Geosynthetics: Applications, Design and Construction, De Groot, Den Hoedt & Termaat (eds)
© 1996 Balkema, Rotterdam. ISBN 90 5410 836 3

Geosystems in hydraulic and coastal engineering – An overview

Krystian W. Pilarczyk
Rijkswaterstaat, Road and Hydraulic Engineering Division, Delft, Netherlands

ABSTRACT: Geosystems has gained popularity in recent years because of their simplicity in placement and constructability, cost effectiveness and their minimum impact on the environment. An overview is given on application of the existing geosynthetic systems in hydraulic and coastal engineering.

1 INTRODUCTION

Various structures/systems can be of use in coastal engineering, from traditional rubble or concrete systems to more novel methods as geosystems and others. 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 works and their maintenance continues to rise. The shortage of naturl rock in certain geographical regions can also be a reason for looking to other materials.

The geotextile systems as bags, mattresses, tubes and containers filled with sand or mortar, and artificial seaweed and geotextile curtains, can be a good and mostly cheaper alternative for more traditional materials/systems as rock, concrete units or asphalt. 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 coastal protection and coastal structures in developing countries. The main obstacle in their application is however the lack of proper design criteria. An overview is given on application of the existing geosystems and reference is made to the design criteria.

2 SYSTEMS AND APPLICATIONS

Geotextile systems utilize a high strengt synthetic fabric as a form for casting large units by filling by sand or mortar, or as curtains collecting sand. At this moment there is a relative large number of products of this type on the markt provided by some specialistic companies all over the world.

The following types and applications of geosynthetic systems can be distinguised:

1. Closed forms/units filled with sand, gravel or mortar: bags, mattresses, tubes, containers
2. Open-matting bags filled with stone or asphalt
3. Geotextile forms/moulds sand-filled structures
4. Geosynthetic sheets for dune reinforcement
5. Geotextile curtains for shore erosion control
6. Artificial seaweed mainly for scour prevention
7. Silt fences with various applications (pollution)
8. Geocells for surface (slope) erosion control
9. Geocomposite mats for drainage/erosion control
10 Traditional applications as geotextile filters
11 Water- or air-filled dams
12 Other (unclassified) systems (bearer for blockmats, temporary slope protection, landfill covers, cabling, pins, pipes, connections).

More detailed informations on these systems is given in (Pilarczyk, 1995) and in other references.

2.1 *Geosynthetic forms*

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 construction of groyns, perched beaches and offshore breakwaters.

The tubes and containers are mainly applicable for construction of groyns, perched beaches and offshore breakwaters. They can form an individual structure conform some functional requirements for the project but also they can be used comple-

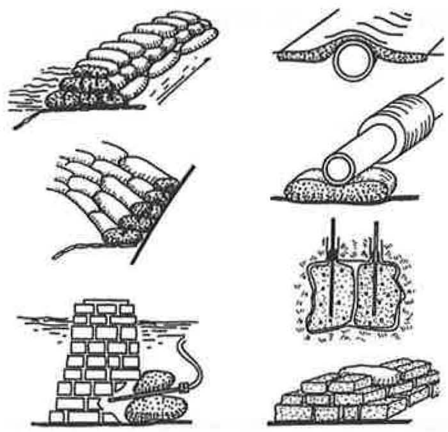

Fig. 1 Application of bags

mentary with the artificial beach nourishment to increase its lifetime. Especially for creating the perched beaches the sand bags and/or sand tubes can be an ideal (often low-cost) solution for constructing the submerged sill (with a low wave loading).

Some coastal engineering concepts are shown in Figure 2. Underwater breakwaters and sills (purched beaches) are not easy to construct with traditional materials. In this respect (sand)tubes, although based on the same principle, are more advanced even by comparison with sandbags, which are only 1.0 to 5.0 m^3 in capacity and are time-consuming as concerns both manufacturing and installation while hydraulic filling of tubes provides a few hunderds m^3 of sand in few hours.

The sand-filled bags and/or tubes can be of use for constructing of groyns. Up till now there is no reliable design methods concerning the functioning of groyns. When the groyne will work satisfactorily such groyne can be strengthend additionally (if necessary) to get a permanent function. If not, the groyne can be easily demolished. In general, the sand-filled structure can be used as a temporary structures to learn the natural interactions/responses, or as the permanent structures at locations with relatively low wave attack (H<1.5m), or as submerged structures where direct wave forces are reduced by submergence. The units (if necessary) can be interconnected by bars or by creating a special interlocking shape.

These systems can also be applied in hydraulic/river engineering for constructing of spurdikes, guide dams, revetments, bottom groins, bottom protection, etc. (Figure 3).

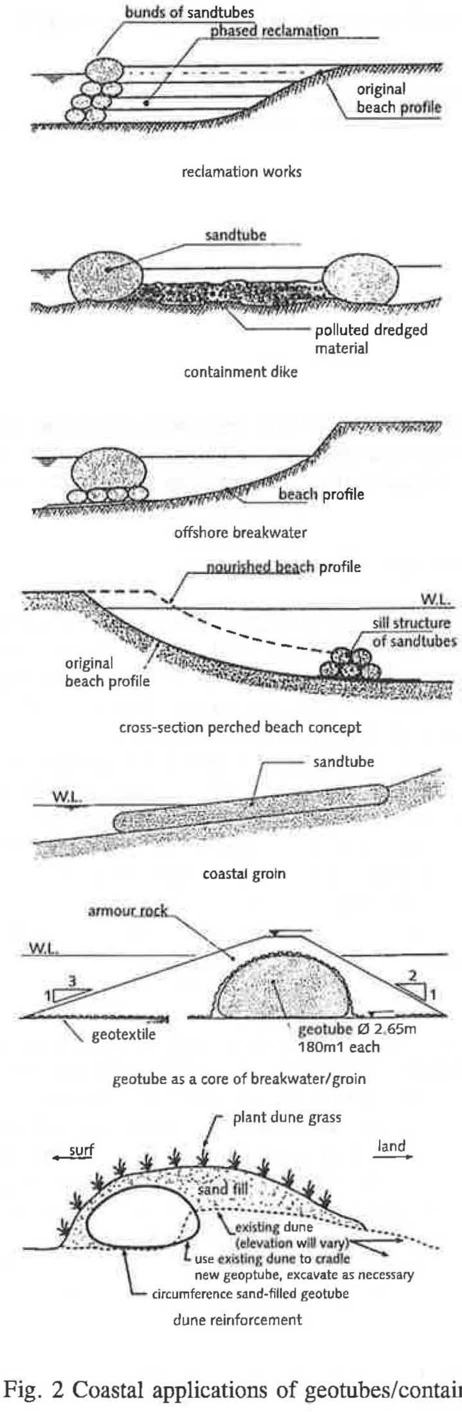

Fig. 2 Coastal applications of geotubes/containers

As other possible applications can be mentioned: containment dikes for storage of (contaminated)

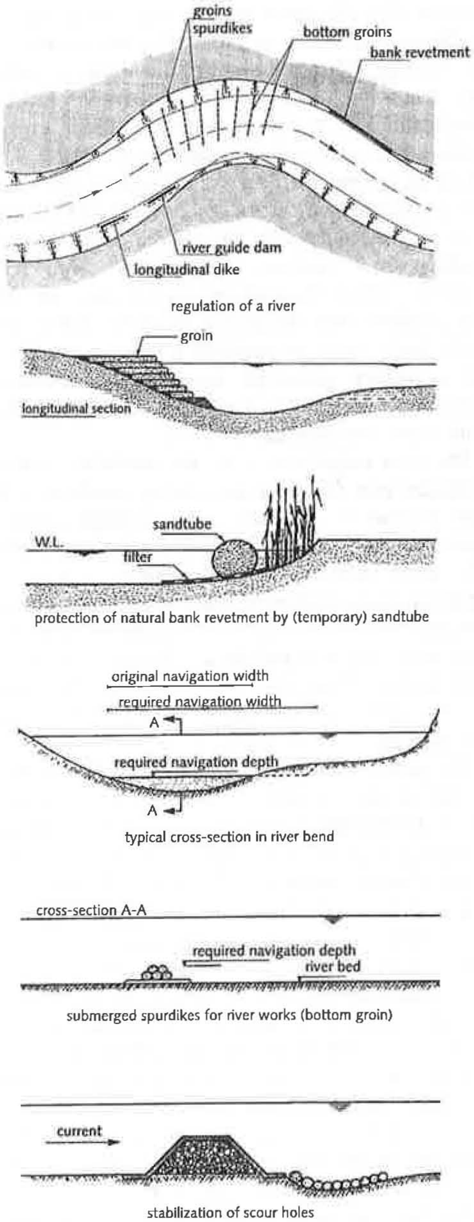

Fig. 3 River applications of geotubes/containers

dredged material, dike or dune reinforcement, moulds for artificial sand structures, etc.

The main advantages of these systems in comparison with more traditional methods (rock, prefabricated concrete units, blockmats, asphalt, etc.) are: a reduction in work volume, a reduction in execu-

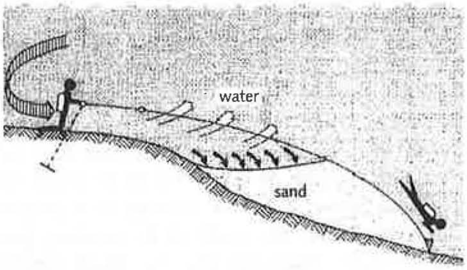

Fig.4 Application of geocurtains (BEROSIN)

tion time, a reduction in cost, a use of local materials, a low-skilled labour and (mostly) locally available equipment.

That means that in most, not too extreme cases/-conditions the werk can be done by a local contractor under supervision of the specialistic experts/company.

2.2 *Geocurtains*

There are a number of various applications of geocurtains, i.e. silt- and/or pollution curtains, guiding screens for sediment control in rivers and harbours, fences for surface erosion control, etc. Information on these systems can be found in references.

An interesting application for shore erosion control is the geocurtain known under the name BEROSIN (Fig. 4).

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 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. It was also recognized that the sheets (curtains) can be easily damaged in vicinity of rock due to abrasion (one curtain was connected to the existing rock groyne). On the other hand, the heads of the existing groynes were badly damaged and the beach between the groynes was eroded during the storms while the area protected by the curtains remainded in proper condition.

It seems that this system can provide a low-cost measure for steering of the morfological processes. However, more prototype experiments in various wave climate are needed before the final conclusions on the effectiveness and durability of this system in various design conditions can be drawn.

The most recent development concerns the application of a number of (anchored) floating screens (grids), placed in a certain pattern along the sea bed (Huygens et al, 1995). However, the first in site experiment has failed because of high wave induced forces and resulting anchorage problems.

2.3 *Artificial seaweed*

The field observations provided that in some coastal areas the natural seaweed plays an important role in retaining sand along the coastlines due to the reduction of the shear stresses exerted by currents and waves on the seabed. This fact was the base of the idea to produce and apply the artificial seaweed for erosion control.

The first users of artificial fibres for erosion control and/or to prevent marine scouring date back to the 60-ies (England, Denmark, Netherlands). The artificial seaweed was composed on polypropylene tape (having a specific gravity of less than one), 3 to 10 mm wide, connected edge to edge to form a continuous serrated sheet. In some cases dozens of tapes were bundled together to form individual tufts of seaweed. Fronds varied from 1 to 2 m in length. In the Netherlands, research on artificial seaweed has been conducted in cooperation with the Shell Plastics Laboratory, Nicolon Geotextiles Company and the Rijkswaterstaat (Dutch Public Works Dpt.), (Bakker et al, 1972).

The unproper anchorage was the main reason of the failures with this system .

The experience from US and European projects indicate that the artificial seaweed can be successfully applied for scour prevention around the legs of offshore platforms and around offshore pipelines when the anchorage is designed properly. Applications of artificial seaweed to beach erosion control were till now less successful. There were often no discernable differences between the shoreline protected with artificial seaweed and adjacent unprotected shorelines. The materials appear to be inadequate to survive moderate to high wave activity. One of the main reason for that was again the problem with anchoring (Rogers, 1987). Due to the high forces of breaking waves in a surf zone the necessary anchorage needs special expensive measures which makes this system less competitive with more conventional solutions.

The past experience with the artificial seaweed indicates that the most promissing application for this product is prevention of localized scour at offshore structures (platforms, pipelines, etc.). The wave induced currents are there of a limited strength (less problems with proper anchorage), because of larger depths no problem with UV-resistance, and less problems with effect of fouling and debris. That also explains why the recent developments and applications are related (limited) to that area.

The product which actually successfully operates on the markt for offshore applications has a form of a underwater artificial sea grass field/mats (developed in 80-ies), and is known as Seabed Scour Control System (SSCS, 1995). Based on the artificial seaweed concept of "arrested sedimentation" SSCS system (mat) suffers none of the drawbacks of similar previous systems. It has superb positional stability, it is not prone to phylloplankton colonisation, it requires no special tools or skills for installation and it actually serves to enhance its own effectiveness and that of other conventional sea defence forms.

The functioning principles are straight-forward; buoyant fronds floating upright from the seabed act to reduce seabed and near-seabed current velocities, encouraging the deposition of transported (eroded) seabed material. In conjunction with this action, at relatively shallow water the fronds also interfere with wave-induced orbital forces, effectively causing waves to break early and thus reducing the impact on threatend shorelines, breakwaters, etc.

This technique employs chemically inert materials to create a flexible barrier to retard the flow of water. The SSCS scour control mats are retained on the seabed by anchores hydraulically driven to

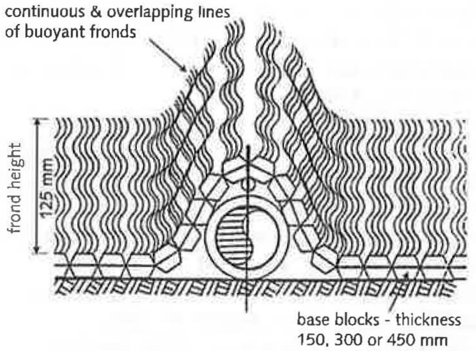

Fig. 5 SSCS frond flexiform mattress

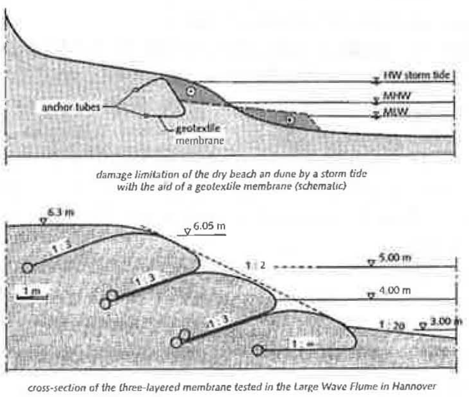

Fig. 6 Geosynthetics as dune reinforcement

a depth of 1 m. The system has been designed and tested for stability in current velocities in exess of 10 knots (> 0.5 m/s).

The flexible fronds-mat can also be incorporated into flexible concrete block mats to provide added effectiveness in stability and in wave dissipation. The main applications are in protecting fixed offshore platforms, mobile rigs and pipelines from the effects of scour.

2.4 *Dune reinforcement*

A new concept for protection of the dune areas against erosion during stormsurges is applied recently in Sylt, Germany (Dette and Raudkivi, 1994).

The geotextile sheet/membrane serves to restrain the sand grains during the drainage periods (after wave up-rush) and to prevent the undercutting. The main requirement, apart from required tensile strength, weathering and abrasion properties, is that it must be enable free flow of water, i.e. it must be more permeable than the sand. This is achieved by using an "opening size" of geotextile of about d_{65} of the sand. During the wave impacts the wave forces are taken by the sandgrains and the geotextile is stressed only by the through flow of water. The pressure waves attenuate in sand very rapidly due to the air in the voids and in the water. Consequently, any liquefaction of sand is confined to the immediate vicinity of the sand face.

A system of geotextile membranes as shown in Fig. 6 was tested in the Large Wave Flume in Hannover with waves up to 1.3 m. The deformations of the installed membrane were generally less than 10 cm.

About 2 km of such a membrane (two layers) were installed as hurricane protection 1992/93 in Fiji and 300 m in three layers in a dune in front of a building at the dune's edge on Sylt 1991. Both have performed according to expectations.

3 CONCLUSIONS

The geotextile systems can be a good and mostly cheaper alternative for more traditional materials/systems. These new systems were applied successfully in number of countries and they deserve to be applied on a larger scale.

In the past the design of these systems was mostly based on rather vague experience than on the general valid calculation methods. Actually, more proper design rules have been established based on some scale investigations and experience from realized projects. The existing research and design rules have been reviewed in (Pilarczyk, 1995).

However, more research, especially concerning the large scale tests and evaluation of performance of already realized projects, is still needed.

The technologies related to geotextile systems have been utilized extensively in Europe, Northern America, Mexico, Japan and Australia, producing often successful installations but only few technical details. Some manufacturers and contractors are inclined to protect know-how to preserve market advantages. Therefore, to effectively commercialize these technologies it is necessary to uncover the technical details. Technically the methodologies have shown to be feasible but there are design and constructibility uncertainties that still must be addressed.

A number of weak points of above reviewed systems can be omitted when the actual knowledge/experience will be applied in the design and technological improving of these systems including such aspects as fabric choice, fabric coating, filling method, installation techniques, stability criteria, and life-time.

The intention of this literature search is to uncover, as far as possible, the technical informations on these systems and make them available for the potential users. It will help to make a proper choice for specific problems/projects and it will stimulate the further developments in this field.

There are more applications of geosynthetic (geotextile) systems in coastal engineering than those mentioned above. It is going too far in the scope of this paper to review all of them. However, the main other applications can be found in the references.

There is a rapid development in the field of geotextiles and geotextile systems and there is always a certain time gap between new developments and publishing that in specialistic books. Therefore, it is recommended to follow the professional literature on this subject (Journal of Geotextiles and Geomembranes, Geotextiles Congresses, Coastal Engineering Congresses, etc.) and manufacturer's brochures for updating the present knowledge.

REFERENCES/BIBLIOGRAPHY

Ahrends, J., 1976, Wave Attenuation by Artificial Seaweed, Miscellaneous Papers, No. 76-9, CERC, US Army Corps of Engineers, Fort Belvoir.

AKZO, 1991, Armater, Enkamat, Company Publi cations, Arnhem, the Netherlands.

Amstrong, J.M. and C.L. Kureth, 1979, Some observations on the Longard tube as a coastalerosion protection structure, ASCE, Coastal Structures '79.

Anwar, H.O., 1967, Inflatable Dams, J. Hydraulics Division, ASCE, HY 3, May.

Bakker, W.T. et al, 1972, Artificial Seaweed: coastal and submarine pipeline protection studies with stretched polypropylene foam strands, Shell Plastic Laboratory, Delft, the Netherlands.

BEROSIN/Bureau van der Hidde, 1995, Product information, P.O. Box. 299, 8860 AG Harlingen, Netherlands.

Bogossian, F., R.T. Smith, J.C. Vertimatti and O. Yazbek, 1982, Continuous retaining dikes by means of geotextiles, Proc. 2nd Intern. Conf. on Geotextiles, Las Vegas.

Brian, E.W. and Dowse, P., 1979, Hydrostatically supported sand coastal structures, Coastal Structures '79, ASCE.

Davis, G.A., D.J. Hanslow, K. Hibbert and P. Nielsen, 1992, Gravity drainage: a new method of beach stabilisation through drainage of the watertable, Proc. 23rd ICCE, Venice.

Delft Hydraulics Laboratory, 1973, Artificial weed as bed protection, Report M 1162.

Delft Hydraulics Laboratory, 1973, Breakwater of concrete filled hoses, Report M 1085.

Delft Hydraulics Laboratory, 1975, Artificial Islands in the Beaufort-sea: M 1271 part III, comparison of stability of shore protection with gabions and sand sausages (2-dim.); M 1271 part V, stability of shore protection with sand sausages on circular island (3-dim.).

Delft Hydraulics Laboratory/Delft Soil Mechanics Laboratory, 1983, Stability of ProFix sand filled mattresses under wave action, Report of model investigation, R 1903.

Delft Hydraulics/Nicolon, 1994, Stability of break waters constructed with Geotubes or Geocontainers, Two-dimensional model tests, Report on the model investigation, H2029.

den Hoedt, G., Metz, H.E., Voskamp, W., 1987, Cost-effective building of breakwaters using geotextiles, 2nd Int. Conf. on Coastal and Port Engineering in Developing Countries, Beijing.

den Hoedt, G., Metz, H.E., Veltman, M. and Voskamp, W., 1987, Cost-effective reduction of sedimentation and maintenance dredging using geotextiele flow diversion screens, 2nd Int. Conf. on Coastal and Port Engineering in Developing countries, Beijing, China, Vol. II.

Dette, H.H. and Raudkivi, A.J., 1994, Dune Protection, Inter. Symposium "WAVES '94", Vancouver, Canada (see also, 24th ICCE, Kobe.

Deron Austin of Jessup, 1992, Steep slope protection using geocells, Geosynthetics World, 4/5

Foreman J.F., 1986, Generalized monitoring of SEASCAPE installation at Cape Hatteras Light--house, North Carolina, Miscell. Paper CERC-86-2, US Army Corps of Eng., Vicksburg.

Gadd, P.E., 1988, Sand bag slope protection: design construction and performance, Arctic Coastal Processes and Slope Protection Design, ASCE.

Gutman, L., 1979, Low-cost shoreline protection in Massachusetts, Coastal Structures '79.

Hall, C.D., 1992, The contemporary approach to the role of vegetation in erosion control, Geosynthetics World, April/May.

Hendrikse, C., 1995, Geocontainers; report test programma (prototype), Van Oord ACZ - Nicolon, the Netherlands.

Huygens, M., de Wachter, D., Verhoeven, R., Himpe, J., Buyck, S. and Wens, F., (1994), Underwater screens for shore protection, Symposium WAVES, Vancouver, Canada.

Huygens, M., de Wachter, D., Verhoeven, R., Himpe, J., Buyck, S., Wens, F., de Putter, B. and de Wolf, P., 1995, Model simulation of the impact of underwater screens on shore protection, PIANC Bulletin No. 86.

Hydraulics Resarch, 1984, A Review of Novel Shore Protection Methods, Volume 2 - Sand or mortar-filled fabric bags, by J.M. Motyka and J. Welsby, Wallingford, England.

Italian Public Works, 1992, Coasts, Harbours and Lagoons Protection Works.

Jackson, L.A., 1987, Evaluation of sand filled geotextile groyne constructed on the Gold Coast, Australia, Proc. 8th Australian Conf. on Coastal & Ocean Engng., Launceston.

Jacobs B.K. and Nobuhisa Kobayashi, 1983, Sand bag stability and wave runup on bench slopes, University of Delaware, Dpt. of Civil Engineering, Research Report No. CE-83-36, July.

Kato, M. and Hamanaka, K., 1993, Analytical and Experimental Study of Characteristics of Textile Sheets Structure, 11th Australasian Conference on Coastal and Ocean Engineering.

Kazimierowicz, K., 1994, Simple Analysis of Deformation of Sand-Sausages, 5thInter. Conf. on Geotextiles, Geomembranes and Related Products, Singapore.

Kobayashi N. and B.K. Jacobs, 1985a, Stability of armor units on composite slopes, ASCE, Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 111, No. 5, September.

Kobayashi N. and B.K. Jacobs, 1985b, Experimental study on sandbag stability and runup, ASCE, Proc. Coastal Zone '85, Vol.2, pp.1612.

Lamberton, B.A.,(1983), Fabric-formed revetment technology opens new engineering opportunities, Geotechnical Fabrics Report.

Lamberton, B.A., 1983, Fabric forming for under water concrete, Coastal Structures'83.

Lamberton, B.A., 1989, Fabric forms for concrete, Concrete International, December.

Linear Composites, 1986, Erosion Control Systems, ICI Fibres, Product info., North Yorkshire, UK.

Longard, 1985, Flexible sand-filled tubes used for constructing underwater breakwaters in coast protection plans, Company publication.

Nicolon Corporation, 1985, Artificial Seaweed Protects the Seabed, Estuaries and Submerged Pipelines, Product literature, the Netherlands.

Nicolon, 1994, Product info. and personal commu nications.

Perrier, H., 1986, Use of soil-filled synthetic pillows for erosion protection, Proc. 3rd Intern. Conf. on Geotextiles, Vienna.

PIANC, 1992, Guidelines for the design and construction of flexible revetments incorporating geotextiles in marine environment, Brussels, Belgium.

Pilarczyk, K.W., 1990, Coastal Protection, A.A. Balkema Publ., Rotterdam.

Pilarczyk, K.W., 1994, 1995, Novel systems in coastal engineering; geotextile systems and other methods, Rijkswaterstaat, Delft, the Netherlands

Pilarczyk, K.W. and M. K. Breteler, 1994, Desig ning of revetments incorporating geotextiles, 5th Int. Conf. on geotextiles, Geomembranes and Related Products, Singapore.

Pildysh M. and K. Wilson, 1983, Cooling ponds lined with fabric-formed concrete, Concrete International, September.

Porraz, M., 1976, "Textile Forms Slash Costs of Coastal Zone Structures", Ocean Industry Magazine, October 1976. pp. 61 - 64.

Porraz, M., José A. Maza and Ricardo Medina, 1979, Mortar-filled containers, Lab and Ocean Experience, Coastal Structures'79.

Rankilor, P.R., 1989, The reduction of soil erosion by pre-formed systems, The International Erosion Control Association, Symposium on Soil Erosion and Its Control.

Ray, R., 1977, A laboratory study of the stability of sand-filled nylon bag breakwater structures, Miscellaneous report no. 77-4, US Army Corps of Engineers.

Rijkswaterstaat - Nicolon, 1988, Bed protection, Old Meuse, by means of geocontainers, report VXT/HJ88.168, Publication of Nicolon B.V.

River and Harbour Laboratory, 1976, Scour prevention system, Hydraulic flume study, SINTEF, Trondheim, Norway.

Rogers, Spencer M. Jr. 1987, Artificial Seaweed for Erosion Control, Shore and Beach, Vol. 55, No. 1.

Saathoff,F. and Witte J., 1994, Use of geotextile containers for stabilizing the scour embankments at the Eidersperrwerk (in German), Deutsche Textvorlage für Geosynthetics World.

Sarti, G. and J. Larsen, 1983, Underwater filling of Longard tubes, Coastal Structure '79.

Silvester, R., 1986, Use of grout-filled sausages in coastal structures, ASCE, J. Waterway, Port Coastal and Ocean Engineering, Vol. 112, No. 1, January.

Silvester, R., 1990, Flexible Membrane Units for Breakwaters, in 'Handbook of Coastal and Ocean Engineering, John B. Herbich, ed., Vol. 1, pp. 921-938.

Sprague, C.J. and M.M. Koutsourais, 1992, Fabric formed concrete revetment systems, published in 'Geosynthetics in Filtration, Drainage and Erosion Control, R.M. Koerner, ed., Elsevier Applied Science (reprinted from Geotextiles and Geomembranes, V. 11, No. 4-6).

Sprague, C.J., 1994, Dredged material filled geotextile containers, prepared for the US Army Corps of Engineers, Vicksburg, MS.

SSCS, (1995), Eliminate the High Cost of Scour: an engineering solution to seabed erosion, Product information of Seabed Scour Control Systems Limited, Great Yarmouth, England.

Stark K.P. and Johnston, A.J., 1985, A marine building material of the future, 7th Australasian Conference.

Stephenson, R.W., 1982, A study of soil-filled synthetic fabric "Pillows" for erosion protection, 2nd Inter. Conf. on Geotextiles, Las Vegas, U.S.A.

SUT Seminar, 1980, Scour prevention techniques around offshore structures, One-day Seminar on 16 December 1980, Society for Underwater Technology, London.

Taiyo Kogyo Corporation, 1994, Design of Silt Protector, Company Publication, Tokyo, Japan.

ten Hoopen, H. (1976), Recent Applications of Artificial Seaweed in the Netherlands, Coastal Engineering Conference, ASCE, New York.

Tutuarima, W.H. and W. van Wijk, 1984, ProFix mattresses - an alternative erosion control system, in Flexible Armoured Revetments incorporating geotextiles, Thomas Telford, UK.

Tetra Tech, 1982, Longard Tube Applications Manual(Aldek A-S Longard), Tetra tech, U.S.A.

US Army, 1981, Low Cost Shore Protection, Final report on the Shoreline Erosion Control Demonstration Program (Section 54), Published by the US Army Corps of Engineers.

van Santvoort, G./Veldhuijzen van Zanten, R./, 1994, Geotextiles and Geomembranes in Civil Engineering: a handbook, A.A. Balkema Publ., Rotterdam.

Voskamp, W., 1983, Construction of steep slopes of sand under water using synthetic fiber screens, 2nd Int. Offshore Mechanics and Arctic Engineering Symposium, Houston, Texas.

Watson, R., 1985, A note on shape of flexible dams, J. Hydraulic Research, Vol. 23, No. 2.