While well drills or churn drills were much used in Culebra Cut for the vertical blast holes, all of the flat or horizontal holes at the bottom of the benches, and a good share of the vertical holes in hard rock, or where twenty-foot benches were employed, were drilled with ordinary air rock drills, mounted on tripods. In this character of work, the Sullivan rock drills and hammer drills of the Sullivan Machinery Company of Chicago played an important part.

About one hundred and twenty-five of the rock drills and thirty-five or forty of the hammer drills were employed. In connection with the excavation of the lock pits, it became necessary to cut smooth rock trench walls, unshaken by the jar of blasting. To accomplish this work, 24 Sullivan channeling machines of the largest size were used.

Much of the heaviest and hardest of the drilling work was at Bas Obispo, where the cut was about one and one-half miles long. The formation here was solid, consisting of a tough, close-grained trap-like rock, requiring very thorough drilling and blasting in order to prepare it for the steam shovel. A ballast quarry was also located here.

In the fall of 1905, twenty-five Sullivan rock drills and a number of churn drills were assigned to this cut, and the Sullivan machines were kept steadily at work here until the excavation was completed. Two holes, twenty to twenty-seven feet deep, were considered a day's work for one drill. The machines were at first operated by steam, but after about a year, the permanent air lines were installed, and for the last six years of work, compressed air was supplied for all drilling operations. Similar drilling methods were employed in the lock excavation, in the terminal work, and in the two rock quarries.

In this work the tappet valve type was selected, on account of the varying hardness of the rock, the presence of mud seams, and the low steam and air pressure which were encountered on account of the distance from the central power plants. The ends of a rocker project into the piston chamber and are shaped so as to afford an ample bearing on the inclined surfaces of the piston, reducing wear and shock to a minimum. The action of the rocker pushes the flat valve back and forth, in a direction parallel to that in which the piston is moving, so that wear is distributed evenly over the whole surface of both valve and its seat. The rocker is of tool steel accurately formed and tempered to proper hardness. The cylinder and valve seat form a housing allowing the rocker free motion, without side or vertical play. The sloping surfaces of the piston are also hardened by special heat treatment, to reduce wear. This valve motion is very economical of air or steam, and secures a rapid blow and powerful recovery, which are well adapted to conditions found on the canal.

In addition to the drills above mentioned, the Sullivan Machinery Company furnished large quantities of drill steel for use on the canal. One order of drill still was shipped from the Chicago works of the company, comprising seven freight car loads in bulk.

From thirty-five to forty Sullivan hand feed hammer drills, employing hollow steel, were used in the Ancon and Porto Bello quarries for breaking up fragments of rock too large to be handled by the shovels, and for other light excavation. These machines weigh twenty-five and forty pounds respectively, and are operated by a single man. They proved of great value in this block hole work, being much more economical than the mud capping method previously employed. An important feature of their design consists in the interior connection of the exhaust ports under the control of an outside valve, so that varying amounts of the exhaust air from the cylinder can be led into the top of the hollow drill steel for cleaning the hole.

Another interesting feature is the cushion valve, which is arranged to entrap a small quantity of air in the rear end of the cylinder, providing a cushion for the piston on its backward stroke, thus greatly


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reducing the vibration of the tool and the fatigue of the operator.

Channeling the Lock Floors

In 1907 the Isthmian Canal Commission purchased twenty-four Sullivan channeling machines, some furnished with boilers for operation by steam, but the majority supplied with air reheaters to render their operation by compressed air as economical as possible. The use of stone channeling machines in engineering work dates from 1892, in the construction of the Chicago main drainage canal. In this enterprise, fifteen miles of canal had to be cut through solid rock. The advantages of a channeled wall over a blasted wall are numerous; the straight, smooth, solid cut made by the channeler, avoids any necessity of either trimming or filling to the engineer's line, the walls left by the channeler remain as solid as the rock itself, not weakened or shattered by explosives, and retaining walls to prevent rock falls or slips are obviated.

Another important advantage secured by channeling consists in the fact that the rock ground or structures adjoining the channeled walls are not disturbed or shattered, and it was in this connection that the channelers found their principal use on the Panama Canal. It had been planned at first to channel the Culebra division from end to end. This idea was abandoned, however, and the use of the machines was restricted to the sites for the locks.

The total amount of channeling performed in the locks was about three-quarters of a million feet, and included, in addition to the lock floor work, the cutting of trenches beneath the curtain walls and across the site of the dam at Gatun. In these trenches, cut-off walls were built to divert the underground water, the presence of which was endangering the foundations of the locks and dam. In this case, also, it was of importance that adjoining ground should not be disturbed by blasting that might affect the stability of the foundations for the great concrete walls.

The design of the Sullivan channelers is exceedingly simple. There are only two engines, the chopping engine and the feed engine, which drives the machine back and forward along the track through worm shafts and gearing. The feed engine also controls the power feed and hoist of the chopping engine. The valve motion is such that the operation of the machine, as to kind of blow and speed, may be modified to secure the best results for any stone and any operating conditions. Special valves in the exhaust ports permit cushioning of the blow, thus preventing damage to the front head, in case a mud seam or other irregularity in the rock is encountered. This was particularly valuable in the broken formation at Panama.

The twenty-four Sullivan channelers were the only channeling machines used on the canal.

The company also supplied much of the equipment for the diamond drilling in testing the location of the canal and the locks and dams.

The record for the number of a particular make of drill on the Panama Canal work belongs to the Star Drilling Machine Company of Akron, Ohio, which maintains branch plants at Portland, Oregon, and Chanute, Kansas.

This company furnished 214 drilling machines for blast hole and other work on the canal, and these figured importantly in the rapid and economical removal of the vast tonnages of rock and earth with which the canal engineers were confronted.

The Star Company makes a specialty of portable drills, and these in various forms were so widely used in the canal's construction that the company made the poetical boast that "Of a truth have the Stars lit the way 'cross Panama."

This form of drill is variously used for blast holes, well drilling, copper mine prospecting and many other forms of drilling. Gasoline, steam or electric power is used in their operation, the steam operated machines being generally used where coal or wood is easily accessible, and gasoline where the ordinary forms of fuel is scanty.

Where electric power is available, the machines are equipped for either direct or alternating current.

One of the advantages which led to the great number of these drills at the canal was the ease with which they could be set up or moved. The entire machine, including the engine and boiler, is compactly mounted on wheels, the traction style machines propelling themselves from place to place with their own power, while the others are easily hauled. The traction machines are powerfully back-geared for hill climbing and with high speed for fast traveling on free roads.

Other types of rock drills used on the canal in large numbers were the improved drills both of steam and air power, manufactured by the Wood Drill Works of Paterson, N. J. This company also furnished its heavy type bronze hose couplings in great numbers.

The Wood drills were used in the construction of the Miraflores lock chamber, in the Culebra Cut, and in getting out trap rock at Porto Bello for the Gatun locks. For these operations, this type of drill was selected after six months of competitive tests, the selection being based on quantity of work performed, long life of the machines, and ease of operation.

The manufacturers of these drills were the first to use vanadium tungsten iron in the construction of their drills, and their plant is devoted exclusively to the manufacture of drills.

The climatic conditions at the Canal Zone had no effect on these drills, it being claimed for them that they work equally well in either tropical or frigid climates. Simplicity and solidity of construction was one of their features, the motto of their manufacturers being that in the canal work they could be "cleaned up with a sledge hammer," "wiped off with a scoop shovel" and be ready to continue operations.

The drills, great and small, used to such large extent on the canal, and which were so large a factor in the rapid excavation, demonstrate that the United States leads the world in this class of machinery. These busy machines, which paved the way not only for the water channel, but for the lock emplacements and other great features of the canal's construction, will remain among the first of the industrial implements and products which aided the directing minds of the work to bring it to rapid and successful completion.

Explosives on The Panama Canal

The casual visitor to the canal during its construction had a good opportunity to see in operation the powerful allies which man now has at his command, which make possible the accomplishment of such magnificent engineering projects. He saw the mighty steam shovels eating into the cut like so many living giants, the myriads of locomotives hauling away to the dumps what was once a part of the backbone of two continents, and the great cranes so gently and so easily lifting into place the massive sections of locks.

And then he met the blaster out on other parts of the work handling the mightiest of them all, the insignificant looking little rolls of yellow paper about one and one-quarter inches in diameter and eight inches long, that made possible the work of all the other giants. For the most powerful steam shovel cannot dig, nor the greatest locomotive haul, solid rock.

The thoughtful person is therefore led to wonder what were the successive steps which have placed at man's command this greatest of all forces, lying so docile in the hand of the powderman; now held together by a couple of turns of waxed paper, yet which upon his demand exerts force of more than 500,000 pounds per square inch, resistless in its force, supreme in its conquering power.

The history of the successive steps which have given us this potent agent, dynamite, without which so many of the greatest engineering projects of to-day would be impossible, is however, unnecessary here. It will be sufficient to sketch briefly what dynamite really is, and to give a short

account of how that which was used in digging the Panama Canal was supplied.

The explosive basis of all dynamite is nitroglycerin. Everybody is familiar with ordinary glycerin as obtained from the drug store. If glycerin is treated under proper conditions with strong nitric acid, assisted by the presence of sulphuric acid, it is converted into nitroglycerin. The latter differs from glycerin not only in having explosive properties, but unlike glycerin it is almost insoluble in water, so that all traces of acid can readily be washed out, leaving the pure nitroglycerin. The chemical action which occurs is similar to that when nitric acid acts upon potash, converting it into potassium nitrate or saltpetre. The explosive properties result because the glycerin, a combustible, has had introduced into its chemical structure groups of atoms containing sufficient available oxygen to support the combustion, independent of air. The same group is introduced into potash when we convert it into saltpetre with nitric acid, and the only reason why saltpetre is not an explosive is because, while the oxygen is there, the combustion is not. By mixing a combustible with it—sulphur and charcoal, for instance—we obtain an explosive, blasting powder.

Nitroglycerin itself is not very well adapted to blasting, for several reasons. Being a liquid, there are many situations constantly arising in blasting operations where it would be difficult or impossible to load it. Then again, it is very sensitive to concussion or friction, which makes it unsafe to handle or transport. These and other conditions finally led to its general applications in the form of dynamite, which in spite of the terror which the name inspires in the mind of the uninitiated, is by all odds, one of the safest of explosives. For, in an explosive, great strength is a measure of efficiency and not of danger; while on the other hand a comparatively weak explosive may be over-sensitive, unstable, and erratic in its behavior, and therefore dangerous.

The first dynamite consisted merely of a very porous variety of earth (Kieselguhr) saturated with nitroglycerin, and its explosive qualities were due entirely to the latter. While this immediately produced a practical blasting explosive of about the consistency of and closely resembling brown sugar, which could be packed into cartridges and safely transported and handled, it is a kind of dynamite that is very little used in this country to-day. Here we prefer to use, instead of inert earth, an absorbent which is of itself an explosive, so that when fired we obtain the effects of two explosives working together. So we use for our absorbent a mixture of woodpulp and saltpetre or its equivalent, which forms a very good absorbent, and a mixture which also explodes with about the force of blasting powder under the influence of the heat from nitroglycerin.

A sixty per cent. strength dynamite made in this way is more than equal in strength to a seventy-five per cent. dynamite made with the inert earthy base. The gain in strength is not the only advantage, however, as the explosive base and the many modifications of it which are possible enable the chemist to control the quickness of the explosion as well as its strength, thus adapting different kinds of dynamite to practically every kind of work for which a blasting explosive is required.

Dynamite has many characteristics which give it an immense advantage over black powder, especially in a piece of work like the Panama Canal. Among the first of these is its resistance to water. While the Panama rock was soft enough to admit of using black powder—and some was used very successfully in the early part of the work, in holes that were chambered or enlarged at the bottom with dynamite so that they would hold enough of the black powder—the fact that black powder softens when wet into a black mud that will not explode forbids its use in a good deal of work where it would otherwise be effective. On the other hand, varieties of dynamite are sold by the du Pont Company which can be immersed in water for a long time without material impairment of their explosive force. That supplied for the Panama work was not as waterproof as this, as the saltpetre would be acted upon by the water in time. But practically, the particles of saltpetre are protected so well by their coating of nitroglycerin that they easily withstood immersion for any length of time required in the work. Indeed, it is safe to estimate that three-fourths of all the dynamite used on the canal was fired after it had been submerged under water in the bore holes for periods of from several hours to several days.

Between January, 1905, and June, 1912, the E. I. du Pont de Nemours Powder Company, Wilmington, Delaware, supplied the following enormous quantities of material for use in constructing the Isthmian Canal: 33,000,000 pounds dynamite, 3,570,000 electric fuses (electric blasting caps) 2,800,000 blasting caps, 4,200,000 feet fuse, 20,000 pounds leading and connecting wire, and 230 blasting machines.

The entire quantity of dynamite was manufactured at the du Pont Repauno plant, which is located near Gibbstown, New Jersey, on about two thousand acres of land bordering on the Delaware River over which are spread the four or five hundred buildings of the works.

Tons of material required treatment before reaching the form of finished dynamite ready for use in blasting operations on the canal work. Each principal raw material was put through special processes in various departments of the du Pont Company's Repauno plant under the supervision of trained experts.

The sulphuric acid used in the preparation of the powder was all manufactured at the Repauno plant of the du Pont Company by the contact process. Nitric acid, the most important acid used in the manufacture of the nitroglycerin, as well as numerous other explosives, is made on a very large scale at the Repauno plant. The two prime materials used in its manufacture are Chile saltpetre (sodium nitrate) and sulphuric acid. The sodium nitrate, first dried in mechanical dryers, is transferred to large cast iron retorts, sulphuric acid added and a sufficient amount of external heat applied to start the chemical reaction which results in the formation of nitric acid. The nitric acid so formed is distilled, condensed and mixed with sulphuric acid and stored in tanks until ready to be used. The nitric acid works at the Repauno plant of the du Pont Company are to-day the largest in the world, the output running into millions of pounds per annum.

To produce the nitroglycerin, the most powerful of modern explosives and the base of the dynamite used on the Isthmian Canal, still a third important material is treated at the Repauno plant in a separate department, *i.e.,* crude glycerin, a by-product of refinement known as "dynamite glycerin."

The sulphuric and nitric acids are combined into "mixed acid" and stored in huge tanks, from which point the latter is transported to the nitrating houses, where it is introduced into nitrators (large iron bowls equipped with appliances for cooling and continually agitating the contents), after which the glycerin is slowly added, great care being exercised during this operation to insure against sudden rise of temperature. A thermometer is located at a convenient point in the nitrator to enable the operator to determine changes of temperature during the process of nitration. When the nitration of the glycerin is complete the contents of the nitrator, which now consist of a mixture of nitroglycerin, water and the excess acid, are conveyed by means of a gutter or trough to the separating house. Here the nitroglycerin, which is lighter than the acids, rises to the top of the mixture, thus facilitating the separation of the liquid explosive from the "waste acids."

After separation is completed, the nitroglycerin is delivered to one or more wash tanks and subjected to the purification treatment. The finished nitroglycerin is

1. Keystone Explosives in action at the canal.
2. Solid train of dynamite ready for shipment to the Isthmus.
(Keystone Powder Manufacturing Company, Emporium, Pa.)

tested for purity or neutrality with an extremely sensitive litmus paper made expressly for the purpose in the laboratories of the du Pont Company, and then sent to storage tanks until required for use in manufacturing the various grades of dynamite and gelatin produced by the Repauno plant.

The waste acid is transported to the acid recovery department of the plant, where it is separated into its component parts (nitric and sulphuric) and again used in the manufacture of nitroglycerin or for other purposes.

The next step in the manufacture of the dynamite is the mixing of the nitroglycerin with dry ingredients by which it is absorbed. This operation is carried on in a special mixing machine.

From the mixing houses the loose dynamite is sent to the cartridge packing houses and packed in suitable printed parafined paper shells.

In a separate building, the box packing house, the dynamite for the isthmian canal was put up in fifty-pound wooden cases containing five ten-pound moisture-proof cartons, each, and in this condition finally reached the storage magazines of the plant to await date of shipment. The dynamite was transported over tramways from the magazines to the wharves of the Repauno plant on the Delaware River and loaded on ships bound direct to Colon.

The workmen in the explosive buildings are an intelligent, sober lot of men, carefully instructed as to their duties in connection with the various processes carried on. They wear pocketless uniforms and special rubber-soled shoes, and have separate buildings from those in which they work for changing their clothes.

For the proper use of dynamite, certain accessories are required which can be grouped under the general term "Blasting Supplies."

Of these the first and most important is the detonator. The detonator is required because dynamite, if ignited, cannot be depended upon to explode like blasting powder. Indeed, if unconfined it will generally burn away with a bright hissing flame without exploding at all. When confined it will explode oftener, but even then it does not develop its full force. To bring about uniformity in its action, therefore, a detonator is used. This consists of a copper capsule containing a small charge of fulminate of mercury, which always explodes at once upon ignition, and in contact with dynamite brings about the most effective type of explosion of the latter.

The detonators used for blasting are of two kinds. One kind consists merely of an open copper capsule containing its charge of fulminate in the bottom, and of a suitable size to be crimped upon the end of a piece of fuse. Thus a piece of fuse, which ordinarily would only set fire to a stick of dynamite, when equipped with one of these blasting caps and the cap inserted into the dynamite is capable of bringing about the most effective explosion (detonation) of any quantity of the latter.

The other kind of detonator consists of the same kind of copper capsule, a little larger in diameter, with the usual charge of fulminate at the bottom. But in place of the open end to receive the fuse, it is equipped with two insulated wires which extend into the cap through a composition plug. The ends of these wires within the cap are connected by a very fine piece of platinum wire, which is surrounded by some of the fulminate so that when an electric current passes the platinum wire becomes red hot and fires the detonator. The complete device is known to the trade as an "electric fuse."

The rest of the blasting supplies comprise the fuse, blasting machines used to supply the electric current, the wire required for making the connections and the testing instruments like the du Pont galvanometer and rheostat.

The major part of the blasting supplies, *i.e.*, electric fuses, blasting caps, etc., were manufactured at the Pompton Lakes, New Jersey, plant of the du Pont Company, and were, with the exception of the electric fuses, ordinary commercial products. When first called upon to supply electric fuses, the ordinary goods, such as were in common use in this country, were furnished, but it soon became apparent that the severe and unusual conditions under which they were to be used at Panama were such that something special would have to be developed. An expert was sent to the canal to study conditions under which the blasting was done and he reported, among other things, that the holes in which the dynamite was loaded were generally partly filled with a saline solution of an unusual nature owing to the volcanic origin of the rock. This solution was a fairly good conductor of electricity, and had surprisingly great powers of penetrating the insulation of the fuse wires as well, resulting in a considerable leakage of current under such abnormal conditions. After solving the difficulty concerning the kind of wire to use, a still further difficulty was encountered as the excavating progressed, deepening the cut below ground level. This necessitated a second trip by an expert of the du Pont Company to the isthmus to further study conditions. As a result it was found necessary to make the electric fuses more waterproof than had been the practice in the past without resorting to the expensive method of covering the detonator with gutta percha, since the situation was, to all practical purposes, similar to submarine blasting. The development of the present waterproof electric fuses resulted, which from the point of quality are superior to anything of the kind previously manufactured in this country, and which met the severe test of the work on the canal with practically perfect success.

Supplying explosives and blasting supplies for Panama, therefore, resulted in a lasting benefit to all users of explosives by imposing abnormally severe conditions. In order to meet these conditions the du Pont de Nemours Powder Company improved its regular product instead of producing a special grade for the isthmian canal trade. With this improved product it seems reasonable to suppose that conditions in the United States will not be so unusual as to cause the du Pont Company trouble from poor execution.

Prominent among the companies furnishing explosives for the excavating and quarrying work on the canal was the Keystone National Powder Company, with factories at Emporium and Sinnamahoming, Pa. In fulfilment of successive contracts, begun in 1908, this company made dynamite shipments aggregating nearly 30,000,000 pounds in the course of the five years following. The largest single shipment reached 1,225,000 pounds, or far more than was required in the removal of the once famous Hell Gate as an obstruction to the water traffic of New York City.

Each shipment went forward under the supervision of an expert crew, by rail to Baltimore and thence by steamer to Colon. Special arrangements for safe transportation were made throughout the entire journey. The dynamite was specially prepared to withstand climatic influences, the absorbing material being composed of potassium nitrate or refined saltpetre, instead of the sodium nitrate generally used as a filler. The explosives, which were first subjected to critical inspection and analysis at the factories by government officials, afterward in every instance met the severe tests imposed by the trying conditions due to the moist atmosphere that prevails on the isthmus.

To again meet the unusual conditions of the canal work, blasting fuse of special match construction insuring uniform resistance of the platinum wire bridges in the exploders were furnished by the Star Electric Fuse Works of Wilkesbarre, Pa. The advanced process of manufacture secured for this company the use of its exploder, while the superior make of batteries led to large requisitions for them for use in setting off charges of dynamite.

The batteries were made in such form that they were in a class by themselves. The magnets had shunt and series winding, which no other manufacturer had attempted, and they were wound for amperage as well as voltage.

The waterproofing of the fuses or exploders made them well adapted for the very wet work encountered in so much of the canal's construction. The batteries held a surplus of current to overcome the leakage of current in wet working. The company supplied its product to the canal for several years, beginning with 1906.

Wire Rope at Panama

An important part of the mechanical equipment for digging the canal, one which impressed itself on every observer, was the number and size of the wire ropes in use.

It is known and taken as a matter of course that a wire rope is made of wires twisted together, and that these wires are in some way produced from bars of metal. It is not so well known that while the reduction of metal bars to slender threads was practiced by the oldest nations it has been only within the past century that wire has become important in the field of engineering.

A rope made of wires laid parallel with each other seems to have been used in Germany in the year 1820, but it was not until 1834 that wires were twisted together in something like the form of the modern wire rope. The advantages of such rope were not at once appreciated, for as late as 1840 wire rope was not used in America; few engineers had heard of it and probably no American had ever seen one.

In the year 1840 John A. Roebling, a young engineer who had a few years before left his native land of Germany, was employed in the construction of canals in western Pennsylvania. At that time the Pennsylvania Canal was an important waterway, the course of which across the state was intercepted by the Allegheny mountains. In order that navigation might be continued, inclined planes were built on the mountain sides. Canal boats were towed to the bottoms of these inclines, hauled up on one side of the mountain and lowered down the other side to the other part of the canal. Hemp ropes were used on the planes, and because of the weight of the boats these ropes necessarily were very bulky, and as a result of running along the planes they speedily became worn and frequently had to be replaced.

It occurred to Mr. Roebling that ropes made of wire might be used in place of the hemp ropes; that such ropes would be easier to handle, have greater strength, and give longer service. Roebling had never seen wire rope, but he had heard that such rope had been used in his native land and he could see no reason why rope used to advantage in Germany should not be used in America. So he bought a quantity of wire, built a rope walk on his farm and with the aid of his neighbors succeeded in twisting his wires into a rope. Permission was given for the equipment of a canal plane with this rope. Its success justified Roebling's confidence and led to the substitution of wire for hemp ropes on all the planes.

The Allegheny mountains did not present the only obstacle to the course of the canal. It was desirable that it should run to basins in Pittsburgh, but here the Allegheny River intervened. Mr. Roebling, impressed by the success of the wire ropes on the planes, proposed to extend the use of wire and by the aid of wire cables carry the Pennsylvania Canal across the river to the basins at Pittsburgh. To do this required the construction of an aqueduct suspended by cables across the river. This aqueduct was built in 1844-5, and notwithstanding many confident predictions that it would collapse under the weight of the water of the canal it proved amply strong and serviceable and brought added prestige to the wire rope maker.

It was therefore in connection with canal navigation and construction that the first attempts were made in America to use wire rope and to apply as a unit the strength of many wires. The manufacture of wire rope begun by John A. Roebling was continued by him during the remainder of his life, and since his death in 1869 has been conducted by his sons, assisted during recent years by his grandsons.

So it happened that nearly three-quarters of a century after the pioneer rope maker watched his rope of twisted wire haul the boats of a canal, now long since abandoned, up steep mountain inclines, there was made at the works founded by him and under the direction of his descendants wire rope to be attached to powerful engines to haul boats through the wonderful locks of the canal at Panama. The wire in this rope is much stronger than would have been thought possible a few years ago. This is due to recent improvements in the treatment of steel from which the wire is drawn. The towing rope for the locks is one inch in diameter and is made of six strands of thirty-seven wires each twisted around a hemp center. A number of these ropes must be used at each lock. These were the last of a great variety of wire ropes made by the Roeblings for the Panama Canal.

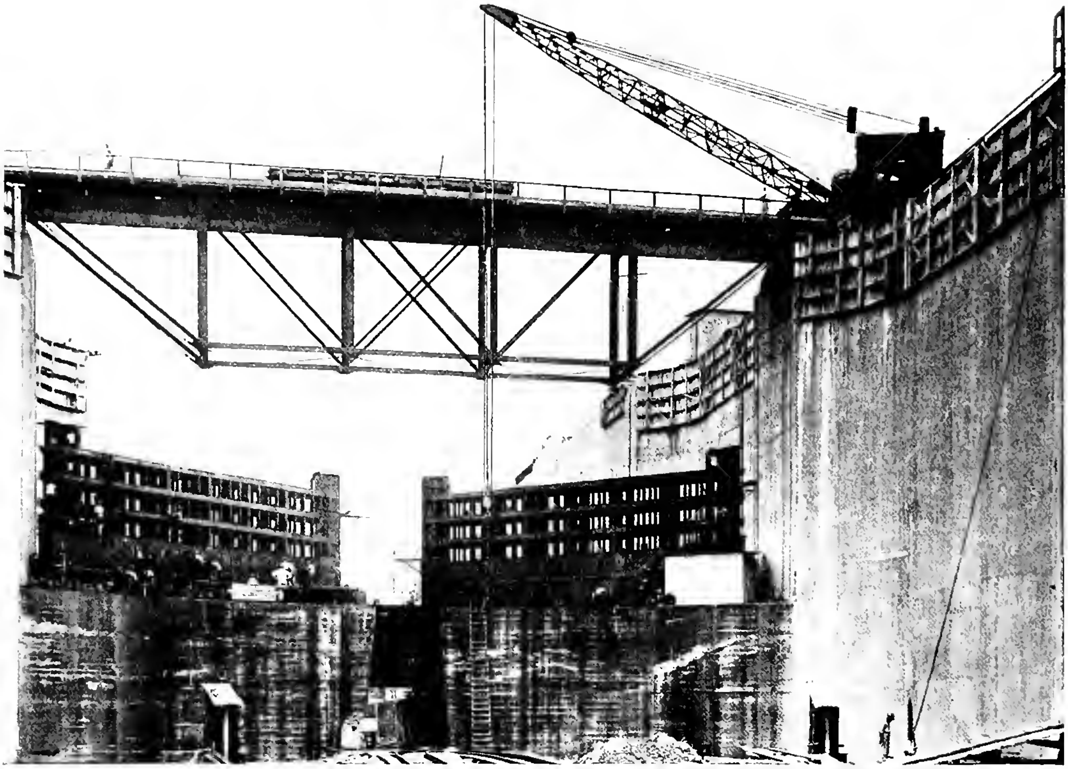
When the digging of the canal began, the firm sent one of its wire rope experts to Panama to study conditions and obtain information which would assist in supplying appropriate wire ropes for different parts of the work. The wisdom of this move was fully justified by subsequent events, for in all over fifty contracts for wire rope, wire strand, and wire were placed with the Roebling Company by the Isthmian Canal Commission. The wire rope and strand called for by these contracts, if placed in a single line, would reach from Colon along the entire length of the canal to Panama and thence twenty miles outward on the Pacific. This, however, was far from being all the material of the kind used, as many lengths of wire rope were supplied those furnishing mechanical appliances of which wire rope is an auxiliary.

Roebling rope was used on cableways for controlling the movements of buckets and for cables along which the buckets ran in the transportation of materials across wide spans. It was used also on unloader plows, dragging them through flat cars piled high with earth and rock, the ploughs clearing the cars as the ropes pulled them along. Great steam shovels and dipper dredges which cleared the way for the canal were also equipped with Roebling wire rope. The rope used for the dipper dredges was in some instances over three inches in diameter, this being the largest wire rope ever used for a like purpose.

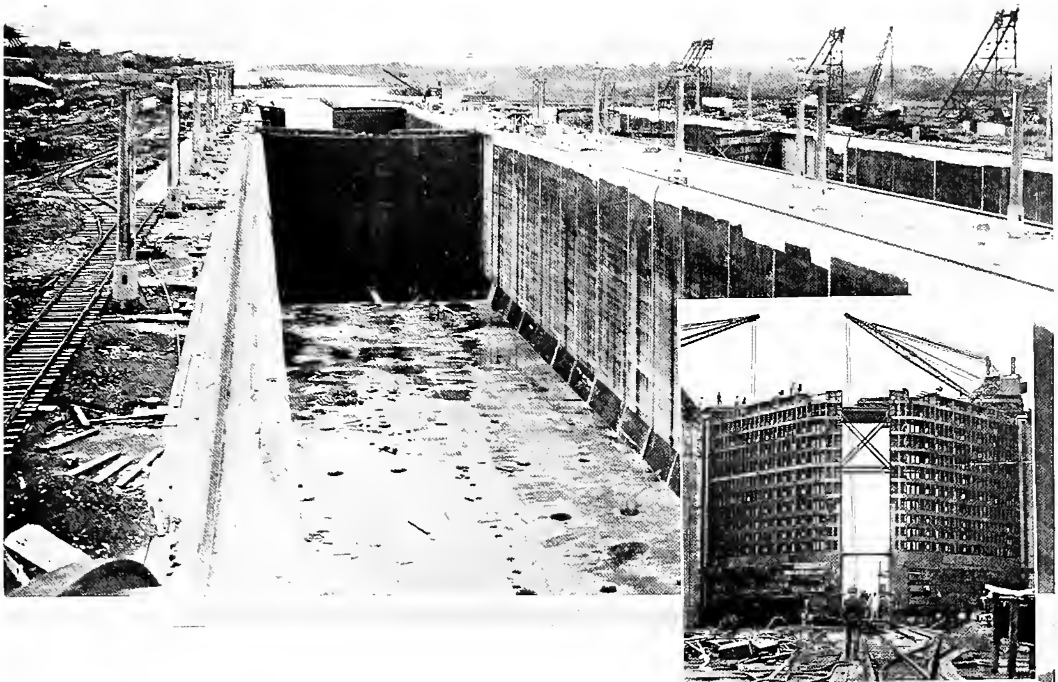
Three different constructions of wire rope were used for the Panama work. One was a rope made of six strands of nineteen wires each; another, eight strands of nineteen wires each, while the third was the same as that of the towing ropes at the locks, six strands of thirty-seven wires each. In each rope the strands were twisted around a hemp center. The hemp center of a wire rope does not provide much additional strength, but acts as a cushion to preserve the shape of the rope and helps to lubricate the wires.

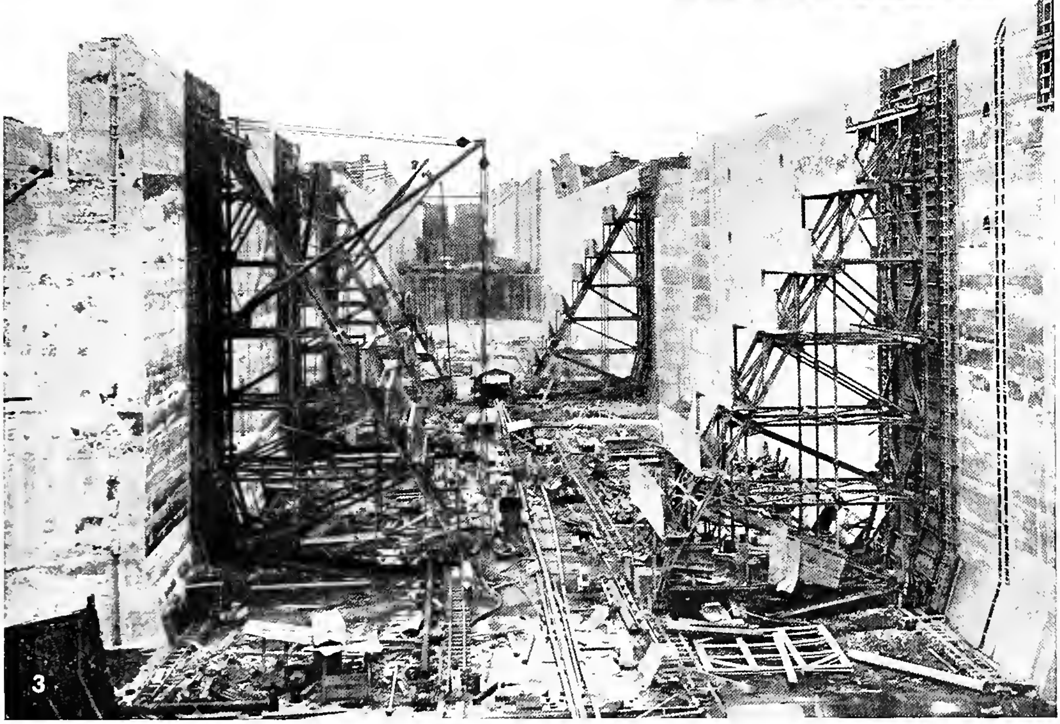
The use of the different constructions was dependent on the conditions encountered. Where rope frequently struck the ground, or was run through earth, as was the case when used with unloader plows, it was necessary to have larger wires to resist abrasion, and wherever possible the rope with six strands of nineteen wires was used. Where resistance to abrasion was not so important and more flexibility was desired, rope with eight strands of nineteen wires or six strands of thirty-seven wires was used. An increase in the number of wires in a rope adds to the pliability of a given diameter, but naturally reduces the size of each wire.

What has been said of the high tensile strength of the towing lines at the locks is true of the other wire ropes shipped to Panama by the Roebling company. All Roebling ropes to be used under conditions where heavy stresses are common—conditions like the excavating, hauling, and towing of the Panama work—are made of wire drawn from steel the quality of which is proven by chemical and microscopic tests before being reduced to wire. Tests are made also of the wire before it is stranded



1. Lifting a girder with wire rope.
2. Wire rope pulling an unloading plough.
(Wire rope supplied by John A. Roebling's Sons Company, Trenton, N. J.)





LESCHEN WIRE ROPE AT WORK ON THE CANAL

1. Wire rope spans for the lock cableways.
2. Rope operating cranes at the lock gates.
3. Lifting material inside the locks. (Wire rope furnished by A. Leschen & Sons Rope Company of St. Louis, Mo.)

into rope, and full-size pieces of the finished rope are pulled apart on the great testing machines at the Roebling works. The result was that the strength and resisting power of every wire rope shipped from this works to the Canal Zone were known to be sufficient for the work to be done.

In addition to the wire ropes used in the work of excavating, hoisting, and loading, the Roebling company furnished many wire hawsers for towing. On the tug boats *Mariner*, *Porto Bello*, *Bohio*, *Gatun*, *M. E. Scully*, *Empire*, *Cocoli*, *La Boca*, *Miraflores*, and *De Lesseps*, and on a number of barges, the American Engineering Company installed automatic steam towing machines, and Roebling hawsers were selected by the commission to complete the equipment.

The towing machines are so constructed that they pay out and reel in the hawsers as the strains of the tow vary with the changing conditions of wind and tide. The tugs and barges were used for conveying material dredged to make the canal opening out to dumping grounds at Limon and Panama bays, and also for bringing in sand and rock. The towing on the Atlantic side was at times very hazardous during the season of "northers," when a heavy sea ran almost continuously and towing had to be done on the ocean, close to the coral-formed coast.

At one time three barges on the Atlantic were needed on the Pacific side of the isthmus. The distance in a straight line from the anchorage on the Atlantic side to Balboa on the Pacific was not more than fifty miles; but to overcome it required a voyage down the east coast, through the Straits of Magellan and up the west coast, in all more than 10,000 miles.

The tug *M. E. Scully*, later named the *Reliance*, with the barges in tow, left Cristobal on the morning of February 11, and arrived in Panama Bay, June 17, one hundred and twenty-six days being taken by the trip, of which eighty-six were actual steaming days.

During the first three days out, the weather was stormy, with great seas that kept the decks awash, and prevented any progress, while terrific strains were brought on the hawsers and towing machinery. However, these strains were not beyond the strength of the towing equipment, and the voyage was accomplished without accident of any kind. This ranks among the great feats of deep-sea towing, being surpassed only by the tow of the dry dock *Dewey* from the Chesapeake Bay to the Philippines, for which also Roebling wire hawsers were used.

The hawsers used for the Panama towing ranged from one inch to one and three-quarter inches in diameter and were composed of six strands of thirty-seven wires each twisted around a hemp center. They were heavily galvanized as a protection against rust.

It is interesting to note that in the Roebling mills, where the steel wire for the ropes was made, there was also drawn a large quantity of bronze wire to make the screens for protecting windows and porches against flies and mosquitoes. The screens were made by the New Jersey Wire Cloth Company, an allied Roebling concern, and the protection afforded by them aided materially in preserving the health of those employed on the canal work.

The importance of wire rope as a factor in the construction of the canal is evidenced by the fact that nearly all the great firms in the United States manufacturing this product contributed large quantities to the canal work, much of it being the specialized product of some particular firm.

The many early failures on this work were due largely to the fact that at the time of the various undertakings the necessary means for carrying on such a work had not been developed sufficiently to meet the many new conditions imposed by such a great enterprise. This is evidenced by the numerous relics of expensive machinery used in former attempts now being allowed to rust away in the places where they were discarded.

While every class and individual piece of equipment on the canal has played its important part, possibly wire rope has been more generally employed than any other one article on account of its diversified use. On the steam shovels and dredges it lifted the soil and rock and placed it upon cars and then unloaded them. On the cableways it handled practically all the material that makes up the mighty locks and dams. Its work is not finished with the canal, for it will be required for towing vessels through the locks, operating the gates, and other purposes.

About fifty years before the beginning of the canal by the United States, there was founded at St. Louis the A. Leschen & Sons Rope Company. The start of this concern was in a small way, but the principle of its foundation was to develop and produce material that would become a standard in its particular line; and by adhering to this principle, it was not only prepared to supply wire rope in large quantities that successfully performed the tasks imposed upon it by the canal work, but was also able to provide wire rope which has taken a prominent part on various undertakings that preceded the building of the Panama Canal, such as the great transcontinental railroads, Chicago Drainage Canal, Roosevelt Dam, Florida East Coast Railway, raising the *Maine*, and other notable enterprises.

During the early period of this company's existence, the best grade of wire rope produced was plow steel, so called because it was originally used for steam plowing—a class of work subjecting a rope to great strains and constant friction from dragging over earth and rock.

It soon became apparent to the Leschen company that plow steel rope was not capable of satisfactory service on many wire rope-using equipments. While it afforded considerable strength, it did not possess a sufficient amount of elasticity, toughness, and flexibility. It, therefore, became their aim to produce a rope that would meet all requirements.

After careful study and numerous experiments, a rope was developed by them that exacting and careful tests proved to combine all the necessary qualities in correct proportions for maximum wire rope service under severe usage. This grade of rope was trademarked under the name of "Hercules," and in order to designate it in appearance, the novel idea was originated of coloring one of its strands red.

Not satisfied with producing a rope of such high quality as "Hercules," constant improvements in construction were made by the Leschen company, and in addition to manufacturing the ordinary types of round strand rope, they produced ropes of the patent flattened strand construction, which on account of simple but correct mechanical principles affords great resistance to wear and is extremely strong and flexible.

Of the many different methods and means employed for excavating and handling material on the canal, the cableways possibly did a greater amount of this work than any other. It required more than an ordinary rope to give satisfactory service on these machines, for there were many severe conditions to be met. The speed at which they were operated was high; the loads heavy; and there were many bends around sheaves and guides.

It was on these cableways that the great efficiency of "Hercules" wire rope was demonstrated. It was here also that the years devoted to the study of wire rope construction were fully justified, for "Hercules" wire rope in the patent flattened strand construction was necessary to successfully do the work.

Another exacting use of wire rope was on the ballast unloaders. These machines removed the excavated material from flat cars by a plow drawn from one end of a train of cars to the other by means of a wire cable, usually one and one-half inches in diameter. When these ballast unloaders were furnished the canal commission, they were equipped with "Hercules" wire rope. Many renewal orders were also placed for "Hercules" rope for this work. Altogether the total length of "Hercules" wire rope furnished for this one purpose alone would reach almost from one end of the canal to the other.

"Hercules" wire rope was also used on steam shovels, dredges, and derricks, both the patent flattened strand and round strand constructions being furnished, depending upon the existing conditions.

In addition to the "Hercules" rope furnished, large quantities of Leschen rope, including cast steel ropes, plow steel, Swedish iron, and tiller rope were furnished. This company was awarded annual contract No. 14 for furnishing wire rope from June, 1909, to June, 1910, which was one of the periods of greatest activity. Altogether approximately a million feet of Leschen wire rope took part in this great work, the greater portion of this being the red strand "Hercules," and much of it was ordered without competitive bids, due to its having demonstrated the economy of its use.

The firm of A. Leschen & Sons Rope Co. was established in 1857. Now the Leschen works cover over thirty-three acres, and Leschen products are distributed over the entire world, through six branch houses and by over one hundred agents. "Red Strand Hercules" is known wherever wire rope is used.

One of the first things the canal engineers discovered when they actually began to "make the dirt fly" was that ordinary tools and machinery were not built to withstand the strenuous and unusual conditions that prevailed at Panama. Great machines that had filled every requirement of similar work at home were found inadequate for the steady and unremitting strain of the canal construction, and had to be rebuilt on stronger lines.

An early discovery that gave concern to the engineers was the short life of the cables used on the soil unloaders.

These unloaders are the same as those used by railroads for unloading ballast. Their operation is very simple. A steel plow is dragged by wire cable from end to end of a string of flat cars, scraping off the dirt or ballast to one side as it goes. One and one-half-inch diameter cables were used for this purpose at Panama. Three or four hundred trains of sixteen and seventeen cars each were about all one cable could unload before breaking. The highest record was about 500 trains.

Early in 1909 Charles E. Bascom, of the Broderick & Bascom Rope Co., St. Louis, and E. P. Frederick, general superintendent of that company, went to Panama for the express purpose of finding out *why* the unloader cables broke so soon; also to remedy the trouble, if possible. The Panama officials encouraged manufacturers to visit the canal, and offered every help in studying conditions under which their products were employed in the big job. It was an excellent policy, and benefited both the canal engineers and the manufacturers.

Here is what Mr. Bascom and Mr. Frederick found when they investigated the conditions affecting the cables of the soil unloaders: The cars of the soil trains were packed high with earth and rock—not mere rubble, but huge boulders. Some weighed three or four tons. The wire cables were drawn over these great, sharp rocks while under a strain of from 90 to 100 tons. The friction actually caused the rocks to smoke, while deep grooves were worn in them. One of their own cables wore a groove ten inches deep in a rock in about six minutes.

Those were the conditions that had to be met, and met squarely by the cable that was to make a success in this particular work. It was a real problem, but Mr. Frederick was equal to it. His many years of experience in wire rope-making gave him a clue. His knowledge of wire rope enabled him to unravel the difficulty. He devised a rope of special construction—a rope within a rope. It is called Brobas Yellow Strand Wire Rope—Frederick Patent. This cable is a "compound" rope, but different in construction from ordinary compound ropes. It is "layed up" differently. In Brobas yellow strand the exterior and interior strands are so arranged that all tendencies of the strands to chafe and cut on each other are practically eliminated. The life of the rope, compared with other compound ropes, is therefore much greater.

Because of the peculiar construction, this Brobas rope is able to withstand sudden shocks, heavy strains and severe bending, up to the ultimate breaking strain of "ordinary" constructed rope of equal size and quality, without affecting its elasticity. The actual breaking strain is twenty-five per cent. greater than that of "ordinary" constructed rope.

Another advantage of this construction is this: the strands of the inner core lying in the interstices of the outer strands tend greatly to prevent the wires of the outer rope from creeping.

Mr. Frederick's new cable idea appealed to the canal engineers, and one and one-half-inch cables of this type were made up. The wire, with slight modifications, was the same that is used in yellow strand of ordinary construction.

The unloading records made by these special cables exceeded all expectations. Instead of unloading 300 to 500 trains of sixteen and seventeen cars, 1,830 trains of seventeen and nineteen cars were unloaded; then 1,875 trains; then 2,010 trains—more than four times as many as had ever been unloaded before the advent of B. & B. compound yellow strand cables.

Here is a complete record of three cables mentioned above, made by the canal commission:

TEST NO. 98

COMPARATIVE TEST OF CABLE ON LIDGERWOOD UNLOADERS ON THE CANAL ZONE CONDUCTED BY THE ISTHMIAN CANAL COMMISSION UNDER THE DIRECTION OF THE DEPARTMENT OF M. P. & M.

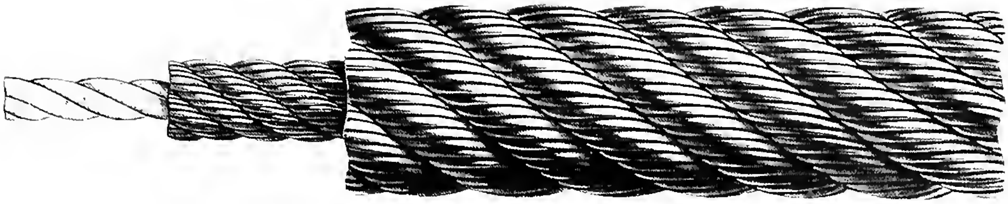
BRODERICK & BASCOM

Reel No. or Brand	Size of Cable	No. of Unloader	Date Applied	Date Removed	Time of Service Days	No. of Snatch Blocks Used	Place of Break	Total Trains Unloaded	Cable Cost per Train Unloaded
No. 1	1½"	32	4/12/09	5/5/10	388	333	8 CARS from Plow	1830 s	$0.218
No. 5	1½"	37	6/5/09	3/19/10	287	410	8 CARS from Plow	1875 s	$0.213
No. 3	1½"	38	6/11/09	11/3/10	510	310	8 CARS from Plow	2010 s	$0.199

Based on nineteen cars per train, this brings the cost of unloading each car to just a trifle over one cent In this connection the late Colonel D. D. Gaillard, who gave his life for the canal work and who was so signally honored by Congress, said, "Yellow Strand from Broderick & Bascom cable on Lidgerwood No. 46 was all right after plowing 1,870 trains. It will be noticed that the yellow paint is on strand after plowing off 35,530 cars, or in other words 296 miles of train. This makes a cost of $0.011 per car for cable."

Nine B. & B. compound yellow strand cables averaged 1,388 trains per cable. All cables of both makes were the same diameter—one and one-half inch. As substantial proof that B. & B. compound yellow strand cables met the situation adequately, it might be mentioned that the government purchased over $25,000 worth of these ropes exclusively for ballast unloaders.

Yellow strand cables are made of a special high-grade steel wire, drawn in Europe to Broderick & Bascom's specifications. They import this wire and control its use in this country. This special wire has an actual tested tensile strength of 240,000 to 260,000 pounds per square inch. But the durability of this special yellow strand wire is due to something deeper than its great strength. It has



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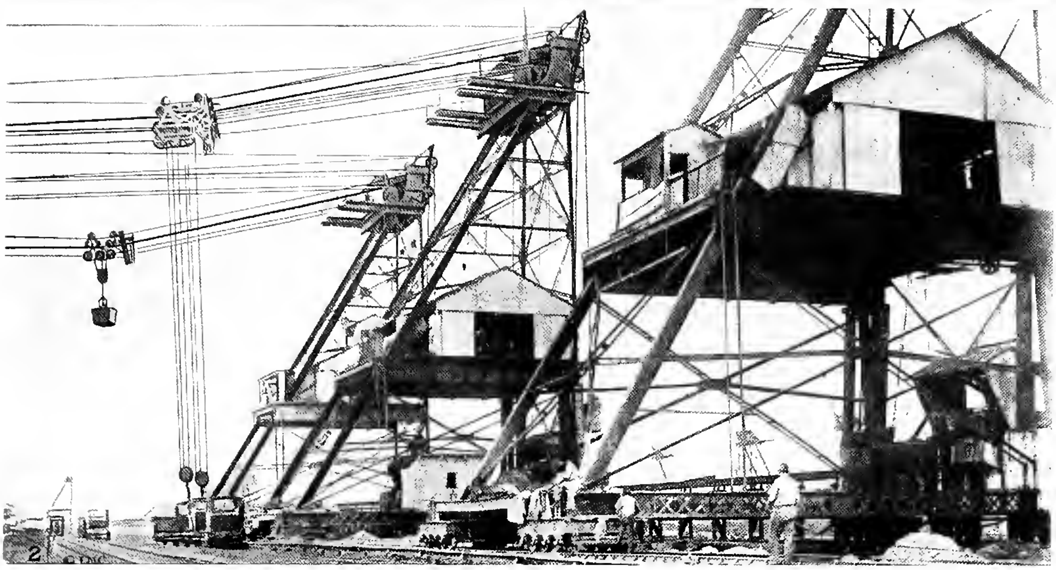
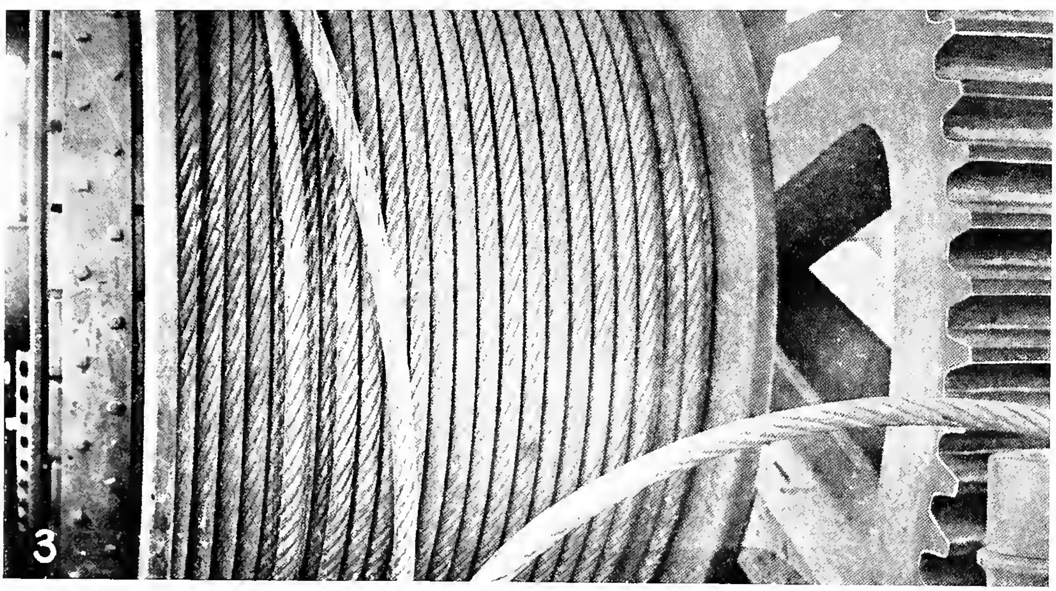




1. Wire Rope, core and weave.
2. The busy Cableway Towers at Gatun during construction.
3. Drum of wire rope.
(Supplied by the Broderick & Bascom Rope Company, St. Louis, Mo.)

a character all its own—a character inherited from the purest of Swedish ore and developed by painstaking manufacturing methods.

The ingot steel is made in England by the Siemen's Martin acid process which produces Sheffield steel. The ingots are rolled into bars and the bars drawn into wire by expert English wire drawers, and it makes wire that makes long-lived wire rope.

The wire rope is in general use for every purpose where great strength must be combined with flexibility and elasticity. The Broderick & Bascom Rope Co., whose main office is in St. Louis, Mo., have been making wire rope for over a third of a century. They have two factories—one in St. Louis, Mo., and the other in Seattle, Wash.

Among the manufacturers who furnished wire rope and insulated wire in the construction of the canal was the Hazard Manufacturing Company of Wilkesbarre, Pa., a firm established in 1848. The insulated wire department of this company was established in 1898, and has grown to be a very important factor in the company's business.

The products of the Hazard Manufacturing Company are known throughout the United States as of the finest quality, made to meet the real needs of purchasers and to give the most economical results in their use.

The wire ropes furnished the Isthmian Canal Commission were mainly of two constructions, one the regular hoisting rope construction composed of six strands of nineteen wires each with the best manila core as a cushion; the other what is known as extra flexible construction composed of eight strands of nineteen wires each with a manila core. The material entering into both constructions was the same, known as plow steel, with a breaking strain in the finished wire of some 115 to 120 gross tons per square inch, to meet the specifications of the commission.

The wire ropes furnished were of various sizes from one-half-inch diameter up to one-inch diameter inclusive. Test pieces were cut from all finished ropes as they were made up and tested by the inspector of the Isthmian Canal Commission to see that they were up to the required breaking strain. The specifications required by the commission were as follows:—

Breaking Strain in Tons of 2,000 Pounds

Diameter	6 Strands	8 Strands
½″	10	
⅝″	15½	14
¾″	23	20
⅞″	29	26
1″	38	

Sizes one-half and one inch were not made in the eight-strand construction.

This company also furnished the ballast unloader ropes which were required to do a most responsible work in connection with the rapid disposal of rock and dirt excavation. These ropes were one and one-half inches diameter, six strands of nineteen wires each, known as Seals patent or cable construction, and were made of the finest obtainable plow steel material drawn to the highest strains.

The insulated wire furnished the commission was for "house lighting," and was made in accordance with N. E. C. rules and requirements as adopted January 1, 1912. This company did not compete for the requirements of bare copper and electric conductors for use in the operation of the locks.

The Hazard Manufacturing Company in material furnished the Isthmian Canal Commission gave the same standard of excellence which it aims to maintain in all its products. Good service is the duty of every patriotic manufacturer in furnishing products to the United States Government, whether entering into supplies or permanent work. The open competition that was adopted by the commission brought about competitive conditions into which it was not always possible for this company to enter. It is a matter of pride and satisfaction, however, to its officers that the Hazard Manufacturing Company had some honorable part in connection with this work of national and world-wide importance.

The ordinary hoisting and other rope, so useful and important in general building and construction, was liberally used on the canal. Here again, American manufacturers had to meet unusual conditions.

Manila rope is always an important article in construction work, as upon its strength the safety of valuable property or life itself often depends, but at the same time it is one of those articles so easy to buy that its importance is seldom recognized. Usually when rope is needed a coil or two is bought at the nearest store and no more attention is given to it, unless it proves to be an inferior quality.

The location of the Panama Canal so far from the ordinary sources of supply made it necessary that all material (including rope) should be of a uniform and dependable quality. During the first few years all manila rope was purchased as the progress of the work demanded. Later it was found that it would be more desirable to have the rope purchased on the basis of an annual contract.

In 1910 the Columbian Rope Company of Auburn, N. Y., bid on these specifications and was successful in securing the award. The contract was for the fiscal year beginning June, 1910, and ending July 1, 1911. During this period the estimated requirements of the Isthmian Canal Commission for manila rope was about 1,000,000 pounds. Such a large amount of rope is difficult to comprehend, but the quantity can be better appreciated when it is known that if it were made into clothes line size there would be enough to make five continuous lines from New York to San Francisco, or in other words, over 15,000 miles of rope.

In the thousand and one different places where rope was used on the isthmus opportunities would arise for incorrect use or excessive strains, resulting in complaints. No more striking evidence of the uniformity and the high quality of "Columbian" manila rope has ever been offered than the one fact that during this entire period not a single complaint of any nature was registered against the wearing qualities of this rope.

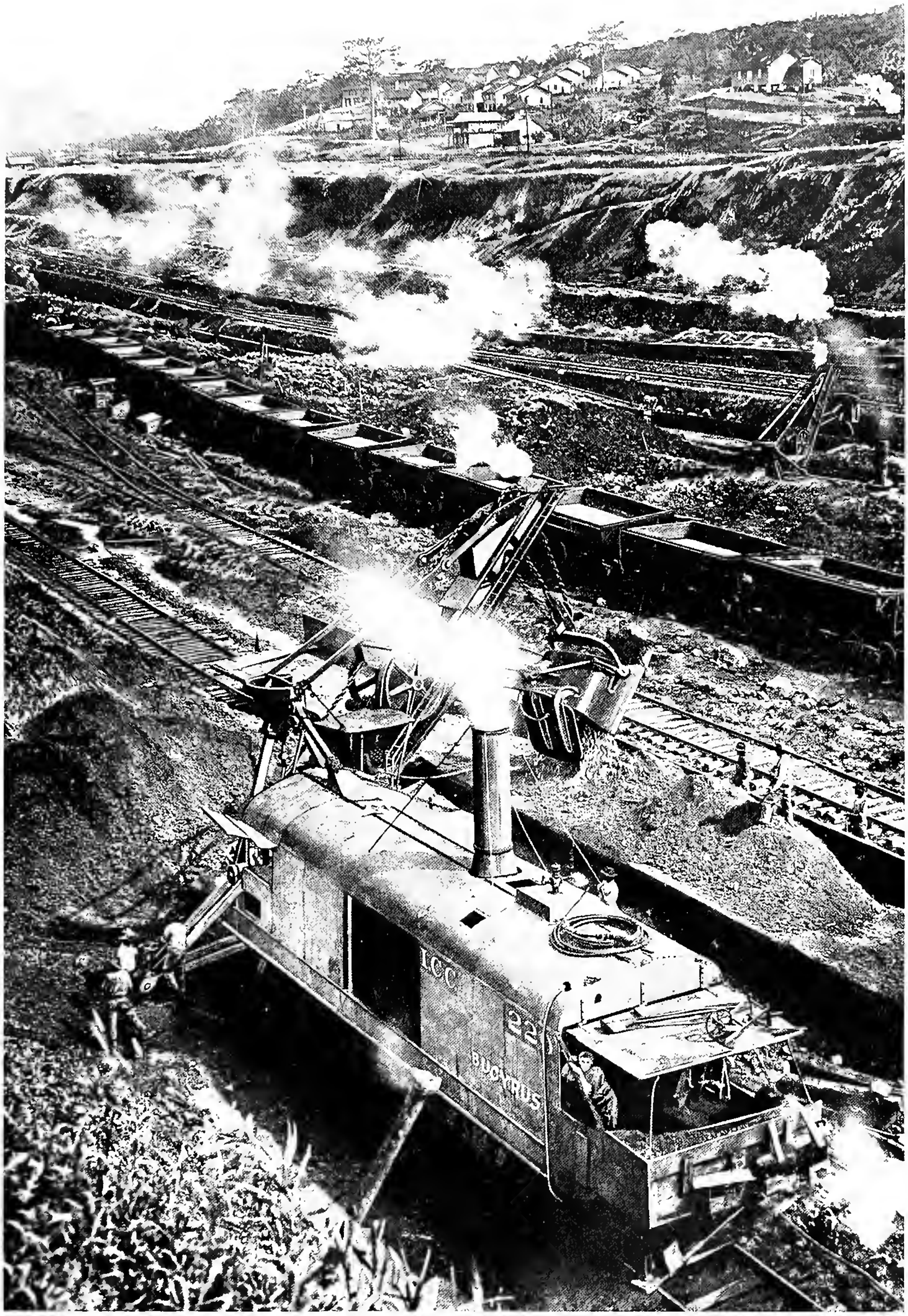
The Columbian Rope Company was again awarded the contract for the entire manila rope requirements for the twelve months ending July 1, 1913, and during this period the rope gave just as good service as before.

When letting this contract the specifications of the Isthmian Canal Commission required that each size of rope should stand a given strain before breaking. The tests for this breaking strain consisted of taking samples of every fifth coil and breaking them on the Rhiele testing machine. During the time that the rope contract was placed with the Columbian Rope Company hundreds of breaks were made, and on each test "Columbian" rope equalled or exceeded the commission's requirements.

In reviewing this item of equipment for the canal's construction, the following points stand out prominently:

The peculiar excellence of "Columbian" rope for use in the climate of the isthmus; the uniformity of the product as shown by the absence of all complaints regarding the quality; the accurate system of inspection and grading of fibre that must be maintained to insure a product of such continuous uniformity; and the unusual facilities for quick manufacture and prompt shipment—no penalties ever having been charged against the company for delay in deliveries, except for penalty of a day or two due to the delay occasioned by the transportation company.

The Columbian Rope Company's plant is located in the city of Auburn, N. Y. It employs about 1,000 people and is the largest single industry in the city. The products consist of rope and commercial twines made from manila, sisal, flax, hemp and jute twines. The raw material is secured from many distant lands, as, for instance, manila fibre from the Philippine Islands; sisal fibre from Yucatan; flax from Russia; jute from India; and hemp from Italy, Russia or Kentucky. The product is principally sold in the United States, al-



Ninety-five-ton Bucyrus Shovels at work. The machine in the foreground for a long time held the canal record but was later beaten by another Bucyrus Machine. (The Bucyrus Company, South Milwaukee, Wis., also furnished two 15-yard dipper dredges, and is now constructing another, to cost $375,000, to handle material thrown into the canal by slides.)

though some goods are shipped to many distant countries, including Argentina, Brazil, South Africa, Norway and Asia Minor.

The officers of the company are: President, E. D. Metcalf; vice-president, T. M. Osborne; general manager, E. F. Metcalf; secretary and treasurer, F. M. Everett; assistant treasurer, H. G. Metcalf; general superintendent, C. A. Clark.

Among other cordage and rope accessories supplied for the canal were several cars of Old Colony braided sash cord, Hartz steel tackle blocks, manila rope, and other items of tackle and cordage shipped by George B. Carpenter & Co., of Chicago. This equipment was adopted because of its adaptability to any climate and uniform good quality and lowest price.

Dredging and Excavating Machinery

Those who were so fortunate as to have witnessed the work during the canal's construction will always retain the picture of the great steam shovels and dredges busily engaged in "making the dirt fly." The machines, more than human in their steadiness and precision, and impressive in their wonderful power, were easily among the most picturesque features of the canal work.

Dipper dredges, especially designed for the canal, were early set to work upon the slides in Culebra Cut. It is difficult, even for one familiar with this type of machinery, to comprehend their enormous size and power. Beside them, the discarded dredges of the French operations were pigmies.

The most graphic illustration of their size may be found in their fifteen cubic yard dippers, which could hold thirty-four men standing on a platform half way down the bowl. The boom of each dredge, with its machinery, weighed about 113,000 pounds, and was sixty-two feet long. The dipper handles were seventy-two feet long, and without the dipper weighed 81,000 pounds.

Before construction work was actively commenced on the isthmus, John F. Wallace, who was then chief engineer of the Isthmian Canal Commission, made his first tour of inspection along the proposed line of the canal, in August, 1904. In order to determine the most efficient method of doing the dry excavation he requested the Bucyrus Company, of South Milwaukee, Wis., to send a representative to the isthmus to discuss with him the types of machinery best fitted for the work.

On the 18th of the same month, a contract was signed with the Bucyrus Company for one seventy-ton and two ninety-five-ton steam shovels. This was followed in October with an order for five seventy-ton and six ninety-five-ton shovels. Subsequently, orders were placed with the Bucyrus Company until ultimately a total of thirty-two ninety-five-ton, thirty-five seventy-ton and ten forty-five-ton Bucyrus shovels were at work, making a total of seventy-seven out of a grand total of one hundred and one steam shovels engaged in the dry excavation of the canal. The ninety-five-ton shovels were equipped with five-yard dippers, the seventy-ton with three-yard, and the forty-five-ton with one-and-three-quarter-yard dippers.

Two fifteen-yard dipper dredges, the largest of their type ever constructed, were supplied by the Bucyrus Company, in addition to their dry excavation steam shovels, a railroad pile driver and three seventy-five-ton and one one-hundred-ton wrecking machines. The railroad pile driver was mainly used for work in connection with the Panama Railroad. The machine was self propelling, and was provided with a drop-hammer weighing 3,500 pounds. The wrecking cranes were used on both canal and railroad work.

The extraordinarily massive construction and enormous power of the dipper dredges attracted wide attention from engineers and technical experts, and were a favorite feature of interest to visitors.

It is not too much to say that without the help of the giant steam shovels and dredges the canal would yet be only in a preliminary stage of completion. An analysis of the records of the official performance of the steam shovels shows that the Bucyrus shovels hold all records of output on the canal proper, where the most severe conditions were encountered. A ninety-five-ton Bucyrus excavated 4,823 cubic yards of material, classified as earth and rock, in five hours and twenty minutes. The same shovel, known in the official language of the commission as No. 213, holds the highest monthly record made in the canal prism, excavating in twenty-six days 70,290 cubic yards of material, or enough to fill a line of ordinary two-yard dump wagons reaching two hundred miles.

As the canal got deeper, the material encountered contained a higher percentage of rock. Down in the lowest cuts of the canal, where the most severe conditions were encountered and the most exacting service required, the giant Bucyrus machines dug stolidly until the last whistle echoed over the completed cuts.

During the earlier periods of excavation practically all of the material was removed by the larger types of shovels, but, as the work progressed, it became apparent that certain operations could be prosecuted more expeditiously and to better advantage by shovels of smaller make.

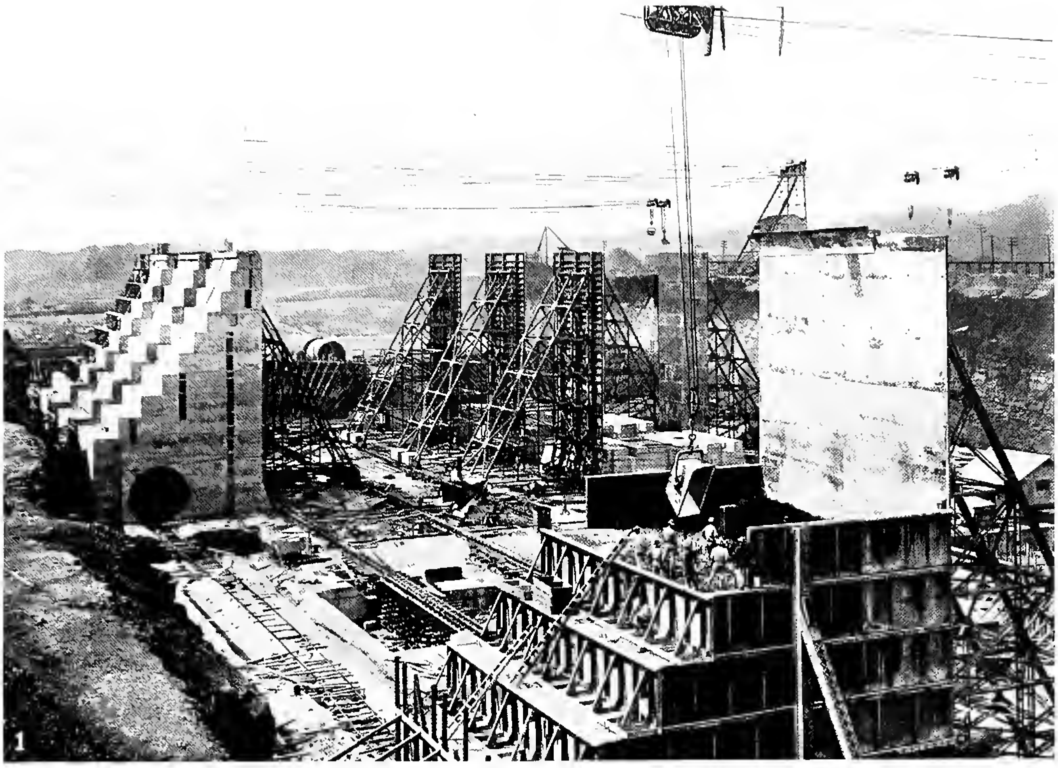
It was at this stage that the canal officials called for bids for the kind of shovel needed to meet the changed requirements. The Thew Automatic Shovel Company of Lorain, Ohio, had refrained from entering the field of competition earlier, largely because the entire output of its plant had been contracted for months ahead when the first bids were made. It answered the later appeal, however, and was awarded, over a large number of competitors, the contract calling for its thirty-two-ton steam shovel. This is a small, full-circle swing steam shovel, representing careful development under various practical tests, as well as the highest possible degree of perfection that the company could devise toward meeting the objects in view—basement excavating, loading material from rock piles, road and street grading, and the different classes of railroad, quarrying and other work in which the heavier excavator type of shovel cannot be used to advantage.

According to the reports of the men in charge of the equipment, the Thew shovels gave most satisfactory results during their entire period of use at the isthmus. As an example of the amount of work possible there may be quoted an eleven-day record recently made by one of the shovels—a duplicate of the Panama equipment—during which 2,605 cars were loaded with an aggregate of 14,942 cubic yards of material. Many other practical tests have shown that where the capacity desired does not exceed 1,000 to 1,500 cubic yards a day, the Thew shovel offers many features of decided advantage over any other similar article now being manufactured.

In addition to the dry excavation and dipper shovels and dredges, other types of dredges were prominent on the canal. One of the most important of these was the bucket "hopper dredge" *Corozal*, constructed by the William Simons Company, of Renfrew, Scotland, a firm distinguished by being one of the few foreign concerns to supply equipment for the canal. Before giving a description of the immense work done by this piece of dredging machinery a little of the history of the evolution in dredging machinery that has taken place within the last few years may be interesting to the reader.

The introduction of dredging machines in England is generally placed in the reign of Charles I, when several Dutch engineers went to that country to carry out some engineering projects. In the latter part of the 18th century important improvements were made in dredging appliances, particularly with operations on the Clyde, and further improvements were made a few years later in connection with the deepening of the Thames, and a dredging machine wrought with steam power was invented by Trevethick in 1806-7.

The application of steam power to dredging appliances culminated in 1861, in the construction of two hopper steamers by William Simons & Co., of Renfrew, for use



1. Lidgerwood cableway conveyors at work on side wall monolith, Gatun upper lock; cable rope furnished by A. Leschen & Sons Rope Co., St. Louis.
2. Lidgerwood unloaders sweeping the cars with Leschen's "Hercules" wire rope.
(Supplied by the Lidgerwood Manufacturing Company, New York.)

on dredging work on the Clyde. These were the first self-propelling vessels employed for transporting and depositing dredgings in deep water. The idea of employing steam power for this purpose was, at the time, looked upon with grave doubts, some regarding it as a piece of folly, and, as was customary in those days, it met with much opposition.

Time and actual accomplishment have amply demonstrated on the Clyde, Thames, and Mersey, and on the Panama Canal, that the substitution of "steam hoppers" for tugs, with their string of punts or scows, was a step in the right direction. This introduction of "steam hoppers" brought about other improvements. Among other suggestions was one that if it were possible to combine in one bottom all the distinctive features of the bucket ladder dredger and the steam hopper barge, many advantages, such as adaptability for working in confined spaces, economy in working, ability to work in exposed situations when it would be impossible for a barge to lie alongside a stationary dredger, etc., would be gained. The result was the invention by Mr. Brown of what is now known as the "hopper dredger." The first dredger of this type was the *Canada*, constructed by Messrs. Simons & Co., in 1872, to the order of the Dominion government. Improvements in detail followed in the course of time, as experience was gained in handling the new type of dredger.

The *Corozal*, used on the work of the Panama Canal, is the most powerful bucket "hopper" dredge yet constructed. It is a twin-screw vessel, built of steel, practically 269 feet in length. The steam generating plant consists of two marine cylindrical multitubular boilers, having a total heating surface of 4,044 square feet, and a combined grate area of 132 square feet. The boilers are constructed of mild steel suitable for a working steam pressure of 180 pounds per square inch, each boiler being capable of driving simultaneously one set of main engines together with all auxiliary engines. There are two main engines, which propel the vessel or run the dredging gear as required.

The air pumps are two independent vertical steam-driven pumps. The circulating pumps consist of two independent steam-driven centrifugal pumps. Other pumps for various parts of the work are supplied, and are operated independently of the main engines by steam direct from the boilers. The propellers are of cast iron secured to steel shafting driven through steel clutches from the main engines. The dredger is fitted with its own refrigerating and electric lighting plants.

The ladder upon which the continuous chain of large buckets revolves is built up of structural steel girders strongly braced laterally and vertically, and is 115 feet long, weighing 100 tons. With buckets and links and mountings on it the total weight of the ladder is 240 tons. The gear is so arranged that with a constant piston speed of the main engines three different speeds of the buckets can be obtained. This arrangement of the gearing permits the dredger successfully and economically to tackle very hard, medium and soft material. Two sizes of buckets are provided, one of fifty-four cubic feet for excavating in soft material, and one of thirty-five feet for digging in hard material. There are thirty-nine buckets in a chain.

For regulating and controlling the cut of the dredger enormous manœuvering winches are placed at bow and stern. These winches are of the most powerful description and were designed with special regard to the very hard nature of the dredging work to be done by the *Corozal* in the canal. The work for which the dredge was used was the digging of about four million cubic yards of hard material, rock, clay and boulders from the Pacific entrance of the canal between Balboa and Miraflores locks, excavation that could not be done by the ordinary ladder or dipper dredges, such as had been used by the French company, because of the character of the material and the depth at which it was found.