Paper No. 6542

The Selsey coast protection scheme†

by

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Discussion

Mr J. R. A. Garland (Chief Engineer, West Sussex River Board), who began by congratulating the Author on his excellent Paper, said that his own particular interest in the Paper concerned the references to shingle movement, as his Board was responsible for the sea defences on either side of Selsey Bill.

155. Perhaps before going on to questions of shingle movement he might add a word to what the Author had said about the Coast Protection Act. The shout which there was for sea defences to be a national expense was, he thought, misguided, and the position could be very greatly eased simply by the grant contribution from the Government being increased; and he hoped that this was not something which was impossible for the future.

156. There was provision in the 1949 Act for the setting up of coast protection boards, but to his knowledge no such board had been formed in this country, and he wished to say that, so far as his Board's relations with the District Councils that the Author advised were concerned, there was certainly no need for a coast protection board. So far—and he hoped it would continue in the future—they married up their ideas very well indeed.

157. Fig. 18 showed the Selsey Bill area and the length dealt with by the Author in his Paper comprised the section which was relatively high ground. The defences that were maintained by the River Board on the northwestern side were shown and these protected the low-lying ground behind them. Similarly, on the north-eastern section there was more low ground around Pagham Harbour, and those defences were maintained by the River Board. In effect, the Author's works had involved the hard fronting of Selsey Bill. The defences maintained by the River Board relied very largely on the retention of a substantial shingle bank which could, of course, be seriously affected by works on the upstream side. It would be remembered that it was pointed out in the Paper that the littoral drift divided at Selsey Bill, going north-westwards on the western side of the Bill and north-eastward on the eastern side. In the last ten years he estimated that about 36,000 cu. yd of shingle had been added to the defences on that length of about 4,000 yd. That was the net increase in the last ten years.

158. Fig. 23* was a photograph of the approach towards Pagham Harbour. The harbour, which was roughly a square mile, had been enclosed in the period 1876 to 1910, but eventually the sea had broken through again in the winter of 1910, and the drainage from the land between there and Chichester now found its way out of various channels out to the sea through the shingle banks.

159. Fig. 24 was a vertical aerial photograph showing the conditions at the mouth of the harbour. Originally a continuous shingle bank had existed from the cut-off of steel sheet piling. There had been a continuous shingle bank from there across to enclose

† Proc. Instn civ. Engrs, vol. 20, pp. 481–506 (Dec. 1961).

* Figs 23-31 are photographs and are printed between pp. 128–129.

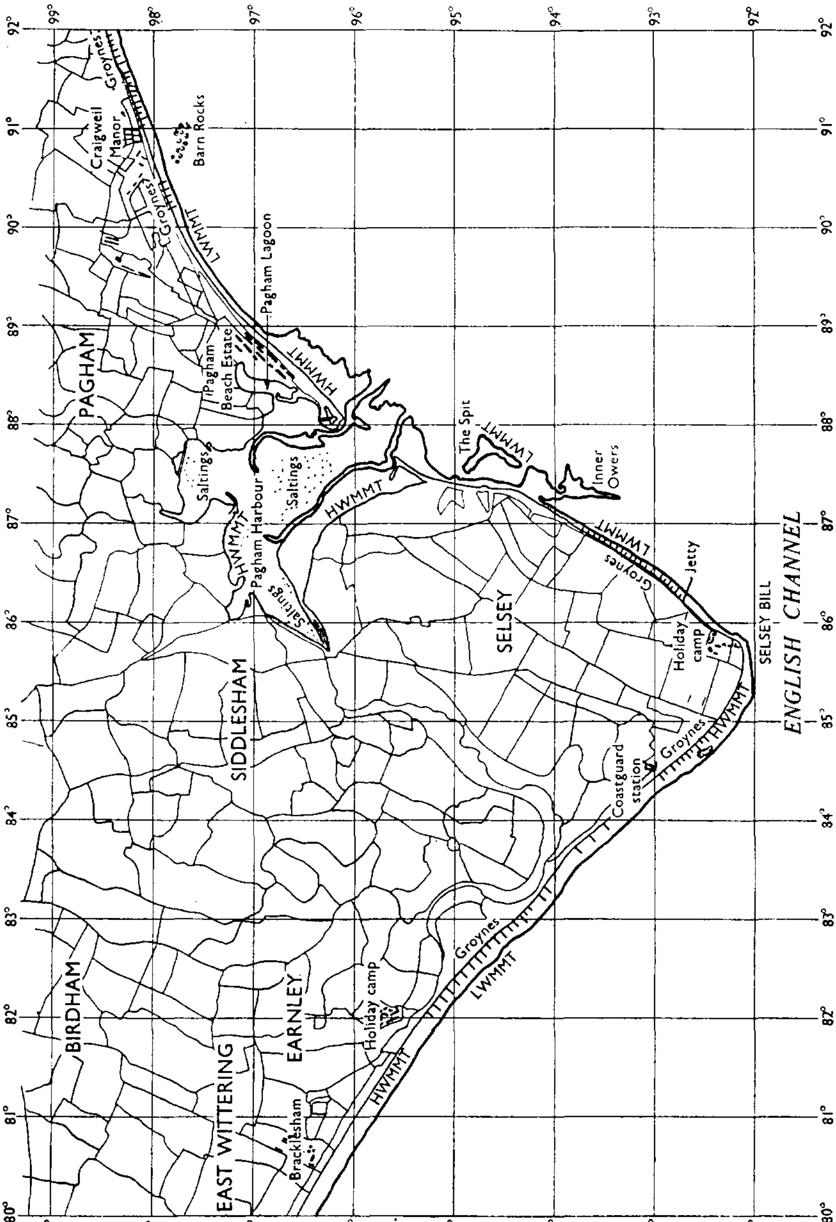

FIG. 18.—THE SELSEY BILL AREA

the steel sheet piling which was the north-eastern side of the harbour mouth. The unprotected shingle spit was 2,000 ft long. In 1955 a breach had occurred just east of the new mouth, and subsequently, within a year, another breach; and in a very short time the shingle bank between the two breaches had been rolled back, so that between the cut-off steel sheet piling and the old mouth created just before the last war there was a new mouth formed to the harbour 1,500 ft wide, with the remains of the shingle bank set back 1,000 ft. The result of the littoral drift coming up from Selsey Bill had been to build a new spit, and today this was 1,200 ft long. The most rapid growth recorded was one of 250 ft in just under a year, and it was estimated that some 100,000 cu. yd of shingle had been needed to form that leap forward in less than a year. The quantities to which he had referred, both on this side and on the north-western side, were not necessarily additions to the total shingle resources of the area, but they were changes in volumes which had been recorded on those two fronts.

160. In § 6 the Author referred to minor surges in the Channel. He had himself recorded a maximum height of surge of only 2 ft. He would be interested to hear the Author's views or any figures that he had, and what he thought was the possibility of increased surges occurring in the future.

161. The figures given in Table 1 could be misleading, as they appeared to indicate an increasing rate of erosion. It was possible, however, that a curve could be fitted to the average rates which were quoted which would show the present-day rate to be falling, and this could have a serious effect on the calculations to assess the land affected and required to contribute by the works scheme procedure under the 1949 Act.

162. Returning to the question of shingle movements, and particularly the source of this material, he entirely supported the Author's suggestions for research into this question. Most of the sea defences on the South Coast relied on shingle for the protection of the defences behind, and it seemed fundamentally unsound to go on putting large sums of money, both public and private, into those works with such a gap in knowledge.

163. He wondered whether the Author had changed his mind over the last years with regard to the source of this shingle material. With the division of the littoral drift at Selsey, surely any additional material to that which was already held in the groyning system must come from the sea; yet in § 57 the Author only said " possibly from the sea". Was there anywhere else that it could come from?

164. The type of foreshore scour experienced on this section of the coast, and referred to in § 95, was shown in Fig. 25, and it could be seen that there was deep scouring in the clay base as soon as the sand was removed. The scouring shown occurred in a matter of two or three tides under extreme conditions.

165. In §§ 151 and 152 reference was made to the erosion taking place between West Street and the river board defences 1,000 ft to the north-west. While he agreed that factors other than engineering ones had influenced work on this front, did not the Author agree that this gap must be dealt with if the defences on either side were not to be outflanked, and that the sooner this work was carried out, the better?

Mr C. H. Dobbie (Senior Partner, C. H. Dobbie & Partners, Consulting Engineers) said that on reading the Paper he had been struck by the care taken to evaluate all the available factors affecting the coast and the consideration given to the effects of the works during construction and in the future. He thought that coast protection was really a professional job and should not be a "Tom Tiddler's ground" for cranks and amateurs. After the verbose nonsense which had appeared recently in the technical press, it was indeed refreshing to read such a workmanlike and honest paper.

167. He thought that the experiments on erosion of clay samples had been abandoned a little early and that the experimenters might have persisted more. An analogy could have been drawn with the work on erosion of river beds, and the conception of critical

traction force as set out in Table 1 of the United Nations publication "River Training and Bank Protection", Flood Control Series No. 4 (1953).

168. The western beach from Selsey Bill to Chichester Harbour could be regarded as one coastal unit with drift predominantly westward terminating in the spit pointing upstream in the harbour, as shown in Fig. 1 of the Paper. As he had reported for two estate companies, whose frontages lay westward of the length described in the Paper, it was possible to add some further figures to Table 1 for three points which could be called X, Y and Z. See Fig. 19 and Table 2. There had been steady erosion on this frontage until 1902 when groynes had been built, since when the high-water line had been more or less stabilized. Erosion was, however, threatened on the western end and

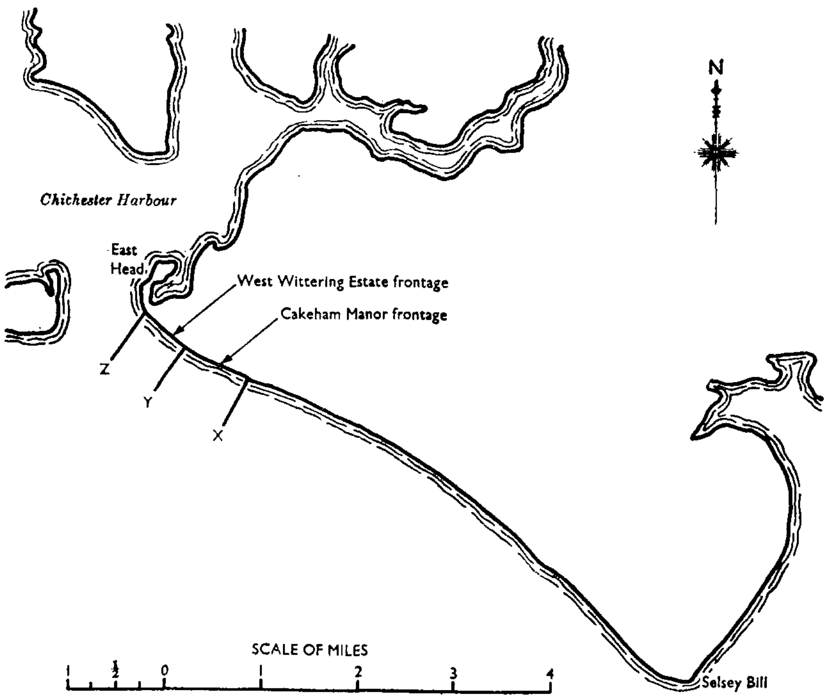

FIG. 19.—COASTLINE FROM SELSEY BILL TO CHICHESTER HARBOUR

TABLE 2

POINT	LOCATION	EROSION: ft/annum		
		1875–97	1897–1933	1933–61
X	West Wittering Estate, 24,000 ft west of A	23	4	2
Y	West Wittering Estate, 28,000 ft west of A	8·5	0	0
Z	Cakeham Manor, 31,000 ft west of A .	8·0	1	1

drift arriving there was whisked around the corner to the spit, which itself was suffering erosion, the material presumably moving upstream to beds below low-water level (Fig. 20).

169. An interesting point was that when the drift was plentiful the spit projected westwards across the harbour mouth, and then between the years had turned through a right angle to point upstream.

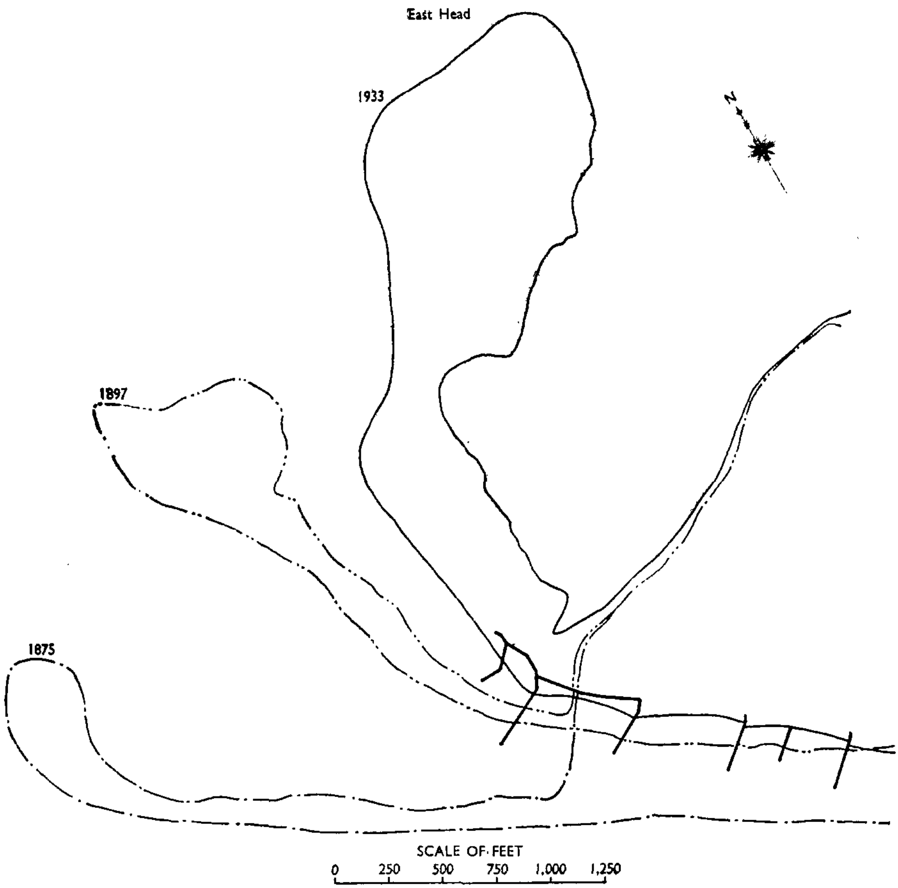

FIG. 20.—CHICHESTER HARBOUR: MOVEMENT OF H.W.M.O.S.T. AT EAST HEAD, 1875–1933

170. The illustration of drift direction by vector analysis of the wind rose related to fetch had novelty and it would be helpful if the Author would elaborate a little on the method he had adopted.

171. A statement at the end of § 135 about design for minimum maintenance had great wisdom, as local authorities simply did not give maintenance to sea walls. Looking after groynes was also often neglected, but perhaps not quite to the same extent. In predicting the coastline beyond the terminal groynes, did the Author look forward to the groynes being maintained and the drift, to some extent, being regulated?

172. In 1945 he had written a Paper for the Institution's Journal and had given an example of what could happen to a terminal groyne where the drift was interrupted abruptly. (Fig. 21).

173. In regard to detailed design, Figs 4 and 5 showed a drain behind the wall, which was obviously a very necessary provision, and he asked the Author how he had dealt with the outlets from that drain, as outlets on some walls had given trouble.

Mr J. A. Lewis (Partner, Messrs Lewis and Duvivier) recalled that when the Chichester Rural District Council had approached them for advice about defending the coast, he had discussed the matter with Mr Duvivier, and they had considered what were the possibilities. Here was a piece of foreshore which was eroding at an extraordinarily rapid rate. Could it be stopped? Why was it eroding? Would they be too rash if they said that they would stop it?

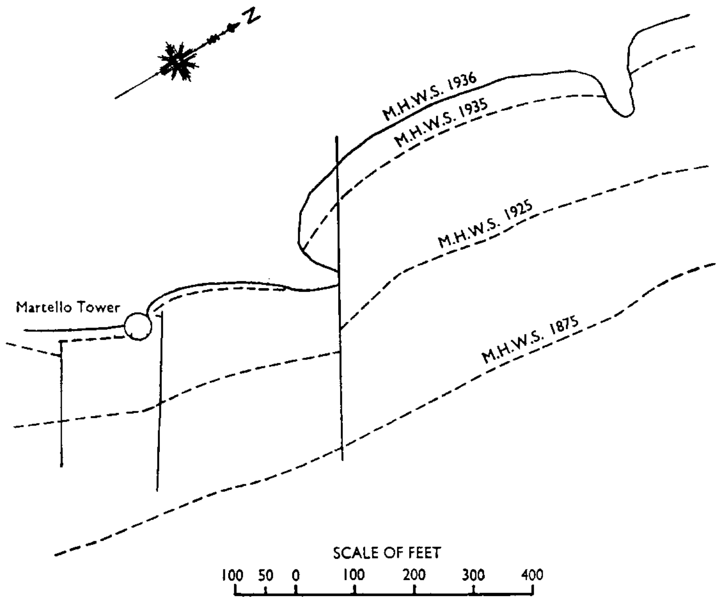

FIG. 21.—TERMINAL GROYNE AT LANGLEY POINT

175. He wished to take up the case of a rapidly eroding foreshore, its cause and the possibility of stopping it. Two points of particular interest in this respect were dealt with in the Paper. One was in Table 1 in § 18 of the Paper, where the rates of erosion were shown. At one period there had been accretion at the east end of the East Beach when there was erosion further along nearer the Bill, and that, combined with the wind rose and the record of the ebb current being in the opposite direction, seemed to emphasise the point that it was wind waves which were the principal cause. He had always felt that the foundation of a beach was to some extent at the top. In some places a beach would remain stable until the crest was thrown back into the marshland, and when the crest was thrown back the whole lower beach followed it. By the same token, if the crest was carried along the foreshore, the outer foreshore would follow it in.

176. The fact that these works had been carried out and that a number of years had elapsed since they were started and the rate of lowering of the foreshore had not continued, seemed to indicate that once the erosion at the top of the foreshore was stopped,

the lower foreshore became stable, and in a case where the lower foreshore was of erodable material, such as clay, when it reached a level at which it was covered permanently by a thin layer of sand or shingle it remained stable; whereas once it was exposed, as in Fig. 25 which Mr Garland had shown, it could erode extraordinarily rapidly.

177. The Author raised the question of movement of the shingle on the sea-bed, and he thought that it would be interesting to take that point further. If the Author could say anything further about the depth of movement which he felt was of significance, it would be of interest. The Author quoted the very high rates of currents and the movement of shingle at 10 ft depth, and then referred later on to the comparison of Admiralty charts showing that at 2 to 3 fathoms deeper there had been very little movement over a long time. He had found that the same was true on examining the source of the shingle replenishing the Chesil Bank near Bridport in order to say whether the Bridport Borough Council could continue to remove it with impunity.

178. In connexion with the possibility of stopping the erosion of a coastline which was eroding rapidly, he wished to show one or two slides referring to a similar problem of some clay cliffs eroding at rates of up to 7 ft per annum, with the clay at the worst point going down about 1 ft per annum, although the average rate was lower than that.

179. Fig. 26 showed the cliffs from the east end before the work was started. On this occasion there had been bad scour and the foot of the cliff was exposed.

180. Fig. 27 showed a typical picture of the foot of the cliff. The cliff slipped down when the toe was eroded by high tides, the clay was washed away, and the shingle was moved further back and the whole beach followed it in.

181. Fig. 28. A wall was constructed in front of the cliff and the contractor had used the excavated clay to form a bank to keep out the sea. Owing to the rapid erosion of silty materials, this had proved effective only in very calm weather; as soon as there were any fierce storms, the bank of clay had been completely carried away.

182. Fig. 29. On 16 May, 1958, a very severe storm, of force 9 gale or thereabouts, had blown up from the north, and the contractors' clay bank was severely eroded.

183. Fig. 30 showed the result. All the clay had spewed down over the foreshore. It was a spongy mess that no one could walk on.

184. Fig. 31 showed the work nearing completion. The groynes had been built and the shingle was lying up against the wall. This photograph had been taken at one of the worst points. It showed the groynes holding the shingle over the foreshore, and the state was virtually the same today, two years after the photograph had been taken.

Mr D. V. Buck (Senior Partner, Messrs Wilton and Bell) considered that the site described in the Paper was a very unusual one for coast protection works in that very little advantage could be gained from the constructive forces of nature to balance or combat her more destructive forces. On the latter point, there were two questions that he wished to put to the Author.

186. Investigations showed that the erosion on the beaches had been largely due to the slow but persistent disappearance of a shingle bank which extended from Selsey Bill to the Mixon, and this erosion had been accompanied by the erosion of inshore shoals. The result of that disappearance in about 1927 had been the complete loss of protection of the beaches from the south-westerly seas, alterations to the line of the east coast due to the formation of a relatively deep inshore channel, and also loss of supplies of nourishment to the beaches. He asked the Author whether consideration had been given to the feasibility of re-establishing, even in part, that bank of shingle connecting Selsey with the Mixon. Presumably this would have had to be done with fairly heavy material, rock spalls or similar, but it would have reinstated the protection from the seas and possibly have nullified the destructive effect of the water moving in the inshore channel; and it would possibly also have allowed for the renewed movement inshore of beach material from the offshore shingle banks. The construction of such a bank would have

been costly, but he imagined that it would have resulted in some economies in the form of construction of sea-walls and groyning that had been adopted on the East and West Beaches.

187. The second point that he had wanted to raise had been largely answered by the Author in his introductory remarks, but it concerned the pre-determined programme of the works. The total cost, a half a million pounds, had been spread over three stages extending a little over seven years. He could certainly see an advantage to the Author in such an arrangement in that he had had the opportunity of designing and constructing works in the second and third stages on the basis of experience gained from erosion or accretion while the first stage was being constructed and completed. But had this been the only advantage? It appeared that if the three stages could have been concertina-ed into one contract, whereas it would have resulted in an increased rate of expenditure, possibly it would have resulted in a reduced overall cost.

Mr W. J. Reid (Senior Scientific Officer, Hydraulics Research Station) said that he wished to make some points in connexion with the littoral drift at Selsey Bill and to comment on the Author's suggestion that fluorescent tracers could be used to investigate the movement of pebbles round the Bill.

189. To deal first with the littoral drift pattern at Selsey Bill and to see how it was related to the wave conditions mentioned by the Author; while he agreed that they should be cautious about using a combination of local wind data and Stevenson's fetch formula to predict predominant waves, he thought it was reasonable to argue that the longest and most effective waves would strike the coast from a direction between west and south. He thought that the erosion at Selsey was exactly what would be expected to occur from a consideration of the pattern of drift even if there was no offshore source of pebbles and that the new groyning system should be effective in stabilising the Bill.

190. Recent work in America had shown that the quantity of littoral drift on a beach could be related very closely to the characteristics of the waves breaking on the beach[1]; the drift had been found to be dependent on the alongshore wave energy, which varied with the square of the wave height, the wave period, and the angle at which the wave crests crossed the beach contours. From a refraction diagram showing the pattern of wave crests round Selsey Bill when waves approached it from a direction between west and south, it could be seen that waves approached the West Beach with their crests only slightly angled to the shore, wave crests were parallel to the shore at the end of the Bill and waves on the East Beach crossed the contours at a considerable angle. The resulting pattern of beach movement would produce very high rates of erosion on the East Beach, and a smaller rate of erosion on the West Beach. This was exactly what occurred at Selsey since 1900, as could be seen from the results given in Table 1 in the paper. Before 1900 the erosion on the East Beach was much less; this might be due either to eroded material passing eastwards around the Bill during storms from the west and being deposited on the East Beach before the construction of defence works at the Bill had held up the drift—as had been found to occur at Dungeness—or to changes in the protection afforded by the offshore banks which had taken place since 1900.

191. The construction of groynes on the eastern and western beaches should effectively stop the erosion and drift along these sections, and produce stable beaches, but severe erosion would occur downdrift of each of these defences, since the dominant waves would obtain their supply of drift material from the areas at the end of the groyning system. It would be concluded that the new groyning system would effectively stabilize the eastern and western beaches, but that the erosion downdrift of each of the defence works might need to be checked with artificial fill.

192. A possible alternative to the groyning system would be a system of continuous artificial fill, taking pebbles from, say, the beach near Inner Owers, and depositing the

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[1] The references are listed on p. 142.

FIG. 23.—PAGHAM HARBOUR MOUTH, AERIAL VIEW JUNE 1959, LOOKING NE FROM SELSEY BILL

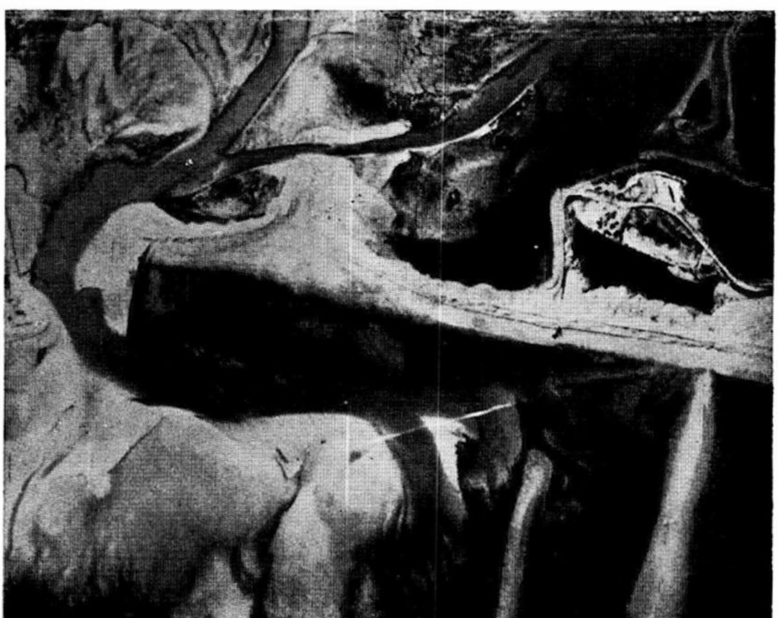

FIG. 24.—PAGHAM HARBOUR MOUTH, VERTICAL AERIAL PHOTOGRAPH MAY 1955

FIG. 25.—FORESHORE SCOUR BETWEEN SELSEY AND BRACKLESHAM

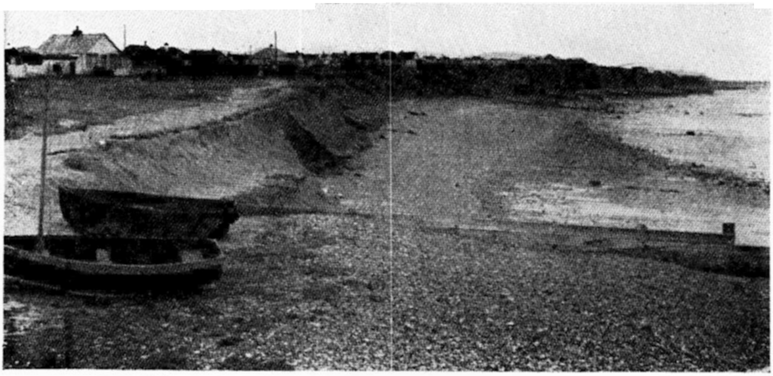

FIG. 26.—HERNE BAY, STUDD HILL, BEFORE START OF WORKS

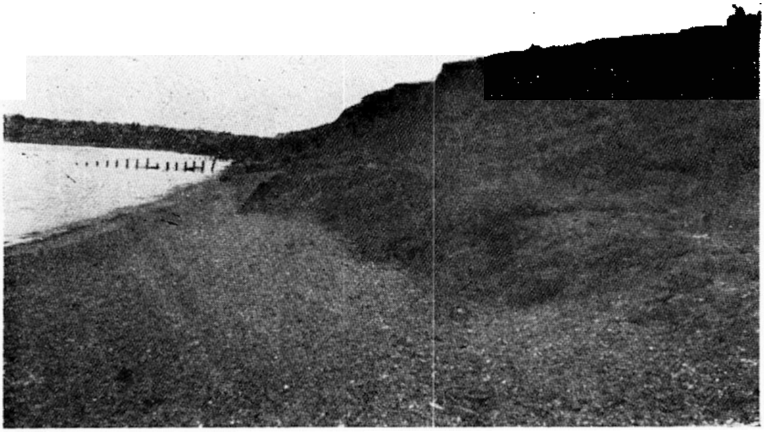

FIG. 27.—HERNE BAY, STUDD HILL, TYPICAL VIEW OF CLAY CLIFFS

FIG. 28.—HERNE BAY, STUDD HILL, WORK IN PROGRESS BEHIND CLAY BANK

FIG. 29.—HERNE BAY, STUDD HILL, STORM 16 MAY 1958

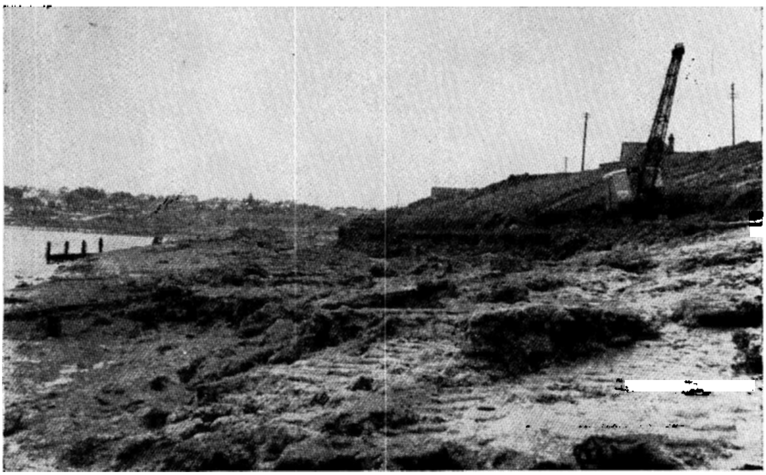

FIG. 30.—HERNE BAY, STUDD HILL, EFFECT OF STORM ON CONTRACTOR'S CLAY BANK

FIG. 31.—HERNE BAY, STUDD HILL, WORK NEAR COMPLETION SHOWING GROYNES HOLDING SHINGLE BEACH

shingle at the end of the Bill. Perhaps the Author would like to comment on the economics of such a scheme. Artificial fill had been standard practice in America for many years, and a successful scheme had recently been carried out in one of the German islands in the North Sea, as described in a paper[2] to the 7th Coastal Engineering Congress held at The Hague in 1960. The method had also been used with some success at Rye by the Kent River Board. Had the Author considered this possibility as an alternative to a large groyning system?

193. The Author had suggested that fluorescent tracers could be used to investigate the drift at Selsey Bill and possible offshore sources of supply. The experiments so far carried out by the Hydraulics Research Station had shown that it was possible to measure the net annual drift on a shingle beach, and littoral drift had been measured in this way at Rye in Sussex and Dungeness and Deal in Kent. In the technique developed by the Hydraulics Research Station 7 cwt of fluorescent tracer pebbles had been dumped in the beach each week and the distribution of tracer pebbles measured at intervals for one year. The net annual drift was then calculated from the distribution of tracer pebbles on the beach. This technique could be applied to the East Beach at Selsey Bill to find the net annual drift, but the net drift was now probably very small since the beach was thoroughly groyned.

194. He thought that a more fruitful experiment would be to dump quantities of artificial fluorescent pebbles of various sizes and colours at points offshore on the shingle bank opposite Bill House. Surveys could then be made at intervals to see if any artificial tracer had come ashore and possibly the Station underwater diving team could examine deposit sites from time to time to see if the injected material had moved. It might even be possible to find out the quantity of shingle—if any—moved onto the beach from offshore. If the number of ordinary pebbles in a given area of seabed could be found, then a given number of tracer pebbles could be placed in that area. Then if the concentration of tracer pebbles to ordinary pebbles was found to be, say 1:10,000, for every one tracer pebble found subsequently on the shore it could be reasoned that 10,000 ordinary pebbles had been moved on to the beach and as a result the quantity of pebbles supplied to the beach for each offshore area could be assessed. However, if no tracer pebbles were found on the beach, it could be either that they had been buried in the beach, or that they had not come ashore in sufficient numbers to be noticeable, so that if no tracer pebbles were found the results would be less conclusive. The Hydraulics Research Station would be very interested in co-operating with the Author in such an experiment.

Mr F. L. Terrett (Partner, Messrs Lewis and Duvivier) noted that in § 111 of the Paper it was stated that the stabilization of the East Beach by groyning was expected to result in consequential stability offshore. This implied that it was unnecessary to build groynes below low-water mark in order to stabilize the sea-bed. Experience showed that this might frequently be true, but it was by no means obvious that it should always be right, and he thought it would be interesting to examine the possible mechanics of the process.

196. They were told in § 112 that the sea-bed which formed a gentle slope from low-water mark to an off-shore channel was covered by a thin veneer of sand and gravel, but this was obviously a mobile material and there was insufficient of it to protect the underlying silts and clays of the Bracklesham beds which would continue to erode, forming scarps. At depths greater than 10 ft below mean low water springs the sea-bed had only eroded very slightly, and this defined the limit of the breaker zone except under the most extreme conditions. It was the depth in which waves 6 to 8 ft in height would be expected to break, and that he would think would be about the maximum size of waves in that locality.

197. It was well known that gravel and particularly sand on a foreshore was drawn down and deposited between low water and the plunge line during onshore gales, but would return to the beach under calmer conditions. As the silts on the offshore slope

were eroded away they would consequently tend to be replaced by gravel from the beach and provided there was sufficient of it the whole profile from the sea-wall to a level of 8 to 10 ft below mean low water springs should adjust itself to the new conditions.

198. Some of the material drawn down from the beach would be lost, particularly the finer particles which could be removed by the strong ebb current, but it appeared that as far as shingle was concerned the current and wave effects were more or less in balance, judging by the results of the test at the lifeboat slipway, and that the shingle would find its way back on to the beach. Probably it would move north-eastward in the process and in time be carried beyond the ends of the groyne system. The ultimate stability of the sea-bed slope appeared, therefore, to be dependent on some replenishment of the shingle and if, as was suggested in the Paper, a supply from the short length of coast between the Bill and Hill Field Road, which was not protected, was insufficient, then artificial nourishment might in time be required.

199. Artificial renourishment was a question of maintenance, and although, for instance, between Rye and Dungeness it was a continuous process, he would not expect it to be so at Selsey, where it would only be required at infrequent intervals and might not be needed at all.

200. He supported the Author's suggestion that the Hydraulics Research Station should use the Selsey Peninsula as an outdoor laboratory for coastal experiments. Mr Reid had already referred to certain experiments that might be done. He had in mind something rather different, and suggested that full-scale research on the coast might enable beach movements as determined by tracers to be related more accurately than was at present possible to the winds prevailing at the time. The need for this could be illustrated by reference to § 44 and 49 of the Paper where the use of a wind rose and vector diagram for checking the direction of littoral drift was described. In recent years he had done work on a number of coastal sites where there had been no natural features or structures which might have acted as a barrier to the drift and thus given an indication of its direction. In some of these cases experiments with markers placed on the beach had been carried out and some details of the most recent of these at Redcar in Yorkshire might be of interest.

201. At that site nine different types of marker had been used in the form of mortar cubes made from coloured cement and marked with metal studs, and these had been placed in batches of 50 on three widely spaced cross-sections of the beach at high-water mark, mid-tide level and low-water mark. A man had been employed to search the beach daily for a month after the markers had been placed, and a satisfactory proportion of them had been recovered and their locations recorded. The experiment had later been repeated over a period of another month and during both, records of wind direction and strength and wave height and direction of approach had been recorded.

202. Before those experiments had been started a wind diagram had been prepared and this seemed to indicate that the drift would be from north-west to south-east. The marker experiments had indicated, however, that the northerly winds were much less effective in moving the beach material than southerly winds, probably due to the influence of off-lying rocky shoals, and the conclusions about the drift there had consequently been reversed. It was this experience that led him to hope that perhaps experiments carried out by the Hydraulics Research Station might enable some correlation between the beach movement and wind direction to be formulated that might be of general application.

203. He also suggested that the wind vector technique described in §§ 44 to 49 of the Paper was worth further study in order to improve the accuracy of its predictions. One step forward might be to introduce not only a weighting for fetch, but also for wind strength, and this could be based on the results of tests carried out by the National Institute of Oceanography and recently published[3,4], from which it had been shown that the wave height in the seas round the coast of England and Wales could be related to the wind speed to the power $\frac{3}{2}$. To introduce this factor would mean subdividing the wind strengths from the various directions into small groups instead of taking together

all strengths above force 4, as he believed had been done at Selsey. This would make the process more complicated, but he thought it would be worth while.

204. Finally, he wished to refer to the erosion experiments mentioned in §§ 138 to 142. These had been carried out in connexion with sea defence works at Fleetwood, Lancashire, in an attempt to find some correlation between soil properties as determined by the usual tests and the ability of the soil to stand up to wave action.

205. This investigation had arisen as a result of a disaster which had overtaken the sea-wall at Fleetwood during a storm in December, 1954. The beach at the time had stood against the sea wall at about +12 O.D., i.e., 2 to 3 ft below mean high water springs. It had consisted of sand and gravel probably not more than 2 to 3 ft thick overlying silts and silty clays. The sand and gravel had been swept away during the storm and the silt eroded so rapidly that the wall collapsed in two places.

206. It might be thought obvious that silt would scour away very rapidly, but at another part of the frontage at Fleetwood similar silts and silty clays had been exposed on many occasions, but had eroded only slowly and still stood against the sea-wall at a level as high as +14 O.D. The test referred to in the Paper had been devised in an attempt to explain the different behaviour at those two sites.

207. Although the laboratory test had not reproduced the known behaviour of the material in situ, a correlation had been found between the test results and the index properties. The first soil mechanics firm who had carried out the tests found a relationship between the loss of weight of material in a given time and the liquid limit, viz:—

$$\mathrm{Log}_{10}\, W = 14 - 0{\cdot}34 \times \text{liquid limit}.$$

208. A second soil mechanics firm who had carried out more recent investigations at the same sites had referred him to the results of some work published by the American Society of Civil Engineers[5] on the erosion of silts in canal beds. In that case separate relationships had been found between the resistance to erosion and apparent cohesion, grain size, and plasticity index. An attempt had been made to fit the data from Fleetwood into those relationships, but without success, the reason for this probably being that the materials from Fleetwood were extremely variable. A point that had come out of the investigation was that the silts which had eroded most had a very high natural moisture content, in some cases higher than the liquid limit.

209 Although the results of that series of tests were so far rather inconclusive, the investigation had not been abandoned, and it was hoped that one day something would emerge of sufficient value to justify its being reported to the Institution. In the meantime, he had thought it worth while mentioning the tests as suggesting a field in which further research would be valuable.

Mr M. G. Barrett (Engineer, Messrs Lewis and Duvivier) said that he considered himself fortunate in having been associated with the Selsey sea defences over the last ten years. It had been particularly interesting because of the large variety of conditions contained in a single scheme.

211. In § 74 of the Paper, reference was made to a number of experimental timbers in the groynes. A further inspection of these timbers had been made last month. No significant deterioration had been observed in any of the 18 experimental piles in the West Beach groynes for which creosoted elm, spotted gum, tallowwood, grey gum, ironbark, incised and creosoted Douglas fir and turpentine had been used or in the ekki, jarrah and greenheart which had been used for the remainder of the groynes. These timbers had now been in position for ten years.

212. The slight gribble attack on the cut ends of some of the East Beach groynes, which was also mentioned, had continued. These planks were 9 in. by 3 in. incised and Celcurised Douglas fir and had been fixed six years ago. Two coats of hot creosote had been specified for any ends which had to be cut due to slight variations in the length required. The attack was very limited and was confined to those cut ends. It was found, however, up to a level of 6 ft above Ordnance Datum, only 1 ft below mean high

water of spring tides. It occurred generally near the site of the old lifeboat station gangway on which some timbers had suffered from gribble attack. In particular, some 12 in. by 6 in. untreated Douglas fir bracings which had been fixed in 1947 in connexion with some emergency repairs had been completely eaten away at their lower ends six years later in 1953.

213. In the Celcurised groyne planking, the impregnated layer, which appeared to be generally about $\frac{1}{4}$ in. thick, had not been touched but the wood had been eaten right up to it. Samples of infested wood had been taken at different levels over the range affected, from which the following marine borers had been identified: Limnoria Tripunctata, Limnoria Quadripunctata, and Chelura Terebrans. As in the case of the Shoreham test blocks, Limnoria Lignorum had not been recorded, though he understood its presence nearby in Southampton Water had been established. Research in America had shown that the Tripunctata could tolerate greater concentrations of creosote than other species of Limnoria. It would be interesting to find out whether this applied to other preservatives such as Celcure. The Chelura was frequently reported as being associated with Limnoria round the coastline of this country, but information on it appeared to be very scanty.

214. The solution in the case of Douglas fir was, of course, to complete all cutting and boring before treatment, but this was difficult to achieve in practice because of site variations. The easier course was probably to use hardwood which, by using a reduced thickness, could still be roughly equivalent in cost as well as in strength to Douglas fir.

215. He had not observed any evidence of Teredo attack in the Selsey area other than in driftwood.

216. Information regarding actual stresses produced by waves was hard to come by. It was therefore interesting to calculate the loads that caused some slight damage to three prototype steel sheet pile (S.S.P.) groynes on the East Beach during a severe storm in 1959. Those groynes had been of lighter construction than the standard groynes subsequently constructed under Stage 2.

217. An equivalent uniformly distributed static force of approximately $\frac{1}{2}$ ton per square foot had been experienced over most of that part of the groyne exposed to the waves and at a few points this force must have been nearer 1 ton per square foot. Considering that the wave impact was oblique, these loads were surprisingly high.

218. With regard to contractors' plant, the basic unit for most of the work had been a $\frac{5}{8}$ or $\frac{3}{4}$ cu. yd excavator fitted as a dragline for excavation and with a ringing frame and drop hammer for pile driving.

219. For work between the tides the contractor generally operated his plant on the beach. He thought that, provided due account was taken of tides and the possible effects of bad weather, an experienced contractor would probably make far better progress and make better use of low tides by getting plant on to the foreshore, rather than by using the security of a promenade or upper beach for his plant.

220. The relatively new type of mobile compressor mounted on a tractor was an extremely useful item of plant for operating on the beach for groyne construction, particularly if fitted with a trailer for carrying tools and materials.

221. The concrete sea-walls on the West Beach had been designed for construction in 20-ft bays. Stripping and erection of the shutter and the concreting of a 20-ft bay had taken about 10 hours. One bay of apron and one bay of sea-wall had generally been completed in a day by separate gangs with a third gang driving the steel sheet piling. Timber shuttering had been used throughout. Zinc lining had been used for exposed surfaces, and a very satisfactory finish had been obtained.

222. The steel sheet piled breastwork on the East Beach had been constructed at about 200 ft per week. The construction of a groyne had generally taken two weeks, except for the long ones, which had taken three weeks.

223. Points of access suitable for bringing in concreting materials had been limited. Mixing points had been set up at each access in turn and the concrete had been transported in $\frac{3}{4}$ cu-yd bottom-opening skips carried on 2-ft gauge light railway to the con-

creting site where the skips were handled by an excavator. Compressed air poker type immersion vibrators had been generally used for compaction.

224. The rate of expenditure had been just under £10,000 value of work per month when the various contracts were well under way.

Mr W. E. Blackmore (Senior Engineer, Sir William Halcrow & Partners) wished to put to the Author a question concerning the design of the West Beach sea wall shown on Fig. 5 of the Paper. This design featured a sloping apron in front of a vertical wall. He wondered whether the Author had a scientific reason for selecting this design rather than one featuring a vertical wall only; on the face of it, the latter type would appear less costly, for equal depth of cut off, than the one adopted if the intermittent steel bearing piles were to be replaced by a continuous curtain of sheet piles. Did the Author consider that an apron was more conducive to the accretion of shingle than a vertical wall?

226. Mr Blackmore added that his own firm had recently constructed a sea-wall on a sandy foreshore and they had also adopted a design featuring an apron in front of a near vertical wall. It certainly looked right and so far it had been successful in inducing beach accretion; it would be useful however to have a scientific reason for this arrangement rather than a purely empirical one.

227. Taking the design of the apron on Figs 4 and 5 he noted that it was a rigid slab spanning between the vertical wall and the sheet piled toe wall. This meant that, should there be any settlement or shrinkage of the supporting ground the apron would have to bear, in bending, the full impact of breaking waves; would it not have been better to make it a flexible apron which would maintain contact with the supporting ground and thus be more able to absorb the shock of breaking waves? In the sea-wall which his firm had constructed the apron was a flexible one of interlocking blocks of about the same thickness as the apron shown in the Paper; so far it had behaved very well. It would be useful to have the Author's reason for the choice of a rigid apron.

Mr R. C. H. Russell (Senior Scientific Officer, Hydraulics Research Station) said that Selsey was his favourite problem-area because it demonstrated so clearly almost the only law that could be firmly established in coastal engineering. This was simply the equation of continuity

$$\frac{\partial A}{\partial t} = \frac{\partial Q}{\partial x}$$

where, as shown in Fig. 22, A was the cross-sectional area of the beach, ∂A the change in area in some time ∂t, Q was the local rate of littoral drift and x was distance along the beach.

229. The equation was valid only for those beaches where there was no loss of material from the beach to the sea-bed offshore and no supply of material from it. A shingle beach having sand at its toe was a fair example of such a beach. The law was familar in the form

(littoral drift Q_2 − littoral drift Q_1) × time =
(mean change in cross-section) × (distance between points 1 and 2),

but in this form it did not reveal the importance of the rate of change of Q with x.

230. One could use the principle to predict that the maximum rate of erosion at Selsey would occur where it did: not on the south-west side where the wave attack was greatest but the littoral drift was small, nor away to the north-east where the coast was straight and $\partial Q/\partial x$ was zero, but just to the east of the Bill where $\partial Q/\partial x$ was a maximum.

Mr J. D. Mettam (Senior Engineer, Sir William Halcrow & Partners) asked the Author why on the East Beach the groynes were inclined eastward of the normal to the shore line, i.e., they were inclined somewhat down-drift, whereas on the West Beach they appeared to be exactly normal to the beach line. What was the purpose of inclining those groynes, and had that purpose been achieved?

232. The Author had mentioned many good reasons for supporting the Coast Protection Act, but there was one thing he had not touched upon. Apart from the normal and natural objection which everybody felt to contributing money to any cause over which he had no control, the contributory owners had real hardship from the moment when the scheme was promoted and they were, as it were, booked to pay out some money until the scheme was complete and an assessment was made of their benefit from it. During that period there was a good deal of uncertainty on the part of landowners who might wish to sell property. Obviously one could not expect the assess-

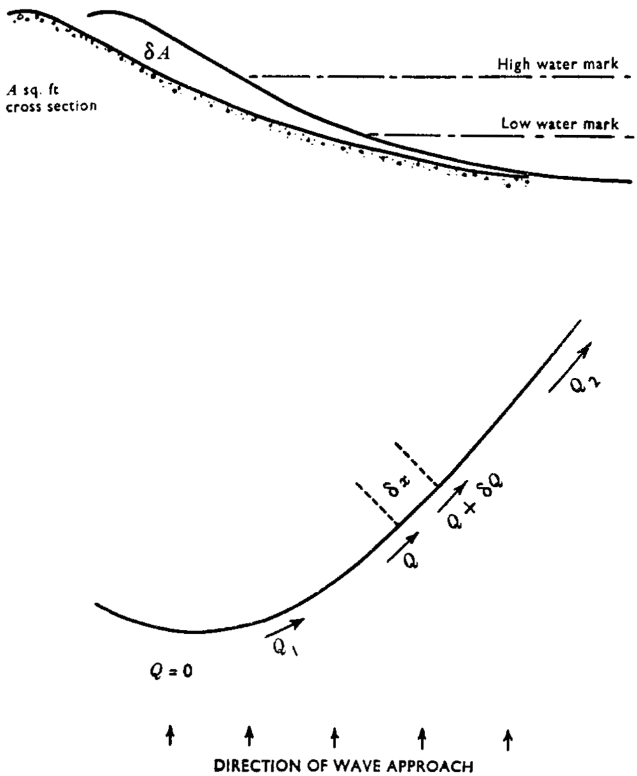

FIG. 22.—PLAN OF BEACH AND CROSS-SECTION
A = cross-sectional area, Q = local rate of littoral drift, x = distance along the beach.

ments to be made before the scheme was started, otherwise the scheme might never come to life at all. Could not the assessments be made before the scheme finished, while it was going on, when the final intention was known, even though it had not yet been achieved?

233. With regard to the wind vector diagrams as a means of assessing the direction of littoral drift, although in this case the wind vector diagrams as they stood gave the right answer, he felt that without taking into account wave refraction due to the bed levels offshore this method could give a false answer in other cases.

234. If one had to work from wind data in making this sort of assessment, it would possibly be better to use the formula developed by Dr Darbyshire from North Sea records[4] to relate the wind data to wave height rather than Stevenson's relationship. But there was an alternative which he commended, which was to use the wave observations which were regularly recorded at a number of light ships along the coast.

235. The nearest to the Selsey area was the Shambles light ship off Portland (50° 31′ N, 02° 20′ W). Twice daily somebody made an estimate, admittedly by eye, of the height, period and direction of the waves. Those records were complete from 1954 to the present day. If one analysed them, one could prepare a probability diagram for waves of various heights from various directions. By doing a fan type of refraction calculation[6] one could determine what waves in deep water produced the waves recorded at the light ship.

236. He did not think it would be too difficult to apply those deep-water waves to the problem of Selsey. One ought, perhaps, in some cases to make an adjustment in the wave height to allow for a difference in fetch, but, having done that, the normal wave refraction calculation could be made to determine in what direction and with what attenuation deep-water waves from each direction would arrive on the coast at various points near Selsey. In doing that calculation it would be possible to take full account of the shoals, the Mixon and the shingle joining it to Selsey Bill. It would also be possible to check the effect of the higher shoal which existed in the past, or of reconstructing that shoal, which Mr Buck had suggested as a possibility—perhaps in this case a little far-fetched, but still a possibility. Having taken wave refraction effects into full account, one should then prepare a vector diagram for the wave forces at the coast itself. It might also be possible, with the vector diagram, to obtain some relationship between wave energy and the Q value (and, of course, the dQ) which Mr Russell had quoted.

237. This could be tedious, and, like some other speakers, he suggested that the Hydraulics Research Station might undertake it. If it could be shown to be a valid method, he thought it could be made quite simple, after a bit of agony, by getting some electro ˙c computor organization to programme for it.

238. He would like to know what the Author thought of this as a procedure to try out.

The following contributions were received in writing:

Dr R. Silvester (Senior Lecturer in Civil Engineering, The University of Western Australia) wrote that although this paper dealt with works costing some half a million pounds, and was, therefore, of engineering significance, it added little to the erudition of coastal engineering. The erosion of Selsey Bill was parochial in concept and a reader, therefore, might expect to learn how to apply scientific analysis to such a problem, or to observe some new approach by way of novel structures or procedures. The writer respectfully submitted that the paper was lacking somewhat on both counts.

240. The problem could be divided into four main points:

(*a*) the geological history of Selsey Bill;
(*b*) the hydrography of the surrounding seas;
(*c*) the factors producing sediment movement;
(*d*) the remedial measures used.

(a) *Geological history*

241. In this case the important issue to resolve was how was Selsey Bill formed in the first place. The solution would require knowledge of land contours of the complete Bill, its rocks and sediments and of changes on the adjacent coastlines. This information might provide the reason for the change from accretion to erosion.

242. The author referred to "A preliminary study of available memoirs" but did not make specific reference to them. The reader was thus unable to verify the facts and so derive his own conclusions.

(b) *Hydrography*

243. The underwater contours were most important in the study of wave action and should be given priority in diagrams of the area. Such hydrographic data reduced the need for lengthy descriptions. Aerial photographs generally conveyed very little information.

244. Together with the bed-contours could be shown the direction of wave movement. This was accomplished by drawing orthogonals for various wave periods. This might assist in showing how the Bill was created in the first place.

(c) *Sediment movement*

245. The factors which produced sediment movement in the ocean were wave action and currents, of tidal or other origin. Dr Silvester believed the former to be the more important.

(i) *Wave action*

246. The wave characteristics of importance in this respect were period, direction, and duration[7]. These would determine the magnitude and direction of the longshore drift, in concert with the underwater contours as previously mentioned.

247. The " wave analysis " in the paper considered only those waves generated within the English Channel. These were still within the fetch and might be termed "storm waves"[7], which had a different action on the beach from that of the swell. The predominance of the swell in shaping coastlines had been discussed elsewhere[8].

248. The swell which would arrive at Selsey Bill from the south-west could be from 10 to 18 sec period and even if of low height could cause substantial horizontal oscillations at the sea bed, to depths of 50 fathoms. The mass transport[9] resulting from such waves could move sediment, even of shingle dimensions, from the Isle of Wight to Selsey Bill. It was this swell that probably maintained the flat profile on the West Beach and was instrumental in transporting sediment swiftly along the East Beach.

249. Although not purporting to be exact, the Author's wave analysis utilized records from only one station. It also assumed (*a*) drift α wave energy α (height)^2 and (*b*) height α (fetch)$^{\frac{1}{2}}$ (according to Stevenson). Many of these assumptions were dubious. As previously discussed the type of wave (storm or swell) determined the magnitude of the drift as much as the wave energy, which varied as the square of the period[10] as well as the square of the height. Although the reference was not given the author must mean the book written by Stevenson in 1874[11]. The validity of this and other wave forecasting formulae had been fully discussed by Saville[12] and Francis[13].

(ii) *Currents*

250. Tidal information could have been added to the hydrographic data suggested previously. This might take the form of arrows indicating ebb and flood currents. These currents were discussed fairly fully for the East Beach, but not for the West Beach.

251. It was stated in § 50 "A further factor in the relative stability of the West Beach compared with the East Beach is the action of the powerful ebb current, which sweeps westward past Selsey Bill". This is difficult to understand since the littoral drift on the East Beach is in the opposite direction to the current, and the two actions should partly counteract each other and make for greater stability. The sorting of the sediment, outlined in § 56, in support of the author's theory, could be produced by the swell action above without the aid of any current.

252. Considering currents along the West Beach it appeared possible for a south-east current to exist in this region throughout the whole tidal cycle—as a deflexion of the flood flow and as a vortex generated by the ebb flow. It was significant that a bank of shingle ran south-east off the end of the Bill, which could have been formed by such a tidal current in conjunction with the long period swell from the south-west.

(d) *Remedial measures*

253. Groynes and seawalls have been used for decades with varying degrees of success. Dr Silvester submitted that in an erosive situation neither structure was really effective, and that the best defence was the provision of adequate sediment for the formation of an offshore bar[7]. The Author referred to previous groyne construction at Selsey Bill and Fig. 11 showed their remains.

254. The action of groynes in promoting erosion, rather than mitigating it, had been discussed in Ref. 7, and their siting for greatest effect in Ref. 8. Perhaps groynes of a different shape in plan[14] might provide a solution, but the problem seemed to call for a completely new approach, the details of which could not be entered into here.

255. Regarding the sea-walls used, it would have been an advantage to test the design in a wave flume. This might have provided information on the following points:

(i) *Vertical wall*

256. The presence of vertical walls within the reach of waves created an extremely erosive situation[15]. The reflected waves set up standing oscillations which accelerated the movement of sediment offshore[7]. This action expedited any long-shore movement which existed and the tendency for erosion, if it were present, was aided and abetted by the wall.

(ii) *Apron*

257. The apron had been provided to protect the base of the vertical sheet pilings against wave forces and erosion. It purported to break the wave before it reached the wall, but as it was only 10 to 15 ft wide its effect was likely to be insignificant. This could have been verified in a flume test. Regarding erosion mitigation, should the wall and apron hold the beach line for a year or two and the offshore area continued to erode, the beach profile would become very steep, and in a particularly bad storm the whole structure would be demolished.

258. The paper provoked the thought that more use could be made by engineers of scientific data available to them. In most cases the original findings of the scientists might have to be interpreted and perhaps modified by "academic" engineers, the dearth of which was apparent in most fields of engineering. In coastal engineering the lack of information was not due to the absence of original data because the oceans, being such a ubiquitous topic, had been studied by scientists the world over.

259. But sufficient was known and was available in the literature for a more scientific approach to be made by engineers to marine problems. The situation called for the establishment of some Institutes of Coastal Engineering in various countries so that basic training and post graduate courses, as well as research, might be conducted in this field so pregnant with opportunities for saving millions of pounds.

Mr A. M. Muir Wood (Senior Engineer, Sir William Halcrow & Partners) wrote that it appeared that the vectors marked as resultant wind directions in Fig. 1 were, from the explanation given in § 45, in fact, resultant wave vectors, taking no account of refraction. It was commonly assumed that drift was proportional to $\sum E \sin 2\alpha$ where E was wave energy and α was the angle of incidence of the breaking wave, although any such analysis was considerably complicated for a groyned beach, especially where reversals of drift occurred. Any such approach tended to become a little academic unless sufficient information was available of wave periods and heights to permit the shallow water effects offshore to be allowed for. In this connexion there were simple graphical methods for estimating the extent of wheeling of approaching waves.

261. Referring to §§ 138–142, Mr Muir Wood was concerned some years ago in an attempt to relate the results of model tests on a sea wall with a mobile bed to a full size wall on a clay foreshore. It appeared that this was a highly complex problem unlikely to be reproducible in simple laboratory experiments. For example, where the clay was exposed between tides the effect of alternate drying and wetting appeared to be more important than direct erosion. In all probabilty the greater part of the scour was due to the abrasive action of material in suspension in the water and it was observed that plastic clays appeared to become protected to some extent by large pebbles which became embedded in the surface.

262. The long term success of the scheme described by the Author appeared largely to depend upon the maintenance of adequate shingle supplies to Selsey Bill. There appeared to be little known about the onshore movement of underwater shingle banks, although in Sandwich Bay, Robinson and Cloet[16] recorded the Brake bank, formed of sand and shingle with its crest in less than two fathoms of water, moving inshore at a rate between 20 and 40-feet per year. It was suggested that the experiments carried out by the Author with individual cement mortar cubes placed on the sea bed would not be likely to reproduce the movement of a shingle bank which appears to move with fairly constant seaward and landward side slopes, the latter being appreciably steeper than the former.

Mr A. W. Shilston (Messrs J. D. & D. M. Watson) wrote that § 74 of the Paper referred to the miscellany of timbers used for the king and sheet piles in the West Beach groynes. Would the Author comment on the manner in which the piles were driven and whether all the stated timbers stood up equally well to driving.

264. It was said in this paragraph that the experimental timbers were found to be in good condition after 9 years; he presumed that this remark was related to their resistance to the attack of marine organisms. Did the various timbers stand up equally well to the influences of attrition?

265. He would like to enquire whether the three contracts were undertaken on a target or conventional measure and value basis. Did the procedure at Selsey conform with the Author's normal practice in this country?

266. Would the Author agree that there might be risks attending the specification of concrete for coastal defence works by strength considerations alone? What concrete mix proportions and control criteria were ultimately found to be most appropriate at Selsey? Was normal Portland Cement used throughout?

Tidal surges

The Author, in reply, said that in regard to Mr Garland's question he had no record of any high tide on the Sussex coast which had exceeded the predicted height by more than 2 ft. He understood that a paper had been written and would shortly be presented to the Institution containing a frequency analysis of very high sea levels on the East and South coasts of England.

Shingle supplies from offshore

268. With reference to § 57 of the Paper, Mr Garland stated that with the division of the littoral drift at Selsey Bill, surely any additional material must come from the sea; otherwise where could it come from?

269. The Author agreed that groynes do not automatically *per se* create beach material out of thin air as was sometimes thought. It had to come from the land, the foreshore or the sea-bed. If you sealed off the coast and the shore by sea walls and groynes, the only place from which fresh supplies could arrive by natural means was the sea-bed, if in fact they did arrive. This fact had not been established at Selsey when

the works were designed in 1953 and would probably not be established with certainty unless or until a tracer experiment was made.

End scour

270. The Author agreed with Mr Garland that the unprotected gap west of the western boundary of the Selsey scheme was a potential source of weakness but it did not follow that the works would be outflanked. Tailing-off works west of West Street had protected the western flank of the Selsey defences and further extensions of the tailing-off works would be necessary from time to time as stated in the Paper.

271. Eventually the unprotected length would assume the shape of a bay between two protected headlands and the rate of erosion, due to the loss of material from the sector by littoral drift, would diminish as the wind-wave vectors approximated more closely to the normal.

272. In reply to Mr Dobbie, the Author had assumed in predicting the form the end scour would take beyond the terminal groynes, that the end groynes would be permanently maintained at their present height.

273. He was not worried at the prospect of maintaining the western flank for reasons given in reply to Mr Garland's question. Neither was he unduly worried at the thought of having to maintain the eastern flank although the problem was not so easy due to the changes which were taking place at Pagham Harbour to which Mr Garland had drawn attention.

274. It might eventually be necessary to build 3 or 4 robust new groynes 1500 ft apart east of the terminal groyne E46 linking up the River Board's protection works at Pagham beach.

275. The changes in the shore line between Selsey and Pagham were being recorded by means of aerial surveys once a year and the Coast Protection Authority were aware of the possibility that further works might be necessary in due course to keep the erosion under reasonable control.

Offshore banks

276. In reply to Mr Buck's question about the possible advantages of re-establishing the shingle bank which formerly connected Selsey with the Mixon, the Author had to confess that this had not been considered as a possible alternative to the East Beach protection scheme. Offshore works are costly to build and costly to maintain and in any case there was no rock in the area which could have been used to build a breakwater.

Wind vector diagrams

277. Several speakers had commented on the method of determining the direction of littoral drift by means of wind vectors and it had been suggested that wind directions should be weighted for wind speeds. In fact another analysis had been made for Selsey in which this was done, the wind strength being subdivided into 3 groups, namely strong winds force 6 and over, medium winds force 4 and 5 and light winds force 2 and 3, winds below force 2 being neglected.

278. The analysis gave materially the same result.

279. The suggestion was made that wave refraction should have been taken into account and the Author agreed that on a coast where the offshore contours were regular a more accurate analysis of wave direction would have resulted. In the case of Selsey such an analysis would have been extremely complicated due to the multiplicity of offshore shoals and banks, particularly when an analysis of the effect of westerly or south westerly winds was being made.

280. An even more exact analysis would result if consideration was given to such factors as the length of time during which winds blew continuously in a particular direction, or the coincidence of winds of various speeds with periods of spring tides.

281. The method described in the Paper had the virtue of simplicity and had been used at a number of places on the east, west and south coast at which the direction of the

drift was uncertain and had in every instance given results which had tallied with the facts as subsequently determined.

Artificial renourishment

282. Mr Reid had asked whether the Author had considered recharging the East and West Beaches with shingle dug from, say, the beach near the Inner Owers as a substitute for groyning.

283. The possibility of digging shingle from this beach for recharging parts of the East Beach from time to time had been envisaged (see § 149) but not as a substitute for groyning. The purpose of the Selsey groynes was to spread the available shingle as evenly as possible along the protected frontage so as to ensure that there would always be a layer of shingle over the underlying clays, silts, and sands. Without a protective covering of shingle these friable unstable materials would be rapidly eroded and swept out to sea, and the level of the foreshore would fall to a level at which it would no longer be economically practicable to maintain the sea wall in the position in which it was built.

284. A sea wall or flood wall was necessary throughout most of the East Beach to protect the low-lying residential areas against inundation during onshore spring tide gales. Groynes were an essential component of a sea wall on all foreshores except solid rock and it would be asking for trouble to rely upon artificial nourishment alone to maintain the shingle at a safe height against the wall under conditions such as those encountered at Selsey.

285. The question of whether or not shingle was moved inshore towards Selsey Bill from the shingle bank opposite Bill House was more of academic than of practical interest. Either it was, or it was not moved and there was nothing that could be done about it either way. It would have been interesting to have known for certain one way or the other but if it was found in time that the occasional loss of shingle by littoral drift from the East Beach groyne compartments exceeded the input, if any, from the shingle bank or from the as yet unprotected strip of coast between the Marine Hotel and Bill House then artificial replenishment with shingle from the Owers beach would have to be resorted to as a matter of routine maintenance.

Design of walls

286. Mr Dobbie had asked about drainage. The backfill behind the West Beach wall contained a fair amount of clay and consolidated to a dense impenetrable mass. However, provision was made for drainage by laying a drain behind the wall consisting of earthenware "seconds" graded towards 3-in. dia. weep-holes at 20 ft intervals through the sea-wall.

287. Mr Blackmore had queried the need for an apron in front of the sea-wall. In the case of the West Beach the apron spread the load over a wide area which was rather necessary having regard to the nature of the ground (§ 69). Admittedly the wall could have been founded directly on a sheet-piled cut-off. The design shown in Figs 4 and 5 was a personal preference and Mr Blackmore would doubtless have had sufficient experience of coast protection to agree that the engineer had to follow his judgement in these matters.

288. Dr Silvester thought that more scientific principles of design should have prevailed and if a code of design had been available which would have enabled the position, level and cross-sectional dimensions of the sea-wall to be calculated instead of relying upon the individual judgement of the engineer the Author would have used it.

289. Dr Silvester's prognostications of disaster had not been fulfilled at Selsey and the beach had settled down comfortably to the new régime. Shingle had accumulated over the West Beach apron while the East Beach apron had only been seen once since it was built.

290. Mr Blackmore had suggested that a flexible apron might have been better than a rigid one in case of settlement or shrinkage of the supporting ground. The Author agreed that on made ground settlement was a difficult problem and at one site on the

Norfolk coast plugged grout pipes had been cast into the apron to allow the voids, if any, caused by vibration of fill due to the impact of storm waves to be grouted after two or three years. At Selsey the aprons were on solid ground and settlement was not likely to occur although, on the West Beach, it was necessary in places to deposit nearly twice the designed amount of concrete in the apron to ensure that it was properly supported.

Groynes

291. Mr Mettam had asked why the inclinations of the East Beach and West Beach groynes differed. It was well known that groynes which were aligned "down-drift", i.e. eastward pointing on the East Beach, produced a more even beach with less variation as between the level of the beach on the up-drift side and that on the down-drift side. The East Beach groynes were accordingly aligned some 10° east of the perpendicular. In the case of the West Beach groynes the drift was intermittent and varied between eastward and westward from year to year or from month to month over a large part of the frontage. The groynes were accordingly aligned in a direction perpendicular to the frontages to suit both conditions.

292. Dr Silvester submitted that in an erosive situation neither groynes nor sea-walls were really effective. This was not the Author's experience. He knew of no more erosive situation than that which prevailed on the East Beach at Selsey before 1953, yet the frontage had been stabilized on a predetermined line by the use of these expedients, as had been the case at countless other places.

293. At Bathurst, Gambia, the sandspit on which the town had been built was nearly breached in 1957 by a sudden unexpected change in the régime of the offshore shoals. The threat had been averted and the spit stabilized by building a large number of sheet-piled Rhun Palm groynes, of almost identical design to the West Beach groynes at Selsey and by revetting parts of the shore line with laterite rubble. The works were effective and would remain so as long as they were properly maintained but all too often such works were forgotten due to some change in administrative régime and after a few years a critical situation would suddenly develop which could have been averted and much money saved if the works had only been accorded a bare minimum of attention.

Experimental timbers

294. In reply to Mr Shilston the miscellaneous hardwood piles in the West Beach groynes referred to in § 74 were driven by drop hammer and a light ringing frame. The frame was moved from place to place and the driving was carried out by a 19 R.B. excavator which also carried out the excavation required for fixing the walings. The piles were ringed and showed no signs of damage. The timbers were driven through sand into clay and he was therefore unable to comment on their relative resistance to attrition. At a nearby site 9 in. × 9 in. Greenheart hewn timbers used as ties in the inner end of a groyne had been rounded by attrition in less than a year. In the East Beach 9 in. × 3 in. planks of Douglas Fir used to deck the fishermen's slip had been secured to the stringers with closed joints and had stood up well to attrition by wave driven shingle. It does not pay to leave drainage gaps between the decking timbers of a slipway as it encourages wear by rounding.

Concrete

295. Mr Shilston had enquired about the concrete mix used in the work. A nominal 1:2:4 mix was used throughout with Ferrocrete and a local flint all-in aggregate. In coast protection work as in all other concrete works exposed to sea action density was of more importance than compressive strength. Maximum density was obtained at Selsey as at other sites by designing the mix to suit the aggregates and by an insistence upon a high degree of consolidation.

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