Hydraulic Engineering
Geosynthetics are used in all fields of hydraulic engineering to increase the quality and longevity of structures. Geosynthetic applications include filtration, sealing, protection, containment, separation, reinforcement as well as erosion control.

Geosynthetics can replace or complement conventional methods of construction, both offshore as well as in coastal areas. Acting as separation or filter layer, they protect dykes, dams and storm tide barrages. They are used in the foundation of groins or wave-breakers. Sand-filled sacks and tubes are used in coastal construction, e.g. for groins or for sea bed stabilisation.

Geosynthetic clay liners and geomembranes are used for sealing purposes in the construction of dykes, while needle-punched nonwoven geotextiles prevent washout of fine particles and thus erosion of the construction.

Geosynthetics perform various functions in inland renovations, extensions and new constructions in flowing or static waters. Geotextiles ensure filter stability and erosion control, geosynthetic clay liners and geomembranes provide waterproofing, while geotextile containers and tubes stabilise the current flow and aid in scour protection.

The following chapters will illustrate and explain the different geosynthetic applications as well as methods used for design.
Geosynthetic Functions

Filtration
In filtration applications such as hydraulic engineering and drainage systems, nonwoven geotextiles are used to retain soil particles while allowing the passage of liquids through the filter media. There are two aspects to filtration that should be evaluated when designing. The mechanical filter efficiency (does the fabric have sufficient soil retention capacity) and the hydraulic filter efficiency (does the water discharge without a hydraulic pressure build-up).

As with mineral filter layers, the geotextile thickness directly benefits the long-term mechanical and hydraulic efficiency of the filter.

Sealing
Acting as liquid and gas barriers, geomembranes have become a fundamental component in civil engineering, due to the heightened need for groundwater protection. High density polyethylene (HDPE) geomembranes, specifically those with a certification by government regulators and thickness of more than 1.5 mm, are most commonly used. Personnel from those companies that have been approved by the certifying agency, are employed to both deploy and weld the geomembranes where an area needs to be sealed.

For sealing purposes in hydraulic engineering, road construction and environmental protection, HDPE geomembranes and geosynthetic clay liners are gaining use due to the importance of a quality seal.

Reinforcement
Geosynthetics are installed beneath or between soil layers to improve the mechanical properties of soil layers by absorbing the tensile forces and minimising deformation. Geotextiles, geogrids and composite synthetic materials are used in applications such as retaining structures according to the principles of "reinforced soil", slope stabilisation or for foundation reinforcement of earthen dams where the subsoil exhibits poor bearing capacity. The use of geosynthetics for reinforcement applications minimises expensive constructive measures, can reduce soil intermixing and eliminate the need for additional soil layers.

Separation
As a separation layer, nonwoven geotextiles are used to prevent adjacent soil layers or fill materials from intermixing. Nonwoven geotextiles that exhibit an high elongation capacity, are the materials of choice in most applications. The selection of a suitable product is dependent upon the base course grain size and the operational loads to be expected. The main use of separation nonwovens are road and railway construction, hydraulic and landfill engineering, and sport fields.

Protection
Geomembranes, structures, coated materials as well as related construction elements must often be protected from potential mechanical damage. Without suitable protection, damage may occur from sharp-edged objects such as stones, from the unevenness of the subsoil or even by the cover material. Mechanically bonded needle-punched nonwovens as well as composite materials manufactured from polypropylene (PP) or HDPE are commonly used for protection layers. Specific to nonwoven geotextiles, the protection function is directly related to the thickness and mass per unit area, as a heavier and thicker nonwoven is more likely to provide better protection.

Containment
Geosynthetic containment applications are those in which a textile in the form of a tube, bag or container, is used to encapsulate a construction material, such as soil or sand. They perform project-specific functions such as protection, filtration and separation. Nonwoven geotextiles as well as geocomposite products are the primary products for these applications due to their high elongation capacity.

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1 Filtration with Terrafix®
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7 Containment with Terrafix Soft Rock®
8 Terrafix® flushing tubes
9 Protection with Secutex®
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Filtration with Terrafix® Geotextiles

For decades, Terrafix® nonwoven geotextiles have been successfully used as three-dimensional filters in hydraulic engineering applications. They are employed between fine grained, and coarse grained soils, as well as scour protection structures to prevent dissimilar soils from intermixing thereby creating filter stability between two distinct grain sizes. In the case of varying differences in water pressure (e.g. reversal of the direction groundwater flow) or turbulent stresses (e.g. impact of waves) nonwoven geotextiles can prevent soil displacement down the slope in the boundary layer.

Filtration

Terrafix® geotextiles are frequently used for filtration in dike applications, on slopes and waterway streambeds for stabilization as well as on associated structures such as dams and side ditches.

The Technical Delivery Conditions for geotextile filters, EU notification of 9.3.1993, describes in detail the minimum requirements for geotextiles - the geotextiles employed must exhibit the following characteristics: resistance to rotting, sea water and frost, be compatible with the environment, as well as remain flexible or be capable of elongation - which allows the geotextile to easily accommodate irregular or soft subsoil. Geocomposite materials (consisting of several filter layers) must be uniformly bonded over the entire surface area yet be distinguishable one from another. The wide range of Terrafix® products offers numerous needle-punched nonwoven geotextiles complying with these basic requirements.

The properties presented in Table 1 must also be fulfilled. Terrafix® geotextiles, meet the material requirements in Table 1.

### Table 1

| Soil type test method of the BAW (Federal Institute for Hydraulic Engineering), Karlsruhe, Germany |
| Tabelle 1: Process for determining soil types of the BAW, Karlsruhe |

**Appendix 1 to Table 1:** Process for determining soil types of the BAW, Karlsruhe

**Appendix 2 to Table 1:** Process for determining soil types of the BAW, Karlsruhe
while addressing project-specific conditions and requirements such as the current velocity in the area of their application. Terrafix® nonwoven geotextiles are applied using standard deployment equipment and are covered with the specified revetment immediately after installation. Terrafix® 609 - with a minimum thickness of 4.5 mm, is suitable for soil type 1 to 3 filter applications, while Terrafix® 813 with a minimum thickness of 6.0 mm is suitable for soil types 1 to 4. Multiple-layered Terrafix® geocomposite materials (with a graduated AOS) are well suited to improve filtration effectiveness, especially in soils with high silt content and where significant hydrodynamic conditions exist. If the shear strength characteristics of the subgrade require improvement, Terrafix® coarse-fibre geocomposite materials are employed. Terrafix® sand mats are used for applications in strong currents as well as in deep water. These products are formed by mechanically encapsulating a uniform layer of sand ballast between two Terrafix® needle-punched nonwoven geotextile layers. This ballast layer facilitates underwater installation and prevents Terrafix® from forming folds by floating to the surface.

Terrafix Soft Rock® are sand-filled tubes, bags or containers manufactured from Terrafix® needle-punched nonwoven geotextiles. They are used for erosion control to withstand extreme current velocities, in applications where scour holes must be filled quickly as well as for permanent stability. A particular advantage of Soft Rock products is that they can be quickly filled on site using existing sandy soils. Manufactured with robust, Terrafix® needle-punched nonwoven geotextiles, Terrafix Soft Rock® sand containers easily accommodate local conditions but also perform well when subjected to the rough site conditions. Terrafix® nonwoven geotextiles also exhibit a higher internal friction angle than woven geotextiles, and can therefore be stacked to steeper angles with greater long term stability.

Soil type test method
The German Federal Institute for Hydraulic Engineering (BAW) has developed a soil type test method to assess the suitability of a geotextile as a filter in navigation canals. The external dynamic and hydraulic filter stresses in waterways are simulated by:

a) the flow-through test method (quick drop and rise in the water level) and;
b) the turbulence test method (turbulent wave action, propeller stream, back flow).

The regulatory requirements for the filter effectiveness of a geotextile are described in Table 1.

Conclusion
Terrafix® filter geotextiles are used when filter stability between two soil layers is absent or when hydrodynamic stresses may cause particle displacement. This condition is typically the case in slope and bed stabilisation for waterways as well as in dams, dykes or side ditches.

In the construction of revetments, robust Terrafix® geotextiles, designed for and capable of elongation, provide long-term stability for the cover layer. Terrafix® sand mats or Terrafix Soft Rock® sand containers are used for erosion control when higher current velocities exist.  

Design  Cross sections  Details

![Flow-through test method](image1.png)

![Turbulence test method](image2.png)

Appendix 3 to Table 1: Process for determining soil types of the BAW, Karlsruhe

Appendix 4 to Table 1: Process for determining soil types of the BAW, Karlsruhe
Sealing with Bentofix® Geosynthetic Clay Liner

The installation of a sealing component in hydraulic engineering is possible both under dry conditions as well as underwater. In the case of a dry installation, conventional compacted clay as well as Bentofix® geosynthetic clay liners (GCL) and Carbofol® geomembranes are commonly used. Dry installations have been known for decades; however, most recently state-of-the-art Bentofix® allows the underwater installation of liners on slopes and beds of waterways with fresh water.

Bentofix® BZ 13-B is a special composite lining system featuring a sand ballast layer that is integrally encapsulated by needle-punched nonwoven geotextiles. The sand layer performs several functions which include ballasting the Bentofix® GCL from floating when installed underwater - even where there are currents, or turbulence caused by ship propellers. Due to the needlepunching of the Bentofix® GCL, the sand layer also has the effect of providing a counter-pressure to the natural swelling properties of the clay, providing more uniform activation of the bentonite layer. Consequently, Bentofix® can remain underwater without additional load or cover for longer periods of time - without loss of performance. During the subsequent placement of stone or other covering layer, this integrated sand ballast layer evenly distributes the load and prevents installation damage to the nonwoven structure.

Requirements

The maximum tensile strength of the GCL should be $\geq 10$ kN/m, and in general, should not be considered in any slope stabilization analysis.

The sealing layer used in Bentofix® consists of more than 4000 g/m² of natural sodium bentonite with a hydraulic permeability of $2.0 \times 10^{-11}$ m/s. Bentofix® GCLs with single woven layers can be elongated up to 12 % without an increase in permeability. Irregular or highly deformed subsoils, (where up to 30 % elongation may occur), require Bentofix® styles that have needle-punched nonwoven geotextiles incorporated on both sides.

Two special tests which simulate typical hydraulic stresses are the impact and the...
turbulence test. The impact test can be used to simulate the deployment of cover stones. That is, the impact energy of 1200 Nm corresponds to an impact stress which occurs when a stone of Type III with a weight of 60 kg falls from 2 m height under dry conditions. For underwater installations, dyke construction or applications where the revetment is not placed directly on the Bentofix®, the impact requirements are considerably reduced. Bentofix® type BZ 13-B is commonly used for underwater installations to resist these loads without loss of performance. The turbulence test which simulates the dynamic wave action caused by a propeller stream shows that bentonite will not “wash out” from the Bentofix® under these conditions. The continuous test duration of 36 hours approximates the stresses that could be expected during a 10-year span on most shipping routes.

Bentofix® is uniformly manufactured with direction-independent needlepunching (fibre reinforcement) over its entire surface area, with more than 2 million fibres per square metre. Due to the surface structure of the needle-punched cover and carrier nonwoven geotextiles and the large internal as well as external friction angles, slope inclinations of 2.5h:1v or greater are possible depending on the existing soil conditions and slope lengths. In poor soil conditions or on steeper slopes, Secugrid® geogrid can be used to further ensure slope stability.

**Conclusion**

Bentofix® is suitable for sealing dykes and dams as well as flowing or turbulent inland waters. Standard or project-specific styles such as Bentofix® BZ 13-B, with the integral sand ballast material, can be employed for underwater installations.

For hydraulic engineering sealing purposes, there are physical properties that are also required for geosynthetic clay liners - not just low permeability. Bentofix® fulfills with these requirements by offering high impact resistance, erosion-stable encapsulation of the bentonite as well as high shear strength.
Coastal protection measures are designed to protect inland flooding and minimize the erosion of the coastline caused by the constant motion of the sea. Geosynthetics are used in various coastal protection applications such as filters in dykes and dams, for foundations under groins and wave-breakers, as well as by using geotextile containers as structural elements in groins, breakers or for bed stabilisation.

Stabilisation of dykes
Terrafix® needle-punched geotextiles are used to protect the coastline when used in the toe area of dams and dykes. They improve the construction efficiency if the sea currents cause surface erosion or unacceptable soil displacement. The three-dimensional, labyrinth-like pores and channels of Terrafix® nonwovens are not only similar to the soil structure itself, but, if correctly designed, also increase the stability of the revetment against impact stress caused by the motion of the sea. For coastal hydrodynamic forces and the typical fine to medium sands in these areas, the following simplified engineering approach can be used to determine the effective opening size $d_{50,W}$ of a filter geotextile when one is used below an open revetment:

$$d_{50,W} \approx d_{50}$$

The minimum thickness of the filter geotextile should be 4.5 mm (please refer to chapter “Filtration”) in order to ensure the stability and permanency of the filter. Due to their extraordinary robustness, Terrafix® geotextiles with a mass of at least 500 g/m² are used below low-stress concrete revetments.

A geotextile with a minimum mass per unit area of 600 g/m² is necessary wherever type II or III armor rock with individual weights ≤ 50 kg are placed directly on Terrafix® geotextiles, or where concrete revetments for high-stress applications have been installed. Where individual stone weights exceed 50 kg, Terrafix® geotextiles with yet a higher mass per unit area are recommended. In the case of low-stressed dykes, Terrafix® filter geotextiles with a minimum mass of 500 g/m² and minimum thickness of 4.5 mm serve to encapsulate and stabilize the sand core from erosion. When flooding occurs, they prevent washout of the sand and ensure the stability of the dyke. Top soil as well as concrete blocks can act as an effective cover layer over the geotextile.

Transverse structures as stabilisation measure
In some cases, dykes alone are insufficient for coastal protection. Transverse structures, such as groins, breakers and sea embankments are used to prevent the erosion of coastal areas and directly influence the localized sea currents. Terrafix® sand mats provide stability as well as scour protection for these structures. Even in deeper waters, the underwater installation of Bentofix is easy due to the integral sand ballast layer. Depending on the subsoil conditions, Terrafix® filter layers that are at least 4.5 mm thick (for soil type 1 to 3) or 6.0 mm thick (for soil type 4), ensure the filter stability of the fine grained subgrade.
Secugrid® geogrids are used as additional reinforcing elements where foundation failure is possible. The reinforcement measures required for transverse structures depend on the prevailing sea current stresses to which they are subjected. For low-current stresses, a Terrafix® needle-punched nonwoven geotextile or a Terrafix® sand mat can be placed on the sandy dam core and covered with rip rap. For medium-current stresses, it is recommended that the dam core be reinforced with two or three layers of Terrafix Soft Rock® sand containers prior to installing the revetment. For high-current stresses, the transverse structure can be built entirely with Terrafix Soft Rock® sand containers, and, if required, be covered with the appropriate revetment.

Terrafix Soft Rock® sand containers consist of needle-punched nonwoven geotextiles with a maximum tensile strength of \( \geq 30 \text{kN/m} \). Over 80% of the nonwoven geotextile strength is required for all seams. One of the remarkable features of Terrafix® is its robustness and elongation capacity. Terrafix Soft Rock® sand containers can be placed in their exact position and over granular terrain without a high risk of becoming damaged by using specific “grippers”. When properly designed, even the dynamic impact of dumping does not reduce the performance of Terrafix Soft Rock® due to the flexibility of the Terrafix® nonwoven geotextile. Mussels and algae attach to the fibres that are partially in a vertical position, so that the Terrafix Soft Rock® sand containers integrate quickly and easily into the sensitive sea ecosystem.

**Erosion control of the coast**

Storm tides can set the entire sea in motion, with its energy reaching the coastal breaker zone inducing erosion and morphological displacement. In such cases, Terrafix Soft Rock® sand containers used as artificial reefs serve as underwater breakers to reduce wave energy. Depending on the requirements, Terrafix Soft Rock® sand containers can have a volume of 1 m³ to 250 m³. Due to the high elongation capability needle-punched Terrafix® nonwoven geotextiles are used to handle the critical stress that can occur during the installation process. Terrafix® sand containers easily accommodate irregular surfaces!

Terrafix® nonwoven filter geotextiles are also used for the construction of artificial dunes. Using a unique wrap-around method, Terrafix® nonwoven geotextiles encapsulate a sand layer and are then planted with locally available bushes and grasses. Due to the high abrasion resistance and elongation capacity of Terrafix® nonwoven geotextiles, this construction technique provides excellent resistance to wave impact year after year - preventing erosion of the coastline (see figure 10).

**Conclusion**

Terrafix® system solutions allow the implementation of new and innovative coastal protection measures. Terrafix® needle-punched nonwoven geotextiles, sand mats and sand containers can be effectively employed in dykes, transverse structures, as well as breakers for erosion control. Placement of the robust and resistant Terrafix® products can be carried out under dry conditions, as well as from ships or underwater. Terrafix® products allow new approaches to coastal protection that are close to nature.
Flowing waters

Geosynthetics are used as filters, sealing elements as well as for scour protection in flowing waters. Natural construction materials are often found to be inadequate in performance without significant over-engineering - the use of geosynthetics is frequently required in support of natural systems for both performance and savings. Ecological aspects play an important role in hydraulic engineering as it is important to protect as well as preserve the natural flora and fauna habitat. Systems from NAUE offer ecological, technical as well as economic benefits together in a single solution.

Filtration
Terrafix® needle-punched nonwoven geotextiles significantly enhance system performance when two soil layers with dissimilar or non filter-stable grain structures are used as well as when a revetment is installed. Even where only hydrostatic loads are anticipated, it is generally recommended to follow the requirements of the MAG (Instructions for the use of geotextile filters in waterways, Federal Institute for Hydraulic Engineering (BAW), Karlsruhe, Germany 1993). In filter applications for soil types 1 to 3, Terrafix® 609 with a minimum thickness of 4.5 mm is well suited (for further details please refer to the chapter "Filtration"), whereas for soil types 1 to 4, Terrafix® 813 with a minimum thickness of 6.0 mm would be appropriate. The installation instructions for different current velocities described in the chapter "Filtration" should be observed during common underwater installations. In the case of deeper water and higher current velocities, the use of Terrafix® sand mats or Terrafix Soft Rock® sand containers is recommended as they provide an excellent stability. The three-dimensional fibre structure of Terrafix® nonwoven geotextiles exhibit high elongation capacity and robustness. With these characteristics, they easily accommodate irregular or soft subgrades and are capable of withstanding installation loads when covered with stone, without loss of their filtration performance. The large effective pore space of the Terrafix® nonwoven geotextile structure offers an excellent environment for the establishment or continued propagation of local flora and fauna.

Protection from scouring
There is always a risk of scouring where current velocities are high. With turbulent currents typical of artificial structures
such as bridge piers and ford foundations, the risk of scouring is particularly high. Terrafix Soft Rock® sand containers are an ideal solution to repair existing scoured cavities in river beds or other water channels. The containers can be filled with local sandy material under dry conditions and placed in the desired position with appropriate equipment. Using robust, needle-punched nonwoven geotextiles, Terrafix Soft Rock® sand containers easily accommodate and resist rough site conditions while preventing further scouring.

Groins manufactured from Terrafix® sand containers are used to prevent scouring in river bends when constructed at right-angles to the river bank. If the subsoil is particularly soft, the ground can be stabilised with Terrafix® sand mats. The additional use of Secugrid® geogrids may be required in certain cases where substantial subgrade reinforcement is required. The wide range of Terrafix® geosynthetic products offer permanent and economical solutions to resist natural destructive forces, regardless of the soil type or design of the revetment.

Sealing
In some cases it is necessary to construct an artificial seal in flowing inland waters (fresh water). Bentofix® offers geosynthetic clay liner product variations that can be installed in both dry and wet conditions for this purpose (For further details please refer to the chapter "Sealing"). Dams and dyke seals may also be necessary to prevent protected areas from flooding. Since this work is usually carried out under dry conditions, Bentofix® as well as Carbofol® geomembranes - combined with Terrafix® or Secutex® protective nonwoven geotextiles, offer one of the industry’s best lining solutions, for slightly gravelly-sands, needle-punched nonwoven geotextiles with a minimum mass of 400 g/m² can be used as a protective layer for the lining component, while nonwoven geotextiles with a minimum mass of 1200 g/m² will work well for coarsely grained soils.

Conclusion
Terrafix® nonwoven geotextiles are effective filters for subgrade erosion control on slopes as well as the base of flowing waters. Due to their robust nonwoven geotextile structure as well as the high elongation capacity and flexibility, they can resist difficult installation conditions while creating a favorable habitat for local flora and fauna. Bentofix® GCLs and Carbofol® geomembranes are used for sealing while Terrafix® or Secutex® nonwoven geotextiles protect the Carbofol® from undue damage from surrounding soils. Terrafix Soft Rock® sand containers protect against scouring in scouring in hydraulic structures, such as bridge foundations and piers. They are particularly well suited for the construction of groins and thus, capable of preventing further scouring.

Design     Cross sections     Details
Dammed-up waters

For centuries, water has been stored or transported in man-made canals and reservoirs to make it usable for transportation, as a source of energy, or for irrigation. A wide range of geosynthetic products can be used in order to create more efficient shipping routes, including those used for the construction or repair of canals and docks. Geosynthetics facilitate economical and ecological methods for the construction of retention reservoirs or barrages.

Filter geotextile

When used for transportation hydraulic engineering, Terrafix® needle-punched nonwoven geotextiles can be used effectively below permeable revetments as a filter layer. They are selected and designed in accordance with the established technical guideline "Instructions for the use of geotextile filters in waterways" (MAG) of the Federal Institute of Hydraulic Engineering (BAW), 1993. Depending on the existing soil type and revetment, Terrafix® nonwoven geotextiles that are at least 4.5 mm to 6.0 mm thick are best suited to prevent erosion and soil displacement (please refer to chapter "Filtration"). Even under high hydrodynamic loads caused by rapid water level fluctuations or by the turbulence from ship propellers, Terrafix® nonwoven geotextiles maintain their mechanical properties and filter efficiency. Composite Terrafix® products which exhibit a coarse fibre layer can be effectively employed to stabilise the soil/filter boundary layer in soils with high single grain mobility, preventing particle displacement under the Terrafix® filter geotextile.

High mechanical stresses can occur during the installation process as well as from ship traffic. For this reason, the geotextile filters must exhibit adequate impact and abrasion resistance. Terrafix® geotextiles offer these properties and more! Their high elongation capacity and robustness allow them to easily accommodate irregular or soft subgrades while preventing damage to the nonwoven structure itself when covered with stone. The three-dimensional needle-punched structure of crimped fibres provides high abrasion characteristics and resistance to any movement of the revetment.

In fast flowing or turbulent waters caused by propeller wash, the general physical characteristics make the installation and positioning of a nonwoven geotextile an inexact science. However, the Terrafix® sand mat enables the filter geotextile to be placed quickly and accurately underwater due to the ballast of encapsulated sand mass, providing simple permanent stability. Terrafix® offers filter stability against finely grained soils while sufficiently robust to resist damage from stone cover.

Sealing

In inland fresh water shipping routes where the water level is an elevation higher than the natural groundwater level, artificial sealing is required to prevent the water from "draining" to the groundwater level. Bentofix® geosynthetic clay liners or Carbofol® geomembranes are well suited lining products for dry installations. When using geomembranes, Terrafix® or Secutex® needle-punched nonwoven geotextiles are recommended as a protective layer. Structured or textured Carbofol® geomembranes are available to effectively transfer shear forces on challenging slope designs. Regardless, project-specific direct shear tests should be performed to verify the required shear strength parameters in order to use them for calculating slope stability analysis.
When ship traffic cannot be disturbed, the underwater installation of Bentofix® BZ 13-B geosynthetic clay liner is recommended. It features a bentonite clay liner with an additional sand ballast layer and an encapsulating nonwoven geotextile. Due to our unique technology, this geotextile/liner composite is uniformly reinforced with direction-independent needle-punching over its entire surface area. With a mass per unit area of 8 kg/m², the heavy sand filling performs several functions: it facilitates the uniform swelling of the bentonite which ensures consistent hydraulic function throughout the entire GCL; it protects against impact stress during the installation of covering stones; and with the appropriate installation technology, it ensures precise positioning so that the Bentofix® BZ 13-B clay liner and sand ballast remain in a permanent, stable position even during shipping traffic. Bentofix® BZ 13-B is also uniformly impregnated with bentonite powder over its entire edge surface area to ensure the proper sealing performance in the overlaps.

Protection

Depending on the subgrade and the cover material, properly specified needle-punched protective nonwoven geotextiles such as Terrafix® or Secutex® both above and below the Carbofol® geomembrane will minimize the potential for damage from surrounding soils. For slightly gravelly-sand (≤ 30% gravel portion) or corresponding cover material, a needle-punched nonwoven geotextile with a mass per unit area of 400 g/m² should be used. Coarser grained soils may require nonwovens exhibiting a mass per unit area of at least 1200 g/m².

Erosion control

On slopes with especially fine grained soils, heavy precipitation and wave impact may cause surface erosion. Significant erosion and rutting can occur if the slope is poorly vegetated. Geosynthetic erosion control mat is commonly used to address difficult, erosion-prone slope conditions. Secumat® erosion control mat can significantly reduce soil washout during heavy rainfalls - its three-dimensional, irregular labyrinth-like structure is designed to allow both fine grained and gravelly soils to fill the open convoluted structure. The irregular Secumat® structure holds the soil in position on steeper slopes and provides structural support to vegetation during the early stages of plant growth. The use of high quality propylene (PP) resins make Secumat® resistant to naturally occurring soil chemicals, soil microorganisms and UV-radiation. The Secumat® product range is also available with a needle-punched nonwoven geotextile attached to the bottom side. Installed with the three dimensional mesh surface side-up, it will then perform two functions - soil separation as well as erosion control.

Conclusion

Robust Terrafix® geotextiles can be effectively employed under permeable revetments to provide filter stability to the subsoil. Bentofix® geosynthetic clay liners and Carbofol® geomembranes are ideal products for a myriad of sealing applications. Carbofol® must be installed under dry conditions and is protected against mechanical loads by Terrafix® or Secutex® nonwoven geotextiles. Conversely, Bentofix® can be installed under water - the integrated sand mat provides a controlling confining load during the swelling of the bentonite and protects the bentonite mat when it is covered with cover stones. In areas where wave impact occurs, Secumat® protects slopes from erosion during the early stages of plant growth.

Design Cross sections Details
For dyke applications, geosynthetics perform important functions, such as long-term stability and waterproofing. Geosynthetics from NAUE have been used in these exacting applications for decades.

**Reduction of the Decrease in pore pressure**

Load filters are placed downstream to improve stability and to reduce the seepage line in the case of flooding. By collecting water downstream, the filter reduces existing pore pressure in the dyke and prevents excess pore pressure build-up, thus providing stability to the dyke. Terrafix® needle-punched nonwoven geotextiles fulfill the challenging filter stability requirements - they can be effectively employed as a filter layer between the dyke body and the filter as well as in the foundation of the dyke itself. Upstream, Terrafix® geotextiles prevent permanent soil washout which could significantly reduce the dyke stability. The three-dimensional, labyrinth-like pore channels of Terrafix® provide excellent filter stability due to their similar structure to the soil. In addition, Terrafix® geotextiles are extremely robust due to their high elongation capacity allowing them to easily accommodate irregular or soft subsoil.

**Sealing**

For the repair or the new construction of a dyke, the 10 mm thick Bentofix® geosynthetic clay liner is an economical alternative when compared to the typical 60 cm thick compacted clay liner. When installed on the upstream surface, the high-swelling natural sodium bentonite offers an excellent low permeability seal. Bentofix® is manufactured with direction independent needle-punching, with more than 2 million fibres per square metre. Slope angles of 2.5h:1v or greater are possible due to the surface structure of the needle-punched cover and carrier nonwovens as well as the large internal and external shear strength. In poor soil conditions or on steeper slopes, Secugrid® geogrid can be used to further ensure slope stability.

Due to their thin profile, Bentofix® clay liners consume less airspace than compacted clay, and can require significantly less soil removal - especially in the case of dyke repair. The Bentofix® BFG 5000 also features a cover nonwoven geotextile that has been uniformly impregnated with bentonite powder over its entire surface area. The additional bentonite in the cover nonwoven geotextile can help the installation proceed more efficiently versus installations where the overlaps must be improved with additional bentonite.

The cover and carrier geotextiles of Bentofix® geosynthetic clay liners protect the bentonite core while providing sufficient robustness for on-site handling. When high normal loads are anticipated, Bentofix® manufactured with nonwoven geotextiles exhibiting a minimum mass per unit area of 270 g/m² should be used.

Alternatively, 1.5 thick Carbofol® HDPE geomembranes can be installed. Not only is placement simple, Carbofol® HDPE geomembranes are easy to weld due to the favorable Melt Flow Index of the resin.

Surface texturing is available to effectively transfer shear forces on slope locations. Regardless, project-specific direct
shear tests should be performed to verify the required shear strength parameters of the confining soils and to calculate the stability.

Depending on the requirements, needle-punched nonwoven geotextiles such as Terrafix® or Secutex® may be installed above and below the Carbofol® geomembranes for added protection. For slightly gravelly-sand (gravel portion ≤ 30 %) protection nonwovens with a mass per unit area of 400 g/m² should be used to protect the Carbofol® geomembrane. Coarser grained soils may require protection nonwovens, exhibiting a mass per unit area of 1,200 g/m².

Protection against rooting
Roots from shrubs or trees can find their way into the downstream filter or into the body of the dyke - which may reduce the drainage performance of the filter or impact the permeability of dyke liner. The vertical placement of 1 mm thick Carbofol® geonembranes ensures the effective protection against root penetration and long-term stability in critical areas. With a thickness of 2.0 mm Carbofol® also provides long-term resistance to rodents.

Erosion control
On steep slopes, heavy rainfall may cause rutting or wash away young grass seed. Secumat® erosion control mats inhibit surface erosion and rutting by retaining the soil and seed in a convoluted three-dimensional structure. Secumat® is installed directly on the slope and filled with soil. Roots gradually intertwine with the three-dimensional structure of Secumat®, efficiently interlocking roots and the Secumat® with the surrounding soil.

Conclusion
Dykes are built for protection against flooding and must perform properly during this limited, yet demanding period. Terrafix® geotextiles are used upstream to prevent soil washout as well as downstream in the outflow area of the seepage lines to prevent erosion. With Terrafix geotextiles, the full drainage performance of the filter is maintained and the stability of the structure is ensured. Bentofix® geosynthetic clay liners and Carbofol® geomembranes are used extensively as sealing components while Terrafix® and Secutex® nonwoven geotextiles can effectively protect the Carbofol® from damage. Secugrid® geogrids further improve stability in the slope area while Secumat® or Carbofol® can provide erosion control and protection against root penetration. When you require complete system solutions for safe and stable dyke construction, think of the products available from NAUE - the natural choice.
Ecology plays an important role in the design of waterways, barrages, retention reservoirs, dykes and coastal protection measures. Tests for environmental compatibility and guidelines for landscape restoration are therefore specific components to be considered in planning new construction or extensions of existing waterways.

Preliminary planning is followed by an environmental compatibility study. This study includes an evaluation of the effects on all environmental aspects. From the cost-effective available options, the most compatible variant is then suggested.

The technical planning details a specific plan considering the environment, navigation as well as economic aspects. If damage occurs, those that are impacted should be compensated by suitable measures.

Ultimately, the use of environmentally beneficial geosynthetics is recommended - products that protect natural resources and cause the minimum amount of emissions during transport and installation.

Protection of resources
Geosynthetics are used in hydraulic engineering as technical equivalents to conventional materials such as mineral liners. Bentofix® geosynthetic clay liners can be employed in lieu of compacted clay layers while Terrafix® filter geotextiles can replace granular filters - to conserve natural resources.

A 1 cm thick Bentofix® sealing liner is technically equivalent to over 50 cm of compacted clay and a 4.5 to 6 mm thick Terrafix® filter geotextile can easily replace a 40 cm thick aggregate filter.

Moreover, the use of geosynthetics generally requires less soil removal, transport and deposition.

Reduction of emissions
Ecological balance sheets developed by NAUE demonstrate the favorable energy balance of geosynthetics over natural construction materials. The use of Bentofix® GCLs requires only 2/3 of the energy required to compact a mineral clay layer under similar conditions to achieve comparable performance.

The transport of 33,000 m² of Bentofix® GTD requires only 8 truckloads while the transport of a corresponding amount of compacted mineral clay for a compacter sealing layer 20 cm thick requires approximately 550 truck loads (24 t each)! Geosynthetics are the clear choice when aiming to reduce vehicle emissions!

Design close to nature
Geosynthetic construction methods can be integrated into almost any landscape. Numerous structures from the seventies illustrate the variety of design and vegetation options.

Extensive research shows that geosynthetics do not have a negative influence on the flora and fauna. To the contrary, they can offer nutrient and heat storage for plants and animals.
Quality Assurance and Control

...the continuous monitoring of raw materials, components, production and products

All incoming raw materials, fibres or components, needed for the production of our geosynthetics, are subject to a strict material analysis. Acceptance test certificates, submitted by base material suppliers, are reviewed and qualified in accordance with our product specific protocols.

During production of all geosynthetics, additional quality assurance measures are performed. To ensure personnel effectiveness, the quality assurance staff is assigned to a separate and autonomous division from the production division.

After all quality assurance measures have been performed as defined in the quality assurance plan, an acceptance test certificate will be issued according to EN ISO 10204 when requested. Material will only be released once it has passed all quality reviews, checks and has all supporting documentation completed.

These quality assurance measures are conducted for all of our products, according to the current standards and guidelines in effect at that time. This continuous manufacturing quality control guarantees product performance characteristics, and enables complete documentation from the raw material to the final product.

NAUE geosynthetics also undergo third party quality process checks that are typically performed twice a year. Independent experts obtain test specimens from the different NAUE production facilities as well as from the various product inventories. The properties of the geosynthetic products are tested and documented in detail, including the notation of production processes, the type and extent of the manufacturing quality control and any other relevant observations.

Project Specific Product Properties

In special cases, independent experts are retained to test project specific product properties and to certify the test results. This testing is in addition to and completes the manufacturing quality control carried out on the raw materials as well as the finished products.

Quality Management According to EN ISO 9001

Since December 1994, the geosynthetics development, production, sales and geotechnical engineering divisions of NAUE GmbH & Co. KG have been certified according to EN ISO 9001. This certification is regularly validated by scheduled audits.

With the aid of this integrated quality management system, the requirements of the customer and/or the projects are understood and fulfilled. While we continually strive to improve the quality level of our existing products and services, a high quality foundation is guaranteed by our EN ISO 9001 standards.

Compulsory CE-marking

From 1st October 2002, CE-marking for most geosynthetics is compulsory (except for sealing systems and erosion control mats). The CE-marking certifies that a product corresponds to the product-specific European guidelines for specific applications and functions (separation, filtration, reinforcement, protection and drainage). By 1st October 2002, NAUE had taken all necessary steps to put into effect the compulsory CE-marking.
Static puncture test according to EN ISO 12236

Direct shear device for the determination of friction coefficients

Determination of the bonded peel strength of Bentofix® geosynthetic clay liners ASTM D6496

Wide width tensile strength test DIN EN ISO 10319

Determination of the strength and elongation properties of single fibres

Determination of the montmorillonite content of bentonite via the methylene-blue-adsorption (titration) method

Determination of the hydraulic properties of water permeable geosynthetics

Tensile test on Carbofol® geomembranes EN ISO 527-3, resp. ASTM D 638

Tensile strength test of Secugrid® geogrids

Raw material identification according to the DSC method

Determination of the strength and elongation properties of single fibres

Tensile test on Carbofol® geomembranes EN ISO 527-3, resp. ASTM D 638
Products

Carbofol® geomembranes are made with high density polyethylene (HDPE). They are available in different thicknesses as well as with different surfaces for all of your sealing tasks.

Secutex® is a needle-punched staple fibre nonwoven geotextile used for separation, filtration, protection and drainage. Secutex® can be used in many civil engineering applications such as hydraulic engineering, landfill engineering, road construction as well as tunneling.

Terrafix® is a needle-punched staple fibre nonwoven geotextile used for multifunctional purposes: single layered filter, multi-layered filter, sandmat, sand container or as scour protection.

Terrafix® is a needle-punched reinforced geosynthetic clay liner (GCL) that uses two geotextile layers to encapsulate a layer of natural sodium bentonite. The needle-punched fibres transmit shear forces through the bentonite core. It is used as a sealing barrier against liquids and gases in various civil and environmental applications.

Data     Facts     Figures

Examples of interface shear values between different geosynthetics and soil. The indicated approximate values result from over 35 years of project experience. The specific design values must be determined on a project by project basis and follow as close as possible on-site conditions.

- Thermally fused nonwoven achieves the higher value.
- Is rarely designed.

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<th>Secutex®</th>
<th>Secutex® nonwoven</th>
<th>Secutex® smooth</th>
<th>Carbofol® smooth</th>
<th>Carbofol® friction</th>
<th>Sand 0/2 mm</th>
<th>Gravel 8/16 mm</th>
<th>Mixed graded top soil</th>
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<td>Gravel 8/16 mm</td>
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<td>Mixed graded top soil</td>
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Secumat® is a three-dimensional erosion control mat consisting of a UV-stabilised labyrinth-like polymer core. Secumat® controls surface erosion by ensuring rapid vegetation growth on slopes while preventing soil erosion during heavy rains and water flows.

Secugrid® is a geogrid made of flat extruded monolithic bars with welded junctions. It is used for soil reinforcement in earth works, road construction, segmented wall construction, landfill engineering and hydraulic engineering.

Combigrid® is a firmly bonded composite of a high strength, low elongation Secugrid® and a needle-punched Secutex® nonwoven geotextile for soil stabilization and filtration applications.

challenges, simplifying your project. NAUE has decades of experience in the development and production of high quality geosynthetics, offering complete geosynthetic solutions.

Contact us - we have the solutions!

www.naue.com

This design-tool disk performs calculations for designing load bearing layers with a „twist of the rist“ for Secugrid® or Combigrid®.
Further information on the subject geosynthetics are available through our website or from our:

- corporate brochure

- application related brochures:
  - Groundwater protection
  - Civil Engineering
  - Hydraulic Engineering
  - Waterproofing Manual

- application related flyers and technical flyers with project specific solutions