The Engineering of Sand

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"All our knowledge brings us closer to our ignorance"
Thomas Stearns Eliot

ABSTRACT

On the basis of study of the east coast barrier island experience with beach replenishment, I have concluded that (1) the parameters used to design beaches don't work, (2) predictions of beach durability are *always* wrong, and (3) nobody in the coastal engineering community evaluates past projects, so no progress has been made in understanding beach replenishment. In addition the public is unaware of the uncertainties of beach replenishment and, consequently, the taxpayers take it on the chin.

Key words: Engineering and environmental geology; geology – public affairs; petrology – sedimentary; surficial geology – geomorphology.

A Personal Odyssey

I'm the "new boy on the block" in coastal geology, and I believe the way I got here may offer some insight into my viewpoints. All during the 1970s, if anyone asked, I said I was a deep-sea sedimentologist. But I began drifting coastward after my parents' Mississippi retirement home was severely damaged by Hurricane Camille in 1969. I became especially interested in the problem of shoreline retreat, otherwise known as shoreline erosion by beach-front property owners (see Figures 1 and 2).

By 1975 I was heavily into coastal affairs when Bill Neal and I began co-editing and sometimes co-authoring the *Living with the Shore Series* (for example, Pilkey and others, 1978; Ward and others, 1988).

Futhermore, I arrived in coastal geology without the usual baggage of grants from political agencies such as Sea Grant and the Corps of Engineers and without a flourishing consulting business. I could speak out and, even if branded a wild man, not damage my career.

I learned a number of things right away. One was that the public is more concerned with eroding shorelines than with deep-sea sedimentation. Another was that finding solutions to problems of eroding shorelines was largely the territory of coastal engineers. Eventually I discovered that engineers are different than scientists.

The Sand Transport System

Understanding the behavior of sand in the nearshore system is critical to understanding the impact of such coastal stabilization structures as seawalls, groins, jetties and offshore breakwaters. The sand transport system that must be understood encompasses the entire zone of seasonally moveable sand known as the shoreface. On east coast barrier islands, the shoreface typically extends several kilometers offshore to depths of 30 to 40 feet. In addition, the sand transport must be understood under a variety of energy conditions ranging from fair weather to big storms. Finally, it must be understood in a time frame of decades or less. In other words, understanding how sand moves on beaches involves understanding a system of great areal extent under a huge variety of possible oceanographic conditions, and all of this in a very short time frame.

Each of the aforementioned structures interferes with the shoreface sand transport system in some way and, before their construction or emplacement, the general public needs to have an accurate assessment of what will happen to adjacent beaches. Are the financial costs or the price in environmental damage worth it? In addition to understanding how structures (hard stabilization) interact with the sand system, an increasingly important question is: "How long will replenished beaches (soft stabilization) last?"

We currently have two views of the shoreface. On the one hand we have the world of marine scientists like Don Swift and Alan Niedoroda (Niedoroda and others, 1985) who study the sand transport system on the shoreface and find great gaps in our knowledge. Particularly, we have much to learn about storms. Most nearshore oceanographers, I am sure, would be extremely reluctant to make firm predictions of shoreface sand behavior in a time frame of a decade or less.

. . . storms should never be viewed as unusual, unexpected or as surprises.

On the other hand, the coastal engineers have developed ways to describe the coastal sand system mathematically, and, while admitting (in the technical literature) to some gaps in their understanding and the need to make certain simplifying assumptions, they are nonetheless willing to provide firm numbers and to make firm predictions (as opposed to statistical ranges) to the public regarding the behavior of sand on the shoreface.

The two groups (that is, the marine scientists and the coastal engineers) live in two different worlds, out of contact with one another. Nearshore oceanographers don't need engineers to accomplish their goals, but engineers do need nearshore oceanographers to accomplish theirs.

I once published, with my mathematician brother and one of his students, a paper purporting to mathematically model turbidity currents (Chu and others, 1980). My name appears before his in the sequence of authors, which is regrettable since I never did understand the paper. I helped Chu make some geologic assumptions which, as I think back on it, are far more shaky than the ones I criticize coastal engineers for using. However, if our mathematical model turns out to be useless, it won't damage society in the slightest. The model will die a very quiet death. On the other hand, if the Corps of Engineers or a consultant predicts that the sand will sit still on a million-dollar-per-mile replenished beach for ten years and it only lasts two (a very common occurrence), the taxpayers may have to fork over five times the original cost estimate if they want to keep the beach.

Beach Replenishment and the Sand Transport System

Nowadays, the more often preferred solution to erosion along America's barrier island shorelines is beach replenishment. Pumping in new sand is temporary and costly, but at least it improves the beach rather than degrading it, like seawalls do (see Figure 1).

Figure 1. Shoreline erosion on beachless Palm Beach, Florida. Here a combination of natural shoreline retreat and acceleration of surf zone processes caused by the seawall has taken away the beach. The community values buildings over the beaches.

Figure 2. Shoreline retreat on Hunting Island State Park, South Carolina. No buildings are threatened here, so there is no erosion problem. Nonetheless the Corps has (very unsuccessfully) replenished this state park beach four times. In each case the bulk of the sand has disappeared within one year.

My associates (Tonya Clayton and Lynn Leonard) and I have recently completed a study of the east coast barrier island beach replenishment experience (Pilkey and Clayton, 1987). Miami Beach, at $5 million per mile and having remained in place for almost a decade, is the east coast's most durable beach replenishment project so far. The least durable replenishment project was at Ocean City, New Jersey, where a 1982 $5.2 million beach lasted for 2.5 months (see Figures 2 and 3).

Our most important conclusions are: (1) the equations and parameters used to design beaches don't work, (2) predictions of beach durability are *always* wrong, and (3) nobody in the engineering community looks back to evaluate the success or failure of past projects, so no progress has been made in understanding beach replenishment.

A number of design parameters or assumptions are made when designing a beach replenishment project and predicting its life span. Some of the important assumptions often made are: (1) the coarser the grain size the more durable the beach, (2) the longer the beach the more durable, and (3) after initial slope adjustment, the erosion rate of the artificial beach will be the same as its natural predecessor. As far as we can tell from our data, these widely held "truths" aren't true on the east coast. What does seem to control beach durability, in significant part, are storm intensity and frequency,which is not at all surprising.

We have found that for the last 25 years, coastal engineers have predicted the life time (and hence the cost) of replenished beaches with unvarnished and unjustified optimism (for example, see Wilmington District, 1988). Most replenished beaches last less than five years. North of Florida, replenished beaches on barrier islands usually last only two to three years (see Figure 4). Despite this experience, a proposed replenished beach on Assateague Island, Maryland was recently given a predicted life span of 40 years. A beach replenished to protect 220 houses at Westhampton, New York was predicted to cost on the order of $100 million for 50 years, whereas we guess the bill will be five to six times that figure. The Corps of Engineers underestimated the true long-term cost of replenishing Wrightsville Beach, North Carolina (see Figures 6 and 7) by more than 600 percent, inflation corrected, and still climbing. The long-term cost of replenishing neighboring Carolina Beach was underestimated by 1,200 percent.

Sand behavior at beach replenishment projects has never been systematically monitored. Since the coastal engineers have not looked back, they are free to continue to make impossible predictions about the life span of replenished beaches and to use meaningless parameters in their design.

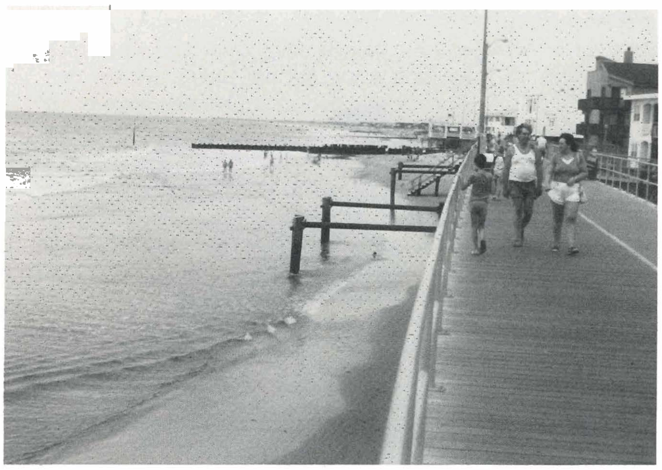

Figure 3. A scene on the Ocean City, New Jersey shore, site of one of the least successful replenishment projects. A $5 million plus beach disappeared in 1982 in 2.5 months.

Naturally I have some theories to explain this behavior of engineers. Perhaps most important is a certain ingrained need of coastal engineers to be positive or optimistic. Among consulting engineers, this comes from the very real and practical requirement to find the truth according to clients' needs and not to be pessimistic. However, most beach life span predictions are made by the Corps and, from its viewpoint, realistic predictions could lead to unfavorable cost-benefit ratios and to communities being unwilling to contribute their share of the costs. Indeed, absolutely consistent overestimates of replenished beach durability on east coast barrier islands has led to absolutely consistent misleading of the taxpayers.

A second problem is the undying faith of the engineering community in the equations which it uses to describe the behavior of sand. The instinct of a scientist is to monitor and systematically check and see if equations are working in the world outside of wave tanks and computers. Meteorologists,

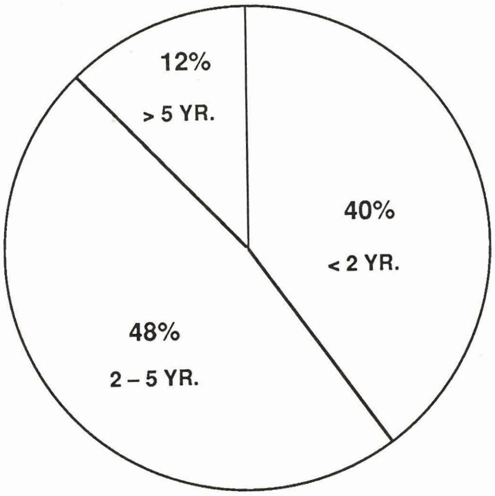

Figure 4. Pie diagram showing the beach life span on east coast barrier island replenished beaches. Beach life span is expressed as the time to lose 50 percent or more of the "artificial" sand. However, in most of the cases making up this pie diagram, beach loss was much greater than 50 percent.

Figure 5. A poor man's replenishment technique. Here a bulldozer moves sand from the low tide beach to the upper beach on Topsail Island, North Carolina. The family owning the beach cottage looks on with high hopes. The bulldozed pile of sand disappeared in the next minor storm.

for instance, seem to spend most of their waking hours worrying about how nearly correct their predictions were. Engineers who design bridges must certainly check back to see if the bridge is still standing. But coastal engineers don't seem to be impelled in that direction. Perhaps this is because of the third problem I see in preventing a realistic view of the sand system, and that is storms. Somehow storms can be used to ask forgiveness since, after all, they are acts of God! Storms that destroy replenished beaches are almost always referred to as being "unexpected" or "unusual." Needless to say, storms should *never* be viewed as unusual, unexpected or surprising. Using probabilistic measures that recognize a spectrum of risks could "solve" this problem. However, such a rational approach is unlikely to be taken soon, as illustrated by the following collection of out-of-context statements, made by coastal engineers:

. . . no systematic study of the impact of jetties on downstream beaches has ever been undertaken.

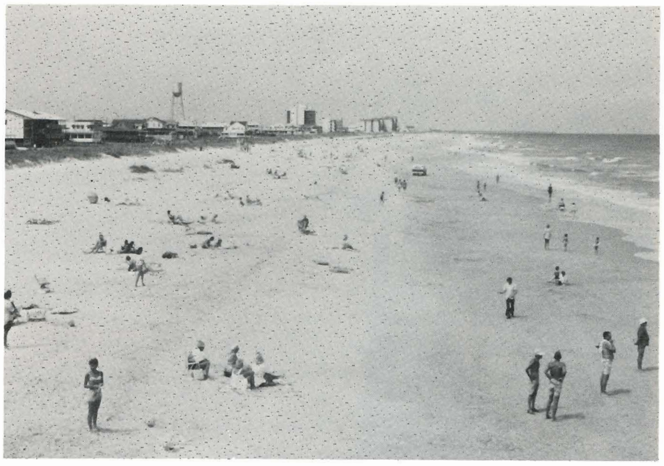

Figure 6. Wrightsville Beach, North Carolina immediately after being replenished a few years back.

1) This beach [Miami Beach] should last indefinitely providing a major storm doesn't come by. (*Time* Magazine quoting a Jacksonville District Engineer)
2) We've had some unusual weather that probably accelerated the erosion slightly but we're pleased with the way things are going right now. (*Savannah* [GA] *Evening* press quoting a Savannah District Engineer)
3) One thing we had not counted on was that a major storm would occur, just as the project [Port Mansfield, TX] was completed, so the experiment was not entirely successful. (Galveston, Texas Corps District Office)
4) Until it failed, the revetment was able to withstand all wave attack. (Michigan Sea Grant Publication)

Just in case I've given the impression that the Corps is the only villain in this piece, consider the following. In a State of Florida publication touting the need for beach replenishment, the public is treated to a graph showing that a typical replenishment project may need a small amount of extra sand every 30 years or so. On the east coast of Florida complete replacement of the original volume of sand every five to seven years or so is more realistic. The State of Maryland put out a brochure last year pushing a proposed new Ocean City beach replenishment project, proclaiming the virtue of a beautiful new beach without a whisper about the ephemeral nature of beaches and the need for continuing commitment by the taxpayers. Taxpayers were also assured that if losses of the beach occurred during winter storms, the sand would return in the spring – this despite the fact that storm recovery of artificial beaches elsewhere has been essentially nil. (While this article was being edited, most of the new Ocean City, Maryland replenished beach (completed in the Fall of 1988) disappeared in two March storms.)

The EPA may take the prize for holding storms in contempt. In a recently circulated draft of an EPA study purporting to estimate the financial burden facing the United States if we replenish our beaches during the expected rise in sea level, the assumption is made that there will be no storms.

Hard Structures and the Sand Transport System

The east coast of Florida has 18 inlets, 17 of which are jettied. Downstream or south from each of these jetties is a zone of high shoreline erosion rates, sometimes extending for many

Figure 7. Wrightsville Beach, North Carolina. A few years back immediately after the beach shown in figure 6 was lost due to storm activity. This beach has been replenished 8 times since 1965. The original cost estimate given to the United States Congress was exceeded by at least 600 percent (inflation corrected).

miles. The erosion caused by these jetties is a major problem for Florida and will be a major drain on state and federal taxpayers in the future.

Yet, as in the case of beach replenishment, no systematic study of the impact of jetties on downstream beaches has ever been undertaken. The Corps is now publishing a series of jetty case histories for all United States shorelines (for example, see Smith, 1988), but the case histories don't include analyses of the aspect of jetties that is crucial to our society, their impact on the sand transport system.

In some cases the impact on the sand transport system is extreme. For instance, the jetties at Ocean City, Maryland have prevented sand from moving to Assateague Island to the south. As a result, the island, which is a national seashore, has virtually migrated off itself in 50 years. That is, the surf zone of the northern 2 miles of Assateague Island is now where the lagoon shoreline was 50 years ago. The jetties at St. Mary's Inlet on the Georgia/Florida line have caused a minimum of 150,000,000 cubic yards of sand to be deposited in deep water offshore at the end of the jetties. This is a truly huge volume of sand in terms of known rates of nearshore sand transport, sand that would otherwise be somewhere in the shoreline system.

New jetties are being planned for several still-natural inlets on the east coast, and the public is already being assured that we have learned from our experience and that downstream erosion will be a thing of the past. The prime example of this is at Oregon Inlet, North Carolina where the Corps claims to have a firm handle on the sand transport system for the next 50 years. The absurdity of this claim is illustrated by events at Murrels Inlet, South Carolina. Here engineers predicted the wrong direction of net longshore sand transportation (a rather fundamental error) and the jetties completed in the early 1980s were designed incorrectly.

The necessary task of looking back at the success and failure of predictions made to the public and reviewing the extensive damage to American shores caused by jetties will undoubtedly be painful to the Corps and to the profession. On the other hand, eating crow leads to progress.

Conclusions

1) The claim by engineers that they can predict nearshore sand behavior is false. Quantifying sand behavior in a time frame of use to society is impossible because such behavior is in large part controlled by the irregular occurrence of storms.
2) An entirely new approach to shoreline engineering and to informing the public about shoreline behavior is called for.
3) The new engineering approach should begin with the careful study of past projects and systematic monitoring of beach behavior at all future projects. The empirical approach should be used where possible. For example, one should predict how long a replenished beach might last by looking at the history of nearby replenished beaches.
4) Future interaction with the public should involve noting how limited our understanding is when it comes to predicting shoreline behavior. Estimates of such behavior and, hence, the costs of projects must be presented with error bars. For example, "this replenished beach may last three years plus or minus two years and the cost of keeping a beach in place for five years could range from $1 million to $5 million."
5) When it comes to understanding the sand transport system, we geologists serve the public better than engineers. We can't predict sand behavior any better than they can, but because we can view the system beyond the impermeable shield of mathematics, we understand how ignorant we are. Engineers and geologists should work together. Engineers can tell the public about stone and steel structures and geologists can tell the public about sand.
6) Geologists must play a larger role in the engineering of sand. But the reality of the situation was illustrated to me by Delaware consultant Evelyn Maurmeyer who tells this symbolic tale. If a community asks an engineer for a long-term solution to its shoreline erosion problem, it will have the solution in a jiffy. If a community asks a geologist for a long-term solution it is likely to be told that there is none. So why hire a geologist?

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