CHAPTER LII

AMERICAN INDUSTRIES AND THE CANAL

CANAL THE RESULT OF A MULTITUDE OF INDUSTRIAL EFFORTS—AMERICAN MACHINERY, EQUIPMENT, AND INDUSTRIAL GENIUS MET EVERY NEED—HEARTY COÖPERATION WITH CANAL AUTHORITIES—THE "INDUSTRIAL ROLL OF HONOR"—ELECTRICITY ON THE CANAL—EFFICIENT DRILLING MACHINERY—BLASTING OPERATIONS—MILES OF WIRE AND MANILA ROPE—CRUSHING AND DREDGING EQUIPMENT—STEAM SHOVELS—ENGINES—ENORMOUS CONSUMPTION OF CEMENT—GREAT VARIETY OF MECHANICAL AND SCIENTIFIC TOOLS AND INSTRUMENTS—SPECIAL DEVICES—TRANSPORTATION—COMMISSARY—HOUSING—GENERAL EQUIPMENT.

STRONGLY as the Panama Canal appeals to the imagination as the carrying-out of an ideal, it is above all things a practical, mechanical, and industrial achievement. The completed work is made up of a multitude of industrial efforts applied to every phase of the actual work of construction, to the machinery used on the canal, and to the health and comfort of the men engaged in the work.

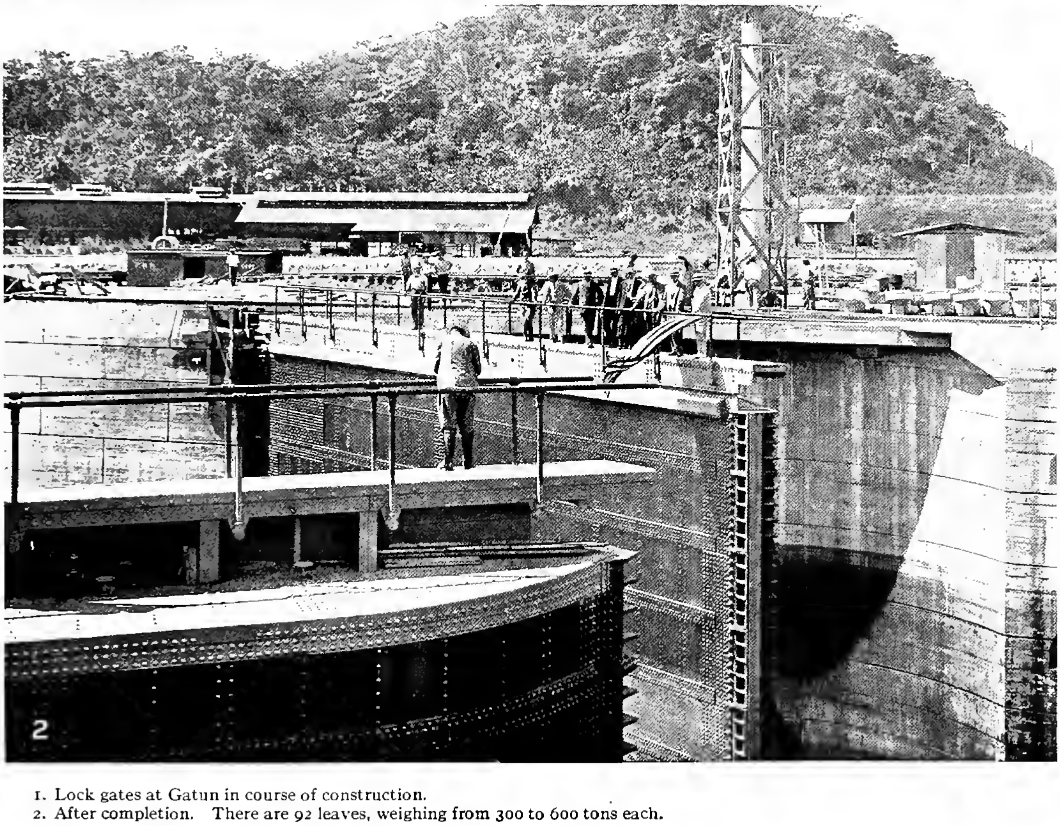
From the gigantic dredges, cranes, and other appliances designed especially for the construction of the canal to the use of bronze instead of iron in delicate machinery to offset the rust conditions of a tropical climate, the practical genius of the American industrial world rose to meet the new and extraordinary conditions under which the work progressed to a triumphant conclusion.

It is a matter of pride to the United States that although the competitive system of bidding was in vogue on the canal, American machinery, American sanitary appliances and American goods of all descriptions were almost without exception found the best and most economical. There was no graft and no waste in the canal work. The products of industry, both of the myriad implements and for the men who labored on the canal, were the best the world could provide.

It may well be that the construction of the Panama Canal will remain for centuries the most stupendous engineering and practical feat of man. For this reason, it was deemed wise to incorporate in this history an outline of the machinery and industrial products and appliances which were used on the canal, not only as a matter of present pride and satisfaction, but because this phase will be of extreme historical value to the student in future years. Even in the short period of time between the cessation of work on the canal by the French and the beginning of the American operations, a remarkable development in machinery and construction equipment had occurred.

The French railways, engines, dredges, hoists, steam shovels and practically all other equipment had become far out of date. The little Belgian locomotives, resurrected from their rust and decay, testified to the good workmanship of their makers by getting into action in the beginning of the American operations, and some of the remaining French machinery was used for a time, but only pending the arrival at the Canal Zone of the more modern equipment which had come into being since the French operations ceased.

In the period following the failure of the de Lesseps plan until the United States began the construction of the canal, the era of steel and machinery development had attained full growth in America. The sky-scraper building had come into being, with its attendant construction machinery. Plentiful supplies of oil and gasoline as fuel



1. Lock gates at Gatun in course of construction.
2. After completion. There are 92 leaves, weighing from 300 to 600 tons each.

had resulted in new types of engines. The great development of American railroads had brought forth heavier engines, and in their path a multitude of machines for excavating, bridge construction, grading, and expeditious shifting or loading of freight. The use of concrete had increased sevenfold, together with the machinery necessary to its use. The giant dredges of the western gold fields, the swamp lands, and the rivers and harbors of the country had been perfected.

When the American engineers came to the building of the canal, all the fruits of this development were ready to aid them. Based on practical experience at home, there was no problem at the canal which American inventive and constructive genius was not ready to solve. If the canal engineers wanted larger machines, the manufacturer was ready to make them. If some types of machinery or equipment staggered under the continuous strain of the canal drive, the manufacturers knew how to strengthen them. They were always ready to fill all requisitions promptly and efficiently. Beyond question, the early completion of the canal is greatly due to the hearty spirit with which American manufacturers coöperated with the desire of the canal builders for speed and efficiency.

Just as the French equipment passed into an obsolete day, so with another turn of Time's wheel, the great engines and machinery which completed the cut from ocean to ocean may take their place on the scrap heap; but at present they embody the high mark of mechanical efficiency in the world, with a record that is well worth the attention of the present generation and that of posterity.

Second only to the roll of honor of the men who had part in the actual construction of the canal is the roll of American industrial concerns which had so great a part in making the labor of the men more healthful, more expeditious, and less arduous. The canal's "Industrial Roll of Honor" is worthy of a high place in the pride which all the world must take in the culmination of the dream of centuries,—the linking of the two oceans by those who work as well as dream.

The various industrial elements which made up the completed canal drop easily into several great divisions. The chief of these are the application of electricity to the completed work and during construction; the efficient drilling machinery which paved the way for the enormous quantity of explosives; the processes of blasting; the part which wire roping played in canal construction; the great steam shovels; the crushing, dredging, and excavating machinery; the sanitary equipment; the enormous consumption of cement; the mechanism of transportation; and the vast amount of miscellaneous equipment which American industry provided.

Electricity in the Construction and Operation of the Canal

In describing the utilization of electric energy in the construction and operation of the Panama Canal, a comprehensive idea of the character of the apparatus provided may be most logically obtained by segregating the references under three general heads:

The first comprises the equipment of the power stations, both steam and hydraulic, in which the necessary energy is generated, and the transmission system by means of which it is distributed to the various working points.

The second includes the motor and control equipment of dredges, cableways, loading and unloading devices, electric locomotive haulage, and the operation of auxiliaries, such as rock crushers, cement mixers, etc., required during the construction period.

The third section deals with the part played by the electric motor in the operation of the lock machinery, the devices designed to insure safety, coördination and positive control of the various sections during the cycle of operations involved in passing a ship through the locks, and the unique type of haulage locomotives adopted for handling the ships during their transfer to different levels.

In providing electrical equipment for the Canal Zone, it was necessary to consider the special nature of the operating conditions imposed by climate, the imperative demand for continuous service in spite of the apparatus being so far away from the manufacturer of electrical supplies, and the importance of having all parts as nearly "fool proof" as possible. All this entailed a great deal of study and care on the part of the Isthmian Canal Commission engineers in preparing the specifications, and on the part of the manufacturer in building the apparatus to meet these conditions.

The power distribution is composed of:

A 2,200-volt hydro-electric power plant at the Gatun dam spillway.

A steam-electric power plant at Miraflores, erected originally to supply power for construction work, but which will be held for emergency operation.

A double 44,000-volt transmission line across the isthmus, connecting Cristobal and Balboa with the two power plants.

Four 44,000/2,200/240 volt sub-stations, stepping down at Cristobal and Balboa, and up or down at Gatun and Miraflores, depending upon which one of the two plants supplies the power.

Thirty-six 2200/240 volt transmission stations for power, traction, and light at the Gatun, Pedro Miguel, and Miraflores locks.

Three 2200/220/110 volt transformer stations for the index and control boards at the three locks.

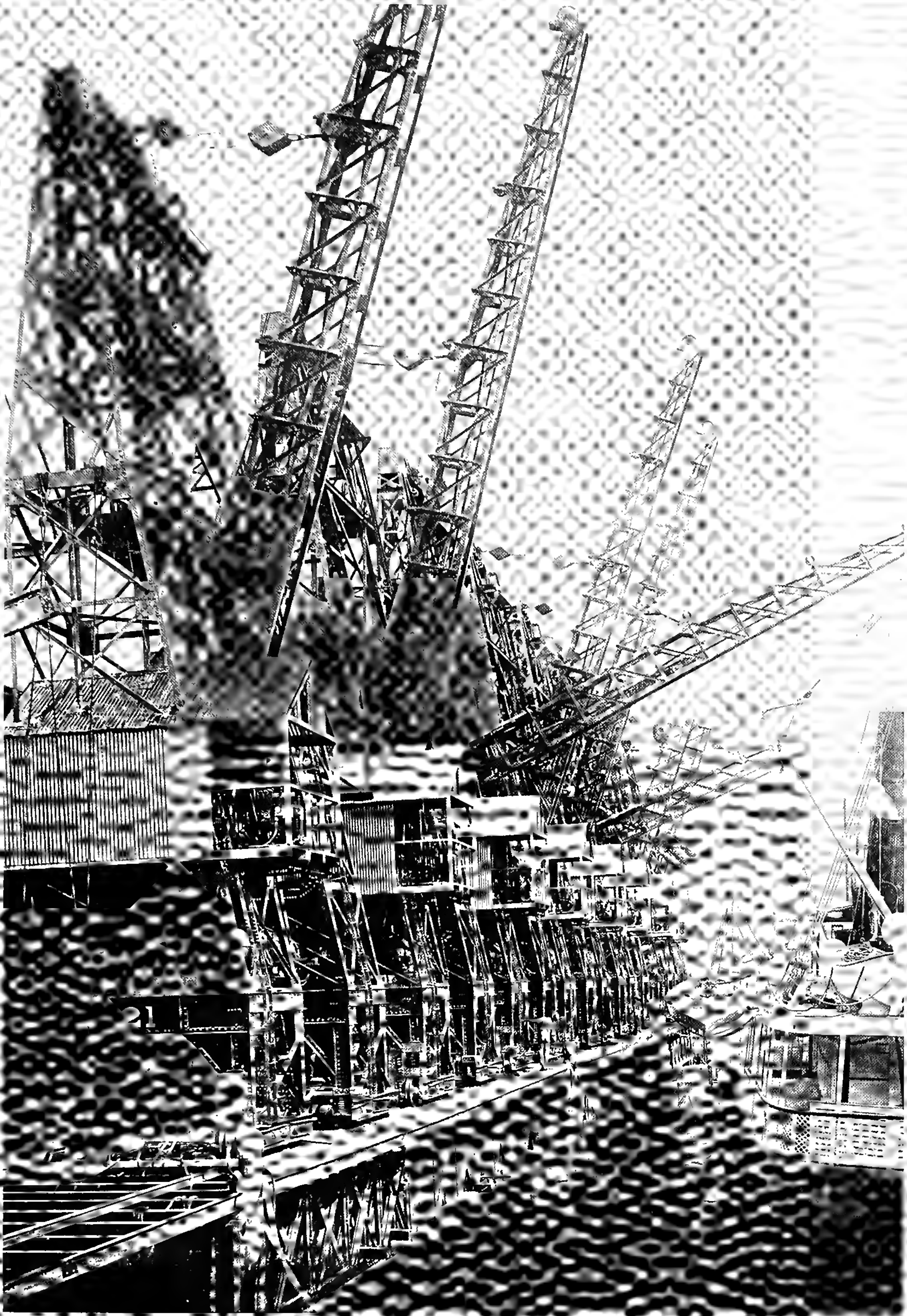
Similar stations at Cristobal and Balboa for coal handling plants, machine shops, and dry docks.

The Gatun hydro-electric station is located at the dam of the artificial Gatun Lake, so that the water from the wheels, together with that from the spillways, discharges into the original channel of the Chagres River. The present installation consists of three 2,000 kw., 2,200 volt, 25 cycle, three phase alternators direct connected to 250 r.p.m. vertical reaction-type water-wheels provided with direct connected exciters, as well as two induction motor-driven exciters with a generator voltage regulator. The station plans anticipate the possibility of three additional generators, should the Panama Railroad be electrified and its traffic be increased to require that amount of power. All switches for the control of machines and 2,200 volt feeders are electrically operated (including rheostats, exciters, and field switches) by a storage battery, which also provides emergency lighting for the station through automatic transfer switches in case of failure of the alternating current lighting source.

Current is transmitted at the generator voltage to the principal sub-station, also located at Gatun, through which it passes, after transformation to 44,000 volts, to the main duplicate transmission line running entirely across the isthmus, and interconnecting the various sub-stations.

These two three-phase transmission lines consist of No. 00 copper cables with ground conductors of the same size and material, all supported by steel towers placed on both sides of the re-located Panama Railroad. The duplicate steel towers on each side of the railroad are tied together by skeleton steel bridges, some twenty-four feet above the tracks, from which catenary trolleys may easily be suspended should the railroad be electrified.

The four sub-stations are almost identical in size and equipment, although the number of 2,200 volt feeders is somewhat different. The Cristobal and Balboa stations have only outgoing feeders, as they are distributing stations for power to coal handling plants, dry docks, machine shops, etc., where the current is again transformed from 2,200 volts to the most suitable voltage for the local conditions. The Gatun and Miraflores stations both receive and distribute 2,200 volt current. As already stated, the Gatun sub-station normally feeds the entire transmission system from the hydro-electric plant; and from the



Electrically operated cargo derricks installed by the General Electric Company, of New York, at Balboa Docks.

2,200 volt busses in this sub-station the current for operating the Gatun locks is also distributed. The Miraflores sub-station is similarly arranged in order that it may, under emergency conditions, feed the transmission system from the steam-electric plant, and also supply the current for operating the Miraflores and Pedro Miguel locks.

During the construction period electric energy was supplied by two Curtis steam turbo-generator plants, one at Miraflores, which was later held as a reserve station, and a second at Gatun; each having an output of 4,500 kw.

Steam power was generally used in connection with the hydraulic dredging, although in a number of instances centrifugal suction pumps were driven by electric motors. For the construction of the large dam at Gatun several such pumps were used driven by three-phase induction motors.

The greatest field for electric power application in the construction of the Panama Canal was in connection with the building of the different locks. The amount of concrete required for this work was over five million cubic yards, and it was in the manufacturing and placing of this vast amount that electricity played an important part.

On the Atlantic division the crushed rock was received from the quarries and crushers located at Porto Bello, about twenty miles east of Colon, from whence it was transported by means of barges to the storage point at Gatun. The sand was also transported by means of barges from the sand pits at Nombre de Dios, about fifteen miles beyond Porto Bello. The rock crushing machinery at Porto Bello was operated by steam engines.

The rock and sand were unloaded and stored at Gatun by means of three cableways, two of which were of the duplex type. These cableways were operated by 500 volt direct current motors; separate motors being provided for driving the cableways along the tracks and for the hoisting and conveying drums. All the cement was shipped by boat from New York, and the transfer from the barges to the cement shed was effected by ten electrically operated traveling cranes. From the cement shed and the stock piles the raw material was transported to the concrete mixing plant by a three-phase automatic railway.

The concrete mixing plant at Gatun consisted of eight electrically operated mixers, each having a capacity of about 2½ cubic yards. From this plant the concrete was hauled to the lock sites on a third-rail, 550 volt, direct current industrial railway by means of thirteen 6½-ton locomotives. Four duplicate cableways spanned the site of the locks of this concrete railway and transported the dump-buckets to any required point in the lock structure. The complete operation of the towers was done by direct current motors, and the cable ways were operated continuously day and night, the lighting at night being effected by searchlights.

For the Miraflores and Pedro Miguel locks on the Pacific division the method of construction was different from that at the Gatun locks. The rock was, in this case, obtained close to the lock site, from the Ancon Hill, where a number of electrically operated crushers were located, the crushed rock being carried from the crushers to the mixing plant by means of conveyors. The sand was transported in barges from Chame Point, twenty miles from the west entrance of the canal. At the docks in Balboa it was unloaded by high speed electrically operated cranes, and transported by rail to the storage yards which were located close to the mixing plants.

Several of these electrically operated concrete mixing plants located in the towers of the cranes were provided; the sand and rock being obtained from the storage piles nearby, while the cement was transported from the Atlantic side by rail.

For removing and placing the concrete forms and for laying the concrete, four berm cranes and four chamber cranes were provided, the chamber cranes operating on tracks in the lock chambers. The berm cranes were used only at Miraflores. They consisted of metal towers, with fixed cantilevers on one side, operating over storage piles parallel to the lock site, and with booms on the other side. The material was transferred to the concrete mixers located in the towers, and the concrete handled by the booms to the side walls, or the batches transferred to the chamber cranes and laid in the central wall.

At Pedro Miguel the berm cranes could not be operated in the same way, and were, therefore, modified, in that fixed cantilevers were provided on either side of the towers.

The mixed concrete was hauled from the mixers on the towers to the lock pit by cars, and thereafter placed in the central and side walls by the chamber cranes. These cranes were all electrically operated, the motors being of the 500 volt, direct current type.

The magnitude of the work involved called for the design and construction of special machinery, and the ease with which motor drive met the most extreme demands in fluctuating loads, and the operation of conveying apparatus carrying unusual weights at unprecedented speeds, constitute a striking example of the flexibility and overall efficiency of electric drive, which became an important factor in securing the excellent operating records which characterized this work.

Electrical Operation

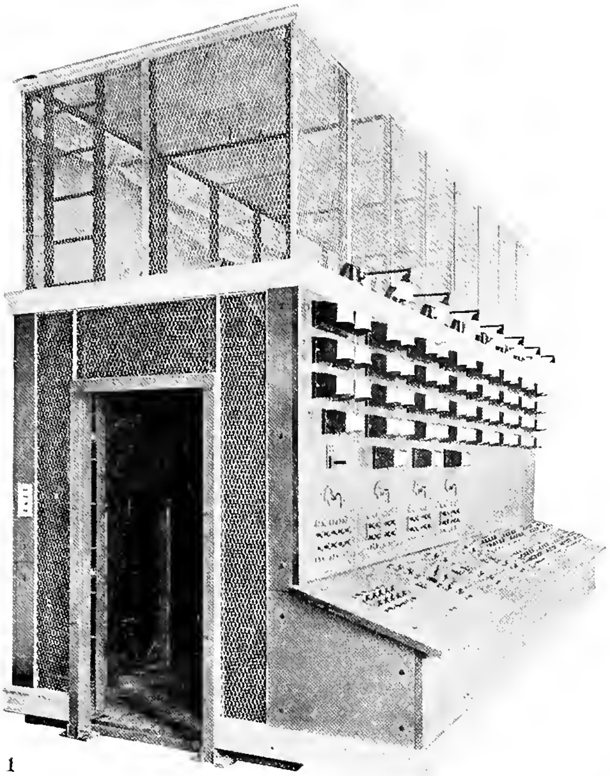
Approximately 1,500 electric motors have been permanently installed for the complete operation of the canal. All of the motors provided for the gates, valves, machinery, dams and cranes are of very substantial construction, being similar to those adopted for heavy duty work in steel rolling mills. They are provided with solenoid brakes and are specially insulated to withstand deterioration due to climatic conditions. The motors are operated on 240 volt, three-phase, 25 cycle circuits.

The rising stem gate valves provided for the main culverts in the side and center walls of the locks, and through which the water from the upper valves will be admitted to the lock chambers, are operated by 116 40 H. P. motors. The upper end of the valve stem is carried by a cross-head actuated by two vertical revolving non-rising screws driven by a reducing gear from a horizontal shaft direct coupled to the driving motor. By means of the solenoid brake the revolving parts may be brought rapidly to rest and, while the machinery is normally operated through a remote control system, auxiliary hand apparatus has been provided for closing the gate in the event of failure of the machinery when it is in the raised position.

At the various locks there are a total of 120 cylindrical valves, each of which is operated by a 7 H. P. motor, the function of these being to control the flow of water from the center wall culvert into the lateral culverts beneath the floor of the lock chamber.

For the operation of the forty-six pairs of lock gates, ninety-two 25 H. P. motors have been provided, one for each gate leaf. In addition to these there are forty-six 7 H. P. motors for operating the miter forcing machines, which force the gate leaves to a perfect junction and lock them in the mitered position. Eighteen 25 H. P. motors are used for operating the guard valve machines which operate the valves that guard the intakes of the side wall culverts at the upper end of each flight of locks.

The hand-rail motors are required to furnish the power for raising and lowering the hand-rails of the footwalk across the tops of the miter gates. These walks provide a passageway for crossing the locks when the gates are closed, and the hand-rail guards the passage. When the gates are opened and in their recess in the lock walls, the hand-rails, if it were allowed, would extend above the level of the top of the lock wall and interfere with the movement of the towing lines. A mechanism was, therefore, devised, and interlocked with the miter gate moving machine, by which the hand-rail is automatically low-



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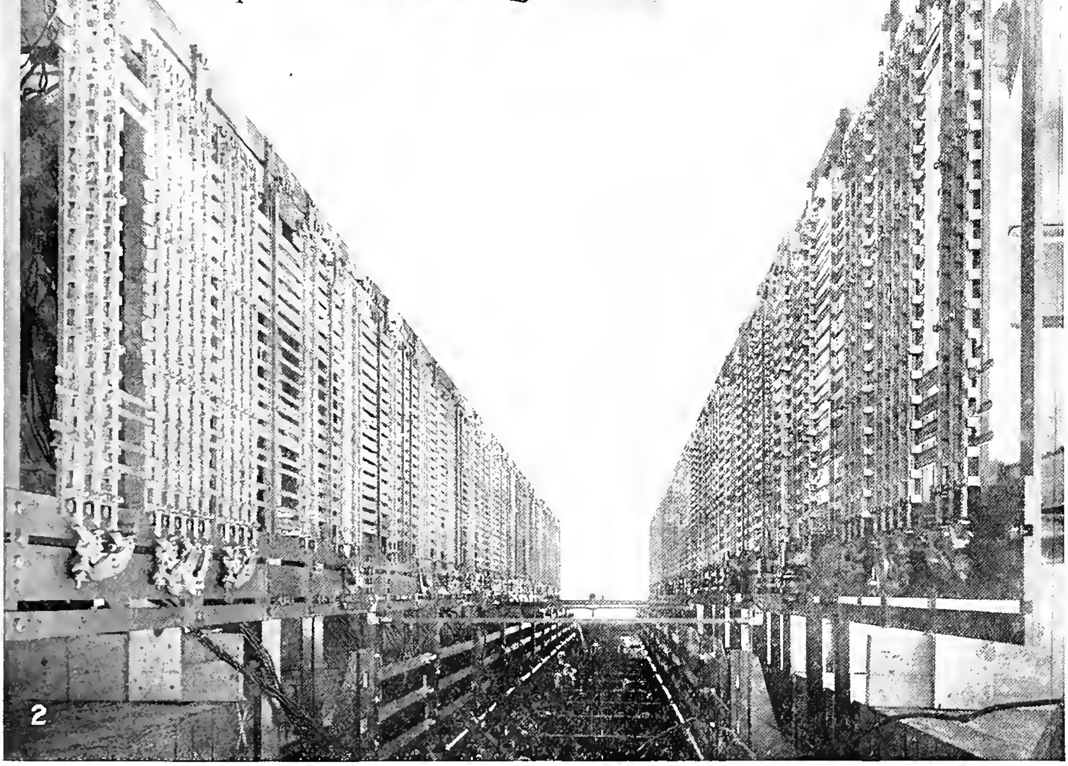

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1. 2200 Volt A. C. instrument and control board for Gatun Hydro Electric Station.
2. Interlocking Rack Lock Control System in Miraflores Locks.
(Installed by the General Electric Company, New York.)

ered when the gate is opened, and raised when the gate is closed. There are 80 motors required for this duty, their rating being 7 H. P.

The chain fenders are operated by means of pumps, and for driving these there are forty-eight motors of 70 H. P. These fender chains are stretched across the lock chambers in front of certain miter gates for the purpose of preventing a ship that might become unmanageable from ramming the gates. The chains are lowered in the floor of the lock chamber whenever it is desired to allow a ship to pass. The mechanism for lifting and lowering the chain consists of a plunger operated by hydraulic pressure, the water for this being furnished by the motor driven pumps.

More than 200 pump motors have been installed. The miter gate sump pumps require ninety-two motors having a rating of 7 H. P. The pump for the drainage sumps at the lower end of each lock utilizes nine motors, also rated at 7 H. P. For the operation of the chain fender sump pumps, forty-eight motors having a capacity of 7 H. P. are used, and for various cable and machinery pits seven motors rated at 7 H. P. To permit the draining of the center wall culverts at intervals, in order to make repairs of the cylindrical valves, there are three semi-portable pumps, one for each lock site. These pumps are of the suspension type and driven by 125 H. P. vertical motors, the pump and the motors being mounted rigidly together.

Six emergency dams have been constructed, two for each of the lock sites. The purpose of these dams is to check the flow of water through the locks, in case of damage, or in case it should be necessary to make repairs, or to do any work in the locks which would necessitate the shutting off of all water from the lake levels. The dams are placed in pairs in the approaches to the upper locks about 200 feet above the upper guard gates, and each can close the approach to one of the twin locks. Each dam will be operated in four movements: the turning and wedging of the dam and the lowering of the wicket girders and the gates. The machinery for these operations is driven by electric motors, but hand capstans have been provided for use in emergency. The turning machinery is installed in the operator's house, and consists of two 150 H. P. motors for turning the bridge and a limit switch to prevent operation beyond an arc of 90 degrees. A 25 H. P. motor operates the wedges which hold the bridge firmly in place when it is at rest across the channel, or on the lock wall. The machine for raising and lowering of each of the six wicket girders of each dam consists of a hoisting drum driven by a 25 H. P. motor, equipped with a limit switch. The gates on the wicket girders are lowered in place with the assistance of gravity, and, when the dam is to be closed, they will be hoisted out of the water. There are, therefore, six gate-hoisting machines for each dam, each machine driven by a 25 H. P. motor.

Each of the gates in the spillways is operated by motor driven machines erected in a tunnel extending the full length of the spillway dam. There are twenty-two of these gates, of which fourteen are located at Gatun and eight at Miraflores. The motors for operating these gates are rated at 7 H. P.

All the motors utilized at the locks are housed in concrete chambers below the surface of the lock walls in order to insure maximum protection, and interruptions to service are guarded against by installing duplicate sets of transformers for supplying current to them.

It might be asked: "Why was electricity chosen to operate the Panama Canal locks? Why not water, steam or air?" This question is answered by saying that only by the use of electricity would it have been possible to control a set of locks from a central point at each flight of locks, and at the same time to arrange the miniature indicating devices in such a way as to be at all times under the control and observation of the attendant. By the use of electricity it was possible to make a combined control and indicating board, and in no other way could a simple, practicable method of remote operation and indication have been devised, particularly since in some cases the distance between the controlling devices and the operating machinery is greater than 2,700 feet.

The commission engineers specified that the lock control boards should be as nearly as possible an operating miniature of the locks themselves, and so arranged that the indicating devices of the control boards would show the positions of the rising stem and other valves, lock gates, and the water level as it changed in the various locks and in the fore bay. It was also specified that in order to pass a ship through any lock it should be necessary for the control board operator always to manœuver the different operating levers in a definite order corresponding to the predetermined sequence of operation of the lock machinery necessary to pass the ship quickly and safely through, and that the operator in control of the eastbound channel of the canal must not in any way be able to interfere with the apparatus under the jurisdiction of the operator controlling the westbound channel. The imposed conditions have been fully cared for. Each lock control board indicates to its operator the actual position of the level of the water and of the lock machinery at any instant. Also, by a system of horizontal and vertical interlocking bars beneath the control board, the control handles are so interlocked that only the proper handle or handles can be operated at any time in the course of a ship's travel through the locks.

The interlocking system forces the attendant to operate the chain fenders, gates and valves always in the proper sequence, and also prevents him from operating these devices in incorrect sequence; for instance, opening the gate when the chain fender is not in position or when the valves are open, etc. There is also an interlocking combination that is used in connection with the intermediate gates which divide the locks into short sections. This arrangement is fitted with Yale lock and key so that the intermediate gates can be used only when the attendant has unlocked the combination, this also being subject to the general interlocking system. Certain valves are used to cross-fill between locks. These also are interlocked so that they can be operated only in proper order and combination to equalize the water between a pair of locks and save water which would otherwise be wasted. This cross-filling consists in allowing water from one lock, which is full, to flow into a lock by its side in the other channel until the level of the water is the same in both locks, thus using a portion of the water over again.

The fact that the control board is a working miniature of the lock which it operates shows the operator the actual condition of gates, height of water, etc., and, consequently, having the whole situation in miniature under his eye he knows what to do next and when to do it; the operator receiving his information as to the movement of the ship from a towing master. The engineers on the locomotives which take the ships through the locks, as well as the towing master, can see the position of the gates, but the position of the fender chains is indicated by semaphore arms on the lock walls.

As ships are not permitted to enter the locks or go through on their own power, a special type of towing locomotive has been designed for handling them during transit from one level to another. This constitutes a unique feature of the electrical equipment of the canal. There are forty of these towing locomotives, each weighing 86,000 pounds, and having an available tractive effort of 47,500 pounds. Mounted in the center of the locomotive body is a windlass having a rope pull of 25,000 pounds. Ordinarily, four of these locomotives will be used to haul ships into and through the locks, two of them on each side, running on tracks parallel to the locks, and obtaining their tractive effort by means of two 75 H. P. totally enclosed motors of the mill type for each locomotive, one motor being direct connected through reduction gearing to the axle. Current is supplied by means of contact plows, and the locomotive is propelled on a rack-rail while towing, and while going up or down the steep grades between levels. The towing speed is approximately two miles per hour, and while running idle on the return tracks the rack pinion is released and the locomotive is propelled by the regular traction at a speed of five miles per hour, the change from one system of propulsion to the other being effected through gearing by manually operated clutches. The two locomotives astern of the ship act simply as a brake on the ship's movement, the forward locomotives doing the towing.

The windlass cable is operated by two 20 H. P. motors, which are totally enclosed, and the cable drum is driven by a friction device which can be set at any desired value—from zero to the full capacity of the motor.

For the supply of coal to naval and merchant ships two coal depots will be provided, located respectively at Cristobal and Balboa. In general, each plant will consist of two water fronts and a storage pile, the water fronts being designated as unloading and reloading wharfs, while the storage pile will consist of a basin for coal, a part of which is to be stored subaqueously, and the remainder piled above it in the dry. The total capacity of the plant at Cristobal will be 300,000 tons, and for Balboa 210,000 tons.

The equipment of the plants will be similar in general construction, and consist of unloading towers, which are self-contained and self-propelled, stocking and reclaiming bridges and reloaders. For the transportation of the coal within the plant a separate conveying system will be arranged. Each reloader will travel on rails laid at the elevation of the decks at the reloading wharves, and will have a normal capacity of 500 tons per hour.

The operation of the entire equipment, excepting the unloading towers, will be electrical, with suitable sub-stations erected at each plant, and steam power will be used only for the operation of the unloading towers.

In addition to the power applications, electricity is used extensively for lighting purposes as well as for such auxiliary service as the operation of the telegraph system, fire alarm, and mining batteries for the defense of the canal. In order that the fortifications may be independent of the main source of electrical supply, they have been provided with small isolated plants equipped with gasolene-electric generating sets.

It is evident that from the foregoing that electricity has played an important part in the construction work involved in this, the largest engineering feat of the ages, and that it is a vital factor in the operation of the completed work, and renders possible in this capacity operating efficiencies not otherwise obtainable.

The success with which the electrical apparatus on the isthmus has met all operating demands serves as an indication of the ability of the designing engineers who were responsible for the detail work, and the possession by the electrical manufacturers of an equipment adequate to meet all the unusual requirements imposed by the remote location and adverse climatic conditions of the Canal Zone.

In this important sphere of the canal equipment, the General Electric Company of Schenectady, N. Y., maintained a dominant position, inasmuch as its factories produced more than one-half of the electrical apparatus used during the construction period, and practically the entire equipment for the generation, distribution and application of electric energy for the permanent operation of the canal proper, the coaling stations at both terminals, machine shops and other auxiliaries.

THE ROCK DRILL ON THE PANAMA CANAL

More than 200,000,000 cubic yards of material have been excavated from the prism of the Panama Canal. Of this great mass, about one-half is classified as rock. All of this rock was drilled and blasted.

An approximation shows that for each cubic yard blasted an average of six inches of blast hole was bored in which to place the explosive required to break the rock. The depths of the holes bored, on this basis, for blasting 100,000,000 cubic yards, would give 50,000,000 lineal feet as the combined depths of all holes drilled. This aggregate of the boring would be of a length sufficient to form a continuous bore more than 1,500 miles longer than would be required to penetrate the earth's diameter from the North to the South Pole. The quantity of material or detritus displaced by the drill bits in forming holes would equal the volume of rock removed in the construction of a railroad tunnel more than three miles long, and of the cross section of the Simplon tunnel in the Alps.

A cumulation of the whole quantity of detritus displaced by all the drills in forming blast holes would, in extent of volume, equal the Pyramid of Menkaura at Ghizeh.

These general approximations afford comparative illustrations that will aid in an appreciation of the essential functions of the rock drill in the excavation of rock, the amount of work performed by the collective operation of drills, and the paramount importance of the work of the rock drill as the prerequisite to the displacement and removal of the vast masses of rock that have been excavated from the quarries and from the prism of the Panama Canal.

Three general types of rock drilling machines were in service on the canal works,—the diamond or core drill, the well or drop drill, and the percussion drill.

The diamond or core drill was used in the determination of the nature, qualities, and depths of the strata on the line of the canal, and the relative quantities of each formation that would be encountered in the creation of the canal. The salient characteristic of the diamond drill is a capability of cutting out a continuous core to the depth of penetration of the substance being bored. This core is a cylindrical section of all the formations penetrated and provides samples of the strata in their natural form. This data on the thickness and qualities of the different formations penetrated, taken from a great number of borings, form a basis for estimating the relative quantities of each formation. This cutting, or more properly abrading, process, by which the core is formed, consists in the rotation of a hollow tool or tube, the end of which is in contact with and pressed against the material being bored. This end is either in the form of a hard steel tubular tool with cutting teeth, of an annular piece of metal with diamonds or bort inserted in the cutting face, or steel shot or other hard substances are supplied to the underface of a plain tubular section where the revolution of the tool under pressure causes a grinding or abrasive action of the hard shot on the rock. The end of the drill or crown in contact with the rock is a separate piece detachable from the main tube of the drill. The rotation of the cutting or grinding surface cuts out an annular section, leaving a solid cylindrical central core which is undisturbed and enters the tube or core barrel as the drill penetrates the rock. This tube is rotated through gearing by an engine, or, in smaller machines, by hand. Water is fed through the tube to remove or wash out the detritus or ground particles. The diamond drill will bore holes to great depths,—a vertical penetration of 7,000 feet has been attained. The mechanical principle and the process of cutting, of this type of drill, has been known and used for cutting stone and boring holes from time immemorial. Stone was cut by bronze saws having jewels inserted on their cutting edges, and drilling was performed by the rotating of copper tubes supplied at their cutting ends with corundum, in the building of the Egyptian Pyramids. These tools were known to be in common use in 4700 B. C. The rotary rock drills now in use are the reinvention of their ancient prototypes, with the application of power in their operation.

The well or drop drills were quite generally used on sections of the canal works where the class of work and nature of the formation were favorable to their employment, and where vertical blast holes of large diameter were required. The well drill is restricted, owing to its action being dependent on gravity, to the cutting of vertical holes. The merits of this type of drilling apparatus are the simplicity of its operation and its adaptability to work in formations overlaid with earth. The holes drilled by this type of machine are usually from five inches to eight inches in diameter.

Blast holes of large diameter permit the use and concentration of heavy charges of slow acting explosive. A slow explosive in heavy charges, when detonated, produces a large volume of gas, and is found most effective in disintegrating the softer strata, friable rock, or loose earth and indurated clay.

The simplicity of the action of the well drill is of great advantage where, as on the isthmus, expert operators were not always available for a more complicated mechanism.

Generally stated, the process of operation of a well drill consists in the raising and dropping of a bar by means of a cable or rod. This bar is formed as a bit or cutting tool on the lower end. The measure of the work performed is dependent upon the weight of the bar and the kinetic energy developed by the attraction of gravity on impact with the rock. The speed at which the bar may be raised is restricted by its inertia, as affecting the cable connections, to about sixty blows a minute.

The drop or well drill is used throughout the world for deep borings. In different countries various modifications in design are adapted. To illustrate: In the United States a hemp cable is almost invariably used for operating the bit; in Canada and Russia, jointed wooden rods replace the cable. In Europe, the use of metal rods is the general practice; wire cable is sometimes used, or a combination of the various systems. The fundamental system of operating is the same, though there are many mechanical differences and modifications.

In drilling, the cable, carrying the drill bit, is suspended from a "walking beam" or lever usually oscillated by an engine. For blast holes or spudding there are differing designs of feed and cable mechanism.

A device called the "temper screw" regulates the feed. The operator rotates the cable at each stroke. This ensures a straight hole and prevents the cutting edge of the bit from striking in the same place as in the preceding blow.

On the Panama Canal work the "oil well system," or rig, was used. The rig is mounted on wheels adapted to run on the ground; the engines, drums, and derrick supporting the working beam are carried by and are an integral part of this wagon. The operating cable carries its so-called "string of tools" which, in the simplest form, consists of the drill or bit, the jars, and rope socket. The jars are a pair of sliding links which on the up-stroke as they come together produce a sharp shock or hammering effect that tends to jar out the bar if binding in the hole. Drills of this type, mounted on wheels, are, where the conditions and formations are suitable, used for blast holes of large diameter or holes of no great depth. Where holes of great depth are to be bored, a permanent and stable frame or derrick is erected over the site of the hole. The oil derrick, as it is called, consists generally of four uprights or legs held in position by ties and braces, the whole resting on strong wooden sills. This structure is usually about seventy feet high, twenty feet across the base, and four feet across the top. The whole derrick is set up with keys and may readily be taken down and erected on a new site. Samson posts for supporting the walking beams are dovetailed and keyed into the sills. For blast holes the drilling usually varies anywhere from fifteen to fifty feet in depth, but in exceptional cases, they are much deeper.

The origin of the well drill is not known; in very early times it was in use in China, the operating power being men, horses or oxen. In Europe, this mode of boring for water was first practiced in the French Provinces of Artois, whence the name Artesian is derived; wells dating from the 12th century are still flowing. Unmistakable evidence of much more ancient bored springs appears in Lombardy, in Asia Minor, Persia, China, Egypt, Algeria, and in the Great Desert of Sahara.

The economic trend towards increase of performance through the application of power to greater speed of operation, to increased flexibility and adaptation to varying conditions, to lightness and portability and consequent ease in handling and in operating, was met by the invention of the modern percussion type of drill about the middle of the 19th century.

The percussion drill is an American invention, the first practical patents having been taken out in 1849, by J. J. Couch of Philadelphia. In Europe the nearest approach to rock drill invention was the German work of Schumann in 1854. Following these came the inventions and developments of Haupt, De Volsen, Wood, Simon Ingersoll, Sergeant, Waring and Githens, with the invention of the Rand drill in 1871.

Power operated percussion drills may be divided into two general classes, distinguished by their characteristic action. Of these two classes the first form is where the drill steel is attached to and forms an extension of the piston rod of the drilling machine and reciprocates with it. This form is shown in the inventions of Ingersoll, Sergeant and Githens. The other class is the "hammer" type where the drill bit is not reciprocated but performs the boring through the effect of the hammering action of the drill piston or hammer on the shank or upper end of the drill steel as the steel is slowly rotated. The Leyner drill is typical of this class.

The reciprocal movement of the piston, in either general class, is controlled by one of three distinctive forms of valve action: the steam or air thrown valve, as exemplified in the Ingersoll type; the valve actuated through mechanical connection, as by tappets, levers, or poppets controlled by the movement of the drill piston, as in the invention of Githens; the action of the third form of valve combines the actuating principles of both preceding types. A small tappet or arc is controlled in its movements by the piston of the drill. This small arc forms an auxiliary valve which controls the movement of the main valve by uncovering small ports and subjecting the pistons on either end of the main valve alternately to air or steam pressure and relief from pressure. This design is illustrated in the inventions of Sergeant.

To make a true straight hole and to prevent the drill bit from repeatedly striking one place, a rotating device, called the "rifle or rotation bar," forms a working part of the percussion tripod drill and of some forms of the smaller hammer drill. This rotating gear consists of a bar having rifled or spiral grooves running the direction of its length, and having a pitch or spiral path of about one-third of a complete revolution in the length of the piston stroke. The spiral bar is integral with a ratchet gear, or other similar device, and is supported in a bearing and encased in the upper head of the steam cylinder. The long piston drill is bored to permit free sliding or reciprocation over this bar; the upper end of the piston is fitted with a fixed nut whose inner face conforms to the spiral grooves of the bar. The pawl and ratchet device permits rotation in but one direction; the consequent action on reciprocation of the piston is that on one stroke the rifle bar being prevented by the pawl from turning, the drill piston carrying the drill bar turns through the part of a revolution corresponding to the spiral of the rifle bar. On the reverse stroke of the piston no rotative action, other than that due to inertia, is exerted, as the rifle bar is free to turn in the reverse direction. In the best practice the rotating bar will release or

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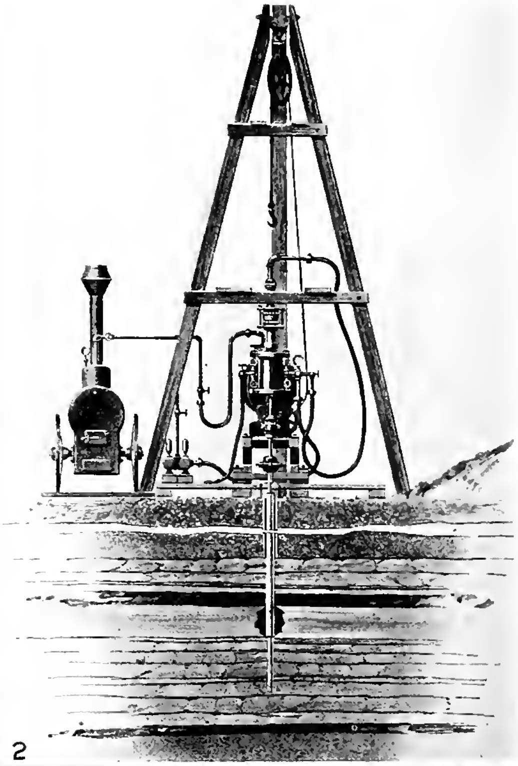

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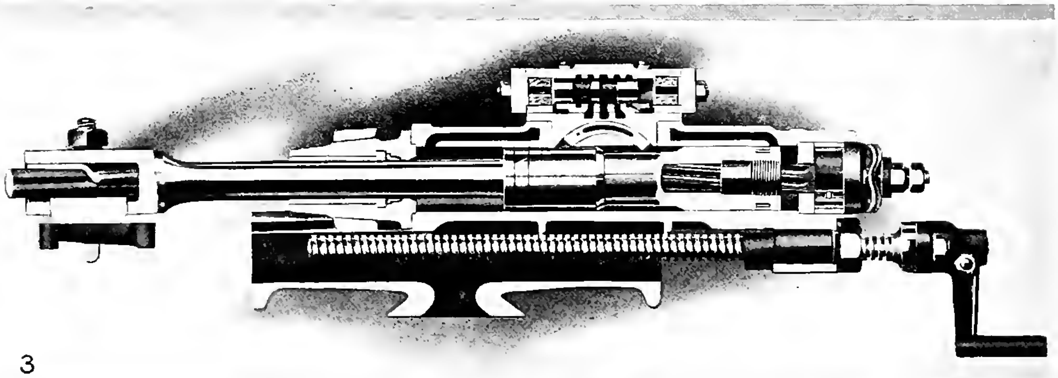

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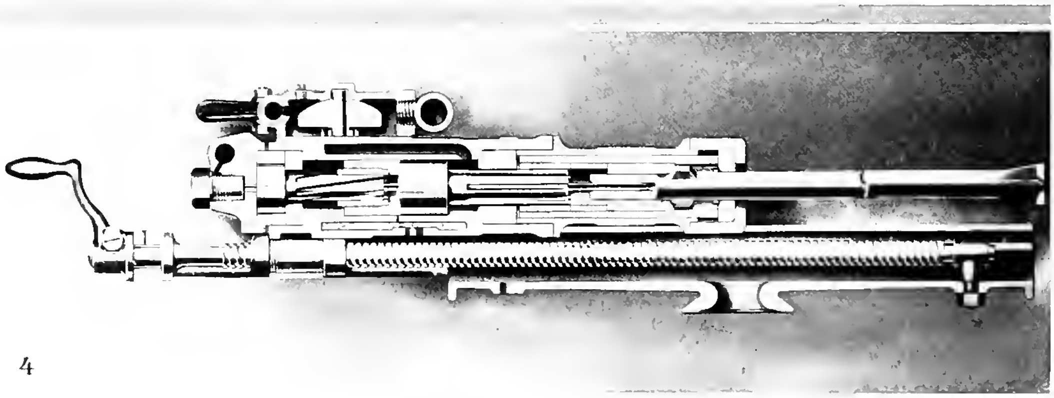


4

1. Types of drill bits.
2. Vertical drill in operation.
3. and 4. Longitudinal section of Leyner-Ingersoll-Rand drills.
(Drilling equipment on the canal furnished by the Ingersoll-Rand Company of New York.)

slip, under extreme torque, in the direction of the resistance of the pawl. This condition of torque may be brought about by jamming or binding of the bit in such a manner as to prevent rotation. Without this precautionary relief serious breakage and disablement of the drilling machine would ensue.

The percussion drill is most markedly different from other common forms of drilling machines by the great merit of being capable of drilling holes at an angle. This characteristic feature has been a factor leading to its present universal employment. Percussion drills are mounted on tripods, on frames supported by a carriage, or supported by hand, as in the use of the small hammer type.

The tripod type of mounting is most generally used. This form permits of holes being bored at any desired angle. Where holes are required of larger diameter and to greater depth, a vertical frame with guides the length of the drill feed, and carried on wheels, is used in land operations; in under-water rock work, drills of great power are mounted on vertical steel guides carried by a suitably designed vessel. For shallow holes of small diameter the lighter unmounted hammer drills are employed.

The small hammer drill, variously known as plug drill, buzzer, or Jack hammer in its different forms, is playing an important part in mining. The standard tripod-mounted piston drills have no equal in the class of work for which they are properly adapted, viz.: the drilling of comparatively large and deep holes at all angles; but as the diameter and depth of holes best suited to blast a given amount of material diminish, a point is reached where the use of the hammer drill is more economical. The drilling speed and consequent cost of compressed air and labor are proportionate to the area of the drilled hole. The hammer drill is of simple construction and has but one or two moving parts. Requiring but a moment to start new holes or change bits, the drill is actually "hitting the rock" probably 80 per cent. of the working time ; for a standard heavy mounted drill, 50 per cent. is a good average. No special skill is required to operate the hammer drill, and one drill will perform the work of from ten to fifteen expert hand drillers. The hammer drill can be used in close quarters where a mounted piston drill could not be placed or hand hammers swung. The field of the hammer drill is in shaft sinking, stoping, ditching, replacing "mud capping," block holing, and any situation where holes of small diameter and no great depth are required.

The most common employment of rock drilling apparatus is in the drilling of blast holes, in mines, quarries, tunnels, shafts, open cuts, and rock excavation generally. To obtain the most efficacious results in the use of explosives in blasting, the explosive must be placed in the position indicated and governed by the nature and aspect of the variations of each formation and by the profile required in the finished excavation. To place the explosive in the position that may be indicated, the blast holes may require to be drilled at any angle from horizontal to the perpendicular. The power-actuated tripod and hammer drills are the only forms of drilling machines adaptable to the economical drilling of blast holes through this range of angularity.

On the land or dry work in connection with the canal, all of the drilling machines were actuated by compressed air. The economies of generating power in a central plant, the absence of exhaust steam and the smoke and heat from numerous portable boilers, which would augment the already high temperatures of a tropical climate, were some of the more evident benefits resulting from the use of compressed air instead of steam.

The vast extent of the mining and blasting operations entailed in the creation of the canal and the large connective and allied works included the situations and conditions to be met with in the operation of drills in tunneling, quarrying, shaft sinking, open cut work, and in submarine rock removal. The rock drills employed were of the varied types and designs best adapted to work in the formations encountered and meet the special conditions of each class of work.

The geological formations in the prism of the canal, broadly stated, consist in the oldest rocks between Bas Obispo and Empire, of basic conglomerates, overlain by volcanic agglomerates, tuffs, lava flows, plugs, dikes and volcanic breccias, all much faulted and sheered. From Empire to Paraiso is a 500-foot sag or downwarp of dark, soft, friable, thinly bedded carbonaceous clays and shales, containing lenses of sand, gravel, marl, and basic tuff. The northern and southern rims of this sag are breccias with intrusions of basalt at Paraiso. This formation, which is estimated to be 250 feet thick, grades upward into sandy limestone and limy sandstone and limestone in beds three to thirty-six inches thick, separated from each other by thin beds of marly shale; these bedded rocks are weak and of low crushing strength. Shell and coral limestones are found at intervals across the isthmus, overlain with fine grained basic volcanic clay rock and containing locally lenses and beds of gravel, sandstone, carbonaceous and lignitic shale beds up to four feet thick, and lava flows twenty feet thick. This formation isweak, crumbly, and easily weathered.

The youngest rocks are intrusions, dikes, and local flows of basalt of a dark, fine hard texture, of high crushing and tensile strength, and of masses of volcanic breccia. The general formations of the under-water rock of the Atlantic and Pacific entrances of the canal are of coral or volcanic origin. The quarries at Porto Bello and at Ancon Hill are of basic andesite, basalt or trap.

This general statement of the nature of the geological formations encountered is given to illustrate their great structural variations and the range in texture, in composition, and in other qualities affecting the working conditions of the rock drills and governing the selection of the class of drilling machine most efficient in each situation. The primary object in blast hole drilling is to enable the blasting process to take place. The method that decreases the number of holes to be drilled over a given area by increasing the blasting effect at each hole will lessen the cost of drilling in proportion to the decrease in feet drilled per cubic yard of rock blasted.

The important factors, pertaining to the nature of the material being drilled, which govern the economical results, are the softness or hardness of the rock, cracks, seams, and the dip or angle of outcrop or strata, the homogeneity or irregularity in composition and formation, and the sludging or mudding tendency from the action of the drill bit.

The mechanical effect in cutting a hole in a homogeneous formation, where the number and force of the blows delivered by the rock drill is constant, as a general proposition, is, in cutting speed, in inverse proportion to the area of the hole. It follows therefore, other conditions remaining constant, that increase in the rapidity and force of the blows delivered in cutting holes of decreased area would produce a proportionate increase in depth of boring in a given time.

The intrinsic purpose of a blast hole is to provide access to that position in the mass where concentration of explosive will produce the most effective results in blasting. The economic rule as applied to the mechanical forces employed is therefore to drill holes of as small diameter as practicable when the holes are to be sprung, and large holes when springing or enlarging the bottom of the hole is not feasible.

The excavation of the Central division of the canal, extending 31.7 miles from the Gatun Dam to the lock site at Pedro Miguel, included the removal of between seventy-five and eighty million cubic yards of rock. In volume this approximates eighty per cent. of all the rock mined from the canal and quarries during construction.

All the variations in form, texture, or other qualities found in the rock excavated over the whole canal are found in the Central division. The drilling operations of this division will be taken as representative of all the dry rock work. An approximation, based on over fifty million yards, would indicate that the rock from this division would classify by volume as consisting of eighty per cent. of soft rock and twenty per cent. of hard rock. Reference to the general geological formations already described will make clear the distinctions of hard and soft rock.

The average number of drills employed when the whole division was in active operating condition was, well or drop drills, 153; tripod percussion drills, 231.

Based on the drilling of 6,412,000 linear feet of blast holes bored for blasting 12,863,000 cubic yards of material, the performance of the well drill averaged six and one-quarter feet in depth of hole per hour, with an average labor operating cost of 6.68 cents per linear foot. The tripod drills averaged, including the drilling of toe holes and working in the hardest rock, five and one-eighth feet per drill hour, at an operating labor cost of 8.96 cents per linear foot. In drilling the hardest trap rock in Culebra Cut, based on cutting 6,297 linear feet, the average cutting speed of tripod drills was 2.47 linear feet per drill hour.

An average of 100 horizontal toe holes fifteen feet in depth were drilled each working day. Six hundred vertical holes nineteen feet deep were bored in the same time. These records of performance are of a period when the organization and working conditions had been developed to a condition productive of high economic and operative efficiency.

The variable nature of the materials drilled was particularly adapted, in a great portion of the excavation, to the use of well drills, owing to the mechanical design and operation of this type of machine being effective in boring holes through an overlay of earth, and through the seams containing loose materials, sand and gravel, so frequently encountered. These conditions and the proportionate depths of rock and earth are exemplified in the record of operation of twelve well drills on the Pacific division. During twelve months 86,827 linear feet were drilled; of this footage, 50,889 feet were through the overlay of earth, and 35,938 feet through a friable rock,—a relative proportion of about ten of earth to seven of rock. The average performance of each drill was about twenty-three linear feet of hole per day. A pipe casing was used in the drilled hole to prevent the overlay of earth from caving into the hole.

From the inception of the canal work in 1904, until the end of 1912, 725 rock drills of the different types had been purchased for use on the canal work at a cost of $288,376. This number of drills approximately served to complete the canal, as operations were at the height of activity and the maximum quantity of plant in use in 1912. From this period the quarrying and other rock sections were ceasing operations owing to completion of work; this led to the reduction and retirement of drilling plant.

The crushed stone used in the concrete construction of the locks and other structures at Gatun was produced at the Porto Bello quarries on the Atlantic side of the isthmus. The crushed stone used in similar structures in the Pacific division, as the locks at Pedro Miguel and Miraflores, was produced from the quarry at Ancon Hill.

The cost of quarrying, covering the production of over 1,300,000 cubic yards, averaged 95.57 cents per cubic yard at the Porto Bello quarries, and the unit-cost of drilling was 4.4 cents.

In the production of about 1,700,000 cubic yards from the Ancon quarry, the average cost of quarrying was 53.85 cents per cubic yard, of which five cents was the unit-cost of drilling. Both quarries were of igneous formation of basalt or trap. Percussion tripod drills of three and five-eighth-inch piston diameter were in quite general use at Porto Bello; at Ancon, in addition to the tripod drills, a number of well drills were in use. The well drill, because of its slower and less powerful blow and the larger area of holes drilled, penetrates these verv close and hard rocks but slowly.

Subaqueous rock drilling was performed in the Atlantic entrance of the canal and in the Pacific entrance. The tidal conditions of the Atlantic give a range between rise and fall of about fourteen inches; on the Pacific side the extreme range is about twenty-four feet.

The rock formation on the Atlantic side is of soft, easily worked coral formation. On the Pacific side the rock is of volcanic origin, of fine texture and of medium hardness.

The nature of the coral deposits to be drilled and the most favorable tidal conditions permitted of very economical results being obtained, on the Atlantic side, with an improvised drilling plant.

An old hull, used on the French works, was fitted with eight old well drills and used as a drill barge. The individual boiler was removed and steam for actuating the drills was supplied from a central boiler. These drills were placed four on each side of the barge. The two lines of drills were twenty-two feet apart, and the drills in each line fifteen feet apart. The total cost of this improvised installation was $4,000. An average of eight holes was drilled, loaded and fired each day.

In mining 174,580 cubic yards, of which 83,800 cubic yards was an overlay of earth, the cost was 4.5 cents per cubic yard, or if all expense is charged to the rock, the cost would be 8.7 cents per cubic yard. The cost per cubic yard of 191,872 yards of subaqueous rock without an overlay of earth was 7.9 cents.

The subaqueous drilling plant in the Pacific entrance of the canal followed in general design and process the standard American system as carried out on the Great Lakes and the St. Lawrence River. There were minor modifications in the spud mechanism to meet the tidal variation in level.

The greater physical difficulties to be met with in the removal of the under-water rock on the Pacific side required a more elaborate and substantial plant than was needed on the Atlantic side. These physical features were the great range in tidal levels, the harder rock formations, and the larger volume to be removed.

The hull of the drill barge was of steel, 112 feet long and 36 feet 8-inch beam. Two longitudinal and six transverse bulkheads divided the hull into twenty-one watertight compartments. Two of these compartments amidships were utilized for water storage and other of the compartments contained six fuel oil tanks, each of forty-barrel capacity. Four timber spuds, twenty-four inches square, were located towards the corners of the hull. These spuds were each controlled and lifted by an independent pair of engines connected by gears with steel racking on the spuds. The function of these engines had a controlling influence on the performance of the plant. The engines were under steam pressure which exerted a downward thrust on the spuds or lifting effect on the hull while the drills were working. This thrust was of a force sufficient to keep the vessel above her line of normal flotation.

The proportion of the weight of the vessel on the spuds served to keep the vessel anchored or fixed in position over the holes being drilled as the water level changed with the stage of the tide. The mechanical principle involved is the condition of equilibrium established when the weight or downward pressure on the spuds equals the resistance of the steam pressure. The rise or fall of the water in which the vessel floats disturbs this equilibrium, with the resultant effect that the engines automatically reëstablish this equilibrium concurrently with the increase or decrease of load on the engines,—the engines are overhauled against the steam pressure, or because of the steam pressure force the spuds downward.

Three drill frames or towers carrying percussion drills were in line over the gunwale on one side of the vessel. The frames were supported on tracks and were movable in the direction of the length of the vessel by connection with an endless chain operated by hydraulic power. The frames had a travel of eighty-five feet. The drill frames or towers, about forty feet in height, were provided with guides, on the outboard side, in which were operated sliding saddles or crossheads to which the percussion drills were bolted. The length of these slides, which approximated the height of the towers, was the length or range (less the length of the crosshead) of the feed or travel of the rock drill. This long range was of advantage, in this design, in providing for feeding the drill according to the depth of the rock cutting, and the changing positions of the drill as affected by the stage or level of the tide. The crosshead to which the drills were bolted was of sufficient weight to resist the lifting force exerted by the drill when striking. The up and down movement or feed of this crosshead was controlled by a steam-operated hoisting winch located on the base of each tower and connected by a steel hoisting cable running up over the tower and down to the crosshead.

The drills, three in number, were of five and one-half-inch piston diameter, steam actuated, and of the Ingersoll-Rand type of submarine drill. The drills in their action and design were similar to the familiar form of percussion rock drill as mounted on tripods, the main differences being in greater power, weight, and corresponding structural increase in dimensions and strength. Drill steels or bars to sixty-five feet in length were used. Steam was supplied to the drills and hoists from a central boiler through swivel and slip pointed pipes. The vessel was manœuvered on four Manila cables attached to kedges.

The average performance of the plant, taken from 24 months of continuous operation, was as follows:

During this time the drills worked 22,854 hours (i.e., the total of hours in work on the separate drills—drill hours) and drilled 286,005 feet of hole of an average depth of 16.5 feet each. The drills averaged thirteen feet of hole per drill per hour. The maximum over a period of one month was 21.64 feet per drill hour, and the minimum over a like period 5.9 feet per drill hour. The unit average cost, over a period of twenty-four months of operating, drilling and blasting, was 39.62 cents per cubic yard.

In forming the Pacific entrance two methods of drilling the under-water rock were employed,—by the drill barge as described and by the well drill. At places where rock below the surface required to be drilled, there was an overlay of earth that came above the water level. Well drills were used in these situations. The rock was the same as that drilled by the submarine drills on the drill barge. The operations of the well drills and of the submarine drills in the same formation demonstrated the relative speed of boring of both types of machines.

During nine months of operations with an average number of 11.2 drills working, the total linear feet drilled was 52,777; of this footage, 19,756 feet, or about thirty-seven and one-half per cent., were through the overlay of earth.

Assuming twenty-six eight-hour days to the month, the performance of each drill averaged 4712.2 feet in nine months, which would equal 523.5 feet per month and 2.52 feet per drill per hour as the average work through earth and rock. The submarine percussion drills averaged in two years' work thirteen feet per drill per hour.

This speed of penetration of the submarine drill is far in excess of the performance of any other type employed on the canal.

The Ingersoll-Rand Company supplied the majority of the drills used on the canal works. This same firm supplied 300 tripod drills of three and one-quarter-inch piston diameter to the French Company. For the commission the firm supplied 184 drills of three and five-eighth-inch piston diameter. Of this number twenty-five were of the tappet valve type, the remainder of the air thrown valve type, or the auxiliary valve form. Fifty drills, tripod mounted, of four and one-half-inch piston diameter, twenty-five of each being of the air thrown and tappet valve form, were also furnished. These drills, because of their weight, were not as handy as the three and five-eighth-inch size, any gain due to their greater striking force being somewhat offset by the inconvenience in shifting position in starting new holes. Of the smaller tripod machines there were fourteen of two and one-half-inch piston diameter and fifty-eight of the two and one-quarter-inch piston diameter. In addition there were two very heavy tripod drills of five-inch piston diameter, and six unmounted submarine drills of five and one-half-inch piston diameter used on the drill barge in the Pacific entrance of the canal.

A rock drill, in common with all other mechanical means of converting energy into useful work, will perform an amount of work that is constant where the factors of force, time, speed, resistance and other influencing causes remain constant. In the actual cutting of a drill hole the force expended is in direct proportion to the area of the hole, and the time of cutting in inverse proportion. An increase in the number of blows in a given time affects a corresponding increase in penetration. A decrease in the area of the hole augments this in proportion to the lessened area. Increase of force to the blows will proportionately further increase the cutting speed. These are the fundamental theoretical conditions governing the performance of a percussion rock drill.

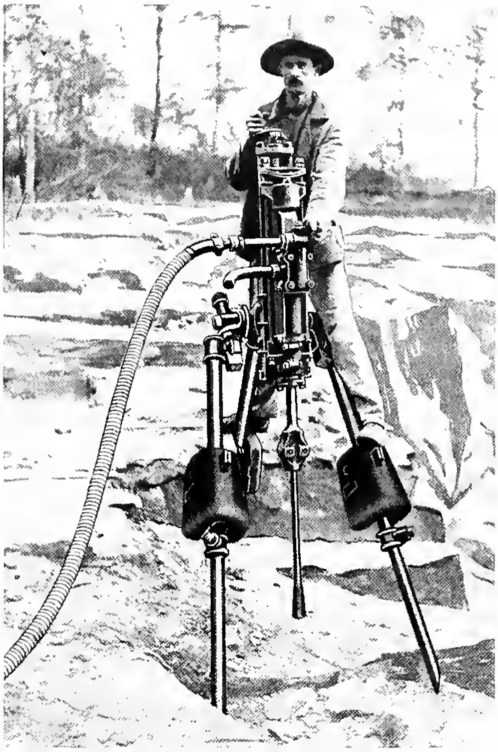
Drill holes range from less than one-half inch in diameter to eight inches or more, as in well drilling. The highest speed of striking is in the small hammer drills, which strike upward of 2,000 blows per minute. The striking speed successively diminishes from the tripod mounted hammer drill, the smaller to larger sizes of direct steam or air-actuated drills, to the largest size of submarine drills striking about 250 blows a minute, and culminating in the slow acting well drill striking less than sixty blows a minute.

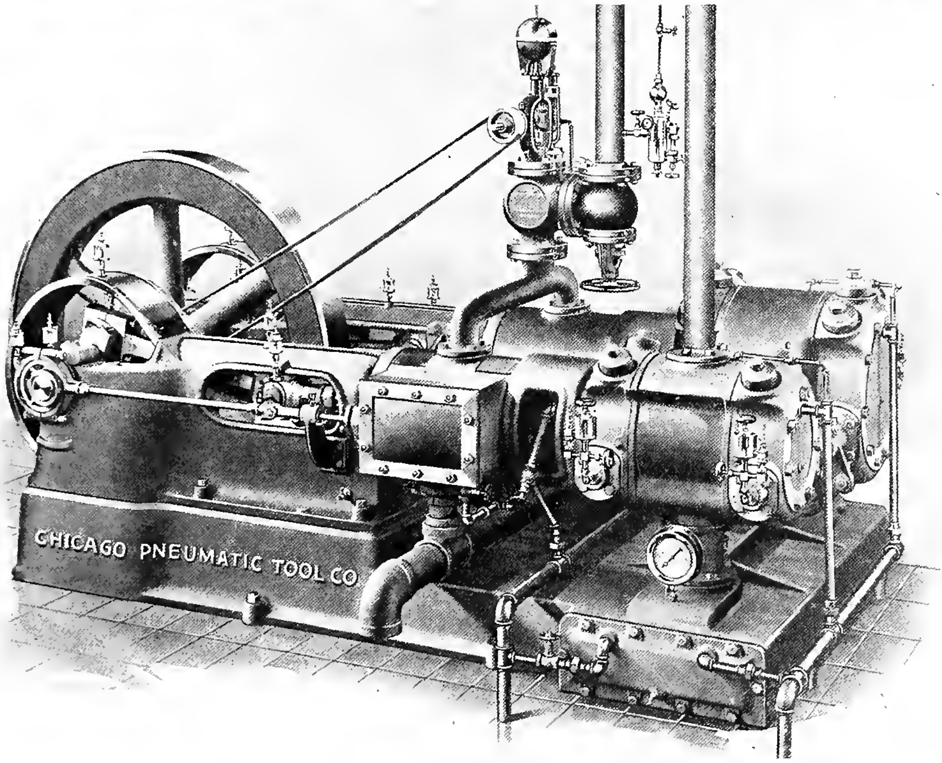
The striking force of the different types runs from the light rapid blows of the small hammer drills to the powerful steam-hammer-like blows of the largest subaqueous drilling machines.

To obtain reliable records of the performance of any type or class of drilling machine it is essential that more or less stable conditions obtain in the formations drilled. The extreme variations in formation and the heterogeneous composition of the rock masses, on the isthmus, brought about by the effects of volcanoes and earthquakes, heat and cold, coral formations, water and other agents of denudation and transport and the sequence of natural phenomena, permit only of most general deductions based on the average collective performance of numbers of drills working in constantly changing and differing conditions. These general conclusions are evident from what has already been stated and require no elucidation for their apprehension.

It may be affirmed that as an economic factor the rock drill was indispensable to the creation of the canal, and its work the physical requisite preliminary to the disruption and displacement of the vast masses upheaved by the great natural convulsion of the surface of the earth which formed the barrier to the reëstablishment of an interoceanic passageway connecting the Atlantic and Pacific as existent in geologic time.

The first use of compressed air to any extent as a means of power transmission was for the operation of drills in mines and tunnels. This followed the development of the steam drill. The superior efficiency of the steam drill as compared to hand drilling having been demonstrated, its use in mining work was advocated, and the use of steam being obviously objectionable, some other elastic fluid had to be utilized, with the natural result that the air compressor was developed to meet the demand for a supply of this fluid in the form of compressed air, which not only has none of the disadvantages of steam, but instead, positive advantages by way of added ventilating effect, allowing the machines to re-





3

1. Underground compressor drilling.
2. Surface drilling.
3. Air compressor for drills.
   (Supplied the canal by the Chicago Pneumatic Tool Company, Chicago, Ill.)

main cool, and increasing the durability of packings and wearing parts on account of more perfect lubrication.

The success of this system of power transmission as applied to rock drills suggested its application in other fields, and inventions multiplied.

At first its use was confined to larger operations, and in addition to rock drills we had such large and unwieldy tools as channelers, gadders, etc. Later these tools were made in smaller sizes adapted to the use of one man for coal mines and the mining of mineral ores, and these tools have continually decreased in size until now they are made almost as diminutive as a watchmaker's hammer. Steam engines of most approved types, electric motors direct connected, common water wheels, Pelton wheels or the more modern turbines furnish the power for compressing the air. Air compressors or pumps are constructed to be driven from belting, with gears or combined direct with a reciprocating steam engine. The initial power being settled upon, it only remains to lay the mains about the plant, provided at convenient distances with valves, to which, by means of rubber hose, the individual tools may be connected.

This gives a flexibility to the plant, hitherto unknown, for the mains once laid and convenient openings provided, any desired tool may be brought to bear at any part of the shop, yard, building, bridge or roadbed. The importance of the drilling operations at the Panama Canal is shown by the fact that at least five great firms in the United States furnished the various forms of drilling equipment.

The pneumatic equipment furnished the Isthmian Canal Commission by the Chicago Pneumatic Tool Company, consisted of air compressors, rock drills, air drills for drilling, reaming and wood boring, pneumatic hammers for riveting, chipping, calking, shell riveters, rivet busters, compression riveters and hoists.

The features of Chicago Pneumatic Air Compressors are simplicity of design and construction, great structural strength, liberal bearing surfaces, adequate valve and port areas, and effective automatic regulation. Their speed ratings are moderate, avoiding the present-day tendency to overrate capacity. The steam cylinders are duplex and the air cylinders two-stage or compounded, and at 150 revolutions a piston displacement of 1,055 cubic feet of free air per minute is obtained. Chicago Giant Rock Drills and Plug Drills were used in great numbers in the drilling of blast holes. These drills are built to stand the roughest usage and while making records for economical upkeep, do their work with great speed. Hundreds of Little Giant Air Drills were furnished the commission by this company for use in the machine and repair shops to assist in the work of maintaining the machinery of various kinds installed along the route of the canal. The Little Giant Air Drill is a portable engine using compressed air as operating fluid. Four single acting cylinders arranged in pairs accommodate the four pistons which are connected in pairs to the opposite wrists of a double crank. A pinion on the crank engages with a large gear wheel to which the drill spindle is directly connected. Little Giant Air Drills have ball bearings on the crank which eliminate much of the friction and thereby increase their power to a marked degree.

There is little work in the way of drilling in metal, reaming, tapping, wood boring or flue rolling that cannot be done advantageously with an air drill.

Hundreds of pneumatic hammers for riveting, chipping and calking were used on the work. All the pneumatic tools supplied by the Chicago Pneumatic Tool Co. were of the highest efficiency and gave uniform satisfaction wherever used in the canal construction.

The largest bulk of rock excavation was naturally in the Culebra division, nine and one-half miles long. The character of rock ranged from shale so soft that it was excavated as it stood by the steam shovel, up to hard, blocky trap rock.