locomotives of which this is an example were built for the Southern Pacific Company, and they have performed their work in a highly satisfactory manner. They are not particularly large locomotives as those matters go at the present day, as they carry

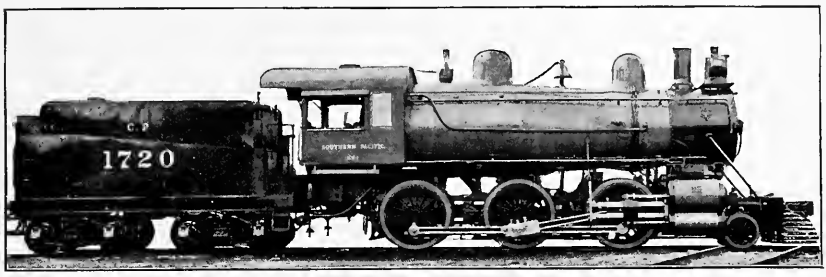

FIG. 36.

about 135,000 pounds on the drivers and 22,000 pounds on the truck, giving a total weight of 157,000 pounds. The characteristic feature of the machine is its adaptation to the burning of oil, which requires practically no labor in firing, although the services of a fireman must still be retained.

304. The "Soo" Decapod Locomotive.—It has been seen that the results of Trevethick's early efforts was a crude and simple machine, with what might be termed, in courtesy to that early attempt, a single pair of drivers. Subsequently, as locomotive evolution took place, two pairs of drivers coupled with the horizontal connecting-rod were employed. Then the Mogul with the three pairs of coupled drivers was used, and at or about the same time the consolidation type with four pairs of coupled drivers was found adapted in a high degree to the hauling of great freight trains. The last evolution in driving-wheel arrangement is exhibited in Fig. 37. It belongs to what is called the Decapod type. As a matter of fact, five pairs of coupled driving-wheels have been occasionally used for a considerable number of years, but this engine is the Decapod brought up to the highest point of modern excellence. As shown, it uses steam by the Vauclain compound system, the small or high-pressure cylinder being underneath the low-pressure cylinder. They have been built by the Baldwin Locomotive Works for

the Minneapolis, St. Paul and Sault Ste. Marie Railroad Company, on what is called the "Soo Line." It has given so much satisfaction that more of this type but of greater weight are being built for the same company. This engine was limited to

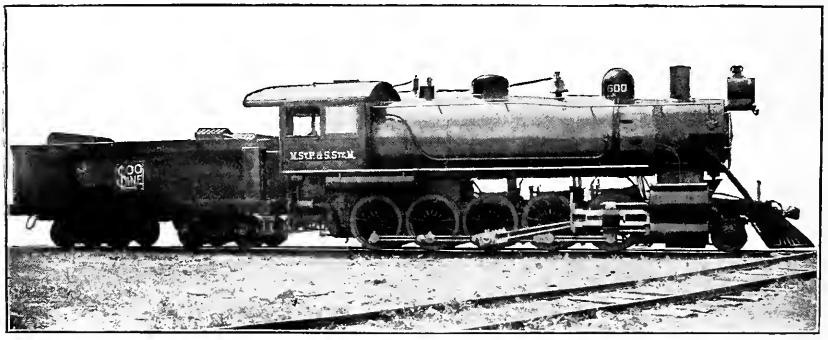

FIG. 37.

a total weight of 215,000 pounds, with 190,000 pounds on the drivers.

305. The A., T. & S. F. Decapod, the Heaviest Locomotive yet Built.—The heaviest locomotive yet constructed, consequently occupying the primacy in weight, is that shown in Fig. 38. It is a Decapod operated with others of its type by the A., T. & S. F.

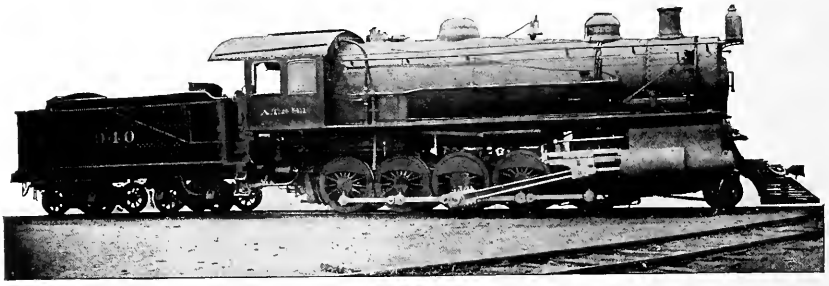

FIG. 38.

Company near Bakersfield, California. It is a tandem compound coal-burner, as shown by the illustration, the high-pressure cylinder being in front of the low-pressure. The dimensions of cylinders are 19 and 32 × 32 inches stroke, and the driving-wheels are 57 inches in diameter. The total height from the top of stack

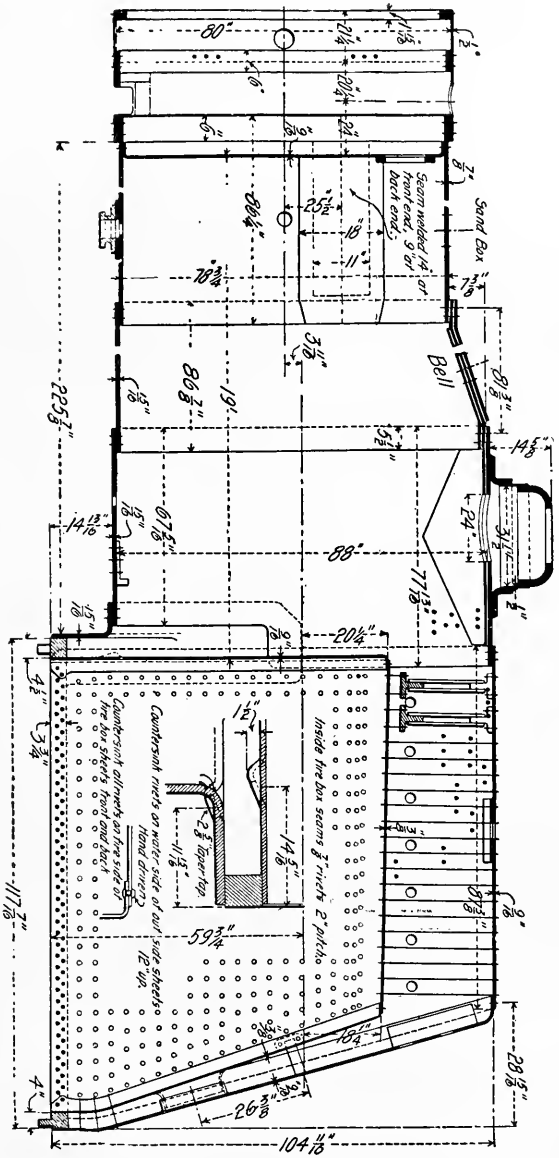
Seam welded 1/4" or front end, 5/16" back end.
Sand Box
Bell
Countersink rivets on water side of outer side sheets
Inside fire box seams 5/8" rivets 2" pitch
Countersink all rivets on fire side of inner fire box sheets
Upper Rail
Lower Rail
80"
88"
104 11/16"
59 3/4"
26 3/8"
225 1/2"
191"
86 3/4"
67 5/8"
77 13/16"
117 7/16"
28 15/16"
20 1/4"
14 5/8"
14 5/16"
12"
4"

FIG. 39.

down to the rail is 15 feet 6 inches, while the height of the centre of the boiler above the rails is 9 feet 10 inches. Figs. 39 and 40 show some of the main boiler and fire-box dimensions. There are 463 $2\frac{1}{4}$-inch tubes, each 19 feet long. The total heating surface is 5390 square feet, about one eighth of an acre, the length of the fire-box being 108 inches and the width 78 inches. The heating surface in the tubes is 5156 square feet, and in the fire-box 210.3 square feet; the grate surface having an area of 58.5 square feet. The boiler is designed to carry a working pressure of 225

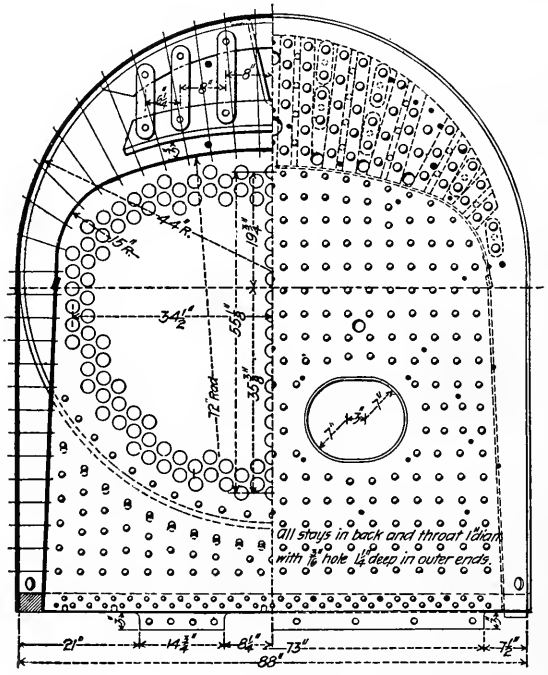

FIG. 40.

pounds per square inch, the boiler-plates being $\frac{15}{16}$ inch, $\frac{9}{16}$ inch, and $\frac{7}{8}$ inch thick, according to location. As shown by the illustrations, the boiler is what is termed an extended wagon-top with wide fire-box. The total weight of the locomotive itself is 267,800 pounds, while the weight on the driving-wheels is 237,800 pounds, making 47,560 pounds on each axle. The tractive force of this locomotive is estimated to be over 62,000 pounds.

306. Comparison of Some of the Heaviest Locomotives in Use. —The following table gives a comparison of the heaviest locomotives thus far built, as taken from the *Railroad Gazette* for January 31, 1902, revised to September 1, 1902.

COMPARISON OF HEAVIEST LOCOMOTIVES.

	Atchison, Topeka & Santa Fe.	Pittsburg, Bessemer & Lake Erie.	Union Railroad.	Illinois Central.	Lehigh Valley.
Name of builder.....	Baldwin	Pittsburg	Pittsburg	Brooks	Baldwin
Size of cylinders.....	19 & 32×32 in.	24×32 in.	23×32 in.	23×30 in.	18 & 30×30 in.
Total weight.....	267,800 lbs.	250,300 lbs.	230,000 lbs.	232,200 lbs.	225,082 lbs.
Weight on drivers....	237,800 lbs.	225,200 lbs.	208,000 lbs.	193,200 lbs.	202,232 lbs.
Driving-wheels, diam..	57 in.	54 in.	54 in.	57 in.	55 in.
Heating surface.....	5,390 sq. ft.	3,805 sq. ft.	3,322 sq. ft.	3,500 sq. ft.	4,104 sq. ft.
Grate area.....	58.5 sq. ft.	36.8 sq. ft.	33.5 sq. ft.	37.5 sq. ft.	90 sq ft.

These instances of modern locomotive construction are impressive, especially when considered in contrast with the type of engine in use not more than fifty years ago. They indicate an almost incredible advance in railroad transportation, and they account for the fact that a bushel of wheat can be brought overland at the present time from Chicago to New York City, a distance of 900 miles, for about one third of the lowest charge for delivering a valise from the Grand Central Station in the city of New York to a residence within a mile of it.

PART V.

THE NICARAGUA ROUTE FOR A SHIP-CANAL.

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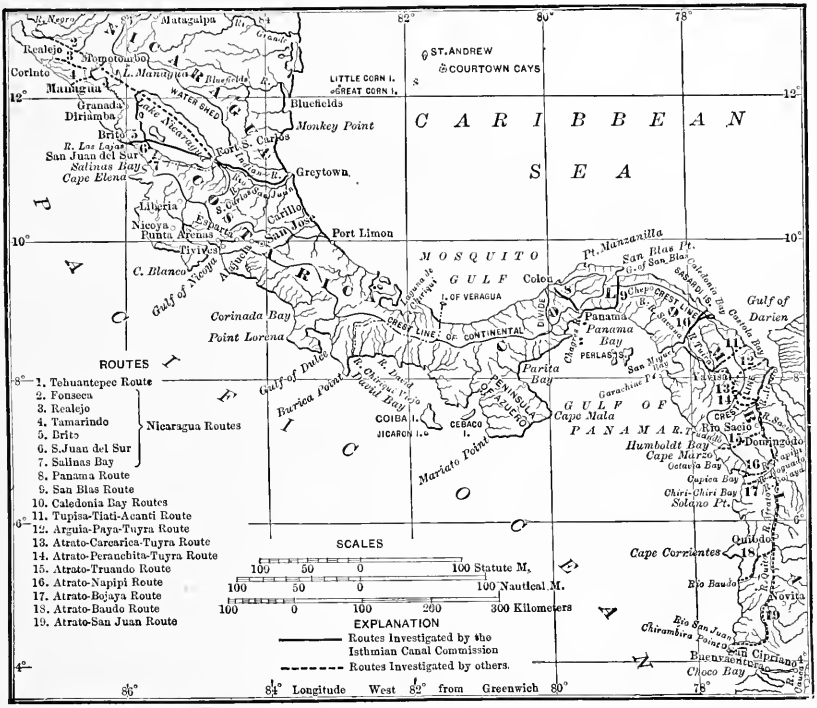
307. Feasibility of Nicaragua Route. — The feasibility of a ship-canal between the two oceans across Nicaragua has been recognized almost since the discovery of Lake Nicaragua in 1522 by Gil Gonzales de Avila, who was sent out from Spain to succeed Balboa, after the execution of the latter by Pedro Arias de Avila at Acla on the Isthmus of Panama.

308. Discovery of Lake Nicaragua. — Gil Gonzales set sail from the Bay of Panama in January of that year northward along the Pacific coast as far as the Gulf of Fonseca. He landed there and proceeded to explore the country with one hundred men, and found what he considered a great inland sea, as we now know, about 14 miles from the Pacific Ocean at the place of least separation. The country was inhabited, and he found a native chief called Nicarao, who was settled with his people at or near the site of the present city of Rivas. As he found it a goodly country, fertile and abounding in precious metals, he immediately proceeded to take possession of it for his sovereign, but the Spanish explorer was sufficiently gracious to the friendly chief to name Lake Nicaragua after him. From that time the part of Nicaragua in the vicinity of the lake received much attention, and the Spaniards made conquest of it without delay. Among those who were the earliest visitors was a Captain Diego Machuca, who, with two hundred men under his command, explored Lake Nicaragua in 1529 and constructed boats on it, a brigantine among them. He seems to have been the first one who entered and sailed down the Desaguadero River, now called

the San Juan, and one of the rapids in the upper portion of the river now bears his name. He pursued his course into the Caribbean Sea and sailed eastward to the Isthmus of Panama.



Map of American Isthmus, showing Proposed Canal Routes.

309. Early Maritime Commerce with Lake Nicaragua. — Subsequently sea-going vessels passed through the San Juan River in both directions and maintained a maritime trade of some magnitude between the shores of Lake Nicaragua and Spain. Obviously these vessels must have been rather small for ocean-going craft, unless there was more water in the San Juan River in those early days than at present. There are some obscure traditions of earthquakes having disturbed the bed of the river and made its passage more difficult by reducing the depth of water in some of the rapids; but these reports are little more than traditionary and lack authoritative confirmation. It is certain, however, that the marine traffic, to which reference has been made, was maintained for a long period of years, its greatest activity

existing at about the beginning of the seventeenth century. It was in connection with this traffic probably that the city of Granada at the northwestern extremity of the lake was established, perhaps before 1530.

310. Early Examination of Nicaragua Route.—Although the apparently easy connection between the Caribbean Sea and Lake Nicaragua, together with the proximity of the latter to the Pacific coast, at once indicated the possibility of a feasible water communication between the two oceans, probably no systematic investigation to determine a definite canal line was made until that undertaken by Manuel Galisteo in 1779 under the instruction of Charles III., who was then on the throne of Spain. Galisteo made a report in 1781 that Lake Nicaragua was 134 feet higher than the Pacific Ocean, and that high mountains intervened between the lake and the ocean, making it impracticable to establish a water communication between the two. In spite of the discouragement of this report a company was subsequently formed under the patronage of the crown to construct a canal from Lake Nicaragua along the Sanoa River to the Gulf of Nicoya, but nothing ever came of the project.

311. English Invasion of Nicaragua.—The country was invaded in 1780 by an English expedition sent out from Jamaica under Captain Horatio Nelson, who subsequently became the great admiral. He proceeded up the San Juan River, and after some fighting captured by assault Fort San Juan at Castillo Viejo. Nelson and his force, however, were ill qualified to take care of themselves in that tropical country where drenching rains were constantly falling, and he was therefore obliged to abandon his plan of taking possession of Lake Nicaragua and returned instead to Jamaica. The tropical fevers induced by exposure reduced the crew of his own ship, two hundred in number, to only ten after his return to Jamaica, and he himself nearly lost his life by sickness.

312. Atlantic and Pacific Ship-canal Company.—Subsequently to this period the Nicaragua route attracted more or less attention until Mr. E. G. Squier, the first consul for the United States in Nicaragua, negotiated a treaty between the two countries for facilitating the traffic from the Atlantic to the Pacific Ocean by

hills into the valley of the San Juan above its junction with the San Carlos. A dam was to be constructed across the San Juan River at Ochoa, below the mouth of the San Carlos, so as to bring the surface of Lake Nicaragua down to that point. From its junction with the San Juan River the canal line followed that river to the lake, across the latter to Las Lajas, and thence down the Rio Grande to the Pacific coast at Brito. It was contemplated under this plan to carry the lake level to a point called La Flor, 13.5 miles west of the lake, and drop down to the Pacific

Breakwater of the Maritime Canal Company.
The closed former entrance to Greytown harbor is shown on the left.

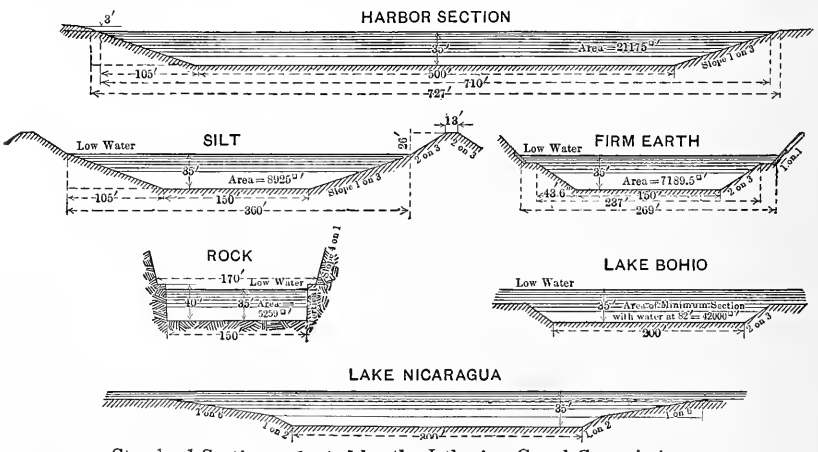
from that point by locks suitably located. After partially excavating the canal prism for about three quarters of a mile from the Greytown Lagoon, constructing a line of railroad up the Deseado valley, as well as a telegraph line, and doing certain other work preparatory to the actual wo k of construction, the Maritime Canal Company became involved in financial difficulties and suspended operations without again resuming them.

315. The Work of the Ludlow and Nicaragua Canal Commissions. —In 1895 and again in 1897 two commissions were appointed by the President of the United States to consider the plans and esti-

mates of the Maritime Canal Company in the one case, and the problem of a ship-canal on the Nicaragua route in the latter. Neither of these commissions, however, had the funds at its disposal requisite for a full and complete consideration of the problem. In 1899, therefore, the Isthmian Canal Commission was created by Act of Congress, and appointed by the President of the United States, to determine the most feasible and practical route across the Central American isthmus for a canal, together with the cost of constructing it and placing it under the control, management, and ownership of the United States. This commission consisted of nine members, and included civil and military engineers, an officer of the navy, an ex-senator of the United States, and a statistician. It was the province and duty of this commission to make examinations of the entire isthmus from the Atrato River in the northwestern corner of South America to the western limits of Nicaragua for the purpose of determining the most feasible and practical route for a ship-canal between those territorial limits. This brings the general consideration of the isthmian canal question to the Nicaragua route in particular, to which alone attention will be directed in this part.

316. The Route of the Isthmian Canal Commission. — The Isthmian Canal Commission adopted a route practically following the San Juan River from near Greytown to the lake, across the latter to Las Lajas on its westerly shore, and thence up the course of the Las Lajas River, across the continental divide into the Rio Grande valley, and down the latter to Brito at the mouth of the Rio Grande on the Pacific coast. As has already been stated, this is practically the line adopted by Col. Childs almost exactly fifty years ago. It is also essentially the route adopted by the Nicaragua Canal Commission appointed in 1897, and which completed its operations immediately prior to the creation of the Isthmian Canal Commission. The amount of work performed in the field under the direction of the commission can be realized from the statement that twenty working parties were organized in Nicaragua with one hundred and fifty-nine civil engineers and other assistants, and four hundred and fifty-five laborers.

317. Standard Dimensions of Canal Prism.—By the Act of Congress creating it, the latter commission was instructed to consider plans and estimates for a canal of sufficient capacity to accommodate the largest ships afloat. In order to meet the requirements of those statutory instructions the commission decided to adopt 35 feet as the minimum depth of water in the canal throughout its entire length from the deep water of one ocean to that of the other, wherever the most feasible and practical route might be located, the investigations of the commission having shown that the final location to be selected must narrow down to a choice between the Panama and the Nicaragua routes. It was further decided by the commission that the standard width of excavation at the bottom of the canal should be 150 feet, with 500 feet for the ocean entrances to harbors, and 800 feet in those harbors. Greater widths than that of the bottom of standard excavations were also adopted for river and lake portions.



Standard Sections adopted by the Isthmian Canal Commission.

The slopes of the sides of the excavation were determined to be 1 vertical on $1\frac{1}{2}$ horizontal for firm earth, but as flat as 1 vertical on 3 or even 6 horizontal for soft mud or silt in marshy locations. In rock cutting below water the sides of the excavation would be vertical, but as steep as 4 vertical on 1 horizontal above water.

The longest ship afloat at the present time (1902) is the Oceanic of the White Star Line, and its length is about 704 feet.

The widest ships, i.e., the ships having the greatest beam, are naval vessels, and at the present time none has a greater beam than about 77 feet. In order to afford accommodation for further development in both length and beam of ships without leading to extravagant dimensions, the commission decided to provide locks having a usable length of 740 feet with a clear width of 84 feet. These general dimensions meet fully the requirements of the law, and were adopted for plans and estimates on both the Panama and Nicaragua routes.

318. The San Juan Delta. — The entire Central American isthmus is volcanic in character, and this is particularly true of the country along the Nicaragua route with the exception of the lowlands immediately back of the ocean shore-line in the vicinity of Greytown. From the latter point to Fort San Carlos, where the San Juan River leaves the lake, is approximately 100 miles. With the exception of the 15 miles nearest to the seacoast the San Juan River runs mostly through a rugged country with high hills densely wooded on either side. The soil is mostly heavy clay, although the bottom of the valley immediately adjacent to the river is largely of sandy silt with some mixture of clay. Between the hills back of Greytown and the seacoast the country is almost a continuous morass covered with coarse grasses and other dense tropical vegetation, but with a number of small isolated hills projecting up like islands in the surrounding marsh, and interspersed with numerous lagoons. All this flat country has the appearance of forming a delta through which a number of mouths of the San Juan River find their way. One of these, called the Lower San Juan, empties into the Greytown Lagoon, but the main mouth of the San Juan, called the Colorado, branches from the main river at the point where the Lower San Juan begins, about 13 or 14 miles from the ocean. The Colorado itself is composed of two branches, and at the place where it empties into the sea there are a number of long narrow lagoons parallel to the seashore, appearing to indicate comparatively recent shore formation. Again, a small river called the Rio San Juanillo leaves the main river 3 or 4 miles above the junction of the lower San Juan and the Colorado, and pursues a meandering course through the low marshy grounds back of Greytown, and finally again

joins the Lower San Juan near the town. This marshy lowland is underlaid by and formed largely of dark-colored sand brought down mostly from the volcanic mountains of Costa Rica by two rivers, the San Carlos and the Serapiqui, the former joining the San Juan about 44 miles and the latter about 23 miles from the sea.

Greytown Lagoon (formerly Greytown Harbor), showing Greytown in the Distance.

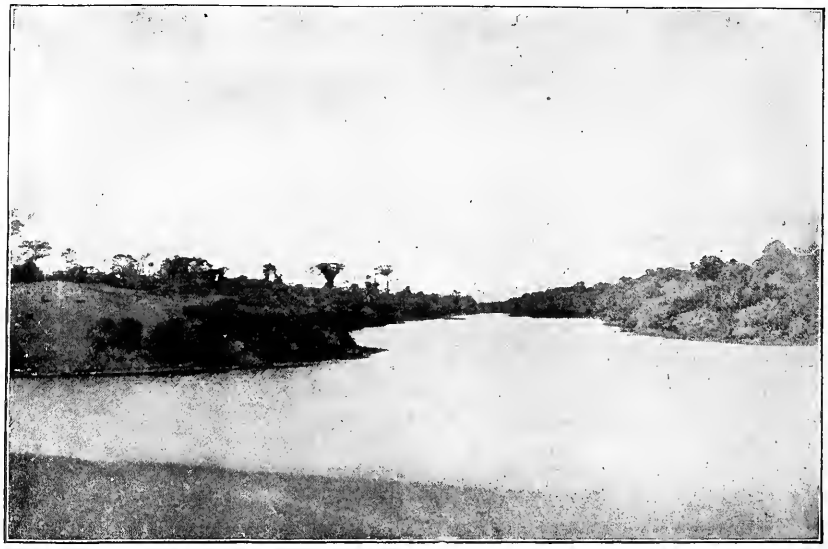
319. The San Carlos and Serapiqui Rivers.—Both those Costa Rican rivers are subject to sudden and violent floods, and they bring down large quantities of this volcanic sand, the specific gravity of which is rather low. The San Carlos bears the greater burden of this kind. In fact its bed, even when not in a state of flood, is at many points at least composed of moving sands. Both rivers are clear-water streams except in high-water stages. Below the junction of the San Carlos the San Juan is necessarily in times of floods a large bearer of silt and sand, but above that point it carries little or no sediment. There are no streams of magnitude which join the San Juan between the lake and the San Carlos.

320. The Rapids and Castillo Viejo.—About 54 miles from the ocean are the Machuca Rapids, and from that point to a distance of about 75 miles from the ocean other rapids are found, the principal of which are the Castillo and the Toro. The Castillo Rapids are at the point called Castillo Viejo, where there is located an old Spanish fort on the top of the high hill around the base of which the river flows. The town of Castillo Viejo has a small population of perhaps 500 to 600 people. It is a place with historical associations, to which reference has already been made. It was here that Captain (afterwards Admiral) Nelson captured the Spanish fort in 1780. It is a place of some importance in connection with the river traffic in consequence of necessary transhipment of freight and passengers to overcome the rapids.

321. The Upper San Juan.—The upper reaches of the San Juan within about 20 miles of the lake are bordered with considerable marshy ground. In the vicinity of its exit from the lake there is a wide strip of soft marshy country around the entire southeastern shore.

322. The Rainfall from Greytown to the Lake. — The entire country between Greytown and the lake is intensely tropical, and the vegetation is characteristically dense. It is particularly so at Greytown, where the total annual rainfall sometimes reaches as much as 300 inches. It rains many times in a day, and nearly every day in the year. The strong easterly and northeasterly trade winds, heavy-laden with the evaporation from the tropical sea, meet the high ground in the vicinity of Greytown and precipitate their watery contents in frequent and heavy showers. The general course of the San Juan valley is a little north of west or south of east, and the trade winds appear to fo low the course of the valley to the lake. The rainfall steadily decreases as the seashore is left behind, so that at Fort San Carlos, the point of exit of the river from the lake, the annual precipitation may vary from 75 to 100 inches. There is no so-called dry season between the lake and the Caribbean Sea, although at Fort San Carlos the rainfall is so small between the middle of December and the middle of May that that period may perhaps be considered, relatively speaking, a dry season. It is evident, therefore, that all the conditions are favorable to luxuriant tropical growths over

this entire eastern portion of the canal route, and the coarse grasses, palms, and other tropical vegetation found in it are indescribably dense. The same general observation is applicable to the forest and undergrowth throughout the entire course of the river from Greytown to Fort San Carlos. All of the high ground is heavily timbered, with undergrowth so dense that no survey line can be run until it is first completely cut out. That observation holds with added force throughout the swampy country



The Maritime Canal Company's Canal Cut leading out of Greytown Lagoon.

adjacent to the seashore. All the heavy forest growth carries dense vines and innumerable orchids, which so cover the trunks and branches of trees as in many places completely to obscure them.

323. Lake-surface Elevation and Slope of the River. — The lake surface has an area of about 3000 square miles and varies in elevation with the amount of rainfall in its basin from about 97 or 98 to perhaps 110 feet above the ocean. The average elevation can probably be taken at about 104 feet above the sea. The length of the lake is about 103 miles, with a greatest width of 45 miles. The area of its watershed is about 12,000 square

miles. Inasmuch as the length of the San Juan River from the ocean to the lake is but a little more than 100 miles, its average fall is seen to be about 1 foot per mile. The greatest slope of the river surface is at Castillo Rapids, where it falls about 6 feet in $\frac{3}{8}$ of a mile. At the Machuca Rapids it falls about 4 feet in 1 mile. From the foot of Machuca Rapids to the mouth of the San Carlos, a distance of a little over 15 miles, the surface of the river falls about 1 foot only. This pool, with practically no sensible current, is called Agua Muerte, or Dead Water. The relatively great depth of this pool shows conclusively that the upper San Juan, i.e., above the mouth of the San Carlos, carries no silt, otherwise the pool would be filled; in other words, that part of the San Juan River is not a sediment-bearer. The slope of the river surface in the Toro Rapids, about 27 miles from the lake, gives a fall of $7\frac{3}{10}$ feet in $1\frac{7}{10}$ miles.

324. Discharges of the San Juan, San Carlos, and Serapiqui.—In times of heavy floods the San Carlos River may discharge as much as 100,000 cubic feet per second into the San Juan, but such floods have a duration of a comparatively few hours only. Its low water-discharge may fall below 3000 cubic feet per second. The maximum outflow of the lake during a rainy season or a season of heavy rainfall probably never exceeds about 70,000 cubic feet per second, but that rate of discharge may continue for a number of weeks. The low water-discharge of the San Juan above the mouth of the San Carlos may fall below 10,000 feet per second, or 13,000 feet per second below the mouth of the San Carlos but above that of the Serapiqui.

325. Navigation on the San Juan.—From what has been said of the San Juan River it is evident that in times of low water no boats drawing more than about 5 or 6 feet can navigate it, and most of the river boats draw less than that amount. In times of low water no boat can navigate the Lower San Juan drawing more than about $2\frac{1}{2}$ to 3 feet of water. Nor, again, can the ordinary river boats pass up the rapids at Castillo except at high water. It is necessary, therefore, that the larger boats used on the river confine their trips on the one hand between the mouth of the Colorado and Castillo, and on the other between Castillo above the rapids to Fort San Carlos. It is the custom, therefore, to

transfer passengers and freight from boats below the rapids at Castillo by a short tramway to other boats in waiting above the rapids at that point. Boats pass up Machuca and Toro rapids at practically all seasons, but sometimes with difficulty.

In order to meet the exigencies of low water in the Lower San Juan a railroad called the Silico Lake Railroad, with 3 feet gauge, has been constructed from a point opposite the mouth of the Colorado, called Boca Colorado, to Lake Silico in the marshes back of Greytown, a distance of about 6 miles. Light-draft boats connect Lake Silico with Greytown for the transfer of passengers and freight. The type of light-draft steamboat used on the San Juan River is the stern-wheel pattern, so much used on the western rivers of this country, the lower deck carrying the engines and boilers as well as freight, while the upper deck, fitted with crude staterooms, furnishes a kind of accommodation for passengers.

326. The Canal Line through the Lake and Across the West Side.—The little town of Fort San Carlos on a point raised somewhat above the lake where the San Juan River leaves the latter is the second place on the entire river from Greytown where any population may said to be found, and probably not more than 400 or 500 people even there. Its position is on the north side of the river, at the extreme southeastern end of the lake, commanding a fine view of the water and the country bordering it in that vicinity. To the westward lie the Solentiname Islands, a group a short distance to the north of which the sailing line for the canal in the lake is located. After passing this group of islands that line deflects a little toward the south, so that its course westward is but a little north of west, straight to a point near to and opposite Las Lajas on the westerly shore of the lake, southwest from the large island on which Ometepe and Madeira are located; indeed those two volcanic cones, the former still active, constitute the entire island. The point called Las Lajas is at the mouth of a small river of that name which discharges any sensible amount of water only during the wet season; it is located not more than 10 miles from Ometepe, and affords a most impressive view of that perfect volcanic cone rising almost an exact mile above the water. The general direction of the

canal route is a little west of south from Las Lajas on the lake to Brito on the ocean shore. The line follows the Las Lajas about a mile and a half only of the 5 miles from the lake in a southwesterly direction to the point where the continental divide is crossed. The elevation of the divide at this place is about 145 feet only above sea-level. The line then descends immediately into the valley of the Rio Grande and follows that stream to its mouth at Brito.

327. Character of the Country West of the Lake.—The country on the west side of the lake exhibits a character radically different from that on the easterly side, i.e., between the lake and the Caribbean. It is a country in which much more population is found. While there are no towns along the 17 miles of the

The Maritime Canal Company's Railroad near Greytown.

route from Las Lajas to Brito, the old city Rivas, containing perhaps 12,000 to 15,000 people, is about 6 miles from Las Lajas, and the small towns of San Jorge, Buenos Ayres, Potosi, as well

as others, are in the same general vicinity. Plantations of cacao and various tropical fruits abound, and there is a large amount of land under cultivation. It is largely a cleared country, so that far less dense forest areas are found.

There are two distinct seasons in the year, the wet and the dry, the latter extending from about the middle of December to the middle of May. The annual rainfall is extremely variable, but in the vicinity of Rivas it may run from 30 or 40 to nearly 100 inches. The country is of great natural beauty, and one which, under well-administered governmental control, would afford many places of delightful residence. The trade winds blow across the lake from east to west with considerable intensity and great regularity. They produce a beneficial effect upon the climate and render atmospheric conditions far more agreeable than in that part of Nicaragua in the vicinity of Greytown.

It will be remembered that Rivas is the city where the American filibuster Walker was taken prisoner by the Costa Ricans and Nicaraguans and shot in 1857.

328. Granada to Managua, thence to Corinto.—At the northwestern end of the lake is located the attractive city Granada, sometimes called the "Boston of Nicaragua." A reference to a map of Nicaragua will show that a short distance north of Granada is the river Tipitapa, which connects Lake Nicaragua with Lake Managua, the latter lying 18 miles to the northwest of the former. A railroad connects Granada with the city of Managua, which is the capital of Nicaragua, running on its way through the city of Masaya, chiefly noted for the volcano of the same name located near by, and which has been subjected to a most destructive eruption. The old lava-flow still shows its path of destruction by a broad black mark extending many miles across the country. A railroad connects Lake Managua at Momotombo with the Pacific port of Corinto.

329. General Features of the Route.—It is thus seen that the proposed route of the Nicaragua Canal lies first along the valley of the San Juan River, then across the lake, cutting the continental divide west of the latter at the low elevation of 145 feet above the sea, thence following the valley of the Rio Grande to the Pacific Ocean at Brito. From Greytown to Castillo the San

Juan River is the boundary between Nicaragua and Costa Rica, and concessions from both governments would be necessary for that part of its construction. From Castillo to the Pacific Ocean the route lies entirely in Nicaraguan territory, and the only concession necessary for that portion of the line would be from the government of Nicaragua. From Castillo to and around the southern end of the lake the boundary-line is located 3 miles easterly from the river, following its turns, and the same distance from the lake shore, all by an agreement recently reached between the two governments. The summit level of the canal would therefore be the surface of the water in Lake Nicaragua, which is carried down to Conchuda, 52 miles from the lake on the San Juan River toward the east, by a great dam located there, and to a lock between 4 and 5 miles from the lake toward the west. Hence the summit level would stretch throughout a distance of about 126 miles, leaving a little more than 46 miles on the Caribbean end and about 12 miles on the Pacific end of the regular canal section. The 50-mile stretch from the lake to the point where the canal cuts the San Juan River near Conchuda is a canalized portion of the San Juan River, as a large amount of excavation must be done there in order to give the minimum required depth of 35 feet. The points of river bends or curves are in some cases cut off by excavated canal section in order to shorten the line and reduce the curvature. Considerable portions of the line in the lake, particularly near Fort San Carlos, would be excavated. For several miles in the latter vicinity large quantities of silt and mud must be removed, as the lake is shallow and the bottom is very soft. The entrance into the western portion of the canal at Las Lajas requires a large amount of rock excavation, as the shore and bed of the lake there are almost entirely of rock.

330. Artificial Harbor at Greytown. — The preceding observations are mostly of a general character, and give but little consideration to the engineering features of the canal construction. In considering the canal as a carrier of ocean traffic probably the first inquiry will be that relating to harbors. In reality there is no natural harbor at either end of the Nicaragua route. Fifty years ago there was an excellent harbor at Grey-

town into which ships drawing as much as 30 feet found ready entrance, and within which was afforded a well-protected anchorage. As early as that date, however, a point of land or sand-pit was already pushing its way northward in consequence of the movement of the sand along the beach in that direction, and in 1865 it had nearly closed the entrance to the harbor.

Scene on the San Juan River.

For many years that entrance has been entirely closed, and now what was once the protected harbor of Greytown is a shallow body of water, completely closed, and known as the Greytown Lagoon. There is a narrow, circuitous, and shallow channel leading from it out to an opening in the sand-bar, which may be navigated by boats drawing not more than 2 or 3 feet, and by means of which freight and passengers are taken from steamers, which are obliged to anchor in the offing. Occasionally heavy storms break through this strip of sand between Greytown Lagoon and the ocean, and for a short time form a shallow entrance to the former. The sand movement in that vicinity northward or westward is so active that it is but a short time before such openings are again closed. The deepest water in the lagoon probably does not exceed 8 or 10 feet at the present

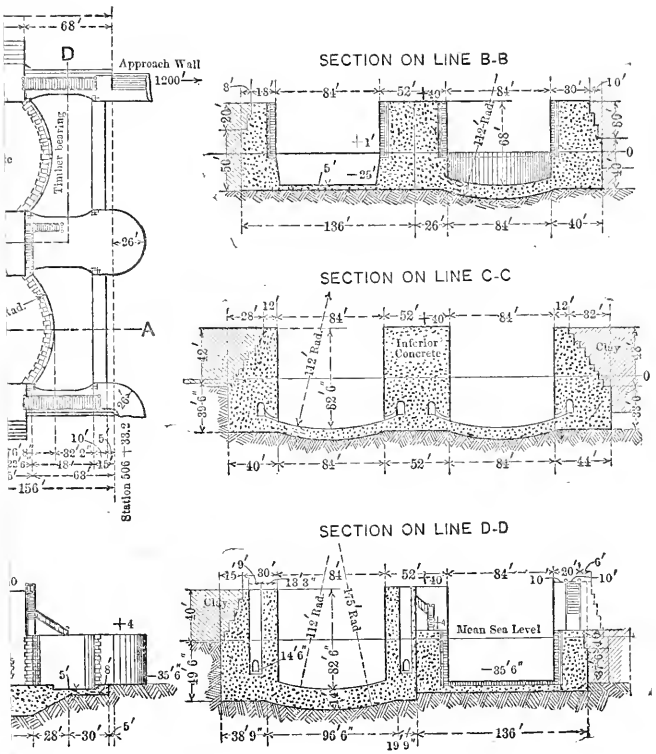
time, and the most of it is much shallower. The tidal action at Greytown is almost nothing, as the range of tide between high and low is less than 1 foot. The mean level of the Caribbean Sea is the same as that of the Pacific Ocean.

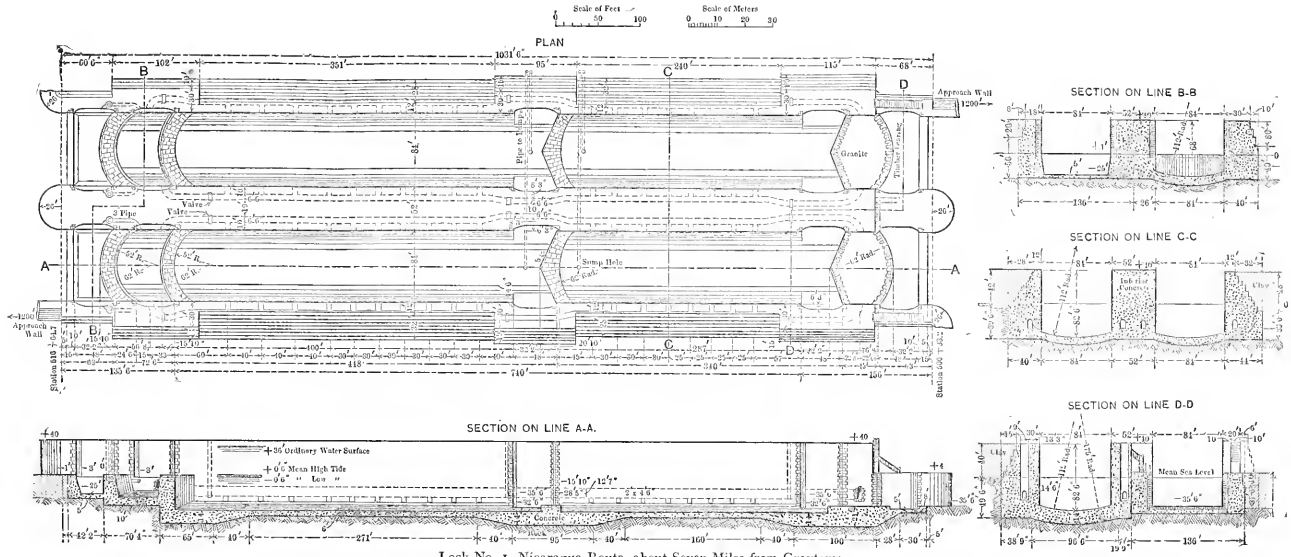
Under these circumstances it is necessary to create what is practically a new harbor at Greytown, and that work is contemplated in the plans of the Isthmian Canal Commission. The canal line is found entering the lagoon about 1 mile northwest of Greytown, where a harbor is planned having a length of 2500 feet and a width of 500 feet, increased at the inner end to 800 feet to provide a turning-basin. The entrance to this harbor from the ocean will be dredged to a width of 500 feet at the bottom, and it will be protected outside of the beach-line by two jetties, the easterly about 3000 feet long, and the westerly somewhat shorter. These jetties would "be built of loose stone of irregular shape and size, resting on a suitable foundation," the largest, constituting the covering, weighing not less than 10 to 15 tons each. These jetties would be carried 6 feet above high water and have a top width of 20 feet. The trade winds, which blow from the easterly and northeasterly, would have a direction approximately at right angles to that of the easterly jetty, and ships making the entrance of the canal would consequently be protected against them while between the jetties. The easterly of these jetties would act as an obstruction against the westerly movement of the sand, but it is practically certain that a considerable amount of the latter would be swept into the channel, and possibly to some extent into the harbor, necessitating dredging a considerable portion of the time. The commission estimates that the maintenance of the entrance and harbor would require an annual expenditure of $100,000.

331. Artificial Harbor at Brito.—The harbor at Brito presents a problem of a different kind. There is absolutely no semblance of a harbor there at the present time (1902); it is simply a location on the sandy beach of the ocean protected against swells from the west by a projecting rocky point called Brito Head, the Rio Grande River emptying into the ocean just at the foot of Brito Head, between it and the canal terminus. The entire harbor and its entrance would be excavated in the low ground of that

vicinity, composed mostly of sand and silt, although there would be a little rock excavation. The entrance to the harbor would be dredged 500 feet wide at the bottom, and be protected by a single jetty on the southeasterly side. The harbor itself would be excavated back of the present beach; it would have a length of 2200 feet and a width of 800 feet. As the depth of water increases rather rapidly off shore, the 10-fathom curve is found at about 2200 feet from low-water mark, hence the jetty would not need to be more than probably 1800 to 2000 feet long. In this vicinity the water is usually smooth; indeed but few storms annually visit this part of the coast. The conditions are quite similar to those found on the coast of Southern California. There is little sand movement in this vicinity, and the annual expenditures for maintenance of the harbor and entrance would be relatively small; the commission has estimated them at $50,000.

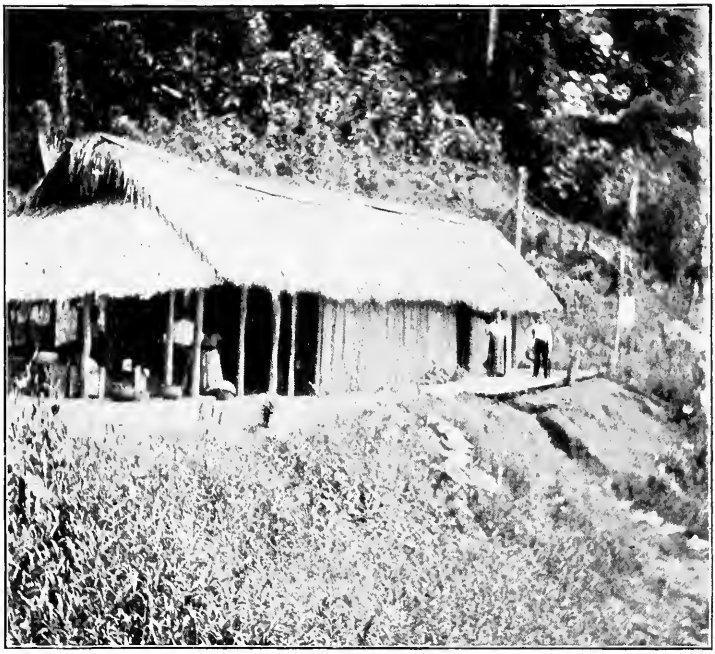
332. From Greytown Harbor to Lock No. 2.—The canal line, on leaving the harbor at Greytown, is found in low marshy ground for a distance of about 7 miles, the excavation being mainly through the sand, silt, mud, and vegetable matter characteristic of that location. Throughout almost this entire distance the natural surface is but little above sea-level. The first ground elevated much above this marshy country is known as the Misterioso Hills, in which Lock No. 1 is founded, having a lift of 36½ feet and raising the water surface in the canal by that amount above sea-level. Another stretch of marshy country, but not quite so wet as the preceding, follows for a distance of about 11 miles, when the Rio Negro Hills rise abruptly to an elevation of a little over 150 feet above sea-level. At this point is located Lock No. 2, with a lift of 18½ feet. This lock is about 21 miles from the 6-fathom line off Greytown. The canal line here practically reaches the San Juan River, the latter lying a considerable distance easterly of the canal, between this point and the ocean. Between Greytown and Lock No. 2 embankments, never reaching a greater height than 10 to 15 feet, are required to keep the water in the canal at various locations along the low ground. These embankments do not necessarily follow parallel to the centre line of the canal route, but are planned to connect hills, or rather high ground, so as to reduce their length and give them a more


SECTION ON LINE B-B
SECTION ON LINE C-C
SECTION ON LINE D-D
Approach Wall
Timber bearing
Inferior Concrete
Mean Sea Level
Station 900 + 33.2



Lock No. 1, Nicaragua Route, about Seven Miles from Greytown.

stable character than if they were located close to the canal excavation. While some embankments will still be found above Lock No. 2, they are few, and even lower than those already noticed. From Lock No. 2 to Lake Nicaragua the route of the canal lies practically along the San Juan River, the chief excep-



Telegraph Office at Ochoa on the San Juan River.

tion to that statement being the cut-off in the vicinity of the Conchuda dam.

333. From Lock No. 2 to the Lake.—Inasmuch as both the Serapiqui and San Carlos rivers flow from Costa Rican territory into the San Juan, that is, from its right bank, the canal line necessarily is located along the northerly or left bank of that river. At a distance of 23 miles from the ocean the canal line cuts through what are called the Serapiqui Hills opposite the mouth of the river of that name, and at a distance of a little over 26 miles from the ocean it pierces the Tamborcito Ridge, where is found the deepest cutting on the entire route. The total length of

bed-rock. In order to determine not only such questions, but the character of all materials to be excavated from one end of the route to the other, a great number of borings were made along the canal line, not only by the water-jet process, but also with the diamond drill. By means of the latter, whenever it was so desired, cores or circular pieces could be taken out of the bed-rock so as to show precisely its character at all depths. These borings, both through earthy material by the jet and into bed-rock by the diamond drill, were made at suitable distances apart along the centre line of the canal, and in considerable numbers, closer together at proposed lock and dam sites. By these means every lock on the line has certainly been located on bed-rock, as well as the great dam at Conchuda. In addition to this the commission has been able to classify the material to be excavated, so that if the canal should be built every contractor would know precisely the character and quantity of the various materials which he would have to deal with.

336. Classification and Estimate of Quantities.—The following table is arranged to exhibit a few only of the principal items of excavation, so as to give an approximate idea at least of the magnitude of the work to be done:

Dredging	130,920,905 cu. yds.
Dry earth	47,440,316 "
Soft rock	14,029,170 "
Hard rock	24,151,214 "
Rock under water	2,780,040 "
Embankment and back-filling	8,389,960 "
Clearing	6,831 acres.
Stone-pitching	250,089 sq. yds.
Concrete, excluding retaining-walls	3,400,840 cu. yds.
Concrete in retaining-walls	424,321 "
Cut stone	22,272 "
Steel and iron, excluding cast-iron culvert lining	61,735,230 lbs.
Cast-iron culvert lining	19,286,000 "
Brick culvert lining	34,542 cu. yds.
Cost of lock machinery	$1,600,000
Excavation in coffer-dam	9,907 cu. yds.
Pneumatic work	145,557 "
Piling	415,600 lin. ft.
Rock fill in jetties	451,500 cu. yds.
Clay puddle, bottom and sides of canal	936,800 "

337. Classification and Unit Prices.—The classification of the material to be excavated, both on the Nicaragua and Panama routes, was one to which the commission gave very thoughtful study no less than to the prices to be used in making the estimates. The following table, taken from pages 67 and 68 of the commission's report, exhibits the classification and the prices adopted by the commission for purposes of its estimates:

Removal of hard rock, per cu. yd	$1.15
Removal of soft rock, per cu. yd	.80
Removal of earth, not handled by dredge, per cu. yd.	.45
Removal of dredgable material, per cu. yd	.20
Removal of rock, under water, per cu. yd.	4.75
Embankments and back-filling, per cu. yd.	.60
Rock in jetty construction, per cu. yd.	2.50
Stone-pitching, including necessary backing, per sq. yd	2.00
Clearing and grubbing in swamp sections of Nicaragua, per acre.	200.00
Other clearing and grubbing on both routes, per acre.	100.00
Concrete, in place, per cu. yd	8.00
Finished granite, per cu. yd	60.00
Brick in culvert lining, per cu. yd.	15.00
All metal in locks, exclusive of machinery and culvert linings, per lb.	.075
All metal in sluices, per lb	.075
Cast iron in culvert lining, per lb.	.04
Allowance for each lock-chamber for operating machinery	50,000.00
Additional allowance for each group of locks for power-plant	100,000.00
Price of timber in locks, per M B. M	100.00
Sheet-piling in spillways, per M B. M.	75.00
Bearing piles in spillways, per lin. ft.	.50
Average price of pneumatic work for the Bohio dam, below elevation −30, per cu. yd.	29.50
Caisson work for the Conchuda dam, in place, per cu. yd	20.00
Single-track railroad complete with switches, stations, and rolling stock, per mile of main line	75,000.00

There are evidently other more or less uncertain expenditures, depending upon all possible conditions affecting the cost of such work, including those of climate, police, and sanitation. In order to cover such expenditure the commission determined to add 20 per cent to all its estimates of cost on both routes, and that percentage was so added in all cases.

338. Curvature of the Route.—Among the engineering features of a ship-canal line it is evident that curvature is one of great importance. Small steam-vessels may easily navigate almost any tortuous channel, but it is not so with great ocean

steamships. On the other hand, it may require very deep and expensive cutting to reduce the curvature of the route, as curves are usually introduced to carry the line around some high ground. It is necessary, therefore, to make a careful and judicious balance between these opposing considerations. The commission wisely

Boring Party of the Isthmian Canal Commission on a Raft in the San Juan River.

decided to incur even heavy cutting at some points for the purpose of avoiding troublesome curvature on the Nicaragua route. The table on page 415, taken from page 135 of the commission's report, gives all the elements of curvature for the entire line.

From the description of the line as given, it is evident that much curvature must be found in spite of the most judicious efforts to avoid it, and the table indicates that condition. Yet the amount of curvature may be considered moderate for a location through such a country as Nicaragua. The smallest radius is seen to be a little over 4000 feet. The result may be considered satisfactory for such a difficult canal country, although the total amount of curvature is rather formidable.

339. The Conchuda Dam and Wasteway.—The most important single engineering feature of the whole plan is the dam at Conchuda. The ordinary low-water elevation in the river at