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Key words strip drains, vertical drainage, quality requirements, quality control, test methods

Abstract

Vertical strip drains have replaced the use of sand drains in Finland since the early 1970's, resulting in an expanding use of vertical drainage in road building. New types of drain strip have become available on the Finnish market in the last few years.

To provide effective consolidation of vertically drained soil layers, e.g. in accordance with the calculated settlement rate, one of the main prerequisites is that the hydraulic properties of the strip drains should remain sufficiently good over the entire time of consolidation period. This research report deals with the requirements for the properties and quality of vertical drain strips and the corresponding testing methods and quality assurance procedures.

The quality requirements for vertical drain strips concern to the long-term permeability and soil retention potential of the filter and the discharge capacity of the drain. To fulfill these requirements the structure and materials of the vertical drain strip must be of sufficient mechanical strength and chemical stability throughout a service life of 2-3 years.

Provided that the requirements for hydraulic and mechanical properties set in the present report are met in laboratory tests, the vertical drain strip can be considered applicable to normal installation and soil conditions. The properties of the drain strip in question should be determined in type inspections before the product is released for use.

The quality of vertical drains should be assessed by the builder and the contractor during installation. Visual inspection and measurements of drain strip samples and results of the manufacturer's internal quality assurance can be used as quality control methods. The quality must show a permanent similarity to that deserved in the type inspections. The samples should be taken from the strip drain after passage through the mandrel, so that the suitability of the machine for drain strip installation can be confirmed.

Type inspection results for five types of vertical drain strip are presented in Appendices 1-5. These indicate that the quality requirements were fulfilled by all the products tested except for the soil retention potential of the filter material in soil types sensitive to internal erosion (medium and coarse silts). In addition, the quality of filter seam of some drain strips was inadequate. In erosion-susceptible soil types, which are rarely found on Finnish sites where vertical drainage is employed, filter tests simulating long-term functioning of the drain should be performed using soils that are representative of the site in question.

PREFACE

The purpose of this report is to improve the quality control procedure of strip drains to be used for vertical drainage. Due to lack of an internationally approved test methodology, also test methods had to be developed for that purpose. The quality requirements for strip drains were set on the basis of a literature review, a thorough developing programme and corresponding type approval tests.

Quality control of strip drains is a two-staged procedure. During the type approval procedure it is judged, if the strip drain fulfils the quality requirements set. On the working site quality assurance measures have to confirm that the strip drain delivered is of approved type and each batch fulfills the quality requirements set.

The research work done for the evaluation of this report implemented a testing programme for five drain strips to ensure their suitability as vertical drains in typical soft soils. For each of the drain strips a test report was compiled. A summary of the test results is attached to this report.

The report was worked out at the Road, Traffic and Geotechnical Laboratory of the Technical Research Centre of Finland by H. Komulainen and H. Rathmayer. The work was supervised by P. Salo on behalf of the National Road Administration.

Helsinki, Feb. 11, 1992

Finnish National Road Administration
Geotechnical Services.

CONTENTS

1 INTRODUCTION

As late as the 1970's, vertical drainage was still being carried out by means of sand drains, the sole installation method employed in Finland being the use of a protective mandrel. Since that time the equipment used for vertical drainage has developed rapidly, thanks to the increasing use of strip drains, and today it is possible to install a strip drain down to a depth of more than 30 m, terminate it at the bottom of a water system and perform the installation work even in winter.

The velocity of the installation mandrel has increased to more than 1 m/s, and the total installation rate may be as much as 6000 metres of drain per working shift in cases where the drains are installed to a considerable depth. The method is almost ten times more efficient than the sand drains employed earlier.

The first strip-like drain type was developed by Kjellman in 1948. The strip employed in the drain had a cross-section of 100 x 3 mm and it was composed of three layers of cardboard, the outer two of which operated as a filter and the centremost, channelled layer as a hydraulically conductive element. The size of the strip was determined by the static capacity (approx. 280 kN) of the drain stitcher constructed at that time. The Geodrain drain strip equipped with a plastic core and paper filter was introduced in the mid--1960's, while totally synthetic strips provided with geotextile filters have been used since the early 1970's, and have now replaced kraft paper almost completely, although the filtering properties of solid paper are among the best. The current dimensions of drain strips are still almost the same as those of Kjellman's cardboard drain.

A strip drain is usually installed by means of a protective mandrel using the replacement technique, which always causes some disturbance in the soil around the drain. Once the mandrel has been removed, the soil regains its former state to a varying extent and by a mechanism of which very little is known. In any case, it is obvious that the soil does not recover its original properties completely and that its discharge capacity etc. will be poorer.

The protective mandrels employed are usually rectangular or diamond-shaped in cross-section. Penetration of the lower end of the mandrel by soil is prevented by means of an anchor plate, the main purpose of which is to fix the strip at the desired depth. An attempt is made to minimize the surface area of the mandrel cross-section and the anchor plate in order to reduce soil disturbance and to minimize the necessary machine capacity. The dimensioning of the protective mandrel is in practice based on its buckling stiffness and the wearing tolerance set for the steel cross-section.

The strip is fed into the mandrel via rollers, usually from above. Drain strips are very light and as such highly vulnerable to weather conditions such as wind. The stress imposed on the strip at the installation stage usually places higher requirements on the strength of the material than do the actual operating conditions.

The aim of vertical drainage is to accelerate the discharge of an excess pressure of pore water from the soil by shortening the seepage distance. The early theories developed to explain the efficiency of sand drains were based on the unidimensional consolidation theory of Terzaghi (1925), later expanded by Rendulic (1935) and Barron (1948) in terms of radial seepage flow. Hansbo adopted a more specific approach in his dissertation of 1960, suggesting that the correlation between the flow velocity of pore water and the flow gradient was non-linear. This theory was later applied to strip drains.

2 NEED FOR SUITABILITY TESTS

A critical parameter in vertical drainage is the available construction time. The subsoil loading schedule and the total time required to achieve the final degree of consolidation are both dependent on the efficiency of the vertical drainage. Attention should thus be paid to the long-term functioning of the drain material in particular.

A number of risk factors were involved in the use of sand drains, with the consequence that some soil improvement projects were unsuccessful. Embankment piling was advocated for some time as an alternative to vertical drainage when building on soft soils, and it was not until the introduction of strip drains of synthetic material that confidence in the vertical drainage method was restored.

The first systematic investigations into the properties of strip drains were carried out at the Chalmers and Delft Technical Universities. The primary focus of the Swedish research was on the equivalent diameter of the strip drain, and a laboratory test method which involved placing a mini-size strip drain inside an undisturbed soil sample was developed for its measurement. This took the form of a consolidation test in a triaxial cell. The research carried out in the Netherlands concentrated on the discharge capacity of a strip drain when either stressed and/or bent, while less attention was paid to the effect of various soil types on the functioning of the drain.

There are a number of drain strips on the market, the strength, filtering and conductivity properties of which are not sufficiently well known. Thus it is difficult for a designer to acquire information on the practicability of the various drain types and their relative superiority under actual operating conditions, as reliable data on their functional properties and experiences of their use are only available for a few drains. The large number of slightly different drain strips and the competition between these has aroused a need to standardize some of the tests and to define general requirements for such drains.

The aim of the current project was to develop methods to be applied in the testing and project-specific quality control of drain strips, together with a testing system which would provide data on their reliability under the general operating and subsoil conditions prevailing in Finland. Five drain strip types were tested during the project, and project-specific quality control inspections were performed at three vertical drainage sites in summer 1991. The testing system was adjusted in accordance with the experiences gained.

3 FUNCTIONING AND PROPERTIES OF STRIP DRAINS

3.1 Strength properties

3.1.1 General quality requirement

The strength properties of a drain strip should allow it to withstand any stress it is subjected to during normal installation and under the operating conditions throughout its anticipated operating life and to maintain a sufficient operating ability throughout this period. A drain strip should thus have the necessary strength properties and adequate deformation resistance.

3.1.2 Stress imposed on drain strips during installation

A drain strip is subjected to short-term tensile forces at the installation stage which result from inertia and friction imposed by the strip reel, and the rollers which guide its passage. The former forces are greater than the latter when the strip runs in a normal manner. Inertia is relative to the acceleration of the mandrel and the tensile forces caused by the inertia and friction are proportional to the tensile stiffness of the drain strip. The latter usually reach their maximum upon a sudden drop in the imbedding resistance caused by factors such as the mandrel penetrating a layer of compacted fill overlying a clay soil.

Tensile forces caused by friction between the drain strip and the mandrel and between the guide rollers usually reach their peak when the mandrel is drawn up. The greatest deformations of the strip are dependent on the minimum curvature radius of its path, while the maximum local deformation normally occurs at the anchor plate attachment.

3.1.3 Stress on a strip drain during operation

Mechanical stresses caused by earth pressure, soil layer compression, possible subsoil deformations and freezing and frost-heave in the surface soil are imposed on a strip drain during its operation time.

Vertical drainage usually leads to major settlements in the subsoil, and compressions in excess of 15% may occur, in which case the drain will adopt a wavelike or irregular 'zig-zag' form (Fig.1) due to its relatively poor compressibility. The form of the deformation is dependent on the magnitude of the relative settlement, the horizontal stiffness of the soil and variations in this (i.e. soil stratification) and the elasticity of the drain strip upon bending.

Any plastic soil deformation caused by a loading berm, freezing of the surface soil or frost-heave will form local tensile force zones in strip drains. The stresses which occur in these zones vary greatly in magnitude and may be highly significant in some cases.

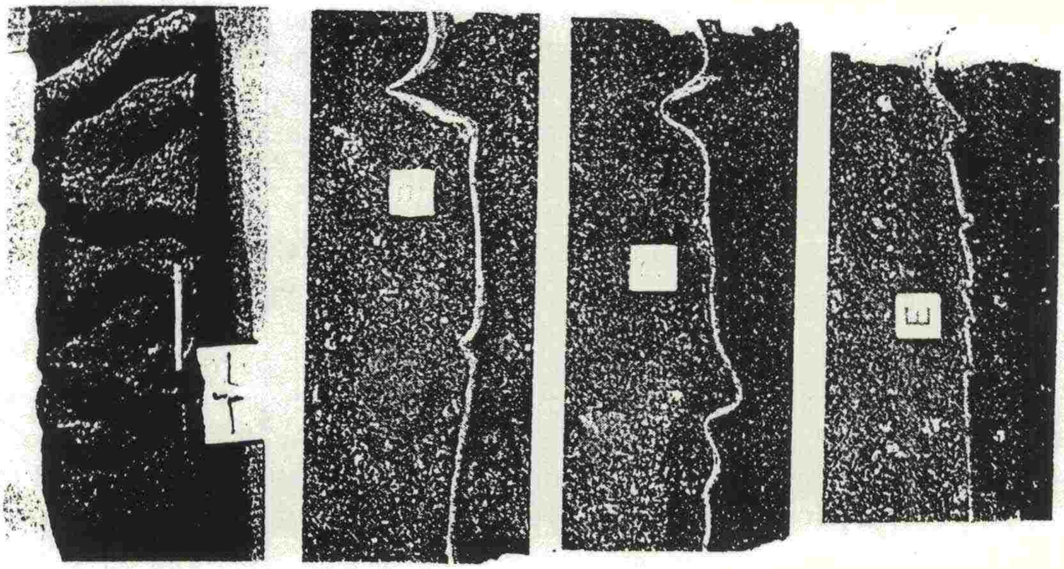

Fig. 1. Curvature of strip drains with a subsoil compression of approx. 15% (Oostveen, 1990).

3.1.4 Strength requirements upon installation

A drain strip, its attachment to the anchor plate and the strip junction should all be capable of withstanding any stress caused by normal installation, such as tearing resulting from an uneven distribution of tensile forces and possible wind loading, without any deformation which would hamper the operation of the drain.

The attachment of the drain strip to the anchor plate by means of a loop should be such that it involves the minimum bending radius and does not break the strip profile or cause any excessive compression in its core. Any forms of attachment likely to impose concentrated tear on the strip should be avoided. As water will also flow into the underlying, hydraulically conductive layer, the attachment should not increase the flow resistance of the strip to any essential degree.

The tensile forces imposed on a strip junction should be distributed over the entire width of the strip. The filter and core of the drain should be attached in the junction in a way that allows it to withstand tension. The junction should correspond to a non-extended drain strip in terms of its hydraulic properties and should not obstruct the flow of water nor cause any infiltration of soil into the drain, which would clog the drain.

3.1.5 Long-term strength requirements

The well-planned, faultless operation of a strip drain requires a sufficient cross-sectional stiffness and deformation resistance with respect to subsoil settlements and other stresses. No deformation in the core of the drain, which would reduce the free cross-sectional area, should be caused by the estimated long-term earth pressure, to any appreciable extent. A cross-sectional deformation or volume change in excess of 30% is regarded here as remarkable. The core should be of a form that it does not give rise to any point or linear stresses which would lead to a break or tear in the filter even when sharply bent.

The filter material should be sufficiently homogeneous in both strength and deformation properties in all directions. The filter seam and the interface between the filter and the core should possess a sufficient deformation ability and strength to resist tensile and shearing stresses and the filter and seams should remain totally unbroken under normal installation and operating conditions.

The filter should not be broken or sheared when pressed against the core of the drain by earth pressure, and any deflections caused by this should be small enough to allow the free flow of water, i.e. the filter material should be tough in terms of its stress-strain behaviour but still possess a sufficient tensile stiffness.

The effect of the bending of a strip drain into a wavelike form (buckling) on its functional capacity must be taken into consideration at least when the estimated relative settlement for a given subsoil exceeds 15%. In order to allow faultless operation of a vertical strip drain with a wavelike deformation pattern, the strip should bend without developing any sharp points of inflection. This requires that the filter and core should behave in a flexible manner so that not even sharp bending will lead to any rupture of the filter or flattening of the core. It is decisive from the point of view of the successful operation of the drain that the filter should remain unbroken, as the probability of the drain becoming clogged will otherwise increase greatly.

The filter sleeve should be composed of fairly long fibres, due to the deformation requirements placed on it. Traditional paper-based materials which contain short fibres are relatively fragile, i.e. their breaking strain is too small.

Major local strains in strip drains are caused by plastic deformations in the subsoil and by frost-heave. The structures of both the core and the filter should be able to withstand major deformations to allow the drain to function under such conditions.

The freezing of a strip drain to the soil involves a considerable adhesive strength between the two surfaces, and the adhesive forces are likely to change radically over a short distance. Freezing can easily lead to rupture of the filter and of the drain should the core and filter not possess a considerable deformation ability. In addition, it would also be profitable in such a case if they could slide with respect to each other.

3.2 Discharge capacity

3.2.1 General quality requirements

The long-term discharge capacity of strip drains with respect to the thickness of the consolidating soil layers, their water permeability, preliminary loading period, magnitude of loading, rate of load increase and distance between the drains should be such that the flow resistance in the drain will not hamper the consolidation process. This means that the pressure differences caused by flow resistance should be very small throughout the drain length.

3.2.2 Equivalent diameter

The equivalent diameter (D_e) of a vertical drain is a measure of its hydraulically efficient size, and can be calculated using the following formula:

$$D_e = \frac{2(b+T_o) - b_s}{\pi}$$

where b = width of core
T_o = thickness of drain strip
b_s = width of cemented section at overlapping seams

3.2.3 Factors affecting long-term discharge capacity

1) Original discharge capacity of the strip drain (efficient cross-sectional area of the core, shape of flow channels),

2) deformation of the filter against the flow channel as a result of earth pressure, and the resulting reduction in cross-sectional area,

3) cross-sectional deformations in the drain core (long-term compression as a result of earth pressure),

4) sedimentation of soil which has passed through the filter to the bottom of the drain or flow channels, and

5) reduction in effective drain cross-section as a result of sharp bending or twisting of the strip or damage caused to it.

As the discharge capacity of strip drains is usually markedly affected by horizontal stresses caused by earth pressure, conductivity data should always be accompanied by information on the corresponding horizontal loading.

3.2.4 Discharge capacity requirements

The amount of water entering a vertical strip drain and the resulting discharge capacity requirement is determined by factors such as the rate of consolidation, drain length and distance between adjacent drains.

The general discharge capacity requirements set for the use of strip drains under varying conditions are typically conservative in Finland. Thus the conductivity requirements discussed here, if strictly observed, will provide the drain profile with an excess capacity under normal operating conditions. This is considered necessary in critical situations such as major deformations or faulty operation of the filter.

To measure the discharge capacity required in a strip drain, the conditions under which the drain will be used can be classified using the following parameters (de Jager, Oostveen, 1990):

1) thickness of the compressible soil layer, which usually corresponds approximately to drain length (L)

2) primary total consolidation settlement (S)

3) relative settlement (S/L)

4) time to achieve the degree of consolidation required (T)

5) magnitude of loading (loading berm)

6) rate of loading.

The above parameters are used to evaluate the maximum quantity of water flowing through a strip drain under given conditions, which then allows measurement of the discharge capacity corresponding to the design earth pressure acting on the drain.

Drain strips can be divided into the following categories on the basis of the necessary discharge capacity and corresponding horizontal pressure (de Jager, 1990):

Class	Drain length (m)	Embankment constructing rate (m/week)	Required discharge capacity (ml/s)	Horizontal pressure (kPa)
1	< 10	< 0.25	> 10	150
2	> 10	< 0.25	> 10	300
3	> 10	> 0.25	> 50	300

As the surrounding soil layer is consolidating, the vertical deformations cause the drain strip to buckle. In a homogeneous soil this will cause it to adopt an almost wavelike form and, as it curves, its cross-sectional area will decrease, thus interfering with its discharge capacity. Any folding of the strip as a result of sharp bends may cause a radical decrease in discharge capacity, the maintenance of which requires that the core of the drain strip should withstand such bending without being flattened.

In order to allow for bending of the strip, for other deformations and the effects of soil accumulating in the drain in the long term, the discharge capacity of a straight drain strip should be at least 10 times higher than the estimated maximum flow rate, as measured in a laboratory experiment conducted at a horizontal pressure similar to that of the actual operating conditions.

3.3 Functioning of the filter sleeve

3.3.1 General requirements

The purpose of the filter sleeve is to prevent soil from entering into the strip drain with the water (mechanical efficiency) without causing any excessive pressure loss which would slow down the flow through it (hydraulic efficiency).

The water permeability of the filter and its retention capacity with respect to a given soil are partly conflicting requirements, as a result of which they are impossible to implement to their maximum extent simultaneously. The aim is thus to find a suitable combination of these two which emphasises mechanical and hydraulic efficiency in accordance with the requirements set by soil conditions.

3.3.2 Nature of geotextile filters

The mechanical and hydraulic efficiencies of a filter are largely dependent on its pore size, pore size distribution and thickness. The most common material employed in strip drain filters is a geotextile composed of thermally bonded non-woven fabric. The filtering properties of a non-woven fabric in general are dependent on the thickness of the fibres and the fabric and the density of the latter (weight per unit area). Thermally bonded non-woven fabrics are thin and often correspond in structure to a sieve which contains holes of varying sizes. As the fibres employed in geotextiles are fairly thin, even smaller in diameter than the pores, the pore structure is relatively open - much more open than that of an earth filter.

3.3.3 Filtering mechanisms

The mechanical and hydraulic efficiency of a geotextile filter is primarily dependent on the relation of its pore size and pore distribution to the grain size distribution of the surrounding soil. The functioning of a filter is based on three main mechanisms (Fig. 2):

1) accumulation of soil behind the filter (cake filtration),

2) blocking of filter pores by soil (blocking filtration),

3) space filtration (deep filtration)

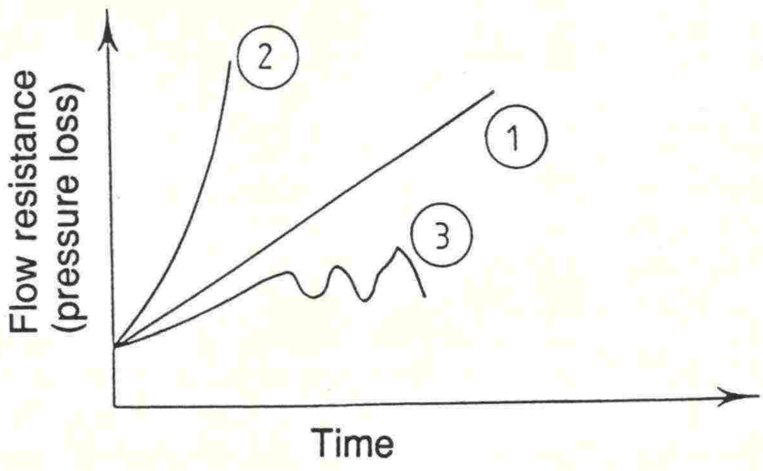

Fig. 2. Flow resistance caused by the filter as a function of time and operating mechanism in principle (Vreeken, 1990).

The long-term mode of functioning of the filter in Fig. 2 can be described in the following manner:

1) Flow of pore water causes soil to accumulate behind the filter when most of the particles are larger than its pores (openings). Flow resistance is increased by the gradually accumulating soil layer in the long term to an extent which is more or less proportional to the thickness and water permeability of the layer.

2) As the soil particles and pores are of almost equal size, the former block the latter. Particles may fill a considerable part of the pore space, which will rapidly increase the flow resistance.

3) Most of the soil particles involved in space filtration are smaller than the pores, and only some of the soil material is retained in the pores by adhesion forces (van der Waals forces). The pore space is open at the beginning of the filtering process and the pressure difference over the filter small. As some of the pores are clogged by the particles, the flow resis-

tance and pressure difference rise until some of the particles are loosened and the pressure difference consequently drops. Space filtration is characterized by a fluctuation in pressure differences as a function of time, as particles are constantly being either retained or released. The flow resistance nevertheless remains more or less at the average level in the long term.

3.3.4 Mechanical efficiency of the filter

Although an ideal filter should be able to retain even the smallest soil particles carried by the water, a geotextile filter is in practice penetrated by a considerable number of fine soil particles at the beginning of the filtering process, as they are smaller than its effective openings. If the pore size is suitable with respect to the size and grain-size distribution of the soil particles, a filtering soil layer is created behind the filter itself (Fig. 3).

The resulting composite geotextile soil filter is able to retain almost all the soil particles carried by the water. The time required for the creation of this self-filtering effect varies and is dependent on a number of factors such as the pore pressure gradient.

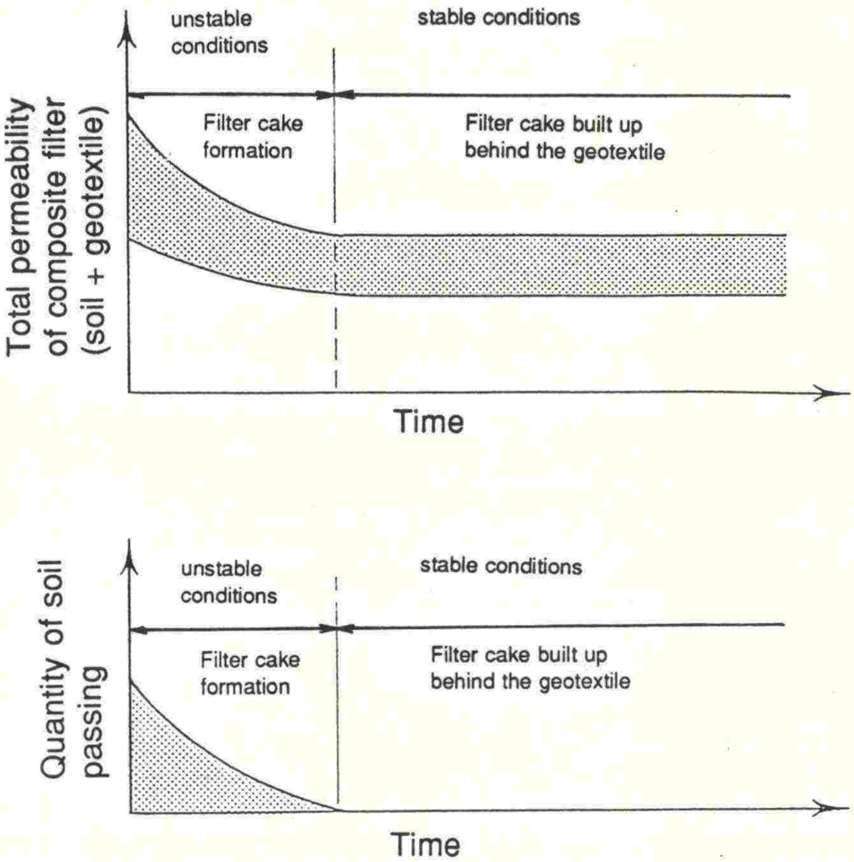

Fig. 3. Long-term operating principle of a geotextile filter of a pore size which matches the soil type.

Geotextile filtration tests, using soils which are technically difficult to filter using hydraulic gradients of 1 and 3 showed the self-filtering effect to be created in 10 - 100 days and water permeability to reach an equilibrium in 100 - 200 days (Lawson, 1990).

Soil infiltration into strip drains

The amount of soil entering a strip drain is dependent on the mechanical efficiency of the filter, the amount of water flowing into the drain and its soil content, while the latter is determined by the erosion susceptibility of a given soil, which is in turn dependent on factors such as grain-size distribution, cohesion and flow velocity (gradient of excess pore pressure, water permeability of soil). If the subsoil is composed of alternating layers of clay and silt, the risk of internal erosion in the silt will increase with the flow velocity while the effect of cohesion will decrease.

Some of the soil which has entered the strip drain is carried away by the water, while the rest is deposited at the bottom of the drain in quantities which are dependent on the grain-size composition of the soil and the flow velocity. The composition of the soil which has penetrated through the filter is dependent on the original soil content of the pore water, the mechanical efficiency of the filter and the alteration in this efficiency with time (partial clogging, creation of self-filtering capacity). The flow velocity in the drain is dependent on the excess pore pressure, its gradient, the rate of consolidation of the soil strata, the drain spacing, and the lengths and cross-sectional areas of the drains.

The amount of soil which enters a strip drain and the resultant clogging of the filter are thus dependent on a number of factors, and it is evident that the degree of mechanical efficiency required in the filter cannot be defined by reference to grainsize distribution only. The mechanical efficiency of the filters used in strip drains is nevertheless evaluated in practice in terms of the gradation (erosion susceptibility) of the soil involved.

If the soil content and grain size distribution of the filtration water were known better, the amount of soil deposited in the drain could be assessed from the flow velocity by means of Stokes' formula, for example. Few results of research into these two features have been published to date (Vreeken, 1983).

Soils difficult in terms of filtration

Soils which are sensitive to internal erosion as a result of their poor cohesion, mainly middle coarse and coarse silt or fine sand, are regarded as problematic in terms of the filter technology required. Difficulties may also arise in the case of well-graded friction soils which may involve suffosion i.e. the scouring of fine material from a coarser grain body. The requirements set for the mechanical filtration properties of geotextiles are consequently determined by the coarser soil fraction and their hydraulic suitability by the finer fraction.

Soils which are problematic from the point of view of filtration technology can be defined using the following alternative criteria (Karge, Collins, 1984, Fig. 4):

1) Grain size < 0.06 mm when the grain size ratio $U = d_{60} / d_{10}$ is < 15,

2) Soil mass in the range 0.02 mm < d < 0.1 more than 50%,

3) The soil involved occurs in the grain-size field A in Fig. 4 (d_{40} < 0.06 mm) and the plasticity index I_p is < 15,
   or, should plasticity index be unknown, the ratio between the clay and silt fractions is < 0.5.

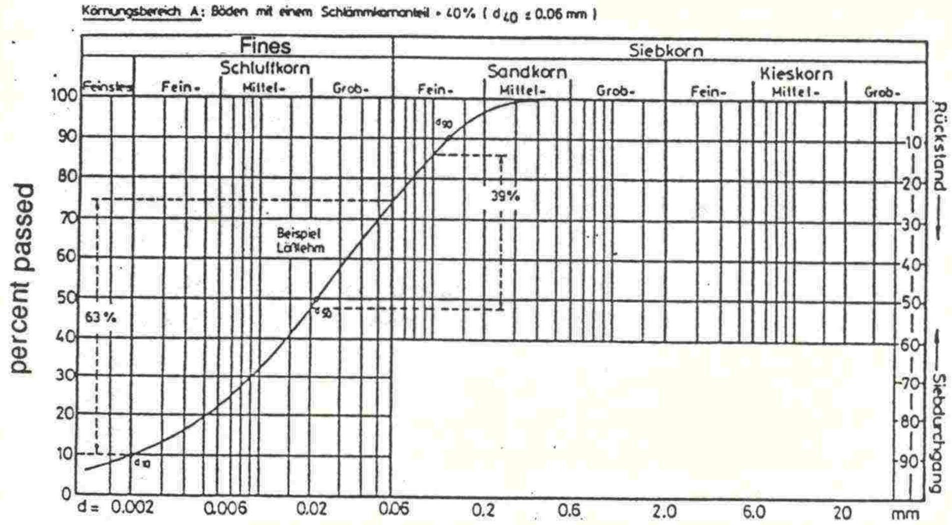

Fig. 4. Grain-size field A (hatched) which may contain soils which are prob lematical from the point of view of filtering technology (DVWK Schriften 76, 1986).

Three grain-size areas are shown in Fig. 5. When the grain-size curve is in area I less stringent mechanical filter requirements can usually be employed, thanks to the efficient cohesion, and as the soil has a low water permeability, the hydraulic requirements set for the filter are also smaller.

Special care should be taken when deciding on the dimensions for filters to be used in area II, which contains the soils defined above as being problematical.

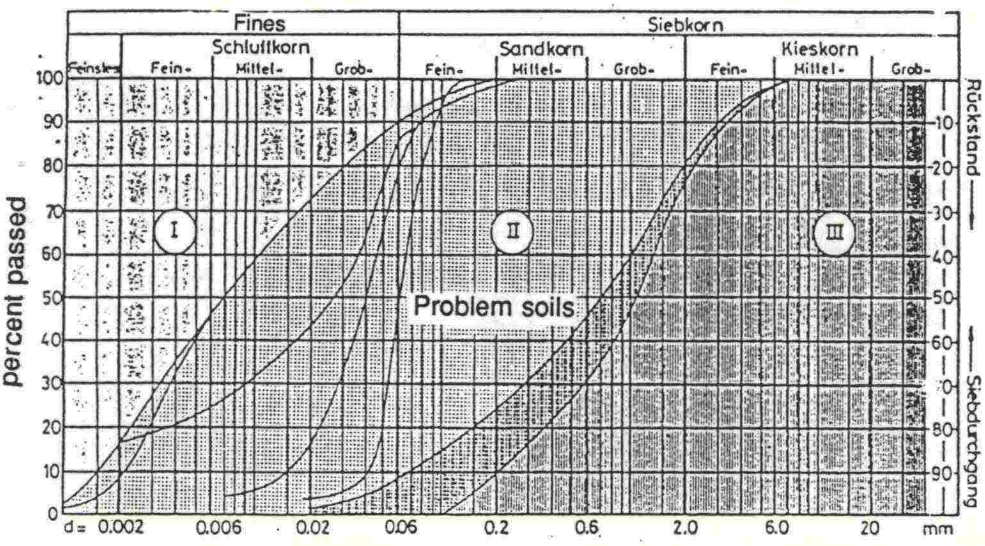

Fig. 5. Distribution of soils into filtering difficulty categories (Schweizer Norm SN 670 125a).

Mechanical requirements for soil filters

Research into the filtering criteria of soil filters has been carried out for decades, and generally accepted filter requirements are currently available. There are a number of totally different requirements set for geotextile filters, however, and the results obtained by applying a given set may differ markedly from those yielded by some other type of geotextile filter. There are no generally approved requirements for geotextile filters, although the discrepancies between the criteria are decreasing. If the pore size distributions of geotextile and soil filters could be combined, the requirements approved for the latter could be applied to the former provided that the thickness difference between the filter types is taken into consideration (Fischer et al., 1990).

Soil and textile filters can be compared in terms of pore size by image processing methods, for instance, the latter often being composed of smaller pores than sand filters.

Mechanical requirements for geotextile filters

Some requirements for the mechanical efficiency of geotextile filters in sand and silt soils are listed in Table 1, i.e. less attention is paid to the effect of cohesion in the subsoil.

Table 1. Requirements for the mechanical efficiency of geotextile filters. O_{90}, O_{95}, D_W denote effective filter pore sizes and d_i soil grain sizes.

Filter requirement	Reference etc.	Application restrictions
$O_{95} < d_{85}$	US Waterways	
$O_{90} < d_{90}$	Delft Hydraulics Laboratory	Woven fabrics
$O_{90} < 1,8d_{90}$		Non-woven fabrics
$O_{90} < Bd_{50}$	Schober and Teindl	Coefficient B is used to account for grain-size distribution (gradation coeff. U) and improve the safety level
$O_{90} < (3\text{-}5)d_{50}$	U>5 non-woven, thin fabrics	
$O_{90} < (1\text{-}2,5)d_{50}$	U<5	
	(U=grain size ratio)	
$O_{90} < (0,5\text{-}1,3)d_{50}$	Ragutski	Woven fabrics under lateral pressure.
$O_{90} < (0,5\text{-}1,5)d_{50}$	-"-	Non-woven fabrics under lateral pressure.
$O_{90} < (0,5\text{-}0,7)d_{50}$	-"-	Woven and non-woven fabrics without lateral pressure.
$D_w < d_{90}$ and	Heerten	$d_{50} \leq 0.06$ mm (silts)
$D_w < 2d_{90}$	-"-	Soils with long-term stable cohesion (when cohesion is not affected by loading)
$D_w < 10d_{50}$ and $D_w < 0,1$ mm	Wittman	Relation between filter thickness and pore size > 25.

The safety coefficient (η) for erosion at the interface between the filter and soil can be expressed by the quantity B_{50} (Schober, Teindl, 1979).

$$\eta = \frac{B_{50cr}}{B_{50all}} \quad , \text{ where } B_{50} = \frac{O_{90}}{d_{50}}.$$

Thus $B_{50} = B_{50kr}$ denotes the situation in which the soil-filter system begins to behave in a critical manner. A safety coefficient of $\eta = 1.5$ can be employed, thus $B_{50all} = 2/3\ B_{50cr}$.

The filter criterion for thin, non-woven geotextile filters is a function of the grain-size ratio U the subsoil (= d_{60}/d_{10}), as indicated in Fig. 6.

$$B_{50} = \frac{O_{90}}{d_{50}} < (1{,}5 - 2{,}8) \; ,$$

where O_{90} = effective filter opening size,

d_{50}, d_{10}, d_{60} = grain sizes in subsoil.

If the subsoil is primarily composed of medium coarse and coarse silts, i.e. it can be estimated as being susceptible to internal erosion, the clogging risk will increase. The function of the grain-size ratio U used as the tiltering criterion (safety coefficient η >2.0, Fig. 6) is then:

$$B_{50} = \frac{O_{90}}{d_{50}} < (1{,}1 - 2{,}1).$$

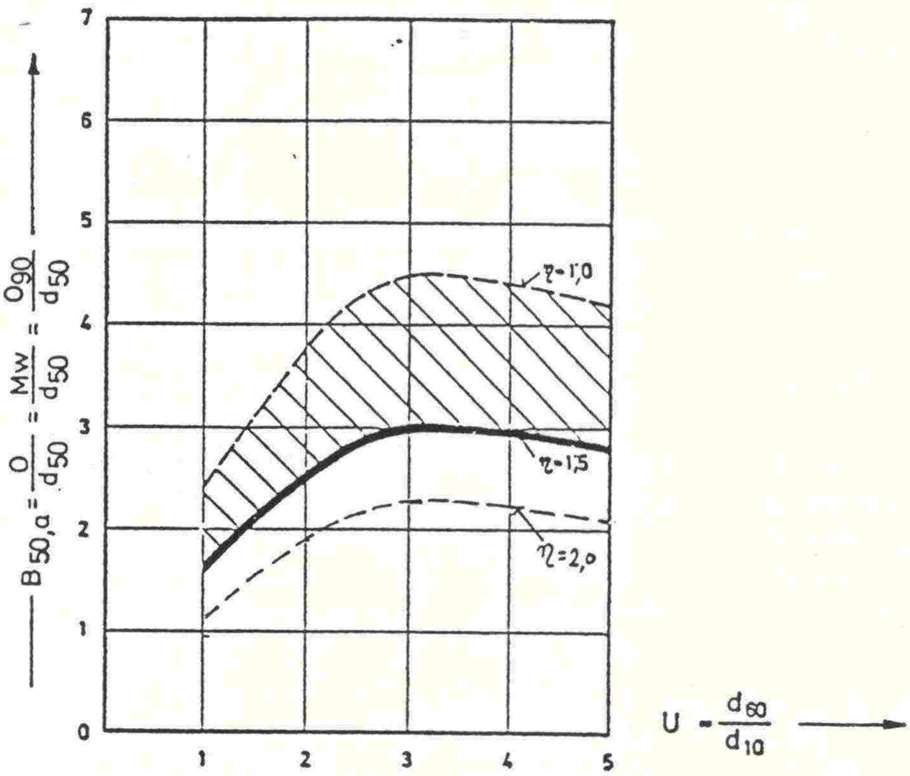

Fig. 6. Mechanical filter requirements for strip drain filter in subsoils com posed of silt and sand (Schober, Teindl,1979).

3.3.5 Hydraulic efficiency of filters

The perpendicular water permeability of the filter must be at least equal to the horizontal water permeability of the surrounding soil to allow pore water to discharge into a vertical drain.

To allow a free flow of water, the water permeability of the filter should remain higher than that of the soil layer when the filter is subjected to long-term flow, despite the accumulation of fine material into the filter pores and the compression caused by loading.

As the filter is thin with respect to the dimensions of the vertical column of soil to be drained (distance between drains), changes in its water permeability usually have relatively little effect on the permeability of the soil-filter composit.

The water permeability of the fabric may decrease drastically when the holes in the filter fabric are clogged by fine material, in which case the size of the soil particles in relation to the pore size plays an important role (Section 3.3.3). Water permeability may decline by as much as 3 - 4 decades, depending on the type of geotextile and soil involved. The decline in the original water permeability of geotextiles of thickness less than 2 mm is presented in Fig. 7 as a function of the grain size d_{10} of the subsoil.

As indicated by research carried out in the Netherlands (Oostveen, 1986), the maximum flow rate in strip drains is 0.5 - 5 ml/s. As this quantity is estimated to accumulate evenly in a drain of length 10 - 20 m, the rate (v_o) at which water flows through a filter with a surface area of 0.2 m/metre of drain is:

$$v_o = 1{,}25 \ldots 2{,}5 \cdot 10^{-6}\ \text{m/s}.$$

If the filter is regarded as causing a maximum pressure loss of 50 mm, the following minimum value is obtained for its required long-term permittivity (Ψ):

$$\Psi > (25 - 50) \cdot 10^{-6}\ 1/\text{s}.$$

Taking into consideration the reduction of water permeability in time as a result of some of the pores becoming clogged up with soil, the initial permittivity of a clean filter should be (depending on drain length):

$$\Psi > (2{,}5 - 5{,}0) \cdot 10^{-3}\ 1/\text{s}.$$

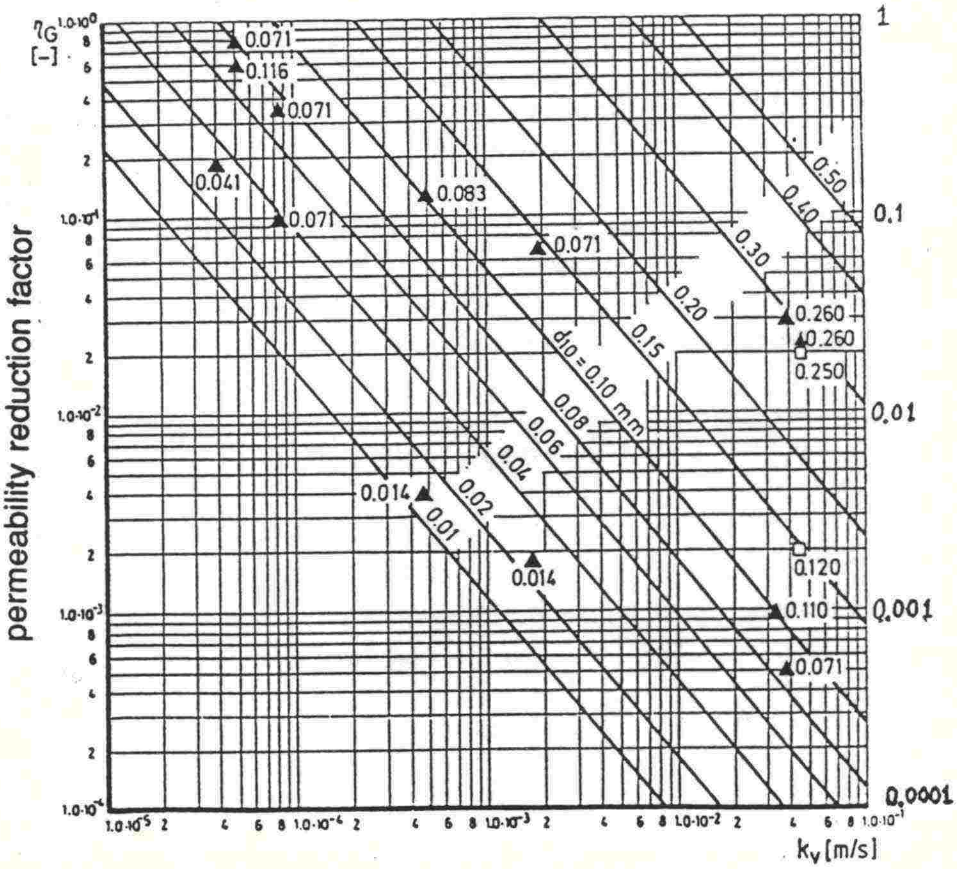

Fig. 7. Effect of subsoil grain-size (d_{10}) on the long-term permeability of geo textile filters of thickness <2 mm (DVWK Schriften 76, 1986), where k_v is the initial water permeability of a clean filter.

3.4 Long-term reliability of strip drains

3.4.1 Preconditions

Vertical drains are usually expected to function for 2 - 3 years. The creation of settlements in accordance with the schedule set requires that the drains maintain a sufficient operating function throughout the time reserved for consolidation. Maintenance of the operating function of strip drains is dependent on the following factors:

1) No deformations should be created in the drain cross-section which would prevent the flow of water (e.g. compression of the drain core as a result of sharp bending of the strip).

2) Pressing of the filter against the core of the drain should not excessively reduce the effective cross-sectional area.

3) The filter should remain unbroken (mechanical and chemical stresses).

4) The filter should not become clogged by soil accumulating inside and behind it, and

5) The amount of soil entering the drain and forming deposits inside it should remain sufficiently small.

Compliance with preconditions 1 - 3 above requires that the strength of the core and the filter materials should not decline excessively during the time of operation of the drain.

The reliable long-term operation of vertical drains requires that the quality criteria discussed in Section 4.4 should be met and the drains be installed properly.

3.4.2 Long-term strength

Conventional polymer plastics, i.e. polyester, polyethene and polypropylene, are used as the raw materials for strip drains. The ultimate tensile strength of polymer plastics is primarily dependent on the type of plastic employed, the duration of loading and temperature. A plastic fibre will creep once it has exceeded a given tension level, i.e. the degree of deformation will increase in time and ultimately lead to tensile failure, if the critical loading period which corresponds to the stress and temperature involved is exceeded.

The correlations between the strengths of the most common types of plastic used in geotextiles and the loading period are presented in Fig. 8. Susceptibility to creep increases in the order polyester, polyamide, polypropylene and polyethene, where the last-mentioned will endure long-term loading only at low levels of tension (not included in Fig. 8).

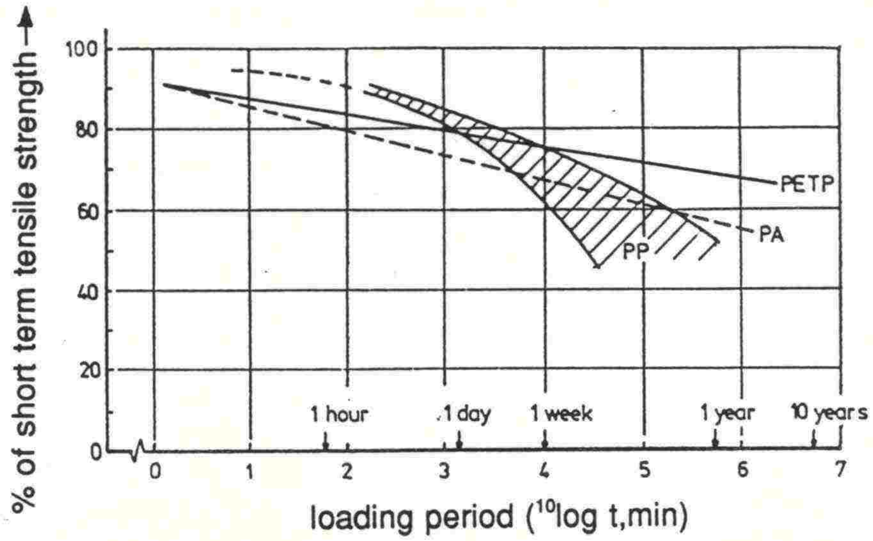

Fig. 8. Effect of loading period on the ultimate tensile strength of polyester (PETP), polyamid (PA) and polypropylene (PP).

A decrease in loading rate will increase the deformation at break of polypropylene and polyethene, but will not affect that of polyester and polyamid.

Fig. 9 shows the effect of loading period and temperature on the ultimate tensile strength of polypropylene, expressed as a proportion of short-term tensile strength. Curves corresponding to temperatures of 10°C - 70°C were estimated from short-term strength values and the curves obtained for the temperature range 90°C - 110°C (Wisse, 1988). An increase in the level of tension is accompanied by a decrease in the loading period leading to failure, i.e. when the long-term stress is 50% or 40% of the short-term failure strength the loading periods which lead to failure at a temperature of 10°C are approx. 0.25 yr. or 2.5 yr. respectively. The long-term strength of polypropylene which corresponds to the operating life of a strip drain is thus approx. 30 - 40% of its short-term tensile strength.

As indicated in Fig. 9, the temperature-oxidation stability of polypropylene is decisive from the point of view of its strength at low tensions (less than 10 - 20% of short-term tensile strength), in which case the stability of the material in the subsoil at a usual temperature of 10°C is sufficient for a loading period which exceeds 200 years. Geotextiles become fragile as a result of oxidation.

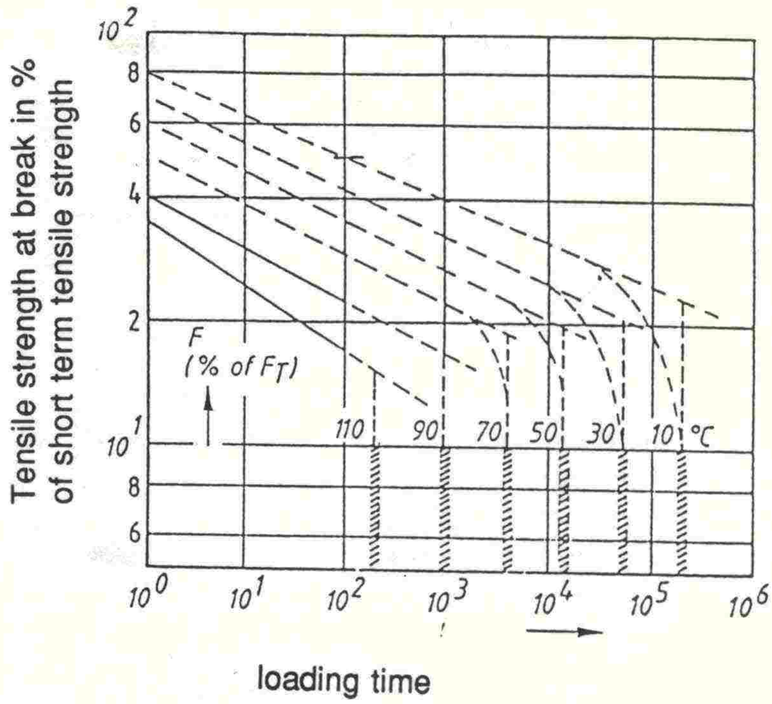

Fig. 9. Polypropylene strength as a function of loading time and tempera ture (Wisse, 1988).

Creep in the plastic material may contribute to deformations in the core of the drain strip if the loading caused by soil pressure is imposed on the core in an uneven manner, i.e. at a given point on the strip, or if the shape of the core is unsuitable. If the core provides inadequate support for the filter, concentrations of tensile forces will develop in the latter, which may lead to increased creep (stretching) and collapse of the filter into the flow channels.

3.4.3 Chemical durability

The conventional types of plastic used in drain strips are unprotected and sensitive to ultraviolet radiation. Long-term exposure to such radiation causes the plastic molecules to disintegrate, resulting in embrittlement of the material. Polypropylene and polyethene are the most sensitive to light, but all types of plastic endure sunlight fairly well if UV-stabilized. The thermal stability of various types of plastic is good in short-term storage.

Table 2 shows structural and material data on drain strips approved for use in Finland.

Table 2. Structure and material composition of drain strips approved for use in Finland.

Strip drain	Mebra-Drain 7407	Colbonddrain CX 1000	Tenax VDR 100	Flodrain FD 6 x 100	Amerdrain 407
nominal mass, g/m	76	67		85	80
measured mass, g/m	65-83	66.5 - 75	85 - 86	87 - 109	105
core					
material	PP	PET	HDPE	HDPE	PP
construction	straight channels	open structure	3-D mesh	egg-box type	straight channels
filter					
material	PP	PET	PP	PP	PP
nominal mass g/m²	136	180		136	136
type	Typar 3407	Colbond	Typar	Typar 3407	Typar 3407

Drain strips should also be protected from UV-radiation at the working site if the coils are not supplied in UV-protected (plastic) packages.

The chemical resistance of the types of plastic used in strip drains to microbial action, for example, has been found to be good in an uncontaminated subsoil, but insufficient data are available on their durability in contaminated soils, which may contain soluble metals, for instance. High concentrations of iron in groundwater increase the risk of blocking of the filter pores.

4. DRAIN STRIP APPROVAL CRITERIA

4.1 Strength criteria

4.1.1 Tensile strength

A drain strip should withstand a short-term longitudinal tensile force of at least 1.0 kN imposed evenly on its cross-section. Both the core and filter of the strip should operate in a flexible manner, and the longitudinal deformation at break or the strain at maximum tensile strength should be at least 15%.

The ultimate tensile strain of both the core and the filter should be at least 30% if the vertically drained subsoil is subjected to frost-heave or plastic deformations.

The attachment of the drain strip to the anchor plate and the junction of the strip should withstand at least the same tensile force as a straight strip (1.0 kN) without any breaking or rupturing which would hamper its operation.

4.1.2 Compression of drain strip

The maximum permitted transverse compression of a strip under an even load of 125 kPa is 30% of its original thickness over a period of 30 d, as indicated by a compression test in which the strip is placed between two stiff plates. The allowable maximum compression rate under the above load may be 0.05 mm / 30 d over a period of 30 - 60 d.

It should be possible to bend the strip until a sufficiently small bending radius is reached without causing any breaking or flattening of its core (R_{min} = 5 mm), breaking of the filter or rupture of its seam.

4.1.3 Strength of the filter sleeve

The minimum longitudinal and transverse tensile strength of the filter material must be 3.0 kN/m and the elongation at break at least 15%, or 30% when exposed to frost-heave. The transverse tensile strength of the filter seam and the seam between the filter and the core should be at least 1.5 kN/m and the mean elongation at ultimate tensile strength of a filter with seam at least 10%. The shear deformation at break of the seam should be at least 10%.

4.2 Discharge capacity criterion

When the depth to which the vertical drains extend is less than 20 m and the consolidation time more than 1.5 years, the minimum discharge capacity (defined under laboratory conditions) q_w = 1m ml/s at a 125 kPa lateral loading. When the drainage depth is more than 20 m, the relative settlement over 15% and the consolidation time less than 1.5 years, discharge capacity should be at least 20 ml/s with a lateral loading of 250 kPa.

The discharge capacity of a curved or buckled drain strip must be at least 75% of that of the corresponding straight strip. The radius of curvature of a curved drain strip is 5 mm.

4.3 Filter approval criteria

4.3.1 Mechanical efficiency

The effective pore size of thin, non-woven geotextile filters used in non-cohesive soils (primarily medium-coarse and coarse silts) should be

$$O_{90} < (1.5 - 2.8)d_{50},$$

where O_{90} = effective filter pore size,
d_{50}, d_{10}, d_{60} = grain sizes in subsoil.

If the subsoil is thought to be susceptible to internal erosion, i.e. the soil is mainly composed of medium-coarse and coarse silts, the effective pore size should be (safety coefficient η > 2.0, Fig. 6)

$$O_{90} < (1.1 - 2.1)d_{50}.$$

The condition

$$O_{90} < d_{85} \text{ and } O_{90} < 0.15 \text{ mm}$$

can also be employed in the case of soils which are problematic from the point of view of filter function, and

$$O_{90} < 0.15 \text{ mm}$$

for other soils.

4.3.2 Water permeability

The initial water permeability (k) of a filter sleeve must be at least 50 times higher than the horizontal permeability of the primary soil at the vertical drainage site. Minimum permeability is

$$k = 0{,}10 \text{ mm/s}.$$

The initial permittivity of the filter (ψ) must be at least $5 \cdot 10^{-3}$ 1/s.

4.4 Summary

The determination of the properties of drain strips for quality control purposes and the values deemed acceptable for them are presented in Table 3.

Table 3. Determination of the properties of drain strips and their critical values.

No.	PROPERTY	SYMBOL	UNIT	REQUIRED VALUE AVERAGE	REQUIRED VALUE MINIMUM	NUMBER OF TESTS type inspection	NUMBER OF TESTS project-related
	Strength and dim. of drain strip						
1	Width	B	mm	nominal	nom. - 5 %	> 10	3*N
2	Equivalent diameter	De	mm	nom.	nom.	> 10	
3	Dry mass	Wo	g/m	nom.	nom. - 10 %	> 10	3*N
4	Thickness at 20 kPa (dry)	T20	mm	nom.	nom. - 10 %	> 10	5*N
5	Thickness at 125 kPa, t=30d	T125	mm	0.7T20	0.7T20	3	2 E1
6	Compression rate at 125 kPa, between 30...60 d (w)	dT125/dt	mm / 30d	< 0.05	< 0.05	3	2 E1
7	Tensile strength (d)	Pu1	kN	1.0	0.9	5	2 E1
8	Tensile strength (w)	Pu2	kN	1.0	0.9	5	
9	Strain at break (d)	Eυ1	%	15 (30)**	15 (30)**	5	2 E1
10	Strain at break (w)	Eυ2	%	15 (30)**	15 (30)**	5	
11	Tensile strength when bent (w)	Ptb	kN	2.0 remaining undamaged		2	1 E1
	Strength of filter sleeve (wet)						
12	Thickness at 2 kPa (d)	Tg	mm	nom.	nom. + 10%	> 10	5*N
13	Tensile strength, longitudinal	Pu3	kN/m	3.0	3.0	5	
14	Strain at break, longitudinal	Eυ3	%	15 (30)**	15 (30)**	5	
15	Tensile strength, transverse	Pu4	kN/m	3.0	3.0	5	2 E1
16	Strain at break, transverse	Eυ4	%	15 (30)**	15 (30)**	5	2 E1
17	Tensile(transv.) and shear strength of seam	Pu5	kN/m	1.5	1.5	5	2 E1
18	Seam strain at break	Eυ5	%	10	10	5	2 E1
	Discharge capacity of drain (at 125 kPa, T=20°C)						
19	at 100 mm water head	qw1	ml/s	10	8	3	
20	at 200 mm water head	qw2	ml/s	10	8	3	
	Water permeability of filter (unloaded, T=20 C) 1)permeability						
21	at 30 mm water head	k1	mm/s	50ksoil	0.10	3	
22	at 50 mm water head	k2	mm/s	50ksoil	0.10	3	
	2)permittivity						
23	at flow velocity of 10 mm/s	Ψ1	1/s	0.0050	0.0050	3	
24	at flow velocity of 20 mm/s	Ψ2	1/s	0.0050	0.0050	3	
	Effective opening size of filter material (hydrodynamic sieving, mass fraction method)			depending on soil type O90 < 0.15 mm)1 O90 < 0.15 mm and O90 < d85soil)2 or O90 <(1,1...2,8)d50soil)2			
25	effective opening size	O90	mm			3	2 E1
26	effective opening size	O95	mm			3	

**when the drain is exposed to frost-heave

LEGEND :

E1 tests shall be performed only if the quality of the drain is assessed to considerably deviate from the quality observed in type inspection tests.

N number of samples

)1 in soils that are considered usual from the point of view of filtering technique

)2 in silty soils that are considered problematic from the point of view of filtering technique

5. PROCEDURES FOR DRAIN STRIP QUALITY CONTROL AND THE SUPERVISION OF VERTICAL DRAINAGE WORKS

5.1 Purpose

The aim of quality control is to ensure that the strips are used in accordance with the design, that they meet the quality requirements set and that the work is carried out in a manner which is practicable from the point of view of the long-term functioning of the drains.

5.2 Material quality control

5.2.1 Type inspection

Type inspection involves examining whether a drain strip meets the quality requirements presented in Section 4.4.

If the aim is to use strip drain on which insufficient quality data are contained in the objective test results available, the material should be subjected to type inspection, which involves measurement of its mechanical and hydraulic properties by means of the tests discussed in Section 6, also taking the soils of the drainage site into account where necessary.

The type inspection tests should be carried out in sufficiently good time before the commencement of vertical drainage to ensure that the strip type which lends itself best to use at the site concerned can be selected.

A minimum of five strip samples should be obtained from the stock of the relevant agent or subcontractor for type inspection. All sampling and testing must be carried out by an independent test institute approved by the builder and the samples must be taken at random in such a manner that they provide as exhaustive a picture as possible of the batches delivered or manufactured.

5.2.2 Project-specific quality control during installation

The purpose of quality control during the actual installation of the vertical drains is to ensure that the strip drain employed at the site has been type-inspected, meets the quality requirements and is of a sufficiently homogeneous quality.

A representative of the builder should check all drain strip batches as they arrive at the site. The builder should have access to detailed data on the items concerned, i.e. type inspection results and a tested specimen.

Acquisition of samples

The quality of the material should be monitored both visually and using samples taken from the site

1) immediately upon the commencement of vertical drainage,

2) at intervals of approx. 50,000 metres of drain in the course of the work, at least one sample being taken from each batch to arrive at the site,

3) whenever defects in strip drain quality are observed or excessive fluctua tion in quality is suspected.

A minimum of 5 samples of length of approx. 5 m should be taken from the coiled strip drain under installation at the lower end of the protective mandrel in the drain stitcher, one from the end (inside) of the coil and the others from three spots selected at random from 4 coils. The sampling data should be recorded on the form shown in Appendix 8, which should be enclosed with the samples.

The builder or contractor should send the samples to an independent quality control institution for inspection of the product and for possible quality control tests.

The samples obtained are then compared with the type-inspected drain strip concerned both visually and by performing the necessary measurements. Samples taken at the beginning of the draining work may also be subjected to laboratory tests of the kind discussed in Section 6 if necessary in cases where qualitative identity of the drain strip with the type-inspected strip cannot be ensured by any other means. Should a drain strip which has not been type-inspected be taken into use, the samples taken from it must be subjected to all the tests performed in type inspection.

Drain strip storage

Drain strip material should be stored in a manner that ensures that it maintains its original physical properties and remains undamaged, i.e. that it is protected from UV radiation and freezing and that the coils are not damaged or fouled during storage or transportation. Storage conditions should be inspected in connection with sampling, observing at least the following factors:

- batch identification data: coil numbers, date and place of manufacture, supplier,
- storage time at the site,
- quantity stored,
- protection against light if stored for more than 1 month,
- protection against damp and freezing,

- undamaged condition and qualitative homogeneity upon visual inspection by random sampling at both ends of the coil.

Storage inspection data and related observations should be recorded on a record form (Appendix 11) and the working site diary.

5.3 Properties required of a drain stitcher

The protective mandrel, coil stand and strip path should be appropriate for the drain strip employed.

The minimum radius of the guide rollers must be in line with the instructions given by the drain strip manufacturer. Otherwise the smallest permitted radius R_{min} = 50 mm.

The strip drain should be released from the coil and guided through the mandrel in such a manner that it is not twisted, bent or ruptured and the tension applied to the strip should be distributed as evenly as possible throughout the drain profile. The inner surface of the strip path must be smooth and the edges of the holes and guiding loops rounded. The drain strip should be guided upwards from the coil to the upper end of the mandrel inside a pipe, e.g. a D = 120 mm plastic pipe. The edges of the reel may be either solid or open and manufactured of round or round-edged tubes. The inner dimensions of the coil should match the reel in order to prevent the coil from swerving in a vertical or lateral direction as it turns.

The turning friction of the strip coil and the guide roller must remain small and its magnitude be inspected at regular intervals. Normal passage of the strip can be inspected by pulling some of it through the pipe manually, in which case it should travel easily.

An attempt should be made when driving the mandrel in to any dense filling layer or other hard soil layer, stone or obstacle which increases resistance, to pass such deposits with particular care in order to avoid damaging the anchor plate or producing thrusting movements of the mandrel.

The freezing of water inside the mandrel should be prevented.

The mandrel should be lifted in an even, continuous manner. Successful anchoring can be checked by holding the strip tight during the lifting process.

5.4 Quality control of vertical drainage works

The successful functioning of vertical drains requires the use of good quality drain strips and appropriate installation. Special attention should be paid to avoiding any break in the strip, avoiding unnecessary subsoil disturbance and ensuring that the drains correspond in location and depth to the original design.

5.4.1 The anchor plate and its attachment

The contractor must ensure before commencement of the vertical draining work that the anchor plate selected is suitable for use in the soil concerned, i.e. it has a sufficient anchoring capacity and it does not cause unnecessary soil disturbance in the course of its introduction into the soil. It should be of a surface area (projection when folded) which does not exceed the cross--sectional area of the mandrel to any appreciable extent. The maximum width of the plate parallel to that of the strip should be < 170 mm. Slightly larger anchor plates up to 2.5 times the cross-section of the mandrel can be used under difficult subsoil conditions, but their surface area should nevertheless not exceed 200 cm^2.

Test drains should be constructed to ensure controlled folding of the anchor plate around the mandrel and reliable anchoring of the strip drain at the required depth in a soil layer which represents the desired base conditions.

The drain strip attachment and the loop of the folded anchor plate should be capable of withstanding a short-term tensile force of 1.0 kN without coming loose.

The contractor should have the anchor plate and strip attachment approved by the builder, and the means of attachment employed should be easy and rapid to implement, not require any special care or skill and allow successful attachment to be confirmed immediately. The strip must be kept tight during the removal of the mandrel to ensure anchoring.

The anchor plate must come away from the end of the pipe immediately once lifting of the mandrel commences, and the geotechnical resistance of the plate with respect to the tensile forces imposed on it at the lifting stage should be sufficient to prevent the lower end of the drain from moving upwards. The anchoring capacity of the plate should also be activated by means of a sufficiently small movement (maximum 50 mm), even when the plate is installed in a soft soil layer.

5.4.2 Drain strip junction

A drain strip junction should correspond as well as possible to the unextended strip in terms of its functioning. Water must flow freely through it, and it should not cause clogging of the drain, i.e. the filter extension joint must be sufficiently tight.

The contractor should construct the extension in accordance with a method approved by the builder. The mechanical strength of the extension can be tested on site by attaching one end of the strip to a solid object and applying a short-term pull of at least 1 kN using a spring scale, for example. The extension should withstand this load without breaking.

A preferable means of constructing a junction is to install the end of a coiled strip inside a new coil for a stretch of approx. 200 mm, preferably without cutting the filter open at the side. The extension can then be attached by stapling the overlapping parts of the two coils together evenly and sealing the opened edge of the filter with a denser row of staples. The power of the stapler should be adjusted such that the staples do not compress the core of the strip.

5.4.3 Requirements for mandrels

A mandrel employed in the installation of a strip drain should be

a) of sufficient stiffness with respect to buckling and wear to prevent excessive tilting or curving of the drain when being inserted into the ground,
b) of small cross-sectional area ($A < 85\ cm^2$), to reduce subsoil disturbance, and
c) straight and with a smooth inner surface.

The end of the mandrel should be shaped with the folded anchor plate in mind, i.e. to minimize lateral soil displacement during installation.

The entry of soil into the mandrel and the formation of ice inside it should be prevented, and any ice that does enter the mandrel should be removed.

5.4.4 Drainage depth and log-book

Implementation of the desired drainage depth is supervised by means of a vertical drainage record maintained by either the contractor or the builder (Appendix 10). At least the following data should be recorded on it:

- identification data for each batch of draining strip,
- draining depth, indicated sufficiently frequently (max. depth of the end of the mandrel from the surface) and corresponding drain location (line position),
- anchor dimension data,
- location and inclination deviations where they exceed the agreed limits,
- measures to be taken in exceptional cases such as the replacement of faulty drains, deviation from the aims, causes of this and corrective measures,
- quality defects in the strip and measures to be taken,
- drain strip samples and quality inspection results,
- designation of drain strip quality control (observations recorded on a separate form, Appendix 8).

6. LABORATORY TESTS IN TYPE INSPECTION

6.1 Strength and elasticity of drain strips

6.1.1 Purpose

The aim of these instructions is to present methods for measuring the strength and deformation properties of drain strips and the requirements set for these.

The methods can be applied to drain strips of all types, with a maximum width of 105 mm. The instructions discussed here comprise means of measuring strength and deformation and calculation methods which can be applied to the results obtained.

6.1.2 Range of tests

The instructions cover the following tests

Test A. strip tensile test,
Test B. filter tensile test,
Test C. bent strip tensile test.

6.1.3 References

ISO/DIS 10319 Geotextiles, Wide-width tensile test. International Organisation for Standardisation 1991.

6.1.4 Definitions

Preload

Force required for the straightening of the sample before tensile tests A and B. Magnitude 50 N, applied for 60 s.

Tensile strength

The maximum force (kN) measured in a tensile test (test A per sample cross-section) or the maximum force measured (kN/m, test B).

Measurement length

Measurement length corresponds to the distance between the clamping jaws by means of which the test specimen is attached to the testing apparatus. Its initial value is 100 mm.

Should some other means of attachment be employed, measurement length denotes the distance between two measurement points marked on the test specimen in the direction of jaw movement.

Measurement length increment is the change in the distance between the measurement points, less the increase caused by preloading.

Strain

The relation between the measurement length increment observed during the tensile test and the original measurement length (%).

Strain rate

The strain rate denotes the speed at which the distance between the jaws (measurement length) increases in an even manner, expressed as a percentage of the original measurement length.

6.1.5 Testing equipment

Tensile apparatus

The jaws should move at an even rate and should be adjustable according to the length of the specimen tested. Their width should be at least 100 mm, i.e. the same as that of the drain strip.

The specimen can be attached to the jaws either by clamping or by means of wedges. The jaws should be sufficiently rigid to allow even application of the clamping force over their entire surface, and the friction surfaces should be parallel.

The clamping force of the jaws should be sufficient to prevent the test specimen from sliding, but not cause any deformation or damage which could affect the test results.

Measurement of strain

Strain in the test specimen is measured in terms of the average change in the distance between the jaws of the testing apparatus, assuming that the specimen does not slip in the jaws.

If the slipping cannot be prevented entirely, strain can be measured by marking two points on the specimen each 50 mm from its centre with respect to the jaws, giving a measurement length of 100 mm in the direction of jaw movement. Strain is now measured in terms of the average change in this measurement length.

6.2 Implementation of the tensile test

6.2.1 Test specimens

Test specimens of length 200 mm are cut perpendicular to the longitudinal direction of the drain strip.

A minimum of 5 parallel test specimens are taken at random from the strip drain batch to be examined or from the set of samples obtained in the course of project-specific quality inspection so as to be as representative as possible of the overall quality of the drain strip material.

6.2.2 Testing conditions

Both dry and wet specimens (5 + 5 pcs) should be subjected to tensile tests at a temperature of 20±2°C and a relative humidity of 65±2%. The dry specimens should be allowed to stabilize under the test conditions, while the wet ones should be kept immersed in water at a temperature of 20±2 °C for a minimum of 24 h immediately before the test.

6.2.3 Testing procedures

The strip specimen of length 200 mm is placed in the testing device so that it is longitudinally exactly parallel with the direction of movement of the jaws. The distance between the jaws is then set at 100 mm and the specimen is placed centrally between them. The specimen is pulled tight manually when closing the jaws so that its entire surface area is flat upon commencement of the actual tensile test.

The jaws should be tightened to such an extent that the test specimen cannot slide between them when the maximum tensile force is applied. Thin lines should be drawn on the specimen along the edges of the jaws to check for sliding.

The tensile force employed is increased to the preload level, i.e. 50 N, and maintained for 1 minute before the actual test pull. The resultant strain is adjusted to zero before performing the actual test.

The strain rate is usually 20% / min, i.e. 20 mm / min.

Tensile force and changes in length during the test are plotted in the form of a continuous curve or dots placed at a sufficient density to allow a reliable graph to be drawn. The maximum tensile force achieved in the test and the corresponding strain (length increment) are marked on the graph in figures. The test is continued until the specimen breaks or alternatively until it has reached a deformation of 60 mm with no obvious breaking point to be observed. Once the maximum force has been achieved, thin lines are drawn along the edges of the jaws. Once the specimen begins to break, the value for the breaking strain is recorded.

Tensile force is measured to an accuracy of 0.2% and strain (%) to an accuracy of one decimal.

If the breaking point is within 5 mm of the edge of a jaw or if the corresponding breaking load is less than 50% of the average load indicated by other tests, the results must be discarded and the test repeated since the break was evidently attributable to damage caused by one of the jaws.

6.2.4 Evaluation of test results

Tensile strength

The tensile strength of a vertical drain strip denotes the maximum force measured during the test (P_{u1} for dry specimens, P_{u2} for wet ones). The approved minimum tensile strength is 1.0 kN.

Strain

Strain (ε) is calculated from the formula

$$\varepsilon = \frac{\Delta L}{L},$$

where L = length increment
L = original measurement length (jaw distance).

The strain corresponding to the breaking force or the maximum force measured must be at least 15% and that produced at a tensile force of 1.0 kN must be less than 15%.

Analogously, the strain corresponding to breaking of filter structure should be at least 15%.

If the vertical drain is likely to freeze under its operating conditions, the breaking strain of the strip and the filter should be at least 30%.

6.2.5 Test reports

A strength test report should contain the following data:

1. the instructions followed and any deviations from the testing procedure specified in these,

2. accurate data on the specimens tested, including sampling,

3. average tensile strength (and standard deviation) and number of parallel tests,

4. average strain corresponding to this tensile strength, and standard deviation,

5. average strain corresponding to a force of 1.0 kN and its standard deviation,

6. complete force-strain graphs,

7. testing conditions,
   - dry/wet samples
   - temperature

8. for the testing device,
   - type and model,
   - jaw type and model,
   - initial jaw distance,
   - strain rate (%/min)

(9. deformation of the test specimen beside the jaws, to estimate slippage where necessary).

6.3 Compression tests

6.3.1 Completion of tests

At least three specimens selected at random from the set of samples should be subjected to a compression test. The specimens should be kept immersed in water at 20±2°C and their initial thickness measured at a load of 20 kPa.

Two test specimens should be loaded as such and one when placed between uniformly compacted 10 mm layers of sand of grain-size 0.5... 1.2 mm, both above and below it. A circular plate of D = 90 - 100 mm should be employed as a loading surface.

The load on the two specimens without sand layers is imposed in two steps, i.e. a preload followed by the actual dimensioning load. The former involves a load of 20 kPa for a duration of 1 h, and the latter a nominal load of 125 kPa for 60 days (minimum 30 days). The actual dimensioning load is selected by reference to the soil pressure to be imposed on the drain strip under the operating conditions concerned.

The sand-specimen-sand composite is subjected initially to loading steps of 20 and 50 kPa, 30 minutes per step, after which the load is increased to 125 kPa for 60 d.

A comparative consolidation test should be conducted on a 20 mm sand layer to examine the compression of the sand. The layers must be precompacted carefully to ensure maximum comparability between the results. The specimens and sand layers are kept immersed in water throughout the tests.

Compression values are recorded at the beginning of the test in the same intervals in time as in a conventional consolidation test, and the test is continued for 60 days or until a compression rate less than 0.05 mm / 30 days has been reached.

6.3.2 Processing of the results

The results obtained for the 3 specimens are presented in the form of compression-time and thickness-time graphs. Final sample thicknesses are recorded at the end of the 60 day testing period and the relative compression is calculated.

The final thickness of the specimen in the sand-specimen-sand combination ($T_{125,60}$) is calculated from the formula

$$T_{125,60} = T_{20} - [(\delta_{HNH125} - \delta_{HNH20}) - (\delta_{H125} - \delta_{H20})],$$

where T_{20} = initial thickness of test specimen at load 20 kPa,
δ_{HNH125} = final compression of the sand-specimen-sand sample at load 125 kPa, t = 60 d,
δ_{HNH20} = compression of the sand-specimen-sand sample at load 20 kPa, t = 30 min,
δ_{H125} = compression of the 20 mm sand layer at load 125 kPa, t = 60 d,
δ_{H20} = compression of the 20 mm sand layer at load 20 kPa, t = 30 min.

6.4 Tensile tests on the drain filter sleeve

6.4.1 Longitudinal tests

6.4.1.1 Test specimens

The specimens selected at random from the strip drain batch under examination should be of length 200 mm in the longitudinal direction of the strip. If the filter is attached to the core of the drain, the sample should be cut along the edges of the attachment to be as wide as possible, so that they will be similar in width, which is then measured (B). The maximum permitted deviation between the widths of specimens is 1 mm, and the nominal width 100 mm.

6.4.1.2 Tensile tests

Filter samples should be subjected to longitudinal tensile tests in cases when their strength properties cannot be identified from the results of the tensile tests performed on complete vertical drain strips.

The tests are conducted in the same manner as for vertical drain strips and using the same equipment (see Section 6.2.3).

6.4.1.3 Processing and evaluation of results

The longitudinal tensile strength P_{u3}(kN/m) is calculated from the formula

$$P_{u3} = \frac{F_{max}}{B},$$

where F_{max} = maximum tensile force measured, kN,
B = width of test specimen, m.

The minimum longitudinal tensile strength of the filter material must be 3 kN/m and its structural breaking strain at least 15%.

6.4.2 Cross-sectional tests

6.4.2.1 Test specimens

A total of 10 cross-sectional pieces of width 100 mm are usually cut at random from the strip batch under examination, the actual number being relative to the size of the batch concerned.

The filter specimens should be removed from the core of the drain strip in such a manner that they maintain their width as well as possible (minimum 90 mm). Five filter specimens should be split by removing their seams, which are left in place at the centre of the other five specimens. The seam may act to join the filter to the core of the drain.

Minimum dimensions of the test specimen are 100 mm x 90 mm.

6.4.2.2 Tensile tests

The specimen is placed on the testing device in such a manner that the direction of tension is perpendicular to the longitudinal direction of the strip. The width of the specimen should be 100 mm and its length in the direction of tension at least 90 mm. The junction of a seamed specimen is placed in a horizontal position and centrally with respect to the jaws.

The distance between the jaws is 50 mm and tension rate 10 mm/min. The test specimen is straightened by hand before tightening the jaws, and the test is continued until the specimen breaks. The strain corresponding to structural failure in the filter, i.e. a marked increase in pore size, is recorded. In other respects the instructions given in Section 6.2.3 apply to this test, which is primarily conducted on wet test specimens (Section 6.2.2).

6.4.2.3 Processing and evaluation of results

Tensile strength is calculated as in Section 6.4.1.3. The cross-sectional tensile strength of seamless filter material must be at least 3 kN/m, and that of seamed material at least 1.5 kN/m.

The minimum strain of a seamless filter which corresponds to structural tensile failure should be at least 15%, while that of a seamed filter should be at least 10%. A seamed filter should have an average minimum strain upon shearing failure along the seam of the filter of 10%.

Apart from item 5, the results of the tensile tests are presented in accordance with Section 6.2.5.

6.5 Bent drain strip tensile test

6.5.1 Purpose

The bent tensile test is used to examine the deformation capability of drain strips and its tensile strength when bent. The test provides data on stresses imposed on the anchor plate attachment and deformations which occur when the strip buckles due to settlements in the subgrade. It can also be used where necessary to examine the strength of a drain strip junction.

6.5.2 Test specimens

A total of 3 specimens of length 500 mm should be selected at random from the strip drain batch. These should be kept immersed in water at 20±2°C for at least 24 h prior to the tests.

6.5.3 Implementation of the test

A bent tensile test involves the use of special jaws in which the radius of curvature of the strip is 7.5 mm (adjustable if necessary).

The ends of the specimen are attached to each other by means of a compression piece and should be parallel with each other at this point. A drain strip loop of approximate length 440 mm is placed centrally in the jaws of the testing device, which are set at a distance of 200±10 mm apart.

A strain rate of 20 mm/min is employed, the tensile force being increased to 2.0 kN and then applied constantly to one specimen for 20 minutes and to two specimens for 1 minute each. Deformations at the bends in the strip are observed during loading and the average strain is measured continuously in terms of the change in the distance between the axes of the jaws. The results are presented for the entire loading period in the form of a force-strain graph.

Any deformation or damage can be observed once the load has been removed. If the bends in the strip are obviously compressed, their thicknesses should be measured in such a manner that the results obtained are directly comparable to the thickness of a straight drain strip.

The tests can be continued if necessary until the test specimens break.

6.6 Measurement of the discharge capacity of vertical drain strips

6.6.1 Purpose and principle

A method is presented here for measuring the longitudinal discharge capacity of a drain strip of maximum width approx. 100 mm which is subjected to a dimensioning transveric load or the compression which corresponds to the dimensioning load employed. The values selected for the dimensioning load and measurement flow should describe the operating conditions in a drain sufficiently well in each case. The nominal load is 125 kPa, and laminar flow is assumed.

6.6.2 References

Oostveen, J.P. and Troost, G.H., Discharge index tests on vertical drains. 4th International Conference on Geotextiles, Geomembranes and Related Products. The Hague, Netherlands 1990.

ASTM Designation: D4716-87. Standard Test Method for Constant Head Hydraulic Transmissivity of Geotextiles and Geotextile Related Products. Approved August 19, 1987.

6.6.3 Definitions

Discharge capacity q_w [l/s] denotes the amount of water of a given hydraulic gradient which flows longitudinally through the drain cross-section during a given unit of time.

Hydraulic gradient dh/dl[-] is the change in hydrostatic pressure (pressure loss) per horizontal unit of flow channel length.

Laminar flow involves the flow of water particles primarily in one direction only, the resulting pressure loss correlating directly with the flow velocity.

6.6.4 Testing equipment

The device used to measure discharge capacity should have the following properties:

- the upper and lower water tanks must be at least 100 mm in width, i.e. of the same width as the vertical drain specimen, and the height of the for mer tank should be at least 400 mm

- the even, cross-sectional load must be adjustable between 0 - 250 kPa

Other equipment and material

- dial gauge for the measurement of drain sample thickness (accuracy 0.01 mm)

- a measuring tank sufficient to hold the amount of water which flows through the drain during 30 s

- equipment or chemicals required for water deaeration

- a stopwatch, thermometer, balance

- elastic sealing compound (non-permeable and non-soluble)

Two intermediate plates of thickness 5 mm, width 100 m and length 305 mm consisting of non-permeable material such as PE plastic are also required for the bent specimens, together with thin, tough plastic film with which they can be surrounded.

6.6.5 Test specimens

Specimens should be selected at random from the drain strip batch in quantities which correspond to the size of the batch. A total of 3 parallel specimens is required in each case.

The length of the straight specimens to be tested should be 300 mm and that of bent ones 920±10 mm. The specimens should be cut perpendicular to the longitudinal direction of the strip in such a manner that no deformations are caused to the cross-section of the strip at the point of cutting. The maximum width for a specimen is 100 mm and minimum 90 mm.

Additional samples should also be taken for the measurement of compression from beside those required for the examination of discharge capacity in cases where the conductivity test does not involve the measurement of the lateral load imposed on the specimen but only its compression (thickness).

6.6.6 Discharge capacity tests

6.6.6.1 Installation of straight samples in the testing device

The specimen, of length 300 mm, is installed in the flow channel of the device. If it is less than 100 mm in width the empty space between it and the channel wall should be packed with a flexible, non-permeable filler employed for the whole length of 300 mm so as to cover the entire thickness of the specimen. It should be possible to remove the filler easily after the test.

The test specimen is adjusted so that its thickness is the same as the smallest thickness T_{125} obtained for a comparative specimen in a compression test (minimum loading time 30 d). All corners of the specimen are measured to ensure that its thickness is correct.

6.6.6.2 Installation of bent test specimens in the testing device

The specimen (length approx. 920 mm) is placed in the flow channel of the device in the form of three layers divided by intermediate plates. The specimen is surrounded with a thin plastic film the seam of which is compacted to ensure impermeability. The film must be attached tightly to the ends of the specimen in such a manner that no part of it is left in front of the drain profile. The specimen is bent to the shape of the intermediate plates so that the strip is also tight at the bends. The hole above and below the flow channel is packed with impermeable material to ensure that water will only flow via the cross-section of the ends of the specimen.

When the bent specimen is subjected to an even load, the **average** thickness of each layer should correspond to that obtained in the compression tests at a load of 125kPa (min. loading time 30 d).

6.6.6.3 Implementation of the discharge capacity test

The purpose of the test is to measure simultaneously the hydraulic head difference between the ends of the specimen and the rate of flow of water through the specimen. The flow should be stationary during the measuring process, in which case the pressure difference and flow rate will remain stable.

The flow rate is regulated by adjusting the height of the overflow pipe of the uppermost tank. The flow is then allowed to stabilize for some time, after which the flow rate is measured and the height of the overflow adjusted more accurately to achieve the desired flow rate, which is calculated as an average of 3 - 5 measurements each lasting normally for 30 seconds.

Flow rates are measured at pressure differences of 50, 100 and 200 mm. Conversely, pressure differences can be measured at flow rate values Q = 5, 10 and 20 ml/s.

Pressure differences are measured to an accuracy of 1 mm and flow rate by weighing the amount of water which has passed through the drain during 30 seconds.

Clean deaerated water at 20±2°C is used in the test, and any air bubbles which remain in the specimens before the measurements must be allowed to pass out of the system with the water. It is particularly important in the case of bent specimens to ensure that no bubbles are left in the bends.

6.6.7 Processing and evaluation of results

6.6.7.1 Formulae

Discharge capacity (q_w) is calculated from the test results using the formula

$$q_w = \frac{QL}{\Delta h}$$

where q_w = discharge capacity = $A_w k_w$ (ml/s)
A_w = hydraulically efficient cross-section of the specimen, mm^2
kw = longitudinal water permeability
Q = measured flow rate (ml/s)
h = water pressure difference between ends of specimen, mm
L = length of specimen (300 mm)

If the water temperature is not 20°C it is necessary to observe the resulting change in its viscosity. Discharge capacity at a temperature of 20°C ($q_{w,20}$) is calculated from the following formula

$$q_{w,20} = q_{w,T} \alpha_{T,20}$$

where $q_{w,T}$ = discharge capacity at temperature T
$\alpha_{t,20}$ = correction coefficient for reference temperature 20°C at temperature T (Table 4).

Table 4. Temperature correction coefficients for discharge capacity, reference temperature 20°C.

T,°C	$\alpha_{T,20}$	T, °C	$\alpha_{T,20}$
15	1,135	20	1,000
16	1,106	21	0,976
17	1,079	22	0,952
18	1,052	23	0,930
19	1,026	24	0,908
		25	0,888

The average of the temperature-corrected conductivity values is calculated from parallel tests.

Discharge capacity (q_w) is indicated at pressure difference values of 100 and 200 mm or at the flow-rate Q = 5 ml/s at T = 20°C.

6.6.7.2 Evaluation of results

The minimum approved discharge capacity of a straight vertical drain strip is q_w = 10 ml/s, as determined in accordance with the present instructions.

The discharge capacity of a bent strip should be at least 7.5 ml/s, i.e. 75% of that of a straight strip.

6.6.8 Test report

The following results should be reported following a conductivity test:

1. instructions followed in the tests and any deviations from them,

2. number of specimens tested and their detailed description,

3. average conductivity values measured at least for pressure differences of 100 and 200 mm or flow-rate Q = 5 ml/s, and number of parallel tests,

4. transverse load employed and its duration, compression rate and original thickness,

5. test conditions,

6. description of the equipment employed.

6.7 Determination of effective opening size of filter sleeve

6.7.1 Purpose and principle

The current instructions are concerned with a hydrodynamic sieving method for the determination of effective pore size in geotextile filters. The test can be applied to thin geotextiles which retain less than 2% of the soil employed in a given test.

The effective pore size is determined by wet-sieving of a dynamically suitable soil material of mixed grain size through a filter specimen and comparing the grain-size curve of the material retained by the filter with that of the material passing through it.

The effective filter pore size (O_{90}, O_{95} or O_{98}) denotes the average (test) soil grain-size of which 90%, 95% or 98% is retained by the filter and represents the approximate maximum grain size of the material which will pass through a clean filter in any appreciable quantity.

Effective pore size can also be determined by means of a wet-sieving test, for which the procedure advocated by the Franzius-Institut, Hannover (FIH) is recommended, as presented in Geotextiles and Geomembranes in Civil Engineering, 1986.

6.7.2 References

ISO/TC 38/sc21 The hydraulic properties of geotextiles: UK Draft Proposals to ISO 8.5.1990

ISO/DIS 9863 Determination of thickness of woven and knitted fabrics

French Standard NFG 38017

6.7.3 Testing equipment and materials

6.7.3.1 Hydrodynamic sieving device

The hydrodynamic sieving test involves vertical movement of a filter sample and the soil above it in a test cell in such a manner that the sample is entirely above the water surface in the highest position and the cell totally immersed in water in the lowest position.

The vertical movement of the test cell, i.e. the distance between its extreme positions, should be at least 100 - 150 mm and rate of movement 15 - 25 mm/s. The test cell remains in the lower position for approx. 3 seconds and in the upper position for at least 15 seconds. The timing of the test is such that the cell performs two (1.5 - 2.5) full cycles per minute, the nominal 30 seconds duration of each cycle being distributed as follows: upper position

20 s, lowering 3 s, lower position 2 s, lifting 5 s.

The distance between the bars of the steel mesh used as the lower support for the filter specimen must be at least 5 - 10 mm to ensure a free flow of water.

The total diameter of the filter specimen is 170 mm and the effective diameter 140 mm (200 mm in a standard proposal by ISO TC 38/SC21/WG4).

Each test cell (test specimen) is provided with a separate water vessel, the soil deposited in which can be collected accurately if necessary.

6.7.3.2 Test soil

The grain-size composition of the test soil should match the effective pore size (O_{90}) of the filter specimen, i.e.

$$d_{10} < O_{90} < d_{90}$$

The grain-size distribution (d_{60}/d_{10}) of the test soil must be higher than 6. The nominal grain-size distribution area for this soil is presented in Appendix 6.

The nominal dry mass of the test soil is 300 g, and since at least 50 g of soil is required to pass the filter, a greater amount of soil may be employed in the test if necessary (1500 g).

The hydrodynamic sieving test usually requires the use of a mixture of two quartz sands of grain-size 0 - 0.2 mm (30%) and 0.3 - 0.6 mm (70%). The corresponding grain-size curve is presented in Appendix 6.

A representative soil sample obtained from the vertical drainage site may be used for the test, if necessary.

6.7.3.3 Other equipment

Equipment required to measure the grain-size of the test soil:

- wet sieving equipment, hydrometer, stopwatch.
- Drying oven, temperature 105 - 110°C.
- Balance, accuracy 0.1 g.
- Filter papers, sieve cleaning device (ultrasonic).

6.7.4 Test specimens

3 - 4 parallel filter samples taken at random from the drain strip batch should be subjected to the sieving test. The samples should be cut from the filter using a D = 170 mm pattern in such a manner that some of the filter seam is contained in 1 - 2 of the samples. A sufficiently thick O-ring should be placed on top of the samples to prevent the seam from impairing the tightness of the installation.

The mass (g/m^2) and thickness of the test specimens should be determined at a temperature of 20±2°C in accordance with standards ISO 9864 and ISO/DIS 9863.

The filter specimens are immersed in water before the test, the remaining bubbles of air in them are removed and they are kept in water at 20±2°C for at least 24 hours.

6.7.5 Implementation of the test

6.7.5.1 Preparations

A total of 300 g (1500 g) of oven-dried soil is selected by weighing (ground, if necessary). The grain-size distribution of the material is measured by wet sieving and with the hydrometer if necessary, after which the entire material is collected up, dried, weighed and mixed carefully.

The filter specimen is placed in the testing device, the soil is spread evenly on it and the device is assembled with special attention to the tightness of seams.

6.7.5.2 Test

The specimen is subjected to 2000 test cycles (lifting and lowering) at a rate of 2.0 cycles per minute (maximum 2.5 per minute) in which case the test will last for approx. 16.5 hours.

The soil retained by the filter specimen is collected carefully after the test, dried at 105°C and the grain-size distribution measured.

If the grain-size distribution of the entire test soil material has been measured beforehand, the soil which has passed through the filter does not have to be collected. If not, this soil is collected from the vessel as carefully as possible by means of filter papers which retain fine material. It is necessary to allow the finer material to precipitate at the bottom of the vessel for a sufficiently long time before the filtration process (at least 24 hours). The soil collected is dried and weighed.

When the grain-size distribution of the 300 g of test sand has not been measured beforehand, that of the sand passing through the filter specimen should be evaluated separately by wet sieving, and by the hydrometer test if necessary.

Parallel test specimens are subjected to the same test using new 300 g portions of sand.

6.7.6 Processing of results

Select a sufficient number of grain-size boundaries for the screen in order to define the distribution curves, and calculate the amount of each fraction which has passed through the filter specimen (T_i) as a proportion of the total fraction (all sizes between two adjacent screen grain-size boundaries):

$$T_i = \frac{P_i}{M_i} \cdot 100\ \% \quad ,$$

where M_i mass of the test soil (300 g) with grain sizes between i-1...i,
Ri mass of the soil material retained by the filter specimen with grain sizes between i-1...i,
$P_i(=M_i-R_i)$ mass of the soil material which has passed through the filter specimen with grain sizes between i-1...i.

Plot the values of T_i on a semi-logarithmic scale as a function of grain size i, and read off the grain size which corresponds to 10% of T_i, i.e. an effective pore size O_{90} of the filter fabric. The figures for effective pore sizes of O_{50}, O_{95} and O_{98} can be read from the graph in the same manner.

The results obtained for each of the 3 test specimens are processed in the same manner, the average pore size is calculated and the results obtained are compared with the thicknesses and mass densities of the specimens. The effect of the filter seam on the results is also taken into account.

6.7.7 Reports

The following results should be presented after completing a hydrodynamic sieving test:

1. instructions followed and possible deviations from them,
2. data on the filter material tested, including mass density (ISO 9864) and thickness (ISO/DIS 9863),

3. test results, including grain-size curves for each sample and averages for effective pore sizes O_{90} and O_{95},

4. description of the test soil employed and its grain-size curve,

5. amount of soil retained inside the filter specimen,

6. description of the test equipment.

6.8 Measurement of water permeability of filter sleeve

6.8.1 Purpose and principle

A method is provided here for measuring the water permeability of the filters employed in vertical strip drains in a direction perpendicular to the filter surface. The method is based on the use of a standard pressure and an unloaded test specimen.

The standard pressure test involves maintaining the difference in water pressure to which the test specimen is subjected constant and measuring the corresponding amount of water which has flowed through the filter specimen. A water column of 30 mm or 50 mm is used to indicate the standard pressure difference, which can be selected on the basis of the water permeability of the sample if necessary.

6.8.2 References

ASTM Designation: D 4491-85. Standard Test Methods For Water Permeability of Geotextiles by Permittivity. Approved 31.5.1985.

ISO/TC 38/SC2/WG41. Determination of water flow normal to the plane of a geotextile under a constant head.

6.8.3 Definitions

Water permeability k [m/s] denotes the laminar flow velocity through a porous material when the hydraulic gradient is 1.

Permittivity Ψ [1/s] denotes the volume of water flowing per unit of surface area and unit of pressure loss in laminar flow.

6.8.4 Testing equipment

6.8.4.1 Water permeability measurement device

The water permeability measurement device creates a constant flow through the filter specimen and measures the specimen-induced pressure loss, which is standardized with respect to time, and the corresponding flow rate. It should be possible to vary the velocity of the water conducted through the specimens between 0 and 60 mm/s.

The hydraulically effective specimen diameter is 72 mm, the minimum acceptable diameter 35 mm.

The pressure loss measured is created inside the filter specimen only, i.e. it is zero when water flows through a test device not containing a filter specimen.

The filter specimen should be fixed in place securely to prevent any deformation caused by the flow pressure. Clean, deaerated water at 20±2°C should be used in the test.

6.8.4.2 Other equipment

A vessel which allows a 30 s measuring time should be used to measure the flow rate. The minimum measurement time should be 20 s. The following equipment is required:

- Stopwatch, accuracy 0.1 s
- Thermometer, accuracy 0.1°C
- Balance, accuracy 0.1 g

A pattern of a given diameter, measured to an accuracy of 1 mm, is also required for cutting the test specimens.

6.8.5 Test specimens

The test specimens are selected at random so as to be maximally representative of the strip batch concerned. A minimum of 3 parallel test specimens should be taken.

Cut the specimens from the filter in such a manner that one of the samples contains a seam, provided it is possible to seal the seam properly.

Measure the dry mass and thickness of the specimens at a load of 2 kPa and then immerse them in water, remove the air bubbles from them and keep them in water at 20±2°C for at least 24 h.

6.8.6 Implementation of the water permeability test

1. Check the tightness of the seams of the testing device.

2. Fill the device with water via a tube, removing all air bubbles which may have remained on the sides of the device at the same time. The test specimen is installed when the water surface is at the appropriate level. Water is then conducted through the specimen and all bubbles and any impurities are removed from the surface of the fabric.

3. Once all the bubbles have been eliminated, adjust the flow rate so that the pressure difference between the ends of the test specimen (Δh) is 50 mm. This pressure difference should remain stable for at least 30 s, after which the flow rate should be measured. This should be done at least three times, making sure that the pressure difference maintains its standard value (Δh = 50 mm). Water temperature should also be measured. Flow rate is measured to an accuracy of 1 g, time 0.3 s (measurement time 30s) and temperature 0.2°C.

4. Repeat the measurements indicated at stage 3 employing pressure differences of 30 and 100 mm. Check sufficiently often that no air bubbles have developed inside the specimen. Any bubbles or impurities should be removed before continuing the test.

5. Perform the same measurements on the parallel test specimens.

6.8.7 Processing of the results

Flow velocity (v), which is presented graphically as a function of pressure loss, is calculated from the formula

$$v = \frac{QR_T}{At}$$

where Q = quantity of water measured
A = effective surface area of specimen
t = time corresponding to water quantity Q
R_T = temperature correction coefficient (Table 4)

$$R_T = \frac{U_T}{U_{20°C}}$$

where U_T = viscosity of water at test temperature T
U_{20C} = viscosity of water at 20°C.

The initial part of the flow velocity vs. pressure loss graph should be linear. As long as the graph maintains its almost linear form, the flow can be assumed laminar. The results obtained for water permeability are valid only in this area of laminar flow.

Permittivity (Ψ), i.e. the tangent of the pressure loss vs. flow velocity graph, is calculated from the formula

$$\Psi = \frac{\Delta v}{\Delta(\Delta h)}$$

where Δv = change in flow velocity
$\Delta(\Delta h)$ = change in pressure difference

Permittivity is indicated using flow velocities v = 10 and 20 mm/s, which should lie in the area of laminar flow.

Water permeability (k) is indicated using a pressure difference of 50 mm, provided that this lies in the area of laminar flow. Otherwise the value must be reduced to fall within this area. Water permeability is calculated from the formula

$$k = \frac{v}{i} = \frac{vT_g}{\Delta h}$$

where v = flow velocity (mm/s)
i = hydraulic gradient
Δh = measured pressure difference, mm
T_g = thickness of specimen at a load of 2kPa, mm

The results obtained for parallel specimens are analysed and average water permeability and permittivity calculated from the results obtained for at least three specimens.

6.8.8 Reports

A permeability test report should contain at least the following:

1. instructions followed in the test and any deviations from them,

2. dimensions of the specimens and other details,

3. test results, including permeability and permittivity, averages of the results, corresponding pressure differences and number of tests,

4. flow velocity vs. pressure difference graph,

5. description of the measurement equipment.

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LIST OF APPENDICES

Quality requirements, quality control and testing methods of prefabricated drain strips

RESULTS OF TYPE TESTS OF PREFABRICATED VERTICAL DRAIN STRIP

Drain strip tested: MEBRA-DRAIN MD7407

Lab.no. 6378

Procedure of choosing the sample tested:

The agent, Kaitos Oy, delivered a drain strip sample 10 m in length on 6.6.1990 to VTT and an additional sample (5 m) in September 1990.

No.	CRITERIA	SYMBOL	UNIT	No.of Tests	MEAN OF RESULTS	RANGE OF RESULTS	REQUIRED VALUE
	Strength and dim. of drain strip						
1	Width	B	mm	10	100		nominal ± 5 %
2	Equivalent diameter	De	mm		65.5		nom.
3	Dry mass	Wo	g/m		76		nom. ± 10 %
4	Thickness at 20 kPa (dry)	T20	mm	5	2.94		nom. ± 10 %
5	Thickness at 125 kPa, t=30d	T125	mm	1	2.52	-	> 0.7T20
6	Compression rate at 125 kPa, between 30...60 d (wet)	dT125 /dT	mm / 30d	1	0.003	-	< 0.05
7	Tensile strength (d)	Pu1	kN	5	2.18	2.11 - 2.26	> 1.0
8	Tensile strength (w)	Pu2	kN	2	2.46	2.42 - 2.51	> 1.0
9	Strain at break (d)	Eυ1	%	5	54.4	49.4 - 66.0	> 15 (> 30)**
10	Strain at break (w)	Eυ2	%	2	90.0	82.0 - 98.7	> 15 (> 30)**
11	Tensile strength when bent (w)	Ptb	kN	1	> 2.0	-	> 2.0 remaining undamaged
	Strength of filter sleeve (wet)						
12	Thickness at 2 kPa (d)	Tg	mm	15	0.47	0.42 - 0.50	nom. ± 10%
13	Tensile strength, longitu-	Pu3	kN/m	5	6.32	6.10 - 6.60	> 3.0
14	Strain at break, dinal	Eυ3	%	5	80.0	77.0 - 88.7	> 15 (> 30)**
15	Tensile strength, trans-	Pu4	kN/m	2	7.2	5.60 - 8.80	> 3.0
16	Strain at break, verse	Eυ4	%	2	67.5	64 - 71	> 15 (> 30)**
17	Tensile(transv.) and shear strength of seam	Pu5	kN/m	7+4	2.08/2.25	1.86 - 2.40	> 1.5
18	Seam strain at break	Eυ5	%	7+4	4.7/ 3.3	3.0 - 8.2	> 10
	Discharge capacity of drain (at 125 kPa, T=20°C)						
19	at 100 mm water head	qw1	ml/s	2	93	79 - 107	> 10
20	at 200 mm water head	qw2	ml/s	2	85	78 - 92	> 10
	Water permeability of filter (unloaded, T=20°C)						
	1)permeability						
21	at 30 mm water head	k1	mm/s	2	0.48	0.27 - 0.70	> 50ksoil
22	at 50 mm water head	k2	mm/s	2	0.45	0.29 - 0.61	> 50ksoil
	2)permittivity						
23	at flow velocity of 10 mm/s	Ψ1	1/s	2	1.3	0.6 - 2.0	> 0.0025 -
24	at flow velocity of 20 mm/s	Ψ2	1/s	2	1.05	0.6 - 1.5	0.0050
	Effective opening size of filter material (hydrodynamic sieving, mass fraction method)						depending on soil type O90 < d85soil and O90 < 0.15 mm
25	effective opening size	O90	mm	4	0.15	0.135 - 0.165	or
26	effective opening size	O95	mm	4	0.175	0.155 - 0.20	O90 <(1,1...2,8)d50

**when the drain is exposed to frost-heave

Based on the results of the type inspection the vertical drain strip MEBRA-DRAIN MD7407 fulfils the quality requirements set in the present guidelines except the following properties:
*** The strain of the filter seam at break is not sufficient.**

Evaluation of the applicability of the drain strip:
Applicable in soil types which are normal, but not problematic from the point of view of filtering technique.

Appendix no. 2

Quality requirements, quality control and testing methods of prefabricated drain strips

RESULTS OF TYPE TESTS OF PREFABRICATED VERTICAL DRAIN STRIP	Drain strip tested:	COLBONDDRAIN CX1000
		Lab.no. 6389

Procedure of choosing the sample tested:

The client delivered to VTT on 15.8.1990 a drain strip sample 25 m in length.
The specimens were taken at random from the sample.

No.	CRITERIA	SYMBOL	UNIT	No.of Tests	MEAN OF RESULTS	RANGE OF RESULTS	REQUIRED VALUE
	Strength and dim. of drain strip						
1	Width	B	mm	5	96.5 / 91		nominal ± 5 %
2	Equivalent diameter	De	mm		61		nom.
3	Dry mass	Wo	g/m	5	66.9	66.4 - 67.8	nom. ± 10 %
4	Thickness at 20 kPa (dry)	T20	mm	15	4.74	4.63 - 4.86	nom. ± 10 %
5	Thickness at 125 kPa, t=30d	T125	mm	1	3.62	-	> 0.7T20
6	Compression rate at 125 kPa, between 30...60 d (w)	dT125 /dT	mm / 30d	1	0.016	-	< 0.05
7	Tensile strength (d)	Pu1	kN	5	1.84	1.74 - 1.89	> 1.0
8	Tensile strength (w)	Pu2	kN	5	1.89	1.77 - 2.01	> 1.0
9	Strain at break (d)	Eυ1	%	5	26.1	24.6 - 28.7	> 15 (> 30)**
10	Strain at break (w)	Eυ2	%	5	33.5	30.3 - 36.1	> 15 (> 30)**
11	Tensile strength when bent (w)	Ptb	kN	2	> 2.0	-	> 2.0 remaining undamaged
	Strength of filter sleeve (wet)						
12	Thickness at 2 kPa (d)	Tg	mm	20	1.11	1.00 - 1.14	nom. ± 10%
13	Tensile strength, longitu-	Pu3	kN/m	5	9.55	9.0 - 10.1	> 3.0
14	Strain at break, dinal	Eυ3	%	5	25.5	24.9 - 26.0	> 15 (> 30)**
15	Tensile strength, trans-	Pu4	kN/m	5	11.76	10.9 - 12.8	> 3.0
16	Strain at break, verse	Eυ4	%	5	30.0	28.4 - 31.8	> 15 (> 30)**
17	Tensile(transv.) and shear strength of seam	Pu5	kN/m	10	1.87	1.73 - 2.08	> 1.5
18	Seam strain at break	Eυ5	%	10	4.0	3.5 - 4.4	> 10
	Discharge capacity of drain (at 125 kPa, T=20°C)						
19	at 100 mm water head	qw1	ml/s	2	104.8	88.2 - 121.4	> 10
20	at 200 mm water head	qw2	ml/s	2	78.1	64.9 - 91.3	> 10
	Water permeability of filter (unloaded, T=20°C)						
	1)permeability						
21	at 30 mm water head	k1	mm/s	2	1.61	1.28 - 1.94	> 50ksoil
22	at 50 mm water head	k2	mm/s	2	1.39	1.15 - 1.64	> 50ksoil
	2)permittivity						
23	at flow velocity of 10 mm/s	Ψ1	1/s	2	2.12	2.00 - 2.25	> 0.0025 -
24	at flow velocity of 20 mm/s	Ψ2	1/s	2	1.70	1.55 - 1.85	0.0050
	Effective opening size of filter material (hydrodynamic sieving, mass fraction method)						depending on soil type O90 < d85soil and O90 < 0.15 mm
25	effective opening size	O90	mm	2	0.108	0.075 - 0.14	or
26	effective opening size	O95	mm	2	0.128	0.08 - 0.175	O90 <(1,1...2,8)d50

**when the drain is exposed to frost-heave

Based on the results of the type inspection the vertical drain strip COLBONDDRAIN CX1000 fulfils the quality requirements set in the present guidelines except the following properties:
*** The strain of the filter seam at break is not sufficient.**

Evaluation of the applicability of the drain strip:
Applicable in soil types which are normal, but not primarily problematic from the point of view o filtering technique.

Appendix no. 3

Quality requirements, quality control and testing methods of prefabricated drain strips

RESULTS OF TYPE TESTS OF PREFABRICATED VERTICAL DRAIN STRIP

Drain strip tested: TENAX VDR 100

Lab.no. 6564

Procedure of choosing the sample tested:

The manufacturer, Tenax SpA, delivered to VTT on 6.11.1990 a drain strip sample 20 m in length and an additional sample (approx. 30 m) in June 1991.

No.	CRITERIA	SYMBOL	UNIT	No.of Tests	MEAN OF RESULTS	RANGE OF RESULTS	REQUIRED VALUE
	Strength and dim. of drain strip						
1	Width	B	mm	10	108 / 96		nominal ± 5 %
2	Equivalent diameter	De	mm		70.9		nom.
3	Dry mass	Wo	g/m	5	86.0	85.6 - 86.4	nom. ± 10 %
4	Thickness at 20 kPa (dry)	T20	mm	30	3.43	3.33 - 3.62	nom. ± 10 %
5	Thickness at 125 kPa, t=30d	T125	mm	2	2.99	2.96 - 3.01	> 0.7T20
6	Compression rate at 125 kPa, between 30...60 d (w)	dT125 /dT	mm / 30d	3	0.026	0.003 - 0.054	< 0.05
7	Tensile strength (d)	Pu1	kN	5	2.15	2.11 - 2.19	> 1.0
8	Tensile strength (w)	Pu2	kN	5	2.30	2.23 - 2.37	> 1.0
9	Strain at break (d)	Eυ1	%	5	37.0	22.0 - 52.0	> 15 (> 30)**
10	Strain at break (w)	Eυ2	%	5	55.3	51.0 - 60.0	> 15 (> 30)**
11	Tensile strength when bent (w)	Ptb	kN	3	> 2.0	-	> 2.0 remaining undamaged
	Strength of filter sleeve (wet)						
12	Thickness at 2 kPa (d)	Tg	mm	20	0.46	0.38 - 0.50	nom. ± 10%
13	Tensile strength, longitu-	Pu3	kN/m	5	7.45	6.75 - 7.97	> 3.0
14	Strain at break, dinal	Eυ3	%	5	57.1	49.7 - 67.5	> 15 (> 30)**
15	Tensile strength, trans-	Pu4	kN/m	5	7.77	6.55 - 8.72	> 3.0
16	Strain at break, verse	Eυ4	%	5	57.2	55.0 - 69.0	> 15 (> 30)**
17	Tensile(transv.) and shear strength of seam	Pu5	kN/m	5	4.71	4.31 - 5.35	> 1.5
18	Seam strain at break	Eυ5	%	5	12.8	8.5 - 15.4	> 10
	Discharge capacity of drain (at 125 kPa, T=20°C)						
19	at 100 mm water head	qw1	ml/s	2	58.8	57.0 - 60.6	> 10
20	at 200 mm water head	qw2	ml/s	2	49.2	48.5 - 50.0	> 10
	Water permeability of filter (unloaded, T=20°C)						
	1)permeability						
21	at 30 mm water head	k1	mm/s	2	0.36	0.28 - 0.46	> 50ksoil
22	at 50 mm water head	k2	mm/s	2	0.295	0.24 - 0.36	> 50ksoil
	2)permittivity						
23	at flow velocity of 10 mm/s	Ψ1	1/s	2	0.88	0.56 - 1.20	> 0.0025 -
24	at flow velocity of 20 mm/s	Ψ2	1/s	2	0.54	0.34 - 0.75	0.0050
	Effective opening size of filter material (hydrodynamic sieving, mass fraction method)						depending on soil type O90 < d85soil and O90 < 0.15 mm
25	effective opening size	O90	mm	3+3	0.177	0.17- 0.185	or
26	effective opening size	O95	mm	3+3	0.20	0.18 - 0.22	O90 <(1,1...2,8)d50

**when the drain is exposed to frost-heave

Based on the results of the type inspection the vertical drain strip TENAX VDR 100 fulfils the quality requirements set in the present guidelines except the following properties:

*** The quality of the filter seam was not sufficiently uniform in the 11/1990 sample. In the 6/1991 sample the filter seam was of appropriate quality.**

Evaluation of the applicability of the drain strip:

Applicable in soil types which are normal, but not problematic from the point of view of filtering technique.

Quality requirements, quality control and testing methods of prefabricated drain strips

RESULTS OF TYPE TESTS OF PREFABRICATED VERTICAL DRAIN STRIP

Drain strip tested: FLODRAIN FD 6x100

Lab.no. 6641

Procedure of choosing the sample tested:

The agent, Solcon Oy delivered to VTT two samples of the drain strip 1,5 m and 10 m in length on 16.1.1991 and 8.2.1991, respectively.

No.	CRITERIA	SYMBOL	UNIT	No.of Tests	MEAN OF RESULTS	RANGE OF RESULTS	REQUIRED VALUE
	Strength and dim. of drain strip						
1	Width	B	mm	10	98.7	98 - 101	nominal ± 5 %
2	Equivalent diameter	De	mm	10	67.2		nom.
3	Dry mass	Wo	g/m	5	97.5	86.7 - 108.7	nom. ± 10 %
4	Thickness at 20 kPa (dry)	T20	mm	15	6.83	5.92 - 7.44	nom. ± 10 %
5	Thickness at 125 kPa, t=30d	T125	mm	2	5.56	5.41 - 5.71	> 0.7T20
6	Compression rate at 125 kPa, between 30...60 d (w)	dT125 /dT	mm / 30d	2	0.01	0.009 -0.011	< 0.05
7	Tensile strength (d)	Pu1	kN	5	3.02	2.83 - 3.36	> 1.0
8	Tensile strength (w)	Pu2	kN	5	3.25	3.00 - 3.45	> 1.0
9	Strain at break (d)	Eυ1	%	5	47.8	37 - 57	> 15 (> 30)**
10	Strain at break (w)	Eυ2	%	5	56.8	54 - 62	> 15 (> 30)**
11	Tensile strength when bent (w)	Ptb	kN	3	> 2.0	-	> 2.0 remaining undamaged
	Strength of filter sleeve (wet)						
12	Thickness at 2 kPa (d)	Tg	mm	15	0.485	0.41 - 0.53	nom. ± 10%
13	Tensile strength, longitu-	Pu3	kN/m	5	9.26	7.27 - 10.58	> 3.0
14	Strain at break, dinal	Eυ3	%	5	53.0	31 - 62	> 15 (> 30)**
15	Tensile strength, trans-	Pu4	kN/m	5	4.79	3.70 - 5.50	> 3.0
16	Strain at break, verse	Eυ4	%	5	36.4	22 - 46	> 15 (> 30)**
17	Tensile(transv.) and shear strength of seam	Pu5	kN/m	5+5	4.65/4.91	3.05 - 6.14	> 1.5
18	Seam strain at break	Eυ5	%	5+5	22.4/26.7	10 - 40	> 10
	Discharge capacity of drain (at 125 kPa, T=20°C)						
19	at 100 mm water head	qw1	ml/s	3	204	140 - 237	> 10
20	at 200 mm water head	qw2	ml/s	2	139	100 - 178	> 10
	Water permeability of filter (unloaded, T=20°C) 1)permeability						
21	at 30 mm water head	k1	mm/s	3	0.39	0.23 - 0.48	> 50ksoil
22	at 50 mm water head	k2	mm/s	3	0.29	0.22 - 0.42	> 50ksoil
	2)permittivity						
23	at flow velocity of 10 mm/s	Ψ1	1/s	3	0.95	0.47 - 1.49	> 0.0025 -
24	at flow velocity of 20 mm/s	Ψ2	1/s	2	0.58	0.40 - 0.77	0.0050
	Effective opening size of filter material (hydrodynamic sieving, mass fraction method)						depending on soil type O90 < d85soil and O90 < 0.15 mm
25	effective opening size	O90	mm	3	0.175	0.15 - 0.20	or
26	effective opening size	O95	mm				O90 <(1,1...2,8)d50

**when the drain is exposed to frost-heave

Based on the results of the type inspection the vertical drain strip FLODRAIN FD 6x100 fulfils the quality requirements set in the present guidelines except the following properties:

*** When the drain is sharply bent the core causes punching stresses to the filter sleeve, which might give rise to small holes in the filter fabric.**

Evaluation of the applicability of the drain strip: Applicable in soil types which are normal, but not problematic from the point of view of filtering technique.

The drain strip is not recommended for use in conditions where it is exposed to sharp bending.

Quality requirements, quality control and testing methods of prefabricated drain strips

RESULTS OF TYPE TESTS OF PREFABRICATED VERTICAL DRAIN STRIP

Drain strip tested: AMERDRAIN 407

Lab.no. 6655

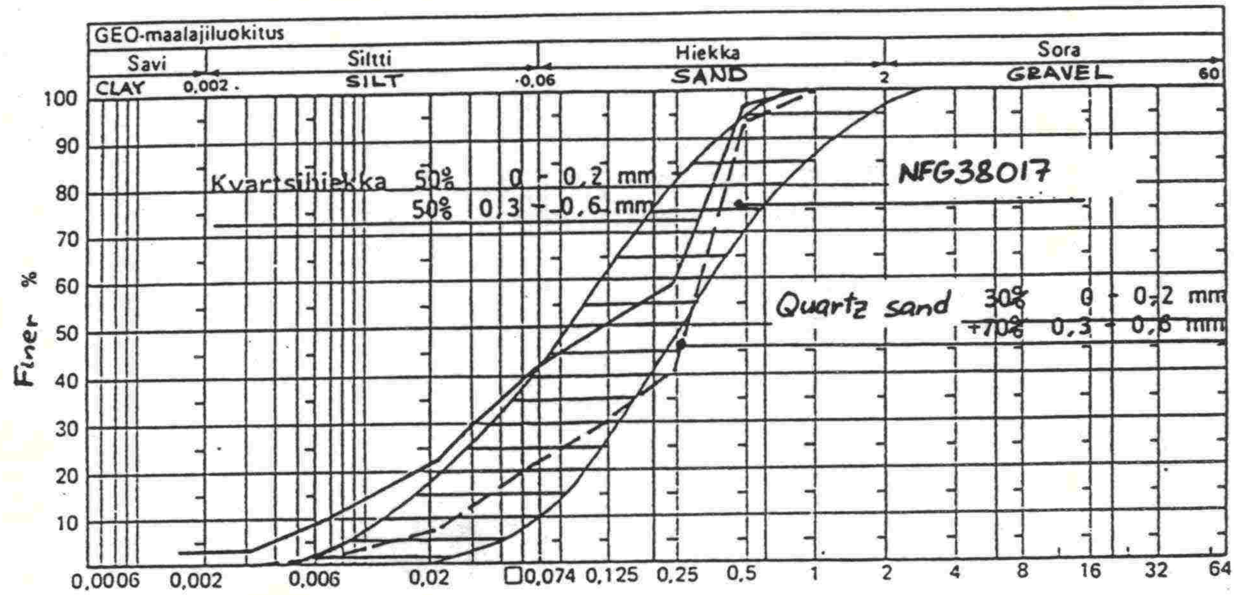
Procedure of choosing the sample tested:
The agent, Algol Oy, delivered a drain strip sample 10 m in length to VTT on 27.3.1991.

No.	CRITERIA	SYMBOL	UNIT	No.of Tests	MEAN OF RESULTS	RANGE OF RESULTS	REQUIRED VALUE
	Strength and dim. of drain strip						
1	Width	B	mm	10	98.5	98 - 99	nominal ± 5 %
2	Equivalent diameter	De	mm		65.5		nom.
3	Dry mass	Wo	g/m	6	105.0	103.2 - 107	nom. ± 10 %
4	Thickness at 20 kPa (dry)	T20	mm	6x10	4.35	3.90 - 4.90	nom. ± 10 %
5	Thickness at 125 kPa, t=30d	T125	mm	2	3.74	3.59 - 3.89	> 0.7T20
6	Compression rate at 125 kPa, between 30...60 d (w)	dT125 /dT	mm / 30d	2	0.03***	0.026 -0.034)***	< 0.05
7	Tensile strength (d)	Pu1	kN	5	2.67	2.30 - 2.95	> 1.0
8	Tensile strength (w)	Pu2	kN	5	2.48	2.30 - 2.66	> 1.0
9	Strain at break (d)	Eυ1	%	5	13.0	9.0 - 18.0	> 15 (> 30)**
10	Strain at break (w)	Eυ2	%	5	11.4	7.9 - 16.0	> 15 (> 30)**
11	Tensile strength when bent (w)	Ptb	kN	3	> 2.0	-	> 2.0 remaining undamaged
	Strength of filter sleeve (wet)						
12	Thickness at 2 kPa (d)	Tg	mm	30	0.483	0.44 - 0.53	nom. ± 10%
13	Tensile strength, longitu-	Pu3	kN/m	5	8.64	8.15 - 9.30	> 3.0
14	Strain at break, dinal	Eυ3	%	5	107.0	83 - 128	> 15 (> 30)**
15	Tensile strength, trans-	Pu4	kN/m	5	7.73	7.18 - 8.50	> 3.0
16	Strain at break, verse	Eυ4	%	5	66.0	55 - 77	> 15 (> 30)**
17	Tensile(transv.) and shear strength of seam	Pu5	kN/m	5+5	4.02/3.71	2.98 - 4.52	> 1.5
18	Seam strain at break	Eυ5	%	5+5	8.4/ 7.4	4.5 - 11.5	> 10
	Discharge capacity of drain strip (at 125 kPa, T=20°C)						
19	at 100 mm water head	qw1	ml/s	3	199	163 - 223	> 10
20	at 200 mm water head	qw2	ml/s	3	168	138 - 188	> 10
	Water permeability of filter (unloaded, T=20°C)						
	1)permeability						
21	at 30 mm water head	k1	mm/s	3	0.19	0.14 - 0.30	> 50ksoil
22	at 50 mm water head	k2	mm/s	2	0.18	0.17 - 0.20	> 50ksoil
	2)permittivity						
23	at flow velocity of 10 mm/s	Ψ1	1/s				> 0.0025 - 0.0050
24	at flow velocity of 20 mm/s	Ψ2	1/s				
	Effective opening size of filter material (hydrodynamic sieving, mass fraction method)						depending on soil type O90 < d85soil and O90 < 0.15 mm
25	effective opening size	O90	mm	3	0.125	0.12 - 0.13	or
26	effective opening size	O95	mm	3	0.15	0.14 - 0.16	O90 <(1,1...2,8)d50

**when the drain is exposed to frost-heave

Based on the results of the type inspection the vertical drain strip AMERDRAIN 407 fulfils the quality requirements set in the present guidelines except the following properties:
*** The strain of the drain strip (partially) and that of the filter seam at break is not sufficient.**
Evaluation of the applicability of the drain strip: Applicable in soil types which are normal, but not problematic from the point of view of filtering technique.
Use is not recommended in conditions where considerable horizontal deformations of the drained soil are possible.

HYDRODYNAMIC SIEVING TESTS



Grain size distribution of test sand according to French Standard NFG38017 (ruled) and grain size distributions of the test sands used in hydrodynamic sieving tests. In all tests a quartz sand mixture containing 30 % of sizes 0 - 0.2 mm and 70 % of sizes 0.3 - 0.6 mm was used.

Quality requirements, quality control and test methods of vertical drain strips

QUALITY CONTROL PROCEDURE OF DRAIN STRIPS ON THE SITE

STAGES OF QUALITY CONTROL	FACTS TO BE CONTROLLED	MEASURES TO BE TAKEN ON THE SITE	FURTHER MEASURES AND CONCLUSIONS
1.ACQUISITION OF IDENTIFICATION AND INTERNAL QUALITY CONTROL DATA OF THE DRAIN STRIP	1.Type of drain strip and its materials 2.Date and size of each delivery lot to site 3.Date of production batch, roll numbers 4.Importer / supplier 5.Results of internal quality control	**Contractor shall obtain the data in question.** The data is recorded on a record form(app. 11) which is added to builder's quality control materials.	The extent and results of manufacturer's internal quality control are taken into account in the amount of external (project-related) quality control.
2. IDENTIFICATION AND QUALITY CONTROL OF STRIP SAMPLES	1.Type and structure of the drain strip 2.Material thickness of core and filter sleeve 3.Seam of filter 4.Strength and filtering properties based on additional tests when necessary.	**Drain strip samples to be taken** Contractor (under supervision of builder) shall take samples as follows: 1)one lot of samples (5 pcs) immediately at the commencement of vertical drainage and from each batch to the site 2)one lot of samples at intervals of 50000 metres 3)additional samples when necessary e.g. whenever insufficient quality is suspected. **For more instructions see the sampling form.**	**The samples taken shall be sent without delay to an independent quality control institution approved by the builder.** The samples are controlled as follows: A) comparison of structure and materials to those of the type tested product B) measurements of mass and thickness C) evaluation of the need of additional testing and the tests necessary to secure sufficient quality (Table 3).
3. CONTROL OF QUALITY UNIFORMNESS		**Contractor shall control quality uniformness** at intervals of approx. 10000 metres as follows:	Observations shall be recorded on the record form (app. 8). The records and the controlled strip pieces are added to builder's quality control materials.
	1.Structure of drain core and filter sleeve	The drain strip is compared visually to a reference (quality controlled) piece of drain.	**Whenever inadequate quality is suspected the builder shall be informed immediately as well as samples shall be taken to be controlled without delay.**
	2.Thickness of filter material	The open-cut filter is studied against light parallelly with the reference piece.	**Any batch of drain strip of essentially insufficient quality shall not be used. Additional QC-measures are required.**
	3.Integrity of filter and its seam.	Visual inspection.	**The importer and manufacturer are informed without delay about insufficient quality found in control tests.**

Quality requirements, quality control and test methods of vertical drain strips

RECORD FOR SAMPLING AND QUALITY CONTROL OF VERTICAL DRAIN STRIPS ON THE SITE

Sampling

1. One lot of samples (5 pcs) is taken without exception at the beginning of each drainage works as well as from each batch of drain strip to arrive at the site.
2. Samples shall be taken at relatively regular intervals, at least one lot of samples (5 pcs) per approx. 50000 meters of installed drain.
3. Additional samples are taken when necessary, e.g. whenever insufficient quality is suspected.

One sample (length 5 m) is taken per one roll. Every 5th sample is taken from the end of a roll, the others are selected at random from 4 drain rolls under installation. The samples shall be taken after passage through the mandrel. The samples are sent to an independent quality control institution (approved by builder).

Control of quality uniformness

Quality of drain strip is controlled by contractor at intervals not longer than 10000 installed metres. The control frequency is increased when necessary. **Control observations are recorded on this form.**

Project	
Contractor	
Builder	
Total planned length of drains	
Date of beginning installation	
Type of drain strip (trade mark)	

SAMPLES TAKEN

Date of sampling						
No. of sample						
No. of the sampled roll						
Batch of delivery No. / date						
Samples taken by						
Additional information						

RESULTS OF QUALITY CONTROL PERFORMED ON THE SITE

Control date / line position		
Batch of delivery (to site)		
Structure of filter sleeve		
Structure of drain core		
Thickness of filter material		
Integrity of filter material and filter seam		

RECORD DRAWN UP BY DATE	
RECORD INSPECTED BY DATE	

The drain strip samples are to be sent for quality control to :

Quality requirements, quality control and test methods of vertical drain strips

QUALITY CONTROL OF VERTICAL DRAIN STRIP SAMPLES
REPORT

Project Contractor Builder Total length of drains (planned)	
Type of drain strip Type of filter sleeve Sample nos / lengths Samples taken by / date	

RESULTS OF INSPECTION

DIMENSIONS	Drain strip			Filter sleeve		
	mean	range	reference value mean/min.	mean	range	reference value mean/min.
Thickness (mm)	(20 kPa)			(2 kPa)		
Dry mass (g/m)						
Width (mm)						
Comparison of dimensions with type test results						
STRUCTURE	Core			Filter		
Comparison of structure with reference (type tested) product						
Integrity						

Based on the results of this inspection the quality of the drain strip is assessed ...

The following imperfections of quality were observed :

Recommendations for further quality control measures :

Quality requirements, quality control and test methods of vertical drain strips

VERTICAL DRAINAGE RECORD

Record no.	Project / draining field
Contractor	Type of drain strip
Builder	Draining machine
	Drain spacing c/c.

Date of installation	Line position (m)	Drain * spacing (m)		Width * of area drained	Drained depth		Total length of drains(m)			Remarks**
		longit.	trans.		planned *	carried out	planned *	carried out	difference	
										* to be prefilled
										** Differences in
										location and inclination,

TOTAL CONSUMPTION OF DRAIN BETWEEN THE LINE POSITIONS ---	PLANNED	metres	loosening of anchor,
	CARRIED OUT (rolls)	metres	breaking of drain,
	DIFFERENCE	metres	samples taken etc.

RECORD DRAWN UP BY DATE	
RECORD INSPECTED BY DATE	

Quality requirements, quality control and test methods of vertical drain strips

INSPECTION RECORD FOR DRAIN STRIP DELIVERIES AND STOCK ON THE SITE

Project	
Contractor	
Builder	
Drain strip type / roll length	
Manufacturer of strip	
Supplier / Agent	

Delivery batches to site				Manufacturing batch		Storage on the site			Observations concerning quality of drain arrived
no.	date	amount (rolls)	total drain length (m)	date (week) of manuf.	roll numbers	duration (weeks)	protection against		
							UV-rad.	mechan.	Inspected by / date
TOTAL ON THIS FORM									
rolls		drain length							

RECORD DRAWN UP BY DATE	
RECORD INSPECTED BY DATE	

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