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Drainage Principles and Applications

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21 Subsurface Drainage Systems

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21.3.3 Envelopes

A variety of terms are used for envelopes, reflecting the purpose and method of application. Common terms are: filter, cover material, and permeable fill. Below, we shall discuss the function of envelopes, their materials, qualitative guidelines, and quantitative specifications.

Functions of Envelopes

An envelope is defined as the material placed around pipe drains to perform one or more of the following functions:

- Filter function: to prevent or restrict soil particles from entering the pipe where they may settle and eventually clog the pipe;
- Hydraulic function: to constitute a medium of good permeability around the pipe and thus reduce entrance resistance;
- Bedding function: to provide all-round support to the pipe in order to prevent damage due to the soil load. Note that large-diameter plastic pipe is embedded in gravel especially for this purpose.

The first two functions provide a safeguard against the two main hazards of poor drain-line performance: siltation and high flow resistance in the vicinity of the drain, as will be discussed in Section 21.7.

In view of its functions, the envelope should, ideally, be so designed that it prevents the entry of soil particles into the pipe, although a limited flow of clay particles will do little harm, because they mainly leave the pipe in suspension. The filtering effect, however, should not be such that the envelope, while keeping the pipe free of sediment, itself becomes clogged. If that happens, the hydraulic function is jeopardized.
Apart from these conflicting filtering and hydraulic functions, the formulation of functional criteria for envelopes is complicated by a dependence on soil characteristics (mainly soil texture) and installation conditions. Despite considerable research efforts over the past 30 years, firm quantitative criteria are still far from established. Instead, to a large extent, drainage practice works with qualitative, empirical guidelines.

Envelope Materials

A wide variety of materials are used as envelopes for drain pipes, ranging from organic and mineral material, to synthetic material and mineral fibres.

Organic material is mostly fibrous, and includes peat - the classical material used in Western Europe - coconut fibre, and various organic waste products like straw, chaff, heather, and sawdust.

Mineral materials are mostly used in a granular form; they may be gravel, slag of various kinds (industrial waste products), or fired clay granules.

Synthetic materials may be in a granular form (e.g. polystyrene) or in a fibrous form (e.g. nylon, acryl, and polypropylene). Glass fibre, glass wool, and rock wool, which all are mineral fibres, are also used.

Envelope materials are applied in bulk, as thin sheets, or as more voluminous 'mats'.

Bulk application is common for gravel, peat litter, various slags, and granules. The classical method is to spread the material after the pipe has been laid in the trench, so that the material will protect the top and the sides of the pipe. A complete surround (e.g. with gravel) is achieved by first spreading gravel on the trench bottom, then laying the pipe, and again spreading gravel.

Thin sheets are commonly used with corrugated plastic pipe as a pre-wrapped envelope. They may consist of glass fibre or synthetic fibres, which are also known as geotextiles.

More voluminous mats of up to about 10 mm thick normally consist of fibrous materials, whether they be organic materials, synthetic fibres, or mineral fibres. These mats are often used as pre-wrapped envelopes with plastic pipes, but they can also be used in the form of strips. One such a strip may be placed only on top of the pipe, or another strip may be placed below the pipe, thereby making it suitable in combination with any type of pipe (clay, concrete, or plastic).

Envelope Requirements in Relation to Soil Characteristics

Qualitative guidelines for designing drain envelopes mainly consider soil texture. Straightforward rules can be given for fine- and coarse-textured soils. For soils in the intermediate texture classes, there is considerable uncertainty.

Fine-textured soils with a clay content of more than about 0.25 to 0.30 are characterized by a high structural stability, even if being worked under Wet conditions. Thus, with trencher-installed pipe drains, no problems are to be expected and an envelope is not required. With trenchless drainage, however, one could easily work below the critical depth (Section 21.4.2), especially in wet conditions, resulting in a high entrance resistance. An envelope is not likely to be of any help. Clogging of the pipe is not to be expected.

Coarse-textured soils free of silt and clay, on the other hand, are permanently unstable, even if undisturbed. Thus, soil particles are likely to wash into the pipe, both from the trench backfill and from the undisturbed soil below the pipe. There is a need for a permanent envelope, completely surrounding the pipe, only as an effective filter, because there is no high entrance resistance. A thin geotextile envelope is probably the best solution here.

Soils of intermediate texture are less simple. In the finer-textured soils of this category (clay contents less than 0.25 to 0.30, but more than say 0.10 to 0.l5), the trench backfill will remain stable and of good permeability, provided that pipe installation is done under dry conditions and, in irrigated land, provided that the trench backfill was properly compacted. In those cases, even without an envelope, no problems will arise. If, however, the pipes were installed under wet conditions, both drain sedimentation and a high entrance resistance could follow. Hence an envelope would be needed. Most likely, only the trench backfill will create problems, because the undisturbed soil remains stable enough. As, assumedly, trench backfill stabilizes with time, an organic envelope, disintegrating in the course of a few years, would be adequate. A commonly applied guideline in The Netherlands is that the envelope should be 'voluminous' in order to fulfil its hydraulic function. Nevertheless, a thin filter sheet wrapped around a corrugated pipe will do the job equally well, because it ensures that water is conveyed towards the perforations (Figure 21 .2).

At the coarse-textured side of the intermediate soils (soils with a clay content below 5% and a high silt content), the trench backfill is likely to be as unstable as the undisturbed soil below the pipe. In addition, the trench backfill may become poorly permeable through a re-arrangement of the soil particles. Therefore, an envelope which completely surrounds the drain, fulfilling both filter and hydraulic functions, is always needed in these soils.

Guidelines developed for The Netherlands are summarized in Table 21.1. It should be noted that an envelope, in spite of its general positive effect, is no guarantee against poor drain-line performance, particularly not if the pipes were installed under wet conditions.

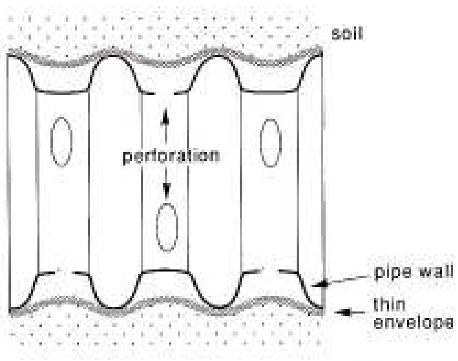

Figure 21.2 A corrugated drain pipe wrapped in a thin envelope

Tabel 21.1 Recommendations on the use of the drain envelopes in The Netherlands based on soil type (after Van Zeijts 1992)

Soil				Envelopes*				
Type based on percentage clay and silt particles**	Geological formation	Remarks	Characteristics related to envelopes***	Function	Material			
					Gravel	Voluminous		Thin****
						Organic	Synthetic	
> 25% clay	Alluvial; marine/fluviatile	Ripe	Stable; high K	-	No envelope necessary			
		Unripe	Stable; low K	Hydraulic (temporary)	+	+	+	-
> 25% clay*****		Ripe	Unstable; high K	Filter	+	-	+	+
		Unripe	Unstable; low K	Filter and hydraulic	+	-	+	-
< 25% clay < 10% silt	Marine	$d_{50} < 120$	Unstable; high K	Filter	+	-	+	+
< 25% clay < 10% silt	Aeolian	$d_{50} > 120$	Initialy unstable; high K	Filter (temporary)	+	+	+	+
< 25% clay > 10% silt	Aeolian, fluviatile or (fluvio) glacial		Initialy unstable; low K	Filter (temporary) and hydraulic	+	+	+	-

* + = suitable; - = not suitable
** texture in soil profile above drain level, clay particles are < 2 μm and silt particles are 2-50 μm
*** high hydraulic conductivity: K ≥ 0.25 m/day, low K ≤ 0.05 m/day
**** only suitable if there is no risk for biochemical clogging
***** lighter layers (< 25% clay) in soil profile above drain level

Gravel Envelopes

The part of gravel envelopes is omitted because it is obsolete

Synthetic Envelopes

Many of the drawbacks of gravel envelopes can be overcome with the use of synthetic envelopes. The wide variety in their materials, however, and in their characteristics makes it extremely difficult to develop sound design criteria. Consequently, many criteria have been developed (Table 2l.4), most of them based on the opening size of the envelope material. Various methods of obtaining characteristic opening sizes of synthetic envelopes exist.

According to Van der Sluys and Dierickx (1990), these methods give practically the same results for the same soil material. A standard developed in The Netherlands for the particle-retention capability of synthetic fibrous mats is the characteristic pore size of the envelope. This pore size is expressed as the ‘O90-value’, which is defined as the average diameter of the soil particles in a fraction, 90% of which is retained by the envelope in a standardized sieving test (NNI 1990).

The testing procedure uses prepared sand fractions, of which the grain size limits correspond with subsequent mesh sizes of a standardized sieve set, The procedure is illustrated in Table 21.5, where three sand fractions (50 g each) with a different particle-size distribution have been used. The quantity of each fraction that is retained by the envelope was measured. Plotting the results, followed by interpolation, leads to the conclusion that 90% of an average grain size of 0.320 mm would be retained by the envelope. The O90-value of the envelope thus equals 0.320 mm (Figure 21 .4).

Table 21.4 Design criteria for synthetic and organic envelopes (after Dierickx 1993)

Reference	Geotextile	Soil	Criteria	Remarks
Calhoun (1972)	Woven	Cohesionless ($d_{50} \geq 74$ mm)	$O_{95}/d_{85} \leq 1$	Dry sieving, glass bead fractions
		Cohesive ($d_{50} < 74$ mm)	$O_{90} \leq 200$ µm	
Ogink (1975)	Woven	Sand	$O_{90}/d_{90} \leq 1$	Dry sieving, sand fractions
	Nonwoven	Sand	$O_{90}/d_{90} \leq 1.8$	
Zitscher (1975) in Rankilor (1981)	Woven	$C_u \leq 2$	$O_{50}/d_{50} \leq 1.7\text{-}2.7$	
		100 µm $\leq d_{50} \leq$ 300 µm		
Sweetland (1977)	Nonwoven	$C_u = 1.5$	$O_{15}/d_{85} \leq 1$	
		$C_u = 4.0$	$O_{15}/d_{15} \leq 1$	
ICI Fibers (1978 in Rankilor (1981)	Nonwoven	20 µm $\leq d_{25} \leq$ 250 µm	$O_{50}/d_{85} \leq 1$	
		$d_{85} >$ 250 µm	$O_{15}/d_{15} \geq 1$	
Schober and Teindl (1979)	Woven and thin nonwoven	Sand	$O_{90}/d_{50} \leq B_1 (C_u)$	Dry sieving, sand fractions B_1 and B_2 are factors depending on C_u:
	Thick nonwoven	Sand	$O_{90}/d_{50} \leq B_2 (C_u)$	$B_1(C_u) = 2.5\text{-}4.5$ $B_2(C_u) = 4.5\text{-}7.5$
Millar, Ho and Turnbull (1980)	Woven and Nonwoven		$O_{50}/d_{85} \leq 1$	
			$O_{50}/d_{15} \geq 1$	
Giroud (1982)	Needle-punched nonwoven	Cohesionless		
		less dense		
		$1 < C_u < 3$	$O_{95}/d_{50} < C_u$	
		$C_u > 3$	$O_{95}/d_{50} < 9/C_u$	
		moderate dense		
		$1 < C_u < 3$	$O_{95}/d_{50} < 1.5\ C_u$	
		$C_u > 3$	$O_{95}/d_{50} < 13.5/C_u$	
		dense		
		$1 < C_u < 3$	$O_{90}/d_{50} < 2\ C_u$	
		$C_u > 3$	$O_{95}/d_{50} < 13.5/C_u$	
	Woven and heat bonded nonwoven	$1 < C_u < 3$	$O_{95}/d_{50} < C_u$	
		$C_u > 3$	$O_{95}/d_{50} < 9/C_u$	
Heerten (1983)	Woven and nonwoven	Cohesionless		Wet sieving, graded soil
		($d_{50} \geq 60$ µm)		
		$C_u > 5$	$O_{90}/d_{50} < 10$	
			$O_{90}/d_{90} < 1.0$	
		$C_u < 5$	$O_{90}/d_{50} < 2.5$	
			$O_{90}/d_{90} < 1$	
		cohesive	$O_{90}/d_{50} < 10$	
		($d_{50} \leq 60$ µm)	$O_{90}/d9_{90} < 1$	
			$O_{90} \leq 100$ µm	
Carroll (1983)	Woven and nonwoven		$O_{95}/d_{85} \leq 2\text{-}3$	
Christopher and Holtz (1985)		Dependent on C_u	$O_{95}/d_{85} \leq 1\text{-}2$	
			$O_{95}/d_{15} \geq 3$	
CFGG (1986)	Woven and nonwoven		$O_{95}/d_{85} < C$	Hydrodynamic sieving, graded soil
			$C = C_1C_2C_3C_4$	
		$C_u > 4$	$C_1 = 1$	
		$C_u < 4$	$C_1 = 0.8$	
		less dense	$C_2 = 0.8$	
		dense	$C_2 = 1.25$	
		$i < 5$	$C_3 = 1$	
		$5 < i < 20$	$C_3 = 0.8$	
		$20 < i < 40$	$C_3 = 0.6$	
		filter	$C_4 = 1$	
		filter and drainage	$C_4 = 0.3$	
		cohesive	$O_{95} \geq 50$ µm	

d_m Sieve mesh (mm) through with m% of the soil fraction passes
O_m Average diameter of the soil particles in a fraction, of which m% is retained by the envelope
C_u Coefficient of uniformity (= $d_{60}F/d_{10}F$)
i Hydraulic gradient (-)

Table 21.5 Test result of synthetic fibrous mats for pipe envelopes, according to the standarized sieving test (NNI 1990)

Fraction	Lower fraction limit (mm)	Upper fraction limit (mm)	Average grain size (mm)	Quantity passed (g)	Quantity retained (g)	Percentage retained (%)
A	0.250	0.300	0.275	8.0	42.0	84
B	0.300	0.355	0.328	4.5	45.5	91
C	0.355	0.425	0.390	3.5	46.5	93

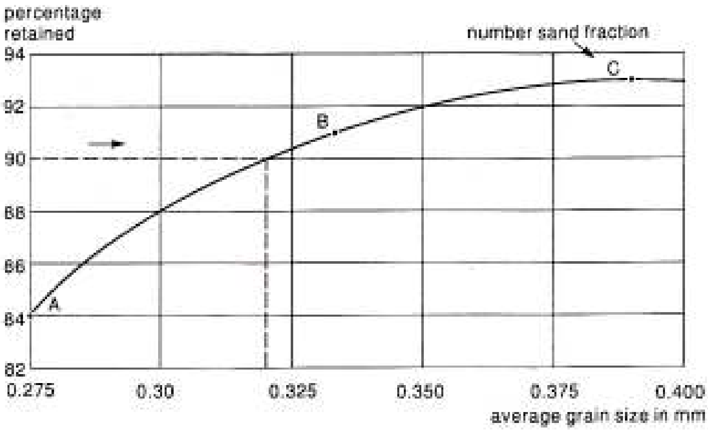

Figure 21.4 Example of standard test for envelopes using O_{90}-values

Organic Envelopes

The part of organic envelopes is omitted because it is obsolete