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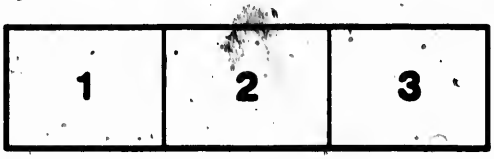

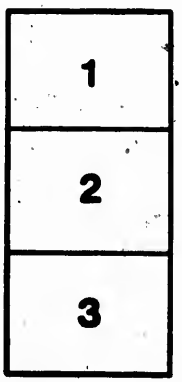

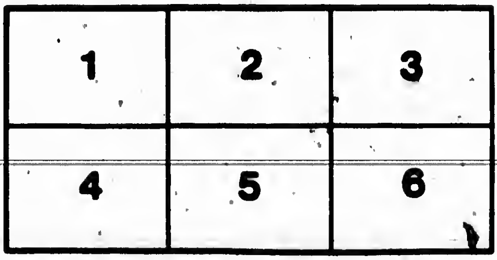

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Canadian Society of Civil Engineers.

INCORPORATED 1887.

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(*To be read on Thursday, December 5th 1889.*)

VANCOUVER WATERWORKS.

By Henry Badeley Smith, M.Can.Soc.C.E.,

ENGINEER IN CHARGE.

INTRODUCTORY REMARKS ON VANCOUVER AND VICINITY.

Previous to the year 1886, the City of Vancouver, British Columbia, had no existence. Where this city now stands, was then a dense tangled forest of huge fir, cedar, spruce and hemlock; the only evidence of the presence of man being a clearing a few acres in extent, on which low frame buildings, not more than a dozen in number, had been erected, and which was vaguely known to the outside world as Coal Harbour, Gas Town, and the Granville Town Plot.

At this date the Canadian Pacific Railway terminated at Port Moody, a small town at the extreme head of Burrard Inlet, 18 miles from the Gulf of Georgia. The Company, desiring a terminus nearer the open sea, negotiated with the legislature of British Columbia for a grant of land in the neighbourhood of the Granville Town Plot.

The Government, foreseeing that a large city would speedily be built up at the terminus of this great trans-continental railway, were it located on the best attainable site near the sea, voted the grant by a large majority, stipulating only that the extension from Port Moody westward to the lands granted should be constructed and in operation by a stated time. When it became known that the terminus of the railway would undoubtedly be at the Granville Town Plot, population began to pour in so rapidly that, on April 6th, 1886, the Legislature passed an act incorporating the locality as the city of Vancouver.

The population at that date did not exceed two thousand. So great, however, has been the influx of all classes, that at the time of writing, it is estimated on reliable data no less than ten thousand souls are contained within the limits of the city.

The City of Vancouver is situated on the south shore of Burrard Inlet, in Lat. 49°, 16′, 31″ N, Long. 123°, 05′, 52″ W, its western boundary being 3½ miles east of the Gulf of Georgia. It is distant from Liverpool on the east 6116 statute miles, and from Yokohama on the west 4991 statute miles. From [illegible] to Vancouver is 2905 miles, and from New York, via Canada, to the same point is 3162 miles.

Burrard Inlet is the first harbour of magnitude on the Pacific mainland north of the United States. It is easy of access to vessels of the deepest draught, and safe anchorage can be found in any part. English Bay, the entrance to the Inlet, is 4½ miles long and 4 miles wide. At its head it divides into two branches,—False Creek on the south, and the First Narrows on the north. False Creek is a narrow arm 4½ miles long, extending due east from English Bay, midway between the North Branch (Burrard Inlet proper) and the south boundary of the City of Vancouver. Being almost uncovered at low water, it is unsuitable for navigation.

The north branch, which leaves English Bay for the First Narrows, extends due east a distance of 14 miles. The width of the Narrows at extreme low water does not exceed 1086 feet, whereas a mile and a half inland it reaches 12,210 feet. Soundings of 120 feet can be obtained at the entrance, and 234 feet at the outlet opposite Vancouver.

The land between Burrard Inlet and False Creek, on which the present Vancouver is built, is for the most part flat, the highest elevation above sea level not exceeding 145 feet. South of False Creek, however, a rapid rise takes place, terminating in a table-land 200 feet above sea level. A few small streams run down from this table-land into False Creek; but these are insignificant, and cannot be utilized for manufacturing or other purposes. The nearest river on the same side of the Inlet on which Vancouver is built passes 15 miles to the westward.

ORIGIN OF THE CITY'S WATER SUPPLY.

The subject of a good and sufficient water supply for the City of Vancouver, or to write more accurately, for the place now known as the City of Vancouver, was first taken into earnest consideration by Mr. G. A. Keefer, Mem. Can. Soc. C.E., in June, 1885, nearly a year previous to the incorporation of the city. Mr. Keefer, foreseeing at that early date that the ultimate destiny of the Canadian Pacific Railway was to reach a point nearer the coast than Port Moody, and knowing that the Granville townsite possessed all the requisites for the foundation of a large city, interested himself in obtaining information as to the best source of a water supply for that locality, should the Railway Company decide upon it as the terminus of their system. He speedily ascertained that no supply could be advantageously and economically obtained on the south side of the Inlet, where the city must necessarily be located, no streams or lakes of any magnitude existing in the vicinity.

He therefore directed his attention to the north side of the Inlet, although confronted at the very outset by the fact that, never before in the history of hydraulic engineering had a system of water mains been laid across such a sheet of water as Burrard Inlet, and under such conditions as pertained thereto.

Acting under instructions from Mr. Keefer, the writer placed a fully equipped party in the field, in the winter of 1885-86, and thoroughly examined all the streams flowing into the Inlet immediately opposite the Granville townsite, from the lofty chain of mountains on the north side.

The results obtained from this survey showed that of all the streams available, the River Capilano, falling into the Inlet at the First Narrows nearly opposite the western boundary of the present City of Vancouver, was the most suitable, the discharge being much greater than that of any of the others, and the average fall of the river so great that an initial point for a gravity system of water supply could be obtained within a reasonable distance upstream.

Having decided on utilizing the waters of the Capilano for the supply of the future city, Mr. Keefer experienced no difficulty in obtaining the co-operation of several prominent and enterprising capitalists of Victoria, who were quite in accord with him in the belief that at a very early day a large population would be located at the Granville townsite, and that an immediate outlay for an efficient system of waterworks would be a remunerative investment.

Accordingly, the extension of the railway to the Granville townsite being an assured fact, and the future name of that locality being definitely decided on as the City of Vancouver, these gentlemen applied to the Provincial Legislature for an act of incorporation of a company, to be known as the Vancouver Waterworks Company, and proposing to construct a gravity system of waterworks, for the purpose of conveying water from a point on the River Capilano, on the north side of Burrard Inlet, to certain specified lots in the New Westminster district on the south side of Burrard Inlet. About the same time, application was made by the inhabitants of these lots for an act of incorporation under the name of the City of Vancouver. Both requests were granted by the legislature on the same day, the 6th of April, 1886.

During the summer of 1886, the writer, acting under instructions from Mr. Keefer, made detailed surveys, definitely locating the point of supply on the River Capilano, and the crossing of Burrard Inlet. In June, 1887, the whole system was finally staked out, and contracts entered into for clearing, close cutting and grubbing. In December, 1887, a permanent Board of Directors was formed, comprising the following gentlemen: President, Capt. John Irving; Directors, The Hon. (now Sir) Joseph W. Trutch, Messrs. R. P. Rithet, G. A. Keefer, Thomas Earle, and D. M. Eberts; Mr. J. W. McFarland was appointed Secretary; Mr. D. M. Eberts, solicitor; Mr. G. A. Keefer, M. Can. Soc. C.E., chief engineer; and the writer, Mr. H. B. Smith, M. Can. Soc. C.E., engineer in charge.

THE RIVER CAPILANO.

The River Capilano is a mountain stream of considerable magnitude. Prospectors who have penetrated its Cañons, and claim to have reached its source, estimate its length at no less than fifty miles. It rises in the snow-covered mountains of the Howe Sound district, and flows almost due south, emptying into Burrard Inlet at the First Narrows.

Although nothing definite is known as to its source, all accounts agree that its origin is not a mountain lake, but the accumulated waters derived from melted snow and ice falling from the mountain summits. For a distance of seven miles from its mouth, the river has been surveyed. Throughout this distance it flows at the average rate of five feet per second over a bed of granite, basalt, and conglomerate boulders. Sand and gravel can be found only in a few sheltered bays. It passes through several cañons of granite and whinstone rock, one of which is only 15 feet wide at its base, 94 feet wide at its top, 500 feet long, and 218 feet deep. Previous to the creation of this cañon, the whole valley to the north must have been one large lake. The wall of rock through which the stream penetrated ages ago, by some sudden effort of the earth's hidden forces, stands like a huge gate at the south end of the valley, the valley itself being but a strip of flat land from 1,000 to 1,500 feet wide, lying at the base of two parallel ranges of mountains, which tower upwards, to a height of 3,000 feet. The fall that took place when the river flowed over the summit of this rocky wall must have equalled the Niagara of to-day for depth, if not for volume. Should the City of Vancouver increase to the magnitude predicted, it may be that its people at some future day will cause a dam to be constructed across the narrow gorge, and once again convert this valley into a lake. Vancouver will then possess a reservoir from whence to draw its water supply, which will not be surpassed by any waterworks system on the continent. These cañons are isolated, standing about a mile apart. Between them the river flows through low lying flats, forming many islands. The immediate banks are but a few feet above the level of the river, and from 100 to 200 feet in width, the ground on each side rising in terraces until it is merged in the uniform slope of the mountains. Both sides of the river are heavily timbered with the huge trees peculiar to the British Columbia coast, Douglas fir, cedar, hemlock, spruce, balsam and white fir being in abundance. The Douglas fir and cedar grow to an enormous size. One cedar in particular was measured by the writer, and found to be 64 feet in circumference, 4 feet from the ground.

As a source of a city water supply, the River Capilano is an ideal one. No purer water can be obtained from any source than that from this mountain stream, flowing swiftly over a boulder bed, through deep rocky cañons, and along shores as yet uncontaminated by the impurities which follow in the wake of settlement. The supply afforded, being by gravitation, is superior to all other methods, whether by reservoir, direct pressure, or stand pipe, and its permanence is beyond question, careful gauging of the river at the initial point of the system having demonstrated the fact, that at the lowest stage of water the river discharges 440 millions of gallons in 24 hours.

CLEARING, CLOSE CUTTING AND GRUBBING.

The first contract entered into by the Company was for clearing, close cutting and grubbing. This work was done by a local firm at the following prices: clearing, $59.00 per acre; close cutting, $95.00 per acre; grubbing $200.00 per acre, under the conditions of the following specification:—

The pipe track is to be cleared a width of not less than 33 feet, and all timber and brush, not required for the purposes of the work, piled up and burned, as in clearing land for cultivation.

The dam site is to be cleared in the same manner, and to such limits as may be directed by the engineer.

Whenever embankments, occurring on the line of pipe track or tramway, are less than two feet in height, all the trees, stumps and brush immediately under the embankment are to be cut close to the ground, and whenever the embankments are from two to four feet high, they shall be cut within six inches of the ground; but when the embankments exceed four feet in height, chopping as for ordinary clearing will be allowed.

Grubbing shall be performed under the seats of the embankments occurring on the line of pipe track, or tramway, that do not exceed one foot six inches in height, and also all excavations for pipe track, tramway and dam embankment, less than three feet deep. The stumps and roots from the grubbing shall be removed to such places as directed.

No Chinese are to be employed, directly or indirectly, on the above works.

THE DAM.

The point on the river selected as the source of supply is at a distance of 6½ miles upstream from its mouth, where the river is confined to one channel, and the banks on either side are sufficiently high to admit of the construction of a dam.

The locality selected is the only point from the river's mouth upwards where a dam could be safely and economically constructed, and give at the same time a sufficient head to overcome the elevation of the high flats 3½ miles below it.

By reference to Plate........., which shows the dam site and its vicinity, it will be seen that immediately south of the site the river is divided into two wide channels.

Still further south, all the way to the cañon below, it is divided into three and even four channels. Similarly, north of the dam site, the river has two branches separated by a large, low, flat island. This island is completely covered at high water, making the river at that stage no less than 830 feet wide.

The cross section of the river at the dam site at low water gave a current of 4½ feet per second, a width of 100 feet, and an extreme depth of 3 feet, the difference of level between low and high water being 6 feet. It has been subsequently ascertained, however, that during occasional floods the water rose much higher, and covered the level flat on the north side to a depth of 2 feet. This flat stands at an average level of 12 feet above low water. The bed of the stream consisted of large granite boulders, closely packed together, small stones and coarse gravel filling up the interstices. The channel of the river in ordinary floods was 210 feet wide.

On the north shore the immediate bank is 12 feet high, and extends at the same level a distance of 140 feet inland. A sudden rise then takes place, terminating in another flat 40 feet above low water, and which stretches to the base of the mountains.

On the south shore, the bank rises abruptly to a height of 22 feet above low water, and continues at that elevation for 200 feet. It then rises rapidly in terraces till it reaches the mountain side hill. The high land on the north shore trends to the northward immediately west of the dam, and that on the south to the southward, immediately east of the dam.

The dam site lies directly between these two high points. The contract for the construction of a stone-filled timber dam at the point selected was let on the 24th of January, 1888, to Messrs. H. F. Keefer and D. McGillivray of Vancouver, and was most satisfactorily completed by them on the 18th of April following. The difficulties encountered by the contractors in carrying out this work were of no ordinary character. Inasmuch as it was the initial work of the system and located in a wilderness in which no roads existed, all supplies, tools and machinery were of necessity packed to the works on the backs of mules. The season was mid-winter, and unusually inclement. Chinook winds and heavy rain storms, melting the snow on the mountain summits, caused frequent freshets, in which the river would rise from 6 to 10 feet in a few hours time.

The formation of the banks in the vicinity did not admit of the river being temporarily diverted, except at enormous cost. The foundations of the structure had therefore to be excavated, and the first courses laid in from 3 to 4 feet of swift running ice cold water.

Plate........ is a reduced copy of the working plan of the dam. It will be seen that the structure is of continuous cribbing, stone filled, planked and sheet piled. It consists of three principal parts, viz., the north abutment, the Tumbling Way, and the south abutment.

The north abutment is located well inland, owing to the tendency of the river in high floods to over-run its channel, and spread over the low lying land in the vicinity. For the purpose of description it may be subdivided into the following heads: The abutment proper, the well chambers, the settling pond, the pipe outlet, and the north wing.

The abutment proper is a right rectangular prism 41', 2" × 20' × 18', 9", constructed of round timbers, laid in alternate courses of cross ties and longitudinals, dove-tailed at the angles, and forming 28 cribs, which are filled up with heavy stone filling and coarse gravel, the latter being rammed into all interstices between the stones and under the timbers. A space equivalent to 4 cribs in the exact centre of the abutment is floored and walled, from the foundation upwards, with double 2" planking over-lapping. A perfectly watertight chamber 10', 6" × 7', 10" is formed. This chamber is subdivided into two smaller and equal ones by parallel walls, 4" apart, of double 2" planking overlapping, and placed at right angles to the length of the main chamber. These constitute the well chambers, by means of which the water from the reservoir formed by the dam is conveyed into the mains. An influent conduit of double 2" planking overlapping 15", 5½' long, and of area sufficient to admit a larger volume of water than can be discharged by the mains, connects the first of these chambers with the settling pond, and consequently with the reservoir in front of the dam. In the 4" space between the double central walls, close to the floor of the chambers, are placed double fish screens of the same area as the influent conduit, and so arranged that they can be easily removed, one at a time, for the purpose of cleaning. The first or outer screen is coarse, being of No. 12 copper wire, woven into meshes 1 inch square. The second or inner screen is finer, being of No. 15 copper wire, 6 meshes to the inch. The rear of the second chamber is pierced exactly opposite the fish screens to admit two bevelled 22 inch rivetted steel pipes, the mouths of which are opened or closed at will by means of timber gates sliding in vertical uprights attached to the walls of the chamber.

Two trap doors cover the top of the chambers, and over all, resting on the top courses of the abutment, is built a compact water-proof shed 12, × 13' × 13'. This shed serves for a tool house, as well as effectually preventing the access of strangers to the gates which control the mains.

In front of the influent conduit is a triangular shaped settling pond, measuring 15½ feet at the base, 16 feet from base to apex, and 14', 2" deep. It is constructed of longitudinal timbers and cross ties, laid one above the other, the whole being firmly bolted to the face of the abutment. At the apex the ends of the longitudinals are dressed, so as to fit closely, and bolted together. The triangular space between the apex and the apex cross ties is filled with large boulders, for the purpose of giving weight to the structure, and retaining it in position.

At the base of the pond, the entrance of water into the influent conduit is controlled by means of a timber gate, sliding in vertical runners bolted to the sheet piling on the face of the abutment. Immediately behind this gate covering the mouth of the conduit is placed a cast iron grating with 4 inch openings. The water from the river has free access to the settling pond through the spaces between the longitudinal timbers of the walls. The main object of its construction is to prevent logs and floating debris from accumulating in front of the influent conduit. It will thus be seen, that, in order to reach the mains, the water must first enter the settling pond, then pass through the iron grating at the mouth of the influent conduit, then, by means of that conduit, enter the first well chamber, then through the double fish screens in the central walls into the second chamber, and finally into the mains in the pipe outlet.

The pipe outlet at the rear of the north abutment is a crib continuation of that abutment, serving as a protection for the mains against the action of the water flowing over the tumbling way, until a safe point is reached on the flat below. It is 138 feet long, 15 feet 3 inches wide, 10 feet high on the side facing the river, and 6 feet on the land side. It has three parallel rows of longitudinals supported on cross ties, the two outside rows, or the rows nearest the river forming cribs 4', 9" × 3', 5" × 10', which are heavily loaded with boulders. Between the cribs and the third row of longitudinals on the land side, is a space 8 feet wide, in which the mains leading from the well chambers are laid.

Provision is made for two mains, but only one is in use at present, the other being capped at its lower end, and closed at its mouth by means of its gate in the second well chamber. The space containing the two mains is filled with coarse gravel, well packed. Above the filling is a covering of 15 inch logs close laid.

In the immediate rear of the abutment the timbers of the pipe outlet are continued upwards in steps to the top of the abutment, forming a "lean to," which prevents the water flowing over the tumbling way from flooding the top of the pipe outlet. The "lean to," as well as the entire face of the pipe outlet, is planked with 3 inch planking, sunk 3 feet below foundation level.

The low lying porous nature of the ground on the north side of the river rendered necessary the construction of an extensive land wing, with deep foundations. This wing is 155 feet long, and 10 feet wide. The first 20 feet out from the abutment is 16 feet 11 inches high, and is in reality part of the abutment proper, its longitudinals being a continuation of the longitudinals of that structure. The remaining 135 feet, being built on higher ground, has a uniform height of 7' 9". Both portions are built in rows of parallel longitudinals, 3 in number, and in lengths of 31 feet, supported on cross ties 10 feet long, and 5 feet apart. These form 62 cribs, which are filled with stone and gravel as previously described.

The connection between the wing and the high land at its extremity is protected by a gravel embankment, extending 57 feet along the face of the wing. This embankment is made of picked material, and effectually prevents all seepage round the end of the wing. The face of both abutment and wing is protected from leakage by a double row of sheet piling, the lower ends of which are embedded in a concrete trench sunk 3 feet below foundation level. The inner sheet piling is 2 inches thick, while the outer and overlapping piling is 1 inch.

The main body of the dam, technically named the Tumbling Way, is 165 feet in clear length, 41' 2" broad, and 13' 9" high in the deepest part of the original channel of the river. Great difficulty was experienced in excavating foundations for this portion of the dam. At first an effort was made to partially divert the river by excavating a new channel, between high and low water mark on the south shore, the intention being, if this succeeded, to excavate the foundations and build the sub-structure up to the toe of the front slope: then to return the river back to its original channel, allowing it to flow through the row of horizontal openings provided in the design of the structure for that purpose. It was found however that the bed of the proposed diversion, being entirely composed of loose boulders, was too porous to admit of the water being confined within the excavation; and as, at that time, no clay fit for puddling was known to exist in the near neighborhood, this project had to be abandoned. The method then adopted and which proved successful, though carried out under great difficulties, was as follows:—

Both abutments having been partially constructed, the foundations for the end divisions of the tumbling way were excavated as far as possible from the abutments towards mid-channel. As much of the structure as the excavations could contain was rapidly built up, and loaded with stone filling. An embankment of gravel and sand was then run out from each extremity, meeting about 20 feet up stream and forming a V, the apex of which divided the current of the river, and forced it through the horizontal openings in the sections already built. This had the effect of leaving still water 3 feet deep behind the embankment, and as this could not be removed, nor lessened in depth, the foundations were excavated and the middle section built under these exceptionally difficult circumstances.

The sills of the north and south sections are on the same level, while those of the middle section in the deepest part of the river bed are 2' 2" lower. The cross sections of the three portions are similar. Plate......... shows that of the middle section.

The ground sills, 10 in number, in lengths of 32 feet, are placed at right angles to the stream, at distances varying from 5' 5" to 6' apart, the distances varying in order to secure a row of longitudinals under each vertical angle of the surface of the tumbling way. Above the sills and at right angles to them are placed a row of cross ties parallel with the stream, each 53 feet long, and from 5' 8" to 6' apart. These project 11' 10" to the rear of the main body of the dam, resting on two of the sills of the ground course. The spaces between these projections are filled in with round timbers laid close. A solid close laid platform to the rear of the main body of the tumbling way is thus formed, which serves to dissipate the force of the water flowing over the tumbling way before it reaches the bed of the river. The next or third course consists of 8 longitudinals, above which on the fourth course are the horizontal openings previously mentioned. These are 28 in number, 5 feet wide, 12" deep, and extend entirely through the structure from its upstream face to the open river in the rear.

They are formed by flooring the spaces between the cross ties of the 4th course with double 1 inch planking, and close laying the longitudinals of the 5th course to serve as a covering. Above the 5th course the longitudinals and cross ties are so arranged that the front face slopes upwards to the ridge at the rate of 2' 3½" to 1'. The longitudinal which constitutes the ridge is placed at a horizontal distance of 17' 2½" from the front face, and is at an elevation of 415 feet (surface planking not included) above high water mark of Burrard Inlet. The rear slope extends downwards from the ridge at the same rate as the front slope, and terminates in a level bench 12 feet wide.

In the tumbling way there are 196 cribs, formed by the intersections of cross ties and longitudinals. Especial care was exercised in filling these cribs. As each course was completed, the largest boulders attainable were placed in the cribs by hoists. The spaces between were filled up with smaller stones and coarse gravel, the latter being rammed into every crevice. In excavating the foundations, certain huge boulders, which were found to be firmly anchored in the river bed, were blasted into a columnar shape, so that the bed sills and cross ties when laid would enclose them. These not only served as stone filling, but also securely locked the whole structure to the bed of the river in a much more substantial manner than any artificial means.

The whole surface of the tumbling way is covered with 3 inch planking, jointed and laid close. The upper half of the front slope, being exposed to floating logs, is laid double. The vertical part of the front face is protected by 1" and 2" sheet piling, embedded in a concrete trench 3 feet deep, and extending over the whole length of the structure.

Inasmuch as it was necessary to keep the horizontal openings open until the whole dam was completed, the placing of this sheet piling was done in two operations.

The lower portion of the piling below the level of the floor of the openings was placed in position in the usual manner, the tops being dressed to a uniform level. A longitudinal 12" by 3" plank, extending over the whole length of the tumbling way, was spiked to the tops of this sheet piling, projecting 1 inch above, and forming a groove into which the upper sheet piling would fit when placed in position. When the proper time arrived to close the openings, a sufficient number of men were ranged along the toe of the front slope, provided with the proper lengths of sheet piling, spikes and hammers. On a given signal each plank was pushed home into the groove below the openings, and the necessary spikes driven into the top ends. It required only five minutes to complete the whole operation, and by that time, the water in front had not risen above the toe of the front slope.

Immediately in front of the tumbling way is an apron of brush, gravel and boulders. This apron extends from the settling pond in front of the north abutment clear across the face of the tumbling way to the gate of the sluiceway. In cross section, it begins at a point halfway up the front slope, and extends horizontally a distance of 9 feet. It then slopes down to the bed of the river at the rate of 3 to 1.

The south abutment, being partially let into the high land, required no wing extension. Properly speaking, it consists of three distinct parts, viz., the abutment proper, connecting with the tumbling way; the land abutment, connecting with the shore; and the sluiceway, which lies immediately between the two. The foundations of all three are on the same level as those of the north abutment, and being above low water mark were excavated without trouble.

The abutment proper is a rectangular prism 41′ 2″ × 15′ × 18′ 9″ constructed of longitudinals and cross ties in alternate tiers, bolted together and dove-tailed at all four corners. As in the north abutment, the longitudinals of the tumbling way at regular intervals project into the abutment, and are securely bolted to it, thus forming an absolute and immovable connection between the three structures. In this abutment, there are in all 21 cribs, 5′ 8″ × 4′ 7″ – 18′ 9″ each, filled and rammed as previously described. In the rear of the abutment is a "lean to," 31 feet long, and tapering from 15 feet at the abutment to 11′ 7″ at its extremity. This also is a stone filled crib structure, the object of which is to prevent any scouring that might take place, by guiding the water flowing over the tumbling way beyond the rear of the abutment, and into the original channel of the river. It may be here mentioned that one year after the completion of the dam, a large scour did take place in the angle formed by the foundation courses of the "lean to," and the rear platform. During a sudden freshet the bed of the river at this point scoured out to a depth of 4 feet below foundation level. The end cribs of the "lean to" were completely undermined, the stone-filling carried away, and the timbers left unsupported. A somewhat similar occurrence had taken place a few months previously at the angle formed between the rear platform and the pipe outlet on the north side. The latter was readily repaired by filling in and constructing a triangular extension of the rear platform as shown in drawing. In this case the extension could be easily bolted to the existing platform and the pipe outlet. But in the case of the first mentioned scour it was quite different. The "lean to" being an addition to the rear of the abutment and not a part of it, timbers extending from its extreme end to the rear platform, so as to cover the large scour made, and prevent further injury, would have been insecure.

Instead, therefore, the damage done was repaired by refilling the scour with a mixture of large boulders and concrete, the latter being in the proportion of 1 part of pure cement to 7 of coarse gravel and sand. Over this filling, and extending 3 feet beyond the rear of the "lean to," was placed a covering of almost pure cement, 1 foot thick. Twenty-one barrels of Portland cement, each weighing 400 lbs., were used in making these repairs. The total length of the abutment and "lean to" combined is 71′ 11″. It therefore projects beyond the rear of the tumbling way a distance of 31 feet. Both sides and rear, as well as the top of the "lean to," are planked with 3″ planking laid close.

The sluiceway is 73 feet long and 14 feet in clear width. From wall to wall it is 15 feet wide, and at the upstream end is the full height of the abutments. Both walls and face are planked with 3″ planking, laid close. It is opened and shut by means of a stop log gate, consisting of 17 stop logs 17′ 4″ × 12″ × 12″, placed horizontally one above the other, each capable of being moved vertically in a groove formed by vertical 12″ × 12″ uprights, let into the walls of the abutments on each side. On the upstream face the uprights are single, connected at the base by a 12″ × 12″ sill. Behind the stop logs the uprights are double, while midway between is a triangular truss of framed 12″ × 12″ timbers, planked with 3″ planks, the sill of which extends back from the rear of the stop logs a distance of 17½ feet, and is securely bolted to the ground flooring. The floor sills beneath the truss are close laid on a concrete bed, forming a solid apron, on which the force of the water falling over the gate when partially open is spent previous to discharge into the channel of the river. From the end of the truss to the outlet of the sluiceway, sills are laid 4 feet apart, extending underneath and bolted to the sills of the walls, or in other words to the sills of the abutments on each side. The two sills immediately behind the rear uprights of the gates, and the three sills at the end of the close laid flooring are squared 12″ × 12″ timbers, 43½ feet long, and pass under the whole width of both abutments. Similarly two caps 43½ feet long are laid across the top of the sluiceway, behind the rear uprights of the gate. These sills and caps are securely bolted to every intersecting timber of the abutments on each side of the sluiceway, thus making a solid union between the three parts.

Above the stop logs is a powerful windlass, with supports on each abutment, the roller being directly above the stop logs. The upper surface of each stop log is provided with a wrought iron ring at each end, the stop log immediately above it being grooved on its under face, so as to admit the rings, when the stop logs are in position, and the gate is closed. The extremities of the chains connected with the windlass are provided with clutches which can be readily guided so as to hook on to the rings, when it is required to open or close the gate.

The sluiceway abutment, or that portion of the south abutment which connects directly with the land, having to withstand much less pressure than other portions of the dam, is not of uniform height, but is built in steps. At the upstream end it is of equal height, 18′ 9″ with the main portion of the abutment on the other side of the sluiceway, and 13 feet wide, while at the extreme rear, the height is only 5 feet, and the width 8 feet. It consists of 16 separate cribs, loaded with stone and gravel, as previously described.

The whole abutment, including the sluiceway, is protected in front by 1″ × 2″ sheet piling overlapping and imbedded in concrete, as in the case of the tumbling way and north abutment. This concrete is in the proportion of 1 part of cement to 5 of gravel and sand. The manner of its preparation was as follows: moist gravel of suitable nature obtained from the river bank was deposited on a plank platform 10 feet square. This was thoroughly worked with shovels, and all stones larger than 1½ inch diameter eliminated, leaving the mass spread over the platform about 9 inches deep. The proper proportion of cement was then spread over the gravel, in a dry state. Very little water was used, the moisture in the gravel being sufficient for the purpose. Six men with shovels then energetically worked the whole mass, shovelling from the outside edges towards the centre. When evident that the mass had been completely turned over once, it was flattened out on the platform, and again turned over in the same manner. This operation was repeated three times, the mixture being then considered fit for use.

The concrete trench mentioned above extends along the whole face of the dam below the level of the sills, forming a perfectly watertight connection between the foundations and the bed of the river, through which no seepage can take place. Seepage round the extremities of the abutments, where they penetrate the banks, is prevented on the north side, as previously stated, by a gravel embankment. On the south side the same purpose is served by a hand-laid stone wall, built in the angle formed by the extremity of the abutment and the natural bank of the river, fine gravel and earth being filled in behind and well rammed.

The reservoir created by this dam is, in the high water season, 380 feet wide by 700 feet long, and contains approximately 14 millions of gallons.

At low water the elevation of the water flowing over the crest of the tumbling way is 483 feet above the lowest depression in the pipe line, 417 feet above the lowest level in Vancouver, 317 feet above the average, and 201 feet above the highest. These elevations correspond to a maximum pressure of 210 lbs., an average pressure of 138 lbs., and a minimum pressure of 87 lbs. per square inch.

The wrought iron drift bolts used were of ⅞″ and ¾″ round iron, and of lengths varying from 12″ to 32½″. Spikes for 3″ planking were 6″ long, weighing 11 per pound, and nails for 1″ planking are 4½″ long, weighing 19 per pound.

From the above description it will be seen that the extreme length of the dam from land connection to land connection is 384 feet, the clear tumbling way 165 feet, supplemented by an additional 14 feet of sluiceway, when required, and the breadth of base, not including rear platform 41′, 2″.

The total cost amounted to $15,039.26.

The country traversed by the mains from the dam to the central point of the city was, from a hydraulic point of view, of a very rough nature, and presented many engineering difficulties.

From the dam for a distance of 12,716 feet in a downstream direction, the ground passed over is a gradually descending flat, the total fall in this distance being 164 feet. The flat is a narrow strip of land, composed of hardpan and granite boulders, lying between the base of the mountains on the one side and the river on the other. At two points the river in former heavy floods has invaded the flat and the adjoining side hill, scouring off portions 500 feet in length, and leaving a bare boulder bottom only a few feet above the low water level of the river. Several streams running down from the adjoining mountains intersect the flat at right angles. Two of these are of considerable size, one being 47 feet, and the other 212 feet from bank to bank. Both flow over rough boulder bottoms.

At the termination of the flat is the rock wall through which the river has cut the deep cañon previously described. Owing to the rugged nature of the walls of the cañon, it was not deemed advisable to carry the mains along its face, and its great height prevented their being laid over the summit. A tunnel therefore was rendered necessary. This tunnel is 280 feet long, 4 feet wide, and 6 feet from floor to centre of roof. In cross section, the walls rise vertically 4 feet from the floor, and are surmounted by a semicircular roof of 2 feet radius. The floor elevation is 27½ feet below the crest of the dam.

Inasmuch as the hydraulic grade line of the whole system passes considerably below the floor of the tunnel, it was necessary that the main from the dam to the tunnel should be of larger diameter than that from the tunnel to the city. It having been decided that the discharge of a 16 inch main was necessary for the city's supply, a 22 inch main is laid between the dam and tunnel, connecting in the centre of the tunnel with the 16 inch main. The total length of the 22 inch main is 13,530 feet, the total available head 29 feet, and the discharge at the tunnel 5,853,600 U. S. gallons in 24 hours.

The 16 inch main, connecting with the 22" main at the centre of the tunnel, for the first 8000 feet of its length, passes over rough, irregular side hill, composed of earth, gravel and boulders. The sinuosities of the side hill are closely followed, all great vertical depressions or elevations being avoided. In one instance, 1400 feet below the rock tunnel, where the side hill juts out in the form of a steep "Hog's back," it was found expedient to pierce it with a timber lined tunnel, 108 feet long, 4 feet wide, and 6 feet high.

At the termination of the side hill, a series of flats, composed of hardpan, gravel and boulders, descending in broad terraces is reached. These are followed by the 16 inch main to ordinary high water mark of Burrard Inlet, the total distance from the centre of the tunnel being 19,320 feet, and the total fall from the floor of the tunnel 388 feet.

At Burrard Inlet the 16 inch main is divided by a cast iron Y breech into two branches of 12" diameter. One 12 inch branch has already been laid across the Inlet, and preparations are in progress for the laying of the second, which will take place at an early date. Plates .... show plan and profile of the First Narrows of Burrard Inlet, at the point selected for crossing. It will be seen that this is at the narrowest part of the Inlet, where the tidal current runs with the greatest velocity. It would naturally be supposed that the greatest depth of water would be obtained here, but this is not the case. The bed of the Inlet at this point being soft sandstone rock, partially covered with mud, gravel and cobblestones, forms a broad flat ridge, extending from shore to shore. The greatest depth of water on the summit of this ridge at extreme low tide is 56 feet, gradually increasing on each side till soundings of 120 feet and over can be obtained.

In extreme low tides the width of the crossing is 1086 feet. These tides, however, are very rare, occurring in May and June. In ordinary tides the width at low water is 1237 feet, and at high water 2140 feet. At extreme high water, which occurs in December and January, the width is 2680 feet.

The north shore is extremely low and flat. From low water mark for a distance of 6750 feet inland, the total rise does not exceed 63 feet. Between high and low water mark, the surface covering consists of cobblestones, small boulders, and coarse gravel, underneath which is a stratum of hard pan overlying sandstone rock. The south shore rises abruptly at high water mark to a height of 12 feet. terminating in a level flat, which extends some distance inland. Immediately west of the crossing on this side of the Inlet, is a steep rocky headland, which rises to an elevation of 216 feet above sea level.

This is the highest elevation within the limits of the city of Vancouver, and may at some future day be utilized as the site of a level reservoir, of sufficient capacity to supply the city for 20 or 30 days. Between high and low water marks on the south shore, and for nearly three-quarters of the distance across the Inlet, the surface formation is soft yellow sandstone rock, which, when blasted and exposed to the air, rapidly disintegrates. The contour of the bottom is an almost perfect curve, the value of which railway engineers would express as 2½ degrees.

Skilled divers made three different examinations of the bottom, and reported fully thereon, agreeing with each other in every particular. The substance of their reports was to the effect that no crevices existed in the rock ledge on the pipe line, or in its neighborhood, and that the bottom from shore to shore was perfectly smooth and free from boulders of any magnitude.

These reports were verified to a certain extent by soundings taken by the writer, at intervals of five feet apart, the lead, which weighed 15 lbs., never being allowed to leave the bottom all the way across.

The greatest depth recorded is, as before stated, 56 feet at low water, increasing to 70½ feet at high water. The "Bore" or tidal current varies from 4½ to 9 miles per hour, the greatest velocity occurring in the out-going tide, 2½ hours after low water. In a volume of water like that flowing from the broad basin of Burrard Inlet through the restricted channel of the First Narrows into English Bay, this velocity of 9 miles per hour is terrific in its effects on any body opposing it. Some idea may be gathered from the fact that a new 9 inch manilla hawser of 20 tons ultimate tensile strain, which, in the preliminary operations of laying the submerged mains, was stretched across the inlet, was snapped like pack thread by being suddenly lifted to the surface, and allowed to float on it.

South of Burrard Inlet, at high water mark, the single 12 inch main connects with a Y breech similar to that on the north side. A 16″ main leads out from this breech, passing over a uniform boulder and gravel flat, known as Stanley Park, the greatest elevation of which above sea level is 73 feet. South of Stanley Park at a distance of 5041 feet from Burrard Inlet, is a long, narrow, shallow bay of Burrard Inlet, known as Coal Harbour. This bay lies directly south of, and parallel to, the First Narrows. The extreme length from east to west is 6720 feet. The entrance to the bay is 3,730 feet wide. This width gradually decreases till the head is reached at a distance of only 1,500 feet from English Bay, and separated from it by a low lying strip of land, the highest elevation of which above sea level is not more than 17 feet. The bottom is of soft mud, thickly studded with boulders. Half a mile from the head of the bay, the shore on each side juts out in long narrow promontories, leaving a waterway 870 feet wide at high water, and 250 feet at extreme low water. This is the point selected for the crossing of the 16 inch main. The bottom is of uniform contour, and consists of tenacious mud and small boulders. The greatest depth at low water which occurs in mid channel is 5 feet.

Immediately south of Coal Harbour the City of Vancouver is reached. The 16 inch main is continued along the graded streets to the centre of the City, a distance of 39,211 feet from the centre of the tunnel, or almost exactly 10 miles from the well chambers of the dam.

The total fall from the level of water in the reservoir at the dam to the termination of the 16 inch main is 384 feet, and from the floor of the tunnel to the same point 355 feet. The total available discharge is 5,103,000 U. S. gals. in 24 hours.

South of Burrard Inlet, all works of excavation, refilling, culvert building, etc., were done by the company by day labor. North of Burrard Inlet, between the First Narrows and the dam, such works were done by Messrs. H. F. Keefer and D. McGillivray, of Vancouver under a lump sum contract, based on a table of quantities furnished by the Company. The trenches were excavated to regular grades, the average depth for 12″ pipes being 3′, 6″, for 16″ pipes, 3′, 10″, and for 22″ pipes 4′, 4″, this gave a covering over all pipes of not less than 2′ 6″, an amply sufficient depth in the climate of Vancouver, frost never being known to penetrate the soil deeper than 14 inches. When the nature of the ground was uneven, and the grade line laid down gave excavations less in places than these depths, the difference was made up by embankments, 3 feet wide on top, with slopes of 1½ to 1. In certain small gullies, embankments 6 feet wide on top were built under the mains, instead of timber trestling, there being danger of bush fires during the summer months. The mains on top of these embankments, and also under all streams, are protected from injury by being enclosed in timber culverts.

ADVANTAGES OF STEEL OVER WROUGHT AND CAST IRON MAINS.

Previous to describing the rivetted mild steel mains used by the Vancouver Waterworks Co.: it may be of interest to trace the origin of steel pipes, and exemplify the many advantages possessed by them over cast iron pipes.

Up to the year 1845, cast iron was in universal use for the manufacture of water pipes; but in that year, Mr. Jonathan Ball invented and laid in Saratoga, N. Y., a wrought iron pipe, coated inside and out with hydraulic cement. This is the first instance on record in which wrought iron water pipes were laid on this continent. Owing to the great saving effected by this invention, it rapidly rose in favor, and was adopted by many cities in the union. It was soon, however, discovered that these pipes required to be laid on a perfectly solid and unyielding foundation. If laid on made ground the slightest settlement caused the cement linings to crack and leakage took place. The method of lining and laying in the trench was cumbersome, and could only be employed to advantage near the centres of civilization where transport was cheap and labor abundant. When it was required to carry long lines of water pipes over mountainous country in wildernesses entirely unsettled, and without roads or means of conveyance, engineers were confronted with the task of devising another and still more economical pipe. In California and the Pacific States of the Union, this problem was successfully solved by the invention of asphaltum coated rivetted wrought iron pipes. The cheapness of construction of these pipes, and the facility with which they could be handled and more especially in the mining districts, brought them at once into general use. In design and construction they are exactly similar to the rivetted mild steel mains described farther on in this paper. Between 1870 and 1885, the Risdon Iron Works Company, of San Franciso, furnished various water and mining companies with over 150 miles of these pipes varying in diameter from 12 to 52 inches. Among the more notable examples may be mentioned the following:

Spring Valley Waterworks Co.—36 miles of pipe from 18 to 52 inches diameter, and from $\frac{3}{16}$ to ⅜ inches thick.

The Virginia and Gold Hill Waterworks Co.—3 miles of pipe 11½ inches diameter, and from ¼ to ⅜ inches thick. This main crosses a deep valley lying between its point of supply at Lake Marlette and Virginia city. The bottom of the valley is 1750 feet below the level of the lake. Therefore this main is subject to a constant static pressure of 750 lbs. per square inch at its lowest point.

The White Pine Waterworks Co.—2 miles of pipe, 12 inches diameter, $\frac{1}{16}$ to $\frac{5}{16}$ inches thick.

The Portland Waterworks Co.—4½ miles of pipe, 30½ inches diameter, and $\frac{17}{100}$ inches thick.

The Cherokee Flat Mining Co.—3 miles of pipe, 30 inches diameter, and from $\frac{3}{16}$ to ⅜ inches thick.

The great success of asphaltum-coated rivetted wrought iron pipes led to still further researches. Manufacturers of water pipes directed their attention to the adaptability of mild steel for hydraulic purposes, and arrived at most gratifying results.

The writer, in seeking information on this subject, received from Messrs. Duncan Bros., of London, England, a pamphlet on mild steel mains, of which only a few copies were published by that firm for private circulation. The following extracts, giving a comparison between mild steel, wrought iron, and cast iron for water mains, may be of interest:

"Scientific investigation proved that in addition to being more ductile, it (wrought iron) had greater tensile strength than cast iron, the relative tensile strengths of cast iron and wrought iron being approximately 1 and 2.7. Mild steel is refined wrought iron, being nearly pure metallic iron, and when rolled into plates its strength compared to cast iron is as 4 to 1. In consequence of its strength and ductility, it is eminently adapted for all purposes to which cast iron has been formerly applied."

With regard to strength the ultimate tensile strength usually mentioned in specifications for cast iron pipes is 18,000 lbs. per square inch mild steel, however, is now made with an ultimate tensile strength of 72,000 lbs. per square inch. It follows, therefore, that if pipes are made of steel plates of the same thickness as would be employed in cast iron, they are approximately four times as strong. The actual strength is not exactly four times, because it is not customary to calculate resistance to internal pressures with the same co-efficient or factor of safety for both materials.

The factor of safety usually employed for cast iron is 10, that is to say, the working strength of the material is taken as only one-tenth of the actual strength, which, in the case of pipes, means that if the internal working pressure is to be 100 lbs. per square inch, the strength of the pipes is calculated to resist 1000 lbs. per square inch. For wrought iron, the factor is 6, and for mild steel 5. The reason for the differences in the factor of safety is because iron and mild steel are more homogeneous, and thus more reliable than cast iron.

The impurities which are present in cast iron are of less specific gravity than metallic iron, and consequently the specific gravity of the mixture called cast iron is less than that of pure metallic iron. Mild steel is the nearest approach to pure metallic iron, which commerce and science combined have yet produced on an extensive working scale. The average weights of the metals are:

Cast iron.	*Wrought iron.*	*Mild steel.*
450	480	489.6

lbs. per cubic foot; the average weight of water is 62½ lbs. per cubic foot; therefore the specific gravities average

Water.	*Cast iron.*	*Wrought iron.*	*Mild Steel.*
1	7.20	7.68	7.83

TABLE OF RELATIVE THICKNESS FOR EQUAL STRENGTH.

	Cast iron.	*Wrought iron.*	*Mild steel*
Weight of plate in lbs., per sq. ft. 1 inch thick	37.5	40	40.8
Tenacity per square inch	18,000	48,600	72,000
Relative strength for equal thickness	1	2.7	4
Factor of safety	10	6	5
Relative of strength due to factor of safety	1	4.5	8
Reduction in strength due to rivetted joints	—	30 p.c.	30 p.c.
Relative strength after reduction for rivetted joints	1	3.15	5.6
Relative thickness for plates of equal strength	1	0.3174	0.1786

TABLE OF RELATIVE WEIGHT FOR EQUAL STRENGTH.

	Cast iron.	*Wrought iron.*	*Mild steel.*
Thickness of plate in inches, 40lbs. weight per sq. ft.	1.066	1.00	0.9804
Relative strength for equal weight	1	2.533	3.678
" " due to factor of safety	1	4.22	7.356
Relative strength after reduction for rivetted joints	1	2.955	5.149

	Cast iron.	*Wrought iron.*	*Mild steel.*
Weight of plain cylinders of equal strength	1	0.3384	0.1942
Increase in weight of pipes due to joints................................	5.8 p.c.	15 p.c.	15 p.c.
Relative weight of pipes of equal strength..............................	1	0.3678	0.2111

The relative thickness for plates of equal strength for materials of the ultimate tenacity under consideration are given on the last line of the first table. In the next table, the results obtained show the relative weights of pipes of equal strength, having socket and spigot joints made from materials of the ultimate tensile strength specified.

Applying these results to an ideal case, we find that if it is specified that cast iron pipes, to stand 300 feet working head of pressure, and 24 inches internal diameter, are to be ⅞ inch (= .875) thick, then wrought iron pipes of the same diameter would be $.875 \times .3174 = .2778$ inches thick, and mild steel pipes would be $.875 \times .1786 = .1563$ inches thick or say ⅞ inches, $\frac{9}{32}$ inches, and $\frac{5}{32}$ inches thick respectively, for equal internal working pressures.

Then again, if one mile of 24 inch cast iron pipes, ⅞ inch thick, made up of pipes in 12 feet lengths, weighing 24.8 cwt. each length, weighs 545.6 tons, the corresponding weight of one mile of wrought iron pipes will be $545.6 \times 0.3678 = 200.6$ tons,
and one mile of mild steel $545.6 \times 0.2114 = 115.2$ tons.

These results show that for equal diameter, 24 inches, equal working pressures of 300 feet and equal lengths of one mile, the weights are respectively:

Cast iron.	*Wrought iron.*	*Mild steel.*
545.6	200.6	115.2 tons.

The price per ton of mild steel pipes averages about 4¼ times the current price of cast iron pipes; as the relative weights for equal strength are as 1 : .2111, it is therefore apparent that the relative costs for a given length are as 1 : 0.90, or in other words, length for length at a cost of 10 per cent. less than cast iron pipes. With regard to carriage, the rate per ton by rail is the same for either cast iron or mild steel pipes, and as the saving is in the direct ratio of dead weight for a given length, the cost of railway carriage is 78 per cent. less than on cast iron pipes, and a like saving can be effected in handling the pipes at the site of the track in which they are to be laid.

The next point to which attention is directed is the jointing. As mild steel pipes are so much lighter than cast iron pipes, it is clear that they may be conveniently handled in longer lengths. The system of construction also favors this, and in fact the pipes may be made in one continuous length, built upon the site if it is desired. The customary methods are to make them in lengths of 24 feet, this being twice the usual length of cast iron pipe, and consequently having only half the number of joints. Taking the 24 inch pipes before mentioned, the lengths and weights would be

	Cast iron.	*Mild steel.*
Diameter	24 inches	24 inches
Length of each pipe	12 feet	24 feet
Weight do	24.8 cwt.	10.47 cwt.
Relative weights per pipe.........................	1	0.42
" lengths "	1	2

Again, taking the case of one mile in length, 440 pipes would be required in cast iron, and only 220 in mild steel, consequently, there is a saving of 50 per cent. in the labor and cost of jointing a given length. Then with regard to each joint, the mean circumference of the space for lead in an ordinary cast iron socket joint is greater than in a mild steel pipe, in consequence of the greater thickness of cast iron. The reduction in the circumference of a mild steel socket is equal to a saving of 9½ per cent. upon the weight of lead required for a 24 inch cast iron pipe socket; assuming that the depth of lead is the same in each case, the total saving in lead is therefore 59½ per cent.

To show the final economical result in the case of one mile of 24 inch pipes previously mentioned, the several relative costs are:

	Cast iron.	*Mild steel.*	*Saving.*
Internal diameter, inches	24	24	
Length, mile..................................	1	1	

	Cast iron.	Mild steel.	Saving
Number of pipes	440	220	
Weight of each pipe, cwts.	24.8	10.47	
" one mile, tons..................	545.6	115.2	
Relative cost per ton	1	4.25	
" of carriage, per ton... ...	1	1	
" " on total	1	0.2111	78 p.c.
" of laying per yard.......	1	0.7	30 p.c.
Relative number of joints..............	1	0.5	50 p.c.
" weight of lead, each joint....	1	0.905	9½ p.c.
" " " each mile	1	0.405	59½ p.c.
" cost of making each joint ...	1	0.8	20 p.c.
" " jointing one mile......	1	0.40	60 p.c.
" cost of total for one mile....	1	0.9	10 p.c.
" " of pipes and carriage...	1	0.84	16 p.c.
" " of carriage and laying.	1	0.834	16.6 p.c.
" " of pipes, carriage, laying and jointing one mile..................	1	0.788	21.2 p.c

The saving actually effected in the total outlay for one mile of 24 inch pipes is therefore:

Cost of pipes.	*Cost of carriage.*	*Cost of laying.*	*Cost of jointing.*
10 p.c.	6 p.c.	0.6 p.c.	4.6 p.c.

or a grand total of 21.2" p.c.

It will be seen that the above extracts treat of a comparison between cast iron mains, and mild steel mains fitted with faucets and spigots. This is a cumbersome arrangement, and has been entirely discarded on the Pacific coast, the Moore and Smith joint, a description of which will be given further on, taking its place. This joint is specially adapted to all pipes between the diameter of 12" and 24". When of larger sizes the pipes are made in plain lengths of 24 feet, 6 inches, and rivetted together in the trench.

THE MAINS.

The rivetted mild steel mains in use by the Vancouver Waterworks Company are of three diameters, 22 inches, 16 inches, and 12 inches. The 22 inch is laid from the dam to the tunnel, a distance of 13,530 feet, the 16 inch from the tunnel to ordinary high water mark of Burrard Inlet on the north shore, and from ordinary high water mark on the south shore to the centre of the city, a total distance of 39,211 feet. The 12 inch are laid on both shores of Burrard Inlet, between ordinary high water marks, and the submerged 12 inch flexible main across the Inlet, a total distance of 747 feet.

The 22 inch and 16 inch pipes are $\frac{10}{100}$ inches in thickness, and the 12 inch $\frac{3}{16}$ inches. The latter, being laid below high water mark, require greater thickness of metal to withstand the corrosive influence of salt water. These pipes were manufactured from plates imported from England by the Company, and rolled, rivetted, coated with asphaltum, and laid in trench by the Albion Iron Works Company of Victoria, B.C. Plate......... shows a longitudinal section of the 16 inch pipe. The 22 inch and 12 inch pipes are constructed in an exactly similar manner. It will be seen that the pipe is made in 7 courses, 4 large or outside courses, and 3 smaller or inside courses, rivetted together, and having a projecting nipple at one end. At the foundry the plates were trimmed to the exact sizes required, and the rivet holes punched with multiple punches at one and the same time. Absolute uniformity in size and spacing of rivet holes was thus secured. Each plate was then rolled in the usual manner, by means of three parallel revolving cylinders, which gave it the circular form of the required diameter. It was then made to encircle the vertical cylinder of a hydraulic rivetting machine, which cold rivetted the straight or longitudinal seams. When 7 plates had been treated in this manner and converted into cylinders 3 ft. 6 in. long, and of diameters differing sufficiently to allow the ends of the smaller cylinders to be passed into the ends of the larger, they were rivetted together, so as to form one length. On the lap, between two thicknesses of steel at the end of each course, the plate was scraped down to a fine edge, and a rivet driven through. Where three thicknesses of metal came together, as when the longitudinal seams of the large course overlap the smaller course, extra heavy lap rivets were used. The edges of each sheet for 3 inches from the laps were chipped and caulked. Straight and round seams were split caulked. The whole length was then heated in an oven, and immersed in a bath of hot asphaltum. This bath was an iron trough, 26 feet long and 3 feet wide, supported on brickwork, and so arranged that a fire could be kept constantly burning underneath. In preparing the mixture, the trough was filled to within a few inches of the top with asphaltum broken up into small cubes of about an inch to the side.

Coal tar, devoid of all oily matter, was then poured in till the asphaltum cubes were completely covered. The mixture was then allowed to boil for three hours, being constantly stirred during the process. As many pipes as the mixture would cover were then dipped and allowed to dry. The coating obtained was smooth, tough, free from brittleness, and of uniform thickness.

The form of joint used in connecting these pipes is, as before stated, that invented by Joseph Moore and Francis Smith, employees of the Risdon Iron Works Co., San Francisco. Plate........shows a longitudinal section of this joint. In making the joint in the trenches, the nipple end of one length of pipe was forced into the larger end of the adjoining length, by means of hammering on wooden blocks placed against the end opposite the nipple. The abutting ends of the two lengths were not driven up tight, a space of from $\frac{1}{4}$ to $\frac{1}{2}$ an inch being left, for the purpose of allowing for any expansion or contraction that might take place. The outside surface of the pipes was then scraped clean for about $2\frac{1}{2}$ inches back from the junction of the two ends. A band or ring of diameter sufficiently great to allow of $\frac{3}{16}$ inch play between its inside surface and the outside surface of the pipe, was then made to encircle the junction. The space between was filled up with lead in the usual manner, and carefully caulked. Joints made after this pattern have been in use for 15 years, and have given entire satisfaction. Care must be taken in making this joint, that no angle greater than one degree is made at the junction of the two lengths of pipe, otherwise the lead packing will be of unequal thickness, and the result, in all probability, a leaky joint. Caulkers accustomed to jointing cast iron pipes must be cautioned, when making for the first time a Moore and Smith joint, that the steel pipe will only admit of the lead being packed to a certain firmness, the degree of which can only be ascertained by actual trial. If the lead is beaten in between the ring and the pipe too tightly, the shell of the latter will bend inward, and render good work impossible.

As before stated, steel mains of more than 24 inches diameter, when subject to heavy pressure, are usually made in specified lengths at the foundry, and rivetted together in the trench. To accomplish this, it is necessary that each length shall have a large course at one end, and a small one at the other. The large course has its extreme end punched for rivets at the foundry, while the small course at the other end of the length is unpunched.

The pipes being placed in the trench, the small course of one length is forced by hammering, or other power, into the punched large course of the adjoining length. The position of the rivet holes on the small course to correspond with those on the large course are then marked and screw punched after separation. This being done, the two lengths are again united, their surfaces pressed firmly against each other by means of a set stool, and cold rivetted from the outside. The seam is split caulked in the usual manner. This makes the most desirable connection for pipes of large diameter.

However, it may be mentioned that a pipe of 41 inches diameter, and subject to a pressure of 300 feet, was laid, ten years ago, in the Sandwich Islands. The lengths were connected by Moore & Smith joints, and are in active service to this day.

The Vancouver pipes were laid in the trench with the straight seams upwards, so that any leakage might readily be detected, and repaired by further split caulking. In most systems, however, the straight seams are laid downwards, the advantage of which is that in course of time, sediment gathers on the bottom of the pipe along the edges of the seams, and tends to prevent leakage.

BENDS AND CASTINGS.

Inasmuch as the steel mains described in the foregoing pages were constructed with a view to securing absolutely tight joints, the outside surfaces of the nipples fitted tightly against the inside surfaces of the adjoining lengths. Consequently, no deviation from a straight line greater than one degree could be made between any two lengths without special bends. By means of specially adapted machinery, steel elbows and bends are made by certain manufacturers, but these lack stability when the angle of curvature is large. All bends in the Vancouver system are of cast iron, one inch thick. They are segments of a circle, the axis of the bend being the circumference, and the radius five feet. Previous to leaving the foundry, they were individually subjected to a pressure of 300 lbs. per square inch.

In certain parts of the pipe line, north of Burrard Inlet, the ground traversed being contiguous to the river is irregular horizontally and vertically, and required bends ranging from 5 to 70 degrees angle of deflection. That portion of the pipe line immediately south of the tunnel, and following the irregularities of the side hill for a distance of 8000 fe t, required no less than 80 bends of all angles of deflection, being an average of one bend to every 100 feet of length. The total number required by the system from the point of supply to the centre of the city was 179.

The other castings connected with the mains, not including the connections with the city distribution system, are as follows: two miles and a half below the dam, at the lowest depression between the dam and the tunnel is placed a blow off, 8" off 22". This is controlled by an eight inch valve, leading into a 12" × 12" box drain, which in turn leads to the river. To the middle pipe length in the tunnel is affixed a self-acting Chabot air valve, the air passage of which is 2¼ inches diameter, and is controlled by a brass valve, so that the upper part containing the rubber ball may be taken off for examination at any time without the necessity of shutting off the main at the dam.

At Burrard Inlet, on the north side is placed a blow off, 8" off 16" and on the south side 12" off 16" reducing to 8", both controlled by valves, and emptying into Burrard Inlet. The ends of the 16 inch main, on both sides of the inlet, are provided with "Y" breeches, two 12 inch branches off 16 inch. These branches connect with the double line of 12 inch mains, that will ultimately cross Burrard Inlet, and are individually controlled by 12 inch valves, so that each main can be shut off independently if required. Between the inlet and Coal Harbour, on the highest elevation between the two waters, is placed another Chabot air valve, arranged in a manner similar to the one already described.

On both sides of Coal Harbour are placed blow offs 8" off 16" discharging into Coal Harbour, and finally a 16 inch valve is located at the point where the mains enter the inhabited part of the city. It will thus be seen that in case of necessity the supply to the city can be shut off at five different places, viz., at the entrance and outlet of well chambers at the dam, on both sides of Burrard Inlet, and at the entrance to the city.

LAYING THE SUBMERGED MAIN AT FIRST NARROWS.

Having in view the difficulty of effecting repairs in pipes laid under water, and the disastrous consequences that might result from a temporary stoppage of the city's water supply should a break take place, through unavoidable causes, the design for crossing the first narrows, instead of being one 16 inch main, comprised its equivalent, two separate lines of 12 inch mains, 50 feet apart, and capable of independent action by means of stop valves placed at high water mark on each side of the Inlet. Up to the present only one of these lines has been laid in position on the bed of the Inlet, made up of 746 feet of plain rivetted steel pipes; 261 feet of rivetted steel pipe, fitted with cast iron flexible joints, and 1236 feet of cast iron flexible joint pipe.

The plain rivetted steel pipe is placed at each end of the line, 584 feet on the north shore and 162 feet on the south shore. The rivetted steel pipe with flexible joints is placed on the north shore between the plain pipes and the cast iron flexible pipes, and the latter are placed on the bed of the Inlet, reaching from low water to low water mark.

The construction and details of the plain pipe have been already described. The flexible steel pipe is in lengths of 22'.2" over all, and is exactly similar to the plain pipe, but provided with cast iron spigots and faucets, bored and turned in the same manner as the cast iron flexible pipes. The latter are of the pattern known as the Ward patent flexible joint pipe. They were manufactured in Scotland, and are of hard close grained white cast iron, throughly coated with Dr. Smith's coal pitch varnish. Each length is 12' 4" over all, $1\frac{1}{8}$ inches thick, weighs 1280 lbs., and is warranted by the manufacturers to stand with safety the pressure due to a column of water 600 feet high. Each joint required 70 lbs. of the best Spanish pig lead. Drawing No. 6 shows a longitudinal section of this joint. The larger portion of the inside surface of the bell or faucet forms a spherical zone, the centre of which is a point on the axis of the faucets at such a distance from its mouth, that the inside diameter of the latter is greater by half an inch than the inside diameter of the shoulder. The extreme end of the spigot is turned truly, and exactly fits the inside surface of the faucet. The outer end, or the end encircled by the mouth of the faucet, is of smaller diameter, so as to allow half an inch of space between the two surfaces for lead packing. At the middle of the spigot is a circular groove, a quarter of an inch deep and an inch and a half wide, which serves the purpose of retaining the lead packing, and prevents the joint from pulling asunder, when exposed to tensile strain. This joint is capable of motion through an angle of 12 degrees, and a complete circle can be made with 30 lengths.

The contract for furnishing and laying the single line of cast iron flexible joint pipe was let on the 1st of November, 1887, to the inventor and patentee of the joint, Mr. John F. Ward, late chief engineer of the Jersey City Waterworks. The price agreed on, which covered all risks, and contingencies, was nine dollars per lineal foot.

Mr. Ward has devoted many years of his life to laying submerged pipes of all diameters, and has, hitherto, met with unfailing success. Among some of the more prominent works standing to his credit, may be mentioned the six inch pipe crossing the Delaware River at Easton, Pa., the 12 inch pipe, 963 feet long above the dam, at Lawrence, Mass., and the two lines of 8 inch pipe crossing Shirley Gut, Boston Harbour, a channel 400 feet wide, and 37 feet deep, through which a tidal current flows at the rate of $7\frac{1}{2}$ miles per hour.

Mr. Ward, on his arrival, made a thorough inspection of the crossing, and expressed himself as confident of being able to complete his contract with ease and rapidity. Accordingly on the 21st of April, 1888, he began operations, his plan being to joint the pipes on a suitable platform stationed at low water mark on the north shore, and by means of a stationary engine on the south shore, haul them across, length by length. Inasmuch as Mr. Ward failed to carry out this plan to completion, the writer, without expressing any opinion as to its practicability, will merely describe his mode of procedure.

The structure erected on the north shore of the Inlet, on which the pipes were jointed, was a frame work staging of sufficient height to reach above extreme high water, and strong enough to resist the force of the incoming and outgoing tides. In the middle of this stage was constructed a sloping platform, extending from the front face, 4 feet below the top, down to the ground at the rear face, or the face fronting the Inlet. The object of the platform was to admit of the pipes being jointed in an inclined position, and therefore sliding easily to the ground, when the hauling power was applied. The 104 lengths of pipe required to reach from shore to shore were piled within easy reach of the platform. The engine on the south side of the river, opposite the platform and at a distance of 1400 feet from it, was of 30 H. P., and reovlved an ordinary drum, to which was attached a hundred feet of wrought iron chain, connecting with a continuous wrought iron rod of $1\frac{1}{4}$ inches diameter. This rod reached clear across the Inlet, and was attached to the rear end of the first length of pipe lying on the sloping platform of the staging. The rod was made from round iron in lengths of 15 feet, jointed together by common screw unions, its whole tensile strength being that due to the resistance offered to stripping by the threads of the unions.

When Mr. Ward had completed these arrangements, he began without delay to joint the lengths together. To the length lying on the platform, the spigot end of which faced the Inlet, a second length was jointed in the usual manner.

The engine on the south side was then put in motion, and the first length hauled forward a distance equal to its own length, leaving the second length to fill the plan previously occupied by the first. A third length was then jointed to the second, the engine again pulled forward, until the third length occupied the place vacated by the second. It was intended to repeat this operation until the whole 104 lengths had been dragged across the bottom of the Inlet. However, after 18 lengths, covering a distance of 216 feet, had been submerged, Mr. Ward concluded to substitute a steel wire cable for the wrought iron rod. In stretching this cable across the Inlet, it unfortunately fouled on a small boulder, about 200 feet above the pipe line, and such efforts as were made to dislodge it proved unavailing. Mr. Ward then notified the company that urgent private business compelled him to leave the works for St. Paul, Minn. He did not return, but shortly afterwards officially abandoned the contract.

On July 9th, more than a month after Mr. Ward's failure, the company contracted with Messrs. H. F. Keefer and D. McGillivray, the gentlemen who already held the contract for trenching refilling, to complete the work according to certain specifications, from which the following clauses are extracted.

"The total length of the crossing to be made is 1248 feet, extending from low water mark on the south shore to low water mark on the north shore. These points will be defined by stakes placed by the company's engineer, and the whole main when finally laid shall be in a perfectly straight line between them.

Each pipe length, previous to being placed in position, shall be well and carefully tested for flaws in manufacture, cracks, air-holes, and other defects, by the usual process of suspending in slings and tapping with hammer. Should any be found defective, they shall be discarded, and the engineer notified of the same.

The lead to be used in jointing shall be that known as "Best Spanish Pig."

The whole number of pipe lengths, previous to being placed in final position on the bed of the first narrows, shall be jointed, leaded, and made perfectly water-tight on dry land, and on such a structure as will admit of the whole length of 1248 feet being of easy access for the purpose of inspection.

A test pressure of not less than 300 lbs. per square inch shall then be applied by the contractors, in the presence of the Company's Engineer, the leakage under which, throughout the whole length of 1248 feet, shall not exceed one cubic foot per minute. Such joints as may prove defective under this pressure shall be made good by the contractors at their own expense, and such pipe lengths as may leak or give evidence of flaws shall be removed by the contractors, and replaced by sound lengths, the cost of which shall be defrayed by the company.

The Engineer's approval of the main, after the application of the above test being given, the contractors shall be at liberty to place it in position on the bed of the first narrows, which being done, a similar test pressure of 300 lbs. per square inch, subject to the same conditions, shall be applied.

A diver will be appointed by the company to inspect the main when finally laid in position, and on his report such alterations in its position as may be rendered necessary by reason of its resting on boulders or sharp irregularities of the bed of the Inlet, shall be made by the contractors, and at their expense, provided the total cost does not exceed five hundred dollars. All costs over this amount shall be defrayed by the company."

Messrs. Keefer and McGillivray entered into the fulfilment of their contract with energy. A 30 H. P. engine was stationed on the north shore of the Inlet, between high and low water marks. With this the 18 lengths submerged by Mr. Ward were hauled back to dry land. A trench, 4 feet wide, 4 feet deep, and 1300 feet long, was excavated on the line of the crossing on the north shore. Parallel continuous runners of barked fir, three in number, were placed in the bottom of the trench, in such a manner that the bell end of each pipe when jointed would rest on the central runner, and be supported on each side by the other two runners. A frame work staging, similar to that employed by Mr. Ward, was built over the trench and supported on rollers, on which it could readily be moved over the whole length of the trench. On this staging with its sloping platform, the whole number of pipe lengths were jointed, the operation being very similar to that of paying off a cable from a moving ship. As soon as the first joint was made, the staging was moved forward till the first pipe length rested on the runners in the trench, leaving the second in the place vacated by the first. A third pipe was then hoisted up by winches, its spigot end inserted into the bell of the second, and carefully adjusted in exact line. Molten lead was then poured in and caulked in the usual manner. This done, the staging was again moved forward and another pipe adjusted, the operation being repeated day by day, till one hundred lengths had been connected. As before stated 104 lengths were provided, but during the process of jointing, four, showing evident signs of fracture, were discarded.

Immediately on the completion of the work of jointing, both ends of the chain of pipes were securely capped, and the stipulated test pressure of 300 lbs. per square inch applied.

A first attempt was made to apply the pressure by means of a hand pump, worked by six men, forcing a stream of water into a circular opening, one inch in diameter, provided for that purpose in the cap on the north end. It was speedily found, however, that owing to the leakage at the joints, slight as it was, this method was not powerful enough to keep the chain of pipes full and attain the required pressure. The stationary engine, situated midway between high and low water mark, was then brought into requisition. The middle length of the chain of pipes was tapped, and by means of the engine, water was pumped in until the first defective pipe manifested itself, which occurred when the gauge registered 30 lbs. per square inch. This length was immediately broken up by sledge hammers, the bell cut by a cold chisel, split open, and the lead removed.

The two portions of the chain of pipes were then hauled together by means of the engine, and re-jointed. Pressure was again applied until the second injured pipe gave way.

This operation was repeated until no less than eight defective pipes had been removed. The remaining 92 sustained the required pressure of 300 lbs. per square inch for a period of five minutes, during which each length was subjected to heavy blows from a 12 lb. hammer. As the joints sustained this severe pressure without exceeding the specified amount of leakage, and as every length seemed to be absolutely free from defects, the test was considered eminently satisfactory. The following table shows the pressures at which the different pipe lengths gave evidence of the fractures they had sustained during their repeated handlings, and which were not detected by the process of "ringing."

Number of Length, reckoning from north end of pipe chain.	Pressure per square inch under which pipe gave way.	Nature of fracture.
5th	30	Longitudinal crack 12″ long
9th	70	" " 36″ "
10th	60	" " 36″ "
31st	50	" " 12″ "
37th	70	" " 18″ "
38th	70	" " 18″ "
51st	40	" " 24″ "
64th	40	" " 12″ "

Notwithstanding the additional loss of these 8 pipes, it was deemed advisable to proceed with the submersion of the remaining 92, the shelving nature of the north shore being such that the north end of the chain of pipes, when laid in position, would not be covered by more than 2 feet of water at low tide, and, therefore, it would be no difficult matter to raise that end at any future convenient time, and add the whole 12 lengths necessary to complete the crossing as planned.

The plan adopted for placing this long line of heavy flexible pipes in position on the bed of the Inlet was direct hauling from shore to shore, during the half tides which occur in the Inlet during the months of July and August. For the purpose of lessening the weight as much as possible, each length was encircled by a wrought iron ring, to each of which floats of 500 lbs. buoyancy were attached. To prevent as much as possible the forward end of the chain of pipes from ploughing a deep furrow in the bed of the Inlet during the process of hauling, it was buoyed up by a number of cedar logs laid lengthways. The hauling gear was as follows—(See Drawing No. 4) To the rear end, that is the end farthest from the water, was attached a 9 inch manilla cable of 44,800 lbs. ultimate tensile strength, and 600 feet long, which was connected with the 30 H. P. Engine, stationed on the same shore, midway between high and low water marks. To the middle length was attached a 4 inch steel cable of 52,000 lbs. ultimate strength, and 1880 feet long, which connected with a 30 H. P. engine stationed on the south or opposite shore. Midway between the middle length and the forward end of the chain of pipes, a similar steel cable 1,600 feet long was attached, which also connected with a 30 H. P. engine on the opposite shore. A third steel cable of the same strength, and 1,325 feet long, was attached to the forward end of the chain of pipes. This latter connected with two 30 H. P. engines on the opposite shore. It will thus be seen that there were no less than three 4 inch steel wire cables, and one 9 inch manilla cable attached to the chain of pipes, the total ultimate strength of which was very nearly 90 tons. The total effective strength of the engines pulling the tackle connected with these cables aggregated 150 horse power.

The four engines on the south side were stationed on the beach at high water mark. The blocks and tackle were arranged in three parallel rows 10 feet apart on the flat immediately to the rear of the engines. This flat being densely timbered with the huge trees peculiar to the Pacific coast, the space cleared in which to operate the tackle was necessarily limited. The blocks were securely anchored to huge stumps in the vicinity by heavy wrought iron chains. The pulleys, one of which was four sheaved and two three sheaved, had a clear distance of 56 feet in which to operate. The manilla cables passing through the sheaves were connected to the wire cables by wrought iron grips invented for the occasion by the contractors.

All arrangements having been satisfactorily completed, the engines were set in motion on the 28th of August last at 10 a. m. The steel cables straightened out and remained taut and stationary, but only for a minute. A sudden slackening took place, and the whole chain of pipes took a forward motion of several feet, and from that instant the success of the undertaking was an assured fact. There had been a question as to whether the joints would withstand the enormous tensile strain brought to bear on them, but it now became certain that the lead packing would remain intact as long as the cast iron bell held together.

Owing to the extreme distance between the blocks and pulleys being no more than 56 feet, the tackle connecting them had to be overhauled every advance of 56 feet made by the chain of pipes. The process of hauling was therefore necessarily slow; but being kept up without intermission, at 7 p. m. the forward end of the chain of pipes arrived at its destination on the south shore.

On the day following, at slack tide, a skillful marine diver walked across the bed of the Inlet, following the chain of pipes, entering on the south shore and emerging on the north. His report was to the effect that the whole line of pipes was lying on the bed of the Inlet in a perfectly straight line, without sag or bend, that the heavy projecting bells of the pipes had scooped, as they were being drawn over, a deep groove in the soft sandstone rock, and that the whole chain of pipes was resting in a rock trench of its own excavating; that above this trench silt was rapidly gathering, and that in his unqualified opinion the pipes would in a few weeks be entirely covered over, rendering their permanency and safety beyond question.

The day following this examination, the contractors applied the final test pressure of 300 lbs. per square inch as called for by the specifications. An opening was made in the cap on the end length, the pipes filled with water by steam pumps, and the required pressure steadily maintained for five minutes of time, without perceptible leakage. The enormous train on the joints apparently had no other than a beneficial effect, having compacted the lead, and rendered the whole line perfectly water-tight. Eleven of the 12 pipes which had been discarded were subsequently replaced by pipes cast by the Albion Iron Works Co. of Victoria, tested to a pressure of 300 lbs. per square inch before leaving the foundry. No difficulty was experienced in attaching these to the main already submerged. The end of that main having been lifted up was buoyed on the deck of a small scow. The additional lengths were added one by one, the scow being moved forward as each length was jointed, until the whole eleven rested in position on the bed of the Inlet. It was found, however, at a later date that owing to the shelving nature of the north shore, and the fluctuations of the tides, a satisfactory connection between the end of the cast iron flexible pipe and the plain rivetted steel pipes could not be made. Twelve of the latter were accordingly fitted with flexible cast iron spigots and faucets, similar to those shown on drawing No. 6, and connected with the cast iron pipes making a total length of 1496¼ feet flexible pipe, covering a horizontal distance of 1483½ feet.

When the project for supplying the city of Vancouver with water from the River Capilano, by means of a submerged main across Burrard Inlet, was first made public, considerable interest was evinced by both engineers and civilians. Printers' ink was called into requisition, and many articles published demonstrating the utter impracticability of the project.

The complete success of the undertaking is an irrefutable answer to all the adverse theories advanced. However, it may be of interest, even at this late day, to mention some of the objections urged and believed in up to the successful completion of the work, and the published answers thereto.

Objection 1.

That the known force of the current in the first narrows would cause the chain of pipes to sway up and down the bed of the Inlet with each change of tide, and eventually result in separation of the joints.

Answer—That it could be mathematically demonstrated (calculation shown), that the force of the current was altogether insufficient to produce the results stated, and that the proposed method of laying the pipes by "direct hauling" from shore to shore would result in the sharp-edged bells of the pipes cutting a groove, [illegible] deep to embed the whole chain, and thus effectually destroy [illegible]ty of motion.

Objection 2.

That the current would create a friction that would scour off any coating that might be put on to protect the pipes from corrosion.

Answer.—That the pipes being embedded in the bottom of the inlet, and covered by silt, would be absolutely free from frictional action.

Objection 3.

That vessels might accidentally drop anchor on the pipes, or that vessels, finding themselves in danger of drifting ashore, through stress of weather or other causes, might be obliged to drop their anchors on the bottom, an[illegible] result hook on to the chain of pipes and break it asunder.

Answer.—That the thickness of the pipe shells if exposed to the shock of a falling anchor would be sufficient to keep them intact, and that if the anchor fluke of a drifting vessel were to bury itself under the chain of pipes, the vessel would be securely anchored, and would be obliged to wait for the turn of the tide to free herself, such cases occurring daily in Boston Harbour and elsewhere.

Objection 4.

That salt water would cause galvanic action of a destructive nature to take place at the joints where lead and cast iron were in close contact.

Answer.—That there is no instance on record of destructive galvanic action having occurred in the case of lead and cast iron in contact under salt water.

Objection 5.

That the chain of pipes, being of cast iron, would, owing to the action of salt water, speedily become soft like Plumbago, and in a few months become utterly worthless.

Answer.—That softening of cast iron exposed to the action of salt water takes place only in castings of inferior metal, and that it is on record that castings of close grained, hard, white metal had resisted the corroding action of salt water for 40 years and upwards.

Objection 6.

That in the case of a Narrows, connecting a large inland basin with the sea, where the tide has a rise and fall of 12 feet, the counter currents in such a restricted passage defied calculation, and were more likely to be greater at the bottom than at the surface.

Answer.—That the laws of nature are unchangeable, and that the future experiments of the company's engineers would amply demonstrate that it was impossible for a current exposed to the influence of a vast friction bed, like the bottom of Burrard Inlet, to be greater than the free and unrestricted current of the surface.

Objection 7.

That the great force of the current rendered it imperative that the whole chain of pipes should be laid in the short interval of slack water between two tides, which did not exceed twenty minutes duration, and that no means could be devised to perform such an arduous undertaking in such a short period of time.

Answer.—That the method proposed by the company, of jointing the pipes and hauling them in a continuous chain across the inlet, would, as before stated, entrench the pipes, and cause a resistance to motion which would render it immaterial whether the pipes were laid in twenty minutes or twenty hours.

Objection 8.

That the method of laying the pipes proposed by the company, viz.—jointing and hauling in one continuous chain, was impossible, as no pipe joint could be made strong enough to withstand the enormous tensile strain this method would entail.

Answer—That the construction of the Ward flexible joint was of such a nature that the lead packing could not be pulled out, and before a joint could break asunder, it would be necessary for the cast iron bell to give way, and that in consequence the strength of the joint was limited only by the sectional area of cast iron exposed to the tensile strain.

Objection 9.

That there were no instances on record of pipes laid in salt water subject to a tidal current of 9 miles per hour, where the depth of the channel was 60 feet, and the width 1240 feet.

Answer—That this was most certainly true, and that when the Vancouver Company's submerged main was laid, it would serve as a precedent for similar works on a more gigantic scale.

The above objections and answers, and many more of a like nature, were publicly discussed and argued upon by professional men. Elaborate and specious mathematical calculations were produced in support of each theory. However, as the work is now an accomplished fact, all opposing theories are thereby proved worthless.

In regard to the ninth objection, the writer is well aware that no similar work of a like magnitude has ever been attemped. Greater lengths of flexible pipes have been laid in lakes, rivers, and ocean bays; but previous to the laying of the submerged main across Burrard Inlet, no pipe of 12 inches diameter and 1100 feet in length had been laid in salt water 60 feet deep, on a smooth rock bottom, and exposed to a tidal current of 9 miles per hour. The nearest approach to it is the Shirley Gut pipe, 8 inches diameter, laid by Mr. Ward many years ago, which, as before stated, crosses an arm of the sea, 400 feet wide, 37 feet deep, and subject to a tidal current of 7½ miles per hour. The double line of 16 inch flexible pipe laid across San Francisco Bay for the San Francisco Waterworks Co. is the longest chain of submerged pipes yet laid. The pipes are seamless wrought iron tubes, 5-16" thick fitted with cast-iron faucets and spigots after the Ward pattern. The bay, where the pipes cross, is 6300 feet wide, and entirely free from currents. A thousand feet out from the Alameda shore it is 60 feet deep, but at two thousand feet it is only 15 feet, and this latter depth gradually decreases till the San Francisco shore is reached. The pipes were jointed on a large scow, fitted with a derrick and sloping platform, and paid out from the rear as each successive length was added. The whole time occupied in jointing and paying out the double line was 40 days.

The following table shows the more prominent instances of submerged pipes, known to the writer as being laid previous to the laying of the Burrard Inlet pipes.

Main.	Length.	Waterworks Co.	Where laid.
Single 36 inches.	4000	Toronto Waterworks.	Lake Ontario.
" 36 "	3044	Milwaukee "	Lake Michigan.
" 36 "	2000	Jersey City "	Hudson River.
" 36 "	960	Philadelphia "	Delaware River
" 12 "	963	Lawrence "	
Double 16 "	6300	San Francisco "	San Francisco Bay.
" 8 "	400	Deer Island "	Shirley Gut.
Single 8 "	3100	San Diego "	San Diego Bay.
" 6 "	800	Easton "	Delaware River.

LAYING SUBMERGED MAIN ACROSS COAL HARBOUR.

Coal Harbour, being shallow and its bed easy of access at all stages of the tide, is crossed by a 16 inch rivetted steel main, 3-16" thick, fitted with cast iron flexible joints, and costing $3.50 per lineal foot at the foundry. Drawing No. 6 shows the form of joint used. Three hundred lineal feet of flexible pipe were provided, but at the time it was necessary to effect the crossing, it was found that unusally high tides prevailed, and that this amount was insufficient. This difficulty was overcome by rivetting two plain lengths to two flexible lengths, the compound lengths, each 48 feet long, being placed at the ends of crossing, the whole covering, when jointed, a distance of 348 feet. The submerging of the pipes was effected without difficulty in the following simple manner:

The total number of lengths were jointed in one continuous straight line on the south shore, between high and low water marks, the forward end resting on and firmly secured to a small scow.

The whole line was buoyed on each side by cedar floats, capable of sustaining the entire weight. On the rising of the tide, the scow and the chain of pipes rose with it, and when well afloat, a dozen men stationed on the opposite shore hauled on a small rope attached to the scow, pulling it forward, till the line of pipes was directly above its destined position on the bed of the Bay. The floats were then cut off, and the pipes allowed to sink to the bottom. At low water the ends of the chain were exposed, and connection with the 16 inch mains on each shore was effected without difficulty. The whole operation occupied three days from start to finish.

THE DISTRIBUTION SYSTEM.

The general plan of the distribution system was designed by Mr. T. C. Keefer, C.E., C.M.G., Past President of the Canadian Society of Civil Engineers. Its excellence is therefore beyond question. Subjoined are a few of the more important details.

The city of Vancouver is laid out on the rectangular system, the streets being 99 and 66 feet wide, forming blocks 260 feet wide by 500 feet long. The 16 inch steel main is carried under the principal streets into the centre of the city. Branching from it, at suitable intervals, by means of special castings, the larger sub-mains, 8" and 6" diameter, form rectangles, from the sides of which the smaller sub-mains, 4", 2½" and 2" diameter, branch out in any required direction. The system is liberally supplied with stop valves. Each pipe feeding direct from the main, and each small sub-main feeding from the larger sub-mains, can be closed independently, when required. In the case of breaks and necessary repairs, a single street or part of a street can be shut off without interfering with the suppiy to other parts of the city. Should it ever become necessary to shut off the whole system, a 16 inch valve is provided on the main for this purpose, outside the limits of the distribution system. In all cases the valves have been placed at a distance of four feet from the initial point of the sub-main, or from the intersecting centre of the two sub-mains. The sub-mains are laid at a distance of 20 feet from and parallel to the street lines, so that the exact locality of the valves can be found without difficulty, even in winter when the ground may be covered with snow and ice. In most cities the practice followed has been to locate the valves uniformly on the lines of the street boundaries, the disadvantage of which is that a break in a sub-main may occur between the valve and the feeding pipe, in which case the valve is rendered useless.

To resist the severe water hammer, due to the great pressure in the system, the valves are made unusually heavy.

The bodies, caps, and nuts are of cast iron; the spindles, stuffing boxes, glands and followers are of composition metal.

The plugs are of cast iron with composition faces, and spindle bushings. The following table gives their dimensions, weight and cost in Victoria.

STOP VALVES.

	Diameter in inches.					
	2"	4"	6"	8"	12"	16"
Shoulder to shoulder of Bells......	3¾"	5¼"	6"	6⅜"	8"	9⅞"
Diameter of Bell in inches...........	3⅛"	5¾"	7⅛"	10"	14⅛"	18½"
Aver. weight in lbs.	34	115	190	298	650	1100
Cost at Victoria....	$12.00	$17.50	$30.00	$44.00	$85.00	$150.00

The body of each valve is enclosed in a square brick chamber, built to such a height that the top of the valve chamber (a small, square cast iron box, weighing 111lbs., and protecting the nut of the spindle), when placed upon it, is flush with the street.

The system is provided with 75 double valves, two hose Matthew's fire hydrants, with 4 inch valve openings. This hydrant is in general use throughout the United States. The manufacturers claim, and the claim is conceded by all cities using them, the following superiorities over all others.

There being two mains valves, possiblo leakage is reduced to a minimum. The lower valve, working independently of the upper valve, the hydrant can be disconnected for repairs, without the necessity of excavation, and without shutting off the feeding sub-main. The rod and automatic waste valve, attached to the upper induction valve, work in such a manner that the opening of the lower induction valve involves the closing of the waste valve, and vice-versa. Waste of water cannot therefore take place, and no water can remain in the stock of the hydrant, when the upper valve is closed.

The lower valve being capable of independent action, the temporary removal of the upper valve for repairs does not interfere with the utility of the hydrant.

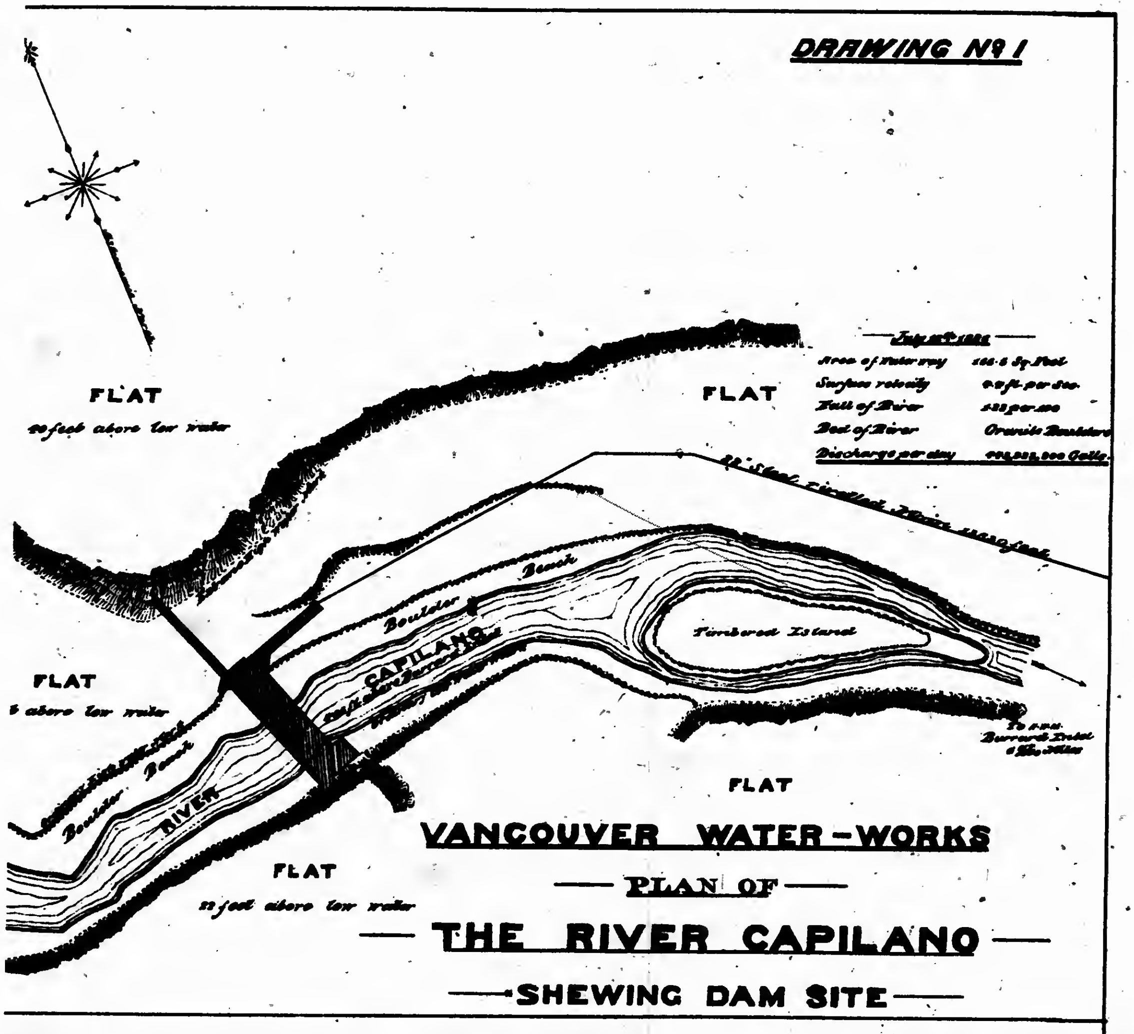
As previously stated, the works of excavation and pipe laying mains included south of Burrard Inlet were carried out by the company by day labour. The average depth of trench for the mains was 3' 10," and for the sub-mains 3 feet. The cost, including tools, laying pipes, placing specials, erecting hydrants, refilling and tamping trenches, taking up and replacing crossings, and works of a like nature, did not exceed 17 cents per lineal foot.

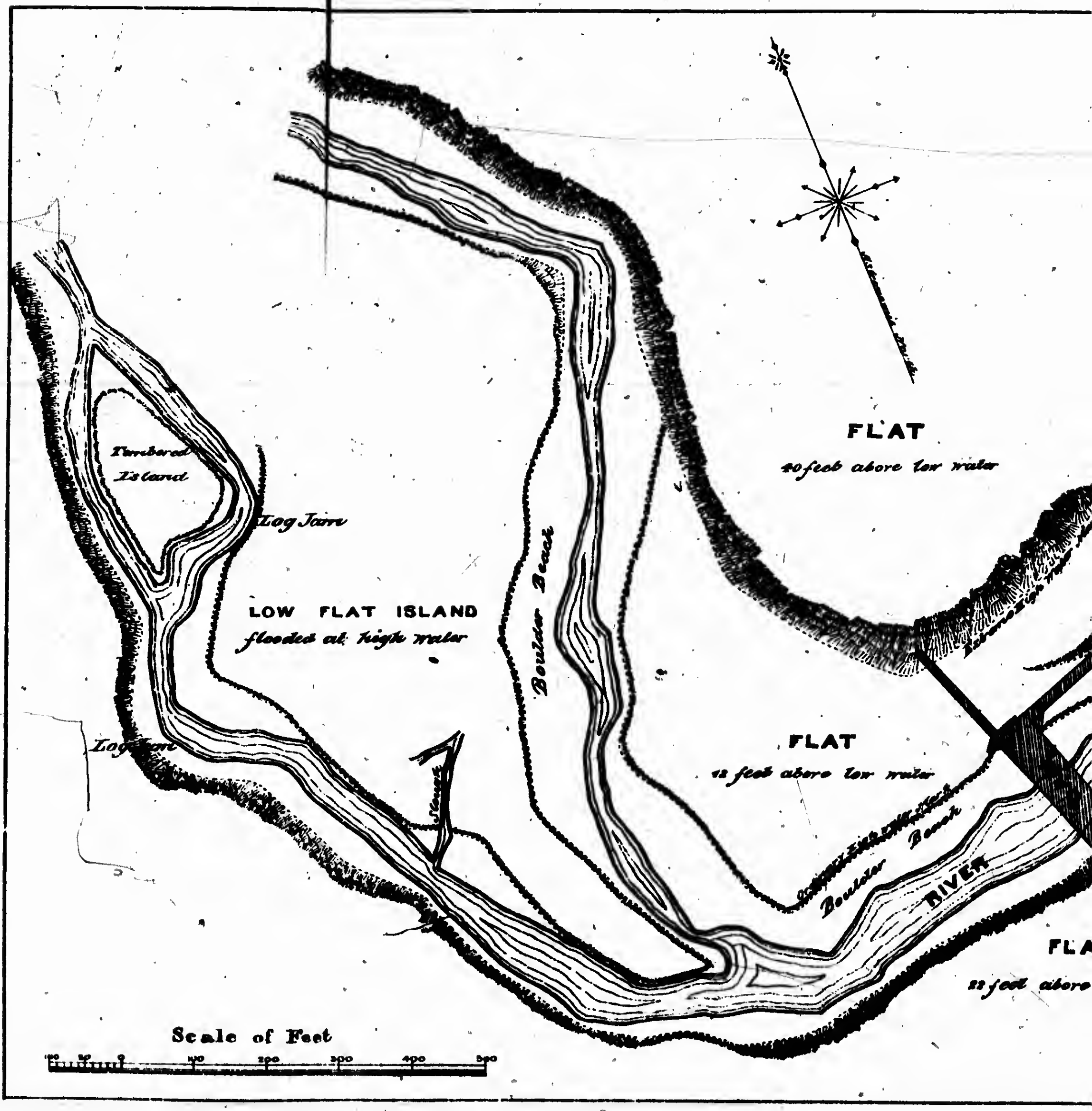
LETTING THER WATE INTO THE MAINS.

On Wednesday, the 20th of March, 1889, the gate in the well chambers of the dam was partially raised, and water allowed to flow for the first time into the 22" main. The 8" blow off near the rock tunnel was kept open, and the water was not allowed for several days to fill up to the level of the tunnel, and flow into the 16" main. On March 25th at 4 p. m., the gate in the well chambers was opened wide, and a full head of water turned on. At 6 p. m. the 22" main was filled, and began flowing through the tunnel into the 16" main. At 9.45 p. m. the water reached the closed 12" valves, on the north shore of Burrard Inlet. At 10 p. m. the valve controlling the 12" submerged main was opened three-quarters full. At 10 minutes past 10 the water reached the south shore. At 3 a. m. it had reached the termination of the 16" main in the centre of the city, and at 4 a. m. it was discharging fully into False Creek, by means of an 8 inch sub-main opened wide.

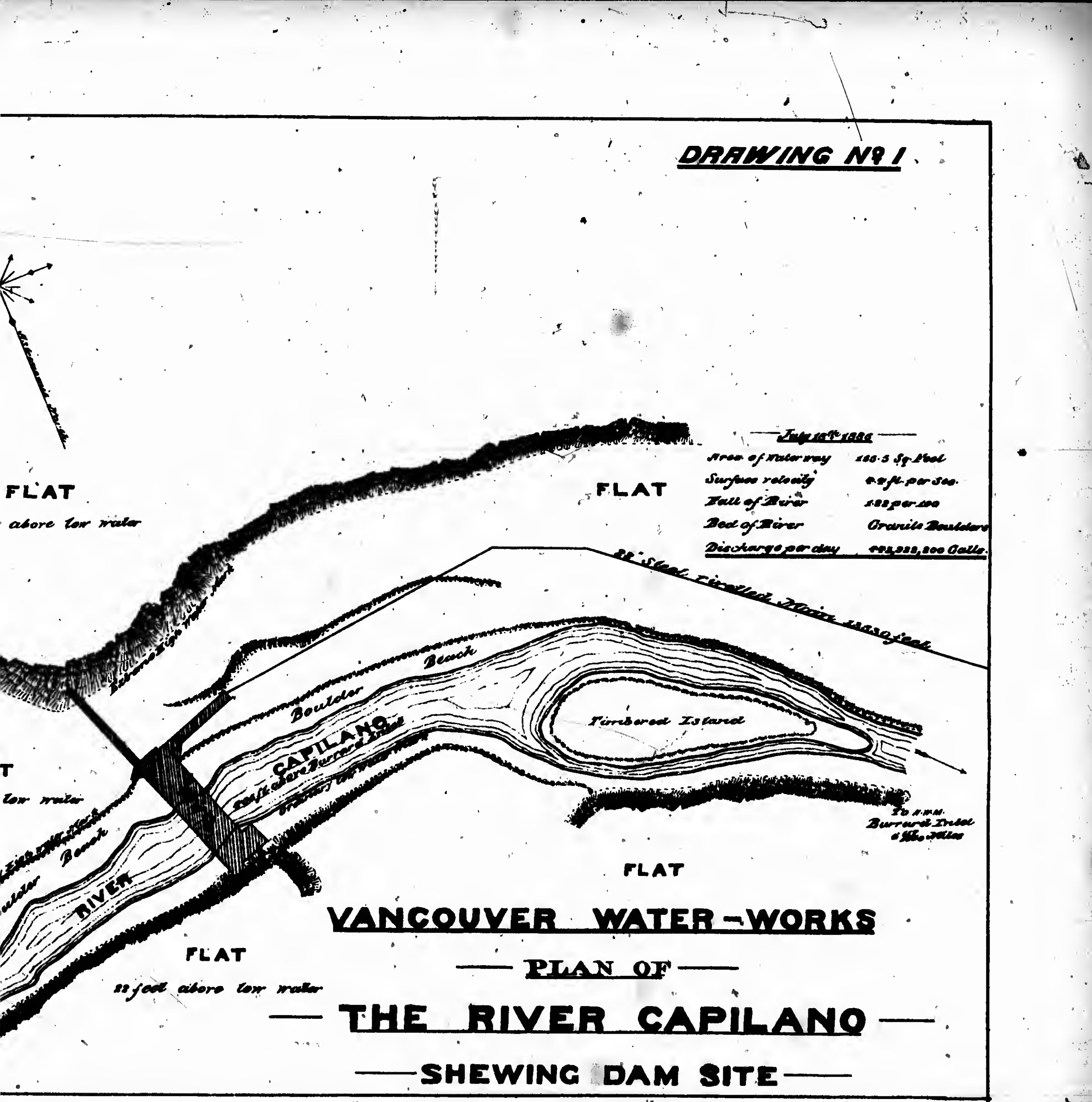
It is worthy of note that in the whole length of the mains, not a single joint was found to leak. Such leaks as were discovered occurred at the seams, where the rivetting and split caulking had been imperfectly done. These were speedily repaired by encircling the mains by steel rings, 4 inches wide, made in two halves, and provided with "Lugs."

The lugs were bolted together, above and below the main, and the space between the ring and the pipe filled up with lead, and carefully caulked in the usual manner.

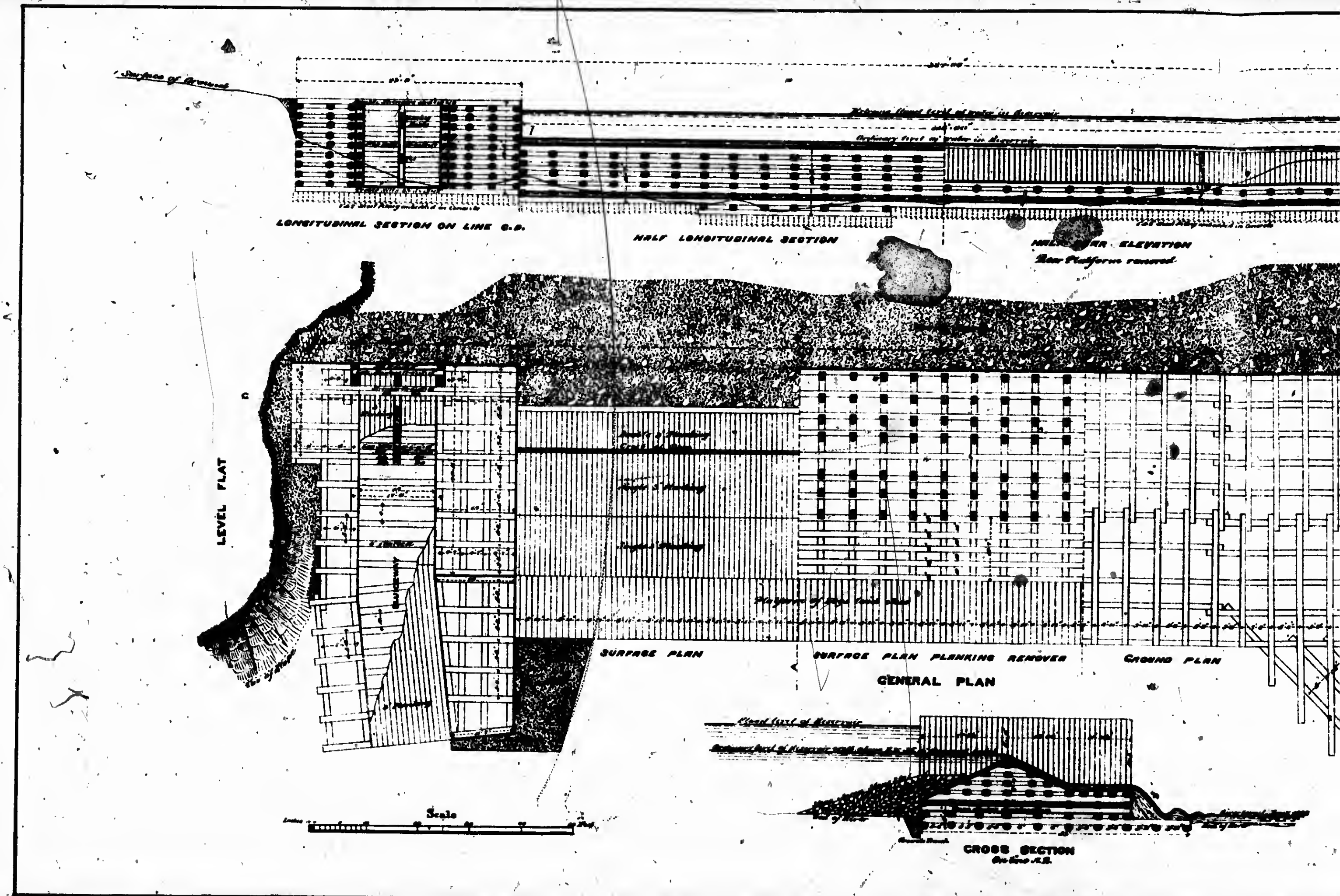

DRAWING No. 1
FLAT
FLAT
FLAT
FLAT
FLAT
Area of Water way
Surface velocity
Fall of River
Bed of River
Granite Boulders
Discharge per day
Boulder Beach
Boulder Beach
CAPILANO
RIVER
Timbered Island
VANCOUVER WATER-WORKS
PLAN OF
THE RIVER CAPILANO
SHEWING DAM SITE

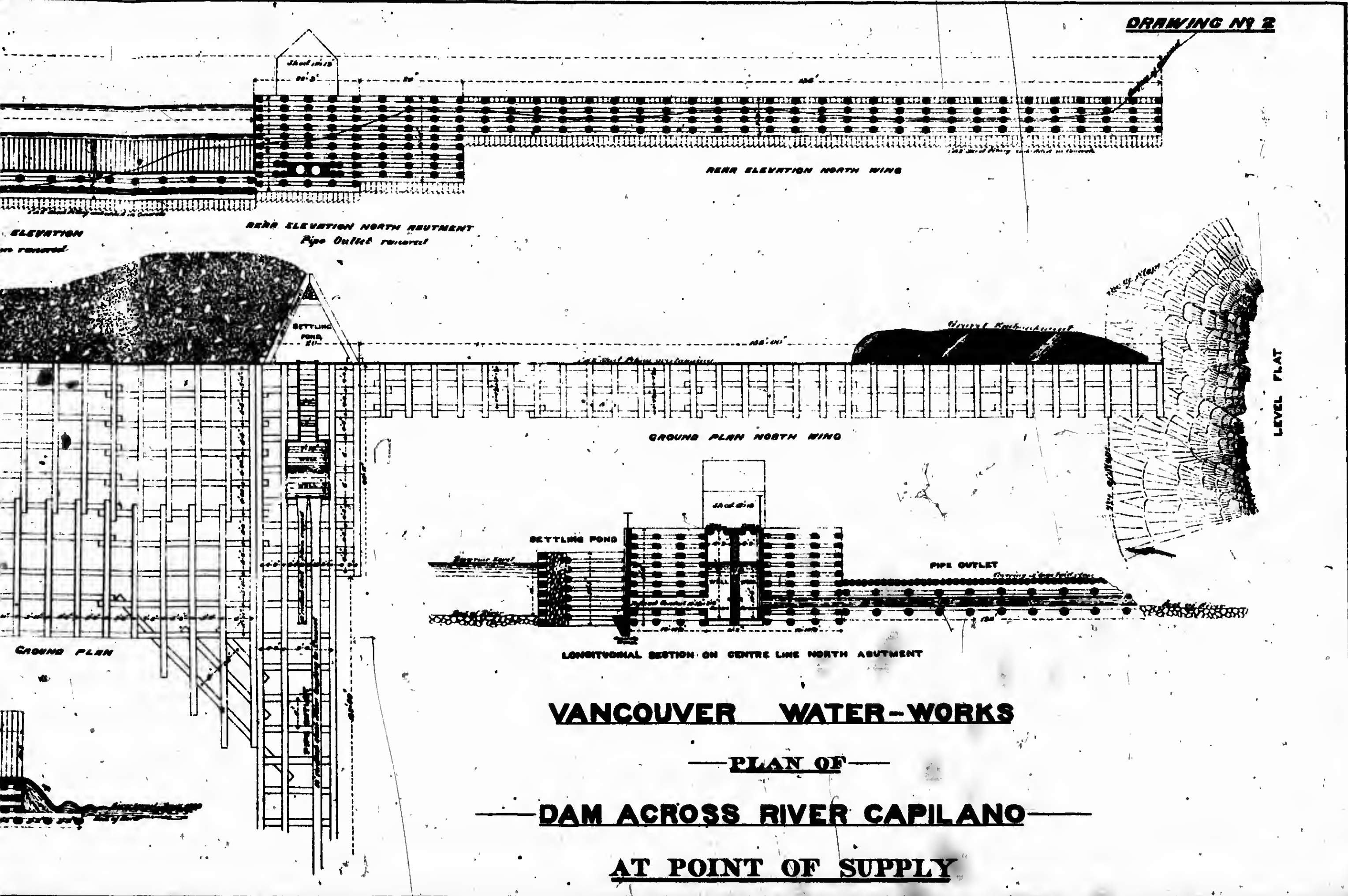


FLAT
40 feet above low water
Timbered Island
Log Jam
LOW FLAT ISLAND
flooded at high water
Boulder Beach
Log Jam
FLAT
12 feet above low water
Boulder Beach
RIVER
Scale of Feet
100 50 0 100 200 300 400 500



DRAWING No. 1
FLAT
above low water
FLAT
Area of Water way
Surface velocity
Fall of River
Bed of River
Granite Boulders
Discharge per day
Steel Riveted Main
Boulder
Beach
CAPILANO
Timbered Island
low water
Beach
RIVER
FLAT
FLAT
22 feet above low water
Burrard Inlet
VANCOUVER WATER-WORKS
PLAN OF
THE RIVER CAPILANO
SHEWING DAM SITE


Surface of Ground
LONGITUDINAL SECTION ON LINE C.D.
HALF LONGITUDINAL SECTION
ELEVATION
LEVEL FLAT
SURFACE PLAN
SURFACE PLAN PLANKING REMOVED
GROUND PLAN
GENERAL PLAN
Scale
CROSS SECTION

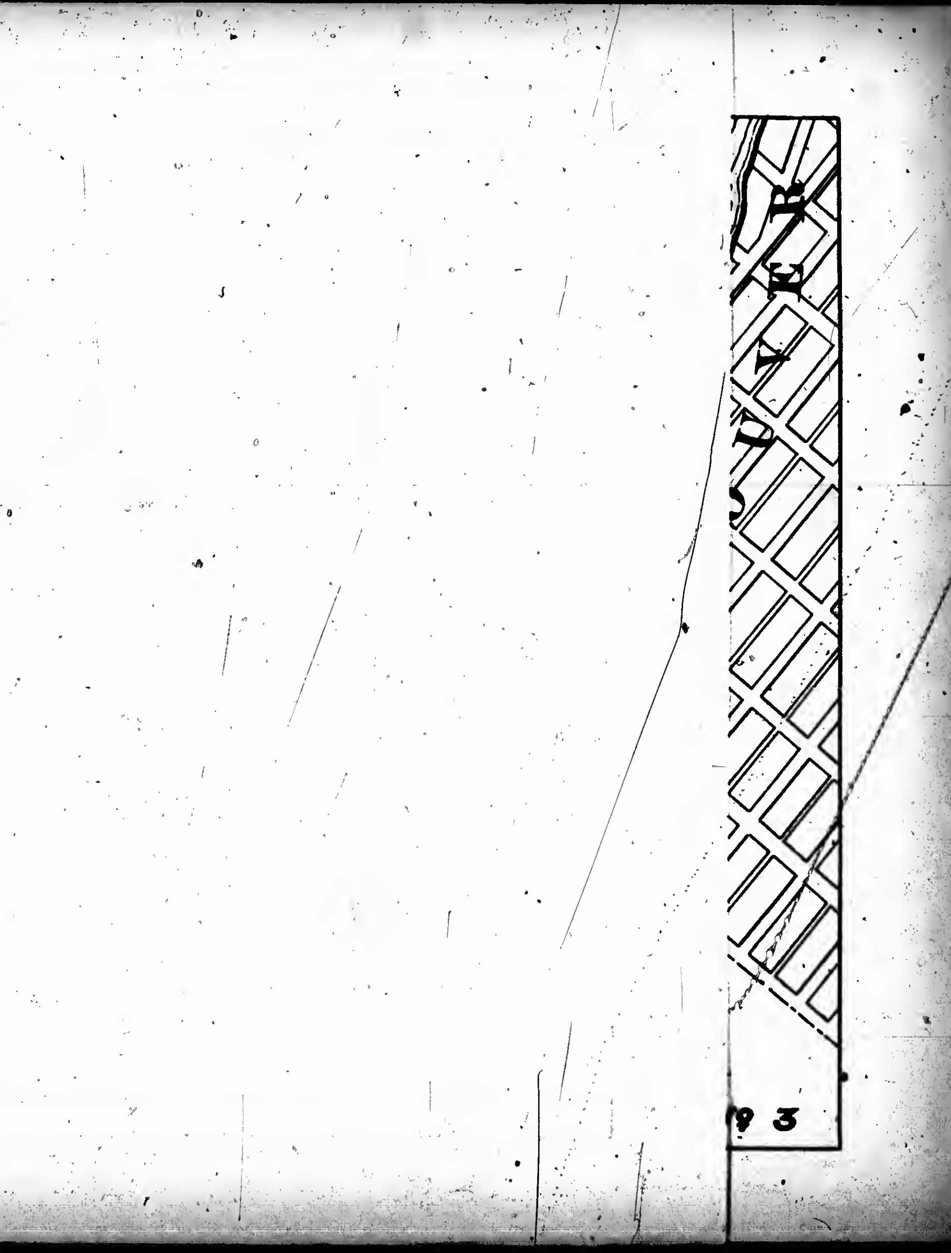


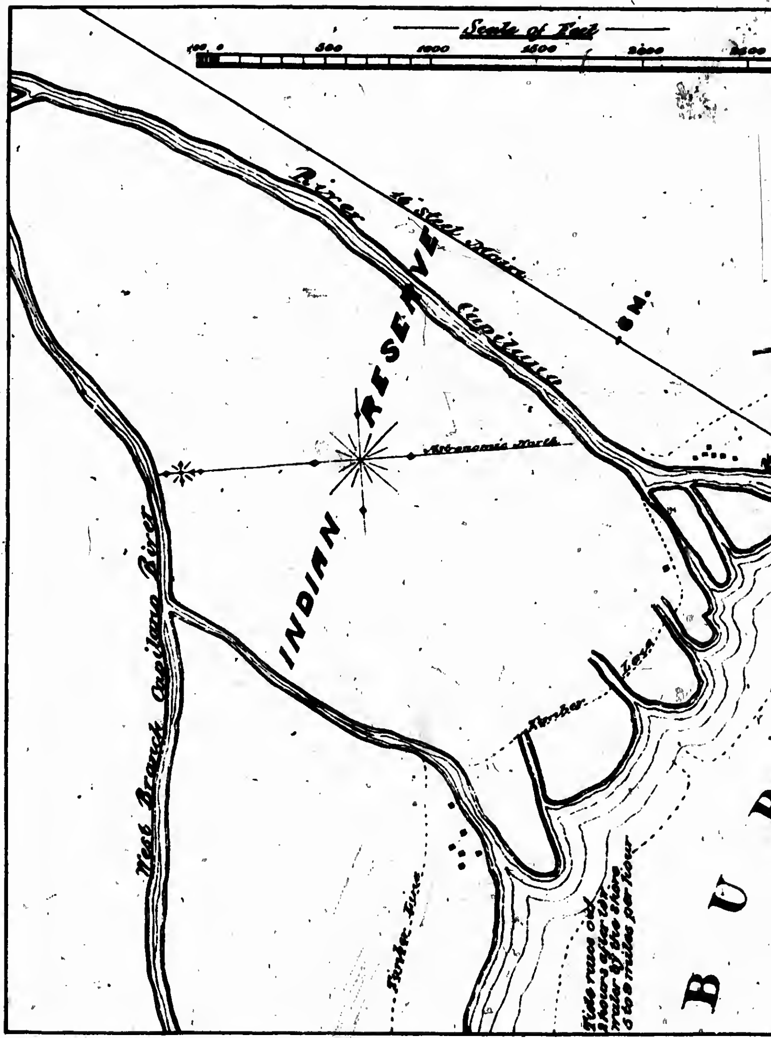
VANCOUVER WATER-WORKS

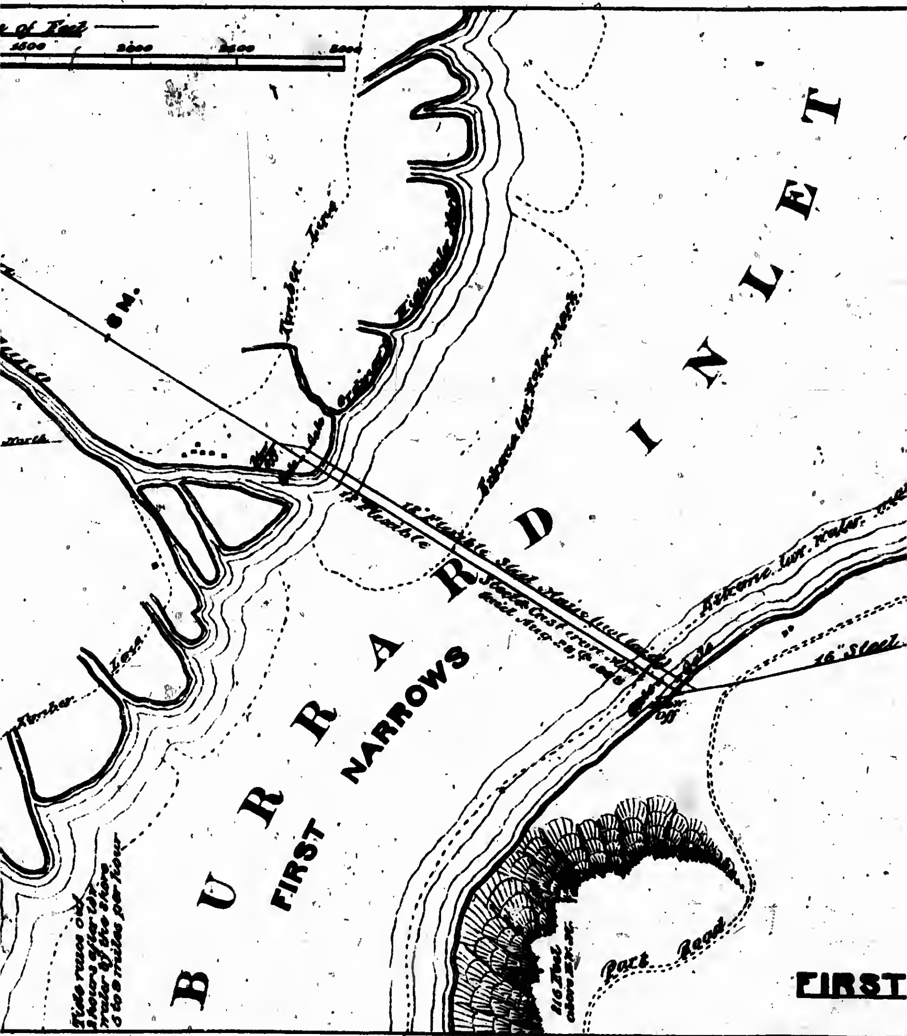
PLAN OF

DAM ACROSS RIVER CAPILANO

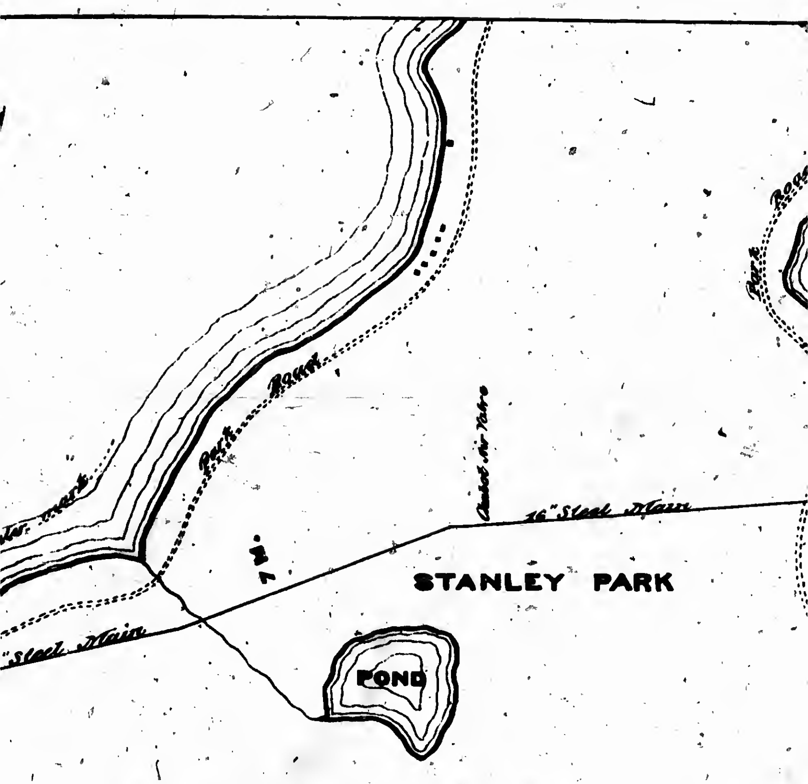
AT POINT OF SUPPLY




Scale of Feet
500
1000
1500
2000
River
Capilano
INDIAN RESERVE
Astronomic North
West Branch Capilano River
Timber Line
B U



BURRARD INLET
FIRST NARROWS
Timber Line
Park Road
FIRST

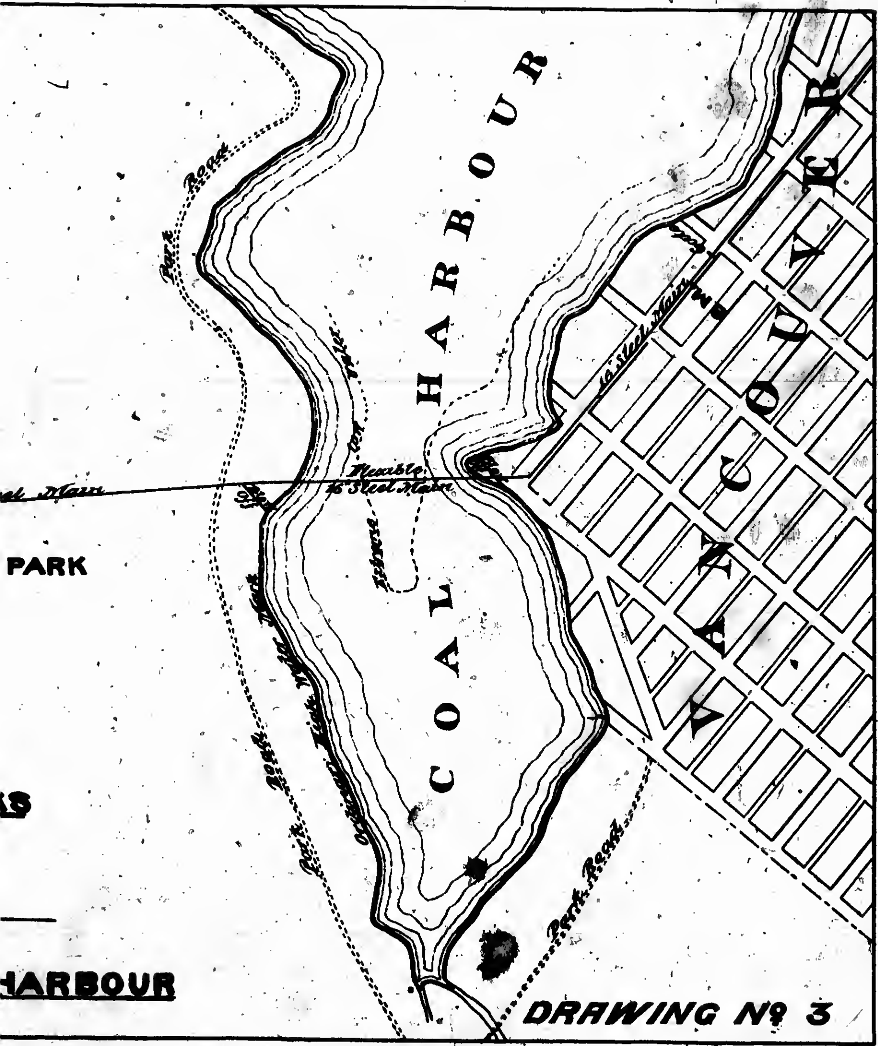


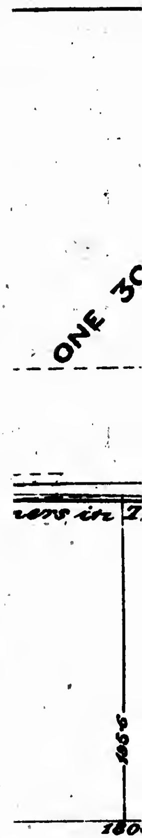
VANCOUVER WATER-WORKS

PLAN

SHEWING CROSSINGS OF

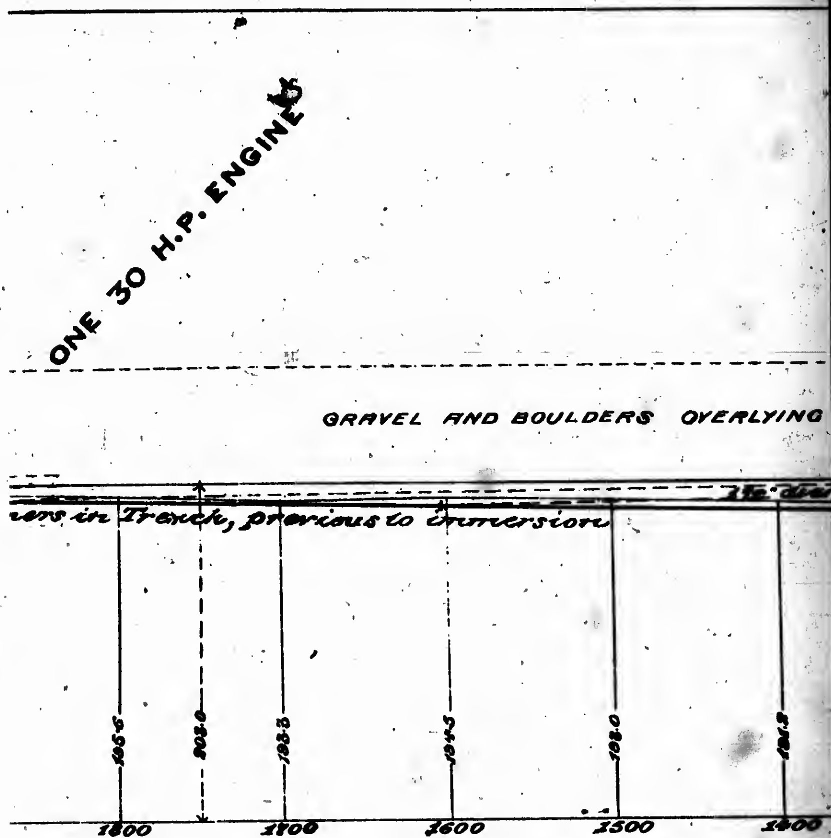
RST NARROWS AND COAL HARBOUR


COAL HARBOUR
VANCOUVER
PARK
HARBOUR
Park Road
Flexible
16 Steel Main
Park Road
DRAWING Nº 3



WAT

hewin

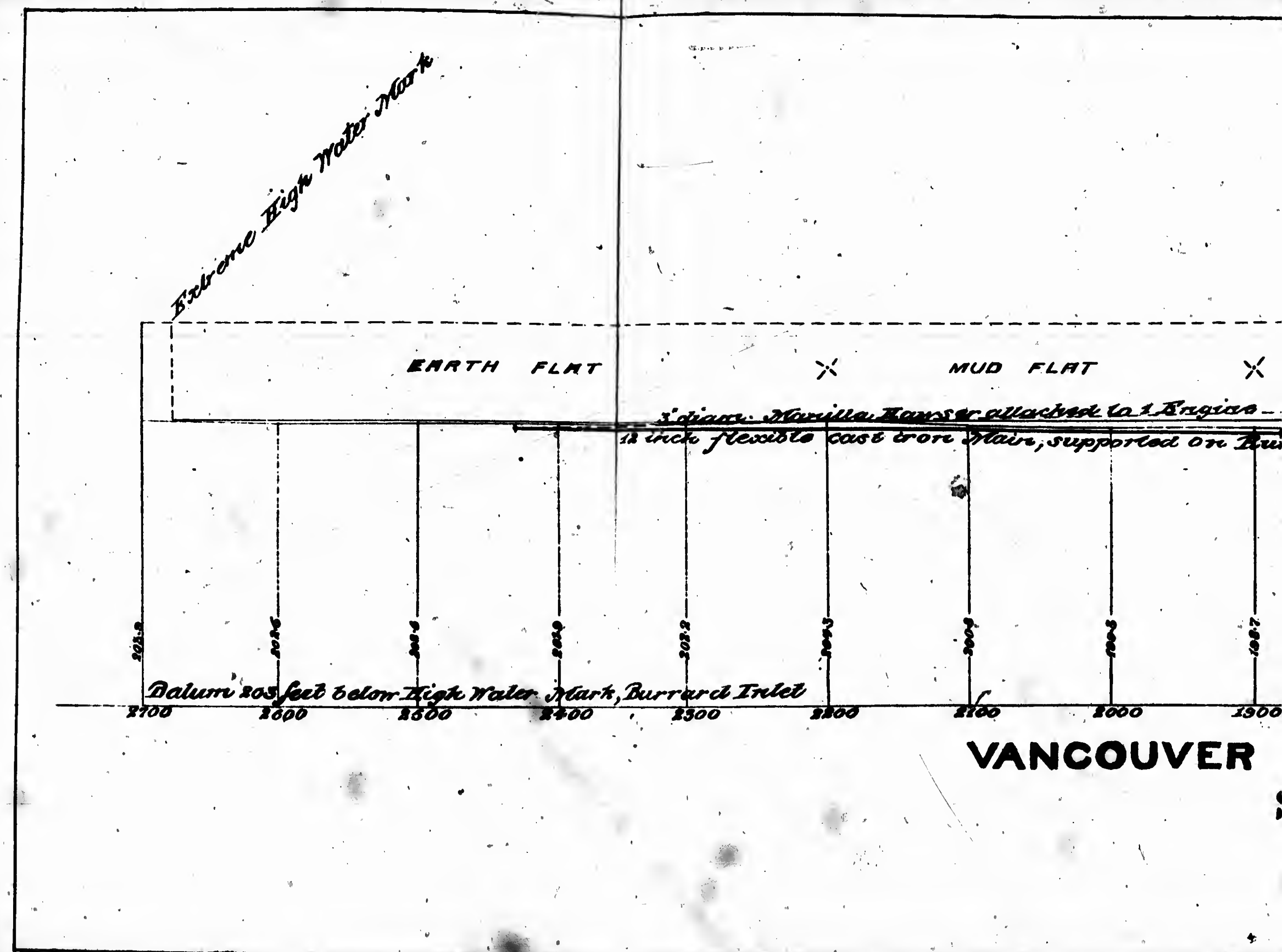


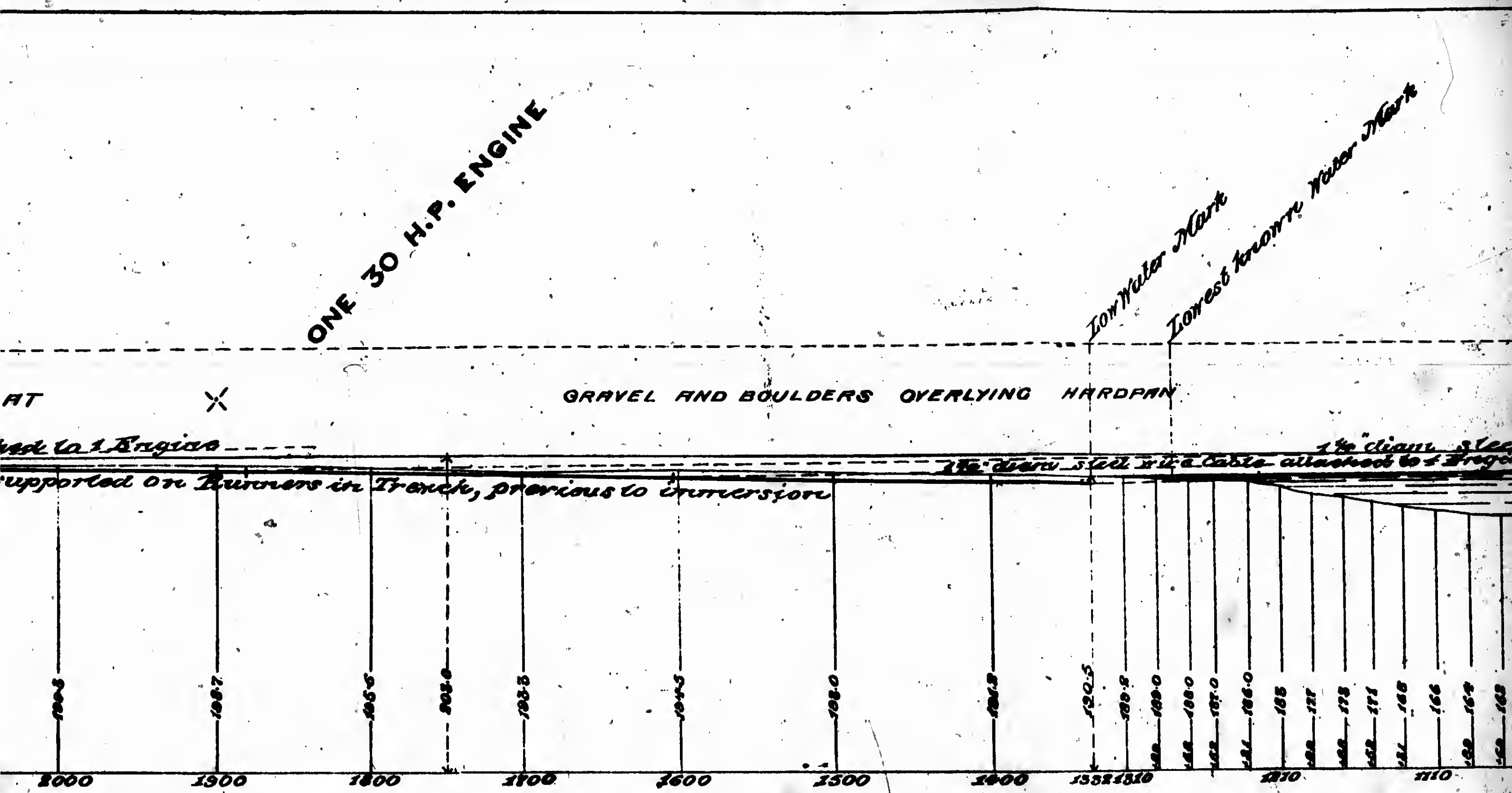
WATER-WORKS; CROSS SEC

hewing position of Flexible 12 inch

Horizo

100 50 0

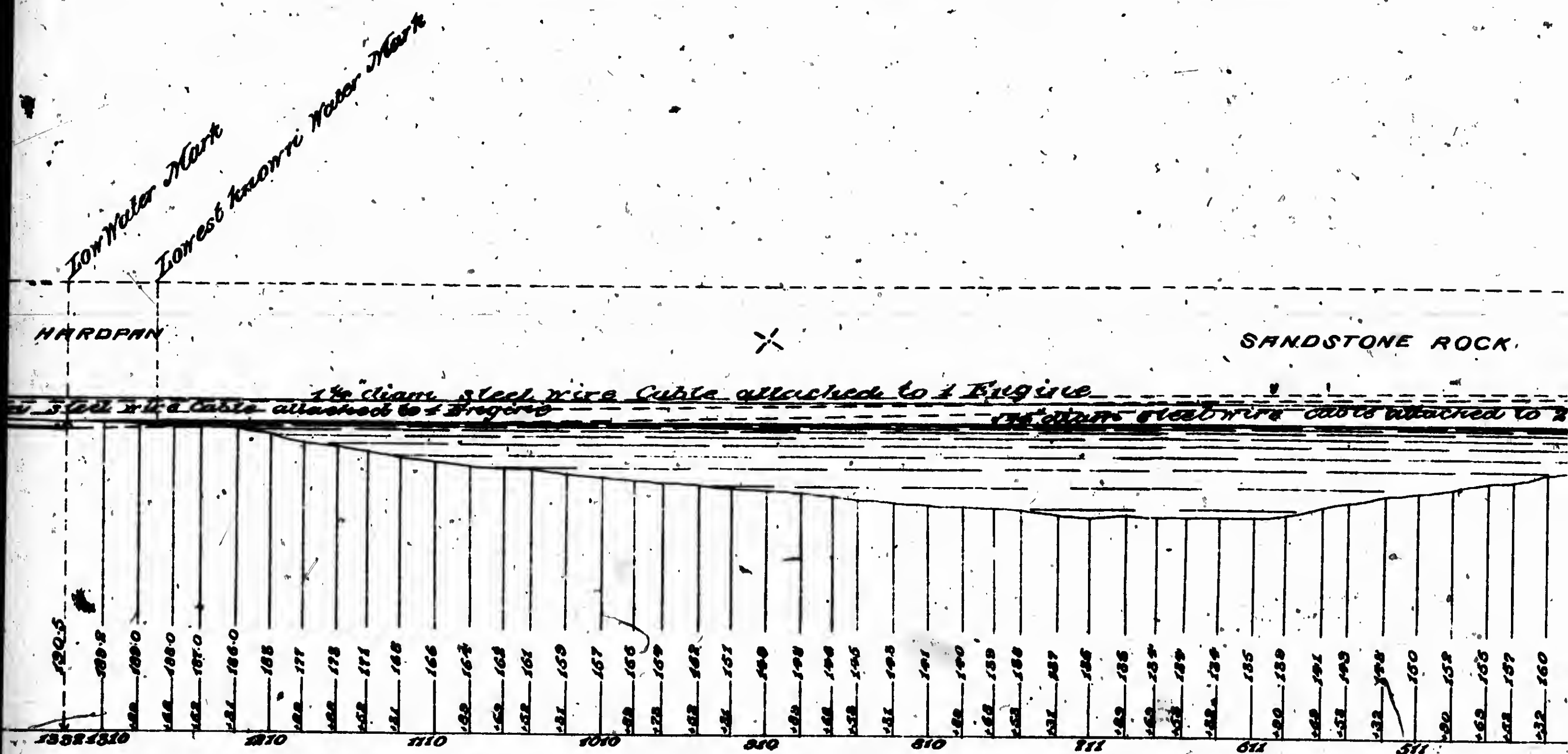

Extreme High Water Mark
EARTH FLAT
MUD FLAT
3" diam. Manilla Hawser attached to 1 Engine
12 inch flexible cast iron Main, supported on
203.2
198.7
Datum 203 feet below High Water Mark, Burrard Inlet
2700
2600
2500
2400
2300
2200
2100
2000
1900
VANCOUVER



COUVER WATER-WORKS; CROSS SECTION OF THE FI

Shewing position of Flexible 12 inch Main and stationary

Horizontal and Vertical Scale of fee

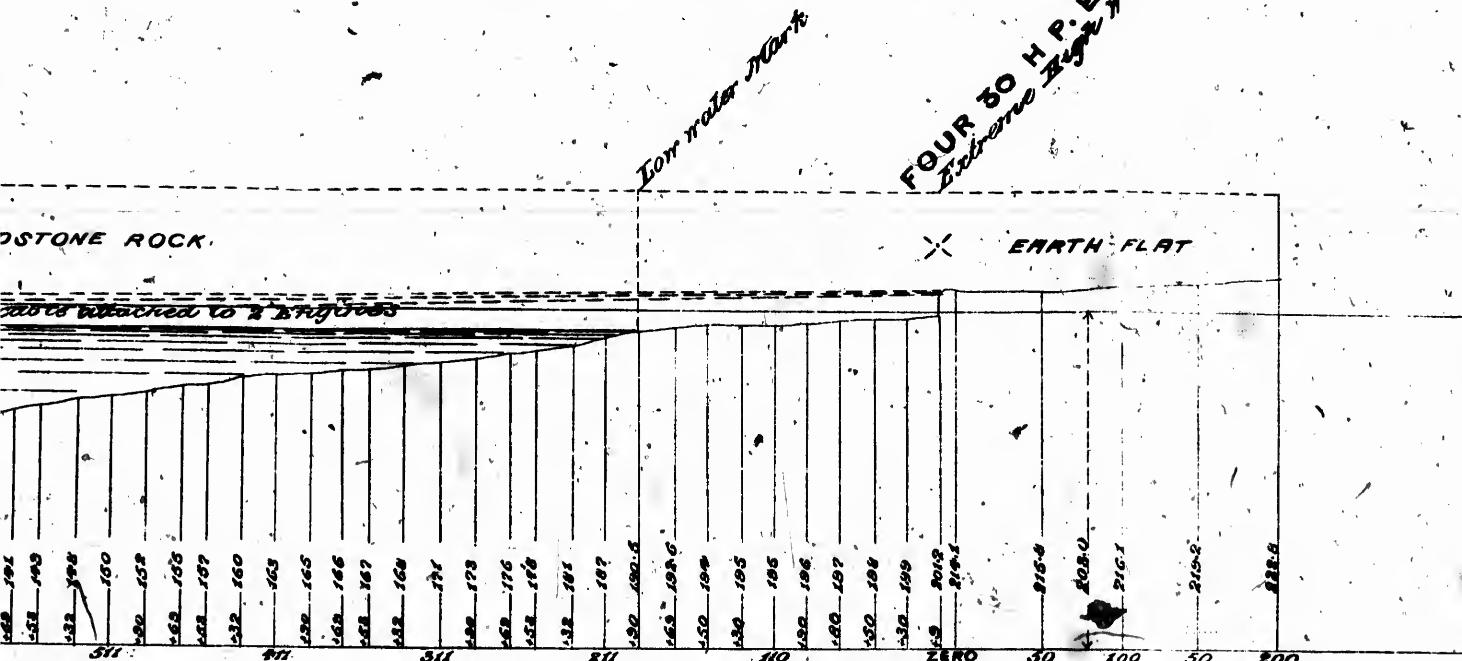


TION OF THE FIRST NARROWS OF BURRARD INLET

Main and stationary Engines previous to hauling

ntal and Vertical Scale of feet

DRAWING No. 4

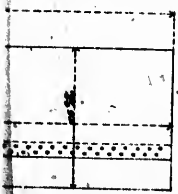


RD INLET

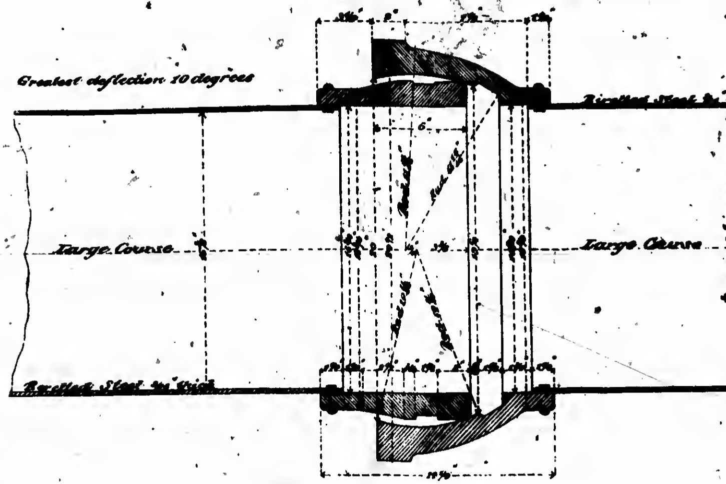
ING Nº 6

2 degrees

ING Nº 5

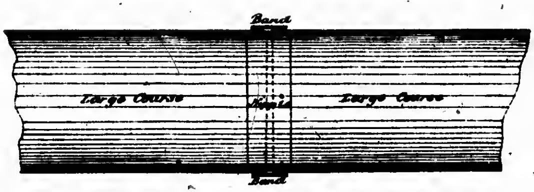


VANCOUV

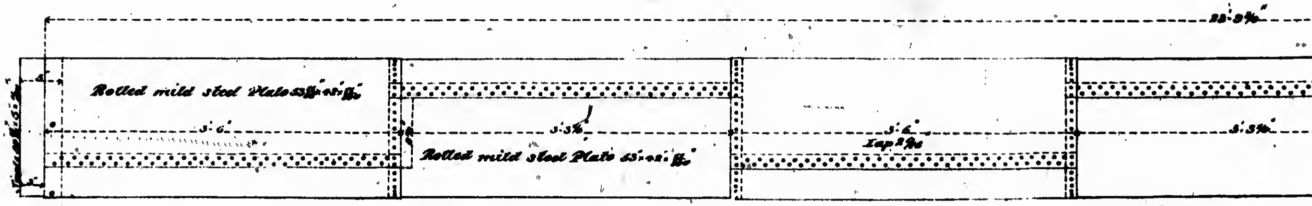


CAST IRON FLEXIBLE JOINT, 16 INCH RIVETTED STEEL MAIN

Submerged in Coal Harbour, Burrard Inlet



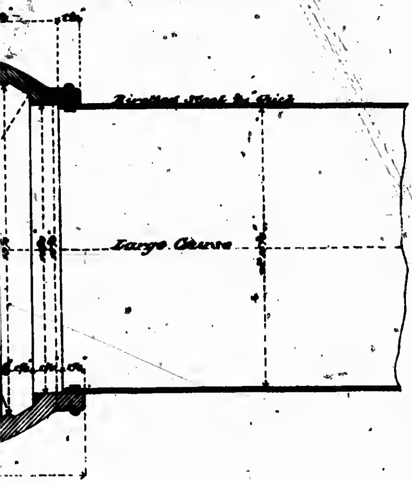
MOORE & SMITH'S JOINT



VANCOUVER WATER-WORKS, 16 INCH

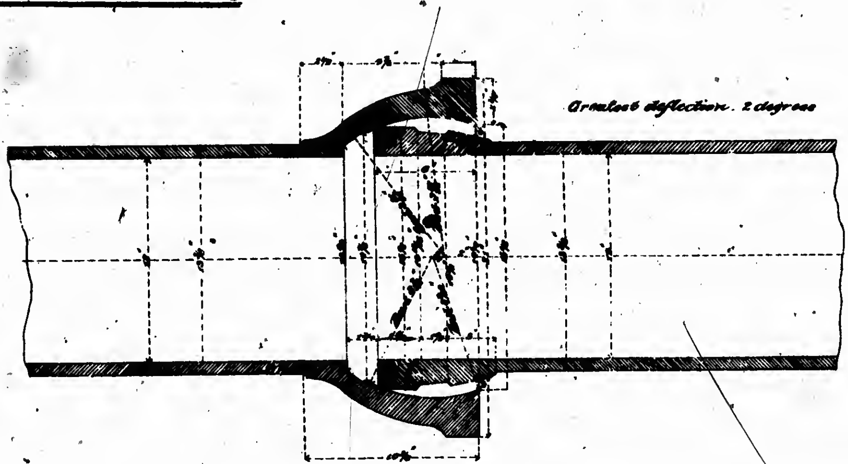
VANCOUVER WATER-WORKS

DRAWING No. 6



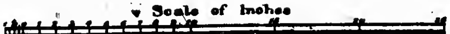
RIVETTED STEEL MAIN

—, Burrard Inlet — —

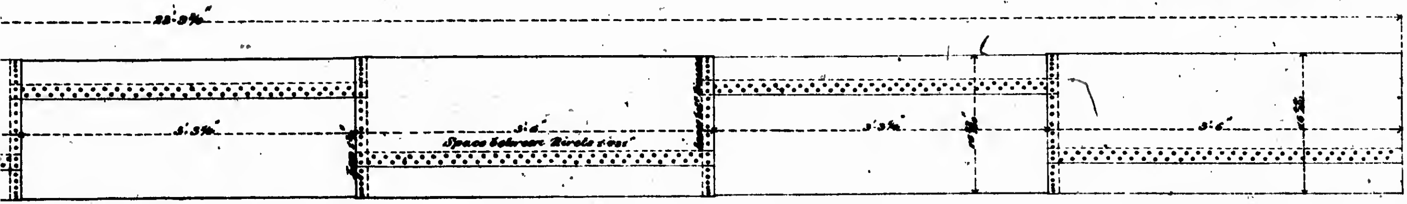


WARD'S FLEXIBLE JOINT, 12 INCH CAST IRON MAIN

— Submerged in First Narrows, Burrard Inlet —



DRAWING No. 5



-ATER-WORKS, 16 INCH RIVETTED STEEL MAIN

and remained taut and stationary, but only for
lackening took place, and the whole chain of
otion of several feet, and from that instant the
king was an assured fact. There had been a
the joints would withstand the enormous tensile
on them, but it now became certain that the
nain intact as long as the cast iron bell held

e distance between the blocks and pulleys being
he tackle connecting them had to be overhauled
et made by the chain of pipes. The process of
ecessarily slow; but being kept up without inter
forward end of the chain of pipes arrived at its
h shore.

g, at slack tide, a skillful marine diver walked
nlet, following the chain of pipes, entering on the
ing on the north. His report was to the effect
pipes was lying on the bed of the Inlet in a per
out sag or bend, that the heavy projecting bells
d, as they were being drawn over, a deep groove
ck, and that the whole chain of pipes was resting
own excavating; that above this trench silt was
that in his unqualified opinion the pipes would
ly covered over, rendering their permanency and