"DESIGN OF DIKES WITH THE APPLICATION OF GEOTEXTILE TUBES"

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Abstract. Among geosynthetic materials, most of which perform reinforcement, drainage, or separation functions, a significant role is also played by geocomposite materials – materials that originated through suitable connection of two or more "basic" geosynthetic products, such as geogrids, nonwovens, or geotextiles. Thanks to that, the resulting materials may demonstrate several functions simultaneously, often performing indeed complex functions, and thus allowing construct very durable, economical and simple-to-execute structures. One of such specialist solutions are geotextile tubes, used – among other product – for protection of dikes. This paper has been devoted to structures of such geotextile tubes, presenting their advantages as well as the spectrum of applications. The methods of designing have also been discussed, with description of one of the applications on the dikes of Warta river provided.

Keywords: Technology of SoilTain® geotextile tubes used for protection of the dikes. Installation of geotextile tubes in dikes. Dimensioning of the geotextile tube. Advantages of application of geotextile tubes. Technical data for sleeve made of geotextile tube SoilTain®. Example of installation for flood protection. Monitoring of Dikes. Dredging of Rivers.

1. Description of the technology – SoilTain® geotextile tubes

Technology with the use of SoilTain® geotextile tubes consists of installing a synthetic sleeve (also referred to as casing or mantle) and filling it with grained material, provided in the form of slurry – a mixture of water and sand, e.g. from dredging. Thanks to the special structure of the composite material used for the geotextile tubes, the water is drained through pores of that coat, whereas solid particles remain inside the sleeve. The compact structure thus made constitutes a stable work of protection, with substantial own mass (Fig 1). This technology is used first of all in hydraulic engineering, for various applications. One of them is the building of cores of linear structures, such as dikes or protection of their toe.

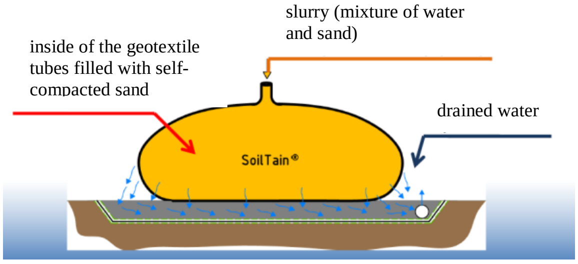

Fig 1. SoilTain® geotextile tubes; general description of technology

2. SoilTain® geotextile tubes used for construction and renovation of dikes

Geotextile tubes used for construction of new dikes, or reconstruction of existing ones are mainly installed as the core of the dike (Fig 2) or as a protective structure in the foot of the dike (Fig 3). Geotextile tubes used at the toe of the existing dike provide the possibility of enhancing its stability and making the filtration route longer – as a result improving the operational parameters without additional costly procedures. This aspect is extremely crucial where local leakages occur, in case of loosening soil at the foot of the dike, and local seeping, which threaten the safety of the structure over time.

Common for both applications, in comparison with traditional technologies used so far, is the economic as well as ecologic advantage. Geotextile tubes are usually filled with local material, obtained by dredging – e.g. from the river bottom. That cuts the financial burden to the contractor substantially indeed – and in the end that of investor – as obtaining the filling material from the river bottom is, as a rule, much cheaper than the cost of purchase and transport of material from a further distance. Such a way of obtaining the material also allows to limit road or railway transport, which does not only influence financial savings, but also positively affects reduction of natural environment degradation. That way, the emission of exhaust gases to atmosphere is reduced, traffic density gets lower, and destruction of local road surfaces is abated, the latter being a complaint often raised by municipalities and inhabitants that are in direct contact with any construction project.

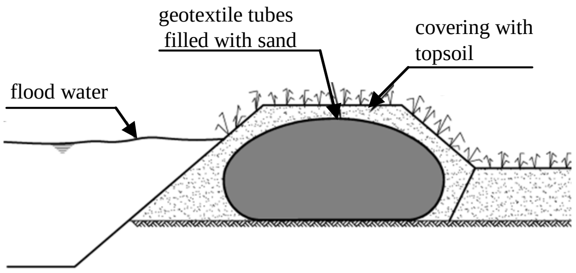

Fig 2. Core of dike using SoiTain® geotextile tube

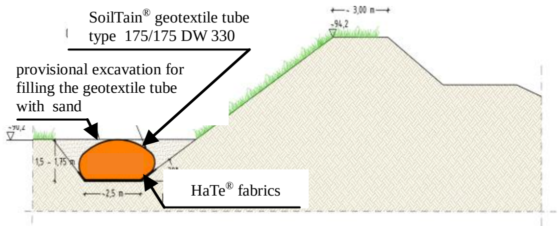

Fig 3. Improvement of the dike toe by use of SoiTain® geotextile tubes

3. Execution technology

The installation of geotextile tubes consists of slurrying up the mixture of sand and water to the inside of a sleeve (mantle) made of geosynthetic material and arranged in its final position. The sleeve should be at least provisionally anchored, in order to prevent uncontrolled sliding and change of position during filling. The water to sand ratio should vary in the range of 4 : 1 to 10 : 1 – this is strictly connected to the capacity of the equipment used. Filling takes place through one or several inlet funnels, attached by means of sewing to the geotextile tube in form of short sleeves enabling the connection of delivery pipes. The funnels usually used have the diameter of 25-50 cm, and are spaced every 5 - 10 m of the geotextile tube length. During filling of the geotextile tube, as well as later in the sedimentation process, sand gets separated from water, and – thanks to the properties of SoilTain® sleeve making up the geotextile tube, excess water flows out through properly selected pore of the material, leaving sand inside. The sand gets self-compacted thanks to water flow. At the same time, the strength parameters of the geotextile tube sleeve selected by calculations, namely the tensile strength, elongation, etc., allow to keep the sand in the closed "packaging" so developed. Having been filled with sand, the geotextile tube takes the target shape assumed in a given design, forming a durable and stable earth structure. Geotextile tubes filled with sand having the grain size bigger than 0.075 mm as a rule obtain a stable height (shape) during the first pumping already, (CUR 2006), (Sobolewski 2011). If sand with finer grain composition is applied, there may be a need to "fill up" the geotextile tube in yet another cycle, or even more than one. In such cases, it is possible to fill the geotextile tube in one pumping stage, if it is fill right away to a suitably increased height (h+Δh), in order to compensate for the sedimentation (Δh) caused by further self-compacting of sand after the pumping is finished. In the final phase of pumping, the geotextile tube takes in its transverse section the shape of an ellipse with flattened bottom, Fig 4.

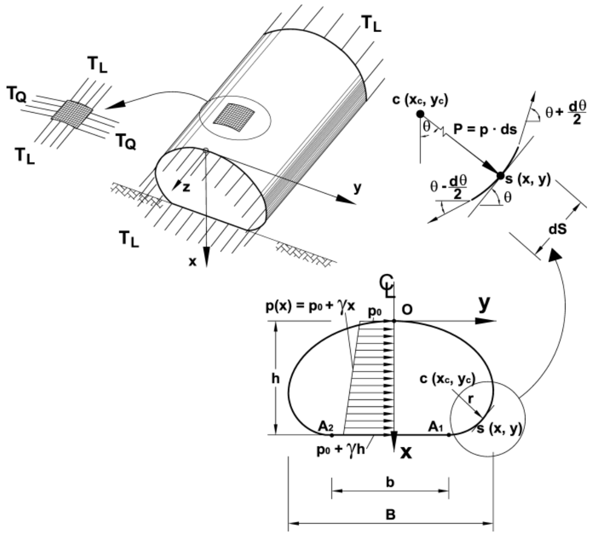

Fig 4. Cross-section of the geotextile tube, with notations, (Leshchinsky et al. 1996)

The input data needed for the design are as follows:

- height of the geotextile tube after filling, h;
- bulk density of the mixture, γ_M;
- circumference of the geotextile tube, L;
- theoretical diameter of the geotextile tube, D.

Resulting quantities are:

- pressure of the mixture at inlet to geotextile tube p_o,
- tensile ring force T_Q;
- longitudinal tensile force T_L.
- width of the geotextile tube after filling, B.

Standard and most often applied diameters of geotextile tubes used for construction and protection of dikes are: D = 3.0 – 5.0 m. They are usually pumped up to the height of h = (50% - 60%) of D. A greater filling degree of the geotextile tube h/D is connected with having to apply higher overpressure p_o, which causes an increase of tensile forces: T_Q and T_L. Then also the cost of manufacturing the geotextile tube increases. As regards the length of the geotextile tube, for logistic and practical reasons usually does not exceed 50 m. In practice, geotextile tubes having the length of L= 25 – 30 m are usually used, as with such dimensions the contractor may more accurately position the "smaller" geotextile tubes. It should be remembered that the length of the geotextile tube is strictly connected with its diameter and the capacity of the device transporting the sand and water mixture.

As results from the above, two parameters of the sleeve are of importance: tensile strength and water permeability. The geotextile tube sleeve should possess properly selected tensile strength in both directions, and suitable water permeability k_f, allowing for draining the water as soon as possible, retaining sand inside the geotextile tube at the same time. The geotextile tube coat should be able to retain the sand material, thus the pore size $O_{90,w}$ in the geosynthetic sleeve should secure stable filtration, without the possibility of soil escape. Hence the geotextile tube design should include, besides structural analysis of the sleeve, performed e.g. according to (CUR 2006, Leshchinsky 1996, Sobolewski 2011, Wiśniewski 2011), also the hydraulic dimensioning of the material used for sleeve, e.g. the guidelines contained in (DVWK 1992, Heibaum 2002).

4. Basic theoretical assumptions and design of geotextile tubes

The present knowledge concerning designing geotextile tubes is wide indeed. Calculations and analyses are performed in line with ultimate limit state method, using specialist software, e.g. based on geotextile tube dimensioning methodology developed by Professor Dove Leshchinsky, (Leshchinsky et al. 1996). That methodology allows to obtain strength parameters of the material from which the geotextile tube should be produced, its target geometry, as well as ultimate and critical dimensions during filling. Determination of those parameters is indispensable for correct and safe execution (filling) of geotextile tubes. Examples of such analyses are provided on Figures No. 5 and 6.

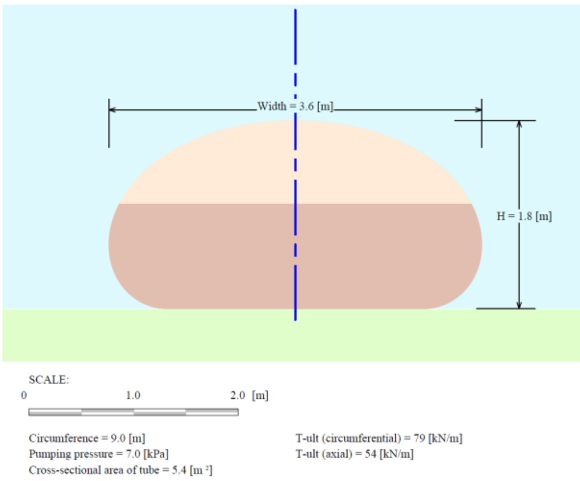

Fig 5. Example of geotextile tube dimensioning; cross-section; two-layer filling

The designing study also requires checking of all cases of possible destruction mechanisms, as well as all possible changes of position of the geotextile tube, shown on Fig No. 7.

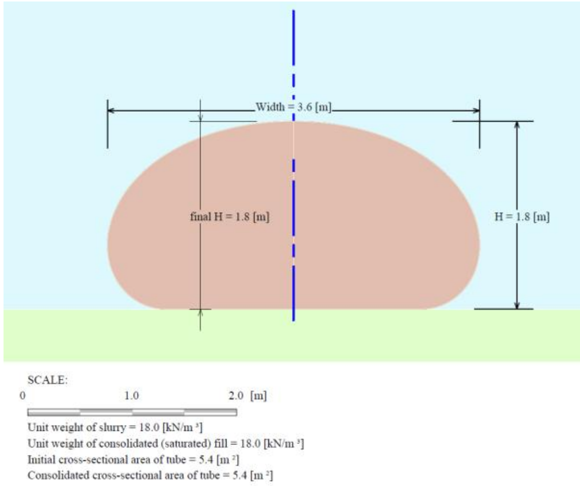

Fig 6. Example of geotextile tube dimensioning; cross-section; one layer filing, final filling condition

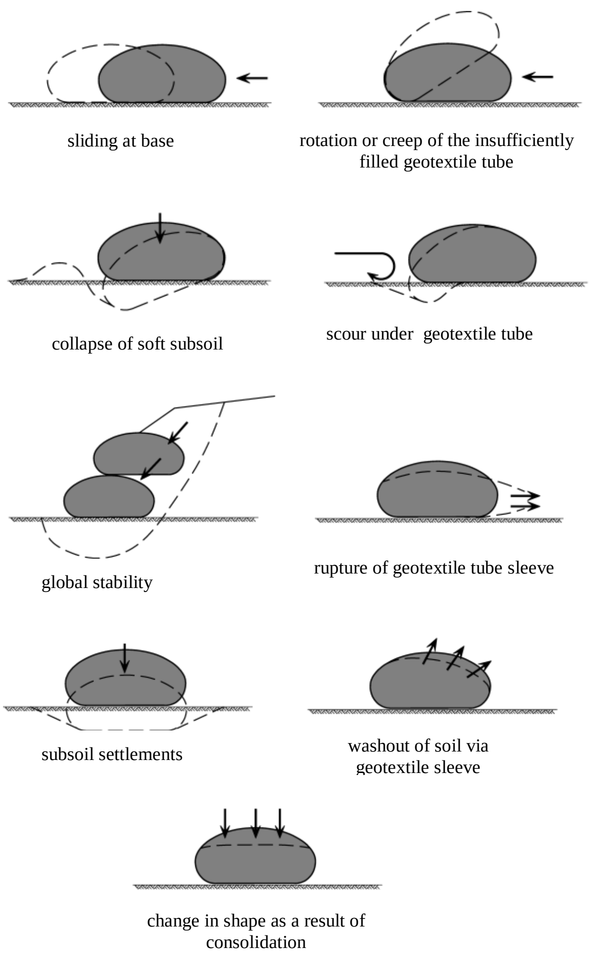

Fig 7. Possible mechanisms of geotextile tube destruction, (Lawson 2010)

Taking into account the experiences gathered so far, as well as the designing methods developed, filling of geotextile tubes is a well identified process, which is predictable and fairly easily designed technically. A contractor with suitable expert knowledge is able to define the most important technological parameters, namely is able to determine – with sufficient safety –

the following values: tensile forces for a given filling height, width of the geotextile tube and width of its support on subsoil, filling ratio, pressure of the slurry at inlet, etc. The knowledge of characteristics of those parameters enable ongoing control of the geotextile tube filling process. Results collected from large analyses enable defining dependencies, among the most crucial ones is the dependence between tensile forces (T_Q, T_L) in the geotextile coat and filling height of the tube, h, (Fig 8). The diagram provided on Figure No. 8, being an example, indicates that at the height of h_k = 2.2 m in the geotextile tube with the circumference of 9,5 m a tensile force of T_Q = 45 kN/m is mobilized, which in that case *de facto* is equal to the critical value R_k, as the geotextile sleeve may be ruptured by such a force.

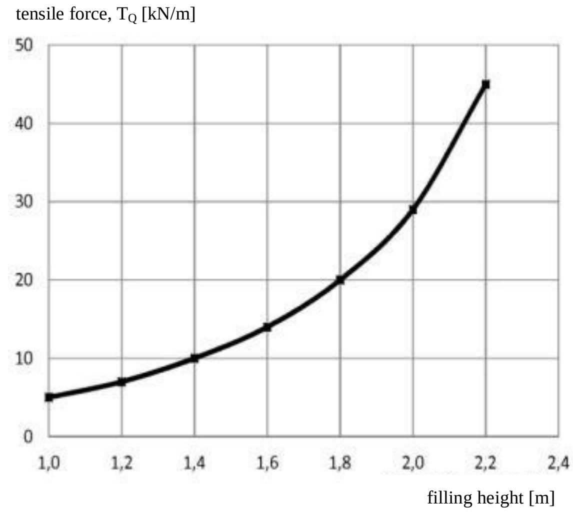

Fig 8. Example of the dependence of the tensile force upon the filling height for the circumference of 9.5m (Pilch 2013).

The critical value of the characteristic strength R_k, of sleeve could be defined as follow:

$$R_k = \frac{F_{o,k}}{A_1 \times A_2 \times A_3 \times A_4 \times A_5} \qquad (1)$$

$$R_k = \frac{175}{1{,}33 \times 1{,}17 \times 2{,}5 \times 1{,}00 \times 1{,}00}$$

$$R_k = 45{,}0 \text{ kN/m}$$

where:
$F_{o,k}$ = UTS – ultimate tensile strength. Tensile strength examined in accordance with EN ISO PN 10319 onsamples having the width of 20 cm, stretched with the standard speed of 20 %/min. It is a value declared for the confidence level of 95%;
R_k – long term characteristic strength
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 geotextile coat could be 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).

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

The diagram on Fig. No. 8 thus allows to determine the limit 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 sleeve may thus occur at the filling height of h_k = 2.20 m, so at the tensile force of R_k = 45 kN/m, which corresponds to the critical strength.

5. Materials for filling of geotextile tubes

As local filling material is usually used for the filling of geotextile tubes, particular attention should be paid to the process of water drainage and sand/soil retention inside the geotextile tube. Using geotextile tubes for the construction and protection of dikes, one usually collects material from the bottom of the river close by, however, one should be aware of the potential lack of homogeneity of its parameters. Depending on the scooping location, the material may differ e.g. in density, specific gravity, compactibility, water permeability, etc. It is not unusual to transport to the inside of the geotextile tube, together with the dregged material, odd materials or objects, different from the soil and found at the river bottom - pieces of glass, plastic, metal, or even rubbish or waste, which man's activity brought there. That creates additional threats that the contractor has to tackle. It is not only the system that collects and transports the excavated material that is at risk, but first of all the geotextile tube itself – this could generate ruptures or punctures of the sleeve during installation, as coarse or sharp objects were introduced to the geotextile tube.

6. Process of draining water from geotextile tube

In accordance with the recommendations of DVWK (DVWK 1992), the water conductivity of geosynthetic materials installed as having contact with soil should be minimum fifty times more than the water permeability of the soil drained.

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

where:
k_v- water permability of the geosynthetic material;
k - water permability 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 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 authors of this paper allow for slight departures from the condition described by formula (3); it is, however, strictly dependent upon the grain-size distribution (in particular the grain size distribution curve) of the filling material, transported in the form of slurry to the geotextile tube interior.

A parameter of supreme significance is also the characteristic opening (pore) size in the geosynthetic material (geotextile tube sleeve), in reference to the grain size of the filling (sand) transported with water. In line with CUR recommendations (CUR 2006), the condition of colmatation of the geotextile may be described by the formula (4).

$$O_{90} \leq 1{,}5 \times d_{10} \times \left(\frac{d_{60}}{d_{10}}\right)^{0{,}5} \qquad (4)$$

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.

7. Example of installation – flood protection on the left bank of the Warta in Koło

One of the examples of installing a geotextile tube at the base of dike in Poland is the flood protection on the left bank of the Warta in Koło, executed in 2011. The flood protection execution was made by a consortium consisting of the following companies: P.R. INORA Sp. z o.o. from Gliwice, Poland; Huesker Synthetic GmbH from Gescher, Germany; and WEMA from Dymaczewo Nowe near Poznan, under the auspices of the Chair of Structural Mechanics and Agricultural Civil Engineering (Katedra Mechaniki Budowli i Budownictwa Rolniczego) of the Faculty of Melioration and Environmental Engineering (Wydziała Melioracji i Inżynierii Środowiska) of Uniwersytet Przyrodniczy in Poznań, Poland.

The work consisted of protective measures for a section of existing dike, which at high water level in the Warta river revealed leakages, which resulted in water penetration in the dike base, and flooding the land in the vicinity. Such a situation also posed a threat for the safety of the entire dike structure. In order to improve the existing dike, a geotextile tube SoilTain® 175/175 DW A30 with the circumference of 9,0 m was installed at the dike base. The technical data of the geotextile tube sleeve are provided in Table 1.

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 geotextile tube has been installed at the toe of the dike, in an excavation having the bottom width of 3.0 m to 3.5 m, and the depth of 1.50 m to 1.75 m (Photo 1). Protective geotextile HaTe® 60.006 had been installed in the excavation base before the geotextile tube was placed. The geotextile had the task of protecting the bottom and slopes from washout during pumping the material into the geotextile tube. Before installing the SoilTain® geotextile tube sleeve, the measurement system by NeoStrain had been attached to it, which allows to measure – in real time – during the filling and possibly later, after installation, the elongation of material, (Photo 2). Results of the mesurement allowed to follow in on-line manner the tensile forces affecting the geotextile tube sleeve, which allowed to perform filling in a controlled manner and protected the geotextile tube sleeve against unexpected rupture. The geotextile tube was filled with a mixture of sand and water in the proportion of 1 : 7 (sand/water).

Photo 1 . Excavation at dike toe, prepared for installation of geotextile tube, Photo by Huesker

Photo 2 . Geotextile tube SoilTain® monitoring system by Neostrain®, Photo by Inora

Locally fine to medium river sand, suited for hydro-transport has been used for filling the geotextile tube. Excess water from the geotextile tube was drained through its structure and via one inlet funnel left open (photo No. 3). After the slurry pumping was completed and sand sedimentation in the geotextile tube took place, backfilling of the remaining excavation was performed at the toe of the dike, together with surface compaction and topsoil (humus) was laid, to restore the original state, (Photo 4).

8. Conclusion

The technology presented in this paper is a novel technology, in comparison with traditional solutions used so far in construction of new dikes and reconstruction of old dikes in Poland. It has been enjoying growing interest and popularity among investors, designers, and contractors. That is due to the big advantages offered by the application of those technologies in the construction and protection of dikes. As has been demonstrated in the paper, it enables the use of local material, usually much cheaper than traditionally used soil from extra excavation. Also the issues of ecology and logistics are not unimportant, as they finally translate also into the financial dimensions. From engineering perspective, the most crucial aspect is the accuracy of designing methods, as well as ease and accuracy of installation – as they allow to design and build safe and durable structures. The implementations made in Poland so far confirm that in practice.

Photo 3. Initial stage of filling the geotextile tube by sand and water mixture, Photo by Huesker

Photo 4. Backfilling of excavation with filled SoilTain® geotextile tube, Photo by WEMA

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