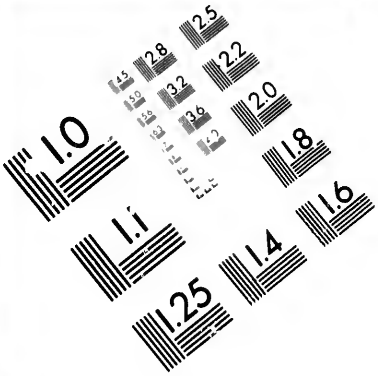

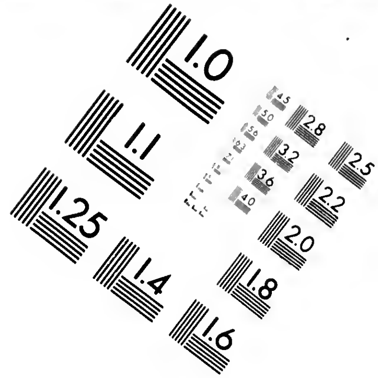

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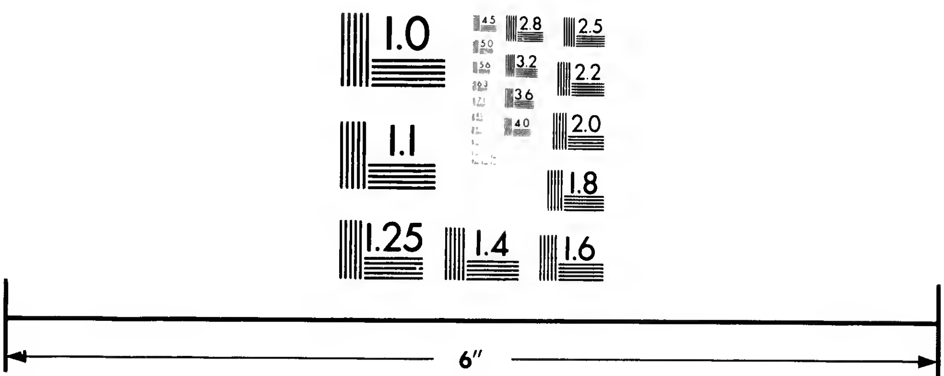

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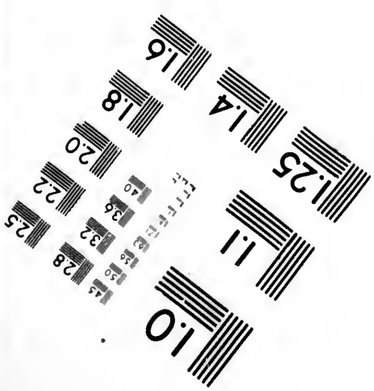

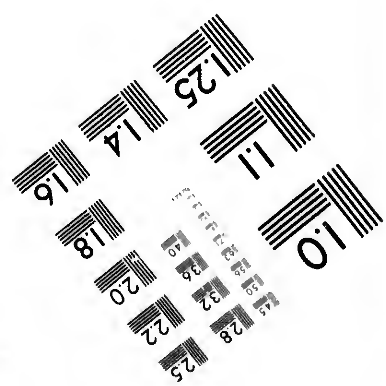

PUB

HARTLEY

ON

PUBLIC WORKS IN THE UNITED STATES AND IN CANADA.

1875
(36)

NOTES

ON

PUBLIC WORKS IN THE UNITED STATES AND IN CANADA,

INCLUDING A DESCRIPTION OF

THE ST. LAWRENCE AND THE MISSISSIPPI RIVERS AND THEIR MAIN TRIBUTARIES.

BY

SIR CHARLES A. HARTLEY, M. INST. C.E., F.R.S.E.

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1875.

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SECT. II.—OTHER SELECTED PAPERS.

No. 1,413.—"Notes on Public Works in the United States and in Canada, including a description of the St. Lawrence and the Mississippi Rivers and their main Tributaries." By Sir CHARLES A. HARTLEY, M. Inst. C.E., F.R.S.E.

HAVING visited the United States and Canada in the autumn of 1873, the accompanying notes on certain engineering works of magnitude are submitted, in the hope that they may prove interesting to the members.

I.—RAILROADS AND BRIDGES.

PHILADELPHIA AND READING RAILROAD.[1] (*Visited 28th November, 1873.*)—Through the kindness of Mr. Gowen, the President of this Company, and Mr. Nicolls, the second Vice-President, the Author had an opportunity of visiting the principal works on this railroad, which, in point of finish and substantial work, is equal to any line that he has travelled on in Europe. Mr. Nicolls has kindly enabled the Author to correct his notes up to the 31st of November, 1874.

The total length of single and double tracks and sidings is 1,452 miles, thus distributed:—

——	Single Track.	Double Track.	Length of Road.	Sidings and Laterals.	Total Length of Tracks and Sidings.
	Miles.	Miles.	Miles.	Miles.	Miles.
Roads owned . .	171·9	155·1	327·0	283·6	765·7
Roads leased . .	279·4	76·0	355·4	196·5	627·9
Roads contracted	42·9	..	42·9	15·3	58·2
Aggregate . .	494·2	231·1	725·3	495·4	1,451·8

[1] For complete statistical information respecting the railways of America reference may be made to the "Manual of the Railroads of the United States," by Henry V. Poor, and to the "American Railroad Manual," by Edward Vernon, both of which are published annually in New York.

The workshops and rolling mills of the Company are at Reading, a flourishing town of forty thousand inhabitants, 58 miles from Philadelphia. Both locomotive and marine engines are fitted up at these shops, where the cranes are all worked by hydraulic power. The mills are connected with four puddling and ten heating furnaces, and the hot blast evolved from the furnaces is employed as at Phœnixville. In 1874, 20,000 tons of iron rails were rolled, the rails being 24 feet long and weighing 68 lbs. per yard. The two holes for the fish-plates at each end of the rails were punched cold simultaneously. Steel rails of the same pattern as the 68-lbs. iron rails weigh 70 lbs. per yard. Up to the 30th of November, 1874, 1,588 tons of steel rails had been rolled in the Company's rolling mill, and an aggregate length of 92 miles had been laid with these rails, with the best results, in the most exposed places on the line.[1]

The Company possess and work four hundred and five locomotive engines. These cost $456,245 for repairs in 1874.

The traffic of the railroad principally consists of anthracite and bituminous coal, iron ore, lime and limestone, grain, petroleum, pig iron, lumber, and manufactures of all kinds. The aggregate amount of traffic transported over the railroads of the Company in 1874 was as follows:—

Number of passengers carried	6,964,869
" tons of coal, of 2,240 lbs..	6,348,812
" " merchandise, of 2,000 lbs.	3,098,831
" " Company's materials	493,591
Total tonnage of the Company in tons of 2,000 lbs., including weight of passengers and Company's materials . .	11,336,261

The Company's line penetrates into the heart of the anthracite basin of Pennsylvania; but owing to the difficulties of the country, the coal is hauled up steep inclines by stationary engines. From the coal field, the anthracite is sent to market by three separate

[1] According to the last report of the American Iron and Steel Association, the iron trade in the United States was more depressed at the close of 1874 than at any time since the panic began in September 1873. Pig iron, which in April 1873 had been sold at $42 to $47, had declined to $23 and $25 per ton; bar iron, then 4½ cents per lb. at Pittsburg, had fallen to 2¼ cents; iron rails, quoted at $82 in 1873, could be bought for $48 per ton in New York or in Philadelphia. Only 1,900,000 tons of pig iron were produced in 1874—a falling-off of one-third from the production of 1873. The manufacture of Bessemer steel rails was about the same in 1874 as in 1873—130,000 tons. The total manufacture of rails of all kinds was 450,000 tons, while 100,000 tons were imported. In 1872 there were 1,000,000 tons made, besides a large importation.

routes; on two of which are three inclined planes of 2,410 feet, 4,650 feet, and 4,755 feet respectively, overcoming elevations of 354 feet, 318 feet, and 404 feet; and by a tunnel 3,400 feet long, through a mountain forming the southern boundary of the coal field. On all these planes the rope is $2\frac{1}{4}$ inches diameter; on the first and steepest of steel, on the two last named of iron. On the first plane the cost of hauling the coal in 1874 was $2\frac{91}{100}$ cents ($1\frac{1}{2}d.$) per ton of 2,240 lbs., including all expenses of fuel, wages, repairs, &c.

The Philadelphia and Reading Coal and Iron Company owns one-third of the anthracite coal basin of Pennsylvania.[1]

The running cost of trains hauling coal in 1874, per round trip of 190 miles from the coal region to tidewater and back with empty cars, transporting average loads of 647 tons, and average through loads of 522 tons of coal of 2,240 lbs. each, was $30\frac{1}{2}$ cents per ton carried through 95 miles, or at the rate of $\frac{1}{3}$ of a cent ($\frac{1}{6}$ of a penny) per ton per mile. The total cost of trains moving coal, including cost of roadway, superintendence, telegraph, police, and all expenses of working the road, proportional to coal, was $\frac{3}{4}$ of a cent ($\frac{3}{8}$ of a penny) per ton per mile.

The Reading Railroad Company owns a fleet of fourteen iron steamers, equipped with the best known means of unloading cargo, weighing anchor, &c. The largest are of 540 HP., carrying 1,700 tons (of 2,240 lbs.) of coal on a draught of 15 feet, and make nearly 9 knots per hour so loaded. They are used for carrying coal from the Richmond terminus of the railway on tidewater in the Delaware river (where the Company's wharves have a frontage of $1\frac{1}{2}$ mile) to New York, Boston, Portland, Washington, and other ports accessible by sea.

The Schuylkill canal now belongs to this Company. It is worked in conjunction with the railroad. The hamlet of Schuylkill Haven is at the head of the canalised river of Schuylkill, which communicates with the Delaware at Philadelphia. The Susquehanna canal is also worked by the Company.

The gross receipts of the railway for the year ending the 30th of November, 1874, were $14,452,121; the expenses, $8,731,916; and

[1] The produce from the eastern extremity of the great Schuylkill anthracite basin—which has its outlet at Mauch Chunk (Blue Mountain), said to be the most picturesque town in America—is conveyed to tidewater along the Lehigh and Susquehanna railway division of the Central railroad of New Jersey. In 1870 the quantity of coal sent eastward from Mauch Chunk averaged 200,000 tons per week. The total production of the anthracite basin of Pennsylvania was 19,585,178 tons in 1873, and 18,700,000 tons (estimated) in 1874.

the net profits, $5,720,205. The expenses, including renewal fund, rents of lateral roads, taxes, &c., were thus $60\frac{4}{10}$ per cent. of the gross receipts. The net loss in 1874 in the business of the canals and of the steam colliers and barges was $420,659. The following balance sheet—abridged from a statement in the last Report of the President and managers of the Railway Company—shows the resources and financial condition of the Company on the 30th of November, 1874:—

Dr.	$	Cr.	$
Railroads and depôts	29,630,192	Stock, $32,722,775. Preferred stock, $1,551,800	34,274,575
Locomotives and cars	8,787,571		
Real estate	7,459,868		
Steam colliers	2,542,149	Mortgages and debentures at from 5 to 7 per cent.	55,080,988
Schuylkill canal and barges	1,607,439		
Ship-yard at Port Richmond	308,977	Loan of Schuylkill Navigation Co.	2,578,250
	50,336,196	Loan of East Pennsylvania Railroad Co.	495,900
		Sinking Fund Bonds	614,800
Philadelphia & Reading Coal and Iron Co.'s bond and mortgage	30,000,000	Reserved Fund, less Dividend Fund	1,870,753
Ditto stock	1,000,000		
Railroad and telegraph stock	1,405,902		
	82,742,098		
Assets in cash—			
Stocks and bonds, materials, &c., less liabilities	12,173,168		
	94,915,266		94,915,266

The Company has paid 10 per cent. dividend on its stock for some years past.

PHŒNIXVILLE BRIDGE WORKS, BELONGING TO CLARKE, REEVES AND COMPANY. (*Visited 26th November*, 1873.)—These works are situated between Philadelphia and Reading. The Author was accompanied by Mr. S. Reeves, the President of the Company, who supplied the principal part of the following information.

From 1869 to 1873 the Company built seventy bridges, having an aggregate length of 35,000 feet, or $6\frac{1}{2}$ miles of single track, comprising in all one hundred and seventy-six spans. With the present facilities they can turn out 100 feet of finished bridge for each working day in the year.

Everything is done on the premises; beginning with the manufacture of the iron from the ore; next rolling it into the shapes required; and, finally, applying the machine labour which completes the structure ready for erection. About fifteen hundred men are employed on the works. Two 300-HP. engines drive the blasts for the furnaces day and night, the air being heated by the consumption of the gases evolved.

The Phœnix columns or tubes are made of from four to eight sections, rolled in the usual way up to 24 feet in length, and riveted together at the flanges. When necessary, they are joined together by cast-iron joint blocks with circular tenons, which fit into the hollows of each tube.

The ends of all the links, to resist tensile strains, undergo a process called die-forging, by which the head is shaped and the hole struck by hydraulic pressure at one operation. The threads of the screws are so formed that rupture, when under pressure, always occurs in the unscrewed part of the bar. The iron is required to be of such elasticity that, after being subjected to a tensile strain of 30,000 lbs. per square inch, it will return to the original dimensions; while it should be so tough that bars, 2 inches in diameter, bent back from 90° to 180°, when cold, should show no sign of fracture.

Mr. Reeves particularly directed attention to the fact that, as a rule, iron trussed bridges in America have all their principal parts formed by machinery. They are of uniform dimensions in similar spans, and hence are perfectly interchangeable. Thus machinery can be applied in their manufacture, and the cost at the works be reduced to a minimum. They are so made, in fact, that nearly all the work is done at the shops, and they can be erected with the least possible amount of unskilled labour.

KEYSTONE BRIDGE COMPANY, PITTSBURG. (*Visited* 15*th November*, 1873.)—Through the kindness of Messrs. McCandlish and Carnegie, the Author was shown over these works by Mr. Nicholls, the second engineer of the Company.

The Company has built numerous bridges throughout the United States. Of these, the Author has seen the Steubenville bridge, which has three spans of 210 feet, four of 255 feet, and one channel span of 320 feet; the Newport and Cincinnati bridge, which has fourteen spans of 150 feet and one channel span of 420 feet; and the Keokuk and Hamilton bridge, which has ten spans of 180 feet and one channel span of 387 feet.

The Company has a capital of $1,500,000, and can turn out more than $3,000,000 worth of work annually. It gives employment to six hundred and fifty men. Its business is to construct general machine work, and the substructure and superstructure of buildings, bridges, &c., in any part of the United States and Canada.

Special pride is taken in obtaining lightness, strength, and economy, by employing wrought iron in tubular forms for compressive strains, and weldless links in tension members. The establishment is now almost exclusively occupied in completing the chrome-steel tubes for the great St. Louis bridge.[1] The ultimate tensile strength of this steel is 100,000 lbs. per square inch; but the Author saw one 1-inch bolt which only yielded to 120,000 lbs. The ironwork for the bridge is required to bear an ultimate tensile strain of 60,000 lbs. per square inch. The steel staves composing the tubes are submitted to a tensile strain of 40,000 lbs., and to a compressive strain of 60,000 lbs., without permanent set. The $\frac{1}{4}$-inch plate-steel for enveloping the staves is tested to 40,000 lbs. for compression and tension. There are six staves in each cylinder, and, after five have been placed, the sixth is driven home by a force of 20 tons.

RAILROAD BRIDGE ACROSS THE MISSISSIPPI AT ROCK ISLAND. (*Visited 1st November*, 1873.)—This bridge, which has often been termed, and apparently with justice, "the strongest and most perfectly finished bridge in America," was opened in the summer of 1872.

The superstructure was designed by Mr. C. Shaler Smith, the President of the Baltimore Bridge Company, to whom the contract for the ironwork was awarded, in September 1870, for the sum of $459,784. The workmanship, which was superintended by Major Benyaurd, under the direction of Colonel Macomb of the U.S. Corps of Engineers, is admirable in every particular. The abutments and piers, the construction of which had been in the charge of Major Stickney, were founded on the rock by means of ordinary cofferdams, at a depth which did not exceed 20 feet below low water. The masonry is uncommonly well built.

There are two spans of 260 feet, three of 220 feet, one drawbridge 368 feet long, covering two openings of 160 feet each, and two land spans of 196 feet and 100 feet. The total length is therefore 1,844 feet.

The trusses of the main bridge are 'double-system Whipple,'[2]

[1] Chrome steel can be welded as well as the best wrought iron. The quantity of chromium required in the steel is so small that the cost of the alloy is not greater than that of carbon steel. In a pure and crystallised state it is a grey, very hard metal, not oxidizable by any acid, nor reducible in a furnace.

[2] The late Mr. Zerah Colburn's Paper on "American Iron Bridges," in the Minutes of Proceedings Inst. C.E., vol. xxii., p. 540, will be found to contain an account of the best known systems.

in which everything but the washers, &c., is of wrought iron. They are 33 feet high and 19 feet apart. There are two floors; the upper, for a single rail track, placed a little below the centre of the trusses, and the lower, for horses and carriages, on the bottom chords. The footpaths are on each side of the lower platform.

The draw-span has a weight of 683 tons, of which four-fifths are placed on the thirty-six bearing wheels of the cast-iron turntable, 30 feet in diameter, and one-fifth on the centre pin. The swing is turned by hydraulic power in two and a half minutes, when there is no wind. It is opened about twelve times a day for the passage of vessels.

The total weight of the superstructure of the bridge is 2,980 tons, distributed thus: 1,910 tons, ironwork; 90 tons, turntable; 90 tons, tramway and spikes; and 890 tons, oak and pine lumber. The total cost of the bridge was $1,000,000 (£200,000).[1] The difference between ordinary high and low water at the lower end of Rock Island, whence the bridge crosses the main branch of the river to the city of Davenport, is 16 feet, except when the ice packs momentarily and dams the water back to a height sometimes of 24 feet above low water.

Iron Trussed Railroad Bridge over the River Ohio at Cincinnati. (*Visited 12th November*, 1873.)—This bridge carries a single 'track' and two wide footpaths over twenty-five 'deck' or undergrade openings, varying from 50 feet to 245 feet, and two overgrade openings, one of 370 feet and the other of 400 feet. On the left or Kentucky bank a drawbridge, worked by two men, gives the river and canal craft two openings of 125 feet each, when they cannot pass freely under the overgrade openings. The 'draws' are spanned by the 'Warren' truss, the two mid-channel spaces by 'Fink' triangular trusses, and all the others by 'Fink' trussed girders. The line of roadway bearers of the Indiana Channel span is 96½ feet above low water and 45½ feet above highest water, the maximum oscillation being 51 feet. The total cost of the bridge from abutment to abutment was $1,615,200 (£323,000, or £61 per lineal foot for 5,294 feet). The piers and abutments are all founded on rock, which is almost bare at extreme low water. The contract price for the masonry was $15 (£3) per cubic yard, but much of it cost from $18 to $20, although the limestone of which the masonry is composed came from quarries in the immediate neighbourhood. The bridge is level for

[1] In these notes the dollar is assumed to be worth four shillings.

2,242 feet, with a fall at each end of 79 feet per mile (1 in 67). Pilot engines assist heavy trains over these approaches. The speed over the bridge is restricted to 12 miles per hour nominally; but the Superintendent said that a speed of 30 miles per hour is often run by risky drivers. The engines on which the Author traversed the bridge weighed 56 tons. Four of them at rest, weighing 200 tons and covering as many feet, only gave a deflection of $1\frac{1}{8}$ inch on the 400-feet span. The deflection, with the same load, on one of the 245-feet undergrade spans was $1\frac{3}{4}$ inch. The weight of the 400-feet span complete, with stringers, cross-ties, track, footwalk, railings, and pier bearings, is 4,162 lbs. (say $1\frac{1}{2}$ ton) per lineal foot. All the wrought iron has been tested to a strain of 20,000 lbs. per square inch, and its breaking or ultimate strength has been proved at 60,000 lbs. per square inch. The maximum strain in practice with a full load is 12,000 lbs. per square inch, and 7,000 lbs. is the minimum strain. The Chief Engineer and designer of this, in every respect, first-class bridge was Col. Albert Fink.

St. Charles Railroad Bridge across the Missouri at 20 miles from St. Louis. (*Visited 10th November*, 1873.)—This bridge, which is remarkable on account of the difficulty of its foundations, was designed and constructed by Mr. C. Shalor Smith. It has seven spans; four 'trellis' or 'double triangular girder truss,' of 320 feet each, and three Fink 'deck' trusses of 305 feet each. The rails are 90 feet above low water, or 51 feet above the extraordinary high-water mark of 1844. The track is single, without footways, and there are no 'draws.'

There are eight river piers, and the foundations of six of them presented new and extraordinary difficulties of construction, owing to the existence of a bed of boulders below a shifting sandy bottom, to the sudden rising of the water, to the great velocity of the current at times of flood, and to the immense fields of ice which float down at the end of the winter season. Nos. 1 and 2 piers were founded easily on the rock at low water. No. 3 pier was founded in 23 feet of water at ordinary water stage. A wooden caisson without a floor was sunk on the site, the decomposed limestone within it was excavated by divers till solid rock was reached, and the crater was filled with concrete and two courses of stone laid upon it. The foundation was then ready for pumping out the water; but the river suddenly rose 26 feet, and crushed the caisson. On the subsidence of the river, the foundation proving uninjured, the pier was built on a caisson boat and sunk on the spot. No. 5 Pier.—The rock was here 68 feet from the surface. The compressed-air system was, in sinking the foundation, combined with Eads' sand-pump and air-lock at the bottom of the caisson, and a peculiar 'boulder shaft,' with a separate lock, was designed to get rid of the boulders. Piers 6, 7, and 8 are alike in the character of their foundations. Inside a circle of piles a caisson was sunk about 30 feet, by dredging, and stones were pitched round the piling as the caisson sank. This was continued till stone began to appear in the dredger buckets, which was a sign that the 'rip-rap' had begun to pass beneath the piles. When this took place, dredging was stopped, and bearing piles were driven down to the rock and cut off at the level of the bottom of the caisson. The pier was then lowered on the top of the pile-heads, and the caisson being filled with stones, the foundation was complete.

The superstructure was erected on three temporary piers of piling, protected by cribwork, under each river span. On these supports Howe truss spans, 80 feet in length, were placed; and from this foundation sprang the 'false work' or centering on which the iron superstructure was put together.

The approaches of the bridge are upon forty iron tressels, and, including these tressels, the bridge is 6,570 feet long. Its entire cost was about $2,250,000, or double the original estimate. This excess was due to the great and unforeseen difficulties encountered in constructing the foundations.

St. Louis Bridge. (*Visited November*, 1873.)—The Mississippi at St. Louis is confined to a single channel, 1,600 feet wide and 8 feet deep at extreme low water, by an embankment or levee on the Illinois side, which is carried up to above the level of extreme high water, at which time the width is augmented to 2,200 feet.

Both shores are revetted below the low-water line with rubble stones, and protected by the wharf pavements above that line. The extreme range between high and low water is 41 feet. Owing to the narrow gorge through which the whole volume of the Mississippi flows, the variations in the bed of the river are very great. Captain James B. Eads, M. Inst. C.E., the distinguished Engineer who designed the bridge and superintended its construction, informed the Author that a rise of 13 feet less than high-water mark caused a scour of 18 feet, and that in the freshet of 1870 the scour reached a depth of 51 feet below low-water mark alongside the east pier. These facts induced him to believe it possible, that the scour at times of extraordinary high flood might extend even to the rock itself. He therefore determined to establish the piers and abutments on the rock; and this was done by means of caissons provided with air chambers and locks at depths, for the east pier and east abutment, reaching 136 feet below high-water mark, or 110 feet from the surface of the water, when the foundation work was actually performed. This feat, which was satisfactorily executed in 1870–71, is quite unprecedented in the annals of engineering.[1]

The piers and abutments are composed of coursed rubble masonry up to low-water mark. Above this level they are faced with grey granite from the State of Maine, which cost £10 per cubic yard *in situ*. The interior of the work is of magnesian limestone. The massive appearance of the granite rock facing, and its close jointing, are very striking.

The contract prices and the total quantities of the steel and ironwork required for the bridge are as follows:—

2,500	tons	of steel, at £60 per ton	of 2,000 lbs.
500	„	wrought iron at £40 per ton. . . .	of 2,000 lbs.
1,000	„	rolled iron, at £28 per ton	of 2,000 lbs.
200	„	cast iron, at £16 per ton	of 2,240 lbs.

The bridge has three spans, each formed with ribbed arches made of cast steel—a novelty in bridge-building. The centre span is 520 feet and the side ones 502 feet each in the clear. The rise of the centre arch is $47\frac{1}{2}$ feet, that of the side ones 46 feet each. These are by far the largest arched spans in the world, and, under the able direction of Colonel Flad, Captain Eads' chief assistant, they are now being rapidly erected gradually from each pier and abutment, without the aid of centering.[2] Each span is composed of four double ribs of steel (well braced together, at their relative distances from each other), and the tubes forming them are jointed butt to butt. They are clasped together by wrought-iron couplings (which proved to be much better than steel), furnished with parallel grooves corresponding with similar grooves on the tubes. Steel pins, varying from $4\frac{1}{2}$ inches to 7 inches in diameter, pass through the centre of the couplings and the ends of the tubes at every joint. The vertical bracing between the upper and the lower tubular ribs—which are 12 feet apart from centre to centre—convert the two members into a single arch.

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[1] Capt. Eads' Reports to the Illinois and St. Louis Bridge Company from 1868–71, containing a full account of the foundations of the bridge, are in the library of the Institution, and the most important of them will be found in "Engineering."

[2] All details concerning the erection of the arches are given in a valuable Paper read before the American Society of Civil Engineers by Mr. J. C. Cooper, C.E., and published in "Engineering" in January 1875.

At the time of the Author's visit two of the openings were already spanned by the steel tubes, which are all 18 inches in diameter and 12 feet to 13 feet long, but of thicknesses varying from $1\frac{1}{8}$ inch to $2\frac{1}{8}$ inches.

The arches are to carry a double railroad track, and above the track a roadway, 54 feet wide, for carriages and foot-passengers. Captain Eads hoped to be able to open the bridge in the summer of the following year. As fourteen railroads were waiting to make use of it, he was of opinion that the Bridge Company would eventually secure a good dividend on their capital, although, from causes too numerous to mention, the outlay on the bridge had already considerably exceeded the original estimate. The extreme range of temperature at St. Louis is 160°; and it is calculated by Captain Eads that at 140° the arches will rise 8 inches, and that at 20° they will fall as much below the point at which they will be maintained at a medium temperature.

Since the above was written, the Author has received a letter from Capt. Eads, dated St. Louis, 15th July, 1874, in which he says:—

"My bridge was thoroughly tested on the 2nd with 560 tons of engines and 140 tons of tenders. This weight of 700 tons was run, first on one track on each span and then on the other, to produce twisting of the arches, and then it was divided into two trains (seven engines and tenders in each), and these were advanced abreast on to each span to produce the greatest distortion of the curve of the arch, and finally each arch was covered with the trains. The latter produced only $3\frac{1}{2}$ inches deflection on the 520 feet span and $3\frac{1}{4}$ inches on the other two. No lateral movement could be detected by the instruments under the effect of the side-loading or twisting strain. The deflections were almost in exact accordance with the theoretical computations. The bridge was opened on the 4th July with great enthusiasm, a procession being formed of all trades and callings, which was five hours in passing a fixed point. It was estimated to be 15 miles long, and passed over the bridge and back."

ROEBLING'S RAILROAD SUSPENSION BRIDGE (SINGLE TRACK) OVER THE NIAGARA RIVER. (*Visited 10th October, 1873, with Mr. McAlpine, M. Inst. C.E.*)—This bridge has one span of 800 feet, which weighs as many tons. The height of the tower on the American side is 88 feet, and on the Canadian side 78 feet. The bridge, which is 24 feet wide, and has a road for carriages suspended 28 feet below the railway line, is hung on four wire cables each 10 inches in diameter. Their combined ultimate capacity is about 12,400 tons. To preserve them from rust they are covered with a thick coating of hydraulic cement. The old timber-work of the roadway, which is 250 feet above the river, is now being removed and replaced. Trains passing over the bridge are restricted to a speed not exceeding 4 miles an hour. The first locomotive passed over it in March 1855. The cost of its construction was £96,000, and the railway companies using it pay an annual toll of £9,000 a year. The road and passenger tolls bring in about £2,000 a year in addition. The rise and fall at the centre of this bridge is stated by Mr. Roebling to be 27 inches under a change of 100° of temperature; that is, the roadways are 2¼ feet higher at zero than at a temperature of 100°.[1]

INTERNATIONAL RAILROAD BRIDGE (SINGLE TRACK) OVER THE NIAGARA, FROM FORT ERIE TO BUFFALO. (*Visited 14th October*, 1873.)—This bridge is being built by a company, of which Mr. Brydges, Assoc. Inst. C.E., is President, and Mr. Hannaford the Engineer-in-Chief. The chief contractors are Messrs. Gzowski and Macpherson. By common consent, the chief credit in overcoming the extraordinary difficulties which beset the building of the piers of this bridge is due to Colonel Gzowski, upon whom all the practical operations devolved.

The river Niagara at Fort Erie is about 1,900 feet wide, and its depth ranges from 16 feet to 48 feet. The variation in the level of the river does not exceed 2 feet when uninfluenced by the wind. Its bed consists partly of rock, and partly of clay and large boulders. The normal current is 5½ miles an hour, but during south-west gales it sometimes attains 12 miles an hour—when the water has risen 4 feet in a few hours. With such unusually strong currents, and with ice floes often 3 feet thick to contend against in the winter months, the founding of the piers was no ordinary task. Five of them on the Canadian side are built on the rock, whilst the three on the United States side rest on bearing-piles. The masonry was got in by means of outer and inner caissons. The anchoring of the former, while being sunk in place, was a most difficult operation, and quite unique in character as an engineering feat.

The main bridge has nine spans, varying from 180 feet to 250 feet, and is 1,968 feet long, including the abutments; but

[1] For a detailed description of the state of this bridge at the time of the Author's visit see letter at page 157, vol xviii. of "Engineering," addressed by Mr. Thos. Curtis Clarke, M. Inst. C.E., Philadelphia, to the Minister of Public Works, Canada.

including the length of the bridge across Black Rock Harbour, or the Erie Canal (600 feet), and the embankment joining the two bridges, the total length of the work is 3,650 feet. The iron superstructure, all from the Phœnixville Works, is known as the 'Pratt' or quadrangular truss. Its great strength is due to its depth, which in the centre of the 240-feet spans is 26 feet, and in the centre of the 'draw' 35 feet. It only weighs 1¼ ton per lineal foot, and was put in place by mooring watertight caissons between the spans, and then building a platform on them to the required height. By means of hydrants in the caissons they can be sunk to any level and be easily removed. The draw or swing is 362 feet long, and can be worked either by hand or by steam; by the latter it can be swung in about a minute.

Since the above was penned, Colonel Gzowski has published a most valuable description of the International Bridge,[1] in which he states that it was opened on the 3rd of November, 1873, and that the cost was about £300,000, including extras and interest on the outlay during construction.

It was intended by the Author that the foregoing Notes should be offered as a contribution to the discussion on Messrs. C. D. and F. Fox's (MM. Inst. C.E.) Paper on "The Pennsylvania Railroad";[2] and if they are still regarded in that light, as he would desire, the scantiness of his remarks on the important subject of railway construction in North America will be explained.

II.—RIVER AND CANAL WORKS. (Plate 6.)

The St. Lawrence and its Tributaries.

The St. Lawrence navigation extends from the Straits of Belle-Ile to Fond-du-lac, at the head of Lake Superior, a distance of 2,384 statute miles. The distance from Belle-Ile to Chicago is 2,383 miles. From the Straits of Belle-Ile to the head of Lake Superior, there are 71¾ miles of artificial navigation, and 2,312¼ of open navigation. From the Straits of Belle-Ile to Liverpool, the distance is 1,942 geographical, or 2,234 statute, miles.

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[1] This work is in the library of the Institution.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxix., p. 62.

TABLE of DISTANCES, COMPILED from CANADIAN BLUE-BOOKS.

From	To	Sections of Navigation.	Statute Miles. Inter-mediate.	Statute Miles. Total from Straits of Belle-Ile.
Straits of Belle-Ile	Quebec	River and Gulf of St. Lawrence .	826	826
Quebec	Three Rivers . .	River St. Lawrence to Three Rivers (highest tidal flow)	74	900
Three Rivers . .	Montreal . . .	Head of tidal flow to head of ocean navigation . .	86	986
Montreal . . .	Prescott . . .	Canal section . .	119	1,105
Prescott . . .	Kingston . . .	Head of River St. Lawrence . .	59	1,164
Kingston . . .	Port Dalhousie .	Lake Ontario . .	170	1,334
Port Dalhousie .	Port Colborne . .	Welland Canal. .	27	1,361
Port Colborne . .	Amherstburgh . .	Lake Erie . . .	232	1,593
Amherstburgh. .	Windsor . . .	Detroit River . .	18	1,611
Windsor . . .	St. Mary's Island .	Lake St. Claire .	25	1,636
St. Mary's Island .	Sarnia	St. Claire River .	33	1,669
Sarnia	St. Joseph's Island	Lake Huron . .	270	1,939
St. Joseph's Island	Sault Ste. Marie .	St. Mary's River .	47	1,986
Sault Ste. Marie .	Ditto ditto .	Sault Ste. Marie Canal . . .	1	1,987
Ditto ditto .	Pointe aux Pins .	St. Mary's River .	7	1,994
Pointe aux Pi? .	Fond-du-Lac . .	Lake Superior . .	390	2,384

It will be seen that the length of the St. Lawrence is 1,334 miles. Its drainage area is estimated at 297,000 square miles (or about the same as the Danube), of which one-third is covered by the largest chain of fresh-water lakes in the world.

1. Lake Superior is 390 miles long, 114 miles broad, and has an area of 32,000 square miles; its depth is 900 feet; and the surface of its waters is 628 feet above the sea level.

2. Lake Huron is 270 miles long, and has an area of 20,000 square miles, a depth of 1,000 feet, and an altitude of 574 feet.

3. Lake Michigan is 320 miles long, 100 miles broad, 1,000 feet deep, and 628 feet above the sea. It is connected with Lake Huron by a narrow but deep channel on the north.

4. Lake Erie is 232 miles long, 50 miles broad, and has an area of 9,600 square miles. It is less than 100 feet deep, and has an elevation of 565 feet.

5. Lake Ontario is 170 miles long, 50 miles broad, 500 feet deep, and has an elevation of 232 feet.

The difference between the elevation of the two last-named lakes (333 feet) causes the great Falls of Niagara. These are divided by Goat Island. The Canadian or Horseshoe Fall is 1,800 feet wide, and 158 feet high. The American Fall is 600 feet wide, and 163 feet high. It is estimated that the Niagara Falls discharge 400,000 cubic feet of water per second, a volume equal to the flow of the Danube at Isaktcha at times of ordinary high floods.

Ocean vessels ascend the St. Lawrence as far as the city of Montreal, where ocean navigation terminates, and inland navigation begins. Prior to 1851, no vessel drawing more than 11 feet could pass through Lake St. Peter—a wide expanse of the St. Lawrence between the mouth of the Three Rivers and Montreal; but since then a cutting, 300 feet wide and 9 feet deep, has been dredged through the lake, so that vessels of 20 feet draught can now reach Montreal at low water. This important work cost £257,250, of which the Government paid two-thirds, and the Harbour of Montreal the remainder. A further deepening of the channel through Lake St. Peter has been determined upon, so as to give a depth up to Montreal of 24 feet at low water.

The Canadian canals[1] are the Lachine, the Beauharnois, the Cornwall, the Farran's Point, the Rapid Plat, the Galops, and the Welland. They were constructed at the expense of the Canadian Government. Their united length is $70\frac{1}{2}$ miles, and the total lockage is $536\frac{1}{2}$ feet, through fifty-four locks.

THE ST. LAWRENCE CANALS are all situated between Montreal and Prescott. As shown by the Table (page 18), they have an aggregate length of $43\frac{1}{2}$ miles, and a rise of lockage of $206\frac{1}{2}$ feet. The cost of construction of these six canals, to the 30th June, 1867, was £1,555,200.

It is now in contemplation to enlarge them, and to increase the size of the locks to 240 feet by 45 feet by 12 feet, a work estimated to cost about £2,000,000, including the deepening of the main channel of the reaches between the canals where necessary, so as to admit of the passage of vessels drawing 12 feet of water.

The eastern extremity of Lake Erie overlaps the western end of Lake Ontario in such a manner as to leave only a narrow peninsula between them. The Niagara river forming the eastern side of this peninsula falls, as has been already observed, 333 feet from the upper to the lower lake in a distance of 31 miles. The navigable

[1] Exclusive of the Richelieu and Champlain canals, which will be referred to farther on, and of the Rideau canal, which joins the city of Ottawa with Kingston, and which need not here be referred to in detail, as it is only a feeder to the main line.

THE ST. LAWRENCE CANALS.

Date of Completion.	Name of Canal.	Length in Miles.	Dimensions of Locks.			Width of Canal.		No. of Locks.	Lift.
			Length.	Width.	Depth on Sill.	Bottom.	Surface of Water.		
			Feet.	Feet.	Feet.	Feet.	Feet.		Feet.
1848	[1] Lachine . .	8½	200	45	9	80	120	5	44¾
1845	Beauharnois .	11¼	200	45	9	80	120	9	82½
1843	Cornwall. .	11½	200	55	9	100	150	7	48
1846	Farran's Point	¾	200	45	9	50	90	1	4
and	Rapid Plat .	4	200	45	9	50	90	2	11½
1847	Galops . .	7⅝	200	55	9	50	90	3	15¾
		43½	..	..	..	..	..	27	206½

[1] The Lachine canal was begun in 1821, and completed for the navigation of vessels drawing 4½ feet in 1824, at an expense of £109,601. It was widened and deepened in 1843–48 to the dimensions shown in the Table.

channel of communication between the two lakes, and by means of which the Falls of Niagara are flanked, is by

THE WELLAND CANAL, which is 27 miles in length. It has twenty-seven lift locks, which are, for the most part, 150 feet long by 26½ feet wide by 10¼ feet deep, and has a total rise of lockage of 330 feet. It was first opened in 1833, for the navigation of small vessels; but it only attained its present dimensions in 1867, when vessels of 400 tons burthen could pass through the locks. Up to that date the cost of its construction and maintenance amounted to £1,557,360. The downward movement of freight of all kinds through the Welland canal, in 1871, was 962,565 tons; but the Author has seen no statement of the distribution of this tonnage by the three routes which lead from Lake Ontario to the sea—viz., by the Gulf of St. Lawrence, by Oswego and the Erie canal to New York, and by the Richelieu and Champlain canals to New York. The total exports of grain in 1872 from the ports of New York and Montreal, as stated in the "Returns" of the Montreal Chamber of Commerce, were:—

——	New York.	Montreal.
	Quarters.	Quarters.
Maize or Indian corn . .	1,750,000	1,001,000
Wheat and flour . . .	3,200,000	944,000
Peas, oats, barley, and rye.	85,000	225,000
Total	5,035,000	2,170,000

Works for the straightening and further widening and deepening of the Welland canal were begun last year, and will probably be completed in 1878, at a further expense of £2,000,000. The locks will then be 270 feet long by 45 feet wide, and have 12 feet of water on their sills.

Lake Navigation.—Lake Huron is connected with Lake Erie by the River St. Claire, Lake St. Claire, and the Detroit river. The navigation is easy throughout, except on Lake St. Claire, where there are extensive sandbanks, covered with a depth of water varying from 6 to 10 feet. Previous to 1858 much inconvenience was experienced in navigating the lake from the insufficient depth of water; but at the end of that year the Governments of the United States and of Canada dredged the navigable channel to a minimum depth of 12 feet, and to a minimum width of 300 feet. In consequence of the improvements already effected, vessels carrying 300 tons of cargo can now pass from Lakes Superior and Michigan to Montreal without breaking bulk; and it is confidently anticipated that in less than five years the additional works of improvement which have been referred to, as being either already in progress or in contemplation, will be completed, and thus enable vessels of 1,200 tons burthen to navigate freely between the same points. By far the best and cheapest, as well as the shortest, water route for the transit and exportation of the produce of the north-west of America will then be by the improved Welland and St. Lawrence canals to Montreal, and thence directly to Europe by ocean steamers of the largest class.

It has been aptly stated by Mr. John Young, M.P., of Montreal, that a vessel from sea in the port of Montreal is 120 miles nearer to ports on the lakes than are any of the seaports in North America; while the distances from Chicago, or from any other lake port, to Liverpool, is 480 miles less by Montreal than *viâ* the port of New York.

The Sault St. Marie Canal, 1 mile in length, and 18 feet lockage, avoiding the Sault St. Marie, and uniting Lake Huron and Lake Superior, was constructed by a company with the aid of the United States Congress.

The Erie Canal.—The downward movement of freight of all kinds by the Erie canal from Buffalo and Oswego to tidewater, in 1873, was 2,466,022 tons. This canal was constructed in 1825, by the State of New York,[1] for the passage of vessels of 60 tons;

[1] The total cost, including maintenance and management to the same date of *all* the New York State Canals, which have a combined length of 907 miles, was

but by the year 1862 it was sufficiently enlarged to allow of the passage of vessels of 240 tons. The trunk line of canal, as it may be called, extends from Buffalo on Lake Erie, from Oswego on Lake Ontario, and from Lake Champlain to Albany on the Hudson river, a combined length of 455 miles. The distance from Albany to New York by the Hudson river is 145 miles.

DIMENSIONS and CAPACITY of the ERIE CANAL and of its TWO PRINCIPAL FEEDERS.

Locality.	Length in Miles.	Size of Canal.			No. and Size of Locks.			Rise of Lockage.
		Width on Surface.	Width on Bottom.	Depth of Water.	No. of Locks.	Length.	Width.	
		Feet.	Feet.	Feet.		Feet.	Feet.	Feet.
Buffalo to Albany .	351	70	56	7	72	110	18	655
Oswego to Syracuse	38	70	56	7	18	110	18	155
Lake Champlain to Albany . . .	66	50	35	5	20	100	18	180
	455							

The cost of construction, maintenance, and management of this length of 455 miles, up to the 30th of September, 1873, amounted to $87,299,924, or £17,460,000.

RICHELIEU RIVER AND THE ST. OURS AND CHAMBLY CANALS.—This route of navigation extends from Sorel, at the confluence of the St. Lawrence and Richelieu rivers, 46 miles below Montreal, to the outlet of Lake Champlain, a distance of 81 miles. Thence the line of navigation is by Lake Champlain and the Champlain and Erie canal (already noticed) to Albany and New York. The Richelieu canal has ten locks, with a total rise of lockage of 79 feet; and vessels of 300 tons, 116 feet long, 23 feet beam, and drawing 7 feet, can be passed through the canal from end to end, a distance of 44 miles. The cost of the Richelieu canal works to the 30th of June, 1867, was $756,249.

$107,906,763, or £21,600,000, and the total receipt from tolls $97,025,066. The total freight service on all these canals for the year 1872–3 was 6,673,370 tons, including timber, vegetables, food, machinery, manufactures, and merchandise of every description, the value being estimated at $220,913,321, and the tolls collected amounted to $3,072,411. In the same year, and included in the tonnage, 2,200,000 quarters of wheat and 453,370 barrels of flour (= 3,964,836 barrels in all) were transported from the United States and Canada to tidewater by the Erie canal.

The total length of navigation between Montreal and New York by this route is 456 miles, divided thus:—

		Miles.
Montreal to first lock on the Richelieu, at St. Ours . . .		60
St. Ours lock	32	
Chambly canal	12	
	—	44
Chambly canal to frontier at north end of Lake Champlain .		23
Montreal to frontier		127
Frontier to New York		329
Total . . .		456

After this brief description of the principal channels of communication, from the great fresh-water lakes of North America to the eastern seaboard, it may be useful to refer to the relative traffic expenses of the most important of these routes as compared with each other, and with the route by rail between the same points, as well as to quote the following paragraphs touching on this subject from a Report, dated 29th April, 1872, on the proposed enlargement of the Welland canal, by Mr. John Page, the Chief Engineer of Public Works, Canada.

"Between the head of Lake Michigan and the eastern end of Lake Erie, the distance by water is about 1,000 miles; by land it is only about 500 miles; but even this advantage has not enabled the land routes to compete successfully with that by water for the carriage of those heavy articles which constitute the main items of export.

"It is nevertheless true that flour, animal food, and such other kinds of freight, as either require to be conveyed speedily to market, or the value of which will bear higher transport rates, are now frequently carried by rail.

"During the season when navigation is closed, the movement by the land routes lightens the pressure on the water lines in the open season. Still, the producing powers of the West are increasing so fast as to threaten to outstrip all the existing means of getting the surplus to market.

"The keen competition which exists for this vast carrying trade, has induced the State of New York to reduce the tolls on her canals, 50 per cent., with a view of regaining the large business which has deserted them.

"This was done in the early part of 1870; but although the eastward movement of the Erie canal has increased considerably since that time, it is quite probable that a large portion of this is due to the fact that the crop for exportation in 1871, was much larger than that for 1870.

"Strenuous efforts are now being made to introduce steam power on this route, with a view of diminishing the time necessary to pass through it, and thus lessen the contrast in this respect, between it and the railways. A very large premium has lately been offered by the State authorities, for any design that can be judiciously brought into use for this purpose.[1]

"The great length and limited capacity of this canal, has enabled the railways to take from it a portion of heavy freights, the carriage of which it formerly monopolized, so that it is questionable whether even the entire abolition of tolls, and the successful application of steam power, would do more than partly restore the traffic which it has lost.

"In this connection it may be observed that all the leading lines of communication in the United States, east of the Mississippi river, from the producing regions of the West to the Atlantic seaboard, cross the Alleghany range at some point, with the exception of the Erie canal and the New York Central railway, which are carried through a break in the chain, forming the valley of the Mohawk river.

"This being the best possible route for a canal in that direction, gives it an advantage, for the western trade, over all other water channels in the United States; still it does not present a continuous downward lockage towards tidewater; the long level at Rome being higher than those to the east and west of it—and although its draught of water is comparatively small, the supply is maintained with great difficulty during dry seasons.

"There cannot be a doubt but that there will always continue to be a considerable competition, between railways and canals, for the carrying trade eastward from the foot of Lake Erie; but from the westward to that point the water route, although twice the length of that by land, will in all probability keep the lead.

"This may safely be inferred from the known characteristics of the navigation, and the large class of vessels employed on it,

[1] It has since been affirmed on good authority that the most economical mode of employing steam on the Erie Canal is in vessels carrying their own machinery and 200 tons of cargo. The greatest obstacle to the development of steam power on the Erie and Welland canals is the smallness of their locks. The last report of the New York State Engineer states that the progress made in the use of steam for towing warrants the belief that it will supersede all other kinds of motive power on the Erie canal.

some of which draw about 12 feet of water, and are capable of carrying from 40,000 to 50,000 bushels of wheat.

"This, together with the rapidity with which vessels can be unloaded, and allowed to proceed on their return voyage, and the attractions of the commercial port of New York, must, to the extent of these advantages, have a tendency to throw the stream of trade towards Buffalo.

"To the westward of this point the route to the heads of Lakes Michigan and Superior, is common to all; so that the rivalry between the New York State canals and those on the St. Lawrence for the carrying trade to the seaboard, may very properly be said to commence at the foot of Lake Erie.

"If vessels of the capacity above mentioned could proceed downwards without breaking bulk, until alongside the ocean-bound ship, a great object would be achieved, and a route established which might reasonably be expected to defy successful competition for the cheap and rapid transport of the heavy and bulky articles of agricultural produce."

In comparing the distances, and in calculating the relative cost of the transport of grain by water and land carriage to the seaboard, the Author has selected the famous port of Chicago—the largest grain emporium in the world—as being the best point of

COMPARISON of DISTANCES and TRANSIT CHARGES from CHICAGO to the SEABOARD by WATER and LAND CARRIAGE.

	Distance in Miles.	Expense per Quarter. s.	d.
To Montreal, by the lakes, the Welland and the St. Lawrence	1,278	4	7
To New York, by Buffalo, the Erie Canal, and the Hudson river	1,418	5	7
To New York, by the lakes, the Welland, Oswego, and Erie Canals, and the Hudson	1,412	5	1
To New York, by the lakes, the Welland, the St. Lawrence, Richelieu, Champlain, and Erie Canals and the Hudson	1,632	5	0
To New York, by railroad	960		
Winter season	..	11	0
Summer season	..	8	0

	Cost of Transport in 1872.
From Buffalo to New York by canal and river, including tolls	$\frac{7}{10}$ cent per ton per mile
Ditto by canal and river, without tolls	½ cent " "[1]

[1] The charge for transport by steam power against the stream on the Rhone, from Arles to Lyons, a distance of 200 miles, is 1 cent (½d.) per ton per mile. Ditto with the stream on the Danube, between Galatz and Sulina, a distance of 106 miles, is ½ cent (¼d.) per ton per mile.

departure eastward, both on account of its pre-eminence as a lake city, also because it is situated at the head of Lake Michigan, and, therefore, as far from the Atlantic as the "Fond du Lac" in Lake Superior.

The exports of grain alone, from Chicago, for home and foreign consumption, reached 10,375,000 quarters in 1872, or nearly two-thirds of the total receipts of grain from all the lake ports together, which, in the same year, amounted to 17,500,000 quarters.[1]

The average rate of freight on wheat by canal and river from Buffalo to New York was—

For 1872	. . . .	10·9 cents per bushel.
" 1864	. . . .	18·9 " "
" 1863	. . . .	17·7 " "
" 1862	. . . .	15·8 " "

When the rate by railways from Buffalo to New York is reduced to 1 cent ($\frac{1}{2}d.$) per ton per mile, the expense will be reduced to 13·5 cents per bushel.

The average charge per ton per mile on all freight, carried on the Lake Shore and Michigan Southern railway,

was 1·5 cent in 1870
and 1·39 " in 1871.

The Author is indebted to Mr. W. J. McAlpine, M. Inst. C.E., for the above information relative to the transport charges by water, and to some of the most influential merchants in Chicago for the account of the charges by rail.

The water communication between the lakes and the sea is practically closed for navigation for five months in the year, viz., from December to April inclusive Grain can then only be transported by rail, and, on this account, the freight by rail is sometimes increased 50 per cent., obviously in the absence of a healthy competition. Notwithstanding the disadvantages that the water transit experiences in this respect, as compared with the transit by rail, in 1872, out of 11,500,000 quarters of grain brought to Buffalo from the west, 7,750,000 quarters arrived by water, and only 3,750,000 quarters by rail. In connection with the enormous shipment of grain, it should be mentioned that it is loaded and unloaded by steam elevators in a very expeditious and practical manner, and at a comparatively small cost. At Chicago, on the 31st of December, 1872, fifteen elevator warehouses, with a total capacity of 1,600,000 quarters, were already built, and by the end of 1875 it is calculated that there will be warehouse accommoda-

[1] The total yield in the United States in 1872 of maize or Indian corn ("corn") was 138,000,000 quarters, and of wheat 30,000,000 quarters.

tion for 2,000,000 quarters. The rates for the storage of grain in these warehouses is about 2 cents per bushel (8*d.* per quarter) for the first thirty days or parts thereof, and ½ cent per bushel (2*d.* per quarter) for each fifteen days additional. Elevator warehouses on a large scale are also provided at Buffalo and at Montreal. At the latter port, as well as at Kingston, and many of the ports on the Atlantic seaboard, floating steam elevators are extensively employed for transhipping grain from one vessel into another. In this way from 400 to 500 quarters of grain per hour can easily be transferred, or say, a ship of from 1,000 to 1,200 tons can readily be loaded in one day. The charge for this operation at Kingston and at Montreal is ½ cent per bushel (2*d.* per quarter), of which one-half (¼ cent) is paid by the vessel discharging and one-half by the vessel receiving. Magazine elevators are of great service where grain is brought to a port by rail, as at Chicago for instance, and floating elevators answer best where lighterage is required, as at Kingston, or where the inland navigation ends and ocean navigation begins, as at Montreal. No doubt similar facilities for the storage and handling of grain might be introduced with great advantage at many of the great corn-exporting ports of the Baltic and Black Sea, where the most primitive modes of loading grain by hand labour are still in vogue.

The Mississippi and its Tributaries.

The Mississippi drains the greater part of the United States lying between the Alleghany and the Rocky Mountains, and its basin surpasses in area the whole continent of Europe, exclusive of Russia, Norway, and Sweden.[1] To compare its rank as a river with that of the Danube, it may be stated—

1. That the Mississippi drains an area of 1,244,000 square miles, the Danube an area of 300,000 square miles.

2. That the mean discharge of the Mississippi is 618,000 cubic feet per second, or 675,000 cubic feet including the three outlet bayous, and that of the Danube is 207,000 cubic feet per second.

3. That the length of the Mississippi, reckoning from its mouth to the source of the Missouri, is 4,194 miles; and that of the Danube, 1,700 miles.

It may therefore be said that the chief river of North America is more than three times greater than the chief river of Europe.

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[1] The topographical description of the Mississippi and its branches is principally derived from Generals Humphreys and Abbot's great work on the "Physics and Hydraulics of the Mississippi River."

The true Mississippi begins at the confluence of the Missouri and the Upper Mississippi. Its five principal tributaries, in the order of the magnitude of their basins, are, the Missouri, Ohio, Arkansas, Upper Mississippi, and Red River.

The area of the basin of the Missouri is 518,000 square miles, and its mean discharge is 120,000 cubic feet per second, or about one-fifth that of the Mississippi at New Orleans. Unlike the other tributaries of the Mississippi, a large portion of the Missouri basin consists of lofty mountain chains. Comparatively little rain falls upon the mountains and the plains, and hence the size of the main river is disproportionately small when the drainage area alone is considered. The annual discharge of the Missouri is only three-fourths that of the Ohio, although its basin is nearly two and a half times as large. Ascending the river, the Missouri divides, at Fort Union (1,894 miles from the Missouri mouth), into two branches of about equal size, the Yellowstone and the Upper Missouri. The source of the Upper Missouri branch, which has an elevation of 6,800 feet above the sea, is 2,908 miles above the mouth of the Missouri; and that of the Yellowstone branch, 2,439 miles. The range of the Missouri, between high and low water, is about 35 feet at the mouth. The navigation of this river depends upon the temporary floods; and barges are loaded and their time of starting is regulated accordingly. Vessels drawing from 3 to 4 feet carry from 150 to 250 tons of cargo to the Yellowstone branch, and make the passage up in from twenty-two to thirty-five days. At seasons of low water there is only a depth of 1 foot on many of the bars of the Missouri, and at such times the navigation is practically closed. No efforts have yet been made to deepen these bars; and operations for clearing the river of impediments have hitherto been confined to the removal of 'snags,' which abound in the lower part of the Missouri, and render the navigation of vessels by night extremely dangerous.

The distinguishing character of the Upper Mississippi is the entire absence of mountains in the basin which it drains. Near the source of the river the country is only about 1,680 feet above the level of the sea. The area of its basin is 169,000 square miles.

DISTANCES.

	Miles from Source.	Miles from Mouth of Missouri.
Source	..	1,330
St. Paul (Falls of St. Anthony)	672	658
Rock Island Rapids (head)	1,020	310
Des Moines River	1,165	165
Illinois River	1,306	24

Falls of St. Anthony.—These falls, which are a complete barrier to the navigation of the Upper Mississippi, are caused by the damming up of the waters by a layer of limestone rock (which is 11 feet thick at the crest of the falls, and 3 feet thick at its upper end, about 1,000 feet above the crest), overlying a mass of sand rock about 100 feet in thickness. The total fall is 50 feet. The crest of the falls is continually receding, and in 1872 it was from 300 to 600 feet above its position in 1857. This retrogression is caused by the falling water undermining the sandstone which sustains the limestone, so that the latter becoming unsupported breaks off by its own weight. In order to preserve the falls from further erosion, and consequently to perpetuate the utility of the water-power caused by them, which involves large interests, works are now in progress to prevent the wearing away of the sandstone at the foot of the falls, and to stop the upper current from passing through the soft sandstone rock under the limestone ledge. The sum of $200,000 (£40,000) will be necessary to fix the position of the falls permanently. The range between high and low water at St. Paul is 20 feet.

Rock Island Arsenal.—This establishment, which is now in course of construction under the able direction of Colonel Flagler, of the Ordnance department, is apparently destined to be the most important arsenal in the United States, for the manufacture and storage of arms and all other military equipments, whether for land or river service. Rock Island has an area of 1,000 acres, elevated from 30 to 35 feet above the river, and is joined at its lower end to the city of Rock Island, in Illinois, and the city of Davenport, in Iowa, by a road and railway bridge. Its upper end is connected with the city of Moline, on the Illinois, or left bank, by a Government wagon bridge. The island is about 3 miles long; and as the river falls 9 feet in this distance, important, substantial, and well-designed works have been constructed, to utilise this fall as much as possible, by the use of turbines in the Illinois channel, not only for working the machinery of the arsenal, but for the large paper and iron mills in Moline city. The water-power is estimated at 2,600 horses, of which the Government is bound to make over one-fourth to the mills in perpetuity. Colonel Flagler is in favour of transmitting the water-power to the arsenal by the wire-rope system, as practised at Schaffhausen and Moline, which he considers to be more economical than the system of compressed air, as adopted at many similar localities. Each of the ten buildings forming the arsenal and armoury will cover an area of 1 acre; and as each will have four floors, the total floor area will be 40 acres. At the time of the Author's visit, only three of the buildings were completed. They are solidly built, and are all fireproof—the walls being of Joliet stone, the girders of malleable iron from the Phœnixville works, the arching between the girders of brick, the floors of concrete, covered where necessary with planking, the framework of the roofing of iron, and the roof itself of slate.

Rock Island Rapids.—These rapids are 348 miles below the Falls of St. Anthony, and extend from St. Claire to Davenport, a distance of 14 miles, with a total fall of 21½ feet. The mean width of the Mississippi in this distance is 2,500 feet; the velocity varies from 1½ mile to 3½ miles an hour. The bed of Rock Island Rapids consists of chains of hard magnesian limestone, which dip to the south more rapidly than the surface of the water. They are seven in number, and, before the improvements, either overlapped each other, leaving only a narrow, tortuous channel between them, or extended entirely across the river. Between the chains, throughout almost the entire distance, there is a wide and navigable channel, and at such places the velocity of the current is much less. These pools have an aggregate length of 11 miles, so that the obstructed portion of the river to be improved has only a length of 3 miles. The ordinary range between high and low water at Rock Island is 16 feet. The maximum range, observed by Lieutenant Warren (now Brevet-Major-General, U.S.A.) in 1851, was 23 feet at Davenport, and 13 feet at the head of the rapids. On account of the hydrographic features of the rapids, it was deemed advisable to cut simple channels through the reefs, rather than to avoid them altogether by adopting the more expensive plan of constructing a lateral canal, furnished with locks, as at the Des Moines and Ohio Rapids. It was therefore decided, in December, 1866, to enlarge by excavation the old steamboat channel of the Rock Island Chains to a width of 200 feet, and to a depth of 4 feet at the time of low water, which is somewhat greater than the ruling depth in the river north and south of the rapids during that season. The estimated quantity of excavation for this work was 57,451 cubic yards, and the estimated cost $813,602 (£162,000). The Author was told by Major Hoffmann, the inventor of an ingenious and accurate mode of sounding a rocky bottom, that the cost of excavating by contract 60,000 cubic yards of rock over large areas, by means of low-water cofferdams, had varied from $10 to $13 per cubic yard during the last six years; whilst, in the same period, the breaking up of half that quantity by of Osgood and Whitney's steel chisels (weighing

8,000 lbs. each, and worked by machinery similar to that used for pile-driving) had varied from $13 to $18 per cubic yard, including the dredging of the pulverised material. The improvements were begun in 1867, and were nearly completed at the time of the Author's visit in November, 1873, when he was informed by Colonel Macomb of the Corps of Engineers, U.S.A., who has charge of the works, that there is now no difficulty in passing by the new channel, except during unfavourable winds; and that, so far as has yet been observed, no lowering in the level of the pools between the chains, or in the river above the rapids, at low water, has been caused by the cutting above described.

Des Moines Rapids.—These rapids are situated immediately above the Des Moines river, at 145 miles below Rock Island. They extend from Montrose, where the width of the channel is 5,000 feet, to Keokuk, where it narrows to 2,500 feet. During the low-water season, they interpose a serious, and at times an impassable barrier, to steamboat navigation. The river bottom, which, for the most part, consists of carboniferous or mountain limestone, is a broad, smooth rock, seamed by a crooked channel 50 feet wide and 3 feet deep, and the rapids, therefore, are not broken and noisy, but, the descent being gradual the water flows over its bed in a smooth, unbroken sheet, with a varying velocity of from 1½ mile to 3½ miles an hour.

After long discussions as to the best mode of overcoming the difficulties of the rapids, the execution of the project of General Wilson, U.S.A., to construct a lateral canal on the right or Iowa bank, was decided upon in 1867. The works were begun in the following year, and by the end of 1873 more than two-thirds had been completed. The Author is indebted to Major Stickney, of the Corps of Engineers, U.S.A., for the greater part of the following particulars concerning the canal works, for which he is the Resident Engineer under Colonel Macomb.

The canal skirts the Iowa or right bank, and is 8 miles long, 200 feet wide in cuttings and 300 feet where embanked. It is furnished with two lift-locks, the lower one of which has a lift of 11 feet, and the upper one—2 miles above the lower one—a lift of 8 feet. At 8 miles above the lowest lock is a guard lock, by means of which, when the water is 3 feet above extreme low water, a depth of 8 feet can be maintained in the canal, which, as well as the lift-locks, will only have a depth of 5 feet at low water. All the locks are 350 feet long by 50 feet wide, and are admirably constructed of solid masonry. The lift-locks are fed and emptied, through the walls of the lock-chambers, by culverts at nearly equal distances apart along the whole length of the chambers. The puddled embankment wall of the canal is mostly founded in the bed of the river, and is carried up to a height of 2 feet above the level of high water. It is 10 feet wide at the top, has slopes of $1\frac{1}{2}$ to 1, and is protected on both sides with "rip-rap" (rubble stones). The range between high and low water is 22 feet at Keokuk, and 12 feet at Montrose. The excavation of rock amounts to 400,000 cubic yards, and of loam to 800,000 cubic yards. The estimated cost of the canal, including $259,000 (37,000 cubic yards at $7) for the excavation of a channel through a chain of rocks at Nauvoo, at the head of the rapids, opposite Montrose, is $3,200,000 (£640,000)—a sum nearly one-third in excess of the original estimate. The cost of the rock excavation, exclusive of cofferdams and pumping (which trebles the expense), has varied from $2·20 to $3·50 per cubic yard, and the earth excavation from 30 cents to 65 cents. The interior of the embankment (derived from the excavation) cost 70 cents per cubic yard. The cost of the cut stone masonry, from quarries in the neighbourhood, was $10 per cubic yard, and of the concrete masonry $4. Major Stickney deprecates the system of executing hydraulic works by contract, and is of opinion that the canal could have been executed at more than 25 per cent. less if, from the first, and as is now the case, the work had been carried on under the immediate orders of the Engineer.

THE ILLINOIS RIVER.—At 145 miles below the Des Moines rapids, and 24 miles above the Missouri mouth, the Illinois river joins the Mississippi after a course of 450 miles through the rich and fertile State of Illinois. A description of the lower part of the river, and of the plan proposed to render it navigable for large steamers, in connection with the improvement of the Illinois and Michigan canal, is referred to in the following extracts from the Report of General Humphreys, the Chief of Engineers of the U.S.A., dated 13th May, 1867:—[1]

"The distance from Grafton, at the mouth of the Illinois to the outlet of the Illinois and Michigan canal at La Salle, is 224 miles. The difference of level between the two points in the plane of low water is 29 feet. The river varies in width from 500 feet to 1,400 feet.

"In ordinary and high-water stages it affords good navigation for the largest class of steamboats used on the Mississippi; while at

[1] *Vide* Annual Reports of the Chief of Engineers, which may be consulted in the library of the Institution.

low water it can only be used by the smallest class of flat-bottomed boats. The whole distance, from the mouth of the Illinois river to Bridgeport, near Chicago, by river and canal, is about 320 miles, and the lockage between the two points (ordinary water level of Lake Michigan and low water of the Mississippi) is about 170 feet, which, by making a through cut from Chicago river to Lockport, on the Des Plaines river, would be all a descending lockage, with the lake as a summit.

"General Wilson recommends the improvement of the Illinois river by a system of locks and dams, and that the navigation be extended from Lockport to Chicago by the enlargement of part of the Illinois and Michigan canal, giving a depth of 7 feet, both in the river and canal, with locks 350 feet long and 75 feet wide.

"The distance from La Salle to Chicago is 97 miles. It is proposed to cut down the present summit to low-water level of the lake. With the exception of two short canals, it is deemed advisable to abandon the old location, and to improve the natural channel of the river by locks and dams, they being less expensive than the enlargement of the original canal.

"Estimated cost of canal from Bridgeport (4½ miles from Chicago) to Lockport, 29 miles long, 160 feet wide, and 7 feet deep	10,098,000
Improvement from Lockport to La Salle.	8,118,200
River improvement from La Salle to Grafton	3,123,796
Total	$21,339,996 (£4,267,999)

Being about $68,000 a mile."

Since the above report was written, the canalisation of the river below La Salle has been begun, and the first slack-water pool has been created over a length of 28 miles by the construction of a lock and dam at Henry—a work which was successfully completed at an expense of $400,000 (£80,000). The lock at Henry is 350 feet long by 70 feet wide; the side walls are 30 feet high, although the lift of the lock is only 6 feet. A similar lock has been commenced at Copperas, 61 miles below Henry; and when this and three other shave been completed, at intervals apart of 61½ miles, 29¼ miles, and 41 miles respectively from Copperas, thus converting the lower half of the Illinois into a series of five pools, each with a lift of 6 feet, vessels drawing 6 feet of water, and carrying from 1,000 tons to 1,200 tons, will be able to navigate at all seasons between the Illinois mouth and La Salle. Until, however, the improvements recommended by General Wilson, between La Salle and Chicago, have been carried out, the dimensions of vessels on that part of the route must be restricted to the size of the locks of the Illinois and Michigan canal, which are only 110 feet long by 18 feet wide. Hitherto, the only executed portion of the proposed improvement, between La Salle and Chicago, has been the cutting through the summit level of 26 miles which divides the valleys of the St. Lawrence and the Mississippi. This work was performed at the expense of the city of Chicago, as it was considered the best means of getting rid of the sewage matter of the city, and was completed at an expense of $3,301,000 (£660,000) in 1871.

THE MICHIGAN CANAL.—By means of this cut, the bottom of which is 8 feet below the level of Lake Michigan, the Chicago river, with most of its impurities, and a clear stream from Lake Michigan itself, now flow into the Michigan canal, and thus help to feed the Illinois river. The real importance of the improvement of the Michigan canal and the Illinois river can only be properly estimated by regarding it as completing a system of water communication between the east and the west.

The Mississippi mouth has ceased, it is alleged, to be the great outlet for the trade of the Upper Mississippi and Missouri. The present course of trade from these vast regions indicates that it is gradually being diverted to the east, and abandoning its natural course by New Orleans and the mouth of the Mississippi, which is inaccessible to the large ocean steamers now trading to Boston, New York, Baltimore, and Philadelphia.

The improvements up to this time, excepting those already mentioned at Rock Island and Des Moines, have been confined to the dredging and scraping of bars, the removal of snags, and the cutting of trees to prevent them from forming new snags.[1]

Dredging and scraping are mere palliatives, and if carried on by fifty dredgers, instead of by the solitary machine now employed, but little impression would be made on the shifting sandy bars which stretch across these mighty rivers in innumerable places, and, at times of low water, make the river impassable

[1] From June, 1869, to June, 1870, four snag boats, which are very ingeniously contrived, removed 3,031 snags, weighing 60,000 tons, and cut down 33,500 trees in the Upper Mississippi, Missouri, and Arkansas rivers. The annual expense of working these four snag boats, the cost of which was 100,000 dollars each, is $340,000, and of the dredger $60,000, or $400,000 (£80,000) in all.

to craft larger than a fishing boat. In respect to this discouraging condition of the Upper Mississippi and Missouri, Colonel Macomb in his Report to the Chief Engineer, on the 20th of September, 1870, remarks :—

"The works of improving the western rivers belong to the class of works which may be considered as indefinite or admitting of no permanent completion. It is indeed in the very nature of these great rivers, flowing through vast bottom lands, that such should be the case; for improve the channel as we may one season, in the following year it will very likely be found that some of the improved reaches of channel have been abandoned by the river, and a channel chosen with dangers in it requiring a repetition of our labours, or new improvements."

THE LOWER MISSISSIPPI.—It has been already remarked that the true Mississippi begins at the confluence of the Missouri and the Upper Mississippi.

DISTANCES AND INCLINATION AT HIGH WATER.

	Inter-mediate Distances.	From the Missouri Mouth.	From the Mississippi Mouth.	Right or Left Bank of the River.	High Water above the Gulf of Mexico.	Slope per Mile.
	Miles.	Miles.	Miles.		Feet.	Inches.
Mouth of the Missouri .	..	..	1,286	right	..	..
St. Louis	16	16	1,270	right	408	..
Mouth of the Ohio (Cairo)	173	189	1,097	left	322	6
„ of the Arkansas.	405	594	692	right	149	5
„ of the Red river	376	970	316	right	49	3½
New Orleans . . .	211	1,181	105	left	15	2
Head of the passes of the Mississippi . .	105	1,286	..	..	..	1½

ST. LOUIS.—This important city of four hundred and fifty thousand inhabitants is situated on the right bank of the river in the State of Missouri, and is the largest inland city in the United States.[1]

[1] The celebrated Horace Greely, late Editor of the "New York Tribune," thus describes "the future great city" in a letter to Mr. L. U. Reavis, of Missouri, on the 4th of Feb., 1870:—"I have twice seen St. Louis in the middle of winter. Nature made her the focus of a region embodying a vast area of the most fertile soil on the globe. Man will soon accomplish her destiny by rendering her the seat of an immense industry, the home of a far-reaching, ever-expanding commerce. Her gait is not so rapid as that of some of her Western sisters, but she advances steadily and surely to her predestined station of the first inland city on the globe."

It is 16 miles from the Missouri mouth, and is now joined to the Illinois bank by the most remarkable bridge of modern times. This bridge has already been briefly described. No other bridge spans the Mississippi between the mouth of the Missouri and the Gulf of Mexico, a distance of nearly 1,300 miles.

THE OHIO RIVER.—This river flows into the Mississippi at Cairo, 173 miles below St. Louis. The average width of the Mississippi between these cities is 4,000 feet, and the least depth at any point is 2 feet at extreme low water. The total area of the Ohio basin is 214,000 square miles, and its annual discharge of water is 150,000 cubic feet per second, or one-fourth that of the Mississippi. The Ohio is formed by the junction of the Alleghany and Monongahela rivers at Pittsburg.[1] Throughout its whole length (967 miles) the river flows with a gentle current uninterrupted by rapids, except at the Falls near Louisville. At low water the Ohio is a succession of long pools and ripples, with a current alternately sluggish and rapid. The bars in the upper part of the river are mostly gravel and boulders, in the lower part shifting sand. The range between extreme high and extreme low water is about 45 feet throughout the entire river.

	Depth.	Distance from Pittsburg.	Fall in Feet.	Fall per Mile in Inches.
At Wheeling	45 feet . .	91 miles	79	10½
„ Louisville, on the Falls .	42 „ . .	598 „	308	5½
„ „ below them .	64 „ . .	601 „	333	100
„ Evansville.	40 „ . .	783 „	384	3⅓
„ Paducah	51 „ . .	920 „	418	2¼
„ Cairo (mouth) . . .	51 „ . .	967 „	427	2

The usual range is 25 feet. The width of the river varies from 1,200 feet to 3,000 feet. Proceeding upwards, the least low-water depth on the bars from the mouth of the river is, to Paducah, about 3 feet; to Louisville, 1½ foot; to Cincinnati, 2 feet to 2½ feet; and to Wheeling, 1 foot.

The business on the river is so arranged, that, at periods of very low water, all through steamboat traffic on the Upper Ohio ceases. The great bulk of the river traffic is, however, carried on

[1] The Alleghany river, 290 miles long, is navigable for steamers for a distance of 259 miles above Pittsburg. The Monongahela river was 'slack watered' in 1842 and 1856 for 84 miles above Pittsburg by the construction of six dams and eight locks. Six of the latter are 190 feet long by 50 feet wide, and the other two are 250 feet by 56 feet. The cost of the work was about $600,000 (£120,000).

when the depth of water is 3 feet or more in the channels, which is on not less than two hundred and sixty days in the year.

The Falls of the Ohio at Louisville, which descend 25 feet in 3 miles, and which have been called a natural rock dam, are not navigable at extreme low water. At very high water any craft can pass them safely; and at medium floods, with good pilots, steamers and other vessels are taken over.

In 1825, the Louisville and Portland Canal Company obtained authority to make locks (184 feet by 50 feet), and a canal on the Kentucky side, and the first boat passed through in 1828. This canal is now superseded by an improved one with new locks, constructed in 1860–66 by the United States Government, under the direction of General G. Weitzel, U.S.A., at an expense of about $1,800,000 (£360,000), after nearly the same amount had been spent on the works by a private company.

The following information concerning the Portland canal was given to the Author by Captain Adams of the Corps of Engineers, U.S.A., who kindly accompanied him over the work of which Captain Adams had then the charge.

The canal is 2½ miles long, and is cut mostly in rock through a neck of land, about 70 feet above low water, between two reaches of the river on the Kentucky shore. By it, a level of 26 feet is surmounted at low water, at which time there is a depth of 6 feet of water in the canal. Of this depth 2 feet are obtained by the backwater caused by a dam of cribwork (not yet completed), which crosses the river at the upper end of the canal. Near the Indiana shore this dam has an opening or 'chute,' 400 feet wide, for the passage of vessels when the locks are not required. The canal is about 80 feet wide, and has vertical walls of masonry 12 feet high. The upper guard lock is about ¼ mile above the entrance to the canal, and its gates being but little higher than the vertical walls will only be useful in case of repairs, and are of no service in damming back the water, which sometimes rises 42 feet above the falls. When the water rises to 12 feet in the canal, the latter is no longer used by vessels descending the river, as they can then run the rapids without difficulty or danger. The two lower locks are 390 feet by 80 feet in the chamber, and each has a lift of 14 feet.[1] The lower gates are 68 feet high to provide against high floods, which have been known to rise 65 feet below the falls.

[1] Although the locks of the Portland and Des Moines canals are the largest canal-locks in the world, some of the steamers on the Mississippi which trade between St. Louis, the Ohio, and New Orleans, from their breadth of beam,

Vessels now pay 50 cents (2*s.*) per ton for passing through the canal, but it is expected that this high rate will soon be reduced 50 per cent.

OTHER WORKS OF IMPROVEMENT ON THE OHIO.—These are of slight importance, and have hitherto been confined to dredging the more obstructive bars, and constructing here and there what are called 'rip-rap' dams (artificial dams of rubble stones), with a view of concentrating the flow of the stream into comparatively narrow channels, to secure an additional depth of water.

Although these measures are of a very palliative kind, they would undoubtedly improve the navigable channel of the Ohio, if carried out systematically year by year on a commensurate scale, throughout the entire length of the river. When it is stated, however, that an annual grant of only $100,000 (£20,000) is allowed for this work, it is not surprising that no one can say precisely how much real improvement in the river has been achieved since the attempt to deepen the channel was begun. Various plans have been suggested by American engineers during the last half century to effect a radical and permanent improvement of the Ohio. Of these may be noticed :—

1. Mr. C. Ellet's plan of artificial reservoirs to store up water enough, when gradually drawn out at low-water seasons, to make a perennial flow 6 feet deep in the channels.

2. The scheme of a continuous canal 200 feet wide on one side of the river.

3. The method of locks and dams similar to the actual navigation on the Monongahela, and to that now under execution on the Illinois river.

Difficulties and objections are inherent to each of these expedients, but of all the schemes proposed it is generally believed by those who have carefully studied the subject, that locks and dams, with chutes so arranged that coal fleets might be passed from one pool to another without division, would be the best and most economical means of securing the desired depth of water from Cairo to Pittsburg, say, 6 feet, at all seasons. This is the decided

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cannot pass through them. For instance, the "City of Richmond" steamer, which the Author inspected at St. Louis, had the following dimensions :—

Extreme length 340 feet.	Two 5-feet cylinders and 10-feet stroke.	Burthen, 2,500 tons.
" width 85 "	Six boilers.	Height, from water-line to top of funnels, 92 feet.
Load line } draft { 11 "	Paddle-wheels, 44 feet in diameter.	Ditto, to top of pilot house, 60 feet.
Light line } draft { 4 "		

opinion of Mr. W. Milnor Roberts, the Engineer in charge of the Ohio river improvement, who, in a report, dated the 11th of April, 1870, to General Humphreys, on the radical improvement of the Ohio, estimates the cost of the system as follows:—

Pittsburg to Louisville 598 miles.			
51 sets of locks double, 370 feet by 80 feet, and 300 feet by 60 feet, with 6-feet lifts, including dams and chutes at . . .	$ 334,357	=	$ 17,052,207
Louisville to Cairo 369 miles.			
15 sets of locks, do. do., with dams and chutes at	334,357	=	5,015,350
Extra length of dams below the falls . .			1,710,105
			$23,777,662

£4,700,000, or $23,550 per mile for 967 miles.

So far as the Author has been able to learn, no works have yet been undertaken for the improvement of the navigable channel of the Mississippi river below Cairo, although at low water the depth on some of the shoals between that city and the mouth of the Red river, a distance of 781 miles, does not exceed 5 feet. Surveys and projects are now being made, however, for the improvement of these bars. The width of the Mississippi at the Red river landing is 3,620 feet at high water and 2,650 feet at low water. The distance from the mouth of the Ohio to tide-water by the Mississippi river is about 1,100 miles, and the average fall is at the rate of 3 inches per mile. The mean area of cross section at high water over this length is 195,000 square feet, and the mean annual rainfall $30\frac{1}{2}$ inches.

The Arkansas River joins the right bank of the Mississippi at 405 miles below Cairo. The area of its basin, including that of the White river, is 189,000 square miles, and the mean annual discharge is at the rate of 63,000 cubic feet of water per second. This river is 1,514 miles long; the width varies from 1,500 to 5,000 feet, and the least depth on the bars at low water is 1 foot. The estimate for its improvement for the year ending the 30th of June, 1874, is $100,000 (£20,000) for the running expenses of four snag boats, five months each at $5,000 per month.

The Red River joins the right bank of the Mississippi 781 miles below Cairo, and at 316 miles from the Mississippi mouth. It is 1,200 miles long, the width varies from 800 to 2,000 feet, and the least depth of water on the bars is also 1 foot. The area of the basin is 97,000 square miles, and the mean annual discharge of water is 57,000 cubic feet per second.

The only expenditure made by the Government for the improvement of this river has been in the many attempts to remove the obstruction known as the "Red river raft," which is composed of an immense accumulation of drift wood, partly sound, partly rotten, partly sunk, and partly afloat, but always advancing steadily up the river. Its length in the summer of 1854 was 13 miles, and it had then advanced to a point 53 miles above Shreveport.[1]

THE DELTA (Plate 7).—Just below the confluence of the Red river is the first of the bayous,[2] which, fed by the Mississippi, discharge into the Gulf of Mexico. Below this point the great river receives no appreciable increase from tributaries. It has, therefore, for these reasons been generally considered the head of the delta. On the assumption that a delta begins where it first sends off a branch to the sea, at the head of the bayou Atchafalaya in this instance, the delta of the Mississipppi has an area of 12,300 square miles, of which one-third is composed of sea marsh. It is contended by some writers, however, that the origin of the delta is 3 miles below Cape Girardeau (47 miles above the mouth of the Ohio), where the waters of the Mississippi used to escape into the St. Francis, and thence through the Arkansas valley into the Atchafalaya, &c.; and that, therefore, the area of the delta is really 38,706 square miles. This is stated in a recent paper by Professor C. Forshey. Between Bayou la Fourche (the last of the outlets) and Fort St. Philip, the Mississippi flows through a tolerably uniform channel, averaging at low water 200,000 square feet in cross section, 2,470 feet in width, and 120 feet in depth at the deepest part. In the low-water stage, these measurements are 163,000 square feet, 2,250 feet, and 114 feet respectively.

LEVEES AND CUT-OFFS.—Between Cairo and Fort St. Philip 1,600 miles of levees, or embankments, have been constructed to protect the adjacent lands from overflow; but the system was so imperfect in 1869 (and the same may even now be said) that General Abbot, U.S.A., reported that an outlay of $38,230,000 was required to raise the existing levees in the states of Arkansas, Mississippi, and Louisiana, ($19,060,000, $4,150,000, $15,020,000 respectively) to their proper height. This sum, at the estimated cost of the work,

[1] Since this was written the Author has been informed by General Humphreys that the raft has been removed, and that by annual grants from Government its re-formation is to be prevented.

[2] A bayou in Louisiana means a stream not so large as a river, and a creek properly so called.

viz., 40 cents per cubic yard, represents embanking to the amount of 95,600,000 cubic yards.[1]

The efficacy of 'cut-offs' as a means of relief from floods has been contested by many authorities on the 'régime' of the Mississippi. In December 1874 General M. Jeff Thompson, Chief State Engineer, reported to the Governor of Louisiana that two out of the six cut-offs, made below the mouth of the Arkansas and Tunica since the days of steamboats, were fast elongating themselves, at the expense of the levees. With regard to these this engineer remarks that there are none from Cairo to Memphis on the left bank, nor from Vicksburg to Baton Rouge, except a few private ones; but that there has been a system of levees along the whole of the right bank, from Commerce to Fort Jackson, near the mouth of the Mississippi. He also adds that from Memphis down to the mouth of the Tazoo, and from Baton Rouge down to Fort Philip on the left bank, the levees form a complete system.

An aggregate length of 107½ miles of levees—wings and main line included—were lost from October 1866 to October 1874, in consequence of the caving of the banks of the river in the State of Louisiana. During the disastrous floods of the spring of 1874, a crevasse of unusual magnitude occurred at Bonnet Carré, in Louisiana, of which a detailed account (from the Levee Commissioner's report) is given in Appendix I.

Twenty miles below Fort St. Philip, a great change takes place. (Plate 7.) The river widens to 8,000 feet, with a maximum depth of about 40 feet, and a cross section of about 250,000 square feet. It then separates into three principal branches, called from the directions they take, the South-West Pass, the South Pass, and the North-East Pass, the latter sending off a branch called the Pass à l'Outre. The dimensions of these passes are shown by the Table on the next page.

The bars at the mouths, are composed of sand and soft mud, and are described in Humphreys' and Abbot's work as being produced by sand and silt rolled along the bed of the river, and not by the precipitation of matter held in suspension by the outflowing waters. The length of the bar of the South-West Pass, or the distance between the 18-feet contour lines, is 2½ miles.

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[1] To the 1st of October, 1874, the Louisiana Levee Company, which was incorporated in February 1871, have built levees containing 4,323,012 cubic yards, at a cost of $2,520,612, being at the rate of 58 cents (2*s.* 4*d.*) per cubic yard. General Abbot's estimate was based on the height obtained by the great flood of 1858, which has not been exceeded since, and an allowance was made of about 1 foot for a possible rise above that extraordinarily high flood.

DIMENSIONS of the MAIN PASSES of the MISSISSIPPI.[1]

Pass.	Length to outer crest of Bar.	Mean Width.	Mean Depth.	Mean Area of Cross Section	Proportion of Discharge, that of the Mississippi being unity.
	Miles.	Feet.	Feet.	Square feet.	
South-West Pass . .	17	1,200	58	70,000	·340
South Pass. . . .	14	700	34	24,000	·080
North-East Pass . .	16	2,500	37	92,000	·225
Pass à l'Outre . . .	15	1,300	36	47,000	·254
Remainder mainly through South-West Pass.					·101

DISCHARGE and VELOCITIES at the head of the SOUTH-WEST PASS, which delivers one-third of the total volume of the Mississippi into the Gulf. The discharge through this Pass exceeds the entire volume of the Danube.

River Stage.	Usual		Minimum	
	Discharge per Second.	Mean Velocity per Hour.	Discharge per Second.	Mean Velocity per Hour.
	Cubic Feet.	Miles.	Cubic Feet.	Miles.
Flood.	340,000	4·9	272,000	3·9
Low water . . .	102,000	1·4	75,000	1·0

The natural depth on the South-West Pass is only 13½ feet, but by the use of two steam-dredgers, or mud-scrapers, a depth varying

[1] Mr. G. W. R. Bayley, civil engineer, New Orleans, an acknowledged authority on all matters connected with the Lower Mississippi, has lately directed attention to the fact that, while the high-water slope of the river, from New Orleans to the head of the passes, is only about 1½ inch to the mile for the whole river, the high-water slope of the South-West Pass channel is about 2 inches per mile; of the Pass a l'Outre, about 2¼ inches per mile, and of the South Pass, about 2½ inches per mile. It is well known, he maintains, that the greater the normal quantity of water flowing in a sedimentary river, below its last affluent, the less will be its surface slope, and the greater its depth and velocity of current and sectional area of channel. The width of the Mississippi river does not increase from the mouth of the Ohio down, but its depth does, below each affluent; while the surface slope diminishes, gradually, as far down as the head of the passes. See Table of Inclinations at page 33; also remarks on the same subject in Mr. Alfred Tylor's highly interesting Paper, on "The Curve of Denudation," Geological Magazine, vol. ix, pp. 392, 485.

from 16 to 18 feet was maintained over a channel from 200 to 300 feet wide, for the two working seasons previous to 1873. It is considered that by this means a channel 18 feet deep could always be maintained, at an expense of $200,000 (£40,000) a year, a sum which includes the entire renewal of a steam-scraper every four years. The cost of the scrapers is $200,000 each. They are arranged so as to bring up the silt, which has been agitated by the screw of the vessel, into the upper stratum of the outgoing current. In the channels where the machines have been employed, the velocity of the surface is generally from 2 to 3 miles per hour; but at 10 feet below the surface the velocity is reduced to 1 mile per hour; and at the bottom, not only to zero, but occasionally on a rising tide,[1] and when the flow of the Mississippi is under 800,000 cubic feet per second, which is the discharge at ordinary high-water, the current flows in an inverse direction, or into the river. Hence the necessity of having the scraper vessels so contrived as to bring the mud, which has been stirred up by the screw, as near the surface of the water as possible. The machines only work on the crests of the bars over a length of less than 4,000 feet, and the current does the rest of the deepening.

Major Howell, U.S.A. (Resident Engineer for the Lower Mississippi), informed the Author that each steamer removes about 10,000 cubic yards of mud a day, and that early last year, owing to obstructions designedly thrown in the way of the navigation by the Towage Steam Company, which has a monopoly of the towing at the mouths, the scrapers were withdrawn to the Pass à l'Outre, where they worked for the remainder of the year. The natural depth of water on the bar of the Pass à l'Outre is only 11 feet, but the effect of the scraping was to deepen it to nearly 18 feet, over a width of about 200 feet, at the end of 1873, by which time the depth on the South-West Pass was again reduced to 13 feet, although vessels drawing 17 feet were actually then being drawn across the bar, through 4 feet of soft mud, by the Steam Tug Company.

Fort St. Philip Canal.—The majority of a Board of Military Engineers, who assembled at the mouths of the Mississippi, in November 1873, to consider and report upon the plan submitted by Major Howell for a ship canal, recommended Congress to construct a ship canal from Fort St. Philip to Breton bay; and accordingly, on the 9th of February, 1874, a Bill was introduced into Congress which "provides for the construction of this canal, and its maintenance

[1] The tide has a mean rise of 15 inches every twenty-four hours at the Mississippi mouths.

as a public highway." In the Bill it is enacted,—"That a ship canal to connect the Mississippi with the Gulf of Mexico, commencing at some convenient point on the river below Fort St. Philip, and terminating at some convenient point in Breton bay, shall be constructed and maintained at the expense and under the control of the Government of the United States: That the dimensions of the canal shall not be less than 200 feet wide at the bottom, and with not less than 25 feet in depth of water, with the necessary guard-gates, locks, &c., which may be necessary for the safe and convenient navigation of the canal." The estimate for the above work is $10,296,500 (£2,000,000), which includes the cost of jetties for extending the canal into the deep waters of the Breton bay.

PARALLEL PIERS VERSUS CANAL.—General Barnard, U.S.A., who was in the minority of the Board of Military Engineers, of which he was the President, is of opinion "that the conditions of the location and execution of a canal have received no adequate study," and he therefore demands "new studies of location, and an entire revision of plans of execution." He is also in favour of an open river mouth rather than of a canal impeded by locks. He likewise agreed with the Author in the opinion, that the South Pass of the Mississippi should be selected for a full trial of the jetty system, on the principle that it is more advisable, in an economical point of view, to improve the mouth of a minor branch of a river, rather than to grapple with the difficulties at the mouth of a principal branch, if that minor branch debouches into deep water, and offers a sufficient breadth and depth of channel for the navigation till its bar is reached. The south branch has a width of from 600 to 800 feet, and a depth of not less than 25 feet throughout its entire length of 13 miles, excepting for about ½ mile at its bifurcation with the main river, where parallel training works would be necessary to secure the depth and width required. Although holding these views in favour of the South Pass, the Author is by no means opposed to the opening of the South-West Pass, by means of jetties, if it is considered that the far greater expense of construction in the first place, and of the maintenance of the works and channel afterwards, contingent on the improvement of the larger mouth, would be compensated by the grander result to be obtained.

Since these notes were written, Captain J. B. Eads has formally proposed to the United States Government to deepen the South-West Pass to 28 feet, for the sum of $11,000,000, by means of parallel piers; and a new commission, consisting of civil and military engineers, has been named to report to Congress on the merits of all the plans of improvement yet devised for providing the river with a deep sea entrance.

III.—WATERWORKS.

CROTON WATERWORKS, NEW YORK. (*Visited 30th December*, 1873, *with Mr. G. M. Van Nort, Commissioner of Public Works, and Mr. Edward H. Tracy, Chief Engineer.*)—The Croton Aqueduct, which supplies the city of New York with water, is a monument to the ability and skill of Mr. John B. Jervis, C.E., the designer and constructor of the works. The aqueduct was begun in 1837, and finished in July 1842, with the exception of the High Bridge at Harlem, which was not completed till 1848, the water in the meantime being conveyed across the Harlem Valley by a temporary pipe.

The following sketch of the principal features of the aqueduct is abridged from Mr. Jervis's report of the 27th July, 1842, to the Water Commissioners, which has not yet been published in England.[1]

The Croton Aqueduct commences about 6 miles above the mouth of the Croton river, where a dam has been constructed to elevate the water of the river 40 feet to the level of the head of the aqueduct, or 166 feet above mean tide. The aqueduct passes along the valley of the Croton to near its mouth, and thence into the valley of the Hudson. The length, from the Croton dam to Harlem river, is 33 miles, for which distance it is an uninterrupted conduit of stone and brick masonry in hydraulic cement.

Description of the Country.—The soil, earth, and rock of the country, from the banks of the Croton to the city of New York, are of one general character. The prevailing rock is gneiss, of great variety in quality. The surface is generally a sandy loam. Below it, soil, gravel, sand, boulders, or detached rock, have in most cases been found. A large portion of the open cutting, and nearly the whole tunnel cutting, has been through rock, more than 400,000 cubic yards of which have been excavated. The general formation of the country is extremely irregular, and unfavourable for the economical construction of an aqueduct.

Aqueduct.—The bottom is an inverted arch, the chord being

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[1] A full description of the Croton Aqueduct in English, German, and French, by T. Schramke (London and Berlin, 1855), is in the library of the Institution.

6 feet 9 inches, and th . sine 9 inches. The side walls rise 4 feet above the s g of the invert. The roofing arch is semicircular, with a us of 3 feet 8½ inches. Thus the greatest interior height is 8 feet 5½ inches, the greatest width 7 feet 5 inches, and the area 53·34 square feet. The inverted arch is of brick, 4 inches thick. The roofing arch is also of brick, 8 inches thick. The abutments are of rubble stone, with a brick facing 4 inches thick. In all cases a course of concrete in hydraulic cement was laid under the extrados of the inverted arch. The area of a cross section of masonry in the aqueduct is 42½ square feet. The proportion of the line of aqueduct masonry on foundation walls over valleys, to that in excavation, is about 1 to 8. The masonry of the aqueduct is covered with earth to a sufficient depth to protect it from frost.[1] There are sixteen tunnels on the line, varying in length from 160 feet to 1,263 feet, making an aggregate length of 6,841 feet. The height of the ridges above the grade level at the tunnels ranges from 25 feet to 75 feet. The foundation walls, in crossing uneven ground and ravines, are of dry masonry.

Culverts.—To pass the streams that intersect the line, one hundred and fourteen culverts, varying in span from 1½ foot to 25 feet, have been constructed, at depths varying from 16 feet to 83 feet below the top covering of the aqueduct.

Ventilators.—There are thirty-three ventilators to give free ventilation of air through the aqueduct.

Waste Weirs.—Six are constructed on the line of aqueduct, so arranged as to allow the water to pass off when it rises to the proper height, with gates to draw off the water when necessary.

Croton Dam.—The greatest height of the weir of the dam is 40 feet above the low-water level, and 55 feet above the bed of the river. The width of the masonry at the low-water line of the river is 61 feet. At 300 feet below the main dam, a second dam was constructed of timber, stone, and gravel, to deepen the water over the apron of the former, and form a pool to check the force of the water as it falls. From the main dam, which raises the level of the water of the river over a length of 5 miles, and forms a reservoir of 400 acres, the water flows into the bulkhead at the upper end of the tunnel, from a level averaging 10 feet below the surface.

Aqueduct Bridge at Sing Sing.—The Sing Sing Kill, where it crosses the line of aqueduct, runs in a deep and narrow gulf, the bottom of which is 76 feet below the top covering of the aqueduct. Over

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[1] The depth is never less than 3 feet.

this gulf an aqueduct bridge has been constructed of stone and brick masonry. Its centre arch has a span of 88 feet and a rise of 33 feet.

Harlem River Bridge.—The width of the river, where the aqueduct line crosses it, is 620 feet at ordinary high-water mark, and its greatest depth is 16 feet at very low tides. The high ground that bounds the north side of the Harlem Valley is very nearly on a level with the aqueduct; and the width of the valley at the aqueduct level is about 1,450 feet, over which a bridge of the same length has been constructed. The south bank of the valley is here a bold, precipitous rock, rising to a height of about 220 feet above the river. Across the river there are eight arches, each of 80-feet span. On the south of this range of large arches there is one arch, and on the north six arches, each of 50-feet span. The arches are semicircular, and their soffits are 100 feet above ordinary high water. The piers are founded partly on the rock, partly on bearing piles. All the masonry is of well-dressed granite. The space—21 feet—between the parapets is arranged to receive and protect from frost two cast-iron pipes, each 4 feet in diameter, which are to lie at the level of 108·25 feet above the level of mean tide.[1] This is 12 feet below the grade line of the aqueduct, to which the pipes descend from the gate-chambers at the end of the bridge. The object in using pipes was more effectually to secure the conduit from any leakage, that might eventually injure the masonry of the bridge, and it incidentally allowed the bridge to be constructed of less height. To make the capacity of the pipes for conveying the water equal to that of the aqueduct, an extra fall of 2 feet has been given across the bridge, and the aqueduct on the southern side of the river is constructed 2 feet lower than the regular grade to accommodate this arrangement.

It was originally contemplated, and the work put under contract, to construct a low bridge with one arch for water-way; but a supposed value, which was attached to the future navigation of the river, was so pressed upon the legislature as to induce them to pass a law requiring that the under side of the arches should be 100 feet above ordinary high water.[2]

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[1] These 4-feet pipes were never laid down, as two of 3 feet diameter were considered to be sufficient at first; the latter still remain, ready for use again in case of need, but the water is now conducted across the aqueduct by a 7½-feet pipe of boiler-plate.

[2] It may be asked, why not have raised the bridge 12 feet more, to the grade of the aqueduct, and thus have saved a fall of 2 feet, besides sparing the

Manhattan and Glendenning Valleys.—After crossing Harlem Valley, the aqueduct of masonry is resumed, and continued 2 miles, to the termination of the high ground on the north of Manhattan Valley. This valley is ⅞ mile wide, and 102 feet below the level of the aqueduct. The conduit of masonry here gives place to iron pipes, which descend to the bottom of the valley, and rise again on the opposite side, from which point the masonry conduit is again continued, and, crossing Glendenning Valley on arches, after 2 miles reaches the receiving reservoir at York Hill.

Receiving Reservoir.—This reservoir has an area of 31 acres, and a capacity of 150,000,000 imperial gallons. It is in two divisions, and is formed with earth banks, the interior having regular puddled walls; the outside, protected by a stone wall, has a slope of 1 horizontal to 3 vertical; the face is laid in cement mortar, and the inside is dry; the inside is protected by a dry wall, laid on the face of the embankment, which slopes 1½ horizontal to 1 vertical. The embankments are raised 4 feet above the water line, and vary from 18 feet to 21 feet in width at the top. They are of moderate height for the northern division of the reservoir, which has a depth of about 20 feet; but in a portion of the southern division, where the depth is about 30 feet, they are 38 feet high above their base.

Distributing Reservoir.—This reservoir is situated on the 5th Avenue, between 40th and 42nd Streets, and is 3 miles from the City Hall. It is built entirely of masonry, and covers an area of 4 acres, divided into two equal divisions, and has a capacity of 20,000,000 imperial gallons. It has a depth of 36 feet, and when full the level of the water is 115 feet above mean tide. Its walls rise 4 feet above the water line, and have an average elevation of 45½ feet above the level of the adjacent streets.

Length of the Aqueduct.—The length of the aqueduct, from the Croton dam to the distributing reservoir, is 40½ miles. It is proper to add to this the length of the Croton reservoir, which is 5 miles, and extends 4 miles for the length of the large mains from the distributing reservoir through the central part of the city, making the total length of the main conduit nearly 50 miles.

Grade Line of Aqueduct.—The general declivity of the aqueduct in

expense of the two gate-chambers? Apropos of this question, Mr. Tracy has written to the Author as follows:—"It is impossible in this country to construct a conduit of masonry, of any considerable length, that will remain watertight. The contraction and expansion of the High Bridge, from the extreme heat of summer to the extreme cold of winter, is more than ⅝ inch by actual measurement."

Westchester County is 0·021 foot per 100 feet (1·109 foot per mile). The grade from Harlem River to Manhattan Valley is the same as the general grade of the aqueduct in Westchester County; but that from the Manhattan Valley to the receiving reservoir, $2\frac{1}{3}$ miles, is 9 inches per mile.

Cost.—Mr. Jervis concludes his Report by stating that the actual cost of the aqueduct, from the Croton dam to the distributing reservoir, inclusive, was under $9,000,000 (£1,800,000), being within 2 per cent. of the original estimate.

The following information respecting the present state of these works was obligingly furnished to the Author by Mr. Tracy. In addition to a new receiving reservoir in the Central Park,[1] which has an area of 106 acres, a depth of 36 feet, and a capacity of 1,000,000,000 gallons, a new storage reservoir at Boyd's Corners, in the Croton Valley, has been built to contain 3,000,000,000 gallons; so that the combined capacity of the reservoirs, including the Croton reservoir or lake, is now 4,570,000,000 gallons.[2] Experience has proved that, as long droughts prevail during the summer and autumn, the quantity of water in the river is inadequate to supply the daily needs of the city, and that, therefore, the only way to secure a constant supply is by storage reservoirs, to be filled during the wet season. Preparations are accordingly being made for the construction of a third large reservoir in the Croton Valley, with a capacity of 3,700,000,000 gallons. When this is done, the combined reservoirs will be able to supply the city for eighty-two days at the present rate of consumption of 100 gallons per head, irrespective of the minimum quantity daily furnished by the Croton river in seasons of extreme drought, viz., 27,000,000 gallons.

From 1842 to 1848, 18,000,000 gallons per day gave an abundant supply. At that time the city had about four hundred and fifty thousand inhabitants, and now, with a population of one million, the quantity consumed is sometimes 100,000,000 gallons per day. Thus, though the population of New York has little more than doubled since 1848, the consumption of water has increased fivefold.

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[1] There are six 4-feet mains into and out of this reservoir (which was completed in 1862), and the valves are so arranged that they can only be fully raised in one hour.

[2] When the word "imperial" is not mentioned, it may be taken for granted that the gallons indicated are United States gallons, which compared with imperial gallons are as 5 to 6: a United States gallon being equal to 231 cubic inches (the capacity of the old English wine gallon), and the British imperial gallon to 277·274 cubic inches.

When the aqueduct was built, it was supposed it would only deliver 60,000,000 imperial, or 72,000,000 United States standard gallons, every twenty-four hours. The discharge was computed from formulæ based on the best-known channels at that time, but all of which were smaller than the Croton Aqueduct. Careful experiments on the present flow of water show that it can deliver 115,000,000 gallons every twenty-four hours, or 60 per cent. more than its estimated capacity.[1]

The watershed of the Croton river is about 340 square miles, and the annual rainfall is 49 inches. At or near the sources of many of the tributaries there are natural lakes, varying in size from 50 acres to 500 acres. These basins are generally of great depth, and their waters, which are remarkably clear and pure, are derived either from springs in the lakes themselves or in the highlands near them.

The new storage reservoir at Boyd's Corners has an area of 300 acres, and has been formed by building a dam across the west branch of the Croton river. The dam is about 700 feet long, and high enough to lift the water 60 feet above the surface of the stream. The masonry wall of the dam, on its inner side, is fortified by a watertight bank of earth, and a canal is cut through the rock at the northern end of the dam to allow the floods to escape over a rock surface into the river below the dam.

The major part of the higher section of the city of New York, north of Manhattan Valley, is supplied from a new high-service reservoir, into which water is pumped by steam from the aqueduct near 173rd Street (close to the Harlem Bridge), whilst the extreme high points are supplied from a tank supported on a tower built to a height of 300 feet above the sea, near the site of the reservoir. The islands in the East and Harlem rivers are supplied with water by pipes, varying from 2¼ inches to 6 inches in diameter, from the shores of New York City. These pipes are generally about 1,000 feet long, and are laid on the beds of the rivers in depths of from 70 feet to 100 feet of water. Until very recently, they were either of cast iron, lead, or gutta-percha. The latter, which are soon abraded on a rocky bottom, are now being advantageously replaced by wrought-iron pipes. These are so elastic, and are so well protected with a casing of planking, that they can be readily laid, already put together, on the bed of the river, at a radius of 300 feet. Shortly before the Author's visit,

[1] The flow in the aqueduct, which is never full, is at the rate of about 2¼ miles per hour.

it was decided to lay down a wrought-iron lap-welded pipe of 6 inches in diameter, made in the same manner as pipes for conveying steam, coupled together with screw couplings. The operation was thus described by Mr. Tracy:—The couplings were strengthened and protected by heavy cast-iron sleeves, secured by lead joints, making the joints as rigid and stiff as any other part of the pipe. The pipe was then placed in a heavy oak case securely bolted and riveted together, and the space between the pipe and case filled with hydraulic cement. The pipe was put together in 62nd Street. When fitted up complete in the box, and the box thoroughly saturated with coal-tar, it was then, by means of a powerful dredge with a steam capstan of 100 HP., hauling on a heavy chain cable fastened to the rocks on Blackwell's Island, drawn across the river. The dredge was assisted by three powerful steamboats, which in case of the breaking of the chain could have held the end of the pipe in position. The pipe as fitted up in the box was 1,350 feet long, weighed over 200 tons, and was put across the river in water 100 feet deep. It was laid without any accident or injury, and it is believed to be strong enough to withstand the anchors of any vessel which navigates the East river.

Six 4-feet cast-iron pipes are now being laid in the 10th Avenue, between 113th and 92nd Streets, preparatory to the removal of the aqueduct work over Glendenning Valley. This tedious and expensive work is necessitated by an Act of the legislature, which directs the Waterworks Department to remove the above-named portion of the old viaduct, as it obstructs the traffic from east to west, and to replace it by a new one, or by pipes, below the newly-established grades of the streets and avenues, which now extend uninterruptedly from the Battery Point to Kingsbridge over Harlem river, a distance of 15 miles.

Owing to an alteration in the grade of the 5th Avenue, it became necessary, about two years ago, to lower two 3-feet main water pipes about 4 feet, in a long cutting through hard gneiss, between 68th and 72nd Streets. It was decided to lower these pipes with the water in them, and to continue their use while the operation was going on. The trench where they lay was widened on one side to allow them to be moved laterally. They were next placed upon saddles resting on greased skids, and moved over, one line at a time, by screw-jacks. Then, after being protected with timber while the new rock trench was blasted, they were moved back, on greased skids, supported by blocking, to their original line, and lowered by screw-jacks into position. This delicate and hazardous operation was successfully performed without accident to life, limb, or property.

Mr. Tracy states, in one of his last reports to the Commissioners, after a personal inspection of the interior of the aqueduct, from end to end, that the brick facing of the masonry shows no sign of either wearing away or of disintegration, and that there is every reason to believe the whole structure, with proper care, will successfully perform the duties for which it was built for centuries to come. To the latter opinion the Author would add the remark, that all the important subsidiary works of the aqueduct which he inspected, and which have been but lately completed, appeared to have been as skilfully designed, and to be as imperishable, as the famous aqueduct itself.

Chicago Waterworks.—Hardly any one who has visited Chicago of late years can resist the temptation, when the name is mentioned, of plunging into a mass of statistics, to enable those who are not acquainted with the marvels of the place to realise the fact of its amazingly rapid progress, from a hamlet of squatters in 1830, to a city of the first rank at the present time. The Author may perhaps, therefore, be excused in stating a few facts relative to the city of Chicago before referring, in some detail, to its water supply.[1]

The population of Chicago in		1830	was	70
"	"	1840	"	4,583
"	"	1850	"	29,963
"	"	1860	"	112,170
"	"	1870	"	295,977

At the time of the Author's visit in October 1873 the number of inhabitants was said to exceed four hundred thousand.

According to the returns of the Chicago Board of Trade, the wholesale trade of the city in dry goods, boots and shoes, clothing, groceries, iron, drugs, &c., for 1872, was $500,000,000. In the same year the receipts of cattle were six hundred and eighty-four thousand and seventy-five, and of hogs three million four hundred and eighty-eight thousand five hundred and twenty-eight, of a total value of $75,475,000. The total receipts of lumber (timber) were 1,183,659,283 square feet (100,000,000 cubic feet), and of all kinds of grain 88,426,842 bushels. Chicago is now, in short, by far the largest market in the world for corn, timber, and pigs.

Chicago is the centre of a network of railways, thirty-nine of which take their first name from the city.

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[1] The word "Chicago" in the Indian language signifies "the place of skunks."

The receipt of grain by rail alone at Chicago has reached two thousand one hundred cars per day. Besides being connected by iron roads with all the harbours on the northern lakes and with every seaport of note on the Atlantic coast from the St. Lawrence to Florida, this great inland city is also in direct communication with the shores of the Pacific and with the following important stations on the banks of the Mississippi; viz., Crow-wing, St. Paul, Prescott, Winona, Prairie du Chien, Dubuque, Savannah, Fulton, Rock Island, New Boston, Burlington, Keokuk, Quincy, Hannibal, Louisiana, Alton, St. Louis, Chester, Grand-tower, Cairo, Columbus, Hickman, Memphis, Helena, Vicksburg, and New Orleans.

THE CITY OF CHICAGO.

The city is bounded on the west by a prairie of vast extent, and was originally built on swampy ground at a level of from 3 to 4 feet only above the surface of Lake Michigan. Its 600 miles of streets and thoroughfares—many of them 100 feet wide, and lined with magnificent buildings of stone, brick, and iron, are now raised, as a rule, to 12 feet above the lake.[1] When

[1] The raising of houses to the level of the new streets was at one time an important trade at Chicago, but it is now seldom practised. In some cases ware-

the first settlers arrived, their huts were 'located' on the banks of the River Chicago and of its north and south branches, which separate from the main stream at about 1 mile from the shores of the lake. In process of time the river—which was formerly fed by the clear waters of the lake, and therefore ebbed and flowed according to the direction of the wind—became greatly polluted, and it was determined to lessen the evil by discharging the sewage matter and other impurities of the city into the Illinois and Michigan canal, and thence into the Illinois river. This work was completed in 1871, in the manner previously described.

Although there is now a constant stream from the lake up the main river and its southern branch, to the great benefit of the city, this is, unfortunately, not the case with the north branch of the river, the foul and unwholesome condition of which is daily increasing. The subject is now under the serious consideration of the city authorities. One remedy suggested is to obtain sufficient water from artesian wells[1] to cleanse the fetid creek; but it is generally considered that the best plan is that of flushing the stream by a covered canal communicating with the lake, through which river or lake water might be forced by steam power as occasion requires. This plan has since been adopted, and was being carried out in February 1875.

The pollution of the river, not only by sewage matter, but by the refuse and garbage thrown in from distilleries, tanneries, manufactories, and slaughter-houses, has always been a source of annoyance and concern to the citizens of Chicago; but in 1863 the nuisance was aggravated to such a pitch, that the water, supplied to the inhabitants by pipes from the shore of the lake, became no longer drinkable. It was then that the Department of Public Works determined to supply the city with uncontaminated water from the lake at 2 miles from shore, in a depth of 32 feet, almost directly at right angles to the shore of the lake at the pumping works.

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houses of iron and stone, six stories high, and weighing as much as 20,000 tons, have been screwed up from 8 to 10 feet without accident. Wooden buildings have also been frequently lifted and slid along bodily from one street to another.

[1] There are now upwards of twenty artesian wells in Chicago and its neighbourhood. The average yield of each was at first about 600 gallons per minute. The average depth is 1,300 feet, diameter of the bore at the bottom 4 inches, and the cost $6,000. The maximum surface-pressure of the water is 35 lbs. per square inch, which indicates a hydrostatic head of 77½ feet. By the end of 1874, the wells had fallen off so much that some hardly flowed at all above the surface of the ground, and the average flow had been reduced to 200 gallons per minute.

This novel plan was designed and carried out by Mr. E. S. Chesbrough, the Chief Engineer of the city, through whose kindness the Author has been supplied with the principal part of the following information.

It was found, by careful borings, that a bed of compact blue clay, at least 100 feet thick, underlay the thin crust of silt and sand at the bottom of the lake. The shaft on shore was begun in March 1864, that under the lake eighteen months later. The tunnel between them was driven from both ends. The most interesting work was the sinking of the lake shaft through a depth of 32 feet of water, and then through 31 feet of clay. This shaft was built within a 'crib' or breakwater of pentagonal form, 90 feet in diameter, 40 feet high, and with walls 25 feet thick, leaving an inner open well about 30 feet in diameter. The crib, which was constructed on shore, consisted of 50,000 cubic feet of whole timbers, 12 inches square, braced together. The inner and outer walls, as well as the flooring, were caulked at the joints; and when the crib was towed to the intended resting-place, its fifteen watertight compartments were filled with 6,000 cubic yards of stone to sink it to the bed of the lake. The top of the crib then stood at 5 feet above the surface of the lake. Within the well of still water a column of seven cast-iron pipes 9 feet in diameter, making a total length of 63 feet, was sunk, through the clay, to 31 feet below the bed of the lake, without resorting to atmospheric pressure, or even to pumps, though these were provided for in the contract. On the removal of the clay the tunnel was started from below. It falls 4 feet towards the shore end, where the land shaft is 70 feet below the surface of the lake, and 77 feet below that the ground. The miners met at a quarter of the distance from the crib to the shore. The vertical axis of the tunnel, which is almost circular, is 5 feet 2 inches, and its horizontal axis 5 feet. The arching consists of two rings of brick in cement 8 inches thick.

The iron column forming the lake shaft is open at the top, and has two inlet gates, the tops of which are 2 feet below low water. Through the sides of the crib are three openings controlled by gates. One is near the bottom of the crib, another midway between the surface and the bottom of the lake, and the third near the surface; so that water may be drawn from any desired depth. Chemical analysis shows that the water at the surface is slightly the purest; in summer the water is coolest near the bottom. The tunnel can be pumped dry at any time from the shore end by closing the inlet gates, each gate being under easy control from above. The cost of the entire work, which was completed in March 1867, was about £100,000.

Since that date the duty of the pumping engines, now five in number, has been as follows:—

Year ending	Average daily quantity pumped. Gallons.	Greatest daily quantity pumped. Gallons.
31st March, 1868	14,724,999	16,414,460
„ 1869	18,633,278	20,689,014
„ 1870	21,766,260	25,712,589
„ 1871	23,464,877	28,000,000
„ 1872	27,536,819	31,485,000
„ 1873	27,500,000	33,250,000

On the 9th of January, 1873, a new double-beam pumping engine, designed by Mr. D. C. Cregier, C.E., and constructed by the Knapp Ft. Foundry Company, Pittsburgh, commenced pumping to relieve the other four engines, and has worked continuously since then. This pumping engine, which is said to be the largest in the United States, has two 70-inch steam cylinders with 10-feet stroke, and works two pumps of 57 inches diameter, delivering 36,000,000 gallons of water per twenty-four hours. The beams are of cast iron, 28 feet long; their weight is 20 tons each. The main columns are 27½ feet long, and weigh 17 tons each. The fly wheel is 25 feet in diameter, with a rim 12 inches broad by 20 inches deep, and the weight, including the eight spokes and 'hub' (nave), is 33 tons. The engine was two and a half years in building, and cost $188,400, exclusive of foundations. The combined capacity of the four engines is 75,000,000 gallons per twenty-four hours.

The water is pumped from wells connected with the tunnel directly into the pipes. The pumping engines are guarded against the danger of this system, not merely by air chambers, but by a stand pipe, open at the top, 140 feet above the lake, supported as well as protected by a stone tower 170 feet high. The pumps are supposed to force the water to a height of 132 feet, but in the day time, when the demand is at its greatest, the water does not rise higher than the second story of the houses.

During the year 1872–3 the engines consumed 13,562 tons of coal, at an average price of 28*s*. per ton, and the cost of delivering water per million gallons amounted to 47*s*., as compared with 32*s*. and 52*s*. respectively for the nine years ending 1872. The water is supplied through 380 miles of mains, the largest of which has a diameter of 36 inches. Owing to the requirements of the navigation, the pipes cannot be carried over the river and its branches (which are spanned by thirty iron and wood swing bridges), and therefore cross the bed of the stream. With the view of preventing damage to the pipes by anchors and by piles driven into the bed of the river, the mains are now being laid down from bank to bank in tunnels, five of which are already built. The last one was completed six months ago, between Michigan Avenue and Pine Street, where shafts, 84 feet and 68 feet respectively, were connected by a tunnel 492 feet in length. The whole is of circular brick masonry, the shafts being 8 feet, and the tunnel 6 feet in diameter. A 24-inch iron water pipe has since been laid through it. The cost of the work was $13,279 (£2,600).[1]

Before describing the new arrangements for increasing and insuring a sufficient supply of water to Chicago, under all eventualities, a few facts should be stated relative to the great fire of October 1871, by which the loss of property was greater than had ever occurred before, from an accidental cause, in the history of the world, amounting, according to the most trustworthy estimates, to $200,000,000 (£40,000,000). The number of people rendered homeless and destitute by this fire is calculated to have been one hundred thousand. It originated in a stable on the west side of the river, on Sunday night, the 8th of October, 1871, in a section of the city composed almost entirely of wooden buildings. Aided by a furious south-west wind—so strong as to blow down a church steeple—it spread in a north and east direction with wonderful rapidity, and finally terminated, at a little before midnight, on Monday, the 9th, having in one day destroyed nearly every building in its course, over a space 4 miles long and about ⅔ mile wide. It reached the pumping works early on Monday morning, when the machinery was so badly damaged that it stopped working; thereby cutting off the supply of water, and leaving the city without the means of checking the progress of the flames. By extraordinary exertions on the part of Mr. Cregier and his staff, the repairs to the engines and the buildings were so far advanced, that eight days after the fire the north engines were started afresh, and continued to supply the city without cessation for a period of two months, when the other two engines were again in working order.

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[1] In addition to the water tunnels, the river is crossed by two subways in masonry for carriage and passenger traffic. These street tunnels were built with great care and skill by Mr. Chesbrough. The steepest gradient in the Washington Street tunnel (which was built first, and proved of immense service during the great fire) is 1 in 16, and in the La Salle Street tunnel 1 in 20. The top of the brick arching in both tunnels is upwards of 20 feet below the bed of the river.

This is only a single instance, among many, of the energy with which the citizens of Chicago began to rebuild a new city on the still burning ashes of the old site. The Author found hardly a gap over the area of 1,700 acres which had been swept, only two years before, by the greatest conflagration of modern times. The rebuilding of the "burnt district" was then all but completed, and public opinion was unanimous in declaring that the Chicago of to-day is far grander than the old Chicago of 1871, before her busiest and wealthiest quarter fell a victim to the flames.[1] It has often been alleged that the wooden block pavement of the streets added fuel to the flames, and thus hastened the great calamity, but this was not the case. The Author has the City Engineer's authority for stating that the blocks were not burnt, and indeed that they were hardly damaged by the fire.

The chief lessons taught to waterworks engineers by the fire were, 1st, to make engine-houses fireproof; 2ndly, to have as much open space round them as possible; 3rdly, not to keep a large city dependent on one set of pumping works only, for a supply of water, especially, if, as at Chicago, there is no suitable ground on which to build a large distributing reservoir.

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[1] A resident of Chicago thus graphically described the characteristics and achievements of the city of his adoption at the time of the Author's visit:—"It has been a distinguishing characteristic of Chicago, that all her undertakings and accomplishments were phenomenal. Her modes of action were original and sensational, both as regarded individuals and the body corporate. She took counsel of no precedents in anything she did. When she wanted to raise the grade of her streets, she elevated the city upon screws and reposed it upon higher foundations. When a supply of fresh and pure water became a necessity of our rapidly augmenting population, she carried an immense aqueduct out miles from the shore, and gathered a pellucid stream from the far-off bosom of Lake Michigan. When the river became a receptacle of the sewage of 350,000 people, and generated an insufferable stench, she carved out a connection with the Mississippi, turned into the channel the crystal floods of the lake, and created a perennially-flowing and purifying current, sweeping away the whole accumulation of impurities, and permanently transforming a cesspool into a stream of cleanliness. And when on the woeful Sunday night of our black October, she departed partly to the skies in flame and smoke, and partly to the earth in ashes and ruins, she maintained her phenomenal reputation, and signalised her exit by a conflagration which outvies every one of history in all that is weirdly sublime, appallingly terrible, and amazingly destructive. Out of that broad extent of blackened desolation arose suddenly, as by the wand of enchantment, a new city, more imposing in its architecture, more colossal in its proportions, more enduring in its structures, more extraordinary in its accessories, more expansive in its enterprise, more ambitious in its projects—a phenomenon of reconstruction so preternatural, that strangers are overwhelmed with the idea that the miles of magnificent buildings before their eyes stand on ground lately occupied by heaps of smouldering and unsightly rubbish."

The erection of duplicate pumping works in another part of the city, and the construction of a second lake tunnel, to meet the constantly increasing demands for more water, were decided on before the fire. The new land tunnel, 7 feet in diameter, to connect the present waterworks with the proposed new pumping engines, will extend 4 miles westward, at a depth of 71 feet below the lake level. It is estimated that the cost of this tunnel, of the new pumping works, and of the necessary extension of mains, will be $1,000,000. The construction of the second lake tunnel and the second lake shaft was in full progress when the Author visited them on the 25th of October, 1873, in the company of Mr. Chesbrough, the Engineer, and of Messrs. Steel and McMahon, the Contractors of the work. The excavation of the new tunnel, which is to run parallel to, and at a distance of 50 feet from, the old tunnel, is now half completed from the bottom of a new brick shaft, 10 feet in diameter, already sunk at the shore end. The present rate of advance is 20 feet per day through compact blue clay, in which there is not a drop of water. It will be lined with bricks in three rings together 11 inches thick. The lake shaft of the new tunnel is being sunk within 9 feet only of the first shaft, in the old crib; and, owing to this close proximity, a disturbance of the ground has taken place between the two shafts, an inconvenience which was aggravated by the plan at first followed of sinking the new iron cylinder, 8 feet in diameter and 2½ inches thick, by pneumatic pressure.

The prices paid to the contractors are as follows:—

			$
Main tunnel and galleries per lineal foot, including bricks			29·50
Land shaft	„	„	50·00
Lake shaft	„	„	253·00
Three gates and bulk-head at lake shaft .	. . . .		4500·00

The top of the lake crib above the water line is now being made permanent with substantial masonry.

The total cost of the waterworks, including all expenses on work in progress to the 1st of April, 1873, has been $5,212,508, and the entire receipts during the past year were $544,465. The money for the payment of the cost of the works has been derived principally from 6 and 7 per cent. bonds.

Both the new tunnels above described—the one under the lake, 2 miles long, and the one under the land, nearly 4 miles long—were finished in 1874. Their estimated capacity for supplying water, combined with that of the first lake tunnel, is 150,000,000 U.S. gallons daily.

The following table, showing the number of United States gallons consumed by each inhabitant daily in America, as compared with London, Paris, and Glasgow, is abridged from a table prepared by Mr. Chesbrough.

	1860.	1862.	1864.	1866.	1868.	1870.	1871.	1872.
Chicago . .	43	44	41	43	58	73	..	75
New York . .	..	..	..	62 in 1867	..	..	85	..
Brooklyn . .	..	17	26	33	43	47	46	..
Jersey City. .	..	..	..	77 in 1865	..	84	..	99
Philadelphia .	..	..	..	..	51	55	55	54
Washington .	..	..	..	.	..	..	..	134
Boston . . .	..	..	..	55	62	60	54	..
Albany . . .	..	..	..	..	..	..	..	80
Detroit . . .	..	58	57	60	67	64	73	83
Buffalo . . .	..	..	..	..	..	..	51	61
Cincinnati . .	..	39	..	..	..	..	..	60
Montreal . .	..	..	..	..	..	..	55	..
London. . .	..	..	..	38 in 1867	..	..	..	..
Paris . . .	..	..	..	..	29	..	..	..
Glasgow . .	..	..	..	..	..	60	61	..

Mr. Chesbrough remarks, that the past rate of consumption in London and Paris is very small as compared with that of most American cities, and that only Glasgow is supplied after the American fashion. He is of opinion that the fairest comparison of the water supply of different cities would be by showing the quantity furnished to each water-taker, instead of supposing it to be used by the entire population; and he is fully aware that the enormous demand for water in some cities is to be attributed largely to leakage in the mains and distributing pipes.

IV.—LAKE HARBOURS.

The lake harbours, of national importance in the United States, are designed by, and constructed under the superintendence of, the Engineer officers of the Army;[1] and in Canada by Civil Engineers in the employment of the Government.

With hardly an exception, the protecting works and quays consist of timber boxes, or cribs, filled with stones, and joined to each other,

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[1] This distinguished corps consists of one hundred and six officers, the majority of whom are engaged on public works and surveys, and the minority on fortifications.

after they have finally settled down, by a continuous timber superstructure carried up a few feet above the level of the water. By this simple expedient, breakwaters, piers at the mouths of rivers, and wharves, have been erected within the last fifty years, at a comparatively small cost, at the most important points along the shores of the great chain of inland lakes, as well as at most of the river harbours communicating with the Atlantic; and experience has hitherto proved, that no cheaper and better system could have been devised for providing efficient harbour accommodation, in localities where timber and stone abound, and where every workman is skilled in the use of axe, hammer, and saw—the only tools required in putting cribwork together. It is superfluous to add that American engineers are well aware that, in building provisional works of this description, the expense of maintenance is much greater that if, in the first instance, the work had consisted of durable materials only, and that therefore it often costs more in the end. They perfectly understand that the advantage gained in the meantime by the construction of a cheap and simple work, which can readily be made permanent when required, far outweighs the element of ultimate economy in the abstract, in a young country where an immediate and strictly economical use of the slender means at the disposal of the inhabitants, to attain the end in view, is a necessity. In consideration of the above circumstances, and on the assumption that a full description of the most approved style of cribwork now built in America will be read with interest by English engineers employed abroad, the Author would draw their special attention to the specifications in the Appendices II. and III., which embody the results of the best experience in this class of work up to the present time; and to the remarks which follow on the same question.

As the lake harbours greatly resemble each other, the Author's "Notes" need only be given here concerning the two principal lake ports, viz., Chicago and Buffalo, which, moreover, offer the best types of harbour works in general on the shores of what may justly be termed the great inland seas of North America.

Port of Chicago.—The great importance of this harbour, which has not yet been in existence half a century, is strikingly evidenced by the following statistics, of the Chicago custom-house authorities, for the year ending the 30th of June, 1873:—

	No.		Tonnage.
Vessels arrived	12,394	..	3,062,979
Vessels cleared	12,324	..	3,142,169
Totals	24,718	..	6,205,148

REVENUE COLLECTED.

	$
Duties on imports	2,150,160
Marine Hospital moneys.	7,859
Tonnage dues.	8,530
Steamboat inspector fees.	6,293
Fines	665
Total . . .	2,173,507

From the establishment of Chicago as a port, when there was only a depth of 2 or 3 feet of water on the bar at the mouth of the river, to the end of the year 1865, the town spent large sums of money in keeping the mouth open by constant dredging, and by frequent extensions of the piers, to keep pace with the growth of the land. From 1821 to 1866, the coast line immediately to the north of the north pier advanced 2,400 feet into the lake, or at the rate of 56 feet per year. "There is a shingly shore north of Chicago, and hence large annual accretions behind the north pier. The Chicago river is not muddy."[1] In the autumn of 1865, General T. J. Cram, U.S.A., recommended a further prolongation of the north pier for 600 feet beyond the extension made by the city of Chicago in 1864 and 1865, and the rebuilding of the old south pier, and its extension for a length of 610 feet. In August, 1866, Colonel Wheeler, U.S.A., then in charge of the works, reported as follows:—"The accretion of the sand on the north side of the pier goes on rapidly, and there appears no better way of counteracting its destructive influence on the channel than to extend the north pier. I see no reason for building the south pier. The object of parallel piers is to confine the volume of water pouring out of a river, and to make use of the current to scour out and maintain a channel. There is no use in attempting this plan with the Chicago river; for I may say there is no perceptible current in that river. We are limited, then, at present to the prolongation of the north pier, and to removing any bars that may form in the channel by dredging."

In pursuance of this opinion, the extension of the north pier for a length of 608 feet was let to a contractor, in the autumn of 1866, for the sum of $86,874. The work was to consist of nineteen cribs, each 32 feet long, 30 feet wide, and 28 feet high, the depth of water in which they were to be built varying from 17 to 23 feet. The contents of the entire work amounted to 18,295 cubic yards. On this basis the accepted tender was at the rate of $143 per lineal

[1] General Humphreys, Ex. Doc. No. 220, 43d Congress.

foot, or $4½ (18s.) per cubic yard.[1] Before the extension was commenced in 1867, the Chicago Canal and Dock Company submitted a project, which was approved by the Secretary of War, for an entrance to their basin at the end of the pier. In his annual report of 1867, the officer in charge recommended a reduction of the length of the new pier to 300 feet, as that would carry the extremity of the extension to the point originally proposed; but sufficient materials having been collected to build 400 feet of pier, it was thought best to use them to complete that length. In October, 1869, General Humphreys reported that the building of the south pier, and its extension as far as the Lighthouse Pier, a distance of 610 feet, had been contracted for, and that the greater portion would be executed by the end of the season. He at the same time recommended that it should be carried on until it was equal to the north pier. By October 1870 the south pier had an extension of 1,224 feet, except the superstructure, which was then only built on the 614 feet of cribwork sunk in the previous year. On the 11th of July, 1870, an Act was passed for the enlargement of harbour facilities, and for a harbour of refuge at Chicago, according to plans submitted from the office of the Chief of Engineers. On this account the work on the south pier was suspended.

The Act takes into account the construction of a commercial harbour, designed by Colonel Wheeler, as follows:—"My plan is to inclose a portion of the lake, forming an outer harbour that would meet the present wants, and capable of being enlarged as the future might require. The extension of the south pier should be continued until it is equal in length to the north, then build a breakwater at right angles, and extending southward for 4,000 feet, and then join this breakwater to the shore by a pier. An opening of 300 feet or more to be left in the pier forming the north side of the basin, to admit vessels from the harbour entrance. This basin would contain an area of about 275 acres, one-third of which would have a depth of over 12 feet of water, and the remainder of over 7 feet, that can be easily deepened to 12 feet, affording a splendid harbour of refuge for all classes of vessels sailing to and from this port at the present time. To make this basin would require, besides the extension of the south pier, already estimated for, the construction of 4,000 feet of breakwater for the eastern side, and 3,460 feet for the southern side. The eastern

[1] The cost of the concrete blocks, now employed at New York for the new quays, composed of 1 of English cement to 7 of broken stone or gravel, is 48s. per cubic yard.

side should consist of cribs not less than 30 feet wide, 50 feet long, and at least 8 feet above the surface of the water. This would require them to be 30 feet high. The southern side, for the first half from shore, should be made of cribs 20 feet wide, 32 feet long, and 17 feet high; the remaining half of cribs 25 feet wide, 50 feet long, and not less than 5 feet above the surface of the water, or 24 feet high on an average.

	= per cubic yard. $	$
"Cost of the breakwater at $150 per lineal foot . .	4·52	600,000[1]
" shore end of the pier, 1,760 feet, at $55 .	4·43	96,800
" outer half of the pier, 1,700 feet, at $99 .	4·40	168,300
" dredging	say	34,900
Total . . .		900,000"

Colonel Wheeler's plan was duly approved by the Department of Public Works, and during the fiscal year ending the 30th of June, 1871, twenty-nine cribs, 50 by 30 feet, were sunk, making 1,450 feet of breakwater, including 300 feet at its north end running west. The first crib was placed in 24 feet of water, and none in less than 18 feet. By the 30th of June, 1872, 2,250 feet of breakwater had been constructed at a total cost of $200,000, or $88·88 per running foot, and it was then estimated that the whole work would not cost more than $100 per foot, including covering and contingencies.

In November, 1871, Colonel D. C. Houston, who then, and at the time of the Author's visit, had charge of the harbour works at Chicago and other ports in Lake Michigan, submitted a modified cross section for the breakwater for the approval of the Chief of Engineers.[2] Colonel Houston gave the following reason for the proposed modification:—"In nearly all the harbours under my charge the natural bed for cribs is sand, and it is found that even in the greatest depth of water, when cribs have been sunk (as at Marquette, in 28 feet of water), the sand moves during storms, causing the cribs to settle unevenly, to tilt outwardly (toward the exposed side), and, in some instances, to shift their position. It is indeed, a rare case that a crib maintains the exact position in which it was at first placed. The grillage bottom, which allows

[1] A detailed estimate of the cost of one of the cribs for this work will be found in Appendix IV., and its mode of construction is shown in the isometrical sketch of a crib 50 × 30 × 27½ feet (Appendix II.).

[2] Col. Houston kindly presented the Author with various designs for cribwork and with upwards of forty plans of harbours in lakes Superior, Huron, Michigan, Erie, and Ontario, where jetties have either been recently carried out or are in progress.

a portion of the stone to work through the sand, is a very partial remedy for these evils. The device of placing aprons of loose stone on the outside of the cribs has been resorted to with great benefit, but it is not satisfactory, and in many cases a storm comes up and shifts the crib by the undermining process before the riprapping can be put in." . . . "It has been my object to devise some economical plan of foundation for cribs on such bottoms to prevent this universal displacement." . . . "In the actual construction of piers during the past season, the efficacy of 'stone foundations' for cribs has been incidentally demonstrated." Colonel Houston therefore recommended the employment of rubble stone foundations for cribwork at Chicago, and stated his opinion that, at that place, stones would rest undisturbed by the waves at a less depth than 10 feet in the most exposed situations. After some correspondence, Colonel Houston's proposal was agreed to, and carried out with the best results.[1]

During the year ending the 30th of June, 1873, the east breakwater was extended 800 feet by the Illinois Central Railroad Company, and up to the same date a length of 3,050 feet had been constructed, including the return at the north end. It was then estimated, that, during the following year, an additional length of 1,100 feet would be added, leaving only 150 feet of this work to be completed according to the original design.

In the annual report on the works for 1873, it was stated by Captain Hinman, U.S.A., that the following method of building a foundation for a crib had been adopted, and had answered admirably. "As soon as the crib is in position, it is loaded with stone until it settles to within about 4 feet of the bottom of the lake. Fine rock is then thrown in, which, passing through the grillage bottom, settles evenly under and around the sides and ends of the crib; the latter is then filled up with coarse stone and riprapped with about ten cords of heavy rock. In order to hasten the building of a foundation, it is suggested that a portion of the fine rock be put in through a dump-scow just before the crib is brought up; in this case coarse rock would be used."

With reference to the south breakwater, it is now a question whether it should be constructed or not; for if the east breakwater is to be extended beyond the length originally proposed, the

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[1] In corroboration of Col. Houston's views regarding the utility and economy of rubble foundations for cribwork on a yielding bottom, the Author has given a short account, at the end of these Notes, of his own experience of cribwork on the shore of the Black Sea.

former would not only be unnecessary, but injurious to the harbour. According to Colonel Houston, the decision of the question depends upon whether the lake front is to be used for dock purposes or not. If not, then the basin will, as it is designed, meet all the requirements of a roadstead for many years to come. In case, however, of the construction of wharves and of the transfer of business to the lake front, an extension of the east breakwater will be a necessity.

As regards further extensions of the north pier, Mr. R. S. Littlefield, U.S.E., foreman in charge of the work, "whose experience and observations entitle his opinion to consideration," reported as follows, in April, 1873:—

"The works on both sides of the entrance to the river are out an equal distance into the lake, and during N., N.E. and N.W. blows a heavy sea rolls in along the return, and into the entrance to the harbour-basin formed by the breakwater, making it difficult, and at such times dangerous, to take out stone and other materials to the works."..."Canal-boat men would not take the risk of towing across the opening between the south pier, and the return, with any sea on outside. At such times, too, the sea strikes the return, and is deflected across and into the slip at the north pier, making difficult navigation from E. of the lighthouse, especially where the water is 14 feet depth and less, as loaded vessels are likely to strike."... "Adding to the return would not prevent the rough sea between the north pier and it, and only partially give protection to the entrance into the basin or harbour, while it would injure materially by narrowing the entrance. Lengthening the north pier 400 or 500 feet would afford all the safety needed to docks inside the basin, and would save the present width between the return and end of south pier, and make it comparatively easy for vessels from outside to sail into the outer harbour or basin. Likely it is only a question of time that the north pier will be extended, and not at greater cost now than at some future time. If done at present the breakwater can be extended with greater economy afterwards."

The above opinion is confirmed by the experience of Colonel Houston, and he has therefore included the cost of extending the north pier 400 feet in his estimates for 1873–74.

Buffalo Harbour is situated at the north-east angle of Lake Erie, and is therefore greatly exposed to the violence of south-west winds, in which direction the lake has a 'fetch' of 200 miles. Thus more than ordinary care is needed, to provide safe harbour accommodation, for the large fleets of vessels constantly arriving at

Buffalo from the upper lakes. The number of vessels entered and cleared at the port, for the year ending the 30th of June, 1873, was ten thousand five hundred and forty-seven, of an aggregate capacity of 4,832,142 tons. The population of the city of Buffalo was only eight thousand in 1830; it is now one hundred and eighty thousand.

The first improvement made at the mouth of the Buffalo Creek, 1½ mile above Black Rock Harbour, the original entrance to the Erie canal, was in 1820 and 1821, when two piers were built. The south pier was carried out ¼ mile into a depth of 13 feet of water, and was built of timber cribs filled with stone and brushwood. The north pier consisted of a double row of piles, with stone and brushwood in the interval. These primitive works only cost $14,000, and they were considered so successful that the Erie Canal Commissioners were induced to extend their canal to Buffalo from Black Rock.

In 1826 Congress appropriated $15,000 for the improvement of the harbour; and, from that time to 1865, the central Government expended $251,794 on the works, under the direction of their own Engineers. The total outlay from 1820 to 1865 was thus $280,794, for the construction and maintenance of a south pier 1,500 feet long, and a north pier 630 feet long, built of cribs filled with rubble under water, and of stone masonry hearting with cement concrete above water. With a view to protect a basin in which vessels could lie with safety during S.W. winds, the State of New York built a breakwater, at great expense, at right angles with, and immediately adjacent to, the north pier. Previous to the construction of this work, if a vessel, coming in under the influence of these winds, did not haul up in time to enter the harbour, she grounded on the soft bottom near the shore, but sustained no damage; since the breakwater was constructed, projecting as it does so near to the north pier, vessels attempting to enter under stress of weather are liable either to strike on the breakwater or on the south pier head. In this manner many valuable vessels with their cargoes have been lost. The breakwater has a stone superstructure similar to that of the south pier. Such masonry, it is considered, is not so capable as a framing of timber, fortified by rubble stones, to resist collisions, besides being more liable to damage by the waves, and, when so damaged, more expensive to repair.

The chief difficulty is caused by the littoral current, which moves sand along the shore in a northerly direction. At first, the evil was arrested by the south pier, but no sooner was an accretion formed behind it, than the sand crept round the head of the pier, and thus a bar was soon thrown up at the very mouth of the pass. To make the matter worse, a current draws the sand farther into the harbour, the current being occasioned by the indraught of lake water to supply the upper level of the Erie canal, and the numerous mills in the direction of Black Rock. Under these circumstances the flow of Buffalo river is not sufficient to scour out the entrance channel, and hence the city is obliged to spend large sums annually in dredging to get rid of the new deposit.

In June 1867, General T. J. Cram, U.S.A., recommended the Government to execute the following works:—

1. Repair and protect the existing piers.
2. Extend the south pier 300 to 600 feet.
3. Remove from 200 to 400 feet of the south end of Erie basin breakwater.
4. Construct a new work in 25 feet depth of water, about 4,000 feet long, to shelter the harbour from prevailing winds, and to secure a larger space for refuge.
5. Ascertain, by careful examination, the practicability of opening a ship channel from the lake at South Cut directly to Buffalo Creek.

This scheme was submitted to a board of Engineers, who on the 27th of March, 1868, recommended—

1st. That the existing piers be thoroughly repaired, the south pier extended, and the channel alongside the extension dredged to 15 feet.

2nd. That the breakwater be built in the position recommended by General Cram.

3rd. That it be constructed of cribwork, filled with rubble, in conformity with the principles already laid down by the board of 1853, for similar localities, as to dimensions of cross sections and length of cribs.[1]

They also stated their belief that, whenever it is made, the proposed new ship canal from the lake to the inner harbour, thus giving an additional ingress and egress, will add greatly to the convenience of commerce.

These recommendations having been approved by General Humphreys, orders were given to proceed with the work, and the following estimate of the board for the breakwater was accepted as a basis for its cost.

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[1] *Vide* "General Description of Cribwork" in Appendix II.

Estimated Cost of one Crib of 50 feet.

	$
11,406 cubic feet of 12-inch square timber, at 25 cents . . .	2,851·50
5,580 feet (board measure) for decking and sheathing, at $25 .	139·50
14,335 lbs. of 1¼-inch square wrought-iron bolts, at 5 cents . .	716·75
350 lbs. wrought-iron spikes, at 7 cents	24·50
1,750 cubic feet of rubble stone, at $2	3,500·00
11,871 cubic feet of framing, at 15 cents	1,780·65
Contingencies 10 per cent.	901·50
Total . . .	9,914·40

(Cost of 4,000 feet, say $800,000, or $220 per lineal foot.)

By the end of the fiscal year ending the 30th of June, 1869, the repairs of the piers, which had been much damaged by storms during the winter, were not quite finished, and on account of unusually bad weather a length of only 150 feet of the new breakwater had been constructed. The extension of the south pier for 318 feet had been completed. The difficulty of this work was thus described by Colonel W. McFarland, the successor of General Cram:—"The cribwork was made much stronger than was originally intended, and the cost much exceeded the original estimate. Owing to the difficulties of the site, yielding sand constantly shifting under the influence of a cross current, the settlement of the cribs continued throughout the whole working season. The work was finally completed only after the constant building up of the cribs as they settled, and when the nature of the site had been practically changed from sand to stone, by the constant settling of the crib filling through the grillage intervals of the crib bottoms. The pier-head crib settled 7 feet bodily on its original site in the course of the season, besides sifting out through its bottom about half its stone filling. A like action, to a lesser extent, took place throughout the whole extension."

During the year ending the 30th of June, 1870, costly repairs were made to the new prolongation of the south pier, on account of further settlement, and of serious damage from storms; the dredging alongside the pier was completed; and the new breakwater had advanced 950 feet, of which a length of 400 feet was provided with its superstructure. At the expiration of the following year the breakwater had attained a length of 1,711 feet, of which 1,183 feet were completed. By the 30th of June, 1872, the breakwater had reached a length of 2,136 feet, of which 1,853 feet were completed.

On the 20th of September, 1872, Colonel Harwood, U.S.A., who had been in charge of the work for two years previously, reported that, during the last season the cribwork had passed from a foundation of sand and rubble, on which there was scarcely any appreciable settlement, to a soft clay stratum, on which, under the influence of heavy weather, cribs had settled as much as 4 feet in twenty-four hours, after having been well placed on their bed. He therefore calculated that, henceforward, it would be safe to estimate the cost of the work at 50 per cent. more than that which had been already performed. On this basis it was estimated, therefore, that a sum of $600,000 would still be required for the breakwater, and that a further sum of $300,000 would be wanted for the proposed south entrance.

Towards the close of the working season of 1872, much difficulty was experienced in keeping the newly-placed cribs in position on their yielding foundation. Six cribs, each 50 feet long, filled with stone and decked over, were left to settle till the opening of the navigation in 1873. A heavy gale displaced these cribs, and, owing principally to this interruption in the regular progress of the work, and to the time occupied in repairing the damage, the breakwater was only 263 feet longer on the 30th of June, 1873, than at the same date the year before. On the 10th of April, 1873, a board of Engineers, who then examined the state of the breakwater, reported that that portion of it which had been built on a firm bottom was a fine specimen of cribwork, and recommended that the remainder of the work, on account of the yielding nature of the bottom, should be founded on a bank of rubble 4 feet high, extending 24 feet exterior to the cribs, and 15 feet beyond them on the harbour side; leaving it to the Engineer officer in charge to vary these dimensions as experience might dictate for the best.

In his annual report of 1873, Colonel Harwood recommended the immediate construction of the south entrance, and accordingly included the sum of $150,000, to be spent on this work, in his estimate for the year ending the 30th of June, 1874.

The commencement, he said, of the south pier of the proposed south channel is a matter of pressing necessity, to arrest the alarming amount of accretion of sand which has already taken place, and which threatens, if not arrested, "to nearly block up the entrance to Buffalo River, and prevent access to the city wharves, unless large sums are spent annually in dredging. This accretion would appear to be due to the confining of the littoral current between the breakwater and the shore without preventing the sand in suspension from being carried along and deposited at the lake-front and behind and about the end of the south United States pier."..."Just in proportion to the extension of this pier, the sand will be arrested in its northward progress along the beach. If several hundred feet of piering could be built next season, it would be of the greatest advantage to commerce in performing the function of sand-catcher."

The Author visited the new breakwater at Buffalo on the 15th of October, 1873, when it had attained a length of 2,600 feet, and was being built in a depth of 30 feet of water. At that time the damage to the six cribs had been effectually repaired as follows:—A crib 220 feet long, of irregular width, so as to rectify the inequalities in the line of the interior facing of the four cribs which had suffered most by the storm, was floated to the spot, lashed alongside steam-tugs, which held it in place whilst it was sunk with stones to the bed of the lake. It was then secured by piles and iron tie-rods to the old work, and finally a timber superstructure was raised on the combined work in line with the breakwater already completed.

It is worthy of remark that some of these displaced cribs were moved as much as 15 feet towards the sea front by the gale, after having been properly placed and filled with stone up to the level of 2 feet above the water line. Mr. Muehle, C.E., Assistant Engineer to Col. Harwood, attributed this phenomenon to the effect of the alternate battering action of the sea on the shore side, and the recoil of the waves on the sea side, of the cribs, thereby producing a vacuum. Mr. Muehle assured the Author that, during the progress of the works, none of the cribs had moved an inch laterally after the superstructure had been carried up to the full height of 8 feet and joined to the old work. This fact is a strong argument in favour of continuity of structure in works built with the same end in view and under similar circumstances elsewhere.

The Author cannot better conclude this Paper than by reproducing literally from his journal the following "Note," which was written at Providence on the 23rd December, 1873:—

"Mr. Corliss called at ten o'clock, and drove me in his buggy to the American Screw Company's establishment, where I remained for more than an hour in company with Mr. Angel, the President of the works, who explained everything to me in a most obliging manner—one more proof, of the hundreds I have had already, of the hearty readiness and good-will displayed by Americans of all classes in giving strangers every species of information they possess relative to their own particular line of pursuits."

The Author experienced the same unwavering civility up to the last day of his stay in America; and, after a long experience of continental travel, he can safely say that there is no country where an unprejudiced Englishman is better received, and more generously treated, than in North America, and certainly not one he can visit where the application of science to industry in all its phases is so well understood and practised.

The communication is illustrated by Plates 6 and 7.

APPENDICES.

APPENDIX I.

Crevasse at Bonnet Carré, Louisiana.

Extract from the Report of General James Longstreet and Mr. W. G. R. Bayley, two of the three members of the Leveo Commission of Engineers, to the Governor of Louisiana, on the 31st of December, 1874.

This crevasse occurred, as we were informed, in consequence of the washing out of a muskrat hole, or burrow in the levee, on the 11th of April, at 5 o'clock A.M. It enlarged too rapidly to be checked or controlled, and remained open during the remaining portion of the flood season. The break occurred when the river there was at its highest stage. The width of the opening when measured at low water, in August, from levee to levee, was 1,370 feet. A channel 550 feet wide by about 30 feet deep at low water, and about 50 feet deep at high water —measured on a line with the levee—was scoured out through the firm clayey bank of the river by the rushing torrent, and this wash-out extended, with a somewhat reduced width and depth however, for a distance of about 1,400 feet. The sectional area of the crevasse, as measured at low water, was 34,895 square feet, to the top of the levee. The area of the washed-out channel, to the level of the bottom of the crevasse channel on each side, between the ends of the levee, was 16,700 square feet; leaving 18,195 square feet as the area of crevasse opening exclusive of the crevasse channel. Allowing 2 feet for depression of surface of the water in the opening, we have about 32.000 square feet as the present area of discharge of this crevasse at high water, and say 15.455 square feet as the actual area of discharge, exclusive of the crevasse channel. We think that at a high stage of the river this crevasse would now discharge about one-tenth of the quantity of water flowing in the river channel to this outlet. The opening gradually enlarged to its present capacity, after the river reached its highest stage, and while it was slowly declining. We have not the data necessary for estimating how much water escaped through this outlet between April 11 and July 15, the latter date being about the time when it ceased to run through, but, of course, it was very much less than the quantity which will flow through it at the next flood stage of the river, if the gap is left open In order to ascertain the effect of the reduction of quantity in the river below this crevasse, Mr. Bayley, of this commission, on the 20th to the 22nd of September last, measured two sections of the river above, one opposite the upper end and two below this crevasse. At that time the river was nearly at its lowest stage, and the river water had ceased to flow through the crevasse for more than two months.

A section taken about one mile above this crevasse, the river being then 20 feet below the high-water mark, showed the then low-water width to be

2,886 feet, the maximum depth 110 feet, and the area of waterway 184,653 square feet, with a firm clay bottom, into which an 11-lb. sounding-lead sank from 1 to 2 inches only. The high-water width had been 3,120 feet.

Section No. 2, taken about three-fourths of a mile above the crevasse outlet, showed a low-water width then of 3,014 feet, a maximum depth of 79 feet, and waterway area of 164,167 square feet. The high-water width was 3,210 feet.

The average depth of the upper section was 64 feet, of section No. 2, 54 feet. The average of the two upper sections was, depth 59 feet, width 2,950 feet, area 174,410 square feet.

Section No. 4 was taken about 750 feet below the lower side of the crevasse, and No. 5 about 1,500 feet below. No. 4 showed a low-water width of 2,406 feet, maximum depth of 62 feet, waterway area of 96,640 square feet, average depth 40 feet; bottom, except near left bank, very soft oozy mud, into which lead sank from 1 to 2 feet. Section No. 5 showed a low-water width of 2,452 feet, a maximum depth of 64 feet, area of waterway 106,150 square feet, average depth about 42·3 feet, bottom same as No. 4. The average of the two lower sections was, depth 41·65 feet, width 2,429 feet, area of channel 101,395 square feet.

The reduction of channel below, evidently caused by the crevasse outlet (as shown by the hard or firm bottom where the two upper sections were taken, and the soft oozy mud or new deposit where the two lower sections were taken, as well as new sand bars on the right bank shore opposite same), taking the averages of the two upper and two lower sections, amounts to 17·35 feet in average depth, 521 feet in width of low-water channel, and 73,015 square feet in sectional area.

The high-water widths of channel on sections 4 and 5 were found to be 3,300 and 3,430 feet respectively, and the average high-water sections for sections 1 and 2, and 4 and 5 were 232,003 and 156,913 square feet respectively; the average of the lower sections, to the high-water line, being 75,090 square feet less than the average of the two upper sections.

It was also noted that there had been very extensive new deposits, forming sand bars out several hundred feet from the shore line in the river bend, next the right bank, below the Bonnet Carré crevasse outlet; and it is known that these were made, principally, during the flood of 1874.

Should the Bonnet Carré outlet not be closed before the next high water, a still further contraction of the channel-way below it may be anticipated. That such was the effect this year is incontrovertible.

APPENDIX II.

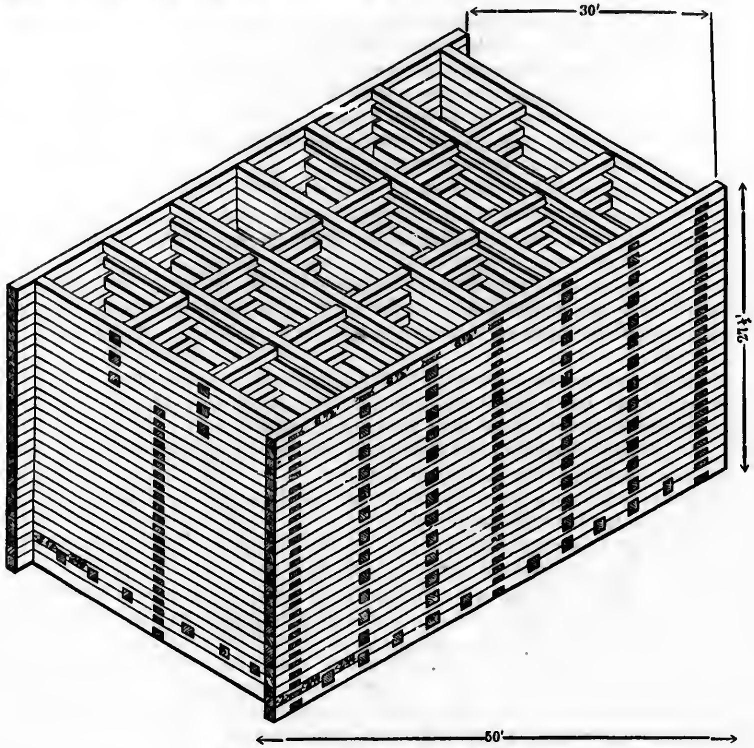
Specification for Cribwork for the Improvement of Lake Harbours in the United States.

General Specification.—The cribs should have a length of from 30 to 50 feet, a breadth never less than 20 feet, even in the shoalest water, and never less than their total height from their foundation to the platform. That the platform should rise at least 5 feet above high-water level of the lake. The bottom of the crib should be of grillage, and all the timber and iron employed should be of a quality to warrant the ultimate construction of a masonry superstructure; should that plan be considered preferable to an entire renewal of the timber-work when, from natural decay, the 'old' superstructure is no longer serviceable.

General Details.—The timber to be of pine, free from rents, splits, shakes, rot or other imperfections; to be accurately sawn or hewn to the required dimensions; if hewn, to require no counter-hewing in framing.

The iron bolts to be of best quality of wrought iron.

The stone to be of a hard, good quality, and of a size to permit of its easily passing through the intervals in the grillage bottoms in the cribs.



ISOMETRICAL VIEW OF CRIBWORK.

The framing to be done in a workmanlike manner; the dovetails of ties and cuts in side timbers to be fitted accurately. The holes for the reception of the bolts to be bored to the full depth to which the bolt is to be driven, and to be 1⅛ inch in diameter.

The timber in a crib is of uniform size (12 inches by 12 inches), except that in the lower course, which is 12 inches by 18 inches; the bolts which hold the timbers together are made by cutting 1⅛-inch square iron into lengths of 20, 24, and 32 inches.

The cribs are built in still water, in the manner about to be described, until their height is a little greater than the depth of the water on the proposed site of the pier; they are then towed to their places and placed in succession on the line of the pier from the shore outward, their ends joining and the channel sides of all as nearly as possible in the same plane; as soon as a crib is in position it is weighted with stone until it touches the bottom, then it is filled with the same material to the level of the top. When the cribs have settled in their places, the structure is continued to a height of 5 or 6 feet above the water surface and filled with stone. This portion of the structure is called the 'superstructure.'

Details of the Framing.—The end walls are placed 2 feet from the ends of the side walls to secure greater strength from the framing. It will be observed that the bottom is not close, but is a 'grillage.' Before driving a bolt, a hole 1¼ inch in diameter is bored for the whole distance the bolt is to be driven. The first bolts in a crib are driven in the second course, and are each 24 inches long; 32-inch bolts are driven in all the remaining courses to the upper one, in which 20-inch bolts are placed. Bolts are also driven at the intersection of the timbers in the interior of the crib. The timbers in the two interior cross walls and in the interior longitudinal wall are called 'ties.'

In selecting a place for framing the cribs it is mainly important that it should be in quiet water, that the shore should be about level and but little above the water's surface, and that there should be a depth of 10 or 12 feet of water within a few feet of shore.

Three or four courses are framed and bolted together on shore, where the structure is launched and additional courses put on until the height is 2 or 3 feet greater than the depth of the water where it is to be placed. As it is usually desired to obtain a depth of 10 or 12 feet of water in the channel, the site of the proposed pier should be dredged to that depth wherever the original depth of water is less. When three or four cribs are finished, if there is a sufficient supply of stone at hand to fill them, they are put in place and filled.

The placing of a crib is attended with considerable risk, for perfectly smooth water is requisite to enable the workman to put it in exactly the proper place. It often happens that a sea arises when the crib is but partially filled, and it is swept from its place and washed ashore.

The bottom on which the crib is to be placed must be level, or nearly so; if there is a variation of more than 1 foot in the depth of water at different points, the bottom must be dredged to a level. The first crib is towed out by a tug, or by lines leading to shore, to the inner or shore end of the work proposed, and is carefully placed so that its face shall be in the direction required; a scow on which are piled 8 or 10 cords of stone being brought alongside, some slabs or boards are laid across the corners of the crib and stone piled upon them in such a manner as to keep the crib level as it sinks; when it rests on the bottom, stone is thrown in as rapidly as possible until it is filled, 4 or 5 scow-loads being necessary to fill it.

The scow being again loaded with stone, and the bottom levelled for the second crib, it is placed with its end against the outer end of the first one, and sunk and filled in a similar manner. Various devices are used to keep the crib in place while sinking. One of the best consists of two iron rods, each about 3 or 4 feet in length, with one end turned down at right angles so as to form a hook, and having the other end connected by a swivel screw, by turning which the distance between the hooks may be varied at pleasure; when the crib is brought into position, this apparatus is placed so that the hooks embrace the end walls of the adjacent cribs, and the swivel is turned until the cribs are brought closely together; a pair of these clamps are used, and they hold the crib firmly in place until it is filled.

In the same manner the remaining cribs are placed.

After being placed and filled, they are allowed some time to settle; it is deemed advisable to let them remain during the winter when possible, but sometimes the superstructure is put on in a month or two. The cribs often settle very irregularly on account of the uneven texture of the bottom, as when one portion of the crib rests on hard sand and another on quicksand, as well as of the shocks of the waves and of their action and the action of the currents in washing out the foundation. They are constantly watched, and the load is shifted from side to side as occasion requires, to induce a more rapid settling of any part; they generally settle in the sand a foot or two after being placed, and often much more; after a month or two they become pretty firmly fixed in place. Should none of them be out of level more than a foot, or a foot and a half, the result is deemed very satisfactory.

When they have settled, they are 'levelled up' by putting on the wedge-shaped pieces until the tops of all are in the same horizontal plane, and the superstructure is then added; this being continuous from crib to crib, serves to bind the pier together. It is usual to place a larger crib, 30 or 32 feet square, at the outer end.

The interval between the end walls of adjacent cribs is filled with slabs or edgings to the water's surface, and thence to the top of the pier with stone.

APPENDIX III.

Specification for the Construction of a Breakwater, Landing Pier, etc., of Cribwork at Chantry Island, Lake Huron, Canada.

The works for which 'tenders' are invited, consist in the construction of a breakwater on the easterly side of the roadstead, starting from a salient point of the mainland, and extending outwards in a slightly curved line about 1,800 feet, or to within 450 feet of the extreme end of the protection works already formed on the westerly side of the island—the construction of a landing pier from the shore outwards to a depth of 14 feet at low water at a place from 300 to 500 feet south of the breakwater.

Breakwater.—To be carried up to the height of 7½ feet over the water level of September 1868; at the shore, and out to a depth of 3 feet water it is to be formed chiefly of gravel, well faced, and protected with boulder stones on both sides; thence outwards it is to be of cribwork up to within 1 foot of low-water line, where a continuous superstructure is to be commenced and carried to the height above stated.

The interior of the work throughout must be filled with a good class of moderate-sized stones; and where the depth of water exceeds 15 feet, a talus of stone is to be placed along both sides of the cribwork up to within 12 feet of the water surface, with an outer slope of 1 horizontal to 1 vertical.

For 300 feet at the inner end, the structure is to be 20 feet in width—the next 300 feet, 25 feet in width, outside of this it is to be made 30 feet wide, except at the extreme end, where a crib 50 feet square is to be placed, connected with the other work, and arranged so as to form the eastern heading pier of the northern channel.

Cribwork.—To be of the widths above stated for the respective places, and in lengths of at least 30 feet. The sides and ends to be of timber not less than 11 inches square, straight, sound, and full on the edges, carried up vertically to within 2 feet of the water surface, where a batter of 1 in 12 is to be commenced on both the front and rear sides.

Framing.—The outer timbers of the cribs are to be framed so as to leave a space of 2 inches between the different courses, and at the angles they are to be connected by double bevelled dovetails, arranged so that every end timber shall be dovetailed into two side timbers, and the side timbers be similarly placed between those forming the ends.

At each corner in every course a rag bolt 12 inches long and ⅝ inch diameter is to be driven through the dovetail.

Cross Ties.—To be at least 10 inches thick, of sufficient size to square 10 inches by 12 inches at both ends, and of the full length (respectively 30 feet, 25 feet, and 20 feet) of the outside width of the different cribs. They are to be placed not more than 10 feet apart, and so arranged that the ties resting on the different rounds of timber shall be midway between those of the courses immediately below and above.

Their ends are to be dovetailed 3½ inches into the timbers under and over them, the dovetail to splay 1½ inches on both sides, so as to stand 8 inches at the neck, and 11 inches at the outer end.

Under the head of each tie, at the joint between the courses immediately below it, a block 2 inches by 11 inches by 11 inches is to be inserted to give a uniform bearing, and a rag bolt 2½ feet long, ⅞ inch diameter, is to be driven through the head of each tie, passing down through the course on which it rests, the block and course under it, and 4 inches into the head of the next cross tie.

Longitudinal Ties.—In all the cribs longitudinal ties, 10 inches thick, are to be framed into, and dovetailed between the alternate tiers of end timbers, have blocks under them, and be secured by bolts of similar dimensions, and in like manner as described for the transverse ties, into which they are to be notched and fastened at the crossings by means of white oak tree-nails, 2 inches diameter and 16 inches long.

In cribs 25 or 30 feet in width they are to be arranged as shown on section; and in those 20 feet wide they will generally be carried up in the centre.

In the cribs forming the terminations of the piers, there must be longitudinal ties in every course placed alternately 10 feet and 20 feet from the face side.

The cribs are to be further secured by vertical ranges of plank placed inside, and extending from the lowest side timber up to the water line. There are to be three ranges on a side, that is to say—one at, or near each angle, and another in the centre; making in all six vertical ranges in a crib. The planks are to be 4 inches thick, and 10 inches in width, fastened from the inside with 10-inch spike, ⅝ inch diameter, two driven through each plank into each of the lowest side pieces, and one at every crossing of a side timber from the floor upwards. They may be put on in lengths of from 8 to 10 feet or more: but they must be so arranged that the upper length in all cases shall reach down at least 2 feet lower than the top of the plank of the same range below.

Ballast Floors.—To consist of flatted timbers, 10 inches in thickness, and of the full length of the width of the respective cribs, *i.e.*, 30 feet, 25 feet, and 20 feet. They are to be laid transversely from 5 to 6 inches apart, and rest on either the first or second course of side timbers, as may be directed, and to which every alternate piece is to be fastened at each end by a bolt ¾ inch diameter, and 18 inches long. In cribs 30 feet, or 25 feet in width, there are to be two longitudinal timbers dovetailed into and secured to the end pieces at the proper height, to form bearings for the floor. In cribs 20 feet wide there will be only one longitudinal bearer under the floor.

The cribs, from the bottom upwards to low-water line, may be formed either of pine, cedar, ash, tamarac, or elm timber; but whatever kind is used, it must be straight and of good quality, free from shakes, sapwood, unsound knots, or other defects.

Before a crib is put together, the contractor must take correct close soundings over the place it is to occupy when sunk, and where such inequalities occur as cannot be removed, the bottom of the crib must be adapted to them, so that when placed in its berth the sides and ends shall be plumb, and the whole form a line corresponding to that marked out by the officer in charge.

Immediately after a crib has been moored in the right position, the contractor, if so directed, must lay a platform of plank over it of sufficient size and strength to carry enough stone to sink it. and when thus sunk, and ascertained to be on the proper line and place, the crib is to be filled with an approved class of moderate-sized stone, closely packed.

As before mentioned, when the depth of water exceeds 15 feet, a talus of stone is to be formed along each side of the breakwater, up to within 12 feet of the water surface. The stones must be placed as compactly together as possible, and arranged so as to have on the respective outer sides a uniform slope of 1½ horizontal to 1 vertical. This work to be proceeded with simultaneously with the sinking of the cribs, and must be conducted in such a manner that there will be at no time more than two cribs sunk in advance of it.

When the whole of the cribs shall have been sunk, well filled with stone, and settled in their respective berths, the sides must be brought to a uniform height at low-water line, either by cutting down and removing the top timbers, or using suitable levelling pieces as may be required.

The Superstructure is then to be commenced, and carried up with a batter of 1 in 12 to the height of 7½ feet over the water level of September 1868, or to such other height as directed. The face timbers to be of pine 12 inches square, generally not less than 40 feet long, or of such other lengths as will break joint properly over and upon the different cribs. They are to be scarfed at the ends where they connect; the scarf to be square at heel and toe, and have a lap of 18 inches, with a block underneath, and be secured with a bolt 18 inches long and ⅞ inch diameter. The timber must be counter-hewn, if required, and laid so as to leave a space of 1½ inch between the courses.

Transverse Ties of flatted pine timber, of a size to square 10 inches by 12 inches at both ends, and of a sufficient length to extend across the pier are to be placed not more than 10 feet apart, in every course of the superstructure. They are to be dovetailed, and let into the side pieces over and under them—have a block 1½ inch by 12 inches by 12 inches inserted between the two courses under the head of each, and be secured by means of rag bolts, ⅞ inch in diameter, in a similar manner to those described for the cribs.

Longitudinal Timbers of flatted pine are to be carried up between the alternate courses of like dimensions, be framed, notched into cross ties, and secured generally as those described for the cribs.

Binding Pieces, of 4 inches by 10 inches pine plank, are to be placed vertically inside for the entire height, and fastened with spikes, ⅝ inch diameter, and 10 inches long—one at every crossing of a face timber.. They are to be not more than 14 feet apart, and are in every case to form continuations of the respective ranges underneath.

Stringers.—To form bearings for the top covering, five stringers, each 7 inches by 10 inches of pine, are to be laid the whole length of the breakwater, secured to the cross ties, and placed at a like height as the side timbers.

The whole interior of the superstructure must be filled with a good class of stone, carried up as the timber-work proceeds, and care taken to pack them well around and between the ties, as well as to have the top part properly levelled.

Top Covering to be of 3-inch pine plank of sufficient length to pass over the side timbers and meet on the centre stringer. They are to be laid crosswise, 1 inch apart, and be fastened at the ends, and at every crossing of a stringer, with 7-inch pressed spikes.

The covering is to be further secured by chamfered cap pieces of white oak or rock elm, each 10 inches by 6 inches—one range laid along each side of the breakwater, and another in the centre over the joinings of the plank. The cap pieces to be fastened with rag bolts, ¾ inch diameter, and 18 inches long.

In case it should be determined to put mooring posts in the breakwater, they are to be of white oak or rock elm timber, 10 feet long, and 16 inches diameter, properly dressed, covered on top with a cast-iron cap piece, and placed so as to stand 18 inches over the top covering. They are to be notched at bottom to receive cross pieces 5 feet long, be secured to the cross ties with screw bolts of 1¼-inch round iron, and have the ballast around them properly packed.

The outer faces of the superstructure, from the top to low-water line, must be hewn down neatly to lines corresponding to the position of the work, and everything done that is necessary to leave the whole in a finished and satisfactory condition.

Landing Pier to be made 30 feet wide and about 400 feet long, placed in the position indicated on the general plan.

The cribwork of the pier is to be built of a like class of timber, framed, put together, secured, sunk, and filled with stone, with a superstructure of pine timber, of like dimensions, arranged, framed, secured, and ballasted with stone, have the sides dressed down to water surface, the top covered with 3-inch pine plank, and the whole work executed and completed as described for the breakwater.

The works are to be commenced immediately after the person or persons whose 'tender' is accepted shall have entered into contract with the Department of Public Works, and must be proceeded with in such a manner that the landing wharf, and approach to it, shall be finished on or before the 1st day of September, 1874, and at least one-half of the cribwork connected with the breakwater sunk by the 1st day of November, 1874; and the whole work completed by the 1st day of October, 1875.

JOHN PAGE,
Chief Engineer Public Works.

Department of Public Works, Ottawa,
30th August, 1873.

APPENDIX IV.

ESTIMATE of the COST of CONSTRUCTING and SINKING a CRIB 50 feet by 30 feet by 30 feet in 24 feet of WATER in the line of the BREAKWATER to the OUTER HARBOUR at CHICAGO.

	$	c.
9,442 cubic feet of pine timber, 12 inches by 12 inches, at 22 cents per cubic or lineal foot	2,077	24
4,000 feet, board measure (12 inches by 1 inch), of white oak plank, 8 inches by 3 inches, for deck of crib at $30 per mètre	120	00
8 sills to support the flooring, each 30 feet long, and 9 inches by 6 inches, 90 cubic feet at 22 cents. . .	19	80
12,772 lbs. of iron bolts, 1⅛ inch square, at 4 cents per lb.	510	88
275 lbs. of wrought-iron spikes, ⅜ inch by ⅜ inch square, at 8 cents per lb.	22	00
247 cords of stone,[1] crib ballast, at $6 50 cents per cord	1,605	50
28 ditto for intervals, at $6 50 cents per cord	182	00
Estimated cost of materials	4,537	42
Superintendence and workmanship	2,306	40
Add 10 per cent. for contingences	684	33
Estimated cost of one crib, 50 feet by 30 feet by 30 feet = $150 56 cents per lineal foot, or $4 52 cents per cubic yard.	7,528	15

[1] A cord of stone or timber is equivalent to 128 cubic feet.

No. 1,413A.—"Cribwork in the Black Sea." By Sir CHARLES A. HARTLEY, M. Inst. C.E., F.R.S.E.

IN the construction of the provisional piers at Sulina, in 1858, it was first of all intended to build cribs from 30 feet to 60 feet long, to load them with stones, and to sink them at intervals of 20 feet along the line of works, filling the space between with piling, driven from staging, supported by the cribs, the whole being protected at the foot by rubble stones. After sinking a few cribs of unusual strength,[1] the mixed system was abandoned in favour of piling and 'pierre perdue' work only. This decision was come to owing to the experience that had been gained of the serious risk and loss of time involved in placing the cribs in position in an open seaway, and of the expense incurred in adding timbers to the superstructure until settlement had ceased. The settlement was very unequal: as much as 4 feet on one occasion after a heavy gale. It was entirely produced by the scour of the sea on the foundation of hard sand, before there had been time to surround the crib with a wide bank of rubble stones. When cribs were placed on a bank of rubble in the first instance, as occurred on three occasions at the head of the piled piers at the end of the working season, no scouring action took place, and, consequently, the cribs never moved from their original position, whilst they served admirably as breakwaters or temporary pier heads during the stormy months of winter.

Although the Author's experience of the use of cribwork in a very exposed seaway was not encouraging, it was such as to convince him that, in a country where timber and stone are plentiful, where cheap cement is not to be obtained, and where an economical stucture in the first instance is a *sine quâ non*, no better plan can be adopted of building a pier or breakwater in greater depths than 15 feet, on a sandy or yielding bottom, and where heavy seas and the 'teredo navalis' are not to be feared,

[1] *Vide* sketch of cribwork in vol. i. of Atlas attached to the first "Mémoire sur les travaux d'amélioration exécutés aux embouchures du Danube," in the library of the Institution.

than that of first of all throwing down a bank of rubble to a depth dictated by the nature of the locality, and then to surmount it with cribwork up to a level of a few feet above the water line. It was this conviction that induced him, nearly fifteen years ago, to propose the construction of a provisional mole, in a comparatively sheltered position on the north-west coast of the Black Sea.

This work was not constructed; but, on comparing its cost, at Chicago prices, with that of a Chicago crib of 1871, in the same depth of water, and therefore 30 feet high and 30 feet wide, it will be found that whilst the cost of the latter plan is $150 per lineal foot, that of the former is only $115 per lineal foot, with the great advantage, moreover, that, by adopting the stone foundation, the expense and inconvenience attending the raising of the superstructure of the cribs, on account of settlement produced by scour, is altogether avoided.

In comparing the cost of works in England and North America, the much higher wages paid to workmen in the latter country must always be kept in view. The following information on this question was gathered by the Author from various sources in the United States and Canada.

WAGES PER DAY IN THE UNITED STATES.

	$
Foremen	4½ to 6
Mechanics, blacksmiths, masons, and bricklayers	3 to 4
Carpenters	2 to 2½
Quarrymen	2½
Labourers	1 to 2
Horse, cart, and driver	3½ to 4

In Canada the wages are about 25 per cent. less; but clothing is far dearer, and taxes are more than 25 per cent. higher in the United States than in Canada; thus, in buying-power, the wages received in Canada are fully equal to those paid in the States.

In 1873, the approximate currency value of the United States dollar was 3*s*. 8*d*., and that of the Canadian dollar, 4*s*.

The cost of clothing, washing, house-rent, spirits, and beer is more than double as much in the United States as in England, whilst in the former the ordinary articles of food are somewhat cheaper than in the old country.

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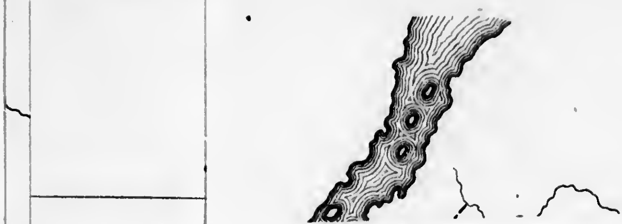

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WATER COMMUNICATION IN

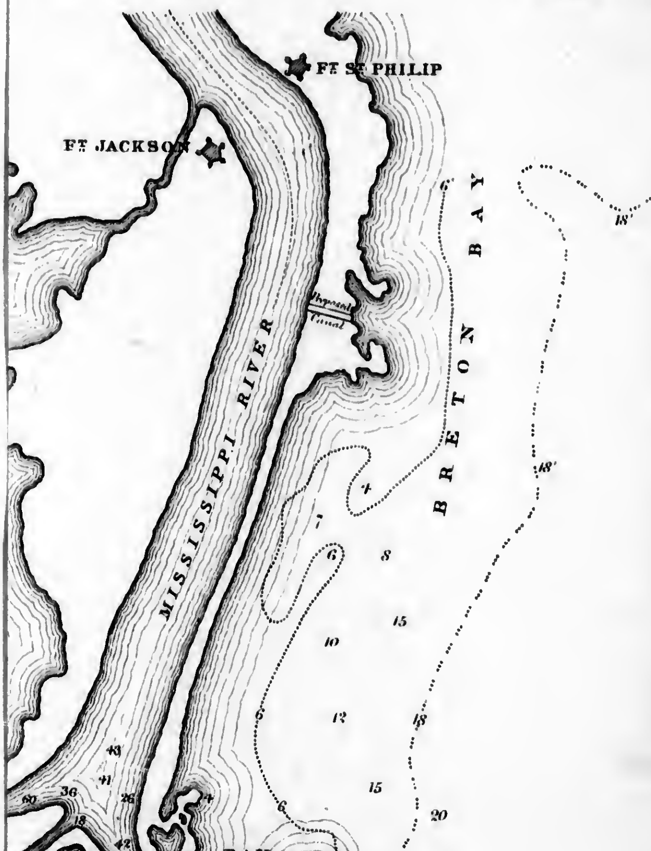
PLAN SHOWING THE NAVIGABLE ROUTES BETWEEN THE LAKES AND THE SEABOARD,

CHAS. A. HARTLEY, DELT.

MUNICATION IN NORTH AMERICA.

LAKES AND THE SEABOARD, AND THE COURSE OF THE UPPER MISSISSIPPI AND THE OHIO RIVERS.

THOS KELL, LITH. 40, KING ST COVENT GARDEN.



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