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GEORGE BERKLEY, President,
in the Chair.

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“The Bishop Rock Lighthouses.”

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THERE are few if any lighthouses of more importance to sailors, or of more professional interest to the engineer, than the Bishop Rock. The scene of the disaster to Sir Cloudesley Shovel's squadron in 1703, may well be an object of popular curiosity, even if there had not been besides, many a catastrophe there fatal to ships and their crews. The recent works undertaken at this rock have a special interest for mariners, as those operations have almost completely nullified what was once a great peril, dreaded by seafarers of all nations. Accordingly a brief record of the lighthouses erected on the westernmost landfall rock of the Scilly Islands, between the years 1847 and 1888, embracing, together with recent improvements, the iron-pile and granite structures designed by the late James Walker, F.R.S., Past President Inst. C.E., cannot fail to be of interest to the members of the Institution.

When in 1846 the Corporation of Trinity House had under consideration the erection of a lighthouse on the Bishop Rock, it was decided to install within it one of the best lights then available, viz., that from an illuminating apparatus of the first order of “Fresnel” for a fixed light, having at its focus a 4-wick “Fresnel” burner consuming colza oil, and giving an intensity in the beam of about 6,500 standard candles, with a nautical range of 15½ miles. It was also determined to provide this lighthouse with a bell weighing 5 cwt., as a signal in foggy weather. The largest passenger ships at that time in existence, trading between America and British ports, did not exceed 2,000 tons register, with a maximum speed of 9 knots. If this state of things is contrasted with the requirements of navigation at the present day for ocean steamships having a tonnage at least five times as great as those

built in 1847, with a speed in some instances exceeding 20 knots an hour, it will be readily perceived that not only had it become a matter of absolute necessity to give the mariner an increase both in the power and range of the light in clear weather, but that he should be more effectively warned of his proximity to danger, when running at high rates of speed, with the surrounding atmosphere impaired by rain, haze, and fog.

The perfection to which deep-sea sounding apparatus, and ships' compasses have of late years been brought—largely due to Lord Kelvin, President of the Royal Society, Hon. M. Inst. C.E.—and the accuracy and completeness with which the depths of the ocean and the variations in the bottom of the sea have been ascertained, decrease in a large measure the risk incurred by commanders of ocean steamers in making a landfall. Notwithstanding these recent additions to science, wrecks are unfortunately of frequent occurrence; and it is with these facts that lighthouse authorities have to deal in designing modern lighthouses, and installing the requisite high powers of light and sound signals.

Between the years 1680 and 1790, the Scilly Islands, which cover a rock-bound area of 35 square miles, had for their sole coast illumination an open coal-fire placed on the summit of a tower on the island of St. Agnes, nearly 5 miles within the outer dangerous reefs and rocks. The "cresset" which formed a part of this primitive Pharos, might have been seen recently in the grounds of the Royal Naval Exhibition. The Corporation of Trinity House, in the year 1790, replaced this primitive apparatus by the first revolving catoptric oil-light established on the coasts of Great Britain. This has undergone successive improvements, though the original type of illumination has been retained.

The Bishop Rock, which probably derives its name from its original resemblance to a bishop's mitre, is of very hard pink-coloured granite. The rock is just covered at high-water ordinary spring-tides. This isolated danger, surrounded by from 20 to 25 fathoms of water close alongside, is situated at a distance of 7 miles from the principal island of the Scilly group in a south-westerly direction, and is exposed to the full force of the North Atlantic ocean with a "fetch" of 3,600 nautical miles. From this fact, and from the instances of heavy seas striking the buildings related in this Paper, it will be understood that in stormy weather the rock is subjected to very severe wave shocks, and that any structures founded upon it must depend for their durability on solidity of construction, excellence of material, and perfection of workmanship. A series of observations on heavy waves encountered

at this station were made in the year 1847 by the late Mr. N. Douglass,¹ then the superintending Engineer to the Trinity House. Mr. Douglass related to the Author that, during the construction of the first lighthouse, an iron column, weighing 3 tons, was landed on the rock during the progress of the iron tower, but the weather did not admit of its immediate erection. The foot of the column was landed on a bench of the rock, and securely lashed to eyebolts by $\frac{1}{2}$ -inch chain; and its upper end was secured to the framing of the tower, the column occupying a vertical position. On sailing round the rock three days later, it was observed that the column had been tossed up 20 feet on to the top of the rock, and was swaying about horizontally like a piece of timber, being held by the lashings at its upper end only. On landing at the rock some days later, it was found that a blacksmith's anvil, weighing $1\frac{1}{2}$ cwt., had been washed out of a hole, 3 feet 6 inches deep and 2 feet in diameter, prepared for the column. Certain facts, moreover, came under the Author's personal observation during the erection of the improved granite tower, which may assist in realizing the difficulties attending the building of the structures upon the westernmost rock of the Scilly Islands. During a severe north-west gale, the solid waves are impelled over the inclined surface of the rock to a considerable height, and thence in broken masses up the shaft of the tower, a further portion being driven in sheets over the lantern vane. A heavy steam-winch bolted to the masonry of the landing platform, at a level of 22 feet above high water, and protected by masonry breakwaters, was completely wrecked and washed away, the bolts and portions of the bedplate alone remaining. Further, a 12-inch iron leading block, shackled direct to the landing jib and fixed at an elevation of 60 feet above high water, was struck by the sea and borne off, owing to the fracture of the $1\frac{1}{4}$ -inch shackle which alone remained. Again, an iron cradle, which was securely guyed, and suspended by $\frac{1}{16}$ -inch chain slings beneath the lantern gallery, at a height of 115 feet above the highest level of the sea, was torn from its attachment. As illustrating the violence of the sea as it strikes exposed positions in the islands of Scilly, another incident may be recorded. On the morning following a heavy storm from the north-west in the winter of 1886, the Author had occasion to visit Round Island, lying 5 miles distant from the Bishop Rock, where a second lighthouse was in course of construction under his supervision. Large masses of water had been driven over the summit of this rocky island, which is 130 feet in

¹ Minutes of Proceedings Inst. C.E., vol. xv., p. 8.

height. On the flat roof of the dwelling-house, the Author discovered a living limpet, and a number of small stones weighing $2\frac{1}{2}$ ounces, waifs and strays carried by the force of the sea to an altitude of 143 feet above high water. Such facts as these will explain much, which would otherwise be almost difficult of credence, in the following narrative.

At the level of low-water spring-tides, the Bishop Rock is 153 feet long and 52 feet broad, from which level it runs down sheer and steep some 20 fathoms or more. Thus it will be readily understood how, in the year 1845, the opinion was generally entertained that the width of the rock was not sufficient for the base of a stone tower, which should be strong enough to withstand heavy wave shocks. Consequently it was decided that an open structure of wrought- and cast-iron should be placed upon the Bishop Rock (Plate 4, Fig. 1). This work was begun in 1847 under the direction of Mr. N. Douglass. The iron columns, strengthened by strong wrought-iron cores, were all deeply sunk and lewised into the rock; and these were designed to offer the least resistance to the passage of the sea between them. Ingress to the living-room, stores, and lantern of this lighthouse was to be obtained through the centre column. After overcoming many difficulties in erection, and at the end of the fourth working season, the tower was ready for the reception of the lantern and illuminating apparatus. In that state, the structure was confidently left to resist the winds and the waves of the coming winter. A heavy storm occurred during the night of the 5th February, 1850, and when morning broke the iron lighthouse had been swept away, and nothing remained above the surface of the rock, except short portions of the main columns. This disaster was doubtless due to the heavy seas sweeping over the rock at an elevation considerably higher than had been estimated, and thus striking with their full force the larger surface of the upper portion of the structure, intended for the residence of the lightkeepers, and for the storage of their provisions, fuel, &c.

Thus the whole matter of placing a lighthouse upon the Bishop Rock came up for reconsideration by the Trinity House; and on the recommendation of their engineers, it was determined to raise a granite tower to replace the iron one (Plate 4, Fig. 2). This work was proceeded with in 1851, again under the direction of Mr. N. Douglass. On the most exposed side of the rock, at the level of 1 foot below low-water spring-tides, the lowest stone was laid—for thus only could the greatest possible diameter of the base permitted by the area of the rock surface be obtained. In

spite of many efforts to lay this stone, the work was not accomplished before the end of the year 1852, although work at a higher level was proceeded with. During the construction of the building, great difficulties were experienced in landing by manual labour the stones conveyed to the rock in barges, which were towed from the workyard at St. Mary's. The year 1858 saw the tower finished, and a dioptric fixed white light exhibited, as intended for the former lighthouse.

In brief space, however, the Trinity House were further reminded of the extreme exposure of the tower to heavy seas, a notable circumstance bringing this fact vividly before them. Fixed 100 feet above high water, on the lantern gallery, was a 5 cwt. fog bell. During a severe storm, it was torn from its bracket, to which it was firmly bolted, and was washed away together with the flagstaff and ladder lashed to the gallery. A portion of the fog bell was afterwards found in a cleft of the rock, and is preserved at the Trinity House. When a hurricane of this type was raging, the tower vibrated considerably; articles were shaken from the shelves in the rooms, and the prisms of the dioptric apparatus fractured. Later on it was discovered that some of the external blocks of granite, situated a few feet above high water, had been split by the excessive strain imposed on the building. Acting upon the advice of their engineer, the Trinity House, in the year 1874, strengthened the tower from top to bottom by bolting heavy iron ties to the internal surface of the walls, and connecting them through the floors. Nevertheless, after a violent storm in 1881, there was again evidence that the heavy strains of the sea had caused further damage. In certain instances, pieces of granite weighing $\frac{1}{2}$ cwt. were split from the face of the exterior blocks, a few feet above high-water level. The Trinity House therefore resolved to strengthen and improve the tower.

In view of the increasing demands of navigation, and the number of vessels wrecked on this coast in foggy weather, the Trinity House decided not only to strengthen the lighthouse, but to thoroughly improve the internal accommodation, the illuminating apparatus and fog-signal, and to effect such alterations as should place the tower in the foremost rank of rock lighthouses. At the same time, an efficient light was to be maintained on the site during the whole of the operations. In carrying this decision into effect, the engineer submitted the improvements shown in Plate 4, Figs. 3 and 4. These consist of an outer casing of masonry, dovetailed horizontally and vertically from the foundation courses

of the original granite building to the level of the service-room floor; above this point, the structure was entirely removed, and four new rooms added, the walls of these rooms being built of through stones. The lantern and illuminating apparatus surpass in power all similar installations to be met with at the present time in rock lighthouses. The height of the mean focal plane of the light above high water of ordinary spring-tides, was increased from 110 feet to 146 feet; and the nautical range was thus extended from 16 miles to $18\frac{1}{4}$ miles.

On the completion of the new Eddystone lighthouse in 1882, the plant used in its construction was taken over at a valuation and conveyed to the Scilly Isles, where a plot of ground for a workyard was leased, adjacent to St. Mary's pier. A portion of this plot was occupied by the Trinity House during the construction of the former towers on the Bishop Rock. The Author was appointed resident engineer, with responsibility for the due execution of the work. Offices, workshops, and overhead travellers were erected, and a line of rails laid down between the workyard and the steam-crane set up on the pier to aid in loading and discharging material. The twin-screw steamer "Hercules," of 130 tons net register and 45 NHP., built in 1870 for service at the Great and Little Basses lighthouses, Ceylon,¹ was taken over as a portion of the plant.

The granite blocks forming the casing of the tower and the upper portion, were obtained by contract from the Eddystone Granite Quarries at Delank, Cornwall. The blocks were carefully dressed in the quarry, and erected temporarily in sections. Each stone up to, and including course eight, had a male dovetail, 6 inches in depth at its inner end, to insure a perfect connection with the granite tower; and, moreover, it was dovetailed to the other blocks of granite with which it was connected. The blocks up to, and including the twentieth course, were each of them further secured—after being bedded and grouted in Portland cement and clean sharp granite sand, in equal proportions by measure—by two $1\frac{1}{2}$ -inch Muntz metal bolts, fox-wedged, passing through the upper stone and 9 inches into the stone below, as used in the first granite tower. In consequence of the frequent sudden rise of the sea, these bolts were found to be especially necessary for securing the lower stones from displacement by the waves until the cement had thoroughly hardened. Below course twenty-five, the joints, both horizontally and vertically, broke joint with those in the

¹ Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 50.

masonry of the old work. It was this portion of the old tower which had given the most significant tokens of weakness, although there was evidence, on cutting into the walls, that the whole of the masonry work had been most carefully and perfectly executed. The quality of the work was further proved by the fact that no evidence existed of water having been driven into the joints. Hydraulic puzzuolana mortar, carefully prepared, had been used throughout the work above high-water spring-tides; below this, all the masonry was set in Roman cement.

The outline of the improved tower (Plate 4, Fig. 3) was designed to meet the conditions imposed by increased height, and so as to utilize fully the utmost extent of foundation afforded by the rock. It was also intended to give the utmost additional strength to the walls, especially at those points where weakness had shown itself, and to preserve as low a centre of gravity as possible. The cylindrical base, 41 feet in diameter, was carried up nearly vertically to a height of 40 feet above the foundation, and terminated in a landing platform, approached from the rock by gun-metal cleats. In this case it was found necessary to carry the cylindrical base to a greater height above high water than the base of the new Eddy-stone, where this form of construction was first employed; and experience proves that the platform is at the most efficient level for the safety of the lightkeepers when landing supplies, &c. When the waves break against the rock or vertical base, and are driven in sheets of water over the platform, the relief of the tower or landing of stores is an impossibility, because of the danger a boat incurs in approaching the rock. From the inner edge of the platform above-mentioned, and at a diameter of 32 feet, the curve of the tower springs, taking the form of a concave elliptic frustum, with generating axes of 237 feet and 62 feet respectively. This curve terminates in a bold cavetto, carrying the gallery on which the lantern rests.

The granite blocks forming the dovetailed casing and upper portion of the tower, ranged in weight from 2 to $3\frac{1}{4}$ tons. These were conveyed to the tower by the twin-screw steamer "Hercules," each block being carefully stowed on elm rollers in the hold. To the southward of the rock (Plate 5, Fig. 6)—a position selected owing to the great depth of water and the space afforded for manœuvring—three moorings were laid down, consisting of 35 fathoms of $1\frac{1}{2}$ -inch ground chain, and 1-inch open link upper chain, shackled at the upper end to a 5-foot spherical steel mooring buoy, and at the other end to a 2-ton cast-iron sinker, which was again attached by 20 fathoms of $1\frac{1}{2}$ -inch chain to a 2-ton backing sinker, to prevent

the first sinker drawing home towards the rock when the vessel was moored and landing stone. During the winter months, the wear of the chain on the rock bottom was so great that it was found necessary to relay the moorings every three months. Three strong iron mooring stanchions were fixed on the rock. The steamer, on her arrival at the "Bishop" was moored as follows. The head mooring buoy was picked up, and a 13-inch coir hawser made fast to it. The vessel was then backed astern, and warped up to the rock by a small hawser. Two 13-inch coir hawsers were made fast to the mooring stanchions, and the slack hauled in by the deck winches. Two additional 9-inch coir hawsers were afterwards run out to the remaining head mooring buoys, to maintain the vessel in her position against a strong beam tide. The assistance derived from the use of twin screws in berthing a vessel in a tide-way, with an adverse tide running at springs at a velocity of from 4 to $4\frac{1}{2}$ knots per hour, cannot be over-estimated. When a moderate ground sea has set in after the vessel has been secured in position, the back send from the rock was occasionally so great that the coir hawsers yielded to the excessive strain, and parted one after the other.

It was found convenient, during the progress of the operations, to land the working party by means of a manilla rope attached to a single-whip winch standing on the gallery of the tower. In this way the working party usually passed to and fro from the landing boat, which was lying under oars at a distance of from 10 to 15 fathoms from the rock, clear of the heaviest of the broken water, and free from risk of being stove in. No serious accident occurred to either of the landing boats, either by collision with the rock or by overturning, although they frequently encountered heavy seas when they had on board a full complement of men. The working party employed on the rock usually numbered thirty, and was actively engaged, when the state of the tide and weather permitted it, in dressing back the face of the granite rock (Plate 5, Fig. 5), and cutting out dovetails for the safe bonding of the new masonry. The work was necessarily very tedious; and progress in erection was much less rapid than would have been the case with an entirely new building. The mode of operation was as follows:—Holes were drilled by manual labour in the face of the tower, then the granite was plugged by means of steel plugs and feathers, and the dovetails were eventually dressed to template by double and single-handed cast-steel points. One mason and one hammerman worked together preparing for each block of the new masonry, and on an average completed their work in rather under

two days for a dovetail stone, the dressing for a stone having no dovetail at its inner end occupying the remainder of the second day.

On completion of the dovetailed casing above mean-tide level, twelve workmen were lodged at the tower to expedite the work by taking advantage of every opportunity to proceed with dressing back the surface of the tower, when it was inexpedient, because of heavy seas, to land the whole of the working party on a rising tide. The workmen stationed at the tower were also of service in the erection of the setting cranes and temporary illuminating apparatus. This work could be proceeded with in moderate weather. The work of dressing back the tower to receive the new masonry between low-water mark and half tide was of a dangerous character, in consequence of the occasional very sudden rolling in of Atlantic waves when least expected. Life-lines were made fast to a chain encircling the tower, and placed beside each workman. Frequently the sea running up the surface of the rock completely buried the men. For the security of the workmen whilst employed between the summit of the vertical base and course sixty-two, and also in order to provide more room than the upper surfaces of the new blocks allowed for carrying out operations at this height, foot boards were fixed to brackets secured in the masonry. In connection with the brackets, a strong manilla rope net was secured to the bracket stanchions and drawn tight round the tower beneath. The workmen had entire confidence in this measure of protection; moreover, the net could be put up and removed in about a quarter of an hour. On completion of the masonry, the number of workmen residing at the tower was considerably augmented, to expedite as far as possible the fitting up of the illuminating apparatus, lantern, wrought-iron partitions, stairs, shutters, machinery, and general internal arrangements.

The blocks of granite forming the dovetailed casing were landed direct from the twin-screw steamer by means of her own steam-power, as previously described in a Paper by the Author on the new Eddystone lighthouse.¹ Frequently the blocks of granite, on emerging from the water under the stern of the vessel, were struck by a heavy sea, causing them to swing over a considerable number of degrees. The force of the swinging movement was further increased by the heavy rolling of the vessel. To meet this difficulty, the block was again lowered into the water to bring it to a state of comparative rest. Then advantage

¹ Minutes of Proceedings Inst. C.E., vol. lxxv. p. 31.

was taken of a temporarily smooth sea to proceed with its landing. At the tower, heavy coir mats were placed to receive the block to avoid damage, and to break the concussion when the winch was reversed in order to land it. It will be easily understood that a sudden rise or fall of the vessel on a wave would frequently cause the block to rise or fall 6 feet. As the work progressed, the blocks were landed on the vertical base platform, and eventually on a temporary stage at the level of the entrance door (Plate 5, Fig. 5). Above this level, it was not found expedient to land the stones direct from the vessel upon the new masonry, as the heavy seas which were occasionally encountered tended to throw an excessive strain upon the central crane and chain falls. No damage occurred during the landing of the blocks after leaving the steamer. One block was, however, lost. It was thrown over the rail of the vessel amidships, from the deck truck upon which it had been deposited. This accident was due to a very heavy beam sea which caused the vessel to roll abnormally. As the loss occurred at the end of the working season, it fortunately occasioned no delay in the work.

A hoisting and setting crane was erected on the lantern gallery, capable of transversing the complete circle. The blocks were lifted by this crane from the landing position, and traversed as required to their setting position, where they were deposited on a cement bed. This specially designed crane was actuated entirely by hand-power, and proved a very efficient machine in setting the whole of the new masonry from the foundation up to course sixty-two, when it was removed and superseded by the central crane. This crane consisted of a hollow wrought-iron mast and topmast, 40 feet in height, carried in iron partners and timbering in the rooms, and stayed by guy chains. Two wrought-iron jibs were carried on the mast for hoisting and setting the blocks. The setting jib, traversing a complete circle, was provided with a winch. The topmast carried an iron pole, to which was attached a Trinity House floating-light lantern, in which was maintained, during the progress of the work, a powerful double flashing catoptric light. The crane, together with the lantern and illuminating apparatus, was raised by hydraulic jacks to its successive positions as the works progressed. In order to facilitate the hoisting of the blocks from the position at which they were landed to their final position in the tower, a steam-boiler and winch were bolted to the vertical base platform, and protected, as far as possible, from the direct force of the waves by masonry breakwaters. The whole of the blocks comprising courses sixty-three

to ninety-one were thus hoisted by the steam-winch, between the 26th of June and the 30th of August, 1886, at the rate of one, and occasionally two courses per day, as circumstances would permit. To avoid giving the hoisting jib unnecessary overhang, a frame carrying two elm rollers was placed behind each stone, which admitted of its passing up over the face of the tower without damage. Before the winch and boiler could be removed to the shore after completing the work, they were swept away during an equinoctial gale.

The strengthening and improvement of the tower by means of an outer casing of dovetailed masonry, the addition of three rooms in height, and the fitting up of a powerful illuminating apparatus and fog-signal, were commenced in the spring of 1883. The first and lowest stone was set on the north-west side of the tower on the 25th of May, 1883; and before the winter season, fifty-seven stones, including a portion of course ten, had been set. The following year, the difficulties of battling with the waves and effecting tide work had in a great measure been overcome. Thus more frequent landings at the tower, and longer hours of work were practicable. The season closed on the 19th of November, when four hundred and fifty-seven stones, including course twenty-two, had been set. The favourable weather experienced in the fall of the year 1885 made work at the tower possible up to the 9th of December, and that day saw the completion of course fifty-four. The sixty-second course, the height to which the dovetailed casing extended, was completed on the 11th of May, 1886; and the demolition of the lantern, the illuminating apparatus, and the masonry forming the service-room of the granite tower, was immediately proceeded with. Without in any degree interfering with the nightly service of the light to mariners, the central crane was substituted for the gallery course setting crane, the temporary lantern fixed thereto, and the original lantern and dioptric apparatus removed for service elsewhere. At the level of course sixty-two, a timber stage was erected, provided with rails and a truck. Upon the latter, the blocks of stone forming the service-room of the former tower were lowered by means of the traversing jib, after removal from the wall. The truck was then run out, and the stones automatically tipped into deep water clear of the tower and rock. The work of erection was again proceeded with on the 26th June, and the masonry of the remaining four rooms completed by the 30th of August following; and here the rapidity of the operations, as compared with the tediousness of the dove-

tailing, is worth noticing. Thus the time occupied in the preparation for, and setting of, the additional masonry, amounting to 3,220 tons, was rather under three and a half years. The permanent light was exhibited on the 25th October, 1887, and the work brought to a conclusion in December.

The temporary catoptric illuminating apparatus consisted of an 8-foot Trinity House cylindrical floating-light lantern, in which were placed two groups of 21-inch parabolic silvered reflectors, three in a group. The reflectors were provided with two-wick "Trinity House Douglass" burners, consuming heavy mineral oil. This arrangement admitted of the exhibition of a light similar in distinctive character to the light designed for the new tower, viz., "double flashing" of one minute period. The power of the flash of light issuing from each group of reflectors was equal to sixteen thousand standard candles, thus exceeding the intensity of the old light of fifteen thousand candles, which had previously been improved by substituting a "Trinity House Douglass" burner of six wicks for the original four-wick "Fresnel" burner. On the erection of the permanent lantern, the temporary lantern and illuminating apparatus were removed, and the latter arranged at the upper portion of the permanent lantern.

The present lantern is of the usual Trinity House cylindrical helically framed type, 14 feet in diameter, and 15 feet high in the glazing. The pedestal is of cast-iron, the framing is of gun-metal, and the steel rafters forming the roof are covered with thick copper sheet. The roof has the improved arrangement of the Trinity House for the thorough ventilation of the interior, without subjecting the flame of the burners to any down-draughts. The lantern and optical apparatus were constructed by Messrs. Chance Bros. and Co., of Birmingham. The optical apparatus consists of two superposed tiers of lenses of the greatest focal distance, viz., 1,330 millimetres, hitherto installed in a lighthouse (Plate 6, Fig. 7). Each tier is composed of ten lenses, each subtending a horizontal angle of 36 degrees, and a vertical angle of 80 degrees. Each lens is built up of a centre, and seventeen rings above and seventeen rings below that centre. The duration of flashes and eclipses are as follows:—

	Seconds.
Flash	4 $\frac{1}{2}$
Eclipse	4 $\frac{1}{2}$
Flash	4 $\frac{1}{2}$
Eclipse	46 $\frac{1}{2}$
Total period	<hr/> 60 <hr/>

In clear weather the lower burner, which is worked at minimum power, transmits through the lower apparatus a light of 40,000 candles to the horizon; but when the atmosphere is impaired for the transmission of light, the two burners are worked at maximum power, thus increasing the aggregate beam transmitted through the double apparatus to 230,000 candle-units. The change from minimum to maximum power is made whenever the light at St. Agnes lighthouse, 5 miles distant, is not clearly visible. For the purpose of securing the utmost efficiency of the flashes of the upper tier of lenses, which are only used during thick weather, these lenses are focussed for utilizing the maximum efficiency of the flame of the burner on the sea at a distance of 5 miles.

In the service-room, two 100-gallon Trinity House improved pressure lamps are placed. These lamps supply the two eight-wick "Trinity House Douglass" burners with heavy mineral oil of 250° Fahrenheit flashing point. The burners are carried on burner changers. The framework of the optical apparatus is necessarily constructed of a heavy section, to withstand the shocks to which it is occasionally subjected by heavy masses of water striking the tower. The power requisite for its rotation is beyond that of the ordinary clockwork actuated by manual power, and thus it became necessary to introduce special machinery for the purpose. This machinery comprises a pair of $1\frac{1}{2}$ effective HP. "Davey" safety motors and air-compressors, working into two vertical steel air-receivers, placed over end at the centre of the tower. Sufficient air is compressed into these by day for working a small air-engine placed in the pedestal of the illuminating apparatus, by which the latter is kept in rotation during the night. A winch worked by compressed air is placed on the lantern gallery, for landing stores and light-keepers. The annual consumption of coke for working the "Davey" motors does not exceed 14 tons. The whole of the machinery is worked by trained light-keepers, without the aid of a skilled mechanic, except for occasional overhaul and repairs.

A gun-cotton explosive fog-signal is attached to the lantern, which takes the place of the fog bell formerly employed. This very efficient type of fog-signal is now in successful operation at five Trinity House rock lighthouse stations, for it was found impracticable to introduce, in the limited space available, special machinery of such power as required to work a siren of the type in use at shore lighthouse stations, and on board light vessels. The apparatus consists of a hollow steel crane attached to the lantern, and actuated by a worm-wheel and pinion. For the attachment of the gun-cotton charges, the crane is lowered, and two

charges are suspended to the firing cables which are connected with a dynamo electric exploder placed within the lantern. After suspending the charges, the crane is raised to its upper position, and contact made at five-minute intervals. A charge consists of 4 oz. of gun-cotton, into which a fulminate of mercury detonator is placed before suspension. Prior to the introduction of this type of fog-signal, a 5-cwt. bell, suspended from the lantern gallery, and actuated by clockwork, was sounded in foggy weather. During the five years the Author was engaged in the reconstruction of the tower, six wrecks took place during thick weather, within a radius of 5 miles of the tower; but since the introduction of the gun-cotton signal, in 1888, the Author is not aware of a single wreck having occurred within this radius during foggy weather.

It is very satisfactory to record that throughout the whole of the dangers incurred in the erection of the three lighthouses at this station, no loss of life or limb has ever occurred.

The cost of the work executed at this station from time to time is as follows :—

	£	s.	d.
1. Cast-iron lighthouse	12,500	0	0
2. Granite lighthouse	34,559	18	9
3. Improved granite lighthouse . .	64,889	0	0
Total	111,948	18	9

If the usual test of cost for such structures is applied to the Bishop Rock lighthouse as it now stands, namely, per cubic foot of granite masonry, it amounts to £1 8s. 6d., which compares favourably with other sea structures.¹ On the other hand, if the value is estimated from a nautical point of view, at per unit of intensity of light provided, it will be found to be lower in cost than any other first-class sea lighthouse.

The Paper is accompanied by a series of drawings, from which Plates 4, 5, and 6 have been prepared.

¹ Minutes of Proceedings Inst. C.E., vol. lxxv. p. 36.

Fig: 1.

IRON TOWER 1850.

Fig: 2.

GRANITE TOWER 1858.

Fig: 3.

IMPROVED GRANITE TOWER 1888.

Figs: 4.

IMPROVED GRANITE TOWER, PLAN OF ROOMS.

Scale: $\frac{1}{4}$ inch = 1 Foot.
Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet.

THE BISHOP ROCK LIGHTHOUSES.

IMPROVED GRANITE TOWER.

W. T. DOUGLASS, DEL.

ELEVATION OF 1330 M/M. BIFORM DIOPTRIC APPARATUS.