

# INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



*This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:*

<https://www.issmge.org/publications/online-library>

*This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.*

*The paper was published in the proceedings of the 17<sup>th</sup> African Regional Conference on Soil Mechanics and Geotechnical Engineering and was edited by Prof. Sw Jacobsz. The conference was held in Cape Town, South Africa, on October 07-09 2019.*

# Geosynthetic tubes as load bearing structural components of coastal infrastructure

G. Dirks

*HUESKER Synthetic, Cape Town, South Africa*

M. Wilke

*HUESKER Synthetic, Gescher, Germany*

**ABSTRACT:** The use of geosynthetic materials as a component of coastal structures is common in modern coastal engineering. The durability of application specific geosynthetics have made them ideal for use in harsh marine environments since the 1960's, as elements in the construction of large scale coastal protection structures. In the past two decades, due to environmental constraints, there has been a shift towards the use of soft engineering solutions for coastal erosion prevention and beach protection. The use of geosynthetic sand filled tubes and bags initially became popular as temporary components in coastal protection works, however its durability has offered long term permanent coastal protection solutions. With its proven track record, these systems have not been exploited to their full potential. This paper investigates in particular, benefits of introducing a geosynthetic sand filled tube system; the types of engineered structures that can benefit from tube technology and the types of geosynthetics required in producing such tubes for this harsh application environment. It also considers the effects of loading on such structures and the influences on its long term durability.

## 1 INTRODUCTION

With a rise in demand for quality infrastructure establishment along coastlines of undeveloped countries, comes a demand for cost effective construction solutions. Geosynthetic sand filled tubes offer a cost effective and durable solution. Where local, readily available materials, such as sand that were previously deemed unsuitable on its own in this application, can now be used as an effective structural component in an engineered design. In the late 1960s and early 1970s, it was the hydraulic engineering sector which pushed forward the development of geotextiles and geosynthetics. The first ever sand-filled geotextile tubes were applied at the north German coast during this period, Erhinger & Snuis (1972). Sand filled geotextile tubes were first used in land reclamation applications acting as borders and outer boundaries of dykes, Newenka & Alexiew (2008). Early tube varieties had limited diameters. The tubes were made from simple woven geotextiles of limited tensile strength. Modern day textile engineering has provided several improvements in geotextiles used in tube applications. With modern knitted fabrics, textile strength can be applied where needed most and tensile strength orientation can be dictated. This opened several doors in terms of more intricate design possibilities with sand filled tubes. With improvements in geotextile tensile strength, tube filling efficiency

improved, which led to vastly improved tube diameters and thus significant improvements in construction economy. Improvements in textile durability, led to large scale design where sand filled tubes were used in revetments; groynes; artificial reefs and even the construction of permanent containment bunds for land reclamation. Sand-filled tube bunds were even used to create artificial islands, such as in Buenaventura, Columbia. A bund with a diameter of 350 m and a 3 m high boundary embankment was constructed from sand filled tubes (Fowler et al. 2002).

## 2 BACKGROUND TO THE PROBLEM AND CONCEPT OF SOLUTION

In the construction of a bunded area, be it for a temporary bund or a permanent structure such as an artificial reef or a groyne and in some cases load bearing examples of these. In selecting a construction method, traditional methods are always the first port of call. In bund construction this often involves a quality heavy grade nonwoven geotextile acting as a separation/filter layer at the base, followed by a non-cohesive fill material. Slopes are protected by Rip-Rap. This results in a heavy and stable structure able to resist and absorb energy from wave and current loads. In addition such structures are designed to bare the loads of construction traffic loads and long term operational

traffic loads. In regions where traditional construction methods might not be viable solutions due to the sparse availability of suitable quality construction materials. Often such materials have to be imported or hauled over long distances placing heavy burdens on already strained project budgets.

In such cases an alternative solution that could include the use of readily available construction materials would be welcomed. Even if the available material quality might be suboptimal, the synergistic end result fulfils and exceeds the final engineering requirements. Introducing sand-filled geosynthetic tubes.

### 3 DESIGN OF GEOSYNTHETIC TUBES

When considering the design geosynthetic tubes the following external and internal failure mechanisms must be taken into account. The external design refers to the stability of a sand-filled tube as a single monolithic element exposed to wave loads. The internal stability analysis focusses on the geotextile tube shell or rather the geotextile from which the tube is manufactured, as well as the fill material and the interaction between these two elements. As optimal filling of these tubes is a critical design factor, the degree of filling, is expressed as the ratio  $h/D$  of the filling height  $h$  and the nominal diameter (diameter of a perfectly shaped circle,  $D$ ) of the geosynthetic tube. This ratio has a significant influence on the tensile forces generated within the geotextile tube shell.

#### 3.1 Definition of the degree of filling

The degree of filling limits the possibility of internal sand migration inside the tube. Moreover it is a good indicator for the overall performance of a geotextile tube. Normally it also acts as a first indicator for the determination of a first indicative permissible filling height. Two approaches exist for the formulation of the filling degree: the one based on the height and the other based on the cross-sectional area.

##### 3.1.1 Degree of filling according to the height

The definition of the filling percentage based on the height according to the definition of Deltares & van Steeg, (2010) is described by the simple equation below:

$$p_h = \frac{h}{h_{100\%}} \quad (1)$$

With  $p_h$  = filling percentage based on the height [-];  $h$  = height of the tube after filling [m];  $h_{100\%}$  = height of the maximum filled tube (equal to the diameter of the tube) [m]

The degree of filling can also be expressed as a ratio between tube height and the theoretical diameter of the tube:

$$\text{Filling Ratio} := \frac{h}{D} \quad (2)$$

With  $h$  = the height of the tube after filling [m];  $D$  = the diameter of the 100% filled tube; cross-section is equal to a perfectly shaped circle [m]

#### 3.1.2 Degree of filling according to the cross-sectional area

The definition of the filling degree for geotextile container according to CUR (CUR 217, 2006) is:

$$f = \frac{4\pi A}{S^2} \quad (3)$$

With  $f$  = degree of filling [-];  $A$  = Cross-sectional area of the filled tube [m<sup>2</sup>];  $S$  = Circumference of the tube [m]

### 3.2 Internal stability analysis

#### 3.2.1 Tensile strength

By using the “Leshchinsky method” (Leshchinsky 1996), the usable tensile strength required by the tube fabric can be determined. The calculation program GeoCoPS 3.0 also follows this design guideline.

Figure 1 below shows the developing circumferential tensile forces generated in the tube shell (y-axis) depending on different tube diameters and the  $h/D$  ratio (x-axis). Please note, this graph is based on GeoCoPS calculations performed with only air surrounding the sand filled geosynthetic tube.

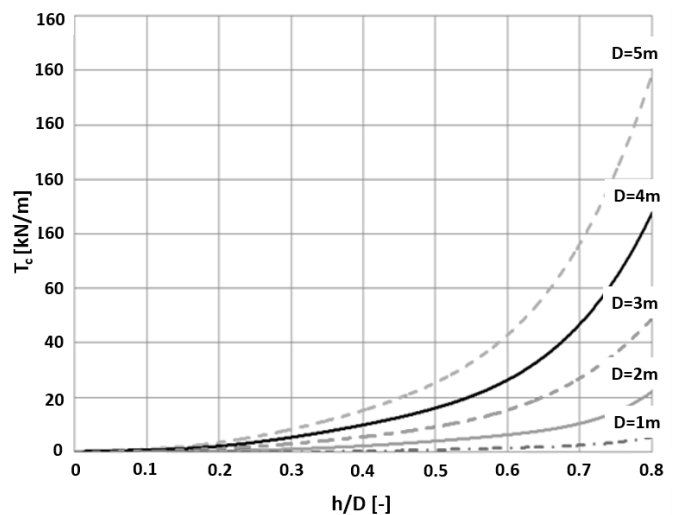


Figure 1. Theoretical circumferential tensile forces depending on filling ratio  $h/D$  for different tube diameters in the dry ( $\gamma = 14 \text{ kN/m}^3$ )

From Figure 1 above, it demonstrates that by increasing the tube diameter and thereby enlarging the filling height, the circumferential tensile forces increase almost exponentially (Wilke & Hangen 2012).

#### 3.2.2 Geotextile permissible opening size

The permissible opening size of the geotextile for the tube can be determined according to the CUR 217.

Also better known as the “sand tightness” of the geotextile for “geometrically tight geotextiles” has been developed for sands with  $D_{40} > 60 \mu\text{m}$ . As per GRI recommendation, the filling material of geo-synthetic tubes as coastal or riverine protection elements, should be a sand with a fines fraction not exceeding 15 % (GRI 1999). In case filling is done with a higher fine content, subsequent increased settlement could negatively impact on tube filling procedures. Hence this is not recommended.

Referring to the CUR document, the permissible opening size for current induced loads can be determined with the following two formulas from (CUR 217 2006):

$$O_{90} < 5 D_{10} C_u^{1/2} \quad (4)$$

With  $O_{90}$  = opening size which corresponds to the  $D_{90}$  of the soil passing the geotextile [mm];  $D_x$  = sieve size of the theoretical sieve with rectangular openings where x % of the grains of the sand passes through [mm];  $C_u$  = coefficient of uniformity [-] and:

$$O_{90} < 2 D_{90} \quad (5)$$

The uniformity coefficient  $C_u$  is defined as:

$$C_u < \frac{D_{60}}{D_{10}} \quad (6)$$

### 3.3 External stability analysis

In the external stability analysis of geosynthetic tubes several failure modes from external hydraulic forces such as current and wave actions are considered, and also geotechnical failure modes such as sliding and bearing capacity failures. A paper by Chris Lawson (Lawson 2008) gives an overview of these failure modes. The main focus of this paper is the stability of sand filled tubes under the influence of wave forces. Other foundation related failure mechanisms that are related (i.e. seepage, consolidation, bearing capacity and current induced loads were not considered in detail.

#### 3.3.1 Stability under wave loads according to CUR 217

Based on small-scale investigations and theoretical approaches (Pilarczyk 2000) the following stability criteria for geotextile tubes under wave attack has been developed (CUR 217 2006):

$$\frac{H_s}{\Delta_t D_k} \leq 1.0 \quad (7)$$

With  $H_s$  = significant wave height [m];  $\Delta_t$  = relative density [-];  $D_k$  = characteristic thickness of the geotextile tube [m];

$D_k = h$  (height of the geotextile tube) for wave attack perpendicular direction of the tube.

$D_k = L$  (length of the geotextile tube) for wave attack in longitudinal direction of the tube; max.  $L = 2h$ .

The advantage of this formulae is its simplicity. However, the disadvantage is, that the stability of a single tube is dependent on both tube height and width (Pilarczyk 2000). In recent work by van Steeg about geotextile stability (van Steeg 2008), he recommends to rather substitute the characteristic thickness  $D_k$  by the product of the width  $B$  times the height  $h$ . This approach takes both parameters into account.

#### 3.3.2 Stability under wave loads according to Deltares

According to observations in large scale physical model tests in the Deltares wave flume, the mode of failure in a geosynthetic tube on a rigid foundation was by sliding. Hence, a theoretical stability analysis based on the stability of rubble mound slopes against sliding led to the following stability formulae (van Steeg 2010):

$$\frac{H}{\Delta \sqrt{BD}} < \frac{\sqrt{\lambda}}{\varphi^2 (C_D + f C_L \lambda)} (f \cos \alpha \pm \sin \alpha) \quad (8)$$

With:

$H$  = wave height [m]

$B$  = (max.) width of tube [m]

$D$  = (max.) height of tube [m]

$\Delta$  = relative density [-]

$\lambda$  = ratio between  $B$  and  $D$  ( $\lambda = B/D$ ) [-]

$\varphi$  = wave velocity coefficient (Pilarczyk 2000):

Where  $\varphi \sim 1 - 1.5$  [-]

$C_D$  = drag coefficient [-]

$C_L$  = lift coefficient [-]

$f$  = friction coefficient [-]

$\alpha$  = slope angle [°]

This theoretically developed stability approach requires three large scale test derived input parameters ( $C_D$ ,  $C_L$  and  $\varphi$ ). This makes the practical application more difficult. Recio's research (Recio 2008) determined the drag and lift coefficients for geotextile bags in wave flume tests: The results were very wide spread. From information gathered from the Delateres tests, increasing the friction between the tube and the foundation has proven to be beneficial against sliding failures.

## 4 EXPERIENCE FROM PAST PROJECTS

The following projects give an idea of the possible applications where sand filled tubes can be used. Additional information can be found in Alexiew (2008) or Sobolewski (2011).



Figure 2. Aerial photograph of the project sites; Port Kuivizu and Port Salacgriva.

#### 4.1 Port Kuivizu, Baltic Sea, Latvia

This project is situated in the Baltic Sea in Latvia adjacent to a similar project where geosynthetic sand filled tubes were used successfully in land reclamation in a harbour construction (in Port Salacgriva).

The reconstruction of the mole at Port Kuivizu took place in 2007 / 2008. As an old fishing harbor, no maintenance had been done for more than 15 years to protect the harbor entrance. Wave action and ice loads severely damaged the heads of the pier structures. The intention was to re-open the nearby area for recreational purposes, thus the damaged piers in the harbor needed to be rebuilt. The requirement for heavy sheet-piling equipment and crane access to place the lighthouse, was an additional concern as there was no access to the pier heads, concern. A temporary access road needed to be constructed.

The solution consisted of placing geosynthetic tubes adjacent to the existing mole. The tubes are made from a high strength Polyester woven textile.

The tubes with nominal diameter of 3.5 m and final height of approximately 2.0 m were used as an outer bund. The maximum degree of filling based on the tube height and width was therefore  $f_{max} = 0.57$ . The geosynthetic tubes together with the existing mole would form a part of the pier core after the end of lighthouse construction. The void between the geosynthetic tube and the damaged pier was filled with stone 50 / 300 mm. After installation and filling, the tubes were protected with a heavy non-woven staple fibre geotextile. Thereafter covered with a stone blinding layer followed by armour stone (Rip-Rap). This method of construction provided two important advantages:

1. The tubes formed a continuous containment bund for the construction processes to follow. The filling of the void between the mole and geosynthetic tube could continue without any wave disturbance as the tubes protected the construction area.

2. Another benefit of using a geosynthetic tube system was to substitute the use of high volumes of rock armour, which required hauling over great distances at high cost. The tubes can be filled with sand sourced locally and filled by a dredger that was connected directly to the tubes via a floating flushing pipe system.

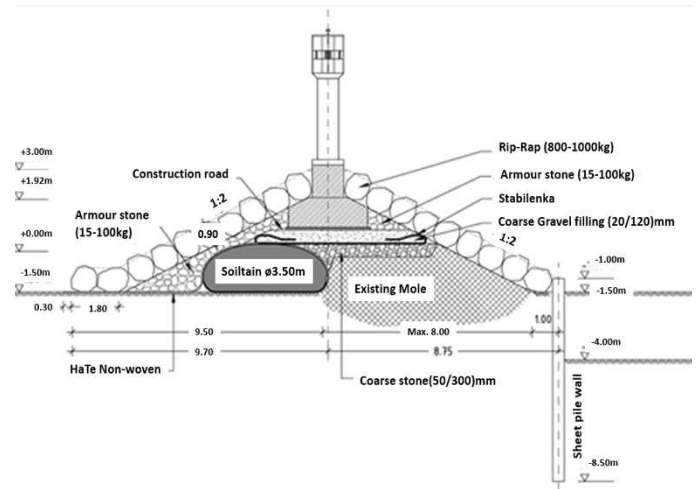


Figure 3. Cross-section of the reconstruction incorporating geosynthetic tubes at Port Kuivizu, Latvia, 2007/2008.

#### 4.2 San Vincenzo, Tyrrhenian Sea, Italy

The purpose of a geosynthetic tube is to fulfil its function over the design life of the structure. Therefore, the durability of the filled geosynthetic tube is critical. In order to prove the long-term performance of geosynthetic tubes and its assimilation with marine flora and fauna a research project was introduced in 2008, where a breakwater was constructed from a submerged geosynthetic tube. The experimental test section was constructed in front of the beach of San Vincenzo/ Italy. The University of Florence provides ongoing scientific research support and. The geosynthetic tube structure consists of a main tube with a circumference of 9.4 m (nominal diameter of 3.0 m), a scour apron made from woven geotextile and two anchoring tubes attached to either side of the apron keeping it in place. The filled tube exhibits a height of 1.6 m, corresponding to a filling ratio based on height of  $f = 0.53$ . A cross-section of the breakwater is shown below in Figure 4.

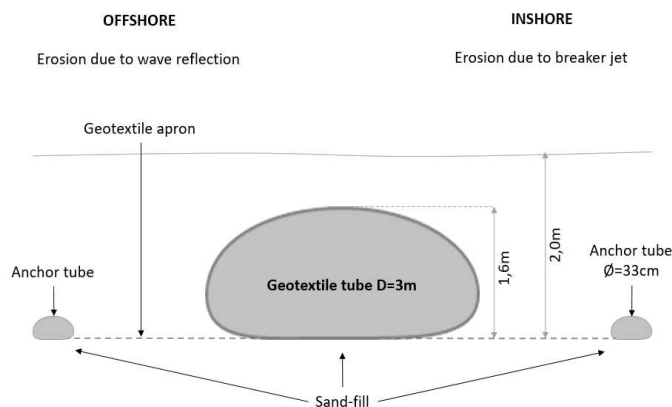


Figure 4. Cross-section of the tube installation in San Vincenzo (Aminti 2010)

A high strength Polyester woven geocomposite was used in the manufacture of the geosynthetic tube. As the tube will be exposed to wave action, sand abrasion and marine life, the geotextile needed to be robust and abrasion resistant.

Table 1 reviews three different geotextiles used in the scour apron test section: a geocomposite Non-woven PET + woven PET, a PP woven geotextile and a PET geocomposite), their material properties are also listed, and technical performances compared.

Table 1. Geotextile selections tested as scour apron fabric. (Aminti 2010)

Technical data	Geotextile A Hate® 175/175 DW A30	Geotextile B woven Hate® A20.606 SP	Geotextile C Hate® B600J
Constitutive material	non woven: PET woven: PET	PP	non woven: PP woven: PP
Unit weight UNI EN ISO 9864	non woven 300 g/m <sup>2</sup> geocomposite 900 g/m <sup>2</sup>	280 g/m <sup>2</sup>	600 g/m <sup>2</sup>
Tensile strength MD and CMD UNI EN ISO 103 19	≥ 175 KN/m	≥ 55 KN/m	≥ 20 KN/m
Elongation MD and CMD UNI EN ISO 103 19	≤ 14 % ≤ 14 %	15 % ± 4 % 11 % ± 3 %	< 20% < 20%
Characteristic opening size O <sub>90</sub> UNI EN ISO 12956	0.11 mm	270 µm	0.10 mm

As a control to assess the tube performance, different sections were constructed, one with a scour apron and another without a scour apron beneath the tube. The negative buoyancy of polyester (SG > 1.0), made installation of scour aprons made from PET geotextiles easier.

To track the performance of the tube and the development of marine life around the construction area, bathymetric surveys were carried out. Differential Global Positioning System (DGPS) was used for tracking movement in the cross-sectional and longitudinal elevation of the geosynthetic tubes.

With periodic diving inspections and the use of the DGPS equipment, the performance and the marine growth colonization process on the submerged geosynthetic tube breakwater could be effectively monitored. From records to date, the geosynthetic tube system performs very well.

The control sections where the scour apron have deliberately been left out were clearly affected by the toe scour, thus making the use of scour protection aprons a necessary requirement. In protected areas, post construction, no settlement in the tube structure was observed and structural alignment remained intact. The ability for marine life to adapt and adhere to the coarse geosynthetic tube fabric can clearly be observed (Fig. 5).

Further results on the continuing research program on this project can be followed (see Aminti 2010).



Figure 5. Geotextile tube surface 13 months after installation (Aminti 2010)

## 5 CONCLUSIONS

As high volume geotextile confined, sand filled structures the use of geosynthetic tubes offer a very cost effective and time efficient alternative to traditional coastal infrastructure protection and remediation projects. From the durable materials used to manufacture geosynthetic tubes, it is clear that it is highly resistant to construction damage during installation followed by subsequent exposure to cyclic wave loads as well as abrasion from a harsh coastal environment. In certain cases geosynthetic tubes can serve a lateral earth support function as a sand confinement system for land reclamation or infrastructure expansion projects. Its high performance under heavy loads from con-

struction traffic during installation and long term operational loads, prove that geosynthetic tubes are designed to last over extended periods of time in less favorable conditions.

## 6 REFERENCES

- Alexiew, N. 2008. Temporary bund of geosynthetics and tubes for bridge piers in the river Daugava, Riga. In *Proceedings of the 31<sup>th</sup> International Conference Coastal Engineering: 3818-3829*. ISBN 13-978-981-4277-40-2. Hamburg, Germany.
- Aminti, P. Mori, E. & Fantini, P. 2010. Submerged barrier for coastal protection application built in tubes with geosynthetics of big diameter in Tuscany - Italy. In *Proceedings of the 9th ICG: International Conference on Geosynthetics: 1235-1240*. ISBN 978-85-63456-00-7. Guarujá, Brazil.
- BAW (Bundesanstalt für Wasserbau; Federal Waterways Engineering and Research Institute). 1994. Guidelines for Testing Geotextiles for Navigable Waterways (RPG). Karlsruhe, Germany.
- Bogossian, F. Smith R.T. Vertematti, J.C. & Yazbek, O. 1982. Continuous Retaining Dikes by Means of Geotextiles. In *Proceedings of the Second International Conference on Geotextiles: 211-216*. Las Vegas, Nevada, USA.
- Cantré, S. 2008. Ein Beitrag zur Bemessung geotextiler Schläuche für die Entwässerung von Baggergut. Universität Rostock, Agrar- und Umweltwissenschaftliche Fakultät, Rostock, Germany. (In German). ISBN: 978-3-86009-032-9.
- CUR Bouw & Infra, Rijkswaterstaat Bouwdienst en Dienst Weg- en Waterbouwkunde, NGO Nederlandse Geotextilorganisatie 2006. Ontwerpen met Geotextile Zandelementen. CUR-publicatie 217, Stichting CUR, Gouda, The Netherlands. (In Dutch). ISBN 90-3760-083-2.
- Erhinger, H. F. Snuis, G. 1972. Kunststoffge webeschläuche im Küstenwasserbau, Wasser und Boden, Issue 1.
- Geosynthetic Confined Pressurized Slurry (GeoCoPS) Version 3.0, 1999-2007. ADAMA Engineering, Inc., The Horseshoe, Newark, Delaware, USA.
- Geosynthetic Research Institute (GRI). 1999. Installation of Geotextile Tubes used for Coastal or Riverine Structures. GRI Test Method GT 11, Folsom, PA 19033-1208, USA.
- Heibaum, M. 2002. Geosynthetic containers - a new field of application with nearly no limits. In *Proceedings of the 7th ICG: International Conference on Geosynthetics: 1013-1016*. ISBN 90-5809-523-1. Nice, France.
- Lawson, C.R. 2008. Geotextile containment for hydraulic and environmental engineering. *Geosynthetics International*. 15(6): 384-427.
- Leshchinsky, D. Leshchinsky, O. Ling, H.I. & Gilbert, P.A. 1996. Geosynthetic Tubes for Confining Pressurized Slurry: Some Design Aspects. *Journal of Geotechnical Engineering*. 122(8): 682-690.
- Pilarczyk, K.W. 2000. Geosynthetics and Geosystems in Hydraulic and Coastal Engineering. A.A. Balkema/Rotterdam/Brookfield, Rotterdam, The Netherlands. ISBN: 90-5809-302-6.
- Recio Molina, J.A. 2008. Effect of Deformation and Stability Formulae: Hydraulic Stability of Geotextile Sand Containers for Coastal Structures. Clausthal-Zellerfeld: Papierflieger, Germany. ISBN 978-3-89720-940-3.
- Sobolewski, J. Wilke, M. & Terauds, J. 2011. Geopipes filled with sand in marine and civil engineering. Dimensioning and practical examples. *Inżynieria Morska i Geotechnika*. 32(1): 34-43. (In Polish).
- Van Steeg, P. & Klein Breteler, M. 2008. *Large Scale Physical Model Tests on the Stability of Geocontainer*. Test report Deltares: Delft, The Netherlands.
- Van Steeg, P. & Vastenburg, E.W. 2010. *Large Scale Physical Model Tests on the Stability of Geotextile Tubes*. Test report Deltares: Delft, The Netherlands.
- Wilke, M. & Hangen, H. 2012. *Geosynthetic tubes as construction element for coastal protection works. Fundamental design aspects; Application possibilities and practical experience*.