Coastal Management

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Introduction to Coastal Management

Oosterscheldekering sea wall, the Netherlands.

In some jurisdictions the terms **sea defense** and **coastal protection** are used to mean, respectively, defense against flooding and erosion. The term *coastal defence* is the more traditional term, but *coastal management* has become more popular as the field has expanded to include techniques that allow erosion to claim land.

Historical background

Coastal engineering, as it relates to harbours, starts with the development of ancient civilizations together with the origin of maritime traffic, perhaps before 3500 B.C.

Docks, breakwaters, and other harbour works were built by hand and often in a grand scale.

Some of the harbour works are still visible in a few of the harbours that exist today, while others have recently been explored by underwater archaeologists. Most of the grander ancient harbor works have disappeared following the fall of the Roman Empire.

Most ancient coastal efforts were directed to port structures, with the exception of a few places where life depended on coastline protection. Venice and its lagoon is one such case. Protection of the shore in Italy, England and the Netherlands can be traced back at least to the 6th century. The ancients understood such phenomena as the Mediterranean currents and wind patterns and the wind-wave cause-effect link.

The Romans introduced many revolutionary innovations in harbor design. They learned to build walls underwater and managed to construct solid breakwaters to protect fully exposed harbors. In some cases wave reflection may have been used to prevent silting. They also used low, water-surface breakwaters to trip the waves before they reached the main breakwater. They became the first dredgers in the Netherlands to maintain the harbour at Velsen. Silting problems here were solved when the previously sealed solid piers were replaced with new "open"-piled jetties. The Romans also introduced to the world the concept of the holiday at the coast.

Middle Age

The threat of attack from the sea caused many coastal towns and their harbours to be abandoned. Other harbours were lost due to natural causes such as rapid silting, shoreline advance or retreat, etc. The Venetian Lagoon was one of the few populated coastal areas with continuous prosperity and development where written reports document the evolution of coastal protection works. Engineering and scientific skills remained alive in the east, in Byzantium, where the Eastern Roman Empire survived for six hundred years while Western Rome decayed.

Modern Age

Leonardo da Vinci could be considered the precursor of coastal engineering science, offering ideas and solutions often more than three centuries ahead of their common acceptance. Although great strides were made in the general scientific arena, little improvement was done beyond the Roman approach to harbour construction after the Renaissance. In the early 19th century, the advent of the steam engine, the search for new lands and trade routes, the expansion of the British Empire through her colonies, and other influences, all contributed to the revitalization of sea trade and a renewed interest in port works.

Twentieth century

Evolution of shore protection and the shift from structures to beach nourishment. Prior to the 1950s, the general practice was to use hard structures to protect against beach erosion or storm damages. These structures were usually coastal armoring such as seawalls and revetments or sand-trapping structures such as groynes. During the 1920s and '30s, private or local community interests protected many areas of the shore using these techniques in a rather ad hoc manner. In certain resort areas, structures had proliferated to such an extent that the protection actually impeded the recreational use of the beaches. Erosion of the sand continued, but the fixed back-beach line remained, resulting in a loss of beach area. The obtrusiveness and cost of these structures led in the late 1940s and early 1950s, to move toward a new, more dynamic, method. Projects no longer relied solely on hard coastal defence structures, as techniques were developed which replicated the protective characteristics of natural beach and dune systems. The resultant use of artificial beaches and stabilized dunes as an engineering approach was an economically viable and more environmentally friendly means for dissipating wave energy and protecting coastal developments.

Over the past hundred years the limited knowledge of coastal sediment transport processes at the local authorities level has often resulted in inappropriate measures of coastal erosion mitigation. In many cases, measures may have solved coastal erosion locally but have exacerbated coastal erosion problems at other locations -up to tens of kilometers away- or have generated other environmental problems.

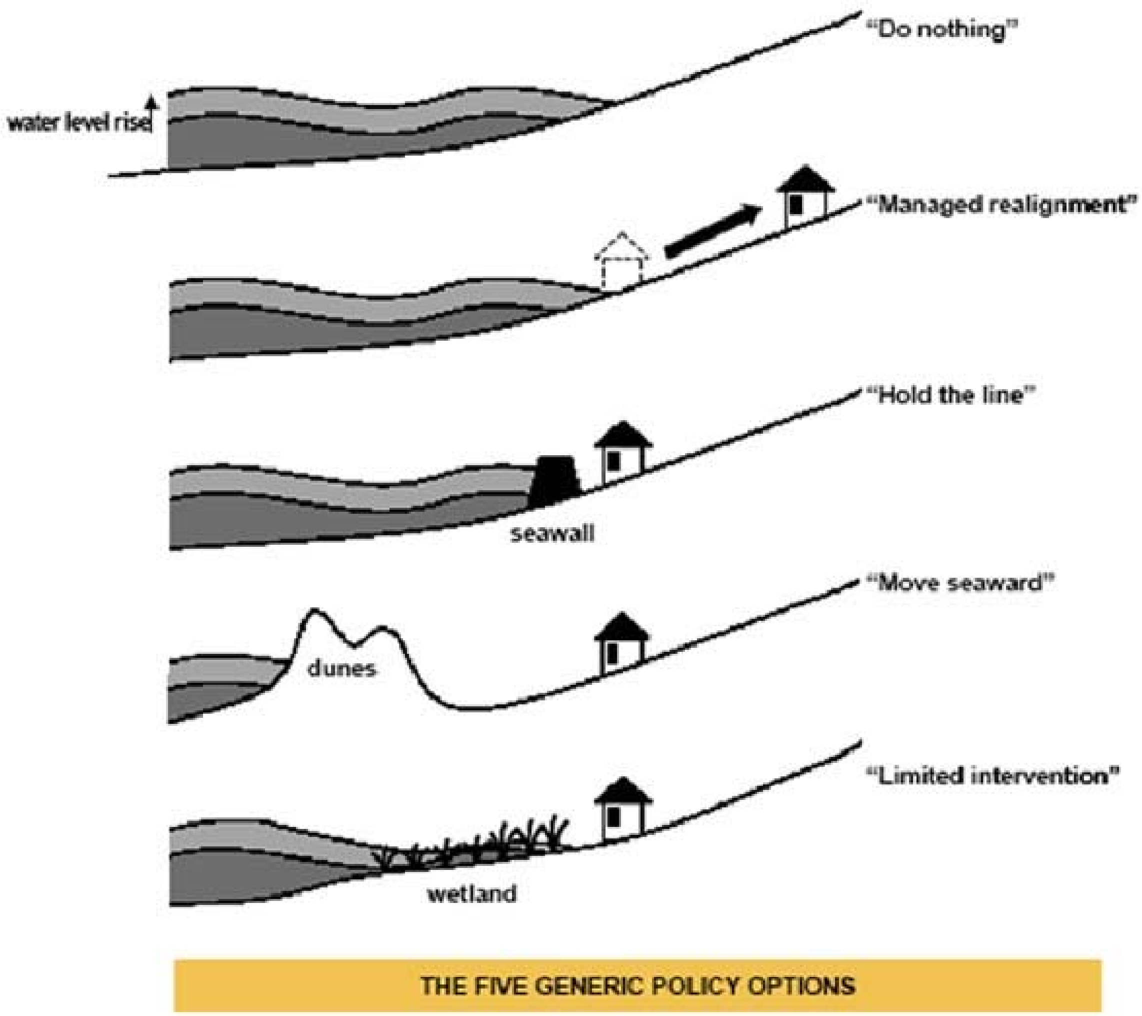
Current challenges in coastal management

The coastal zone is a dynamic area of natural change and of increasing human use. They occupy less than 15% of the Earth's land surface; yet accommodate more than 50% of the world population (it is estimated that 3.1 billion people live within 200 kilometres from the sea). With three-quarters of the world population expected to reside in the coastal zone by 2025, human activities originating from this small land area will impose an inordinate amount of pressures on the global system. Coastal zones contain rich resources to produce goods and services and are home to most commercial and industrial activities. In the European Union, almost half of the population now lives within 50 kilometres of the sea and coastal zone resources produce much of the Union's economic wealth. The fishing, shipping and tourism industries all compete for vital space along Europe's estimated 89 000 kilometres of coastline, and coastal zones contain some of Europe's most fragile and valuable natural habitats. Shore protection consists up to the 50's of interposing a static structure between the sea and the land to prevent erosion and or flooding, and it has a long history. From that period new technical or friendly policies have been developed to preserve the environment when possible. Is already important where there are extensive low-lying areas that require protection. For instance: Venice, New Orleans, Nagara river in Japan, Holland, Caspian Sea

Protection against the sea level rise in the 21st century will be especially important, as sea level rise is currently accelerating. This will be a challenge to coastal management, since seawalls and breakwaters are generally expensive to construct, and the costs to build protection in the face of sea-level rise would be enormous.

Changes on sea level have a direct adaptative response from beaches and coastal systems, as we can see in the succession of a lowering sea level. When the sea level rises, coastal sediments are in part pushed up by wave and tide energy, so sea-level rise processes have a component of sediment transport landwards. This results in a dynamic model of rise effects with a continuous sediment displacement that is not compatible with static models where coastline change is only based on topographic data.

Planning approaches



Five general coastal management strategies

There are five generic strategies for coastal defense:

- inaction leading to eventual abandonment
- Managed retreat or realignment, which plans for retreat and adopts engineering solutions that recognise natural processes of adjustment, and identifies a new line of defence where to construct new defences
- Hold the line, shoreline protection, whereby seawalls are constructed around the coastlines
- Move seawards, by constructing new defenses seaward the original ones
- Limited intervention, accommodation, by which adjustments are made to be able to cope with inundation, raising coastal land and buildings vertically

The decision to choose a strategy is site-specific, depending on pattern of relative sea-level change, geomorphological setting, sediment availability and erosion, as well a series of social, economic and political factors.

Alternatively, integrated coastal zone management approaches may be used to prevent development in erosion- or flood-prone areas to begin with. Growth management can be a challenge for coastal local authorities who often struggle to provide the infrastructure required by new residents seeking seachange lifestyles. . Sustainable transport investment to reduce the average footprint of coastal visitors is often a good way out of coastal gridlock. Examples include Dongtan and the Gold Coast Oceanway.

Do nothing

The 'do nothing' option, involving no protection, is a cheap and expedient way to let the coast take care of itself. It involves the abandonment of coastal facilities when they are subject to coastal erosion, and either gradually landward retreat or evacuation and resettlement elsewhere. This option is very environmental friendly and the only pollution produced is from the resettlement process. However it does mean losing a lot of land to the sea and people will lose their houses and their homes.

Managed retreat

Managed retreat (also managed realignment) allows an area that was not previously exposed to flooding by the sea to become flooded by removing coastal protection. This process is usually in low lying estuarine areas and almost always involves flooding of land that has at some point in the past been claimed from the sea.

Managed retreat is often a response to sea level rise exacerbated by local subsidence of the land surface due to isostatic rebound in the north.

Coastal defence

In the UK the main reason for implementation of Managed Realignment is generally to improve coastal stability, essentially replacing artificial 'hard' coastal defences with natural 'soft' coastal landforms (Pethick 2002). This process can be used to protect areas of land further inland rather than that near the coast by relying on natural defences to absorb or dampen the force of waves.

Habitat loss

In addition to being used as a means of coastal defence, Managed Realignment has also been used in a number of cases to mitigate for loss of intertidal habitat.

Although land claim has been an important factor for salt marsh loss in the UK in the past (Allen 1992) the majority of current salt marsh loss in the UK is believed to be due to erosion (Morris et al. 2004). This erosion may involve coastal squeeze, where protective sea walls prevent the landward migration of salt marsh in response to sea level rise when sediment supply is limited (Hulme 2005; Morris et al. 2004). Salt marshes are protected under the EU Habitats Directive as well as providing habitat for a number of species protected by the Birds Directive. Following this guidance, the UK's biodiversity action plan aims to prevent net losses to the area of salt marsh present in 1992. It is therefore a legal requirement that all losses in marsh area must be compensated by replacement habitat with equivalent biological characteristics (Crooks et al. 2001). This equates to the need to restore approximately 1.4 km^2 of salt marsh habitat per year in the UK.

Advantages

There are no direct costs apart from that of removing any defences already in place and maintenance costs are very low.

Sediment flow is also restored to its natural state, beaches can be naturally replenished due to erosion of the coast, providing protection and the balance of the coastline returns.

Disadvantages

A certain amount of land will inevitably be lost in this process while beaches are being built up resulting in settlements, farmland and other property being destroyed. Because of this, managed retreat is often not a socially acceptable plan and may invoke the need for compensation to land-owners. Intertidal sites are often a rich archaeological resource and the loss of heritage is a factor to weighed in managed retreat projects.

There are no agreed protocols on the monitoring of MR sites (Atkinson et al. 2001) and, consequently, very few of the sites are being monitored consistently and effectively (Wolters et al. 2005c). Due to the low levels of monitoring there is little evidence on which to base future managed realignment projects. This has led to the results of Managed Realignment schemes being extremely unpredictable.

Examples

Freiston Shore Managed Realignment site, Lincolnshire

In the UK, the first managed retreat site was an area of 8,000 square metres at Northey Island in Essex flooded in 1991, followed by larger sites at Tollesbury and Orplands (1995), Freiston Shore (2001) and Abbott's Hall Farm, at Great Wigborough in the Blackwater Estuary, it is one of the largest managed retreat schemes in Europe. It covers nearly 280 hectares of land on the north side of the estuary (2002) and a number of others.

Current progress

At present approximately 6 km² of salt marsh have been restored by MR in the UK (Mossman et al. In prep). One of the major reasons cited for the slow pace of current salt marsh restoration in the UK (Morris et al. 2004) is the uncertainty associated with the practice (Foresight).

Managed retreat is an alternative to constructing or maintaining coastal structures. Managed retreat allows an area that was not previously exposed to flooding by the sea to become flooded. This process is usually in low lying estuarine or deltaic areas and almost always involves flooding of land that has at some point in the past been reclaimed from the sea. Managed retreat is often a response to a change in sediment budget or to sea level rise. The technique is used when the land adjacent to the sea is low in value. A decision is made to allow the land to erode and flood, creating new sea, inter-tidal and salt-marsh habitats. This process may continue over many years and natural stabilization will occur.

The earliest managed retreat in the UK was an area of 0.8 ha at Northey Island in Essex, that was flooded in 1991. This was followed by Tollesbury and Orplands in Essex, where the sea walls were breached in 1995. In the Ebro delta (Spain) coastal authorities have planned a managed retreat in response to coastal erosion (MMA 2005, Sitges, Meeting on Coastal Engineering; EUROSION project).

Cost – The main cost is generally the purchase of land to be flooded. Housings compensation for relocation of residents may be needed. Any other human made structure which will be engulfed by the sea may need to be safely dismantled to prevent sea pollution. In some cases, a retaining wall or bund must be constructed inland in order to protect land beyond the area to be flooded, although such structures can generally be lower than would be needed on the existing coast. Monitoring of the evolution of the flooded area is another cost. Costs may be lowest if existing defenses are left to fail naturally, but often the realignment project will be more actively managed, for example by creating an artificial breach in existing defences to allow the sea in at a particular place in a controlled fashion, or by pre-forming drainage channels for created salt-marsh.

Hold the line

Human strategies on the coast have been heavily based on a static engineered response, whereas the coast is in, or strives towards, a dynamic equilibrium (Schembri, 2009). Solid coastal structures are built and persist because they protect expensive properties or infrastructures, but they often relocate the problem downdrift or to another part of the coast. Soft options like beach nourishment, while also being temporary and needing regular replenishment, appear more acceptable, and go some way to restore the natural dynamism of the shoreline. However in many cases there is a legacy of decisions that were made in the past which have given rise to the present threats to coastal infrastructure and which necessitate immediate shore protection. For instance, the seawall and promenade of many coastal cities in Europe represents a highly engineered use of prime seafront flange-eating space, which might be preferably designated as public open space, parkland and amenities if it were available today. Such open space might also allow greater flexibility in terms of future land-use change, for instance through managed retreat, in the face of threats of erosion or inundation as a result of sea-level rise. Foredunes areas represent a natural reserve which can be called upon in the face of extreme events; building on these areas leaves little option but to undertake costly protective measures when extreme events (whether amplified by gradual global change or not) threaten. Managed retreat can comprise 'setbacks', rolling easements and other planning tools including building within a particular design life. Maintenance of those structures or soft techniques can arrive at a critical point (economically or environmental) to change adopted strategy.

- Structural or hard engineering techniques, i.e. using permanent concrete and rock constructions to "fix" the coastline and protect the assets locate behind. These techniques--seawalls, groynes, detached breakwaters, and revetments--represent a significant share of protected shoreline in Europe (more than 70%).

- Soft engineering techniques (e.g. sand nourishments), building with natural processes and relying on natural elements such as sands, dunes and vegetation to prevent erosive forces from reaching the backshore. These techniques include beach nourishment and sand dune stabilization.

Move seaward

The futility of trying to predict future scenarios where there is a large human influence is apparent. Even future climate is to a certain extent a function of what humans choose to make of it, for example by restricting greenhouse gas emissions to control climate change. In some cases - where new areas are needed for new economic or ecological development - a move seaward strategy can be adopted. Some examples from EUROSION are: Koge Bay (Dk) Western Scheldt estuary (Nl), Chatelaillon (F), Ebro delta (E)

There is an obvious downside to this strategy. Coastal erosion is already widespread, and there are many coasts where exceptional high tides or storm surges result in encroachment on the shore, impinging on human activity. If the sea rises, many coasts that are developed with infrastructure along or close to the shoreline will be unable to accommodate erosion, and will experiment a so-called "coastal squeeze". This occurs where the ecological or geomorphological zones that would normally retreat landwards encounter solid structures and are squeezed out. Wetlands, salt marshes, mangroves and adjacent fresh water wetlands are particularly likely to suffer from this squeeze.

An upside to the strategy is that moving seaward (and upward) can create land of high value which can bring the investment required to cope with climate change.

Limited intervention

Limited intervention is an action taken whereby the management only solves the problem to some extent, usually in areas of low economic significance. Measures taken using limited intervention often encourage the succession of haloseres, including salt marshes and sand dunes. This will normally result in the land behind the halosere being more sufficiently protected, as wave energy will be dissipated by the accumulated sediment and additional vegetation residing in the newly formed habitat. Although the new halosere is not strictly man-made, as many natural processes will contribute to the succession of the halosere, anthropogenic factors are partially responsible for the formation as an initial factor was needed to help start the process of succession. This must not be confused with 'accommodate' which is about property e.g. effective insurance, early warning systems and not about habitat.

Construction techniques

The following is a catalogue of relevant techniques that could be employed as coastal management techniques. *The costs given are very rough estimates made during 2005, based on UK Pound sterling.*

Hard Engineering methods

Groynes

Groyne at Mundesley, Norfolk, UK.

Groynes are wooden often made of greenhart, concrete and/or rock barriers or walls perpendicular to the sea. Beach material builds up on the updrift side, where littoral drift is predominantly in one direction, creating a wider and a more plentiful beach, therefore enhancing the protection for the coast because the sand material filters and absorbs the wave energy. However, there is a corresponding loss of beach material on the downdrift side, requiring that another groyne to be built there. Moreover, groynes do not protect the beach against storm-driven waves and if placed too close together will create currents, which will carry sand material offshore.

Groynes are extremely cost-effective coastal defence measures, requiring little maintenance, and are one of the most common coastal defence structures. However, groynes are increasingly viewed as detrimental to the aesthetics of the coastline, and face strong opposition in many coastal communities.

Many experts consider groynes to be a "soft" solution to coastal erosion because of the enhancement of the existing beach.

But groyne construction creates a problem known as Terminal Groyne Syndrome. The terminal groyne prevents longshore drift from bringing material to other nearby places. This is a common problem along the Hampshire and Sussex coastline in the UK; a perfect example is Worthing.

Sea walls

Walls of concrete or rock, built at the base of a cliff or at the back of a beach, or used to protect a settlement against erosion or flooding. Older style vertical seawalls reflected all the energy of the waves back out to sea, and for this purpose were often given recurved crest walls which also increase the local turbulence, and thus increasing entrainment of sand and sediment. During storms, sea walls help longshore drift

Modern seawalls aim to destroy most of the incident energy, resulting in low reflected waves and much reduced turbulence and thus take the form of sloping revetments. Current designs use porous designs of rock, concrete armour (Seabees, SHEDs, Xblocs) with intermediate flights of steps for beach access, whilst in places where high rates of pedestrian access are required, the steps take over the whole of the frontage, but at a flatter slope if the same crest levels are to be achieved.

Care needs to be taken in the location of a seawall, particularly in relation to the swept prism of the beach profile, the consequences of long term beach recession and amenity crest level. These factors must be considered in assessing the cost benefit ratio, which must be favourable in order to justify construction of a seawall.

Sea walls can cause beaches to dissipate rendering them useless for beach goers. Their presence also scars the very landscape that they are trying to save.

Modern examples can be found at Cronulla (NSW, 1985-6) , Blackpool (1986–2001) , Lincolnshire (1992–1997) & Wallasey (1983–1993) . The sites at Blackpool and Cronulla can be visited both by Google Earth and by local webcams (Cronulla, Cleveleys).

A most interesting example is the seawall at Sandwich, Kent, where the Seabee seawall is buried at the back of the beach under the shingle with crest level at road kerb level.

Sea walls are probably the second most traditional method used in coastal management.

Revetments

Wooden slanted or upright blockades, built parallel to the sea on the coast, usually towards the back of the beach to protect the cliff or settlement beyond. The most basic revetments consist of timber slants with a possible rock infill. Waves break against the revetments, which dissipate and absorb the energy. The cliff base is protected by the beach material held behind the barriers, as the revetments trap some of the material. They may be watertight, covering the slope completely, or porous, to allow water to filter through after the wave energy has been dissipated. Most revetments do not significantly interfere with transport of longshore drift. Since the wall greatly absorbs the energy instead of reflecting, it erodes and destroys the revetment structure; therefore, major maintenance will be needed within a moderate time of being built, this will be greatly determined by the material the structure was built with and the quality of the product.

The *Cost* – Confirmed by material used; est. $2340 – $4000. Average $10 per meter built.

Rock armour

Also known as riprap, rock armour is large rocks piled or placed at the foot of dunes or cliffs with native stones of the beach. This is generally used in areas prone to erosion to absorb the wave energy and hold beach material. Although effective, this solution is unpopular due to the fact that it is unsightly. Also, longshore drift is not hindered. Rock armour has a limited lifespan, it is not effective in storm conditions, and it reduces the recreational value of a beach. The cost is around £300 per metre, depending on the type of rocks used.

Gabions

Boulders and rocks are wired into mesh cages and usually placed in front of areas vulnerable to heavy erosion: sometimes at cliffs edges or jag out at a right angle to the beach like a large groyne. When the seawater breaks on the gabion, the water drains through leaving sediments, also the rocks and boulders absorb a moderate amount of the wave energy.

Gabions need to be securely tied to prevent abrasion of wire by rocks, or detachment of plastic coating by stretching. Hexagonal mesh distributes overloads better than rectangular mesh.

Downsides include wear rates and visually intrusiveness.

Cost – est. £11 per m

Offshore breakwater

Enormous concrete blocks and natural boulders are sunk offshore to alter wave direction and to filter the energy of waves and tides. The waves break further offshore and therefore reduce their erosive power. This leads to wider beaches, which absorb the reduced wave energy, protecting cliff and settlements behind. The Dolos which was invented by a South African engineer in East London has replaced the use of enormous concrete blocks because the dolos is much more resistant to wave action and requires less concrete to produce a superior result. Similar concrete objects like the Dolos are the A-jack, Akmon, Xbloc and the Tetrapod, Accropode.

Cost – est. £1,950 per m. Water depth may increase the cost.

Cliff stabilization

Cliff stabilization can be accomplished through drainage of excess rainwater of through terracing, planting, and wiring to hold cliffs in place. Cliff drainage is used to hold a cliff together using plants, fences and terracing, this is used to help prevent landslides and other natural disasters.

Entrance training walls

Rock or concrete walls built to constrain a river or creek discharging across a sandy coastline. The walls help to stabilise and deepen the channel which benefits navigation, flood management, river erosion and water quality but can cause coastal erosion due to the interruption of longshore drift. One solution is the installation of a sand bypassing system to pump sand under and around the entrance training walls.

Cost – Expensive - Gold Coast Seaway was a A$50M project in the 1980s and the adjacent sand bypassing project costs A$3M per year to pump 500,000 cubic meters of sand across the trained entrance.

Floodgates

Storm surge barriers, or floodgates, were introduced after the North Sea Flood of 1953 and are a prophylactic method to prevent damage from storm surges. They are habitually open and allow free passage, but close when the land is under threat of a storm surge. The Thames Barrier is an example of such a structure.

Soft Engineering methods

Beach nourishment

Beach nourishment or replenishment is one of the most popular soft engineering techniques of coastal defence management schemes. This involves importing alien sand off the beach and piling it on top of the existing sand. The imported sand must be of a similar quality to the existing beach material so it can integrate with the natural processes occurring there, without causing any adverse effects. Beach nourishment can be used alongside the groyne schemes. The scheme requires constant maintenance: 1 to 10 year life before first major recharge. *Cost* – est. £5,000-£200,000 per 100 metre, plus control structures, ongoing management and minor works.

Sand dune stabilization

Vegetation can be used to encourage dune growth by trapping and stabilising blown sand.

Cost – est. of £1.1 million per annum

Beach drainage

Beach drainage or beach face dewatering lowers the water table locally beneath the beach face. This causes accretion of sand above the drainage system.

Grant (1946) – the elevation of the beach watertable had an important bearing on deposition and erosion across the foreshore. A high watertable coincided with periods of accelerated beach erosion, and conversely, a low watertable coincided with pronounced aggradation of the foreshore A lower watertable (unsaturated beach face) facilitates deposition by reducing flow velocities during backwash and prolonging laminar flow. In contrast, a high watertable results in condition favoring beach erosion. With the beach in a saturated state, Grant proposed that backwash velocity is accelerated by the addition of groundwater seepage out of the beach within the effluent zone.

Turner and Leatherman (1997) moving from the origins and development of the dewatering concept to field and laboratory studies available at the time of writing concluded that there was too little evidence for being convinced that the systems had a positive effect. None of the case studies provide full scientific evidence of undisputable positive results regarding beach stabilisation although in some cases an overall positive performance was reported. In many cases no adequate long-term monitoring was undertaken at a frequency high enough to discriminate the response to high energy erosive events.

A useful side effect of the system is that the collected seawater is very pure because of the sand filtration effect. It may be discharged back to sea but can also be used to oxygenate stagnant inland lagoons /marinas or used as feed for heat pumps, desalination plants, land-based aquaculture, aquariums or seawater swimming pools.

Beach drainage systems have been installed in many locations around the world to halt and reverse erosion trends in sand beaches. Twenty four beach drainage systems have been installed since 1981 in Denmark, USA, UK, Japan, Spain, Sweden, France, Italy and Malaysia.

Costs

The costs of installation and operation per meter of shoreline protection will vary due to

- system length (non-linear cost elements)
- pump flow rates (sand permeability, power costs)
- soil conditions (presence of rock or impermeable strata)
- discharge arrangement /filtered seawater utilization
- drainage design, materials selection & installation methods

- geographical considerations (location logistics)
- regional economic considerations (local capabilities /costs)
- study requirements /consent process.

The costs associated with a beach drainage system are generally considerably lower than hard engineered structures. They also compare very favorably with beach nourishment projects, particularly when long-term project economics are considered (nourishment projects often have a limited life or a program of re-nourishment).

Monitoring coastal zones

Coastal zone managers are faced with difficult and complex choices about how best to reduce property damage in the shorelines. One of the problems they face is error and uncertainty in the information available to them on the processes that cause erosion of beaches. Video-based monitoring lets collect data continuously at low cost and produce analyses of shoreline processes over a wide range of averaging intervals.

Event warning systems

Event warning systems, such as tsunami warnings and storm surge warnings, can be used to minimize the human impact of catastrophic events that cause coastal erosion. Storm surge warnings can also be used to determine when to close floodgates to reduce the physical impact of such events.

Wireless sensor networks can be deployed quickly to set up a coastal erosion monitoring system, and scaled accordingly.

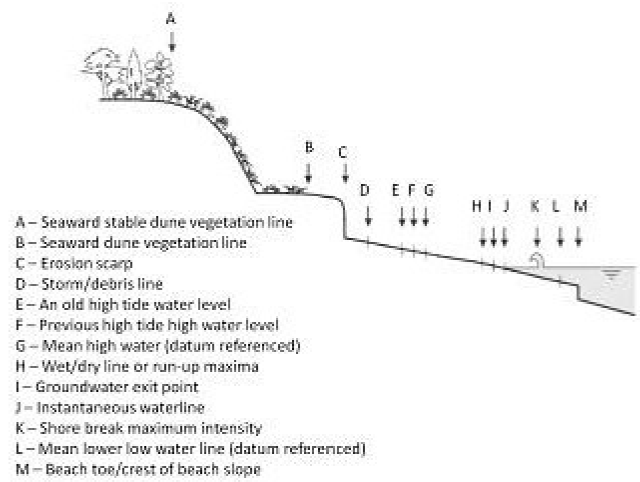
Shoreline Mapping

Defining the shoreline is a difficult task due to the dynamic nature of the coast and the intended application of the shoreline (Graham et al. 2003; Boak & Turner 2005). Given this idea the shoreline must therefore be considered in a temporal sense whereby the scale is dependent on the context of the investigation (Boak & Turner 2005). The following definition of the coast and shoreline is most commonly employed for the purposes of shoreline mapping. The coast comprises the interface between land and sea, and the shoreline is represented by the margin between the two (Woodroffe, 2002). Due to the dynamic nature of the shoreline coastal investigators adopt the use of shoreline indicators to represent the true shoreline position (Boak & Turner 2005).

Shoreline Indicator

The choice of shoreline indictor is a primary consideration in shoreline mapping. According to Leatherman (2003) it is important that indicators are easily identified in the field and on aerial photography. Shoreline indicators may be physical beach morphological features such as the berm crest, scarp edge, vegetation line, dune toe, dune crest and cliff or the bluff crest and toe. Alternatively, non-morphological features may also be used. These indicators are based on water level including the high water line, mean high water line, wet/dry boundary, and the physical water line (Pajak & Leatherman 2000). Figure 1 provides a sketch of the spatial relationship between many of the commonly used shoreline indicators.

The high water line (HWL), defined as the wet/dry line (H in Figure 1) is the most commonly used shoreline indicator because it is visible in the field, and can be interpreted on both colour and grey scale aerial photographs (Leatherman, 2003; Crowell et al. 1991). The HWL represents the landward extent of the most recent high tide and is characterised by a change in sand colour due to repeated, periodic inundation by high tides. The HWL is portrayed on aerial photographs by the most landward change in colour or grey tone (Boak & Turner 2005).



A diagram representing the spatial relationship between many of the commonly used indicators. (Adapted from Boak and Turner 2005)

Importance and application

The location of the shoreline and its changing position over time is of fundamental importance to coastal scientists, engineers and managers (Boak & Turner 2005; Pajack & Leatherman 2002). Present day shoreline monitoring campaigns provide information about historic shoreline location and movement, and about predictions of future change (Appeaning Addo et al. 2008). More specifically the position of the shoreline in the past, at present and where it is predicted to be in the future is useful for in the design of coastal protection, to calibrate and verify numerical models to assess sea level rise, map hazard zones and formulate policies to regulate coastal development. Accurate and consistent delineation of the shoreline is integral to all of these tasks. The location of the shoreline also provides information regarding shoreline reorientation adjacent to structures, beach width, volume and rates of historical change (Boak & Turner 2005; Pajack & Leatherman 2002).

Data sources

A variety of data sources are available for examining shoreline position however, the availability of historical data is limited at many coastal sites and so the choice of data source is largely limited to what is available for the site at a given time (Boak & Turner 2005). Shoreline mapping techniques applied to data sources have moved towards automation in association with technological advances and the need to reduce uncertainty. Although these changes have resulted in improvement in coastal data processing and storage capabilities, the frequent change in technology has prevented the emergence of one standard method of shoreline mapping. This has occurred because each data source and associated method have their own unique capabilities and shortcomings (Moore 2000). A number of the data sources used for shoreline mapping and their associated advantages and disadvantages are discussed below.

Historical maps

In the event that a study requires the shoreline position to be mapped before the development of aerial photographs, or if the location has poor photograph coverage it is necessary to employ historical maps in order to detail shoreline position (Moore 2000). The main advantage and reason for using historical maps is that they are able to provide a historic record that is not available from other data sources. Many potential errors however are associated with historical coastal maps and charts. Such errors may be associated with scale, datum changes, distortions from uneven shrinkage, stretching, creases, tears and folds, different surveying standards, different publication standards, and projection errors (Boak & Turner 2005). The severity of these errors depends on the accuracy standards met by each map and the physical changes that have occurred since the publication of the map (Anders & Byrnes 1991). The oldest reliable source of shoreline data in the United States dates back to the early-to-mid-19th century and is the U.S Coast and Geodetic Survey/National Ocean Service T-sheets (Morton 1991). In the United Kingdom, many maps and charts were deemed to be inaccurate until around 1750. The founding of the Ordnance Survey in 1971 has since improved the accuracy of the mapping.

Aerial photographs

Aerial photographs have been used since the 1920's to provide topographical information about an area. They are therefore a good database for compilation of historical shoreline change maps. Aerial photographs are the most commonly used data source in shoreline mapping because many coastal areas have extensive aerial photo coverage therefore providing a valuable record of shoreline position (Moore 2000). In general, aerial photographs provide good spatial coverage of the coast however temporal coverage is very much site specific depending on the flight path of the aeroplane. A second disadvantage associated with aerial photography is that the interpretation of the shoreline position is subjective given the dynamic nature of the coastal environment. This combined with various distortions inherent in aerial photographs can lead to significant error levels (Moore 2000). The minimisation of further errors is discussed below.

Object space displacements

Conditions outside of the camera can cause objects in an image to be displaced from their true ground position. Such conditions may include ground relief, camera tilt and atmospheric refraction.

Relief displacement is prominent when photographing a variety of elevations. This situation causes objects above ground level to be displaced outward from the centre of the photograph and objects below ground level to be displaced toward the centre of the image (Figure 2). The severity of the displacement is affected negatively with decreases in flight altitude and as radial distance from the centre of the photograph increases. This distortion can be minimised by photographing numerous swaths and creating a mosaic of the images. This technique will create a focus for the centre of each photograph where distortion is minimised. It is important to note that this error is not common in shoreline mapping is the relief is fairly constant. It is however important to consider when mapping cliffs (Moore 2000).

Ideally aerial photographs are taken so the optical axis of the camera is perfectly perpendicular to the ground surface thereby creating a vertical photograph. Unfortunately this is not often the case and virtually all aerial photographs experience tilt whereby up to 3° is not uncommon (Camfield et al. 1996). In this situation the scale of the image will be larger on the upward side of the tilt axis and smaller on the downward side. Moore, (2000) notes that many coastal researchers have not realised the severity of this error and therefore do not consider it in their methods.

An example of relief displacement. All objects above ground level are displaced outwards from the centre of the photograph. The displacement becomes more evident near the edges.

Radial Lens Distortion

Lens distortion varies as a function of radial distance from the iso-centre of the photograph meaning that the centre of the image is relatively distortion free, but as the angle of view increases the distortion becomes more prominent. This is a significant source of error in earlier aerial photography but as technology has increased and camera lens have become more refined it has become less of an issue with later photographs. Such a distortion is impossible to correct for without knowing the make and model of the lens used to capture the image. However if overlapping images have been acquired one can digitize the centre portions of the aerial photographs (Crowell et al. 1991).

Delineation of the shoreline

The dynamic nature of the coast has meant that accurate mapping of an instantaneous shoreline position has been associated with significant uncertainty. This uncertainty arises because at any given time the position of the shoreline is influenced by the short-term effect of the tide and a wide variety of long term effects such as relative sea-level rise and along shore littoral sediment movement. Not only does this affect the accuracy of computed historic shoreline position but also any predicted future positions (Appeaning Addo et al. 2008). As mentioned earlier the HWL is most commonly used as a shoreline indicator. This can usually be seen as a significant tonal change on aerial photographs. There are however many errors associated with using the wet/dry line as a proxy for the HWL and shoreline. The errors of largest concern are the short term migration of the wet/dry line, interpretation of the wet/dry line on a photograph and measurement of the interpreted line position (Leatherman 2003; Moore 2000). Systematic errors such as the migration of the wet/dry line may arise from tidal and seasonal changes. Storm-induced erosion is another factor which may cause the wet/dry line to migrate landward. Field investigations have shown that these changes can be minimised by using only summertime data (Moore 2000; Leatherman 2003). Furthermore, the error bar can be significantly reduced by using the longest record of reliable data to calculate erosion rates (Leatherman 2003). Finally it is important to note that errors may arise due to the difficulty of measuring a single line on a photograph. For example where the pen line is 0.13 mm thick this translates to an error of ±2.6 m on a 1:20000 scale photograph.

Beach profiling surveys

Beach profiling surveys are typically repeated at regular intervals along the coast in order to measure short-term (daily to annual) variations in shoreline position and beach volume. (Smith & Zarillo 1990). Beach profiling is a very accurate source of information however measurements are generally subject to the limitations of conventional surveying techniques. Shoreline data derived from beach profiling is often spatially and temporally limited due to the high cost associated with such a labour intensive activity. Shorelines are generally derived by interpolating between a series of discrete beach profiles. It is important to note however that the distance between the profiles is usually quite large and so the accuracy of the interpolating becomes compromised. In contrast to aerial photographs, survey data is limited to smaller lengths of shoreline generally less than ten kilometres (Boak & Turner 2005). Beach profiling data is commonly available in from regional councils in New Zealand such as those compiled by the Hawkes Bay Regional Council.

Remote sensing

Technological advancement over the last decade has led to the development of a range of airborne, satellite and land based remote sensing techniques (Smith & Zarillo 1990). Some of the remotely sensed data sources are listed below:

- Multispectral and hyperspectral imaging
- Microwave sensors
- Global positioning system (GPS)
- Airborne light detection and ranging technology (LIDAR)

Remote sensing techniques are attractive as they are cost effective, reduce manual error and remove the subjective approach of conventional field techniques (Maiti et al. 2009).Remote sensing is a relatively new concept and so extensive historical observations are unavailable. Given this idea, it is important that coastal morphology observations are quantified by coupling remotely sensed data with other sources of information detailing historic shoreline position from archived sources (Appeaning Addo et al. 2008).

Video analysis

Video analysis provides quantitative, cost-effective, continuous and long-term monitoring beaches (Turner et al. 2004). The advancement of coastal video systems over the past 15 years has resulted in the extraction of large amounts of geophysical data from images. Such data includes that about coastal morphology, surface currents and wave parameters. The main advantage of video analysis lies in the ability to reliably quantify these parameters with high resolution and coverage in both space and time. This in particular highlights their potential importance as an effective coastal monitoring system and an aid to coastal zone management (Van Koningsveld et al. 2007). Interesting case studies have been carried out using video analysis. Turner et al. (2004) used a video-based ARGUS coastal imaging system to monitor and quantify the regional-scale coastal response to sand nourishment and construction of the world-first Gold Coast artificial (surfing) reef in Australia. In addition, Smit et al. (2007) demonstrated the added value of high resolution video observations for making short-term predictions of near shore hydrodynamic and morphological processes, at temporal scales of meters to kilometres and days to seasons.

Chapter- 2

Groyne

Groynes in Sitges

A **groyne** (**groin** in the United States) is a rigid hydraulic structure built from an ocean shore (in coastal engineering) or from a bank (in rivers) that interrupts water flow and limits the movement of sediment. In the ocean, groynes create beaches, or avoid having them washed away by longshore drift. In a river, groynes prevent erosion and ice-jamming, which in turn aids navigation. Ocean groynes run generally perpendicular to the shore, extending from the upper foreshore or beach into the water. All of a groyne may be under water, in which case it is a **submerged groyne**. The areas between groups of groynes are **groyne fields**. Groynes are generally made of wood, concrete, or rock piles, and placed in groups. They are often used in tandem with seawalls. Groynes, however, may cause a shoreline to be perceived as unnatural and unattractive.

Groynes in the Waal river, part of the Rhine in the Netherlands

In coastal engineering

A groyne's length and elevation, and the spacing between groynes is determined according to local wave energy and beach slope. Groynes that are too long or too high tend to accelerate downdrift erosion because they trap too much sediment. Groynes that are too short, too low, or too permeable are ineffective because they trap too little sediment. Flanking may occur if a groyne does not extend far enough landward.

Groyne on the East coast of England

How groynes work

A groyne creates and maintains a wide area of beach or sediment on its updrift side, and reduces erosion on the other. It is a physical barrier to stop sediment transport in the direction of longshore transport (also called Longshore Drift). This causes a build-up, which is often accompanied by accelerated erosion of the downdrift beach, which receives little or no sand from longshore drift (this is known as terminal groyne syndrome, as it occurs after the **terminal groyne** in a group of groynes). Groynes do not add extra material to a beach, but merely retain some of the existing sediment on the updrift side of the groynes. If a groyne is correctly designed, then the amount of material it can hold will be limited, and excess sediment will be free to move on through the system. However, if a groyne is too large it may trap too much sediment, which can cause severe beach erosion on the down-drift side.

Timber groynes in Bournemouth, England

In rivers

River groynes (**spur dykes** or **wing dykes**) (American English: "dikes") are often constructed nearly perpendicular to the riverbanks, beginning at a riverbank with a root and ending at the regulation line with a head. They maintain a channel to prevent ice jamming, and more generally improve navigation and control over lateral erosion, that would form from meanders. Groynes have a major impact on the river morphology: they cause autonomous degradation of the river.

They are also used around bridges to prevent bridge scour.

Types

Submerged Groin, Hunting Island, South Carolina

A "Keep of the groynes" sign in Brighton with a groyne showing in the background.

Groynes can be distinguished by how they are constructed, whether they are submerged, their effect on stream flow or by shape.

Timber groyne in Sandown, Isle Of Wight, England

By construction method

Groynes can be permeable, allowing the water to flow through at reduced velocities, or impermeable, blocking and deflecting the current.

- **Permeable groynes** are large rocks, bamboo or timber
- **impermeable groynes** (**solid groynes** or **rock armour groynes**) are constructed using rock, gravel, gabions.

By whether they are submerged

Groynes can be submerged or not under normal conditions. Usually impermeable groynes are non-submerged, since flow over the top of solid groynes may cause severe erosion along the shanks. Submerged groynes, on the other hand, may be permeable depending on the degree of flow disturbance needed.

By their effect on stream flow

Groynes can be attracting, deflecting or repelling.

- **Attracting groynes** point downstream, serving to attract the stream flow toward themselves and not repel the flow toward the opposite bank. They tend to maintain deep current close to the bank.
- **Deflecting groynes** change the direction of flow without repelling it. They are generally short and used for limited, local protection.
- **Repelling groynes** point upstream; they force the flow away from themselves. A single groyne may have one section, for example, attracting, and another section deflecting.

By shape

Groynes can be built with different planview shapes. Examples are straight groynes, T head, L head, hockey stick, inverted hockey stick groynes, straight groynes with pier head, wing, and tail groynes.

Groyne in Schobüll, Nordfriesland, Germany

Chapter- 3

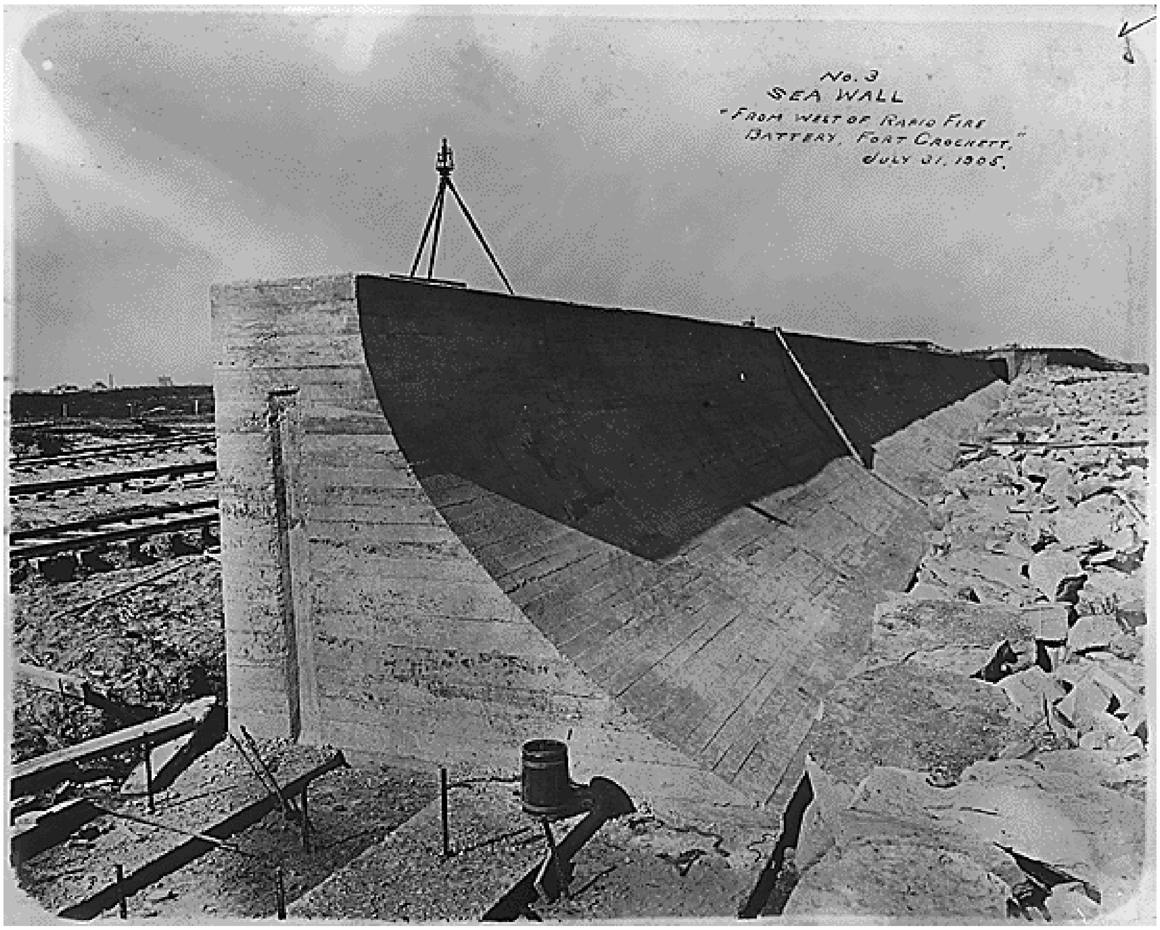
Seawall

An example of a modern seawall in Ventnor on the Isle of Wight in the UK.

A **seawall** (also written as **sea wall**) is a form of hard and strong coastal defence constructed on the inland part of a coast to reduce the effects of strong waves.

In the UK, *sea wall* also refers to an earthen bank used to create a polder, or a dike. The term is also sometimes used for walls used to make artificial harbours and port facilities.

Seawalls may be constructed from a variety of materials: most commonly, reinforced concrete, boulders, steel, or gabions. Additional seawall construction materials may include vinyl, wood, aluminium, fibreglass composite and with large biodegrable sandbags made of jute and coir. Modern concrete seawalls tend to be curved to reflect the wave energy back out to sea. Poor designs require constant maintenance as waves erode the base of the seawall.



Seawall in production in Galveston, TX, USA, 1905

Remains of the first seawall of Canvey Island built c.1622.

Design principles and types

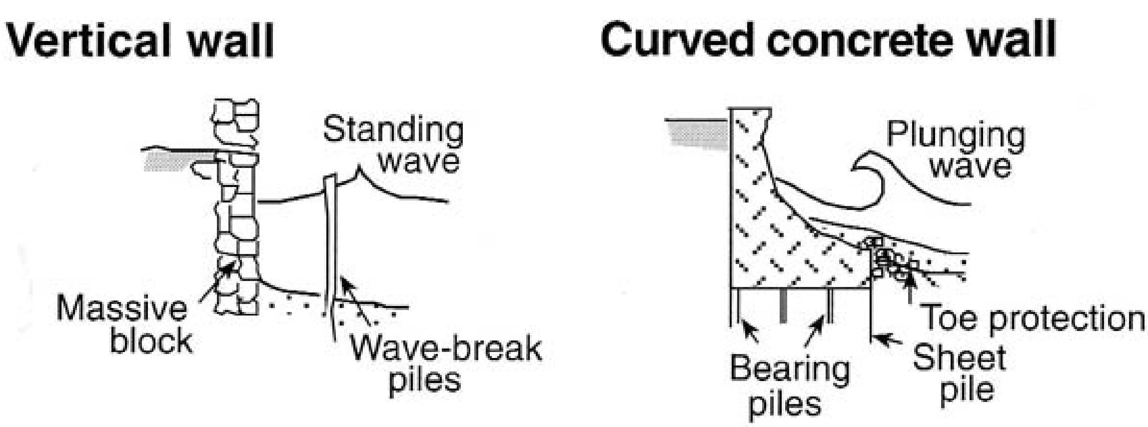
A range of seawall types can be envisaged in relation to wave energy, resembling cliff and beach profiles. *Vertical seawalls* are built in particularly exposed situations. These reflect wave energy and under storm conditions standing waves (clapotis) will develop. In some cases piles are placed in front of the wall to lessen wave energy slightly.

Curved or stepped seawalls are designed to enable waves to break and to dissipate wave energy and repel waves back to the sea. The curve can also prevent the wave overtopping the wall, and provide additional protection for the toe of the wall.

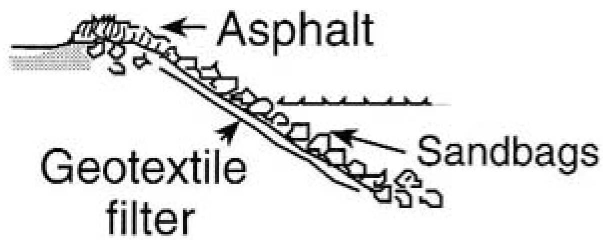
Seawall in Sicily

Seawall in Poland

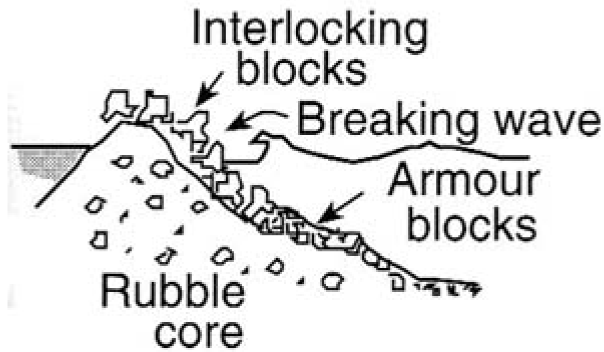
A series of rubble mound-type structures (revetments, riprap) are used in less demanding settings. The least exposed sites involve the lowest-cost bulkheads, or revetments of sand bags or geotextiles. These serve to armour the shore and minimize erosion. They may be either watertight, covering the slope completely, or porous, to allow water to filter through after the wave energy has been dissipated.



Revetment



Rubble-mound



History

Pondicherry

On December 26, 2004, when towering waves of the 2004 Indian Ocean earthquake crashed against India's south-eastern coastline killing thousands, the former French colonial enclave of Pondicherry (now Puducherry) escaped unscathed. During the city's nearly three centuries as a French colony, French engineers had constructed and maintained a massive stone seawall, which kept Pondicherry's historic centre dry even though tsunami waves drove water 24 feet above the normal high-tide mark.

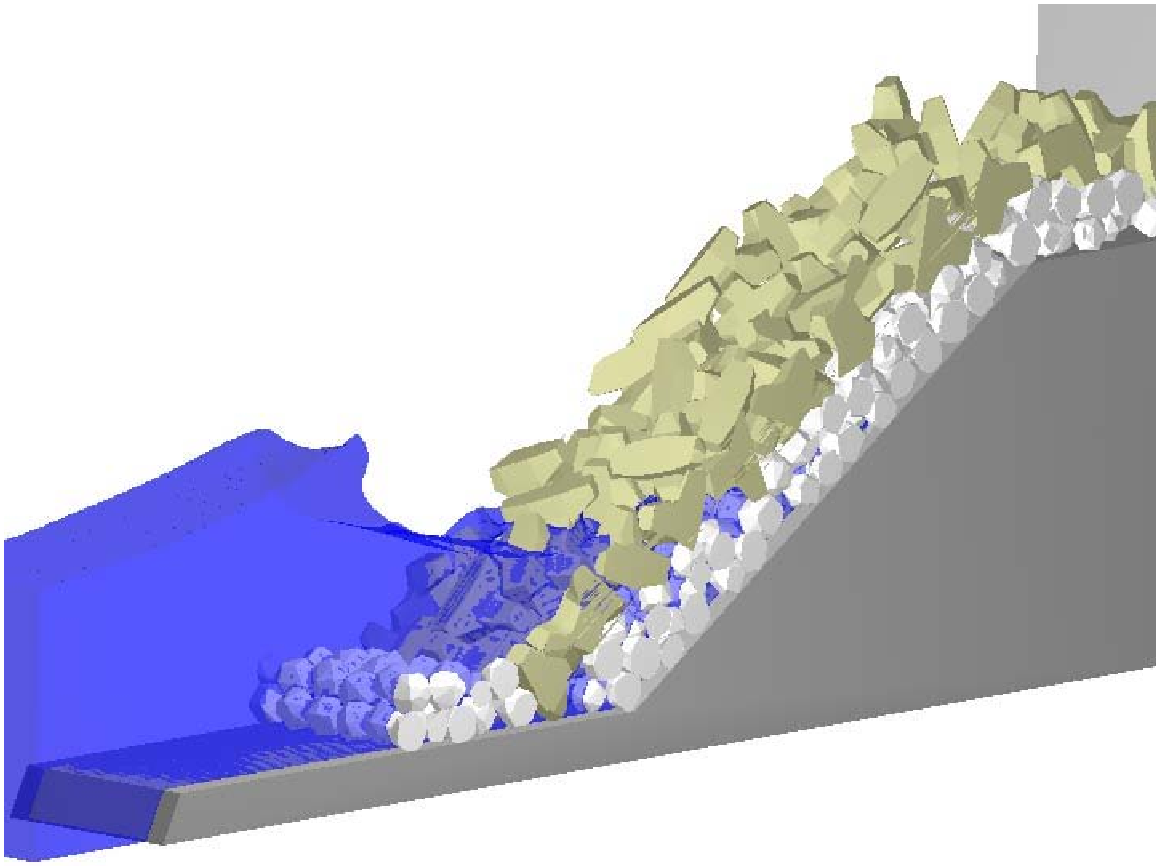
The barrier was initially completed in 1735. Over the years, the French continued to fortify the wall, piling huge boulders along its 1.25-mile (2-km) coastline to stop erosion from the waves pounding the harbour. At its highest, the barrier running along the water's edge reaches about 27 feet above sea level. The boulders, some weighing up to a ton, are weathered black and brown. The sea wall is inspected every year. Whenever gaps appear or the stones sink into the sand, the government adds more boulders to keep it strong.

The Union Territory of Pondicherry recorded some 600 deaths from the huge tsunami waves that struck India's coast after the mammoth underwater earthquake (which measured 9.0 on the moment magnitude scale) off Indonesia, but most of those killed were fishermen who lived in villages beyond the artificial barrier.

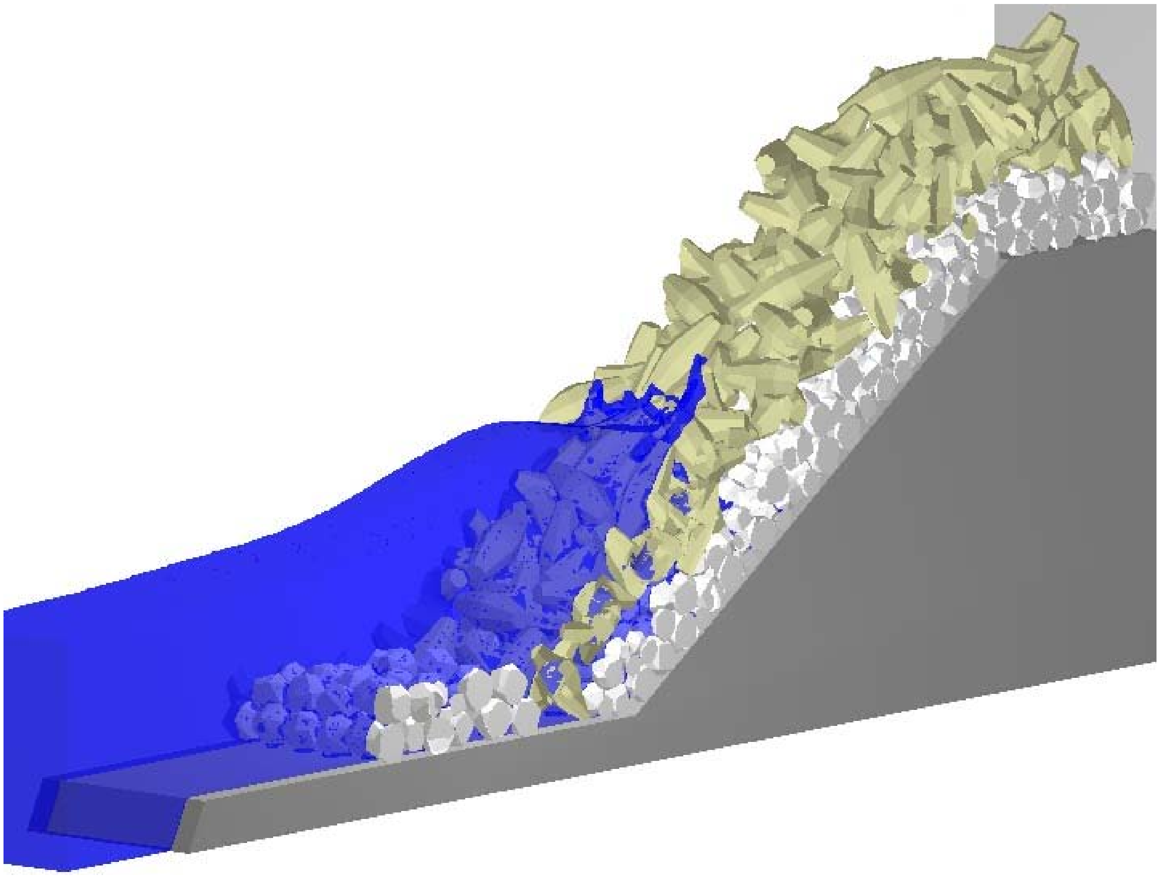
Seawall in Bembridge, UK

Seawall on Goat Island in Newport, Rhode Island, USA

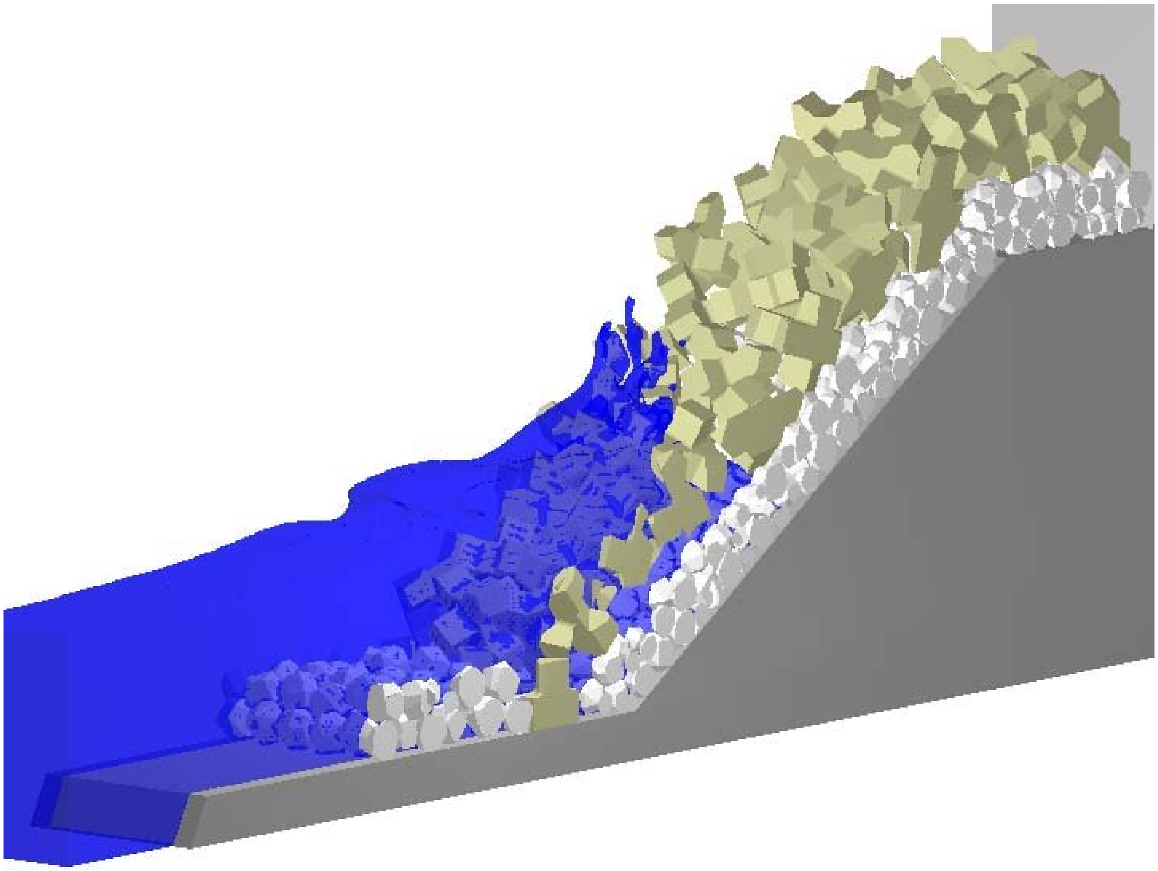
Advanced Numerical Study



3D Numerical Simulation - MEDUS 2009



3D Numerical Simulation - MEDUS 2009



3D Numerical Simulation - MEDUS 2009

The Maritime Engineering Division University Salerno(MEDUS) developed a new procedure to study, with a more detailed and innovative approach, the interactions between maritime breakwaters (submerged or emerged) and the waves, by an integrated use of CAD and CFD software.

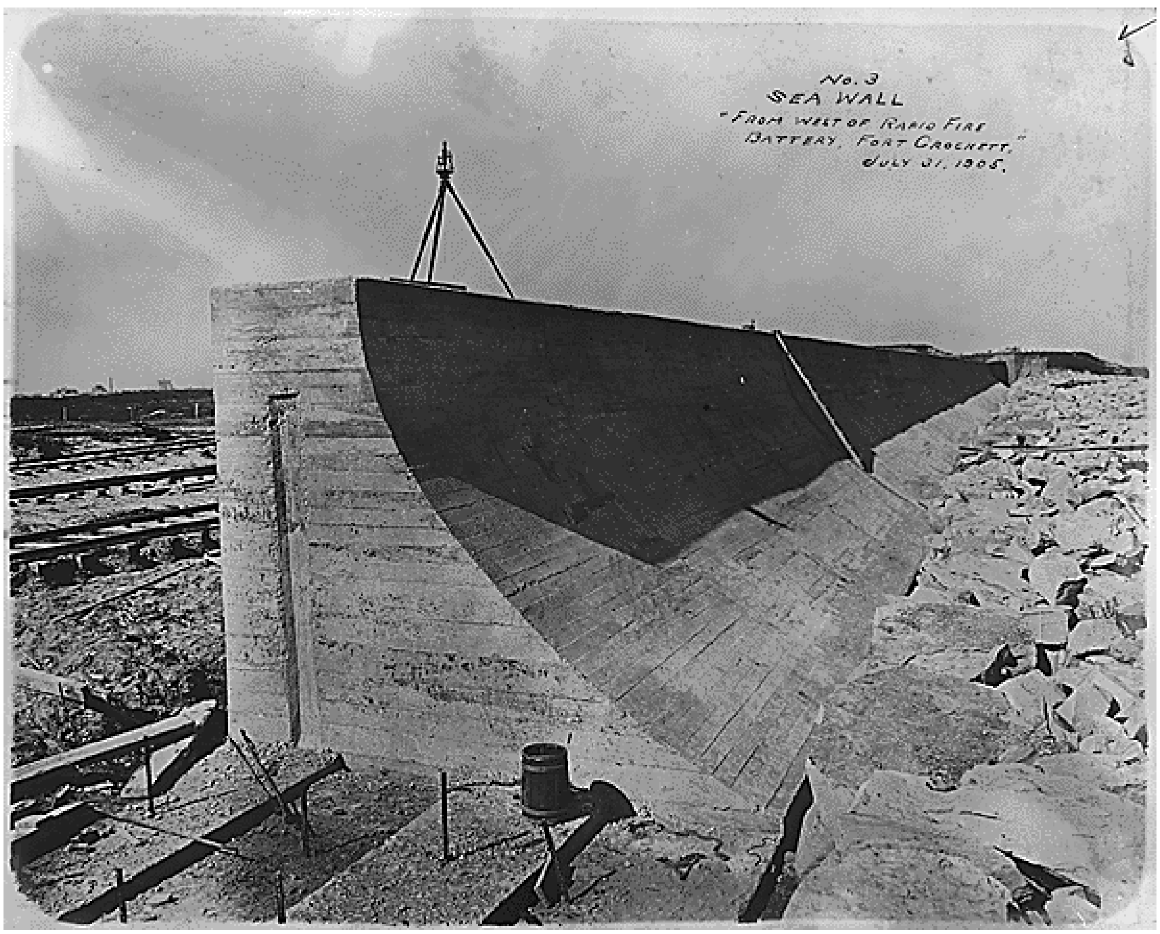
In the numerical simulations the filtration motion of the fluid within the interstices, which normally exist in a breakwater, is estimated by integrating the RANS equations, coupled with a RNG turbulence model, inside the voids, not using a classical equations for porous media.

The breakwaters were modelled, as it happens in the full size construction or in physical laboratory test, by overlapping three-dimensional elements and the numerical grid was thickened in such a way to have some computational nodes along the flow paths among the breakwater's blocks (AccropodeTM, Core-locTM, Xbloc®).

Alaskan Way Seawall

The **Alaskan Way Seawall** is a seawall which runs for 7,000 feet along the Elliott Bay waterfront southwest of downtown Seattle from Bay Street to S. Washington Street. It was built to provide level access to Seattle's piers and supports the Alaskan Way Viaduct and Alaskan Way itself, which is a surface street. Completed in 1934, the seawall was built on top of wood piling which has significantly deteriorated due to wood eating gribbles. In addition, everything behind the seawall from Alaskan Way to Western Avenue is built on top of fill, making for a very dangerous situation should a large earthquake occur. The viaduct itself is particularly at risk; experts give a 1-in-20 chance that it could be shut down by an earthquake within the next decade, and so plans are underway to replace both seawall and viaduct. The seawall replacement is estimated to cost $800 million US dollars.

Galveston Seawall



Galveston Seawall during construction

Galveston Seawall paintings

The **Galveston Seawall** is a seawall in Galveston, Texas, USA that was built after the Galveston Hurricane of 1900 for protection from future hurricanes. Construction began in September, 1902, and the initial segment was completed on July 29, 1904. From 1904 to 1963, the seawall was extended from 3.3 miles (5.3 km) to over 10 miles (16 km) long. Reporting in the aftermath of the 1983 Hurricane Alicia, the Corps of Engineers estimated that $100 million in damage was avoided because of the seawall. On September 13, 2008 Hurricane Ike's storm surge and large waves over-topped the seawall. As a result, a commission was established by the Texas Governor following the hurricane to investigate preparing for and mitigating future disasters. A proposal has been put forth to build an "*Ike Dike*," a massive levee system which would protect the Galveston Bay, and the important industrial facilities which line the coast and the ship channel, from a future, potentially more destructive storm. The proposal has gained widespread support from a variety of business interests. As of 2009 it is currently only at the conceptual stage.

Texas F.M. 3005, otherwise known as Seawall Boulevard along the wall, runs along the seawall.

The seawall is presently 10 miles (16 km) long. It is approximately 17 feet (5.2 m) high, and 16 feet (4.9 m) thick at its base. The seawall was listed in the National Register of Historic Places in 1977 and designated a National Civil Engineering Landmark by the American Society of Civil Engineers (ASCE) in 2001.

Many miles of the seawall are painted with murals called "wall art". These huge murals are painted by children and depict underwater life. The art is meant to make the seawall more interesting to visitors.

Georgetown Seawall

Georgetown seawall

The most famous stretch of seawall in Guyana is the **Georgetown Seawall**.

Seawall is the name given to the wall of concrete built along the foreshore with the sea in Guyana, mostly in Demerara. It is part of the battle against the Atlantic Ocean. Earth walls are called sea-dams.

Seawalls were found necessary because of constant erosion of land by the sea. Historians note that two estates, Kierfield and Sandy Point, known to be existing in 1792 north of the present Georgetown Seawall, were completely washed away by 1804.

The foreshore is subject to cycles of erosion and accretion. (Tables of erosion and accretion, started by G.O. Case have been maintained by the government). It appears that accretion in the early 1840s was followed by erosion in the late 1840s. By 1855, the great Kingston Flood took place when the sea-dam was breached. It was after this catastrophe that the sea wall between Fort William Frederick and the Round House was started in 1858. Built principally by convict labor with granite from the Penal Settlement at Mazaruni (now Mazaruni Prison), it was completed in 1892.

Serious flooding resulting from breaches in the sea wall took place at Enmore in 1955, at Buxton in 1959, and at Bladen Hall in 1961.

The Georgetown Seawall is a favourite place for afternoon walks, for listening to music (at the bandstand), for races on the beach, for spontaneous cricket matches, for lovers' trysts and other activities.

In 1903 the Georgetown Seawall Bandstand was built with funds subscribed by the public as a memorial to Queen Victoria. The shelter north of the bandstand, called the Koh-i-noor Shelter, was erected in 1903.

Gold Coast Seawall

The Gold Coast seawall in Australia is contained within the Gold Coast's shoreline management plan. The original seawall was laid out following 11 cyclones in 1967 with assistance from coastal engineers from Delft University. The seawall alignment was selected to pick up as many of the older seawalls as possible. The seawall consists of three layers, armour boulders up to 4 tonnes, secondary armour around 360 kg and a clay shale foundation layer. The seawall is 16m across and 6m high and has a front slope of 1:1.5. The seawall was tested in a wave tank to withstand attack from a 1:100 cyclone wave.

A Gold Coast Seawall costs around A$3000 per meter to construct in 2006. The seawall is constructed along a designated seawall alignment along urban sections of the Gold Coast coastline. Non-Urban sections of coastline including South Stradbroke Island and the Southport Spit are not licenced for the construction of a seawall. The Gold Coast Planning Scheme requires private property owners along the beach to construct the seawall at their property at the property owners expense prior to making any investment into their house. The Council constructs sections of seawall that protect public land.

Saemangeum Seawall

Saemangeum Seawall

Picture taken in January 2004.

Korean name

The **Saemangeum Seawall**, located on the southwest coast of the Korean peninsula, is the world's longest man-made dyke, measuring 33 kilometres. It runs between two headlands, and separates the Yellow Sea and the former Saemangeum estuary.

A view of the Saemangeum Seawall.

In 1991, the South Korean government announced that a dyke would be constructed to link two headlands just south of the South Korean industrial port city of Gunsan, 270 kilometres southwest of Seoul, to create 400 square kilometres of farmland and a freshwater reservoir. Since then, the government has spent nearly 2 trillion won on construction of the dyke, with another 220 billion won budgeted on strengthening the dyke and a further 1.31 trillion won to transform the tidal flats into arable land and the reservoir.

The construction of the Saemangeum Seawall has caused controversy from the moment it was announced as environmental groups protested against the impact of the dyke on the local environment. Supreme Court challenges in 1999 and 2005 led to temporary production stoppages but ultimately failed to stop construction of the seawall. Major construction was completed in April 2006, with the seawall 500 metres longer than the Afsluitdijk in the IJsselmeer, the Netherlands, previously the longest seawall-dyke in the world.

With remaining minor construction and inspection finished, the Seawall was officially open to the public on 27 April 2010. Lee Myung Bak, the incumbent president of Korea, has commented that Saemangeum would be "...the kernel and the gateway of South Korea's west coast industrial belt.", and is "another effort by us for low-carbon and green growth, along with the four-rivers project". A ceremony was held in Saemangeum the same day, with cabinet officials, politicians, and delegates from countries around the world.

Seawall (Vancouver)

The seawall in Stanley Park.

The **seawall** in Vancouver, Canada is a stone wall that was constructed around the perimeter of Stanley Park to prevent the erosion of the park's foreshore. Colloquially, the term also denotes the pedestrian, bicycle, and roller blading pathway on the seawall, and which has been extended far outside the parameters of Stanley Park. It has become one of the most used features of the park by both locals and tourists. Despite perennial conflicts between pedestrians, cyclists, and inline skaters, park users consider the seawall to be the most important feature of Stanley Park and it is the most used park facility.

Construction

The original idea for the seawall is attributed to park board superintendent, W. S. Rawlings, who conveyed his vision in 1918:

> “ It is not difficult to imagine what the realization of such an undertaking would mean to the attractions ”

of the park and
personally I doubt if
there exists anywhere
on this continent such
possibilities of a
combined park and
marine walk as we
have in Stanley Park.

The proposal was made to the federal government that it should help finance seawall construction because it owned the park and only leased the land to the city. It was argued that the waves created by ships passing through the First Narrows were eroding the area between Prospect Point and Brockton Point. On this basis, the federal government helped pay for the wall only until 1967 because the portions of the park vulnerable to erosion were now protected.

Park visitors walk, bike, roll, and fish on the seawall. The Lions Gate Bridge is in the background.

Reserve soldiers walking on the pedestrian side of the seawall, near Siwash Rock in Stanley Park.

Most of the Stanley Park portion of the wall was built between 1914 and 1971, although the park portion was not completed until 1980. Much of the original wall was constructed under the direction of James "Jimmy" Cunningham, a master stonemason who spent 32 years on the project until his death in 1963. Cunningham continued supervising construction into his last days despite being ill, and on at least one occasion, went to check the seawall's progress still wearing pajamas. He died in 1963, long before the wall was finished, but remains the one most associated with the project, and a commemorative plaque can be found near Siwash Rock, also where his ashes were scattered. In contrast to the continuity during Cunningham's oversight of the project, construction of the seawall was intermittent, owing to the short-term funding commitments of the civic and federal governments. The first 4,000 feet was completed between 1914 and 1916. A series of storms threatened the foreshore near Second Beach during the war, when water flooded the patch of land between the beach and Lost Lagoon. In 1920, the wall served as a workfare project for 2,300 unemployed men (the largest number of workers at any one time), and by 1939, 8,000 more feet of the wall was finished. Another 9,100 feet was built between 1950 and 1957, and the final 2,500 feet was not taken on until 1968. The last block, completing the original vision of the seawall, was tapped into place by H. H. Stevens, who also helped initiate the project in 1914 as a Member of Parliament for Vancouver. Others that laboured on the wall included unemployed relief workers again during the Great Depression and seamen on from HMCS Discovery on Deadman's Island facing punishment detail in the 1950s. Also in that decade, stone sets from the recently dismantled BC Electric Railway streetcar system were incorporated into the seawall.

Seawall conflict

A protracted conflict between pedestrians and cyclists plagued the seawall for years. Strolling pedestrians took issue with cyclists speeding by, while cyclists felt they had a right to cycle the seawall. As traffic increased over time, collisions were becoming more frequent. Cycling on the seawall was consequently outlawed, and by 1976, the Vancouver Police Department had issued 3,000 tickets to offenders. A solution was proposed in 1977 by a Calgary-based group of charitable foundations. It offered to pay $900,000 to widen the path on the English Bay side to six metres in order to accommodate both cyclists and pedestrians on the condition that the city match that amount. The proposal triggered an outcry from environmentalist groups, such as the Save Our Parkland Association. City council nonetheless agreed to the plan, but conflict between user groups persisted. The issue was not resolved until 1984 when the bicycle lane of the seawall was designated one-way in a counterclockwise direction around the park, which it remains today. That resolution brought fewer accidents, but as late as 1993, proposals to ban cycling on the seawall continued to be put forth. The popularity of inline skating in the 1990s also contributed to the debate over seawall use, as well as skateboarders to a lesser extent, until users were divided into wheeled versus non-wheeled camps. It appears unlikely that a consensus will emerge over the most appropriate mode of travelling the seawall, but as long as accidents remain minimal, it is unlikely to re-emerge as a pressing park-use issue. A survey conducted for a 1992 task force on the park found that 65% of park users were opposed to the elimination of bicycle traffic from the seawall compared with 20% who favoured such a ban. Needless to say, the task force's recommendation to phase out cycling went unheeded.

The seawall route has continued to expand, so that a continuous, mostly seaside, path for pedestrians, cyclists, and inline skaters now extends for a total of 22 kilometres. Starting from Coal Harbour, it winds around Stanley Park, along Sunset Beach, around False Creek, past the Burrard Street Bridge, through Vanier Park, and finishes off at Kitsilano Beach Park.

Chapter- 4

Breakwater (Structure)

Breakwaters create safer harbours, but can also trap sediment moving along the coast. Alamitos Bay, CA entrance channel.

Breakwaters are structures constructed on coasts as part of coastal defence or to protect an anchorage from the effects of weather and longshore drift.

Purposes of breakwaters

Offshore breakwaters, also called bulkheads, reduce the intensity of wave action in inshore waters and thereby reduce coastal erosion. They are constructed some distance away from the coast or built with one end linked to the coast. The breakwaters may be small structures, placed one to three hundred feet offshore in relatively shallow water, designed to protect a gently sloping beach. Breakwaters may be either fixed or floating:

the choice depends on normal water depth and tidal range. They are made of large pieces of concrete and are spaced about 50m from each other. Breakwater construction is usually parallel or perpendicular to the coast to maintain tranquility condition in the port. Most of Breakwater construction depends upon wave approach and considering some other environmental parameters

When oncoming waves hit these breakwaters, their erosive power is concentrated on these structures some distance away from the coast. In this way, there is an area of slack water behind the breakwaters. Deposition occurring in these waters and beaches can be built up or extended in these waters. However, nearby unprotected sections of the beaches do not receive fresh supplies of sediments and may gradually shrink due to erosion, namely longshore drift.

Breakwaters are subject to damage, and overtopping by big storms can lead to problems of drainage of water that gets behind them. The wall also serves to encourage erosion of beach deposits from the foot of the wall and can increase longshore sediment transport.

3 of the 4 breakwaters forming Portland Harbour

The eight offshore breakwaters at Elmer, UK

Protection of anchorages

An anchorage is only safe when ships anchored there are protected from the force of high winds and powerful waves by some large underwater barrier which they can shelter behind. Natural harbours are formed by natural barriers such as headlands or reefs. Mobile harbours, such as the D-Day Mulberry harbours were floated into position and acted as breakwaters. Some natural harbours, such as those in Plymouth Sound, Portland Harbour and Cherbourg, have been enhanced or extended by breakwaters made of rock.

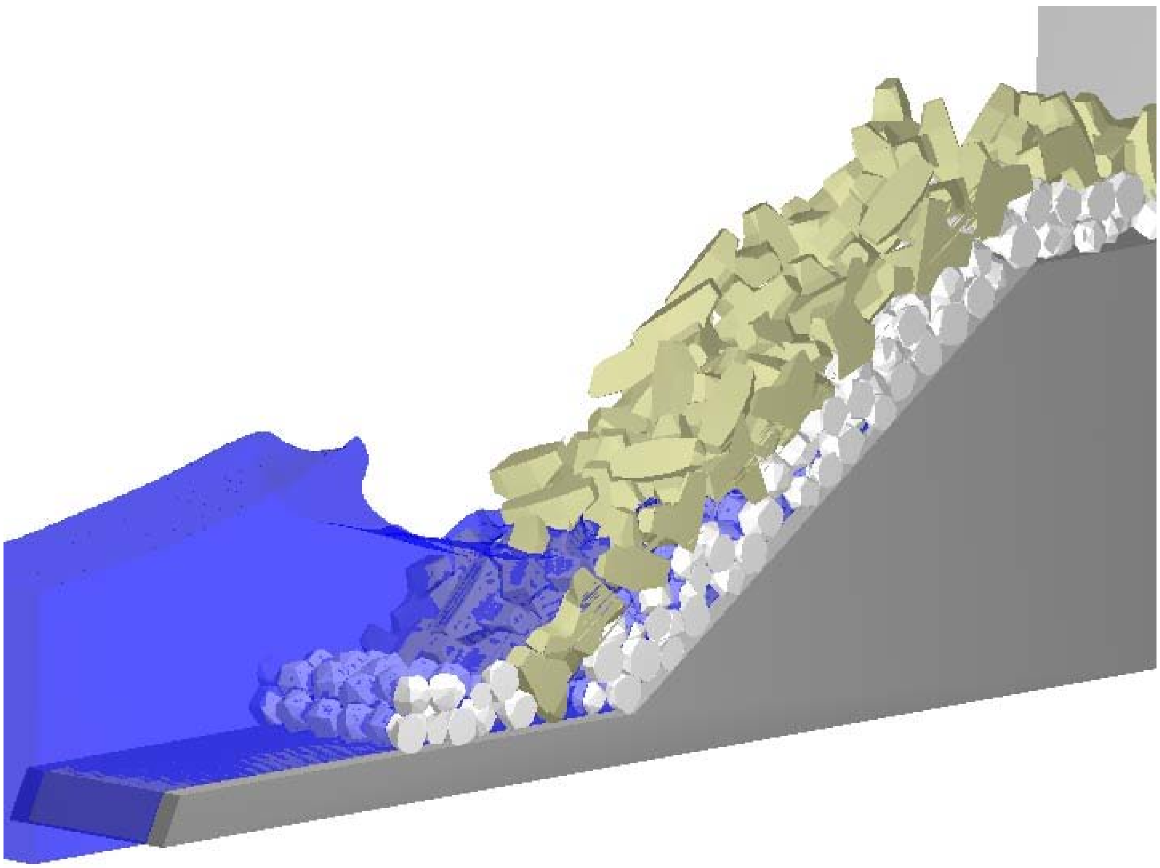
Types of breakwater structures

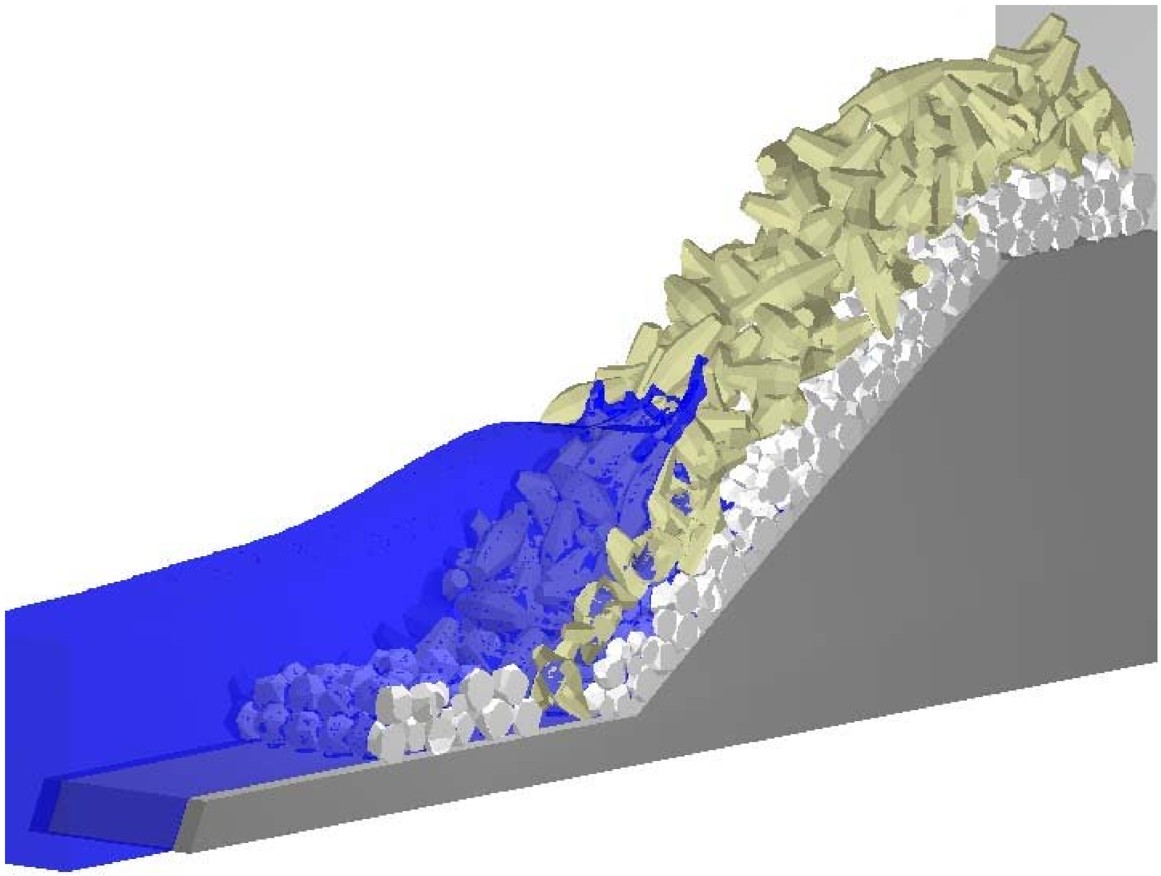
A breakwater is constructed some distance away from the coast or built with one end linked to the coast. Breakwaters may be either fixed or floating: the choice depends on normal water depth and tidal range. A breakwater structure is designed to absorb the energy of the waves that hit it. This is done either by using mass (e.g. with caissons) or by using a revetment slope (e.g. with rock or concrete armour units).

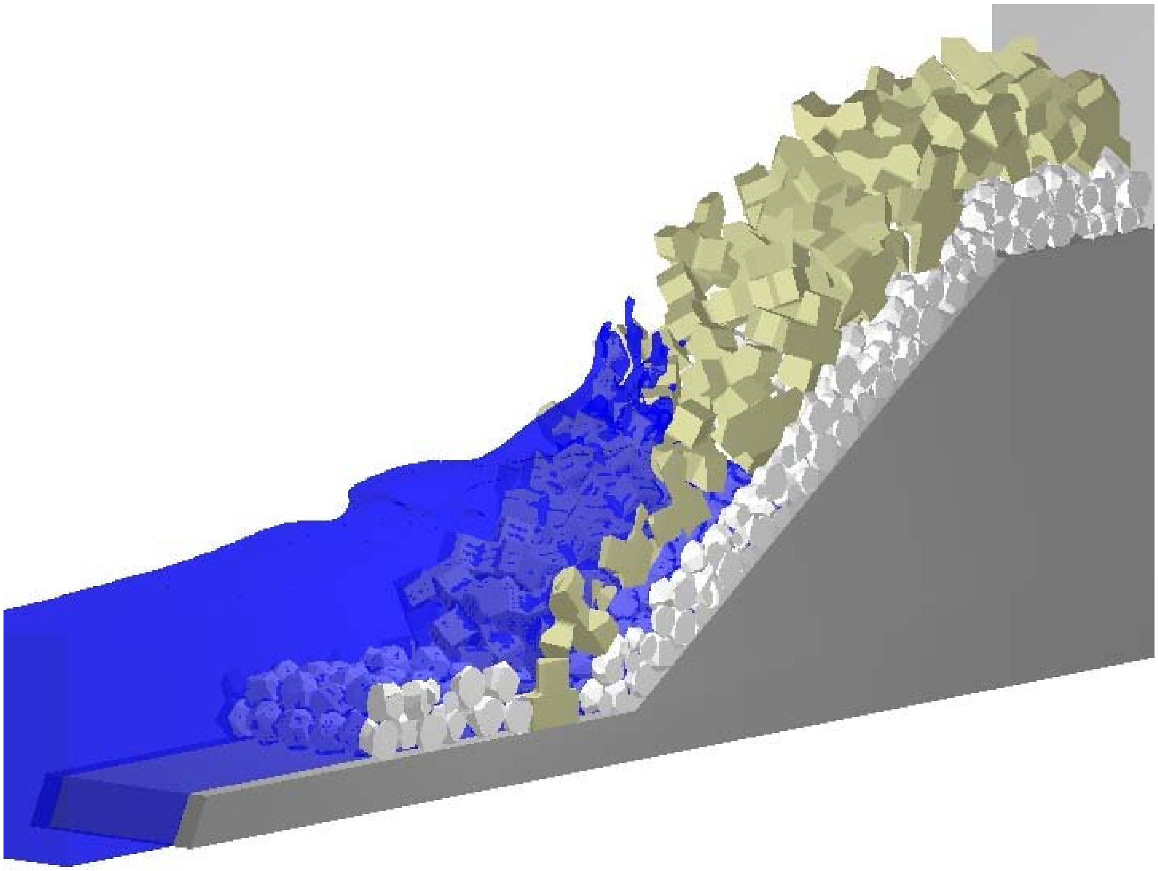
Caisson breakwaters typically have vertical sides and are usually used where it is desirable to berth one or more vessels on the inner face of the breakwater. They use the mass of the caisson and the fill within it to resist the overturning forces applied by waves hitting them. They are relatively expensive to construct in shallow water, but in deeper sites they can offer a significant saving over revetment breakwaters.

Rubble mound breakwaters use the voids in the structure to dissipate the wave energy. Rock or concrete armour units on the outside of the structure absorb most of the energy, while gravels or sands are used to prevent the wave energy continuing through the breakwater core. The slopes of the revetment are typically between 1:1 and 1:2, depending upon the materials used. In shallow water revetment breakwaters are usually relatively cheap, but as water depth increases, the material requirements, and hence costs, increase significantly.

Advanced Numerical Study






3D Numerical Simulation - MEDUS 2009

The Maritime Engineering Division University Salerno (MEDUS) developed a new procedure to study, with a more detailed and innovative approach, the interactions between maritime breakwaters (submerged or emerged) and the waves, by an integrated use of CAD and CFD software.

In the numerical simulations the filtration motion of the fluid within the interstices, which normally exist in a breakwater, is estimated by integrating the RANS equations, coupled with a RNG turbulence model, inside the voids, not using a classical equations for porous media.

The breakwaters were modelled, as it happens in the full size construction or in physical laboratory test, by overlapping three-dimensional elements and the numerical grid was thickened in such a way to have some computational nodes along the flow paths among the breakwater's blocks (AccropodeTM, Core-locTM, Xbloc, IAS (Integrated Armor System).

Chapter- 5

Floodgate

Tokyo floodgates created to protect from typhoon surges

Floodgates are adjustable gates used to control water flow in reservoir, river, stream, or levee systems. They may be designed to set spillway crest heights in dams, to adjust flow rates in sluices and canals, or they may be designed to stop water flow entirely as part of a levee or storm surge system. Since most of these devices operate by controlling the water surface elevation being stored or routed, they are also known as **crest gates**. In the case of flood bypass systems, floodgates sometimes are also used to lower the water levels in a main river or canal channels by allowing more water to flow into a flood bypass or detention basin when the main river or canal is approaching a flood stage.

Types

A sluice gate on the Harran canal

A flood wall gate at Harlan, Kentucky

- **Bulkhead gates** are vertical walls with movable, or re-movable, sections. Movable sections can be lifted to allow water to pass underneath (as in a sluice gate) and over the top of the structure. Historically, these gates used stacked timbers known as stoplogs or wooden panels known as flashboards to set the dam's crest height. Some floodgates in large levee systems slide sideways to open for various traffic. Bulkhead gates can also be made of other materials and used as a single bulkhead unit. Miter gates are used in ship locks and usually close at an 18° angle to approximate an arch.

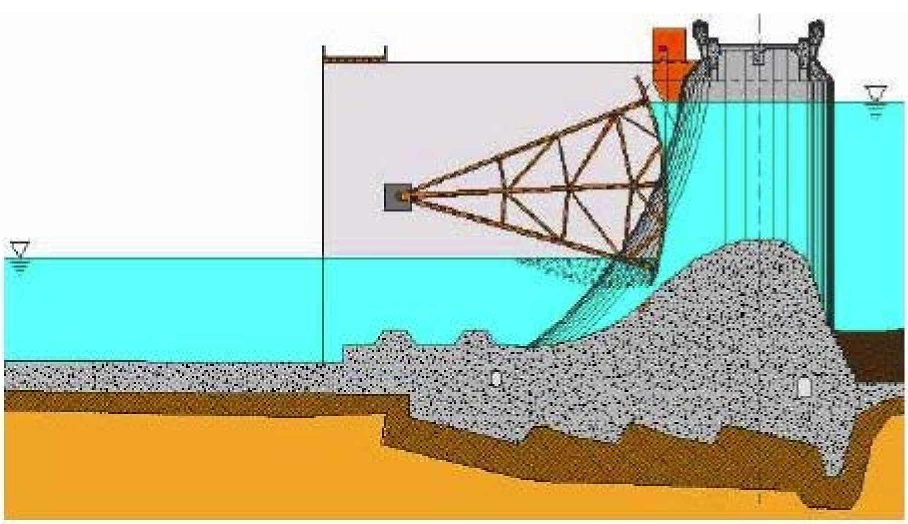
A hinged crest gate during installation

Fish belly flap gates at the Scrivener Dam, Canberra

- **Hinged crest gates**, are wall sections that rotate from vertical to horizontal, thereby varying the height of the dam. They are generally controlled with hydraulic power, although some are passive and are powered by the water being impounded.

  Variations;

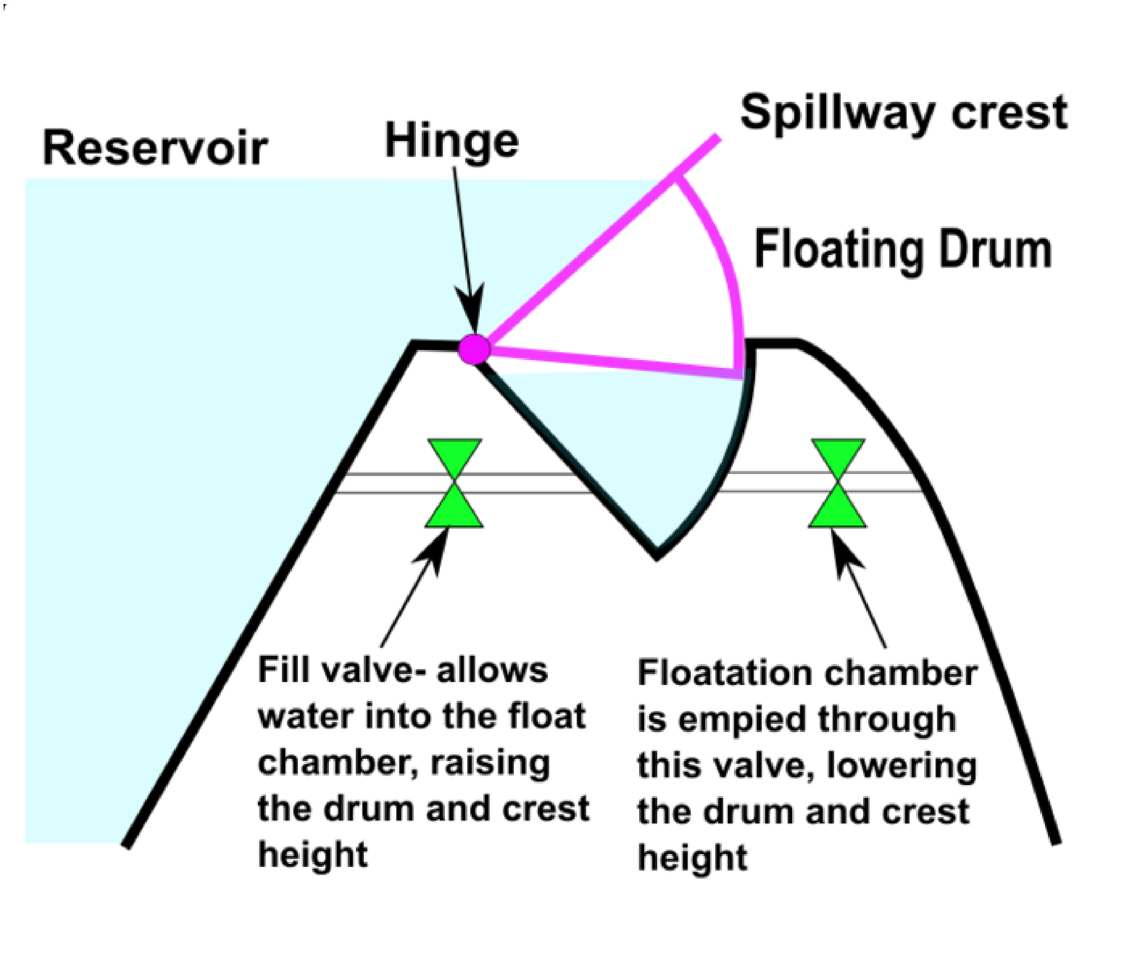
  - flap gate
  - fish-belly flap gates
  - Bascule gates
  - Pelican gates



Tainter gate diagram

Tainter gates and spillway

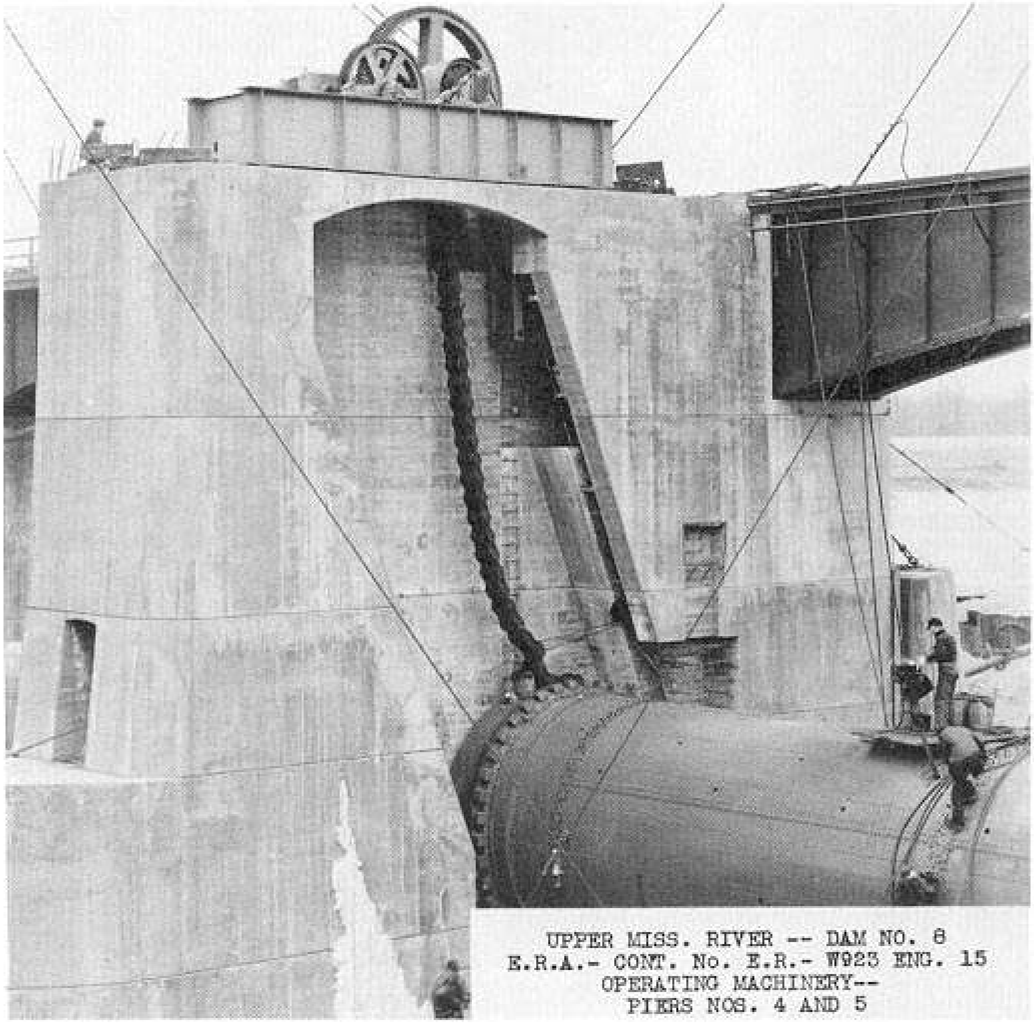
- **Radial gates** are rotary gates consisting of cylindrical sections. They may rotate vertically or horizontally. Tainter gates are a vertical design that rotates up to allow water to pass underneath. Low friction trunnion bearings, along with a face shape that balances hydrostatic forces, allow this design to close under its own weight as a safety feature.



Drum gates are controlled with valves.

Drum gates on a diversion dam

- **Drum gates** are hollow gate sections that float on water. They are pinned to rotate up or down. Water is allowed into or out of the flotation chamber to adjust the dam's crest height.

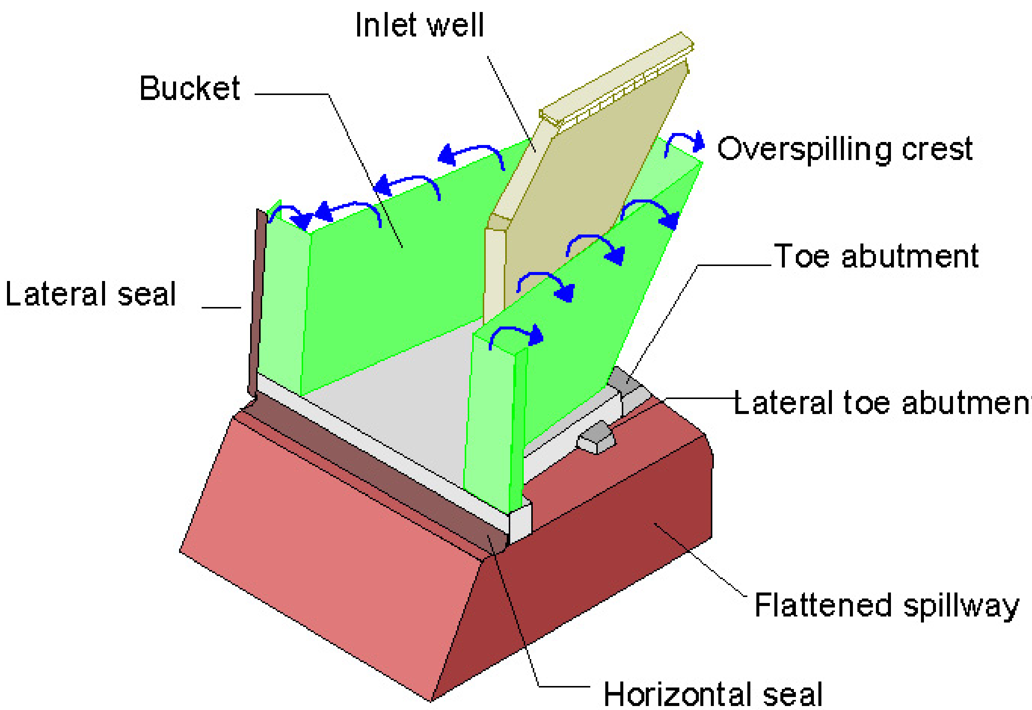


A roller gate on the Mississippi.

Clamshell floodgates at the Arrowrock Dam.

- **Roller gates** are large cylinders that move in an angled slot. They are hoisted with a chain and have a cogged design that interfaces with their slot.
- **Clamshell gates** have an external clamshell leaf design.

- **Fusegates** Fusegate System is an innovative spillway control technology, which consists of free standing blocks (the Fusegates) set side by side on a flattened spillway sill. The Fusegate blocks act as a fixed weir most of the time and operate independently without any remote control or energy source only in case of excessive flood conditions. The System is developed and patented by Hydroplus from Paris, France. It has been installed on more than 50 dams around the world with sizes ranging from 1m to more than 9m in height. Fusegate are typically used to increase the storage capacity of existing dams or to maximize the discharge potential of undersized spillways.



Typical fusegate sketch

Fusegate in Terminus Dam - Lake Kaweah

Valves

Discharge from a Howell-Bunger valve

Valves used in floodgate applications have a variety of design requirements and are usually located at the base of dams. Often, the most important requirement (besides regulating flow) is energy dissipation. Since water is very heavy, it exits the base of a dam with the enormous force of water pushing from above. Unless this energy is dissipated, the flow can erode nearby rock and soil and damage structures.

Other design requirements include taking into account pressure head operation, the flow rate, whether the valve operates above or below water, and the regulation of precision and cost.

- **Fixed cone valves**, also known as **Howell-Bunger valves**, are designed to dissipate the energy from a water flow during reservoir discharge. They are a round pipe section with an adjustable sleeve gate and cone at the discharge end. Flow is varied by moving the sleeve away or towards its cone seat. The design allows high pressure water from the base of a dam to be released without causing erosion to the surrounding environment. Fixed cone valves are able to handle heads up to 300 m.

- **Hollow jet valves** are a type of needle valve used for floodgate discharge. A cone and seat are inside a pipe. Water flows through an annular gap between the pipe and cone when it is moved downstream, away from the seat. Ribs support the bulb assembly and supply air for water jet stabilization.

- **Ring jet valves** are similar to fixed cone valves, but have an integral collar that discharges water in a narrow stream. They are suitable for heads up to 50 m.

- **Jet flow gate**, similar to a gate valve but with a conical restriction prior to the gate leaf that focuses the water into a jet. They were developed in the 1940s by the United States Bureau of Reclamation to allow fine control of discharge flow without the cavitation seen in regular gate valves. Jet flow gates are able to handle heads up to 150 m.

Physics

In order to do a simple calculation of the force on a rectangular flood gate one can use the following equation:

$$F = pA$$

where:

F = force measured in the SI units $kg \cdot m \cdot s^{-2}$ which is called the newton (N)
p = pressure $= \rho g h$ measured in N/m^2, which is called the pascal (Pa)
where:

- ρ (rho) is the density of fresh water (1000 kg/m^3);
- g is the acceleration due to gravity on Earth (9.8 m/s^2);
- h is the height of the water column in meters.

A = area = rectangle : length × height measured in m^2
where:
length = the horizontal length of a rectangular floodgate measured in meters
height = the height of a non-submerged flood gate from the bottom of the water column to the water surface measured in meters

If the rectangular flood gate is submerged below the surface the same equation can be used but only the height from the water surface to the middle of the gate must be used to calculate the force on the flood gate.

Chapter- 6

Beach Nourishment

Before and after photos of beach restoration efforts, Florida coastline, USA.

Beach nourishment device

Beach nourishment— also referred to as **beach replenishment**—describes a process by which sediment (usually sand) lost through longshore drift or erosion is replaced from sources outside of the eroding beach. It involves transporting and depositing sand from elsewhere to the depleted area. Beach nourishment is typically part of a larger coastal defense scheme. Nourishment is typically a repetitive process, since nourished beaches tend to erode faster than natural beaches unless nourishment is complemented by measures to reduce erosion rates.

Field studies and theory confirm that a wide beach can reduce storm damage to coastal structures by dissipating energy across the surf zone and beach rather than impacting upland structures and infrastructure.

In many coastal areas, the economic impacts of a wide beach can be substantial. The 10 miles (16 km)–long Miami Beach, Florida, beach was replenished over the period 1976–1981. The project cost approximately $64,000,000 and revitalized the area's economy. Prior to nourishment, in many places the beach was too narrow to walk along, especially during high tide.

History

The first nourishment project in the U.S. was constructed at Coney Island, New York in 1922-23.

Causes of erosion

Beaches can become eroded naturally and due to the impact of humans.

Erosion is a natural response to storm activity. During storms, sand from the visible beach submerges to form storm bars that protect the beach. Submersion is only part of the cycle. During calm weather smaller waves return sand from the storm bar to the visible beach surface in a process called accretion. The term *erosion* conjures visions of environmental damage so the term submersion often replaces it in describing a healthy sandy beach. Continental drift erodes coastlines naturally. Ocean currents can change, disrupting the submersion/accretion cycle.

Some beaches do not have enough sand available to coastal processes to respond naturally to storms. When there is not enough sand left available on a beach, then there is no recovery of the beach following storms.

Many areas of high erosion are due to human activities. Reasons can include seawalls locking up sand dunes, coastal structures like ports and harbors that prevent longshore drift, dams and other river management structures. These activities interfere with the natural sediment flows either through dam construction (thereby reducing riverine sediment sources) or construction of littoral barriers such as jetties, or by deepening of inlets; thus preventing longshore transport of sediment across these channels.

Visible and submerged sand

The distinction between total sand in a beach and the proportion of the sand above the waterline (submersion fraction) critically impacts beach nourishment. Two beaches with the same amount of visible sand may look much different under water. An eroded beach with substantial submerged sand surrounding it may recover without nourishment. Nourishing a beach that has little submerged sand requires addressing the reason that the submerged sand is missing. Otherwise, the same forces that stripped the submerged sand once are likely to do so again. The amount of submerged sand eroded is typically much greater than the amount of missing sand on shore. Replacing only the visible sand is insufficient without replacing the sand that once supported the accretion part of the process is insufficient. In that circumstance, the beach is unstable and the visible sand quickly erodes. If human activity is a major cause of the erosion, mitigating that activity may be more cost effective over both short and long term periods than nourishment.

Requirements for effective nourishment

Sediment texture (grain size and sorting) is critical for success. Sand fill must be compatible with native beach sand. In some cases, beaches have been nourished using a finer sand than the original. Thermoluminescence monitoring reveals that storms can erode such beaches far more quickly than the natural beach. This was observed at the Waikiki nourishment project in Hawaii.

Profile Nourishment

Beach Profile Nourishment describes programs that nourish the full beach profile. In this instance, "profile" means the slope of the uneroded beach from above the water to well out to sea, not just the visible portion. The Gold Coast profile nourishment program placed 75% of its total sand volume below low water level. Some coastal authorities *overnourish* the below water beach (aka "nearshore nourishment") so that over time the natural beach increases in size. These approaches do not permanently protect beaches eroded by human activity. Doing so still requires mitigating that activity.

Replenishment material

The selection of suitable material for a particular project depends upon the design needs, environmental factors, transport costs considering both short and long-term implications.

The most important material characteristic is the sediment's grain size, which must closely match the native material. Excess silt and clay fraction (mud) versus the natural turbidity in the nourishment area disqualifies some materials. Projects that did not match grain sizes performed relatively poorly. Nourishment sand that is only slightly smaller than native sand can result in significantly narrower equilibrated dry beach widths compared to sand the same size as (or larger than) native sand. Evaluating material fit requires a sand survey that usually includes geophysical profiles and surface and core samples.

Type	Description	Environmental issues
Offshore	Exposure to open sea makes this the most difficult operational environment. Must consider the effects of altering depth on wave energy at the shoreline. May be combined with a navigation project.	Impacts on hard bottom and migratory species.
Inlet	Sand between jetties in a stabilized inlet. Often associated with dredging of navigational channels and the ebb- or flood-tide deltas of both natural and jettied inlets.	
Accretional Beach	Generally not suitable because of damage to source beach.	
Upland	Generally the easiest to obtain permits and assess impacts from a land source. Offers opportunities for mitigation. Limited quantity and quality of economical	Potential secondary impacts from mining and overland transport.

	deposits.	
Riverine	Potentially high quality and sizeable quantity. Transport distance a possible cost factor.	May interrupt natural coastal sand supply.
Lagoon	Often excessively fine grained. Often close to barrier beaches and in sheltered waters, easing construction. Principal sources are flood-tide deltas.	Can compromise wetlands.
Artificial or non-indigenous	Typically, high transport and redistribution costs. Some laboratory experiments done on recycling broken glass. Aragonite from Bahamas a possible source.	
Emergency	Deposits near inlets and local sinks and sand from stable beaches with adequate supply. Generally used only following a storm or given no other affordable option. May be combined with a navigation project.	Harm to source site. Poor match to target requirements.

Nourishment projects

The setting of a beach nourishment project is key to design and potential performance. Possible settings include a long straight beach, an inlet that may be either natural or modified, and a pocket beach. Rocky or seawalled shorelines, that otherwise have no sediment, present unique problems.

Cancun, Mexico

Federal and state governments in Mexico have invested about $71 million dollars ($957 million pesos) throughout the state of Quintana Roo in restoring the beaches along Cancun, Playa del Carmen, and Cozumel.

Hurricane Wilma hit the beaches of Cancun and the Riviera Maya in 2005. The initial nourishment project was unsuccessful, leading to a second round that began in September 2009, and was scheduled to complete in early 2010. The project designers and the government committed to invest in beach maintenance to address future erosion. Project designers considered factors such as the time of year and sand characteristics such as density. Restoration in Cancun was expected to deliver 1.3 billion gallons (6.1 million cubic meters) of sand to replenish 450 meters (1,476 ft) of coastline. This time, the beach is promised to last at least 10 years.

Northern Gold Coast, Queensland, Australia

Gold Coast beaches in QueenslandAustralia have experienced periods of severe erosion. In 1967 a series of 11 cyclones removed most of the sand from Gold Coast beaches. The Government of Queensland engaged engineers from Delft University in the Netherlands to advise them. The 1971 Delft Report outlined a series of works for Gold Coast Beaches, including beach nourishment and an artificial reef. By 2005 most of the recommendations had been implemented.

The Northern Gold Coast Beach Protection Strategy (NGBBPS) was a Aus$10 million dollar investment. NGCBPS was developed between 1992 and 1999 and the works were completed between 1999 and 2003. The project included dredging 3,500,000 cubic metres (4,580,000 cu yd) of compatible sand from the Gold Coast Broadwater and delivering it through a pipeline to nourish 5 kilometers (3 mi) between of beach between Surfers Paradise and Main Beach. The new sand was stabilized by an artificial reef constructed at Narrowneck out of huge geotextile sand bags. The new reef was designed to improve wave conditions for surfing. A key monitoring program for the NGCBPS is the ARGUS coastal camera system operated by the University of New South Wales.

The cost/benefit ratio for NGCBPS was conservatively estimated at 75:1 for a AUS$10million investment into beach replenishment. The benefits were estimated from a model of lost visitor nights in hotels following previous erosion events. NGCBPS so improved beach health that recovery following minor and moderate storms occurred within weeks. Additional unquantified benefits included lifestyle benefits for residents, additional public open space and improved fishing, diving and surfing conditions.

Netherlands

More than one-quarter of the Netherlands is below sea level and about 80% of the coast consists of sand dune or beach. The shoreline is closely monitored by yearly recording of the cross section at points 250 meters (820 ft) apart, to ensure adequate protection. Where long-term erosion is identified, beach nourishment using high-capacity suction dredgers is deployed.

Hawaii

Waikiki

Hawaii planned to replenish Waikiki beach in 2010. Budgeted at $2.5 million, the project covered 1,700 feet (520 m) in an attempt to return the beach to its 1985 width. Prior opponents supported this project, because the sand was to come from nearby shoals, reopening a blocked channel and leaving the overall local sand volume unchanged, while closely matching the "new" sand to existing materials. The project planned to apply up to 24,000 cubic yards (18,000 m^3) of sand from deposits located 1,500 to 3,000 feet (460 to 910 m) offshore at a depth of 10 to 20 feet (3.0 to 6.1 m). The project was larger than the prior recycling effort in 2006-07, which moved 10,000 cubic yards (7,600 m^3).

Maui

Maui, Hawaii illustrates the complexities of even small-scale nourishment projects. A project at Sugar Cove transports upland sand to the beach. The sand allegedly is finer than the original sand and contains excess silt that envelops coral heads, smothering the coral and killing small animals that live in and around it. As in other projects, on-shore sand availability is limited, forcing consideration of more expensive offshore sources.

A second project, along Stable Road, that attempted to slow rather than halt the erosion was stopped halfway toward its goal of adding 10,000 cubic yards (7,600 m^3) of sand. The beaches had been retreating at a "comparatively fast rate" for half a century. The restoration was complicated by the presence of old seawalls, groins, piles of rocks and other structures.

This project used sand-filled Geotube groins placed that were originally to remain in place for up to 3 years. The pipeline was anchored by concrete blocks held on by fiber straps. A video shows the blocks bouncing off the coral in the current, killing whatever they touch. In places the straps broke, allowing the pipe to move across the reef, "planing it down". Bad weather exacerbated the damaging movement and led to the final shutdown. The smooth, cylindrical Geotubes can be difficult to climb over before they are covered by sand.

Supporters claim that this year's seasonal summer erosion is much less than in prior years, although the beach was narrower after the restoration ended than it was in 2008. Authorities are studying whether to require the project to remove the groins immediately. Potential alternatives to Geotubes for moving sand include floating dredges and/or trucking in sand dredged offshore.

A final consideration is that sea level is rising and that Maui is sinking under its own weight and that of the Island of Hawaii (The Big Island). Both islands surround massive mountains (Haleakala, Mauna Loa, and Mauna Kea) and are expanding a giant dimple in the ocean floor, some 30,000 feet (9,100 m) below the mountain summits.

Alternatives/complements to nourishment

Nourishment is not the only technique used to address eroding beaches. Others can be used singly or in various combination with nourishment, driven by economic, environmental, and political considerations.

Structural

The structural approach attempts to prevent upstream erosion. This can take the form of revetments, seawalls, detached breakwaters, or groins, etc. Shore parallel structures (seawalls or revetments) placed on an eroding shoreline prevent erosion of the upland. Such protections are temporary; erosion continues, albeit more slowly; eventually the beach will disappear.

Groins and breakwaters trap sand from the littoral stream and may impact adjacent shorelines. There is growing evidence that nearshore breakwaters, if filled with sand, do not negatively impact the littoral drift system.

Recognizing that there are briefer cycles of shoreline advancement and recession superimposed on the long-term shoreline change, armoring tends to occur during periods of erosional cycles. The time required before no fronting beach is present may be decades.

Retreat

Moving inland has been exercised infrequently along the United States shoreline. Retreat is the most appropriate option where erosion is rapid and in the absence of substantial economic activity.

Pressure Equalizing Modules

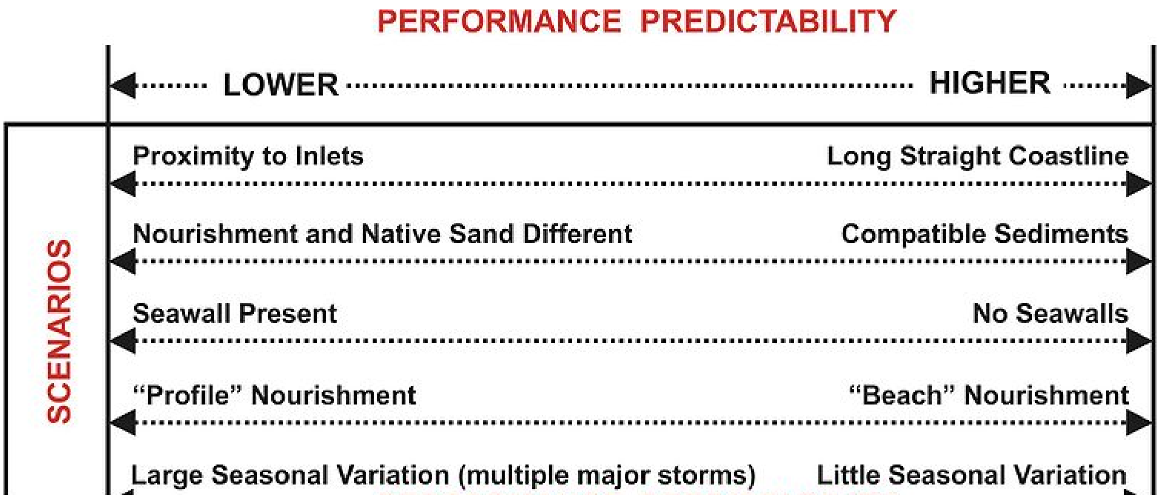
All beaches lose and gain sand depending on the tides, precipitation, wind, waves etc. Wet beaches tend to lose sand. Waves infiltrate dry beaches easily and deposit sediment on the beach. Generally a beach is wet during falling tide, because the sea sinks faster than the beach drains. As a result most erosion happens during falling tide. PEMs drain the beach to drain more effectively during falling tide. Fewer hours of wet beach translate to less erosion. Permeable PEM tubes inserted vertically into the foreshore connect the different layers of groundwater. The groundwater enters the PEM tube allowing gravity to conduct it to a coarser sand layer, where it can drain more quickly. The PEM modules are placed in a row from the dune to the mean low waterline. Distance between rows is typically 300 feet (91 m) but this is project-specific. PEM systems come in different sizes depending. Modules connect layers with varying hydraulic conductivity. Air/water can enter and pressure equalize.

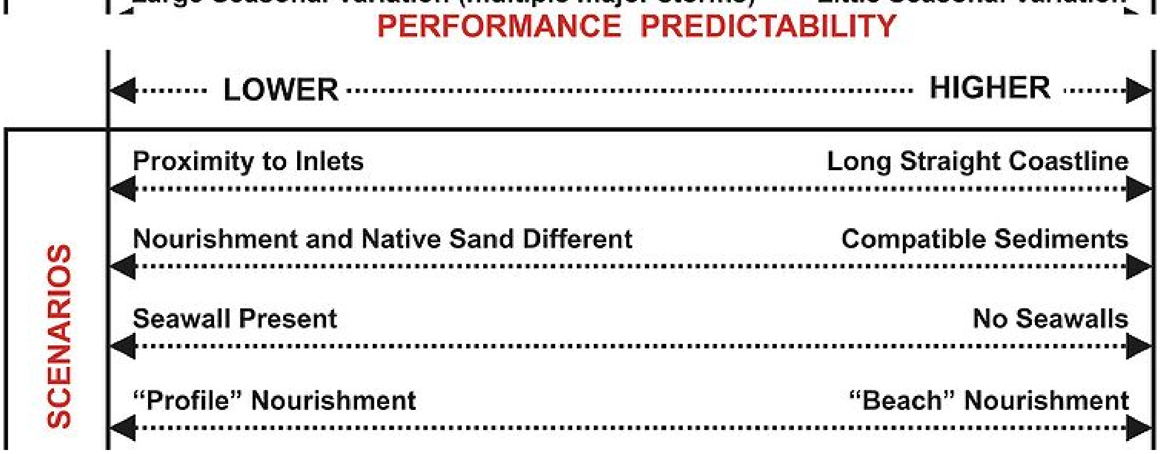
PEMs are minimially invasive, typically covering approximately 0.0005% of the beach. The effects are local, and bring no known harm to flora or fauna, including nesting sea turtles. The tubes are below the beach surface, implying no visible impact. Installation takes little time. Costs are low, because PEMs require few materials, and no energy-intensive dredging. PEM installations have been successfully installed on beaches in Denmark, Sweden, Malaysia, and Florida, USA.

Recruitment

Appropriately constructed and sited fences can capture blowing sand, building/restoring sand dunes, and progressively protecting the beach from the wind, and the shore from blowing sand.

Measuring project impact





Performance Predicability Beach Nourishment

Nourishment projects usually involve physical, environmental and economic objectives. Typical physical measures include dry beach width, remaining post-storm sand volume, post-storm damage avoidance assessments and aqueous sand volume. Environmental measures include marine life distribution, habitat and population counts. Economic impacts include recreation, tourism, flood and "disaster" prevention. Techniques for incorporating nourishment projects into flood insurance costs and disaster assistance remain controversial.

Environmental issues

Beach nourishment has significant impacts on local ecosystems. Nourishment may cause direct mortality to sessile organisms in the target area by burying them in the new sand. Seafloor habitat in both source and target areas are disrupted, e.g., when sand is deposited on coral reefs or when deposited sand hardens. Imported sand may differ in character (chemical makeup, grain size, non-native species) from that of the target environment. Reduced light availability, affecting nearby reefs and submerged aquatic vegetation. Imported sand may contain material toxic to local species. Removing material from near-shore environments may destabilize the shoreline, in part by steepening its submerged slope. Related attempts to reduce future erosion may provide a false sense of security that increases development pressure.

Sea turtles

Newly-deposited sand can harden and complicate nest-digging for turtles. However, nourishment can provide more/better habitat for them, as well as for sea birds and beach flora.

Chapter- 7

Other Coastal Management Techniques

Revetment

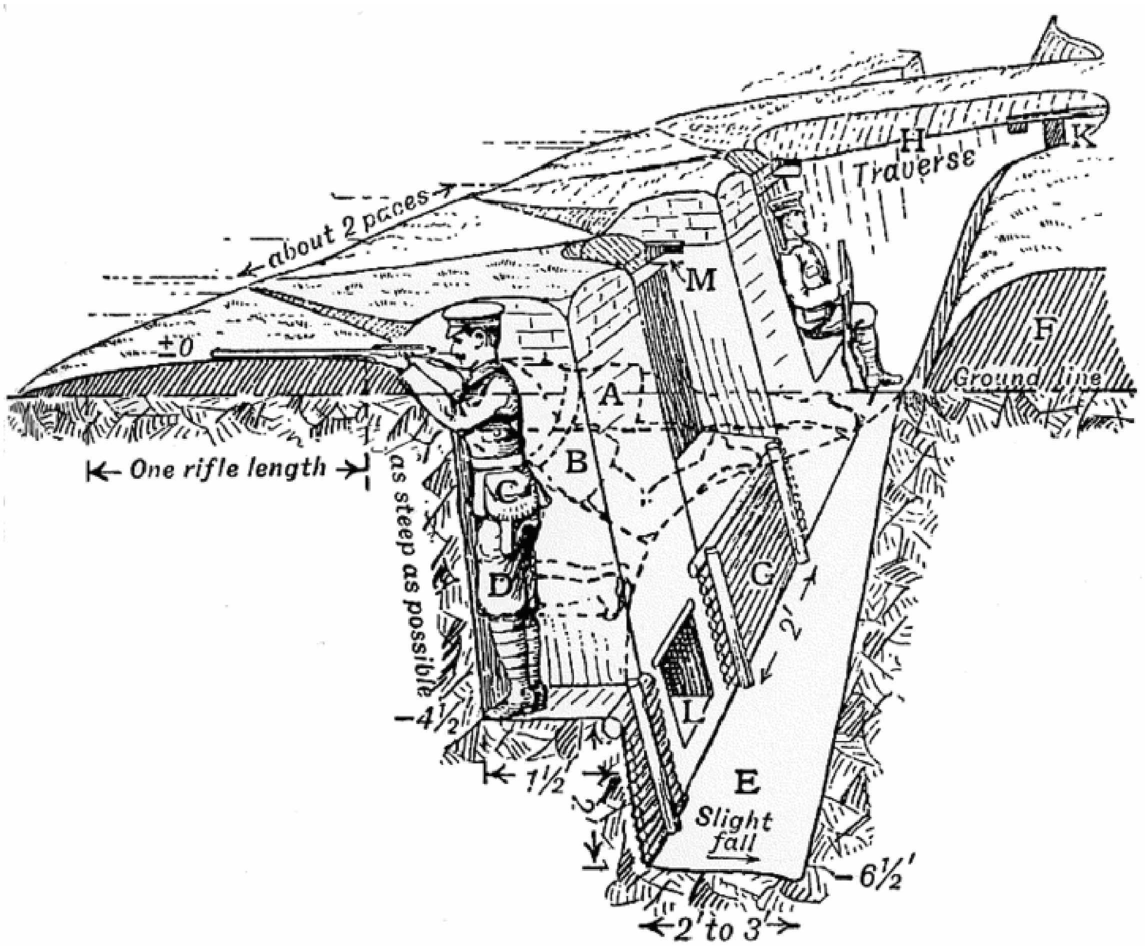
Rocky revetment at a restoration site along Keene Creek, Duluth, Minnesota. Spring 1994.

Revetments, or **revêtiments** (the original French word, meaning something to re-cloth or re-cover), have a variety of meanings in architecture, engineering and art history. In stream restoration, river engineering or coastal management, they are sloping structures placed on banks or cliffs in such a way as to absorb the energy of incoming water. In military engineering they are structures, again sloped, formed to secure an area from artillery, bombing, or stored explosives. In architecture they are a variety of structures, normally vertical, used to retain a wall, or sometimes just to decorate it. River or coastal revetments are usually built to preserve the existing uses of the shoreline and to protect the slope, as defence against erosion.

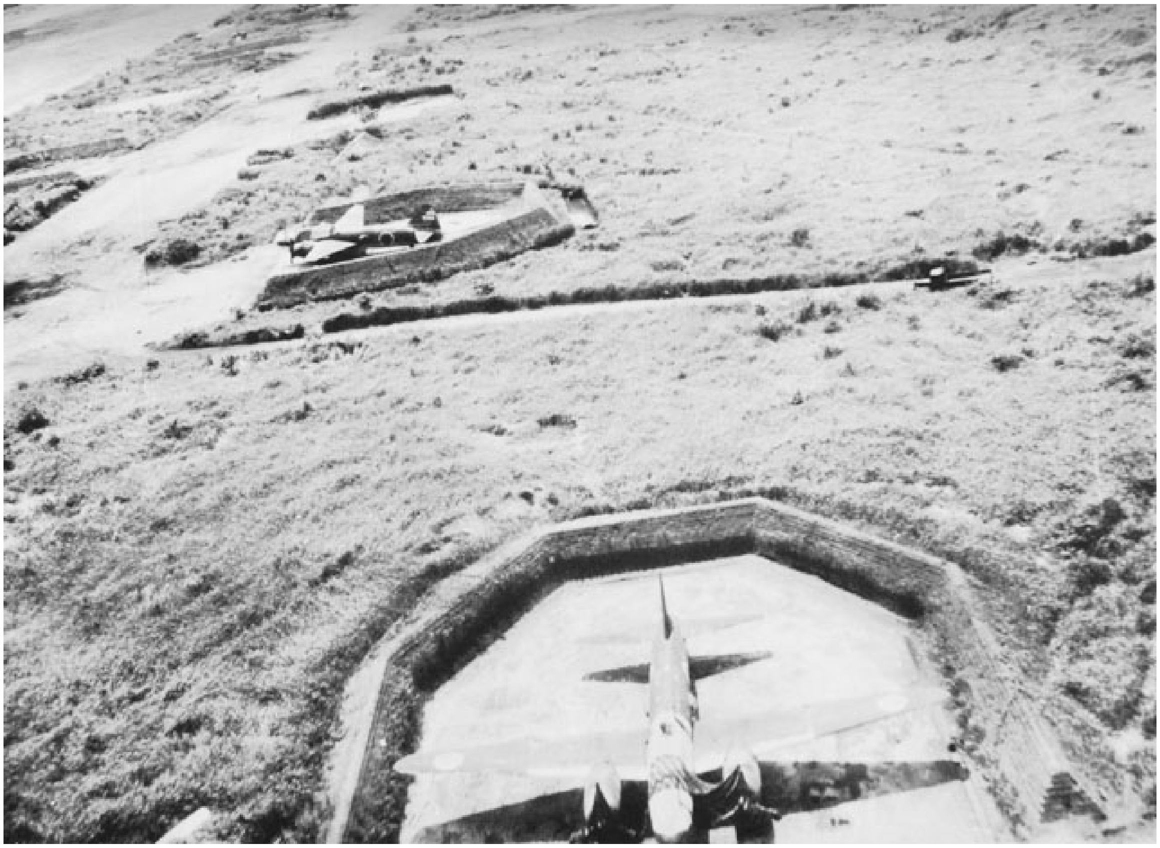
Freshwater Revetments

Many revetments are used to line the banks of freshwater rivers, lakes, and man-made reservoirs, especially to prevent damage during periods of floods or heavy seasonal rains. Many materials may be used: wooden piles, loose-piled boulders or concrete shapes, or more solid banks.

Fortifications



World War I: British diagram for the construction of reveted trenches - the revetment here is the part forward of the standing soldier.



World War II: Japanese aircraft sheltered in revetments on Rabaul, 1943

According to the U.S. National Park Service, and referring mostly to their employment in the American Civil War, a revetment is defined as a "retaining wall constructed to support the interior slope of a parapet. Made of logs, wood planks, fence rails, fascines, gabions, hurdles, sods, or stones, the revetment provided additional protection from enemy fire, and, most importantly, kept the interior slope nearly vertical. Stone revetments commonly survive. A few log revetments have been preserved due to high resin pine or cypress and porous sandy soils. After an entrenchment was abandoned, many log or rail revetments were scavenged for other uses, causing the interior slope to slump more quickly. An interior slope will appear more vertical if the parapet eroded with the revetment still in place."

Architecture and art history

Revetment can be used as a term for a retaining wall, or just for the covering of a wall. In particular the term is used for stone slabs or decorated ceramic plaques used as the outer facing layer of a wall, especially in Ancient Roman architecture. These may or may not have a structural function in the internal construction of the wall, and may be essentially decorative. Marble or terracotta was used, the latter often decorated in moulded reliefs. Revetment is also a term used for a riza or decorated metal cover for most, typically all but the face and perhaps hands, of an Eastern Orthodox icon.

Sand dune stabilization

Sand dunes are common features of shoreline and desert environments. Dunes provide habitat for highly specialized plants and animals, including rare and endangered species. They can protect beaches from erosion and recruit sand to eroded beaches. Dunes are threatened by human activity, both intentional and unintentional. Countries such as the United States, Australia, Canada, New Zealand, the United Kingdom, and Netherlands, operate significant dune protection programs.

Stabilizing dunes involves multiple actions. Planting vegetation reduces the impact of wind and water. Fences catch sand and other material. Footpaths protect dunes from damage from foot traffic.

Vegetation

Ammophila or "Beachgrass"

The location on the dune limits the types of plant that can thrive there. Beach dunes consist of the *foredune*, the angled side which faces the ocean, the *sand plain* at the top of the dune, which may or may not be present, and the *backdune*, the angled side that faces away from the ocean.

Foredune flora

Plants that thrive on the foredune must be tolerant to salt spray, strong winds, and burial by blowing/accumulating sand. Typical vegetation includes Ammophila arenaria, Honckenya peploides, Cakile maritima, and Spartina coarctata.

Backdune flora

Plants which thrive on the broad dune plain and backdune grow together into dense patches termed *dune mat*s that hold the dune together. Vegetation typical of the plain and backdune include Hudsonia tomentosa, Spartina patens, Iva imbricata, and Eregeron glaucus. Introduced species can outcompete native plants and disrupt animal life, making them formally "invasive species".

Shrub stage

The above species are herbaceous plants. After they have rooted and developed fully, a second stage, the "shrub stage", can begin. During this phase, larger plants with deeper root systems can be planted. Examples are Empetrum nigrum, Ilex vomitoria, and Vaccinium ovatum. The shrub stage is usually the final phase and may last for short or long periods of time depending on microclimatic conditions such as distance from the shoreline, availability of groundwater, or salt spray effects.

Coastal management

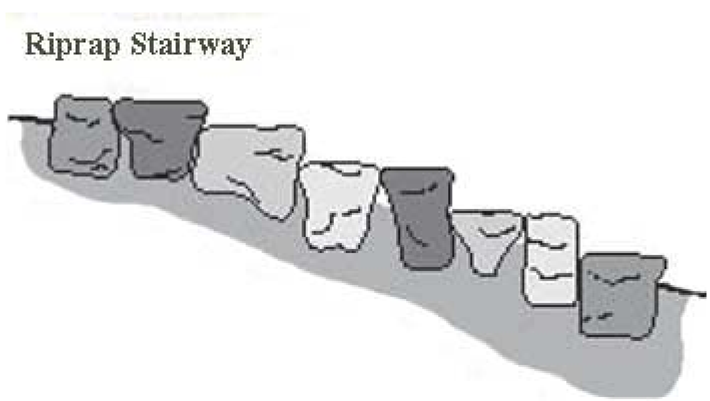
A single beach may be divided into segments with different owners. Gaining agreement among all owners complicates the process of stabilizing the dunes. Without agreement, some parts of the dune may go unplanted, while others host visually appealing plants that do little to stabilize the dune. Inconsistent vegetation, known as a fragmented or decoupled gradient, can create weak points in the dune that limit its effectiveness against floods and even its continued existence.

Publicly owned beaches, found in U.S. states such as California and Hawaii and in other jurisdictions, present the opportunity to systematically manage—or mismanage—beaches and their accompanying dunes.

Riprap

Riprap lining a lake shore

Concrete rubble used as riprap along the San Francisco Bay shoreline



Riprap Stairway

Riprap — also known as **rip rap**, **rubble**, **shot rock** or **rock armour** — is rock or other material used to armor shorelines, streambeds, bridge abutments, pilings and other shoreline structures against scour, water or ice erosion.

It is made from a variety of rock types, commonly granite or limestone, and occasionally concrete rubble from building and paving demolition. It is used to protect coastlines and structures from erosion by the sea, rivers, or streams. It can be used on any waterways or water containment where there is potential for water erosion.

Protection mechanism

Riprap works by absorbing and deflecting the impact of a wave before the wave reaches the defended structure. The size and mass of the riprap material absorbs the impact energy of waves, while the gaps between the rocks trap and slow the flow of water, lessening its ability to erode soil or structures. The mass of riprap also provides protection against impact damage by ice or debris, which is particularly desirable for bridge supports and pilings.

It is frequently used to protect the base of old Edwardian and Victorian sea walls, which being vertical are often undermined. The riprap absorbs the impact of the waves as they shoot up the wall and then fall back down.

In the Western United States, *riprap* can also mean a cross between cobblestones and stairs.

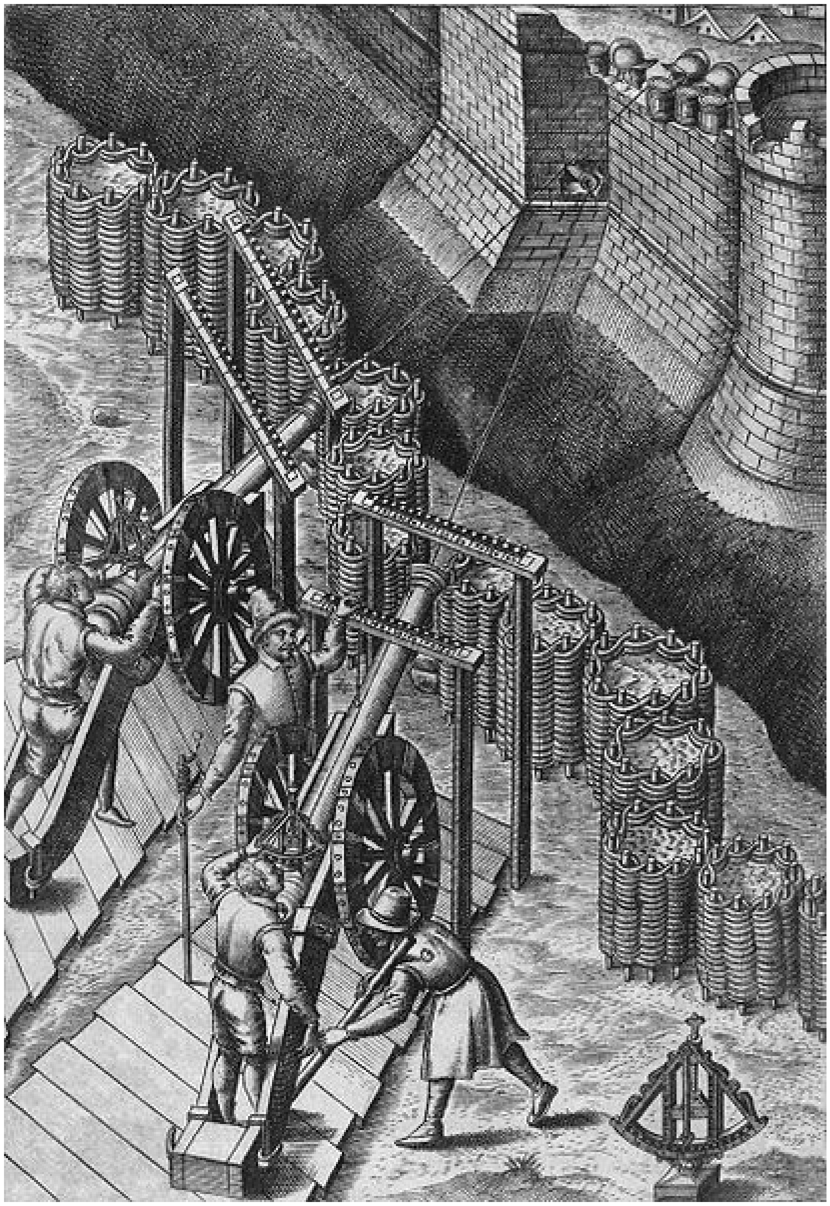
Training (civil)

Training or **entrance training** refers to coastal structures built to constrain a river discharging across a littoral coast so that it discharges only where desired. Untrained entrances on sandy coasts tend to move widely and violently to discharge into the ocean, often upsetting those enjoying land nearby. With many cities (and buildings) constructed close to rivers, such management has historically been considered a necessary course of action, even though ecologically, non-intervention would be better and more sustainable.

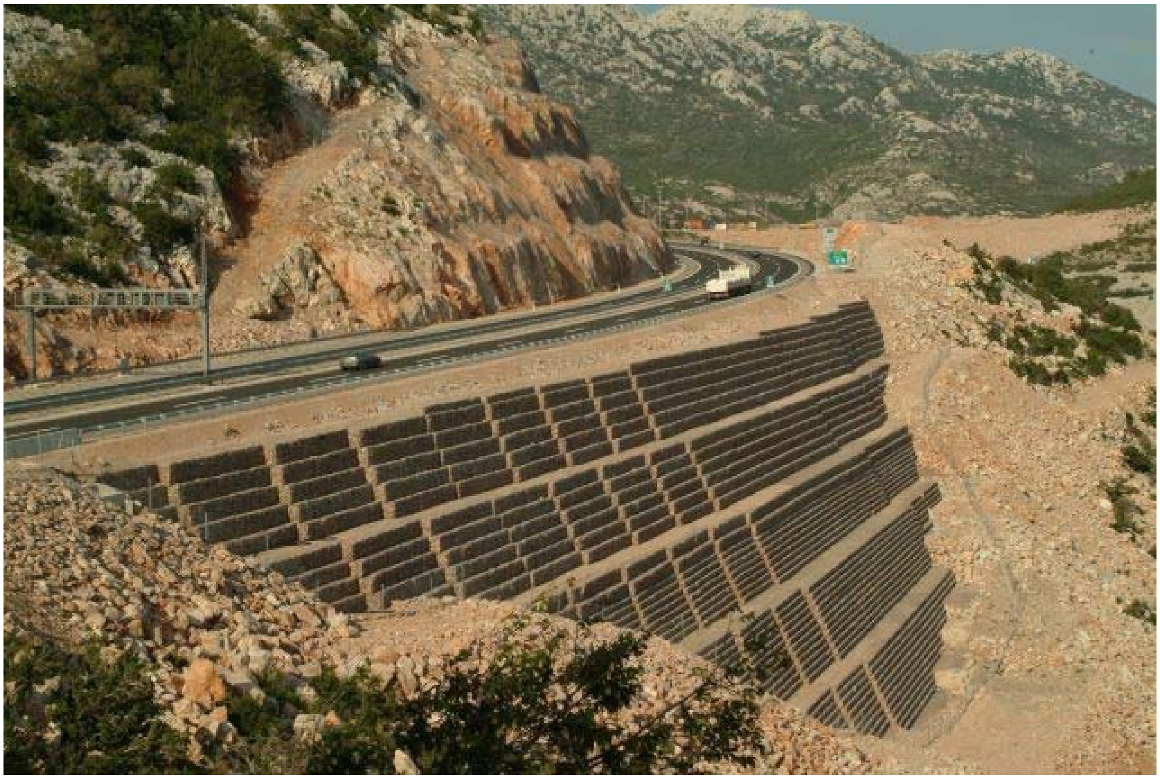
A trained entrance often consists of rock walls that force the water into a deeper more stable channel. Trained entrances can provide better navigation, water quality and flood mitigation services, but can also cause beach erosion due to their interruption of longshore drift. One solution is the installation of a sand bypass system across the trained entrance.

Training is also used on mountainous rivers and streams, and ensures that a fast-flowing river is reduced in violence (and hence erosive capability), usually by the use of weirs and other structures like gabions.

Gabion



Gabions with cannon, from a late 16th century illustration.



Reinforced earth with gabions, Sveti Rok, Croatia.

Up close view of a bank protection made with mattresses in Vrtižer, Slovakia.

Gabions (from Italian *gabbione* meaning "big cage"; from Italian *gabbia* and Latin *cavea* meaning "cage") are cages, cylinders, or boxes filled with soil or sand that are used in civil engineering, road building, and military applications. For erosion control caged riprap is used. For dams or foundation construction, cylindrical metal structures are used. In a military context, earth or sand-filled gabions are used to protect artillery crews from enemy fire.

Leonardo da Vinci designed a type of gabion called a *Corbeille Leonard* ("Leonard[o] basket") for the foundations of the San Marco Castle in Milan.

Bridge abutment with gabions.

Civil engineering

In civil engineering a gabion wall is a retaining wall made of rectangular containers (baskets) fabricated of heavily galvanized wire, which are filled with stone and stacked on one another, usually in tiers that step back with the slope rather than vertically.

The most common civil engineering use of gabions is to stabilize shorelines or slopes against erosion. Other uses include retaining walls, temporary floodwalls, to filter silt from runoff, for small or temporary/permanent dams, river training, channel lining. They may be used to direct the force of a flow of flood water around a vulnerable structure. Gabions are also used as fish barriers on small streams.

Gabion baskets have some advantages over loose riprap because of their modularity and ability to be stacked in various shapes; they are also resistant to being washed away by moving water. Gabions also have advantages over more rigid structures because they can conform to ground movement, dissipate energy from flowing water, and drain freely. Their strength and effectiveness may increase with time in some cases, as silt and vegetation fill the interstitial voids and reinforce the structure. They are sometimes used to keep stones which may fall from a cutting or cliff from endangering traffic on a thoroughfare.

Gabions have also been used in building, as in the Dominus Winery in Napa Valley, California. The exterior is formed by modular wire mesh gabions containing locally quarried stone; this construction creates an environment of moderate temperatures within the building.

Military use

In the medieval era, gabions were round cages with open tops and bottoms, made from wickerwork and filled with earth for use as military fortifications. These early military gabions were used to protect field artillery gunners. The wickerwork cylinders were light and could be carried relatively conveniently in the ammunition train, particularly if they were made in several diameters to fit one inside another. At the site of use in the field, they could be stood on end, staked in position, and filled with soil to form an effective wall around the gun. Today, gabions are often used to protect forward operating bases (FOBs) against explosive, fragmentary, indirect fires such as mortar or artillery fire. Examples of areas within a FOB that make extensive use of gabions would be sleeping quarters, mess halls, or any place where there will be a large concentration of unprotected soldiers.

Chapter- 8

Integrated Coastal Zone Management

Integrated coastal zone management (ICZM) or Integrated coastal management (ICM) is a process for the management of the coast using an integrated approach, regarding all aspects of the coastal zone, including geographical and political boundaries, in an attempt to achieve sustainability.

This concept was born in 1992 during the Earth Summit of Rio de Janeiro. The policy regarding ICZM is set out in the proceedings of the summit within Agenda 21, *Chapter 17*.

The European Commission defines the ICZM as follows:-

ICZM is a dynamic, multidisciplinary and iterative process to promote sustainable management of coastal zones. It covers the full cycle of information collection, planning (in its broadest sense), decision making, management and monitoring of implementation. ICZM uses the informed participation and cooperation of all stakeholders to assess the societal goals in a given coastal area, and to take actions towards meeting these objectives. ICZM seeks, over the long-term, to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics. 'Integrated' in ICZM refers to the integration of objectives and also to the integration of the many instruments needed to meet these objectives. It means integration of all relevant policy areas, sectors, and levels of administration. It means integration of the terrestrial and marine components of the target territory, in both time and space.

To further understand the idea of ICZM several aspects can be defined and further explained. The coastal zone, the concept of sustainability and the term integration all within a coastal management context can be individually defined, while the expectations and framework of ICZM can be further explained. This entry uses the example of the New Zealand national framework to illustrate ICZM.

Defining the Coastal Zone

Defining the Coastal zone is of particular importance to the idea of ICZM. But the fuzziness of borders due to the dynamic nature of the coast makes it difficult to clearly define. Most simply the coast can be thought of as an area of interaction between the land and the ocean. Ketchum (1972) defined the area as:

The band of dry land and adjacent ocean space (water and submerged land) in which terrestrial processes and land uses directly affect oceanic processes and uses, and vice versa.

Issues arise with the diversity of features present on the coast and the spatial scales of the interacting systems. Coasts being dynamic in nature are influenced differently all around the world. Influences such as river systems, may reach far inland increasing the complexity and scale of the zone. These issues make it difficult to clearly identify hinterlands and subscribe any subsequent management.

Whilst acknowledging a physical coastal zone, the inclusion of ecosystems, resources and human activity within the zone is important. It is the human activities that warrant management. These activities are responsible for disrupting the natural coastal systems. To add to the complexity of this zone, administrative boundaries use arbitrary lines that dissect the zone, often leading to fragmented management. This sectored approach focuses on specific activities such as land use and fisheries, often leading to adverse effects in another sector.

The importance of the Coastal Zone and the need for management

The dynamic processes that occur within the coastal zones produce diverse and productive ecosystems which have been of great importance historically for human populations . Coastal margins equate to only 8% of the worlds surface area but provide 25% of global productivity. Stress on this environment comes with approximately 70% of the world's population being within a day's walk of the coast . Two-thirds of the world's cities occur on the coast.

Valuable resources such as fish and minerals are considered to be common property and are in high demand for coastal dwellers for subsistence use, recreation and economic development . Through the perception of common property, these resources have been subjected to intensive and specific exploitation. For example; 90% of the world's fish harvest comes from within national exclusive economic zones, most of which are within the sight of shore . This type of practice has led to a problem that has cumulative effects. The addition of other activities adds to the strain placed on this environment. As a whole, human activity in the coastal zone generally degrades the systems by taking unsustainable quantities of resources. The effects are further exacerbated with the input of pollutant wastes. This provides the need for management. Due to the complex nature of human activity in this zone a holistic approach is required to obtain a sustainable outcome.

The concept of sustainability

The concept behind the idea of ICZM is sustainability. For ICZM to succeed, it must be sustainable. Sustainability entails a continuous process of decision making, so there is never an end-state just a readjustment of the equilibrium between development and the protection of the environment. The concept of Sustainability or sustainable development came to fruition in the 1987 report of the World Commission on Environment and Development, Our Common Future. It stated sustainable development is "to meet the needs of the present without compromising the ability of future generations to meet their own needs".

Highlighted are three main standpoints which summarise the idea of Sustainable development, they are:

- Economic development to improve the quality of life of people
- Environmentally appropriate development
- Equitable development

To simplify these points, sustainability should acknowledge the right of humans to live a life that is healthy and productive. It should allow for equal distribution of benefits to all people and in doing so protect the environment through appropriate use.

Sustainability is by no means a set of prescriptive actions, more accurately it is a way of thinking. Adapting this way of thinking paves the way for a longer-term view with a more holistic approach, something successful ICZM can achieve.

Expectations of ICZM

As previously stated, for ICZM to be successful it must adhere to the principles that define sustainability and act upon them in ways that are integrated. An optimal balance between environmental protection and the development of economic and social sectors is paramount. As part of the holistic approach ICZM applies, many aspects within a coastal zone are expected to be considered and accounted for. These include but are not limited to: the spatial, functional, legal, policy, knowledge, and participation dimensions. Below are four identified goals of ICZM:

- Maintaining the functional integrity of the coastal resource systems;
- Reducing resource-use conflicts;
- Maintaining the health of the environment;
- Facilitating the progress of multisectoral development

Failure to include these aspects and goals would lead to a form of unsustainable management, undermining the paradigms explicit to ICZM.

Defining Integration

The term 'integration' can be adopted for many different purposes, it is therefore quite important to define the term in the context of the management of the coastal zone to appreciate the intentions of ICZM. Integration within ICZM occurs in and between many different levels, 5 types of integration that occur within ICZM , are explained below;

Integration among sectors: Within the coastal environment there are many sectors that operate. These human activities are largely economic activities such as tourism, fisheries, and port companies. A sense of co-operation between sectors is the main requirement for sector integration within ICZM. This comes from the realisation of a common goal focused around sustainability and the appreciation of one another within the area.

Integration between land and water elements of the coastal zone: This is the realisation of the physical environment being a whole. The coastal environment is a dynamic relationship between many processes all of which are interdependent. The link must be made between imposing a change on one system or feature and its inevitable 'flow on' effects.

Integration among levels of government: Between levels of governance, consistency and co-operation is needed throughout planning and policy making. ICZM is most effective where initiatives have common purpose at local, regional, and national levels. Common goals and actions increase efficiency and mitigate confusion.

Integration between nations: This sees ICZM as an important tool on a global scale. If goals and beliefs are common on a supranational scale, large scale problems could be mitigated or avoided.

Integration among disciplines: Throughout ICZM, knowledge should be accepted from all disciplines. All means of scientific, cultural, traditional, political and local expertise need to be accounted for. By including all these elements a truly holistic approach towards management can be achieved.

The term integration in a coastal management context has many horizontal and vertical aspects, which reflects the complexity of the task and it proves a challenge to implement.

ICZM Framework

Management must embrace a holistic viewpoint of the functions that makeup the complex and dynamic nature of interactions in the coastal environment . Management framework must be applied to a defined geographical limit (often complicated) and should operate with a high level of integration . Due to the diverse nature of the world's coastline and coastal environments, it is not possible to create a framework that is 'one-size-fits-all.' Different activities, interests and issues also complicate matters. So management will always be unique to countries, regions and ultimately on a local scale.

A common thought process and decision making framework however, can be fairly uniform as a part of ICZM around the world. To achieve the principles set out in sustainable types of management a step by step process can be adhered to.

Firstly, issues and problems need to be identified and assessments of these need to be quantified. This first step will include integration between government, sectoral entities and local residents. The assessments also have to be broad in their application. Once the issues and problems have been identified and weighted, an effective management plan can be made. The plan will be specific to the area in question. Thirdly, the adoption of the plan can be carried out. They can be legally binding statutory plans, strategies or objectives which are generally quite powerful or they can be non-statutory processes and can act as a guide for future development . This duality is largely beneficial as the future can be taken into account, but still provide for a firm stance based in the present . The fourth step is implementation, this active phase includes; law enforcement, education, development etc. The implementation activities will be of course, be as unique as their environments and can take many forms. The last phase is evaluation of the whole process. The principles of sustainability mean that there is no 'end state.' ICZM is an ongoing process which should constantly readjust the equilibrium between economic development and the protection of the environment. Feedback is a crucial part of the process and allows for continued effectiveness even when a situation may change.

Constraints of ICZM

Major constraints of ICZM are mostly institutional, rather than technological. The 'top-down' approach of administrative decision making sees problematisation as a tool promoting ICZM through the idea of sustainability. Community-based 'bottom-up' approaches can perceive problems and issues that are specific to a local area. The benefit of this is that the problems are real and acknowledged rather than searched for to fit an imposed strategy or policy. Public consultation and involvement is very important for current 'top-down' approaches, as it can incorporate this 'bottom-up' idea into the policies made. Prescriptive 'top-down' methods have not able to effectively address problems of resource utilization in poor coastal communities as perceptions of the coastal zone differ with regard to developed and developing countries . This leads on to another constraint to ICZM, the idea of common property.

The coastal environment has huge historical and cultural connections with human activity. Its wealth of resources have provided for millennia, with regard to ICZM how does management become legally binding if the dominant perception of the coast is of a common area available to all? And should it? Enforcing restrictions or change to activities within the coastal zone can be difficult as these resources are often very important to people's livelihoods. The idea of the coast being common property fouls 'top-down' approaches. The idea of common property itself is not all that clean, This perception can lead to cumulative exploitation of resources – the very problem this management seeks to extinguish.

ICZM: The New Zealand case study

New Zealand is quite unique as it uses sustainable management within legislation, with a high level of importance placed on to the coastal environment. The Resource Management Act (RMA) (1991) promoted sustainable development and it mandated the preparation of a New Zealand Coastal Policy Statement (NZCPS), a national framework for coastal planning. It is the only national policy statement that was mandatory. All subsequent planning must not be inconsistent with the NZCPS making it a very important document. Regional authorities are required to produce Regional coastal policy plans under the RMA (1991) but strangely enough, they only need to include the marine environment seaward of the mean high water mark. But many regional councils have chosen to integrate the 'dry' landward area within their plans, breaking down the artificial barriers. This attempt at ICZM is still in its early days running into many legislative hurdles and is yet to achieve a fully ecosystems-based approach. But as part of ICZM, evaluation and adoption of changes is important and ongoing changes to the NZCPS in the form of reviews is currently happening. This will provide an excellent stepping stone for future initiatives and the development of a fully integrated form of coastal management.

Conclusion

The Integrated Coastal Zone Management (ICZM) appears to be a key element for the sustainable development of these zones. However this recent notion may not be adapted to all cases. Successful implementation is still a major challenge to the idea of ICZM.