is also the plane to which soundings for charts of the U. S. Coast Survey are reduced.

On July 4 and 5, 1891, this locality was visited by a severe storm which displaced a number of the track timbers and also a comparatively small quantity of riprap, as well as some 2 to 3-ton blocks of stone from the jetty. The timbers and blocks displaced were mostly at the sea end of the unfinished work, and the riprap displaced was mostly along the shore branch and at the junction of the jetty with Fort Point. The timbers—some of which had been piled up on the outer end of the jetty, they having been removed from piles that had been acted upon by the teredo—were recovered, with the exception of about half a dozen pieces, and none of the stone was lost. The jetty withstood the storm satisfactorily.

An account of this storm was rendered to the Department, July 23, 1891.

The tide-gauge houses on the outer bar and in Bolivar Gorge were destroyed by that storm. They have since been replaced by more substantial structures, for an account of which, as well as of tidal data, reference is made to the report, herewith, of First Lieut. William C. Langfitt, Corps of Engineers.

For an account, in detail, of the work done by the contractors, and also of the survey of the harbor in May and June, last, please see the appended report of Mr. E. M. Hartrick, assistant engineer.

For the statement of shipments from Galveston, contained in the table of commercial statistics for the year ending June 30, 1892, accompanying this report, I am indebted to Mr. Julius Runge, president of the Galveston Cotton Exchange. For the number, character, and tonnage of vessels entered and cleared for the same period, acknowledgement is due Mr. N. W. Cuney, collector of the port. The statistics for this work and others in charge of this office were compiled by Mr. Elliott Jones, chief clerk.

The comparative tables of statistics herewith, to which attention is invited, show that the shipments of cotton have increased from 1,114,133 bales or 258,638 tons in 1891, to 1,237,937 bales or 287,377 tons in 1892, and that the total tonnage of vessels entered and cleared has increased from 1,073,920 tons in 1891 to 1,134,326 tons in 1892, a net increase of 60,406 tons.

Total expended on the improvement under all projects to June 30, 1891, inclusive	$2,273,920.90
Expended on the present project to June 30, 1891	796,017.88
Expended on present project to June 30, 1892	1,234,940.51

The balance of funds available will be applied to continuing the extension of the south jetty.

The sum of $1,000,000 can be profitably expended during the fiscal year ending June 30, 1894, most, if not all of it, to be applied to construction of the projected north jetty.

Originally estimated cost of the work as revised in 1886	$8,478,000.00
Aggregate amount appropriated to July 1, 1892	3,378,000.00
Total amount expended	2,712,843.53

In addition to this there was expended the sum of $100,000 subscribed by the city of Galveston in 1883.

The work is located in the collection district of Galveston. The nearest light-houses are at Bolivar Point and Fort Point at the entrance to Galveston Bay.

The amount of revenue collected at the port of Galveston for the fiscal year ending June 30, 1892, was $161,052.48.

Galveston Co. Rolled Sketch

Received from J. S. Boyles
on 7-12-35

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File No. Sketch Files 65

Galveston County

Jetty Construction; Tide Gauge Info.

Filed 7- 12 19 35

GARRY MAURO, Com'r

By (Douglas Howard)

Galveston Co. Sk. File #65

Counter 23718

Abstract of appropriations made by Congress for improving harbor at Galveston, Tex.

By act approved—	
July 11, 1870	*$25,000
March 3, 1871	*20,000
June 10, 1872	*31,000
June 23, 1874	60,000
March 3, 1875	150,000
August 14, 1876	142,000
June 7, 1878	75,000
June 18, 1878	50,000
March 3, 1879	100,000
June 14, 1880	175,000
March 3, 1881	250,000
March 4, 1882	100,000
By act passed August 2, 1882	300,000
By act approved August 5, 1886	300,000
By act of August 11, 1888	500,000
By act approved September 19, 1890	500,000
By act approved March 3, 1891	600,000
Total	3,378,000

Money statement.

July 1, 1891, balance unexpended		$1,104,079.10
June 30, 1892, amount expended during fiscal year		438,922.63
July 1, 1892, balance unexpended		665,156.47
July 1, 1892, outstanding liabilities	$19,838.72	
July 1, 1892, amount covered by uncompleted contracts	†618,207.64	
		638,046.36
July 1, 1892, balance available		27,110.11
Amount appropriated by act approved August 5, 1892		450,000.00
Amount available for fiscal year ending June 30, 1893		477,110.11
Amount (estimated) required for completion of existing project		4,650,000.00
Amount that can be profitably expended in fiscal year ending June 30, 1894		1,000,000.00
Submitted in compliance with requirements of sections 2 of river and harbor acts of 1866 and 1867.		

REPORT OF FIRST LIEUTENANT WILLIAM C. LANGFITT, CORPS OF ENGINEERS.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., June 30, 1892.

MAJOR: I have the honor to submit the following short progress report on the tidal observations for the fiscal year ending June 30, 1892.

On July 4–5, 1891, just after the close of the last fiscal year, a severe storm occurred which destroyed the tide-gauge house in the Gorge and the one on the Bar, thus leaving only the Government Wharf gauge in operation. This fact has prevented me from making the developments of the tidal data indicated in my last report as desirable. I refer more particularly to those bearing on the tidal prism, slopes, velocities, and, generally, all those data which would naturally be sought for in a study of a tidal harbor.

There have been submitted to you during the year a number of tables regarding tidal slopes, but it is not thought desirable to insert these here in their present state, incomplete from want of sufficient extension.

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* These appropriations were mostly expended in small dredging operations prior to the adoption of the project of 1874.

† Balance of the appropriations of September 19, 1890, and March 3, 1891, available for disbursement under present contract.

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counter 23719

Some study has been given to the points raised in my last report from Table 6 on, and, so far as it has gone, it has been confirmatory of what has been there said.

Table 4, of my report of last year, has been revised to include the results from all the record obtained, before their stoppage, from the Bar, Gorge, Hannas Reef, Red Fish South, and Red Fish North gauges; also the figures for the Government Wharf gauge have been revised to include record obtained to December 31, 1891. There having been no additional record obtained from the other gauges, viz, Rollover, Morgan Point, and Round Point, the values for them given in Table 4 have not been changed but are reproduced as there given.

The quantities given in the table are the heights of the mean high and low water planes referred to the plane of reference and the mean fluctuations for the various classes of tide (see last report) and mean of all tides for the various gauges.

Mean planes of high and low water and mean fluctuation.

Name of gauge.	G. D. T.			I. D. T.			S. D. T.			M. T.		
	Mean high water.	Mean low water.	Mean fluctuation.	Mean high water.	Mean low water.	Mean fluctuation.	Mean high water.	Mean low. water.	Mean fluctuation.	Mean high water.	Mean low water.	Mean fluctuation.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Bar	+2.09	−0.67	2.76	+1.82	−0.28	2.10	+1.56	+0.34	1.22	+1.82	−0.20	2.04
Gorge	+1.98	−0.29	2.27	+1.81	−0.04	1.85	+1.57	+0.58	0.99	+1.76	+0.07	1.69
Government Wharf	+1.68	+0.07	1.61	+1.54	+0.34	1.20	+1.38	+0.72	0.66	+1.53	+0.41	1.12
Hannas Reef	+1.67	+0.18	1.49	+1.51	+0.29	1.22	+1.40	+0.73	0.67	+1.52	+0.42	1.10
Red Fish South	+1.55	+0.39	1.16	+1.45	+0.51	0.94	+1.34	+0.89	0.45	+1.45	+0.60	0.85
Rollover	+1.65	+0.11	1.54	+1.53	+0.28	1.25	+1.39	+0.54	0.85	+1.51	+0.34	1.17
Red Fish North	+1.46	+0.67	0.79	+1.36	+0.71	0.65	+1.25	+0.94	0.31	+1.37	+0.76	0.61
Morgan Point	+1.29	+0.47	0.82	+1.25	+0.59	0.66	+1.10	+0.69	0.41	+1.21	+0.61	0.60
Round Point	+1.37	+0.50	0.87	+1.36	+0.62	0.74	+1.23	+0.79	0.44	+1.31	+0.65	0.66

The preliminary statement of record available from each gauge is here given revised to include records used in the revision of this table as stated above.

Round Point.—From May, 1887, to March, 1890, of which about 15 months' record is lost.

Morgan Point.—From May, 1887, to March, 1890, of which about 8 months' record is lost.

Rollover.—From May, 1887, to December, 1890, of which about 14 months' record is lost.

Red Fish North.—From July, 1889, to June, 1891, of which about 6½ months' record is lost.

Red Fish South.—From July, 1889, to June, 1891, of which about 7 months' record is lost.

Hanna Reef.—From July, 1889, to June, 1891, of which about 4 months' record is lost.

Government Wharf.—From May, 1887, to December, 1891, of which about 5 months' record is lost.

Gorge.—From July, 1889, to June, 1891, of which about 5½ months' record is lost.

Bar.—From April, 1888, to June, 1891, of which about 22 months' record is lost.

On April 11, 1892, by your direction, I hired a schooner and crew of men for the purpose of reërecting the Gorge and Bar tide-gauge houses. Owing to the unprecedented continuance of strong northeasterly, easterly, and southeasterly winds, causing such heavy seas as to prevent work, this operation was not finally completed until June 9, 1892. Of the total number of days, on but nineteen were the schooner and crew employed at the site of the houses, the remainder of the time the sea being too rough, and even on many of these nineteen the water was so rough that work was slow and difficult.

As the destruction of the former structures seemed to indicate that much stronger ones were needed, as both of them vibrated considerably under strong winds and seas, in designing the new ones these points were kept in mind. Both houses are practically 8 feet square. The Gorge house is supported on eight 8 by 8 inch square, coppered, wooden piles drawn together two and two to clasp a square 8 by 8 inch timber forming the corner posts of the house. The Bar house is supported on four solid iron piles 6 inches in diameter from about 2 feet above low water to their lower ends and 4 inches in diameter above. They were driven about 12 feet apart at the corners of a square and then inclined by means of a pump until their heads formed the corners of a square about 7 feet on a side. The piles are provided with two tiers of horizontal and diagonal bracing.

In order that full utility may be made of the record obtained from these gauges the elevation of their zeros should be determined by precise levels.

Very respectfully, your obedient servant,

WM. C. LANGFITT,
First Lieutenant, Corps of Engineers.

Maj. CHAS. J. ALLEN,
Corps of Engineers.

REPORT OF MR. E. M. HARTRICK, ASSISTANT ENGINEER.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., June 30, 1892.

SIR: I have the honor to submit the following report of operations for improving Galveston Harbor, Texas, during the fiscal year ending June 30, 1892.

Condition of work at beginning of fiscal year.—At the beginning of the fiscal year the contractors, Messrs. O'Connor, Laing & Smoot, were employed in removing rails and stringers and securing everything of value in connection with the trestle and track that had been extended in advance to complete the contract of Messrs. A. M. Shannon & Co.

The piles of this trestle had been over a year exposed to the ravages of the *Teredo navalis*, and were so badly honeycombed that they were no longer of any use as a bearing pile, and it was a cause of great satisfaction that most of the stringers and rails had been secured before the storm of July 4 and 5, 1891.

Casualties.—The storm of July 4 and 5, 1891, developed in West Gulf, attaining at Galveston two maximum velocities, one 44 miles per hour from the NE. at 6:50 a. m. on July 5, and one 60 miles per hour from the SE. at 8:05 p. m. of the same day. There were two maximum tides on the 5th, one at 8:00 a. m., when it reached 4.65 feet above M. L. T., and one at 9:50 p. m., when it registered 3.95 feet by the automatic tide gauge at Government Wharf. The damage to the jetty was slight; the shore branch settling in places where the covering of riprap was thin and base narrow. This tendency to scour and settle has been counteracted by strengthening the jetty with an apron of small riprap placed at the toe of the side slopes, where the jetty is only a few feet high. A survey of the bar proper was made immediately after the storm and compared with last annual survey, but no marked change could be detected. A more detailed description of the storm and its effect can be found in my report with accompanying charts and tables of July 22, 1891.

The usual equinoctial disturbances occurred in September, 1891, and March, 1892, with a continuance through the months of April and May and the end of June, fresh gales, rough seas, and high tides more or less retarding progress, but with no damage to the work.

General progress.—The contractors during the month of July were engaged overhauling and repairing trestle and track, laying rails for switch to track scales and yard, and delivered the first stone of the contract on the last day of the month. On the 27th of August the first pile was driven for an advance at the front. The stone received before this date and to the end of August was used in repair of shore branch and other places, the actual work at the front commencing September, 1891.

On September 17, 1891, the delivery of stone was discontinued, as that presented was not up to the specifications. This same month the Government track scales, with special foundation, was completed and put in active use.

The delivery of acceptable sandstone riprap recommenced on the 26th of October, 1891, and the first granite block was received on the 30th of the same month, but it was not until the 11th of April, 1892, that the contractors brought on the work a derrick capable of handling block from 5 to 10 tons, and then not of sufficient capacity to overtake and keep up with the work as it advanced.

Inspection and examination of quarries.—The first stone delivered was from Ledbetter (No. 1), on the Houston and Texas Central Railway. This quarry not furnishing the quantity, a second was opened a few miles from the first (No. 2), but had to be abandoned, as it did not come up to weight. The contractors then moved their plant to Quarry Station on the Gulf, Colorado and Santa Fé Railway, but early in November they began claiming inability to procure the sandstone riprap of the desired weight and in sufficient quantities for the work. Their statement being submitted in writing, a careful examination was undertaken, and the report made on the 23d of December, 1891, by First Lieut. W. C. Langfitt, Corps of Engineers, U. S. Army, and myself.

General inspection.—On the arrival of the stone in the contractors' yard at Fort Point it is inspected as to its hardness, toughness, weight, and durability. The hardness and toughness is determined by the hammer, the weight by specific gravity, viz, immersing a large sample of stone of known weight dry in a tank filled with water, then catching and weighing the displaced water and reweighing the sample wet, the amount of water imbibed by the sample is also noted; using the specific

B.—*Abstract of proposals for improving entrance to Galveston Harbor, etc.*—Continued.

Articles.	Tons.	1. Samuel Hawks, New York.		2. John P. Nelson, San Antonio.		3. B. Lantry & Sons, Strong City, Kans.	
		Price.	Amount.	Price.	Amount.	Price.	Amount.
In the north jetty—Continued.							
Granite riprap	518,000	$4.27	$2,211,860	$3.75	$1,942,500	$3.81	$1,973,580
Granite blocks, ¾ to 1 ton each	2,200	4.27	9,394	4.61	10,142	4.27	9,394
Granite blocks, 1 to 2 tons each	35,000	4.27	149,450	4.61	161,350	4.27	149,450
Granite blocks, 2 to 5 tons each	49,000	4.27	209,230	4.61	225,890	4.27	209,230
Granite blocks, 5 to 10 tons each	82,000	4.27	350,140	4.61	378,020	4.74	388,680
Concrete blocks, 5 to 10 tons each	82,000	4.27	350,140	7.50	615,000	4.74	388,680
Granite blocks, 10 tons and over each	75,000	4.27	320,250	4.70	352,500	4.74	355,500
Concrete blocks, 10 tons and over each	75,000	4.27	320,250	7.55	566,250	4.74	355,500
	Lin. feet.						
Railway and trestle	34,500	4.00	138,000	3.95	136,275	4.10	141,450
Total for sandstone and railway	....	....	3,042,180	....	3,400,935	....	2,849,064
Total for granite and railway	....	....	4,919,274	....	4,694,307	....	4,557,814
Total for sandstone riprap granite blocks, and railway	....		3,539,214	....	3,578,707	....	3,604,094
Total for sandstone riprap and blocks under 2 tons, granite blocks 2 tons and over, and railway	....	....	3,465,910	....	3,497,685	....	3,533,854

Articles.	Tons.	4. Henry Bennett, Topeka, Kans.		5. John F. Gaynor, Fayetteville, N. Y.	
		Price.	Amount.	Price.	Amount.
In the south jetty:					
Sandstone riprap	220,000	$2.30	$506,000	$2.75	$605,000
Sandstone blocks, ¾ to 1 ton each	1,000	2.30	2,300	3.20	3,200
Sandstone blocks, 1 to 2 tons each	1,000	2.30	2,300	3.30	3,300
Sandstone blocks, 2 to 5 tons each	1,000	2.49	2,490	3.50	3,500
Sandstone blocks, 5 to 10 tons each	105,000	2.68	281,400	4.50	472,500
Concrete blocks, 5 to 10 tons each	105,000	4.40	462,000	5.00	525,000
Sandstone blocks, 10 tons and over each	7,000	3.24	22,680	5.00	35,000
Concrete blocks, 10 tons and over each	7,000	4.75	33,250	5.00	35,000
Granite riprap	220,000	3.76	827,200	4.70	1,034,000
Granite blocks, ¾ to 1 ton each	1,000	3.84	3,840	4.70	4,700
Granite blocks, 1 to 2 tons each	1,000	3.84	3,840	4.70	4,700
Granite blocks, 2 to 5 tons each	1,000	4.06	4,060	4.70	4,700
Granite blocks, 5 to 10 tons each	105,000	4.23	444,150	4.70	493,500
Concrete blocks, 5 to 10 tons each	105,000	4.40	462,000	5.50	577,500
Granite blocks, 10 tons and over each	7,000	4.78	33,460	4.70	32,900
Concrete blocks, 10 tons and over each	7,000	4.75	33,250	6.00	42,000
In the north jetty:					
Sandstone riprap	518,000	2.63	1,362,340	2.45	1,269,100
Sandstone blocks, ¾ to 1 ton each	2,200	2.63	5,786	3.00	6,600
Sandstone blocks, 1 to 2 tons each	35,000	2.63	92,050	3.00	105,000
Sandstone blocks, 2 to 5 tons each	49,000	2.82	138,180	3.00	147,000
Sandstone blocks, 5 to 10 tons each	82,000	3.00	246,000	4.50	369,000
Concrete blocks, 5 to 10 tons each	82,000	4.73	387,860	5.00	410,000
Sandstone blocks, 10 tons and over each	75,000	3.57	267,750	5.00	375,000
Concrete blocks, 10 tons and over each	75,000	5.00	375,000	6.00	450,000
Granite riprap	518,000	4.09	2,118,620	4.40	2,279,200
Granite blocks, ¾ to 1 ton each	2,200	4.09	8,998	4.40	9,680
Granite blocks, 1 to 2 tons each	35,000	4.09	143,150	4.40	154,000
Granite blocks, 2 to 5 tons each	49,000	4.29	210,210	4.40	215,600
Granite blocks, 5 to 10 tons each	82,000	4.49	368,180	4.40	360,800
Concrete blocks, 5 to 10 tons each	82,000	4.73	387,860	5.00	410,000
Granite blocks, 10 tons and over each	75,000	5.00	375,000	4.40	330,000
Concrete blocks, 10 tons and over each	75,000	5.00	375,000	6.00	450,000
	Lin. feet.				
Railway and trestle	34,500	3.99	137,655	4.00	138,000
Total for sandstone and railway	....	....	3,066,931	....	3,532,200
Total for granite and railway	....	....	4,678,364	....	5,061,780
Total for sandstone riprap, granite blocks, and railway	....	....	3,600,883	....	3,622,680
Total for sandstone riprap and blocks under 2 tons and granite blocks 2 tons and over, and railway	....	....	3,543,491	....	3,567,700

Galveston C Relief Sketches

Received from J. S. Bayles
on 7-12-35

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B.—*Abstract of proposals for improving entrance to Galveston Harbor, etc.*—Continued.

Articles.	Tons.	6. Ricker, Lee & Co., Galveston, Tex.		7. O'Connor, Laing & Smoot, Dallas, Tex.	
		Price.	Amount.	Price.	Amount.
In the south jetty:					
Sandstone riprap	220,000	$2.70	$594,000	$2.45	539,000
Sandstone blocks, ½ to 1 ton each	1,000	2.70	2,700	2.50	2,500
Sandstone blocks, 1 to 2 tons each	1,000	2.70	2,700	2.55	2,550
Sandstone blocks, 2 to 5 tons each	1,000	2.70	2,700	2.65	2,650
Sandstone blocks, 5 to 10 tons each	105,000	3.00	315,000	2.75	288,750
Concrete blocks, 5 to 10 tons each	105,000	5.00	525,000	5.00	525,000
Sandstone blocks, 10 tons and over each	7,000	3.00	21,000	2.80	19,600
Concrete blocks, 10 tons and over each	7,000	5.00	35,000	5.25	36,750
Granite riprap	220,000	4.00	880,000	4.00	880,000
Granite blocks, ½ to 1 ton each	1,000	4.20	4,200	4.05	4,050
Granite blocks, 1 to 2 tons each	1,000	4.20	4,200	4.10	4,100
Granite blocks, 2 to 5 tons each	1,000	4.20	4,200	4.15	4,150
Granite blocks, 5 to 10 tons each	105,000	4.75	498,500	4.25	446,250
Concrete blocks, 5 to 10 tons each	105,000	5.25	551,250	6.00	630,000
Granite blocks, 10 tons and over each	7,000	4.70	32,900	4.40	30,800
Concrete blocks, 10 tons and over each	7,000	5.25	36,750	6.25	43,750
In the north jetty:					
Sandstone riprap	518,000	2.50	1,295,000	2.45	1,269,100
Sandstone blocks, ½ to 1 ton each	2,200	2.50	5,500	2.50	5,500
Sandstone blocks, 1 to 2 tons each	35,000	2.50	87,500	2.55	89,250
Sandstone blocks, 2 to 5 tons each	49,000	2.50	122,500	2.65	129,850
Sandstone blocks, 5 to 10 tons each	82,000	3.00	246,000	2.75	225,500
Concrete blocks, 5 to 10 tons each	82,000	5.00	410,000	5.00	410,000
Sandstone blocks, 10 tons and over each	75,000	3.00	225,000	2.80	210,000
Concrete blocks, 10 tons and over each	75,000	5.00	375,000	5.25	393,750
Granite riprap	518,000	3.90	2,020,200	4.00	2,072,000
Granite blocks, ½ to 1 ton each	2,200	3.90	8,580	4.05	8,910
Granite blocks, 1 to 2 tons each	35,000	3.90	136,500	4.10	143,500
Granite blocks, 2 to 5 tons each	49,000	3.90	191,100	4.15	203,350
Granite blocks, 5 to 10 tons each	82,000	4.08	334,560	4.25	348,500
Concrete blocks, 5 to 10 tons each	82,000	5.25	430,500	6.00	492,000
Granite blocks, 10 tons and over each	75,000	4.08	306,000	4.40	330,000
Concrete blocks, 10 tons and over each	75,000	5.25	393,750	6.25	468,750
	Lin. feet.				
Railway and trestle	34,500	4.00	138,000	4.00	138,000
Total for sandstone and railway			3,057,600		2,922,250
Total for granite and railway			4,553,940		4,613,610
Total for sandstone riprap, granite blocks, and railway			3,542,740		3,469,710
Total for sandstone riprap and blocks under 2 tons, granite blocks 2 tons and over, and railway			3,487,660		3,408,950

Bid No. 7, lowest. Acceptance recommended for sandstone riprap, granite blocks, and railway. Amount available $1,100,000 (less office and inspection expenses), appropriated as follows: River and harbor act of September 19, 1890, $500,000; sundry civil act of March 3, 1891, $600,000.

REPORT OF FIRST LIEUTENANT WM. C. LANGFITT, CORPS OF ENGINEERS.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., June 30, 1891.

MAJOR: I have the honor to submit the following progress report on the tidal observations of Galveston Bay for the fiscal year ending June 30, 1891:

The Rollover gauge was discontinued during the latter part of January, 1891. The gauges at Hanna Reef, Red Fish South, and Red Fish North were discontinued the latter part of this month, thus leaving going at the present time the gauges at Government Wharf, the Gorge, and Bar. It is thought that sufficient record has been obtained from the other gauges, and that these three gauges, costing nothing for keepers, will furnish record of more than sufficient value to pay for the slight expense of maintenance.

The precise level party mentioned in my last report succeeded in connecting the zeros of the Gorge and Hanna Reef gauges with the adopted bench mark on the Hendley Building, thus practically conneting these two with the Government Wharf gauge.

Before presenting such data as I have been able to compile from the platted records, it will be well to state in some detail the extent of record available from each gauge, as this varies very much from gauge to gauge. This amount for each gauge is as follows:

Round Point.—From May, 1887, to March, 1890, of which about 15 months' record is lost.

Morgan Point.—From May, 1887, to March, 1890, of which about 8 months' record is lost.

Rollover.—From May, 1887, to December, 1890, of which about 14 months' record is lost.

Red Fish North.—From July, 1889, to December, 1890, of which about 5 months' record is lost.

Red Fish South.—From July, 1889, to December, 1890, of which about 6 months' record is lost.

Hanna Reef.—From July, 1889, to December, 1890, of which about 3 months' record is lost.

Government Wharf.—From May, 1887, to December, 1890, of which about 4 months' record is lost.

Gorge.—From April, 1890, to December, 1890, of which about 1½ months' record is lost.

Bar.—From April, 1888, to December, 1890, of which about 19 months' record is lost.

The losses of records thus shown are due to stoppages of the gauges or to doubts as to the accuracy of the records either as to time or to fluctuation.

The tides have as usual been divided into three classes, called respectively the great declination tides (G. D. T.), the small declination tides (S. D. T.), and the intermediate tides occurring between these two (I. D. T.). The first class occur when the moon's declination is large and show as one large tide in the 24 hours. The second class occur near the time of the moon's nodes and show as two small tides every 24 hours. The intermediate tides are those occurring in the passage from one of these classes to the other. The result obtained by combining all the tides are also usually given (M. T.).

It is now proposed to discuss in some detail, with the aid of the precise level determinations, the values of the relative elevations, which have heretofore been assumed, of the zeros of the various gauges.

In 1872–'3 Mr. H. C. Ripley, then United States Assistant Engineer, determined by observations that the water table of the northeast corner of the Hendley building, of this city, was 6.879 feet above the plane mean low tide, and this has been the adopted plane of reference since that date, being easily established by means of the above bench mark for any gauge near the city. But when gauges were established at various points of the bay it became necessary, in order to have a uniform plane of reference, to find the elevations of their zeros referred to the adopted plane. As level lines were generally out of the question, this has usually been done by using Mitchell's rule, which is based on the assumption that the average plane of high water at any given gauge will be as much higher or lower than the plane of high water at a second gauge as its average plane of low water is lower or higher than the average plane of low water at the second gauge. In other words, it assumes that the maxima and minima at all gauges are symmetrically placed with reference to the same plane. Hence, having established this plane at any one gauge, and having given the readings of the corresponding tidal maxima and minima at the various gauges (including the known one), the determination of the elevation of the zeros becomes a simple matter. But if this assumption is not true the results from the rule will be erroneous. It becomes then a matter of importance to determine how far this rule can be trusted. The results of the precise levels give an opportunity to make this determination, partially at least. For this purpose a series of comparisons was made between the 3 gauges (Government Wharf, Gorge, and Hanna Reef) whose zeros have been connected by the level party, and the resulting corrections compared with the true corrections found by the levels. The errors thus found are compiled in the following table. But it is evident that the readings of the high and low water planes at each gauge give sufficient data for applying Mitchell's rule, if, in their determination, no tides were omitted at any of the gauges. But supposing that the omissions at the various gauges would counterbalance one another, I have applied the rule to these readings and determined the resulting errors. They are given in the table with the others specially made, the column of remarks showing whether the value was deduced from corresponding tides only, or from determination of the high and low water planes without selecting corresponding tides.

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TABLE 1.—*Errors of Mitchell's rule for determining the relative elevation of zeros of tide gauges.*

Gauges compared.	Tide. G. D. T. Number of observations.	G. D. T. Error.	I. D. T. Number of observations.	I. D. T. Error.	S. D. T. Number of observations.	S. D. T. Error.	M. T. Number of observations.	M. T. Error.	Remarks.
		Feet.		*Feet.*		*Feet.*		*Feet.*	
Gorge and Government Wharf	40	−0.18	39	−0.11	52	−0.13	131	−0.14	Corresponding tides.
	62	−0.16	60	−0.12	57	−0.10	179	−0.13	Do.
Gorge and Hanna Reef	40	−0.19	39	−0.12	52	−0.01	131	−0.09	Do.
	55	−0.16	60	−0.08	59	....	174	−0.08	Do.
	.....	−0.10	......	−0.16	......	−0.09	......	−0.11	H. & L. water planes.
Hanna Reef and Government Wharf	40	+0.01	39	+0.01	52	−0.13	131	−0.05	Corresponding tides.
	.....	+0.02	......	−0.04	......	−0.05	......	−0.03	H. & L. water planes.
	.....	−0.05	......	−0.07	......	−0.11	......	−0.08	Do.

An inspection of this table does not show that any one kind of tide possesses any marked superiority over the others, and that the corrections deduced from the mean of all the tides are as likely to be correct as any, for where the true correction is unknown we can not tell which tide will give the best result. It is, of course, to be expected that gauges near to each other, and those situated in relatively similar positions, will give better results than others. This influence of relative position on the result is shown by the following values obtained for the elevation of the zero of the bar gauge when compared with the three gauges named:

	Feet.
From Gorge gauge, mean of 179 observations, all tides	−0.62
From Government Wharf, mean of 179 observations, all tides	−0.49
From Hanna Reef, mean of 174 observations, all tides	−0.54

The tides used for the first two values are the same as those used in comparing the Gorge and Government Wharf, line 2, in the above table, and for the last they are the same as those used in comparing Gorge and Hanna Reef, line 4, in the above table. The first value is considered the most accurate. The accuracy of the resulting corrections also increases with the number of observations. This is illustrated by the fact that the first approximate value of the constant for the Gorge gauge was in error by 0.27 foot, and that for Hanna Reef by 0.21 foot, both being based on a comparatively small number of observations.

Applying Mitchell's rule then to those gauges whose zeros have not been connected by precise levels, and using the determined planes of mean high and low water, a new and more accurate value of the elevation of their zeros referred to the adopted plane of reference has been found. These elevations and those found by the aid of levels are given in the following table:

TABLE 2.—*Elevation of the zeros of the tide gauges in Galveston Bay referred to the adopted plane of reference.*

Gauge.	Old value of zero elevation.	New value of zero elevation.	Remarks.
	Feet.	*Feet.*	
Bar	−0.40	−0.62	By comparison with Gorge gauge.
Gorge	−2.90	−3.17	By precise levels.
Government Wharf .	−3.20	−3.20	Standard.
Hanna Reef	+0.60	+0.81	By precise levels.
Red Fish South	−3.00	−2.77	By comparison with Hanna Reef and Government Wharf.
Red Fish North	−3.00	−2.76	By comparison with Red Fish South.
Morgan Point	−2.56	−2.55	By comparison with Red Fish North.
Round Point	−4.56	−4.40	Do.
Rollover	−3.24	−3.14	By comparison with Hanna Reef.

These values of course remain good only so long as the staff gauges remain at the same elevations. It therefore becomes a matter of some importance to be able to reproduce these elevations at any time. This has been rendered possible by putting a permanent mark on or near each tide gauge house and determining its elevation referred to the adopted plane of reference, using the corrected elevations of the zeros of the gauges.

These bench-marks are as follows:

In March, 1887, at Morgan Point, a 1-inch iron rod 3 feet long was driven into the ground at the WNW. corner of the main part of John Nelson's house, the elevation of the top of which was found by Mr. H. C. Ripley, assistant engineer, to be 14.035 feet above the plane of reference; the changed value of the gauge correction makes this 14.045 feet above that plane. The house has since been moved but the rod is still there and can easily be found. On November 10, 1890, a new bench-mark was established on the opposite side of the canal by Mr. G. Bagnall, assistant engineer, on the top of the iron rod under triangulation station Morgan Point, whose elevation as determined from the first bench-mark is 14.857 feet.

At Round Point and Rollover there are permanent staff gauges attached to the piles of the gauge houses, the elevation of whose zeros are given in the above table.

At Red Fish North a copper nail was driven into the southwest pile of the gauge house and a horizontal scratch made across the head. The elevation of this score mark is 6.56 feet above the plane of reference. An exactly similar bench-mark was put on the southwest pile of the Red Fish South tide-gauge house, whose elevation is 6.62 feet above the plane of reference. Small pieces of sheet lead were tacked over them to protect them.

At Hannas Reef a galvanized-iron spike was driven into the pile of the house nearest the steps, the elevation of the score mark on the head being 3.946 feet above the plane of reference. A piece of sheet lead was tacked over the spike.

At Gorge gauge a copper nail was driven into the northwest pile, of which the elevation of the score mark on the head is 7.839 feet above the plane of reference. It is covered as the others.

At the Bar gauge a permanent bench-mark has been placed on one of the piles nearest the ladder, the elevation of which is 8.04 feet above the plane of reference. A coating of black paint was put on around the mark to protect it.

The Government Wharf gauge can always easily be connected with the bench-marks on the Hendley Building, of which there are two, the water table at the northeast corner, elevation 6.879 feet above the plane of reference, and a copper bolt let into the corner column, elevation 10.796 feet above the plane of reference.

The precise level party also established several permanent bench-marks both on Galveston Island and on Boliver Peninsula, the elevations and descriptions of which are given in the report of Mr. G. Bagnall, assistant engineer in charge of that work.

The fundamental assumption of Mitchell's rule is, as stated above, that the same horizontal plane will lie midway between the mean high and mean low water marks at all the gauges. But this assumption has been shown to be in error by the amounts given in Table 1. Now if at the three gauges which have been connected by precise levels the elevation of a point midway between mean high and mean low water be found for the different kinds of tide and their differences taken, these should equal the errors found and thus give an excellent check on the work. In the following table such a comparison is given. The agreement is all that could be expected when the variable nature of the tides and varying effects of the wind at the different gauges are considered.

TABLE 3.—*Comparison between differences of mid-level and errors of water comparison.*

Gauges compared.	G. D. T.		I. D. T.		S. D. T.		M. T.	
	Difference of mid-level.	Error of water comparison.	Difference of mid-level.	Error of water comparison.	Difference of mid-level.	Error of water comparison.	Difference of mid-level.	Error of water comparison.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Gorge and Government Wharf	−0.18	−0.18 −0.16	−0.18	−0.11 −0.12	−0.13	−0.13 −0.10	−0.14	−0.14 −0.13
Gorge and Hannas Reef	−0.17	−0.19 −0.16	−0.17	−0.12 −0.08	−0.02	−0.01 0.00	−0.08	−0.09 −0.08
Hannas Reef and Goverrment Wharf	−0.01	+0.01	−0.01	+0.01	−0.11	−0.13	−0.06	−0.05

The following table gives the same facts as given in Tables 1 and 5 of my report of last year, revised to include the results of 1890 and those from the new gauges. The quantities are the heights of mean high and mean low water planes referred to the plane of reference and the mean fluctuation for the various classes of tide and the mean of all the tides at the various gauges.

TABLE 4.—*Mean planes of high and low water and mean fluctuation.*

Name of gauge.	G. D. T.			I. D. T.			S. D. T.			M. T.		
	Mean high water.	Mean low water.	Mean fluctuation.	Mean high water.	Mean low water.	Mean fluctuation.	Mean high water.	Mean low water.	Mean fluctuation.	Mean high water.	Mean low water.	Mean fluctuation.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Bar	+2.08	−0.65	2.73	+1.84	−0.22	2.06	+1.57	+0.35	1.22	+1.83	−0.17	2.00
Gorge	+2.03	−0.21	2.24	+1.75	+0.02	1.73	+1.63	+0.64	0.99	+1.80	+0.16	1.64
Government Wharf	+1.63	+0.06	1.57	+1.53	+0.37	1.16	+1.36	+0.70	0.66	+1.49	+0.37	1.12
Hannas Reef	+1.71	+0.27	1.44	+1.49	+0.38	1.11	+1.46	+0.80	0.66	+1.56	+0.50	1.06
Rollover	+1.65	+0.11	1.54	+1.53	+0.28	1.25	+1.39	+0.54	0.85	+1.51	+0.34	1.17
Red Fish South	+1.60	+0.47	1.13	+1.51	+0.60	0.91	+1.43	+0.99	0.44	+1.51	+0.70	0.81
Red Fish North	+1.49	+0.69	0.80	+1.38	+0.72	0.66	+1.25	+0.95	0.30	+1.38	+0.78	0.60
Morgan Point	+1.29	+0.47	0.82	+1.25	+0.59	0.66	+1.10	+0.69	0.41	+1.21	+0.61	0.60
Round Point	+1.37	+0.50	0.87	+1.36	+0.62	0.74	+1.23	+0.79	0.44	+1.31	+0.65	0.66

Below is given Table 3 of my report of last year, giving the delay in high and low water, revised to include the results from the newer gauges and a new determination of the interval between the Bar and Government Wharf. The Bar time of high or low water is taken as the origin, and the intervals show how much later the corresponding phase of any tide is at the gauge considered.

TABLE 5.—*Delay in high and low water from the Bar gauge.*

Name of gauge.	Distance from Bar.	Delay in high water.				Delay in low water.			
		G. D. T.	I. D. T.	S. D. T.	M. T.	G. D. T.	I. D. T.	S. D. T.	M. T.
	Miles.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
Gorge	4	0.63	0.60	0.56	0.60	0.56	0.51	0.49	0.53
Government Wharf	6¼	1.25	1.19	1.01	1.16	1.17	1.15	0.84	0.95
Hannas Reef	14½	3.24	2.77	2.44	2.80	2.89	2.66	2.29	2.51
Rollover	30	4.60	4.39	4.21	4.41	5.55	5.23	4.62	5.01
Red Fish South	16½	4.82	4.07	3.23	4.00	3.63	3.40	3.13	3.29
Red Fish North	17	7.53	6.54	4.90	6.31	5.29	4.99	4.47	4.81
Morgan Point	30¾	8.27	7.10	5.17	6.64	6.26	5.92	5.28	5.69
Round Point	35½	8.10	6.87	5.71	6.75	6.56	6.17	5.64	5.99

The figures of the last two tables call for some explanation. Taking up Table 4 first, it will be noticed that the plane of mean low tide for each different class of tides rises as we pass from the Bar to the more distant gauges, and that the fluctuation decreases at the same time. This is a natural consequence of theory arising from considerations of the depth of the bay, its form, the friction, and the fresh-water flow in it.

At all the gauges it will be noticed that the plane of mean low tide rises in elevation from that for the G. D. T. to that for the S. D. T., and that the fluctuations decrease passing the same way. While the facts necessary to explain this were given last year, it is thought better to enter into the explanation a little more in detail, even at the risk of some repetition.

At the generality of ports where the tides have been made the subject of study it is found that there is a decrease of fluctuation and a rise in height of low water when referred to a fixed plane in passing from the springs or tides occurring at or near the syzygies to the neap tides or those occurring at or near the quadratures. But the variations given in the above table are not connected at all, or, at least, but very slightly, with the relative position of the sun and moon. That this has but slight effect is shown from the following values for the bar gauge of the fluctuation at springs and neaps and the elevations of the plane of mean low tide at the same periods, what is called the diurnal inequality having been eliminated in the determination.

	Feet.
Mean fluctuation spring tide	1.37
Mean fluctuation neap tide	0.91
Elevation plane mean low tide above plane of reference, springs	0.50
Elevation plane mean low tide above plane of reference, neaps	0.62

It is to be understood that these values are but rough approximations, but they are sufficiently exact for the purpose in view, to show the comparatively small effect of the phases of the moon on the tidal phenomena at this port. Moreover, as both spring and neap tides enter into each class of tide, the tabular values will correspond to a mean tide so far as the effects depending on the phases of the moon are concerned. But the diurnal inequality stated as eliminated in the determination of the spring and neap tide fluctuations is the determining quantity in the tabular classification. This inequality has been long known, and remarked in tidal studies. The following quotation from the article on tides in the Encyclopedia Brittanica gives an idea of its nature:

"So far we have supposed the luminaries to move in the equator. Now let us consider the case where the moon is not on the equator. It is clear in this case that at any place the moon's zenith distance at the upper transit is different from her nadir distance at the lower transit. But the tide-generating force is greater the smaller the zenith or nadir distance, and, therefore, the forces are different at successive transits. Thus there is a tendency for two successive lunar tides to be of unequal heights, and the resulting inequality is called a 'diurnal tide.' * * * One of the most remarkable conclusions of Laplace's theory of the tides, on a globe covered with ocean to a uniform depth, is that the diurnal tide is everywhere nonexistent. But this hypothesis differs much from the reality, and, in fact, at some ports the diurnal tide is so large that during two portions of the lunation there is only one great high water and one great low water in each 24 hours, whilst in other parts of the lunation the usual semidiurnal tide is observed."

This latter state exists at this port, and such a condition of affairs necessarily complicates and renders extremely laborious any analysis of the tides looking to tidal prediction or astronomical calculation. After considerable study of the methods employed in such cases it is believed that for the purposes for which these tidal observations were made no useful result would be obtained by such a discussion. I have therefore limited my analysis to that amount which will explain sufficiently for my purposes the facts exhibited in the tables.

As a consequence of the quotation given above, the diurnal tide is evanescent twice in a lunar declination month, or at or near the time of the moon's nodes. For a full understanding of the effect of this diurnal tide it becomes necessary to decompose the observed tide into its diurnal tide or component and the usual semidiurnal tide or component. By referring to Pl. 2, Fig. 1, where this decomposition is shown graphically, it will be seen that near the nodes the diurnal component is zero, and that as the moon's declination increases, passes to a maximum and decreases again to zero, the diurnal component goes through corresponding changes. Its period is seen to be about a day. Moreover this component soon passes in magnitude the semidiurnal component with which it combines to produce the observed tide. As a consequence the observed tide passes from the usual semidiurnal type with two nearly equal maxima and minima a day to a single great tide with one great high and one great low water in a day, the reverse taking place as the moon again approaches her node. It has therefore been convenient to divide the tides into three classes depending on the moon's declination, and which have been called, as above, the great declination tides, the small declination tides, and the intermediate declination tides.

Assuming that each component follows the law of the sines, either one at any particular time can be represented by an equation of the following form:

$$y = A \cos 2\pi \frac{t}{T}$$

in which y = ordinate of curve referred to an axis midway between high and low water, t = time in hours from place of maximum ordinate. T = duration of one tide. A = coefficient. Taking two equations of the above form and combining them we get for the equation of the comple curve,

$$y = A \cos (2\pi \frac{t}{T} - E) + A' \cos 2\pi \frac{t}{T'}$$

in which y = ordinate of obsecured curve, T and A = same quantities as above for diurnal curve, t, T', and A' = same quantities as above for semidiurnal component, E = distance between the place of the maximum ordinate of the diurnal component and that of the maximum ordinate of the preceeding semidiurnal component.

While the coefficients A and A' are variable, the one depending mainly on the declination and the other mainly on the phase of the moon, yet for any short time during which they may be regarded as constant it is evident that where A has a relatively large value the character of the resulting curve depènds largely on the value of E. Two approximate values for A and A' were found for a particular day, and the calculated and reserved curves given in my report last year, where it was stated

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that the value of E was about 5 hours. These curves are reproduced on Pl. 2, Fig. 10, and one other, Fig. 11, added, showing the effects of a change in the value of E to zero hours on the resultant tide, the effect of a change in the relative values of A and A′ being shown by Fig. 1. Now, since the height of the observed tide at any time is equal to the algebraic sum of the heights of its components at that time, a glance at the graphical analysis of the observed curve shows that the two components have such a relation to each other (E being so large) that the high water of the diurnal component occurs at a little before low water of the semidiurnal component resulting in its practical obliteration; while low water of the diurnal component occurs a little before, but near the next low water of the semidiurnal component, resulting in a great lowering of the low-water plane. These remarks apply to the period near the moon's maximum declination, either north or south, or, more properly speaking, to when the coefficient A of the diurnal component bears a sensible ratio to A′. Hence it is seen that as A increases relatively to A′, one of the low waters of the semidiurnal tides occurring in a day is obliterated and the other is lowered greatly. From this, then, we have the values of the elevation of the plane of mean high and mean low tide given in Table 4. It is of course understood the S. D. T. give two values each day, the others but one.

Taking up Table 5, the first point which strikes the attention is that the delay in high water for the large tides is much greater than that for the small ones. This may be accounted for in the following manner: It is a well known consequence of theory that of two tidal waves propagated under similar circumstances from the sea into a reservoir that the smaller wave will be reduced in a greater proportion than the larger one. Now, referring to Plate 2, Fig. 1, we see that for the G. D. T. the diurnal component of the observed tide largely exceeds in magnitude the semidiurnal component. But these two bear such a relation that with the value of E existing (about 5 hours) high water of the observed tide precedes high water of the diurnal component by about 4 hours, and follows by about an hour the high water of the first semidiurnal tide. Now, should the latter component be reduced in magnitude in a greater proportion than the former the effect would be to move the time of high water nearer the time of high water of the diurnal component and away from the time of high water of the semidiurnal component. This is exactly what takes place, and there is, therefore, in addition to the delay that would naturally follow the propagation of the tide into a shallow bay, an additional delay caused by the change in the relative magnitudes of the two components. A comparison of Figs. 4, 5, 6, 7, and 8, Pl. 2, giving the two components and the observed tide at the five gauges named above the figures, for the same day, illustrates this clearly.

Again, the Rollover gauge excepted, the delay in high water for the large tides is greater than the delay in low water for the same tides. This is also explained by the relative positions of the two components, for the low water of the diurnal component occurring so near in time to the second low water of the semidiurnal component, any change in their relative magnitudes will have but little effect on the time of low water.

The exception of the Rollover gauge is difficult of explanation, but the following seems to be a probably correct one:

From theory and observation it is found that a tidal wave passing up a shallow estuary gradually changes its form so that its front becomes steeper and its back flatter. As a consequence, the tidal rise occupies a shorter time and the fall a longer time than they occupied at the mouth of the estuary. Now, since the duration of the tide from low water to low water must average the same at the two places in a long series, it results that the delay in high water under such circumstances must be less than the delay in low water. For let us take two triangles of equal bases to represent the duration of the tide from low water to low water and of equal altitudes for convenience, but suppose that a perpendicular let fall from the apex of the one divides the base into two equal parts while in the second it cuts the base at a point to the left of its middle point, Fig. 2, Pl. 2. For this purpose we can suppose the first to represent the tidal rise and fall at the mouth of the estuary and the second that at some distance up. Now place these two triangles on a horizontal time scale graduated from left to right. Since high water at the place up the estuary can not be earlier and generally must be later than high water at the mouth, the second triangle to represent properly the phenomena observed must be placed with its apex to the right of the vertical from the time scale to the apex of the first triangle; hence it is readily seen that the delay in high water must be less than the delay in low water. But if this is true the same state of affairs, other things being equal, should exist at all the other gauges, and in fact this cause does operate to produce such an effect, but at them it is overcome by the causes already given for the opposite state of affairs at those gauges.

The following rule given by Sir G. B. Airy is in point: "If D1, D2, D3, D4 are in arithmetical proportion, then the phase of low water travels with a velocity due to the depth D1, and the phase of high water with the velocity due to the depth D4." It

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is, of course, understood that the greater depth gives a greater velocity of travel. And I conceive that this effect is shown at the other gauges in the fact that the low-water delay for the larger tides is greater than that for the small tides, for in this case we have a less low-water depth and the rise of tide is a greater fraction of the depth of water. But at Rollover it will be seen that the semidiurnal and diurnal components retain more nearly their relative magnitudes, and as a consequence the effective cause of the greater delay in high water for the larger tides does not exist here. The explanation of this seems to be as follows: The tidal wave having passed through the gorge spreads out into the lower bay and as a consequence is greatly reduced both from the effects of friction and from having passed through a narrow pass into an extended reservoir. Consequently, for all gauges existing in this lower bay the same state of affairs exists, and, as previously stated, the semidiurnal component receives a greater proportionate reduction than the diurnal. Regarding the lower bay as the immediate source of the tides in the upper bay we see at once that the gauges in the upper bay are related to those in the lower bay as these latter were to the one in the Gulf, and similar effects follow the passage of the tide over Red Fish Bar into the broad expanse of the upper bay. But at Rollover the local conditions are entirely different; the tidal wave, after passing over Hannas Reef, passes into a funnel-shaped bay, decreasing in width and depth.

It is a well-known consequence of theory of tidal propagation from a sea into a canal decreasing in width and depth that there are two causes operating to produce opposite effects. These are the friction to reduce and the contraction to increase the tidal fluctuation as it travels up the canal; hence if the latter cause be more potent than the former the tidal fluctuation may increase as the distance from the mouth of the canal increases. Of this there are many examples in nature, of which may be mentioned the estuary of the river Thames, where the tidal range increases from 13 feet at Sheerness to 17 feet at Dufford, is 15 feet at London Bridge, and then gradually decreases, the frictional effect now predominating. From what has been said and by referring to plate 1, it is seen that such an effect, that is, an increase in the tidal range as compared with Hannas Reef, might be expected at Rollover, and in fact such has been found to be the case as shown in Table 5. As a result we may also expect the two components to retain their relative magnitudes, and thus permit the causes producing a greater delay in low water than in high water to have their full effect in the manner shown above. For the same two days near the time of the moon's maximum declination I found that the mean fluctuation of the diurnal component divided by that of the semi-diurnal component gave the following ratios: Bar, 1.57; Gorge, 2.02; Government Wharf, 2.12; Hannas Reef, 2.03; Rollover, 1.60; Red Fish South, 2.42; Red Fish North, 3.60; which are in direct confirmation of what has been advanced. On plate 2, figure 3, is given the theoretical form of a tide wave in a shallow river as deduced by Sir G. B. Airy; it is believed that some resemblance to it can be observed in the Rollover curves. It is to be noted that the right-hand side of this curve becomes the left-hand side of the tide curve as given by a self-recording tide gauge. A further confirmation of the above views is found in the fact that at Rollover the time of rising for the S. D. T. is approximately 5.6 hours, and time of fall approximately 7.0 hours, while at Hannas Reef these quantities are 6.1 and 6.5, respectively.

One of the main objects of the series of tidal observations now being discussed is the determination of the tidal prism which passes through the gorge, or rather the tidal velocities which occur there and which may be expected to effect scour on the bar by the influence of jetties, but as yet it is the portion of the subject upon which the least of anything precise can be said. That the question for the larger and more effective tides is an extremely complicated one is evident from the unique character of the tides, as well as from other causes which will appear further on. It is therefore to be regretted that it has not been practicable to take a series of observations in the gorge extending over a period of at least a synodical month, to determine the actual velocities of ebb and flow, their directions, durations, and distribution throughout a tide; without this nothing but the roughest approximation can be expected.

The following general considerations are necessary to a clear understanding of what follows:

Assuming that the tide is near low water but still falling, and an ebb current running out, it is evident that the approaching flood must meet and partially overcome this current before any water can enter the bay. It is not believed that this ebb current is reversed completely at the moment of low water, but that, for some time after that event, water is both entering and leaving the bay through the gorge, the two currents, outgoing and incoming, existing at the same time. It is a matter of common observation that the tide will begin to rise some time before the surface ebb current ceases, and divers in their descent have found an outgoing current on the surface and an incoming one near the bottom, and I have read of similar observations being made elsewhere. Now if the moment could be exactly determined when

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the incoming volume equals in amount the outgoing volume, the readings of the water surface at a number of gauges located throughout the bay, at that instant, would give a lower surface for determining the tidal prism. Proceeding similarly at high water an upper surface could be determined and the prism calculated. But in the absence of any observations to determine these moments of equality, I am forced to make suppositions more or less unsupported in order to render the problem a determinate one.

Before proceeding further it may be well to show that in the calculation of the tidal prism a volume far in excess of the truth would result from using the total fluctuations given in Table 5. For, taking Morgan Point Gauge as an example, we see that it is low water there from 5.2 hours to 6.0 hours after it is low water at the gorge. It is not at all probable that the moment of equality mentioned above is nearly so long as this amount after low water at the gorge, consequently the fall at the former gauge occurring after this moment of equality should be eliminated in the calculation; and similarly at high water it is seen that the water has been falling at the gorge from 5.2 to 7.5 hours before it begins to fall at Morgan Point. It is evident that taking the total fluctuations at both gauges will again err in excess. Since the flow of water depends directly on some function of the slope, some light may be thrown on this question by a consideration of the slopes existing during flood and ebb tide. But to get precise data as to these quantities requires that the zeros of the gauges be connected very closely, and this has, so far, been done only for the Government Wharf, Gorge, and Hannas Reef gauges, and since these results have been availed I have not had time to investigate this question as thoroughly as desirable. In fact, from these three gauges alone sufficient data for a very accurate investigation can not be obtained. With this explanation I will now give some data bearing on the question.

In the following table are given, referred to the hour of high and low water, respectively, for the flood and ebb slopes, the time before these epochs that the maximum slope occurs and the time after them that the corresponding slope ceases, the gauges compared being the Gorge and Hannas Reef:

TABLE 6.—*Hours of maximum and zero slope referred to Gorge hour of high water.*

Tide.	Flood.			Ebb.	
	Maximum slope before high water.	Zero slope after high water.		Maximum slope before low water.	Zero slope after low water.
	Mean.	First mean.	Second mean.	Mean.	Mean.
	Hours.	*Hours.*	*Hours.*	*Hours.*	*Hours.*
S. D. T	1.5	2.2	....	2.1	1.0
I. D. T	2.5	5.5	2.4	1.4	2.0
G. D. T	2.1	7.8	3.9	1.4	2.6

From this table it is seen that between the two points, Gorge and Hannas Reef, the ebb-slope has entirely ceased at about 2½ hours after low water at the Gorge. But these gauges are 10 miles apart, and for gauges nearer to the Gorge than Hannas Reef this time would be reduced. Moreover, the Gulf has been rising during this 2½ hours and much faster than the gorge, and as the water is rising rapidly on the bar and falling inside the gorge it is evident that the moment of equality of transfers in and out will soon be reached after the Bar and Gorge gauges are at the same level. This point evidently lies somewhere between 0 and 2½ hours after low water at the gorge. In lack of anything to indicate more definitely its position, I will assume it to be at 1 hour after low water at the gorge for the G. D. T., and for the S. D. T. in the same way it will be assumed at one-half hour after low water.

Again, referring to Table 6, it is seen that the flood slopes between the Gorge and Hannas Reef gauges cease for the S. D. T. 2.2 hours after high-water at the Gorge. But in this 2 hours the Gorge Gauge has fallen a little, and if the water which this fall represents passes into the bay it will be accounted for on some other gauge; if it does not pass into the bay it adds nothing to the tidal prism and therefore should not be counted; hence for these small tides we may take the upper surface of the tidal prism as that existing at about 2 hours after high water in the gorge. Turning to the larger tides Table 6 gives two values for the hour of zero slope, the explanation of which is that the slope may decrease to zero, become ebb in character, again become zero, pass to flood, then to zero, and begin the main ebb. These variations are illustrated in Fig. 9, Pl. 2, where flood slopes are shown above (positive) and the ebb slopes below (negative) the zero line, the tidal curves at the two gauges, Gorge and Hannas Reef, being also given. It is evidently difficult under such c[ir]cumstances to draw any general rule. But as it is evident that but little water wi[ll] escape during the short duration and small slopes of the small intermediate ebb an[d] but little water added during the small intermediate flood (they will probably abou[t] counterbalance each other), we may say that the upper surface of the tidal pris[m] will be given at the time of the first flood zero, or say 4 hours after high water at the Gorge. For the same reason as before the fall during this time at any of the gauges should not be counted; moreover, as during this period there is no counter slope to produce an ebb current, the whole tendency will be to force water into th[e] bay.

Based on the above reasoning I have determined a mean tidal prism for the S. D.T. and for the G. D. T.; the I. D. T. I have omitted, as the above remarks for either class of tide do not apply to them so closely; they are therefore reserved for a future date, together with a further study of those presented now.

For the G. T. D. I find that the tidal prism is 10,729,960,000 cubic feet, and for the small tides 3,187,875,000 cubic feet, made up of the partial prisms as given in the following table:

TABLE 7.—*Tidal prisms of Galveston Bay.*

Basin.	Area.	G. D. T.	S. D. T.
	Square miles.	*Cubic feet.*	*Cubic feet.*
Upper Bay	233.8	2,542,000,000	130,360,000
East Bay	72.8	2,486,200,000	882,850,000
West Bay	30.6	682,460,000	170,615,000
Lower Bay	131.9	5,019,300,000	2,004,050,000
Total	469.1	10,729,960,000	3,187,875,000
Bar area	8.0	107,610,000	50,739,000

The quantities given for the G. D. T. pass through the gorge twice every day and those for the S. D. T. four times a day whenever the particular class of tide exists to which they belong. From the series of slopes from which Table 6 was deduced I found that on an average the flood slope from its commencement to its first zero lasted about 10 hours and that the ebb from the last flood zero to its end lasted about 9.4 hours during G. D. T. For the S. D. T. the ebb and flood slopes are of about equal duration of about 6 hours each. Taking the cross section of the gorge as about 160,000 square feet, it is easily calculated that the water must flow through the gorge with an average velocity for the different cases as follows:

For G. D. T. during flood....................feet per second..1.87
For G. D. T. during ebb....................do....1.98
For S. D. T. during flood and ebb....................do....0.92

It is here assumed that the duration of flow and slope in the same direction are equal. This, from lack of observations to determine the relation between these quantities, is the only one that can be made, and is no doubt very near the truth. I have left out of consideration the time when the slopes vary about the zero, as was done in the calculation of the tidal prism.

But in the case of tidal flow we know that the current in either direction begins at zero, increases to a maximum, and then decreases to zero, and I know of no formula which will apply to such a case; that is, to where the slope, the cross section, and probably the coefficient of friction vary with the time. Such a formula, could it be devised, would be extremely complicated, and require an immense number of observations for its determination. Nor is it believed that tidal velocities bear the same relation to the slope that holds in rivers and canals, where the slope remains constant for a considerable length of time. Moreover, in the G. D. T., the existence of the large diurnal component, occurring at the time it does in relation to the semidiurnal component, tends to produce a complexity of currents, making it unsafe to predict anything as to the actual velocities from the slopes existing at any particular time. In a report of a board of engineers dated January 21, 1886, in which this harbor is considered, it is stated that "where the tidal heights give with time as abscissas a tidal curve of regular and nearly sinusoidal form, as is the case at the Narrows in New York harbor, the velocity curve during a tide with times as abscissas has a similar form, which may be represented approximately by a triangle; whence it follows that the maximum mean velocity during a tide is about double the mean velocity for the whole period of the rise or fall."

It will be seen by reference to fig. 9, plate 2, that this representation can be made at the gorge for the ebb in both the tidal and slope curves, and also approximately for the flood-slope curve, but less so for the flood-tidal curve. Assuming this law as true, the maximum mean velocities become 3.74, 3.96, and 1.84 feet per second. A good series of velocity observations taken in the gorge would test these results. What velocity observations have been taken in the past are too few in number, have not been located in the gorge, and have been taken for other purposes. They consequently throw no light on the present discussion. It will be noted that these velocities are in excess of those given by the Board of Engineers in the report quoted above; this arises mainly from the fact that I have assumed a shorter period of ebb and flow than there assumed.

The ebb velocities above given for the G. D. T. are stronger than those given for the flood. This arises from the fact that the time of filling the bay was assumed longer than the time of emptying. That this supposition is probably correct is shown by the following data compiled from a comparison between the Gorge and Hannas Reef gauges through seventeen G. D. T.:

	Feet.
Average flood slope between these gauges	0.353
Average ebb slope between these gauges	0.430
Average maximum flood slope between these gauges	0.630
Average maximum ebb slope between these gauges	0.910

From which it is seen that the average and maximum ebb slopes are greater than the corresponding flood slopes, and hence greater velocities may be expected from them. There is another factor which may at times increase the ebb velocities over the flood, and that is the fresh water which the bay receives from the bayous and rivers emptying into it. In times of flood this undoubtedly amounts to a considerable volume, but it has never been evaluated. An indication of its amount is given by the fact that when the San Jacinto and Trinity rivers are both very high the Upper Bay becomes fresh almost throughout its whole extent.

As shown in Table 6 the maximum flood slopes occur for the G. D. T. 2.1 hours before high water, and the maximum ebb slopes 1.4 hours before low water, and as a consequence the maximum velocities should be expected somewhere near these same times and probably after them. From the same table it is seen that that the main ebb does not begin for the same class of tides until about 8 hours after high water, and that it ceases about 2.5 hours after low water. In table 3 of my report dated July 1, 1889, it is shown that on the bar the rise to high water occurs in about 8 hours. An inspection of the G. D. T. will show that for the purposes of this discussion the rise may be taken as proportional to the time; consequently, when the ebb slope has ceased or become very small it may be said that the tide has risen say one-third of its way to high water, or about 0.91 feet. Hence considering the slopes occurring after the maximum, it may be said that the ebb current has practically ceased when the tide has risen from low water to 0.91 feet above the plane of mean low tide for the G. D. T., or 0.26 feet above the plane of reference. In the same table (3) of July 1, 1889, it was shown that the tide on the bar fell 0.5 of a foot in 4 hours, and to low water in 16.9 hours; hence in this case it can not be assumed that it will fall a foot in 8 hours, because it fell one-half foot in 4 hours. But it will fall more than one-half and less than 1 foot. In lack of more exact data let us take 0.75 of a foot as the probable fall in 8 hours. Then it is seen that the ebb current for the G. D. T. practically does not begin until the water has fallen from high water 0.75 of a foot below the plane of mean high tide, or to a point 1.33 feet above the plane of reference. As the ebb current commences at zero and gradually increases it would seem that the strong velocities will not be reached until the water has fallen considerably below this latter limit (+1.33 feet), but may occur before it has fallen to the former one (+0.26 feet).

The flood velocities, of course, practically begin when the water has risen to the first limit (+ 0.26 feet), and end when it has fallen to the second (+ 1.33 feet).

In the I. D. T. the above limits will apply equally well to at least that half of them which is nearest the G. D. T.; therefore, the above limits will apply to the tides occurring on more than one-half of the days in a synodical period. As these tides furnish the controlling or greatest velocities the others have not been considered.

The above figures are to be considered approximate; exact ones could only be obtained by comparisons made after the bar and gorge gauges had been connected by a line of precise levels.

In Table 7 it will be seen that for the S. D. T. the Upper Bay adds only 130 million cubic feet, corresponding to a tidal rise of only 0.02 of a foot. For the G. D. T. 0.39 of a foot was found to represent the effective tidal fluctuation. These figures show what a reduction in the effective tidal prism the delays in high and low water cause.

In the table of tidal prisms, the horizontal line under the totals gives the area and prism to be added when the jetties are both carried out to the bar, other things supposed to remain equal.

Very respectfully, your obedient servant,

WM. C. LANGFITT,
First Lieut., Corps of Engineers.

Maj. CHAS. J. ALLEN,
Corps of Engineers, U. S. A.

REPORT OF MR. E. M. HARTRICK, ASSISTANT ENGINEER.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., June 30, 1891.

SIR: I have the honor to submit the following report of operations for improving Galveston Harbor, Texas, during the fiscal year ending June 30, 1891.

Mr. H. C. Ripley, assistant engineer, had immediate supervision of the work to August 13, 1890, when First Lieut. W. C. Langfitt, Corps of Engineers, took supervision, followed by Mr. E. M. Hartrick, assistant engineer, from October 1, 1890, to the end of the fiscal year.

CONDITION OF CONTRACT.

At the end of the last fiscal year the contract with Messrs. A. M. Shannon & Co., was still unfinished, although they had had two extensions. The present fiscal year was entered on with a third extension to August 30, 1890, on which date they finally completed their contract, the expense of inspection and measurement of material being deducted as before.

SUPPLEMENTARY REPORT TO LAST FISCAL YEAR.

In Lieut. W. C. Langfitt's report of October 15, 1890, supplementary to the report for the last fiscal year, he states that, from longitudinal profiles and cross sections taken after the work was finally completed by the contractors, compared with those of the year before, he deduces the following:

"From Station 0 to Station 9 + 60 the crest has been raised. This is due to riprap placed during the year to fill voids which existed among the blocks. From Station 9 + 60 to Station 96 the work was left unfinished in the center to allow as much settlement as possible to take place before completing the crest. This distance was completed during the year and the effect has been to raise the crest except in a few places which had been completed at the end of the fiscal year 1888-'89. Notwithstanding these additions, from Station 59 to Station 70 the average settlement has been 0.829 feet and maximum 2 feet, and from Station 70 to Station 74, the average settlement has been 0.285 feet, with a maximum settlement of 1 foot. This settlement was due probably to the high tides of April, May, and June this year (1890); which caused a general settlement of the shore branch, but which was covered up by additions made after its occurrence. From Station 96 to Station 134, or over that portion of the jetty where the clay core exists, there was more or less settlement going on throughout the year, but as stone was added continually, this portion of the jetty has been raised in height. * * * A continuation of this settlement may be expected throughout this portion of the jetty. From Station 134 to Station 150, the end of the completed work June 30, 1889, there has been practically no addition of stone during the year.

"I have divided this distance into three portions, as follows:

"1. From Station 134 to Station 138 there has been practically no change.

"2. From Station 138 to Station 144 the average settlement has been 0'.46 with a maximum of 1.2 feet.

"3. From Station 144 to Station 150 the average settlement has been 0'.45 with a maximum of 1 foot. * * *

"It is evident that the consolidation and settlement goes on slowly and that several years will be required from the completion of such a jetty until such movements cease.

"The remainder of the completed work having been finished since June 30, 1889, no comparison has been attempted.

"It will be noticed that a scour is shown in advance of the completed work from Station 195 + 50 to Station 198 + 68. This scour averages 1'.56, with a maximum of 3 feet. * * * The scour is evidently the result of the current whipping around the

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end of the work, and as it may take place as fast as the work is pushed out, it practically adds so much in height to the jetty to be constructed. From data in hand, the distance which this scour extends out can not be determined, but the facts so far as they go would indicate the advantage of at once carrying out a layer of riprap over the old mattress jetty, should the scour extend further than the length of the jetty under construction at any one time. * * *

"In regard to changes in the bottom in the vicinity of the jetty, it may be said that from Station 0 to Station 79 there practically has been no change; that from Station 80 to Station 153 a fill on both sides of the jetty is shown, and the bottom is generally raised above what it was originally. As the work advances a deep trench is scoured along the jetty near the end and is filled up as the work progresses, the final result being to eliminate the shallower trench which generally existed on both sides of the old mattress jetty."

INCIDENTAL SURVEYS AND OBSERVATIONS.

In August and September, 1890, a survey of part of the outer bar and its channels was made to determine any changes that might have occurred after completion of the contract. On plotting the survey and comparing the curves of depth with those of the survey made in April, May, and June, 1890, no appreciable change could be observed.

About six months after the completion of the work a profile over the axis of the jetty was taken in the latter part of January, 1891, together with cross sections every 1,000 feet in the first part of February, 1891. By comparing these sections with those taken at the end of last fiscal year and completion of contract it was found that there had been no decidedly marked change, with the exception of a slight settlement between Stations 22 and 24, and a general settlement over that part of the jetty completed toward the end of last contract.

In April, during and after the running of a construction train for the repairs of the Life-Saving Station, a slight settlement was observed between Stations 9 and 60.

There has been no profile nor cross sections taken over the completed jetty for this report, as the change would be so slight that a comparison could not be made of any practical value.

ADVANCE OF THE WORK DURING THE YEAR ON SOUTH JETTY.

End of completed work June 3, 1890, Station 180; end of completed work June 30, 1891, Station 194; advance this year, 1,400 feet. End of incomplete work June 30, 1890, Station 192; end of incomplete work June 30, 1891, Station 195 + 50; in advance of completed work, 150 feet. End of trestle June 30, 1890, Station 196 + 28; end of trestle June 30, 1891, Station 198 + 68; constructed this year, 240 feet.

TABLE No. 1.—*Showing kind and amount of stone used.*

Month.	Cars.	Riprap.	Cars.	Blocks.	Total cars.
July	426	5,991.99	321	2,025.65	747
August	337	4,977.54	363	2,294.35	700
Total	763	10,969.53	684	4,320.00	1,447

TABLE No. 2.—*Showing quantities of stone used and cost of same in the work and other items of expense, not including office and inspection expenses.*

0 to 79 + 64 (7,964 feet).

Items.	Cubic yards.	Cost.	Cubic yards per foot.	Cost.
				Per foot.
Riprap	4,179.88	$8,694.15	0.52	$1.09
Blocks				
Railway				
Extras		13.86		
Total for year	4,179.88	8,708.01	0.52	1.09
Previous expenditures	40,080.24	135,681.08	5.03	17.04
Grand total	44,260.12	144,389.09	5.55	18.13

THIRD APPROXIMATION,

FIG. 4

BAR

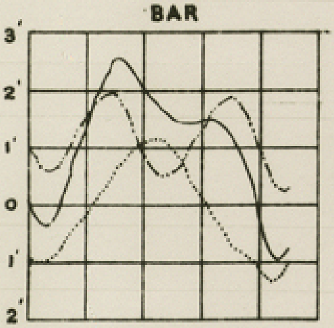
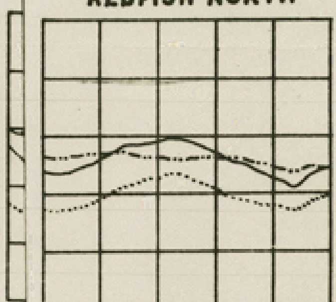


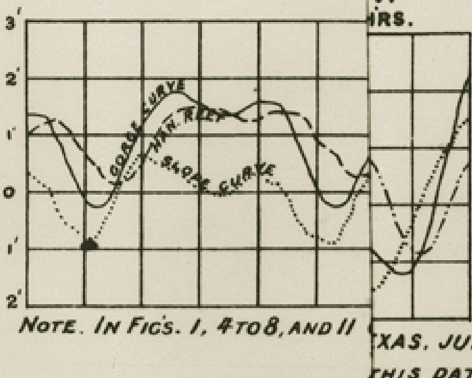
FIG. 8

REDFISH NORTH



FI 11

HRS.



NOTE. IN FIGS. 1, 4 TO 8, AND 11 … EXAS. JUNE 30. 1891

… THIS DATE

THE DIURNAL COMPONENT IS PL… Wm C. Langfitt.

LIEUT. CORPS OF ENGRS. U.S.A.

Photo-Lith. by A. HOEN & CO.

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Plate II

Graphical analysis of Tide Curve, Gov't. Wharf
Galveston Harbor
Jan 28 to Feb. 19. 1890

Note.
Observed curve shown thus ————
Semi diurnal component " —·—·—
Diurnal " " ··········
Vertical lines are 6 hrs. apart
Horizontal " " 1 ft. "

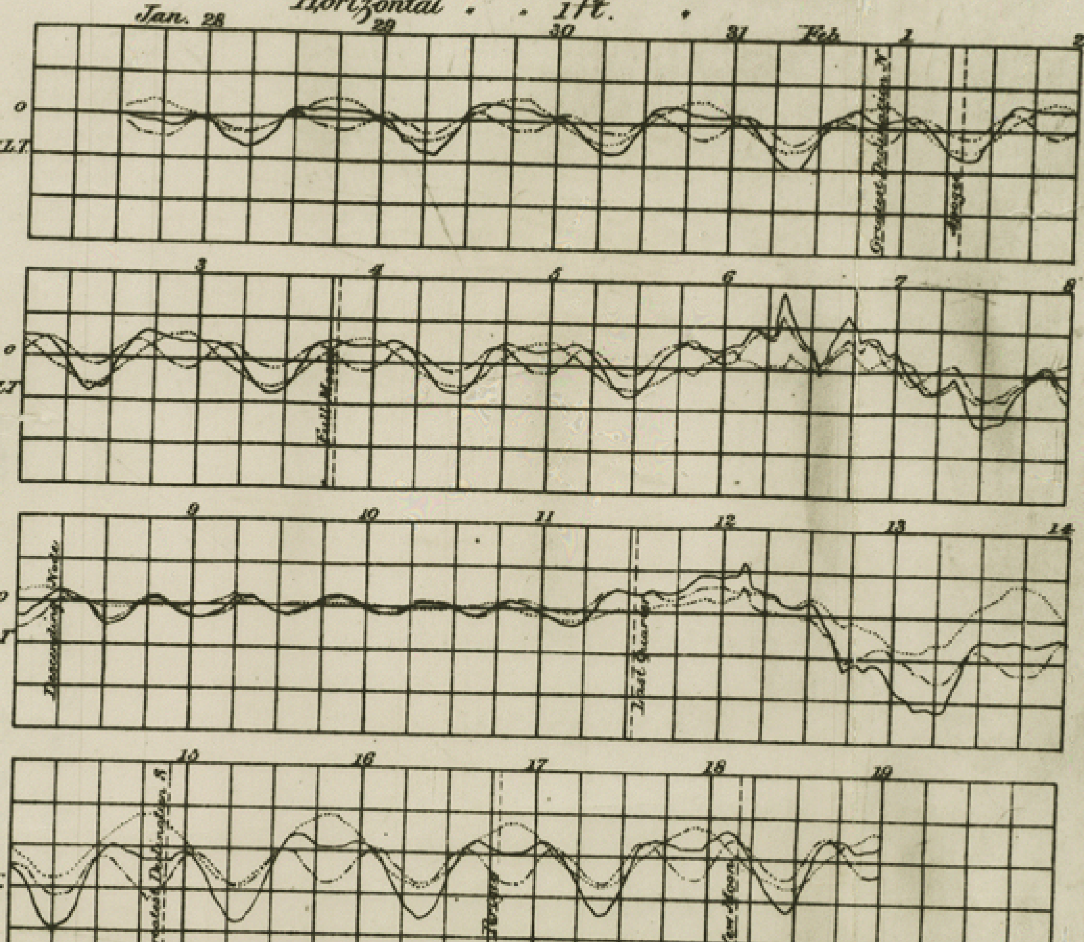

Photo Lith. by A. Hoen & Co. Balto. Md.

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Money statement.

July 1, 1889, amount available		$38,763.46
July 1, 1890, amount expended during fiscal year, exclusive of liabilities outstanding July 1, 1889, and exclusive of payments made on contracts in force July 1, 1889	$19,022.19	
July 1, 1890, outstanding liabilities	123.25	
		19,145.44
July 1, 1890, balance available		19,618.02
Amount appropriated by act of September 19, 1890		500,000.00
Amount available for fiscal year ending June 30, 1891		519,618.02
Amount (estimated) required for completion of existing project		5,700,000.00
Amount that can be profitably expended in fiscal year ending June 30, 1892		2,350,000.00

Submitted in compliance with requirements of sections 2 of river and harbor acts of 1866 and 1867.

REPORT OF FIRST LIEUTENANT WILLIAM C. LANGFITT, CORPS OF ENGINEERS.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., June 30, 1890.

MAJOR: I have the honor to submit the following progress report on the tidal observations of Galveston Bay:

As stated in my last report, three new gauges were put in operation at the places designated, the record from them beginning in July, 1889. The relative elevations of the zeros of the new gauges, referred to the adopted plan of reference, were determined in the usual manner by water comparisons.

It being evident that the presence of a gauge located in the gorge of the harbor would give results of great importance, it was decided, in view of the fact that the records from Round Point and Morgan's Point gauges were so similar that one of them could be dispensed with, to dismantle the Round Point Gauge and establish it in the gorge. This has been done, the Round Point record ceasing in March and the Gorge record commencing in April, 1890. The Round Point tide-gauge house was left standing, with two-staff gauges on different piles, with their zeroes at the same level. A line of precise levels can be run to them at any time and tie in the records already obtained.

On the 3d 4th, 5th, and 6th of April a freshet occurred in the San Jacinto River, during the course of which the current of the river entering Morgan's Canal completely carried away the tide-gauge house at Morgan's Point and the revetment of the canal on the same side as the house. The keeper, Mr. Warren, thoughtfully saved the instrument and all movable property. The gauge was located on the east side of the canal and behind the revetment. It was erected in 1887.

The gauges have been inspected much more frequently this year, resulting in a marked improvement in the records.

A greater part of the time I have been unaided in the reduction and plotting of the records, and have had to compile all numerical data for myself. As a consequence the new matter which I can present in this report is meager, and, in fact, no complete report can be made until further physical data are obtained, notably the relative elevations of the zeros of the gauges; current observations, including relative velocities of ebb and flood currents, with their relative durations and times of slack.

A party is now engaged in running a line of precise levels to connect the various zeros, but the results so far reported have not been received in time to be used.

While I have some data reduced from the records of the new gauges, the results depend upon too few observations to be comparable with those from the older ones; they are consequently reserved for future discussion.

For these reasons the remaining portion of this report is abridged as far as may be, only such results of my reductions being given as will give relatively correct results when compared with my report of last year, together with a short explanation of the cause of the one tide a day during large declinations of the moon.

The following table gives the same facts as given in Table I of the last year's report, revised to include the results of the year 1889, viz, elevation of mean low tide referred to the plane of reference adopted at Galveston, mean fluctuation of the tide at the various gauges for the great and small declination tides, the intermediate tides, and mean of all the tides. The bar record for 1889 is much broken, record having been obtained in eight months only, no single month complete and some with but very little record at all.

TABLE I.—*Rise and fall of tide.**

Location of gauge.	Plane of M. L. T above established plane of reference. †	G. D. T.	S. D. T.	I. D. T.	M. T.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Bar	−0.10	2.63	1.27	2.00	1.91
Government Wharf	+0.36	1.57	0.67	1.16	1.05
Rollover	+0.17	1.50	0.94	1.19	1.12
Morgan's Point	+0.56	0.81	0.42	0.67	0.60
Round Point	+0.46	0.85	0.44	0.74	0.65

* Record used begin in May, 1887, and run to include December, 1889. All records more or less broken and some very much so.

† Plane of reference is the plane of M. L. T. at Government Wharf as determined by Mr. Ripley, United States assistant engineer, from observation in 1872 and 1873.

A comparison of this table with that of last year shows:

1. That the plane of M. L. T. at the bar has been largely lowered by the additional observations, while the mean fluctuation has been largely increased. This can be partially accounted for by the fact that the whole number of observations is small and the additional ones introduced happened to contain a relatively large number of tides with very low low-water and large fluctuation.

2. That the plane of M. L. T. at all the gauges has been lowered.

The plane of M. L. T. at the various gauges for 1889 only is as follows:

Bar	−0′.17
Government Wharf	+0′.28
Rollover	+0′.07
Morgan's Point	+0′.53
Round Point	+0′.43

All of which show a lower plane than heretofore.

3. The plane of M. L. T. at Rollover still continues lower than at Government Wharf and its mean fluctation slightly larger.

4. The mean fluctation at all the gauges has been slightly increased.

Tables IV and V of last year's report are combined in the following table, the results being determined from the observations to include 1889.

TABLE II.—*Rise of G. D. T. and S. D. T. divided by rise of M. T.**

Location.	G. D. T. / M. T.	S. D. T. / M. T.
Government Wharf	1.495	0.638
Rollover	1.339	0.750
Morgan's Point	1.350	0.700
Round Point	1.308	0.674

* See remark (*) Table I.

These results give the same indications as those given last year, yet when the absolute differences are so small, a positive conclusion can not be drawn until a longer series of observations confirms the results in their relative values.

Tables II and VI of last year's Report are consolidated in the following table, and extended to include the various classes of tides and the mean tide. These results differ somewhat from the partial determination of the delays in high and low water given last year, but the conclusions are in no wise affected as the relation between the values is still in the same direction. The time of high and low water at the Government Wharf gauge was taken as the origin in the reduction and the results transferred to the bar gauge as an origin by adding to the difference of time found between the Government gauge and the other gauges, the difference of time found between that gauge and the Bar gauge. Owing to the limited amount of record from the Bar gauge, these last differences are not so well determined, but as their absolute amounts are relatively small, the other results are, I think, practically correct.

TABLE III.—*Delay of high and low water.**

Location of gauge.	Distance from Bar Gauge.	Delay high water.				Delay low water.			
		G. D. T.	I. D. T.	S. D. T.	M. T.	G. D. T.	I. D. T.	S. D. T.	M. T.
	Miles.	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*	*Hours.*
Government Wharf	6¼	1.28	1.35	1.10	1.226	1.23	1.12	1.01	1.110
Rollover	30	4.63	4.56	4.30	4.474	5.61	5.20	4.79	5.169
Morgan's Point	30¾	8.30	7.26	5.26	6.706	6.32	5.89	5.45	5.848
Round Point	35½	8.13	7.02	5.80	6.811	6.63	6.14	5.81	6.153

* See remark (*), Table I.

This table brings out two facts very clearly: (1) That the delay for the large tides is larger than that for the smaller ones; and (2) that the delay in high water is greater than that in low water, the Rollover gauge excepted, this gauge again giving an unexpected result.

Below is given Table VII of last year's Report, revised to include results of 1889. It was obtained by adding to the plane of M. L. T. (Table V) for each kind of tide, its corresponding half fluctuation.

TABLE IV.—*Mid-level of water.**

Location.	G. D. T.	S. D. T.	I. D. T.	M. T.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Bar	0.815	0.915	0.830	0.855
Government Wharf	0.775	0.955	0.880	0.885
Rollover	0.670	0.770	0.725	0.730
Morgan's Point	0.875	0.840	0.875	0.860
Round Point	0.775	0.840	0.770	0.783

* See remark (*), Table I.

This table gives about the same relative results as Table VII of last year's Report, but, as there stated, the quantities are so nearly equal that no positive conclusion can be drawn from them.

In Table VIII of last year's Report I gave the results obtained for the plane of M. L. T. taken out for each kind of tide independently. This table is here repeated, revised to include results of observations of 1889.

TABLE V.—*Plane of M. L. T. for G. D. T., I. D. T., and S. D. T.**

Location of gauge.	G. D. T.	I. D. T.	S. D. T.
	Feet.	*Feet.*	*Feet.*
Bar	−0.50	−0.17	+0.28
Government Wharf	−0.01	+0.30	+0.62
Rollover	−0.08	+0.13	+0.35
Morgan's Point	+0.47	+0.54	+0.63
Round Point	+0.35	+0.40	+0.58

* See remark (*), Table I.

The explanation of these results will be found in the following remarks on the observed tide and its components.

So far as I know no explanation has ever been given by this office for the apparent anomaly of only one tide a day here during parts of a lunation, and two during the remainder. Stated briefly the reason is this: That as the moon leaves her node there is developed a tide having a period approximately of a day, which increases in size as the moon's declination increases (either north or south), and soon passes in magnitude the regular tide which occurs twice a day. This last tide is called the semi-diurnal component, and the former the diurnal component of the observed tide, the latter

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being produced by the combination of the two. Plate I, herewith, presents a graphical analysis of the tide observed at the Bar gauge into its diurnal and semi-diurnal components, and will give a good idea of their relative importance during a lunation.

Assuming that each component follows the law of the sines, either one at any particular time can be represented by an equation of the following form:

$y = A \cos 2\pi \frac{t}{T}$ in which

y = ordinate of curve referred to an axis midway between high and low water.
t = time in hours from place of maximum ordinate
T = duration of one tide
A = Coefficient.

Taking two equations of the above form and combining them we get for the equation of the complex curve

$$y = A \cos\left(2\pi \frac{t}{T} - E\right) + A' \cos 2\pi \frac{t}{T}, \text{ in which}$$

y = ordinate of complex curve
t, T, and A = same quantities as above.
T, and A′ = quantities for the semi-diurnal curve similar to T and A for the diurnal curve.
E = distance between the place of the maximum ordinate of the diurnal component and the maximum ordinate of preceding semidiurnal component.

For a particular case I deduced the values of the coefficients and of E in the equation and then calculated the resultant curve. This is shown on Plate I, and just below it the corresponding observed curve. The agreement is all that could be expected from such a rough determination.

It is evident that this decomposition explains all or nearly all the circumstances of the rise and fall of the tide; as, for instance, when the moon's declination is large, the sudden rise to high water, the subsequent rapid fall for a short time followed by a more slow decline, stand or small rise, and then rapid fall to low water. These remarks suppose wind effects small.

The value of E in the above equation determines largely the character of the complex curve, as do also the relative magnitudes of the coefficients A and A′. With a correct value of E, and proper changes in value of A and A′ any observed form of curve can be produced. I have not had time nor sufficient data to determine the law of the changes in these coefficients.

These methods of analysis are not new. The graphical method has been used in the office of the U. S. Coast Survey for many years. Again, Professor Bache, formerly superintendent of that service, gives an analytical expression similar in form to the one given above, for the tides at Cat Island, Gulf of Mexico (Report of 1866). His expression is:

$$C \cos 2t + D \cos (t - E) - y = 0,$$

in which t = time in hours from place of maximum ordinate of semi-diurnal curve. C, D, E, and y are similar quantities to A′, A, E, and y in the equation given above.

It may be of interest to state that at Cat Island E is about nine hours, while for Galveston Bar it is about five hours.

On Plate II is given a similar graphical analysis for the tide at the Government Wharf gauge. A comparison of the two will show the changes undergone in passing from the bar to the Government Wharf, a distance of about 6¼ miles.

Before closing this report, I wish to call attention to an error in the last table (VIII) in the published copies of my report of last year. The signs of all the quantities in the table should be *plus*, except that of the top number (0.32) in the column headed G. D. T., which is correctly minus.

Very respectfully, your obedient servant,

WM. C. LANGFITT,
First Lieut., Corps of Engineers.

Maj. CHAS. J. ALLEN,
Corps of Engineers, U. S. A.

REPORT OF MR. H. C. RIPLEY, ASSISTANT ENGINEER.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., July 1, 1890.

MAJOR: I have the honor to make the following report relating to the improvement of Galveston Harbor, Texas, for the fiscal year ending June 30, 1890:

Plate 1

Graphical analysis of Tide Curve, Galveston Bar

Jan 28 to Feb. 19. 1890

Note.

Observed curve shown thus ———

Semi diurnal component " —·—·—

Diurnal " " ··········

Vertical lines are 6 hrs. apart

Horizontal " " 1 ft. "

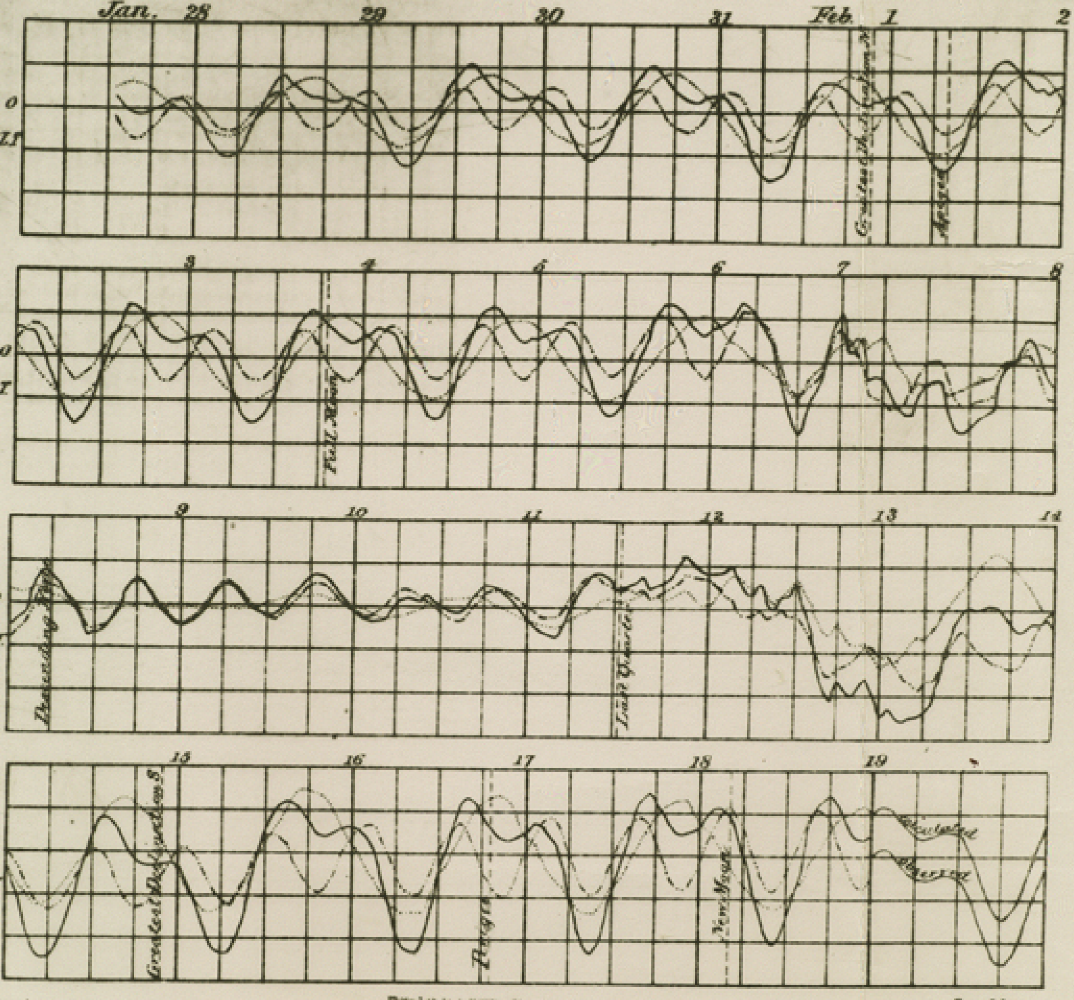

Photo Lith. by A. Hoen & Co. Baltimore

Abstract of proposals for building a jetty at the entrance to Galveston Harbor, Texas, received in response to advertisement dated August 21, 1888, and opened September 20, 1888, by Maj. O. H. Ernst, Corps of Engineers, at Galveston, Tex.

No.	Name and address of bidder.	Riprap, 105,000 cubic yards.	Blocks stone ½ to 2 ton each, 8,000 cubic yards.	Blocks stone 2 to 5 ton each, 23,000 cubic yards.	Railway, 13,500 linear feet.	Rails, 6,900 linear feet.	Amount.
		*Pr. cu. yd.**	*Pr. cu. yd.*	*Pr. cu. yd.*	*Pr. ft.*	*Pr. ft.*	
1	A. M. Shannon & Co., Galveston, Tex	$2.08	$4.30	$4.30	$3.25	$1.00	$402,475
2	G. W. Burkett, Palestine, and T. C. Stribling, Brenham, Tex	2.60	4.40	4.50	3.80	.80	468,520
3	Louisiana Jetty and Lighting Company, New Orleans, La	2.55	4.33	4.33	3.10	.70	448,660
4	Ricker, Lee & Co., Galveston, Tex	2.06	3.43	4.12	*30.97	*7.31	807,034
5	Samuel W. Swift, Galveston, Tex	2.21	3.85	4.25	3.50	1.00	414,750

*After bids were opened Messrs. Ricker, Lee & Co. stated that their figures for railway and rails were clerical errors, and should have read $3.09 per foot for railway and 73 cents per foot for rails.

No. 1, lowest; acceptance recommended.

REPORT OF FIRST LIEUTENANT WILLIAM C. LANGFITT, CORPS OF ENGINEERS.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., July 1, 1889.

SIR: I have the honor to submit the following progress report on the subject of the tides and tidal records of Galveston Bay.

I was placed in charge of these records about the middle of October, 1888. At this time the plotted records were about four months behind the rolls as taken from the tide gauges. After familiarizing myself with the mode of plotting and the necessary data, my first efforts were directed to bringing them up to date.

Other duties have interrupted the plotting and study of the records, among which may be mentioned the survey and examination of the bank of the Rio Grande River in the vicinity of Fort Brown, Tex., in November and December, 1888, and the survey of Galveston Harbor and Entrance in May and June, 1889. There was also a delay of a month in the arrival of the lithograph sheets upon which the records are reduced during which no plotting could be done.

All of the gauges have been visited by me at least once and some of them oftener. I regard it as very desirable that they should be visited at least once every month, and oftener, if practicable, to insure that they are working properly, and that the clocks are set correctly. Hence it is to be regretted that some means of communication with the distant gauges is not in possession of this office.

Owing to the experience gained during the preceding year, the records as a whole have been more satisfactory. The defect in the "fixed pencil holder," mentioned by Lieutenant Zinn in his report of last year, has been corrected by the substitution of a new one on each gauge. They are so constructed that by placing small weights on them any desired constant pressure of the pencil on the paper can be obtained. A little care thus gives a uniform distinct line.

The manner of plotting the records has been described in the report of Lieutenant Zinn mentioned above.

About the middle of October, 1888, finding that the gauge at the Government wharf was not working properly, I had the float tube, which was of cast-iron, 4 inches in diameter, raised. It was found to be so badly eaten by galvanic action as to be unfit for further use, and I decided to replace it by a wooden coppered tube of about 6 inches by 6 inches inside dimensions, which were suited to another larger float then on hand, the increase in diameter being advantageous. The float was attached to a brass ribbon which wound or unwound from the slotted rim of a wheel. It is evident that as the ribbon wound or unwound the diameter of the wheel changed, thus giving a constantly changing scale of heights, not indicated in any manner on the paper roll. Hence if these were plotted on the uniform scale of one-half inch to the foot an error would be introduced. Upon investigation this error was found to be about 8 per cent. of the total height, that is, in a tide of, say, 5 feet rise the plotted

Galveston Co. Rolled Sketches

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record would show only 4.6 feet. As there was in the office another instrument of a scale of 1 inch to the foot, and without this defect, it was placed in order and then set up in place of the old one.

The gauges now in use are all of the same scale of 1 inch to the foot and hour, except the bar gauge, whose scale is one-tenth of a foot to a foot rise.

The bar gauge until September, 1888, had a pendulum clock. The clock was frequently stopped by vibrations of the tide-gauge building, this causing much loss of record. During September the clock was removed and altered to a spring-balance one, under the direction of Mr. H. C. Ripley, assistant engineer. The gauge was not put in working order again until early in February, 1889, since which time a great improvement has been shown and much good tidal record obtained.

In plotting these records it became desirable to see whether the zero of the staff gauge had not changed its position. A comparison with the Government Wharf record, made in the usual manner, showed that the zero line of all records plotted during 1888 should be lowered nine one-hundredths of a foot.

This method of deducing the reading of the zero of one gauge at mean low tide of another is not satisfactory when the gauges are so far apart. As it is proposed during the ensuing year to connect all the gauges by a line of precise levels, this fact will then be obtained independently of such comparisons and enable all observations to be reduced to the plane of mean low tide of any desired location.

The records so far accumulated are of insufficient extent for a proper determination of the tidal movements. There are especially lacking observations on the velocities and directions of the tidal currents at the entrance and throughout the bay. The gauge on the bar has an apparatus attached, designed by Mr. Ripley, assistant engineer, intended to show the direction and velocities of the currents at that point. It is hoped that when the records from it are satisfactory and sufficiently extended some light may be thrown upon this subject.

I have devoted some time to the study of the records, the results of which are given below. The record for the bar gauge extends from April, 1888, to September, 1888, and is much broken. For the other gauges the records extend from May, 1887, to December 31, 1888, but they are also very incomplete. It may be well to state that during the three or four days when the moon has her greatest declination there is developed but one tide per day; for the same length of time near the nodes there are developed two tides of much smaller fluctuation. These are called, respectively, the great declination and small declination tides. The tides connecting these I have called the intermediate declination tides.

In the following table is given the reference of the plane of mean low tide at each gauge to the plane of mean low tide to Galveston, as previously determined; also the rise and fall of the tide at the gauges, for the tides of the moon's greatest declination, least declination, the intermediate tides, and mean of all tides:

TABLE I.—*Rise and fall of tide.*

Location of gauge.	Plane of M. L. T. above established plane of M. L. T. at Government Wharf.	G. D. T.	S. D. T.	I. D. T.	M. T.
		Feet.	*Feet.*	*Feet.*	*Feet.*
Bar	+0.295	2.37	1.19	1.67	1.60
Government Wharf	+0.42	1.53	0.63	1.206	1.034
Rollover	+0.28	1.34	0.79	1.11	1.04
Morgan's Point	+0.58	0.82	0.45	0.69	0.61
Round Point	+0.52	0.77	0.45	0.71	0.65

The above table presents several facts of peculiar interest. The first is the apparent elevation of the plane of mean low tide at Government Wharf. This amount (0′.42) is far beyond the limits of any error that may have been made in determining it. The plotted records and the rolls as they came from the gauges have been examined, but no error found in them. An examination of the wind record during the period of high low waters may throw some light on the subject. A redetermination of the zero of the staff gauge of the Government Wharf, compared to the B. M. on the Hendley building, was made, but it was found to be practically unchanged. This bench-mark reads 6.879 above the M. L. tide as established from the observation of 1872–'73.

The second is the fact that the plane of mean low tide at Rollover is, for the period embraced, 0′.14 lower than the plane of mean low tide at Galveston, and that the mean fluctuation at that point is slightly greater than at Government Wharf. Roll-

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over is, approximately, 30 miles from the bar gauge at the bottom of a shallow bay obstructed by a reef across its entrance, while Government Wharf is only 6¼ miles. These results were therefore entirely unexpected. The shape of East Bay, in which Rollover is situated, may possibly affect the fluctuation, as it is of funnel shape.

It will be noticed also that at all of the gauges the plane of mean low tide is above that assumed at Galveston. The amount at the bar (0′.29) may perhaps be partially accounted for by the imperfect comparison of the gauges. The amount of the elevation at Round Point, and at Morgan's Point, is larger than expected. Whether in the future the plane of mean low tide at Government Wharf will fall to what it has heretofore been assumed, and whether also the planes at the other places will be lowered proportionally, can only be determined by future observations.

A partial determination of the delay in time of high and low water referred to the bar gauge, is given in the following table, together with their approximate distance from that point:

TABLE II.—*Delay in high and low water from the bar gauge.*

Location of gauge	Distance from bar.	Delay in hours.	
		High water.	Low water.
	Miles.		
Government wharf	6.25	1.43	1.49
Rollover	30.	4.8	5.8
Morgan's Point	30.75	7.1	6.3
Round Point	35.50	7.9	6.8

The amounts of these delays in the cases of the last three gauges has raised the question whether the upper bay above Red Fish Bar, and East Bay back of Hannah's Reef, added materially to the effective tidal flow back and forth over the bar. The solution of this question is important, and to help determine it three new gauges have been ordered, one of which will probably be placed near to and above Red Fish Bar. A second will be placed near to and below the same bar, while the third will be placed near to Hannah's Reef. These gauges have been received and are in operation on the Government Wharf for the purpose of testing and adjusting them before putting them up in their permanent place. The records of these gauges, it is thought, will throw much light on this question and the one at Hannah's Reef may help to explain the unexpectedly large fluctuation at Rollover. It may be of interest to state in this connection that during a "norther" on January 28, 1889, the tide just above Red Fish Bar at the light-house read 1.3 feet, and at Halfmoon light-house the same tide read 3.1 feet below mean low tide, both being at their lowest. Red Fish Bar is 17 miles from bar gauge, while Halfmoon light-house is 10. These figures were obtained from Mr. Hartwick, United States assistant engineer in charge of the Ship Channel Improvement. This same tide read at—

Government Wharf, 3.65 below mean low tide.
Rollover, 0.80 below mean low tide.
Morgan's Point, 0.65 below mean low tide.
Round Point, 0.80 below mean low tide.

The above facts illustrate the great obstructions caused by Red Fish Bar and Hannah's Reef to the tidal flow.

In the following table are given the average values of the following quantities for the Government Wharf and bar gauges deduced from the same records as Table I, viz: The mean fluctuation, the time to rise .5 of a foot, the time to high water, the time to fall .5 of a foot, time to low water, for the tides when the moon's declination is greatest and least, and for the intermediate tides and the mean of all tides:

TABLE III.

	At bar.					At Government wharf.				
	Mean rise and fall.	Rise to .5 foot.	Rise to high water.	Fall to .5 foot.	Fall to low water.	Mean rise and fall.	Rise to .5 foot.	Rise to high water.	Fall to .5 foot.	Fall to low water.
		Hours.	*Hours.*	*Hours.*	*Hours.*		*Hours.*	*Hours.*	*Hours.*	*Hours.*
G. D. T	2.37	2.2	7.9	4.1	16.6	1.53	2.98	8.8	9.31	16.52
S. D. T	1.19	2.4	5.7	2.7	5.9	0.63	3.91	5.93	4.17	6.30
I. D. T	1.67	2.5	6.4	3.3	9.4	1.296	3.31	7.90	9.68	16.50
M. T	1.60	2.4	6.4	3.3	9.44	1.034	3.44	7.30	7.53	11.70

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The quantities given in the third and fifth columns include the time at stand or slack. In a great majority of cases this is small, especially on the bar, and can not be evaluated with accuracy from the plotted records.

In this table there will be noticed a great disparity between the time it takes the tide to rise .5 of a foot and that taken to fall the same amount. While this ratio might be slightly reduced by the determination of the high and low water stands, it would still remain very large. This, I think, arises from the fact that the water on the bar rises very rapidly to its highest point and then begins to fall, not from an ebb current but from the water flowing up the bay, the ebb current not setting up until the tide has fallen very considerably. An examination of such current observations as has been obtained from the bar gauge confirms these conclusions.

It will be further noticed that the mean of all the tides on the bar gives a much shorter tide than at Government Wharf. This arises from the fact that on the bar there is developed a second tide during the transition from the single great declination tide to the two small declination tides before this is done at the Government Wharf. This peculiarity is also noticed at Rollover.

It has been assumed (Report of Board of Engineers of January 21, 1886, on Galveston Entrance, Report of Chief of Engineers for 1886, II, p. 1301) that, because at Bolivar the tides rise to high water in 8.9 hours and only fall .5 foot in 9.2 hours (the table above for Government Wharf gives 8.18 and 9.31 hours, respectively) that the great declination tides in the interior will be increased in the same or greater ratio over the mean tide. The following are these ratios deduced from the above tables:

TABLE IV.—*Rise of great declination tide divided by rise of mean tide.*

Government Wharf	1.478	Morgan's Point	1.344
Rollover	1.288	Round Point	1.183

Now, if we take the ratio of the mean tides to the small declination tides for the same points we get the following results:

TABLE V.—*Rise of small declination tide divided by rise of mean tide.*

Government Wharf	.609	Morgan's Point	.737
Rollover	.759	Round Point	.692

A consideration of these two tables shows that the great declination tides are not increased in the same ratio above the mean tide as we go up the bay, but that this ratio apparently approaches unity by a decreasing series; further, the small declination tides show a smaller proportionate decrease as we go up the bay, the ratios increasing towards unity. In other words, the great declination tides suffer a greater reduction proportionately than the smaller ones.

This result seems confirmed by the fact that the delay in high water is greater during great declination tides than it is during small declination tides, as shown by the following table, bar time of high water being taken as the origin:

TABLE VI.

Location.	Delay low water.		Delay high water.	
	G. D. T.	S. D. T.	G. D. T.	S. D. T.
	Hours.	*Hours.*	*Hours.*	*Hours.*
Government Wharf	1.6	1.4	1.5	1.4
Rollover	6.3	5.4	5.0	4.6
Morgan's Point	6.5	6.0	8.3	6.1
Round Point	7.0	6.5	9.2	6.8

These results probably arise from the fact that during the great declination tides the water is disturbed to greater depths, the velocities of movement greater, and consequently the proportionate effects of the resistances are larger during these tides than during the smaller ones.

The following table gives the mid-level of the water at the various gauges referred to M. L. T. of the Government wharf, for the great declination tides, the small declination tides, intermediate tides, and mean of all tides:

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TABLE VII.—*Mid-level of water.*

Location.	G. D. T.	S. D. T.	I. D. T.	Mean of all tides.
	Feet.	*Feet.*	*Feet.*	*Feet.*
Bar	0.775	0.950	0.91	0.912
Government Wharf	0.825	1.015	0.953	0.937
Rollover	0.690	0.875	0.780	0.800
Morgan's Point	0.870	0.905	0.905	0.885
Round Point	0.765	0.935	0.890	0.845

This table was obtained by adding to the reading of the plane of M. L. T. for each kind of tide, its corresponding half fluctuation.

The resulting quantities are so nearly equal that no positive conclusion can be drawn from them, but the mid-level seems practically constant at all the gauges for any one kind of tide, and a trifle higher for the small declination tides than for the larger ones.

This table confirms, I think, by its uniformity, the correctness of the results of Table I, as I see no reason to suppose that the mid-level of the bay should be higher or lower than that of the gulf. Hence if any important error was made in determining the reading of M. L. T. it should show itself here, the other factor, mean fluctuation, being practically the same as heretofore determined.

A mean level could be found by adding the co-ordinate of heights of each tide for every hour and finding the mean. The result would for the great declination tides, on account of their form, be slightly greater than the values above found, while for the same reason the values for the smaller tide would not be affected. Hence it is probable that the mean level of the gulf and bay are nearly if not exactly equal. This result arises from the fact that the plane of M. L. T. rises during small declination tides very much above what it is for the great declination tides, as shown in the following table:

TABLE VIII.—*Plane of M. L. T. for the G. D. T. and S. D. T. and I. D. tides.*

Location.	G. T. D.	S. D. T.	I. D. T.
Bar	−0.32	−0.45	−0.17
Government Wharf	−0.06	−0.70	−0.35
Rollover	−0.02	−0.48	−0.23
Morgan's Point	−0.46	−0.68	−0.56
Round Point	−0.38	−0.71	−0.42

It would seem, therefore, that in passing from G. D. T. to S. D. T. the bay received more water than it passed out, and in passing from S. D. T. to G. D. T. the reverse is the case.

As subsequent reductions are made the values of the quantities in all of the above tables may be changed more or less. They are in fact introduced more to give a general idea of the problems involved and to show the need of more extended observations at a greater number of places than on account of their value in their present unfinished state.

It is to be regretted that lack of time has prevented a more extended study of the tidal movements and the solution of the unexpected elevation of the M. L. T. at Government Wharf over what had heretofore been determined.

Very respectfully, your obedient servant,

WM. C. LANGFITT,
First Lieut. of Engineers.

Major O. H. ERNST,
Corps of Engineers, U. S. A.

REPORT OF MR. H. C. RIPLEY, ASSISTANT ENGINEER.

UNITED STATES ENGINEER OFFICE,
Galveston, Tex., July 5, 1889.

MAJOR: I have the honor to make the following report relating to the improvement of Galveston Harbor, Texas, for the fiscal year ending June 30, 1889:

JETTY CONSTRUCTION.

At the end of the last fiscal year the work under contract with A. M. Shannon & Co. for building a jetty was incomplete. The work was therefore continued until

July 15, 1888, when their contract expired. After the expiration of their contract the work was continued as extra work, but at contract prices, until July 17, when, on account of the exhaustion of the appropriation, the work was suspended.

On September 20, 1888, bids were opened for a continuation of the work under a new appropriation, and the contract was again awarded to A. M. Shannon & Co.

The specifications require that the stone to be furnished shall consist of large-sized riprap of random sizes, but at least 75 per cent. of it must be in pieces weighing from 250 to 1,500 pounds, of blocks weighing not less than three-fourths of a ton each for the protection of the top and sides on the shore branch, and of blocks weighing not less than 2 tons each for the protection of the top and sides on the gulfward extension. They also require the contractors to build a railroad trestle over the line of the proposed work, to alter the grade of the track over that portion of the jetty already constructed, and to furnish new rails for the same. The changing of grade was to be done at cost price.

Work under this contract was commenced October 15, 1888, by the commencement of the construction of the railroad trestle for the shore branch. The placing of stone did not commence until the 2d of the following month.

LOCATION OF THE WORK.

The shore branch of the jetty commences at a point on the axis of Avenue A 105 feet west of the west face of Ninth street, and extends as follows:

From O (sta. zero) to P, on a tangent whose bearing is 73° 17′, 105 feet; from P to Q, on a curve whose radius is 835 feet, 625 feet; from Q to R, on a tangent whose bearing is 30° 24′, 1,040 feet; from R to S, on a curve whose radius is 1,965 feet, 750¼ feet; from S to T, on a tangent whose bearing is 8° 37′ 28″, 5,500¼ feet; from T to U, on a compound curve whose radii are 1,000 feet and 1,200 feet, 380¼ feet; from U to V, on a tangent whose bearing is 30° 53′ 54″, 950$\frac{7}{10}$ feet; from V to W, on a curve whose radius is 560 feet, 368$\frac{5}{10}$ feet; from W to station 13 (of last year's work), on a tangent whose bearing is 68° 47′, 43$\frac{7}{10}$ feet. At W the line coincides with the axis of the old work, and in the gulf extension of the new work the axis coincides with that of the axis of the old mattress jetty, except on the curves where it was necessary to make a deviation to avoid an angle. The line of the work has been measured and marked at an interval of 100 feet, designated as stations. The old work has been renumbered, to correspond with the new, so that all distances given either on the new or old work refer to the zero of the shore branch. The difference between the new and old numbers is 84+64′, so that station 11 (old No.), which is the inner end of last year's completed work and the outer end of the shore branch, is, according to the new numbering, station 95+64′.

AMOUNT OF STONE USED.

The following table (No. 1) shows the number of cars and amount of each kind of stone placed during each month throughout the year.

TABLE 1.—*Showing kind and amount of stone used.*

Month.	Cars.	Riprap.	Cars.	Blocks.	Total cars.
		Cu. yds.		*Cu. yds.*	
July	276	4, 598. 76	131	1, 146. 30	407
August	....	....	....	....	....
September	....	....	....	....	....
October	....	....	....	....	....
November	191	3, 656. 77	1	9. 66	192
December	382	7, 788. 00	67	739. 65	449
January	393	7, 308. 40	194	1, 899. 87	587
February	593	10, 860. 52	301	2, 823. 89	894
March	468	8, 238. 16	378	3, 181. 54	846
April	187	3, 147. 60	177	1, 542. 11	364
May	135	2, 158. 47	148	1, 347. 56	283
June	100	1, 692. 23	107	1, 027. 26	207
Total	2, 725	49, 448. 91	1, 504	13, 717. 84	4, 229

It will thus be seen that the total number of cars of stone placed during the year was 4,229. Of these, 2,725 cars contained 49,448.91 cubic yards of riprap, and 1,504 cars contained 13,717.84 cubic yards of blocks, making a total of 63,166.75 cubic yards of stone placed.

PLATE 2

FIG. 1

GRAPHICAL ANALYSIS OF TIDE CURVE FROM GORGE GAUGE

NOVEMBER 1890

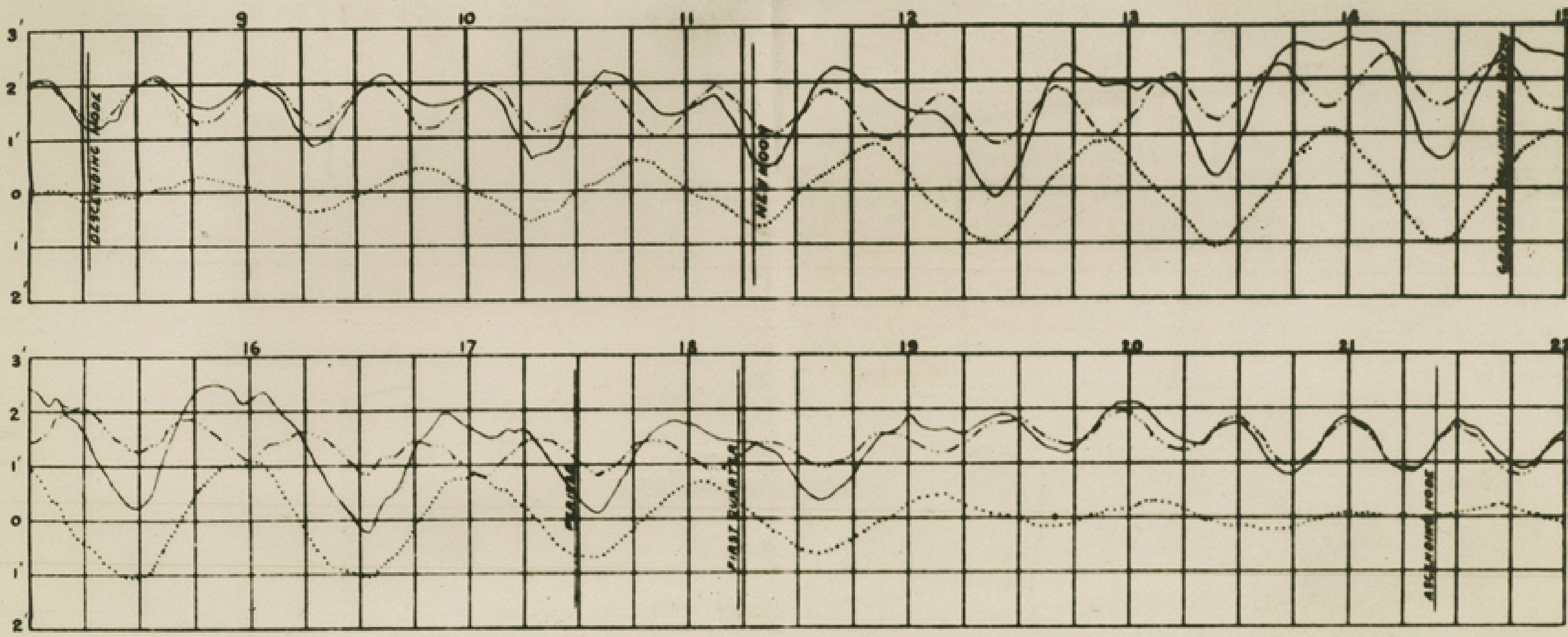


FIG. 2

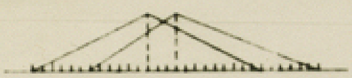


FIG. 3

THEORETICAL FORM OF TIDE WAVE IN SHALLOW RIVER, TO THIRD APPROXIMATION, WITH SMALL TIDE. (AIRY).

FIG. 4

BAR

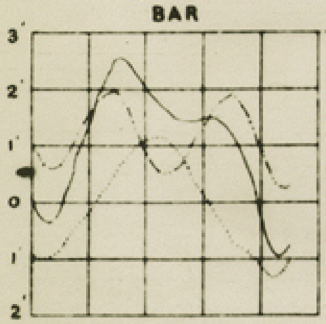


FIG. 5

HANNAH'S REEF

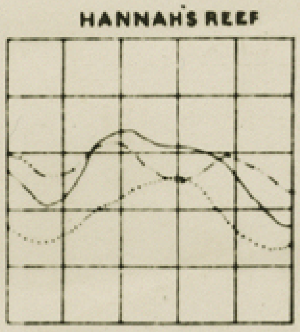


FIG. 6

ROLLOVER

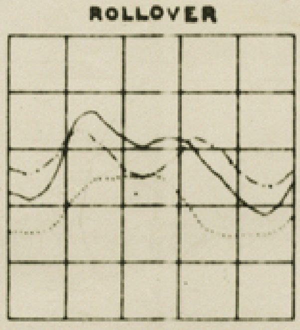


FIG. 7

REDFISH SOUTH

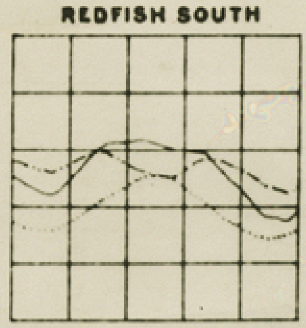


FIG. 8

REDFISH NORTH

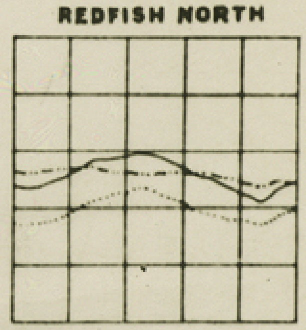


FIG. 9

FIG. 10

E = 5 HRS.

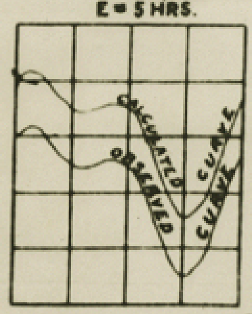
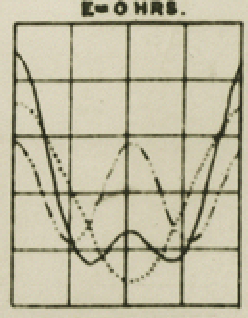


FIG. 11

E = 0 HRS.



NOTE. IN FIGS. 1, 4 TO 8, AND 11 OBSERVED CURVE SHOWN THUS ———
SEMI DIURNAL COMPONENT — · —
DIURNAL " ....
THE DIURNAL COMPONENT IS PLACED BELOW THE OTHER CURVES FOR CLEARNESS

GALVESTON TEXAS. JUNE 30. 1891
TO ACCOMPANY REPORT OF THIS DATE

Wm C. Langfitt
1ST. LIEUT. CORPS OF ENGRS. U.S.A.

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