CHAPTER 40

Reach of Waves to the Bed of the Continental Shelf

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ABSTRACT

The physiography of Continental Shelves and their major composition of sediment indicate strongly their terrigenous origin and their smoothing by wave action This premise is supported by the geologic time over which waves have existed and the mass-transport velocity in these relatively shallow depths, particularly the net movement within the wave boundary layer at the bed A given wave train arriving obliquely to the shore can transport material along the coast, both beyond the breaker line and within the surf zone It is shown that for equal over-all discharge in the two zones, the average sediment concentration offshore close to the bed need be reasonably small, indicating that transport near the beach could be a fraction of that from the breakers to the reach of the waves This latter limit is shown to extend at least half way across the Shelf, with possibilities of greater reach when more realistic prototype conditions are introduced into experiments

INTRODUCTION

The margins of landmasses are made up mainly of mildly sloped under-water zones which are termed Continental Shelves The legally accepted limit for these, where the slope increases substantially, has been taken as 100 fathoms (183 metres), although the accumulation of data over decades has shown[1] that the edge of this feature is closer to 65 fathoms (120 metres)

Of the various classifications of Shelves the most important to the coastal engineer is the sediment accreted variety, which provides the widest marine margins available and also make up the largest percentage area of all Shelves Hayes[2] reports that 80% of the inner Shelf is covered by gravel, coral, shell, sand or mud, the last two constituting around 70% Another important fact is that material is still being furnished to these zones by the rivers of the world[3]

Whilst the sediment is supplied at specific locations along the coastlines, it is spread relatively evenly along them by wave action and possibly currents Whilst geographers and geologists have stressed the role of tidal and other oceanic streams in this distribution process, it would seem that wave action could well be the predominant agent in this massive task The following observations would appear to support this thesis

(a) Where waves (particularly swell) arrive obliquely to a reasonably long length of coastline there is evidence of accretion at the downcoast area and a dearth of movable material in the upcoast region The former occurs as an enlarged width of Continental Shelf and/or wide expanses of sedimentary plain Such physiographic units(4) are displayed on margins of enclosed seas as much as on boundaries of oceans where tidal currents are more pronounced

(b) There are indications that the net littoral drift in places is in the opposite direction to the strongest tidal streams For example on the Mozambique coast the predominant drift is northward whilst the strongest tides run southwards This is understandable when it is realised that lengthy orbital water particle motions of tidal period will be circular and will suffer shearing stresses near the bed, and thus contain large scale vortices in both horizontal and vertical planes The net transverse movement over a tidal cycle, particularly near the bed may thus be negligible or random in any direction

(c) When a Continental Shelf consists of sediment over its complete width it has a mean slope of 0 002(1), being steeper near shore and milder at the edge The uniformity of this profile over long lengths of coastline, and from one landmass to another, does not seem to correlate with the vast differences in tidal range or tidal currents associated therewith As noted previously, totally enclosed seas, such as the Mediterranean, Baltic etc , should have Shelves only at river outlets if tidal action were the sole or major source of energy distribution

(d) The edge of the Shelf, demarcating the limit of sweeping action by waves, has already been noted as around 65 fathoms (= 390 ft = 119 metres) This is around the reach or limit of influence of 13 second waves It has been shown elsewhere(5) that waves of this period are predominant in the ocean wave spectra generated in the storm zones of the oceans Such waves traverse the oceans with very little loss of energy Hence most oceanic margins of the world receive swell waves with periods from 11 to 15 seconds The western margins of Continents(6) in particular have swell incidence from the strong westerly gales in the 40^{o} to 60^{o} latitudes in both hemispheres In enclosed seas where the spectra of waves are limited to the local storm centres, swell from major generating areas of the oceans being excluded, the Shelf edge is not so deep In the Mediterranean it approximates 50 fathoms and in the Red Sea it is nearer to 30 fathoms, where sediment has accumulated

(e) A ubiquitous feature of coastlines is the crenulate shaped bays formed by sedimentary sections between rocky headlands The sculpturing of this shape has been shown to be the work of waves arriving obliquely to the coast[7] These bays are of vastly differing size, some encompassing many miles length of coast and some miles width of Shelf They indicate that waves can modify the sea bed to substantial depths and finally bring the bed and shoreline profiles into a compatible equilibrium with the direction of the most persistent swell waves in the adjacent ocean area The orientation of such bays has been used to determine the net sediment movement around the coastlines of the world[4]

(f) Finally, the oscillatory motion of the water particles at the bed produced by wave propagation involves a net advance each wave period which has a maximum value at the sea bed This is particularly so for small ratios of depth to wave length, and so is relevant to this discussion of predominant swell waves with periods from 11 to 15 seconds This net motion is termed mass transport and results from the viscous forces creating a boundary layer in the oscillatory motion of the water particles near the bed This boundary layer is in the order of 1 to 2 centimeters thick and yet the mass transport velocity is maximum within it Thus, if bed particles can be lifted temporarily from the floor during part of the wave cycle they can readily be carried forward in the net advance of the water itself As soon as the bed is so affected small ripples and then dunes form[8], so creating a rough bed which changes the boundary conditions The ability of the waves to disturb bed particles is thus increased, so that sediment transport due to mass transport is enhanced The point of concern here is the comparison of this force with that of a tidal stream Whilst this latter may be strong at the surface, where it is most noticeable, it will be greatly reduced as the bed is approached, and be practically zero near the boundary layer previously mentioned Its transporting efficiency is further decreased by the vortices accompanying it,as noted earlier

From the above discussion it is seen that waves appear to have exerted a great influence on the sediment existing on Continental Shelves The motions of particles are slow and are in fact zero for large periods of a year, when wave heights or periods are too small for adequate reach to the bed However, when it is realised that waves, both storm type and swell, have been available on the oceans since their inception, there has been a surfeit of time for Shelves to be accumulated and even for vast expanses of landmasses to have been accreted

LONGSHORE COMPONENT OF MASS TRANSPORT

The mass transport velocity at the seabed has been derived theoretically for the case of waves of very small height, a smooth bed and laminar boundary layer[9] An empirical relationship has also been found for the case of a rough bed and laminar or turbulent boundary layer[10] It is thus possible to compute this net advance in the direction of wave propagation at any point across the Continental Shelf when the wave characteristics are known

Assuming a wave arrives at the edge of a uniformly sloped Shelf at some given deepwater angle, it is possible to compute the shoaling and refraction coefficients for it and find its angle to the shoreline during propagation towards the shore The variable wave height can be substituted into the bed mass-transport equation, assuming a roughness for the floor and the status of the boundary layer This latter is determined from a knowledge of the limiting wave height for a given wave train when the transition from laminar to turbulent boundary layer occurs The longshore component of the mass transport can be determined at each location to give its distribution across the Shelf

For smooth or rough bed and laminar boundary layer, we have

$$\frac{U_L\, g\, T^3}{H_o^2 \sin \alpha_o} = \frac{k}{A} \qquad \text{------------------(1)}$$

where
- U_L = longshore component of mass-transport velocity at bed
- g = acceleration due to gravity
- T = wave period in seconds
- H_o = deep-water wave height
- α_o = deep-water angle of crest to bed contour
- k = dimensionless factor dependent on

$$D/\delta = D(\pi)^{\frac{1}{2}}/4.6(\nu T)^{\frac{1}{2}}$$

where
- D = dimension of bed roughness (grain diameter or ripple height)
- δ = boundary layer thickness
- ν = kinematic viscosity of seawater

Experimental values of k derived by Brebner et al[10] give values as in Figure 1

$$A = (1-\sin^2\alpha_o \tanh^2 2\pi d/L)^{\frac{1}{2}}[\tanh 2\pi d/L(1+\frac{4\pi d/L}{\sinh 4\pi d/L})]\sinh^2 2\pi d/L/\cos \alpha_o$$

where
- d = water depth
- L = wave length

(The expression for A is graphed in Figure 2)

For the smooth and rough bed turbulent boundary layer condition, Brebner et al[10] found

$$\frac{U_L\, g\, T^{2.6}}{H_o^{1.2} \sin \alpha_o} = \frac{28.9}{A^{0.6}} \text{ for fps units} \qquad \text{---------(2)}$$

(Unlike Eq (1) this relationship is not dimensionally homogeneous, indicating the need for further experimental confirmation)

The transition from laminar to turbulent boundary layer as found by the same workers[10] can be expressed as

$$\frac{H_o^2}{T\nu} = 8150\ A \qquad \text{-----------------------(3)}$$

It will be seen in the subsequent calculations that turbulent boundary layer conditions exist for nearly all the waves and depths chosen

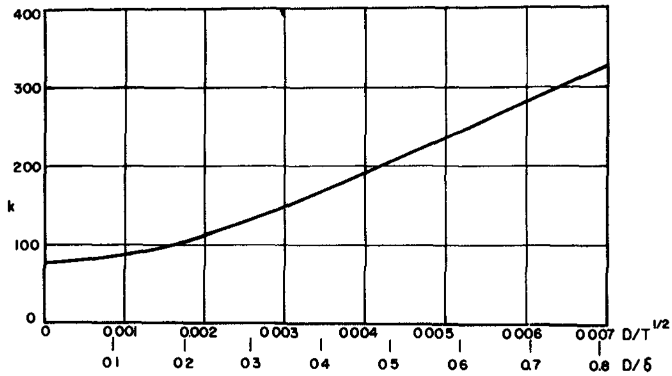

Fig 1 Values of k in equation (1) from roughness height in proportion to boundary layer thickness or $D/T^{\frac{1}{2}}$

AVERAGE WAVE SPECTRA

In order to determine some reasonable values of wave height and wave period to substitute in the above equations, the optimum storm conditions of the oceans must be assessed As noted elsewhere(5), the 35 knot wind is the strongest that can normally generate a fully arisen sea Winds of higher velocity either have limited duration or fetch (or both), so restricting the waves to $H_{1/3}$ = 33 ft and T_{max} to 12 seconds The energy distribution curve(11) for this condition is depicted in Figure 3 where it is seen that the equivalent triangular distribution indicates upper and lower engineering limits of 19 4 and 4 2 seconds respectively Proportional energy values for wave bands centered on 8, 10, 12, 14 and 16 seconds result in wave train heights ($H_{1/3}$) of 3 2, 4 9, 5 3, 4 2 and 2 0 feet respectively, based upon proportional areas under the curve

If these wave trains emerged from a fetch a long distance away they would arrive at the Continental Shelf separately The total energy available at any one time would depend upon the angular and radial dispersion from the fetch, but the resultant wave heights would be in proportion to those computed above for the discrete wave bands For the purpose of this comparison it will be assumed that waves of all periods are arriving from the one direction, with the crests angled at 50^{o} to the uniform and straight underwater contours

In Figure 4 is depicted the Continental Shelf with uniform slope of 0 002 1 Conditions at each d/L_o value represent the mean for a certain width of Shelf, from which it can be seen that $(\Delta d/L_o)(b/L_o)$ = 0 002

so that $b = (\Delta d/L_o)\ 5\ 12\ T^2/0\ 002$

At intermediate depths the differential $\Delta d/L_o$ is the difference of values midway between adjacent points, whilst at the extremeties of d/L_o = 0 01 or 0 5 the outside half width is assumed the same as the inner half (e g $\Delta d/L_o$ = 0 015-0 005 = 0 01) The b values are listed in Table I The product b U_L represents a mass transport discharge across the Shelf width b per unit depth of liquid at the bed When multiplied by a thickness to which U_L is considered to apply (½" has been assumed), the discharge of water in this layer of liquid is obtained The summation $\Sigma b U_y/24$ gives the said discharge across the active width of the Shelf (Σb) for the wave train under consideration Although calculations have been carried out to d/L_o = 0 5, the limit of disturbance of the respective components (derived later) is indicated by the double lines in Table I

EQUAL SEDIMENT TRANSPORT IN SURF ZONE AND OFFSHORE

For the wave conditions specified in Table I it is possible to compute the littoral drift in the surf zone by one of the many relationships available The one employed here is that presented by Castanho(12) which has been discussed elsewhere(13) The volume of sediment passing a plane normal to the beach per unit of time (e g ft^3/sec) can be expressed as

$$Q = \omega H_o^2 L_o E_r \sin \alpha_o / 7 \, f \, \gamma_s \qquad \text{----------------}(4)$$

where
Q = volume of sediment of specific weight γ_s passing a plane normal to the beach per second (γ_s = 110 lb/ft^3)
ω = specific weight of seawater (= 64 lb/ft^3)
H_o = deep water wave height (ft)
L_o = deep water wave length (ft)
$E_r = \dfrac{\text{energy dissipated}}{\text{longshore energy component}}$ (see Ref 13)
α_b = angle of crest to beach at breaking (deg)
α_o = deep water approach angle (deg)
T = wave period (secs)

Values have been computed in Table I for $\alpha_o = 50^o$ and the respective wave heights and wave periods

Let it be assumed that an equal volume of material is passing the plane beyond the breaker line, out to the reach of each wave train Also let it be assumed that sediment particles are moving at the same net speed as the water near the bed (i e in the ½" thick layer previously employed) Then the concentration of sediment by volume to accomplish this task can be calculated, as listed in Table I

It is seen that for the wave characteristics chosen the concentration necessary for equal transport offshore and in the surf zone are feasible Whilst the longshore velocity U_L is substantially reduced, the further from the beach and the longer the wave period, the widths of Shelf over which these operate are substantially enlarged

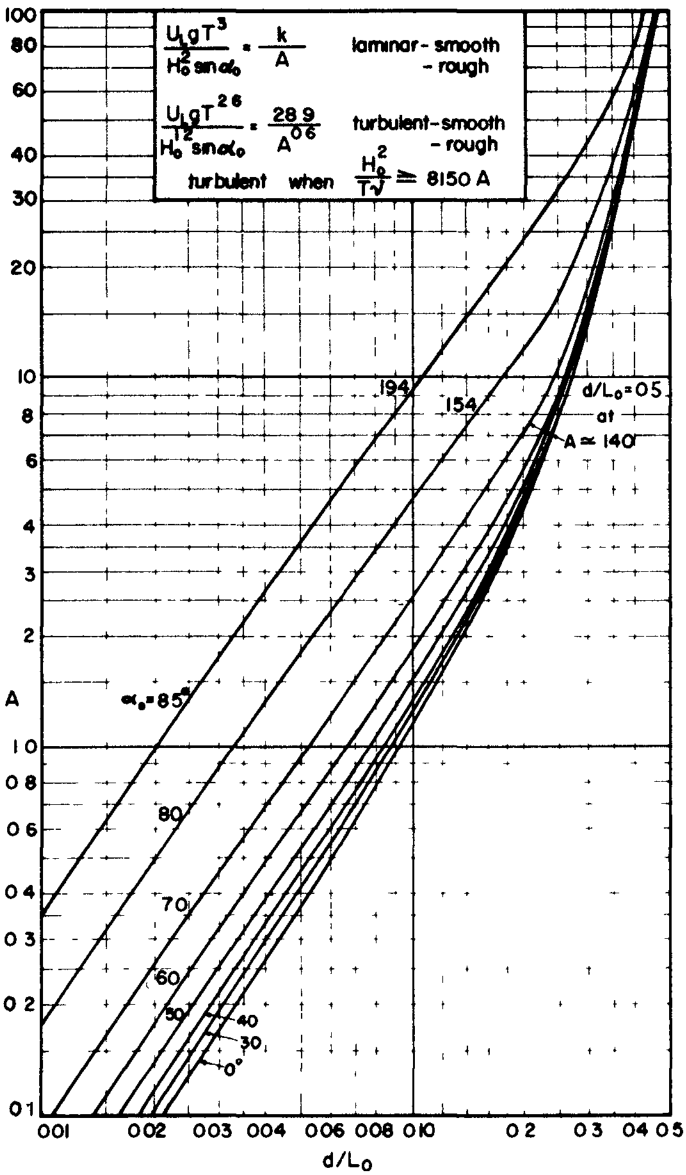

Fig 2 Factor A used in equations (1)(2) & (3)

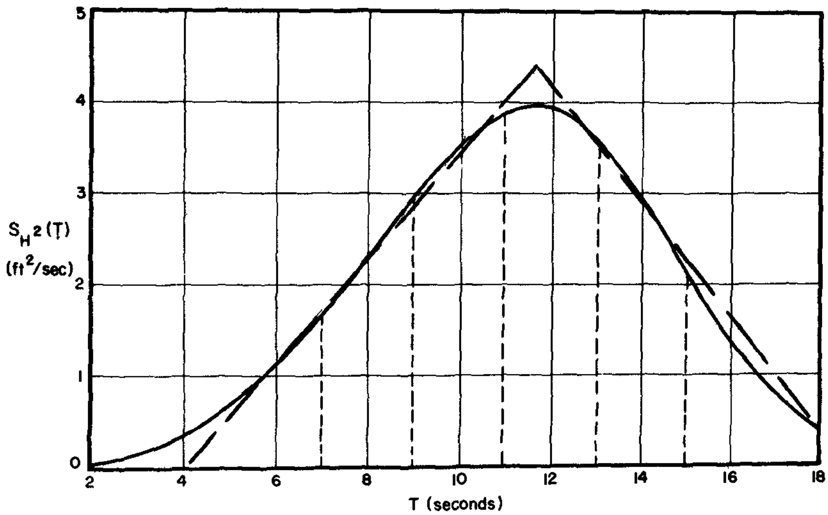

Fig 3 Energy distribution curve for a fully arisen sea generated by a 35 knot wind

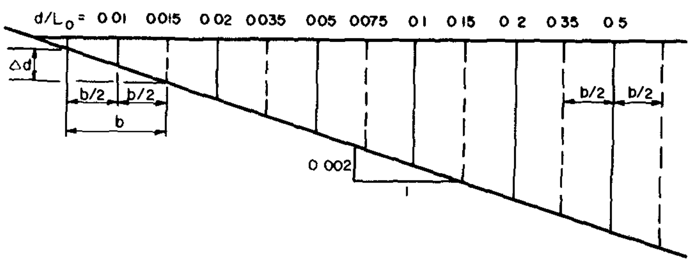

Fig 4 Assumed uniform Continental Shelf for purposes of calculations in Table I

Table I Longshore mass transport in various wave trains across portion of the Continental Shelf (See Figure 2)

$\alpha_o = 50^o$		8	10	12	14	16	T secs
$\sin\alpha_o = 0\ 766$		3 2	4 9	5 3	4 2	2 0	H feet
		2 10	1 75	2 59	6 56	43 0	$g\,T^3/H_o^2\ \sin\alpha_o\ 10^3$
		2 3	2 49	3 63	7 13	24 4	$g\,T^{2\ 6}/H_o^{1\ 2}\ \sin\alpha_o\ 10^3$
		14 35	26 9	26 3	14 1	2 78	$H_o^2\pi/T\nu\ 160^2 \geq A$
d/L_o	0 01	-	-	-	-	-	$U_L \times 10^3$ (laminar)(1)
$\Delta d/L_o$	0 01	78 1	72 1	49 5	25 2	7 4	$U_L \times 10^3$ (turbulent)(1)
A	0 048	1 64	2 56	3 69	5 02	6 55	$b \times 10^{-3}$ (feet)
$A^{0\ 6}$	0 161	128 0	183 0	183 0	127 0	48 5	$b \times U_L$
	0 02	-	-	-	-	-	
	0 02	41 2	38 0	26 1	13 3	3 9	
	0 138	3 28	5 12	7 40	10 04	13 10	
	0 305	135 0	195 0	193 5	133 8	51 0	
	0 05	-	-	-	-	-	
	0 04	18 3	16 9	11 6	5 9	1 7	
	0 530	6 56	10 24	14 80	20 08	26 20	
	0 685	120 0	173 0	171 7	123 0	44 5	
	0 10	-	-	-	-	-	
	0 075	9 8	9 1	6 2	3 2	0 9	
	1 52	12 30	19 20	27 70	37 70	49 10	
	1 28	120 5	174 8	172 0	121 0	44 2	
	0 2	-	-	-	-	1 4	Note For laminar con-
	0 2	4 8	3 8	3 0	1 5	-	ditions it is assumed
	5 10	32 9	51 2	73 8	100 5	131 0	that $D/T^{\frac{1}{2}} = 0\ 007$
	2 64	158 0	195 0	221 5	150 5	183 2	equivalent to ripples
	0 5	1 1	1 3	0 9	0 3	0 05	1/4" to 1/3" high on
	0 3	-	-	-	-	-	bed
	140	49 2	76 8	110 5	150 5	196 0	
	19 4	54 2	99 9	99 5	45 0	9 8	
(1) U_L (feet/sec)		0 075	0 20	0 3	0 325	0 31	limiting d/L_o
(2) MT = $\Sigma bU_L/24$		1 00	0 50	0 75	0 87	0 80	prop of last b
(ft^3/sec)		120	97 5	166 0	131 0	146 8	final $b \times U_L$
(3) G littoral		383	823	886	636	335	$\Sigma\, b\, U_L$
drift (ft^3 sand/sec)		16	34	37	27	14	MT in 1/2" layer(2)
(1 ft^3 = 110 lbs)		0 37	1 08	1 26	0 61	0 76	G(3)
(4) Concentration by volume		2 3	3 2	3 4	2 3	5 4	C/(4)

INCIPIENT MOTION OF BED PARTICLES

Before sediment particles can be carried forward and backward by the oscillatory motion of the water particles near the bed, they must be removed from the bed. This topic needs much more active research, but results are available from a number of workers on the incipient motion of sand particles under wave action. The differences and similarities of their results have been discussed elsewhere(8), but it can be concluded that, as the replication of bed conditions has tended towards the prototype scale of action, the greater has been found the reach of the waves. The types of equipment employed in generating the necessary oscillatory water motion have been described elsewhere(14). A more recent rig, used at the University of Western Australia(15), essentially oscillates a block of water with amplitudes and periods applicable at the sea bed. Results from these tests are presented in Figures 5A & B.

The empirical formulae derived for incipient motion of sand particles on a flat bed can be put into similar dimensionless form as in equations (5) to (17).

The relationship by Abou Seida(29) cannot be written in such a form but a modification and iterative process carried out by Mogridge(25) permits it to be plotted as in Figure 5. The graph of Bonnefille and Pernecker(17) consisted of two curves which have been modified into one for the presentation in the figure. The condition of the boundary layer has been indicated in the equations or been presumed (?).

Bagnold(16) (laminar ?)

$$\frac{U_{max}}{(s-1)^{2/3} g^{2/3} D^{1/3} D^{0.1} T^{1/3}} = 3.18 \quad \text{------(5)}$$

Bonnefille and Pernecker(17) (laminar)

$$\frac{U_{max}\, \nu^{1/6}}{(s-1)^{5/6} g^{5/6} D^{1/2} T^{1/2}} = 0.072 \quad \text{---------(6)}$$

Bonnefille and Pernecker(17) (turbulent ?)

$$\frac{U_{max}\, \nu^{19/30}}{(s-1)^{16/15} g^{16/15} D^{6/5} T^{1/2}} = 0.01 \quad \text{-------(7)}$$

Bonnefille and Pernecker(17) (modified)

$$\frac{U_{max}\, \nu^{5/18}}{(s-1)^{8/9} g^{8/9} D^{2/3} T^{1/2}} = 0.069 \quad \text{----------(8)}$$

Carstens et al(18)(19)(20) (turbulent)

$$\frac{U_{max}}{(s-1)^{1/2} g^{1/2} D^{1/2}} = 3.5 \quad \text{----------------(9)}$$

Eagleson and Dean(21) (laminar)

$$\frac{U_{max}\, \nu^{1/2}}{(s-1)\, g\, D\, T^{1/2}} = 0.131 \quad \text{---------------(10)}$$

Goddet(22) (turbulent)

$$\frac{U_{max}}{(s-1)^{2/3} g^{2/3} \nu^{1/24} D^{1/4} T^{3/8}} = 3.0 \quad \text{-------(11)}$$

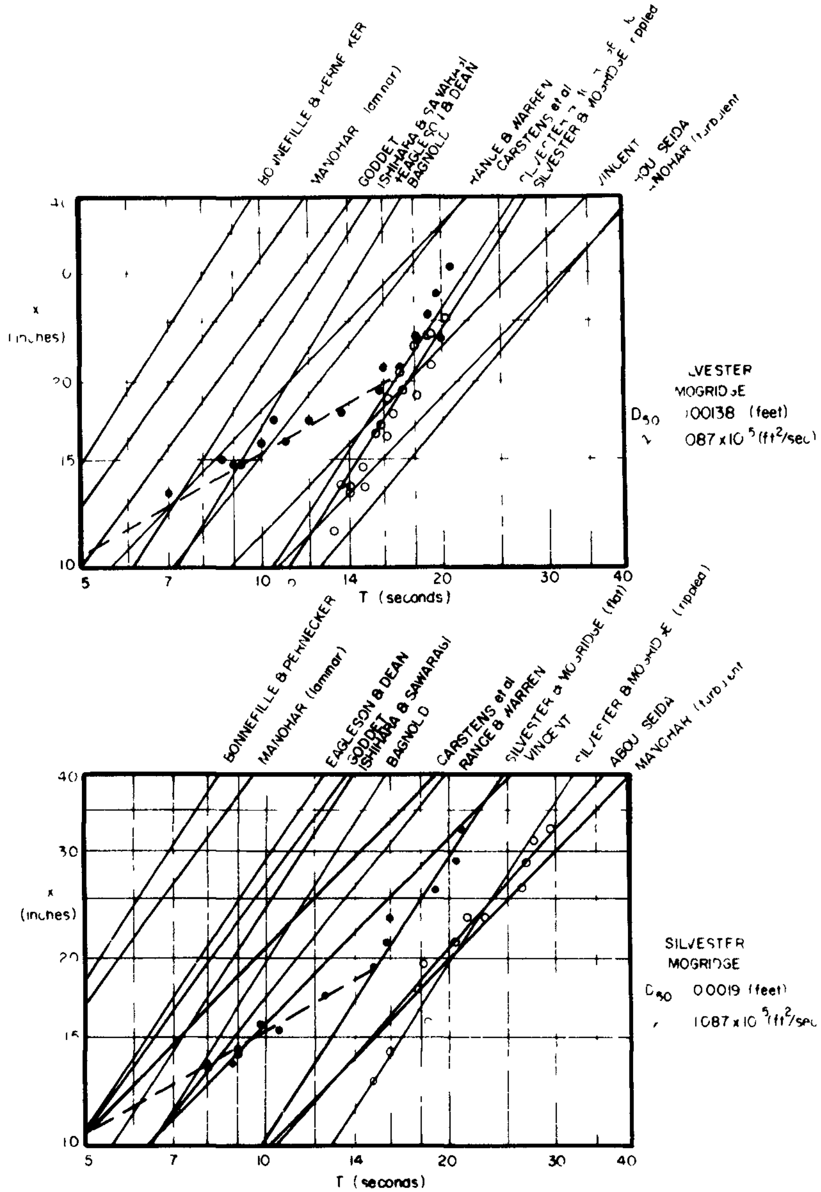

Fig 5 Wave periods (T) and amplitudes (x) at the sea floor to produce incipient motion on a flat bed with sand particles of mean dia A = 0 00138 ft (0 42 mm) and B = 0 0019 ft (0 58 mm)

Ishihara Sawaragi[23] (turbulent) $$\frac{U_{max}}{g^{3/4}(s-1)^{3/4}D^{1/4}} = 0.093 \qquad (12)$$

Manohar[24] (laminar) $$\frac{U_{max}\,\nu^{1/3}}{(s-1)^{2/3}g^{2/3}D^{2/3}} = 0.159 \qquad (13)$$

Manohar[24] (turbulent) $$\frac{U_{max}}{(s-1)^{0.4}g^{0.4}D^{0.2}\nu^{0.2}} = 7.45 \qquad (14)$$

Silvester and Mogridge[25] (flat bed) $$\frac{U_{max}\,\nu^{1/18}}{(s-1)^{7/9}g^{7/9}D^{1/3}T^{1/2}} = 0.034 \qquad (15)$$

Rance and Warren[26] (sand) $$\frac{U_{max}}{(s-1)^{3/5}g^{3/5}D^{2/5}T^{1/5}} = 0.69 \qquad (16)$$

Vincent[27] (turbulent) $$\frac{U_{max}}{D^{1/2}} = 19.1 \qquad (17)$$

The U_{max} can also be expressed in terms of amplitude of motion when the wave period is known or assumed, in which form these equations have been graphed in Figures 5A & B, for D_{50} = 0.00138 and 0.0019 ft respectively. Also assumed in the figures is $\nu = 1.087 \times 10^{-5}$ (ft^2/sec), s-1 = 1.6 and g = 32.2 ft/sec^2. It is seen immediately that these relationships are not compatible, probably through being extrapolated beyond the zones of verification.

Also included in the figures are the results of the authors' tests, the black dots representing flat bed conditions and the open circles the rippled surface produced from prior oscillatory motion. For the flat bed two relationships were found, one in which x varied approximately as $T^{1/2}$ for smaller x and T values, and the second in which x varied as $T^{3/2}$. The transition from the one to the other occurred at x = 20.5" and T = 17 seconds in Figure 5A, and x = 19" and T = 15 seconds in Figure 5B. Sleath[28], in his velocity measurements in the boundary layer at the bed of a wave tank, found a parameter $U_{max}\,D_{50}/\nu$ which displayed the transition in the velocity profile from laminar to one still laminar but influenced by vortex formation around the grains of sand. Appropriate substitutions from the above tests give values for incipient particle motion of 82.5 and 116 for the 0.00138 and 0.0019 ft diameter sands respectively.

Sleath observed his critical condition to occur at a value approximating 50. He states: "This may be compared with the value of $U_{max}\,D/\nu$ = 200 obtained from the formula proposed by Manohar (1955)[24] for the transition from laminar to turbulent conditions with sand of median diameter = 0.0445 in. It is probable that the phenomenon observer by Manohar and his colleagues was vortex formation rather than turbulence."

Carstens et al(18)(19)(20) from their tests with oscillating water in a conduit obtained U_{max} values when certain changes in the bed were observed For the sand size D = 0 00097 ft and ν = 11 0 x 10^{-6} ft^2/sec the following values of U_{max} D_{50}/ν were obtained

boundary layer transition commences (sand bed)	56 3
boundary layer transition commences (smooth bed)	74 8
incipient bed motion, bed undisturbed	71 3
spontaneous appearance of ripples	94 0
fully turbulent boundary layer (smooth bed)	119

From these values it seems quite probable that Manohar's observations were commencement of turbulence A significant observation of the above results is that incipient bed motion and even ripple formation occurred before full turbulence was experienced in the boundary layer It is at such a stage that mass transport will exert its influence on the bed particles As seen in Figures 5A & B the presence of ripples on the ocean floor will produce incipient motion at smaller amplitudes of the water particles for a given wave period, or at longer periods for a given amplitude However, the curves for this more realistic condition do not match the one equation, so the conservative flat bed relation of equation (15) has been put in terms which are graphed in Figure 6

With this diagram a wave of any specific period in a certain depth of water will have to have a minimum height in order to initiate particle movement on a flat bed The respective heights and periods for a fully arisen sea of a 35 knot wind previously derived are indicated in Figure 6 It is seen that the 12 and 14 second waves can disturb sediment at over 200 feet depths This is half way across the Continental Shelf

It is believed that for similar wave conditions the ability of waves is greater than that indicated in Figure 6 due to the following prototype phenomena

1 Velocities of water particles near the ocean bed may be higher than those derived by first order theory

2 The interaction of wave trains of slightly differing period can generate greater instantaneous velocities than implied in the present analysis

3 Wave trains angled to each other produce vortices of large dimensions with associated turbulence which may disturb the bed more readily

4 In storms at sea, where fetches are changing location and orientation continually, waves may move in opposite directions so creating clapoti or partial clapoti These create high water particle velocities near the bed They will also temporally build up furrows of material which will be readily swept away when the standing wave has dispersed

5 Currents and internal waves associated with tidal action at the

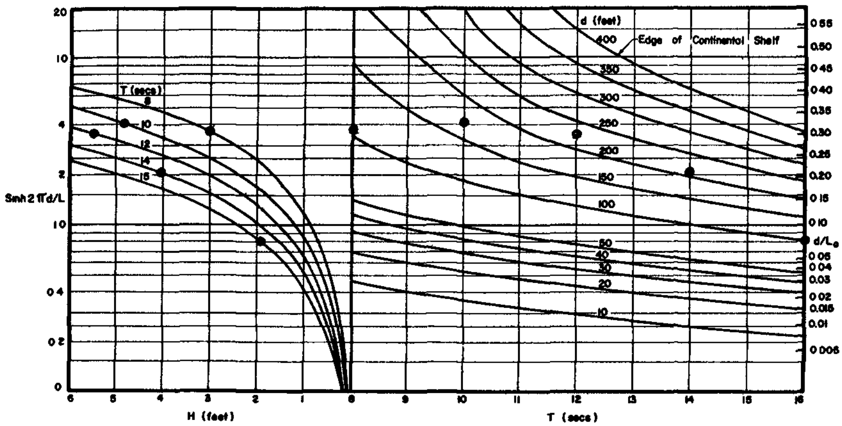

Fig 6 Wave conditions for incipient motion on a flat bed for sand (D_{50} = 0 00065 ft = 0 2 mm)

edge of the Shelf could assist the waves in disturbing the bed at these larger depths

6 Shell debris on the sea floor can initiate movement of sand particles sooner than for rippled or smooth beds Carsten's tests[19] showed that, with small protruberances on the bed, motion is initiated at about half the water particle velocity of that for a smooth sand bed This implies in Figure 6 that the same reach can be effected with half the wave heights previously considered It can be shown by drawing curves in the left hand side of the figure with half the wave height for each period band, that for the original wave heights the reach is increased about 30% For example, the 5 5 ft high 12 second wave which had a reach of 230 ft for rippled bed conditions can influence a bed at 300 ft depth which contains shell-like debris on it

7 It is possible that fish life is concentrated heavily at the floor of the ocean Any motions by them on or near the bed will disturb sediment which the mass transport of the waves will carry into and along the shore

These prototype conditions could increase the concentration of suspended sediment above those recorded in model studies They could also effect movement well above the boundary layer, on which the previous comparison was based

CONCLUSIONS

1 Since the major proportions of Continental Shelves consist of sediment which has accreted to around the 400 feet depth, it would appear that wave action is the predominant spreading agent

2 The mass-transport due to wave action is at a maximum within the boundary layer at the bed where initial suspension of material occurs

3 Roughness of the sea floor due to the sediment particles or undulations formed thereon would appear to increase the mass-transport velocity and assist in the initial disturbance of the bed

4 For an oblique wave train, the mass-transport velocity at the bed, and its longshore component, can be computed at all depths across the Continental Shelf, to the limit where shoaling invalidates the theory employed

5 With certain simplifying assumptions, it can be shown that for equal sediment transport within the surf zone and beyond the breaker line for a given wave train, the volumetric concentration of sediment within the 1/2" bottom layer of water does not have to exceed 5%

6 Empirical relationships of wave and sediment characteristics for incipient motion on a flat bed vary considerably, with those utilising prototype velocities and amplitudes in their experimental rigs showing a greater reach of wave action

7 Further tests are required to verify beyond all doubt that the average wave spectra to be expected over the Continental Shelves can sweep sediment on them to their recognised outer limit These test should include normal marine debris on the bed, so that initiation of sediment motion and the frictional effects on the boundary layer can be studied

8 More analytical and experimental work needs to be carried out on mass-transport, both for simple wave trains and the more complex water and sediment systems

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