Mr. Maurice H. Thatcher, Head of Civil Administration, Ancon,
H. A. Gudger, Chief Justice, Ancon,
Frank Feuille, Counsel and Chief Attorney, Ancon,
Col. W. C. Gorgas, Chief Sanitary Officer, Ancon,
Edward J. Williams, Disbursing Officer, Empire,
H. A. A. Smith, Examiner of Accounts, Empire,
Maj. F. C. Boggs, General Purchasing Officer, Washington, D. C.,
J. A. Smith, Superintendent, Panama Railroad, Colon.

The headquarters of the division engineers and the department heads are in the towns nearest to the scenes of their activities. Beneath the higher officials are a host of assistants who exercise important supervisory functions, and then come the 35,000 employees.

How largely the Army and Navy have dominated the canal, since 1907, is shown by the foregoing organization, in which nine out of seventeen heads of departments are from the government forces. But this does not show the extent of this domination, because the full organization of subordinate officials shows twenty-two additional Army and Navy men in important positions.

The Pacific Division is the only one of the three grand divisions with a civilian engineer in charge, and there are no Army or Navy men in this division from top to bottom. The idea seems to have been to pit a civilian engineer against the Army men, who are in charge of the Atlantic and Central Divisions. The

Pacific Division, under Mr. Williamson, substantially demands the same engineering ability as the Atlantic Division under Lieut.-Col. Sibert, because each includes lock and dam construction and channel dredging. The cost-keeping accountant has shown where the civilian engineer has done his work more cheaply than the Army engineer, but the difference is accounted for in the physical obstacles that must be surmounted in the Atlantic Division, in obtaining sand and rock for the locks.

None of the complaints at government red tape which bristled all through the annual reports of Messrs. Stevens and Wallace may be noted in Col. Goethals' reports. The Army men on the canal might exclaim, with Brer Rabbit, that they were born and bred in the briar patch of red tape, and were just in their element when dropped into the Big Ditch. Col. Goethals looked ahead in making up his annual estimates of appropriations needed for the year in advance, and in making orders for equipment, materials and supplies, so that much of the vexation of the early years was avoided. Every head of a department must hand in an estimate of what will be needed to run him for the ensuing year and this plan keeps the canal ahead of its demands in all lines.

The equanimity with which Col. Goethals has met every unexpected development in the construction work is a distinguishing feature of the man's mental processes. If he ever has for one moment entertained the shadow of a doubt of the success of the lock-type canal, he has not allowed his fears to be manifested.

The slides, the slip in the Gatun dam, the volcanic evidences in the Culebra cut, the cracks in the lock walls, earthquake disturbances, and a host of lesser troubles have not shaken his faith. One can hear employees and subordinate officials voicing all kinds of dark forebodings, but never the Chief Engineer.

The mammoth Gatun dam had been begun in 1906, and by 1908 was taking form under the constant dumping of rock and earth from the Culebra cut. On November 20, 1908, a toe of the great dam slipped, where the dam intersected the old French canal channel, carrying about 200 feet of the structure away. The hostile press, and those who had consistently opposed a dam at Gatun, immediately raised a storm of criticism against the stability of the proposed artificial mountain. The old wound, caused from the battle of the levels, was reopened and so violent was the outburst that President Roosevelt took a characteristic step to quiet the issue.

He asked President-elect Taft to go to the Isthmus, accompanied by Frederic P. Stearns, Arthur P. Davis, Henry A. Allen, James D. Schuyler, Isham Randolph, John R. Freeman and Allen Hazen, all eminent engineers, to make an investigation. The report made on February 16, 1909, completely vindicated the plan for a dam at Gatun with the statement that if any error had been made, it was on the side of precaution. They found the dam started along lines so excessively stable that they recommended that the height be cut from 135 feet above sea-level to 115 feet, which would still

leave the top of the dam thirty feet above the level of Gatun Lake.

An absolutely free hand always has been given to critics of the canal. Having nothing to conceal, and with firm faith in the technical soundness of the plans adopted, the government has had nothing it wished to keep from the light. Whenever criticism of any feature became especially severe, President Roosevelt promptly answered it by a full and scientific investigation with the inevitable result that the critics slunk into silence. Since President Taft has been in office the canal has been advanced to the point where the sceptical are cautious in criticism, and only some catastrophe of nature, in reasonable probability, can undo the achievement.

The six years from January 1, 1907, to January 1, 1913, constitute the main construction period of the Panama Canal. Col. Goethals has been Chief Engineer all but three months of that time. Steadily, foot by foot, the walls of the locks crept up and the bottom of the Culebra cut went down. By October, 1908, the preparatory work, substantially accomplished by Mr. Stevens, passed its highest point, and all energies were centered on the work of construction. Quarters, municipal work, road-making, subsistence and commissary were solved problems and the "No Help Wanted" sign was displayed, the labor problem, too, being substantially worked out. The chief business was to make the organization more efficient by anticipating needs of equipment and supplies, and keeping the morale of the workers to a keen edge through ab-

solute justice. Col. Gorgas had the health problem in hand.

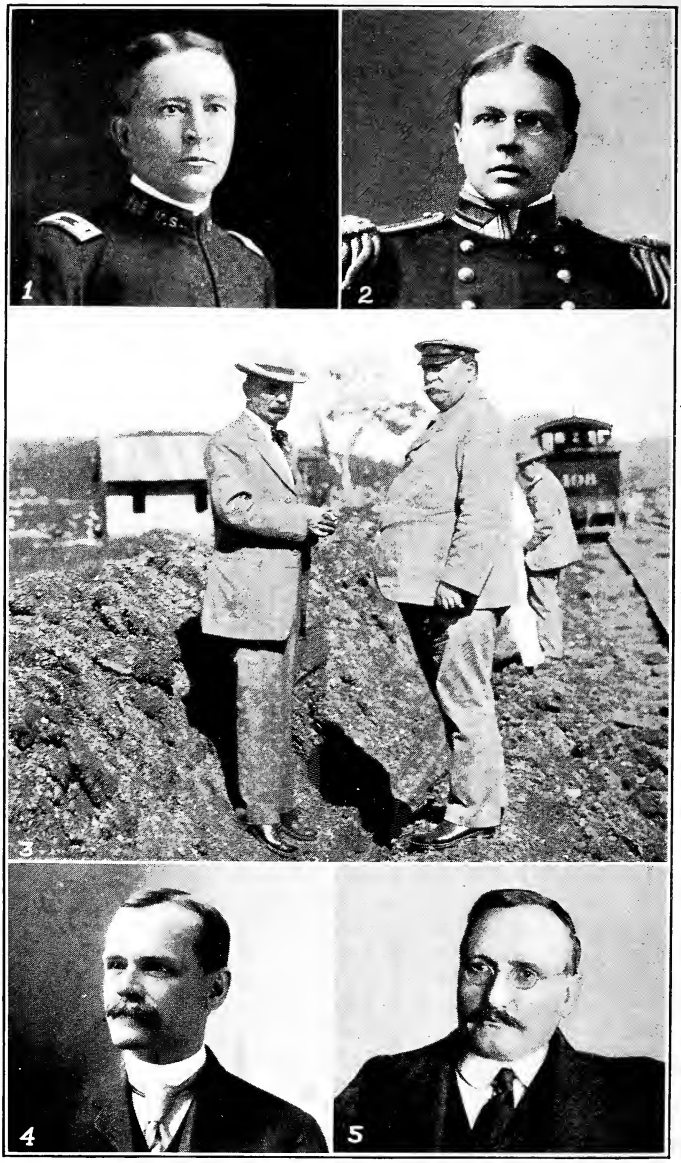
Sixty-three steam shovels, in 1907, were increased to 100; the 284 locomotives were augmented to 315; cars of all kinds from 2,700 to 4,356; the mileage in the Canal Zone was increased from 185 to about 500 miles for the Panama Railroad and Commission tracks; the number of unloaders, bank spreaders, track shifters and pile drivers was increased from a third to three times the number left by Mr. Stevens; twenty dredges were put in service, 560 drills for blasting, fifty-seven cranes, twelve tow boats, eleven clapets, seventy barges and lighters, fourteen launches, beside much other machinery and equipment not so noteworthy. The foregoing figures do not include the Panama Railroad equipment, which consists of seventy locomotives, 1,534 cars and coaches, and various other rolling stock common to a railroad. Practically all repairs and creative mechanical work was concentrated in the Gorgona and Empire shops, with capacities commensurate with the equipment. The Empire shop specialized on steam shovel repairs, but in July, 1912, the bulk of its work was consolidated with Gorgona. The date when the equipment reached a maximum is fixed by Col. Goethals as July 1, 1910. About 350,000 tons of coal and 500,000 barrels of oil have been used annually.

Dredging had progressed in the Pacific entrance to a point where five miles of the canal could be opened to navigation, on February 1, 1909. The *Newport* and *San Hose,* of the Pacific Mail Fleet, of American

register, were the first ships to go through. Considerable excavating was done in both entrances by steam shovels, the water being held out by dikes.

A striking instance of miscalculating the cost of one phase of canal construction is found in the estimate made by Prof. Burr, of the first Commission, which placed the cost of private lands that would be used in the Gatun Lake and elsewhere at $18,656,000. As a matter of fact something more than $300,000 has been spent in this way and $500,000 is the maximum as estimated by Col. Goethals, in 1908. The area of the Gatun Lake crosses into the Republic of Panama on the West side of the canal, and the private property so condemned as well as in the Canal Zone is valued by a joint commission of Panamans and Americans.

Columbus had been honored by naming Colon and Cristobal for him at the Atlantic entrance of the canal, and an Executive order on April 30, 1909, honored the discoverer of the Pacific by changing the name of the Pacific terminal from La Boca to Balboa. It is at Balboa that the permanent machine shops, dry docks, yards, wharves, warehouses, and general equipment to cost $20,000,000 will be located. Col. Goethals' conception of making the canal adequate for all the needs of shipping has a military utility that is not sufficiently recognized. By making it possible for vessels to coal at the canal, secure fresh provisions, get repairs made and expeditiously handle cargoes, the United States makes it unnecessary for any foreign power to establish a coaling station and similar facili-



Photos, 1, Harris & Ewing, Washington, D. C.; 2, 4, 5, Clinedinst, Washington, D. C.; 3, Pictorial News Assn.

1. Lieut.-Col. H. F. Hodges. 2. H. H. Rousseau, U. S. N. 3. S. B. Williamson with President Taft. 4. Lieut.-Col. D. D. Gaillard. 5. Lieut.-Col. William L. Sibert.

ties in this hemisphere, on the pretext of caring for its merchant marine. With ice plant, cold storage, bakery and other subsistence and commissary facilities already established, it will be easy for the government to institute the practices mentioned at Balboa coincidental with the opening of the canal. Col. Goethals has been working toward that end for years and the bill passed in the 1912 Congress approves his ideas.

In 1909, Col. Goethals seems to have had the idea of making the Canal Zone habitable, for an extensive scheme of road-making was begun, and $75,000 was spent in a survey of the Canal Zone. The survey never was finished, and since then Col. Goethals changed his views, in favor of making the Canal Zone a military reservation, the part not in use to be left to the jungle and only canal employees allowed, without special permission, in the ten-mile limits. Critics in the United States displayed their ignorance by protesting that the land in the Canal Zone should be opened to settlement, like our western lands. The canal occupies 96 square miles of the 436 in the Canal Zone and 73 square miles are privately owned. There is very little of what is left that Americans would occupy. It is in the main mountainous, and without a system of roads that would be prohibitive in cost, would not be accessible in the rainy season. Col. Goethals disposes of the idea of settlement in his usual terse way when he says: "The inducements offered by farm lands in the Canal Zone are not likely to attract Americans. Other occupants are not desirable."

The Americans have made an investment at Panama

which should be guarded from every possible danger. In times of war everybody in the Canal Zone, of course, would be subjected to scrutiny and possibly to ejection. It will, therefore, save trouble and expense to begin, right at the start, to treat it as a military reservation is treated in the United States. The expense of sanitation and civil government would be too great to make settlement profitable.

Work on the fortifications was begun in 1911, on Flamenco Island, three miles out in the bay at the Pacific entrance, and on Toro Point at the Atlantic entrance. The estimate for their cost, as fixed by the officers appointed to design them, is $12,475,328, and Congress, in March, 1911, appropriated $3,000,000 of that amount. The latest and largest disappearing rifles will be installed after the concrete work is finished. The locks at the Pacific end are nearly ten miles from the fortifications, which insures them against bombardment by an enemy's ships, and the Atlantic locks are seven miles from the fortifications. Some form of defense from airships must be worked out.

It would be just as logical to say that New York should remove its traffic policemen from Thirty-fourth Street and Broadway, as to argue that the United States should not fortify the canal. The policemen are there to aid traffic by enforcing the rules which make order possible, and fortifications are necessary at Panama to insure that no nation, whether fighting the United States or some other nation, shall disable a world transit route. Neutrality would be a myth without a strong police power at Panama. It is to

the interest of every nation that the canal be so policed and fortified that commerce could not be disrupted through the deliberate, or unintentional, actions of belligerent nations. Warships of all nations may pass through the canal, but if of nations engaged in war, they cannot linger at either end of the canal after or before passage.

When the canal is completed, the beautiful towns along the route will be abandoned. Gorgona, Bas Obispo, Las Cascadas, Empire, Culebra, and Paraiso will be razed. A permanent camp for the Army will be located on the East side of the canal, across the Cut from the town of Culebra. Marines have been in the Canal Zone since 1904, and in 1911 the Tenth Infantry was added to the permanent garrison, which will be further augmented by several regiments. The soldiers will police the Canal Zone after construction work is finished. Balboa and Cristobal will be the principal cities, though at Gatun and Pedro Miguel forces to operate the locks will be housed.

President Taft signed, on August 24, 1912, a bill for the permanent government and operation of the canal. Col. Goethals' ideas were followed almost to the letter in drawing this bill. The President is authorized, as soon as the canal is sufficiently near completion, to abolish the present Commission and to appoint a Governor, for a term of four years, at a salary of $10,000 per annum. In time of war, the President may substitute an Army officer for this Governor. Salaries and wages are not to be more than twenty-five per cent greater than in the United States, and

many of the perquisites now enjoyed by the employees are to be eliminated. The Canal Zone will be open to only such persons as the Governor may admit; American coast-wise ships are exempted from paying tolls for passage; foreign-built ships owned by Americans may register under the American flag; ships owned by railroads cannot pass through the canal; the Interstate Commerce Commission is given power to determine questions of competition; and the present judiciary system is continued with right of appeal to the Federal courts in the United States. In addition, the government may sell ships supplies and coal and provide facilities for repairing vessels at the canal terminals.

At the close of the fiscal year ended June 30, 1912, Col. Goethals could look forward to one year more of the arduous labor and heavy responsibility he has borne, before the big job would be in the clear. Invoicing conditions at that date, we find that the great Gatun dam was more than 90 per cent completed; the concrete work in the locks and spillway was about 90 per cent completed; the Culebra cut was approximately 90 per cent completed; the relocated Panama Railroad was finished, and the work of establishing permanent shipping facilities at Balboa and Cristobal was under way.

Owing to fresh slides in the Culebra cut, and to changes in plans in the Pacific division, a new estimate of the total excavation for the completed canal and accessory plant became necessary at the beginning of the last complete fiscal year of canal construction—July 1, 1912, to June 30, 1913. The revised estimate

then placed the excavation at 212,227,000 cubic yards, of which amount 175,901,052 cubic yards had been removed at the end of July, 1912, leaving to be excavated for the completed canal, 36,325,948 cubic yards. The latest estimate, however, raises the total excavation to 221,000,000 yards. The canal organization cannot remove the uncompleted portion before the first ship is scheduled to pass through the canal, in September, 1913, but of the 47,000,000 yards left, more than 8,000,000 yards are to be excavated outside of the canal proper, or in the sites for the coaling station, dry docks and terminal at Balboa, so that the actual canal channel substantially will be finished before the passage of the first ship.

The Atlantic division in July, 1912, lacked 8,009,778 yards of completion; the Central division, including the Culebra cut, lacked 10,678,953 yards; and the Pacific division, 17,637,217 yards—a grand total for the whole canal of 36,325,948. The ancient trouble, slides, prevented the completion of the Culebra cut in 1912.

During the early part of 1912, the Gatun Lake was stationary at about 17 feet, but with the beginning of the rainy season in May it began to rise, and the plan was to hold the lake, by use of the spillway, at a head of water of 50 feet until the beginning of the rainy season in 1913, when it will be allowed to raise to 80 feet, and this would back the water up, by September, 1913, to a depth through the Culebra cut to permit the passage of some kind of a ship. The ultimate level of the lake will be 85 feet.

There have been many estimates of Col. Goethals in the magazines and newspapers and in books. They all pay tribute to him as an administrator without a superior. Some writers have been so impressed by the man that they rate him a larger fact than the canal itself. Yet it is possible to gauge the man without overshooting the mark in that fashion. Congress gave him a credit of $290,000,000 and allowed his estimates of annual expenditures. He has missed the worries of a private contractor who has to consider the financial ways and means of his operations, and besides, the dissatisfaction of employees have been stifled by an unparalleled standard of pay and by gratuities that make nearly every position in the Canal Zone in the nature of a sinecure. Contentedness has been bought by pouring millions of dollars into creating not merely comfortable, but even luxurious conditions of living for the employees.

No private enterprise could succeed for a moment on such a basis. On its economic side, the canal proves nothing because any competent organization could bring things to pass if only enough money is forthcoming, as has been the case under the government in Panama. An admirable job has been done in Panama, but it has not been economically done, in the usual understanding of that word. Nobody set out to do it economically. Every leak has been plastered with a dollar. At no point does the canal project affect a complete economic operation. Money is being spent but it is not being made. The work is being done without regard to its ever paying.

Socialists, therefore, should be cautious in holding up the canal as an example of their theories in successful practice. Industrial life, even under Socialism, would have to do what the canal project has not done and is not required to do, namely, justify itself as a business proposition. The canal ultimately may do this, but it will not be because it was designed and constructed with that imperative end in view. Even the commissary and subsistence operations that usually evoke strong approval as evidences of governmental efficiency, possess no socialistic and slight communal aspects. The government has made them pay by arbitrarily exacting a profit under noncompetitive conditions. None of the forces of industrial life that tend to make for favorable or unfavorable economic conditions, can operate in a government job which secures its capital, not because of the intrinsic merit of the enterprise, but through the gratuitous function of taxation.

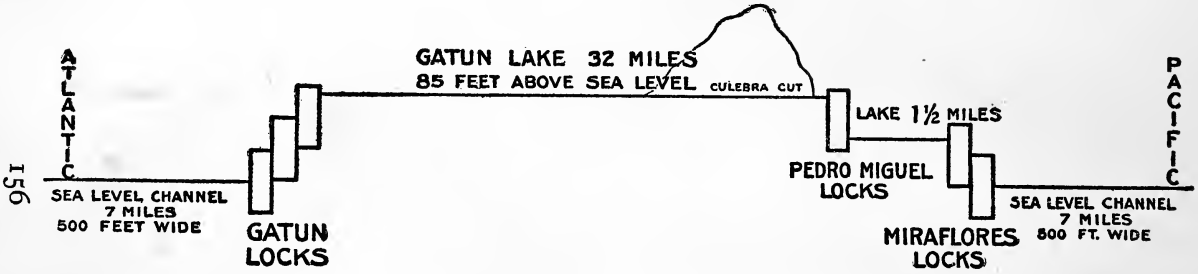
If we turn to the purely technical side of the project, unquestionably the highest praise is due to the Army engineers. On its engineering side, the canal proves that the government does not have to go outside its own forces to find the highest order of ability. The American people never again will clamor for private initiative and execution of any enterprise they may want accomplished.

Col. Goethals is indeed a great administrator. Even if the employees have had soft conditions of employment, it is an achievement to impress 35,000 men with a faith both in your capacity as an engineer and your

sense of justice. This writer knows of no higher tribute that can be paid to him than the statement that in five months in the Canal Zone he never heard anyone speak slurringly of the Chief Engineer. Col. Goethals has been no respecter of persons. In 1912, two officials drawing $300 a month salary each, were discharged as summarily as any common laborer would have been, for breaches of the rules. It has been his practice to give his Sunday mornings to hearing grievances from employees, and those without just grounds of complaint are sent about their business peremptorily, while those who have been wronged are given justice, no matter how high the official who is in error. The man's admirable poise is shown in the just way he has exercised the absolute power of a Czar, for when he sets his pen to paper a new law is made in the Canal Zone. Those who cannot square their conduct with his fiat, go out on the next steamer, whether an individual or a labor union *en masse.*

As Admiral Schley said of the controversy over the battle of Santiago, " there is honor enough for us all," so with regard to the Panama Canal. Col. Goethals, as the star of the last six years, gets the curtain calls, but even if we assign Messrs. Stevens and Wallace to the rôles of villains, they, too, did their parts well. And the whole company of Americans, composing the chorus or supernumeraries, have contributed vitally to the success of the play. After all, it is no one man, but the Spirit of Americanism, indomitable and triumphant, that we admire in Panama. Future generations will see in Col. Goethals the outward head

of this national characteristic, but the final verdict of approval will be much broader and more just than that, even to the admission that all praise belongs to the Americans in Panama.



PROFILE MAP OF THE PANAMA CANAL.

CHAPTER XIV

LOCKS AND DAMS

AN elevator system for ships is being installed at Panama at a cost of $58,000,000. These elevators, known as locks, will raise ships to and lower them from the great artificial, inland lake which is 85 feet above sea-level.

In a sea-level canal, such as Suez, ships steam through a dug-out channel from one ocean to another. But at Panama, the plan adopted involves the lifting of ships over the Isthmus and the locks are the means whereby they are lifted. For this physical operation there are six locks on the Atlantic side and six on the Pacific side, at each end of the Gatun Lake.

A ship arriving at Colon from New York, on its way to San Francisco, enters the sea-level channel in Limon Bay and steams for seven miles through the canal, which is 500 feet wide and 41 feet deep, to Gatun. Here its way is barred by a massive pile of masonry with impressive steel gates and towering 85 feet above the ship is the surface of the Gatun Lake. To the West of the ship runs the man-made mountain, the Gatun dam, which holds the lake in bounds. The problem is to lift the ship to this lake.

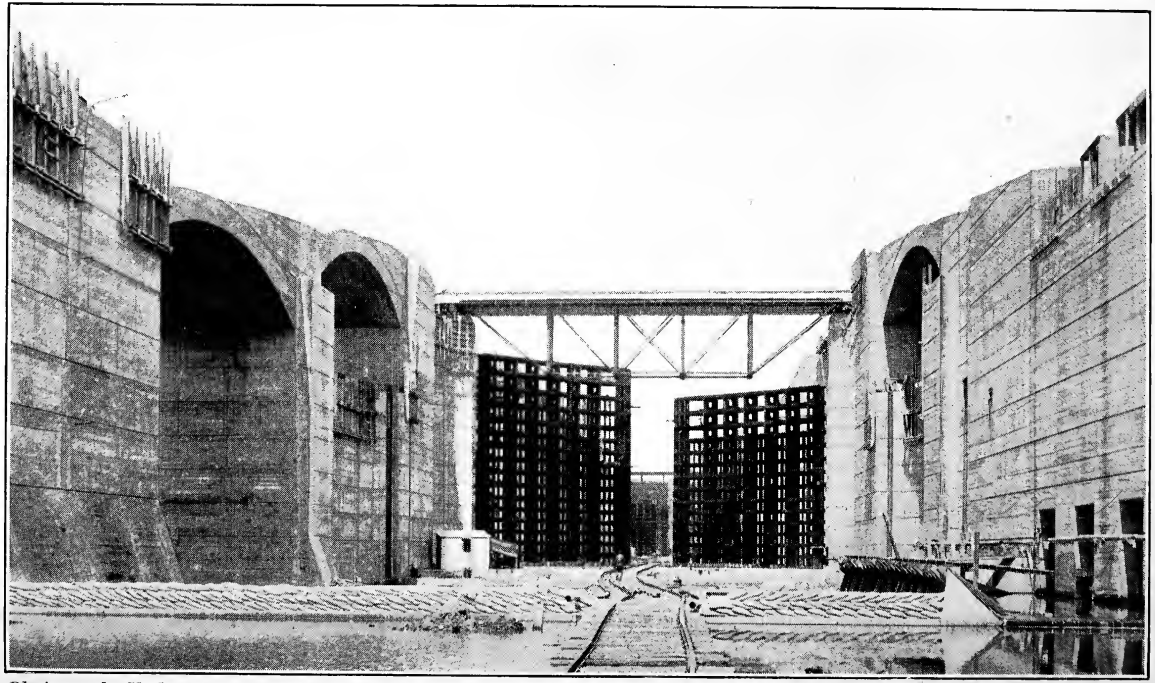
As if by magic, the gates swing open and an electric locomotive, which has run out on a guide wall and fastened to the ship, tows it into the first lock. The

gates swing together and the ship is imprisoned in a chamber 1,000 feet long and 110 feet wide and built of concrete. In a moment the water in this chamber begins to rise, being supplied through holes in the bottom, and the ship rises with the water.

Fifteen minutes after entering the lock, the ship has risen with the water for 27½ feet. If the full capacity for filling the lock should be used the ship would rise that height in eight minutes. Another set of gates swing open in front of the ship, and the locomotives tow it into the second lock, a concrete chamber of the same dimensions. The gates having closed behind, this chamber begins filling with water until the ship is raised again for 27½ feet. A third set of gates open and the ship is towed into the final lock where the operation is repeated with a raise of 30 feet, or a total lift for the three locks of 85 feet. When the gates in front swing open the ship steams out into the Gatun Lake. The time spent in climbing 85 feet was an hour and a half.

For sixteen miles through this lake the ship steams in a channel 1,000 feet wide; for four miles in a channel 800 feet wide, and for three miles in a channel 500 feet wide, or twenty-three miles in all. Then it enters the famous Culebra cut, which is 300 feet wide through the continental mountain divide, and nine miles long. At the end of the Cut is the Pedro Miguel lock, thirty-two miles from Gatun.

After entering this lock, which essentially is the same as the ones on the Atlantic side, the ship goes through the reverse of the process at Gatun. The



Photograph, Underwood & Underwood, N. Y.

ENTRANCE TO A LOCK—GATES UNDER CONSTRUCTION.

water in the concrete chamber begins falling, taking the ship down with it. When it has fallen 30 feet the gates in front open and the ship goes out into another artificial lake, a mile and a half long, at the end of which are the Miraflores locks. These two locks lower the ship $27\frac{1}{2}$ feet each, or a total for the three locks of 85 feet, which was the height the ship was raised on the other side. The ship then steams through a sea-level channel for seven miles to the Pacific, having made the whole journey from deep water in the Atlantic to deep water in the Pacific, fifty miles, in ten hours.

Thus it will be seen that the Atlantic and Pacific oceans are still separated by thirty-two miles of land at Panama, on which is a fresh-water lake 85 feet above sea-level. The locks simply are so many stair-steps up to and down from this lake. At both ends the locks are built in pairs, or twins, so that ships going in opposite directions may pass through them simultaneously. A wall 60 feet thick separates the locks, and if one set should become disabled, the adjoining set still would be available for passage. The time required for a ship to mount the three locks on one side and descend the three locks on the other side is three hours.

On the Atlantic side, the locks at Gatun are connected and constitute one solid piece of masonry. On the Pacific side the lock at Pedro Miguel is separated from two locks at Miraflores by a small lake a mile and a half long. This lake, like the great Gatun Lake, is formed by damming rivers. A dam at the Pedro

Miguel lock, which is the first lock encountered going toward the Pacific, holds the waters of Gatun Lake from spilling down the Pacific slope.

Chief Engineer Stevens began the excavations in the Gatun and Pedro Miguel lock sites in 1906, shortly after the decision was made for a lock-type canal, but most of the excavation and all of the concrete laying has been done under Col. Goethals. It was necessary to remove about 5,000,000 cubic yards of rock and earth from the site of the three locks at Gatun to prepare a foundation for the tremendously heavy structure. Careful borings had been made to ascertain if a suitable foundation could be found there.

On August 24, 1909, the first concrete was laid in the Gatun lock site. Rock of a desirable kind for use in making the concrete, as well as sand, could not be found in the Canal Zone, and experiments along the coast showed that at Porto Bello, twenty miles East of Colon, good rock could be quarried, and sand was discovered in suitable quantities and quality at Nombre de Dios, forty miles East of Colon. These two places are the oldest on the Isthmus, Columbus having been there in 1502.

Rock crushing began at Porto Bello on March 2, 1909. If all the rock and sand removed from Porto Bello and Nombre de Dios was placed in barges separated by the usual distances in a tow, they would reach from Colon to New Orleans, or 1,500 miles. This material was towed to Colon and thence through the old French canal to Gatun. Here it was unloaded

by machinery and stored conveniently for the concrete mixing plant.

All the machinery and equipment for building the locks was designed on a scale commensurate with the unprecedented size of the structures. Eight giant mixers were fed with rock, sand, and cement by cars operated by electricity, the finished product coming from each of the mixers at the rate of 64 cubic feet for each complete operation.

To get the concrete into place, four cableways, suspended across the lock site on towers 85 feet high, were installed. Electrically operated cars brought the concrete to these towers where great buckets were filled. These buckets then were run up to the cables, and out on the cables to a given point, where they were lowered and the concrete dumped into the proper position.

After the floors of the locks had been laid, the walls were built in the usual manner of erecting steel forms, which were removed when the concrete had hardened. At Gatun the walls of the locks were built in sections 36 feet long, and joined together, on the idea that such construction would have less tendency to settle and crack than if it was built in one solid, continuous wall. This may be appreciated when it is understood that at Gatun the locks form a concrete wall about 3,500 feet long, or considerably more than half a mile. The usable part of each lock is 1,000 feet long and there are three in flight. The twin locks have an outside wall 52 feet wide, an inside measurement 110 feet wide, a separating wall 60 feet wide, another inside

measurement of 110 feet, and a final outside wall 52 feet wide, or a total width for both locks lying side by side, from outer wall to outer wall, of 384 feet.

In each of the outside walls and in the center wall tunnels 18 feet in diameter were constructed for use in filling and emptying the locks with water during the processes of raising and lowering ships. Smaller tunnels run out from these main longitudinal tunnels, under the floors of the locks with openings through which the water is turned into or withdrawn from the lock chambers by gravitation. Valves operated by electricity regulate the flow of the water. The water for operating the locks starts from the Gatun Lake and flows through the tunnels downgrade, through the three locks, until it finally is used in the lowest lock when it is spilled into the sea-level channel.

The first concrete for the Pacific side locks was laid at Pedro Miguel on September 1, 1909, seven days after the beginning of operations at Gatun. It was in February, 1910, that concrete work was started in the two locks at Miraflores, which, in 1912, were the most backward feature of canal construction. For all twelve locks, 4,302,563 cubic yards of concrete is required. Three years after beginning the concrete work, or in August, 1912, the locks were more than 90 per cent completed, the one at Pedro Miguel being the nearest done with 98 per cent of the estimated concrete in place. The three locks at Gatun then had about 95 per cent in place and the two at Miraflores about 80 per cent.

For the three locks at Gatun, 2,000,000 cubic yards

of concrete was required; for the one lock at Pedro Miguel, 889,827 cubic yards; and for the two locks at Miraflores, 1,412,736 cubic yards. A contract was awarded the Atlas Portland Cement Co. for 4,500,000 barrels of cement, with the privilege of increasing this order by 15 per cent, and in 1912 another 1,000,000 barrels were bought to complete the canal. The stability of the locks depends upon the quality of cement used, hence the Government inspectors have watched this factor jealously.

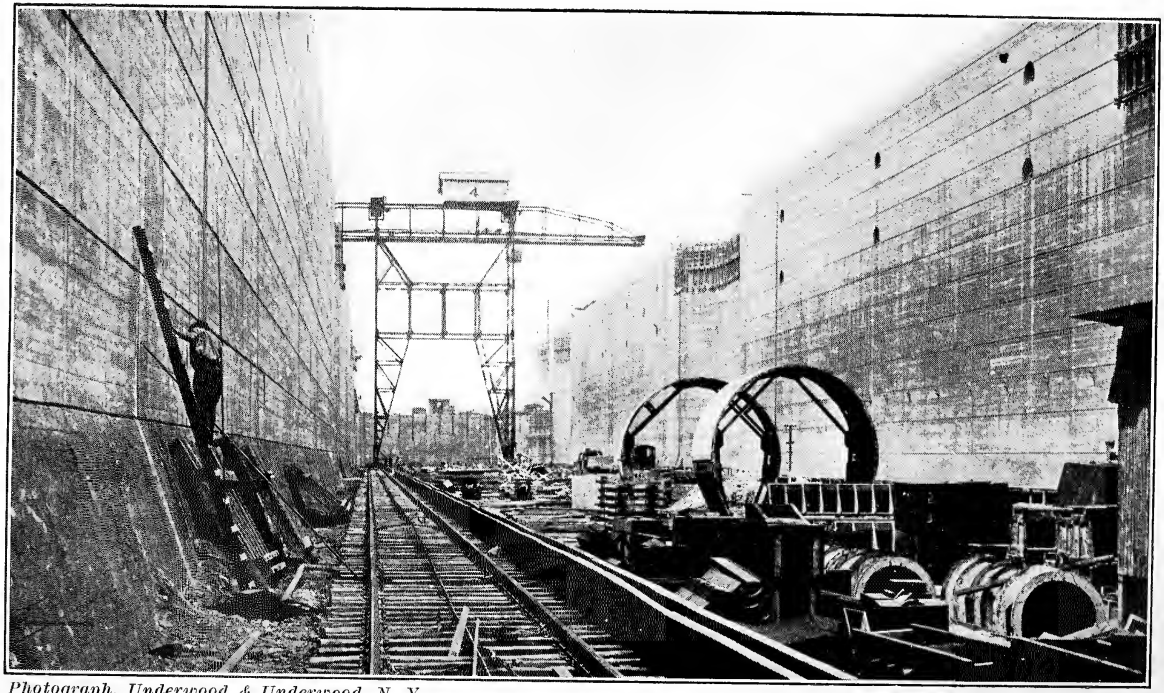
Rock for the Pacific locks has been obtained at a quarry opened in Ancon hill, at the Pacific entrance of the canal. The sand has been brought from Chame, about 23 miles up the coast from Panama. The Pacific division has been at much less expense in obtaining materials than the Atlantic division, accounting for the difference in the cost of construction in the two divisions. The Pacific division was at one disadvantage in that the three locks were not together, as on the Atlantic side, necessitating practically two separate jobs. The amount of excavation at Pedro Miguel to secure a foundation was 770,000 cubic yards and at Miraflores, 2,247,600 cubic yards, a total for the three locks of 3,017,600 yards, which is nearly 2,000,000 yards less than had to be excavated in the site of the three Atlantic locks.

All twelve locks were half done as regards the concrete work, about May 1, 1911. The best month's record for laying concrete was made in April, 1912, in the Pacific division, when 97,735 cubic yards were laid. The concrete is all of reënforced construc-

tion, and an unusual feature has been the placing of rocks weighing many tons throughout the walls. The lock walls at Pedro Miguel were not built in sections as at Gatun, but as one solid piece of masonry more than 1,000 feet long. At Miraflores the two locks were built in sections, as at Gatun.

The gates for the locks were contracted for, in 1910, to cost $5,374,474.82. Their construction and erection are by the McClintic-Marshall Construction Company, of Pittsburgh, under the inspection of the Commission. This concern, in 1912, had more than 1,000 men at work and were rushing the construction to meet the dates agreed upon for their completion. Under the contract this company had until January 1, 1914, to finish the work, but estimated that this time could be beaten by six months. The date for finishing the gates at Pedro Miguel lock was May 1, 1912, but the contractor was behind on this program; at Gatun the gates were to be erected by February 1, 1913; and at Miraflores by June 1, 1913. Work was rushed on the gates at the lake end of the Gatun locks, in the summer of 1912, to hold out the rising water. On July 1, 1912, out of a total of 58,000 tons of steel required in all the gates, 19,631 tons had been erected, or 34 per cent, leaving to be erected before September, 1913, when the first ship is scheduled to go through, 38,369 tons.

There are 46 gates in all twelve locks, with two leaves to the gate, or 92 leaves. The gates are from 47 to 79 feet high, are 7 feet thick, and weigh from 300 to 600 tons each leaf. They are constructed with



Photograph, Underwood & Underwood, N. Y.

INTERIOR OF A LOCK—CAPACITY, TWO SHIPS AN HOUR.

interior cells, which at the bottom will be air chambers to assist in their manipulation, and at the top, water chambers, to increase their weight as the water rises in the locks. The sheathing is with steel plates riveted on heavy girders. These gates will be opened and shut, to permit the entrance or egress of ships, by electrical apparatus.

As 95 per cent of the vessels in the world are less than 600 feet long, it would be a great waste of water and time to use the full 1,000-foot lock in each passage. So intermediate gates are being constructed which will permit the use of only 400 or 600 feet as the particular vessel may require. There are recesses in the lock walls which allow the gates to be opened and still leave a clear width of 110 feet. At the entrance of the locks, a chain, with links three inches in diameter, stretches from one side to the other to stop vessels which might not obey the signals. In case the first gates should be rammed and broken, a second set of gates especially provided for emergencies have been constructed behind the first set. If both sets of gates should be demolished, the water would rush through with a fearful velocity, but provision has been made against this contingency by having in readiness emergency dams, which would be swung out over the lock and forced down through the inrushing water. This dam, built of steel, is open at the bottom and steel plates are then shoved down it, gradually closing the openings until the flow is stopped. A floating caisson would then be placed in position and sunk, completely shutting out water from

the lock, the emergency dam would be raised, and repairs begun.

It is to prevent such accidents that the plan of towing vessels through the locks with electric locomotives was adopted, as then no misunderstanding of signals from the captain to the engineer of a ship could result. The tracks for these locomotives are on each side wall of the locks, and two will fasten to the rear and two to the front of a ship to effect a passage. If all twelve locks were joined end to end they would make a canyon nearly three miles long, 110 feet wide and 80 feet deep.

The Gatun Dam

The natural topography of the Isthmus at Panama permitted the Chagres River to escape into the Caribbean Sea through a break in the mountains at Gatun. Engineers logically considered that this was the point at which a dam should be thrown across the Chagres River. Two valleys were formed at Gatun by a hill which rose in the center to an elevation of 110 feet, and the dam that was designed runs from the Gatun locks to this hill and from this hill to the mountains, a total distance of 7,500 feet, or a mile and a half.

As the Chagres River every year discharges enough water to fill the lake, some means of disposing of the surplus water had to be provided. The plan adopted called for a spillway to be constructed in this hill, about third-way in the dam site. This spillway is of concrete, requiring 225,000 cubic yards to complete.

On July 1, 1912, it was more than 90 per cent completed.

The floor of the spillway is 10 feet above sea-level, and 300 feet wide through the hill, which involved excavation through rock for a depth of 100 feet at the highest point of the hill. A concrete dam was built on this floor to a height of 69 feet above sea-level and in shape like a semicircle. On top of the concrete dam, piers were built with an arrangement for steel gates. These steel gates will be electrically operated and regulate the flow of water out of the lake. As much as 140,000 cubic feet of water per second may escape through the spillway when the gates are open.

There will not be a complete loss of this water, as on the east side of the spillway a power plant of the hydro-electric type will be operated. A drop of 75 feet by the water will operate turbine engines which in turn will operate the electric machinery that will generate all the power and illuminating current needed from one end of the canal to the other. But an additional power plant will be maintained at Miraflores for emergencies. The power to operate the lock gates will come from the spillway plant.

The Gatun dam is so stupendous that it almost seems to be a continuation of the hills that enclose the lake. It in fact does complete the natural mountain chains that form the barriers of the Chagres River. It is 105 feet high, or 20 feet above the ordinary level of the lake at 85 feet elevation. The plan of construction has been to build parallel mounds, for the mile and a half, 1,200 feet apart. Between

these mounds, built of rock and earth, a core for the dam has been constructed by pumping mud and sand from the bed of the Chagres River. About 20 per cent of the material pumped is solid matter, and when it has deposited the water is pumped off. This operation has been repeated until an impervious heart has been made in the dam. Even if water from the lake penetrated the outside walls of rock and earth, it would find this core water-tight. The dam is nearly half a mile thick at the base, 398 feet thick where the water surface strikes it at 85 feet, and is 100 feet wide at the top. The outer coverings of rock and earth on the dam close over the hydraulic core at the crest. For about 500 feet the dam will be subjected to the full pressure of 85 feet of water, at other points to a less severe pressure.

Engineers consider the dam excessively safe and the layman has no difficulty in appreciating its strength. This feature was subjected to a storm of criticism throughout the early days of the canal because some engineers believed the earth would not support so heavy a structure, but the present Chief Engineer never has doubted its stability. About half of the material required, 21,994,111 cubic yards, has been brought from the Culebra cut. On July 1, 1912, the dam was more than 90 per cent completed, leaving less than 10 per cent to be done before the passage of the first ship.

On the Pacific side, the first dam encountered is at Pedro Miguel and serves to hold the waters of Gatun Lake at its southern end. It is 1,400 feet long and

forty feet wide at the top. The maximum height of the water against this dam will be 40 feet. The plan of construction is much the same as at Gatun, but only about 1,000,000 cubic yards will be required.

After a ship is lowered 30 feet by the Pedro Miguel lock, it finds itself in an artificial lake a mile and a half long. This lake is formed by two dams, the one to the west being 2,300 feet long, and 40 feet wide at the top, holding a maximum head of water of 40 feet. It is constructed with a hydraulic core like the Gatun dam. On the east a concrete dam 500 feet long, and provided with a spillway, as at Gatun, and capable of discharging 7,500 cubic feet of water per second, will hold the small lake in control. The Cocoli River is the principal feeder of this lake.

Records kept by the French, and by the Americans since 1904, show conclusively that enough water always will be available to keep the Gatun Lake and the tiny Miraflores Lake adequately supplied with water. No trouble at all can develop during the eight months of rainy season, and in the dry season of four months enough water will have been stored in the lake by means of the regulating works in the Gatun dam spillway to allow for all losses through evaporation, seepage, power consumption, and loss through the locks. During the wet season the lake will be raised from elevation 85 for two feet, to elevation 87, over an area of 164 square miles. This water could be used until the lake falls to about 82 feet, or five feet over the 164 square miles. In an average dry season this would permit 58 complete transits of the canal

every 24 hours, if the full 1,000-foot capacity of the locks is used, or more than the period would allow if vessels followed at intervals of one hour.

The Gatun Lake is backed up among the hills by the dam until it reaches a width of more than twenty miles at the widest point, and a length between Gatun and Pedro Miguel of thirty-two miles. It will be broken by many small islands, and stretches of high lands, and is narrowest in the Culebra cut where for nine miles the width is 300 feet. From Gatun to the entrance of the Cut, a distance of twenty-three miles, lighthouses are stationed at commanding points to guide ships at night. The channel throughout is at an average depth of 45 feet. In order to raise the relocated Panama Railroad above the level of the lake it was necessary to make fills to the extent of 16,425,292 cubic yards.

The Navy Department has selected a site near San Pablo, about twenty miles inland from the Atlantic, and on the East side of Gatun Lake, for a high power wireless station. It is to be at an elevation of 110 feet above the level of the lake and capable of sending a message for 3,000 miles, to Washington, D. C., or to a similar station on the California coast. Smaller stations will be maintained at Colon and Balboa in the Canal Zone, and at Porto Bello. The Republic of Panama and private companies will not operate stations in competition with the American government.

If the great Gatun dam should break, the water in the lake might sweep devastatingly over the city of

Colon, seven miles away, or pass through the old bed of the Chagres River harmlessly into the Caribbean Sea. While the pressure on the dam will be terrific, no such catastrophe is considered probable.