Can We Predict the Behavior of Sand: In a Time and Volume Framework of Use to Humankind?

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In the world described by the nearshore sediment transport models currently used in American coastal engineering projects, sand movement on shorefaces works as follows: sand is moved exclusively by wave orbital interaction with bottom sediments. With few exceptions, the shoreface is a smooth featureless surface with parallel contours covered by a sediment of uniform grain size. Variations in the cross-sectional shape of this shoreface from location to location are determined only by surficial sediment grain size. Cross shore transportation of sand is limited in a seaward direction by a closure depth, usually at around 10 meters, beyond which no significant amount of sand is lost. At the upper end of the shoreface, sand is neither lost nor gained by aeolian, overwash or longshore transport processes. Waves striking the shoreline do not vary seasonally, are of a single wave length and height and come from a single direction. Individual random storms do not occur in most models but if they do, the storm waves are of a single wave length and height and come from a single direction. According to most models, all of the world’s shorefaces can be described and differentiated solely on the basis of sediment grain size and a broadly defined wave climate.

In the real world, sand movement on the shoreface is only poorly understood. Sand movement is believed to be accomplished by a complex combination of processes involving wave orbital interactions with the bottom sediment and with wave induced longshore currents, wind-induced longshore currents, turbidity currents, rip currents, tidal currents, storm surge ebb currents, gravity driven currents, wind-induced upwelling and downwelling currents and wave-induced upwelling and downwelling currents. All other things being equal, the amount of sediment moved will be strongly affected by the beach state (e.g. the oft-observed phenomenon of the first winter storm moving much more sand than subsequent storms). Sediment transport will also be affected by the formation of shell lags and a wide variety of bedforms (ranging from ripple marks to offshore bar systems), organic scum layers plus variations in sediment pore pressure and variations in the degree of sediment compaction and consolidation between storms. During fairweather conditions, sediment expelled into the water column by various types of infauna can represent a significant portion of the sediment under transport. The shoreface is not made up of a single grain size nor does grain size simply decrease offshore, rather it is often covered by a wide range of grain sizes which may vary temporally and spatially. Sediment-free rock outcrops are common on many shoreface reaches. The shape of many shorefaces is sufficiently irregular to cause nearshore wave refraction and the wave energy absorbing characteristics of the local sediment cover or rock outcrops or surface roughness in general may change wave energy in the surf zone.

The cross-sectional profile of the shoreface is due to many factors including wave climate (particularly the frequency of big storms), sediment supply, rate of shoreline and shoreface retreat, surficial sediment grain size and especially underlying geology. Sediment may be lost from the shoreface by overwash processes or may be gained.
or lost from longshore current and aeolian processes. Transportation of sand in a seaward direction is not limited by a closure depth. Sand is probably frequently “lost” to the shelf and in the case of big storms, sediment may be transported to the outer continental shelf. Even in fairweather, net sand transport may be offshore if ripples are present. Surf zone characteristics vary seasonally and both storm and fairweather waves may be simultaneously of many wavelengths and wave heights and from any direction. Multiple randomly occurring storm events are often responsible for sudden major changes in transport volumes. Engineering structures and replenished beaches may impact on the sediment transport on frontal beaches and on adjacent downdrift and updrift beaches.

The number of factors impacting on shoreface sediment transport is large. The number of possible combinations and permutations of these factors is vast. Clearly, sediment transport processes on each shoreface is unique; each beach is different. Clearly, sediment transport models currently used in coastal engineering can not come close to reality. In fact, many geomorphologists now argue that all geomorphic systems are chaotic (too deterministically complex to make long term predictions).

In this issue, we criticize the concept of the shoreface profile of equilibrium which is a mainstay of virtually all engineering models of nearshore sand transport. We find that there has been little communication between engineers and nearshore oceanographers to the detriment of the working engineering models. We find that there is no appreciation in engineering models of the geologic framework of shorefaces. The latter point was emphasized to us during the time we were working on this paper because we were simultaneously sampling the shoreface off Wrightsville Beach NC. There we found abundant outcrops of various types of ancient sediments ranging from well indurated Tertiary limestones to highly compacted Mid-Holocene muds. Clearly the shoreface off Wrightsville Beach owes its shape to more than just grain size of the surficial sediment. We also observed the presence of a large amount (perhaps more than 3 million cu m) of nourishment sand on the continental shelf well seaward of the so-called closure depth.

I believe we have demonstrated major shortcomings in the concept of the shoreface profile of equilibrium; shortcomings which are fatal to its application. Until the profile of equilibrium is replaced or strongly modified in engineering models, as it most certainly must be, the concept should not be used. In the final analysis, perhaps only the statistical approach, that is detailed study of individual shoreface systems, is likely to provide a basis for predicting sand behavior in such a complex and varied natural system.

Finally, some reviewers of our paper have made comments along this line: “Of course, the concept of shoreface profile of equilibrium isn’t perfect but it’s the best we’ve got for now so we should continue to use it until something better comes along”.

I disagree. The validity of the equilibrium profile concept can not be supported, it’s weaknesses are most fundamental and it should not be used to predict the behavior of sand in the nearshore zone.