FACTS ABOUT

An Information Update from the IADC

COASTAL PROTECTION

WHAT IS COASTAL PROTECTION?

Coastal protection spans the interventions, structures and measures put in place to protect coastal areas and their inhabitants against flooding.

WHY IS COASTAL PROTECTION NECESSARY?

Urbanisation and development to accommodate global population growth in combination with the effects of climate change has led to the growing need to protect coastal areas and their resident populations.

A report by the United Nations predicts the world's population living in urban areas will increase by over two billion people by 2050. The largest share of city dwellers will live in vulnerable coastal floodplains and half of the world's population is projected to be living within 100 kilometres of a coast.

Climate change contributes to the observed trend of increased storm intensity and many coastal zones around the globe are already exposed to tsunami risks. The destructive capacity of such natural events has been witnessed, especially with hurricanes such as Katrina in 2005 and Harvey in 2017 as well as the tsunamis in Indonesia in 2004 and Fukushima in 2011. Soil subsidence of inhabited coastal floodplains is also occurring in many locations. All these trends combined demonstrate the need for sustainable and resilient flood protection measures. The combination of an increasing probability of flooding and higher-impact flood-related events lead to greater socio-economic impacts.

Taking place over the course of millennia, sea level rise has been an ongoing process and is currently observed in a vast majority of the globe. According to the conclusions of the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climatic Change (IPPC), sea levels are expected to continue rising in the coming century although the pace of acceleration is still a matter of discussion.

Above: In Den Helder, the Netherlands, a coastline is protected by a sea dyke. Photo Rijkswaterstaat

HOW CAN A COAST BE PROTECTED?

Coastal protection may be ensured through natural or man-made systems, or a combination of both. Available techniques which can be implemented fall into two categories: hard strategies and soft strategies.

WHAT ARE HARD COASTAL PROTECTION STRATEGIES?

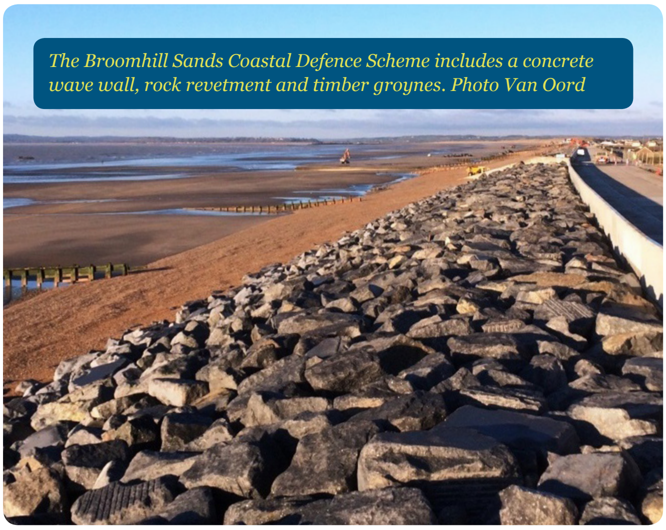
To maintain the coastline's integrity, rigid or semi-rigid structures are constructed along or in front of the coastline to resist deformation from wave or current action. Structures are built in areas facing erosion in an effort to stabilise a dune foot, intertidal beach or fix an existing or new coastline. These structures are designed to resist extreme storm events, prevent excessive overtopping and preserve existing infrastructure. Hard coastal protection structures fall into the categories of sea dykes, seawalls, revetments, groynes and offshore breakwaters.

WHAT ARE SEA DYKES?

To prevent flooding of the hinterland, sea dykes have an impermeable core surrounded by a protection layer which can be formed with combinations of blocks and masonry, asphalt, and grass revetments. A crown wall is usually constructed on top to reduce the overtopping of water.

A sea dyke protects Terschelling, the Netherlands. Photo Rijkswaterstaat

Built in 1915 and photographed in 1975, Ocean Beach's seawall is a concrete wall and stairway.



The Broomhill Sands Coastal Defence Scheme includes a concrete wave wall, rock revetment and timber groynes. Photo Van Oord

WHAT ARE SEAWALLS?

Massive vertical or near vertical retaining walls, seawalls are conventionally constructed with concrete or masonry, or a combination of both materials. Built in 1915, the O'Shaughnessy Seawall in Ocean Beach, California remains a prime example of functioning seawall infrastructure more than a century after its construction (see above).

WHAT ARE REVETMENTS?

Revetments are sloping rubble mound structures comprised of various types of material such as quarried rocks, concrete blocks and sand or gravel-based asphalts. Often constructed as permeable structures, revetments enhance wave energy absorption, reducing reflection and wave run-up. As a result, the rate of shoreline regression is slowed as the structures are built at locations where the coast is susceptible to erosion.

WHAT ARE GROYNES?

Another form of beach control, a groyne is constructed perpendicular – or nearly perpendicular – to the coastline, extending into the sea beyond the low-water (LW) mark (see below). The structures block part of the longshore drift in the surf zone and stabilise the beach between them. The length and spacing between each groyne are determined by the degree of wave and current action as well as the beach material itself. Groynes may be constructed as rubble mound or masonry structures but can also be built from timber piles and planks.

Combining various hard structure solutions, the Broomhill Sands Coastal Defence Scheme stretches for 2.4 kilometres along Camber's coastline in the United Kingdom (see above). With an aim to improve flood risk protection for nearly 2,000 properties, the scheme consists of a concrete wave wall and rock revetment. Eight new timber groynes – each 54 metres in length – were constructed to stabilise the beach and retain its material. A 1700-metre-long rock revetment and wave wall was constructed along the remainder of the frontage and 700 metres of shingle beach was nourished.

WHAT ARE OFFSHORE BREAKWATERS?

Offshore, shore-parallel breakwaters are beach control structures constructed as rubble mound structures which may be either raised or submerged (see below). The intensity of wave and current action is then reduced allowing the formation of tombolos – beach growth reaching the breakwater – or salients – beach growth not extending to the breakwater – behind them. Their length, spacing and distance from the shoreline are determined by the wave and beach characteristics.

A groyne dissipates energy from waves and currents to slow down coastal erosion.

Offshore, shore-parallel breakwaters with tombolo formation in Dubai. Photo Van Oord

WHAT ARE SOFT COASTAL PROTECTION STRATEGIES?

Through the reclamation of a body of sand, coastal dynamics – and their flexible nature – are secured or even restored. Soft coastal protection can be the result of one or a synthesis of the following diverse strategies: dune, supratidal beach, foreshore, mega- and morphological nourishment.

HOW DOES DUNE NOURISHMENT WORK?

Dunes provide a physical buffer between the sea and inland areas, and can naturally shift during storms. As waves hit a dune and its sediments move, the wave energy is absorbed, protecting landward areas from the full brunt of the storm.

Dune nourishments comprise the installation of a dune-shaped reclamation on the supratidal beach where the water level is above the high-water (HW) mark. Artificial and nourished dunes increase the level of protection to inland areas by acting as buffers and the added sediment from dune projects supports the protective capacity of an entire beach system which can include dunes, beaches and nearshore areas.

However, for the dunes to be effective, sediment needs to be added regularly to maintain the dune's height, width and volume at appropriate levels. The dune body is conceived to allow for a certain amount of erosion, always ensuring a minimum amount is secured even after the design storm has damaged the dune.

The dunes also need to be stabilised by vegetation from 'Aeolian blow out' which is the loss of sediments from wind action. This vegetation should be native and salt tolerant, controlling erosion with extensive root systems of marram grass plantations and twig-hays which can be further combined with other natural screens.

HOW DOES SUPRATIDAL BEACH NOURISHMENT WORK?

Supratidal beach nourishment involves the placement of a volume of sand above the HW mark with natural slopes according to the geotechnical equilibrium slopes. Hence, part of the reclamation may spread out at sea under the waterline. A supratidal beach nourishment plans for wave, tide- and wind-action to disperse the reclaimed sand until equilibrium is reached.

A supratidal beach nourishment functions similarly to a dune nourishment as it absorbs the incident storm-wave action by allowing some erosion of the reclaimed sand. In fair weather conditions, sand can be moved to the eroded parts by beach-building waves or be redistributed with earth-moving equipment.

HOW DOES FORESHORE NOURISHMENT WORK?

A foreshore nourishment involves the reclamation of the subtidal beach by placing sand on specific areas of the beach below the water-line. The foreshore induces the wave-breaking process in which incident waves – waves moving landward – lose a substantial amount of their energy. As such, strengthening the foreshore area will act as a foundation and may slow down the erosion of the emerging beach. The stability of beach nourishments is greatly influenced by the natural morpho-dynamics of the system.

The first large-scale foreshore nourishment was executed in 1992 along the coast of Den Haan in Belgium as part of a morphological nourishment project. Several foreshore nourishments have been implemented along the North Sea in the Netherlands as part of the maintenance programme of the primary coastal protection system since 1996.

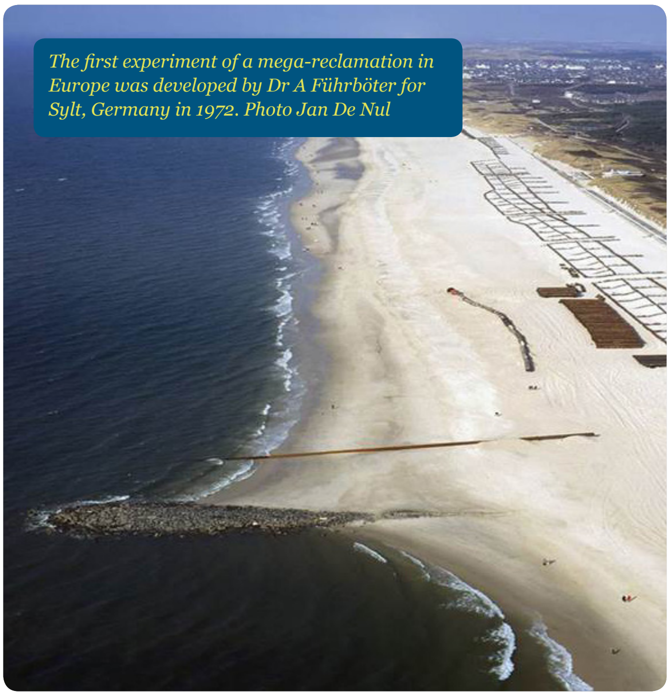
In general, a foreshore nourishment should be seen as a part of a morphological nourishment and preferably combined with a profile nourishment to cure the entire eroding beach profile which includes all supra-, inter- or subtidal beach components.

HOW DOES MEGA-NOURISHMENT WORK?

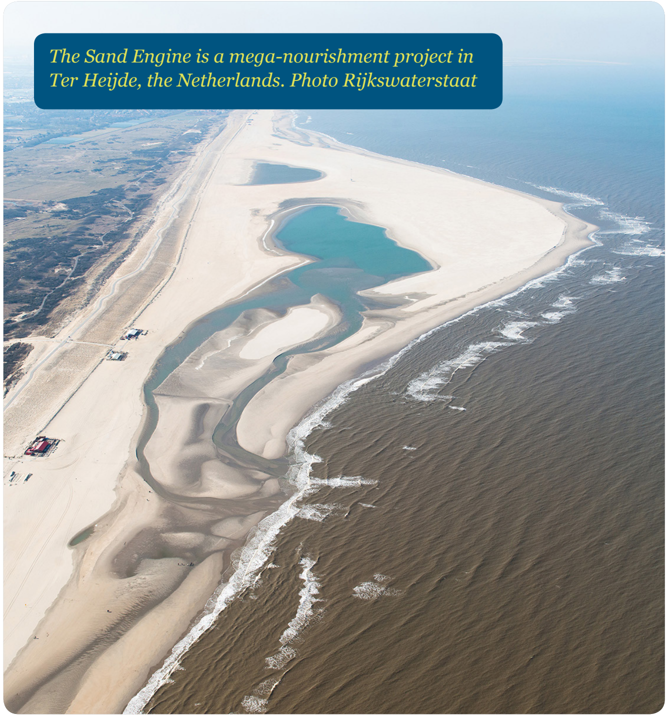
Mega-nourishments consist of large reclamations concentrated on a particular stretch of coast. Large bodies of sand or sediment are moved to a specific location along the coast and are gradually dispersed by the actions of waves, tides and winds. The reclaimed sand body is designed to protrude into the sea in order to capture wave and current energy which then facilitates its dispersion. Based on the volume of material initially placed, nourishments are designed to take place over years or decades without further maintenance.

In 1972, Dr A Führböter developed the first experiment of a mega-reclamation in Europe to restore the eroding coastline of Sylt, Germany (see below). Named 'sand-groyne', the concept involved the placement of 1.73 million cubic metres of sand on a coastal stretch spanning nearly 500 metres.

The Sand Engine – *Zand Motor* in Dutch – is a project situated off the coast in Ter Heijde, the Netherlands.



The first experiment of a mega-reclamation in Europe was developed by Dr A Führböter for Sylt, Germany in 1972. Photo Jan De Nul



The Sand Engine is a mega-nourishment project in Ter Heijde, the Netherlands. Photo Rijkswaterstaat

The country's western shoreline is below sea level and threatened with serious erosion. In order to protect the coast in a more sustainable and natural way, the Sand Engine mega-nourishment project was constructed between March and November 2011 (see above).

Extending one kilometre into the sea, the hook-shaped land form was created after 21.5 million cubic metres of sand was deposited over a stretch of around 2.5 kilometres of coastline. Covering 128 hectares, the pilot project intends to make use of natural processes to redistribute the sand and mitigate coastal erosion while also providing new areas for nature and various types of recreation. Measurements are still being taken by researchers to ascertain if this method of coastal protection is cost-effective over the long term.

HOW DOES MORPHOLOGICAL NOURISHMENT WORK?

Morphological – or moving sand – reclamations combine profile nourishment with foreshore nourishment. A profile nourishment is part of a morpho-dynamic approach in which reclaimed sand is immediately spread and trimmed according to the natural equilibrium slopes and morphology of a beach. Sand is hydraulically – and mechanically – placed in its intended location. A profile nourishment absorbs incident waves by shoaling just as a natural beach would do. It is recommended to combine a profile nourishment with a foreshore nourishment – subtidal beach – in order to maintain natural equilibrium profiles of the entire beach, both inter-and sub-tidal parts alike.

In February 1990, a severe North Sea storm caused serious erosion to Belgium's coastal cities of Bredene, De Haan and Wenduine. Completed in 1992, the first morphological nourishment which implemented a profile nourishment in combination with a foreshore nourishment spanned a seven kilometre stretch (see right). The nourishment involved an average fill of 740 cubic metres for every metre and the natural equilibrium profile of beach and foreshore were replicated by combining controlled hydraulic fill methods – twin-pipelines and shallow draft split-trailers – with bulldozers as an earth-moving method. After more than 25 years, more than 75 per cent of the original fill volume is still active and present in the beach system.

WHICH ARE BETTER, HARD OR SOFT COASTAL PROTECTION STRATEGIES?

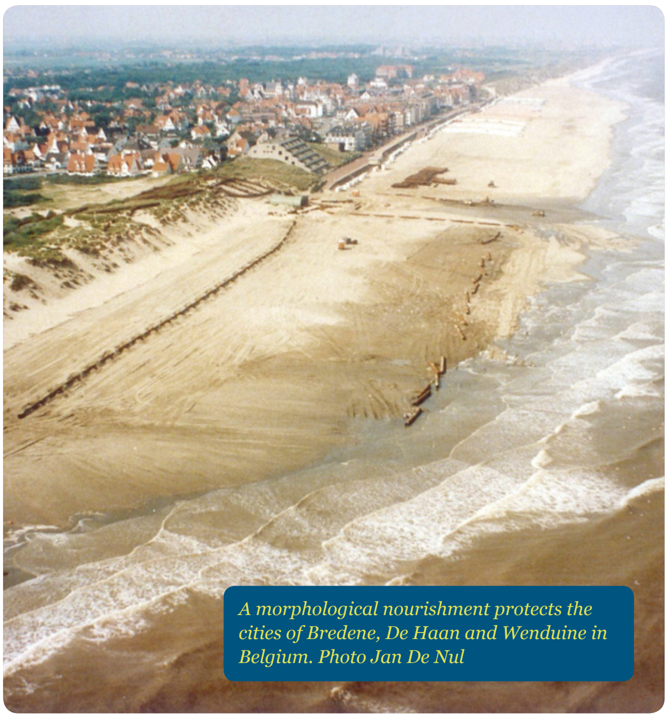
When it comes to coastal protection, there is no single, perfect option and it should be noted both hard and soft strategies have their benefits as well as their drawbacks. Along with dredging contractors, clients need to decide which strategy is most suitable for their site-specific coastal erosion problem.

Benefits of hard coastal protection strategies are as follows:

- Structures are designed using existing civil engineering methods and materials, and if designed properly, their behaviour and performance are predictable and reliable.
- Other functions such as recreational facilities, seafront promenades and parking lots can be integrated.
- Structures can be designed for a specified maintenance strategy.
- Structures protect the hinterland behind naturally eroding coastlines such as areas of high economic value and assets in residential and industrial areas.
- Submerged components of structures can provide space for the habitats of small fish and mammals.

Drawbacks of hard coastal protection strategies are as follows:

- Structures are not able to adapt to changing variables – such as uncertainties of sea level rise and climatic changes – and are not resilient in regards to the natural dynamics of beaches under various hydro-meteorological loads.
- Structures with steep slopes induce more reflections of incident waves and as such may cause adverse indirect



A morphological nourishment protects the cities of Bredene, De Haan and Wenduine in Belgium. Photo Jan De Nul

damages, such as increased erosion (scour) in front of them or downstream.
- Structures cause disturbances to the natural environment of beaches or dunes and may not preserve the provided ecosystem services.
- Research must be conducted to determine a structure's carbon footprint and CO_2 impacts.

Benefits of soft coastal protection strategies include:
- Reliance on a 'proven nature-based technology' which is flexible, resilient and adaptable to changes and variables in hydrometeorology and site conditions, including sea level rise and climatic changes.
- Use of natural processes to protect against floods, preserving the ecosystem services provided by a beach and dune system in the medium and long run. These systems are nature-friendly and rely on a proven technology of coastal protection which can integrate the Building with Nature approach.
- Lower investments in comparison with hard structures as maintenance costs can be addressed on a case-by-case basis.
- Resilience and flexibility to adapt to changing hydro-meteorological conditions, such as sea-level rise and climate change.

Drawbacks of soft coastal protection strategies include:
- Difficult to predict behaviour after implementation, during extreme storm events or across the life cycle since engineering and computation of morpho-dynamic processes of reclaimed sand on beaches is still approximate.
- Must have a source of suitable beach-building material with sufficient quantities and an environmentally acceptable sand-borrowing plan.
- Thorough monitoring of completed projects.

WHAT SHOULD BE CONSIDERED FOR COASTAL PROTECTION IN THE FUTURE?

More than a decade ago, the European Commission issued a directive towards Member States to implement an Integrated Coastal Zone Management (ICZM) strategy. In 2013, the commission launched a joint initiative regarding ICZM and maritime spatial planning (MSP) to promote wholistic consideration of coastal and nearshore marine systems by encompassing geological, hydrographical, biological and ecosystem services aspects, the latter of which comprises the wide range of benefits provided to humans by nature including food, water and raw materials as well as air quality regulation and recreation.

In addition to the strategies highlighted in this publication, additional viable measures include constructing artificial reefs, strategic relocation of risk-exposed populations, raising land levels or stopping man-induced soil subsidence, building controlled flooding areas, and the re-vegetation of tropical tidal flats with mangrove fringing forests to absorb wave energy.

Working with the dynamics of nature, the Building with Nature concept is an integral coastal zone management approach, instilling resilience by combining smart engineering and ecological rehabilitation while introducing sustainable land-use practice. Similar concepts which integrate project and environmental objectives include Working with Nature by the World Association for Waterborne Transport Infrastructure (PIANC) and Engineering with Nature by the US Army Corps of Engineers.

Each protective measure presents its own challenges and needs, therefore needs its own specific and most cost-efficient option. The selected solution should be flexible, sustainable as well as robust in order to offer coastal protection in an optimal way.

FOR FURTHER READING AND INFORMATION

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