Advanced internal geosynthetic tube design

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ABSTRACT
The external tube design concerning wave loads and currents has been discussed in great detail for coastal protection tubes during the last years. A lot of research dealing with this topic has been carried out. The additional external design aspect, the geotechnical stability of the tube installation area, can be managed by conventional geotechnical analysis. Also the performance of dewatering tubes has been analyzed extensively. Yet, not covered in detail has been the internal tube design concerning two dominating aspects: The filling degree with a proper definition and the seam orientation. Especially the seam orientation and as a consequence the acting loads on the seams substantially influence the integral tube stability. In addition the type of seam being used affects the tube integrity. Based on seam type and the current tube fabrication methods a general design guidance for the tube seaming pattern has been derived. In combination with the filling degree a tube design factor called the Tube Performance Factor (TPF) has been developed in accordance with the "overall" strength-reduction material factor of the CUR guideline "Geosystems. Design Rules and Applications".

1. INTRODUCTION

1.1 Geotextile tubes

Geotextile tubes are long, approximately elliptic hydraulically in-situ filled geotextile containment elements. The tube containment shell consists of a permeable, woven geotextile which absorbs the occurring hoop stresses during filling and service life. Two main applications exist for geotextile tubes:

- Erosion protection and
- Dewatering of slurries.

Although the applications are completely different and the external impacts are not comparable, the method of production is basically the same. Adjacent sheets of fabric are connected by seams in order to form the tube body.

The base fabrics are different (permeability, tensile strength)

1.2 Tube designations and materials

In order to provide a common basis for tub For simplification of the

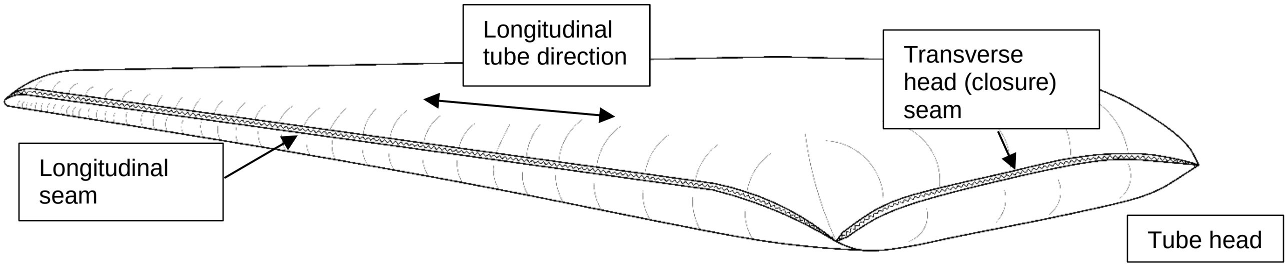

Figure 1. Schematic tube drawing with basic tube designations

1.3 Seam types

In the following a brief overview of seams used for tube fabrication is provided. Each of these seam types can be sewn with varying threads, stitches per unit length, or lines of stitching. All mentioned parameters influence the final seam strength. Final seam strength is hardly predictable and should be tested in advance by sample elements.

1.3.1 Prayer seam

1.3.2 J-Seam

1.3.3 Z-seams

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1.4 Seam strengths

Two ways of specifying the seam strength are present within the market:

- as absolute value in kN/m
- as relative value in %

The relative seam strength is defined as the relation of the initial tube material strength to the seam strength.

2. TUBE ASSEMBLY TYPES

There are several different seam pattern arrangements in order to assemble a tube. The seams are normally aligned in longitudinal tube direction or positioned perpendicular to the main tube axis. In some rare cases the seams can be orientated under an angle with regard to the tube main axis. Due to this the orientation of the fabric machine direction may deviate from the longitudinal tube axis. Main limiting factor for tube production is generally the overall weight of the final assembled element, relying on the unit weight of the used woven tube material and the tube dimensions. Some tube types have been designed for specific purposes, for example like the “flat head” tube (type VI) which is used for continuous transition in longitudinal direction between different tubes in erosion control projects. This tube is normally not used for dewatering applications, where the tube types I to IV are commonly utilized. The following six types could be identified, which are schematically illustrated in Figure 1.

2.1 “Pillow tube” (Type I)

This way of tube production is the basic one: two quadratic or rectangular geotextile sheets are connected together by a seam on each four sides. For this perimeter seam most frequently prayer or J-seams are used. The tube dimensions are restricted by the mill width (approximately 5 m) and length of the woven base material (approximately 200 m). Due to way of fabrication, generally the cross machine direction of the fabric is orientated in circumferential direction of the tube.

2.2 Longitudinal seams plus head seams (Type II)

This tube type can be considered as an enlarged “pillow tube”. By adding longitudinal sheets in the circumferential direction the possible tube width/circumference is increased. For connecting the sheets and closure of the tube head prayer or J-seams are used. Weft and warp orientation of the tube fabric is equal to tube type I.

2.3 Longitudinal seams plus transverse bottom seams (Type III)

The base fabric orientation concerning the longitudinal tube axis and the way of tube production including the kind of seams are comparable to the tube type II. The main difference is the location of the perpendicular closure seams. Instead of transverse heads seams the closure seams are located at the tube bottom.

2.4 Circumferential seams plus longitudinal bottom seam and head seams (Type IV)

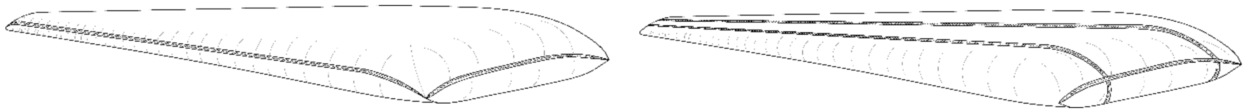
Several fabric sheets are connected by transversal/circumferential seams. The seams compromise predominantly Z-seams. The fabric weft is aligned in longitudinal tube direction. To form the tube body the warp ends of the sewn sheets are connected by one longitudinal seam which is located at the centerline of the tube bottom. Normally the tube heads are closed by transverse J-seams.

2.5 Helical seam pattern (Type V)

Instead of having several longitudinal seams, this tube type has a helical seam along the length. This also as spiral tube known type has disappeared in the market and is not commonly used.

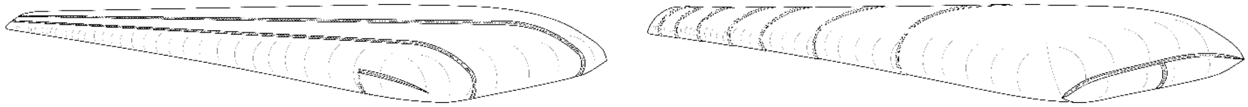
2.6 "Flat head tubes" (Type VI)

For this type the tube main body can be formed by tube type one to four. The transverse closure seams are substituted by lids, having the same cross-sectional shape as the inflated tube. Due to this method of closing the opposing ends an almost vertical tube head can be achieved.



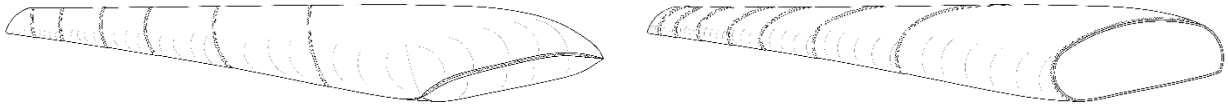
a) Schematic seam pattern arrangement of the "pillow tube" (Type I)

b) Schematic seam pattern arrangement of the tube with longitudinal and head seams (Type II)



c) Schematic seam pattern arrangement of the tube with longitudinal seams and transverse bottom seams (Type III)

d) Schematic seam pattern arrangement of the tube with circumferential seams, a longitudinal bottom seam and head seams (Type IV)



e) Schematic seam pattern arrangement of the tube with a helical seam (Type V)

f) Schematic seam pattern arrangement of the "flat head tube"; here with circumferential seams and longitudinal bottom seam (Type VI)

Figure 2. Schematic tube assembly illustrations showing the seam pattern

2.7 Tables

Number tables consecutively in order of appearance and locate them close to the first reference to them in the text. Refer to tables as Table 1, or Tables 1 and 2, in the body of the text. Avoid abbreviations in column headings (other than units).

Center and type the caption above the table to the same width as the table, and leave one (1) open line between the table caption and the table and between the table caption and the preceding text. Leave one (1) open line between the table and following text. Center the table on the page.

Use the following example for the format of table.

Table 1. Characteristics of tested soils.

Characteristics	Vancouver	Richmond
Organic matter (%)	0	1
Water content (%)[1]	40	60

Liquid limit (%)	22	44
Plastic limit (%)	15	18
Sand (%)	35	8
Silt (%)	45	44
Clay (%)	20	48

[1] water content of specimens after preparation for testing

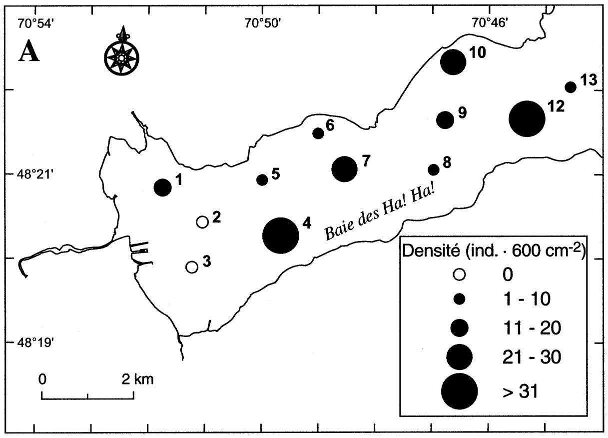


Figure 1. Spatial distribution of the macro-benthic organisms (from Pelletier et al. 1999).

3. FILLING DEGREE DEFINITION

For tubes in erosion protection applications the degree of filling is a good indicator for the overall performance of the geotextile tube. Due to the confinement strength, which rises with increasing filling degree, the possibility of internal sand migration inside the tube is prevented. Normally it also acts as a first indicator for the determination of an indicative permissible filling height. This aspect is also valid for dewatering tubes. 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 Based on the cross-sectional area

The definition of the filling degree for geotextile container according to CUR (CUR 217 2006) and the Dutch recommendations “Geosystems. Design rules and applications” (Bezuijen et al. 2013) in relation to the cross-sectional area is:

$$f = (4\pi A) / S^2 \qquad [1]$$

with	f	filling percentage	[-]
	A	cross-sectional area of the filled tube	[m²]
	S	Circumference of the tube	[m]

3.2 Based on the height

The definition of the filling percentage based on the height according to the definition of Deltares (van Steeg et al. 2010) is:

$$p_H = h / h_{100\%} \qquad [2]$$

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]

As a very common and practical approach the filling degree can be re-written as the ratio between the tube height and the theoretical diameter of the tube:

Filling ratio := h / D [3]

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

3.3 Filling degree comparison

Figure X illustrates the filling degree development of

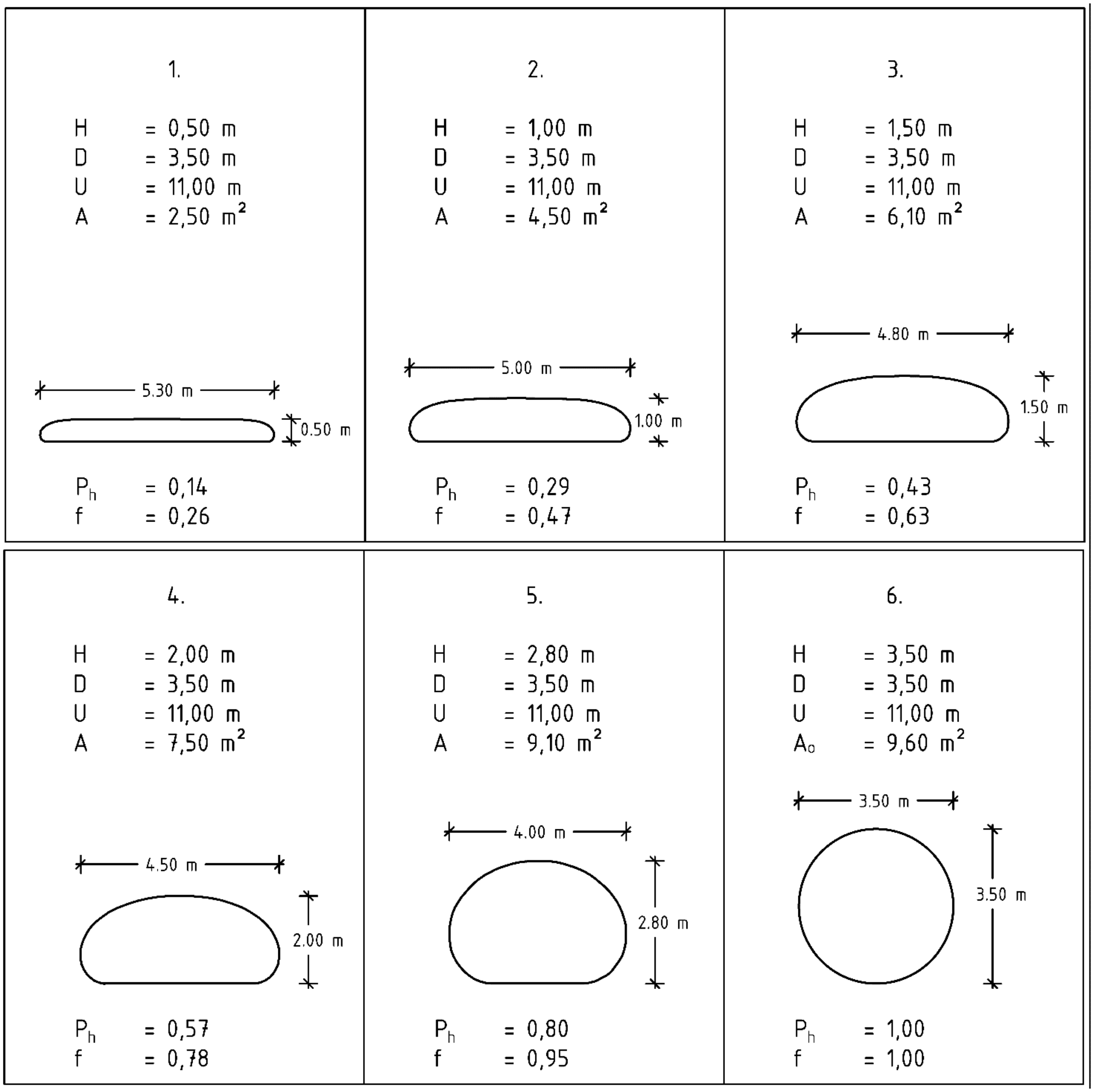


Figure X. Illustrated comparison of the different filling degree definitions p_H and f for a tube with a circumference of 11.0 m (designated U), which corresponds to a theoretical tube diameter of D = 3.5 m; A indicates the cross-sectional area of the tube at the given filling height H (data have been derived by GeoCoPS)

4. OCCURING LOADS ACCORDING TO TUBE THEROY

$$\tau = \sigma \tan \phi + c \qquad [1]$$

5. RECOMMENDED SEAM ORIENTATION AND PRODUCTION TECHNIQUE

6. TUBE PERFORMANCE FACTOR (TPF)

With

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Leshchinsky, D. and Perry, E.B. (1987). A design procedure for geotextile reinforced walls, *Geosynthetics '87,* IFAI, New Orleans, LA, USA, 1: 95-107.

Koerner, R.M., Wayne, M.H. and Carroll, R.G., Jr. (1989). Analytic behavior of geogrid anchorage, *Geosynthetics '89*, IFAI, San Diego, California, USA, 2: 525-536. [Note: all authors are authors listed, do not use “et al.” in the reference list.]

Format for a ASTM test standard:

ASTM D 638. Standard Test Method for Tensile Properties of Plastics, *American Society for Testing and Materials*, West Conshohocken, Pennsylvania, USA. [do not include year since standards are re-published every year).