59th Congress, 1st Session. | SENATE. | Document No. 264.

DOCUMENTS

RELATING TO THE

INTEROCEANIC CANAL

AND

A LETTER FROM THE SECRETARY OF STATE TRANSMITTING CERTAIN INFORMATION IN REGARD TO

THE EARTHQUAKE AT PANAMA IN 1882.

March 12, 1906.—Referred to the Committee on Interoceanic Canals and ordered to be printed as one document.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1906.

IN THE SENATE OF THE UNITED STATES,
May 15, 1902.

Ordered, That the following documents, heretofore printed, be reprinted and bound in one document for the use of the Senate, namely: 1. The report of the Nicaragua Canal Commission of May 9, 1899, without appendices. 2. Chapter VII of the report of the Isthmian Canal Commission of November 30, 1901. 3. The letter of Maj. E. C. Dutton of June 22, 1891, printed in Report No. 2126, made to the House of Representatives, first session, Fifty-fourth Congress. 4. And the chapters on "Earthquakes," pages 132 to 136, and on "Seismic Records of the Canal Region," pages 136 to 137 of Appendix 2 of the report of E. S. Wheeler, chief engineer of the Nicaragua Canal Commission.

Attest:

CHARLES G. BENNETT, *Secretary*,
By H. M. ROSE, *Chief Clerk*.

[Senate Document No. 357, Fifty-seventh Congress, first session.]

REPORT OF THE NICARAGUA CANAL COMMISSION.

WASHINGTON, D. C., *May 9, 1899.*

The PRESIDENT OF THE UNITED STATES.

SIR: The Nicaragua Canal Commission, having completed its labors, has the honor to report as follows:

The Commission was organized July 29, 1897, and its first meeting was held on that day. It consisted of Rear-Admiral John G. Walker, United States Navy, president; Capt. O. M. Carter, United States Corps of Engineers, and Prof. Lewis M. Haupt, civil engineer, members. Captain Carter was relieved from duty with the Commission and was succeeded on October 18 by Col. Peter C. Hains, United States Corps of Engineers.

This Commission has understood the law, approved June 4, 1897, by which it was constituted, to require that all routes heretofore proposed, having any merit, should be considered; new routes that appear to have merit should be developed; and the entire region of canal possibilities should be examined with sufficient thoroughness to enable a just and comprehensive comparison of the various routes to be made and the most desirable one selected; in short, to enable it to make a complete and exhaustive report.

With this in view the Commission established its headquarters in the Army Building, in New York, and devoted considerable time to a careful examination and study of all data bearing upon the Nicaragua Canal question obtainable in the United States, including Government surveys and surveys by private parties, going back nearly fifty years. During this time an engineering staff was engaged, and the organization of exploring, surveying, geological, and hydrographic parties was proceeded with, considerable delay being caused by the necessity for a change of engineer members of the Commission. A commissary department was also organized for the handling of supplies and food from the United States, as it was impossible to supply the large force employed with promptness and certainty from the resources of Nicaragua in the wild part of the country where the work was prosecuted.

The preliminary studies having been made and the organization completed, the expedition sailed from New York on the U. S. S. *Newport* on December 5, 1897, nearly one hundred strong, and arrived off Greytown December 17. The men and stores were landed as promptly as possible, and as fast as laborers could be engaged the various parties were put into the field and entered upon the work assigned them.

Through the courtesy of the Secretary of the Navy, the U. S. S. *Newport* was assigned to the service of the Commission for the survey of Greytown Harbor and vicinity, the U. S. S. *Alert* for the survey of Brito and its vicinity, and a strong hydrographic party under Lieutenant Hanus, of the Navy, was assigned to the survey of Lake Nicaragua and the San Juan River.

The following instructions for the guidance of the chief engineer of the Commission were issued December 21, 1897:

SAN JUAN DEL NORTE, NICARAGUA,
December 21, 1897.

Mr. E. S. WHEELER, C. E.,
Chief Engineer to the Nicaragua Canal Commission.

SIR: The Nicaragua Canal Commission, appointed by the President under the act approved June 4, 1897, has selected you to take charge of the field work and direct the operations of the various parties to make the surveys and examinations provided for in the act above referred to in reference to the Nicaragua Canal.

The scope and character of the work are indicated by the words of the law, "to continue the surveys and examinations * * * into the proper route, the feasibility and cost of construction of the Nicaragua Canal, with the view of making complete plans for the entire work of construction of said canal as therein provided."

Your familiarity with the methods employed in conducting surveys and examinations under the Government with a view to projecting works of improvement renders it unnecessary at this time for the Commission to give you other than general instructions. The details and methods the Commission leaves to you to work out as you find best and as circumstances render advisable, the field parties being directly under your orders. The Commission desires as a final result to be in possession of all the physical data which bear in any important way upon the construction of the Nicaragua Canal, and it is expected that the accuracy and trustworthiness of these results shall be unquestioned. Due care will be exercised not to unnecessarily duplicate any of the accurate work already done.

Naval hydrographic parties working under the direction of the Commission will survey Brito Harbor and vicinity, Greytown Harbor and vicinity, Lake Nicaragua, and the San Juan River. All these parties will connect their gauges with the benches established by your topographical parties, so that their soundings and your work shall conform to the same datum plane. You are expected to confer freely with the chiefs of these parties, that you both may have a clear understanding of your mutual work.

The Commission desires, among other things, that you determine at Greytown and Brito the mean sea levels, and connect them, if practicable, with a line of precise levels from ocean to ocean. You will also make such surveys between Brito and Lake Nicaragua as may be necessary to locate the best line for the canal, and such other investigations as may serve to determine the practicability of controlling the lake level by a weir on the west side.

Borings should be made to ascertain the kind and quantity of material to be removed in forming the harbor at each terminus of the canal and along its entire route, including the San Juan River. These borings should be made more numerous at the proposed site of locks, sluices, and dams than are necessary elsewhere. Particular attention should be given to the Ochoa and other important dams and to the San Francisco and San Carlos embankment lines. The feasibility of the canal company's project hinges on the control of the lake level, the Ochoa Dam and, the maintenance of the Divide cut. All possible data bearing on these questions should be gathered.

The proper naval hydrographic party will make the necessary survey of Lake Nicaragua to determine with sufficient accuracy its area, in order that the question of controlling its level may be properly studied, the extent of the available anchorage between Ometepe Island and the west shore be ascertained, as well as the safety of the course which would be followed by steamers between the western entrance to the canal and the head of the San Juan River.

Where the bends of the river are sharp it may be necessary to cut through them. The survey should be made to cover such possible contingency. The disposal of the spoils from the excavations in the river must be taken into consideration. These should be deposited where they will facilitate rather than interfere with navigation.

A suitable number of rain and evaporation stations should be established at the most desirable points in the drainage basin affecting the canal. The records of these should be continued as long as practicable.

The low-level line following the San Juan to near its junction with the Colorado should also be surveyed, and an estimate of its cost determined for comparison with other projects. This line has always been regarded as practicable, and while it has considerably greater length than the comparatively direct line through the Divide, it will avoid some of the difficult engineering problems of the latter route.

The survey of the San Juan should also include the gauging of the river at numerous points, the determination of its slope in high and low stages, its discharge in both stages, the discharge and regimen of the principal streams that empty into it, and generally all information necessary to determine the best method of improving its navigation, whether by canalization or otherwise.

All the field parties will receive their instructions directly from you. It is expected, however, that you will keep the Commission fully informed as to the character of the work being done and the methods adopted by you in doing it. For this purpose you will submit monthly reports to the Commission (which shall contain a concise history of the operations and progress of the work) and such special reports as may from time to time be necessary. These instructions are not intended to be final and complete, but may be supplemented by others from time to time as the exigencies of the work demand.

I am, very respectfully, J. G. WALKER,
President of the Commission.

The Commission remained in Greytown until January 8, 1898, when it proceeded in a special steamer, kindly placed at its disposal by the Nicaraguan Government, to the examination of the San Juan River from the sea to where it leaves Lake Nicaragua, including the Colorado branch.

Five days were occupied in this examination. The Commission arriving at Fort San Carlos, the head of the San Juan River, on the evening of January 13 proceeded at once by steamer to San Jorge, where it arrived on the following morning, and after putting ashore its equipment, supplies, and extra baggage continued to Granada and Managua for the purpose of paying its respects to the President of the Republic.

Arriving at Managua on the afternoon of the 15th of January the Commission was specially received by the President at 8 o'clock on the same evening with all the ceremonies and honors pertaining to such occasions. During its stay in Managua every attention was shown by the President, members of the cabinet, and other officers of the Government. On the morning of the 18th the Commission called upon the President to take formal leave, and then proceeded by rail to Granada, was transferred to the lake steamer *Victoria*, and reached San Jorge late the same afternoon, arriving at Rivas shortly afterwards, where temporary headquarters were established.

Promptly upon its arrival at Rivas the Commission took up the investigation of the canal route from the lake to the Pacific, and remained either in Rivas or upon the proposed line of the canal until February 13, having been somewhat delayed by an attempt at a revolution during that period.

On the 13th the Commission left by steamer for San Carlos, at the head of the river San Juan, arriving at that point on the morning of the 14th.

After inspecting the work of the parties under Lieutenant Hanus, U. S. N., and Mr. Stuart, assistant engineer, the Commission, on the following morning, proceeded down the river, landing that afternoon at Ochoa, and, after examining the work going on in that neighborhood, which included borings at the proposed site of the Ochoa Dam, started on foot upon the trail over the Divide for a personal examination of that part of the line, arriving at Greytown at 6 p. m. on the 21st.

The Commission remained in Greytown until February 27, when it left on board the U. S. S. *Newport* for Port Limon, Costa Rica, arriving there on the following day, and proceeding by special train, provided by order of the Costa Rican Government, to the capital (San José), for the purpose of paying its respects to the President of Costa Rica. The Commission was pleasantly received by the President, by special appointment, at 8 p. m. March 1. The next day was spent in visiting the neighborhood of the capital, leaving San José by special train on the morning of the 3d for Port Limon, and going immediately on board the *Newport*. During the trip to and from San José the cuts and embankments along the line of railroad were carefully observed with a view to obtaining information with regard to the stability of slopes in tropical regions in connection with the proposed canal.

The *Newport* sailed at 6 p. m., March 3, for Colon, arriving the following day (March 4). The five succeeding days were spent in examining the Panama Canal line, the work being done, and the plans, drawings, and data in the office of the company in Panama.

In this connection the Commission wishes to express its warmest thanks to M. Belin, the director-general, and to the officers of his staff, for their kindness and untiring efforts to facilitate its work in every way possible, also to Mr. John F. Shaler, the superintendent of the Panama Railroad, for his aid, assistance, personal efforts, and care during its entire stay upon the Isthmus.

On the 10th, having taken leave of the officers at Colon, the *Newport* sailed for Port Limon and Greytown, arriving at Greytown on March 12.

On March 26 the Commission, having completed its personal examination of the proposed Nicaragua Canal route, took its departure for the United States, leaving its working parties in the field to prosecute the work assigned them under the direction of Mr. E. S. Wheeler, its chief engineer.

Much delay to the work and great annoyance to working parties were caused by attempts at revolution and by the strained relations between the Governments of Nicaragua and Costa Rica, which rendered it difficult and often impossible to forward supplies, provisions, and orders to working parties in the field and to receive reports from them. It is a difficult country in which to carry on work of the kind assigned to this Commission at any time, but the difficulties were increased many fold and great delay was caused by the disturbed conditions referred to. The outbreak of the war between the United States and Spain was also a serious matter. It deprived the Commission of two ships and the naval parties which were working with and under its direction, rendering a new organization of parties necessary and with a much decreased force.

Further delay was caused by the assignment of Colonel Hains to military duty in command of troops at Chickamauga, and later in Porto Rico.

But in spite of these troubles and delays the work was prosecuted as rapidly as practicable.

As portions of the work were completed parties were withdrawn, until the last surveying party left Greytown February 18, 1899, leaving thirteen men in the country at ten stations for the purpose of continuing the observations for rainfall and evaporation and for the gauging of the lake and the various rivers necessary to a complete understanding of the hydrology of the region of the country through which a canal through Nicaragua must pass.

Soon after the commission's arrival home, the necessities of the war forced it to vacate its headquarters in the Army Building in New York, and they were removed to Washington, where the work of examining, computing, and assembling the data has been steadily prosecuted.

The Commission desires to express its obligation to the Maritime Canal Company, which kindly and freely furnished all data and information in its possession;

To the Navy Department for assistance with ships, parties, and instruments;

To Commanders Tilley and Leutze, commanding the U. S. S. *Newport* and the U. S. S. *Alert*, for their excellent surveys of Greytown and Brito;

To the Director of the Geological Survey for the services of C. W. Hayes, geologist, and A. P. Davis, hydrographer;

To the Chief of Engineers and to the Superintendent of the Coast Survey for instruments kindly loaned;

To the Panama Canal Company and the Panama Railroad for aid and courtesies rendered;

To E. S. Wheeler, C. E., chief engineer to the Commission, and to the members of the engineering staff for their faithful services in connection with the work.

PHYSICS.

To secure the best location for the canal careful attention must be given to the physical features of the isthmus and their adaptation to the purpose.

As the reports of the specialists, hereto annexed, cover the subjects of geology, topography, hydrology, and meteorology quite fully, it would seem unnecessary to do more than call attention to a few distinct features which characterize the route on which this Commission is directed to report.

LAKE NICARAGUA.

It is an interesting and peculiar feature of this route that in early geologic time the lake was evidently an arm or bay of the Pacific Ocean, while the Continental Divide traversed the isthmus to the eastward in the vicinity of Castillo Viejo, and the Rio San Juan, as an outlet of the lake, had no existence. This is attested by the remains of an old river channel of large dimensions, which crossed the Western Divide and formed the outlet of the lake after it became separated from the ocean, and by other geologic features.

An old drainage channel is also traceable under the Rio San Juan west of Castillo, which has gradually filled up with alluvium to the present bed of the stream. There is, therefore, but little rock found in this portion of the river.

In consequence of the closure of the western outlet and the elevation of the lake to a mean altitude of over one hundred feet above the sea, the outflow was diverted to the eastward over a depression in the original divide, so that this river now forms the only outlet for the drainage of the entire basin.

The physical elements which are of most importance in the consideration of the problem of water supply, lake regulation, storage, and operation have been ascertained by observation, surveys, and measurements as far as possible, and may be stated as follows:

Area of water surface of Lake Nicaragua..........2,000,000 acres, 3,000 square miles.
Approximate area of entire drainage basin ....12,900 square miles.
Maximum dimensions of Lake Nicaragua ....101 by 45 miles.
Elevation of Lake Nicaragua...........98′ to 111′, mean 104½′ above mean sea level.
Elevation of Lake Managua (above Lake Nicaragua), approximately.........28 feet.
Area of Lake Managua..438 square miles.
Length of Rio San Juan..121.7 miles.
Extreme range of temperature on line of canal for 1898 (65° to 96°) .....31 degrees.
Maximum rainfall observed at Rivas was in 1897, when it was.........123.43 inches.
Minimum rainfall observed at Rivas was in 1890.....................31.81 inches.
The average rainfall in the basin for 1898 is found to be 28 per cent less than at Rivas.

The lake is elliptical in form and has several islands. The principal one, containing the symmetrical cones of the extinct volcanoes Ometepe and Madera, rises over a mile above the lake level and affords an excellent harbor to leeward, convenient for anchorage. Near the outlet of the lake it shoals to such an extent as to require a considerable amount of dredging through soft material. No rock is found near this portion of the channel. The area of that portion of the lake extending below sea level is about 20 square miles. A steady northeast trade sweeps over the lake during a large portion of the year.

WESTERN DIVISION.

The lake is separated from the Pacific on the west by a strip of land about 12 miles wide with a range of hills having heights varying from 155 feet to more than a mile above sea level. The lowest point has been selected for the route of the canal, and is where a low plateau separates the drainage of the Rio Lajas, which empties into the lake, from the Rio Grande, emptying into the Pacific near Brito head. This latter is a bold, rocky promontory 248 feet high, which guards a natural bight in the coast and affords an admirable site for an artificial entrance and harbor.

The streams of this section are small and have a limited drainage, being nearly dry for five months of the year. The slope of the upper Rio Grande, however, is steep and its bed is therefore sinuous and deeply eroded. Between Espinal and the sea, a distance of less than 11 miles, it falls about 120 feet. The topography of the valley is, however, well adapted to the purposes of a canal on either bank, or to the creation of an artificial basin by a dam closing the gorge through which the lake drainage formerly passed to the sea. The rocks on this division are sedimentary and readily worked, being loose shales and sandstones with traces of calcium. The material composing the coastal plain is a light sandy loam and easily eroded.

EASTERN DIVISION.

The country traversed by the San Juan may be conveniently divided into two sections, to wit, that portion lying above the confluence with the San Carlos, in which the deposit of sediment is relatively small, and that below, in which it is large. Further subdivisions are suggested by the topographic conditions. From the lake to the first rapids at Toro, 27 miles, the slope is gentle, being about 2½ inches per mile, while the banks are low and the adjacent swamps extensive. From the head of the Toro to the foot of the Machuca, embracing the four rapids, the fall is nearly 43 feet in 23 miles, or 22½ inches per mile. This comprises the rocky section of the ancient Continental Divide and is the gorge of the river valley. Below Machuca occurs a stretch of about 15 miles of deep water, the bottom of which extends in places to below sea level, known as the Agua Muerta (dead water). This is a portion of the old river channel not silted up by the volcanic sands brought into the lower San Juan by the San Carlos River. This sand becomes a characteristic feature of the entire lower reach of the river and its delta from this point to the sea. It is confined, however, mainly to the bed of the channel, the banks through the hill country being the stiff clays resulting from the weathering of the rocks of the region. These banks are remarkably stable, notwithstanding the heavy rains and large volume of water which sweeps past their bases at high stages.

PHYSICS OF THE STREAM.

As the bed of the upper river forms an important part of the route, a more detailed description of it is believed to be necessary.

The slope as given by the survey and corrected for stage may be stated to best advantage in tabular form. This, taken with the cross sections, velocity, and volume of discharge as stated in detail in the accompanying report, of the assistants will show the characteristics of the streams in a state of nature.

San Juan River statistics—slopes and distances.

UPPER RIVER.

[Lake at 105.]

Reach.	Distance.	Fall.	Rate of fall per mile.
	Miles.	*Feet.*	*Feet.*
From the lake to Sabalos	27.16	5.4	0.198
Sabalos to foot of Toro rapids	1.70	7.3	4.294
Toro to head of Castillo	7.98	1.2	.150
Castillo to bottom of rapids	.38	.0	15.789
Bottom of Castillo rapids to Punta Gorda	2.08	2.5	1.202
Punta Gorda to 1 mile below Machuca rapids	10.62	26.0	2.448
One mile below Machuca rapids to Boca San Carlos	14.79	1.0	.067
Upper river	64.71	49.4	.763

LOWER RIVER.

Boca San Carlos to San Juanillo	33.02	30.0	0.908
San Juanillo to Colorado	5.28	4 0	.757
Colorado to sea (via San Juan)	18.65	21.0	1.128
Lake to sea	121.66	104.4	.86

The slopes are, however, constantly varying with the stage and local conditions. In fact, a heavy rainfall on the San Carlos Basin may reverse the slope for a time in the Agua Muerta, causing the water to run up stream.

At Sabalos, where the slope is about 2½ inches per mile, the maximum velocities and discharges as observed were reported as follows:

Date.	Cross section. (square feet).	Mean velocity (feet per second).	Discharge (cubic feet per second).
January 21, 1898	8,819	2.16	19,000
February 21, 1898	8,576	1.92	16,530
September 11, 1898	11,273	1.95	21,995
September 14, 1898	10,684	2.12	22,673
September 21, 1898	10,720	2.09	22,431
December 3, 1898	11,273	2.39	26,700

In the upper reaches, the slope being very flat, the river carried over 20,000 cubic feet through sections of over 10,000 square feet at velocities exceeding 2 feet per second, with corresponding increase at the gorges and rapids.

OBSERVED MAXIMUM VELOCITIES OF SAN JUAN.

At Ochoa Station, about 69 miles from the lake, the banks are steep clay slopes The bed of the river consists of black sand of the same character as that composing the sea beach near Greytown.

Date.	Cross section (square feet).	Mean velocity (feet per second).	Discharge (cubic feet per second).
January 8, 1898	13,100	4.00	52,400
June 28, 1898	14,462	4.25	61,410
November 17, 1898	19,717	5.32	104,930
September 12, 1898	10,336	4.00	41,199
September 16, 1898	12,761	4.47	57,047
September 26, 1898	9,895	4.24	41,975

From which it appears that in a state of nature the mean velocity of the stream is frequently over 4 feet per second and at times exceeding 5, while the lower river discharges over 50,000 cubic feet per second, and occasionally over 100,000, without perceptible effect upon the banks.

The slopes of the stream, therefore, vary from about 1 inch per mile in the Agua Muerta to 6 feet in one-third of a mile on the rapids at Castillo, and the velocity from less than 1 foot per second to over 12, while the recorded discharge of Ochoa ranges from 16,145 to 104,930 cubic feet per second. To pass the Castillo Rapids at low stages of the river a tramway has been constructed under the brow of the hill for the purpose of transferring passengers and freight. The width of the upper river is quite variable. Its narrowest limits are about 350 feet, while in some places it widens out to 1,200 feet. Its general alignment is direct, but there are several sharp horseshoe curves where cut-offs would be required across alluvial flats by which over 4 miles of distance would be saved.

THE LATERAL DRAINAGE.

The principal tributaries from the Costa Rican side are the Rio Frio, Poco Sol, San Carlos, and Sarapiqui, the former emptying into the lake just at the head of the river. These large streams exert a controlling influence in confining the location of the canal to the left bank. The streams on the left bank are the Melchora, Palo de Arco, Negro, Sabalos, Machuca, La Cruz, Machado, Danta, San Francisco, and others, none of which have a large drainage basin. They have many small branches permeating the swamps and ravines which characterize the broken topography of this section.

On reaching the edge of the coastal plain the river drainage is distributed through the San Juanillo, Colorado, Lower San Juan, Taura, and their branches, Parado and Caño Bravo, leading to the sea.

The minimum computed discharge of the upper river at the Sabalos Station during 1898 was found to be 11,206 cubic feet per second on May 13, while the maximum occurred on November 13, when it was 28,490 feet, the difference in stage being 3.55 feet. At Ochoa, below the mouth of the San Carlos, the minimum computed discharge on May 10 was 16,300, and the maximum was 107,000 cubic feet per second on November 17, the variation in stage being 13.35 feet. To provide for extreme cases, however, it is estimated that the river above the San Carlos may, at rare intervals, under the cumulative discharges from the lake and river, reach a possible maximum of 100,000 second-feet, and that the San Carlos, a flashy and torrential stream, may add 100,000 more to this quantity in the lower section for a short time.

THE CAPACITY OF THE CHANNEL.

The entire river bed has been carefully surveyed with a view to determine its carrying capacity under the regimen resulting from the creation of such dams and locks as may be found best adapted to convert it into a navigable channel for deep-draft vessels. The upper river will require dredging from the lake to the Castillo Rapids, and as the channel as proposed will be 300 feet wide at bottom and extend to a depth of 30 feet below the lowest lake level, this cut will largely increase the cross section and thus enable a larger volume to be discharged without any material increase of velocity. Moreover, the river falls about 13.9 feet below the 105 stage in the lake before reaching the head of the Castillo Rapids, so that a dam farther down stream impounding this water would still further augment the cross section by raising the surface. As the capacity is regulated by the smallest sections, it is necessary to ascertain their location and effects upon the discharge under the new regimen.

THE CONTROLLING SECTION.

Under existing conditions the ruling sections of the stream are found to be at stations 1494 and 1515, near the head of the Toro Rapids and Castillo Rapids, in that section of the upper river between Fort San Carlos and the Castillo Viejo, as indicated below. The relation of the existing cross section of the stream to that of the improved section when raised to the upper level of the lake and dredged to the requisite depth of 30 feet, with a bottom width of 300 feet, is stated in square feet and percentages.

Relative areas at controlling sections.

Location (station).	Miles.	Original area (square feet).	Enlarged area (square feet).	Percentage of increase.
268	5	7,810	[1]15,200	94.6
680	13	7,697	[1]15,920	94.0
1,265	24	7,960	17,200	116.0
1,494	28¼	[1]2,948	21,840	641.0
1,515	28¾	[1]3,758	32,824	775.0
1,665	31½			
Castillo		6,435	23,406	264.0
Lower Machua		6,060	44,370	632.0

[1] Minimum.

From this it appears that the location of the controlling section would be changed from its present position to a point 5 miles from the lake, while the area of that section would be very nearly doubled at a lake elevation of 110 feet above tide. As the maximum discharge required to pass through this section, with a range of 6 feet for the greatest fluctuation, would not produce velocities exceeding 3.3 feet per second, such a discharge would not materially affect the stability of the channel nor its navigation. A further discussion of the resulting velocities under different volumes of discharge is submitted by Mr. F. L. Stuart, assistant engineer, showing that at no other place in the channel would the velocity be as great.

Computed velocity in river and canal at various points, with different discharges, referred to lake at 110.

Location.	Discharge, 30,000 cu. ft. Velocity (ft. per sec.).	Discharge, 50,000 cu. ft. Velocity (ft. per sec.).	Various discharges (cu. ft. per sec.).	Velocity (ft. per second).
Station 268, in river	1.9	3.3	55,000	3.6
			35,000	2.3
Station 680, in river	1.9	3.1	60,000	3.7
			40,000	2.5
Station 1265, in river	1.7	2.9	70,000	4.1
			50,000	2.9

Cut-off Palo de Arco to Isla Grande.

[Surface of water 110.]

Location.	Discharge, 30,000 cu. ft. Velocity (ft. per sec.).	Discharge, 50,000 cu. ft. Velocity (ft. per sec.).	Various discharges. Cu. ft.	Vel.	Cu. ft.	Vel.
In river	1.16	1.86	62,500	2.4	42,500	1.66
In canal	1.3	2.2		2.8		1.86

Cut-off Sombrero de Quero to Santa Cruz River.

[Surface of water 110.]

Location.	Discharge, 30,000 cu. ft. Velocity (ft. per sec.).	Discharge, 50,000 cu. ft. Velocity (ft. per sec.).	Various discharges. Cu. ft.	Vel.	Cu. ft.	Vel.
In river	1.4	2.3	75,000	3.56	50,000	2.3
In canal, bottom 150	2.3	4.00		5.9		4.0
In river	1.03	1.72	75,000	2.56	50,000	1.72
In canal, bottom 250	1.9	3.23		4.86		3.23

Cut-off 2 miles west of Boca San Carlos.

[Surface of water 110.]

Location	Discharge, 30,000 cu. ft. Velocity (ft. per sec.).	Discharge, 50,000 cu. ft. Velocity (ft. per sec.).	Various discharges.			
			Cu. ft.	Vel.	Cu. ft.	Vel.
In river	0. 6	1. 0	100, 000	2. 01	80, 000	1. 6
In canal	0. 7	1. 18		2. 36		1. 8

Two dams above cut-off, 8-lock system.

[Surface of water 82.4.]

Location.	Discharge, 30,000 cu. ft. Velocity (ft. per sec.).	Discharge, 50,000 cu. ft. Velocity (ft. per sec.).	Various discharges.			
			Cu. ft.	Vel.	Cu. ft.	Vel.
In river	0. 8	1. 35	100, 000	2. 7		
In canal	1. 23	2. 1		4. 1		

Two dams above cut-off, 8-lock system.

[Surface of water 73.2.]

Location.	Discharge, 30,000 cu. ft. Velocity (ft. per sec.).	Discharge, 50,000 cu. ft. Velocity (ft. per sec.).	Various discharges.			
			Cu. ft.	Vel.	Cu. ft.	Vel.
In river	0. 83	1. 39	100, 000	2. 77	80, 000	1. 2
In canal	1. 30	2. 17		4. 33		3. 45

This table further demonstrates that instead of having velocities exceeding 12 feet per second over the rapids, which would be submerged, the maximum current in the river under a discharge of 30,000 cubic feet would not exceed 2 feet or $1\frac{1}{3}$ miles per hour, which would not readily disturb the banks of this section of the stream. Under ordinary conditions and throughout nearly this entire reach the velocities would be less than 1 foot per second.

With a discharge of 50,000 cubic feet, which is higher than will probably ever be reached in this (upper) part of the river, the maximum velocity through the controlling sections would not therefore much exceed 3 feet per second, imposing no material restrictions on navigation.

STABILITY OF SLOPES.

NATURE'S COMPENSATIONS.

So much stress has been laid upon the excessive precipitation and its destructive effects upon the proposed works, as well as upon the labor and machinery required, that the Commission is impelled to call attention to the fact that the physical features of the country furnish the most convincing and conclusive evidence that these uncontrolled forces are not so injurious as has been alleged, for the angle at which freshly made earth slopes stand is found to be much steeper than that prevailing in our more northern latitudes, where they are also exposed to the destructive action of frost and the internal stress due to greater ranges of temperature. In some cases in the northwest the range covers 160 degrees, whereas in Nicaragua the greatest fluctuation seldom exceeds 25 degrees. The absence of frost more than compensates for the excessive downpour.

Observations by engineers of experience in tropical countries lead them to believe that the same security and greater permanency may be obtained with less first cost and economy of maintenance by making the side slopes steeper, and thus reducing the prisms of cut and fill, than by employing the typical sections of our own latitudes. Nature compensates for the greater rainfall by the uniformity of heat and moisture. The spontaneous growth of vegetation revets the natural surface, clothing it with a protecting thatch which not only acts as an elastic cushion to break the impact, but also to retain the water and thus prevent the sudden and destructive floods so familiar to us during the spring, when the rain and melting snows combine to produce their maximum effects.

The board of 1895, in referring to the character of the work done in Greytown Harbor, remarks that:

> The material excavated was almost entirely volcanic sand, similar to that of the beach. * * * When piled in heaps, it forms a porous mass through which the torrential rainfalls descend with surprisingly little effect upon its contour, even though the slopes be steep. This feature was noted both in the mounds of dredgings near the entrance and in the canal banks, where the sand dropped from the dredge chutes still stood, seemingly undisturbed since they were put there.

Of the cuts along the railroad the board also adds:

> The cuts have heights up to 20 feet, with slopes from vertical to 45 degrees, and in most cases stood with an extraordinary stability under the tropical downpours. At several the original tool marks were still visible, both picks and steam shovel. In several others there had been slides, but none of great extent. The ditches were generally clean, and in but few points had wash reached the rail. The surface of the cuts was in some cases protected by vines, but in most was quite bare unless for a minute lichen.
>
> As these clay cuts have been exposed for over three years to the severest rainfall of record on this continent and were found in better condition on the whole than an exposure in the United States for a single winter would have left them, it is evident that the absence of frost more than balances the tropic downpour, and for the material in question constructions can quite as safely be designed as in the United States. * * * The natural growth in the roadbed was unexpectedly slight, although in two or three cases the canebrakes had invaded the track.
>
> On the whole, taking into account the condition of the sand dumps at Greytown and of the clay cuts and fills on the line of the railroad, it is evident that the heavy rainfall is not necessarily as formidable an obstacle to outdoor construction as might be supposed.

The geologist, Dr. Hayes, also states, concerning the resistance of the slopes to abrasion on the western division, that—

> The present channel of the Rio Grande is from 15 to 25 feet in depth and its sides are generally steep, often nearly or quite vertical. They serve to show the capacity of the material to stand at very steep slopes. It would also probably form fairly impervious embankments.

There is no reason, therefore, for departing from the usual engineering practice, unless it be to make the slopes steeper and thus reduce the cube of excavation and the consequent cost of the work.

SANITARY AND CLIMATIC.

The impression that this position of the Isthmus is usually unhealthy is erroneous. On the contrary, the local conditions are such that with ordinary hygienic precautions the risks from disease are slight.

The frequent rainfall on the east coast furnishes an ample supply of fresh soft water, condensed directly from the clouds; the porous, sandy soil absorbs it so rapidly as to prevent stagnation, while animal refuse is quickly removed by the scavenger birds and fish, continually on the alert for food.

With their light, loose clothing, vegetable diet, and cleanly habits, the natives seldom suffer from fevers. Even our unacclimated Americans passing from a rigorous winter temperature to the mild region of the trade winds were, with few exceptions, exempt from febrile complaints, and among the large number of engineers sent out there was no mortality in the country. The constant motion of the wind, sweeping through the low divide, appears to remove the noxious exhalations which characterize other portions of the Isthmus. Yellow fever finds no habitat at Greytown, and even when imported it does not become epidemic. Abstemious habits and careful police of camps will insure as good health among laborers as will be found in many localities in this country. The climate would affect the labor question, therefore, chiefly by the lassitude resulting from its enervating influence.

Assistant Engineer Stuart says that—

> The atmospheric conditions are excellent, and for the seven months we were in the field we worked in all conditions of weather, losing but one entire day on account of a heavy downpour of twelve hours.

The narrow limits within which the temperature ranges are shown from a few selected observations at various stations during the year, as below. The Rio Viejo station is located on the western slope of the Cordilleras, east of the lake and at a higher altitude than the others. Hence its greater range of 30°. This uniformity of temperature is one of the important factors in the consideration of the permanency of important works as well as in the health of the inhabitants.

Exhibit of extreme range of the observed temperature in Nicaragua.

Location.	Date.	Maximum.	Minimum.	Date.	Range.
	1898.	°F.	°F.	1898.	°
Brito and Tola stations	Dec. 22	88	75	June 28	13
Las Lajas station	May 12	91	73	Sept. 10	18
Rio Viejo station	Mar. 3	97	62	Mar. 12	35
Fort San Carlos station	May 8	91	70	Mar. 28	21
Sabalos station	Mar. 20	90	65.2	Dec. 25	24.8
San Carlos River	May 7	95	66	Feb. 7	29
Ochoa station	Oct. 1	95	66.5	Jan. 3	28.5
Deseado River station	May 25	91	65	Jan. 3	26
Greytown	Sept. 29	96	69	Mar. 14	27

EARTHQUAKES AND VOLCANOES.

From the most reliable data obtainable the Commission believes that the canal region is practically exempt from any seismic influences of sufficient force to cause destruction or danger to any part of the canal route or suspension of its traffic. Dr. C. W. Hayes has treated this question fully in his report.[a] He says that—

> Earthquakes due to the dislocations of strata (faults) are perhaps no more liable to occur in the vicinity of the Nicaragua Canal route than elsewhere, and hence they do not constitute a danger which is peculiar to this region more than to almost any other in which a ship canal might be constructed.

[a] See Report of Dr. Hayes, Appendix II.

He then proceeds to discuss those due to volcanic agencies at some length, and concludes that those activities are on the wane and so remote from the route as not to constitute a menace. In quoting from Major Dutton, he adds:

Briefly, then, the risk of serious injury by earthquakes to the constructions proposed for the Pacific section of the canal is so small that it ought to be neglected; * * * also that the risks to the Atlantic section are still smaller than those to the Pacific section.

MATERIALS FOR STRUCTURAL PURPOSES.

The cost and durability of the canal are also affected by the character and distribution of such native material as may be utilized for the purposes of construction. These consist chiefly of earth, rock, timber, and sand, all of which are abundant and free. Cement, iron, explosives, tools, plant, and some provisions and clothing will need to be imported, but will be exempt from duty.

ALLUVIUM.[a]

All unconsolidated material which has been transported and deposited by streams is classed as alluvium. * * * It varies considerably in composition, depending upon the source from which it was derived and the manner in which it was deposited. It varies all the way from coarse, clean-washed sand or gravel to the finest clay. It may for convenience be separated into three subclasses: (1) sand, (2) silt, a variable mixture of fine sand and clay, and (3) clay silt, composed chiefly of clay, with little or no sand. All three subclasses contain variable quantities of vegetable matter.

The alluvium is everywhere of such character that it can be easily handled with dredges. Almost everywhere the silt and clay silt are sufficiently solid to stand at moderate slopes, the slope of one on one probably being sufficient. In some cases, as in the Florida lagoon, special precautions may be needed to preserve the slopes. The material becomes very hard when dry, and even when it is piled up so that the water can drain off it becomes comparatively firm. This is shown in the vertical stream banks where drainage is possible, while the same material forms a soft mud in the swamps at some distance from the stream channels. The black sand when free from clay is of course quite pervious to water and would not be suitable for banks where the water level was permanently different on its two sides. This material, however, will not be encountered beyond the site of the first lock on the proposed low-level line. It is probable that wherever the canal is more than half in excavation the silt will form banks sufficiently impervious to hold the required height of water without the addition of any other material. Where the head is greater than 15 feet it may be necessary to add a puddled core to the bank unless the latter is made of more than ordinary thickness.

SAND.

The black volcanic sand of the east coast and lower river section is not composed of the partly-decayed minerals derived from a deeply weathered rock, but is made up entirely of finely-comminuted fragments of fresh volcanic rock, evidently broken up and ejected by explosive volcanic eruptions. It would thus make a good, sharp, clean material for hydraulic mortar, concrete, or béton. Its specific gravity is 1.68, or 104 pounds per cubic foot, comparing very favorably with the best building sand in the United States.

CLAY.

Clay of excellent quality is abundant and well distributed. When mixed in suitable proportions with sand and gravel it makes an admirable puddling material.

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[a] See Report of Dr. Hayes, Appendix II.

Quartz occurs in only a few of the rocks, so that much of the clay is remarkably free from grit, tough and compact. Although it is penetrated by numerous roots and burrowing insects, the absence of frost permits it to remain more compact than any surface clay in higher latitudes. Next to the silt it will form by far the largest part of the excavation. It will make perfectly impervious embankments if some means are taken to puddle it as it is deposited, but probably if simply dumped in the bank it would be pervious to water.[a]

WOOD.

Numerous large trees occur in the forests along the river and on the border of the lake which are denser and stronger than our American oaks and pines. The clearing of the canal route will also furnish a large number of cross-ties. Some of these native woods, according to Colonel Childs, will last above ground from forty to fifty years. The madera negra is one of the most valuable ties and is abundant. It may also be obtained for dimension timber up to 30-foot lengths and 11 inches square.

The nispera will cut in lengths of 50 feet and square 18 inches. It is very common and durable, but heavy. Many other varieties exist, as the palo cortez, guachipilin, roble, cocobole, pine, cedar, niambaro, caoba or mahogany, paolo-de-arco, granadillo, guayacan, almendro, feniscaro, etc. The shipment of timber is one of the industries of the port of San Juan del Sur. As much of the native timber is valuable for export, and as no mills exist for its local manufacture, it may doubtless prove more expedient to import the piling and dimension material from the extensive forests of the Southern States and to use the local product mainly for fuel and ties.

SHELTER.

There is also ample material available without cost for the protection of men and materials from the rain and sun. The usual habitations of the natives consist of a carefully laid thatched roof, substantially built, reaching nearly to the ground, with walls of bamboo or adobe. These afford free circulation of air and are cool and dry. Their only cost is for the labor of erection, which is slight.

The fuel in general use is wood, which is cut and stacked under shelter on the banks of the river. A considerable quantity of cord wood can be secured from the clearing of the route and adjacent forests. In some localities water power may be made available.

IRON AND STEEL.

These metals will necessarily be imported, but the climatic conditions are such as to cause remarkably little deterioration. Templates of the rails which have been exposed to the rain and sun for about nine years do not exhibit any measurable loss in section of weight. The spikes also retain the sharp edges of the tool marks on their heads and shanks. Only where the salt water of the ocean reaches the iron rails and bolts on the pier is there any considerable amount of scale visible.

STONE.

A large amount of material on the route of the canal, classified as rock and soft rock, will require excavation to create the channel. A

[a] See Report of Dr. Hayes, Appendix II.

portion of this is suitable for structural purposes. On the western division the rock is generally a calcareous nonfissile shale, interstratified with beds of sandstone varying from a few inches to 2 or 3 feet in thickness. The shales constitute the greatest bulk of the rock to the eastward of Brito Head, where the sandstones of the northern headland are too thin for use as building stones but are suitable for concrete or riprap.

About half a mile east of Brito, however, is found a group of heavy sandstone beds forming a spur extending into the Rio Grande Valley.

These beds would probably yield a good quality of dimension stone; would be easily quarried in dimensional blocks up to 20 or more inches in thickness; would dress readily and be as durable as the average sandstone.[a]

North of the canal line at Buen Retiro is a large deposit of intruded andesite or trap, which makes a very desirable material for structural purposes.

It is probable that all the material on the west side which has been classed as soft or disintegrated rock can be excavated with a steam shovel without blasting. The material stands in natural slopes of 60° or more (to the horizontal), and artifical slopes equally steep will probably be entirely safe.[a]

The rocks on the eastern division are chiefly of igneous origin, but from a few miles below Castillo to halfway between Machuca and Boca San Carlos they are largely sedimentary with a few small igneous dikes.

No coarse conglomerates nor pure limestones have been discovered in this formation, although they may occur.

The beds of massive sandstone exposed on Machuca Creek, being to a large extent free from joints, could probably be quarried for dimensional building stone, which would be easily worked and fairly durable.[a]

The principal varieties of the igneous rock found in this section are *augite-andesite*, *olivine basalt*, *hypersthene basalt*, and *dacite*. The first three are commonly known as *trap* rocks. They are generally compact and heavy. The dacite is lighter than the trap and somewhat softer. (This was called conglomerate by the canal company.)

The basalt (trap) extends from the Boca San Carlos eastward beyond the San Francisco hills, forming the Sarapiqui hills and others bordering the lower portion of the San Juan River, as well as those in the vicinity of Silico Lake, and is suitable for dams, jetties, and concrete.

The dacite is found at lower Ochoa and Tambor Grande, where it comes to the surface and continues to the Eastern Divide. It is there interbedded with the andesite tuffs and basalt.

Associated with the above-named massive rocks is a group of fragmental igneous rocks whose members vary from coarse conglomerate or breccia to beds of fine volcanic ash. The coarser varieties resemble in their physical properties the igneous rocks from which they are derived, while the fine ash is generally talcose and crumbles on exposure to the air.

Deposits of hard rock also exist near the site of Lock No. 1 of the canal company's line, to which the railroad has been built.

Several outcrops of rock reported to be suitable for jetty construction exist on the coast at Point of Rocks and at Monkey Point, but no samples from these ledges have been secured. The quarries are readily accessible from the sea and furnish material for ballast to coasters.

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[a] See report of Dr. Hayes, Appendix II.

CLASSIFICATION AND WEATHERING.

The three classes of materials—alluvium, residual clay, and soft rock—should be considered as earth in making estimates for excavation. The soft rock, however, may require some blasting, particularly toward the bottom and where it contains very large bowlders. It will stand with much steeper slopes than the silt and clay and will be less liable to slip. Not being plastic, it will also support a heavier load, and hence may be relied upon for foundations where the weight of the structure is not excessive. For these reasons it seems desirable to make the distinction between clay and soft rock wherever possible.[a]

The weathering of rocks is brought about by two processes—rock disintegration and rock decay. The first varies directly and the second inversely with latitude when humidity is constant. The first process depends on changes of temperature and expansion of interstitial water by freezing, hence is inactive in the Tropics. The second process depends on high temperature and a rapidly decaying vegetation, hence is inactive in the Tropics. Special attention is directed to the fact that it is chiefly the first process of disintegration which is inimical to the permanence of structures, and hence that their relative durability will be greater in the Tropics than in higher latitudes.

Such being in brief the physical conditions of the route, it remains to determine the dimensions, which all things considered, will best subserve the interest of the world's commerce in making this transit of the Isthmus.

DIMENSIONS OF CANAL.

To provide ample facilities for the safe and expeditious passage of vessels the trunk of the waterway has been considerably enlarged over that of any previous project. The dimensions adopted by the Commission as the basis of the estimates are as follows:

The canal nowhere to be less than 30 feet in depth. The width varying with the local conditions as follows: From Greytown Harbor to Boca San Carlos the width to be 150 feet, with slopes in earth of 1:1 and in alluvial silt of 1:2. In hard rock vertical sides up to 40 feet from the bottom, then slopes of 5:1. In soft rock the slopes to be 2:1.

In the river the width at bottom to be 300 feet, with slopes of 1:2, with enlargements at the bends, and at the eastern end of the lake the excavation to be 600 feet wide at the outer end, decreasing to 300 feet at the river, and having slopes of 1:5 to the depth of 6 feet and then 1:3; for all routes from the Caribbean Sea to the lake, excepting the Menocal route, the same dimensions are used. The bottom width of the canal from the lake to the Pacific to be 150 feet, with slopes as on the east side, and the computations have been based upon a minimum lake elevation of 104 feet above mean sea level, Caribbean Sea, as a datum. The minimum radius is limited to 3,000 feet, with enlargements of width in bends varying according to the degree of curvature.

The locks are 80′ x 30′ x 665′ between quoins, giving an available length of 620 feet, with variable lifts.

Estimates were also made upon numerous modifications of the above dimensions.

For convenient reference and comparison with the canal prism as

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[a] See Report of Dr. Hayes, Appendix II.

proposed by the Maritime Canal Company the areas of the several cross sections and the percentages of increase are stated herewith:

	Area of cross sections in square feet.	Per cent of increase.
Between jetties, Greytown	23,400	....
Entrance to harbor, Greytown	14,700	....
Coastal section	6,300	10.3
Canal proper	5,400	9.1
Through rock	4,500	50.0
In the river (in rock)	9,900	131.0
In the river (in earth)	10,800	84.0
In the lake	7,272	73.0
	13,272	216.0
WEST SIDE.		
Western Divide	4,500	50.0
Across costal plain	5,850	8.0 less

Distances along the line of the canal route proposed by this Commission from the 7-fathom curve in the Pacific Ocean to the 7-fathom curve in the Caribbean Sea.

	Miles.
1. Brito Harbor	0.93
2. Brito to Buen Retiro	8.12
3. Buen Retiro to west side of lake	8.71
4. Lake Nicaragua	71.34
5. East side Lake Nicaragua to Boca San Carlos	56.96
6. Boca San Carlos to Sarapiqui	21.59
7. Sarapiqui to Greytown	20.59
8. Greytown Harbor	1.74
Total	189.98

REGULATION OF THE LAKE LEVEL.

All plans for a canal by the Nicaragua route contemplate using the lake as the summit for the canal and as a feeder. The regulation of its level is therefore a matter of the greatest importance.

It is known with reasonable certainty that the lake has varied in its elevation above sea level as much as 13 feet. It has probably been as low as 98 feet above mean sea level and as high as 111 feet above the same plane. These extremes have occurred at relatively remote intervals, but their occurrence must be admitted, and their recurrence in the absence of regulating works must be reasonably anticipated. It is also known, as a result of the observations of 1898, that notwithstanding the losses due to the outflow through the San Juan River and to evaporation, the lake has risen as much as 2 feet in six weeks.

The higher the lake is held the less will be the excavation in the upper level, and as this is a heavy item in the cost of construction, the effort has always been to keep that level up as high as practicable without causing unnecessary damage to private property. On the other hand, a spillway of capacity sufficiently great to prevent the lake from rising is expensive. The problem, therefore, is how best to meet the varying conditions. A careful investigation has been made of the discharge of all streams of importance, measurements of rainfall observed at points widely distributed throughout the basin, and the rate of evaporation from the lake surface determined.

The area of Lake Nicaragua, in round numbers, is 3,000 square miles, nearly 2,000,000 acres. The drainage area, including both lakes, is about 12,900 square miles. During the dry season of 1898 measurements were taken to determine the total inflow into Lake Nicaragua, which was found to be only about 1,700 cubic feet per second, showing that in the dry season the inflow into the lake is very small, scarcely worth considering. Nearly all the streams showed evidences of being stagnant several months, yet the year 1898 was one of more than average rainfall.

RAINFALL.

Observations to determine rainfall have been kept at Rivas for the last nineteen years. During the year 1898 observations were taken at several scattered stations in the drainage basin to determine the rainfall of the lake region. These records are given in the accompanying appendices.

Comparing the records at Rivas for the year 1898 with those for the other points it will be noted that the rainfall at Rivas was greater than the average for other parts of the basin, that at Rivas being 108 inches and the average in the basin 78 inches, a difference of about 28 per cent in favor of Rivas. This might at first appear anomalous, but it may be accounted for by the peculiar topographical features of the country in connection with the prevailing winds. It will therefore be assumed that, in order to obtain the rainfall in the basin for other years than that of 1898, the Rivas record will have to be reduced by 28 per cent. The number of observation stations in the basin are not great, but they offer a basis for estimating rainfall in those years for which there is no other record than that of Rivas.

There are two distinctly marked seasons in the drainage area of the lake—the wet and the dry. The latter begins about December 15 and lasts until about May 15, a period of five months. The wet season then begins and lasts until December 15 following. This period has a duration of about seven months. It is probable, however, that the length of the wet and dry seasons may vary in some years, but it is well understood among the people in that region that those are the dates from which they are reckoned, and the observations for the year 1898 confirm this.

EVAPORATION.

The amount of evaporation as determined for the year 1898 was 52 inches. That year was an abnormally wet one and it is therefore probable that the evaporation was somewhat below the average. Mr. Davis estimates a normal annual aggregate at about 60 inches, or five feet. The amount of evaporation in the lake itself is greater during the dry and less in the wet period. It has been taken at 4 inches per month during the wet period, and 6 inches during the dry, which corresponds closely with the observations for 1898.

These results have been checked by the Commission's study of the exhibits, as follows:

From Plate XVIII, Appendix III, it appears that during the year of 1898, throughout which careful observations were made, the lake fell about 3.09 feet between January 6 and May 15, a period of 131 days or 4.5 months, while in the following season of rainfall it rose 4.72 feet by December 5, when it again began falling. The net grain in storage during this entire year from January 5, 1898, to January 5, 1899, was 15.6 inches.

It will be observed that during that portion of the season beginning February 1 and ending May 15 the lake surface declined uniformly (the slight fluctuations being due to wind and not to rainfall), and that in this time the total rainfall did not exceed 2¾ inches over the lake surface. The run off from the parched ground at this season is practically zero. Hence the only gain was the direct rainfall while the losses were those due to evaporation and outflow, which latter quantity was measured by continuous observations at the Sabalos station on the San Juan River, the only outlet.

The outflow between February 1 and May 15 is given as 2,817,748 acre-feet, equivalent to a vertical depth over the lake area (2,000,000 acres) of 1.408 feet. If this be deducted from the loss in storage and rainfall, which is 2.840 feet, it leaves 1.432 feet loss due to evaporation in one hundred and four days, or a diurnal rate of 0.165 inch (one-sixth inch), or 5 inches per month, or a rate of 5 feet per annum for a dry year. This being deduced during the dry season would doubtless represent the maximum for the year.

RUN-OFF.

The run-off or inflow to the lake from rainfall on its drainage basin, exclusive of the lake proper, for the year 1898 has been found to be about 30 per cent of the rainfall. This is computed as follows: The average rainfall at six stations in the basin of Lake Nicaragua for 1898 was 78.29 inches. During that year the lake rose 18 inches. The outflow, if held, would have raised the lake 84 inches. Evaporation as determined was 52 inches, so that if there had been no outflow nor evaporation the lake would have risen 154 inches. Of this, 78.29 was by direct fall on the lake, leaving 75.7 inches as the rise due to the fall on the land, or the run-off. The area of the lake is 3,000 square miles; the area of the tributary basin is 9,900 square miles. The latter is therefore 3.3 times that of the former. Dividing the inflow into the lake, 75.7 inches, by 3.3, the ratio of the lake surface to the exterior drainage, we have 22.94 inches as the rise due to run-off. This is 29.3 per cent of the rainfall.

LOCKAGE.

When the canal is built the lake will be drawn upon for water for lockage and for power. There will also be some leakage, the amount depending largely on the kind of dams and waste ways used. The estimate for leakage is necessarily arbitrary, but a computation based on large traffic through the canal gives 3 inches as the estimate for annual requirements for lockage, leakage, and power.

REGULATION.

The surface of the lake is acted upon by several opposing forces. They must be so regulated that its fluctuations can be controlled within proper limits. Evaporation, outflow, and use of the canal will lower the lake's level. Rainfall and inflow will raise it. Water must therefore be stored for evaporation and use, and the excess of rainfall and inflow be discharged. For purposes of storage against evaporation years of minimum rainfall must be considered, and for determining spillway capacity years of maximum rainfall.

The data for an absolute determination of these problems would necessitate a series of observations extending over many years. But with the records for 1898, in connection with the rainfall records of Rivas for the past nineteen years, conclusions may be reached which, while they may not be absolutely correct, will be sufficiently close for all practical purposes.

The year of minimum rainfall, as determined by the Rivas record, is 1890. During that year 31.81 inches of rain fell. If this be reduced by 28 per cent, the difference between Rivas and the average of other parts of the basin, we have 22.9 inches as the average for the basin in an extreme dry year. It is well known that variations in annual rainfall are greater at single stations than over an extended area. It is therefore probable that this estimate is too low for a very dry year. Twenty-eight inches have therefore been assumed as the minimum annual rainfall in the basin.

The estimated run-off for 1898 was 29.3 per cent of the rainfall, and as the run-off will diminish with the diminution of rainfall, 25 per cent of the rainfall has been taken as the average for a dry year. We then have 28 inches falling directly on the lake and 28 inches on the drainage area tributary thereto. The latter being about 9,900 square miles, enough water would fall on the land to raise the lake 23.1 inches. This added to that falling direct would raise the lake 51.1 inches if all sources of loss were cut off. But the loss from evaporation would be about 60 inches, and 3 inches would be lost by lockage, leakage, and use—a total of 63 inches, or 5 feet and 3 inches. There would, then, be a deficit of 11.9 inches at the end of the year. If the year ends with the end of the wet period, the succeeding dry period will be begun with this deficit. For this period, lasting about five months, during which the lake would receive practically no rain and evaporation would be at the maximum, the loss to the lake would be 30 inches for evaporation and 1½ inches for lockage, leakage, etc.; total loss, 31½ inches, which, added to the deficit of 11.9 inches, gives 43.4 inches as the deficit at the beginning of the wet season, when the lake would probably fill up again. Temporary storage of about 4 feet in the lake is therefore needed to provide for evaporation and use in a time covering two dry periods and one wet one. In other words, if the lake had been at 108 at the beginning of the first dry period it would have fallen to 104 at the end of the succeeding dry period.

Substantially the same result is reached by Mr. Wheeler in another way (see his report).

In a year of maximum rainfall and minimum evaporation the conditions are reversed. The problem will be to get rid of surplus water and prevent the lake from rising to a high level.

The year of maximum rainfall, according to the Rivas record, was in 1897, when 123 inches fell. Reducing this by the 28 per cent ratio we have a rainfall in the basin of 88.6 inches for the maximum year. As before stated, the variation in annual rainfall over a large area is not as great as it is at one station. It is therefore probable that for the entire basin this estimated rainfall is too great. Suppose it be taken at 84 inches, or 7 feet, there results:

Rainfall direct on the lake	84 inches.
Run off, 30 per cent, about	84 inches.
Total inflow	168 inches.
Deduct for evaporation and use	63 inches.
	105 inches = 8′ 9″

This represents what must be taken care of by storage and discharge.

This rainfall will not be extended uniformly over a year, but most of it will fall within the wet season of seven months. A mean discharge of about 40,000 cubic feet per second would discharge it all in this time; or if 4 feet be stored in the lake, a mean discharge of 22,000 cubic feet per second would take care of it. Inasmuch as it is impossible to know in advance whether the rainfall of a season is to be heavy or light it will not be safe to begin discharging at the full capacity of the outlet until enough water has been stored for possible deficiencies. Consequently, instead of having seven months' time in which to discharge the surplus, a large part of it might have to be discharged in a less time, and a spillway of greater capacity would be needed. With a spillway capacity of 50,000 cubic feet per second the entire surplus could be handled in about ninety-two days.

The following method is used by Mr. E. S. Wheeler for determining the amount of water to be taken care of in years of maximum rainfall:

Between June 18 and October 29, 1898, a period of one hundred and thirty-two days, the rainfall at Rivas was 76.36 inches; the lake rose 48 inches; the outflow lowered it 32.76 inches and the evaporation of the lake surface lowered it 16.38 inches. Therefore, if there had been no evaporation on the lake nor outflow from it, it would have risen 97.64 inches.

Between May 17 and October 27, 1897, a period of one hundred and sixty-four days, the rainfall at Rivas was 112.42 inches. This was the period of greatest rainfall shown in the Rivas records since 1879. The amount of fluctuation in the surface of Lake Nicaragua caused by this rainfall was not observed; an attempt will be made to determine it by comparison with the wet portion of 1898, when both fluctuations and rainfall were carefully measured. The problem may then be briefly stated as follows: If a rainfall of 76.36 inches in one hundred and thirty-two days would cause a rise in the lake surface of 97.64 inches, what rise would be caused by a rainfall of 112.42 inches in one hundred and sixty-four days? The ratio between rainfall and change in lake level, as given in the preceding table, can not be used for this problem, because in this case only portions of a season are considered. At the beginning of these periods the streams and marshes were drained and empty; at the end they were overflowing and the entire run-off due to the rainfall had not yet occurred. Therefore this problem must be solved as a special case. If the rise was exactly proportional to the rainfall it would be 143.7 inches, provided there was no evaporation on the lake or outflow from it. It is, however, probable that in this case, as in the preceding one, the greater daily rate of rainfall in 1897 would cause the lake to rise slightly more than the proportional amount. An examination shows that the daily rate of rainfall in 1897 was 18 per cent greater than in 1898. Using the ratio as before, the rise in the lake would be 22 per cent greater. Applying this per cent, the computed rise in the lake for 1897 would be increased from 143.7 inches to 148.58 inches. This, then, is the estimated amount of fluctuation that would have occurred during the period of greatest rainfall of the last twenty years if there had been no evaporation on the lake or outflow from it.

The question as to what amount of fluctuation in the lake will be necessary to take care of this rainfall will next be considered. The estimated rise of 148.58 inches must be provided for by evaporation, outflow, and temporary storage in the lake.

Assuming the ratio of evaporation from the lake surface to be the same as in 1898, it would for the one hundred and sixty-four days amount to 20.97 inches. Subtracting this from 148.58 inches leaves 127.61 inches that must be provided for by the outflow and temporary storage.

The lake has an area of 3,000 square miles; a rise in its surface 127.61 inches would be equivalent to 889,408,618,000 cubic feet. If this should run out of the lake in one hundred and sixty-four days the mean discharge would be 62,769 cubic feet per second and there would be no change in the elevation of the lake surface. If the lake should be permitted to rise 1 foot then the mean discharge would be reduced to 56,866, and each additional foot that the lake is allowed to rise will reduce the mean rate of discharge by an equal amount. The following table shows the required rate of discharge for each foot of fluctuation:

0 feet require 62,800 cubic feet of discharge.

1 foot requires 56,900 cubic feet of discharge.

2 feet require 51,000 cubic feet of discharge.
3 feet require 45,100 cubic feet of discharge.
4 feet require 39,200 cubic feet of discharge.
5 feet require 33,300 cubic feet of discharge.

It appears from this table that if a waste-way having a capacity of 33,000 cubic feet per second be provided, the fluctuation in the lake could be limited to 5 feet for rainfall—as great as any that has occurred in the last twenty years.

Since the canal itself will incidentally provide waste-ways exceeding this in capacity, it appears that not more than 5 feet of rise will be caused by the largest rainfall. Therefore no addition need be made to the 6 feet already provided for dry periods.

The Commission has therefore concluded that in any plan of a canal by the Nicaragua route a spillway of 50,000 cubic feet per second capacity should be provided, and that the lake may vary in its level from elevation 104, the minimum, to 110, the maximum.

The endeavor would be to approach the dry season with the water level of the lake at about 108, and during that dry season to draw it down to 106, if it did not go to that level from natural causes. At the beginning of the wet season the lake would be allowed to rise, but when it reached 108 the spillway would be opened, gradually at first, and at its full capacity if necessary. In this way there would be a margin of 4 feet for the lake to fall in dry seasons and the same amount for it to rise during wet seasons. This is believed to be ample.

The possibility of securing complete control is manifest by inspection of Plate XIX*a*,[a] which shows that had all the water entering the lake been impounded, the surface during the first twenty days of January, 1898, would have risen 3 inches, or, since there was no rainfall, that the run-off and seepage from the previous season were still feeding it.

From this period it would then have declined quite uniformly from loss by evaporation until the end of the dry season, May 15, when it would have stood at an elevation of 104.07 above datum, after which it bore a nearly constant relation to the accumulated rainfall and would have reached its highest level of 113.69 on January 20, 1899, a gain of 9.6 feet in about eight months had all the water been held. If, on the contrary, it had been desired to prevent any further rise at any particular stage, even the lowest, it might have been done by a spillway having a capacity of discharge indicated by the red line of the chart, which represents an increment at the rate of 45,940 cubic feet per second. With this spillway capacity for this year the lake could have been held at any desired stage, or, by a reduction of the discharge, it could have been allowed to fluctuate within any reasonable limits.

A spillway of 50,000 cubic feet capacity divided between the eastern and western outlets will afford ample facilities for the regulation and control of the lake and its drainage.

The relation of such a spillway capacity to the observed fluctuations during 1898 may be exhibited graphically by assuming this quantity of water to be poured into the lake basin and drawing a curve representing the rise due to this inflow, all the water being stored. (See Plate XIX, Appendix III.)

By taking the difference between the curve representing the lake fluctuation and the curve representing 45,940 second-feet at any date, as, for example, on July 14, and plotting this difference, the result will represent the fluctuation of the lake under the physical conditions

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[a] See Plate XIX*a* in Atlas.

as they existed between July 14 and the end of the record. Had the sluices remained closed between January 1 and July 14 the lake would have risen to 107, and if then thrown fully open the lake would have risen only 1 inch higher during the entire season. Had they been entirely closed again on October 28, the lake would have gained 2 feet more in storage preparatory to the next dry season, which it would have entered at 108.68. By closing earlier more water could have been stored. This matter could readily be regulated by the judgment of the manager, who would doubtless have closed the valves throughout the dry season and thus have stored the entire outflow during that time.

LOCATION OF SPILLWAYS.

An important matter in connection with the regulation of the lake level is the location of the regulating works or spillway. It is seen that the lake may at times have to discharge as much as 50,000 cubic feet per second. An ideal arrangement would be to have the spillway entirely independent and separated from the canal proper or canalized river. A careful search has been made for such location on the west side between the lake and the Pacific, but no suitable place could be found that did not involve an expense almost as great as the construction of the western division of the canal itself. It has therefore been suggested that this surplus water might be discharged through the canal itself as far as Buen Retiro, and there turned into the valley of the Rio Grande, which it would be forced to follow on its way to the sea. This plan is objectionable for several reasons.

It will necessitate a widening of the canal proper from the lake to Buen Retiro, a distance of about 9 miles, the most of which will be excavation in rock. This part is the Divide cut of the western division. Even if this cut be made reasonably wide, the current through it will be swift. Of course the greater the width the less the current, but it may be questioned whether a current of 5 feet a second in a canal 200 feet wide would be entirely satisfactory to navigation. Moreover, 200 feet width will only discharge about 35,000 cubic feet per second with a 5-foot current, and there may be times when the discharge ought to run as high as 50,000 cubic feet per second. To carry this amount of water with a 5-foot current would require a width of about 300 feet.

A further objection would be the difficulty of properly controlling these discharged waters after they had left the canal. The discharge of 35,000 to 50,000 cubic feet of water per second into the valley of the Rio Grande means the creation of a torrential river 10 times the magnitude of the existing river in its highest floods. This might not be an insuperable objection if the valley of the river were rock or some material not easily eroded. The soil of this valley is for the most part light, sandy and easily put in motion by swift-running water. The distance from Buen Retiro to the Pacific is about 8 miles, and the river in that distance would have a fall of about 80 feet from the foot of the spillway. Moreover, the canal itself will be located in this valley, and at the gorge the width is reduced to 2,000 feet. A stream like the one thus created might endanger the canal itself. The difficulties of controlling it would be great, and a large amount of the material would be scoured and carried to the ocean, perhaps to the great detriment of the entrance to the canal. It is possible that from 10,000 to 15,000 cubic feet of water per second might be discharged through the canal on the west side and into the Rio Grande river if widened and straightened without damage, but the discharge of two or three times that amount is believed to be impracticable except at unwarranted expense.

Nor does there appear to be any absolute necessity for discharging all the surplus water of the lake on the west side. The San Juan River is to-day, and has been, its natural and only avenue of discharge. According to the estimates of the geologist and the hydrographer, its discharge in high stages has at times been as much as 50,000 cubic feet per second. The evidence appears to be conclusive that even this great discharge does not erode its banks to such a degree as to carry much sediment. The Agua Muerta below the Machuca Rapids indicates that no great amount of sediment is carried in the upper San Juan, and this notwithstanding the fact that the currents have been greater than they would be under the new condition of affairs created by the canalization of the river. The fact that the small tributaries that drain into the San Juan may at times discharge as much as 50,000 cubic feet per second between the lake and the San Carlos River is objectionable, but such discharges come at rare intervals and last but a short time. Even if the regulating works could not take care of it, the only effect would be to raise the water in the river and stop the discharge from the lake for a short period, or possibly turn the current toward the lake. If, then, the San Juan River, discharging sometimes as much as 50,000 cubic feet per second in addition to that of its own drainage basin as it exists to-day, with a fall from the lake to the foot of Machuca Rapids of 48 feet, does not seriously erode its banks, it does not seem reasonable to expect more erosion when that fall is reduced and the discharge area of the river increased.

The Commission has therefore concluded that the discharge from the lake through the canal and down the Rio Grande River on the west side should not exceed about 15,000 cubic feet per second, and that the remainder should be discharged through the San Juan River. The principal regulating works are therefore designed to be located at the site of the dam near Boca San Carlos, capable of a maximum discharge of 85,000 cubic feet per second, while the works on the west side should have a capacity of 20,000 cubic feet.

PROJECTS AND ROUTES.

The region within which a canal can be constructed is comprised within comparatively narrow limits. By the term "Nicaragua Route" is understood a canal route which uses Lake Nicaragua as a part of its system. For convenience this may be divided into three divisions:

First. The division between the Pacific and the lake, called the western division;

Second. The lake itself;

Third. The division between the lake and the Caribbean Sea, called the eastern division.

WESTERN DIVISION.

Colonel Childs, an eminent civil engineer, in 1850–51, surveyed and located a route for a canal over this western division. His route, starting from the Pacific Ocean and going eastward from Brito at the mouth of the Rio Grande, followed the valley of this river to a point about 11 miles from the lake, thence across the Divide to the valley of the Lajas, which it followed to the lake. There was no harbor at Brito, and he proposed to form one by the construction of jetties and by excavating the alluvium of which the coastal plain is composed. A detailed description of the project is given in the report of the board of 1895.

In 1873 a survey was made by Commander Lull, of the United States Navy. He proposed to construct a harbor at Brito and to follow the route suggested by Colonel Childs up the valley of the Rio Grande, but to cross the Divide farther to the north and to follow the valley of the Medio to the lake. This line was somewhat shorter than the other, but involved heavier cutting in the Divide. A full description of this route is given in Commander Lull's report.

Mr. Menocal, the chief engineer of the Maritime Canal Company, after further surveys, proposed to abandon the Medio route on account of the heavy cutting in the Divide, and adopted practically the route suggested by Colonel Childs. His first project was for a canal in excavation along the north side of the valley of the Rio Grande. Subsequently he suggested a modification of this project, which was adopted by the Maritime Canal Company, of building a dam at La Flor and creating an artificial basin 6.25 square miles in area, reaching from near the westerly side of the Divide to within 4 miles of the Pacific Ocean. At the proposed site of the dam the valley of the Rio Grande narrows to about 2,000 feet, and the surface indications of the adjacent hills seemed to promise good foundations for a dam. The construction of this dam would practically extend the lake level westward to within 4 miles of the Pacific Ocean. From the basin thus created the Pacific Ocean was reached by a canal with three locks.

The board of 1895 suggested still another project for a canal across this western division, which did not differ in location materially from that at first proposed by Colonel Childs, but followed the left bank of the Rio Grande instead of the right. These several routes are shown on the map accompanying this report, and a further description of them seems unnecessary, as full descriptions are to be found in the various reports and Congressional documents published by the United States Government from time to time.

The relative advantages and disadvantages of these several routes will now be considered, but solely on a physical basis without reference to relative cost.

The Menocal project of creating a basin in the valley of the Rio Grande by the construction of a dam at La Flor has the advantage of bringing the lake level close to the Pacific Ocean. The deep part of such a basin could be more rapidly and conveniently navigated than a canal in excavation. Moreover, the flood discharges of the Tola and Rio Grande could be admitted into the basin without materially affecting the surface level, and it avoided all necessity for diverting the waters of these streams from the canal eastward of the dam.

The disadvantages of this plan are, first, the La Flor Dam itself. Its crest would have to be about 120 feet above sea level, allowing 10 feet for freeboard, while the solid rock is found at about 45 feet below sea level. The total height of the dam in the deepest part would, therefore, be not less than 165 feet.

Second. If a high dam be built at La Flor to hold the level of the basin at 110 feet above sea level, all the locks will have to be placed on the west side of the Rio Grande. This is a disadvantage, because the area suitable is limited.

The locks will necessarily be of high lift and located on the slope of the hills close to each other, where there is little room for additional locks should they become necessary by future developments in the commerce through the canal. Moreover, a part of the canal itself will necessarily be built with heavy embankments or retaining walls on the slope of these hills, and the lower Rio Grande will either have to be crossed, taken into the canal, or discharged to the eastward of the proposed harbor.

Third. The creation of this basin would submerge many acres of land, not at present of great value, but which would become valuable should a canal be built.

A canal in excavation, whether it follows the right or left bank of the Rio Grande, avoids the construction of the La Flor Dam, presents no special engineering difficulties, enables good sites for locks to be selected, and preserves for cultivation the fertile land bordering immediately on its banks. Of the two routes in excavation the one on the east side allows the river to discharge through its natural mouth on the west side of the proposed harbor. It is somewhat shorter than the other, but the most important advantage is that it enables the harbor at Brito to be constructed on the east side of the Rio Grande, which is considered advisable, since it is contemplated to discharge a part of the water of the lake on the west side for regulation of lake level.

The Menocal project could, however, be varied by providing a lock and dam at or near Buen Retiro and dropping down to a lower level. The basin would in this case be diminished in size, and the dam would be lowered in height by the number of feet lift in the lock. Less land would be submerged, but the basin would not be as deep nor as long. On the other hand, fewer difficulties would be encountered in constructing the locks from the La Flor Dam to the Pacific, and the canal could be carried down to the sea on either side of the river with less difficulty.

The Commission is of the opinion, in view of all the circumstances, that the best location is on the left bank or east side of the Rio Grande.

LAKE DIVISION.

The lake division will be the same for any project.

EASTERN DIVISION.

The projects that have been proposed and considered for the eastern division admit of more variants than those on the western division, but all projects for the eastern division look to canalizing the San Juan River by means of locks and dams from the lake to the vicinity of the mouth of the San Carlos River.

Three projects with their variants are all that need be considered on the eastern side.

The first is that for canalizing the San Juan River from its source at the lake to the sea. So far as the canalization of the river from the lake to Boca San Carlos is concerned, no doubt exists as to its practicability. But for that portion of the river from thence to its mouth it is not deemed practicable, because of the difficulties of securing good foundations for dams, the torrential discharge of the San Carlos and Sarapiqui rivers and the great quantities of sand carried by them and deposited along the river channel of the Lower San Juan.

A second project is that suggested by Mr. Menocal, which had for its object the extension of the lake level through the "Divide cut" to within 12 miles of Greytown. It is similar to that suggested by him for the west side. It looked to the construction of a high dam at Ochoa a short distance below the mouth of the San Carlos River, by means of which the waters of the San Juan were to be raised to the level of the lake. From the south end of this dam embankments were to be built in the saddles of the San Carlos ridge, to connect with the hills in Costa Rica, thus cutting off the escape of the raised waters of the San Juan on that side. In this embankment line sluices were to be built to discharge the surplus waters of the lake which find their way down to the San Juan River, as well as the floods of the San Carlos itself.

From the north end of the Ochoa Dam similar embankments were to be built across the saddles in the hills on this side, until connection was made with the high ridge known as the "Divide." This was known as the San Francisco embankment line, and it crossed the rivers San Francisco, Danta, and Chanchos. The number of dams, large and small, was 67, those across the rivers named being the largest. This embankment line had a length of about 15½ miles from the north end of the Ochoa Dam to the Divide, of which 6 miles were artificial. Sluices were to be built at convenient places along this embankment to discharge the surplus waters of the drainage area to the northward.

By means of the Ochoa Dam and the San Francisco and San Carlos embankments a large pool or basin of irregular shape was to be created and the surface of the water maintained at or near the level of that in the lake itself. The excavation in the upper river and in the pool was thus reduced to a minimum.

From a point near the eastern end of the Ochoa Dam the canal was carried in excavation to the valley of the Danta, or Florida Lagoon, and from thence in pools and cuts to the valley of the Limpio, which it followed to the Divide cut. This cut is about 3 miles long and has an average depth of 134.4 feet, the maximum depth being about 350 feet. After crossing the Divide the canal descends, by means of three locks of high lift, into the valley of the Deseado, which it follows to the coastal plain, after reaching which it continues in a nearly direct line to Greytown.

A third project is to construct a dam in the San Juan River just above the mouth of the San Carlos, giving slack-water navigation from the lake to the dam, and thence by a canal in excavation along the left bank of the San Juan or near it to the junction of the San Juan with the San Juanillo, and from thence across the coastal plain to Greytown.

Each of the two latter projects admits of variants. The Menocal project can be varied by locating the dam across the San Juan above the mouth of the San Carlos River, starting with excavation to the eastward of that dam and thence following a route substantially as projected by Mr. Menocal himself. Or a lock may be used in connection with this dam and the height of the embankments be correspondingly reduced. This would increase the depth of the Divide cut by the same amount. The practicability of a dam only a short distance above the mouth of the San Carlos River has heretofore been doubted, but the surveys show that such a dam is not only practicable but will be easier of construction than one at Ochoa.

Another variant would be to build a dam near the Lower Machuca Rapids and lock down 24 to 30 feet, then follow the rest of the route practically as laid down by Mr. Menocal, the object of the latter variant being to avoid the construction of a high dam at Ochoa and to reduce the height of the San Francisco and San Carlos embankment lines. This would increase the depth of the Divide cut.

Another variant would be to construct a dam at Tambor Grande and an embankment on the south side connecting with the hills in Costa Rica. This would take the place of the Ochoa Dam and eliminate the San Francisco and San Carlos embankments. This is regarded as impracticable.

Other variants, such as increasing the number of locks or varying their location, suggest themselves.

The third project can be varied by constructing one or more dams with locks in the upper river, thus reducing the height of the dam at San Carlos. Or after reaching the junction of the San Juan with the San Juanillo any one of several routes may be taken to the sea.

Mr. Menocal's project has an advantage in that it is 2 miles shorter than the other project following the bank of the river.[a]

Its disadvantages are, first, the engineering difficulties encountered in building the Ochoa Dam. This dam being located but a short distance below the mouth of the San Carlos River, its construction would be attended with no little risk.

Second, the San Francisco embankment line is another troublesome engineering construction. This embankment follows an irregular line from Ochoa to the Divide. No less than 67 dams will be required, some of them insignificant in size, but four of them of great length and of more than ordinary difficulty to build and maintain, because of their great height and the pressure of water to which they would be subjected, as well as to the fact that the soil on which they would have to be founded is overlain for a great depth with soft ooze.

A third disadvantage is the Divide cut itself. This, as before stated, is over 3 miles long. In addition it is curved, the curvature being in places the maximum that should be allowed in a canal of this magnitude. This would render navigation difficult. Its great depth would also be a constant menace, for while it is believed that the rock for the most part would stand, there is some likely to cause trouble. A large portion of it, dacite, a rock that weathers rapidly, is of light specific gravity and not to be trusted in a deep cut like that through the Divide. Again, on account of its depth and length it would necessarily be made of the minimum width practicable for navigation; consequently if the canal were working to its full capacity, there would inevitably be some delay to vessels passing through it, since two large ships could not pass each other. Vessels would therefore accumulate at either end, to be passed at stated intervals in fleets.

The variant providing for the construction of a lock and dam at Machuca, locking down, say, 24 feet, would reduce the height of the

[a] Comparison of distances between the lake and Greytown Harbor.

San Francisco embankments and the Ochoa Dam; but the excavation in the San Juan River and eastward to the eastern end of the Divide cut would be increased by this extra depth. There would still be the Ochoa Dam, though of less height, to be constructed in contention with the floods of the combined San Juan and San Carlos rivers. If the dam be built above the mouth of the San Carlos River instead of below it at Ochoa, there would yet remain the objectionable San Francisco embankments and the Divide cut.

The project which looks to the construction of a dam above the mouth of the San Carlos River, and follows close to the north bank of the San Juan River as far as the junction of the San Juan and San Juanillo, has the disadvantage of an increase in length of about 2 miles,[a] but on the other hand it is believed the difficulties of construction will be lessened because of the reduction in the height of the embankments and by avoiding the Divide cut.

There are, nevertheless, several hills of considerable height to be cut through on this route. The Tamborcito hill will require a maximum depth of 230 feet of cutting in rock, but it is less than a half mile in length, and the material will be required on the work, while an attempt to circumvent the hills may involve an embankment founded upon a depth of 80 feet or more of black sand in the bed of the river. From this point to Lock No. 1 most of the canal trunk will be inclosed between embankments built of the silt from the excavations. In short distances they may exceed 30 feet in height, with a a pressure of 20 feet of water.

A variant on this project will be in the construction of two dams in the river above the one near the mouth of the San Carlos. But it has no advantage over the other except that it enables the lower dam to be reduced in height. This is not considered of great importance, for while the construction would be easier, the main difficulty would be in the foundations, and they would not be materially different. It has several serious disadvantages, however, in obstructing the passage of large volumes of water at narrow sections of the river and in confining the navigation below the upper dam to a narrow channel excavated in large part through rock.

Numerous other adjustments in detail may be made, both in the alignment and grade, but they are not of sufficient importance to warrant consideration prior to final location.

GREYTOWN HARBOR.

A suitable harbor with a safe entrance, at the eastern end of the canal, is an essential requisite to its proper operation. No such harbor now exists. About fifty years ago there was a good harbor at Greytown, with 30 feet of water in the anchorage and at the entrance. The sand, however, that has been brought down by the San Juan River and deposited in the sea has closed the entrance, and in a large measure filled up the harbor itself. This sand movement has been going on for ages, as the numerous lagoons that have been formed parallel to the coast line testify. The sand has been ejected from volcanoes in the region of the headwaters of the Costa Rican tributaries of the San Juan, carried down to the sea by the river, deposited on the ocean bed, and then transported by wave action in one direction or the other, according to the prevailing winds and the resulting direction of the waves.

By the term "harbor" it is not intended to convey the idea that a large harbor should be constructed for commercial purposes. A harbor of sufficient area to accommodate the vessels that arrive for the purpose of passing through the canal is all that is considered necessary. It is not expected that vessels will lie in such a harbor for any length of time, but will move through, either in one direction or the other.

For canal construction purposes a harbor is necessary. One of the first things, therefore, to be done in undertaking the construction of the canal will be to form a harbor of reasonable depth. This has an important bearing in estimating the cost of construction.

The San Juan River drains a basin of about 17,000 square miles. The silt deposited in its delta during past ages has built out the coast, with characteristic lagoons and extensive marshes covering the broad plain between the present shore line and the original foothills of the Cordilleras.

The delta may be said to begin at a point 12 miles in an air line from the outer coast, where the San Juanillo leaves the main trunk. This stream has been turned parallel to the coast, and finally reunites, through a series of lagoons, with the Lower San Juan. The latter is flanked by lagoons indicative of original beaches, the three to the north being typical of the prevailing direction of the drift on this portion of the coast, due to the angle of wave incidence. These lagoons are nearly parallel to the existing coast line and are separated by strips of land inclosing long, narrow lakes. The date of these formations is not ascertainable from any existing records.

It would seem that what is now the Lower San Juan River was at one time the main stream and discharged most of the sediment, the waves produced by the trade winds carrying a part of the material to the westward and a part of it to the southward, the westerly movement of this sand having formed lagoons whose longer axes are nearly parallel to the coast. The prevailing winds are from the northeastward, and while they rarely blow with great violence, they blow steadily and with considerable force, creating a sea which stirs up the light sand of which the beach is composed and carries it along in great volume. One has only to observe the waves charged with black sand, running diagonally along the beach, to realize their potent agency in transporting this material.

The board of 1895 gives a very complete description of the sand movement on this coast, a full discussion showing how the destruction of Greytown Harbor as it formerly existed was brought about, and the steps necessary to be taken in the construction of a new harbor. The conclusions arrived at by that board were that the Maritime Canal Company's proposed entrance is inadmissible, and the harbor head entrance inexpedient, and that the best results will be obtained by locating the entrance approximately halfway between the two. This Commission is of opinion that equally good results, at less cost, can be obtained by a change in the entrance and form of the harbor itself. The Commission has, therefore, located the east jetty about 2,000 feet westward of the position suggested by the board of 1895, the harbor itself to be about 5,000 feet long by 1,000 feet wide, and the entrance between the jetties to be 600 feet.

The construction of a jetty across the path of moving sand must of necessity cause accumulations of drift to windward; hence the angle formed between any such projecting structure and the shore must gradually fill up and the shore line advance seaward until the capacity of this receptacle is exhausted. This advance diminishes as the depth and consequent capacity of the pocket increase, but it shows that some expense must be incurred for the maintenance of the harbor either by jetty extension or by the removal of the material from time to time, which would otherwise find its way around the end of the jetty and into the channel. A study has therefore been made of the various surveys of the harbor with a view to determining the probable amount of material to be controlled in the maintenance of the entrance. This amount is estimated to vary from 500,000 to 730,000 cubic yards annually.

The entrance to the harbor will be formed by two parallel jetties about 600 feet apart, the easterly one about 2,670 feet in length, the westerly one 2,500 feet. They will extend seaward in a northerly direction, thus giving shelter from the sea, which comes generally from the northeastward. As the sea strikes the shore line with considerable violence at times, these jetties will be constructed chiefly of heavy stones not easily moved by the force of the waves. To obtain suitable stone for this purpose in large quantities and with the utmost dispatch, so that a part at least of the jetty can be quickly constructed, quarries will have to be opened at the most favorable locations.

BRITO HARBOR.

At the westerly terminus of the canal there is no harbor. The nearest harbor is that at San Juan del Sur, about 8 miles to the southeastward, but this can not be put to any useful purpose so far as the canal itself is concerned, though it may be utilized in a measure during the early stages of canal construction. A harbor will have to be constructed at Brito as at Greytown. San Juan del Sur could only be used to advantage during construction by the building of a railroad from there to the canal.

The remarks as to the capacity of a harbor at Greytown will apply with equal force to Brito. In other words, a harbor of refuge is not needed, but only such a harbor as will make the canal available for commerce. Vessels will seldom go to Brito unless entering or leaving the canal.

The conditions on this coast are not as forbidding as they are on the eastern. The sand movement is slight and the winds are mostly off-shore, consequently the difficulties to be encountered will be more easily overcome. The mean rise and fall of tide is about 7 feet. The sea during the greater part of the year breaks normal to the direction of the shore; the prevailing wind is from the northeast, and while west and south winds sometimes blow, they are of rare occurrence.

The shore is bold, and deep soundings are found at no great distance from it. The shore line trends from northwest to southeast, but the rocky promontory on the north side of the Rio Grande projects into the sea and gives a certain amount of protection.

On account of the rapid increase in depth from shore seaward, an outer harbor is almost impracticable within the limits of reasonable cost, so that one is restricted to the formation of an inland harbor within the area that is now occupied by a swamp. From borings made and all information obtainable it is believed that this material is easy to excavate. In fact, it is known that some of the borings taken by the canal company in close proximity to the proposed harbor, which seemed to indicate rock at no great depth, were deceptive and that the boring apparatus struck bowlders which were supposed to be solid rock.

The harbor proposed by Colonel Childs opened directly to the south, and was protected by two jetties, one springing from the sandy beach and running southward, the other, but smaller, jetty springing from the Brito promontory and running southeastward. The entrance was 400 feet wide. An inner harbor was formed by a change in direction of the entrance at nearly a right angle, which gave good protection. The size and depth of the harbor proposed would be utterly inadequate to the present size and draft of ships. A diversion of the Rio Grande to the eastward of the entrance was a necessary feature of this scheme.

Captain Lull, in his project for a harbor, made some changes in the Childs project, with a view to giving a wider entrance and more capacious and deeper harbor, suited to the increased depth which he proposed.

The Maritime Canal Company also proposed a plan for a harbor, increasing the area to 103 acres.

The board of 1895 suggested still another project, the main feature of which was the extension of the west jetty of the Lull plan to a length of 3,600 feet. This was, however, only provisional, with a view to an approximate estimate and not as a definite project necessarily to be followed. That board distinctly stated that "the information available is not sufficient to enable final plans and estimates to be made."

All the plans proposed have certain inherent defects, and it is scarcely possible to construct a harbor at this place that will be perfect. A breakwater to shelter an entrance becomes a very expensive structure in such a place as Brito and is liable to introduce other objectionable features.

It is believed, however, that the difficulties of a vessel's entering between two jetties that project seaward in the direction of the advancing waves have been overestimated in the case under consideration. San Juan del Sur is a fairly good harbor, yet its entrance is open to the sea. It is said that no trouble is esperienced by shipping at this place from such exposure. A Pacific mail steamer calls at this harbor once a week throughout the year. She does not go to a dock, for there is none at which she could lie, but it is understood no trouble is experienced in lightering from her anchorage.

To permit a vessel to enter the harbor normal to the swell and at the same time to guard it against agitation from the admission of large waves are conditions not easily satisfied, but the Commission believes that the form of harbor presented with this report will meet the conditions as nearly as it is practicable to do within the limits of reasonable cost and in a manner less objectionable than any other yet proposed.

The plan is to build a jetty from a point on the beach about 3,600 feet east of the Brito promontory, extending out into the sea in a direction nearly south-southwest to the 7-fathom curve, then excavate a harbor of the form shown on the plan to the eastward of a north and south line through the root of the jetty, the entrance to be 600 feet wide at the throat. This will give security and comparatively still water in all winds except those coming from south by west and a few degrees either side. The promontory will protect from winds coming from a more westerly direction and the jetty from all winds coming from a direction east of south. The basin to be excavated has a bottom area of about 135 acres and a depth of 30 feet at mean low tide, with a depth of 36 at the entrance. As the movement of sand is slight, the cost of maintenance will not be great.

The Rio Grande in this project will not be diverted at its lower end, but it will have to be enlarged in cross-section in order to carry increased discharge.

If the conclusions reached by this Commission, that this harbor gives all the protection that is needed, be found by time and experience to be incorrect, a jetty from the promontory eastward can be added at any future time. It is believed, however, that such jetty will never be required, and no provision has been made in the estimate for one.

DAMS AND EMBANKMENTS.

To construct safe, durable, and stable structures for the control of the drainage and for navigation is a sine qua non.

The principal causes for the failures of dams or reservoirs may be traced to defective foundations, improper design, or imperfect construction, single or combined. Probably the most frequent causes of their failure are their permeability causing a breach by seepage and their lack of spillway capacity, allowing the dams to be overtopped by floods.

The sites proposed in Nicaragua for the dams are such that, in connection with the large impounding capacity of the lake acting as a reservoir, there is little or no danger of sudden floods reaching their crests, so that the risk from this source is believed to be eliminated by providing an ample waste way and free board. This remark applies with still greater force to the embankment lines, which may be used for the purpose of inclosing large artificial lakes in basins of limited drainage area and not subject to the discharge from the river.

Moreover, there is an abundance of material suitable for puddle, which, if properly applied, will secure impermeability. The main difficulty, therefore, is that resulting from insecure foundations. For the dams in the rivers closing the summit level satisfactory rock bottoms and abutments are available, but to reach rock on the San Francisco embankment line is a more difficult and expensive problem.

DAMS ON THE EASTERN DIVISION.

In view of the large amount of earth and rock excavation and the necessity for disposing of the spoils, it was decided by the Maritime Canal Company to construct high rock-fill dams on both sides of the lake for the purpose of impounding the waters of the summit level, but the desirability of avoiding the San Carlos River and of facilitating the construction of the dam itself has led this Commission to select a new and better site a short distance above the mouth of the San Carlos River.

The borings made on the site of the proposed Ochoa Dam revealed rock at 17 feet below sea level suitable for foundations. The width between banks is relatively narrow, for at an elevation of 100 feet above sea level it is about 1,400 feet. As this site is below the junction of the San Carlos River, which at flood stages it is estimated may discharge 100,000 cubic feet per second, in addition to the lake and San Juan River drainage, this large volume must either be disposed of over spillways on the San Carlos ridge or be allowed to waste over the dam itself. Its sediment also would be deposited in the bed of the stream above the dam and cause constant shoaling. At lower Ochoa the sand extends to 30 feet below sea level. To avoid these serious objections, as well as to eliminate if possible the embankments of the San Francisco and Florida lagoons, examinations were made for a dam site at Tambor Grande Island. The subsequent borings in the bed of the river at this site, however, showed an erosion of the bed rock extending to 128 feet below sea level, which would necessitate a dam in this narrow gorge of the river nearly 250 feet in height, subject to the flow of the entire drainage basin. This project was therefore discarded.

The more recent examinations and surveys, made on the wider reach of the river above the San Carlos, gave results which were quite satisfactory. Here the flowage line is almost continuous, requiring but one small embankment, while the section affords ample weir length. Good solid rock foundations exist at about 15 feet below sea level. Thus, the maximum height of the dam from the bottom of the foundation would be 138 feet. The construction of a dam at this point avoids the serious objections to the Ochoa site, and also reduces the cost and difficulties of construction.

The estimates are based upon concrete, which can be mixed on the site. Regulating works and sluices can be provided in the original river channel, and the entire length of the crest may be utilized for a spillway in case of necessity.

The typical section on which the estimates are based is the ogee rising from the natural bed of the stream at an elevation of about 38 feet above sea level to the proposed weir sill at 98, with regulating sluices to control the higher stages. The width of the base at the deepest point is 100 feet. The ordinary stage of water at the foot of the dam is about 55 above sea level, while extreme low water is about 45.

SITES FOR LOW DAMS.

There are various locations on the river where dams may safely be placed for variations of project. Taking these in order, coming down stream, the first may be at *Castillo*, where the river flows over ledges of basalt which is somewhat jointed, giving it the appearance of being stratified, but it is believed to be firm and strong. The anchorages also are good.

At *Upper Machuca*, 3 miles above Machuca, the rock is calcareous sandstone, with limited weathering. Solid rock is usually found under a few feet of sand in the river channel, but the rock in the adjacent hills is weathered down nearly to the same level as the surface of the solid rock in the channel, so that the anchorage must be in residual clay and soft rock.

The *Machuca site* is situated across the head of Campaña Island. It is based on a fine-grained light-bluish gray rock, evenly bedded, and closely resembling a fine-grained quartzite. The borings on the south banks, however, show great depths of weathering, making it desirable to shift the location farther up or down stream.

Conchuda, about 2 miles above the Boca San Carlos, also affords a possible dam site, and has been considered with a view to reduce the large amount of rock excavation incidental to the Machuca dam projects.

Relative cost of the several concrete dam projects between the lake and Boca San Carlos, including the latter.

[These estimates are based upon the same prices in each case, and are submitted merely as a guide to the relative merits of the plans.]

Low dam at Upper Machuca	$1, 045, 569
Low dam at Lower Machuca	866, 040
Low dam at Boca San Carlos	2, 633, 124
	4, 544, 733
Low dam at Lower Machuca	1, 240, 785
Low dam at Conchuda	2, 721, 411
Low dam at Boca San Carlos	2, 633, 124
	6, 595, 320

Both of the above schemes would require in addition a large amount of rock excavation in the river to create navigable channels in the pools, which would be avoided by the higher single dam.

High dam at Boca San Carlos, of concrete, $4,570,340.

SAN CARLOS AND SAN FRANCISCO EMBANKMENT LINES.

The hills to the southeast of the San Carlos River contain depressions which would have to be closed by earthen embankments to provide for the Menocal project, with weirs through the saddles. The depth to hard rock varies from probably 60 to 100 feet, but as the San Carlos embankments will be avoided by the change of the dam site to a point above the Boca San Carlos, no further discussion of its embankment line is required. It would be necessary, however, to extend the San Francisco embankment line from Ochoa up the left bank of the river to connect with this new location, involving heavy work.

EMBANKMENT FOUNDATIONS.

To ascertain the character of the material underlying the proposed embankments crossing the Florida, San Francisco, Nicholson, and Chanchos depressions deep borings were made in each, which revealed the residual clay and soft rock beneath the alluvium but in thinner strata than on the hills.

"The rock is only moderately hard, consisting chiefly of talcose volcanic tuff, with a thin bed of earthy limestone." The silt in these depressions and swamps apparently extends to about ten feet below sea level and renders it desirable to reduce the height of the embankments as much as possible. All the routes traverse the reach on the left bank of the San Juan from Boca San Carlos to the San Francisco near its mouth and hence cross these lateral tributaries, but at different elevations, dependent upon the number and location of the locks.

DAMS ON THE WESTERN DIVISION.

THE LA FLOR SITE.

Much has been said pro and con concerning the possibility of constructing a dam at this site, and the board of 1895, basing its conclusions upon certain exhibits as to geological structure, declared it inexpedient, in view of the slight advantages and the ability to construct a canalized channel at a somewhat greater cost on the left bank of the Rio Grande.

In the light of more recent borings and their interpretation by Dr. Hayes, this Commission is of opinion that a dam at this point is practicable.

BUEN RETIRO.

The summit level would terminate at Buen Retiro, about 9 miles from the lake, where the topography is well adapted for the purpose, as it affords opportunities for spillways directly into the bed of the Rio Grande and Guachipilin, and for a good lock site. Here a small ovoidal hill rises from the bottom of the valley "composed of a calcareous shale more or less disintegrated, but sufficiently firm for foundation purposes." The rock is about 50 feet above sea level, and comparatively little silt would have to be excavated to place the foundations. The regulating works with the lock will close the summit level, making it unnecessary to build a dam at this site.

No other dams are required on the west side under any of the variants.

CANAL LOCKS.

On the route selected as a basis for the estimate it is proposed to construct six locks of 18.41 feet lift each on the eastern division, giving a total of 110.46 feet, and four locks of 29 feet lift each on the western division, giving a total of 116 feet, the difference of 5.54 feet being due to the difference in rise of tides in the two oceans.

In estimating the cost of the locks the large Poe lock at the Sault Ste. Marie Canal at the outlet of Lake Superior was taken as a standard, and the dimensions of lock chamber, fore and tail bays, gates, culverts, etc., were modified to adapt them to the present requirements. The lock pits were extended to 15 feet below the floor to provide for the culverts and valves and the necessary foundations. The following are the dimensions used for one of the 18.41 feet lift locks:

	Feet.
Number of culverts	4
Length of floor and side walls	939.5
Width of floor in the clear	80
Height of side walls = lift + draft + 4 feet	52.41
Length of sides between abutments	601.75
Width of side walls at top	10
Width of side walls at bottom	21.53
Width of abutment walls at quoins	31.77

On the western division the topography is such that the best results are obtained by the use of four locks having the same dimensions as to length and breadth, the only modification being in the lift and thickness of the walls and foundations.

Upon this basis the six locks on the eastern division will cost	$9,560,400
The four locks on the western division will cost	7,412,580
Making the total cost	16,972,980

QUANTITIES.

The general advantages and disadvantages of the several locations have already been stated under the head of "Projects and routes," but no final location nor estimate could be completed until after the quantities of the different classes of material on the several routes had been determined.

As a large number of variants are possible, particularly on that part of the route lying between Boca San Carlos and the sea, and as it was impossible to determine before the preliminary surveys were completed and platted which would give promise of the best results, the detailed geological examination by borings on any specific route had to be deferred for a later date. The classification which has been made along these low level routes is therefore based upon outcrops, borings by the canal company confirmed by the Commission at a few points, and an examination of the region, which is believed to be ample for the purpose of an estimate.

The collection, platting, and computing of these data have required considerable time, but so far as quantities are concerned they are quite reliable. There may be variations in the classification where the lines of separation between different materials merge into one another, but they will be more or less equalized, so that errors due to this cause will be small.

For more convenient reference and comparison of the quantities under the variations of line and grade they have been arranged in a table[a] which gives the amount of excavation and embankment in each division and for each project and class of material, excepting for the harbors, railroad, and dams. The cost of the dams, locks, weirs, and other structures is given in the item entitled "Auxiliary cost" appended to each division.

By the aid of this tabular statement of quantities an estimate of the cost of constructing the canal trunk may readily be obtained by applying any suitable unit price to the factors as stated. The amount of dredging for the two harbors not included in the table, which should be added to the totals is, for Greytown, 10,748,900 cubic yards, and for Brito, 9,500,000 cubic yards. The jetty and other harbor work is not included in the table, but is stated in the estimates.

For the route recommended by the Commission, passing to the north side of Silico Lake, following the left bank of the San Juan and Rio Grande rivers, and having a bottom width of 150 feet, with ten locks and one dam, the quantities from ocean to ocean, exclusive of the railroad, are:

	Cubic yards.
Dredging, river and coastal plain	61,738,842
Dredging, lake and harbors	37,557,750
Earth excavation and embankment	29,907,996
Disintegrated rock	15,248,312
Solid rock	7,573,992
Rock under water	754,378
	152,781,270

UNIT PRICES.

The Commission has endeavored to reach conclusions in respect to the probable cost of the canal that will be fair and just. It has tried

[a] See "Table of quantities" in Atlas.

to have the figures represent the probable cost of the canal as nearly as can be ascertained, without being too high or too low. It must be admitted, however, that any estimate of probable cost is to some extent a matter of judgment. It is not possible to determine this matter with absolute certainty, as many of the elements on which one's judgment would be based are not accurately known. One's experience in like work, and the experience of others, are the only guides. There has never yet been a work of similar character executed under exactly similar conditions, and it should be remembered that work on a small scale, or which is greatly distributed and not en masse, involves more loss of time and labor and is consequently more expensive. The work on the Panama Canal would perhaps come near it in some respects, but no one would think of comparing the extravagant methods which characterized the early history of that enterprise with the methods that should be employed on this.

The latest work of magnitude of this character which affords to some degree a means of comparison is the Chicago drainage canal. The total excavation for this work amounted to about 12,318,000 cubic yards of rock and 26,087,000 cubic yards of earth, a total of 38,405,000 cubic yards, of which about 10 per cent was dredging. The earth was of every variety from soft mud to hard, indurated clay with bowlders, all being included under the name of "glacial drift." The rock was the Joliet limestone, stratified in nearly horizontal layers, and is described as ideal for ease in excavation. The proportion of rock to earth is less in Nicaragua than in the Chicago drainage canal. The actual average price paid for excavating "glacial drift" at Chicago was 29 cents per cubic yard. The average cost of rock was 77 cents. If the Nicaragua Canal were located near Chicago and its rock and earth similar in character to those of the Chicago drainage canal, it is probable that the average cost for earth excavation would be the same in each. The earth in the Nicaragua Canal varies in character from stiff, indurated clay to diluted silt. The range is equally wide in the Chicago drainage canal. It can not be asserted that the earth is alike in the two places, but it is believed that it may be substantially so. Under such circumstances it might be fairly assumed that the average cost of earth excavation, if the canal were located near Chicago, would be 29 cents.

As the Chicago drainage canal affords the nearest precedent available and as the actual average prices of that work have been taken as a basis, it is necessary to state the classification of the material as specified for that work, which was as follows:

> For the purpose of letting the contracts the material to be excavated was divided into two classes, rock and "glacial drift." The first term explains itself, but the character of the material termed "glacial drift," this being an entirely arbitrary classification, needs some further explanation. As defined in the specifications, "glacial drift shall comprise the top soil, earth, muck, sand, gravel, clay, hardpan, bowlders, fragmentary rock displaced from its original bed, and any other material that overlies bed rock." In fact, all these materials are found in all degrees of intermixture, from soft black muck, which can be pumped with centrifugal pumps, to a conglomerate of sand, gravel, clay, and bowlders cemented together with almost the hardness of rock, and only to be excavated by means of the strongest steam shovels, and sometimes even requiring blasting to break it up.

In Nicaragua the rock on the western division is chiefly a calcareous shale, thinly stratified and much broken. Some pits of considerable depth have been excavated without blasting, and the rock has been used for macadamizing the roads. It is believed that a large part of this rock could be excavated with steam shovels without blasting. It is drilled slightly easier than the Chicago limestone and is more brittle. The location of the spoil banks would be quite similar to that of the Chicago work. It is therefore probable that some of this rock could be excavated for a price slightly cheaper than the Chicago rock. Some of it, however it is known, will cost more. It is probable that, taken as a whole, it could be done for the same price, and it is so assumed.

Between Lake Nicaragua and the Caribbean Sea, viz, the eastern division, the rock is basalt, dacite, sandstone, and volcanic tuff. The basalt and dacite are both considerably harder to drill and blast than the Chicago limestone. In the larger cuts the waste material will have to be transported some distance to the dumping grounds. For these reasons it is estimated that the cost per yard will be increased 10 cents. Therefore it is assumed that if the Nicaragua Canal were located near Chicago the cost of excavating its rock would be 87 cents per cubic yard on the eastern division and 77 cents per cubic yard on the western division.

With reference to the actual work at Chicago, Mr. Isham Randolph, the present chief engineer of that work, writes as follows:

> The prices on our work ranged from 59 cents to 80 cents for solid rock and from 19.9 cents to 56 cents per cubic yard for glacial drift. This glacial drift, however, covered material which under railroad specifications would come under the heads of loose rock and hardpan. The average price paid on this work per cubic yard was for solid rock, 77.3 cents, for glacial drift, 28.7 cents. * * *
>
> In the light of our experience, I believe that a work of like magnitude prosecuted under similar conditions could be put under contract at a reduction of about 15 per cent from our ruling prices; in other words, that rock work should be done for 65 cents and earth for 24½ to 25 cents, which prices would, I believe, provide a fair margin of profit for the contractor.

Mr. Lyman S. Cooley, former chief engineer and director of this work, also concurs in this opinion, stating that some very hard glacial drift was removed for 26 cents per cubic yard and that the actual cost of rock work was about as follows:

	Cents per cubic yard.
For plant	15
For loading	15
For hoisting	15
For channeling	5
For drilling	6
For explosives	8
Total	64

Including contractor's profits.

It yet remains to assign the relative cost of work in the United States and in Central America. This will involve greater uncertainty, for the reason that there have been no large works in Central America with which comparison could be made. There has, however, been some railroad building in all of the Central American States, often in amount sufficiently large to require the importation of labor, thus making the conditions of labor similar to those which would obtain if the Nicaragua Canal should be built.

Mr. William H. Keith, contractor, reports the cost of work on the National Railway of Costa Rica to be for solid rock 60 cents in gold per cubic yard, for loose rock 30 cents in gold per cubic yard, and dry earth 18 cents in gold per cubic yard; concrete in place, including "forms," $9 per cubic yard.

Mr. Louis Wichmann, general manager of the Atlas Company, who has been engaged in building a railroad, $6\frac{1}{2}$ miles in length and $2\frac{1}{2}$ feet gauge, from Greytown to the Lower San Juan River, states "that the total cost per cubic yard of excavation on the Silico Railroad is $1.25 Nicaraguan currency, equal to 50 cents gold."

In explanation of this abnormally high price, he says that—

The disadvantages were extremely bad weather, especially in June and July, during which time we had some seven weeks of continuous rain, and the principal part of the material being heavy clay it was very difficult to handle.

Being entirely without mechanical appliances I had to rely on manual labor, which, considering the nature of the soil and constant downpour of rain, has proved a great drawback.

The material on the first big through cut at the Silico end consisted of conglomerate with large round bowlders, which could only be removed after blasting, and unfortunately, owing to the Spanish-American war, we were unable to secure explosives at the time when they were most needed.

Other difficulties mentioned were the long carriage to the spoil banks and the fact that all supplies, tools, and provisions had to be transported on the backs of the laborers.

These conditions and prices can not therefore be cited as being comparable to the probable cost of so great a work as the construction of this canal, where the most modern appliances should be used.

Quite recently it is credibly stated that the Silico Railroad had cost more than was anticipated, and that the total cost was from $110,000 to $120,000, length $6\frac{1}{2}$ miles, equivalent to $16,923 to $18,461 per mile, and that this cost included everything—roadbed, rails, rolling stock, bodegas, wharves, and all terminal facilities at both ends. It was built in very bad weather and under great difficulties. The rolling stock consists of 1 locomotive, 8 freight cars, 2 construction cars, and 2 passenger cars, which were imported. The ties on this road were furnished and put in place for about 24 cents apiece in gold.

The cost of excavation varied from 50 cents to $1 (Nicaraguan currency) per cubic yard, depending upon the condition of the weather and the labor. During the early part of the construction Fortune Island negroes were employed, but were found unsuitable for the work. While these men were employed the cost of excavation was rather high. The labor now consists of natives and Jamaicans, and the cost of excavation is kept below 70 cents.

The cost of food for each man per day varied from 52 cents to 75 cents. This is included in the cost of excavation. The material chiefly excavated was blue and brown clay. In handling the blue clay the rains had no effect upon it whatever. The brown clay becomes rather difficult to shovel when wet, as it has a tendency to stick. In the former the same amount of material can be hauled on a wet day as on a dry day. The haul in some cases was over 400 feet. During rainy days the work was not interrupted.

The rate of exchange at present is 200 per cent premium.

An engineer of large experience in Guatemala states that prices for grading on railroad work in that country were as follows: For earth, from 30 to 40 cents; for loose rock, from 65 to 85 cents, and for solid rock, from $1.40 to $1.75, exclusive of cost of administration and engineering. The prices paid for clearing ranged from $65 per acre on the swamp work to as low as $25 for the upper end of the line. The cost of masonry, where the haul was less than half a mile, was about $24 to $28 for first class, $14 to $18 for second, and $10 to $12 for third. "In all of the foregoing, prices are expressed in the silver of the country." The rate of exchange is not stated.

Another engineer, also in Guatemala, states that the unit prices there were for earth 40 cents, telpetate $1, loose rock $1.25, solid rock

$1.80; masonry exclusive of cement, third class $10, second class $16, and first class $25 per cubic yard. "These prices include a good profit if work is properly handled." They are all on a silver basis. Converted into gold at the Nicaragua ratio they would be: For earth, 16 cents; telpetate, 40 cents, loose rock, 50 cents; solid rock, 72 cents; third-class masonry, $4; second-class, $6.40; first-class, $10.

Mr. M. P. Carter, civil engineer on the construction of the Cauca Railroad in Colombia, where the rainfall is said to exceed 300 inches a year, testified under oath that "a man working in earth work would move 3 or 4 yards a day at 40 cents a yard; that is the average. For loose rock, that has been loosened a little with a pick, he might move 1½ or 2 yards a day at 80 cents a yard, and for conglomerate a man would not move more than two-thirds or three-quarters of a yard per day at $2.20 per yard." All of the above prices are in Colombian money, which would make the equivalents in gold for earth 17.2 cents, for loose rock 34.4 cents, for conglomerate 92 cents.

[Extract from a letter from Mr. Harold R. Miller, dated Atlas Line of Mail Steamers, New York, April 22, 1899.]

The three rates for earth work and conglomerate were 40 cents, 80 cents, and $2.20, Colombian, as per Mr. Carter's evidence. The exchange at that time was 130 to 150, say 140, per cent. That makes 17 cents, 34 cents, and 92 cents gold. To-day the exchange is 230 per cent, viz, $1 gold is $3.30 Colombian. Labor, of course, has not risen in proportion with the exchange, so that construction work is really cheaper to-day than then, because contractors get more currency for their gold and pay about the same rates. Labor is about $1 Colombian in the interior, $1.40 to $1.60 on the coast. The conditions on the Isthmus are different from the rest of the Republic, owing to the silver currency, which alone prevails on the Isthmus. The rest of the Republic uses paper, which has about 20 per cent discount as compared with silver.

[Extract from communication, dated October 30, 1887, from Edwin F. Smith, civil and hydraulic engineer.]

In conclusion, I desire to say that processes of dredging have improved very much in recent years, and large companies in the United States would, I think, be found willing to take such contracts at Greytown, and on the line of the Nicaragua Canal, at less than the figures given in the estimates of the canal company.

This is true not only of dredging, but also of rock excavation. There are construction companies and contractors handling material on the Chicago Drainage Canal with modern appliances who would, no doubt, eagerly compete for such contracts as those of the rock cut through the Eastern Divide and the building of the Ochoa Dam, and the dredging of Greytown Harbor and the canal through the lagoons.

[Extract from a communication from Col. T. P. Roberts, chief engineer Monongahela improvement.]

On the Nicaragua Canal, if extra prices are paid foremen and bosses, the actual cost of work will not be much in excess of that for which it could be done here. A general increase of 25 per cent over American prices ought to be sufficient. While I would thus suggest a reasonable unit price for items of labor, I would advise a liberal percentage on the whole work, to cover engineering and managment. Administration expenses will doubtless be very high at first, but this item will diminish after the officials have become acclimatized. Physicians and sanitary engineers should be employed to select the places for camps, provide the water supply, and look after the drainage. If this be properly done, the cost for hospital service would not be great. I do not see why this item should be differentiated. * * * A millage tax on all salaries and wages should be fixed to maintain hospitals.

It has been my observation for several years past that American engineers have been overestimating the cost of work. They appear to me to not fully realize the wonderful improvements which have been made in this country. Many of them still think that French and German methods on canal work admit of little improvement, but such engineers have not been attentive students of the Chicago Drainage Canal experience.

In July of this year six locks and dams were let on the Monongahela River. The United States engineers' estimate for them all was about $1,200,000, which amount

I thought was about the right thing, but, although the estimate was publicly known, a number of responsible contractors bid less than $800,000, and it was actually awarded for less than $700,000. The bidder failing to secure bondsmen, the Department ordered another letting.

For convenience of comparison these prices are tabulated as follows:

	Earth.	Loose rock.	Solid rock.
Chicago basis	29	....	77
Costa Rica	18	30	60
Guatemala	14	30	63
Do	16	50	72
Colombia	17	34	92
Average	16¼	36	71¾

From this it appears that the actual cost of earth work in these tropical countries is in general less than that given for the Chicago basis. The average for earth and loose rock is 26 cents, which is less than the Chicago price of 29. The average of the rock work is also 5 cents below that at Chicago, so that it would seem that the statement of Mr. Shunk, chief engineer of the Intercontinental Railroad Commission, is apparently correct that "an estimate of like work at home would be fairly applicable down there."

In view, however, of the difficulties of securing a sufficient supply of laborers for so great a work, and of regulating their wages, the Commission has concluded to increase the actual average prices paid at Chicago by 33⅓ per cent for all earth and rock work on the western division, and by 50 per cent for work on the eastern division, after allowing an increase of 10 cents for rock on the eastern division because of local differences and character of material.

The prices applied to the quantities will therefore be as follows:

ON THE EAST SIDE.

For Greytown Harbor, dredging	per cubic yard	$0.25
For Greytown Harbor, jetties	do	2.50
For dry earth excavation	do	.44
For solid rock excavation	do	1.30
For dredging in upper river	do	.30
For dredging in lake	do	.20
For rock under water	do	5.00
Timber cribs	do	3.25
Clay puddle and back filling, exclusive of cost of excavation	do	.50
Concrete in structures other than locks	do	8.30
Concrete in locks	do	7.23
Stone pitching on embankments	per square yard	2.00
Timber in structures	per M. B. M.	60.00
Clearing	per acre	75.00
Clearing and grubbing	do	100.00

ON THE WEST SIDE.

For dry earth excavation	per cubic yard	.39
For solid rock excavation	do	1.03
For dredging harbor	do	.20
For rock under water	do	5.00
For jetties	do	2.00
Timber cribs	do	3.00
Clay puddle and back filling, exclusive of cost of excavation	do	.50
Concrete in structures other than locks	do	8.30
Concrete in locks	do	7.23
Stone pitching on embankments	per square yard	1.75
Timber in structures	per M. B. M.	60.00
Clearing	per acre	75.00
Clearing and grubbing	do	100.00

The prices for structural work of locks and weirs are based on the cost of similar work in the United States, to which 33 per cent has been added for difference of location, including climate, etc.

FEASIBILITY.

Under this division of the subject the Commission would respectfully submit that it has failed to find any competent authority that denies the feasibility of constructing a canal across Nicaragua.

The feasibility of the canal is conceded for the following reasons:

1. There are at this date sufficient precedents for ship canals capable of passing the largest vessels, so that any question of the navigation of such a channel is eliminated.

2. The ability to construct and operate locks of the requisite dimensions is sufficiently established by existing structures on the Manchester and Keil canals, at Davis Island on the Ohio, and at the St. Marys Canal, Michigan.

3. The possibility of constructing the necessary dams, weirs, sluices, and embankments, which shall be sufficiently stable and impermeable to control the water required for navigation, as well as to regulate the floods, is within the resources of the engineering profession and is fully demonstrated by the many hundreds of miles of embankments, levees, and dams, both at home and abroad. There is no reason to doubt the ability to build them out of the native rocks and earth and to give them the required strength and tightness to retain or to discharge the water with safety.

4. There is no question as to the adequacy of the supply of water for all purposes at all seasons nor as to its control in times of flood.

5. Neither is there any doubt with reference to the ability to secure good supporting ground for the trunk of the canal nor suitable sites for locks and dams.

6. The harbor question is only a matter of money, and it is believed that good, capacious, and safe artificial harbors can be created at a reasonable cost. In brief, this Commission sees no reason to doubt the entire feasibility of the project, but it realizes the necessity of exercising due care in the preparation of the specifications and in the conduct of the work, that the details of construction be thoroughly inspected and properly executed under competent supervision.

ESTIMATE.

After a careful analysis and comparison of the physical features and quantities affecting the numerous variants, the Commission has selected that route which it believes will give the best results.

This route, starting from the harbor at Greytown, crosses the coastal plain, passes to the north of Lake Silico, and up the left bank of the San Juan to the dam at Boca San Carlos, thence follows the improved river channel, crosses the lake, and traverses the valleys of the Lajas and Rio Grande to Brito, on the Pacific.

It is characterized by six locks on the eastern division, having a lift of 18.41 feet, all lying east of the dam, and four locks on the western division, having a lift of 29 feet. The summit level extends from the lock 0.43 of a mile east of the beginning of the cut at Boca San Carlos to the lock 1.86 miles west of Buen Retiro, a distance of 139.3 miles.

The details of the estimates are stated in the reports of the assistants hereto appended, and it will suffice here to summarize and classify the quantities for the excavation of the canal trunk and to affix their unit prices in order to ascertain the approximate cost. The auxiliary works have also been computed for each subdivision separately and in detail, but the totals only are stated in this connection. The calculations are based upon a minimum elevation of 104 for the summit level, with a depth of 30 feet and a minimum bottom width of 150 feet, as set forth more particularly under the "Dimensions of the canal."

General estimate of cost.

Classification.	Cubic yards.	Price.	Amount.
East side, with 50 per cent over Chicago prices for earth and rock:			
Earth	23,206,836	$0.44	$10,211,007.84
Rock	1,309,375	1.30	1,702,187.50
Rock under water	472,705	5.00	2,363,525.00
Dredging (harbor)	10,748,900	.25	2,687,225.00
Dredging (lake)	17,308,850	.20	3,461,700.00
Dredging river and canal	46,555,742	.30	13,966,722.60
Dredging upper river	15,183,100	.39	5,921,409.00
	114,785,508	....	40,313,846.94
West side, with 33⅓ per cent over Chicago prices:			
Earth	21,949,472	.39	8,560,294.08
Rock	6,264,617	1.03	6,452,555.51
Rock under water	281,673	5.00	1,408,365.00
Dredging harbor	9,500,000	.20	1,900,000.00
	37,995,762	....	18,321,214.59
	152,781,270	....	58,635,061.53
AUXILIARY WORKS.			
Jetties, Greytown	550,000	2.50	1,375,000.00
Jetties, Brito	144,107	2.00	288,214.00
			1,663,214.00
Concrete dam and regulating works at Boca San Carlos			4,570,340.00
4 locks on west side, 28 feet lift			7,412,580.00
6 locks on west side, 18.41 feet lift			9,560,400.00
Weir on west side, Buen Retiro			1,102,300.00
Weirs on east side below San Carlos			207,890.00
Clearing and grubbing (7,463 acres)			615,625.00
Guard gates, timber piers, piling, etc.			1,089,343.00
			24,558,478.00
			84,856,753.53
MISCELLANEOUS.			
100 miles of railroad for construction purposes, at $50,000 per mile (double track)			5,000,000.00
Sanitary and police			2,000,000.00
For maintenance of harbors during construction of canal, and for buoys, beacons, and lighting			1,000,000.00
			92,856,753.00
Engineering and administration, 6 per cent			5,571.405.00
			98,428,158.00
General contingencies, 20 per cent			19,685,632.00
Total			118,113,790.00

For the cost of engineering and administration an estimate of 6 per cent has been made. This estimate is large, but in a work of such great importance the engineering and superintendence must be thoroughly and carefully done by men of ability and integrity, who will necessarily command higher rates of pay than would be deemed sufficient in the United States.

An estimate of 20 per cent for contingencies has been made. It is intended to cover all items of expense due to unforeseen accidents or emergencies. Owing to the extent and character of the work, there are more uncertainties than usual, including that of labor, which will have to be largely imported from the islands of the West Indies and from our Southern States. No work of this character and importance has ever been completed within the Tropics. There is therefore nothing to serve as a precedent or guide for the proper contingent percentage, but after careful consideration and with a desire to make an ample allowance, the board has decided to include an estimate of 20 per cent, which is believed to be quite sufficient for all probable accidents or emergencies.

It is believed that if honestly and properly administered, with money at command as required, the canal can be built within the limits of the above estimate.

CONCLUSIONS.

The Commission after mature deliberation has adopted and estimated for the route from Brito to Lake Nicaragua, called Child's route, variant No. 1, and from the lake to Greytown, that called Lull route, variant No. 1. This line leaving Brito follows the left bank of the Rio Grande to near Buen Retiro, crosses the Western Divide to the valley of the Lajas, which it follows to Lake Nicaragua. Crossing the lake to the head of the San Juan River, it follows the upper river to near Boca San Carlos, thence, in excavation, by the left bank of the river to the San Juanillo, and across the low country to Greytown, passing to the northward of Lake Silico. It requires but a single dam, with regulating works at both ends of the summit level.

The new location selected for the dam at Boca San Carlos eliminates one of the most serious engineering difficulties by avoiding entirely the San Carlos River with its torrential floods and large volume of sediment, and by locking down immediately from this dam the difficulties and risks of the high embankments of the Menocal line are also avoided.

Instead of the dam at La Flor a lock and regulating works have been substituted at Buen Retiro, where the topography is well adapted for the purpose. It is also proposed to divide the surplus waters of the lake basin between the east and west sides, thus reducing the velocities in the San Juan and securing ample waste-way capacity for the maximum discharge that can ever occur, if stored and distributed over a short period of time. Ample provision has also been made for a possible fluctuation of the lake of 6 feet or more without injury to property, by fixing the elevation of the bottom of the canal sufficiently low to cover seasons of minimum rainfall. The surveys have in general revealed better physical conditions than were hitherto supposed to exist, especially as to the amount of rock in the upper river, whereby it is possible greatly to reduce the estimated cost of construction. This fact will account largely for the comparatively moderate amount of the estimate when the enlarged dimensions of the project are taken into consideration. Other reductions are due to the improved methods and machinery available, as developed on the Chicago Drainage Canal, and which can not be ignored in discussing a work of this magnitude.

The creation of sufficiently capacious interior harbors presents no unusual difficulties, and they can be secured at a reasonable cost.

The field work, under the authority of this Commission, has been carefully and well done, and is believed to be all that is necessary for the preliminary location of a canal, and to determine, within narrow limits, the final location of dams, locks, and other constructions. Should a canal across Nicaragua be authorized, it will be necessary to make further minute and careful investigations by borings to determine the exact location of locks and dams, for which this Commission had neither the time nor money, nor would it have been justified in doing work of this character until the construction of a canal was assured. The computations of amounts to be excavated have been carefully made and checked to guard against errors, and are believed to be accurate within narrow limits. All possible information has been sought with regard to cost of similar work in the United States and in Central America, and a careful comparison made of the probable difference between Nicaragua and the United States.

To determine the proper unit prices for excavation the average of prices actually paid to contractors on the Chicago Drainage Canal, which represent cost of plant, prices paid for work done, and contractors' profits, were taken. Up to this point the Commission dealt only with facts. To the prices paid at Chicago certain percentages have been added for the difference in location, climate, etc. These percentages are, of course, a matter of judgment, upon which men may honestly differ. But from all the information obtainable by this Commission and after careful consideration, with a desire to arrive at a proper conclusion, those used in the estimate are deemed fair and reasonable.

In obtaining the estimate for cost of locks the prices actually paid for building the Government locks at the Sault Ste. Marie were taken, and 33 per cent was added for the difference of location. This percentage is believed to be ample, as a large part of the expense of constructing the locks will be for material, much of which can be furnished in Nicaragua at the same or only a small advance upon the prices in the United States.

After giving due weight to all the elements of this important question and with an earnest desire to reach logical conclusions, based upon substantial facts, the Commission believes that a canal can be built across the isthmus on this route for a sum not exceeding that stated in the estimate.

The dimensions of the canal proposed are much larger than any hitherto considered, and will be ample not only to meet the present requirements of commerce, but also for many years to come. A navigable channel of smaller dimensions than those proposed, only sufficient for present needs, can be constructed for a lesser sum if deemed expedient.

We have the honor to be, sir, your obedient servants,

J. G. WALKER,
Rear-Admiral, U. S. Navy, President of Commission.
LOUIS M. HAUPT,
Civil Engineer, Member.

In appending my signature to this report, I desire to state that I concur generally with the views expressed, but my estimate of the cost is $134,818,308.

PETER C. HAINS,
Colonel, U. S. Corps of Engineers, Member.

CHAPTER VII.

EARTHQUAKES, VOLCANOES, CLIMATE, HEALTH.

Earthquakes.

So much has been written upon the liability of an isthmian canal to injury or destruction by earthquakes that a brief discussion of the subject seems desirable.

Obscurity of subject.

The cause of earthquakes is not well understood, but amid the obscurity surrounding the subject there are a few salient facts which seem to be generally accepted.

Volcanic regions most subject to earthquakes.

The first is that the geographical distribution of volcanoes corresponds with the areas most subject to earthquakes. One of the most celebrated and destructive earthquakes known to history—that of Lisbon in 1755—occurred far from any volcano; and so with that of New Madrid, Mo., in 1812, and that of Charleston, S. C., in 1886; but the general statement is correct, that they are more frequent in volcanic countries than elsewhere, though there is probably no part of the earth's surface which is entirely exempt from these disturbances. It does not follow that volcanoes and earthquakes bear to each other the relation of cause and effect, but it is highly probable that they represent different manifestations of the same subterranean forces.[a]

Volcanoes safety valves.

The doctrine that volcanoes are safety valves which diminish the violence of earthquakes in their vicinity is accepted by such writers as Baron von Humboldt, Sir Charles Lyell, Prof. Charles Daubeny, and J. Le Conte.[b]

In general terms, then, the region of volcanoes is the region of earthquakes, but the immediate vicinity of the volcanoes is not necessarily the most dangerous part of the region.

Entire isthmus in volcanic region.

The location of the principal volcanoes in the part of the world where lies the isthmus is shown on plate 70. From a glance at this map it is evident that the entire isthmus between North and South America is a volcanic region. Humboldt thus speaks of it: "The grandest example of a continental volcanic 'chain' is offered by the great rampart of the Andes extending from the southern part of Chile to the northwest coast of America."[c] No portion of it is exempt from earthquakes.

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[a] "Earthquakes," by John Milne. D. Appleton & Co., N. Y., 1899.

[b] Humboldt's "Cosmos," Sabine's translation, eighth edition, Vol. I, p. 202; "Principles of Geology," by Sir Charles Lyell, first American edition, Vol. I, p. 32; "Volcanoes," by Charles Daubeny, second edition, p. 691; "Elements of Geology," by J. Le Conte, fourth edition, p. 105.

[c] Cosmos, Vol. I, p. 228.

The record of those which have occurred is meager, being as a rule confined to those severe enough to inflict damage upon buildings or otherwise attract general attention. The most complete catalogue to which the Commission has had access is that prepared by Mr. F. de Montessus de Ballore,[a] published in 1888. It covers the entire period from the time of the Spanish conquest to the year 1886. No very important earthquake has occurred upon either the Nicaragua or Panama lines since the latter date.

Records available.

The record for points upon the line of the Nicaragua Canal shows 14 earthquakes. Two of these were felt at Grey Town, which has been supposed by some writers to be exempt. The only one which is reported to have caused serious injury was that of 1844—Rivas was almost destroyed, and great damage was done at Grey Town. Rivas is 4 miles from the canal line, and is the only town of consequence in that part of Nicaragua. It has had a continuous existence since a period antedating the conquest, when it was known as Nicarao. It was subsequently known as Nicaragua.

Earthquakes on Nicaragua line.

For Panama the records show 28 earthquakes. Of these, 12 occurred in the three years 1882, 1883, and 1884, which illustrates the incompleteness of the record as a whole. The only one that could be called destructive was that of 1621, which destroyed nearly all the houses in Panama. The next most severe was that of September 7, 1882. During this earthquake a part of the front of the cathedral in Panama was thrown down and the headquarters building of the canal company was cracked; the railroad had its track and roadbed in places thrown out of line, and the masonry of three or four bridges and culverts was damaged; at Las Cruces the church was thrown down; at Colon some lives were lost and crevasses were opened, and the Jamaica telegraph cable was broken

Earthquakes on Panama line.

It is evident that this list is not complete enough to justify a comparison between the Nicaragua and Panama routes as to either the number of earthquakes or their severity. They are on precisely the same footing historically as they are geographically. In neither case is there recorded any great disasters such as have occurred in neighboring countries. The earthquake of Caracas to the eastward in 1812, and that of Jamaica to the northward in 1692, are well known as among the most destructive in history. To the northwestward the town of San Salvador has been ruined ten times and that of Guatemala seven times. To the southward, the earthquake of Riobamba, in the province of Quito, in 1779, was one of the most terrible phenomena in the history of the globe.[b] With the exception of the injury to Panama in 1621 and to Rivas in 1844, the worst that has ever happened at the Isthmus upon either line was to throw down or crack a few walls; and even in those cases it is to be remembered that comparatively few of the houses were substantially built.

No difference between the two lines.

The internal disturbance which results in an earthquake is trans-

[a] Tremblements de Terre et Eruptions. Volcaniques au Centre-Amerique, by F. de Montessus de Ballore, p. 61. Societe des Sciences Naturelles de Saone-et-Loire, Dijon, 1888.

[b] Cosmos, vol. 1, p. 194.

mitted to any given point of the earth's surface in the form of an elastic wave of compression, and its effects may be of infinite variety, depending upon the varying elasticity of the different media through which it passes, and their shape, as well as the strength and distance of the original impulse. The resulting motion may be vertical, horizontal, or oblique, and a circular or twisting effect may be produced if the direction of the force be not in a vertical plane passing through the center of gravity of the object acted upon. Twisting motion would also be produced by two waves crossing each other. The ground may be elevated or depressed, and fissures may be opened, these effects being sometimes temporary and sometimes permanent. The effect of the undulations of the earth's surface upon any structure increases with the height of the structure above the ground. A force which would leave the foundation intact might throw down a high wall.

Mechanical action of earthquakes.

The works of the canal will nearly all of them be underground. Even the dams are low compared with the general surface of the country and with their broad and massive foundations may be said to form part of the ground itself as they are intended to do. The locks will all be founded upon rock. It does not seem probable that works of this kind are in any serious danger of destruction by earthquakes in a country where lofty churches of masonry have escaped with a few minor injuries.

Power of canal works to resist.

When an earthquake originates beneath the sea, one of its attendant phenomena is often a tidal wave, and this is sometimes of enormous height and destructive character. At Lisbon the sea rose to a height of 50 feet above its ordinary level.[a] With a given force of impulse, the dimensions of such a wave must bear some relation to the depth and area of the water disturbed. A lake like that of Nicaragua is insignificant compared with the ocean. It is not probable that a tidal wave of great proportions could be generated therein. The probability is still less for Lake Bohio.

Tidal wave.

It is possible and even probable that the more accurately fitting portions of the canal, such as the lock gates, may at times be distorted by earthquakes, and some inconvenience may result therefrom. That contingency may be classed with the accidental collision of ships with the gates, and is to be provided for in the same way, by duplicate gates.

Injury to be expected.

It is possible also that a fissure might open which would drain the canal, and if it remained open, might destroy it. This possibility should not be erected by the fancy into a threatening danger. If a timorous imagination is to be the guide, no great work can be undertaken anywhere. This risk may be classed with that of a great conflagration in a city like that of Chicago in 1871, or Boston in 1872.

Danger from a fissure.

It is the opinion of the Commission that such danger as exists from earthquakes is essentially the same for both the Nicaragua and Panama routes, and that in neither case is it sufficient to prevent the construction of the canal.

Climate.

The climate of the isthmian canal regions is generally damp and enervating. The temperature is not extreme, rarely rising as high as 95° or falling below 70°, but

[a] Keith Johnston's Physical Atlas, p. 40.

the excessive humidity greatly restricts the capacity for physical exertion. The lowlands near the coast have long been known as insalubrious, and the seaports are subject to fevers.

Health.

Perhaps the greatest difficulty to be encountered in the construction of the canal will be the procurement of an adequate force of laborers and the preservation of their health and efficiency.

In this respect the Panama route has a lugubrious history from which the Nicaragua route is free. The notorious mortality which attended the construction of the Panama Railroad and later the operations of the Panama Canal Company has taught a lesson which will not soon be forgotten for that route. Among the white employees of this Commission sent to Nicaragua there were fewer cases of sickness than there would probably have been among the same number of men employed in some parts of the United States. Among those sent to Panama the proportion of sick was greater. On the Nicaragua line during the operations of the Maritime Canal Company the health of the force was reported to be good. These operations, however, were of a preliminary character, employing but a limited number of men. It is probable that when ten or twenty thousand men are assembled and the rank soil is being turned up over a widely developed line of works the experience will be different.

Experience at Panama and Nicaragua.

There are some slight differences of climate. In Nicaragua the trade winds are more regular than at Panama, tempering the heat and removing miasma more effectively; but, on the other hand, the rainfall is greater at Nicaragua, at least for the east side, and the resulting humidity is greater. Both are covered with the rank vegetation peculiar to the Tropics, and swamps abound in both. The lessons taught at Panama should be heeded for Nicaragua also.

Lessons from Panama.

It is stated by Mr. Bunau-Varilla, at one time chief engineer of the old Panama Canal Company, that out of one hundred individuals sent to the Isthmus not more then twenty, as an average, could remain there, and even these lost a part of their value. The negro alone could perform manual labor; the white man must supervise and direct. After costly and fatal experiments with other races the company ceased sending to the Isthmus as laborers any but native Colombians and negroes from the British Antilles, particularly Jamaica. The Panama Railroad Company grants to its white employees from the United States two months' leave of absence each year, with transportation to their homes.

Careful selection, including physical examination, of persons sent to the Isthmus, a well-organized hospital service, an efficient sanitary supervision of camps and barracks, a rigid quarantine service, a liberal water supply and sewerage system, with the authority and the police force necessary to enforce the rules, and regular leaves of absence to white employees, are among the requirements for a successful prosecution of the work, and will probably be found necessary at either place.

Precautions for preservation of health.

EXHIBIT C.

A GENERAL DESCRIPTION OF THE VOLCANIC PHENOMENA FOUND IN THAT PORTION OF CENTRAL AMERICA TRAVERSED BY THE NICARAGUA CANAL.—THE POSSIBLE EFFECTS OF EARTHQUAKE SHOCKS ON THE STRUCTURES OF THE CANAL.

[By Maj. C. E. DUTTON, United States Army.]

SAN ANTONIO ARSENAL,
San Antonio, Tex., June 22, 1891.

The President Nicaragua Canal Construction Company.

MY DEAR SIR: I have your letter of 13th instant, in which you invite me to give a general description of the volcanic phenomena found in that portion of Central America traversed by the Nicaragua Canal, and to express any conclusions which I may have reached concerning the effects of possible earthquake disturbances upon the proposed structures of the canal.

In reply, I would say that the portion of the canal between Lake Nicaragua and the Caribbean, apart from the San Juan River, traverses a country in which the rocks of the surface are mainly volcanic, but belong to a past geological age. No recent volcanoes or lavas are known to exist anywhere in the vicinity. Volcanic action has been wholly extinct there during the present geological age, and the surface lavas have been decomposed into a red clay, containing occasionally rounded bowlders of the original rock as the last remnants. Underneath these red clays other lavas are found, some of them in a good state of preservation, others showing a partial decomposition. Interstratified with them are beds of volcanic ashes, to which your surveyors have given the name of slate and telpetate.

The active volcanoes which are nearest to this portion of the canal are situated in Costa Rica. There are two chains of volcanoes in Costa Rica which exhibit signs of unrest and which may be regarded in a certain sense active, though the activity of some of them is nothing more than a little steam at the summits or from lateral vents. Much the greater number of peaks in these two chains have given no sign during the present century, and in most cases have been silent ever since the discovery of the country. There are, however, four or five of them which must be regarded as active, for they have within a century broken out in strong eruption and still maintain a condition of unrest.

Of the two chains, the one nearest to the San Juan River is situated 15 to 18 miles north of San Jose, the capital of the country, and include three volcanoes which may be regarded as active. Of these, the one nearest the San Juan is named Poas. It is 40 miles due south of the junction of the Rio San Carlos with the San Juan, and about 58 miles from the proposed location of the eastern locks.

About 30 miles southeast of Poas is Irazu, the most active and forcible of all the Costa Rican volcanoes. It is about 58 miles from the junction of the San Carlos and a little more, say, 62 or 63 miles, from the eastern locks. About 6 miles east of Irazu, and substantially the same distance from the canal, is Turialla, also an active vent.

The other volcanic chain is much longer. It lies near the Pacific coast, being only 12 to 15 miles distant from Puntarenas. It extends in a northwesterly direction as far as the Volcano Orosi, which is 38 miles southeast of the town of Rivas. It contains but one or two cones which may be regarded as active, though there are in all four or five which have at times disclosed some traces of volcanic action, but hardly enough to warrant us in calling them active. The Volcano Orosi, which is the northwesternmost of the chain and much nearer than any other to the canal, is not positively known to be in active vent; certainly it has given no sign within the memory of men now living in its vicinity. Nor does it have the appearance of an active cone. I was within 8 miles of it on the northern side, whence it seemed to be an old cone in an advanced stage of degradation by weathering, and no traces of recent action were visible. I have been unable to find any record of an eruption from it. Yet it is reputed in the works of several writers to be active, though no dates or incidents of such an occurrence are given, so far as I have been able to learn.

Nicaragua contains a single chain of volcanos parallel to the Pacific coast and generally about 20 miles from it. The southeasternmost cones of this chain are the twin peaks Madera and Ometepe in Lake Nicaragua. They are about 15 and 11 miles, respectively, from the shore of the lake, and opposite the point at which the canal will leave it leading to the Pacific. Madera is apparently extinct, but Ometepe is active, having been in eruption in 1883. The proximity of these two cones to the canal makes them objects of special interest, for they are much nearer to it than any others. The next volcano of this chain is Mombacho, at the foot of which the large town Granada is situated. While there has been no eruption from it during the history of Nicaragua, there are some lava streams emanating from it which bear the look of recency, and can not be more than a very few centuries old. It is also one of the principal sources of earthquakes and tremors. Its distance from the canal locks near Brito is, I believe, a little over 40 miles.

About a century ago a considerable eruption occurred near Masaya, some 16 or 18 miles beyond Granada. From the meager accounts preserved, it would seem to have been attended with very little violence, though a very considerable body of lava was ejected and overflowed a large tract of country. This quiet form of eruption is sometimes seen elsewhere among basaltic outbreaks, and is especially characteristic of the vast lava floods of Mauna Loa and Kilauea in the island of Hawaii. There is no mountain or even large cinder cone to make the orifice of the Masaya eruption, which was situated in a comparatively low country.

There is a group of volcanic cones on the southwest shore of Lake Managua, near the city of Managua, but they appear to be extinct. No other active volcano exists in this chain until Momotombo, at the extreme western bay of Lake Managua, is reached. It is a large cone, and is always steaming at the summit, and gives evidence of a dormant activity in many ways. It is reputed to have erupted twice during the present century, the last time only a few years ago. Twenty miles northwest of it and north of Leon is the volcano Santa Clara, which is also steaming, but as these two are more than 100 miles distant from the canal they may be regarded as outside the limits of discussion.

In only one instance has any eruption in Central America been of the extremely violent class. The exception was the outbreak of Coseguina, on the Bay of Fonseca, in 1835, which was one of the most forcible of the present century. Otherwise the eruptions have been of small or moderate energy, causing no serious and widely spread disasters. The ejections are largely in the form of scoria and ashes, though lava streams sometimes flow.

As regards earthquakes, it is well known that they are comparatively frequent, especially in Costa Rica and Nicaragua, and a few have been destructive in very restricted localities. It is no doubt a matter of great interest to the canal company; for the question at once arises whether there is not danger of serious damage from this cause to the works of construction, and of the still more serious damage of long suspensions of traffic. In order to reach some estimate of the magnitude of this danger, it may be well to state, as briefly as possible, some general considerations which must serve for a logical basis of any estimate:

(1) The forecast of earthquakes contemplates probabilities only and not certainties. That one will happen in a particular region in a specified number of years is a probability which is great or small according to the nature of the locality and its extent. We may view such probabilities as having the nature of risk analogous to those of fire and shipwreck, with the following difference: Fires and shipwrecks are of such frequent occurrence, and have been so thoroughly investigated by insurance companies, that their probabilities under widely varying circumstances can be estimated with great precision, and the commercial value of the risk accurately determined. Earthquake risks have never been so investigated, and it is therefore impossible to assign specific numerical values to them. Nevertheless, it is sometimes practicable to show that the risk is so small that it can be left out of consideration with prudence, though we may not be able to assign its precise value.

(2) In attempting to forecast the future probabilities of earthquakes, we must assume that the future will be like the past, precisely as is done in insurance probabilities. We must assume that where they have been frequent and violent they will continue to be so, and that countries seldom visited by them in the past will be as seldom visited in the future. There is no other possible basis of reasoning.

(3) Earthquakes originate at very different depths in the earth, rarely, perhaps never, exceeding 12 miles, and generally not exceeding 3 or 4 miles. We know almost nothing of the ultimate nature of the forces or causes which generate them; but we know considerable about the manner in which they are propagated after they have been started, and concerning their subsequent action and effects. Whatever may be the causes, we must assume that the subterranean track or seat in which they originate occupies some space of very limited extent and contains some point which may be regarded as its center—commonly called the centrum. From the seat of origin the impulses are propagated as elastic waves in every direction, in a manner having much in common with waves of sound in the air.

(4) The intensity or violence of these waves diminishes like that of

the air, at as rapid a rate as they are propagated. At any given spot the intensity is inversely proportional to the square of the distance from the centrum.

(5) In all destructive earthquakes, the extent of country in which they are destructive is but a small fraction of the total area throughout which the tremors are perceptible. Ordinarily it is not far from the four-hundredth part of the area perceptibly shaken. The area in which the shocks may cause damage varying from slight to serious (but not demolition or what are usually considered destructive effects) is commonly about four to eight times as large as the destructive area, or from the fiftieth to the one-hundredth part of the area of perceptible vibration. Those ratios are only roughly approximate, and they are subject to some qualification, ordinarily not large, dependent on the depth of the centrum. They are of importance as showing the comparatively narrow localization of destructive and even damaging effects. Still, the destructive areas may in some cases be absolutely considerable, being proportional to the total energy of the shock at the centrum. The destructive area of the Charleston quake had a radius of not far from 40 miles, but its tremors were perceptible at a distance of 700 to 1,000 miles. Its great extent, as well as the distances at which its tremors were felt, cause it to rank among the most powerful shakes of the present century. Its intensity at the surface, however, while formidable, was not so excessive as has been experienced in some other memorable earthquakes. This was because its depth was extreme, being in all probability one of the most deeply seated of which we have sufficient knowledge to form an opinion. In striking contrast was the Casamicciola earthquake, on the island of Ischia, in the Bay of Naples, in 1884. Here the destructive area had a radius of less than 2 miles, but within that area the violence was superlative and the havoc great. At Naples, 25 or 30 miles away, the shock was only a faint tremor. The depth of the Charleston quake is computed at about 12 miles, with a very moderate probable error. The Casamicciola quake had its origin at a depth, probably, of less than half a mile. Immediately over the centrum its intensity was apparently quite equal to that in the central area of the Charleston, but the total energy of the shocks was hardly one seven-hundredth part as great. These two extreme instances may illustrate the varying effects of total energy and depth upon surface intensity. The comparison is analogous to one on a smaller scale between the explosion of 100 pounds of dynamite at a depth of 100 feet and of 30 tons at a depth of half a mile. The effects at the "epicentrum" (point on the surface vertically over the centrum) would not differ much, but the larger and deeper charge would affect a vastly greater area and would be felt at a much greater distance.

The foregoing will suffice for our purpose, and it is needless to enter into a general discussion of the principles involved in earthquakes. It only remains to put those already set forth into relation with the facts presented in Nicaragua and Costa Rica.

In both of these countries the principal earthquakes, so far as we know them, and perhaps we may say all the forcible ones, have had their centra in close proximity to the volcanoes or underneath them, and are incidents apparently of the volcanic activity. There is no evidence nor any suggestion, so far as I can ascertain, that any of them have originated at a considerable distance from the volcanoes. The country on either side of the volcanic chains has not been visited by any earthquake shock except such as have been transmitted through the rock from the centra within the volcanic areas.

Earthquakes are frequent in the vicinity of San Jose, the capital of Costa Rica, and of the other towns surrounding it upon the high, fertile, and populous plateau of this country. A very few of them have been more or less destructive. By far the most energetic one occurred in 1841, completely destroying the large town of Cartago, situated at the base of Irazu, and killing many people. The intensity or violence of this quake, in close proximity to the centrum, appears to have been very great. But the indications, from the imperfect accounts we have of them, are to the effect that the intensity declined with increasing distance at a very rapid rate; for at San Jose, only 13 miles distant from Cartago, the intensity hardly reached the destructive stage, and the injuries to the buildings were seldom great. In towns somewhat more remote the shocks caused great terror, but no serious damages, while at a distance of 40 miles or more they appeared to have been harmless. These accounts are very characteristic of the Casamicciola type of earthquake, involving a shallow centrum, a rather small "epicentral tract" with high intensity (because of the shallowness of the origin), and a rapid decline of intensity with increasing distance, because of a relatively small or moderate amount of total energy. The accounts of other earthquakes in Costa Rica which have occasioned serious damage or destruction are very meager. But their general tenor is indicative of similar characteristics, but of less total energy. In general, it may be said that the earthquakes of that country appear to be very local in their destructive effects, and the shocks become harmless quivers or tremors within 20 or 30 miles of their origin.

The portion of the canal between Ochoa and the Caribbean is, in my opinion, too remote from the localities in which the Costa Rican earthquakes originate to be liable to any serious injury from them. At long intervals of time, averaging perhaps from five to ten years, some exceptionally powerful shock may transmit waves as far as the canal with sufficient intensity to produce marked vibrations and tremors; but that they will have force enough to materially injure the structure of the canal is, in my judgment, too improbable to call for any special precautions against them. Very light and barely noticeable tremors will be much more common. If it could be shown that strong shocks have had their origin near the line of the canal, the danger would be much more pronounced. But I am not aware that there is any indication whatsoever of such an occurrence. It is true that light tremors have been noticed in Greytown, but they are in all probability the vanishing waves of forcible shocks originating far to the southward. There is no reason to suppose that the country through which this portion of the canal extends is an earthquake country. The risk of damage from that cause I regard as immaterially small.

With respect to the portion of the canal leading from Lake Nicaragua to the Pacific there seems to be a somewhat larger risk, but not large enough to cause any serious apprehension. The volcano Ometepe in the lake is only about 13 miles from the outlet of the canal, and about 21 miles from the locks. Its eruption in 1883 was a somewhat forcible one, attended with strong tremors, which sufficed to produce some cracks in the houses and area walls in Rivas.[a] I saw several of these cracks, though they were not common and in no case endangered the

[a] Rivas is about halfway between Ometepe and the locks.

structures. The canal locks, if they had been in existence at the time, would probably not have been injured, if built on rock foundations or upon very solid earth not liable to slip or settle under a series of such tremors. The tremors there were considerably lighter than at Rivas, and they would be much less susceptible of damage than the fragile walls of which Central American houses are built. A few cracks in a large town indicate a fairly definite degree of intensity, and give a far better measure of it than the terror and panic of the inhabitants.

Although the eruption of Ometepe in 1883 was the first since the conquest, earthquakes have before emanated from it, and some of them have been as forcible as the one spoken of, but none, so far as can be ascertained, that were measurably more so.

With regard to the possibility of earthquakes originating from Orosi,[a] we have not sufficient data to warrant any very definite opinion. It stands in a wilderness which has always been little inhabited except by Indians, and if any earthquakes have originated there the shocks were so enfeebled by the time they reached the settled portions that they were harmless. Nor would it be practicable for a people unobservant in such matters to ascertain their source, or to collate from an uninhabited country the facts which would enable others to determine it. As this volcano is situated 40 miles from the canal locks, it would require much more decisive indications of seismic activity in its neighborhood than we now know of to justify any fears from it. To all appearance it is a long-extinct volcano, not likely to trouble the world again with any eruption or violent shakings.

The Volcano Mombacho[b] is a center of decided earthquake activity. A very few years ago—the exact year I do not recall—the city of Granada, at its base, was severely shaken, many houses being damaged and a number of them wrecked. A large church nearly ready for the roof was badly shattered. A few lives were also lost. This shock was felt forcibly at Managua, about 30 miles distant, and though it caused much alarm and even panic there, it does not seem to have produced any serious damages. At Rivas,[c] which is about twice as far from Mombacho as Managua, it was harmless, though causing much alarm. It requires only a light and harmless shake, but one perceptible to everybody, to cause great fear and even panic. Other shocks, some of great force, have been known to emanate from Mombacho. The seismic center, however, is too remote from the canal to be a source of any apprehension.

No shocks are known ever to have originated along the line of the canal from the lake to Brito, nor in any dangerous proximity to it, except those from Ometepe. This section of the canal does not in reality lie within the volcanic axis or areas. The Nicaraguan chain, beginning with Madera and Ometepe, is a little to the north of it, and the western Costa Rican chain ends with Orosi. The nearness of Ometepe,[d] however, would be a source of danger were it not for the fact that the past behavior of the volcano has been for more than two centuries so moderately demonstrative as to give little cause of apprehension of more vigorous action in the future. Unless future shocks from it should be much more powerful than in the past, they will not

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[a] In Costa Rica.

[b] In Nicaragua, 35 miles north of the canal line.

[c] Rivas is between Mombacho and the canal.

[d] Ometepe is 22 miles distant from the locks.

endanger the locks; and there is nothing else on this part of the line which an earthquake would be likely to injure.

There is a tendency on the part of nearly all persons who have not made special study of the subject to entertain exaggerated ideas of the risks and dangers of what are termed earthquake countries. The terrors of the "epicentral tract" in a great devastating series of shocks can not, indeed, be exaggerated. The error consists in assuming them to be frequent, widespread, and typical of the country. In truth, they are rare, even in the most afflicted region, and when they do come they are destructive within relatively narrow limits only, while the country at large is shaken only by harmless quivers. It is exceedingly rare for one generation living on any spot on earth to have seen two destroying earthquakes in the same locality. In many volcanic countries there are a few spots where such catastrophies repeat themselves, though usually after very long intervals of years. These are known and can be shunned by the engineer and architect, if need be. Apart from these, all localities within an earthquake country sufficiently removed from the known centers or axis may be regarded as being in far less peril from earthquakes than from sweeping destruction by an uncontrollable fire.

Briefly, then, my opinion is that the risk of serious injury by earthquakes to the constructions proposed for the Pacific section of the canal is so small that it ought to be neglected alike by the Maritime Canal Company, the Construction Company, and by contemplating investors; also, that the risks to the Atlantic section are still smaller than those to the Pacific section.

You suggest that I submit "some observations upon the subjects of the effects upon engineering superstructures and substructures of those earth movements which in some instances have destroyed cities and population, changing topographical features of localities, and, on the other hand, movements which have destroyed in some instances massive works and have passed harmlessly others of seemingly frail construction."

Observations of the effects of great shocks upon buildings of many kinds are very abundant and have been carefully made and studied. It may be said in general that superstructures of stone or brick are far more liable to injury than substructures, excepting in those transcendent quakes which nothing, not even the earth mass itself, can withstand.

In shocks which are less than superlative, though still destructive, foundations are seldom much injured, even when superstructures are extensively demolished. A superstructure is liable to cumulative vibration, i. e., to oscillations of steadily increasing amplitude, while a substructure is not. Any ordinary walled structure is liable to have, either as a whole or in some of its parts, a definite vibratory period. If this period be the same as or a small but exact multiple of the period of a series of earthwaves the extent of vibration will rapidly increase and the liability to destruction is greatly multiplied.

A substructure can have no greater amplitude of movement than the ground itself. Only in the most formidable earthquakes are foundations likely to suffer, except, perhaps, incidentally and secondarily from abnormal strains thrown upon them by the rocking of the superstructure. The escape of fragile structures while strong ones are overthrown is not a mystery. They are not in harmony with the wave period, and therefore not liable to cumulative vibration.

There is a mistaken impression prevailing among those who are unfamiliar with recent progress in seismic investigation, which it is important for engineers to be advised of. It is a common impression that earthquake motion has a definite direction in each case. There is no warrant for this in theory, and the seismograph wholly disproves it. There is no one direction of motion to a particle on the ground during an earthquake. The motion is in every direction. Perhaps I can best express it by saying that the ground squirms and wriggles. The path of an earth particle during a shake is like a long hair rolled up into a ball between the flattened palms of your hands, or like the path of a fly hovering under a chandelier. Still, it is usual for the components of all the motions to have some slight, and sometimes a very marked, predominance in one direction. The vertical components are generally smaller, except in very close proximity to the epicentrum, where they may become very large. Away from the epicentrum the largest horizontal component will more frequently, but by no means always, be in a line connecting the place with the epicentrum, or nearly in that direction. But the maximum vibration may be in any direction, being determined probably by accidents of the ground. It would be illogical, therefore, to attempt to fortify against earthquakes by building structures calculated to resist movements coming from any specific quarter, unless, indeed, it be decided to follow the example of the deacon in building the "One Horse Shay." The only precaution I know of which is of the slightest utility is to build on solid rock instead of subsoils, gravels, or any sort of unconsolidated strata. The amplitude of motion during a quake is less, and there is less liability to permanent displacement. But in the visitation of a first-class earthquake even this precaution would be useless.

The structures most easily injured would undoubtedly be the locks. The masonry might be cracked by a powerful shock, but unless the ground beneath were permanently displaced or the walls moved bodily the damage could be repaired at small cost. The gates might be jammed or broken or slightly displaced also. But shocks of sufficient severity to produce any of these results are hardly to be anticipated. The dams, if built in the manner proposed, of loose rock with very long slopes (6 or 8 to 1), would require shocks of extraordinary power, accompanied with considerable displacement of the ground beneath them, to damage them. As against earthquakes, they would be the safest that could possibly be built.

Being already nothing but shattered fragments, it is not apparent what more an earthquake could do except to dislocate the earth beneath them. Such permanent distortions of the earth do not occur except in the most forcible convulsions, far more forcible than any that have ever been known to occur in Nicaragua.

Very truly, yours,

C. E. DUTTON,

Major, Ordnance Department, United States Army.

EARTHQUAKES.

RELATION OF THE CANAL ROUTE TO CENTERS OF VOLCANIC ACTIVITY.

Most earthquakes for which a cause can be assigned with any degree of probability are produced either by an explosion at greater or less depth below the earth's surface or by a dislocation of the earth's crust producing a fault. The former class is confined chiefly to volcanic regions, and if the explosions are sufficiently long continued they eventually find a vent at the surface and produce an active volcanic eruption. Earthquakes produced by faulting are also to some extent characteristic of volcanic regions, but may occur remote from any scene of volcanic activity, especially in regions which are undergoing rapid elevation or depression. They are especially characteristic of regions in which the mountain-building forces are active. Earthquakes of the latter class, due to dislocations of the strata, are perhaps no more liable to occur in the vicinity of the Nicaraguan Canal route than elsewhere, and hence they do not constitute a danger which is peculiar to this region more than to almost any other in which a ship canal might be constructed. Earthquakes of the first class, however, are assumed to constitute a menace to the permanence of the canal, inasmuch as the region is one of considerable volcanic activity. The question of the risk incurred from this source is certainly one which should be considered.

In the foregoing description of the topography and geology of the region the distribution of modern volcanic activity was indicated. It was shown that, while the Nicaraguan depression is occupied to a considerable extent by volcanic rocks, these belong in large measure to a former geological period, and the activity to which they owe their origin has long since entirely ceased. It was shown, further, that the only manifestation of volcanic activity in recent times has been along two lines of vents which have given rise respectively to the Costa Rican and the Nicaraguan volcanic ranges. The former terminates to the northward in the peak of Orosi. This volcano appears at present to be entirely extinct, and there is no authentic record or tradition of its having been in eruption since the occupation of the country by the Spaniards. Dutton described it as to all appearances a long extinct volcano; an old cone in an advanced stage of degradation by weathering and showing no traces of recent action. Squire,[a] however, speaks of it as in a state of constant activity, but he does not describe it from personal observation, nor does he give the date of any authenticated eruption.

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[a] E. G. Squire, "The States of Central America," New York, 1858, p. 361.

Of the numerous volcanoes in the Costa Rican range to the southeast of Orosi only one has shown any activity within historic times. This is Irazu, near the center of the range, which was last in eruption in 1726. As described by Hill, "the entire crater occupies but a relatively small portion of the great mountain mass which it caps and is apparently a later parasitic summit growth upon a much older mass."[a] It is evident that the eruption which gave rise to the present conical summit of Irazu is an expiring phase of the activity which produced the massive mountain range.

The Nicaraguan range terminates to the southward in the twin peaks of Madera and Ometepe, occupying the island of Ometepe. The interval between the northern terminus of the Costa Rican range and the southern terminus of the Nicaraguan range is about 30 miles, and between these points passes the sailing line of the canal in Lake Nicaragua. Madera may be regarded as extinct. There is no tradition of its having shown activity, and its summit has been greatly modified by erosion, indicating that there have been no eruptions for a very considerable time. Ometepe is quiescent. It manifested a slight activity in 1883 when there was an eruption of lapilli with explosions of moderate violence. At present the only sign of activity consists in numerous fumeroles from which steam and sulphurous gases escape. While no eruption of Ometepe appears imminent, there is no certainty that its activity has entirely ceased, although the indications are that it is on the wane. Mombacho has been extinct for a long time. Its last eruption was probably one of the explosive type and destroyed its conical summit. Masaya was in eruption in 1858, but the eruption was not accompanied by explosion, simply consisting of the welling up and overflow of fluid basaltic lava. Momotombo, at the northern end of Lake Managua, shows signs of moderate activity. It is not at present erupting solid material, but throws off great volumes of vapors, which form a black cloud over its summit. Steam and other vapors are escaping from several craters to the northward of Momotombo, but from none of them are any lavas or lapilli being extruded.

It is thus seen that the present activity of the volcanic vents which form the Costa Rican and Nicaraguan ranges belongs almost entirely to the solfataric stage which characterizes the extinction of volcanic activity. Considering the great mass of material which has been extruded from these vents in comparatively recent geologic times, it is very clear that the activity in this region is on the wane; and while eruptions will doubtless occur in the future, it can be asserted with a fair degree of confidence that these will be less violent and occur at longer intervals than in the past. It is also clear that the greatest activity at present and hence the source of greatest danger in the immediate future is not in the vents which terminate the volcanic ranges, but rather in the central portion of those ranges; that is, in central Costa Rica and in northern Nicaragua. The experience of many years proves that these regions which are the centers of greatest volcanic activity are also the centers from which emanate most of the earthquakes felt throughout the Nicaraguan depression.

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[a] The Geological History of the Isthmus of Panama and Portions of Costa Rica, by Robert T. Hill, Bull. Mus. Comp. Zool., Vol. XXVIII, 1898, p. 230.

CONSIDERATIONS AFFECTING EARTHQUAKE FORECASTS.

The subject of earthquakes in this region and their bearing upon the problem of the canal have been studied by Maj. C. E. Dutton, than whom no one is better qualified to speak on this subject. His report accompanies the report of the Nicaragua Canal Board of 1895, and his discussion of some of the principles of earthquakes in general and their application to this particular region are quoted below.

As regards earthquakes, it is well known that they are comparatively frequent, especially in Costa Rica and Nicaragua, and a few have been destructive in very restricted localities. It is no doubt a matter of great interest to the canal company; for the question at once arises whether there is not danger of serious damage from this cause to the works of construction, and of the still more serious damage of long suspensions of traffic. In order to reach some estimates of the magnitude of this danger, it may be well to state, as briefly as possible, some general considerations which must serve for a logical basis of any estimate:

(1) The forecast of earthquakes contemplates probabilities only and not certainties. That one will happen in a particular region in a specified number of years is a probability which is great or small according to the nature of the locality and its extent. We may view such probabilities as having the nature of risk analogous to those of fire and shipwreck, with the following difference: Fires and shipwrecks are of such frequent occurrence, and have been so thoroughly investigated by insurance companies, that their probabilities under widely varying circumstances can be estimated with great precision, and the commercial value of the risk accurately determined. Earthquake risks have never been so investigated, and it is therefore impossible to assign specific numerical values to them. Nevertheless, it is sometimes practicable to show that the risk is so small that it can be left out of consideration with prudence, though we may not be able to assign its precise value.

(2) In attempting to forecast the future probabilities of earthquakes, we must assume that the future will be like the past, precisely as is done in insurance probabilities. We must assume that where they have been frequent and violent they will continue to be so, and that countries seldom visited by them in the past will be as seldom visited in the future. There is no other possible basis of reasoning.

(3) Earthquakes originate at very different depths in the earth, rarely, perhaps never, exceeding 12 miles, and generally not exceeding 3 or 4 miles. We know almost nothing of the ultimate nature of the forces or causes which generate them, but we know considerable about the manner in which they are propagated after they have been started, and concerning their subsequent action and effects. Whatever may be the causes, we must assume that the subterranean tract or seat in which they originate occupies some space of very limited extent and contains some point which may be regarded as its center—commonly called the centrum. From the seat of origin the impulses are propagated as elastic waves in every direction, in a manner having much in common with waves of sound in the air.

(4) The intensity or violence of these waves diminishes like that of the air, at as rapid a rate as they are propagated. At any given spot the intensity is inversely proportional to the square of the distance from the centrum.

(5) In all destructive earthquakes, the extent of the country in which they are destructive is but a small fraction of the total area throughout which the tremors are perceptible. Ordinarily it is not far from the four-hundredth part of the area perceptibly shaken. The area in which the shocks may cause damage varying from slight to serious (but not demolition or what are usually considered destructive effects) is commonly about four to eight times as large as the destructive area, or from the fiftieth to the one-hundreth part of the area of perceptible vibration. Those ratios are only roughly approximate, and they are subject to some qualification, ordinarily not large, dependent on the depth of the centrum. They are of importance as showing the comparatively narrow localization of destructive and even damaging effects. Still, the destructive areas may in some cases be absolutely considerable, being proportional to the total energy of the shock at the centrum. The destructive area of the Charleston quake had a radius of not far from 40 miles, but its tremors were perceptible at a distance of 700 to 1,000 miles. Its great extent, as well as the distance at which its tremors were felt, cause it to rank among the most powerful shakes of the present century. Its intensity at the surface, however, while formidable, was not so excessive as has been experienced in some other memorable earthquakes. This was because its depth was extreme, being in all probability one of the most deeply

seated of which we have sufficient knowledge to form an opinion. In striking contrast was the Casamicciola earthquake, on the island of Ischia in the Bay of Naples, in 1884. Here the destructive area had a radius of less than 2 miles, but within that area the violence was superlative and the havoc great. At Naples, 25 or 30 miles away, the shock was only a faint tremor. The depth of the Charleston quake is computed at about 12 miles, with a very moderate probable error. The Casamicciola quake had its origin at a depth, probably, of less than half a mile. Immediately over the centrum its intensity was apparently quite equal to that in the central area of the Charleston, but the total energy of the shocks was hardly one seven-hundreth part as great. These two extreme instances may illustrate the varying effects of total energy and depth upon surface intensity. The comparison is analogous to one on a smaller scale between the explosion of 100 pounds of dynamite at a depth of 100 feet and 30 tons at a depth of half a mile. The effects at the "epicentrum" (point on the surface vertically over the centrum) would not differ much, but the larger and deeper charge would affect a vastly greater area, and would be felt at a much greater distance.

There is a tendency on the part of all persons who have not made special study of the subject to entertain exaggerated ideas of the risks and dangers of what are termed earthquake countries. The terrors of the "epicentral tract" in a great devastating series of shocks can not, indeed, be exaggerated. The error consists in assuming them to be frequent, widespread, and typical of the country. In truth, they are rare, even in the most afflicted region, and when they do come they are destructive within relatively narrow limits only, while the country at large is shaken only by harmless quivers. It is exceedingly rare for one generation living on any spot on earth to have seen two destroying earthquakes in the same locality. In many volcanic countries there are a few spots where such catastrophes repeat themselves, though usually after very long intervals of years. These are known and can be shunned by the engineer and architect, if need be. Apart from these, all localities within an earthquake country sufficiently removed from the known centers or axis may be regarded as being in far less peril from earthquakes than from sweeping destruction by an uncontrollable fire.

Briefly, then, my opinion is that the risk of serious injury by earthquakes to the constructions proposed for the Pacific section of the canal is so small that it ought to be neglected; * * * also, that the risks to the Atlantic section are still smaller than those to the Pacific section.

SEISMIC RECORDS IN THE CANAL REGION.

On the 29th of April, 1898, there occurred an earthquake which was perceptible throughout the greater part of the Nicaraguan depression, and which was moderately destructive in the towns of Leon, Managua, and Chinandaga. A commission consisting of Dr. Carlos Sapper and Dr. Bruno Miersch was appointed by the Government of Nicaragua to investigate the cause of this earthquake. This commission visited the region affected and made the ascent of numerous volcanic peaks in the vicinity of its greatest violence. They found no signs of imminent eruption in any of the craters visited, and reached the conclusion that the earthquake was due, not to a volcanic explosion beneath one of the numerous craters of the region, but to a dislocation of the strata. It is probable, as has been indicated in a preceding part of this report, that this region to the north of Lake Nicaragua has been affected by faults in comparatively recent times, and the present earthquake may be due to a further displacement along one of these old lines of fracture or to the inauguration of a new fracture. The absence of any signs of increased activity in the volcanic craters, however, is scarcely conclusive evidence that the earthquake was not due to a deep-seated explosion intimately connected with the causes of the vulcanism. It is the deep-seated explosions, those not relieved by an eruption at the surface, which probably cause the most destructive earthquakes. When a vent is formed with an open passage from the seat of the explosion to the surface, the violence of the effects is diminished, or rather it is manifested in an eruption of lapilli and lava rather than in earthquake waves transmitted through the crust to the surface.

Leon was visited by the writer shortly after the earthquake of April, 1898. The effects observed in that city were chiefly the formation of cracks in the walls and the partial destruction of buildings constructed of adobe. This material has very slight coherence and is poorly adapted to resist the strains produced by earthquake vibrations. No solidly built wooden or stone buildings suffered greater damage than the formation of a few cracks over the doors and windows. The cathedral of Leon suffered no damage except the displacement of a large globe which rested on a slender support on the ornamental façade of the building. It was concluded that if such a structure as a canal lock built on a suitable foundation had occupied the epicentral tract of the Leon-Chinandaga earthquake it would have suffered no material damage, almost certainly not enough to interfere with its continuous use. The risk at points 200 miles distant from the epicentrum, that is, at the nearest point on the canal route, would have been entirely negligible.

The only source of possible danger from earthquakes to the eastern division of the canal lies in the Costa Rican volcanoes. Occasional earthquakes are experienced in central Costa Rica, the most violent since the occupation of the country by the Spaniards having been the one which destroyed the town of Cartego in 1841. This emanated from the neighboring volcano of Irazu and was of the shallow type with a small epicentral tract. It was only slightly destructive at San Jose, about 13 miles farther from the source than Cartego. The much greater distance of the canal from this volcano renders the probability of an earthquake from that source extending its destructive area so far as the canal structures extremely small.

Two sources of danger to the western division of the canal are present, in Orosi to the south and in Ometepe to the northeast. As stated above, there is some doubt as to the condition of Orosi. The probability, however, is that this volcano is extinct. There are no records or traditions of destructive earthquakes having affected this region, although from the absence of large towns it is doubtful if the absence of records should be considered as conclusive evidence that such earthquakes have not occurred. The distance of this volcano from the nearest canal structures which would be liable to injury is so great that unless the disturbances were of exceptional violence the only effect at the canal line would be harmless earth tremors. The extent of the danger from Ometepe can be somewhat more accurately gauged. This volcano was regarded as extinct up to the date of its eruption in 1883. It was clothed with vegetation entirely to the summit. Some earthquakes had emanated from Ometepe before the eruption. Squire speaks of the town of Rivas as having suffered much from earthquakes previous to 1850, but gives no details of their frequency or violence. The one which accompanied the eruption of Ometepe in 1883 was only very slightly destructive even at Rivas, and at the line of the canal its destructive violence had doubtless entirely disappeared. Even with the intensity manifested at Rivas it would in all probability have been entirely harmless to such a structure as a canal lock. It is not probable that those which preceded that of 1883 were much more destructive or some record of them would have been preserved. Indeed, the excellent state of preservation in which the ancient churches of Rivas and San Jorge are found is conclusive evidence that the region has not been visited by earth quakes of destructive violence for more than a century.

A consideration of the present activity in these two volcanoes, therefore, and of the available records of earthquakes in this region would seem to remove all apprehension concerning the probability of damage to canal structures by earthquakes emanating from them. If the danger from these sources, which are comparatively near, be considered so small that it may be disregarded, that from the more distant centers of volcanic activity, both to the north and the south, may be dismissed as altogether too small to merit consideration. Even if there should originate at the present centers of greatest activity an earthquake with as great violence as that which has characterized some that have wrought the most destructive effects in Peru and San Salvador, it is probable that the earth waves would there be so far dissipated before reaching the line of the canal that they would be comparatively harmless. It therefore appears to the writer that the opinion above quoted from Major Dutton is entirely correct, namely, that the risk of serious injury by earthquakes to the constructions proposed is so small that it ought to be neglected.

[Senate Document No. 393, Fifty-seventh Congress, first session.]

LETTER FROM THE SECRETARY OF STATE, TRANSMITTING COPY OF A DISPATCH FROM THE FORMER VICE-CONSUL OF THE UNITED STATES AT PANAMA CONTAINING DATA IN REGARD TO THE EARTHQUAKE THERE IN 1882.

DEPARTMENT OF STATE,
Washington, June 5, 1902.

SIR: I have the honor to acknowledge the receipt of your letters of May 31 and June 2, 1902, requesting copies of certain records of the Department in regard to earthquakes and riots in Panama, Colombia.

In reply I inclose herewith a copy of a dispatch from the former vice-consul of the United States at Panama, transmitting newspaper clippings in regard to the earthquake there in 1882.

The records on the subject of the riot in Panama in 1856 will make about 1,000 pages of typewriting, and with our available force it will be impossible to furnish copies of these records within a month.

Referring to your letter of the 3d instant, I have to say that the Department's records contain nothing at all with reference to a proposition by Colombian authorities respecting annexation.

I have the honor to be, sir, your obedient servant,

JOHN HAY.

Hon. JOHN T. MORGAN,
United States Senate.

UNITED STATES CONSULATE,
Panama, September 14, 1882.

SIR: By this mail I forward to the Department a copy of the weekly edition of the Star and Herald of to-day's date, which contains a full and graphic account of the severe earthquake which visited this city on the 7th instant at 3.25 o'clock a. m.

I am, sir, your obedient servant,

ROBERT W. TURPIN,
Vice-Consul.

Hon. WILLIAM HUNTER,
Second Assistant Secretary of State,
Washington, D. C.

[Star and Herald, September 14, 1882.]

SEVERE EARTHQUAKE ON THE ISTHMUS—MUCH DAMAGE DONE.

During the past week the Isthmus has been visited by several earthquakes which have done damage, but which fortunately have only caused two deaths. The following, copied from the daily Star and Herald, describes the events as they occurred from day to day:

[Daily Star and Herald, September 8.]

On Thursday, 7th instant, at 3.20 in the morning, the inhabitants of Panama were aroused from their beds by one of the longest and most severe earthquake shocks which has ever been experienced in this city. It was preceded by a hollow, rumbling noise which aroused and alarmed many persons. The motion was wave like, and proceeded almost directly from north to south. The first and most severe shock must have lasted at least 30 seconds. Commencing with a moderate movement, it deepened in intensity, and toward the finish was so violent in strength that had it lasted 10 seconds longer it is probable that at this moment there would not be a house standing in Panama. The shock had hardly terminated when the streets were filled with people, many of whom sought the outskirts of the town in order to avoid danger from the fall of edifices. A second and milder shock occurred about half an hour after the first one.

It is almost impossible to depict the alarm and excitement which followed. Panama has always been considered exempt from the mighty natural convulsions which are experienced almost periodically in the countries through which the giant Cordillera stretches its mountainous and volcanic ridges. That the shocks this morning were of exceptional violence appears to indicate a terrible calamity in some of those districts—and in all probability in the north—rather than a possibility that the old-time freedom of the Isthmus from earthquakes is about to disappear, and that henceforth we are to be subject to such dangerous and fearful visitations as those which on that morning threatened the city with ruin.

The amount of damage done can not as yet be estimated, but it must amount to at least $250,000. The municipal building and assembly rooms, under which the Cascada is situated, were much damaged. The whole of the massive balcony fell bodily into the square, dragging with it the roof and all adjacent timber.

The cathedral also suffered severely. Almost the whole of the ornate pediment, composed of heavy blocks of masonry, fell through the roof or onto the steps leading to the principal entrance. Every arch in the nave is cracked and split, and large stones and pieces of cement have fallen from them. The side aisles are also seriously damaged, and an expenditure of at least $50,000 will be required to restore the building. The roof of the assembly room will be repaired at any early date, Governor Borbua having acted with remarkable celerity and commenced work at once in order that the archives and furniture may not be exposed to damage from the rain.

Private houses damaged are innumerable, and owners as yet fail to form a correct idea of the losses they have incurred. The walls of the canal office are cracked in several places, and the edifice requires strengthening. No estimate of damage can be made, but an expenditure of several thousand dollars must be incurred to render the building as safe as it was before the shock.

The ruins of buildings destroyed by fire are unfortunately too conspicuous in the center of the city. Their danger has frequently been pointed out, and the earthquake has now accentuated the peril consequent on their being allowed to remain as heretofore. Masses of these ruins have fallen down, and gaping cracks prove the necessity that they should be torn down. Outside the city a number of houses have suffered. The tower of Malambo Church has fallen, and a piece several yards square of the roof of Santa Ana Church has tumbled in. The crash among glassware and bottles has been universal, Mr. Brakemeier alone being a loser to the extent of $2,000 from this cause. General Aizpuru's house, in the Calle Real, has suffered severely, as has also that of Don Manuel Hurtado, in front of the Government house. Others who have suffered damage are Señores Antonio Jimenez, Agustin Clement, José Manuel Casis, Barsallo, and the Grand Hotel, but the full extent of the damage done will not be known until the investigating committee has concluded its labors.

Several hours have now elapsed and there has been no repetition of the shocks. It may therefore be confidently anticipated that they will not be repeated.

The Pacific Mail steamship *Clyde* arrived from San Francisco on the night of the 6th. The earthquake was severely felt on board. Passengers declared that it appeared as if the vessel were lifted bodily from the sea and allowed to fall back.

Thanks to the kindness of Mr. J. B. Stearns, general manager of the Central and South American Cable Company, we are able to inform our readers that the offices at Buenaventura, in Cauca, and San Juan del Sur, in Nicaragua, announce that no shock has been felt in either of those ports. The cable is working excellently and gives no sign that a general volcanic disturbance has taken place.

The effects of the earthquake along the railroad have been most marked. The stone abutments of several of the bridges have been cracked and split, and the earthwork has sunk in a half a dozen places. Gangs of men were put at work on Thursday so that traffic might be resumed as usual at the earliest possible day. Mr. Woods and his subordinates have been active and energetic as usual, and cars were busily employed loading ballast to fill the sunken places, while lumber was being cut and prepared to support the short bridges which have been weakened, as already mentioned, through the cracking of the abutments.

All along the railroad track the earthquake was severely felt. At Emperador, Gatun, Matachin, and all the canal stations much alarm was created.

In several places where the direct action of the shock appears to have made itself most strongly felt the rails were curved as if they had been intentionally bent.

Mr. Woods, general superintendent of the railway, went across the same morning and returned as far as Bailamona in the afternoon. Neither train crossed in the afternoon. The Panama train stopped on this side of Bailamona bridge and the passengers and their baggage were transferred to hand and push cars, and thus conveyed 8 miles over the road to Bohio Soldado—the farthest point the train from Colon could reach.

The earthquake created great alarm in Colon. The freight house was damaged, and it was rumored that one or two were killed, but no certain information on this point has been obtainable. It is known, however, that two gentlemen broke their legs through jumping from the upper stories of houses.

The telegraph wire was down during the early part of the day, but communication was reestablished at about 4 p. m.

The sea was remarkably calm at Colon at the time of the severe shock, thus tending to prove that the earth motion has not extended, as at first supposed, to the West Indies.

The passengers and mails per Royal Mail steamer *Don* could not come across yesterday, so that the *Lima*, after being delayed a day, had to leave for the south without them.

[Daily Star and Herald, September 8.]

Mother Earth on the Isthmus has not as yet returned to her ordinary quiescent condition. The severe shock of the morning of the 7th has been followed by several of less intensity, but which do not appear to make their effects felt over such a wide area. On Thursday afternoon several vibrations were experienced in different localities which were not felt in Panama.

At 11.30 p. m., on the 7th, a sharp shock alarmed the whole city, and drove the people from their houses to the squares. Hundreds of ladies, accustomed to every convenience and comfort, preferred to pass the night on mattresses, couches, and chairs in the public plazas to running the risk of being crushed to death in the houses. The inconveniences of the situation they thus accepted were obvious to the less timid, who walked from one square to another to see these temporary and uncampaign-like encampments.

A slighter shock occurred at about 3 in the morning, but fortunately neither it nor its predecessor added further ruin to that already incurred in the city.

All the shocks have been felt on the islands in the bay and some houses have suffered at Taboga.

La Chorrera has been very unfortunate. The church and the cemetery are a mass of ruins and a number of houses have fallen. A bakery took fire and it and the adjoining house were totally destroyed by fire.

Between Gavilan and Punta Mala, in the vicinity of this city, a crevasse has opened which is 10 meters in width.

Some of the ruinous walls are being taken down, but there are several yet standing which are a permanent menace to adjoining properties and the lives of their inhabitants.

[Colon correspondence Daily Star and Herald, September 9.]

On the morning of September 7, at about 3.15, the residents of Colon were aroused from their peaceful slumber by the earthquake shock which has caused so much alarm and so considerable damage to the whole Isthmus. The duration of the shock was fully sixty seconds and was so severe that the whole populace rushed from their domiciles into the streets as rapidly as their feet could carry them.

The greatest alarm prevailed. About half an hour afterwards another shock was felt, but much lighter than the first. The sensation produced by the first and more violent shock was that the whole town was about to sink into the bowels of the earth. No very considerable damage was done Several buildings were more or less damaged, including the French consulate, the house of Mr. F. R. Cowan, the Panama Railroad freight houses, and the wharves, the International Hotel, some smaller tenements in the rear of the town in the alley known as Cash street. One of the latter, built of brick and wood in the style known as brick noggin, was wrecked completely, and one unfortunate occupant, a native, was killed. Two others, one a Frenchman and the other a bookkeeper for Messrs. Isaacs & Asch had each a leg broken in their haste to escape. The former will have to submit to the painful operation of amputation.

A deep fissure was opened in the earth from the south end of the freight house for a distance of about 400 feet along the walk leading in the direction of the ice houses. Many buildings were moved slightly from their foundations, but on the whole remarkably little damage was done. On board the vessels in the harbor the shock was also felt very severely.

The losses sustained were principally in the breakage of bottles in the various stores and shops, and the smashing of crockery, mirrors, etc., in private residences. This is pronounced the most severe shaking up ever before experienced in the history of the country since the discovery and conquest, but on the whole the town has escaped without serious injury. On the 7th instant, about 1 p. m., another much slighter shock was felt, and during the night of the same day two more slight disturbances were reported. The people of the town have become quite alarmed and quite demoralized by these events, many rushing to the churches and calling upon God for protection and deliverance. If the result proves beneficial to the moral tone of the city, the tonic, although severe, may not be regretted.

It may be of meteorological interest to observe that the sea at the time remained here calm, the atmosphere quite clear, and the stars and waning moon remarkably brilliant. Soon after, say about 4 o'clock, a slight fog wafted from inland. No rain fell. All day an ominous calm prevailed, without rain, with fluctuating barometer and excessive heat, which led many to fear a return of the shocks during the night of the 7th, and few slept. But with the slight exceptions noted all remained quiet.

Another correspondent writes from Colon:

"At about 10 minutes past 3 this morning we experienced the most horrible earthquake that I ever felt in my life. The damage done I can not estimate. A German employed as bookkeeper by Messrs. Isaacs & Asch threw himself out of the window and broke his leg, and a colored man followed his example, with a similar result. Two men have been killed, one of them being buried under a falling roof. The whole of the made ground between the wharves and the lagoon is split in a number of places.

"A number of houses have suffered severely. Some have fallen down bodily. Number four mole and the freight house has been damaged. All here think the motion lasted at least one minute, and that it moved from the southeast toward the northwest."

[Daily Star and Herald, September 11.]

A slight earthquake shock occurred on the morning of the 9th, a little before 5 o'clock. Much alarm was naturally created, but fortunately no damage was done. The frequent repetition of these movements causes a painful and uneasy feeling among the populace. A number of families passed the night on board the vessels in the bay and many in the public squares, and on Saturday a great many occupied the light cane houses on the outskirts of the city and at the Savana.

The same shock was lightly felt in Colon and along the railroad track. No damage was done and work was continued on the houses injured by the shock of the 7th instant.

All day on Saturday no shock was felt and the night passed quietly. At midday on Saturday there was a marked change in the atmosphere, and, with a refreshing shower which fell, the murky, sultry air of the previous days entirely disappeared.

The rumor of a volcanic eruption at the town and fort of Chagres is pronounced entirely false. Thoroughly reliable persons were there at 1 p. m. on Saturday and reached Colon the same evening. They report the earthquake to have been felt there, and that the earth had cracked slightly in two or three places. Beyond this no damage was done.

The shocks have been lightly felt on board the vessels in the bay, but they have experienced absolutely none of the tidal-wave effects which so frequently accompany widespread and powerful convulsions.

Passenger and freight trains will run over the road to-day as usual, as it is believed all the breaks will have been thoroughly repaired last evening.

The earthquake destroyed the little church at Cruces and damaged a few houses.

The rumors of a volcanic eruption at Chagres are entirely without foundation. The earthquake was felt there, did some little damage, and opened a few cracks in the ground.

A cablegram received from Mr. Scrymser, the president of the Central American Cable Company, announces that in New York it was known the Colon cable was broken and that nothing had occurred in Cuba and the other islands.

[Daily Star and Herald, September 12.]

A commission of canal employees left Panama on Sunday afternoon and proceeded to Chagres to inspect the ground where the volcanic eruption is said to have taken place. A photographer accompanies them in order to obtain exact representations of any physical changes which may have occurred. The principal members of it are MM. Canel, Alvo, and Canell. It is believed they will be absent about a fortnight, as they have to examine a wide field.

The rumors of the volcanic eruptions near Chagres and Cruces are declared to be entirely false by people arrived from there. One or two persons declare, however, that at 20 miles from Chagres, in the direction of "the coast," a small mud volcano has been observed, but these statements are as untrustworthy and false as many which have been set current within the past few days.

The truth of the matter appears to be that the repeated shocks have settled the loose alluvial soil, and that subsidence has occurred in several places, leaving fissures in some, and in others ejecting the thin mud formed on the lower strata by the percolation of water. All the fissures observed so far present the same characteristics, and appear to be formed in the manner described and not by volcanic rents originating in the bowels of the earth.

The bridges on the railroad are now fully repaired, and freight and passenger trains crossed as usual yesterday.

More rain is falling at Colon and on the other side of the Isthmus than on the Panama side.

Three old and valueless ranches fell at Gatun when the severe shock of the 7th took place. A beam from one of them struck and instantly killed a poor woman, who was asleep.

A number of people have walked, ridden, and canoed through the center of the Isthmus in order to discover the supposed volcanic center. Their labor has been valueless, and all have returned convinced that no excessively severe motion has been experienced in any part. No loss of life has occurred, save the three cases we have reported.

[Daily Star and Herald, September 13.]

The earthquake of the 7th instant was felt at the Pearl Islands in the bay. At San Miguel one of the walls of the church fell in, and the inhabitants took the saints out and carried them in procession in the hope of preventing the repetition of the convulsion. They were panic-stricken. A correspondent writes that the earth continued moving for five minutes, but this must be incorrect.

At Donoso, Govea, and Rio Indio a number of shocks have been felt, and the people have been much frightened. At Miguel la Borda, 35 miles from Colon, in the direction of Bocas del Toro, the tide rose to an unusual height and flooded some of the houses, which are built on the beach almost on a level with the sea. The earth is said to have sunk in about a dozen places, and that cattle have been lost from this cause. The governor of the district writes officially that several boiling springs have suddenly appeared, some of which throw hot water to a considerable height. Although official, this report lacks confirmation.

Many people believe they felt shocks in Panama during the night of the 11th instant, but the majority declare no movement took place. Overexcitement in many cases conduces the belief that the earth is trembling, and the least sound, such as a heavy cart passing through the streets, is at once converted by the excitable into the commencement of a catastrophe.

A number of houses in Colon have suffered. A list is being drawn up. The heavy stone offices of the canal company have been badly cracked, and the employees are removing the desks, etc., to another building. The International Hotel, one of the largest buildings in Colon, has been somewhat damaged, but the trivial nature of the injury in such an extensive edifice seems to prove that good brickwork can resist movements which seriously injure houses which have been cheaply constructed. The moles in front of the freight house and the made ground at the back of it show signs of the movement, but the heavy stone walls of the building, although cracked in some places, are sound and good, while the iron trestlework which sustains the roof and holds the walls together is as tight and plumb as the day it was put together. Many frame houses have sagged over in different directions. The majority of these houses were never remarkable for symmetry; now they zigzag one way and the other and give the town a most peculiar appearance. It must be remembered there are a number of frame buildings in Colon which were run up as the earth was dumped into the sea to form the spit on which the town stands, and that consequently it is not surprising if the slightest shake should affect these frail wooden structures which have been exposed during nearly thirty years to the vicissitudes of the variable tropical climate.

The bronze statue of Christopher Columbus was shaken free from the stone pedestal on which it stands, and moved about 4 inches from its former location. It can be readjusted at slight cost.

At 6 a. m. yesterday the rain was pouring down in torrents in Colon.

The Harrison steamer *Mediator* has arrived at Colon, and reports that a slight shock of earthquake was felt in Cartagena on the morning of the 7th. No damage was done. Letters from there dated the 9th scarcely mention the occurrence, thus proving the little importance attached to it.

Letters have been received from the towns of La Villa, Chitre, Macaracas, and Nata, all in this State, announcing that several shocks have been felt, but that the material of which the houses are built—bamboos and adobes—resisted the movements and have suffered no damage. At La Villa the bells in the church rang several times. The people do not appear to have been so alarmed as they have been in other parts of the Isthmus.

[Daily Star and Herald, September 14.]

Messrs. Schuber Brothers' steamer *Cargador*, from ports in the northern departments of the State of Panama, arrived yesterday, reports that repeated earthquakes have been felt, but that no damage to life or property has followed.

The canal commissioners sent to examine reported volcanic effects in the center of the Isthmus have telegraphed that they are unable to find traces proving that the shocks have been sharper there than anywhere else in the State.

Two or three slight tremblings were experienced in this city during the night of the 12th, but they caused no alarm. Many people are returning to their houses.

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