

CHAPTER XI.

THE MIRAMICHI BRIDGES

Location of the two Bridges - Original Design - Borings - Great depth to bed-rock discovered - Engineering Opinions - Original Design adhered to - The South-West Bridge - The North Abutment - General Description of Pier Foundations - Pier E - Pier F - Pier G - Pier H - Pier I - South Abutment - The North-West Bridge - Borings - Pressure Experiments - Modified Plan of Foundations - The South Abutment - The North Abutment - The Caissons for Piers - Pier X - Difficulties met with - Pier D - Pier C - Pier B - Pier A - Concrete - Masonry - Plant - Contractors - Engineers - Completion.

After the River Miramichi had been carefully surveyed, it was decided that the Railway should cross two miles above the point of junction of the northwest and southwest branches; here the Northwest Branch is 1,350 feet wide, and the Southwest 1,600 feet. The range of ordinary tides is about five feet; but that of extreme tides is more than ten feet. Tidal influences extend up the two rivers some fourteen miles above the points of crossing. Owing to the presence of shoals, especially in the Southwest River, navigation is difficult for sea-going vessels beyond the junction of the branches.

The town of Newcastle, the port for vessels of deep draught, is situated below the confluence of the two Rivers, and a branch Railway 1½ miles in length, has been constructed from the main line to the deep water terminus at that place.

It was originally designed that the Northwest should have five, and the Southwest Branch six spans of 200 feet; but it was found expedient to make the Northwest bridge of six spans. Thus both structures have precisely the same water-way, 1,200 feet.

The first survey led to the opinion, that rock was met in both rivers at a depth of from 45 feet to 50 feet, under extreme high tide; that the actual depth of water varied from 15 to 33 feet; and that the bed of both rivers consisted of silt from 17 to 30 feet deep.

The plan originally adopted for the foundations was to construct them of huge caissons filled with concrete. The lower part of the caisson was to be a chamber, designed in the form of an inverted hopper, to admit of undermining and of dredging operations; each chamber being accessible by a shaft. During the work these shafts were designated, "wells," which indeed they resembled; and it was through them that the silt, when removed by dredges, was lifted to the surface. It was designed that the caissons, when undermined, should sink through the silt of the river bed to the rock; and that, when finished, they should be brought to the level of six feet under low water, and be entirely filled with concrete; thus giving a solid foundation to the masonry. It was originally determined, that the Southerly abutments of both bridges should have their foundations on these concreted caissons; and that the Northerly abutments should be built, in the ordinary way, on the dry land of the two shores.

When the work described was placed under contract, and operations were commenced, it was discovered that the stratum immediately under the silt was not rock, as supposed, but a bed of gravel, more or less compact, and of varying thickness, overlying a thick deposit of sand and silt in the northwest river, and of clay in the south west. It was found that the average depth to the bed rock under high water, was, in the Northwest branch 112 feet, and in the Southwest 90 feet, instead of less than half these depths as at first believed.

After careful investigation, the Engineer did not consider it necessary to incur the

enormous expense involved in the carrying of the foundations to the bed-rock of the River. He satisfied himself that it would be sufficient to sink the caissons to the depth of the gravel stratum which formed the hard substance assumed to be rock when the preliminary survey was made. He did not deem it expedient to change in any way the contract plans for the Southwest Bridge; but he thought it advisable to make some modification in the designs for that of the Northwest. In this case he proposed another span, so as to throw the southerly abutment upon the river bank, and thus secure a rock foundation, relieving the comparatively thin gravel bed, and the other strata forming the bed of the river, from the weight of the high embankment which formed part of the original plan. He also considered it prudent to enlarge the base of each pier, in order to distribute the super-incumbent weight over a greater supporting area.

The Chief Engineer announced to the Commissioners the decision he had come to.

The latter, however, in view of the magnitude of the work, referred the matter to two other Engineers, Messrs. Samuel Keefer and C. S. Gzowski.

These gentlemen reported against the plans of the Chief Engineer and expressed a strong opinion adverse to the practicability of carrying them out. At the same time they brought forward a design their own, which they recommended the Commissioners to adopt.

The plan proposed appeared to the Chief Engineer to be open to grave objections; and he advised the Government not to hazard its adoption.

After several communications had passed on the subject between January 13th and March 9th, 1872, the Government finally passed an order in Council, sustaining the views of the Chief Engineer, and throwing upon him the responsibility of carrying into execution his own plans.

THE SOUTHWEST BRIDGE.

It has been stated that the original borings, made during the preliminary survey of 1868, led to erroneous conclusions respecting the river-bed. The only tools and appliances which could then be obtained, were imperfect and not well adapted for ascertaining, with accuracy; the character of strata at a considerable depth under water. The consequence was, that a hard substance met with, at from 40 to 50 feet under high water, was assumed to be a continuation of the rock formation, which cropped out on the banks of the river.

During the winter of 1870-1, more perfect implements were used, and the discovery was made that the hard stratum was only a bed of gravel and that the true bed-rock was, in the southwest river, some 50 feet lower than it was previously believed to be. Plate No. 26, shows the relative position of the several strata which underlie the river.*

* The following is an abstract of the borings made at the several piers and abutments subsequent to 1870:

AT FACE OF NORTH ABUTMENT.			AT CENTRE OF PIER G.		
Water,	5'	4"	Water,	14'	7"
Sand,	1'	6"	Sand,	30'	5"
Tough brown clay, 41'	6"		Gravel,	7'	0"
			Tough brown clay, 43'	0"	
Rock at	48'	3" Below datums.	Rock at	95'	0" Below datums.
AT CENTRE OF PIER E.			AT CENTRE OF PIER H.		
Water,	26'	9"	Water,	13'	10"
Sand,	13'	10"	Sand,	34'	8"
Gravel,	2'	0"	Gravel,	6'	2"

Tough brown clay, 34'	6"		Tough brown clay, 42'	4"	
Rock at	77'	1" Below datums.	Rock at	97'	0" Below datums

AT CENTRE OF PIER F.			AT CENTRE OF PIER I.		
Water,	22'	4"	Water,	16'	3"
Sand,	21'	3"	Sand,	31'	0"
Gravel,	7'	10"	Gravel,	6'	3"
Tough brown clay, 41'	7"		Tough brown clay, 42'	3"	
Rock at	95'	0' Below datums	Rock at	93'	0" Below datums.

The Chief Engineer, nevertheless, decided to carry out the original design, and to sink the caissons of the piers down to the gravel bed, and that of the south abutment to some distance into the underlying clay.

The work has been accordingly carried out as shown in the drawings. The north abutment is at the river's edge. The south abutment stands about 300 feet from the shore, an earthen embankment connecting it with the river bank.

THE NORTH ABUTMENT

When the north abutment was proceeded with, the foundation for the front wall was excavated to the depth of 16½ feet below high water, and the area filled with concrete to a depth of eighteen inches. The foundation for the wing walls was stepped back, as shown on the drawings, plate No. 29.

The masonry was commenced on the 27th July, 1871, the foundation stone being laid by the Chairman of the Commission, Mr. Aquila Walsh, on the 3rd of August. The work was continued until the end of November, when a few stones only were wanted in the parapet walls to complete the structure.

THE PIERS.

The five piers are lettered E, F, G, H and I; they are placed at the points indicated on the drawings; E being next the north abutment and I nearest the southern side of the river.

The following table gives the depths, to the supposed rock, from the preliminary borings; to the gravel bed, from subsequent borings; and also the depths to which the caissons have been actually sunk.

AT SOUTH ABUTMENT.				
	<u>Face.</u>		<u>Centre.</u>	<u>Back.</u>
Water,	17' 2"	17' 4"	17' 4"	
Sand,	6' 0"	5' 0"	5' 3"	
Sand and Gravel	1' 0"	2' 0"	1' 0"	
Mud and Vegetable Mould,	8' 9"	6' 8"	2' 6"	
Gravel,	1' 4"			
Tough, brown clay,	43' 9"	45' 0"	47' 3"	
Rock at	78' 0"	75' 0"	73' 4"	

Site of Pier	Depth to supposed rock from preliminary borings.	Depth to gravel bed from subsequent borings.	Depth to which caissons were actually sunk.
Pier E,	44 feet	40.6 feet	40.2 feet
Pier F,	44 feet	43.6 feet	44 feet
Pier G,	41 feet	45.0 feet	45 feet
Pier H,	49 feet	48.5 feet	49 feet
Pier I,	<u>41 feet</u>	<u>47.2 feet</u>	<u>47 feet</u>
Mean	43.8 feet	45.0 feet	45 feet

The original design for the foundations of the piers, as shown in Plate No. 27, was adhered to; and as all the five cases were alike, a brief description of one will suffice.

The foundation works consisted, essentially, of a large caisson formed of hewn timber and water-tight planking; the top dimensions 73 feet by 17 feet were constant, the bottom varying according to depth. The caisson was divided into compartments, all of which, except the lower ones, designated "bottom chambers," were filled with concrete as the work proceeded.

The bottom chambers were left for the purpose of excavating underneath the caissons, either by dredges, steam pumps or divers; they communicated with the open air by means of vertical shafts or wells, through which the excavated material was elevated. The bottom chambers, as the drawings show, were constructed like inverted hoppers, terminating in a cutting edge formed of hardwood timber and boiler plate.

As the material underneath was removed the caissons were sunk until they reached the required depth; the bottom chambers and the shafts leading to them were then filled in solid with concrete, from the cutting edges to the surface.

For the purpose of building the masonry, coffer-dams were attached to the tops of the caissons, but so as to be removable when the piers were completed. In order that they should extend above high water, they were from 12 to 14 feet deep. They were made of such strength as, when pumped out, would resist the pressure of the outside water, and they were thoroughly secured to the caisson. The outsides were covered with three-inch planks, put on with close water-tight joints.

PIER E.

The first of the caissons built was that for pier E. It was commenced on the 12th of June, 1871, and when the building was sufficiently advanced it was launched on the 17th of August. A staging upon piles driven into the river bottom was erected around the site of the pier, forming a platform along both sides, and across the down river end, the upper end being left open. Into this space the caisson was floated, the building proceeded with, and finished, to the full height of 30 feet, before any concrete filling was done.

The depth of water at the site of the pier was 26 feet 9 inches and it was required to sink the caisson to the depth of 43 feet, or 16 feet 3 inches below the bed of the river.

The filling of the compartments with concrete was begun on the 14th of September, and

proceeded at the rate of 20 cubic yards a day. The caisson settled down gradually. By the end of October the compartments were filled and the caisson had sunk 2 feet 9 inches into the bed of the river.

Two Woodford "Dredge Pumps" were then put in operation for the removal of the underlying material; they continued at work up to the end of the season, during which time the caisson sank a farther depth of 2 feet.

Work was resumed on the 21st of May, 1872, but the progress made with the pumps was so slow that it was determined to substitute dredging machinery. Frequent interruptions arose from sunken logs and branches, which had to be removed by divers. Nevertheless by the 20th of June a further depth of 5 feet had been obtained.

When the dredges commenced operations the cutting edges stood 36 feet 6 inches below high water. It was soon discovered that the caisson was passing through a heavier description of material than what had been anticipated. It consisted of gravel mixed with clay, and was so compact that the dredge buckets made little impression upon it. It therefore became necessary for divers to excavate, by pick and shovel, the material from beneath the cutting edges, and to remove stones by hand. This subaqueous work was very tedious, and it was only after a month's incessant labour, that the caisson finally obtained a level bearing 2 feet 9 inches higher than at first intended.

To give the caisson additional weight to aid it in sinking, it was arranged that the material dredged out of the chambers should be deposited within the coffer-dam, the wells having been continued to the top of the coffer-dam by temporary planking.

The chambers and wells up to the proper level were filled with concrete. On the completion of this work the dredged material was removed from the coffer-dam preparatory to laying the masonry. When the coffer-dam was pumped out, there being very little leakage, the water was perfectly under control, and in no way impeded building operations.

The masonry was commenced at 11 feet 6 inches below high water level. It was begun on the 3rd of October 1872, and during the season was carried to the top of the cut-water, 6 feet above high water mark.

Work was resumed on the 12th of May 1873, and the pier was completed on the 18th of June following.

PIER F.

The caisson for this pier was ready for launching with the high tide in the middle of September 1871.

The depth of water was 23 feet 4 inches. The top of the gravel bed was found at 43 feet 7 inches. The depth required to be reached was fixed at 44 feet below high water.

On the 31st of October the concrete filling was begun, and continued to the end of the season, at which time the caisson had settled about a foot into the sand.

During the winter a scour took place around the up-river end of the caisson, which had the effect of lowering it a further depth of 5 feet.

Work was resumed on the 12th of June 1872, and after some concrete filling had been done, the caisson was brought to a horizontal bearing by the operations of a Woodford pump, and the cutting edges lowered to 31 feet below high water.

The dredge towers were then erected and carried directly upon the top of the coffer-dam lending their weight to the sinking of the caisson. Figure No. 36 shows the dredging machinery in position.

On the 17th of September the dredges commenced operations; the caisson sinking gradually. Meeting with no obstructions, it reached the required depth on the 25th of the same month. During the following month the bottom chambers and wells, were filled with concrete to within 6 feet of the top. The work was stopped for the season on the 1st of November.

Work was resumed on the 5th of May 1873, the concrete filling was completed and the coffer-dam pumped out. There was a considerable leakage in this dam, probably from the fact that it was exposed to the action of ice. Two pumps were required to permit the lower courses of masonry to be laid.

The laying of masonry was begun on the 15th of May, and was completed on the 21st of July, 1873.

PIER G.

The depth of water at the site of this pier at high tide was 14 feet 7 inches. The top of the gravel was found at the depth of 45 feet below high water. The caisson had therefore to be sunk over 30 feet through the sand.

The construction of the caisson was begun on the 18th of September 1871 and considerably advanced in October. It was deemed advisable to leave it on the stocks until the following summer. It was successfully launched on the 23rd July 1872, and two days afterwards floated into position.

The building of the caisson was suspended when it had reached a height of 22 feet. No further building was done until the 26th of September, when the concrete filling was begun. There being only about 3 feet of water in the compartments at low tide, advantage of this was taken to have the concrete in the compartments deposited about the time of low water, and consequently, most of it had time to partially set in the air before it was subjected to the action of water.

By the 12th of October, the filling of the caisson, to the extent it was built, was completed. It was then necessary that the dredging should be commenced before the building could be continued. To enable the dredges to work, and at the same time admit the other operations to be proceeded with, it was necessary to erect a strong frame to carry the dredge towers, at some height above the floor of the general platform. The work of sinking the caisson was resumed early in June 1873, and by the 18th of the month, the cutting edges had reached the required depth of 45 feet below high water.

In removing the dredged sand from the coffer-dam it was found that the quantity of water coming in was so great that two steam pumps were required to keep it under control during the laying of the first courses of masonry. The masonry was begun on the 25th of July, and completed on the 15th of September 1873.

PIER H.

The depth of water at high tide at the site of this pier was 13 feet 10 inches. The depth to the gravel bed on which the caisson had to rest was 49 feet.

Construction of the caisson was commenced early in June 1873. It was launched on the 10th of July, and floated into position on the 15th. The filling with concrete was continued up to the 21st of August, at which time the caisson was 24 feet high and had settled 2 feet 6 inches into the river bottom.

The dredges commenced operations on the 14th of October. On the 1st of November the depth of 35 feet was reached; and the work was then closed for the season. Operations were resumed on the 23rd May, 1874, and continued until the 23rd of June, when the full depth of 49 feet was reached.

After filling up the caisson with concrete, one steam pump was sufficient to keep the water under control.

The setting of masonry began on the 11th of August, at 14 feet below high water, and the pier was finished on the 28th of September 1874.

PIER I.

The depth of water at high tide at the site of this pier was 11 feet 3 inches. The depth to the top of the gravel bed was 47 feet below high water; the height of the caisson had therefore to be 33 feet.

The caisson was commenced on the 21st of July 1873, on the 10th of September it was floated into position, and soon afterwards concrete filling was proceeded with.

A scour having taken place at the up-river end, the caisson was brought to a horizontal bearing by means of the pumping machinery, and the weak points protected by rip-rap. Work was suspended on the 14th of November, the cutting edges then standing 20 feet 6 inches below high water.

Work was resumed on the 9th of June 1874, and Woodford pumps were used to lower the caisson, until on the 29th of July the dredges were ready for work. The operations were then continued and after sundry interruptions, the caisson reached the required depth on the 6th September.

The Chambers and wells were filled with concrete as in the other piers; and on the 29th, masonry was commenced. The leakage of the coffer-dam, in this case, was so considerable, that two steam pumps were required to keep the water sufficiently low. The masonry was completed on the 31st of October.

SOUTH ABUTMENT.

This abutment was about 300 feet from the shore, with a depth of water at high tide at its site of 17 feet 4 inches. It was necessary that the caisson should rest horizontally and therefore that the cutting edges should be sunk into the brown clay which the borings showed as lying 26 feet below high water at the back of the abutment and 34 feet at the face. The sinking to the necessary depth was tedious and expensive.

The foundation works were similar to those already described, except that the caisson had four wells or chambers through which the silt was removed.

The construction of the caisson was begun about the 1st of September 1872. When it was floated into position, the building was carried on until the 31st of October, when work was suspended for the season.

The building was resumed on the 7th of June 1873, and finished shortly after. During the winter a scour took place around the Northwest corner, which gave a depth of 20 feet below high water and the caisson settled accordingly. Before proceeding farther, it was necessary to bring the caisson to a level bed; and therefore the sunk corner was supported by a couple of 2 inch iron rods from a truss resting on the surrounding staging: the iron rods having long adjusting screws. Towards the end of June the caisson was brought to a level. When the clay was reached, the sinking became very slow. The clay was too hard to be excavated by the dredges and had to be excavated by hand by the divers with pick and spade. This labour had to be carried on to the depth of 8 feet at the back of the abutment, but to a less depth along the front and sides. It required the constant exertions of two divers and a large number of other men for two months.

By the 6th of October, the front of the caisson was brought to rest on the clay, with horizontal bearing throughout. When building commenced, the water coming into the coffer-dam was kept under by one steam pump.

The masonry was begun on the 21st of October, and continued to the 13th of November, at which period, the masonry had reached 6.5 feet under high water, and further work was suspended.

At this time the heavy earth embankment had approached close to the abutment. During the winter the material was tipped over the front and sides of the coffer-dam, till it appeared above the surface of the water.

The false works were destroyed during the winter, but were restored in the spring of 1874. The masonry was completed on the 6th of August of the same year.

The embankment was formed around the abutment, and the slopes and sides covered with rip-rap, three feet thick, from the bed of the river to five feet above extreme high water.

THE NORTHWEST BRIDGE.

It has already been stated, that the first design for the North West Bridge was similar to that for the South West; the chief difference being in the number of spans. The northwest structure was to have had five spans, each 200 feet wide; while the other was designed to have six spans of the same size. It has also been explained, that the first survey led to a misconception with regard to the strata in the bed of the River; that, instead of rock being found at an average depth of 48 feet under high-water, the hard substance struck by the boring tools was only a bed of gravel overlying a great deposit of silt, and that the rock was actually 112 feet below high water.

It is necessary to state, that, when the preliminary survey was made, only such boring implements could be obtained; as could be extemporized in the neighbourhood by a country blacksmith, and that with these imperfect implements the attempt was made to ascertain the nature of the river bottom. The bed of the river was from twenty to twenty-five feet below high-water; and after the boring rods had passed through about the same extent of mud, they, in every trial, struck a hard substance. The operator saw sandstone rock cropping out on the river bank; and he naturally, but as it afterwards proved, incorrectly, inferred, that he had struck a continuation of the rock formation, underlying the river.

During the winter of 1870-1, more perfect boring implements were employed in testing the nature of the river bottom before building operations were commenced. It was then that the true nature of the river bed was discovered.

A series of accurate borings was then instituted. These borings were made from scows during the summer of 1871; and from the ice during the following winter. The site of each pier was carefully established: and besides the test borings on the centre line, others were made on parallel lines 50 feet distant on each side of the centre line. The results did not materially differ from those obtained on the centre line, and showed that the strata were horizontal.

The boring was performed in the usual manner, 7-inch tubing being used. Some arrangement was, however, necessary to meet the difficulty which the rise and fall of the tide presented when operating from the ice, in order that the tube should be maintained vertical and steady and free from all liability to derangement, as the ice rose and fell. A wooden tube or box, 9 inches square inside, and of sufficient length to extend beyond the range of tides, was sunk through the ice, and had arms which rested upon and were made fast to the surface. This box protected the upper end of the iron tubing from the ice, while itself rose and fell with the tide. When operating from a scow, a well through the floor of the scow served the same purpose. On reaching a suitable depth a smaller tube - 5 inches diameter - was introduced, telescopic fashion; care being taken that the upper end of the smaller tube did not fall below the bottom of the larger one. The point of the tubing was in all cases made to precede the point of the valve auger or other boring tool in use, and thus the exact depth and character of the various strata were ascertained. The results are shown on the section of the river bottom, plate No. 31.

As the boring proceeded for the northwest bridge, experiments were made to ascertain by direct pressure the load which the strata would carry. On the tubes reaching the point to be tested, and the material within having been removed, iron rods smaller than the tubing were passed down. The rods terminated in a blunt end with an area of three square inches. They were kept clear from friction, and were loaded above the surface of the water with different weights, which were allowed to remain for definite lengths of time. In this manner the supporting power of the different strata in the bed of the river was distinctly ascertained.

The result of these tests may, possibly, possess some interest to the professional reader.*

* See Appendix

The information thus obtained having established that the piers might safely be founded on the gravel stratum, the Chief Engineer did not deem it necessary to change in any way the original plan; he, however, held it expedient to increase the width of the caissons from 24 to 30 feet, in order to distribute the weight over an area one-fourth greater than at first designed. But a difficulty arose with the contractors. They argued that an increase in the width of the base of the caissons would render the sinking of them extremely difficult; and they demanded a large increase in price for the additional labour and expense which they asserted the change would exact. To meet these objections the Engineer proposed a modification in the form of the caissons with an increased base, which the contractors undertook to carry out for little more than the original contract price.

The modified plan of foundations for the Piers, adopted and carried into execution, is shown in Plate No. 32. A large oblong caisson open at the top and bottom, was first sunk in proper position at each pier site; its lower edge resting on the bed of the river, and its upper edges extending above water. Around the four sides were square piles driven close together. Within the enclosed area; all the sand and mud, down to the gravel bed, were removed, and the space filled with rubble stone and concrete in equal proportions. The space within the caisson, and

above the original river bed, was then filled with concrete up to the bed for the masonry. The concrete thus formed a huge monolithic mass for the support of the superincumbent pier.

It has already been stated that an additional span was given to the Northwest Bridge; by this arrangement the two abutments were placed on the shore, where no difficulty was experienced in founding them.

The five piers were lettered consecutively from north to south; A. B. C. D. and X.

Plate No. 31 shows the relative position of the piers and abutments; together with the strata which underlie the River.

THE SOUTH ABUTMENT.

Operations were commenced on the 13th of May, 1872, at the Southerly abutment. One-half of the site lay within the water mark; and in order to obtain a foundation, a coffer-dam was necessary. This was constructed of crib work and sheet piling, and of only three sides, carrying a platform about 20 feet wide. A wharf for the discharge of building stone was formed on the front, and a traveller was constructed, by which the material for building was lifted directly into position. The sheet piling within the crib work was in two rows, 5 feet apart, driven to the rock; and the space between the rows was filled in with clay puddle. The rock bottom was laid bare, and then cut into steps to receive the masonry, the front wall of which commenced 12½ feet below high water level. Little trouble was experienced from water; what little was met with, flowed in through fissures in the rock.

The masonry, 985 cubic yards, was commenced on the 13th of June, and completed on the 28th of August, 1872.

THE NORTH ABUTMENT.

The site being entirely within high-water mark, it was necessary to construct a coffer-dam. The shore at this point is bold, and the rock dips towards the river, when, at the face of the abutment, it drops to a slope of about one to two. The whole abutment is placed on solid rock, the front wall commencing 19 feet 6 inches below highwater. The rock lay in a series of irregular benches, and was cut into horizontal steps, to receive the masonry. The coffer-dam was well constructed; and in consequence the water was controlled by one Woodford pump, driven by an engine on a scow alongside. The masonry was placed in position by a Traveller erected on the cribwork. The masonry, 1,115 cubic yards, was commenced on the 15th of August, 1872, and completed in the following November. The mass of the masonry is of freestone from quarries in the locality: the girder seats are of granite, in single blocks, 6 feet by 4½ feet, and 2½ feet deep. The upper surface is 23 feet 7 inches above extreme highwater.

Plate No. 29 shews the form and detail of these abutments.

THE CAISSONS FOR PIERS.

The caissons were each 60 feet by 30 feet, built of timbers, 12 inches square, hewn true on their beds, halved together at the corners and breaking joints on the sides and ends. A roll of oakum was laid between the timbers, both on the flat, and at the butt joints, to render all water-tight. The timbers were fastened every 4 feet of their length, and at the butts, with juniper treenails.

The caissons were commenced on launch-ways near the Bridge site, and were built to a height of six or eight feet previous to being launched. The construction was then proceeded with, afloat, until the requisite height was obtained. The tops when in place were, in all cases, left above high-water level, as each caisson had eventually to serve as a coffer-dam.

As the caissons had to be pumped out to permit the building of the masonry, it was necessary to strengthen them internally by means of longitudinal and lateral struts and braces, which were afterwards removed.

When the caissons were floated into position, they were loaded down with stone, to hold them in place. Square piles were then driven round the four sides, to the gravel bed. The piles were each bolted to the upper timbers of the caissons, and a waling timber was secured along the outside faces, about midway between high and low tide mark.

PIER X.

Pier X was the first commenced; and as the difficulties met were here first overcome, a brief account will suffice for all the piers. The caisson for this pier was commenced on the 19th day of June, 1872. Some little difficulty was experienced in launching it, but it was eventually floated into position on the 6th July, and temporarily secured by driving a few piles on each side and end. Building was then proceeded with, and the required height was reached on the 26th. On the caisson grounding, it was found that the bed of the river was somewhat uneven, and it became necessary to level it by dredging away the inequalities and so allow the caisson to rest horizontally.

In order to sink the caisson, a platform was formed on its top, and loaded with stone.

Two steam pile-drivers were then employed in driving the sheet piling. The piles were twelve inches square; driven, as close as possible, to a depth of 47 feet 6 inches below high water; passing 8 inches into the gravel bed, which, at this pier, is 6 feet 8 inches in thickness. The driving for the last few feet was very slow. This work was completed by the 6th of September, when temporary piles were driven for a platform 20 feet wide on each of the four sides of the caisson. On the platform a gantry was erected, of such height and length as would allow the traveller which it carried to lift building stone from the scows and set them on any part of the structure. Before commencing the masonry, the traveller was constantly in use in moving the engines and pumps employed in dredging, and in raising any sunken trees found embedded within the area of the foundations. The engines and machinery used in dredging and in pumping, were placed on the platform, which further served as a wharf for the discharge of material of all kinds.

The river bed at this pier consisted of a black vegetable deposit, fully 16 feet in depth, and a mixture of mud and sand about 8 feet deep. Two pumps, driven by separate engines, commenced operations on the 21st of September 1872, but the progress made in the vegetable deposit was very slow. The pumps simply settled down into an area a little larger than their base, while the material stood firm with nearly vertical sides. The action of water jets was brought to bear on it; and by means of this expedient, it was reduced, and ultimately removed by the pumps.

The upper layer of material contained a quantity of partially decayed wood, which continually became jammed in the working parts of the pumps, and necessitated frequent disconnecting of the machines for the removal of the obstruction. Two logs of Birch were found

embedded in the deposit, 30 feet below high water. The removal of these occupied several days, as the material overlying them had to be dredged out for their whole length before they could be moved. Eventually, chains were made fast to them by divers, and the logs were raised by the traveller overhead: one piece measured 26 feet long and 16 inches in diameter, the other 15½ feet long, and 20 inches in diameter.

The pumps continued in operation up to the 20th of November, when the formation of the ice rendered a suspension of work necessary. Up to this time a great proportion of the vegetable deposit had been removed. Work was resumed on the 5th of May 1873, and the whole material within the area of the caisson was dredged out to the depth of 46 feet below high water mark by the 31st of May.

The dredging of this foundation extended over a period of twelve weeks; but deducting for wet weather and other delays, the actual pumping occupied sixty days of two engines and two pumps.

The quantity of material removed was 1,416 cubic yards; and taking the capacity of each pump at seven cubic yards (1,200 gallons) per minute, it appears that a cubic yard of water carried out with it on an average 0.075 cubic feet of solid matter, or at the rate of 1 cubic yard of the deposit to 356 cubic yards of water.

Preparations were at once made to put in a 2½ feet layer of concrete over the whole area excavated. It was deposited through large spouts reaching to the bottom. Alternate layers of quarry rubble stone and concrete were evenly distributed over the area until the space was filled up to the level of the bed of the river. A layer of concrete 6½ feet thick was then put in by means of boxes with movable bottoms. These boxes were contrived to open only when they touched bottom, in order that the concrete should be as little diluted as possible, by passing through the water.

The concrete was brought to the proposed level by the middle of July; when, after a few days delay, an attempt was made to unwater the dam with two Woodford pumps; but the concrete had not sufficiently set, and the machinery was overpowered and pumping had to be postponed.

With a view to make good the defects in the concrete and to reduce the head of water, another layer of concrete 18 inches deep was put in, which brought the surface up to 15 feet below high water.

On the 30th of July a second attempt was made to pump out the dam with two pumps, but without success. On the following day bags filled with clay were laid over the places where the leaks seemed to be greatest, viz. along the timbers of the caisson. The two pumps then, with ease, ran the water down to within three feet of the concrete, and held it there; though the leak was still considerable, and evidently was increasing. Walls of clay puddle were now built over the heaviest leaks, and a third pump introduced. On the 9th of August the three pumps were started with the falling tide, and in fifteen minutes the surface of concrete was laid bare.

This condition was maintained for some time; when, without the slightest warning, a large mass of concrete, close to the timber on the northern side, was forced up and the dam immediately filled, notwithstanding the pumps continued running. The Chief Engineer decided to make good the concrete, to add an additional layer, and defer further pumping for some months, in order to give the concrete time to harden. At the same time, with the view of securing and strengthening the caisson, he directed that heavy iron rods should be passed through from

side to side, dividing it into six equal lengths, and that similar rods anchored in the concrete should be placed at both ends. All these rods were firmly tightened by nuts and screws; and as they were placed at some distance under water, divers in ordinary waterproof armour were employed. Rods such as described were placed in all the other piers.

The work was not proceeded with in winter, but was resumed on the 11th of May 1874. Two pumps were then started, the water was speedily lowered to the concrete which proved hard and solid. The leaks between the concrete and the timber were still considerable, but there was no appearance of leak through the body of the mass. In putting in the concrete in July 1873, wells were left at each corner into which the pumps were set. It was considered that much of the leakage came in at these points; and on the additional layers of concrete being put on, the wells were filled up. As the Woodford pump requires water at least 12 inches deep in order to work with advantage, the concrete could not be laid quite bare, and the first course of footings - 2½ feet deep - was set partly in water. Any irregularities in the surface were removed by making up the concrete to a uniform level, so that every block had a solid bed. That the water might be entirely under control at any state of the tide a second engine and pump were put in position. The first course was set by the 18th of May.

There was no further difficulty in keeping the dam free of water, and the masonry soon rose above the surface; but all anxiety was not removed.

It was discovered at the end of June that the foundation of the structure, since the commencement of the masonry, had settled about six inches. Accurate measurements were regularly taken, and it appeared that a gradual settlement was going on. The building of the masonry was continued until the 6th of July, when the work was suspended, the pier being then four feet from the required height. Up to the 29th of August, the work had settled in all ten and a half inches. It was now determined to place on the pier a load several hundred tons greater than, on the completion of the bridge, it would be required to carry, and thus by direct weight force the whole structure to a permanent bearing. This course was the more called for as doubts had been strongly expressed as to the sufficiency of the strata, underlying the river, to carry the bridge. For this purpose a platform was built on the footings of the masonry; upon this and the unfinished pier, stone and rails to the weight of about 450 tons were placed. Up to the 3rd of October, under this load, a further depression had taken place of 2½ inches. The work remained thus loaded until the following spring, when another 100 tons were added, but no farther settlement was perceptible. Figure No. 38 shows the pier partially loaded.

Careful investigation showed that the close piling around the concrete had not been disturbed in any way; that each pile remained precisely in the same position as when first driven; and that the gravel stratum which supported them had not yielded in any way. The settlement was therefore wholly within the caisson; and was undoubtedly due to the compression and consolidation of the stone filling below the concrete, under the load which had been built over it. It was evident from the fact that the masonry was without the slightest sign of crack or flaw, that the concrete had a monolithic character, and had gradually sunk *en masse* as the material under it became compressed by the superincumbent weight.

When the structure was completed, and the false works removed, the sheet piling and dam were cut off below low water level, and a mass of rip-rap deposited, as shown in Plate No. 32, so as entirely to cover and secure the whole of the works on which the masonry rests. The

rip-rap was allowed to take a natural slope, and was rounded at the up and down stream ends to reduce the effects of any cross-currents produced by the obstruction of the stream; and to obviate, as far as possible, the chances of a scour.

PIER D.

The foundation caisson, as constructed, is as that for Pier X. It was launched on the 9th August, 1872, and moved near to the site of the pier. The building continued till the 16th of October, when it had attained the required depth of 30 feet. On the following day, and while the tide was running out, the caisson broke from its moorings, but it was recovered without being damaged. It was loaded and sunk, and the driving of the sheet piling commenced: but when the works were closed for the season on the 20th November, the piling was not completed. In this case the piling was driven to the depth of 43 feet below high water level.

The work was resumed on the 6th of May, 1873, and by the 1st of June, the sheet piling and the piling for the surrounding platform were completed, and the plank and machinery placed in position. The dredging, carried on as in the last pier, was commenced 5th of June, 1873. The material, a clean coarse sand, yielded readily to the action of the Woodford pump; the result accordingly differed from that at pier X. The depth of the sand was over 11 feet, and the excavation measured 700 cubic yards.

By the 18th, the dredging was completed to the depth of 41 feet under high water; and although it extended over fourteen days, only 10½ days were employed in actual pumping, with two engines and pumps. The capacity of each pump being twelve hundred gallons, or seven cubic yards per minute, a cubic yard of water carried with it 0.21 cubic feet of sand, i.e., 1 cubic yard of sand was removed with 126 cubic yards of water.

The concrete filling was completed by the 25th September. No masonry was, however, laid that season.

On the 21st of August, 1874, an unsuccessful attempt was made to pump out the coffer dam. On the 24th, a second attempt was made; but the water could not be lowered more than 11 feet below high water with the pumping power employed. An additional engine with pump being put in operation, the water was run down sufficiently for the first course of masonry to be started. The stream of water discharged was at least 7,000 gallons per minute.

The masonry progressed rapidly, and was soon brought above the water level. No settlement took place until between the 17th and 24th September, when it was found that the pier had settled slightly. On the 2nd of October, building was suspended, the top of the structure being then 6 feet from the required height. The pier was then loaded with stone and iron, weighing about 500 tons, and it was found, on the 7th November, that a further settlement had taken place, of 0.17 feet. On the 27th January, the total settlement had reached 0.46 feet. Since the latter date no further subsidence has been detected. The load remained on the pier all winter, building was resumed on the 1st June, and in four days the structure was completed. As in pier X, the masonry settled with the mass of concrete on which it rested without loosening a joint or fracturing a single stone.

PIER C.

The depth to the bed of river at the site of this pier was 29 feet. The caisson for the

foundation was similar to those already described. It was launched on the 16th of May, 1873, floated away, and finished to the height of 30 feet. On the 23rd of June, it was placed in position and loaded down. The sheet piling, driven to the depth of 44 feet below high water, was completed on the 8th of July.

The dredging commenced on the 15th of August. The material overlying the gravel bed, consisted altogether of 13 feet of clean coarse sand. The dredging extended over seventeen days, but the machinery ran only nine days in all. The quantity of sand removed was 800 cubic yards, every cubic yard of water thrown out carrying with it 0.28 cubic feet of sand, or 1 cubic yard of solid matter in 94.5 cubic yards of water pumped.

The filling of the space dredged out was treated differently from that of piers X and D. Instead of the alternate layers of concrete and rubble stone, the whole space up to the level of the river bed was filled in with stone, crushed to the size used for concrete, but without sand being added; and a layer of concrete 13 feet in depth was deposited upon this base. The concrete was completed by the 29th of October, 1873, when the works were closed for the season.

On the 16th of June, 1874, everything being ready, three pumps driven by two engines, were started, with a favourable tide. The water in the dam was then run down to 12 feet below high water, but the pumps in operation could do no more. It was apparent that more power must be used. On the 22nd, a trial was made with four pumps, driven by three engines; and, for a short time, they succeeded in lowering the water to 14 feet below high water. It was necessary, however, for the four pumps to run without intermission to hold their own. On the stoppage of a pump, the water at once began to rise. A third effort was made on the following morning with the same result. The greatest head obtained was 8 feet 10 inches. On the stoppage of all the pumps, the water rose in the dam 52 inches in eleven minutes. Operations were now suspended at this pier for three weeks. It was simply a question of pumping power, and it was accordingly determined to add a large Gwynne dredge pump, and a fourth engine. In the mean time blocks of stone for a 2½ feet course were placed roughly in position by divers. The five pumps were put in operation. They succeeded in lowering and holding the water 14 feet below high water level.

On the stones being laid bare they presented an uneven appearance, some having been carried upon the *laitense*, and others upon points of concrete standing above the surface. It was accordingly necessary to raise the stones in order to obtain a level bed. By the 27th of July the first course, 2½ feet thick, was set, after which no difficulty with the water was experienced.

The Masonry steadily progressed, and no settling was discovered until the 7th of August. On the 15th, when there had been 13½ feet of masonry built, a subsidence of 2 inches had taken place. Up to the 17th of September when building was suspended at 6 feet from the full height, the total settlement was 0.24 feet. As in the other cases the pier was loaded by placing on it 575 tons over and above the weight of pier when finished. During the operation of loading, a settlement of 0.13 feet at the up-river end, and 0.07 feet at the down river end took place, and from the 23rd of November to the 31st of December 1874, a still further settlement 0.07 at the up river end, 0.09 feet at the down river end was observed. At this date the total settlement was 0.48 feet. The load remained on the pier until the 6th of April 1875, when work was resumed and completed. But no change whatever has taken place since the close of 1874; and the masonry as in the other piers remains without a flaw.

PIER B.

The depth of water was 27 feet 4 inches, and the material a clean sharp sand 24 feet 5 inches deep; the gravel bed being reached at 51 feet 9 inches below high water; a thickness of gravel 5 feet 6 inches overlying the deep deposit of silt between it and the rock.

The caisson was floated into its exact position on the 8th of July 1873. In grounding it indicated unevenness of bottom. The inequalities were rectified by the use of a force pump and hose. The piling, 50 feet long, was at once begun.

The dredging commenced on the 15th of September, and extended over 36 days. The actual running time of the two pumps was 16½ days. The quantity of material removed from within the limits of the foundation was 1,495 cubic yards. Each cubic yard of water thrown out by the pumps must therefore have carried with it 0.29 feet of sand, or 1 cubic yard of sand with 92.7 cubic yards of water.

The dredging was completed on the 22nd of October, and the foundation was then filled with crushed stones to the level of the river bed. On the 10th of November, work ceased; at which time the filling was completed.

On the 27th of May, 1874, work was resumed. The concrete filling was completed on the 12th of June, bringing the surface up to 16 feet below high water. During the period allowed for the concrete to harden, divers were engaged putting in iron tie-rods similar to those already referred to.

An attempt was made to pump out the dam on the 13th of October, with the hope that the footings of the masonry might be laid before the season closed. Four engines with five pumps, however, after repeated attempts, failed to lower the water to the full depth required. During the winter it was determined to add another layer of concrete 4 feet in thickness and thus bring the surface to 12 feet below high water, as at pier X. The concrete was finished on the 22nd of May, 1875.

On the 13th of June, the pumps were started and the surface of the concrete laid bare in 20 minutes. The concrete was found hard and compact. The surface was levelled off, and the masonry began on the following day. It continued without interruption till the 24th of July, when work was suspended preparatory to loading the structure to test for settlement. The load in this case was 550 tons. During the process of loading, from the 24th of July to the 4th of August, the pier had settled 0.18 feet. On the 9th of August, a further settlement had taken place of 0.14 feet. On the 20th of August no further change could be observed. Building was resumed on the 24th and completed on the 30th of August.

PIER A.

The depth of water at high tide is 31 feet 6 inches at the site of this pier. The material under the river bed was a black vegetable deposit 18 feet 9 inches deep, overlying the gravel bed found at 48 feet 6 inches below high water.

The caisson was made fast in position on the 4th of September, 1873. The dredge pumps were put in operation on the 25th of October and continued until the 15th November when the work was suspended for the season.

Work was resumed on the 29th of May, 1874, and the dredging completed on the 30th of June. This work extended altogether over 54 days, but the actual running time was 24 days.

There were 1,044 cubic yards of material removed, giving 0.14 cubic feet thrown out with each cubic yard of water, or 1 cubic yard of solid matter with 193 cubic yards of water. The space dredged out was filled in with crushed stone to the level of the bed of the river.

Early in July the concrete was begun, and deposited to a depth of 15 feet 6 inches below extreme high water. No attempt was made to pump out the foundation of this pier, as it was anticipated the same difficulties would be experienced as at pier B, and it was allowed to stand over to the following summer. During the winter it was decided to put in another 4 feet layer of concrete. This work was done early in the summer of 1875, and on the first attempt to pump out the dam the surface of the concrete was laid bare with comparatively little trouble. The water was lowered to 12 feet in 15 minutes and readily maintained there during half tide. Building was commenced on the 27th of July, and finished for the purpose of applying the load by the 21st of August. The first settlement observed was on the 4th of August, when it was found to be 0.05 feet. On the 21st of August previous to loading for test, the structure had settled 0.42 feet. The load applied was 550 tons. During the process of loading the structure settled 0.33 feet.

The load remained for ten days without further settlement. The masonry was completed on the 14th of September 1875. The total settlement was 0.74 feet.

CONCRETE.

The concrete used in the foundations was made from broken stone, coarse river-sand, and the celebrated English Portland cement. The stone was broken to pass through a ring less than three inches in diameter. As the breaking of the stone by a Blake Machine, pulverized much of the material, the proportion of sand depended upon the condition of the stone; but sufficient sand was always added to the broken stone to fill up all the interstices and render the mass compact.

The concrete for the foundations of the Northwest Bridge was made with two barrels of cement to the cubic yard of crushed stone, that for the foundation of the Southwest Bridge with one barrel to the cubic yard; except in the filling of the caisson for Pier E, and of the wells of all the other caissons, the concrete for which had two barrels per cubic yard of broken stone. Care was taken to thoroughly mix the ingredients. The total quantity of cement used in these bridges was about 14,000 barrels.

MASONRY.

The masonry of the abutments and piers was of a thoroughly massive and substantial character. The stones were of large dimensions, well proportioned and put together in the best style of workmanship.

Each stone in the cutwaters and exposed angles was secured by iron dowels run in with cement. The masonry was laid in Portland cement mixed in the proportion of two measures of sand to one of pure cement.

The stones for the girder seats and faces of the ice breakers were massive blocks of granite; some of which were brought from the Nipissiguit River near Bathurst, a distance of about 175 miles by water.

The greater portion, however, was obtained from boulders near the river banks, from twelve to sixteen miles above the railway crossing. The building stone proper is a light coloured free-stone obtained from two quarries; one on the River Miramichi, about four miles below the

site of the bridges; the other, from which the greater quantity was brought, near the mouth of the River Bartibogue, a tributary of the Miramichi, about seventeen miles distant from the railway crossing. Both quarries furnished stones similar in colour and quality.

The remaining work at this bridge was now confined to the deposit of rip-rap around the piers and the erection of the iron superstructure.

The plant employed in the construction of these bridges was large and costly; besides a full assortment of ordinary tools and appliances, it consisted of a steam tug, with 21 large scows; machinery worked by steam for excavating, crushing stone, pile-driving, dredging, lifting and moving material; also diving apparatus. The pumping machinery was especially effective; it consisted of 4 Woodford pumps, with 7½ inch discharge pipes, and 1 Gwynne pump with a 12 inch discharge. These were driven by 5 steam engines, of 50-horse power each. The pumps made, on an average, 400 revolutions per minute, at which rate they threw from 1,200 to 1,500 gallons per minute each. The Gwynne pump threw as much as 2,500 gallons per minute. The Woodford pumps had their pipes in lengths of 9 feet, attached to light angle-iron frames 3 feet square; each length having its own driving shaft attached. The lengths were easily fitted into each other, and secured by small bolts at the angles, the shafting at the same time locking together. The driving pulley was quickly raised or lowered on the shafting to suit the situation, and was secured with screws. The pumps rested on the material to be removed, and although secured to the caisson so as to prevent lateral motion, they were free to move vertically and they settled down with their own weight as the material was thrown out.

In conjunction with the Woodford pumps, two powerful Cameron force pumps, with a supply of three-inch hose, capable of throwing six heavy streams, were constantly in operation. The flexible hose terminated in metallic nozzles of one-inch bore, which were attached to the ends of long guide poles, by means of which powerful jets of water were directed against the material in the coffer-dams, to loosen it, and bring it within the operation of the pumps.

The work of both bridges has been satisfactorily completed by the Contractors, Messrs. Brown, Brooks, and Ryan.

The difficulties experienced in carrying out the north-west bridge have been fully described. Mr. Joseph Tomlinson acted as Superintendent in connection with the foundations of the south-west bridge. This structure was carried to completion without any departure from the original designs, and without any claims for extras on the part of the contractors.

Mr. A. L. Light was Engineer of the District; and under him, Mr. W. B. Smellie had direct charge, as Resident Engineer, of both the Miramichi bridges, from the commencement of construction until their final completion.

The south-west bridge was first completed. The first train was passed over, and the bridge was opened for use, on August 26th, 1875, by His Excellency, General Sir William O'Grady Haly, Administrator of the Government.