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SUB-AQUEOUS PRESSURE TUNNEL FOR WATER SUPPLY

AT VANCOUVER, BRITISH COLUMBIA.

There has recently been completed by the Administration Board of Greater Vancouver Water District at Vancouver, British Columbia, a tunnel for carrying water supply which is distinguished by several features of unusual interest.

The Greater Vancouver Water District is a Corporation created by special act of the Legislature of the Province with the object of supplying water to the area within its limits. It began its operations in 1926.

The tunnel is a unit in the projects of the District for increasing the supply of water to its constituent members comprising the Cities of Vancouver and New Westminster and several adjacent municipalities covering an area of 290 square miles. The population of the District together with the additional areas to which water is supplied in bulk by the District is approximately 325,000.

The water is drawn from two independent sources of supply contiguous to Vancouver and nearby municipalities and one contiguous to New Westminster and adjoining municipalities. These sources are all mountain streams lying in the high land to the north of Burrard Inlet from whence an average daily supply of about 35 million gallons is taken and for the maximum day about 55 million gallons. The extensive use of water for lawn sprinkling and gardening purposes during the dryest period of summer accounts for the heavy maximum daily delivery.

Immediately after the incorporation of the District investigations were put in hand with a view of ascertaining the physical factors in the watersheds and the intervening areas that would have a determining effect on the steps to be taken from time to time to increase the water supply to the fullest extent the run-off would permit. Many detailed surveys and investigations and subsurface borings were made at possible sites for storage or diversion dams, and for tunnels, pipe lines and other structures to the end that whatever plans should be decided upon for future development the various steps would be in proper sequence. The completion of the Pressure Tunnel under the First Narrows at the entrance of Vancouver Harbour marks one of the steps. Among the others will be the construction of a dam at Capilano Canyon (3½ miles north of the tunnel) perhaps eight to ten years hence and a dam at Seymour Canyon possibly twenty-five or thirty years later. These dams will create impounding reservoirs in the valleys for the regulation of the widely fluctuating stream flows. Regulation is accomplished for the present and early future needs by three small mountain lakes at elevations of approximately 3,000 feet above sea level. Meantime the 144 square miles of land above these dam sites have with the exception of less than one per cent of the total area been acquired by the District, while in the Coquitlam Watershed contiguous to New Westminster the whole catchment area is under a Government Reserve.

The Capilano supply system of which the tunnel now forms a part was the first to be developed for the then City of Vancouver in 1888, and considerable parts of the original 22-inch and 16-inch diameter rivetted steel mains constructed at that time are still in operation though about at the end of their useful lives. It is interesting to note that these old pipes as well as one of the same age on the Coquitlam system supplying New Westminster and neighborhood were built in the Province, of British Steel brought directly by ship from England.

The distance from the Capilano Intake to the North Shaft of the Pressure Tunnel is seven miles. About 1.7 miles of this distance has been provided with new 60-inch diameter steel pipes while the intervening length

PROVIDED WITH 60" ⌀ STEEL PIPE WHILE THE INTERVENING LENGTH is of old 16, 22 and 26-inch steel and 30-inch wood-stave pipes. Replacement, shortly required, will be of 60-inch diameter steel northward to the Canyon Damsite and probably by a stretch of continuous wood-stave pipe upstream from the Canyon to serve for the time until the dam is constructed. The present intake structure, at Elevation 470 feet above sea level, will then be submerged.

Heretofore the water has been carried across the Harbour by means of submerged flexible-jointed cast-iron pipes lying on the sea-bed.

The Port of Vancouver, in recent years, has handled a larger number of vessels than any other Canadian port, arrivals approximating to 20,000 per year, and as all this traffic passes through the First Narrows and a considerable percentage of it through the Second Narrows it can be seen that the requirements of navigation are of paramount importance in any consideration of these channels. The widths of the two Narrows, with 30 feet at low water, were formerly 500 feet and 450 feet respectively. The First Narrows have now been dredged to a width of 1200 feet at 35 feet at low water, but the Second Narrows have not been improved to any great extent. These particulars and the fact that rapid currents, up to about 6 knots, occur daily in the channels will help to explain why the maintenance of underwater pipe crossings at the Narrows has been a matter of considerable anxiety. The occasional breakage of the mains near the shore connections caused by the grounding of ships, and other maintenance difficulties, as well as the possibility of serious damage due to the sinking of a ship over the pipe lines, rendered imperative a more permanent and satisfactory crossing for the water supply to the rapidly developing City and its surroundings. Many detailed surveys and studies were carried out in determining the best possible method of achieving this object. Eventually a pressure tunnel at a depth of 400 feet under the First Narrows was decided upon, to be of such dimensions that it could be incorporated in the ultimate development scheme. It is this tunnel that has just now been completed.

A cross section along the center line of the tunnel, which is straight in plan, is given in an accompanying illustration. The south end of the tunnel (i.e. that at the City) was fixed within relatively narrow limits by the location of the road across Stanley Park in which lies the existing supply line. Sandstone rock was found at the point selected at about 65 feet below the surface. The location of the North Shaft presented more difficulties. Future navigation requirements had to be allowed for, and these include future dredging of the glacial deposit in the bed of the channel, which can be seen from the section to start at about mid-channel increasing in depth to about 300 feet half a mile to the north. Further a suitable solid rock foundation had to be obtained for the founding of the shaft and for its junction with the tunnel. Extensive subsurface investigations were carried out by means of borings and eventually a suitable site was selected at which solid rock was found at a depth of 110 feet below high water level and which also met the requirements of navigation.

The location of the two vertical shafts resulted in a tunnel 3,104 feet long. The internal diameter of the tunnel was fixed at 7' 6", its designed capacity being 200 million gallons per day, which is the ultimate supply expected from the Capilano Creek works. The two shafts are 8 feet in internal diameter. The sandstones, shales and conglomerates at the tunnel site are recent rocks and as no pressure tunnel had heretofore been built in recent sedimentaries it was concluded, on the advice of Mr. J. Waldo Smith, Consulting Engineer of the New York Board of Water Supply, to design both tunnel and shafts with a continuous steel interlining.

As the tunnel is to operate under an unbalanced head of 470 feet the lining provided required to be of unusually heavy design. The tops of both shafts are surmounted by cast-steel caps 2½-inches in thickness, each having four 48-inch flanged outlets for connection to the mains. The shaft caps are connected to the upper course of the 1 1/8-inch steel cylinder interlining, which is here decreased in diameter to 7' 4". The space between the line of excavation and the steel interlining is filled with concrete. The steel interlining diminishes in thickness to 1 1/16 inches as the load of about 760 tons due to the upward thrust on the shaft cap is transferred to the concrete surrounding the interlining and to the solid rock. Inside the steel cylinder is an inner lining of 4-inches of concrete which forms in these parts of the shafts the finished waterway 8 feet in diameter.

The remaining lengths of the shafts and the whole length of the tunnel are lined with partially pre-cast steel cylinder reinforced concrete pipes. Each section consists of a steel cylinder 14-feet long, 5/32 inch thick surrounded by two or three rows of spirally wound 5/8-inch diameter steel rods, the number of rows and the spacing depending on the rock condition at the particular place the pipe is to occupy. The tunnel is connected to the bottoms of the two shafts by heavy steel quarter-bends fabricated in two sections and welded in place in the work. These were lined with concrete by the use of specially moulded wooden forms to give smooth flow conditions.

CONSTRUCTION:

The contract for the construction of the work described was awarded in July, 1931, and active work started almost immediately. The South Shaft was completed by the end of November of the same year and tunnel driving started from it. The North Shaft involved much more difficult construction work, and it was not completed until May 10th, 1932, by which time the tunnel face was very close to this shaft. The tunnel was finally holed through on May 21st, 1932, having been driven almost entirely from the south end. By the end of December, 1932, all the reinforced concrete pipes in the shafts had been set in place and more than half the lining of the tunnel completed. The entire contract was finished within a few days of contract date for completion, viz., June 1st, 1933. The tunnel was placed in commission as a part of the supply system on June 30th. Certain surface work required to be carried out by the Water District is still in progress.

The South Shaft was excavated to a diameter of 20 feet and timbered through the 65 feet of hardpan until it reached the surface of the solid formation. For the remainder of the depth this shaft was lined with concrete instead of timber.

The 127 feet of boulders, sand, gravels and soft shales penetrated by the North Shaft between the surface and bedrock was composed by a concrete caisson with walls 5 feet thick and an interior diameter of 14 feet.

The sand and gravel at the shaft site were excavated to a depth of about 30 feet and replaced with pea gravel in order to reduce the skin friction on the caisson. Over and around this a mound of gravel about

8 feet in thickness was deposited, bringing the surface on which the caisson-shoe was built, to a plane above the reach of high tide. This mound was surrounded by a framework of timber piles and heavy timbers to form a working platform. The shoe was built of structural steel angles and plates rivetted together having a bell-shaped inner surface 7 feet in height. The cutting-edge was about 6-inches in width. The steel shoe was concreted and the caisson completed to a height of 30 feet before excavation began. Open dredging by a 1½ cubic yard clam-shell bucket and, later when more boulders were encountered, by an orange-peel bucket was used throughout. The steel forms allowed an 8-foot lift of concrete to be poured and carefully bonded to the preceding work.

Lying on bedrock to a depth of 10 feet or so was a considerable nest of boulders, some measuring as much as 5 cubic yards. Some of these were removed by slings placed by a diver but others were tightly wedged under the cutting-edge and blasting had to be resorted to. The surface of bedrock was disintegrated and soft requiring the caisson to be sunk to a total depth of 130 feet to a foundation in the harder sandstones. Some of this latter sinking was done by the use of water jets from a centrifugal pump under a pressure of 165# per square inch until the rock became too hard to yield to the impact of the jet. The cup-shaped basin in the bottom was cleaned up and concrete to a depth of 12 feet was placed to form a seal. When the concrete had set the caisson was pumped out and a shaft 6 feet in diameter, blasted with light charges, was sunk through the seal. The shaft was enlarged to 10 feet and the small quantity of water leaking through was grouted off. The remainder of the shaft was excavated in the ordinary way under open atmospheric conditions. Timbering was not used, a thin lining of concrete similar to that in the South Shaft poured in 8 or 16 foot lengths being substituted.

The infiltration of water into the shaft from the solid rock was small, the larger part of the inflow came through the rock below the caisson seal. The maximum quantity of water pumped from both shafts and tunnel was 60 gallons per minute and that only for a short period. Indeed the absence of water in any considerable quantity made the working conditions much more satisfactory than might otherwise have been the case and reduced the cost of construction to the Contractor.

No problems of magnitude were met in the actual driving of the tunnel. Sandstones of varying textures prevailed in the tunnel. These dipped to the south at an inclination of about 10 degrees and interbedded with them were sandy and pebbly to highly slickensided shales and one or two beds of conglomerates occupying altogether about one-third of the tunnel length. The sandstones in general furnished a small quantity of water and required no timbering, this being the case for 1200 feet from the South Shaft. Of the remainder of the tunnel only 876 feet were timbered, 600 feet of this being in the softer shales.

Upon completion of the excavation the floor of the tunnel, working from the South Shaft northward, was cleaned up, all loose or friable material removed and a concrete invert poured in which was embedded to careful line and grade the steel rails upon which the lining pipes were transported to position. When this was completed the placing of the concrete pipes beginning at a point a few feet from the South Shaft and working northward was proceeded with.

The reinforced steel and concrete pipes for the tunnel and shaft linings were fabricated by the Pressure Pipe Company of Canada Limited at a special plant in North Vancouver.

Here the steel sheets were formed into cylinders and welded. The reinforcing bars were welded into a continuous rod and wound under tension on the outside of the cylinder being spot welded to the longitudinal bars separating the "cages". The ends of cylinders were flanged or turned normal to the axis for one inch for welding to the adjacent cylinder in the tunnel. A welded mesh was inserted in the cylinder and a 2-inch lining of concrete (except for 2-inches on each end) with 1/4 inch coarse aggregate placed centrifugally. Short 2-inch diameter steel grout pipes were placed in each cylinder in such a position that in the finished tunnel they would be at 7-foot intervals. The cylinders were then water cured for 14 days and transported to the North Shaft through which all the tunnel lining was taken.

A station was cut at tunnel level extending the tunnel about 75 feet to the north in which a double track provided convenient storage for cars, pneumatic gun and other equipment. In this station a car specially constructed with a cantilever arm and appropriate counterweights received each length of pipe after it had been lowered end-on down the Shaft and turned by means of a small tugger hoist and suitable slings to a horizontal position. The pipe-carrying car pushed by a small storage battery locomotive, used for all the underground haulage, delivered the pipe to its final location in the tunnel. Easy and sensitive vertical and horizontal adjustment on the car allowed the pipe to be placed in position on concrete blocks set on the invert of the tunnel and brought to proper grade and alignment. The peripheral opening between the northerly end of the cylinder and the rock walls was then carefully fitted with a sandbag bulkhead. Through the bulkhead projected a pipe for the discharge of concrete from the pneumatic gun at a pressure of about 30# per square inch.

On removal of the sandbags the next cylinder was placed with the turned-over end of the steel interlining in contact with that of the preceding cylinder. Electric arc welding of the joints creating a continuous bead of metal on the adjacent edges of the turned-over ends of the interlining was proceeded with shortly after the pipe setting and, for the major part of the work, before the concrete backing was put in place and the water pressure built itself up in the rock formation. The cylinders were so placed that the grout pipes were in a vertical plane in the roof. Through these openings the whole tunnel was grouted under moderate pressures at first and finally, where required, up to about 180# per square inch.

Narrows bands of reinforcing mesh were placed in the joint spaces and they were carefully filled with cement grout, trowelled and finished off so as to give a smooth and continuous water surface. The lower parts of the shafts extending downward from the heavy steel lining already described were also lined with the semi-finished concrete pipe and were backed with concrete to the solid rock in the same way as in the tunnel and then grouted.

Four 48-inch pipes connect each shaft cap with a corresponding valve-chamber about 40 feet away where provision for an equal number of 48-inch gate valves will permit of additional future connections at both the supply and delivery ends of the tunnel.

On completion of the shafts and tunnel and the valve chambers and connecting pipes between the shaft caps and the valves, the tunnel was filled with water chlorinated and drained and on refilling was tested for 36 hours under a pressure of 210# per square inch. The leakage from the tunnel, shafts and connecting 48-inch pipes under this test proved to be less than 250 gallons in 24 hours.

The entire project is being carried out for the Greater Vancouver Water District under the supervision of Mr. E. A. Cleveland, M.E.I.C., Chief Commissioner. Mr. W. H. Powell, B. Sc., M.E.I.C., Engineer to the Water District, is in direct charge of the work and Mr. F. C. Stewart, B.A.Sc., is Resident Engineer.

The general contract for the work was held by the Northern Construction Company and J. W. Stewart, Ltd. of Vancouver - a widely known firm of Canadian contractors.