CHAPTER 79

THE EFFECT OF OFFSHORE DREDGING ON COASTLINES W A PRICE J M MOTYKA AND L J JAFFREY

1. Introduction

The South of England is well endowed with land deposits of river gravel and sand. Nevertheless, the demand for aggregate and the need to conserve agricultural land have increased to the point where in 1976 sea dredged aggregate was accounting for 11% of the total sand and gravel production. In addition to this annual home consumption of about 12 million tonnes of dredged aggregate a further 3.5 million tonnes was exported to Europe in 1976.

Understandably, authorities responsible for coast protection and sea defence view the increase in the removal of marine deposits with concern and a system of licensing by the Crown Estate Commissioners who are responsible for the sea bed from high water to the UK Continental shelf limit has been developed over the years. Dredging by port authorities within their area of jurisdiction, for navigational purposes, is outside this licensing system. Within the three mile limit local authorities have powers under the Coast Protection Act to regulate dredging.

In 1976 a report by an advisory committee to the Department of the Environment⁽¹⁾ recommended, among other things, that further studies should be carried out by HRS aimed at reviewing the existing constraints on marine dredging for gravel. In general, the material which is sought for construction purposes is a 60% shingle, 40% sand mixture, but sand is also needed for reclamation fill and for industrial purposes. The areas dredged at present are shown in Figure 1.

This paper deals briefly with the licensing procedure and at some length with the involvement of the Hydraulics Research Station in assessing how dredging might affect the coastline. The effect on fisheries, navigation, coastal ecology, and other interests is considered by other organisations.

Very little is known of the criteria applied to offshore dredging by other countries, apart from Germany, but with the increased exploitation of the sea bed it is important that information gained by other countries should be used to improve our existing criteria.

2. Consultation Procedure

The licensing system for offshore dredging in the United Kingdom started in 1963. It has now evolved to a stage where a licence is granted only after comprehensive consultations have taken place with many authorities.

After prospecting an area and proving the presence of suitable material the dredging company which is equipped with ships purpose built for gravel extraction submits an application for a licence to the Crown Estate Commissioners to dredge a defined area at a given rate. The Hydraulics Research Station is then asked to give an opinion on whether dredging at the stated rate is likely to effect the adjacent coastline. The questions to be considered and the studies which have assisted in providing some answers are dealt with later in the paper but if our opinion is unfavourable i.e. if damage may result, then the licence application is unlikely to proceed further.

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If, on the other hand, we consider that coastal changes will not take place then the following bodies are consulted: -

Department of the Environment (Coast Protection and Petroleum Division) Ministry of Agriculture, Fisheries and Food (Fisheries Laboratory) Department of Trade (Navigation) Post Office (Marine Division) Local coast protection authorities Regional Water Authorities

These opinions are received by the Construction Industry Directorate of the Department of the Environment and a view on the issue of a licence is prepared after considering the interests of all parties. There is no right of appeal against a decision. In practice, now that the HRS guidelines are well known and with some measure of early discussion the submission of unreasonable applications is unlikely. Finally a licence is issued by the Crown Estate Commissioners who have the right to levy a charge on each ton of material landed.

3. Evaluation of Proposal by Hydraulics Research Station

In forming an opinion on a licence application HRS aims to answer the following questions:-

- (1) Is the area of dredging far enough offshore so that beach drawdown into the deepened area will not take place?
- (2) Is the dredging to be carried out in deep enough water so that it will not affect possible onshore movement of shingle?
- (3) Does the dredging area include bars and banks which might provide protection to the coast from wave attack?
- (4) Is the area to be dredged sufficiently far offshore and in deep enough water that refraction of waves over it will not cause significant changes in the pattern of alongshore transport of bed material?

<u>Collection of data</u>. A limited amount of information on sea bed levels and tidal currents is available from published Admiralty charts although various other sources are also used for additional information. However, unless an area has been the subject of particular study, the movement of bed material in the zone from low water to say, a depth of 20m, is difficult to quantify, although the general direction of movement can usually be inferred. Such measurements, particularly over a wide area and extending several kilometres offshore, would be extremely difficult to carry out and would almost certainly require time-consuming and high cost radio-active tracking techniques. It is possible that, if the demand for gravel continues to grow, areas where the effects of dredging are difficult to establish may have to be critically re-examined. In such cases a detailed investigation of material movement would be necessary for each particular licence application.

For most of the present applications that we receive, however, existing guidelines are adequate for assessing the effects of dredging on the coastline. These guidelines are

described below. The research carried out at the Station for the development of some of these guidelines is described in the next section, 4.

Beach Drawdown. This usually occurs during storms due to the action of high steep waves. Beach material is eroded from the upper foreshore and moved seawards. However, during periods of calmer weather the material is returned to the beach by long low swell. If the dredged area is too near the coastline then this dynamic equilibrium can be upset; in that material may be transported from the upper portion of the beach into the dredged hole and erosion of the foreshore may result. Some of the most comprehensive information concerning the seasonal offshore-onshore interchange of sand has been recorded by Inman and Rusnak off La Jolla, California⁽²⁾. Observations of sea bed levels were made by divers equipped with scuba who installed a series of rods at water depths of 1.8, 5.5, 9.1, 15.8 and 21.3 metres. The change in sand level at the reference rods was measured over a period of three years. The most inshore site provided very little useful information since the rod was usually completely buried. The rod at a depth of 5.5 metres showed large fluctuations in sea bed level but was lost after a short time, after a period of erosion. In water depths of 9.1 metres or more the vertical variation in level was only \pm 0.03 metres or so. At the deeper stations, any seasonal trends were so small as to be masked by fluctuations of a shorter period. From this work it would appear that the active zone of offshore-onshore movement extends to 9.15m, say 10 metres, and beyond this depth seasonal movement takes place intermittently.

Most of the licences are issued for areas on the South and East coasts of the United Kingdom (Figure 1). The wave climate in these areas is certainly less severe than that at La Jolla, California and therefore we believe that dredging in water depths of 10 metres or more will not result in beach drawdown into the dredged hole due to seasonal changes in onshore—offshore movement.

In exceptional circumstances, even this criterion can sometimes be relaxed. For example in the case of beach nourishment from within the 10 metre contour, a redistribution of littoral material takes place but there is no actual loss incurred. Monitoring of beach nourishment projects by Watts, of the US Army Corps of Engineers⁽³⁾ has shown that dredging has been carried out as close inshore as 300 metres with no apparent detriment to the shoreline. Surveys of the borrow pits have shown a general infilling with silt sized material which normally would settle out further offshore. An increase in the proportion of fines can be undesirable from an amenity or fishery point of view and the Station recommends that dredging should not take place within twice that distance from the shoreline, namely 600 metres.

Thus, with respect to beach drawdown there are two criteria -a minimum depth of 10 metres and a minimum offshore distance of 600 metres. These considerations are applied usually to small scale or short term operations for winning sand for beach nourishment or for land reclamation purposes. For the majority of licences which involve longer term working of shingle deposits, a more severe criterion is applied. This is discussed under the next heading.

<u>Interception of sediment.</u> If the beach is being fed from offshore by current and wave action then dredging may trap a proportion of this material and interrupt the supply to the shore. It is very important therefore that dredging should be excluded from any deposits which are moving actively. Research into the threshold of movement of material by waves

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and tidal currents forms an important and continuing part of the Station's programme. The first investigations were made using radio-active labelled shingle. The movement of this material was tracked at a number of water depths off Worthing, see next chapter. We concluded that shingle movement seaward of the 18 metre depth contour was negligible at all times. The present criterion therefore applied on the south and east coasts of the United Kingdom for the dredging of shingle is a minimum depth of water of 18 metres. Other ways of predicting the mobility of bed material are currently being pursued. Recently we have completed a study into the threshold of movement of shingle south-east of the Isle of Wight. Wave action and tidal currents here would appear to be strong enough to induce shingle movements in depths as great as 22 metres, see next chapter.

<u>Protection by offshore banks</u>. Offshore banks help to protect the coastline from wave attack either by dissipating wave energy as a result of bed friction, by partial breaking of the waves, by reflection or by any combination of these three. A permanent lowering of the crest of a bank due to dredging or indeed by natural means can result in changes of the wave refraction pattern and hence changes in the net angle of wave attack at the shoreline. Thus, under certain circumstances, dredging from offshore banks can alter the rate of littoral drift and hence affect the stability of the shoreline. Changes in wave refraction whether it be due to an overall lowering of the seabed or dredging from offshore banks are discussed under the next heading.

Where accretion on offshore banks has been well documented and where the coastline is sheltered from wave attack a limited amount of dredging is sometimes allowed. Dredging under such conditions is of course strictly controlled and is only considered on a short term basis. A desk study is first carried out to determine the wave height transformation by bed friction, refraction and shoaling using the method developed by Bretschneider and Reid⁽⁴⁾. The calculation of wave height is very dependent on the value of the friction factor f used in the calculation. Until the present time we have used the value of f = 0.01 adopted by Bretschneider for a sand seabed. The latest research from field work and model studies⁽⁵⁾ indicates that the value of the friction factor can be substantially greater than 0.01, and clearly further work is necessary before large values of f can be used with confidence.

Because of the uncertainty in the appropriate value of the friction factor to be used in wave height calculations, dredging of banks adjacent to the coastline is generally not allowed. The only exception to this rule is when the rate of accretion at the coastline is so high that any increase in wave activity and possible reduction in the rate of accretion would have no harmful effect on shoreline stability.

The effect of changes in wave refraction. As waves approach the shore they travel with a group velocity that is dependent upon their period and upon the depth of water. If the water depth increases locally, eg over a dredged hole, the velocity and wavelength change. The local increase in wave celerity due to the increased water depth causes changes in the angle of wave approach to the beach. Such changes result in a variation in the rate of littoral drift along the shoreline and can cause either accretion or erosion. An example of the result of such changes in wave approach took place in Botany Bay, Australia, where severe erosion followed a period of dredging within the Bay. Wave refraction diagrams were plotted showing the angle of wave approach to the beach. Changes in wave angle agreed closely with positions of beach erosion. A beach mathematical model has been developed by Hydraulics Research Station⁽⁶⁾ and is used to predict changes that could occur from offshore

dredging. Results have shown that, in general, the effects of wave refraction are insignificant when dredging takes place in water depths greater than 14 metres. The study is described in the next chapter.

4. Research by HRS

<u>Tracer study off Worthing</u>. In 1968 the Hydraulics Research Station began an investigation, for the Crown Estate Commissioners, into the movement of shingle by using radio-active tracers. This experiment was carried out on the south coast of England off Worthing, some 15 kilometres to the east of Brighton, see Figure 1. The object of the study was to obtain quantitative data on the mobility of shingle under wave action in water depths of 9 to 18 metres. The area was particularly suitable for such a study – firstly, because a number of firms wanted to dredge there and had already applied for licences, and secondly because the bottom topography was uncomplicated and wave conditions were fairly typical of those in British coastal waters.

Previous investigations carried out by Kidson and Carr⁽⁷⁾ off Orfordness on the East Anglian coastline failed to show any significant movement of shingle even under severe weather conditions. The duration of these experiments however was short, 8 weeks or less. The dispersal of radio-active pebbles over this period was small, a maximum of about 50 metres and a minimum dispersal of about 30 metres. It should be noted that the seabed in this area consists of sand, silt or mud and it is possible that the movement of the pebbles was hampered by burial within the soft surface layer.

In the HRS investigation the sea floor was first examined by divers and then radioactive tracer pebbles were placed at mean water depths of 9, 12, 15 and 18 metres.⁽⁸⁾ This operation was carried out in mid-September 1969 and the pebble movement was tracked over a period of 20 months. Wave observations from the Owers Light Vessel, situated off Selsey Bill, were used to relate the rate of movement of shingle to the prevailing wave conditions.

The results clearly demonstrated an increase in shingle mobility with decreasing water depth and also showed the existence of a small net landward movement of shingle inshore of the 12 metre contour. However, even at the inshore sites, in depths of water of 9 metres and 12 metres the quantities of shingle moved towards the shore were very small. The centroid shifts at these two sites indicated that the average pebble would take about 200 years to advance 3 kilometres shorewards from the 12 metre to the 9 metre contour.

It was concluded from the results of this study that the movement of shingle beyond the 18 metre depth contour on the South Coast will be negligible at all times. On this basis, therefore, the Station recommends that dredging of shingle should not take place in depths of water less than 18 metres below low water level.

Numerical model of shoreline changes due to wave refraction over dredged areas. A study financed partly by the Crown Estate Commissioners has been made on the effects that offshore dredging may have on shoreline changes. The Station's wave refraction computer program⁽⁹⁾ was linked to a beach mathematical model⁽⁶⁾. Predictions were made of changes in the plan shape of an initially straight shoreline due to changes in the height and the direction of the waves at breaking. The beach mathematical model is based on the reasoning that the alongshore sediment transport rate is a function of the wave height and

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the angle between the breaking wave crest and the beach. For a given set of deep water wave conditions these variables can be easily calculated by the use of the wave refraction program. In the beach mathematical model the following operations are carried out:-

- (1) From the data obtained from the refraction program calculate the wave height and angle at breaking.
- (2) Calculate the rate of alongshore sediment transport rate using the Scripps equation as modified by Komar.⁽¹⁰⁾
- (3) Having determined a stable time step calculate the amount of accretion and erosion from changes in the rate of littoral drift. Distribute these changes over the inshore seabed.
- (4) Return to the wave refraction program to recalculate the input wave conditions i.e. go to (1).

Preliminary results from this study were presented at the 14th Coastal Engineering Conference in Copenhagen, Denmark⁽¹¹⁾. The model showed that the shoreline erosion decreased very rapidly as the area of dredging was moved offshore into deeper water. At this stage it was prudent to "err" on the safe side and we stated that the effects of wave refraction were insignificant in water depths greater than 18 metres in British Coastal Waters. However more work was needed to define the amount of shoreline erosion for different depths of dredging.

After further tests we now consider that the effects of wave refraction are insignificant in water depths of 14 metres or more. Our report to the Crown Estate Commissioners was published in April $1976^{(12)}$. This report shows that the mean shoreline erosion plotted against water depth is approximately an exponential curve with the asymptote occurring at 18 metres or so. However for all depths of dredged hole the difference in erosion due to dredging at 14 metres and at 18 metres is negligible. Inshore of the 14 metre depth, erosion was significant even for the shallowest depth of dredging tested (1 metre).

The effect of hole length was investigated for a 4 metre depth of dredging (dredging to greater depths is not generally considered). An increase in hole length, parallel to the shore resulted in a small but measurable increase in erosion. The shoreline recession was found to increase at the rate of about 1.4 metres for every kilometre increase in the length of the dredged hole. For depths of dredging shallower than 4 metres the effects of wave refraction were reduced and hence recession increased more slowly with increased length of hole. These tests were carried out inshore of the 14 metre depth contour. Beyond this depth, these effects can be considered insignificant.

All the results show that the water depth over the dredged area is the controlling factor for any particular wave climate tested. In British coastal waters dredging is not allowed shoreward of the 18 metre contour on sediment supply considerations. This mathematical study shows that a 14 metre depth limit is quite acceptable so far as wave refraction effects are concerned. At present we do not generally allow dredging between the 14 metre and 18 metre water depth. However, if all other criteria are satisfied then we might under some circumstances allow dredging closer inshore than at present.

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<u>Movement of shingle under waves and tidal currents</u>. The studies with radioactive tracers off Worthing established a depth limit for no movement under wave action but with weak currents. There are areas where contractors would like to dredge, where currents as well as wave action contribute to the initiation of sediment movement. Such an area is off the Isle of Wight on the South coast of England. If the beaches at the adjacent coastline are being fed from offshore by current and wave action then material might be trapped in the dredged areas and the onshore supply of shingle interrupted. It is necessary to develop new criteria to help decide whether a dredging licence can be granted.

There were two parts to the studies designed to establish a criterion now to be desribed. A theoretical approach was developed to calculate the shear stress at the seabed due to the combined action of waves and tidal currents. The shear stress was then used to predict the threshold of movement of shingle using a modified form of the Shields curve. Also a field study was carried out to measure the strength of tidal currents south-east of the Isle of Wight — an area of high dredging potential. It was therefore possible to apply the criteria established theoretically to a practical case.

The shear stress due to tidal currents alone was calculated using the Karman–Prandtl velocity profile equations. Using Prandtl's mixing length hypothesis the velocity distribution can be written as: -

$$U = \left[\frac{\gamma_c}{\rho}\right]^{\frac{1}{2}} \cdot \frac{1}{K} \cdot \log_e \left[\frac{33y}{Ks}\right] \cdot \dots (1)$$

where U

= velocity measured at 0.4 of the water depth (m/s)

 γ_c = shear stress exerted at the bed by the current flow (N/m²)

 ρ = density of sea water (kg/m³)

K = Von Karman's constant, the value taken was 0.4

y = water depth at the height of the current velocity meter (m)

Ks = Nikuradse roughness parameter

The maximum bed shear stress due to wave action was calculated using Jonsson's wave friction factor $fw^{(13)}$. The maximum shear stress being related to the wave conditions by the equation:-

$$\gamma_{\rm W} = \frac{fW}{2} \cdot \rho \cdot Um^2 \qquad \dots (2)$$

where γ_w

 $\gamma_{\rm w}$ = maximum bed shear stress (N/m²)

fw = wave friction factor, a function of the sea bed roughness and the wave conditions

 ρ = salt water density (kg/m³)

Um = maximum horizontal wave orbital velocity (m/s)

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The maximum orbital velocity was found from small amplitude sinusoidal wave theory, and was then used to calculate the water particle displacement at the seabed i.e.

$$Am = \frac{Um \cdot T}{2\pi} \qquad \dots \qquad (3)$$

where Am = maximum particle displacement (m)

T = wave period (s)

The value of fw in equation 2 was found from the Jonsson friction diagram where it is plotted against the relative roughness of the seabed Am/Ks.

So far we have considered the shear stress exerted near the seabed by tidal currents and wave action acting independently of each other. The combined shear stress was determined by considering the general formula for fully turbulent flow

$$\gamma = \rho L \left[\frac{\delta v}{\delta y}\right]^2 \qquad \dots (4)$$

where γ = shear stress (N/m²)

L = Prandtl's mixing length (m)

v = velocity at a small height y above the bed (m/s)

Rearrangement of the equation gave :-

$$\frac{\delta \mathbf{v}}{\delta \mathbf{y}} = \left[\frac{\gamma}{\rho}\right]^{\frac{1}{2}} \cdot \frac{\mathbf{I}}{\mathbf{L}} \qquad \dots \quad (5)$$

Hence the combined maximum velocity δv at the outer edge of the viscous sublayer with thickness δy is:-

$$\delta \mathbf{v} = \left[\frac{\gamma_{\rm C}}{\rho}\right]^{\frac{1}{2}} \cdot \frac{\mathbf{I}}{\mathbf{L}} + \left[\frac{\gamma_{\rm W}}{\rho}\right]^{\frac{1}{2}} \cdot \frac{\mathbf{I}}{\mathbf{L}} \quad \dots \quad (6)$$

And substituting back into equation (4) we have:-

$$\gamma = \gamma_{\rm c} + 2\sqrt{\gamma_{\rm c} \cdot \gamma_{\rm W}} + \gamma_{\rm W}$$
 ... (7)

The combined instantaneous maximum shear stress is greater than the straight addition of the shear stress due to waves and tidal currents. Madsen and $\text{Grant}^{(14)}$ found that the Shields curve predicted the threshold of movement by waves if the boundary shear stress was replaced by the maximum value of the oscillatory shear stress. It would therefore seem reasonable to use this curve to predict the threshold under the combination of the two and this is the approach used here.

The method has not been checked under prototype or model conditions and further experimental work will be carried out to refine the method.

The field study consisted of tidal current measurements in mean water depths ranging from 16 to 29 metres. The observations were made with a Plessey M021 current meter held at 0.4 of the mean water depth by means of a moored submerged float. This instrument translated the readings of current strength and direction at 10 minute intervals onto a self contained magnetic tape recorder. The data was fed into an HRS computér program which calculated a number of tidal current parameters e.g. magnitude, duration, direction, direction, directional scatter of the velocity readings.

A desk study was then carried out using the tidal current velocity information together with wave data from the nearby Owers Light vessel. This data was used to calculate the threshold of movement of shingle under the combined action of waves and currents using the theoretical approach described above.

Preliminary results from this study show that off the Isle of Wight the mobility of shingle is significantly increased by the action of tidal currents. It is not possible at this stage to give definite recommendations about the minimum depth of dredging. It would appear however that 25mm shingle for example is likely to be mobile in depths of water up to 22 metres. Further research by the Station will indicate whether the existing criterion of 18 metres applicable in areas of weak tidal action needs to be strengthened, and by how much.

5. Conclusions

1. An increasing amount of shingle is being won from the sea. This source accounts for some 11% of the total sand and gravel production in the United Kingdom. In the procedure leading up to the granting of a licence by the Crown Estate Commissioners, the first to be consulted is the Hydraulics Research Station. We are asked to say whether there is a possibility that dredging could affect adjacent coastlines. If the answer is "yes" the application is usually turned down; if "no" then other authorities are consulted. We attempt to answer a number of questions:

- (i) Is the dredging far enough offshore that beach drawdown into the hole cannot take place? The approximate limit for onshore/offshore movement off the South Coast of England is considered to be about 10 metres below low water and this is usually taken as the minimum depth to ensure that beach drawdown will not take place into the hole. We also have a limit in terms of distance offshore of 600 metres. This criteria is hardly ever invoked because it is usually over-ridden by other considerations.
- (ii) Is dredging to be carried out in deep enough water so that the hole will not intercept the onshore movement of shingle? Field tracer studies have shown that for the south coast wave climate and in regions of weak tidal currents shingle will not move in depths greater than 18 metres. A method of including the effect of tidal currents has been developed. We believe it errs on the safe side. As an example, the 18 metre criterion changes to 22 metres for a tidal current of 1.1 m/s. However it is stressed that the method is at an early stage of its development.

- (iii) Does the dredging area include banks which if removed would increase wave activity at the shoreline? In this case it is usual for the application to be turned down. There are exceptions under special conditions. If for example it can be shown that the beach is well protected from wave attack, eg by a very wide foreshore, then dredging of a limited quantity of material under controlled conditions may be allowed. For such special cases a desk study is carried out by HRS.
- (iv) Is the area sufficiently distant from the shore and in deep enough water so that changes in wave refraction over the dredged area do not lead to changes of littoral transport at the shoreline and hence changes in beach plan shape? A beach mathematical model developed at HRS has shown that in general the effects of wave refraction are insignificant when dredging takes place in water depths greater than 14 metres.

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7. References

- 1. Report of the Advisory Committee on Aggregates. "Aggregates: the way ahead". Department of the Environment Great Britain 1976.
- Inman D L and Rusnak G S. "Changes in sand level on the beach and shelf at La Jolla, California". US Army, Corps of Engineers. Beach Erosion Board. Technical Memorandum No 82 July 1956.
- 3. Watts G M. "Behaviour of offshore borrow zones in beach fill operations". Proceedings of the 10th Congress of the International Association for Hydraulic Research. London 1963. Vol 1 pp 17–24.
- Bretschneider C L and Reid R O. "Modification of wave height due to bottom friction, percolation, and refraction". US Army, Corps of Engineers. Beach Erosion Board. Technical Memorandum No 45 October 1954.
- 5. Treloar P D and Abernethy C L. "Determination of a bed friction factor for Botany Bay, Australia". Coastal Engineering, 2 (1978) pp 1–20. Elsevier.

- Price W A, Tomlinson K W and Willis D H. "Predicting changes in the plan shape of beaches". Proceedings of the 13th Conference on Coastal Engineering, 1972. Vol 2, pp 1321–1330.
- 7. Kidson C and Carr A P. "The movement of shingle over the sea bed close inshore". The Geographical Journal. Vol 125 (1959) pp 380–389.
- Crickmore M J, Waters C B and Price W A. "The measurement of offshore shingle movement". Proceedings of the 13th Conference on Coastal Engineering, 1972. Vol 2, pp 1005–1025.
- 9. Abernethy C L and Gilbert G. "Refraction of wave spectra". Hydraulics Research Station, Report INT 117. May 1975.
- 10. Komar P D. "The longshore transport of sand on beaches". PhD Thesis. University of California, San Diego. 1969.
- 11. Motyka J M and Willis D H. "The effect of wave refraction over dredged holes". Proceedings of the 14th Conference on Coastal Engineering, 1974. Vol 1 pp 615–625.
- 12. Hydraulics Research Station. "The effect on coastline changes of wave refraction over dredged areas". Report No EX 728, April 1976.
- 13. Jonsson I G. "Wave boundary layers and friction factors". Proceedings of the 10th Conference on Coastal Engineering, 1966. Vol 1 pp 127–148.
- Madsen O S and Grant W D. "Sediment transport in the coastal environment" Ralph M Parsons Laboratory for Water Resources and Hydrodynamics, Massachusetts Institute of Technology. Report 209, January 1976.