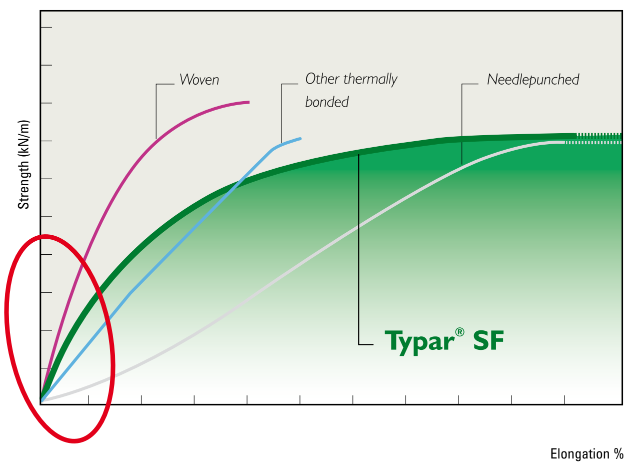
Technical handbook

DuPont™ Typar® SF

GEOTEXTILE

ASK FOR MORE ENERGY



- High energy absorption
- High initial modulus
- High elongation (> 50 %)
- Long-term filtration
- Outstanding uniformity

DuPont®

Typar®

Luxembourg site

Disclaimer

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DuPont™ Typar® SF Introduction

1. DuPont™ Typar® SF introduction

1.1. Introduction

The purpose of this guide is to provide basic information on geotextiles, their functions and their required properties for different applications. This technical handbook provides guidance on the design, selection and utilisation of DuPont™ Typar® SF geotextiles in civil engineering applications such as the construction of aggregate bases, drainage and erosion control systems. A description of test methods for determining the properties of geotextiles and technical data is given. Details on the DuPont Typar® Geosynthetics product range can be found in our DuPont™ Typar® SF and Typar® HR brochure and on our website www.typargeo.com. For additional advice and technical assistance, please contact the DuPont Geosynthetics Technical Centre.

1.2. DuPont Quality

For two centuries now, DuPont inventions have been leading industry forward with innovative and pioneering high performance materials such Nylon, Kevlar®, Tyvek®, Lycra® and Teflon®. Engineering excellence and quality standards which are second to none: these are just two of the reasons why DuPont Typar® Geosynthetics provide reliable long-term performance for civil engineering and construction projects.

Invented 30 years ago and manufactured at the DuPont Luxembourg site, the high quality and performance of DuPont™ Typar® SF has proven the test of time. With more than 1 billion m^2 sold world-wide, DuPont™ Typar® SF geotextiles have been used in roads, railway tracks and construction surfaces equivalent to a six lane motorway of 23 meter width once around the world.

Typar® is manufactured to ISO 9001 standards. The stringent quality requirements of DuPont ensure that only high quality products are released into the market. The integrated production and laboratory system guarantee that the manufacturing process conditions and laboratory results for every roll are traceable.

The environmental management system of DuPont is in accordance with the requirements of the environmental standards of the EMAS (Eco-Management and Audit Scheme) Regulation as well as the ISO 14001. Furthermore DuPont™ Typar® SF geotextiles are CE marked and are submitted to several different certification systems such as the French ASQUAL and the German external audit system "Fremdüberwachung DIN 18200".

1.3. What is DuPont™ Typar® SF?

DuPont™ Typar® SF is a thin, thermally bonded, water permeable nonwoven geotextile made of 100% continuous polypropylene filaments. It is designed to have a combination of a high initial modulus (stiffness), high elongation (typically > 50%) and outstanding uniformity, to give superior performance, to make it resistant to damage and to have excellent filtration properties. DuPont™ Typar® SF is an isotropic material, which means that its physical properties are the same in all directions. This mirrors the stresses and strains of a typical separation application.

Furthermore, the fact that DuPont™ Typar® SF is made of 100% polypropylene, makes it resistant to rotting, moisture and chemical attack, particularly alkalis[3].

[1] DQS – Deutsche Gesellschaft zur Zertifizierung von Managementsystemen mbH
[2] BVQI – Bureau Veritas Quality International
[3] details on chemical resistance can be found in the annex section 7.6

1.4. DuPont Typar® fibre production

In the fibre extrusion process, thousands of extremely fine, continuous filaments are produced, which pass through a DuPont patented "pre-stretch" stage. These fine but tough filaments are then laid down (Fig. 1) producing an isotropic fibre web sheet which is then thermally and mechanically bonded.

Figure 1: Filament laydown

Figure 2: Typar® microscopic view

By varying the process conditions, a range of high strength Typar® nonwoven structures with different denier and physical properties can be produced. This DuPont patented production technique is one of the main reasons for the unique properties of DuPont™ Typar® SF compared to other geotextiles.

1.5. Características

The following figure 3 shows the typical stress-strain behaviour of several geotextiles of similar weight. DuPont™ Typar® SF has a high tensile strength, a high elongation, and also a high initial modulus which is the ideal combination of properties for geosynthetic applications (for comparison see also table 1).

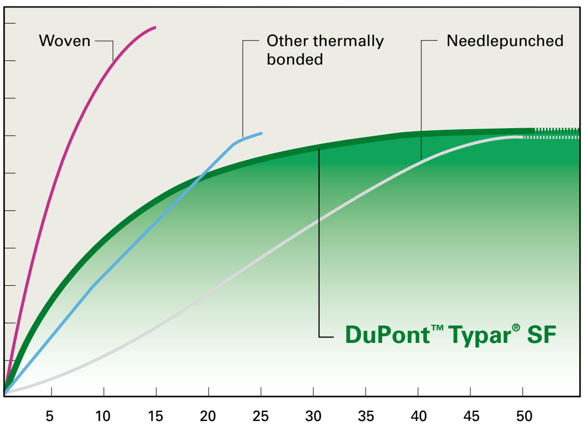


Figure 3: Typical stress-strain curves of DuPont™ Typar® SF and other geotextiles

DuPont™ Typar® SF is manufactured to a very high level of uniformity using a continuous on-line, ß-ray and ultrasonic monitoring process. Any product that fails to meet the required standards is rejected and recycled.

In the process stabilisers are added to the polypropylene which increase the durability of DuPont™ Typar® SF. It can endure up to several weeks in direct sunlight, but prolonged exposure, particularly in tropical sunlight, can cause strength losses[4]. Generally a geotextile should be covered immediately after laying to avoid UV degradation, wind uplifting or mechanical damage.

	DuPont™ Typar® SF	Woven	Needlpunched staple fibre	Needlpunched continuous	Other thermally bonded
Energy	**high**	low	medium	medium	very low
Tensile Strength	**high**	very high	medium	high	high
Initial Modulus	**high**	high	very low	low	high
Elongation	**high**	low	high	high	low

Table 1: Stress-strain curves properties of several geotextiles types

[4] Details on UV resistance can be found in the annex section 7.6

Functions and requirements

2. Functions and requirements

2.1. Introduction

Depending on the different applications, the main functions of the geotextile are separation, filtration, reinforcement, protection to stabilisation. For most applications a combination of several functions is required. A further requirement is its resistance to damage during installation.

The purpose of this section is to provide a basic, technical understanding of these functions and requirements with respect to geotextiles and to the different mechanisms within each function. It should aid in the selection of the appropriate geotextile for a specific purpose, a difficult task, because the interaction between interrelated factors, such as mechanical and hydraulic properties, clogging, structure, time and degradation etc. is very complex.

2.2. Separation

Separation is defined as: "The preventing from intermixing of adjacent dissimilar soils and/or fill materials by the use of a geotextile or a geotextile-related product"[5] .

The main application areas of a geotextile used as a separator are in road and railway projects. The use of the geotextile preserves and improves the integrity and function of the different materials. Two mechanisms occur when an aggregate base is laid over a soft subsoil and a vertical load is applied.

First of all the geotextile prevents the loss of aggregate into the soft subgrade (Fig. 4). An engineering adage describes this very well: "10 kilos of stone placed on 10 kilos of mud results in 20 kilos of mud". The geotextile confines the aggregate base and thus a higher degree of compaction can be obtained with subsequent higher bearing capacity.

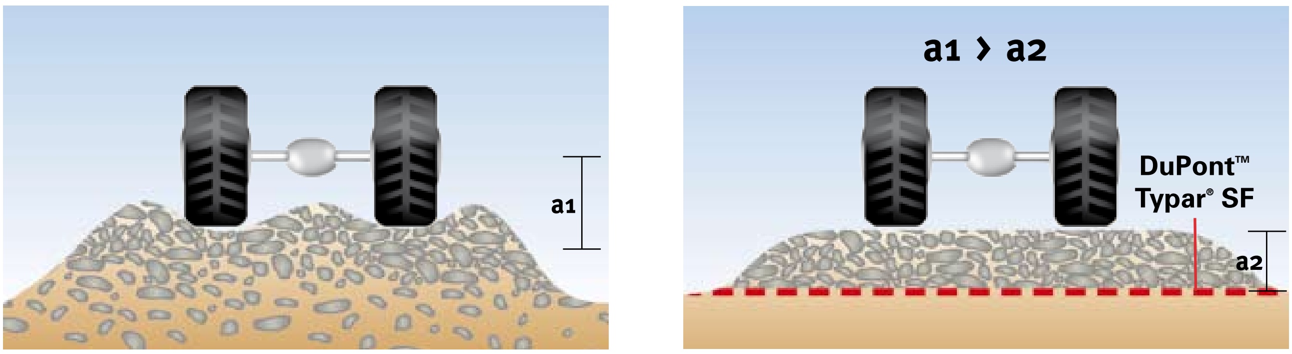


Figure 4: left: Without geotextile - loss of aggregate into soft subgrade, right: With geotextile – no loss of aggregate, better compaction

Secondly the contamination of the aggregate base with soil of the subgrade is prevented and thus the reduction of the bearing capacity avoided. The migration of fine soil particles into the clean aggregate occurs especially under dynamic stress and is called "pumping effect". These fines act as a lubricant between the coarse aggregate grains and can so substantially reduce the shear strength of the aggregate.

Also, an uncontaminated aggregate will continue to effectively perform in its drainage function as well as maintain a higher resistance to frost heave effects.

[5] EN ISO 10318 Terms and Definitions

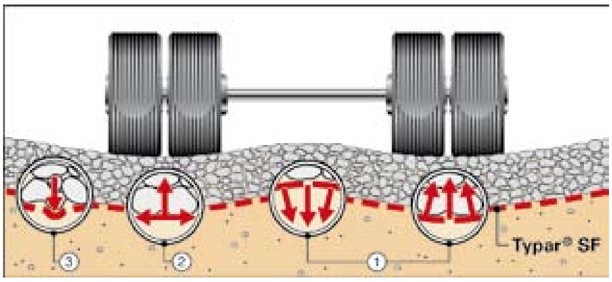
In its separation function a geotextile can:

- Prevent the reduction of load bearing capacity caused by the mixing of fine-grained subgrade with the aggregate base.
- Increase the bearing capacity by preventing the loss of aggregate into soft subgrade and increasing the degree of compaction.
- Reduce the deterioration of roads through frost heave effects.
- Eradicate the need to remove weak subgrade.
- Maintain the drainage capacity of the aggregate base.
- Prevent migration of fine particles especially under dynamic loads.

2.3. Stabilisation and Reinforcement

In many applications a geotextile fulfills a stabilisation or reinforcement function[6]. In its stabilisation function the geotextile provides the soil with tensile strength and thus complements the soil's lack of tensile strength when subject to vertical loads.

There are three distinct mechanisms by which a geotextile can stabilise the aggregate base and improve its resistance to permanent deformation under repetitive loading (see Fig. 5):



① Restraint + Confinement
② Membrane mechanism
③ Local Reinforcement

Figure 5: Three stabilisation mechanisms

The higher the initial modulus of the geotextile the more effective these mechanisms are. Geotextiles with a low initial modulus will have large deformations and provide little restraint, membrane mechanism or local reinforcement. A high initial modulus and high elongation are important to withstand large local deformations and resist puncturing.

2.3.1. Restraint and Confinement

As indicated in the picture above (Fig. 5), there are two types of restraint. One is related to the reverse curvature of the geotextile outside the wheel path where a downward pressure is created. This has the effect of a surcharge load, which levels out the deformation and enforces the compression of the subsoil. The other is the restraint the geotextile provides when aggregate particles attempt to move away from under the load. The geotextile provides tensile reinforcement to the aggregate layer. This confinement of the aggregate increases its strength and modulus, which in turn decreases the compressive stress on the subgrade by spreading the load better underneath the wheel load.

2.3.2. Membrane Mechanism

The membrane mechanism is effective when a geotextile is laid on deformable soil and vertical loads are applied. In-plane tensile stress develops in the geotextile, relieving the soil which is not capable of absorbing it. This in-plane force induces a component of stress perpendicular to the plane of the geotextile sheet, in the direction of the force.

Therefore this is of great significance in temporary road constructions, where it can reduce rutting tremendously. The higher the initial modulus of the geotextile, the higher the possible reduction of rutting[I].

[6] For more information and details on the use of geotextiles in reinforced earth structures please refer to the Typar® HR product and design guide. Typical applications for earth reinforced structures are retaining walls, steep slopes, landslide repairs, soft-soil embankments, reinforcement under foundations, reinforcement or bridging over karstic areas or cavities, ... etc.

2.3.3. Local reinforcement

Loads on individual stones can cause spot failures in the subgrade. A geotextile with a high initial modulus allows to distribute the load, to reduce the stress and to provide resistance to displacement.

A high elongation avoids the local puncturing of the geotextile because it allows the geotextile to stretch around a penetrating stone.

2.4. Filtration

Filtration is defined as "The restraining of soil or other particles subjected to hydrodynamic forces while allowing the passage of fluids into or across a geotextile or a geotextile-related product".[7]

Typically the opening size and the permeability are used to describe the geotextile's filtration properties. The pore size of an efficient geotextile should be small enough to retain larger soil particles to prevent soil erosion. Small soil particles initially have to pass through the geotextile in order to support the build-up of a bridging network of larger particles which act as a natural soil filter adjacent to the geotextile (Fig. 6). If the pore size of a geotextile is too small, then the small particles cannot be drained away and a small diameter bridging network will be formed. This will produce a natural soil barrier with a lower permeability .

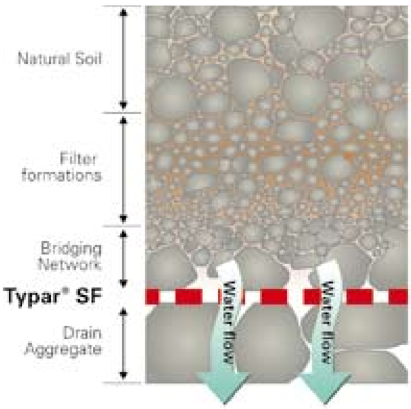


Figure 6: Natural soil filter adjacent to geotextile.

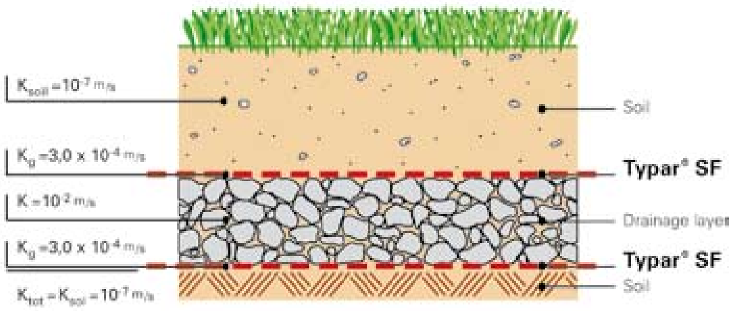


Figure 7: Drainage system, soils and geotextile with different permeabilities. Ktot is determined by the least permeable soil layer [10]

Efficient geotextile filters must have pores of different shape, size and size distribution similar to the particle size distribution of soil.

It is often ignored that in an aggregate-subbase system (Fig.7) the permeability of the least permeable layer determines the system's permeability. Usually the soil has a permeability which is significantly lower than that of the geotextile.[8]

Typical Soil Permeabilities[9]:	
Gravel	3×10^{-2} m/s
Silt	$10^{-9} – 10^{-7}$ m/s
Sand	10^{-8} m/s
Clay	$10^{-8} - 10^{-10}$ m/s

The permeability of a geotextile is also influenced by the compressibility of the geotextile. Generally thick geotextiles are susceptible to compression. When installed under pressure, the permeability is reduced. This needs to be taken into account when specifying the required permeability of a geotextile. The thickness itself is rather a descriptive than a design property [11].

The filtration function is associated with dam construction, erosion control, road drainage and subsoil drainage. In these constructions the geotextile replaces a conventional granular filter. In an erosion control system of a riverbank or earth slope, coarse material (gabions/riprap) or concrete slabs are commonly used to protect against waterflow or wave action. The erosion of the fine particles is prevented by the use of a geotextile as a filter.

[7] EN ISO 10318
[8] except coarse sand and gravel
[9] see annex section 7.10 for more details on soil permeabilities
[10] regarding permeability see also 4.4.2

2.5. Drainage

Drainage is the collecting and transporting of precipitations, ground waters and/or other fluids. Traditionally, water has been controlled and evacuated using graded natural materials. Over the past 30 years or so, more and more geotextile filters have replaced the aggregate filters to increase the natural drainage capacity of impervious soils.

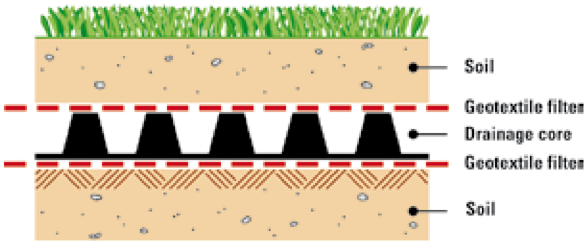


Figure 8: Composite drainage element

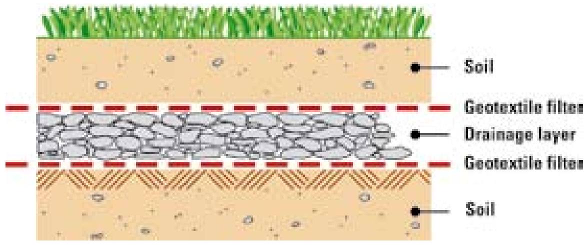


Figure 9: Conventional aggregate drainage layer

A geotextile should not be used as a (direct) drainage layer by itself because even though its drainage capacity can be measured in a laboratory using clean water, under realistic site conditions (soil trapped inside the structure) the drainage capacity is unpredictable. It is also important for drainage systems to be capable of maintaining adequate drainage capacity for long term performance even when subjected to high earth pressures. To avoid clogging and contamination of the drainage layer a filter must always be incorporated in a drainage system.

Synthetic drains incorporating a geotextile filter have proved to be a more economic alternative to traditional sand drains, soakaways and other drainage systems. Typically geosynthetic drainage mats or drains are made of a core sandwiched between geotextile filters.(Fig.8).

The filter material is required to show consistent quality and physical properties, outstanding strength and durability, good resistance to installation stresses and long term filtration performance.

The malfunction or premature failure of a drainage system can create serious safety and functional problems with the earth structure concerned. At the very least, a drainage failure will necessitate costly remediation and attendant disruption. It is vital that a filter material is used that can function effectively over the long term even with the most critical soils.

2.6. Protection

Protection is defined as "The preventing or limiting of local damage to a given element or material by the use of a geotextile or a geotextile-related product"[11].

Typically geotextiles are used for protection of geosynthetic barriers in landfill, roofing, tank and water projects.

The most important properties of a geotextile in a protection function are puncture resistance and product uniformity (i.e. no weak spots). Nail puncture resistance tests[12] have shown that properties such as thickness and unit weight of the product alone do not provide good protection efficiency.

2

2.7. Resistance against Damage During Installation

A geotextile will not perform any function if it is destroyed during or immediately after installation. Analyses indicate that the critical period in the life-cycle of a geotextile is during the construction process rather than during the service life. Thus 95% of the damage usually occurs during installation, very often simply the result of impact damage during the off-loading and compaction of aggregates. Usually, if the geotextile survives these installation-related stresses, it will also withstand the in-service stresses.

Considerable work has been undertaken to understand the relationship between the physical properties of a separation geotextile and its actual performance in the field. Test research has confirmed a close correlation between the ability of a geotextile to absorb impact energy and its susceptibility to damage during installation[III].

[11] EN ISO 10318
[12] nail tests simulating on-site behaviour developed by DuPont and performed at DuPont Typar® QC laboratory

The following figures demonstrate the different forms of failure of a geotextile and the importance of a high energy absorption potential:

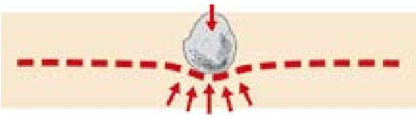


Figure 10: high elongation allows the geotextile to stretch around penetrating stone

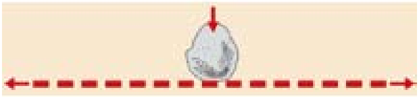


Figure 11: high strength allows the geotextile to withstand force from falling stone

Figure 12: failure of the geotextile due to lack of strength or lack of elongation

Energy Absorption

Definition: Energy is the capacity of a physical system to do work. The standard unit is the joule, symbolised by J. One joule (1 J) is the energy resulting from the equivalent of one Newton (1 N) of force acting over one meter (1 m) of displacement. There are two main forms of energy, called potential energy and kinetic energy. Potential energy, is energy stored in a material.

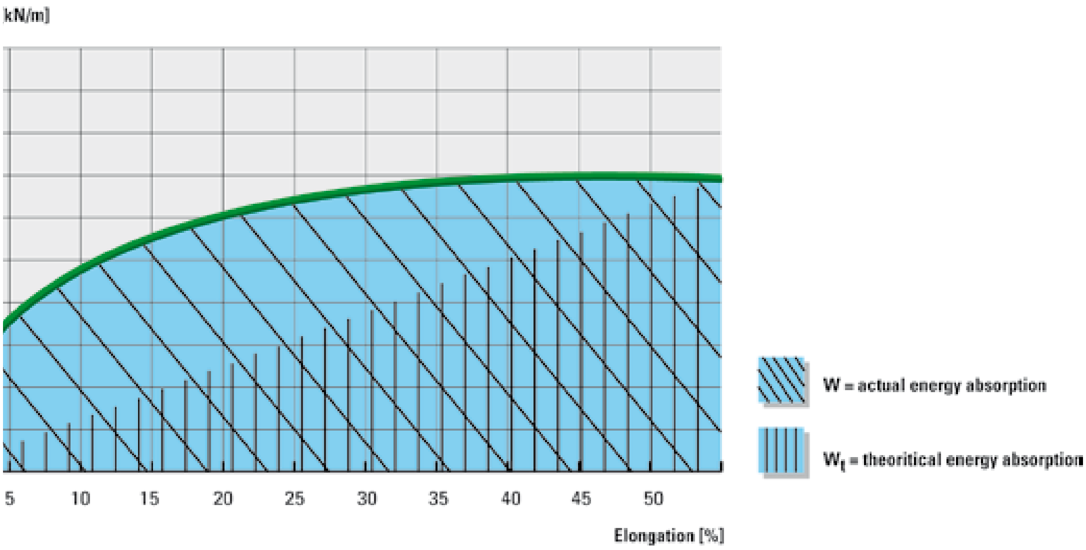


Figure 13: Comparison of actual and theoretical energy absorption potential

The energy absorption potential (W) of a geotextile can described as the combination of its elongation and its applied strength. It is determined using the stress-strain curve of a geotextile obtained in a tensile strength test. The area under the curve (∫) is the energy absorption potential of the geotextile.

Several national specifications are in the process of adopting the energy absorption concept. Some specifications however are based on theoretical values or energy absorption index rather than calculating the surface under the curve $W = \int (T * \varepsilon)\, d\varepsilon$. The calculation is simplified to $W_{index} = ½T * \varepsilon$.

As a result the energy absorption index (Windex) of some products is significantly higher while for others the theoretical energy absorption is lower than the actual energy absorption potential measured during the tensile strength test (EN ISO 10319). The following graph (Fig.13) illustrates this: it shows the different shapes of the actual energy absorption and the theoretical energy absorption potential.

Bibliography

[i] Love, J.P., Burd, H.J., Milligan, G.W.E. and Houlsby, G.T. (1987). Analytical and model studies of reinforcement of a granular layer on a soft clay subgrade. Canadian Geotechnical Journal, Vol.24, No 4, p. 611-622
[ii] Koerner, Designing with Geotextiles, 4th edition 1998, p.96
[iii] SINTEF Report, Arnstein Watn, Non woven geotextiles – Field test on damage during installation, SINTEF Civil and Environmental Engineering, Norway
Evaluation of Installation Damage of Geotextiles - A Correlation to Index Tests, R. Diederich, DuPont de Nemours, Luxembourg

Aggregates bases

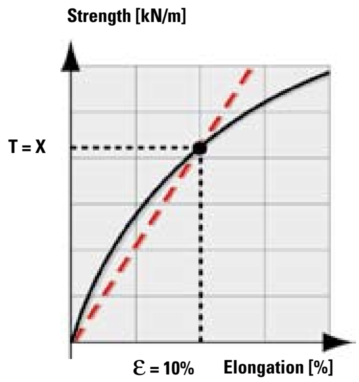
3. Aggregate bases

3.1. Introduction

This section is a guideline for the design and construction of aggregate bases for permanent and temporary traffic structures using DuPont™ Typar® SF geotextiles. The technology applies to aggregate bases supporting more or less dynamic loads in runways, roads and highways, temporary construction/access roads, storage areas, parking lots and sports facilities.

For paved surfaces, such as roads, highways and runways, design methods have been developed by National Road Administrations based on local conditions and wide experience. Therefore it is not the intention of this guide to propose new design methods but simply to emphasise the benefits of using DuPont™ Typar® SF in such paved structures. However, the design procedures presented hereafter might be applied to paved structures, by considering that the subbase is to be used as a temporary construction road during the construction period.

This design procedure for using DuPont™ Typar® SF is the result of knowledge gained from several full-scale road tests built over various subgrades of low bearing capacity and of over 30 years experience.



What is the initial modulus?

The initial modulus describes the behaviour of a geotextile at low deformation. Using the secant modulus at, for example, 5% strain gives a clear indication. A line is drawn from the axes' origin to the designated curve at 5% strain (Fig. 14). The initial modulus (slope) is measured $K = T/\varepsilon$ The steeper the gradient the higher the modulus.

The higher the tensile strength of a geotextile at an initial deformation, e.g. 5%, the higher the initial modulus, the higher the resistance to rutting!

Figure 14: Initial modulus = Secant modulus at e.g. e = 10%

3.2. Functions

The combination of functions of a geotextile to provide additional strength to the aggregate base (compared to an equal thickness of aggregate over a subgrade without DuPont™ Typar® SF) is different for every application. For aggregate bases the main functions are separation and stabilisation. Studies have shown that stabilisation functions depend largely on the modulus of the fabric[i]. Furthermore the aggregate layer thickness can be reduced significantly by using a geotextile.

3.2.1. Stabilisation

The effectiveness of the mechanisms described in the previous chapter are all related to the stress-strain behaviour of the geotextile (see Fig. 15). Different types of geotextiles have a different stress-strain curve. This difference can best be described as the energy absorption potential W (see also section 2.7).

Woven geotextiles have a very high initial modulus and high maximum strength but a low elongation which results in a low energy W. Needlepunched nonwovens have a low initial modulus, and a large deformation is needed before a noticeable tensile strength is developed in the geotextile; this results in low energy absorption potential W. DuPont™ Typar® SF has a high initial modulus, high strength and a high elongation at maximum load, and therefore has a high energy absorption potential W. As a high energy absorption gives high damage resistance DuPont™ Typar® SF is particularly suitable for stabilisation.

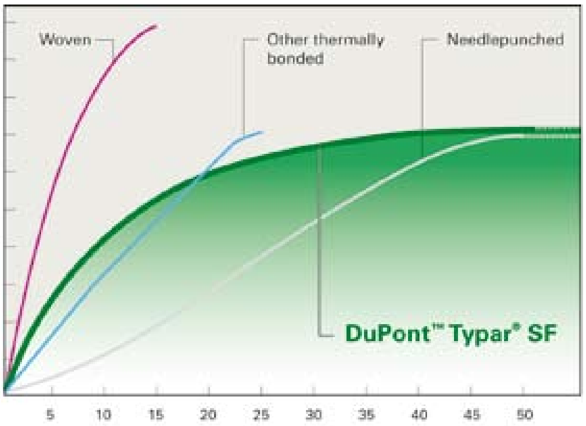


Figura 15: Curvas convencionales de tensión-deformación de diferentes geotextiles.

3.2.2. Separation and Filtration

The hydraulic requirements such as an adequate range of pore sizes to perform an efficient filtration function are provided by the range of opening sizes of DuPont™ Typar® SF, which are similar to that of soil. The water permeability of DuPont™ Typar® SF is generally higher than that of most subsoils[13]. Furthermore the water permeability of DuPont™ Typar® SF is unaffected by load compression as it has a precompressed structure in contrast to thicker compressible geotextiles.

3.2.3. Rutting

Rutting can become a serious problem, especially for temporary roads. The regular passage of wheeled transport results into tension stresses that deform the subsoil. Different from most other geotextiles, DuPont™ Typar® SF needs much lower elongation and deformation to take up stresses (high initial modulus) and will therefore considerably reduce rutting. In the graph below (Fig. 16) the results of tests simulating a traffic load [11] by submitting various geotextiles to 1000 dynamic loading cycles show the difference between DuPont™ Typar® SF and two needlepunched geotextile products (NP staple fibres, NP continuous fibres) with a low initial modulus.

The results indicate a correlation between initial modulus and deformation (rutting). The high initial modulus enables DuPont™ Typar® SF to absorb more external stress before transferring this energy absorption to strain.

Due to its high energy absorption DuPont™ Typar® SF has a very good resistance to damage during installation. Furthermore sufficient elongation at break is necessary to withstand local penetration by stones and to provide a good safety margin once the geotextile is under stress.

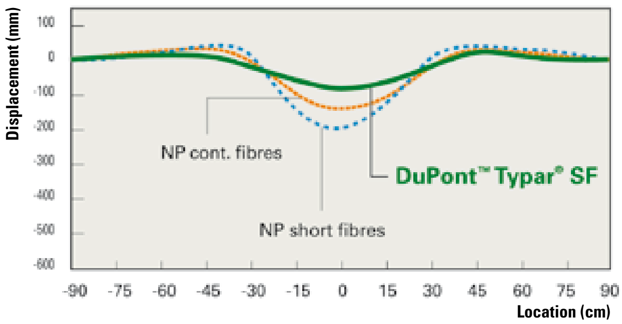


Figure 16: Estimated deflection bowls after 1000 cycles - deflection measured at the geotextile level - Class 3 products[14]

3

[13] with the exception of coarse sands and gravel
[14] according to the Norwegian Classification System

3.3. Designing Aggregate Bases with DuPon™ Typar® SF

The main causes of pavement degradation are:

- The contamination of the aggregate base by a fine-grained subgrade under dynamic loading ("pumping effect") that causes a substantial reduction of the shear resistance of the aggregate. The thickness of the "clean" aggregate and therefore the bearing capacity of the structure is reduced down to unacceptable levels
- Contamination of the aggregate base as described above which will make the aggregate sensitive to frost, with subsequent reduction of bearing capacity during thaw periods
- Lack of subsurface drainage
- Unpredicted traffic increase

The use of DuPont™ Typar® SF will prevent aggregate contamination and therefore results in an increased service life.

This guide uses the CBR[15] value as a measure of soil strength. The correlation factors between CBR, Cu (undrained shear strength), Ev (rigidity modulus) and ME (compressibility modulus) are given in the following table 2. The design properties presented here for unpaved and paved roads are based on a standard DuPont™ Typar® SF style with an energy level 2. Depending on the installation and traffic conditions a geotextile with a higher energy level may be chosen.

Correlation chart for Estimating the subgrade CBR value:

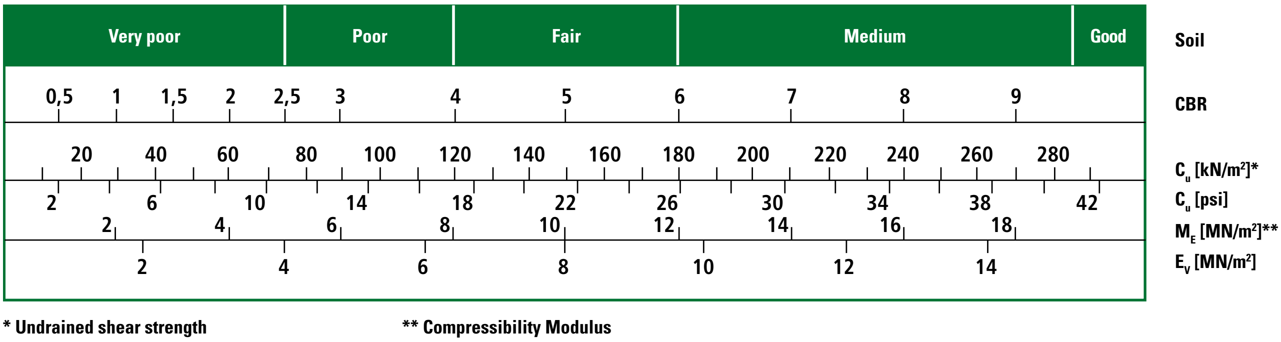


Table 2: Correlation chart for estimating the subgrade CBR value (ref. Barenberg)

3.3.1. Unpaved Roads

An unpaved road that gives temporary or permanent access (i.e. construction or gravel road) normally consists of a simple, unbound aggregate base.

The proposed design method below assumes that the installation of DuPont™ Typar® SF between subgrade and aggregate base allows for:

- Better aggregate compaction
- Subgrade consolidation under dynamic loads
- Reinforcement of the structure by membrane and restraint effect
- Admissible pressure on subgrade increased to the ultimate bearing capacity $p = (\pi + 2) * Cu$

The combination of these benefits is equivalent to an increase of the subgrade CBR by approximately 3 percent points based on empirical data. This design method can only be applied to designs using DuPont™ Typar® SF.

The procedure is first to determine the initial aggregate thickness according to load and subgrade conditions, and then consider the service life and aggregate efficiency. After specifying the effective aggregate thickness Teff a style of DuPont™ Typar® SF with the suitable energy level needs to be chosen.

A. Initial Aggregate Thickness T_0

B. Adjustment of T_0 for Service Life ⇒ T

C. Adjustment of T for Aggregate Efficiency ⇒ T_{eff}

[15] Índice de capacidad de carga californiano (capacidad de carga del suelo); los métodos de aproximación al terreno se pueden consultar en el anexo 7.10.

Attention needs to be paid to axle loads > 130 kN. The appropriate curve for the determination of the initial aggregate thickness T_0 needs to be chosen and the actual number of passes N is used to determine the service life adjustment factor C.

Design Method Unpaved Road

A. Initial Aggregate Thickness T_0	
Soil bearing capacity	CBR, C_u
Axle Load	P_i

Enter Figure 17 using the subgrade CBR and axle load P_i [16] to determine T_0, the compacted crushed stone thickness for 1000 axle loads. Alternatively, Table 3 lists the formula to calculate T_0.

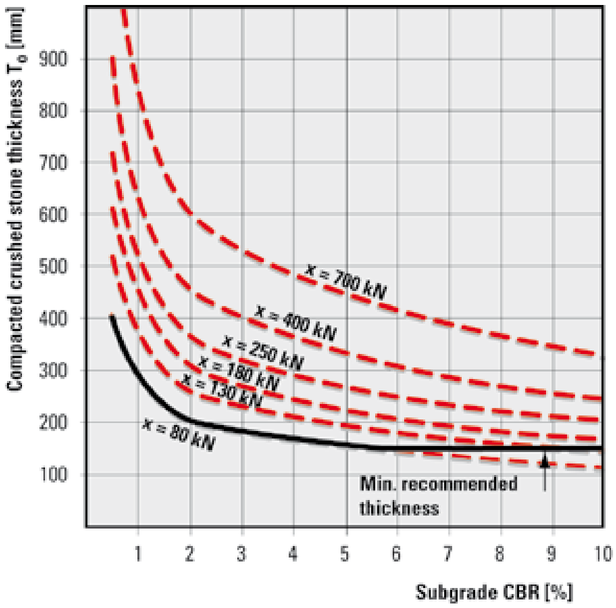


Figure 17: Unpaved roads: Compacted crushed stone thickness for 1000 axle loads.

CBR [%]	P_1 [kN]	P_2 [lbs]
0,5	45.31	0.119
1	32.37	0.085
1.5	25.89	0.068
2	22.47	0.059
3	20.56	0.054
4	18.66	0.049
5	17.14	0.045
6	16.00	0.042
7	14.85	0.039
8	13.71	0.036
9	12.95	0.034
10	12.19	0.032

$$T_0\ (\text{mm}) = P_1 \sqrt{\text{Axle Load (kN)}}$$

$$T_0\ (\text{in}) = P_2 \sqrt{\text{Axle Load (lbs)}}$$

Table 3: Factors to determine curve P_i

B. Adjustment of T_0 for service life	
Axle Load	P_i
Actual number of passes	N_i
Compacted crushed stone thickness	T_0

$T = C * T_0 =$ $\mathbf{T = (0.27 * \log(\Sigma N_i * ESAL) + 0.19) * T_0}$

3

- If the most frequent axle loads are heavier than 130 kN (e.g. quarry haul roads), the use of the $Ne = \Sigma N_i * ESAL$ (Number of Equivalent Axle Loads) is not appropriate. The service life adjustment factor C must be determined using the actual number of passes N_i
- The service life is expressed as the total number of 80 kN axle load application. The actual axle load is first converted to an equivalent standard axle load (P_0= 80 kN) using the equivalence factor ESAL:

$$\mathbf{ESAL = (P_i/P_0)^{3.95}}$$

[16] an axle load is usually determined by dividing the gross weight of the vehicle by the number of axles, unless the actual axle loads are known. Each axle load can be converted to an equivalent standard axle load Po = 80 kN using the equivalence factor ESAL.

Axle load (kN)	ESAL	Axle load (kN)	ESAL
10	0.0003	140	9,12
20	0,004	150	11,98
30	0,021	160	15,45
40	0,065	170	19,64
50	0,16	180	24,61
60	0,32	190	30,47
70	0,55	200	37,31
80	**1,0**	250	90,08
90	1,59	300	185,10
100	2,41	400	576,70
110	3,52	500	1392,30
120	4,96	600	2860,80
130	6,80	700	5259,30

Table 4: Equivalence factor (ESAL)

Table 4 lists the equivalence factor ESAL for different axle loads.

- By multiplying the actual number of axle passes (Ni) with ESAL, N_E the number of passes of equivalent standard axle loads is determined

$$N_E = \Sigma N_i * ESAL_i$$

Since T_0 is indexed to a service life of 1000 axle load application, it must be adjusted by a factor C that depends on the actual number of standard loads N_E. The relationship between N_E and C is shown in Fig. 18.

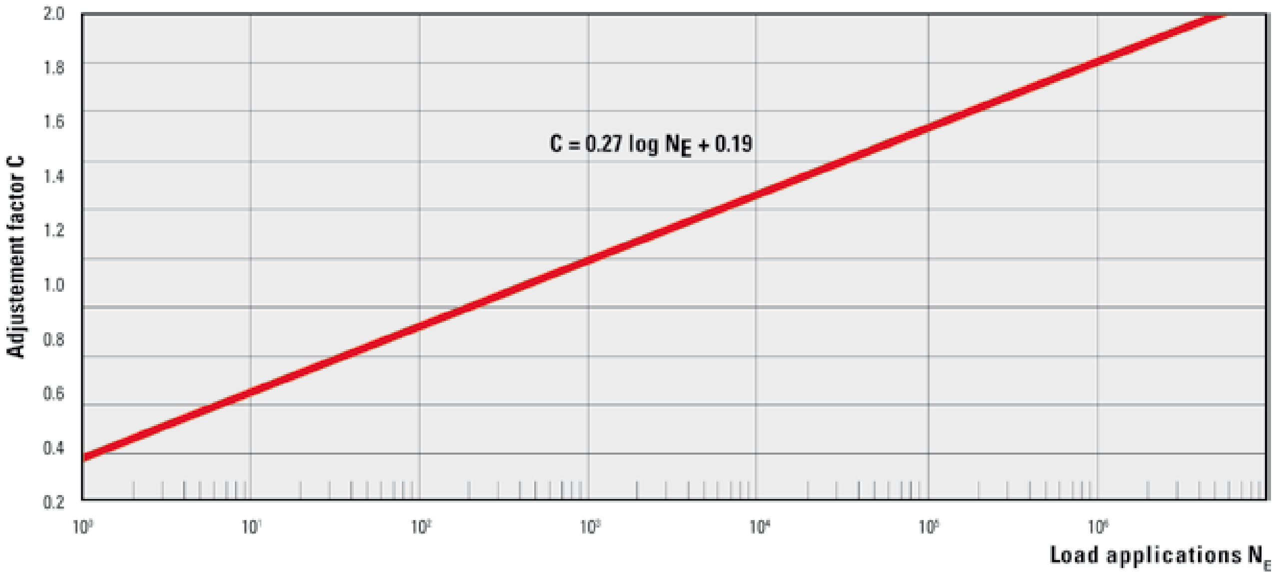


Figure 18: Adjustment factor for service life[iii]

- Then the aggregate thickness T becomes:

$$T = C * T_0 = (0.27 * \log(\Sigma N_e) + 0.19) * T_0$$

C. Adjustment of T for aggregate efficiency

$$T_{eff} = \Sigma T_i / \alpha_i$$

The different materials used for aggregate bases are more or less effective. This difference is accounted for by using the aggregate efficiency factor α. The chosen aggregate should be compactible.The idea is to lock the whole mass together under load in order to take advantage of the reinforcement mechanisms of DuPont™ Typar® SF. Angular crushed aggregate is the best because it interlocks well and provides a high bearing capacity. Depending on availability, other materials or blends can be used. Table 5 indicates typical thickness efficiency factors a of various surfacing and base materials.

Material	Efficiency α
Paving Stone	2
Hot Mix (Dense-Macadam)	2
Dense Surfacing Course	2
Soil-cement (> 5MPa compression)	1.5
Soil bitumen	1.5
Hard crushed stone aggregate - "standard"	1.0
Medium crushed stone aggregate (CBR > 80%)	0.8
Hard round stone aggregate (CBR > 80%)	0.8
Medium round stone aggregate	0.5
Sandy gravel (CBR = 20 - 30%)	0.5
Crushed limestone	0.5
Loose gravel, compactable sand	0.4
Ex: 10mm Hot Mix = 20mm hard crushed stone "standard"	

Table 5: Adjustment for aggregate efficiency

The original designed thickness T of crushed stone can therefore be replaced by the superposition of materials of thicknesses T_i and of efficiency α_i to obtain the final design value of aggregate thickness T_{eff} (efficient thickness):

$$T_{eff} = \Sigma\, T_i / \alpha_i$$

Examples can be found in section 3.6.

3.3.2. Paved Roads

Permanent paved roads generally consist of an aggregate base, a bituminous road base and a concrete or bituminous surface coating.

The proposed design method assumes that the installation of DuPont™ Typar® SF between subgrade and aggregate base of paved structures results in:

- Better aggregate compaction
- Subgrade consolidation under dynamic loads
- Prevention of long term aggregate contamination

These benefits mean a prolonged service life or, in other words, the ability to carry more traffic loads with a given aggregate base thickness. In addition, by using part of the aggregate base as an access road for construction traffic, one can take advantage of the stabilising effect of DuPont™ Typar® SF. Separation and filtration functions will favour subgrade consolidation under static and dynamic loading. This tends to be as efficient as soil stabilisation itself.

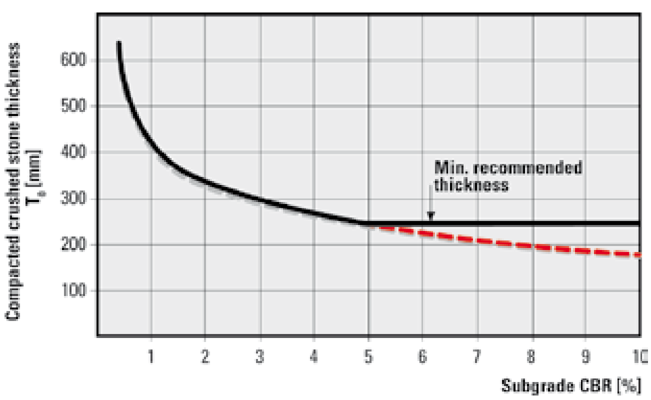


Figure 19: Compacted crushed stone thickness T'_0.

The design procedure is similar to that of unpaved roads (see previous section). However, the compacted crushed stone thickness T'_0 for 1000 axle loads for paved roads is determined from figure 19.

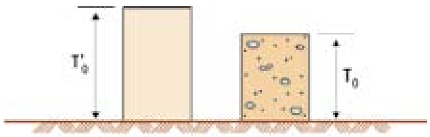
This thickness should be adjusted for service life and aggregate efficiency as for the unpaved structure.

3

3.3.3. Paved Roads with Construction Traffic Subbase

Take full advantage of the reinforcement mechanism of DuPont™ Typar® SF using figure 17 to determine the minimum aggregate thickness for temporary construction traffic roads. Then integrate this structure in the final paved road construction by adding the remaining aggregate to build up the necessary thickness as determined with figure 18. The design steps are summarised as follows:

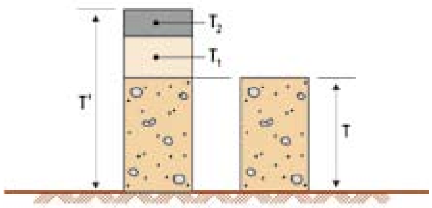
Paved Structure		Unpaved construction road[17]	
A. Initial Aggregate Thickness T'_0		**A. Initial Aggregate Thickness T_0**	
Soil bearing capacity Axle Load	CBR P_i	Soil bearing capacity Axle Load	CBR P_i
Figure 19 →	T'_0	Figure 17 →	T_0



B. Adjustment of T'_0 for service life		**B. Adjustment of T_0 for service life**	
Axle Load Actual number of passes Compacted crushed stone thickness	P_i N'_i T'_0	Axle Load Actual number of passes Compacted crushed stone thickness	P_i N_i T_0

$$ESAL = (P_i/P_0)^{3.95}$$

$N'_E = \Sigma N'_i * ESAL \rightarrow C$ Fig 18	$N_E = \Sigma N_i * ESAL \rightarrow C$ Fig 18
$T' = C * T'_0$	$T = C * T_0$
$\alpha = 1$	



C. Adjustment of T' for aggregate efficiency	**C. Adjustment of T for aggregate efficiency**
$T_{eff}' = T_{eff} + \Sigma T_i / \alpha_i$	$T_{eff} = \Sigma T_i / \alpha_i$
with T_{eff} effective minimum thickness for construction traffic	

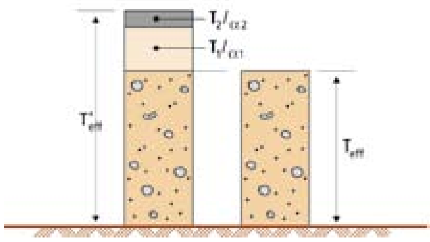


Figure 20: design chart[18]

[17] see also 3.3.1.
[18] see also example section 3.6.2.

3.4. Selection of the right DuPont™ Typar® SF style

The design guidelines presented in the previous section are based on a standard DuPont™ Typar® SF energy level 1. Higher performing energy level 2, 3 or 4 may be used in case of additional design requirements to withstand the:

- Effect of Traffic
- Effect of Installation Conditions
- Effect of Compaction

Determine the required level according to figure 21 to 23 and select the equivalent energy level of DuPont™ Typar® SF from table 6 below.

Energy Level			Level 1	Level 2	Level 3	Level 4
Test	Standard	Unit				
Energy Absorption (actual)	EN ISO 10319/ ASTM D4595	**kJ/m²**	**2,5**	**5**	**8**	**11**
Tensile Strength		kN/m	7	12	20	25
Elongation		%	45	50	50	50
Strength at 5% Elongation		kN/m	3	5	8	10
Puncture CBR	EN ISO 12236	N	1000	1500	2500	3500
Cone Penetration	EN 918	mm	35	30	25	20
minimum recommended DuPont™ Typar® SF			SF 32	SF 49	SF 77	SF 94

Table 6: Minimum values for different Typar® SF energy levels[19]

3.4.1. Effect of Traffic

Higher fabric properties are required to withstand:

- Fatigue caused by large number of equivalent standard axle loads (ESAL)
- Additional stresses caused by heavy duty equipment (generally with axle loads larger than 130 kN). The correct DuPont™ Typar® SF energy level can be selected using figure 21 according to subgrade CBR and the number of axle load applications.

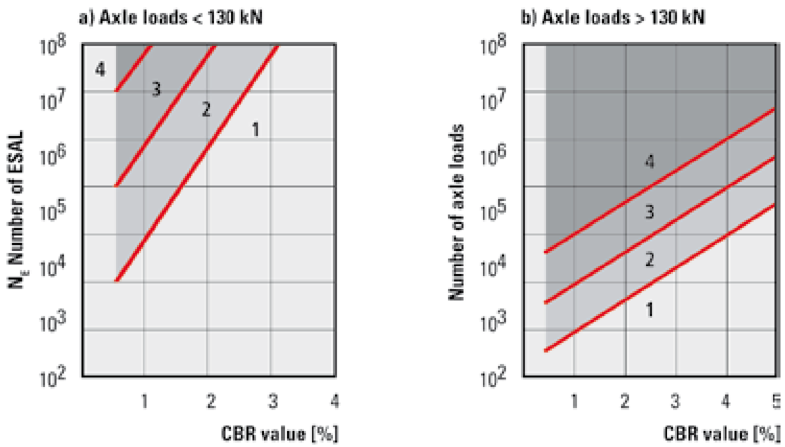


Figure 21: Recommended energy levels as a function of traffic [20]

3

[19] Please note that the selection of Typar® energy levels may depend on national classification systems and specifications.
[20] $NE = \sum N_i * ESAL_i$.

3.4.2. Effect of Installation Conditions

To fulfill its long-term functions, the geotextile should withstand installation stresses, particularly aggregate dumping and compaction. Figure 22 indicates the recommended DuPont™ Typar® SF energy level as a function of aggregate size and drop height. It is evident that aggregate backdump and push-ahead over an existing layer instead of dumping directly on the geotextile allows the use of styles with a lower energy level.

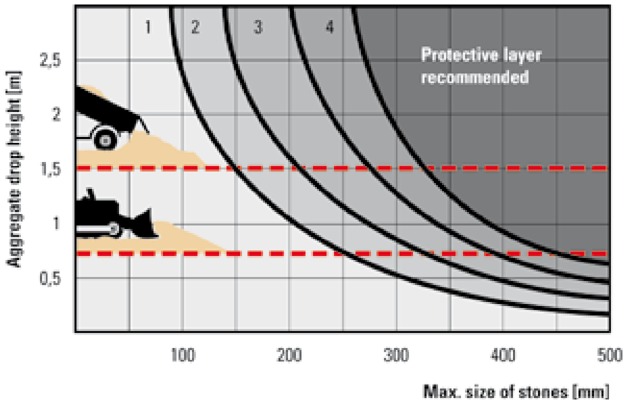


Figure 22: Recommended energy level as a function of aggregate size and drop height

3.4.3. Effect of Compaction

Puncture by sharp stones during aggregate compaction is detrimental to the long term separation function. Figure 23 indicates the recommended DuPont™ Typar® SF energy levels as a function of soil CBR and D_{90} (90% passing size) of the crushed aggregate in contact with DuPont™ Typar® SF.

Remark: Styles with a lower energy than 2 kJ/m² may be used if there is light traffic (cars) only and maximum aggregate size does not exceed 50mm.

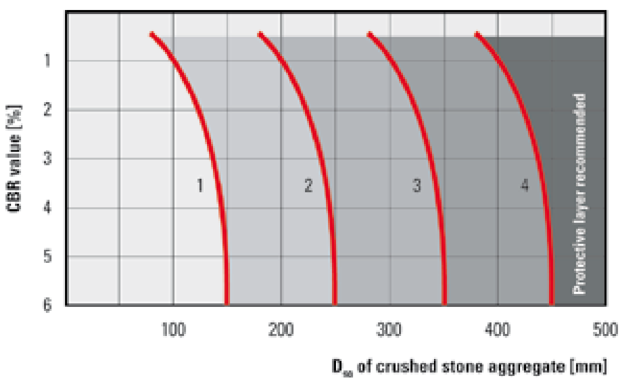


Figure 23: Recommended energy level as a function of «crushed stone» size and subgrade CBR

3.4.4. Filter requirements

To perform efficient long term separation and filtration functions, the geotextile should meet simplified criteria of table 7 in which the O_{90} is measured by wet sieving test method (EN 12956).

very fine, cohesive soils	non cohesive soils
$D_{85} < 0.06$, $D_{10} < 0.002$	
$O_{90} \leq 0.200$mm	$O_{90} \leq 2 * D_{85}$

Table 7: General filter requirements.

3.5. Installation Guidelines

The following measures should be followed when installing DuPont™ Typar® SF in road constructions and aggregate bases:

- 1) Remove all large debris which might puncture DuPont™ Typar® SF
- 2) DuPont™ Typar® SF should be at least as wide as the base of the aggregate layers
- 3) When using two or more rolls, ensure sufficient overlap (usually min.30cm)
- 4) If it is windy, use shovelfuls of coarse aggregate at regular intervals to hold DuPont™ Typar® SF in place
- 5) Backdump aggregate without driving directly on the geotextile (Fig. 24)

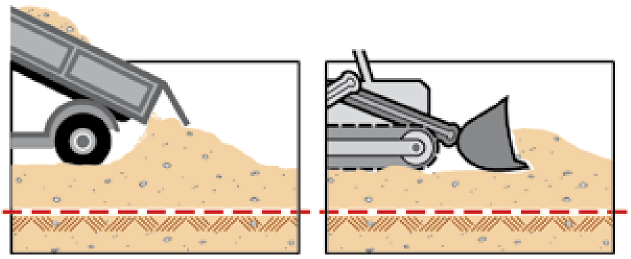


Figure 24: Backdumping aggregate on DuPont™ Typar® SF without driving on it

- 6) Level and compact aggregate before any heavy traffic occurs
- 7) Avoid aggregate size in excess of 1/3 of the aggregate layer thickness
- 8) Fill up ruts, if any, as soon as they exceed 1/3 of the aggregate layer thickness. Rutting will then be stopped.
- 9) First aggregate layers must be at least 250mm thick

3.6. Design Examples

3.6.1. Example 1 (according to 3.3.1)

A contractor desires all-weather access to a remote bridge construction site over an organic clay with a CBR of 2.5%. About 6 trucks (3 axles) will enter the site daily over a period of 5 months.

A source of inexpensive gravel is close ($\alpha = 0.4$, $D_{max} = 100$mm).

A. Initial aggregate thickness T_0	
Soil bearing capacity	CBR = 2.5
Axle Load	$P_i = 80$ kN
Figure 17 →	$T_0 = 190$ mm

B. Adjustment of T_0 for service life	
Axle Load	$P_i = 80$ kN
Actual number of passes	$N_i = 6$ trucks/day
Compacted crushed stone thickness	$T_0 = 190$ mm

3

ESAL= $(P_i/P_0)^{3.95}$ = 1
$N_E = \Sigma N_i * ESAL_i$ N_E = 5 months * 30 days/mont * 6 trucks/day * 3 axles * 1 = 2700
Fig 18 → C = 1.12
T = C * T_0 = 1.12 * 190 = 212 mm

C. Adjustment of T for aggregate efficiency
$T_{eff} = \Sigma T_i / \alpha_i$ = 212/0.4 = 530 mm

Selection of the suitable DuPont™ Typar® SF energy level

CBR = 2.5%	N_E = 2700	Fig 21 : → level 1
Drop height = 1 m	$D_{máx}$ = 100 mm	Fig 22 : → level 1
Fig 23 : only applicable to crushed aggregate		
Table 7: cohesive soil	$O_{máx} \leq$ 0.200 mm	

→ SF 37

Installation: follow the installation guidelines see 3.5 install two layers of gravel each 330mm and compact to 265mm

3.6.2. Example 2 (according to 3.3.3)

A transport company will build a terminal and parking area with an expected life time of fifteen years. 20 trucks per day will use the facility and 8 of these will be empty one way. The trucks have 4 loaded axles.

The site is in low area and on uneven ground. A CBR of 1% was obtained during a site investigation. The access road and parking area will be paved with a 70mm (= T_{hotmix}) surfacing course of hot mix. A sandy gravel will be used for the base of the construction traffic road (α = 0.5) and then topped off by a good quality round stone aggregate (α = 0.8 , Dmax = 100mm) for the final structure.

Initially the contractor will create a stable working and assembly area to and around the terminal. This aggregate structure will be incorporated in the final paved structure which will save time and money.

Following figure 20 design chart:

Paved Structure		**Unpaved construction road**	
A. Initial aggregate thickness T'_0		**A. Initial aggregate thickness T_0**	
Soil bearing capacity Axle Load	CBR = 1% P_i = 80 kN	Soil bearing capacity Axle Load	CBR = 1% P_i = 80 kN
Figure 19	T'_0 = 420 mm	Figure 17	T_0 = 280 mm

B. Adjustment of T'_0 for service life		**B. Adjustment of T_0 for service life**	
Axle Load	P_{full} = 80 kN P_{empty} = 30 kN	Axle Load	P_i
Actual number of passes	N'_i	Actual number of passes	N_i
Compacted crushed stone thickness	T'_0	Compacted crushed stone thickness	T_0

$ESAL_{full} = (P_i/P_0)^{3.95}$ = 1	
$ESAL_{full} = (30/80)^{3.95}$ = 0.021	$ESAL_{construction\ estimate}$ = 3000

N'_{full} = 32 x 6 x 52 x 15 x 4 axles = 599040	$N_{E\ construction\ estimate}$ = 3000
N'_{empty} = 8 x 6 x 52 x 15 x 4 ejes = 149760	
N'_E = 599040 x 1 + 149760 x 0.021 = 602185	
Fig 18 → C = 1.75	Fig 18 → C = 1.13
$T' = C * T'_0 = 1.75 * 420 \cong 740$ mm	$T = C * T_0 = 1.13 \times 280 \cong 320$ mm
$\alpha = 1$	

C. Adjustment of T' for aggregate efficiency	C. Adjustment of T for aggregate efficiency
$T_{eff}' = T_{eff} + \Sigma T_i / \alpha_i$	$T_{eff} = \Sigma T_i / \alpha_i$
with T_{eff} effective minimum thickness for construction traffic	

Of the total thickness T' of 740mm, 320mm (α=1) were used to support the construction traffic. 70 mm of wearing course are equivalent to 140mm of a material with an efficiency of α=1. The remaining 280mm (T_{rem}) can be provided by 350mm (= 280/0.8) of round stone aggregate. This results in a effective minimum thickness of 790mm.

$T'_{eff} = T_{eff} + T_{hotmix}/\alpha_{hotmix} + T_{rem}/\alpha_{rem}$ $T_{rem} = T' - T - T_{hotmix}$ (α=1) = 740 - 320 – 140 = 280 mm T'_{eff} = 640 + 140/2 + 280/0.8 = 1060 mm	T_{eff} = 320/ 0.5 = 640 mm

Note: T'_{eff} is the thickness of the unpaved construction road.
T_{hotmix} is the thickness of the wearing course.
T_{rem} is the additional thickness necessary to fulfill thickness requirements for permanent paved road.

Selection of the suitable DuPont™ Typar® SF energy level

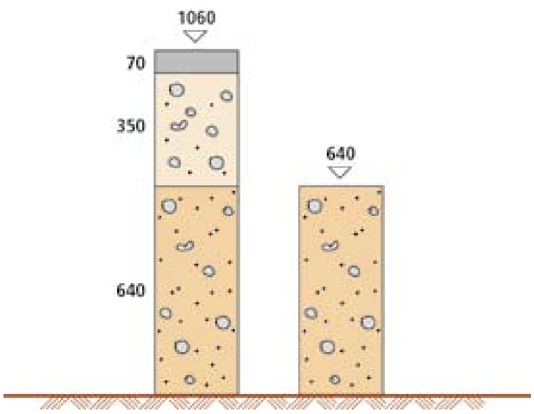
CBR = 1.0 %	N'_E = 602185	Fig 21 : → level 2
Drop height = 1 m	$D_{máx}$ = 100 mm	Fig 22 : → level 1
Fig 23 : only applicable to crushed aggregate		

→ SF 49

Installation

- Follow the installation guidelines (section 3.5)
- Install 640mm of round stone aggregate for construction traffic in two layers
- Install 350mm of round stone aggregate and 70mm hot mix wearing coarse

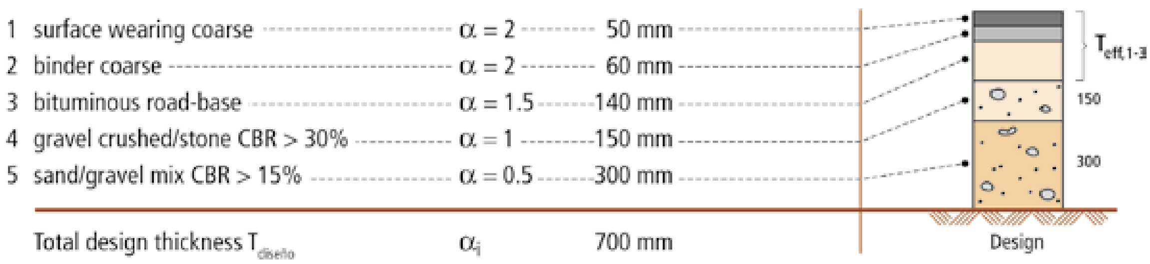
3



3.6.3. Example 3

A contractor wants to suggest a refined road design to the road authority in order to show possible savings by using a geotextile. The original design presented by the road authority to tender for is as follows:

Road structure:

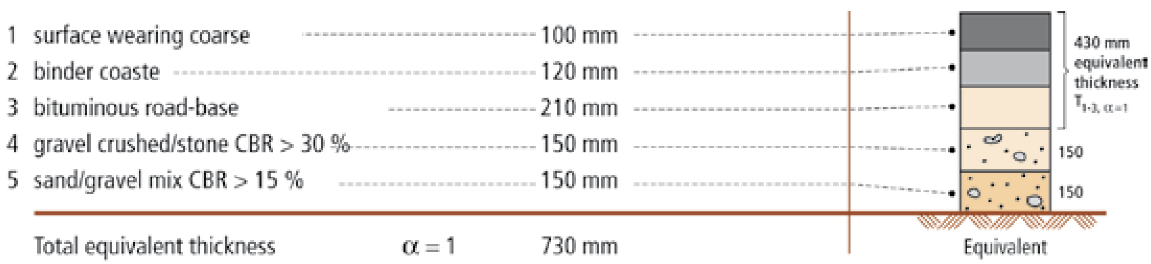


This design is based on the following estimates for traffic:

- Traffic: axle load is 8 tons or 80 kN
  10 years design life
  total of $15*10^6$ axle loads / lifetime of the road
- Bearing Capacity: existing roadbed CBR 1 – 5%

As the CBR of the existing roadbed varies a new road structure is determined for the CBR = 1%, 3% and 5%. Furthermore layers 1, 2, 3 will remain unchanged with the current design thickness of $T'_{eff1\text{-}3}$ = 250mm and an equivalent thickness $T_{1\text{-}3}$, $\alpha_{=1}$ = (T1+T2) * $\alpha_{1,2}$ + T3 * α_3 = 430mm using the aggregate efficiency factors $\alpha_{1,2}$ = 2 and α_3 = 1.5. The equivalent thickness for layer 4 is 150/ (α = 1) = 150mm, for layer 5 the thickness is 300/ (α=0.5) = 600mm. All of the following comparisons are based on an aggregate efficiency of α=1.

The equivalent road structure is outlined below:



A. Initial Aggregate Thickness T_0	
Soil bearing capacity	CBR = see table below
Axle Load	P_i = 80 kN
Figure 17 →	T'_0 = see table below

CBR	1%	3%	5%
T_0' (thickness) (Fig. 8) [mm]	420	300	250

B. Adjustment of T_o for service life	
Axle Load	P_i = 80 kN
Number of passes (ESAL)	N'_E = 15 * 10^6 axle loads
Compacted crushed stone thickness	T'_0 = see table above

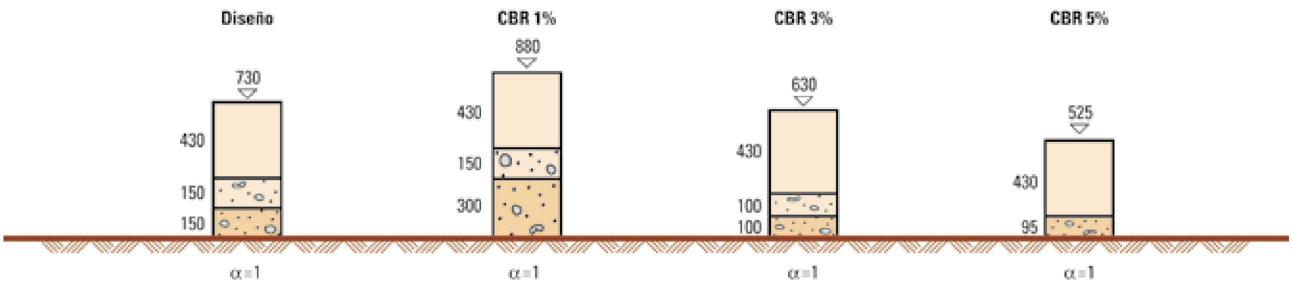
CBR	1%	3%	5%
C (service life adjustment)	2.1	2.1	2.1
T = T_0' * C (mín. with α=1) [mm]	880	630	525

C. Adjustment of T for aggregate efficiency

CBR	1%	3%	5%
T_{remain} (= T – $T_{1\text{-}3,a=1}$) [mm]	450	200	95

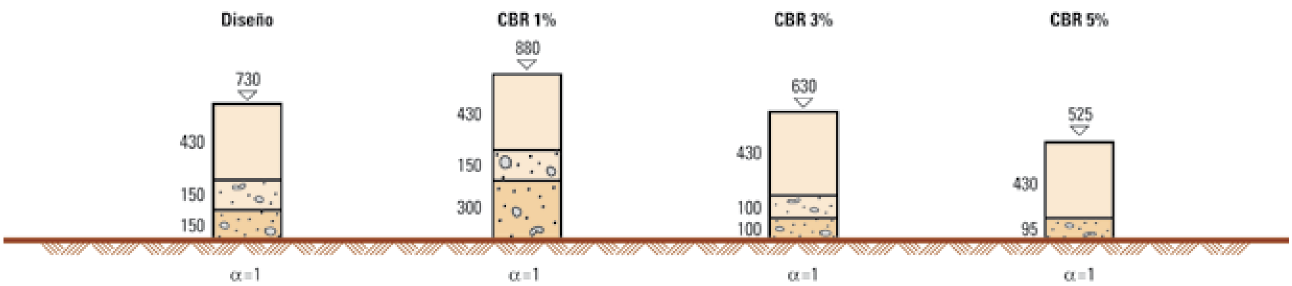
The remaining thickness T_{remain} can be divided between the two available materials in the following way :

T_4 (standard aggregate) [mm]	150	100	-
T_5 (sand/gravel mix) [mm]	300	100	95
Reduction (= T – 730 mm) [mm]	+150	-100	-205



This leads to savings in the effective thickness for CBR = 3% and 5% and to an augmentation of thickness for CBR = 1%.

CBR	1%	3%	5%
$T_{4,eff}$ (standard aggregate) [mm]	150	100	-
$T_{5,eff}$ (sand/gravel mix) [mm]	600	200	190
eff reduction (=T_{design} - T_{eff}) [mm]	+300	-150	-260



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Drainage systems

4. Drainage systems

4.1. Introduction

This section is a guideline for the use of DuPont™ Typar® SF as a filter medium, the basic design and the construction of some typical drainage systems. The design procedure for using DuPont™ Typar® SF is the result of knowledge gained from several laboratories and field tests, as well as the experience gained from thousands of installations throughout the world.

4.2. Functions

In drainage applications (controlled discharge of water) it has become standard practice to replace the conventional granular filter with a geotextile filter. A geotextile filter fulfills the same function: it prevents the clogging of the drain but with the advantage of easy installation and a controlled filter quality that is not compromised by poor construction conditions. The use of geotextiles leads to substantial cost savings thanks to shorter installation times, reduced excavation and reduced material use.

The properties of a geotextile are significantly influenced by its structure. Woven tape geo-textiles usually have a low percentage open area. As the limited number of pores generally have the same diameter they are subject to blocking or blinding by soil particles. Thick geotextiles have a long and tortuous flow path, the small soil particles can be easily trapped in the narrow channels. This partial clogging and their sensitivity to compression can cause significant reduction of permeability.

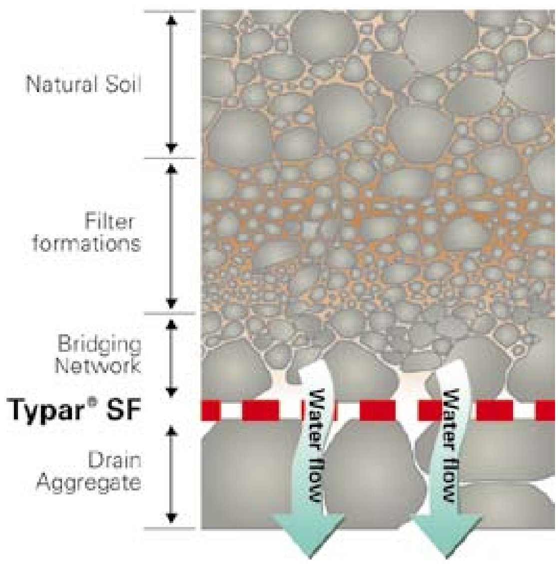


Figure 6': Natural soil filter adjacent to geotextile

DuPont™ Typar® SF, on the other hand, has a superior soil particle retention and water permeability properties. It has a good soil particle retention because of its wide range of pore sizes and shapes. The soil particles are unlikely to be trapped in DuPont™ Typar® SF because of its thin precompressed structure, which is also the reason for its hydraulic property's insensitivity to compression.

Additionally the geotextile needs to withstand the installation stress to be able to perform its filtration function properly. Due to its high initial modulus and high elongation DuPont™ Typar® SF has a high energy absorption potential which makes it very resistant to damage during installation as well as providing dimensional stability for pore size and permeability.

And how does DuPont™ Typar® SF work? DuPont™ Typar® SF permits the build-up of a natural soil filter adjacent to the geotextile after being installed. This resulting bridging network will only develop if the geotextile has an adequate pore size distribution (Fig.6'). The following guidelines will help you make the right filter selection.

4.3. Geotextile properties

Extensive research programmes have been run world-wide to define the filtration performance of geotextiles by correlating the particle size distribution of the soil-to-be-filtered and the hydraulic conditions to the pore size distribution and water permeability of the geotextile.

The most important properties of a geotextile filter are the pore size and the permeability. The characteristic pore size can be read from the pore size distribution of a geotextile. This distribution is determined by using either a soil with a defined particle size distrubution (EN 12956) or glass beads of defined sizes (ASTM D4751). The result is the opening size O_{90} or O_{95}, which describe the opening size through which 90/95 % of the soil/glass beads passed. A more detailed description of the test mehods can be found in chapter 7.1.3.

Choosing the right opening size is vital for the functioning of a filtration system. It assures the build-up of a natural soil filter on top of the geotextile. The wrong opening size can result in continuous piping and soil erosion or even reduction of permeability.

The permeability of a geotextile can be defined by the permeability coefficient k . It describes the flow of water perpendicular to the plane of the soil or geotextile. The permeability coefficient k of a geotextile can be useful when comparing to the permeability of the geotextile to that of a soil. To evaluate the suitability of geotextiles with different structures it is best to compare the permeability under load. The following figure 25 shows how the permeability of a thick, compressible nonwoven geotextile changes under pressure compared to a precompressed DuPont™ Typar® SF.

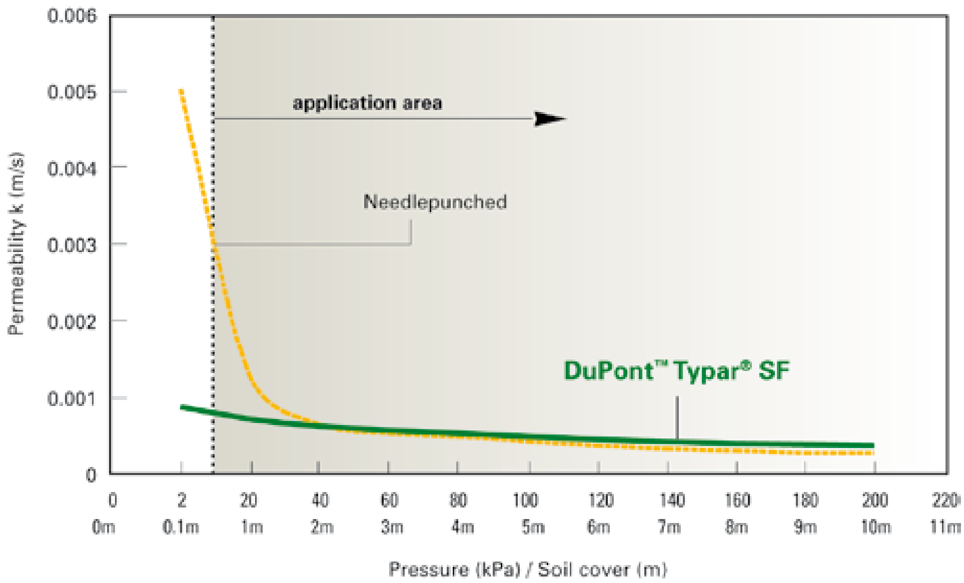


Figure 25: Permeability under pressure – Comparison of Needlepunched with DuPont™ Typar® SF

Another way to describe the permeability of a geotextile is the hydraulic conductivity or flow rate [l/(m²*s)] at a given water head, for example V_{H50} according to EN 11058. The most important aspect is to select a geotextile with a permeability that is higher than that of the soil to be filtered. This is necessary to allow the natural flow of water.

4.4. Designing Drainage Systems

The selection of the right filter is a complex process because a number of factors govern the interaction between soil and filter:

- Geotextile properties: pore size distribution (O_{90}), water permeability, compressibility, and structure
- Soil conditions: particle size distribution, uniformity coefficient, compaction, plasticity, and cohesion
- Hydraulic conditions: unidirectional or reversible flow, gradient, and chemical precipitation
- Installation conditions: physical damage during installation, and soil water content during installation

The two main criteria to be considered when designing for a filter application are soil retention and permeability.

4.4.1. Soil retention criterion

The selection starts with determining the soil particle distribution of the soil to be filtered. The limits for the maximum opening size O_{90} can be determined. The general criteria for non-critical situations (steady flow, low gradient) is:

$$O_{90} < 2 * D_{85}$$

For applications where limitation of piping is the predominant factor the following criteria are to be applied:

	Very fine, cohesive soils $D_{85} < 0.06$ and $D_{10} < 0.002$	Fine, non-cohesive soils $D_{40} < 0.06$	Coarse soils $D_{40} > 0.06$
steady flow	$O_{90} < 0.200$	$O_{90} < 6 * D_{60}$	$O_{90} < 5 * D_{10} \sqrt{C_u}$ [21]
dynamic flow	laboratory test required[22]		$O_{90} < 1{,}5 * D_{10} \sqrt{C_u}$ $O_{90} < D_{60}$

Table 8: Filter criteria for different soils and flow conditions

In case of gap-graded soils such as indicated in the graph (Fig. 26) below D'_{85} (the D_{85} of the finer part of the soil) should be used instead of D_{85}. To determine D'_{85} prolong the gradient of the finer soil part and the plateau. The cross section determines D'_{100} for the finer soil part. Connecting D'_{100} and D_0 allows to mark out D'_{85}.

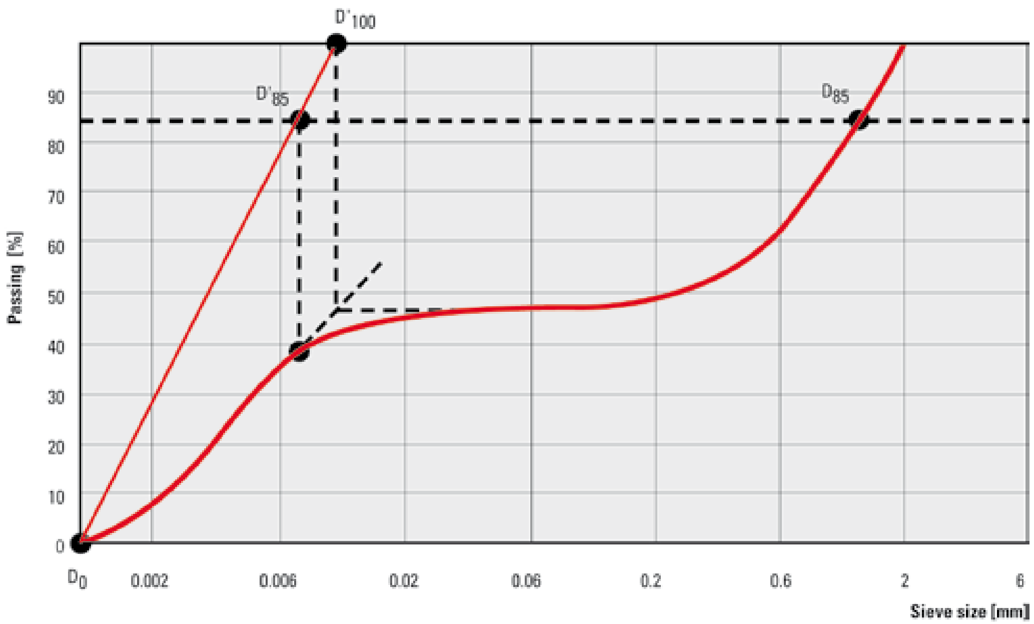


Figure 26: gap-graded soils

[21] $C_u = D_{60}/D_{10}$.
[22] Puede consultar al Centro Técnico de Geosintéticos de DuPont o utilizar el esquema que figura en el anexo 7.10.

4.4.2 Permeability criterion

As a general rule the permeability of the geotextile needs to be larger than that of the soil to be filtered. When comparing granular filters to geotextile filters J.P. Giroud [II] suggests that to ensure equivalent discharge capacity the geotextile's water permeability should be 10 times greater than the permeability of the soil to be filtered. Murray and McGown again suggest a factor 10 for wovens and thin nonwovens (≤ 2mm) and a factor 100 for thick nonwoven geotextiles (> 2mm) for the use in road pavement and structural drainage [III].

We suggest:

$$K_{geo} > 5\text{-}10 * K_{soil}$$

The soil permeability can be approximated from the particle size D_{20} with the aid of Fig. 27

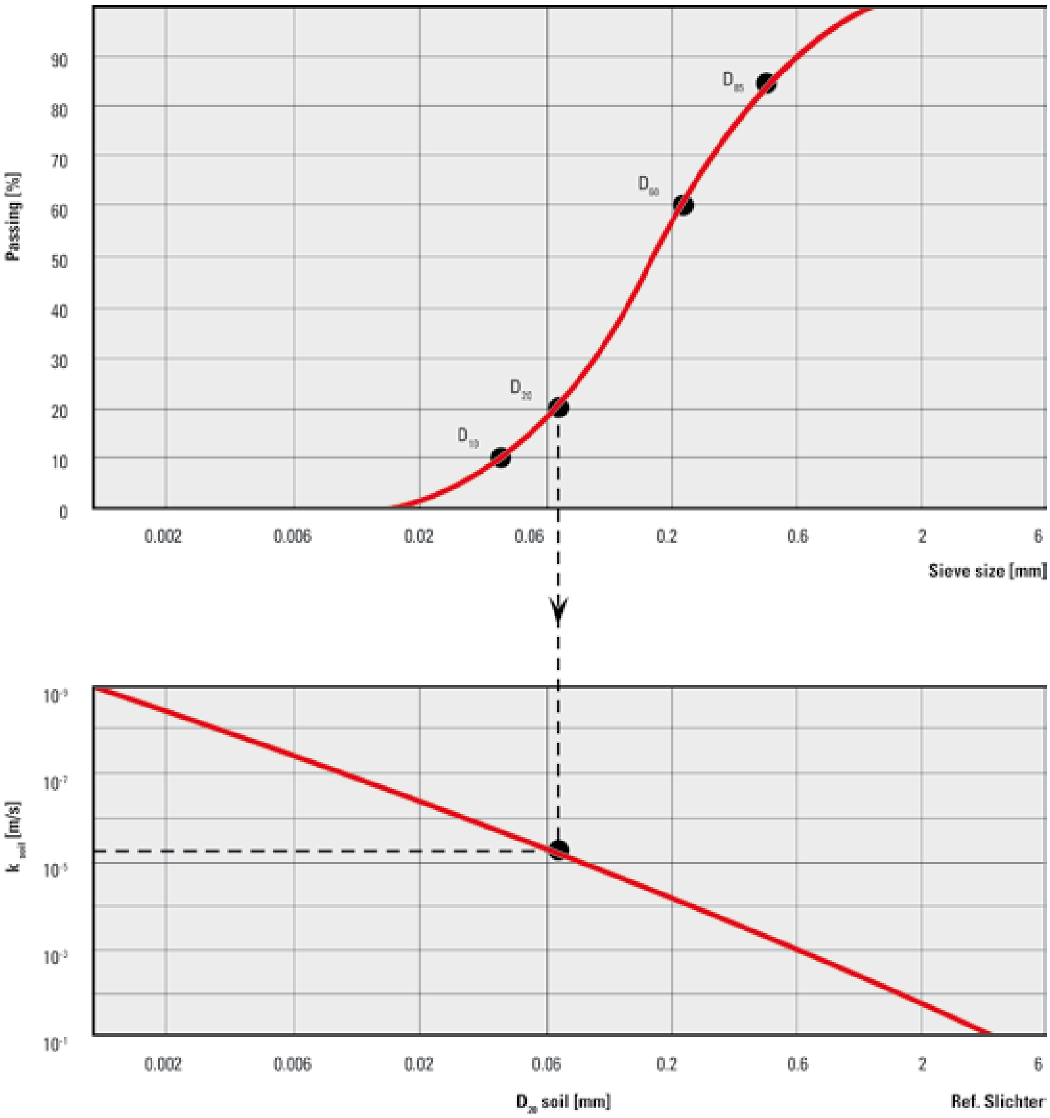


Figure 27: Approximation of soil permeability as a function of D_{20}

4

4.4.3. Special soils

The figure 28 below indicates for:

- Soils with C_u < 3 and less than 10% particles < 0.002mm, whose particle size distribution curve is entirely within the grey zone, that they are not well retained by the indicated DuPont™ Typar® SF styles. Laboratory testing is required prior to geotextile selection. When the particle size distribution curve crosses the shaded areas the usual filter criteria apply.
- Soils whose particle size distribution curve crosses the shaded rectangle that the permeability criteria is not fulfilled. Water pressure build-up can cause structural problems.

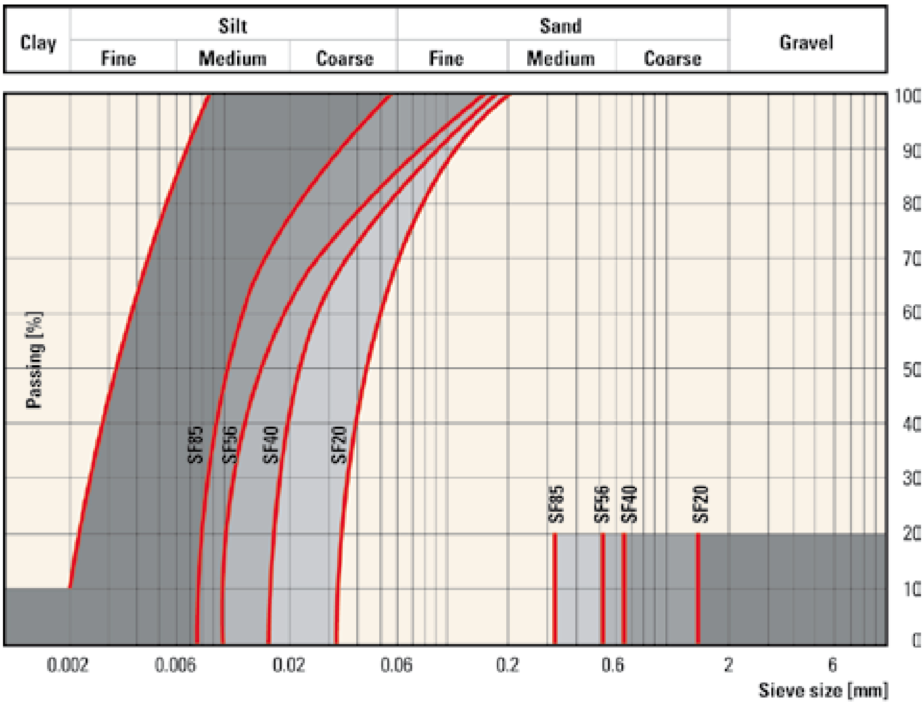


Figure 28: Special soils requiring extra consideration when selecting DuPont™ Typar® SF style

4.4.4. Comments and additional selection criteria

Laboratory test and field experience have shown that DuPont™ Typar® SF grades with pore sizes larger than those specified by the above mentioned filter criteria performed well over long periods of time with very fine soils [IV].

With respect to installation conditions (dropping height, aggregate type, compaction) a heavier and stronger DuPon™ Typar® SF style than necessary for permeability or filter requirements may be recommended. Details can be found in table 9:

Application	Recommended DuPont™ Typar® SF style
Agricultural drainage	SF20 or SF27
Drainage systems using aggregate d < 20 mm	SF32
Drainage systems using aggregate d > 20 mm	SF37 or higher

Table 9: Recommended DuPont™ Typar® SF styles for different applications

4.5. Typical drainage systems

4.5.1. French Drains

DuPont™ Typar® SF finds popular use in the construction of French Drains, where DuPont™ Typar® SF acts as a filter and maintains the drainage capacity of the aggregate drain. The discharge capacity of stone-filled drains is proportional to both cross-section and gradient.

Aggregate size	Drain gradient	Discharge Capacity Q [l/seg]				
[mm]	[%]	0.3 x 0.3	0.3 x 0.6	0.6 x 0.6	0.6 x 0.9	0.6 x 1.2
50	1.0 2.0	0.7 1.4	1.4 2.8	2.8 5.6	4.2 8.4	5.6 11.2
19 - 25	1.0 2.0	0.4 0.8	0.8 1.6	1.6 3.2	2.4 4.8	3.2 6.4
9 - 12	1.0 2.0	0.1 0.2	0.2 0.4	0.4 0.8	0.6 1.2	0.8 1.6
6 - 9	1.0 2.0	0.02 0.04	0.04 0.08	0.08 0.16	0.12 0.24	0.16 0.32

Table 10: Discharge Capacity of French Drains

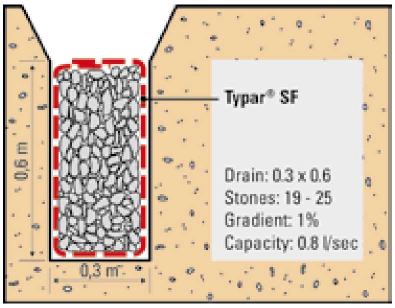


Figure 29: Example French Drain

4.5.2. Shoulder Drain

A road subsurface shoulder drain must rapidly discharge infiltrated water to prevent the deterioration of the subbase (see Fig. 30).

W = road + shoulder width
i = drain gradient [%]
P_R = rainfall penetration [%]

L = length of drain section between outlets [m]
R = max. rate of rainfall [m/sec]

The discharge capacity Q is determined:

$$Q = 10^3 * L * W * R * P_R \text{ [l/sec]}$$

The necessary drain section is then determined by using table 10 above.

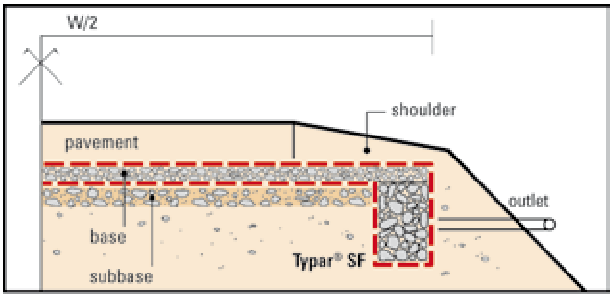


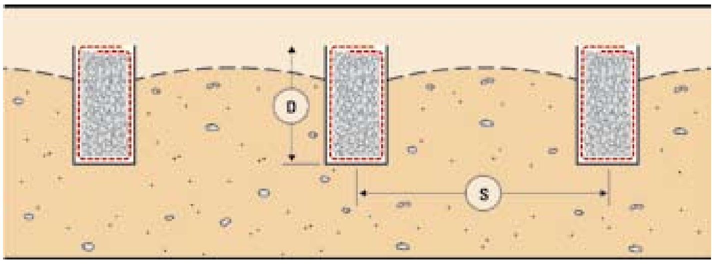
Figure 30: Section of a shoulder drain

4.5.3. Area Drainage

In conditions where surface saturation is caused by excessive precipitation the drain spacing for lowering the ground water can be determined with table 11. Assuming that each drain will have to remove both run-off water and infiltrated water, the discharge Q is:

$$Q = 10^{3} * S * L * R \text{ [l/sec]}$$

With L= length of rain section between outlets [m], R= max. rate of rainfall [m/sec]



S= spacing, D= depth

Figure 31: Section of an area drainage

The necessary drain section is then determined by using table 10 page 33.

Soil Type	Permeability k [m/sec]	Sub-drain spacing S [m] for various depths of trench		
		D = 1.0 m	D = 1.3 m	D = 1.6 m
Organic Clay	3.0 x 10-7	5 m	6 m	8 m
Silt	5.0 x 10-6	18 m	25 m	30 m
Sandy Silt	3.0 x 10-5	47 m	62 m	77 m
Silty Sand	7.0 x 10-5	67 m	88 m	109 m

Table 11: Necessary sub-surface drain section

4.5.4. Blanket Drains

Sportsfields are a typical example where the application of blanket drains as surface water run-off is not permissible. A drainage blanket must be provided below the surface soil and vegetation to ensure water can seep away rapidly. The drainage blanket should be contained between two layers of DuPont™ Typar® SF as a filter to prevent it from silting up. When installing a combination of stone filled drain and sand blanket drain, an extra layer of DuPont™ Typar® SF should be installed inbetween the two different soils to avoid contamination.

Figure 32: Section of two different blanket drains using DuPont™ Typar® SF

Blanket drain thickness t, or necessary blanket permeability kd is calculated:

$$t = s/2 \sqrt{R/k_d}$$

with

- t = thickness [m]
- s = drain spacing [m]
- k_d = permeability of drainage material [m/s]
- R = max rainfall [m/s]

As a sufficient safety margin we recommend a safety factor 10 to the permeability kd. Drain spacing s and drain section can be determined either by using table 10 or

$$Q = 10^3 * S * L * R \text{ [l/sec]}$$

Note that the surface-soil has to be sufficiently permeable to pass the surface water to the drainage layer.

4.5.5. Composite Drainage

Figure 33: Installation of composite drainage as road shoulder drain

During the last years, a new kind of drainage material has appeared on the geosynthetic market and is gaining rapid acknowledgement in the construction and civil engineering industry: composite drainage products.

A composite drainage product is composed of a rigid synthetic core surrounded by or wrapped into a geotextile filter. The core will have a rather open but uncompressible structure that allows the free flow of water even when installed. The filter will prevent the core of being clogged by the soil.

These products come in many shapes and sizes depending on the specific applications that they will be used in:

Civil engineering applications

- Road drains: edge drains, blanket drains, asphalt drains
- Waste disposals: gas venting or leachate collection
- Blanket drains under sport fields, …
- Agricultural pipe drains
- Vertical or wick drains

Construction applications

- Sheet drains for protection of underground walls, basements, parking lots...
- Blanket drains for terraces , green roofs, balconies, …

Composite drainage products are increasingly replacing traditional drainage systems consisting of aggregates wrapped into a geotextile. Their industrial manufacturing and ease of installation make them an economic alternative to the traditional drain.

For further information on these products, their applications and availability, please contact your local DuPont™ Typar® SF representative.

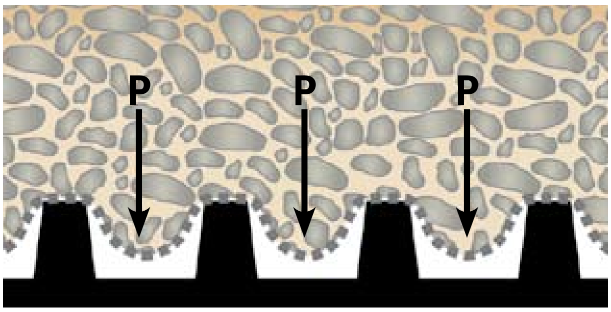


Figure 34a: Reduction of drainage capacity due to deformable filter fabric

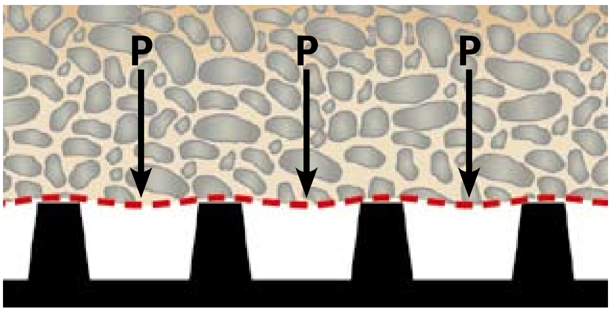


Figure 34b: DuPon™ Typar® SF and its superior performance as a filter in a composite drainage system

4.6. Installation guidelines

It is very important to cover Typar® SF as soon as possible after it has been rolled out. During rainfalls small particles are washed out of the soil and might dry on the geotextile forming an impermeable soil (clay) layer. The following guidelines for the different drainage systems should be followed when installing Typar® SF:

4.6.1. Trenches

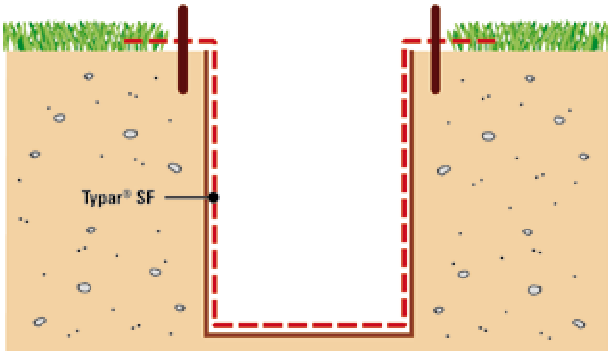


Figure 35: Fix Typar® SF to avoid the fabric being pulled down, allowing contamination of the drainage aggregate

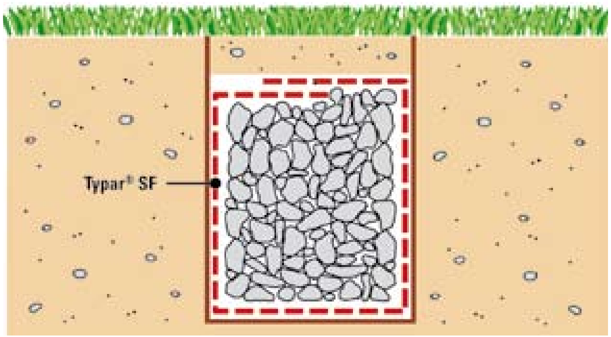


Figure 36: Enclose aggregate with Typar® SF and overlap by at least 30cm

- The base and side walls of the trench should be as free of irregularities as possible (holes, roots, etc.).
- Lay Typar® SF parallel to the trench and anchor the edges of the geotextile.
- Do not drag the fabric in the mud. This can result in the deposit of a large amount of fine particles on the surface of Typar® SF thus creating an impervious film.
- Off-load the drainage aggregates carefully to avoid the sides of the fabric being dragged towards the bottom of the trench.
- Do not use over-large stones to fill up the trench. Gravel of a maximum size of 2cm is required to ensure good fabric-to-soil contact
- Compact the aggregate and enclose it with Typar® SF before backfilling to the top of the trench.
- Overlap lengths of Typar® SF by at least 30cm

4.6.2. Blanket drains

- Overlap by a minimum of 30cm.
- Do not unroll Typar® SF too far in advance, especially in windy conditions.
- Use relatively small sized aggregate to ensure good fabric-to-soil contact.

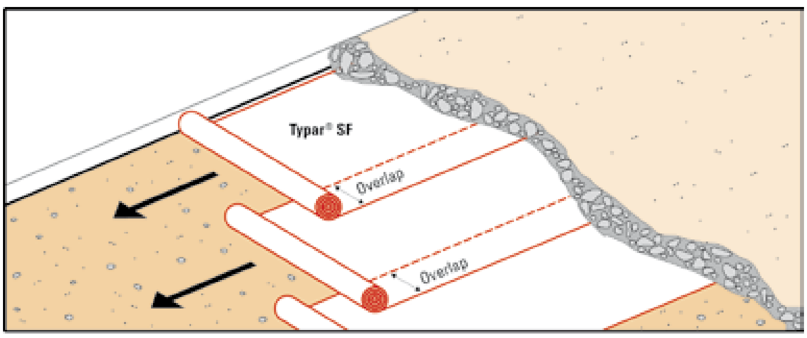


Figure 37: Application of Typar® SF for a blanket drain

4.6.3. Vertical drains with Typar® SF

- In some cases vertical drains are required to accelerate the consolidation of soft, saturated soils. To permit the specialised installation of vertical drains using heavy equipment, it is necessary to install a layer of coarse aggregate on Typar® SF. The aggregate layer will then also act as a drainage blanket.
- Since Typar® SF is sandwiched between the subsoil and the gravel layer, friction forces are usually sufficient to hold it in place during perforation by the vertical drain mandrel.
- For further information on pre-fabricated vertical drains please contact DuPont.

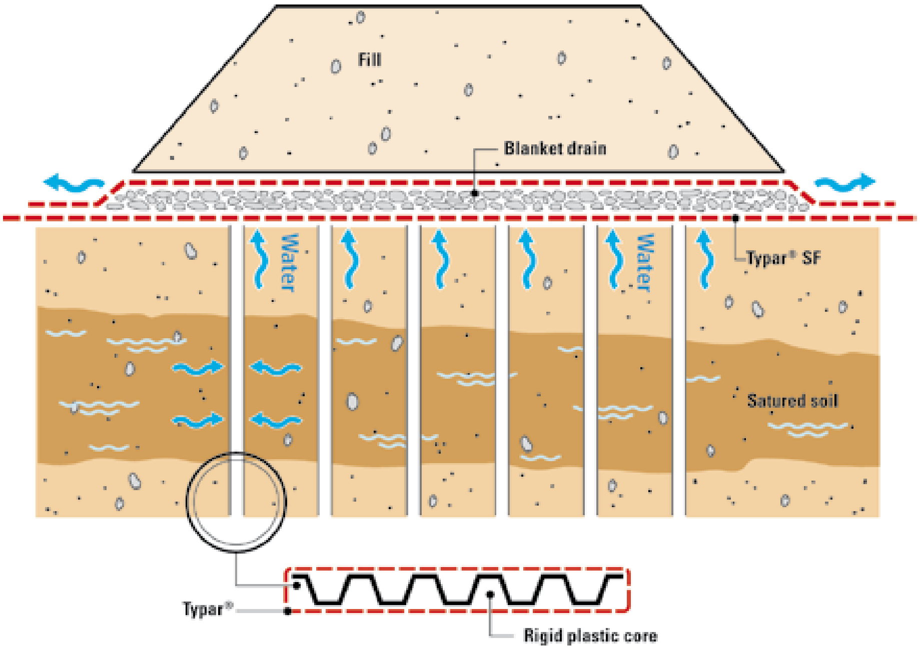


Figure 38: Fast removal of water in saturated compressible soils by using prefabricated vertical drains

4

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Erosion control

5. Erosion control

5.1. Introduction

Erosion control is defined as: "The use of a geotextile or a geotextile-related product to prevent soil or other particle movements at the surface of, for example, a slope"[23].

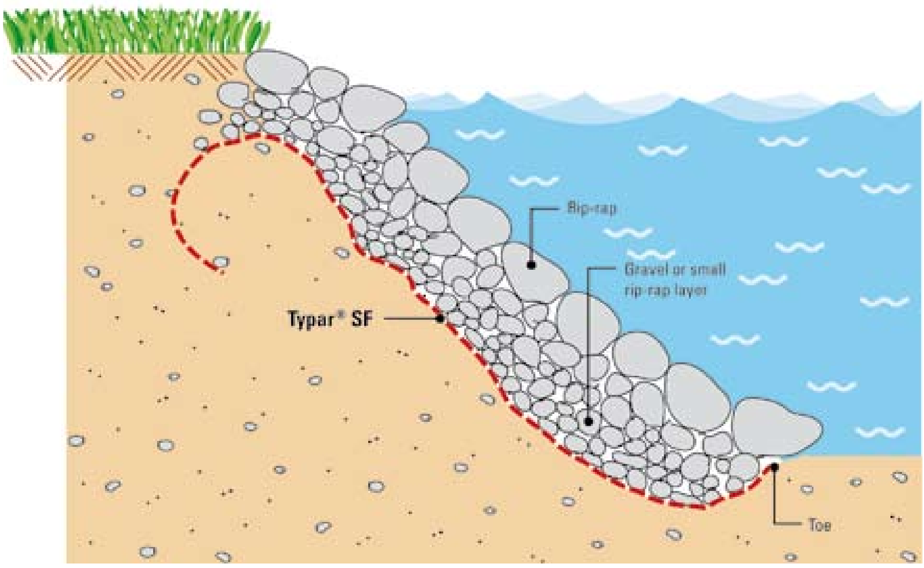


Figure 39: DuPont™ Typar® SF in an erosion control application

The erosion process is part of the geological cycle, a natural phenomenon, wherein water and air are particularly aggressive factors causing soil erosion. A geotextile is used as part of an erosion control system to protect the soil (sea embankment slopes, river banks, bed protection) from this influence. Depending on the water's force (flow rate, wave action, tidal surges) and the characteristics of the soil the effects can be devastating (e.g. landslides).

5.2. Functions

The main function of the geotextile in an erosion control system is the retention of the basic material without the generation of unacceptable excess pore water pressure. The geotextile replaces a conventional well-graded filter between soil to be retained and gabions, rip-rap or concrete slabs revetments, which protect the filter geotextile. Its particular opening size retains the soil and so avoids erosion of the slope. Furthermore the geotextile must fulfill the strength requirements.

DuPont™ Typar® SF is the ideal filter for erosion control and is used to replace multi-phased aggregate filters because:

- Its strong, homogeneous, cohesive structure absorbs and dissipates frontal water forces more effectively thus resisting disintegration.
- Its permeability characteristics allow the passage of water while retaining soil particles thus eliminating long term hydrostatic pressure build-up.
- Its structure is more consistent in quality and uniformity compared to aggregates.
- It more effectively prevents the undermining of structures by preventing piping and scouring of soils around them.

[23] EN ISO 10318.

5.3. Selecting the correct DuPont™ Typar® SF style

The important elements to be considered by the engineer when designing drainage systems are the topography, water table, soil composition and characteristics of the drain and filter to be used. The selection of the geotextile filter must consider both the filter and energy absorption criteria.

5.3.1. Filter criteria

The geotextile used in erosion control systems must satisfy the filter criteria under dynamic flow conditions (reversible flow), i.e. under the condition of satisfying the permeability requirement, the maximum opening size of the geotextile (O_{90}) should be as small as possible. For example, for coarse soils ($D_{40} \geq 0.06$mm [24]), the following must be observed:

$$O_{90} \leq D_{60} \text{ y } O_{90} \leq 1.5 * D_{10} * \sqrt{Cu}$$

Concerning the permeability, the following aspects should be considered:

- Contact condition between subsoil and DuPont™ Typar® SF: For erosion control applications, the geotextiles may not be firmly connected with the subsoil locally because of the occurrence of ballooning effect of the geotextiles due to reversible water flow causing liquefaction of subsoil underneath the geotextiles and decomposition of the natural filter layer under the geotextiles. However, using small size gravel with particle size not more than 50mm to 100mm, good contact between the geotextile and the underlying soil can be achieved.
- The influence of the top layer on the permeability: The permeability of DuPont™ Typar® SF is adapted to that of the subsoil. However, situations may occur where adoption according to the permeability of the top layer is necessary. For instance if concrete blocks are applied directly on to the DuPont™ Typar® SF and there is minimal space between the geotextile and the blocks, the permeability of DuPont™ Typar® SF remains the same but cannot be utilised along the entire surface. The water from the subsoil must first be directed to the openings between the blocks. The effective permeable area is reduced. To eliminate this effect and to provide some additional protection against installation damages, a layer of gravel or sand is placed between the geotextile and the concrete blocks. Furthermore this protects the geotextile from possible UV exposure.

5.3.2. Energy criteria

During the construction of the erosion control system, the stone may be dumped on the geotextile. In this case a DuPont™ Typar® SF style with a high energy absorption potential is required, such as a style with an energy level 3 (see Fig. 22 and table 6).

When the subsoil locally deforms, while the adjacent part remains unchanged, large local tension deformation can occur in the geotextile. This local deformation can occur from two mechanisms: non-uniform settlement and transport of material underneath DuPont™ Typar® SF. Differential settlement can be caused by variation in the bearing capacity of the subsoil, variation in the top load and softening and plastic deformation. A high initial modulus can stabilise the underlying soil and reduce non-uniform settlement. Movement of material underneath the geotextile may result from excavations along the border of the geotextile or damage in form of wear or tear. A geotextile with a high energy absorption is optimally suited to withstand such harsh installation conditions and minimise potential damages.

[24] EN ISO 10318

5.4. Installation Guidelines: Erosion control systems with DuPont™ Typar® SF

- If possible, grade and compact slopes.
- If slope width is less than 8m, unroll DuPont™ Typar® SF along the length of the lower half of the slope first, then place DuPont™ Typar® SF on upper half of the slope with 0.5 to 1m overlap.

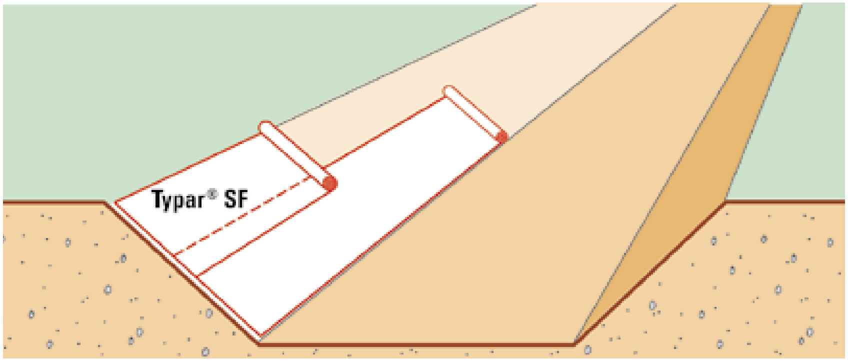


Figure 40: DuPont™ Typar® SF unrolled first on the lower half of the slope and then on the upper half

- If slope is over 8m, place DuPont™ Typar® SF in full-width lengths from slope top to bottom. Overlap in direction of waterflow.
- Excavate ditches for anchoring DuPont™ Typar® SF at top and toe of slope. The toe is the foundation of the structure and should get special attention to prevent undermining (see Fig. 41).
- When placing rip-rap or gabions, start at toe and work up the slope to prevent sliding. Install rip-rap smoothly, without dropping it from a big height on DuPont™ Typar® SF.
- To ensure good fabric-to-soil contact, first of all place a layer of bedding material (gravel) on the DuPont™ Typar® SF.
  This layer will also help prevent puncturing by heavy rip-rap.
- Anchor the fabric in the ditch at the top edge of the slope with soil and vegetation. This deep anchoring method will prevent large volumes of surface water from getting under the fabric and lifting the entire structure.

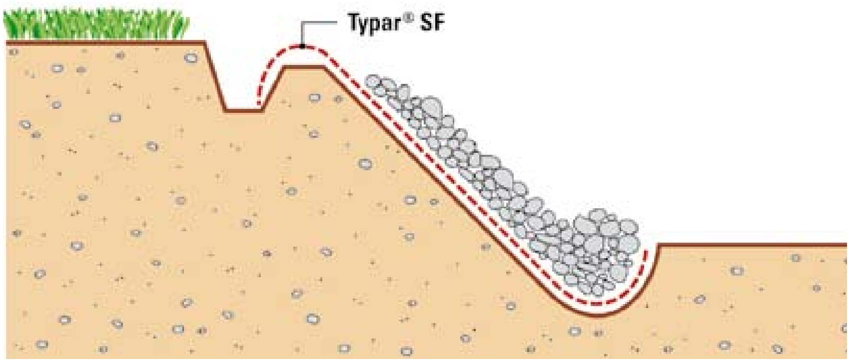


Figure 41: Anchoring DuPont™ Typar® SF at the top edge of the slope

Hydraulic applications:

When installing the geotextile under water level DuPont™ Typar® SF floats on the water, because the density of polypropylene is lower than that of water (0.91). In order to hold the geotextile in place, sand or gravel need to be dropped on the geotextile immediately following the layout machine.

For rapid and consistent installation, attach steel rods (e.g. typical 6mm diameter reinforcement bar) every 5 metres. These rods will keep the fabric flat, thus allowing a regular overlap (no need for divers; smaller overlap = cost savings)

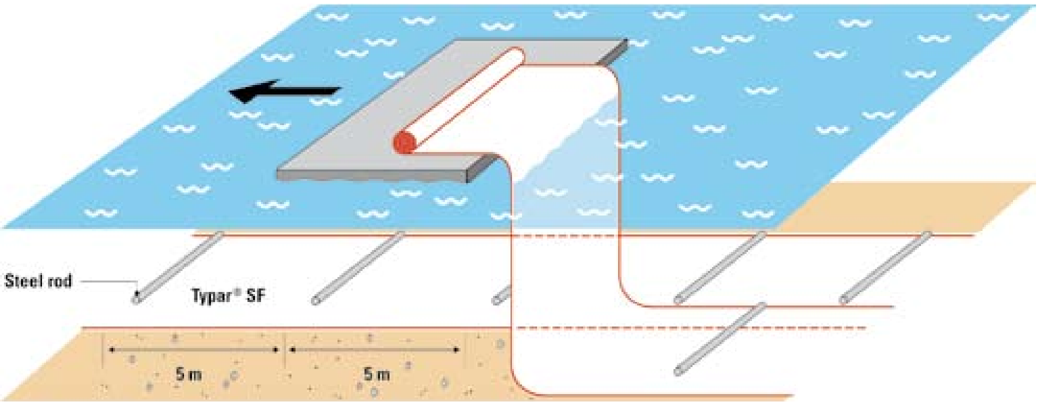


Figure 42: Attaching steel rods to DuPont™ Typar® SF will keep fabric flat and allows installation under water

Application suggestions

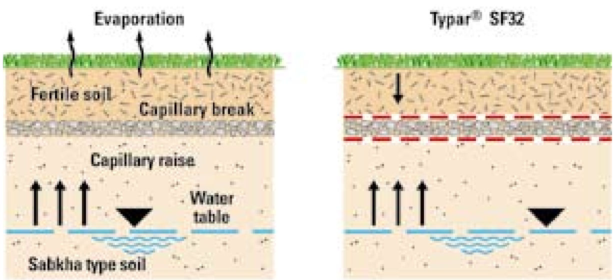
6. Application suggestions

Apart from the most common applications in road, drainage and erosion control projects geotextiles are also widely utilised in a multitude of other applications such as:

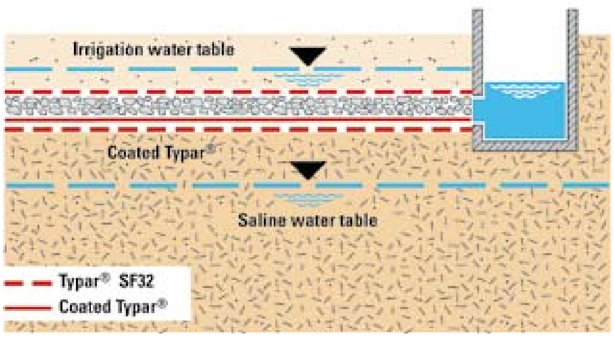
- roofing systems
- landscaping
- building foundations
- foot paths etc.

Below special applications of Typar® are illustrated.

Controlling capillary raise of saline water.

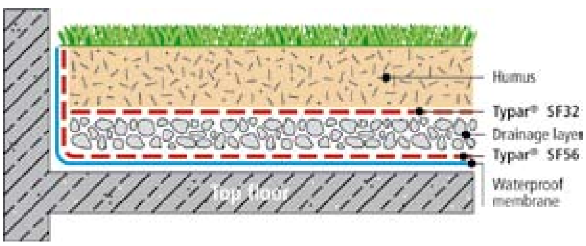


- In arid countries intense surface evaporation causes the capillary rise of underlying salt water into fertile soil, to the detriment of vegetation.
- When newly installed, a granular capillary break will prevent capillary rise of salts. However downwash of fertile soil will eventually fill the granular material and again favour the capillary process.



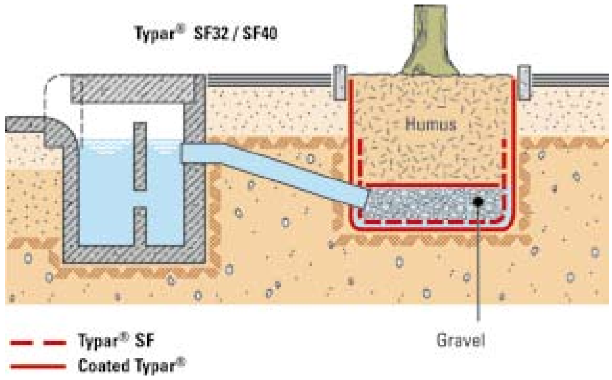
- DuPont™ Typar® SF filter prevents downwash of soil.
- The efficient separation with DuPont™ Typar® SF permits installation of thinner capillary break layer.
- The installation of impervious coated Typar® at the bottom of the capillary break will retain irrigation water and/or allow irrigation water supply through the granular layer, thus diminishing evaporative losses and encouraging deep root growth.
- This system can also be used in normal conditions, the granular layer simply acting as a drainage or irrigation layer.

Roof gardens



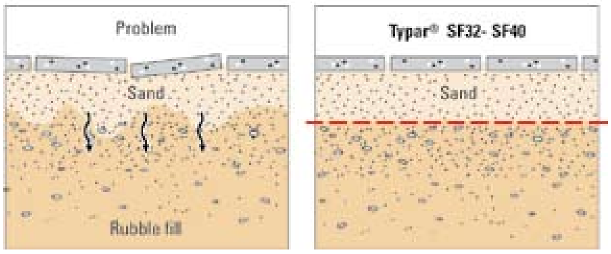
- Upper Typar® layer prevents downwash of humus into the drainage layer.
- Bottom DuPont™ Typar® SF layer protects the waterproof membrane from puncturing and acts as a root barrier.

Vegetation irrigation along roads



- Excess rainwater can be used for plants irrigation.
- If in situ soil is too porous, coated DuPont™ Typar® SF can be used to prevent rapid water absorption
- DuPont™ Typar® SF prevents washing out of humus.

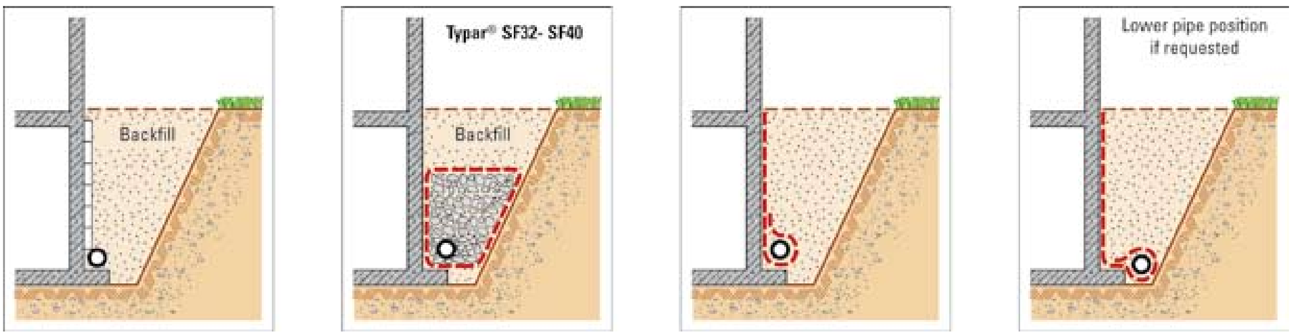
Pathways with concrete slabs or paving stones



- DuPont™ Typar® SF prevents downwashing of sand used for setting paving stones and concrete slabs.
- DuPont™ Typar® SF minimizes subsidence of slabs.

Drainage of foundation walls

Drainage systems with DuPont™ Typar® SF are easier and quicker to install. DuPont™ Typar® SF prevents silting of the drainage pipe and maintains efficient performance.

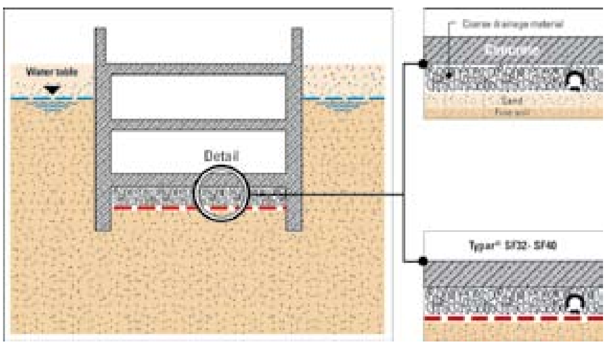


Conventional

With Typar® and gravel

With Typar® bonded to draining material (composite drainage) corrugated plastic/styrofoam drainage sheet, etc.

Drainage of building foundations



Conventional solution

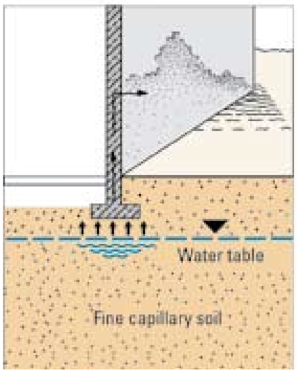
- Graded granular filter.
- Risks of drainage silting.
- Difficult and uneven installation in wet conditions with risk of filter contamination.

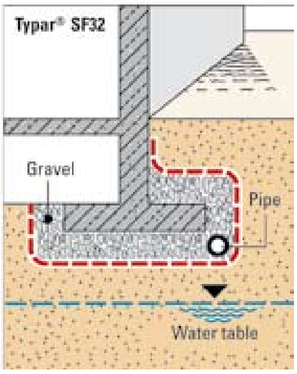
Solution with DuPont™ Typar® SF

- Easy to install.
- Prevents contamination of drainage layer.
- Open-graded aggregate.

6

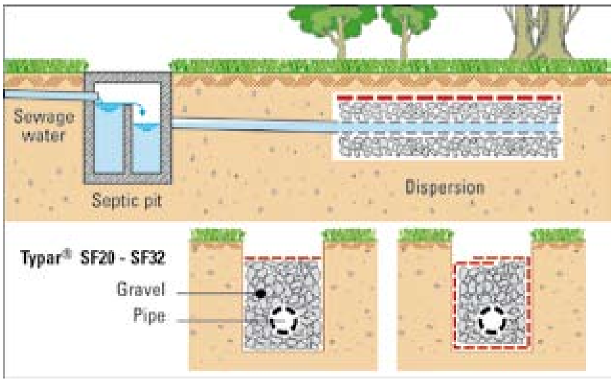
Capillary break for building walls





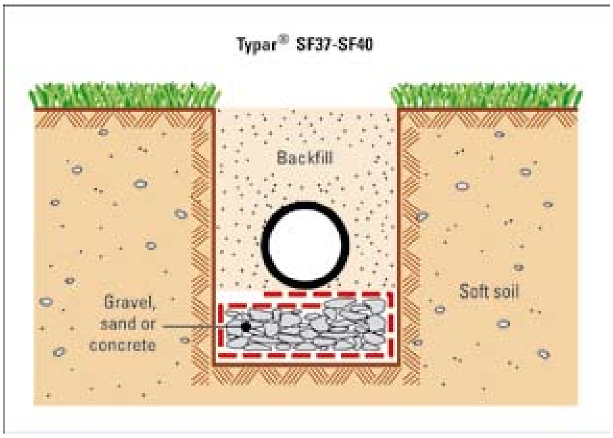
- In fine soils a high water table may rise by capillary effect into the building walls, causing wall humidity and revetment degradation.
- A coarse gravel layer will provide a capillary break.
- DuPont™ Typar® SF prevents the capillary break from being contaminated by fine soils.

Individual housing sewerage



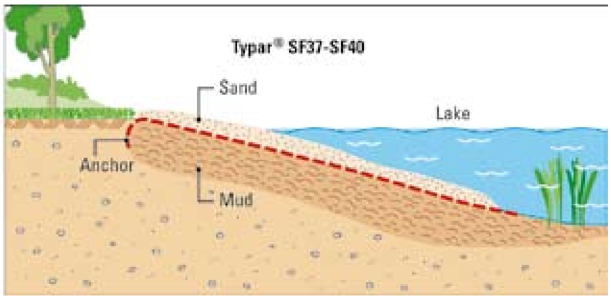
- DuPont™ Typar® SF prevents contamination of gravel by fill or surrounding soil, thus allowing efficient biological transformation through good aeration of the gravel.

Pipes on soft soil



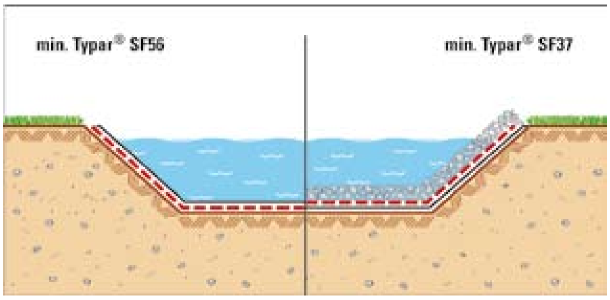
- DuPont™ Typar® SF allows clean installation of pipe-support material.
- Better compaction can be achieved.
- DuPont™ Typar® SF minimizes differential settlement.

Artificial beaches on lakes



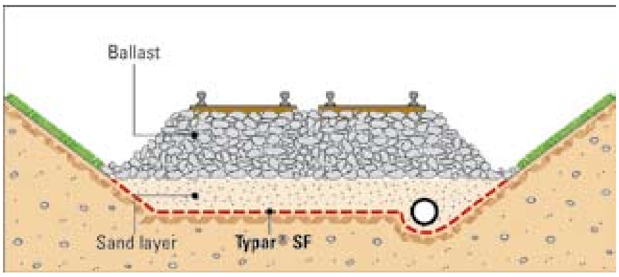
- DuPont™ Typar® SF prevents sand from sinking into the muddy lake-shore.
- DuPont™ Typar® SF is easy to install.
- In northern countries, DuPont™ Typar® SF and sand can be laid on to frozen lake surface. When the ice melts they will deposit on the lake bed.
- DuPont™ Typar® SF prevents weed growth.

Liner protection



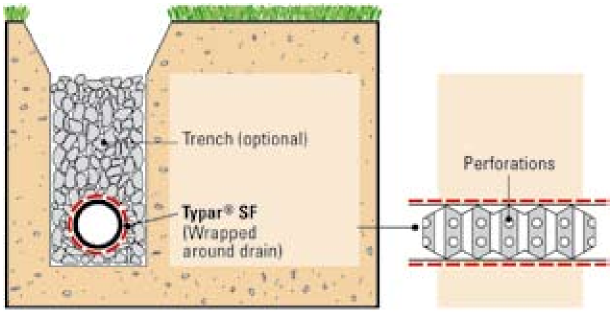
- DuPont™ Typar® SF between pond liner and supporting soil > SF56 (min).
- DuPont™ Typar® SF between pond lines and protective layer of sand > SF37.
- DuPont™ Typar® SF Provides protection against puncturing.

Railways, new tracks and track renewal



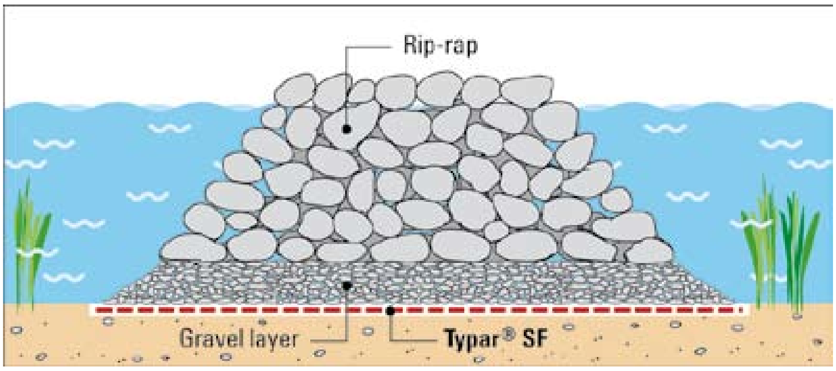
- DuPont™ Typar® SF avoids ballast contamination by pumping effect due to dynamic loading.
- It allows better compacting and aggregate saving.
- DuPont™ Typar® SF retains soil particles without clogging.
- It ensures longer service life.

Agricultural and pipe drains



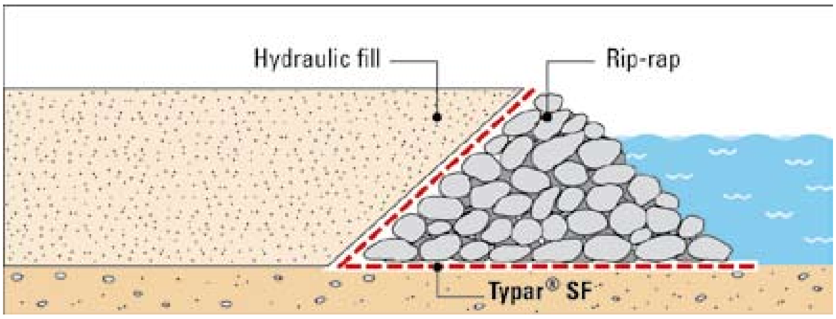
- A corrugated pipe wrapped with DuPont™ Typar® SF can be put into subsoil with or without digging a trench.
- The drainage surface of corrugated pipe is increased up to 90 times.
- The influence zone of wrapped drain is higher.
- Drain spacing can be increased.
- The stiffness of DuPont™ Typar® SF prevents fabric from entering the pipe corrugations.

Breakwater and jetties on soft soil sea bed



- A separation layer of DuPont™ Typar® SF prevents rip-rap from sinking into soft soil.
- DuPont™ Typar® SF must be protected by a layer of smaller-sized stones.

Land reclamation with hydraulic fill



- The separation and filtration layer of DuPont™ Typar® SF avoids piping of hydraulic fill.
- DuPont™ Typar® SF avoids use of expensive and difficult-to-install filter lay.

Annex

Annex

7.1. Standard Test Methods

Since geotextiles have been initially developed by the textile industry, geotextile properties were first measured using test standards for textiles. It soon became evident that these properties and standards were not relating well to the geotextile applications such as e.g. filtration and separation.

Institutes in different countries developed new test equipment and test methods more appropriate to the geotextile end-uses. But this also made it more difficult to compare the various products from different countries. Since several years the European Standard Tests provide a common basis (see 7.1.1 –7.1.3) and are applied not only throughout the European Union but accepted throughout Europe and have widely been adopted by ISO (International Standard Organisation).

The tests that are described below are so-called index tests. Index tests allow significant comparisons of different products when using the same test standard. But index tests are not providing any information on the soil-geotextile interaction. They only highlight one side of the geotextile's properties. Contrary to performance tests, which are used to determine the performance of geotextiles under the specific site conditions for a defined application. They do not necessarily have to be field tests but can be carried out in a laboratory or as a large scale model.

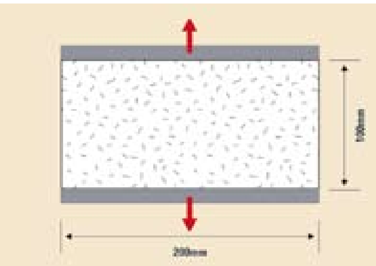
7.1.1. Descriptive Properties

These properties are not indicative for the geotextile's performance but simply describe the products physic.

Mass per Unit Area EN 965 –The mass is determined by the weight of small samples of known size, which have been taken along the full width and length of the sample.

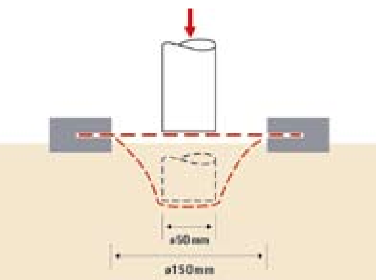
Thickness at specified pressures EN 964-1 –The thickness of the geotextile is determined at pressures from 2 kPa to 200 kPa, which simulates the geotextile being in service.

7.1.2. Mechanical Properties



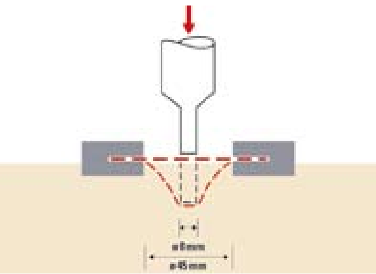
Wide-width tensile test EN ISO 10319

This test is performed for all kinds of geotextiles and geogrids on a specimen of 200mm width and 100mm length. A longitudinal force is applied to the specimen until it ruptures while the maximum tensile strength, the elongation and the energy absorption is measured. This test is similar to ASTM D4595. The main difference between this method and others such as DIN 53857, ASTM D1682 etc. is the width of the specimen or the rate of strain.



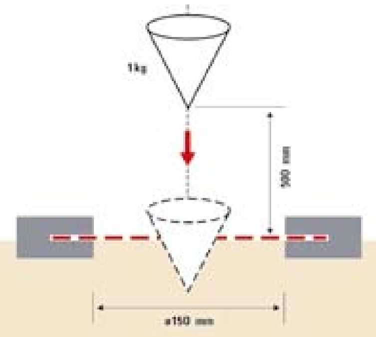
Static puncture test (CBR) EN ISO 12236

A steel plunger (50mm diameter)is pushed at a constant rate on the centre of the specimen which is clamped between two steel rings. Maximum push-through force and displacement at maximum force are measured. This test is similar to ASTM D6241.



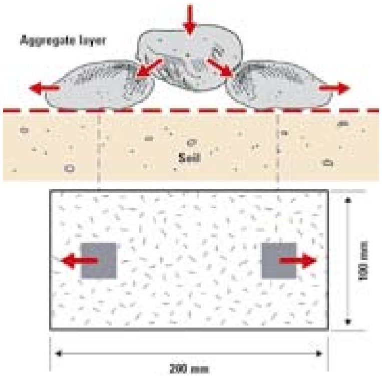
Puncture Resistance (US Rod) ASTM D4833

This test is similar to the static puncture test (CBR) but a different plunger (ø 8mm) is used and the specimen is smaller. Koerner though recommends the CBR test because it gives more consistent resultsl.



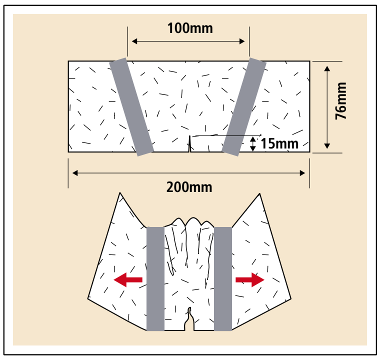
Dynamic perforation test (cone drop test) EN 918

A steel cone is dropped from a distance of 50 cm on to the centre of a fixed geotextile specimen. The degree of penetration is measured by the hole diameter.



Grab Strength ASTM D4632 – the same

Trap Tear Strength ASTM D4533 – the same



Hydraulic Bursting Strength of Textile Fabrics (Mullen burst test) ASTM D3786

An inflatable rubber membrane is used to deform the geotextile into a shape of a hemisphere of 30mm diameter until it bursts. Due to the small sample size and high variation in the test procedure, the results of this test vary widely. In the last revision of AASHTO M288 in 2000 this property has been removed from the list of mechanical properties for the installation survivability requirements!

7.1.3. Hydraulic Properties

Characteristic opening size EN ISO 12956

A defined graded granular material is washed through a single layer of the geotextile sample used as a sieve and the particle size distribution is established. $O_{90,wet}$ is the characteristic opening size of the geotextile determined from the particle size distribution.

Apparent Opening Size ASTM D4751
This test method covers the determination of the apparent opening size (AOS = O_{95}) of a geotextile by sieving glass beads through a geotextile. A geotextile sample is placed in a sieve frame, and sized glass beads are placed on the geotextile surface. The geotextile and frame are vibrated to induce the beads to pass through the test specimen. The procedure is repeated on the same sample with various size distributions of glass beads until its apparent opening size $O_{95(dry)}$ has been determined from the particle size distribution.

Flow rate BS 6906-3
The flow of water with a 10 cm water head through a single layer of geotextile normal to the plane of the geotextile is measured under specified conditions [l/(s*m²)]. Note: This test has been replaced by EN ISO 11058.

Water permeability (Velocity Index) EN 11058
Constant head method: a single layer of the geotextile specimen is subjected to a unidirectional flow of water normal to the plane under a range of constant water heads. Falling head method: like the constant head method but with falling water head. The result is the velocity index V_{H50} (mm/s) corresponding to a head loss of 50 mm across a specimen, and the permittivity (s^{-1}) (Conversion V_{H50} /50mm = (l/m² * s)/mm = m/s). This test has been introduced in 1999 and since then is often confused with the permeability coefficient k due to the unit m/s. But the velocity index is a flow rate (m/s = l/m² * s).

Permeability under load E-DIN 60500-4
The permeability coefficient k normal to the plane is measured under a constant water head, hydraulic gradient i = 1 and a range of different loads. This test is of particular interest when comparing geotextiles of different thickness since the hydraulic gradient is fixed at i = 1.

7.2. Hydraulic Characteristics

- The permeability k [m/s] describes the flow of water perpendicular to the plane and is measured by means of a permeameter with demineralised and de-aerated water. The measurement of the flow rate Q and hydraulic gradient i allow the determination of the water permeability coefficient k= Q/i for a steady laminar flow (i < 3). The hydraulic gradient i is defined as the head loss dh divided by the thickness of the soil $i= dh/t_s$. For geotextiles the formula is adapted using the thickness tg of the geotexile: $i= dh/t_g$. Ideally for geotextiles a hydraulic gradient of i= 1 should be used thus eliminating the influence of the geotextile thickness. Otherwise products of different thicknesses but the same water flow will have different k-values and that is not correct (see also 4.3). As a general rule, the geotextile's permeability should be higher than that of the soil in order to not reduce the water flow rate.
- Transmissivity $\Theta= k*t_g$ [m²/s] describes the permeability in the plane or discharge capacity of a geosynthetic. Factors such as the amount of fine particles caught in the structure of the geotextile (clogging) and soil pressure influence the transmissivity of a geotextile in service. While soil pressure can be simulated in the lab (foam plates under pressure), possible clogging or blinding cannot be foreseen in advance. Therefore the transmissivity is best applied to geosynthetics combining a drainage core and adequate filter, which ensures the long term discharge capacity. The transmissivity of "thick "geotextiles measured in a laboratory does not reflect the discharge capacity on the site.
- The permittivity $\Psi= k /t_g$ [s^{-1}] is the ratio of k divided by the thickness tg of the geotextile. This value allows comparing geotextiles of different thickness.

7.3. Energy absorption

- Definition: "Energy absorption, W" – Work done to elongate the specimen defined as the integral of the stress-strain curve (to a chosen point) and expressed in kJ/m² or kN/m.
- Energy absorption W at maximum load (based on EN 10319): Calculate the energy absorption W, expressed in kilojoules per metre (or kN/m²), directly from the data obtained from the tensile testing machine, using the following equation:

$$W= \int_0^{F_f} Ff(x)\, dx*c*d \ [kJ/m^2]$$

F(x) is the recorded function of the stress strain curve d= 1/H, where H is the specimen nominal height in metres c is obtained from the equation (1)or equation (2) as appropriate:

For nonwovens, closely woven fabrics or similar materials,
c= 1/B (1)
where B is the specimen nominal width in metres.

For coarse-woven geotextiles, geomeshes, geogrids or similar open-structure materials,
$c= N_m /N_s$ (2)
where N_m is the minimum number of tensile elements within 1m width of the product being tested and N_s is the number of tensile elements within the test specimen.

7.4. Comparison of properties

Engineers are frequently required to compare the properties of different brands of geotextiles. Often the properties are given according to different norms or the products differ strongly (such as a woven and a nonwoven material) which makes it difficult to compare them. A good and easy method of comparing these is to compare the energy absorption similar to the method recommended by the Swiss Geotextile Committee. It is a valid comparison because the energy absorption is a combination of properties. A geotextile with a high tensile strength but a low elongation may have the same energy as another with a lower tensile strength and a high elongation. So when comparing tensile strength and elongation alone the products would not seem equivalent.

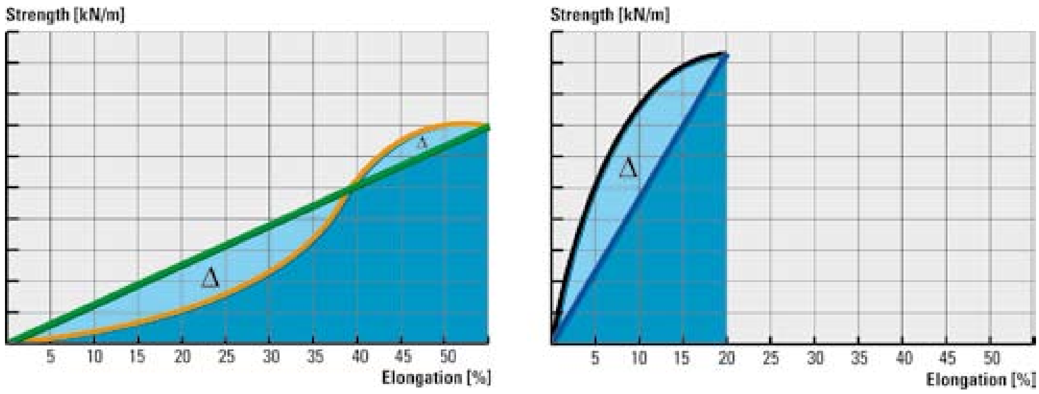


Figure 43: Difference between the actual and theoretical energy absorption potential shown with stress-strain curves of two different geotextiles.

It is a comparison of the resistance to installation and construction stresses. As illustrated in the second chapter, the geotextile's resistance to damage is achieved primarily as a combination of high tensile strength and high elongation at break (energy absorption).

In several countries the theoretical energy absorption ($W_{index} = 0.5 * T * \varepsilon$) is used, which is a simplification. The actual energy absorption potential W is more accurate and should be the value used because this takes into account the characteristics of the stress-strain curve (e.g. the initial modulus).

7.5. Raw materials

A whole range of different polymers is used for the production of geotextiles, the most common being polypropylene and polyester. Each polymer has its own advantages and disadvantages. The typical density and melting temperature are listed in the following table.

	PP	PET	PA	HDPE
Density (g/cm^3)	0.91	1.38	1.12	0.95
Melting temperature (°C)	165	260	220-250	130

- Polypropylene (PP) is a thermoplastic long chain polymer which has a high stiffness, good tensile properties and resistance to acids and alkalis.
- Polyamide (PA) is a thermoplastic which has a high strength, high wear and abrasion resistance and good chemical resistance.
- Polyethylene (PE) used in its high density form HDPE is a thermoplastic with a high strength and stiffness and a good resistance to chemicals.
- Polyester (PET) is a thermoplastic with a high strength, a low creep strain rate and good chemical resistance to most acides and many solvents. Although for applications of polyester in highly alkaline environments with pH > 10, particularly in the presence of lime, cement or concrete further testing should be considered.

7.6. Durability

In the production process stabilisers are added to the polypropylene to increase the durability of DuPont™ Typar® SF.

7.6.1. UV resistance

DuPont™ Typar® SF can endure up to several weeks in direct sunlight, but prolonged exposure, particularly in tropical sunlight, can cause strength losses. Generally a geotextile should be covered immediately after laying to avoid UV degradation, wind uplifting or mechanical damage. According to EN 12224, DuPont™ Typar® SF should be covered within 2 weeks after installation.

7.6.2. Oxidation resistance

Numerous accelerated ageing tests have shown that the resistance of DuPont™ Typar® SF highly exceeds a lifetime of 100 years. And also according to CE Marking requirements, Typar® SF is predicted to be durable for a minimum of 100 years in all natural soils.

The oxidation resistance according to prEN ISO 13438 is:

- Oven test >100% retained strength
- High pressure test >100% retained strength

7.6.3. Microbiological resistance

Typar is made of 100% polypropylene which makes it resistant to rot and moisture.
The microbiological resistance according to EN 12225 is 100% retained strength.

7.6.4. Chemical resistance

The chemical resistance according to EN 14030 is:

- for acid environment (method A) 100% retained strength
- for alkali environment (method B) 100% retained strength

Note: for oxidation, microbiological and chemical resistance > than 50 % retained strength is acceptable.

Agent	Conc.%	Temp. °C	Time, Hours/Months	Effect on DuPont™ Typar® SF [1]
Acids				
Acetic	100	20°	6 months	None
Chromic	10	21°	10 hrs.	None
Hydrobromic	10	21°	10 hrs.	None
Hydrochloric	10	21°	1000 hrs.	None
Hydrochloric	37	71°	10 hrs.	None
Nitric	10	99°	10 hrs.	None
Nitric	70	21°	10 hrs.	None
Nitric	95	21°	1000 hrs.	Considerable
Phosphoric	85	21°	10 hrs.	None
Sulphuric	60	99°	10 hrs.	None
Sulphuric	96	21°	1000 hrs.	None
Formic	100	20°	6 months	None
Hydrochloric	30	60°	6 months	None
Hydrochloric	30	100°	6 months	Degraded
Sulphuric	98	20°	6 months	None
Sulphuric	98	60°	6 months	Considerable
Sulphuric	98	100°	6 months	Degraded

Agent	Conc.%	Temp. °C	Time, Hours/Months	Effect on DuPont™ Typar® SF [1]
Alkalis				
Ammonia	30	20°	6 months	None
Ammonia	58	21°	1000 hrs.	None
Sodium Hydroxide	50	21°	6 months	None
Sodium Hydroxide	50	60°	6 months	None
Sodium Hypochlorite	20	20°	6 months	None
Sodium Hypochlorite	20	100°	6 months	Considerable
Organic Chemicals				
Acetone	100	20°	6 months	None
Acetone	100	56°	6 months	None
Benzene	100	21°	1000 hrs.	None
Benzene	100	20°	6 months	Moderate
Benzene	100	60°	6 months	Considerable
Carbon Tetrachloride	100	20°	6 months	Considerable
Cyclohexanone	100	20°	6 months	None
Cyclohexanone	100	60°	6 months	Considerable
Ethanol	96	20°	6 months	None
Ethanol	96	60°	6 months	None
Ethanol	96	81°	6 months	None
Ethylene Glycol	100	20°	6 months	None
Ethylene Glycol	100	60°	6 months	None
Dimethyl Formamide	100	93°	10 heures	None
Dimethyl Formamide	100	153°	10 hrs.	Degraded
Dimethyl Sulphoxide	100	93°	10 hrs.	None
Gasoline	100	20°	6 months	Considerable
Linseed Oil	100	20°	6 months	None
Linseed Oil	100	60°	6 months	None
Methylene Chloride	100	20°	6 months	Considerable
Perchloroethylene	200	93°	10 hrs.	Considerable
Perchloroethylene	250	121°	10 hrs.	Degraded
Stoddard Solvent	100	93°	10 hrs.	None
Transformer Oil	100	20°	6 months	None
Transformer Oil	100	60°	6 months	Considerable
Trichloroethylene	100	20°	6 months	Considerable
Turpentine	100	100°	6 months	None
Xylene, meta	100	93°	10 hrs.	None
Xylene, meta	100	20°	6 months	Considerable

[1] Change in breaking strength caused by exposure:

None: 90% through 100% of original strength retained
Slight: 80% through 89% of original strength retained
Moderate: 60% through 79% of original strength retained
Considerable: 20% through 59% of original strength retained
Degraded: 0% through 19% of original strength retained

7.7. Temperature Resistance

7.7.1. Low temperatures

Resistance to low temperatures is important if the geotextile is to be used in cold areas such as Alaska, Northern Scandinavia etc. Under extremely cold conditions the tensile strength will increase, along with a decrease in elongation of a few percent. This effect is reversible as the temperature is increased. No significant tensile strength changes were observed on a DuPont™ Typar® SF of 200g/m² after 4 cycles of 0 to –18°C both wet and dry. Since DuPont™ Typar® SF does not absorb water, rolls will not freeze.

7.7.2. High temperatures

The tensile strength will decrease and elongation increase at high temperatures. The hydraulic properties are little affected. For more details please contact the DuPont Geosynthetics Technical Centre.

7.8. Joining Methods

7.8.1. Sewing

Sewing DuPont™ Typar® SF for wide width support, drainage and erosion control installations is a practical method of eliminating fabric overlap and reducing its cost. Sewing is the most reliable jointing method, especially because it can easily be performed on site while welding and gluing require a clean and dry work space.

A recommended seam type is shown in figure 44 below. The sewing machine should be adjusted to give 2 stitches/cm. Even though a sewn seam is the preferred choice a welded or glued seam can also give good results regarding the tensile strength. For more details please contact the DuPont Geosynthetics Technical Centre.

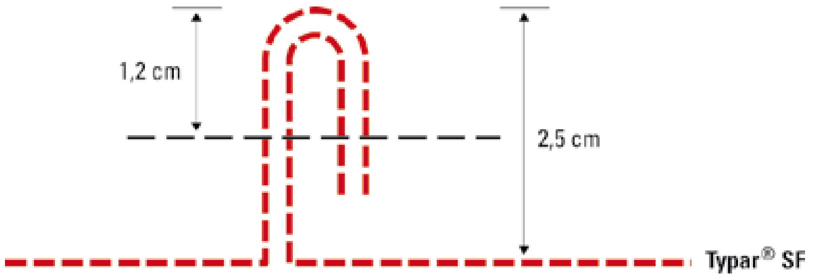


Figure 44: Recommended seam style

7.8.2. Overlap

The required side and end overlaps depend on soil properties (CBR), the project nature and on the deformations, which might occur. In general the following overlaps are used:

- Drainage systems: min 30cm
- Parking lots, permanent roads: 30 to 50cm
- Erosion control systems: 50 to 100cm
- Temporary roads: see figure 45

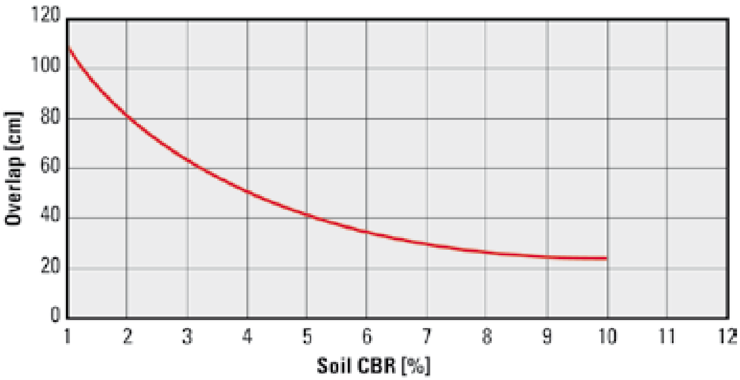


Figure 45: Overlapping of DuPont™ Typar® SF for temporary roads

The following graph shows the extra amount of DuPont™ Typar® SF needed when overlapping depending on the surface area and the overlap width. Estimates of the possible savings by sewing or welding instead of overlapping are clearly demonstrated.

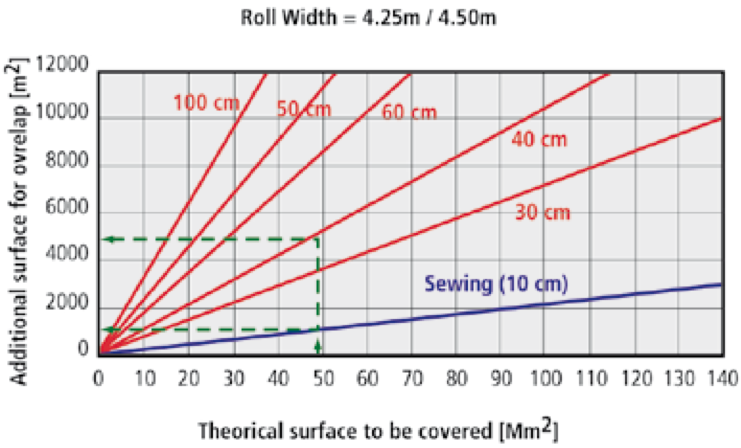


Figure 46: Necessary surface depending on width of overlap

For applications where DuPont™ Typar® SF is used for reinforcement purposes, overlapping requires special attention. Calculations by experienced design engineers may be needed to check the correct transmission of stresses.

7.9. Useful data

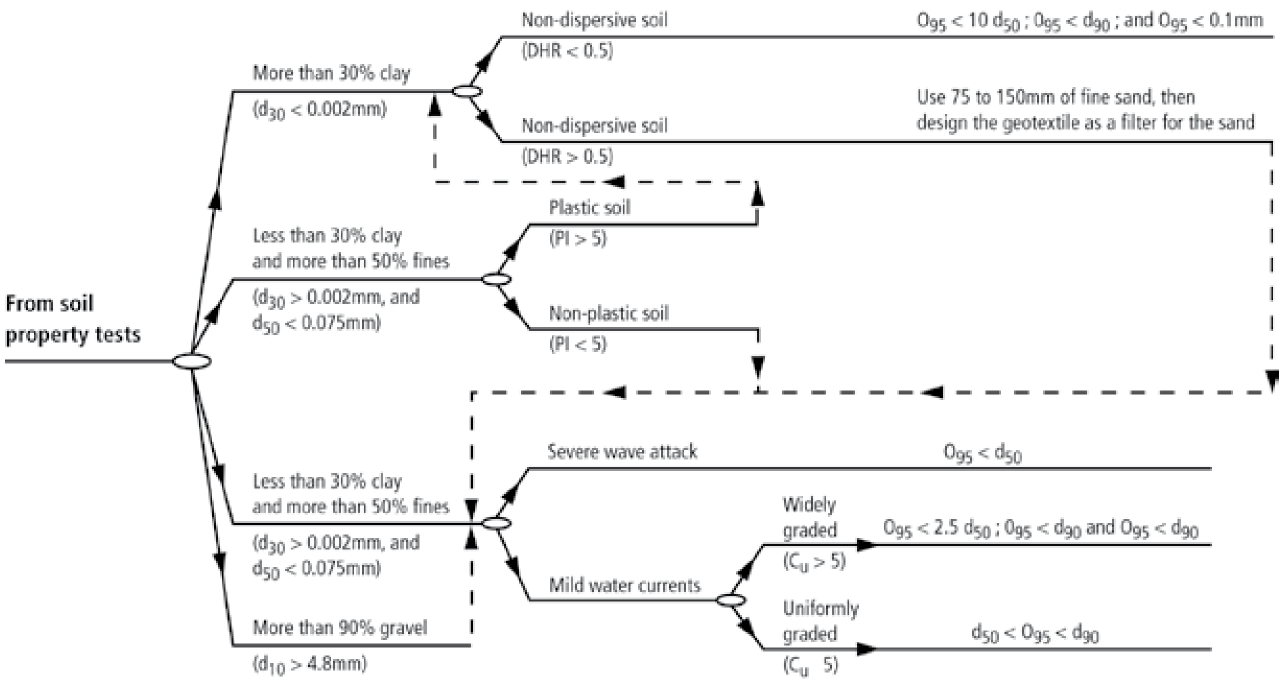
Approximate range of soil properties for the most common types of soil (for preliminary design).

Soil Property	Symbol	SI Unit	Sand			Gravel	Gravely riprap non-uniforme	Angular riprap sandfree	Cobbles	
			Loose	Medium dense	Dense				Sand free	With gravel and sand
Unit weight,										
dry soil	γ	kN/m³	17	18	19	18	20	17	17	19
saturate soil	γ_g	kN/m³	19	20	21	20	21	-	-	20
Porosity	n	%	45	35	25	25 - 45	20 - 35	40 - 60	40 - 50	25 - 45
Permeability coefficient	k	cm/sec	10^{-1}	10^{-2}	10^{-3}	10^{0}	10^{-2}	10^{1}	10^{1}	10^{0}
Height of capillary rise	h_k	cm	20	25	30	1 - 5	25	-	-	20
Simple Proctor density	γ_p	kN/m³	17 - 20			19	22	-	-	-
Optimum moisture content	W_{opt}	%	6 - 10			5	7	-	-	-
Stiffness modulus	E_s	MN/m²	20 - 50	40 - 100	80 - 150	100 - 200	150 - 250	100 - 200	100 - 150	150 - 250
Deformation modulus	E_{v1}	MN/m²	15 - 40	30 - 60	50 - 80	70 - 120	100 - 150	70 - 120	60 - 100	100 - 150
CBR value	CBR	%	10 -20	20 - 30	30 - 40	50	70	90 - 100	100	90 - 100
Effective friction angle	φ'		30	32,5	35	37,5	37,5	40	35	37,5

Table 12: non-cohesive soils

Soil Property	Symbol	SI Unit	Clay			Drift loam	Loam, mari		Silt	Organic clay, silt	Peat
			Semi solid	Stiff	Soft		Stiff	Soft			
Unit weight	γ_g	kN/m³	19	18	17	21	21	19	18	15	11
Porosity	n	%	50	60	70	30	30	40	40	60	90
Natural moisture content	w	%	20	30	40	10	15	20	30	80	400
Liquid limit	W_L	%	40 - 100			30	20 - 40		15 - 30	70 - 120	-
Plastic limit	W_p	%	20 - 30			15	10 - 20		10 - 15	20 - 30	-
Plasticity index	I_p	%	20 - 70			15	10 - 25		5 - 15	50 - 90	-
Permeability coefficient	k	cm/sec	10^{-7} - 10^{-9}			10^{-5}	10^{-6} - 10^{-8}		10^{-5}	10^{-8}	10^{-3}
Height of capillary rise	h_k	m	5 - 100			1 - 5	1 - 5		1 - 5	1-5	-
Simple proctor density	γ_p	kN/m³	14 - 17			18 - 22	17 - 19		17-19	14-17	-
Optimum moisture content	w_{opt}	%	15 - 30			10 - 15	12 - 20		12-20	20-25	-
Stiffness modulus	E_s	MN/m²	5 - 10	2 - 5	1 - 3	30 - 100	5-20	4 - 8	3-10	1-5	0,5 - 2
Deformation modulus	E_{v1}	MN/m²	3 - 8	1 - 4	0,5 - 2	15 - 50	5-15	3 - 6	2-8	1-3	0 - 1
CBR value	CBR	%	2 - 5	1 - 3	0 - 2	10 - 20	3-10	2 - 5	1-5	0-2	0
Effective friction angle	φ'	.	20	17,5	15	15	25	22,5	25	17,5	15
Effective soil cohesion	c'	MN/m²	25	20	10	25	10	0	0	10	0
Effective shear strength	c_u	MN/m²	40 - 100	20 - 60	5 - 40	200 - 500	50 - 200	40 - 100	20 - 100	5 - 40	0
Consolidation coefficient	c_v	m²/sec	10^{-6} - 10^{-9}			-	10^{-5} - 10^{-7}		10^{-4}	10^{-7} - 10^{-9}	10^{-3}

Table 13: cohesive soils.



NOTES:

$$C_u = \frac{d_{60}}{d_{10}}$$

d_x = particle size of which x percent is smaller
PI = Plasticity index of soil
DHR = double-hydrometer ratio of the soil
O_{95} = geotextile opening size according to ASTM 04751-87

Figure 47: (b) Soil retention criteria for geotextile filter design under dynamic flow conditions. (after Luettich et al. [6])

	Designation	% particles			Plas. index I(%)	Typical permeability K(m/s)
		<0.006	0.06-2mm	>2mm		
GW	Well-graded gravel, sandy gravel	< 5	VAR	> 50	-	10^{-1} - 10^{-4}
GP	Poorly-graded, sandy gravel	< 5	VAR	> 50	-	10^{-1} - 10^{-4}
GM	Silty gravel, G + S + M	< 15	VAR	> 50	< 7	10^{-5} - 10^{-8}
GC	Clayey Gravel, G + S + C	< 15	VAR	> 50	> 7	10^{-8} - 10^{-10}
SW	Well graded sand, gravelly sand	< 5	> 50	VAR	-	10^{-2} - 10^{-5}
SP	Poorly graded sand, gravelly sand	< 5	> 50	VAR	-	10^{-2} - 10^{-5}
SM	Silty sand	< 15	> 50	VAR	< 7	10^{-5} - 10^{-8}
SC	Clayey sand	< 15	> 50	VAR	> 7	10^{-8} - 10^{-10}
ML	Silt, very fine sands	> 50	~ 50	VAR	< 4	10^{-5} - 10^{-8}
CL	Clay	> 50	~ 20	VAR	> 7	10^{-8} - 10^{-10}
GM - ML	Silty gravel	> 15	VAR	> 40	< 4	10^{-5} - 10^{-8}
GM - GC	Clayey-silty gravel	> 15	VAR	> 40	4 - 7	10^{-8} - 10^{-10}
GC - GL	Clayey gravel	> 15	VAR	> 40	> 7	10^{-8} - 10^{-10}
SM - ML	Silty sand - sandy silt	15 - 50	~ 50	VAR	< 4	10^{-5} - 10^{-8}
SM - SC	Clayey-silty sand	15 - 50	~ 40	VAR	4 - 7	10^{-8} - 10^{-10}
SC - CL	Clayey sand - sandy clay	15 - 50	~ 40	VAR	> 7	10^{-8} - 10^{-10}
CL - ML	Clayey silt	> 50	VAR	VAR	4 - 7	10^{-7} - 10^{-10}
OL	Organic silt	> 50	VAR	VAR	> 10	-
OH	Organic Clay	> 50	VAR	VAR	> 20	-
PT	Peat	-	-	-	-	-

Table 15: USCS soils classification

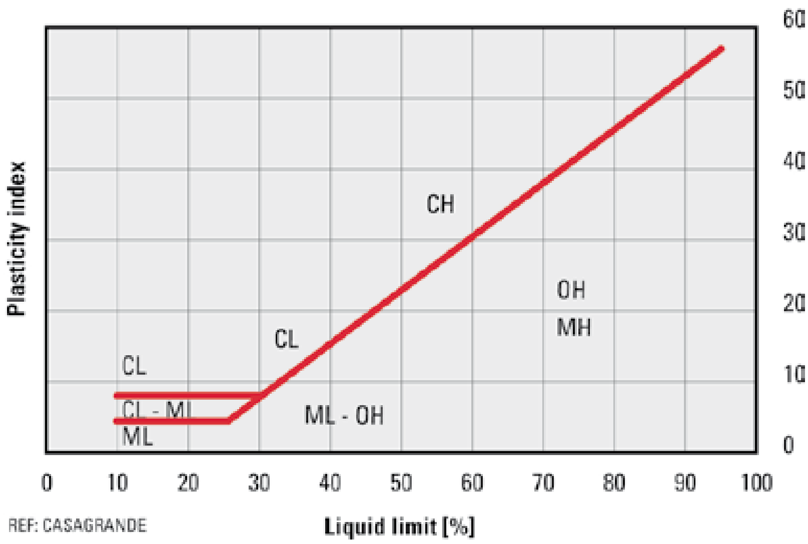
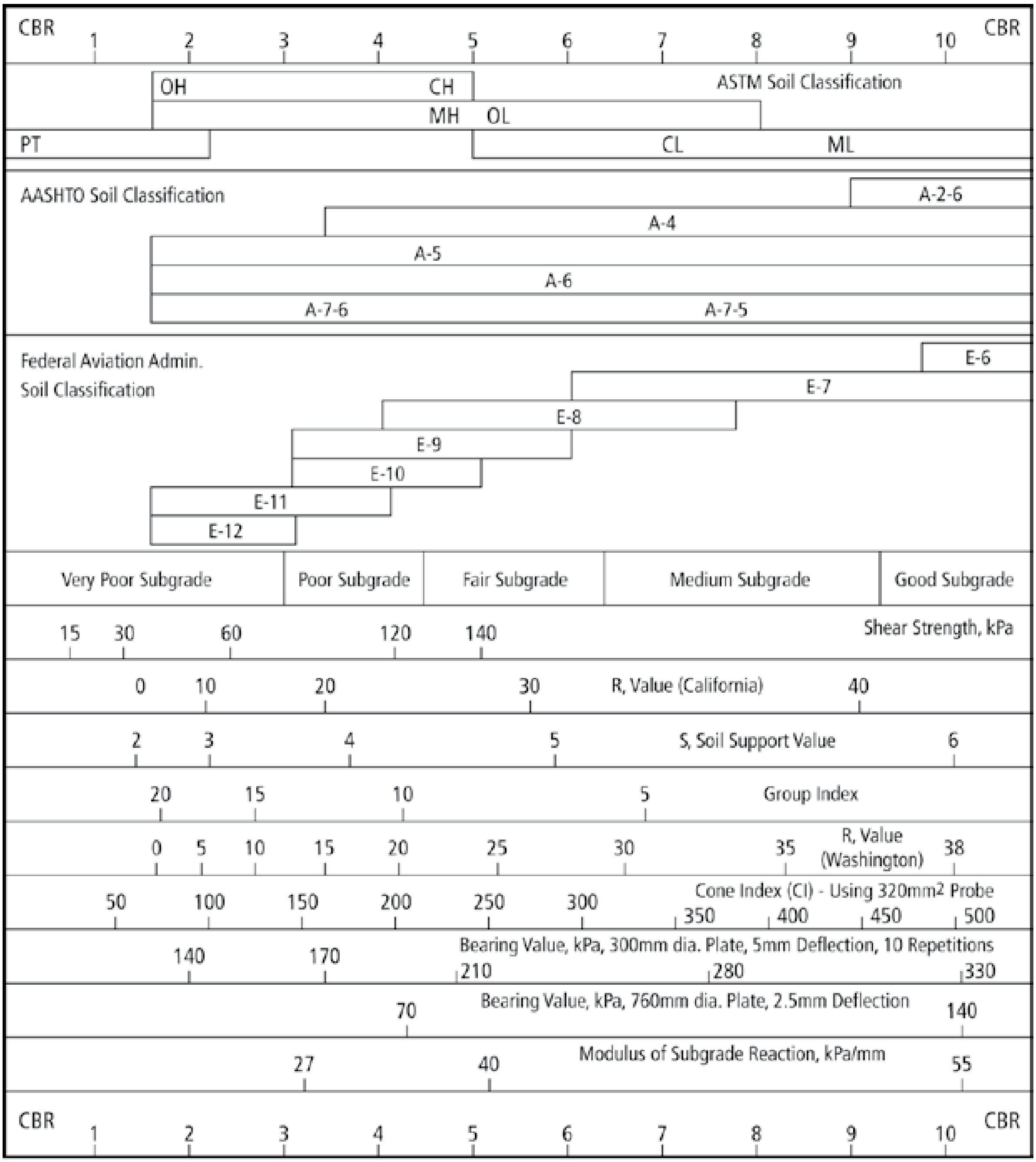


Figure 48: USCS soils classification based on plasticity index



Approximate CBR	Identification Procedure
Less than 2	Easily penetrated with thumb
2-3	Moderate effort to penetrate with thumb
3-6	Indented with thumb
6-16	Indented with thumbnail
Over 16	Difficult to indent with thumbnail

Group Symbols	Soil Group Name
ML	Silt
MH	Micaceous silt
OL	Organic silt
CL	Silty clay
CH	High plastic clay
OH	Organic clay
PT	Peat and muck

Tableau 16: Correlation chart for estimating unsoaked CBR values from soil strength or property values.

7.10. Specification Text

Geotextiles Used to Separate Earthworks Materials

______ m^2 geotextile shall be delivered and installed.

Specification for DuPont DuPont™ Typar® SF ______ or equivalent.

Thermally bonded nonwoven manufactured

- from 100% Polypropylene continuous filament
- according to Quality system ISO 9001, ISO 14001

Compressibility ratio at 200kN/2kN	EN 964	< 15 %

Energy absorption	EN ISO 10319	≥ ____ kN/m or kJ/m^2
Tensile strength	EN ISO 10319	≥ ____ kN/m
Tensile strength at 5% elongation	EN ISO 10319	≥ ____ kN/m
Elongation	EN ISO 10319	≥ ____ %
Puncture strength CBR	EN ISO 12236	≥ ____ N
Dynamic Cone Puncture	EN 918	≤ ____ mm
Tear Strength	ASTM D4533	≥ ____ N

Velocity index	EN ISO 11058	≥ ____ mm/s
Water permeability at $20kN/m^2$	DIN 60500	≥ ____ 10^{-4} m/s
Pore opening size O_{90}	EN ISO 12956	≤ ____ _m (microns)

The geotextile fabric shall be UV stabilised and inert to chemicals commonly encountered in soil and water.

Geotextile rolls shall be furnished with suitable wrapping for protection and each roll shall be labelled and identified for field identification as well as for inventory and quality control purposes.

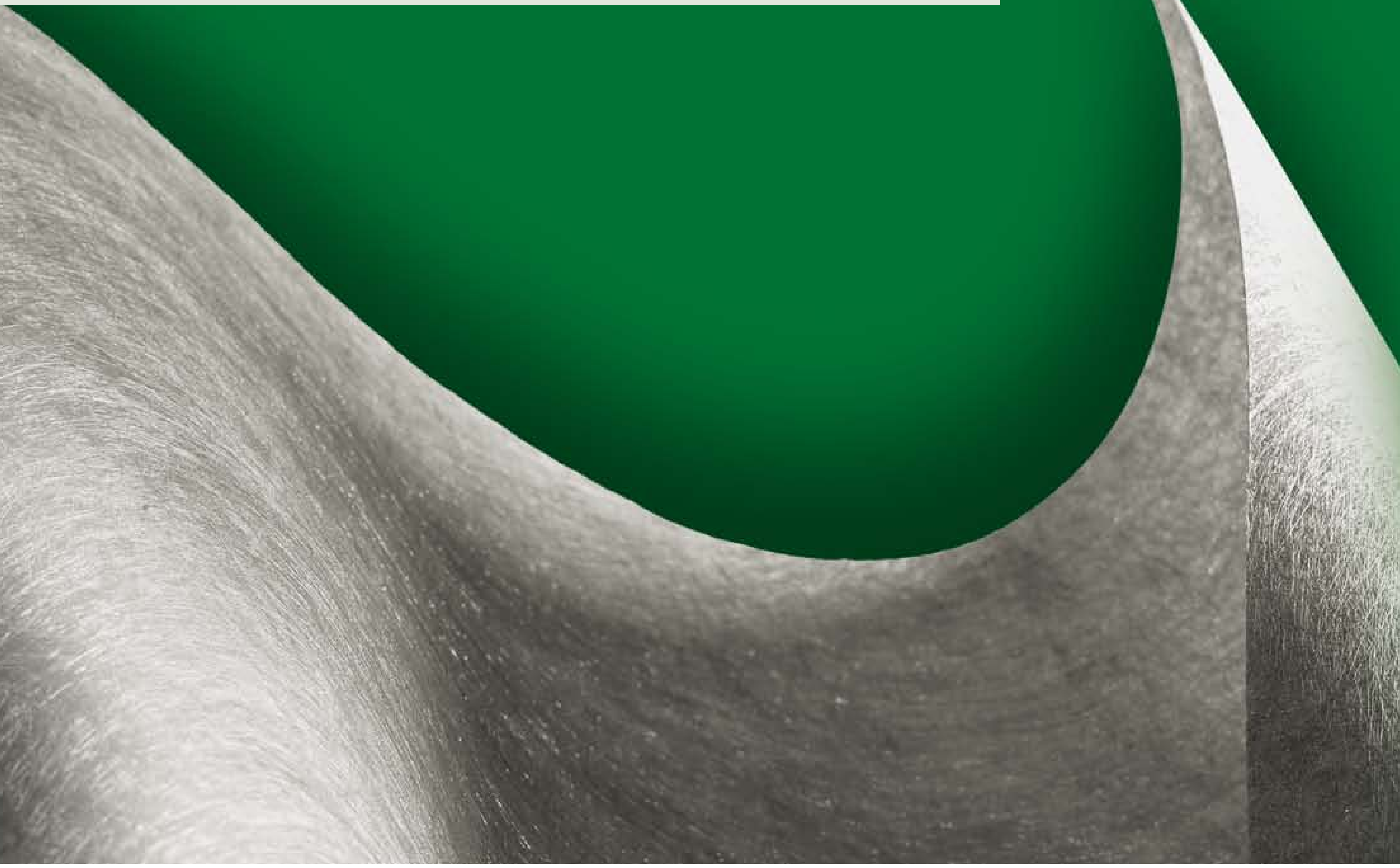
The surface to receive the geotextile fabric shall be prepared to a relatively smooth condition, free of obtrusions, depressions, and debris. Geotextile installation shall proceed in the direction of construction. Longitudinal joints in the fabric shall have a minimum overlap of 30cm, sewn or otherwise specified by the Engineer. In the event construction machinery is used to place the fabric, the working platform for the machinery shall be the soil and not the previously laid geotextile.

Bibliography

[1] R.M. Koerner, Designing with Geotextiles, p.110, Fourth Edition, 1999, Prentice Hall

DuPont™ Typar® Geosynthetics

Other publications



Other publications from DuPont™ Typar® Geosynthetics:

- **Typar® SF brochure**
- **Recommended Typar® SF styles**
- **Typar® datasheets**
- **Typar® HR product and design guide**
- **HR reinforcement geocomposite brochure**
- **Typar® case histories**

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