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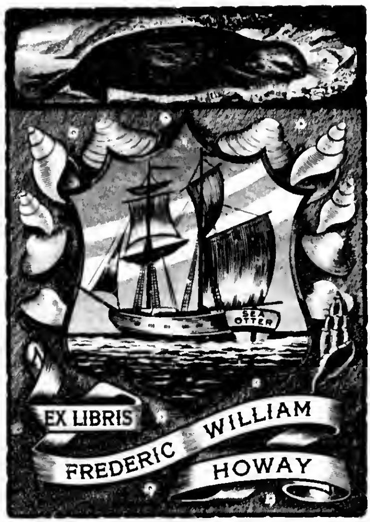
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Canadian Society of Civil Engineers.

VANCOUVER WATER WORKS

BY

H. B. SMITH,

M. Can. Soc. C.E.

BY PERMISSION OF THE COUNCIL.

EXCERPT MINUTES OF THE TRANSACTIONS OF THE SOCIETY.

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Paper No. 35.

VANCOUVER WATER WORKS.

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

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, that 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 Montreal 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 $4\frac{3}{4}$ 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 $4\frac{1}{2}$ 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, M. 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 town-site 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 town-site, 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 town-site, and that an immediate outlay for an efficient system of water works would be a remunerative investment.

Accordingly, the extension of the railway to the Granville town-site 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 Water Works Company, and proposing to construct a gravity system of water works, 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 being 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 water works 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 $6\frac{1}{2}$ 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 $3\frac{1}{2}$ miles below it.

By reference to Plate XVI, which shews 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 $4\frac{1}{2}$ 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 XVII 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 four 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' $5\frac{1}{2}$" 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 one 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 of 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 enbankment, 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 neighbourhood, 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 three 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 XVII shews 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 eight longitudinals, above which, on the fourth course, are the horizontal openings previously mentioned. These are 28 in number, five feet wide, 12 ins. 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 one 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 obtainable 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 three feet deep, 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 one 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 half-way 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, each 5′ 8″ × 4′ 7″ × 18′ 9,″ 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 ft. 7 ins. 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 shewn 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 three 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 ft. 11 ins. 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 $17\frac{1}{2}$ 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 four 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, $43\frac{1}{2}$ feet long, and pass under the whole width of both abutments. Similarly two caps $43\frac{1}{2}$ 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 ft. 9 ins., 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 satisfied 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 fourteen 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 $\frac{7}{8}''$ and $\frac{3}{4}''$ round iron, and, of lengths varying from 12″ to $32\frac{1}{2}''$. Spikes for 3″ planking were 6″ long, weighing 11 per pound, and nails for 1″ planking were $4\frac{3}{8}''$ 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 ft. 2 ins.

The total cost amounted to $15,039.26.

ROUTE OF THE MAINS.

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 rug ged 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 27¾ 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 inch main at the centre of the tunnel, for the first 8000 feet of its length, passes over a 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 XVIII and XIX shew 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 $2\frac{1}{2}$ 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 neighbourhood, 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 $70\frac{1}{2}$ feet at high water. The "Bore" or tidal current varies from $4\frac{1}{2}$ to 9 miles per hour, the greatest velocity occurring in the out-going tide, $2\frac{1}{2}$ 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 of its force 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 in. 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 cuts 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.

TRENCHING, TUNNELLING, ETC.

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 $1\frac{1}{2}$ 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. (See Appendix, p. 358.)

ADVANTAGES OF STEEL OVER WROUGHT AND CAST IRON MAINS.

Previous to describing the rivetted mild steel mains used by the Vancouver Water Works 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 favour, 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 labour 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 further on in this paper. Between 1870 and 1885, the Risdon Iron Works Company, of San Francisco, 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 Water Works Co.—36 miles of pipe from 18 to 52 inches diameter, and from $\frac{8}{100}$ to $\frac{3}{8}$ in. thick.

The Virginia and Gold Hill Water Works Co.—3 miles of pipe $11\frac{1}{2}$ inches diameter, and from $\frac{1}{4}$ to $\frac{3}{8}$ in. 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 Water Works Co.—2 miles of pipe, 12 inches diameter, $\frac{12}{100}$ to $\frac{5}{16}$ in. thick.

The Portland Water Works Co.—$4\frac{1}{4}$ miles of pipe, $30\frac{1}{2}$ inches diameter, and $\frac{17}{100}$ in. thick.

The Cherokee Flat Mining Co.—3 miles of pipe, 30 inches diameter, and from $\frac{8}{100}$ to $\frac{3}{8}$ in. 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 $62\frac{1}{2}$ 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 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 shew 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 $\frac{7}{8}$ inch (= .875) thick, then wrought iron pipes of the same diameter would be .875 × .3174 = .2778 inches thick, and mild steel pipes would be .875 × .1786 = .1563 inches thick or say $\frac{7}{8}$ in., $\frac{9}{32}$ in. and $\frac{5}{32}$ in. thick respectively, for equal internal working pressures.

"Then again, if one mile of 34 inch cast iron pipes, $\frac{7}{8}$ 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 × 0.3678 = 200.6 tons.
and one mile of mild steel 545.6 × 0.2111 = 115.2 tons.

"These results shew that for equal diameters, 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 $4\frac{1}{4}$ 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 favours 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 there are, consequently, 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 labour 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 shew 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	
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	

	Cast Iron.	*Mild Steel.*	*Saving.*
Relative cost of Carriage 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	$9\frac{1}{2}$ p.c.
" " " each mile	1	0.405	$59\frac{1}{2}$ 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 Water Works 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 $\frac{11}{100}$ in. in thickness, and the 12 inch $\frac{3}{16}$ in. 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 XX shews 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 ea 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 XX shews 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 scarped 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 $\frac{5}{16}$ 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 will, in all probability, result in 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. (See Appendix, p. 361.)

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 with out 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 feet, 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 were 179. (See Appendix, p. 363.)

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 nch 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 $2\frac{1}{4}$ 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.

DISTRIBUTION OF MAINS, LEAD AND CASTINGS.

Inasmuch as the pipe line between the centre of the City and Coal Harbour follows well graded streets, the distribution of steel mains, lead and castings was attended with little or no difficulty. Ordinary four-wheeled drays, drawn by two horses and accompanied by two teamsters, accomplished this work in a most satisfactory manner, at a cost of $3.00 per ton.

The flexible mains for the crossings of Coal Harbour and Burrard Inlet, were transported on scows and discharged on the beach between high and low water mark at a cost of $5.00 per ton.

Between Coal Harbour and Burrard Inlet the first difficulties were encountered. The land between these two waters being heavily timbered, and only accessible by waggon road at both ends, rendered necessary the construction of a temporary road parallel to the pipe trench, and within easy reach of it. This was of the simplest character, being a roughly graded track, 8 feet wide, along which and at right angles to it were placed, at regular intervals of ten feet, rough undressed skids. Sleighs similar to those used by loggers in winter, and drawn by two powerful horses, carried two lengths of pipe per load along this road and deposited them where required. The cost of this service, including the construction of road, averaged $5.00 per ton.

Between Burrard Inlet and the Dam the work of distribution was accomplished under very great difficulties. As before stated, the country traversed by the pipe line is very irregular and heavily timbered. No roads exist in the vicinity, and the construction of an economical mode of conveyance for the 480 tons of steel mains, lead and castings, which were to be laid continuously along the pipe trench, was a problem, the solution of which involved considerable ingenuity. The mode adopted was a combination of waggon road and tramway. A tramway 15,400 feet long was built from the Inlet to a point on the side hill ground, about 4,000 feet south of the rock tunnel. This tramway is of three feet gauge with 4″ and 5″ track timbers, supported on ties placed four feet apart. At four points in its course there occur sudden breaks in ground level. The first takes place 5,800 feet north of the Inlet, the ground rising 37 feet in a distance of 135 feet; the second at 9,400 feet north of the Inlet, the ground rising 54 feet in a distance of 260 feet; the third at 11,100 feet north of the Inlet, the ground rising 27 feet in a distance of 82; and the fourth at the termination of the tramway, where it leaves the pipe trench and climbs the face of the side hill to the flat above. The total rise at this point is 80 feet in a distance of 150 feet. In distributing the pipes along the tramway, each car, pulled by one horse, carried three lengths of 16-inch pipe. On arrival at one of the above-mentioned changes of level, the horse was removed from the car to the top of the rise, where it was made to haul on a cable connected with the car, until the car also had reached the top. At the termination of the tramway a waggon road was built following the edge of the flat, a distance of 4,000 feet, to the rock tunnel. At suitable intervals clearings were made from the waggon road to the pipe trench on the side hill below, down which the pipe lengths were lowered, one at a time, by cables.

At the rock tunnel the face of the Cañon slopes downwards 164 feet in a distance of 400 feet. A short tramway was built down this steep descent, and loaded cars lowered down by cables. From the foot of this Cañon a waggon road was built and operated in a manner similar to that between Coal Harbour and Burrard Inlet.

The prices paid for the distribution of mains, lead and castings north of Burrard Inlet were, for the first 1268 feet \$7.64 per ton, for the next 18,859 feet \$12.87 per ton, and for the next 13,516 feet \$14.85 per ton. These prices included the building of the tramway and the waggon roads as well as the cost of the distributing mains.

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, thoroughly coated with Dr. Smith's coal pitch varnish. Each length is 12′ 4″ over all, $\frac{11}{16}$in. 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. Plate XX shews 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 Water Works. 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 7½ 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, to 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 revolved at ordinary drum, to which was attached a hundred feet of wrought, iron chain, connecting with a continuous wrought iron rod of 1¼ 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 51 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 place 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 and 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, shewing 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 shews 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 two 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 Plate XIX). 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 a 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, 1888, 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 train 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, as they were being drawn over, had scooped deep grooves 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 strain 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 shewn on Plate XX, and connected with the cast iron pipes, making a total length of 1496½ feet of 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 shewn), 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, sufficiently deep to embed the whole chain, and thus effectually destroy the possibility 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.

[illegible].—That the pipes being embedded in the bottom of the inlet, and [illegible]ed 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, and as a 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 attempted. 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 Water Works 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 ine was 40 days.

The following table shews 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.	Water Works Co.	Where laid.
Single 36 inches.	4000	Toronto Water Works.	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. Plate XX shews 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 unusually 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″, $2\frac{1}{2}$″ 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 supply 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......	$3\frac{3}{4}$″	$5\frac{1}{4}$″	6″	$6\frac{3}{8}$″	8″	$9\frac{7}{8}$″
Diameter of Bell in inches..........	$3\frac{1}{8}$″	$5\frac{3}{4}$″	$7\frac{7}{8}$″	10″	$14\frac{1}{8}$″	$18\frac{1}{2}$″
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 advantages over all others.

There being two main valves, possible 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 main 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 THE WATER 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 he 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, the space between the ring and the pipe being filled up with lead, and carefully caulked in the usual manner.

From the drawings accompanying this paper, Plates XVI to XX have been prepared.

FINAL ESTIMATE COVERING ALL WORKS BETWEEN THE SUBMERGED MAIN, BURRARD INLET, AND THE CAPILANO DAM, BASED ON FINAL LOCATION OF PIPE LINE, MAY, JUNE, 1888.

Station. From	Station. To	Description of Work.	Quantities.	Rate.	Amount.
		TUNNELLING.		$	$
		6′ x 4′ in solid rock	Lin. ft. 280	15 00	4,200 00
		Earth filling on floor of tunnel	C. yds. 42	0 40	16 80
		Excavation of approaches to same in rock.......	" 283	2 50	707 50
		Excavation of approaches to same in earth.......	" 125	0 40	50 00
		6′ x 4′ in hardpan	Lin. ft. 108	6 50	702 00
		Excavation of approaches.	C. yds. 118$\frac{4}{10}$	0 50	59 20
					5,735 50
		EXCAVATION AND REFILLING OF PIPE TRENCH.			
12+76	19+00	Hardpan and mud below high water mark......	C. yds. 206	1 00	206 00
19+00	27+00	Earth and water below high water mark......	" 322	0 75	241 50
27+00	48+00	Earth, small boulders and hardpan	" 1093	0 75	819 75
48+00	70+00	Earth and sand	" 1062	0 60	637 20
70+00	87+00	Gravel, hardpan and boulders	" 933	1 00	933 00
87+00	91+00	Earth and boulders	" 153	1 00	153 00
91+00	105+00	Earth, boulders and hardpan	" 753	1 00	753 00
105+00	122+00	Earth and boulders......	" 879	1 00	879 00
122+00	128+00	Sand, clay and water....	" 333	1 00	333 00
128+00	131+50	Gravel and boulders.....	" 170	1 00	170 00
131+50	134+00	Earth and sand	" 152	0 60	91 20
134+00	144+00	Earth, hardpan and boulders	" 541	1 00	541 00
144+00	211+54	Earth, boulders and gravel	" 7,407	0 60	4,444 20
211+54	213+43	Solid rock	" 83	2 50	207 50
217+20	231+38	Earth and boulders......	" 897	1 00	897 00
231+38	237+38	Sand and boulders.......	" 489	1 20	586 80
237+38	255+38	Earth, gravel and boulders.....	" 1162	1 20	1,394 40
255+38	268+38	Sand and boulders	" 735	1 00	735 00
268+38	270+28	Boulders	" 360	1 20	432 00
270+28	274+28	Earth, gravel and boulders..............	" 345	1 20	414 00
274+28	285+00	Earth, boulders and hardpan	" 698	1 20	837 60
285+00	293+00	Clay, gravel and boulders.	" 618	1 20	741 60
293+00	303+00	Earth, boulders and hardpan..................	" 611	1 20	733 20

Station. From	Station. To	Description of Work.	Quantities.		Rate.	Amount.
					$	$
303+00	308+50	Boulders................	C. yds.	451	1 20	541 20
308+50	317+60	Sand, hardpan and boulders..............	"	611	1 20	733 20
317+60	320+00	Boulders	"	284	1 20	340 80
320+00	350+74	Earth, sand and boulders..	"	2,066	1 00	2,066 00
12+76	350+74	Excavation for 1,402 pipe joints................	"	800	1 00	800 00
12+76	350+74	Additional excavation for pipe culverts under Streams.............	"	340	1 00	340 00
12+76	350+74	Catchwater drains at embankments	"	400	0 60	240 00
350+74		Filling pipe outlet at dam.	"	100	0 25	25 00
						22,267 15
		EMBANKMENTS.				
Earth		Over and under pipes at various points along pipe line	C. yds.	2,594	0 40	1,037 60
Gravel and boulder.		At base of certain land slides.................	"	1,100	0 50	550 00
		Rip rap for same	"	900	0 50	450 00
						2,037 60
		CULVERTS.				
		Close fitted timber culverts, enclosing pipe above various embankments, and under various streams, including earth packing round pipes.................	L. ft.	860	2 50	2,150 00
		DISTRIBUTION OF PIPES, SLEEVES, LEAD, ETC.				
14+32	27+00	Hauling and distributing along line of trench, ready for laying, $36\frac{1}{3}$ lengths of 12″ Steel rivetted mains $\frac{3}{16}$″ thick, in lengths of 23′, $9\frac{3}{4}$″, each weighing, sleeve included, $715\frac{6}{10}$ lbs	Tons.	$11\frac{61}{100}$	7 64	88 70
		Hauling and distributing as above castings and lead for 12″ main......	"	239	7 64	18 26

Station From	Station To	Description of Work.	Quantities.		Rate.	Amount.
22+34	27+00	Hauling and distributing as above 19 lengths of 16″ steel rivetted main, $\frac{11}{100}$″ thick, in lengths of 23′ 9¾″ each, weighing sleeve included, 550$\frac{1}{10}$ lbs....	Tons.	4$\frac{67}{100}$	$ 7 64	35 68
		Hauling and distributing lead for same....	"	0$\frac{44}{100}$	7 64	3 37
6+00	215+59	Hauling and distributing as above 767 lengths of 16″ rivetted steel main $\frac{11}{100}$″ thick, in lengths of 23′, 9¾″, each weighing, sleeve included, 550$\frac{1}{10}$ lbs....	"	188$\frac{36}{100}$	12 87$\frac{31}{47}$	2425 43
		Hauling and distributing as above, castings, lead and extra sleeves for 16″ main as above....	"	46$\frac{16}{100}$	12 87¾	94 38
27+00	215+59	Partially distributing 6 lengths of 16″ steel main (rivetted) as above....	"	1$\frac{48}{100}$	6 44	9 53
215+59	350+89	Hauling and distributing as above 568 lengths of 22″ steel rivetted main, $\frac{11}{100}$″ thick, in lengths of 23′ 9¾″ each weighing, sleeve included, 746$\frac{1}{10}$ lbs....	"	189$\frac{37}{100}$	14 85	2812 14
		Hauling and distributing as above 2 rivetted steel thimbles for connection at dam, each weighing 242 lbs....	"	$\frac{22}{100}$	14 85	3 27
		Hauling and distributing as above, castings, lead and extra sleeves for 22″ mains....	"	30$\frac{38}{100}$	14 85	458 57
		Partially distributing as above 7 lengths of 22″ rivetted steel main....	"	2$\frac{34}{100}$	7 43	17 38
		Partially distributing as above 6′ 22″ castings....	"	2$\frac{33}{100}$	7 42	17 29
						$38,674 25

DETAILS OF RIVETTED STEEL MAINS.

Description.	12 inch Main.	16 inch Main.	22 inch Main.
Large plates	$42\frac{1}{10}'' \times 42''$	$53\frac{11}{16}'' \times 42''$	$72\frac{9}{16}'' \times 42''$
Small plates	$40\frac{9}{10}'' \times 42''$	$53'' \times 42''$	$71\frac{7}{8}'' \times 42''$
Thickness of plates	$\frac{3}{16}$	$\frac{11}{100}''$	$\frac{11}{100}''$
Ultimate tensile strain per square inch	72000 lbs.	72000 lbs.	72000 lbs.
Weight of large plate	94.024 "	70.359 "	95.07 "
Weight of small plate	91.344 "	69.442 "	94.15 "
Number of large plates in one length	4	4	4
Number of small plates in one length	3	3	3
Total weight of plates in one length	650.128	489.762 lbs.	662.73 lbs.
Outside measurement of large plates in place	42″	42″	42″
Outside measurement of small plates in place	$39\frac{1}{4}''$	$39\frac{1}{4}''$	$39\frac{1}{4}''$
Straight seam laps	$2\frac{5}{8}''$	$2\frac{1}{16}''$	$2\frac{1}{16}''$
Round seam laps	$1\frac{3}{8}''$	$1\frac{3}{8}''$	$1\frac{3}{8}''$
Length of pipe, exclusive of nipple	$23'.9\frac{3}{4}$	$23'.9\frac{3}{4}''$	$23'.9\frac{3}{4}''$
Nipple	$38\frac{3}{10}'' \times 5'' \times \frac{11}{100}''$	$50\frac{15}{16}'' \times 5'' \times \frac{11}{100}''$	$69\frac{3}{4}'' \times 5'' \times \frac{11}{100}''$
Exterior projection of nipple	3″	3″	3″
Weight of nipple	5.97 lbs.	7.94 lbs.	10.88 lbs.
Band	$4'' \times \frac{1}{2}''$	$4'' \times \frac{1}{4}''$	$4'' \times \frac{1}{4}''$
Inside diameter of band	$13\frac{3}{8}''$	$17\frac{65}{100}''$	$23\frac{65}{1000}''$
Weight of band	24.72 lbs.	15.43 lbs.	20.77 lbs.
Outside diameter of pipe at joint.	$12\frac{3}{4}''$	16.44″	22.42″
Thickness of lead in joint	$\frac{5}{16}''$	$\frac{5}{16}''$	$\frac{5}{16}''$
Weight of lead per joint	21.29 lbs.	27.30 lbs.	37.08 lbs.
Asphaltum coating $\frac{1}{16}''$ thick	$20\frac{1}{2}$ "	27 "	37 "
Space between ends of pipes when laid	$\frac{1}{4}''$	$\frac{1}{4}''$	$\frac{1}{4}''$
Number of lengths per mile	221.538	221.538	221.538
Straight seam rivets, head	$\frac{5}{8}' \times \frac{5}{32}''$	$\frac{5}{8}'' \times \frac{5}{32}''$	$\frac{5}{8}'' \times \frac{5}{32}''$
Do do body	$\frac{5}{16}'' \times 1''$	$\frac{5}{16}'' \times \frac{5}{8}''$	$\frac{5}{16} \times \frac{5}{8}''$
Distance apart centre to centre	1.348″	1.4306″	1.4306″
Distance between each row	$\frac{7}{8}''$	$\frac{11}{16}''$	$\frac{11}{16}''$
Distance centre of row to edge of plate	$\frac{7}{8}$	$\frac{11}{16}''$	$\frac{11}{16}''$
Number of rivets in each row	28	28	28
Do per lb	40	$51\frac{2}{10}$	$51\frac{8}{10}$
Total number of seam rivets per length	392	392	392
Weight of seam rivets per length	9.8 lbs.	7.656 lbs.	7.656 lbs.
Round seam rivets, body	$\frac{5}{16}'' \times 1''$	$\frac{5}{16}'' \times \frac{5}{8}''$	$\frac{5}{16}'' \times \frac{5}{8}''$
Do do head	$\frac{5}{8}'' \times \frac{5}{32}''$	$\frac{5}{8}'' \times \frac{5}{32}''$	$\frac{5}{8}'' \times \frac{5}{32}''$
Distance apart centre to centre	1178″	1.076″	1.068″
Distance centre of row to edge of plate	$\frac{11}{16}''$	$\frac{11}{16}''$	$\frac{11}{16}''$
Number of rivets per seam	34	48	66
Do per lb	40	$51\frac{2}{10}$	$51\frac{2}{10}$
Total number of round seam rivets	204	288	396
Weight of round seam rivets per length	5.1 lbs.	5.625 lbs.	7.734 lbs.

Weight of each length..............	690.928 lbs.	534.663 lbs.	726.078 lbs.
Weight per lineal foot..............	29.015 "	22.453 "	30.491 "
Steel plates, less rivet holes, per mile..............................	142,945 lbs.	107,748 lbs.	145,957 lbs.
Nipples, per mile..............	1323 "	1759 "	2410 "
Rivets, do	3323 "	2960 "	3427 "
Bands, do	5476 "	3418 "	4601 "
Lead, do	4717 "	6048 "	8215 "
Asphaltum, do	4542 "	5982 "	8197 "
Average weight per foot..........	30.7435 lbs.	24.226 lbs.	32.728 lbs.
Cost of pipe per foot run, including rings, but exclusive of bands and special castings, delivered at Vancouver	$1.53½	$1.35	$1.72½
Cost of unloading from scow at Capilano Wharf (lead and bands included) per foot run...........	2.3058 cts.	1.8169 cts.	2.4546 cts.
Cost of distributing along trench, lead and bands included, per foot run........................	10.4857 cts.	13.9191 cts.	21.6969 cts.
Cost of laying per foot run, including lead..................	0.13	0.13	0.17½
Total cost of pipe in trench per foot run	$1.792915	$1.63736	$2.141515
Number of rivets in nipple........	4	4	4
Weight of same..................	$\frac{1}{16}$ lbs.	.078 lbs.	.078 lbs.
Total weight of rivets per length	15 "	13.359 "	15.468 "
Dimension of pieces punched out...	$\frac{5}{16}$" × $\frac{3}{16}$"	3.$\frac{5}{16}$" × $\frac{11}{100}$"	$\frac{5}{16}$" × $\frac{11}{100}$"
Weight of pieces punched out......	4.8[illegible] lbs.	398 lbs.	3.896 lbs.

DETAILS OF BENDS AND CASTINGS.

CAST IRON BENDS FOR 16 INCH MAIN.

Angle of deflection.	Number required	Weight of each.	Length of chord from bell to bell	Distance covered when in place in trench.	Cost of each at Foundry.
5 degrees	15	310 lbs	1′.$1\frac{1}{2}$″	$5\frac{7}{32}$″	$10.85
10 "	28	409 "	1′.$5\frac{1}{2}$″	$10\frac{15}{32}$″	14.31
15 "	16	487 "	1′.10″	$15\frac{23}{32}$″	17.04
20 "	14	580 "	2′.$2\frac{1}{4}$″	$20\frac{15}{16}$″	20.30
25 "	11	674 "	2′.$6\frac{1}{2}$″	$26\frac{3}{16}$″	23.59
30 "	11	772 "	2′.11″	$31\frac{13}{32}$″	27.02
35 "	9	870 "	3′.3″	$36\frac{21}{32}$″	30.45
40 "	12	939 "	3′.7″	$41\frac{7}{8}$″	32.86
50 "	4	1188 "	4′.$3\frac{1}{4}$″	$52\frac{11}{32}$″	41.58
55 "	1	1267 "	4′.7″	$57\frac{19}{32}$″	44.34
60 "	3	1347 "	4′.11″	$62\frac{27}{32}$″	47.14
70 "	1	1490 "	5′.$6\frac{1}{2}$″	$73\frac{5}{16}$″	52.15
80 "	1	1860 "	6′.$7\frac{3}{4}$″	$94\frac{1}{4}$″	65.10

CAST IRON BENDS FOR 22 INCH MAIN.

Angle of deflection.	Number required.	Weight of each.	Length of chord from bell to bell	Distance covered when in place in trench.	Cost of each at Foundry
5 degrees	12	470 lbs	1′.$1\frac{1}{4}$″	$5\frac{7}{32}$″	$16.45
10 "	18	630 "	1′.$5\frac{1}{2}$″	$10\frac{15}{32}$″	22.05
15 "	10	785 "	1′.$9\frac{3}{4}$″	$15\frac{23}{32}$″	27.47
20 "	3	910 "	2′.2″	$20\frac{15}{16}$″	31.85
25 "	3	1050 "	2′.6″	$26\frac{3}{16}$″	36.75
30 "	4	1270 "	2′.$10\frac{1}{4}$″	$31\frac{13}{32}$″	44.45
35 "	2	1435 "	3′.$2\frac{1}{2}$″	$36\frac{21}{32}$″	50.22
50 "	1	1895 "	4′.$2\frac{1}{2}$″	$52\frac{11}{32}$″	66.32

DISCUSSION.

Mr. E. Mohun

The author, in his very interesting and comprehensive paper, gives the average velocity of the Capilano River for the first seven miles from its mouth at five feet a second. A difficulty has been frequently encountered,—notably in the precipitous mountain ranges of the Pacific Coast,—in maintaining impounding reservoirs in somewhat similar situations. In these torrential streams it has been found that the boulders and gravel washed from the banks and bed above the dam are liable to be swept down and gradually fill the reservoir. A velocity of five or six feet a second will move good sized boulders, and less than half that velocity will move gravel. From the author's description of the bed of the stream, it would appear that the velocity has been great enough to remove most of the gravel from the channel, except at points where from the formation of the banks slack water was encountered. On the other hand, as even the most sanguine Vancouverites do not anticipate a population of four or five millions requiring a daily supply of 440 millions of gallons, a storage reservoir, as such, is not an essential, provided means are adopted to keep the entry conduit clear.

The steel mains which were built and laid by the Albion Iron Works Company of Victoria did not when first laid give satisfaction. Many were leaky, and considerable damage was done to the streets. These defects have, it is believed, been since remedied, and the writer is informed that the same Company subsequently laid a similar main with complete success for the Victoria Water-Works. The writer understands that the Iron Works Company was solely responsible for making and laying the steel mains in Vancouver.

On the 15th November, 1889, a serious accident happened to the submerged main, by which the city was deprived of its water supply for eight days. One of the 12 in. cast iron pipes, lying in 40 feet of water, was badly fractured, and it can hardly be doubted, from the position of the pipe, that the break was caused by a water ram. The writer understands that Mr. G. A. Keefer had recommended automatic blow offs at each end of the submerged main, to guard against just such an accident; but unfortunately his advice had been neglected. The blow offs referred to by the author are not automatic. The break was repaired by a diver, who covered the fracture with a wrought iron sleeve, in two parts bolted together and lined with vulcanite. In justice to the Water-Works Company, it should be added that it did all in its power to reduce the inconvenience to a minimum, bringing water across the Inlet, and delivering it free to its customers by cart.

Having been resident in Vancouver at the time of the discussion of the rival water-works schemes, the writer is aware that the main objections raised to the Capilano project were based upon the supposed difficulty of crossing the Narrows. One party said that it could not be done, because no similar work on the same scale had yet been attempted. It is to be hoped that there are but few engineers with whom such a reason would have weight. The more reasonable opponents of the work did not dispute the practicability of laying the pipe, but thought that, in only having a single main, in the event of an accident to it, the safety of the city would be imperilled, putting on one side the terrible inconvenience of a short water supply. From Mr. Smith's paper it appears that the duplicate submerged main was a part of the general plan which hitherto the company has failed to carry out.

The writer has always believed in the feasibility of laying the submerged main, and has never hesitated to express this opinion to the opponents of the scheme. Looking, however, to the vast interests at stake, he has always insisted upon the necessity of the submerged main being in duplicate, and is glad to learn that since the accident the company has taken active steps towards laying an additional main across the Narrows. From the reports of the diver it would seem that the pipe has not been moved by the current from the position in which it was first laid.

With regard to the dangers to be apprehended from vessels' anchors, the writer is inclined to think they have been exaggerated; nevertheless, were he responsible for the maintenance of a single line of pipe across the Narrows, upon the integrity of which the very existence of the city might at any moment depend, he would be very uneasy until all human precautions had been taken to secure its safety. A simple mode of obviating any risk from ships' anchors would be to cover the pipe with concrete in sacks laid by a diver. This if done properly would also add greatly to the strength of the pipe; and if the diver's report, that the pipe was lying in a groove in the sandstone rock, is correct, the pipe, by the means suggested, would be completely incased in a shell of rock.

The unfortunate accident referred to has, for a time, put a stop to submitting to the ratepayers a scheme for the purchase of the Water works by the city; and though the vast majority of the citizens are agreed that the city should own its water supply, no by-law approving of the purchase would pass, unless it was felt that such another failure was practically impossible. The burnt child dreads the fire. Vancouver has once been wiped off the face of the earth, and it cannot be wondered that her citizens should refuse to purchase a system, which, under the same circumstances as occurred a month or two ago, would leave them at the mercy of a conflagration which might occur at any moment.

Mr. P. Summerfield.

The conception of the Capilano Water-Works for the supply of the city of Vancouver, was of its very nature one of the best examples of hydraulic engineering to be met with on the Pacific Coast of the Dominion. The great difficulty to be encountered was the crossing of an arm of the sea under conditions entirely unparalleled in water-works engineering, and in some respects the pipe line across the Narrows of Burrard Inlet is almost without an equal.

The design of Mr. G. A. Keefer, M. Can. Soc. C. E., for the Capilano Water-Works was not the only design for Water-Works for the city of Vancouver.

The Coquitlam Water-Works, designed by Mr. E. A. Wilmot, M. Can. Soc. C. E., was also under consideration at the same time that the Capilano Water-Works was being matured, and as both projects received a great deal of consideration at the time, their merits and demerits being frequently discussed both in the press and elsewhere, it may not be out of place for an outsider to present the features of both schemes to the Society of Civil Engineers. The data before the writer are the reports by Col. W. R. Eckhart, of San Francisco, on the Capilano River Scheme, and which is now constructed, and the Coquitlam Lake Scheme, which is now being matured for the supply of the city of New Westminster, reported upon by Mr. H. Schussler, chief engineer of the Spring Valley Water-Works of San Francisco.

The elevation of the pipe inlet as given by Mr. Eckhart for the Capilano was 422 ft.

The elevation of the pipe inlet, as given by Mr. Schussler for the Coquitlam, was 435 ft., so no important difference obtained between the elevations of the two proposed systems.

The entire length of the Capilano scheme, as given by Mr. H. B. Smith in his valuable report, is 52,741 ft. from the dam to the centre of the city, or very nearly 10 miles.

The entire length of the Coquitlam scheme as given by Mr. Schussler is 105,600 ft., or 20 miles.

It will thus be seen that the laying of the submerged pipe across the Narrows of Burrard Inlet was the direct means of saving 10 miles of piping so far as Vancouver water supply was concerned.

Mr. Thomas C. Keefer, C.M.C., Past President of the Society, reported upon the Capilano scheme; and looking now upon the accomplished work, the only feeling is one of admiration for the design of so bold an engineering feature as the submerged pipe line across Burrard Inlet Narrows. For a country or carrier main, mild steel enables the engineer to undertake works of magnitude, that, if he were compelled to use cast iron mains, would almost render the cost of such works prohibitive.

At present ruling prices, a steel main of equal dimensions can be laid complete in the trench for about the same figure that a cast iron main could be landed on the wharf in Vancouver or any other port on the Pacific Coast; thus shewing clearly that it is possible to effect a saving of nearly 40 per cent. in the cost of the pipe line. But valuable as mild steel is for mains of large dimensions, there appears to be a tendency among engineers to exact too much from it.

Thus in the Vancouver Water-Works system, the ultimate strength of the 16 inch main, allowing a tensile strength of 60,000 lbs. per inch for plates, and .7 for strength rivetting, would be 580 lbs. per sq. inch, and the same data for the 22 inch would permit of 420 lbs. per sq. inch. Now, according to Mr. Smith's report, the 22 inch main has to sustain a head of water equal to 164 feet in height or a pressure of 71.17 lbs. per sq. inch, as a maximum. The factor of safety in this case is therefore 6.

In the case of the 16 inch main, the head of water sustained is equal to a column of 415 feet, and equal to a pressure of 180.11 lbs. per sq. inch as a maximum. The factor of safety in this case equals a little over 3 or nearly 3¼. It is apparent therefore that no very great amount of corrosion can take place without very materially reducing the factor of safety, and that moreover the workmanship and material must be the best obtainable.

From Mr. Smith's report there is a flush valve on the 22 inch main, and likewise one air valve in the tunnel. On the 16 inch main there is a flush valve on the north side and another on the south side of the Inlet, one air valve located between the Inlet and Coal Harbor, and two flush valves on opposite sides of Coal Harbor.

The total number of vertical and horizontal bends are given by Mr. Smith at 179. It would be interesting to know how many of these are horizontal and how many vertical bends; for no matter how free from sediment the waters of the Capilano may be, there are certainly a great number of elevations and depressions without either air or flush valves, and doubtless there will be a great difference of opinion as to the capacity of the 16 inch main after accumulations of air and silt have taken place.

From the description of the turning on of the water, it is very evident that water-ram and air compression were treated as a myth, and it would afford a great deal of valuable information if Mr. Smith would give a detailed account of the behaviour of steel mains, having a factor of safety ranging from 3 to 5, a large number of angles of elevation and depression along the pipe line, few air valves and very few flash valves, with a full head of water flowing with a velocity of 1.4 feet per second. The water seems to have taken 3¾ hours to traverse 19,320 feet from the tunnel to the north shore of Burrard Inlet. That something occurred may be inferred from the last two paragraphs of Mr. Smith's paper.

It appears that a tank is now placed on the north side of the Inlet at an elevation of about 230 feet above tide water mark, thus reducing the pressure upon the lower portions of the system by 200 feet of head, and likewise reducing the pressure upon the upper portion of the system by the difference between the velocity and static pressures, as the tank is allowed to flow over and to discharge the surplus water into the river. Some kind of provision is made for inserting a plug so as to utilize the full head of 430 feet in case it should be required.

Taking Mr. Smith's description of the Vancouver Water-Works, one cannot help feeling that there can be no difference of opinion about the works as projected by Mr. Keefer, for they are without a doubt unrivalled in this section of country; but there is a wide field for discussion relative to the manner in which Mr. Keefer's plans have been carried out. Doubtless other engineers who are conversant with the question will give us the benefit of their extended and valuable experience on this very important branch of engineering,—water-works construction.

Mr. D. J. Russell Duncan.

The writer has read the advance proof of Mr. H. B. Smith's paper on the Vancouver Water-Works with very great interest, and as copious extracts have been made from a small pamphlet, which the London Steel Pipe Co. published a few years ago, and the joint referred to in that pamphlet is described on page page 338 (Vol. III) of the author's paper as a *cumbersome arrangement*, the writer desires to bring under the notice of the Society some particulars with reference to this joint.

The advantages of a single socket, as compared with the Moore & Smith joint, are the great reduction in the quantity of lead consumed, the adaptability of the joint to overcome angular deviations in the pipe track, and the increased strength of the spigot, which must be of sufficient firmness to resist the strains due to caulking by inexperienced workmen.

The Moore & Smith joint, although it has no doubt been very largely employed, is inferior to the joints referred to, because the nipple reduces the internal diameter of the pipe, and tends to create any increased velocity of the flow of water through the pipe and the joints; whereas the joint now referred to is so constructed, that the pipe is actually larger in internal diameter wherever the joints occur, and this system of construction is of decided advantage by reducing the friction of flowing water.

It cannot be fairly said by the author that the joints to which the writer refers have been entirely discarded on the Pacific Coast, for the simple reason that they have never yet been employed there, with the exception of the pipe line constructed by the Steel Pipe Company, Limited, London, for the water supply of the town of Mazatlan, Mexico. This is the first pipe line on the Pacific Coast fitted with the improved joints, and is a line 20 miles in length and 14 and 12 inches internal diameter.

With regard to the 22 inch and 16 inch pipes, it is a matter of some surprise that these pipes were specified so thin. The pressure upon the pipe line is about 400 feet near to the Burrard inlet, and the pipes at this point are 16 inches diameter, and .11 of an inch in thickness. So far as the writer's investigations go, the ordinary working pressure on a Californian wrought iron pipe of this thickness and diameter would not exceed about 265 feet head, and according to the practice of this company, pipes of this thickness would not be made of mild steel for a higher pressure than 285 feet. It is clear therefore that the pipes laid by the Vancouver Water-Works Company are subject to much higher strains than is customary, and there is every reason to believe that the life of the pipe will thereby be injuriously affected. The paper gives no information regarding the test pressures imposed upon the steel pipes, indicating that the cast iron connections only were tested to a pressure of 300 lbs. per square inch.

It is unfortunate that the author has not given details of the rivetting. On the 2nd of May, 1889, this Company received a long letter from him, indicating that the pipes leaked to such an extent that when the water was turned on it was found impossible to stop them. In his letter dated April 13th, 1889, he says: "In two days time it was discovered that the leaks were enlarging, and the plates being actually cut by the jets of water forced out between the laps. The holes made in this manner are just beyond the edge of the outside lap, and are of all shapes, some being circular and nearly half an inch in diameter. After the pressure the appearance presented by the pipes was as if they had been acted on at several points by a sand blast." He then goes on to state that attempts were made to repair the leaks by cast iron rings; but on again subjecting the pipes to pressure, new leaks were developed, and at the date of his letter 5,700 feet of the pipes were leaking so badly that their removal was ordered and new pipes decided upon.

It is somewhat misleading to read in the latter paragraphs of the paper that the leaks discovered at the seams were speedily repaired by steel rings four inches wide, made in halves, which were made to go round the pipes, in the face of the information contained in the letter of the 13th April, to which reference has been made, and the writer would suggest that the author should correct the latter part of his paper.

In replying to the author's letter about the leaks, the following questions were asked, and it is desirable that the information should be communicated to the Society:

Were the rivets put in hot or cold?

Were they closed by power, and if so by what power?

How were the longitudinal seams distributed round the circle?

What was the length of the rivets?

Were any sections of pipe rivetted up and tested by hydraulic power in excess of the working pressure, to prove the quality of the rivetting, and was any test whatever made of the rivetting?

With what were the pipes coated, and how was the coating applied?

How were the pipes jointed together?

The length of pipes being 23 feet, $9\frac{3}{4}$ in., seven plates was a very large number to employ. Four would have been preferable, thus saving a number of rivetted seams.

The rivetting was apparently faulty and the plates not properly laid together at the seams, and possibly burrs were left at the rivet holes which prevented the perfect contact of the surfaces.

Although a rivetted joint may be made strong enough to resist the strain brought to bear upon it by a tension testing machine, and may be proved to be very nearly equal in tensile strength to the original plate, yet the rivets may not be close enough to secure water-tightness under pressure. Experience has proved that there is considerable difference between pipes being strong enough to resist a certain tensile strain across the joint and being water-tight under fluid pressure, which may exert no greater tensile strain across the joint than that for which it was designed. The evidence submitted at the time led this firm to the opinion, that the defects in the pipe were due to faulty workmanship and inexperience on the part of the contractors.

No information is given in the paper as to the means adopted for letting off air in the pipe, and possibly the leakages which were found were aggravated by the accumulation of air in the mains before the pipes were properly filled with water. Neither is any evidence given as to the hydraulic tests upon specimens of the pipes to prove the tightness of the rivetting.

The writer considers it bad practice to make up the pipes of so many small plates. It is found much more satisfactory to make the plate cylinders in lengths of from 6 to 8 feet; and if this system had been adopted for the steel pipes described by the author, there would have been a great reduction in the number of circumferential rivetted seams.

Caulking, in the manner described by the author, tends rather to aggravate leaks than to prevent them whenever mild steel plates are employed. A better system for preventing leakages and to make perfectly water-tight joints is to employ suitable plate closing apparatus upon the rivetting machines, the effect of which is to close the plates perfectly together, so that the laps are thoroughly overlaid and the surfaces brought into close contact before the rivets are inserted; then when the rivets are closed by hydraulic pressure there is no liability to leakage, and caulking is entirely dispensed with.

The description of the method in which the lead joints were made is such as to indicate that the work of making a Moore & Smith joint is at least twice as much as that of making the patent socket joint recommended by the writer. The great care which has to be taken in making the Moore & Smith joint in a perfectly straight line is a very serious disadvantage. A particular feature in an efficient joint should be its facility for overcoming angular deviation in the pipe line, and thereby reducing the number of bends.

It may be mentioned that a 9 inch steel pipe, which was laid by this firm in the Tay Viaduct some years ago, was laid round a very sharp curve on the bridge, without any special connections whatever, the flexibility of the joint permitting the curvature of the pipe line. The joints were made above ground, and 360 feet of jointed pipe in a single curved line lowered into the trench.

Nor is there any necessity in a joint such as is recommended for the caulkers to be cautioned with regard to the packing of the lead. The spigot ends of the pipes are welded into cylinders, and made about 50 p.c. thicker than the pipe, so that any pressure the caulker imposes upon the lead will not indent the pipe, or in any way cause it damage. The sockets for pipes up to 24 inches diameter are stamped by hydraulic pressure on the system invented by Mr. James Riley, General Manager of the Steel Company of Scotland, Limited. This is known as the Riley Patent Socket. This socket has an external lip or flange which adds very greatly to its strength, and with this joint it is not found that the shell of the pipe is bent inward nor the mouth of the socket bent outward, as is the case with the Moore & Smith joint, described by the author on page 339 (Vol. III) of his paper.

With regard to the system of constructing pipes with inner and outer courses, this method is entirely discarded by this Company on pipes of all diameters made of plates under .2 of an inch in thickness. A much more correct and reliable method of making perfect circumferential seams is obtained by the use of suitable machinery for expanding the circumferential lap at one end of the plate cylinder, after the plates have been punched and bent into cylinders; all the circumferential seams are carefully punched by multiple punching machines precisely to the same pitch, and the increase in pitch due to the enlarged diameter of the overlap is obtained by stretching the plate in the manner described.

For pipes made of plates exceeding .2 of an inch thick, the circumferential seams of the outer course are punched when the plate is flat, by dividing machines which divide the pitch into the most minute fractions necessary to overcome the irregularities between the diameter of the outer and the diameter of the inner course of plates. The system described by the author, of leaving one end of the plate cylinder to be punched while the pipe is rivetted up in the pipe track, is not only one which causes enormous delay in the execution of a pipe contract, but one which is liable to very great inaccuracies of workmanship. The method described of fitting the pipes together in a trench, drawing them apart, punching the holes, putting them together again, and rivetting them up is most unsatisfactory.

With regard to the distribution of the longitudinal or straight seams, a pipe made of very thin plates, such as those employed for the Vancouver Water Works, is made stronger and better by a uniform distribution of the longitudinal seams of the several courses around the circumference, instead of having them all in one straight line. Sometimes in constructing pipes with the longitudinal seam all in one line along the pipe, much greater care has to be taken in straightening the pipe, as there is a tendency to curvature.

The paper is one of very great interest to all engineers interested in water-works, and the author has displayed conspicuous ability in the execution of the works under his charge.

Mr. G. H. Henshaw.

Mr. Henry Badeley Smith's able paper on the construction of the dam and pipe line of the Vancouver Water Works leaves little for the critic to say, beyond expressing admiration for the successful manner in which difficulties both novel and otherwise have been met under exceptional circumstances. The moderate height of the dam no doubt permitted the foundation (in the absence of puddling clay) to be laid with safety in the manner described; nevertheless, the accident to the "lean to," and one of a similar nature that occurred previously to another part of the structure, would seem to be a warning in case it should be proposed at any future time to increase the height of the dam.

With regard to the objections and answers to the plan of laying the pipe across the Narrows of Burrard Inlet, a few remarks may be in order.

The first objection begs the question by claiming as known a force that is not known, while the answer claims a mathematical demonstration not given, but doubtful in its fundamental basis, as all calculations of the forces of the sea must be without actual previous experiment.

The true reply to the objection is philosophical not mathematical. The bed of the inlet at the point of crossing is stated to be composed of soft sandstone, partially covered with mud, gravel and cobble stones. Now a stream with no friction on the bottom, other things being equal, would flow with equal swiftness at every depth, hence the difference in speed between the bottom and top would be a measure of the friction at the bottom. But the present case is one of a tidal current, whose efflux and reflux are governed by so many and complicated conditions, extending even to the existence, occasionally at least, of an outward current at bottom and an inward current at top, that even the most careful observation would fail in producing reliable formulæ. It is plain then that where the erosive force is actually unable to remove mud, gravel and cobble stones, a 12 in. metal pipe would lie undisturbed, quite independent of its self-made trench. This argument also answers the second and sixth objections. The third has a little more in it, and is more weakly replied to. It is decidedly doubtful whether such a pipe could resist the direct impact of a falling anchor, or that any engineer would invite a trial; nor is it likely that he would be free from anxiety should a vessel, whose anchor fluke embraced the pipe, be caught in a violent gale. It would be interesting to see what mathematicians would make of the problem. The wisest course would seem to be to protect those parts which are not sufficiently trenched already in the bottom. The fourth and fifth are speculative, and need facts capable of clear verification in their support before they have a right to claim notice. The seventh and eighth are mathematical, to which a very decided practical answer has been given. The ninth objection is of unascertained antiquity, and is still voiced wherever old settled habits of thought are disturbed by new ideas. "Who ever heard of such a thing?" "Don't take much stock in these new fads," etc.

It is true that it is sometimes difficult, without giving more attention than is convenient, to decide whether a certain scheme is the work of a "crank" or of a scientific mind, but if it is worth considering at all, it is surely the duty of critics to meet arguments with something more than mere assertion, and to support their own statements on facts and premises which are undisputed or capable of ready proof. Mr. Smith is to be congratulated on having contributed such an interesting paper to the Society.

Mr. Peterson. As the paper is a long one, it will be better to discuss that portion relating to the dam this evening. If the paper is all read through at once, the points relating to the dam will probably be forgotten by next evening.

Mr. Blackwell. Was there not some mistake about the size of the tree? It would be hard to get the stumps out.

Mr. C. L. Smith. The author was perhaps a little misleading. The tree must have been one badly formed at the root. He did not think there was a tree of that size solid right through.

Mr. C. E. Goad. It was a rare thing to see a tree solid right through there. The paper is well written and the subject elaborately gone into. There seemed to have been great difficulty in regard to the carriage of material, etc., but this matter could not be followed out properly without being able to see how the plans were adapted to the peculiar formation of the ground.

Mr. Peterson. It would have been much better had a large sketch been made showing the most important points of the dam, etc., and the methods taken to prevent the water following through the longitudinal timber, which is a great source of trouble in all works of this kind. As he understood it, in this case the water was kept back by sheet piling. Then there was the question of getting round the end, also a difficulty that had been overcome by a brush and gravel bank, but he did not understand how the concrete was put in. It would be a good plan to make a rule, such as was in force in the Institution, that all papers should be accompanied with large drawings which could be hung on the walls. This would very materially tend to aid the discussion.

Prof. Bovey. In reading the paper over, it would seem that some of the concrete had been made by mixing a certain amount of cement with gravel, out of which stones over a certain size had been eliminated. This was contrary to the practice recognized by many eminent authorities, who said that the best concrete was made of stones of irregular sizes—not limited to $1\frac{1}{2}$ inches.

Mr. Gower. The material was different from what we had here. Take the London gravel, which was similar to that they had in Vancouver, and the practice was the same. All big gravel was taken out. It was more of a sea gravel than anything else, and generally it ran $1\frac{1}{2}''$ to $\frac{3}{4}$,″ and with a fine kind of grit was mixed six to one with Portland cement. This plan was invariably adopted by engineers in the south of England.

Prof. Bovey. The best concrete was made of gravel of different sizes—the more irregular the sizes the better. As to limiting the size of the gravel, some engineers say that large blocks of stone can be put in without injuring the concrete in the least.

Mr. Gower. Col. Hayward, City Engineer of London, in his specification for gravel, specifies for a small gravel nothing larger than $1\frac{1}{2}$,″ mixed in proportion of six to one.

Mr. Peterson. The idea of having stones larger than $1\frac{1}{2}'$ taken out was probably because the concrete had to go into a small space and had to be rammed. In filling large spaces there was no question but that large stones, two or three feet square, might be put in. In the Lachine bridge they put large masses of concrete—$20' \times 40' \times 15'$—in the middle of which they might have put large stones and filled in all round them, and in many cases stones larger than $1\frac{1}{2}''$ were put in. In the case under discussion, however, they were quite right in taking out everything over $1\frac{1}{2}$,″ for the reason that they had to pack the cement, and it would be much easier to ram and make a much better job with small stones than with large ones.

Prof. Bovey. The timber in Burrard Inlet would in all probability be affected by worms. He did not know to what extent the Teredo Navalis had appeared on the Pacific coast. Some member present might be able to say whether any information had been obtained on this subject.

Mr. Blackwell. Had seen specimens in the Library of the House of Commons at Ottawa, showing the effect of the "Teredo Navalis" on the timber of the Pacific coast, which is very disastrous. It had occurred to him what a fortunate city Vancouver was as compared with other towns having the average system of water-supply and cost of same. In Vancouver they had an abundant supply of cold, clear, running water for almost nothing. He imagined that if these works had been economically carried out, there would be a supply of water for all time at a cost of from one to two dollars per head per annum. There was a pressure of 80lbs. at the highest part of the town, which was remarkable

Mr. Peterson. In the harbour of Vancouver, on Burrard Inlet, piles of 18″ diameter are eaten through sometimes in a year and in a sawn section one can scarcely find half a square inch in any one place of solid wood. The holes are ½″ in diameter, and some probably larger. The wood is just as if it had been perforated with a series of auger holes. He felt certain the teredo would never reach the dam, there is a great elevation with a very heavy current. They did not find them even where the water was brackish.

Prof. Bovey. It had been stated that good cast-iron would resist the action of salt water, but he did not know of a case on record in which it had been found to do so. In a case that had come under his own notice columns taken up from foundations in salt-water were just like sponge.

Mr. Blackwell. He had not had much experience with cast-iron in salt water, but had seen cast-iron taken out of columns or piers just like cheese. That was the ordinary gray cast-iron of foundry casting. He would like to know something more about these pipes, which he believed were made in Glasgow. The sheet steel pipes had ends rivetted on which were described as "white cast-iron." There must be something more than that, because if simply white cast-iron they would be of no use at all; they would be like glass, having no tensile strength. In Glasgow there were several firms which made a specialty of producing a metal called "McCaffie's metal"—a sort of white metal. In the first place when cast it was like white pig, and was then decarbonized in a furnace, which converted it into a kind of semi-steel. If simply white metal they would not be fit for the purpose. It might be assumed that these joints were made of a material superior to ordinary "white pig" or "white cast-iron." A little more information regarding these joint castings would be interesting.

Mr. Peterson.

Plenty of white metal water pipes could be obtained from Scotland and the north of England. He had got some out of pure white metal, which were nearly useless.

Mr. Blackwell

White metal was useless, as it had so very little tensile strength.

Mr. Peterson.

When in Vancouver last year he saw this cast-iron pipe, a portion of the wrought-iron pipe, and also the valve that was placed between the cast and wrought iron pipe. There was a very heavy stream of water pouring out, and he was told that the wrought-iron pipe was not sufficiently strong to stand the pressure. Its thickness was less than $\frac{1}{4}''$—about $\frac{3}{16}''$, and the rivets, he imagined, were about 4″ or 5″ apart. It was a very thin plate, and the water was flowing in little streams out of nearly all the joints of the sides. He believed that they had since put straps round the pipe to hold it together, but they had reduced the pressure by means of a safety valve. He was astonished to see the small size of pipes which had been put in for mains, viz. :—4″ and $2\frac{1}{2}''$, and he thought this was a mistake. He considered streets should have nothing less than 6″ pipe, that is in places where there was to be fire protection. A 4″ pipe was not large enough, and a hydrant on a 2″ pipe, in the case of a large fire with three streams going, would be utterly useless—there would be no water. It was, however, a case where the water supply was furnished by a company, which he thought should never be done. There can be no possible reason why every city or town should not build and own its water works. The corporation can certainly borrow money at a lower rate of interest than any company, and can afford to put in just such distribution of pipes as are wanted, and the corporation will then have complete control of its own streets. He knows of no instance where corporations have been supplied by water companies in which the supply has not been unsatisfactory, or in which the cost to the citizens has not been greater than if they had had a much more liberal supply under their own control.

Mr. H.B. Smith

In reply to the remarks of Mr. Mohun, the bed and banks of the Capilano having been, for ages past, swept by flood currents of great velocity, all loose boulders have long since been carried away, leaving the larger boulders so interlocked that it is rarely, and only in extreme floods, that one is loosened and carried down stream. In the course of years, it is probable that detritus from the banks may lodge itself in front of the dam; but, should this accumulate to any inconvenient extent, it can be readily removed, and at small expense. In the ordinary quiescent state of the river, when the current does not exceed 5 miles per hour, it is not probable that stones or good-sized boulders, as suggested by Mr. Mohun, are in motion along the bed of the stream. Smeaton's observations go to prove that a velocity of $11\frac{1}{2}$ feet per second will not derange quarry rubble stones not exceeding half a cubic foot.

The considerations which decided the construction of a dam and reservoir at the point of supply were as follows:—A pressure as nearly uniform and invariable as possible would be obtained. There would be a direct gain of 11 feet of head, which would allow the system to be carried through the rock bluff at the end of the 22 inch main, by means of a tunnel of moderate length. To obtain the same head without a dam, the 22 inch main would have to be extended at least 1,500 feet further up stream, under conditions which presented features especially unfavourable for pipe laying, and for the permanency of the pipes when laid. By reference to plate XVI., it will be seen that, at a point 1,500 feet above the present dam, the channel of the river is not confined to one permanent position. Moreover, as the eastern branch, at the present period, is dry at low water, and the island between the channels is invariably flooded at high water, an extension of the 22 inch main above the dam must necessarily cross the western branch to its western side, and following that side, where the banks are high and rock in situ is exposed, reach a point where works for an entry conduit of a safe and reliable character, during all stages of the river, would be of a costly nature.

Finally, as the Capilano is a stream which has only become known since the construction of the water works, reliable data as to the lowest possible stage of water are still wanting. It is impossible to say with certainty what changes in its volume may occur in the future; more especially when it is taken into account that its banks may be denuded of timber by forest fires and the improvements of settlers, and that at any season the snowfall in the mountains, on which its very existence depends, might be very much less than it has ever been known to be. Giving due weight to these considerations, no doubt Mr. Mohun will acquiesce in the opinion that the dam is a very valuable addition to the system.

Several lengths of steel main in the low lying parts of the system subject to full head, when first laid, developed leaks more or less annoying. These leaks were, however, overcome in the usual manner, by means of cast-iron lugs, leaded and caulked, and by the substitution of new lengths where the originals were leaky enough to warrant this step. The Iron Works Company, who furnished the pipes, under contract for manufacturing, laying, and maintaining the line of mains for two months after completion, were solely responsible for the leaks; and it is worthy of note that the substituted lengths, made by them from the same design as the original leaky ones, were found to be entirely satisfactory, showing that the leaks in the original lengths arose, not from the character of the pipes used, but from some fault in the construction of these lengths. The Victoria Water-Works, for which the same company subsequently made and laid a main exactly similar in all its details, is no parallel case, the total head of that system being under 200 feet.

When the break in the submerged main occurred, the writer was in England, and can give no account of it from personal knowledge. All the evidence in his possession goes to prove that it was a break pure and simple, due to a severe water ram created by a too sudden closing of the hydrants, and acting upon a defective pipe casting. The outer and inner skins of the metal at the point of rupture were found to be as perfect as on the day of immersion, 15 months previously, proving conclusively that the action of the salt water had had no deteriorating effects. There appeared, however, in the centre of the fracture, a globular mass, showing a check by cooling or some other cause, which had prevented a proper fusion of the metal during the process of casting. The fracture beyond the flaw showed the hard, close-grained, white surface of a casting of good quality.

Inasmuch as there has been a great diversity of opinion, and so much has been written and spoken as to the possibility of repairing a break in the submerged main, it is fortunate that this accident occurred at the time it did, as it has demonstrated beyond question, even to the most sceptical mind, that this part of the system can be got at and repaired almost as readily as any other part. Although, on this occasion, the city was deprived of its water supply for a period of eight days, this was not due to the difficulty of effecting actual repairs, but to the unusually stormy weather which unfortunately prevailed at the time of the occurrence, preventing the company's divers from locating the leak. As soon as this was done, the necessary repairs were accomplished within 24 hours. Under the ordinary summer and winter conditions appertaining to Burrard Inlet, any similar leak can be repaired in the same or possibly a less period of time.

There can be no doubt that had Mr. Keefer's recommendation (that automatic blow-offs be placed at each end of the submerged main) been adopted, the possibility of a break from water ram, even under the conditions described, would have been greatly lessened; and had the general plan of the system been carried out in its entirety before the works were put in operation, such a break would have caused no inconvenience whatever to the city. It is even doubtful whether the citizens would have been aware of its occurrence. By referring to plate XVIII, it will be seen that the general plan provides for duplicate mains at the Narrows—one of cast-iron (laid) and one of steel (to be laid). Without presuming to criticise the action of the company in not having completed the crossing of the Narrows, as designed, up to the time of the break, there can be no doubt that it would have been well had they done so. At the same time, it must be conceded by all disinterested parties, that, as Vancouver is a young city, with as yet a small population, the citizens deserve every credit for the energy already displayed, and for the confidence they have expressed in the future progress of the city, by risking so much private capital in completing the system all but this one link, the more so as the chance of a break was infinitesimal. Since the occurrence of the accident, pipes have been ordered and tenders invited for the laying of the duplicate main.

The method proposed by Mr. Mohun, for protecting the single submerged main from ships' anchors, is not a new idea. From the inception of the scheme, it was intended, should circumstances render it advisable, to insure the safety of the pipes by a covering of concrete in sacks. In the present instance, however, the pipe shell being of great strength, and to a large extent imbedded in the soft sandstone bottom of the Narrows, it is a matter of opinion whether such a costly addition to the works would have been advisable; the more so, as the author is not aware that this or any other protection has been adopted in the case of the submerged mains of other systems.

Mr. Summerfield is labouring under a misapprehension when he quotes the Vancouver Water Works system as an example of the tendency amongst engineers to exact too much from mild steel. To make good this assertion, he has endeavoured to show that the factors of safety of the 22 inch and 16 inch mains are respectively 6 and $3\frac{1}{4}$, assuming the ultimate tensile strength of mild steel at 60,000 lbs. per square inch, with a loss of 30 per cent. for double rivetting, and that, with these factors of safety, no great amount of corrosion can take place.

The tensile strength of the mild steel employed in the construction of the mains in question is, as per contract, 72,000 lbs. per square inch; 60,000 lbs. being little more than is ordinarily allowed for rolled wrought-iron plates of the best quality. The double rivetting of the horizontal seams has been so designed that 75 per cent. of the full strength of the plates has been retained. The ultimate strength of the 22 inch main $\frac{11}{100}$ of an inch thick is, therefore, 540 pounds. This main, being subject to a maximum pressure of 71 lbs. per sq. inch, has consequently a factor of safety against rupture at the horizontal seams of $7\frac{6}{10}$ instead of 6.

The ultimate strength of the 16 inch main, $\frac{11}{100}$ of an inch thick, is 743 pounds. The maximum pressure it is called upon to withstand at its lowest levels (which it may be here mentioned form but a small part of its whole length, and are so situated as to be easy of access both for inspection and repairs) is 180 pounds per sq. inch. Its factor of safety against rupture at the horizontal seams is, therefore, $4\frac{13}{100}$, instead of $3\frac{1}{4}$.

These calculations refer to the ultimate strengths of the mains at their weakest part, namely, the double rivetted horizontal seams. As far as corrosion is concerned, and this is what Mr. Summerfield more particularly refers to, the seams, being of two thicknesses of metal, are the strongest parts of the pipe. The shell will be the first to give way under this cause; and, in calculating factors of safety with reference to corrosion, the full strength of the plate must be allowed. These factors may readily be ascertained to be 10 and $5\frac{1}{2}$ for the 22 inch and 16 inch mains, respectively. The author is of opinion that these results give satisfactory evidence of the permanent safety of the mains, and in support of this opinion would mention, that in the Pacific States of the Union long systems of rivetted wrought-iron pipes have been in constant and satisfactory use for many years, under pressures sometimes as great as one-half their ultimate strength.

In connection with this subject, the following table, showing the strengths and pressures in the various parts of the Virginia City, Nevada, supply main, $11\frac{1}{2}$ inches diameter and 37,000 feet in length, may be of some interest.

VIRGINIA CITY, NEVADA, RIVETTED WROUGHT-IRON SUPPLY MAIN.

Ultimate strength 55,000 lbs. per sq. inch, less 30 p.c. for double rivetting.

Head in feet.	0 to 200	200 to 330	330 to 430	430 to 570	570 to 700	700 to 950	950 to 1050	1050 to 1250	1250 to 1400	1400 and over
Extreme pressure in lbs. per inch.............	87	143	187	247	304	412	456	543	608	750
Thickness in inches....	.065	.072	.083	.109	.120	.148	.180	.220	.259	.340
Ultimate strength in lbs. per sq. inch..........	435	482	556	724	803	991	1205	1473	1734	2276
Factor of safety........	5	3.4	2.96	2.93	2.64	2.40	2.64	2.71	2.85	3

It may be here incidentally mentioned that, in a recent publication of the London Steel Pipe Company, issued under the auspices of Messrs. Russell Duncan and H. C. Mylne, Associate Members Inst. C.E., it is stated: "Wrought-iron pipes have been extensively used in the States, and it has been proved that no risks are run from fear of corrosion. Hundreds of miles of wrought iron pipes have been used for periods extending to over 30 years, and no indications are shown of injurious oxidation. In some cases the pipes have been used without coating of any kind, in others they have been coated with natural asphaltum, which is the common method of coating pipes in the United States. Under ordinary conditions, the coating of natural asphaltum is not affected by water, earth, or atmosphere."

In May of this year, 1890, 14 months after the opening of the Vancouver system, an official examination of the steel mains was made for the purpose of ascertaining to what extent corrosion had taken place. The earth covering was removed at numerous points along the line, and the pipes and castings closely examined without an indication of oxidation being found.

The number of horizontal bends in the 22 inch main is 33, and in the 16 inch main 103. Of vertical bends the 22 inch main has 20, none of which exceed 10 degrees deflection; and the 16 inch main 23, none exceeding 15 degrees deflection. As is the case in all properly constructed systems, every elevation of any magnitude is tapped by an air-cock; a fact, which, though not mentioned in the paper on the Vancouver Water Works, was so obviously necessary, that it might have been taken for granted. The profile of the 22 inch main from the dam to the blow-off at the tunnel, a distance of 2½ miles, is very uniform. Naturally the greater part of any sediment brought down from the well chambers will be deposited in this main. The 8 inch blow-off is amply sufficient to flush it when required.

The greater number of the vertical bends in the 16 inch main are located in the first 8,000 feet beyond the tunnel, where the pipe line passes over unavoidable sidehill. Whatever small proportion of sediment may be carried past the deep depression, where the blow off at the tunnel is situated, into the 16 inch main, will be of minute particles, and will have little opportunity to settle in the bends, inasmuch as the velocity of flow in that main is 5$\frac{6}{10}$ feet per second, a velocity amply sufficient to keep fine particles in a constant state of progression towards the 8 inch blow-off at Burrard Inlet. However, should an accumulation of silt from some unexpected cause take place at any of these bends, the deposit may readily and with reasonable expense be removed by the ordinary means adopted in such cases, such as self-acting scrapers, spring gouges, etc.

Mr. Summerfield unhesitatingly states that it is very evident, from the description given of the turning on of the water, that "water ram and air compression were treated as a myth." This is, to say the least, a hasty and ill-considered assertion, in no wise warranted by the account given. It is evident that, in this instance, he has pictured to himself a system of water works, being opened for the first time with a full velocity of water flowing, and every air-valve and blow-off closed. This portion of the paper was necessarily brief, and did not contain details minute enough to give a full and complete description of how the work was accomplished. Moreover, Mr. Summerfield, although he makes no mention of the fact, may have been led somewhat astray by a clerical error which appears to have crept into the manuscript or print. In the latter it is stated—"at 9.45 p.m. the water reached the closed 12 inch valves on the north shore of Burrard Inlet." For "valves" should be read valve. If this faulty paragraph had anything to do with the misunderstanding which seems to have occurred, it is to be regretted. But, in any case, in order that a clear conception be obtained of the manner in which the mains were first filled, the following more minute description is given.

When it was decided to make a test trial of the line of mains, the gate at the well chambers of the dam was lifted high enough to expose a segment of the 22 inch main 3 inches deep; the 8 inch blow-off at the tunnel and all the air-valves being wide open. By means of these, the air was expelled, the incoming water occupying its place, and very gradually filling up the main until it was discharging freely through the blow-off. The 22 inch main was allowed to continue in this state for a period of 48 hours. No breakage or sign of leakage having taken place, the gate at the well chambers was lifted from time to time, until, on the 5th day from the first partial opening, it was opened wide, the water in the main discharging freely through the 8 inch blow-off.

This trial being so satisfactory, it was then decided to test the 16 inch main. The 8 inch blow-off, before mentioned, was partially closed, and the water allowed to rise up the steep incline to the tunnel, until that part of the 22 inch main passing through the tunnel, and connecting with the 16 inch main, was filled one quarter full. How very slowly this was accomplished will be understood from the fact that, although the 22 inch main was nearly full up to the 8 inch blow-off, it required two hours from the time of partially closing that blow-off to reach the floor of the tunnel. The 22 inch main was not allowed to exceed about one-quarter full, but was maintained at this level, slowly and uniformly filling up the 16 inch main, until it was discharging freely by means of one of its 12 inch valves and the 8 inch blow-off at Burrard Inlet, the other 12 inch valve being kept closed in order to prevent the water entering the 12 inch main under the narrows. As in the case of the 22 inch main, all air-valves were kept wide open, allowing free vent for the escape of air, and affording absolutely no opportunity for air compression or hydraulic ram.

It is much to be regretted that Mr. Summerfield cannot be gratified in his desire for information as to the behaviour of the 16 inch main, under such (very contradictory) conditions as "*a full head of* water flowing with a velocity of 1.4 feet per second." As Mr. Summerfield calculated the velocity with which the water in this main travelled during the test trial, using the time and distance given in the paper, it is somewhat surprising that he did not also calculate the velocity due to the head and length, and thus avoid the error into which he appears to have fallen. From the data at his disposal, he might readily have deduced, that, under a full head of water, the velocity of discharge at the termination of the main in the city is 5 $\frac{6}{10}$ feet per second. But, as the portion referred to in the present instance is only that between the tunnel and Burrard Inlet, if a full head of water had been allowed to enter the 16 inch main at the tunnel, the velocity of out-flow would have been found to greatly exceed 5 $\frac{6}{10}$ feet per second, using as data the total fall 388 feet, and total length 19,320 feet, between these two points.

Had Mr. Summerfield ascertained these facts, he could not have fallen into the rather extraordinary belief that water ram and air compression had been treated as a myth; and it may be here mentioned, that, had both 12 inch valves been closed, and only the air-valves along the line and the 8 inch blow-off at Burrard Inlet been open, these latter would have been amply sufficient for the discharge of air and the prevention of hydraulic ram.

The day following the turning on of the water, a thorough examination of the whole line of mains from Burrard Inlet to the dam was made. Throughout the whole distance, no sign of leakage was apparent. Mr. Summerfield's inferences that "something occurred" are without foundation.

The reducing tank referred to is entirely temporary, having been built solely to relieve the pressure on certain defective pipe lengths in the lower levels of the system, until new lengths could be manufactured and substituted.

With reference to the remarks of Mr. Russell Duncan, in a comparison between steel pipes jointed by the Moore and Smith joint, and those jointed by means of faucets and spigots attached to the shell, the word "cumbersome" was used in reference to the latter. This was a general expression, and not intended to particularize any individual joint, such as the Riley patent referred to by Mr. Duncan, and it may have been used without due consideration.

It is merely a matter of opinion, which is the simpler joint of the two; but on comparing them, it certainly seems that a joint consisting of a plain nipple and ring is simpler and more easily handled than a joint made in imitation of ordinary cast-iron joints.

Without details of the particular joint referred to by Mr. Duncan, it cannot be determined whether it requires a less quantity of lead, as he avers, than the Moore and Smith joint; but it is open to question, whether any safe spigot and faucet joint can be designed for 16 inch or 22 inch pipes, which will require less lead than $27\frac{3}{10}$ lbs. and $37\frac{4}{100}$ lbs., respectively, the amounts used in the Vancouver water works for these diameters. In the pamphlet issued by the London Steel Pipe Company, it is claimed that the steel spigot and faucet joint of a 24 inch pipe requires $9\frac{1}{2}$ per cent. less lead than the joint of a cast-iron pipe of the same diameter. (See author's paper, page 337.)

According to American practice, a cast-iron joint for a 24 inch pipe would require not less than 50 lbs. of lead; consequently, Mr. Duncan's joint for the same diameter would require 50 lbs. less $9\frac{1}{2}$ per cent., or $45\frac{1}{4}$ lbs. But it can be easily calculated that a Moore and Smith joint for a 24 inch steel main $\frac{11}{100}$ of an inch thick with $\frac{5}{16}$ inch thickness of lead, the usual allowance, would require only $39\frac{1}{2}$ lbs. It appears, therefore, that in the case of a 24 inch pipe, according to the London Steel Pipe Company's pamphlet, as applied to American practice, the Moore and Smith joint requires $5\frac{3}{4}$ lbs. less lead than the spigot and faucet joint recommended by them.

As for great flexibility at the joints, it is not advisable in any system of water works to make with large mains much angular deviation, without special castings. It is not necessary, however, with the Moore and Smith joint to lay the pipes in a perfectly straight line, as claimed by Mr. Duncan, contrary to the description given. It will, on occasion, admit of deflection to the extent of one degree per length. In the case of 24 feet lengths, this would form an 8 degree curve of 716 feet radius. Without actual knowledge of such curves having been put in practice, it would be unwise to express an opinion as to their suitability; but there can be no question, that by means of this joint, such a curve as that on the Tay Viaduct, alluded to by Mr. Duncan, round which his 9 inch spigot and faucet pipe was laid, can be easily overcome, it being only a 4° 10′ curve with a radius of 1386 feet.

The nipple of the Moore and Smith joint in the Vancouver Water Works pipes does not decrease the internal diameter of the pipes at the joints; but in thickness of pipe shell over $\frac{11}{100}$ of an inch actually increases it. Had careful consideration been given to the drawing (Plate XX), there could have been no misconception on this point. It is there plainly shown, that the end courses of each pipe length are large or outer courses. The nipple being inserted in the end of a large course must, therefore, when of the same thickness as the shell, have the same inside diameter as the inner or small course, which, it is unnecessary to state, is the governing diameter of the pipe. The nipple adds greatly to the stiffness of the shell at the joint, but having no water pressure to withstand is, for economy sake, usually made of thin material, so that, in the case of a thick pipe shell, the inside diameter at the joint is greater than the governing diameter.

The reply given to Mr. Summerfield fully answers Mr. Duncan's doubts as to the strength of the 16 and 22 inch mains in comparison with ordinary Californian practice. When he reviews this subject, it would be well to bear in mind that there is no equality of strength between wrought-iron and steel.

The omission of mention of the test pressures imposed on the mains was an oversight. The engineer's specification, and the company's agreement with the contractors for supplying and laying the steel mains, provided that the pipes should withstand safely and without leakage a column of water 600 feet high or 260 lbs. pressure to the square inch; and in order to insure the application of proof tests by the contractors, a special clause bound them to maintain and keep the whole system perfectly tight for two months after completion. So far as the engineers are concerned, these are the terms of the contract to this day. It will be admitted that no more stringent agreement for the laying of properly tested pipes could have been entered into.

Full details of the rivetting of the 12 inch, 16 inch, and 22 inch mains in the form of a table headed, "Details of Rivetted Steel Mains," accompanied the paper under discussion, when forwarded to the Society. That this table did not appear in the advance proof is to be regretted. However, it has now been embodied in the appendix to the paper, Vol. III., page 361.

Mr. Duncan's inferences and quotations from the author's letter to him are liable to mislead.

Immediately after the successful turning on of the water, the concluding portion of the paper, in which the account appears, was written, and the whole forwarded to the Society. There is nothing in this account at variance with the facts contained in the letter of April 13th. The primary leaks which were discovered up to the time of forwarding the paper to the Society were being readily repaired in the manner described. But, on the second day after the main had been put under *full pressure*, leaks developed themselves in the low-lying parts of the system, of an altogether different nature, and too numerous to be economically repaired in the same manner. The extracts quoted by Mr. Duncan were not intended by the author to reflect in any way on the character of the mains, as would be plainly seen were the latter given in full. The information afforded him was to serve as data on which to answer the questions, whether in his experience he had ever known a jet of water forced out between the laps of a rivetted pipe to actually cut the shell of the pipe beyond the laps, and, if so, what remedies were adopted by him? This was what had occurred in the Vancouver system, after the paper had left the author's possession.

Mr. Duncan in his reply could state no similar case; but very kindly advanced many theories, among which were the following:—"That an hydraulic ram had occurred; that the rivetting of the seams was faulty; that the plates were not laid flat together at the seams; that there may have been burrs left at the rivet holes; that in caulking, the edge of the plate may have been upset so as to spring one plate more than another; and that the rivets may have been pitched too far apart." Any one of these causes would have been sufficient reason for leakage between the laps, but would not account for the cutting of the steel plates beyond the laps, which was the point upon which information was desired. The most probable explanation of this phenomenon, of a water jet apparently cutting steel, is that, in rivetting the plates together, too much power was used, the effect being to compress the plates at the rivets, and to buckle them in the intervals between, thus allowing the water when under full pressure to be forced out with great velocity. As the soil in which the injured pipe lengths are laid is nearly pure sand, the sand particles mixed with the escaping jets, and being kept in constant motion, acted as sand blasts at the points where the jets struck the shell just beyond the laps. This theory is supported by the fact, that the pipe shells were not cut where the excavations were in earth or clay, and that part of the 12 inch steel main which was uncovered, though leaking at several laps, showed no sign of abrasion. It has since been learned that similar occurrences have taken place in eastern cities, where the practice is, either to box the mains, or remove the sand and substitute clay.

Answers to the queries proposed by Mr. Duncan as to rivetting, coating, etc., etc., are to be found in the paper.

With reference to the statement that the pipe lengths being 23′ 9¾″, four courses would have been preferable to seven in the manufacture of each length, it may be briefly replied, that four courses would not have answered in the kind of pipe used. In order to admit of a nipple which would not lessen the governing diameter of the main, it was necessary that a large or outer course should be at each end of each length. This could only be (see Plate XX.) when each length consisted of 2, 5, or 7 courses. The "preferable pipe" of 4 courses would have had a small course at one end, which would not have received a nipple, except of lese diameter than itself. If a nipple were dispensed with, and the smaller course forced into the larger, this latter, overlapping the other, would make the thickness of lead, at each side of the junction, unequal.

As to its being bad practice to make up each pipe length of 7 courses of so-called small plates, this is a matter of opinion, and not warranted by custom on the Pacific Coast. The pipes of the Vancouver system have been endorsed by the best authority in California, and as a notable example of similar design, the 36 inch wrought iron main of the Spring Valley Water Works, Cal., may be cited. The specification of this pipe calls for plates 116″ × 44″.

It is a questionable statement, and unsupported by proof, to say that caulking the seams as described tends to aggravate leaks. Experience on this coast has shown that, to obtain perfectly tight seams, chipping, caulking and split caulking are necessary. A reference to the specification of the Spring Valley Water Works, California, and the Portland Water Works, Oregon, will give further information on this point.

The spigot and faucet joint, having only one surface to be caulked, requires less labour in laying than the Moore and Smith joint, which, owing to its simple construction, has two surfaces. This advantage, however, is more than counterbalanced by the original labour of making the spigots and faucets, and attaching them to the shell. Had the cost of these details been given, a satisfactory comparison could have been made, which might not have been unfavorable to the Moore and Smith joint.

The statement made, that in the Riley patent socket joint it is not found that the shell is bent inward by caulking, as is the case with the Moore and Smith joint described in the paper, is misleading. The paper merely says: "That if the lead is beaten between the ring and the pipe too tightly, the shell of the latter will bend inward; and that it is necessary to caution inexperienced caulkers with regard to this." But in the hands of caulkers who have learned their business, the Moore and Smith joint is as free from liability to defective workmanship as any other joint; an assertion which is amply proved by the fact that in the Vancouver Water Works system, after the pipes had been subjected to a full pressure for several weeks, no joint in the whole length of 10 miles was found to leak.

Mr. Duncan claims that owing to the spigot end of the socket joint pipe being made 50 per cent. thicker than the shell, no pressure imposed in caulking will indent it. This is somewhat strange, seeing that he admits the possibility of the shell of the Moore and Smith joint pipe being bent, where the extra thickness exposed to the pressure of caulking is often, as in the case of the Vancouver mains, 100 per cent. In the latter joint, a nipple or ring 5 inches wide, and of the same thickness as the pipe shell, is closely fitted to the interior surface of the pipe, directly under the 4 inch ring of lead to be caulked, thus doubling the thickness of metal exposed to the pressure of caulking.

Mr. Duncan's concluding observations afford very valuable information as to the manufacture of pipes by the London Steel Pipe Company. When in London some months ago the author had the pleasure of seeing various specimens of these pipes, and was much struck by their excellence. For finish and workmanship, they are not likely to be surpassed; and it is very desirable that full information regarding them should be well known.

In reply to Mr. Henshaw, as to the question of an anchor falling on the submerged main, it is conceded that it would be undesirable to invite a trial; but in the event of such a test being made, it is by no means certain that the disastrous effects hinted at would take place. In any case, such an occurrence is a very remote possibility, even with one submerged main; while, that an accident should happen to two at the same time is almost an impossibility.

With reference to the remarks of Messrs. Blackwell, Smith, Goad, Peterson, Gower and Bovey, there is no mistake about the dimensions of the Cedar in question. Should Messrs. Blackwell, Smith and Goad care to visit British Columbia, they can have the pleasure of verifying the measurements. The Cedar is dead, but is very uniform from the ground upwards, and has no abnormal enlargement at the base. Such trees are rarely solid, and this is no exception. In trenching for pipe lines, it is not usual to extract such stumps, it being much more economical to tunnel under them.

A working plan of the dam, drawn to the scale of 8 feet to the inch, accompanied the paper on the Vancouver Water Works. It was considered that this would, if hung on the wall, have afforded all necessary information.

As the whole front of the dam is protected by double sheet piling, overlapping, with the ends imbedded in a trench of concrete sunk in the bottom of the river, and the shore connections protected on the south side by a hand-laid stone wall with a well rammed gravel and earth backing, and on the north side by a gravel embankment of picked material, the chance of water percolation through the body of the dam, and seepage round the ends, has been reduced to a minimum. Certainly, none has taken place during the two years of the dam's existence. The trench in which the sheet piling is imbedded, owing to the shallowness of the river, was filled with concrete in a simple manner. The concrete was wheeled over gangways extending along the face of the dam, within a few inches of the water, was then deposited over the sides, and allowed to settle in the trench. Twenty-four hours after the trench had been filled, the concrete was firm enough to resist moderate probing.

The definite object in view in the manufacture of the concrete was imperviousness and a thoroughly secure connection between the foundations of the dam and the bed of the river. The space in which it was to be placed was very confined, being a narrow trench, not exceeding at any point a depth of 3 feet; and being for the most part entirely under water, it would not permit of the filling being packed and rammed. These objects could only be obtained by making the concrete of such small materials that the whole would form as nearly as possible a homogeneous mass.

The author's experience in the manufacture of concrete is not extensive enough to permit of his expressing an opinion as to the advisability of employing large stones. But it is worthy of note, that the specifications for the water works systems of Gosport, Lambeth, Bideford, Halifax, and Aberdeen distinctly require that either sharp gravel be employed, or that all stones shall be broken so as to pass through a ring 1½ or 2 inches diameter. Also, Trautwine (page 680, edition 1886) states "that broken stone for concrete is generally specified not to exceed about 2 inches on any side; but if well freed from dust, all sizes from ½ inch to 4 inches on any side may be used."

It is therefore apparent that if eminent authorities advocate the use of large stones, many quite as eminent do not.

The Teredo Navalis, not being gifted by nature with the aerobatic powers of the salmon, is not likely to ever find a home in the timbers of the dam.

Corrosion of metal exposed to the action of salt water is a subject of great importance; and it is a matter for surprise that really reliable information with regard to it is difficult to obtain. But experience, so far, goes to prove that steel and wrought or cast iron of proper quality resist this action for long periods. Trautwine says "that certain cast-iron sea piles of hard white metal showed no deterioration after 40 years immersion." (page 218, edition 1886.) The double 8 inch cast-iron pipes laid across Shirley gut nearly 20 years ago are in active operation to this day. In the discussion on the Avon Bridge, published in the last volume of the Society's Transactions, Mr. Uniacke in reply to Mr. Blackwell (page 286) says: "That bolts and plates used in the construction of the old bridge, 50 years ago, and exposed to salt water at different stages of the tide, showed not the slightest corrosion." Also, in constructing the new steel dock gates of Limerick Floating Dock, the pintles of the old gates were found to be so little affected by their 38 years' exposure to salt water, that they were used again.

It is to be noted that the cast-iron in the Vancouver submerged main is of the quality approved of in Trautwine; and, also, that there are many instances of similar mains submerged in salt water, designed by eminent engineers; as, for example, the aforementioned Shirley gut pipes, the Bournemouth storm outfall, the San Francisco Bay mains and the San Diego Bay main. Full information as to the manufacture, specification, quality, and proof tests of the submerged main are given in the paper on pages 344, 348, 351.

It is difficult to believe that Mr. Peterson's remarks relating to his observations when in Vancouver are uttered in any other than a jocular spirit. No one can suppose that because an irresponsible individual volunteered the information that the steel mains (wrought iron, he calls them) were not sufficiently strong to withstand the pressure, he credited that statement without investigation. It is hard to understand his imagining the rivets to be 4 or 5 inches apart, seeing that this is nearly 4 times the extreme distance. The round seam rivets of the 12 inch and 16 inch mains, referred to by him, are 1.2 inches and 1.08 inches apart, from centre to centre, respectively; and the straight seam rivets, which are in double rows, 1.3 inches and 1.4 inches. It is impossible he can believe that any steel or wrought iron pipe, which had so yielded to pressure that water was flowing in little streams out of nearly all the joints of the sides, could be held together and rendered serviceable by straps placed round it. All new rivetted pipes weep more or less at the laps, when first put under pressure. The great majority of the leaks he observed, being on the south side of the Inlet, where there was little or no sand to cut the plates, "took up" of their own accord, without special repairs.

The submains are 8 inches, 6 inches, and 4 inches in diameter; not 4 inches and 2½ inches. 2½ inch welded wrought iron tubes have been laid for short distances, as a temporary means of supply for certain buildings. No hydrants are connected with 2½ inch pipes.

The distribution system was designed by the most eminent authority on water works in Canada, Mr. T. C. Keefer, C.E., C.M.G.

In the case of Vancouver, there is a very substantial reason why the water works should be in the hands of a private company. They were projected before the city had an existence, and constructed at a time when the city's resources were being fully employed in making absolutely necessary improvements, and it is doubtful whether even at this day the city would care to incur the expense of water works construction.

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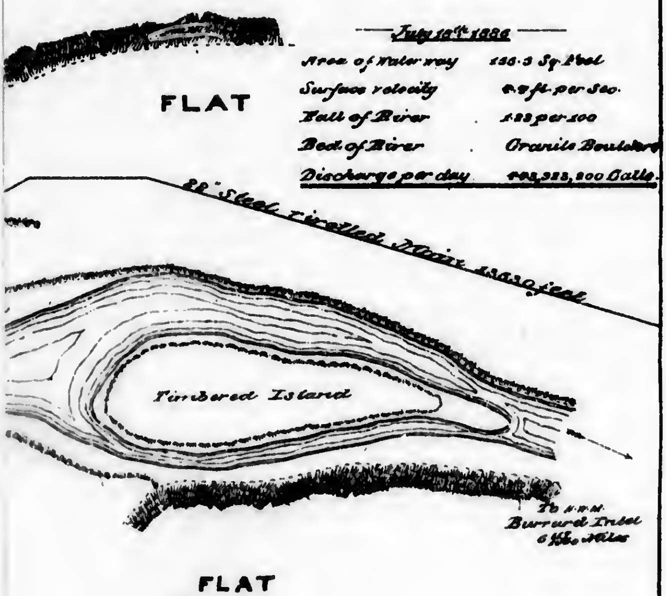
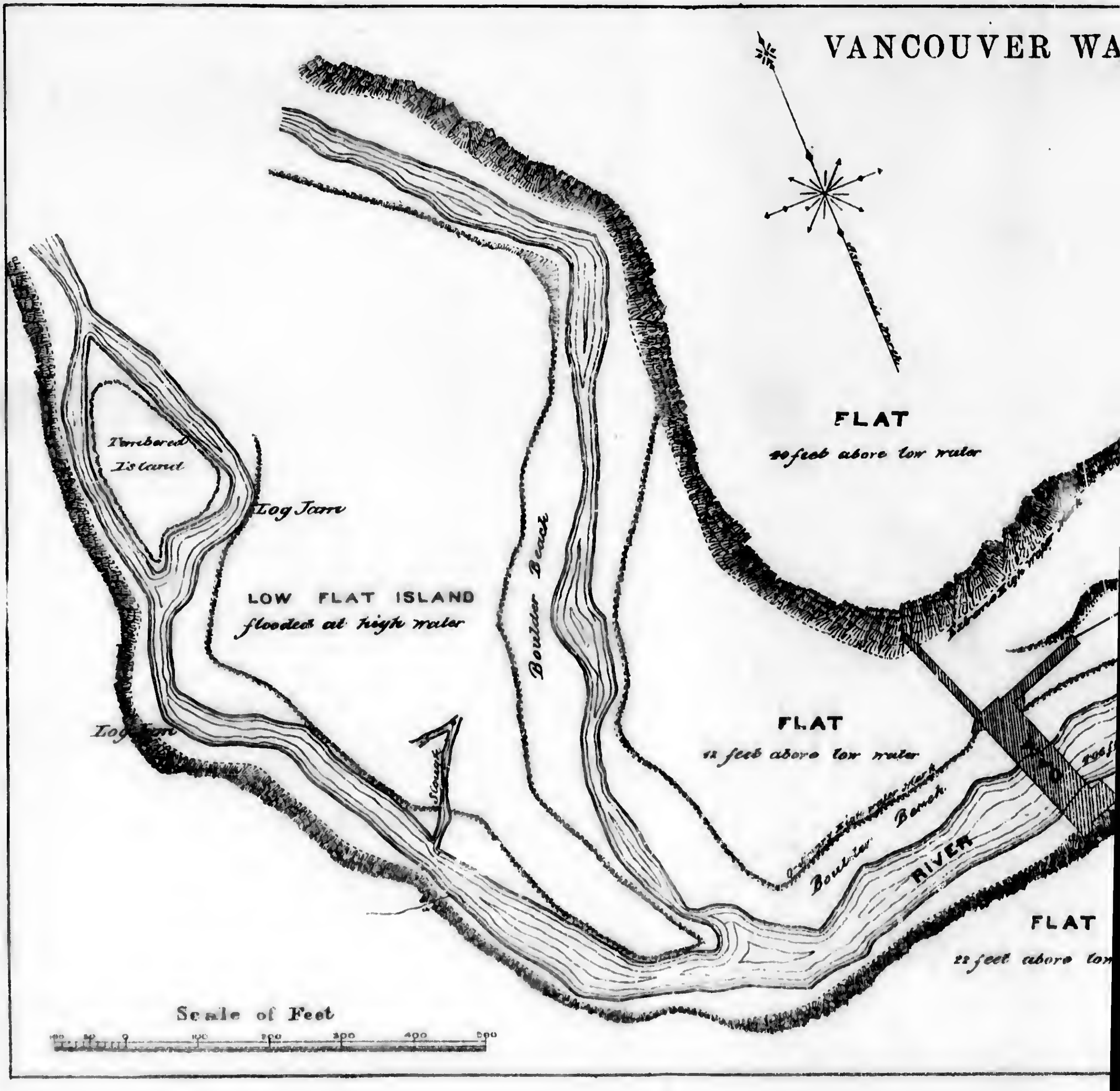
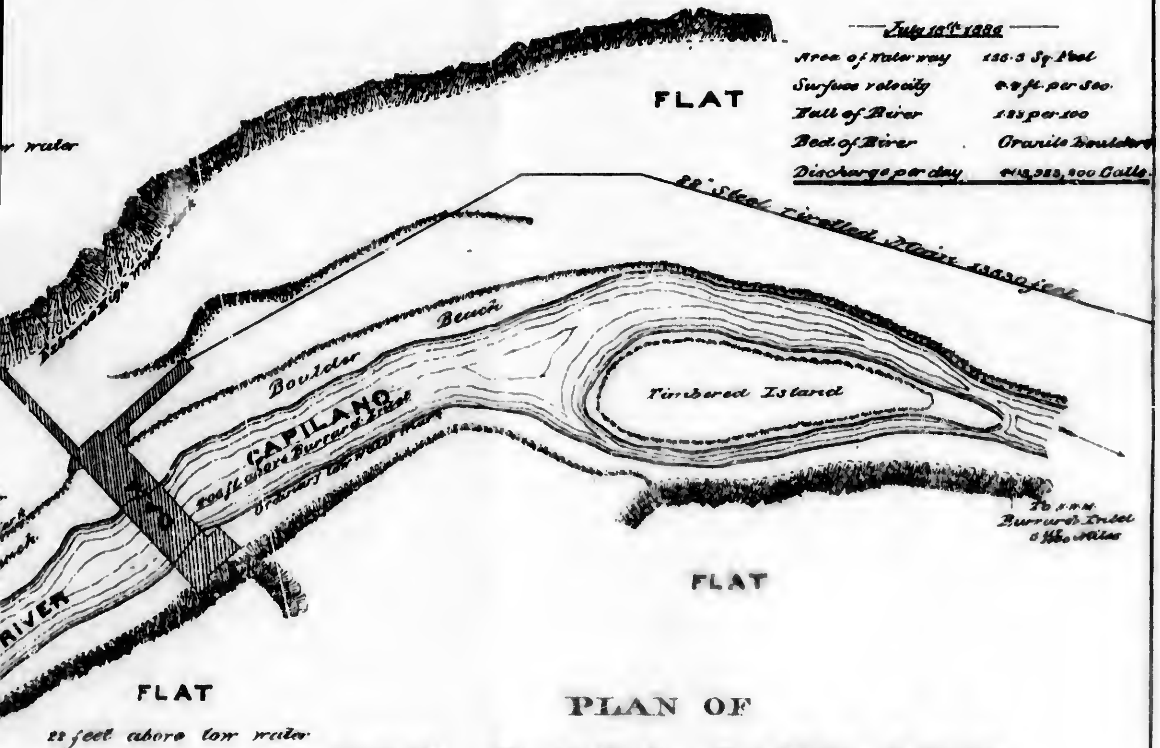
PLATE XVI.



PLAN OF
RIVER CAPILANO
EWING DAM SITE



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



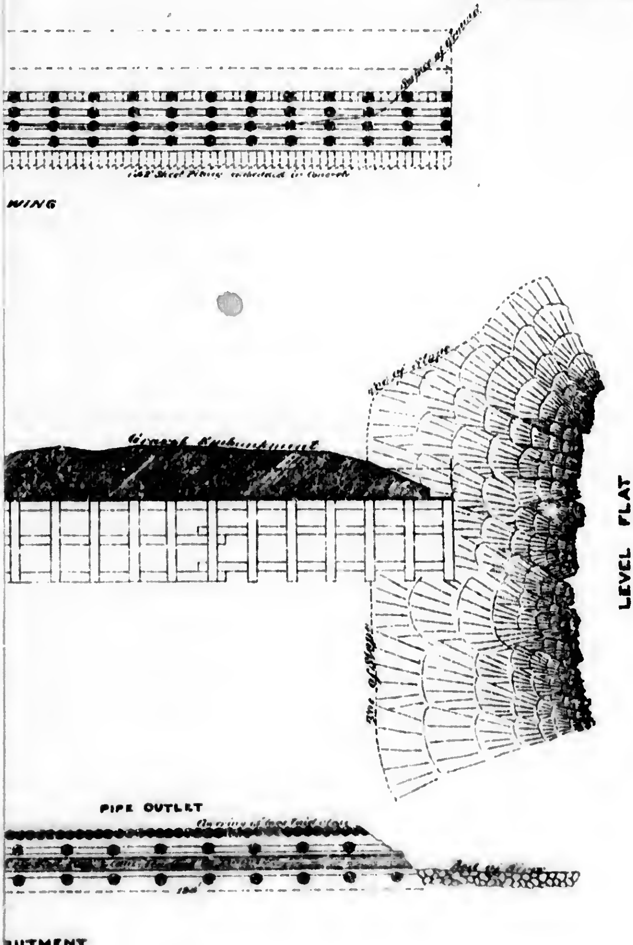
PLAN OF

THE RIVER CAPILANO

SHEWING DAM SITE

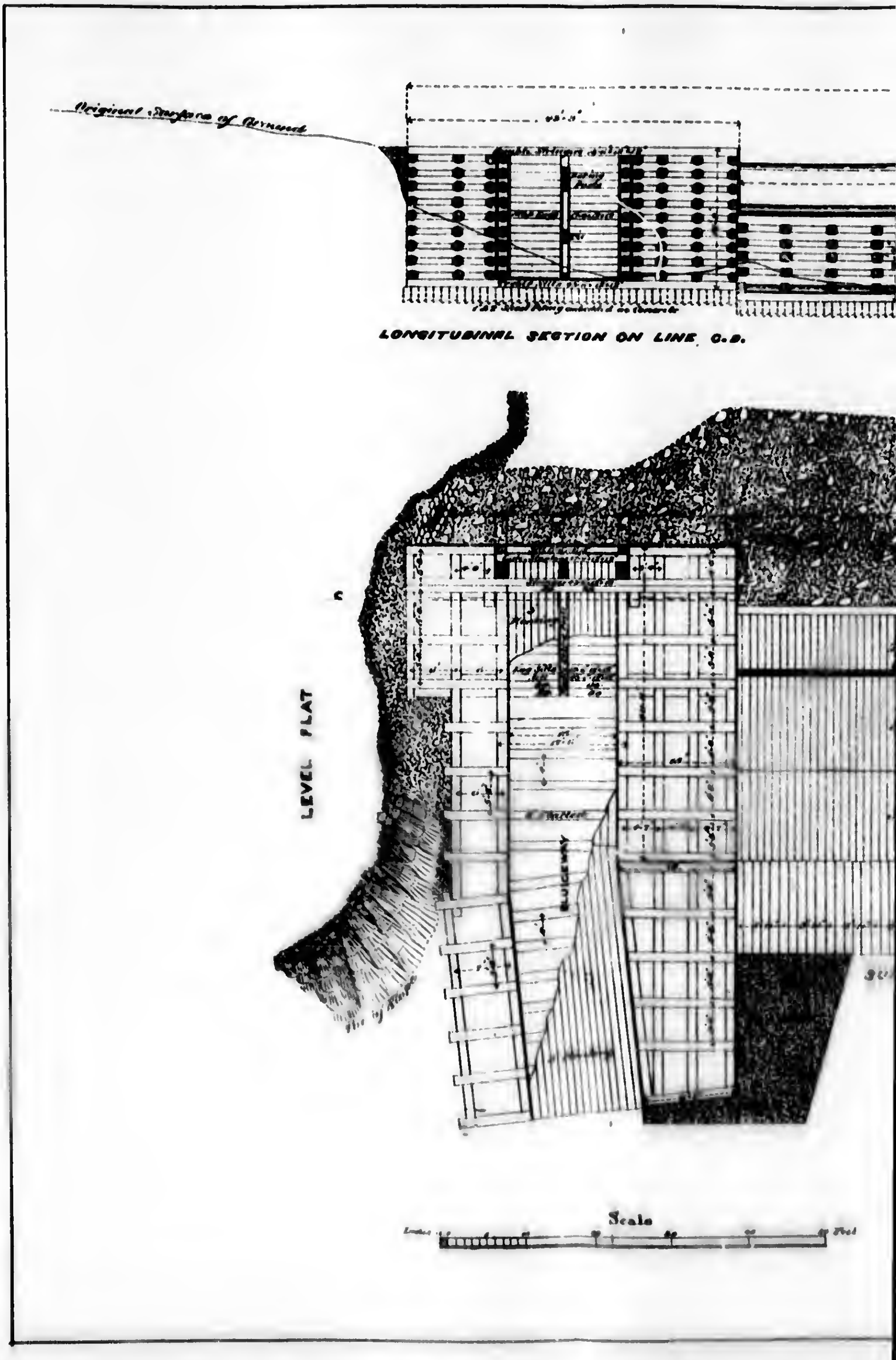

WING

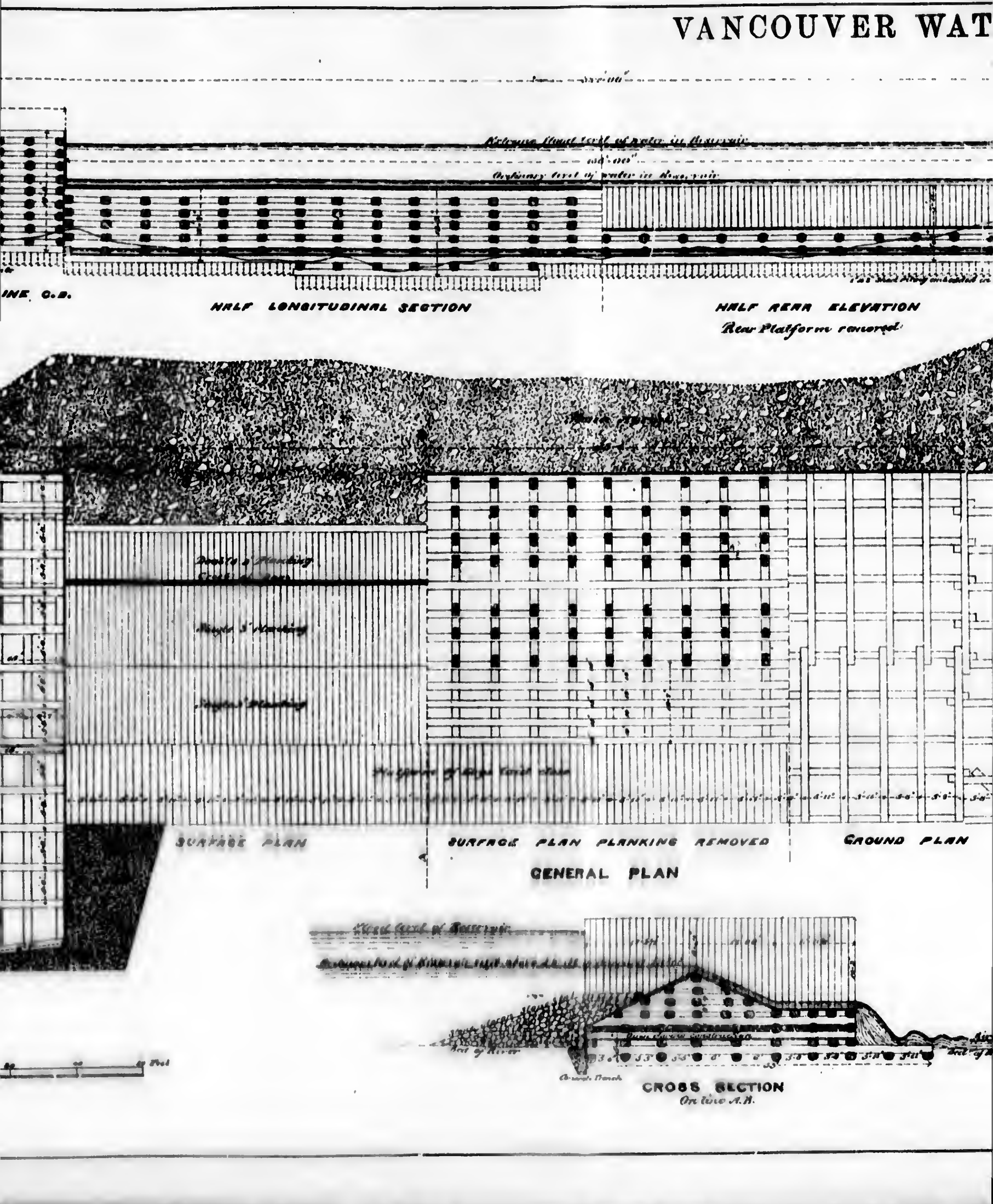
PLATE XVII.



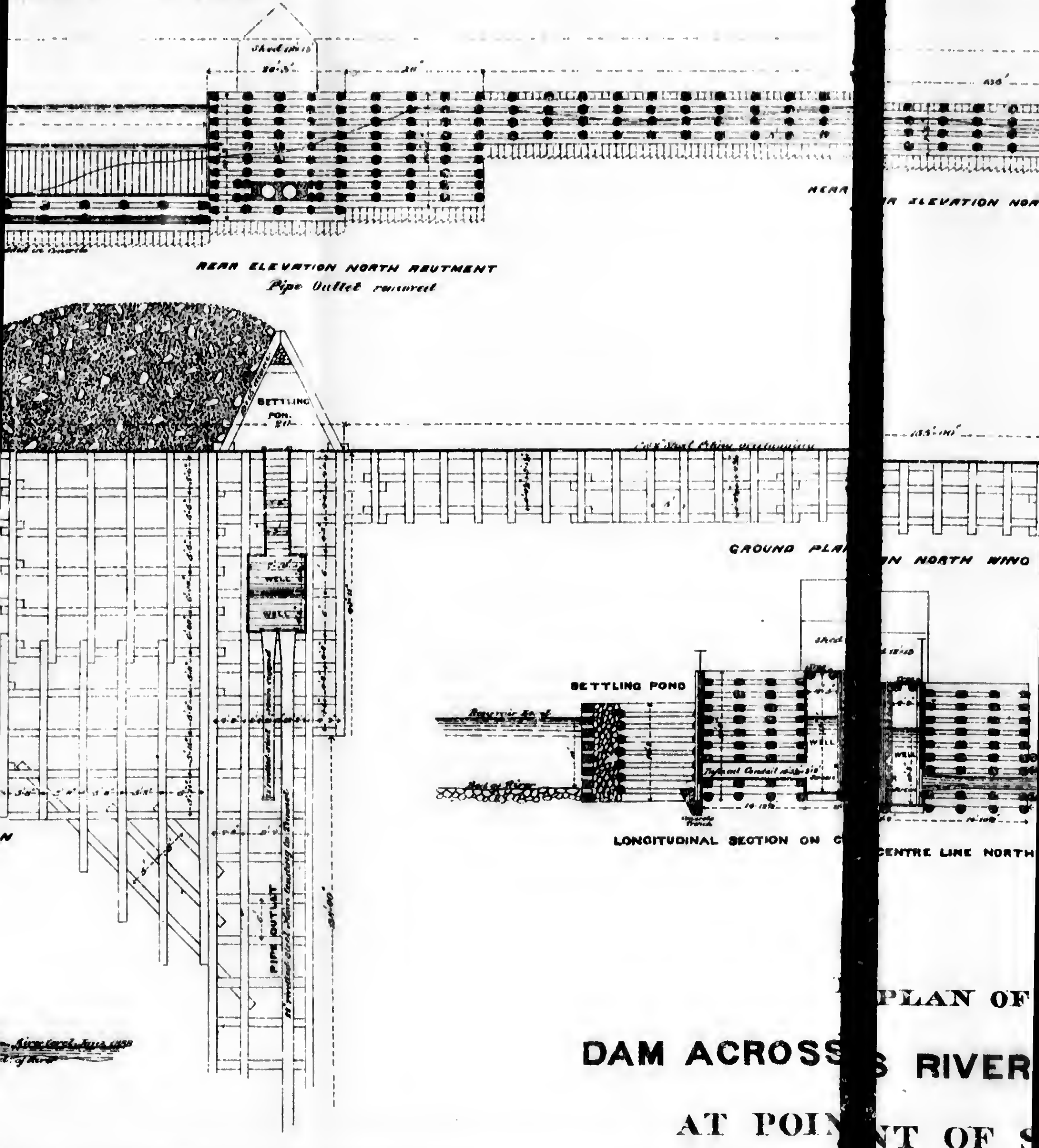
CAPILANO

PPLY


Original Surface of Ground
LONGITUDINAL SECTION ON LINE C.D.
LEVEL FLAT
SLUICEWAY
Scale


VANCOUVER WAT
INE C.B.
HALF LONGITUDINAL SECTION
HALF REAR ELEVATION
Rear Platform removed
SURFACE PLAN
SURFACE PLAN PLANKING REMOVED
GROUND PLAN
GENERAL PLAN
CROSS SECTION
On line A.B.

ATER WORKS.

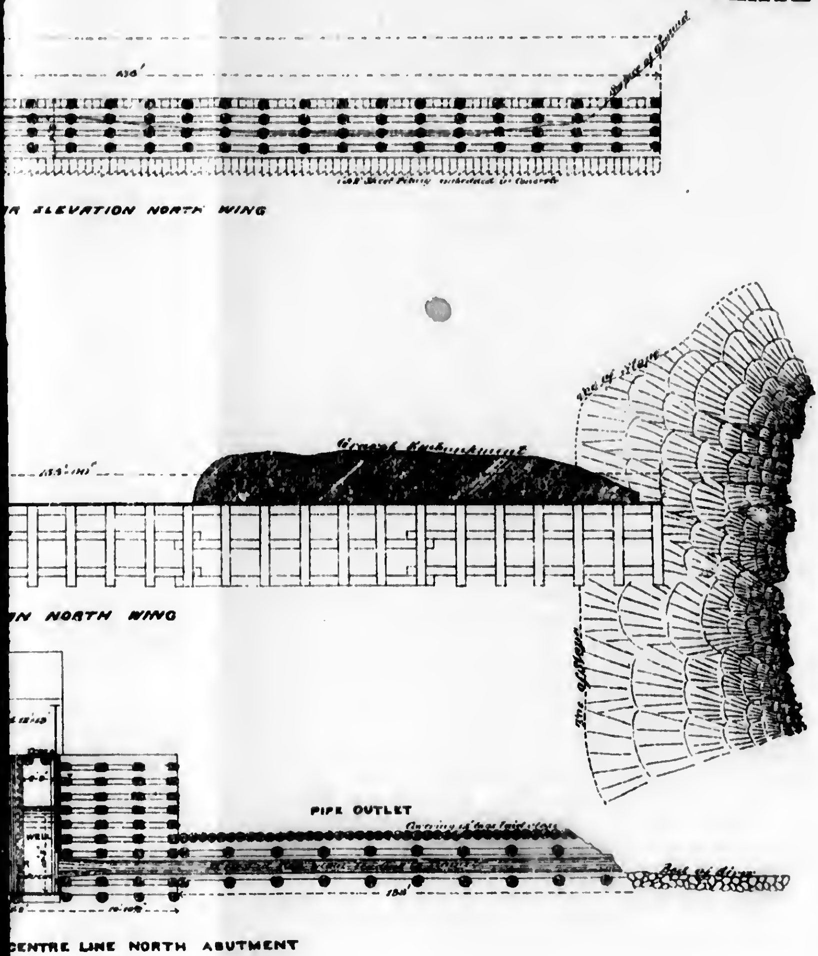


PLAN OF

DAM ACROSS S RIVER

AT POIN NT OF S

PLATE XVII.

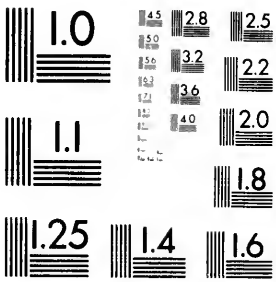


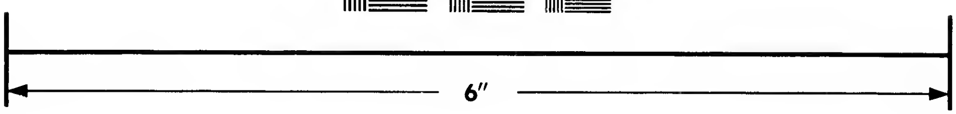
PLAN OF

S RIVER CAPILANO

NT OF SUPPLY

IMAGE EVALUATION TEST TARGET (MT-3)





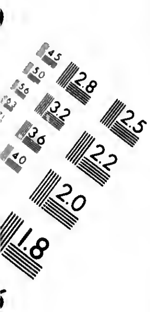
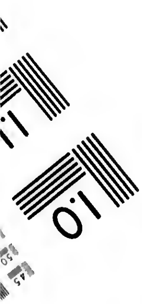
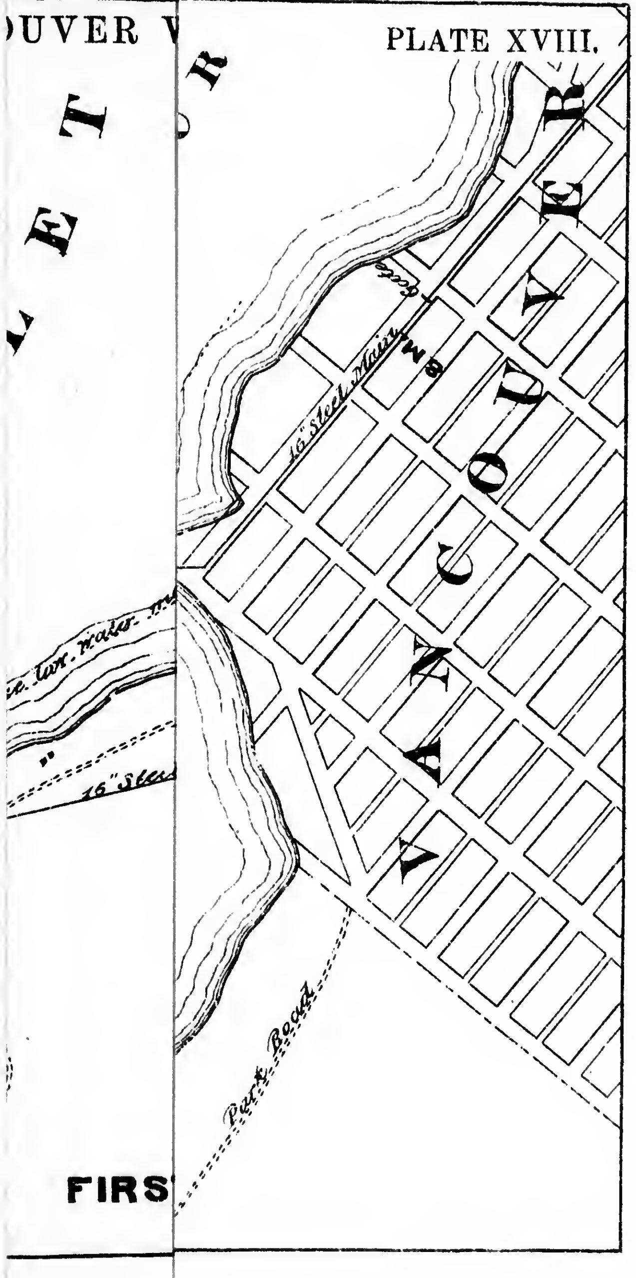
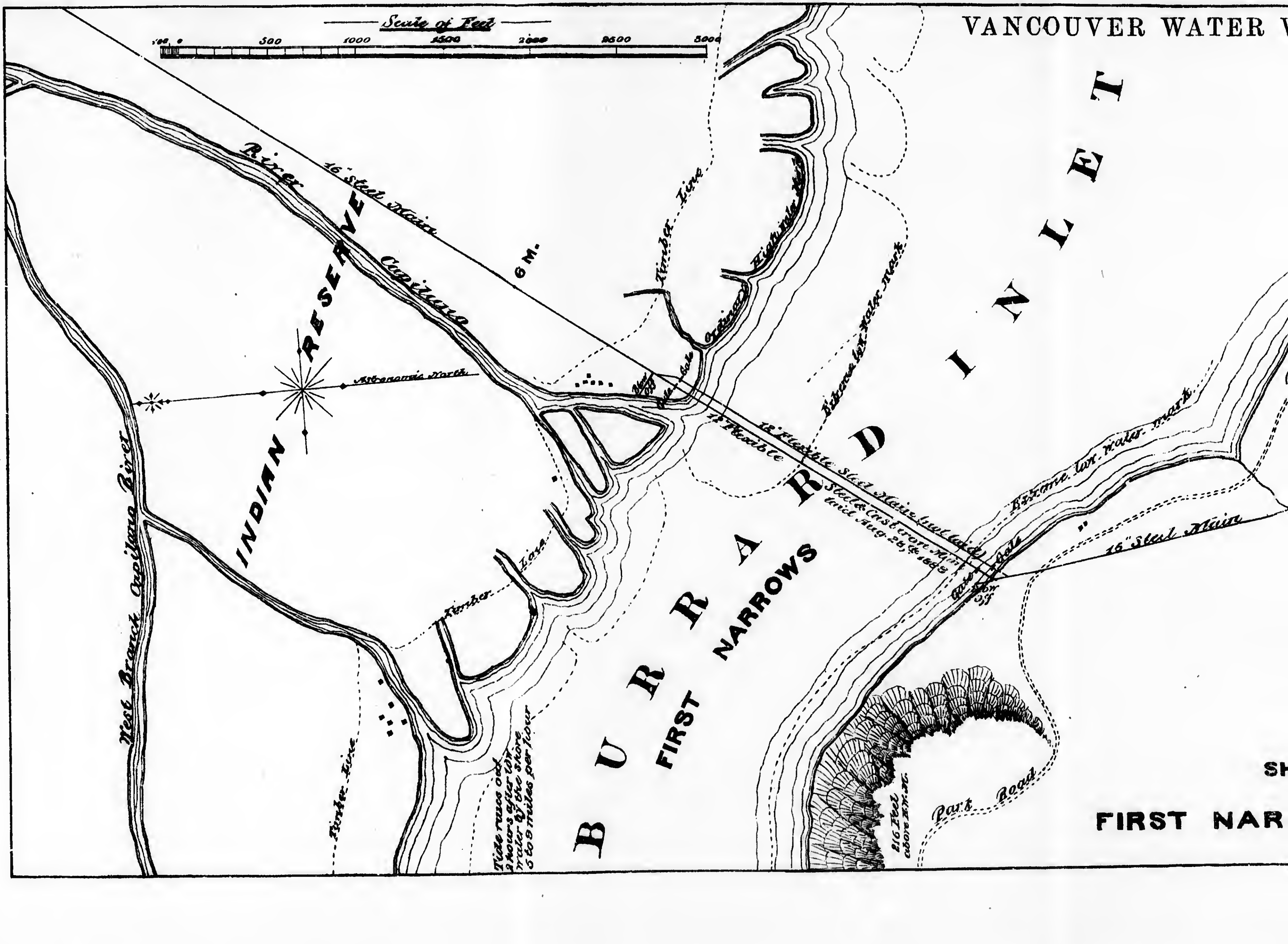

2.8
2.5
3.2
2.2
3.6
2.0
1.8

1.1
1.0

PLATE XVIII.

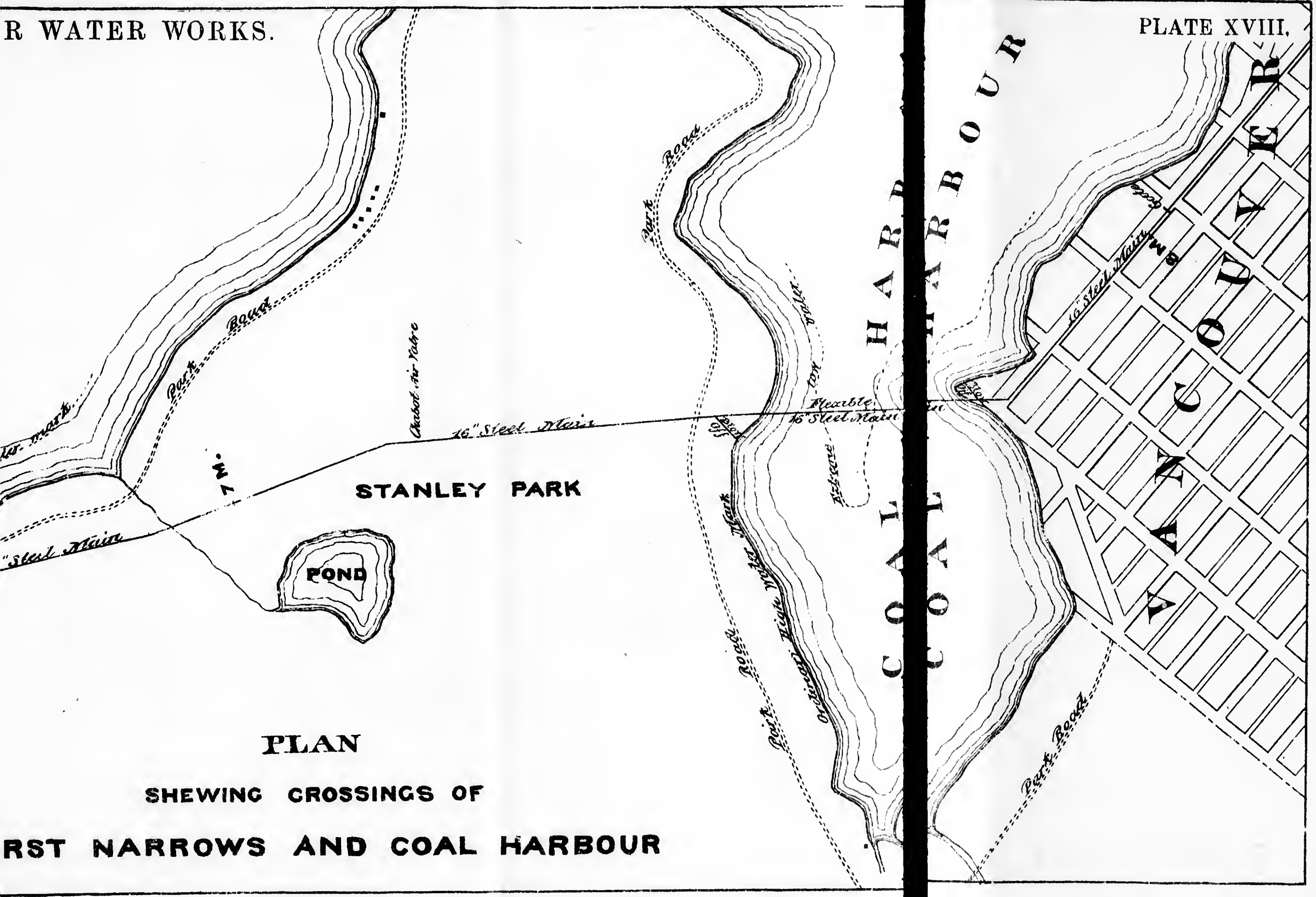




VANCOUVER WATER W
Scale of Feet
500
1000
1500
2000
2500
3000
BURRARD INLET
FIRST NARROWS
INDIAN RESERVE
Capilano River
West Branch Capilano River
16" Steel Main
Astronomic North
Timber Line
Timber Line
Extreme low water mark
Park Road
SH
FIRST NAR

R WATER WORKS.

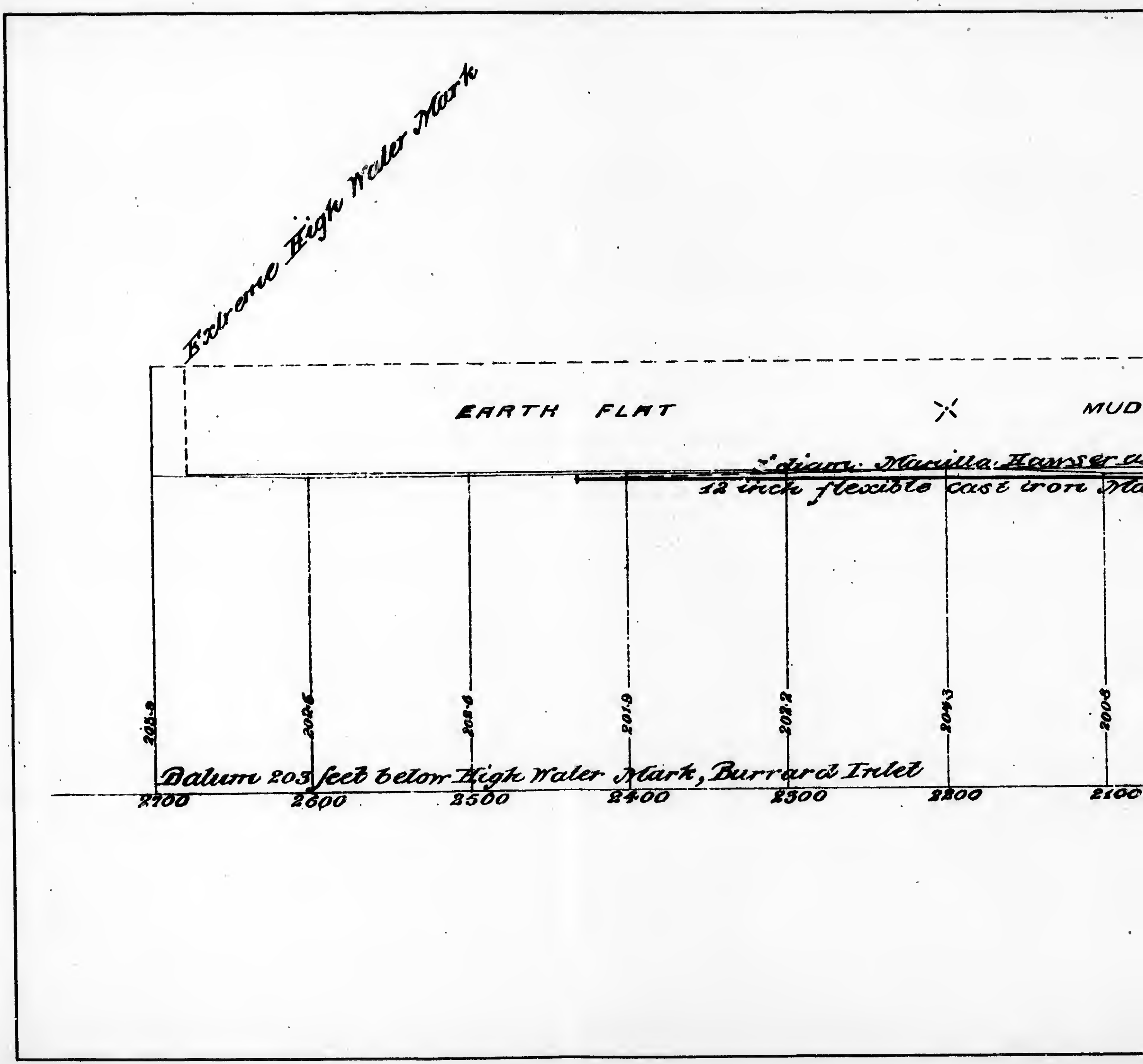
PLATE XVIII.



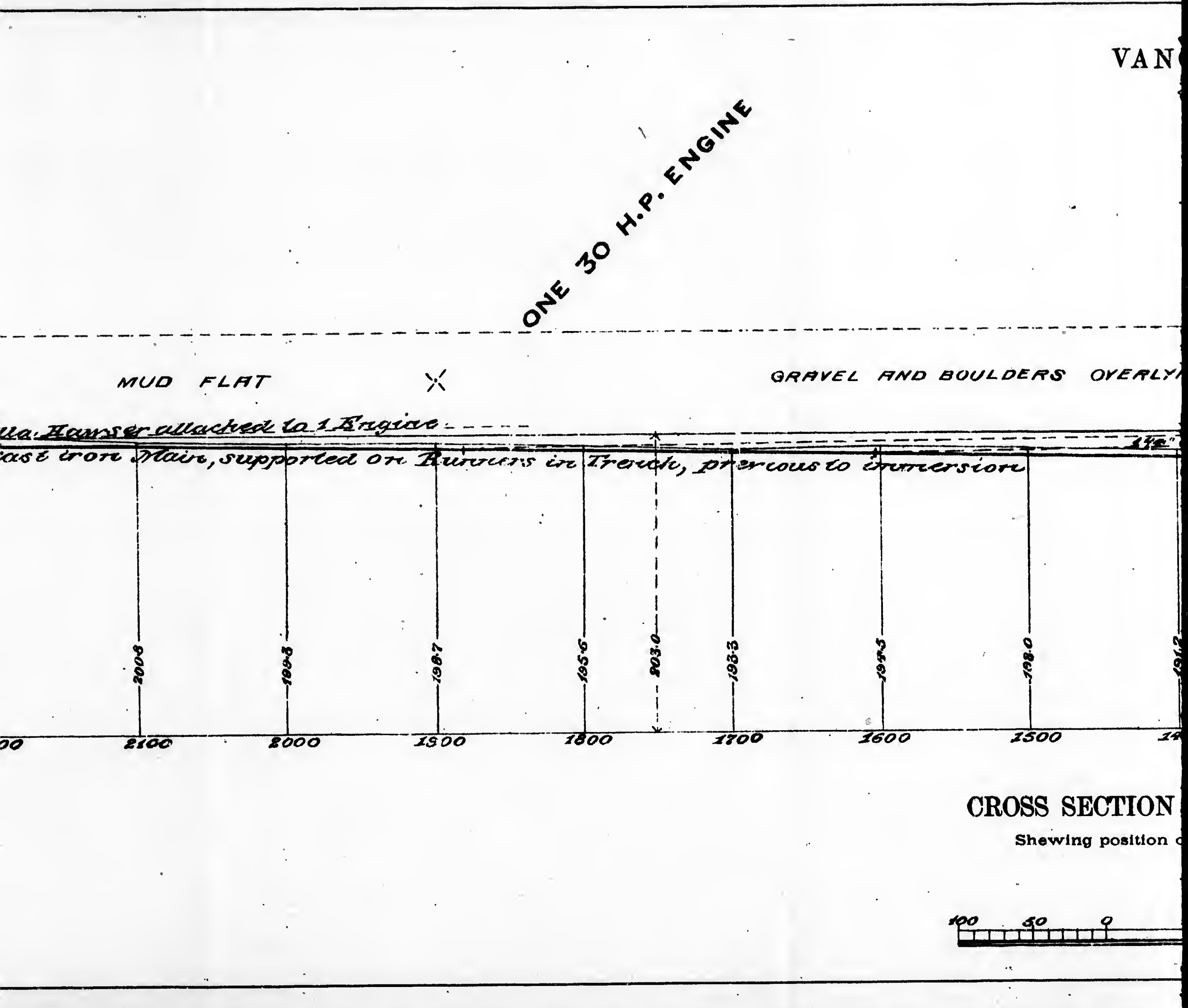
PLAN

SHEWING CROSSINGS OF

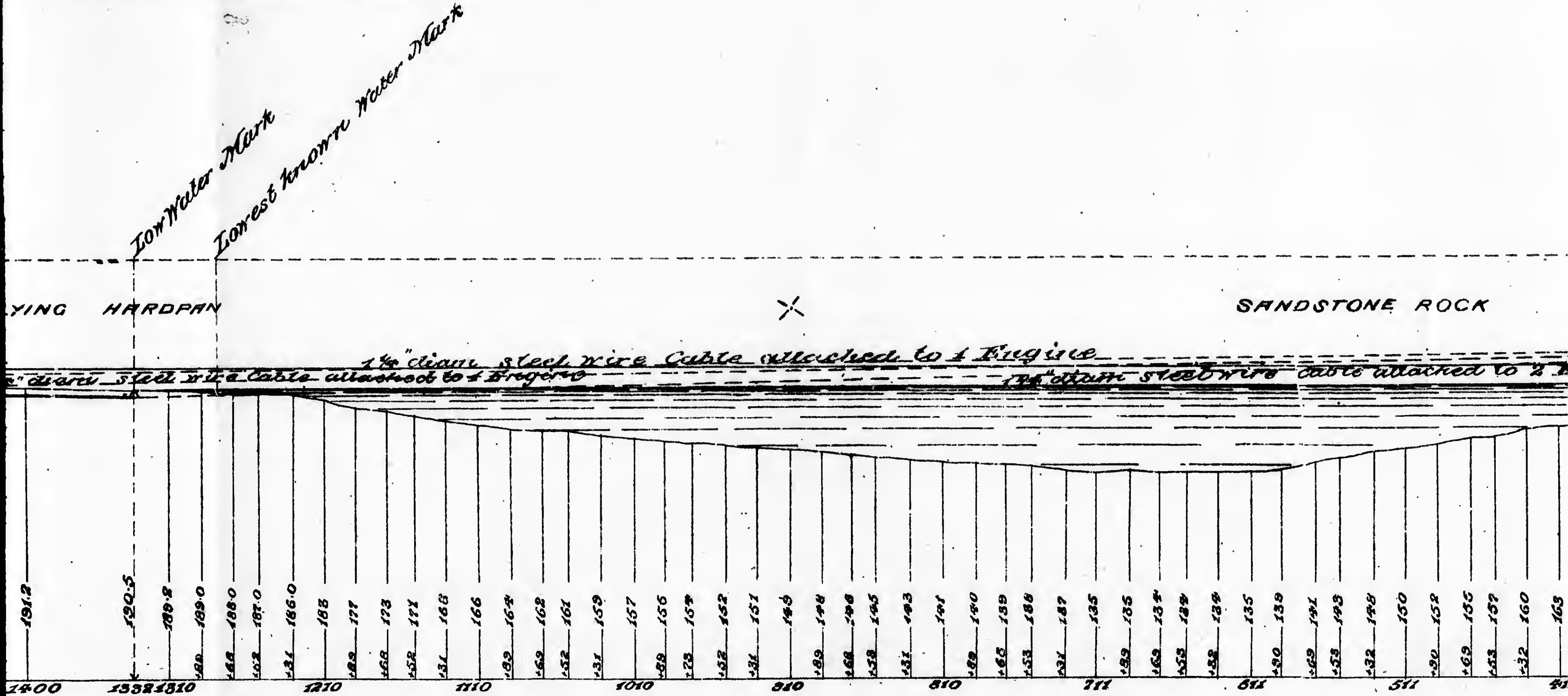
RST NARROWS AND COAL HARBOUR



Extreme High Water Mark
EARTH FLAT
MUD
12 inch flexible cast iron
202.6
201.9
202.2
204.3
200.8
Datum 203 feet below High Water Mark, Burrard Inlet
2700
2600
2500
2400
2300
2200
2100


VAN
ONE 30 H.P. ENGINE
MUD FLAT
GRAVEL AND BOULDERS OVERLY
ia Hawser attached to 1 Engine
ast iron Main, supported on Runners in Trench, previous to immersion
200.8
199.5
198.7
195.6
203.0
193.3
194.5
198.0
2100
2000
1900
1800
1700
1600
1500
CROSS SECTION
Shewing position
100
50
0

NCOUVER WATER WORKS.

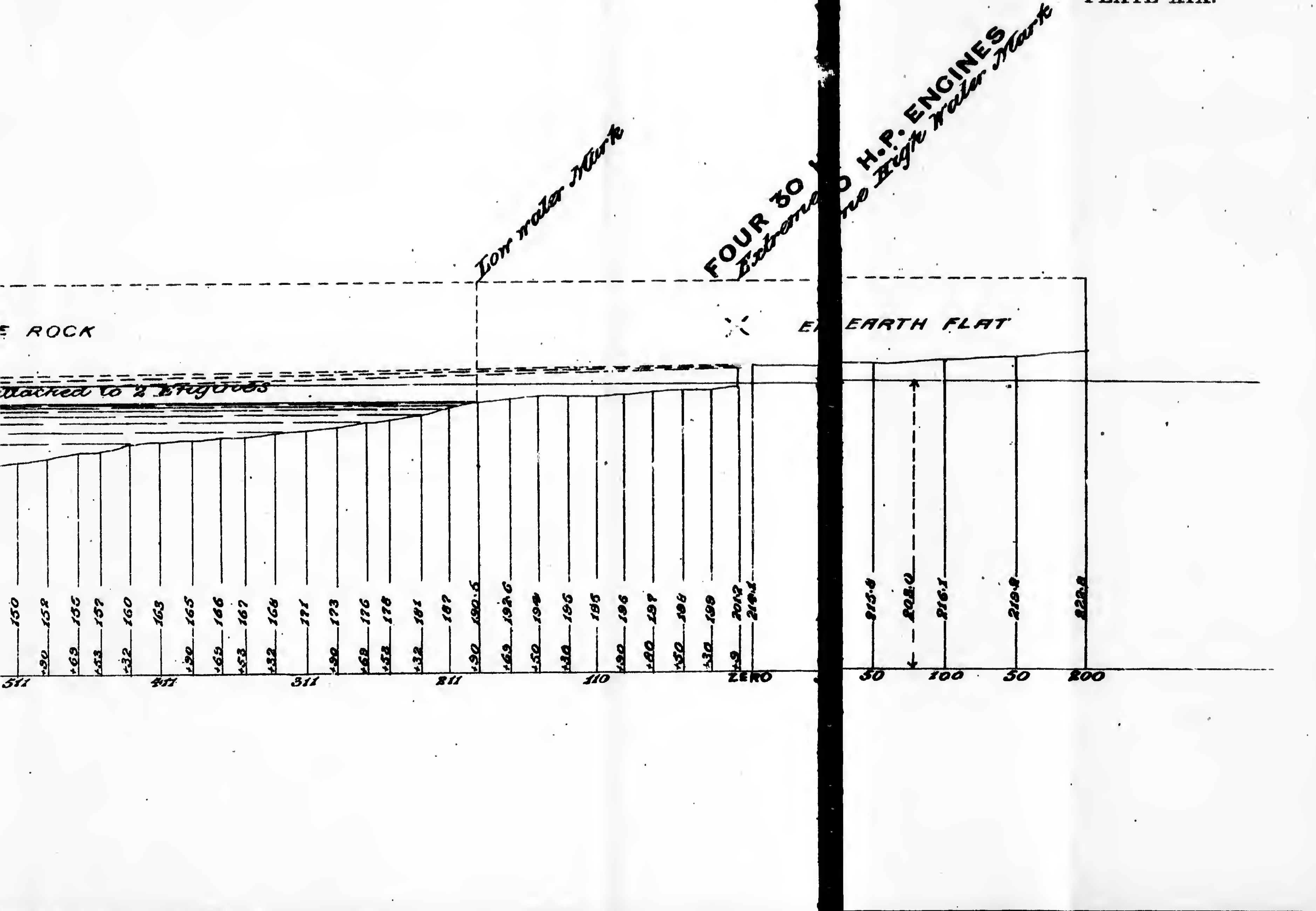


N OF THE FIRST NARROWS OF BURRARD INLET,

n of Flexible 12 Inch Main and Stationary Engines previous to hauling.

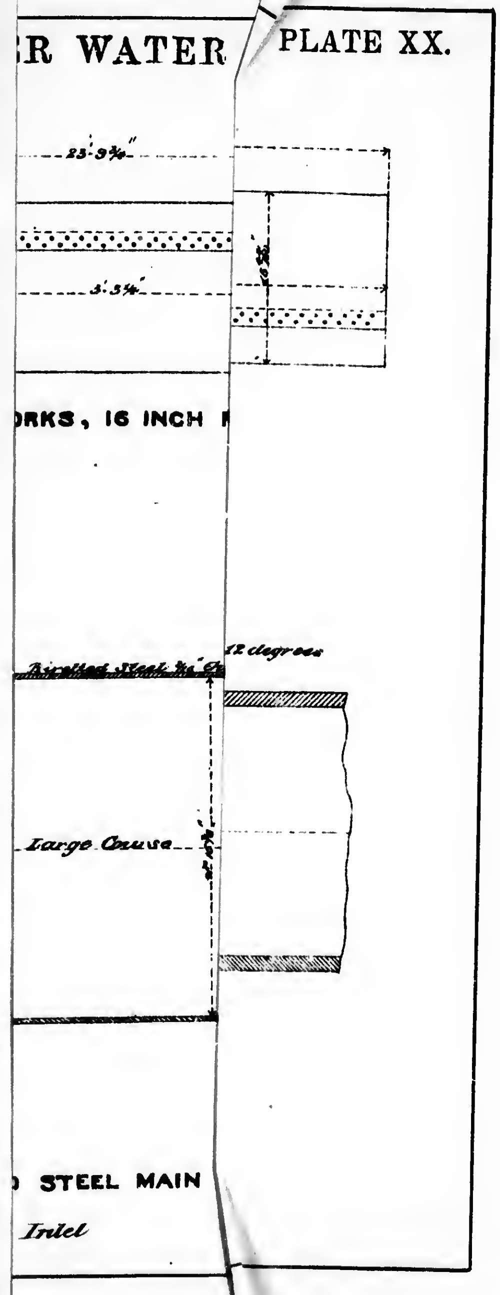
HORIZONTAL AND VERTICAL SCALE OF FEET.

PLATE XIX.

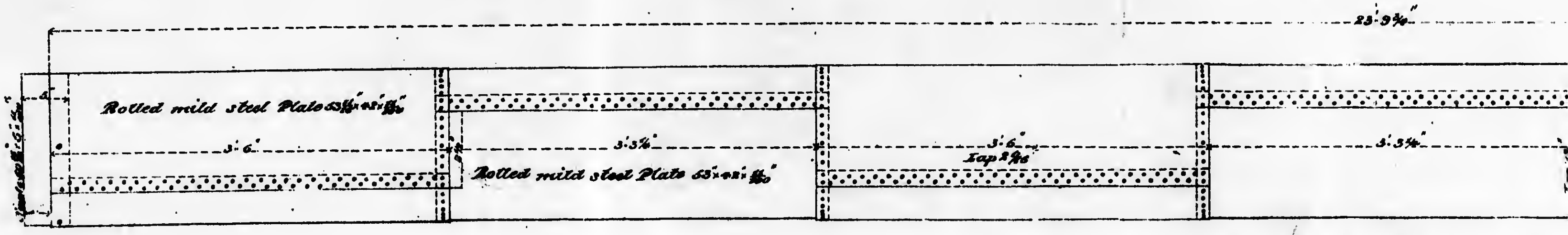


Low water Mark
FOUR 30
H.P. ENGINES
Extreme
High Water Mark
ROCK
EARTH FLAT
ZERO
50
100
50
200

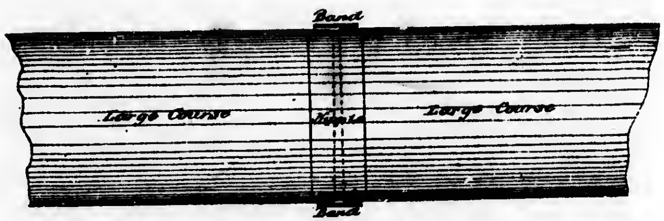
PLATE XX.


R WATER
23' 9¾"
5' 3¼"
ORKS, 16 INCH
12 degrees
Large Course
STEEL MAIN
Inlet

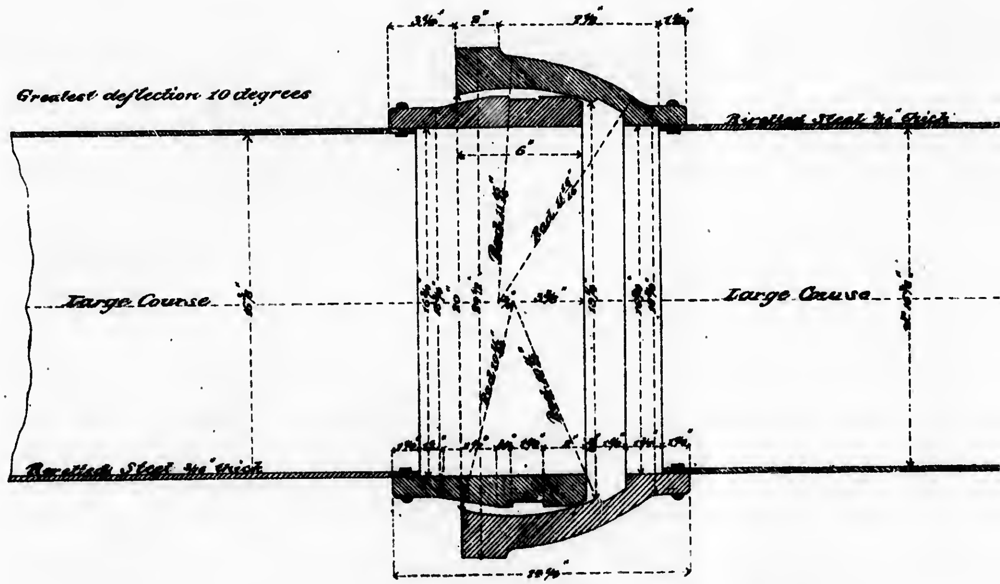
VANCOUVER WATER WO



VANCOUVER WATER–WORKS, 16 INCH RIVETT



MOORE & SMITH'S JOINT

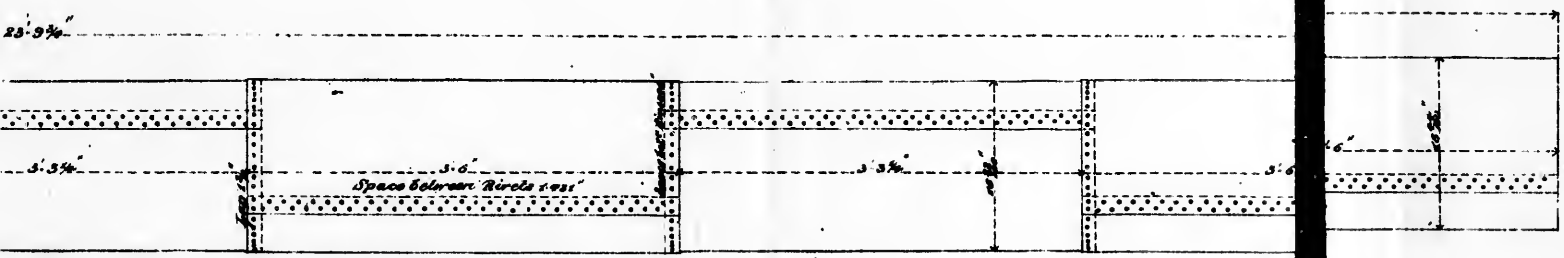


CAST IRON FLEXIBLE JOINT, 16 INCH RIVETTED STEEL MAIN

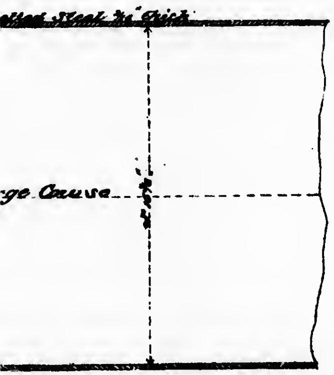
Submerged in Coal Harbour, Burrard Inlet

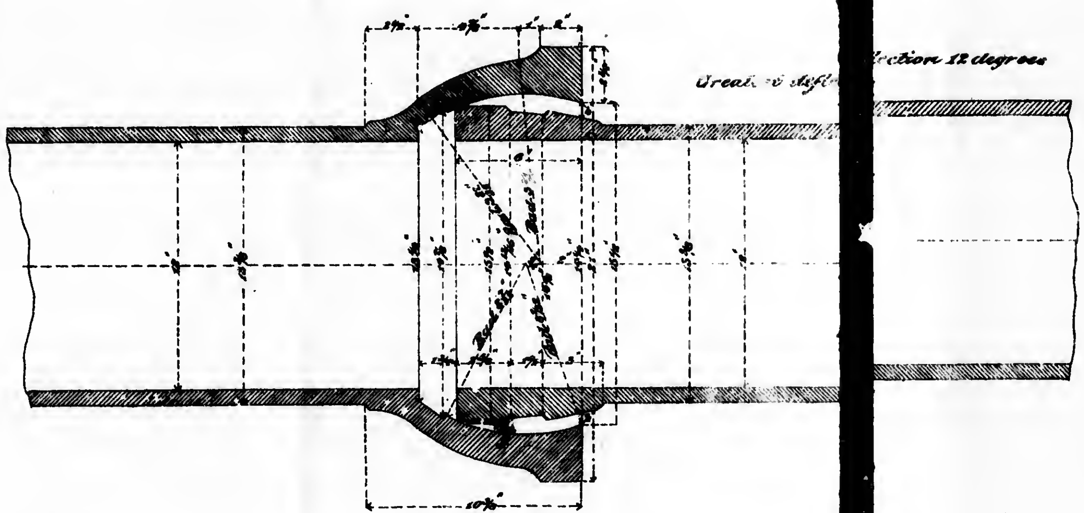
WATER WORKS.

PLATE XX.



S, 16 INCH RIVETTED STEEL MAIN





TEEL MAIN

el

WARD'S FLEXIBLE JOINT, 12 INCH CAST IRON MAIN

Submerged in First Narrows, Burrard Inlet