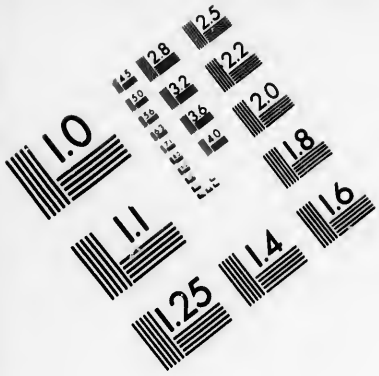

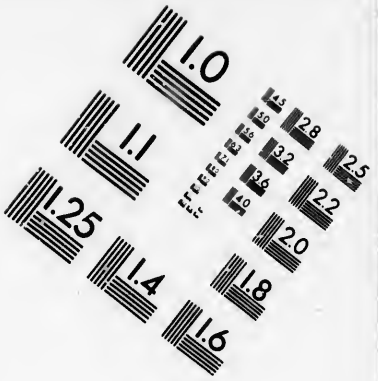

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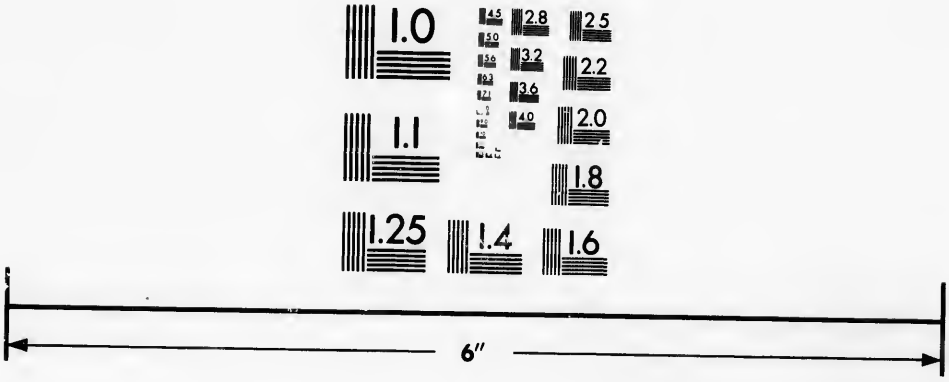

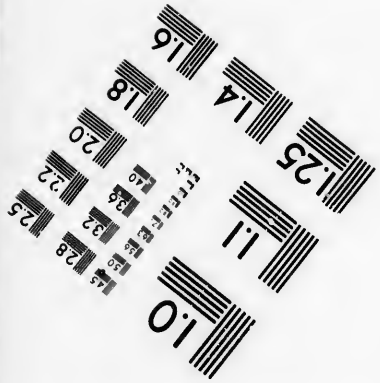

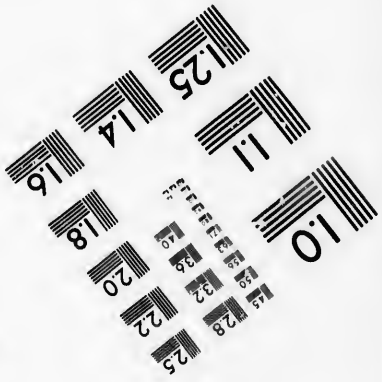

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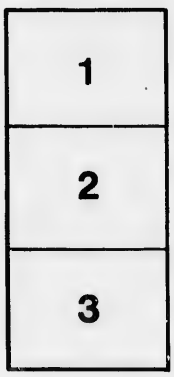

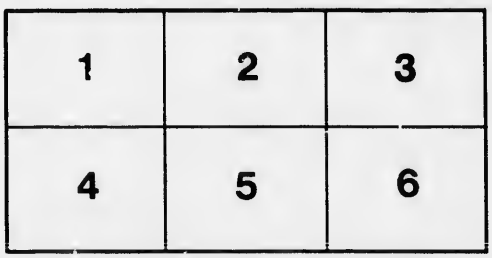

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Canadian Society of Civil Engineers.

INCORPORATED 1887.

TRANSACTIONS.

Paper 10.

THE WORKS ON THE RIVER MISSOURI AT ST. JOSEPH.

By H. H. Killaly, M. Can. Soc. C.E.

(To be read on Thursday, Dec. 1.)

The works which form the subject of these notes were undertaken in connection with a bridge, which was, at the same time, being built across the Missouri River, at St. Joseph, Missouri.

A general description of the latter, as to location, etc., is necessary to explain the circumstances under which the former were undertaken.

These works were built under authority of an "Act of Congress," approved March 5th, 1872; and entitled: "An Act to authorize the "construction of a bridge across the Missouri River, at or near St. Jo- "seph, Missouri." In this Act it is stated "that the corporation build- "ing said bridge may, if not unauthorized by the provisions of its "charter of incorporation, enter upon the banks of said river, either "above or below the point of the location of said bridge for a distance "of seven miles; and erect and maintain break-waters; or use such other "means as may be necessary to make a channel for said river; and "confine the flow of the water to a permanent channel; and to do what- "ever may be necessary to accomplish said object; but shall not im- "pede or obstruct the navigation of the said river; and all plans for "such works or erections upon the banks of the river shall first be sub- "mitted to the Secretary of War for his approval.

"This Act also provides that the bridge, at the option of the corpo- "ration building the same, may be built as a drawbridge, with a pivot "or other form of draw, or with unbroken continuous spans; provided, "that if the same shall be made of unbroken continuous spans, it shall "not be of less elevation in any case than fifty (50) feet above extreme "high-water mark, nor shall the spans of said bridge be less than three "hundred and fifty (350) feet in length. That if a bridge shall be "built under this Act, as a drawbridge, the same shall be construeted "as a pivot drawbridge, with a draw over the main channel at an

"mitted to the Secretary of War for his approval.

The treacherous nature of the Missouri "bottom," together with constant changes which occur in the channel, rendered it necessary that the piers should be placed on the bed rock, and that the lowness of the banks settled the question of a high or low bridge, in favor of the latter.

The masonry of the bridge, as built, consists of one small abutment on east bank, and five river piers; the former placed on the top of the bank and founded at a depth of 3 feet below the natural surface; the five latter piers built upon inverted caissons, and sunk, during building, to bed rock, at a depth of 45-ft. to 48-ft. below ordinary water (low).

The superstructure is of wrought iron, of the form known as the "Pratt Truss," and carries a "through" single line of R.R. track and carriage way combined, at a level of 12 feet above the highest water or of 80 feet above bed rock.

The spans are as follows:

Each shore span, 80-ft. from centre to centre of piers; pivot draw-span, 364 feet over all, giving two openings of 160 feet each.

Three Fixed spans, 300 feet centre to centre of piers.

From the above description of the bridge, it is seen that the total width of the natural channel at low water, is only 350 feet; and the whole of this channel is covered by the 364 feet draw-span; the pivot pier being placed exactly in the centre of the low water channel, a clear opening of 160 feet is given, on either side, for the passage of vessels.

It is evident, therefore, that in order to preserve uninterrupted navigation of the river, the low water channel must be controlled, and compelled to run through the draw span; the high water channel must also be watched, and means taken to prevent a cut-off or any serious change taking place. This involves the supervision of the river for some miles above the bridge. Equal care is not required below the bridge, where, only at one point, can any danger be anticipated. This would occur, only in case of the neck of the main "bend," at a distance of $3\frac{1}{2}$ miles below the bridge, being gradually cut away; an occurrence to be apprehended only in the distant future.

The accompanying map shews a portion of the Missouri River, surveyed in connection with the bridge works proper, as well as with the work for the diversion and controlling of the river in the vicinity of the bridge.

The length of the river surveyed was in all, about $13\frac{1}{2}$ miles, comprising one complete "bend," representing the general character of this river for a great portion of its length.

The river at this point runs through a valley of from four to six miles in width, enclosed by ranges of bluffs or rolling, knolly hillsides of from seventy-five to two hundred feet in height above the river water.

The bluffs on the Missouri bank are composed of stiff clay, while on the Kansas bank, rock crops out at Belmont and Wathena.

The clay banks, when excavated and exposed to the weather, stand for a long time with little change; this was instanced in St. Joseph, in 1871–73, where many streets were graded down to a depth of 30 to 40 feet, while the lots, with houses built upon them, were left standing, the only means of access to and from the street, being by stairways placed in very nearly vertical position in front of each house.

The nature of these clay bluffs is such that they are affected but

At low water the discharge is very much reduced (the proportion between high water and low water being about as 11 : 1), and runs in a channel or channels confined generally within the high water banks, meandering about and cutting out its course in a variety of curves, forming figures of more minute pattern than at time of high water.

The river is at its lowest stage during the months of November and December. First running ice appears about the middle of November, and the river gorges a few days afterwards.

A slight rise generally takes place in January, and between the middle of February and 15th of March the ice from above generally runs out, with a rise of from six to nine feet. The river continues rising during the months of March, April and May. In June and July the highest water occurs, and lasts generally for six or seven weeks. From the end of July until the end of November, the river generally runs out, and reaches its lowest stage about the end of the last named month.

Before making mention of levels or heights it is well to explain the method adopted in their notation.

The highest water in the river, on record, was, after much research, established by sworn testimony of parties who pointed out marks which they had made, and objects which they had noted in regard to high water of 1844. By connecting these points by levels and comparing their elevations the correct height was established for the flood of 1844. This level of highest water was called (in the notation upon all the bridge and river works) 100, as being that distance (100 ft.) above an imaginary line which was assumed as datum for all the work.

TABLE OF HEIGHTS.

Highest water on record, 1844,	100·00	above datum
" " " 1871,	92·50	"
" " " 1872,	93·50	"
" " " 1873,	92·50	"
Ordinary low water,	80·00	"
Extraordinary "	78·00	"
Low sand bars,	up to 86·00	"
High " "	86 to 96	"
General level of "bottoms," Kansas,	96·00	for 1880 ft. back
" " " "	100·00	beyond 1800′ to bluff, with ridges, slightly higher.
" " " Missouri,	104·00	

The greatest difference between high and low water being 22 feet.

A profile showing the record of water gauge kept at the work at St. Joseph, and also at Leavenworth, Ka., is attached hereto.

In order to record the many changes taking place upon the river, notes were taken every month and full surveys were made after all great changes. These notes were plotted upon the original map, in pencil, and tracings made and fyled away. By applying any one of these tracings upon the original map, the change is distinctly seen; in the same way, the tracing for any month can be compared with that for any other month, and the various changes noted. All these different surveys, if plotted on the original map in a permanent manner, would form such confusion of lines and colours, that the result would be unintelligible.

[illegible] attached hereto.

The nature of the material in the Missouri "bottom," is shewn in the following table. This is all formed from deposits from the river.

No. of Sample	Description.	Weight. Per cub ft. lbs.	Weight. P.3″ cb lbs. oz.
No. 1.	Sand from surface, stratum 18″ thick.....	$61\frac{1}{4}$	0 $15\frac{3}{16}$
	Same, shaken down, microscopic grains of sand	74	1 $2\frac{1}{2}$
" 2	Two feet from surface, 4″ thick. Clay, organic matter and fine sand.....	$74\frac{1}{4}$	1 $2\frac{1}{16}$
	Same, shaken	$81\frac{1}{4}$	1 $4\frac{5}{16}$
" 3	Next stratum, 2″ thick ; little organic matter.	.....	.....
" 4	Next stratum, 6″ thick ; sand nearly as fine as No. 1.....	67	1 $0\frac{12}{16}$
	Same, shaken down.....	$81\frac{1}{4}$	1 $3\frac{11}{16}$
" 5	Stratum, 1″ thick, similar to No. 1.....	64	1 0
	Same, shaken down	$81\frac{1}{4}$	1 $4\frac{5}{16}$
" 8	Seven feet from surface, clean sand crystals, as fine as in No. 4, some loam	86	1 $5\frac{1}{2}$
	Same, shaken down	97	1 $8\frac{1}{4}$
	Sand from pit on East side ; coarse, with small fragments of lignite and gravel.....	97	1 $8\frac{1}{4}$
	Same, shaken down.....	$109\frac{1}{2}$	1 $11\frac{9}{16}$
	Sand from pit East bar	$103\frac{1}{2}$	1 $7\frac{7}{8}$
	Same, shaken.....	$113\frac{1}{2}$	1 $9\frac{5}{8}$
	Drifting sand from East bar.....	94	1 $7\frac{1}{2}$
	Same, shaken down.....	108	1 11

The sediment carried in suspension in the river was examined and was found to consist chiefly of sand in the following quantities, taken from different localities.

Amount of water in all cases was a gallon.

Weights. Filtrate.	Weights. Filter.	Weights. Sediment.	Weight per cub. In. Loose.	Weight per cub. In. Pressed.	Remarks.
g. mill'g	g. mill'g.	g. mill'g.	g.	g. mill'g.	
47·360	15·200	32·160	22	25·970	Surface of channel.
21·150	7·250	19·900	22	25·970	"
40·600	15·25	25·350	22	25·970	"
43·400	7·700	35·900	22	25·970	Bottom at bridge.
		108·310=	27·0775 M'n	Water per	gal. =1 $\frac{0426}{}$ cub. in.
	1 $\frac{0426}{}$ × 6·	2324=6·49	75 Cub. In.	in one cub.	foot of water.

The discharge of sediment is as follows:

At low water, 78· cub ft. per sec. 73·5 or cub. yds. per 24 h., 235200

" med " 86· " " 187·32 " " 500424

47·360	15·250	32·160	22	25·970	Surface of channel

To prevent further encroachments of the river, many years ago, works were undertaken for the protection of the bank in front of the city. These proved successful. They consisted of a number of groins built out from shore, for a short distance, and forming an acute angle with the current.

At each of these groins the current was slightly deflected, and thus gradually forced to follow the bend of the shore.

From what could be seen of these old works, they appeared to be formed of heavy piles driven near the foot of the slope of bank, the space behind being filled with stone and brush; they were, however, so completely embedded in the sand, that it was impossible to see exactly how they were constructed.

This form of protection by groins had been considered with some favour by the chief engineer; but when it was decided to force the current to the east bank it was abandoned and another plan adopted and finally carried out.

This comprised the building of two principal dykes: one to act in turning the channel, causing it to cross from the Kansas shore to the Missouri side; there to follow the east bank, and in a straight course, to pass through the draw-span of the bridge. The second to act as a shore protection on the Kansas side, for a short distance above the bridge.

When these dykes were designed it was assumed that undermining would take place; and they were proportioned in a manner which was considered would give them sufficient tenacity to hold together, while they conformed to any slope which might be caused by undermining, and without much risk of being overturned.

For this reason they were given a wide base, a sloping face and a top load of stone placed so that its centre of gravity was thrown as far back as possible.

The base was made 60 ft.; the face sloping back so as to give a width of from 24 ft. to 30 ft. on top. The back was carried up vertically. The heights varied: in deepest water the height to top of the brush was 25 ft. The depth of channel at low water is taken at 20-ft.

Bed rock was found at a depth of about 45 ft. below low water; upon the bed rock there was a bed of boulders of 5 ft. in thickness; and on top of the boulders, a stratum of clay also of 5 ft. Scour would not take place below the top of the clay. The scour would therefore be restricted to a depth of 15 ft. below the bottom of the channel. When the brush was placed in water less than 20-ft. in depth, and sunk nearly to the bottom, it was considered that scour would take place during the process of sinking; and that the sand would be washed out to, probably, the full depth of the channel.

These assumptions were based upon the results of experiments made on a small scale.

Two sketches shewing cross sections of the dykes are hereto attached: —one shewing the position of the dyke, as built and placed upon the bottom without scour, the other shewing the position which the dyke was assumed to take, under a scour of about 15 ft. and which it did, eventually, in most cases, take.

The work upon the dykes was commenced Sept. 27, 1871, the stage of river being ordinary low water.

These assumptions were based upon the results of experiments made

feet from the butts according to the length of the tree. The loose branches were placed among the tops, and interwoven with them. On top of this brush bank was placed a pile of stone 18-ft. in width, and 3 feet in depth, the rear line of the pile being placed 3 feet in from the line of the butts of the trees.

To hold the brush in position, while being built and sunk to bottom, stout piles were driven by a floating steam driver, generally to a depth of about 14 feet, and spaced at distances of about 10 feet.

Starting from a point on the Kansas shore, nearly opposite to the centre of the city of St. Joseph, and running downwards, making an angle of about 40 degrees with the centre thread of the stream at high water this dyke was carried across the steamboat channel, the sand bar island, and the shallow channel beyond, and terminated on a sand bar with 2 feet of water on the east side of this second channel.

The steamboat channel here is 550 ft. in width with a greatest depth of 20 ft. and current of a little less than four miles per hour.

Here a mole was built in the same manner as the dykes, to form a finish to the end of the dyke.

It was not considered advisable at this time to extend the dyke any farther, and it was determined to await the effect of the next flood, and mark the result.

The total length of this dyke is 2,100 feet.

During the building of this dyke across the steamboat channel, the area of the water way was steadily contracted; and scour took place in proportion to this contraction. The bottom of the channel was, in this way, scoured to a depth of 25 feet below water. The eastern side of the channel was also scoured from the same cause, to such an extent that the greater part of the lower end of the sand bar island was cut away, as the head of the dyke approached.

About the time when this dyke had been built as far as the island, the change in the channel, previously mentioned as having been caused by dyke No. 3, took place, and at once relieved the pressure upon dyke No. 4, the flow through this channel being now almost stopped, by being turned, at the head of the Island, into the centre of the river.

In continuing the dyke across the second channel there was much less difficulty in placing the brush.

A few piles had been driven with intention of forming a temporary breakwater at No. 7: this now was rendered unnecessary, and work upon it was discontinued.

Work upon dyke No. 4 was completed Feb. 16, 1872.

The works of "protection" were also commenced, on the Kansas shore, at the same time as the work above described. These consisted of dykes Nos. 5 and 6.

No. 5 was merely a small dyke placed at a point 1300 feet above the bridge, to check scour which was found to be taking place at the time of commencement of No. 6.

No. 6, "Weavers Dyke" was commenced on the shore at a point about nine hundred feet above the bridge line; and built for a distance of some nine hundred (900) feet; running downwards and outwards, and striking the current at a more acute angle than in the case of dyke No. 4. The manner in which this dyke was constructed is exactly

On approaching dyke No. 5, and when within about 500 feet, it turned suddenly to the left; and curving on a radius of about 500 feet, for a half circle, reversed suddenly, and curving to the right on a radius of 700 feet and describing and arc of 120 degrees, it passed, on a straight course of about 500 feet, through the spot chosen for the location of the draw span.

The channel followed the same curves, with change only caused by the wearing away of the east bar, until the breaking up and running out of the ice on 21st February, 1872.

The works were completed not too soon; the last stone being placed on dyke No. 6 on the 17th of same month.

Up to this date no real injury was done to the works of protection. At dyke No. 6, however, from the constant scouring for a period of two months, the brush had been undermined along the exposed face, and had settled on that side, at places, to amount of 25 feet; the rear line of the dyke being but little disturbed.

The form of the channel immediately before the "breakup" of the river is shewn upon the general map by a heavy dotted blue line.

The ice in the neighborhood of St. Joseph broke up February 21st; and on the 23rd it came down from above, with a rush, causing a sudden rise in the river to level of 89. For the few hours at which it remained at this stage, the flow consisted of a succession of gorges, forming and breaking away. The river foamed and hissed. The whole water-way was filled with broken ice grinding along the bottom, and pitching and tossing on the surface. The water itself was not to be seen, as the mass of broken ice, and drift rolled by; forrest trees and masses of brush, wreckage of all sorts, whirling around, and forced into the air by the upward action of the heaving ice.

A gorge had broken above. On the 24th a gorge occurred, commencing on the east side of the channel, a short distance below the line of dyke No. 4. The channel below this point was very crooked, and retarded the escape of the gorge.

The river hurled itself, with great force, against dyke No. 6; and washed along its face, increasing the undermining which had been already done.

In a few hours the whole face of the dyke had been undermined; the channel having scoured out to a depth of thirty-four feet. The dyke "turned over"!!

It remained, however, as was expected, and now forms a breakwater founded so deep that it is not likely to be disturbed.

No. 4 was not as saulted in so violent a manner; and received no injury. No. 3, however, suffered, some two hundred feet at the lower end having been carried away; and deposited near dyke No. 4.

After a few hours the attack on Weavers Dyke seemed to relax; the current did not strike with equal force, nor in so direct a manner; and it gradually changed, so that the dyke was entirely relieved; the gorge ran out; and the river dropped to 84.

This relief was caused by the cutting through, by the flood, of a bend which had occasioned the jamming of the ice and drift.

At the end of April the channel had assumed a tolerably direct course; and followed what was nearly a central course between the

lower end having been carried away; and deposited near dyke No. 4.

Under the circumstances then existing, it did not appear necessary that the work should be extended; and it was also considered prudent to await the result of the high water of another year.

The work upon the bridge was completed in a few more months; and the staff was discharged in May, 1873.

No work was done on the dykes during these months; and the channel continued to run along the Missouri bank.

The changes which were effected in the channel by the action of the current, during the construction of the dykes, and up to date, September 30th, 1872, involved the removal of an enormous quantity of sand; and also the placing of a quantity equal to 5-6ths of that removed. It is natural to suppose that a portion of this deposit was formed with material removed from other parts of the work above; what proportion it is impossible to estimate.

Removed from east sand bar.	Cub yds.	3,050,000
Deposited on west sand bar.	1,500,000	
" Island shoal	900,000	
Total deposited in bars.		2,400,000

The total cost of dykes was $58,655.

Cost per cubic yard $\frac{\$58.655}{3.050000}$ -1.92 cents, for material removed.

It is a matter of regret to the writer of these notes, that he is unable to give, from personal experience, any later information about the work which they describe.

He has never visited St. Joseph since the year 1873. Information has been received, however, in reply to letters written to persons, whose statements can be depended upon.

From these it appears: that the low water channel has continued to flow along the east bank of the river; that damage had been done to this bank, at a short distance above the bridge, at a point where no rip-rap had been placed, and extending down to the bridge, causing the small shore abutment to slide into the river; that this was stopped by the placing of quantities of rock, by the K. C. St. Joseph and C. B. R.R. company, and a new pier was put in; that a large portion of the town front had to be held up by heavy stone dykes, buttressing the shore; it has since been made secure by a second track of the railway; the material of which was mostly rock.

From the above information it would appear, that the fall of the shore abutment was caused by want of care in not protecting the bank above the bridge works.

It would also prove that the river has continued to run along the east bank; no reference being made to any injury having been done on the Kansas side of the river.

The channel also is said to have run constantly through the draw span, up to the present, a period of fourteen years.

The dykes, therefore, seem to have accomplished the end for which they were designed.

The protection of the east bank, at the time when these river works were completed, was a thing to be considered. It does not appear to have received attention, until serious injury had been done; and the old works of protection of the city front had proved insufficient to withstand the continual wear, and the more frequently repeated attacks of the river.

The channel also is said to have run constantly through the draw

"mitted to the Secretary of War for his approval.

"This Act also provides that the bridge, at the option of the corpo-
"ration building the same, may be built as a drawbridge, with a pivot
"or other form of draw, or with unbroken continuous spans; provided,
"that if the same shall be made of unbroken continuous spans, it shall
"not be of less elevation in any case than fifty (50) feet above extreme
"high-water mark, nor shall the spans of said bridge be less than three
"hundred and fifty (350) feet in length. That if a bridge shall be
"built under this Act, as a drawbridge, the same shall be constructed
"as a pivot drawbridge, with a draw over the main channel at an
"accessible and navigable point; and with spans of not less than one
"hundred and sixty (160) feet in length in the clear on each side of the
"central or pivot pier of the draw, and the next adjoining spans to the
"draw shall not be less than two hundred and fifty (250) feet, and
"said spans shall not be less than thirty (30) above low water mark
"and not less than ten feet above high water mark."

In selecting a location for the bridge much scope was not allowed to the engineer, as the terms of his instructions required that the bridge be placed within the limits of the corporation of the city of St. Joseph.

These restrictions gave a distance of only about $2\frac{1}{2}$ miles, in which to select the best location for the bridge.

More extensive surveys were, however, required in order to obtain a knowledge of the river, with a view to controlling its movement, and to compel it to follow a permanent course through the bridge.

Within the above described limits, soundings, and borings to rock, were made upon several trial lines, and finally a location was made, on the east side of the city, within the corporation boundary, and at a point where, in the opinion of the chief engineer, a bridge could be constructed more economically than at any other point within the fixed limits, and where it was considered that the natural formation of the river offered greater facilities than at any other point in the neighborhood or within some miles.

The location of the bridge was fixed at this point for the following reasons:

1st. That the channel, both at high or low water, was more narrow than at any other point.

2nd. That the bed rock was found at a less depth than elsewhere; and in very regular form, varying from 45-ft. to 48-ft. below ordinary water.

3rd. That the permanency of the banks was greater than at any other point embraced in that portion of the river surveyed in connection with this work.

4th. That at this point the channel had, for a great many years, followed the same course, hugging the east bank, and unaffected by the many changes taking place in the stretch of the river above.

The width of channel at the place chosen for the bridge, was, at ordinary high water, only 1500 ft, and at ordinary low water, 350 ft.; the depth at low water being from 15-ft. to 20-ft.

the Kansas bank, rock crops out at Belmont and Wathena.

The clay banks, when excavated and exposed to the weather, stand for a long time with little change; this was instanced in St. Joseph, in 1871–73, where many streets were graded down to a depth of 30 to 40 feet, while the lots, with houses built upon them, were left standing, the only means of access to and from the street, being by stairways placed in very nearly vertical position in front of each house.

The nature of these clay bluffs is such that they are affected but slowly by the action of the flood, except in cases where undermining is caused by the washing of sand and gravel deposits. In such cases, large slides occur at intervals.

The current after striking at the foot of these solid banks, at an acute angle, is deflected gradually, and after following, for some distance, the bank is turned from it, and directed into a course tending towards the opposite side of the valley.

The "bottoms," or lands situated between the high sides of this valley, are generally formed of sandy alluvial deposit, timbered in part with heavy growth of cotton wood and other trees. In other parts, the later formation of the deposit is indicated by the smaller growth of timber, which gradually diminishes in size, until upon bars of recent formation a short growth of brush, only, is found. In the low ground, however, in front of the eastern portion of the city, and for some distance downwards, along the Missouri shore, the bank is composed of the toughest sort of clay, "gumbo," as called in western language. This stands almost vertically where washed by the current, and wears away but slowly.

In sinking pier No. 1 to bed rock, at the foot of this bank, sand was struck at a depth of 20 feet below low water, and was found to extend to bed rock, forming a stratum of 25 feet in thickness. This accounts for the subsiding of portions of this bank, which occurred during the progress of the work.

The great changes in the course of the river occur at times of flood Cut-offs occur also at times, caused by the wearing of the neck of points formed by the bends of the river. In these cases the old channel remains in form of a "horse-shoe lake," the ends becoming silted up by wash from the new channel.

The frequency with which these horse-shoe lakes are found in following the course of the river demonstrates plainly the changes which have taken place, and which are to be expected to occur in future.

Through these bottoms, at high water, the river cuts its way, varying in width from 1500 to 5500 feet, alternating from bluff to bluff, on opposite sides of the river, describing in its course a succession of curves and reverse curves; removing sand bars, and placing them in new positions, rolling them (as it were) down stream, carrying destruction to any portion of the bottom lands where it strikes with force, and at points where it washes the base or face of hard clay banks wearing them slowly away; and at times undermining them, and causing slides of large dimensions.

In order to record the many changes taking place upon the river, notes were taken every month and full surveys were made after all great changes. These notes were plotted upon the original map, in pencil, and tracings made and fyled away. By applying any one of these tracings upon the original map, the change is distinctly seen; in the same way, the tracing for any month can be compared with that for any other month, and the various changes noted. All these different surveys, if plotted on the original map in a permanent manner, would form such confusion of lines and colours, that the result would be unintelligible.

The material found in the bed of the river where borings were made, generally consisted of sand, with layers and balls of clay, and some quicksand; and subsequently in sinking the piers of the bridge, an opportunity was afforded for verifying, by sight, the information which had been obtained by boring. In most cases a deposit of boulders, small stones, and gravel was found immediately on top of bed rock.

In one case, at a depth of 34 feet below the river bottom, the remains of brickwork, and also a bar of railroad V iron were found, proving that scour had taken place to that depth.

The fall in the water surface of the river was established by careful levels taken at different stages. At stage of 86, in a distance of 4·70 miles, the fall was found to be 4·37 feet, or 0·93 feet per mile, at low water 0·80 feet per mile. During the running of the ice, and at time of highest water, no satisfactory levels could be obtained. The changes were so rapid between the level of 86 and 92, that it was found impossible to get accurate results.

The rate of current, as found by experiments with floats at different stages of the river, varied from $2\frac{1}{2}$ miles to $3\frac{3}{4}$ miles per hour, at stage of 92.

The calculated rate of current at stage of 100·0 is $4\frac{1}{3}$ miles per hour.

At times of flood, in places, the current is greatly increased by gorges breaking loose; so much so that steamers sometimes find it difficult to stem the stream in getting around the bends.

The following table shows the sectional area, velocity and discharge at several stages of the river.

TABLE OF DISCHARGE.

Stage of Water.	Sectional Area.	Fall. Per foot.	Fall. P. mile	Velocity. F. p. sec.	Velocity. M. p.H.	Discharge per sec. cub. ft.	Remarks
	Sq. feet.	Feet.	Feet.				
78	5355	.0001515	0·80	3·65	2·49	19545	By float.
80	6205	.0001649	0·87	3·94	2·69	24448	Calculation.
86	13095	.0001761	0·93	3·81	2·60	49892	By float.
92	21975	.0001809	0·96	5·50	3·75	120863	By float.
100	33175	.0001860	0·98	6·36	4·34	210993	Calculation.
	7200			1·0	0·68	7200	
Gorge.				9·88	6·74		

47·360	15·260	32·160	22	25·970	Surface of channel.
21·150	7·250	19·900	22	25·970	"
40·600	15·25	25·350	22	25·970	"
43·400	7·700	35·900	22	25·970	Bottom at bridge.
		108·310=	27·0775 M'n	Water per	gal. =1 $\frac{0426}{}$ cub. in.
	1 $\frac{0426}{}$ ×6·	2324=6·49	75 Cub. In.	in one cub.	foot of water.

The discharge of sediment is as follows:

At low water, 78· cub ft. per sec. 73·5 or cub. yds. per 24 h., 235200
" med. " 86· " " " 187·32 " " " 599424
" high " 100· " " " 820·43 " " " 2625376

From the above figures it is not difficult to account for the formation of bars in slack water, independent of the shifting of the sand.

The bridge, as well as the river works, were designed by Col. E. D. Mason, engineer in chief, and were carried out under his supervision.

The survey was commenced February 1st, 1871, and completed 15th of March following.

Upon the accompanying map are shewn the lines of the centres of the low water channels, as located after all great changes.

The exact form of the channel and bars, immediately before the commencement of the work (Sept. 27th, 1871), is distinguished by red shading of the water line, while the changes effected by these works are shewn by the blue shading of the general map which was made from surveys in September and October, 1872.

Until the location of the bridge had been made, the chief engineer was unable to decide definitely upon the plan for controlling the river above the bridge.

To this subject he gave much of his time; watching the working of the river during the high water; and making experiments upon the sandbars as soon as they began to appear, upon the subsiding of the river. On small water courses he built dykes, formed of the smallest brush loaded with sand; and noted minutely the effects produced by the current. In this manner he succeeded in turning the miniature rivers, and in making them run as he willed. Encouraged by his success in these experiments, he determined to apply the same means in undertaking to divert the existing channel from the course which it then followed, along the Kansas shore; and to force it, in course of time, to run along the Eastern shore, and follow the high water bank in front of the city of St. John, and thus secure a permanent and direct approach to the draw span, as located.

In adopting this course he was attempting only to force the river to run in an old, natural channel which had been deserted by the river and filled in with sand.

Much damage had been done, in previous years, along the frontage of the city, by floods washing away the clay bank; and th ty suffered to great extent in loss of valuable buildings. In fact the principal business part of the city was either destroyed, or liable to be destroyed, at any time of high water.

These assumptions were based upon the results of experiments made on a small scale.

Two sketches shewing cross sections of the dykes are hereto attached: —one shewing the position of the dyke, as built and placed upon the bottom without scour, the other shewing the position which the dyke was assumed to take, under a scour of about 15 ft. and which it did, eventually, in most cases, take.

The work upon the dykes was commenced Sept. 27, 1871, the stage of river being ordinary low water.

The position of the different dykes is shewn upon the map, numbered in order in which they were commenced; No. 4 was designed to turn the channel. Before commencing to build this dyke it was thought expedient to reduce the current in the channel, across which this dyke was to be built. For this purpose dams were built across two small channels; thus connecting two dry sand bars with the main shore, and excluding a large flow of water.

From the head of the outer of these bars, a dyke, No. 3, was commenced and built downwards and slightly outwards; and, as the work progressed, slowly closing the upper end of the steamboat channel, across which the main dyke, No. 4, was at the same time being built, at a distance below of 2,300 ft.

These dams Nos. 1 and 2 being required only for temporary service, were built of small trees, and brush held in place while sinking by small piles driven by hand; and loaded with sand at an elevation of about 2 feet over ordinary low water.

Dyke No. 3 was built in the same manner, and was extended, eventually, for a distance of nearly 800 feet, crossing almost entirely the steamboat channel which at this point was 600 feet in width, with rapid current and water from 8 to 12 feet in depth. This dyke, although intended only for temporary purposes, was the means before long, of causing a total change in the low water channel, forcing it out of its course along the Kansas shore and throwing it eastward, forming a deep channel through the centre of the other existing and shallow channel.

Dyke No. 4 was commenced shortly after the dams above described, and was carried on at the same time as No. 3.

This dyke being intended to act permanently as a means of directing the river, was built in a more solid manner than the structures already described. The form of cross-section of this dyke has been already described. The embankment was formed of alternate courses of trees and brush laid crosswise; and of poles laid lengthwise, and breaking joint. The courses of trees and brush were about 3-ft. 6-ins, and the courses of poles from $1\frac{1}{2}$ to 2 feet in depth. The bottom and top courses were always formed of trees and brush laid crosswise. The trees varied in length from 30 to 60 feet, according to their position in the bank, the whole width being always made with trees of the proper length. They were trimmed by having their branches lopped so as to lie close to the stem; or the branches were cut off entirely for 20 or 30

No. 5 was merely a small dyke placed at a point 1300 feet above the bridge, to check scour which was found to be taking place at the time of commencement of No. 6.

No. 6, "Weavers Dyke" was commenced on the shore at a point about nine hundred feet above the bridge line; and built for a distance of some nine hundred (900) feet; running downwards and outwards, and striking the current at a more acute angle than in the case of dyke No. 4. The manner in which this dyke was constructed is exactly similar to that of dyke No. 4.

This dyke was intended to act more as a protection to the existing bank than as a means of deflecting the river; although it acted in the latter service to a slight extent.

The channel at this point was about 850 feet in width with depth of 10 to 15 feet; and current, at low water of 3½ miles per hour.

This dyke was completed March 17, 1872; and proved of great service in protecting the bank; and in saving the piling, and other false works of the bridge below.

A large quantity of stone, for rip-rapping the shore, had been piled along the bank, opposite the rear of this dyke.

Nothing was done at this time, on the East bank of the river, in the way of protection. Reliance was placed upon the old works which had been built to protect the city front.

It is well to note, at present, the changes in the low water channel, which had been taking place during the construction of the dykes; during this time the water had been at a low stage; the water at the gauge showing from 815 to 84 feet. At this stage of the river, the greater part of the bars, standing above the level of low water, were visible; and all changes were easily detected.

By the construction of the small dams Nos. 1 and 2, and dyke No. 3, the steamboat channel had been turned entirely out of the course which it had last established along the Kansas shore; and the whole flow of the river was discharged through one channel of 1006 feet in width, with hidden shoals which had rendered it unnavigable. The additional current, caused by the stopping of the principal channel of the river, had the effect of slightly inclining the current of the one remaining channel; and, from a point of some distance above dyke No. 3, to crowd it upon the western face of what is called here the east bar; scouring out the bottom, and, in short time, forming deepwater channel across the river. This current scoured the west shore of this bar, cutting into it; and curving to the right as gradually deflected in that direction. It then, after cutting out a large portion of this bar deserted the east side, and ran as if intending to attack the head of dyke No. 4, as it then existed, following this course until it felt the influence of the lesser current of the water backed up, or retarded, by dyke No. 4; it again curved to the east, and made another attack upon the east sand bar; digging again into it; and, turning suddenly around the head of dyke No. 4, made in direct line for dyke No. 5.

lower end having been carried away; and deposited near dyke No. 4.

After a few hours the attack on Weavers Dyke seemed to relax; the current did not strike with equal force, nor in so direct a manner; and it gradually changed, so that the dyke was entirely relieved; the gorge ran out; and the river dropped to 84.

This relief was caused by the cutting through, by the flood, of a bend which had occasioned the jamming of the ice and drift.

At the end of April the channel had assumed a tolerably direct course; and followed what was nearly a central course between the high water banks.

The river began to rise May 1st, and from this date until September the bars were generally covered.

On September 30th the river had reached the stage of ordinary low water, and complete surveys were made on that date and during the following week.

From this survey the general map has been drawn.

On this plan the action of the river is shewn by centre lines of the channels formed from time, together with the shore lines of the surveys made immediately before the commencement of these works and again in September and October, 1872.

During the time included between these dates, or a little over one year, the low water channel has been turned away from the Kansas shore, and forced to follow the opposite, or Missouri shore, for a distance of 9000 feet. A small channel has also been formed (by the carrying away of a portion of dyke No. 3), from the upper end of the works to the head of dyke No. 4, thence to the head of dyke No. 6; thus forming an island, extending across the whole front of the city, over one mile in length and averaging about 600 feet in width.

The principal channal along the east bank varies in width from 500 to 1500 feet.

While these new channels had been scouring out, large deposits of material had been made. A large bar had been formed on the Kansas side, extending from the head of dyke No. 6 to nearly the head of dyke No. 4; thence to dam No. 1. A large quatity of sand has also been placed at the head of the island just referred to, this extends as far up as No. 3 dyke.

These changes were of very great extend. A large portion of the east bar was removed by scour during the progress of the works upon the river; but the bulk of work was done during high water.

There was low ground on the east bar at the mouth of Blacksnake creek, on rising over the level of this part of the bar the current rushed in and a channel was commenced; this, as the remainder of the bar was submerged, continued to run along the east bank, eventually cutting out a channel of from 1500 to 500 feet in width. A portion of the east bar was left in place and now forms the lower end of the island bar in front of the city.

The effect of the high water of 1872 was considered very satisfactory. The dykes had done their duty; and the channel had been compelled, after a stubborn resistance, to move 3000 feet to the east; and to follow the Missouri shore.

The channel also is said to have run constantly through the draw span, up to the present, a period of fourteen years.

The dykes, therefore, seem to have accomplished the end for which they were designed.

The protection of the east bank, at the time when these river works were completed, was a thing to be considered. It does not appear to have received attention, until serious injury had been done; and the old works of protection of the city front had proved insufficient to withstand the continual wear, and the more frequently repeated attacks of the river.

There is reason, also, to suppose that the works for deflecting the river may have been a means of increasing the effect of floods upon the east bank.