

(*Paper No. 2164.*)

“Colombo Harbour Works, Ceylon.”

By JOHN KYLE, M. Inst. C.E.

THE idea of providing Ceylon with an artificial harbour was originated by the Earl of Carnarvon, who, in 1866, suggested the improvement of the natural harbour at Pointe de Galle with this object. In 1870, however, the Governor, Sir Hercules Robinson, pointed out that Colombo was the best place for providing increased harbour accommodation. It was shown that Colombo, being only 30 miles out of the direct course between Aden and Galle, and 18 miles from the direct course between Bombay and Galle, might serve as the great coaling station of the east; and that Colombo was a more accessible port than Galle, being free from the treacherous currents which exist off Galle. Moreover the tonnage of Colombo had increased more than thirteen-fold between 1830 and 1869; and the trade statistics proved that a revenue of £32,000 might be raised for the harbour works. Accordingly a report was obtained from Mr. R. Townsend, M. Inst. C.E., who advised the construction of a harbour on the site of Colombo Lake, protected by a breakwater seawards, and a rubble jetty on the land side, with an entrance between them in the rear of Custom House Point, at an estimated cost of £720,000.

In 1872 Sir John Coode, Vice-President Inst. C.E., having had Mr. Townsend's scheme submitted to him, advised the construction of a breakwater from Custom House Point, as best suited to meet the requirements of the Colony; and this recommendation having been approved by the Home and Colonial Governments, Sir John Coode was instructed, early in 1873, to take the necessary steps for carrying out the work.

The scheme, as executed, comprises the sheltering of a water-area of 502 acres, at low-water, by a breakwater, 4,212 feet long; the reclamation of some of the foreshore as a site for coal stores; and dredging some of the shallow portion of the harbour to a depth of 26 feet at low-water (Plate 2, Fig. 1). As it was resolved to construct the works without a contractor, the Author was appointed Resident Executive Engineer in May 1873. During a visit of three months to the Colony, he investigated all the conditions of

the site; and having arranged for the opening-out of a suitable granite quarry, the formation of a block-yard at Galle Buck, and the construction of lines of railway from the quarry to the main line, and from the Colombo terminus to the works, he returned to England, when the plans and arrangements for carrying out the works were settled with Sir John Coode; and in June 1874 the engineering staff arrived at Colombo. The foundation stone of the work was laid on the 8th of December 1875, by H.R.H. the Prince of Wales, Hon. M. Inst. C.E., during a visit to the Colony; and the works were completed in April 1885, at a total cost of 84,62,484 rupees, or £705,207.

PRELIMINARY WORKS.

Quarry.—The quarry is situated at Mahara, $1\frac{1}{4}$ mile from the main line, and 11 miles from the Colombo terminus. About 8 acres of land were obtained, rising about 98 feet above the service railway, and containing about 500,000 cubic yards of granite having a specific gravity of 2.625. The first train-load of rubble was delivered at Colombo in October 1874; the minimum output was 100 tons a day, and never exceeded 600 tons owing to the limited extent of the working floor-space. The top rock was bored from 12 to 18 feet deep by $2\frac{1}{2}$ -inch drills, and blasted down in masses by pebble-grain powder; and then redrilled with $1\frac{1}{4}$ -inch holes, from 6 to 8 inches deep, and broken up by $\frac{3}{4}$ to $1\frac{1}{2}$ -oz. charges of Nobel's dynamite. The firing was done out of working hours; and the blasting-operations were all effected by free labour, whilst convicts were employed for loading the wagons. Accommodation was provided at Mahara for three hundred convicts, who worked in the quarries, and proved an important addition to the breakwater staff and a great profit to the Colony.

Branch lines.—The breakwater branch commences at the Colombo terminal station, and, skirting the lake along Norris Road, terminates at Galle Buck. It has a total length of 1 mile 62 chains, and cost £17,210 exclusive of land. The Mahara quarry line, having a length of 1 mile 34 chains, branches off from the main line at the ninth mile from Colombo, and cost £5,979.

Block-yards.—The site at Galle Buck had to be levelled by the removal of 26,368 tons of granite and 66,726 cubic yards of earth; and 6,860 tons of the granite were utilized in the construction of a north and south dry stone sea-wall, reclaiming some bights along the shore. Workshops were erected, and lines laid down on this site (Plate 2, Fig. 1). A cement-shed, 205 feet by 35 feet, was

erected near the stone-breaking and dry skip-filling yards, with a cement floor raised on débris 2 feet above the ground; being close to the sea, it was walled in on three sides and roofed without ventilation, so as to exclude the sea-air from the cement. Two cement floors, each 1,000 feet by 53 feet, formed of a $2\frac{1}{2}$ -inch layer of cement mortar placed on 18 inches of well-packed rubble, were laid down for block-yards, with three lines of way between them and a service road running along the centre of each floor (Plate 2, Fig. 1). Two 32-ton overhead travelling-cranes, tested to 42 tons, and two 3-ton travellers, stretched across the floors, could traverse their length on outside rails to a 53-foot gauge; the former being employed in loading the blocks when made, and the latter in discharging the dry and wet skips into the machines and moulds.

ROOT WORK.

Sea-wall.—The Root work, extending seaward of Custom House Point, and covering an area of 5 acres, formed a starting point for the breakwater, and enclosed a reef of dangerous rocks. On the sea side, it is protected from the south-west monsoon by a wall of three courses of 7-ton concrete blocks, with occasional buttresses of blocks at the back, resting upon a rubble mound at about half-tide level and backed with rubble (Plate 2, Fig. 4). The tipping of rubble was commenced in January 1875; 28,259 tons of rubble were deposited in the work, at a cost of £7,109; and four hundred and ninety-eight blocks were laid, at a total cost of £3,321. The blocks were laid by the aid of two sheer-poles and 3-ton hand-winches; and the quarrying of the stone, and the manufacture and setting of the blocks, were performed by convict labour.

Depot-wharf wall.—This wall, under shelter of the breakwater, consists of concrete cylinders with a concrete-in-mass superstructure and backed with rubble. A portion of the wall, on each side of the eastern corner, is built on a double row of 5-foot cylinders, founded 16 feet below low-water ordinary spring-tides; and the remainder of the north-east wall, nearly up to the breakwater, is on 7-foot cylinders, founded 28 feet below low-water, with concrete-in-mass capping joggled 6 and 9 inches respectively into the cores of the cylinders (Plate 2, Figs. 2 and 3). The junction piece, up to the breakwater, is built of concrete-in-mass on a boulder reef. The total length of the wall is 829 feet; and the coping is 9 feet above low-water. The 5-foot cylinders were in sections, $3\frac{1}{2}$ feet deep and 3 feet internal diameter, and the 7-foot, 4 feet 10 inches deep with a $4\frac{1}{2}$ -foot core, weighing 3 and 7 tons respectively. The ordinary

rings were composed of 3 parts of stone, 2 of sand, and 1 part of cement; but the cutting-rings were made with one-fourth part of cement. The total cost was £22,317.

Rubble and earth filling.—The surface level of the Root is 10 feet above low-water. The filling consisted of 131,424 cubic yards of earth and 26,368 tons of rubble, obtained from Galle Buck, from a “cabook” cutting on the Kandy Railway, and from harbour-dredgings, and cost £17,329. The surrounding conditions, and the expedients necessary to preserve the filling from the backwash of each south-west monsoon, rendered the Root work costly.

Abutment block.—A huge block of concrete-in-mass, weighing 320 tons, deposited within timber casing lined with canvas, in 16 to 24 feet of water, on the jagged rock, forms an abutment for joining the breakwater to the Root. After the destruction of one casing by a westerly storm, the work was completed in April 1876, at a cost of £976.

BREAKWATER.

Delivery of rubble.—The stone was loaded at the quarry into side-tipping wagons, and on the arrival of the train of about twenty-four wagons at Galle Buck, it was distributed between the yard and the shoot at the depot wharf. A train of ten wagons was run alongside the shoot, and the rubble tipped into the well of the hopper-barge. The iron shoot, 13 feet by 11 feet, was supported at the sides by a timber frame pivoting between uprights through which the lowering and raising chains were reeved. The amount of rubble thus delivered into the hopper-barge was 141,147 tons.

Depositing from hopper-barge.—The 80-ton steam hopper-barge, running 6 knots an hour with a full load, was loaded from the shoot alongside the depot wharf; and on reaching her destination ahead of the breakwater, the exact position for dropping the cargo was ascertained by means of high diamond and circular-shaped beacons on shore, and floating beacons in the sea. Five tiers of cargoes were deposited on the transverse line by means of marks on the vessel's gunwale, corresponding in shape to the land beacons numbered from 1 to 5. Three transverse sets of buoys were placed at the end of the work, marking the lines of the tiers of cargoes; and the man stationed at the number of the cargo to be dropped shouted out “let go” on getting into the corresponding beacon line. Cross sections of the mound are given in Plate 2, Figs. 5 to 7.

The top of the mound was usually kept about 2 feet below the foundation-level of the pier-wall, and was subsequently raised by

the hand-cargo boats and divers. The length of mound completed each season varied from 500 to 900 lineal feet, being kept in advance of the pier at least a length equal to the progress of the wall during the same season; so that, having a whole season to consolidate before receiving the superstructure, the chances of undue settlement were reduced to a minimum.

Berms and Hearting.—During the block-setting season, thirty-five wagon-loads of stone were daily discharged from the wall into the hand barges alongside, from whence they were thrown over on to the mound, as directed by the divers. Eighty-five wagon-loads a day were at the same time deposited on the sea and harbour berms of the breakwater, to make them up to their full section; and a portable shoot of old rails was provided for this purpose, overhanging the face of the wall, having the same slope as the bottom of the tip-wagons at their angle of discharge, and capable of withstanding the shock of falling pieces of rock of 3 tons weight (Plate 2, Fig. 7). Large blocks could thus be deposited, over a core of ordinary rubble, for protecting the berms in bad weather; and the berms were always fully made up at the close of each season. At the commencement of the setting-season, a series of cross sections of the mound were taken, 50 feet apart, whereby any settlement was detected, and was then made up with $3\frac{1}{2}$ -ton rubble. In shallow water, the berm was exposed to the action of the sea for about three years before reaching the condition shown (Plate 2, Fig. 5).

The quantities of rubble deposited in the mound, berms, and hearting, were 141,147 tons by the hopper-barge, 104,479 tons from boats, 59,822 tons on berms, and 14,917 tons by hand in hearting.

Bag-work on Sea Berm.—An apron, 24 feet broad, composed of 10-ton bags of concrete, protects the top of the sea berm from disturbance (Plate 2, Figs. 5 to 9). The bag, having been sewn up on five sides, was adjusted in a skip, carried on a wagon under a shoot, through which concrete was poured into the open mouth of the bag from the mixer-skip. The top of the bag was sewn up during its journey to the derrick, by which the skip with its contents was hoisted, run out, and lowered, and the bag dropped into its place (Plate 2, Fig. 6). No damage was done to any bag, either by the sea, or by the rubble mound on which it fell. The depositing of the bags was commenced on February 11th, 1884, when the progress sections showed that the first length of 2,150 feet of berm, having attained its normal slope, was ready to receive the bags; proceeding landwards, the whole seven hundred and

twelve bags were deposited, up to the junction line, by the 2nd of April following. About sixteen and three-quarter bags, in a single row, covered a length of 100 feet; and the average space between each bag did not exceed 3 inches.

The total cost of the rubble mound, berms, hearting, and bag-work, up to the end of 1884, was £106,553.

Block-making for Pier-Wall.—By the end of 1876, six hundred blocks, averaging 20 tons each, had been made and stacked in the yards. Owing to the unavoidable deficiency of storage space, the blocks were stacked close together, two deep, in the yards, and also two deep on the harbour-wall of the breakwater, by which means two thousand blocks were in stock on the arrival of the setting season; and all blocks over six weeks old were set in the work.

During the monsoon season, the prisoners worked eight hours a day; in the setting season, a twelve-hour system was adopted. In the slack season, one hundred and sixty-six prisoners manufactured six blocks a day; whilst during the twelve-hour system, three hundred and nine prisoners made twelve blocks a day, without increasing the cost per cubic yard. A charge of $37\frac{1}{2}$ cents per day of eight hours was made for each prisoner employed, which included the guards and police in charge of the gangs.

The trains of dry materials consisted of eight wagons, with two skips in each; and the skips were divided into three compartments, containing stone, sand, and cement, in the proportions of 6, 2, and 1 respectively. Travelling 3-ton gantries, with an overhead travelling steam-winch, were used for lifting the dry, and depositing the wet materials. When the mixture was poured into the mould, two masons and four prisoners forced it into the corners and sides of the mould with iron-shod rammers; after three days the mould was removed, and three weeks later the block was stacked.

Block-setting in Pier-Wall.—Twelve divers, with nineteen attendants, prepared the bed on the mound in advance of the wall; they worked three and a half hour shifts, in relays of four divers each, at a total daily cost of £9 7s. 6d. The divers used four 6-foot lengths of 50-lb. rails for levelling the bed, which were ringed at each end for moving them about; and they finished off the surface with a trimming of small quarry chips.

The concrete blocks were set by a Titan (Plate 2, Figs. 10 and 11), the first block being set on the 12th of December 1876. The Titan could carry a load of 40 tons, on an overhang of 28 feet; its weight, including rubble-ballast, water, fuel, &c., was 180 tons; and it cost £5,562 set up in Colombo. The foundation blocks,

standing on the slant on the truck, with the lewises vertical, were lifted by the Titan in that position; but the other blocks, being square, were lifted in the yard on to the truck by a pair of outside grips, and when canted on the truck to the setting angle of 68° , the lewises were dropped in vertically, and the block was raised and set by the Titan. The five courses, of three blocks each, in the 34-foot wall were set in seven hours (Plate 2, Fig. 7); and under the most favourable conditions, thirty blocks were set in twelve hours. The Titan, in passing over the work as it progressed, made it settle from 3 to 5 inches; and a further settlement of 5 or 6 inches was effected by the waves of the south-west monsoon, giving a total maximum of about 9 inches, for which allowance was made by keeping up the scar end as the work advanced.

Along the inner portion of the breakwater, consisting of two walls (Plate 2, Fig. 5), a 40-ton steam derrick was used for setting the harbour-wall blocks; it travelled on the sea-wall, and its jib hung over the harbour-wall.

The lines for the Titan, derrick, and trains, were fixed upon longitudinal balks, secured to the wall by dowels and concrete-in-mass, so as to resist the attacks of the south-west monsoon waves, and enable the Titan to be drawn to land after the close of the setting-season; for the experience of the first stormy season showed that it was not safe to leave the Titan out on the breakwater.

Joggle Grooves, Scar End, and Capping.—The joggle grooves left between each row of sloping blocks (Plate 2, Fig. 10) were filled up to high-water level with strong concrete in bags, dropped into the hole and rammed down hard.

Towards the termination of each season, before the setting in of the south-west monsoon, the three last upper courses of the scar end were secured together, through their lewis holes, by four 2 inch wrought-iron screw-bars, stretched longitudinally over the work, to prevent the sea disturbing the blocks.

The final capping of the pier-wall with concrete-in-mass binds all the top blocks together, and gives additional weight to the structure. It is $48\frac{1}{4}$ feet broad across the wide inner portion of the pier, and $31\frac{3}{8}$ feet across the outer portion; and 4 feet deep in the centre, and $3\frac{1}{2}$ feet at the sides. The concrete was mixed by the machine in the yard, and sent off in a series of three trains of one wagon, each carrying four skips.

Pier-Wall.—Near the land, the wall was founded 13 feet below low-water; this was increased to 16 feet at 977 feet, to 20 feet at 2,070 feet, and continued at this depth close up to the pier-head,

where the foundation was stepped down to $23\frac{3}{4}$ feet below low-water (Plate 2, Figs. 5, 6, 7, and 9). The block-work rose to 8 feet above low-water; and the capping raises the centre of the wall to 12 feet above low-water.

The first 1,326 feet of the pier was built with a sea- and a harbour-wall, having an interval between them of 14 feet, filled in with rubble (Plate 2, Fig. 5). The sea-wall consists of two foundation blocks, 13 feet long and weighing 28 tons each, supporting three courses, 24 feet long, composed of blocks of 14 to $26\frac{1}{2}$ tons each. The harbour-wall is 12 feet wide, making a total width of 50 feet. At 1,326 feet from the commencement, a single wall, 34 feet in width, was adopted, with four to five courses of blocks weighing from $16\frac{1}{2}$ to 31 tons each (Plate 2, Figs. 6, 7, and 10). The sloping joints are $5\frac{1}{2}$ feet apart on the square, and have an inclination of 68° to the horizon (Plate 2, Fig. 11). The last sloping courses of blocks, and the closing blocks up to the pier-head, were laid before the close of the setting-season, in March 1883 (Plate 2, Fig. 9).

The total number of blocks placed in the pier were nine thousand six hundred and fifty-six, containing 124,984 cubic yards; and their total cost in position was £247,313.

Pier-Head.—The pier-head consists of a circular block of concrete-in-mass, 62 feet in diameter and 27 feet high, surmounted by another block 60 feet in diameter and 11 feet high (Plate 2, Fig. 9). The lower portion, being under water, was deposited in a wrought-iron circular tank, formed of $\frac{1}{4}$ -inch plates stiffened and braced by T-irons and angle-irons, with a square corner to fit on to the pier-end. The tank was ballasted with 400 tons of concrete-in-mass, and subsequently towed into position with a further load of 600 tons, which left it a freeboard of 5 feet. A favourable opportunity occurring on the 1st of December 1883, the groove of the caisson was drawn up to the tongue of the pier-end; the water was then let in, and in six minutes the caisson settled down upon its bed; and by the 8th of January 1884, the filling of the tank with concrete was completed. A heavy sea tore away 50 feet by 14 feet of the sea side of the plating, leaving a gap which was filled up in five days by one hundred and seven 10-ton concrete bags. The completion of the pier-head was deferred, after being raised to the service-road level, till the landing stage had been constructed. The outside circular blocks were then raised to the floor-level, and the interior was filled with concrete-in-mass; in the following season, 1884–5, the pier-head was surmounted by a $7\frac{1}{2}$ -foot parapet.

Landing-Pier.—A landing-pier projects from the pier-head, 120 feet long, 21 feet broad, $37\frac{3}{4}$ feet deep, and founded 24 feet below low-water (Plate 2, Fig. 8). Being sheltered by the break-water, it is provided with landing-stairs, for the light-keeper to have access in all seasons. The blocks, nine hundred and twenty in number, were set in forty-nine days by a 7-ton overhead travelling-crane from a timber stage erected as shown on the section; and 186 cubic yards of concrete-in-mass were laid on the top. The total cost was £7,039.

Lighthouse Tower.—A circular tower, $36\frac{1}{2}$ feet high, was erected on the pier-head, built of a moulded concrete-in-mass basement and concrete blocks above; it carries a second-order light, with its focal plane 58 feet above low-water (Plate 2, Fig. 9). The external diameter of the tower below the coping is 17 feet, and the internal diameter is 11 feet. The lighthouse contains an oil-room at the base, over which are a store-room, a bedroom, a living-room, and a watch-room, with concrete floors supported on rolled iron joists, and a cast-iron staircase.

Progress of the Work.—The amount of work accomplished each season, up to 1882-3, is shown in the following Table:—

Season.	Working Days.	Blocks set.		Length of Wall.
		Sea Wall.	Harbour Wall.	
	Number.	Number.	Number.	Feet.
1876-77	123	617	—	375
1877-78	$134\frac{1}{2}$	923	141	556
1878-79	23	107	—	74
	$198\frac{1}{2}$	—	491	680 ¹
1879-80	$88\frac{3}{4}$	822	—	458
	139 ¹	—	355	434 ¹
1880-81	$130\frac{1}{2}$	1,953	—	946
1881-82	$129\frac{3}{4}$	2,340	—	952 $\frac{1}{2}$
1882-83	118	1,907	—	787 $\frac{3}{4}$
Totals	1,085 $\frac{1}{4}$	8,669	987	4,149 $\frac{1}{6}$

In April 1878, an unusually heavy south-west monsoon set in, and swept away a 14-ton block from the second upper course of the scar end; increasing in strength in July, the sea drove in the scar end of the sea-wall, which was 700 feet in advance of the harbour-wall, to the extent of 15 inches, pivoting on a point 150 feet landwards, and lowered the end 12 inches, diminishing to nothing 450 feet in. Accordingly, to avoid damage, the exten-

¹ These lengths of harbour-wall do not form part of the total length.

sion of the sea-wall was stopped till the harbour-wall was brought up to it. During the season 1879-80, the harbour-wall progressed very slowly, owing to large quantities of sand having been washed on to the foundations by the south-west monsoon of 1879, which had to be removed by divers. For instance, in November and December 1879, only four sloping sections of the harbour-wall were set; whereas twenty-four sections of the sea-wall, having double the width, were set in the same time.

In the eighth season, 1883-84, with one hundred and ninety-five working-days, the pier-head up to quay-level, the lighthouse tower, the landing-pier, and the apron of concrete bags on the berm, were completed, comprising 6,922 cubic yards of concrete-in-mass, and three hundred and fifty-three 3-ton, and nine hundred and twenty-eight 7-ton blocks altogether.

The work was finished in the season 1884-85, comprising the completion of the pier-head and the lighthouse fittings, and also the concrete-in-mass capping from the pier-head to the shore, containing 15,000 cubic yards.

Settlement.—The amount of subsidence which took place during each south-west monsoon was carefully measured. The maximum settlement along the centre line was 2 inches, and the average $1\frac{1}{2}$ inch. In 1877, there was a settlement of 18 inches on the sea side; and during the monsoon of 1884, a maximum settlement of 4 inches occurred between 400 and 500 feet from the shore.

DREDGING, RECLAMATION, MOORINGS, &c.

Dredging.—The position of the $85\frac{1}{2}$ acres in the harbour, to be dredged to a depth of 26 feet at low-water, is shown by a dotted line on Plate 2, Fig. 1; the amount to be dredged was 887,459 cubic yards, of which 678,459 cubic yards had been completed up to 1884. The sheltered water-area in the harbour is 502 acres at low-water, 329 acres with a depth of 18 feet and upwards, $242\frac{1}{2}$ acres of 26 feet and over, and $90\frac{1}{2}$ acres of 30 feet and more. A single ordinary bucket-dredger, of 75 nominal HP., was employed, capable of dredging in 29 feet of water. The dredgings from the harbour were conveyed 4 miles out to sea, and dropped in 15 fathoms of water by a hopper-barge carrying 500 tons, and making three trips a day in full work, or on the average two and a half trips. The barge cost £11,333 delivered at Colombo. An auxiliary barge took its place whilst absent on its trips, and carried away three cargoes of 75 cubic yards each.

Reclamation.—A rubble mound, 9 feet wide at the top, and

averaging 37 feet in width at the base, and 14 feet in height, extends 2,600 feet along the southern shore-line of the harbour, reclaiming an area of 20 acres, which was filled up with harbour-dredgings (Plate 2, Fig. 1). A backing of cabook, 6 feet in width, was deposited behind the mound; and the quay-level was completed with a 12-inch layer of cabook, 5 feet above low-water. The dredged sand was brought to the landing-stage in two trains of five barges, containing 20 tons each, towed by a steam-tug. The total quantities of material used were 51,475 tons of rubble and 290,641 cubic yards of cabook and dredgings, at a cost of £45,344.

Moorings.—Four tiers of six buoys each were fixed parallel to the breakwater (Plate 2, Fig. 1). The first tier is 300 feet from the pier-wall; and the buoys are 600 feet apart each way.¹ Twenty-five steamers of the largest class can moor in depths of from 26 to 40 feet of water; whilst there is space at low-water for a great number of vessels drawing from 6 to 26 feet. A vessel entering the harbour at night steers into the line of the fairway lights, where a passage of 600 feet is kept open for convenience in berthing. The cost of the moorings was £7,411.

Revenue of the Harbour.—The collection of revenue from the new harbour began with 1883; during the two years 1883 and 1884 it amounted to 4,11,318 rupees and 4,08,566 rupees, equivalent to about £34,276 and £34,047 respectively.

Management of Works.—The whole of the drawings from which the works have been executed, including the contract drawings for the special plant and machinery, were prepared by the Engineer-in-Chief, Sir John Coode; and the works were carried out by the Author, who had the charge and management of their execution, as Resident Engineer, from the commencement, Mr. Charles Good, Assoc. M. Inst. C.E., being the Assistant Engineer. The special plant and machinery were constructed, and their working was thoroughly tested before leaving England, under the superintendence of Mr. William Matthews, M. Inst. C.E.

The Paper is illustrated by numerous drawings and diagrams, some of which are reproduced, to a smaller scale, in Plate 2.

¹ The Author adopted the following method for sinking the collar of the screws. A cylinder, 5 feet in diameter and 6 feet high, was lowered from a barge fitted with suitable gearing, and it was sunk by divers removing the sand from inside. The screw and collar were then lowered into the cylinder, and screwed into the bottom to the full depth; after which the cylinder was removed.

APPENDIXES.

APPENDIX I.

COST OF WORKS.

SUMMARY OF GROSS TOTAL EXPENDITURE IN CURRENCY AND STERLING UP TO 31st DECEMBER, 1884, WITH ESTIMATE TO COMPLETE THE WHOLE WORK.

Description of Works.	Expenditure to 31st Dec. 1884.	Estimated Expenditure to complete the Works.	Gross Total Cost of Works.	Expenditure to 31st Dec. 1884.	Estimated Expenditure.	Gross Total Cost of Works.
	Rs. a.	Rs.	Rs. a.	£. s. d.	£. s. d.	£. s. d.
Root work	733,718 76	82,350	732,718 76	61,059 17 11	6,862 10 0	61,059 17 11
Breakwater mound	1,278,644 92	136,283	1,360,994 92	106,553 14 10	11,273 11 8	113,416 4 10
Breakwater pier	3,675,716 13	67,300	3,810,999 13	306,309 13 7	5,698 6 8	317,583 5 3
Harbour-dredging	570,995 41	4,280	638,295 41	47,582 19 1	5,386 13 4	53,191 5 9
Foreshore-reclamation	482,580 32	3,900	486,860 32	40,215 0 6	325 0 0	40,571 13 10
Harbour moorings	88,943 77	38,100	92,843 77	7,411 19 7	77 15 4	7,736 19 7
" leading lights	933 18	30,000	933 18	77 15 4	3,175 0 0	77 15 4
Administration	519,860 03	38,100	587,960 03	45,821 13 5	2,500 0 0	48,996 13 5
General workshops	645,054 84	30,000	575,054 84	45,421 4 9	..	47,921 4 9
Extraordinary expenditure for work done not connected with construction account, loan charges, &c., &c.	132,681 02	..	132,681 02	11,056 15 0	..	11,056 15 0
Spare gear, tools, and stores not used up	43,142 62	..	43,142 62	3,595 4 4	..	3,595 4 4
Totals	8,101,271 00	361,213	8,462,484 00	675,105 18 4	30,101 1 8	705,207 0 0

APPENDIX II.

TESTS OF CEMENT AND CONCRETE.

TABLE SHOWING the RELATIVE TRANSVERSE STRENGTH of CONCRETE BLOCKS, 4 feet long by 1 foot wide by 1 foot deep, BROKEN by HYDRAULIC PRESSURE BROUGHT to BEAR on a 6-inch TIMBER PLACED ACROSS the CENTRE of the BLOCK, the END SUPPORTS BEING 3 feet APART INSIDE.

Fresh water was used in mixing, and the concrete blocks were kept wet for the three months that intervened between making and testing.

No.	Materials.					Blocks Broken.	Breaking Strain.				Average Break- ing Strain.	Average Break- ing Strain per Sq. Inch of Section.
	Cement.	Sand.	Hand Broken Stone 3½ ins.	Machine Crushed Stone 1½ in.	River Gravel.							
	Proportions.					No.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1	1	2 coarse	..	..	..	3	20,160	14,560	14,480	17,360		120
2	1	2 fine	..	..	..	3	10,080	14,000	14,000	12,693		88
3	1	2	4	2	..	3	5,880	7,560	4,200	5,880		41
4	1	2	..	..	6	3	4,480	6,720	4,480	5,227		36
5	1	2	..	6	..	3	6,160	3,920	3,640	4,573		32

¹ This test was a failure, as the indicator was found to be pressing on the dial, and is not taken into account in the result.

TABLE SHOWING the CRUSHING WEIGHT REQUIRED to BREAK CEMENT and CONCRETE BLOCKS, 3 inches cube, by HYDRAULIC PRESSURE.

Fresh water was used in mixing, and the concrete blocks were kept wet for the three months that intervened between making and testing.

No.	Materials.					Blocks Broken.	Crushing Weight.				Average Crush- ing Weight.	Average Crush- ing Weight per Sq. inch Area.
	Cement.	Sand.	Hand Broken Stone 3½ ins.	Machine Crushed Stone 1½ in.	River Gravel.							
	Proportions.					No.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	
1	Neat	..	..	..	..	3	42,560	56,000	45,920	48,160		5,351
2	1	2 coarse	..	..	..	3	26,880	24,640	21,840	24,453		2,717
3	1	2 fine	..	..	..	3	15,680	15,120	15,680	15,493		1,721
4	1	2	4	2	..	3	36,400	37,520	40,320	38,080		4,231
5	1	2	..	..	6	3	22,400	17,360	20,160	19,973		2,219
6	1	2	..	6	..	3	21,840	22,400	15,680	19,973		2,219

The cement in barrel, stored in the cement-shed, maintained its quality for at least a year. Three tests were made in every case, with a sample of each delivery of cement, by a Michel machine.

The tests prove that induration increased steadily till the cement attained its average maximum strength in about twelve months. The minimum tensile strength allowed in the concrete was 200, 400, and 500 lbs. after two, four, and seven days respectively. When a test indicated a tensile strength less than the above, an additional quantity of cement was added to the mixture, in which the cargo of cement was being used, in proportion to the deficiency in strength, according to a fixed tariff hung up in the cement shed.

APPENDIX III.

TESTS OF ORDINARY CEYLON BRICKS.

TABLE SHOWING THE CRUSHING WEIGHT REQUIRED TO BREAK ORDINARY CEYLON BUILDING-BRICKS. HYDRAULIC PRESSURE BROUGHT TO BEAR ON A HALF BRICK, $4\frac{1}{2}$ inches by $4\frac{1}{2}$ inches, and 2 inches thick.

No.	Weight of Full-sized Brick.	Crushing Weight required to Break Half Brick.	Average Crushing Weight per Square inch Area.	Remarks.
1	Lbs. $5\frac{1}{4}$	Lbs. 68,320	Lbs. 3,374	Very soft brick.
2	$6\frac{1}{2}$	40,320	1,991	
3	$5\frac{1}{4}$	78,400	3,872	

APPENDIX IV.

TIDES.

The range of tide during the north-east monsoon is from 5 to 37 inches, and from 5 to 30 inches during the south-west monsoon, and averages about 24 and 18 inches respectively. The extreme highest and lowest tides occur at full moon in April, when the tide falls to the zero of the gauge and rises 40 inches within twenty-four hours.

APPENDIX V.

WINDS and WAVES.

The worst weather from the south-west occurs during June, July, and August. The general direction of the wind during these months is from W. to S.W.; and the heaviest wave-stroke against the breakwater is from W.S.W. The following Table gives the results of observations made by Mr. Good to determine the period of certain waves of a series, or of a series of long waves, when the sea was unusually high.

Dates.	Average period of Waves.	Remarks.
1883.	Seconds.	
June 9	10	Sea moderate, W.; calm and squally from N.W. to N.E.
„ 19	10	Sea heavy, W.; wind fresh, W.S.W.
„ 25	10½	Heavy swell, W.S.W.; wind light, S.S.W.
„ 28	12½	Heavy swell, W.; wind calm.
July 13	12	Sea heavy, W.S.W.; strong wind and squalls from S.W.
„ 28	9	Strong wind and sea from W.
August 1	16	Long swell, W.S.W.; wind fresh, S.W.
„ 16	9½	Sea heavy, W.S.W.; heavy squalls from S.W.

In 1873, the Author found that the velocity, in the offing, of a long S.W. wave of a series was 16 miles an hour. It was supposed at that time that 9 feet was the greatest height of the waves at Colombo, as this was the extent of chafe discovered on the chain of the Isaure Rock buoy; but subsequent observations showed that waves rise to 12 feet in the offing, and to 15 feet just outside the breakwater. During the period of construction, between 1876 and 1885, the date of arrival of the south-west monsoon varied between the 12th of May (1876 and 1880) and the 8th of June (1884).

As the harbour is open to the north, careful observations were made of the maximum heights attained by waves during the north-east monsoon; and it was found that the worst weather and waves came from N.N.W. during December, January, and February. Between the pier-head and the opposite shore, the gauge registered 6½ feet in December 1879 and January 1880, and gave way when it is believed the wave rose 7 feet from trough to crest.

STATEMENTS of WAVE-GAUGE OBSERVATIONS MADE DURING the N.E. MONSOON,
SHOWING the MAXIMUM HEIGHTS RECORDED BETWEEN 1878 and 1882.

		ft.	ins.	
1878 March	5	5	6	A.M. Wind W.S.W., blowing light.
"	5	5	0	Noon. Very heavy swell from W.S.W.
"	5	5	0	P.M. Wind W.S.W., blowing fresh; very heavy swell.
1879 Dec.	11	5	0	A.M. Wind light W.; heavy swell, W.N.W.
"	11	5	0	Noon. Wind fresh from W.N.W.; heavy swell, W.N.W.
"	17	5	6	P.M. Wind very strong, N.W.; sea very heavy, W.N.W.
"	17	6	0	P.M. Wind strong, N.N.E.; sea very heavy, W.N.W.
"	18	5	6	Noon. Wind strong from N.; sea very heavy, short swell, W.N.W.
"	18	5	6	P.M. Wind strong from N.E.; sea very heavy, short swell, W.N.W.
"	19	6	6	" Wind fresh, N.W.; heavy short sea, N.W.
1880 Jan.	15	5	0	" Wind N.E., light; sea very heavy, N.W.
"	16	5	0	" Wind E., light; sea very heavy and short, N.W.
"	19	5	0	" Wind strong, N.W.; sea very heavy, N.W.
"	19	6	6	" Wind N.E., light; sea very heavy, N.W.
"	24	5	0	" Wind W.N.W., strong; very heavy swell, W.N.W.
"	27	5	0	" Wind W.N.W., strong; heavy short swell, N.W.
"	28	5	0	" Wind W.N.W., strong; very heavy short swell, N.W.
"	29	5	6	" Wind W.N.W., strong; heavy swell, N.W.
Feb.	17	5	0	" Wind S.W., light; heavy swell, W.S.W.
1881 Jan.	25	5	0	A.M. Wind N.; sea, N.
"	25	5	6	Noon. " " "
1882 Jan.	2	5	0	A.M. Wind N.E.; slight swell, N.

APPENDIX VI.

BED of HARBOUR.

The bed of the harbour consists of sand, with some very small patches of mud in certain parts. Borings indicated that the harbour could be dredged to a depth of 30 feet below low-water without anything harder than hard sand being encountered; and rock has only been discovered along the shore line. The Isaure Rock, composed of sandstone, of which the shallowest point, 20½ feet below low-water, was formerly indicated by a buoy, is now partly under, and partly outside the breakwater (Plate 2, Fig. 1). Its total length above the level of the harbour bed is about 2,500 feet, 1,500 of which form the base of the breakwater foundation.

