(*Paper No. 4248.*)

**“Hong Kong Waterworks: Low-level Reservoirs and
Contingent Works for Pumping Supply.”**

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THE Island of Hong Kong was ceded to the British Government in 1841, and, during the early years of occupation, the water-supply to the city of Victoria was obtained from wells and from the streams which flow down the slopes of the hills above the city. The supply from these sources must have proved very inadequate during the dry season, but it was not until 1860 that a scheme which included the provision of some storage was embarked upon. The Pokfulam Valley on the south side of the Island (Fig. 1, Plate 7) was tapped for a further supply, an earthen dam being constructed across it in 1866 to form a reservoir of 66 million gallons capacity. The overflow sill at 555 feet above datum (datum is about L.W.O.S.T.) permitted water to be delivered by gravitation to all parts of the city, including the hillsides above it to the height then built upon.

The improvement in the supply which this scheme effected did not long suffice for the rapidly growing needs of the Colony and the late Sir Robert Rawlinson, K.C.B., Past-President Inst. C.E., who was consulted in 1873, recommended the utilization of the Taitam Valley on the lines of a scheme prepared by Mr. John Macneill Price, then Surveyor-General of Hong Kong. This project, carried out during the years 1883–90, comprised the construction of a masonry and concrete dam to impound 312 million gallons. From this reservoir the water was conveyed by gravitation through a tunnel 1·4 mile long and a conduit of double this length to filter-beds, and thence to a service-reservoir above the city.¹

¹ Minutes of Proceedings Inst. C.E., vol. c, p. 246.

In 1890-92 filter-beds were added to the Pokfulum supply, the distribution mains in the city were relaid with larger pipes, and the service was extended to the Peak, for which pumping was necessary, power being obtained from a hydraulic motor connected to the low-level supply, and a steam-driven set being provided as a stand-by.

In 1895, the capacity of Pokfulum reservoir was increased to 70½ million gallons by the addition of overflow boards, and, in 1897, the capacity of Taitam reservoir was increased to 407 million gallons, by raising the height of the dam 12 feet 6 inches.

In 1899, a further addition of 33¼ million gallons was made to the storage by the construction of Wongneichong reservoir, which brought the storage up to 510¾ million gallons, and in 1904 a small bywash reservoir containing 26¼ million gallons was added to Taitam reservoir, which brought the total storage of all the reservoirs up to 537 million gallons.

The growth of Hong Kong at this period was very great (the census returns showed a water-consuming population of 156,396 for 1891, 182,576 for 1897, 205,626 for 1901, 203,408 for 1906 and 248,473 for 1911), the supply failed to keep up with it, and in 1901 a very low rainfall resulted in so severe a water-famine that water had to be transported in barges from the mainland, and other expedients adopted to supplement the supply. An extension which would add very materially to the Colony's water-supply was therefore necessary, and, as the late Mr. Osbert Chadwick, C.M.G., M. Inst. C.E., was in the Colony at the time, reporting on sanitary matters, the question was referred to him. Mr. Chadwick recommended that the entire Taitam Valley down to sea-level should be developed for waterworks purposes, thus involving pumping arrangements of considerable magnitude.

Mr. Chadwick recommended :—

- (1) The construction of a pumping-station on the shore of Taitam Bay.
- (2) The immediate installation of machinery capable of pumping 1¼ million gallons in 24 hours, to be ultimately triplicated.
- (3) The construction of a low-level reservoir of at least 400 million gallons capacity.
- (4) The provision of a 15-inch pumping main in the first instance, to be supplemented later by a 21-inch main.

These recommendations were in part given effect to during 1904-7, when the first section of the Taitam Tuk works was undertaken.

These works comprised the construction of a concrete and masonry dam designated the Intermediate dam, 90 feet in height, about midway down the valley between Taitam dam and the sea, impounding 210 million gallons; the erection on the shore of Taitam Bay, where coal could be delivered at all states of the tide, of a pumping-station having two sets of triple-expansion vertical pumping-engines, each capable of raising $1\frac{1}{4}$ million gallons in 24 hours; the laying of an 18-inch supply main from the Intermediate dam to the pumps, and the provision of a road for and laying of a similar discharge main from the pumps to the gauge-basin at the inlet or east end of the tunnel which conveys water from Taitam reservoir to the City.

These works did not fully develop the resources of the Taitam Valley, nor did they suffice for a full supply to be maintained throughout the year; but, as other large works were in progress at the time, the Government decided that, for financial reasons, the larger extensions contemplated must remain in abeyance. The result was that, except in very favourable years, a restricted supply by rider-mains alone was available during some part of the dry season.

The rainfall over the year is divided into two well-defined periods, a wet season which generally extends from May to September inclusive, and a dry season from October to April inclusive. The rains during the first months of the wet season are due to the change of the monsoon and are generally fairly light and pretty well distributed, but thunderstorms, which often occur at this period of the year, are generally accompanied by very heavy rain. The rains during August and September are chiefly caused by typhoons, and the influence of these storms may make itself felt in heavy rain, even when they pass no closer to the Colony than 300 miles. In years when there are no typhoon disturbances the rainfall may cease early in August, but in most years at least one typhoon passes sufficiently close to the Colony to bring rain. The maximum annual rainfall recorded at the Observatory since 1884 is 119·72 inches in 1889, and the minimum 45·83 inches in 1895. The mean for the 30 years 1884 to 1913 inclusive is 83·16 inches. As an instance of the heavy falls, between 3 A.M. on the 29th of May and 5 P.M. on the 30th of May, 1889 (38 hours), 33·11 inches was recorded, the maximum hourly rainfall being 3·4 inches. The

monthly distribution of the rainfall for the maximum and minimum years, and the mean for the 30-year period is tabulated below:—

Month.	Rainfall recorded at Observatory.		
	1889.	1895.	Mean, 1884 to 1913.
January	Inches. 0·73	Inches. 0·41	Inches. 1·442
February	0·72	0·83	1·688
March	2·49	1·39	2·987
April	12·27	2·61	5·511
May	48·84	5·64	11·713
June	9·72	4·97	15·681
July	4·57	18·87	12·555
August	18·14	6·13	14·362
September	11·80	3·96	9·668
October	8·72	0·50	4·911
November	1·54	0·32	1·421
December	0·18	0·20	1·226
Total for year	119·72	45·83	83·165

In 1910 the Author, who carried out the works previously detailed under the direction of Mr. William Chatham, C.M.G., M. Inst. C.E., Director of Public Works, was called upon to report on further extension. The position was as follows:—

The aggregate storage-capacity of the reservoirs affording a gravitation supply amounted to 537 million gallons, and of that requiring pumping to 210 million gallons, making, in all, 747 million gallons, to which must be added the dry season discharge of the various streams feeding the reservoirs, about 170 million gallons,¹ thus giving, if all the reservoirs were filled at the beginning of the dry season, 917 million gallons to tide over the dry season. On a full supply the consumption was 5 million gallons per diem (20½ gallons per head for a population of 240,000), or 1,060 million

¹ This figure is obtained from the contents of the reservoirs less the quantities withdrawn for supply, and therefore includes the loss from evaporation.

gallons during the seven months of the dry season, and as a consequence even with the reservoirs fully charged at the end of the wet season—a state of affairs which was exceptional rather than otherwise—there was a deficit.

Thus a much greater storage-capacity was necessary, especially if provision was to be made not only for the ordinary increase in population but also for the large increase which would follow on the completion of extensive reclamations then under consideration. The Author estimated at 482 million gallons the increase in storage which was absolutely necessary if full supply was to be maintained throughout the year for the population at that date, whatever the incidence of the rainfall might be, and he considered 558 million gallons the minimum provision which should be made for growth (normal and due to reclamation), or a total additional storage of 1,040 million gallons.

Gaugings in the main stream in the Taitam Valley below the Intermediate reservoir from 1906 to 1911 showed that a yearly average of 982 million gallons had flowed to waste; the returns of the reservoirs within the catchment-area of the gauges gave a yearly average supply for this period of 1,033 million gallons; the total average annual yield from the catchment area of 1,509 acres above the gauges was therefore 2,015 million gallons. The yield varied from 75·4 to 65·8 per cent. of the rainfall. Assuming that the effective yield of the catchment above the gauges holds good for that from gauges to sea-level (446 acres) the average quantity of water which flowed to waste into the sea for the years recorded by the gauges was 1,577 million gallons, the maximum being 2,016 million and the minimum 1,186 million gallons. The annual rainfall (Taitam gauge) over this period ranged from 96·51 inches to 72·64 inches, and, as the average rainfall is 83 inches, it was clear that a reservoir of large capacity would fill in years of average rainfall: further, it is possible to supplement the natural catchment area by catchwatering in adjacent gathering-grounds which are available to the extent of about 2,600 acres. The Author herefore felt safe in recommending a capacity of about 1,400 million gallons, making, with the Intermediate reservoir, a total capacity of fully 1,600 million gallons.

The works, which were designated “The Taitam Tuk Scheme—Second Section,” comprise:—

- (1) The construction of a dam at sea-level forming the Taitam Tuk Reservoir, with a capacity of 1,420 million gallons.
- (2) An extension of the existing pumping-station in Taitam Bay.

- (3) The provision of two further sets of pumping-machinery, each capable of raising 3 million gallons per day of 24 hours.
- (4) The laying of two 18-inch diameter supply mains from the draw-off tower of the Taitam Tuk dam to the pumping-station and of two additional 18-inch diameter pumping-mains (making, with the existing main, which is of the same size, three in all) from the pumping-station to the gauge-basin.

TAITAM TUK DAM (Figs. 2-6, Plate 7).

The dam is constructed across the Taitam stream where it discharges on to the tidal flat at the head of Taitam Bay, and is therefore at sea-level (Fig. 2). Its length, excluding the tongues which extend into the hillside at each end, is 1,195 feet, formed in plan of two straight lengths of 728 feet and 310 feet respectively, inclined to one another at an angle of $144^{\circ} 23'$ and joined by a length of 157 feet curved to a radius of 253 feet (Fig. 3). The height from stream-bed to overflow crest is 117 feet and to the roadway 127 feet. As the foundations of the dam over the key trench in the stream-bed extend to a depth of 44 feet, the total height of the dam from the lowest part of its foundation to road-level is 171 feet. The stream-bed at the site of the dam is at a level 3 feet above L.W.O.S.T. The width of the dam at the lowest part of the foundation is 115 feet. The profile is a 1-in-15 batter for the up-stream or reservoir face, except the top 35 feet, which is vertical, and a curve of 400 feet radius for the down-stream face. The roadway has a clear width between parapets of 16 feet 6 inches, the masonry immediately below road-level being corbelled out on both faces of the dam to obtain this width. An overflow crest curved to a radius of 10 feet is formed for a length of 240 feet of the dam where it crosses the stream-bed, and the base of the dam over this section has been given an outward curve of 20 feet radius in order better to deflect the overflow into a water-cushion. The roadway over the overflow crest is carried on twelve arches of 20 feet span.

The valve-tower, which forms part of the dam, projects from the up-stream face and is divided into two dry valve-wells, each measuring 12 feet by 8 feet. The valve-wells connect at the base of the dam with two culverts 12 feet by 10 feet which were originally provided for carrying off storm-water whilst the foundation-work was in progress. A valve-house surmounts the tower.

FOUNDATIONS OF THE DAM (Fig. 4, Plate 7).

Trial prickings made by driving 3-inch steel pipes into the stream-bed at numerous places indicated that rock would be met at depths varying from 15 to 23 feet below L.W.O.S.T., but these prickings did not establish the depths to which the excavation would have to be carried, because they gave little indication of the soundness of the rock. Trial-pits excavated on the centre line of the dam on either side of the stream-bed for its entire length, at intervals of 100 feet, indicated that soft rock would be met at depths ranging from 24 to 40 feet below the surface.

The Taitam stream above the site of the dam was diverted and the sea was excluded from the site by coffer-dams. A fold in the hillside, about midway between the southern end of the dam and the stream-bed, formed a natural line for a diversion cut, and it was also chosen as the site for the valve-tower. The culverts through the dam, where it crossed the fold, provided for the escape of the waters of the stream and served subsequently for housing the supply mains.

The up-stream coffer-dam, 245 feet in length, for diverting the stream into the cut consisted of an earth embankment 15 feet in height above the stream-bed, 10 feet top width, and 2-to-1 inner and outer slopes. The water slope was pitched with dry-rubble, supported by a pell-mell rubble toe. A single line of close-driven grooved and tongued sheet-piles was driven down to rock on the centre line of the coffer-dam for 203 feet of its length. For the remaining length, where the depth to rock was not great, a trench was excavated and filled with clay puddle.

The down-stream coffer-dam, 174 feet in length, for excluding the sea from the excavation, consisted of a pell-mell rubble embankment 6 feet in height above stream-bed level, $18\frac{1}{2}$ feet top width, and 2-to-1 inner and outer slopes. The top and outer slopes were pitched with coursed rubble, part of which was set in cement mortar. A single line of grooved and tongued sheet-piling close-driven down to rock for the entire length of the dam, and a layer of selected filling material rammed against the projecting portions of the piles was all the provision made to secure watertightness. The guide-piles were pitched 10 feet apart and the lower waling was placed just above stream-bed level, the upper waling being 7 feet higher. Each sheet-pile was bolted to both walings after driving. The guide-piles were of squared Oregon pine 12 inches by 12 inches in cross section, and the walings 12 inches by 6 inches in cross

section. The sheet-piles were of sawn Oregon pine 12 inches by 6 inches, and were V-grooved for a 2-inch-square hardwood tongue secured in place by nails. The piles for both coffer-dams ranged from 20 to 41 feet in length, 9 feet being left projecting above the stream-bed. All the piles were driven to refusal, and only three failed to reach the rock.

Before the coffer-dams were completed, the stream-diversion cut was finished and two culverts for the passage of the water through the dam were built, each 12 feet in width by 10 feet in height, and lined throughout with ashlar masonry. The invert was 5 feet above stream-bed level, and, below each culvert, a 21-inch diameter cast-iron scour-pipe for draining the reservoir was laid at stream-bed level.

The coffer-dams were completed and the stream was diverted into the cut in March, 1914. The reservoir scour-pipes proved of sufficient size to take the normal flow of the stream, and the culverts only came into operation during flood times.

The excavation for the foundations of the dam in the stream-bed was, with the exception of a layer of small water-worn boulders overlying the rock, entirely in sand. Rock was encountered at about the estimated depths, and was nowhere, except in the key trench, excavated to a greater depth than 30 feet below stream-bed (27 feet below L.W.O.S.T.). The rock, which is a schist, was generally sound. The excavation of the stream-bed was made of sufficient width to permit of side slopes being formed to a batter of 1 to 1, at which the sand would stand, and no timbering was required. On the up-stream side of the foundation a tongue or key, ranging from 10 to 20 feet in width and about 16 feet in depth, was cut into the rock to ensure greater watertightness.

For draining foundations a 10-inch steam-driven ram-pump, assisted at intervals by a 6-inch centrifugal pump, was sufficient, but two additional centrifugals driven by oil-engines were provided as a stand-by. There were, unfortunately, many days when work had to be discontinued owing to the partial breakdown of the pumping-plant, but the excavation was not excessively delayed on account of this, and by January, 1915—i.e., 9 months after it was commenced—part of the foundation in the stream-bed was ready for concreting.

The key into the rock, being deeper than the remainder of the excavation, would naturally have acted as a drain for the water percolating through the up-stream coffer-dam, but this was prevented by constructing, parallel with the tongue, a channel formed of two concrete walls about 6 feet in height, separated

from one another by a distance of 2 feet (Fig. 4, Plate 7). The outer wall was built on a foundation of concrete in bags, between which all leakage water freely passed to the channel. An 8-inch cast-iron pipe was laid from this channel spanning the key trench and discharging into a sump within the foundations of the dam.

Immediately clear of the down-stream toe of the dam, another channel for the better collection of the sea-water leaking through the down-stream coffer-dam was similarly constructed. The sump already referred to was utilized during the depositing of concrete in the key trench and the forming of the inner and outer toes of the dam. On the completion of this part of the work, another sump was formed in the channel at the down-stream toe of the dam, the pipe from the up-stream channel being connected with it.

The blasting of the surface rock for the first few feet in depth of the key trench opened up the joints, and a wooden launder was fixed to collect the water percolating through them. During the first stages of the concreting, the water which collected in the launder was dealt with by hand-pumping, but later, when the concrete rose above the original surface of the rock, the fissures were stanchied. The wooden launder which had been carried up with the concrete, was then removed and the space between the face of the concrete and the inner wall of the main drainage channel was arched over, grout-pipes 4 inches in diameter being concreted into the crown at intervals of 10 feet for the whole length of the supplementary channel. The pipes were carried up to a height of about 30 feet, and grout composed of 1 cement to 1 fine sand was poured simultaneously into alternate pipes until it rose in the intermediate ones. This did not occur in every case, and intermediate pipes in which it did not occur were filled with grout after no more could be poured into those on either side. The key trench was completed in the dry season, and was filled with concrete forthwith, as the leakage through the upstream cofferdam was then small, after which the inner toe of the dam was formed while the remainder of the excavation in the stream-bed was being completed.

The excavation was finished with pricking-bars and levers, and the surface was very carefully picked over to remove any small loose pieces. The few springs, which appeared after the final picking-over, were piped and either connected with a main pipe-drain which discharged into one of the culverts, or led into the flood-water channels. The quantity of water which had to be dealt with in this way was very small. The excavation in the stream-bed amounted to 16,429 cubic yards, 4,057 cubic yards being rock and the remainder sand. The excavation for the stream-diversion cut

amounted to 11,461 cubic yards, of which 5,704 cubic yards was rock.

The excavation for the foundations of the dam on either side of the stream-bed did not present much difficulty. Rock was generally found at very nearly the estimated depths, except for a length of 200 feet adjoining the stream-bed at the northern end of the dam. For this length the foundation had to be carried down to a maximum depth of 70 feet below the original surface of the ground, and this proved rather a troublesome matter. The excavations in the hillsides were in earth of a clayey nature, which increased in density with the depth below ground surface until soft laminated rock was reached. Sound rock was generally found after a few feet of soft rock had been removed. Practically no timbering was required for the foundation trench except for the length which had to be carried down 70 feet below ground-surface. The excavation for the foundation trench of the dam on either side of the stream-bed amounted to 58,928 cubic yards, of which 14,077 cubic yards was rock.

HEARTING OF THE DAM (Figs. 5 and 6, Plate 7).

The hearting of the dam is entirely of cement concrete, which, with the exception of a backing to the masonry of the up-stream face, has granite displacers, embedded in it, ranging in size from 2 to 10 cubic feet. Care was taken to see that all such stones were bedded on a fresh layer of concrete at least 6 inches in thickness, and that not less than 6 inches separated adjacent stones. Larger stones than 10 cubic feet could not be used, because no crane power was available. Stones of these weights are carried by the Chinese slung from bamboos supported on the shoulders of two or more coolies as required. In order to ensure the proper bedding of the stones in the plastic concrete, they were several times in succession levered up at one end a few inches and allowed to fall back. This system was found to be effective in getting rid of imprisoned air and much better than striking the stones with a heavy mallet. The proportions of the concrete ranged from 1 of cement to 6 of sand and stone, at the base of the dam, to 1 of cement to 8 of sand and stone at top water-level. The proportions of sand to broken stone were: for the 6-to-1 mixture, 2 sand to 4 stone ($1\frac{1}{2}$ inch); for the 7-to-1 mixture, $2\frac{1}{2}$ sand to $4\frac{1}{4}$ stone ($1\frac{1}{2}$ inch); and for the 8-to-1 mixture, 3 sand to 5 stone (3 parts 2 inches and 2 parts $1\frac{1}{2}$ inch). The concrete backing adjoining the masonry of the water face of the dam is $4\frac{1}{2}$ to 1, and,

as already mentioned, has no displacer stones embedded in it. The proportions of the mixture were 1 cement, $1\frac{1}{2}$ sand and 3 stone, all of which passed through a $1\frac{1}{2}$ -inch diameter, and half through a 1-inch diameter ring. The thickness of the backing, including the face masonry, ranges from 11 feet at stream-bed level to 5 feet at top water-level. The stone used for the concrete throughout the work is granite and was all hand-broken, and the concrete was all hand-mixed. The total quantity of cement concrete in the dam is 128,668 cubic yards, of which 28,805 cubic yards is $4\frac{1}{2}$ -to-1; 31,209 cubic yards 6-to-1; 39,900 cubic yards 7-to-1; and 28,754 cubic yards 8-to-1. Concreting was begun in January, 1914, but, owing to the short length of dam trench then finished, only 6,999 cubic yards were deposited during that year. In 1915, when the foundations of the dam across the stream-bed were ready for concrete, 48,690 cubic yards was deposited, and in 1916, when the entire length of the dam was available for concreting, 65,039 cubic yards. The remaining 7,940 cubic yards was deposited in the early months of 1917. Between top water-level and road-level, the hearting of the dam is of lime concrete surrounding a core of hand-packed rubble, the interstices being filled with earth. The quantity of lime concrete used for this purpose only amounted to 3,338 cubic yards and the rubble core to 655 cubic yards.

The whole of the cement used in the work was of local manufacture, and was supplied by the Green Island Cement Company of Hong Kong. It was required to conform to the specification of the British Standards Committee dated August, 1910.

MASONRY.

The dam is faced with masonry throughout, and in order to suit Chinese methods of handling without crane power, 12-inch coursing was generally used. Each course of ashlar was composed of alternate headers and stretchers, set so as to break bond not less than 9 inches, the stretchers being not more than 6 feet or less than 3 feet in length, with a minimum breadth of bed of 12 inches, while the headers were not less than $2\frac{1}{2}$ feet in length nor less than 1 foot in width of face. All masonry was set in 2-to-1 cement mortar. Over the entire water face of the dam, the joints of the facework were raked out to a depth of 2 inches for the reception of 1-to-1 mortar, which was mixed very dry and thoroughly caulked into the joints with steel caulking-tools. The facing of the overflow-crest and toe of the dam is composed of larger stones

in 15-inch courses. The piers supporting the arches of the roadway over the overflow-crest are of rough-punched ashlar in 18-inch courses, composed of stones weighing up to 2 tons each. These stones were bonded together from top to bottom of the piers with steel bars ($1\frac{1}{2}$ inch in diameter), 3-inch holes being drilled right through them for this purpose and filled with cement grout after the bar had been inserted. The arches between the piers are of reinforced cement concrete, faced on both sides with ashlar.

All the granite for the facing, displacers and broken stone was obtained from three quarries in Taitam Bay. The stone was rough-dressed at the quarries and then transported by junk to a landing-stage near the site of the works, the distribution was by a light railway, and the elevation of the stone to the dam was effected by hand-hauling the trollies up a series of inclined-plane scaffoldings formed of China fir and bamboo poles tied together with bamboo lashings. The Chinese excel at this kind of scaffolding and can be relied upon to erect it of sufficient strength for the purpose for which it may be required. The facing of the dam required 164,858 cubic feet of ashlar and 59,400 cubic feet of rubble.

GENERAL.

The arrangements in the valve-tower (Fig. 5, Plate 7) for drawing the water from the reservoir comprise two 18-inch diameter stand-pipes, one in each valve-well, from which 15-inch draw-off pipes at intervals of 10 feet connect with the reservoir. Valves for controlling the draw-off pipes are placed within the valve-wells, external penstocks being also provided for cutting off the water in the event of damage to valve or pipe. The valves are operated by head-stocks and the penstocks by bevel gearing placed in the valve-house, which also contains a water-level indicator.

The roadway over the dam forms part of a road which encircles the greater part of the Island of Hong Kong, and as this road is now being widened and improved for motor-traffic, it was decided to construct the portion over the dam with a clear width of $16\frac{1}{2}$ feet between the parapets, so as to admit of two cars passing each other: to get this width two corbel courses and one string course were required on each face of the dam. The road surface is of "granolithic," 2 inches thick, composed of 1 cement to 3 granite siftings ($\frac{1}{2}$ inch to dust).

The culverts through the dam were permanently closed in May, 1915 (2 years and 7 months after the signing of the contract), and

water was allowed to rise in the reservoir to 10 feet above the lowest draw-off, which enabled 86 million gallons to be pumped from it in that year. In 1916 the water in the reservoir was allowed to rise to 50 feet above the lowest draw-off, at which level the effective impound is 211 million gallons. In 1917 the dam was completed, and water was allowed to accumulate in the reservoir throughout the year. The distribution of the rainfall during 1916 was an unfortunate one, as out of a total of 79·8 inches 45 inches fell in May and June and only 24·7 inches during the latter 6 months of the year. The result of this was that the dry season, which proved to be a very severe one, opened with only 740 million gallons in store, and it became necessary to resort to drastic measures for the restriction of the supply. The reservoirs reached their lowest levels on the 15th May, 1917, when the aggregate storage only amounted to 69 million gallons (*Fig. 7*).

The prospect of filling the Taitam Tuk reservoir in 1917 was therefore a poor one, especially as none of the catchwaters for augmenting the drainage-area had been constructed. Nevertheless, though the rainfall for the year only amounted to 81·49 inches at the Observatory (80·37 Taitam gauge), 970 million gallons were collected by the 13th October, when the reservoir attained its greatest height of 80 feet above the lowest draw-off, or 20 feet below overflow level. The Intermediate reservoir was then at sill level and contained 196 million gallons, so that the total storage in the pumping-supply reservoirs amounted to 1,166 million gallons on that date. This quantity, in conjunction with the contents of the gravitation reservoirs (346 million gallons on the 13th October) assured full supply for the ensuing dry season.

PUMPING-STATION (Figs. 8, Plate 7).

The pumping station was constructed in 1904 to 1905, to accommodate the pumping-machinery installed in connection with the Intermediate reservoir, but the site was prepared with a view to enlargement for the additional pumping-plant required later for the Taitam Tuk reservoir. The engine-room was made of sufficient width for the bigger engines which would then be installed. The site is on the shore of Taitam Bay, and was prepared by cutting a plateau in the hillside at the level of 23 feet above L.W.O.S.T. The earth and stone removed in the course of the excavation were dumped into the sea to form a reclamation adjoining the plateau at a level of 12 feet above low water (4 feet above high water). This reclamation proved useful during the construction of the first

section works, for stacking pipes, etc., a landing-stage, built at one end of it, permitting craft to come alongside. The landing-stage has now been extended by a reinforced-concrete jetty, 40 feet in width, which projects into sufficiently deep water to enable coal-junks and small craft generally to come alongside at all states of the tide. The piles for this jetty are 12 inches by 12 inches in cross section, 42 feet in length, and are formed of concrete composed of 1 cement, $1\frac{1}{2}$ sand and $2\frac{2}{3}$ broken granite ($\frac{3}{4}$ to $\frac{1}{2}$ inch). The reinforcement consists of four 1-inch diameter steel rods, one at each corner of the pile, laced together with $\frac{1}{4}$ -inch diameter steel ties at 12-inch intervals. The piles were driven through 18 feet of mud and clay to the hard, into which they penetrated for a depth of about 3 feet. The walings, bracing, decking, and bollards are also of reinforced concrete.

The pumping-station buildings are built of locally-made red bricks, cement mortar being used below ground and in piers, jambs, etc., and lime mortar for the remainder. The engine-house measures 129 feet by 30 feet, and the boiler-house 83 feet by 47 feet. A workshop, store, and quarters for the engine-room staff (both Chinese and European) are also provided. A feature of the station is the inclined flue up the hillside.

Two sets of pumping-machinery were installed for pumping from the Intermediate reservoir, each capable of lifting $1\frac{1}{4}$ million gallons in 24 hours against a maximum effective head of 400 feet. The sill of the gauge-basin, at the inlet of the tunnel, for the gravitation supply to the city, over which water has to be pumped, is 383 feet above the level of the engine-house floor and 397 feet above the invert of the pump-pit. When pumping from the Intermediate reservoir the full power of the plant was not required, because the top-water level of that reservoir is 176 feet above the engine-house floor and the lowest draw-off is 96 feet; but, in view of the subsequent developments, the plant was designed to give the maximum efficiency when working against a head of about 350 feet. The engines are triple-expansion, vertical, having high-pressure cylinders 15 inches, intermediate 24 inches, and low-pressure 38 inches in diameter; the stroke is 30 inches and the revolutions $24\frac{1}{2}$ per minute. The pumps, three to each engine, have 12-inch diameter rams, driven direct from the cross-heads, by side rods straddling the crank-shaft. The boilers, two in number, are of the Lancashire type, working at a pressure of 135 lbs. per square inch, and are fitted with superheaters. A 6-ton travelling crane spans the engine-room.

Two additional sets of pumping-plant have been installed in connection with the Taitam Tuk reservoir, each capable of lifting 3 million gallons in 24 hours to a maximum height of 387 feet. The pump-lift will, however, vary from 287 feet to 387 feet, exclusive of friction in the mains, there being a difference of 100 feet between the lowest draw-off of the Taitam Tuk reservoir and the level of the overflow crest. The lowest draw-off is 4 feet below the level of the engine-house floor.

These engines are triple-expansion, vertical, having high-pressure cylinders 18 inches, intermediate 31 inches, and low-pressure 50 inches in diameter, the stroke is 36 inches and the revolutions 30 per minute. The pumps, three to each engine, have 15 $\frac{3}{8}$ -inch diameter rams, driven direct from the cross-heads, by four side rods directly connected. The boilers, three in number, are of the Lancashire type; they are fitted with superheaters, and there is an economizer in connection with the main flue; the boiler-pressure is 150 lbs. per square inch.

The total pumping-capacity of the station is now 8 $\frac{1}{2}$ million gallons per day. As the present requirement of full supply is 5 to 5 $\frac{1}{2}$ million gallons per day, the combined plant is sufficient to maintain the full service with either the two old engines or one of the new engines in reserve.

ROADS AND MAINS.

The laying of a main from the pumping-station to the inlet of the tunnel for the gravitation supply entailed the construction of an entirely new road; but for laying the main from the Intermediate reservoir to the station an existing road which led down the valley was utilized. It was, however, necessary to extend it along the foreshore from the head of Taitam Bay to the pumping-station. The existing road could not have been used for the pumping-main because it was within the area which would be submerged when the Taitam Tuk reservoir was filled. For the supply main from the Intermediate reservoir this did not matter, because this was to be taken up and relaid for further service in connection with the Taitam Tuk reservoir. The new road to the tunnel inlet is 3,430 yards in length. As the greater portion of the road was intended for public traffic, and had also to accommodate three 18-inch diameter mains, it was made 20 feet in width. Where it was intended for the mains only, the width was 12 feet. The road for a continuous length of 1,689 yards is of a uniform gradient of 1 in 250 but for the remainder it ranges from 1 in 50 to 1 in 8.

In addition to many heavy cuttings and retaining-walls, four bridges were required, the largest of which consisted of three spans of 50 feet each, the height from ground-level to the crown of the central arch being 85 feet. The bridges are all granite-faced concrete structures.

The extension of the existing road along the foreshore of Taitam Bay for the supply main from the Intermediate reservoir to the pumping-station was all light work. After being shortened and straightened by the construction of an embankment, 358 yards in length, it now serves for the accommodation of the two supply mains from the Taitam Tuk reservoir. As the foreshore on which the embankment is formed was soft, piers on pile foundations were built within the embankment, at intervals of 12 feet, for the support of the mains. The embankment is pitched throughout with coursed granite dry rubble springing from a pell-mell rubble toe.

Both pumping- and supply-mains are 18 inches in diameter, formed of cast-iron spigot-and-socket pipes $\frac{7}{8}$ inch in thickness and 12 feet in length. Very few curves of smaller radius than could be got round with the play in the joints of the pipes were necessary; but, where they occurred, angle collars were used. Each pumping-main is divided into three sections by two reflux-valves of the multiple-flap type. These valves are placed in brick chambers below road-level. In addition to the reflux-valve, a sluice-valve, air-valve, wash-out and a by-pass for the reflux-valve is provided for each main at these places. Additional wash-out and air-valves are provided at intervals along the pumping- and supply-mains. The pumping-mains are 3,430 yards in length from the pumping-station to the inlet of the tunnel and the supply-mains from the Taitam Tuk dam to the pumping-station are 900 yards in length. All three pumping-mains are now being pumped through, but two are of sufficient capacity to convey the present full supply to the city, in the event of the third main requiring repairs.

INTERMEDIATE RESERVOIR.

The Intermediate reservoir, which was constructed in 1904-7 in connection with the first section of the Taitam Tuk works, has a capacity of 210 million gallons. This reservoir now only supplements the Taitam Tuk reservoir, as its contents can no longer be pumped separately, but must be drawn off by the standpipe in the valve-tower of the dam and allowed to flow down the stream-course

into the lower reservoir. The dam (Fig. 9, Plate 7) is constructed of 6-to-1 cement concrete containing displacer stones, except the backing of the masonry of the water-face, which is of $4\frac{1}{2}$ -to-1 cement concrete without displacers. It is faced throughout with granite masonry. The total quantity of concrete used in its construction was 24,520 cubic yards and of facing stone 59,930 cubic feet.

The length of the dam is 440 feet, and the height is 90 feet from stream-bed to crest-level, and 110 feet from the lowest part of the foundation to crest-level. An overflow crest, 100 feet in length, is provided. The thickness of the dam at stream-bed level is 65 feet, and at crest-level 5 feet. A valve-tower with 10-inch draw-off pipes connected with a 12-inch stand-pipe is provided. The construction of this dam presented no special difficulties.

CATCHWATERS.

The catchwaters for augmenting the drainage-area of Taitam Tuk reservoir have not yet been constructed, but surveys are being made for two of them. These two catchwaters will intercept the flow from about 1,107 additional acres; the construction of further catchwaters to intercept that from the remaining 1,493 acres will doubtless be proceeded with when necessary.

COST.

The cost of the first section of the Taitam Tuk works was \$896,140. Taking the average pre-war rate of exchange which has been current in recent years as 2s., this is equivalent to £89,614. The costs of the various parts of the work constituting the first section were:—

	\$
Intermediate dam	383,435
Pumping-station site and buildings	86,466
Pumping-machinery and erection	111,821
Roads, bridges, etc.	154,508
Pumping- and supply-mains	135,095
Miscellaneous charges	24,815
Total amount	<u>\$896,140</u>

The cost of the second section of the works has amounted to \$2,417,562, which at the same rate of exchange as above is

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equivalent to £241,756. The costs of the various parts of the work constituting the second section were:—

	\$
Taitam Tuk dam	1,828,273
Pumping-station, extension of buildings, etc.	56,587
Pumping-machinery and erection (£24,700) and) Crown Agents and other charges	270,126 ¹
Pumping- and supply-mains and road-improve- ments, etc.	246,115
Miscellaneous charges	16,461
Total amount	<u>\$2,417,562</u>

The cost of the works has exceeded the estimate only by a small amount.

The works were formally opened by His Excellency the Governor of Hong Kong, Sir Francis Henry May, K.C.M.G., LL.D., on the 2nd February, 1918, when a suitable commemoration stone was set at the termination of one of the parapets of the roadway over the dam.

Throughout the whole of the work the Author received the assistance of the Director of Public Works, Mr. William Chatham, C.M.G., M. Inst. C.E., and he wishes to express his indebtedness not only for the help given, but for the kindness and encouragement that he could always rely on.

Mr. Richard McNeil Henderson, Assoc. M. Inst. C.E., was the Chief Assistant-Engineer for the Taitam Tuk dam, and Mr. Edward Newhouse was Assistant Engineer for the pumping-mains and machinery foundations.

The Paper is accompanied by three tracings, from some of which Plate 7 and the Figure in the text have been prepared, and by twelve photographs.

¹ Approximate, the final account has not been settled.