COASTAL RESTORATION CONSIDERATIONS

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Abstract

The paper discusses the problems associated with the loss of coastal resources, which is often the result of applying traditional coast protection measures in densely developed areas. It is recommended to distinguish clearly between coast protection, as measures mainly securing the coastline, and shore protection, as measures protecting also the shore and the natural coastal resources. The planning concepts Shoreline Management Planning and Management Unit Master Planning have been discussed, in which connection the importance of obtaining broad consensus for a management strategy and for cost sharing has been highlighted. The importance of preserving the coastal resources by working with the nature has been illustrated and innovative shoreline protection principles have been proposed for different types of coastal classifications. New types of environmentally optimised coastal structures have been proposed and an overall comparison of various protection measures has been made.

Introduction

The paper discusses the important physical and management issues in the delicate balance between (a) the requirements of primary protection against coastal erosion and (b) protection of the coastal resource, which in this context is constituted mainly by the dynamic coastal landscape. Historically, protection measures have been reactive in nature and have concentrated on preventing loss of existing facilities and coast due to coastal erosion. This type of protection has at many locations resulted in loss of the shore (or beach) and it has seriously degraded the fascinating scenery of the dynamic coastal landscape. Such protection measures can consequently not be ealled "shore protection" as they result in loss of the shore, but should rather be called "coast protection", where the term coast is defined as the strip of land that extends inland from the coastline. For clarification, the definition of the generally used terms for the form elements in the coastal area is presented in Figure 1.

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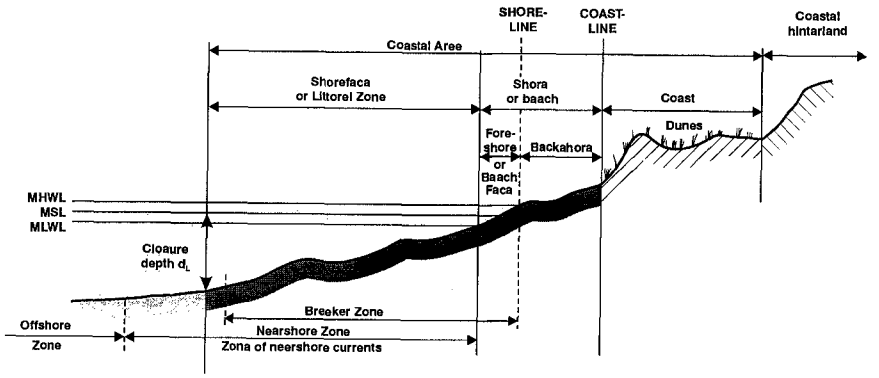

Figure 1. Definition of Coastal Terms, mainly from (Shore Protection Manual, 1984).

The most important terms are the following:

- COASTAL AREA: The land and sea areas bordering the shoreline.
- COAST: The strip of land that extends from the coastline inland to the first major change in terrain features.
- COASTLINE: Technically the line that forms the boundary between the COAST and the SHORE, i.e. the foot of the cliff. Commonly, the line that forms the boundary between the land and the water.
- SHORE or BEACH: The zone of unconsolidated material that extends from the low water line to the line of permanent vegetation (the effective limit of storm waves).
- SHORELINE: The intersection between the mean high water line and the shore.
- SHOREFACE: The active littoral zone off the low water line.
- CLOSURE DEPTH: The depth beyond which no significant longshore and cross-shore transports take place, and where no significant bed movements due to littoral transport processes take place. The closure depth can thus be defined as the depth at the seaward boundary of the littoral zone. (Hallemeyer, 1981)
- OFFSHORE ZONE: The offshore zone is not well defined. In relation to beach terminology, it is thus not clear if it starts from the littoral zone, from the breaking or from the nearshore zone or even from the shoal zone. In the present context, the offshore zone is defined as the zone off the nearshore zone.

There is, however, some confusion between the terms "shore" and "coast", as these terms in common perception are synonymous. Consequently the terms "shore protection" and "coast protection" are also synonymous in common perception and signal that the shore (or beach) is protected when such measures are introduced, which is not the case with traditional hard protection measures. Actually, traditional hard coast protection maintains the location of the coastline and protects the coast, according to above definition, but at the expense of the shore (or the beach); consequently it is proposed in the future to distinguish clearly between the two terms:

- COAST PROTECTION, as measures aiming at protecting against coastline retreat, thus protecting housing and infrastructure, the coast and the hinterland from erosion, however often at the expense of losing the beach and the dynamic coastal landscape;
- SHORE PROTECTION, as measures aiming at protecting, preserving or restoring the shore and the dynamic coastal landscape as well as protecting against coastline retreat to the extent possible.

Causes of Coastal Erosion

Most coastal erosion problems have their origin in deficit in the littoral budget for a specific area, such deficits can have many causes of which the most common are the following:

- Blocking, or reduction, of the littoral transport by some kind of protruding coastal structure, such as port structures, inlet regulation works, or coastal protection works.
- Reduction of the supply of littoral material to a section by river regulation works, sand mining or by protection of neighbouring coastlines.
- Loss of littoral material into tidal inlets.
- Loss of littoral material by dumping of maintenance dredging material offshore.
- Loss of sand inland by dune destruction.
- Blocking of part of the buffer zone on the shore by structures on the shore.

All these causes are well known, and in many cases their damaging effects have been eliminated, at least partly, by regulatory measures. However, many developed areas are characterised by a highly degraded coastal environment, brought on by a historic combination of the above mentioned causes and where sufficient mitigation of these is not realistic.

Problem Scoping and Overall Planning Concept

In modern legislation there are often requirements for sustainable development and preservation of natural resources, which has resulted in seeing shore protection in a new long-term perspective, which has led to the discipline of Integrated Coastal Zone Management (ICZM). The concept of ICZM may be defined as a structured co-ordination of the various activities and resource demands that occur in the coastal zone in order to achieve economically, environmentally and socially sustainable development in compliance with adopted relevant local, regional or international goals. ICZM is often expressed in the form of a Coastal Zone Management Plan (CZMP), which provides input to national or regional development plans. A CZMP thus provides an overall framework for a balanced development of the following main issues, which are normally exposing the coastal zone to competing pressures: (a) Coast protection and shore protection; (b) agriculture and fisheries; (c) habitation, infrastructure, industrial development, public utilities and navigation; (d) recreation, landscape and environmental preservation; and (e) raw material utilisation

The ICZM concept is best suited for planning in areas where there are still some options for the planning of the coastal hinterland. In areas prone to long term erosion and where the coastal development is already so advanced that comprehensive hard shore protection measures have been constructed years ago, the consequence is very often that

the shore has been heavily degraded or completely lost. Such highly developed areas, where the coastal resource has been degraded over many years, are numerous in most coastal countries. Typically, the population pressure on the sparse remaining coastal resources is very high, and the value of the development is correspondingly high. The present paper concentrates on management and technical methods for restoring such highly developed coastal areas.

Detailed Planning Concept

The modern management of shore protection and/or coastal restoration projects have their origin in the world-wide legal requirements for preservation and restoration of the natural resources through a sustainable holistic management. The challenge in this context is to combine the public shore protection/restoration interests with the private interests for coast protection. There are often inherent conflicting interests in such projects, both with respect to the objectives of the protection and with respect to cost sharing. Resolving these planning matters often proves to be equally challenging than to finding a suitable technical solution. Resolving planning matters is normally not the strong side of the coastal engineer, but it is important for the success of the entire planning and design process that the coastal engineer is aware of these conditions.

The level where coastal engineers are involved in the planning is normally not in the ICZM process, but at the more specific and project orientated level, where the planning concepts are Shoreline Management Planning and Management Unit Master Planning. A Shoreline Management Plan (SMP) is a strategic plan for shore protection or shore development covering a sediment cell or a sub sediment cell.
An SMP normally contains the following items:

- Basic data collection for the following types of data: Meteomarine conditions, coastal processes, coastline development and coastal structures, present and planned land use and environmental conditions.
- Programme for additional data collection.
- Overall description of coastal morphology and sediment budget.
- Identification of Management Units.
- Consultation with all interested parties with the purpose of obtaining consensus on the goal for a management strategy.
- Definition of the Management Strategy.

In Denmark the SMPs are prepared by the Counties. In other countries this may be the responsibility of other similar bodies. The SMP sets the strategy for shore protection projects in the various Management Units (MU). A Management Unit is a length of shoreline with basically similar characteristics in terms both of natural processes and land use. Different shore or coast protection measures may very well be used for neighbouring MUs, as the preferred measures are dependent on the land use and the ownership of the coastal land. However, the SMP has set out the general guidelines for applicable protection measures assuring that there will be no negative impact from one MU to the neighbouring units. The development of the protection options is often performed in the form of a Management Unit Master Plan (MUMP) or a Shoreline

Master Plan. In Denmark it is normally the landowners who take the initiative to request the County to prepare a MUMP. However, the County can also take the initiative by itself. The County is also responsible for the allocation of costs among the landowners and others, as found relevant in the specific cases. The general rule in Denmark is that the landowner must pay for the protection. The County will normally not prepare the MUMP itself, but it will establish a project organisation, which typically has the following composition:

Consulting team:	This should as a minimum include the following professionals: Coastal Morphologist, Coastal Design Engineer, Landscape Architect/Planner and Environmentalist.
Steering Committee:	County, Municipality, Coastal Authority and representatives from land owners and other involved groups (NGO's).

The preparation of a MUMP will normally involve the following activities:

- Establishment of consensus on local goals, especially with respect to the weighting between shore and coast protection objectives and on cost sharing.
- Performance of detailed data collection, field surveys and analysis.
- Detailed analysis of coastal morphology.
- Detailed analysis of land use and public access corridors.
- Preparation of conceptual design of alternative shore protection projects, including coastal and environmental impact assessment (by numerical modelling) and aesthetic optimisation.
- Preparation of costing for alternative projects and preparation of financing plan.
- Maintenance of contact to authorities responsible for approving alternative projects.
- Selection of preferred project.
- Preparation of plan for monitoring of project performance.
- Preparation of plan for maintenance organisation and follow-up.

The main output of a MUMP is thus a well documented conceptual design of a combined shore and coast protection scheme, which has been documented and balanced with respect to coastal impact, environmental impact and aesthetic considerations. Furthermore the cost sharing and the financing plan have been agreed and the project has been approved.

Based on this MUMP, the responsible body can now call for tenders for detailed design, including preparation of tender documents for construction.

Main Physical Principles in Shoreline Restoration

A precondition for establishing a successful shoreline restoration project is that all the involved parties have a minimum understanding of the coastal morphological processes, so that they can understand why the present situation has developed and why certain solutions are applicable and others are not.

The following perspectives should be considered in connection with shoreline restoration projects:

- Work with nature, for instance by re-establishing the coastal profile by nourishment and by utilising site specific features, for instance by strengthening of semi hard promontories.
- Manipulate littoral drift rate and gradient by use of a minimum of structures.
- Preserve sections of untouched dynamic landscape. Allow only protection measures if valuable buildings/infrastructure are threatened.
- Secure passage to and along the beach.
- Enhance aesthetic appearance, such as by minimising the use of structures thereby providing long uninterrupted sections of beach.
- Minimise maintenance requirements to a level, which is possible to manage by the concerned owner(s) of the scheme. A clean nourishment solution at an unstable section of coastline, which for many reasons may be the preferred one, will normally not be practical to handle by a group of land owners, as recharge will be required at short intervals.
- Secure good local water quality and minimise risk of trapping debris and seaweed.
- Secure safety for swimmers by avoiding structures generating dangerous rip currents.
- Be realistic and pragmatic, keeping in mind that the natural untouched coastline is an utopia in highly developed areas. Create small attractive locations at otherwise strongly protected stretches if this is the only realistic possibility.

Coastal classification

The general principles, which should be followed to develop a successful shoreline restoration project, were discussed above. However, in order to be able to arrive at the optimal shoreline restoration measure in an actual case, it is also important to take into account the actual coastal morphodynamic conditions of the site. A coastal classification has been established in the following in order to provide some guidelines as regards which measures are best suited for different types of coasts.

Only littoral coasts, which are characterised by the presence of non-cohesive sediments on the shoreface and on the beach, will be included in the following classification.

The littoral transport for a given coastal environment is mainly dependent on the wave climate in terms of wave height-direction distribution. A simplified classification of coastal areas based on wave exposure and the angle of incidence of the prevailing waves is presented in Figure 2.

The coastal classification is closely related to the variation in transport capacity as function of the angle of incidence and the magnitude of the waves, which has been expressed in form of exposed, moderately exposed and protected coastal areas. The possibility of artificially establishing a practically stable sandy shore is very much dependent on the angle of wave incidence of the prevailing waves and the magnitude of the transport deficit, which is closely related to the transport capacity.

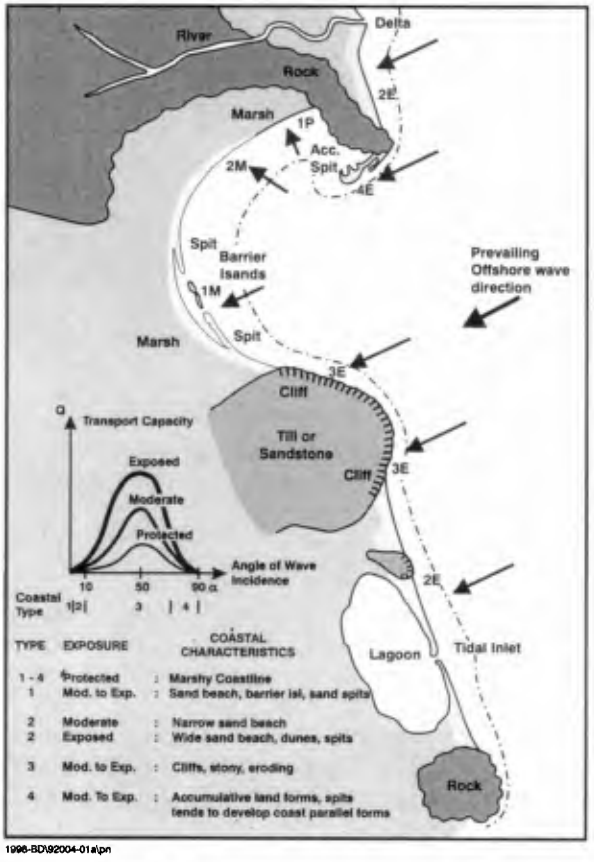

Figure 2 Coastline classification

It should be noted, that a prerequisite for obtaining an attractive sandy shore is that the location is exposed or moderately exposed, as it is the constant movement of the beach sand under these circumstances which generated the attractive clean sandy beach.

The coasts have been divided into four main types in relation to the angle of incidence of the prevailing waves and in subtypes in relation to the exposure. The resulting coastal characteristics are presented in Table 1.

It should be noted, that the above given classification is very simplified, and is in practice also dependent of many other parameters, such as the type of coast and sediment supply from the neighbouring areas, as well as seasonality in wave climate, tides and storm surges etc. Figure 2 also shows a schematised coastline, where different typical coastal types have been shown.

Coastal Type	Angle of Incidence (0° = shore normal)	Exposure	Coastal Characteristics
1P	< 3°	Protected	Marshy
1M		Moderate	Sandy beach, barrier isl., sand spits
1E		Exposed	Sandy beach, barrier isl., sand spits
2P	3 – 10°	Protected	Marshy
2M		Moderate	Narrow sandy beach, sand spits
2E		Exposed	Wide sandy beach, sand spits
3P	10 – 70°	Protected	Marshy
3M		Moderate	Mobile eroding beach with cliffs
3E		Exposed	Mobile eroding beach with cliffs
4P	70 – 90°	Protected	Marshy
4M		Moderate	Accumulative land forms, spits
4E		Exposed	Accumulative land forms, spits

Table 1 Coastal classification as function of angle of incidence and wave exposure for littoral coasts.

Discussion of Innovative Coastal Restoration Schemes

The discussion of the different types of suitable restoration schemes will be divided into the four main types of coastal areas, which reflects the angle of incidence of the prevailing waves, as the different types require different restoration measures.

Type 1P to 4P, Protected, all directions

These physical conditions result in a marshy coastline, where there will normally not be any problems related to coastal erosion, but where there may be some problems in relation to flooding. Furthermore, there may be a requirement for upgrading to a sandy shore. However, this is only possible if the reason for the protected status of the coastline is related to a very shallow shoreface. If this is the case, an attractive and more exposed coast can be constructed by moving the shoreline seawards by nourishment. The plan stability of the beach shall also be considered. This principle is shown in figure 3, left.

Type 1M and 1E, Perpendicular wave approach, moderate to exposed

These conditions will often result in a sandy beach. The perpendicular wave approach is characteristic for accumulative sand formations in bays, where the net littoral drift is close to zero. If the original bathymetry in such a bay is shallow, there will be a tendency towards formation of sand spits and barrier islands, which are separated from land by a shallow lagoon, refer Figure 2 and Figure 3, right. As these morphological features are characterised by accumulative processes, they will normally not be associated with erosion problems. However, there might be a requirement for upgrading of the entire coastal area towards a more attractive beach environment from a recreational point of view. This can be obtained in two principally different ways:

1. By filling the lagoon and moving the beach seawards, whereby a more exposed and attractive sandy beach is obtained with easy access, as the difficult access caused by the lagoon is eliminated.
2. By dredging the lagoon, whereby it can be upgraded to a recreational protected water area, in combination with seaward movement of the coastline.

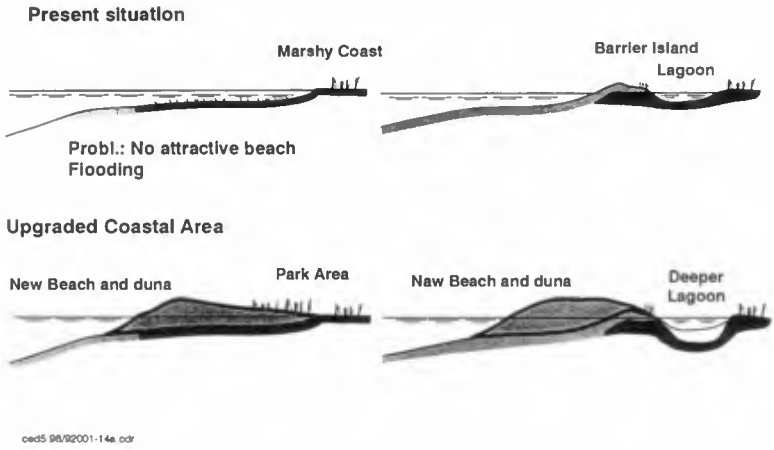

Figure 3 Upgrading of: (a) Protected coastal areas with all directions of wave approach, coastal types 1P – 4P and (b) Moderate/exposed beaches with perpendicular wave approach, coastal types 1M and 1E.

These two beach park rehabilitation solutions are shown in Figure 3, lower part. The Køge Bugt Beach Park, near Copenhagen, has been constructed according to this principle and the New Amager Beach is presently being planned also following these principles, Anderskouv et al. (1998).

Type 2M and 2E, Moderate/exposed beach with small angle of incidence

These types of wave conditions will often result in a narrow to wide sandy beach, however, also depending on tidal and storm surge conditions. These beaches are close to their equilibrium direction and normally subject to a moderate littoral drift; they are often seen in the form of crescentic beaches suspended between headlands or in connection with deltas or tidal inlets, see Figure 2. Their stability is dependent on a continuous supply of littoral material. If such supply does not occur or is interruped they will tend to rotate towards the direction of the new equilibrium. This will normally lead to shoreline setback.

Coastal protection of such beaches has traditionally been performed by revetments, groyne fields and coastal breakwaters. These traditional measures normally provide good protection of the coastline and, in the case of groynes and breakwaters, some short sections of beaches. However, they have also a series of negative effects on the beach quality as shown in Figure 4. These can be summarised as follows: (a) Revetments: Loss of the beach, erosion of down-drift beach, difficult passage and aesthetically undesirable, (b) Groyne field: Trapping of sand and debris, lee-side erosion, rip currents and offshore loss of sand, rips dangerous for bathers, difficult passage on beach and aesthetically undesirable, (c) Segmented breakwaters: Trapping of

sand and debris, poor water quality in narrow bays, lee-side erosion, rip currents and offshore loss of sand, rips dangerous for bathers, and obscured view to the sea.

An ideal rehabilitation of a coastal section, which has been protected by a combination of traditional coastal protection measures and thereby been degraded, will, from a physical point of view, be a beach nourishment programme. However, this has the disadvantage that is has to be maintained at regular intervals. This is not very attractive for most landowners. Normally, landowners have as one of the main objectives to a shoreline restoration project that the maintenance requirements shall be small. Therefore the coastal engineer has to find restoration solutions, which fulfil this objective. Such a rehabilitation solution is shown in the lower part of Figure 4. The philosophy behind this rehabilitation is to tidy up the old unplanned mixture of small structures, and to re-establish a wide stable sandy beach by the combined use of a few large structures and considerable initial nourishment, plus limited regular recharge.

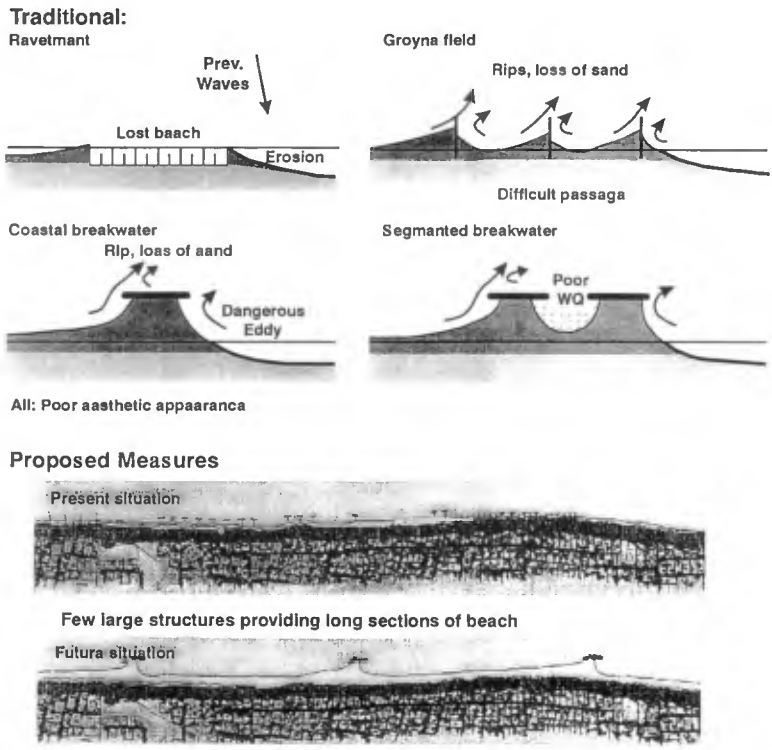

Figure 4 Performance of traditional coast protection measures and proposed upgrading to shore protection scheme for moderate/exposed coasts with small angle of incidence.

This concept is only applicable on coasts where the incidence angle of the prevailing waves is small, which means that a fairly long section of beach can be supported by each structure. The equilibrium angle of the new beach section is mainly dependent on the wave conditions and the supply of littoral material to the section from the updrift coastal section. The new beach concept can be characterised by the following qualities: (a) Long sections of natural looking sandy beaches, (b) Small maintenance, (c) Small downstream effects, (d) The protection against coast erosion is provided partly by the wide beach and partly by the structures. Identical safety towards coast erosion along the entire section may require the introduction of buried emergency revetments or the use of beach drains along the narrowest sections of the new beaches, and (e) The new large structures can be used as active elements in the landscaping, for instance to underline natural strong points in the original coastline.

The supporting structure has in Figure 4 been shown as a slightly curved coastal breakwater. However the layout of this structure can be optimised according to the principles shown in Figure 5.

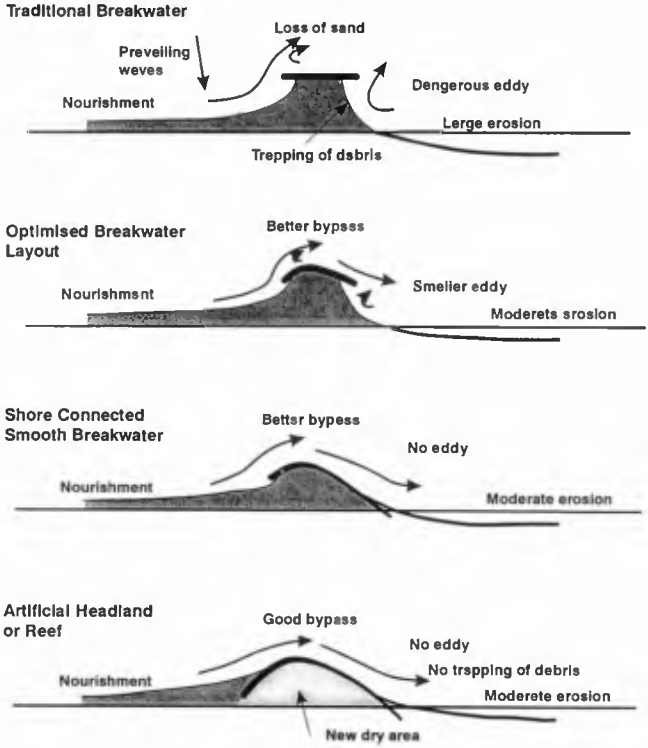

Figure 5 Optimisation of coastal breakwater to artificial headland, applicable for moderate/exposed coasts for small angles of incidence.

The philosophy in the optimisation of the breakwater in terms of a curved breakwater, a shore connected smooth breakwater or ultimately an artificial headland is to: (a) Improve the bypass, minimise the offshore loss and minimise the lee-side erosion, (b) To eliminate dangerous rip currents and to eliminate lee areas, thereby minimising the risk of trapping of debris, (c) To enhance the aesthetic appearance of the coastal structure and to gain some useful land.

Type 3M and 3E, Moderate/exposed beach with large angle of incidence

This type of coast has a large littoral transport potential, it is often eroding and will therefore in many cases already have been protected. Whereas a suitable coast protection measure for this type of coast is revetments, it is difficult to propose an optimal shore protection system. The protection principles counting on long sections of accumulated material upstream of protruding coastal structures cannot be used in this situation due to the very oblique wave attack. This type of coast is normally neither suitable for artificial nourishment as a stand alone measure, as this will result in large maintenance requirements, nor nourishment in connection with structures, as the structures can only hold a short beach section due to the oblique wave exposure.

A possible solution for an innovative upgrading of a small coastal section from being protected by a revetment into an attractive recreational environment is the construction of a small cove, as shown in Figure 6. The shape of the small cove will be fairly independent of the oblique wave attack due to its relatively narrow opening.

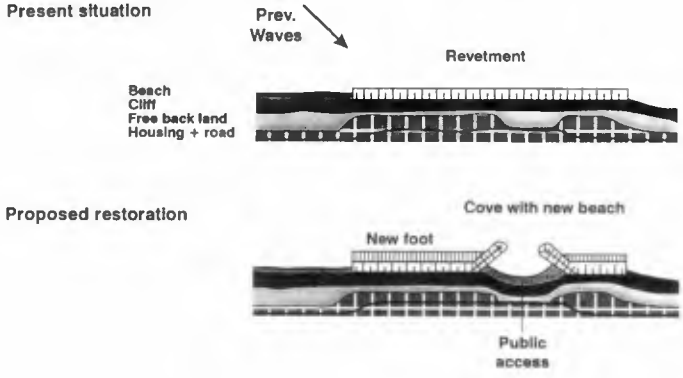

Figure 6 Innovative shore protection measure for a moderate/exposed coast with oblique wave attack.

Type 4M and 4E, moderate/exposed beach with nearly parallel wave attack

This type of coast is the downdrift section of a coastline of one of the other types; the littoral drift capacity is small due to the very large angle of wave incidence. This type of coastline is often accreting as the supply of littoral material is typically greater than the transport capacity. However, due to the very oblique wave attack, the coastline development is often unstable and shows a tendency to form coast-parallel land

forms some distance from the coastline, see Figure 7. A characteristic of this separated spit formation is that the coastline downstream of the spit has no supply of sediments, and consequently will be exposed to erosion.

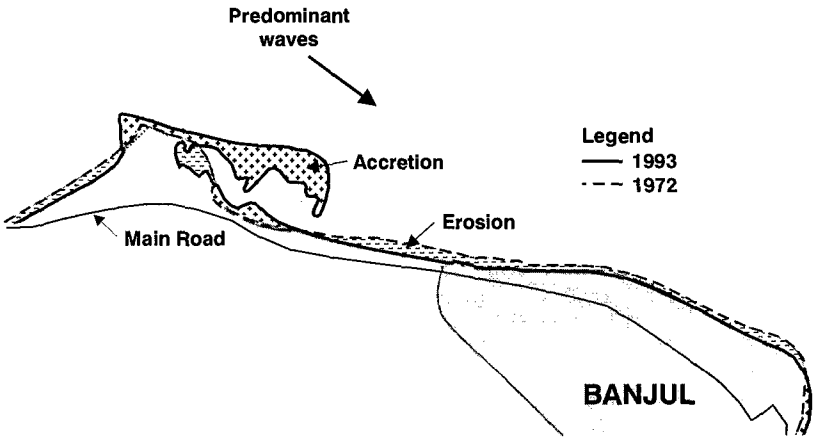

Figure 7 Special shoreline erosion problem at coastline with very oblique wave attack.

It is important to note that protruding coastal structures in such an environment can initiate the above-mentioned separation, for which reason such structures shall be avoided under these circumstances. The recommended shore protection measures at such a location are withdrawn emergency revetments in combination with artificial nourishment. The source for the nourishment could be the accumulated material in the spit, which is causing the local downstream erosion.

Final evaluation of coast protection and shore protection measures

Evaluations of the different kinds of coast protection and shore protection measures, which have been discussed in the paper, have been given in table 2. The protection and restoration measures have been divided in four categories:

- Structures
- Combined, which is combinations of nourishment and structures (beach parks)
- Soft, which is nourishment and beach drain
- Natural, which is management solutions without any structures or other physical measures

The evaluation of the different measures have been divided into four main categories:

- Protection, capability of protecting the coast and influence on adjacent stretches
- Recreation, divided into: capability of protecting the shore, safety for bathers and water quality
- Sustainability, divided into: aesthetics and preservation of coastal resource

- Management requirements, which is the associated efforts for obtaining consensus between stakeholders (not to be underestimated) and to the performance of shoreline management planning

Please note that the cost of the different measures has not been taken into account in the evaluation scheme.

Influence on Coastal Area / Protection and Restoration Measure		Protection		Recreation			Sustainability		Management Requirements	Score		
		Coast	Adjacent Coasts/ Beaches	Shore/ Beach	Safety for Bathers	Water Quality	Aesthetics	Preser-vation of Coastal Resource	Consensus, Shoreline Man. Planning	Pro-tec-tion	Rec. + Sust.	Total
Structures	Revetment (single)	1	0	-1	-1	0	-1	-2	0	1	-5	-4
	- (long stretch)	2	-1	-2	-1	0	-2	-2	-2	1	-7	-6
	Dyke (withdrawn)	2	0	0	0	0	-1	-1	-2	2	-2	0
	Groyne (single)	1	-1	1	-2	-1	-2	-2	-1	0	-6	-6
	Groyne Field	2	-2	1	-2	-1	-2	-2	-2	0	-6	-6
	Single Breakwater	1	-1	1	-2	-1	-1	-1	-1	0	-4	-4
	Segmented Breakw.	2	-2	1	-2	-2	-2	-2	-2	0	-7	-7
	Headland	2	0	2	0	0	1	0	-2	2	3	5
Combined	Beach Park	2	0	2	1	2	1	-1	-2	2	5	7
	Cove	1	0	1	0	0	0	-1	-2	1	0	1
Soft	Nourishment	1	1	1	0	0	0	0	-2	2	1	3
	Beach Drain	1	0	2	0	0	1	0	-1	1	3	4
Natural	Setback - Do nothing	-2	0	1	0	0	2	2	-2	-2	5	3
	Legend: +2	Good Protection		High rec. value			Enhances Sustainability		No demand			
	+1											
	0	Neutral		Neutral			Neutral		Moderate			
	-1											
	-2	Causes Erosion		Negative impact on Rec.			Non Sustainable		High demand			

Table 2 Evaluation of function and impact of coastal protection, shore protection and shoreline restoration measures.

It is of course difficult to make the scoring and some of the given scores can be discussed, however, the tendency is quite clear:

- Structures can provide coast protection, but most often at the expense of the coastal resources
- Combined solutions can be very attractive providing both protection and restoration
- Soft solutions can be attractive providing both protection and restoration
- Natural. Setback restrictions can normally not be used in already highly developed areas and do-nothing can only be used if continued coastal erosion can be accepted

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General Experience from numerous DHI projects, which are not available in public domain.