beach had been lifted 11 feet against the vertical wall built by the late Mr. Jaffrey, to which Mr. Marriott had alluded, and he thought that was sufficient to show that a vertical wall was quite efficient, besides being less expensive to construct. Foreshores naturally eroded in a manner similar to the adjacent cliff, and produced beach material. Dr. Cornish's remarks with reference to wave-action were very interesting. If the master of a sailing vessel were asked which tide carried him the farthest, he would pin his faith to the flood-tide rather than to the ebb. Stone groynes, such as had been referred to by Mr. Darley, were of course very effective. Mr. Darley had mentioned that he had never been able to collect light material by means of groynes. In the case of the spur groyne to the south of Lowestoft harbour very fine sand was collected to a height of 12 feet in 12 months, and the low-water mark was driven back 150 yards; that showed that very fine sand could be collected. All the groynes on the south beach had collected nothing but fine sand. With reference to Mr. Hawksley's remarks on the protection of the gasworks to the south of the sea-wall at Lowestoft, the fact was that in 1902 the foreshore there did not belong to the Corporation, and consequently they were unable to extend the wall. As to the expense of doing so, they rather hoped to obtain a contribution from the Gas Company, which at that time was not forthcoming. He was glad to hear that arrangements had now been made for the continuation of the wall and the groynes, and that the work had proved effective. The Author.

Correspondence.

Mr. E. T. Beard remarked that the action of the sea in destroying cliffs was greatly assisted by rain, frosts, and springs. Marine denudation wore down the cliffs to a level surface below the waves: subaerial denudation, on the contrary, produced a picturesque shore. The two worked together, destroying the cliffs in proportion to their hardness and the strength of the waves. On rocky coasts the waves forced water into the joints and fissures of the rock; this compressed the air contained in these fissures; and on the waves receding, the air forced out the water. The constant repetition of this process loosened material, and caves and hollows were formed at the foot of the cliff, which was gradually weakened until it fell. Where possible, such places should be filled up by a strong wall to Mr. Beard.

Mr. Beard. prevent further damage. What denudation took away, deposition returned. It had been calculated that the Tay, Forth, and Thames together discharged annually into the North Sea upwards of 2 million cubic yards of sediment, which was carried about by tidal currents until it came to rest in sheltered positions, forming shoals and banks. Where sea and land met, a beach was produced by the rise and fall of the tide and the action of the waves. Wind-waves moved the loose material forming the beach before them. Wherever the force of the waves was felt, from above high-water to below low-water mark, shingle, grit, and sand would travel. The level of permanent beaches, such as those at Chesil and Dungeness, was always well above high-water mark, the run of the waves having carried the shingle above high-water level. That shingle did travel below low-water mark had been shown during the construction of the Hove sea-wall, when 25,000 tons were thrown into the sea, 400 to 800 yards from the shore; observations had proved that this shingle travelled rapidly towards the foreshore. On open stretches of the south coast south-easterly gales moved the shingle rapidly westward, which coincided with the direction of the ebb-tide; but as the wind for about 9 months of the year blew from the south-west, the shingle was generally travelling eastward, in the direction of the flood-tide. On the east coast the sand and shingle was moved southward, owing to the north-east wind having the greatest power on this coast, which was sheltered from westerly winds. Although the movement of beach-material was mainly dependent upon the action of waves, it could be accelerated or retarded by littoral currents, which influenced the direction of the impinging and recoiling waves. On this coast the tidal wave travelled at 50 miles per hour, and along the English channel at 45 miles per hour, according to Dr. Whewell's chart. Sea-walls were frequently built as a protection against the sea. Their effect often was to throw the waves upward, and the recoil of the water, in proportion to the strength of the waves, tended to scour away the beach-material from the front of the wall. Unless the wall was founded on durable rock, or the beach could be retained in front of it by some means, its destruction was almost certain. The usual foundation-level of sea-walls was well above low-water mark, but the Scarborough Marine Drive sea-wall, for which Mr. Beard had been engineer during the 4 or 5 years taken to complete it, in front of the exposed Castle Hill promontory, had its foundation laid 4 feet below low water of spring-tides. The foreshore, being of denuded rock, was covered with masses of boulders, varying in size from 1 ton to 100 tons. Although the top of this wall was 20 feet above high water, he had frequently seen the crests of breakers running along the wall within a foot or two of coping-level. In section the wall was 10 feet thick at the top for 10 feet in height, and curved outwards to the toe, where the wall was 33 feet thick. So far as the permanent work was concerned, no unusual trouble or damage had occurred. Groynes, by collecting the beach-material moving along the shore, formed a sea-defence by holding up a sloping beach produced naturally by the action of the waves; this varied its inclination according to the force it had to meet. On most parts of the south and east coasts, where erosion was taking place, there was an abundance of beach-material to fill up any number of groynes. It had been calculated that 10,000 tons of beach-material passed Hove in two tides. A properly designed groyne should do three things, namely, it should form a permanent beach; it should form a sloping foreshore leading up to the permanent beach and preventing its removal; and finally, it should not hinder the passage of the drift along the foreshore when once filled up. The secret of successful groyning was to form small sheltered bays to hold up permanent beaches, where waves could expend their full force without doing any damage. Mr. Beard.

Mr. HAROLD BERRIDGE thought the Author was to be congratulated on being able to record some successful attempts to deal with an engineering problem which had so often resisted satisfactory solution. About 20 years ago he was engaged in the preparation of plans in connection with a Bill in Parliament relating to the protection-work at the mouth of the Mersey, and the expert opinion brought forward in the Committee Room by the promoters and opposers of the Bill, as to the causes, duration and effect—and even as to the very existence—of the erosion, together with the convincing arguments produced on either side by learned counsel as to why the other side should pay for attempting to prevent it (if it existed), left on his mind an abiding impression of the difficulties of the question, which neither subsequent experience nor the present excellent Paper had dissipated. Looking at the geological map of the British Isles it was obvious that the west and north coasts were composed of the older and more compact formations, which had been almost completely denuded of the softer strata by the waves of the Atlantic, while at present the south and east coasts, composed of more recent and softer formations, were undergoing the process of denudation by the waves of the Channel and the North Sea. Erosion on a large scale, therefore, was confined principally to these latter coasts, though it was of course proceeding on the west coast at places like Hoylake, where during the last 100 years a large area of land had disappeared. Sir Mr. Berridge.

Mr. Berridge. Archibald Geikie,[1] who had pointed out that most sea-cliffs sloped backwards from the sea, was of opinion that subaerial action was more powerful than marine. This might be true of harder rocks, but as regarded the softer (clays, etc.) it left out of consideration the fact that such material would only stand at its "natural slope," so that the washing-away of the toe brought down the whole face of the cliff. When the debris had been dissolved or scoured away, the process was repeated indefinitely at a rate far exceeding that attributable to all combined atmospheric forces. Again, the same geologist pointed out that "the amount of waste by the sea must be inconceivably less than that effected by subaerial agencies"[2]; yet the manner in which it was effected was much more violent and local; and the lowering of the surface of a county by $\frac{1}{12}$ inch in 75 years[3] would be more easily supported than the loss of 250 yards of foreshore in the same time along the promenade of a single seaside town. The opinion was also expressed that[4] sooner or later the destiny of all land is to be engulfed in the great ocean from whence it can only re-arise by renewed upheaval of the earth's crust; and possibly the Author had similar thoughts in his mind when writing (p. 97) that destruction was not in all cases capable of being checked effectually and permanently by any human effort. Such considerations, however, brought small comfort to the public or private owner of a vanishing beach or threatened promenade, and therefore it behoved the engineer to study more closely the forces at work. Mr. Berridge thought it to be scarcely proved that the flood-tide was the predominant cause of the travel of the beach. On both the south and east coasts the direction of the flood-tide and that of the wind from the direction of greatest exposure approximately coincided. His opinion was that the latter caused 90 per cent. of the erosion from any coast, and of the damage to defence-works. It was a matter of common knowledge that beaches accumulated in fine summer weather and were swept away by winter storms, and the direction of the most violent waves would undoubtedly determine that in which the beach travelled. The tidal current along the shore was incapable of moving any material but the finest; while wave-action in a storm disturbed the whole of the foreshore and the bed of the sea as deep as 30 fathoms.[5] When breaking, the waves created local currents and eddies of high velocity which transported

[1] "Text Book of Geology," p. 573. London, 1903.
[2] *Ibid*, p. 593.
[3] *Ibid*, p. 592.
[4] *Ibid*, p. 1388.
[5] *Ibid*, p. 562.

the disturbed material in a state of semi-suspension (so to speak) in the general direction of the travel of the wave. This explanation would account for all movements of beach along straight shore-lines, as well as in more or less protected bays. An example of the latter occurred at Poole Bay on the south coast. The shores were clays and sands of the Lower Bagshot formation, and, though protected from south-westerly gales by Ballard Down, a high chalk promontory, they were fully exposed to the south-eastern gales, which drove the eroded material westward (against the flood-tide) and finally pocketed it in Studland Bay. This also explained why at Lowestoft the beach travelled southward on the north side of the harbour and northward on the south. Where a beach faced squarely to the line of greatest exposure, its longitudinal travel was therefore nil, and erosion was comparatively small, being only that due to attrition; the beach then swung as a whole on either side of its mean position, as was the case at Westward Ho! and Chesil Beach. What finally became of the eroded material was unknown to Mr. Berridge. The quantity must be enormous, and it would be interesting to know whether it was merely drawn down along the bed of the sea to a position below wave-action (say the 30-fathom line) or whether it was kept travelling coastwise in a kind of moving strip, extending down to the same line, until arrested by opposing forces. Local soundings or surveys alone would not elucidate this point, for, as Sir Archibald Geikie pointed out, though the bank or bar of shingle retained its place, its component pebbles were being constantly moved.[1] Mr. Berridge would suggest with some diffidence that possibly the two motions were combined, and that the eroded material reached the 30-fathom line by a diagonal or curvilinear path down the sea-floor, under the combined influence of wave-action and gravity; thus no marked accumulation would take place—as might be expected if the supposition of a moving strip were correct—at points where the forces of wind and wave conflicted. Doubtless the labours of the Royal Commission would throw light on this and many other points. Whichever view might be correct, there was no doubt that groynes must form the backbone of any system of protection against the sea. By arresting the travelling material and causing local accumulation, they rendered possible the construction further inshore of sea-walls which would otherwise inevitably meet the fate described by the Author. The remarkable success which had attended Mr. Case's system at Romney made it worthy of serious attention by all who were confronted with similar

Mr. Berridge.

[1] "Text Book of Geology," p. 580. London, 1903.

Mr. Berridge. conditions. It consisted briefly in pushing out low groynes to low water of spring-tides and extending them in length and height *pari passu* with the growth of the beach. The same success had not always attended groynes put down at any angle with the shore, and of any length or height. He had seen expensive masonry groynes demolished of necessity, owing to their being found to act as wave-traps, and increasing the destruction which they were intended to avert. The best angle, length, height, and distance apart could be ascertained only by experience and trial. As regarded height and distance apart, for a seaside resort a much better pleasure-beach was obtained if the groynes were comparatively close together, thus avoiding too great a drop on the "lee" side, and this plan also demanded a less substantial form of construction. The protection of the filling behind a sea-wall from the action of the waves falling on it in rough weather was of the greatest importance. No doubt steel reinforcement, which the Author appeared to have employed at Hornsea in the concrete decking and in the wall itself (Fig. 4, Plate 3), would enable the structure to resist the pounding which it generally received, and even to withstand the stresses due to undermining and settlement of filling, which could not always be avoided, until such time as repairs were effected. The vertical face of the wall ought to be above high water if possible, in order to avoid the destructive action of waves meeting a wall at the top of a slope. Generally, he thought a great deal might be learnt from the methods and resources employed by the Dutch for the protection of their coast.[1] In one particular instance, in dealing with blown sand-dunes, the object to be attained was to cover them with suitable grass. This could not be grown directly in the sand, but the Dutch discovered that by sticking in the sand a small bundle of straw and leaving it for a year, a suitable medium was produced in which the grass would take root.

Mr. Brenan. Mr. G. Woulfe Brenan, referring to his experience of the stability of sea-walls on a sandy foreshore, particularly on the west coast of Scotland, remarked that below the sand there generally occurred a clay bed, or a hard layer of shells, gravel, and clay, suitable for a foundation, and if the wall-foundations were not carried down and into this, either by piles or pillars, movement was certain to follow. There were two principal causes which brought about injury to sea-walls: the first was insufficient depth of foundations, and the second was the overfall of the sea at the top. A method of protection against the latter was the construction

[1] Minutes of Proceedings Inst. C.E., vol. clxxxiv, p. 1.

of a concrete pavement 10 or 12 feet shoreward from coping-level, but this must be supported at the rear either by a sub-wall, or by pillars 10 feet or so apart, with walls running transversely from them to the front. The common practice of laying such a pavement on the surface soil, insufficiently supported below, caused settlement and fractures at the junction with the wall. On the other hand, without the protection afforded by a covering pavement the sea got in at the back of the wall and forced its way out below the foundation when the tide fell, thus causing voids and channels in the rear filling and ultimate destruction. Drainage of the land water must also be provided for by a conduit and fixed outlets at certain places. Mr. Brenan.

Mr. W. D. Cay stated that he had studied carefully the coast-protection works at Southwold, Pakefield, Lowestoft, Gorleston, or Yarmouth, and Cromer, the first five in 1909 and Cromer a year or two earlier. At that time, September 1909, the Lowestoft Town Council had under consideration the construction of 1,805 feet of the sea-defences at the North Denes (Fig. 7, Plate 3) on the report of their Surveyor, whose estimates were:— Mr. Cay.

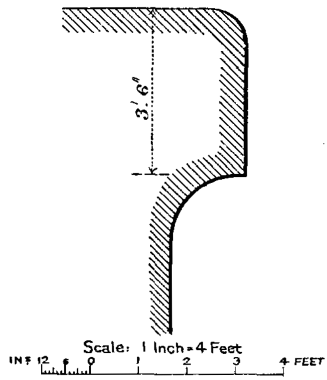
	£
Wall; 1,805 lineal feet at £2 10*s*.	4,513
Main groynes; 630 lineal feet at £6	3,780
Planking and piling shore ends of groynes; 572 lineal feet at £1	572
Two slipways at £75 each	150
Contingencies	235
Total	£9,250

This worked out at £5 2*s*. 6*d*. per lineal foot of beach-front. At the shore end of the groyne farthest south, between the Grand Hotel and Pakefield, there was an interesting example of an effective timber wave-screen breakwater (Fig. 7, Plate 3). The beach was a rising slope (say 1 in 10) of stones and shingle, in which, along the sea-front, was driven a row of 10-inch square piles 10 feet apart from centre to centre, with sheet-piling between them rising about 2 feet above the shore. Behind there were two rows of 11-inch piles also about 10 feet apart both longitudinally and transversely. Walings connected the piles longitudinally; and 9-inch by 5½-inch rafters were fixed transversely, that was, perpendicularly to the coast-line, sloping upwards from the sheet-piled front on an inclination of 2 to 1. The rafters were cleaded with planks, 12½ by 4½ inches, laid longitudinally parallel to the coast-line, with 3½-inch open spaces all along between each plank and the next. This defence appeared to be very suitable for its position on the coast. Nothing was so striking, when looking at failures, such as Pakefield and Southwold were at the time of his visits, as the

Mr. Cay. mistake of supposing that because a work was successful at one place, the same specification would answer elsewhere. For example, groynes admirable in some places where long, sloping foreshores occurred, became useless where the shore was steep and heavy seas rolled close in. Again, heavy concrete walls founded on a sandy bed, though good in interior dock-works, could not stand on a beach where there was a rising and falling tide and wave-action, which pumped out the base; piling, of course, was necessary as a protection.

Mr. Colson. Mr. C. Colson noticed that while the Author referred (p. 98) to a typical example of what might and did happen when the strata or foreshore material was erodible, he did not, apparently, offer any suggestion as to the course to be adopted for the avoidance of the pitfalls inherent in such cases. He would be glad to hear the Author's views on that matter. He inclined to the opinion that the causes of failure of the walls in the instance cited, as in many others, were want of mass in the section, deficient depth of foundation, and want of efficient surface protection against the force of the falling water. From the section it would appear that the wall had been treated as a retaining-wall only, and from that point of view it would probably have answered perfectly; but as a sea-defence, it was a failure, owing to the absence of these essential elements of resistance. In the case of sea-defence its function as a retaining-wall was secondary, the crux of the problem being the effect of the wave-stroke, whether on the face, on the surface, or on the erodible material in front. No one who had watched the impingement of a heavy sea on a wall could have failed to notice the resulting tremor or vibration, and this vibration was by no means the least potent force leading to failure in a wall weak in the essentials of resistance; it was sure to tell sooner or later. In many cases defence-walls had stood for a long time without showing weakness, and then, under exceptionally heavy hammering, vibration had assisted to destroy the equilibrium and to start an outward movement. Another point arising from this typical section was that the falling water, after striking the face of the wall, impinged with augmented force on the erodible material. This would appear to be a further strong reason for a deep foundation. Unfortunately, the engineer had not always a free hand financially, with the result that section and details were too often pared down to a minimum, against his better judgment. It had been said that there should be no projection on the face of a sea-wall; whether such a detail proved a source of weakness would depend largely upon the design. The object of a projection was to send the mass of rising water outwards, after striking the wall; and although no projection on the face could be altogether a success in the teeth of a heavy gale, nevertheless, a properly designed projection had its merits. The most satisfactory form Mr. Colson had seen was that adopted at Hastings, where it was very efficient in sending the bulk of the rising water outwards. A feature in this design (*Fig. 13*) was the weight above the projection. Too much attention could not be drawn to the suicidal policy of allowing the removal of shingle from the beach, except where it was used for purposes of defence, and even then careful discrimination should be exercised. Mr. Colson.

Fig. 13.



Mr. R. F. Grantham thought that, of the three propositions laid down by the Author on p. 97, the first would be, for the most part, accepted. The second and third propositions, however, were open to much doubt, and there appeared to be insufficient evidence to prove them. Evidence had been given before the Royal Commission to show that shingle and stones moved below low water and were thrown upon the shore during storms. Reference to a few points on the coast might serve to elucidate this question. At Pagham Harbour, east of Selsey Bill, there was now an immense accumulation of shingle which had increased to a large extent since the harbour was reclaimed about 35 years ago. Before enclosure, the tide, which had filled the harbour, as it flowed out, scoured out the shingle and so assisted its removal eastward by the tide. West of Selsey Bill to Chichester Harbour the shingle moved westward, as he had observed from having erected groynes there. East of the Bill, the shingle travelled eastward, so that at the Bill and at Pagham Harbour there was no source to supply shingle from falling cliffs. Whence, then, came this very large accumulation along the shore at Pagham Harbour? The only possible source, although the drift might originally have been derived from cliffs somewhere, must be below low water, and the shingle must be brought up during heavy gales and deposited on the beach there. Again, on the Yorkshire coast, north of Spurn Point, an enormous quantity of drift, consisting of sand and shingle, was Mr. Grantham.

Mr. Grantham. deposited at times on the shore. At other times, and during a single gale, the shore was completely denuded, and the clay on the shore became much furrowed by the scour produced by the waves. A change in the wind would again bring in large quantities, and the falls of cliff, which consisted largely of clay, were not sufficient, between the times of denudation of the shore and its replenishment, to account for the large fresh deposit of sand and shingle. The drift denuded from the shore must be deposited in the bed of the sea when the wind dropped, and be stirred up again during violent gales. Other instances could be cited, but there was evidence enough to show that the second and third propositions could not be accepted as principles governing all parts of the coast. Mr. Grantham was inclined to think that movements of this kind depended very much on the nature and conditions of the particular shore. Where the depth of water was not great and the tide receded to a considerable distance over flat sands, it was probable that very little shingle would be brought in by the tide; but where the water deepened at high water and the tide did not recede far, then quantities of shingle might be brought in, unless intercepted by some pier or breakwater. A case in point was the north shore of Morecambe Bay, where he erected groynes a few years ago. Here there was a rather narrow beach of shingle and sand derived from falls of the neighbouring cliffs. The tide receded over the sands until it reached a channel about 2 or 3 miles away from the shore. It was quite clear that here no shingle could be brought in by the tide, as never a stone was to be seen on the sands. Although the groynes had caused a considerable accumulation on the shore, the accretion was comparatively very slow, as the shingle and sand were moved only during high spring-tides and strong winds. The beach was subject to no fluctuation in its contour, such as denudation at one time and immense deposits at another, which might be seen on parts of the south and east coasts. On p. 101 the Author appeared to suggest the erection of high groynes in certain situations. Such groynes, built up to their full height at once, inevitably caused damage to the shore on their lee sides, and of late years there had been a consensus of opinion, derived from long experience, that it was much safer and better either to keep the groynes low or to build them up as the beach rose. The high groynes at Brighton illustrated the injurious scour which might be created on the lee side, a drop of 15 to 20 feet from the tops of the groynes sometimes occurring at their upper ends. With regard to the statement on p. 102 that sea-defences must necessarily consist of a combination of sea-walls and groynes, he would point out that long lengths of the south coast were protected entirely by groynes without any sea-walls, such as the frontage of the Pevensey Levels between Eastbourne and Bexhill, and again along the shore from Shoreham to West Worthing. The frontage of the town of Worthing was defended entirely by groynes, and the erection of a sea-wall there would at once cause depletion of the beach. As Mr. W. H. Wheeler said in his book,[1] sea-walls were the cause of their own destruction. When groynes were first constructed, the sea, as the Author had said, was apt to scour round their upper ends. But this scour could easily be prevented by fagots wired together, and when sufficient shingle had been accumulated the scouring action would cease altogether. This method had been adopted with success in the groynes on the Pevensey Levels. In his own experience, where protection of the coast only had to be considered, groynes were quite sufficient for the purpose under nearly every condition. On the frontages of towns by the sea, and at seaside resorts, sea-walls were built in order to form esplanades as an aid to the attractions of those places; but for protection from erosion only they were not essential. In conclusion, he found the Paper of particular interest, as affording an opportunity to discuss many debatable and difficult points connected with the subject. Mr. Grantham.

Mr. LEWIS M. HAUPT, of Philadelphia, observed that, in view of the recent Paper by Mr. Carey,[2] it would seem as if but little remained to be said; yet the great diversity of opinions and of practice, varying, as they must, with local conditions, and the necessity of protecting the coast from the incessant ravages of the sea in the most economical and effective manner, rendered this topic always fascinating and timely. Hence a few suggestions were volunteered, in the hope that they might add something to the preservation of riparian lands by modifications of the present practice. This question was of great moment to Great Britain, because of its insular position, and as the Author said, many millions sterling had been expended in the course of the last 100 years on the defence of its coast-lines. Had this century of experience produced results sufficient to justify the cost or to indicate any prospect of successful permanent resistance? That was the crux of the question. It was well known that under certain conditions the combined forces which were operating on alluvial coasts sometimes caused erosion, and at other times deposited material, so that, if Mr. Haupt.

[1] "The Sea Coast." London, 1902, p. 88.

[2] Minutes of Proceedings Inst. C.E., vol. clxxxiv, p. 1.

Mr. Haupt. possible, the latter conditions should be made to predominate in order to reclaim the lost territory. The physical forces necessary for this purpose had been thoroughly analysed, with the result set forth in the Institution Proceedings in 1905,[1] to the effect that low groynes gave better results, in general, than high ones, and that jetties were cheaper than and preferable to continuous sea-walls. A high wall on high-water line becomes one of the most effective excavators of a foreshore that could be imagined. This was abundantly confirmed by *Fig. 1* of the present Paper (p. 98), showing two attempts to arrest the encroachment of the sea by stone barriers reaching in the first instance to 20 feet and in the second to 30 feet in depth below the surface of the cliff; but, having no footing below low water, they did not even check the rate of 10 feet per annum, so that the expenditure was in vain and the moral had apparently been lost. The impossibility of laying down any hard and fast rule was evidenced by the stability of a sea-wall built to protect the city of Galveston, Texas, which was as stable to-day as when erected after the cyclone of 1900. The foundations extended below low water and the toe was protected by rip-rap footings; the outer face had a vertical curve. The Author also showed a section of a sea-wall at Hornsea (Fig. 4, Plate 3), where the beach had made up in height 9 feet in about 4 years, but in this instance the wall was flanked by two groynes 400 and 430 feet in length, spaced 639 feet apart, and the beneficial results were so great that the high tide never reached the sea-wall under ordinary conditions. It would appear, therefore, that this condition of equilibrium was due to the deposits held by the groynes, and the function of the sea-wall was secondary, namely, to protect the uplands from cliff-erosion in gales from the north-west. These were offshore winds, which were those that promoted the building up of foreshores (p. 96). In this instance the combination seemed to have worked to advantage, but the cost had been £10,820 sterling for an isolated protection covering about 700 feet. At this rate the cost per foot would be £15 10*s*., a sum which for agricultural lands would not seem to be justified, considering the relatively small waste. At the rate of 10 feet per annum, the annual waste per mile would be 1·2 acre, and for a cliff 30 feet in height the volume of erosion would approximate to 55,000 cubic yards per annum. This very interesting and able Paper contained data which would be of great value to the profession. The plan of the beach at Lowestoft (Fig. 7, Plate 3) indicated the high-water line of 1854 as forming a well-defined salient spit, which by 1903 had become a gently

[1] Minutes of Proceedings Inst. C.E., vol. clix, pp. 42–142.

rounded curve reaching to the North Pier. At groyne A the high-water contours intersected, thus forming the node between scour and deposit. As measured on the chart, the recession between 1854 and 1882 was at the rate of 20 feet per annum, and in the years 1882-1903 it was 21 feet, a remarkably uniform movement in view of the flattening of the curve. At an equal distance south of the node the advance was about 900 feet, and the areas of erosion and deposit were nearly equal, excluding the basins of the harbour. The rate of scour at the northern boundary between 1882 and 1903 was about 5 feet per annum, and at the latter date the slope of the foreshore was twice as steep as in 1882. The erosion south of the entrance, before protection, ranged from 5 to 7 feet per annum, or about the same as the normal coast-line, but the groynes had arrested this waste and impounded the silt, thus cutting off the drift alongshore, and in consequence, below the last groyne at Pakefield the cliff crest had retired about 300 feet, or at the rate of about 10 feet per annum. These changes in the rate of wear within a stretch of 3 miles of beach, subjected to the same exposure, could best be accounted for by the form of the contour, erosion taking place at the salient points and deposition in the re-entrant angles. The littoral drift was manifestly cut off by the main groyne A, which extended to 12 feet below mean low water, and the ridge thrown up by the subsidiary groynes starting at 50 feet from the wall had its crest at 90 feet out, and considerably above high-water line, thus pointing strongly to the normal uplift of the material from below low water to above high water; this accretion had continued and grown shoreward behind the ridge until it reached the coping of the sea-wall. As the function of the wall was defensive rather than offensive, and as these deposits had manifestly been carried up from the immediate foreshore by breaker-action, the question arose whether the same reclamation might not have been achieved had the groynes been constructed first with suitable abutments, when the wall might have been unnecessary. This query was emphasized by the experience at Sheringham, where a single groyne abutting on the septic tank had served to trap the shingle, which protected the shore until 11 years later, when a second groyne was built to windward, 500 yards distant: after that, owing to the cutting-off of the supply of shingle, the sea attacked the cliffs in front of the town and a sea-wall was built to save them from destruction. But this did not serve its purpose, for the Author stated that the denudation continued uninterruptedly, and that groyne No. 1 was left entirely bare of shingle. The foundations of the wall were denuded, and it was in danger of being overturned, Mr. Haupt.

Mr. Haupt. when two groynes were built, which accumulated deposits 11 feet in height and completely protected the wall. Thus the material must have come largely from the strand immediately in front of the groynes, as the steeper slopes would indicate. These examples would seem to cast serious doubts upon the Author's second postulate, that shingle travelled along the coast between high- and low-water mark. If by this it were intended to convey the impression that the source was limited to this narrow belt, the statement was very doubtful, since ordinary breakers would disturb the bed to a depth of 2 fathoms, and in the region of "the trades" the coastal currents were often muddy for hundreds of yards offshore with silt from the bed of the sea. Another marked instance of securing a supply from the foreshore below the low-water line had been briefly cited by Mr. Haupt in the Correspondence on Mr. Carey's recent Paper, where reference had been made [1] to the reclamation-work on the Edgemere beach, on which the littoral drift had been effectively arrested by two normal straight groynes, which had not accumulated sand and were flanked in the rear by the tide. In this case a sand-trap was built out from a bulkhead on the east, whence the drift should have come, with a hook at its outer end, and from this a stockade was sprung to the westward jetty acting as an abutment. The area enclosed had rapidly filled up, and the shore contours had been extended seaward by material, which could only have come from the bed of the sea below low water, being thrown over by the breakers charged with this sediment. No sea-wall was necessary, and thus the total cost of the work had been reduced to the very moderate sum of £900 sterling.

As to the effect of wind in conjunction with tides and wave-action, it was stated on p. 95 that shingle travelled between high- and low-water mark in line with the flood-tide, so long as the direction of the wind coincided more or less with that of the tide. On this point Mr. Haupt had made extended researches and had found that the drift frequently travelled in opposition to the wind and usually with the flood-tide, depending on the inclination of the coast contour with reference to the axis of approach of the tide or the breaking waves, as was notable in a cove or bay where the trend set towards the bight and the drift followed. The relation of the prevailing onshore winds was not found to be usually with the flood-tide, and could not well be so in the case of an island; but storm-winds often did reverse for the time being the angle at which the normal waves broke, and propelled the beach-drift in the

[1] Minutes of Proceedings Inst. C.E., vol. clxxxiv, p. 57.

opposite direction. It was the resultant movement, however, with which the engineer had to deal for successful results, and this was readily ascertained by the contour of the coast with reference to the approaching tides and breakers.[1] Another recent instance of the use of a groyne, to protect a drawbridge crossing an inlet on the New Jersey coast, might be cited. This could best be done in the language of the engineer-in-charge, who reported on the 16th February, 1911, that the work was begun on the 20th July, and suspended on the 4th December, 1910, from stress of weather; when there were in place 1,220 lineal feet of piles in two rows 5 feet apart and well braced. The total length was to have been 1,500 feet. The work had been subjected to four severe north-easterly storms. The engineer said:— Mr. Haupt.

"That portion of the jetty within the high-water line has been filled up entirely with drifted sand so that 300 feet of it is covered. It has caused bars to form at low water which are bare both north and south of it, and has driven the low-water mark out to 850 feet. It has formed a low-water area of 10 acres which will continue to grow. The cost of the jetty has been about £2 8*s.* per lineal foot. This reclamation jetty is doing its work in a very creditable manner."

There was no sea-wall in this case, and the accumulation of the beach was rapidly driving the high- and low-water marks seaward. It was said that, but for this work, the drawbridge would have been carried away, as had happened several times before. As the jetty extended far beyond the original low-water line, and as deposits had formed on both sides of the work, the top of which was above high-water level throughout, it would seem to be not always true that a groyne caused a lowering of the foreshore level on the down-stream side of the obstruction, nor that the greater its elevation and extension into the sea, the more pronounced would be the erosion on its leeward face. Theoretically this would happen if the groyne arrested all the drift, though the action would be confined to the narrow belt between high and low water. Notwithstanding this tendency to lower the foreshore on the leeward face of the groyne, the Author justly laid stress on the utility of groynes for breaking the force of the seas and raising the height of beaches. He also instanced the case of storm-waves raising the crest of the ridge of shingle to an elevation of 12 feet above extreme high water, but added that the ridge must be sufficiently backed up at the rear to afford the requisite stability. On this point, which again brought forward the sea-wall, attention might be called to a sand-fence with groynes built in front of a

[1] See Franklin Institute Journal, 1888, p. 306.

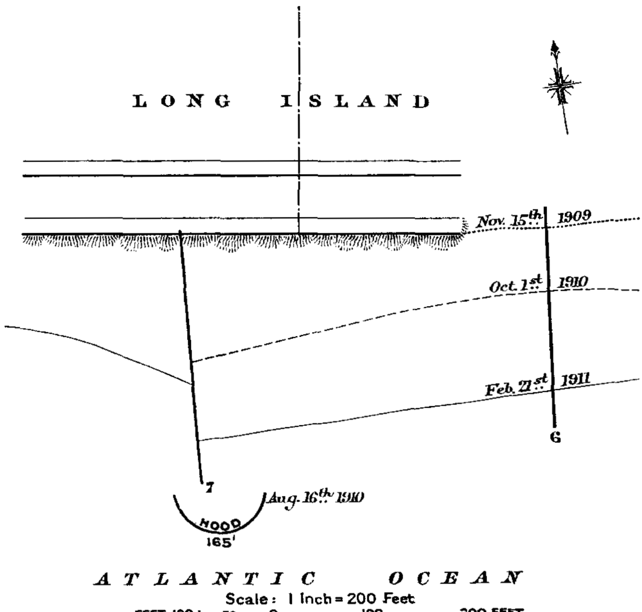
Mr. Haupt. low earthen bluff at Coronado Beach, California: this gave excellent results under ordinary conditions, but in a severe storm the breakers surmounted the glacis, reacted on the bluff, and tore out all the work.[1] These variations from generally accepted principles were cited in order to point out the necessity of advancing the defensive works so far from the footing of the cliffs as to prevent the seas from reaching them even in high storm-tides; the groynes must also be planned so as to cause the breakers to drive the shingle and silt shoreward, thus rapidly raising the foreshore and submerging the works for protection from waves and the teredo. For this purpose the customary normal straight groynes were not well adapted. Flying buttresses, with stockades or sand-traps composed of curved spurs in echelon, had given some remarkable results at a very low cost on the alluvial coasts of the United States.

A departure from established precedents which had given satisfactory results had been carried out at Arverne. This resort adjoined Edgemere on the west, and was likewise being rapidly eroded, so that early in the winter of 1909–10 seven normal jetties of timber were built across the strand without any backing. The first of these was 400 feet from the east line of the town; the next five were 200 feet apart, and the last 300 feet distant. They ranged in length from 200 to 243 feet, except No. 7, which was 300 feet long. They were all straight, and resulted in gradually catching the sand first on the windward side, until it drove over and filled on the leeward side to some extent. The movement proceeded from east to west, but groyne No. 7 remained almost denuded, especially on its west flank, so that the builders requested him to suggest a means of protecting it from destruction, and to aid in gathering the drift, which had been cut off by those to the east. For this purpose a simple "hood," consisting of a segmental arch having a radius of 50 feet (*Fig. 14*), was designed and placed seaward of the end and eccentric with the axis of the jetty. This was built in August, 1910, of some short refuse piles, cut for the inshore jetties, but, being placed in deeper water and exposed to the full fetch of the southerly waves, the crown was washed out in a storm, and the jetties were then replaced at a lower level in the central portion, making a stockade to pass the breakers above half-tide. This work withstood the winter storms and gave immediate results: thus, measurements made every 25 feet along the jetty from the top to the sand indicated that, up to the 21st February, 1911, there had been a gain on the east side of 5 feet, and on the west side

[1] See Report of the Geological Survey of New Jersey, 1905, p. 90.

of 1·3 foot of sand, at a point 125 feet out, and at the outer end the deposits on both sides averaged 1·5 foot. This simple device exemplified to a limited extent the ideas which Mr. Haupt had been advocating for beach-reclamation works for some time, namely, to place the resistance offshore and break the force of the sea before it could undercut the cliffs. The well-known spur jetties, when properly designed and placed, were effective in impounding the drift in the bays thus created, but were not active agencies in gathering sand from the foreshores. The drift travelled over them Mr. Haupt.

Fig. 14.



as soon as it reached their tops, and was washed along the strand as before. Attempts had been made to improve on the curved reaction jetty by setting the rows of piles closer and adding wings, but the effect in severe storms indicated the inefficiency of this plan, as the sloughs were not prevented, while the wings obstructed the uplift of the incoming waves. The bulkhead or sea-wall, surmounted by a board-walk and supplemented by spurs, destroyed the beach as an asset for pleasure and bathing, and threw the spray over the promenade; moreover, it did not invite deposition, and was too expensive to maintain. It would seem, therefore, that the stereo-

Mr. Haupt. typed spur jetties backed by bulkheads might be improved upon in many cases, with good results and at a cost that would warrant the individual riparian owner in undertaking the work, which otherwise must be left to the community or to the Government, because of its prohibitive cost. Each case furnished a distinct problem, and while based on general laws the works must be adapted to meet the local conditions. The same applied to the utilization of natural agencies in the creation and maintenance of channels, rather than the mechanical application of dredging in the open sea, though that was a distinct problem. Many other instances might be cited, but Mr. Haupt felt that he must not take further advantage of the privilege accorded to him, and he would therefore conclude by thanking The Institution for the opportunity of offering these observations upon Mr. Douglass's very suggestive and valuable Paper.

Mr. Jenkin. Mr. CHAS. J. JENKIN thought the Author was to be congratulated on the presentation of a lucid Paper on a very interesting subject. The question of coast-erosion was of great and almost national importance, especially in relation to coast-lines formed of friable cliffs. The encroachment on the east coast, especially, had for a number of years caused great damage and loss of property, and the case of Dunwich, between Southwold and Aldeburgh, was especially noteworthy. There, a prosperous county town of more than 40,000 inhabitants, with rich ecclesiastical and other buildings, had entirely disappeared, and a church built within comparatively recent years was now gradually falling on to the beach. In the case of friable cliffs, too little attention appeared to have been given to the action of rain, frost, and the sun. The numerous falls of the chalk cliffs were by no means entirely attributable to wave-action at the base of the cliffs, but, once fallen, the material was generally rapidly removed by winter gales. The sea formed its own protection in the even sweep of the shingle beach, and any sudden obstruction placed on the beach, by either artificial or natural means, caused scour and eddies, which were often very destructive. This, however, was not the case with a properly constructed groyne. Movement of material on the foreshore was almost universal over the entire kingdom, but where there were rocky cliffs little damage resulted from the depletion of the beaches; further, the even contour of the coast-line on the east coast set up conditions of currents which did not obtain on a broken rocky coast. A mistake often made was the construction of sea-walls with an insufficient margin of safety in the matter of depth, as shown in *Fig. 1.* Once the toe of the wall was exposed, the cutting action of the "floating" shingle was very severe. He had known it to cut some inches into a well-built concrete wall in a single winter. The abstraction of shingle was generally greatest at about high water, much of the removed material being replaced as the tide dropped, rendering an inspection of the damage after the tide had receded generally misleading. He was unable to agree with the Author that a vertical wall was the most suitable for coast-protection, especially where a promenade or other flat surface existed at the back of the sea-wall. The severe hammering action due to the waves falling back after striking the wall was not sufficiently taken into account, with the result that the often insufficient protection was broken through, and the ultimate collapse of the wall was greatly hastened. This had been particularly noticeable in the destruction of some promenade walling east of Bournemouth, and Mr. Jenkin was of opinion that all such walls should be formed with a wave-deflector along the top, in order that the broken wave might fall back into the sea. On the south coast of Cornwall many beaches were completely denuded of sand after the first winter gales had taken place, there being often a drop in material, at or above high-water mark (mean springs), of 15 to 20 feet. Similar depletion took place to a less extent during a very stormy summer. A heavy sea, with a tendency to ground-swell, would always remove more or less sand from these beaches. The sand commenced to return in the spring, and, generally speaking, remained during the whole of the summer, the local fishermen having a saying, "the sand travels against the wind." He did not quite agree with the contention that no material was contributed to the beaches from the deep sea. It would appear that a given condition of current formed a given contour of sea-bed, and any interference with the currents or with the sea-bed would often cause a deposit of material on the nearest shores. Some years ago several hundred thousand tons of material were dredged in Falmouth harbour and deposited about 2 miles west of Pendennis Point. The greater part of this material was washed up at Gwllynvase, and remained to the present time, forming a magnificent beach. There was also a beach on the west coast of Cornwall, just north of Land's End, the sand on which differed greatly from the sand on most beaches in the neighbourhood, being composed largely of shells that were not generally found on the coast. A friend had informed him that he had found on this beach several shells which, he thought, must have come from almost tropical waters. It would therefore appear that this beach was contributed to by the deeper waters of the Atlantic. Mr. Jenkin.

Mr. Jordan. Mr. Wm. Leighton Jordan noticed that, in describing the formation of a "middle ground" near the entrance of tidal estuaries (p. 96), the Author supposed it to be merely a consequence of the force of the ebb-tide preponderating over that of the flood-tide, and completely ignored the difference in the action of the earth's rotation on the flowing and the ebbing stream; this Mr. Jordan had described in connection with the creation of a similar "middle ground" under the railway-bridge over the Netravati River.[1] He urged that a great mistake was being made by those who persisted in ignoring the argument that the effect of the earth's rotation tended to cause the flood and ebb tides to diverge in opposite directions from any given channel, so that the course of the outflow could not be identical with that of the inflow. Further, the relative position of those channels was normally such as to make the flood and ebb streams form complementary parts of a cyclone.

Mr. Mann. Mr. I. J. Mann felt that the Author had treated the subject so comprehensively and clearly that little room was left for further observations of a general character. There was, however, no allusion to a closely allied subject which was of great interest to the harbour-engineer, namely, the pernicious effect of coast-erosion on adjacent harbours and on the neighbouring seaway. It let loose large quantities of sand and silt which subsequently were either, under the influence of tidal currents, carried into the harbour, or formed banks and shoals in the vicinity of the erosion. A well-marked instance of these effects was observable in South Bay on the east coast of Ireland. The south side of this bay consisted of marl or gault clay cliffs averaging about 50 feet in height, and the result of their erosion had been the blocking up of the harbour of Wexford and the formation of shifting sands. There could be little doubt that the banks known as the "Long Bank" and "Holden's Bed," lying seaward of South Bay, also owed their existence to the continuous erosion of the coast in their vicinity.

Mr. Meik. Mr. C. S. Meik quite agreed with the three propositions laid down by the Author on p. 97. Of course these principles must be considered from a broad point of view, as it was quite possible for shingle and sand, in rough weather, to travel along the coast for some little distance below low-water mark, and it was also possible for shingle and stones to be thrown up by the sea from considerable depths; but this would only be the result of a temporary disturbance, which would right itself when the weather abated. As a state

[1] Minutes of Proceedings Inst. C.E., vol. clxxiv, p. 55.

of equilibrium in the sea-bed must have been reached before now, it Mr. Meik. was evident that no permanent deepening could take place under normal circumstances. With regard to the fact referred to on p. 103, that the beach-material travelling on the coast was insufficient to afford protection to all foreshores, it was interesting to note that on the Norfolk coast severe erosion took place from the Wash past Cromer, and as far southward as Happisburgh. To the south of that place the shore had varied very little within recent years, and had, if anything, accreted, this action continuing as far southward as the entrance to Yarmouth Haven at Gorleston. This opinion was based upon Mr. Meik's knowledge of the coast-line, and was borne out by the information contained on plans supplied to him by Mr. Cockrill, the Borough Surveyor of Great Yarmouth. These plans showed that the beach had varied very slightly since 1884, a small denudation having taken place to the north of Caister and some accretion to the south of that place; but as a whole there had been very little alteration in the coast-line of the Yarmouth district. As no groynes existed in this district, it was apparent that there was a sufficient supply of beach-material from the coast northward of Happisburgh to make up any deficiency that might occur southward of that place. Indeed, it would seem that only a portion of the material washed away northward was necessary to make good the wastage southward of Happisburgh, some of the shingle evidently going to make up the shoals off the coast. The bulk of the shingle as it travelled southward collected to the north of the pier at Gorleston, a portion being removed from the beach for ballast, and some of it no doubt crossing the entrance to the harbour and travelling southward, until ultimately it found a lodgment behind the groynes on the north beach at Lowestoft, referred to in the Paper. A spur groyne, erected within the last few years behind the south pier at Gorleston, in a manner similar to the groyne behind the south pier at Lowestoft, had caused considerable accumulation on the beach at Gorleston, and there could be no doubt that a large quantity of material which would otherwise have travelled southward had been trapped at this place. It would be interesting if the Author would afford some information as to whether the sea-wall built in front of the Kirkley Cliffs, and subsequently destroyed by the sea, had been rebuilt, and if so, in what form. He noted that in Fig. 7, Plate 3, the most recent high-water mark indicated in front of the Kirkley Cliffs was that of 1903. Would the Author state whether the high-water line had been pushed further seaward since then by the action of the groynes, and also

Mr. Meik. if in his opinion the construction of the groynes on the north beach had robbed the beach in front of the Kirkley Cliffs of much material?

Prof. Robinson. Professor HENRY ROBINSON considered that the vertical walls shown in *Fig. 1* should have had aprons at their lower part to throw the sea away from the base of the wall, instead of the sea passing down the face, with the inevitable result of wearing away the footings. He had had to investigate a similar case, where a vertical sea-wall was built to form part of, and to protect, a promenade at a watering-place. When he examined it, only a few years after it was built, the sea had washed away the chalk foundation to a depth of several feet below the footings. If the wall had not been promptly underpinned and an apron added, together with groynes, the whole promenade would soon have disappeared. Before the positions of groynes were determined, careful observations should be made as to the direction of the waves during the heaviest seas and prevailing winds, so that the groynes could be placed at the proper angle for the waves to pass up the foreshore between them, and to deposit the beach-material which they carried, instead of striking the face of each groyne. Many years ago he carried out a series of groynes at Hornsea, to prevent the erosion of the base of a lofty clay cliff. The direction of the groynes was determined as stated, with the result that the foreshore had accreted ever since, and the cliff had been preserved instead of losing a foot per annum. Reference was made in the Paper to sea-defences at Hornsea, built to protect the Borough Council's property, being destroyed by heavy gales in 1906, but that was not the part of the coast where he carried out the groynes in question. He had dealt with the subject of coast-erosion 3 years ago in a Paper[1] in which he referred to the desirability of having a Department of State to deal with erosion, which department should be empowered to divide equitably the cost of the protective works between the local authorities and the owners of the land abutting on the foreshore dealt with.

Mr. Siccama. Mr. H. T. H. SICCAMA considered that the rate at which a coast-line was eroded depended on the form of the sea-bed to windward. The longer the fetch in the direction of the prevailing winds, and the greater the depths there, the heavier would be the attack. Changes in the conformation of the sea-bed affected the rate of erosion on the lee shore. For instance, before the chalky isthmus between Dover and Cape Grisnez was breached,

[1] "Foreshore Erosion and Reclamation." Transactions of the Surveyors' Institution, vol. xl, p. 109.

the southern part of the North Sea was a shallow gulf, open to the north, and surrounded by lagoons between the sea and the higher English hills on the west and the foothills of the northern diluvium on the east. The tides in this gulf were feeble, and came round the north coast of Scotland. This was evident from the situation of the old estuaries, which all lay in a northerly direction. The Scheldt, the Meuse, and the Rhine all had their principal estuaries flowing from south-east to north-west, through the soft, alluvial sandy formations. On the east coast of England the ancient estuaries were less marked, as their direction had been in most cases determined by the shape of the harder formations; but the older estuaries of the Thames, the Ouse, and the Humber, all running north-east, could still be traced. It was a law that an estuary subject to tidal influence lay so as to scoop in the tide, its deepest channels being found in the direction from which the flood approached the coast. If, through changes in the bed of the sea, the flood-current changed in direction or was affected by a stronger flood-wave from another quarter, then the channels in the estuary would slue round towards the stronger flood. The mouths of the Scheldt, Meuse and Rhine now lay in a south-westerly direction, and the estuary of the Thames had its deepest channels towards the south-east, opening up against the flood-tide sweeping round the North Foreland. This slow and gradual change was still going on. It began when the isthmus near Dover was broken down and the low-lying lands to the north-east were washed away; and it increased as the flood-current from the west scoured a deeper and wider channel. The same course of events could be observed in other parts of the world. Long ages ago a string of islands lay between Trinidad and the Azores. The flood-wave coming up from the south was deflected, and on the coast of British Guiana the flood-current then flowed from the north-west to south-east, the ancient estuaries lying towards the north-west. Now, however, the flood-current, no longer deflected, came up from the south-east, and all the estuaries on that coast had their deepest channels in that direction. The sea-bed in front had increased in depth, and the alluvial coast, formed under other conditions, was now much eroded and was being gradually washed away again. The erosion on that coast presented special features. While the sea attacked the Dutch coast of the North Sea fairly evenly along the whole line from the Scheldt to Texel, the erosion of the Guiana shore was intermittent. In some years one part suffered seriously, in other years an adjacent stretch was eroded, while the damage to formerly dangerous spots lessened. This could be due only to changes in the bed of Mr. Siccama.

Mr. Siccama. the sea in front. Where this shallowed, the coast to leeward was protected, and where it deepened, the sea-waves travelled on coastward in greater volume and velocity with a more disastrous result to that part of the coast on which they impinged. As to the more practical side of the question—the defence of attacked shores—there was a great similarity between the works required and those dams which were used for land-reclamation. In that case also a hard covering of softer material was required. Hitherto the most efficacious covering had been one of stone. This was liable to press too heavily on soft ground, and required constant attention and repair. Lately reinforced concrete had been utilized, with good results so far. The method employed by Mr. de Muralt,[1] chief engineer to the island of Schouwen, answered the purpose perfectly, being light and strong, and affording an adequate covering, excluding the danger of infiltration through interstices, which was a source of considerable trouble in packed stone-pitching. This system was worthy of the attention of engineers entrusted with sea-defence works, where the subsoil was soft and could not carry massive structures and heavy loads.

Capt. Stapleton. Captain NICHOLAS STAPLETON remarked that the tendency of all seaside towns, especially pleasure-resorts, was to drive the front as far seaward as possible, in order that every square yard of parade area might be utilized. This was often a thorough mistake, as it rendered inevitable the upright sea-wall. There was no doubt that in the vast majority of cases to copy Nature by constructing a sloping retaining embankment would result in less risk of damage to the front and less expenditure in construction. Here the practice of the Dutch coasts was well worth consideration. The methods by which a sloping face abutting on the sea might be covered with concrete and protected from disturbance had been brought before The Institution recently by Mr. A. E. Carey. In the Correspondence on that Paper a reinforced-concrete vertical wall of L section was described[2] which was intended to utilize the weight of the backing of the wall to give it stability, thus avoiding a massive retaining-wall on the designs hitherto adopted. If an upright sea-wall had to be employed, it seemed obvious to him that the vertical section, being the cheapest, was the best type. In many sea-walls a bull-nosed coping was adopted, but the advantage of this was very doubtful. It was expensive to build, and threw a severe strain on the structure of the wall under the assaults of the sea. When a

[1] Minutes of Proceedings Inst. C.E., vol. clxxxiv, p. 13.
[2] *Ibid*, vol. clxxxiv, p. 61.

sea-wall was heavily battered by waves, the exact contour of the section appeared to be relatively unimportant, as in this case the wall was a mere target for the blow of the waves. If a spending beach could be brought into existence in front of the wall, this would be its best security; but failing such protection, it became simply a contest between dead weight and moving force. Capt. Stapleton.

The Author. The AUTHOR, in reply, remarked that the point made by Mr. Beard, that shingle did travel below low-water mark—as shown by dumping 25,000 tons into the sea off Hove, which travelled rapidly towards the foreshore—did not controvert the statements on p. 97 that shingle travelled along the coast between high- and low-water mark, and that no shingle was procurable by tidal or wave action from the deep sea for the building-up and preservation of foreshores. The Royal Commission on Coast Erosion, whose final Report had been published since the Paper was read, in dealing with this subject, said:—

"With regard to the question of the derivation of beach material from below low-water mark, we should point out that a little may come from the scour of the sea bed in times of exceptional gales, as, for instance, where angular flint nodules are loosened from the subjacent strata. Again, seaweeds attach themselves to rocks on the sea bed and, owing to the break of the waves during gales, fragments may be detached and carried on shore; loose boulders, indeed, may be floated shorewards during times of comparative calm owing to the lifting power of growths of seaweed attached to them. As sand can be carried in suspension and therefore is more easily moved than shingle, some of it may be carried in from even greater depths."

This finding was generally in agreement with the Author's statement. As to the flood-tide being the predominant cause of the travel of the beach, which Mr. Berridge considered the Author had not proved, the Royal Commission reported:—

"The weight of evidence leads us to the conclusion that the direction of the travel along shore is usually that of the prevailing winds, the cause of the travel being the action of the waves as governed by those winds. The fact that the drift along the shore usually coincides in direction with the set of flood tides is, in the opinion of some witnesses, a mere coincidence though others think that the flood tides are a contributory factor."

In giving evidence, Messrs. Clement Reid, Vernon-Harcourt and William Shield attributed primary influence to waves. Mr. Wheeler said: "My theory is that it is due entirely to tidal action; the general opinion is that it is due to wind-waves." All agreed that when the tidal action and the wave-action were in the same direction the latter was intensified. Having inspected the whole of the coast-line of the British Isles, the Author had found no position, exclusive of bays and between islands, where the travel of shingle was not

The Author. in the direction of the flood-tide. The action of all the groynes constructed on the Lowestoft foreshores by the Author was to retain a full beach on their northern sides. The accumulation of sand and shingle under the South Pier was due to the sheltered area there provided.

With reference to the travel of shingle on the Pebble Ridge at Westward Ho! the pebbles were derived from the cliffs between Hartland Point and Westward Ho! They were washed along the toe of the cliffs, in a belt visible at low water, in the direction of the flood-tide, towards Bideford, making up the estuary of the rivers Torridge and Taw. There was a very large accumulation of pebbles off the most northerly point of Northam Burrows, which was due to the fact that the tidal action prevented the pebbles from being transported across the estuary on to the Saunton Sands. Mr. Berridge would find very useful memoranda as to the methods and resources employed by the Dutch for the protection of their coast in the Report of the Royal Commission on Coast-Erosion.[1] Mr. Brenan's experience with sea-walls on a sandy foreshore on the west coast of Scotland went to prove that sea-defence works required to be of exceptional strength on such foreshores. The timber revetment between the Grand Hotel and Pakefield Street, Lowestoft, mentioned by Mr. Cay, was constructed in the year 1902 from the Author's designs. In consequence of serious erosion at this point the rectory adjoining Pakefield Street was vacated and the adjoining house pulled down. Since the erection of the revetment and groyne the sea had not reached the cliff, which was now overgrown with grass. The rectory had of late years been inhabited again. Mr. Colson asked for the Author's views in the matter of avoiding the pitfalls inherent in such cases as that shown in *Fig. 1.* The Author had already stated in the Paper that the moral of the diagram was that sea-walls alone under these conditions were of little or no value for stopping the inroads of the sea; and naturally the course to be adopted was the inclusion of groynes for holding the beach and driving back the water-line. As a matter of fact these walls would have been overturned whatever their design might have been, since their overturning was due to the lowering of the foreshore, and not to any want of stability in the walls. If Mr. Grantham would read the Final Report of the Royal Commission he would find that the Commissioners held similar views to those expressed in the Paper with reference to the travel of shingle and

[1] See also A. E. Carey, "The Winning of Coastal Lands in Holland." Minutes of Proceedings Inst. C.E., vol. clxxxiv, p. 1.

the supply from the deep sea for the building-up and preservation of foreshores. The Author's experience of the sudden denudation of the foreshore on the Yorkshire coast north of Spurn Point at certain periods—mainly with north-west gales—was that the shingle and sand was drawn down below low-water mark and returned on the advent of fine weather. The Paper gave full particulars of the construction of high groynes built to their full height at once at Lowestoft and other places. These groynes were full on both their weather and lee sides. Mr. Grantham was in opposition to the Author's views as to the necessity for the construction of sea-walls at the landward end of groynes, and mentioned the Pevensey Levels—between Eastbourne and Bexhill—in support of his view. The Pevensey beach was a long flat beach with a "full" between the beach and the low-lying marsh, the "full" forming sufficient protection in that case. The adjoining cliffs between Pevensey and Bexhill continued to be eroded, in spite of the many groynes which had been constructed in recent years and were still being erected. This erosion was due entirely to the absence of a sea-wall. If scour at the head of groynes was prevented by wired fagots, the sea-stroke could not be very heavy. Mr. Haupt's suggestion that the result of a north-west gale on the Hornsea coast would be to build up the foreshore, the direction being off the land, was the exact opposite of what obtained, as mentioned on p. 96. The cost of protecting the 720 feet of wall was £13 not £15 10*s.* per lineal foot. Three groynes were included in the total expenditure of £10,820. The defence protected valuable property in this case. Before the construction of the Lowestoft North Denes sea-defences, described in the Paper, groynes were tried on that foreshore, the result being that erosion was not stayed, and in the end the groynes were washed away. The present sea-wall protected the Denes from flooding and the land from erosion, thus fulfilling a double duty. The whole of the shingle trapped by the two new groynes at Sheringham was washed over groyne No. 2, erected in the year 1894. No beach-material was driven up from low-water mark on this foreshore, and no pebbles were found seaward of the main bank. In stating his views as to the travel of shingle along any foreshore the Author had excepted bays such as those referred to by Mr. Jenkin. Bays formed settling-ponds for sand carried in suspension in the water, and any shingle which might be dumped on their sea-beds would, in course of time, be driven shoreward. Mr. Jordan referred to the Author having completely ignored the difference in the action of the earth's rotation on the flowing and the ebbing stream. The Author was equally guilty The Author.

The Author. of having ignored other phenomena which resulted in the force of the ebb-tide preponderating over that of the flood-tide. The remarks made by Mr. Meik as to erosion and accretion on the Norfolk coast were entirely in agreement with the Author's views. The sea-wall fronting Kirkley Cliffs, built by the Corporation of Lowestoft in 1901, and subsequently partially destroyed, had not been rebuilt. On the advice of the Author, groynes had been constructed in front of the wall, with the result that the foundations of the latter had been covered by the beach-material collected, and moderate repair had sufficed to maintain the structure. The action of the groynes along the Lowestoft South Beach up to the year 1903 had been to raise the beach-levels and drive back the line of high-water. There had been a further improvement in this respect since that year. Undoubtedly the construction of the harbour-piers was the chief cause of the depletion of the south beach. The groynes on the north beach trapped shingle which would otherwise find its way into the harbour or be removed by dredging. The Author did not agree with Professor Robinson that the walls shown in *Fig. 1* should have been constructed with aprons. The walls required groynes for the purpose of retaining the shingle and raising the beach-levels, which raising would have safeguarded the works from overturning. The four groynes referred to by Professor Robinson as having been built at Hornsea to protect the base of a lofty clay cliff were put down on the South Beach about 30 years ago for a French firm. For the first 5 years these groynes accreted sand, then the sea washed round their landward ends and pulled out the cliff, with the result that within 10 years the groynes had entirely disappeared with the exception of a few piles. This was another instance of the necessity for combining a sea-wall with groynes.