

December 7, 1858.

JOSEPH LOCKE, M.P., President,  
in the Chair.

The following Candidates were balloted for, and duly elected :—  
GEORGE FOSBERY LYSTER, ROBERT MANNING, JOHN McVEAGH,  
WELLINGTON PURDON, and EDWARD BRAINERD WEBB, as Mem-  
bers ; JOHN ASHBURY, JOHN DAVID BARRY, GEORGE LEEDHAM  
FULLER, ROBERT BARLOW GARDINER, WILLIAM HALL, GEORGE  
HAWKINS, LEWIS HENRY ISAACS, JASPER WILSON JOHNS, SAMUEL  
PONTIFEX, SAMUEL ALFRED VARLEY, and WALTER WILLIAMS,  
as Associates.

No. 991.—“Description of a Breakwater at the Port of Blyth ;  
and of Improvements in Breakwaters, applicable to Harbours  
of Refuge.”<sup>1</sup> By MICHAEL SCOTT, M. Inst. C.E.

THE interest at present excited on the subject of Harbours of  
Refuge, combined with the desire to submit to his professional  
brethren, at the earliest opportunity, some assumed improvements  
in Breakwaters, is sufficient reason for bringing this matter before  
the Institution.

It is not the Author's intention, on this occasion, to enter upon  
the subject of harbours generally ; for although, should this com-  
munication prove interesting to the Institution, he will be glad of  
a subsequent opportunity of referring to that topic, in the present  
instance, it is proposed only to describe, very briefly, the Break-  
water at Blyth ; and secondly the improvements, some of which  
have been suggested by the Author's experience in connection  
with that work. It has also been kept prominently in view, that  
it is desirable to contribute to the elucidation of those general  
principles, which ought to guide the engineer in designing piers  
and breakwaters. For, although it is admitted, that the work  
may require to be modified, in reference to local conditions ; still  
it is contended, that there are general principles which guide  
under all circumstances.

In the following Paper, it will be impossible to avoid the repe-  
tition of certain views and statements, which have already been  
before the Institution ; as, for example, under the head “Theory  
of Waves,” the Author has freely availed himself of the labours  
of Messrs. Scott Russell, Airy, Robertson, and others ; and, under

<sup>1</sup> The discussion upon this Paper extended over portions of five evenings, but  
an abstract of the whole is given consecutively.

the head "Theory of Form," of the published views of Sir Harry Jones, and Messrs. Airy, Vetch, Denison, &c.; but he believes that sufficient will remain which is novel to lead to an interesting discussion.

The Port of Blyth is situated on the coast of Northumberland, about ten miles north of the river Tyne. It need hardly be stated, that the whole surrounding district is rich in coal, there being a large virgin field of steam-coal in the immediate vicinity of Blyth. Until recently, only a small class of vessels could trade to that port, and a great part of the coal raised in the neighbourhood was transmitted, by rail, to the Tyne, for shipment. But a few years ago, a Company of enterprising gentlemen, headed by the Lord of the Manor, Sir M. W. Ridley, associated themselves, and obtained powers for improving the harbour. Mr. James Abernethy, M. Inst. C.E., was engaged as Engineer-in-chief, and under his direction the works were commenced. Certain reasons, with which the Author need not trouble the Institution, induced him to undertake the construction of a portion of these works; and merely observing, that the present communication has reference exclusively to the breakwater, he will proceed to describe it in detail.

It is well known, that there is a very heavy sea on this part of the coast; and that this must be the case will be obvious, when the great reach of water east and north is taken into consideration, the nearest land being the coasts of Norway and Denmark, which are distant from 400 miles to 500 miles. But it is not so commonly understood, that gales spring up, with a suddenness which increases the peril to men, and the risk of injury to works in progress. It is necessary to note this peculiarity, because it increased the difficulty of carrying out the work as originally designed. For a length of a mile, the river was exposed to the action of the sea, and it followed, that no vessel could then lie in this portion of, what is now, the harbour. Along the seaward side of the river there is a rocky reef, and upon the base thus provided by nature the breakwater has been erected. The work was originally intended to be, and for a length of 1800 feet was constructed, entirely of stone; but a failure in the supply of material led to a change, which has resulted in the work shown by Plate 1, Figs. 1 and 2. Mr. Abernethy proposed to employ timber and stone, after the manner adopted at Boulogne and Calais, and furnished a design similar in outline to Fig. 1. As the contractor for the work, being aware of the impossibility of obtaining, on the site, stone suitable for facing, and seeing that during very high tides there was great risk of damage to the open end, which had already been injured several times, the Author gladly undertook to do all in his power to carry out Mr. Abernethy's views; and

after a good deal of consideration, the forms shown in Figs. 1 and 2 were arranged, and were erected with entire success some time ago. It will be observed, that those portions of the breakwater which are illustrated by Figs. 1 and 2, consist of a framework of timber, filled with stone, and arranged as follows:—First, there is a sole piece resting on the ground. Upon this sole are raised two uprights, the one next the sea being supported by a strut from the sole piece. Cross-bearers, or half-balks, embracing the uprights, carry the roadway above; and this is protected by a simple handrail. The frames, thus formed, are placed at intervals of 10 feet from centre to centre, and are tied together, longitudinally, by walings, two on the sea face, and one on the river face, and also by the open planking, the space contained within which is filled with rubble-stone. It will be seen, that, in the first section, Fig. 1, this space is triangular, the planking on the river face being on the strut. The object of this arrangement was, partly to provide a sloping surface, and to leave the river-uprights isolated, opposite the entrance of the proposed docks, for the purpose of destroying, as much as possible, the swell which passes up the river. In the second section, Fig. 2, the exposure, and consequent strength required, being greater, the planking was put upon the river upright, and the whole space was filled with rubble, and was covered with an open flooring of horizontal timbers. The work has added more than 4000 feet, in length of the river, to the harbour, where there is still-water; and not only effectually breaks the waves, but it acts as a training wall, to direct the current, and to confine, and to intensify within the new limits, the action of the tidal scour. During its erection, there was no risk of injury, and no part of the timber-work has been breached, although the weakest portion has been exposed, for more than two years, to as heavy seas as were ever seen on that coast. The cost of the work has been, on an average, about £10 per lineal foot. The timber has all been creosoted, and bids fair to resist decay for many years.

In the case of the portions of the pier just referred to, the site was either dry, or nearly so, at low-water spring tides; but the line upon which it was to be continued, led into a depth of 5 feet, or 6 feet at the lowest ebbs, and about 22 feet at high-water spring tides. From this arose the necessity for a change of plan; but in arranging the breakwater, so far as hitherto described, the Author's attention had naturally been turned to the question generally; and Mr. Abernethy having suggested, that he should attempt the application of timber to deep-water sections, the Author considered the subject, and, as early as January 1857, succeeded in attaining that object, having then designed deep-water sections very similar to those to be described.

Before proceeding further, it is necessary to state a few propositions, bearing upon the subject in hand, and belonging to the theory of waves.

There are two kinds of waves ;—one long, low, but extending deep, which is the wave of translation, or wave of the first order ;—the other kind short, high, and superficial, being the oscillating wave, or wave of the second order.

#### WAVE OF TRANSLATION.

1. In a wave of translation, such as is generated in a canal, the whole of the disturbed water moves in the same direction as the wave itself, the motion of the particles increasing from nothing at the commencement of the wave, to a maximum at the crest, and diminishing again to nothing at the termination, but uniform throughout the depth.

2. The velocity of the wave varies as the square root of half the depth of the water, measured from the crest of the wave nearly ; and,

3. The length of the wave varies as the depth of the water. Hence as the velocity varies as the square root of the depth,

4. The period of a wave, or the time it takes to travel its own length, varies also as the square root of the depth.

5. For a given height of wave, the velocity of the particles is inversely as the velocity of the wave, for, in deep water, the particles move a shorter distance, and have more time to do it in.

6. The ground-swell acts nearly as much at the bottom as at the top, and is almost limited to moving bodies towards shore, having little, or no, back action, except when the water breaks. This is, probably, the cause of vessels forging ahead, during a calm, with the swell.

#### WAVE OF OSCILLATION.

1. In wind waves, the motion of the particles is not uniform throughout the depth, being greatest at the top, and diminishing rapidly, with the increase of depth, below the surface.

2. The depth to which agitation extends, is in the ratio of the height and the length conjointly. Thus, a wave 10 feet high and 32 feet long would only agitate water 6 inches, at a depth of 10 feet below the bottom of the wave. If the wave were 100 feet long, and the same height as before, it would produce a motion of 18 inches at the same depth.

3. The motion of the particles at the top, is in the same direction as the wave, in the hollow in the opposite direction.

4. When waves come upon a slope, the vertical oscillation is converted into a motion parallel to the slope.

5. Surf waves are greatest when the deep water suddenly shoals ;

for when the water shoals more gradually, the retarding influence of friction is more felt.

6. When water shoals, the wave rears up, increases in height, alters in profile, the back lengthens, the mass of water is thrown into the forepart of the wave, and progressive motion is given.

7. When a wave meets a vertical barrier, in deep water, it rises to twice its height, and is reflected, travelling backwards with the same velocity;—if equal waves meet, the same effect follows, as if there were a vertical partition between them, and an oscillation is produced without progress. If a wave meets a hollow, it is absorbed.

8. The greatest force which a wave can exert, is at the moment when the crest breaks over into the hollow.

9. When a moving body impinges upon a body at rest, and communicates motion to it, the momentum of the whole mass, after impact, is the same as the momentum of the impinging body. If, therefore, the mass in motion, after impact, be greater than before, the velocity is less;—if the mass be less, the velocity is greater. In the former case the destructive energy is diminished—in the latter it is increased. If a wave in deep water, when the mass is great, and the velocity of the particles small, travel into shallow water, the quantity agitated is less, but the energy of the motion is increased. Therefore, *ceteris paribus*, the destructive energy is less, against a wall vertical from the bottom, than against a wall built upon a slope. When the foreshore causes a wave to break upon the wall, the destructive effect is greatest.

10. Waves will be broken by any slope having an inclination of less than  $45^\circ$ ; but from that angle to the perpendicular, the wave will not be broken, unless it is nearly upon the point of breaking when it reaches the slope.

#### THEORY OF WORK, INCLUDING THE THEORY OF FORM AND THE THEORY OF CONSTRUCTION.

If the principles just enunciated be correct, it appears clear, that when waves can be reflected, they ought not to be broken; and secondly, it is evident, that when, from shallowness of the water, the wave must break, then the operation should be spread over the largest surface, and over the longest time possible. It is also desirable, if it be practicable, so to direct the water, that the force of one portion shall tend to neutralize the destructive energy of another portion; it being better to effect the object of stilling the water, by changing the direction, than by absorbing the force of the water in motion. The first condition will be fulfilled by a vertical wall, and the second by a slope. The third is more difficult of attainment. Under the term vertical wall, may be included steep slopes, say from  $60^\circ$  upwards.

It appears to be a matter of such general observation, that vertical faces in deep water do reflect waves, that it will be unnecessary to dwell upon this point. The fact that a vessel may pass in safety, close to a vertical face, in a heavy sea, without risk of collision with it, shows that the waves are reflected; for if they broke, the vessel would, in such circumstances, be dashed to pieces; and it may be noticed in passing, that this is an argument in favour of having the seaward face of breakwaters—especially near the entrance to a harbour—built nearly vertical; for should it be a slope, the risk to a vessel approaching the entrance would be increased. An interesting illustration of this was communicated to the Author by the harbour-master at Blyth, an old Polar navigator. He stated that, on one occasion, he suddenly found his ship nearing an immense iceberg. It was blowing so fresh, that the vessel was under double-reefed topsails, and he expected she would be dashed to atoms against the vertical side of the iceberg; when, to his surprise, he found that the ship did not touch, and she passed alongside in safety. The *rationale* of the matter seems to be this,—the forward horizontal motion of the water, on coming in contact with the vertical face, is changed into vertical motion, and the water forms an inclined plane, down the surface of which any body would be impelled seaward. Then, although on the recession of the wave the surface is inclined in the opposite direction, or towards the face, the motion of the water is backwards, carrying a floating body away from the face.

With regard to the inner, or harbour side of a breakwater, it is obvious, that a vertical face is the best, inasmuch as the work then constitutes a valuable quay, alongside which ships may lie, to load and unload passengers, cargo, or stores; whereas in the case of a slope, no vessel can approach.

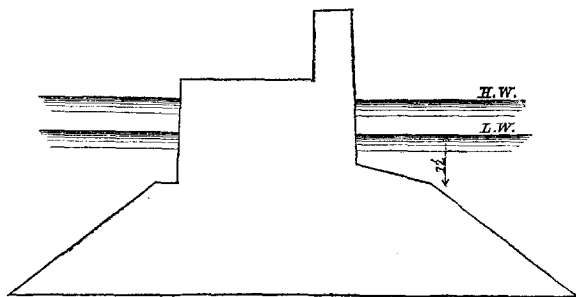
Much might be said upon the form of slopes, which have been constructed at various angles, and both straight and curved. It is believed, that this variety has not been altogether due to differences of opinion amongst Engineers, but, in a great measure, has been rendered necessary, by the varying nature of the materials employed, or which were readily obtainable, in the respective localities, combined with the different exposure to the sea. But as the Author intends to advocate the employment of a material which is easily procured in every port, viz.: timber, and with which almost every variety of form can be produced, he will, for the present, confine himself to the illustration of that which, in his opinion, is the best. On considering the causes of injury to slopes exposed to the action of waves, it would appear, that the return of the water which has rushed up a slope, increases the violence with which the following wave breaks, by falling against the lower part of the advancing bank of water; and, to use an inelegant

expression, it knocks the feet from under the advancing wave. In the case of shallow water, the recession of the wave rushing down the slope with an accelerating velocity, strikes the toe with violence, and disintegrates it; in fact, in the majority of instances, such slopes first give way at the foot. The evil is, that the force of the waves, when they reach the slope, is expended on the work; whilst the true principle appears to the Author to be, that a slope should be employed only for the purpose of directing, or guiding, the waves to neutralize one another.

This is sought to be effected, at least to some extent, as follows. First, the slope formed of timber is not to join the ground at the foot; there is to be no toe to be injured, but a space through which the water will pass freely. Secondly, the surface of the slope, instead of being continuous, is to have horizontal open spaces, like a gridiron, through which part of the water will fall in its passage upwards, and part on its recession. Then, although a limited undulation may pass under the lower edge, or foot, the water which rushes up the slope, falling, at intervals, perpendicularly through the open spaces, will tend to destroy that swell, in the same way that heavy rain will kill a sea, as it is termed.

There remains to be considered an important combination of the vertical wall and the slope. It is generally believed, that, even during a heavy sea, there is but little agitation at a depth of 15 feet under the surface; and it has been proposed to take advantage of this fact, and to construct breakwaters of the section shown in Fig. 1. It has been found, the Author believes, at

Fig. 1.



Cherbourg and at Plymouth, and more recently at Alderney, Holyhead, and Portland, that a mass of pierre perdue will lie permanently at a slope of about from 1 to  $1\frac{1}{2}$  to 1, up to 12 feet below low-water. Assuming such a mass to be deposited, then upon this a vertical wall would be built, and this section would present nearly, if not all the advantages of a vertical wall

carried up from the bottom of the sea; being in many localities, where facing stone cannot readily be procured, cheaper than the latter plan. Where rubble is not to be had, except at great cost, then, as the vertical wall contains so much less material, it would be the more advantageous form; but it should be remembered, that the stone for vertical facing requires to be of a superior quality, such as few localities yield. At Alderney, Mr. Walker first deposited, from barges, a mass of pierre perdue, which reached to within 12 feet of low-water; and thereon he built a nearly vertical wall, thus forming the section which, the Author considers, it is so desirable to obtain; but then, the angle formed by the top of the mass of pierre perdue, and the face of the vertical wall up to low-water mark, appears to have been filled in; thus in fact continuing the slope to low-water mark. Finally, there is the section adopted at Holyhead and at Portland, originally designed by the late Mr. Rendel, and now being carried out by Mr. Hawkshaw and Mr. Coode. In these cases, the mass of rubble is carried up above high-water mark, the stone being tipped from waggons, running on a temporary staging; and after being allowed to consolidate, a trench is excavated, along the crest of the rubble embankment, down to low-water, and from that point a vertical wall is built. As the seaward slope, from 12 feet below low-water upwards, averages at least 6 to 1, the quantity of stone in these works is very great; and, therefore, although this method of construction may be available where, as at Holyhead and at Portland, there is a mountain of stone close at hand, there are many situations where it would be inapplicable. But there are other disadvantages which attach to this form. First, these breakwaters are not available as quays. Secondly, the seaward profile is such, that the waves must break upon the wall with all their violence; and hence the weight of material, and the nature of the work necessary to resist such a shock, are no criterion of that required in a vertical face, from which the waves are reflected, and against which they do not break.

#### THEORY OF CONSTRUCTION. STONE WORK.

It is known that, in reference to the position of stones in a given work, they resist removal in virtue,—

1st. Of their own weight, which is greatest when laid in a horizontal plane;

2ndly. Of the pressure of the superincumbent stones, which is greatest in a vertical wall; and

3rdly. Of the binding influence of any cement used, which is also greatest in a vertical wall.

Further, from what has just been stated, it follows, that settlement is fatal to the stability of a vertical wall, and hence the



importance of having a good foundation ; for if one course sinks, all the power of resistance, due to the weight of the superincumbent masonry, is lost. In pitched slopes, this does not obtain to so great an extent, neither settlement, nor displacement, being of so much importance. In loose rubble slopes lying at the general angle due to their situation, the work only suffers from the waste of material, which arises from the attrition of the stones against each other. The motion caused by the action of the sea is considerable where the waves break upon the slope, as may be seen at Holyhead Breakwater, where the piles of the staging are cut, by the stones knocked against them. Although there are limits within which the motion is confined, still, as two gales do not necessarily produce the same seas, the slopes will tend to vary, and this involves wear, as well as the action of the waves in breaking. At Portland, the stones on the seaward slope are worn and rounded from this cause. Slopes in shallow water suffer at the toe, from the stones being torn out by the receding water ; whilst, at the same time, the toe is of little, or no, use in breaking the waves. When there is a parapet at the top, the slopes are injured by the water curling over, and falling backwards on them.

Both pitched slopes and vertical walls suffer when the joints are not closed, from being blown up by condensed air, and partly by hydrostatic pressure. As this is a fruitful source of mischief, the Author proposes to say a few words upon the point. When a wave curls over, and breaks on any given work, whether the surface is horizontal, sloped, or vertical, although of course the effect differs in degree, the result is, that the air confined under the wave is compressed, and is forced into the joints, and from its extreme mobility, it communicates the pressure through all the neighbouring interstices of the work, almost instantaneously, and thus blows it up. But no such effect takes place, when solid water merely rises against the face, simply because there is no blow, and the water cannot penetrate with sufficient rapidity to communicate the pressure. This is illustrated by a certain form of tide-gauge, which consists of a large tube, connected with the sea by a small orifice ; the effect of which arrangement is, that the external oscillations are not communicated, and the level of the water in the large tube shows the mean level of the surface of the sea. But whilst this is true in the main, it ought to be noticed, that if the interstices are filled with water under pressure, the stone might be moved, to a limited extent, the difference being, that, if filled with air, the stone is not only moved, but the expansion of that air sustains the motion through a larger space. Further, in the case of a vertical face, if the water rises against it during its ascent, it fills the interstices, and receding suddenly, the pressure is removed from the face of the stone, and the water which has

penetrated behind it may force it out. In a word, when there is no air present, as in the case of a wave rising without breaking against a vertical face, it is simply a question of pressure, whilst in the case of breaking waves, the momentum is, through the medium of the confined air, applied to the interior, tending to blow the stones out. From this it is apparent, that the faces of works exposed to the sea, should either have the joints sealed, to prevent the entrance of air, or the work should be so open, as to allow the air to pass out with facility.

There is no doubt, that continuity of face is one of the greatest desiderata in constructing breakwaters, particularly with vertical faces, for without this, the strength of the work, as a whole, will be dependent upon, and be measured by, the power of resistance of the weakest part. Hence arises the necessity for exercising great care during the construction, as the displacement of a single stone may lead to the destruction of the whole work.

The Author knows of no case on record, of a breakwater being carried away, or being overturned, bodily; and, therefore, the question is not so much the strength as a whole, which could readily be calculated, but the action of the sea upon an individual portion, which cannot be calculated; and if this obtains as regards the finished work, for the same reasons the danger during the process of construction must be very great, especially in the case of a vertical wall.

#### THE AUTHOR'S DESIGNS.

This section of the Paper will be occupied with a description of the Author's improvements in the construction of breakwaters, examples of which are represented in Plate 1, Figs. 3 to 9.

The Author divides these works into two classes; those intended for deep water being Wave Reflectors, and those for shallow water Wave Breakers. Excepting the Wave Screen, the Reflectors and Breakwaters are of a similar character, and consist of a timber casing filled with stone. The stone hearting constitutes the power to resist removal as a whole, and the timber facing secures the stone from being disintegrated, or carried away in detail; so that if the work is moved it must be bodily. Further, the work is so connected together, that each part supports its neighbouring portions: the importance of this will be obvious, when it is considered, that waves seldom strike any great extent of surface at the same moment. A marked peculiarity of the arrangement is, that there is no tie between the work and the ground. It simply rests on the surface, and the stability depends wholly upon its weight. The Author is opposed to the idea of piling the face, and filling in behind with stone, not only because it is difficult and expensive to pile in a sea-way, but because, in his estimation, it is false in  
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principle. For the piles would necessarily bend before they took any appreciable part of the strain, and before they could deflect, the stone backing must have been moved. Piles may, however, be used in some cases, as a convenient method of filling the space between the frames, for the purpose of keeping the stone from spreading; but then, on the Author's plan, these piles would be driven subsequently to the erection of the frames, which constitute an efficient staging from which to drive them.

Other leading features are,—the framework is so arranged, first, that the strains are, as much as possible, taken in the direction of the length of the timbers, thus developing its greatest strength; secondly, the joints are covered by whole timbers; thirdly, each piece is proportioned to the work it has to do; and lastly, there is such a variety of size, as to admit of average cargoes being wholly worked up, without waste. The faces are so tied inwards, as to prevent the rubble from being forced out; and whilst the interstices are sufficient for the free escape of air, there is, after a short time, no motion amongst the stones, and consequently no waste. It will be seen, that an excellent foundation is secured as the work proceeds; and the lower tie will accommodate itself so perfectly to an uneven surface, that the erection may proceed on sand and on clay, as well as on rock; on broken, as well as on even ground, almost indifferently. A proof that the foundation is sufficient, has been afforded by the work at Blyth, where, although the bottom varies from hard rock to soft clay, there is no observable settlement, in a length of more than 2,000 feet. The difficulty of obtaining timber of the requisite length, combined with the certainty that single balks would be fractured, on uneven ground, by the superincumbent stone, led to the designing of the chain tie, which has just been referred to.

The round ends, at the entrances to harbours, are proposed to be constructed of planking, arranged like basket-work, by which great strength is obtained.<sup>1</sup> Moreover, there is considerable elasticity, so that in the event of a ship touching, neither the pier, nor the vessel, is damaged. When these ends are of comparatively small diameter, as the one now constructing at Blyth, they are tied into the centre; but when large, the frames vary in breadth according to the exposure; that is to say, the face wall, as it may be termed, increases in thickness from the inner, or harbour face seaward.

#### FACILITY OF CONSTRUCTION.

Before entering upon details under this head, the Author claims for his improved arrangements one important advantage, viz., that

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<sup>1</sup> A model of this arrangement was exhibited at the Meeting.—Ed.

the work is not liable to be breached during erection. Those only who have had to contend with the sea can appreciate this risk; for although every precaution may be taken, still, in the case of vertical walls, of the ordinary kind at least, there is great danger during erection. The stone wall at Blyth, for example, was repeatedly damaged, but no part of the new construction has ever been breached, although exposed to a heavier sea; but, even in instances in which the permanent work has not been much injured, the staging has suffered; whilst at Blyth, the work itself serving for a staging, no loss has arisen from this cause. It is not only loss of money which is avoided, but loss of time; for there is much less risk of the work being interrupted by bad weather.

In the arrangement proposed, no stone of a high class is required, and no dressing. With respect to the timber, it is easily procurable at any port, and it is all converted on shore, the frames being put together complete, and then floated to their place. It might be thought that, in very deep water, the frames would be difficult to manage; but the experience of the Author leads him to a contrary opinion, and he would not hesitate to undertake the erection, even in comparatively great depths. With reference to this point, it should be remembered, that the addition of 9 lbs. or 10 lbs. of creosote per cubic foot materially reduces the floating power of the timber, so that the following is a statement of the buoyancy of a 10-fathom section (Fig. 6). Supposing the whole timber immersed, the total buoyancy would only be 15 cwt. per foot run of the breakwater; but as the timber is not wholly immersed, there is no buoyancy. At half-tide, when standing on end, each frame would have a weight, or downward pressure, equal to 8 cwt., to sink it. The timber-work, when finished, will have a downward pressure of 25 cwt. per foot run. Thus, it appears, that the weight to be lifted is but little, and that the frame, in position, can easily be made to gravitate sufficiently to steady itself until secured.

In the direction of the length of the breakwater, the frames are kept parallel by the sliding ties, which are simply barks of timber, with chocks between them embracing two frames, and being secured together above water, they are slid down to the bottom. To obviate the employment of divers, the spaces between the frames, under low-water mark, are either filled with panels, lowered from above, or by vertical pieces secured by the sliding-ties, or by piling. These piles may be driven, or screwed, the sliding-tie forming a guide for the foot of each pile. In driving piles, the Author has placed the shoe on the corners of the piles which are exposed to the greatest pressure, and are most liable to abrasion. If screws are adopted, the Author has designed an arrangement which, he thinks, would cost less than Mitchell's

screws, and which is as follows:—The angles of the wood being removed, a thin T iron is heated, and wound spirally round the lower end, and this being cooled, shrinks and grasps the wood, like the tire of a wheel. The advantage of this plan is its cheapness, and the strain, instead of being concentrated, as in Mitchell's piles, upon the short piece of the pile embraced by the iron socket, is distributed over a considerable length of the balk.

It would be tedious to go further into detail upon such points. It may suffice to say, that no system of piling can be compared with the plan of first sinking frames, for cheapness and speed of execution, and in hard ground piles are inadmissible. The progress at Dover is said to be 100 feet per annum; and as the breakwaters at Alderney, Portland, and Holyhead have each been about ten years in hand, the systems pursued at those places do not appear to secure rapid execution. In this particular it is thought a saving would be effected by the new arrangements; and as an illustration of what can be done, although of course on a comparatively small scale, it may be mentioned, that of the Blyth work 130 lineal feet have been erected in five days.

#### POWER OF THE WORK TO RESIST WAVES.

It has been said, that the timber-faced work cannot be breached and broken up in detail, that it must go as a whole, in fact be overturned bodily; and it is now necessary to ascertain what amount of force would effect its destruction, which unlike the case of most stone piers is readily calculated. In the section designed for deep water, the power of the sea to overturn the work would be represented by the statical pressure of the water rising against the parapet, and the power of resistance in the work, by the weight of the stone, less its displacement, the timber having no buoyancy. Proceeding upon this principle, and taking the 10-fathom section (Fig. 6) as an example, it is found, that the stability is double the greatest force which could be brought to bear upon it.

It has been stated, that waves travelling into shallow water must break, and in situations where it is necessary to provide a protection under these circumstances, a Wave-Screen, such as is represented in Figs. 8 and 9, is to be preferred. It will be observed, that the Screen consists mainly of a grating of timber, supported on piles, and inclined towards the sea; so that the waves will run up, and the water will drop through the transverse openings, both on its ascent and descent, and little if any will return to the foot. In the case of a stone slope, the whole of the water which has been projected up the slope runs back, and it is by this recoil that the great damage is done. The dropping through of the water has another important advantage. Suppose

the oscillation of the water passing under the toe of the screen to be only partially destroyed, the remaining motion cannot be more effectually combated, than by the vertical and continual fall of water through the screen. Moreover, the effect of the blow of the waves upon the slope is diminished, by the openings between the planks. There is, however, a limit to increasing these spaces, for if they are too wide, the water falling through, instead of neutralizing the existing oscillation, would produce a fresh one. The longer the slope, the greater the surface over which the force of a given wave is distributed, and the less, the horizontal strain produced; but if the slopes were too flat, the effect would be, that the wave would run up and fall over.

This Wave-Screen has a peculiarity which, in many situations, is of the greatest importance, namely, the allowing the tide, or currents, of the sea, to pass through with little interruption, thereby preventing the silting-up of a bay, or the estuary of a river, which is a general consequence of its enclosure, by any breakwater of an ordinary kind.

The construction of the screen is of the simplest kind. It consists of piles at considerable intervals. To these the main timbers are secured, upon which the grating of planks is laid. It will be observed, that these planks are tapered in cross section, making the lower edge thinner than the upper edge. The object of this is threefold. First, it diminishes the shock of the water on the planks as it rises; secondly, it insures the interception of the water on its descent; and thirdly, it gives to the main timbers a secure hold of every plank.

#### DURABILITY AND COST.

These two stand in such intimate relation to each other, that it is proposed to consider them together. The first question which arises is, how long will the timbers last? To this it is not easy to give a definite reply. The chief enemies to be encountered are the *Teredo Navalis*, or great worm, and the *Limnoria Terebrans*, or surface worm, as it is often called, but which, in fact, is a species of shrimp. The operations of the *Teredo* are said to be confined to the space between low-water and the bottom, as they cannot exist out of water; whilst the *Limnoria* attacks the wood chiefly near low-water, and particularly at the surface of the ground, in cases where the bottom is dry at low tide. There is no doubt, that unprepared fir timber, excepting the more resinous pines, would, in some cases, be destroyed, in a few years, by these animals; and, it is said, that even greenheart succumbs, in time, to their efforts; but there are instances which indicate great durability. The piers at Boulogne and at Calais may be mentioned, as having stood for many years, a part of the latter, which is of

oak, being above seventy years old. But the true question is, with regard to the durability, not of raw, but of prepared timber; and the experience of the Author, of the process of creosoting, leads to the belief that, when properly done, it will preserve timber for many years, though how long it is impossible to say, as time alone can show.

There is another material which the Author is at present testing, but a sufficient period has not elapsed to prove its qualities. The author is of opinion, that there can be little doubt that the timber would last twenty years; but, without speculating further upon this point, it will be sufficient to show, that the difference in first cost, between ordinary stone breakwaters, and the new arrangement, is so great, as to leave an ample margin in favour of the timber system. The 10-fathom section, Fig. 6, would cost, complete, about £70 per lineal foot; whereas the stone breakwater at Alderney is said to have cost £190 per foot, and that at Portland £150 per foot. The cost of these, as compared with the timber system, for a length of say 2,000 yards,—about the length of Portland and Holyhead,—would stand as follows:—

|  | £.        |
|--|-----------|
| Timber System, Fig. 6 . . . .                                      | 420,000   |
| Portland . . . . .   | 900,000   |
| Holyhead, unknown, but believed<br>to have cost a great deal more. |           |
| Alderney . . . . .   | 1,140,000 |

The manner in which the timber of such a work, as is shown in Fig. 6, would be renewed, would depend on the nature of the bottom. If it was clay, or sand, for instance, the face might be simply close piled, and by the application of the new arrangements for piling, this would not be an expensive operation. But if the bottom were hard, then a cradle filled with stone might be lowered, and thus the face would be renewed. This cage, as it may be called, would have several hundred tons of stone in it, and this would represent the weight of the smallest pieces of the face.

Finally, it remains to be shown, that even if the new arrangements be regarded merely as a means for forming the back-bone, as it were, of a more permanent stone structure, it is the best and cheapest way of attaining that object; for, viewing the timber only in the light of a temporary staging, the following would be some of the advantages of the system—rapidity of execution; the enclosure of the harbour, and the protection to the shipping being completed years before an ordinary stone-work could be erected; and an excellent staging from which to build the stone facing, which might be proceeding at several places at once, as there would be no interference from the current, and no danger of

breaching. Then the rubble hearting, having been exposed to the sea for years, would be thoroughly consolidated, and would form an impenetrable backing, which is always of great importance, and from the strength of the staging, very large blocks might be employed in the facing.

The Author does not recommend the plan of depositing rubble, up to low-water mark, and then erecting upon this a wall either of stone, or timber and stone, considering such an arrangement to be incorrect in principle; but he does recommend that the wall be built from the bottom, or from about 15 feet below low-water. No doubt the first-mentioned plan has been adopted, chiefly on account of the difficulty and expense of building under water, but the Author hopes to show, that these need no longer be regarded as such formidable objections. In the system hitherto adopted for building piers under water, the operations have been confined to one end of the work, and the progress has, consequently, been very slow, the pier at Dover, for instance, advancing only at the rate of 100 feet per annum. This slow progress is mainly to be accounted for by two great obstacles to the operations of either helmet-divers, or of bells, which are current and ground swell; and with respect to the former, the further the pier projects, the more rapid is the current past the end likely to become; indeed, in some cases, the scour might endanger the stability of the work. Now, it will be observed, that in facing an existing pier, the work might proceed with great rapidity, for it might be carried on at a number of places at once, and there would be little, if any, current to interfere with the operations.

To illustrate the advantages in these respects, the Author will describe the method proposed by him for completing one form of the permanent work. Suppose the form of breakwater shown in Fig. 4 to be selected. Frames are sunk at intervals of 30 feet, and stand on the natural bottom. Rails being laid on barks of timber between these principals, rubble is tipped from waggons to form the bank, of the dimensions shown, up to a level of 15 feet below low-water; and intermediate frames are then erected upon it, leaving spaces of 5 feet. On the outside of these frames, above low water, planks are attached, and are secured by pieces of timber bolted through to the frames. The object of placing them on the outside is to allow of their being easily removed afterwards. Below low-water, the spaces are filled in with panels, or vertical pieces, secured by the sliding ties, as shown in Fig. 5. The interior is then filled with rubble, up to 6 feet above high-water, and covered with an open flooring of timber. On the sea side, a parapet is carried up, and there is then a breakwater sufficient to last for many years. For the purpose of forming the permanent stone face, the projecting portion of the rubble bank is to be levelled, and upon this large



blocks are to be laid. With regard to the composition of these blocks, on the Author's system, even when the mass of the block was composed of ordinary material, the face exposed to the sea would be hard and impenetrable, and yet the evil of a distinct line of demarcation between the face and the body of the block would be carefully avoided. As these blocks are deposited, the planking is to be removed, and the space between the face-work and the original rubble heart is to be carefully filled. There are some peculiarities in the method proposed by the Author for setting these face-blocks. It may be stated generally, that the main objects in view are, first, to afford increased facilities for handling heavy masses, and secondly, as a considerable part of the faces must be built under water by divers, to place within easy reach of these men the power of moving the stone in every direction, without the necessity of communicating with any one above water.

It has frequently been proposed to employ large concrete masses in the building of piers: one principal reason, which suggests itself to the Author, for this idea not having been extensively put in practice, is the difficulty of handling such great weights. As has been stated, not only must the staging be of great strength, but the crane gearing to deal with, say 25 tons, must be cumbersome and expensive. As regards hydraulic machinery, the difficulty is to arrange it, so that it shall not be still more so. Now as the Author proposes to deal with masses weighing more than 25 tons, it is essential to devise some method of moving them, and the following is the result:—With the aid of bars, divers can do something with blocks weighing from 5 to 8 tons, as so much of the weight is neutralized when they are immersed; but even with these, when laying a face course, it requires the signal-man to act in perfect unison with the diver, or time is lost. It will be observed that, in the case under consideration, the work consists only of face courses, and is composed of blocks of such weight, that so far as any direct action on the mass is concerned, the divers would be nearly helpless. Hence arises the necessity of employing some new means by which the diver would be able to move the blocks in every required direction. This involves six distinct motions—down, up, forward, backwards, to the right, and to the left. The apparatus<sup>1</sup> which the Author proposes to employ may be briefly described as follows:—There is a traversing-frame, with one end projecting over the side of the pier. This frame moves by means of wheels upon four lines of rails. Upon the inner end of the frame is placed an accumulator (which was patented by the Author in 1851), which serves at once as a reser-

<sup>1</sup> For drawings of this apparatus see "Report of the Commissioners, &c., on Harbours of Refuge," vol. i., Plate 3. Folio. London. 1859.—M. S.

voir of power, and a back balance. Upon the front end of the frame, there is a cross frame carrying a crab. The operation of depositing a block is performed thus: the block is conveyed on a waggon under the traveller; the crab is over head, and instead of the chain being attached directly to the mass, a cylinder containing a piston is interposed, the cylinder hanging from the chain, and the piston-rod being connected to the block. A flexible tube from the lower end of the cylinder communicates with the accumulator, and a stop-cock being opened, the water flowing from the reservoir under pressure forces up the piston, and lifts the block. When thus suspended, the crab is moved, by means of a rack and pinion, to near the end of the frame, and then, with the aid of the break, the workman lowers the block, until it rests on the previous course. He then fixes the break, and the mass is consigned to the care of the divers. If the diver wishes to raise the block, he opens the communication between the accumulator and the cylinder, and the piston is forced up. When the block is raised far enough, he shuts the cock, and it remains suspended. When it is desired to lower the block, a second cock is opened in the same tube placed between the first and the cylinder, which allows the water to flow out of the latter, and the mass descends. If the block is to be moved laterally, the piston of a small cylinder, fixed to the framing above is, attached to the crab, by means of a chain passing over a pulley, fixed on the opposite end of the frame. This cylinder is connected directly with the accumulator, by means of a tube, and the communication being always open, the tendency is always to draw the crab to the left. Another cylinder is fixed in the opposite direction, and connected to the crab in the same manner. This cylinder also communicates with the accumulator, and being larger in diameter than the former one, when the communication is opened, it draws the crab from left to right, and the water in the first cylinder being forced back into the accumulator, there is no loss of power, arising from the use of the first cylinder. The tube connecting the second cylinder with the accumulator passes down to the divers, and up again. When the crab is to return to the left, the communication between the second cylinder and the accumulator is shut, and another being opened, the water is allowed to flow out, the small cylinder pulling the crab back. The motion forward and backward is communicated in the same way.

It will be seen that, by means of three tubes within reach of the divers, motion in every direction is obtained, without the necessity of communicating with any one above water. It is thought, that by the means now described, the great difficulty of signalling is overcome; for that difficulty does not consist so much in indicating the direction in which the motion is required,

as the amount of that motion. This becomes of more than ordinary importance in the case of large blocks, which men cannot easily swing from the perpendicular.

For moving the great frame, a long cylinder, of small diameter, is fixed at each side of it; the piston-rods are hooked on to chains, made fast to the forward end of the work, and the water being admitted as before, the frame is moved forward. When the piston reaches the end of the stroke, it is drawn out and is again hooked on to the chain; this can be easily effected by continuing, downwards, for a few feet, the tube which empties the cylinder, as it tends to produce a partial vacuum.

The Paper is illustrated by a series of Diagrams, from which Plate 1 has been compiled, and by a number of models.

[Mr. T. R. WINDER

VIEW OF BREAKWATER AT BLVTH,  
IN NOVEMBER 1858.

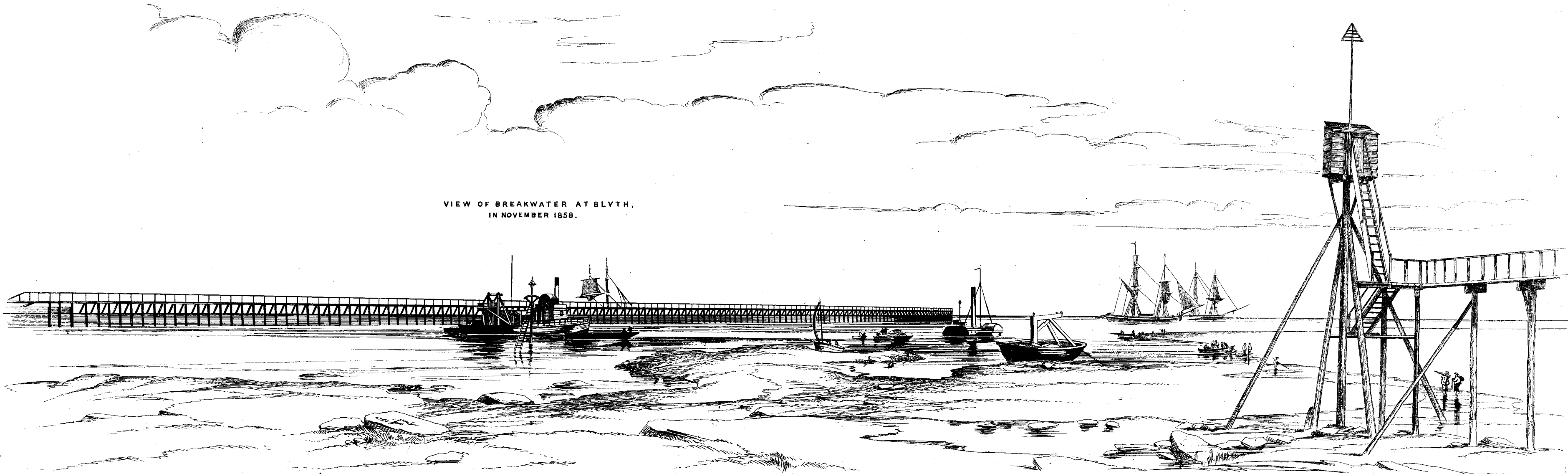


Fig. 1.

Fig. 2.

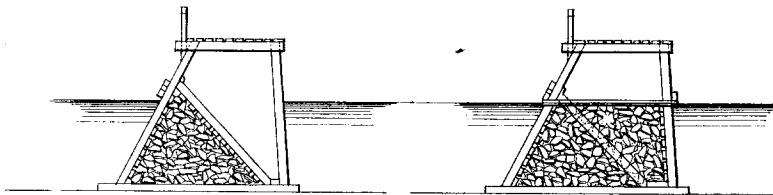


Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

