

Mr. J. N. DOUGLASS remarked that the Messrs. Stevenson were to be congratulated for having completed the work without loss of life or limb to any of the persons employed, and also for having adopted granite for the tower. No doubt the tower might have been constructed with wrought iron or cast iron, but, in doing so, little reduction would have been effected in the cost, while an annual outlay would have been involved for the preservation of the work, and there would have been a limit to its duration. The Author had furnished some interesting particulars relative to the heavy seas experienced at Dhu Heartach. The position of the rock and the nature of the soundings seaward were doubtless sufficient to account for heavy seas, but he did not consider there was evidence to show that heavier seas occurred there than at the Bishop or the Wolf rocks on the west coast of England, as might be expected by comparing the soundings. On the north-west, or most exposed side of the Bishop, at a distance of 4 miles, there was a depth of 50 fathoms, gradually shoaling to 30 fathoms close to the rock, which had a gradient to the westward of about 1 in 1. These were favourable conditions for heavy seas, and for the concentration of their force upon the building. Both at the Bishop and at the Wolf, where the soundings and gradients of the rock were similar, heavy seas rose several feet higher than the building before cresting; but, fortunately, they crested after they had passed the building. Such seas fell and were spent at about a cable's length from the tower. The destruction of the iron pile lighthouse first erected on the Bishop was due to unbroken seas striking the dwelling, the floor of which was 85 feet above high water and the surface of the rock. During a storm on the 30th of January, 1860, the fog bell, weighing 3 cwt., was torn from the bracket, on the lee side of the lantern gallery, 100 feet above high water; and during a storm in the winter of 1874-5 the heaviest seas experienced since the completion of the lighthouse in 1858 were encountered. On this occasion the tremor of the building was so great as to cause articles to leave the shelves. On his recommendation the building had since been strengthened by strong internal vertical and radiating ties of wrought iron secured to the walls and floors. At the Wolf, before the erection of the lighthouse, there was evidence of the enormous force of the heavy seas falling on it, in the breaking off, on three occasions, of the masts of the beacon—one of English oak and two of wrought iron, the last being 9 inches in diameter. He did not think that seas could fall so heavily on the Dhu Heartach rock as on the Bishop or the Wolf rocks; otherwise

he could not conceive it possible for the workmen's barrack to have withstood them. He preferred, for the form of the structure, a curve nearer that of the Edystone, with a comparatively larger base grasping the rock. The method of stepping, or offset courses, first adopted by the late Mr. James Walker, Past-President Inst. C.E., at the Menai lighthouse, combined the advantage offered by such a form for stability with that of a vertical wall in checking the tendency of heavy seas to rise to the upper and weaker part of the structure. The statement of the comparative height of the solid portion of the building above high water would, he thought, have been more complete if the height above the surface of the rock at the base of the tower had been given. Although, in the seven lighthouses referred to, the heights of the solid portion above high water were found to vary between 10 feet 3 inches for the Edystone and 64 feet 4 inches for Dhu Heartach, thus showing a difference of 54 feet 1 inch, the heights above the surface of the rock were respectively 32 feet and 12 feet—a difference of only 20 feet. He did not consider the erection of a barrack on the rock an economical arrangement for such a work. In addition to the first cost of the structure, the time in erecting it was not, he thought, compensated by any advantages, as, after the foundation of the lighthouse had been prepared, which should be accomplished by the time that a barrack could be erected, workmen were not required on the rock, except at such times as materials for the tower could be landed. He had always found that workmen could be got on or off such a rock whenever materials could be landed; and, in getting away with a sudden rising of the sea, his men were ready enough to be drawn off by a line, with a life-belt on, when the landing boat could no longer approach the rock with safety. With regard to the conveyance of workmen and material to the rock, instead of the tug and barges that had been described (and which had been adopted in the cases of the Bishop and the Wolf), he preferred two screw steamers, as had been employed at the Great and Little Besses lighthouses, off the south-east coast of Ceylon.<sup>1</sup> These vessels, carrying steam machinery for the purpose, were more speedily loaded at the workyard and moored at the rock; the material was more rapidly landed there; and they were safer at sea in rough weather than a tug towing barges. He agreed with the Author that it was difficult to contrast the cost of the work with that of other works of a similar character; but such comparisons must be made.

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E.*, vol. xxxviii., p. 56.

It was, therefore, only fair to submit a work of that kind to the usual standard of estimates, namely, the price per cubic foot of the work executed. The cost of the Dhu Heartach lighthouse, irrespective of the shore establishment, was stated to have been £65,784 9s. 7d. The weight of the structure was 3,115 tons, and, taking  $13\frac{1}{2}$  cubic feet of granite to the ton, the cost amounted to £1 11s. 3 $\frac{1}{4}$ d. per cubic foot. The cost of the Bishop lighthouse was £34,559 18s. 9d., or 19s. 7 $\frac{1}{2}$ d. per cubic foot, which was  $37\frac{1}{2}$  per cent. below the cost of the Dhu Heartach. When it was remembered that part of the foundation of the Bishop was laid at 1 foot below low water spring tides, and the foundations of the Dhu Heartach at 32 feet above high water spring tides, he thought the cost of the latter did not compare favourably with that of the former. True the Bishop had been completed in 1858, when wages and material were lower than at present; but the improvements since effected in steam appliances for executing such works had fully compensated for this increase.

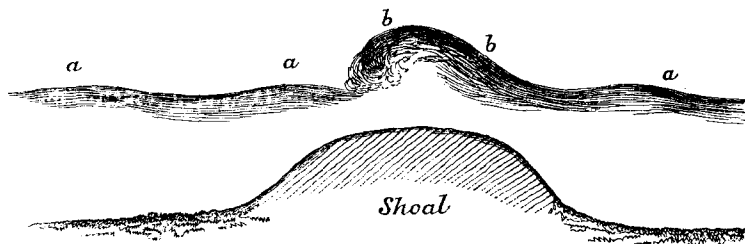
Mr. LONGRIDGE asked upon what evidence Mr. Douglass based his statement as to the height to which the sea rose against the Bishop lighthouse. According to that statement, as he understood it, the solid wave rose 70 feet against the lighthouse, and continued rising 30 feet higher than the top, making a total height of 160 feet above the rock. The depth of water being 34 fathoms, and the slope of the rock 1 in 1, he could not conceive how such a thing could happen. He had paid some attention to the height of the waves in the Atlantic, and did not think he had ever seen a wave higher than 35 feet in the deepest water. The only people who had seen the sea rising against the Bishop lighthouse were probably the keepers, who had been no doubt considerably frightened, and had exaggerated the height of the water.

Mr. REDMAN thought that there had been some misapprehension as to the statement of Mr. Douglass. The height of the waves in the Atlantic, from the trough to the crest, had been variously estimated at from 30 to 40 feet. The waves striking the British coast were from 20 to 30 feet high. Mr. Douglass, he presumed, did not mean that the waves breaking upon the lighthouse were 60 or 70 feet high from the trough to the crest, but that from the configuration of the bottom and the slope of the face of the submerged rock at an angle of  $45^\circ$  the water was shot over in the manner he described; and considering the general accuracy of Mr. Douglass's remarks on such subjects, he had no doubt that the account he had given was a faithful one. The site of the Dhu Heartach lighthouse was peculiar; and at Skerryvore, which was contiguous to it, a pressure of 3 tons to the superficial foot, being the greatest amount

ever observed, had been recorded by the dynamometer of Mr. Thomas Stevenson. The peculiar conformation of the bottom reminded him of a diagram he recently presented to the Institution,<sup>1</sup> showing how different were the conditions attendant upon various national harbours. His attention was particularly directed to that subject in the discussion on the Alderney breakwater, when he remarked upon the fact that that breakwater, being in a condition somewhat similar to the site of the Bishop lighthouse, with 120 feet depth of water, and with an offing to the West Indies, was not comparable to the other harbours of the country, and in the discussion on the Holyhead New Harbour his remarks were embodied in a diagram. Undoubtedly the facts recorded by the Author on the rock in question should be regarded as the results of its exceptional position; because, as Mr. Douglass had remarked, although it was in an exposed part of a peculiar ocean, the foundation was 35 feet above the level of high water.

Sir JOHN COODE, while fully agreeing with the Author as to the importance to be attached to the configuration of the bottom in its effect upon the height of waves, did not think that the diagram quite bore out the view which had been put forward. The Dhu Heartach lighthouse was in 30 fathoms of water; the next contour was 40 fathoms, a difference of only 60 feet in about 5 miles, or 12 feet per mile. Such an inclination—1 in 440—was not, he thought, sufficient to affect the rise of the waves. He believed Mr. Longridge must have been misled by not distinguishing between undulations in deep and in shoal water. Of the difference between the two he had once had a good illustration. Looking seaward at

FIG. 1.



a point where his eye struck the horizon 4 miles off, the general configuration of the sea surface was a slight undulation, as at *a a a*; but at a point where there was a shoal, with 2 fathoms of water over it, the line was as at *b b* (Fig. 1). This would give some

<sup>1</sup> *Vide Minutes of Proceedings Inst. C.E., vol. xlv., p. 121.*

idea of the effect of the gradual shoaling of the bottom upon the height of sea waves. He thought great credit was due to Messrs. Stevenson for the manner in which the work had been carried out under exceptional difficulties, and the more so that it had been executed without loss of life or injury to any individual engaged upon it.

Mr. BRAMWELL said Mr. Longridge appeared to think that there must be some mistake in the statement that a solid wave could rise 100 or 130 feet above the water-level, because the height of the waves in the Atlantic did not exceed 35 feet. The Author had referred it to the underground configuration. Mr. Bramwell was not in a position to say whether the configuration was such as to justify the conclusion drawn from it; but it was perfectly easy to suppose that there might be such a configuration. He might instance two well-known cases of high tides. The tide at Chepstow had been variously stated at between 40 and 50 feet, and that was at the head of a stream where the rise and fall at the mouth was not one-half. The excess of the rise was due to the momentum of the water in that particular shape of channel, which momentum must be spent in some way. Again, there was the still more remarkable case of the Bay of Fundy. At the head of the bay the rise and fall were still greater than at Chepstow, sometimes amounting to 60 or 70 feet, and at the mouth they were only 8 feet. Those two cases were produced entirely by the configuration of the channel; and in the case of a submarine channel of adequate shape, and a wave coming along with great velocity, it appeared to him that the same rule would subsist, and that such results might be obtained as had been described. One point was quite clear: Whatever the alarm of the keepers, and however they might have exaggerated, an inanimate bell, which could not feel fear and could not exaggerate, hanging from the gallery, was torn away by something, and that something, depend upon it, was not mere spray, but was a strong body of water.

Mr. D. A. STEVENSON observed, through the Secretary, in reply on the discussion, that Mr. Douglass, in comparing the cost of the Bishop and the Dhu Heartach lighthouses, had not elucidated what could be of any real practical importance to Engineers. The particulars of each case, as to facilities for getting materials, for accommodating workmen, and, above all, the "regulating prices" of the period, must obviously be taken into account before any useful result could be attained. At Dhu Heartach the workmen had to be accommodated on an uninhabited island. The Bishop light-

house, moreover, was completed in 1858, after a period when prices were abnormally low, while the Dhu Heartach lighthouse was finished in 1872, when the prices of materials, provisions, and labour had been exceptionally high. The rise in these items, even between 1866 and 1872, had been, for provisions, 17·3 per cent.; for materials, 22·6 per cent.; and for wages, 14 per cent. No one would contend that the Bishop lighthouse could be built, at present prices, for £34,559.

Both Mr. Douglass and Sir John Coode seemed to have thought that it was the gradually sloping form of the bottom to which the Author attributed the peculiarly heavy action of the sea at Dhu Heartach. But this was not the case; it was to the submarine valley leading deep water up to the lighthouse, and increasing the height of the waves by its converging and comparatively precipitous sides, that the violent action was attributed. He had consulted the Admiralty charts before completing the Paper, and had found that neither the site of the Edystone, Bishop, Bell Rock, or Sker-vore lighthouses had any similar submarine feature open to the waves which assailed the towers on those rocks.

---