RIVER BARS

NOTES ON THE CAUSES OF THEIR FORMATION, AND ON THEIR TREATMENT BY 'INDUCED TIDAL SCOUR,' WITH A DESCRIPTION OF THE SUCCESSFUL REDUCTION BY THIS METHOD OF THE BAR AT DUBLIN

BY

I. J. MANN

ASSISTANT-ENGINEER TO THE DUBLIN PORT AND DOCKS BOARD

LONDON
CROSBY LOCKWOOD AND CO.
7 STATIONERS'-HALL COURT, LUDGATE HILL
1881

CONTENTS.

CHAPTER I.

BAR FORMATION.

CHAPTER II.

WAVE ACTION.

CHAPTER III.

CURRENTS AND SCOUR.

CHAPTER IV.

DUBLIN BAR.

CHAPTER V.

DUBLIN HARBOUR, IMPROVEMENT SCHEMES.

CHAPTER VI.

DUBLIN BAR—TREATMENT BY INDUCED TIDAL SCOUR.

RIVER BARS

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

RIVER BARS

NOTES ON THE CAUSES OF THEIR FORMATION, AND ON THEIR TREATMENT BY 'INDUCED TIDAL SCOUR,' WITH A DESCRIPTION OF THE SUCCESSFUL REDUCTION BY THIS METHOD OF THE BAR AT DUBLIN

BY

I. J. MANN

ASSISTANT-ENGINEER TO THE DUBLIN PORT AND DOCKS BOARD

LONDON
CROSBY LOCKWOOD AND CO.
7 STATIONERS'-HALL COURT, LUDGATE HILL
1881

PREFACE.

THE principal portion of the following pages appeared in *Engineering* at various times during the last two years, and is now, with some additions, reproduced in a more connected and convenient form.

My observations are limited almost exclusively to facts and figures which have a practical bearing on the subject, and which on this account may perhaps be found useful for reference.

The reduction of Dublin Bar, of which the following is the first detailed account published, presents a conspicuous example of what may be accomplished by Tidal Scour; and there is every reason to believe that the same agency can be advantageously and economically employed in improving many other Ports, now hampered with bars and other sand accumulations.

I. J. MANN.

DUBLIN: *December* 1880.

CONTENTS.

CHAPTER I.

BAR FORMATION.

CHAPTER II.

WAVE ACTION.

CHAPTER III.

CURRENTS AND SCOUR.

CHAPTER IV.

DUBLIN BAR.

CHAPTER V.

DUBLIN HARBOUR, IMPROVEMENT SCHEMES.

CHAPTER VI.

DUBLIN BAR—TREATMENT BY INDUCED TIDAL SCOUR.

LIST OF ILLUSTRATIONS.

RIVER BARS.

CHAPTER I.

BAR FORMATION.

General definition and classification of bars—Carlingford bar—Diversity of opinion as to methods of river improvement—Sir J. Rennie's erroneous conclusions with respect to bar removal—Classification of theories as to formation of bars—Action of rivers—Bars at the mouth of the Danube—Mr. W. A. Brooks' explanation of bar formation—Mississippi bars—Action of the sea in producing bars—Encroachments of the sea on coasts—Wave influence on the bottom.

In the widest acceptation of the term, a 'Bar' may be taken to mean that part of the navigable channel or approach to a port or harbour which is shallowest and which has deeper water both landward and seaward of it.

The origin of the expression is probably more nautical than scientific.

A Bar may consist of a comparatively narrow ridge, or a flat shoal of considerable area, or the prolongation of an adjoining beach across the Channel.

'River bars,' or those occurring at or near the mouths of navigable rivers, may with equal propriety be termed 'Sea bars,' inasmuch as in almost every instance their formation is traceable, directly or indirectly, to the action of the sea; their effect in blocking the entrances of rivers, and thus interfering with the navigation, has led to their being more identified with the latter than the former.

The British Isles, with their shallow seas and irregularity of coast line, present the first serious obstruction to the passage of the great tidal wave in its movement northward from the Atlantic; this obstruction gives rise to innumerable eddies and changes in the direction and velocity of the tidal currents, which, together with the action of wind-waves on the sea bottom, may be regarded as the chief primary causes of the formation of the numerous and extensive accumulations of sand which, in the form of banks, shoals, and sea bars, &c., impede navigation, and block our harbours.

The celebrated Smeaton, whose memory has been recently revived by the reconstruction of his most celebrated work, the Eddystone Lighthouse, seems to have been among the first English engineers who recognised in their practice the importance of tidal scour in clearing harbour entrances. There probably exists no wider field for the exercise of engineering skill than the improvement of tidal navigation, and the great increase of commercial prosperity in the ports where such improvements have been carried out presents a strong incentive both to the engineer and to those who avail themselves of his services.

For our present purpose bars may be conveniently divided into two classes, viz.—

Sand Bars, which as their name implies consist of sand varying only in the degree of granulation, from coarse sand to fine silt or alluvium.

Hard Bars, which may consist of rock, indurated clay, or a mixture of clay with gravel or boulders. The latter are simply the result of geological accident, and can generally be removed by excavation aided by such operations as blasting, dredging, &c., and being once removed are not liable to form again. The first mentioned are much more difficult to deal with, being generally the result of a constantly recurring action, and requiring the exercise of all our available knowledge on the subject to remove or improve them and prevent their re-formation.

Bars consisting of shingle are sometimes to be found—they are not, however, of very frequent occurrence.

The bar at the entrance to Carlingford Lough, on the east coast of Ireland, may be mentioned as an illustration of what I have termed, for the sake of distinction, hard bars; the material of which it is composed consisting for the most part of plastic blue clay, occasionally free from all stone, but generally with boulders of limestone, greenstone, or granite imbeded, and these varying from shingle up to stones of four tons weight. A channel 400 feet wide and having a depth of from 14 to 18 feet at low-water has been cut through this bar by dredging, the larger stones being lifted by chains attached thereto by divers.[1]

Sand bars are of much more frequent occurrence than those of the second class; indeed, they may be said to be more or less developed at the mouths of the majority of navigable rivers, notably at the entrances of the Mississippi, Danube, Rhône, Mersey, Tyne, Liffey, &c. Similar accumulations are also frequently formed outside harbour entrances, as for example at Hartlepool, &c.

There is perhaps no branch of Civil Engineering relative to which greater diversity of opinion has been expressed than the treatment of rivers, and it is almost superfluous to remark that much caution is necessary in attempting to generalise the results obtained in any particular instance.

[1] *Min. Proc. Inst. C. E.* vol. xliv. p. 133 *et seq.*

The literature connected with the subject affords more than one example of false conclusions having been arrived at by sufficiently plausible reasoning. As an illustration the author would refer to the account of the Dublin river given by Sir J. Rennie, in which, after describing the then existing condition of the port, he deduces therefrom, amongst others, the following general conclusions: 'That it is preferable to make a new artificial entrance and deep-water channel to a port, the natural entrance to which is closed by a bar, and whose channel is so obstructed by sand banks and shoals that there is no reasonable prospect of obtaining the desired depth, than to encounter a great first outlay in attempting to improve it, and continually renewed expense of maintenance hereafter. The natural causes which are at work in all analogous positions are so powerful, and so constant, and increasing in their operation, that the wisest policy is to avoid the difficulties rather than employ time, skill, and money in a contest where they must be employed to such great disadvantage.'[1]

Time has amply shown the fallacy of these deductions, for by a first outlay, probably less than one sixth of that which would have been required for the construction of a suitable ship canal, the great difficulty of the case has been completely overcome, and the depth on the bar already increased to such an extent as to open the port to fully 96 per cent. of the merchant vessels now afloat.

From the time that the phenomena of bars first attracted the attention of engineers and other scientific authorities, attempts have been made to devise a theory regarding their formation which would admit of general application. Various explanations are to be found, each of which may perhaps

[1] *Rennie on Harbours*, 1854, p. 205.

be satisfactory with respect to some particular instances; every additional investigation connected with the subject, however, increases the difficulty of generalisation. Nor, indeed, is it possible to fix any hard-and-fast rule that will apply equally to all cases of bar improvement.

These explanations or theories may for convenience be divided into two classes, in one of which the producing cause is referred mainly to the action of the river, and in the other to that of the sea. The action of the river itself, as the most apparent cause of the occurrence of bars, was among the first explanations suggested, and has been stated in terms to the following effect: 'The surcharged current of the river after leaving the *embouchure*, meeting with resistance from the comparatively stationary water of the sea, loses its velocity and deposits the material held in suspension, the deposit forming a bank or bar.' This explanation has been adopted by Sir C. Hartley in the case of the Danube; the waters of this river during floods bear to the sea by its various mouths large quantities of diluvial detritus; at times of high floods the bars are further from the shore, and their magnitude considerably increased, the flood current by its quickened speed at first deepening the channel over the bar, the portion so displaced is carried further out from the shore, and there the river current checked by the stationary water of the sea precipitates the particles held in suspension to form a new bar; 'as soon as the floods subside the effect produced by the strong current ceases, the new formations are gradually pared down by the action of the waves, the alluvium of the river is precipitated nearer to the shore, and the bars by degrees resume their old position.'[1]

[1] *Minutes of the Proceedings of the Institution of Civil Engineers*, vol. xxi.

Modified in its details, the theory of the deposition of material held in suspension has been, and as far as the author is aware is still, held by many who have investigated the subject. The manner in which the sea water acts in causing precipitation is described by Mr. W. A. Brooks as follows: 'At the period of the first quarter, the flood tide, by reason of its greater specific gravity, occupies the lower stratum of the tide-way, and like a wedge endeavours to force its course up the channel, which it is unable to effect, but merely elevates the lighter effluent water, the lower stratum of which, being checked by the opposition of the tidal water, yields to the latter the sand or other materials which it was capable of holding in suspension previously to its encountering the conflicting action of the flood tide; and where this takes place the bar is formed.'

Mr. Brooks also attributes the existence of bars to the too great declivity of the bed of the river, or of its low water surface near the mouth.[1]

On the other hand, Sir J. Rennie accounts for bars found at the mouths of rivers passing through a flat district by the diminished velocity due to the want of sufficient inclination of the bed.[2] Bars have also been referred to the casual circumstance of the main current of the flood tide not running in the same channel as that of the ebb,[3] and also to the conflicting action of river currents and tides entering the sea at right angles with the coast line.

The bars at the mouths of the Mississippi have probably occupied more attention than those of any other river, and

[1] *Treatise on the Improvement of the Navigation of Rivers.* By W. A. Brooks.

[2] *Pritchard on Harbours*, vol. i. p. 17.

[3] *Nautical Magazine.*

for many years have been the subject of careful investigation; they were at first accounted for in a similar manner to those of the Danube. Mr. C. Ellet, however, adopts a different hypothesis, and attributes their formation to the action of an induced counter-current of salt water flowing over a soft muddy bottom, from the Gulf into the river, to replace the sea-water carried by the impetus of the river current into the Gulf, and supposes an eddy to be thus produced, the movements of which are in a vertical instead of a horizontal plane. This ingenious hypothesis has been to some extent corroborated by more recent investigation, for the surface current over the bars at the South-west Pass is found to be generally from two to three miles per hour, but at ten feet below the surface the velocity is reduced to one mile per hour, and at the bottom not only to zero, but occasionally on a rising tide (spring tides in this part of the Gulf of Mexico rise only eighteen inches), when the flow of the Mississippi is under 800,000 cubic feet per second, which is the ordinary discharge at high water, the current flows in a reverse direction or into the river.[1] River action is not, however, confined to the transport of material held in suspension, the coarser and heavier particles of detritus being pushed or rolled along the bottom by the current, and the Mississippi bars have been recently, and with good reason, considered to be due more to this species of action than to precipitation.

The explanations in which the sea is regarded as the chief agent in the production of bars are more applicable to the rivers and harbours of the United Kingdom, owing to its insular position and consequent exposure to the influence of

[1] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xl. p. 201.

sea waves and tidal currents. The tendency of the sea to produce accumulation of sand, &c., in certain situations, noticed by the Abbot Castelli, in the middle of the sixteenth century, has been variously described by more modern writers on the subject, and is thus stated by Colonel Emy: 'The action of the ground (or bottom) waves is the true cause of the phenomenon of the bar. In tempests they carry with them sand which they deposit when met and dispersed by the current of the river.'[1] De la Bèche also states that 'the action of winds on coasts piles up detritus in the direction of their greatest force, heaping up bars at the mouths of rivers and rendering the navigation dangerous.' On the other hand it has been contended that the only materials thrown beyond the line of tranquil flotation consist of substances upon which the direct influence of the wind acts, such as timber, seaweed, &c., all others being carried out towards the sea by the back sweep of the waves.[2] Mr. D. Stevenson, who has devoted much attention to the subject, attributes the formation of all such bars as those of the Mersey, Ribble, Tyne, &c., solely to the action of the sea, which he describes as follows: 'The waves, as is well known, throw up a girdle of light or heavy material varying with the exposure, from sand to boulders, round every bay and headland of our coasts, and the entrances to rivers form no exception. The effect of this constant action of the sea is to form a continuous line of beach across the mouths of our tidal rivers and inlets.'[3] Mr. Stevenson does not appear to attach any importance to river currents as agents in the production of bars, but, on the contrary, observes that

[1] *Movement of Waves, and Hydraulic Works.* By Col Emy.

[2] *Brooks on the Improvement of Navigation*, 1841, p. 2.

[3] *Canal and River Engineering.* By D. Stevenson, p. 267 *et seq.*

according to his explanation 'a sea bar would be formed although the outgoing current held not one particle of matter in suspension, its only effect being to scour away what the waves have thrown up.'

In support of this explanation the bar at the entrance to Dornoch Firth is referred to, this bar occurring fourteen miles seaward of the point where the River Oykell enters the sea, being of such magnitude that its formation could not by any possibility be due to the very small quantity of detritus brought down by the river. Although agreeing with Mr. Stevenson's views on the subject, the author cannot but regard his statement of sea action as being of rather too general a character, and requiring some further explanation.

There is, however, sufficient evidence to show that such an action as that mentioned by Mr. Stevenson is of very frequent occurrence, and what appears to be a satisfactory explanation will be suggested in a following chapter.

Dr. S. Haughton, Professor of Geology in the University of Dublin, in evidence before a committee of the House of Lords relative to the erosion of the cliffs southward of Dublin Bay, states that the action of the sea is confined to its surface, that the greatest waves will not at a depth of ten fathoms produce a motion of more than two or three inches, and that the tidal currents moved the sand in a north and south direction only, and not on to the coast. Sir J. Coode also stated before the same committee that none of the shingle came from the sea, but what is taken off the shore by one storm is replaced by another, in corroboration of which he referred to his well-known researches relative to the origin of the Chesil Bank.

The numerous instances of the encroachment of the sea on the land prove beyond doubt that the action of the sea, instead of throwing up material, has occasionally had the opposite effect, and in some instances, as on the coast of Hampshire, where the depth was formerly such as to admit of being easily forded, it has been so increased by the action of the waves as to be now sufficient to float the largest vessels. Leland, writing of Folkestone, remarks that 'the town there by a lykeliod is merveloudly sore wasted with the violence of the se, yn so much that they say one Paroche Chyrche of our Lady, and another of St. Paul, is clene destroyed and etin by the se.'

CHAPTER II.

WAVE ACTION.

Two agencies chiefly concerned in bar formation—Depths to which wave action is propagated—Mr. Scott Russell's first report—Opinions of Si G. Airy, Mr. Stevenson, Mr. Douglass, and others—Wave agitation of the bottom on banks of Newfoundland, Bay of Biscay, &c.—Sand held in suspension in sea-water during rough weather—Movement of sand and shingle at Land's End—Observed movement of materials at the bottom exceeds theoretical—Experiments of the Brothers Weber.

THE agencies chiefly concerned in the formation of nearly all bars, and to which alterations in their position and dimensions may be traced, are evidently reducible to two, namely, waves and currents. These naturally produce results of an extremely varied character; acting sometimes antagonistically, as, for example, at the mouths of the Danube, where the accumulations brought down by the floods are subsequently dispersed by the waves; and sometimes conjointly as at Dublin, where the formation of the bar is due to the united influence of waves and tidal currents.

The action of waves at and near the surface is sufficiently well understood, and there is little difference of opinion on the subject; the depths to which their motion is transmitted, and the manner and extent of their action on the bottom, is not, however, so well known, and appears to be still open to further investigation.

Whether regarded as an adjunct to tidal scour, or as an active agent in the development of sand-banks and shoals, the action of ordinary waves on the bottom is an element materially affecting the design of works connected with the deepening or removal of river and harbour bars; and although it is perhaps impossible to assign definite limits to the depth at which wave disturbance produces effects sufficiently marked to be appreciable in practice, there is abundant evidence that in the comparatively shallow waters, in which bars are usually formed, the effects produced on the bottom by wind-waves of even moderate dimensions are very considerable.

Some differences of opinion have, however, existed in connection with this subject, and the author has endeavoured to condense some information of a practical and reliable character relative thereto.

The report of the British Association Committee on Waves—Mr. Scott Russell, reporter—contains the following statement: 'It became necessary to determine whether waves of the sea produced an agitation which extended to the deep parts of the water. It was found that even in moderate depths they do not. Thus in a depth of 12 feet waves 9 inches high and 4 or 5 feet long do not sensibly affect the water at the bottom.' Sir J. Rennie considered that waves produced little or no effect at a fathom and a half below the surface, and a depth of from 12 ft. to 15 ft. under low water was believed by Mr. J. M. Rendel to be the level below which the ordinary *pierres perdues* remained undisturbed.[1]

Twenty-two feet below low-water is mentioned by Mr. Murray as the limit below which wave action had no effect on small stones.[2]

[1] *Design and Construction of Harbours*, by T. Stevenson, p. 85.

[2] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xviii. p. 108.

The Astronomer Royal, whose name is so intimately connected with the investigation of the theory of waves, has expressed opinions on this part of the subject difficult of reconciliation; stating, with reference to the construction of a harbour of refuge in Dover Bay, that on the whole it was very unlikely that shingle is sensibly moved at a depth of a few feet, while more recently, in the discussion which followed the reading of a paper by Professor Prestwich 'On the Origin of the Chesil Bank,' Sir G. Airy contends that a great part of the shingle forming this bank had actually been pulled up out of the bottom of the sea by the enormous agitation of the water which sometimes takes place there.[1] Professor Haughton, in the evidence before alluded to, considers that the greatest waves do not produce more than a very slight disturbance at a depth of ten fathoms, are therefore quite incapable of moving large gravel at that depth, and that the only materials moved by the sea are those moved by currents and not by waves.

On the other hand, Mr. R. Stevenson states that large drift stones weighing upwards of two tons each have during storms been thrown on the Bell Rock, which is twelve miles seaward of Arbroath, from deep water; and these large boulders are so familiar to the light-keepers at this station as to be by them termed 'travellers'[2]: the soundings in the immediate vicinity of the Bell Rock vary from 12 to 28 fathoms. Sir J. Coode also found from personal examination made by the aid of a diving dress that the shingle of the Chesil Bank was moved by winter storms at a depth of eight fathoms.[2] It is also stated by Mr. J. N. Douglass that at the Bishop Lighthouse,

[1] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xl. p. 91 *et seq.*

[2] *Stevenson on Harbours*, p. 17.

situated on the westernmost rocks of the Scilly Isles, coarse sand has been thrown during heavy storms from a depth of 25 fathoms on to the lantern gallery, which is 120 ft. above low-water.[1] The effect of submerged elevations of the sea bottom in reducing waves has been frequently observed to occur in comparatively deep water. At the Gulf of Spezzia, for instance, on the north-western shore of Italy, a sand-bank stretching across the entrance to the gulf, on which there is a depth of 9½ fathoms of water is described as forming a natural breakwater which prevents large sea waves from entering the gulf.[2]

On the edge of the Banks of Newfoundland the agitation during storms has been known to affect the bottom at a depth of over 80 fathoms, and at St. Jean de Luz, in the Bay of Biscay, it is said that wave disturbance has extended to a depth of 300 metres (over 160 fathoms).[3] Waves of moderate size have also been frequently observed to change their colour from the abrasion of the bottom after passing into water of 7 or 8 fathoms.

In some experiments made by the author during the summer of 1878, for the purpose of determining the amount and description of solid material held in suspension by the sea-water in the neighbourhood of Dublin Bar, it was found that in calm weather the suspended material always consisted of soft impalpable alluvium varying from one grain to three grains per gallon, but in a few instances, when the samples were obtained during moderately rough weather, the waves averaging about 4 ft. high and the depth from 5 to 6

[1] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xl. p. 103.

[2] *Revue Maritime*, 1874.

[3] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xii. p. 551.

fathoms, the principal part of the precipitate consisted of fine sand amounting to as much as 6 grains per gallon; the samples in every case were taken from a depth of 20 ft. below the surface.

The fishermen at Dalkey, on the south side of the entrance to Dublin Bay, are unanimous in stating that the wicker traps used by them in lobster fishing are frequently broken or otherwise injured during heavy gales, while lying on the bottom in 10 fathoms at low-water, the largest waves on this part of the coast rarely exceeding 9 ft. to 10 ft. in height. Mr. J. N. Douglass also alludes to similar effects produced at the Land's End, where the lobster traps were frequently filled with coarse sand and shingle during heavy ground swells in depths of water up to 30 fathoms.[1] This information is stated by Mr. Douglass to have been obtained from the fishermen; there seems, however, no reason to doubt its accuracy, for Sir G. Airy mentions that ground swells frequently break in a depth of 100 fathoms.[2]

In an elaborate treatise on the movements of the sea with respect to its hydraulic relation to ports and shores, recently read before the Royal Venetian Institute of Science, Signor A. Cialdi states that what has been called the 'zone of sanding up' extends from the coast line to a depth of 164 fathoms in the ocean, to 82 fathoms in the Mediterranean, and to 44 fathoms in the English Channel, and that sea waves have a visible transporting power to a depth of 109 fathoms in the ocean, 27 fathoms in the Mediterranean, and about 22 fathoms in the English Channel; the materials deposited in this zone he regards as being derived from

[1] *Minutes of Proceedings of Institution of Civil Engineers,* vol. lx. p. 103.

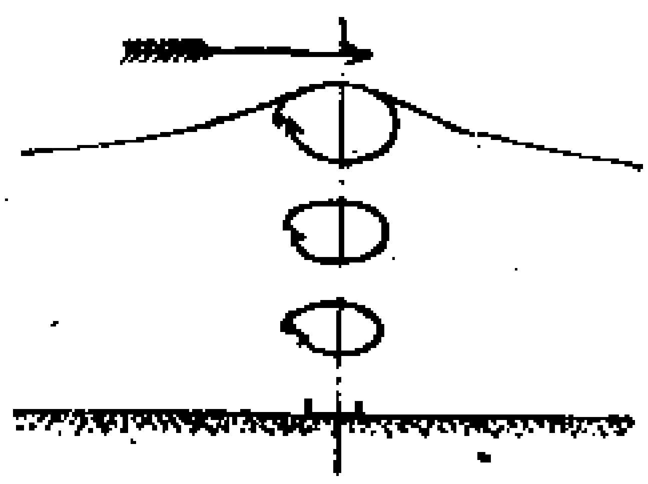
[2] *Encyclopedia Metropolitana.*

deposits brought down by rivers, from coast erosion, and from the productions of the sea itself.[1]

Most of the effects just described appear to be somewhat at variance with theory, showing a greater amount of disturbance below the surface than should be expected, Sir G. Airy having deduced *from theoretical considerations that* at a depth equal to the length of the wave, or distance from crest to crest, the motion would be only about 1-534th of that at the surface.

The results of various investigations and observations would seem to lead to the following conclusions: that each

FIG. 1.



particle of water under the influence of an ordinary wind-wave moves in a vertical plane parallel to the direction of the wave's motion, and describes an elliptical curve; starting from a level a little below the centre of the ellipse, each particle returns to a position slightly in advance of that which it originally occupied; as the depth below the surface increases, the ellipses become smaller and flatter (the longer axes being horizontal); *until at the bottom the curve* merges into a straight line, and the motion is simply forwards and backwards, but still continuing to deposit each particle in advance of where it was picked up (see Fig. 1). The peculiar motion just described was first observed by the

[1] *Ravista Maritima*, vol. ix.

Brothers Weber, who used for their experiments a long trough furnished with transparent sides, and containing water holding numerous minute particles of matter in suspension: the actual movements produced by a wave were thus made visible. The forward and backward movement of light substances in contact with the bottom is easily observable in any body of clear shallow water when agitated by ordinary waves.

This explanation, regarded by Professor Rankine as admitting of general application, leads to the conclusion that all sea waves partake more or less of the character of waves of translation. According to Messrs. Weber's experiments, in the case of perfectly *uniform* waves, the liquid particles describe complete ellipses returning to the points from which they started, and the forward movement shown in Fig. 1 was only observed when a small wave-hollow followed a large wave-ridge; allowance must be made, however, for the great difference between the waves of the sea which are so extremely varied and irregular—two consecutive waves being rarely of the same form or dimensions—and those mechanically produced in a long shallow trough having the direction of their motion confined to a straight line.

The forward transference of the particles thus produced satisfactorily accounts for observed phenomena; extraordinary high tides in the Irish Channel, for example, may be referred to the accumulated heaping up of the water of the Atlantic by waves moving under the influence of strong southerly or south-westerly winds. Double tides, which will be further alluded to, are also referable to the same cause. (See p. 54.) In the Sea of Tuscany this heaping of the waters on the coast by the action of the wind and waves is stated to amount to 19 inches; in the Adriatic to 3¼ ft.; and in the ocean to about 6½ ft.

There is additional reason to believe that this explanation may be applied to the waves which have to be dealt with in connection with bar formation or removal, for these waves, generated in the deep water of the adjoining sea, on entering the shallow water in which bars generally occur have a decided tendency to become waves of translation, even if they were not so before.

CHAPTER III.

CURRENTS AND SCOUR.

Tendency of waves to move sand, &c., towards coasts—Bars occasionally formed by wave action only—Method of dealing with bars proposed by Mr. Kapp—Wave disturbance a beneficial element when scour is employed—Artificial agitation of the bottom—Water-jets—Screw propellers—Bar of the Rhone—Littoral currents necessary to carry away material removed by scour—Experiments on currents in the La Plata and Parana—Laws deduced therefrom—Convenient form of float for the observation of currents—Rise and velocity of tides chiefly affected by physical features of land—Scouring efficiency of tides proportionate to the range—Velocity of currents at harbour entrances—Method of determining quantity of material in suspension—Steam dredging—Upland and tidal water.

FROM the foregoing considerations and the evidence adduced, it may be taken as unquestionable that the motion of sea waves is such that sand and other materials exposed to their action are freely transported by them; and that considerable wave disturbance of the bottom occurs in depths much exceeding those met with in or near the great majority of harbours and river *embouchures*.

Apart from local circumstances, and the influence of currents, the prevailing movement of the sand, &c., so far as waves are concerned, will generally be found to take place in the same direction as that of the wind which produces the greatest agitation for the longest time. When wave disturbance of the bottom occurs in the open sea, permanent transference of the sand in any one direction is counteracted by the variety of directions from which the wind blows; but in the vicinity of coasts where the shelter of the land prevents off-shore winds from producing waves of sufficient size to disturb the bottom, the effect of the on-shore winds remains to a considerable extent uncounteracted and accumulation occurs. The existence of what has been aptly termed 'the zone of sanding up'—for the universality of which, however, there is perhaps hardly sufficient proof—appears to be principally attributable to this cause.

There is sufficient evidence to show that bars are occasionally formed by wave action alone; for example, that at the mouth of the Swan River, on the west coast of Australia, where there is practically a total absence of tidal currents, spring tides rising only from 1 ft. to 1½ ft.; while at the mouth of the Yarra Yarra, on the south coast of the same country, there is no bar, the conditions as regards tidal currents being the same in each case; in the former instance the entrance of the river is fully exposed to ocean waves, but in the latter the river discharges into a sheltered estuary.

A somewhat novel method of dealing with bar improvement has been suggested by Mr. H. F. Kapp, in a paper recently read before the New York Society of Engineers, which is deserving of brief notice. Having shown from theoretical considerations that the action of sea waves on a sand-covered bottom is to build up bars and shoals in situations favourable to their formation, he proposes as a remedy to construct a submerged barrier directly across the mouth of the river or harbour seaward of the bar proposed to be removed, the height of the barrier being regulated by the depth of water it is desired to obtain over the bar. The effect of such an arrangement is described as 'destroying the building up power of the waves, and leaving unimpaired the full force of the river.'

Apart from the great difficulty and cost of constructing such a work in an exposed situation and in deep water, and presuming the result to be such as described, the remedy would obviously be of but a temporary character; the detritus from the river arrested on the one side, and the sand thrown up by the sea on the other, overtopping the crest of this submarine breakwater, would ultimately produce a much more formidable obstruction than the original one, so that in all probability the last state of the harbour entrance would be worse than the first.

Wave disturbance, however, becomes a beneficial element when induced tidal scour is employed for bar removal or improvement, causing not only a greater quantity of solid matter to be removed by the outgoing current, but also enabling it to carry the material to a much greater distance from its original position.

Artificial means of various kinds have been resorted to for the purpose of stirring up the bottom during the time that the ebb or scouring current is running out over the bar or shoal. A harrow drawn backwards and forwards along the bottom by a steam tug has not unfrequently been employed.

In the early part of the present century a machine termed a scrubber was used at Dublin for the same purpose; it consisted of a wooden raft or float, to the sides of which were attached a number of vertical rods sliding in guides, so that they could accommodate themselves to the varying depth produced by the falling tide; the lower ends of the rods reached to the bottom and were furnished with wooden spheres armed with a number of sharp iron points. This scrubber was anchored on the bar and kept in motion by the waves; its use, however, seems to have been abandoned after a short time.

A peculiar form of dredger or scraper used in deepening the south-west pass of the Mississippi was so constructed as to bring up the silt from the bottom, where the current was extremely feeble, into the upper stratum, which, having a velocity of from 2 to 3 miles per hour, was found sufficient to carry the suspended material clear of the bar.

M. Bergeron proposes to produce an artificial agitation by causing a number of small jets of water to impinge on the surface of the sand, and describes his apparatus as consisting of a horizontal cast-iron pipe, perforated with holes from ½ in. to 1 in. in diameter and about 2 ft. apart; to each hole is fitted an india-rubber pipe terminated with a metallic nozzle which is allowed to hang close to the bottom, a vertical cast-iron pipe and flexible hose making connection with powerful force pumps placed on the barge from which the apparatus is suspended. The continuous action of the jets forced through the nozzles is described as producing a series of deep furrows as the barge passes over the bar, these furrows being subsequently levelled by the current. The author is not aware that this apparatus has ever been used in practice.

Ordinary screw propellers have been employed at Rotterdam for a similar purpose within the last few years, and are said to be effective. The propellers are so arranged that they can be lowered to any required depth within practical limits, and are made to revolve close to the bottom.

Mr. C. J. Applebe mentions that on the River Maas two propellers of about 3 ft. 6 in. in diameter, driven by a 12 horse power engine, and working in a depth of about 13 ft. of water, lowered a shoal by about 3 ft. over an area of 1200 square yards, the time occupied being about forty minutes.

It is manifest, however, that the successful application of artificial expedients, such as those just described, depends almost entirely on the presence of natural currents, the strength, continuance, and direction of which will enable them to carry away the disturbed material into deep water clear of the bar or shoal, and whether it is proposed to treat these obstructions by employing the aid of mechanical contrivances or by induced scour, an accurate knowledge of the existing currents becomes of the first importance. Failure may not unfrequently be traced to the want of sufficient investigation on this point.

The attempted improvement of the Rhone bar may be mentioned as a striking example. This river previous to the year 1852 flowed into the Mediterranean through a number of branches, and in that year it was determined to scour away the bar by closing all the mouths except the principal one; the river was thus narrowed 2 to 2½ miles at mean-water level, and its waters confined in one channel by training banks.

It was assumed that the littoral currents known to exist in that part of the Mediterranean would carry away the sand removed from the bar, clear of the entrance. The result, however, was merely a displacement of the bar to a position further seaward, the littoral currents having failed to act in the manner expected. In 1856 it had advanced about 4,000 ft. into the sea, and rendered the navigation more dangerous than before. The littoral current on which the whole success of the scheme depended was then made the subject of investigation, and it was found that it existed only at the surface, and that at a depth of 6½ ft. there was still water. The project was, therefore, abandoned, and a locked ship canal turning the flank of the bar has been since constructed.

A full and accurate knowledge of existing currents as regards their extent, velocity, and direction is therefore of the highest importance in dealing with obstructions such as those under consideration. We may confine our attention chiefly to the principal of these, namely, river and tidal currents; there are, however, others which in certain localities cannot be neglected, as, for example, those produced by the action of wind blowing continuously in the same direction, a familiar instance of which is presented by the Gulf Stream. The effect of wind in augmenting or retarding tidal currents will be subsequently noticed.

In ordinary rivers of moderate dimensions the maximum velocity of the current is generally assumed to occur at a level slightly below the surface; practically, however, the surface velocity at the centre is the maximum, from which the mean and bottom velocity may be approximately derived by Prony's formula, viz.:—

$$\frac{\text{mean}}{\text{greatest}} = \frac{\text{greatest} + 7{\cdot}71 \text{ ft. per sec.}}{\text{greatest} + 10{\cdot}28 \text{ ft. per sec.}},$$

the bottom velocity being about as much less than the mean as the greatest is greater than the mean.

Considerable light has been thrown on this part of the subject by the experiments and researches made by M. J. J. Révy, under the direction of Mr. F. Bateman, and published by the former in his 'Hydraulics of Great Rivers,' in which the following conclusions are mentioned as the result of observations of the La Plata and Parana:—

1. At a given inclination surface currents are governed

by depth alone, and are proportional to the latter, *i.e.* with double the depth the surface current is twice as great, with treble the depth three times greater, and so on.

2. The current at the bottom of a river increases more rapidly with the depth than that at the surface.

3. That for the same surface current the bottom current will be greater with the greater depth.

4. That the mean current is the arithmetical mean between that at the surface and at the bottom.

5. That friction on the bottom is the cause of different velocities at different depths, and therefore in an open channel free from local disturbances the current of maximum velocity should establish itself at a maximum distance from the retarding force, namely, at the surface.

Holding these laws in view, M. Révy considers that the gradual formation of banks, islands, and channels of great depth is readily explained: 'Wherever the estuary is shallower the current is weaker, and deposit of earthy or sandy matter will not only take place more rapidly, but when deposited it is less likely to be removed by the current which may be only one-half or one-third of that existing at the greater depth,' the shallow parts becoming thus more and more shallow until they reach the level for growth of vegetation.

If the laws just enumerated are true in the case of great rivers, there can be little doubt that they hold good for tidal estuaries, and we are therefore justified in believing that if the scour is able to commence the deepening process, the increased depth and the attendant increase of the bottom current acting and reacting on one another, will tend to make the deepening continuous, until some new force is brought into action to modify this result. Some of the conclusions arrived at by M. Révy differ considerably from those generally admitted; they have not, however, as far as the author is aware, been questioned, and seem to have been obtained from numerous and carefully conducted experiments and observations.

The following Table of velocities, founded on those given by Du Buat and Beardmore, shows the approximate water velocities required to move various materials:—

Velocities			Material
Feet per second	Feet per minute	Miles per hour	
0·50	30	0·34	Will just move fine sand
0·70	42	0·49	„ „ coarse sand
1·00	60	0·68	„ „ fine gravel
2·25	135	1·53	„ „ pebbles 1 in. diameter
3·33	200	2·26	„ „ „ 1½ in. diameter
4·00	240	2·72	„ „ heavy shingle

The velocities given in this table refer to fresh water; in sea water they would probably be about one-fortieth less on account of the difference in density.

Owing to the frequent roughness of the water in the vicinity of bars in exposed positions, there is occasionally some little difficulty in measuring the velocity of the currents at various depths. The extremely simple arrangement used by the author is shown in the annexed diagram; the upper float is reduced to a minimum, in order to present as small a surface as possible to the action of the wind and surface current, the lower float is weighted so as to exceed very slightly the weight of the water displaced, and its distance from the surface can be regulated by the length of the cord connecting the two floats. After immersion the float is followed in a boat, and its position determined every ten or fifteen minutes with an ordinary sextant, or by any other suitable means.

The varying height of the tidal wave, and the differences in the velocities of the currents produced thereby, are almost entirely governed by the depth, the irregularity of the bottom, and the contour of the coast line.

In mid-ocean as at St. Helena and Ascension the rise of springs does not exceed from 2 to 3 feet, and the produced current is barely perceptible. On the other hand, in situations where the gradual approach of the shores and the shoaling of the bottom favour concentration, the tides rise to a considerable height. In the Bay of Fundy there is a rise of over 50 feet at springs and at times considerably more—indeed, it is stated that the rise occasionally attains to double the height just mentioned; a vessel having grounded there during the night at high-water, on a sunken rock, the crew were astonished to find themselves at daybreak looking down a precipice into the water far below.[1]

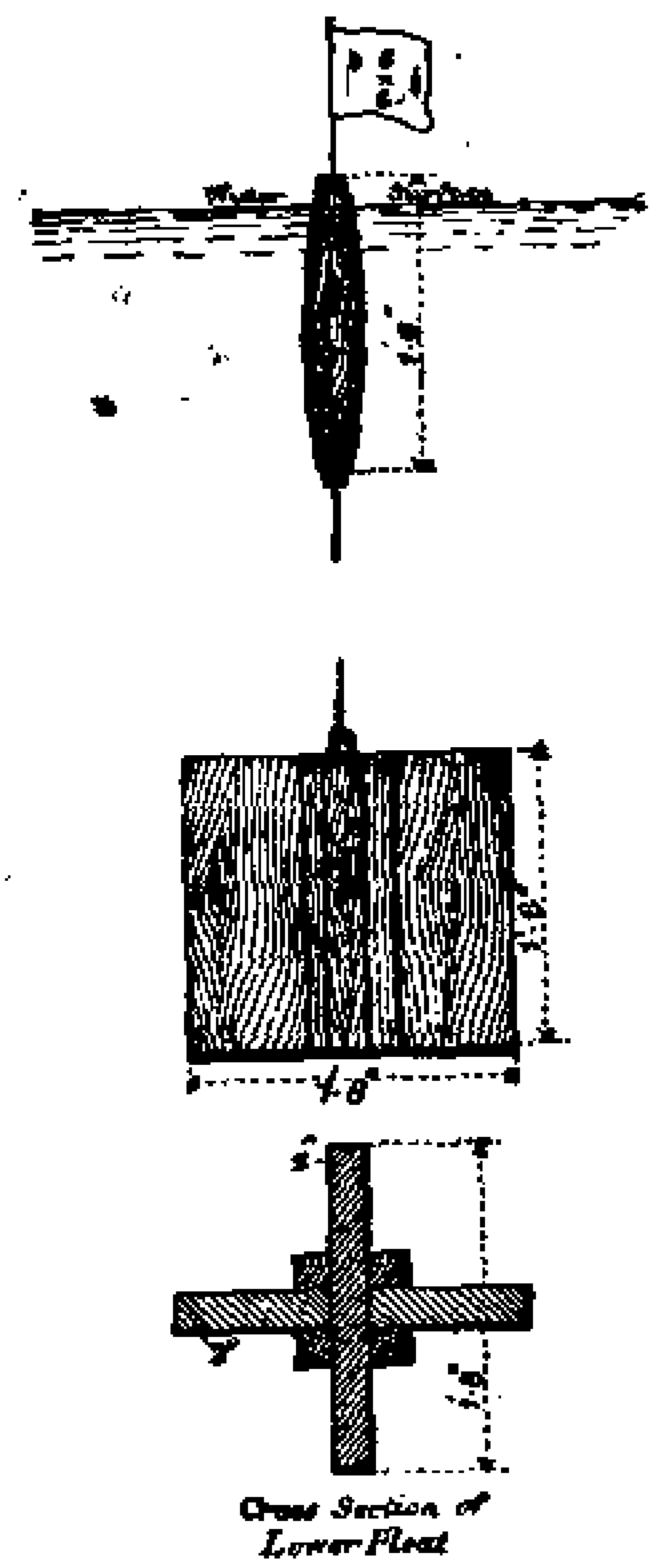


FIG. 2.

The same concentration takes place in the estuaries of some of the large rivers, and is well marked in the Amazon, Hooghly, Garonne, and others. Probably, the greatest natural velocity produced by the tide is to be found in the river Tsientang in China, where the tidal water in its passage up the river runs at the rate of about 25 miles per hour.

[1] Herschell's *Phys. Geog.*, 1875 ed., p. 69.

In our own seas and rivers we have perhaps a greater variety of tidal phenomena than is found in any equal area elsewhere. In the Bristol Channel springs rise 40 fee, while off the coast of Arklow there is little or no rise. In the Pentland Firth the current reaches a velocity of over 11 miles per hour, and between Carlingford and the Isle of Man there is no perceptible tidal current.

The disturbance caused by comparatively trifling inequalities of the bottom is propagated through considerable depths to the surface. Shoal spots have been detected by the surface ripple in a depth of 47 fathoms. On the north shoal off the Orkneys, where the depth is 30 fathoms, and even when the tidal stream is moving at only 1 mile per hour, inequalities of from 10 to 15 ft. in height are readily distinguishable in this way.[1]

Independently of their bearing on the question of scour, these facts are found useful in the selection of suitable discharging ground, when, as is now commonly the case, dredged material is deposited at sea in comparatively moderate depths, any approach to the production of broken water in the fairway or offing being undesirable.

In bar improvement works the relative efficiency of springs and neaps may be taken under ordinary circumstances as proportionate to the range. Along the coasts of the British Islands the average rise of neap tides is about three-fourths that of springs, the extremes being found at Tiree Island on the west coast of Scotland, and Red Bay on the north-east coast of Ireland. At the former place neap rise is half that of springs, and at the latter both springs and neaps rise to the same height. The scouring power of a

[1] *Admiralty Tide-Tables*, p. 116.

current is *cæteris paribus* proportionate to its velocity: the latter, however, in the case of bar improvement is limited to that which will not injuriously interfere with navigation. It has been remarked with reference to allowing a comparatively high velocity to occur at the period of half-ebb, when the speed of the current is usually at its maximum, that sailing vessels could enter at or near high-water, as there would be then little or no current. It should be remembered, however, that if the entrance of these vessels was thus limited, the great object to be attained by the removal of the bar, namely, that of allowing vessels to enter and leave at all or nearly all states of the tide, would, to a considerable extent, be frustated. For this reason it appears desirable that at harbour entrances the maximum velocity of the current should not exceed about 4 miles per hour, which in most instances will probably be found sufficient for the required purpose.

Scouring action should be regarded as producing transference of material in two ways, namely, by carrying it clear of the bottom while in suspension, and by conveying it along the bottom with a motion consisting of a combination of pushing and rolling.

The capability of running water to hold material in suspension is attributed by Mr. Ellet to the different velocity of each stratum which causes the suspended particles to be acted upon by unequal forces on opposite sides.

The current velocities required to move sand, gravel, &c., determined experimentally by Mr. Beardmore and others, are of course much below those necessary in practice, the material acted upon having not merely to be 'just moved,' but to be transported with all consistent rapidity into deep water, as far removed from its original position as possible.

Mr. Bergeron states that sand remains in suspension in any current having a velocity of over 2½ ft. per second which is less than 2 miles per hour: the quality of the sand is not mentioned.[1]

As it is sometimes desirable to determine the quantity and quality of the material held in suspension by tidal water in the neighbourhood of harbours, a short description of the method adopted by the author may perhaps be found useful. A cylindrical sheet-iron vessel, capable of containing 10 gallons, and having an aperture 2 inches in diameter in its upper end, was weighted and attached to a light rope, so as to sink when empty; the aperture was closed by a short wooden plug with a shoulder to prevent undue tightening under pressure; a piece of ⅜ in. round iron about 18 in. long was driven into the plug, and to this was attached a strong cord, which by an oblique pull enabled the plug to be removed and the vessel filled at any moderate depth below the surface. The sample thus obtained was allowed to remain undisturbed for forty-eight hours, or longer when convenient; the water was then drawn off by a siphon to within about 2 inches from the bottom; this residue was well agitated and poured into a vertical leaden tube about 5 ft. long and 2½ inches in diameter, the tube being furnished with two small plugs, one at the bottom, the other 3 inches higher; after standing two or three days, the upper plug was removed and the water above it allowed to flow off. The remaining portion, after agitation, was withdrawn by taking out the lower plug, filtered, and the filtrate weighed.

The samples obtained in calm weather in the vicinity of Dublin Bar yielded an extremely fine alluvium which soiled the finger, and when examined microscopically was frequently

[1] *Min. Proc. Inst. C. E.*, vol. lviii, part iv.

found to contain a quantity of what appeared to be minute fragments of coal, the presence of which was probably due to unconsumed particles emitted by passing steamers.

The employment of steam dredgers in deepening bar channels is generally attended with so much risk and expense, and the times at which the weather will permit them to be worked are so limited, that much assistance cannot be expected from this source, Instances, however, are not wanting in which dredging operations have been of considerable service both directly and indirectly.

If, for example, the dredging is conducted in the finer qualities of sand, and while a strong ebb current is running, it will generally be found that the disturbance of the bottom by the dredge buckets enables the current to carry off large quantities of the sand, &c. Scour has also been considerably increased by dredging away irregularities of the bottom, so as to give the current a free run. The dredging of the approach channel at Barrow-in-Furness may be mentioned as a recent instance of the beneficial effect referred to.

Steam dredgers can be employed to great advantage in deepening, widening (if necessary), and straightening of the esturial portion of a river channel near the entrance, so as to give to the ebb current, before leaving the harbour, volume and direction, on both of which depends its subsequent efficiency.

The relative value of tidal and upland water for scouring purposes has been frequently discussed; in the majority of cases, however, when fresh and salt water are both present it seems evident that the former can have little or no direct scouring power on a sea bar, for owing to its specific gravity it is always uppermost, and prevented from coming into contact with the bottom by the heavier sea water beneath.

In the tidal portion of almost any river, the fresh water can be seen running *down*, while the flood tide is forcing its way *up* along the bottom.

This has been found to occur even in such extreme cases as the Mississippi, where the volume of upland water is very great and the rise of tide extremely small.

CHAPTER IV.

DUBLIN BAR.

Varying conditions require modification of treatment—Bar near the entrance to Dublin Harbour—General description of the Liffey—Its rain basin—Discharge, estuary, &c.—Dublin Bay, its general features—First important work connected with improvement of the harbour—The Great South Wall, cross sections, &c.

HAVING in the preceding chapters briefly recapitulated the principal theories and explanations which have been advanced to account for the formation of bars, and laid before the reader some of the leading considerations and examples bearing on the subject, I propose to trace the history and describe the details of a well-defined and successful instance of the application of induced tidal scour in bar improvement.

It should be observed, that in dealing with bar and river improvement generally, the natural conditions vary so considerably in different cases as to require to be specially provided for, but the results of distinctive treatment under known conditions furnish perhaps the most useful information obtainable with regard to the difficult subject under consideration.

The instance referred to, namely, the reduction of the bar near the entrance to the Liffey, is one of the most remarkable in the history of harbour improvement, and as the author in his professional connection with the Port of Dublin has carried out various investigations relative to the formation and removal of the bar, and as no detailed account of the works has hitherto been published, the following description may not be found uninteresting.[1]

The Liffey is a river of comparatively insignificant proportions, taking its rise in the mountains of the County Wicklow, at an elevation of 1,750 feet above the mean sea level, and, after an extremely devious course, discharging itself at Dublin into an estuary situated at the north-western extremity of the picturesque bay to which that city gives its name.

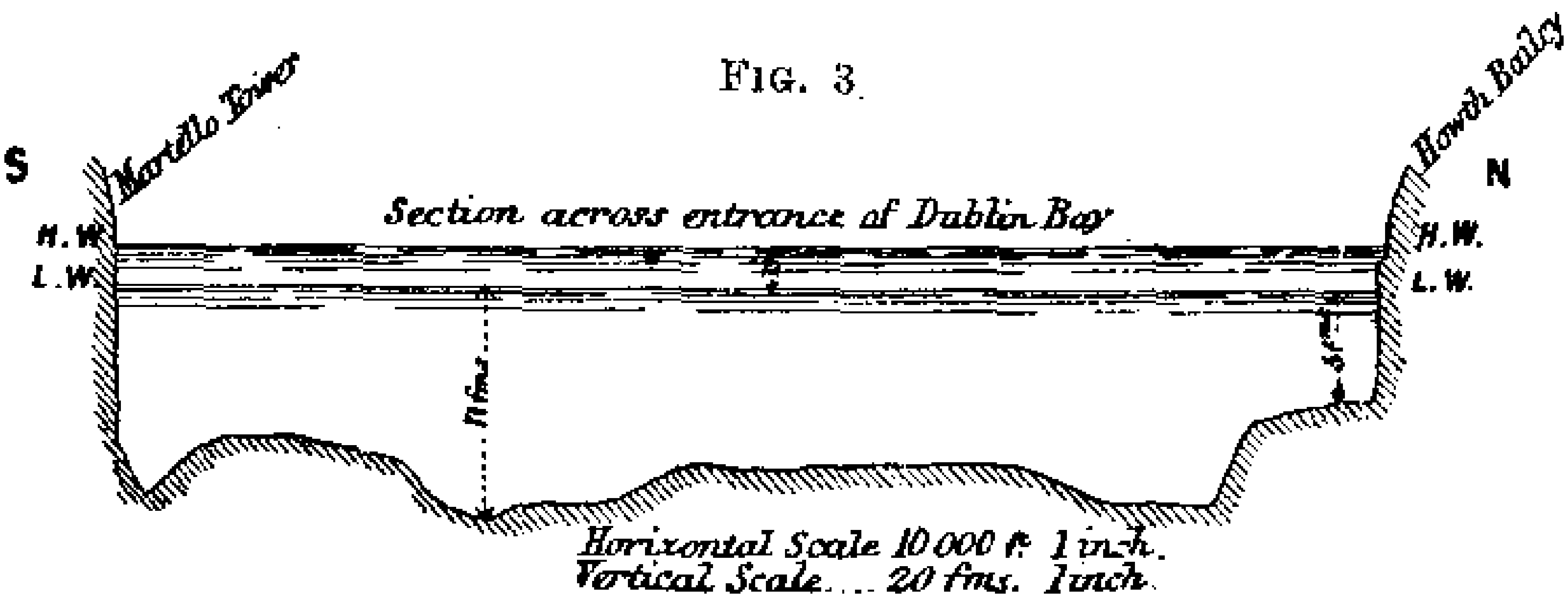
The total length of the river is about 82 miles, and the course it traverses so circuitous that the distance from its source to its mouth measured in a straight line is not more than 13 miles. The rain basin of the Liffey has an area of 476 square miles. Two small streams, the Tolka and Dodder, also discharge into the same estuary, their united watersheds having an area of about 108 square miles. The Liffey is tidal as far as the weir at Island Bridge, a distance of 3½ miles from the commencement of the esturial portion at Ringsend. No reliable measurements were to be found of the quantity of water discharged by the river, and in order to arrive at some conclusions on this part of the subject gaugings were made by the author in December 1877, which gave a mean result of 51,000 cubic feet per minute, the river being at the time apparently in its normal condition. This quantity is equivalent to an available rainfall of 24·25 inches per annum. There is no system of intercepting sewers at present in operation in Dublin, the city being drained through a number of outfalls which empty into the river at various points.

[1] The description of the works connected with the improvement of Dublin bar was contributed by the author to *Engineering* in 1878 (see vol. 25 of that journal).

Dublin Bay, situated on the east coast of Ireland, and therefore sheltered from the heavy seas which break with such extreme violence on the western shores, is formed by the projection of the bold promontory of Howth on the north, and the high lands of Dalkey, Sandycove, and Kingstown on the south; its entrance is $5\frac{3}{4}$ miles wide, measured in a direction nearly north and south, from the Martello tower a little west of Dalkey to the Bailey Lighthouse at the eastern extremity of Howth, and the average distance from a line joining these points, to low-water mark, measured in an east and west direction, is about 3 miles, and from low-water mark to the western end of the estuary at Ringsend is a further distance of about 3 miles.

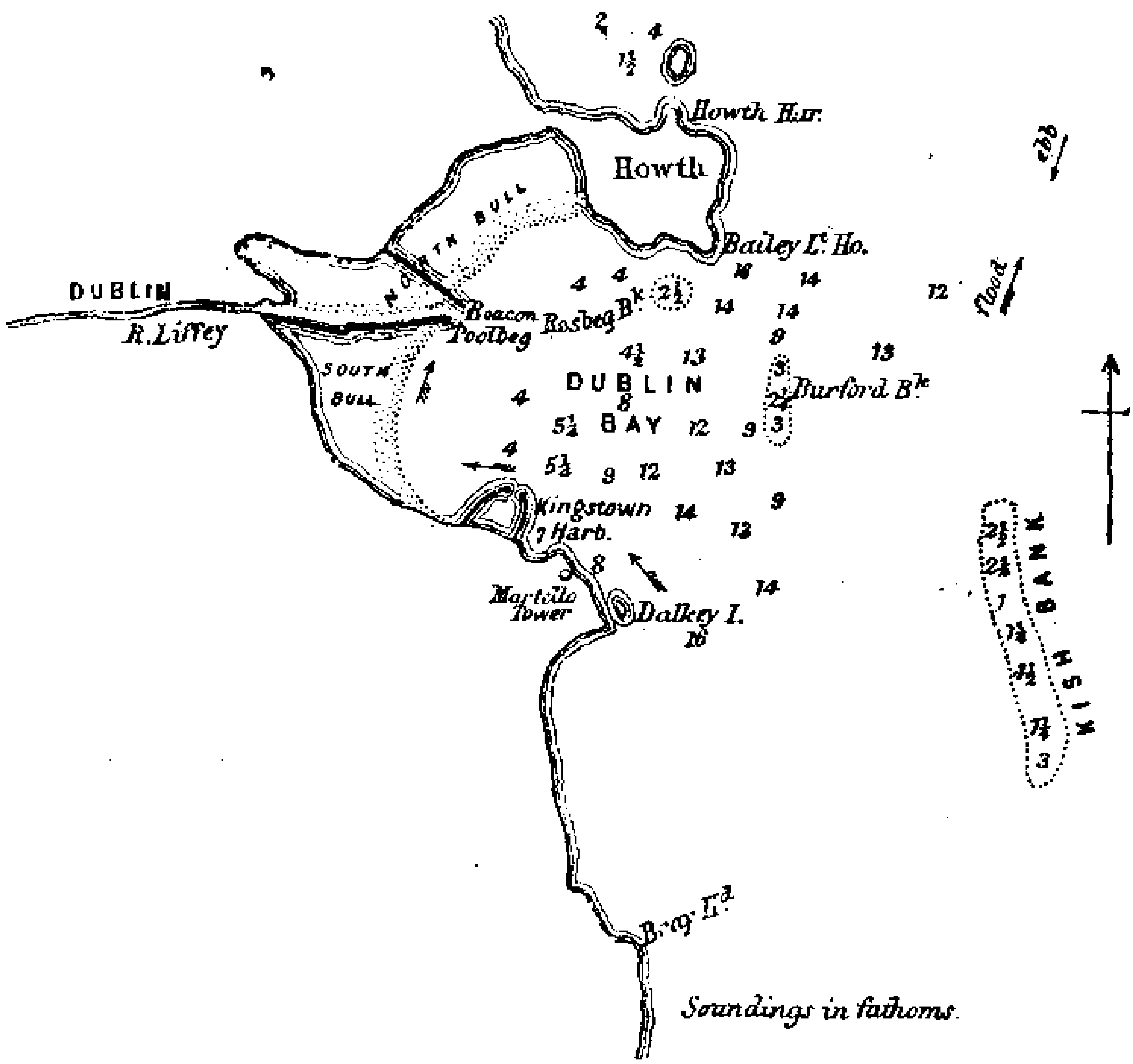
Fig. 3 represents a section of the entrance to the bay: the average depth is about $8\frac{1}{4}$ fathoms at low-water; the

FIG. 3.



bottom consists of sand, except close along the shores, where it is rocky. The heaviest seas enter the bay from the south-east, which is the direction of greatest exposure. The nearest point on the opposite coast of the Irish Channel is Holyhead, distant 60 miles nearly due east. At the head or western extremity of the bay are two extensive sand-banks, named respectively the North and South Bull, between which the river is discharged. In the north-eastern part of the bay there is a small bank called Rosbeg, on which there is $2\frac{1}{2}$ fathoms at low-water. Lying more towards the centre, but outside the north and south line above referred to, is the Burford bank, on which there is a depth of $2\frac{1}{4}$ fathoms

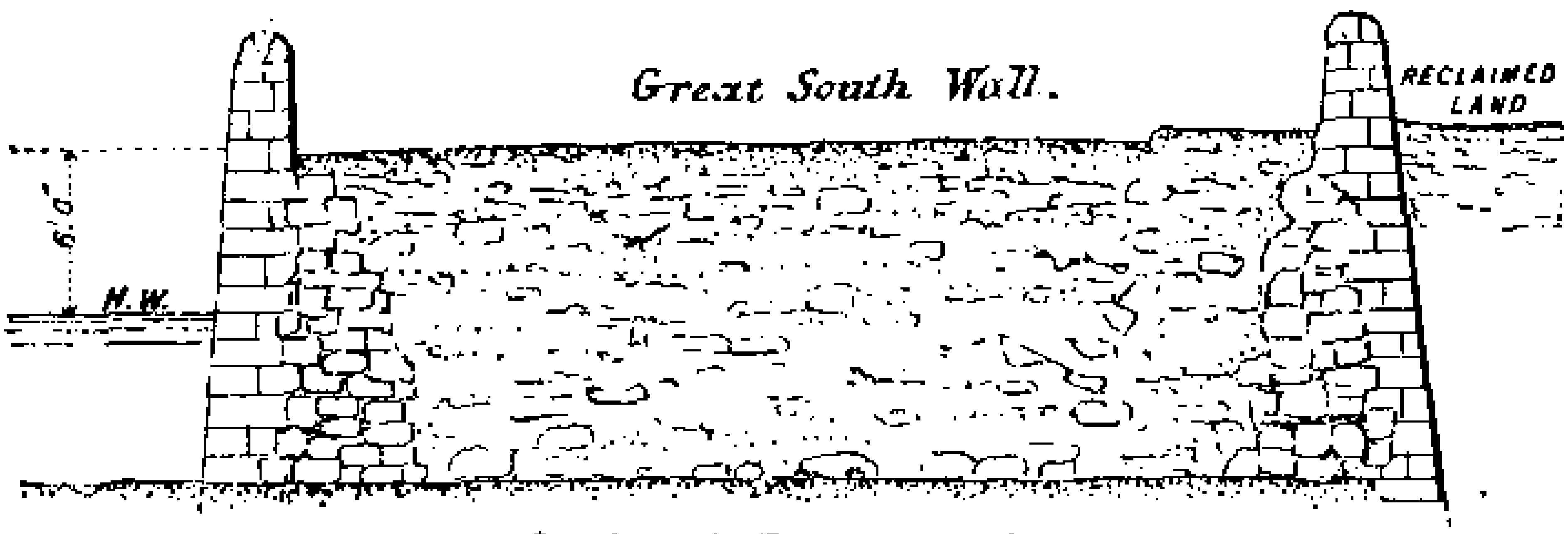
FIG. 4.



at low-water, and a few miles farther to the south-east lies the Kish Bank with a depth at the shallowest point of one fathom. The above description will be better understood by referring to Fig. 4, which shows the general features of the bay and harbour.

The first important work connected with the improvement of the port was the construction of the Great South Wall, which was commenced in the year 1748, and carried in an easterly direction for a length of about 1½ miles, terminating at the Pigeon House Fort, where a small harbour was subsequently constructed for the accommodation of vessels carrying passengers between England and Ireland. A cross section of this portion of the Great South Wall is shown in Fig. 5; it consists of two parallel rubble walls

FIG. 5.



Section of Western portion.
Scale 16 ft = 1 inch.

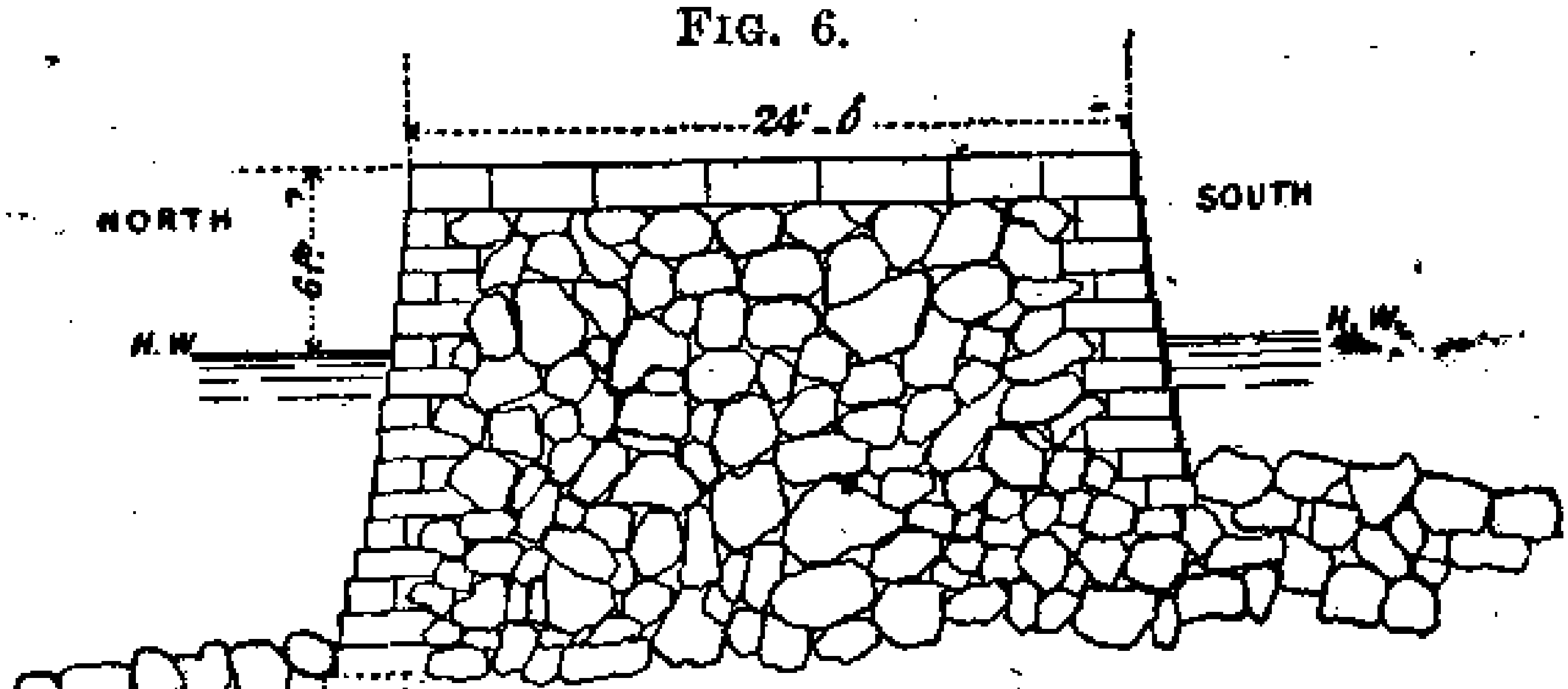
varying from 37 feet to 48 feet apart, the space between being filled up with sand; the walls carry parapets, and thus a roadway is formed which affords communication with the Pigeon House. A considerable quantity of land has been reclaimed on the south side of this wall by the more recent deposition of material dredged from the river. The seaward portion of the Great South Wall, between the Pigeon House and Poolbeg, appears to have been built between the years 1761 and 1768, and the foundations of Poolbeg Lighthouse, which is situated at the eastern extremity of the wall, were laid in 1764.

A cross section of this portion of the wall, taken about a quarter of a mile from the lighthouse, is shown in Fig. 6; the eastern end—over which the sea breaks freely in S. and

S.E. gales—for a length of about half a mile measured from the lighthouse, is raised about 4 feet higher than the remaining portion extending to the Pigeon House.

The wall is built of dry rubble stone, faced on both sides and top with granite ashlar in long lengths and well bonded,

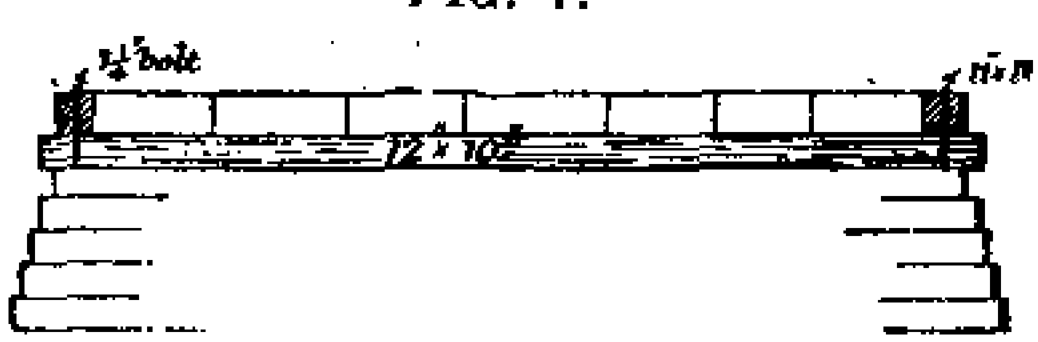
FIG. 6.



Cross Section of Gt. South Wall between Half Moon Batty. & Poolbeg.
Scale 16 ft.-1 inch.

but laid dry except on the top where the joints are pointed. The sides have a batter of about 1 in 12, each course of face ashlars being laid with a vertical face and horizontal offset. Timber coping was used on part of the wall bolted to bond timbers crossing at intervals (*vide* Fig. 7); this coping,

FIG. 7.



however, is now nearly all decayed or washed away, its place being supplied from time to time with Portland cement concrete.

The total length of the wall from Ringsend to Poolbeg is about 3 miles. The actual cost is not known, but from the simplicity of the design and the small outlay required for maintenance, it would probably compare favourably with that of most other piers.

Viewed as a whole, the Great South Wall may be considered as one of the most extensive works of the kind in existence at the time of its construction; and although it cannot be said *per se* to have produced much beneficial influence on the bar, it was most successful in accomplishing two important objects, namely, the protection of the river from the encroachment of the South Bull, and as a training wall confining the ebb and flood currents in a more defined channel, and also, as will be seen, subsequently taking an important part in producing the tidal scour which has been so effectively applied for the removal of the bar.

CHAPTER V.

DUBLIN HARBOUR, IMPROVEMENT SCHEMES.

Captain Perry's scheme—Effects produced by Great South Wall—Difficulty of dealing with the river—Sir T. H. Page's scheme—Proposed outport and ship canal—Recommendations of Captains Bligh and Corneille—Training walls—Report of Mr. Rennie and Captain Huddart—Messrs. Giles and Halpin's report—Mr. Telford's opinion—Plan finally adopted—Great North Wall—Sections, &c.

PREVIOUS to the construction of the Great South Wall, Captain Perry, in the year 1725, had proposed that a harbour should be constructed at Sutton, which is situated on the south-west side of the promontory of Howth, and distant from Dublin about 6½ miles. This harbour was to provide accommodation for vessels drawing up to 12 ft., and to be connected with the city by means of a canal, the cargoes being conveyed by barges to and from the metropolis.

Captain Perry's scheme seems to have engaged considerable attention at the time, but was not adopted, being manifestly defective, for the depth on the bar being then 6 ft. at low water, and the rise of spring tides from 12 ft. to 14 ft., vessels drawing 12 ft. could enter the harbour at high water, except when a heavy sea was running on the bar. The delay and expense attending the transhipment of the cargoes, and the cost of maintaining the canal, were also fatal objections to this project.

With reference to the older charts, it may be stated that before the publication of Captain Grenville Collins' chart in

1693, the only maps of the British coasts were made by the Dutch, and were both inaccurate and deficient in detail. In 1725 Gabriel Stokes published his chart in connection with Captain Perry's scheme before alluded to. In 1762 a plan of the bay, &c., was made by Murdoch McKenzie, which was not published until 1775, and a survey made in 1800 by John Cowan showed in a general way the state of the harbour. In the same year the bay and harbour of Dublin were surveyed by Captain William Bligh, under the direction of the Admiralty. This chart contains a large amount of information, and is much more complete than any of those which preceded it. Among the more modern charts are those by Giles in 1819, Frazer in 1838, Wright in 1856, and Kerr in 1873.

The amount of the alterations caused by the Great South Wall in the river channel and adjoining sand-banks cannot be determined with any great degree of exactness, owing to the deficiency of information given on the older charts, particularly as regards the datum to which the soundings had been reduced. The general effects produced may be briefly enumerated as follows :—

1. The ebb and flood currents which formerly flowed over the South Bull were confined and diverted into the direction of the river channel, which was thereby slightly deepened.

2. The South Bull was prevented from further encroachment on the river.

3. The esturial portion of the river was sheltered from the south and south-east winds.

4. A slight alteration was produced in the bar, a small portion of the south end of which was deepened, while the north end became proportionately shallower.

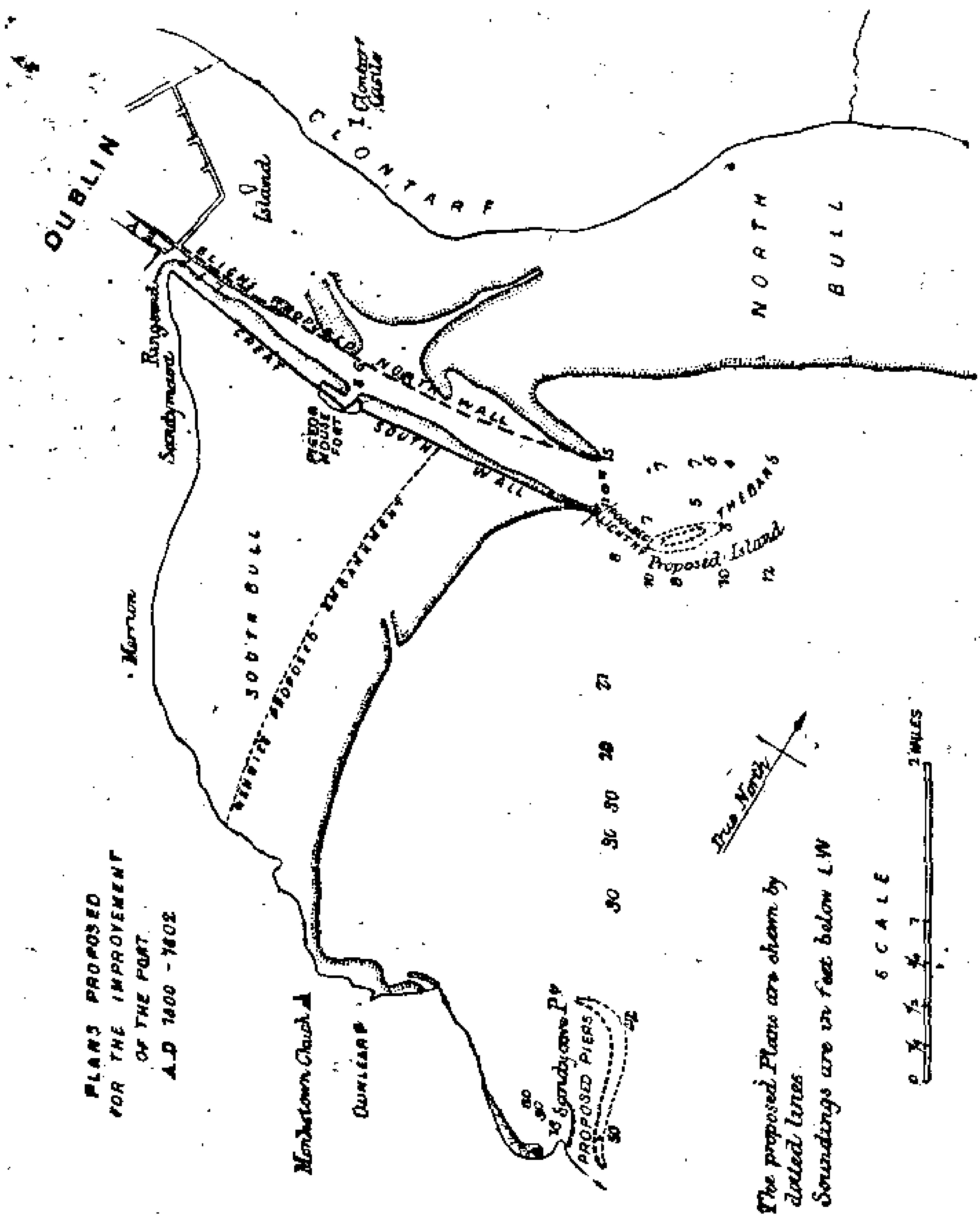
5. The South Bull being deprived of the back-water from the river and harbour, an extensive dry bank was thrown up at the north-western end by the action of easterly winds on the finer particles of sand.

6. The water of the bay along the eastern edge of the South Bull was deepened.

Although these effects were decidedly beneficial, the navigable portion of the river still remained in an extremely defective condition, and the great obstruction caused by the bar was unaltered.

In the year 1801 the conservancy of the port was, by an Act of Parliament, placed under the control of the Corporation for Preserving and Improving the Port of Dublin. Shortly before this, however, the increasing necessity for a further improvement of the harbour occupied the attention of the Directors-General of Inland Navigation, who consulted several of the highest engineering and nautical authorities on the subject. Among others who were requested to furnish plans and reports may be mentioned Sir Thos. Hyde Page, R.E., Messrs. Rennie, Huddart, Jessop, Bligh, and Corneille. The object to be gained was beset with many formidable difficulties. An insignificant river discharged itself into an extensive estuary filled with sand, its course through which for a distance of three miles was extremely shallow and tortuous, some parts of the channel having a depth of only 2 or 3 ft. at low-water, while about half a mile seaward of the harbour entrance lay the extensive sand-bank forming the bar, the depth on which was a little over 6 ft. at low water. The difficulties of the case were fully recognised at the time, Mr. Rennie stating in his report, dated March 1801, that ‘the improvement of Dublin harbour is perhaps one of the most difficult subjects which has ever come under the consideration of the civil engineer.' Reserving for a more detailed account the plan which was finally adopted, and which was originated by the Corporation

FIG. 8.



for Preserving and Improving the Port of Dublin, a brief notice of some of the principal plans proposed may not be uninteresting; they are embodied in a Report of the

Directors-General of Inland Navigation presented to the Lord-Lieutenant of Ireland in the year 1801, and will be better understood by reference to the small sketch-map shown in Fig. 8, copied from a plan of the same date.

Sir Thos. Hyde Page, to judge from his report and plans, seems to have considered the removal of the bar as hardly feasible; he proposed, however, that 'a portion of the bar in the bay might be raised above high-water by means of fascines and stones, with some small old vessels filled with the same kind of materials, and sunk into the body of the work to form an island, which would be attended with great advantages, confining the current to certain lines of direction, and causing deeper water.' In addition to this he proposed to build training walls on the north side of the river, following the irregular line of low-water. Neither of these plans appears to have been regarded with favour, and indeed it is difficult to conceive how the conversion of part of the bar into an island could assist the navigation; on the contrary, it would seem more likely that a nucleus would thereby be formed for the additional accumulation of sand, &c.

Page himself evidently did not expect any very considerable improvement to result from the proposed operation, for shortly afterwards he furnished a plan for the construction of a harbour at Sandycove Point, on the south side of the bay. This harbour was to form an out-port, communicating with Dublin by means of a ship canal carried across the country to the west side of the city. He also recommended the improvement of Dalkey Sound, so as to render it capable of affording shelter to inward and outward-bound vessels, and the formation of a harbour at Ireland's Eye, on the north side of Howth, for the same purpose.

The position of Sandycove Point at the entrance to the bay, where there is a depth of from 5 to 8 fathoms at low-water close to the shore, and sheltered from the prevailing S. and S.W. winds, was well selected for a harbour of refuge, but the project of a ship canal practically ignored the natural entrance to the port, and involved great outlay both for construction and maintenance.

The proposed canal was to be supplied with water from the Grand Canal, which connects Dublin with the River Shannon, the surface-level to be the same as that of the Grand Canal Harbour, at James's-street, and the depth 24 ft.

In the words of the report, 'a basin for ships will be proposed near the Grand Canal, from which the same level will be carried by an aqueduct over the river Dodder, near Milltown, and from thence on the same level across Mount Merrion-avenue, passing near Stillorgan Obelisk and Monkstown Church, to the falling ground near Sandycove Point, where locks will communicate with an entrance basin, and the deep water in the Day of Dublin, and be so constructed that ships may enter and leave the canal from the time of half-flood to half-ebb. From the ship basin near the Grand Canal a branch will communicate by locks with the river Liffey.'

The estimates for the works proposed by Sir Thomas Hyde Page are as follows:—

	£	s.	d.
Total estimate for Dalkey	246,796	16	0
Sandycove piers	1,204,305	12	0
Ireland's Eye and Howth	86,400	0	0
North training wall (7,000 linear yards)	168,000	0	0
Bar and a lighthouse at Dalkey	79,000	0	0

The project of a ship canal seems to have been favourably received, and indeed was revived in the year 1833, shortly after the construction of Kingstown Harbour, which is about one mile to the westward of the site of Page's proposed harbour at Sandycove.

Captain Bligh and Captain Corneille both recommended a continuous training wall on the north side of the river nearly parallel to the Great South Wall. It was intended 'to be continued from the present (A.D. 1800) end of the North Wall in the direction of a regular curve, dividing the waters without giving the ebb any resistance or any inclination but such as it has already.' The chief result to be expected from this wall would manifestly be the confining of the backwater from the upper portion of the river more to the esturial channel, which might have produced some improvement by deepening the then existing shoals. Its effect on the bar would probably have been inappreciable owing to the insufficient quantity of backwater.

The elder Rennie, whose report and plans were furnished in conjunction with Captain Joseph Huddart, appears to have availed himself of the information and ideas contained in the various schemes presented by his predecessors, and states his belief that the improvement of the port could be best effected and easier access obtained to the quays of Dublin by making an entrance harbour in another part of the bay, so far removed from the bar as to be uninfluenced by it, and where there would be a sufficient depth at low water, carrying the traffic thence by a ship canal to the city. Approving of Captain Perry's scheme, he also recommended a harbour at Sutton capable of accommodating vessels drawing 14 ft., having an area of about 5 acres, and communicating with the city by means of a ship canal 160 ft. in width at the surface, 80 ft. at the bottom, with a depth of 20 ft.

These works he estimated at £657,000. With regard to an out-port on the south side of the bay, he advocated a position westward of that proposed by Page, and close to the site which was subsequently selected for Kingstown harbour; his estimate for the entrance basin and ship canal to Dublin amounted to £490,000, exclusive of the necessary dock accommodation at the city end of the canal. Captain Huddart did not agree with Mr. Rennie as to the eligibility of the proposed site at Sutton.

Mr. Rennie also approved of the plan originally proposed by the Corporation for preserving and improving the port, namely, the construction of a north pier commencing on the Clontarf shore and terminating about 300 yards from Poolbeg Lighthouse, but in order to increase the scour on the bar he proposed to extend the Great South Wall 800 yards, and the north pier 1,100 yards, both in an easterly direction; also to carry a wall or embankment across the South Bull, inclosing a scouring basin of about 1,300 acres (see Fig. 8), the water from which could be discharged into the river channel where found most desirable. The total estimate for these works was £656,000.

Sir John Rennie states that by this outlay Mr. Rennie anticipated that it would be possible to increase the depth on the bar to such an extent as to obtain from 8 ft. to 9 ft. at low-water, and, although the cost might seem disproportionate to the result, he argued that if it could not be obtained by a less sum, the importance to the trade of Dublin of such an increase of depth was sufficiently great to warrant the outlay.

The expensive and elaborate schemes for the improvement of Dublin harbour which have been enumerated, although emanating from some of the highest engineering and nautical authorities of the time, were ultimately superseded by the much simpler expedient of a northern pier or Great North Wall before alluded to. It was not, however, until the year 1818 that any definite steps were taken to carry this project into execution, about which time the Port Corporation requested Mr. Francis Giles to prepare a new and complete survey of the river, and particularly of that part of the bay in which the bar was situated.

This survey, which was furnished by Mr. Giles in 1819, is most comprehensive, and contains full and accurate details of all the information required. The joint report of Messrs. Giles and Halpin, the latter of whom was then inspector of works to the Port Corporation, is dated May 6, 1819, and in it, having jointly agreed as to the most eligible position and direction of the proposed pier from the Clontarf shore towards Poolbeg Lighthouse, they state that 'the leading objects to be obtained by this wall are:—

'1. The sheltering of the harbour.

'2. The prevention of the sand passing from the North Bull into the harbour; and

'3. To admit as great a body of tide water as possible into the harbour, and to return the same past the lighthouse within such limits and in such direction as will produce the best scouring power to deepen the bar with the least obstruction to the navigation.'

The direction proposed was S.E. ¼ E. true bearing from a point on the Clontarf shore 500 ft. west of the road leading to the Green lanes: 'This straight line we propose to extend to the distance of 2,000 yards south-east from the shore of Clontarf, and there to commence a parabolic curve towards a point due north of the lighthouse, by which curve the direction of the ebb current will be graduated to a suitable course for effecting the best scour at the entrance of the harbour and upon the bar, and the proper width of the entrance will be practically determined as the embankment proceeds by its operation upon the current in the channel. The direction of the above line will likewise be well adapted to obviate the ravages of the south-easterly winds upon the embankment.' Accordingly in the same year the construction of the Great North Wall was commenced at the shore end in the position recommended, and in August 1822 it had been carried out to a distance of 5,500 ft. to its full height, viz. 6 ft. above standard high-water, about 1,500 ft. further to the level of high-water, and 500 ft. more to the level of half-flood.

At this period Mr. T. Telford was consulted, and, agreeing with Mr. Halpin that a still further extension was desirable, he recommended that it should be carried forward in the same direction for a further length of 500 ft. and to half-flood level, carefully observing the effects which would be produced upon the ebb and flood currents. This addition having been made, Mr. Telford in the following year recommended a still further extension in order to remove a sand-bank which was found to be forming between the point at which the wall then terminated and Poolbeg Lighthouse; it was accordingly extended 300 ft., and the additional scour thus obtained at once reduced the sand-bank, so that the depth upon it was increased from 4 ft. to 8 ft. at standard low-water. Subsequently another small sand-bank commenced to form near the centre of the channel, and in order to remove this obstruction the wall was further extended; this sand-bank will be again referred to.

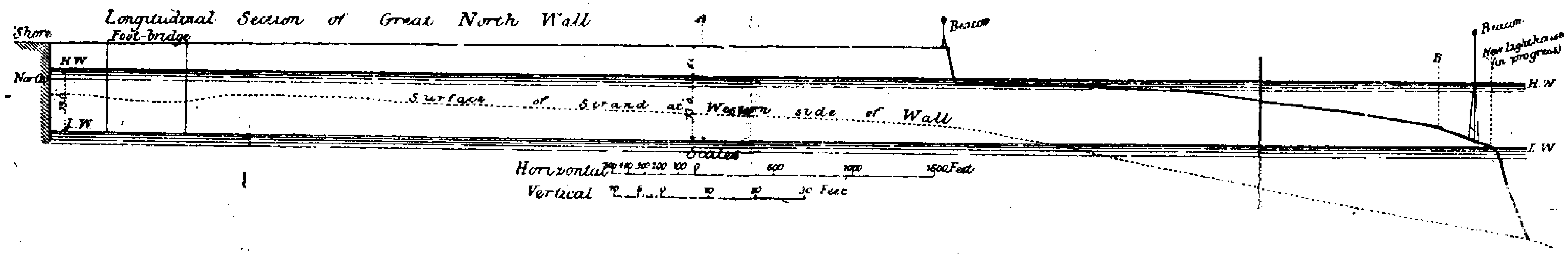
The Great North Wall as built has a total length of about 9,000 ft., and for a distance of 5,600 ft. from the shore the level of the top is 6 feet above standard high-water; for the remainder of its length it may be more fitly termed a submerged mound, the height varying from high-water level to about 1 ft. above low-water, from which, at its extreme end, it slopes down to a sandy bottom 25 ft. below low-water. A distorted longitudinal section is shown in fig. 9.

The wall or embankment is of the simplest possible character, consisting of large and small stones, rough from the quarry, deposited so as to form a rubble mound which was allowed to find its own foundation under the surface of the strand; the stone was obtained from both sides of the Bay, that from the north side was drawn in carts from limestone quarries situated not far from the shore end of the wall, the granite quarries on the south side furnishing the larger blocks, which were transported and deposited in position by small sailing vessels.

It is somewhat remarkable that the oldest method of constructing sea-moles, practised many centuries before the Christian era, has not been superseded in cases the conditions of which are at all similar to those of the work under consideration; indeed *pierre perdue* seems still to form part of the construction of nearly every breakwater of importance, and has been used as a foundation even in such modern instances as Holyhead, Kurrachee, and Brest.

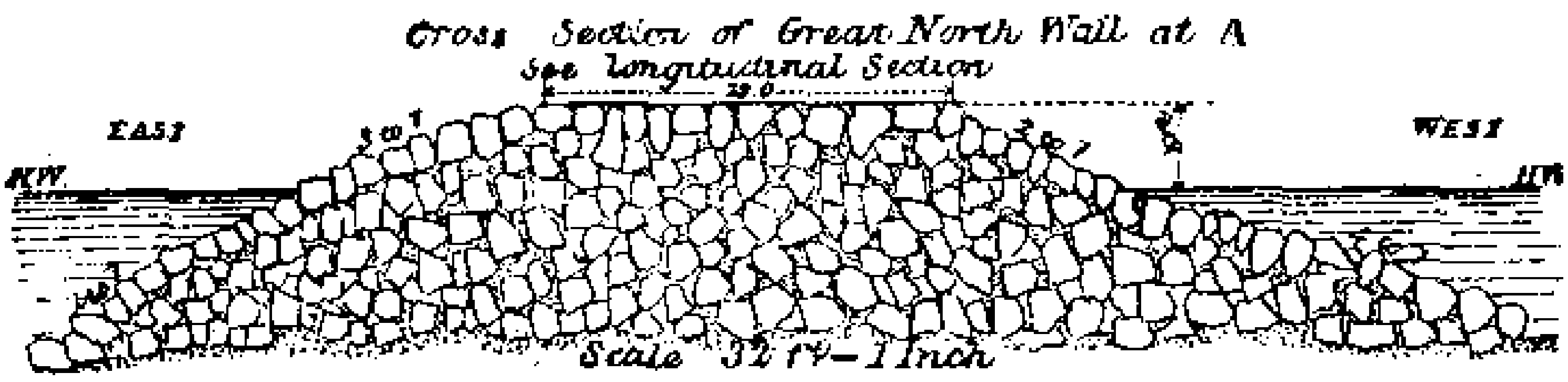
In the present instance it can be safely affirmed that no modern method would have answered the purpose more effectively or with smaller cost than the plan adopted. The building of the wall occupied nearly five years, being commenced in 1819 and completed as it now stands in 1824; the total cost was £103,055, or, on the average, rather more than £11. 10s. per foot forward. The direction of the wall is S.E. ½ E. from the north shore, and it terminates at a dist-

FIG 9


Longitudinal Section of Great North Wall
Shore
Foot-bridge
H W
L W
A
Beacon
B
Beacon
New lighthouse (in progress)
Surface of Strand at Western side of Wall
H.W
L.W
Scales
Horizontal
1500 Feet
Vertical
30 Feet

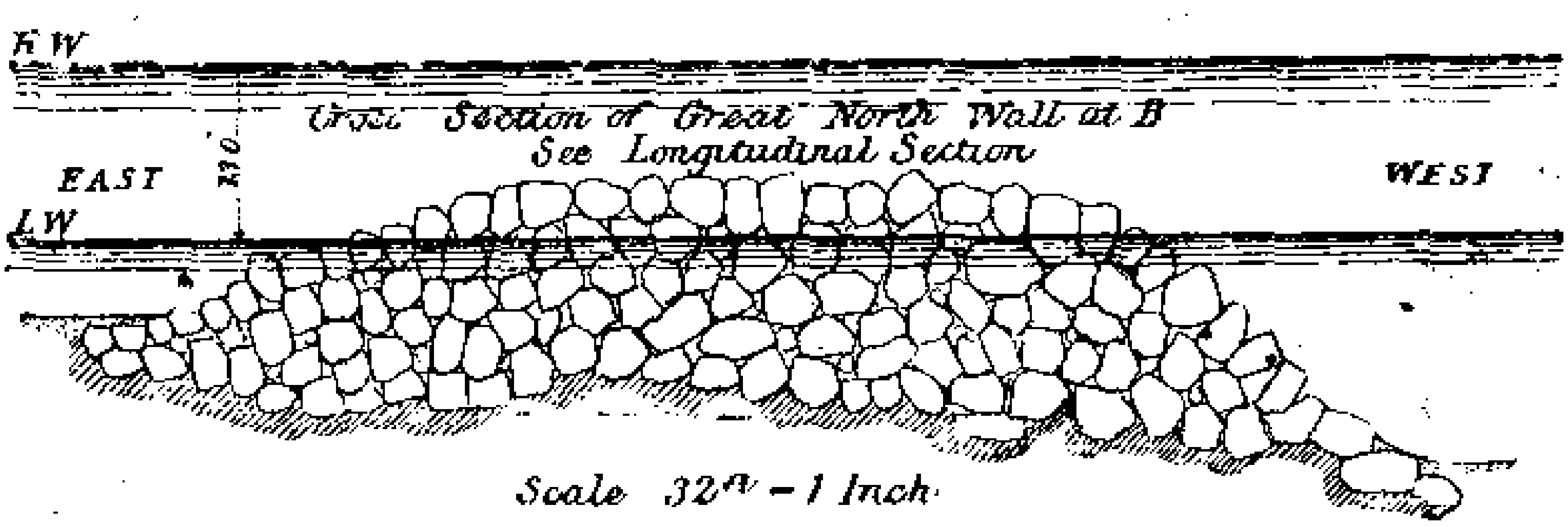
ance of about 1,000 ft., measured N.E. by E. from Poolbeg Lighthouse. The wall is practically straight from end to end, the parabolic curve recommended by Messrs. Giles and Halpin not having been adopted.

FIG. 10.



Cross sections are shown in figs. 10 and 11; the former may be taken as the average section of the higher portion, the slopes of which were no doubt steeper when first formed, but have become flattened and otherwise modified by the action of the sea, which sometimes breaks on them with violence, occasionally displacing portions of the rubble, and on the western side making slight breaches; these, however, very seldom occur, and the repairs are easily effected by filling up the cavities with fresh rubble. The section of the lower portion varies at every point owing to the gradual

FIG. 11.



alteration of its height. The section shown in fig. 11 is taken near the southern end of the wall, where it is much exposed to the action of the sea.

CHAPTER VI.

DUBLIN BAR—TREATMENT BY INDUCED TIDAL SCOUR.

Description of the bar—Standard tidal levels—Tides in the Irish Channel and Dublin Bay—Effect of depressing seaward end of Great North Wall—Amount of deepening produced by the scour—Sections of bar channel—Progress of removal of bar—Mumbles bank—Efficiency of ebb current assisted by dredging—Rapid increase of tonnage entering the port—Accumulation of sand on North Bull.

THE bar which in 1819 so effectually blocked the entrance to Dublin Harbour consisted of a flat shoal or bank of moderately fine sand, its western extremity was about 500 ft. east of Poolbeg Lighthouse, from whence it extended in an easterly direction for nearly 5,000 ft. The deepest channel into the harbour at this time was situated between the western edge of the southern part of the bar and the South Bull, having a direction about S. by W. true bearing from Poolbeg, and curving round to the S.E., with a minimum depth of 8 ft. 3 in. below standard low-water. This channel was formed and kept open by the scour of the flood tide, which, entering the bay from the S.E., flows round the edge of the South Bull; it has remained practically unaltered to the present time, as indeed might naturally be expected, from the fact of the producing cause having undergone no alteration.

The deepest channel over the bar had a direction E. by S. true bearing from Poolbeg with a minimum depth of 6 ft. 6 in. below standard low-water; the main set of the ebb tide is shown on Mr. Giles's chart to have been somewhat to the southward of this line. The difference in direction is singular, for the bottom of the bay consisting of fine homogeneous sand, the deepest channel would, *cæteris paribus*, be the best indication of the direction of the strongest current. The harbour, therefore, was approached by two shallow channels, the deeper and more indirect formed by the scour of the flood tide and the other by that of the ebb tide. The esturial portion of the river extending from Poolbeg to Ringsend was shallow, the channel irregular in depth, and obstructed by shoals, one of which between the Pigeon House and Ringsend had a depth upon it of only 2 ft. to 3 ft. at low-water.

Frequent reference having already been made to the standard low-water of the port, it may here be stated that previous to Mr. Giles's survey of 1819 this important datum plane had not been properly defined, for which reason an accurate comparison of the older charts with one another, or with those of more recent date, is impossible. It is usual in every port to establish a definite standard tide, the high-and low-water level of which should be referred to suitable fixed bench-marks and tide-gauges. The standard tide of the port of Dublin was determined by Mr. Giles by observing the high- and low-water of spring tides at the following places and times, viz. at Kingstown from November 1815 to March 1816, at Howth Harbour from May 1817 to November 1818, and at Poolbeg Lighthouse from June 1818 to November 1818.

The low water or zero of this tide is 6·66 ft. below the mean level of the sea round Ireland, and 1·43 ft. above the Irish Ordnance datum plane. The latter is the level of the low-water of a spring tide observed at Poolbeg Lighthouse on April 8, 1837. That the ordnance datum should have been referred to a single observation of such an extremely fluctuating level seems somewhat singular, the apparently more obvious course being to assume the datum plane at a definite number of feet below the mean sea level. The standard tide has a range of 13 ft., or, in other words, standard high-water is 13 ft. above zero; its half-tide level is, therefore, about 2 inches below the mean sea level.

From recent and more extended tidal observations it would appear that Giles's low-water is rather below, and his high-water rather above, that of ordinary spring tides, the standard high-water and low-water representing more nearly those of equinoctial springs; this, however, is on the whole rather an advantage, as it gives a wider margin of safety to soundings reduced to the standard low-water, which are those given on the Admiralty charts of the bay and river. The average high-water of springs and neaps is about 11 ft. 3 in., and the average low-water about 2 ft. 5 in. above standard low-water; the mean range is, therefore, 8 ft. 10 in. High-water at full and change occurs at eleven hours twelve minutes. The tides besides being influenced to a slight degree by alterations in atmospheric pressure, are at Dublin as elsewhere considerably affected by winds, a strong S. or S.W. wind in the Atlantic heaping up the water in the Irish Sea, and on some occasions producing a double tide. In one instance, which came under the author's observation, the tide having fallen 15 inches from high water rose again 22 inches, causing a second high-water 7 inches higher than the first. The effect of wind in raising the water on coasts has been found to amount to 1½ ft. in the Tuscan Sea, 3¼ ft. in the Adriatic, and frequently to 6½ ft. in the Ocean.

The tide from the Atlantic enters the Irish Channel simultaneously through its northern and southern entrances;

the western portion of the stream from the south flowing northward follows a direction nearly parallel to the Irish coast. Abreast of Arklow, which is about 40 miles south of Dublin, there is scarcely any rise or fall of tide, although the current sweeps past at the rate of 4 miles an hour. From this remarkable spot the velocity of the stream gradually decreases, and when off the entrance to Dublin Bay it flows during spring tides at the rate of from 1½ to 2 miles per hour; continuing its course it ultimately blends with the corresponding branch of the stream from the northward, between the Isle of Man and Carlingford, both currents expending themselves in a large body of permanently currentless water, where the reverse phenomenon to that described as occurring near Arklow takes place, the tide rising and falling without producing any current. The course of the ebb tide corresponds very nearly with the flood, except that the direction is reversed.

The flood tide begins to fill Dublin Bay from the south side of the entrance, the main body setting across the bay in a north-westerly direction on to the North Bull; a branch of the stream flowing westward past the entrance to Kingstown Harbour curves round to a direction nearly due north, while a second branch, keeping more to the westward, skirts the edge of the South Bull, passing round the base of Poolbeg Lighthouse into the estuary contained between the Great North and South Walls. At the north side of the entrance to the bay the flood sets in an easterly direction; in the outer part of the bay, therefore, the flood current describes a curve entering from the south side, passing round and coming out at the north side and again joining the main flood stream in the Channel.

The course of the ebb current may be taken generally as the reverse of that of the flood tide, except that at the north-east side of the Bay the first half of the ebb for a comparatively short distance from the Bailey runs in a westerly direction, the remainder of the ebb and the whole of the flood forming a nine hours' stream, setting to the north-east; this stream, however, is confined to a comparatively small area on the north side of the outer part of the bay. The whole of the ebb from the estuary runs in an easterly and south-easterly direction, some of the first part of the ebb meeting and blending with a small part of the westerly current just mentioned, in deep water nearly 2 miles eastward of the bar.

The area of the estuary confined by the Great North and South Walls, including the tidal portion of the rivers discharging into it, and a strip of backwater between the North Bull and the mainland, is about 2,600 acres, or a little over 4 square miles, viz.:—

Estuary proper	2,240
Tidal portions of Liffey and Dodder	100
Backwater between North Bull and mainland	260
Total	2,600

Of this about 600 acres are below low-water, and the remainder is estimated to be about 3 ft. 6 in. above low-water. The average quantity of water flowing into and discharged from the estuary is about 25 million tons per tide each way.

The width of the opening through which this tidal backwater is discharged diminishes as the tide falls; at the commencement of the ebb the width is over 4,000 ft., the water flowing over that part of the Great North Wall which is below high-water; shortly before low-water the outlet is narrowed to rather less than 1,000 ft., the effluent stream being then confined between Poolbeg Lighthouse and the extreme end of the wall.

The main ebb current as defined by the deepest channe flows over the bar in a direction E. ½ S. true bearing from Poolbeg, frequently attaining a velocity of 3¼ miles per hour; the greatest velocity generally occurring at half-ebb of high spring tides, and in all cases decreasing considerably as the stream spreads and enters the deep water east of the bar. A branch of the ebb stream from the estuary flows across the bay in a south-easterly direction, and the remainder of the ebb, taking a course to the north of east, runs nearly straight for the Bailey.

The object sought to be gained by terminating the higher portion of the Great North Wall at so considerable a distance from the southern side of the entrance was apparently to avoid producing such a current as would be injurious to navigation; a greater velocity than 4 miles per hour at the entrance to a harbour being undesirable and liable to cause inconvenience if not danger, particularly to sailing vessels. It appears, however, to the author, that the wall might have been carried to its full height considerably further with advantage, as the effect of prolongation—say to the point where the wall is at present only raised to half-tide level—would be to increase the present velocity of the tidal current during the first half of the ebb only, and to assist in confining and concentrating its beneficial influence nearer to the entrance channel. Any arguments in favour of the depression of so great a length of the wall that have come under the author's notice are too conjectural to be of much practical value.

The history and method of the construction of the Great North Wall, as also the tenour of the reports which were obtained from eminent engineers and others, at intervals

FIG. 12.
CHART OF DUBLIN BAR.

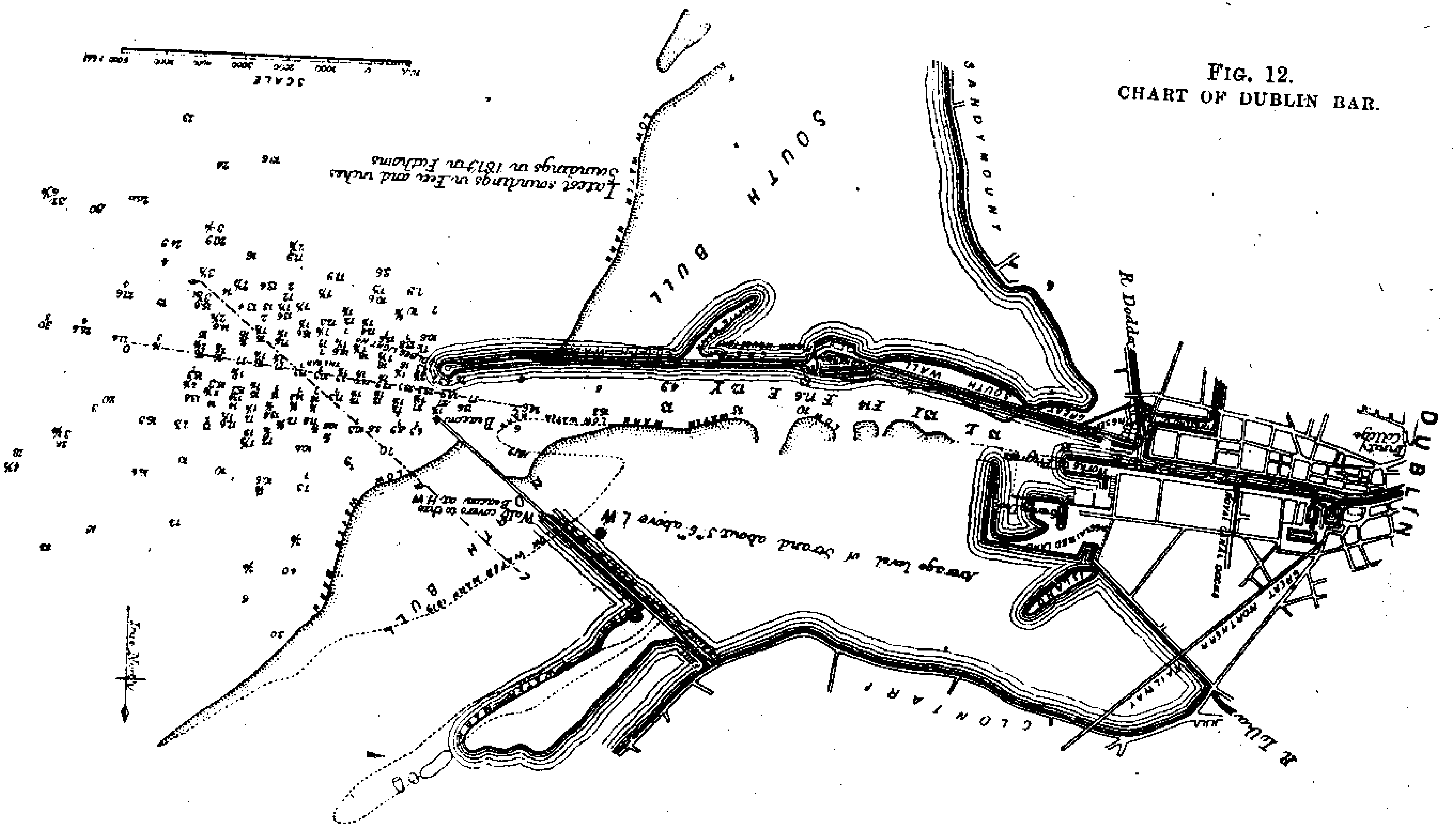
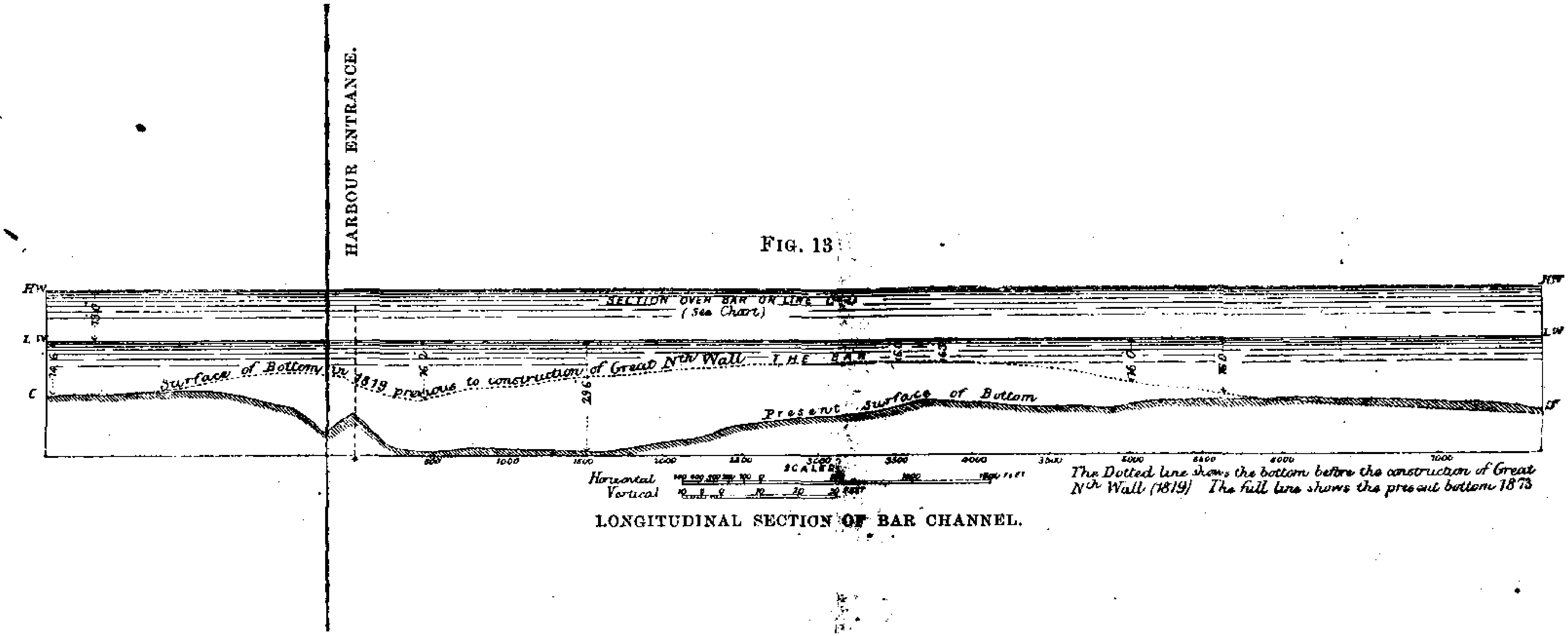


FIG. 13



LONGITUDINAL SECTION OF BAR CHANNEL.

during the progress of the work, show plainly that its present form was the result of a tentative process quite in accordance with Messrs. Giles and Halpin's first report before quoted, the governing considerations being, the production of 'the best scouring power to deepen the bar, with the least obstruction to navigation'; the non-completion of the southern portion to its full height being attributable simply to the fear of increasing the velocity of the current to an inconvenient or dangerous extent. Nor is the feeling of over-caution to be wondered at when it is remembered that at the time steam towing was practically unknown, and that the wall even in its unfinished condition had nearly doubled the velocity of the ebb current at the entrance, and had already developed such a large amount of scouring power.

The remarkable success which has attended the application of induced scour in the removal of the bar at Dublin will be understood by reference to the chart and sections shown in figs. 12 to 20.

Fig. 12 is a chart showing the river, estuary, and bar; fig. 13 is a distorted section along the deepest channel (line C D on chart); figs. 14 to 20 represent cross sections of this channel 1,000 feet apart, the first being taken across the harbour mouth. The line C D does not strictly follow the course of the deepest channel, as will be seen from the cross sections; it is, however, sufficiently near for the purpose required, and can be more conveniently dealt with, being straight.

In fig. 12 two sets of soundings are shown, those in *fathoms* are the depths in 1819; the latest soundings, taken from Commander Kerr's survey, 1873, are marked in *feet and inches*. In the cross sections of the Bar channel, the upper figures marked on the centre line (line C D in fig. 12) are the depths in 1819, the lower figures, the depths in 1873. The increase in the depth of the channel is remarkable, amounting in some instances to 20 ft., the point of maximum useful effect occurring at about 1,500 ft. from the

FIG. 14.

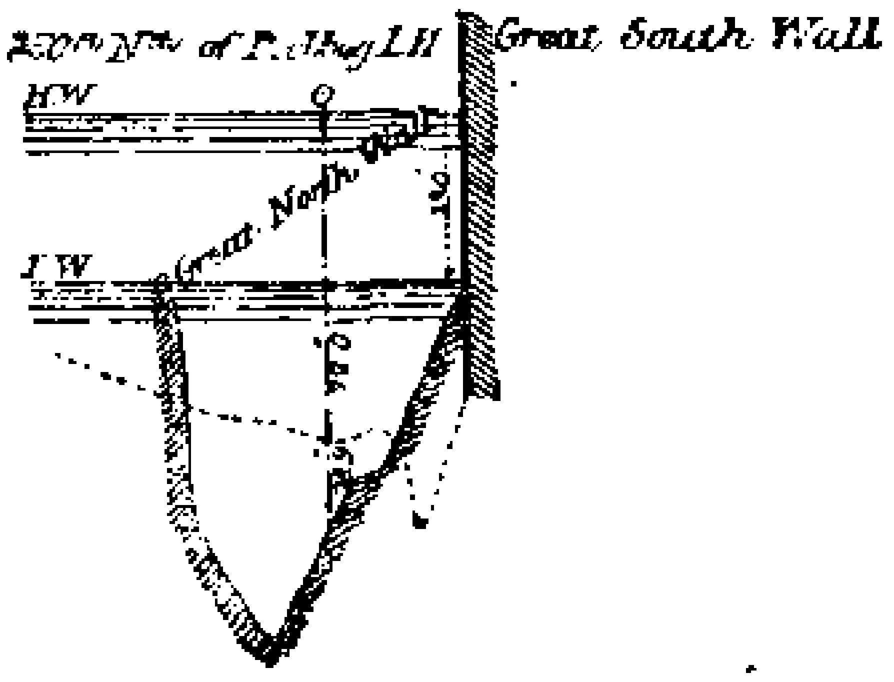
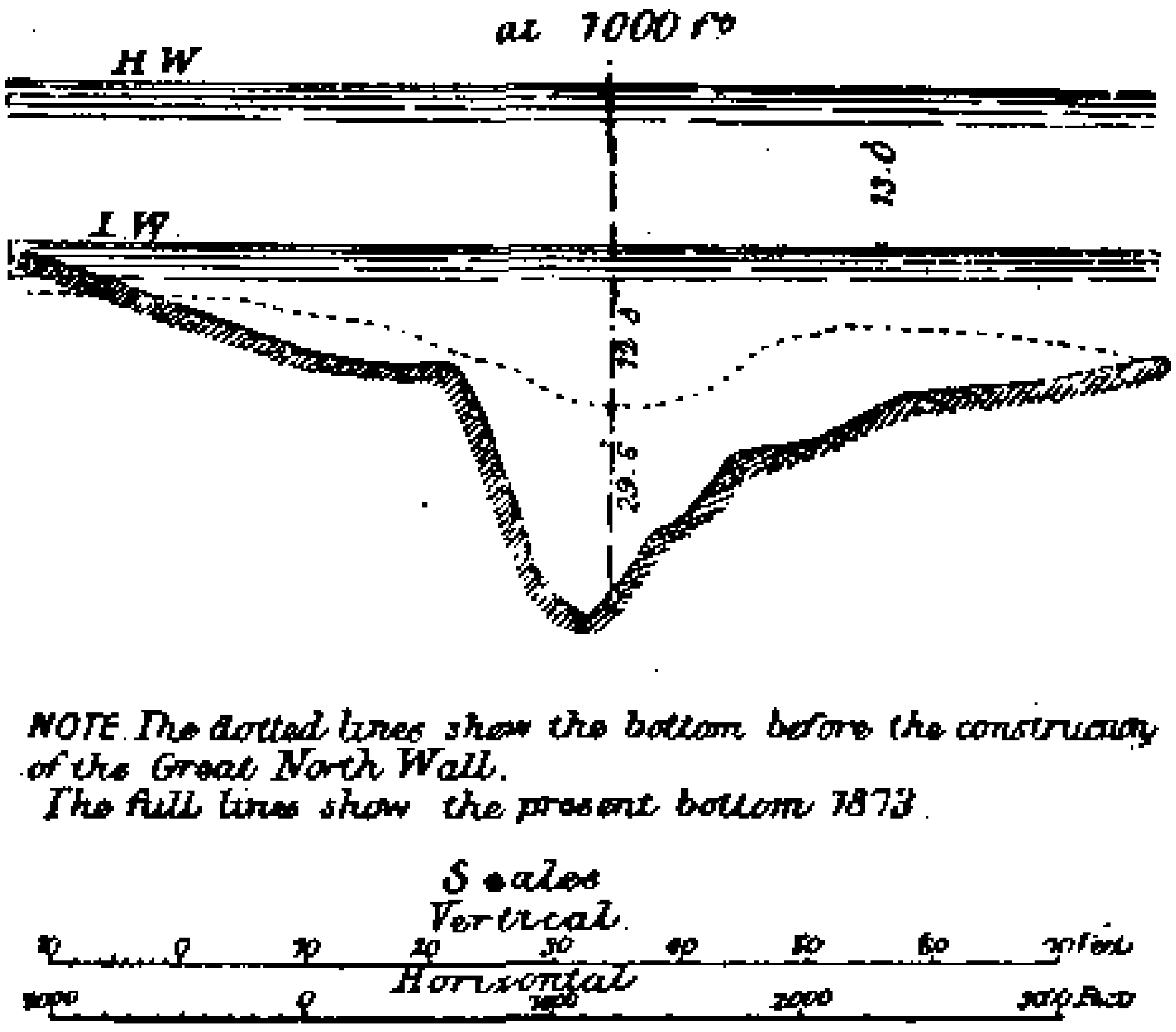


FIG. 15.



entrance. The scouring action extends over a large area, difficult to define, but probably exceeding 800 acres; on a considerable portion of this, however, lying northward of the bar channel, the alteration is but trifling, while a little to the south-west of the end of the Great North Wall the current has excavated the bottom to such an extent that there is now a depth of about 33 ft. at low-water where formerly the depth did not exceed 8 ft. or 9 ft.

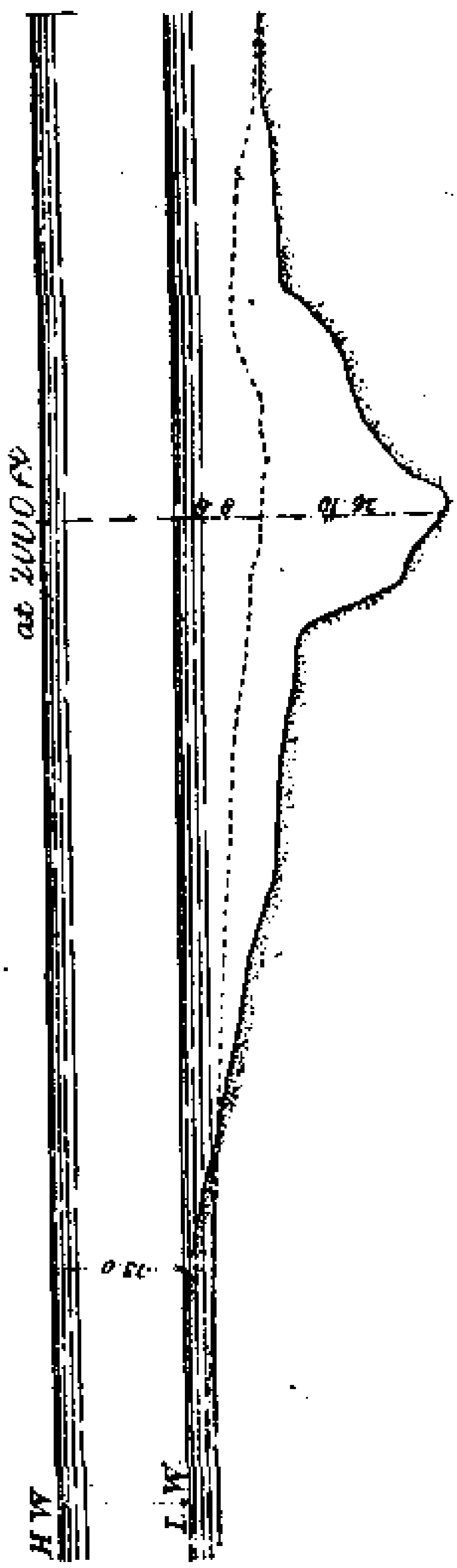


FIG. 16.

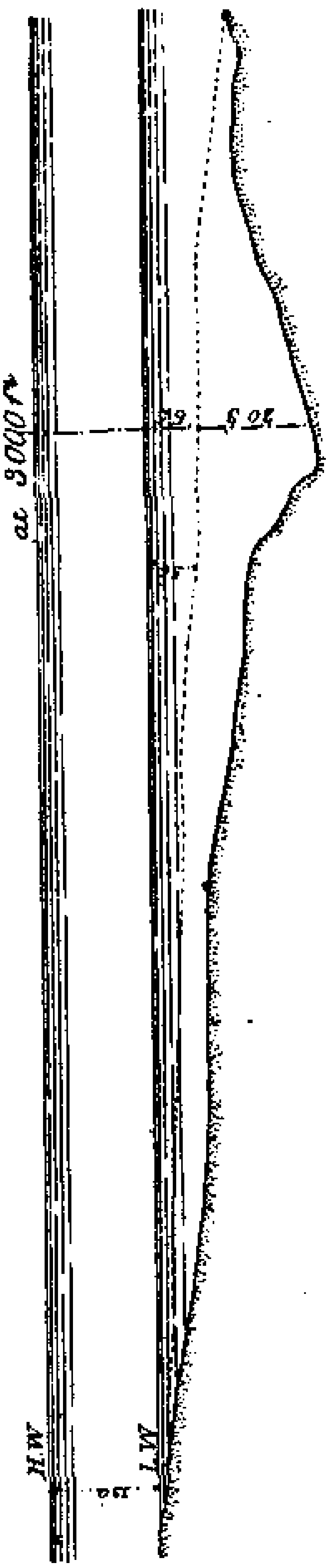


FIG. 17.

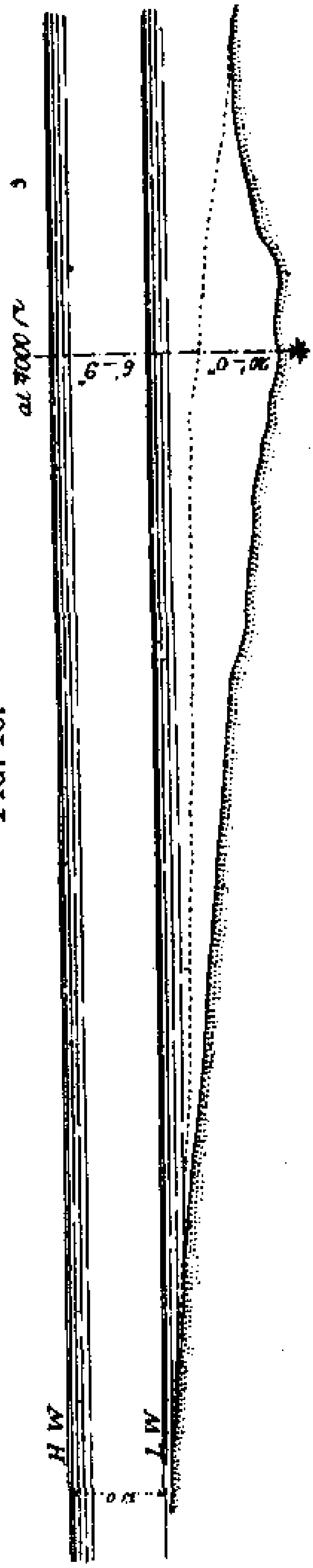


FIG. 18.

The effect of the scour in deepening the channel through the bar may be briefly summarised as follows.

For a distance of about 2,500 ft. from the harbour entrance the average depth below low-water has been increased from 11 ft. to 27 ft.; for the next 2,000 ft. the average depth has been increased from 6 ft. 9 in. to 18 ft., and the remaining part of the channel, to about 6,000 ft. from the entrance,

FIG. 19.

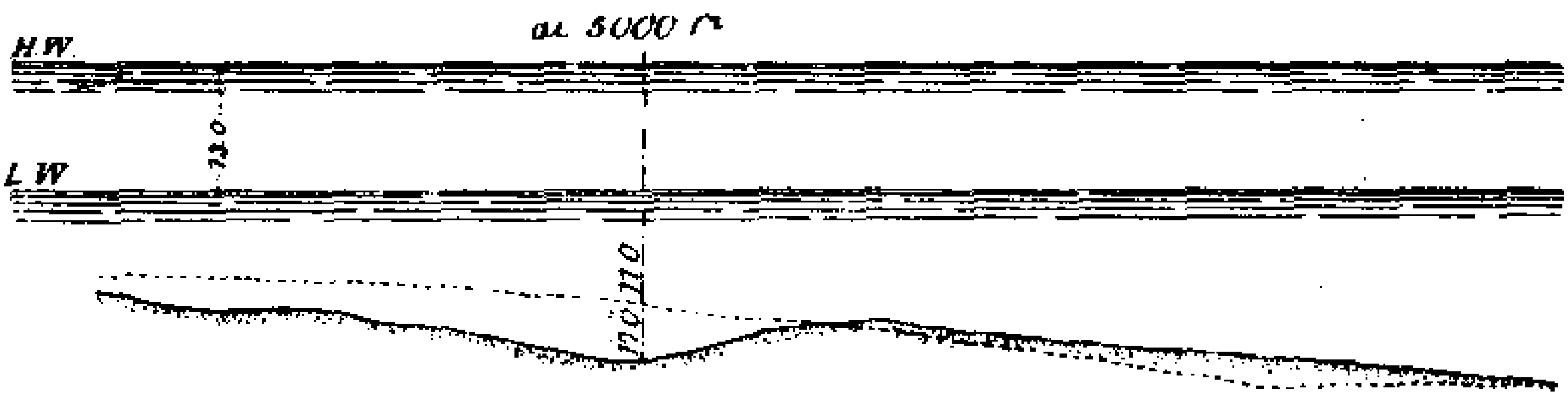
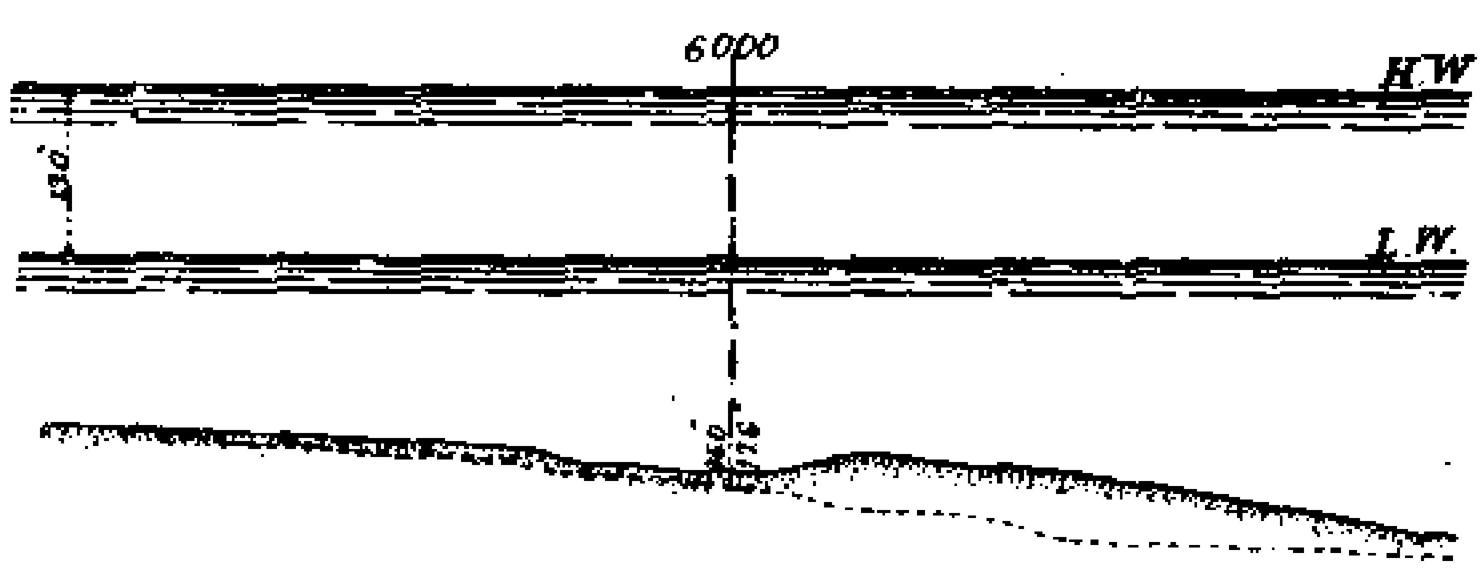


FIG. 20.



has had its average depth increased from 13 ft. to 16 ft., so that there is now an available depth over the bar of 29 ft. at standard high-water, or about 28 ft. at ordinary springs. These results the author believes far exceed those of any other recorded instance of artificial scour.

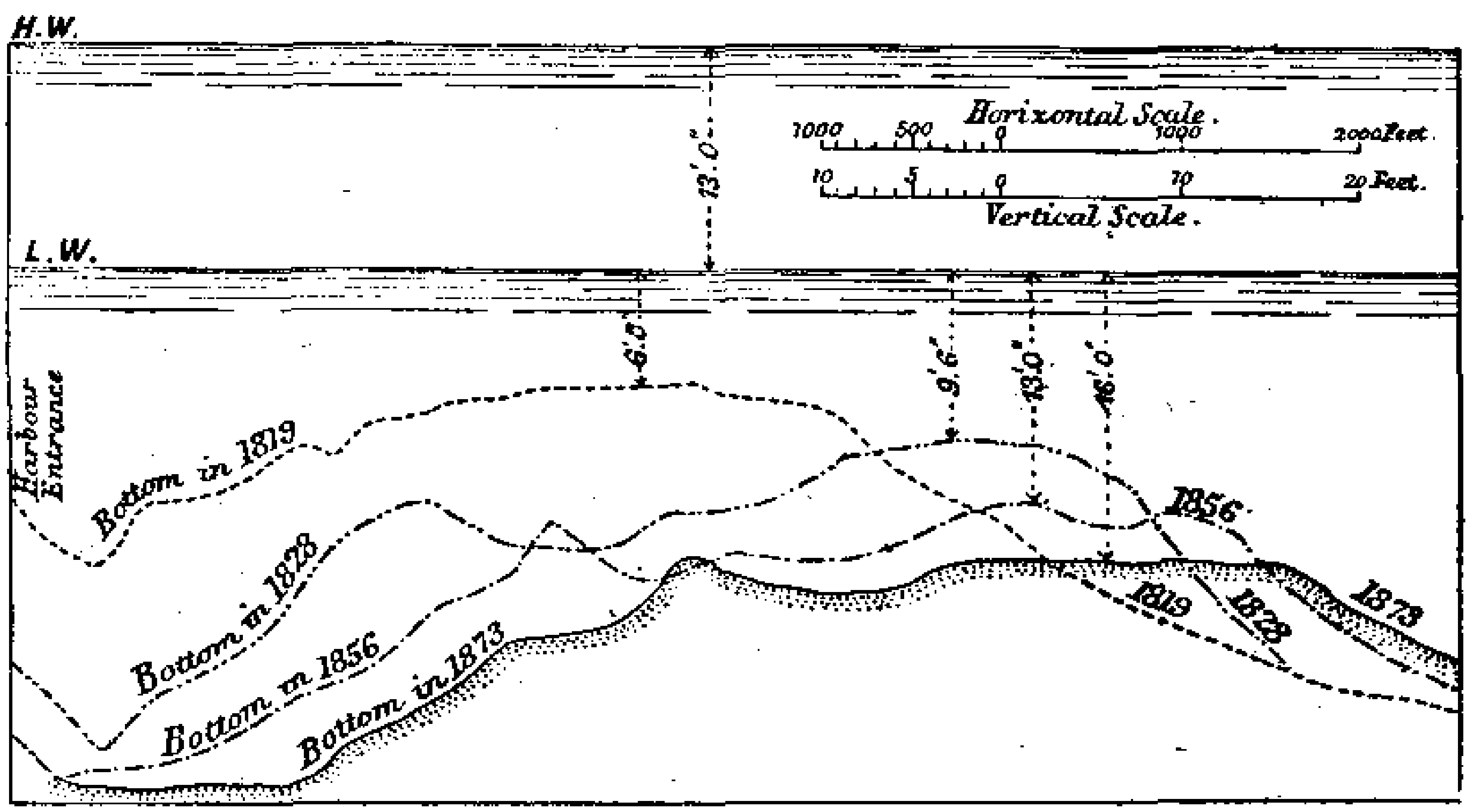
At about the last-named distance is situated what may be termed a nodal point, the depth being the same now as in 1819. To the eastward of this point the soundings show a slight decrease in the depth, due to the presence of some of the sand removed by the tidal current from the channel and pushed out nearer to the deep water of the bay. Including spring and neap tides, the mean quantity of tidal water entering and leaving the estuary as before mentioned can scarcely be less than about 25 million tons per average tide, but it is hardly possible to form any estimate as to what proportion of this has been available in producing the effects above described. From half-tide to low-water the average discharge is about 10½ million tons per tide. The quantity of upland or fresh water flowing into the estuary is comparatively insignificant, not exceeding about one thirty-eighth part of the tidal discharge. The cross sections are taken looking eastward; in the figures the north is therefore to the left and the south to the right.

The width of the channel varies considerably, as will be seen from the sections. Taking 16 ft. below low-water as a minimum depth, the channel is about 600 ft. wide at the entrance, increasing towards the middle of the bar to 1,400 ft., and diminishing to 400 ft. at a distance of 5,500 ft. from the entrance; further to the eastward it narrows still more, until it meets the deep water at about 8,000 ft. from the entrance. Figs. 19 and 20 show part of the slight accumulation of sand before alluded to, southward of the assumed centre-line.

A reference to the chart will show that inside the four-fathom line, and to the south of the point D, there has been a slight diminution of the depth, but when the vast quantity of sand which has been dislodged by the scour is taken into consideration, this decrease must be regarded as comparatively trifling; the mass of the material removed from the bar having evidently been carried far out into the bay and distributed over so large an area as to be practically imperceptible.

Fig. 21 shows the progress of removal of the bar; the sections are taken from the harbour entrance, along the line C D (see chart, fig. 12), and are plotted from surveys made at four different dates, viz. that by Giles in 1819; by Commander W. Mudge and Lieut. Fraser, R.N., in 1828; by Robison Wright in 1856; and the latest by Commander Kerr, R.N., in 1873.[1] The sections harmonise with one another, and show the persistent action of the scour in the continuous improvement of the channel through the bar.

FIG. 21.



Assuming the induced scour to have commenced in 1820, although the Great North Wall was then only partly constructed, it will be seen from the figure that the greatest effect, relatively to the length of time occupied, took place between that date and 1828; the chief part, however, of the material removed appears to have been merely pushed further to seaward, and to have accumulated again east of a nodal

[1] A survey of the Liffey and Dublin Bar was made in October 1880, by Staff Commander C. H. Langdon. See p. 73.

point then situated about 5,000 ft. from the entrance. In the interval between 1828 and 1856 a similar effect is apparent, the nodal point being 1,500 ft. further out, and the shoaling eastward of it much less than that produced during the previous period. Between 1856 and 1873 the quantity removed is considerably less than that of either of the preceding periods, but the nodal point is still further to seaward, and nearly the whole of the sand excavated by the tidal scour has been carried away completely clear of the bar.

The quality of the sand forming the present bottom of the bar channel varies with the distance from the entrance; at the west end the sand is coarse, and mixed with fragments of broken shells, the granulation being such that the greater part would be stopped by a sieve with perforations of one-sixteenth of an inch in diameter, while at the east end the bottom consists of what is usually known as fine sand, about 90 per cent. passing through a sieve with 3,000 meshes to the square inch. The ridge shown in fig. 13 to exist in the present bottom near the entrance is of small extent, deep water occurring a few feet to the north; it is therefore omitted in fig. 21. The two sets of figures shown in the cross sections of the channel are the respective depths below low water in 1819 and 1873.

The following Table shows the progress and rate of the increase of the minimum or limiting depth caused by the tidal scour, which is still active in producing a further gradual improvement of the channel through the bar.

TABLE I.

Date	Minimum depth on bar at low water	Interval years	Increase of minimum depth	Rate of increase of minimum depth per year	Depth on bar at standard high water
	ft. in.		ft. in.	in.	ft. in.
1819	6 6	—	—	—	19 6
1822	8 6	3	2 0	8·0	21 6
1828	9 6	6	1 0	2·0	22 6
1838	10 6	10	1 0	1·20	23 6
1856	13 0	18	2 6	1·66	26 0
1873	16 0	17	3 0	2·11	29 0

Total increase of minimum depth between 1819 and 1873,—9 ft. 6 inches. Average rate of increase a little over two inches per annum.

The effects which have been described are almost entirely due to the action of the ebb currents, but the flood, running into the harbour in an opposite direction at a velocity approximating, near the entrance, to that of the ebb, produces similar results, and there can be little doubt that the great increase of depth at the western end of the bar-channel is attributable to the joint action of both the ebb and flood currents; we should, therefore, expect that the material removed by the scour of the flood tide should manifest itself somewhere to the westward of the position from which it had been removed.

The Mumbles bank, which has already been referred to as having begun to form shortly after the construction of the Great North Wall, appears to the author to owe its formation chiefly to the action of the flood current. It consists of a ridge of loose sand situated inside the harbour mouth, on the south side of the river channel, about 100 to 150 yards north-west of Poolbeg lighthouse, and is composed of a mixture of coarse and fine sand and broken shells. From the loose manner in which these materials are deposited they would appear to be heaped up by an eddy, the production of which is favoured by the shelter afforded by the Great South Wall and the large rubble mound protecting the lighthouse foundations on the north and north-west sides; this accumulation does not, however, appear to be wholly due to the action of the flood tide, the finer sand of which it is composed being probably washed off the strand westward of the Great North Wall by the ebb tide.

The Mumbles bank accumulates at the rate of about 10,000 tons per year, which is removed every alternate summer by dredging; the sand being of excellent quality for building purposes, a considerable quantity is reserved for use in the Port works.

The deepening produced by the scour of the flood current after passing through the entrance into the estuary is but inconsiderable compared with the corresponding effect of the ebb current after its passage through the entrance into the bay.

This great difference the author believes to be mainly attributable to two causes:—

1. The flood tide, approaching the entrance from different directions, almost immediately after entering the estuary, expands over a large open area; while, on the other hand, the ebb stream, particularly the latter half, has a definite direction imparted to it before passing out into the bay, by which it is kept together and its energy concentrated.

2. The flood current enters comparatively still water, and an area so sheltered that waves of sufficient size to affect the bottom are seldom generated, whereas the action of the ebb current is considerably enhanced by the agitation of the sandy bottom produced by waves, the generation of which is favoured by the exposed position of the bar.

The dredging operations which have been carried out in that portion of the river channel near the entrance have doubtless added to the efficiency of the scour by deepening and straightening the channel, and thus assisting to impart greater definiteness of direction to the ebb current and enabling it to flow more freely.

The great importance of a deep-water channel through the bar, to the trade and commerce of Dublin, can scarcely be over-rated, particularly when we consider the remarkable increase in the size of merchant vessels which has taken place during the last forty years.

In the year 1835 the largest vessels employed in the foreign trade rarely exceeded 400 tons register; at present these are replaced by vessels of 1,600 tons register, carrying usually about 2,200 tons, and drawing up to 23 ft., the economy of employing such large vessels being so considerable as to render deep water accommodation absolutely essential to the carrying on of the foreign trade. The advantage to the coasting trade is no less apparent, for vessels drawing up to 13 ft. or even 14 ft. may now enter and leave the port, so far as the bar is concerned, independently of the tide, except when an extraordinary low water, combined with a heavy sea, renders it more advisable to wait for one or two hours' flood.

The following table (p. 69) is condensed from the official returns of the tonnage entering the port.

The tonnage entering the port annually between the years 1788 and 1825 fluctuated between 193,830 tons and 416,978 tons; since the latter date, which corresponds with the completion of the Great North Wall, the annual tonnage, with a few trifling exceptions, has steadily increased from 396,053 tons in 1825, producing an income of £12,841,

TABLE II.

Average annual tonnage entering the port in five year periods.		Increments
	tons	
1801–5	346,225	
1806–10	357,947	11,722
1811–15	371,574	13,627
1816–20	340,017	31,557
1821–25	366,472	26,455
1826–30	472,189	105,717
1831–35	525,308	53,119
1836–40	552,379	27,071
1841–45	596,822	44,443
1846–50	765,329	168,507
1851–55	874,532	109,203
1856–60	950,715	76,183
1861–65	1,215,149	264,434
1866–70	1,447,502	232,353
1871–75	1,618,876	171,374

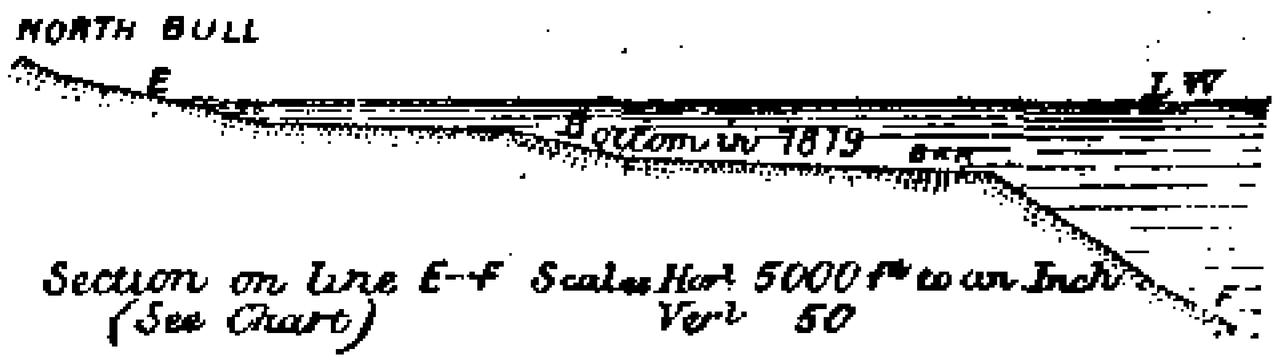
£59,315 6*s.* 5*d.*: thus in a little over fifty years the income has been considerably more than quadrupled.

From the table it will be seen that the average annual tonnage for the five years ending 1815 exceeded that of the two following periods, the first substantial increase occurring between 1826 and 1830. The greatest increase took place during the five years ending 1865, the increments in the two succeeding periods not being so considerable. Many causes have doubtless combined to produce the favourable results shown in the table; railways have connected the metropolis with all parts of Ireland; the river channel has been considerably deepened by dredging, and deep water quays, probably unsurpassed by those of any other port, have been constructed under the direction of Mr. B. B. Stoney, Engineer to the Dublin Port and Docks Board.

With reference to the origin of the bar at the mouth of the Liffey, the author has no hesitation in attributing its formation to the combined action of waves and the current of the flood tide; the former stirring up and keeping in agitation the fine sand of which the bottom of the bay is composed; the lower stratum of the water becomes, therefore, surcharged with sand which is carried along the bottom by the flood current setting across the bay from the south, and heaped against the North Bull sand-bank, which in the author's opinion has itself been formed in a similar manner, the bar being nothing more than the submarine extension of this bank.

Fig. 22 represents a section across the bar, before the construction of the Great North Wall, taken nearly at right

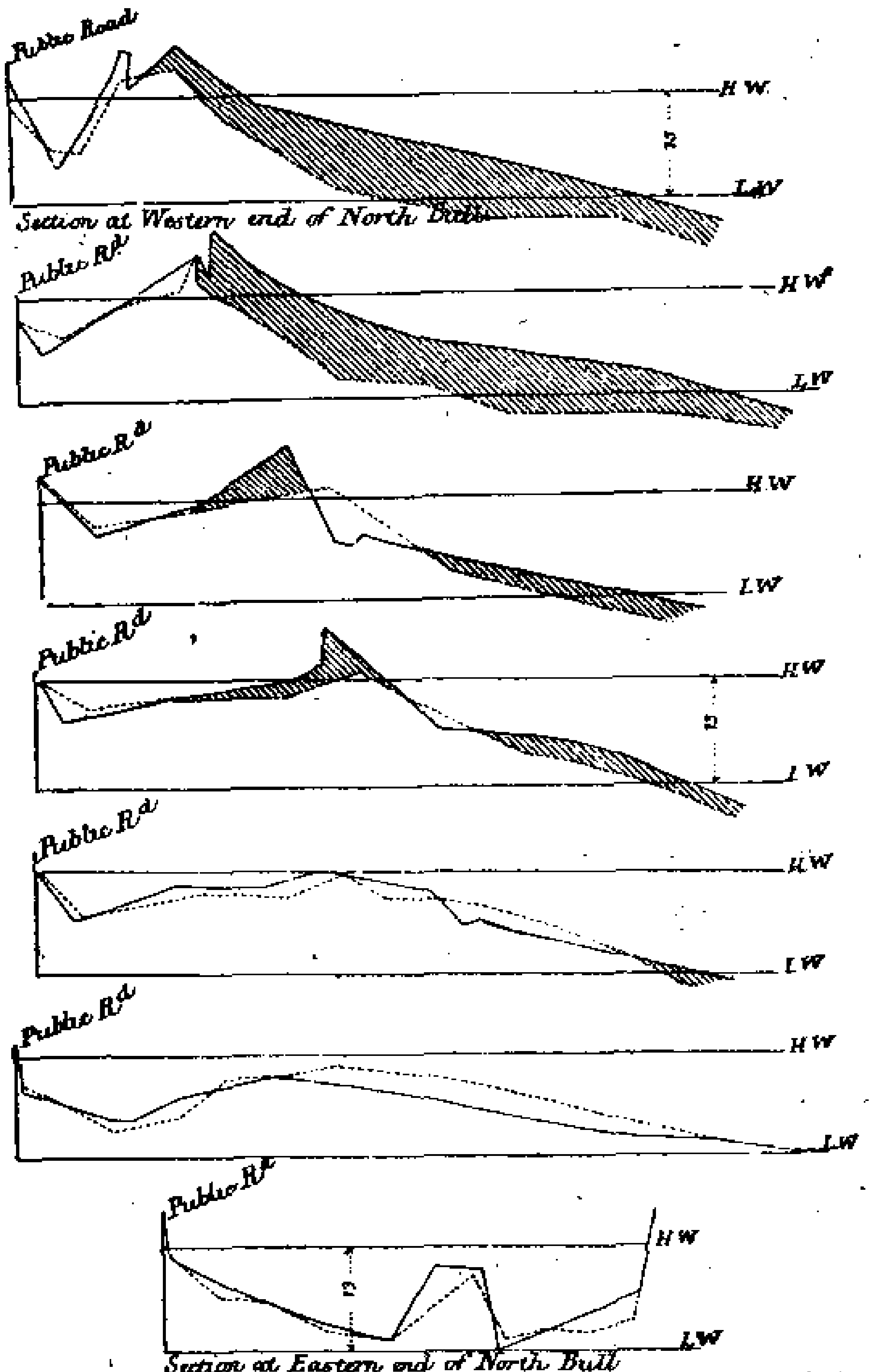
FIG. 22.



angles to the line of low-water on the North Bull (line E F on chart, Fig. 12), the contour of the part below low-water presenting all the appearance of a submerged beach.

A scheme for the reclamation of the North Bull in connexion with the disposal of the Dublin sewage proposed in 1865, necessitated the interference of the port authorities, and the author was directed to make a series of sections over the Bull parallel to the Great North Wall; a comparison of these with similar sections taken from Mr. Giles' survey of 1819 shows that since the latter date a considerable accumulation of sand had taken place on the western portion of the south side of the Bull, the position of the low-water mark being altered to a corresponding extent and carried further out to the southward. (See Fig. 12, p. 58.) The total quantity of sand thrown up by the sea above low-water on the North Bull between the years 1819 and 1865 may be estimated at about 9,000,000 cubic yards,

FIG. 23.



The dotted lines show the surface before the construction of the Great North Wall (1819) The full lines show the surface in 1865

Scales
Horizontal, 4000 ft. = 1 inch.
Vertical 40 ft. = 1 inch.

or at the rate of nearly 196,000 cubic yards per annum, and the low-water line at the western end of the southern flank had advanced about 3,000 feet seaward, equivalent to an annual advance of more than 60 ft. On the north-eastern portion of the Bull, as may be observed in the sections, a considerable amount of wasting had occurred, estimated altogether at about 2,750,000 cubic yards. Fig. 23 represents the sections referred to, which are taken at intervals of half a mile; the accumulated sand is shown by the shaded part of the figures.

At the western or inner side of the Great North Wall no accumulation has occurred, but on the contrary the depth has been increased so that the passage of sand into the harbour, as anticipated, has been effectually arrested.

The sand which has been thrown up on the North Bull is extremely fine, about ninety per cent. passing through a sieve of 10,000 meshes to the square inch; it is therefore capable of being easily held in suspension by agitated sea water.

As regards the future of Dublin Bar, it is of course difficult to speculate with any degree of certainty; it seems reasonable, however, to assume that the flood-current assisted by wave-agitation will continue active in producing further accumulation.

Should this accumulation ultimately threaten to encroach upon the present deep-water channel through the bar, several expedients still remain to meet the exigencies of the case. The present scour can be increased by raising the depressed portion of the Great North Wall; the capacity of the Estuary can be enlarged by dredging that part which is now above low-water, the volume of tidal water being thereby augmented, and the Great North and South Walls can if necessary be carried further eastward, so as to concentrate and impart a more definite direction to the effluent water.

It is obvious that reclamation either within the estuary, or on the adjoining banks outside, should not be permitted, the former reducing the scour by diminishing the capacity of the scouring basin, the latter assisting the encroachment of the banks on the entrance channel.

Apart from considerations of a local character it will be seen that the history of this port contains many features of great interest and importance, and forms the record of a most encouraging instance of the improvement which can be effected in the face of extremely adverse conditions.

There are probably few harbour entrances beset with greater difficulties, or presenting a more discouraging aspect, than that of Dublin before the application of tidal scour, and it does not appear unreasonable to expect that a similar method of treatment, modified in details to suit existing circumstances, may be successfully adopted in many other instances.

Since the foregoing account of the reduction of the bar at Dublin was written, a survey made by Staff Commander C. H. Langdon, R.N., in the latter part of the present year, shows that no material change has taken place in the condition of the bar since 1873. The slight alterations that have occurred are, however, favourable; the minimum depth is still 16 ft. at low-water, but extends over a smaller area; the outer face of the bar has not advanced seaward, but on the contrary shows a tendency to recede; the low-water mark both on the North and South Bull showing also a like tendency; the development of the Mumbles bank has apparently ceased (whether permanently or otherwise remains to be seen), and it is not shown on Captain Langdon's chart.

It would appear therefore that the present scour is amply sufficient to maintain the depth reached in 1873 ; its want of power to produce further deepening being probably due to the depression of the seaward portion of the Great North Wall, which has been already alluded to.

INDEX.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET