work was very moderate, being only £122 per lineal foot; the depth of water being 35 feet, and the average cross section 5400 square feet.

Of the three examples given above, the work at Marseilles is undoubtedly the best, the careful arrangement of the materials, combined with the large concrete blocks, has effectually prevented the disturbance of the foreshore, so marked in the case of Alderney and Holyhead. Although, at the same time, it must be remembered that the tide at Marseilles is all but imperceptible, and the works are therefore not subjected to the maximum effect of the waves to the same extent as in the other cases, where there is a large range of tide.

Before describing the system of construction for breakwaters that has been pronounced by the English Select Committee on Harbour Accommodation as the best system of construction for breakwaters, it is proposed to describe two works that stand pre-eminent among engineering failures, and to point out what appears to be the lesson to be learned from this dearly bought experience. The Wick breakwater (Plate 11, fig. 9) was commenced in 1863. The outer exposed part of the breakwater was founded on a rubble mound at a level of 18 feet below low water of spring tides, and was carried up to the level of 11 feet above high water where it was 43 feet in breadth. In a severe storm in February, 1870, this work was greatly damaged, and it has since been all but completely demolished by the action of the waves. It is recorded that in 1872 a huge monolithic block of concrete, weighing in all 1,350 tons, was moved bodily out of its position and carried to the lee of the breakwater, and in 1873 a block of 2600 tons was similarly displaced. Wick is, no doubt, a very exposed bay, and this failure has been attributed to the abnormal force of the waves moving these large blocks bodily out of place, but after a very careful study of the history of this failure, the author thinks the balance of evidence goes to prove that the initial cause of this failure was the unequal settlement and displacement of the rubble base under the action of the exceptioually heavy waves, causing the superstructure to take a list to leeward, and subsequently to slide off the foundation course. The experience at Alderney gives strong evidence that the tendency of the waves is to cause the rubble base to settle unevenly in the way above described, and as there was no bond between the upper part of the work and the foundation course of concrete blocks, it is not difficult to imagine that in the event of unequal settlement the force of the waves, assisted by the force of gravity on the inclined plane, would be more than enough to slide the superstructure off the foundation course.

The second case is the harbour of Madras. It was proposed to construct a large artificial harbour on the coast of Madras. The breakwaters were constructed of a double row of concrete blocks (each block weighing about 27 tons) founded on a rubble base, at a depth of 22 feet below low water (Plate 11, fig. 10.) This work was all but completed when a violent cyclone in November, 1881, disturbed the foundation mound 22 feet below low water, and scooped out the materials, a large portion of the work being thus destroyed. This partial destruction of the works is attributed to the above settlement of the rubble mound and the imperfect bonding of the concrete blocks.

It is recorded that laterite rubble, 150 lbs. per cubic foot, in blocks varying trom 5 lbs. to 2 cwt., composing the mound at Madras were removed at depths exceeding 40 feet by the cyclonic ground swell.

These examples show that when breakwaters are constructed on rapidly shelving coasts the action of the waves extends to a much greater depth than was formerly supposed. In the case of Wick the depth of water rapidly increases seaward, and the bay is of a V shape, thus giving every facility for an undulating wave to be converted into one of translation as it approaches the shore. The coast at Madras also shelves very rapidly, thus affording a similar opportunity for the nature of the waves to be changed, and it seems not at all improbable that in times of great storms the whole body of water under such circumstances would be more or less in motion, thus greatly increasing the destructive force on a rubble base.

These works were designed by engineers of great eminence and experience, and in referring to these failures it is simply with the object of pointing out the lesson to be learned from their experience, for, if there is one branch of engineering more than another where the works of others require careful study in order to make the best use of past experience, it is in the construction of sea works, and there is often more to be learned from a careful study of a failure than from the record of many successes.

The consideration of the construction of breakwaters built up solid from the bottom of the sea will conclude this part of the subject. Speaking of this system the Select Committee of the House of Commons, reporting on Harbour Accommodation, expresses the following opinion:—"Your committee have examined many eminent engineers, and have been much impressed with the practical unanimity of opinion expressed by them that the best system of construction for piers and breakwaters is to be found in building them up in solid monolithic walls of concrete. Different engineers have different methods of effecting this object, but whether, as at Newhaven, the system is adopted of sinking the concrete in bags, or whether, as recommended by Mr. Rendel, by means of caissons, or whether building it up without such assistance round a staging, as adopted by Mr. Strype at Wicklow, or whether by the system adopted by Mr. Dyce Cay, at Aberdeen, they are unanimous in declaring that the new system is far preferable to the older system of rubble or *pierre perdu* foundation."

The special advantage of a solid vertical wall over a long slope for a breakwater is, that on the long slope system, waves of oscillation are converted into ones of translation as they advance up the slope; whereas, with a vertical wall, they simply expend their force by rising up against the wall, and are deflected on to the waves approaching the works, as explained in the early part of the paper. The amount of material in a vertical breakwater is very much less than in a long slope breakwater.

Before Portland cement had been brought to its present high quality, and thus affording a cheap material by which reliable concrete could be manufactured, the difficulties of constructing a breakwater on the vertical system were very great. The cost of dressing and setting large stones rendered this system all but impracticable on account of the great cost.

The pier at Dover is an example of this system, it being constructed with nearly upright sides from the bottom (Plate 11, fig. 11.) The choice of this form was, it is said, induced by the want of suitable stone in the district necessitating the carriage of stone from a long distance. The material below low water was put in place with the aid of diving apparatus, and the work was, of course, expensive, costing £290 per lineal foot for the first contract of 800 lineal feet, and for the second contract let in 1854, £415 per lineal foot. It is constructed with granite facings and a breasting of rectangular blocks of Portland cement and shingle concrete up to a little above half-tide level; above this the filling consisted of liquid concrete. The pier, though at present it is essentially a landing pier, is intended ultimately to be extended so as to form a harbour of refuge. It is formed with a uniform batter on each side, and is in section about 80 feet wide at the base, and 42 feet at the top, comprising a roadway 30 feet wide, and a heavy parapet on the seaward side. It is founded 45 feet below low water mark.

Another example of the vertical system is the breakwater enclosing the harbour at the entrance to the Amsterdam ship canal. This work is of special interest on account of the treacherous nature of the foundations.

The north and south breakwaters enclosing the harbour are each nearly 1550 métres (1695 yards), or together nearly two miles long. They shelter an area of about 250 acres, through the centre of which a channel 225 métres (738 feet) wide has been dredged. At the landward end this channel has at its junction with the canal a guide pier on each side, the northernmost being called the North Mole, and the southernmost the South Mole, each being 335 métres (366 yards) long.

The north and south breakwaters are similar in design (Plate 11 fig. 12). They were built on a very unfavorable foundation, consisting of very fine sand.

It was attempted in the first place to construct them by a staging of screw piles, but a slight disturbance of the sea excavated a hole round the piles, laying them bare or sufficiently so to destroy the staging. This plan was abandoned, and it was then tried, after partially excavating the sand, to set the concrete blocks by an overhanging travelling crane, which was to advance on the pier as the work was brought up. It was hoped that when the bottom blocks had been set they would, notwithstanding the disturbance of the sand, form a bed which could be levelled, and upon which the structure could be raised. This mode of procedure did not answer. It was then determined to substitute for the bottom course a layer of loose material consisting for the most part of basalt from the Drachenfels, and limestone from Belgium, thrown in as random work.

This was the plan finally adopted to secure a foundation. The mound of stone was deposited about 1 mètre ($3\frac{1}{4}$ feet) thick, and to a width about three times that of the pier at the base, so that when, by the disturbance of the sea, a trench was excavated at the sides of the mound, as was always the case, the loose deposit fell into the hollow until the normal slope was attained, leaving a central portion upon which to build the pier. By this plan when the piers advanced, the trench, which in places had been no less than 14 or 15 feet deep, gradually filled up. The stones of the deposit varied in size from about one cubic foot and under. In levelling the deposit for the reception of the first course of block work, the interstices were filled with hard broken bricks, big shingle, or stone broken to sizes of about 3 inches square. When possible the deposit was exposed for twelve months to the action of the sea before being built upon, by which time the surface became covered with mussels, and was very hard, so that it was difficult to disturb it by iron bars or otherwise.

The concrete blocks of which the chief portion of the solid structure of the piers is composed varied in weight from 6 tons to 12 tons, and were made of one measure of Portland cement, three measures of coarse river sand, and five measures of shingle, the sand being obtained from the Rhine at Vreeswijk, and the shingle being dredged from the Rhine chiefly in the neighbourhood of Nymegan.

The concrete blocks were put in place for the most part by powerful overhanging travelling cranes, there being one such crane or "Titan" to each breakwater. Several designs of "Titan" were tried, which generally answered very well, but the north breakwater being more exposed, it was decided after the works had been considerably advanced and two "Titans" had been swept away, to employ a steam travelling crane, which was run out to its work by a locomotive engine, and brought back every evening for security in case of storms.

The rubble deposit was levelled and the blocks under water laid by divers. Laying the blocks was much facilitated by the use of a self-disengaging apparatus designed by Mr. Hutton. Below low water the blocks were set dry, but above low water they were set in Portland cement mortar, and were well clamped together. The upper portion of the structure was formed of concrete *en masse*.

The pier heads are square with rounded corners, and are 1 mètre ($3\frac{1}{4}$ feet) higher than the adjoining length of pier, which slopes up to the head with a gradient of 1 in 100. The heads are in line with the piers on the seaward side, but on the harbour side they have a projection of six feet.

The concrete mixers were designed by the contractors, and answered perfectly. Similar mixers had before been used by Messrs. Lee in the construction of the Admiralty Pier at Dover. When the piers were originally designed, the information supplied as to the rise of the tides was inaccurate, the tidal range being at times much greater than was then assumed. Partly in consequence of this the design proved too near the margin of safety for a sea work, and when the breakwaters were considerably advanced seawards, the wave breaker on the sea side was added. The extent of the wave breaker on each breakwater was determined by the degree of exposure. It begins about 100 mètres (328 feet) nearer the coast line on the north breakwater than on the south breakwater, on account of the former being exposed to seas somewhat heavier than the latter. Gales of wind affecting the breakwater being from the south-west and strike upon the south breakwater, and almost invariably end from the north-west, striking on the north breakwater, the latter part of the gale being generally more destructive than the former.

The wave-breaker consists of concrete blocks deposited *perdu*; the weight of the lower blocks is about 10 tons, and of the upper blocks 20 tons These blocks are disturbed by the sea until they form a slope of about $1\frac{1}{2}$ to 1. The cost of these breakwaters, including the wave breaker was about £107 per foot forward.

The south breakwater at Aberdeen is another example of this system. It is 1050 feet in length, in a depth of water of 22 feet 3 inches at the head, low water spring tide. The total height at the head is 40 feet, and the breakwater stands 11 feet above high water, with a rise of tide of 12 feet 9 inches. At the shore end the width at the top is 30 feet, and (Plate 11, fig. 13) near the outer end it is 35 feet; the batter at the sides is $1\frac{1}{2}$ inches to 1 foot. The foundations rest on granite rock, on boulders and gravel, and on clay mixed with gravel. Upon the ground which was cleared of loose stones and sand, a layer of bags of concrete was deposited. The bags of concrete, each holding five tons, were lowered in wrought iron skips, the bottoms of which were on hinges, and were opened to let the bags fall when they were into position. Each bag was flattened out, and when it stood too high it was beaten down; or if partially set, cut down. Small holes in the surface were filled with bags deposited by hand. The proportions of the concrete were, 1 of cement, $2\frac{1}{2}$ of sand, and $3\frac{1}{2}$ of gravel.

For a length of 393 feet, extending to low water, and to the edge of the rocky foreshore, the breakwater was built of liquid concrete deposited in place in frames or cases. The upper portion of the breakwater, from a depth of 18 feet, was likewise constructed of liquid concrete to the head of the breakwater. Each piece of concrete, as laid, extended completely across the breakwater, and the lengths of pieces were from 8 feet to 31 feet, making pieces weighing from 305 to 1300 tons. In the construction of the larger pieces, blocks of concrete were thrown into the mass. The concrete was composed of 4 of sand, and 5 of gravel, to 1 of cement.

From the bag work in the foundations up to 1 foot above low water of neap tides, where the liquid concrete work just described was commenced, the work was composed of blocks of concrete 4 feet high and usually 6 feet wide, weighing from $10\frac{1}{2}$ tons to 24 tons. The composition of these blocks was the same as that of the concrete just described. Large rough pieces of broken stone were incorporated.

An apron of concrete was placed along the seaward side of the foundations, consisting of 15 bags of concrete, containing 100 tons each, to obviate the chance of damage from undermining by the sea.

The work was commenced in 1869, and completed, with a lighthouse, in 1873. The net total cost, including the charge for plant and sea-staging, amounted to £68,000, being at the rate of £65 per lineal foot.

This work illustrates the great advantage to be gained by the use of concrete, both as regards the time taken to construct the works and their cost, which, considering the amount of bad weather on this part of the coast, and the substantial nature of the work, must be considered very moderate.

In the above examples of the vertical system the method of construction has involved the use of expensive cranes, and the constructures can hardly be considered monolithic as the separate blocks below water being set dry are therefore depending upon their own weight, and the superincumbent weight of the upper part of the structure for their stability, and to a certain extent the joints may be looked upon as lines of weakness.

A description will now be given of some of the most recent examples of the monolithic system, and its special advantages pointed out.

The small fishing harbour of Buckie on the East Coast of Scotland has recently been protected by a breakwater built on a very exposed site on a rocky bottom. This breakwater is a very good example of a monolithic breakwater; it is constructed throughout of Portland cement concrete built in *situ*, the material being deposited between timber framework planked inside, made and erected to suit the various sections of the work. The planking was lined inside with several thicknesses of jute cloth, to prevent the cement being washed out. Although the timber was of great strength it was on several occasions washed down by the sea during the progress of the work, but in spite of these mishaps the work was successfully completed at a moderate cost, the amount spent on plant being very small. The rise and fall of tide at Buckie is about 11 feet.

The breakwater at Newhaven now being carried out under Mr. F. D. Banister, M. Inst., C.E., and in accordance with his plans, is constructed of Portland cement concrete, on a system that was carried out to a minor degree at Aberdeen, but which has been very successfully carried out at Newhaven, at a comparatively very low cost.

The foundation is formed by sinking bags of soft concrete, weighing 100 tons each, from a steam hopper barge which is put under a concrete mixing machine in the interior of the harbour, and in the space of 20 minutes the 100 ton bag is filled. The men on board immediately sew up the top of the bag while the barge is passing from the inner harbour to the side of the breakwater. It then steams slowly across the line of the breakwater, and at a given moment a man lining it on the centre of the breakwater gives the signal, the hopper is struck, and the bag descends into its place. The system goes on constantly, and the material being in a soft state accommodates itself to the concrete already set at the bottom, and forms one homogenous mass. The work is thus brought up to low-water mark. The bags are found to bind together in one complete mass and form a solid rock. When the bags have been deposited, and the work brought up to about one foot above low water mark so that the men can just work upon them without being washed, the surface is formed and a framing erected for the superstructure, the frame is lined with timber work, and the concrete mixing machine is taken along the breakwater very nearly to its extremity and tips the concrete into waggons which run down to the framing and shoot in the material between the frames, the work is thus brought up to a height of ten feet above high-water mark.

The breakwater is forty-two feet wide at the bottom and thirty-two feet at the top. The depth of water is from 15 to 16 feet at low tide, and the work is to be extended out to a depth of 18 feet. The rise and fall of the tide at Newhaven is 20 feet spring and 15 feet neap tides.

The cost of the concrete, including plant, averaged 15s. per cubic yard in place. The proportion of the concrete are one of Portland cement, five parts of shingle and two of sand.

The 100-ton bags of concrete are 42 feet long; each bag therefore being the full width of the breakwater. The bags are made of jute cloth, and are double thickness at the bottom.

The average cross section of the breakwater is 1840 square feet, and the cost of the work has averaged £57 per foot forward.

The nature of the bottom is sand on clay and chalk, the surface of the clay and chalk is overlaid by about two feet of sand.

The breakwater at Wicklow (Plate 12. fig. 14) recently constructed under the harbour engineer, Mr. William George Strype, Assoc. M. Inst., C.E., is a work of great interest on account of the novel system upon which it has been carried out, and its small cost.

The breakwater has a total length of 750 feet. The depth of water at low water spring tide is 18 feet at the head. The rise and fall of the tide is about 9 feet. This work took about 2½ years to construct. The following is the plan upon which this work was carried out:—A central stage was first formed on which the engines, the waggons and the cranes ran. The stage was extended in advance of the work to about half the length of the breakwater, and the staging trestles secured by means of a pad of concrete, which is shown upon Plate 12, fig. 14. (1). A pad of about 70 or 80 tons of concrete being deposited, the trestles thus secured are carried (as will be seen by the elevation) a long distance in advance of the general progress of the work. As soon as the staging was secured by this means a large mound of concrete was deposited as shown in Plate 12, fig. 14 (2); this mound of concrete representing about two-thirds of the volume of the solid structure below low water. This mound steadied the staging very considerably, and also admitted of very rapid progress in the construction of the work. During the construction of the mound as much as 2000 tons of concrete were deposited in a week, and for a small work that is considered a very remarkable pace at which to lay concrete. Upon the mound an outside deposit of concrete was added to the form of the breakwater, as shown by Plate 12, fig. 14 (3), by means of a panel rendered heavy so as to make it sink. This deposit was raised to within three feet of low water line. The difficulty of this system of construction is more when you get near to the level of low water. At low water the disturbing waves are apt to wash the cement out of the concrete before it is set. By putting the first stretch of panel within three feet of low water, the first profile toe can be deposited or formed as shown in the figure. As soon as that sets, which it does in a day or two, a second panel is placed in position, as shown in Plate 12, fig. 14 (4), and the profile of the work is carried up above the level of high water. For this part of the work it is necessary to select very calm water so as to avoid disturbance of the work; this being the most trying part of the work. While the structure is being formed, as shown in Plate 12, fig. 14 (4), the inside is carried up to the height of low water as shown in Plate 12, fig. 14 (5) the work being over low water mark is quite easy. Plate 12, fig. 14 (6) shows the building of the superstructure which can be readily accomplished.

The concrete used at Wicklow was made of gravel and sand obtained by dredging, the material being remarkably good; the proportion of cement to gravel and sand was one of cement to six of gravel and sand for the face, and one of cement to seven of gravel and sand for the inside of the work. The concrete for the submerged portion of the work was mixed dry, and left to find its own water on submersion.

The volume of the breakwater is about 40 cubic yards per foot run, and the cost of the work is about 17s. 3d. per cubic yard; the works therefore costing under £40 per foot run. The breakwater is built on a marl bottom.

The system adopted at Wicklow, and by which the breakwater was successfully carried out, possesses several points of peculiar interest. Firstly: compared with most other works of its class, the appliances used were of the simplest and cheapest description; no heavy cranes or special barges being required; secondly, in the event of a storm during the progress of the work, the mischief done would be simply confined to washing away the unset concrete which could be replaced without difficulty. There seems good reason to believe that where works are carried out on this system the amount of loss resulting from the washing away of the unset concrete, even in an exposed position, would be a less serious item than the cost of the heavy plant required for setting large blocks or depositing bags of large capacity, and with care and judgment on the part of those entrusted with the work, the loss could be reduced to a minimum, and a good rate of progress secured.

From a study of the above imperfect history of the progress that has been made in the science of constructing breakwaters, with a view to the arrival of a sound conclusion as to the best method of carrying out works of this class on the coast of New South Wales, the author is of opinion that there can be little question as to the advantage of the monolithic system, both as regards economy in first cost, and freedom from disturbance after completion; as, even in the case of a sandy bottom, works on this principle can be successfully carried out if similar precautions are taken to those found necessary in the breakwaters at the entrance to the Amsterdam canal.

It must also be remembered that, with the small range of tide along our coast, the difficulties of construction would be reduced, and for a given low-water depth the bulk of material required would be much less than in the case of most of the works referred to, where the range of tide varies from 10 to 20 feet, as against our tidal range of from 3 to 5 feet.

Again, comparing the average number of days, when the sea is sufficiently calm to enable works of this class to be carried on, it must be admitted that New South Wales is by no means unfavourably placed.