21 February, 1911.

ALEXANDER SIEMENS, President,
in the Chair.

The PRESIDENT announced that the Council had heard with regret that day of the death of one of the Honorary Members of The Institution, Mr. Octave Chanute, of the United States. The Council had passed the following resolution: "That the Council record the regret with which they have learned of the death of Mr. Octave Chanute, who has been an Honorary Member since May, 1895."

(*Paper No. 3923.*)

"Coast-Erosion."

By WILLIAM TREGARTHEN DOUGLASS, M. Inst. C.E.

THE Author proposes to discuss in this Paper the various causes which operate in the erosion of foreshores and of the bed of the sea in their vicinity. The principles which should guide the engineer in designing works useful for defensive purposes will also be dealt with; including the pitfalls to be avoided, the circumstances which have to be permanently borne in mind, and the limitations which Nature imposes on all human activities that aim at restraining the working-out of her laws. From what has been accomplished already in different parts of the country, remedial and other effects may reasonably be expected to ensue on the construction of soundly-designed sea-defences over isolated sections of the coast. Lastly, expenditure, with its necessary variations according to differing local conditions, and the financial requirements of the situation as it affects the United Kingdom as a whole, will be taken into consideration.

COAST — EROSION.

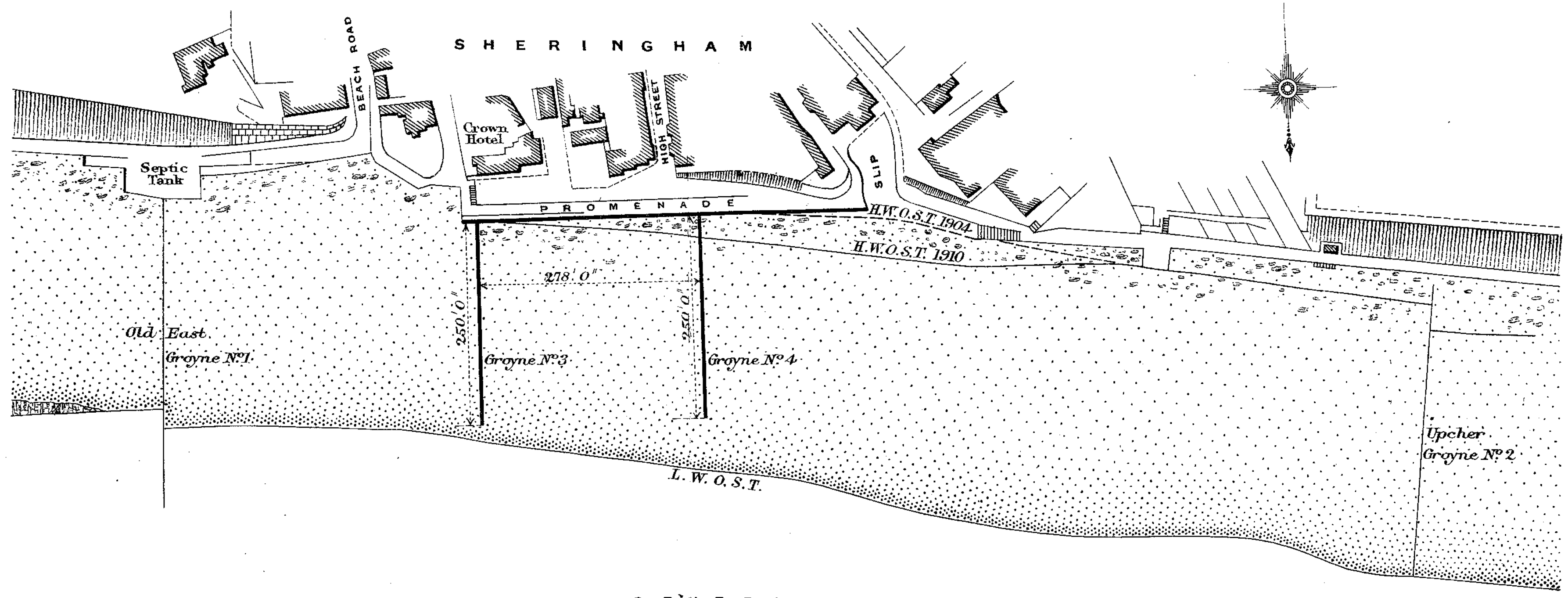
Minutes of Proceedings of The Institution of Civil Engineers. Vol: CLXXXV. Session 1910-1911. Part III.

W. T. DOUGLASS.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

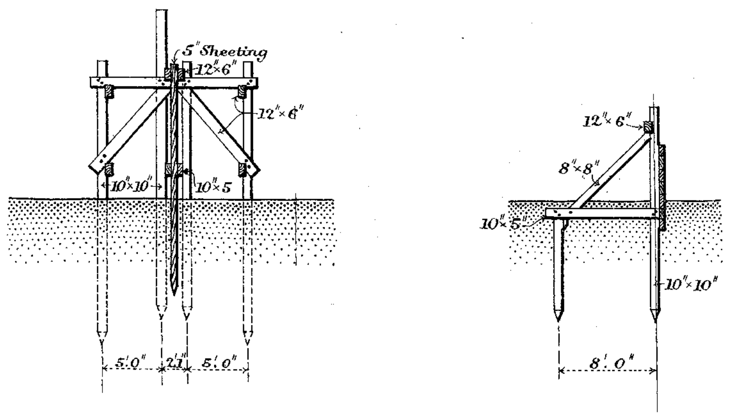
COAST-EROSION.

Figs 11.

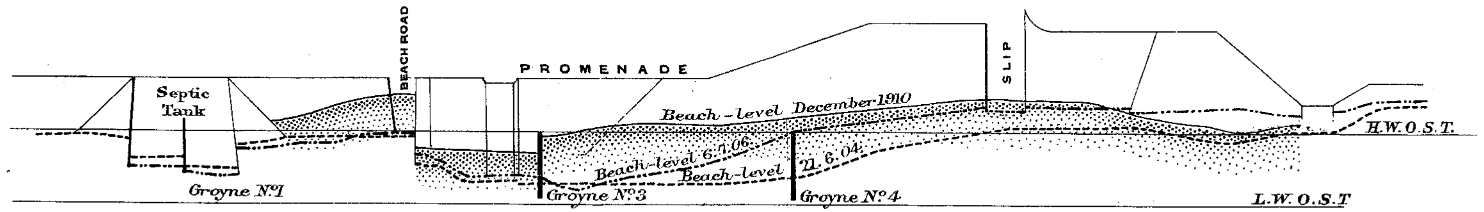


GENERAL PLAN
SHOWING WALL AND GROYNES

Figs 12a.

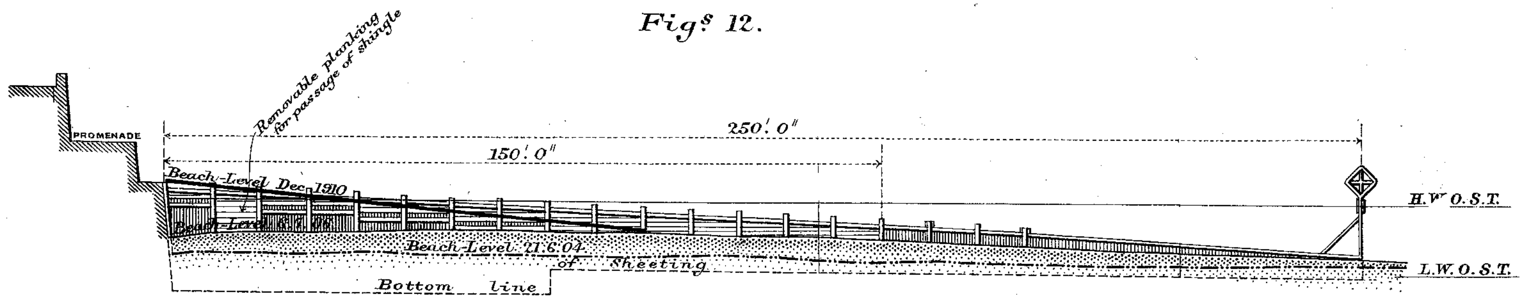


DETAILS OF GROYNES

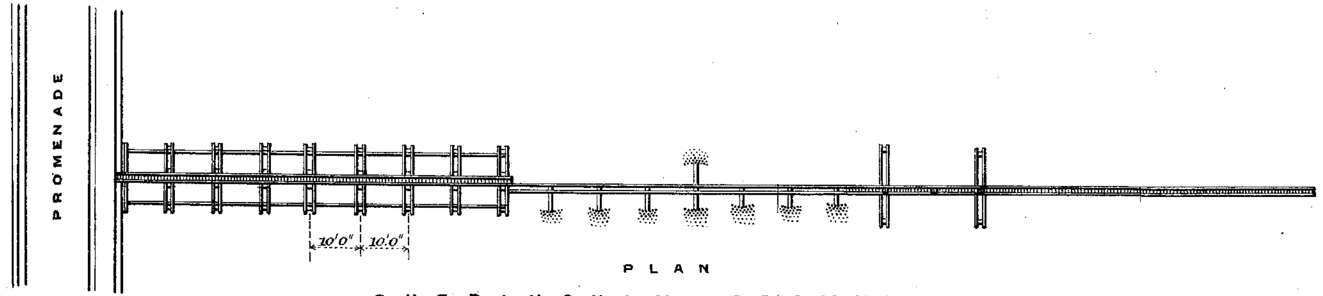


ELEVATION OF SEA FRONT

Figs 12.



ELEVATION



PLAN

SHERINGHAM GROYNES

SHERINGHAM PROTECTION-WORKS

— SCALES —

Figs 11 Plan and Horizontal. Feet 100 50 0 100 200 300 400 500 Feet

Figs 11 (Vertical) and Figs 12. Feet 10 5 0 10 20 30 40 50 60 70 80 90 100 Feet

Figs 12a. Feet 10 5 0 10 20 30 Feet

THOS KELL & SON, LITH. LONDON.

W. T. DOUGLASS.

The Royal Commission on Coast-Erosion.

In consequence of the appointment in 1906 of a Royal Commission to inquire into and report on certain questions affecting coast-erosion and the reclamation of tidal lands in the United Kingdom, public attention has been drawn in a marked manner to the ravages wrought by the sea upon the coast-line. The subject is one which has appealed to popular imagination by its tale of vanished townships and historical landmarks. It has also aroused interest on more practical grounds, owing to the economic loss to the country involved in the destruction of land to which modern developments had given a value not formerly possessed, and to the heavy expenditure necessarily incurred by local authorities of coastal districts in the setting-up of efficient barriers between the sea and the large maritime properties which modern enterprise has created.

The matters of inquiry submitted to the Royal Commission on Coast-Erosion were:—

(*a*) As to the encroachment of the sea on various parts of the coast of the United Kingdom and the damage which has been or is likely to be caused thereby; and what measures are desirable for the prevention of such damage.

(*b*) Whether any further powers should be conferred upon local authorities and owners of property with a view to the adoption of effective and systematic schemes for the protection of the coast and the banks of tidal rivers.

(*c*) Whether any alteration of the law is desirable as regards the management and control of the foreshore.

(*d*) Whether further facilities should be given for the reclamation of tidal lands.

The Royal Commission, presided over by The Hon. Ivor Guest (now Lord Ashby St. Ledgers), has taken evidence from England, Scotland, and Ireland, and its work under this head is complete. Members of the Commission have visited the coasts of England, Scotland, and Ireland, wherever it was desirable to do so in connection with their inquiry. They have also visited the coasts of Holland and Belgium.

A short Report, dated the 1st August, 1907, recording progress, together with the evidence taken up to the 18th April, 1907, has been published.

Having made all the inquiry that was necessary, the Commissioners are now giving consideration to their report, which in all probability will be presented almost immediately.[1]

Erosion.

All friable cliffs and low-lying lands bordering on the sea and washed by the waves are subject to erosion, especially in stormy weather. Granite, dolomite, and other rocky cliffs and foreshores undoubtedly suffer least from the beach-material driven against them; but even in their case the grinding action of the moving shingle is clearly to be discerned along the line of their sea-hardened bases.

The west coast of Ireland, the north coast of Scotland, and the south-west coast of England present to the sea ranges of cliff which consists invariably of hard rocks of a close-grained texture. Indications are not wanting that softer material, which overlay these cliffs formerly, has been carried away by the impact of the seas hurled against them in the storms of the Atlantic.

The cliffs and foreshores on the east and south coasts of England, between Berwick and Start Point, Devonshire, are, however, more easily eroded. As a consequence, many millions sterling have been expended in the course of the last 100 years on the work of defending these coast-lines, with more or less success.

The Yorkshire villages of Wilsthorpe, Hartburn and Clayburn, to mention no others, have been swallowed by the sea. Since 1747 the sea-front of Cromer has receded to the extent of 100 yards. It was found from systematic observation of the sea on the foreshore at Lowestoft, which began to be made in 1885, that between that year and 1902—when the groynes were erected—the annual encroachment of the sea amounted to 20 feet 6 inches. It will be recollected that it was found necessary on two occasions to move farther from the sea the lighthouse at Lowestoftness.

On portions of the coast-line adjacent to Herne Bay encroachment amounting in the aggregate to 180 feet has taken place since 1878. Practically all the well-known watering-places situated along the more prominent coast-lines of Kent, Sussex, Hampshire, and Dorsetshire have suffered from erosion, and are engaged in perpetual warfare with the sea, whilst the coasts of the Isle of Wight have also undergone an extensive process of denudation.

[1] The Report was published on the 31st May, as "Third (and Final) Report of the Royal Commission . . . on . . . Coast Erosion, the Reclamation of Tidal Lands, and Afforestation in the United Kingdom."—Sec. Inst. C.E., July, 1911.

The material that has been eroded is carried by tide and wave along the line of least resistance, until it is deposited—possibly only for a time—in some sheltered bay or channel. The softer materials, with which erosion is mainly concerned, are contained in such sedimentary deposits as sandstones, limestones, chalk, slates, and clays, and in glacial drifts holding boulders, gravels, and sands. These deposits are disintegrated, and frequently dissolved, by the action of the weather and by tides and waves in their progress along the foreshores, and ultimately are found distributed as shingle or sand, both of which come under the general denomination of beach-material. Thus beach-material is the result of the crumbling away of cliffs under the influence of climatic conditions and wave-action.

The movement of the material deposited by tidal action on the foreshore can be determined with precision by ascertaining carefully the local contours of the coast, the depths of water, the set of the tide, and the direction of the prevailing winds. Any difficulty which may be found in arriving at a decision as to the direction of travel of beach-material is due to imperfect acquaintance with the factors just mentioned.

The set of the tides may be obtained from Admiralty charts in considerable detail, while it is also referred to in sailing-directions. The general contour of the coast-lines, soundings, elevation of salient cliffs, etc., may also be learned from Admiralty charts and Ordnance surveys. The direction of the prevailing onshore winds usually coincides with that of the flood-tide. In this connection useful information has been collated by the Meteorological Office; but in the absence of more precise data, the line of the longest fetch will indicate the direction of the greatest exposure. Geological maps will also afford useful information as to the local stratification.

In giving consideration to the travel of shingle along any foreshore where there is a long stretch of coast uninterrupted by bays, the points to be borne in mind are easily understood, and admit of perfectly simple statement.

Shingle travels between high- and low-water mark in line with the flood-tide so long as the direction of the wind coincides more or less with that of the tide, and the force of the tide or wave-action suffices to move the material along the foreshore.

The strength of the flood-tide along the coast is superior to that of the ebb-tide. The correctness of this statement is easily proved by placing a log of timber in the sea and measuring the distance travelled up and down the coast in a given period under fine-weather conditions, with both flood and ebb.

The vast volume of water in the Atlantic Ocean tends to give greater force to the flood-tide as it moves up the shore than is behind the ebb-tide when it withdraws itself into the same ocean.

With strong winds emanating from the opposite or ebb-tide direction, the stream of beach-material travelling along a foreshore will be checked in its movement. The check will be of but temporary operation however, the shingle—under normal conditions—resuming its ordinary course afterwards.

Where the coast-line is broken by headlands and deep bays, both the normal travel of beach-material and the set of the tide undergo changes, since both are deflected from their main-channel courses. Thus, the shingle comes under the influence of eddy tides and onshore gales. As a rule, it rests at last on the expending beach situated in the bay, where it is pocketed and affected least by tidal currents.

In estuaries, where the ebb-tide currents do not undo the work of the flood-tide, the travel of shingle is normal. Usually an estuarial ebb-tide preponderates in force, because of the quantity of fresh water impounded by the action of the flood-tide. The shingle travelling up the estuary is consequently diverted from its course and deposited in the form of a bank, or "middle ground," near to the entrance.

The greatest possible erosive effect on a foreshore occurs where the various forces in operation combine, as it were, to produce such result. To illustrate this point it may be mentioned that the occurrence of an equinoctial spring-tide high water simultaneously with a north-westerly gale immediately following a southerly gale, will bank up the water in the North Sea to an abnormal level. Fortunately this combination of the elements does not occur more frequently than once in 6 years on an average. When it does take place, however, the foreshores on the east coast are seriously depleted, the cliffs are undermined and sea-defence works are strained to their utmost.

If a pebbly or sandy foreshore covered by the tide is closely observed during heavy weather, it will be found that the surface sand, and shingle, and even small boulders, are in a restive condition and more or less afloat. This fact will account for the large quantity of beach-material which is moved in heavy weather from one place to another in the course of a single tide.

Protection.

The building-up of foreshores by natural means proceeds most rapidly under the influence of offshore winds, and it is on these occasions that beaches are at their best. The consequent tranquillity of the sea leads to the deposition of the sand it carries in suspension. At the same time the tide, assisted by wave-action, drives the beach-material along and up the beach towards the cliff.

It is necessary, then, to bear constantly in mind the following three points: first, that all beach-material is the result of the breaking away of cliffs or land; secondly, that shingle travels along the coast between high- and low-water mark; and lastly, that no shingle is procurable by tidal or wave action from the deep sea for the building-up and preservation of foreshores.

Where the natural supply of beach-material travelling along the coast is intercepted by headlands, points of rock, or artificial obstacles such as groynes, a lowering of the foreshore-level will be noticeable on the down-stream side of the obstruction, if the foreshore is composed of an erodible material. The greater the elevation of the obstruction, within certain limits, and the greater its extension into the sea from the cliff-line, the more pronounced will be the erosion on its leeward face. Bearing in mind what has been said already as to the travel of shingle along a foreshore, it will be perceived at once that this erosion is a necessary result of the complete or partial stoppage of the supply of beach-material. Such leeward erosion involves, of course, a deepening of the water over the eroded area, and as a further consequence, a heavier wave-stroke, with its inevitable outcome of still more erosion.

One of the most swiftly operative causes of erosion is the removal of beach-material from a foreshore. What may appear at first sight to be more than ample protection for a foreshore, with an unlimited supply for making-up purposes, is rapidly depleted when beach-material, even in small quantities and over a restricted area, is removed. Such removal lowers the beach-level, and opens a passage for the waves to the cliffs, which have probably never been previously attacked within living memory. Every year, around the coasts of England, beach is removed in this way, and often the delinquents proceed unchecked until they have done damage which can only be repaired by a very heavy expenditure of money.

Again, dredging-operations carried out in proximity to foreshores or cliffs necessarily tend to weaken the coast, since they deepen the contiguous bed of the sea. The natural sea-bed level is disturbed, fresh channels are formed, and eddies are set up which often exercise an adverse influence on the conservancy and maintenance of foreshores. Taking into account all these considerations, it will be obvious that the destruction of the coast-line does not proceed from one cause alone. It is also certain that it is not in all cases capable of being checked effectually and permanently by any human effort.

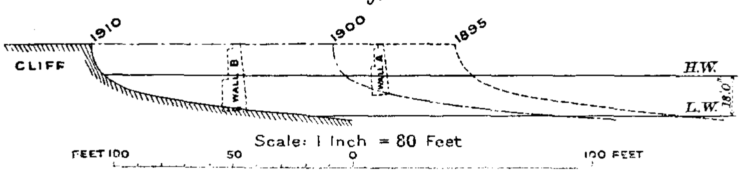
Defence-Works.

Sea-defences may be taken to include all works which are constructed for the purpose of maintaining the efficiency of foreshores and cliffs. They may be divided into two main categories, namely, sea-walls and groynes, the functions of which differ widely, although both are meant to serve the same end of coast-protection.

The truth of the statement that no two cases are alike is brought home to anyone who has been compelled to examine at close quarters the problem of conserving by artificial means the cliffs of the British Isles from the ravages of the sea.

The sea-stroke, tidal movements, depths of water in the offing, rise and fall of tide, composition of cliff and foreshore, gradient and length of foreshore uncovered at low water, quantity of beach-material available for collection, direction of travel of material, position of site as regards headlands, piers, or other works jutting

Fig. 1.



out into the sea, are all circumstances to be weighed carefully before an attempt is made to deal effectively with any specific instance of coast-erosion.

Sea-Walls.—Fig. 1 should elucidate many points which are a frequent cause of lengthy consideration and discussion. It is intended to bring home to the eye what is taking place on foreshores where the material is erodible and is being eroded, and to suggest, to those who have not hitherto given special attention to the subject, the pitfalls to be avoided by the engineer whose task it is to fight the encroachments of the sea.

A section of a friable cliff and foreshore, where erosion persists, is taken as it was in the year 1895, when a massive concrete wall was constructed. It was considered at the time that the foundation of the wall, which was carried 20 feet below the surface of the cliff, was sufficient for protective purposes. The encroachment having continued to make its normal advance, the wall was undermined and overturned in 1900. Another wall, 30 feet in depth, was constructed in the same year, but in 1910 a similar misfortune overtook this second wall. It will be observed that the sections of the beach taken on the three occasions are identical, the rate of erosion being constant, namely, 10 feet per annum. The moral of the diagram is that sea-walls alone, under these conditions, are of little or no value for stopping the inroads of the sea. Of course, if the walls had had solid rock as a foundation, the design, in spite of the friability of the cliff, would have proved effective for the end in view.

Preference is given in some cases to the elliptical section for sea-walls, as offering the least resistance to the impact of the moving waves; and it may be conceded without hesitation that, when built on a rock foundation, this section possesses certain recommendations. If, however, the foundation is erodible and the beach-level is variable, the elliptic form of wall has no higher value than the vertical form, either as a means of sea-defence or for the purpose of preventing the cutting-out of the beach at its foundation. Moreover, the vertical wall costs less to construct.

All projections in vertical section are best avoided, though to meet the requirements of stability in design, exception may be made of offsets or steps, preferably placed at the rear of the wall. It is found in practice that a sea-wall, except in cases of undermining, usually first exhibits distress at its coping or upper section. This is caused by the upward force exerted by the impinging wave.

The racing of the waves along a sea-wall, due to their striking it obliquely, erodes the foreshore at the toe of the wall. No general section yet produced has overcome this difficulty where the wave has any considerable force, though bastions built out from the face of the wall at intervals tend to minimize the amount of mischief thus caused.

When a wave strikes a sea-wall with considerable force, it will be usually the case that there is a strong wind at the same time. Under these combined circumstances the wind will drive spray and solid water over the summit of the wall, in spite of any projections which may have been embodied in the design.

The promenade-deck placed immediately behind the wall does not escape its fair share of wave-hammering as the sea runs up the face of the wall and falls in upon the deck. Care should be taken, therefore, that the deck is so constructed as to protect the filling beneath from attack during abnormal weather. Probably one-half of the mischances which befall walls may be attributed to the exposure of the filling to the waves, through the disturbance of the promenade-deck.

Storm-Beaches.—Unquestionably the ideal sea-defence is the natural storm-beach, which will always accommodate itself to the force and length of the waves. It acts as an expending beach at the time of high as well as low water, whether at neap-tides or during an abnormal equinoctial tide. It provides the requisite curves and gradients, as designed by Nature herself to the end that the waves shall expend themselves without injury to the beach.

After a particularly violent gale the lines of a storm-beach will be found to exhibit perfect and uniform curves between low water and the top of the shingle ridge thrown up by the advancing waves, always presupposing that the ridge is sufficiently backed up at the rear to prevent it from being breached. Such a ridge frequently attains a height of 12 feet above extreme high water, its summit being level throughout.

Any attempt on the part of the engineer to tamper with or improve this type of natural beach on a foreshore where erosion is in progress will result in the breaking-up of the symmetrical beach-lines and curves and the disfigurement of an invaluable bulwark of the coast. Unless the encroachment of the sea on the land seriously affects a densely-populated area, and cannot be suffered, it will be to the interest of all concerned that the storm-beach be left untouched and not disfigured by artificial sea-defences.

The Pebble Ridge at Westward Ho! may be instanced as a fine example of the storm-beach achieved by unaided Nature. The beach lies on the sea-face of the Westward Ho! golf-links, the sea-banks of which are subject to periodical erosion. Violent onshore gales drive the shingle up the face of the storm-beach, over its crest, and upon the surface of the land behind. The ridge accommodates itself to circumstances, and no breach in it occurs where the land in its rear is situated well above high-water level, although volumes of water are driven over its crest on to the adjacent land.

As the encroachment does not for the moment affect the golf-links, the construction of a clay bank shoreward of the ridge will have the effect of keeping back the sea-water at periods of severe storms, at one-fiftieth of the cost which would necessarily be incurred in building sea-walls and groynes; since the latter must be of exceptional strength to withstand the waves which attack this foreshore.

Groynes.—The principle emphasized by the foregoing facts is that, in designing works of sea-defence, the object aimed at should be to give the utmost freedom to the waves to expend themselves by a process of exhaustion. This purpose is best achieved by raising the beach-levels by the accumulation of beach-material. To this end means must be devised to form sheltered areas where sand, carried in suspension in the water, will be deposited, and to secure that shingle driven along the foreshore by the action of the tides and waves shall meet with impediments calculated to diminish its rate of progress, if not to stop its movement entirely. The means at the command of the engineer for these purposes are covered completely by one word—"groynes."

Groynes may be constructed practically of any more or less durable substance capable of offering resistance to the passage of beach-material. Their design and consequent cost per lineal foot depend entirely upon the situation, total height, etc. On a low sandy foreshore of small exposure much may be accomplished at a cost of 5*s.* per lineal foot, but where the Atlantic waves roll in upon a short steep beach, the requirements of the case will scarcely be met for a less expenditure than £10 per lineal foot.

The question of design resolves itself into the provision of such stability as will eliminate all risk of overturning when the utmost pressure is applied to a surface exposed over its full extent by the denudation of the foreshore. The striking force of the impinging wave in foot-pounds is the basis for calculation.

It is an axiom generally accepted that, the longer the groyne, the greater is its utility as a collecting agent for beach-material. Should anyone be disposed to question this, he will probably admit that where a short groyne fails somewhat in effectiveness, the defect will be largely remedied by extension; always provided, however, that beach-material is to be found in the neighbourhood of the groyne.

In positions where a foreshore is greatly exposed and lies more or less parallel with the longest line of fetch—a circumstance which causes the surface to be severely raked by the waves in heavy weather—the beach-material may best be encouraged to collect by the provision of efficient shelter from wave-stroke.

This object is attained by a system of high groynes with their surface terminating at or above high-water mark throughout their entire length. They may conveniently be spaced 500 feet apart, the intervening foreshore being protected by shorter and lower groynes. When this system is adopted on a foreshore which is composed entirely of beach-material in the form of shingle and sand, sufficient beach will travel around the outer ends of the long groynes to feed the intervening beach. The intermediate low groynes serve to check the travel of shingle and sand, and assist in maintaining a level beach-line.

It is usually found advantageous on a foreshore subject to moderate exposure, and where the waves strike at a high angle, to fix the height of the shoreward end of the groyne so as to correspond with the highest level to which shingle is thrown up by the action of the waves in the immediate neighbourhood of the proposed work. The seaward end of the groynes should be practically on a level with the foreshore. Between these points the general line must follow—but keep somewhat above—the anticipated beach-level, with modifications to meet conditions of exposure.

The planking-up of groynes as the beach grows is frequently advocated. It is not a very satisfactory procedure in all cases, since groynes require to be sufficiently planked to arrest beach at the time of the advance of a sudden storm. Many groynes are constructed of sheet-piles driven into the foreshore. In these instances gradual building up is not possible. The point is met, however, by completing the groyne in the first instance, and making provision for beach-material to pass through a hole, or a series of holes, at or about the position of neap-tide high-water mark. By this means the travel of the beach may be regulated, and any shortage on the lee side of the groyne can be made up by manipulating the area of the holes so as to meet the variable conditions, which obtain on most beaches.

The distance apart at which groynes are required must depend mainly on the obliquity of the prevailing impinging waves on the foreshore. Where these waves strike end-on, the number of groynes per mile will naturally be less than where the waves impinge at an angle. Each foreshore must be considered with reference to these conditions and the degree of exposure to which it is subjected, before the spacing can be decided upon satisfactorily. Should it be found that the groynes when erected are spaced too far apart, the difficulty can easily be met by building intermediate groynes.

Sea-defence works must necessarily consist of a combination of sea-walls and groynes, if erosion on a coast-line is to be prevented entirely. The raising of a foreshore for the formation of an expending beach may be accomplished satisfactorily by means of groynes alone, but without the addition of a sea-wall the accreted material is liable to be carried around the shoreward ends of the groynes during an abnormally high tide accompanied by a severe storm.

When protective works are undertaken on an open foreshore, the object of the authority which is paying for them is naturally to obtain its money's worth, regardless of the fact that its works may denude the foreshore of a neighbour to leeward. Probably its neighbour to windward has previously been similarly careless as to the outcome of its own acts where others were concerned, and so has been a contributing cause to the denudation of the immediate beach on its lee side, which is the one the authority is engaged in protecting.

As a matter of fact, the total quantity of beach-material travelling on the coast is not sufficient to afford the necessary protection to all foreshores. The question of its proper apportionment therefore becomes a crucial one. So far as the law is concerned, as understood and applied hitherto, it has hampered with but few conditions or restrictions action taken by anyone—whether private owner or public authority—to protect the foreshore.

The case of a typical seaside resort will serve to illustrate this aspect of the general question. Expensive promenades, piers, etc., have been built, valuable buildings have been erected in the rear of the sea-walls, and an extensive bathing-beach is required for visitors. It will appear but natural under the circumstances that the local authority should do everything in its power to safeguard costly works, created by the enterprise of its ratepayers, from invasion by the sea, without giving very anxious thought to the effect its prudent municipal activities may have on the coastal interests of a sleeping neighbour. Naturally it hopes for the best, trusting that the sea will not invade its neighbour, who may, if he chooses and is able to do so, safeguard his own coast-line by spending money on sea-defences. In these matters the existing law requires to be amended for the purpose of protecting owners of coastal lands.

It may not be irrelevant to mention here that excessive erosion due to the erection of harbour-piers of solid work, carried far out into the sea, has been dealt with successfully. This was the case notably at Yarmouth and Lowestoft, where works were designed and executed to meet such a condition of things, with the result that the beach-levels have been raised and maintained on the south or lee-side faces of the south piers at those two places.

Examples of Coast-Protection Works.

It may be laid down as a general principle that beneficial results will follow the construction of sea-defences, however limited in length the section of coast-line selected, if the works are designed competently and adequately to cope with the inconveniences and dangers created by coast-erosion.

The following examples will serve to illustrate and emphasize the practical truth of the general principle laid down.

Hornsea, Yorkshire.—The denudation of the Holderness coast is a fact which is not in dispute. The cliffs are composed of glacial drift, consisting of boulder clay interspersed with gravel and sand-beds. The foreshore is covered with sand and shingle, overlying clay and peat in many places. The sea-front is exposed between the bearings of N.N.E. and S.E. In addition, a potent cause of cliff-erosion is a gale from the north-west.

The sea-defences of Hornsea were practically destroyed by heavy gales in 1906, rendering the construction of fresh sea-defences a matter of the utmost urgency. The foreshore seaward of the Borough Council's property was entirely denuded of beach-material, while many thousand tons of cliff were washed away.

The works shown in Figs. 2–6, Plate 3, were undertaken in 1906, and completed in the following summer. They consist of a concrete sea-wall 720 feet in length, and three groynes, 745, 430, and 400 feet in length, respectively. A larger scheme was put before the Council, but it was eventually decided to proceed in the first instance with these works only.

Within 3 months of the completion of the defences the shoreward ends of the groynes had become buried in beach-material, with a resultant increment of the beach, at the promenade-wall level, of 9 feet, as compared with the state of things prevailing before the works were designed. High tide does not now reach the sea-wall under ordinary conditions of weather.

The beach-levels along the entire length of the wall before and after construction are indicated in Fig. 3, Plate 3. The outlay on works was £10,820.

Lowestoft, Suffolk.—The memorable gales of November, 1897, and March, 1901, were severely felt here. The North Denes were flooded, and encroachments of the sea on the land became so persistent that prompt action had to be taken for the defence of the Denes and other portions of the town, to prevent the demolition of houses by the sea.

The North Denes are subject to erosion during north-westerly and north-easterly gales, whilst the cliffs on the south beach towards Pakefield suffer most when gales blow from the south-east (Fig. 7).

The construction of the harbour-piers had caused shingle to bank up to the north, and had brought about denudation of the foreshore on their southward face. In order to cope with this persistent erosion, the sea-defence works shown in Figs. 7–10, Plate 3, were put in hand in the winter of 1901.

The concrete wall on the North Denes was constructed for a length of 1 mile between the gasworks and the northern boundary of the borough.

Fronting the sea-wall, four main groynes were constructed on the foreshore, three having a length of 290 feet and the fourth of 340 feet, and spaced 1,500 feet apart. Between these main groynes sixteen intermediate groynes, each about 110 feet in length, were erected. The main groynes were built with their shoreward ends 4 feet above high-water level, and their seaward ends 3 feet below the same level. The intermediate groynes follow the accreted beach-level, their starting-point being generally at a distance of 50 feet from the sea-wall.

On completion of these defences in the summer of 1903, the beach along the sea-wall had been raised to an average height of 5 feet 3 inches above its level at the commencement of operations (Fig. 10). The accumulated beach-surface along the face of the wall was left, by the action of the waves, level within 6 inches over the full extent of the work. This level is 8 feet above ordinary high-water mark. The encroachment of the sea on the Denes over this length of sea-defence was, as already mentioned, 20½ feet per annum.

On the south beach, Kirkley Cliffs, at the southern boundary of the borough, had been eroded to the extent of 80 feet in the course of one winter. Houses were vacated and pulled down, as their destruction appeared to be imminent. This incursion of the sea affected injuriously the whole foreshore between Kirkley and the Great Eastern Railway Company's harbour-piers to the north.

With a view to prevent further erosion, a massive timber groyne 245 feet in length was built from the south face of the south pier, and a second groyne of equal length at the Borough Council's boundary at Pakefield, the latter being flanked by a revetment. These works were constructed *pari passu* with those on the North Denes. At a later date further groynes were added to the sea-front.

Upon the erection of the spur groyne on the south face of the harbour-pier, the summit of which terminated 1 foot below high-water level, the foreshore in the immediate neighbourhood was at once raised 12 feet in height, and the influence of the groyne as a beach-raiser was visible for 400 yards in a southerly direction. Within 1 year of the completion of the groyne, low-water mark in front of the "Royal Hotel" was driven back 150 yards. Since 1903 the beach has continued to improve, with the result that the foreshore is bare at low water some distance seaward of the groyne.

The groyne at Pakefield was the means of raising the foreshore 5 feet in height, while it drove back for 43 yards the line of low water and gave to the cliffs complete protection.

The following Table shows the costs at which the several works were executed :—

Description of Work.	Rate per Lineal Foot.	Rate per Cubic Yard or Foot.
	£ s. d.	
North Denes.		
Concrete sea-wall, steps, filling and excavation. Total length with returns, 5,744 feet run	1 17 2	21*s.* 2*d.* per cubic yard.
Main groynes	7 7 1	5*s.* 2*d.* per cubic foot.
Intermediate groynes	5 1 1	
South Beach.		
Spur groyne	8 18 5	
Pakefield groyne	6 6 7	
„ revetment	6 10 0	

The total outlay on these works was :—

	£
North Denes (1 mile)	30,000
South Beach	6,126
Total	36,126

The erosion of the cliffs at Pakefield during recent years is a matter of common knowledge. Some idea of the amount of land and buildings which has been claimed by the sea since the year 1882 is given in Fig. 7, Plate 3. The erosion of these cliffs between 1882 and 1901 was 150 feet, whilst a further inroad of 150 feet had been made since 1901.

Sheringham, Norfolk.—The sea-front here has suffered from the ravages of the sea, which simultaneously affected the neighbouring seaside resort Cromer.

The situation thus created was met by the construction of groyne No. 1 (Figs. 11, Plate 4), which took place about 1883. This groyne served to trap the beach travelling in an easterly direction from Weyborne.

Groyne No. 2 was erected 500 yards west of No. 1 in 1894, to protect the cliffs in the immediate neighbourhood where erosion was in progress; and the results were satisfactory. At a still later date Case groynes were laid down westward of No. 2, which contributed further to the accumulation of shingle under the cliff.

Before the erection of groyne No. 2, the foreshore between groyne No. 1 and the site of No. 2 was well provided with shingle.

This will be evident when it is mentioned that high water of spring-tides did not reach the cliff. After the construction of No. 2 groyne it became imperative to build sea-walls between the groynes, in order to safeguard the town. These works were completed in 1901.

The denudation, however, continued uninterruptedly. Groyne No. 1 was left entirely bare of shingle, whereas previously it had been filled to overflowing, while the foreshore fronting the Council's sea-wall was eroded in places to such an extent as to expose the very foundation of the new wall.

Groynes Nos. 3 and 4 were constructed in 1905, with the object of affording protection to the sea-wall, which was then in danger of being overturned. The result has been satisfactory beyond anticipation, since the shingle, having accumulated 11 feet in height along the sea-wall, has buried the exposed foundation and now affords the wall the additional protection of an expending beach (Figs. 11 and 12, Plate 4).

The shingle pebbles lying on this foreshore are of the dimensions of a hen's egg, without any admixture of smaller material. Although during offshore winds sand may accumulate temporarily on the foreshore below the toe of the shingle, it is removed immediately onshore gales occur. The cliffs here are glacial deposits.

Cromer, Norfolk.—The whole of this seaboard is subject to erosion. The defences in the form of walls and groynes, constructed over a length of 3,730 feet of foreshore by the Cromer Protection Commissioners, have been entirely effective against the undermining by the sea of the sand, gravel, marl, and clay cliffs. If the whole of the foreshore is taken into consideration, a larger area is exposed to view at low water than was the case 10 years ago. This is conclusive proof that the long groynes have met satisfactorily the local requirements in the matter of sea-defences.

These examples of recent sea-defence works on the east coast of England, where the formation of the cliffs and foreshores is characterized by extreme friability, and coast-erosion has been exceedingly persistent, have been chosen because in each case it is plain that the problems involved in holding back the sea from the land have been solved successfully.

The greatest difficulty has been encountered where sea-walls are already in existence and are being attacked by the waves at every tide, as in the case of Sheringham. The groynes added to that foreshore provided a certain amount of shelter and broke up the waves which had hitherto prevented the shingle from accumulating at the toe of the wall.

The examples of foreshores that have been raised include both short and long sections of exposed coasts. Bays have been purposely excluded from consideration, as their treatment demands special study, the details of which have little or no bearing on the questions arising in connection with main coast-lines.

The Author therefore, to sum up his argument, would observe that beaches are the natural protection of a weakened coast-line, and that where Nature has not provided them they may be created by the erection of groynes and sea-walls in conjunction; but as the supply of beach-material for all purposes of coast-protection is inadequate, the question how it is to be used most economically, how apportioned as between different claimants to it, and how protected from depredations, which in view of the public and private interests concerned are nothing less than vandalism of the most wantonly destructive kind, is one of national importance.

The Paper is accompanied by four drawings and a diagram, from which Plates 3 and 4 and the Figure in the text have been prepared.