a unit and its efficiency increased in a marked degree. If a cog in the machine slipped or was broken, it was replaced automatically without jar or loss of time.

All requisitions for labor were made upon and furnished by the Division of Labor and Quarters, this division being also charged with the securing, housing and feeding of all employees. Only in cases of doubt or controversy were such matters referred to the Chief Engineer for decision, once the system was established and its correct principle proved in actual practice. The fields of operation of the other divisions were as indicated by their titles. Each division engineer was free to select his own subordinates and was held responsible to the last degree for their conduct of work. Such a policy developed a spirit of confidence and emulation among the officers, the value of which it would be difficult to estimate. Every man knew that, while responsibility rested upon him and quiet censure, in case of poor results, would surely visit him, ample and quick credit would be given him for his good work. He knew that the success of his efforts meant his personal success and that all promotions were based solely upon merit.

The efficiency of the individual unit of the common labor being comparatively low, it was necessary to employ larger gangs than is usually the case. As a rule, white men were employed as foremen of gangs, although in some cases men selected from the ranks of the laborers gave good service in such capacities. Close supervision was given all foremen to make certain that a proper spirit was exhibited toward the laborers. And the latter, especially those from the British islands, had such an innate respect for authority, that friction and clashes seldom took place and were easily settled.

The work of skilled labor was largely along special lines. Locomotives and trains were manned by forces picked from among the best from the United States and governed by the same general regulations. Steam-shovel operators and men of all classes, who were in charge of the many machines employed, were carefully selected for their fitness. Without any special effort made by their superior officers, they soon developed a spirit of emulation in regard to the amount of the daily output of each machine, which added materially to results. Shop and field mechanics, whether carpenters, plumbers, steamfitters, or painters, once the organization details were perfected, settled down upon a business basis, and their work moved along satisfactorily.

During the two years while the gathering and organization of the vast force of workers were in progress, there were no labor disturbances of a serious nature. Without the announcement of a definite rule, the "open shop" policy prevailed, and the fitness of an employee for his service was the only standard recognized. Undoubtedly the majority of the skilled laborers were affiliated with organizations in the United States, and to their credit it may be said they were a superior class of workers. The management always had the active coöperation of such organizations in securing the best men.

It was inevitable that among such a host of employees of different races, classes, and such varied lines of industries there should be some who came to the Isthmus looking for individual preferment rather than the good of the work. The fact that it was, as often expressed, a "government job" had created in the minds of some of the more thoughtless the idea that loose business methods would prevail and that full efficiency would not be demanded. It required patient endeavor and an absolutely firm line of action to eradicate such mistaken notions and to harmonize all interests as far as humanly possible. Complaints there were, some justifiable, many not. All were promptly and diligently considered and adjusted for the ultimate good of the greatest number. The force, assembled with comparative haste and beginning a new life under unusual and unique conditions, was a great and undigested mass, which required time for assimilation and adjustment, and could only be made an effective machine by discipline and careful attention to details of organization.

The vast majority of the men quickly and heartily accepted the situation with little comment and recognized that every effort was being made that was possible for their welfare and comfort. As under all circumstances and situations, the good sense and intelligence of the average American could be depended upon to adjust himself to proper conditions and regulations.

The policy in handling this army with firm and even justice to all alike, of maintaining open house at headquarters and of keeping in personal touch everywhere with men and conditions, was a success that cannot be controverted. No stronger evidence of this can be given than the universal and sincere regret manifested in many ways when, early in 1907, it became known that a change in administration was at hand. Petitions carrying the names of nearly every one of the white employees went to headquarters, asking that such action be rescinded. Delegations representing the common labor made the same appeal. And the demonstration of regard and affection which honored the retiring Chief Engineer on the evening of his departure still stands as the greatest peaceful function on the Isthmus since the American occupation.

From a state of unrest, uncertainty and pessimism, which prevailed among the few employees on the Isthmus early in 1905, the entire large force in a year completely changed its attitude and exhibited a spirit of hope and loyalty, which could only produce one result. This change came not only from the improved living and sanitary conditions, but also from the workings of a proper organization and the fact that monthly, daily and hourly every man of intelligence could see distinct progress was being made toward a definite, comprehensive and successful conclusion of the great project.

The civil engineers, whether employed directly on preparatory work, actual construction or field surveys miles distant in the tropical jungles, carried their share of the burden, as engineers always do, with vigor and skill. Much of the credit of the satisfactory solution of intricate details of plans and their execution belongs to them. As a whole, the organization was well fitted to carry on the vast work. During the latter years some changes were made as found desirable by the progress and practical completion of some parts of the work or as opportunities presented to simplify methods. But no fundamental innovations were introduced and, in the light of time and experience, it is believed that it was eminently well adapted to the purposes for which it was created.

CONSTRUCTION PERIOD: MARCH, 1907, TO APRIL, 1914

CHAPTER VIII

THE ADOPTED PROJECT

The period prior to March, 1907, has been designated as the preparatory period, the period of organization and plant preparation.

Engineers fully appreciate the far-reaching effects of a mistake made during the preparatory period. A mistake, then, as to a general principle or as to the proper relation between size of plant and work to be done, taking into consideration the element of time, is basic and can never be fully overcome.

The preparatory period, in so far as the excavation plant and the shops incident to its maintenance were concerned, was completed by March, 1907. Of course experience caused many additions to this plant and many changes in the method of its operation. The original conception, however, was broad enough to permit of such changes without serious disarrangement.

In the great majority of undertakings with which the public is familiar, living arrangements already exist in the neighborhood of the work. At Panama, however, it was necessary to create all these facilities, such as houses, water supplies, sewerage systems, hotels, eating-houses, etc. The necessary structures were materially different from those in an ordinary mining camp.

It was necessary to fight and eliminate disease, and the hygienic surroundings had to be as nearly perfect as man could make them. This phase required the coöperation of the Engineering and Sanitary departments. The success of the entire undertaking depended largely upon the health, happiness and contentment of a large force of Americans unaccustomed to a tropical climate.

No basic changes were made in the system of housing, feeding, and caring for the force during the construction period, other than the enlargements and improvements that experience indicated as necessary.

Before commencing the history of the construction period of the Canal, a short description will be made of the adopted project, the changes in such project during the construction period and the discussions that accompanied such changes, together with an outline of the designs made during such period.

ADOPTED PROJECT AS RECOMMENDED BY MINORITY OF BOARD OF INTERNATIONAL CONSULTING ENGINEERS

The adopted project contemplated a lift-lock canal with a summit level 85 feet above sea-level, extending from Gatun to Pedro Miguel and an intermediate level from Pedro Miguel to La Boca, 55 feet above sea, with other parts of canal at sea-level. Ships were to be passed to and from the various levels of the Canal by means of a double flight of three locks at Gatun, a double lock at Pedro Miguel, and a double flight of two locks at Sosa Hill, La Boca.

The project provided a channel 500 feet wide and 41 feet deep, from deep water in the Atlantic to Gatun. In the summit level section extending from Gatun to Pedro Miguel, a distance of 30 miles, a least width of 1,000 feet with a depth of 45 feet was provided in the channel for a distance of about 15½ miles from Gatun south. As the excavation in Gatun Lake increased, in obtaining a depth of 45 feet, the channel width was decreased, first to 800 feet for a distance of about 4 miles, then to 500 feet for a distance of about 3¾ miles, and to 300 feet for a distance of about 1½ miles. Through the Continental Divide from Obispo to Pedro Miguel, popularly known as the Culebra Cut, a channel width of 200 feet was contemplated.

On the Pacific side from Pedro Miguel to a short distance beyond Miraflores the channel was to be 500 feet wide, which channel was to rapidly increase in width until the terminal locks on that coast were reached at Sosa Hill, La Boca.

The channel through that part of the summit level contained in the Gatun Lake followed quite closely the Chagres River to Obispo. It then left the valley of the Chagres and crossed the Continental Divide to Pedro Miguel by the route that would produce a satisfactory navigable channel with the least amount of excavation.

The summit level was to be created by an earthen dam not only across the Chagres River, but across the Chagres Valley at Gatun. The crest of this dam was to be 50 feet higher than the level of the lake that it created. Regulating works were provided for the purpose of controlling the elevation of this lake. The area of the lake at normal level created by this dam was about 164 square miles. On the Pacific side dams were to be constructed across the Rio Grande Valley from the locks at Sosa Hill to the hills to the west. Sosa Hill or Ancon Hill was to be joined by a dam to the high ground near Corozal, thus creating a terminal lake of 7¼ square miles in area on that side.

A harbor at Colon was to be created by a breakwater extending from Colon Point to deep water on the east side of the Canal entrance. On the west side of the channel, a breakwater was to be constructed extending from deep water in the Atlantic entirely across Limon Bay to the shore near Mindi, approximately parallel to the Canal.

The locks were to be 900 feet long, 90 feet wide, and to provide a navigable depth of 40 feet.

THE ADOPTED PROJECT

The Secretary of War, in transmitting the report and recommendation of the minority of the Board of Consulting Engineers, as to type of canal across the Isthmus of Panama, recommended the adoption of plans proposed, except as far as they related to the location of the locks at Sosa Hill, La Boca. In his letter transmitting this project to the President, he stated:

> 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 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.

The International Board of Consulting Engineers consisted of thirteen members—eight Americans and five foreigners. Five of the eight Americans voted for, and submitted a minority report recommending, the lift-lock type of canal, and all of the foreigners voted against such type and in favor of a sea-level canal which was recommended in the report of the board as a whole.

There had not been constructed and operated in any of the foreign countries represented by members of this board a canal for the passage of large ships with as high lift-locks as those in the St. Mary's Falls Canal which connects Lake Superior with the St. Mary's River. No European canals had the commerce to justify the construction of such effective aids to the safe passage of ships through locks as had been built in America at that canal. Most prominent among said aids were long approach walls at both ends of locks, so located as to aid ships in entering the locks. 46,015,016 tons of commerce had been passed through the canals at Sault Ste. Marie the year the report was made—more water-borne commerce than enters London and New York combined.

The largest lock in this canal had then been in service twenty years and no serious accident had actually happened, although on two occasions such accidents had been narrowly averted. This lock was 100 feet wide, 800 feet long, and had a lift of 18 feet; practically in the same class with the locks recommended in the project referred to above.

There is no profession in which experience is a greater factor than in that of the engineer, especially as to the design of works affecting navigation; the adaptability of such works to the needs of the navigator; the chances of accident, and the necessary appliances to reduce such chances to a minimum are questions that experience largely determines. It is probable that such considerations as the above were largely the reasons that practically aligned the American and foreign engineers on different sides when the type of canal was being investigated. The Isthmian Canal Commission, the Secretary of War, and the President of the United States, all recommended to Congress the adoption of the project recommended by the minority of the board.

After the submission of this project and prior to the time of the adoption of a canal project by Congress, efforts were made by the then Chief Engineer of the Isthmian Canal Commission to find a location for the three locks on the Pacific side of the Isthmus at a place about a mile south of Miraflores, thus removing the military objections raised by the Secretary of War as to the location of locks at the Pacific terminal. It was thought that a suitable foundation had been located and plans were proposed for the three locks in flight; but before these plans were submitted, additional borings indicated that the foundation was unsuitable for the needed structures. There was not time to permanently settle the question of lock location, and the need of a decision as to type of canal was urgent and Congress approved the lock-canal project as submitted, with two of the locks on the Pacific side at La Boca along the edge of Sosa Hill, and one at Pedro Miguel.

The words *la boca,* in Spanish, mean "the mouth," and in Spanish-speaking countries that name is quite generally given to towns near the mouths of streams. At the suggestion of the Peruvian Minister at Panama, the President of the United States changed the name of the Pacific terminal of the Canal to Balboa, a fitting recognition and monument to the discoverer of the Pacific Ocean.

CHAPTER IX

CHANGES IN THE ADOPTED PROJECT

The exposed position of the proposed lock at the Pacific entrance in so far as ship-fire from an enemy's fleet was concerned, in addition to foundation troubles in the construction of the necessary dams, especially the dam from Sosa Hill to near the mouth of San Juan River, caused investigations to be continued with a view to moving the locks in question inland to a position where the natural hills would protect them from hostile gun-fire.

The advantages of a commodious lake at the Pacific terminus were many from a navigation and commercial standpoint, but the military features were considered paramount. The investigations which consisted principally in making borings in search of suitable foundation material were commenced at the old French lock location, at Miraflores, and continued south. These borings soon established the fact that suitable foundations existed at Miraflores for at least two locks. Work was proceeding, building the dams connecting Sosa Hill with the highlands on either side and starting the excavation for the Sosa Hill Locks, so if a change were to be made it was necessary that the decision should be arrived at quickly so as to stop expense on a project that might be discarded. When the question was brought before the Isthmian Canal Commission for recommendation, it was not known that suitable foundation existed at Miraflores for three locks and it was thought and stated by those conducting the explorations that there was not a suitable foundation for three locks at this site, so two locks were recommended at Miraflores and one at Pedro Miguel, which plan was approved by the President of the United States.

It was thought by some of the engineers connected with the Canal that there would be a great advantage in having the three locks in one flight at Miraflores, making the two ends of the Canal symmetrical. Investigations were therefore continued and soon established the fact that the three locks could advantageously be built at Miraflores on a rock foundation, thus making it practicable to carry out a little further up the valley essentially the same plan that had been studied in 1906 and abandoned because suitable foundations had not been located.

As soon as it was ascertained that suitable foundation existed near Miraflores for a duplicate flight of three locks, comparative estimates were made for that construction and for the locks separated—one at Pedro Miguel and two at Miraflores. These estimates showed that the three locks on the Pacific side could be built in flight in one structure for about $4,000,000 less than if separated. This saving resulted largely from the following facts:

First, that only one set of guide and flare walls aggregating a length of about four thousand feet would be needed if the locks were in one structure, while two sets of such walls would be necessary if the structures were separated as stated.

Second, that only twenty lock gates and thirty-three sets of gate valves were necessary if all locks were together, while twenty-six gates and fifty-one sets of valves would be needed if the locks were separated. The six extra sets of gates would also require a material increase in length of lock walls to accommodate them.

Third, the smaller number of expensive machines for operating the gates and valves.

Fourth, only one emergency dam would be needed in the first case, and two in the second.

The estimates also showed that the operating and maintenance cost would be about $250,000 a year less for the three locks in flight.

The advantages and disadvantages to navigation afforded by each of the propositions were discussed. One line of thought led to the conclusion that the navigation interests and the water-supply question would be best met if all the locks of the Panama Canal were separated by material distances, and that where this could not be attained it should be approximated as closely as possible, and that not more than two locks should be built together if it could be avoided; it being thought in the beginning that the saving of water due to the use of intermediate gates could not be effected in a flight of three locks.

These intermediate gates divide the 1,000-foot lock chamber into two smaller chambers of lengths sufficient to accommodate to the best advantage ships of commerce not exceeding 550 feet in length. Ships of this class constitute over 95 per cent. of the world's shipping which may reasonably be expected to use the Canal.

It was also pointed out that a ship breaking through the upper gates in a flight of locks would be more surely and completely wrecked than if it broke the upper gate of a lock where only one lift existed. General H. L. Abbott proved that, if the boats going from Colon to Panama were always passed through the same flight of locks—the west side, for instance—and those going the opposite direction through the east flight, that the same saving of water could be accomplished by the use of intermediate gates in a flight of three locks as could be if the locks were separated—without any cross-filling devices—which devices are of doubtful utility when the locks are used to maximum capacity.

The advocates of the three-lock design contended that it would probably make very little difference to a ship whether it plunged down one fall of thirty feet, or three; that it would be wrecked anyway; and that the damage to shipping would, in the three-lock design, be largely confined to the ship actually breaking the lock gates; while if the locks were separated, many other ships might be involved in the disaster on account of quickly draining the levels between locks and grounding the ships in such levels.

It was pointed out in the case of the flight of locks at Gatun that the upper miter-sill, which is about twenty-five feet above the general lake bottom in that vicinity, would limit the available depth in Gatun Lake, with the water flowing through the locks, to about thirty-one or thirty-two feet, and that, as the lake fell there would be no unusual difficulty in stopping the flow before the largest draft vessel would ground in the anchorage space south of the locks. That is, should such a catastrophe happen, the damage to shipping would be limited to the ship breaking the summit level.

It was also pointed out that should such an accident happen the damage to the Canal would be practically limited to the wreckage of the lock gates involved in the collision. The flow of about 100,000 cubic feet per second, which might result from breaking the summit level could not damage the masonry of the lock walls or floors and there was nothing below the locks to be damaged except the sea-level section of the Canal. This section is 500 feet wide and 41 feet deep and would carry 100,000 cubic feet with a mean velocity of about 5 feet per second, or less than 4 miles per hour. In that part of channel immediately below the locks where the guide wall divides it, the velocity should not exceed 7 miles per hour. To have no essential structures below the locks leading to the summit level of a canal, which in this case was a reservoir 164 square miles in area, was considered a material advantage.

It was also pointed out that should a lock gate be carried away at Pedro Miguel, there would develop almost immediately in the section through the Culebra Cut, which was then planned with a width of 200 feet, a current velocity of about 10 miles an hour which would imperil all vessels in such cut and would fill to overflowing in about thirty minutes the small lake between Pedro Miguel and the two locks at Miraflores. This might result in serious injury to the earthen dams and fills at Miraflores unless the spillway in the dam at that place was surely operated in a very short space of time.

It was pointed out that, if three locks were placed at Miraflores, the size and depth of the lake would be so increased over that in the two-lock project that, should a lock gate be carried away at Miraflores, the lake would fall so slowly that all ships in the Culebra Cut would probably have time to safely pass into either Gatun or Miraflores lakes before currents could be developed in that cut destructive to shipping.

The congestion and consequent difficulties to navigation brought about by providing a lock at the end of a long narrow channel such as the Culebra Cut, due to the fact that ships accumulate and pass each other at locks, was pointed out. It was also pointed out that large ships could not pass each other in a 200-foot channel and that in order to attain the maximum number of lockages per day, it might be necessary to dispatch ships through the Cut in fleets and that lakes at both ends of the summit level would facilitate this.

The advantage of such lakes was still further emphasized by the fact that dense fogs are frequent in the Culebra Cut during the year, especially in the rainy season. These fogs rise from eight to ten P. M. and disappear about sunrise. The records showed that navigation would experience practically no difficulty in the sea-level parts of the Canal on account of fogs.

It was pointed out that the ability to pass ships to the summit level and have there a commodious harborage, where they could await the disappearance of the fog, would be a material advantage.

It was also pointed out that the greatest chance of accident in passing a ship through a lock was in entering the lock from the pool level above, as evidenced by the construction of duplicate lock gates at both ends of a lock next the summit or other levels, and by the construction and maintenance of expensive devices to stop the flow of water through a lock so situated, should its gates be carried away. Such entrance would take place only once if the three locks were in flight in one structure, and would take place two or three times if the locks were built at two or three sites.

A board of seven consulting engineers reported confidentially to the President that the better plan would be to build three locks at Miraflores. The matter was never passed upon by the Isthmian Canal Commission. An extended and bitter public discussion was then being carried on in the papers of the United States concerning the type of the canal. Changes in the adopted project could be utilized, it was thought, by the advocates of the sea-level plan in their arguments. Changes in plans were classed as admissions of weakness in the lock-type canal.

It is interesting to note, in this connection, that the *Annual Report of the Panama Canal,* 1914, shows that the three locks on the Atlantic side of the Canal cost $2,130,000 less than the three locks on the Pacific side notwithstanding the fact that the sand, stone and cement in a cubic yard of concrete in the Atlantic locks cost $2.01 more than

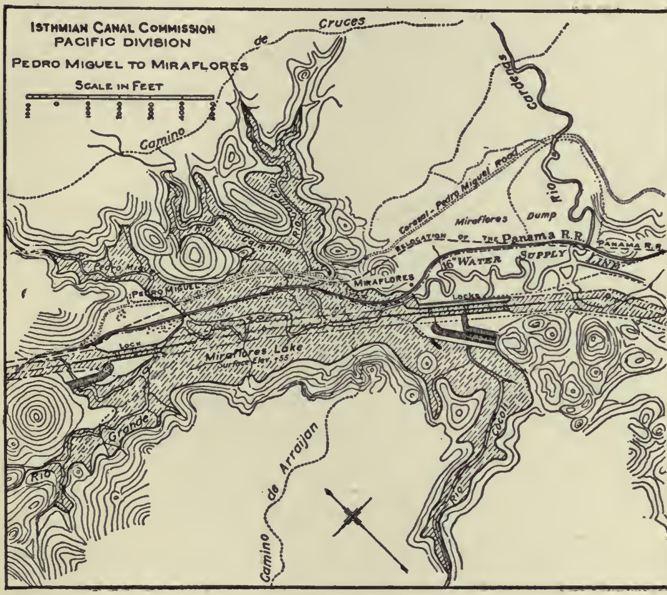


DIAGRAM 1

in a cubic yard of concrete in the Pacific locks.

The decision afterwards to widen the Culebra Cut to 300 feet will reduce the current in that cut to 6½ miles an hour in case such an accident as that described above should happen. The many devices adopted to prevent accident to the lock gates, of course, make it very improbable that any such accident will occur, and the entrance to Pedro Miguel Lock can be still further widened, and thus minimize the disadvantage of having a lock at the end of a long narrow section of a canal.

The change of lock location on the Pacific side was the only change in location of the essential parts of the Panama Canal excepting the following changes in channel location: first, from the Pacific terminal to the south side of the group of islands about three or four miles off shore; second, the extension of the sea-level section to Miraflores, which route followed quite closely that followed by the French in their last plan.

The change in location of the channel leading from the Pacific terminal to deep water in the Pacific, placing the same on the west side of the Islands, was primarily for the purpose of reducing the cost of maintenance, experience having shown that the currents in Panama Bay caused a movement of fine silt along the shore to the westward. By changing the channel and building a causeway on the east side of it from the shore to the Islands, this channel silting would be stopped, and furthermore this causeway constituted a line of communication from the shore to the sea-coast fortifications on the Island that could be protected by guns on the shore on that side of the Canal that would be least subject to surprise by a raiding force.

CHAPTER X

CHANGES IN DIMENSION OF PARTS OF CANAL

The planned dimensions of locks were first increased so as to provide for a width of 100 feet and usable length of 1,000 feet; and were finally changed so as to provide a width of 110 feet and length of 1,000 feet with a fresh-water depth over sill that would allow the passage of a ship that drew 40 feet in salt water. The decision to make the first change was based on the ordinary proportions of merchant vessels not requiring a greater length than 1,000 feet, i. e., a merchant ship 1,000 feet long would not, in ordinary practice, have a beam width as great as a 100-feet. Naval vessels, however, are built on different lines, and the requirements of law that the Canal should be so built as to reasonably meet the demands of the future. not only as to merchant vessels but as to battleships, was referred to the General Board of the Navy for recommendation especially as to naval needs. This board finally recommended a width of 110 feet as one complying with the law in so far as naval needs were concerned; which width was adopted. It is understood that some members of the naval board advocated a width of 120 feet. The locks in the new Kiel Canal in Germany have a width of 147 feet. These locks, however, are of low lift and the solution of the gate problem is much easier than for locks with relatively high lifts. The probability of the width of battleships being largely increased in the near future in an effort to meet by extra compartments around the hull the attacks of submarines, was considered in determining the dimensions of locks for the Panama Canal.

In designing the locks adjoining the summit level the upper miter-sill was placed three feet lower than had been originally contemplated. By so placing the miter-sills, the storage in the lake could in the future be increased three feet at the cost of digging three feet out of the channels in the summit level.

The width of lock had also direct bearing upon the water supply of the Panama Canal; the wider the lock, the greater demand on the water supply. It was calculated at the time of the discussion that in the driest of years the Chagres River, with the storage facilities provided in the project, would furnish only enough water for the maximum number of lockages mechanically practicable through a 110-foot lock of the length decided upon. Mitering gates for locks of the lift of those at Panama and a width of 120 feet could be easily built and operated. A different type, a rolling gate, was adopted for the Kiel Canal, one maneuvered on a track across the lock chamber.

The engineering problems of the Panama Canal for the future will be met by the engineer of the future. Larger locks can be built and the water supply can be increased within limits.

The design for locks in the report of the minority was of necessity in outline only.

CHANGE OF WIDTH IN CULEBRA CUT

The deep excavation across the Continental Divide from Obispo to Pedro Miguel is ordinarily called the Culebra Cut. The adopted bottom width of this cut was 200 feet and as actually built, it has a least width of 300 feet. This was the most extensive and expensive change in the Canal; it makes a more commodious waterway; a sufficient width possibly for large ships to pass if one of them comes to a stop and is moored. The ability of ships to pass each other in this cut, however, can only be determined by actual trial. What effect, if any, this increased width has had in increasing the slides that are accompanied by a lifting of the bottom is a mooted question.

CHANGES IN THE SECTION OF GATUN DAM

The section proposed for Gatun Dam in the adopted project is shown in Diagram 2.

Diagram 3 shows the first approved change in this plan.

This dam was the controlling feature in the

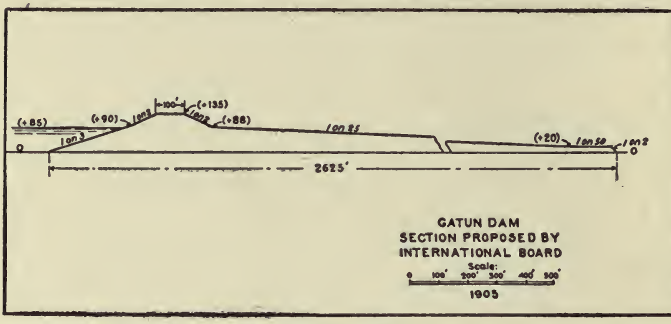


DIAGRAM 2

project; it created the summit level, and the lake formed by it constituted about thirty-two miles of the route to be navigated across the conti-

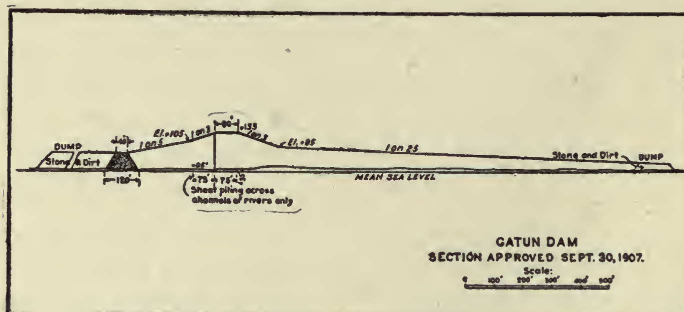


DIAGRAM 3

nent. It impounded and constituted a great controlling reservoir for the flood-waters of the Chagres. It also acted as an efficient storage reservoir for water needed in the dry season; the low-water flow of the Chagres River alone not being sufficient for the operation of a lift-lock canal.

Gatun was practically the only place at which a dam could be built so well fulfilling all of the functions deemed necessary in the solution of the general problem. The feasibility of the construction of this dam was questioned by many engineers and the majority of the Board of Consulting Engineers were of the opinion that "no such vast and doubtful experiment should be indulged in."

The principal fear of this majority was based on the supposed probability of seepage or percolation in dangerous quantities through the material underlying the dam. The borings had developed the existence under the site of the Gatun Dam of two geological gorges the rock bottoms of which were from 200 to 250 feet below sea-level. The studies of the geologists led them to the conclusion that these gorges were former beds of the Chagres or its tributaries that had subsided some 300 feet in some former adjustment of the earth's crust at this place, and that these gorges or valleys had afterwards been filled with a sea deposit of fine clay with some sand. Concerning the design of the dam at Gatun, the minority of the board stated:

It was thought best to provide a dam which could not be destroyed by any of the forces of nature, and which could only be destroyed by making excavations which would require a large force working for a long time.

Practically no experience as to the bearing capacity of material similar to that under the Gatun Dam was available at the time the plan was made and the adoption of a section with a 1 on 3 slope as shown on the lake face of the dam presupposed that the material under the dam would safely carry such a load. In fact, the bearing capacity of the material under the dam seems not to have been seriously questioned by the minority of the board in its plans, or by the majority in its criticisms.

As soon as construction commenced on the proposed dams on the Pacific side and at other points on the Isthmus where loads were placed on material similar to that under the proposed dam at Gatun, a thought soon grew into a conviction that it was not practicable to build a slope of 1 vertical on 3 horizontal by the hydraulic method, of material such as that available for building the Gatun Dam. This thought found expression in proposing a rock fill about 50 feet high along the foot of the south slope of the dam as originally proposed. The top of this ridge was to be 60 feet above sea-level. With this built a slope of 1 vertical to 5 horizontal could then be adopted until the dam was higher than the level of the lake. It was then thought that such a slope could be constructed with the available material by the hydraulic method.

Very soon after this conclusion was tentatively accepted, a further thought began to impress itself on those charged with the execution of the work and that was the insufficiency of the bearing capacity of the foundation of the dam for the loads resulting from the rock fill and the south face of the dam itself. Experience at other places indicated that when loads became excessive on such material a violent vertical movement ensued, in some instances the drop being as much as twenty feet, accompanied by a bulging-up of the ground on either side. In making a fill about 80 feet high across a flat near Gatun, while rebuilding the Panama Railroad, many such subsidences occurred. It was attempted to make this fill from trestles, allowing the dumped material to take its natural slope. One trestle was built and filled and another trestle built on the fill and material dumped from that. Vertical drops of from 15 to 20 feet at the crest were frequent and the ground bulged or lifted 500 or 600 feet away. It was found necessary to construct a slope of about 1 vertical to 7 horizontal on the west side of this fill before its final elevation was reached. The material on which this fill was made was similar to that found under part of the Gatun Dam. The only practical way to prevent similar occurrences was to load down the material contiguous to the fill so as to counterbalance the higher part of the fill. This simply meant widening the base of any fill on such material and making the slopes flatter. The two above considerations led to changing the dam section from the adopted project to that shown in Diagram 3. The change was authorized in September, 1907. For comparison, Diagrams 2 and 3 show the difference between the dam section as recommended by the minority of the International Board and that resulting from the changes referred to above.

Those parts of the dam foundation lying over the deep geological gorges referred to above proved quite unstable when the actual construction of the dam started. When a pile trestle was driven on the 30-foot contour on the north face of the dam where it crossed the eastern gorge, piles when placed in the pile-driver would sink of their own weight from 10 to 15 feet in the underlying material, indicating a softer foundation than had ever supported a dam of the height of that proposed at Gatun. It was of course appreciated that if the base were wide enough to make sufficiently flat slopes, a dam as high as that at Gatun could be built on almost any kind of material.

The softness of the foundation led to the consideration of two other important features of the dam—its height and the slopes on both faces. The dam as originally planned was to be 50 feet above the level of Gatun Lake. Twenty feet free board would ordinarily be considered ample for an earthen dam such as this, with a spillway having the relative discharging capacity of that proposed at Gatun. The extra 30 feet was proposed so as to increase the labor necessary should an enemy try to dig a trench through the top of the dam deep enough to form an initial outlet from the lake. A desire to satisfy a public apprehension of some imagined danger was also a factor in the design. As stated before, at that time no experience was available as to the actual bearing capacity of the particular soil under the dam, and a sandy loam such as the preliminary borings seemed to indicate would ordinarily safely carry the load contemplated. But later investigations proved that the percentage of sand in much of this material was very small. Experience proved its instability and that it would be a distinct disadvantage to add the load necessary in building the last 30 feet of the height proposed for the dam. The section was therefore changed, limiting the height of the dam to about 20 feet above normal lake level and the dam was so built.

The yielding nature of the material in the foundation caused a reconsideration of all the slopes on the two faces of the dam. It was thought by some that there should only be one slope on a face of a dam built on such yielding material and that the slope on the two faces should be the same —the idea being that the increase in the load from the foot of the slope to the top of the dam should be uniform, with no such sudden changes of loading as would result from adopting several slopes on the face of the dam. The dam having been commenced it was impracticable to carry out this idea completely, but it was approximated as nearly as could be.

Diagram 2 shows the section of dam in project as originally adopted.

Diagram 4 shows the section as actually built.

Diagram 2 presupposed that the foundation would safely carry the load due to the steep slope on the lake face and that the material that would support such a load could be placed in the dam on a slope of one vertical to three horizontal. Had the information afterwards obtained from actual experience been available, it is quite certain that the original design would have followed quite closely that shown in Diagram 4.

Engineers have often remarked that the slopes of the Gatun Dam were flatter than necessary, that its unusual dimensions were adopted to stop an unreasonable popular impression as to the insecurity of a dam built across the lower valley of the Chagres. It is thought, however, when they read of the slides and of other difficulties of construction to be described later, that they will conclude that the adopted slopes were necessary in

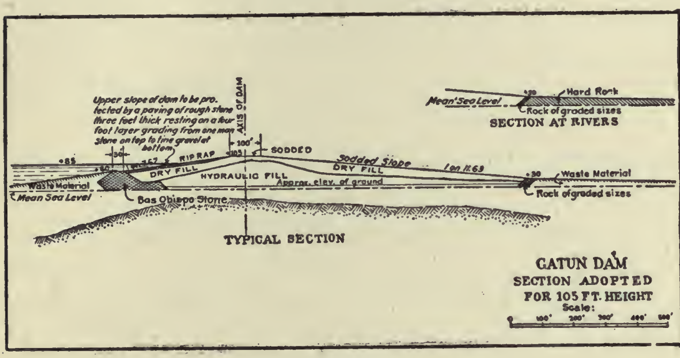


DIAGRAM 4

obtaining that factor of safety that should be given to a dam which constitutes the keystone of a project that has cost about $375,000,000, and which will ultimately be one of the most valuable assets, both from a military and commercial standpoint, that the United States possesses.

CHANGES IN PLANS FOR COLON HARBOR

Here again the military idea predominated to some extent. The advantage of a commodious harbor with sufficient anchorage in deep water for a large fleet of naval vessels was an important desideratum, which could best be accomplished by a long breakwater leading from the shore and giving protection to a considerable area of deep water. In carrying out this idea the west breakwater, two miles long, starting from Toro Point, was proposed and built.

The destructive storms at Colon, the "northers," come from the north or slightly west of north, and the west breakwater as built affords a protected anchorage during such a storm. The trade winds, which blow continuously during the dry season, which includes December, January, February and March, come from the northeast, and the west breakwater gives no protection from such winds. These winds, however, are not destructive to shipping, but do create at times a sufficiently rough sea to inconvenience the commerce of Colon Harbor. It was first decided to build the west breakwater and await developments.

It was soon established that the channel in Limon Bay was filled with silt to the extent of more than 2,000,000 cubic yards of material a year, and that this silting was due to the currents created in the bay by the trade winds and the stirring-up of the soft bottom of the bay by the waves. In consideration of these facts and of the further fact that the protection of a fleet in Colon Harbor from submarine attacks would be facilitated if the entrance to the harbor were made as narrow as possible, it was decided to construct the east breakwater as shown. At present this breakwater is not connected with the shore, but it can be easily so connected and thus bar the passage of any kind of craft into the harbor by any route except the prepared opening between the sea ends of the two breakwaters.

CHAPTER XI

DESIGNS FOR PERMANENT BUILDINGS AND LOCKS

PACIFIC TERMINAL: DRY DOCKS, SHOPS, ETC.

No specific estimate or plan for dry docks, shops, etc., that would be necessary in any comprehensive operating plan for the Canal was included in the adopted project. Of course, the cost of all shop and other appliances necessary in the prosecution of the estimated work would be included in the estimates in question.

As the work progressed, the question of an operating plan for a completed Canal was studied and it was finally decided that the United States would control practically every activity connected with the operation of the Canal—that it would furnish fuel, water, ship supplies, wharfs, dry docks, etc. The appliances necessary for many of these operations were of necessity built in connection with supplying and housing the construction forces.

The extent of permanent shops and dry dock facilities, however, were determined by many considerations; prominently among them were the possible repair needs of the Navy. The advisability of being able to effect any repair that might be desired in the case of a merchant ship would, of course depend on the probable amount of such business and whether it would justify the necessary plant expenditure. The question was finally determined by the prospective, or rather possible, needs of the Navy. The dry docks and shops were so planned as to furnish the appliances for such war repairs as might be necessary to a battle-fleet; the mechanical force kept in the shops to depend upon the amount of work that came in the ordinary course of events.

The Panama Canal is of great strategic value to the United States from a military standpoint, but like all points or lines with such a value, it is liable to be the scene of conflict in case of war, and both ends of the Canal are likely to become, in such a contingency, more or less naval bases.

While there are other sites from a purely naval standpoint that may have a better location, strategically, one great consideration is that a land force sufficient to prevent the destruction of the locks and other appurtenances of the Canal must be kept on the Isthmus and would at the same time be a protection for a naval base. The value of a naval base, among other things, depends largely on the chance of its being captured by a land force during war. The question of constructing commodious dry docks on the Atlantic side was considered, the decision being not to do so at the present time. The dry docks at Balboa provide for docking ships of as large dimensions as can pass through the Canal.

FORTIFICATIONS

The original project made no provision in its estimate for fortifications. In order to enable the United States to maintain the neutrality of the Canal—a duty placed on it by the Hay-Pauncefote treaty—Congress authorized seacoast fortifications at both the Atlantic and Pacific entrances. Any uses of this Canal, when the United States is at war, that tend to its military advantage increases the ability of that country to defend the neutrality of the Canal and is consequently justifiable under the treaty. These fortifications are modern and will be effective if ever needed.

In addition to the seacoast fortifications provision has been made for defending the more vulnerable parts of the Canal from raids that might occur just prior to a declaration of war.

The entire Canal Zone has been declared a military reservation and all private titles to land have been or will be extinguished.

DESIGN

The general design was of course comprised in the adopted project.

The only design required in making a cut of certain bottom width and depth is a determination of the side slopes, benches, etc., considered necessary to secure stability. This, except in hard rock, amounts to laying down on paper the slopes that one's experience and study would lead

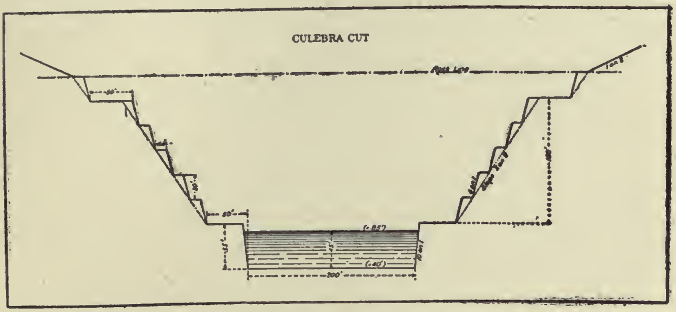


DIAGRAM 5

him to assume that the material in question would require in order not to slide.

The slopes shown in Diagram 5 are those that the consulting engineers considered necessary for stability in the cut through the Continental Divide. It is evident from these sections and from the absence of criticism concerning them, that the International Board of Engineers anticipated no material difficulty in making and maintaining a cut through the Continental Divide at Culebra. It is also a noteworthy coincidence that the critics of the sea-level project failed to point out the one thing that proved, more than anything else, the impracticability of the sea-level plan, namely, the inability to maintain, within any reasonable limits of time and expense, the sides of a cut through the Continental Divide with its bottom 45 feet below sea-level.

The angle of repose of the material in question was dependent on conditions of which the engineer was uninformed, and which could be known only by making the excavation itself. This material has or will ultimately make its own design as to slopes. The designing work of the Canal was therefore essentially confined to the locks, dams, regulating works, dry docks, shops and breakwaters.

DESIGN OF LOCKS

During the preparatory period a general design for the locks of the Panama Canal had been worked out, many features of which design were never changed. The lock gates remained essentially the same, as well as the general thought governing the filling and emptying system; the only radical change in the latter being the adoption of a single culvert in the middle wall, instead of two as originally proposed. This single culvert is connected by lateral culverts with the lock chamber on each side, and the flow of water through each lateral is controlled by a cylindrical valve.

During this period a study was made of the regulating works for the spillways. Vertical rising sluice gates of the Stoney type, bearing against trains of rollers, were decided upon and a detailed study completed to determine the most economical dimensions of the gates and piers, which dimensions were not changed when the final design and plans were made.

The dimensions of the lock chambers having been determined, the design in all locks is practically confined

First, to so proportioning the walls as to make them stable under all possible conditions;

Second, to devising a means of filling and emptying the lock chambers;

Third, to designing the lock gates;

Fourth, to designing such appurtenances as will facilitate and make safe the entrance of ships into the locks, their passage through and departure from such locks.

Fifth, to designing the machinery for operating the locks.

Assuming an unyielding foundation with no upward water pressure or one definitely known, the design of lock walls is simple, but the character of the foundation material under locks may radically vary the design. At Gatun, especially, the foundation material was the subject of much discussion and criticism in the newspapers. The earlier borings were misleading, or at least were so recorded as to form the basis for criticism. The following figure shows the rock strata at Gatun as finally determined. In the earlier borings when the rock was not hard enough or was so constituted that the diamond drill machine would not cut out a cylindrical sample, it was chopped into small pieces and washed out by the drilling process, and such material was classified as chopped clay, sand and gravel. Later investigations proved all material so classified to be some form of rock capable of sustaining any load that would be placed on it. Holes were drilled through the rock, preserving core samples where the same could be made, to a depth of 50 feet below the foundation of the various parts of the locks. Shafts or test pits were excavated into the material that would not core. These pits were large enough for men to enter and of such size as to facilitate a careful inspection and test of the material in place by engineers and others. These investigations, supplemented by test loads on the various classes of material, clearly established the fact that the foundation materials at Gatun, as well as those at Pedro Miguel and Miraflores, were all properly classible as rock and would safely bear the expected loads, provided such foundations were properly prepared.

At Gatun, however, the question of lake pressure being transmitted under the floors of the locks, and the methods of resisting such pressure should it be transmitted, were subjects of much discussion and investigation.

It was assumed that, at the time the subsidence occurred that lowered the old gorges of the Chagres River in the vicinity of Gatun about 300 feet, all the surrounding country was similarly lowered. The geologists also found evidences that an uplift of 10 feet or more had taken place in the same locality at a later date. It was concluded by some that these motions could not occur without creating many minute fissures in the rock and that such fissures probably extended to great depths, and that, consequently, lake pressure under the lock floors at Gatun should be expected. To make provision against such pressure would be quite expensive, and a thorough investigation of the situation was made for the purpose of deciding whether or not the floor, of a portion at least of the lock next to the lake, should be so built as to stand the lake pressure.

As previously stated, holes were drilled through the underlying material to a depth of about 50 feet below the level of the masonry of the locks. Water, of course, rose in all of these holes to the same level as that of the ground water in the adjacent country. Lowering the water surface in one of these holes by pumping and observing how quickly the water in other holes was lowered and the distance to holes that had their water level affected, formed a basis for an opinion as to whether or not there existed crevices in the rocks through which water could pass to an extent sufficient to create and maintain pressure. It was proven that, in pumping out a hole, the water level in a hole two thousand feet away was affected. A test pit was finally dug outside the lock area down into the material that was thought to be most water bearing and the effect of pumping out this pit on the water level in other holes was observed and recorded.

The rock formation in Spillway Hill is the same as that under the Gatun Locks but a different line of investigation was pursued there. The conclusions indicated were considered applicable at both places. Some of the drill holes in the foundation for the Gatun Lock as well as some in Spillway Hill encountered water under such pressure as to cause a slight artesian flow through such holes. This water under pressure was first encountered sometimes as much as 40 or 50 feet below sea-level.

A shaft was sunk in the rock on Spillway Hill from about 40 feet above sea-level to 30 feet below sea-level, the object being to observe the character of the rock, the crevices in it, and the pumping capacity needed in keeping the water out. It was noted in pumping out this shaft when it was nearing completion, that the artesian flow in a drill hole 600 feet away stopped and commenced again when the shaft was allowed to fill with water to the natural ground water-level.

It was then decided to determine the extent of the connection between this shaft and the drill hole. The records showed that artesian water was first encountered in this hole at 50 feet below sea-level. A pipe connection was made from the water-supply system in Gatun to the shaft, and the shaft filled with water. The casing in the drill hole was connected with a glass tube, so that if the pressure in the hole was increased as the shaft was filled, the consequent increase of head could be measured. When the water in the shaft reached 30 feet above sea, that in the glass tube had risen 16 feet.

Water at this time was oozing through the small crevices in the rock everywhere. These experiments showed conclusively that water pressure could be transmitted through the material in Spillway Hill and under the locks at Gatun.

The floors of the upper locks at Gatun for about 600 feet of their length next to the lake were so designed as to stand lake pressure, and for the remaining length of locks provision was made for carrying the seep water into drains behind the lock walls so as to prevent any pressure under that part of the floor, and the design was made under that assumption. The floor of the lower lock being more than forty feet below sea-level, it was considered necessary to protect it by weep holes when the lock was pumped out.

In addition to the strong floor in the upper end of Gatun lock a concrete cut-off wall from 12 to 18 feet deep was built in a trench excavated in the rock around three sides of this foundation. It was thought by some that this wall would prevent water from getting under this floor.

In order to know whether there would be pressure under this floor when the Gatun Lake was formed, a telltale system was provided under the floor. Small grooves or trenches were dug in the underlying rock and porous tiles of small diameter were placed in them. These tile drains were connected with iron pipes that were extended vertically to the top of the lock walls and encased in the concrete of such walls. If pressure were developed under the lock floor, the head of water would be shown in the vertical pipes leading to top of wall. The observations, taken as the lake was forming, indicated that the pressure under the lock floor varied with the elevation of the lake and that the strong floor was necessary.

WALLS

The side walls of the upper lock at Gatun are wider and stronger than the walls of any of the other locks on the Canal. They were designed on the assumption that in the back-fill of the walls, which back-fill is part of the Gatun Dam, the ground water might be at the approximate level of Gatun Lake and thus give rise to full water pressure against the walls. At all other places the back-fill was of coarse material through which water could easily percolate and thus insure that the ground-water level would be but slightly higher than the water level of the channel below the locks.

A cut-off wall of concrete, founded on rock, was built to extend from the lock wall about 105 feet into the Gatun Dam. This wall was to make difficult the passage of water from the lake along the surface of the back of the lock walls.

The ground for about 200 feet on each side of the completed locks slopes gently away from the walls to carry away the rainfall. The top surface of concrete walls, machinery rooms, etc., aggregate several acres, and on account of the heavy rainfall which is common to Panama it was necessary to provide means for rapidly disposing of the water falling on these flat surfaces, and large drainage culverts were constructed about 15 feet below the ground surface and running the entire length of all walls, to which water falling on concrete surfaces was conducted by numerous small drains.

This drainage culvert formed the lower portion of a reënforced concrete structure, the top portion of which was an operating tunnel 5 feet wide by 7 feet high, connecting by means of branch tunnels or openings with all the machinery chambers containing the machines for operating the lock gates, valves and other parts of operating equipment. In the thick floor between the drainage culvert and operating tunnel was located the extensive wiring system necessary for the electrical operation, by remote control in the operating house, of all the lock machinery. On the top of the operating tunnel was placed the return track for the electric towing locomotives. This track is used by the locomotives only to return to the proper end of the lock after having towed a ship through the locks. It is equipped with racks only on the inclines, whereas the towing track located close to the edge of the lock walls has a rack for its entire length. This rack is necessary in order to obtain sufficient pulling force on the tow lines. It is engaged by a pinion on the towing locomotive and, by this arrangement, a 40,000-pound pull can be exerted.

The walls of the locks proper were designed and constructed under assumptions of severe lateral pressure and with conservative factors of safety, as their stability was of vital importance to continuous operation of the Canal. The center approach walls and flare walls, however, were merely aids to navigation, and various types were used as best suited the local conditions; for economical reasons, reënforced concrete walls were permitted under some conditions except where exposed to salt water.

The south center approach walls of the Pedro Miguel and Miraflores locks were of massive concrete, stepped on the back so that the back-filled space was V-shaped. The north center approach walls of these locks were of cellular reënforced concrete construction, the wall for Miraflores Locks resting on reënforced concrete cylinders, sunk to rock and filled with concrete, whereas the wall at Pedro Miguel rested directly on the rock three feet below the bottom level of the Culebra Cut.

Part of the flare walls at these locks were of massive gravity type and part of reënforced concrete, the latter consisting of a vertical slab from 27 inches thick at the bottom to 15 inches at the top, tied at intervals of 15 feet, to reënforced concrete buttresses which, in turn, were tied to a bottom slab to hold the earth which gave the wall stability. The south flare walls at Miraflores were of massive concrete because of their exposure to sea water.

At the Gatun Locks the foundation difficulties for the approach and flare walls were numerous. A description of the difficulties met with in the construction of the north approach will be given further on.

The rock under the south approach wall dips rapidly down and for several hundred feet of the outer end of the wall is from 10 to 100 feet below the desired elevation of the bottom of the wall, and the natural ground surface about 30 feet below. The material overlying the rock was too soft to support piles, with the exception of a stratum of clay about 10 feet thick and 30 feet below the ground surface. To give piles the necessary frictional resistance, a 30-foot hill, 100 feet wide, was made along the axis of the wall and, after some time had elapsed, reënforced concrete piles were driven through this fill and to several feet penetration in the hard stratum previously mentioned. On these piles was constructed a thick reënforced concrete slab upon which was built a cellular reënforced concrete wall which, to relieve the weight on the foundation, was not filled with earth as were similar walls of the Pedro Miguel and Miraflores locks.

Soon after the construction of this wall was begun it was noted that settlement was occurring.

This settlement continued throughout the time of its construction and until the Gatun Lake had been filled. The total settlement was over two feet and the top slabs and tracks were omitted until the settlement ceased. The wall was designed with three longitudinal rows of cells to give it stiffness against the impact of ships, and this proved fortunate as, at one period, the wall was settling unevenly and tending to tip over. To correct this tendency one outside row of cells was filled with water with the hope that this added weight would balance the pressure which was causing the unequal settlement, and this proved actually to be the case.

The general design of the north approach wall is shown in the accompanying illustration, Figure 1. This was devised at a later date, and a similar design for the south wall would have been preferable. The open spaces between the piers permit a free flow of water when a ship docks alongside the wall, and eliminates the swinging of the vessel, due to the inability of the water to so quickly flow from between the vertical wall surface and the side of the ship as to prevent the creation of a head with its consequential pressure tending to force the vessel away from the wall. A wall of this design costs no more than the cellular type and has the advantage of being founded on rock and can be built in less time.

DEVICES FOR FILLING AND EMPTYING LOCKS

From the standpoint of speed of passage of ships from ocean to ocean through the Canal, the shorter the time in which locks can be filled and emptied the better, but larger culverts and passage-ways for the water means greater expense, and the relative tranquillity of the water in the lock chamber during the operation of filling has a direct bearing on the safe handling of the ship during such operations, i. e., the water should not be allowed to enter the lock at such a rate as to create currents and eddies that would endanger or interfere with the handling of the ship.

In order to fill a large lock as quickly as practicable and keep the water relatively smooth during the operation, water should enter through as many openings as practicable, well distributed over the entire floor. This was accomplished in the Panama Canal locks by constructing under the floor, running directly across the lock, culverts about 6½ by 8 feet in diameters with five circular holes in the top of the culvert 18 feet apart. These lateral culverts were about 36 feet apart and were connected with large longitudinal culverts 18 feet in diameter, built in the lock walls. The design contemplated the passage of water both into and out of the lock chambers through the same openings. The longitudinal culverts were in communication

Fig. 1.—North Guide Wall, Gatun Locks.

Fig. 2.—Dam Construction Through Gatun Village.

with the lake or a higher lock level when the locks were being filled, the downstream end of such culvert being closed. These connections were reversed when the locks were emptied. The flow of water in the main culverts is controlled by rising stem gate valves of the Stoney type, bearing against a train of free rollers which transmit the water pressure to the masonry. A single valve, rectangular in shape, for this culvert would have been approximately 19 feet high by 21 feet wide and at times would be subjected to over 60 feet head of water. While unprecedented in size, there is no reason why such valves could not be satisfactorily built and installed, but taking everything into consideration it was decided to divide the main culverts at the valve chambers by a central pier into two culverts controlled by valves 10 feet by 18 feet in size. There was nothing new or novel about these valves, except the sealing device on the sides to make them watertight. This seal consisted of a curved bronze spring with bronze point kept in contact with the wall plate by the tension in the spring and the pressure of the water. These valves, when tested for watertightness, proved very efficient.

It was desired that the center wall culvert should serve the lock on each side of it and permit water to be passed from one lock to its twin by cross-filling and therefore, in addition to the main, rising stem valves, each small lateral culvert which passed under the lock floor was controlled by a cylindrical valve. The cross-filling feature was desired in order to make possible a considerable saving of water during lockages, should such saving ever become necessary.

APPLIANCES FOR PREVENTION OF ACCIDENTS WHILE SHIPS ARE PASSING THROUGH LOCKS

This subject received thorough study in the United States at the St. Mary's Falls Canal, Michigan; also previously at the same canal, for several years before the commencement of the building of the Panama Canal, it was supplemented by a study of the most practicable method of stopping the flow of water through a lock should its gates be carried away through collision with ship or otherwise. The final conclusion at St. Mary's Falls Canal was that the passage of ships would be reasonably safe if duplicate gates were built at each end of the lock—thus providing for a good gate in position in case its duplicate was damaged—and that the flow of water through the lock could be most surely stopped by an emergency dam of the swing bridge type, that is, by use of a bridge that could be swung over the opening and which carried the parts of a movable dam that could be lowered into position by power on the bridge and thus stop the flow.

It was considered safe to allow boats to enter and leave the St. Mary's Falls Lock under their own steam. It was assumed that lockmen would be ready at all times to drop a line over a snubbing post and thus assist in handling the boat.

The results of the studies at the "Soo" Lock were adopted at Panama in so far as the duplicate gates and emergency dam were concerned. This type of emergency dam was a development from one originally built at the Weitzell Lock, St. Mary's Falls Canal, improved in a structure on similar lines at the Canadian lock on the opposite side of the river. The only difference, in general thought, between the emergency dam at Panama and that at the Canadian lock was the system of curtains that shut off the flow of water. In the former, when the swinging girders had been lowered in position, a section of curtain was run down on each set of girders, shutting off the water for the same vertical height all the way across the opening, then another section was run down all the way across. See Figure 3. At the Canadian lock a curtain was run down from top to bottom of a set of girders at one operation. This causes the difficulties of stopping the flow to increase as the operation proceeds, whereas the opposite will be the case with the dams at Panama. While the emergency dams for Panama locks were being designed an accident occurred at the Canadian lock in question that opened a route for Lake Superior water through the lock. This was the first and only opportunity to test the dam under the conditions for which it was designed. The closure was finally made utilizing the dam. The difficulties encountered and the weak points developed during this operation were of much value in perfecting the design of the dams for Panama.

In addition to the above safety devices, fender chains are provided, i. e., a chain that is stretched across the lock entrance above water while the boat is approaching the gate protected by such chain. This chain can be lowered below the bottom of the lock entrance into a recess or groove, and is connected with a system of hydraulic cylinders in such a way that it requires a very strong force to cause the chain to play out. A 10,000-ton ship moving at 5 miles per hour, with power shut off, could be stopped by this chain within a distance of about 70 feet.

The decision was also reached not to permit ships to pass through the locks under their own steam. Inability to surely stop a ship before it reaches a certain point, together with the giving of wrong signals or the misunderstanding of signals, have in the past been the principal causes of collisions with lock gates.

A system of electrically operated towing locomotives were therefore designed. These locomo-

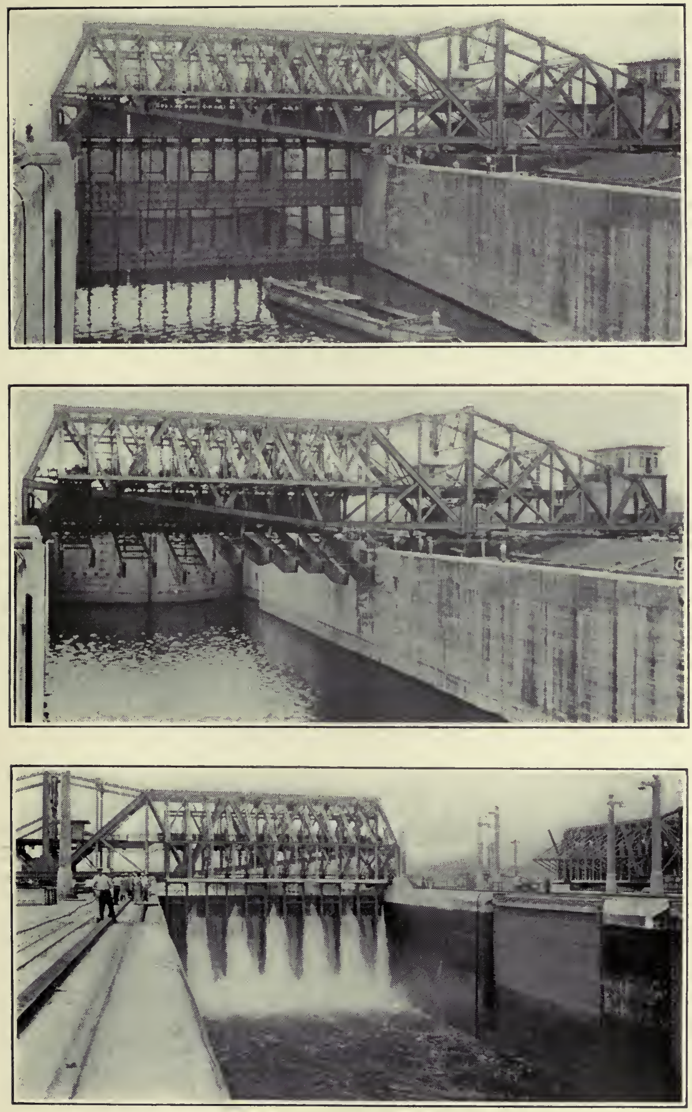


FIG. 3.—VIEWS OF EMERGENCY DAM AT GATUN IN OPERATION.

tives will control the movement of vessels from the time they land alongside the approach walls of the locks until the passage through the locks is complete.

LOCK GATES

The lock gates are of the mitering type, and built of steel in the form of girders. A gate of the arched type which was of course found much lighter than the girder type was studied, but was discarded on account of the excessive depth of recess required, which in the wall separating the lock chambers could not be provided, except by materially increasing the thickness of such wall for its entire length, at great expense. The leaves in the largest gates on the Canal weigh more than six hundred tons and it is an impressive sight to see two such huge structures swinging leisurely across the lock chamber and meeting gently in the center and there making closures from top to bottom that hardly allow the passage of a drop of water, not only where the leaves meet each other but also where they abut against the walls.

SPILLWAY

The control of the level of Gatun Lake in such a way as to absolutely insure that its waters will never overflow the locks and thus endanger the

Canal, and the control of Miraflores Lake so that its water can never overflow the locks at that place under the assumption that the summit level at Pedro Miguel is broken, were interesting problems for the designing engineers. Fortunately the complete discharge records of the Chagres River kept for many years by the French canal companies and continued by the United States, furnished more accurate data as to the hydraulics of that stream than is known about almost any stream in the United States. If the amount of water to be discharged is known the size of the openings necessary can be accurately calculated. The rainfall on the Isthmus of Panama is extremely heavy, ranging from 100 to 140 inches per year within the watershed of the Chagres. Excessive amounts of waterfall at times within a few hours, the maximum records being about 3 inches an hour at Colon and Gatun. Fortunately for the flood situation such rainfalls are confined generally to small areas, the rains in general being heavy showers over small areas indiscriminately located. While long records were available as to the flood discharge of the Chagres, the chance of an unusual combination of these heavy rainfalls, involving an extensive area, which might occur only once in a century, received consideration in the design of the spillways, especially that at Gatun, at which place the surplus waters of the entire watershed

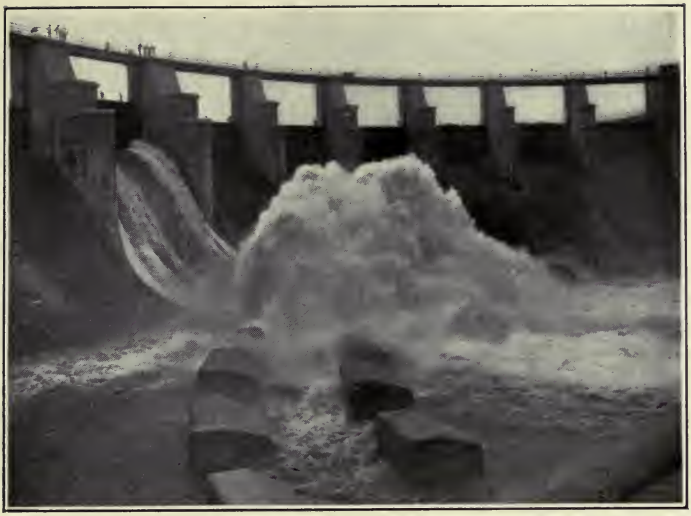


FIG. 4.—THE OPENING OF THE FIRST GATE, GATUN SPILLWAY.

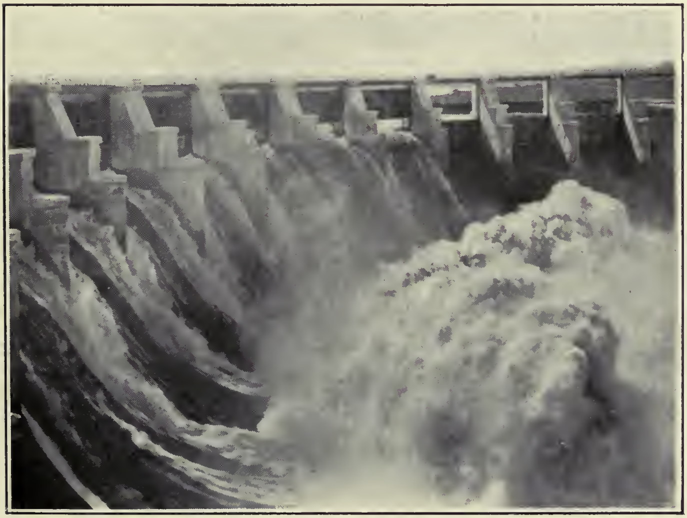


FIG. 5.—GATUN SPILLWAY WITH SEVEN GATES OPEN.

of the Chagres River must find an outlet to the sea. It is always good engineering practice to lean strongly toward the safe side in designing a spillway, because its failure to meet any possible condition might be fatal.

The reservoir capacity of the Gatun Lake within the allowed limiting variations of levels is itself a large factor of safety. The tops of the lock walls are five feet above the maximum service elevation of this lake. The maximum known discharge of the Chagres River for a period of 33 hours is 137,000 cubic feet per second. Assuming that this maximum flow continued and that no water was passing out of the lake through the spillway or through the locks, about 47 hours would elapse before the lake reached the top of the lock walls. The discharge capacity of the Gatun Spillway at the beginning of such a flood would be 154,000 cubic feet per second, which could be augmented by a discharge of 40,000 second feet through the locks at Gatun and Pedro Miguel, making a total of 194,000 second feet. At the extreme danger stage, just as the lake reached the top of the lock walls, the combined discharge of the spillway and the lock culverts would be about 262,000 cubic feet per second. It is therefore seen that the combination of reservoir value of the lake with the outflow capacity of spillway and culverts gives a factor of safety that will provide for the century flood and for marked negligence on the part of the operating force.

In order to provide a discharge capacity fulfilling the above conditions, the upper 16 feet of the spillway dam was made movable. A fixed dam was built to a height of 16 feet below normal lake level; on this fixed portion piers 45 feet apart were constructed. In the spaces between piers movable gates of the Stoney type are operated. These gates are raised and lowered vertically on trains of live rollers in grooves in the piers. With this arrangement it will be seen that when the spillway gates are opened the flow of water will be immediately actuated by a head of 16 feet. There are fourteen such gates. Figures 4 and 5 show the operation of the Gatun Spillway in its first official try-out. Only seven of the fourteen gates are open. The spillway at Miraflores is similar in design but has only half as many gates.

In the design of all the parts of the Panama Canal a generous factor of safety was allowed. It was felt that the resultant structures were not for a day or a generation, but that the completed Canal would be the embodiment of a great conception of our country to connect the Atlantic and Pacific for the benefit of the commerce of the world; the neutrality of which she was to maintain.

When practicable, all designs were based on successful precedents. There were no precedents, however, for many features of the lock designs, especially some of the operating machinery and other appurtenances necessary for the safe passage of ships.

CHAPTER XII

CONSTRUCTION FROM COLON TO GATUN

A canal of the dimensions of that just completed across the Isthmus of Panama could not have been built in any reasonable time without the mechanical appliances that this age has developed. Dry excavation at the rate of 50,000 cubic yards of material a day and placing concrete at the average rate of 3,000 cubic yards a day with one plant, would have been looked upon as impracticable by the engineer of twenty years ago and are astounding accomplishments to many engineers of today. These rates of work, however, were necessary in completing the Canal within the time fixed in the original project.

The most important stage in any great undertaking is the preparatory stage. During this stage a proper conception must be formed as to relation of plant to work to be done, and as to the relation of plant to those appurtenances necessary in keeping it working at maximum efficiency. Any failure during this period as to design of appliances commensurate with the size of the undertaking is a basic mistake and can never be fully corrected.

Efficient transportation in some form or other is nearly always the key to success in construction. It matters not whether it be hauling dirt and rock from steam-shovels to dumps, or hauling material from storage to concrete mixers, or concrete from mixers to forms.

The work in the spring of 1907 can be truly said to have just passed through the preparatory period, at least so far as the dredging and dry excavation necessary in building the Canal were concerned. It was not until the fall of 1906 that Congress had finally decided the type of canal, and the plan of construction for the locks and dams needed in the type selected had not passed through the preparatory period, although much thought had been devoted to that plan. The general questions that concerned the source of supply of stone and sand needed for concrete and the methods of transporting same to the site of the work had been decided.

The fact that the Canal was completed in the time specified, although the quantities involved largely exceeded those contemplated, stands out as strong proof that those responsible for the preparatory period conceived the needs of the problem in a broad, comprehensive manner. Of course many improvements were made, but such improvements were practicable without any basic change in the original conception.

COLON BREAKWATER

The final plans for Colon Harbor were determined March 10, 1910, and the construction of the west breakwater immediately commenced. This breakwater started from Toro Point and extended 11,526 feet in a direction a little north of east. No rail connection existed between the Panama Railroad and Toro Point. A survey was made for a line from Gatun, which indicated that its construction would be difficult and expensive. Furthermore its connection with the Panama Railroad would be broken when rail connection with the Gatun Dam was broken, Toro Point being on the west side of the Canal. This survey was made in connection with studies as to the best source of supply of stone for breakwater construction. These studies showed that there existed at Toro Point a rock that would be acceptable for the core or hearting of the breakwater and that since the heavy rock required for armor must be delivered by water, that the best and most available source of supply for such stone was Porto Bello. Stone could be easily quarried there in pieces weighing from twelve to fifteen tons.

The general plan of construction followed was to drive a double-track trestle from Toro Point out into the Caribbean Sea along the axis of the breakwater; to open a quarry at Toro Point; load cars there with steam-shovels, and dump stone from the trestle to a height necessary to make the trestle steady in a moderate sea, and to follow this operation by raising the fill above water with large rock from Porto Bello. Derrick boats working under the lee of this rock ridge were to complete the section of the breakwater with stone weighing from twelve to fifteen tons. This stone came from Porto Bello and was delivered alongside the derrick boats in barges.

The thought was that the placing of the heavy stone should follow the trestle driving as closely as practicable so as to minimize the damage should a severe "norther" occur while the breakwater was being constructed. The Porto Bello rock, first placed, forming a ridge above water on the sea face of the breakwater, was transported in barges to a small harbor constructed at Toro Point; it was then loaded on flat-cars, run out on the trestles and plowed off in position by a Lidgerwood unloader. The sight of these big stones splashing into the sea was an impressive one. This ridge only gave protection during a moderate sea and derrick boats were often unable to work.

The west breakwater was successfully built in the manner described for less than the estimate. See Figure 6.

The east breakwater was not commenced until

1914. It being on the east side of the Canal and a rail connection from Mount Hope to Magarita Point having already been made in connection with the construction of fortifications, it was decided to obtain all the stone for this breakwater on the Isthmus and transport it to the breakwater by rail; a double-tracked trestle being utilized in its construction as was done in the west breakwater. The heavy armor rock was to be obtained from near Sosa Hill, Balboa. A severe "norther" visited Limon Bay, Colon, February 8 to 10, 1915, and destroyed 4,700 feet of trestle on the east breakwater.

SEA-LEVEL SECTION, COLON TO GATUN

Both steam-shovels and dredges were utilized in excavating this part of the Canal; steam-shovels in making the channel through the Mindi Hills, and the dredges in the remainder.

In making the cut through Mindi Hills it was first decided to complete the excavation to sea-level with steam-shovels, drill and blast the underlying material and remove it by dredges. But as the work progressed it became apparent that the rock excavation in this section of the Canal, other than that at Mindi, would completely occupy that part of the dredging plant capable of rock excavation. The records showed very little differ-

Fig. 6.—Toro Point Breakwater, Looking Towards Water End, July 12. 1913.

Fig. 7.—A Dredge Grounded Fifty-five Feet Below Sea-Level, Gatun Locks.

ence as to cost by the dry and wet methods of excavation, considering the dredges available for the work. The ladder dredges engaged were built during the French régime and had small buckets—good machines for their day. The dipper dredges were modern; the type, however, is not the best for such deep digging. The stone from this excavation, if dug by steam-shovels, could be advantageously used in building the toes of Gatun Dam. It was therefore decided to install a pumping plant and complete the rock excavation to a depth of 41 feet below sea-level by steam-shovels. The cost of this excavation was 66.8 cents per cubic yard. This included pumping, cost of extra engines in pushing the trains up to the country level, and all other costs, except dumping the cars on the dam.

No untoward circumstances — not counting slides—occurred in the making of this excavation, except that the Chagres River forced its way, during a flood, through the spillway cut, while the latter was being excavated. The greater part of its flood discharge passed down the old French canal and overflowed the surrounding country in places. This resulted in flooding the Mindi excavation and in submerging some of the shovels to a depth of 40 feet, the bottom of the cut being at that time 40 feet below sea-level in places. The entire excavated space being filled with water, an entrance channel was made into it and a pipe line suction dredge sent in to remove the soft material that had been sliding into the cut for some distance back from the canal line. More powerful pumps were installed, the entire space unwatered, the steam-shovels cleaned up and greased, and the excavation continued.

The same flood, which lasted for some time, interfered most seriously with towing rock and sand to Gatun via the old French canal. The current was so swift that the tug boats could not stem it with a tow. In order to deliver their tows, the tugs would run ahead for a thousand or more feet, make fast to a tree and, with their towing machines, pull the barges up, and then repeat the operation. Fortunately, the storage piles were able to supply the deficiency during this period.

DREDGING SEA-LEVEL SECTION

Four distinct classes of dredges were used on this work. The sea-going suction dredge handled the material in Limon Bay, which was so soft that dredges could suck it in without any previous mechanical agitation. The pipe-line suction dredge handled the next harder grade of material, including all not classible as rock. These dredges were equipped with a steam-driven mechanical cutter operating just in front of the suction pipe.

The cutter tore up the material so that it would be sucked into the pipe and be driven out by the pumps. The ladder and dipper dredges handled the rock which was previously disrupted by dynamite. Several of the old ladder dredges owned by the French Company were utilized on this work advantageously, notwithstanding that they were twenty years old. The pipe-line dredges could deliver material through their discharge pipes to points from a half to three-quarters of a mile away, and the discharge from these dredges was so directed as to fill as many of the swampy places as practicable, thus enabling the Sanitary Department to construct drainage ditches and destroy breeding-places for mosquitoes.

In connection with these dredging operations 39,032,400 cubic yards of material, rock and dirt, were removed, at a cost of 23¼ cents. This cost included all plant charge and overhead expense. The drilling and blasting for the greater part of the rock below sea-level was done from the ground surface, which was above sea-level: that is, holes were drilled, loaded and fired, disrupting the rock to a depth of 42 feet below sea-level, working on the natural ground, before the dredges commenced work. This made the blasting costs light. The rock encountered was soft.

CONSTRUCTION OF LOCKS AND DAMS—GATUN LOCKS

In 1906 a decision had been reached to obtain from Porto Bello, a point on the Caribbean Coast twenty miles east of Colon, the crushed stone for the concrete in the Gatun Locks, and the erection of quarters there had commenced in the spring of 1907, and advertisements were out calling for bids for a rock-crushing plant. It had also been decided to obtain the sand needed at Gatun from some point on the Caribbean shore, possibly at Nombre de Dios, a place about twenty miles east of Porto Bello.

In searching for suitable sand on the Atlantic Coast some of the field parties penetrated the country occupied by the San Blas Indians, about ninety miles east of Colon. These Indians lived on small coral islands, cultivating land on the main shore. They did not look with favor upon the visits that the white man was making in search of sand in their territory: they suspected that the search was for gold and not for sand.

These investigations soon developed a supply of suitable sand and a party of higher officials made a visit to the Indian country with a view to making arrangements for procuring sand. The tug on which this party came was a strange sight to the Indians. As soon as the island on which the Chief lived came into plain view one could see, looking through a glass, all of the women seeking a hiding-place, as seems to be the custom in that country when strange men appear.

As this tug drew near the island a naked Indian boy about ten or eleven years old was noticed in a small dugout pulling frantically for the shore: his fear and his efforts were so appealing that the tug was stopped in order to give him time to safely reach land without crowding him too much with the tug. These Indians are efficient sailors and learn to handle a boat when very young.

When the inspection party reached the island on which the Chief lived they ascertained that he was not at home but that he would be at home in the afternoon and that if the party returned it could then find out whether or not he would receive them.

In the meantime an inspection was made of the deposits of sand and of the country generally thereabout, and at the appointed time the inspection party proceeded to the island on which the Chief lived. In the meantime a great many Indians had come to this island from the surrounding islands. The contemplated visit had probably excited the Indian community more than it had been excited for a long time.

When the party landed on the island it was led through a labyrinth of Indian dwellings and finally conducted into the Chief's quarters. This old

Chief—about seventy years of age—was seated upon a block of timber and he motioned the visitors to a seat on the sand at his feet—the floor of the house being sand. An air of solemnity surrounded the whole proceeding.

This Chief was told of the intention of the United States Government to connect the Atlantic and Pacific oceans by a canal so that boats could cross in a short time; he was told how this would improve the trade of the Indians; and how it would increase the price of his cocoanuts and his ivory nuts. The old Chief listened to the story and after it was finished, stated that God had given the Indians that country, the land and water, and the sand that was under the water, and that which God had given the Indians they would neither sell nor give to the white man; and, after another attempt was made to present further arguments, with a wave of his hand, he said: "There is no need to talk further."

The Chief was informed that permission could be obtained from the Republic of Panama to get this sand and that it could be taken, but that the United States preferred to pay for it and would pay for all of the sand procured from their territory if suitable arrangements could be made. The Chief replied that he owed no allegiance to the Republic of Panama and would not permit the United States to take the sand.

From this interview it was evident that sand could not be procured from the San Blas Indian country without bloodshed. In addition, it seemed a pity to disturb a life that was so unique and strong, in an Indian way at least.

Permission was asked to anchor for the night, which was granted on condition that the party leave early next morning and never return.

The discipline of these people, the power of the Chief, and the respect of the tribe for him, as shown during this visit, were remarkable.

The physical condition and strength of these island Indians attracted one's attention immediately, and the reason for it in this tropical country was sought. Investigations showed that there was no fresh water on the little coral islands where the Indians lived and, consequently, no breeding-places for malarial or yellow-fever mosquitoes, such mosquitoes never breeding in sea water. This, coupled with the fact that the malarial mosquito does not bite or feed in the daytime, when the Indians were on the main land looking after their banana and cocoanut plantations, largely furnishes the reason why these particular Indians were not cursed with the two worst tropical diseases—yellow fever and malaria.

It was known that it would be expensive to obtain stone from Porto Bello and sand from Nombre de Dios, as previously mentioned, because it would primarily involve the construction of a staunch and consequently expensive sea-going transportation plant capable of delivering more than an average of 3,000 cubic yards of crushed stone and 1,500 cubic yards of sand a day across a portion of the Caribbean Sea. It was also known that considerable expense would be incurred in deepening the old French canal from Cristobal to Gatun and that it would be necessary to make provision for storing large quantities of sand and stone so as to insure no delay in the concrete work on account of quarry breakdowns or rough weather on the Caribbean. In order to fully meet these requirements provision was made for storing 200,000 cubic yards of stone and 100,000 cubic yards of sand. About $800,000 was spent on the sea transportation plant, dredging the channel from Cristobal to Gatun and on the unloading plant designed especially for accomplishing the needed storage, all of which was absorbed in the cost of sand and stone. When these materials were delivered they were still 1,700 feet away and 60 feet below the site of the concrete mixing plant, which of course involved extra plant and extra expense in mixing the concrete.

The above considerations coupled with the fact that the Porto Bello stone was exceedingly refractory, and that the rainfall there was excessive, being 237 inches the first year of operations there, whereas it was only 70 inches at Panama, and of the further fact that the Nombre de Dios sand was mixed with mud and had to be handled with a suction dredge in order that the pumping might wash it, were the causes of the excessive cost of sand and stone and consequently of the concrete for the Gatun Locks as compared with that of the locks at Pedro Miguel and Miraflores. This extra cost has been criticized by some, and the question was often asked why this sand and stone was not obtained from the same source as that for the locks on the Pacific side, hauling that needed for Gatun by rail across the Isthmus at a considerable saving in cost. The source of supply of sand and stone for Gatun was decided upon during the preparatory period and was an element in the general problem of transporting material to and from other parts of the Canal and of freight across the Isthmus by the Panama Railroad. An obligation existed on the part of the United States to do a general freight and passenger business with this railroad.

It was recognized that the stone at Gatun would cost more than that quarried at a hill near the sites of the locks on the Pacific, but it was decided that the increased cost would be at least offset by the increased transportation facilities thus accorded the other parts of the Canal, in addition to the advantage of not having the work at Gatun hampered by an uncertain supply of material. Furthermore it was expected that the partial formation of Gatun Lake would drown out the old line of the Panama Railroad before concreting in the locks was finished, which of course would throw all the traffic on the relocated line, which line at that time was not planned as a freight carrying road, a much cheaper line than that afterwards determined upon and built. The cost of the stone and sand in the stock pile at Gatun, all plant cost absorbed, was: Stone $2.44 per cubic yard; sand, $1.95 per cubic yard.

In order to relieve the Panama Railroad still further, it was decided as a part of the plan for transportation of concrete materials to Gatun, that the cement be shipped by water from Cristobal to Gatun. This involved the absorption of the cost of the barges and boats necessary to this service, in the cost of the cement for Gatun. The operating cost of this plant was about the same as the railroad charge for the cement to other parts of the Isthmus.

CHAPTER XIII

EXCAVATION AND CONCRETE WORK AT GATUN

EXCAVATION OF LOCK SITE

This excavation comprised the removal of 4,660,455 cubic yards of material by steam-shovel; 1,756,917 by dredges. In preparing the foundation after the general excavation had been completed 228,376 cubic yards were removed by crane and by hand. There was nothing unusual in any of this excavation until the lower end of the lower lock was reached. On the east side of this lock the rock dipped rapidly to the northeast and at the lower end of the lock proper was found at 66 feet below sea-level and overlaid with the softest of mud. On the west side of the locks the rock commenced to dip rapidly to the north near the caisson sill, imposing many difficulties in making the excavation for the flare and guide walls. The engineering difficulties connected with the flare and guide wall excavation will be treated separately.

STEAM-SHOVEL EXCAVATION

During the last week in September, 1906, one steam-shovel commenced excavation at the lock site; other shovels were added as fast as they could be advantageously cut in. By July, 1907, the excavation had sufficiently advanced to install a satisfactory track system. After that the work followed ordinary lines of development. The problem was to complete the excavation to the foundation level of the upper locks as soon as practicable, so that concrete work could be commenced in that lock; excavation to be continued at a rate that would enable the concrete force to spread into the middle lock before it was cramped in the upper lock. In order that the wall foundations could be prepared in advance and the trenches for the lateral culverts excavated in time, it was necessary for the lock excavation to proceed with celerity and certainty. The success of a great construction job like the Gatun Locks depends upon an orderly procedure of the various parts. No part must be allowed to delay another part if it be practicable to avoid such delay.

The average output per day per shovel for the entire year ending June 30, 1908, was 1,142 cubic yards, and the corresponding average for 1909 was 1,101 cubic yards, showing that the machine worked with regularity. The requirements placed upon the excavation force were met and the concreting was not delayed until the lower end of the last lock was reached, when the entire plan of excavation had to be changed on account of the fact that the material overlying the rock was too soft to hold up a steam-shovel. The uniform rate at which concrete was placed is the most lucid proof of this statement. The material from the lock excavation was utilized in building the toes of the Gatun Dam and in making fills in the reconstruction of the Panama Railroad.

The average cost of the excavation for Gatun Locks was 67.8 cents per cubic yard. The space was contracted, especially in the middle and lower locks, and hauling excavated material from a depth of 45 feet below sea-level to the general track level, utilized in disposing of this material, was very expensive.

Notwithstanding these difficulties all of the excavation for the locks proper, including the caisson sill of lower lock, was done by steam-shovel. In accomplishing this for the last 400 feet of the east wall, a depth of 66 feet below sea-level was reached, in spite of a succession of slides, that at times turned over steam-shovels, and on more than one occasion, covered up workmen. The fact that the rock dipped both east and north enabled the shovel and the loading track to be kept on rock.

This material sometimes assumed slopes as flat as one vertical on thirteen horizontal. No one expected on returning to work in the morning to find things as they were left the evening before. The force, however, were never discouraged and felt determined to conquer the situation in time so as not to interfere with building the lock walls.

The experience in this part of the excavation proved that it would be impracticable to make the excavation for the flare and guide walls by steam-shovel. The rock was so low that initial tracks for shovel and trains could not be placed on it. It was then decided to complete the lock walls to the caisson sill, build reënforced concrete dams between such walls to hold back the sea from the lock chambers, in order that the installation of lock gates and machinery might proceed, and to complete the excavation by dredges.

In making this excavation a sound log was found 56 feet below sea-level and about 65 feet below the surface of the ground. Its envelope of soft, impervious blue clay had evidently prevented any circulation of water and thus prevented its being petrified or destroyed by chemical agencies. It was a hard, heavy, beautiful wood capable of receiving a high polish. Canes and cribbage boards made from it are among the most cherished mementos of many of the employees of the old Atlantic Division. This log may have been thrown into the position where found, during the geological disturbance that lowered the old channels of the Chagres River previously referred to;

the overlying material being a sea deposit of the finer clays delivered by the Chagres River into the area of sea that extended up the Chagres Valley after the subsidence. There were evidences of this subsidence brought to light in the excavation for the Gatun Locks.

Below the soft blue mud was found the same kind of red clay that formed the tops of the small hills around Gatun. A few feet beneath this clay the same class of rock was encountered. The line of demarcation between the original hilltops and the sea deposit on them was very clear; the sea deposit being dark blue mud filled with shells. The old natural surface of the ground had the same broken, uneven appearance that characterizes the surrounding country. This unevenness made the construction very difficult, unexpected depressions being encountered frequently—depressions not fully developed by the borings.

The channel excavation from Limon Bay to Gatun was stopped 1,000 feet south of the site of the flare and guide walls and the undisturbed earth left as a barrier or dam to hold the sea out of the deep excavation to be made for the walls. As soon as the lock walls were completed, as stated before, and the reënforced concrete dams across the sea end of them built, dredges cut a channel through this barrier wide enough for their entrance, allowing the sea water to come against the temporary dams at the south end of the locks.

Dredges then commenced to excavate the space in which the flare and guide walls were to be built. These dredges were of the pipe-line suction type and could discharge the excavated material through the pipe, as shown, to distances of a half-mile or more, but they could only dig to a depth of 41 feet below sea, while it was necessary to excavate to a depth of 70 feet below sea in order to uncover the rock under the east flare wall.

The borings indicated that, while it was 70 feet below sea-level to rock under a part of the flare walls, a hundred or more feet back of these walls the rock was at about 40 feet below sea and could be uncovered by the dredges floating at sea-level.

Experience in digging the sea-level section of the Canal between Gatun and the sea, had established the fact that where the ground was not more than six to ten feet above the sea the sides of a cut 50 feet deep would not slide if the sea water followed the dredges in making the cut.

The plan of excavation, therefore, contemplated uncovering the rock behind both the flare walls without lowering the water level; then to drive a trestle into this rock, using shod piles, and from such trestle make a rock fill, dumping the rock through the water. These rock fills resting on the rock bottom were expected to act as retaining walls and to hold the mud out of the excavation when the water surface was afterwards lowered and the excavation continued.

After this was accomplished, an earthen dam was built across the entrance cut in the barrier made by the dredges, shutting off their connection with the sea. A suction dredge in operation pumps six or seven times as much water as it does solid material. Being disconnected from the sea the operation of these dredges lowered the water surface in the space where the walls in question were to be built. The dredges floating at a lower elevation could uncover the rock at greater depths: as this process continued the rock fills referred to above were widened. In this way the dredges uncovered rock 70 feet below sea under the flare walls and the rock dams kept the mud out. A water supply for the dredges was pumped into the dredged space when needed.

This process could not be followed in building that part of the guide wall north of the flare walls on account of the extreme depth of the rock below sea-level. In lowering the water level many slides came into the excavation north of the flare walls and were pumped out by the dredges, the water being held at constant level during such process. After the excavation had all been made to grade, the water surface being at thirty-two feet below sea-level, the entire space was filled with water to sea-level, an opening made in the barrier, and all but one of the dredges were then taken out to be used at other places where needed. The opening in the barrier was again closed and the dredge left within the inclosure finally pumped all the remaining water and earth brought in by slides out of the excavated space. This dredge ultimately was grounded 55 feet below sea-level, where it remained until the work was finished. See Figure 7.

After all the masonry was finished and the sea gates of the locks completed ready to take the pressure of the water and keep it out of the lock chambers while the gates and valves were installed, the reënforced concrete dams at the ends of the locks were removed and the space excavated for the guide walls was filled by dredges pumping water from the sea-level section of the Canal. The sea gates were thus gradually subjected to a full head of water. See Figure 8. The grounded dredge was thus floated and commenced to cut away the barrier between the Gatun Locks and the sea. Other dredges worked on the same barrier from the sea toward the locks, thus completing the Canal from Gatun to the ocean.

Figure 9 shows one slide that came into this space and covered a large part of the guide-wall

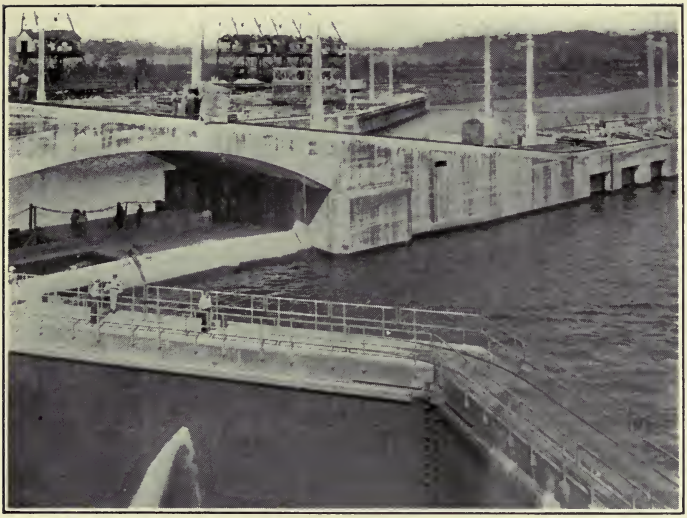


FIG. 8.—SEA GATES, GATUN LOCKS, UNDER PRESSURE FOR THE FIRST TIME.

FIG. 9.—SLIDE INTO SPACE EXCAVATED FOR NORTH GUIDE WALL, GATUN LOCKS.

foundation with mud from 6 to 18 feet deep while the process of driving piles was proceeding. This happened two months after the space had been pumped out and in the middle of the dry season. The sliding material finally came to rest with slopes as flat as one vertical on twenty horizontal. This slide wrecked two pile-drivers and caused a serious delay to the work. The mud brought in by this slide was sluiced into a hole in front of the grounded dredge; water sufficient for the operation of the dredge being pumped into the excavated space, and the dredge put in operation, sending this mud through its pipe line a quarter of a mile to the east of the scene of trouble. It was an odd sight, one probably never seen before —a 20-inch suction dredge on the ground 55 feet below the level of the sea and doing useful excavation. This dredge kept the excavated space unwatered until a less expensive pumping plant could be installed.

The excavation for the flare and guide walls of the Gatun Locks was the most difficult task in connection with the building of the Gatun Locks, if not of the entire Canal. An open cut over 70 feet below sea-level in soft mud is difficult to make and even more difficult to maintain. Had the rock foundation for these walls been at a suitable elevation and the banks reasonably stable, the masonry of the locks could have been completed about ten months sooner and the cost of concrete materially reduced. Concrete operations were practically stopped for ten months.

The rock surface under the Gatun Locks was very uneven, its elevation varying as much as 30 feet within a horizontal distance of 50 feet. These depressions were evidently small valleys that existed in this section before the 300-foot submergence referred to in connection with the submerged old Chagres River gorges. Evidently the surface flow of the streams excavated these valleys to rock before the submergence, and after the submergence they were filled entirely with a sea ooze.

Slides down these various submerged valleys into the north end of the Gatun Locks and into the excavated space for the flare walls and guide walls during construction constituted a most serious bar to rapid and cheap prosecution of work. Slides at times would flow around the end of the work and into the lock chamber for half its length.

PLACING CONCRETE: GATUN LOCKS

The main construction plant finally decided upon for Gatun consisted of four traveling duplex cableways for placing concrete at any place where needed in the construction of the locks.

There were two cableways spanning the lock site and connecting each pair of towers, the towers being equipped with railroad trucks on tracks so as to permit their being moved up or down the lock site for a distance of nearly a mile. Eight two-cubic-yard concrete mixers supplied the concrete. All of these mixers were in one building, four facing the east and four the west to facilitate the delivery of the buckets of mixed concrete to the cableways by an electric road which ran north and south under the west end of the cableways. The ordinary mine type of electric locomotive was used. The material in proper proportions and amounts for two yards of concrete was brought from storage and delivered into the mixers by an automatic electric road. There were a maximum of forty-two cars on this road and each car made three trips an hour. More than a million tons of material were handled by this automatic road in one year. Its cars, without operators, moved around with absolute regularity and constituted one of the most insistent accelerators on the job. It was up to the mixing force to mix the material that they brought and to the transporting force on the other electric railway to haul it from the mixers, and to the cableways to dispose of it.

In addition to the main or principal construction plant at Gatun a mixer plant of two two-cubic-yard mixers, steam-driven, was erected at the south end of the lock. This plant had overhead storage in bins for rock and sand, which materials were brought by regular railroad equipment from the main storage piles and dumped into the bins. The concrete was hauled in side dumping cars from the mixers to its destination by narrow-gauge steam equipment.

It was known in the beginning that the south guide wall and flare walls of the Gatun Lock could not be constructed by the cableways of the main construction plant, and this auxiliary steam plant was erected primarily for the construction of such walls: its use, however, spread far beyond this. With it was constructed practically all the floors of the Gatun Locks, dumping concrete directly from the cars. This proved a very efficient and economical way of placing concrete, and through its use the floors could be prepared in advance of the construction of the lock walls, thus providing tracks for the wall forms and facilitating in many ways the construction of the lock walls. Not only the floors of the locks were placed in this way but the foundation of the lock walls themselves to the level of the floors. This part of the wall foundation included enough of the bottom of the curve of the 18-foot culvert to provide space for the track therein on which rested trucks for supporting and carrying forms for the construction of the remainder of these culverts. These forms could be slightly collapsed on the trucks and moved from monolith to monolith with great ease.

There were more than two million cubic yards of concrete in the Gatun Locks. No structure in the world contains as large an amount of such material. At the time the construction of these locks was contemplated about 1,700 cubic yards of concrete per day, for short periods, constituted the world's record. In order to complete the locks in question within the contemplated time it would be necessary to practically double this rate of placing concrete. This meant increasing the number of concrete plants or increasing the capacity of a central plant beyond anything attempted before.

The decision to obtain the crushed rock from Porto Bello and the sand from Nombre de Dios, 20 and 40 miles, respectively, from Colon down the Caribbean Coast, and to transport same in barges across the Caribbean Sea and up the old French canal to the vicinity of Gatun, largely determined many features of the plant. The Caribbean Sea was noted for storms during which navigation would be impracticable and dangerous. The desire to eliminate all chance of shortage of material, caused the construction plant to provide for large storage—about 200,000 cubic yards of stone and 100,000 cubic yards of sand. This material, when delivered as closely as practicable to the Gatun Lock site, was still 1,700 feet away and 60 feet below a centrally located mixer plant. To transport these materials from the storage piles to the mixer involved quite an expensive addition to the plant, one not ordinarily necessary.

The preliminary plans for the lock construction plant at Gatun, studied prior to 1907, contemplated unloading the sand and stone and placing concrete by cableways. While the general thought in this layout was retained, duplex cableways for placing concrete, were substituted for single ones, thus doubling the capacity of this part of the plant. An automatic electric road was substituted for a cable road as a means of transporting sand and stone from the storage piles to the concrete mixers.

The advisability of using cableways for building the locks was questioned by many. Their disadvantages in placing concrete in contracted places were known. It was thought, however, that building lock walls, the bases of which were from 50 to 60 feet wide, would not be working in contracted spaces. The width of base of lock wall was about the same as the width of lock chamber in the majority of such structures in the rivers of the United States. The advantages of covering the entire space in which a structure is to be erected with overhead lines of delivery for any class of material, are many. The men referred to this advantage as one that gave them a "sky hook" over all the work. An overhead system keeps the space in which the work is being carried on relatively free of all plant, except forms. It facilitates the delivery in the work of all material, whether it be lumber for forms, mixed concrete, necessary iron, etc. Material trains in this case ran on tracks outside the excavation on the inside of the cableway towers, from which position material was taken directly from the cars and placed in position in the locks.

The decision of the question as to type of plant where such a great undertaking is involved requires much thought, because its failure to meet expectations means that the entire construction is materially delayed. A serious mistake in plant layout can never be fully rectified.

In the solution of this problem those in charge of the construction of the locks on the Atlantic side reached different conclusions from those in charge of the construction of the locks on the Pacific side. Of course the topographic conditions were different; consequently, methods of doing the work were different. That the plants on both sides were the results of careful study is shown by the fact that the cost of taking material from storage, mixing it into concrete, and building the lock walls, shows very little variation as between Gatun, Pedro Miguel, and Miraflores.

Prior to 1907 no thoughts had materialized into plans for forms for concrete at Gatun. All engineers know that no single thing influences the rate of concrete work as much as forms. The mixing and placing forces are always calling for a place to put concrete. To design a system of forms and complete the plans for the construction plant was, therefore, one of the first duties of the organization of 1907.

It was decided primarily to build the lock walls in monoliths 36 feet long, i. e., to complete the wall for that length from bottom to top and design forms that would box in that length of wall. This decision led to the adoption of duplex instead of single cableways. A tower carrying two cableways eighteen feet apart could be so placed with respect to a form 36 feet long that any concrete delivered would not be more than 9 feet from its final destination. And it was thought that by using wet concrete it would flow to place and that no rehandling would be necessary and that a monolith in each wall could be built with the cableway towers in one position. No such massive walls of concrete had been built as those designed for the locks of the Panama Canal, and the forms at Gatun met this unusual and exacting condition in a new way. Of course the type of construction plant was also a material factor in the design of forms.

Fig. 10.—Steel Forms, Gatun Locks.

The wall form adopted was a steel box that could be knocked down and set up easily. See Figure 10. The front of the box was a steel plate 80 feet high and 36 feet long, permanently supported by and transported on a steel tower that traveled on tracks on the floor of the locks parallel to the walls. The sides and back of this form were made of steel pieces six feet high and, when in position, were connected by bolts to each other and to the front piece. The sides were handled by booms on the form tower and the back pieces by the cableway. Two such forms were provided for each cableway, with one form in reserve. These forms could be dismantled, moved and set up in two days and would contain about 3,500 cubic yards of concrete. It required about a week for the cableway to fill one of these forms. Two forms, therefore, kept a cableway occupied. It was recognized that if the foundations could be prepared ahead and the lock floors laid in advance, the building of the walls with these forms would be a continuous process.

Collapsible forms were provided for all the culverts and openings that were repeated, such as the circular holes through the floors into the culverts. All the large culvert forms were on trucks which could be collapsed and moved. See Figure 11.

The form system, with some minor changes, proved very efficacious. In fact, the entire construction plant came up to expectations.

MOVEMENT OF MATERIALS

The point of delivery of materials enforced by the source of supply made the problem of transporting this material from storage to mixer an expensive one. This was accomplished by devising an automatic electric railroad. Each car carried the materials for two yards of concrete: its cycle was under the cement shed, where it received its charge of cement; then under the sand pile where a compartment was filled with sand; then under the stone pile where a compartment was filled with stone. The cars ran under all material and were loaded by gravity. After being loaded each car was started and ran automatically to a point over the mixers where it was stopped, dumped and started on a new cycle by a workman. There were no operators on the cars; their speed was only four miles per hour and they were stopped and started by men under the cement shed and under the sand and stone piles.

As soon as the material was mixed into concrete it was dumped from the mixer into buckets holdin the entire batch, two cubic yards. These buckets rested on flat-cars which were hauled by the electric railroad under the cableways. The

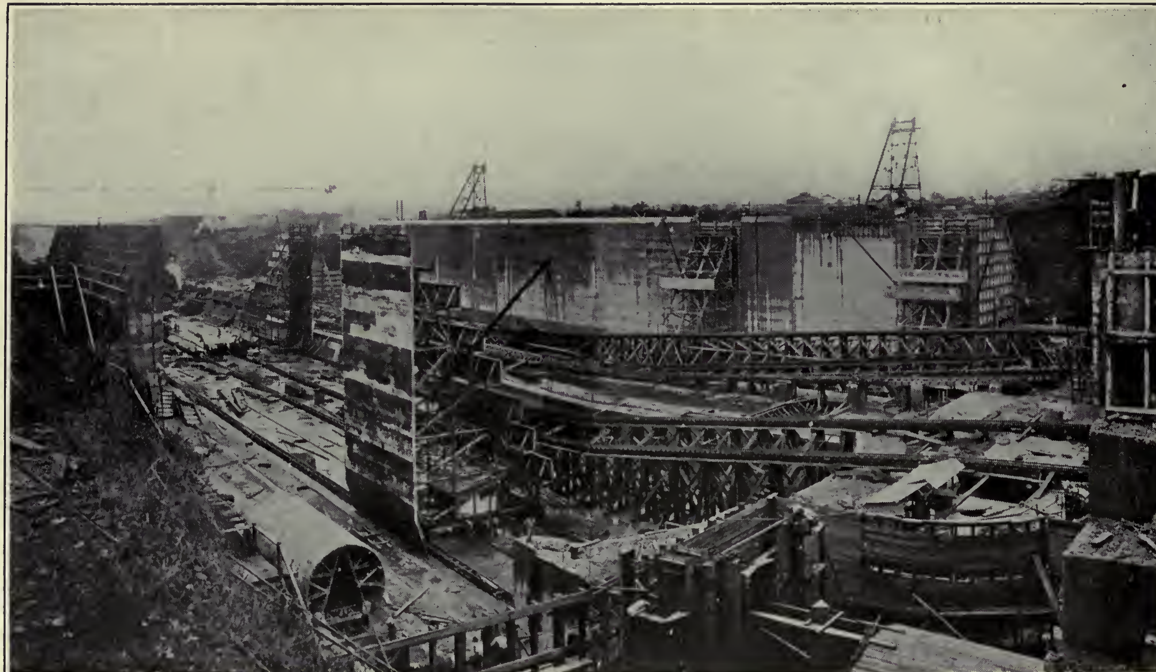


Fig. 11.—Steel Forms, Gatun Locks.

buckets were then taken up by the cableways, run out to the point where the concrete was needed, lowered and dumped, and the cycle repeated.

It was recognized in the design of the plant that in order to obtain speed and keep all parts of the construction going at its full capacity, every operation connected with the erection, moving and reërection of forms must be facilitated in every way. It was also recognized that the capacity of the smaller elements of the plant should be greater than that of the more important units, such as the duplex cableways, so as to be sure to meet the peak capacity of such units. This principle was followed in designing the various forms; it was followed in the mixer building by having two two-cubic-yard mixers always in reserve and kept in perfect repair so that they could immediately take the place of other mixers while the latter were being repaired.

The operation of such an extensive plant, many parts of which involved novel features, was naturally accompanied by many troubles in the beginning. These troubles, however, were of relatively short duration, and in a few months the plant was working with marked regularity.

From June, 1910, to June, 1911, 950,000 cubic yards of concrete were placed, constituting an average of about 3,000 cubic yards per working day. The plant was operated for twelve hours per day during the greater part of the work, thus taking advantage of all the daylight in that tropical country.

The interest that the entire force took in the operation of this plant and their enthusiasm when it fully reached the expectation of the designers was marked. It not only extended to the entire working force but also to their families. The Division Engineer, in walking to his office in the morning, would be accosted by the children in Gatun who would proudly inform him of the number of cubic yards of concrete that had been placed in the locks the day before.

CHAPTER XIV

CONSTRUCTION OF GATUN DAM

The Gatun Dam has covered with rock and earth to a depth of one hundred feet the site of the old village of Gatun. This village, thus erased from the map, was located between the Chagres River and the old French canal. It had the appearance of having been there forever and of intending to remain there forever. It was ideally located for the transportation needs of its inhabitants; having streams on both sides of it which provided mooring places for the *cayuco* or "dugout," the only means of travel and transportation for the villagers along the waterways in the Republic of Panama. This village had easy water connections with the valleys of the Chagres, Trinidad, and Gatun rivers to the south, and with Colon and Cristobal to the north.

The great buccaneer, Morgan, afterwards Governor-General of Jamaica, passed through this place in 1671, on his way to capture old Panama. The same route was followed by the "Forty-niners" on their way to the gold fields of California. In fact, prior to the completion of the

Panama Railroad, in 1855, this village was in the direct line of many expeditionary forces traveling from our Atlantic to our Pacific shores, including one made by Lieutenant U. S. Grant. Two old cannons were found that had been placed in a position to defend this reach of river.

Its inhabitants could see no reason for disturbing such an ideally located settlement, nor could they see why its site should be utilized for the construction of a dam, and were consequently loath to move their belongings to a new site selected along the Panama Railroad east of Gatun. After their property had been purchased and they had been assigned lots in the new village and offered cars on which to load the material composing their houses they still would not move. They did not believe in the stories told as to the intentions of the Americans, and stated that the French had told them thirty years before of impossible things that would happen in the shape of great locks and dams, and lakes that would submerge their little homes along the streams. It was not until the United States commenced to actually dump material in the toes of the Gatun Dam, as shown in Figure 2, which material even rolled into and under the houses, that they finally realized the necessity of moving.

The Chagres Valley was divided into two parts where it is crossed by the Gatun Dam. These parts were separated by a hill more than one hundred feet high through which the spillway channel was excavated. This hill and that part of the dam site to the west of it was heavily wooded. All of such woods had been cleared away prior to the spring of 1907, but no other work had been done toward the building of the dam.

As indicative of the proximity of wild-animal life to the habitations along the streams in Panama, monkeys chattered in protest as the timber was cut from Spillway Hill, and the force performing this work actually killed a tiger cat with the machetes used in making the clearing.

EXPERIMENTS AND TESTS

While the preliminary explorations concerning the material out of which the Gatun Dam was to be built, and that on which it was to rest, had been sufficient to warrant those members of the International Board of Engineers who had recommended a lock canal to conclude that it was practicable to build a stable and satisfactory dam across the Chagres Valley at Gatun, it was decided to continue these investigations, both as an extra precaution and as a matter of record. The construction of the dam, however, did not await the completion of these tests, but was carried on on the supposition that the original conclusions were correct and in accordance with the then approved plans.

The experiments and investigations made for the purpose of testing the impermeability of the material available for the construction of the Gatun Dam consisted in building a short length of two experimental dams of one-twelfth the size of that proposed for the Gatun Dam. These experimental dams were built of the same material that was to be used in the Gatun Dam and placed by the hydraulic method in the same way as proposed for the Gatun Dam.

The first of these dams was built by pumping all of the material into the downstream edge of the dam, which of course resulted in placing the finer, more impermeable, material on the water-face of the dam.

In the second experimental dam the material was pumped from both faces, the finer material thus being segregated in the center.

Both of these experimental dams were subjected to a head of water corresponding to the head that would be against the Gatun Dam proper.

Seepage tests were made, from which the conclusion was reached that a dam built of either type, utilizing the material available for the construction of the Gatun Dam, would be relatively impermeable.

Ease of construction ordinarily determines whether all of such material shall be delivered at one face of the dam or at both faces. It was necessary in this instance to build ridges of dry material to hold the hydraulic material in place during consolidation. In consequence of this and of the necessity of building up these ridges as the dam grew, hydraulic material was delivered on both faces of the dam.

Tests of the material underlying the Gatun Dam were made both by borings and by test pits. Wash drill borings were made in all of the dam foundation, except Spillway Hill. In these borings a hole would be washed down a certain number of feet and then a sample taken of the material. This sample would be obtained by driving an open pipe into the material, such pipe hanging free within the casing surrounding the hole. The pipe would be filled with material to the depth that it was driven. The hole would then be washed four or five feet deeper and another drive sample taken, etc. All of these samples were labeled and stored away. The holes were located generally over the entire dam site. A test pit was then sunk in the east half of dam to a depth of eighty feet below sea-level. The amount of pumping necessary to keep this pit dry was a direct measure of the watertightness of the material. By comparing the material actually encountered at the various depths in this pit with the drive samples at the same depths, obtained in the many holes, an accurate conclusion could be drawn as to the character of the material generally existing under the dam.

From these tests the conclusion was drawn that the material underlying the Gatun Dam was relatively impermeable. The work of building the dam was continued during the time of these tests in accordance with an approved plan.

Coincident with the tests, careful examinations were made of all the saddles or low places in the ridges surrounding Gatun Lake that approximated the same height as the lake level. Holes were drilled in all of these saddles in order to determine the character of the material, its watertightness and general suitability to form a portion of the rim of the lake. An accurate contour survey of the lake bed had been made in the beginning, the contours extending to fifteen feet above the proposed lake level.

In April, 1907, one steam-shovel commenced grading for a pilot or preliminary track along the axis of the spillway cut. This shovel was transferred to the site by a barge. In June work was commenced driving a trestle along the 30-foot contour on the north face of the dam.

An examination of Diagram 6 will show that the waters of the Chagres at this time were passing the site of the Gatun Dam through three channels; the old bed of the Chagres River, the old

French canal, and the west diversion channel dug by the French west of Spillway Hill to divert the Chagres from the then proposed canal. These channels are shown by dotted lines in the figure.

The Gatun Dam is 8,200 feet long and is made up of three parts—an earthen dam, connecting the locks with Spillway Hill; a concrete dam with

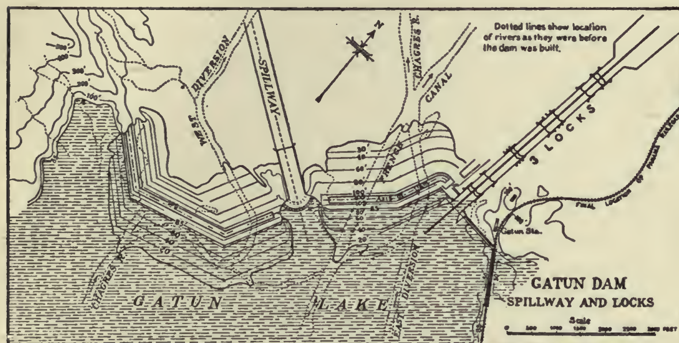


DIAGRAM 6

regulation works across the channel in Spillway Hill, and an earthen dam from Spillway Hill to the high ground bounding the west side of the Chagres Valley.

The plan of procedure determined upon was, first to build a dam across the Chagres River proper and one across the old French canal, thus diverting all the flow of the Chagres into the channel west of Spillway Hill. These operations would remove all water difficulties from that half of the dam east of Spillway Hill and enable work of dam construction to be started in that part. The next step was to cut a channel three hundred feet wide through Spillway Hill into which channel, when completed, the entire flow of the Chagres was to be diverted. With this completed, the west half of the dam was to be built. After the earthen parts of the dam were completed the step next planned was to build a dam with regulation works across the south end of the spillway channel passing the Chagres through temporary culverts during such construction.

No serious difficulties were encountered in building the dams across the Chagres channel and the old French canal. The river had an outlet through the west diversion channel while this work was being done and the water surface of the Chagres was not materially raised while the dams were being built.

In forcing the Chagres from the west diversion channel into the spillway channel many difficulties were encountered. The bottom of the spillway channel was constructed at an elevation of 10 feet above sea-level and the bottom of the west diversion channel was about 20 feet below sea-level. The effect of the tides was felt in the Chagres River for about ten miles above Gatun. In order to force the river through the channel excavated for the spillway it was necessary to bar the passage of the river through the west diversion. During the construction of the dams necessary for accomplishing this, the river would have no outlet until it had risen ten feet, at which stage it would commence to flow through the spillway channel. Its entire discharge could not, however, be thus accommodated until it had risen 14 feet.

The sides and bottom of the west diversion channel were mud for depths of about 200 feet, its location being over the old geological gorge to the west of Spillway Hill. In making the diversion in question it was decided to build two dams across the channel simultaneously, one on the 30-foot contour on the north face of Gatun Dam and one on the 30-foot contour on the south face.

The reason for attempting to build the two dams at once was the hope that during construction the head of water that would result from the rising river would be divided between the two dams; that is, should the river rise, say, 6 feet, there would be a fall of 3 feet at the upper dam and 3 feet at the lower. The diversion dams were to be encompassed by the main dam when built.

An unlimited amount of rock spoil from the Culebra Cut was available for the construction of these diversion dams.

The first step in the construction was to drive trestles across the stream at the selected location and to try to build the dams by dumping rock from the trestles directly into the stream. Rock was at first dumped next to the banks for purposes of protecting the same. Then the fill was gradually worked out into the river. As soon as the flow had been contracted sufficiently to develop a strong current, medium-size stone was dumped for the full length of the trestle, expecting that the current would distribute such stone downstream, forming an apron below the dam. After this had been continued for some time an attempt was made to complete the dams for their entire length by increasing the rate of dumping stone. When the stream had been contracted until the channels through the dams were about 80 feet wide and 6 feet deep, the force of the water was such that all stone would be carried downstream; none of the pieces seemed big enough to stand the current.

The original plan was to make this diversion in the dry season, but the excavation in the spillway channel had been delayed for a month or more the previous wet season, on account of the Chagres washing the barriers away during a flood and occupying the incompleted channel, and the diversion could not be attempted until the latter part of April when the rains were commencing, and it was necessary to make the closure quickly, otherwise it could not be done until the next dry season. It was therefore decided to dump car-loads of crooked rails into the river above the trestles, the piles of the trestles being well supported by the stone previously dumped. It was thought that these crooked rails would form an entanglement that would stop the stone on the upstream side of the trestle and this would result in either closing the river or tearing out the trestle. A large number of trainloads of rock were gathered together so that the process of dumping could be made continuous after the rails were placed. This process was successful and resulted in building the diversion dams above water. One of the trestles cracked and moved downstream a few inches, but not enough to prevent its use after minor repairs had been made.

After the flow of the river was completely stopped these two dams were raised to the top of the trestles and widened, with a view to making them secure, and the Chagres River had commenced to flow through the spillway channel. Before attempting to build these dams levees had been built across the valley which, with the dams, would make a continuous barrier.

It should be remembered that the space between these two diversion dams constituted the site of the Gatun Dam proper.

In order that this site should be free from water, 20-inch pipes were laid through the levee that formed an extension of the diversion dam on the north face, the object being to drain off any water that seeped through the dam on the south face.

The second day after the completion of the two diversion dams a settlement occurred in this levee that mashed the drain pipes and stopped the flow of water through them. When the space between the two diversion dams was partially filled with water the north dam moved leisurely downstream and spread itself out in the bottom of the west diversion. Piles that had 30- or 40-feet penetration moved downstream vertically. See Figure 12.

Thus one of the dams for diverting the Chagres passed away, and the sudden release of water caused the bank against which the other dam abutted to slide into the river. This slide was of such an extent as to break nearly through the levee joining the dam, a lip of earth about 3 feet wide being the only barrier left that kept the Chagres from resuming her old course. Trains were immediately run out onto the trestle and an attempt made to rebuild the levee through this slide; about 30,000 cubic yards of rock were dumped into the area. Immediately after the completion of this fill this entire body of rock slid out into the river and cracked the small lip of earth yet standing as a barrier, and it looked as if the Chagres River were the victor. It was thought that if an attempt were made to dump any

Fig. 12.—Remains of the North Diversion Dam, Gatun Dam.

Fig. 13.—Slipping of the South Toe of Gatun Dam, Top View, November 21, 1908.

more rock into this sliding area it might precipitate a slide that would break entirely through the levee and open a route for the river. The rising river had formed, at this time, a lake with an elevation of 14 feet above sea.

It was then decided to utilize two suction dredges, bought for the purpose of building the Gatun Dam, in raising the lake bed just above the weak place, and to trust that nothing would happen while this was being done. These two dredges, pumping material from some distance away, gradually filled up the lake bed with clay and sand until an island about three-fourths of an acre in area was formed immediately above the threatened place. This gave a factor of safety. Should the slide break farther back toward the lake there would still be ground out of water that would bar the passage of the Chagres and form a footing for protective operations.

It was not long after this fill was made before the repairs to south dam were completed and the north diversion dam rebuilt to its full height. New drainage pipes were inserted under the levee. The Chagres was now permanently diverted into the spillway channel where man's control over her became more and more complete. Now her waters are sent to the sea when man wills and in such quantities as man elects.

This diversion eliminated all further trouble with the Chagres in so far as the construction of the earthen parts of Gatun Dam were concerned.

The first operation in building the earthen parts of the dam was to drive a pile trestle along the 30-foot contours on each slope of the dam and then to dump rock from cars run out on the trestles. This operation was continued until ridges were formed entirely across that part of the valley to be occupied by the dam. When this ridge reached the height of the trestle the dumping track was thrown onto the fill and the rock slopes shown on the section made by dumping directly from cars.

Before, and while this was being done, dredges were at work cleaning out that portion of the beds of the streams that would be covered by the dam. It was feared that there were layers of old logs in the beds of the streams that might make a leakage plane under the dam. All the stumps on the dam site were blasted and removed and steam-shovels were set to work removing the surface of the ground to a depth of two or three feet between the rock ridges or toes. The object of this last operation was to remove all roots and vegetable matter that might ultimately form a porous layer. When these operations were finished a cut 20 feet wide and about 10 feet deep along the axis of the dam was made by a steam-shovel, and the remaining surface for 400 feet on either side of the axis was either plowed or picked so that a good bond or watertight connection would be made between the material placed in building the central part of the dam and the material on which it rested. The central or watertight part of the dam—that part between the rock toes—was composed of a mixture of sand and clay and was pumped into place by suction dredges.

The rock fill on the south side of the east half of the dam was to be carried to an elevation of 60 feet above sea-level before placing any of the hydraulic fill, except in the stream beds. It was with difficulty that this stone fill was brought to the required height, especially where it crossed the bed of the old French canal.

Five quite serious slides were encountered at this place, the effect of which was to carry the rock toward the axis of the dam. See Figure 13. This resulted in a decision to construct a bench at an elevation of 25 feet above sea. With the increased width of base thus provided it was found practicable to carry the fill to proper elevation. This operation accounts for the unusual shape of the rock fill shown in section on Diagram 4. After this toe or ridge was brought to full height on the south face and that on the north face to 30 feet above sea-level, dredges were started pumping material into the dam between these ridges.

About this time a slide occurred in the Necaxa

Dam, Mexico, which was then under construction. The reports indicated that the slide was caused by fluid pressure in the center of the dam, the component material not having consolidated. This pressure shoved out the toes or ridges impounding the soft material. In consequence of this information it was decided to increase the section of the dry fill forming the toes of the Gatun Dam so that it could better resist pressure exerted by semi-fluid material in the center of the dam. Diagram 4 shows the relative amount of dry fill and hydraulic fill, determined by borings made when the dam was nearing completion.

After the original toes were constructed the rate of placing wet and dry fill thereafter depended upon the relative capacities of the dredges and the railroad transportation equipment available for dam building.

The dry fill for this dam was obtained from several sources: in the beginning a large portion of the excavated material from the site of the Gatun Locks and from the cut at Mindi was so utilized; in addition practically all of the material removed in excavating the spillway channel was placed in the dam. For one entire year practically all of the dry fill placed in Gatun Dam was waste material hauled from the Culebra Cut. After the old line of the Panama Railroad was flooded by the rising waters of Gatun Lake, a quarry was opened on the west end of the dam and material excavated solely for the dam. Rail connection with the dam was then difficult and, furthermore, the single-tracked relocated line of the Panama Railroad could not well stand an extensive addition to its traffic.

As the dam increased in height the dry fill overlapped the wet fill and compressed it, often sliding out into it. An effort was made to keep the dry fill 10 to 15 feet higher than the wet fill. It was thought that the weight of this material with the added weight of trains running over it would either compact the underlying hydraulic material or force it to the center, where that part of it that would not consolidate could be taken off through the drain pipes.

The pipe-line suction dredges utilized in building the central portion of the dam pumped seven or eight times as much water as they did solid material. In building a dam in this manner it is necessary to make provision for carrying off the surplus water after it has deposited its burden of solid matter; otherwise, the pond or lake between the rock ridges would fill and overflow.

In this dam the surplus water was drained off through 20-inch pipes, entering the dam generally from the north face and extending to that edge of the pond farthest removed from the lake face of the dam. These pipes entered the dam in trenches dug into or down to the rock. An elbow was placed on the end of the pipe and vertical lengths of $2\frac{1}{2}$ feet were added as the dam increased in height. A drainage system of this type once established could be utilized for the entire construction. The facility of adding short lengths to the vertical part of the pipe gave the builders complete control as to depth of the pond into which the dredges were discharging. If the character of the material being delivered was such as to make it desirable to retain practically all of it in the dam, the water in the pond would be increased in depth. If the material contained too large a proportion of unctuous clay, the pond would be lowered and that part of the material wasted which would not consolidate quickly.

The material available for the construction of the Gatun Dam contained too large a proportion of clay for quick or proper consolidation; consequently a large proportion of it was wasted through the drain pipes. This not only increased the cost but added many construction difficulties.

A remarkable incident occurred in connection with the drain pipes during the construction of the dam. These pipes were 20 inches in diameter; the entrance to them was protected by a screen for the purpose of keeping out any floating chunks or pieces of timber. It was necessary occasionally to clean these screens. On one occasion, when the hydraulic fill had reached an elevation of 30 feet above sea-level, three Jamaica negroes were cleaning the screens and in doing so had removed the screen from one of the pipes. One of the Jamaicans accidentally fell into the pipe, head first; the other two caught him and tried to pull him out, but the force of water under a 30-foot head was too much and they let him go. This pipe extended down vertically for about 30 feet, then turned at a right angle and extended about 300 feet horizontally to its outlet at sea-level. These two Jamaicans, as soon as they had released their hold on the man in the pipe, ran at full speed to the outlet of the pipe and, on reaching there, found their companion out of the water and uninjured, except for one of his ears which had been torn slightly in making the turn in the 20-inch pipe.

After the Chagres River was under control no unexpected circumstances happened in connection with the construction of the Gatun Dam until its full height was approximately reached, except the slides into the old French canal during the construction of the rock toe on the south face. There were of course many local slides toward the center of the dam involving relatively small areas. These slides were due to the inability of the hydraulic fill to support the overlapping dry fill. On many occasions these slides carried loaded cars with them into the wet fill. The disarrangement of tracks on account of local settlement and slides was almost a daily occurrence. The consolidation of the wet fill in this manner was considered a necessary step in the dam construction and the risks taken and troubles encountered were considered a part of the operations incident to the proper consolidation of the dam.

A foreman on the job, however, after his tracks and cars had slid into the hydraulic fill, forcing him to build new tracks and send for a wrecker to recover his cars, could not appreciate the statement that such slides were a necessary part of the dam construction and made the dam more stable. See Figures 14, 15 and 16.

UNEXPECTED SLIDES IN THE DAM

When that part of the dam between the locks and Spillway Hill was nearing its final height a settlement of from 10 to 15 feet occurred at the crest of the dam for a length of about 1,000 feet, the slopes on both sides moving out and lifting slightly. This was the first slide from the center of the dam toward its edges.

Observation points had previously been established on the various contours of both faces of the dam for the purpose of measuring settlement or any lateral motion. During this slide a lat-

FIG. 14.—SLIDES INTO WET FILL, GATUN DAM.

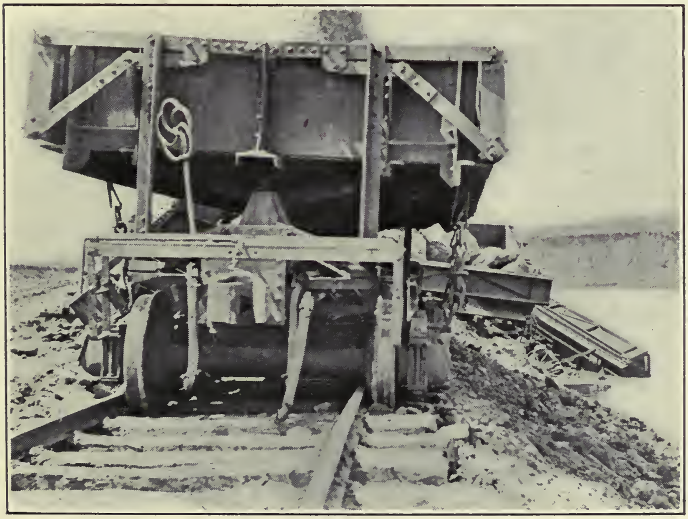


FIG. 15.—SLIDES INTO HYDRAULIC FILL, GATUN DAM.

eral movement of over 15 feet occurred in the center of the moving mass; on the 60-foot contour north face, accompanied an uplift of about 1¼ feet. This lateral movement extended beyond the 30-foot contour. The north slope of the dam was being built at that time with a slope of 1 vertical to 16 horizontal from the 30-foot to the 60-foot contour, and with a slope of 1 vertical to 8 horizontal from the 60 to the 90-foot contours. The extent of the movement in this case caused those in charge of the work to tentatively conclude that it had its origin in, or at least involved, the material underlying the dam; this opinion was strengthened by the fact that there was a lateral movement of more than 5 feet in a portion of the south face of the dam under which there was no hydraulic fill. This thought was still further supported by the fact that a pile bridge, entirely outside the dam crossing the spillway cut, was squeezed until its length was decreased by 7 inches.

Thorough investigations were therefore started for the purpose of ascertaining the cause of this extensive slide. A line of borings was made through the part of the dam involved in this slide. The holes were cased throughout with 2½-inch pipe and extended down to the underlying rock. Drive samples of the material encountered in these holes were taken at 5-foot intervals, both in the dam and under it. Tests were made, at same intervals, of the compactness or bearing capacity of the material throughout the entire depth of hole. An open-ended pipe, hanging free in the casing, was driven into the material, using a 100-foot weight falling 3 feet, and a record kept of the number of blows necessary to drive the pipe a certain distance into the underlying material. The dirt forced up in the pipe was examined. All samples so obtained were labeled and stored. In this way the character and bearing capacity of the material composing the various layers of the dam could be compared with the layers of material underlying the dam and a conclusion reached as to the material most likely to move under pressure. A compilation of these tests showed that the material under the dam was softer than that which composed the dam after the latter had had a reasonable time to consolidate. This corroborated further the thought that this extensive slide had its origin in the foundation material of the Gatun Dam.

In the construction of dams on soft foundations, slides occurring about the time the loads are at a maximum are of unusual value. They show the loads under which slides can be expected under similar circumstances. A widening of the base thereafter gives a factor of safety, concerning the value of which one can at least form an opinion. If an engineer knows just when a structure reaches an unstable state, he knows that all additional strengthening makes for safety.

After this slide steps were immediately taken to flatten the slope on the north face of the dam and make it uniform from top to bottom.

The swamp area north of this part of the dam was raised so as to counterbalance, by additional weight, any pressure that might be transmitted to it, and the slope on the south side toward the spillway cut was flattened.

These changes in the slopes of the dam made them conform to the section shown in Diagram 4. No further sliding occurred in this part of the Gatun Dam.

In that portion of the west half of the dam that overlapped some low ridges jutting from the main hills out into the dam, a steeper slope was adopted—a slope of 1 vertical to 5 horizontal. See Diagram 6. It was thought that the underlying material would certainly carry safely the load and that the hydraulic fill itself could be built to that slope if properly supported at the toes. This, however, did not prove to be the case, and a slide did occur on the south face of this portion of the dam, which slide was accompanied by a bulging-up of the lake bottom south of the dam, which indicated movement for a considerable distance in undisturbed material. It was concluded that this slide originated in the clay covering of the hillside and was brought about by the increased load placed upon it. The material in the flat country abutting the foot of this hill was very soft and, consequently, had very little lateral resistance. As a result of this slide the slope in this part of the dam was changed from 1 vertical on 5 horizontal to 1 vertical on 8 horizontal and, in addition, the ground south of the dam on that face was raised by means of suction dredges so as to counterbalance the pressure from the hillside above. The slope previously adopted for the north face of this part of the dam was the same as that on the south face and, after the slide on the south face, it was determined to flatten the slope on the north face also.

This work, however, had only been started when, on August 28, 1912, a settlement of about 20 feet occurred along the crest of the dam for a length of about 800 feet. This settlement was accompanied by a lateral movement from the center out, that affected the entire face of the dam, bulging up the material north of it. There was no movement on the corresponding part of the south face, the slope of which had been previously flattened. The dam at this time was nearing its full height. A lateral movement of about 20 feet on the 30-foot contour was recorded.

In the earlier period of construction on this

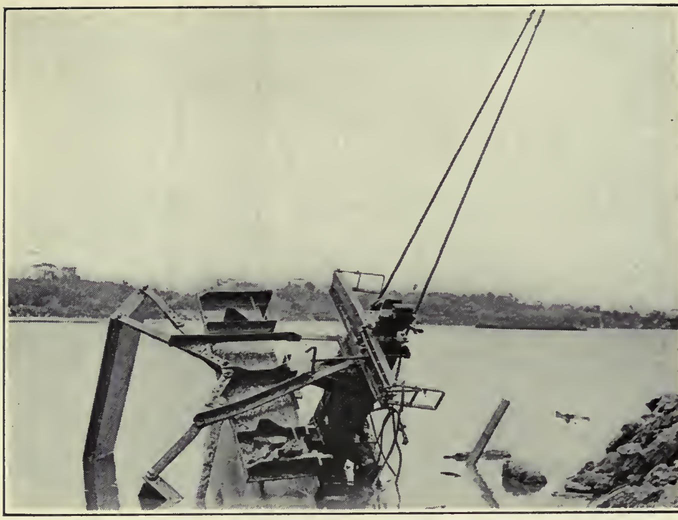


Fig. 16.—Removing Cars From Wet Fill, Gatun Dam.

Fig. 17.—Spillway Channel During Construction, Gatun, Canal Zone.

portion of the dam, all the dredges had been concentrated in the west half of the dam in order to bring it above any expected flood during a rainy season that was approaching. The dry fill in this part was consequently relatively less in amount than in other parts of the dam. After investigations, similar to those made on the eastern half of the dam, it was concluded that the most probable cause of this slide was the pressure due to the soft material in the center of the dam. The dry fill was immediately widened and other steps taken to flatten the slope on this face from 1 vertical on 5 horizontal to 1 vertical on 8 horizontal. After this was accomplished the dam was successfully brought to its full height. A gradual settlement, however, of the dam along its axis continued.

After the completion of the dam similar explorations to those described above were carried out along its axis for its entire length. The records of these tests show a gradual consolidation both in the hydraulic fill and in the material underlying the dam, the entire mass during this process continually becoming more compact and more stable.

These explorations also showed that the original surface of the ground under the dam was in places from 15 to 20 feet lower than its original position, which indicated a marked compacting and consequent improvement in its bearing capacity.

Practically all the difficulties connected with a hydraulically filled dam occur during the period of construction when the material is largely in solution and before it has had time to drain and consolidate.

If such a dam can be built—and it can be if the slopes be made flat enough—its stability will gradually increase with time. It may be necessary to bring the crest to grade occasionally as the material in and under the dam consolidates and contracts.

The Gatun Lake has been filled to its full height, placing against the dam its greatest pressure without the slightest indication of any weakness. The physical condition of the dam will continue to improve with time and its factor of safety continually increase.

There is probably no type of dam that could stand any unusual disturbance, such as earthquake tremors, as well as an earth dam with such flat slopes as those employed on the Gatun Dam.

In building this dam the dredges, with two relay pumps, forced material through two miles of pipe, lifting such material one hundred feet. The necessity of this was due to the fact that the material in the east side of the valley had a larger proportion of sand than that in the west and, consequently, would drain and consolidate more quickly.

This method of making a hydraulic fill was in many respects unusual, concerning which the details are too technical for a general description such as this.

In general, the electrically driven relay pumps were so placed as to distribute the work between themselves and the pump on the dredge. The relays were placed essentially in the delivery line. A pipe-line dredge requires next to it a certain length of flexible pipe line in order that she may swing freely in making her cut. This part of the line is expensive on account of the rubber sleeves jointing the sections of pipes.

In this work trestles were driven in the water as a support for a fixed line for as great a portion of the distance from the dredge to the shore, as possible, thus reducing to a minimum the expensive floating pipe line. The point of discharge of the material into the dam was changed from time to time so as to insure a proper mixture.

CHAPTER XV

GATUN LAKE

SPILLWAY DAM AND CHANNEL

While the construction of the channel through Spillway Hill was one of the first operations, the construction of the spillway dam was, of necessity, the last; because its construction would complete the barrier across the Chagres Valley and cause the creation of Gatun Lake. It was not safe to allow this lake to exceed a certain height before the earthen parts of the Gatun Dam had reached their final heights, nor could it be allowed to rise high enough to overflow the miter-sills of the Gatun Locks before the gates and appliances were erected at the south end of the locks. Neither could the lake be allowed to fill until the relocated Panama Railroad had been practically finished and the work in Culebra Cut so advanced that it could be completed with dredges.

In making the cut for the channel through Spillway Hill it was necessary to make it big enough to permit the floods of the Chagres to pass without the river rising high enough to interfere with construction work on any part of the Canal. The bottom of this cut was 10 feet above sea-level and its width 300 feet. This contracted outlet caused a material increase in the flood height of the Chagres. The earthen parts of the dam were kept well above such possible flood heights. This contracted outlet caused the river to overflow the Panama Railroad just south of Gatun, and necessitated making a new and partially raised connection between Gatun and Lion Hill station. To have dug the spillway channel deeper and thus give the Chagres a freer outlet would have increased the height of the spillway dam and increased the water difficulties during its construction.

There was nothing unusual in excavating this channel, except the interference of the Chagres River which, on one occasion, asserted her right to go where she pleased, and took possession of this incompleted channel for a time, sweeping out all appliances and materials that could not be removed. It was on this occasion that the work at Mindi was flooded and the delivery of sand and stone to Gatun seriously interfered with by strong currents developed in the old French canal.

The currents developed in the old French canal during this flood called attention to the fact that no provision had been made in the adopted project to prevent water wasted through the spillway finding its way into the Canal when completed and interfering with navigation.

The result was a decision to construct a levee crossing the bed of the old Chagres, extending from Spillway Hill to Mindi Hills, so located as to force all water wasted over the spillway dam from Gatun Lake down the old Chagres River channel to the sea at Fort Lorenzo. This work involved about two miles of levee and a dam across the old bed of the Chagres. The excavation of spillway channel involved moving 1,544,202 cubic yards of material, at a cost of seventy-one cents per cubic yard, including plant and overhead charges.

All work done in this channel, after the Chagres River was once diverted into it, would, of course, have to be done under many difficulties; consequently, all concrete work that it was practicable to do was completed before this diversion.

The bottom and sides of this channel were argillaceous sandstone, a soft rock that could be eroded and which would decompose in the air. It was therefore necessary to cover all exposed rock surfaces with concrete—not only for its protection but to prevent seepage. Above the site of the spillway dam, rock was uncovered to a depth of 15 feet below sea-level and entirely covered with concrete and back-filled with clay to prevent seepage.

The bottom of the spillway channel was lined with concrete throughout. This concrete was 12 feet thick just below the dam site. Concrete retaining walls were built along the sides of the channel, and the foundation of the spillway dam placed. In addition, preparations were made for resuming work on the dam when operations on the other parts of the Canal had advanced to such a state that the formation of the lake would not interfere with their completion.

Stubs of small piers were built 20 feet apart along the upper face of the dam. These piers were made of such a height that their upper surface would be out of water during the dry season and would thus afford a starting-point for future work. Grooves were made in the face of these stubs. After all this had been accomplished the Chagres River was turned through the spillway channel and was allowed to there run undisturbed until work on the dam was resumed, which was done when the formation of the lake would not interfere with the other work on the Canal.

When the time arrived to complete the dam, the first operation was to extend, in the dry season, the pier stubs referred to above to a height of 35 feet, continuing the grooves to the top; then, on these piers, erect a railroad bridge.

The plan of construction contemplated first completing about two-thirds of the dam to a height of 50 feet above sea-level, and to provide in this part three openings each 8 by 18 feet, through which the flow of the Chagres River could pass for ten months of the year. Valves with operating machinery were provided for opening and closing the sluices, thus enabling the construction forces to regulate, for the greater portion of the year, the elevation of Gatun Lake; when this part was completed, allow the water to pass through the sluices and complete the remainder of the dam to the same height. All this work was to be accomplished during the dry season. Practically all of the concrete used in building the dam to the height of 50 feet above sea was placed from cars on the railroad bridge described above, by dumping it directly in place or into chutes that carried it into place.

Figures 17 and 18 show the spillway channel before the water entered; show it during construction, and show the use of the openings in passing the waters of the Chagres. The grooves in the small piers referred to above enabled the builders to easily shut the flow of the Chagres out of any part of the dam by dropping watertight curtains down these grooves. The central part of the dam was finished to a height of fifty feet above sea; the lake level was controlled by the valves in the openings through the dam until

Fig. 18.—Gatun Spillway Dam Under Construction.

Fig. 19.—Flood Water Passing Over Incompleted Spillway Dam at Gatun.

the rainiest part of the year came. During this time it was expected that the Chagres River would rise, in spite of the openings in the dam, and overflow the incompleted part of the dam, for which flow provision was made. Figure 19 shows the water flowing over the dam during this period. As soon as the rains had stopped sufficiently to allow the openings through the dam to lower the lake below +50 the work of completing the dam was resumed, all water passing under the dam through the openings. In order to build the piers and install the Stoney gates composing the regulating works, a heavy trestle was constructed on the incompleted dam, as shown in Figure 18, from which trestle the piers were completed and the spillway gates placed. These gates weighed 42 tons; were loaded on cars at the shop, run out on the trestle and placed in position by two wrecking cranes.

Running longitudinally through this dam is a watertight operating tunnel in which is placed all the operating machines that raise and lower the fourteen gates forming the crest of the dam. The operation of regulating works on the top of the spillway dam is one of the most spectacular sights connected with the entire Canal. While the operating machines are in the tunnel referred to above, they are operated from a switchboard in the power house.

In connection with the construction of the spillway dam a hydro-electric plant was built. This plant is operated with water from Gatun Lake which has a fall ordinarily of about 75 feet. It is expected to generate at this plant all of the power necessary to operate the locks, to light the Canal, to operate the Panama Railroad, and to do such other work as experience may indicate. There are three units 2,000 kilowatts now installed in the power house and provision is made for doubling this capacity of plant, if such additional power is ever needed, and if the water supply of Gatun Lake is sufficient to care for the increased number of lockages as commerce grows and provide water for the extra power units.

GATUN LAKE

On June 27, 1913, the temporary sluice-ways through the spillway dam were closed and the lake, which had been held in the neighborhood of 48 feet above sea-level for some months, was allowed to rise to its normal height. This stage was reached in December, 1913. The rising lake was watched with interest by all. On the water-tightness of the lake basin depended the success of the entire project. While all practicable investigations had been made to determine this question in those parts of the rim of the lake where the distance through the hills was small, and while it was known that the general lake bottom was composed of impermeable material, yet those responsible for the work would naturally anxiously watch the rising waters in fear that there might somewhere be an exposed rock surface through which material leakage might go. Great satisfaction was therefore felt when the lake rose according to program.

The filling of this lake permanently submerged 164 square miles of territory, including the bed of the old Panama Railroad and many farms and villages, making a permanent change in the topography of the country.

After all property rights had been adjusted in this area it was, in many cases, necessary to forcibly remove the inhabitants. They could not appreciate, understand, or accept the proposed topographical changes that were being made in this section.

Many square miles of swamp were permanently flooded by the lake, and a large portion of this old swamp bottom, made up of submerged logs and decayed vegetation, with high grass growing therein, rose with the lake and gave the appearance of large bodies of land, or islands, in the lake. Acres of this old swamp bottom, with its green grass and small trees, would become detached and would be driven by the winds aimlessly across the waters. Deer were found on some of these floating islands.

Where the sailing channel through the lake crossed the area previously known as the "Black Swamp," this floating material completely blocked the channel. It was in some places fourteen feet thick, and the snags, sticks, and living vegetation were so completely matted as to be often immovable. The floating swamp bottom was evidently connected with parts that did not float. The only practicable way to rid the lake of these floating islands was to tow them to the spillway dam and let them be drawn over that dam and sent out to the ocean. It was an odd sight to see a little tug chugging along pushing acres of apparent land before her en route to the spillway dam. It was impossible for the tugs to move the obstruction found in the channel of the old "Black Swamp," and it was necessary to send a boat there with sufficient power to tear this floating mass in pieces in order that tugs might carry it away.

As the waters of the lake rose the more attractive orchids, that had grown high up on the big trees, where they could not be reached, became accessible from boats, and the lovers of flowers in and about Gatun spent their Sundays rowing through the forest and gathering orchids. The hornets and the bees, however resented this intrusion of man in the tree-tops and some of the orchids cost dearly.

We have often heard of "blazed trails" for land travel in new countries, but it is probable that on Gatun Lake trails were first blazed for regular boat travel.

The rim of the lake at two places was only a foot or so above lake level and it was necessary to increase the height of this rim at those places. One of these low saddles was on the Trinidad River and no work was attempted at this saddle until the lake was nearing its full height. The place was practically inaccessible by land.

After the creation of the lake the necessary plant for building a dam on this saddle could be transported to the site by water, provided a route could be located, cleaned out and blazed so that boats could safely follow it. It was no easy matter to find a particular place under such circumstances, and this saddle was located, after many efforts, by finally having some native Indians go overland to the place and build fires, smoke from which could be seen long distances. Each day in this search the boat would blaze the route that she came so as to guarantee a safe return. It was a queer sensation to travel in a boat through the tops of live trees in a wilderness. Of course the water soon killed the timber, and the aspect changed to one of dreariness.

For nearly a year the Gatun Lake was held at an elevation of about thirty feet above sea-level. This killed the trees in the low lands along the streams, the routes that would be followed by any boats should local commerce develop on the lake. During the time that the water stood at this elevation all of the dead timber rotted. With the lake at its full height the water will be free of obstructions for navigable depths along such routes.

There were many hills in the lake area that were not covered by water. These became islands as the lake rose, and much of the game that inhabited the lake area congregated on these islands. This gave the huntsmen on the Isthmus an advantage in securing game that the thick jungle had denied them before, and their Sundays were spent in going from island to island.

The game in this section consists of deer, tapir, and several species of the cat family. The deer and tapir, being especially good swimmers, would take to the water when pursued by dogs and a large portion of them finally worked their way to the surrounding high lands. A tapir sometimes weighs as much as 800 pounds and it was most exciting to watch a pack of hounds follow him in the water. The dogs could not hurt him—his skin was too thick to allow that—and when

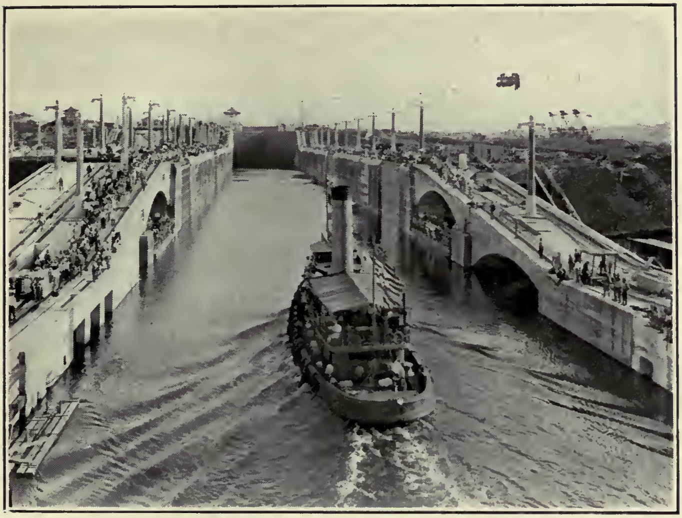


Fig. 20.—Tug *Gatun*; the First Boat to Pass from Sea-Level to Summit Level of the Panama Canal. September 26, 1913.

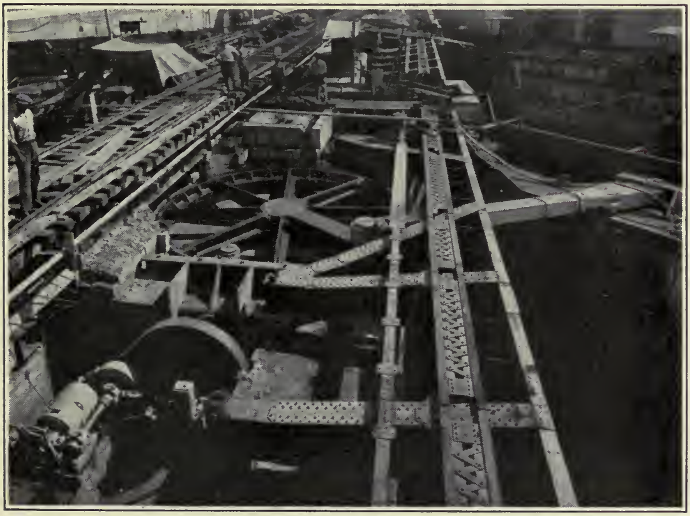


Fig. 21.—Gatun Upper Locks, Miter Gate-Moving Machine; Structural Steel Girders for Towing-Locomotive Track Supports in Foreground. June, 1912.

they bothered him too much by crawling on his back three or four at a time, he would submerge himself leaving them swimming in the water. As soon as he emerged some distance away the hounds would start for him again, and this process would be continued until some hunter killed him.

The locks at Gatun being ready for the passage of ships, the dam having been finished and the lake having reached the elevation of about sixty-four feet above sea, it was decided on September 26, 1913, to pass the tug *Gatun* from the sea-level section of the Canal to the summit level. Since all the locks are similar in structure this test was a test for all locks. A test of the locks meant a test of the Canal. No formal notice was given of this trial, but the news spread over the Isthmus and thousands of people gathered to see this first trial. It was a day of pride for all, the enthusiasm surrounding which was never repeated at the subsequent tests.

This trip (see Figure 20) was an ocular demonstration to those who had labored so long that the route across the Isthmus was practically open and that the appliances for the passage of ships between the various levels of Canal would work as planned. The steam-shovel excavation in the Culebra Cut was nearing completion and the locks on the Pacific side were about ready for operation and, in consequence, all could see a successful termination to their long labors.

The construction work so far described was in the Atlantic Division.

In June, 1908, the construction work on the entire Canal was divided into three grand construction divisions: the Atlantic, Central, and Pacific.

The Atlantic Division extended from deep water in sea, near Colon, to Gatun, and included the construction of the Gatun locks and dam.

The Central Division comprised all the work between Gatun and Pedro Miguel.

The Pacific Division comprised all the locks and dams on the Pacific side, together with the channel from Miraflores Locks to the Pacific.

CHAPTER XVI

CONSTRUCTION FROM GATUN TO PEDRO MIGUEL—CULEBRA CUT

The work to be described in this chapter was comprised in the Central Division, which extended from the Gatun Dam to the Pedro Miguel Lock, a total distance along the axis of the Canal of about thirty and a half miles. It embraced the former Culebra and Chagres divisions.

While the work in the Central Division has often been referred to as a "transportation job," yet that appellation does not describe it. While efficient transportation in some form or other underlies the proper solution of nearly all construction problems, it is only one of the elements of success.

A larger portion of the plant needed for the construction of this part of the Canal had been purchased and tried out than for any other part of the work. During the year 1906 new pieces of plant were continuously being placed upon the work and tried out. The useful excavation accomplished during such try-out increased from month to month. In July, 1906, 159,789 cubic yards of material were removed from the Culebra Division, whereas in March, 1907, 769,693 cubic yards of material were removed.

At the beginning of this—the construction period—there had been delivered, erected, and accepted, on the Central Division, 52 steam-shovels, 132 locomotives, 1,245 flat-cars, and 32 dump-cars, with the necessary accessories for work of excavation, such as spreaders, plows, unloaders, etc. One hundred and seven miles of railroad track had been built in connection with the operations of this division. In the bottom of the Canal from the summit level near Culebra to the material yard to the north there were four running tracks, and three such tracks extended from the summit to the material yard for the south-bound traffic.

At the beginning of the fiscal year 1907 there were only 20 shovels ready for work and only 66 miles of track in operation.

The problem given during the construction period in the Culebra Cut was to take a plant largely erected, partially tried out, develop it and do the dry excavation work of the Canal with it as expeditiously and economically as possible.

At the beginning of this period the machine was running—though roughly—as great machines do run at the beginning of great undertakings, before the parts have reached their proper bearing.

One of the first problems to receive attention in connection with digging the cut through the

Continental Divide at Culebra was the question of diversion of flood-waters of small streams that crossed the line of the cut or would drain into it.

The bottom of Culebra Cut when finished was to be 40 feet above sea-level. The low-water surface of the Chagres River at the point where the Canal leaves the Chagres Valley proper is 44 feet above sea-level. The extreme flood-level of the Chagres River was 79.9 feet above sea-level.

From the foregoing facts it was evident from the beginning that the work of excavating the Culebra Cut to its full depth involved, during the rainy season, pumping a large amount of water from the excavation which, in turn, meant leaving a barrier where the channel left the Chagres Valley, that would keep the waters of the Chagres out of the cut. This barrier was afterwards known as the Gamboa dike.

The above condition made it essential that the watershed tributary to the cut should be as small as possible. Diversion channels were therefore planned so as to intercept as large a portion of the drainage as possible, divert it from the cut and send it to the Chagres River.

While the diversion of this water during construction was an essential, its permanent diversion was also important, because it would facilitate maintenance after the completion of the Canal. Streams emptying into the Canal, when completed, would tend to block the channel with deposit and might make currents, where the navigation was already difficult.

Permanent diversion channels were therefore decided upon for both sides of the cut; that on the west side is known as the Comacho diversion, and that on the east as the Obispo diversion.

The Comacho diversion was opened up on the lines originally planned by the French. In doing this a new channel was cut through White House Yard; a dam was built across Obispo River, and the old French tunnel at Bas Obispo was cleaned out. This work, in connection with that already done by the French, created a diversion channel from the Continental Divide south of Culebra Hill to the Chagres River near Matachin.

For taking care of the water on the east side of the cut, including the Obispo River and other streams, surveys were made and a channel located extending from Gold Hill to the Chagres River, running practically parallel to the Canal and having its outlet in the Chagres River near Gamboa. This diversion drains 10 square miles of territory, and was quite expensive to build. Its construction involved excavating 1,132,000 cubic yards of material, two-fifths of which was rock, driving sheet piling along 896 feet of dike, building 1½ miles of embankment containing 1,260,000 cubic yards of material.

This work would ordinarily be considered quite an undertaking, but the magnitude of the work in the Culebra Cut was such that tasks such as the Obispo diversion were looked upon as merely side issues.

The French did not contemplate the permanent diversion of the water on the east side of this part of the Canal, but expected to confine their operations to diverting such water during the construction period only.

In accomplishing this they proposed to gather the water between Gold Hill and Empire into a channel and carry the same by an aqueduct across the Canal and into the west diversion channel. From Empire north on the east side it was proposed to start another diversion channel and cross the Canal again with this water, delivering it, as before, into the west diversion farther north. Experience, however, has shown the advantage of solving the problem permanently in the beginning.

Labor Difficulties

About the only labor difficulty that threatened to interfere with the prosecution of the work, happened about the beginning of the construction period.

During the latter part of 1906, the President of the United States visited the work. His visit was in the middle of the rainy season during which time the Chagres reached an unprecedentedly high stage, and the difficulties and hardships connected with the work were many. It is said that the President, in his talks, praised the men for their patriotism and enlarged upon their hardships to such an extent that immediately after his visit the steam-shovel men and cranemen asked for a raise in wages. The former were then receiving $210.00 per month, and the latter $185.00 per month. The steam-shovel engineers asked for an increase to $300.00 per month, and the cranemen to $250.00. It was recognized, of course, that if unusually high wages were paid the men in any class of work on the Canal that other classes would claim, and would have a right to, a correspondingly high wage.

The application of the steam-shovel engineers and cranemen was referred to the authorities in Washington and, instead of granting the increase asked for, longevity pay was authorized for all employees in the mechanical trades and in the transportation Department. This decision authorized an increase of 5 per cent. per annum in the pay at the end of the first year's service and an additional increase of 3 per cent. at the end of each succeeding year of service. This decision was unsatisfactory to the steam-shovel men and a large number of them stopped work in May,

1907. The number of steam-shovels actually working was reduced to thirteen.

The Government would not yield or reconsider the case, but gave the men who had stopped work the privilege of returning. Some of them did this; others were hired in the States, and many deserving subordinates were promoted, with the result that by the first of July, 1907, the work in the cut was on a normal basis and the full number of steam-shovels were at work. There was no attempt on the part of the men to injure or damage anything whatever: it was merely a peaceful strike.

CONSTRUCTION EFFICIENCY

The best measure of construction efficiency in excavation like the Culebra Cut is the cost per cubic yard of such excavation. Efficiency finds expression in the final cost figure.

With a total annual output of about 18,000,000 cubic yards, the saving of one cent a cubic yard of material meant a saving of $180,000 per year to the United States in the excavation.

The table on the following page gives the various items of excavation cost for the years 1908-1913, inclusive.

In comparing cost of work done in connection with building the Panama Canal with work in the

Class of Work	1908	1909	1910	1911	1912	1913
Loading, steam-shovels.	$0.1150	$0.1001	$0.0888	$0.0717	$0.0681	$0.0863
Loading, hand..........	......	.3993	.3442	.2567	.3056	.3150
Drilling and blasting...	.1413	.1149	.1190	.1048	.1157	.1069
Transportation........	.1854	.1452	.1522	.1414	.1331	.1740
Dumps................	.1344	.0911	.0657	.0541	.0479	.0645
Tracks................	.1190	.0838	.1001	.1014	.0885	.0966
Division office and supervision...........	.0163	.0114	.0150	.0120	.0142	.0128
General surveys.......	.0008	.0001	.0003	.0002	......	......
Clearing site..........	.0004	.0048	.0046	.00005	.0001	......
Division structures....	.0002	.0012	.0013	.0005	.0003	.0003
Drainage and sumps...	......	......	.0052	.0038	.0041	.0091
Total division cost...	.7128	.5517	.5416	.4880	.4707	.5505
General expense and administrative expense.	.1882	.1049	.0646	.0457	.0361	.0355
Plant arbitrary........	.1300	.1300	.1300	.1000	.0395	.0040
Total..............	1.0310	.7866	.7362	.6337	.5463	.5900

United States, it should be remembered that skilled labor was paid from 40 to 70 per cent. more on the Canal than in the States. Eight hours constituted a day's work, while in the greater number of private enterprises the day consists of ten hours. Fuel cost was materially greater than in the States, as well as machinery and supplies of all classes.

There is nothing that facilitates the study of economy in the performance of work so much as a well-devised system of cost-keeping. In a great undertaking such as the one under discussion there were many construction units doing the same class of work which made a direct comparison between the various elements of cost practicable. If one superintendent had a less cost than the others on any particular item of work, a study was made of it and the reason determined. If the lower cost were due to any particular system or contrivance of that superintendent, the other superintendents were expected to profit by it. It is easily seen how strong the emulation became between the various construction units, and how keenly they studied and worked to reduce costs.

The higher official devoted his time to the system and to investigations that led to the solution of the general problems.

With the plant furnished and the dumps selected, the problem as first presented was to so plan the general operations, such as drilling, blasting, operation of shovels, laying of tracks and hauling material, that no element of the work would seriously interfere with any other element, or, rather, that the interference would be limited as much as practicable. This required most careful study. With all the drills, tracks, shovels, etc., located daily on a map, an accurate estimate could be made of the time when shovel number so-and-so would finish her cut and must have a new position; or, when track so-and-so must be moved so that the drilling and blasting can proceed uninterruptedly; or, how best to effect a change in the elevation of the entire system of running tracks as the cut was deepened, etc.

The first of these general studies resulted in abandoning the idea of general yards to which cars were brought as soon as loaded by the shovel, and in which trains were made up and then run to the dumps.

It was found that by running trains direct from the shovels to the dumps the same railroad equipment would haul more material, which meant a reduction in cost, either through lessening the number of trains or increasing the number of shovels.

The next question to receive general consideration was the method of blasting. The standard method of firing holes by blasting batteries of the usual magneto-electric type was being followed. This method, under the climatic conditions on the Isthmus, resulted in a large number of misfire holes, entailing both danger and expense in removing unexploded dynamite.

The result of the studies and investigations led to the decision to install, for the entire length of the cut, a continuous electric firing-line connected with the regular lighting station at Empire. To this line were connected blasting spurs, on the end of which were installed transformers, switchboards, etc. Fuses were thereafter wired in parallel. One of the greatest advantages resulting from this method of firing blasts was that a larger number of holes could be fired at one time, and the various holes exploded at the same instant, thus increasing the disruptive effect of the dynamite.

The many minds in the various districts were continually studying ways of reducing costs under each of the subheads shown on cost sheet. These involved the spacing of drill holes, their depth; explosives best suited to the particular material, etc.

The effect of the concentrated and intelligent study of the men in authority in the Central Division, from the division engineer to the foreman, is read best under the heading of the total division cost in the table on page 270. This cost was sixteen cents less per cubic yard in 1909 than in 1908. About 18,400,000 cubic yards of material was excavated in 1909. A saving of 16 cents a yard on this amount was $2,944,000.

A further reduction of one cent a yard was made in the year 1910; a still further reduction of five cents a yard was made in 1911, and another of 1.8 cents in 1912. In 1913 the cost was increased; the work was nearing completion; the output was reduced, and the grades over which the trains passed were heavier.

The continued efficiency of this organization enabled those in authority to complete the excavation within the estimate, notwithstanding the large additions caused by slides.

Sick leave or injury leave was charged to the particular work on which a man was employed and, consequently, all superintendents labored to reduce accidents and preserve health, etc.

There were about 23,000,000 pounds of high explosives used in breaking up the rock in the Central Division, and only eight men were killed by such explosives, which speaks volumes for the care and system that those in charge exercised in the prosecution of the work.

The work was divided into districts, but all those features that were common to all the districts were handled by one head. In this category were the water service, the compressed air service, the delivery of high explosives into the magazines, etc.

There was no work on the Canal that required such a comprehensive knowledge of detail as that in the Central Division, if a systematic effort were to be made to reduce cost.

Such questions as the efficiency of shovels, measured by the number of cubic yards of material moved per hour while under steam; the efficiency of an entire working unit as measured by the percentage of time that the shovels actually operated, were studied; in fact these studies extended to the performance of every machine and to the average cost of its repair and maintenance.

The striving for efficiency of man and machine on the Panama Canal work led to many improvements in appliances that had hitherto been considered standard. No job before this had subjected steam-shovels, cars, unloaders, spreaders, etc., to such exhaustive tests.

It is very difficult to write a description of the work in the cut. The operation of trains over 200 miles of track is nothing unusual. But if those tracks are never permanently located it may become unusual. With the ever-shifting scene of drilling, blasting, cutting in shovels, and hauling away material, one can hardly imagine the track-laying and changing essential to economical work under such circumstances. Maintaining 200 miles of loading and running tracks on this job involved, during each of the busiest years, removing about 150 miles of old track and relaying about 225 miles of track. It also involved shifting about 1,400 miles of track, removing about 640 frogs and switches and laying 1,000, and all without seriously interfering with the movements of about 160 trains a day. Complicate this situation with slides that at times disrupt practically every track in the cut, and one begins to see the difficulties that confront the management that is charged with the completion of such a work in a specified time and for a specified amount.

On account of unexpected slides the estimate of yardage to be removed was increased by about

26,000,000 cubic yards of dry excavation. The additional excavation that has been and is to be done by dredging is, at the present writing, an unknown quantity.

As long as there was room for the full use of all the dry excavation plant available for the Culebra Cut, that plant could remove more material than any dredging plant available. As the work approached completion, however, the number of shovels were reduced as the number of available points of attack were reduced, until finally it was apparent that the work could best be completed by dredges.

Arrangements were made to allow Gatun Lake to rise to its full height, and it was calculated that by October, 1913, its height would be such that the barrier across the cut at Gamboa would become ineffective in keeping the water out of the cut. October 10, 1913, was therefore fixed as the date for blowing away this barrier and thus allow Gatun Lake to extend itself through the cut to Pedro Miguel Lock. Prior to blowing up this dyke the cut had been allowed to fill to within six feet of the level of the lake through the pipes that remained from the old pumping plant located at the north end of the cut.

While there was nothing unusual in the operation of blowing up the Gamboa dike, its destruction practically removed the last obstacle to the passage of ships across the continent, excepting the Cucaracha slide. An unsuccessful attempt was made on the same day to blast a passage through this slide, but it was not until two days later, October 12, 1913, that such a passage was made and a line of water established across the Isthmus.

The blast that made an opening through Gamboa dike was fired by President Woodrow Wilson, at Washington. The connections had been previously made through land telegraph and submarine cable lines. This blast made a hole 125 feet wide through the Gamboa dike, which opening was immediately widened by dredges. On the twentieth of October, dredges were enabled to proceed to the Cucaracha slide from the north end, and by the twenty-fourth from the south end.

SLIDES

Lieutenant-Colonel D. D. Gaillard, who had charge of the excavation across the Continental Divide practically throughout the construction period, divided the slides that interfered with the construction of the Canal into two classes—natural slides and breaks: a slide being simply the moving of a permeable top layer generally composed of earth or clay upon a smooth surface of some harder, more impermeable material, the joint between these two classes of material being often lubricated by surface water.

The movement of earth designated by Colonel Gaillard as a "break" resulted from removing the lateral support from the material alongside the cut by digging the cut itself. As the cut increased in depth the pressure of the high banks crushed the underlying layers of softer material; this broken-up underlying material was squeezed toward the center and was accompanied by an elevation or "humping" of the bottom of the Canal.

This type of slide has occurred more frequently than the true slide described above. Only one true slide has given serious difficulty in the construction of the Panama Canal—that is the Cucaracha slide: it is on the east bank of the Canal just south of Gold Hill: it involves about forty-seven acres. This slide commenced to give trouble during the French time and, in the fall of 1907, just after the beginning of the construction period proper, it again, in a striking manner, disputed the right of way through that part of the cut south of Gold Hill by moving entirely across such cut, which movement continued until the material rose up to a height of thirty feet along the west bank of the Canal. After the removal of the greater part of the material brought down from the cut in the fall of 1907 this slide gave no serious trouble. Of course it continued to come in gradually, but the material so brought in could be removed by the steam-shovels until the latter part of the year 1913, just prior to the time that the water was let into the Culebra Cut, when a final protest was made by this slide against the Panama Canal by extending itself again entirely across the cut. In this last movement it broke back practically to the crest of the Divide and a limit could be seen as to the amount of material that could be brought into the cut through the agency of this slide.

After the water was allowed to enter the cut, dredges attacked this slide from both north and south and have so far removed it at this writing that there is no material interference with navigation at this place.

The "breaks" at Culebra, both on the east and west side, however, continue to give trouble. The one on the east bank just north of Gold Hill moved considerably in October, 1914, and is still active. Since that time about 2,500,000 cubic yards of material have been dredged from this slide and, with a few interruptions, traffic has been maintained through it. The indications are that when this slide comes to rest there will be a slope of about 1 on 6.

There are no indications of serious slides elsewhere, except on the west side at Culebra, from

Zion Hill north. If this slide moves into the Canal again before the one on the other side is removed there may be some interference with navigation; but from present indications, when these two slides or breaks are cleaned up, those in authority

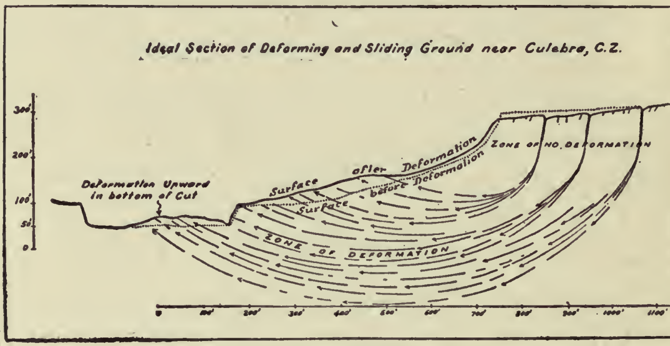


DIAGRAM 7

on the Canal feel that there will be no further serious trouble with slides, although past experience has indicated that the prophet concerning slides on the Panama Canal has often been mistaken.

The geologist of the Isthmian Canal Commission, in Diagram 7, shows his idea as to the way the material moves in one of these breaks.

CHAPTER XVII

SOUTH END OF CULEBRA CUT TO THE PACIFIC OCEAN

The water level of the lake created by the dam at Gatun extends through the Culebra Cut across the Continental Divide to the locks at Pedro Miguel on the Pacific slope.

It is eleven miles from Pedro Miguel to deep water in the Pacific. During the building, this part of the Canal was known as the Pacific Construction Division.

The work in that division included building duplicate locks, with necessary dams, at Pedro Miguel; a duplicate flight of two locks, with necessary dams, at Miraflores; a connecting channel between these locks through Miraflores Lake, and the channel from Miraflores Locks to deep water in the Pacific Ocean.

While the mean sea-level in the Atlantic and Pacific is essentially the same, the tidal variation on the Pacific is about 20 feet and on the Atlantic about 2 feet; consequently, at low tide on the Pacific it is necessary to lift boats about 9 feet more in placing them on the summit level than in lifting them from the Atlantic to this level. At high tide the lift from the Pacific to the lake would be about 9 feet less than from the Atlantic to the lake.

Besides the changes to meet these tidal variations, the plans of the locks on the two ends of the Canal are essentially the same.

As stated previously, all of the locks on the Atlantic side are together, forming one structure, whereas those on the Pacific side are separated.

The dams on the Pacific side have less head of water against them, are shorter, and their construction was not complicated with foundation difficulties such as those that existed at Gatun.

PEDRO MIGUEL DAMS

The dams at Pedro Miguel simply connect the locks with the sides of the cut. On the east side this connection was made by a core wall extending back into the bank; on the west side by means of a dam approximately 1,400 feet long, top elevation 105 feet above sea-level, top width 50 feet, side slope approximately 1 vertical on 8 horizontal. The maximum pressure to which this dam is subjected is that due to a head of 40 feet; the average head is from 25 to 30 feet. In its construction two rock ridges were formed near the foot of the slopes on both faces of the dam. These ridges were made of spoil from the lock excavation; between them clay was placed and well puddled by the use of water jets. The minimum thickness at the bottom of this clay core was 140 feet. The material underlying the dam is impervious, with the exception of a stratum of gravel in the old bed of the Rio Grande. Through this stratum a trench was cut and refilled with clay. This dam was tied to the hill against which it abuts and to the west wall of the lock chamber by concrete core walls.

PEDRO MIGUEL LOCKS

The Pedro Miguel Locks are founded on durable rock of ample strength to bear safely the maximum loads that have been brought upon it. There was no underlying water-bearing stratum. The floor of the locks was made about one foot thick in which weep holes, about 10 feet apart, were placed.

These locks are at the end of a long narrow cut in which there would normally be developed a current of about one foot per second when the lock was being filled, which condition would have caused surges in the cut during the operation of the Canal, surges that would have interfered with the handling of ships. In order to prevent this as far as practicable and also to provide as much sea room as possible for ships entering and leaving the locks, the Canal just north of the locks was widened to 600 feet. This width was gradually reduced to 300 feet at a point about two-thirds of a mile from the locks. The extra supply of water in this basin should prevent any serious surges in the cut when a lock is filled.

MIRAFLORES LOCKS AND DAMS

In the Rio Grande Valley, about one and three-quarter miles southeast of Pedro Miguel, the Miraflores Locks were erected. In order to provide the requisite depth of water on the lower sills of the Pedro Miguel Locks it was necessary to so build the Miraflores Locks and connect them with dams to the high land on both sides of the Rio Grande River as to form a basin for a lake extending from Miraflores Locks to Pedro Miguel Locks with its surface elevation about 55 feet above sea. The area of this lake is very small, being only about 1.6 square miles—so small, indeed, that the amount of water necessary for one lockage would cause a variation in the surface of the lake of .12 of a foot. Several small streams empty into this lake—the Cameron, the Caimito, the Pedro Miguel, and the Cocoli. While the flow of these streams is considerable in the rainy season, such flow is not enough in the dry season to more than provide for evaporation in the lake and leakage through the Miraflores Locks, the result being that the principal water supply of the lake comes through the summit level cut from Gatun Lake.

There are two dams at these locks, one to the east and one to the west. The west dam extends from the head of the lock wall to Cocoli Hill in a direction almost parallel to the axis of the lock. It has a length of approximately 2,300 feet with a top width of 40 feet at reference 70: side slopes approximately 1 vertical on 12 horizontal. The average head to which this dam is subjected is 30 feet; maximum about 45 feet. This dam crosses the Cocoli River bed, which necessitated diverting that stream into Miraflores Lake through a channel cut in the depression in the adjacent hills.

WEST MIRAFLORES DAM

This dam was constructed by building two rock fills, or ridges, near the foot of the slopes on each face in the manner similar to that followed at Pedro Miguel. The portion of the dam, however, between these rock ridges was filled by the hydraulic method with material obtained from below the locks. This dam contained 1,758,423 cubic yards of material; its crest is about fifteen feet above normal level of Miraflores Lake. The foundation on which it rests is compact and impervious, except where it crosses the bed of the Cocoli River. At this crossing a wide ditch was dug down to rock and afterwards filled with clay puddle. At other parts of the foundation, the usual practice of bonding the hydraulic fill of the dam with the natural surface of the ground, by ditches, was followed.

EAST DAM

The east dam connected the Miraflores Locks with the east side of Rio Grande Valley; it was built of concrete and founded on rock; was approximately 500 feet long, and was provided with regulating works similar to those in use in the spillway at Gatun Dam.

In determining the capacity of this spillway it was necessary to take into consideration a situation resulting from the destruction of one of the lock gates at Pedro Miguel Lock, allowing a free flow of water through such chamber into the lake between Pedro Miguel and Miraflores. This flow has been calculated to be approximately 100,000 second feet; and since the lock grounds at Miraflores would be flooded in twenty-five minutes if no spillway were provided, which would result in great damage, it was thought necessary to provide a discharge capacity of 100,000 second feet through the spillway and culverts of the lock:

the spillway itself permits a discharge of 75,000 second feet. Were it not for this possible contingency a very small spillway would have sufficed at Miraflores. It was not thought necessary in the design for this dam to provide for the remote contingency of having the gates broken in both of the locks at Pedro Miguel at the same time. The section adopted for the spillway differs from that at Gatun only when forced on account of different heights. The parabolic form of the upper part of the dam adopted at Gatun was followed at Miraflores.

MIRAFLORES LOCKS

There are two locks in flight at Miraflores. The condition at the lower lock of this flight was complicated by a tidal variation of 20 feet. If a lockage were made from the upper lock to the lower, at low tide, a certain height of lock wall would be necessary to contain the water; whereas, if made at high tide, walls of greater height would be needed; otherwise they would be flooded. Excessively high walls meant excessive cost, not only in gates but in masonry. The question of gaining capacity by lengthening the walls of the lower lock was considered but abandoned on account of cost.

A compromise was finally reached: the lower lock was made of such capacity as to hold all the water from the 550-foot portion of the upper lock, at high tide. No intermediate gates were installed. When ships of size sufficient to require the entire upper lock are passed at stages above mean tide it will of course be necessary to waste a certain amount of water through the lock culverts.

CONSTRUCTION PLANT—LOCKS ON PACIFIC SIDE

The plant for manufacturing and placing concrete at Pedro Miguel and Miraflores Locks was of an entirely different design from that used in the construction of the locks on the Atlantic side.

The main portion of the plant consisted of eight cantilever cranes; four of these cranes were placed on tracks outside and parallel to the lock excavation. The function of these cranes was to handle the concrete material into the mixers which were on the cranes and to deliver mixed concrete to other cranes. These latter cranes were placed in the lock chamber on tracks and were of such dimensions as to enable them to place concrete in any part of the lock walls. Those cranes working outside of the excavation for the locks were called berm cranes; those working in the chamber were called chamber cranes. All of these cranes, working together, performed the same functions at Miraflores Lock that the four duplex cableways, the automatic railroad, and the electric railroad performed at Gatun Lock.

PEDRO MIGUEL CONSTRUCTION PLANT

The high and unstable banks existing after the excavation had been made for the lock pit at Pedro Miguel did not permit of the normal installation of this plant. The berm cranes and storage piles could not be placed upon the bank alongside the lock excavation; they were located in the forebay of the lock in the space to be occupied subsequently by the upper or north center approach wall.

This location forced the introduction of another element in this plant, i. e., some means of handling the mixed concrete from these cranes to the placing cranes. This was accomplished by a narrow-gauge steam railroad. In the forebay of these locks two storage trestles were erected at an average height of 28 feet and length of 800 feet. Sand and crushed stone were delivered on these trestles by trains made up of dump-cars. The sand was dumped on one side of the trestle and the stone on the other—all within reach of one arm of the berm crane.

The same system of storing material was adopted at Miraflores except that the storage trestles were built in a normal position there.

The construction plant at the locks on the Pacific side proved to be a very efficient machine. The cost of manufacturing and placing the concrete, however, did not materially vary at the three places—Gatun, Pedro Miguel, and Miraflores. The handling or construction plants were, of course, in no way responsible for the cost of sand and stone, their efficiency being measured by the cost of taking materials from storage, manufacturing them into concrete, and placing such concrete in structures. The records show that this operation was performed more cheaply at Gatun than at Pedro Miguel, but more cheaply at Miraflores than at either of the other places. Upon the Gatun handling plant, however, was imposed the additional duty of transporting material about 1,700 feet and lifting it about 60 feet. This was due to the fact that the sand and stone for Gatun was delivered by water—not by rail—and the nearest points of delivery were separated from the mixer site by the distances given above. The cost of installing and operating the plant necessary to perform this extra duty was 19 cents per cubic yard. Crediting the work at Gatun with this amount, the cost of taking material from storage and manufacturing and placing concrete, was: Gatun, $2.42 per cubic yard; Pedro Miguel, $2.59 per cubic yard; Miraflores, $2.14 per cubic yard.

FORMS

Collapsible forms were used on the Pacific Division for the culverts and for the various openings that were repeated many times. The wall forms were materially different from those on the Atlantic side and were composed of wood in built-up panels 15 feet long and 6 feet high; to these panels were secured a series of uprights 14 feet long; the lower 8 feet of these uprights acted as cantilevers and were anchored by bolts to the hardened concrete previously placed.

CHANNEL EXCAVATION—MIRAFLORES TO THE SEA

In addition to the old French ladder dredges and the modern dipper dredges, there were utilized, in digging the sea-level part of the Canal on the Pacific side, the Lobnitz rock breaker, a large modern ladder dredge, and a hydraulic excavation plant. The pipe-line suction dredge was not extensively utilized on this work.

LOBNITZ ROCK BREAKER

This machine is a device for breaking rock by the impact of a heavy compressed steel ram or spar, alternately hoisted and allowed to fall and, by its own weight, disrupt or break the stone to be removed. The extreme range of tide in connection with the contemplated depth of channel, caused these rams to be long and heavy; the heaviest being 56 feet long and weighing 19.5 tons. This spar is lifted up and let fall in one position until it penetrates about 3 feet; it is then moved to another point about 4 feet away and the process continued until the entire area is broken. A dredge then removes the broken rock and another layer is broken.

DREDGE "COROZAL"

Experience with the old French ladder dredges caused a decision to be reached to procure, as late as 1912, the "Corozal," a modern sea-going ladder dredge of large capacity. Such an expensive piece of plant would probably not have been bought, in connection with the channel excavation, at that stage of the work, had its use not been indicated in maintaining the Culebra Cut. It was expected that the slides in that cut would continue for a year or two, before they brought about slopes sufficiently flat for stability.

This dredge was designed to excavate sand and mud at the rate of 1,200 cubic yards per hour from a depth of 50 feet. It was utilized in completing the channel, and has found continuous occupation since in maintaining the cut.

In excavating the channel from Miraflores to the sea, 39,962,470 cubic yards of material was removed, at a cost of .2579 cent per cubic yard.

HYDRAULIC EXCAVATION

A rather novel experiment in hydraulic excavation was made in the channel excavation about 1½ miles south of Miraflores Locks. The material to be excavated consisted of about 8,000,000 cubic yards of soft material overlying about 1,500,000 cubic yards of rock. It was decided to remove the overlying soft material by the hydraulic excavating plant, the material excavated to be utilized in building the impermeable part of the Miraflores Dam and in raising swamp lands adjacent to the excavation to a height sufficient to enable the Sanitary Department to drain them and thus eliminate or destroy mosquito breeding-places which they constitute.

The plan proposed was to break up the material by monitors and to wash it into sumps where dredging pumps were located. These dredging pumps were mounted on reënforced concrete barges. About a million cubic yards of material was thus pumped into the west dam at Miraflores, and after a part of the soft material had been removed by the hydraulic operations, the remainder, including the rock, was excavated in the dry by steam-shovels. The total amount of material thus removed was 1,549,904 cubic yards, at a cost of 72 cents per cubic yard.

A portion of this plant was afterwards utilized in removing the high ground in the vicinity of slides just north of Gold Hill and in rear of the hill back of the Cucaracha slide.

AIDS TO NAVIGATION—RANGE LIGHTS AND BUOYS

Range lights are used to establish directions throughout the Canal, except in the cut and on four of the shorter sailing lines. The sides of the channel are marked by gas buoys spaced about a mile apart. Lights will be placed on both the west and east breakwaters in Limon Bay and a fog signal is provided for the west breakwater. Ships sailing on the ranges at the entrance of the Canal will follow the center line of the Canal; whereas on all of the other sailing lines ships will follow a course 125 feet to their starboard of the axis of the Canal. If two ships pass each other, both of them on their ranges, there will be 250 feet between the center lines of the ships.

Both gas and electricity will be used as illuminants—electricity where the ranges are sufficiently accessible. On the floating buoys and inaccessible beacons and towers, compressed acetylene, dissolved in acetone, will be used as the illuminant. White lights will be used in all of the aids to navigation, such aids being distingushed from each other by systems of flashes and combinations of flashes.

Prior to the formation of the lake, visitors, traveling on the railroad, were astonished and nonplussed at times when they saw lighthouses, as they termed them—but really towers for range lights—erected in the jungle and on the hills bordering the lake area.

It was, of course, necessary to have all of this work completed before the Canal was available for use. The construction of many of these towers, however, was exceedingly expensive, there being no easy means of transportation for necessary building material until the lake was partially formed.

CHAPTER XVIII

MUNICIPAL ENGINEERING

Municipal engineering and sanitary engineering comprise many of the same subjects. A good water supply, an efficient sewerage system, and well-paved streets, are the most important steps in improving the health of a city, as well as in providing the necessary comforts of modern life.

At the end of the preparatory period there had been either created, or enlarged, four reservoirs and two pumping stations, sufficient to provide water for the various settlements along the line of the Canal, including, of course, the cities of Panama and Colon.

The reservoirs were located at Rio Grande, Camacho, Carabali, and Brazos Brook near, respectively, the towns of Culebra, Empire, Gorgona and Colon.

The pumping stations were located at Tabernilla and Gatun. There were other pumping stations used in conjunction with the water service already described—some of them continuously used and some occasionally when emergencies arose.

For purifying the water at Ancon and Colon, filtration plants, of the pressure type, had been provided but not installed. At other places drinking water was to be distilled and distributed to the employees.

The temperature of the water on the Isthmus is nearly constant and practically the same as that of the atmosphere. This gave rise to a condition that characterizes stagnant water in the United States in the summer and fall, giving to the lower strata of water in the reservoirs a strong odor and disagreeable taste.

These systems of water supply met the demand fairly well, with occasional assistance from the Chagres River, except at Gatun and at Colon and Cristobal. The water at Gatun was pumped from the Gatuncilla River. The flood height of this stream was very much increased when the entire flow of the Chagres River was diverted into one channel to the west of the spillway. This flooded the pumping station to such an extent that at times it was necessary to build watertight bulkheads six or seven feet high around the electrically driven machinery in order to keep up the supply.

In addition to this difficulty a typhoid epidemic broke out in Gatun, due, undoubtedly, to the human pollution of its water supply by the inhabitants of construction camps established in the watershed of the Gatuncilla River, above Gatun, by the Panama Railroad during the construction of its new line. Due to these troubles, an immediate solution of a permanent water-supply system for Gatun was undertaken.

It was known that Gatun would be a permanent settlement comprising, at least, the operating force for the Gatun Locks, and possibly a military force for the protection of such locks. A permanent water supply being necessary for this place, it was decided to provide such supply as early as practicable so as to profit by it during the construction period. This supply was provided by building a dam across the Agua Clara, a small stream about one-half mile northeast of Gatun, thus creating a reservoir of sufficient capacity to safely store the water needed at Gatun and vicinity during the dry season. It was estimated that two million gallons per day would be required and that the watershed of this reservoir, which was only 676 acres, would be ample to furnish this water. It should be remembered that the annual rainfall in this vicinity is about 130 inches.

Experience proved that the daily average use of water was greater than anticipated, being more than two and one-half million gallons daily. The reservoir, however, fully met all of the calls made upon it.

On account of the odor and taste of this water it was decided to filter it. For this purpose a rapid gravity mechanical filter plant was constructed. This filter plant has a maximum capacity of 3,300,000 gallons of water per day. It was built along the lines of the best practice in the United States, and provided Gatun with a most satisfactory water supply.

Trouble was early experienced with the water supply at Colon and Cristobal. Brazos Brook Reservoir Dam was largely built of material taken from the bed of the reservoir. This exposed permeable material, with the result that there was an excessive amount of leakage from this reservoir and no practicable way to stop it.

During ordinary years this water supply was augmented by pumping water from the east diversion, a channel excavated by the French to divert the Gatuncilla water from the Canal and carry it independently to the sea. During the year 1912, even with this assistance, the water supply for Colon and Cristobal was practically exhausted, and it became necessary to haul water in barges from Gatun to Cristobal. From May 10 to June 24, of that year, 550,000 gallons a day were thus delivered. This water was piped into the barges from the Gatun Reservoir and pumped from such barges into the Cristobal main.

The operation of the pressure filters at Mount Hope was very unsatisfactory, largely due to the fact that the amount of water forced through them exceeded their maximum capacity by nearly 50 per cent. This situation led to an investigation that had in view a plant for providing an adequate supply of filtered water for Colon and Cristobal.

These investigations indicated that it would be very expensive to provide such a supply before the formation of Gatun Lake, but that after such a lake was formed it would be feasible, at a small expense, to deliver any amount of water from such lake into Brazos Brook Reservoir for use in Colon and Cristobal, and that this could be done by driving an inexpensive tunnel six hundred feet long through the divide separating the lake from the reservoir.

Such a project was adopted and provision was made for filtering a maximum of 7,500,000 gallons of water per day. This involved the construction of an entirely new plant. In this plant the water was brought from the reservoir through two 20-inch mains to an aëration basin where, by means of specially designed sprinkling nozzles, it was thoroughly aërated. From the aëration basin the water was passed to the head house and mixing chambers where it was mixed with a solution of aluminum sulphate (common alum) and then passed into sedimentation basins where the alum caused the coagulation and settlement of nearly all sediment in the water; after sedimentation the water passed into the filter building and through the filters into the clear-water basin. This plant was finished during the construction period and constitutes a satisfactory and permanent water supply, not only for the Atlantic end of the Canal proper, but for all ships that call at that port.

The water-supply system provided for the Panama end of the Canal became inadequate by the beginning of the year 1910, the Rio Grande Reservoir proving to be inadequate. Investigation showed that the Rio Grande watershed could not be counted upon to furnish more than three million gallons of water per day. This deficiency was supplied from Cocoli Lake, which had been formed by the preliminary work of construction already done at Miraflores. This involved the creation of a pumping and filtration plant of capacity sufficient to furnish the additional water needed for Panama and adjacent towns. This provision successfully met the situation until the early spring of 1913, when the Canal construction had advanced to such a stage as to cause the creation of Miraflores Lake and the flooding of the Cocoli pumping station.

The adopted plans for the operation of the Canal contemplated the concentration of the heads of all departments at the Pacific end of the Canal. This, with the development of the terminal facilities and shops at Balboa and the consequent growth of the city of Panama made the solution of a permanent and adequate water supply for this section an urgent problem.

The preliminary studies concerning this problem led to the conclusion that the design should be based upon a plant with a maximum capacity of about twelve million gallons of filtered water per day which water could best be treated in a purification plant of the rapid mechanical gravity type. The source of the water supply, however, was a puzzling question.

The project as first decided upon contemplated obtaining the water from Miraflores Lake—an artificial body of water created by dams extending from Miraflores Locks to the high ground on either side of the Rio Grande Valley. Comparative estimates indicated that this would be the cheapest source of supply. The question of a material increase in the chlorine or salt content of the water of this lake, on account of the operation of the Miraflores Locks, was considered, but it was decided that the chance was remote of this happening to a hurtful extent, and the construction of plant for pumping water from Miraflores Lake was commenced. The purification plant planned for this place was modeled largely after the plant that had just been completed at Mt. Hope for Colon and Cristobal.

Work was commenced on this general project in August, 1913, but by January, 1914, trouble was experienced with the boilers in the Miraflores power plant on account of the salt content of the water. This led to the establishment of sampling stations to determine the chlorine content in the water. The records of these stations showed that the chlorine content continued to increase at such a rate as to render Miraflores Lake an unsuitable water supply. The surface of this lake is 55 feet above sea and is connected by a flight of two locks with the sea-level portion of the Panama Canal on the Pacific side; the bottom of the upper lock being 13 feet below sea-level. The upper sill of this lock, however, is about 11 feet above mean sea.

The situation as described caused the approval of the proposition to obtain the water supply from the Chagres River area of Gatun Lake, near Gamboa; the water to be pumped to the summit of the Continental Divide through pipes of suitable size, from which point it is allowed to run by gravity to the Miraflores purification plant; the location of this purification plant being equally available for water coming from Gamboa or directly from the Miraflores Lake.

This permanent water-supply system for the south end of Panama Canal was not completed during the construction period proper, but has since been completed and is now in operation.

The purification plants at Gatun, Mount Hope, and Miraflores, are in all essentials similar to plants of like character built in the United States, except the system of aëration which, it is thought, has not been previously embodied in plants of this character.

This aëration of the water not only assists in improving the taste and odor, but it so changes the iron content of the water as to reduce the amount of aluminum sulphate needed in the purification process.

CHAPTER XIX

SHOPS AND TERMINAL FACILITIES

SHOPS

It is only the completed structures that remain as permanent monuments in any great engineering undertaking like the building of the Panama Canal. Practically all of the appliances that assist in such construction are lost sight of in history; among these are plant and the shops in which such plant was erected, maintained, and repaired; all of which soon find their way to the scrap heap. The ability shown by the employees in meeting emergencies in the construction and repair of tools needed in shaping the permanent structures is also soon forgotten.

The importance of the shops during the construction period of the Panama Canal cannot be portrayed in a general description such as this, but an approximate idea of the scope of such shops can be obtained by remembering that the following plant was in the service of the Isthmian Canal Commission during the average year of the construction period: 4,400 cars; 277 locomotives; 92 steam-shovels; 55 cranes; 25 spreaders;

27 unloaders; 10 track-shifters; 17 pile-drivers, in connection with steam-shovel excavation; and 76 barges; 33 clapets; launches, etc.; 20 dredges; 12 tugs, and quite a variety of general equipment, in connection with dredging operations and transportation of material by water.

In the shops of the various classes all of this equipment was erected and afterwards kept in repair. The magnitude of the problem was largely increased by the distance of such shops from needed supplies, which meant that many things had to be manufactured on the job.

There were handled in the great Gorgona shops a monthly average of work, as follows: heavy and general repairs to locomotives, 17; repairs to all classes of cars, 1,500; repairs to equipment other than locomotives and cars, 204.

In addition, there were at this shop a monthly average of about nine hundred shop and casting orders for repairs to stationary equipment, manufacture of repair parts and for special equipment.

Time is often the controlling element in shops on a construction job. A day's delay may mean more than cost of the machine, and the shop's predictions as to time that completed work can be expected are of unusual importance. Each construction official of course thinks his work the most important in the shop.

When orders were sent in from the construction divisions a date of delivery was always requested by those divisions, and to meet these requests required a remarkable coördination of the various elements of work in the shop and an unusually close supervision on the part of those in authority. When a new order was received it first passed through the planning department where all drawings were checked and requisitions made for material; these requisitions, with bill of material and drawings, were all then forwarded to the shop; copies of these were sent to each foreman who would take part in the accomplishment of the order in question. A meeting of these foremen was called each day at a certain specified hour for the purpose of checking all orders overdue and all new orders. It was at these meetings that the data for the estimate as to the time of completion of each order were obtained; and now after the dust and smoke have all cleared away and each construction official can view the total demand made upon the shops of the Panama Canal, he will, it is thought, testify that such shops did their full share toward the completion of the work in the specified time.

TERMINAL FACILITIES

A decision was reached in 1911 that the Panama Canal should provide berthing space for vessels using the terminal ports and the Canal itself; that the Canal should provide facilities for docking and repairing vessels of all classes and for supplying them with fuel, water, foodstuffs, ship chandlery, etc.; all of these facilities being for the joint use of the ships of commerce and of the ships of war.

The design of these facilities was primarily such as to make the structures suitable for military use.

The general plan adopted called for a main coaling plant at the Atlantic end of the Canal, capable of handling and storing 200,000 tons of coal, having a subaqueous storage of 100,000 tons, to be connected with the railroad and of course convenient for ships.

This plant was to be supplemented by a subsidiary coaling plant at the Pacific terminus of the Canal, capable of handling and storing 100,000 tons of coal, 50,000 tons of this to have subaqueous storage.

In addition to the coaling plants described above the general plan provided that a fuel oil supply be maintained at each end of the Canal with an initial storage capacity of 80,000 barrels at each point, the design for these plants to be so made that their capacity could be increased if required.

Plans for the necessary commercial docks at each end of the Canal were so drawn as to permit of an extension in number of such docks if commerce demands it.

All commercial docks are to have steel superstructures and suitable loading and unloading devices to facilitate the handling and caring for commerce.

Those on the Pacific side are constructed of reënforced concrete throughout and supported by concrete piers. The piers were composed of reënforced concrete caisson shells, 6 feet inside and 8 feet outside diameter, cast in 6-foot sections on the ground near the mixing plant, sunk to rock and filled with concrete. The bottom section was provided with a steel cutting edge which is imbedded about 1 foot in the rock. A section was put in place and the material excavated from the inside, the section sinking from its own weight as the excavation progressed, until other sections could be added. The firm material was excavated by hand into buckets and removed from the caisson. The soft material was excavated by orange peel buckets operated from cranes. The piers were reënforced against bending by old French rails. These docks were located in low ground and none of the caissons were sunk through open water. The basin in front of the docks was excavated after their completion.

For docks at the Atlantic terminals a different design and plan was adopted. The docks were constructed of steel beams and girders encased in concrete, for protection against corrosion, and the decking of reënforced concrete. The piers were sunk largely through open water and were composed of steel plate cylinders, 6 feet in diameter, in 6-foot sections, driven with a pile-driver, excavated by hand, and filled with concrete. The material through which they were driven was coral rock, rotten at the top but increasing in hardness as the depth increased.

At the Pacific end of the Canal were to be erected the great permanent shops and the docks for large ships. These docks were to have a usable length of 1,000 feet, with a width of 110 feet, thus providing for docking the largest ship that could pass through the Panama Canal. An auxiliary dock was also planned, with a usable length of 350 feet and a width of 71 feet. Both of the docks have a hard rock foundation and there were no unusual construction difficulties.

An idea of the extent and use of the permanent shops erected at Balboa can probably best be drawn from the following statement, giving the use of the shop and its floor area in square feet:

Building	Floor Area *Square Feet*
Machine, erecting, and tool shops	67,420
Forge, pipefitters', tinsmiths', and copper shop	31,650

SHOPS AND TERMINAL FACILITIES

Building	Floor Area *Square Feet*
Steel storage shed	18,080
Boiler and shopfitters' shop	45,940
General storehouse	89.920
Paint shop	12,760
Car shop	38,800
Joiner, carpenter, and pattern shop	48,240
Galvanizing shop	5,620
Lumber and equipment store shed	67,060
Steel, iron, and brass foundry	37,060
Coke shed	3,070
Boiler house	2,380
Pattern storage building	13,870
Office building	9,500
Total	491,370

The erection of these terminal facilities was commenced but not completed during the construction period of the Canal. Enough of the shop buildings, however, were finished for the installation of the machines that had occupied the construction shop buildings, all of such shops being dismantled prior to the completion of the Canal, the site of the shops at Gorgona being now covered by the Gatun Lake.

CHAPTER XX

OPERATION OF PANAMA CANAL

As soon as a ship arrives at either end of the Canal she is boarded by a pilot, a quarantine officer, and such other officials as have duty connected with the passage of this particular ship. All ships that have not prepaid their tolls are required to pay in cash. The passage of ships is facilitated, however, by paying the tolls before reaching the Canal. These tolls can be paid through the various subtreasuries in the United States or through the Panama Railroad Company, in New York.

If the boat has a through cargo and requires no supplies, the pilot proceeds with her across the Isthmus, otherwise the necessary business is done, or arranged for, before she proceeds. The most important operations in connection with the journey from ocean to ocean is the passage through the locks.

LOCK OPERATION

While locks have been in use for many centuries and the devices for operating them have undergone a gradual growth, the operating conditions, especially with respect to safety imposed upon the Panama locks, caused the development of several new designs to meet these conditions, namely: a new device for opening and closing the lock gates; another for forcing the gates to close tightly and to lock them in this position; another for towing ships through the lock by electric towing apparatus; and still another for operating all machinery of the lock by remote electrical control.

In swinging a heavy lock gate, slow motion and great power are needed at the beginning and end of the operation. Slow motion is required in bringing the gates together with their miter faces in contact and in moving the gate into or out of its recess in the wall to give time for the water displaced by the movement of the gate to flow to or from the recess without creating an objectionable head to resist the movement. Great power is necessary in breaking the miter seals, frequently against a small head, and in forcing the gate into or out of its recess against a small head of water.

These requirements were met most effectually in a simple but new and patentable design consisting of a large horizontal gear wheel, to the rim of which is attached a strut, the other end of this strut being attached to the gate. See Figure 21. The large wheel revolves through an arc of 197° and the strut is so connected to it that at the beginning and end of the revolution the maximum force can be exerted with a minimum movement of the gate. The maximum movement being when the gates are swinging free in the lock chamber.

A perfect closing of the gates is insured by means of a special device called the miter forcing and locking machine. This device consists of a pair of movable jaws on the end of one leaf that engages a large pin on the end of the other leaf. The application of power closes these jaws and forces and holds the gates to their proper position.

TOWING LOCOMOTIVES

More precautions have been taken to avoid accident in the operation of the locks on the Panama Canal than upon any locks in the world. The most effective of these precautions is probably the electric towing locomotives. By means of these locomotives ships can pass through the locks without using their own power, which use, as previously pointed out, has been the source of the majority of accidents to lock gates. Vessels are expected to land alongside the guide walls at either end of the locks. But in practice they do not always actually land but do approach these walls at a very slow speed and, while thus proceeding, take the tow lines from the locomotives on the middle wall. If the gates are not open and everything ready for the entrance of the ship, it would, of course, be required to land alongside the guide wall. If the gates are open the ship will probably not land but will slow down and take the lines from the locomotives on the center wall, as described above, and will proceed along the center wall under the control of the towing locomotive, aided slightly by her own engines, until the lines from the locomotives on the flare wall can be passed to the ship. This is ordinarily done by means of a skiff.

As soon as the ship is under the control of the towing locomotives on both walls no further use is made of her own engines. It was expected that four locomotives would be sufficient to safely tow any ship through the locks of the Panama Canal and hold such ship in the center of the lock during the filling and emptying process. In practice, however, six locomotives are used on the larger vessels—three on each side of the ship—one forward, one aft, and one nearly amidships. The movements of these towing locomotives are controlled by a lock pilot on the bridge of the vessel, by a system of signals. These towing locomotives are simply moving capstans.

OPERATION OF LOCK MACHINERY BY REMOTE CONTROL

The switchboard in the control house is essentially a combination of a switchboard with a model of the lock. All operations in the lock proper are reproduced on the switchboard, so that the operator can see at any moment the exact situation as to machines, stage of water, etc., in the lock that he is operating.

It is an impressive and never to be forgotten sight to stand in the control house at the lower end of the upper lock at Gatun and watch the operator at the switchboard when a ship is passing from lake to sea-level, for instance. A touch of his hand sets in motion the powerful machines which, in their proper order, lower the huge fender chain and swing the ponderous gates, making an opening as wide as a city street. These movements of the chain and gates can be observed through the windows of the control house in addition to their reproduction on the switchboard. The slow entry into the lock of a gigantic steamship in tow of two electric locomotives can also be seen from the same window. These locomotives are so small in comparison with the size of the ship that they appear like pigmies attempting the impossible, but their combined pull of 50,000 pounds on the tow lines slowly but surely draws the ship until her stern is past the open gates. As soon as this comes to pass two other locomotives, which have been trailing close behind with their tow lines at such an angle as to keep the ship steady on her course, begin to pull backward and

FIG. 22.—SHIP PASSING THROUGH GATUN LOCKS.

FIG. 23.—GATUN SPILLWAY AS SEEN FROM THE LAKE.

just as slowly and surely, stop the ship and hold her securely in the middle of the lock chamber. The operator then closes the gates behind the ship and pulls another lever which opens the valves in the filling and emptying culverts. You soon notice that the ship is slowly being lowered in the lock chamber as the water-level lowers. See Figure 22. Turning around and looking into the lock below, you see the water surface in violent agitation caused by the water rushing up through the holes in the floor from the culverts underneath. The water in the two locks soon comes to rest at the same elevation, another chain is lowered, the gates ahead opened, the ship towed into the middle lock, the gates closed behind her, the culvert valves at the upper end closed and those at the lower end opened, and in the same way the ship is lowered and passed into the lower lock where similar operations finally lower her to sea-level. The locomotives take her out of the lock, the tow lines are cast off and she steams away at increased speed as though glad to be at last rid of those controlling cables and confining lock walls.

This task of raising or lowering the largest ship that floats 85 feet in one hour's time is accomplished with no more human energy than is possessed by a child, the only requirement being the pulling of switches.

The lock operating switchboard in the control houses of the locks is about 64 feet long and 5 feet, 4 inches wide, and upon it are the levers which operate the switches. On this board are indicators in proper relation to each other that represent the various parts of the lock-operating mechanism; such as miniature fender chains, swinging arms to represent gates, members which move vertically and show the exact position of the moving parts of valves, and indicators which show by moving pointers the height of the water in the various locks; thus enabling the operator at a single glance over the switchboard to know the exact position of any machine about the locks, as well as the water-level in the locks.

The operations required to pass a vessel through the locks must necessarily be made in a progressive order. To avoid accidents, the proneness of man to err is eliminated by having certain important switches so interlocked that the operator cannot make a mistake and operate the wrong switch.

POWER HOUSE—ELECTRICAL

While steam and compressed air found quite general use during the construction period in all parts of the Canal, except at the locks, electricity will be almost solely used in operating the Canal;

largely on account of the fact that there is a fall of about 75 feet at the Gatun Spillway, and that power can be generated cheaply by using the surplus water. There will, therefore, be about one thousand individual motors installed in connection with the operation of the locks and their appurtenances. Many of these motors will only be used occasionally. The Isthmian climate being exceedingly humid the management was confronted with a condition in this connection which forced special study covering, in particular, questions of corrosion of metallic parts and of insulation.

The entire fall from the summit level of the Canal to near sea-level is at one place on the Atlantic side, while on the Pacific it is divided; consequently greater power can be developed with the same amount of water on the Atlantic side than on the Pacific. For this reason the only hydro-electric plant is at Gatun, and the power needed on the Pacific side is transmitted across the Isthmus. A reserve steam plant, however, is kept ready for service on the Pacific side.

While the Panama Railroad is still a steam road, the towers for the transmission line across the Isthmus were designed with a view to electrifying the road.

The Panama Railroad may prove to be almost as important an element in operating the Canal as it was in building it. This railroad, although operated under a charter granted by the state of New York, is essentially a government-owned road, all of its stock being owned by the Government of the United States. While it is true that each director is required, by the charter, to be a stockholder, such stock ownership is merely nominal. On purchasing it the director enters into a contract to sell the stock to the Secretary of War and accepts part payment. This railroad has been referred to as a convenient device for avoiding many of the restrictions imposed on the transaction of Government business by law and regulations.

During the construction period the laundry, bakery, cold-storage plant, and commissary stores were all operated through the Panama Railroad, and there are many advantages in continuing these operations through this same agency and enlarging it into a general shipping supply business, including fuel. This railroad is also acting as agent for companies operating ships through the Canal; and since the governor of the Canal is also president of the Panama Railroad, probably the most advantageous way to arrange for passing a ship through the Canal and supplying her while en route is through the agency of this road and directly with the Marine Department of the Panama Canal.

It is quite probable that a larger force will be required in connection with supplying and repairing ships than with the actual passage of such ships through the Canal. All instruments for supplying and repairing ships should, however, be self-supporting.

It will probably be some years before the banks of the Canal are entirely stable and the cost of maintenance approximately constant. When such a condition comes to pass the operation of the Canal proper will be an easy task and relatively an inexpensive one.

CHAPTER XXI

THE WORK AND ITS COST

Practically all of the work involved in the building of the Panama Canal was performed by employees serving directly under the United States. The only work of consequence not performed in this manner was that of the lock gates and emergency dams. These structures were erected by contract, it being thought practically necessary that the firm fabricating these structures should erect them. No work on the Canal required greater accuracy than that of the lock gates, and the responsibility could be more clearly fixed if the same contractor both fabricated and erected the structures.

The wisdom of abandoning the idea of building the Panama Canal by contract became more and more apparent as the work progressed. In the first place, the power of the Government was necessary in enforcing all needed sanitary regulations, and the credit of the Government was necessary in launching the work upon a scale that would insure its completion in the specified time.

Contractors would have hesitated in investing the necessary millions in plant long before any estimates were in sight. The needed changes in plans and projects, the innumerable slides in the Culebra Cut, and other unforeseen and unspecifiable difficulties would have together probably formed the basis for lawsuits that would have extended over many years.

There never would have been the same *esprit de corps* in the force working for contractors as existed in the force working for the Government. Every man was proud to be a member of the force; proud of the fact that his Government had undertaken to build the Canal after others had failed. He felt that the job was commensurate with the strength of his Government, and his loyalty to the job was one of the most striking features of the undertaking. It was not a loyalty to individuals—because the same force exhibited it through three administrations—but a loyalty to the country.

The Panama Canal is one of the few Government undertakings that were essentially completed within the estimate both as to time and money. The greatest reason for this was the fact that the Congress of the United States provided the money as fast as it could be properly used. Those in authority knew that they could plan the construction work on a scale that would insure its completion on time and that the money would be available to pay for the plant, material, and labor. The entire force felt that positions were secure and that employment would be continuous for the man who did his work and that there would be no cessation of work for lack of funds.

A COMPARISON OF COSTS:

MAY, 1904, TO JUNE 30, 1914

DRY EXCAVATION

	Cu. Yds.	Unit Cost
Gatun to sea	2,181,998	.6746
Gatun to Pedro Miguel	110,261,883	.7800
Pedro Miguel to sea	4,819,969	.7287
Gatun Spillway	1,544,202	.7131
Gatun Locks	4,660,055	.6776
Pedro Miguel Locks	1,133,280	.9136
Miraflores Locks	2,222,582	.9302

HYDRAULIC EXCAVATION

Gatun to sea	29,605	.3942
Gatun to Pedro Miguel	1,441,729	.2179
Pedro Miguel to sea	1,549,904	.7233
Miraflores Locks	332,703	.5870

DREDGING EXCAVATION

Atlantic entrance	39,032,400	.2325
Pacific entrance	39,962,470	.2579

PREPARING FOUNDATIONS

Gatun Spillway	44,715	2.2086
Gatun Locks	228,376	1.9880
Pedro Miguel Locks	175,987	2.7242
Miraflores Locks	415,981	1.9065

Plain Concrete	Cu. Yds.	Unit Cost
Gatun Spillway	228,723	7.9316
Miraflores Spillway	73,277	6.7568
Gatun Locks	1,945,487	7.2200
Pedro Miguel Locks	839,398	5.5932
Miraflores Locks	1,408,484	5.0487
Cost of Concrete Material		
Gatun Locks		4.8808
Pedro Locks		2.8850
Miraflores Locks		2.8550
Reënforced Concrete		
Gatun Spillway	2,456	16.7212
Miraflores Spillway	977	17.1484
Gatun Locks	95,753	12.6151
Pedro Miguel Locks	67,777	9.6558
Miraflores Locks	71,255	11.8570
Dry Fill		
Gatun Dam	12,229,104	.4374
Pedro Miguel Dam	699,518	.4815
Miraflores Dam	1,758,423	.4986
Back Fill		
Gatun Spillway	50,183	.5940
Gatun Locks	2,119,406	.5539
Pedro Miguel Locks	834,288	.4470
Miraflores Locks	2,366,252	.4225
Filling Center Wall		
Gatun Locks	113,163	.8020
Pedro Miguel Locks	220,768	.5239
Miraflores Locks	249,457	.6433

Total Division Cost of Certain Items of Locks, Dams, and Spillways

Gatun Locks—complete	$28,607,286.51
Pedro Miguel Locks—complete	12,433,768.81
Miraflores Locks—complete	17,975,260.41
Gatun Dam, except spillway	7,570,228.03
Gatun Spillway—complete	3,159,204.49
Pedro Miguel Dam	341,627.72
Miraflores Dam, except spillway	905,032.29
Miraflores Spillway—complete	992,015.73
Lock gates (most of the expense of fixed ironwork not included), 46	6,194,846.17
Spillway gates, 22	126,774.51
Emergency dams (including operating machinery), 6	2,453,430.88
Chain fenders and machines, 24	1,021,846.37
Lock irons *	2,106,589.55
Towing track system, except locomotives	1,400,627.08
Electrical distribution system:	
Transformer rooms, high tension switch chambers, power cables, lighting cables and fixtures $1,317,562.50	
Lamp posts 137,431.27	
	1,454,993.77
Towing locomotives, 40	598,082.79
Control boards, 3	108,324.33
Miter gate-moving machines, 92	1,005,384.20
Miter gate-forcing machines, 46	69,904.02
Rising stem and guard valve machines, 134	1,076,151.47
Cylindrical and auxiliary culvert valve machines, 132	229.267.54

* Includes purchase and installation of fixed irons for quoins and sills of gates and caissons; snubbing irons, buffer castings, etc.; and installation of Stoney valve frames and cylindrical and auxiliary culvert valves.

Smaller machines:		
Miter gate handrail, 92	$36,237.95	
Miter gate sump pumps, 92	34,849.65	
Culvert sump pumps, 3	12,746.14	
Drainage sump pumps, 9	4,036.98	
Machinery and cable pit pumps, 7	3,542.04	
Float well, 46	25,298.74	
		116,711.50
Rising stem and guard valves, moving parts only, installed, 134		448,132.58
Fixed irons for same, contract price, not installed		392,600.00
Cylindrical and auxiliary culvert valves, contract price, not installed, 132		236,000.00
Spillway gate machines, 22		209,924.15
Gatun Locks—masonry, 2,068,636.4 cu. yds.		14,942,706.17
Pedro Miguel Lock—masonry, 929,405.15 cu. yds.		5,304,758.46
Miraflores Locks—masonry, 1,509,469.17 cu. yds.		7,865,085.30
Gatun Spillway—masonry, 231,179 cu. yds.		1,740,085.54
Miraflores Spillway—masonry, 74,313 cu. yds.		464,751.95

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