Coast protection with SoilTain® tubes - Case study of sand dune protection in Rowy, Poland

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The paper is devoted to the issues of coastal protection using geosynthetic tubes filled with sand. It describes the technology of coastal improvement by SoilTain® tube *technology with a practical example of a dune protection on the beach in Rowy (Poland). The article presents assumptions taken in the design and the methodology of stability analysis. In addition it provides the results of measurements and verification of the design, details of the construction stages as well as the effect of a large storm three years after construction.*

1. Introduction

Coast protection has always been a very popular topic at conferences and trade meetings. The reason for this is the fact, that the sea constantly destroys beaches, posing at the same time, a threat to the nearby buildings. One of the examples is a gothic church in Trzęsacz near Szczecin (Poland), built at the turn of 15th and 16th century. Originally the church was located about 2 km from the coastline. Due to the effects of ongoing erosion, in 1870, the church was already on the edge of the cliff, but still intact (Photo 1). Today, however, there is only the south wall that is left (Photo 2). Attempts were made to protect the cliff, which, but unfortunately, these measures have not been completely successful. All Polish cities and villages located near the sea potentially face the same problem. Various kinds of protection technologies have been applied (eg. gabions, as in Trzęsacz), but with differing results – and can sometimes have a negative impact.

Photo 1. Church in Trzesacz; year 1870; (http://www.wybrzeze-rewalskie.pl/atrakcje/ruiny.htm)

Photo 2. Church wall in Trzesacz (photo Inora - 10.09.2015)

This article describes the technology of coastal protection by SoilTain® (geotextile tubes) with an example of dune protection on the beach in Rowy (Poland). The article also presents the assumptions of the project and the stability analysis. In addition, it demonstrates the results of measurements and verification of the design assumptions in practice.

2. Description of technology SoilTain® geotextile tubes

Technology with the use of SoilTain® geotextile tubes consists of installing a synthetic sleeve (also referred to as encasement, shell, casing or mantle) and filling it with granular material , provided in the form of slurry – a mixture of water and sand, e.g. from dredging. Due to the special structure of the composite material used for the geotextile tubes, the water drains through the pores of that encasement, and solid particles remain inside the sleeve. The final composite structure thus provides a stable protection element with substantial self-mass (Fig. 1). This technology has been applied in hydraulic engineering, for various applications. [6].

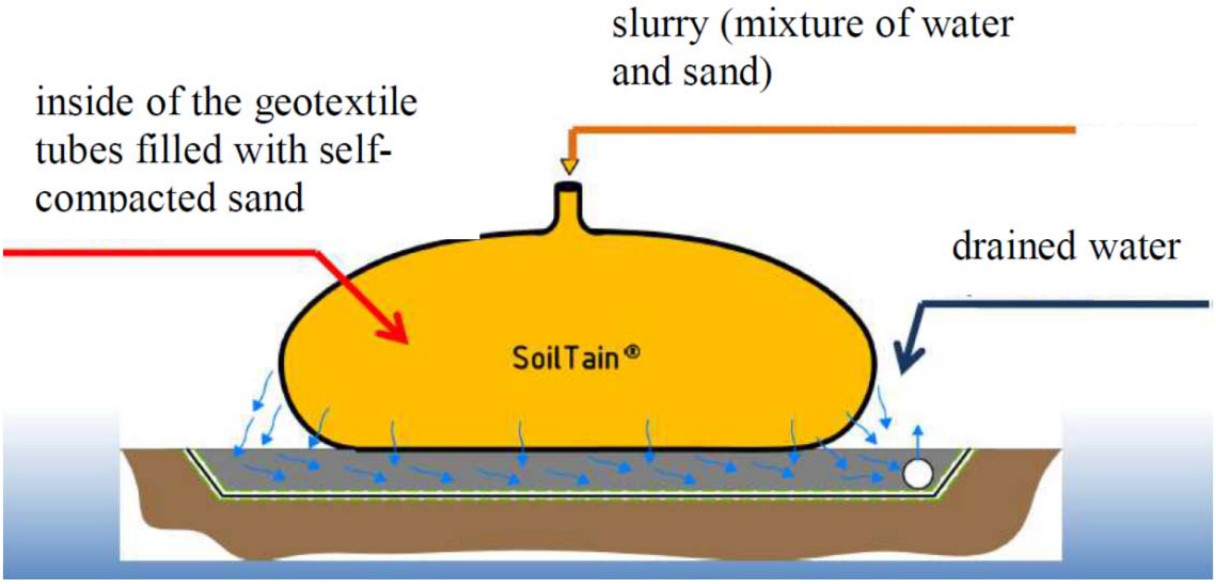

Fig. 1. SoilTain® geotextile tubes; general presentation of technology [6]

3. Design assumptions

The implementation of coast protection has been designed according to the current state of the art in this field. The calculations and analysis are performed in line with the ultimate limit state method, using specialist software, e.g. based on geotextile tube dimensioning methodology developed by Professor Dov Leshchinsky. On the basis of the GeoCoPS analysis (Fig. 2 and Fig. 3) the data obtained was, among others: target geometry, strength parameters, as well as ultimate and critical dimensions during the filling process. The determination of these parameters was necessary in order to fill the SoilTain® geotextile tube in Rowy. In accordance with the calculations, the following dimensions of the filled SoilTain® geotextile tube were specified: circumference = 9,5 m, width = 4,5 m, height = 1,9 m, length = 25 m.

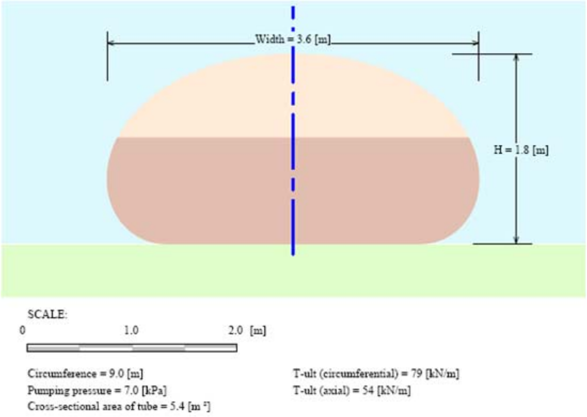

Fig. 2. GeoCoPS; tube shape in cross-section; two-layer filling

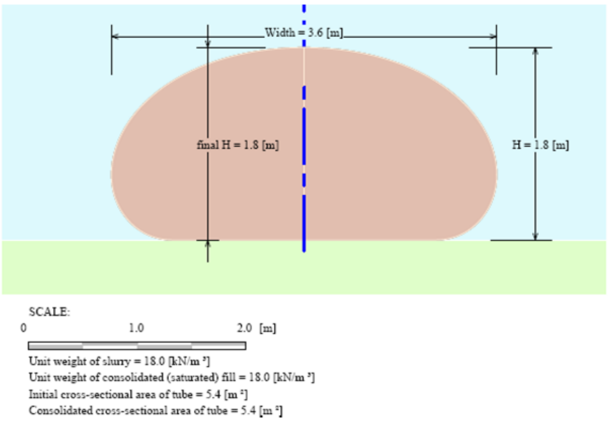

Fig. 3. GeoCoPS; tube shape in cross-section; one layer filing

During design all cases of possible failure mechanisms and changes of position of the geotextile tube (Fig 4) are checked. In the next step, appropriate materials were determined, and the ideal filling technology was specified.

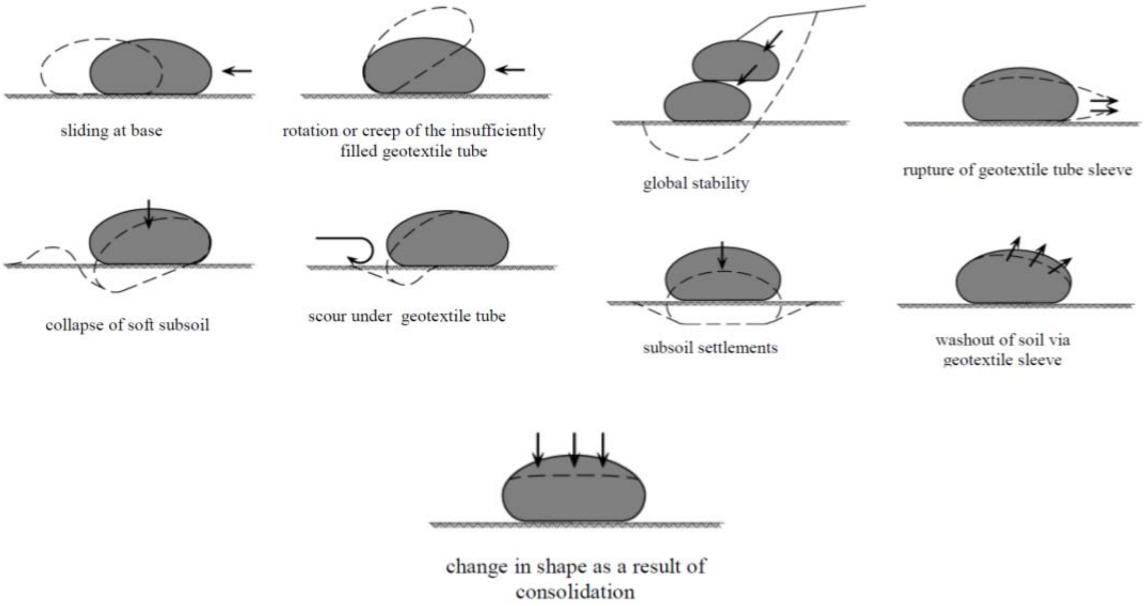

Fig. 4. Possible mechanisms of geotextile tube destruction [4]

The final design consisted of two tubes , one stacked on the other, as shown in Fig 5. To protect SoilTain® geotextile tubes against vandalism a thick non-woven around the tubes was installed, with a high resistance to puncture CBR = 3500 N. However, based on the author experience it is recommended that a higher specification of geotextile should be used for better protection, especially in tourist areas. The parameters of the SoilTain® geotextile sleeve are presented in Table 1. The foundation level of the SoilTain® geotextile tubes is set on the level of +1,00 m ASL. At this point, the author also recommends to found the tubes as low as possible in the given conditions.

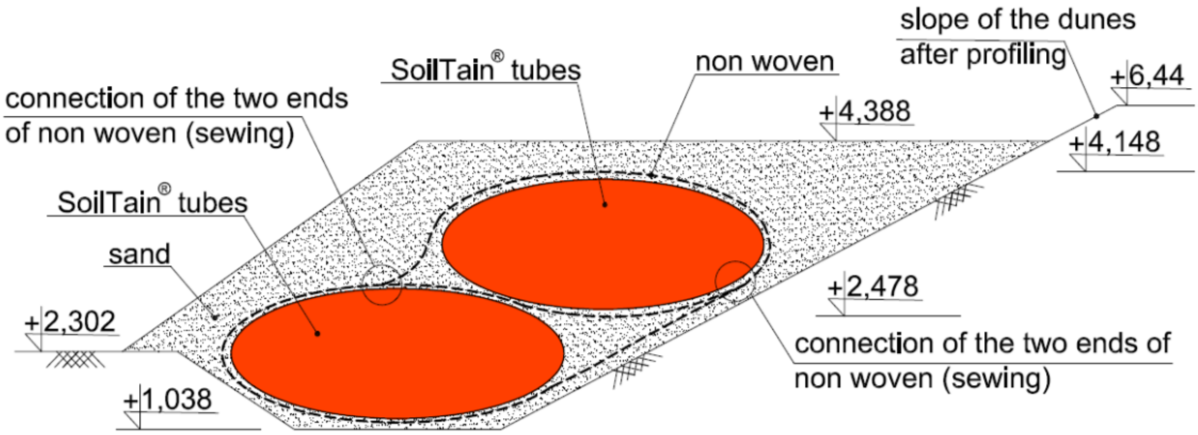

Fig. 5. Typical cross-section

Table 1. Technical data for sleeve made of geotextile tube SoilTain® 175/175 DW A30

Unit mass	900 g/m^2
Polymer: geotextile and nonwoven	Polyester
Specific gravity of the polymer	1.38 g/m^3
Ultimate tensile strength (UTS) of the geotextile tube sleeve acc. to EN ISO PN 10319: - longitudinal - crosswise	 ≥ 175 kN/m ≥ 175 kN/m
Elongation at break acc. to EN ISO PN 10319: - longitudinal - crosswise	 ≤ 12 % ≤ 12 %
Resistance to UV radiation, tensile strength after 4300 hours of exposure, acc. to EN ISO 12224	≥ 80 % UTS
Peel strength between the geotextile and nonwoven material acc. to EN ISO 13426	≥ 1000 N/m
Water permeability index acc. to EN ISO 11058	$13 \cdot 10^{-3}$ m/s
Characteristic opening size for geotextile tube sleeve, acc. to EN ISO 12956	0.10 mm

The process of filling tubes is a well-known process, and engineers can determine the most important technological parameters using specialized software. It is possible to estimate, following parameters: a tensile strength at a given filling height, a maximal width tube and a width tube at foundation level, the rate of filling, the pressure at the inlet, etc. If the project is determined by these parameters it is possible to control the filling process. The relationship between filling height and circumferential tensile force of the geotextile shell in Rowy is shown in Fig. 6

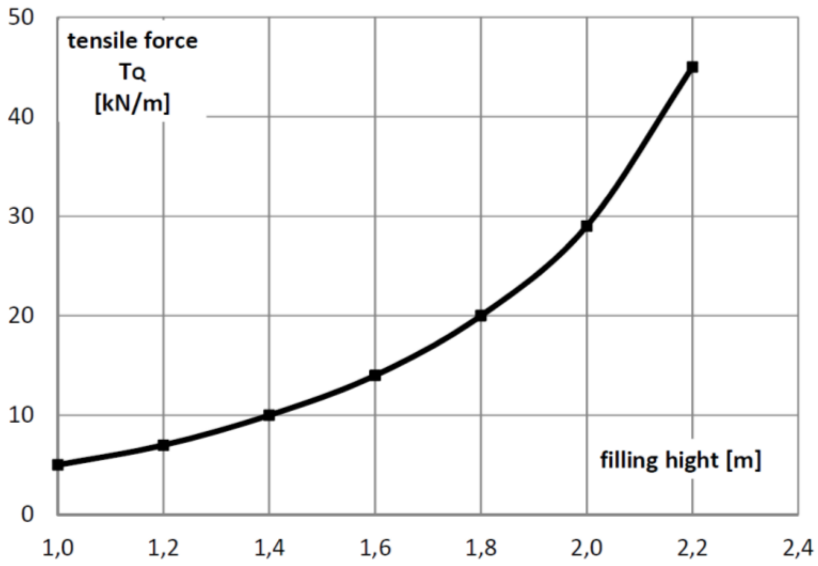

Fig. 5. Tensile force upon the filling height for a tube with the circumference of 9.5m [5].

One of the most important design issues is the dependence of the tensile force upon the filling height. From the Fig. 5 can be estimated, that at the height of 2.2 m the tensile force in the sleeve of $T_Q = 45$ kN/m will be mobilized. It is a critical value, because SoilTain® 175/175 DW A30 has the same characteristic value of long term tensile strength, R_k.

The characteristic values of long term tensile strength R_k can be estimated by reference to EBGEO 2010 [2] as follows:

$$R_k = \frac{R_{B,0,k}}{A_1 \times A_2 \times A_3 \times A_4 \times A_5} \qquad (1)$$

$$R_k = \frac{175}{1{,}33 \times 1{,}17 \times 2{,}5 \times 1{,}00 \times 1{,}00} = 45{,}0\ kN/m$$

where:

$R_{B,0,k}$ = UTS – ultimate tensile strength. Tensile strength examined in accordance with EN ISO PN 10319 on samples having the width of 20 cm, strained at the standard speed of 20 %/min, this being the value declared for the confidence level of 95%;
A_1 = 1.33 reduction factor for creep;
A_2 = 1.17 reduction factor for mechanical damage;

A_3 = 2.50 reduction factor for connections, joints;
A_4 = 1.00 reduction factor for environmental action;
A_5 = 1.00 reduction factor for material fatigue due to cyclic loading or dynamic loads.

The design value of tensile strength of the geotextile shell was estimated as below:

$$R_d = \frac{F_k}{\gamma_M} \qquad (2)$$

Where γ_M = factor for Material Safety (assumed for short time of construction works, 1,3, EBGEO 2010).

$$R_d = \frac{45{,}0}{1{,}3} = 34{,}60\ kN/m$$

The diagram on Fig. 5 thus allows the determination of the safe filling height: h_d = 2.10 m corresponding to the design value at tensile strength of R_d = 34.6 kN/m. Rupture of the geotextile sleeve may thus occur at the filling height of h_k = 2.20 m, so at the tensile force of F_k = 45 kN/m.

4. Construction stage

In the presented project 300 m^3 of sand from the beach was used for filling the two tubes. Of course, a small excavation that remained after the dredging, was quickly offset by the waves. Such a construction activity was only possible outside the tourist season. The sand, which was taken directly from the beach was tested in a laboratory to determine its properties. Characteristics of this sand is as follows: medium sand, U=1,5, d_{10} = 0,25 mm, γ = 16-18 kN/m^3 (at the bottom of tube to a height of 1.0 m γ = 18 kN/m^3, above 1,0 m level γ = 16 kN/m). Water permeability of this sand was estimated using well known empirical formulas as $k = 5 \cdot 10^{-4}$ m/s.

In accordance with the recommendations of DVWK [3], the water conductivity of geosynthetic materials installed and having contact with soil should be minimum fifty times more than the water permeability of the soil drained.

$$k_v \geq 50 \cdot k \qquad (3)$$

where:
k_v- water permeability of the geosynthetic material;
k - water permeability of the soil drained.

It is, however, a condition referring to long term functioning, e.g. drainage system made of geosynthetic material, for example the so-called French (trench) drainage systems, working under semi-hydrodynamic loads, thus in principle there is no need to adapt it a hundred percent for such works as short-term filling of geotextile tube. On the basis of projects executed so far, the author of this paper allows for slight departures from the condition described by formula (3); it is, however, strictly dependent upon the grain-size distribution (the grain size distribution curve, in particular) of the filling material, transported in the form of slurry to the geotextile tube interior.

For the case in Rowy there was:

$$\frac{k_v}{k} = \frac{1{,}3 \times 10^{-2}}{5 \times 10^{-4}} = 26 < 50$$

On the basis of observations from Rowy, it can be assumed that even with kv/k ≥ 25 filling process of SoilTain® geotextile tube will proceed satisfactorily.

A retention criteria calculation was also undertaken comparing the characteristic opening (pore) size in the geosynthetic material (geotextile tube sleeve), with reference to the grain size of the filling (sand) transported with water. In line with CUR recommendations [1], the condition of sand retention in the geotextile may be described by the formula (4)

$$O_{90} \leq 1{,}5 \cdot d_{10} \cdot \left(\frac{d_{60}}{d_{10}}\right)^{0.5} \qquad (4)$$

where;

d_{10}= equivalent diameter of grains, which together with smaller ones constitute 10 % of dry mass of sand;

d_{60}= equivalent diameter of grains, which together with smaller ones constitute 60 % of dry mass of sand;

O_{90}= opening (pore) size in the geotextile tube sleeve.

$$\boldsymbol{O_{90}} \leq 1{,}5 \cdot 0{,}25 \cdot \left(\frac{0{,}38}{0{,}25}\right)^{0{,}5} = \boldsymbol{0{,}462\ mm}$$

$$\boldsymbol{0{,}10\ mm} \quad < \quad 0{,}462\ mm$$

As it is evident from the calculations, characteristic opening (pore) size in the geosynthetic material (geotextile tube sleeve) in Rowy (O_{90} = 0,10 mm) was much smaller than the value calculated by CUR (O_{90} = 0,462 mm). Despite this, no clogging effects of the geotextile tube sleeve, were observed and water exiting the tube sleeve was transparent (clear).

Therefore, it can be concluded, that for washed beach sands the recommendation in DVWK [3] O_{90}(geosynthetic) = 0,80 · O_{90} does not necessarily always have to be achieved

The filling of the first row of SoilTain® geotextile tubes took place during good weather conditions (October) via a dredger operating in Rowy harbour . The second row of SoilTain®, was installed during bad weather conditions (November), using a pump connected with a hydraulic excavator (Photo 3). The second solution was more effective and cheaper. The water/sand slurry mix was transported into the tube by a pipeline (with diameter 150 mm). After filling both geotextile tubes (Photo 4), they were covered by a non-woven geotextile to protect the structure against vandalism (Photo 5). Next, the structure was covered with sand. In the last stage, the whole area was covered with additional brushwood and stones to create a natural landscape (Photo 6).

Photo 3. Dragflow® pump connected to Volvo® hydraulic excavator (photo Inora - 5.11.2012 -)

Photo 4. SoilTain® tubes after filling (photo Inora - 6.11.2012)

Photo 5. SoilTain® geotextile tubes covered by non-woven (photo Inora - 7.11.2012)

Photo 6. SoilTain® geotextile tube covered by sand brushwood and stones (photo Inora - 4.02.2013)

5. SoilTain® costal protection system three- years after construction

Within two years, the biggest test for the protective structure that was built in Rowy was a storm Xavier, that moved across Europe in December 2013. The effect of the storm on adjacent sections of the beach is shown in Photo 7 and Photo 8. After the storm the structure was only slightly exposed, the storm waves had washed away the sand that was covering the SoilTain® tubes but the structural core of tubes was untouched (Photo 9). Sand cover was quickly rebuilt, restoring the natural aesthetics of the area. The re-covering of the SoilTain tubes after a storm was assumed during the design phase and it was a part of planned maintenance works on the beach. After the retreat of the storm, the structure was again covered with sand and brushwood as shown in Photo 10.

Photo 7. The destruction of sand dunes on the beach after the passage of storm Xavier 27.12.2013 (photo UM Slupsk)

Photo 8. The destruction of sand dunes on the beach after the passage of storm Xavier - see bags filled with sand used as temporary protection (photo UM Slupsk - 27.12.2013)

Photo 9. SoilTain® geotextile tubes after storm Xavier, 27.12.2013 (photo UM Slupsk)

Photo 10. SoilTain® geotextile tubes after three year implementation (photo UM Slupsk - autumn 2015)

6. Summary

The protected system by SoilTain® geotextile tubes confirmed in practice the effectiveness of this solution. After the storm Xavier, and after almost two years of further operation, there is solid data about the behaviour of this construction under most extreme conditions. As can be seen from the observation, even after strong storm that occurred in late 2013 there was no visible movement or damage to the structure, only a local exposure of part of the structure, and this required limited reconstruction .

Summing up the costs of implementation and maintenance together with the fact that the structure does not interfere in the shape and view of the existing landscape, (it is part of the escarpment dunes), SoilTain® tubes have demonstrated very well that they provide a very cost effective measure for the protection of the coast.

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