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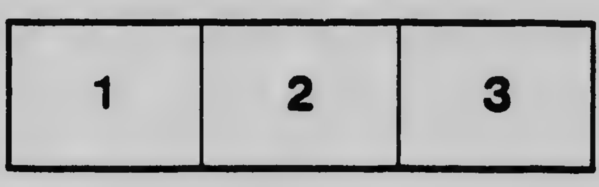
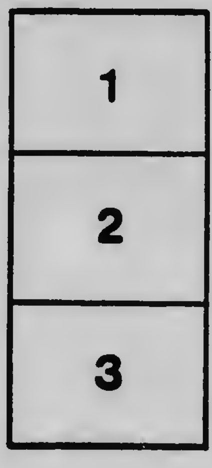
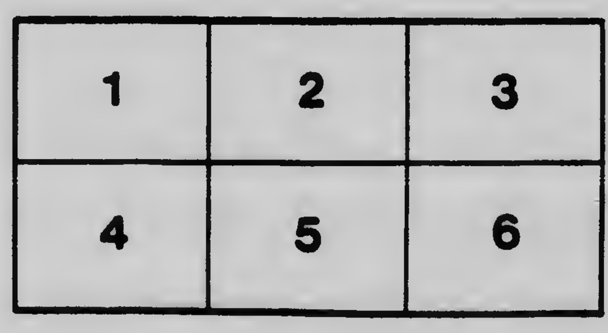






THE

SOULANGES CANAL WORKS

CANADA

By C. R. COUTLÉE.

Associated Member, Canadian Society of Civil Engineers.
Assistant Engineer, Soulanges Canal Works.

(Reprinted from Engineering News of April 18 and July 11, 1901.)

NEW YORK.
1901.

PART I.

Between Prescott and Montreal the freight traffic of the St. Lawrence River is, on account of rapids, forced to take to canals. Fourteen-foot navigation has been secured, and boats of this draft can pass from Lake Superior to tide water. The Soulanges Canal is the link in this chain of ship canals, that replaces the old Beauharnois Canal, which was 9-ft. draft only. The location, design of locks and superintendence of construction [illegible] entirely in the hands of Mr. Thor[illegible] Past-President of the Canadian Soci[illegible] Engineers. His 20 years' exper[illegible]ngineer of the Welland Canal, cou[illegible]dies of foreign practice, have led to th[illegible]n of s[illegible] entirely new features, and the canal is an exam[illegible]e of matured practice in hydraulic engineering of this class.

PLAN, PROFILE AND CROSS-SECTION.

The Soulanges Canal, about 14 miles in length, couples Lake St. Louis, the expansion of the St. Lawrence above Lachine, with Lake St. Francis, the expansion below Cornwall. Lake St. Francis is generally 82.5 ft. higher than Lake St. Louis, and this is surmounted by five locks, the first three having the exceptionally high lift of 23.5 ft., the fourth a lift of 12 ft., and the head, or guard, lock, a lift of about 2 ft. The location on the north side of the St. Lawrence was decided upon as requ'ring less curvature, fewer locks, and because quicksand was in evidence on the south shore. In addition, the enlarging of the old canal would have led to many difficulties and unforeseen expense. From the general plan, Fig. 1, it will be seen that there are only two curves. The longer extends for 60° on a radius of 14,800 ft. (about 24'), and was necessitated by the great bend in the river itself. The shorter extends through 16°, on a radius of 12,800 ft. (about 27'). Both are so easy that for purposes of navigation the canal may be considered a straight line.

The supply of water was, of course, inexhaustible; therefore only its admission into the canal was to be considered. The cross-section of the canal prism, Fig. 2, is 100 ft. width at bottom, with 2 to 1 slopes throughout in rock or earth and 16 ft. of water at extreme low water. The area of prism at mean low water is about 2,400 sq. ft., or say four times the submerged transverse area of the typical vessel for its navigation. This section of canal is nowhere diminished, but on the contrary a larger area is given at bridges.

The admissible current was fixed at about 1 mile per hour, or say as high as 100 ft. per minute. The canal bottom, Fig. 3, has a fall of 0.1 ft. per mile, and the current serves to change the water and slightly aids the seaward traffic. The banks along the summit level are high enough to admit of the canal surface being raised to the highest water level of Lake St. Francis, and still be 3 ft. above water. This would give a depth of 20.5 ft. in the canal prism.

GUARD LOCK.

A guard lock, Fig. 4, is located near where the axis of the canal intersects the original shore line. This protects the entire artificial channel to the east from an influx of Lake St. Francis: (1) were the summit level banks to break at any point, or (2) were it required to run the level dry for repair work. It also prevents the piling of the lake water into the eleven-mile summit level by westerly winds, whereby the banks might be overrun. Guard gates would not suffice, as, were the lake water to pile against them, it would be impossible to open them and admit vessels until the storm fell.

To feed the canal a supply race, Fig. 4, is provided to the south of the guard lock. Across the head of this is a weir consisting of a masonry wall pierced at the bottom by four arched openings 9 ft. wide and 10 ft. high. These openings are throttled by submerged "Stoney" valves, which are exclusively used throughout the canal.

Splay walls extend above and below the guard lock to guide vessels in and out. Above the upper splay walls are two parallel piers 200 ft. apart and extending 1,600 ft. into the lake, which give mooring accommodation to boats awaiting lockage.

Canals leading from rivers at the head of a rapid, are always subject to a current setting across their entrances. To obviate this means entering land higher up and increasing the cost of construction and land damages. So long, however, as the entrance is amply wide and deep enough to allow of boats swinging well in toward shore, the cross set of the current becomes a small matter even to tows.

SUMMIT LEVEL.

The summit level has its top bank elevation at 161 (above sea), or the same height as the coping of the guard lock. By this means it is assured that the top of banks will always be well above the highest water at the entrance, which has been recorded as 157.5 above sea. This level is over 10½ miles in length, or 75% of the whole canal, which can be navigated without stop of any kind whatever. A depth of 20 ft. can be had if desired at high water, giving nearly 3,000 sq. ft. transverse area and 176 ft. width at the water line. This, of course, means speedy and safe navigation for large boats.

The bank protection consists of a notch cut along the 2 to 1 side slopes and solidly refilled with broken stone of various sizes, as indicated by Fig. 2. The face is finished with macadam rammed to a 2 to 1 slope, and the top line is finished with a rough coping, 6 ins. thick and 1 ft. wide, laid in 2½-ft. lengths. This cope is 3 ft. above the working level, and the base of the lining is 5 ft. vertically below water surface. There are no large boulders to become displaced and carry several others with them; but the 2-in. metal and fine grit form a knit slope, and repairs are easily made by dumping broken stone where required.

Sod is laid upon a slope above the coping and for a width of 5 ft. along the top of bank. Along the north bank, which is 50 ft. wide, a macadamized public road is provided. Between this road and the edge of the canal is the pole line, bearing the power and light wires. All the poles are painted white, and every fourth one carries a 2,000-c. p. closed arc light. Along the north side trees are being planted, and the appearance of this artificial river is both finished and pleasing.

CULVERTS.

Three small rivers are passed underneath this upper reach by means of culverts, the Delisle, the Rouge and the Grease.

DELISLE.—The Delisle is the largest, its flood flow sometimes nearing 300,000 cu. ft. per minute. Its channel was diverted slightly by straightening a bend and a rock foundation thus secured. In fact, all three streams were diverted somewhat, allowing the flow to continue uninterruptedly in the old channel during construction. Fig. 5 shows the details of the culvert construction. The foundation pit was 50 ft. wide, excavated in limestone rock. In this, four parallel lines of cast-iron pipe were laid. Each ring of the pipe was 10 ft. in diameter, 5 ft. in length and 1 in. thick, strengthened by three fillets. They were laid plain butt joints, and then the whole pit was filled with concrete, which was carried up 2 ft. over the iron. The rings provide against a bursting up-pressure, which would occur if the river were in flood and the canal were emptied for repair work. H. R. Ives & Co., of Montreal, Quebec, made the castings in a most creditable manner.

ROUGE.—The Rouge is passed under the prism in a similar manner to the Delisle, but only two lines of 10-ft. diameter pipe are used. The foun-

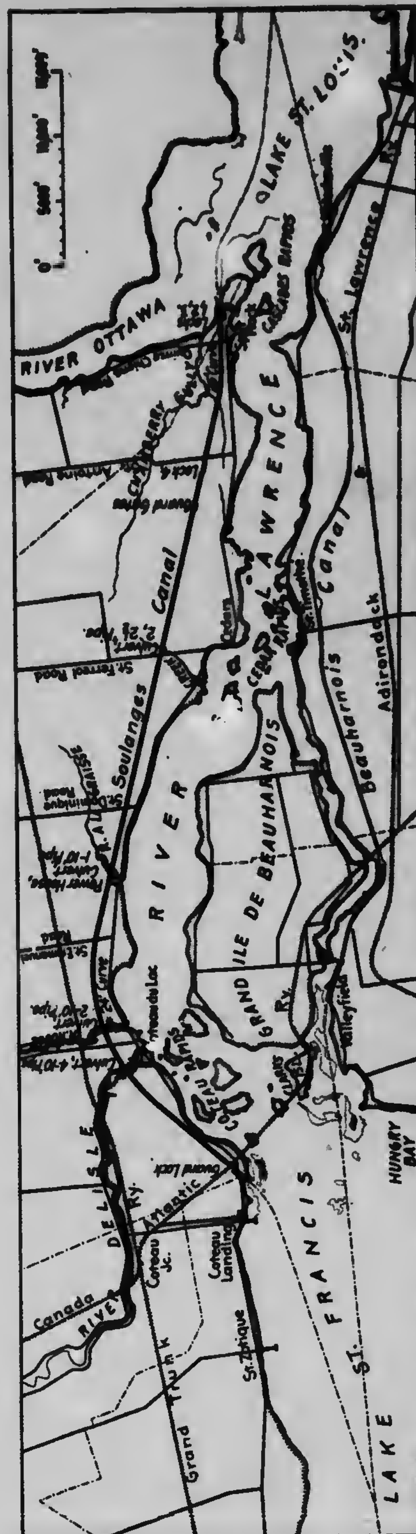


FIG. 1. MAP OF CANAL AND RAPIDS AND CONTIGUOUS TERRITORY; SOULANGES CANAL WORKS, CANADA.
Thomas Monro, Engineer.

dation was on boulder material underlying some 30 ft. of blue clay.

GREASE.—Only one line of 10-ft. pipe was required for the Grease River culvert; the foundation was on piles. An accident occurred during construction. Fig. 6 shows this pipe in place and partly covered with the concrete filling. The water, with which the pit was filled for protection against frost, burst out and its heavy ice covering settled down on top of the cast-iron tube, which had only been half concreted. Many rings were broken, but they were repaired in place with angle irons and bolts.

DRAW BRIDGES.

Four bridges cross the summit level, all of similar design. There is no pivot pier in midchannel, but instead the pivot is placed in line with the south bank, and the whole width of the bottom 100 ft., is free for navigation. A boat passing along the prism resembles a movable dam and piles the water at any restricted part of the channel. The currents thus created tend to swing vessels across the canal. To avoid this the prism area is increased at the bridges by excavating in rear of the pivot piers (Fig. 7). One arm of the bridge spans this side basin and the other spans the canal proper. Practically all the bridge masonry is concrete, only the copings and parapets being of stone. All ironwork is painted with white lead, and the graceful superstructures, contrasting with the green banks and adjacent woods, give quite a picturesque effect. On top of each bridge a red lantern is placed exactly on the center line of the canal, showing both up and down, as a danger signal, when the draw is closed against navigation.

POWER-HOUSE.

The canal power-house is situated about the middle of the summit level, advantage being taken of the crossing of the Grease River to use it as a tail race. The power-house is combined with a waste weir and will be described further on under electrical installations. Some 720 HP. is generated for lighting and for operating gates and valves.

GUARD GATES FOR LOCK NO. 4

The summit level ends with a guard gate and lift lock. The guard gates are 1,000 ft. above the lock, Fig. 8, and are never opened until the lock gates are closed. To the south is a feed raceway 50 ft. wide on bottom, with 2 to 1 slopes. It is throttled by two large "Stoney" sluices, 20 ft. x 22 ft., which hoist up into a steel superstructure resembling a double gantry. The guard gate itself is 46 ft. wide—the width of a lock—and consists of two hollow quoin abutments with splay walls above and below, Fig. 9. A pair of gates exactly similar to lock gates revolve in the quoins and close against miter sills. The splay walls above and below are of concrete, and are made 10 ft. wide to form a roadway on the south side. Through these, arches of 15-ft. span are pierced to pass the feed water into the raceway and out of it. A foundation platform was first made of concrete 12 ft. wide and 2 ft. deep, and upon this the arches were built. These slabs and that under the guard gate and sluice rest directly on hard blue clay, and have given no trouble.

LOCK NO. 4.

Between guard gate and lock the ordinary section of canal prism is resumed for about 800 ft. Splay walls, as usual, are placed above and below the lock to lead in vessels. A raceway to the south, Fig. 8, passes the feed water to the reaches below. It is 27 ft. wide on the bottom, with 2 to 1 slopes giving a transverse area at working level of 1,100 sq. ft. A regulating weir placed across the end of the raceway in line with the foot of the lock, governs the feed to the reaches below. This weir is a concrete dam faced with cut stone and pierced by two submerged arches, which are closed by "Stoney" valves 9 ft. wide and 7 ft. high, Fig. 10. The face of the wall is buttressed and four blind arches widen the top sufficiently to give a 10-ft. roadway. Below this weir the water is turned into the canal again through the arches of the raceway bridge.

The lock itself is of concrete construction, only the face of the chamber above the lower reach water level being of cut stone. The lower sill is at elevation 125 (above sea) and the upper is at 137. On top of the sills 15 ft. of water is provided for 14-ft. navigation, so the lower reach working water level is (125 + 15) El. 140 and the upper (137 + 15) El. 152. This would be a lift of 12 ft., but usually the summit level will be worked at El. 154 or 155, making the lift 14 or 15 ft. For the foundation of this lock 1,100 rock elm piles were driven 40 to 45 ft. into blue clay at 4-ft. centers under each lock wall and across the upper and lower ends. The tops were cut off and

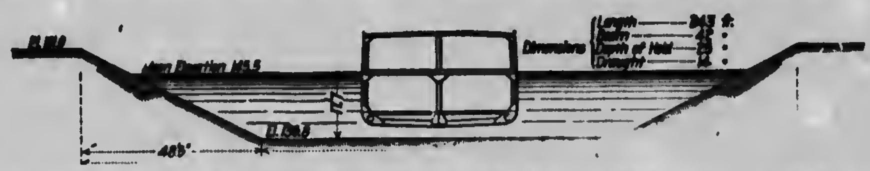


FIG. 2. TRANSVERSE SECTION OF CANAL PRISM; SOULANGES CANAL WORKS, CANADA.

embedded in concrete, which was rammed about them. Between the walls the lock floor is a concrete slab 250 ft. long and 43½ ft. wide and finished to an invert 18 ins. thick along the center and 8 ft. at the sides. The upper end of this floor fits against the circle of the breast wall and the lower end is finished with a line of cut stone blocks. The lower miter sill is carried on piles; it consists of a mass of concrete extending 8 ft. below the floor, which forms both an anchor block for holding down the sills and a cut off against leakage. Two I-beams are laid directly under each sill and through them pass seven bolts, 1½ ins. in diameter and 7 ft. long, the whole being buried in the mass of concrete. The ends of the anchor bolts are threaded and pass vertically through the 18 × 18-in. oak sills, which are held down by large nuts and washers. The upper miter sill is carried on a circular breast wall extending across between the lock walls and is anchored down in the same manner as the lower one.

The breast wall is a mass of concrete faced with heavy cut stone ashlar. It serves to take the ram of ascending boats, thus preventing their bows pushing open the miter of the upper gates from the lower side—a frequent source of accident. In front of the breast wall is another cross wall, which revets the end of the upper reach. It forms with the breast wall a bay, 30 ft. across, and the full width of the lock, 46 ft. From this head well the longitudinal wall culverts are fed in filling the lock. The culverts are 6 ft. × 6 ft. with arched roof and are provided at each end with "Stoney" valves. These allow the water to flow into or out of the lock chamber, with which the culvert is connected by 30-in. pipes, ten on each side.

The method of construction was to lay the whole concrete foundation slab under the walls and across the ends. The floor of the head well, the floors of the culverts and the lower miter sill are all on the same level (El. 125). Upon this the molds for face and rear of walls and for sides of culverts were set up. The concrete was mixed by hand along the sides of the pit and wheeled in until the spring line of the culvert arch was reached. A trestle had then been completed through the lock chamber and two traveling derricks erected upon it. These swung in the concrete with skips. The posts of the trestle served to hold the chamber face molds, which were 14 ft. high. Above this height the lock wall was ashlar, the first course projecting 2 ins. and being rounded to form a rubbing course.

REACH BELOW LOCK NO. 4.

Below Lock No. 4, a reach similar to the [illegible] mit level extends for nearly 2½ miles. [illegible] a mile below the lock there is a road bridge like those on the summit level. It is founded on hard blue clay and has given no trouble from settle[illegible]nt. All swing bridges are at right angles to

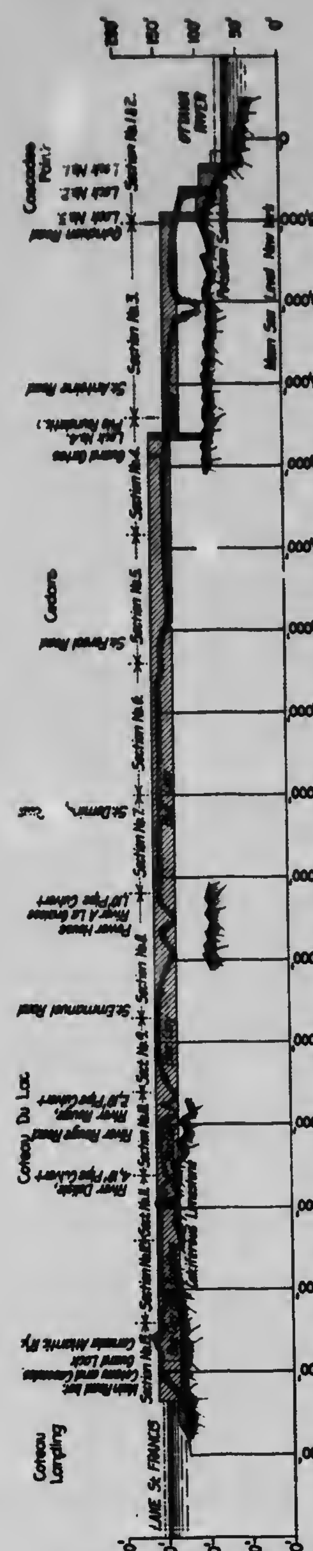


FIG. 3. PROFILE OF SOULANGES CANAL WORKS, CANADA.

the line of canal. The north bank, as on the summit level, is 50 ft. wide to allow space for a macadam road to replace the old river road cut off by the canal. The south bank is 15 f[illegible] wide at an elevation of 3 ft. above wat[illegible] level with 2 to 1 slopes.

BISSONETTE EMBANKMENT.

The chief feature of this level is its crossing of a ravine about 500 ft. long and 40 ft. deep below the "tow-path" elevation. The canal is carried across by an embankment containing 250,000 cu. yds., built of clay excavated from the prism. The full cross-section is maintained, viz.: 100 ft. bottom width and 2 to 1 slopes. The exterior slopes are also 2 to 1, making the base of bank nearly 500 ft. across. Under this fill a 30-in. cast-iron pipe passes a small creek. The reach ends at the Cascades Locks. The water surface is constantly kept at elevation 140, giving 16 ft. of water, or 2 ft. under vessels drawing 14 ft.

EARTH WORK.

The lower entrance of the canal is cut into a tongue of land separating the Ottawa River from the St. Lawrence River. This point is of [illegible]dam sandstone, but unfit for building mas[illegible], though it was much [illegible]ed for concrete. For a distance up of 1,000 ft. it is denuded, then it is lost to sight under a 50-ft. clay bluff. The Potsdam continues fairly level for about eleven miles west when it overlaid by calciferous rock. From the general profile, Fig. 3, it will be seen that the clay surface rises abruptly at Cascades, then very gradually for about five miles, after which it continues at a general level only slightly above the surface of Lake St. Francis. The lower half of the canal is in hard brown clay overlying a compact blue clay. The next quarter is in a soft blue clay with only a scant covering of sandy brown clay. The upper quarter is in boulder. Over 200,000 cu. yds. of rock were excavated at the upper end and nearly 100,000 cu. yds. at the lower. Besides this there was over 7,000,000 cu. yds. of earth excavation of all kinds, varying from soft blue clay to quicksand, wet gravel and hard pan.

Generally the surface brown clay was removed by wheel scraper, and the front parts of the banks made up of it. The bottom was excavated by steam shovels and cars (Fig. 11). Three-yard cars of 3-ft. gage hauled by ten-ton locomotives on 30 to 56-lb. rails were extensively used.

Standard gage plant was used on the Onderdonk sections five miles in length. Sixteen miles of track were employed and the main line along the canal bank connecting with the Grand Trunk Ry. carried all the materials and supplies to Lock 4.

Earth from the steam excavators is often in large lumps which cannot be cut up and compacted into banks as the output is too rapid. Flooding the dumped clay with a [illegible] hose was found to be a successful means [illegible] meeting this difficulty. A demand for dig[illegible] apparatus would no doubt be met by the shovel manufacturers.

The rock excavation was done in the ordinary manner by steam drilling and derrick handling. All the rock at Cascades has been used up for concrete, etc., and other large amounts have been employed for bank lining along the canal.

The stone side slope protection amounts to 155,000 cu. yds.; it was generally dumped into the notch from carts, but some has been transported by scows, since opening the canal, and deposited from gang planks.

CRIBWORK.

The only extensive use of timber was in submerged cribwork foundations for the upper and lower entranc[illegible] This was all made "close-work," of 12 [illegible]-in. timber, mostly hemlock. The cribs are [illegible] ft. wide and about 16 ft. in height with two rows of longitudinals, and cross-ties every 5 ft. They were generally built in 100-ft. lengths, floated to place and filled with stone or b[illegible]lders from the excavation. Along the face a platform of 12 x 12-in. timber was laid just below water and a concrete dock wall built upon it. The wall and crib foundation was heavily backed with stone filling. Cast-iron mooring posts are employed throughout. They are cylinders 10 ins. in diameter and 1 in. thick set in cubes of concrete 5 ft. deep, from which they project 19 ins. Before setting each post is rammed full of concrete.

For each contract a bulk sum was bid for unwatering, which included pumping, making and removing dams, and removing ice and snow.

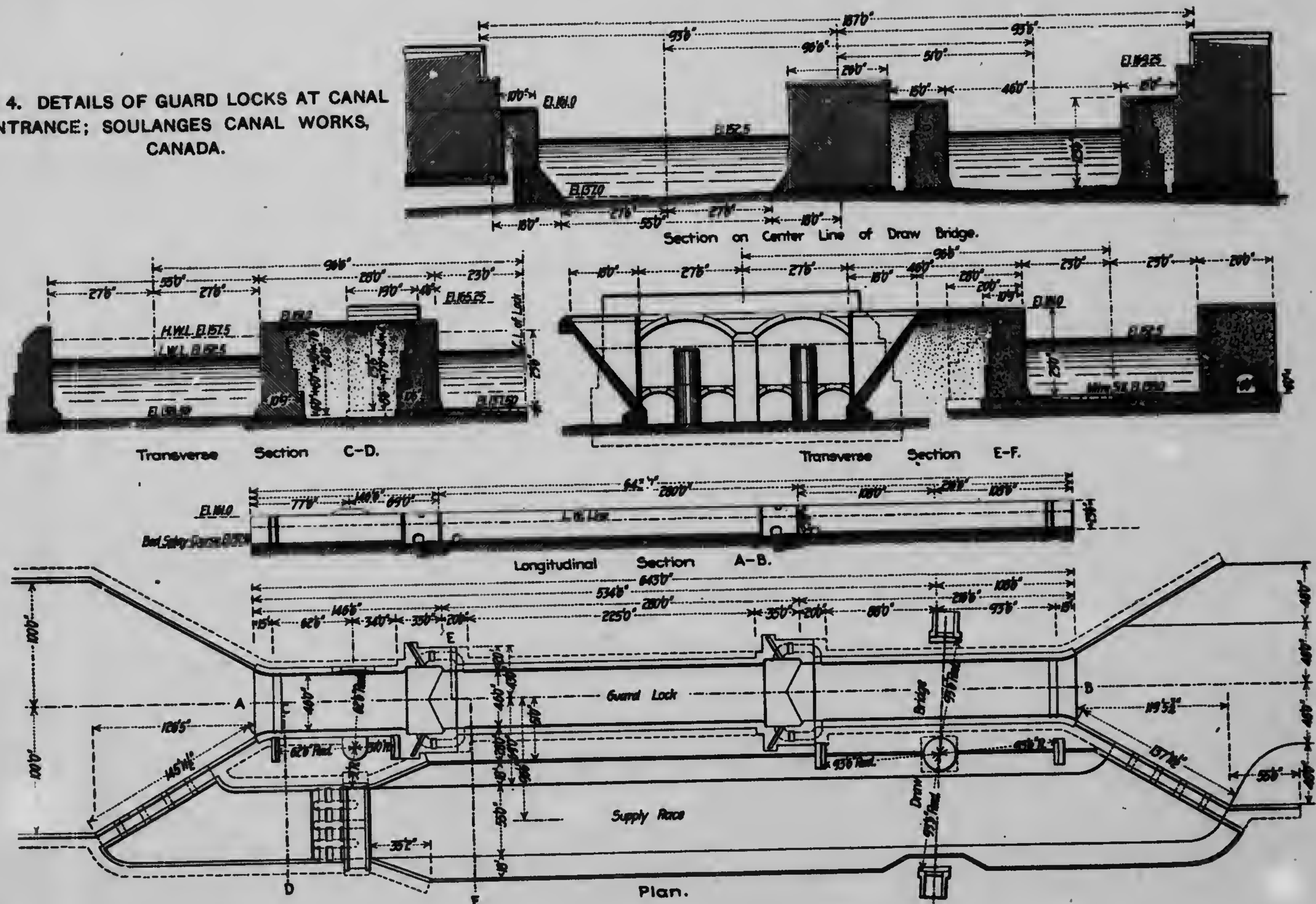
SLIDES.

The greatest difficulty encountered in construction was the slipping of the clay sides of the can[illegible] along about two miles of the summit level. Most trouble was experienced at the St. Emmanuel road crossing. Here an inch rod could be easily pushed down 80 ft. through blue clay fetching up on rock or hard material.

The canal is in 25-ft. cutting and for the north abutment of the road bridge, piles were driven down 40 ft. more below the bottom. A concrete foundation slab, level with canal bottom, was laid upon these piles about the beginning of November. A few days later 300 ft. in length of the north slope slid out over the foundation and half way across the cut. Next season this slip was excavated, and the north abutment—a concrete monolith of 1,200 cu. yds.—was built upon the foundation, which had not been injured. Between this abutment and the face of the old slip, about 100 ft. in width, all the blue clay was excavated to canal bottom and the space refilled with dry brown clay laid up in layers by wheel scrapers.

Toward the end of October, 1897, however, another sudden slip occurred at the same place com-

FIG. 4. DETAILS OF GUARD LOCKS AT CANAL ENTRANCE; SOULANGES CANAL WORKS, CANADA.



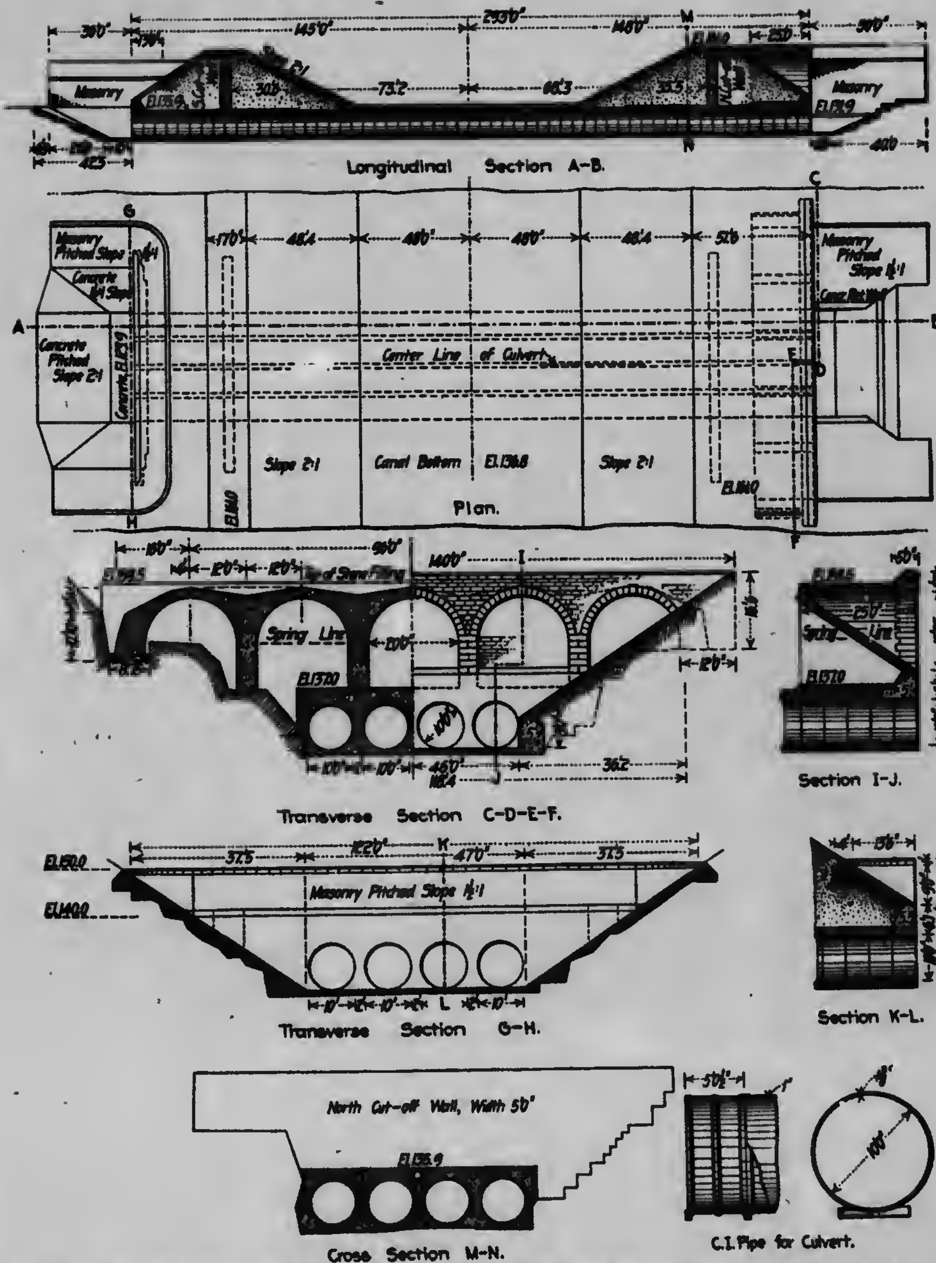


FIG. 5. DETAILS OF CULVERT FOR DELISLE RIVER; SOULANGES CANAL WORKS, CANADA.

pletely filling the canal again. Fig. 12 shows the appearance of this slide. The abutment was forced out 30 ft. into the prism and canted over, bending the foundation piles like whips. It was not even cracked, however, and had to be blasted out piece by piece.

For over a mile this north canal slope has finally been flattened from a 2 to 1 slope to a 4 to 1 with a heavy stone toe.

The blue clay deposit constitutes a "mere bleue" or saturated clay lake, through which the canal, during construction, formed a deep drainage ditch. The subwater plane gradually sloped down to the canal bottom, draining in under the slope until its friction was destroyed and the mass slid forward, settling down along vertical cleavage planes as it moved. The whole matter was aided by the fact that the blue clay beds, 3 ins. thick, seem to have dried after deposit and cracked like a mud beach. These vertical cracks allow the water to percolate down and create hydrostatic pressure. The surface covering being sandy along this section allowed storm water to enter more readily than lower down the canal where the brown clay covering is thicker and nearly impervious.

SURVEY WORK.

In establishing the center line, posts 10 ins. in diameter and 20 ft. high were set at the intersection points of tangents and also along tangents at about three-mile intervals. A transit was interpolated between these poles and during ten years it has never been necessary to keep reference hubs. The long curves of large radius required all calculations to be actually worked out as the difference between a 100-ft. chord and the curved arc became noticeable, and the tables could not be applied. The upper curve, three miles in length, was divided into halves and tangent poles set at the intersection of the tangents for each half.

For field work steel band chains and 1-in. gas pipe pickets were used. A 500-ft. chain did not prove itself of much value.

The ground surface for 300 ft. on each side of canal center line was accurately cross-sectioned, some 20,000 readings being taken. This work was

FIG. 6. VIEW OF SINGLE-PIPE CULVERT FOR GREASE RIVER DURING CONSTRUCTON; SOULANGES CANAL WORKS, CANADA.

greatly hastened hy the use of two rods for each level. The right of way varies in width, hut is generally 200 ft. on each side of the center line of the canal. About 950 acres were taken altogether, including farms bought for wasting ground.

The cross-sections were plotted on a natural

Fig. 7. View Showing Typical Highway Swing Bridge Crossing Canal; Soulanges Canal Works, Canada.

scale of 10 ft. to an inch and bound in books, contract by contract. On the right-hand page was plotted the north half of two cross-sections and on the left the south halves, the middle of the book being the center line. This generous spacing, though hulky, has proved to be very convelent for progress, estimates, etc.

Borings were taken every ten chains with a 2-in. auger attached to gas pipe. Numerous test pits were also dug, some being 40 ft. in depth. Generally 5 to 10 ft. of hard hrown surface clay was found to overlie hlue clay varying from the consistency of tough cheese to soft butter.

The preliminary hydrographic survey at the lower entrance was made hy a fan of sounding

For close soundings a line of boards 4 ins. wide and hinged together in 10-ft. lengths was floated into the line and soundings made along it from a boat. Slight breezes deranged this long float, so it was only useful in calm water. Skeleton rafts, 200 ft. long and 25 ft. wide, were also used, the sounding man walking along the timbers which are fished together with plank and spikes and well cross-hraced.

Sounding through the ice at Cascades was impracticable owing to anchor ice and "frazil." This is caused by the agitated water pouring through the Cascades Rapids being unahle to crystalise through cooled far below 0°. C. In an instant of rest, however, articular crystals are suddenly formed. These drift down and accumulate in still water beneath the surface ice, forming immense masses resembling wet wool and eventually packing the river full to the bottom. Suhmerged bergs, several square miles in area, are thus formed, which choke the flow, and the water stands at various levels in isolated pools. Differences of 2 ft. in level were noted in holes cut only 50 ft. apart, so no soundings could be done under such conditions. "Frazil" or "cinder" ice mixed with large cake ice has heen observed 80 ft. in depth. Long lines of soundings were generally made by stretching steel wire with a cork float every 20 ft. between rafts anchored in exact positions.

The transit work included traverses of roads and the shore line of the St. Lawrence between the head and foot of the canal. All these were tied on to the center line forming closed traverses of about three miles in extent; the results have been very good. There was also a large triangulation of the vicinity.

The leveling has been very extensive as lines

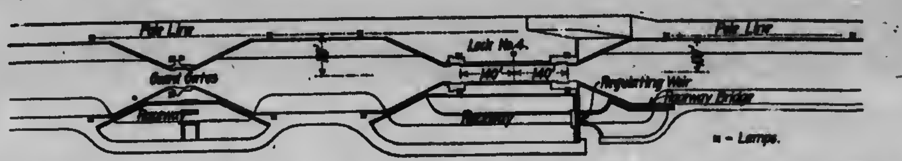


FIG. 8. DIAGRAM PLAN OF LOCK NO. 4 AND GUARD GATE; SOULANGES CANAL WORKS, CANADA.

lines radiating from a fixed point ashore and extending two or three miles out. A boat with sextant observer, sounding man and recorder ahoard, was rowed out, keeping in range with the fixed hub and a movahle hack flag. Each sounding was fixed by measuring the angle hetween the range aft and a distant known side point. To plot, a line, parallel to the range line, is drawn through the distant side station, and from this the sextant angles are laid off to intersect the range.

were run to Kingston, to Rouse's Point and to Montreal, thus connecting with sea level at New York and at Quebec. The results proved wonderfully correct, though no attempt at precise leveling was made, and there is the satisfaction of having elevations, which convey some meaning and may be compared with distant points and referred to in descriptions and reports. A photographic record has heen kept of all the construction.

PART II.

THE CASCADES LOCKS.

The three Cascades locks, Fig. 13, are each 23½ ft. lift. With their attendant system of basins and reaches, they occupy about 4,000 ft. in length, the total descent made being 70½ ft. at low water. They are all in direct line, and between each the full prism of the canal, with 2 to 1 earth slope sides is resumed. The reach between the uppermost lock and the middle one is 1,600 ft. in length, and that between the middle and lower entrance lock is 1,000 ft. long. Alongside these locks and reaches, but sufficiently separated from them to prevent currents, are raceways and basins to feed the lower levels.

Each lockage requires about 303,000 cu. ft. of water, which, if drawn from the short canal reaches only, would lower them sufficiently to strand boats. To avoid this the surface is increased by side basins. The middle lock has a draft area of about 675,000 sq. ft., and the entrance lock has nearly 580,000 sq. ft., over which their respective "draw-offs" are distributed. As the full lift of the entrance lock (23½ ft.) is only attained at extremely low stages of the lake, its expenditure of water is generally less than the others. The side ponds are connected by regulating culverts, which can be made to operate automatically, and through these any loss in the lower reaches is quickly rectified.

Communication is secured throughout the system by three lines of roads, or tow-paths, 15 ft. wide each; one along the north of locks and reaches and one along the south of raceways and around the basins. A central path, with arch bridges, to allow of feed water communication, divides the reaches from the raceways. Over these paths carts can pass with machinery or supplies for repairs. The tow-paths are really only service roads, as all towing is done by tugs. Cast-iron mooring posts are provided along them at about 100-ft. intervals.

Splay walls below and above each lock secure the safe entry of boats. These are tangent to the lock wings and flare out at an angle of about 25° to the canal center line. Stone steps below each lock secure the rapid handling of hawsers from the lower to the upper level. In fact, easy access to all parts of the system is provided.

The topography is peculiarly well suited to this bold design of high lift locks. The first, or foot lock (Lock 1) is located just where the rock, Potsdam sandstone, reaches the greatest height in the Beauharnois anticlinal, and dips sharply into the Ottawa. To the west, the rock surface, though irregular, continues on a general level slightly above the canal bottom, as far as the second lock (Lock 2). Here it rises sufficiently to place this structure in from 2 to 12 ft. of rock

FIG. 9. VIEW OF GUARD GATE ABUTMENT, SHOWING GATE ANCHOR BOX AND OPERATING BAR; SOULANGES CANAL WORKS, CANADA.

cutting. The steep clay bluff, rising sharply from the rock at this point, serves to enclose the lock solidly in 50 ft. of impervious earth. Up to the next lock (Lock 3) the reach is a clay cut over 30 ft. in depth, the bottom being tough blue clay. Lock 3 was from 2 to 12 ft. above the rock surface, so pedestals of concrete were built and the lock walls founded upon them.

LOCK CONSTRUCTION.

All three of the Cascades locks are founded upon rock. The pits were excavated and the loose stone piled at one side for use in making concrete. The irregularities of the bottoms of the pits were concreted up to floor level, and upon this the side walls were begun. Fig. 14 shows the general structural details of Lock No. 3, which will also serve to illustrate the similar construction of Locks Nos. 1 and 2.

The side walls of each lock are 355 ft. in length, 41½ ft. high, and 22 ft. wide at the base, finishing with a coping 5 ft. wide. Across the upper end a cross wall 23½ ft. high (the lift of the lock) acts as a revetment for the upper end of the pit. A breast wall, also 23½ ft. high, upon which are the miter sills for the upper gates, extends across about 50 ft. below the revetment wall, forming with it a head bay, from which the wall culverts are filled. All walls are built with plumb faces, and the backs are in steps. The full height of the face is of bush-hammered ashlar, which is backed with concrete. Vertical recesses, 4 ft. deep and 28½ ft. long, are made in the side walls to allow of the gates opening back flush with the general line of chamber wall. Each gate turns in a hollow quoin cut out of the stone; its heel rests upon a pivot casting, and it is held by a gudgeon and collar at the top. The gates miter against each other and close against sills of 18-in. x 18-in. oak, which are held down by bolts buried in a mass of concrete, as described for Lock No. 4.

The lower gates Fig. 15, of these three locks are over 40 ft. high and 28 ft. wide, the clear width of the lock being 46 ft. The inclination of the miter sills in plan is 2 normal to and 1 along the center line of lock. The gates are of "built-up" construction, the bottom bars being 34 ins. through. The timber, Douglas fir, came from Vancouver. The large gates weigh 70 tons.

Through each lock wall there is a longitudinal tunnel 6 ft. wide and 6 ft. high, with arched roof, having a total area of 67 sq. ft. These tunnels connect with the lock chamber through 20 openings, 10 each side, each 30 ins. in diameter, their combined area being about 98 sq. ft. The upper and lower ends of the tunnels are closed by "Stoney" sluices 6 ft. wide and 6 ft. high, which are operated by chains and counterweights through vertical wells in the masonry, 8 x 4 ft., extending from floor to coping. These valves, like the lock gates, have been subjected to 38½-ft. head, and are constantly operated under 23½-ft. head.

To fill the lock the lower valves are closed and the upper ones opened, which operation occupies about 1 min., the lock being full 8 mins. afterwards. The small locomotive tugs, which lose no time in entering the locks, are passed through in 7 mins. The filling by jets at the floor level produces no commotion, so vessels do not surge about. The valves being at floor level, are also easily got at for repairs, and the filling system requires no special foundations nor construction, but the long-

FIG. 16. VIEW SHOWING MASONRY OF REGULATING WEIR AND RACEWAY BRIDGE AT LOCK NO. 4; SOULANGES CANAL WORKS, CANADA.

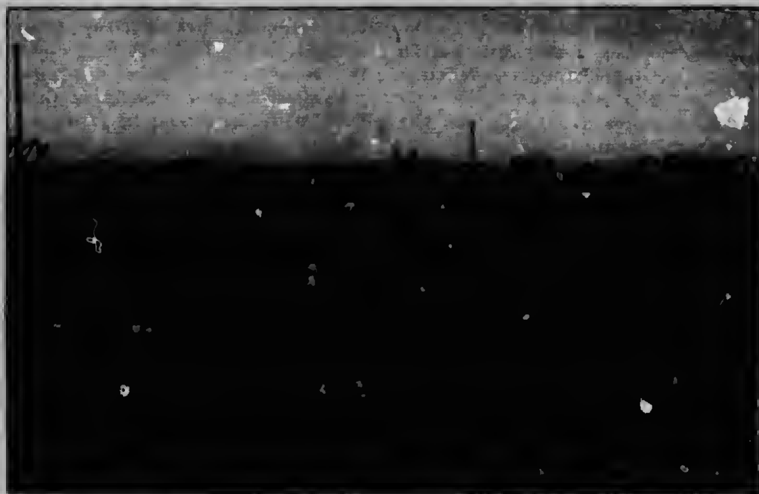


FIG. 11. TYPICAL VIEW OF EXCAVATION IN EARTH; SOULANGES CANAL WORKS, CANADA.

FIG. 12. VIEW SHOWING EARTH SLIP ON SUMMIT LEVEL; SOULANGES CANAL WORKS, CANADA.

itudinal tunnels tend to widen the base of the walls without increasing the quantities.

Concrete is largely used here and elsewhere on the canal. Of 200,000 cu. yds of masonry, 150,000 cu. yds. are of this material. The essential part of concrete is cement, and this was all furnished by the Department of Railways & Canals, and not by the contractors. Thus the highest grade cements only have been used and in sufficient quantity. The half-dozen brands contracted for have invariably more than fulfilled the tests, which were continuously carried on at a laboratory upon the work.

The masonry work was carried on rapidly, 10,000 cu. yds. of concrete and face ashlar per month being laid during part of the year. No building was done at night; in fact, the night was needed to bring up supplies of cement, stone and sand for the next day's work. On the lock walls a course of ashlar was laid in full beds of 3 to 1 mortar, approaching ⅝-in. in thickness. The front of each vertical joint was plastered up for a couple of inches back before the adjoining stone was laid, and then the rest of the joint was dashed full of

3 ft. above; the box being allowed to drop upside down upon its contents. Very little leveling was required, but the concrete was well rammed back of the ashlar and along the back molds. These molds were of rough 1-in. boards assembled in panels and supported by posts and braces or anchored into the wall by telegraph wire. The panels were of the same height as the insteps along the back of the wall, and were used over and over again.

A four-mast traveler would lay 100 cu. yds. of ashlar and back it up with 300 cu. yds. of concrete and place in this 100 cu. yds. of displacers in a ten-hour day provided the material was supplied fast enough. Machine mixing of concrete was found to be quicker, better and more economical of cement. Carts or barrows dumped the stone in a ring around the hopper, then sand was spread over, and finally a barrel of cement for each cubic yard of broken stone. Twenty men were kept busy shoveling the dry materials over and over toward the hopper. The mixer did the rest, and the concrete dropped into boxes and was hauled by locomotives or horses to the lock. Gates crush-

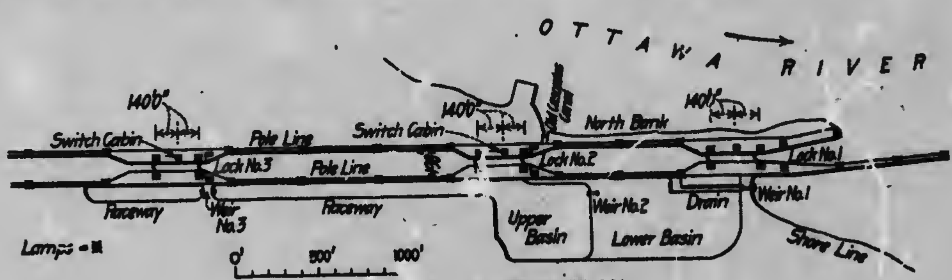


FIG. 3. DIAGRAM PLAN.

mortar from the rear. This gave strength enough to prevent the soft concrete backing, which was immediately laid, from bursting through the joints. After the concrete backing had set the whole course was grouted.

METHOD OF BUILDING.

Generally a four-mast traveling derrick, Fig. 16, mounted upon a strong trestle about half the height of the lock walls was used in constructing the lock. Beneath this were the supply tracks, one along each wall, and an outgoing empty track along the center. The two leading booms of the traveler laid the ashlar, and the two following booms lifted and deposited the concrete backing. Between times large masses of rough rock, from the excavation, were run in and let fall upon the viscous concrete.

Boxes, mounted on trolleys, were filled under a Cockburn concrete-mixer, which gave an almost continuous stream. An abundance of water was used in mixing and the walls were kept as wet as possible. The cubic-yard boxes were hoisted off their cars, swung over the wall and tripped about

ers were used for breaking the concrete stone, and when possible the crushers and mixer were worked in battery side by side.

Large quantities of concrete were also mixed by hand. Sand was brought up in dump cars, partitioned off to give proper proportions, and the charge was spread upon a platform in a layer about 3 ins. thick. Over this a barrel of cement was spread, and the whole thoroughly mixed dry to an even purple color. Generally three barrels of sand to one barrel of cement were the proportions for the mortar. Water was added to make a liquid paste, and onto this 1 cu. yd. of broken stone, fine and coarse as it came from the crusher, but thoroughly wetted, was dumped and spread. It was then shoveled out into four heaps at the corners of the platform, then back to a heap in the middle, and lastly into cars, barrows or carts for conveyance to the walls. From 18 to 22 batches of about 1 cu. yd. each were mixed and loaded by five or six men in ten hours.

Generally, for both ashlar and concrete, including grouting and a mortar finish on exposed faces, the expenditure of cement was one barrel to a

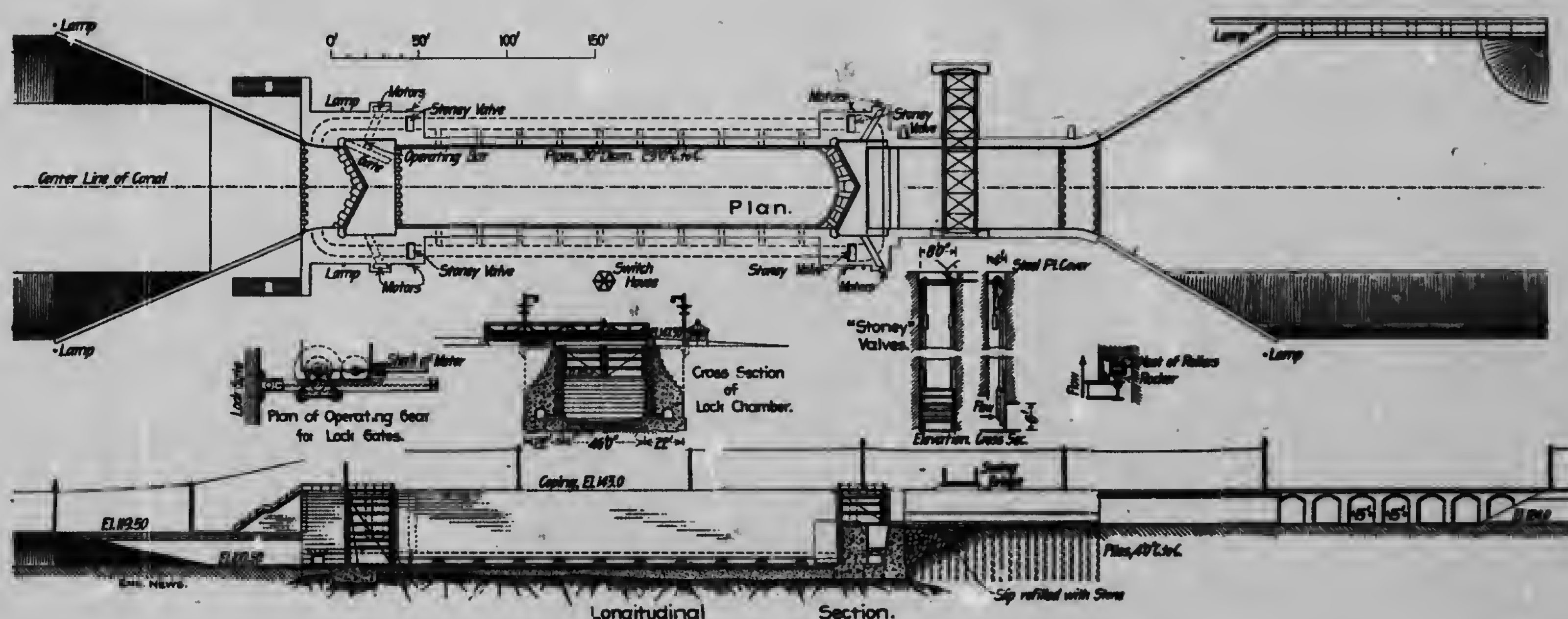


FIG. 14. DETAILS OF LOCK 3.

cubic yard. For concrete 1 barrel of cement = 3.2 cu. ft., and 3 barrels of sand = 9.6 cu. ft., and 8 barrels of broken stone = 25.2 cu. ft., were used. Great economy was effected by the use of displacers, often over a cubic yard in size, which saved cement to the Department and sand and broken stone to the contractor, and which hastened the work. Gravel would have further cheapened the concrete, but it was not used.

The ashlar is all bush-hammered limestone, and of large size, varying from 3 ft. to 1½ ft. in height and often 5 ft. deep and 8 ft. long. The contractors early appreciated that, as rough backs were allowed to project into the concrete backing, the larger the area the more profitable was the stone. Headers running 5 ft. back into the wall were required at 11-ft. intervals, and the bond was strictly not less than 12 ins. Stretchers were being paid for. Steps and large blocks were at special prices, of from $20 to $25 per cu. yd.

The general price for concrete, whether in backing of lock or in monolithic structures, was over $3, say $3.25 per cu. yd., and the barrel of cement cost on an average $2.50.

The derricks used upon the work had generally 70-ft. masts of Douglas fir and 60-ft. booms of the same timber. Six wire guys were used, and double blocks for the boom fall, and sometimes also for the main fall, rove with ⅝ to ½-in. steel wire. They were all furnished with a 12-ft. horizontal swinging circle and operated by one runner. The hoist boilers were about 25 HP., and the capacity of the derricks about 10 tons. To avoid hook holes, a face plate, lined with a 1-in. layer of lead, was used, and gave great satisfaction.

FIG. 15. VIEW OF LOWER GATES; LOCK 2.

to be at least 2½ ft. deep into the wall, but generally they are nearly 4 ft. Hollow quoins are 6 x 6 ft., and recess quoins are of similar area of bed. Large block-stones, 5 x 5 ft. and 3 ft. thick, were placed under the gate pivots in a mass of concrete, and the miter sills are backed by blocks 3 ft. in thickness. Lock copings are uniformly 18 ins. thick, and 5 ft. wide on top, with a 1 to 1 frost batter. Some of these are upwards of 9 ft. in length.

The price per cubic yard bid for ashlar was from $14 to $16, and included all kinds of copes, quoins, arch stones, etc., only the net content of stones

The locks are all founded upon rock, but at Lock No. 1 a transverse cravasse was encountered, which extended 12 ft. below the floor. From this 3,000 cu. yds. of wet clay gravel were excavated and replaced by concrete. The bottom of this crevice was 30 ft. below the water surface of the Ottawa, outside the entrance dam. In the pit for Lock No. 3, the rock dipped irregularly below the floor, so pedestals of concrete were made under each wall, 6,000 cu. yds. of concrete being used for the purpose. The pit was 50 ft. in depth, excavated largely in blue clay. A slip occurred at the head, where it was proposed to found a swing bridge. The material was partly excavated and then piles were driven. Between these the slipped material was replaced by loose stone, over which a 2-ft. platform of concrete was laid and the bridge built thereon.

REGULATING CULVERTS.

No overflow weirs are used, but regulating culverts, Fig. 15, the design of J. L. Allison, C. E., are used instead. There are two of these communicating between the side ponds and an outfall one. Each one consists of twin tunnels of concrete leading through the bottom of the embankment and throttled by "Stoney" sluices which operate upwards through shafts by the usual chains and counterweights.

The parallel tunnels are 6 ft. wide and 7 ft. high, with an arched roof 2 ft. thick, all formed as a concrete monolith. A smooth face finish was secured by the use of tarred paper spread over the molds, against which a 2-in. layer of mortar was plastered. This gave a smooth finish, but the imprisoned air left "worm marks." Stove-pipe iron gave a very smooth finish, and was much used by the writer in curved work.

For mortar facing a large "rake," or grating, 4 ft. long and 18 ins. high, formed of vertical iron rods, set 1 in. apart like teeth, in a flat bar, was used with economy and success. It was set against the face mold about 1½ ins. from it and held back the stone in the concrete mass till mortar was tamped in front and the grating withdrawn.

SPLAY WALLS.

Above and below each lock splay walls revet the sides until the 2 to 1 slope is reached by their spreading flare. These are very massive, and built as concrete monoliths, only the coping being of stone. Their section was determined by the Engineering News rule: "3-7 height and odd inches thrown in." The mean thickness thus obtained was multiplied by the height and this area distributed as the case allowed. All walls have plumb faces and their backs formed in steps, upon which, as far as possible, loose stone filling was piled. The base projected 1 ft. front and rear, which allowed of setting up mold posts and correcting alinement of face. The walls varied from 120 to 140 ft. in length, and were built without transverse bulkheads, but vertical slip joints were made where the wall joined the lock wing. These have proved quite sufficient for contraction, even though subjected to a range of from — 30° F. up to 120° F. Walls of immense size have developed hair cracks, but they are of no consequence, while

FIG. 16. VIEW OF LOCK 3, DURING CONSTRUCTION.

the use of transverse bulkheads is a hindrance during construction, and a certain defect afterwards. Every structure stands upon its own bottom, however, slip joints having been formed at all junctions, and the results are most satisfactory after severe accidental tests.

Many "plums" were used in all the walls, some of "one-man" size stone, where the wall was narrow or derricks could not be had. Foundation concrete made of 1 to 5 mortar and 10 parts broken stone has given good results. No imitation of masonry coursing was permitted, but the layer marks were obliterated by a thorough coating of cement whitewash.

In the splay walls L-bolts are embedded by which horizontal 9 × 18-in. oak fenders are attached at about water level.

again, and all the repairs necessary was to grout up the cracks.

MACHINERY.

At each lock there are four submerged "Stoney" sluices 6 × 6 ft. They are of the well-known "Stoney" type—a plate of steel fortified by I-beams and sliding upon nests of live rollers at each side. The valves are hung by chains passing over pocket wheels on a horizontal shaft with counterweights on the free ends (Fig. 14). The shafts can be evolved either by hand or by electric motors. These and the lock gates are arranged for operation from a switch house situated at the middle of the lock on the north side.

The lock gates are closed and opened by a steel I-beam having a rack attached to one side, into

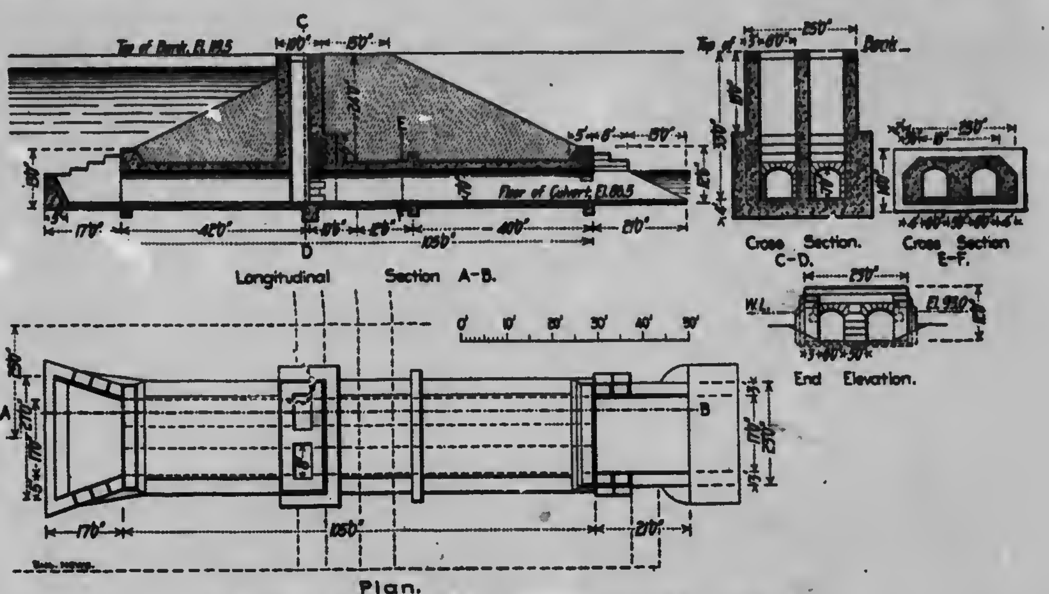


FIG. 17. DETAILS OF REG[illegible] CULVERT; LOCK 2.

ARCH BRIDGES.

Along the south side of the reaches arch bridges are placed through which the side ponds connect with the canal proper (Fig. 14). These arch bridges are concrete monoliths in which a succession of arched openings 15 ft. span and 3.75 ft. rise are left. The bridges are all 10 ft. wide and have a stone coping on each side. A concrete platform 12 ft. wide and 2 ft. thick was first laid, and upon this the piers were built. Though many foundations are upon clay, timber grillages have not been used at all. Cracks in concrete slabs have been rare and of no consequence. In places where it was impracticable to keep structures flooded during winter the foundation slab with arches upon it was raised bodily 6 ins., but settled back to place

which a pinion meshes. The point of attachment of the strut to the 42-ft. gates is 16 ft. from the bottom and 14 ft. from the heel. A chamber is provided in the lock walls into which the gate arm recedes.

For hanging the lock gates a pontoon (Fig. 18), 30 ft. square and drawing 10 ft., with a square tower about 30 ft. in height and the full size of the hull is used. A gate leaf is raised from a floating position to hang vertically against one side of the tower by wire cables passing over the top and wound around winches on each side. The gate is then floated into its recess, gently lowered onto its heel pivot and the top secured by a steel collar fitting over a gudgeon pin. R. & J. Miller were the contractors.

ELECTRICAL INSTALLATION.

As mentioned previously, the power-house is in combination with a waste weir about half-way down the summit level, the Grease River, which passes under the canal at this point being used as a tail race. A 20-ft. head is easily secured here

FIG. 18. VIEW OF PONTOON USED FOR HANGING LOCK GATES.

and the area of the canal prism admits of a large discharge without creating an objectionable current, besides which, discharging into the stream creates no damage claims. Mr. A. M. Rice, of Dayton, O., designed the hydraulic development, and the Royal Electric Co., of Montreal, worked out the electric power required and its application to locks, bridges and lighting. The contract for the work, however, was secured by the Canadian General Electric Co., who placed Mr. Hoffmeister in charge of the erection work.

POWER-HOUSE.—A gap in the south bank, about 120 ft. in length, is barred by a heavy concrete wall founded upon piles (Fig. 19). The middle third of this is widened out into the canal to form two vaults for wheel chambers. Three arched openings, closed by "Stoney" sluices, are placed on each side of the wheel pits to form regulating valves for the summit level. In each wheel chamber are four Victor wheels working on one horizontal shaft. Both shafts pass through the concrete dam in packing boxes to the generators. The dam forms one wall of the power-house, which is a handsome brick building with sandstone trimmings (Fig. 20).

There are two, 3-phase, 60-cycle generators of 264 K-W. each, direct-connected to the wheel shafts, which make 225 revolutions per minute, generating a pressure of 2,500 volts on the line. Two exciters of 15 K-W. each are belted direct to the wheel shafts. The switchboard is of marble; there are 2 generators, 2 feeders and 1 exciter panels fitted with the latest operating instruments.

DISTRIBUTION.—The pole line being on the opposite side of the canal, the current is carried across in four-lead armored cables to a switch cabin on the north bank, whence one power and light circuit is run up and one down the canal. The poles are of British Columbia red cedar, dressed octagonal and painted with four coats of white lead. They are spaced 120 ft. apart, every fourth pole carrying an enclosed arc lamp of 2,000 c. p. All poles are set 6 ft. into the ground, the

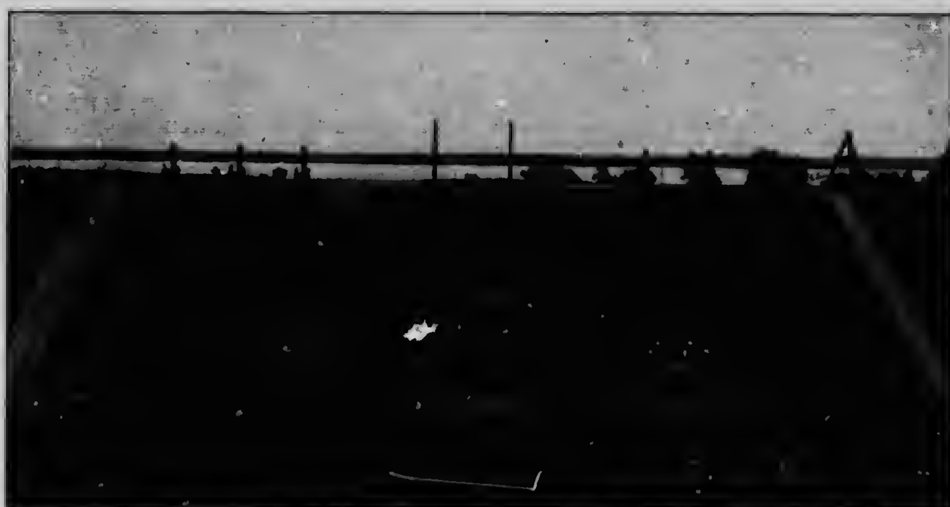


FIG. 19. VIEW OF POWER HOUSE DAM FROM CANAL SIDE.

line poles being 30 ft. and the lamp-posts 35 ft. in length.

On the upper circuit 6 wires of No. 6 B. & S. soft round copper are used, and on the lower 3 No. 4 wires and 3 No. 2. The line is protected by 91 Wurts lightning arresters, placed wherever junctions are made with underground cables

trance piers are lighted along both sides. Navigation is thus as easy by night as by day.

MOTORS.—At every lock four gate and four valve motors are provided, and one at each highway bridge. There is also a 15-HP. motor for the canal repair shops. The high-tension wires enter a switch cabin at each lock, where two transform-

FIG. 20. VIEW OF SOUTH FRONT OF POWER HOUSE.

at locks or bridges. Six miles of armored cable are employed.

There are 220 long-burning, alternating-enclosed arc lamps of 2,000 c. p. each. Every light is equipped with a transformer of 1,000 Watts capacity. Besides the lights, placed at 480 ft. intervals along the canal bank, all the locks and en-

ers of 7,500 Watts capacity each reduce the pressure from 2,500 to 220 volts. This current is led direct to the gate and valve motors by underground cables controlled by the operating switchboard in each cabin. To facilitate the operation of the canal a bridging Bell telephone system connects all the locks, bridges and offices.