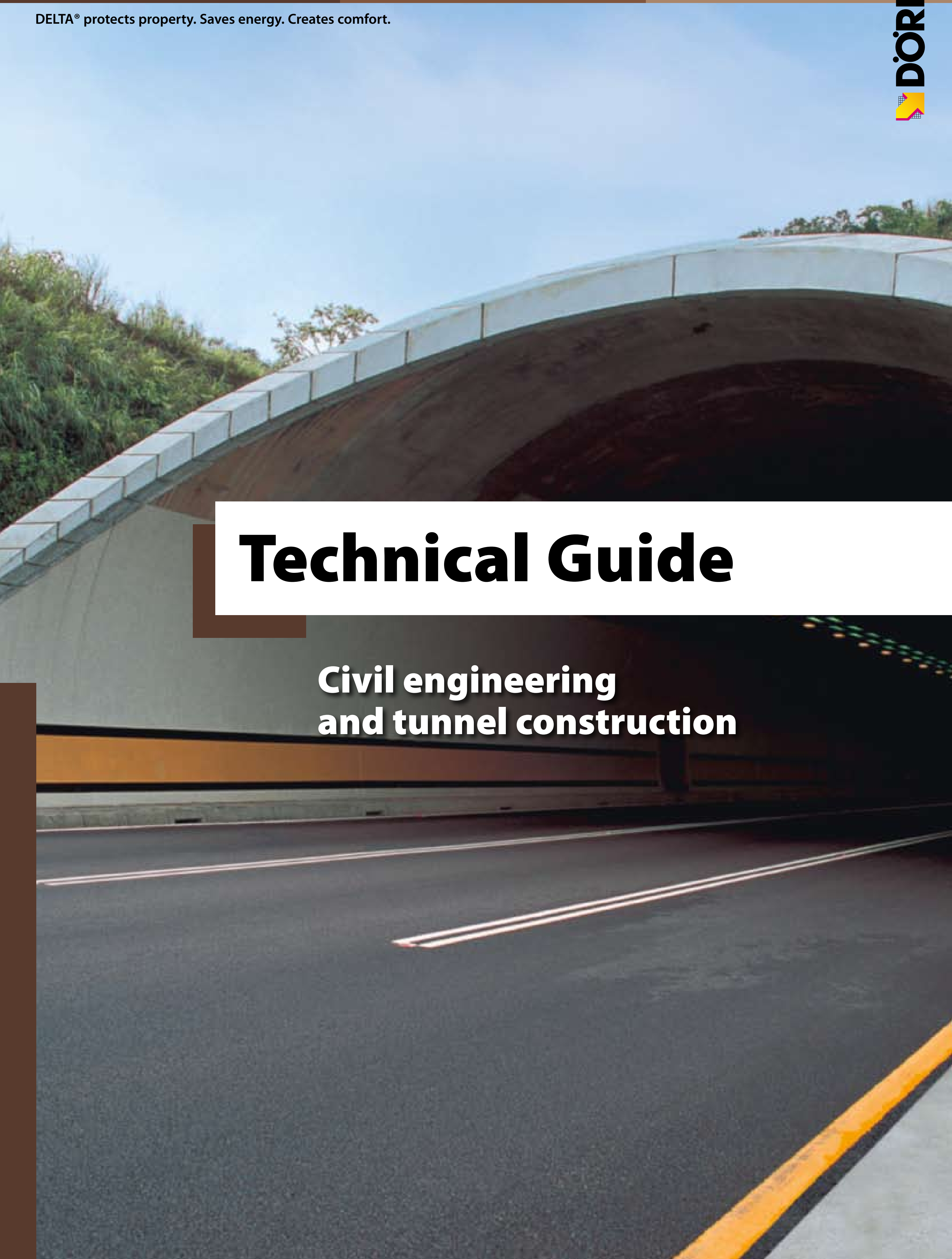
DELTA®

DELTA® protects property. Saves energy. Creates comfort.

DÖRKEN

Technical Guide

Civil engineering and tunnel construction



DELTA®

Dörken – innovative and competent. For more than 100 years.

This technical guide provides planners and users with an extensive range of products tailored to a large variety of end uses and fields of application in civil engineering and tunnel construction. Developed from innovative ideas and manufactured in leading-edge production facilities, the top-quality products made by Dörken GmbH & Co. KG for foundation protection, drainage, and waterproofing set standards for reliability, durability, and energy conservation. Located in the Westphalian town of Herdecke, the company is committed to supplying its clients with premium products and customised solutions. Having lived up to this standard for more than a hundred years, Dörken is and will always be a powerful partner for planners, dealers, and craftsmen.

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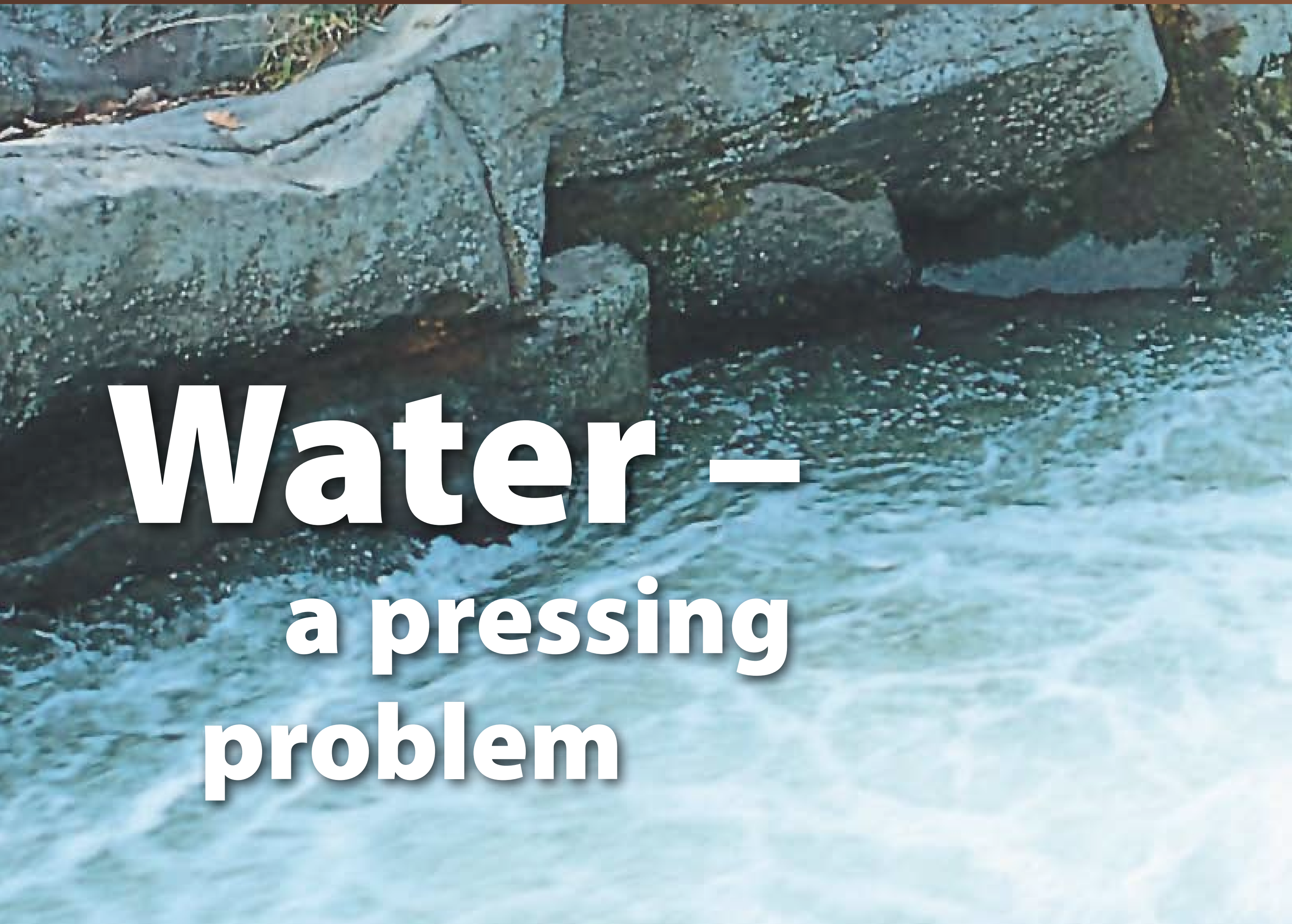


Water – a pressing problem

Water that reaches the ground in the form of precipitation always finds its own way. Ideally, it will seep away quickly and immediately without building up pressure against a building structure. If, however, it seeps away only slowly it will exert pressure on a building as long as precipitation endures. A similar situation applies whenever water that has seeped into the ground encounters and easily permeable soil layer through which it pushes towards a building. These two variants occur fairly frequently. Things get tough, however, when precipitation water encounters impermeable ground through which it cannot seep away. In such a case, a building will be permanently exposed to water pressure.

These three degrees of water exposure crucially determine the planning of waterproofing, drainage, and protection measures. Therefore, any building project should be based on a careful investigation and evaluation of the local ground structure and any other relevant factors such as, for example, the terrain configuration.

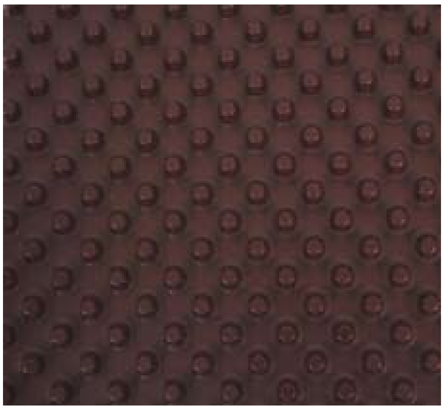
Depending on local constraints, very different volumes of water may be involved. If, for example, a building does not stand on level ground but is built against a slope water may normally be expected to accumulate against the building wall at a rate of up to 0.3 l/s · m, as DIN 4095 suggests. This is the minimum volume which the drainage layer must be designed to handle if the building is to be safely protected from damage by moisture.

Effective protection from seepage water is essential not only because water will worm its way in, as building experts are aware. When waterproof concrete is made, its quality and thus its impermeability crucially depend on complying exactly with the water-cement ratio specified. Whenever this ratio is changed by intruding water, the concrete will become water-permeable or worse: a water vein may penetrate the entire wall, forming a local leak.

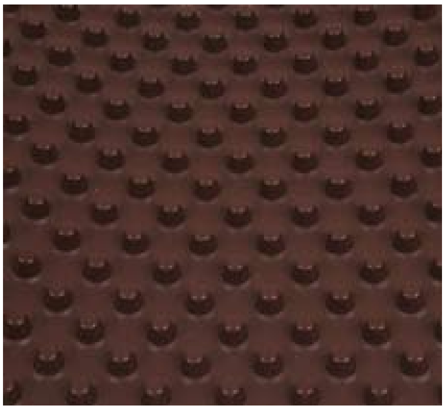
However, hydrostatic pressure also stresses the waterproofing of a building, threatening its functional reliability. Besides, a water column several meter in height exerts great structural strain on a building. This strain becomes particularly critical whenever water pressure is confined to certain circumscribed areas, generating asymmetrical loads. In many cases, effective drainage may help in this context as it facilitates markedly simplifying the construction of the waterproofing, thus reducing its susceptibility to defects.

For these reasons, seepage water should always be drained away across entire surfaces. In such cases, dimpled and drainage sheets made of plastic have been tried and trusted as compression-resistant seepage layers for many years, one reason why the are so frequently used being that they are easy and inexpensive to install.

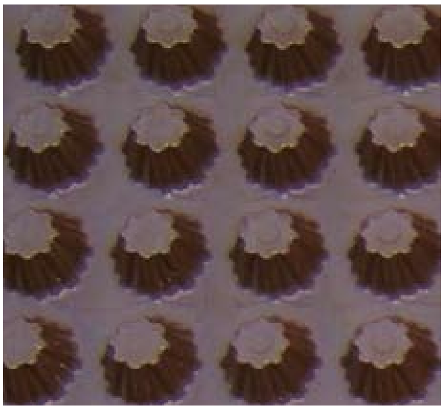
DELTA®-Products for tunnel construction and civil engineering



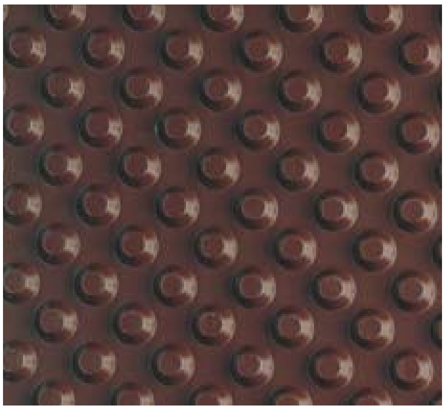
DELTA®-AT 1200



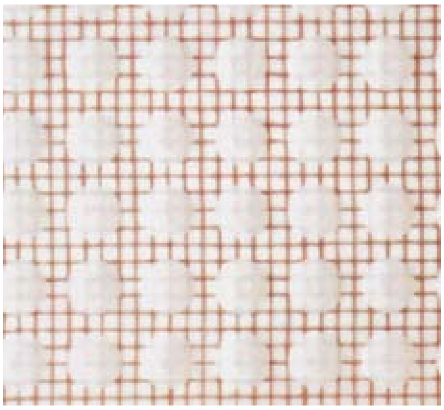
DELTA®-AT 800



DELTA®-MS 20



DELTA®-MS



DELTA®-PT

DELTA® products for foundation-wall protection, drainage, and waterproofing are best suited for a wide range of building and rehabilitation applications. Including a variety of dimpled sheets and accessories for any application, DELTA® products offer a tailor-made solution for every problem. Our method of combining precisely-matched products into complete DELTA®-systems provides added value easily to be reached.

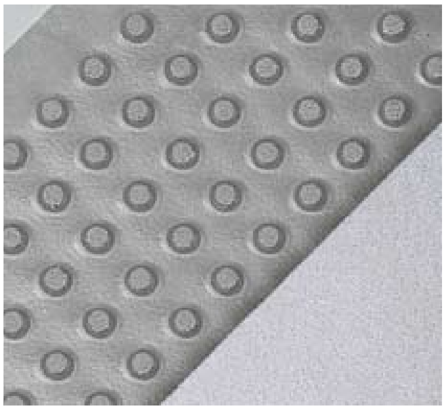
Made of a special type of polyethylene, DELTA® dimpled sheets form highly efficient seepage and drainage layers. They are compression-resistant, maintaining their outstanding hydraulic properties even under heavy and permanent loads.

With a welded-on plaster mesh, dimpled sheets may be used as backing for shotcrete and mortar.

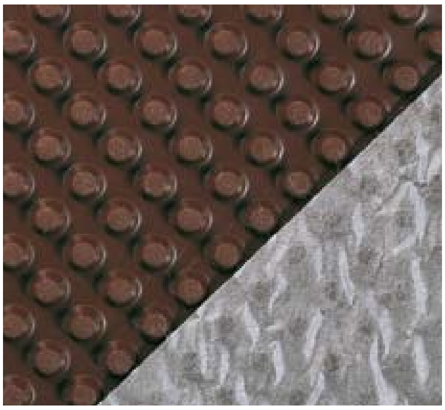
The fused-on geotextile layer of the multi-layered DELTA® dimpled sheets filters soil particles out of the seepage water, thus preventing the air gap from becoming clogged up.

DELTA® dimpled sheets are rot-proof, resisting saline solutions, inorganic acids, alkalines, and polar liquids. They are proof against attack or modification by any of the minerals, humic acids, and bacterial catabolic products that naturally occur in the soil, as well as by bacteria, fungi, and micro-organisms. The response of all sheet types to soil or underground water is completely neutral, nor will they leach any harmful and/or ecologically doubtful substances. Care should be taken to ensure that they are not permanently exposed to UV radiation.

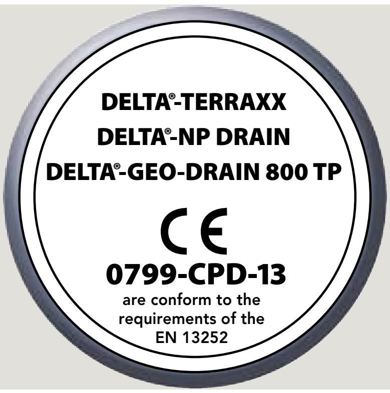
DELTA®-GEO-DRAIN TP 800



DELTA®-TERRAXX



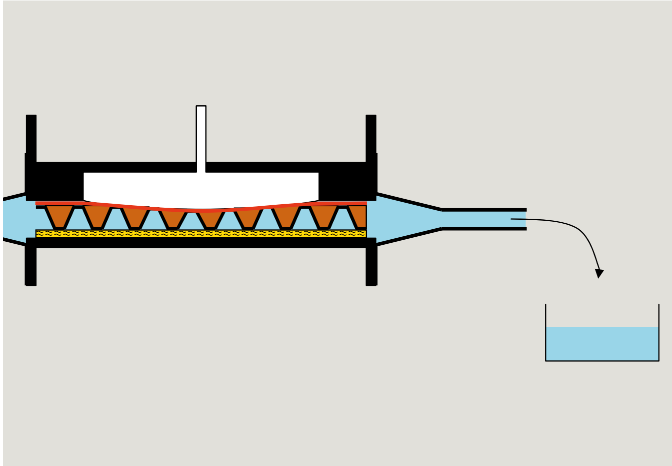
DELTA®-NP DRAIN



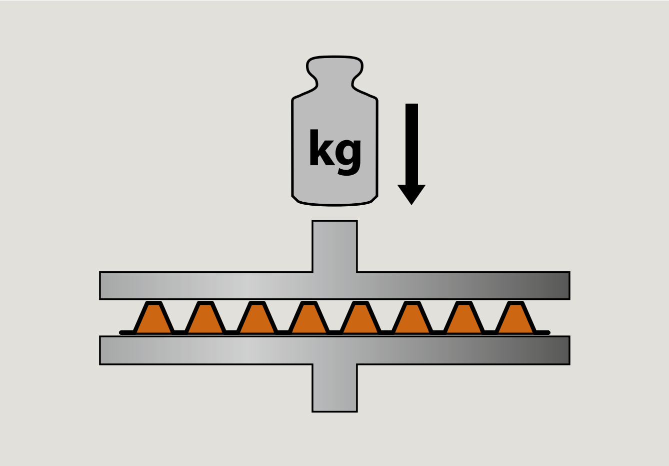
Our drainage products with geotextile DELTA®-NP DRAIN, DELTA®-TERRAXX and DELTA®-GEO-DRAIN 800 TP – conform to the requirements of the CE sign of the EN 13252 standard (Certificate No. 0799-CPD-13).

Test methods as per EN 13252

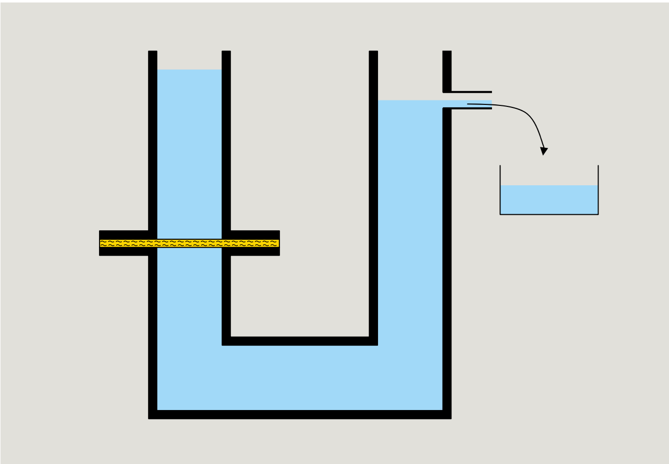
DIN EN 13252 specifies the properties required of geotextiles and geotextile-related products that are integrated in drainage systems essentially to perform the functions of filtration, separation, and drainage. These properties include water flow capacity in the plane, material resistance, water permeability, tensile strength, dynamic perforation resistance and characteristic opening size. The standard does not define minimum requirements for materials but rather test methods for measuring these properties which apply in all EU countries.



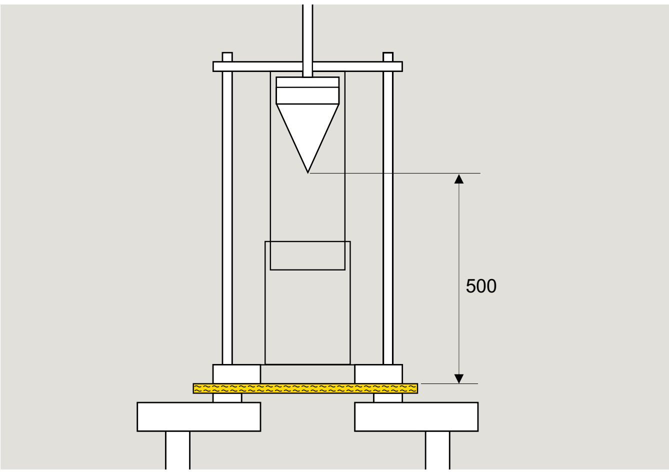
Water flow capacity in the plane (drainage capacity), EN ISO 12958
The parameters for measuring the water flow capacity in the plane of a geotextile or a geotextile-related product include various normal pressure stresses, typical hydraulic gradients, and defined contact surfaces.



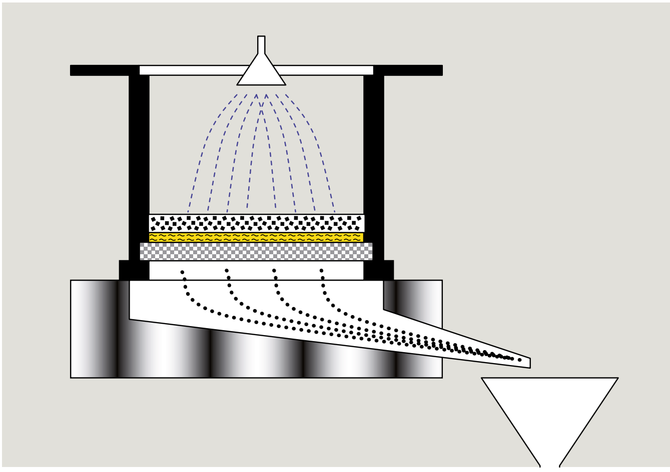
Compressive strength, DIN EN ISO 604
The test specimen is compressed along its main axis at constant speed until it breaks or its length decreases to a predefined value. The force sustained by the test specimen is measured throughout the process.



Water flow capacity vertical to the plane, EN ISO 11058 (GT)
Water is conducted through a single layer of unstressed geotextile or geotextile-related product in a direction that is normal to its plane. The amount of water that flows through the material being tested is measured.



Dynamic perforation resistance (cone drop test), EN 918 (EN ISO 13433) (GT)
A geotextile specimen is clamped horizontally between two steel rings. A defined cone of stainless steel is dropped point forward on to the centre of the specimen from a height of 500 mm. The extent of penetration is established by measuring the diameter of the hole by placing a pointed conical gauge in it.



Opening width O90, DIN EN ISO 12956 (GT)
This European standard defines a method to determine the characteristic opening size of a single layer of a geotextile or geotextile-related product by wet screening. Graded granular material (commonly soil) is washed with water through an unstressed specimen of a geotextile or geotextile-related product which acts as a screen. Afterwards, the distribution of grain sizes is measured. Characteristic opening size corresponds to a certain grain size of the screened material.

Tensile strength test, EN ISO 10319 (GT)
This standard describes an index test to determine the tensile strength of geoplastics by examining a wide strip (200 mm wide, 100 mm long). Stress-strain curves are recorded under constant load increase.

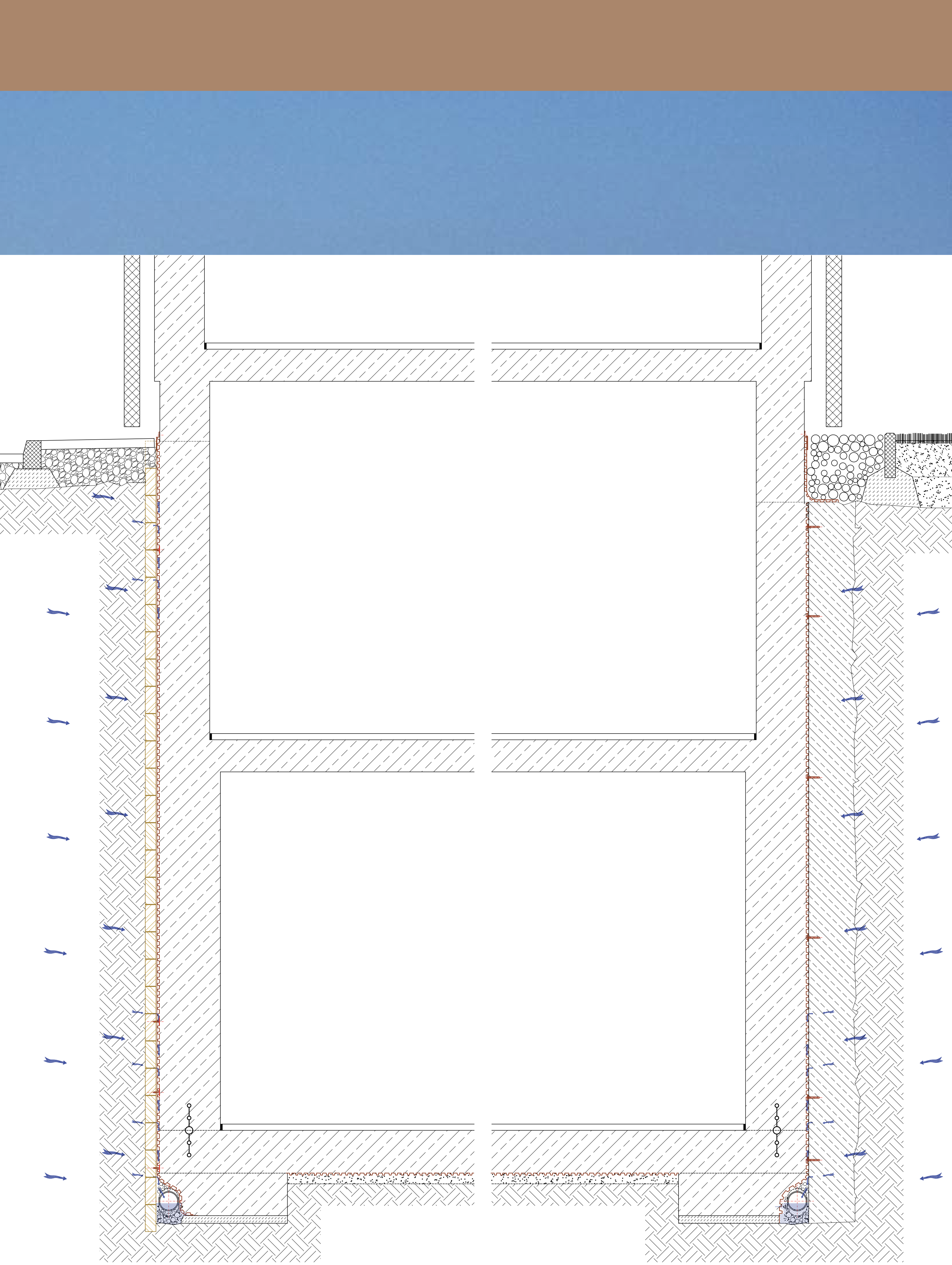
Civil engineering

Safety in pit lining

When a new building is erected in the centre of a town, there is generally not enough room for allowing the sides of the excavation to slope naturally. Particularly on sites that are wedged in between two existing buildings, where every inch counts, excavation sites are normally shored up to keep the soil from subsiding. The linings that are used in these applications must be quick and economical to build, largely waterproof, and robust as well as safe to avoid any danger to the neighbouring buildings. For these safety-related reasons, building authorities demand structural calculations for cleadings.

What kind of lining is actually used depends on a host of very different constraints including the condition of the soil, soil pressure, the underground water level, and the loads exerted on the pit by neighbouring buildings, traffic flows, or special climatic conditions. Further criteria that need to be figured in include faults originating in the pit itself and, of course, the cost of building and operating the lining and the water management system.

Lining types may be either temporary or permanent, and these, in turn, may be relatively waterproof, partially permeable (allowing filtered water to pass), or fully permeable (allowing water to pass unfiltered).
Many cleading varieties absolutely call for efficient structural drainage, for seepage water traversing the lining under pressure will later on affect the waterproofing of the building itself and may even, under unfavourable conditions, give rise to structural problems. If the contiguous building element is to be made of waterproof concrete, care must be taken to ensure that no seepage water can penetrate to the concrete during the pouring and subsequent setting process.



Permeable linings.

Partially permeable linings.

DELTA®

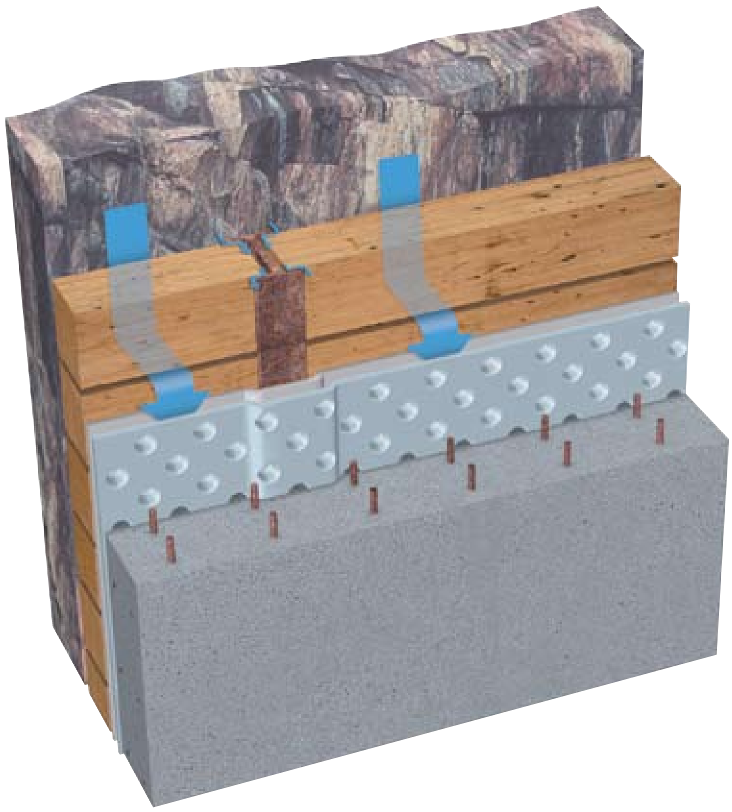
Permeable

Timber walls / 'Berlin' lining

One of the most common methods of securing the sides of an excavation is timber walling. This horizontal lining is made by inserting planks, square or round timbers, precast reinforced concrete slabs, or trench sheeting between piles rammed into the floor of an excavation. Rolled-steel sections, steel girders, reinforced-concrete piles or unreinforced concrete piles with permanent shells may serve as vertical elements. The most popular variant of timber walling is the classical 'Berlin' lining technique, so called because this method was developed in the 1930s for the construction of the first 'Berlin' subway. It involves manually removing the soil between the piles along the edge of the excavation, pushing planks that have been cut to size between the flanges of the piles, and hammering in wedges to press them firmly to the soil. For practical and other reasons, 'Berlin' lining is still one of the most commonly used cleading methods: it may be used in almost all types of soil, and it may be optimally adapted to obstructions such as pipes, shafts, or old foundations. For this type of lining, however, the bottom of the pit must be above the underground water level.

The 'Essen' and the 'Hamburg' lining method are common variants of the 'Berlin' timber wall.

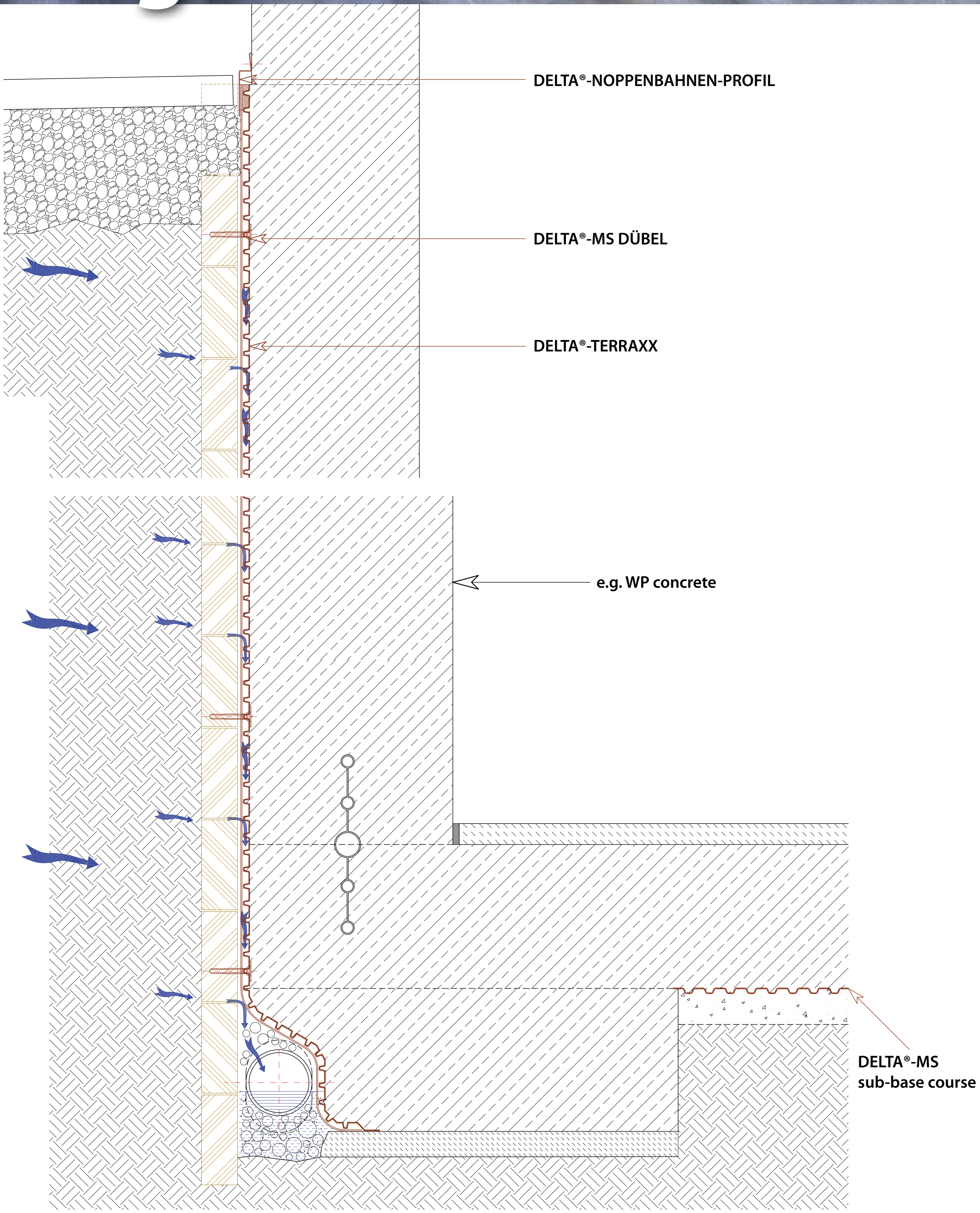
As timber walls are not waterproof, it is common for seepage water to emerge from large areas of the lining. This holds particularly true for the 'Berlin' lining whose wooden components normally rot away completely over the years. Such seepage water may be effectively conveyed away by a surface drainage system such as DELTA®-TERRAXX. Any drainage system must be equipped with a geotextile for filtration because seepage water may contain solids that would otherwise clog up the drain.



'Berlin' lining.

'Berlin' lining: Volkswohlbund building in Dortmund.

linings



Cross-section of a permeable lining.

Permeable linings

Bored pile walls as a reliable support

Bored pile walls constitute a permanent method of shoring up vertical earth walls. Featuring a much greater bending stiffness than, for example, timber walls, they are also used if the lining is to be integrated into the future building, as a cellar wall, for instance. Standing side by side, the cast-on-site piles of this lining are made by filling pre-drilled holes with concrete. In the presence of neighbouring buildings, the advantage of this method is that it does not require pile drivers which generate a great deal of noise and vibration. Unless they overlap, bored pile walls are rarely water-proof so that seepage water may penetrate the lining across large surfaces. This seepage water may be drained away by a structural drainage layer such as DELTA®-TERRAXX installed with the geotextile facing the pile wall.

DELTA®-TERRAXX in a bored pile wall.

Bored pile wall before the application of a drainage layer.

Partially permeable linings

Timber walls with shotcrete

A special variant of timber walling is the so-called 'Essen' lining which is used in slightly inclined walls featuring a slope and back anchors. The slope is secured by vertical piles spaced 1.50 to 2.00 m apart. The spaces between the piles are first covered with wire netting, rib mesh, or steel wire mesh and then covered with shotcrete to protect them from erosion.

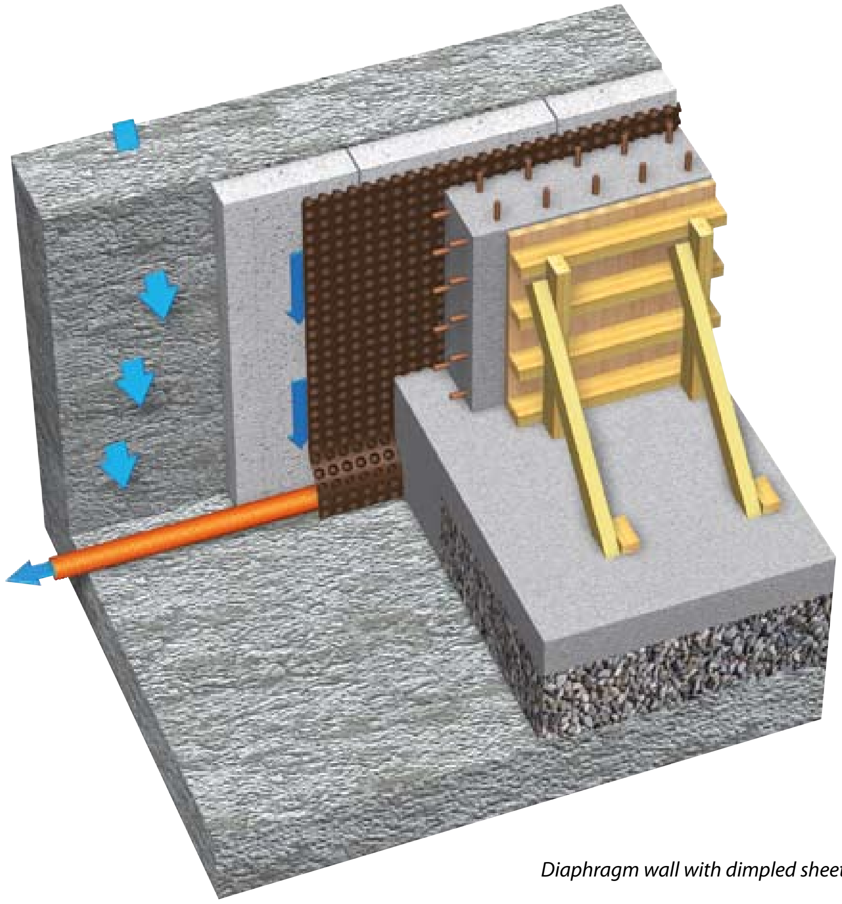
In 'Berlin' timber walls, too, shotcrete is sometimes used to stabilise the lining. Shotcrete is applied because it ensures that a lining is largely waterproof and will permit only 'filtered' water to pass. This eliminates the need for a geotextile as a filtration layer. Any seepage water that penetrates the lining may be drained away by dimpled sheets, such as DELTA®-MS 20 or DELTA®-MS.

'Essen' lining with DELTA®-MS.

Partially permeable

Diaphragm wall as part of a building

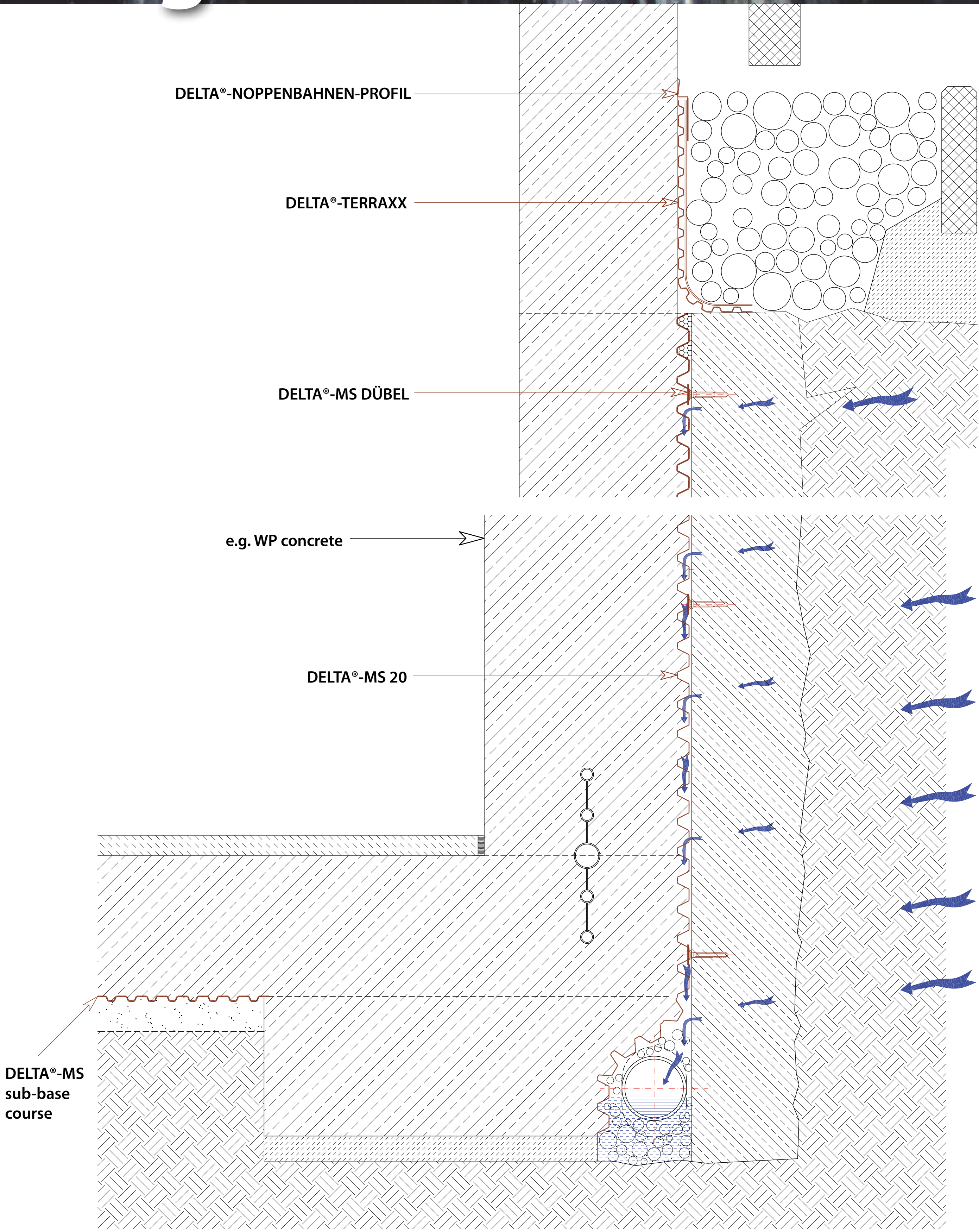
Diaphragm walls, also called curtain or slurry walls, on the other hand, are largely waterproof. They are made by pouring concrete into a trench 0.40 to 1.20 m wide and up to 40 m deep that is dug by special diaphragm wall excavators. The trench is stabilised by filling it with slurry (normally a bentonite suspension, i.e. a mixture of bentonite and water). After the reinforcing cage has been inserted, the concrete is poured in, forcing out the stabilising slurry. Diaphragm walls may be made either by pouring one segment after the other or by the pilgrim process, in which every other segment is left out at first.
Walls made in this way often become part of the future building. Like all concrete walls that are cast in place, diaphragm walls may let water through in places where construction joints or small cracks are present.
Such seepage water may be drained away by dimpled sheets like DELTA®-MS 20 or DELTA®-MS. No geotextile is required because the diaphragm wall acts as a filtration layer.



Diaphragm wall with dimpled sheet.

Example: diaphragm wall application in Duisburg.

Example: building project on the river Danube (Hungary) with DELTA®-MS.

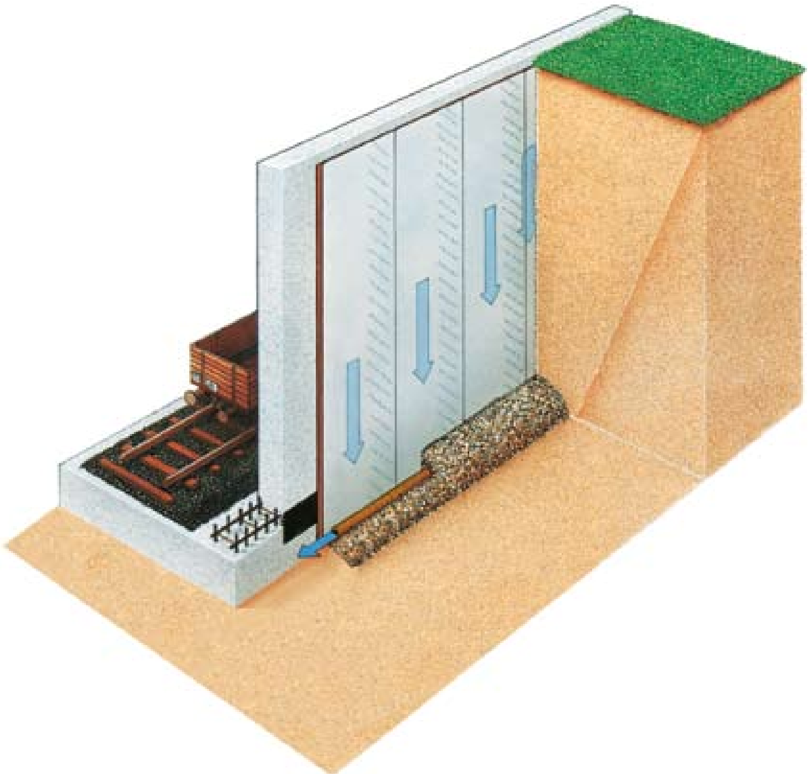


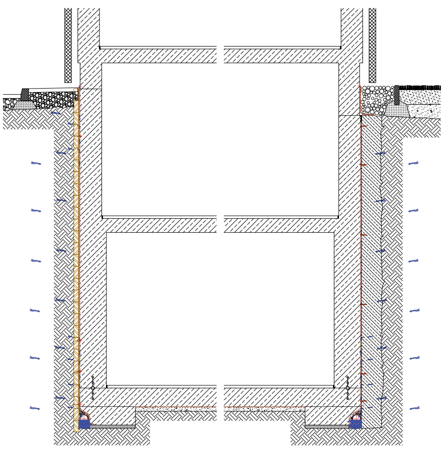
Cross-section of a partially permeable lining.

Other applications in ci

Reliable protection of retaining walls

To retain and secure escarpments where conditions do not permit a natural slope, retaining walls are required. They are found – often in angular form – in railway cuttings, tunnels, bridges, riverbank roads, access ramps to underground car parks, etc. Because their loading is normally unilateral, they are exposed to bending stress. Even if these walls are quite low, the possibility that their stability might be threatened by water pressure cannot be ruled out. This threat can be effectively controlled by installing a structural drainage system such as DELTA®-TERRAXX which consists of a dimpled sheet and a fused-on geotextile that holds back soil but allows water to pass.





Partially permeable/impermeable lining.

DELTA®-TERRAXX ensures stability.

Safe discharge of bridge abutments

It is the function of bridge abutments to transmit the vertical and horizontal forces caused by the weight and traffic load of the bridge as well as by braking and wind forces from the superstructure into the subsoil. By absorbing the pressure of the soil, abutments secure the embankment in its position.

A bridge abutment consists of a foundation, the abutment walls, and a surface to support the bridge bearing. All these must be configured to withstand movements and torsions caused by traffic, temperature differences, earthquakes, prestress, shrinkage, creep, etc. Bridge abutments absolutely require an outside drainage layer made of, for example, geotextile-covered DELTA®-TERRAXX dimpled sheets, for without such a layer, the structural stability of the abutment might be impaired by intruding water. In Germany, a standard drawing (WAS 7) issued by the Federal Road Research Institute prescribes installing efficient drainage layers behind bridge abutments to relieve them of head water.

Bridge abutment: well protected from headwater pressure.

DELTA®

The solution

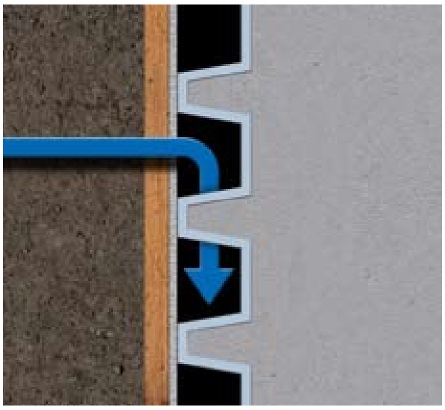
for permeable linings and soil

Retaining walls, bridge abutments, pile walls, and especially 'Berlin' timber walls should be equipped with efficient drainage sheets in conformance with the requirements of DIN 4095 concerning soil-boundary surfaces.

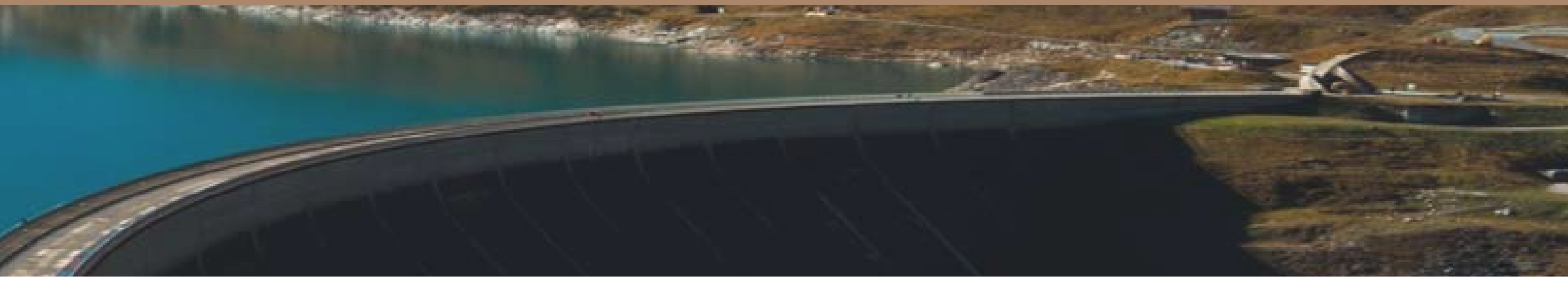
This means that there must be a filtration layer to keep the seepage layer from being clogged up by soil particles carried through joints in the lining.

The optimum solution to the problem is DELTA®-TERRAXX with its twin function as a filtration and seepage layer. The fused-on filtration geotextile should face the water-bearing layer. Self-adhesive overlap zones prevent cement sludge from entering and clogging up the seepage layer when concrete is poured. Because its dimples are arranged diagonally, DELTA®-TERRAXX is capable of moulding itself very closely to the shape of shell-less pile walls.
Two more geotextile-laminated dimpled sheets that are suitable for such applications are DELTA®-GEO-Drain TP 800 and DELTA®-NP-Drain.

Water seeping in through the lining or the ground is filtered by the geotextile and drained away by the dimpled sheet.



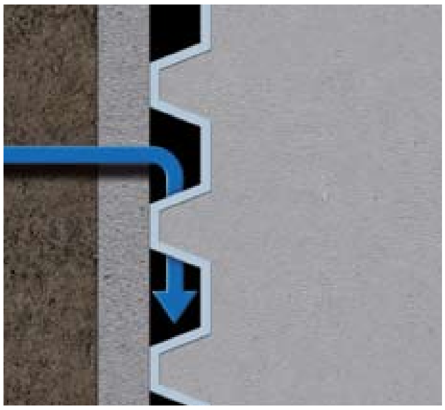
Properties	DELTA®-GEO-DRAIN TP 800	DELTA®-TERRAXX	DELTA®-NP DRAIN
Dimpled sheet	HDPE, brown	HDPE, silver	HDPE, brown
Filtration geotextile	PP grey	PP grey	PP grey
Dimple height	9 mm	9 mm	8 mm
Compressive strength (transient loading)	650 kN/m^2	400 kN/m^2	150 kN/m^2
Compressive strength (permanent loading)	200 kN/m^2	90 kN/m^2	70 kN/m^2
Tensile strength	6.0 kN/m^2	6.0 kN/m^2	6.0 kN/m^2
Opening size O90	150 µm	150 µm	110 µm
Dynamic perforation resistance	40 mm	40 mm	40 mm
Max. installation depth	20 m	10 m	7 m
Drainage capacity in l/s · m i=1			
Without compression	3.5	3.5	2.25
At 20 kN/m^2	3.2	3.1	2.06



for partially permeable linings

On diaphragm walls or shotcrete linings, the 'bare' dimpled sheets of the DELTA®-MS 20 or DELTA®-MS type will safely perform their function. They may be installed either horizontally or vertically as permanent shuttering between a shotcrete lining or diaphragm wall and the concrete wall of a building, with the dimples facing the lining.

Acting as a filter, the shotcrete or concrete layer keeps the seepage layer free from soil particles. This approach permits draining away and/or diverting intruding water under controlled conditions during the construction phase so that it cannot interfere with the setting process of concrete, especially waterproof concrete. Once the structure has been completed, any intruding water will be drained away without any pressure.



Properties	DELTA®-MS 20	DELTA®-MS
Dimpled sheet	HDPE, brown	HDPE, brown
Dimple height	20 mm	8 mm
Compressive strength (transient loading)	200 kN/m²	250 kN/m²
Compressive strength (permanent loading)	70 kN/m²	90 kN/m²
Drainage capacity in l/s · m i=1		
No compression	10.0	2.25
At 20 kN/m²	8.40	2.06

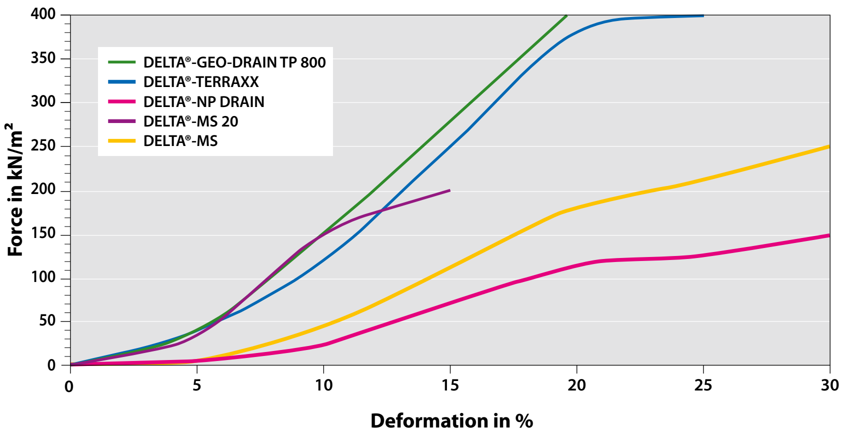
Performance characteristi

Compressive strength under transient loading

As in all modern drainage systems, the drainage capacity of DELTA® dimpled sheets is influenced by local compression loads. Compression will crush any drainage material to a greater or lesser extent. In the field, dimpled sheets may be exposed to transient pressure (caused by the shuttering, for example) as well as permanent loads (e.g. soil pressure).

Example:
When exposed to a transient pressure of 250 kN/m² (corresponds to a load of 25 t/m²), DELTA®-TERRAXX will be compressed by 15 %.

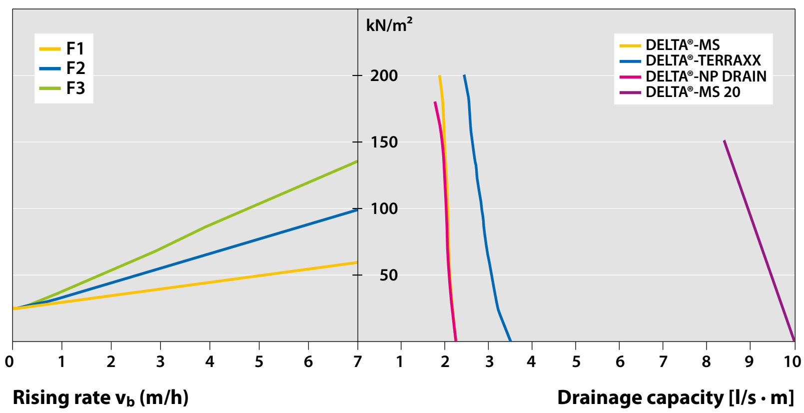
Compressive strength, transient loading



Shuttering compression / dimpled sheets as permanent shuttering
Dimpled sheets are often used as permanent shuttering, meaning that concrete is poured directly against them.
Essentially depending on the consistency of the material and the rate at which it rises as it is poured, the pressure exerted by freshly-poured concrete is approximately hydrostatic. Its maximum pressure can be limited by restricting the rising rate. Concrete will exert pressure only until it has settled.

Example:
Concrete belonging to the F2 consistency class that is poured at a rate of 5 m/h will exert pressure amounting to about 60 kN/m² on the shuttering. Under these conditions, the water drainage capacity of DELTA®-MS 20 will be about 9.4 l/s · m.

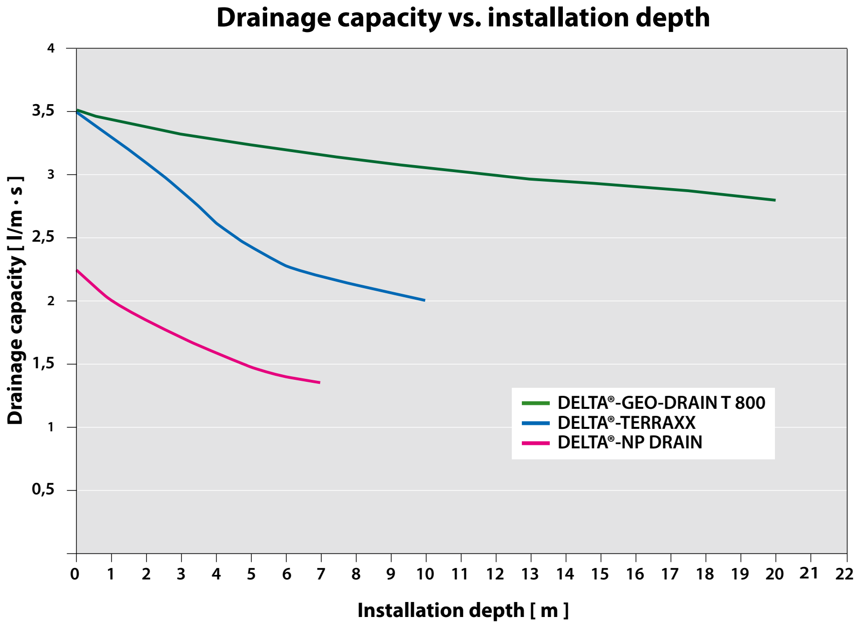
Shuttering pressure as per (t_E=5h)



Compressive strength under permanent loading

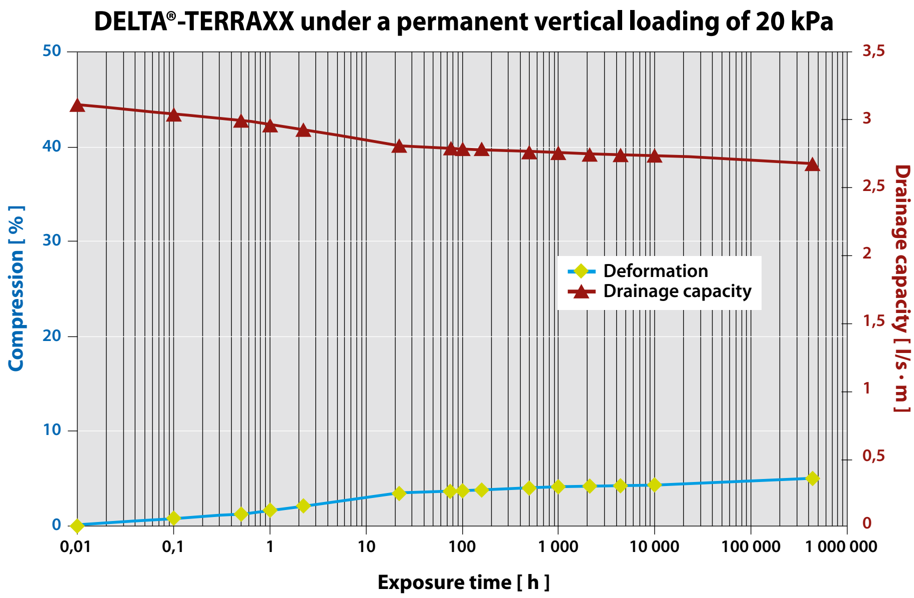
Permanent loading and installation depth
Acting permanently on the structure of a building and, by the same token, on any dimpled and drainage sheets installed, soil pressure depends on installation depth. The drainage-capacity figures quoted in the diagram are based on long-term tests extrapolated to show the condition of the sheets after 50 years of use.

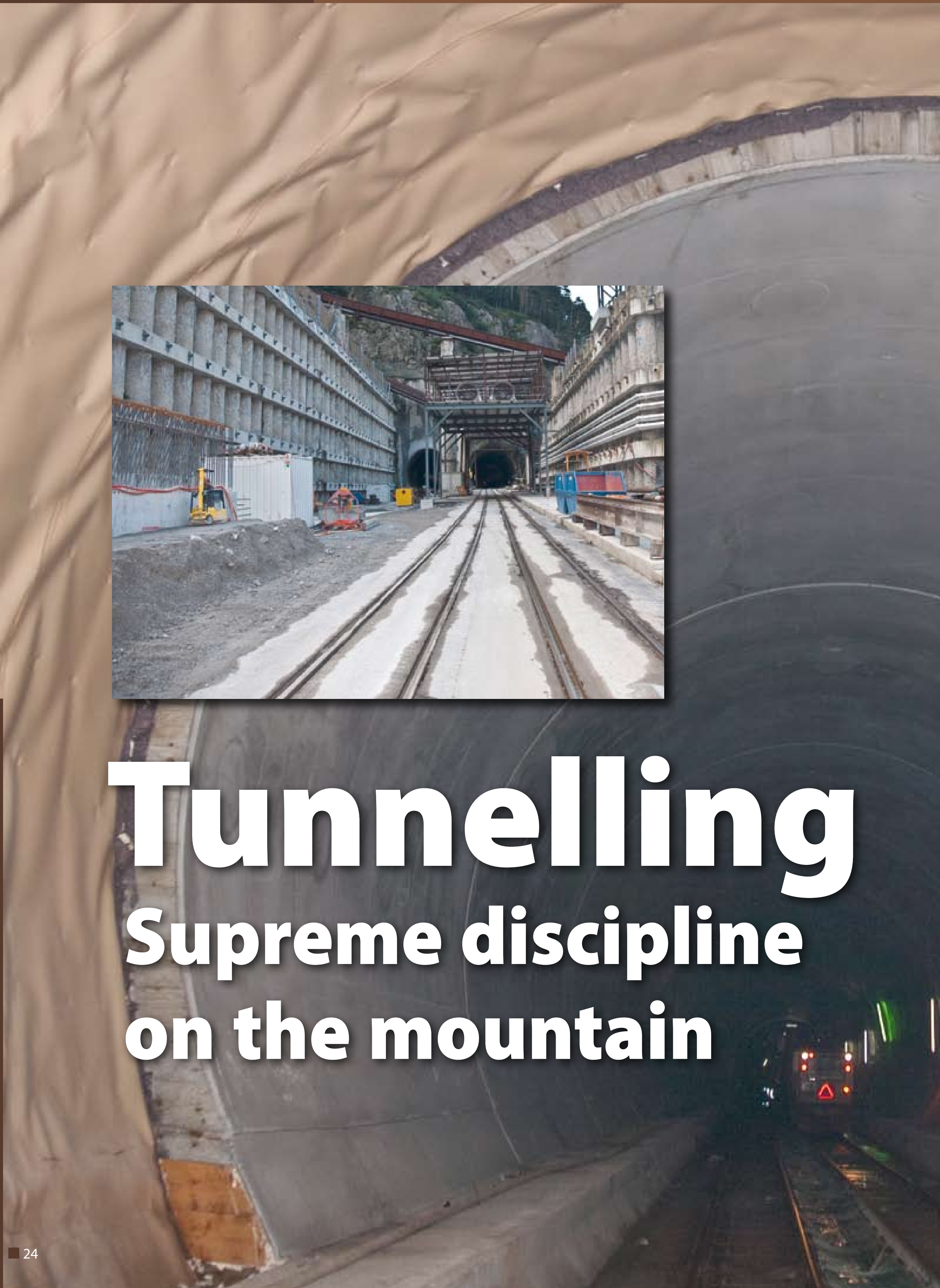
Example:
When installed at a depth of 3 m, the water-drainage capacity of DELTA®-TERRAXX amounts to 2.8 l/s · m.



Drainage capacity under permanent loading
An independent test institute has investigated the way in which the drainage capacity of DELTA®-TERAXX changes over time when exposed to a permanent loading of 20 kN/m². Measurements were conducted over a period of one year and extrapolated to 50 years (1 000 000 h).

The result:
DELTA®-TERRAXX offers maximum safety. The brown and blue curves indicate drainage capacity and deformation, respectively. Both are shown as a function of exposure time.




Tunnelling

Supreme discipline on the mountain

Tunnel builders make use of millennia-old knowhow from the mining sector where galleries are secured with props and timbering as they advance. Similarly, they use techniques gleaned from barrel-vault construction.
Any tunnel project demands exact information about the geological condition and strength of the rock as well as about the configuration, composition, and course of its layers. Further factors of crucial importance include the water regime of the rock layers, the pressures that occur, and analyses of soil mechanics. A 'draft cross section' describes the confines of the clear space, the strength of the lining, the waterproofing, the water management, and the ventilation.
As a general rule, a tunnel consists of 2 tubes, one inside the other – the outer and in the inner shell. Depending on the condition of the rock, the water situation, and the configuration of the outer shell, the arch as well as the floor of a tunnel may be exposed to water intruding from fissures and, if the overburden of the construction is thin, by water seeping in from the surface.

In such cases, effective drainage is of the utmost importance during building as well as in the completed state. Whether or not a tunnel will remain stable and usable in the long run crucially depends on whether its inner shell and floor have been reliably protected from intruding water and any frost damage that may ensue. Aggressive water emerging from the rock may attack and destroy concrete shells and steel reinforcements.
Surface and fissure water that intrudes between the inner and the outer shell must be caught and drained from the crown, the bench, and the floor of a tunnel by structural drainage and seepage layers under controlled conditions.
Particularly where aggressive water from fissures is present, cost-efficient waterproofing systems not designed to withstand headwater pressure may be employed when combined with efficient drainage.

If a tunnel is situated above the underground water table and the fissure water is free from aggressive components, seepage or fissure water impinging on the crown and bench sections may be drained away laterally to the base of the tunnel. In such a case, no waterproofing or drainage is needed in the tunnel floor, which is why this arrangement is called the 'umbrella principle'.
Wraparound waterproofing is normally executed in two layers.

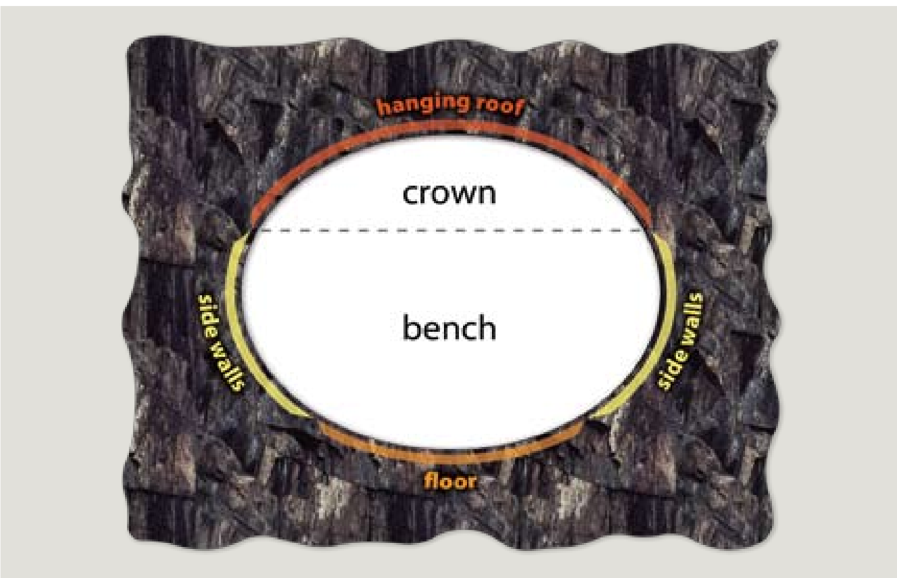
Dimpled and drainage sheets for tunnel construction are often developed for specific customers and occasionally subject to extensive quality-assurance processes.

DELTA®-MS 20 and DELTA®-MS are standard drainage sheets for tunnel construction. DELTA®-AT 800 and DELTA®-AT 1200 are specially developed heavy-duty dimpled drainage sheets that are used, for example, in the Gotthard base tunnel.

When waterproof concrete is used in the building of a tunnel, it is highly advisable as well as rational to install a drainage system for protection even in the building phase as this kind of concrete may not be exposed to seepage water or hydrostatic pressure during setting.

Dimpled sheets are necessarily perforated by the process of fastening. This, however, is no drawback since it is not the dimpled sheet but the concrete inner shell (if made of waterproof concrete) or an extra layer of plastic sheeting which guarantees water impermeability. The function of the dimpled plastic sheet is to act as a seepage layer and thus relieve the waterproofing by allowing seepage water to drain off without pressure.

Building and driving methods
In tunnel building, a basic distinction is made between the cut-and-cover method and the closed mining method in which a tunnel is driven ahead from one or both of its end points.



***The major elements of a tunnel are** the crown (the upper third of the tunnel cross-section), the bench (the lower part of the tunnel cross-section), the hanging roof (the ceiling of a tunnel), the side walls, and the floor.*

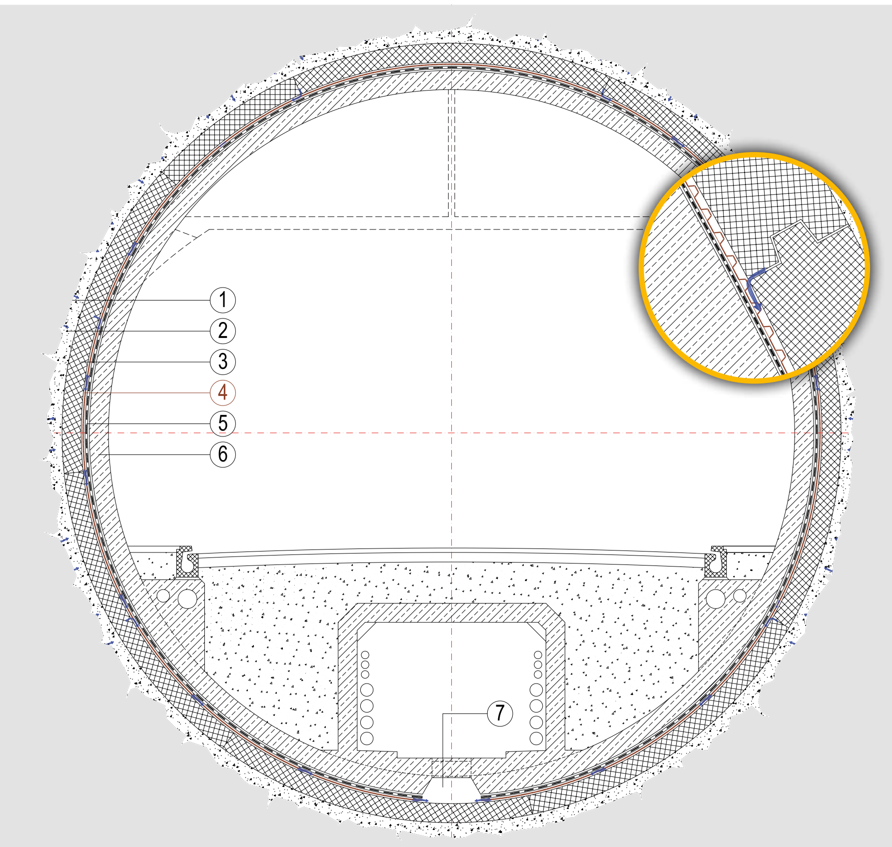
Underground tunnel-

Enclosed structures with tubbing segments

To build a tunnel entirely under the ground, shield or boring machines TBM are used. The design of these machines only permits circular cross-sections. Full-section excavation protects the rock and normally makes for construction times that are shorter than in partial-section excavation. However, it involves a relatively great operational effort, and it is rarely employed where the condition of the rock is difficult because it does not permit reacting to unforeseen situations flexibly enough.

Tubbings
Tubbings are prefabricated concrete segments used as stiffeners in tunnel construction. As a general rule, seven segments form a complete ring. A tunnel is composed of a number of such rings.
Tubbings are laid by tunnel boring machines that brace themselves for traction against the sides of other tubbings laid previously.

Joints between tubbings are sealed with waterproofing tapes made of neoprene etc. Yet tubbings are not always really waterproof. Leaks develop especially in joints between two tubbings and where cracks are present in the edges of the prefabricated components. This is why it is advisable to apply drainage sheets which are often laid out across the entire surface or, more rarely, only where they are needed.



Cross-section of a tubbing tunnel: ① Theoretical excavation ② Circumferential gap grouting ③ Tubbings ④ Drainage sheet ⑤ Waterproofing layer ⑥ Inner shell ⑦ Line drainage.

Seven tubbings form one ring.

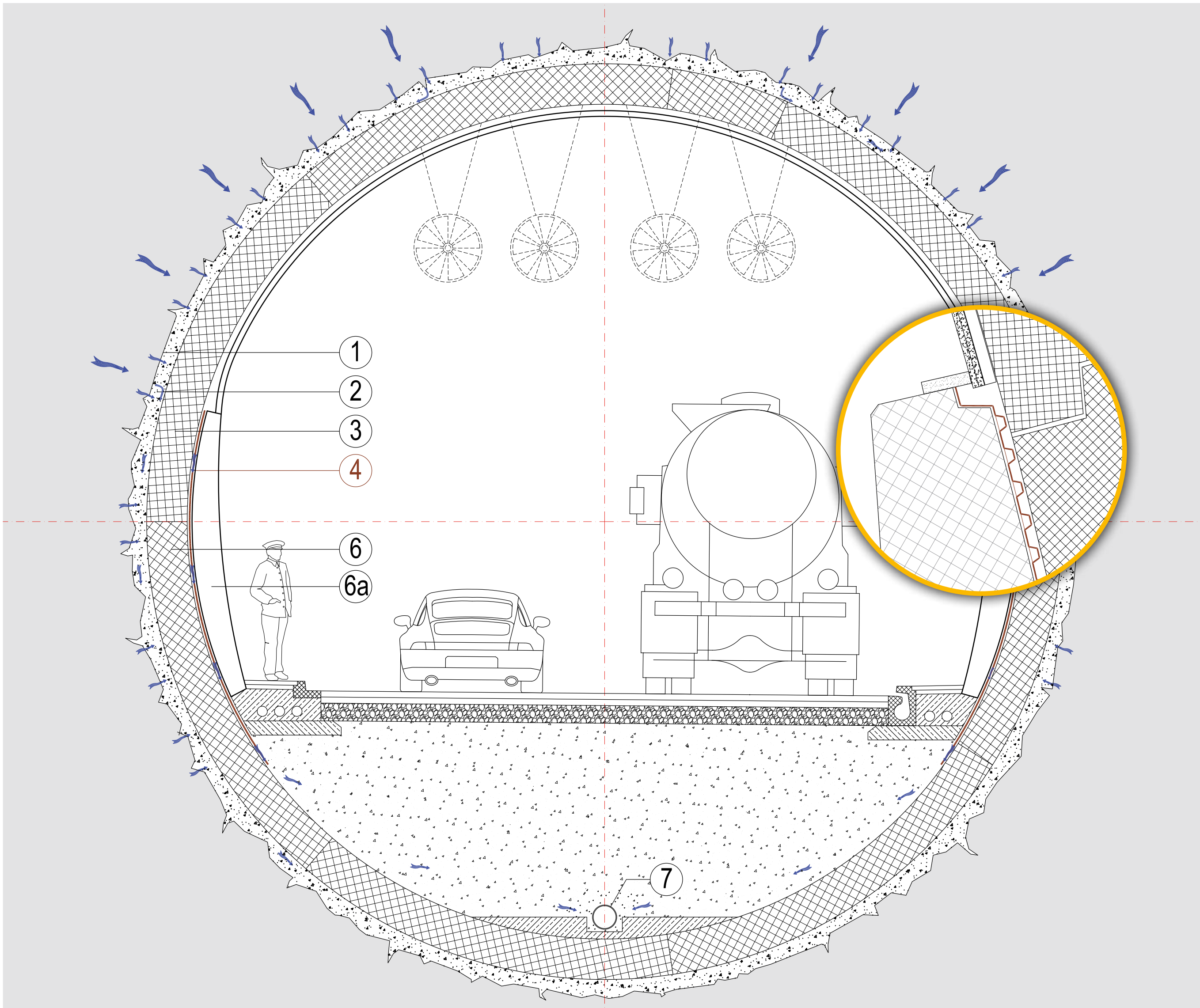
Leaks before the application of a drainage sheet.

-building methods

Examples from the field

The tunnel under the river Weser was completed in 2004. Linking Bremerhaven to Nordenham, it is 1.6 km long. Both tubes were built from tubbings by a TBM. For extra safety, 100 000 tonnes of rock were poured into the Weser to consolidate the layer of soil between the river and the tunnel. The lowest point of the tunnel lies 40 m below sea level and 20 m below the Weser.

To protect the supporting tubbing structure, the side walls were reinforced with concrete to protect them from collisions. Between the collision protection and the tubbings, a permanent shuttering of DELTA®-MS sheets made of a special formulation was inserted to form a seepage layer. The crowns were sheathed with building slabs.
Tube 4 of the Elbe tunnel in Hamburg was built on the same design principle.



Example: cross-section of the Bremerhaven Weser tunnel: ① Theoretical excavation ② Circumferential gap grouting ③ Tubbings ④ Drainage sheet ⑥ Inner shell ⑥a) Collision protection from concrete ⑦ Line drainage.

Shotcrete: Safety in the mountains

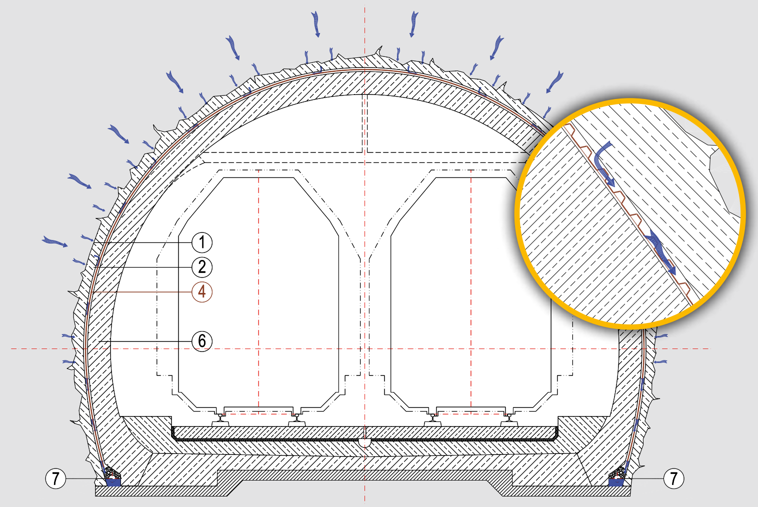
Tunnels are driven into the rock either by the traditional process of blasting or by tunnel-boring machines. Loose rock is transferred to conveyors by loaders and carried away.
In modern fully-equipped tunnels, exposed surfaces are secured by shotcrete, rock anchors, steel arches, and other building elements. As large fully-automated machines are employed, no timbering is required. This method is called shotcrete construction.

The construction element that essentially secures the rock is shotcrete together with anchors, reinforcement mats, and steel arches. This creates a positively-locked composite of building and rock that is free from cavities and ensures that most of the supporting effect comes from the rock. To avoid stress concentrations, tunnel cross-sections are kept circular or oval wherever possible.

One of the most important prerequisites on which the operational safety and longevity of a tunnel depends is to keep harmful rock water away from the inner sheathing and the traffic zone. This is why the efficiency and longevity of drainage layers is of particular importance in this context. Under-dimensioned drainage layers such as thick protection cloths may sinter up relatively quickly.

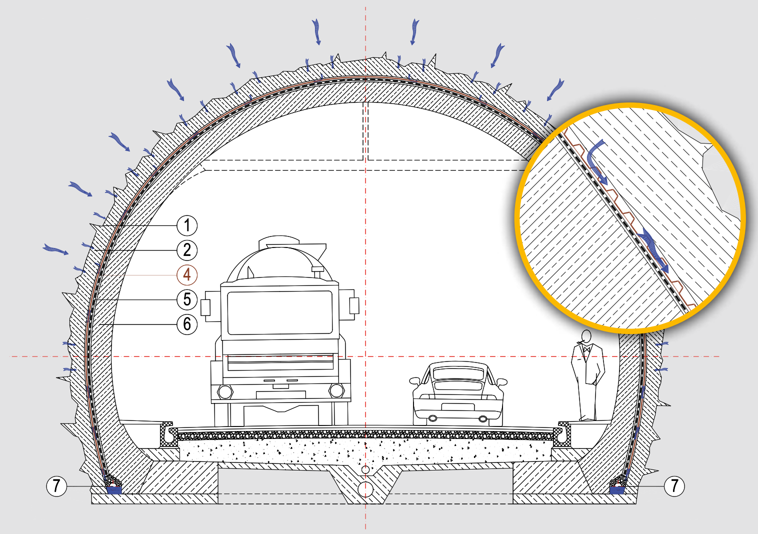
The term 'sintering' refers to a problem that tunnel builder knows: the formation of $CaCO_3$ deposits that are crystalline and infused with metal oxides. Whenever this substance cannot remain in solution because of the evaporation of water, temperature or pressure differences, or the presence of nucleating agents, it will settle in the drainage layer. DELTA® dimpled sheets offer an efficient alternative in this case: their drainage capacity of 2.25 l/s · m to 10 l/s · m makes them rational and reliable tools for permanent water management in tunnel construction projects of all kinds.

Rock water drainage in tunnel construction



① Theoretical excavation ② Outer shell ④ Drainage sheet ⑥ Inner shell, WP concrete ⑦ Line drainage.

Example 1: Railway tunnel featuring spring-mass plate vibration damping and WP-concrete waterproofing, with the dimpled sheets serving as permanent shuttering. Seepage water is thus kept away during the setting phase.

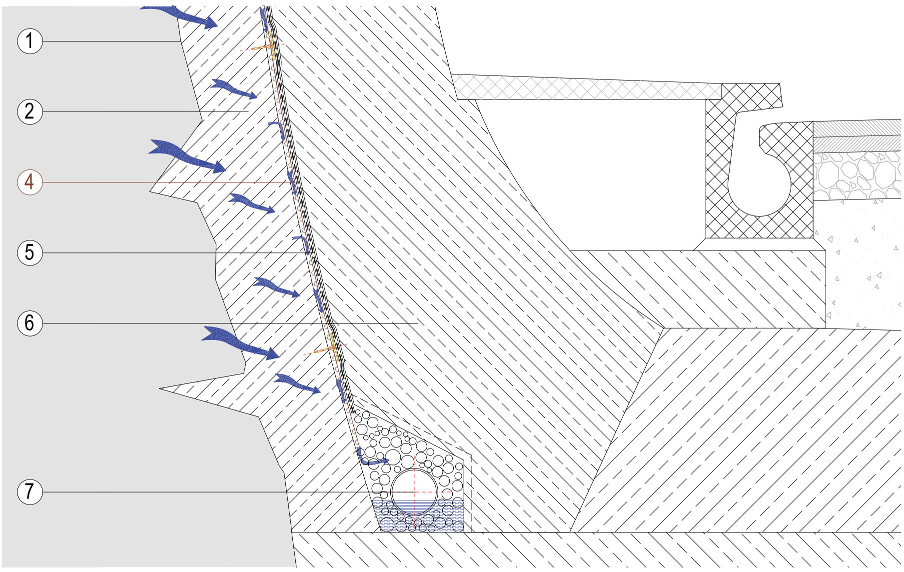


① Theoretical excavation ② Outer shell ④ Drainage sheet ⑤ Waterproofing layer ⑥ Inner shell ⑦ Line drainage.

Example 2: Road tunnel featuring plastic-sheet umbrella waterproofing. Drainage by dimpled sheets that convey seepage water to the drain pipe at the base. Optimum waterproofing protection (see Base detail).

-building methods

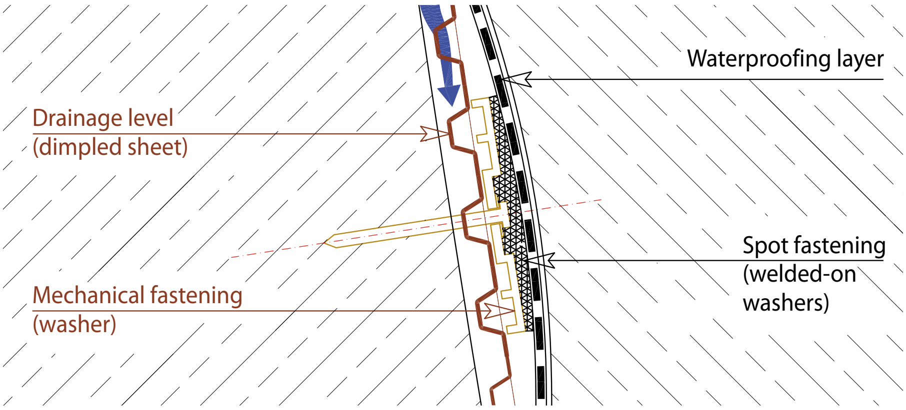
With the dimples facing outwards, i.e. against the surrounding rock or a shotcrete layer for stabilisation and filtration, they form a coherent system of channels through which any water emerging from the rock may drain away without obstruction (see base detail).



Example 2: base detail.

① Theoretical excavation ② Outer shell ④ Drainage sheet ⑤ Waterproofing layer ⑥ Inner shell ⑦ Line drainage.

The plastic waterproofing layers that are applied directly to the dimpled sheets and held in place by washers (see fastening detail) are not exposed to any hydrostatic water pressure from the start.

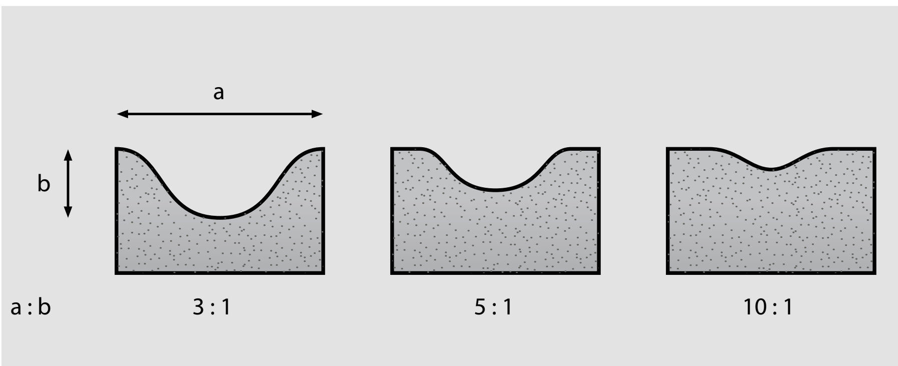


Detail drawing showing washer fastening.

Substrate condition for shotcrete outer shells

The condition of the substrate must be such that the dimpled sheet and/or the waterproofing layer are nowhere exposed to excessive local stress.

Depressions that are to be covered with dimpled sheets should have a minimum size of 20 cm and a diameter-to-depth ratio that should be no less than 10 : 1. Any sharp edges must be removed.



Depressions in shotcrete.

The solution

Dimpled sheets in the mining tunnel

The DELTA®-MS-20 and DELTA®-MS dimpled sheets are used standard for drainage in tunnel construction. The DELTA®-AT 800 and 1200 dimpled sheets are specially-developed heavy-duty drainage sheets that are used, for example, in the Gotthard base tunnel.

DELTA®-AT 1200 und DELTA®-AT 800
Featuring a drainage capacity of 3.5 l/s · m at i = 1, the extreme compressive strength of these heavy-duty drainage sheets makes them ideal drainage layers in areas exposed to heavy loads. DELTA®-AT 800 is a variant of DELTA®-AT 1200 that was developed for areas where compressive-strength requirements are less exacting. Dimensioned for a service life of 100 years, the sheets are characterised by extreme chemical resistance even at markedly increased temperatures underground (see the Gotthard tunnel). The drainage capacity of both sheets remains greater than 3 l/s · m even under high loads of 20 tonnes/m².

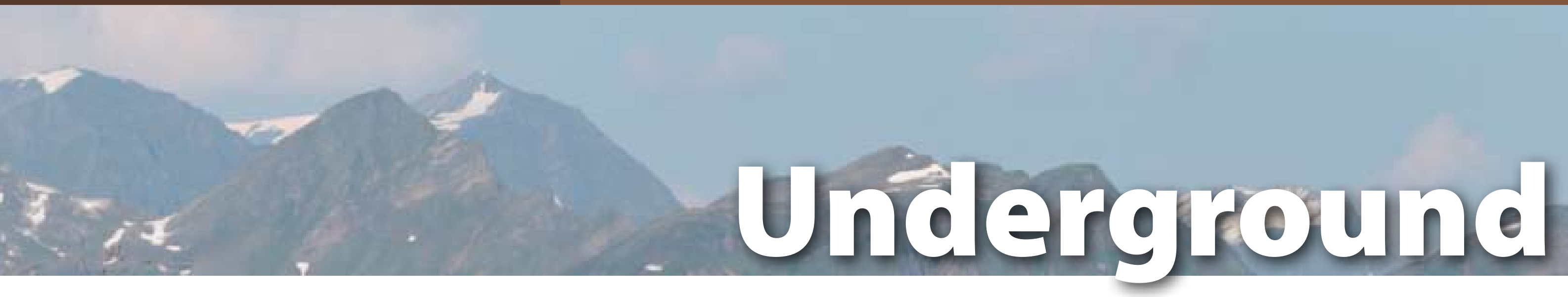
DELTA®-MS 20 offers many times the drainage capacity of normal dimpled sheets, which makes it even safer. Affording a drainage capacity of 10 l/s · m at a hydraulic gradient of i = 1, its 20 mm air gap offers enough reserves in the event of cross-sections being reduced by sintering over the years.

DELTA®-MS too, may be used in tunnel constructions with a lesser water yield; its 8 mm air gap offers a drainage capacity of 2.25 l/s · m at i = 1.

Properties	DELTA®-AT 1200	DELTA®-AT 800	DELTA®-MS 20	DELTA®-MS
Dimpled sheet	HDPE, brown	HDPE, brown	HDPE, brown	HDPE, brown
Dimple height	9 mm	9 mm	20 mm	8 mm
Compressive strength (transient loading)	950 kN/m²	650 kN/m²	200 kN/m²	250 kN/m²
Compressive strength (permanent loading)	min. 200 kN/m²	min. 200 kN/m²	70 kN/m²	90 kN/m²
Drainage capacity in l/s · m i = 1				
Without compression	3.5	3.5	10.0	2.25
At 20 kN/m²	3.5	3.5	8.40	2.06
At 200 kN/m²	3.2	3.1	–	–

Gotthard base tunnel



Underground

Example of a major project Gotthard base tunnel

The 'new railway link through the Alps' (NEAT) is one of the most spectacular tunnelling projects of the modern era, a 57 km tunnel that will be the longest in the world: the Gotthard base tunnel. Linking Erstfeld in the Swiss canton of Uri to Bodio in the Ticino, it consists of two tubes that run through the mountain at distance of about 40 meter. Two underground emergency stops (Sedrun and Faido) will permit passengers to leave the tunnel in the event of an accident.
At what is currently the world's longest building site, four tunnel-boring machines, each measuring 440 meter in length (trailer included) and 9.58 meter in diameter, have been chewing their way into the mountain, advancing 20 to 25 meter each day. In some segments where boring machines could not be used, the tunnel was blasted into the rock, advancing six to ten meter a day. The Gotthard base tunnel is built by the shotcrete method which produces a cavity-free bond between the tunnel structure and the rock. The concrete inner shell is at least 30 cm thick. The tunnel will probably be completed in December 2017.

The strictest standards apply to the project in matters of safety. This equally applies to the materials used, waterproofing and drainage sheets included. As only system solutions were accepted, Dörken entered a system partnership with a manufacturer of waterproofing layers. The resultant joint solution was certified and approved as a waterproofing system for the Gotthard tunnel by AlpTransit Gotthard AG.

Sheets used in the Gotthard tunnel must have a service life of no less than 100 years, and that under highly unfavourable environmental conditions, for the seepage and fissure water is highly alkaline in spots and may be as warm as 45 °C because of geothermal effects.

This is why a drainage sheet featuring a maximum of chemical resistance was specially developed for this project.

View of the Gotthard tunnel with DELTA®-AT 1200 installed.

Drainage sheet atop a shotcrete inner shell.

Initially, sheets are fastened only in the overlap zones.

DELTA®-AT 1200 is extremely robust and stable, having a square weight of 1 200 g/m^2 and a compressive strength of 950 kN/m^2.

During the entire process of development, harmonisation, modification, and authorisation, the new dimpled sheets had to undergo a very strict process of certification and examination. Thus, they were subjected to a 24-month ageing test in which they were exposed to water at up to 70 °C, an 0.5 % solution of sulphuric acid at 50 °C, and oxygen-enriched water at 70 °C, after which they were tested again.
The production of the sheets also has to meet extremely stringent standards. Samples are regularly taken from the production line and tested for compliance with formulation and quality requirements in an oxidation induction time (OIT) test.
In addition, rolls are regularly taken from the current production and tested by accredited Swiss laboratories for technical data compliance on behalf of the Swiss building supervision. Only those lots of dimpled sheets whose quality has been certified may be delivered to the Gotthard tunnel building site.

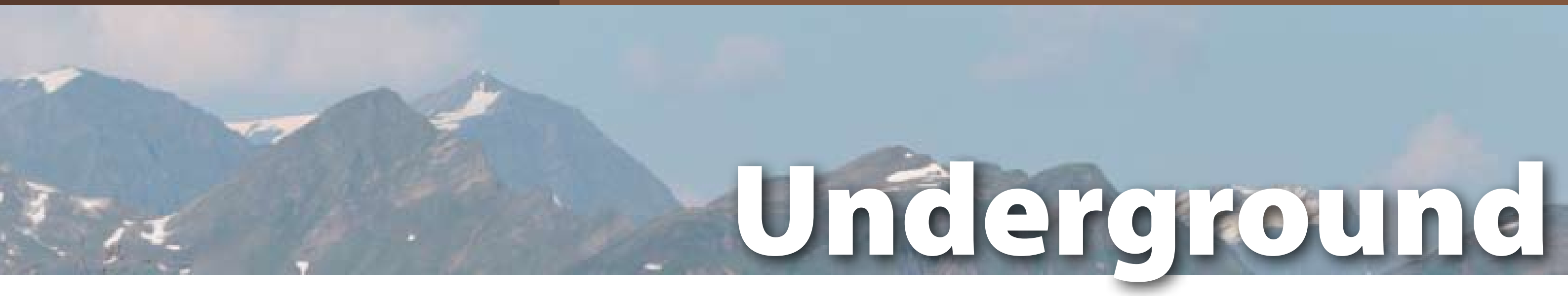
Another heavy-duty drainage sheet has been employed in the Gotthard tunnel since 2009: DELTA®-AT 800, a somewhat lighter variant of DELTA®-AT 1200, has been developed for those areas where less stringent requirements apply to drainage sheets.
Made from the same high-quality formulation, the service life of this sheet is just as long, but its square weight is 800 g/m^2 and its compressive strength 650 kN/m^2. Even so, its performance is still markedly better than that of normal drainage products for civil engineering.
So far, more than 500 000 m^2 of DELTA®-AT 1200 and 350 000 m^2 of DELTA®-AT 800 have been integrated in the Gotthard tunnel.

Additional fastening by washers to which the waterproofing will be welded later on.

Washers being fixed.

Laying the waterproofing layers.

DELTA®



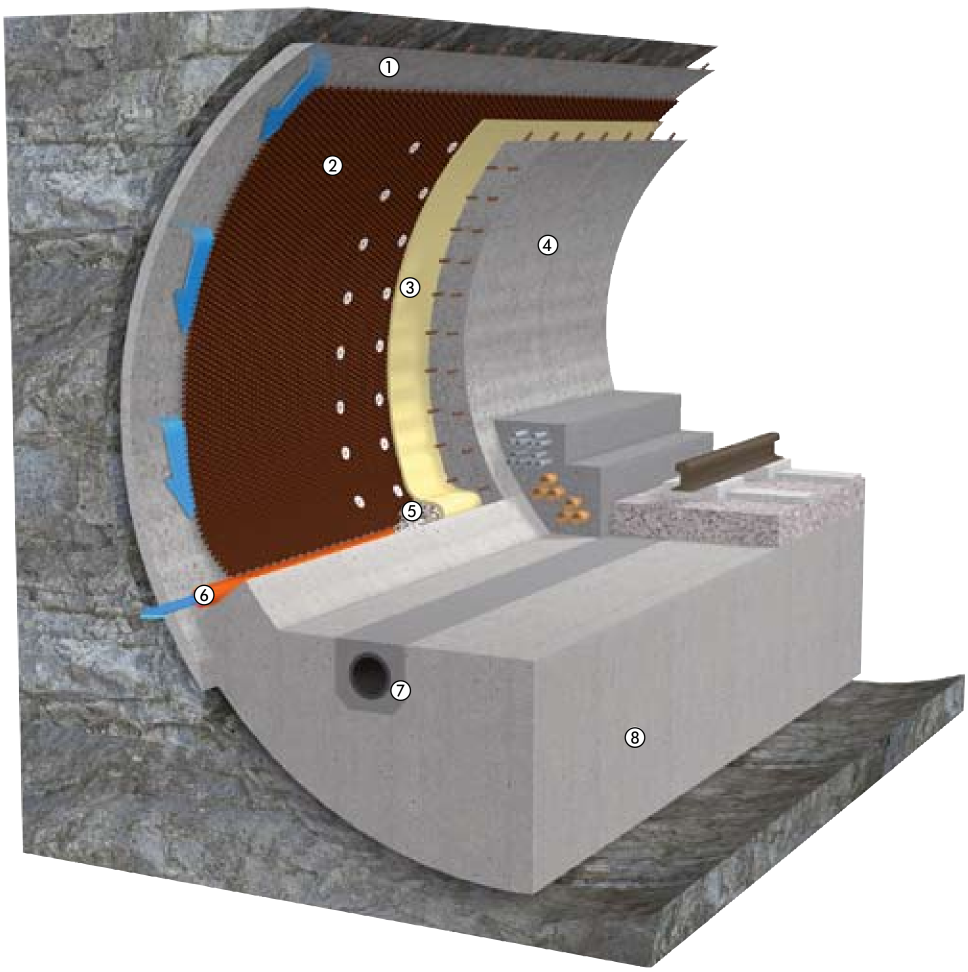
Underground

Example of a major project Gotthard base tunnel

Welding the waterproofing layers to the washers.

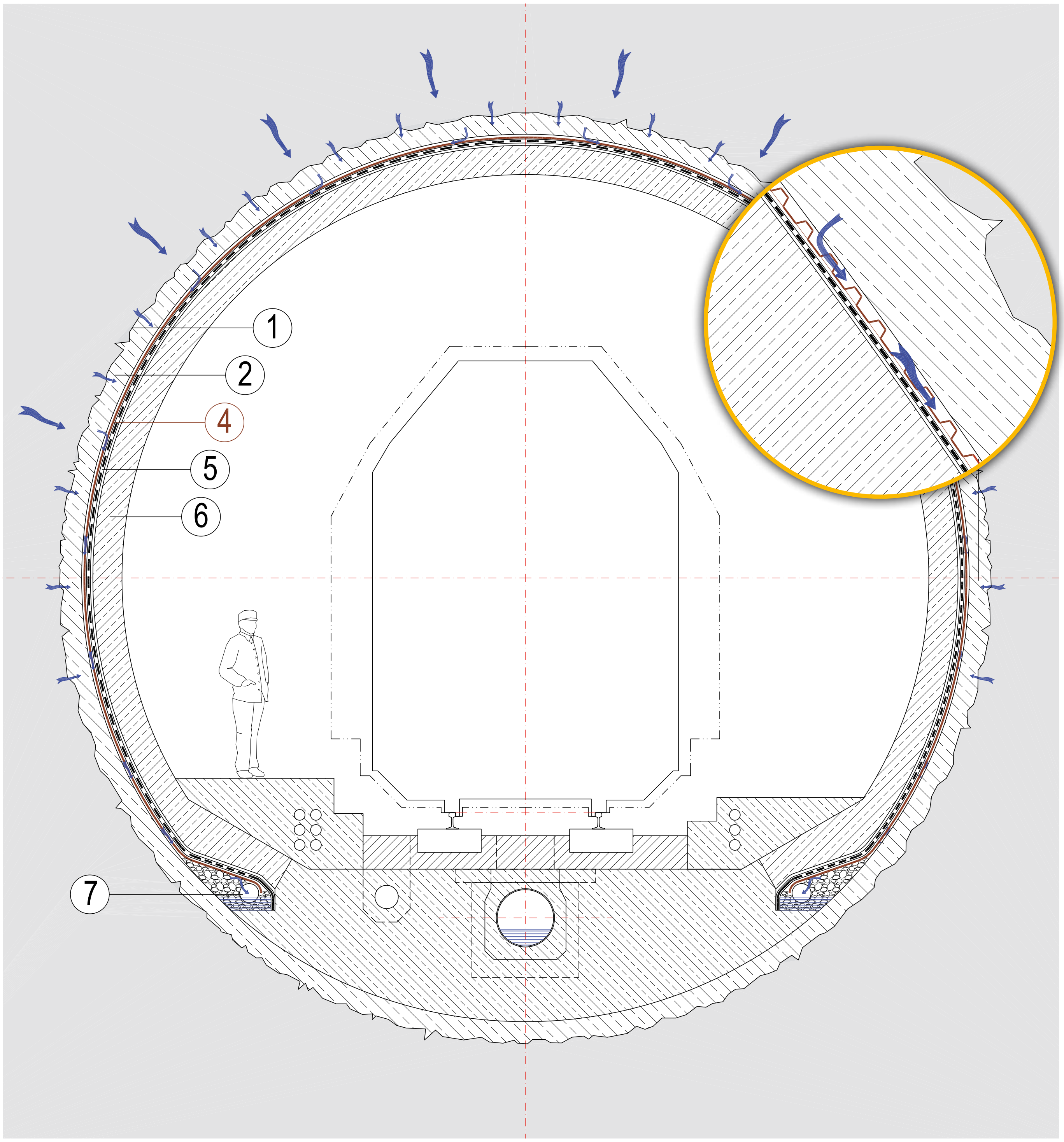
Sheets being fastened directly from the installation truck.

One layer follows another.

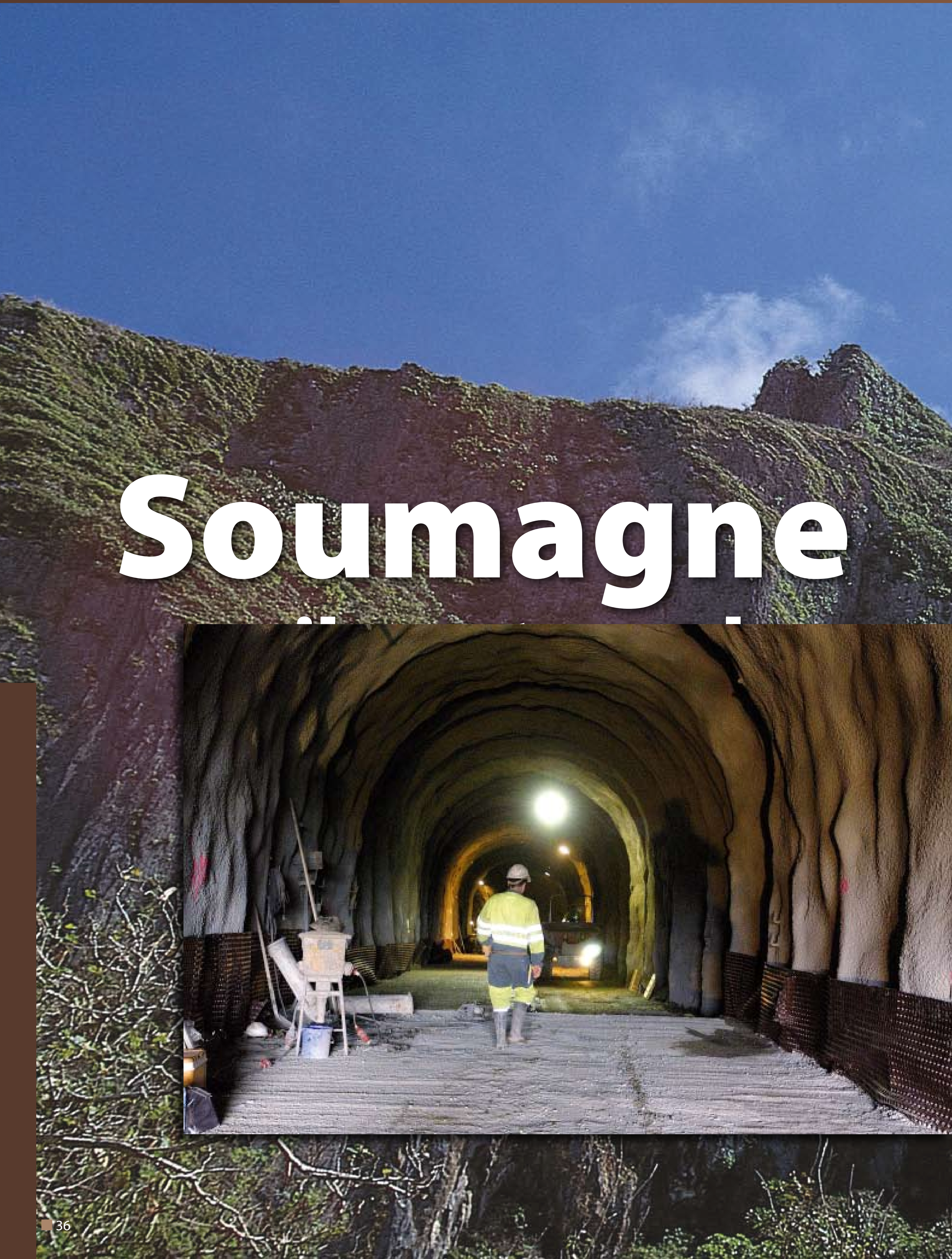


① *Excavation lining*
② *DELTA®-AT 1200 drainage sheet*
③ *Waterproofing layer*
④ *Tunnel vault (inner shell)*
⑤ *Drainage gravel*
⑥ *Line drainage*
⑦ *Underground water collection pipe*
⑧ *Concrete floor*

construction



Gotthard base tunnel cross-section showing drainage sheet.
① Theoretical excavation ② Outer shell ④ Drainage sheet ⑤ Waterproofing layer ⑥ Inner shell ⑦ Line drainage.



Soumagne

Example Soumagne railway tunnel

Between May 2001 and August 2005, Belgium's longest railway tunnel with an overall length of 6.4 km was built east of Liège.
There were three operations involved in excavating the tunnel: the crown came first, the bench next, and the floor last. The excavation was made by blasting.
The finished tunnel structure consists of an outer shell of fibre shotcrete reinforced with light supporting arches, heavier arches fastened to the rock with anchors being used only in exceptional cases. Next comes the drainage and waterproofing system, followed by an inner shell of in-situ concrete. The floor is made of reinforced concrete in 22 meter segments.

To catch water seeping from the rock and convey it to a drainage pipe at the base of the tunnel, DELTA®-MS was installed directly against the shotcrete layer. Its purpose is to keep headwater stress away from the tunnel waterproofing proper. In addition, it offers mechanical protection to the sensitive waterproofing that is laid out on partially extremely uneven ground, with depressions featuring a diameter-to-height ratio that occasionally reaches 5 : 1.

To save the expense of levelling these inequalities and reduce the quantity of shotcrete needed to equalise the surface, dimpled plastic sheets were used as a kind of liner in the depressions. The waterproofing could then be fastened directly onto the dimpled sheet.

DELTA®-MS 20 to protect the tunnel floor.

Putting up DELTA®-MS.

DELTA®-THENE T 300 for overlaps.

Underground

Example Soumagne railway tunnel

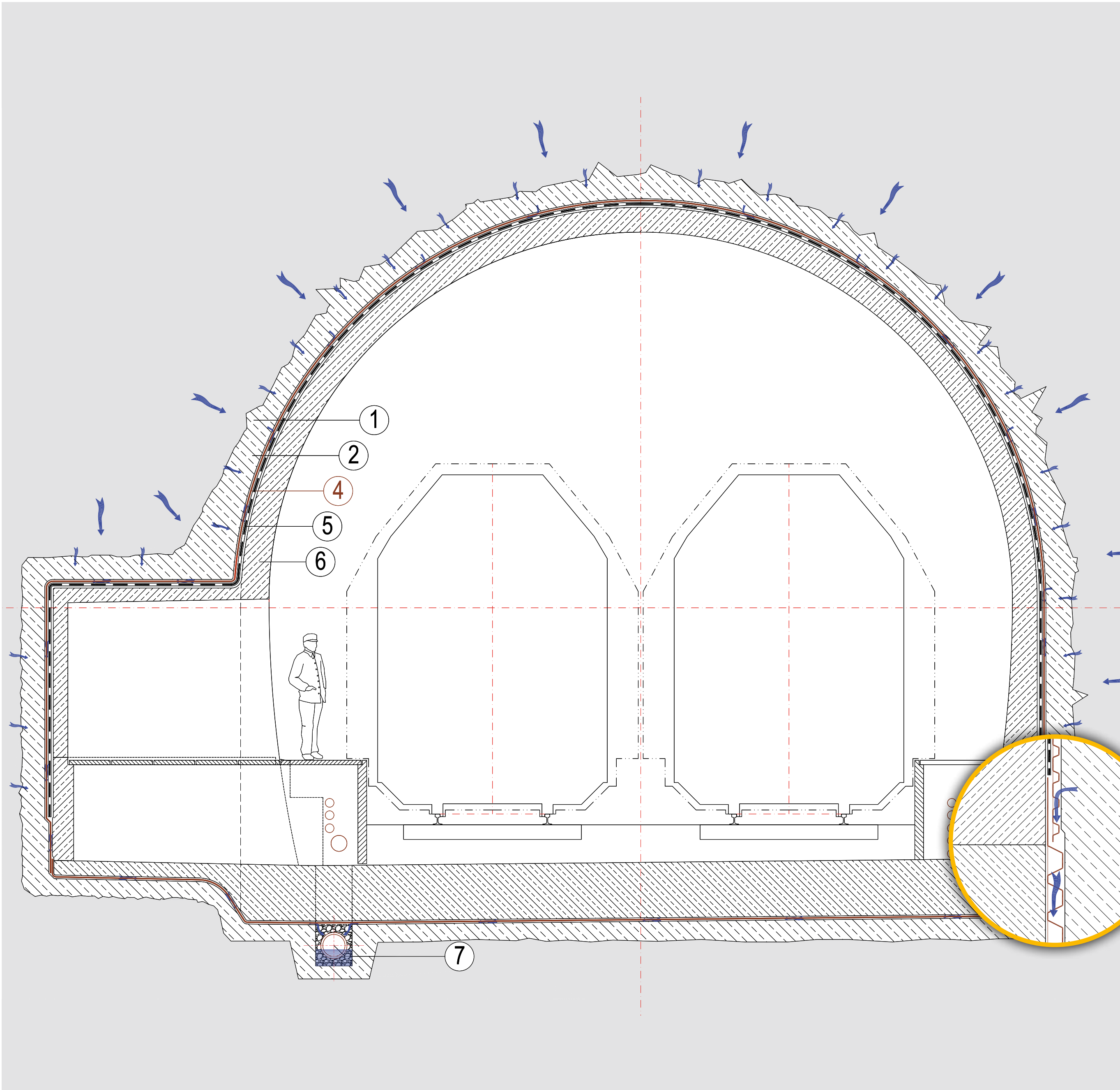
To protect the tunnel floor from water rising from below, DELTA®-MS 20 dimpled sheets were laid out at a slight gradient between the floor vault and the inner shell of reinforced concrete. By catching an average of up to 36 000 liter of water per hour and draining it away to the base of the tunnel, they reduced hydrostatic pressure so much that a flatter floor slab could be installed.

One detail was the seam between the horizontal seepage layer and the surface drainage of the tunnel vault. In this critical zone, the dimpled sheets were installed in a double layer. The horizontal seepage layer was run up vertically along the tunnel vault and overlapped by a wide strip of the vertical surface drainage. The overlaps between the drainage sheets along the floor were safely joined and sealed with 30 cm wide strips of DELTA®-THENE, a cold-setting self-adhesive bitumen waterproofing membrane.

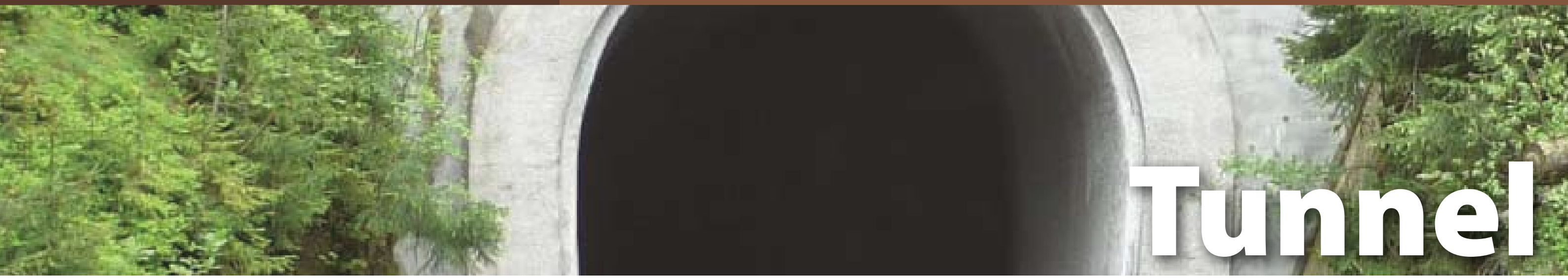
180 000 m^2 of DELTA®-MS and 70 000 m^2 of the 20 mm special dimpled sheet DELTA®-MS 20 were integrated in the tunnel of Soumagne

Sheets laid out double along joints.

DELTA®-MS 20 on the floor, DELTA®-MS on the wall.



Cross-section of the Soumagne railway tunnel
① Theoretical excavation ② Outer shell ④ Drainage sheet ⑤ Waterproofing layer ⑥ Inner shell ⑦ Line drainage.



Example railway tunnel Nové Hamry

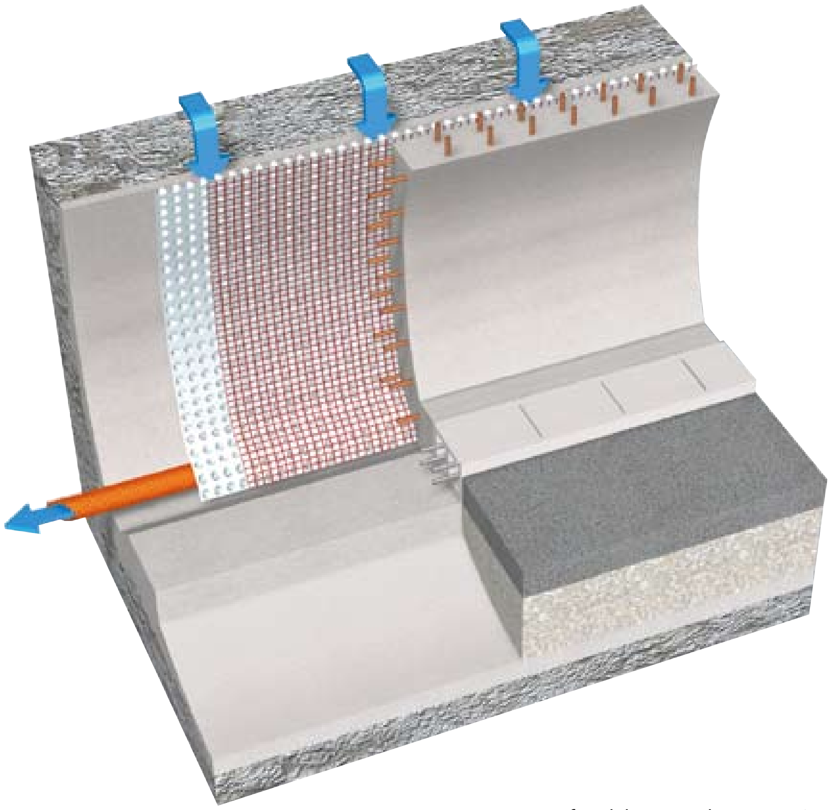
Many older tunnels leak because they are made of masonry, because their water-proofing is inadequate, or simply because of their age; long, dangerous icicles may form in them in winter. The vaults are not only wet; they also lose their structural stability as the mortar between the bricks leaches out.

Where railway tunnels are concerned, it frequently happens that the line cannot be closed for rehabilitation. In such cases, the tunnel must be partially dismantled section by section and rebuilt by the shotcrete method which, however, does not permit waterproofing the arch in its entirety.

The solution for rehabilitation

In many cases, water damage may be effectively prevented only by retrofitting a drainage system. By lining the arch with DELTA®-PT, a dimpled sheet with a fused-on plaster mesh, a gap is created against the face of the rock through which fissure water can drain away safely.

The fused-on plastic mesh offers safe anchorage to shotcrete being applied.



Retrofitted drainage sheet DELTA®-PT.

Properties	DELTA®-PT
Dimpled sheet	HDPE Translucent
Dimple height	8 mm
Compressive strength (transient loading)	70 kN/m²
Drainage capacity in l/s · m i = 1	
Without compression	4.39
At 20 kN/m²	3.6

rehabilitation

The railway tunnel complete with DELTA®-PT lining.

Example from the field
Nové Hamry railway tunnel in Czechia
The Nové Hamry tunnel is an old railway tunnel situated in Carlsbad county. It had several leaks which caused severe problems in winter because icicles formed below them. To rehabilitate the tunnel, a surface drainage layer was to be installed. This was done by fastening DELTA®-PT with its fused-on plaster mesh to the tunnel vault. Not only does the material provide efficient drainage, it also retains shotcrete safely. Sheets were welded together, and any penetrations were sealed. In the next step, a new reinforced inner shell was made of shotcrete in two passes.
2 100 m² of DELTA®-PT were integrated in the Nové Hamry tunnel.

A niche in the tunnel during rehabilitation.

The new inner shell of reinforced shotcrete.

DELTA®

Open construction

Two examples of cut & cover tunnelling

The cut-and-cover method is used whenever a tunnel is covered only by a thin layer of ground. The pit remains open throughout the building operation. In many cases, pit lining methods (see page 10) are used to secure the excavation. Tunnels featuring lines and mouths are always exposed to water. In many cases, backfill materials that are available locally do not permit much seepage, so that an efficient drainage system becomes indispensable.

The solution for cut-and-cover building
The high compressive strength of the DELTA®-TERRAXX protection and drainage system ensures that there will be no exposure to water under hydrostatic pressure. For this reason, the system is ideal for tunnels built by the cut-and-cover method, even when soil pressures are as high as 90 kN/m² max.

Examples from the field
Kemalpaşa cut-and-cover railway tunnel near Izmir, Turkey
A new 27 km long railway line is currently being built in the vicinity of Izmir, including a number of tunnels. The Kemalpaşa tunnel was built by the cut-and-cover method. Made of reinforced concrete, the tunnel tube was waterproofed with plastic sheets. To protect this waterproofing, and to avoid exposure to headwater, DELTA®-TERRAXX was installed. Its unusual width of 2.40 m speeds up the laying process, and its high compressive strength ensures a high level of safety even under thick layers of ground. All in all, 12 000 m² of DELTA®-TERRAXX were consumed by this project.

Examples from the field
Föhrlibuck tunnel
200 m in length, the Swiss Föhrlibuck tunnel which links the Neugut and Weidenholz viaducts in Wallisellen consumed more than 6 000 m² of DELTA® drainage sheets. Thanks to their high compressive strength, the tunnel could be covered with a layer of 150 000 t of loose rock with a thickness of 2.0 to 3.5 m.

Properties	DELTA®-TERRAXX
Dimpled sheet	HDPE, silver
Filtration geotextile	PP grey
Dimple height	9 mm
Compressive strength (transient loading)	400 kN/m²
Compressive strength (permanent loading)	90 kN/m²
Tensile strength	6.0 kN/m²
Opening size O90	150 µm
Dynamic perforation resistance	40 mm
Max. installation depth	10 m

Drainage capacity in l/s · m i = 1	
Without compression	3.5
At 20 kN/m²	3.1

Fastening methods

Fasteners and fastening methods

For fastening in a soft medium such as, for instance, green shotcrete, steel nails should be used which may be hammered in by hand. To avoid tearing the sheets, it is recommended either to use nails with washers or to drive the nails through wooden battens. As an alternative, DELTA®-MONTAGEKNOPF washers may be used to keep the plastic sheets from tearing. For fastening in hard aggregates, shot bolts should be used.

Suitable gun models include HILTI (type DX 36 M or DX A41) or SPIT (type SPIT P 60 with tapered nozzle).

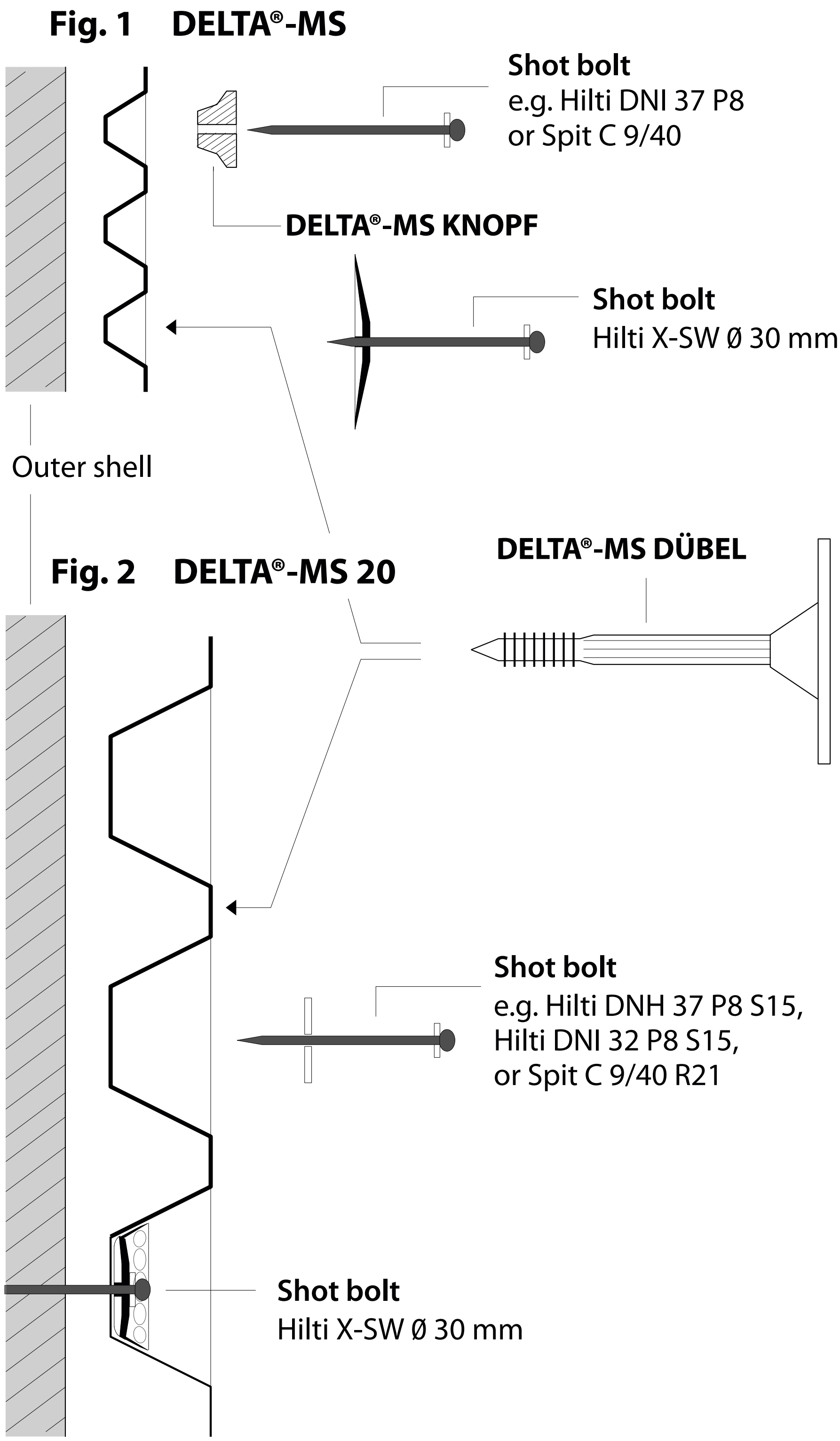
The following nail versions may be used:
(see Fig. 1)
HILTI DNI 37 P8
SPIT CR 9/40

To prevent the sheets from tearing and the nail heads from punching through, nails should always be used together with either DELTA®-MONTAGEKNOPF or metal or plastic washers. Both HILTI and SPIT offer shot bolts ready fitted with washers. Since these bolts are easier to use, they should be given preference.

The type designations of theses bolts are:
(see Fig. 2)
HILTI DNI 32 P8 S15
HILTI X-DNH 37 P8 S 15
HILTI X-SW, diameter 30 mm
SPIT C 9/40 R21

In the place of shot bolts, plastic washer plugs may be used where hard aggregates are involved.

The following plug types are suitable:
DELTA®-MS DÜBEL
HILTI type IDP O/2
SPIT type DSH 40
FISCHER type DHK 40
UPAT type IMD 8/30-40



Tunnelling projects with DELTA® dimpled sheets

Objekt / Project	Land / Country	Ausführendes Unternehmen / Contractor	Menge / Quantity [m²]	Jahr / Year	Produkt / Product
U-Bahn Bauabschnitt U3/9, Wien	**A**	Hofmann + Maculan	6 000	1985/1987	DELTA®-PT
Tunnel A 7 Füssen-Reute/ Tirol	**A**		4 000 / 3 000	1997/1998	DELTA®-PT, DELTA®-MS
Tunnel Soumagne	**B**	Tunnel Soumagne	89 000	2003/2004	DELTA®-MS 20
Tunnel Soumagne	**B**	Tunnel Soumagne	180 000	2003/2004	DELTA®-MS 580
Tunnel Soumagne	**B**	Tunnel Soumagne	8 300 rm	2003/2004	DELTA®-THENE T300
Hondrichtunnel, BE	**CH**	Gunimperm, Castione TI	13 000	1985	DELTA®-MS
Föhrlibuck-Tunnel, Wallisellen	**CH**	Lerch AG, Spaltenstein AG, SNZ Ing.-Büro	6 000	1986	DELTA®-DRAIN
Wipkingertunnel, ZH	**CH**	Züblin/Brunner	8 000	1989	DELTA®-MS
Zubringertunnel Sanierung Gotthard, UR	**CH**		5 000	1997	DELTA®-MS 20
Tunnel Gorgier Chez le Bart	**CH**		6 000	1999	DELTA®-MS 20
Tunnel Concise	**CH**	Gunimperm, Castione TI	13 800	1999	DELTA®-MS
Lüsslingen, N 5	**CH**	ARGE Lüthi, c/o Sarnafil	19 500	1999	DELTA®-MS
Eindeckung Spitalhof, N 5	**CH**		4 300	1999	DELTA®-MS 20
Tunnel Toira, TI	**CH**	Gunimperm, Castione TI	7 000	2000	DELTA®-MS
Tunnel Uznach	**CH**			2001	DELTA®-MS 20
Lötschberg Basistunnel	**CH**	Satco, Mitholz	1 000	2001	DELTA®-MS 20 spez.
Entlisberg-Tunnel, Zürich	**CH**	ISOTECH AG, Schlieren	2 000	2002	DELTA®-GEO-DRAIN TP
Sanierung Sunnegg-Bahn, Zermatt	**CH**	U. Imboden, Zermatt	2 000	2005	DELTA®-PT
Sicherheitsstollen, Gotschna	**CH**	ARGE ASGO	2 400	2005	DELTA®-MS 20
Tunnel de la Perche et du Banné	**CH**	CITP TSA Rupp & Partner, Giffers FR	15 000	2001/2003	DELTA®-MS
Bahn 2000, Gishubel Tagbautunnel	**CH**	ARGE Gishubel, Herzogenbuchsee	3 600	2002/2003	DELTA®-GEO-DRAIN TP
Uetliberg-Tunnel, Zürich	**CH**	Sika-Bau AG, Zürich	15 000	2002/2003	DELTA®-MS 1200
Metro Lausanne	**CH**	div. Unternehmen	6 500	2003-2006	DELTA®-MS 20
Lötschberg Basistunnel Süd	**CH**	ARGE Ledit, Ferden, Goppenstein	8 000	2004/2005	DELTA®-MS 20
Tunnel du Mont Chomin A 114	**CH**			2005	DELTA®-MS
A4 Knonaueramt	**CH**	Tagbautunnel	8 000	2006	DELTA®-TERRAXX

Objekt / Project	Land / Country	Ausführendes Unternehmen / Contractor	Menge / Quantity [m²]	Jahr / Year	Produkt / Product
Tunnel Moutier	**CH**	Marti Tunnelbau	30 000	2008	DELTA®-MS 1200
Transjurane, N 16	**CH**	Marti Tunnelbau	30 000	2003	DELTA®-MS 20
Gotthard-Tunnel	**CH**	ATG Strabag	530 000	2006/2010	DELTA®-AT 1200
Gotthard-Tunnel	**CH**	ATG Strabag	350 000	2009/2010	DELTA®-AT 800
Tunnel Westtangente, Bochum	**D**	Philipp Holzmann AG	1 400	1980	DELTA®-MS
U-Bahn, Baulos 10, Dortmund	**D**	Wiemer + Trachte		1984	DELTA®-MS
Neckarstollen, Heilbronn	**D**	Wix + Liesenhoff		1986	DELTA®-PT
Mündener-Tunnel, Hann. Münden	**D**	Bilfinger + Berger		1986	DELTA®-MS
Weltkugel-Tunnel, Melsungen	**D**	Hochtief AG		1986	DELTA®-MS
U-Bahn, Mülheim	**D**	Hochtief / Holzmann / Wayss + Freytag / Thyssen Schachtbau	3 000	1988	DELTA®-MS
ICE Strecke München-Nürnberg	**D**	Hoch-Tief / Kunz	5 000	2002	DELTA®-MS, DELTA®-MS 20
Herrentunnel, Lübeck	**D**	ARGE Herrentunnel	15 000	2004	DELTA®-MS 1000 natur
U-Bahn, Baulos D 4, Dortmund	**D**	Bilfinger + Berger Leonh. Moll	1 000	1982/1984	DELTA®-MS
U-Bahn, Düsseldorf, Los 3.4 Kölner Str.; Los 3.5 Erkrather Str.	**D**	Heitkamp / Hochtief / Bilfinger / Wayss + Freytag		1990/1991	DELTA®-MS 20
ARGE Nordrampe Elbtunnel	**D**	Wiemer + Trachte	3 000	1999/2000	DELTA®-MS 20
ARGE Nordrampe Elbtunnel	**D**	Wiemer + Trachte	4 500	1999/2000	DELTA®-DRAIN
Elbtunnel Hauptröhre	**D**	Dyckerhoff + Widmann	22 000	2000/2001	DELTA®-MS natur
Autobahntunnel A 5, Alicante, Villafrangnez	**E**	Dragados Y Construcciones	30 000	1988/1989	DELTA®-DRAIN
Tunnel (TGV Méditerranée) Tartaiguille	**F**	E.I.	4 000	1996/1997	DELTA®-MS
Finiculaire Lyon-station Les Minimes	**F**	E.I.	1 000	1988	DELTA®-PT
Tunnel des Chavants	**F**	E.I.	8 000	1989	DELTA®-MS
Tunnel de L'Épine	**F**	E.I.	10 000	1989	DELTA®-MS
Tunnel TGV de Meyssies	**F**	E.I.	11 000	1990	DELTA®-MS
Tunnel de Puymorens	**F**	Bauveg	12 000	1993	DELTA®-MS
Tunnel de Chamoise A 40	**F**	E.I.	13 000	1994	DELTA®-MS

References

Tunnelling projects with DELTA® dimpled sheets

Objekt / Project	Land / Country	Ausführendes Unternehmen / Contractor	Menge / Quantity [m^2]	Jahr / Year	Produkt / Product
Tunnel Pas de Léscalette A 75	**F**	E.I.	9 000	1994	DELTA®-MS
Tunnel Mesnil le Roy A 14	**F**	Sofrete	10 000	1994	DELTA®-MS
BPNL Lyon Tunnel de la Duchere et de Rochecardon	**F**	G.I.E. Lyon Nord	11 000	1995	DELTA®-MS
Puits ventilation-Tunnel Routier du Fréjus	**F**	Etandex	18 000	1996	DELTA®-MS
Baillet-en-France (95)	**F**	E.I. GCC	4 000	1999	DELTA®-NP DRAIN
Galerie du Pas de la Reyssolle (04)	**F**	E.I. GCC	300	1999	DELTA®-MS 20
Tunnel San Quil co-RN 193 (20)	**F**	E.I. GCC	1 300	1999	DELTA®-MS
Tunnel Saorge (06)	**F**	E.I. GCC	2 000	2000	DELTA®-MS
Traversée souterraine de Toulon (83)	**F**	SLEG	3 000	2000	DELTA®-MS, DELTA®-MS 20
Mont Blanc Tunnel	**F**	Freyssinet	4 000	2001	DELTA®-PT
Traversée souterraine de Toulon (83)	**F**	Europroof	5 500/5 000	1996/1997	DELTA®-MS, DELTA®-MS 20
Tunnel d'Orelle A 43	**F**	E.I.-Sofrete	19 000	1997/1998	DELTA®-MS
Tunnel de Foix	**F**	E.I.	20 000	1997/1998	
Galerie du Cern ref. ATIC (01)	**F**	E.I. GCC	30 000	2000/2001	DELTA®-MS
Galerie du Cern ref. T.W.A (01)	**F**	E.I. GCC	40 000	2000/2001	DELTA®-MS
Galleria Bozano	**I**	Mahlchnet	3 500	2000	DELTA®-NP DRAIN
Tunnel Gousselbierg	**Lux.**	Iraco	140 000	2002/2004	DELTA®-MS
Cut & Cover Tunnel Izmir Devlet Demir Yollari	**TR**	Acilim Insaat	12 000	2009	DELTA®-TERRAXX
Queens Tunnel, New York, NY	**US**	Grow Perini Skanksa	6 000	2000	DELTA®-MS
Chatahouchee Tunnel, Atlanta, GA Phase 1	**US**	Gilbert Healy	30 000	2002	DELTA®-MS
Chatahouchee Tunnel, Atlanta, GA Phase 2	**US**	Nancy Creek Construction	50 000	2004	DELTA®-MS
Chatahouchee Tunnel, Atlanta Phase 3	**US**	Nancy Creek Construction	40 000	2006	DELTA®-MS

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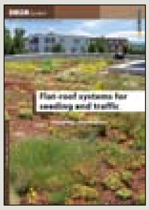

Technical Guide
DELTA®-TERRAXX for horizontal applications.

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