Panorama of the History of Coastal Protection

Authors: Charlier, Roger H., Chaineux, Marie Claire P., and Morcos, Selim

Source: Journal of Coastal Research, 2005(211) : 79-111

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/03561.1

Journal of Coastal Research	21	1	79–111	West Palm Beach, Florida	January 2005

Panorama of the History of Coastal Protection

Roger H. Charlier†, Marie Claire P. Chaineux‡, and Selim Morcos§

†Free University of Brussels [VUB], Belgium
Institute for Development and Research of the Coastal Zone (Brussels-Chicago)
roger.charlier@pop.kpn.be

‡Catholic University of Mons [FUCAM] (Belgium)
Currently Institut Ste Marie, Brussels (Belgium)

§University of Alexandria, Egypt
UNESCO, Paris

ABSTRACT

CHARLIER, R.H.; CHAINEUX, M.C.P.; and MORCOS, S., 2005. Panorama of the history of coastal protection. *Journal of Coastal Research,* 21(1), 79–111. West Palm Beach (Florida), ISSN 0749-0208.

Changes of sea-level, retreat of shorelines have occurred throughout geological times. They have taken a special significance since Man has appeared. Man has been simultaneously awed by the sea and attracted by its shores. He has consistently attempted to protect his settlements against the onslaughts of the sea. Coastal defenses can be traced back to remote times. It is probable that dams or walls were erected before the Frisians did, but their "defenses" were described by Pliny, and, *jusqu'à preuve du contraire,* are considered as the first "dike builders".

Earthen artificial hillocks are the forerunners of stone constructions built to hold back the advances of the sea, particularly when sizeable areas of land were gobbled up by the waters along coasts, but also in estuaries, witness i.e. the Dutch *Verdronken Land van Saeftingen.* The groins, seawalls, breakwaters and the like proved to be illusory shields, to solve little, but to create new problems.

Engineers and scientists tried different approaches, inspired by Nature's own ways, nourishment for instance. Other methods are being honed. They must as well consider the economic and social impacts of coastal erosion. The paper follows the historical evolution of man's attempts to retain his "land".

ADDITIONAL INDEX WORDS: *Hard structures, beach nourishment, feeder-berm, alternate and composite approaches, breakwaters, levees, dykes, groins, etymology, various countries.*

INTRODUCTION

Construction of coastal defenses can be traced back to remote times; in fact, attempts seem to have been made as soon as sedentary men settled along coasts. The oceanic domain bordering a coast has been eyed, for centuries, by particularly the Dutch as territory to be recovered, dammed, drained, and transformed into agricultural and/or pasture land. Reclamation goes back to the 13th and 14th centuries though the *pièce de résistance* was started in 1923 when the Zuiderzee, a deep sea indentation was dammed and became IJ ssel Meer (Lake Yssel). True, their southern neighbors—Belgium and France—also added *polderland* and *wateringen* (Fr.: *wateringues*) to their territory with equal success. One even finds, abutting Bordeaux on the Gironde estuary (France), Bruges, a town settled by people from Brugge (Fr. and Engl.: Bruges) who were brought to Aquitaine, centuries ago, to drain the then prevailing marshes.

The Dutch, then commonly known as Hollanders, Zeelanders and Brabanters, and the Frisians (Lat.: *Frisii*) were either the first, certainly among the first in Northern Europe, to protect their establishments by earth mounds, and this as early as a thousand years ago. Even then the sea-level was rising. And by the twelve hundreds they had managed reclamation and some coastal protection, particularly among estuaries, the Dordrecht area being an example (Figure 1).

03561 received and accepted in revision 6 July 2003.

The earliest written reports about the Frisians labeled them water-men and mud-workers (VAN VEEN, 1962), but they had also caught the attention of the Romans who took notice of the Frisii's artificial hillocks. (Julius Caesar: *De Bello Gallico*). Plinus (Engl.: Pliny the Elder) described the Frisii (contemporary Frisians) as poor people who "try to warm their frozen bowels by burning mud, dug with their hands out of the earth and dried to some extent in the wind more than in the sun, which one hardly ever sees." Documents seem to indicate that a little over 1260 mounds were built in an area of less than 2,200 km (800 sq. miles), varying in size between 2 and 5 hectares (5 to 12 acres) and protruding about 10 m (33 ft) above sea-level. Historians speak about moving 80,000 m^3 of clay (100,000 cu. yards) to achieve these constructions. It is true, however, that no certainty exists about these elevations being anthropic, even though Pliny's text uses the term built. The XIth century dike building methods, aimed at land protection and reclamation, were adopted by the Flemings and Hollanders who even adapted them to the plain of the Elbe River in Germany. Cistercian and Premonstatensians monks contributed substantially to the establishment of dikes in Flanders, Zeeland and Friesland.

Frisians seem to have been among the first to write about and build sea-walls. Yet no mention is made of the mounds in the *Lex Frisionum,* the body of legal texts of the Frisii dating from 802. Only in the Middle Ages are sea-walls (*zeeburghen*) mentioned. Medieval manuscripts deal extensively with *zeeburghen* (Old Dutch spelling for "sea-cities"); a *burgh*

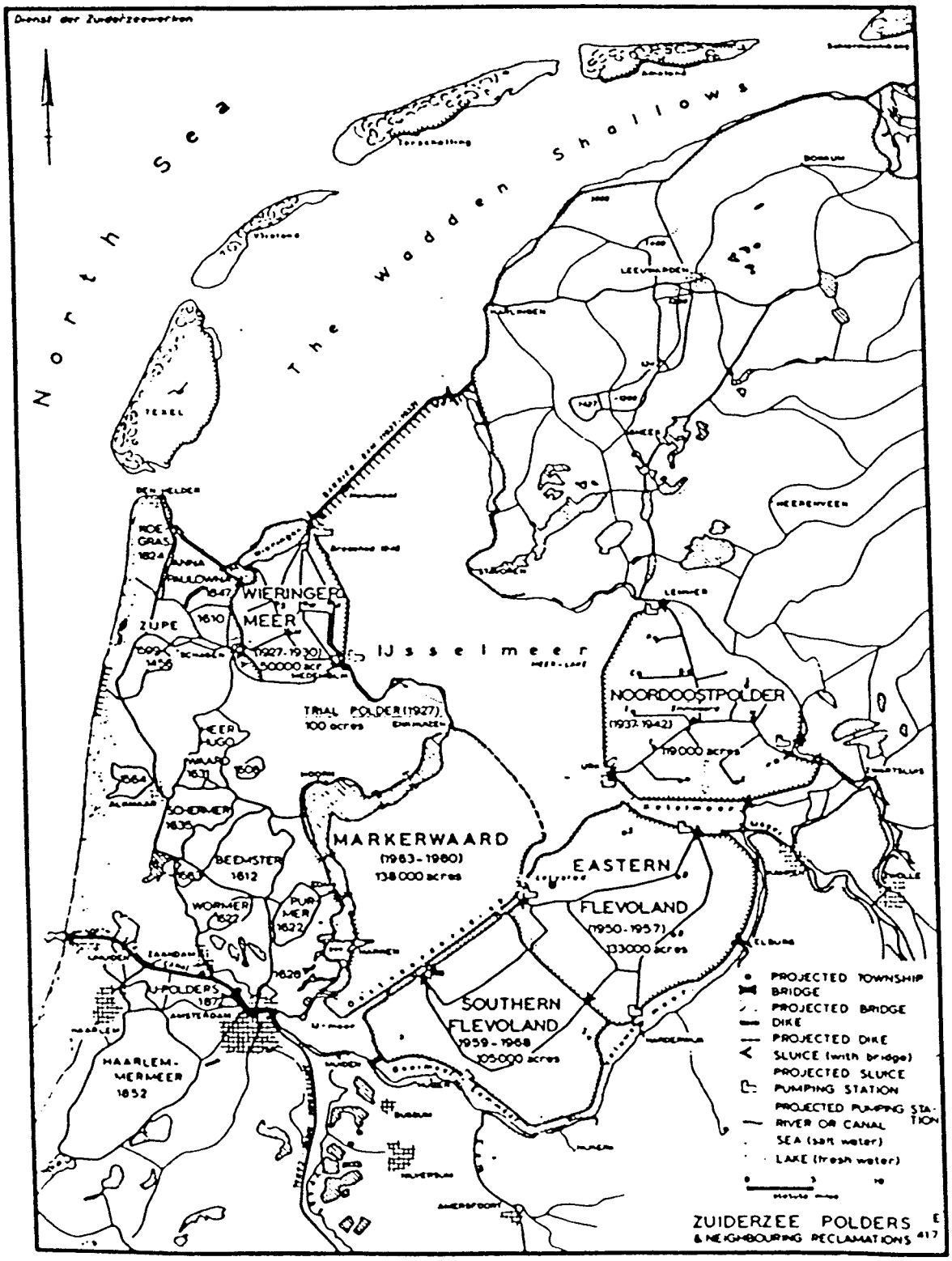


Figure 1. Reclamations in The Netherlands. Top left caption of figure reads "Dienst der Zuiderzee-werken." Bottom caption reads "ZUIDERZEE POLDERS AND NEIGHBORING RECLAMATIONS."

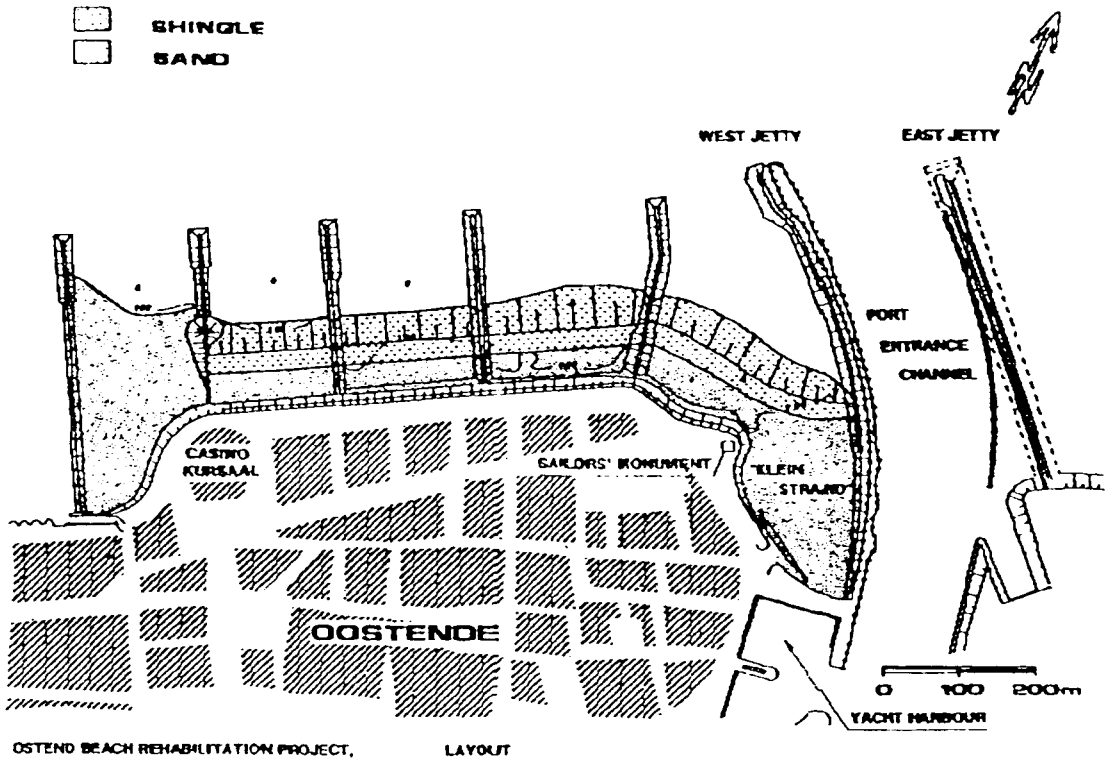


Figure 2. Layout of the beach rehabilitation project at Oostende, Belgium.

meaning also walled-in, stronghold, castle, fort, it has occasionally been translated as sea-walls, with walls first made out of clay, later stone.

The Dutch, and their Frisian cousins were, and are, fine engineers in setting up sea defenses, yet, in the Middle and Far East, dikes, dams, and water walls had been built either at the same period or probably even earlier.

More recently groins were built in the British Isles, Denmark and North America. Papers published in England in the mid eighteen hundreds discussed groin design, while Danes projected to heighten dunes. The first groins were "implanted" along the Danish coast in 1870 and their number reached close to 100 units in between the two world wars.

Groins were probably built in the United States by private parties to protect their sea fronting property as the Federal Government showed concern only for its own property. Things changed after the Second World War when both the individual States and the Federal Government got involved in controlling erosion. Quoting Per Bruun, structurally the art of coastal protection suffered shortcomings [in the United States] compared to the low countries in Europe. [. . .] The difference between the low countries lies 'in the scale' and in

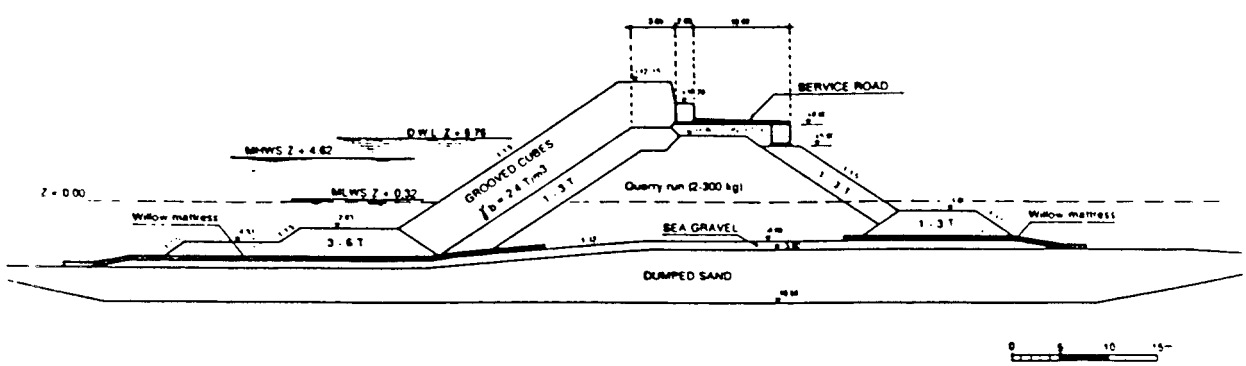


Figure 3. Typical cross-section of Zeebrugge outer harbour breakwaters.

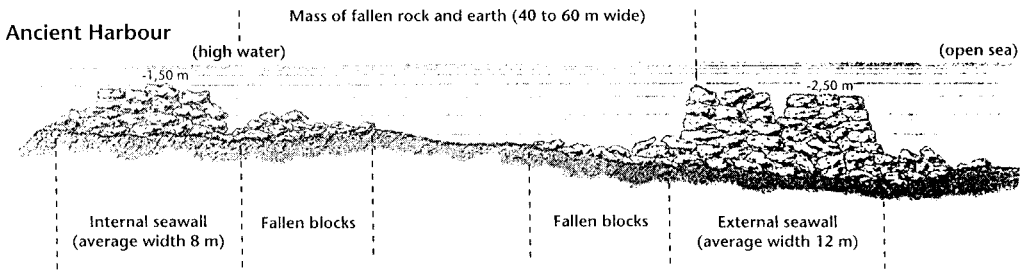


Figure 4. An average section across the Great Ancient Breakwater. After Jondet, 1916.

'the degree of involvement'. The European is [. . .] complex . . . and the American is relatively simple.

Coastal protection against an advancing sea became increasingly a concern for governments during the last century and a half. Massive engineering works best characterizes the approach but, in the more recent decades, artificial nourishment has gained in favor, the more so since cost assessments and technical improvements make it an attractive alternative. This does not mean, however, that many other alternative approaches to the coastal protection problem have not been put forward.

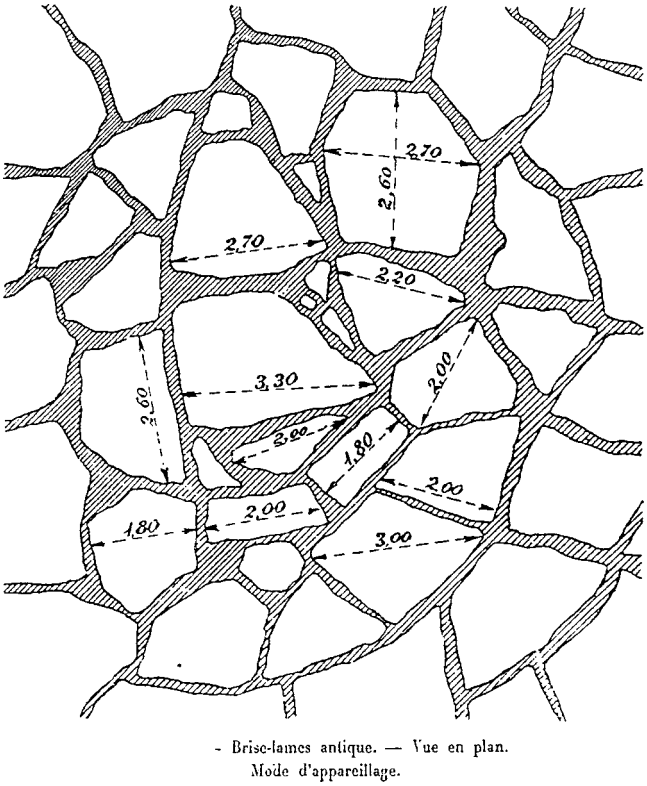


Figure 5. Upper surface view of the Great Ancient Breakwater. After Jondet, 1916.

The Zeeburgh

Coastal protection seems to have been a major concern in the "Lowlands" in the 13th and 14th centuries. William I, count of Holland, surrounded the coasts of his territory with dykes—and probably the islands of Walcheren and Schouwen as well, though these belonged to the county of Zeeland. Some credit him with being the founder of the still existing *Rijkswaterstaat,* the Water Administration of the contemporary Netherlands (VAN VEEN, 1962). Predecessors and strongly

Figure 6. Geographical subdivision of Italian seas and coasts.

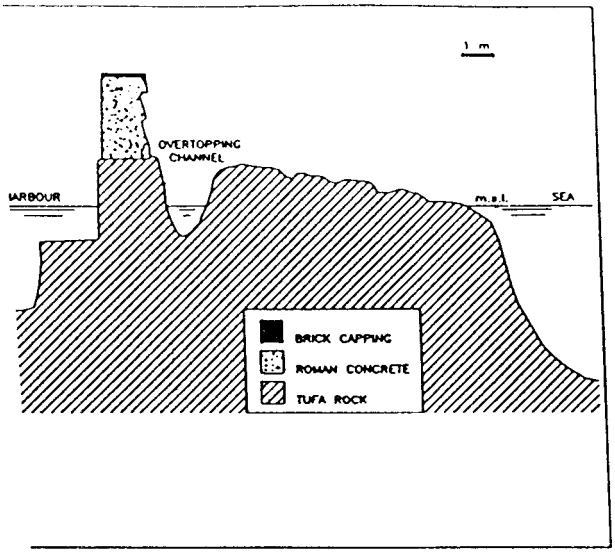


Figure 7. Cross-section of the existing Roman "carved rock breakwater" with overspill stilling channel at Ventotene (Built 2 BC).

entrenched in local authority were the *hoogheeraadschappen* (higher water authority) at whose head stood a dike reeve.

William may have traced a network of canals to drain the moors. The Dutch refined the technique to an art and are responsible for drying-up, under Mussolini's rule, the malaria-plagued Pontine Marshes. As mentioned earlier some credit similarly Flemish Belgians with draining areas of the Gironde estuary, near Bordeaux, France, where they founded Bruges, named after their area of origin.

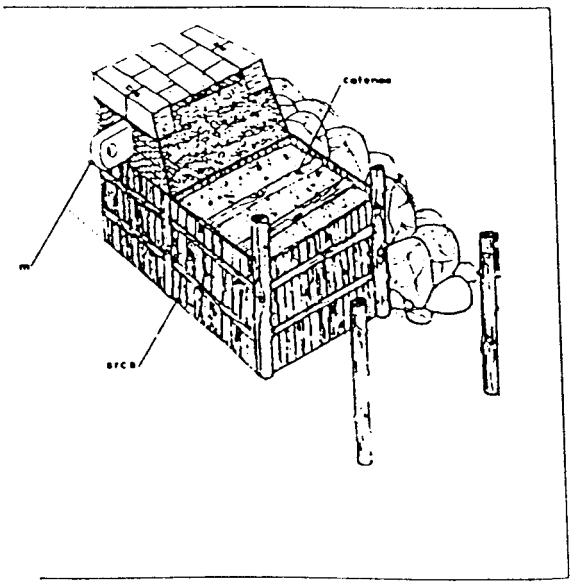


Figure 8. Reconstruction of the Roman construction system of a vertical water with cast-in-situ concrete within wooden forms and tie-rods (Clementi, 1981).

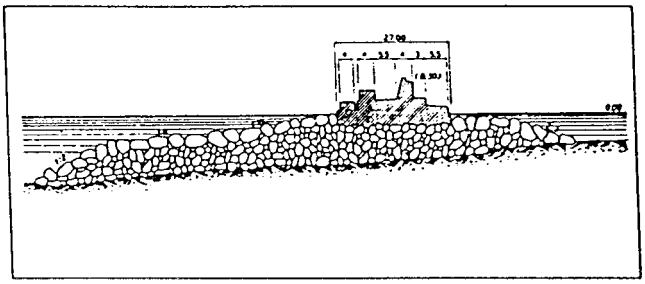


Figure 9. Modern section of the Trajan island breakwater of Civitavecchia harbour.

The earliest reference to the art of accelerating the natural rate of [sediment] accretion is perhaps in Andries Vierlingh's (*also spelled* Vierlinck) mostly conserved manuscript "Treatise on Dike building" (*Tractaet van Dijckagie*) written in the 16th century (1576–1579). He discusses "cross dams" construction on not-yet-dry at low tide mud-flats. As inexpensive protection he recommends to sink old ships on top of which earth should be dumped, so that suspended sand and silt would be held back (VIERLINCK, 1579) thus creating artificial islands or flats that would hold back silt and sand suspended in the water. It is probably not improper to compare these views and the contemporary insertion of feeder-berms. He suggested to link these artificial islands afterwards with low dams.

Though his approach is not known to have been frequently implemented, perhaps because of the work and cost involved to dump materials, and also that of constructing linking dams, use of shipwrecks to close dyke breaches is commonly documented. The wrecks formed the basis, the frame, for the fill material secured with mats and/or brushwood. Yet, Vierlingh strenuously opposed this method of repairing dyke breaches decrying the non-homogeneity shipwrecks created

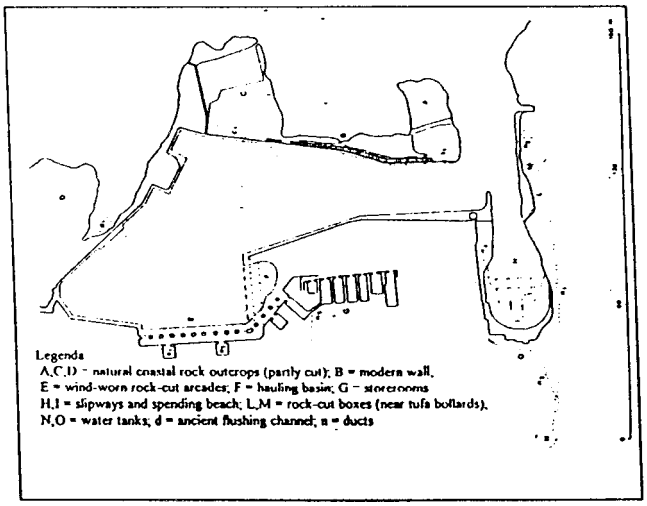


Figure 10. Layout of the Roman imperial port of Ventotene.

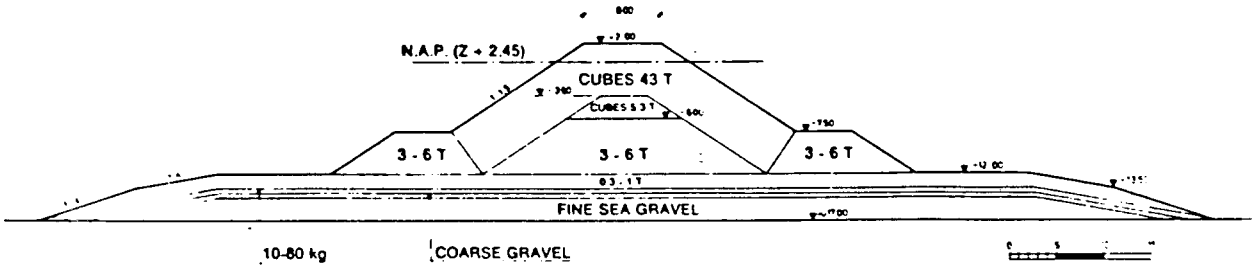


Figure 11. Cross-section of the North Breakwater at Rotterdam.

in the dyke structure. Regardless, the approach remained for considerable time in favor in The Netherlands and also in Danish Schleswig-Holstein.

Vierlingh's advice can be spelled out in a nutshell as: "No *fortse* (force) can compel water, or it will revert the *fortse* against you". At least two-thirds of The Netherlands' lower lying areas is an anthropic achievement with the remainder of the country a natural moorish swamp or sea-marsh.

Weed-dykes are special to western Friesland and areas surrounding the [former] Zuiderzee (also spelled Zuyderzee), now largely drained [IJsel Meer]. The regions have ample zones of sea-weeds and sea-grasses along the coast. West Frisian, and also some Wieringen, sea-dykes were long reinforced with seaweed. Sea-grass gathered offshore in the Zuiderzee and Wadden Sea for dyke building was dried and used as a broad tough protective layer placed on the dike's sea face.

Though there is no certainty about weed-dykes' ages, they were constructed from the 8th century on. Records show that such a dyke was constructed at the northernmost point of Schokland Island in the 16th/17th century and a similar one in 1734 in the northern part of today's Province of North [*Noord*] Holland.

Layering was used in dike building. Such a method was proposed a decade ago for the artificial nourishment of a beach in Ostend, Belgium. Layers of silt, or silt-and-sand, coquina, shell, willow mattresses *et al.* were gradually placed on top of one another; remains of old ships, brick- and pile-walls were not disdained in the building-up process. Furthermore, brick-walls, pile-walls and rotting ships were used to construct dykes. Bottom mattresses of willows are still occasionally used, but more sophisticated materials are of course gradually called upon (Figure 2).

FLOODS, DIKES AND GROINS

As ambition grew, dykes also grew. Moving them steadily closer to the dangers, it became necessary to reinforce them by hard surfaces such as basalt blocks and/or other structures parallel as well as perpendicular to the shore. The reinforcing

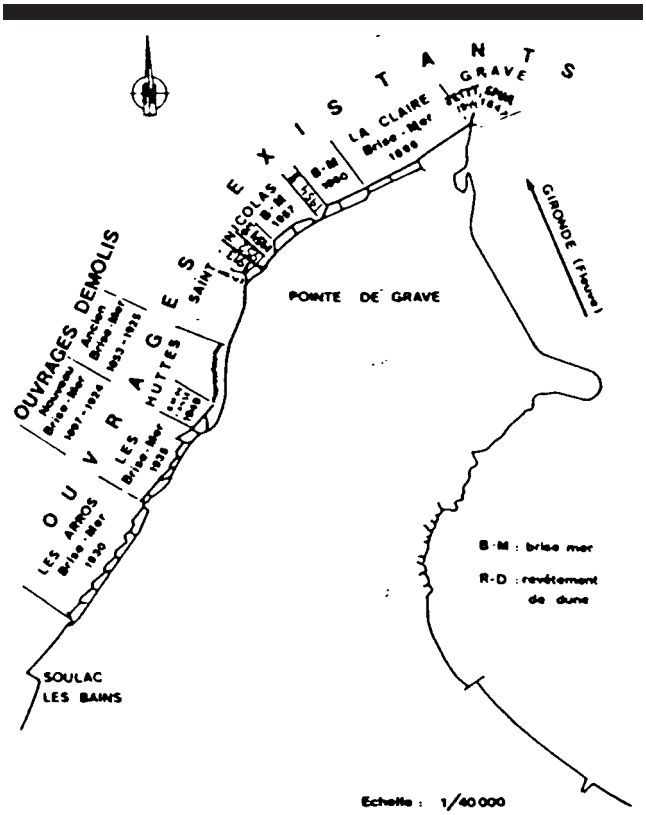


Figure 12. Shoreline protection, Pointe de Grave, France. After Laboratoire Central d'Hydraulique de France, 1979. Redrawn and modified by R. H. Charlier.

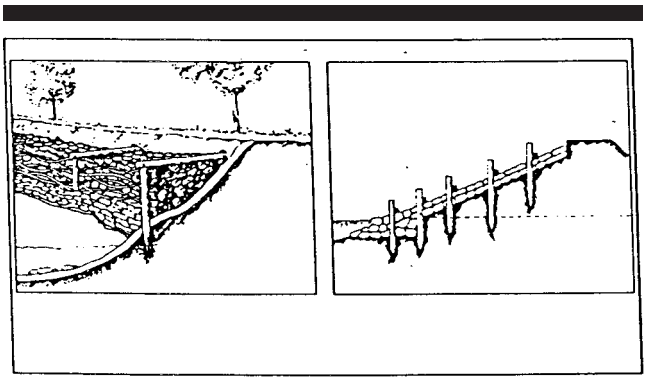


Figure 13. Ancient coastal defences in Venice: rubble vetments within timber piled fences (6th to 17th century).

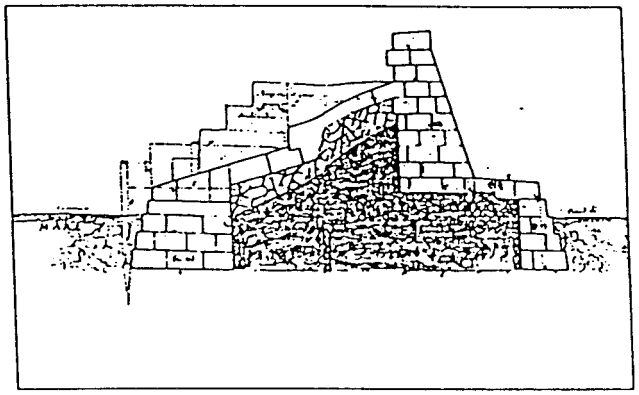


Figure 14. Original design of the "murazzi" seawall by Zendrini in 1743.

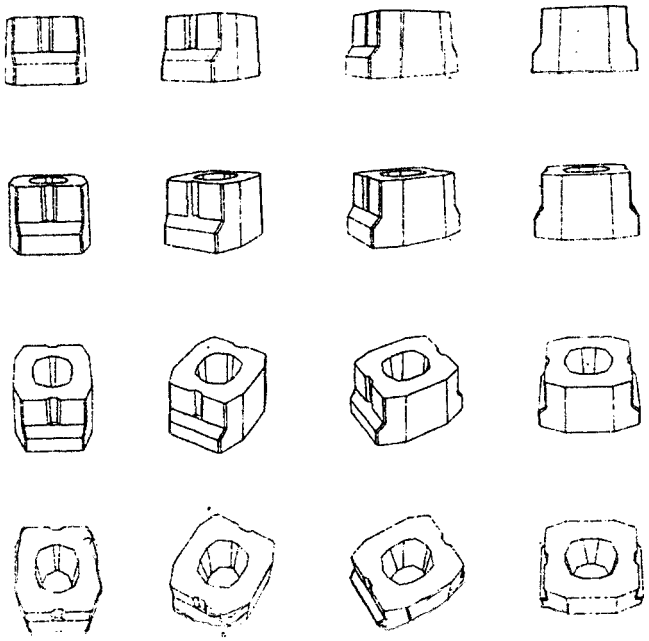


Figure 15. Various views of the "Haro" used in breakwater and groin construction.

or supporting structures developed and modified as experience and exposure increased. The gradual reinforcement by structures like sea-walls and groins [groynes] may have contributed to a not fully justified sense of security. It has been said that groins were not raised rapidly enough to keep in step with the sinking of the land and the rise of the sea level, and that dikes were not subjected to thorough investigation of their structural soundness.

About the 15th century John (*Jean,* in French and *Jan* in Flemish), duke of Brabant, constructed a dike [dyke] along what is today's Belgian coast, as a response to the early 13-hundreds floods that gobbled up wide bands of land areas, drowning several villages. The remnants of John's engineering efforts are still traceable and maps refer to them as Count John's Ditch which had backed the coastline since 1304. The dune belt, some kilometers wide in the west and east but narrowed down to barely 100 m (330 ft), was put in place between the 9th and 13th centuries.

Indeed, according to medieval documents, the sea pushed the coastline back perhaps as much as 5 km (3.1 miles) and "swallowed" several coastal communities, such as Harendijke situated between Wenduine (Wenduyne) and Blankenberge. Two other coastal communities were lost to the North Sea on November 24, 1334: one, Scarphout, seawards of Blankenberge, the other Ter Streep, offshore of Mariakerke near Ostend.

The early breakwaters parallel or perpendicular to shore, waves or currents breakers, sometimes floating, and either vertical or sloping, evolved into bulkheads and revetments, permeable or not, vertical or sloping, shore detached or not. To them were gradually added groins, adjustable or not, permeable or not. In the 15th century protection efforts encompassed plantings, and in the next century small groins consisting of wooden stakes and poles with twig mats were constructed in Blankenberge (1502). The dune belt, some kilometers wide in the west and east, narrowed to barely 100 m (330 ft), was put in place between the 9th and 13th centuries.

Various sea defense types have been called upon by man, some well before 1000. These include ditches (reclamation, drainage and defense), longshore sea-walls, groins placed perpendicularly to shore and longshore drift, "permeable" jetties, breakwaters, sand fences, dune protection (fences, walkways, vegetation cover), and beach nourishment (profile, berm, Longard, back-passing).

Masonry groins with twig bundle (*fascine*) cores and stone blocks fixed with wooden pegs or poles have in time yielded to block masonry with concrete debris cores. Breakwaters placed at Zeebrugge in 1870 were made of concrete, but a hundred years later the preference went to stone blocks dumped in place (1980). Detailed descriptions are provided by CHARLIER and AUZEL (1961), DE MOOR and BLOMME (1988) and MOLLER (1984) (Figure 3).

Stone/rock hard defense structures were constructed starting 150 years ago: a seawall in Ostend (1885), Wenduine, Blankenberge and Zeebrugge (1870), Nieuwpoort (1897), Middelkerke (1898) and Heist (1899). Only in Ostend, Mariakerke and Heist were these sea-walls close to the settlement core. Since the eighties the seawall in Koksijde (Coxyde) stands landwards from the local dune string. The concrete seawall between De Haan (Le Coq) and De Haan-Golf built after 1912 was "lost", buried under sand drifts and "re-discovered" in 1976. Short stretches of seawalls were constructed prior to World War II in Knokke and Oostduinkerke.

The catastrophic flood of 1953, and subsequent extremely severe storms, fostered extensions of sea-walls, sometimes "temporary" ones—such as from De (La) Panne to the French border, and it is here that [re-]creation of tidal inlets has been considered instead of restoration of the dune toe protection.

Modern groins (groynes) placement started with the XXth century. Some backed the existing seawalls. Besides 17 groines in the Ostend areas, some 75 were in place in 1912 west of Wenduine, and very little (except more groins) had changed in the pattern. Groins in Belgium, like in The Neth-

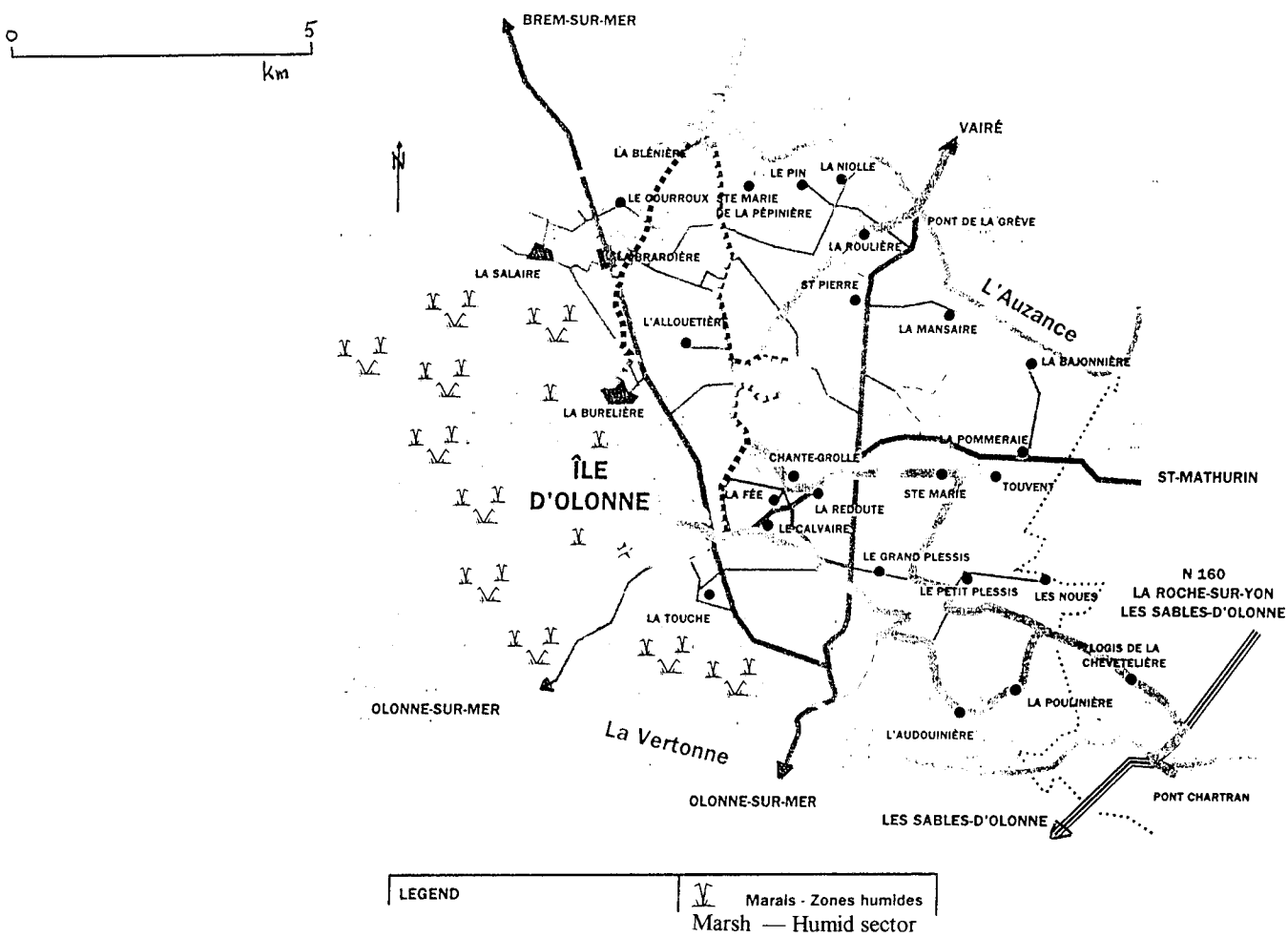


Figure 16. Location map of "marshes" (*viz.* wetland) in SW France.

erlands are said to have a "positive impact", but this view is not unanimously shared (De Moor and Blomme, 1988). Whether they prove beneficial for re-nourished beaches is still uncertain. Product and service literature from such consulting bureaus as HAECON provide excellent information on the construction of contemporary groins.

Dikes in the Mediterranean Area

Dikes were built on the Egyptian Mediterranean shores (Alexandria) under the reign of Apollonios Ptolaemeus II Philadelphis, Egyptian ruler, during 259–258 B.C. He donated to his employee Stothoaetis, a large section of land in Ghoram, Fayoum (Philadelphia); here the owner decided to exploit the embankments by establishing a network of canals and dikes, well before "westerners" drained land in more northern areas. A cursory examination of a picture of the Alexandria Lighthouse, one of the seven wonders of the world of the classical times, that crumbled to the bottom of the sea due to a XIVth century earth tremor, shows rather sophisticated dikes around Pharos Island. A French expedition funded by the Electricité de France, brought back to the surface in 1998, the colossal statue of Ptolaemeus II that stood in front of the lighthouse (Figures 4, 5).

Early in the 30s Captain Cull, a Royal Air Force pilot from the Abur Qir Base, observed below the surface waters of Alexandria Bay, a sea bed area littered by remains, statuary and ruins, and by mid-1933 several locations of archaeological significance were identified and artifacts retrieved (Morcos, 1968). But already from 1911 through 1915, Gaston Jondet, then Chief Engineer at the Egyptian Department and Ports and Lighthouses, discovered compelling evidence that there had been an "ancient harbor of Alexandria". Though he published his observations in the *Mémoires présentés â l'Institut Egyptien,* these documents are quite difficult of access. His 1916 study covered the ancient Great Western Harbour, Anfouchy Bay and the western part of Pharos Island at Qait Bay.

Jondet produced a large scale map (1:6000) which shows the modern great breakwater dating from 1890–1897 extending westwards from the Ras El-Tin Lighthouse to just south

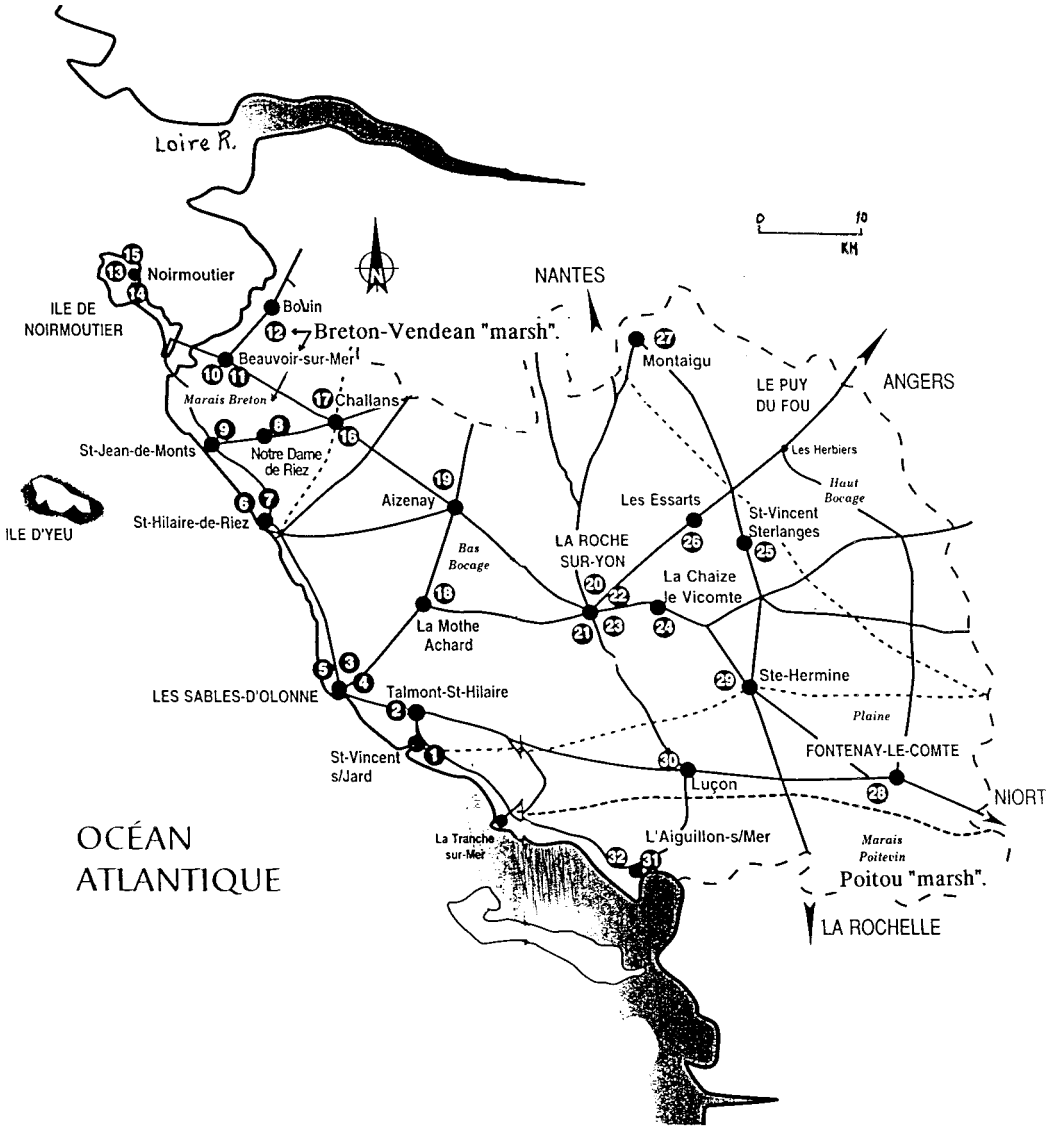


Figure 17. Location map Polders and reclaimed wetlands of Atlantic France. Legend: 1–5: dikes and marshes; 6–12: Breton-Vendean marsh; 13: dikes; 14. salt-extraction marshes (*marais salants*), polders; 15: dikes; 16–17: reclaimed marsh; 18–19: low bocage area; (20–27 not relevant to this paper); 28: Poitou marsh; 28–30: examples of former harbors, now inland; 31–32: dikes.

of Abu Bakar Rock. Jondet believed this to be the cornerstone of the Great Ancient Western Harbour. He described the submerged ruins of larger structures forming the "ancient great breakwater" extending 2.36 km (1.46 mi) from Abu Bakar Rock to the western edge of Anfouchy Bay, at a depth of 4.5 m (14.76 ft), and a distance of 300 m (924 ft) north of the coastline; it acted as a protection for the harbor against prevailing northerlies and northwestern winds.

Jondet also designated as entrance to the great harbor a gap, west of Ras El-Tin, starting point of the modern breakwater, 200m (660 ft) wide free of submerged structures. A pier or jetty or dyke, some 800 m (2624 ft) long can be seen on the sea floor extending from west of said "entrance" to Abu Bakar Rock; a 200m (660 ft) long double pier, connecting with the ancient great breakwater, surrounding west and north Abu Bakar Rock, constituted a formidable coastal defense, *de facto* closing the ancient harbor. The upper side of the offshore dyke shows a seaward slope of 3 to 4 cm (± 1 to 1.4 inches); the median line is free of masonry and constitutes a trench roughly a meter (3.28 ft) wide whose depth seems to equal, in the mean, half of the dyke's height. Jondet surmises that this trench was used to place military defense works (JONDET, 1912). A line of interrupted external submerged ruins, 200 m (660 ft) to the north and parallel to the ancient great breakwater discovered in 1915 forms the external breakwater stretching eastwards from north of Abu Bakar Rock, now at depths ranging from 6.5 to 8.5 m (21.3 to 27.9 ft). The external basin of the ancient port laid between the

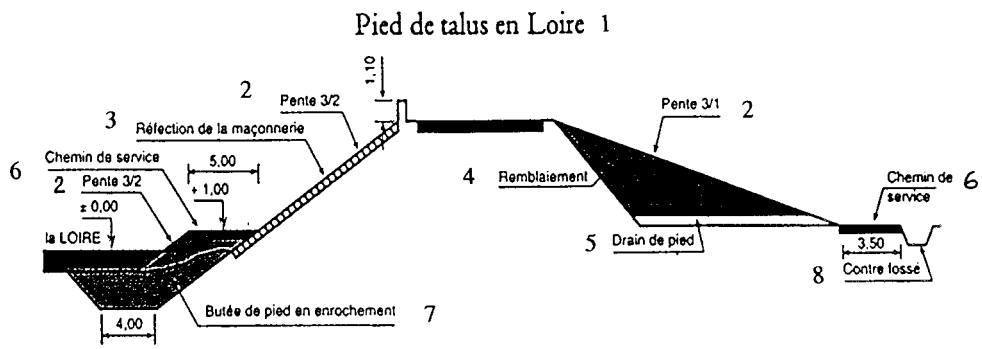


Figure 18. Reinforcement of the Levee Project (Loire River). Legend: 1. Talus foot in the Loire. 2. Slope. 3. Masonry repair. 4. Embankment. 5. Foot drain. 6. Service path. 7. Rubble mound foot block. 8. Counter ditch. (All measurements in meters).

two breakwaters. The artificial structures surrounding the harbor, exclusive of those of Pharos Island, are 4 km (2.48 mi) long. The sea walls are in uneven pieces, mostly 10 to 30 m (33 to 100 ft) separated by intervals varying between 4.5 and 2 m (1.6 and 6.6 ft).

Except for Homer's reference to a port on the Island of Pharos, nowhere is such harbor mentioned in classical times literature. Dating of the age of the breakwaters remains controversial with credit given the Greco-Romans (THUILE, 1922), by others to the Pharaohs (EL-FAKHARANY, 1963) Ramses II or III or the Old Kingdom—in which case this would be the oldest known man-made harbor— and still by others to the Cretans during the Minoan Civilization with the support of pharaoh Sensuret II of the XIIth Dynasty around 2000 BC (WEILL, 1919). When Alexander the Great reached contemporary Alexandria in 332 BC, the ancient great Western Harbor had already been gobbled up by the sea. His engineers lined Pharos Island and the mainland by a narrow causeway, the *Heptastadium,* seven stadia long (± 1300 m or 4264 ft) which gradually silted up causing the decline of the Eastern Harbor. That harbor was protected to the east by Cape Lochias (also lost to the sea except for El-Silsila Promontory) wherefrom a seawall extended to the harbor entrance providing protection from sea currents and northerlies.

The Red and Mediterranean seas were linked several times before de Lesseps dug his Suez Canal (1869): under the early Pharaohs, the Persians, the Ptolaemae and the Arabs, a waterway linked these seas by the Pharaoh's Canal, Trajan's River and the Prince of the Fidels [Faithful] Canal. A caliph had it filled in 762 to punish, and economically ruin, Medinah, which had revolted. The canal had dikes whose masonry was exposed on December 27, 1798 by the future Napoleon I and an escort of scientists, sent there by the French government.

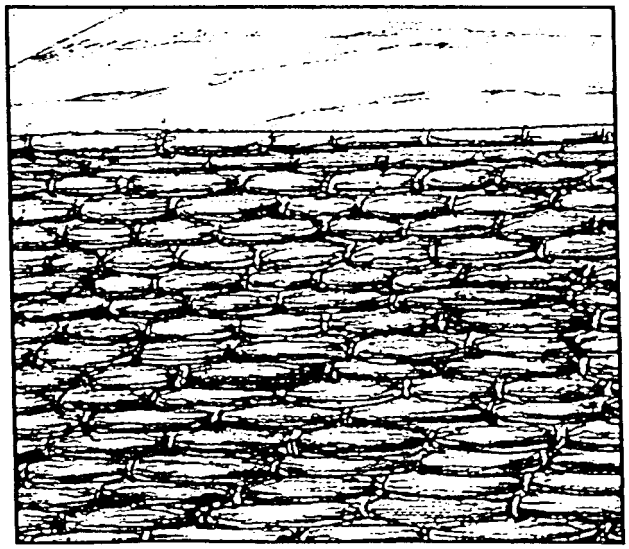


Figure 19. Revetment of a "turcie" (small individual dike) in 1967. Reproduced from a photograph from the Departmental Archives of Maine-et-Loire by B. Rousseau.

Northern Rim of the Mediterranean Basin

The Frisians probably appropriately claim to have been the first to devise an embryonic system of coastal defense in Northern Europe; others may equally assert their right to a first place: coastal engineering can be traced back in China to the East Han dynasty era. Indeed large coastal defense projects were initiated between about 25 and 220 before our era (XU OIWANG, 1993). In the Mediterranean, likewise, coastal engineering had an "early start" particularly among Greeks, Etruscans and Romans, but also Carthaginians, Minoans, Phoenicians, Sumerians and Egyptians (Figure 6).

Coastal defense history is, naturally, closely linked to harbor creation and development. Primitive breakwaters were put in place occasionally with ramps allowing the top of the waves to pass over them. Phoenicians had devised wave catchers by excavating holes and establishing trenches in the rocks lining the shores (RABAN, 1988). Carved breakwaters were cut out of bedrock: a suitable wave-absorber profile was created which had a gentle grooved slope at the waterline. The classical example dates from 2 before the present, is still visible at Ventotene; it had an over-spill. One may see in it an early version of today's Fontvieille breakwater (Principality of Monaco) (Figure 7).

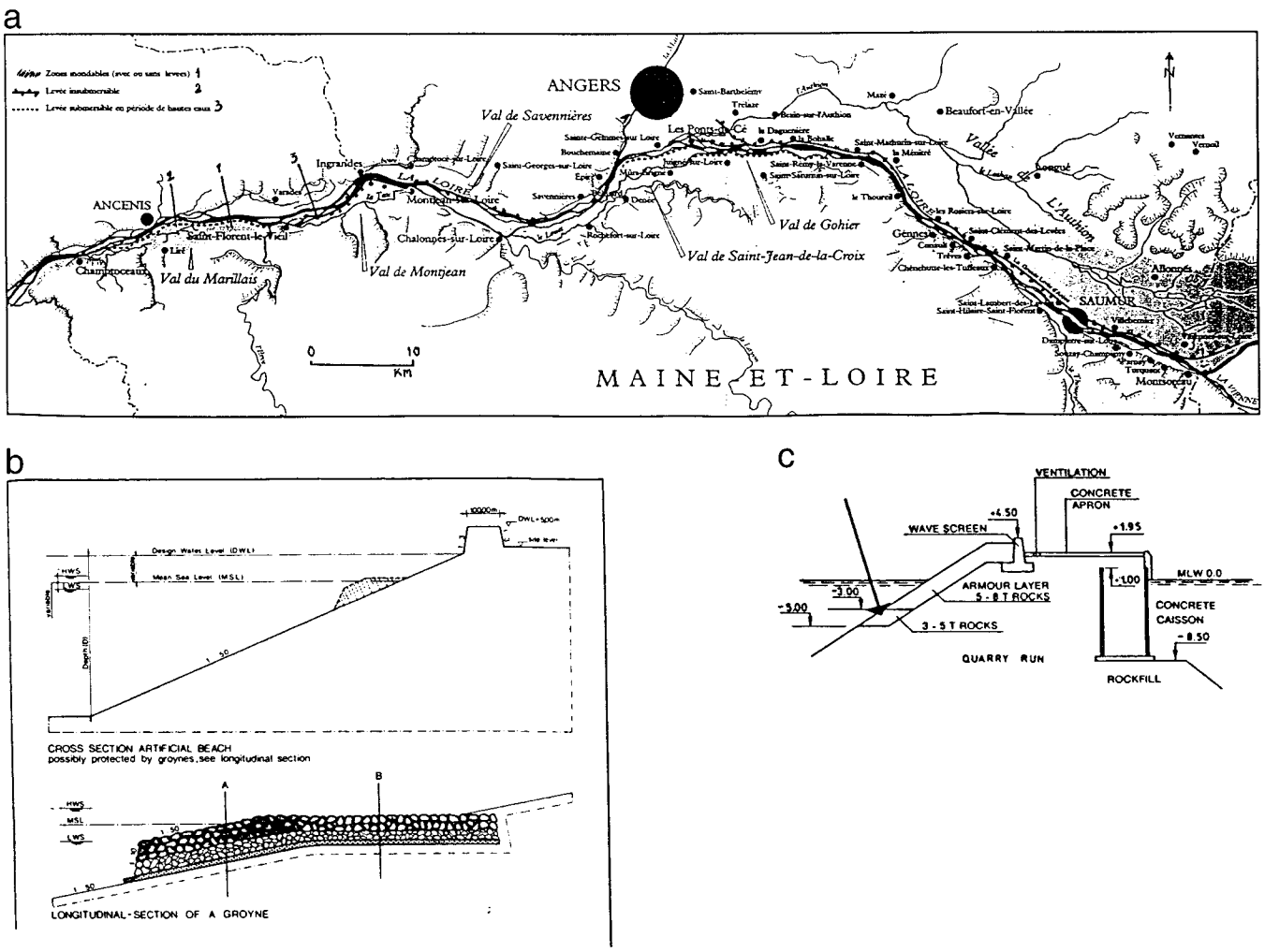


Figure 20. 20a. Map of the Loire in the French Département de Maine-et-Loire. River mouth lies west. (Infographic M. Brugier) Legend: relative city size shown by circle dimension; dark line: river course; shaded area: submersible area with or without levees; —·—·—: insubmersible levee; – – –: submersible levee at high water. 20b. Longitudinal-section of a groyne. 20c. Torshavn Breakwater, Denmark (after Sorensen *et al.,* 1965).

Greek and Etruscan breakwaters and sea-walls consisted in rubble mounds topped by cut rocks; though no mortar was used, neighboring blocks were sometimes held together by clamps and joints made out of metal. With the discovery of pozzolanic ash hydraulic cement solid breakwaters could be built underwater, and several vertical composite concrete walls have been preserved from the second century before our era to the fifth century. CLEMENTI (1981) provides an illustration of a vertical breakwater made *in situ* within a wooden frame and tie-rods. Toe protection against scouring was provided occasionally by a bronze slab (OLESON, 1988) (Figure 8).

Not only had these engineers mastered the art of erecting cofferdams for construction "in the dry", but they also thought of caissons, forerunners of contemporary building methods. Watertight wooden cellular caissons were used to cast the large concrete breakwaters, *e.g.* at Caesarea. "Permeable" breakwaters and "arched moles" were installed in various sites (FRANCO, 1996). Apparently well before the Dutch dyke-builders thought of sinking old ships, the Romans sank old hulls, filled them with concrete and had a breakwater placed in no time; under Emperor Claudius' reign, Caligula's "monster" ship was sunk at Ostia (50) to provide a breakwater (TESTAGUZZA, 1970). Remnants are still visible at 4 km from Fiumicino airport near Rome.

Roman Emperor Trajan (98–117) had a rubble mound breakwater built on an "island", reshaped by nature, and man, during centuries leading to a subsequent mild slope profile (FRANCO, 1996) (Figure 9).

GRILLO (1989) reports that the earliest written document dealing with shore protection dates back to 537 when *fagines* or *fascines,* wicker faggots, supplemented by timber piles and stones, held up earthen dikes (*cf.* Frisian earth mounds) adding their protection to that of the dunes (Figure 10).

"Timber and rock revetments and groynes have been used [in the Venice area] until 1700 to halt beach erosion and silt-

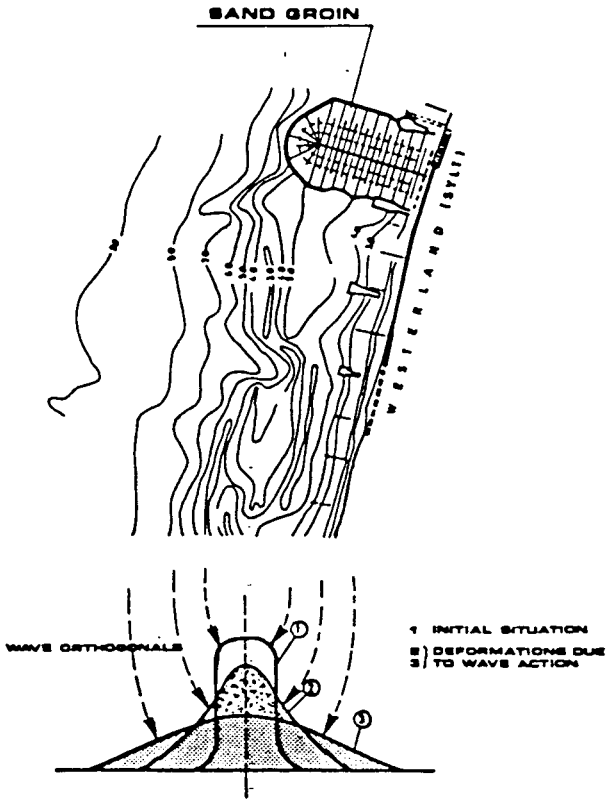


Figure 21. Construction of sand groin as coastal protection, Sylt, West Germany. Source: HAECON N.V., Ghent, Harbour and Engineering Consultants.

ing" notwithstanding a lengthy transport for rocks and short lifespan of wood (FRANCO, 1996). Strict environmental regulation governing shore protection can be traced back to legal documents of 1282 and 1339: prohibition to cut or burn trees from coastal forests, to pick mussels from rock revetments, to let cattle walk the dikes, to remove sand, and vegetation, from beach or dune, and to export materials used in coastal defense (GRILLO, 1989). The *Magistrato alle acque,* created in 1501, invited suggestions to reduce the high cost of the coast defenses, so, in the 18th century, appeared rip-rap revetments, gabions, staircase placed limestone blocks, and the use of mortar and steel links and flexible steel strips became common (Figures 11, 12).

Whereas beaches protect the littoral, they had to be maintained, and artificial nourishment with offshore dredged sand was initiated as early as the 17th or 18th century, hence long before California used the method (1919).

Massive *murazzi,* devised by Zentini and his team were constructed from 1741 on; with an average width of 12 m (39 ft), their crest peaked at 5 m (16 ft) above mean sea level. It took 40 years to construct a protective sea-wall 20 km (12.4 miles) long (CHARLIER and DE MEYER, 1998). *Murazzi* have withstood the test of time, though storms took their toll and toe protection was eventually provided by a rubble mound structure and, more recently, jet-grouting diaphragms. Com-

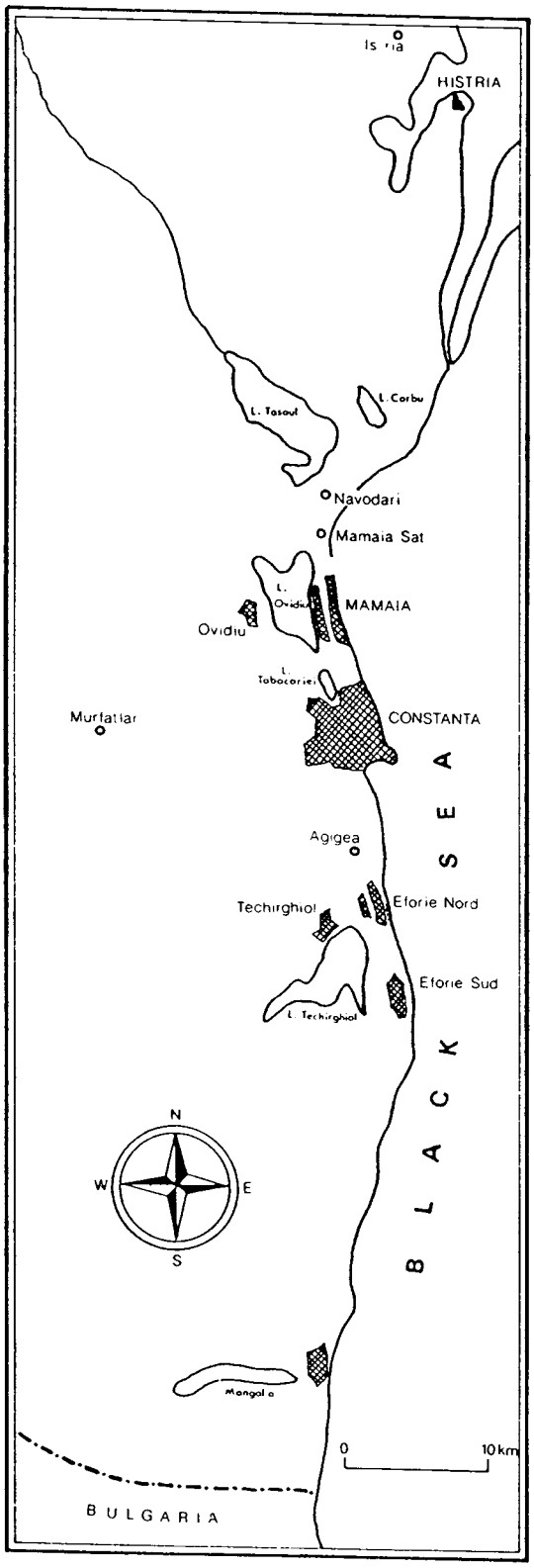


Figure 22. Modifications of a segment of the coastline on the Romanian sector of the Black Sea. The coastline has left inland several salt water lakes (*limans*), but currently the coast requires protection measures.

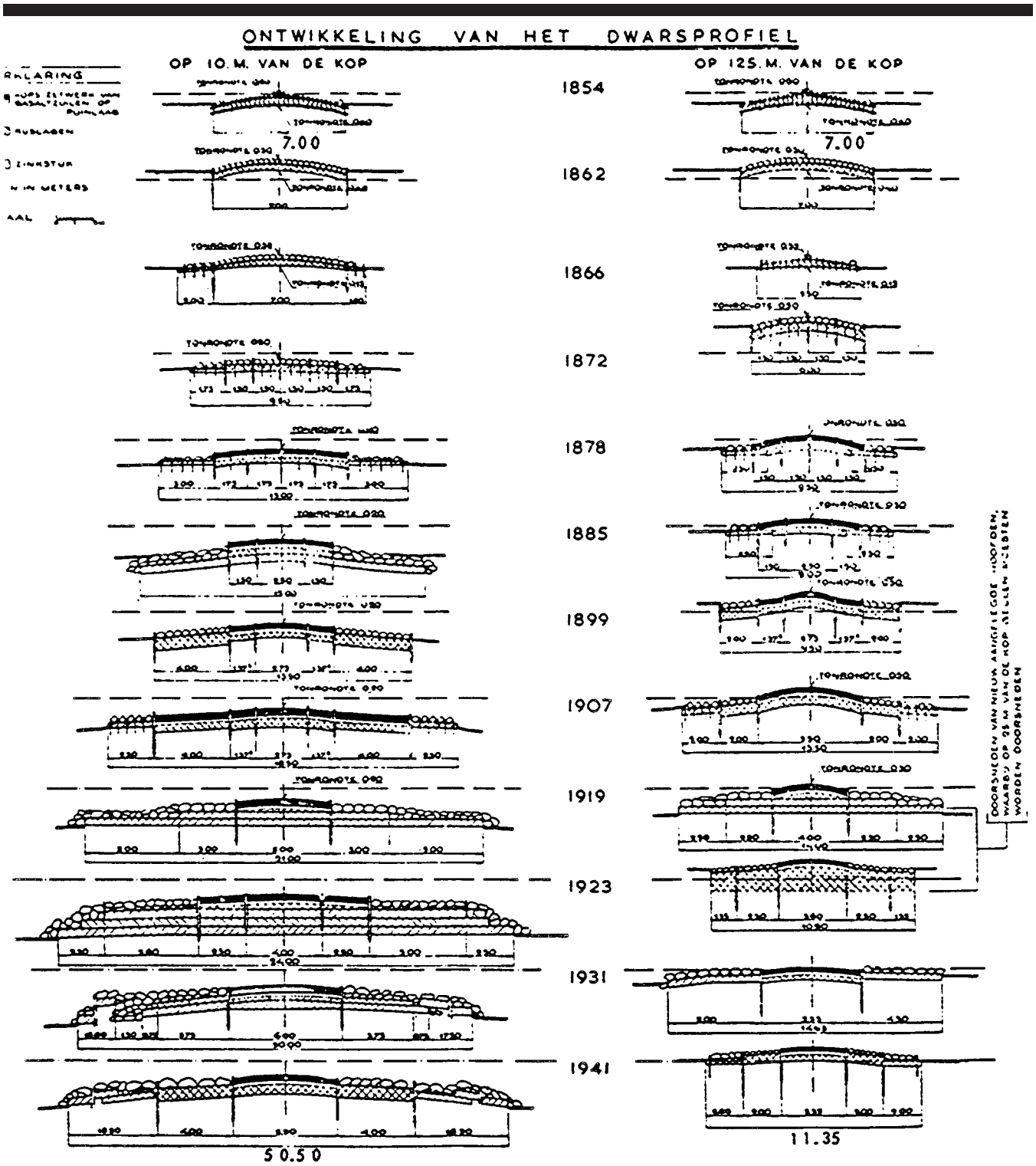


Figure 23. Development of groins in Holland 1854–1941 (Visser, 1953).

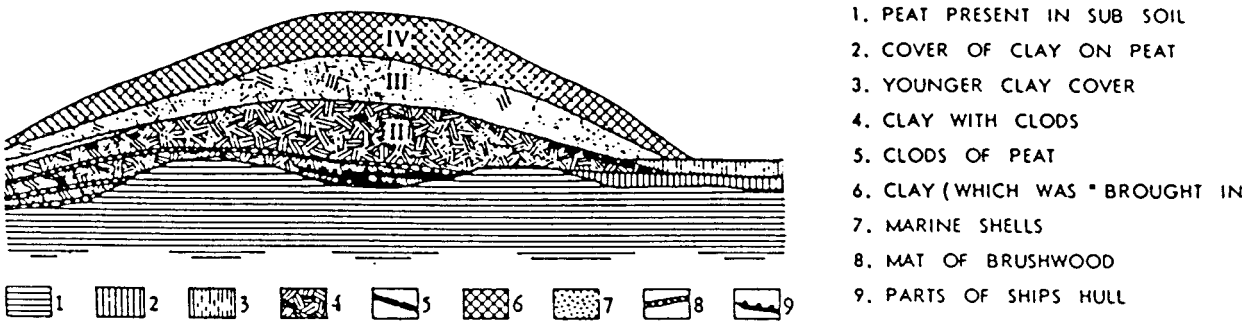


Figure 24. Cross section of ancient dike, Netherlands. ("Antiquity and Survival", 1959).

menting on the Genoa breakwater, an actual fortification with a superstructure, Franco underscores its importance as in 1245 it was proclaimed a "pious work" thereby compelling every citizen of the Republic of Genoa to provide in his will for the breakwater's maintenance (Figures 13, 14).

The need to follow in Nature's steps is by no means a new formula: Vitruvius advocated the nature-wise approach as far back as 27 BP; he inspired Alberti's 1452 gentle-sloping breakwaters and the convex island and horseshoe-shaped breakwaters of Di Giorgio Martini.

Of course no Renaissance technology review can pass over Leonardo da Vinci whose talents included hydraulics and is the father of a proposed triangular shaped island breakwater (RICHTER, 1970). He too championed the credo of "working with Nature", rather than against it: "*ne coneris contra ictum fluctus: fluctus obsequio blondiuntur*" [Nature should not be faced bluntly and challenged, but wisely circumvented].

Franco has virtually provided a catalog of Italian designed breakwaters: use of irregular blocks with pozzolanic concrete crown and large rock armor porosity (CRESCENTIO, 1607), a monolithic superstructure over a leveled rubble mound foundation (DE MARI, 1638), armored with precast blocks (San Vincenzo mole at Naples, 1850), vertical composite structures (1896), caisson construction (1915, 1931, 1936, 1938, 1995).

As elsewhere, in the Mediterranean, engineers and environmentalists have second thoughts about hard structures, *e.g.* detached rubble mound breakwaters, are being replaced by star-shaped piles and perforated and articulated blocks—somewhat reminding of the Belgian designed Haro™—and submerged barriers, all not infrequently combined with artificial beach nourishment, also by-passing. An environmental impact assessment is in process as regards mobile storm surge barriers (Figure 15).

Defenses in Europe

Groins and dikes were thus constructed in Europe, particularly in Northern Europe, from at least the 14th century on. Netherlandish ones may have been put in place in the early 16th century. But it may be as far back as Roman Britain when coastal protection was contemplated; the Rhee wall was built during that period. So-called sea banks have been of course built since the 13th century. Made of earth, it was not exceptional that they were constructed with *fascine* or were

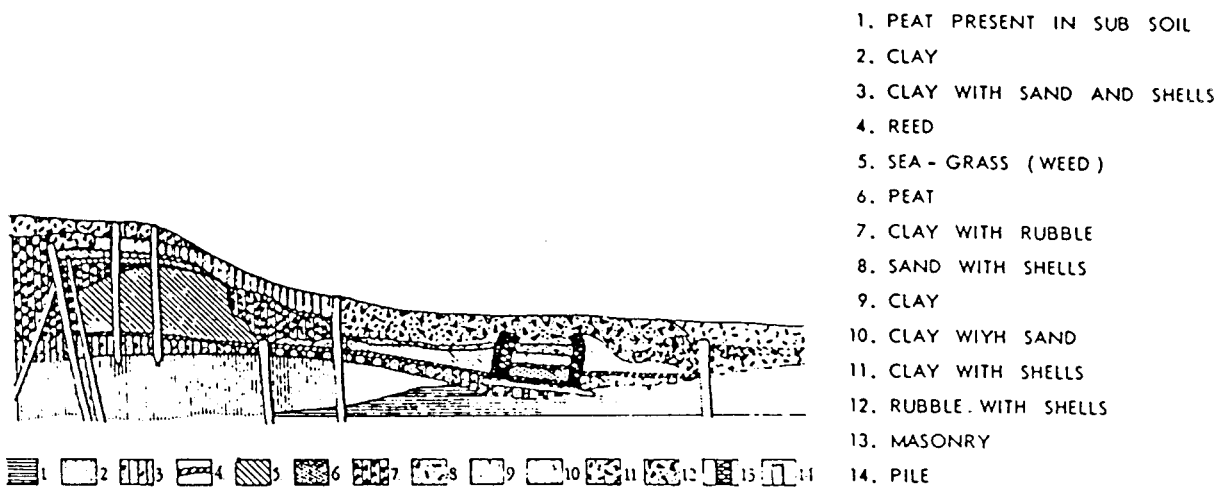


Figure 25. Cross section of ancient dike with pile support ("Antiquity and Survival", 1959).

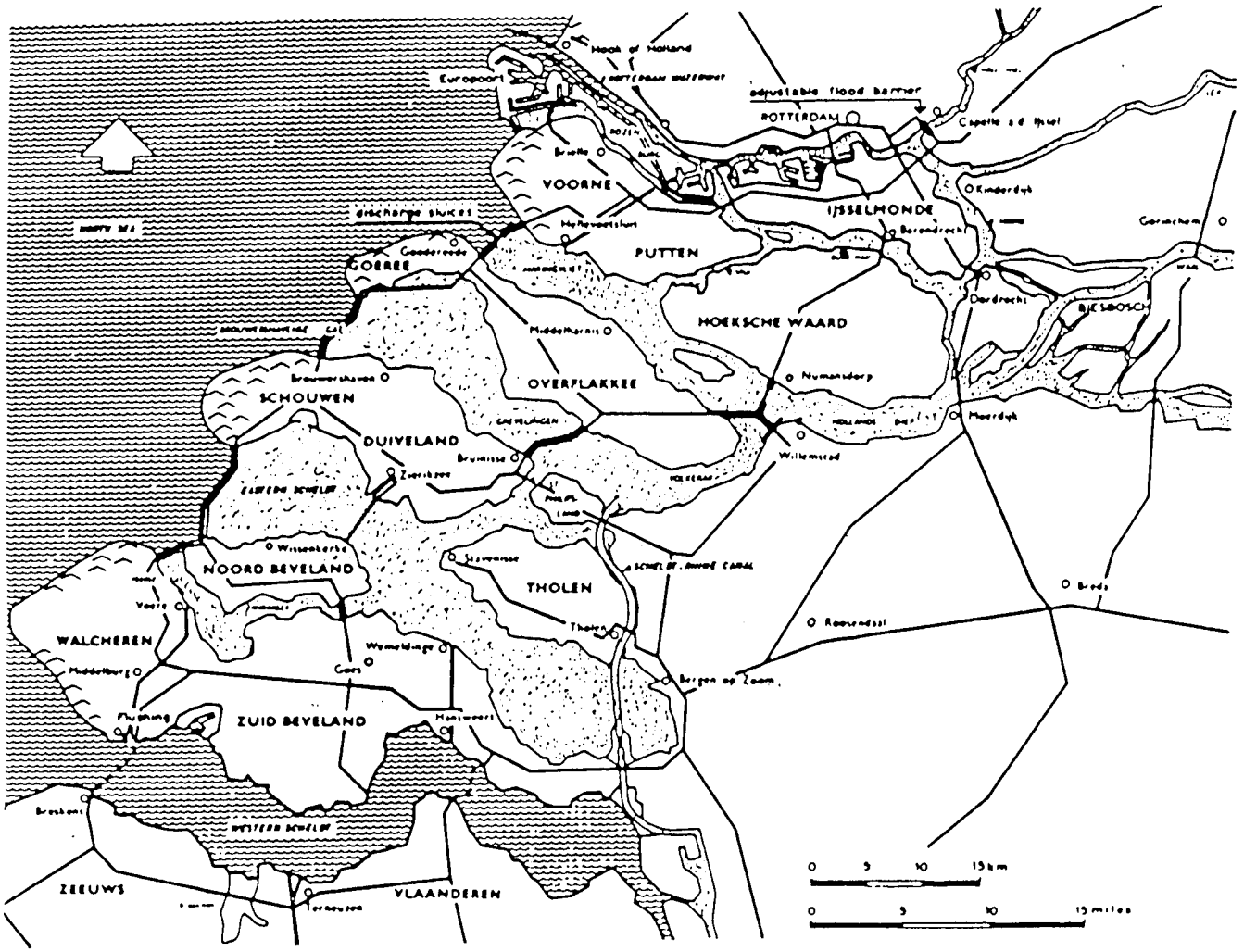


Figure 26. Map of The Netherlands Delta-Plan.

pile-walls. Vertical bulkheads were also, later on, put in place. THORN (1960) praised the flexibility of block walls and their low reflection. Groins were placed approximately at the same time in The Netherlands.

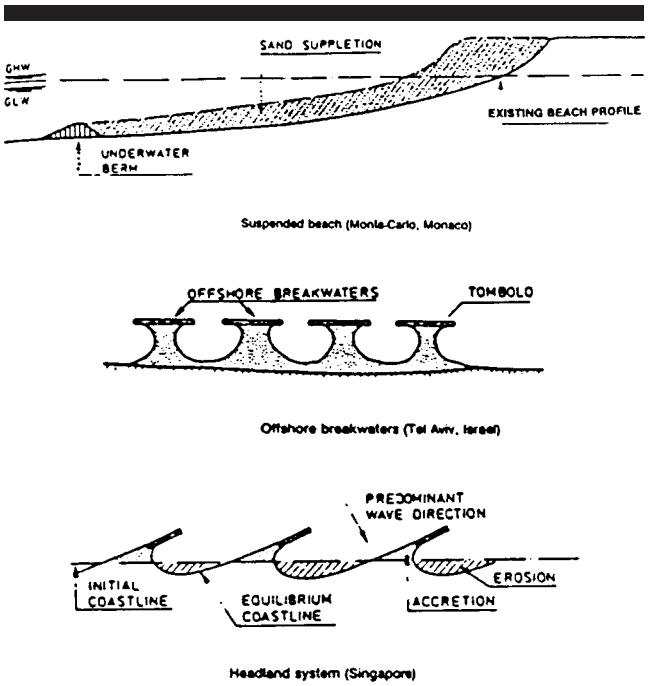
From Dijc to Dike

During Classical Times harbor construction and protection had required "coastal engineering" works and one cannot stop at admiring the ingenuity of the early engineers, particularly around the Mediterranean. Latin (*molus* [*molis*]) and Classical Greek terminology thus exists. The word in classical and contemporary Greek is identical.

A word common to Romance and Germanic languages, which gradually differentiated locally as time moved on, designates the protective structure against the common problem: the onslaught of the sea. "Modern" languages' coast defense vocables probably find their origin in old Netherlandic, bearing witness to the pioneering role played by Frisians, Zeelanders and Hollanders in that domain. Frisians, those "wretched creatures" from Pliny are e.g. credited with co-founding and contributing to the early development of Antwerp. Though protection systems of some kind thus existed earlier, the words designating hard structures entered "modern" languages much later.

The word dic is common to Dutch, German and English meaning ditch in Old Netherlandish and English, and dam in Middle Low German. Spelled dyke in English, the word has meant fortification, *e.g.* Offa's Dyke, a structure on the Severn River and Dee Estuary built by the King of Mercia. Without claiming etymological accuracy, the word designating protective structures probably derives in English and French from the Middle Netherlandic *dijc*; *digue* appears in French texts around 1360, and even *dike* in 1373, although the spelling *dicque* is used in the 15th century. The near-obsolete term *chaissée* meant an earth *levée* (mound) in the XIIIth century more usually called *levée* as of 1200.

Other terms with related meanings are in use in 1631 (*épi,* from the Latin *spica* meaning a point, thus a pointed struc-



Figures 27–29. Some beach-restoration possibilities. Top, suspended beach (Monte Carlo, Monaco); Center, offshore breakwaters (Tel Aviv, Israel); Bottom, headland system (Singapore). Source: HAECON N.V., Ghent, Harbour and Engineering Consultants, Belgium.

ture)) and *brise-lames* can be found from 1818 on. *Digue* has at least three different meanings in [contemporary] French: it designates a structure protruding into the sea, also called *jetée* or *mole,* but also a latticed structure (often in the past made out of wood) erected on poles or stakes usually called *estacatte* (1566) today *estacade,* in Italian *steccata* (meaning pole), and even a detached structure at sea and for which the term *brise-lames* is commonly used nowadays. *Mole,* found as early as 1584 in French, originates from the Latin *moles* [-is] and the Italian *molo* (1546), corresponding to the Portuguese *molhe*; Flemings and Dutch have used *muur* (*e.g.* in Zeebrugge, Belgium) for such defensive, but also harbor, structure; a mole is also a *jetée* (French), jetty (English), *molo* or *gettata* (Italian), *muelle* (Spanish) and *pier, mole* or *Hafendamm* [harbor-dike] (German). Germans commonly use *Damm* or *Deich* (close to the Netherlandic *dam* and *dijk*).

Similar to dike are the Italian *diga,* Spanish *dique,* Rumanian *dig* and Portuguese *dique.* While *dijc* does not disappear in Netherlandic, the spelling is modified in later Dutch and Flemish into *dijk,* with an intermediate phase of *dijck* as in Vierlinck's book's title *dijck-agie.* The term *jetée* (in English, jetty) appears in 1362. Greeks were not unfamiliar with dikes (cf. protective works in the ancient harbor of Alexandria) yet both in classical and modern Greek τάφρος means ditch as well as dike. The protective ditch constructed in the 13th century along the Flanders coast has similarly been called *digue du Comte Jean* in some writings, and in Old English dike is also a ditch.

In Flemish, groins were popularly called *barenbrekers* (wave breakers) in the 19th century, until the more sophisticated *golvenbrekers* came into use, following Dutch custom. Germans will call groins *Wellenbrecher.* Today groins and revetments are not uncommonly labeled *strandhoofden* (strand- or beach-heads) in Dutch and Flemish alike. The English *dike* comes from a Middle English word itself derived from the Old Netherlandic *dik* (dike is found in West Flandrian Flemish dialect, pronounced "*dikke*"), perhaps adopted from (or passed on to) the Middle Low German (Mittel Plattdeutsch) *dik* about the 13th century, meaning a dam. *Dike,* in Old English synonymous to ditch, designated a bank usually constructed of earth to control or confine a water body, close to the modern American levee, (Mississippi River) itself originally French (*levée*) as in the Grande Levée d'Anjou on the Loire River.

The verb to dike, and its present participle diking, considered variants of to dyke and dyking, is in use in the 14th century. Breakwater appears in a text from 1769, and groin already for some time used as a noun, supposedly coming from Old English *grund* and even ground, and Middle English *grynde,* becomes also a verb from 1816 on, perhaps an indication of the more frequent construction of such defensive structures. In British usage groin (groyn, groyne) has designated also wooden breakwaters or frames of woodwork constructed across a beach between low and high water to retain sand or mud thrown by the tide.

The Netherlands and Belgium

These contemporary states did not exist in the 15-hundreds; they made up, with today's Grand-Duchy of Luxembourg and areas now in France, a territory referred to as the XIX Provinces, thus the contemporary names are used here for geographical location purposes.

Generally approximately 200 m (roughly 660 ft) long, some groins carry a "piggy-back" whose purpose it is to slow down long-shore currents. Though groins usually starve down-current beaches, BAKKER and JOUSTRA (1970) claim that Dutch structures decreased erosion, even fostered accretion.

Bruun (1994) explained this as follows: "Tidal currents combined with swell action provide the shore with materials from offshore so that the groins [do] not suffer [*viz.* induce] starvation as often as is normally the case [. . .]. Nature itself made a demonstration of "artificial nourishment". In The Netherlands the groins however, are not corner stone in the [land] protection. This [role] has always been the dykes'. But foreigners who came and saw the results of the [effects] of Dutch groins sometimes misinterpreted the situation very seriously. The massive Danish North Sea groins, which gradually increased in length to several hundred meters at the Thyboron Barriers due to continued shore recession, is just one of these misinterpretations by which enormous quantities of materials were sacrifi[c]ed because of earlier misunderstanding of the mechanism involved".

Groins in the northern sector of the French Atlantic coast—an area part of "the Lowlands" until annexation by Louis XIV (1638–1715) are similar to those in The Netherlands and Belgium. None have, in fact, solved the erosion problem. They are 18th and 19th centuries features. Down to the Gulf of

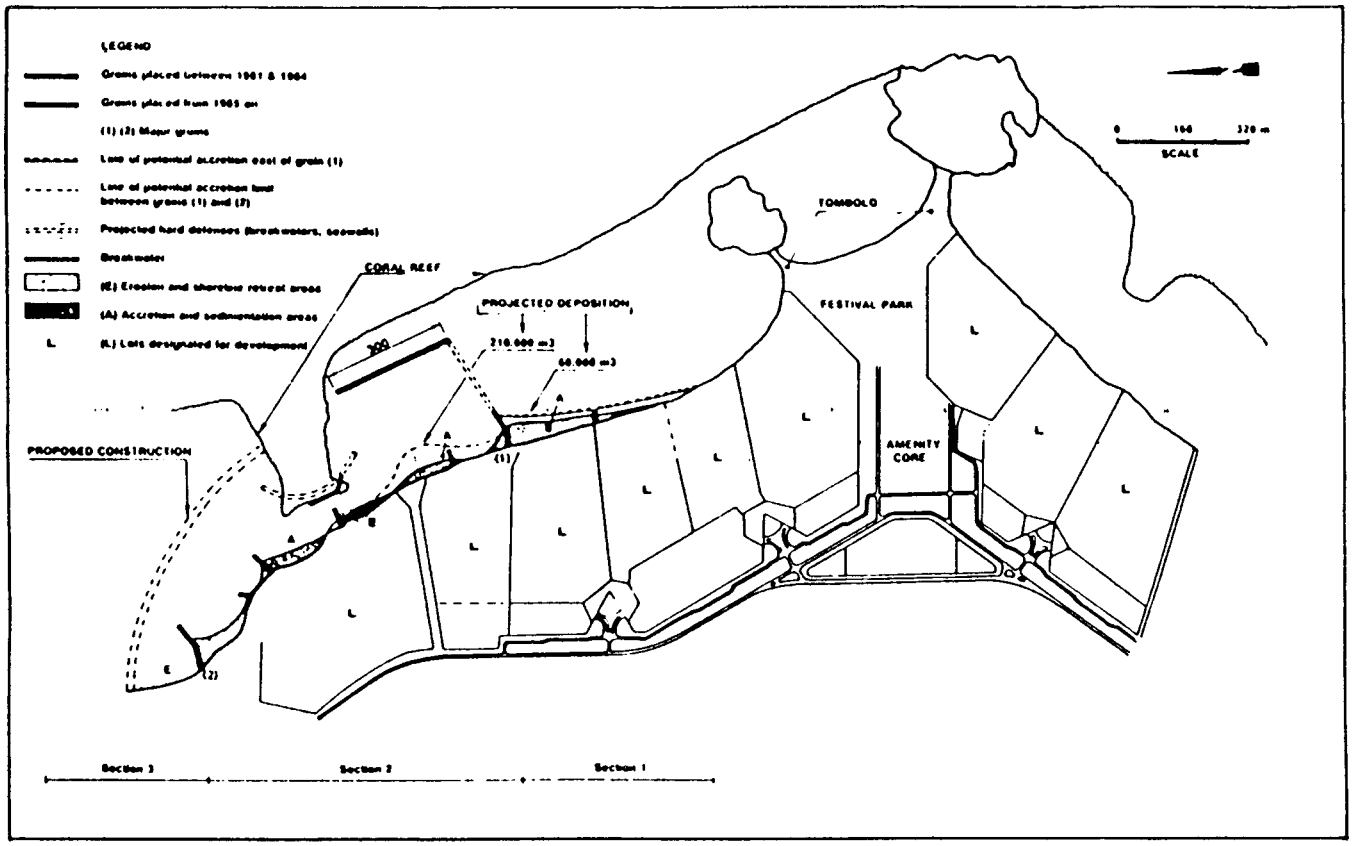


Figure 30A. Location of defenses, erosion, and accretion along some shore areas of Bali, Indonesia. After Indonesian Institute of Hydraulic Engineering.

Biscay and the Gironde estuary (Aquitaine), at the Soulac beaches, the groins are a historical topic rich in coastal protection lessons (Figure 12).

France

Dikes were built early in the Xth century, perhaps before, on the Atlantic coasts of France; the future St Philbert, a monk, landed on Noirmoutier Island and constructed dikes, in 673, to protect the east coast. To conduct the siege of La Rochelle, a Protestant hold-out, a gigantic dike was built across the bay, by Clement Métezeau (1581–1632), on orders of cardinal Armand du Plessis, duke of Richelieu (1585–1642), King Louis XIII's prime minister. Between long poles heavy stones and *gravats* (construction rubbish) were piled up; an opening was left to allow the rather strong tides to enter and exit the harbor (1627–1628). The structure withstood tides and storms and its blockade caused a famine that led to the death of 82% of the city's 28,000 inhabitants.

The Poitou wetland (marsh) [*marais poitevin*] is born from a large marine bay, whose present day remains are Aiguillon Bay, now silting, north of La Rochelle. Monks dug a drainage canal in the XIIIth century and improved rudimentary XIth century dikes, but the creation of polders got its major impetus under Henri IV (1553–1610), when a Dutch dike-builder from Bergen-op-Zoom laid out the "Hollanders' Belt". Gradual colonization of the marsh proceeded henceforth with dike building: Limousins' Levee, dikes of the Moors, of Morocco, of the Wagons, of Aiguillon, 1771-dike, Year VII-Village. Dikes-protected polders were established in the 19th and 20th centuries on the mainland, for instance St. Seran polders, near Bouin, Bourgneuf Bay, and on Noirmoutier Island (Sebastopol Polders) (Figures 16, 17). The former wetlands encompass landwards the humid marsh–nicknamed the Green Venice and close to the ocean the dry marsh cut up by dikes and canals (Figure 17).

Drying up of the Breton-Vendean (Figures 16, 17) wetland (marsh) is largely due to Dutch technicians who established, in the XVIIth century, a canals and tide channels network by means of dikes. Low farms, similar to many of those encountered in Flanders and Holland, called *bourrines* (perhaps after the Dutch-Flemish word *boerin,* meaning the farmer's wife, or more probably *bourre,* a type of *pise* (dry-wall stone facing), occupy hillocks and buttes, formerly islands of the ancient shoreline (Figure 17).

To reclaim salt from the sea, in salt marshes (*marais salants*), small clay dikes and canals were built, as early as the XIth century, and subsist along the French Atlantic and Mediterranean coasts (Brittany, Charentes, Camargue). They are of course encountered elsewhere as well.

Submerged groins were placed at right angle to the natural

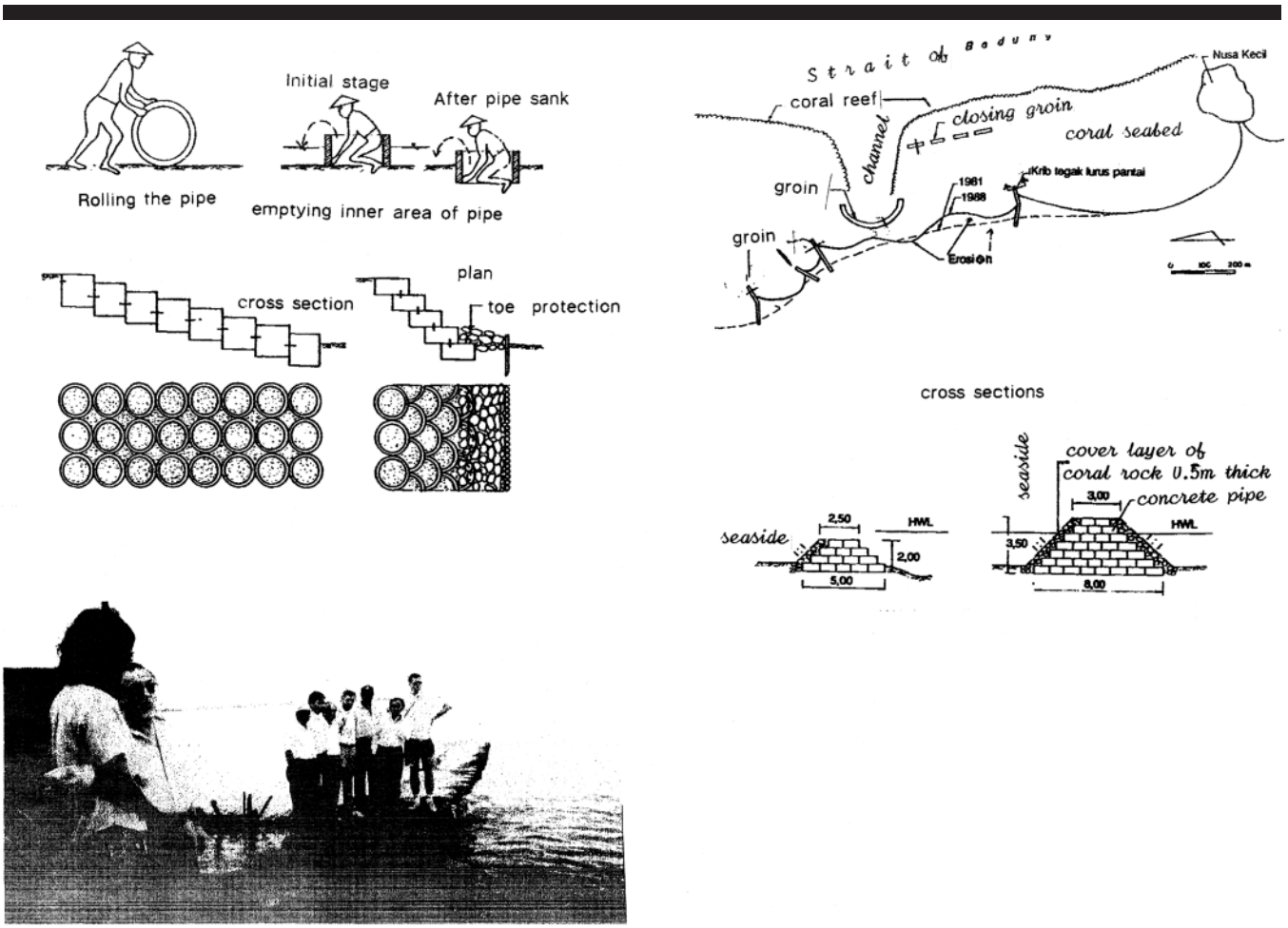


Figure 30B. Java, Indonesia. Concrete round pipes used to build breakwaters near a tourist resort (Belgian co-operation project. Author is second in picture front, to the left).

embankments between 1904 and 1926 in such tidal rivers as the Loire. Made of wooden poles or stakes garnished with chestnut tree claires, a rubble-mound string allows to insure their foundation towards the bottom. Such groins had medieval forerunners, some of which still subsist, for instance at St. Georges-sur-Loire: they were constructed of small poles placed very close to one another with small size rubble stones, mostly covered by alluvions as time went by (Figure 18).

Levees mentioned earlier were constructed along the Loire and the groins were implanted to protect banks and valley land. The dramatic spate of the Yang-Tse River illustrates the importance of such levees, and the need to provide "valves" against unruly waters. The Grande Levée d'Anjou was built between 1160 and 1170, urged by Henri II Plantagenet (1133–1189), husband of Alienor d'Aquitaine, Duke of Anjou and King of England. Maintenance and surveillance of the levee was carried out by settlers in exchange of some privileges, among which exemption from military service. Small individual earthen dikes, called locally *turcies,* had protected houses, since the end of the High Middle Ages, against floods (Figure 19).

By the end of the XIIth century the levee protects the area from St Patrice to St Martin de la Place: it is then an earth mixed with *fascines* bank, faggots held in place by posts. These *turcies* are sometimes earth mixed with *fascines* held in a flexible containment of rush and osier (water willow) placed on inverted, the entire "construction" being held together by stakes and sod clods. Up to the XIXth century it will be repaired, heightened and lengthened. In the XVth century trees protect levees from corrosion. A road is built on top in the XIVth century and marshes are dried up. In the next century it is used to insure navigability, and by the Colbert Decree (June 4, 1668) levee sizes are standardized. Stones replace gradually wood in the revetments protecting the ramp of levees, though sod remains in use in the upper parts. After an Administration of Dikes and Levees has been put in place, many works are undertaken (XVIIth and XVIIIth centuries) and thus the height is increased to 6.80 m (22 feet) above low water level. Rock envelopes reinforced at their base by rubble stone stake supports, cover the slope in contact with the currents, while the levee itself stands at 2 meters above the natural embankment. Engineers neverthe-

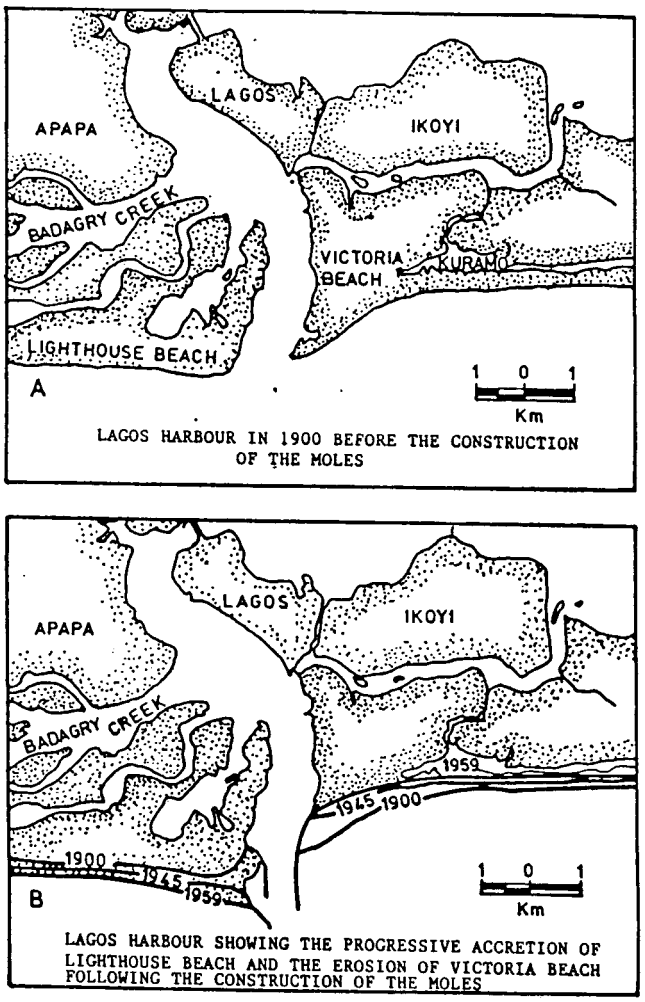


Figure 31. The Lagos coastline before (A) and after (B) the construction of the breakwaters (after Ibe *et al.,* 1984).

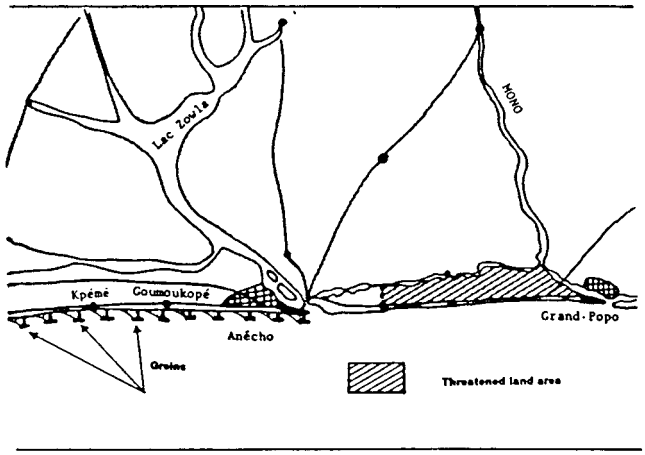


Figure 33. Proposed shoreline protection scheme, Victoria Island Beach. After M. Akle, "Problèmes d'érosion côtière dans le Golfe du Bénin," *Siren* 29 (September 1985): 20–31.

less get blamed for lack of foresight in believing in an insubmersible dike without waste-weirs capable of keeping a river in a bed that proved too narrow. Major improvements have been underway in the nineties (Figure 20).

Denmark

In Denmark coastal protection endeavors started in 1840 on the North Sea coast when the government decided to increase the height of the dunes on the Lime Fiord Barriers. In the 1870s experimental groins were built on the Danish West coast, using a Dutch design which soon proved to be too weak to withstand the violent wave action on that shore. Then the design was reinforced and during the ensuing 50 to 60 years close to 100 massive groins ranging in length between 100 and 400 m (about 330 to 1340 ft) were built in an area covering approximately 50 km (31 miles); the design used was

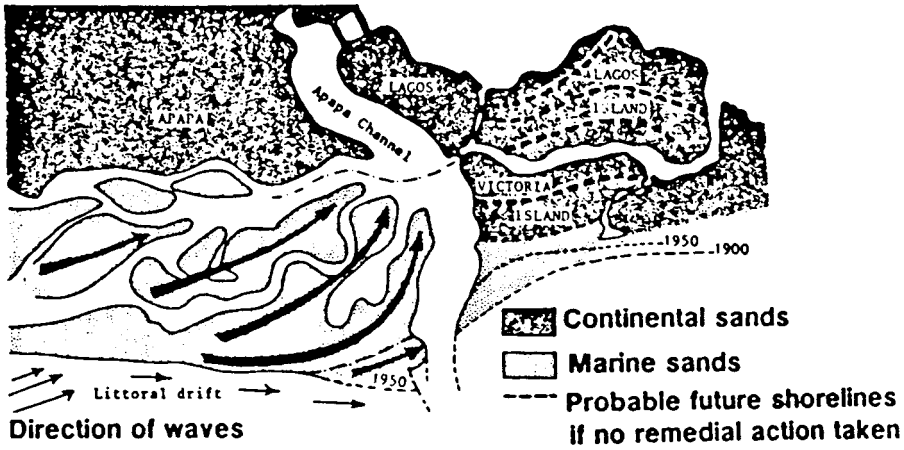


Figure 32. Shoreline shift, Victoria Beach Lighthouse, Lagos. After M. Akle, "Problèmes d'érosion côtière dans le Golfe du Bénin," *Siren* 29 (September 1985): 20–31.

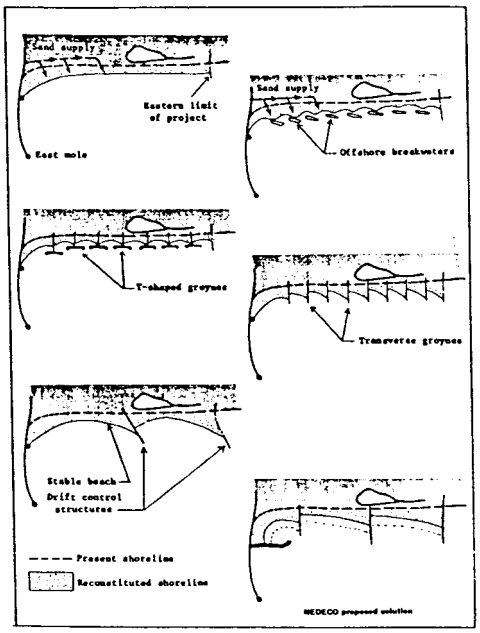


Figure 34. Proposed protection scheme for Kpémé and Anécho (Togo).

of concrete blocks placed by specially conceived cranes, each block weighing from 4 to 8 tons, often with side slopes of 2 to 8 tons of granite. Nevertheless erosion was not stopped outside the groins' extreme end, and furthermore the outer parts were not kept up. Lack of maintenance played a role. The land ends were extended gradually as dunes and dikes were withdrawn. Artificial nourishment using bay and offshore sources has not, surprisingly, been called upon though needed, in particular on the Lime Fiord Barriers (Figures 20b, 20c).

Germany

Along the coasts of Germany, especially those on the North Sea, situations similar to those of Denmark and The Netherlands prevailed throughout history. The eastern Friesland islands belong politically to Germany but differ in no way from their counterparts under Dutch sovereignty. Groins were implanted along the coast and some failures made history. Beaches on Sylt and Langeoog received artificial nourishment (CHARLIER, DEMEYER, DECROO, 1998) (Figure 21).

England

England, like Belgium, has lost several shore towns to the sea. Erosion is a harsh reality. It has a similar long history of coastal protection because of the steady retreat of strategic coastlines on the South Coast, in Lincolnshire, South Yorkshire and along several estuaries. Reclamation works have been undertaken as far back as during the Roman administration in the Dungeness area, the Rhee Wall bearing witness. Abundant and continuous historical evidence of sea incursions along the Lincolnshire coast exists, for instance the references in documents to loss of land and damage to "sea banks", a necessary defense since the 13th century. Other records indicate waves breached the sea banks at Maplethorpe with ensuing flooding of the surrounding area. Here, by 1340, the sea wall needed repair again. Erosion continued and the fight against the onslaughts of the sea persisted. As elsewhere earthen banks were the predecessors of *fascines* and pile-walls. After vertical bulkheads were installed, sloping blocks were placed. Groins complemented the bulwark: in 1690 one was built at Hornsea, and later, six groins were placed at Spurn Head (1890). Floating breakwaters were also used in the late 18th century as shown in a painting hanging in Brighton's Museum and attributed to John Constable, an English painter of renown.

Romania and the Black Sea

Romania has long opted for the hard coastal defenses to protect its coastal zone activities which, besides tourism, include industries, agriculture and fisheries. Annual beach profiles have shown an erosion rate reaching as high as 60 and even 70% (Figure 22).

Anthropogenic influences upon this environment is significant: decrease in Danube sand supply, contour morphology modification, molluscs' thanatocoenoses. The range of factors is wide: port construction, maintenance of navigation channels, irrigation, countering of soil erosion, hydroelectric power generation, marine pollution, creation (unintentional) of sand traps, and others. Strong erosion has been observed in the northernmost part of the 250km long coast. Figures released by the Romanian Institute for Marine Research (RIMR) show losses of some 77 ha/year (1962–1991) between Sulina and Vadu, an inland migration of the shoreline on the average 200 m (but in spots reaching 340 m) during 1965–1995, and in accretion areas a gain of 6 ha/year, leaving a net loss of 71 ha/year! Cliff destruction results in a retreat of 15 m on the average.

Protection efforts have been mainly aimed at preserving tourist resorts. In Mamaia harbour construction in adjoining areas have resulted in sand starvation. A longshore breakwater has been built: made of plastic tubes it did not show concrete results. Beach nourishment has been carried out but involved merely 2700 m^3 (3537 cu.yd) of sand. In the 22 years span of 1966–1988 the beach in its northern part lost about 59m (approx.180 ft) of width and its area shrunk by 89,000 m^2 (163,760 sq.yd) (TANASE, 1992). In terms of "beach space utilization" 11,100 places were lost.

Hard structures were put in place south of Constan, a (9 sea-walls) and at Eforie (19 sea-walls). Further to the south shore linked jetties were built, drainage carried out and cliff protecting embankments put in place. Lack of financial means has severely curtailed coastal protection efforts since 1990. Concommitant with erosion, degradation has been reported under the form of biological changes and declining biodiversity.

The two major sectors of the coastline differ geomorphologically. In the north the barrier islands and spits that frequently shift remind of the United States' southern Atlantic coast problems. The southern sector is the site of both cliff retreat and inland migration of the shoreline. Romanian re-

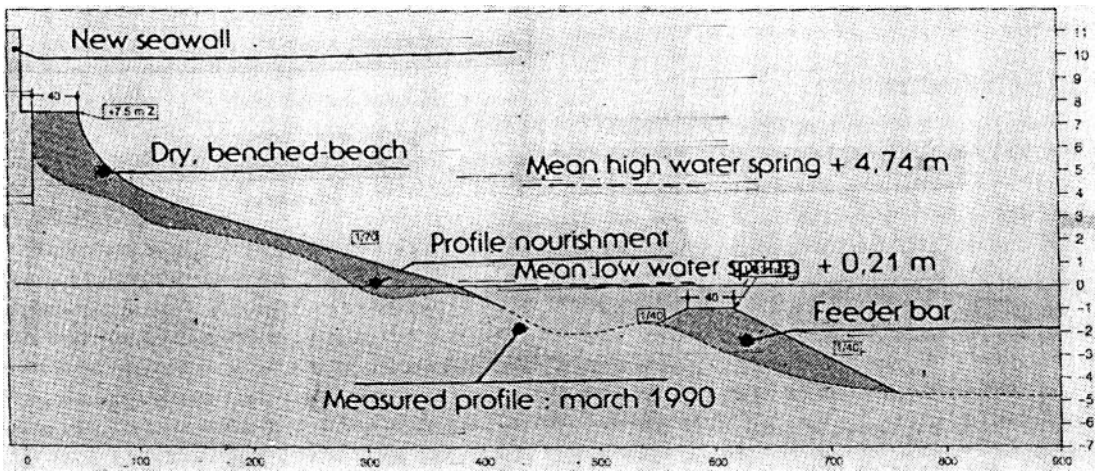


Figure 35. Relative position of feeder bar, beach and dry benched beach (De Haan, Belgium).

searchers for the western Black Sea, Russians and Ukrainians for their own coasts, have followed the developments for decades and reported on the shifting of the coastline; it appears that traditional hard defenses have not stayed regression and loss of beach and that at best where breakwaters, groins and the like have been implanted the problem has been shifted down-current. Beach nourishment has been utilized along the Black Sea coasts. It provided regional relief but maintenance proves a costly undertaking, and quantities of material seem to be hardly sufficient for a prolonged defense and restoration.

Elsewhere

Estuarine and Riverine Protection in China

Authors were unable to ascertain when the first levees were constructed in China, but there is no doubt that they are contemporary of, or older than their European counterparts. Apparently they are earthen dykes offering little protection when their basis is water saturated. They line the Yangtze-Kiang but also other rivers and water bodies such as the Hanjiang, Songhua, Nenjiang and Yellow rivers and Dongting Lake. Dike cave-ins have led to the official admission that the protection and flood control systems are antiquated and that the 1998 catastrophe has been mismanaged with more victims and losses than the previous worst flood of 1954 (*China Daily* p. 1, Aug. 25, 1998; ibid. p. 1, Aug. 26; Int. *Herald Trib.* p. 1, Aug. 27, 1998). Similar problems have arisen with the Loire and Scheldt rivers throughout history.

Defenses in North America

In the United States experiments were conducted with a variety of hard structures: seawalls, groins, permeable- and other types of breakwaters. The American approach, with conservation of the touristic and economic patrimony in mind, has eyed as much beach restoration as coast protection. Because much coastal property—in opposition with Europe—is privately owned, the government's role has been hamstrung to help where it might have wanted to.

Up to the thirties, the United States government showed no concern for coastal erosion affecting privately owned shoreline property. But the role of government, mostly through the US Army Corps of Engineers, has steadily expanded. Though increasingly controversial, a Federal insurance program, compensating private citizens for damages suffered through storms and erosion, was initiated many decades ago. It may well be faced out. Individual States have also taken anti-erosion measures, mostly in cooperation with the Federal agencies. Many have enacted drastic regulations compelling abandon of property at constant risk and rolling back permitted construction lines inland. An abundant literature exists dealing with coastal protection and the topic is brought to the fore very regularly and frequently at international conferences (International Coastal Symposium 1998). Groins have been placed in several locations such as the sea side of Long Island (NY) and Miami Beach with at best mitigated success and the usual down drift starving of beaches. Artificial nourishment has been carried out in many sites, however it too has come under fire to the extent of being likened—perhaps unfairly—to building sand castles.

Development of Lowlands Groins

Groin-like structures were put in place, in The Lowlands (today parts of The Netherlands, Belgium and Northern France) well before the dawn of the 16th century. There is no information on what they looked like; on the other hand we are far better informed on the history of development of protective structures, streamlined and submitting themselves as little as possible to the forces of waves and currents, covering the last 100 to 150 years. Even though the groins have expanded size-wise, the engineering principles remained the same: stone (rubble) pitching on gravel and mattresses in the center, stones on mattresses on the sides with two, or more, pile walls as supports (Figures 23, 24, 25).

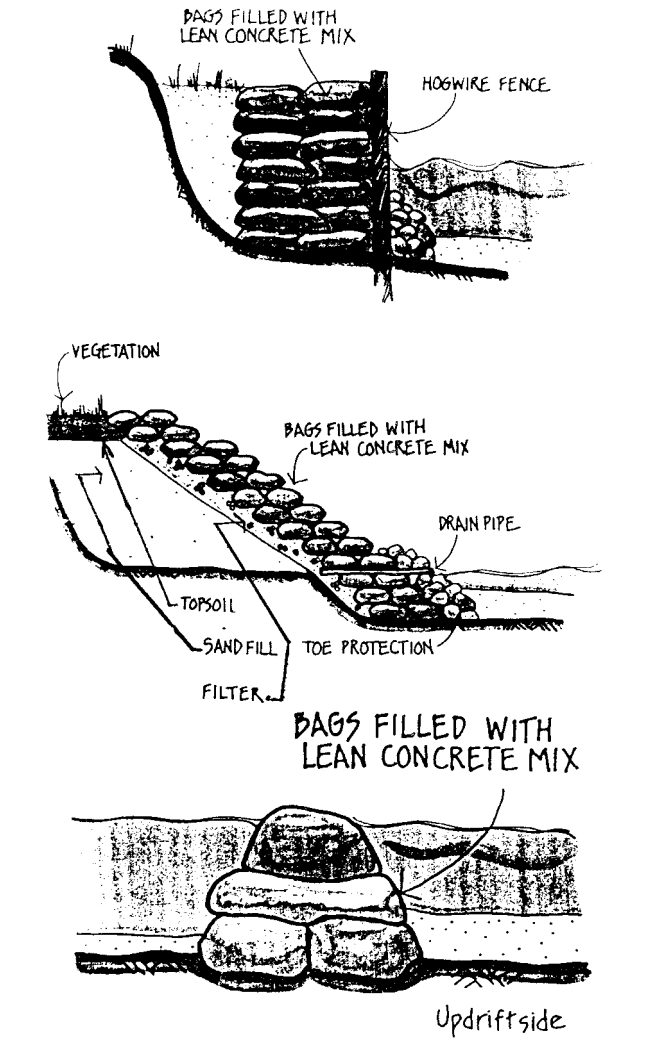


Figure 36. Relatively efficient, slightly sophisticated, in use locally since the fifties, these schemes may be a base for artisanal protection devices in developing countries: using bags filled with lean concrete and held with hog wire fencing an inexpensive "groin" may be constructed, even improved with filter and drain and toe protection. On the right, devices made of H-piles and railroad ties; pile-and-plank; anchored floating tires; a sloping model with concrete blocks or slabs, and rock filter with filter cloth.

Nothing is new under the sun: if coastal defense approaches include nowadays artificial reefs, the artificial character being merely that they are man-installed or that the fronds are artificial as well, already in he 8th century were weed-dikes installed in West Friesland and near the Zuiderzee shores. These sea-grasses, gathered off-shore in the Zuider- and Wadden seas, were dried and then placed on the sea side of the dike.

However before long hard materials were brought in to reinforce dikes, as said before, and rock blocks were placed perpendicular or parallel (even in some rare cases at an angle) to the coastline. Obviously these hard structures became the groins, breakwaters and seawalls we know today. Much has been said about the "Delta-Works" and there was no unanimity about their completion. Their impact has not always been favorable for areas of the upstream Scheldt River (Dutch: Schelde; French: Escaut) (Figure 26).

Coastal protection originated from medieval industry as well! The demand for mechanical power fostered tapping ocean energy (HOUMUALCK, 1987; FOUCHER, 1998; CHARLIER and MENANTEAU, 1998). Development of tide mills, particularly from the 15th century on, encouraged their better protection against severe storms. Often indeed mills were completely destroyed by the sea, a consideration that in fact led to their demise in various sites, *e.g.* in England.

Such mills had dotted the coasts of England, Wales, France, Spain. Millers protected their structures sea-side with abutments which constituted strong breakwaters and, indirectly, benefited neighboring areas as well in their stand against the onslaught of unchained seas. Some of these structures have been preserved, occasionally restored; on the coasts of the French department of the Côte d'Armor the mills near Perros-Guirec provide remarkable examples.

VISSER (1953) gave a picture of groin development since 1854, but it is certain that groin implantation goes back to the early 16th century, or even earlier (see above). Also during the second half of the 19th century groins were built along the Belgian coasts often with piggy-back poles, and on the French North Sea coast (*e.g.* from Bray-Dunes to Malo-les-Bains facing Dunkirk). What BAKKER and JOUSTRA (1970) say for Dutch shoreline is generally equally true for the coasts south of the Dutch border.

It seems, however, that the groins which slowed down or stopped erosion at one time, and even nurtured accretion, do not carry out the same effect since a decade in Belgium and France. In Holland and Zeeland currents and swell action bring in offshore material avoiding or reducing the usual groin caused starvation. This is one case of rebuilding the beach with Nature's help, a case of artificial nourishment by Nature.

If there are several instances of Dutch workers reclaiming land and drying up marshes abroad (*e.g.* Russia, Italy), they are also instrumental in protecting shores in Germany, Poland and Russia. As mentioned earlier among the first countries to put groins in place figure Denmark and the United States. "In Denmark coastal protection started on the North Sea coast in 1840 with a government project to increase the height of the dunes on the Lime Fiord Barriers" (BRUUN, 1953). Groins were tried out in 1870, successively reinforced. In Miami Beach the groins proved inadequate as sole protection, and on Long Island (New York), regardless of claims to the contrary, they were not efficient and created very serious problems (CHARLIER, 1956). On the coast, groins put in place in the thirties caused leeward erosion that resulted in losses of up to 10 m (33 ft) of land a year.

Contrary to the lack of understanding shown in a Belgian high government level bureaucratic report at the turn of the century, engineers and geologists there were well aware of the disadvantages of groins, and of their effects down-drift.

Taking Distance from Hard Structures

Since the latter part of the 20th century planners responsible for coastal protection have taken their distances, when-

Table 1. *Comparison of coastal protection approaches.*

GROINS		TRAINING WALLS, SHORE PARALLEL STRUCTURES, SEAWALLS, REVETMENT	
A) Classification:		A) Classification:	
Beach Groin	A coastal structure usually built perpendicular to shoreline to trap littoral drift and thereby retard erosion or shore. Narrow in width, with it's length varying from less than 100 feet to several hundred feet. Stabilizes, restores or widens a beach.	Training Wall	A structure placed parallel or nearly parallel to shoreline affording protection against waves and/or currents and retaining and preventing sliding of upland areas.
		Sea Wall Bulkhead	A vertical or nearly vertical structure primarily designed to retain fill and stop erosion at a certain point or line.
Current Breaker Groin	A groin with primary purpose to intercept currents which cause movement of material along a beach. Light to heavy design with lengths up to 1,000 to 2,000 ft.	Revetment	A sloping facing with primary purpose of providing protection against erosion of a dune scarp and beach in front. Sand accumulation in front is a secondary result from reduced wave energy.
B) Type:		B) Type:	
Nonadjustable	A fixed groin high enough to block most of normal littoral drift but low enough to allow over-topping by storm waves carrying sand over groin.	Vertical	A massive structure with variations in shape such as stepped and re-entrant curved face, vertical face, non-re-entrant curved face, cellular sheet pile and rubble mound.
Adjustable	Groin with adjustable length and height.	Sloping (revetment)	A concrete or stone facing placed on seaward slope.
Impermeable	A solid or nearly solid structure preventing littoral drift passing through structure.	Impermeable	A solid or nearly solid structure. Seepage through structure through properly located drains only.
Permeable	A groin with openings through structure, of sufficient size to permit passage of littoral drift through openings, will obstruct currents to some (variable extent).	Permeable	A stone crib vertical wall or sloping rubble mound or rough stone revetment allowing movement of water inward and outward thereby dissipating energy,
OFFSHORE BREAKWATERS		**ARTIFICIAL NOURISHMENT**	
A) Classification:		A) Classification:	
Shore-parallel breakwater	A structure built parallel to and at a distance from the shore to absorb and/or dissipate wave energy and thus prevent or reduce wave action on the lee side.	Direct nourishment of beaches	Operation of replenishing and nourishing an eroded beach directly by artificial means, that is, supply of dredged or other sediment material to eroded areas as a whole.
Shore-perpendicular breakwater	A structure connected to the shore in a perpendicular or nearly perpendicular direction mainly used to provide a protected area or harbor.	Bypassing at inlets and entrances	Operation by which normal littoral drift interrupted by inlets or entrances (littoral barriers) is restored on downdrift side by artificial means of sediment transfer across barriers.
Wave breakwater	An offshore structure built perpendicular or parallel to the shore to dissipate wave energy and thus prevent or reduce wave action on the lee side.		
Current breakwater	A structure used to break current.		
Floating breakwater	A structure of hydraulic or pneumatic or barge fabricated type to serve as a breakwater.		
B) Type:		B) Type:	
Vertical	A vertical or nearly vertical structure of masonry concrete, concrete, or steel caison, sheet piling cells, or timber crib. May be of solid impermeable, permeable or of rock crib. Main purpose is to protect against wave action.	Offshore dumping method	Dredged material dumped in offshore zones of eroded areas.
		Stockpile method	A stockpile established on an eroded area and nourished intermittently.
Sloping	Most common is rubble mound of natural rock or built-up pre-cast concrete blocks. Used extensively as wave energy absorbers in the open sea as well as on shores.	Direct placement method	A method similar to stockpile method except entire fill is spread out over entire area to be protected.
		Bypassing or continuous nourishment method	A mechanical method of intermittent sand bypassing from updrift (accretion) side of inlet or jetty entrance to downdrift (erosion) side without interference to navigation channel. Also continuous nourishment of eroded area.

Table 2. *Overview of alternative approaches and systems for coastal protection on the market as of 1997. Some available schemes are not yet included herein. (Summarized from O. Pilkey)*

Device	Harms Beach Access	Erosion of downdrift beaches	Erosion of fronting beaches	Potential hazard to swimmers	Impact on water quality	Impact on turtle nesting*	Impact on clam resource*	Impairs Aesthetics*
IN WATER								
Atlas Shoreline Protection System	X	X		X	X			X
Beach Prisms		X		X	X			
Beachsaver Reef		X		X	X			
Menger Submerged Reef		X		X	X			
MOTO		X		X	X			
Pep Reef		X	X	X	X			
Sealift		X		X	X			
Shoreprotector		X		X	X			
Surge breaker		X		X	X			
Temple Beach Systems	X	X		X	X			X
Waveblock		X		X	X			
Waveshield		X		X	X			X
Wave Wedge		X		X	X			
Beach Cones		X		X	X			
Beach Protector Tire Mat								
Burns Beach Erosion Device		X		X	X			
Cegrass		X		X	X			
Coil System		X		X	X			
Seabee				X				
Seascape		X		X	X			
ON THE BEACH								
Brush Fence		X		X	X			X
Holmberg Undercurrent Stabilizer		X	X	X	X			
Parker Sand Web	X	X						X
Shoreline Construction Corp.		X	X	X	X			
Stabilito		X	X					X
High Energy Return Wall		X	X	X				X
Marine Bin Walls		X	X	X				X
Ravens Retaining Wall		X	X	X				X
Wave Buster		X	X	X				X
Z-wall		X	X	X				X
HDSI	X					X	X	X
Stabeach	X					X	X	X
Biodune Sand Gel			X					
Dune Guard			X					X
Fabric Fence			X					X
Nicolon Geotube			X					X
Soukup Rubber Tire Revetment			X					X
Subsurface Dune Restoration System			X					
Triton Marine Mattress			X					X
Beachbuilder Technique						X	X	X
Stabler Disks	X					X		X

SOURCE: Journal of Coastal Research, Special Issue No. 26, 1998, p. 270.
* These columns are of significance only for specific areas.

ever possible, from the hard structures. Several new approaches have been developed, both to protect the coasts and to rebuild beaches ravaged by erosion. The alternative, soft approach, artificial nourishment is not so new. The method has been used in the United States when just after World War I, sand was deposited on some California beaches. Since then soft methods have encompassed beach nourishment, bypassing, back-passing, dumping and stockpiling, occasional and continuous nourishment; but there is also de-watering, profile nourishment, and berm feeding, a more sophisticated offshore dumping method.

Sand groins have been built in Sylt (Germany) early in this century. The groins placed near Soulac (Gironde estuary, France) from the 1880s on, have been steadily demolished by the sea, but there is still a groin field in existence (Figure 12). Monaco constructed a suspended beach with an underwater berm in the seventies at Monte Carlo (Figure 27). Israel has experimented with offshore breakwaters near Tel Aviv (Figure 28) and a headland system has been put in place in Singapore (Figure 29). Groins proved of little help in Bali (Indonesia) (Figure 30). On Java, breakwaters made of metal drums filled with concrete proved to have disappointing effects even though they provided some spacing (Figure 30b).

Another concept of relatively recent date is that of "episode" in nourishment assessments proposed as "an event when sand is deposited on a dry beach or, in some cases, the nearshore, by truck or dredge". Construction of a feeding berm would thus be for Pilkey and some others an "event".

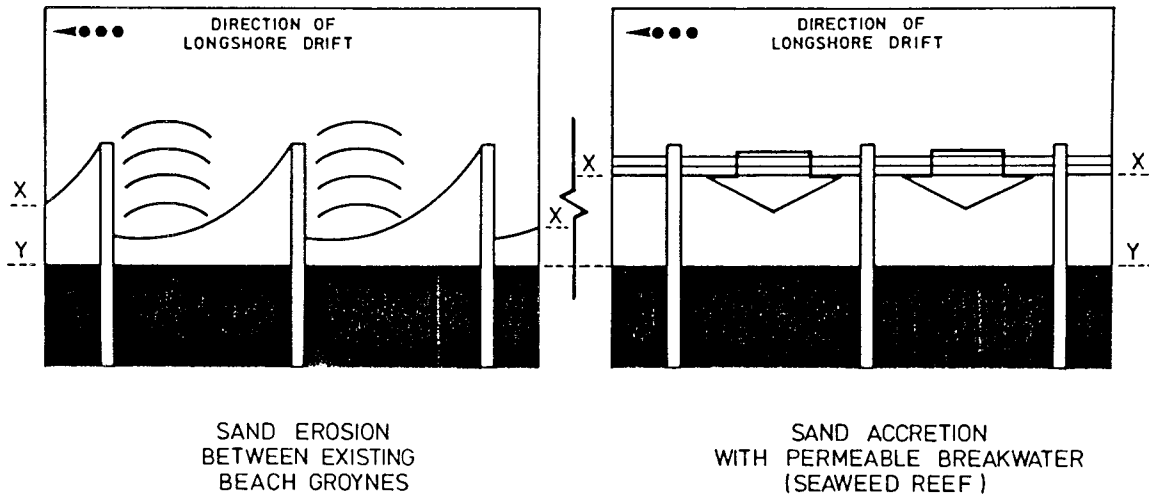


Figure 37. Beach stabilization, scheme with algae.

A "nourishment project" in turn would then be "a location where a series of nourishment episodes have occurred". Furthermore considerable attention is given to another development concept, ICZM (Integrated Coastal Zone Management), whereof nourishment is now commonly an ingredient. Something that was ignored, with dire consequences, in Taiwan. Re-nourishment projects take on very large aspects: the largest British one may well be that between Maplethorpe and Skegness in Lancashire where some 6.5 million m^3 of sand (8.42 million cu. yd; 2,927 million cu. ft) were placed along an 18 km (6.7 miles) stretch of shore.

TODAY'S DEFENSE APPROACHES

If new approaches to coastal defenses were slow, and little new technology was introduced during the centuries—though improvements and refinements were often made—the pace of change accelerated considerably in the 20th century, even more so during the last decades. The largest beach nourishment achievement (Belgium, 1980s) has been surpassed, profile nourishment and berm feeding have been implemented—aimed simultaneously at restoration and protection—not less than forty alternative methods have been proposed and tried out (Table 2). But the problem has not been solved; for instance all 30 of the US coastal states suffer from erosion and some see Hawaii's tourist industry in jeopardy.

Barrier islands line US coasts for instance of Alaska, Virginia, the Carolinas, Georgia, Florida, in fact all the way from New York to Texas, but also of China, India, Australia, and in Europe for instance The Netherlands. Jennifer Ackerman (1997, ("Islands at the edge": *National Geographic* 192, 2, 2–31) recently made a plea for the plight of beaches and ecosystems of barrier islands of the United States. However, the remarks can address any coast, mainland or other.

Protagonists and opponents of beach artificial nourishment alike, underscore the cost of maintaining the beaches of Miami Beach, a barrier island on Florida' east coast: the fine coral expanses of *sable coquillier* (coquina-sand) had to be replenished with coarser sand and the renewed beach has lasted sixteen years thanks to $60 millions of US taxpayers money. The 8.5 km of new beach at Sea Bright, close to Monmouth Beach, New Jersey, once protected by a 5.2 m high seawall, successor to many modest predecessors, extracted $36 million. On the average the price tag in the United States to restore a beach runs $366,000 per km. Opponents of artificial beach feeding point to the fact that it took only about a year for the sea to swallow up half the beach at Monmouth. It is like filling up the Danaides' barrel (CHARLIER, DE MEYER, DE CROO and LAHOUSSE, 1998).

Opponents of groins, breakwaters, jetties and the like have plenty of cases to buttress their position: in the late twenties the lighthouse of Little Egg Harbor on New Jersey's Tuckers [barrier] Island tumbled into the sea after standing as a beacon for 79 years on the Atlantic coast. Why? The island was 'sand-starved' because jetties, at Long Beach to the north, deviated longshore currents and let waves scour Tuckers Island's beach. Damming the river of sand [that moves along the shore], a stone [or rubble-mound] groin essentially robs Peter to pay Paul (S. Leatherman, public statement). If jetties damage less as they "train natural effects, sea-walls take wave action head on, with disastrous results" (R. Thieler, public statement). But whether made out of wood, steel, concrete or rock, shore parallel sea-walls deflect wave energy and thus offer wave and storm surge protection but may increase current force and accelerate downdrift beach erosion, and by preventing the landward movement of sand in an area, curtail its ability to respond to the storm's energy.

Beach erosion is also increased by constructing too close to the water line. The construction line must, and has been in some US States, moved inland and dunes must be kept, not bulldozed, even rebuilt if possible. Along the US coast a true *Atlantik Wall,* a name of sinister memory, has been built on barrier islands: in the eighties some 2430 hectares were gobbled up a year. There are today 466,620 hectares (1,152,551 acres) of barrier islands "protected" by US law, but the Acts

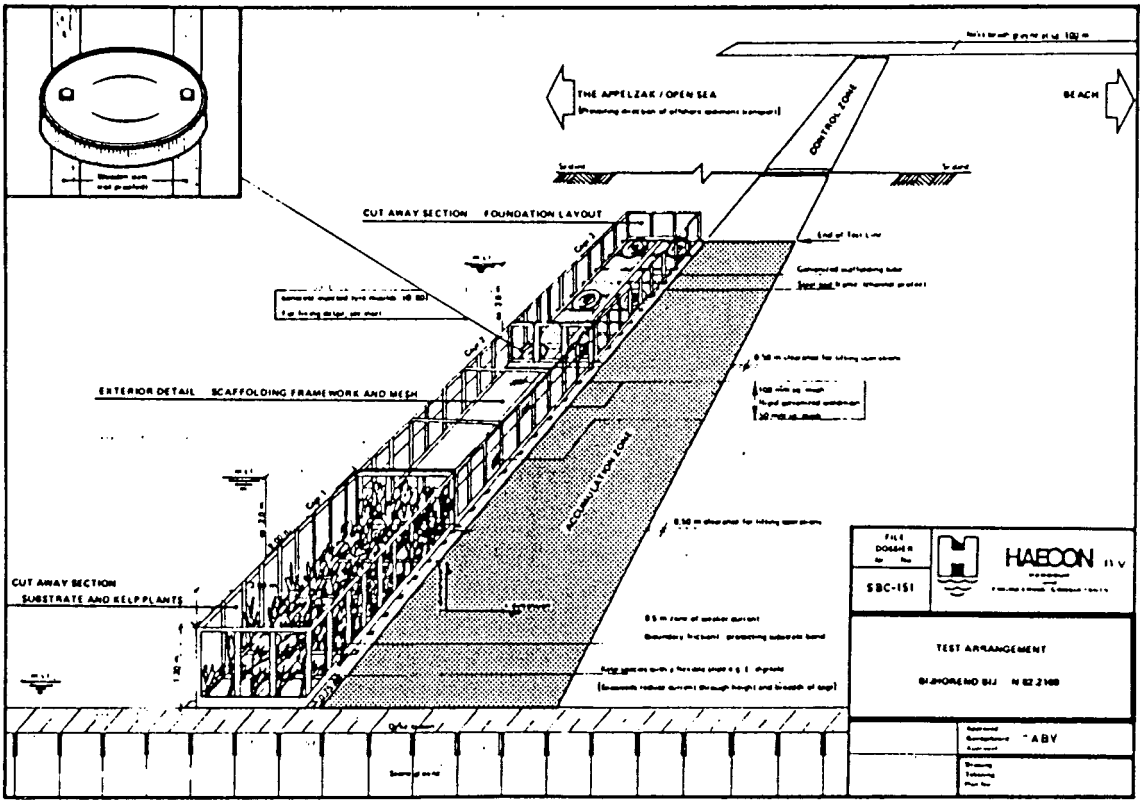


Figure 38. —Cages array for algae artificial reef. Source: HAECON N.V., Ghent, Harbour and Engineering Consultants.

of Congress of 1982 and 1990 do not actually forbid development, they only warn would-be builders that they cannot count on the Federal Government to provide insurance or reconstruction funds in case of damage due to storms, floods and so on.

Current and Past

Man has imitated Nature in his endeavors to protect shorelines (CHARLIER and DE MEYER, 2000). Rock structures, headlands may be compared to sea-walls, mounds, breakwaters, reefs, limestone formations to offshore breakwaters; artificial nourishment from land and offshore sources have effects similar to drifts. The role of reefs in coastal protection has been widely re-emphasized during the 1997 International Year of the Reef. Living corals, but also limestone, coquina formations and beach rock play an anti-erosive part; damage caused them may cost dearly the coasts behind them. And the importance of dunes in coastal planning should not be underestimated.

An unusual "training" wall placed offshore Durban (Republic of South Africa), gradually completed between 1966 and 1972, required 5 million m^3 (176.5 million cu.ft) of sand; for Bruun it remains stable and reduced wave action. May this not be compared to a berm, even if its purpose is protection rather than restoration? Furthermore were the sand breakwater to fail, the material would provide artificial nourishment, just like a feeder berm does.

Interesting anecdotes in connection with the Indian Ocean coast of South Africa are recalled by J. R. E. Lutjeharms of the University of Capetown (Rondebosch) [(unpublished, personal communication at the 6th International Congress on the History of Oceanography, Qingdao, P.R. of China]. Near Port Elisabeth (RSA) an accumulation of lost anchors, just offshore of the port, had been attracting the attention of two entrepreneurs who proposed to retrieve them—by actually just lifting them from the sea bed and "tugging" them—and depositing them close to the harbor entrance. They would act as a breakwater made up of interlocking units much less vulnerable to destruction than stone, rubble or concrete. The idea was accepted but to the dismay of harbor-masters the anchors-made breakwater soon constituted a problem for navigation and port access. Removal of the "structure" was decided but proved difficult, costly, required blasting as the anchors had solidly interlocked into an insolite chain.

Such a type of "permeable" breakwater may be compared to coastal protection made with dolosses, also interlocking units, yet "permeable". Lutjeharms provides an explanation of the name dolosse: European settlers of South Africa were poor and their children had to use their ingeniosity to create toys. They made carts or wagons out of the jawbones of large animals; their boney protuberances, somewhat irregular in

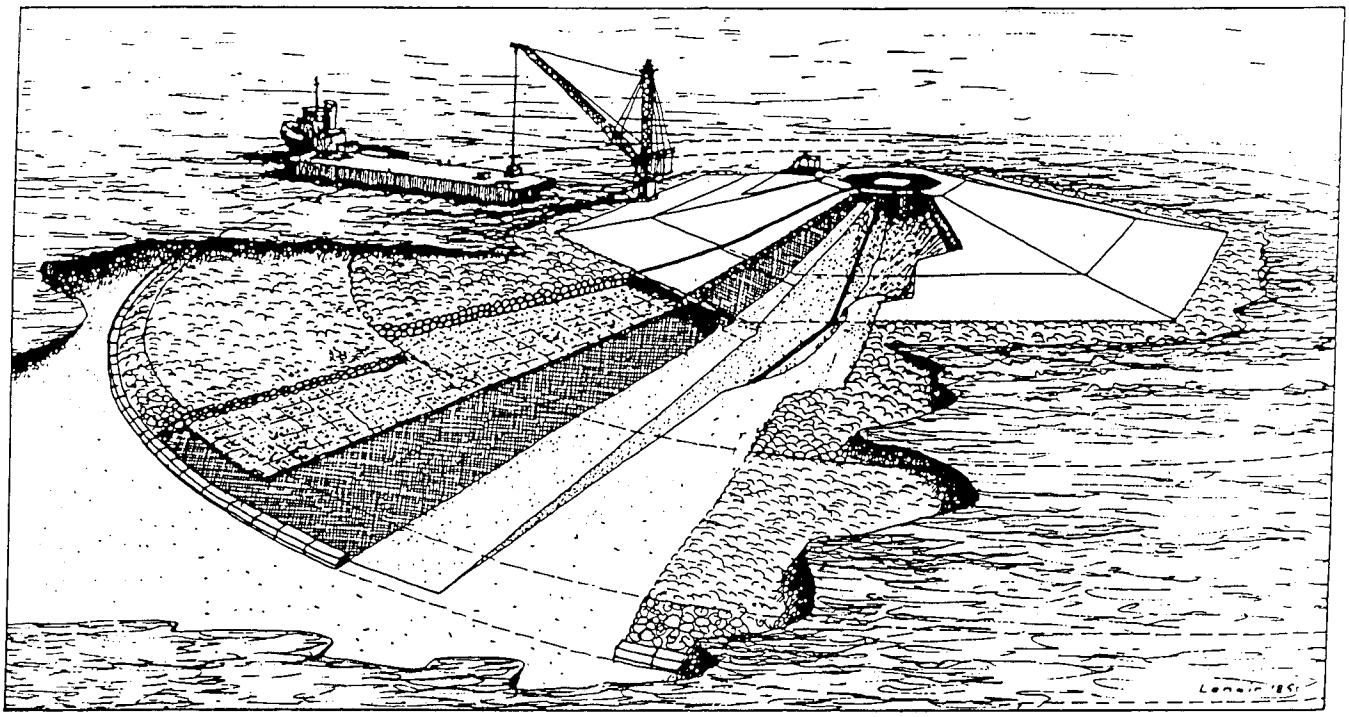


Figure 39. Boskalis Westminster's award winning design for a slope-protected, sand-fill island to be used by the Dutch hydrocarbon company NAM as a pipeline valve station.

shape were called by the children (in Afrikaansch) *dolos.* We will leave the responsibility of the etymology to our distinguished colleague!

HARD AND SOFT PROTECTION METHODS

There are many groins, breakwaters, dikes, sea-walls, revetments, dolosses, tetrapods and other structures still in use today but many engineers and geologists look askance at the hard protection schemes. Artificial nourishment whereby sand is brought to a site has its detractors as well but is favored in many instances. To simple deposition of material on a beach decision-makers prefer commonly profile feeding and/or berm feeding. Many lessons have been learned that encompass judicious choice of feeding material, preservation of source material sites, wave climate, *etc.* Beach nourishment may act as both a protection and restoration project. It has been implemented in Europe, North and South America, Australia, Asia, but also in Africa. Hard structures have been inefficient in Sierra Leone, Guinea, Nigeria and Ghana. Beach nourishment is used as a stop-gap measure even under panic conditions when the beaches are not raised above mean high water level and/or the foreshore gradient is too steep. (DE WOLF *et al.,* 1995; ARWOSICA, 1997; JOHNSON and JOHNSON, 1997) (Figures 31–34).

Likewise in Taiwan the economic success exacerbated erosion by proceeding a.o. with large scale land reclamation in tidal areas, and the loss of wetlands. At Pali Beach, on the northwest coast, the shoreline receded 500 m (1640 ft) over two decades, affecting 1000 hectares (2,741 acres), even 15,000 hectares (41,115 acres) (CHIAU, 1995). Lack or neglect of understanding the natural processes, of harmonization with neighboring coastal projects, and dam construction created additional erosion problems. Furthermore acute downdrift damage resulted from an attempt to solve the problems by placing hard structures, unfortunately inadequately conceived, which proved inefficient. Though CHIAU (1993, 1995) does not say so, apparently beach nourishment seems to have been indicated, and so are a systematic study of Taiwan's coast and promotion of education and training programs dealing with coastal issues for decision-making and decision-implementing officials, and the general public.

In the late fifties new groins were placed on the Belgian coast between Nieuwpoort (Nieuport) and Zeebrugge made of cemented basalt slabs; the central part is lowered over a small third of their length starting at the shore so as to provide easy access to maintenance vehicles even at mid-tide. This ingenious design has one drawback: it favors the generation of eddies at incoming tide. Simpler groins are placed in front of dunes, which are in spots anchored by tree plantations (*Pinus austriaca nigra*), in locations in between resorts. They were common east of Bredene and west of Wenduine; made of concrete their height can easily be increased as sand piles up. Few still subsist.

Cells and Pockets

Cells and pockets have been mentioned, but the "novelty" of the concept may be compared to Nature's own way; though one may attempt to improve on the large natural pocket

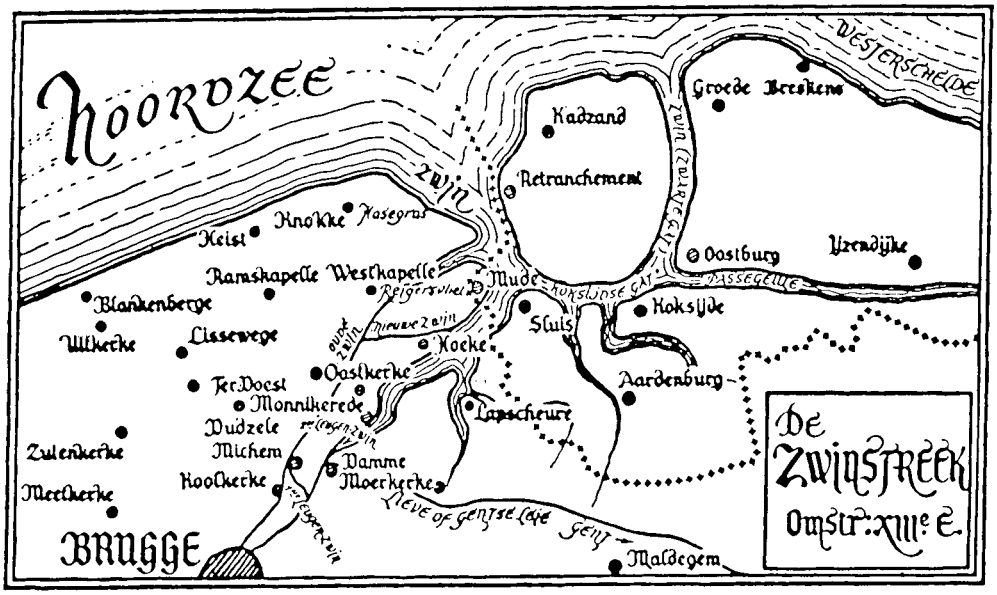


Figure 40. The Zwin Region in the 13th century. The inlet allowed large ships (for the times) to reach Brugge—then nicknamed the Venice of the North because of its wealth, ship traffic and canals (*reien*). Notice the "inland" location of the towns of Knokke, Heist, Blankenberge, e.g., currently on the shore, prior to the subsequence "advance" of the sea; the ++++ boundary, superimposed (not by author) on the original map, is meaningless for a 13th century document, it represents the 19th century Belgian-Netherlands State boundary. (Translations: *Noordzee* = North Sea; *Westerschelde* = Western arm of Scheldt River; Brugge = Bruges; *Lieve of Gentse Leve* = Ghent branch of Lys River).

beaches. Taking advantage of headlands, extending them further offshore by a breakwater, several pocket beaches may be created. Pocket beaches may also be made by sand stockpiling at intervals on a beach. This approach was successfully tried in the sixties in Venezuela.

Great Britain has frequently executed major artificial nourishment projects. It undertook several large "coastal reviews", some covering more than 10,000 km (6,200 miles) of coastline.[1] Some led to the definition of "management cells and sub-cells" as a basis for defining "sustainable shoreline management". A cell is classified according to coastline length within its boundaries: 50 m (164 ft) long are micro-cells, 50 to 1000 m (164 to 3280 ft) are meso-cells and larger than 1000 m (3280 ft) are macro-cells. Sediment transit occurs either within a cell or between cells. Larcher sees thus countering uneven sand-budget triggered erosion by use of a coast-smoothing device such as artificial cells integrating eroded area within the inter- and intra-cell transits (ANONYMOUS, 1995a; LARCHER, 1995). They are made of artificial ripple systems, made out *e.g.* of easily installed hollow modular careens. This eventually creates sandbanks, in other words feeder berms. Littoral and Patrimoine Ltd claims that the system applies equally to bluff and beach protection.

[1] For a historical sketch of beach nourishment 1914–1984 see R.H. Charlier, C.P. De Meyer & D. Decroo, 1989, Soft methods for beach protection. In E.M. Borgese, N. Ginsburg & J. Morgan (eds), *Ocean Yearbook VIII:* Chicago, Univ. of Chicago Press, pp. 289–328; for more recent years see a.o. Anonymous 1995b, Charlier & De Meyer 1995, 1998: Larcher 1995; see also P. Bruun, 1990.

Feeder Berms

A beach profile nourishment scheme put in place at De Haan (Le Coq), Belgium aimed at restoring the beach and the dunes back of it gained in protection. 2200 m (about 6500 ft) long it was built with 600,000 m^3 (864,600 cu.yd) placed offshore and 800,000 m^3 (1,048,000 cu.yd) placed directly on the beach. Such feeder berms have also been placed at Agadir (Morocco) and Mobile Harbor (Long Island, NY) (CHARLIER and DE MEYER, 2000; BRUUN, 1990) (Figure 35).

Sand By-Passing and Compensation-Dredging

Sand by-passing consists in transferring sand from the side of a man-made structure where it has accumulated to the other starved side (BRUUN, 1990). By-passing of littoral drift is de facto reestablishment of Nature's processes with which man had interfered. Either by-passing plants or by-passing schemes can be used; plants can be fixed, *viz.* they are permanently established in a given location, or movable such as is the case in India and offshore Durban (until 1953) in the Republic of South Africa. Back-passing is a similar method.

In compensation dredging material is dredged and carried away from one site to another where a beach needs feeding.

Sand Dunes

Sand dunes may be "anchored" by Nature or by man, using vegetation. (CHARLIER and BEAVIS, 2000) The oldest dike on record in Northern Europe was built in Friesland. The willow mattresses have usually been replaced by mats made of synthetic materials like nylon or polypropylene.

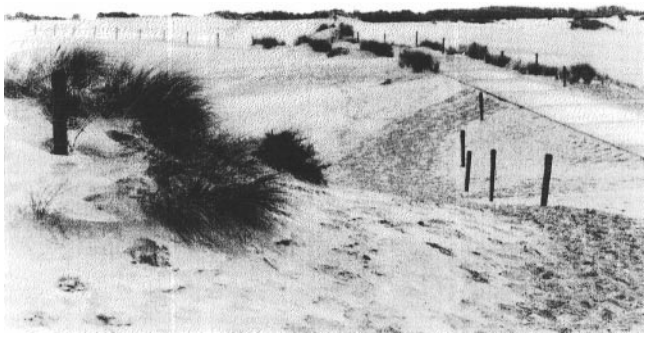


Figure 41. Entrance channels provided for the sea into the dunes where once armored seawalls had toe protection. Photograph courtesy Flemish daily from Ghent; Belgium "Het Volk".

Sausages and De-Watering

Synthetic sand-filled tubes—"sausages"—have tested satisfactorily but require anti-ultraviolet rays protection.

By draining way-below-surface water, a beach dries out and re-establishes friction between sand grains, stabilizing and allowing accretion. Sometimes a self-sufficient system, de-watering is often a complement that extends the useful life of artificial beach nourishment.

Curtains and Sheets

Such methods as Berosin™ and Beachbuilder™ use covers to retain sand grains. The Beachbuilder may be used as a complement to nourishment.

Inlets

In Northern France and Belgium breaches have been made into the dunes bordering the beaches so that the sea can enter this barrier. The results are said to be encouraging and local erosion reduced.

RIBs

The earth mounds of the Frisians would not do today, hard defenses are generally rejected as a solution, but "breakwaters" are still proposed with a new twist. To name a few there is the HARO™, a lighter, permeable structure; segmented breakwaters; Y-shaped groins; and perhaps the most recent innovation: the RIB. It unequivocally has military applications, but this product of the US Army Corps of Engineers has widespread civilian applications ranging from rescue and recovery operations, marine construction to temporary craft-shelters and dredging operations. The Rapidly Installed Breakwater (RIB) is a floating device consisting of a V-shaped structure with rigid vertical "curtains" extending from the surface toward the bottom. Its tip is oriented into approaching waves, spreading or deflecting them. Incident waves are not absorbed but deflected (reducing net force on mooring lines), directed away from the "V"'s interior. The V's legs, joined at the front of the "V" by a noise buoy, allow their interior angle to vary from 0 to 60°, measure in length from 213 to 305 m (700 to 1000 ft), and can be linked together for easy towing.

Two RIB versions have been tested: a hard, welded-steel segmented structure with closed-cell foam flotation and a monolithic soft one made of two large "water beams", a watertight vinyl sock encased by a polyester webbing, deployed from large reels and using seawater to pressurize the legs. With either one wave height was reduced more than 15 m (50 ft). However, a smaller, less expensive "civilian" version, more versatile is believed to be ideal for temporary, in situ, emergency or construction situations with wave height reduction exceeding 18 m (60 ft). A RIB system was to be deployed off Florida's East Coast during the Summer of 1998 in 15 m (50 ft) deep water with legs 120 m (400 ft) long. No results have been publicized thus far.

Semi-Permeable Structures and "Home-Made" Defenses

The West African coastline, southwards of Senegal, has suffered severe erosion for decades, and land loss reached alarming and devastating proportions. Seawalls, groins and revetments have mostly been ineffective in stemming erosion. Local authorities ask for help in sand nourishment projects while recommending simultaneously semi-permeable groins, disused oil field hoses and sand-bagging. Construction of moles in Lagos has caused steady retreat of the coastline since 1900. Shoreline protection schemes include groins on Victoria Island near Lagos (Nigeria) (Figure 33) but also beach nourishment, sea-walls in Dakar (Senegal), groins on Jamestown Beach and revetments on Labadi Beach both near Accra, offshore breakwaters in Conakry (Guinea), St. Louis and Rustique (Senegal). "Local" methods are bulkheads, sand-mattresses and -bagging in Brass (Nigeria), timber groins, Chicoco blocks, wooden bulkheads and afforestation (Figures 31–34).

In Ghana and Benin short groins made of rock chips, stone revetments and gabions have proven valuable. But such "home remedies" are not unique to developing countries 20th century protection devices in the United States have included discarded Christmas trees (on Long Island, NY), bags filled with lean concrete mix and hog-wire fences, so-called sand-filled sausages, pile and plank structures, floating tires chained together, and numerous proposals for seaweed reefs (Figure 36).

OTHER APPROACHES

There are on the market several other approaches which have been listed by Pilkey. Still other proposed methods suggest "polyvalent" and multipurpose schemes. Among those are synthetic and natural "algal reefs", and a protective weed screen that would dampen wave effect, retain sediment and provide biomass energy, feed, even food. (GREENFIELD *et al.,* 1989; DONOGHUE *et al.,* 1995; DE MEIJER *et al.,* 1988; LARCHER, 1995; ANONYMOUS, 1995b; VALVERDE *et al.,* 1997; DE WOLF *et al.,* 1997; MALHERBE and LAHOUSSE, 1998; CHARLIER and DE MEYER, 2000; BEROSIN, n.d.) (Tables 1–2) (Figures 37–38).

A "radiometric" fingerprinting system permits the rapid de-

Figure 42. Let us work with, not against Nature.

tection of the presence and approximate concentration of economic heavy minerals in nearshore sand deposits and thereby suggests the possibility that a single sand deposit could be examined and eventually used for exploitation of valuable minerals resources, *e.g.* ilmenite, rutile, zircon, and as a source for feed material to renourish eroding beaches.

Engineering works, proposed and completed, not designed as coastal defenses, play often such role. Artificial islands come particularly to mind. Boskalis proposed a slope-protected, sand-fill island as a pipeline valve station to the Dutch company Nederlandse Aannemers Maatschappij (NAM) [Figure 9]. The Belgian company HAECON similarly proposed constructing an "environmental island" off the Belgian coast in connection with waste disposal, power station *et al.* (Figure 39).

Conventional hard structures intruding along coastlines upset the dynamic balance of the coastal ecosystem in many ways. Floating structures, wave screens and ruff breakwaters are no absolute barriers to water and fish passage. They can be aesthetically integrated into a shore stabilization scheme. Recently examined in Canada and Finland they were reported on by P.A. Tschirky, J.T. Silander and others (*Coastal Zone Canada 96, Abstracts*). There is a wide array of coastal protection schemes; O. Pilkey provided a table listing no less than 40 "systems" (*cf. Proc. International Coastal Symposium 98,* Royal Palm Beach). No approach should be considered the absolute solution and any one should strive to act with rather than against nature (CHARLIER *et al.,* 1998; BEARDSLEY and CHARLIER, 1998; ANONYMOUS, 1995). (Table 2)

The Delta-Plan *de facto* closed the Eastern [branch of the] Scheldt River and linked the Scheldt River's delta islands by drained land. Less often mentioned are the serious problems created for upstream areas along the Scheldt River's pre-delta course which are not limited to Dutch territory (Figure 25).

Without necessarily agreeing that "despite the widespread use of beach nourishment as a means of shoreline stabilization, the extent of its use on a large scale remains relatively undocumented", praise is due the [US] Program for the Study of Developed Shorelines studies and similar efforts to determine government's role in such schemes. (Valverde *et al.* 1997; De Wolf *et al.* 1997; Larcher 1995; Malherbe and Lahousse 1998; CHARLIER and DE MEYER, 2000; Berosin n.d.). Should it not be mentioned here that the so-labeled [then]

largest beach-nourishment project in the world in Heist-Knokke-Zoute, Belgium has been monitored since its completion? Conclusions are satisfactory and convincing for the Authority concerned. In this regard on the Belgian-Dutch border, the Zwin natural channel access that once linked Bruges and the North Sea, now an ornithological reserve, and already merely a deep coastal indentation, is further silting progressively. Beach nourishment nearby on the border's both sides may be, partly, responsible. To decide whether to "feed" requires indeed a wide scope inquiry on results, even if these seem to confirm the optimism of teams having tried out the profile approach or laboratory tested soft methods. (De Wolf *et al.,* 1995; Arwosika, 1997; Johnson and Johnson, 1997) (Figure 40).

The Near-Universal Lament

A short *promenade* along the coasts of the eastern United States illustrates the plight of the beaches and the efforts to save them. In the *Florida State of the Coast Report* (Tallahassee, 1996) it is shown that of 715 km of coast 60% are in critical situation, 229 km are beaches receiving artificial renourishment (at a cost of about $3.73 million per km in 1996) with the damage primordially ascribed to inlet construction and channel protection and maintenance. The *State of Texas Report* (AUSTIN 1996) describes erosion control attempts by artificial reef construction near Galveston, the [US] Federal Emergency Management Agency (Washington, 1997) stresses the problems related to the manufactured homes installation in field hazards areas. The Westport, Massachusetts township has reported a critical situation at *Coastal Zone 97* in Boston for its beaches.

But solutions are not easy to find and among 41 alternative devices to protect beaches, McQuarrie and Pilkey (C.W. Finkl Jr & P. Brunn, editors, *J. of Coastal Research:* Spec. Issue 26, 1998, p. 270) find only the "Beach Protector Tire Mat" and the "Beachbuilder Technique" without a potential negative impact, with the latter however impairing aesthetics.

Several devices present themselves as a complement to beach nourishment, in that they delay the loss of deposited sand. The "Beachsaver Reef" for instance—which Pilkey (*op. cit. supra*) rates as causing downdrift beach erosion, having an impact on water quality, and posing a potential hazard to swimmers—is stable, massive and reduces loss of sand to offshore currents. But, we wonder, is it not some sort of breakwater? The sloping, angled grooved "modules" weigh 21 tons, 3 m long, 4.8 m wide at their base and 1.8 m high, are placed at a depth below mean low tide water line of 1.8 m (R.E. Creter, 1994, Offshore erosion control takes on new dimension: *Sea Technology* 35, 9, 23–26). The structure holds sand in near the shore and new sand placed on the beach in place. With half the volume of sand used for a replenishment often washed away over a two-year period, the enhanced concrete "reef" supposedly provides 2½ times the usual staying duration of nourished material. One test was run over 100 m, 33 m offshore Oakwood-on-the-Sound (Long Island, New York) and the designers claim beach width increase and 1 m elevation on both sides of the device; another pilot try-out took place off Sea Isle City, New Jersey, and still in New Jersey, at Avalon, a 330 m system was installed in 1993. Other pilot projects were on the books for Cape May and Belmar (Spring Lake). The New Jersey Pilot Reef Program encompasses a major shoreline protection program. The State also eyes beach restoration programs, such as using the "Beachbuilder". Laboratory tests were conducted at the Stevens Institut of Technology (Hoboken, New Jersey) for the "Beachsaver", but also for the "Beachbuilder" to which one can only object that it is unaesthetical. However, as it is easily movable, the device may be taken away at peak tourist season. This system uses flow-sheets that actually put the waves to work to build up the beach by stopping sand to move back offshore. Never tested on a beach, it functioned satisfactorily in wave tank tests with a simulated beach. Its designer, incidentally, can claim paternity of the Hoovercraft as well (M.W. Beardsley, 1998, *The perpetual beach story:* Carmel, CA, The Beachbuilder at Walker Avenue; M.W. Beardsley & R.H. Charlier 1995, Beach accretion as beach defence: *Actae Littoral 1995, Nantes, France 14–16* [also published 1998 in *Les Cahiers Nantais,* Geography Department Univ. of Nantes]; M.W. Beardsley & R.H. Charlier, 1998, *op. cit.: Int. J. Env. St.* 54, 1, 1–33). Also tested in various sites has been the Dutch-designed "Berosin" based in Den Helder, Netherlands.

CONCLUSION

In the 19th and 20th centuries coastal protection against an advancing sea has been centered on a variety of hard structures (groins, breakwaters, seawall, tetrapods, *etc*) and artificial nourishment. Environmental concerns have played a steadily more important role. Some forty types of alternative schemes have been proposed over the last decades, with a large number of them faulted for negative environmental impacts. As the economic consequences of the landwards migration of the shoreline are often disastrous the search of solutions remains on the foreground.

The Dutch reclamation works, subject of so much justified pride (though there are polders in Belgium, France, New Zealand, even Lake Chad) may have seen their "end". Indeed there have been suggestions to "return" some land to the sea and if little is heard about it, it may well be due to the raising of swords and shields by Dutch farmers [personal confidential communication in connection with international Scheldt River dredging works].

An adequate, if somewhat tongue-in-check conclusion, is provided by Bruun's "Ten Demands for Coastal Protection":

(1) Thou shalt love thy shore and beach
(2) Thou shalt protect it against the evils of erosion
(3) Thou shalt protect it wisely yea, verily and work with nature
(4) Thou shalt avoid that nature turns its full fortse gainst ye
(5) Thou shalt plan carefully in thy own interest and in the interest of thine neighbour
(6) Thou shalt love thy neighbour's beach as thou lovest thy own beach
(7) Thou shalt not steal thy neighbour's property, neither shalt thou cause damage to his property by thy own protection
(8) Thou shalt do thy planning in cooperation with thy

neighbour and he shalt do it in cooperation with his neighbour and thus forth and thus forth. So be it

(9) Thou shalt maintain what thou has built up

(10) Thou shalt show forgiveness for the sins of the past and cover them up in sand.

Thoughts from two French authors-philosophers applicable to our dilemma come to mind; de la Rochefoucauld commented on Man's efforts to dominate Nature: "on ne commande à la Nature quèn lui obéissant", and his landsman Romain Gary—perhaps in a premonition of the concept of sustainability—reflected: "il faut toujours connaître les limites du possible," adding perhaps less wisely "pas pour sàrrêter, mais pour tenter l'impossible, dans les meilleures conditions"[2,3] (Figures 41, 42).

ACKNOWLEDGMENTS

Deep appreciation is expressed to all who contributed to this overview and particularly to Dr. J. R. Senten, Geog. D. Kuechen and Eng. V. Ricci for their help with the summaries.

LITERATURE CITED

ANONYMOUS, 1995a. Automatic beach accretion proves its worth in the U.K.: *Dredging & Port Construction* XXII, 11, 18–19.

ANONYMOUS, 1995b. *Dredging & Port Construction:* spec. issue XXII,11.

ALBERTI, L.B., 1465. *De re aedificatoria:* Roma, De Luca [in Latin, republished, 1998].

BAKKER, W.T. and JOUSTRA, D.S., 1970. The history of the Dutch coast in the last century: *Proc. 12th Coast. Engng Conf. (Washington DC)* Chapt. 43.

BEARDSLEY, M.W. and CHARLIER, R.H., 1998. Beach accretion with erosive waves: Beachbuilding. Proposal for coastal defence: *Int. J. Env. St.* 54, 1–33.

BRUNN, P., 1994. *Coastal stability:* København, Danish Soc. Civ. Eng. Press.

BRUNN, P., 1990. Beach nourishment—Improved economy through better profiling and back-passing from offshore sources. *J. Coastal Res.* 6(2), 265–277.

CHARLIER, R.H. and AUZEL, M., 1961. Gémorphologie côtière: migration des sables sur la côte belge: *Zeitsch. für Geomorph.* 5, 181–184.

CHARLIER, R.H. and BEAVIS, A., 2000 Development of a nearshore weed-screen. A Nature coastal defense idea: *Int. J. Env. St.* 57(4), 457–268.

CHARLIER, R.H. and DE MEYER, C.P., 2000. Ask Nature to rebuild beaches: *J. Coast. Res.* 16(2), 385–390.

CHARLIER, R.H. and DE MEYER, C.P., 1998. *Coastal erosion: Response and management.* Heidelberg & New York, Springer Verlag pp. 194–222.

CHARLIER, R.H.; DECROO, D.; DE MEYER, C.P., and LAHOUSSE, B., 1998. To feed or not to feed, that is often the question: *Int. J. Env. St.* 55, 1–23.

CHARLIER, R.H. and MADSEN, J., 1956. Vanishing beaches: *Long Island Bus.* IV, 1–16.

[2] "One can only 'order around' Nature by obeying it" (de la Rochefoucault, XVIIIth century).

[3] "It is necessary to be always aware of the limits of the possible. Not to stop, but to try the impossible, under the best conditions" (GARY, 1977).

CHARLIER, R.H. and MENANTEAU. L., 1998. The saga of tide mills: *Renewable and Sustainable Energy Review* 1, 1–33.

DE MOOR, G. and BLOMME, E., 1988. Belgium. *In:* WALKER, H.J. (Ed.), *Artificial structures and shorelines:* Dordrecht NL, Kluwer pp. 115–126.

DI GIORGIO MARTINI, F., 1475 (in Latin, republished in Italian in 1967). *Treatise of architecture, engineering and military art:* Milano, Il Polifilo.

EL-FAKHARANY, F. 1963. The old harbor of Alexandria: *Public Lectures Series, University of Alexandria 1962–1963,* 38 pp. [in Arabic].

EL-SABH, M. (ed.), 1996. *Coastal Zone Canada 1996 B Abstracts:* Rimouski QU, Université du Québec-Rimouski.

FRANCO, L., 1996. Ancient Mediterranean harbours: a heritage to preserve: *J. of Oc. & Coast. Man.* 30(2/3), 115–151.

FRANCO, L., 1996. History of coastal engineering in Italy. *In:* KRAUS, N. (Ed.), *History and heritage of coastal engineering.* New York, Amer. Soc. Civil Eng. pp. 275–335.

FOUCHER, F., 1998. Les moulins à marée: *Le Chasse-Marée. ArMen* No. Spéc. Juillet 24–25.

GRILLO, S., 1989, *Venice sea defences:* Venice, Ed. Arsenale [in Italian].

HOMER, *Odyssey:* Book IV.

HOUMUALK DE LILLE, Ch., 1987. *Les moulins de l'ouest:* Fromentine, France, Vieux Chouan pp. 24–32.

JONDET, G. 1912. Les ports antiques de Pharos: *Bull. Soc. Archéologique d'Alexandrie.* 14, 252–266.

JONDET, G. 1916. Les ports submergés de l'ancienne île de Pharos. *Mémoires présentés à l'Institut Egyptien.* IX, 101 pp + 4 plates.

JONDET, G. 1921. Atlas historique de la ville et des ports d'Alexandrie: *Mémoires présentés à la Société Sultanieh de Géographie.* II, 17, 13 pp + 54 plates.

LARCHER, M., 1995. Bluff base and beach protection: *Bordomer 95: Coastal Change—Abstr.* [no pp. nbrs, papers classif. alphab. by author's last name].

MOLLER, J.T., 1984. Artificial structures on a North Sea coast: *Geoskrifter* (Aarhus, Denmark) 19, 25pp.

MORCOS, S.A. 1968. Submarine archaeological discoveries in the Mediterranean Sea. *Archaeological and Historical Studies, Alexandria Archaeological Society* I, 39 pp [in Arabic].

OLESON, J.P., 1988. The technology of Roman harbors: *Int. J. Nav. Archit.* 17(2), 147–157.

POSTOLACHE, I, 1990. Man's impact on the Romanian coastal zone. *XXXIII Congress of CIESM,* 32.

RABAN, A., 1988. Coastal processes and ancient harbour engineering: *Proc. 1st Int. Symp. "Cities on the Sea—Past and Present"* B.A.R. Int. Ser. 404, 185–261.

RICHTER, J.P., 1970. *The notebooks of Leonardo da Vinci:* New York, Dover.

SOLE, R., 1998. *Les savants de Bonaparte:* Paris, Le Seuil.

TANASE, S.; CONSTANTIN, R., and SPATARU, A., 1992. Protectia plajei Mamaia: *Studii de hidraulica* (Bucuresti) 43–63. [in Romanian]

TESTAGUZZA, O., 1970. *Portus:* Rome, Julia [in Italian].

THORN, R.B., 1960. *The design of sea defense walls:* London, Butterworks.

THUILE, H., 1922. Commentaires sur l'*Atlas* de Jondet. *Bull. Société Géographique (Le Caire)* XI.

TRARIÉ, J. and CARMIGNIANI, J.C., 1988. *Bonaparte. La campagne d'Egypte:* Paris, Gérard Watelet, Pygmalion.

VAN VEEN, J., 1962. *Dredge, drain, reclaim. The art of a nation:* The Haghe, Martinus Nijhoff.

VIERLINCK (Vierlingh), A., 1579. *Tractaet van dijckagie:* Amsterdam.

VISSER, J.C., 1953. De Noorzeekust van Vliesland: *Waterbouwkundig Tijdschrift* OTAR.

WEILL, R., 1919. Les ports antéhelléniques de la côte d'Alexandrie et l'Empire Crétois: *Bull. De l'Institut Français d'Archéologie Orientale (Le Caire)* 16, 37 pp.

XU, Q., 1993. Brief history of marine development in Ancient China: *Abstr. Intern. Congr. Hist. Oceanogr.* V, 58.

□ RÉSUMÉ □

La construction de digues a parfois été attribuée, en premier, aux Frisons (les *Frisii* de César et Pline l'Ancien). Sans nul doute ils furent des innovateurs en Europe septentrionale, utilisant même des plantations d'algues. Des digues en matériaux de plus en plus résistants, y compris l'incorporation de vieilles épaves, devinrent plus nombreuses dès le 13e siècle. Les *murazzi* vénitiens datent du 18e.

Toutefois dans le monde méditerranéen des digues furent construites par les Romains, Grecs, Phéniciens et à Alexandrie. Celles-ci semblent, dans certains cas, avoir été plus sophistiquées que les monts de terre des Frisons et les *zeeburghen* qui leur succédèrent. Les écrits chinois font état de travaux de constructions défensives le long des côtes de l'empire.

Quant aux épis et autres structures dures ils firent leur apparition sur les plages il y a plus d'un siècle; ils restèrent la démarche de protection jusqu'au 20e siècle, même si par endroits il y eut quelques essais d'alimentation artificielle de plages (Californie).

L'évolution des démarches en protection côtière s'accéléra dans la seconde moitié du 20e siècle et aux ouvrages défensifs dits durs, s'ajoutèrent, et souvent se substituèrent, l'alimentation artificielle, sans ou avec berme, l'alimentation du profil, la déshydratation des plages, l'utilisation des processus mêmes de la Nature et d'autres approches, à tel point qu'on déchiffre aujourd'hui plus d'une cinquantaine de "systèmes alternatifs" aux oeuvres d'art maritimes traditionelles. Ils ne sont bien entendu ni tous également efficaces ni tous libres d'impact sur l'environnement.

□ SAMENVATTING □

De eerste dijken zouden gebouwd zijn door de Friesen. Wellicht wel juist voor wat Noord Europa betreft. Deze werden vanaf de 13de eeuw wel met sterkere materie vervaardigd en oude schepen werden soms in het verdedigingsstelsel omgewerkt. De veneziaanse *murazzi* dagtekenen uit de 18de eeuw.

Echter in het Middelandse Zee gebied werden vroeger reeds verdedigingswerken ("dijken") gebouwd, met name door de Romeinen, Phoeniciers en te Alexandrië. Deze structuren schijnen wel meer geperfectioneerd te zijn gewezen dan die van de Friesen en de zeeburghen die hen opvolgden. Chinese geschriften vermelden verdedigingswerken tegen de zee langsheen de kusten van hun gebied.

Golvenbrekers, strandhoofden, dijken, dolossen en andere structuren verschenen op en bij de stranden meer dan een eeuw geleden.

Gedurende het tweede gedeelte van de 20ste eeuw vermeningvuldigde zich de methodes om de kustlijn in stand te houden. Bij de zg. harde aanpak voegden zich kunstmatige voeding, ontwatering, profiel voeding, berm instelling en nog meer; ook tracht men met de Natuur te werken in plaats van ze te bestrijden. Er zijn wel een vijftig-tal methodes die thans commercieel aangeboden worden, uiteraard zijn ze allen noch even efficient, noch vrij van impact op het milieu.

□ ZUSAMMENFAßUNG □

Die Friesen sollen es gewesen sein, die als erste in Nordeuropa Dämme bauten, die als Befestigung gegen das Fortschreiten der Meere dienten. Aber die Römer, Phoeniziër und Ägypter hatten schon früher Dämme erstelt. Die Zeeländer, Holländer und Italiener verfeinerten die Befestigungkunst. Es dauerete nicht sehr lange bis stärkere Materialien benutzt wurden, so auch alte Schiffe, die in die Dämme mit eingearbeitet wurden. Die *murazzi* aus Venedig gehören dem 18en Jahrhundert.

Zur Zeit werden harte Strukturen nich mehr als einzige oder beste Methode betrachtet.

Heute wird manchmal künstlicher Strandernährung angewandt. Der erste Versuch mit solche "Ernährung" wurde in Kalifornien kurz nach den ersten Weltkrieg unternommen. Wenn heute diese Methode angewandt wird, dan wählt man am liebsten Profilernährung, und manchmal zusammen mit einer Unterwasserberme.

Andere Systeme bestehen aus Entwäßerung, Dünenbruch, Dünen-bau oder -reparatur, u.s.w., oder gar die Einlegung von synthetischen Decken in den Strand.

Selbstverständlich sind alle diese Methoden nicht gleichwertig oder gleich unweltfreundlich. Dieser Bericht gibt einen kurzen Überblick über die Entwicklung des Küstengeschutzes und die gegenwärtig Methoden zur Verhinderung des Fortschreitens des Meeres gegen das Land. In jeden Fall darf nicht vergeßen werden, daß das Fortschreiten der Meere bekämpft, aber nicht überwunden werden kann.

□ RIASSUNTO □

La costruzione delle prime dighe costiere, o dei primitivi sistemi protettivi conto la furia del mare, e attribuita ai Frisoni. Questo vale per l'Europa Settentrionale, mai prima di loro, nei tempi classici, erano gia state costruite dighe costiere dai Romani, dai Fenici e ad Alessandria. Sostanziali progressi si devono agli Olandesi ed aagli Titaliani, che perfezionarono l'arte delle protezioni costiere. In breve tempo vennero incorporati nelle opere di protezione anche materiali solidi, e perfino rottani di vechhie navi.

Attualmente strutture ad alta resistenza come "pennelli" transversali, scogliere parallele, tetrapodi in calcestruzzo, ecc., non sone piu considerate l'unica, e neppure la migliore soluzione. A partie d'agli anni venti sono stati proposti ed utilizzati sistemi flessibili in California. I "ripascimenti" artificiali (con sabbie) della spiaggia sono diventati piu sofisticati, e comprendono spesso il ripasciemento del profilo attuale e/o la messa in opoera di una strettoia di alimentazione. Soluzioni alternative propongono il prosciugamento, la creazione di insenature, la costruzione o rifacimento di dune, parallele o perpendicolari alle isoipse, il draggagio di compensazione, ovvero l'uso di setti sommersi o paratie. Vi sono sul mercato una cinquantina di sistemi, ma non so tutti ugualmente efficenti, ne esenti uguali da effetti ambientali negativi.

Il lavoro passa in rassegna i vari sistemi di protezione delle coste, ed illusta diverse proposte piu recenti. Conclude dichiarando che, purtroppo, la erosione marina e inarrestabile.

□ RESUMO □

A construção dos primeiros diques, ou das primitivas proteçôes contra a füria do mar, è attribuida a os Frisoes. Isto è verdade para a Europa do Norte, mas, antes deles, no periodo clàsico, os Romanos, os Fenicios e em Alexandria jà se construiam diques. Avanços substaciais foram feitos pelo Holandeses e pelos Italianos: ambos aperfeiçoaram a arte de proteção costeria. Muito cedo foram incorporados nos diques meteriais solidos e eté destroços de navios. Actualmente, para a proteçâo costeira, soluçõestais cono estrutura transversais de alta resistência, quebra-mares, tetràpodos, etc. Jà não são consideradam nem as melhores.

Jà a parttir dos anos vinte, na California foram adoptados sistema mas flexiveis. Ã nutrição artificial das praias por meio de areias fosseis tornou-se mais sofisticada e inclui, muitas vezes, a reformulação do perfil actual e/ou a criaçào de bermas de alimentação. Soluções alternativas apontam para a secagem, a criação de aberturas, a construção de dunas, as dragagens de compensaçâo, ou a utilizaçâo de cortinas submersas.

Existem actualmente no mercado cerca de cinquenta soluções diferentes, mas nem todfas são totalmente eficazes, nem a prova de efeitos ambientalis negativos.

O trabalho examinas os varios sistemas de proteõào das costas, e apresenta algumas soluções recentes. A conclusão è, no entanto, que a erosàão marinhya è un fenomeno inexoràvel.