Coastal Defense and Beach Renovation

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ABSTRACT

Coastal erosion is a worldwide occurrence principally along sea shores but also along many lake shorelines. It has been reported in the literature for several decades. It encompasses considerable economic consequences, endangering, for instance, valuable properties. The rise in water level is a major cause of the phenomenon, but anthropic actions have also played an important part.

Traditionally, eroding coastlines have been protected by civil engineering structures ranging from groins to seawalls. This approach, while providing local relief, has proven to generally transfer the problem from one geographical site to another. Replenishment of a depleted area by artificial nourishment, sometimes buttressed by some hard structures, has been tested and shown to help in rebuilding beaches and countering shore erosion. The largest such undertaking anywhere in the world has been carried out on the Belgian east coast. The successful results have led to a similar project on the west coast. This paper reviews various ‘hard’ defense approaches and describes beach nourishment at certain sites where it has been tried.

1 COASTAL EROSION

‘The more construction, the more erosion’ is the comment of longtime residents and vacationers alike on the Outer Banks of North Carolina.

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Yet, today, many have their house or cottage moved so they can sell (at considerable profit) their site, on which a high rise or a condominium will take its place. The statement is basically true, but construction is not the original cause of erosion: nature is.

The term coastal erosion applies to the shoreline proper and to a strip of sea-floor immediately bordering on the coast. The most 'visible' manifestation is coastline recession, a phenomenon which is our primary concern here. Cliff erosion in hard rocks is less obvious than erosion of unconsolidated beaches. Coastal erosion—and accretion—is subject to significant changes.

1.1 The causes of erosion

Erosion is a natural phenomenon. It is progressing relentlessly and cannot be stopped. Man can at best retard its progress or displace geographically its effects. Man can also, and with increasing frequency, hasten, and worsen, its progress.

Storms and hurricanes are not the only causes of erosion: landslides may cause retreat of a shoreline, chemical solution will gnaw at it, so will subsidence phenomena; but currently a major force, besides wave attack, causing the landward migration of the coastline is the worldwide rise of the sea-level. Other factors responsible for erosion are winds, tides, subaerial processes, the petrological nature of the coast, climatic, chemical, mechanical, and biological agents. The classical examples of coastal erosion by landsliding are provided by the slopes of Vesuvius and the Rissa event in Norway. However, such coastal landslides can be due to man's interference. Removal of groundwater and of lateral support by erosion may cause repeated damage, e.g. as happened to beach line property in Seal Cove, California. The coast of Bulgaria, north of Varna, is another example of erosion due to landslide activity. However, material that slides into the sea may then act as temporary natural breakwaters.

The overall rate of limestone erosion has been estimated at 1 mm/year; however, in tropical and subtropical areas, this figure is probably much higher due, partly, to the forms created; and for erosional reefs, a figure of 10 mm/year has been advanced even if waves are not particularly strong. Subtidal notches of 5 m (horizontal) were measured by Neuman in Harrington Sound, Bermuda.¹² This type of subtidal erosion is enhanced by biological agents such as borers (e.g. worms, pelecypods and sponges) and browsers (e.g. echinoids). Boring can cause an erosion rate up to 14 mm/year, and browsing of up to 6 mm/year.

Fairbridge³ has estimated that in 1500–2000 years, the general sea
level rise was about 2 m or 1.2 mm/year, but between 1946 and 1956 that average was 5.5 mm/year for the Florida East coast. Depending on geomorphology and offshore profile steepness, coastline retreat is from 0.3–1 m/year in that region.

The effects of natural forces are compounded by man’s actions. The construction of groins, seawalls, breakwaters and similar hard defensive structures will commonly result in transposition of the erosion problem downdrift. Sewers, pipelines and cables often induce local scour. Construction of buildings too close to the beach or on top of dune crests pose beach and dune maintenance problems, while dune bulldozing, a common practice, engenders disastrous results. Harbor structures, for instance in Seal Cove, California, by causing erosion through their impact on the shoreline adjacent to them, are contributors to slope failure. Mining of sand and gravel is not uncommonly carried out too close to the shore, removing a beach’s nourishment source. The phenomenon has been reported for Israel and Lebanon a decade ago, and in 1987 was confirmed for Long Island, New York, USA. Studies conducted at the University of North Carolina have revealed an accelerated deterioration of salt marshes along the coast of South Carolina. Here, the marshes already threatened by a relative sea level rise that averages 1.9 mm/year over the last forty years, are placed in additional jeopardy by sand removal for beach nourishment on the nearby developed barrier islands.

Recreational use of the shore area itself has nefarious effects, and includes repeated tramplings of dune vegetation, camping, sand removal and dune buggy rides. But man’s actions at even considerable distance from a specific site may be additional causes for rapid erosion. Beaches along the Gulf of Benin have been depleted because of an important barrage built on the Niger River. Indeed, river damming and construction of hard structures—piers, harbor jetties, and so on—along river banks, lead to sediment starvation and as a corollary to an impoverishment in coastal sand supplies. Existing coastline structures are thus imperiled. It is desirable that regulations be enacted governing any further building, by imposing a set-back line for development proportional to the anticipated life of proposed ‘hard’ structures. On the North Carolina coast, this is thirty times the annual rate of erosion.

The International Geographical Union’s Commission on Coastal Changes examined, in the period 1972–1984, the world’s coasts, and produced evidence of the important local effects of structural works and coastal land reclamation (e.g. polderization) on sea levels, and warned of the indirect effects of the climatic changes resulting from increasing pollution and modifications in the global atmosphere.
1.2 Geographical extension

It has often been written that coastal erosion occurs worldwide. This is geographically true in as much that it occurs on all continents (Table 1); but the statement is misleading because in some areas there is accretion resulting in other kinds of problems. This paper considers only erosion. Erosion affects both rocky coasts and unconsolidated shorelines (whether sandy or muddy). Erosion is not limited to sea shores but affects the shorelines of lakes as well.

The extent varies widely from one place to another: while one site in France suffered 26 m retreat in a single year, 16% of the country's Atlantic shores move landward only 1 m or slightly more/year.11-15 Belgium's east coast beaches were totally submerged at high tide until counter-measures were taken.16,17 The Holderness Coast (Yorkshire, England) has retreated 1·6 m per hundred years for the last 2000 years.18 Coastal wetlands along the Atlantic and Gulf of Mexico coasts of the United States are being lost by shoreline recession and drowning, a retreat averaging 0·3 m per year, but substantially more important in some locations.18 Migration of a tidal channel has caused a landward retreat of 30 m in a single year at Cape Shoalwater, Washington.18 On Roanoke Island, close to the border between Virginia and North Carolina, the beach retreated as much as 850 m since the 16th century, and lost as much as 100 m over the last 28 years.19 The lighthouse of Cape Hatteras (2000 tons and 63·4 m high—a US landmark) was built in 1870 and sited 800 m from the shoreline; today it is 48·8 m from the shoreline, and is likely to topple if struck by a severe hurricane.

'Hard' solutions to the problem, such as groins, sand bags, revetments have been used as temporary measures; so have 'soft' remedies: artificial dunes, beach nourishment, seagrass plantations. A seawall has now been suggested, but the cost of such a structure and its upkeep are high. Half-hearted artificial nourishment will not be very effective. The chosen remedy is to be movement of the lighthouse approx. 152 m inland at a cost of US $4·6 million, and then during the 21st century probably to repeat the manoeuvre for another US $1·6 million (estimated cost in 1987), because coastal erosion is sure to continue. Houses on the northern shores of Long Island, New York, worth $100 000, in 1956 were sold for $5000–10 000 in 1958 because they were doomed to fall into the sea; on North Carolina's Outer Banks houses are currently (1988) sliding into the sea, and $250 000 properties find no buyer at $165 000. East of Ponce, on Puerto Rico, the coast comprises beaches, mangrove swamps, alluvial plains and rip rap positioned by man, but is eroding on 50% of its length.
### TABLE 1
Selected Examples of Coastline Recession (in m/year)

<table>
<thead>
<tr>
<th>Location</th>
<th>Rate (m/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMERICA</strong></td>
<td></td>
</tr>
<tr>
<td>Washington (State)</td>
<td>35.0</td>
</tr>
<tr>
<td>California Coast</td>
<td>0.15–0.6</td>
</tr>
<tr>
<td>Bolinas, CA</td>
<td>9.1</td>
</tr>
<tr>
<td>Monterey Bay, CA</td>
<td>1.5–4.5</td>
</tr>
<tr>
<td>Cape Shoalwater</td>
<td>30</td>
</tr>
<tr>
<td>North Carolina</td>
<td>0.5</td>
</tr>
<tr>
<td>Barrier Islands</td>
<td>18.2</td>
</tr>
<tr>
<td>South Carolina (rocky coast)</td>
<td>0–0.6</td>
</tr>
<tr>
<td>Morris Island Light (400 m over 20 yr)</td>
<td>20</td>
</tr>
<tr>
<td>South Carolina (extreme south)</td>
<td>0.15</td>
</tr>
<tr>
<td>Padre Island, Texas (some sites)</td>
<td>2.0</td>
</tr>
<tr>
<td>Chambers County, Texas</td>
<td>2.7</td>
</tr>
<tr>
<td>Westhampton Beach, NY</td>
<td>1.0</td>
</tr>
<tr>
<td>State of Louisiana (loss 777 km² in 17 yr)</td>
<td>2.4</td>
</tr>
<tr>
<td>Boca Grande Pass, Gulf Coast, (loss 153 km² million m³ in yr)</td>
<td>0.5–2.0</td>
</tr>
<tr>
<td>Barbados, West Coast</td>
<td></td>
</tr>
<tr>
<td><strong>EUROPE</strong></td>
<td></td>
</tr>
<tr>
<td>Scania, Sweden</td>
<td>0.3</td>
</tr>
<tr>
<td>Finnish Gulf, southern part</td>
<td>1.7</td>
</tr>
<tr>
<td>Poland</td>
<td>0.6–1.0</td>
</tr>
<tr>
<td>Federal Rep. Germany (Baltic coast)</td>
<td>0.5</td>
</tr>
<tr>
<td>Holderness, Yorkshire, UK</td>
<td>2.0</td>
</tr>
<tr>
<td>Selsey Bill, Sussex, UK</td>
<td>5.8</td>
</tr>
<tr>
<td>Pointe de Grave, France</td>
<td>17.0–19.5</td>
</tr>
<tr>
<td>Albania (local)</td>
<td>0.1–0.3</td>
</tr>
<tr>
<td>North of Cape Sabla (some sites)</td>
<td>8.0</td>
</tr>
<tr>
<td>Southern Bulgaria (maximum)</td>
<td>15.0</td>
</tr>
<tr>
<td>Northern Black Sea, USSR</td>
<td>0.33</td>
</tr>
<tr>
<td>Azov Sea, USSR</td>
<td>0.2–6.5</td>
</tr>
<tr>
<td>Gulf of Mezen, USSR</td>
<td>4.0</td>
</tr>
<tr>
<td>Yamal Peninsula, USSR</td>
<td>5.0–10.0</td>
</tr>
<tr>
<td>New Siberian Island Archipelago, USSR</td>
<td>15.0–50.0</td>
</tr>
<tr>
<td><strong>NEAR EAST</strong></td>
<td></td>
</tr>
<tr>
<td>Israel (Kurkar cliffs)</td>
<td>0.03–0.04</td>
</tr>
<tr>
<td>Nile River estuary (Rosetta mouth)</td>
<td>35.0</td>
</tr>
<tr>
<td>Ras-el-Bar (Egypt)</td>
<td>31.0</td>
</tr>
<tr>
<td><strong>AFRICA</strong></td>
<td></td>
</tr>
<tr>
<td>Cap of Naze, Senegal</td>
<td>0.22</td>
</tr>
<tr>
<td>Lagos to Kweme, Nigeria</td>
<td>5.0</td>
</tr>
<tr>
<td>Victoria Beach, Nigeria</td>
<td>35.0</td>
</tr>
<tr>
<td><strong>ASIA</strong></td>
<td></td>
</tr>
<tr>
<td>Kerala, India</td>
<td>6.0</td>
</tr>
<tr>
<td>South of Allepey, India</td>
<td>8.3</td>
</tr>
<tr>
<td>North of Sheyang River, China</td>
<td>150.0–200.0</td>
</tr>
<tr>
<td>Shizuoka Prefecture, Japan</td>
<td>8.0</td>
</tr>
</tbody>
</table>
On the northern coast of Kerala, India, two opposing effects result in net beach depletion: the southerly ocean current dominates the erosion process and its action is not compensated by the depositional travail of the northerly current. On Aruba in the Netherlands Antilles, erosional processes are a topic of concern for tourism authorities. Here, in the breaker zone, there is longshore sand transport westwards during wind wave conditions and eastwards during occasional swell wave events; over the long term, this results in a net westerly sand movement, but in the short term the transport occurs eastwards, resulting in a severe beach erosion during swell events. Restoration is slower than erosion, resulting in a net beach loss.

1.3 Monitoring the beach

Protection of recreational areas is by no means the only, perhaps not even the major, incentive for beach protection and eventual restoration efforts. Billions of dollars are at stake in property, industry and commercial undertakings. While the natural processes cannot be stopped—erosion rates may increase by 200–500% over the current rate in the next hundred years—measures can and are being taken to slow them down, minimize locally their effects and to closely monitor their progress.

Monitoring the beach and keeping a watch on erosion requires continuous surveying. Beach topographic profiles must be taken at regular intervals, and on a time scale significantly less than a year. If protective structures have been built, their maintenance must be assured, which includes regular inspection and profile-taking in their vicinity. An erosion study involves taking profiles ‘cross-island’ or up to a point beyond the dune barrier, whichever the case may be, together with nearshore profiles and sediments samples. Aerial photography may be called upon for beach monitoring but is of limited use because cameras cannot penetrate at a sufficient depth beneath the water surface, and some depth changes escape attention. However, use of satellites for beach monitoring has opened excellent possibilities. Coastal erosion, which is quite severe in the area of the Rosetta mouth of the Nile and the Ras-el-Bar, Egypt, has been revealed from Apollo-Soyuz photographs. A recent study conducted by the University of Sheffield, UK, used an airborne multispectral scanner to gather data to assess erosion and sediment transport. The spectral radiance \( L \) recorded a positive correlation with the suspended sediment concentration \( (SSC) \) at 95% confidence level. However, a far too high error level was found for the inverted relationship for the estimation of SCC. Adjustments must thus be made for this method.
Coastal defense and beach renovation

The United States Army Corps of Engineers has also put into use a coastal research amphibious buggy—acronym CRAB—which resembles a very long-legged go-cart. Not only can it operate easily in the surf zone, it can also be used in water up to some ten meters. The device measures erosion or accretion of the offshore seabed. A laser beam shot from the shore bounces off a prism on the CRAB’s platform, accurately gauging up-and-down movement.

2 DEFENSE AND RESTORATION

Halting coastal erosion and shoreline retreat is considered impossible. Reducing the rate of erosion and restoring endangered areas, on the other hand, falls within the reach of coastal engineers. Various approaches have been tried, with unequal success and, occasionally, with undesired if not unexpected consequences.

The traditional approach has been to construct hard coastal defense structures such as groins, breakwaters, seawalls, revetments, tetrapods, and the like. Often they have been destroyed, all require maintenance, while many have merely displaced the problem from one site to the other. In more recent years another approach, either used solely, or in conjunction with the conventional measures, has been tried: artificial beach nourishment. The ‘soft’ approach is not new, since records mention beach nourishment immediately after the end of World War I near Santa Barbara, California. However, techniques have been refined and source material varies more in origin. The US Army Corps of Engineers has used dredgings in beach restoration works. Artificial beach rebuilding has, in some instances, even extended to beach creation, as has been the case, for instance at Monte Carlo, Monaco, and at sites in Turkey.

Unconsolidated beaches result from a building process linked to accumulation processes and appear as sandy beaches (less than one third of world beaches) or muddy beaches (either colonized by mangroves or in other sheltered environments). The principal types are dunal systems, estuarine environments, littoral spits, lagoons and ponds. Currently, the majority of beaches, due to natural and/or anthropic action, are thinning or retreating. On the French Atlantic coast, some 850 km of shoreline lose about a meter each year, while worldwide sea-level increases on average between 12 and 15 cm/year.

On the Lower Médoc coast of France, the persistence and amplitude of coastal erosion demands decisive action, on a scale higher than for the other affected sectors of the Aquitaine littoral. For example, a retreat of 250 m has been recorded at Les Arros over the last 150
years, while south of Soulac 3.3 m per year are lost on average. Occasionally, in a single month, the dune’s foot moves inland by 35 m (e.g. north of Amélie).

In Italy, massive settlement of coastal regions, added to touristic and industrial use, enlargement of harbors, construction of coastal defenses, pumping of underground water and reclamation works have accelerated natural subsidence. Inland modifications for a variety of purposes have compounded the ensuing problem for Italian beaches. According to a report of the Commissione di Studio Sistemazione Idraulica e Difesa del Sudo of 1970–74, only rare stretches of the Italian coasts are still subject to natural conditions.

Demand for ocean-side space does not originate only with holiday-makers and tourists; equal pressures arise from energy and manufacturing industries, commercial enterprises, and from the traditional vocations of agriculture, animal husbandry and fisheries.

Little attention, however, has been paid in the planning process to possible negative consequences on beach evolution and marine erosion. Construction of dams on rivers, harbor extensions, or reclamation for industrial purposes and marinas, led to extensive dredging of access channels, particularly in estuaries, and/or scale retrieval of bottom material for construction works, with the concomitant risk of important reductions in bed-load material, material thus withdrawn from a possible natural sand supply for beach nourishment. Hence, because beaches and other unconsolidated littorals are in constant evolution, continuing surveillance and impact studies prior to any artificial modification of the shoreline are required.

In recent years, artificial beach nourishment has been called upon as a coast protection method. Such an approach has been followed in Belgium, as shown by the beach replenishment project at Knokke–Heist, near the Dutch border. A beach renourishment project involving sluicing of about 8.4 million m³ of sand was executed along the eastern part of the Belgian coast between Zeebrugge and the Dutch border. Further nourishment schemes will be undertaken on the west coast (Nieuwpoort vicinity) in the near future. Completed in 1979, the east coast works covered a stretch of 8 km, which meant a supply of rather more than 1000 m³ of sand per running meter of shoreline. The beach itself was widened by about 100 m; and in some places the construction of an entirely new beach was required.

A few kilometers to the west, extensive works had already been undertaken to greatly expand the harbor of Zeebrugge. The neighboring resort of Heist had no ‘beach’ left at high tide; while just along the coast, the so-called beaches of Duinbergen and Albert-Strand were
actually remnants of the dune barrier. Knokke-Zoute itself had only a few meters of dry beach left at high tide. Heavy storms were carrying the meager supply of sand seaward. Once completed, beach renourishment required a comprehensive survey program to observe the beaches’ further evolution, to ascertain the accuracy of the study prognosis, and to enable any new measures to be initiated in good time. At present, survey data covering several years are available. A follow-up study has also been carried out for Balaena Beach in New Zealand. Dune losses may be reduced by plantations and brushwood fences. Low cliffs may be walled, high cliffs toes walled or rip rap placed in front of them.

3 ‘HARD’ COASTAL DEFENSE WORKS

Common ‘hard’ defenses are groins (usually set perpendicular to the coast), detached breakwaters (built parallel to the coast and sometimes submerged), and seawalls. Each of these protective structures has a specific function.

3.1 Structures

3.1.1 Groins

Groins (groynes), short, squat structures, jutting out to sea, are built to reduce the longshore sediment transport in a certain beach area and capture passing sand. If not well designed (length, height) they can cause severe erosion on their leeside, perhaps extending over several kilometers along the coastline. The latter, in turn, bring about the need for an extension of the defense system over more and more coastline (e.g. Belgium, Holland). Sand trapped by groins may be severely missed downdrift, and the latter areas continue to be stripped of their sand. A wider beach is built just above the groin, but no further.

Assuming that a longshore current moves from east to west, groins are to be built first at the far western end of the shore to be protected. The field can then be gradually extended eastward. Additionally, an appropriate quantity of sand must be placed on the eastern side of each groin—a technique called backfilling, which ensures a continued westward flow of sediment.

To counter recession of weak outcrop cliffs, it is often proposed that a broad beach should be built and maintained, through the construction of groins that intercept longshore drift, and supplemented by beach
nourishment on the foreshore or updrift. However, when such groins intercept longshore drift, erosion may become accentuated because sediment is withheld from the downdrift area, as has happened in the Newhaven area of southern England.\textsuperscript{18}

3.1.2 Jetties
Jetties are more massive than groins. Their principal function is to redirect tidal flow to either protect a beach or a navigation channel. However, construction of jetties results in groin-like effects by redirecting littoral drift. They are occasionally used to cause sediment bypassing. Bypassing consists of dredging sand from behind the updrift jetty and conveying it via pipeline to behind the downdrift jetty.

3.1.3 Breakwaters
Detached breakwaters (parallel to the coast) are offshore barriers intended to reduce wave action on the existing coastline. They absorb wave energy before waves reach the shore. This effect will not only reduce onshore-offshore sediment transport (especially during storm conditions) but will, in certain circumstances, reduce littoral drift and create tombolos due to wave diffraction effects (cf. the Mediterranean coast of Italy). However, in regions with significant tidal ranges, such as parts of the North Sea, these structures would normally have their crest at mean or low water level. Under severe storm conditions (extreme high water levels) the water above the crest will no longer abate incoming waves, which will keep on attacking and eroding the beach area. Furthermore, wave attack on the structure can be considered.

3.1.4 Seawalls
Seawalls are built to prevent the coastline from further regression. Revetments and bulkheads play the same role. Revetments are similar, for a sloping coast, to seawalls, while bulkheads are used to prevent backshore property from sliding into the surf zone, as happened, for instance, on Long Island, New York. Revetments are layers or blankets of strong, non-erodable material placed on the shore. Stone revetments have been used, for instance, at John's Pass, Treasure Island (Florida). On eroding beaches with predominant longshore transport, such defenses will not alter the longshore transport and beach erosion in front of the seawall will continue. The latter increases wave attack on the seawall, and also offshore sediment transport. As a consequence, the stability of the structure is undermined and it may fall over, a not exceptional occurrence. The beach may even disappear as wave energy is reflected seaward instead of being spent across the beach. Sand,
when disturbed, may be carried seawards or alongshore, but away from the wall-protected area.

3.1.5 Gabions and mattresses
Attempts have been made to counteract beach erosion, or to encourage accretion, by using flexible concrete mattresses, or by synthetic seaweed grids, for example in the Netherlands.

Gabions afford a similar approach. They are rectangular-shaped metallic cages filled with stones; spread out one gabion type resembles a mattress, usually half a meter high and as long as 8 m, and usually with mesh from 8–12 cm. The mattress is laid upon a slope of appropriate gradient. However, the fill materials must be present in situ, and one has to cope with corrosion of the metal.

3.1.6 Artificial reefs
The idea has been advanced to use artificial reefs as ‘natural breakwaters’, using both living and non-living material.

3.2 Environmental aspects

Groins and breakwaters will only affect the wave regime and sediment transport in the immediate area. They do not provide solutions for the adjacent coastal area where the sediment transport capacities are unchanged. To the contrary, they may cause a spectacular increase in sediment transport on the lee-side of the structure, causing renewed coastal erosion. In that case, the problem has merely shifted from one area to another.

If recreational aspects are important, any coastal structure (e.g. groin) on the beach should be avoided. Furthermore, considerable sums of money have to be repeatedly spent on maintenance and repair due to storm damage to the structures.

Reefs made of non-living material have been tested. Though manufacturers claim successful results, they are put in doubt by numerous researches, including studies conducted by the US Army Corps of Engineers. Florida University has carried out a survey of beach nourishment efforts, since 1985; it covers history, theory and results of artificial seaweed reefs implantation.

4 BEACH NOURISHMENT AS COASTAL PROTECTION

More appropriate coastal protection solutions are perhaps provided by a durable defense system and modifying the beach material itself.
Beach nourishment has been considered a potentially desirable form of shore protection. It is beneficial as wave action spreads the material along the shoreline and reproduces more closely the natural processes.

Potential material supplies must be examined vertically and horizontally, and cores taken several meters below the bottom. Such cores, compared with seismic data, will provide information about the sediment characterization in each layer and the extent of the layers.

Sediment selected for beach nourishment must be at least as coarse texturally as the original beach material. Somewhat coarser and better sorted sand than the beach material is preferable. The source area must be so selected that no significant deepening of the nearshore zone occurs, otherwise wave energy may be intensified and initiate or accelerate coastal erosion.\(^{39,40}\) When dredging material for beach nourishment, care must be taken to select appropriate depths so as to avoid any beach damage. Beach damage has been reported in several geographical areas as a result of dredging for building material too close to the coast.

Close to one hundred sites in the United States have been the beneficiaries of Federal Government beach rebuilding projects using dredged material. It has been shown that such use of dredged material has the least environmental impact. Projects were carried out, among others, at Jacksonville Harbor, Sea Girt (New York), Channel Islands Harbor (California), Ediz Hook (Washington), Miami Beach (Florida) and Wrightsville Beach (North Carolina). In all these projects, coastal defense was combined with the recreational aims to be attained.

Many projects combine sand supply with construction of hard defense structures. This was done in Monaco, Israel and Singapore and is a commonly recognized approach, especially where suitable material is available locally.

However, in some cases, as for instance in Belgium, depending on the predominant wave direction governing the littoral drift, simple sand addition alone can provide adequate coastal protection. In Westhampton, New York, when sand feeding was stopped but more groins added, storms stripped the sand beyond the groin-field in the downdrift direction.

By adding new sand to a beach, but not to the adjacent nearshore zone, the beach slope will be out of equilibrium with the underwater profile, so steepening the shoreface profile. Waves during storms remove sand, flatten the profile and the 'shoreline' again migrates landwards. This must be carefully considered when undertaking an artificial accretion project.

Material to be used, carefully selected with regard to its nature and
source site, may be brought to the beach area in question and dumped offshore, leaving it to the sea to carry it to the shore and ensuring its geographical distribution. It may also be deposited at a single location on the beach (called stockpiling), so allowing the artificial supply point to act as a distribution center or feeder beach. Still another approach is to directly spread the material on the endangered beach, restore it *stande pede* and simultaneously adopt appropriate 'soft' measures to protect it. Finally, the continuous supply method involves the creation of a fixed or semi-fixed plant, which first intercepts and then passes on the littoral drift to the down-drift side.

4.1 Completed projects

4.1.1 Knokke–Heist, Belgium
Offshore transport of beach material resulted in near total beach submergence at high tide east of Zeebrugge. The Appelzak Channel gradually extended itself to within 500 m of the harbor seawall, leading to beach erosion; while the seawall, itself threatened by storm waves, hampered sand transport to, and accretion on the beach. Though the dune area expanded during the 1980s, the fore- and backshore zones lost ground due to deflection of longshore currents (Duinbergen, Knokke–Zoute) and sand withdrawal (Heist). Beach regression due to the effects of tidal currents affected by the new Zeebrugge harbor is to be expected.

In the case of Knokke–Heist, predicted sand losses and coastline regressions were compared with solutions in which sand supply and groin building were considered. Total capital and maintenance costs of beach nourishment, with or without groin construction, were not significantly different. This, and the fact that beach restoration was at the time a necessity, led to the choice of beach renourishment as a coastal protection measure. The entire project was accompanied by a well-defined coastal observation program which is still ongoing. This allows monitoring of any coastal changes due to the harbor extension works at Zeebrugge.

A detailed description of the project has been presented, and the recent beach evolution has been the subject of several reports.

4.1.2 Bournemouth, UK
At Bournemouth, in Dorset, the construction of a seawall cut off the sand supply from neighboring cliffs. Beach nourishment was decided upon to remedy the situation.
4.1.3 Dungeness, UK
At Dungeness, in Kent, beach material is dredged in areas of surplus and spread where the beach is eroding, thereby balancing the sediment-budget.19

4.1.4 Sylt and Langeoog, FRG
The projects at Sylt and Langeoog considered construction of a sand spit (refraction groin) as adequate coastal protection. Under wave action, the sand groin moves shoreward feeding the adjacent beach. The orientation of the sand groin has to correspond with predominant wave direction.42,43

4.1.5 France
In the Huttes area of the Médoc, a groin built in 1854 was rapidly broken up and carried out to sea. With an average retreat of the beach of 10 m/yr, the beach is artificially renourished and reprofiled each year. One of the earliest beach renourishment schemes was undertaken near Cannes (France), on the fashionable La Croisette Beach, where 100 000 m³ were placed on the beach during 1961–62.15

4.1.6 Scheveningen, Netherlands
Westerly gales reduced the width of Scheveningen’s (Netherlands) most celebrated beach, to the extent that at high tide and under bad weather conditions, the sea washed over and against the boulevard. Beach widening became a necessity, for both economic and safety reasons. Sand is derived 20 km inland. The operating ship berths near the pontoon whereupon a short pipeline ends. This pipeline is connected to the ship; sand is pumped from pontoon to beach. At Goeree, in 1971, beach nourishment works involved 600 000 m³.11,13,19

4.1.7 Australia
Restoration of the Melbourne coast beaches was carried out by piping sand onshore from the floor of Port Phillip Bay. On Australia’s Queensland Gold Coast, south of Brisbane, beach nourishment was used to reconstruct beaches.44

4.1.8 Rio de Janeiro
The famed Copacabana Beach has been subject to erosion for some time. Artificial nourishment was decided upon after studies carried out on a physical model that took into account the characteristics of wind, waves, tides and sand, and surveyed bathymetric conditions.45 A mixed approach was decided upon: 2 million m³ of sand were dumped offshore
while another 1.5 million m$^3$ was deposited on Copacabana Beach itself over a distance of 4.2 km. This allowed the beach to be widened from its remaining 55 m to about 140 m.

4.2 Projects under study

4.2.1 India
Some fifteen years ago, beach nourishment was recommended for a 300 km stretch of the severely eroding southwest coast of India, when a short segment was restored at Purakkad. 20

4.2.2 Lazio Coast, Italy
A feasibility study for coastal protection works on the Lazio Coast showed that beach nourishment could be considered as an effective and apparently preferable alternative to the traditional building of detached breakwaters. 46 Appropriate sand qualities are required to contribute to predominant longshore transport. A future maintenance program for the beach, based on a 5-year cycle, has been proposed.

4.2.3 Ostend, Belgium
The following requirements were considered for the Ostend project: reduction of wave overtopping of the existing seawall (flood prevention); prevention of increased sedimentation in the existing port access channel, as a result of the coastal defense works; future recreational beach activities to be taken account of; and limitation of the project within the existing groin structure extension.

As sand addition alone would not effectively contribute to the above-mentioned requirements, the mixed use of sand and gravel is envisioned. This approach allows maximal regard to the transversal coastal dynamics, without any 'hard' defense structure. The gravel layer thickness, the equilibrium profile and the overtopping frequencies of the seawall were tested in a wave flume. In a further layout, wave attack and deformation of the gravel core were successfully tested in a wave tank at the Hydraulic Research Laboratory of the Belgian Ministry of Public Works at Borgerhout, Antwerp. The mixed gravel-sand option apparently provides a feasible and dynamically stable coastal protection.

4.2.4 West Coast, Belgium
The largest beaches are located west of Ostend, in the direction of the French border; heretofore they have not been affected by erosion. Recently, however, some concern has been voiced about the area
between Coxyde (Koksijde) and Nieuport (Nieuwpoort). It has been decided to provide nourishment to the area.

5 ‘LAISSEZ-FAIRE’

For many years, the US Government has intervened and helped maintain and restore beaches. This policy has come to a virtual halt and is now replaced by the policy of allowing nature to take its course. It will no longer compensate owners for lost or damaged property through ‘Federal insurance’. Retreat of the ‘property line’ has been advocated, and in some instances, e.g. in North Carolina, regulated. Such an approach is not possible everywhere, and in some areas economic realities compel protection and restoration.

6 CONCLUSIONS

Shoreline retreat cannot be stopped but it can be slowed, and loss of beach material can be compensated. The phenomenon is nearly universal, due to natural causes, but compounded by man’s intervention and the desire to use the coastal zone to its fullest extent. The economic consequences of coastal erosion are considerable. In some areas, property retreat has been advocated, regardless of the loss. Make-shift breakwaters have been installed by private owners at many sites, particularly along the East Coast of the United States. These artisanal structures imitate the usual practice of placing ‘hard’ structures along eroding shorelines.

Hard defenses are either perpendicular or parallel to the coastline, although some structures have been placed at an angle, or in a zig-zag pattern. The cost of maintenance of breakwaters, jetties, seawalls, groins, etc. is often high; such structures are even occasionally severely damaged, even destroyed, during heavy storms. Moreover, in most cases, while a stretch of beach is indeed protected from erosion, the adjoining down-drift segment suffers from increased erosion as it is starved of material.

While, in some instances, a mixed hard-and-soft approach appears adequate or even necessary, artificial sand nourishment offers an alternative which conforms closer to natural processes. It has been tried for many decades on a small scale. Newer technologies have lowered the relative cost involved. Some agencies find it a useful and acceptable way to dispose of harmless waste for this purpose. Many modest
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projects have been implemented since the end of World War II, in Europe and in North and South America. Loss of deposited materials, according to follow-up observations, is commonly slight, so that maintenance is economically bearable. One of the largest beach nourishment schemes, at least as far as volume of material deposited is concerned, has been completed in Belgium, simultaneously with the construction of a new harbor at Zeebrugge. The results are satisfactory, and similar works are underway for another segment of the coastline. Furthermore, the new situation has contributed to the gradual disappearance of a gully to which material removed from the beach was carried.

This ‘soft medicine’, which is designed to restore ailing beaches, should be considered as an advisable solution for endangered beaches where economic considerations call for their protection and restoration.

REFERENCES


32. Carter, L. & Mitchel, J. S., Stability of an artificial nourished beach,


