Alternatives for coastal protection

Krystian Pilarczyk[1]

Abstract: A brief overview of some available alternative systems for shore stabilization and beach erosion control is presented. Special attention is paid to artificial reefs and geosystems. Geosystems (geobags, geotubes, geocontainers, geocurtains, etc.) have gained popularity in recent years because of their simplicity in placement, cost effectiveness and environmental aspects. However, all these systems have some advantages and disadvantages, which have to be recognized before application. For design and installation criteria the reader is guided to relevant documents.

Keywords: coastal protection, alternatives, artificial reefs, geotextiles, geosystems

1. Introduction

Coastal users and managers all over the world are frequently faced with serious erosion of their sandy coasts. Possible causes of erosion include natural processes (i.e. action of waves, tides, currents, sea level rise, etc.) and sediment deficit due to human impact (i.e. sand mining and coastal engineering works). Countermeasures for beach erosion control function depend on local conditions of shore and beach, coastal climate and sediment transport. Continuous maintenance and improvement of the coastlines, together with monitoring and studies of coastal processes have yielded considerable experience on various coastal protection measures all over the world. In general, a coastal structure is planned as a practical measure to solve an identified problem. Starting with identification of the problem (e.g. shoreline erosion), a number of stages can be distinguished in the design process for a structure: definition of functions, determination of boundary conditions, creating alternatives, geometrical design and the final choice of functional solution. After the choice of functional solution has been made the structural design starts including creating structural alternatives (ie. using different materials and various execution methods). The final choice will be made after verification of various structural solutions in respect to the functional, environmental and economic criteria.

This contribution presents an overview of the various available methods for shore stabilization and beach erosion control, with special emphasis on the alternative solutions and novel materials and systems in various design implementations. Within alternative systems special attention is paid to artificial reefs and geosystems. Additional information on alternative systems can be found in references and on the related websites.

2. Alternative systems for coastal protection

Various coastal structures can be applied to solve, or at least, to reduce erosion problems. They can provide direct protection (seawalls, dikes, revetments) or indirect protection (groins and offshore breakwaters of various designs), thus reducing the hydraulic load on the coast. Rock and concrete are usually the construction materials. Groins of various designs (including pocket and perched beaches) are often called ‘shore connected’ structures (Figure 1).

However, there is a growing interest both in developed and in developing countries in low cost or novel methods of shoreline protection particularly as the capital cost of defence

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works and their maintenance continues to rise. The shortage of natural rock in certain geographical regions can also be a reason for looking to other materials and systems. Despite this interest there is little published and documented information about the performance of low cost or patented structures especially at more exposed wave climate.

Novel systems as geosystems (geotubes, geocontainers, geocurtains) and some other (often patented) systems (Reef Balls, Aquareef, prefabricated units, beach drainage, etc.) have gained popularity in recent years because of (often but not always) their simplicity in placement and constructability, cost effectiveness and their minimum impact on the environment.

These new systems were applied successfully in number of countries and they deserve to be applied on a larger scale. Because of the lower price and easier execution these systems can be a good alternative for traditional coastal protection/ structures. The main obstacle in their application is however the lack of proper design criteria. An overview is given on application and performance of some existing novel systems and reference is made to the actual design criteria. Additional information can be found in [1] and [2], and in references.

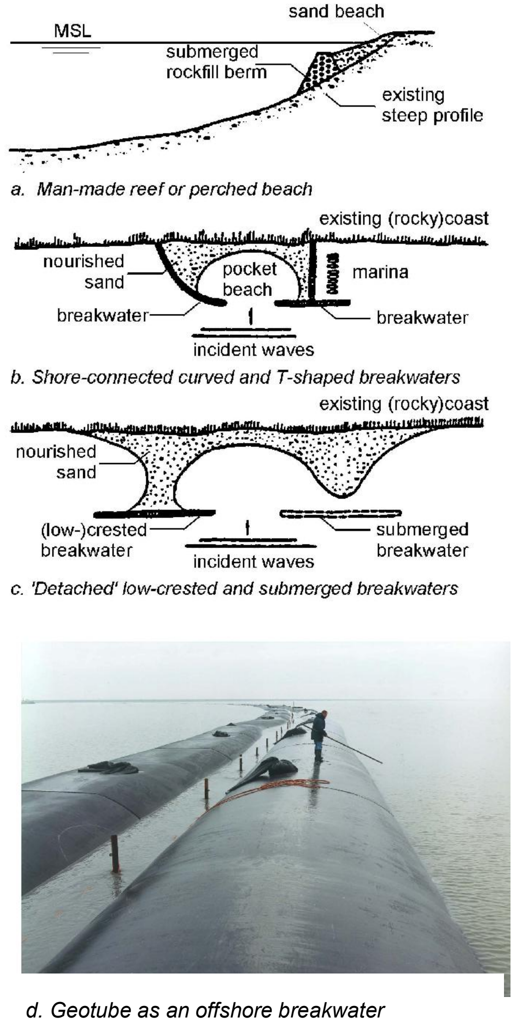


Figure 1. Examples of shore-control and low-crested structures

2.1 Low-crested Structures

Low crested and submerged structures (LCS) as detached breakwaters and artificial reefs are becoming very common coastal protection measures (used alone or in combination with artificial sand nourishment) [3]. As an example, a number of systems and typical applications of shore-control structures is shown in Figures 1 to 4.

The purpose of LCS structures or reefs is to reduce the hydraulic loading to a required level allowing for a dynamic equilibrium of the shoreline. To obtain this goal, they are designed to allow the transmission of a certain amount of wave energy over the structure in terms of overtopping and transmission through the porous structure (emerged breakwaters) or wave breaking and energy dissipation on shallow crest (submerged structures). Due to aesthetical requirements low freeboards are usually preferred (freeboard around SWL or below). However, in tidal environment and frequent storm surges they become less effective when design as a narrow-crested structures. That is also the reason that broad-crested submerged breakwaters (called also, artificial reefs) became popular, especially in Japan (Figures 2 and 3). However, broad-crested structures are much more expensive and their use should be supported by a proper cost-benefit studies. On the other hand the development in alternative materials and systems, for example, the use of sand-filled geotubes as a core of such structures, can reduce effectively the cost [2], [3] [4]. The upgrading of (integrated/muldidisciplinary) design criteria for LCS structures took recently place in the scope of European project DELOS [5]; see also: www.delos.unibo.it.

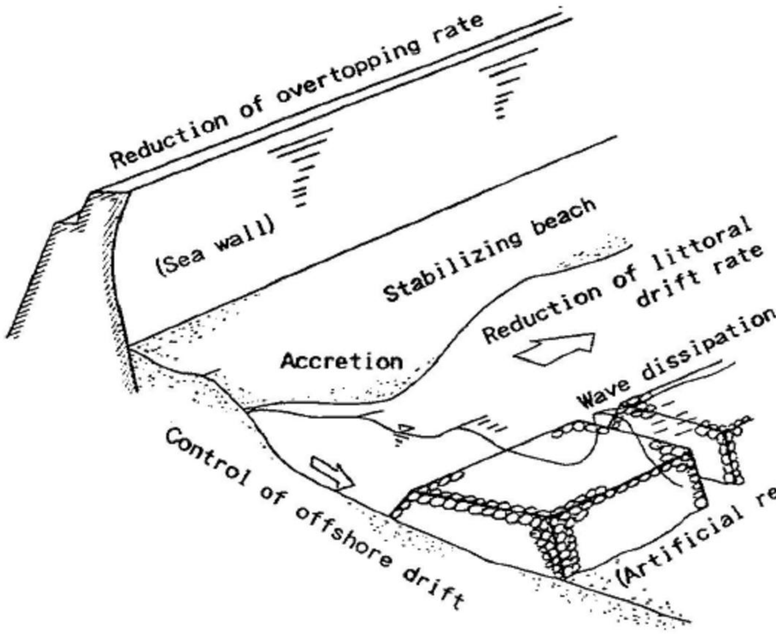


Figure 2. Objectives of low-crested/reef structures

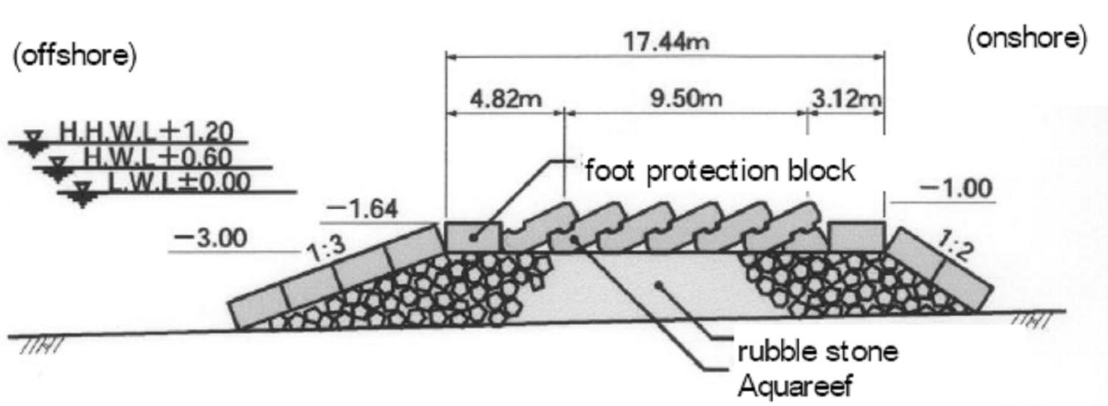


Figure 3. Example of Aquareef [6]

The relatively new innovative coastal solution is to use artificial reef structures called "Reef Balls" as submerged breakwaters, providing both wave attenuation for shoreline erosion abatement, and artificial reef structures for habitat enhancement. An example of this technology using patented Reef BallTM is shown in Figure 4. Reef Balls are mound-shaped concrete artificial reef modules that mimic natural coral heads. The modules have holes of many different sizes in them to provide habitat for many types of marine life. They are engineered to be simple to make and deploy and are unique in that they can be floated to their drop site behind any boat by utilizing an internal, inflatable bladder. Worldwide a large number of projects have already been executed by using this system.

The first applications were based purely on experience from previous smaller projects. Since recently, more well documented design criteria are available. Stability criteria for these units were determined based on analytical and experimental studies. For high energetic wave sites the units can be hydraulically anchored with cables to the sea bed). Wave transmission was studied in Canada[7]. Technical design aspects are treated by Lee Harris on the websites [8].

2.2 Prefabricated systems

Figure 4. Example of Reef Balls units

There exist a number of other novel and/or low cost materials and methods for shore protection (gabions and stone mattresses, open stone asphalt, used tire pile breakwaters, sheet pile structures, standing concrete pipes filled with granular materials, concrete Z-wall (zigzag) as breakwater, geotextiles curtains (screens), natural and mechanical drainage of beaches, and various floating breakwaters, etc. Most of them are extensively evaluated and documented. However, more recently, a new family of prefabricated concrete elements as URGEBREAKER offshore reef system, BEACHSAVER reef, WAVEblock, T-sill elements and others have been developed and applied. The details on these systems can be found in references and on the websites. However, because of very narrow crest these prefabricated breakwaters are only efficient during mild wave conditions and their effect usually disappear during storm conditions, and because of scour and/or settlement, even loosing their stability. The recent evaluation of performance of prefabricated, narrow-crested breakwaters can be found in [9] and on the US Army website: (http://chl.erdc.usace.army.mil/CHL.aspx?p=m&a=MEDIA;352).

Some of these breakwaters are applied for comparison with other systems in recent US National Shoreline Erosion Control Development and Demonstration Program (227):and better/more reliable information on the effectiveness of these systems can be expected within a few years. The website http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=PROGRAMS;3 provides details on sites and systems applied, and also provide documentation if available.

2.3 Some other systems

2.3.1 Distorted ripple mat

A new concept for creating shore accretion is actually developed and applied in Japan. A distorted (precast concrete blocks) ripple mat (DRIM) laid in the surf zone induces a landward bottom current providing accretion of a shore [10]. The strong asymmetry of (artificial) ripple profile generates current near the bottom to one direction and thus sediment movement, whose concentration is high near the bottom, can be controlled with only very little environmental impact. The hydraulic condition on which the distorted ripple mat can control the sediment transport most effectively is studied experimentally and numerically and its capability to retain beach sand is tested through laboratory experiments (Figure 5) and field installation. The definite onshore sediment movement by the control of DRIM is expected if the relative wave height H/h is less than 0.5, where H is the wave height and h is the water depth. The optimum condition for the efficient performance of DRIM is that $d_o/\lambda>1.7$, where d_o is the orbital diameter of water particle and λ is the pitch length of DRIM, and this condition coincides with the condition in which natural sand ripples grow steadily. DRIM is able to control bottom currents so long as wave direction is within 50 degrees from the direction normal to the crest line of ripples.

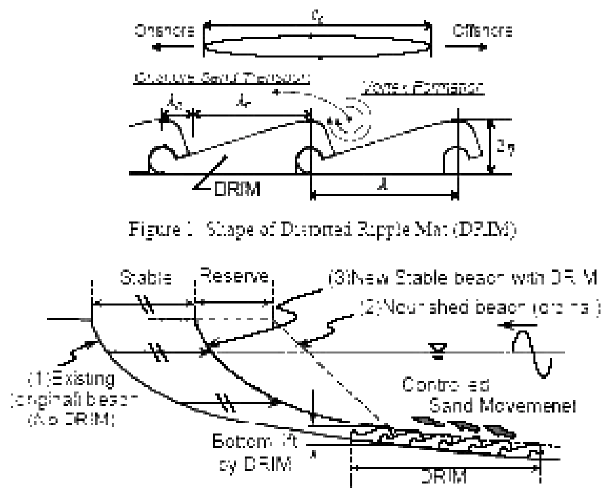


Figure 5 Principle of distorted ripple mat and application

2.3.2 Beach drainage (dewatering)systems

Beach watertable drainage is thought to enhance sand deposition on wave uprush while diminishing erosion on wave backwash (Figure 6). The net result is an increase in subaerial beach volume in the area of the drain. The larger prototype drainage by pumping istallations used in Denmark and Florida suggest that beach aggradation may be artificially induced by beach watertable drainage. The state of the art of this technique is presented in [11]. Most recent evaluation of drainage systems can be found on the website: http://chl.erdc.usace.army.mil/CHL.aspx?p=s&a=ARTICLES;191. It is concluded that the drainage system has, in general, a positive effect on diminishing the beach erosion, however, its effectiveness is still difficult to control.

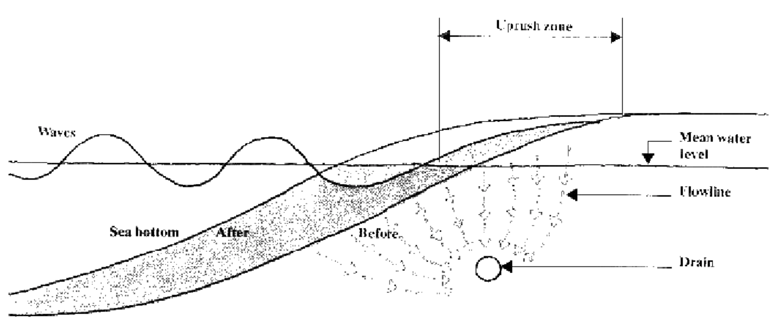
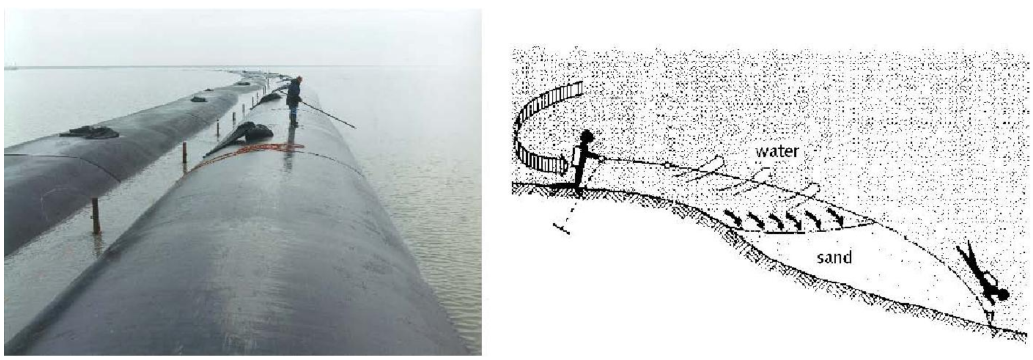


Figure 6. Principles of beach drainages

The idea to achieve lowering of the water table without pumps by enhancing the beach's own drainage capacity or hydraulic conductivity through the use of strip drains has been applied in Australia and in Japan [12]. However, these new techniques are still in rudimentary stage and much more research and practical experience is still needed before application on larger scale.

3. Geosystems in coastal applications

Geotextile systems utilize a high-strengt synthetic fabric as a form for casting large units by filling with sand or mortar. Within these geotextile systems a distinction can be made between: bags, mattresses, tubes, containers and inclined curtains. All of which can be filled with sand or mortar. Some examples are shown in Figure 9.Mattresses are mainly applied as slope and bed protection. Bags are also suitable for slope protection and retaining walls or toe protection but the main application is the construction of groynes, perched beaches and offshore breakwaters. The tubes and containers are mainly applicable for construction of groynes, perched beaches and (offshore) breakwaters, and as bunds for reclamation works (Figure 10). They can form an individual structure in accordance with some functional requirements for the project but also they can be used complementary to the artificial beach nourishment to increase its lifetime. Especially for creating the perched beaches the sand tubes can be an ideal, low-cost solution for constructing the submerged sill.



a) Geotube as a breakwater   b) BEROSIN system (inclined curtain) as bed protection

Figure 9. Examples of application of geosystems

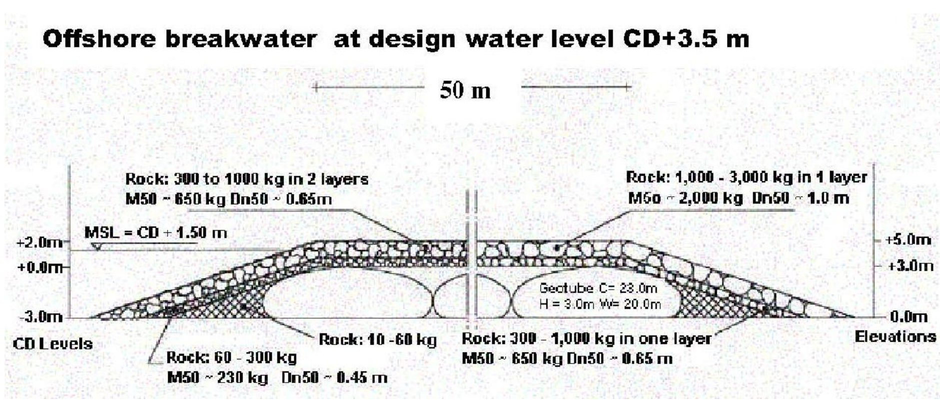


Figure10. Example of reef structure composed with geotubes [4]; http://geotecassociates.com

They can also be used to store and isolate contaminated materials from harbour dredging, and/or to use these units as bunds for reclamation works.

An interesting application for shore erosion control is the geocurtain known under the name BEROSIN (Figure 9b). The BEROSIN curtain is a flexible structure made of various woven geotextiles, which after placing by divers near the shore and anchoring to the bed catches the sand transported by currents and waves providing accretion on a shore and preventing the erosion. The horizontal curtain (sheet) can be easily spread (at proper sea conditions) by a small workboat and two divers. The upper (shore-side) edge, equipped with some depth-compensated floaters, should be properly anchored at the projected line. The sea-side edge is kept in position by the workboat. By ballasting some of the outside pockets at the lower edge with sand or other materials and with help of divers, the lower edge is sinking to the required position. The proper choice of permeability of geotextile creates the proper conditions for sedimentation of suspended sediment in front/or under the curtain and at the same time allowing the water to flow out without creating too high forces on the curtain and thus, on the anchors. In case of Pilot project at the coast of Vlieland (NL), some of the horizontal curtains placed in the intertidal zone have provided a growth of a beach/foreshore of 0.5 to 1.0 m within a week while others within a few weeks [2]. These geocurtains can also be applied for construction of submerged sills and reefs.

In the past, the design of geotextile systems for various coastal applications was based mostly on rather vague experience than on the general valid calculation methods. However, the increased demand in recent years for reliable design methods for protective structures have led to the application of new materials and systems (including geotextile systems) and to research concerning the design of these systems. Contrary to research on rock and concrete units, there has been no systematic research on the design and stability of geotextile systems. However, past and recent research in The Netherlands, USA, Germany and in some other countries on a number of selected geotextile products has provided some useful results which can be of use in preparing a set of preliminary design guidelines for the geotextile systems under current and wave attack [2]. The results from the recent, large scale tests, with large geobags, can be found on the website: http://sun1.rrzn.uni-hannover.de/fzk/e5/projects/dune_prot_0.html, [13].

The main (large) fill-containing geosystems (geobags, geotubes and geocontainers filled with sand or mortar) and their design aspects are discussed [2]. For more detailed information on these and other coastal protection systems and measures applied nowadays throughout the world, together with recommendations and guidelines, the reader will be guided to the relevant manuals and publications.

4. Conclusions

There is a number of alternative systems for coastal protection [14] [15]. Offshore breakwaters and reefs can be permanently submerged, permanently exposed or inter-tidal. In each case, the depth of the structure, its size and its position relative to the shoreline determine the coastal protection level provided by the structure. To reduce the cost some alternative solutions using geosystems can be considered. The actual understanding of the functional design of these structures needs further improvement but may be just adequate for these structures to be considered as serious alternatives for coastal protection.

It is hoped that this information will be of some aid to designers looking for new sources, which are considering these kinds of structure and improving their designs. However, much more mathematical and experimental work is still to be done. Systematic (international) monitoring of realised projects (including failure cases) and evaluation of the prototype and laboratory data may provide useful information for verification purposes and further improvement of design methods.

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Biography

Krystian Pilarczyk received the MSc from the Technical University of Gdansk in Poland in 1964. Former Manager R&D of the Hydraulic Engineering Institute of Public Works Dpt. in Delft, Netherlands. His research interests include research and design in the field of hydraulic and coastal engineering, including dikes, revetments and geosystems. Involved in activities in China and Vietnam. Retired in 2005 and actually working as a private consultant.