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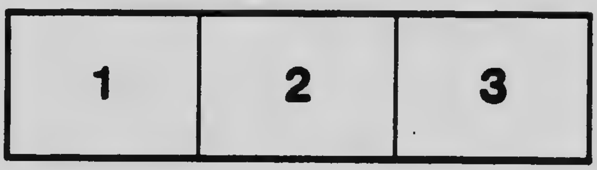
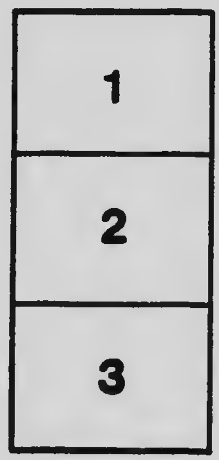




Extension to the Ontario Power Company's Plant

Reprinted from Contract Record, July 16th, 1919

Extension to the Ontario Power Co.'s Plant

Unique Features are Wood Stave Pipe 13½ ft. in Diameter and 6700 ft. Long, Largest Differential Surge Tank, and Power House with Walls Designed to Withstand 40 ft. Rise in Tail Water—Pipe Trench Excavated by Blasting or Channeling Where Proximity of Old Pipe Prevented Use of Explosives

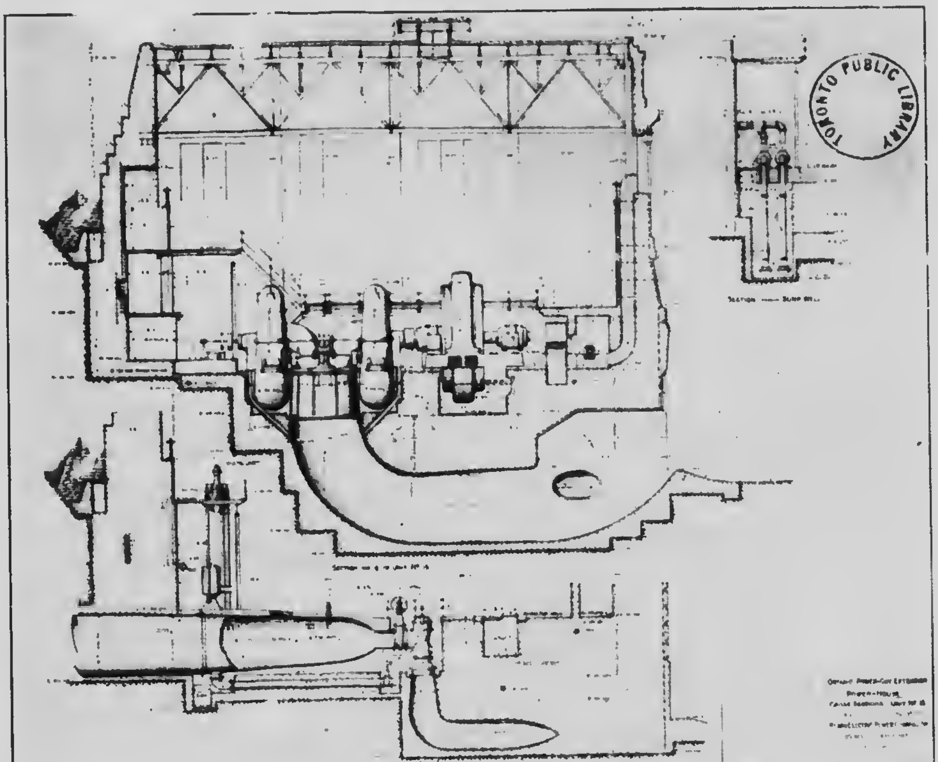
OWING to the power shortage caused by the extra energy needed for essential war industries and the fact that two of the plants at Niagara Falls had reached their capacity, work was commenced in March, 1918, for the extension to the Hydro-electric plant of the Ontario Power Co., at Niagara Falls, Ontario. Completion of the work within twelve months after it was started not only adds from 40,000 to 50,000 horse-power to the plant, but also co... splendid record of attainment for the eng... ted with the work. Although the dem... gy created by the war emergency has ceased to exist, the demand created by the large number of new industries attracted by the power facilities offered by the Hydro-Electric Power Commission, has already appropriated a large part of the additional output provided by the new unit.

The construction of this extension involved the excavation of 133,000 yards of earth and 14,000 yards or rock to permit the placing and erection of a 13.5 foot diameter wood stave pipe 6,700 feet long, a 13.5 foot diameter steel distributor 179.5 feet long, a 60-foot diameter steel differential surge tank 94 feet high, four Johnson hydraulic operated valves, two 10.5 foot diameter penstocks and two 20,000 horse-power turbines with direct connected generators, also the erection of the additional power house to hou... these units.

One of the Largest Wood Stave Pipes Ever Built

The unique features about this extension are the wood stave pipe which is one of the largest ever built, the differential surge tank which has the largest diameter and has also the greatest height of any similar tank not equipped with an auxiliary spillway, and the power house walls which were designed to withstand a pressure due to a 40 foot rise in tailwater elevation, this extraordinary condition having occurred in the year 1909.

The original pla... the Ontario Power Company



Section through power house extension on centre line of No. 15 unit. Also section of No. 15 penstock

Trench for wood stave pipe through rock section, showing tunnel beneath International Railway Company's tracks. Both sides of cut are channeled here

Rock excavation in pipe trench near International Railway crossing. Rock drills at work

Erection of wood stave pipe, using saddles as forms

No. 3 conduit completed, showing method of bracing Lackawanna steel sheet piling between conduits Nos. 2 and 3

Erection of wood stave pipe, using sɪdu... as forms

No. 3 conduit completed, showing method of bracing Lackawanna steel sheet piling between conduits Nos 2 and 3

Scaling loose material from cliff above power house site. International arch bridge in background

No. 5 draft tube forms in position ready for concreting

Wood stave pipe, showing details of bands, shoes and saddles

No. 3 conduit, showing mudsills in position: No. 2 concrete conduit exposed

Excavation for surge tank and riser. Sullivan channellers at work

Power house extension site ready for forms. Two tunnel portals appear in background with penstock No. 16 being assembled. Draft tube form for No. 15 in position at left as controlled and operated by the Hydro-Electric Power Commission, consisted of an installation of fourteen turbines, seven with a rated capacity of 11,800 horse-power, five rated at 15,000 horse-power, and two at 16,000 horsepower, making a total of 189,600 horse-power. The generators, which are direct connected, have a total rating of 119,012 kv.a. Water was supplied through two 18 foot diameter conduits, each approximately 6,600 feet long, having a combined maximum capacity of about 162,000 horse power.

No addition to the forebay to accommodate the new conduit was necessary since the forebay and gatehouse were built to accommodate a third conduit.

Excavation for distributor and valve chamber

The arrangement of the forebay is such that an accumulation of ice above the entrance to the conduits is very improbable. That the forebay accommodation is adequate is indicated by the fact that a blind thimble 20 ft. in diameter to provide for an extension was installed when the gatehouse was erected.

The existing No. 1 conduit, which is of steel plate construction, was installed in 1903, while No. 2 conduit, which is of reinforced concrete construction, was installed in 1910. This second conduit, when inspected in April, 1918, after being in service eight years, showed no signs of cavitation or deterioration, although a velocity of 25 to 28 feet per second had been maintained during operation, nor was there any vegetable growth whatever appearing on the walls.

Features of New Conduit

No. 3 conduit, the one recently constructed, is 13.5 feet inside diameter. The staves are of B. C. fir 4 inches thick by 6 inches wide and banded with 7/8 inch diameter steel bands, in two sections with two shoes. The pipe is carried on timber saddles spaced at 4½ foot centres except where the pipe is concreted in place. Connection is made with the 20-ft. diameter thimble at the gatehouse by means of a reinforced concrete reducer 25 feet long. The connection between the wood stave pipe and the concrete reducer is made by means of another steel thimble 13.5 ft. in diameter and 6 ft. long. This thimble, which projects 2 ft. from the concrete reducer, extends 1½ ft. into the wood-stave barrel. The union between the wood, and the thimble was sealed by tightening the bands around the staves. Connection with the surge tank and penstocks is made by means of a steel distributor, the diameter and length of which are 13.5 and 179.5 ft., respectively. The steel distributor is united to a section of reinforced concrete pipe leading to the surge tank. The concrete pipe is laid on a horizontal curve, the end of which bends upward through 90° to form an elbow connection with the centre of the bottom of the surge tank.

The excavation for trench for the wood stave pipe line was handled from the cut by shovels, derricks, and locomotive cranes. The difficulties in this work were varied and in some places severe due to the close proximity of No. 2 conduit and to large quantities of water which were encountered at the upper end of the pipe line and at Dufferin Island crossing. A portion of the excavation was deposited along the sides of the cut for back-fill while the remainder was placed on dumps located at convenient points.

Excavation at site of power house extension

Surge tank floor assembled ready to lower onto foundation

Saddles Supporting Pipe

The saddles used to support the pipe are built-up timber sections so constructed as to make a continuous form for the lower half of the pipe. Mud sills were used under the saddles through the earth cut, in order to distribute the load of the pipe and prevent settlement as far as possible. Through the rock cut the mud sills were left out and the lower limits of the saddles were placed on the rock which was evened up to grade after excavating the trench. They served also during the construction work as forms for the lower half of the conduit. These saddles were designed not only to support the finished conduit in its proper line and grade; but also to prevent diametrical deformation caused by uneven settlement of backfill, or uneven hydrostatic pressure, when the pipe may not be running full. Prevention of spreading of the upper ends of the saddles is obtained by cantilever action in the upper 3 ft. of the ribs of the saddles. The cantilever action is obtained by the stiffening effect of two ¾-in bands in each saddle, which enter the structure of the saddle about 3 ft. below tops of the ribs, which pass around under the lower side of the conduit and which react against heavy cast-iron washers braced against diagonal offsets in the ribs of the saddles.

Drainage of Pipe Trench

On account of the bottom of the trench being below the water level in the Niagara River for the greater portion of its length it was necessary to provide ample drainage for the pipe trench. The drainag system consisted of two vitrified tile drains one on either side of the pipe trench, laid with open joints in broken stone. These two tile drains run from Station 9+00 on the conduit to the steel distributor, where they are connected to the penstock drains which carry the drainage water down through the power house to the lower river. The first 300-ft. section of the drain is 6 in. in diameter, whereas the rest is 8 in. The two drains are interconnected at 200-ft. intervals by 6 in. horizontal laterals laid under the conduit.

For 1,000 feet at the upper end, and 825 feet at the lower end, the pipe is concreted in place. This was necessary in order to allow the pipe in these sections of the trench to be backfilled and thus restore the surface of the park to its original condition.

Steel Distributor to Connect Penstocks

The steel distributor at the lower end of the wood stave pipe is made of 5/8 inch steel plate and is 13.5 feet in diameter and 179.5 feet long. Four penstocks are connected to this distributor by means of bell-mouthed tees made of ½ inch steel plate. The distributor is incased in concrete so as to allow the surface of the park above it to be restored to its original condition. A section of 13.5 foot diameter reinforced concrete pipe 77 feet long connects the distributor with the surge tank. The tees connecting the penstocks are riveted together in sections cut from beaver board patterns. In preparing the patterns, wood frames were built around the shop-assembled distributors in such a manner that the framework resembled joists or ribs shaping the tees. The beaver board strips were tacked to these joints, were match-marked and were used as patterns from which to lay out the corresponding steel plates. The patterned plates later were sheared, punched and assembled and bolted to the distributors to insure their assembly in the field.

Penstocks Nos. 15 and 16 which deliver the water to the two new turbines in the power house are 216 feet in length. Each penstock ends in a supply pipe with taper connections bolted to the spiral casings of the turbine. The steel plate used in the construction of the penstock varies in thickness from 3/8 inch at the upper end to 13-16 inches at the lower end. The supply pipes are constructed of 13-16 in. plate throughout. The penstocks are designed for a pressure equal to 150 feet of head at the upper end, increasing to 320 feet at the lower end, these figures including pressure rise due to a turbine gate closure time of three seconds, with relief valve closed.

After the penstocks were erected the space between the excavation and the outside of the pipe was filled in with lean concrete. This holds the penstock in position and protects the outside from corrosion.

Unit stresses adopted in designing the penstocks to resist the static heads only, exclusive of metal provided to compensate for corrosion, were 15,000 lb. per sq. in. for tension, 10,000 for shear and 20,000 for compression. The desirability of maintaining maximum joint efficiency necessitated a change in the type of longitudinal joints as the thickness of the shell changed. This efficiency was maintained by adopting triple riveted lap construction in longitudinal seams in plates varying from 3/8 to 7/16 in, and by adopting triple riveted butt construction in the seams in plates thicker than 7/16 in. Single riveted lap construction was adopted for the circumferential joints.

Penstocks and Surge Tank

The new penstocks drop vertically through 48.3 ft. from the distributor, then bend 45 degrees and extend 99 ft. toward the power house, and then bend 45° more and extend horizontally into the power house. Each penstock tube, which is surrounded by lean concrete containing a 12-in. drain discharging into the corresponding draft tube, terminates in a reducer with two openings making 90° horizontal bends from the axis of the horizontal portion of the delivery end of the penstock. The flanges on the openings of a reducer are bolted to the metal casing of the turbine. The steel plates for the penstocks were assembled in place. Two 10-ft. and two 10.5-ft. valves responding to hydraulic control are set with their top ends approximately 20 ft. below the centre line of the distributor.

The surge tank is of the Johnson differential type, 60 ft. outside diameter and 78 ft. high. The tank is built of steel plate varying in thickness from ¼ inch plate at the top to one inch plate at the bottom, while the internal riser, 12 ft. in diameter and 60 ft. high, is built of ½ inch plate. The roof for the tank is constructed of steel roof trusses with wood covering. Anchors with turnbuckles connect the trusses with the riser to prevent vibration during load changes. The steel bottom of the tank is constructed of ½ in. flat plates, field riveted, resting on a carefully levelled 2-in. grout course spread over a thin concrete footing poured on the solid rock.

The water wheels are double runner, central discharge turbines with spiral casings, running at 187.5 r.p.m. and delivering 20,000 horse-power under 180 foot head. The turbine gates are operated by vertical servo-motors which are controlled by actuators mounted on the gallery. These actuators are equipped with distance speed controllers, hydraulic hand controllers, gate limiting device, manual speed adjuster, gate opening indicator and tachometer. The pressure oil for operating servo-motors is furnished by a helical gear rotary pump, delivering 62.5 gallons per minute against 200 lbs. pressure. The sump tanks are each of 350 gallons capacity and are provided with screens for cleaning the oil before it is returned to the pressure tank.

Power House Designed for Severe Stresses

The power house is of concrete and structural steel construction. In the substructure plain concrete has been used throughout except for the concrete over the draft tubes, which has been reinforced for the upward pressure, which will occur with high water in the river. The generator pits, air ducts and sump well are also reinforced to prevent injury developing from the temporary severe loading of portions of the structure during the erection of the units and from vibration when the plant is in operation. In the superstructure reinforced and plain concrete and structural steel are used.

In order to protect the power house against a recurrence of the high water conditions which prevailed in 1909, the window sills in the front and end walls were placed at elevation 388 and the walls designed to withstand pressure due to water at this elevation on the outside power house. This necessitated an

Bottom sections of spiral casings of turbines Nos. 15 and 16

unusual amount of reinforcing steel. The steel work for the interior columns, roof trusses and crane was designed to act independently of the walls, so that it could serve in place of falsework for the erection of the machinery.

No special considerations were necessary in the design of the rear wall on account of the fact that the lower portion of it is set 20 ft. into solid rock. The wall was designed to act as a stepped gravity structure, although some reinforcing steel was provided along the inner vertical face and about openings for drains and conduits as a means of compensating for the concrete eliminated. A 6-in. reinforced concrete slab roof, designed to support 150 lb. per sq. ft. moving load, was adopted for the new portion of the power house to provide against accidents caused by rocks falling from the cliff, or by water flowing down the cliff and freezing on the roof. The concrete for the power house is placed by the pneumatic process.

Excavating Pipe Trench

Means employed to excavate the trench depended upon the material and the situation of the trench. The rock was blasted where possible and was channeled where blasting was dangerous to the adjacent conduit. Blasting was used only where the centre lines of conduit No. 2 and proposed conduit No. 3 were separated more than 24 feet. Even where blasting was resorted to, it was done on the side of the trench away from conduit No. 2. Channeling was done on the entire near side of the trench and on the outside along the rock portions along which the centre lines of conduits No. 2 and No. 3 were 24 ft. or less apart. The material was taken from the trench by locomotive cranes, derricks or shovels, depending on the material and other conditions. In earth cut, one side of the trench was allowed to slope but the other side was held vertical by the old steel sheet piling driven along the trench when conduit No. 2 was built. This piling had to be braced by sills stretched along the top and held by wire cables anchored in solid ground beside conduit No. 1. The excavated material was disposed of locally by dumping some of it in uneven places along the bank in front of Victoria Park and by using the rest for backfill.

A tunnel crossing under the International Railway tracks was adopted instead of an open cut on account of the fact that the solid rock extends to the surface of the ground. The crown thickness under the tracks was between 4 and 5 ft. Channeling was necessary in all surface cuts near the surge tank on account of the presence of the old surge tanks and other installed equipment. The rock in the penstock tubes and in the excavation for the addition to the power house was blasted and removed by cars which were loaded by cranes and dump buckets. Careful scaling of loose stone on the cliff had to be done before work could be started with safety on the power house excavation.

Hydraulics of Plant

The hydraulics of the plant are of more than ordinary interest, due to the fact that each of the three pipe lines and surge tanks that have been installed differ considerably. For this reason an excellent opportunity is presented of making a comparison of their respective hydraulic characteristics and capacities.

No. 1 tank has very little capacity and is of the simple tank type. Its only function is to limit the surge pressure on conduit No. 1 during load changes and provides entrance to a spillway for discharge of water at times of load rejection.

No. 2 surge tank, of the Johnson differential type, was the first tank of this character ever built. This tank serves the double purpose of relieving pressure surges and furnishing or storing water during load changes while the velocity in conduit No. 2 is being accelerated or decelerated. It is also equipped with a spillway as an additional safeguard, to prevent spilling over the top at times of abnormal surge, and to limit the height which would have been required without this provision.

No. 3 surge tank is of the same type as No. 2, but has no spillway. Its design is such that full load rejection under the most abnormal conditions will not cause overflow.

During 1913, a series of tests was made to determine the hydraulic characteristics and carrying capacities of conduits Nos. 1 and 2, also of penstocks Nos. 1 to 14, inclusive. The results of these tests indicate some very striking facts regarding the relatively greater carrying capacity of concrete pipe as compared with riveted steel and also the exceedingly smooth surface that can be obtained with concrete if proper and careful construction methods are used.

Capacity of Wood Stave Pipe

The capacity of No. 3 conduit, which is of wood stave construction, is 2,750 cubic feet per second, giving a velocity of 19.2 feet per second in the pipe on the basis of a coefficient of roughness "C"= 135 in the Williams and Hazen formula. Under such conditions, there will be a total loss in the conduit, from gate house to penstock, of 32 feet, which includes entry losses, friction loss and velocity head: This figure was arrived at by assuming low water elevation in forebay at 554, and the minimum elevation of the gradient at penstock No. 15 at 522, which is eight feet above the top of the conduit. From past experience with conduits Nos. 1 and 2, it was found advisable not to go below elevation 522 in order to prevent the gradient being drawn down below the top of the pipe under operating conditions. Under the above conditions the capacity of the pipe will be approximately 45,000 turbine horse-power. With a coefficient of roughness C= 150 in Williams and Hazen formula, which value is within the limits of possibility, and the same total loss of 32 feet, the discharge capacity would be 2,930 cubic feet per second with a velocity of 20.5 feet per second in the pipe. This quantity of water in turn would give approximately 48,000 turbine horsepower. In comparing the coefficients of roughness of the concrete and steel pipes, as obtained by test, and the assumed coefficients of roughness for the wood stave pipe, based on the tests published by the U. S. Department of Agriculture, it appears that the concrete pipe has the highest coefficient, with the wood stave pipe a good second, and the steel pipe a poor third.

A coefficient of roughness of 100 in Williams and Hazen formula was used in figuring the losses in the steel penstocks. The use of this coefficient was based on the result of tests on the other penstocks.

It was, of course, necessary to design the tank for a drop of full load on No. 3 conduit, under which condition the tank will receive all water without the provision of a spillway, and on the assumption that none of the pressure regulators on the turbines in the power house are in service. The condition of design for load thrown on, was that of an increment of load equivalent to a 20 per cent. velocity change from 80 per cent., up to full capacity of the conduit.

The new construction was carried out under the direction of the technical staff of the Hydro-Electric Power Commission of Ontario, of which Sir Adam Beck is chairman and F. A. Gaby is chief engineer. The technical staff responsible for the design and construction includes H. G. Acres, hydraulic engineer; T. H. Hogg, assistant hydraulic engineer; M. V. Sauer, designing hydraulic engineer; E. T. Brandon, electrical engineer; A. H. Hull, assistant electrical engineer; A. V. Trimble, construction engineer; Walter Jackson, resident engineer; J. F. McGraw, general superintendent of construction; F. A. Burgar, field superintendent.

The contract for the structural steel for the extension was awarded to the Standard Steel Construction Company, Port Robinson, Ontario. The erection of the steel was carried out by the construction department of the commission. The Pacific Coast Pipe Co., Vancouver, B.C., supplied the wood staves for the pipe line. The generators were made by the Canadian General Electric Company and the turbines by the S. Morgan Smith Company, York, Pa. Other materials and equipment were supplied as follows: Bands and washers, Steel Company of Canada, Hamilton; shoes, Malleable Iron Company, Owen Sound, and Pratt and Letchworth Company, Brantford, Ontario; steel distributor, surge tank, penstocks, valve casings and supply pipe, Canadian Des Moines Steel Company, Chatham, Ontario; Johnson valves, Larner-Johnson Valve and Engineering Company, Philadelphia, Pa.; pressure regulators, Wellman-Seaver-Morgan Company, Cleveland, Ohio; turbine governors, the Lombard Governor Company, Ashland, Mass; servo-motors, Canadian Allis-Chalmers Company, Toronto; gate valves, Chapman Valve Manufacturing Company, Indian Orchard, Mass.; blowers, Canadian Blower and Forge Company; potheads, Standard Underground Cable Company, Hamilton; conductors, Eugene Phillips Electrical Works, Montreal; switches and bus bar supports, General Devices and Fittings Company, Chicago, and A. H. Winter-Joyner, Ltd., Toronto.