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# FINLAND NORWAY SWEDEN

## Guidelines for the Use of Geosynthetics in Nordic conditions

Product requirements, Installation and Quality Control
(reinforcement/stabilisation, filtration, drainage, sealing)


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**ABSTRACT**

The Guidelines present the requirements for the installation of geosynthetics under Nordic conditions (sub-zero temperatures, soil types and working conditions: drop height, compaction, etc.). They cover the use of geosynthetics for the applications in roads, railways, reservoir and dams, rivers, waste disposal, sport fields, where the function(s) reinforcement/stabilisation, filtration, drainage, or sealing are required. They have been supported by the major findings of the collaborative project "ROUGH". A full-scale on-site experiment on installation under real Nordic conditions (- 10°C) has been realised for the functions reinforcement / stabilisation, filtration, drainage in Kemi (Northern Finland). It was completed by a synthesis of the state of the art for sealing applications. These Guidelines have been established at the request of the Finnish Transport Infrastructure Agency (Finland), Statens vegvesen (Norwegian Public Roads Administration, Norway), and Trafikverket (Swedish Transport Administration - Sweden). The authorities asked Sintef (Norway) to prepare and manage the writing of these guidelines.

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# Table of contents

# FOREWORD

These Guidelines have been established at the request of the Finnish Transport Infrastructure Agency (Finland), Statens vegvesen (Norwegian Public Roads Administration, Norway), and Trafikverket (Swedish Transport Administration - Sweden).
The authorities have asked SINTEF (Norway) to prepare and manage the writing of these guidelines.

SINTEF has realised the elaboration and the writing with the help of:

- Arnstein Watn (WatnConsult AS) and Pauli Kolisoja (Tampere University, Finland) for chapter 1.1 "Nordic conditions";
- Margarida Pinho Lopes (Universidade de Aveiro, Portugal) for chapter 1.4 "Synthetic review of the existing knowledge on damage during installation to geosynthetics";
- Eric Blond (Eric Blond Consultant Inc., Canada) for the chapter 3 "Geosynthetics used in sealing".

To collect all existing information and provide the missing data, the Rough project (**R**ec**O**mmendations for the **U**se of **G**eosynt**H**etics in Nordic conditions) was organized to allow the writing of these recommendations.
This preparatory work of the ROUGH project was focused on the behaviour (mechanical and hydraulic) during installation to geosynthetics in Nordic conditions (sub-zero temperatures, soil types and working conditions: drop height, compaction, etc.). The project was organised in two parts:

1- a full-scale on-site experiment in Kemi (Northern Finland) on installation under Nordic conditions for the applications with the functions reinforcement / stabilisation, filtration, drainage;

2- considering the difficulty of the realisation of a similar on-site experiment for sealing applications, it was decided to realise a literature study associated with a synthesis of the state of the art for this function.

The ROUGH project was realised with the contribution of the Finnish Transport Infrastructure Agency (Finland), Statens vegvesen (Norwegian Public Roads Administration, Norway), and Trafikverket (Swedish Transport Administration - Sweden), and of the following Manufacturers: BontexGeo, Cetco, DuPont, Fibertex, Huesker, Maccaferri, Naue, Solmax, Tensar, Thrace, Viacon. The second part of the ROUGH project on sealing was realised with the important contribution of Eric Blond Consultant Inc. (Canada) and Tutkimuskeskus Terra (Tampereen yliopisto, Finland).
The coordination and the interpretation were realised by SINTEF with WatnConsult AS.

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**TERMS AND DEFINITIONS**

Terms related to products (according to EN ISO 10318-1, 2015)

Geosynthetic (GSY): generic term describing a product, at least one of whose components is made from a synthetic or natural polymer, in the form of a sheet, a strip, or a three-dimensional structure, used in contact with soil and/or other materials in geotechnical and civil engineering applications.

Geotextile (GTX): planar, permeable, polymeric (synthetic or natural) textile material, which may be nonwoven, knitted, or woven, used in contact with soil and/or other materials in geotechnical and civil engineering applications.

Geotextile-related product (GTP): planar, permeable, polymeric (synthetic or natural) material used in contact with soil and or other materials in geotechnical and civil engineering applications, which does not comply with the definition of a geotextile.

Geogrid (GGR): planar, polymeric structure consisting of a regular open network of integrally connected, tensile elements, which may be linked by extrusion, bonding, interloping or interlacing, whose openings are larger than the constituents.

Geomat (GMA): three-dimensional, permeable structure, made of polymeric monofilaments, and/or other elements (synthetic or natural), mechanically and/or thermally and/or chemically and/or otherwise bonded.

Geosynthetic barrier (GBR): low permeability geosynthetic material, used in geotechnical and civil engineering applications with the purpose of reducing or preventing the flow of fluid through the construction.

Polymeric geosynthetic barrier (GBR-P), geomembrane: factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is essentially fulfilled by polymers.

Clay geosynthetic barrier (GBR-C), geosynthetic clay liner: factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is essentially fulfilled by clay.

Bituminous geosynthetic barrier (GBR-B), bituminous geomembrane: factory-assembled structure of geosynthetic materials in the form of a sheet in which the barrier function is essentially fulfilled by bitumen.

Geocomposite (GCO): manufactured, assembled material using at least one geosynthetic product among the components.

Terms related to products (for this document)

**Family (product family)**: a product's family corresponds to products from a given manufacturer produced with the same manufacturing process, the same polymer and same function.

**The Vulnerability Index (VI)** is an index which allows the evaluation of a possible influence of the temperature on the installation damage for a given characteristic of the geosynthetic (e.g., - 10°C / 20°C). This index is just an indicator, stating whether there is an influence of the temperature or not: if there is no influence of the temperature, VI = 1, if the opposite is the case, VI = 0.
*Note: this index does not allow the evaluation of a modified value of the characteristic, such as for instance $RF_{ID}$ for tensile strength.*

# 1 INTRODUCTION

## 1.1 Nordic Conditions

**General boundary conditions for construction works in the Nordic countries.**

All three Nordic countries extending beyond the Arctic Circle – Norway, Sweden, and Finland – have a number of common features relevant to the construction and maintenance of infrastructure and buildings.

All three countries are fairly large geographically and inhabited throughout, but the population of the countries is relatively small. As a result, their population density is low and the total length of road network in relation to the population is considerably large. Therefore, a very large part of the total length of the road network in all three countries consists of roads with low traffic volumes.

Heavy transport, which extends to the lower-class road network, is of great importance to the economies of all three Nordic countries. In Finland and Sweden, transport needs are primarily related to the forestry industry, while in Norway, the fishing industry is important too. In addition, it is noteworthy that the transport needs of industry, agriculture and livestock cover almost the entire road network in all three countries.

Climatic conditions in the Nordic countries are challenging. Of particular importance are frost heaves caused by seasonal frost, and the melting of snow and the thawing phase of frost in the spring that is a very critical time regarding the condition and durability of road structures. Temperature fluctuations combined with precipitation and snow melting commonly lead to problems related to flooding, erosion and water-triggered landslides which may pose threats to life and health and cause considerable damage. Continuous pressure to increase the efficiency of heavy transport and reduce the climate impact of transports has led to the maximum permissible weights of heavy vehicles, especially in Finland and Sweden, being clearly greater than in the rest of Europe. For example, in Finland, trucks with a total weight of 76 tons are allowed to operate on the entire public road network, unless temporary weight restrictions impose other limits. With special permits on certain routes important for heavy transport, super-heavy trucks weighing up to one hundred tons (eventually up to 400-500 tons with special permits) are currently possible in Finland.

Correspondingly, in Norway an R&D-project "Bedre utnyttelse av bæreevnen" (Better utilization of the bearing capacity) led to the axle-load restrictions in the thaw period being partly cancelled, as these restrictions imposed major obstacles for truck transport Additionally, there is also pressure in Norway to allow heavier trucks on more of the network (modulvogntog). Figures 1.1.1 to 1.1.4 show typical Nordic conditions in construction during the cold period.

*Figure 1.1.1. Gravel road during thaw period (copyright ROUGH project participants)*

*Figure 1.1.2. Winter construction works in Nordic countries (copyright ROUGH project participants)*

Figure 1.1.3. Geosynthetic Clay Liner under cold climate installation, mining application Finland Jan 2022 (copyright ROUGH project participants).

Figure 1.1.4. Geosynthetic filter in a split-bottom barge (copyright ROUGH project participants)

**Climatic conditions**

Seasonal frost affects virtually the entire country in Finland, Sweden and Norway, but there is basically no permafrost in the Nordic countries, except for the Svalbard islands in Norway. During the coldest winters, the freezing index in inland Norway, northern Sweden and northern Finland can easily exceed 60,000 Kh (2,500 Kdays), which corresponds to a frost penetration depth of more than two metres in typical subgrade conditions, and in open-graded blasted rock or crushed-rock aggregate even significantly deeper than that. In the coastal regions and in the very southern parts of the countries, however, the penetration depth of frost remains at a few tens of centimetres, at least in milder winters.

The variation in air temperature during the year in the inland area east of the Scandinavian mountains is considerable. The coldest temperatures in the northern regions of Finland and Sweden can be as low as - 40 degrees, while the highest summer temperatures in the same regions can reach +30 degrees. However, especially in coastal areas, the differences in temperature extremes are smaller than this.

The annual rainfall is highest in the mountainous area of the west coast of Norway, about 3,000 mm/year, while in the inland areas of Sweden and Finland, east of the Scandinavian mountains (Skandes), it is about 600 mm/year. Correspondingly, the thickness of snow cover varies both geographically and annually, but in Swedish and Finnish Lapland snow thicknesses of more than one meter are not uncommon. In the mountainous areas of Norway and Sweden, there can be snow in places up to more than two meters thick. Due to the ongoing climate change, the intensities of rainfalls have increased and thus increased the risk of local flooding.

**Topography and soil conditions**

The highest points in the Nordic countries, almost 2,500 meters above sea level, are located in Norway in the region of Scandens. On the Finnish and Swedish sides, however, the mountains have been lowered and become more gentle fells due to the wear and tear caused by the ice ages. The geological formations formed during the melting phase of the latest glaciation period, which ended about 10,000 years ago, are otherwise characteristic for the Nordic topography and soil conditions. Figures 1.1.5 to 1.1.12 show typical topography and soil conditions in Nordic area.

Typical features include:

- The soil cover above the bedrock surface is typically fairly thin, usually only a few metres and at most only a few tens of metres. In many places, the bedrock surface is visibly bare and completely without soil cover.

- Especially in areas further away from the coastal areas, the very mixed-grained moraine is by far the most common soil type. The moraine is typically very tightly packed and practically always consists of frost-susceptible material.
- Fine-grained clay and silt are the most common soil types in coastal areas, that especially in Sweden and Finland are generally fairly flat. The highest population and road network densities are also concentrated on these fine-grained marine deposits that are characterized by both low shear strength and very high compressibility under, for example, structures founded on ground surface. The marine clays may also, if the salty porewater is washed out and replaced by fresh water, become quick-clay, which will collapse and behave like a fluid if disturbed. This may lead to catastrophic landslides involving large areas and represents a considerable risk to life and damage.
- In many areas, the top layer of soil is peat, which consists entirely of organic material and is even more problematic than fine-grained clays and silts, because the settlements in peat are not only large but also very long-lasting. Construction works in peat areas may impose significant challenges related to stability and deformations.

*Figure 1.1.5. Construction of access road on peat subsoil in Lofoten, Northern Norway (copyright ROUGH project participants).*

*Figure 1.1.6. Challenging Ground Conditions, Soft Soil 02 (copyright ROUGH project participants)*

*Figure 1.1.7. Construction of road in Ukraine (copyright ROUGH project participants).*

*Figure 1.1.8. Construction of road in Estonia (copyright ROUGH project participants).*

Figure 1.1.9. Access road Kamloops Canada (copyright ROUGH project participants).

Figure 1.1.10. Rehabilitation of road Ontario Canada (copyright ROUGH project participants).


Figure 1.1.11. Construction in Lassabacka Sweden (copyright ROUGH project participants).

Figure 1.1.12. Road construction in Norway (copyright ROUGH project participants).

**Special features of road and railway structures in the Nordic countries**

In order to avoid the adverse effects of frost, high-quality road and railway structures in the Nordic countries must be built using very thick, non-frost-susceptible structural layers with a thickness exceeding two metres, or with frost insulation layers. Because the need for building materials is very high due to this, gravel and sand are used, but the main materials used in construction are blasted rock and crushed-rock aggregates. Blasted/crushed rock is often used in open gradings that in worst cases make them cooling machines: high air convection in winter and insulation in summer. Care should be taken for the grading curve to avoid problems. Fortunately, these materials are also normally much more readily available to construction sites than coarse-grained natural materials, gravel and sand. One of the essential special features of these artificially produced blasted rock materials and crushed-rock aggregates are the sharp edges of the particles, which poses an obvious risk of damage to other materials installed next to them, such as geosynthetics. The combination of soft subsoil and angular rock fill material imposes also considerable deformations and stress on the structure and the material. This risk is exacerbated by the need to use heavy vibratory compaction equipment to compact angular crushed-rock particles.

The use of insulation against frost is typically related to areas with a limited amount of rock fill material or coarse-grained natural materials, or a limitation related to excavation depth. Typically, the frost-insulation layer is placed with a separation geotextile on the subsoil and with a road superstructure of 60 -100 cm above. Figures 1.1.13 & 1.1.14 illustrate this topic in both road and railway application.

*Figure 1.1.13. Frost insulation using expanded clay lightweight aggregate at Sandmoen test field in Trondheim (copyright ROUGH project participants).*

*Figure 1.1.14. Base Reinforcement, construction of track beds (copyright ROUGH project participants).*

Due to the shortness of the most favourable summer season in terms of construction conditions, construction teams are under constant pressure to do some part of the construction works at times that are not optimal for the conditions. In practice, this means low working temperatures and construction activity during rainy seasons in which case, for example, the load-bearing capacity of the subsoil on which the construction works are carried out may be poor. Possible remoulding of the roadbed in soft and water susceptible soils may not only give problems during the construction but also imply deformations and damage during the service lifetime. Laying of asphalt at low temperatures and in rain/snow will lead to poor compaction and a shorter working life.

Given the sparse population typical for the Nordic countries, the extensive road network, and the harsh climatic conditions, it is not economically feasible to build all roads using structural layer thicknesses corresponding to the local frost penetration depth. Due to this, various problems caused by frost are very typical on Nordic roads. The most common of these include:

- Frost bumps caused by uneven frost heave of the subsoil under the road, highlighted by, for example, culverts passing under the road, large stones and boulders in the subsoil and inadequate drainage of the road structure. Also, in some cases ice lenses causing frost heave may be formed in the structural layers if mistakes have been made during the construction works.
- In areas where the thickness of the snow cover during the frost season is significant, a very typical road structure problem associated with frost heave is the longitudinal cracking of road surface. The cracks arise when frost penetrates deep into the subsoil below the centre of a road that has been ploughed, but snow ploughed to the sides of the road acts as thermal insulation and prevents frost from penetrating as deeply below the edges of the road. The resulting frost heave difference leads to a high tensile stress on the road surface which causes the road surface to crack.
- During the thawing phase in the spring, a very typical problem for weaker road structures is the reduction in load-bearing capacity and the resulting deformation damage. Since the melting of frost in the spring takes place mainly from above, a situation is easily created in the road structure in which the subsoil still frozen below the structure prevents it from draining. The situation can be significantly exacerbated by the meltwaters absorbed into the structure from the sides of the road if the snow walls have not been ploughed lower into the road slopes early enough.

- Especially in silty soil types, one typical specific problem related to the frost thawing stage is the liquefaction of the side slopes and the consequent collapse of them into ditches, which significantly disrupts the drainage of the road structure.

Drainage problems of road structures due to the topography of the ground surface and soil conditions occur in areas with both varying and flat topography. The steep terrain is characterized by conditions in which the road is often located on a sloping terrain, where both surface runoff and groundwater flow increase the moisture load on the road structure. Very typically this results in frost problems on the side of the road towards the rising terrain. Correspondingly, especially in coastal areas, a typical drainage problem of road structures is that it is difficult to drain water from the vicinity of the road due to the flatness of the ground surface. In areas where fine-grained soils and peat occur, the problem is often exacerbated by the fact that the road embankment gradually settles below its original height due to the consolidation settlement of wet subsoil layers and commonly ground water table is close to ground surface, so that draining the road structure is a challenge.

The most typical applications of geosynthetics in Nordic road-construction projects are related to filtration and separation of soil layers. In particular, these properties are needed on thinly built lower-class roads, where the risk of mixing of structural layer materials and subsoil is high, especially during the thawing phase of seasonal frost in spring. Other typical uses include strengthening of the road foundation or the lower part of road embankment and ensuring the operation of drainage structures. But achieving the tensile strength required to combat the longitudinal cracking of the road surface due to the uneven frost heaves described above with conventional geosynthetic materials is challenging.

Some more detailed information on the challenges and solutions related to the maintenance of the low-volume road network in the northern periphery areas can be found, for example, under: www.roadex.org

**Future Trends**

As climate change progresses, the most significant frost-related problem in the northern regions is likely to be the discontinuity of frost periods. During one winter season, the road structure can freeze and thaw several times, as a result of which conditions similar to thawing can prevail in the road structure throughout almost the whole winter season. The lengthening of autumn rainy season, which precedes the actual freezing of the road structure, has the same effect. Especially on thin-structure roads, this increases the bearing capacity problems of the road structure and the consequent risk of mixing of the structural layers and the subsoil, for which geosynthetics are a potential solution. Undoubtedly, the predicted increases in the overall amount of rainfall as well as in rainfall intensity will also place even greater demands on drainage solutions for road structures. Here the application potential of geosynthetics is also significant.

The goals of the circular economy and the growing pressure for more sustainable use of non-renewable natural resources will inevitably put pressure on increasing the use of various types of alternative construction materials in infrastructure construction. As these alternative materials often differ in both mechanical and chemical properties from conventional construction materials, these effects must also be taken into account. From the point of view of the mechanical behaviour of road structures, this can even mean changes in the failure mechanisms of a traffic-loaded structure. From the point of view of geosynthetics, this can mean both the opening up of new types of applications, but also of course the existing ones becoming more demanding than before. In addition, especially for structures using alternative materials or products, it is important to remember to take into account the possible effects of an abnormal chemical environment on the long-term behaviour of synthetic materials.

## 1.2 Project background

The best designs and regulatory requirements will not necessarily translate into facilities that are protective of human health and environment unless they are properly constructed. Therefore, for geosynthetics, both manufacturing quality assurance (MQA) and manufacturing quality control (MQC) are equally important.

The existing NorGeoSpec system is a certification and specification systems for geosynthetics in Civil Engineering applications but does not include regulations and requirements for geosynthetics and geosynthetic-related products that address the specific conditions regarding low temperatures, installation conditions and soft subsoils which are a common problem in the region of the Nordic countries. This has even been in the past the topic of some court cases related to the evaluation of "fitness for purpose" of geosynthetics for Nordic conditions.

Based on discussion with different traffic authorities it was therefore proposed to establish a development project addressing which special requirements must be placed on geosynthetics and geosynthetic-related products to ensure technically and economically optimal solutions in country-specific climates and soils.

The overall aim of the project was to develop guidelines for requirements on geosynthetics and geosynthetic-related products characteristics to country-specific conditions.

For this purpose, the guidelines will provide recommendations which are useful for producers, distributors, consultants, specifiers, buyers, and construction companies. They are also useful to authorities who are responsible for up drawing requirements, recommendations, and guidelines.

The following functions of geosynthetics and geosynthetic-related products are the subject of the project: filtration + drainage, reinforcement / stabilisation, and sealing.

## 1.3 Field of application and scope

### 1.3.1 Field of application

Geosynthetics are widely used throughout the Nordic countries for a number of applications and functions. Generally, the main functions and applications of the geosynthetics used are:

- separation and filtration in roads and railways,
- reinforcement / stabilisation in roads, railways, and trafficked areas,
- reinforcement in embankments on soft subsoil,
- reinforcement in steep slopes and retaining walls,
- filtration in drainage ditches, riprap coastal structures, stone plastering of slopes,
- drainage in construction backfill and embankments,
- sealing in waste disposals, dams.

Some applications and functions are illustrated in Figure 1.1.15 to 1.1.28.

Figure 1.1.15. Filter in drainage trench in Norway (copyright ROUGH project participants).

Figure 1.1.16. Filter in a rip-rap erosion protection in water reservoir (copyright ROUGH project participants).

Figure 1.1.17. Drainage under a tram construction (copyright ROUGH project participants).

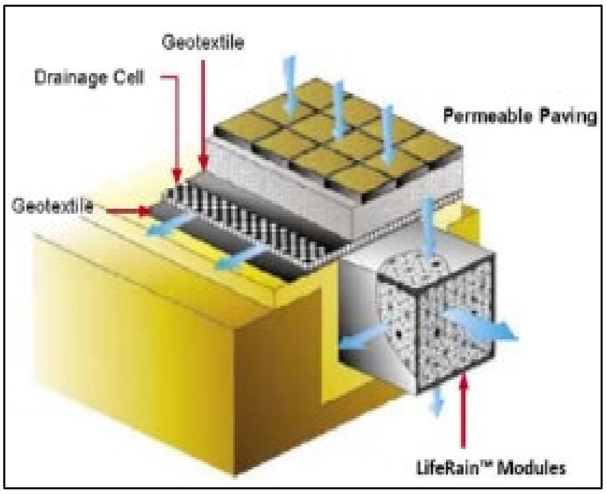


Figure 1.1.18. Filter and drainage layer in pavement (copyright ROUGH project participants).

Figure 1.1.19. Steep vegetated slope (copyright ROUGH project participants).

Figure 1.1.20. Reinforced soil structure (copyright ROUGH project participants).


Figure 1.1.21. Embankment on soft subsoil (copyright ROUGH project participants).

Figure 1.1.22. Embankment on soft subsoil (copyright ROUGH project participants).


Figure 1.1.23. Construction of base re-inforcement (copyright ROUGH project participants).

Figure 1.1.24. Construction of base reinforcement in Lithuania (copyright ROUGH project participants).

Figure 1.1.25. Solid waste disposal (copyright ROUGH project participants).

Figure 1.1.26. Solid waste disposal (copyright ROUGH project participants).

Figure 1.1.27. Liquid waste disposal (copyright ROUGH project participants).

Figure 1.1.28. Construction of a dam (copyright ROUGH project participants).

By volume the use as separation / filtration in construction and roads and railways is by far the largest application area. A common Nordic system for specification and certification of geosynthetics for this area, NorGeoSpec, has been in operation since 2002. The NorGeoSpec system has now been extended to include products for the function reinforcement as well.

However, despite more than 50 years of experience in use, requirements on the characteristics of geosynthetics, and guidelines for installation and construction relevant to country-specific conditions in Nordic countries are lacking. There are no regulations and requirements for geosynthetics and geosynthetic-related products that address the specific conditions regarding low temperatures, installation conditions and soft subsoils which are a common problem in the region. Some challenges related to the use of geosynthetics in Nordic conditions are:

- problems with installation due to cold and/or wet/snowy weather (brittle material - resistance to compaction, geosynthetic frozen in the soil)
- problems with subsoil and aggregates (wrong grain size distribution, frozen soil / fill, too thin or thick fill against the geosynthetic)
- problems with installation / construction of seaming/joints (especially of welded joints)
- problems with design (suitability of geosynthetic product, details too difficult to execute etc., totally wrong design / structure…)
- problems during service lifetime; settlements, deformations, cracking, clogging of filter, leaking, collapses / failures, etc.)

Accordingly, there is a need to establish general and special requirements for geosynthetics and geosynthetic related products to ensure technically and economically optimal solutions in country-specific climates and soils. The focus of these guidelines is general and specific requirements related to the installation and construction with geosynthetics in Nordic countries. The guidelines are covering the functions separation and filtration, reinforcement/stabilisation, drainage and sealing. The guidelines are focusing on requirements related to the installation and construction and does not cover the long-term behaviour in the structure. However, some requirements and recommendations are also relevant for the service lifetime of the geosynthetic.

### 1.3.2 Scope

The scope of the present Guidelines is the use of geosynthetics in Nordic conditions for the applications in roads, railways, reservoir and dams, rivers, waste disposal, sport fields, where the function(s) is reinforcement/stabilisation, filtration, drainage or sealing.

The guidelines concentrate mainly on the installation under Nordic conditions; long term behaviour like freeze/thaw action and traffic loading is not included in these guidelines.

*Note: The function protection is not included as well as reinforcement used in mechanically stabilised earth (MSE) structures (e.g., steep slopes, retaining walls) or veneer stability.*
*The function protection is not covered in these Guidelines. Nevertheless, considering that some protection geosynthetics are similar than the ones used in filter and/or in drainage, some results obtained in the ROUGH project may be considered to draw some advice for the determination of the behaviour at -10°C of these types of protection products. Usefully the Appendix B may also be used in this purpose.*

In order to be able to propose these recommendations for the use of geosynthetics in Nordic conditions, important preparatory work needed to be carried out. This has been realised within the ROUGH project to collect information and provide missing data.

This preparatory work has been focused on the behaviour (mechanical and hydraulic) during installation of geosynthetics in Nordic conditions (sub-zero temperatures, soil types and working conditions: drop height, compaction, etc.).

The means implemented within the ROUGH project were:
1- a full scale on-site experiment in Kemi (Northern Finland) on installation under Nordic conditions for the applications with the functions reinforcement / stabilisation, filtration, drainage; this is presented in the ROUGH project, report part 1, (2022);
2- considering the difficulty of the realisation of a similar on-site experiment for sealing applications, it has been decided to realise a literature study associated with a synthesis of the state of the art for this function; this is presented in the separate ROUGH project, report part 2, (2022).

## 1.4 Synthetic review of the existing knowledge on damage during installation of geosynthetics

In all the uses of geosynthetics, the installation may have an important influence on the short- and long-term performances of the products and of the geotechnical structures.

This short synthesis presents a general review of the existing knowledge on damage during installation of geosynthetics.

*Note: this paragraph gives the general principles of the evaluation of installation damage and shows the way it is considered in existing guidelines and recommendations. Its objective is to provide the basic general knowledge to facilitate the presentation of the Guidelines for the Use of Geosynthetics in Nordic Conditions. It does not present an exhaustive state of the art of this topic nor a detailed overview of the different behaviours of the numerous types of the geosynthetics, which would have needed a much longer development.*

### 1.4.1 Introduction and definition of possible installation damage to geosynthetics

In most existing studies on this topic, the influence of the installation on the integrity of the structure of the product and on its mechanical performances is the subject mainly considered.

The effect of the installation on geosynthetic's hydraulic properties should also be taken into consideration, especially in Nordic conditions with freezing and thawing, or when the products are placed on (in) soils with the presence of water, mud, etc. Similarly, the influence of the evolution of the hydraulic performance of the products (short and long term) has very rarely been studied and discussed when considering their importance on freeze thaw cycles and on the structure behaviour.

Nevertheless, the following synthesis of the existing publications will present mainly the evolution of the integrity of the structure of the geosynthetic during handling and installation and its mechanical performance.

### 1.4.2 Characteristics affected by the installation.

The evaluation of the influence of possible damage during installation on the performance of the geosynthetics shall be made based on the critical parameters linked to the application considered. This is also particularly true for use in Nordic conditions. Considering the present Guidelines, this paragraph will concentrate on the applications in which the geosynthetics are used in applications for reinforcement / stabilisation, separation, filtration & drainage.

*Note: sealing is covered in a separate chapter.*

The evaluation is made based on the change of performance between the characteristics of the product immediately after production and their values after installation.

It is generally considered that the damage during installation mainly results from placement and compaction of the backfill material on the geosynthetics (Greenwood, 1998), and it is also sometimes recognised that the stresses associated with on-site installation processes may be more important than the design stresses of the products (Koerner, 2005).

Table 1.4.1 presents for each function the critical characteristics for the evaluation of the influence of the installation damage on the performance of geotextiles and related products.

*Table 1.4.1 Critical characteristics for evaluation of the influence of installation damage on the performance for each function of geotextiles and related products*

| Characteristics (*) | | reinforcement / stabilisation | separation | filtration | drainage | sealing |
|---|---|---|---|---|---|---|
| Tensile strength | *EN-ISO 10319* | X | | | | |
| Elongation | *EN-ISO 10319* | X | | | | |
| Energy index | *(EN-ISO 10319)* | | X | X | | |
| Stiffness | *EN-ISO 10319* | X | | | | |
| Opening size | *EN-ISO 12956* | | X | X | | |
| Permeability $V_{H50}$ | *EN-ISO 11058* | | X | X | | |
| Water flow capacity in plane | *EN-ISO 12958* | | | | X | |
| Compressive strength | *EN-ISO 25619-1/2* | | | | X | |
| Compressive strain | *EN-ISO 25619-1/2* | | | | X | |
| Strain at 1 MPa | *EN-ISO 25619-1/2* | | | | X | |

*(*) Mass per unit area may be used for check of the product in the context of Quality Control.*

### 1.4.3 Installation conditions of geosynthetics and key parameters affecting damage during installation

For most applications, geosynthetics are installed on a subsoil layer and covered with a fill material which is compacted. The installation conditions can vary significantly, depending on the application and on the actual site conditions.

The effect of damage during installation of geosynthetics depends on factors related to:

- the subsoil (stiffness, strength, and surface evenness / roughness).
- fill material (grain size, angularity).

- method of installation (procedures, including drop height and compaction level; construction equipment; thickness of layers).
- climatic conditions (temperature, humidity).

For a given installation condition, the geosynthetic's performance will then depend on its structure, constituent polymer, and different characteristics.

#### 1.4.3.1 Subsoil

A foundation layer (subsoil) that has been levelled and is free from sharp and protruding objects is less prone to induce damage on geosynthetics that an unprepared foundation layer, as stress concentrations are minimised.

The bearing capacity and stiffness of the subsoil also influence the consequences of installation. Strong and stiff subsoil layers limit the deformation of the geosynthetic, avoiding areas of high tensile strains in the geosynthetics, but may be favourable to local puncturing by blocks in the backfill. Soft subsoils may reduce this risk but require specific tensile behaviour of the geosynthetic due to deformations of the soil (high capability for allowing elongation parallel to required strength). In the case of drainage trenches, the shape of the trench (especially its depth) will also influence the possible damage of geosynthetics.

#### 1.4.3.2 Fill material

Very large particle sizes usually induce high levels of damage on geosynthetics; well graded aggregates, i.e., those with broad particle-size distributions, cause less damage than more uniform aggregates with similar average (or maximum) particle sizes, $D_{50}$ (or $D_{max}$).

Soils with hard and angular particles tend to induce more severe damage than soils with rounded particles, due to puncturing and stress concentration. Large diameter crushed rock as fill material is commonly used in Nordic conditions and can often cause damage.

If the fill material is prone to fragmentation, soil spreading and compaction may lead to a decrease in particle sizes, and thus less damage. However, if the soil fragments into particles with sharp edges, the opposite effect may occur.

#### 1.4.3.3 Method of installation

Heavy equipment and thin layers of fill material above the geosynthetic lead to increased damage.

For the same compaction equipment, using higher compaction energy (for example, a larger number of passes) will tend to increase damage to the geosynthetic.

A greater drop height of the backfill material will lead to a higher impact on the contact between the backfill material and the geosynthetic; this is particularly important for coarse backfill (e.g., coastal protection applications).

#### 1.4.3.4 Climatic conditions

The Nordic climatic conditions, especially temperatures below 0° C with possible presence of water, may influence the behaviour of the subsoil and therefore affect the damage during installation. Especially the freeze-thaw cycles may affect the soil conditions significantly within a short time period.

*Note: the ROUGH project has been established to detail the effect of the Nordic conditions on the geosynthetic damage during installation and supports the current guidelines (see ROUGH* project, part 1 & 2, (2022)*)*

### 1.4.4 Observed damages on geosynthetics.

#### 1.4.4.1 Methods of evaluation of installation damage to geosynthetics

The installation damage to geosynthetics is generally assessed either (1) using real conditions on site in a real project, or (2) in the laboratory under controlled conditions. The first method can be defined as assessment by “exhumation after on-site installation”. The second one can be defined as assessment by “full-scale installation trials”.

Installation damage can be induced on-site under real conditions, if these conditions (soil, aggregates, installation technique, compaction, etc.) are controlled and allow to ensure the reproducibility of the procedure.

The basic principle is to build test sites where geosynthetics are installed using project-specific conditions and materials, or generally accepted and representative materials and procedures. Usually the construction sequence includes: 1) preparing the subsoil; 2) laying the geosynthetic; 3) tipping and spreading the fill material; 4) compacting the fill material; 5) repeating steps 3 and 4 until the desired final fill thickness is achieved. After completion of the test items, the fill material is removed carefully to avoid additional damage and the geosynthetics are exhumed for testing. The effects of installation are assessed by comparing test results on exhumed and reference (control) specimens.

There are several publications on test items built on-site to assess the effects of damage during installation of geosynthetics: Bush (1988), Koerner and Koerner (1990), Troost and Ploeg (1990), Watts and Brady (1990), Rainey and Barksdale (1993), Sandri et al. (1993), Wayne Hsieh and Han Wu (2001), Müller-Rochholz and Mannsbart (2004), Hufenus et al. (2005), Bathurst et al. (2011), Lim and McCartney (2013), Pinho-Lopes and Lopes (2014).

The main limitations of the exhumation of geosynthetics after on-site installation are their cost, the time required for their completion and the difficulty of including them in the schedule of the construction work.

Note: *EN ISO 13437 2019 describes a generic method for installing and retrieving samples in the field, for durability assessment, including damage during installation; a standardised procedure to induce installation damage in full scale from a test section for project-specific or representative conditions and materials is under preparation at CEN TC189 (pr EN 17738) similar to the existing ASTM D5818–11.*

**Full-scale installation trials**

To address the limitations of exhuming geosynthetics after on-site installation, standardised full-scale, outdoor, laboratory tests have been developed.

The basic principle is to build test items in a manner similar to that on site, but on a smaller scale and with a closer control of the parameters (soils, compaction, etc.).

The first version of this type of full-scale installation trial was proposed by Watts and Brady (1994). Currently, there are different procedures to induce damage during installation under realistic, simulated, conditions, such as BS 8006-1 (Annex D), EBGEO (2011), or NorGeoSpec Annex G (SINTEF, 2016).

For geosynthetics used as reinforcement, EBGEO (2011) recommends installation tests under real site conditions (including geosynthetic, subsoil, fill material, layer thickness, compaction equipment and number of passes). Nevertheless, if the fill material is more aggressive (broken and angular particles, stone, recycled materials) and if mechanical damage cannot be minimised by engineering measures, site testing must be carried out.

For example, the procedure in NorGeoSpec Annex G (SINTEF, 2016) includes three different aggregate particle sizes (fine, medium, coarse).

#### 1.4.4.2 Damage mechanisms

Often, six mechanisms of mechanical damage associated with on-site installation processes are identified: abrasion, splitting, punching, tension rupture, fibre shear and tearing. In general, several of these mechanisms tend to occur simultaneously. The following description of these mechanisms is based on the reference paper by Watn and Chew (2002).

**Abrasion**

Abrasion is caused by a repeated contact action between the geosynthetic and an abrasive material or whenever there are cyclic actions involving relative movement between the geosynthetic and the soil in contact with it.

This type of damage can occur, for example, in the application of geosynthetics in canal erosion control or filtration; coastal protection, where there is shear movement of soil close to the geosynthetic which may be due to mechanical equipment or external forces (e.g., waves, etc.); deposition of waste on geosynthetics installed in landfills; applications in railway lines, and temporary roads.

The abrasion damage mechanism may occur on all types of geosynthetics. Abrasion due to contact with small, sharp particles can vary significantly. In fact, the angularity of the particles has a greater influence on the generation of this type of mechanism than their size. Thus, during spreading and compacting the backfill material on geosynthetics and the associated traffic of construction equipment, abrasive mechanisms are involved which are evident in the visual observation of exhumed materials.

The main consequences of abrasion are a destruction of the surface, which may result in a local decrease in the strength of the geosynthetic and in changes of its hydraulic properties, namely those required for filtration.

**Splitting**

The direct contact of angular and sharp-edged particles of the backfill material with the geosynthetic material, together with the effect of the movement of construction equipment (compaction and vibrating equipment), may cause cracking of the material and, consequently, its separation. This may be sometimes considered as a typical behaviour of extruded polyethene geogrids and in that case, it is designated as splitting. Splitting can also occur in slit film woven materials (Greenwood et al., 2012). Splitting can lead to local embrittlement of the material and consequently a reduction in its mechanical properties.

**Puncturing**

Puncture damage may occur in two conditions: i) when backfill material with sharp-edged particles is poured directly onto the geosynthetic; ii) when thin layers of backfill material are compacted with heavy compaction equipment.

Macroscopically, as puncturing occurs on a geosynthetic surface, it is typical of continuous (sheet) materials, such as geotextiles and geomembranes. If puncturing is considered on a smaller scale, it can also occur in geogrid bars. In the case of geotextiles, penetration of coarse particles can create cavities of significant depth or even holes through the geosynthetic. In such cases the performance of the separation, filtration or protection function may be severely compromised. Puncturing is a typical risk for geotextiles used as separators or as filters in coastal revetments or road structures. This may happen when the geotextiles are placed on a stiff support. In the case of soft support, if the geotextile is too stiff and not strong enough to allow the high deformation needed, a different mechanism occurs (see “stress rupture” below).

**Stress rupture**

Stress rupture can occur when the geosynthetic is subjected to excessive loads and deformations (e.g. due to large backfill material in contact with the geosynthetic) or during installation on a soft base layer if thin layers of backfill material are compacted using heavy equipment. These conditions, particularly when combined with high stiffness of the geosynthetic, may lead to rupture. Stress rupture can also occur due to installation on an uneven foundation with areas likely to induce stress concentrations (e.g., depressions, protrusions, tree trunks and stumps). After stress rupture the geosynthetic function may be compromised, for example for separation or reinforcement.

**Fibre cutting**

Fibre cutting is observed when sharp-edged particles are in contact with a geosynthetic, particularly if the geosynthetic is installed on a hard base. Fibre cutting is often observed on woven geotextiles, geogrids and reinforcement strips, as thin fibres tend to have lower resistance to cutting. Some geosynthetics (woven geogrids and strips) have an external coating, which provides some protection against fibre cutting.

**Tearing**

On-site installation can also induce tearing of geosynthetics. In general, this damage mechanism occurs when there are tearing forces acting on an area of the geosynthetic in which there is some initial damage, such as fibre cutting or stress rupture. The resultant stress concentration on the fibres around the damaged areas, leads to propagation of tears.

Tearing may mainly occur on some types of heat-bonded or woven geotextiles in areas of stress concentrations due to sharp-edged particles, for example.

#### 1.4.4.3 Influence of installation damage on functional characteristics

The complexity of the phenomenon observed requires a global approach to evaluate the consequences of damage during installation on the performance of the geosynthetic. This is made in the existing guidelines and/or recommendations via the evaluation of the change of performance of the products based on their index characteristics depending on the specific installation conditions.

### 1.4.5 Overview of the way of considering the installation damage on geosynthetics in the existing guidelines

There are a number of guidelines or recommendations which help to take into account the possible damage of geosynthetics during installation. In this document, it was decided simply to present the existing rules from some European countries. Note that similar approaches exist also in other countries (e.g., ASHTOO M 288: 2021 in USA).

Table 1.4.2 present different ways of considering installation damage in the following existing systems:

- NorGeoSpec (SINTEF, 2016), “A Nordic Specification for the certification and specification of geosynthetics and geosynthetic-related products”.
- N200 Vegbygging v1.1 (Statens vegvesen, 2021) “Guidelines for Specification of Geosynthetic Filters in Roads”
- TRVINFRA-00230 (Trafikverket, 2022), "Geokonstruktion, Dimensionering och utformning".
- NF P 94-270 (AFNOR, 2009). “Geotechnical design — Retaining structures — Reinforced and soil nailing structures”.
- M GeoK E, (FGSV, 2016). “Merkblatt über die Anwendung von Geokunststoffen im Erdbau des Straßenbaus“.
- BS 8661 (2019) “Geotextiles - Guide for specification for basic separation and filtration functions”

Most classification systems define the requirements based on 3 key parameters: strength of the subsoil (2 to 3 types), type of backfill (2 to 5 types, depending on size of particles and angularity), aggressivity of the installation method (2 to 4 types, depending on drop height and compaction technique).

The influence of the installation on the performance of the geosynthetic is considered either:

- directly via a reduction factor (e.g., on tensile strength for reinforcement applications) or via a minimum requirement on the Energy Index
- or via specification profiles which include also other parameters like the traffic.

*Note: to date, the specific climatic conditions have not yet been considered as a parameter in these guidelines / recommendations.*

### 1.4.6 Quantifying the installation damage resistance of geosynthetics

As expressed in the previous paragraph, the quantification of the resistance of the geosynthetics to installation damage may be usefully taken from the "Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement" (ISO/TR 20432:2007), with the use of the reduction factor on installation damage ($RF_{ID}$). Generally, this factor is applied on the tensile strength. Nevertheless, as mentioned by Allen and Bathurst (1994), for reinforcement applications it should also be applied to the stiffness ($RF_{ID,\ J}$) or the elongation ($RF_{ID,\ \varepsilon}$).

Several studies (e.g., Müller-Rochholz J., 2003) have shown the difference between the external damage, corresponding to fibre (or cables) cutting, and the internal damage when the reinforcing elements are protected. In this case, the damage to the reinforcing element may be relatively reduced. These studies show that for geosynthetics undergoing external damage, installation and compaction result in a reduction in stiffness, whereas for those undergoing only internal damage there is less reduction in stiffness.

Nevertheless, as mentioned in the paragraph 1.4.2 the characteristics affected by the installation presented in Table 1.4.1 are cover a wider spectrum than simply those of tensile behaviour because the functions and the applications of geosynthetics are more than simply reinforcement.

For this reason, taking into consideration the objectives of these Guidelines to enlarge and exactly detail the behaviour of geosynthetics under specifically Nordic conditions, quantifying the influence of installation damage must reasonably be extended to more critical characteristics than just those linked to tensile behaviour.

Nevertheless, considering that installation damage to geotextiles and related products is linked to many parameters defining the installation conditions on a given job site (temperature, in-situ soil, type of backfill, drop height, thickness of layer, compaction), it seems interesting to focus on the influence of temperature, keeping all other job site conditions identical. In fact, generally data already exist for installation in Nordic conditions at positive temperatures; and, if not, they could be relatively easily evaluated.

For this reason, it is proposed to check the influence of a low temperature (e.g., - 10°C) compared to a positive one (e.g., 20°C) on the same given installation conditions, and to introduce the concept of the Vulnerability Index (VI) which can be applied to any critical characteristic as defined in Table 1.4.1.

The Vulnerability Index (VI) is defined for a given characteristic and for comparison of the installation damage at two temperatures (e.g., at + 20°C and – 10°C).

If there is no influence of the change of temperature on this characteristic:
Characteristic value (after installation - 10°C) = Characteristic value (after installation + 20°C) (*)

*(*) within the tolerance of NorGeoSpec* the corresponding value of the Vulnerability Index is VI = 1.

In contrast, if there is an influence of the change of temperature on this characteristic (measured after installation) (**):

*(**) the change of temperature modifies the value of this characteristic after installation outside of the NorGeoSPec tolerance to be considered. T*he corresponding value of the Vulnerability Index is VI = 0.

In this case, the quantification of the modified value of the characteristic after installation at the given temperature must be evaluated by a separate procedure (e.g., via a full-scale preliminary installation test procedure under Nordic conditions – see table 2.3.1).

*Note: the Vulnerability Index (VI) is simply an indicative index which characterises whether there is an influence of the change of temperature on a given characteristic or not. If there is an influence, VI = 0, if not, VI = 1. The VI does not allow quantification of the level of influence of the change of temperature on the given characteristic.*

*Table 1.4.2. Installation parameters considered in different guidelines/recommendations systems.*

| | Functions (applications) | Subsoil "types" | Fill material "types" | Methods of installation | Geosynthetics requirements | Geosynthetics "profiles" |
|---|---|---|---|---|---|---|
| **NorGeoSpec (SINTEF, 2016) (Norway, Sweden, Finland, Estonia)** | | | | | | |
| Nº of types | | 2 | 4 | 2 | *(5)* | 5 |
| Notes | Separation and filtration (roads) | Soft or stiff | $D_{max} < 63$<br>$63 < D_{max} < 200$<br>$200 < D_{max} < 500$<br>$D_{max} > 500$ | Normal or favourable. Considers: traffic, fill material, compaction, fill layer thickness | *Included in the design profiles* | Product specification profiles |
| **N200 Vegbygging v1.1 (Norway)** | | | | | | |
| Nº of types | | 3 | 2 | 2 | 4 | |
| Notes | Filtration in drainage systems (Roads) | Soft medium or stiff | Angular or round | Drop height (2) for trenches<br>Normal or favourable (mattress) | 4 Energy Index classes | *Combination with hydraulic design* |
| **TRVINFRA-00230 (Finland)** | | | | | | |
| | | 2 | 4 | 2 | 5 | 5 |
| Notes | Separation (roads and railways) | Soft or stiff<br>($c_u < 20$ kPa soft<br>$c_u \geq 20$ kPa stiff) | $D_{max} < 60$<br>$60 < D_{max} < 200$<br>$200 < D_{max} < 500$<br>$D_{max} > 500$ | Normal or favourable. Considers: traffic, fill material, compaction | *Included in the design profiles* | Geotextile categories, N1-N5; equivalent to NorGeoSpec |
| **NF P 94-270: 2009 (France)** | | | | | | |
| Nº of types | | 4 (*) | 4 | 4 | | |
| Notes | Reinforcement | (*) Same as fill material | Fine soil, sand<br>Sandy or round gravel<br>Crushed gravel / Soils with large particles | *Installation conditions:*<br>very severe, severe, medium severity, low severity. | Reduction factor on tensile strength | Design stability method |
| **EBGEO (2010) - site specific test (Germany)** | | | | | | |
| Nº of types | | (-) | 5 | 2 | | |
| Notes | Reinforcement | site specific,<br>a) Compacted<br>b) Soft condition | site specific or crushed 0/45 mm<br>a) 25 cm or site specific<br>b) site specific | compaction with 10 – 12 to. roller compactor or site specific, until achieving requested compaction | Reduction factor on tensile strength | Design stability method |
| **M GeoK E (2016) (Germany)** | | | | | | |
| Nº of types | | (-) | 5 | 2 | *(5)* | 5 |
| Notes | Separation, filtration protection (roads) | | Angular or round<br>< 40 % or > 40% of stones or blocks | Influence of compaction or not | *Included in the design profiles* | Geotextiles: robustness classes; *depending on the type of geotextile* |
| | **Functions (applications)** | **Subsoil "types"** | **Fill material "types"** | **Methods of installation** | **Geosynthetics requirements** | **Geosynthetics "profiles"** |
| **BS 8661:2019 (United Kingdom)** | | | | | | |
| Nº of types | - | 3 | 4 | 2 | *(5)* | 3 |
| Notes | Filtration, separation | Soil strength: extreme low to very low; low to medium; high to very high | $D_{max} < 63$<br>$63 < D_{max} < 200$<br>$200 < D_{max} < 500$<br>$D_{max} > 500$ | Normal & favourable. fill material, compaction equipment, fill layer thickness | *Included in the design profiles (Considers traffic)* | Geotextiles: high-extension (≥ 30%) and low-extension (< 30%); 3 specification profiles |

# 2 GEOTEXTILES & GTX RELATED PRODUCTS USED IN THE FUNCTIONS REINFORCEMENT/STABILISATION, FILTRATION, DRAINAGE

## 2.1 General requirements on the products

### 2.1.1 Aspects related to the raw material / structure of the product.

The frost resistance of polymeric products refers to the maintaining of or change in performance properties within acceptable limits at temperatures below 0°C. In general, the basic mechanical performance properties of geosynthetics, such as strength and stiffness, increase with decreasing temperature (Jie Han, Yan Jiang, 2013). The durability of the material also improves. Chemical reactions, such as the hydrolysis of PET or the oxidation of PP and PE, which lead to the degradation of polymeric products, proceed so slowly at low temperatures that they can even be neglected in the geotechnical design. However, the frost resistance of geosynthetics involves considering not only the properties of the polymeric raw materials, but also the properties of the geosynthetic as a whole, taking into account its morphological characteristics as well as its interaction with water.

**Influence of the raw material on the properties of a geosynthetic at low temperatures.**

In general, 0°C is not a critical or characteristic temperature for polymeric products. The critical temperature for polymers is not the freezing point of water, but the temperature at which the structural changes such as glass transition, crystallisation etc. take place in the polymer itself. For example, below the glass transition temperature, a partially amorphous polymer may abruptly change from a flexural elastic to a brittle state and tear or break under even light impact loads, e.g., during installation. For this reason, installation at temperatures close to the critical phase transition temperature of a polymer is critical for geosynthetics with this polymer. Therefore, for materials with a glass transition temperature close to the negative temperature of installation, more thorough testing of their suitability for installation or operation under alternating loads close to or below the glass transition temperature is required.

Table 2.1.1 presents the glass transition temperature for some usual polymers used in GSY. The glass transition temperature of specific polymers when formed into geosynthetics is dependent on the polymer properties, such as molecular weight, percentage of crystallinity, formulation ingredients such as additives and fillers and degree of molecular orientation from manufacturing process. The values in Table 2.1.1 relate to pure polymer pre-manufacture and are therefore only a guide.

*Table 2.1.1. Typical physical properties of polymeric geosynthetics*

| Polymer | Density of blended polymer g/cm³ | Melting temperature °C (*) | Glass transition temperature (tg) °C (*) |
|---|---|---|---|
| PP | 0,900 to 0,910 | 170 | < - 10 |
| fPP | 0,89 | 150 | < - 20 |
| HDPE | 0,940 to 0,960 | 130 | < - 80 |
| LLDPE | 0,910 to 0,925 | 120 | < - 80 |
| PET | 1,38 to 1,40 | 250 | 80 |
| PVC | 1,3 to 1,5 | N/A | - 25 to 100 |
| PA.6 | 1,2 | 220 | 50 |
| EPDM | 1,40 | NA | - 60 |
| CPE | 1,2 | 170 | < - 50 |
| CSPE | 1,47 | NA | - 55 |
| MB | 1,2 to 1,3 | NA | < - 50 |
| Aramid | 1,44 | 550 | 300 |
| PVA | 1,2 to 1,3 | 228 | 85 |
| PS | 1,05 (solid material) | 230 | 100 |

*(*) Approximate temperatures are given. The values of tg are derived from Differential Scanning Calorimetry (DSC) measurements. The values of tg for the very slow processes relevant for durability are generally markedly lower than those measured using DSC, example values of tg lower than 60 °C have been observed while DSC gives 80 °C. For the purposes of durability assessment, values of tg measured by Dynamic Thermo-Mechanical Analysis (DTMA) are preferred, if available. (Source: ISO TS 13434: Geosynthetics - Guidelines for the assessment of durability)*

The perceived risk linked to installation of PP close to -10°C was one of the reasons for the full-scale test realised in Kemi (ROUGH project part 1, 2022).

*Note: dependent on additives, or the production method and the degree of molecular orientation during manufacture used in the polymer, the behaviour of the polymer may vary consequently;*
*Note: the results of the tests in Kemi have shown a good behaviour under installation at - 10°C of the PP geosynthetics used in this full-scale test (see paragraph 2.2.2).*

**Influence of water on the properties of a geosynthetic at low temperatures.**

The situation is quite different when the geosynthetics contain water. Thus, capillary action may lead to geosynthetics absorbing and storing water (e.g., needle-punched geotextiles, drainage geocomposites, reinforcement geocomposites, etc.), and water may also penetrate into the junctions of some forms of geogrids. The freezing of the water thus creates a composite "ice-geosynthetic" with new composite properties. In this case, the issue of frost resistance is considered in a similar manner to the frost resistance of concrete or asphalt. In this context, it is simply a matter of the effects of frozen water on the behaviour of the geosynthetic. Testing (Sintef GISSAC report, 2010) has shown that generally the freeze and thaw cycles of wet geotextiles do not show degradation of the performance of the geotextiles (for the functions separation, filtration). Nevertheless, in the case of rolls of geotextiles, frozen water may lead to a loss of flexural elasticity, which in turn makes it difficult (if not impossible) to unroll a roll of geotextile during installation or can even cause the product to break. Similarly at the welds of the geosynthetic strips of a strip geogrid, the frozen water may weaken or even destroy the bonds and thus significantly impair the soil-geogrid interaction. For this reason, installing geosynthetics at low temperatures places additional requirements on the transport and storage of the rolls. For example, care must be taken to ensure that no water can penetrate the material during transport and storage (see paragraph 2.2.1.1). As example, wrapping tear as shown in (Figure 2.1.1) shall be avoided.

*Figure 2.2.1. Examples of tear of the wrapping which may lead to water entering in the roll and then freezing.*

**Influence of the production-related morphology**

The residual stresses in the material, which are a result of its temperature history or the orientation of the molecular chains during cold drawing, should also be taken into account. The temperature decrease may have a negative effect on the performance of the material or on the characteristics that are important for installation, e.g. for unrolling, where a memory effect means that the roll tries to re-wind. Nevertheless, there is a lack of systematically recorded boundary conditions and quantifiable requirements for the installation processes of the various geosynthetics.

### 2.1.2 Aspects related to rolls.

For the handling of geotextiles and geotextile-related products on construction sites with low installation temperatures (< 0°C), the packaging and storage of the products is important (Keywords: unrollability and visibility). Therefore, the protection of the materials during delivery to the construction site, storage and subsequent handling must be ensured.

It is important to mention at this stage two important topics essential for the performance of the geosynthetic in the structure: packaging and storage.

- packaging: some packaging films tend to tear at low temperatures; therefore, the packaging should be waterproof, frost-proof; and the core of the roll should also be waterproof or should be protected against incoming water by adequate packaging; where appropriate, the packaging material should be clearly visible, especially considering possible surrounding snow; rolls with damaged packaging should be replaced or the packaging repaired immediately;
- storage: for the storage of the rolls on site, a flat, load bearing and appropriately cleaned (snow, stones or other contaminations) storage area must be prepared before delivery of the goods; in order to prevent damage to the packaging when unloading the goods, appropriate equipment (e.g., lifting beams and straps) should be available.

*Note: these two topics will be presented more in detail in paragraph 2.2.1.1.*

## 2.2 Requirements on Installation

### 2.2.1 General installation requirements

*Note: the general installation requirements to ensure the short and long-term performance of the sealing geosynthetic (geosynthetic barriers-GBR) under Nordic conditions are presented in chapter 3.*

The process of defining the general installation requirements to ensure the short and long-term performance of the geotextiles and related products (GTX & GTP) under Nordic conditions can be summarised as shown in Figure 2.2.1.

The GTX & GTP shall preserve its integrity during transportation and storage

⇩

It must be possible to unroll the GTX & GTP in place under freezing temperatures, on a frozen soil subgrade, without damaging it.

⇩

Worker safety must not be affected by the GTX & GTP under Nordic conditions

⇩

Sub-base preparation, the deployment, cutting & assembly of GTX & GTP, and the backfilling process shall allow the GTX & GTP to exhibit adequate short and long-term properties when exposed to Nordic conditions (especially cold temperatures) during service

*Figure 2.2.1 General installation requirements for geotextiles and related products (GTX & GTP).*

#### 2.2.1.1 Preservation of GTX & GTP's integrity during transportation and storage

This requirement involves the properties of the packaging and the cores of the rolls. For all products the packaging shall avoid exposure to dirt and UV during transportation and storage (NorGeoSpec SINTEF, (2016)). But in Nordic conditions, special care shall be taken to protect all parts of a roll likely to be exposed to water:

- special care should be taken that water-sensitive products, such as mechanically bonded nonwovens, drainage geocomposites or reinforcement geocomposites, etc.; are wrapped to avoid any accidental exposure to water.
- to avoid degradation, it is recommended to use either plastic cores or cardboard cores treated to be water repellent. Alternatively, the wrapping of the roll must be designed to avoid any contact of water with the core.

**Storage arrangements:**
Rolls must be stored on platforms, i.e. flattened areas relatively rigid to prevent large deformations of the rolls, and necessary precautions must be taken to avoid direct exposure to runoff water.

The usual precautions to ensure the stability of the stacking of stored packages, especially when dealing with rolls, must be taken (cushioning, securing, etc.);

Cores must have an adequate crush strength. The use of caps on the ends of the cores is recommended to avoid infiltration of water into the geotextile or geotextile-related product through the core.

Labels should be water-resistant and of sufficient quality.

*Note: the use of open flames or heaters to remove ice from a roll accidentally frozen is not acceptable. Rolls accidentally exposed to water and frozen cannot be used until the ice has melted naturally following storage in a warmer environment, and after an inspection to check if any damage has occurred.*

#### 2.2.1.2 Worker safety during installation of the GTX & GTP

Smooth GTX & GTP may become slippery under freezing temperatures. As soon as there are snowflakes or ice lenses on their surface, it may become virtually impossible to walk, affecting worker safety and productivity. Using materials with sufficient grip for workers' boots while covered by a thin layer of snow is recommended.

#### 2.2.1.3 Subgrade preparation

The rules prevailing for construction in normal conditions apply to frozen subgrades. In principle, these should be compacted and smoothed to the project specification; nevertheless, if the geotextile is installed straight on soft subsoil, compaction is not needed, or it may sometimes be impossible to compact such subsoils.

The installation of the geosynthetics must start with the inspection and approval of the subgrade. The presence of snow and ice should be avoided in the subgrade as well as in the fill material, so they can be handled and compacted. Melting of ice blocks or snow located under the GTX & GTP may result in the creation of cavities which could generate strain in the geosynthetics.

Specific subgrade acceptance requirements may vary with the type and properties of the GTX & GTP selected for a given project, as well as with the type of protection layer used, if any.

Construction and quality assurance activities should be planned to ensure that a prepared surface can be covered the same day with the next layer, to minimize the risk of accumulation of snow in an area which is still to be covered. This recommendation applies to all layers: subgrade, GTX & GTP and any other layer, until the last layer is installed.

In case snow or ice would accumulate on a prepared surface before installation of the GTX & GTP, their removal is determined on a project-by-project basis.

Removing snow may accidentally create substantial damage to a substrate. The decision to remove a small thickness of freshly fallen snow from a previously approved substrate should therefore be weighed carefully. This decision should be taken by the QA Engineer in consultation with the designer, considering the thickness and quantity of snow, complexity of removal, weather forecast, type of subgrade, potential effects of snow confined under the GTX & GTP and other project-specific considerations.

#### 2.2.1.4 Deployment

Given the additional stiffness caused by the lower temperature, some types of geosynthetics may require more effort to unroll. Their lay-flat ability may also not be as good as under milder environmental conditions. They may therefore be more susceptible to wind uplift, offering more air access to the underside of the geosynthetic. If necessary, a ballasting strategy should be adopted (sandbags, used tyres, blocks of stone, soil, etc.).

Removal of snow from a large area of GTX & GTP is virtually impossible without damaging the product. The construction schedule should therefore favour the installation of all superposed layers, instead of finalizing installation of a layer before installing the next one. This aspect may affect the quality management strategy. Before starting to deploy the GTX & GTP, agreement must be reached with the contractor in charge of backfilling regarding the management of granular materials, considering the necessity to cover the geosynthetic materials rapidly after installation of the geosynthetic layer.

#### 2.2.1.5 Assembly, cutting.

Overlapping: in this assembly process, the layers are laid by unrolling or deploying adjacent strips, allowing a certain overlap between them. The width of the overlap may vary from 0.3 m to 1 m or more for certain structures depending on the deformability of the support soil, the function of the geosynthetic, the nature and extent of the imposed stressing, and the friction characteristics between GTX & GTP and soils. This assembly process is particularly suitable when the geotextile has a separation, filtration or drainage function. It may be used in the direction perpendicular to the stresses on the GTX & GTP.
Sewing: in this case, an overlap of at least 0.10 m shall be respected. The stitch and yarn used shall maintain the functional specified characteristics.

Cutting of rolls or other forms of packaging: this must be carried out with suitable tools: a chainsaw may be suitable for certain GTX & GTP on rolls; however, care must be taken during cutting not to melt the geotextile locally which may lead to welding the windings together. Manufacturers' specific requirements should be also followed.

#### 2.2.1.6 Backfilling over the GTX & GTP

In the case of linear structures (traffic roads, railways, etc.) or structures with large areas to cover, the backfill should be placed progressively and no trucks should be allowed to drive directly on the GTX or the GTP.

The direction of placement of the backfill shall be in accordance with the overlapping of the layers.

When backfilling rock or boulders onto the GTX & GTP, which is generally the case in typical Nordic conditions, evaluation of the degradation created by the fall of the heaviest or most aggressive elements shall be evaluated.

For this evaluation, a test item (see paragraph 1.4.4.1) shall be used to determine the maximum possible drop heights, considering the GTX & GTP used, the weight and shape of the blocks and the deformability of the support.

### 2.2.2 Specific installation requirements (aspects related to application and function)

#### 2.2.2.1 Filtration: parameters (drop height, aggregate shape, temperature)

Geotextiles for filter applications must be installed with a fill overlay to ensure they are not subjected to damage that may prevent their intended function during the service lifetime. Basically, the main impact during the installation is related to the subsoil, the fill material, the machinery and the procedure used for installation and construction. The main influence factors for the impact are related to:

- the structural solution (type of drainage system: trench, mattress, etc.);
- subsoil evenness, stiffness, and strength;
- fill material (mainly particle size and angularity of particles);
- temperature during installation.

The Norwegian guidelines for construction works (N200 Vegbygging, 2021) are a good basis for requirements for the use of geotextiles in filtration in Nordic areas. They include requirements for the geotextile to ensure the functionality of the product during the intended service lifetime.

Firstly, the geotextiles shall conform to the General Requirements as presented in paragraph 2.2.1. Additionally specific requirements need to be added: based on (N200 Vegbygging, 2021) they include a robustness factor (Energy Index, EI) basically intended to ensure the geotextile is not damaged during installation and construction; to an extent this may prevent the filter functionality during the service lifetime.
The robustness factor (EI) requirements are related to robustness classes as presented in Table 2.2.2.

*Table 2.2.2: robustness classes based on the energy index (EI).*

| **EI 2** | **EI 3** | **EI 4** | **EI 5** |
|---|---|---|---|
| EI ≥ 2,1 kN/m | EI ≥ 3,2 kN/m | EI ≥ 4,5 kN/m | EI ≥ 6,5 kN/m |

The required robustness class (EI) is based on an evaluation of impact on the filtering geosynthetics related to type of structure, underground conditions, and type of fill material. Required robustness (EI) classes for geosynthetics for drainage ditches are given based on (N200 Vegbygging, 2021) in Table 2.2.3.

*Table 2.2.3: requirements for energy index (EI) in drainage ditches.*

| Maximum grain size against filter geosynthetic | $D_{max} \leq 100mm$ | | $D_{max} > 100mm$ | |
|---|---|---|---|---|
| Material in drainage ditch | Natural gravel (rounded) | Crushed rock (sharp edged) | Natural gravel (rounded) | Crushed rock (sharp edged) |
| In-situ soil mechanical class | | | | |
| Very soft (soft clay and silt) $c_u < 25$ kPa | EI 3 | EI 4 | EI 4 | EI 5 |
| Medium (medium firm clay and silt) 25 kPa ≤ $c_u < 50$ kPa | EI 2 | EI 3 | EI 4 | EI 5 |
| Firm (very firm clay, sand and gravel) $c_u > 50$ kPa | EI 2 | EI 3 | EI 3 | EI 4 |

The results from the Test site in Kemi (ROUGH project part 1, 2022) indicate that the current requirements on robustness classification may possibly be reduced under certain conditions. However, the number of products in the test is limited and may not be representative for all the products and loading conditions that may be relevant in the specific case. Accordingly, it is proposed to use the general requirements as set out in N200 Vegbygging (2021), but allow specific products to be approved based on the specific properties and experience with the product.

*Note: this means that if a product fulfils N200 at a positive temperature, it can be considered that it will fulfil the installation requirements at -10°C. If the product does not fulfil N200 requirements, a similar test to that in Kemi shall be performed to approve the corresponding product for an installation at -10°C.*

#### 2.2.2.2 Separation

The function separation is generally the application area with largest volume of geosynthetics. Typically, for practically all applications the function separation also includes the function filtration as there is almost always water present. For nearly 50 years now, there has been a system for the specification of geosynthetics intended for separation and filtration in roads, railways, and trafficked areas. Since 2002 there has been a common Nordic system for the specification and Certification of geosynthetics for separation and filtration, NorGeoSpec. This system specifies requirements for the products to be used, to ensure the products are suitable for installation and function during the intended lifetime. The system is related to application classes and specifies requirements based on standardised properties as presented in Table 2.2.4.

*Table 2.2.4: required values, product specifications according NorGeoSpec.*

| | Function: separation and filtration | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Characteristic | Testing standard | Unit | Maximum tolerance 1) | Required2) values corresponding to 95% confidence limit | | | | |
| | | | | Product Specification profiles | | | | |
| | | | | 1 | 2 | 3 | 4 | 5 |
| Min tensile strength | EN ISO 10319 | kN/m | -10% | 6 | 10 | 15 | 20 | 26 |
| max. load | EN ISO 10319 | % | -20% | 15 | 20 | 25 | 30 | 35 |
| Max cone drop diameter | EN ISO 13433 | mm | +25% | 44 | 38 | 28 | 22 | 13 |
| Min energy index | | kN/m | | 1.2 | 2.1 | 3.2 | 4.5 | 6.5 |
| Min velocity index | EN ISO 11058 | $10^{-3}$ m/s | -30% | 3 | 3 | 3 | 3 | 3 |
| Max characteristic opening size, $O_{90}$ | EN ISO 12956 | mm | ±30% | 0.2 | 0.2 | 0.2 | 0.15 | 0.15 |
| Max tolerance for mass per unit area | EN ISO 9864 | g/m² | ±10% | | | | | |
| Max tolerance for static puncture strength | EN ISO 12236 | kN | -10% | | | | | |

1) The tolerance shall be stated by the manufacturer; this table gives the maximum allowable tolerance.

2) The tolerances are not to be added to the required values. The nominal values ± the tolerance shall fulfil the requirement.

As such, the ROUGH project has not specifically included products intended for the separation function. However, both the application and the products intended for the function filtration are highly relevant for the function separation too. Accordingly, the results from ROUGH from the products filtration are assumed to be relevant for the function separation as well. As stated for the function filtration, the results indicate that the current general requirements are also relevant for installation in temperatures down to - 10 °C. The results also indicate that the required properties on Strain Energy (for filtration expressed as robustness factor – Energy Index - EI) may possibly be reduced for the product specification profile 2. However, the number of products tested, and limited variations in subsoil conditions and loading, is not sufficient to justify a general revision of the requirements but can be relevant for approving specific products for specific application and project conditions.

#### 2.2.2.3 Drainage (placement of above layer, aggregate shape, temperature)

Geosynthetics for drainage purposes generally consists of drainage core between two layers of geosynthetics for filtering of the soil. The products are commonly used as drainage layers, typically between concrete structures (house basement, bridge abutments….) and the backfill. There are currently no specific requirements for this application in the Nordic countries. The ROUGH project included two types of products used as drainage layers as a part of a road superstructure. The products were installed at low temperatures, with installation and compaction of crushed rock fill on top of the products. The products were excavated and examined both visually and in the laboratory after the test. Also, laboratory testing were carried out on virgin products to examine their susceptibility to damage by mechanical impact at low temperatures.

The results indicate that the amount of damage did not affect the intended function of the products. Also, no specific effect of the low temperatures related to installation and construction was identified. This indicates that there is no need to apply specific requirements for this type of product for installation and construction in temperatures down to - 10 °C compared to the general requirements.

The number of products tested and the limitations on application area and boundary conditions make it difficult to draw general conclusions related to the use of geosynthetics for drainage applications. A possible approach may be to use the requirements for robustness factor (Energy Index - EI) as given from the filter function for the filtering geosynthetics combined with a requirement on compression strength for the core based on the intended application (i.e. evaluation of effective loading conditions for the specific application).

#### 2.2.2.4 Reinforcement / stabilisation (drop height, aggregate shape, temperature)

The use of geosynthetics for the function reinforcement / stabilisation is relatively common in the construction of roads, railroads & working platforms. The principle consists of placing the geosynthetic on the relatively flat subsoil, which may be frozen at the time of installation, to support, reinforce and stabilize the superstructure (embankment / traffic structure) for the long term. The placing of the upper soil requires adequate compaction to ensure the short- and long-term performance of the structure.

Generally, in the Nordic countries the backfill is crushed rock. The influence of the backfilling and the compaction on the damage during installation is well known for temperatures above 0 °C. Nevertheless, considering the poor level of existing information in the case of installation at low temperatures (e.g. -10 °C), it was decided to realise a full-scale experiment on site in Kemi (north of Finland) involving a large number of different types of geosynthetics (ROUGH project, part 1, 2022).

To obtain site-realistic damage behaviour during placement and compaction of materials, specifications based on Finnish guidelines for road construction were used for the field conditioning.

For the application of reinforcement / stabilisation the important functional characteristic is the tensile stiffness, which ensures the long-term performance of the structure. And as usual for any reinforcement application, the tensile strength after installation shall obviously avoid failure of the product but appears as a secondary parameter compared to the tensile stiffness.

*Note on the Kemi full-scale experimentation:*

*The results of the Kemi installation tests show the following results concerning the evolution of tensile stiffness: the stiffness of the samples exposed to Kemi installation at - 10°C and measured at + 20°C shows a very small variation (< - 7%).*

*The stiffness of the virgin rib (- 10°C / + 20°C) shows a large increase in stiffness of virgin ribs due to low temperature (- 10°C) (33% to 85%).*

*It is reasonable to think that this was the same in Kemi when the products were exposed to a temperature of – 10°C during installation.*

*Nevertheless, after exposition to Kemi conditions, the samples were tested in the lab at + 20°C, and the stiffnesses measured in the lab are almost unchanged compared to those of the reference products.*

*Concerning the evolution of the tensile behaviour, the Kemi installation tests show the following results:*

- *all products have a very low variation of stiffness (except 2 products)*
- *5 products show a small reduction of strength on the "Kemi" samples (≤ 13%), where a small increase in strength is observed on the virgin rib in lab (≤ 13%);*
- *the 2 other products show a clear reduction in strength (- 50 % to – 60 %) for the Kemi samples; for these 2 products the analysis reports of installation damage tests in similar conditions (+ 20°C) show that the observed reduction of strength at + 20°C is in the range of that observed in Kemi (Ref. confidential reports of the producers).*

On the base of the Kemi full-scale experimentation, the following conclusion can be drawn: if the geosynthetic product has been correctly designed for a positive temperature (e.g., + 20 °C) for the defined geotechnical conditions of installation (type of soils, drop height, compaction, etc.), no additional installation damage is observed in the tensile stiffness or the tensile strength when the products are installed under the same conditions at - 10°C.

Nevertheless, it should be mentioned that significant damage has been observed on extruded geogrid junctions under typical Nordic installation conditions in Sweden and Norway on some sites.

This type of damage was not observed on the products tested at the Kemi experimental site. However, it cannot be excluded that some products may have a specific sensitivity. In the absence of a proven and standardized tool for evaluating the corresponding performance of such products, the resistance to this specific damage of this type of product shall be checked carefully in a full-scale preliminary installation test procedure under Nordic conditions (acc. Paragraph 2.3).

***IMPORTANT NOTE:*** *All presented results and the conclusion are only valid for the products tested in Kemi (or similar products). The transfer of positive results from Kemi to other product families than those tested and to other conditions of application is not recommended and may only be done taking significant precautions after additional specific studies.*

## 2.3 Quality control

The results and evaluations from the laboratory tests realised on all the products tested during the ROUGH project in Kemi (see ROUGH project, part 1, 2022) have shown that cold temperatures generally have no negative influence on the material behaviour compared to its behaviour at a positive temperature.

This means that for these products the influence of low temperatures on the aspect of installation damage resistance does not need to be considered further.

However, this does not answer the question of whether every material can be installed at low temperatures. In this respect, the studies realised during the ROUGH project show that two seemingly identical raw materials may nevertheless behave differently or show different behaviours after installation damage tests (see ROUGH project, part 1, 2022).

Therefore, appropriate approval should be available before installing the materials at cold temperatures.

Such approval shall be achieved through performance tests carried out and documented in advance under conditions similar to those during later installation.

To facilitate these approvals, the requirements for a full-scale preliminary installation test procedure under Nordic conditions can be described as follows.

**Requirements for a full-scale preliminary installation test procedure under Nordic conditions (*)**

*Note: (*) the requirements are defined to reach a similar performance of the installation in Nordic conditions as obtained during the ROUGH project in Kemi (ROUGH project, part 1, 2022).*

The tests shall be carried out under the surveillance of an independent third party.

*Table 2.3.1: Requirements for full-scale installation test procedure under Nordic conditions.*

| Parameters | Controlled item | Comments |
|---|---|---|
| Temperature | - 10°C (± 5°C) [(1)] | Shall be monitored (as far as possible by an official institute), during installation of the geosynthetics, during the compaction & during the removal periods. |
| In-situ soil (foundation soil) | Class | Geotechnical characterisation (at least particle size, strength and stiffness) |
| | $E_{V2}$ (MN/m²) | Average bearing capacity modulus |
| Backfill material | Crushed stone | Geotechnical characterisation (at least aggregate size and angularity e.g., 0/56) |
| | Drop height | According to function (reinf/stabilisation DH = 1.0 m, filtration DH = 1.0 & 2.0 m, drainage DH = 1.0 m) |
| | Thickness of layer | Thickness = 30 cm |
| | $E_{V2}$ (MN/m²) | Compaction acc. Finnish (InfraRYL) road construction guidelines or Swedish (AMA Anläggning) or Norwegian (N200) |
| Geosynthetic | Test specimens pre-marking before installation | Locations of specimens for further laboratory testing shall be pre-marked on the product according to the planned functional characteristics to be evaluated. |
| | Recovery of samples | To avoid additional damage to the samples during the recovery, a vacuum / sucking lorry should be used. |
| | Laboratory testing of the recovered samples | Shall be performed at + 20°C on the relevant characteristic according to the function (Table) |
| | Performance under Nordic conditions | Expressed as Vulnerability Index (VI) on the relevant characteristic(s) according to the function (Table 1.4.1.) |
| | Laboratory testing on virgin samples | Complementary testing at negative reference temperatures (e.g., -10°C, - 20°C) on relevant functional characteristic(s) may usefully complete the evaluation of performance under Nordic conditions. |

*[(1)] Other reference temperatures may be chosen depending on the area (e.g., - 15°C, - 20°C)*

*Table 2.3.2: Relevant critical characteristics depending on the function for evaluation of the performance under Nordic conditions.*

| Function | Relevant critical characteristic(s) |
|---|---|
| Reinforcement / stabilisation | Tensile strength, tensile stiffness |
| Filtration | Robustness factor (Energy Index), opening size |
| Drainage | Tensile strength/strain, hydraulic capacity |

*Note: the product families tested during the ROUGH project in Kemi are considered to have been tested according to the Requirements for a full-scale preliminary installation test procedure under Nordic conditions.*

*Note: the collection of the results of these full-scale preliminary installation tests under Nordic conditions may be usefully integrated in an adequate certification system (e.g., NorGeoSpec).*

# 3 GEOSYNTHETICS USED IN SEALING

## 3.1 General requirements for products used in sealing applications under Nordic conditions.

### 3.1.1 Impact of the environmental conditions on design choices

Guidance on the design of geosynthetic barrier (GBR) and geosynthetic lining systems is outside the scope of this document, which focuses solely on the selection of the GBR material itself. ISO 18228-9 (in press) provides general concepts which can be used to design a lining system and select an adequate GBR. Many recommendations proposed in ISO 18228-9 address chemical compatibility and other aspects which do not depend on weather or installation conditions. However, winter installation with low temperature, presence of ice and snow and freeze / thaw cycles may influence the selection of the sealing product (polymer / type, thickness, finish), and can also affect:

- The choice of products used to complement the sealing layer – and in particular the cushioning layers used for puncture protection, especially considering the type of subsoil and fill material typical to a northern environment.
- The thickness of overburden layers.
- Some details of the design itself, such as the characteristics of the slopes (angle and length, presence of berms), which may be affected by a change in interface friction properties.
- The installation process (e.g., scheduling, welding strategy).
- The quality assurance programme (type of control, approval process, use of electrical leak location).
- In some cases, operations may also be influenced by environmental conditions.

Overall, selection of the sealing material is only one of the many issues which must be addressed to ensure adequate performance of a sealing structure. The design of such a structure includes several other steps which may have significant impacts on the cost and feasibility of the project, beyond the availability of an adequate GBR.

The performance of a sealing layer is defined by the flow of liquid and/or gases passing through the sealing layer. The smaller the leakage rate, the better, which is a reason why geosynthetic barriers are used. However, these products may be damaged during installation or in service, due to their interaction with soil or external loading. The number of leaks per hectare of GBR-P or GBR-B reported in the literature ranges between 0.25 (Gilson-Becks, 2019) and 7 (Nosko, 2015) for projects where Electrical Leak Location Surveys were specified and conducted. This number may be even higher where no or insufficient quality control is conducted, as reported by Forget (2005).

To mitigate the risk of leakage, while acknowledging that the GBR is more likely to be damaged if installed during winter, engineered, multi-layered lining systems should be preferred to single liners. These engineered lining systems typically include:

- A geotextile protection layer, or cushion, installed above the polymeric or bituminous geosynthetic barrier (GBR-P or GBR-B), to protect it from static or dynamic aggregate puncture during backfilling or in service.
- A compacted clay liner (CCL) or a clay geosynthetic barrier (GBR-C), installed below the GBR-P. This material offers a low-permeability substrate to reduce the flow of liquid passing through a potential leak in the GBR-P. Such a structure is called a 'composite lining system'.
- Addition of a second barrier as well as a geocomposite drain between the primary (upper) and the secondary (lower) barrier. The aim of this design is to reduce the head of liquid prevailing on the secondary barrier. As the flow is proportional to the water head, doing so reduces the flow of liquid released into the environment. Such a structure is called a 'double lining system'.

Typical structures of composite, double, and double-composite lining systems are depicted in Figure 3.1.1. A more detailed discussion on the benefits and limitations of multi-layered geosynthetic barrier systems can be found in Rowe (2005).

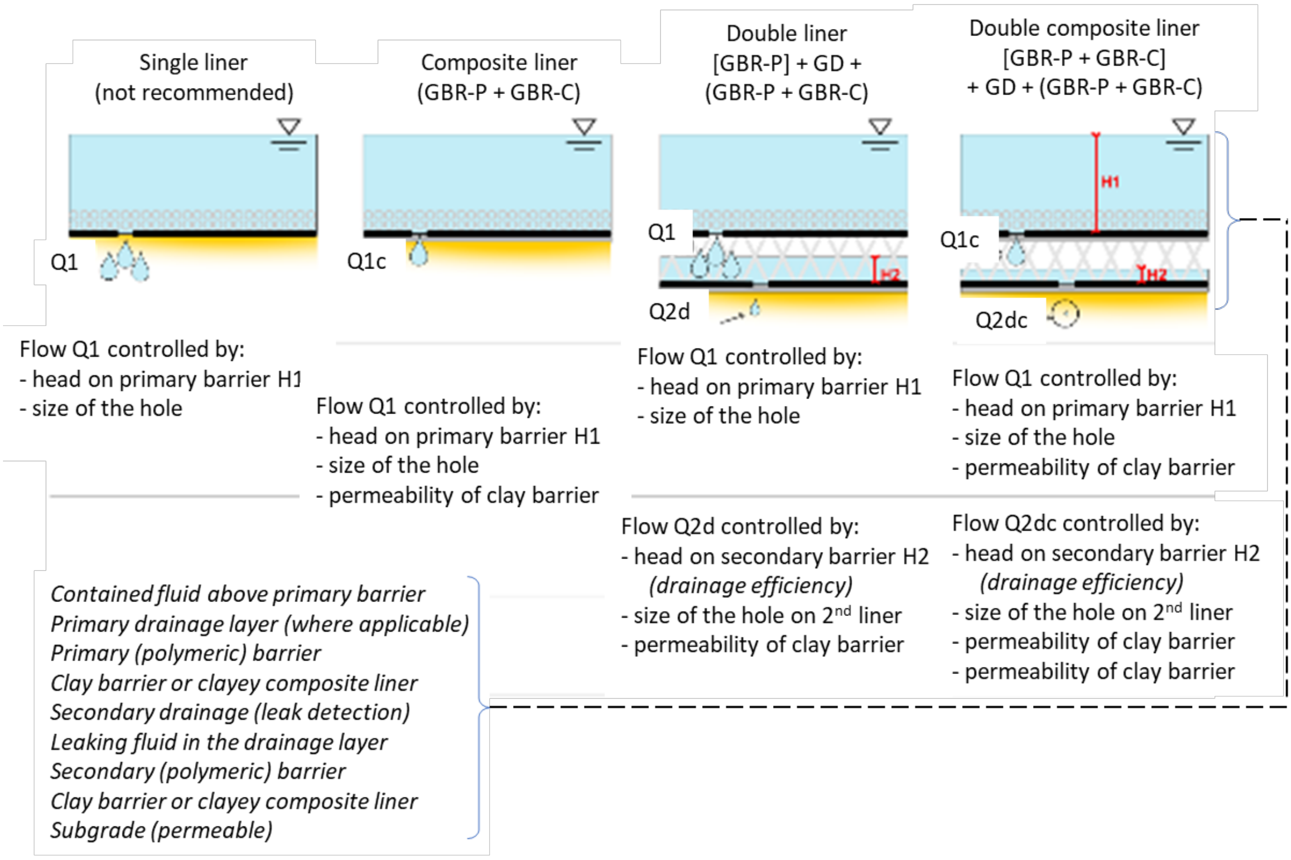


*Figure 3.1.1: Typical structures of composite and double lining systems*

It is important to highlight that the use of double and composite lining systems improves the performance of the lining system and significantly reduces the risk of leakage. However, installation of a geosynthetic lining system and backfilling of soil on top of it in winter remains significantly more challenging than if these actions are taken while the environmental and soil conditions are much easier to handle, during the summertime. Consequently, as far as possible, delaying the project until the temperature is permanently above 0 degrees (e.g., summertime) remains the best solution to minimize leakage.

### 3.1.2 Aspects related to the raw material/structure of the products.

The ease of installation and the long-term performance of geosynthetics are partially defined by how much the products will be exposed to cold weather, and at what time of their life – including transportation, storage, installation and during their service life. If the product is highly temperature-sensitive but is intended to be covered by a thick layer of soil that will protect it from cold temperatures just after installation, it is theoretically possible to store it at a warm temperature and wait until the weather conditions permit its installation and installation of the soil cover. The actual possibility to use a particular product is not defined by strict boundaries and should be assessed on a case-by-case basis considering the flexibility of construction schedule and likelihood of extreme environmental events during the projected construction period. However, the less sensitive the product is to the anticipated environmental conditions, the less complex will be its installation and therefore the more manageable the construction schedule.

Figure 3.1.2 summarizes the various issues that must be considered for any given project. The section following discusses these issues.

The GBR must preserve its integrity during transportation and storage

⇩

It must be possible to unroll the GBR in place under freezing temperatures, on a frozen soil subgrade, without damaging it

⇩

Worker safety must not be affected by a behaviour of the GBR

⇩

Welding of GBR-P or GBR-B to assemble panels or to repair a tear must be possible under the anticipated environmental conditions.

⇩

The GBR must not be affected by the installation of the next layer, such as the soil cover (when applicable)

⇩

The long-term performance of the GBR must not be affected by the installation process

⇩

The (installed) GBR must exhibit adequate long-term properties when exposed to cold temperatures during service

*Figure 3.1.2: Issues to consider when selecting a geosynthetic barriers to be installed under freezing temperatures.*

To define performance criteria, it is also important to assess the service conditions that will be experienced by the product. For the most common applications, the following classes of service were defined. Each of them reflects a type of stress that may affect the selection of the geosynthetic barrier, and/or that may be mitigated by implementing particular measures during storage, installation, and backfilling.

**Class 1 – Exposed applications**

where the geosynthetic barrier system is intended to be left exposed in a Nordic region, therefore experiencing extreme temperatures, temperature cycles, ice and snow but may NOT covered and therefore confined when in service. Examples of such applications include liquid containment or secondary containment structures where the geosynthetic barrier is left exposed, or canals with an exposed geomembrane liner.

**Class 2 – Shallow cover**
where the geosynthetic barrier while in service is intended to be permanently covered by a shallow layer of soil that will provide a uniformly distributed confining stress on the geosynthetic barrier or lining system. For these applications, the geosynthetic barrier will experience almost similar freeze / thaw conditions as for Class 1, but the confining stress will prevent temperature-induced contraction/expansion, offer a protection layer against impact, prevent wind uplift, etc. Examples of such applications include road ditches and ponds where the geosynthetic barrier could be covered by 300 to 500 mm of soil.

**Class 3 – Fully covered applications**
where the geosynthetic barrier is intended to be covered by a thick layer of soil and never exposed to extreme environmental conditions once the project is completed. In these applications, exposure of the geosynthetic barrier to freezing temperatures is limited to the construction phase, and the liner will be confined under a sufficiently thick layer of soil to prevent any temperature-induced contraction during its service life. Examples of applications include landfills and other waste containment structures where a sufficient thickness of material is installed rapidly, or heap leach pads using a granular drainage layer. Depending on the service and operating conditions of the structure, class 3 may initially have to be considered as class 2 for a certain duration.

### 3.1.3 Performance requirements for the geosynthetic barrier

In further sections, the performance requirements for the geosynthetic barrier are proposed and modulated considering the above-defined classes of service. When applicable, proposals pertaining to the design of secondary layers (e.g., cushions) or installation conditions are considered. All the requirements are summarized in Appendix A.

#### 3.1.3.1 Preservation of GBR's integrity during transportation and storage

This aspect of geosynthetics installation does not involve the properties of the product itself but the packaging. Care should be taken that water-sensitive products, such as GBR-C, are wrapped to avoid any accidental exposure to water, dirt and UV during transportation and storage. To protect all the surfaces likely to be exposed to water, it is recommended to use:

- Packaging that maintains the integrity of GBR-C during shipping, unloading and storage, tied at both ends of the roll.
- Plastic cores, or cardboard cores treated to be water repellent to avoid degradation.

Cling-wrap is sometimes used for packaging geosynthetics as it also helps to tighten the rolls. However, cling wrap is not a waterproof barrier, and it exhibits a much lower mechanical resistance than adequate polyethylene film. Should water enter a GBR-C roll anyway, on an edge, between laps, or through a damage, the roll could be hard or impossible to unroll. Should GBR-C rolls be wrapped with cling-wrap, additional measures must be taken to protect them from accidental exposure to water, i.e., they must be transported in closed trailers (instead of flatbeds), and enhanced measures must be taken to protect them while in storage on site.

For GBR-C, the duration of onsite storage should be minimized, to reduce the risks of accidental exposure to water. The rolls should be moved as late as possible from the well-organized site storage to their final location – where good storage conditions are sometimes difficult or impossible to achieve. Ideally, the rolls should only be moved to their final location on the day they are deployed.

Other geosynthetic barriers, e.g., polymeric, are not sensitive to water and are therefore more tolerant to exposure to water and ice during transportation and handling. No specific packaging is needed beyond usual recommendations.

These requirements are summarized in Table 3.1.1.

*Table 3.1.1: Summary of recommendations applicable to criteria 'a' – integrity of the GBR during transportation and storage*

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Packaging | Water-sensitive GBR must be wrapped in adequate watertight wrapping | Preferred (GBR-C only) (1) | | |
| Cores | The cores must be insensitive to water | Mandatory | | |

(1) Use of other wrapping materials, such as cling wrap, may be considered if transportation and storage are adapted, e.g., transportation in closed trailers, on-site storage avoiding contact with snow or rain, and delaying distribution to the final location as much as possible.

#### 3.1.3.2 Possibility of unrolling the GBR in place under freezing temperatures, on a frozen soil subgrade, without damaging them.

There are three material-related issues to address to make installation possible:

- Low temperature increases both tensile and flexural modulus by changing the properties of polymeric and bituminous geosynthetic barriers (GBR-P and GBR-B), and by freezing water for GBR-C.
- Macro-discontinuities – e.g., edge between two passes of a compaction roller – may abrade, tear, or cause plastic deformations to the product when the soil is frozen.
- Installation under freezing temperatures often leads to the use of greater force by workers, while the product has become stiffer because of the increase of flexural modulus.

Installation must be planned considering that the product may adhere to a frozen subgrade due to frost action.

**Clay Geosynthetic Barriers**

A high water-content, frozen GBR-C can hardly be unrolled if frozen. This may happen when GBR-C are manufactured with damp bentonite, e.g., moisture content in excess of 50%, or when the packaging of a GBR-C is damaged and lets water make contact with the bentonite. Such high water-content GBR-C must be stored at a temperature above freezing point to minimize exposure of the wet clay to low temperature. Their deployment should also be planned at a time when all the layers can be laid, and the soil backfilled while the temperature remains above freezing point.

It is very difficult to achieve proper subgrade preparation and compaction in winter, and to completely remove snow and ice in cases where there is a snow event between subgrade preparation and deployment of the GBR-C. This leads to a higher risk of exposure of the GBR-C to moisture uptake from a thawing subgrade (thawing being a consequence of the installation of the geosynthetics). This scenario can be prevented with the use of laminated or coated clay geosynthetic liners, with the laminated film layer or coating installed downward. Selection of a laminated or coated GCL may require further confirmation of the structural stability of the veneer, should it lead to the entrapment of liquid water between the laminated/coated GBR-C and a frozen subgrade. Subgrade conditions shall follow manufacturers' installation guidelines or requirements in the specification.

A GBR-C with enhanced tensile properties is also recommended because installation under freezing temperatures often requires using greater force for deployment. Products with sufficient stiffness to preserve dimensional stability, a higher tensile strength, and better cushioning properties should therefore be preferred.

Nevertheless, considering that no corresponding specifications on mechanical properties exist yet, mass per unit area is generally used to ensure this requirement (See Finnish guidelines InfraRYL Appendix 8, Table 8: T11).

In this respect, it is recommended that GBR-C manufactured with a nonwoven geotextile of at least 200 g/m² and a 100 g/m² woven fabric should be used. Should the subgrade conditions be exceptionally harsh, further investigation should be conducted to assess adequate puncture protection of the GBR-C.

To meet these requirements, the properties of the GBR-C can be defined as follows:

- The minimum weight of the geotextile components is recommended to be 300 g/m²: 200 g/m² nonwoven + 100 g/m² woven.
- Presence of a stiff component can be confirmed by a first peak strength measured at an elongation of 30% or less acc. EN ISO 10319. The product should exhibit a minimum strength at the first peak of at least 10 kN/m, (value taken from the Finnish guidelines InfraRYL Appendix 8, Table 8: T11)

These requirements are summarized in Table 3.1.2.

*Table 3.1.2: Summary of recommendations applicable to criteria 'b' – unrolling and placement, for GBR-C*

| Preferred characteristics | Criterion (GBR-C) | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Lay-flat properties | W < 35% (1) | N/A (2) | Preferred, or (3) | Preferred, or (3) |
| Resist excessive moisture uptake during installation on icy, snowy, or damp soils | Use of laminated/coated GBR-C (4) | N/A (2) | Recommended (5) | Recommended (5) |
| Improve cushioning properties | minimum weight of the geotextile components: 200 g/m² non-woven + 100 g/m² woven | N/A (2) | Recommended (6) | Recommended (6) |
| Resist mechanical stress | Strength at break: 10 kN/m | N/A (2) | Recommended (6) | Recommended (6) |
| Preserve dimensional stability during installation | Elongation at first peak (%): < 30% | N/A (2) | Recommended (6) | Recommended (6) |

*(1) note: in case of very exposed critical conditions (e.g., truck-bed without protection) certain installers recommend a lower value of the water content (e.g., ÖNORM S 2081).*

*(2): exposed applications are not recommended for GBR-C*

*(3): store the product at a temperature greater than 0°C, install and cover when no frost is expected until all layers and the soil backfill are completed.*

*(4): laminated/coated GBR-C includes a film of polymer on one side of the product.*

*(5): this recommendation applies essentially to subgrades which are difficult to compact and exhibit a high content of frozen water. It may be avoided if no excessive moisture is anticipated in the subgrade or when a soil cover is to be installed within hours after laying the GBR-C.*

*(6): may be avoided if mild installation conditions are anticipated.*

**Polymeric- and Bituminous-Geosynthetic Barriers**

For GBR-P, the intrinsic property of the material must permit its deployment without endangering its integrity. This requirement can be expressed in terms of engineering properties considering the bending stiffness, or flexural modulus, which affects the lay-flat properties of the product.

Most geosynthetic barriers exhibit relatively low flexural modulus at room temperature, therefore good lay-flat properties. However, the flexural modulus increases as the temperature decreases, which may eventually endanger the ease of installation. Such an increase of flexural modulus may be overcome using different construction practices. However, sudden changes of flexural modulus with small changes in temperature (leading to a significantly worse lay-flat) may eventually become problematic. For example, it may require significantly more effort to position the panels, rolls may tend to rewind back, folds may be hard to flatten, etc. To minimize these problems, it is recommended to limit changes in flexural modulus to a factor of ~2 compared to the properties measured at 23°C.

*Note: This factor reflects the change of properties of HDPE, for which installation at low temperature is known to be feasible. HDPE was used as a reference and the authors suggest extending this criterion to other polymers in the absence of other evidence.*

This criterion is expressed in Equation 1:

$$\frac{E_T}{E_{23°C}} \leq \sim 2 \qquad (1)$$

Where:

- $E_T$: Flexural modulus at the anticipated temperature of installation
- $E_{23°C}$: Flexural modulus at 23°C

The flexural modulus can be measured using ISO 178.

Certain types of GBR-P can be prefabricated and delivered to the site in very large panels, such as PVC-P, EPDM and LLDPE. In this case, an increased stiffness / flexural modulus may lead to the development of tears at the time the folded GBR panels would be deployed on site. This phenomenon has been observed with standard grades of PVC GBR (e.g., complying to ASTM D7176, FGI 1120 or similar), and more research is needed to assess the performance of advanced grades of PVC-P, EPDM and LLDPE prefabricated panels at the time they are deployed under extremely cold environments.

*Note: using heated tents to control storage conditions and to maintain the geosynthetic barrier at a temperature higher than the outdoor temperature is possible. This strategy may facilitate its installation by controlling its lay-flat properties at the time the product is unrolled. This strategy presents two limitations: firstly, it requires extremely fast operations, which are often not compatible with extreme field conditions; secondly, once unrolled, the temperature of the geosynthetic will quickly be controlled by the subgrade, the air, and solar exposure, leading to thermal contraction, and to stiffening of the product within hours. Its use should therefore be considered with caution.*

Products with higher robustness against mechanical damage are also recommended because installation at freezing temperatures often leads to the use of greater force for deployment, and/or abrasion from the subgrade if no cushioning material is installed underneath.

For GBR-P made from HDPE or LLDPE, this typically leads to the use of products with a thickness of at least 1.5 mm. Other design considerations may lead to the selection of thicker products.

*Note: the 1.5 mm requirement is based on field experience gathered with HDPE or LLDPE GBR-P. Although thickness does not qualify mechanical properties, it is suggested as a criterion in the absence of detailed information.*

These requirements are summarized in Table 3.1.3.

*Table 3.1.3: Summary of recommendations applicable to criteria 'b' – unrolling and placement, for GBR-P and GBR-B*

| Preferred characteristics | Criterion (GBR-P and GBR-B) | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Lay-flat properties | $\frac{E_T}{E_{23°C}} \leq \sim 2$ | Recommended (1) (2) | Recommended (2) | Recommended (2) |
| Offer mechanical resistance | GBR-P: Thickness > 1.5 mm<br>GBR-B: Thickness > 4.0 mm | Recommended (3) | Recommended (3) | Recommended (3) |

*(1): proposal made in absence of supporting literature.*

*(2): store the product at a sufficiently high temperature, install and cover the GBR when environmental conditions are favourable. The anticipated temperature of the liner once covered should not be lower than the low-temperature flexibility.*

*(3): may be avoided with an extremely cautious installation.*

#### 3.1.3.3 Worker safety during installation of the sealing layer.

Smooth GBR-P become extremely slippery under freezing temperatures, even at low humidity levels. As soon as there is any dampness or snowflakes on their surface, it may become virtually impossible to walk, affecting worker safety and productivity. Using materials with sufficient grip to workers' boots while covered by a thin layer of snow is recommended for GBR intended to be covered and should be considered mandatory for GBR intended to be left exposed (Table 3.1.4).

*Table 3.1.4: Summary of recommendations applicable to criteria 'c' – properties influencing worker safety.*

| | Criterion (GBR-P and GBR-B) | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Preferred material features | Sufficient friction surface / textured / non-slip surface facing up | Mandatory | (1) | |

*(1): using a textured / non-slippery material may be considered to improve worker safety if no other measure is taken; nevertheless, it may have an impact on the ease of welding on textured regions of the GBR and it should be considered a compromise.*

#### 3.1.3.4 Welding of the GBR to assemble or to repair.

Weldability of geosynthetic barriers should be considered with respect to two aspects:

- It must be possible to weld the panels together, i.e., to prepare the surfaces and adjust the welding equipment to create a seam that will offer the required performance, i.e., mechanical properties (peel and shear strength) and adhesion.
- The micro-structure of the polymer and the macrostructure of the area should not be overly affected by the seaming, to the point where welding could affect the long-term performance of the sealing layer. For GBR-P, welding parameters must be selected to ensure effective welding,

while avoiding over-heating of the seam. For GBR-B, the quantity of heat must be just enough to melt the bitumen and permit welding, without 'emptying' the nonwoven by excessive heating.

There is evidence of well-performing welds of HDPE or LLDPE GBR-P made under extremely cold environments. Assembling geosynthetics by means of thermal welding is possible, although very challenging in the field, requiring more preparation and caution than under warmer environments. Practically, it is possible to control the environmental conditions locally to assemble two panels, or to repair a leak (see section 2.5.2 figure 8). It requires well-qualified workmanship and good practices which are described later in the document.

However, other methods such as chemical fusion (for PVC) or vulcanization (for EPDM) may be more challenging for a variety of reasons. The use of thermal welds with adapted procedures should be considered the only acceptable method, when performed as described in Section 3.2.5.

Torch-welding of GBR-B is more challenging at low temperature than it is at high temperature. The lower the temperature of the GBR-B, the higher the temperature difference between the membrane and the welded area, where the bitumen must melt enough to facilitate assembly of the rolls, but not too much to avoid loss of bitumen from the nonwoven. In the absence of mechanized welding equipment for GBR-B, excellence of the workmanship is critical to the quality of welding.

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Weldability of a GBR-P may also be affected by the following properties of the product:

- The surface texture, or, more precisely, the possibility of cleaning the surface of the GBR-P to prepare for welding. Textured HDPE and LLDPE GBR-P are often supplied with smooth edges, which facilitates welding. When welding is necessary in the textured area, thorough cleaning – and drying, e.g., with a heat gun – of the surface is essential.
- The thickness: managing high temperature gradients between the membrane and the temperature of welding increases the risk of faulty welds, 'burnings', and holes. Based on hands-on experience, GBR-P with a thickness of 1.5 mm or more can be welded under cold environments – i.e., using a wedge-welder or extrusion welder. In a similar fashion, the thicker a GBR-B, the easier the control of temperature between the sheets, therefore the less risk of excessive melting of bitumen. A 'soft' criterion of 4.0 mm is proposed for installation at low temperature, bearing in mind that the use of a thinner material is possible but makes the welding more challenging.
- Crystallinity, for polyethylene GBR-P: the higher the crystallinity, the stiffer and more sensitive to cracking the sheet, especially in the area of the seams. When acceptable for the anticipated chemical environment, GBR-P made of LLDPE resin should be preferred over HDPE resin to reduce (but not suppress) the risks of cracking and facilitate welding.

These requirements are summarized in Table 3.1.5.

*Table 3.1.5: Summary of recommendations applicable to criteria 'd' – assembly and repair of geosynthetic barriers (GBR-P and GBR-B)*

| | Criterion (GBR-P and GBR-B) | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Preferred material features | Smooth edges | Recommended | | |
| | Lower crystallinity of GBR-P resin | Recommended | | |
| | (for PE: LLDPE preferred to HDPE) | Recommended | | |
| Thickness | GBR-P: Thickness > 1.5 mm<br>GBR-B: Thickness > prefer thicker grades | Recommended (1) | | |

*(1): using thinner products is possible but increases the risk of problems during welding or at a later date.*

### 3.1.3.5 Installation of the soil cover on the GBR (when applicable)

Aggregate puncture resistance (Figure 3) may be mobilized at the time of installation when vehicles will be circulating over the lining system. A stress may then be applied whose magnitude will be related to the ground pressure of the vehicle (i.e., from tyres or tracks), as well as to the thickness and properties of the fill. The performance of the geosynthetic barrier (or lining system) can be assessed using a performance test involving project-specific aggregate and the candidate geosynthetic materials, including geotextile cushions and GBR-C when applicable. Such tests are performed at room temperature.

Appendix B proposes the concept of a procedure for conducting such tests and making them applicable to low-temperature service conditions. A more detailed recommendation has to be developed concerning the requirement on the protective cushion and the geotextile characteristics. Based on hands-on observations, the mass per unit area of protective cushions must be higher for winter installations than those defined by standard design.

Should a GBR-C be installed as single plane of sealing, cover soils with a well graded particle size distribution should be preferred, unless the intended function of the cover soil prohibits this. The maximum particle size in contact with the product should not exceed 31.5 mm for natural soils exhibiting rounded or sub-rounded particles, or 16 mm with crushed rock for angular or sub-angular particles to minimize the risk of mechanical damage, based on Finnish experience (InfraRYL 14231.3.2 Bentoniittimaton asentaminen (Installation of GCL)" Bentoniittimattoa vasten tulevan materiaalin enimmäisraekoko on kalliomurskeella 16 mm ja luonnonkiviaineksella 31,5 mm.

Tables 3.1.6 & 3.1.7 present the summary of recommendations applicable to criteria 'e' – installation of soil cover (GBR-P and GBR-B & GBR-C)

*Table 3.1.6: Summary of recommendations applicable to criteria 'e' – installation of soil cover (GBR-P and GBR-B)*

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Aggregate puncture during installation | Increase the mass per unit area of the geotextile cushion by 1.5x to 2x the calculated value, and to at least 500 g/m² | Not applicable | Recommended | |

*Table 3.1.7: Summary of recommendations applicable to criteria 'e' – installation of soil cover (GBR-C)*

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Gravel puncture during installation | 1 - well graded particle size distribution<br>2 - $d_{100}$ of the soil in contact with the GBR-C:<br>Angular or sub-angular particles: $d_{100} \leq 16$ mm<br>- Rounded or sub-rounded particles: $d_{100} \leq 31.5$ mm | Not applicable | Recommended | |

#### 3.1.3.6 Influence of installation process on the long-term performance of the sealing layer

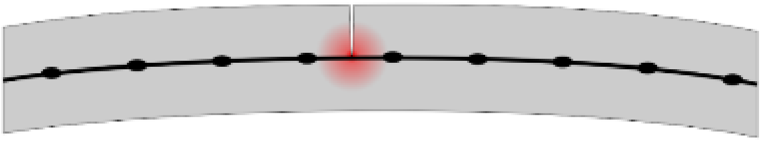
The long-term performance of geosynthetic barriers is beyond the scope of this document. Long-term performance depends on the service conditions, overall design of the project, failure criteria considered, in addition to the properties of the product and quality of installation. The long-term performance of GBRs is discussed in more detail in ISO-18228-9 (in press).

The scope of this section is limited to the effect of installation, which must not affect the properties of the geosynthetic barrier to the point at which these will affect its long-term performance.

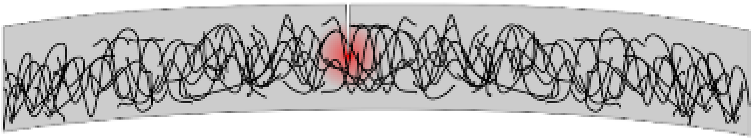
Geosynthetic barriers manufactured with components sensitive to cracking at low temperature such as GBR-B manufactured with an insufficient amount of SBS (Styrene-butadiene-styrene) additive, as well as some GBR-P (e.g., fPP and some formulations of PVC) may exhibit brittle behaviour during installation, and microcracks may appear. A phenomenon such as micro-cracking must be avoided even if there is no loss of continuity of the sealing layer, for two reasons:

- It locally reduces the thickness of material not in contact with the environment, which may affect its durability in the region of the crack by providing an easier access to oxygen or chemicals.
- It creates a stress concentration, therefore a region which is more likely to crack should the material be exposed to stress, e.g., because of further thermal contraction.

For some reinforced geosynthetic barriers such as bituminous GBR-B, reinforced flexible polypropylene (fPP-R), PVC (PVC-R) or EPDM (EPDM-R), the matrix may be more sensitive to cracking at low temperature than the reinforcement. The reinforcement may therefore preserve the overall integrity of the barrier and its apparent integrity. However, microcracks expose the reinforcement to oxygen and/or chemicals, and thus accelerate its degradation, which may eventually endanger the structural integrity of the geosynthetic barrier (Figure 3.1.3).



(a): woven tapes or scrim-reinforced GBR with a cracked matrix



(b): nonwoven – reinforced GBR with a cracked matrix

*Figure 3.1.3: Exposition of the reinforcement of a reinforced geosynthetic barrier, polymeric or bituminous*

Microcracks in GBR-B may sometimes heal themselves if the bitumen is exposed to a temperature greater than its softening temperature. However, healing may only take place if the bitumen reaches a temperature high enough to soften before it is contaminated by dust or exposition to chemicals. Reaching a sufficiently high temperature is unlikely during the winter season, i.e., when these microcracks are most likely to develop.

The ability of the product to resist cracking when bent can be assessed using a low-temperature flexibility test. When bent over a mandrel at a temperature similar to the temperature experienced onsite, the geosynthetic barrier should not exhibit cracking based on visual observation. The test should be conducted on both faces of the geosynthetic barrier. The diameter of the mandrel should be between 3 and 25 mm. The smaller the mandrel, the less sensitive the material is to low temperature. For some products, the performance depends on the type and quantity of additive added to the main polymer (e.g. SBS for bitumen, plasticizer for PVC) while it depends on the grade of polymer for others (e.g., polyethylene). Accepting products offering a mediocre performance (i.e., passing the low-temperature flexibility test on a 25 mm diameter but not on a smaller mandrel) for a given application temperature may be considered when associated with a more stringent quality assurance programme and the use of heated storage until installation.

This criterion is expressed in Equation 2:

$$T_{Flex} \leq T_{installation} \qquad (2)$$

Where:

- $T_{Flex}$: Low temperature flexibility
- $T_{installation}$: Lowest expected installation temperature

The low-temperature flexibility can be measured by bending the GBR 180°±5° around the selected mandrel after conditioning at the desired temperature for 2 ± 1 seconds.

*Note: As for criterion b, using heated tents to control storage conditions and to maintain the geosynthetic barrier at a temperature higher than the outdoor temperature is possible. This strategy may facilitate its installation by controlling the risk of cracking at the time the product is unrolled. This strategy presents two limitations: firstly, it requires extremely fast operations, which are often not* *compatible with extreme field conditions; secondly, once unrolled, the temperature of the geosynthetic will quickly be controlled by the subgrade, the air, and solar exposure, leading to thermal contraction and stiffening of the product within hours. Its use should therefore be considered with caution.*

These requirements are summarized in Table 3.1.8.

*Table 3.1.8: Summary of recommendations applicable to criterion 'f' – effect of installation on long-term properties*

| | Criterion (GBR-P and GBR-B) | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Low temperature flexibility | $T_{Flex} \leq T_{installation}$(1) | Recommended | | |

*(1): The criterion is applicable to GBR-P, GBR-B and to the lamination/coating of GBR-C*

#### 3.1.3.7 Long-term properties of the GBR when exposed to low temperature.

*Note: the new reference document ISO guide ISO/TR 18228-9 "Design using geosynthetics - Part 9: Barriers" (publication 04 2022) may help to establish a basis for defining the specific requirements linked to cold temperatures.*

**Polymeric and bituminous geosynthetic barriers**

The rate of degradation of geosynthetic barriers is influenced by the temperature, as the temperature influences the kinetic of chemical reactions controlling the degradation. A common rule of thumb is to consider that an increase of 10°C leads to a kinetic of degradation 2x faster. Therefore, exposure to low temperature will typically reduce the rate of degradation of geosynthetics. Material selection for chemical compatibility and long-term durability can therefore focus only on the temperature and chemical exposure defined by the application.

Consequently, the long-term performance of geosynthetic barriers systems used in northern climates is typically controlled by mechanisms affecting their physical integrity.

Most failure mechanisms can be avoided by following good construction practices and by covering the lining system with soil. The cover soil limits the exposure of the material to extreme environmental conditions and to accidental stresses during its service life.

For materials fully exposed, performance will be controlled by their ability to resist the following stresses at the temperature to which they are exposed: wind uplift and wind-induced vibrations. The wind speed is higher in winter due to the lack of vegetation, and this must be considered when selecting the mechanical properties of a GBR to resist impact from gravel, ice, floating equipment or other sources, including impact by floating ice for ponds.

These requirements are summarized in Table 3.1.9. They are limited to the behaviour of the GBR-P or GBR-B itself and do not cover the effect of a freezing temperature on the surrounding soils.

*Table 3.1.9: Summary of recommendations applicable to criteria 'g' – long-term exposure to cold temperature of GBR-P and GBR-B*

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Low temperature flexibility | $T_{Flex} \leq T_{service}$ (1) | Mandatory | Recommended | N/A (3) |
| Preferred material feature | Surface with sufficient friction / textured / non-slip surface facing up | Recommended | Preferred | |
| Minimize sensitivity to slow crack growth and rapid crack propagation | For GBR-P: prefer LLDPE to HDPE resins | Recommended (2) | Recommended (2) | |
| General design consideration, e.g.: wind uplift, impact resistance, etc. | Include effects of a stiffened material in the design methods | Recommended | Recommended | |

*(1): The criterion is applicable to GBR-P, GBR-B and to the lamination/coating of GBR-C*

*(2): The risk of cracking is a combination of factors, which includes the material sensitivity to cracking as well as aspects related to the design and quality of installation.*

*(3): Class 3 is not exposed to low temperature after installation.*

**Clay geosynthetic barriers**

The long-term behaviour of GBR-C exposed to freeze / thaw cycles has been evaluated by several authors. No significant changes of index flux were observed after 150 cycles, i.e., sodium bentonite does not appear to be significantly affected by freezing temperatures. However, the following aspects should be considered at the time of material selection:

- The absence of confining stress may affect the structure of a GBR-C exposed to hydration: swelling of the clay may lead to the separation of the layers This mechanism may result in a reduced internal shear strength of the GBR-C, which could affect the stability of the structure. Therefore, only as much GBR-C shall be deployed as can be covered at the end of the working day with soil, geomembrane, or a temporary waterproof tarpaulin. The GBR-C shall not be left uncovered overnight. As freezing environment may affect construction schedule and delay the installation of the soil cover, the risk is higher than in summer. It is therefore preferable to use products with higher peel strength to exhibit a resistance to delamination (bonding peel strength). Note that GRI GCL 3 requires at least 360 N/m according to ASTM D6496.
- There is no information available regarding the effect of freezing temperature or freeze-thaw cycles on the performance of polymers used in polymer-enhanced GBR-C. As there are numerous types of polymers used, it is recommended to confirm on a case-by-case basis the freeze-thaw resistance of a candidate polymer-amended GBR-C.

The risk of dehydration of GBR-C exposed to freezing temperatures for extended lengths of time has been highlighted by recent research. Their use as single barriers in environments where they may be continuously exposed to freezing temperatures over extended periods should therefore be thoroughly analysed. A cautious approach would be to prefer using GBR-C in combination with a GBR-P.

These requirements are summarized in Table 3.1.10. They are limited to the behaviour of the GBR-C itself and do not cover the effect of a freezing temperature on the surrounding soils.

*Table 3.1.10: Summary of recommendations applicable to criterion 'g' – long-term exposure to cold temperature of GBR-C*

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| Prevent accidental swelling | Never leave the GBR-C exposed overnight | N/A (1) | Mandatory | Mandatory |
| Prevent dehydration if continuously exposed to freezing temperatures | Install a GBR-P above the GBR-C | N/A (1) | Recommended (2) | Recommended (2) |

*(1): GBR-C cannot be left exposed.*

*(2): GBR-C – GBR-P composites or laminated/coated GBR-C with the lamination/coating side up may be considered. In that case, the film or coating of laminated / coated GBR-C must meet the requirements specified for GBR-P, summarized in Table 9 and also the CE requirements.*

## 3.2 Specific installation requirements (aspects related to sealing applications)

### 3.2.1 Project management

Contracting and planning the installation of geosynthetics in winter should be done considering the high sensitivity to weather.

Other aspects to consider include:

- Installers with demonstrated experience of the installation of geosynthetics in similar conditions should be required.
- Prefer design-build projects when applicable.
- Ensure fluent communication between parties with sufficient coordination activities.
- Ensure project planning and limitations associated with the installation of geosynthetics are well understood by the general contractor, who should include a provision in his master schedule to account for potential weather-related delays.
- Ensure that avoidable delays are avoided, e.g., administrative, QA approval, etc.

Based on historical data from experienced contractors, productivity in winter may be at best 65% of the productivity in summer, because of the slower welding rate, workers needing to rest, etc. In addition, workable hours per day are reduced, and bad weather may completely stop the progress of the project. An allowance for delays in the range of weeks or months should be considered.

### 3.2.2 Packaging, storage, and handling

Respecting the usual storage and handling recommendations is of paramount importance when the products are to be stored and installed under freezing temperatures. Most importantly, the products must be protected from exposure to water. This water concern applies to the entire process, i.e., transportation from the plant, on-site storage, and final storage before unrolling, especially for porous products such as GBR-C. Rolls or porous materials hauled on a truck-bed without protection may capture water and become difficult or impossible to unroll (Figure 3.2.1).

*Figure 3.2.1: Packaging of a drainage geocomposite damaged before arrival onsite, making the product impossible to install (photo courtesy Scorpion Containment).*

The following aspects must be considered for GBR-C:

- Individual roll packaging is mandatory, using a UV-resistant packaging. Should a packaging be torn, it must be repaired immediately. The use of sleeve polyethylene packaging tied on each side of the roll should be preferred. The polyethylene film is more resistant to damage and offers a better protection to water exposure. If a watertight shrink/cling wrapping is preferred, additional measures must be taken to protect the rolls from accidental exposure to water, i.e., transportation in closed trailers (instead of flatbeds), enhanced measures to protect them while in storage, and delayed distribution to the final location as much as possible.
- GBR-C with moist bentonite over 35% (*) should be stored at a temperature above freezing temperature as long as possible to minimize exposure of the wet clay to low temperature. GBR-C with bentonite moisture contents of < 35% (*) can be stored and installed under freezing temperatures.

(*) *note: in case of very exposed critical conditions (e.g. truck-bed without protection) certain installers recommend a lower value of the water content (e.g., ÖNORM S 2081).*

- On-site storage time must be minimized considering that the water content of the GBR-C may increase over time even when adequately wrapped.
- Every stack of rolls must be covered by an additional tarpaulin to protect them from rain and snow, which could develop into ice between the rolls and make their manipulation more complex (Figure 3.2.2). This requirement applies until the rolls are distributed close to their final storage location on the site.

*Figure 3.2.2: Tarpaulin installed on top of a pile of GBR-C for site storage (photo courtesy Terrafix Geosynthetics)*

For all geosynthetic barriers: GBR-C, GBR-P and GBR-B

- Rolls must be stored on platforms elevated from the ground, and necessary precautions must be taken to avoid direct exposure to the soil and to runoff water.
- Rolls must be handled with a stinger bar inserted into the core, a spreader bar, or slings. No other technique is acceptable.
- Cores must have a sufficient crush strength. Use of caps on the end of the cores is recommended to avoid infiltration of water into the product through the core.
- Labels should be water-resistant and of sufficient quality.
- The use of open flames or heaters to remove ice from a roll accidentally frozen is not acceptable. Rolls accidentally exposed to water and frozen cannot be used until the ice has melted naturally following storage in a warmer environment, and after an inspection to check if any damage has occurred.

In all cases, minimizing the storage time onsite should be preferred to minimize storage problems, whenever possible.

The use of temporary structures (e.g., textile buildings) may be considered for temporary storage to completely avoid exposure of the rolls to snow or water (Figure 3.2.3). However, the related cost makes this solution applicable to large and/or critical projects only.

*Figure 3.2.3: Use of an air-supported textile structure to control environmental conditions on a critical project (photo courtesy Scorpion Containment)*

### 3.2.3 Subgrade preparation

The rules prevailing for construction in normal conditions apply to frozen subgrades: they must be compacted and smoothed to the project specification. If the work is executed in unfavourable conditions such as cold weather, it is strongly recommended that a project-specific quality management and installation plan is prepared by the GBR installer with the general contractor and approved by all the parties involved. This plan should consider the risk of extended and unpredictable delays caused by environmental conditions prevailing during the various steps of the project.

The installation of the geosynthetics must start with the inspection and approval of the subgrade. The surface must be as smooth as possible with no loose grains, and no visible edges (compactor, tire, etc.) on the finished surface. The presence of snow and ice should be avoided in both the subgrade and the fill material, so they can be manipulated and compacted. Melting of ice blocks or snow located under the GCR may result in the creation of cavities which could generate strain in the geosynthetics.

The choice of construction equipment – notably its ground pressure and total weight – must be selected considering the higher risk of damaging the layers.

Specific subgrade acceptance requirements may vary with the type and properties of the GBR selected for a given project, as well as with the type of protection layer used, if any. Hence, installation guidelines provided by the selected GBR manufacturer must be consulted when developing acceptance criteria for the subgrade.

If it is not possible to prepare the subgrade to the specifications, the GBR cannot be installed without adjustment to either the subgrade, or the design of the project. Examples of possible measures include:

- For large discontinuities (e.g., roller edges, ruts, etc): addition of a thin layer of dry, fine-grained soil.
- For minor discontinuities, increase of the efficiency of the protection layer, for example by adding a GBR-C under the GBR-P, or a geotextile under the GBR-C.

Should additional protection layers be considered, their impact on the structure must be assessed, e.g., on slope stability / global safety. As example, for systems designed as composite lining systems where the GBR-P or GBR-B must be installed in direct contact with a low permeability subgrade

(GBR-C or compacted clay liner), the high in-plane flow capacity of a thick geotextile makes it not suitable for installation between the GBR and the substrate. For these designs, only GBR-C can be used as protection layers.

Construction and quality assurance activities should be planned to ensure that a prepared surface can be covered the same day with the next layer, to minimize the risk of accumulation of snow in a region which is still to be covered. This recommendation applies to all layers: subgrade, GBRs (after welding) and any other layer, until the last layer is installed (mineral backfill or GBR for exposed applications).

If it is not possible to finish the installation of every layer in a region, this region should be protected from snow and rain. If snow or ice accumulate on a prepared surface before installation of the GBR, their removal is determined on a project-by-project basis.

Removing snow may accidentally create substantial damage to a substrate. The decision to remove a small thickness of freshly fallen snow from a previously approved substrate should therefore be carefully considered. This decision should be taken by the QA Engineer in consultation with the designer, considering the thickness and quantity of snow, complexity of removal, weather forecast, type of subgrade, potential effects of snow confined under the GBR and other project-specific considerations.

### 3.2.4 Deployment

Given the additional stiffness caused by the lower temperature, geosynthetics may require more effort to unroll. Their lay-flat ability may also not be as good as under milder environmental conditions. They may therefore be more susceptible to wind uplift, offering more air access to the underside of the membrane. Ballasting strategy should therefore be adapted, i.e., more bags should be considered to ensure the materials are adequately laid.

The temperature of GBR-P and GBR-B still in a roll does not follow the air temperature beyond the first few wraps, given their thermal inertia and relatively low thermal conductivity. Significant thermal contraction of GBR-P may take place immediately after the material is laid. Some time should therefore be given to allow the GBR to reach temperature equilibrium before welding, usually one to a few hours depending on the material.

Removal of snow from a large surface of GBR is virtually impossible without damaging the product. The construction schedule should therefore favour installation of all superposed layers, instead of finalizing the installation of one layer before installing the next one. This aspect may affect the quality management strategy, as discussed in a later section.

Before starting to deploy the GBR, agreement must be reached with the contractor in charge of backfilling regarding the management of granular materials, considering the necessity to cover the geosynthetic materials rapidly after installation of the last geosynthetic layer. Thick layers of soil (500 mm to 1000 mm, see 3.1.2.e) must be planned for circulation of vehicles, and materials must be stockpiled at close distance to facilitate quick backfilling.

### 3.2.5 Assembly

#### 3.2.5.1 Overlap between rolls (GBR-C)

GBR-C are overlapped, not welded, and there are no specific requirements applicable to winter installation. Bentonite is poured between the two overlapping rolls to ensure the continuity of the sealing from one roll to the next. The minimum overlap is 300 mm. The quantity of bentonite applied is typically 0.4 kg per linear meter.

### 3.2.5.2 General considerations

A good seam will offer a long-lasting continuity between the panels, capable of withstanding the same service conditions as the sheet itself and of ensuring a sealing function similar to, or better than the sheet itself.

The quality of thermal welds is determined by the amount of energy received by the sheet during the welding operation. It is affected by the exterior temperature and by the specific properties of the material being welded, in particular the type and grade of polymer, type and quantity of additives, as well as the thickness and finish of the sheet (texture, colour, electrical conductivity skin). The welding parameters used, i.e., temperature, speed, and pressure, must therefore be adjusted to deliver the exact amount of energy that will ensure the melting of a thin layer of the surface of the interfacing geomembranes. These two melted surfaces are then pressed together to permit the interpenetration of the polyethylene molecules from both sheets and to allow them to recrystallize to form a continuous structure.

The quality of the seam greatly depends on the selection of the three welding parameters. It is common to describe this by referring to the 'welding bubble' illustrated in Figure 3.2.4: a good seam will be created only when the coordinates of the welding parameters (temperature, speed, pressure) are within the boundaries of this bubble.

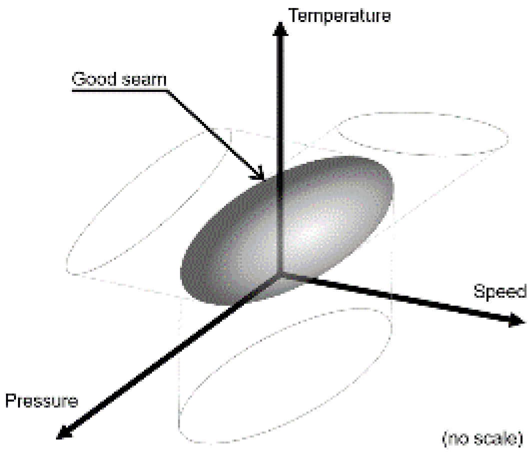



*Figure 3.2.4: three-dimensional welding parameters bubble leading to good seams*

Selection of welding parameters within this 'bubble' should also be made considering the risk of change of environmental conditions during the forthcoming shift. For example, if the air temperature is expected to decrease, or clouds to appear, the speed should be set at the lower end of the bubble, so that the energy supplied to the welded region remains sufficient despite a cooling down of the sheet.

When welding below the freezing point, it is commonly accepted that best results are achieved by maintaining a similar welding temperature and roller pressure to that which would be used in milder conditions but using a reduced welding speed. Increasing temperature may overheat the polymer, induce oxidation or even molecular chain scission, and could favour the development of cracking.

Ambient humidity may also affect the quality of the weld, when condensation or frost deposition takes place in the region to be welded. To avoid such risk, welding GBR-P or GBR-B should only be conducted when the temperature of the sheet is less than 3°C higher than the dew point (above 0°C), or frost point (below 0°C).

Remark: Some regions have adopted more stringent requirements, limiting welding to temperatures above 8°C and 3°C above the dew point under DVS 2225-1 to -6 and DVS 2227-1.

#### 3.2.5.3 Thermal welding (GBR-P)

Adequate welding of GBR-P requires the following preparation:

- The surfaces to be welded must be dry and free of dirt or any contamination.
- The lower surface of the bottom layer must be free of ice, to avoid slipping of the drive wheels of the welder.

Various strategies can be considered to control the condition of the surface to be welded and the environmental conditions, including the application of moderate heat followed by wiping-off of the surface (Figure 3.2.5). The use of movable tents can be considered in order to reduce the influence of wind and stabilize the temperature in the region of interest (Figure 3.2.6).

*Figure 3.2.5: Controlling cleanliness of both sides of the geomembrane being welded together (photo courtesy of A&A Technical Services)*

*Figure 3.2.6: Use of tents to control environmental conditions and reduce humidity around a seam (photo courtesy of A&A Technical Services)*

GRI Test Method GM9 provides guidance on the seaming of GBR-P. As a general rule, welding in a cold environment will use temperature settings similar to welding at higher ambient conditions but the use of a reduced speed.

> The following paragraphs correspond to the reproduction with permission of the guidance on seaming of GBR-P of GM9.

***1. Preparation of the geomembrane surfaces to be seamed:***

*a) Seaming is not to take place when it is snowing, sleeting or hailing on the geomembrane in the area to be seamed.*

*b) In the area to be seamed, all frost must be removed from the opposing surfaces of the geomembrane sheets in the regions where the actual seaming is to be performed.*

*c) The residual moisture left after removing frost must be wiped dry.*

*Note 1: Perhaps the most difficult surfaces to prepare in this regard are textured geomembranes where the texturing extends to the roll edges or roll ends.*

*d) The application of heat to remove moisture using a handheld hot air device can be used providing care against excessive heat application is taken. An assessment using trial seams is recommended.*

*e) The specific area to be seamed must be free of soil particles and other foreign matter.*

*f) For thermal fusion welding, such as the hot wedge method, the underside of the lower sheet should be free of frost so that the lower drive wheels of the device can move evenly and do not slip.*

*Note 2: It may be necessary to use a rub sheet beneath the area being seamed to separate the geomembrane from frozen soil subgrade. Various materials have been used for rub sheets including smooth membranes, smooth films and even certain types of geotextiles.*

*g) For fillet extrusion welding the thermal tacking of the sheets together should proceed as with similar welding at temperatures above freezing.*

*h) Preheating of the geomembrane area to be seamed is common but the amount of preheat and its timing preceding the actual production seaming is at the option of the installer based upon past practice and experience. An assessment using trial seams is recommended.*

***2. Thermal fusion seaming (e.g., using a hot wedge welding device):***

*a) In general, the rate of seaming, i.e., the speed of the hot wedge device, is usually slower than when seaming at temperatures above 0°C. Furthermore, the rate should decrease with decreasing sheet temperature.*

*b) Cold temperature seaming requires more frequent trial seams than when welding at temperatures above freezing. For example, if the CQA plan calls for two trial seams a day at temperatures above freezing, the number should be increased by one per day for each 7.5°C less than freezing. Trial seams should be made at the discretion of the CQA Engineer.*

c) *Cold temperature seaming may also require more destructive tests on production seams than when welding above freezing. For example, in addition to the CQA plan written around above freezing temperatures, additional destructive seam samples may be taken at the end(s) of each continuous production seams.*

*Note 3: The actual schedule for destructive test samples is at the discretion of the CQA Engineer.*

d) *Movable enclosures (i.e., tents) traveling along with the welding device and personnel are particularly effective at sites with high wind. Cold temperature, per se, will not demand the use of protective tents. The decision to use tents is that of the installer and CQC personnel.*

**3. *Extrusion fillet seaming:***

a) *The necessary grinding of the geomembrane surfaces in preparation of placing extrudate should be no further ahead of the extrusion gun than 10 m (30 ft.), or as stated in the CQA plan.*

b) *At the discretion of the parties involved, the profile of the base of the extrusion gun barrel is often shaped more rectangularly than when seaming at temperatures above freezing. The reason for this is to minimize the cooling rate in the thinner extrudate regions, see Figure 9.*

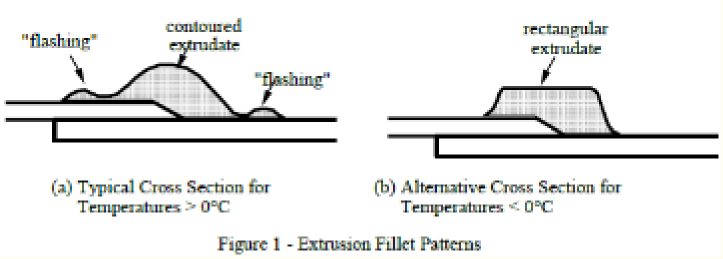



*Figure 4: Extrusion Fillet Patterns*

c) *In general, the rate of seaming, i.e., the speed of travel, is slower than when seaming at temperatures above 0°. Furthermore, the rate should decrease with decreasing sheet temperatures.*

d) *Cold temperature seaming requires more frequent trial seams than when welding at temperatures above freezing. For example, if the CQA plan calls for two trial seams a day at temperatures above freezing, the number should be increased by one per day for each 7.5°C less than freezing. Trial seams should be made at the discretion of the CQA Engineer.*

e) *Cold temperature seaming may also require more destructive tests on production seams than when welding above freezing. For example, in addition to the CQA plan written around above freezing temperatures, additional destructive seam samples may be taken at the end(s) of each continuous production seam.*

*Note 4: The actual schedule for destructive test samples is at the discretion of the CQA Engineer.*

f) *Movable enclosures (i.e., tents) traveling along with the welding device and personnel are particularly effective at sites with high wind. Cold temperature, per se, will not demand the use of protective tents. The decision to use tents is that of the installer and CQC personnel.*

#### 3.2.5.4 Thermal welding (GBR-B)

In general, the concept of a 'welding bubble' introduced in 2.5.2 applies to GBR-B as well as to GBR-P. GBR-B are typically welded using a torch, and sometimes hot air. When using a torch, the welding parameters are poorly controlled due to an entirely manual operation, while the use of hot-air welders gives a better control of the welding parameters. Welding of a GBR-B essentially consists of melting the bitumen of the two surfaces which are to be assembled over a width of 200 millimetres and pressing them together using a metal roller. A good weld should be continuous across the entire 200 mm width and should exhibit a small bead of bitumen, up to a maximum of 30 mm, which has flowed out of the edge of the roll. When the welding process of GBR-B is not mechanized, the quality of the seam heavily depends on the experience of the welding technician.

Two winter-specific factors can affect the quality of the seams between panels of bituminous geomembrane:

- Bituminous geomembranes require a flat subgrade to permit application of a pressure using a metal roller (the pressure being one of the three welding parameters that must be controlled). The quality of preparation of the subgrade in a cold environment can therefore affect the quality of the seams.
- When torch welding is used, the quality of the seam depends entirely on the skills of the welding technician, who must manually control the amount of heat generated by the torch blower and the speed at which the weld is performed. When the temperature of the sheet decreases, welding requires much more heat, which increases the risk of overheating the bitumen, and hence its liquefaction and flowing away from the membrane, which could affect the sealing properties of the geomembrane. An excessive loss of bitumen (in excess of 30 mm) can be visually observed on the upper side of the welded geomembrane, but not on the lower side.

Hence, welding of GBR-B should only be performed by technicians designated and trained by the manufacturer according to predefined methods (e.g., ultrasonic testing acc. ASTM D7006).

#### 3.2.5.5 Backfilling

Backfilling is not part of the scope of work of the GBR installer, but it represents a highly critical task with respect to the integrity of the lining system. Only aggregates with a very small amount of fines (ideally with no particles less than 75 μm) should be used as backfill, to ensure that entrapped water cannot freeze and generate an apparent cohesion in the soil or create large blocks highly likely to damage the geosynthetic during backfilling. When a small percentage of fines is present in the backfilled material, a cushioning layer must be selected to resist impact and improve hydrostatic puncture resistance arising from the contact with this coarse aggregate. The maximum particle size of the backfill must be defined according to section 3.1.2.d.

Before backfilling, the geomembrane must be secured against wind uplift, and this is typically achieved using sandbags or other moveable weights not liable to damage the GBR – e.g., the rolls of geosynthetics themselves. However fine sand must be replaced by pea gravel to avoid creation of hard blocks of frozen sand under freezing temperatures.

## 3.3 Quality control (aspects related to sealing applications)

### 3.3.1 Quality assurance strategy

The risk of a leaking GBR is much higher during winter because of a combination of harsher environmental conditions, stiffer materials, and human factors. Consequently, stringent quality control and quality assurance programs must be followed. On the other hand, implementation of these controls should not affect the schedule of work, e.g., certification of the subgrades or of each individual layer (for multi-layered systems) must be done immediately after their installation to avoid delays and the likelihood that the site will be covered by snow before completion of a given region (Figure 3.3.1).

To permit this:

- A quality assurance inspector must be on site at all times.
- Testing of the seams must be performed on-site on the same day, under the supervision of a third party (i.e., the QA Inspector) in full conformance with the test method, i.e., under controlled environmental conditions and after complete cooling of the seam, typically a few hours.
- The QA inspector present on site at all times must have the authority to approve the subgrade and the installed layers immediately.

*Figure 3.3.1: Example of GBR covered by a 500 mm snowfall before completing installation (Courtesy FC Geosynthetics)*

### 3.3.2 Conformance testing of geosynthetic materials

To avoid delays caused by conformance testing for weather-sensitive and therefore time-sensitive construction schedules, quality control of the materials should be completed before the rolls are delivered to the site. This may be achieved using one of the two following methods:

- Sampling the products in the plant or distributor's storage location and testing sufficiently ahead of time to permit installation immediately after reception of the material on-site. The sampling activity must then be coordinated with the manufacturer before the production is initiated.
- Using products holding an appropriate certification involving third-party testing, when available.

### 3.3.3 CQA Report – GBR-P seams

GRI Test Method GM9 provides guidance on Quality Assurance, reproduced below with permission.

- The report should include hourly temperatures during cold weather seaming which include the actual temperature of the surface of the geomembrane (using a pyrometer) and the ambient air temperature measured approximately 1 m (3 ft.) above the geomembrane.
- The method of removing frost from the area to be seamed (if any is present), as well as drying and cleaning of the surfaces involved, should be described.
- The condition of the subgrade beneath the area being seamed should be assessed. If a rub sheet is used during the seaming process, this should be noted.
- Complete identification of the field seaming system used, including material, methods, preheat, seaming rate, use of tents or enclosures and other details of the procedure should be documented.
- The type, nature, number, condition, and details of trial seams, as well as the results of such tests, should be detailed.
- The type, nature, number and details of destructive samples and disposition of sections of the sample should be described. Proper identification is required to identify results of CQA laboratory testing in the final as-built plans of the project.
- Any unusual condition with respect to personnel, equipment, sampling and/or testing that may be attributable to the cold weather should be described and documented.

### 3.3.4 Electrical leak location of GBR-P and GBR-B

Considering the higher risk of damage, electrical leak location (ELL) should be part of the acceptance strategy for the project. However, frozen soils exhibit an electrical conductivity typically much lower than unfrozen soils, which limits the use of ELL to time periods where the temperature of the lining system is above freezing temperature. A temperature below freezing brings several challenges:

- Testing exposed GBR can only be performed using a spark test, with the condition that an electrically conductive layer is available below the GBR: either a conductive layer co-extruded to the GBR, or a conductive geotextile laid under the GBR. Feasibility of spark testing may be affected by the presence of snow or ice of the surface of the GBR, sometimes requiring laborious surface preparation.
- Leak detection after backfilling, using the dipole method, can only be performed when environmental conditions permit. This may be as soon as the cover soil is defrosted, when a conductive layer is available under the GBR-P; or as soon as both the cover soil and the subgrade are defrosted when electrical leak location relies solely on the electrical conductivity of the soils.

# 4 CONCLUSIONS AND REQUIREMENTS ADVICE

## 4.1 Geotextiles and geotextile-related products

***IMPORTANT NOTE:** the conclusions and requirement advice presented here are based on the results and conclusion observed during the full-scale experimentation in Kemi and are therefore only valid for the products tested in Kemi (or the corresponding product families with a higher (or equal) performance).*
*The transferability to other types of products than those tested and to other conditions of application is not recommended and may only be done with a great deal of precaution after additional specific studies.*
*For other products, the realisation of a specific experimental full-scale test, under the surveillance of an independent third party, is strongly recommended to establish the Vulnerability Index(s) of critical characteristics under the specific Nordic installation conditions (different temperature, different backfill, drop height, compaction, etc.).*

### **4.1.1** Filtration

If geosynthetics are correctly designed for a positive temperature (e.g., +20 °C) for the defined geotechnical conditions of installation (type of soils, drop height, compaction, etc.),

- no additional installation damage is observed on the robustness factor (Energy Index EI) (and similarly on tensile strength) when the products are installed under the same conditions at -10 °C, when storing, handling and deployment, subgrade preparation, backfilling (drop height, thickness of fill layer, fill material, compaction) are executed according to recommendations presented in these guidelines.
  *Note: For a low drop height, the Energy Index (EI) may be a relevant parameter to assist in designing against installation damage; nevertheless, for a greater drop height, no specific increase of damage with an increase in drop height is observed.*
- no influence on the opening size is observed when the products tested are exposed to installation at -10 °C in a trench with crushed rock under a drop height of 1.0 m & 2.0 m.
  *Note: no clear influence on opening size of the location of the samples in the trench was observed; similarly, no clear influence on strength of the location of the samples in the trench was observed.*

<u>Requirement advice</u>

For the applications using geosynthetics for filtration in ditches, installed under the following Nordic conditions:

| | |
|---|---|
| Temperature: | -10 °C |
| Backfill: | crushed rock 0/56, layer ~ 30 cm |
| Drop height: | ~ 1.0 m to 2.0 m maximum. |
| Compaction: | according to the Finnish road construction guidelines (InfraRYL Table T1) or similar. |

The Vulnerability Index to be considered is:

VI (robustness factor - EI) (-10 °C / +20 °C) = 1 (*)

VI (opening size) (-10 °C / +20 °C) = 1 (*)

*(*) valid only for the products tested in the ROUGH project (or products of the same family with a better (or equal) performance - see definition in paragraph Terms and definitions.). For other products it is strongly recommended that specific experimental full-scale tests are conducted.*

*Note: observations during the ROUGH project (2022) on a full-scale test show that requirements on robustness classification may possibly be reduced under certain conditions. Accordingly, it is proposed to use the general requirements given in N200 Vegbygging (2021) but to permit specific products to be approved based on the specific properties and experience with the product.*

*Note: requirements on installation procedure for all geosynthetics shall also be applied (see 4.3)*

#### 4.1.2 Drainage

On the two geosynthetics tested during the ROUGH project, it was observed that when the products are installed under crushed rock and compacted under normal conditions at -10 °C, the reduction in both tensile strength and tensile strain remains in a reasonable range (≤ ~ - 40%), which is acceptable for normal use of drainage composites.

This means that, if a product is correctly designed for a positive temperature (e.g., +20 °C) for the defined geotechnical conditions of installation (type of soils, drop height, compaction, etc.),

- no additional installation damage due to negative temperature (-10 °C) was observed on the tensile strength and strain, when storing, handling and deployment, subgrade preparation, backfilling (drop height, thickness of fill layer, fill material, compaction) were executed according to the recommendations presented in these guidelines.

The compression strain at 1 MPa enables a comparison of the behaviour at different temperatures under the same geotechnical conditions.

- The laboratory tests show that there is almost no influence on the strain at 1 MPa at the different temperatures (≤ 4% at -10 °C).

As shown on the samples from full-scale testing in Kemi (-10 °C, crushed rock, compaction), a compression strain increase seems to be related to a similar reduction in water flow capacity.

- Thus, it can be expected that the decrease in the water flow capacity linked to low temperature (e.g. -10 °C) should be reduced by only (~ - 4 % to - 5%).
- A greater decrease may be possible but is then linked to the installation conditions as would be the case for positive temperatures.
- The effect of the negative temperature (-10 °C) on the hydraulic capacity of the geosynthetic drainage composites appears to be negligeable.

<u>Requirements advice</u>

**The two drainage geosynthetics tested during the ROUGH project are 100% polypropylene geomats. As these 2 products are relatively similar, it is difficult to draw some general requirement advice.**

For the two drainage composites installed under the following Nordic conditions:

| | |
|---|---|
| Temperature: | -10 °C |
| Backfill: | crushed rock 0/56, layer ~ 30 cm |
| Drop height: | ~ 1.0 m maximum. |
| Compaction: | according to the Finnish road construction guidelines (InfraRYL Table T1) or similar. |

The Vulnerability Index to be considered is:

VI (tensile strength, strain) (-10 °C / +20 °C) = 1 (*)

VI (hydraulic capacity) (-10 °C / +20 °C) = 1 (*)

*(*) valid only for the products tested in the ROUGH project (or products of the same family with a better (or equal) performance - see definition in paragraph Terms and definitions.). For other products it is strongly recommended that specific experimental full-scale tests are conducted.*

*Note: requirements on installation procedure for all geosynthetics shall also be applied (see 4.3)*

#### 4.1.3 Reinforcement stabilisation

If geosynthetics are correctly designed for a positive temperature (e.g., +20 °C) for the defined geotechnical conditions of installation (type of soils, drop height, compaction, etc.),

- no additional installation damage is observed on the strength when the products are installed under the same conditions at -10 °C, when storing, handling and deployment, subgrade preparation, backfilling (drop height, thickness of fill layer, fill material, compaction) are executed according to the recommendations presented in these guidelines.
- no additional installation damage effect on stiffness is observed if products are installed at -10 °C compared to +20 °C; nevertheless, the stiffness of the geosynthetic is significantly increased at -10 °C compared to +20 °C, which is also the case for the surrounding soil at -10 °C.

*Note: the tensile stiffness is significantly increased by a reduction in temperature (0 °C to -20 °C) when tested in the laboratory: e.g., with a reduction in temperature from +20 °C to -10 °C, the average of all products tested is ≥ +40 %; it should be noted that this is also the case for the surrounding soil.*

<u>Requirement advice</u>

For the applications using geosynthetics for reinforcement stabilisation, installed under the following Nordic conditions:

| | |
|---|---|
| Temperature: | -10 °C |
| Backfill: | crushed rock 0/56, layer ~ 30 cm |
| Drop height: | ~ 1.0 m maximum. |
| Compaction: | according to the Finnish road construction guidelines (InfraRYL Table T1) or similar. |

The Vulnerability Index to be considered is:

VI  (tensile strength) (-10 °C/ +20 °C) = 1 (*)

VI (tensile stiffness) (-10 °C / +20 °C) = 1 (*)

*(*) valid only for the products tested in the ROUGH project (or products of the same family with a higher (or equal) performance - see definition in paragraph Terms and definitions.). For other products it is strongly recommended that specific experimental full-scale tests are conducted.*

*Note: requirements on installation procedure for all geosynthetics shall also be applied (see 4.3)*

## 4.2 Sealing (Geosynthetic barriers, GBR-P, GBR-B and GBR-C)

### 4.2.1 Sealing requirements on service conditions

The service conditions will contribute to the definition of performance criteria applicable to the selection of an adequate lining system. Three classes of service were defined. Each of them reflects a type of stress that may affect the selection of the geosynthetic barrier, and/or that may be mitigated by implementing particular measures during transportation / storage, installation, and backfilling:

- Class 1 – Exposed applications, where the geosynthetic barrier system is intended to be left permanently exposed in a Nordic region, therefore experiencing extreme temperatures, temperature cycles, ice and snow but may NOT be confined while in service.
- Class 2 – Shallow cover, where the geosynthetic barrier is intended to be permanently covered by a shallow layer of soil providing a uniformly distributed or almost uniformly distributed (in some cases the fill cover may change from 300 mm to e.g., 700mm etc.) confining stress on the geosynthetic barrier or lining system but will still experience almost similar freeze / thaw conditions as for Class 1.
- Class 3 – Fully covered applications, where the geosynthetic barrier is intended to be covered by a thick layer of soil (or confining material) and will therefore not be exposed to extreme environmental conditions once the project is completed.

Requirements for Class 1 are more stringent than for Class 2, which are also more stringent than for Class 3.

### 4.2.2 Sealing requirements on geosynthetic properties

The GBR properties are selected to make sure the product will survive installation and perform as requested during its entire service life. The issues to consider when selecting a geosynthetic barrier that will be installed under freezing temperatures are:

a) The GBR must preserve its integrity during transportation and storage.
b) It must be possible to unroll the GBR in place under freezing temperatures, on a frozen soil subgrade, without damaging it.
c) Worker safety must not be affected by a behaviour of the GBR.
d) Welding of GBR-P or GBR-B to assemble panels or to repair a tear must be possible under the anticipated environmental conditions.
e) The GBR must not be affected by the installation of the next layer, such as the soil cover (when applicable).
f) The long-term performance of the GBR must not be affected by the installation process.
g) The (installed) GBR must exhibit adequate long-term properties when exposed to cold temperature during service.

When a product cannot meet one of these requirements, it is sometimes possible to modify the installation process or require that installation is made under less problematic environmental conditions, and/or to modify the design of the structure to minimize exposure of the product.

*Note: requirements on installation procedure for all geosynthetics shall also be applied (see 4.3)*

### 4.3 Requirements on installation procedure for all types of geosynthetics

The successful installation and long-term performance of a project using geosynthetics will be affected by project management and the quality of coordination between the installer, earthwork contractor and general contractor. Example of factors affecting the quality of installation include:

- Management of storage conditions and on-site handling of the products.
- Timely response at every stage of the project, and in particular for subgrade approval and authorization to cover the geosynthetics.

# REFERENCES

## Standards & Guidelines

AASHTO M 288 (2021) Standard Specification for Geosynthetic Specification for Highway Applications

ASTM D5818–11(2011), Standard Practice for Exposure and Retrieval of Samples to Evaluate Installation Damage of Geosynthetics. ASTM International, West Conshohocken, PA, USA.

ASTM D7007: Standard Practices for Electrical Methods for Locating Leaks in Geomembranes Covered with Water or Earthen Materials

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# ANNEXES

## APPENDIX A – Summary of the requirements applicable to GBR-P, GBR-B and GBR-C

The requirements identified in this project are summarized in the following Tables:

- Table A1: polymeric geosynthetic barriers GBR-P;
- Table A2: bituminous geosynthetic barriers GBR-B;
- Table A3: clay geosynthetic barriers GBR-C.

Table A1 – Requirements applicable to GBR-P

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| criterion 'a' – integrity of the GBR-P during transportation and storage | | | | |
| Cores | The cores must be insensitive to water | Mandatory | | |
| criterion 'b' – unrolling and placement, for GBR-P | | | | |
| Lay-flat properties | $E_T/E_{23°C} \leq \sim 2$ | Recommended (1) (2) | | |
| Offer an overall better mechanical resistance | Thickness > 1.5 mm (3) | Recommended (4) | | |
| criterion 'c' – properties influencing worker safety | | | | |
| Preferred material features | Textured / non-slip surface facing up | Mandatory | (5) | |
| criterion 'd' – assembly and repair of geosynthetic barriers | | | | |
| Preferred material features | Smooth edges | Recommended | | |
| | Lower crystallinity of resin (LLDPE preferred to HDPE) | Recommended | | |
| Thickness | Thickness > 1.5 mm | Recommended (6) | | |
| criterion 'e' – installation of soil cover | | | | |
| Gravel puncture during installation | Increase the mass per unit area of the geotextile cushion by 1.5x to 2x the calculated value, and at least 500 g/m² | Not applicable | Recommended | |
| criterion 'f' – effect of installation on long-term properties | | | | |
| Low temperature flexibility | $T_{Flex} \leq T_{installation}$ (7) | Recommended | | |
| criterion 'g' – long-term exposure to cold temperature | | | | |
| Low temperature flexibility | $T_{Flex} \leq T_{service}$ (7) | Mandatory | Recommended | N/A (9) |
| Preferred material feature | Textured / non-slip surface facing soil | Recommended | Preferred | |
| Minimize sensitivity to slow crack growth and rapid crack propagation | Prefer LLDPE to HDPE | Recommended (8) | | |
| General design consideration, e.g.: wind uplift, impact resistance, etc. | Include effects of a stiffened material in the design methods | Recommended | | |

(1): proposal made in absence of supporting literature.

(2): store the product at a sufficiently high temperature, install and cover the GBR when environmental conditions are favourable. The anticipated temperature of the liner once covered should not be lower than the low-temperature flexibility.

(3): this requirement mainly applies to HDPE and LLDPE.

(4): may be avoided with extremely cautious installation.

(5): using a textured / non-slippery material may be considered to improve worker safety if no other measure is taken; nevertheless, it may have an impact on the ease of welding on textured regions of the GBR and it should be considered a compromise.

(6): Using thinner products is possible but increases the risk of problems during welding or at a later date.

(7): The criterion is also applicable to the lamination/coating of GBR-C, when used.

(8): the risk of cracking is a combination of factors, which includes the material sensitivity to cracking as well as aspects related to the design and quality of installation.

(9): Class 3 is not exposed to low temperature after installation.

Table A2 – Requirements applicable to GBR-B

| | Criterion | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| criterion 'a' – integrity of the GBR-P during transportation and storage | | | | |
| Cores | The cores must be insensitive to water | Mandatory | | |
| criterion 'b' – unrolling and placement, for GBR-P | | | | |
| Lay-flat properties | $E_T/E_{23°C} \leq \sim 2$ | Recommended (1) (2) | | |
| Offer an overall better mechanical resistance | Thickness > 4.0 mm | Recommended (3) | | |
| criterion 'c' – properties influencing worker safety | | | | |
| Preferred material features | Textured / non-slip surface facing up | Mandatory | (4) | |
| criterion 'd' – assembly and repair of geosynthetic barriers | | | | |
| Thickness | Thickness > 4.0 mm | Recommended (5) | | |
| criterion 'e' – installation of soil cover | | | | |
| Gravel puncture during installation | Increase the mass per unit area of the geotextile cushion by 1.5x to 2x the calculated value, and at least 500 g/m² | Not applicable | Recommended | |
| criterion 'f' – effect of installation on long-term properties | | | | |
| Low temperature flexibility | $T_{Flex} \leq T_{installation}$ | Recommended | | |
| criterion 'g' – long-term exposure to cold temperature | | | | |
| Low temperature flexibility | $T_{Flex} \leq T_{service}$ | Mandatory | Recommended | N/A (6) |
| Preferred material feature | Textured / non-slip surface facing soil | Recommended | Preferred | |
| General design consideration, e.g.: wind uplift, impact resistance, etc. | Include effects of a stiffened material in the design methods | Recommended | | |

(1): proposal made in absence of supporting literature

(2): store the product at a sufficiently high temperature, install and cover the GBR when environmental conditions are favourable. The anticipated temperature of the liner once covered should not be lower than the low-temperature flexibility.

(3): may be avoided with extremely cautious installation.

(4): using a textured / non-slippery material may be considered to improve worker safety if no other measure is taken; nevertheless, it may have an impact on the ease of welding on textured regions of the GBR and it should be considered a compromise.

(5): Using thinner products is possible but increases the risk of problems during welding or at a later date.

(6): Class 3 is not exposed to low temperature after installation.

Table A3 – Requirements applicable to GBR-C

| | Criteria | Class 1 (exposed) | Class 2 (shallow cover) | Class 3 (fully covered) |
|---|---|---|---|---|
| criterion 'a' – integrity of the GBR during transportation and storage | | | | |
| Packaging | Water-sensitive GBR must be wrapped in adequate watertight wrapping | Preferred (1) | | |
| Cores | The cores must be insensitive to water | Mandatory | | |
| criterion 'b' – unrolling and placement, for GBR-C | | | | |
| Lay-flat properties | Water content < 35% (2) | N/A (3) | Preferred, or (4) | |
| Prevent excessive moisture uptake during installation on icy, snowy, or damp soils | Use of laminated/coated GBR-C (5) | | Recommended (6) | |
| Improve cushioning properties | minimum weight of the geotextile components: 200 g/m² nonwoven + 100 g/m² woven | | Recommended (7) | |
| Resist mechanical stress | Strength at break: >10 kN/m | | Recommended (7) | |
| Preserve dimensional stability during installation | Elongation at first peak (%): <30% | | Recommended (7) | |
| criterion 'c' – properties influencing worker's safety. | | | | |
| Preferred material features (this applies to coated/laminated GCL) | Textured / non-slip surface facing up | N/A (3) | Preferred | |
| criterion 'd' – assembly and repair of geosynthetic barriers | | | | |
| (Not applicable to GBR-C) | | | | |
| criterion 'e' – installation of soil cover (GBR-C) | | | | |
| Gravel puncture during installation | 1 - well graded particle size distribution<br>2 - $d_{100}$ of the soil in contact with the GBR-C:<br>Angular or sub-angular particles: $d_{100} \leq 16$ mm<br>- Rounded or sub-rounded particles: $d_{100} \leq 31.5$ mm | Recommended | | |
| criterion 'f' – effect of installation on long-term properties | | | | |
| Low temperature flexibility of the coating or laminated film, when applicable | $T_{Flex} \leq T_{installation}$ | Recommended | | |
| criterion 'g' – long-term exposure to cold temperature | | | | |
| Prevent accidental swelling | Never leave the GBR-C exposed overnight | N/A (3) | Mandatory | |
| Prevent dehydration if continuously exposed to freezing temperatures | Install a GBR-P above the GBR-C | Mandatory (3) | Recommended (8) | |

(1) Use of other wrapping materials, such as cling wrap, may be considered if transportation and storage are adapted, e.g., transportation in closed trailers, onsite storage avoiding contact with snow or rain, and delaying distribution to the final location as much as possible.

(2): in case of very exposed critical conditions (e.g. truck-bed without protection) certain installers recommend a lower value of the water content (e.g., ÖNORM S 2081).

(3): GBR-C cannot be left exposed.

(4): store the product at a temperature greater than 0°C, install and cover when no frost is expected until all layers and the soil backfill is completed.

(5): laminated/coated GBR-C includes a film of polymer on one side of the product.

(6): this recommendation applies essentially to subgrades which are difficult to compact and exhibit a high content of frozen water. It may be avoided if no excessive moisture is anticipated in the subgrade or when a soil cover is installed within hours after laying the GBR-C.

(7): may be avoided with extremely cautious installation.

(8): GBR-C/GBR-P composites or laminated/coated GBR-C with the lamination/coating side up may be considered.

## APPENDIX B - Concept for design of a cushioning geotextile using a test performed at room temperature.

Figure A.1: Point load caused by a gravel on the GBR. To be able to project this performance at low temperature, these tests should be performed considering a 'soil' replicated to model the anticipated properties of the frozen subgrade, and performance requirements adapted to consider the change in intrinsic properties of the geosynthetic barrier, i.e., its multiaxial elongation (EN 14151, DIN 61551 or ASTM D5617, using a diameter of at least 500 mm), which may be significantly lower at low temperature than at room temperature.

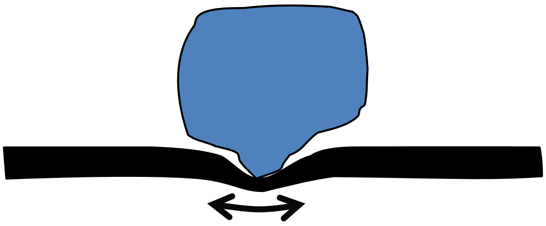

Figure B.1: Point load caused by a particle on the GBR.

Considering the difficulties associated with modelling, then performing such a test, a simplified approach may be to use design requirements used in local practice, but to consider as inputs modified soil properties, service load and performance criteria as proposed here, for GBR-P:

- Apparent particle size: the value selected should be larger than the actual particle size to account for the presence of frozen soils. This should be estimated considering the properties of the frozen soil, i.e., the particle size distribution, water content and likelihood of observing frozen agglomerates.
- Service load: the value selected should be determined considering the ground pressure of the equipment circulating on the soil cover and the thickness of the soil cover. For a cover soil thickness of 500 mm, the ground pressure of the equipment should be used directly. For a cover soil thickness greater than 500 mm, the load considered should be calculated considering the soil thickness minus 500 mm, to account for potential formation of frozen blocks in the soil cover. A minimum cover soil thickness of 500 mm is often recommended to allow circulation of low ground pressure equipment, or 1000 mm for tyre-equipped vehicles.
- The performance criteria should be based on local design practice, i.e., maximum arch elongation, no yield deformation or other. However, considering the influence of the temperature on elongation at yield, it is reasonable to modify this criterion by reducing the permissible elongation of the geosynthetic barrier by a factor $A_T$ defined in Equation 3.

$$A_T = \frac{\varepsilon_{23°C}}{\varepsilon_T} \qquad (1)$$

Where:

- $A_T$: reduction factor for frozen condition
- $\varepsilon_T$: elongation at yield measured at the anticipated installation temperature.
- $\varepsilon_{23°C}$: elongation at yield measured at 23°C.

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