Profile Nourishment: Its Background and Economic Advantages

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Abstract


Much has been said and written about the geometry of beach and bottom profiles as well as about artificial nourishment of eroding beaches. Little has been done to integrate the two subjects including materials-characteristics. This article explains by theory and field experiments procedures combining these subjects and the economic advantages in nourishment procedures.

ADDITIONAL KEY WORDS: Artificial nourishment, beach nourishment, coastal protection, equilibrium profiles, nearshore transversal drift.

INTRODUCTION

The 1985 Iceland Symposium on Sedimentary Sea/Land Interactions provided data on sea level rises and coastal responses including eustatic rises as well as short-duration storm tides (see papers by FINKL, HOFFMAN, LISLE, TITUS, TOMASSON and BRUUN in the proceedings volume).

The combined results by TOMASSON and BRUUN (1985) show that there is a quantitative balance between river output of sand on the 140 km long shore between Torlakshofn and Dyrholaey on the South Coast and the approximate 3.5 mm per year sea level rise over the 9,000 m wide continental platform that extends to 50 or 60 meters depth. Grain sizes decrease from the wide beach (of dark volcanic sand) but oceanward the materials become less sorted and more mixed. The bottom profile outside the enormous bar cresting at 6 m depth follows the equation $y^{3/2} = 0.05x$ ($y = \text{depth, } x = \text{distance from shoreline to point with depth } y$). The same equation is valid for exposed profiles on the Danish North Sea coast at Thyborøen until about 20 meters depth (BRUUN, 1954, BRUUN and SCHWARTZ, 1985). Comparing the two locations one observes a similar trend in the grain sizes which decrease oceanward at the same time becoming less sorted.

The expression $y^{3/2} = \rho x$ was already derived by Bruun in 1952-54 and published in Denmark (1954) and in the United States (1954) by the US Army Corps of Engineers (BEACH EROSION BOARD) as Technical Memo No. 44. A brief description of the theory is given below (from BRUUN and SCHWARTZ, 1985) in citation:

"(1) a) The profile is formed by the shear stress due to the wave action and is at right angles to the shoreline. The material detached by the oscillating water is removed by longshore currents. As the shear stress due to wave action in general—and particularly during storms—is far greater than the shear stress originating from the longshore currents, this assumption seems logical.

b) In the equilibrium profile the shear stress per unit bottom area ($\tau$) may be assumed to be constant, i.e. the "condition" at the bottom is the same ($d\tau/dx = d\tau/dt = 0$). Confirmation of this assumption only can be attained by experiments. One obtains $\tau = k U_{ave}$, where $\sigma$ is the density, $k$ the resistance coefficient and $u$ the bottom water velocity. If is assumed a constant, then $U_{ave} = H\pi/T \cdot \sinh 2\pi y/L$ is also constant where $T$ is the wave period; $H$, the wave height; $L$, the wave length; and $y$, the water depth.

c) $dE_{i}/dx = \text{constant}$, where $E_i$ is the transported wave energy per unit area of the wave, and $x$ is the distance from the shoreline. The loss of energy is made up of a loss by spilling of the wave and a loss by internal friction (very small). The correctness of this assumption can
only be proven by experiments. Calculations give:

\[ x = L_o \sqrt[3]{2 \pi y \left[ \frac{2 \pi y}{L_o} + \frac{1}{3} \left( \frac{2 \pi y}{L_o} \right)^2 \right] + \frac{43}{180} \left( \frac{2 \pi y}{L_o} \right)^3 + \ldots } \]

where \( y \) is the water depth and \( L_o \) the deep water wave length. The series is convergent for \( y < L_o/8 \), i.e., for storm waves on the Danish west coast out to depths of about 12 m (40 feet) where \( L_o = 100 \) m (300 feet). Since \( y << L_o \), the equation may be reduced to

\[ y^{3/2} = \rho x \]  (1)

where \( \rho \) is a constant.

If it now is assumed that the loss of energy is due only to bottom friction and that this loss per unit area \( \eta \), is constant, then

\[ \tau = k \eta \]  (2)

where \( k \) = constant \((a/R)^{3/4}\), \( a \) is the length of the ripple marks and \( R \), the half amplitude of the oscillating water motion at the bottom \((R >> a)\). Calculations then give:

\[ y^{3/2} = \frac{\pi x}{T\omega^3} \quad (y < \text{about} \ L_o/8) \]  (2)

This profile is similar to the one above. Certainly the profile depends on the wave period \( T \), but as the profile is shaped mainly by storm waves and as the variation in \( T \) for these is small, the profile in reality will be the same as that given by (1).

BRUUN (1954) found confirmation of this profile geometry on the Danish North Sea Coast as well as in Southern California. \( \rho \) is calibrated to local environmental conditions (waves, materials)." By experiments published in his thesis "Beach and Dune Erosion during Storm Surge" (Delft University, Holland, 1986) Pier Vellinga found the following model law for profiles in the surf zone:

\[ n^w/n^d = (n_d/n_w)^{0.28} \]  (3)

where \( n^w \) is the length scale, \( n^d \) is the vertical scale and \( n^w \) is the settling velocity scale. Transforming this expression by Stokes law for settling velocities one has \( n_w^{0.5} = n_d^{1/4} \) where \( D \) is grain size diameter. One has \( n_d/n_w^{1/4} = n_d^{0.5} \)

In the prototype \( n_t = n_d = 1 \) (one)

One therefore has

\[ n_t n_w^{0.5} = n_d^{0.4} \]

Putting \( n_t = x \) and \( n_d = y \) one gets

\[ X \cdot n_w^{0.5} = Y^{1.4} \]  (4)

This equation has a surprising similarity not only to the results by VELLINGA (1986) but to other full-scale results from the field.

A profile, however, has different grain sizes varying with depth and actual exposure The \( k \)-value in the above expression (under item b mentioned) for shear stresses \( \tau = k \eta u_{\text{max}}^2 \) \((U_{\text{max}} = \text{max velocity of the orbital flow at the bottom})\) varies with grain size.

\[ k \]

may be written:

\[ k = (D/A)^{3/4} \]  (5)

(LOSADA and DESIRE, 1985)

(BRUUN, 1954, 1985, 1986). \( D \) = grain size diameter taken as \( D^0 \), \( A = \text{semi-excursion of water particles right over the bottom}. \)

In order to maintain the same shear stress over the bottom \( \tau \) must remain the same, or:

\[ \tau_{\text{max}} = (D/A)^{3/4} \cdot u_{\text{max}}^2 \text{ constant} \]  (6)

\( u_{\text{max}} \) can be written:

\[ u_{\text{max}} = \frac{\pi H}{T} \text{cosh} \left( \frac{2\pi d}{L} \right) + \ldots \]  (7)

This equation in its first approximation is fairly accurate for the area outside the breaker zone. One therefore has:

\[ \tau = (D/A)^{3/4} \cdot \left( \frac{\pi H}{T} \text{cosh} \left( \frac{2\pi d}{L} \right) + \ldots \right)^2 \]  (8)

shall remain the same over the profile subjected to shear stresses by the oscillating water movement by the wave action. Consider one particular storm of extreme intensity and a narrow range of periods which is normal.

Wave heights decrease relatively little moving from the offshore towards the relatively steep bottom. Energy loss will mainly take place by bottom friction and little or less by top-breaking and internal friction. The wave height, \( H \), in relation to depth, \( d \), may be approximated as:

\[ H \approx d^{1/3} \]  (9)

or

\[ H \approx d^{1/4} \]  (10)

Eq. (8) may for one particular storm wave period be written as:
TABLE 1. Examples from Iceland and Denmark

<table>
<thead>
<tr>
<th>Depth = d meters</th>
<th>Iceland</th>
<th>South Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H = d^{1/4}</td>
<td>H = d^{7/4}</td>
</tr>
<tr>
<td>6</td>
<td>D mm</td>
<td>D mm</td>
</tr>
<tr>
<td>12</td>
<td>0.7</td>
<td>0.75</td>
</tr>
<tr>
<td>18</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>24</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Danish North Sea Coast at Thyborøn

<table>
<thead>
<tr>
<th></th>
<th>H = d^{1/4}</th>
<th>H = d^{7/4}</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>12</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>18</td>
<td>0.11</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Putting

\[(D/A)^{3/4} \cdot H^{2} \text{ constant} \quad (11)\]

Putting

\[A = H \text{ one has } D^{3/4} \cdot H^{5/4} \text{ constant} \quad (12)\]

and for

\[H = d^{1/3} \text{ one has } D^{3/4} \cdot d^{5/12} \text{ = constant} \quad (13)\]

Similarly for

\[H = d^{1/4} \text{ one has } D^{3/4} \cdot d^{5/16} \text{ = constant} \quad (14)\]

Using the two assumptions one arrives at the following d/D ratios:

\[H = d^{1/3} \cdot d \rightarrow D \quad 2d \rightarrow D = 0.7 \]

\[3d \rightarrow D = 0.5 \]

\[4d \rightarrow D = 0.4 \]

\[H = d^{1/4} \cdot d \rightarrow D \quad 2d \rightarrow D = 0.75 \]

\[3d \rightarrow D = 0.6 \]

\[4d \rightarrow D = 0.5 \]

This is actually similar to what has been found so far, but more details have yet to be worked out. In reality, grain sizes will not become that differentiated because storms are composed of a spectrum of waves, not regular waves, and storms vary in intensity. Each storm tries to produce its own grain size distribution, but never actually achieves the ideal theoretical distribution, as indicated in Table 1.

The distribution in a less severe and in a severe storm may be as shown below for three different depths

Severe       0.4 mm    0.3 mm    0.2 mm
Less severe  0.3 mm    0.22 mm   0.15 mm

In addition, small storms will carry the smaller grain sizes out in less deep water for temporary deposition. The result is that bottom material becomes somewhat mixed and this is what we actually find, e.g. in Iceland. The ultimate result is still a slow migration of all grain sizes away from land until the single grain sizes come to a “rest”. Silt and clay sizes will, however, continue their transfer to waters deep enough to make settling possible, if ocean currents do not interfere with the process. Grain sizes, therefore tend to become a little lower than predicted by the ratio-procedure - and no wonder: samples were all taken during the summer season, when the coarser grains move sho­ward, while the finer materials tend to move oceanward to deposit in the offshore calmer waters. This decreases the mean diameter and the sorting of the offshore material. In practical coastal-engineering planning we must use the winter grain sizes corresponding to maximum exposure as design criteria, because they determine the erosion pattern.

ARTIFICIAL NOURISHMENT

Consider an equilibrium profile outside the breaker zone, following the equation:

\[y^{3/2} = px \quad (15)\]

It is assumed that the adjustment from an artificial profile, e.g. a dredge spoil, to a natural profile depends upon the difference in steepness between the two profiles. If the artificial slope is S, when \(S = f(t)\), where \(t\) is the time factor in the development, the adjustment depends upon the difference in slope between S and the final equilibrium profile. The steepness of the equilibrium profile is found with the following formula:

\[dy \frac{2}{3}y^{1/2} - \frac{2}{3}x^{2/3} \quad (16)\]

depending first of all upon the steepness parameter, \(p\). The rate of change of steepness along the profile is:

\[d^{2}y \frac{2}{3}x^{1/3} \quad (17)\]

In other words the rate of change of steepness is proportional to \(x^{1/3}\) where \(x\) is the distance from the shore.

If the loss of material from a profile is to be minimal the movement from a steeper to a less
steep profile must be as small as possible, because any deviation from the equilibrium slope will be subject to a net change, which will temporarily increase the littoral drift transversal to the profile towards or away from the shore. Consequently, the best profile resulting from nourishment with material corresponding to the original material will be another equilibrium profile, which must therefore be established by moving the initial equilibrium profile in an offshore direction—as a whole! If the total height of the active profile is $h$, the nourishment per linear meter is $ah$, where $a$ is the horizontal distance moved (BRUUN, 1962; SCHWARTZ, 1967; BRUUN and SCHWARTZ, 1986).

If nourishment by beach dumping initially produced a straight profile with a slope $S$, the difference in inclination between the natural and the artificial profile, $\Delta S$, is:

$$\Delta S = S - \frac{2}{3}p^{2/3}/y^{1/3} = S - \frac{2}{3}p'y^{1/2} \quad (18)$$

It is obvious that the largest $\Delta S$ occurs when:
1. $S$ is large;
2. $p$ is small (gentle offshore bottom);
3. $y$ is large (deeper waters). The smaller $\Delta S$ occurs when:
4. $S$ is small; and
5. $p$ is large (steep offshore bottom). In other words, the “new profile” shall be as close to “the old” as possible. In practice this means “profile-dumping,” not “beach-dumping”.

Let us now take a look at the equilibrium of particles on the bottom. According to EAGLESON et al. (1961), there is in any sand bottom profile a “point of equilibrium,” EQ, defined as the point where material transport towards the shore due to the oscillating water movement equals the movement away from the shore. Inside EQ material moves towards the shore, outside away from the shore. There is also a “point of incipient movement,” IM, where material just starts moving. This point, where threshold velocities are just exceeded, has been the subject of considerable study, for instance by NIELSEN (1979) and HALLERMEIER (1980, 1981, 1985). The location of the two points depends upon wave characteristics, slope and grain sizes. This means that each particular combination of $H$, $T$, slope and grain size has its specific EQ as well as IM. Consequently, if IM is situated outside EQ, erosion will take place; in the opposite case, accretion will be predominant. In nature conditions are more complex. There is of course no distinct EQ or IM, but apart from that it is still true that if one disturbs the natural equilibrium geometry of a profile, e.g. by steepening the beach and nearshore bottom profile by dumping material, the EQ must be relocated, so that the new EQ will be situated on the same slope and at the same depth as the original EQ. This means that the entire profile has to be shifted into a new equilibrium position with the same equilibrium geometry as before. If artificial nourishment steepens the nearshore natural profile, the artificial straight profile will move excessively in an offshore direction in an attempt to re-establish equilibrium. During this process the drift, not only transversal but also longshore, will increase. From the point of view of wave mechanics this is obviously the result of more wave breaking such as plungers, together with an increase in the longshore current. The two processes may be integrated as shown for example by DEIGAARD et al. (1985) who, by analytical methods, found that the longshore transport, $Q_s$, may be expressed by the equation:

$$\phi = \frac{Q_s}{H_o \sqrt{\beta} \sqrt{(s-1)gd^2}} \quad (19)$$

where $H_o$ = deepwater wave height, $\beta$ = bottom slope, $S$ = specific gravity, $g$ = acceleration, $d$ = particle diameter and $\theta$ = dimensionless total sediment transport.

BEREK AND DEAN (1982) and KRIEBEL AND DEAN (1985) considered a linear relationship between longshore drift in the profile and slope: where $g = m'$ refers to a specific contour.

Comprehensive testing on a very large-scale model in DE VOORST (Holland), reported by VELLINGA et al. (1985), revealed a rather rapid decrease with slope of transversal drift in the profile related to the dissipation of wave energy per meter in the breaker zone $\Delta Enc/\Delta x$, which in turn depends upon the steepness of the beach-bottom profile. The steeper the beach and beach-bottom are, the larger the dissipation of wave energy per unit of travel length and the faster the profile adjusts itself to a more stable, i.e. less steep profile. The slope dependency therefore seems clear and the increase of drift with steepness is obvious. This is an unfortunate “side-effect” of the present nourishment technique by which sand is dumped on the beach with a steep deposit-slope towards the
It would be much better to nourish the profile as a whole in its equilibrium shape, thereby avoiding both transversal and longshore losses due to an "unnatural steep profile". If nourishment is undertaken offshore by a split-hull dredger, the situation would be the opposite when material is placed inside EQ with a slope which is more gentle than the natural bottom. The IM point is usually in deeper waters. Tracer experiments can determine the depth at which it is practical and economic to place the material. Such experiments have been undertaken in Florida and in South Carolina to clarify the modes of nearshore transversal drifts. Material moving shoreward from an off-shore dump finally settles on a steeper slope corresponding to the actual equilibrium slope. Whether the longshore transport on the bottom thereby increases or decreases, together with the steepening of the bottom, depends upon the currents, tidal or wind, in the offshore area. According to Eqn. (19), which is based solely on wave action, the longshore drift would increase. However, in general longshore currents decrease with depth and distance from the shore, and as the area influenced by currents able to carry longshore drift decreases with steepening of the bottom, it is possible that the net result of a steepening would be a decrease in total longshore drift. It is also true that the two-dimensional movement of the oscillating water will tend to balance when EQ is reached, and, combined with the longshore current, this can of course result in a decrease or an increase in offshore drift, depending upon the grain size. With coarse material the drift increases. With fine material it is more likely to decrease. Furthermore, in the nearshore area the "academic" equilibrium situation is disturbed by rip currents and eddy diffusion. The net result is the outcome of the struggle between stir-up stresses and settling velocities of the sand grains (VELLINGA, 1983) resulting in an ever-decreasing particle size offshore. LOSADA AND DESIRE (1985) showed that all existing expressions for initial movements by oscillating water of amplitude a can be described by:

\[ \frac{a}{D} = \alpha \cdot \gamma \left( \frac{g}{w/a} \right)^n \]  

Where \( a = \) amplitude, \( D = \) grain size, \( g = \) acceleration of gravity, \( \gamma = 1/\rho \) \((\rho_s - \rho)\), \( w = 2\pi/T \), \( \alpha \) and \( n \) are exponents. One has:

\[ a^{n-1}w^2 = \alpha \cdot \gamma g^2 D \]  
\[ a w^{2(n+1)} = \alpha \cdot \gamma g^{2(n+1)} D^{1/3} \]

They found that \( p = 2 \) and \( n = 2 \) presented the best approximation for tests covering all ranges, from smooth to turbulent flows. Inserting \( p = 2 \) and \( n = 2 \) into Eqn. (17) one obtains:

\[ au^{4/3} = \alpha^{3/2} \gamma g^{2/3} D^{1/3} \]

Tests by these authors showed that is the important factor controlling the different modes of initial sediment movements. Introducing \( a = H/2 \) sin \((2n/L)\) one obtains:

\[ \left( H/2 \sinh(2\pi d/L) \right)^{4/3} = \alpha^{3/2} \gamma g^{2/3} D^{1/3} \]

This assumes a horizontal bottom in deeper waters. In shallow water, movements will be asymmetrical.

From Eqn. (24) it can be seen that:

(a) when \( H \) increases \( D \) increases, but only to a power of 1/3, or if \( D^1 = 0.4 \) mm and \( D^2 = 0.2 \) mm \( H \) changes 30% and \( d \) changes 20%. If previously the total height of the active profile was \( A + d \) (A above SWL) it will be \( A + 0.8 \) d with coarser material. If \( D^1 = 0.3 \) mm the changes will be 10-15%.

(b) if \( d \) increases, \( D \) decreases.

(c) if \( \gamma \) decreases, \( D \) increases for the same wave characteristics. The opposite occurs with an increase in \( \gamma \) — this applies to heavy minerals, which are more stable on the bottom than normal sands of the same grain size. In nature innumerable variables are involved in wave action. Still it is obvious that the "stable grain size" decreases with increasing depth (Figure 1). The practical consequences of this for artificial nourishment will be dealt with later.

**PRACTICAL ANALOGIES OF RIVER TRANSPORT TO THE SEA—ARTIFICIAL NOURISHMENT**

The normal procedure for artificial nourishment of beaches is to dump, usually by hydraulic pipeline dredge, material on the beach itself, after which wave action shapes the fill. This method is always accompanied by large losses of material from the beach as a
deposit slope of about 1 in 5 is too steep for equilibrium under wave action. The question may therefore be raised as to whether beach dumping is the most practical or economic procedure. During recent years offshore nourishment has been tested using a split-hull barge (see for example, Bruun, 1985a). This procedure has, so far, given some promising results, but its efficiency is highly dependent upon the depth of the nearshore area upon which it is possible, for reasons of draft, to dump the material. Wave action is supposed to bring the material to the beach, so it has to be dumped well inside the annual limit of seasonal fluctuations of the profile. The location of this "point" is a function of slope, grain sizes and wave action. A "secondary effect", however, is that the "shoal" created by the offshore dump slows down wave action, at least temporarily. The material dumped offshore is gradually distributed over the bottom. Some of it may reach the beach while other parts drift offshore due to the fact that the depth of initial movement of bottom sand, as explained below, may be located so far offshore that the net drift will be in a seaward direction during the more severe storms. Consequently, the material is lost for the beach and nearshore area. One may therefore ask, "Why not dump the material where it has a better chance of remaining more or less permanently, or at least in accordance with, the normal erosion rates for that particular depth or range of depths?" This obviously would be an advantage, as losses to the offshore bottom and particularly to adjoining beaches not in (the same) need for artificial nourishment will become less.

**PRACTICAL HANDLING OF NOURISHMENT OF A PROFILE IN RELATION TO GRAIN SIZE AND TIDAL RANGES**

Let us consider three different ranges of grain sizes, which in practice may only deviate a few tenths of a millimeter, and 3 tidal ranges—high, mean and low. Nourishment is undertaken over the entire "active" profile in order to utilize all available grain sizes by distributing...
TABLE 2. Dumping of sand of 3 different grain sizes, C, M and F at 3 tidal elevations: high, mean and low on 3 different bottom areas from +1 to −5 m

<table>
<thead>
<tr>
<th>Tide</th>
<th>Area</th>
<th>A: +1 to −1 m</th>
<th>B: −1 to −3 m</th>
<th>C: −3 to −5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Spring C (e.g. 0.25 mm)</td>
<td>C</td>
<td>M</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>C</td>
<td>M (e.g. 0.21 mm)</td>
<td>F (e.g. 0.18 mm)</td>
<td></td>
</tr>
<tr>
<td>Neap</td>
<td>C</td>
<td>M</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>C</td>
<td>M</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Neap</td>
<td>C</td>
<td>M</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Low</td>
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<td>--</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>--</td>
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<td>--</td>
<td></td>
</tr>
<tr>
<td>Neap</td>
<td>--</td>
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<td></td>
</tr>
</tbody>
</table>

sands in accordance with their size; relatively coarse, medium and relatively fine. The equipment used consists of hydraulic “pump to shore” machinery and split-hull barges with or without dredge pumps (BRUUN, 1985a).

Table 2 gives the distribution of material on three bottom areas: +1 to −1, −1 to −3 and −3 to −5, all to MLW. A tidal range of about 3 m is assumed. The wave action during storms is 4-5 m Hs, normal wave action is 0.5-1.0 m. The wave period is in the 5-12 s range. This is a shore of moderate exposure like the SE coast of Florida (U.S.A.) or British and Belgian shores of the Straits of Dover in Europe, where d' (limiting depth) is about 15 m long-range.

From this table it may be noted that all sand in area A should be “coarse”. Medium sand is dumped in area B, but if plenty of coarse sand is available (which seldom is the case) some may also be dumped in area B at high tides. All fine sand—or the finest, still suitable fractions—is dumped in area C. In all cases the sand to be used must have grain sizes as good as or better than the original sand to ensure an improvement in the stability of the entire profile.

**ECONOMY**

The economical advantages of such a diversified procedure depend upon fewer losses of material with profile-dumping compared to the conventional method. At this time we do not have any direct results by which the two methods can be compared—but we can still make an intelligent guess. In certain practical cases it seems that profile-dumping would have been an advantage. As an example: on Hilton Head Island in South Carolina (U.S.A.), out of 800,000 cubic yards of material dumped on the beach, 400,000 cubic yards were lost in one and a half years. Admittedly, about one third of the material was unsuitable due to its close-to-silt size. The normal loss of native sand on the same shore section is 100,000 cubic yards. Thus, the relative loss by beach dumping to both transversal and longshore drifts was 200,000 minus 100,000 = 100,000 cubic yards during the short period in question. Based on tracer experiments it is believed that most of the material was transported along the shore to the nearshore area, where improvements were noted in the adjoining beaches. This may not be a disadvantage in the overall picture. Partly dumping offshore, instead of full beach-dumping undoubtedly has economic advantages, as it is obvious that in the case of a shortage of medium sands, let alone of coarse sands, the finest particle size groups can in many practical cases be used for nourishment of the offshore profile, where these sands “feel at home”. Hopefully, future practical tests including extensive tracing will lead to better results at lower cost. Practical bid prices in Queensland, Australia (1986) are $3.50/m$^3$ for beach dumping, and $1.50/m^3$ for profile dumping. With 1/3 beach and 2/3 offshore the large economic gains of profile dumping are obvious (prices in A$, 1 A$ = 0.7 US$). This price is “unbeatable”, but we may come close to it in the United States, if we start using profile nourishment in a larger scale than just be split-hull barges of rather low capacity. Only two slightly different grain sizes are enough to justify profile-nourishment economically.

Figure 2 shows how profile nourishment is undertaken on the Danish North Sea Coast south of the headland Bovbjerg by a permanently installed pipeline in the bottom for discharge on the beach and by direct discharge from a shallow water hopper dredge or by a split-hull barge. Figure 3 shows dumping offshore from the bow of the dredger (top photo) and through a terminal buoy from a pipeline to the bottom. Procedures are similar in Queensland (Australia) but the pipeline is only installed temporary, as it is customary in the United States too. Economic aspects of the Australia-operation are explained by Figure 2.
SUMMARY AND CONCLUSION

The natural bottom material is adjusted to an equilibrium condition between acting shear forces and friction related to the detailed bottom geometry (mostly ripple marks). Bottom material, thereby friction, decreases oceanward to produce the optimum equilibrium condition mainly related to extreme events of wave action, but "confused" by minor storms. Bottom material also adjusts itself to seasonal events of the wave climate, as explained.

Artificial nourishment by dumping material on the beach is probably not the most economic nourishment procedure. Profile-dumping with material of selected grain sizes, depending on the availability of material, will undoubtedly prove to be more practical as it provides a higher degree of stability from the beginning. However, at the same time beach dumping will result in an (initially) wider beach. From a technical and economic point of view the highest stability is preferable. The opposite may be true from a public relations standpoint, this depends upon the sponsor's psychology! Equipment for the new procedure of profile nourishment is becoming available. In the United States split-hull barges have been in operation (USCE) for about 10 years. It seems to be definite economic advantages associated with a well planned profile nourishment.

Acknowledgement

Danish Coastal Directorate, Lemvig. Golden Coast's Special Beach Project, Queensland, Australia. Icelandic Coast Guard. And last, but not least, to the late professor Hans Albert Einstein, Jr., because after review of my stability calculations using shear stresses (1952) he said: "You may assume that you are right, as long as no-one can prove that you are wrong and I can not!"

LITERATURE CITED


HALLEMEIER, R.J., 1981. Critical Wave Condi-
Figure 3. Profile nourishment on the Danish North Sea coast. Top Photo: pumping over the bow. Bottom photo: pumping through a permanently installed pipeline in the bottom with a buoy terminal offshore. (Courtesy Danish Coastal Directorate, Lemvig).


Iceland Symposium on Sea-Land Interaction, 1985. Proceedings available from The National Energy Authority, Grensavégur 9, REYKJAVIK.


Note added in proof.

Source material for nourishment of beach and bottom profiles may be found on land, in bays or lagoons, or in lakes. During recent years, in the latest decade, source material was often located in the offshore area, e.g. in ocean shoals at tidal inlets, or in shoals produced by offshore currents (rare case) or as nearshore remains of extreme event outwash deposits of very low frequency of occurrence. It may, in northern countries, also be found in glacial meltwater deposits, the latter being the case in Denmark. Such material is coarser, and therefore better, than normal beach material. To consider the offshore bottom as a source for “natural nourishment under a rising sea level,” as suggested by Robert Dean in a paper published in the 1987 October issue of Shore and Beach, must be regarded as “wishful thinking.” Dean’s paper and reasoning are based on incorrect assumptions and misunderstandings – geologically, coastal geomorphologically, as well as sedimentarily and hydraulically. His concepts are based on incorrect ideas of sea level movements or fluctuations during the last 6,000 years are incorrect. Most shores all over the world erode and sea-level rise is partly responsible for that. No other reason is found. Consequently, we will have to rely on our own power.