

**aestuver**



AESTUVER

# Fire safety concepts for underground transport systems

**xella**

# Research and development for higher safety standards

Increasing mobility and rapidly growing transport volumes point to an equally growing demand for modern and high-capacity tunnel systems.



Tunnels planned and built today are getting longer and more complex, and there is a growing need for refurbishing existing tunnels. Serious accidents that have in the recent past caused grave damage to persons and property have in addition triggered a general discussion of safety standards in tunnel systems. These are the considerations that guide today's tunnelling projects.

A decisive criterion against which tunnel safety is measured is the scenario of an accident involving a fire. Due to the spatial limitations of a tunnel, tunnel fires render all escape,

rescue and repair measures rather difficult, and are hence regarded to be the greatest risk to people, vehicles and the tunnel structure itself. Safe escape routes, fire load containment along escape and rescue routes, and the integrity of electrical systems are basic elements of safety concepts for underground transport systems. Other aspects have been gaining significance, namely the prevention of spalling in structural concrete, which results from quickly rising temperatures and extreme heat radiation, and the installation of efficient smoke extraction systems.

The products AESTUVER offers for preventive fire engineering concepts have been developed specifically with a view to the requirements and conditions in underground transport systems.

In a large number of projects and tailor-made solutions we have acquired expertise in structural fire protection, which we will be pleased to place at your disposal for your preventive fire engineering requirements.

# Fire performance of concrete

Concrete is generally considered to be a fire-resistant construction material, since it offers adequate heat insulation properties and since it is non-combustible. However, requirements of time-temperature curves for underground transport systems, and the thermo-hydraulic, thermo-mechanical and chemical conversion processes affecting the concrete do not confirm this assumption.

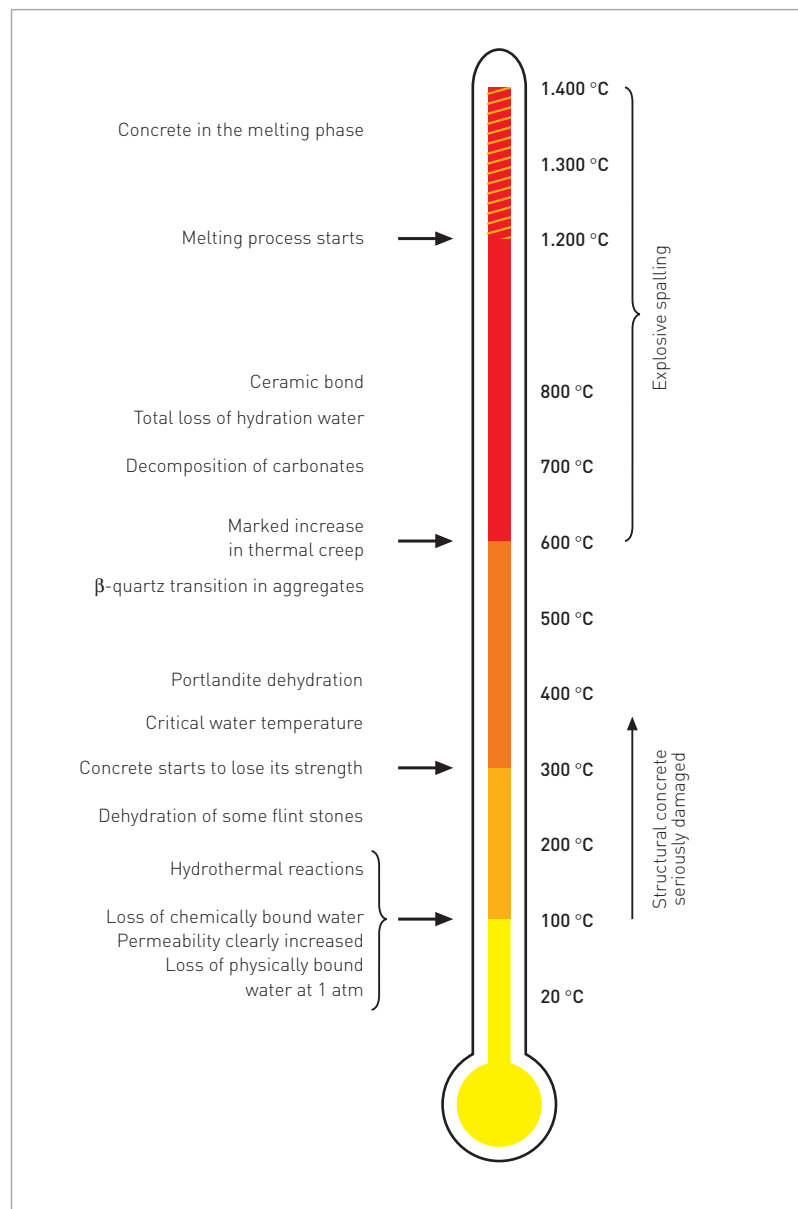
Explosive spalling of concrete is a thermo-hydraulic process which is based on the following mechanisms: In a fire, the water that is physically and chemically bound inside the concrete is released due to the quickly rising temperatures. As the water changes to the gaseous state, its volume increases by a factor of 1,100.

As a result of pressure compensation in near-surface concrete layers, the concrete dries in this region, whereas condensation produces zones that are almost completely water-saturated in deeper regions of the concrete. As the ambient temperatures continue to rise, the concrete has to sustain very high steam pressures on the inside. Once the tensile strength of the concrete is exceeded, the material reacts with explosive spalling, a behaviour which becomes more marked with increasing strength of the structural concrete: the pore volume in high-strength concrete is reduced, lowering its permeability. Another unfavourable factor are the complex tunnel geometries.

## Other destruction mechanisms:

At the high temperatures that are typical of tunnel fires, the structural fabric tends to change above all in the quartz-ose aggregates. Since this also means a change in volume, the concrete may start to crumble.

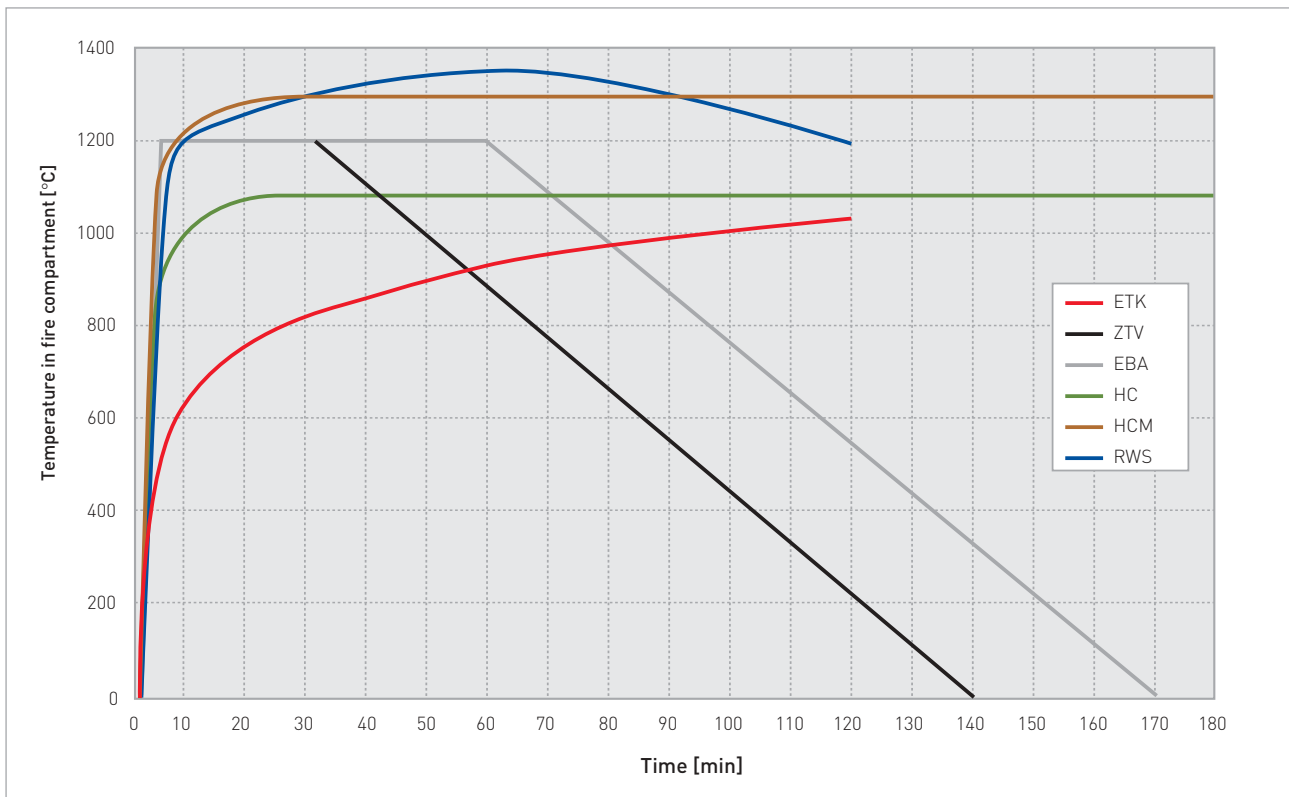
Smoke enters the concrete through hairline cracks that develop in the material when exposed to a fire, accelerating the carbonation process and attacking the reinforcing steel.



Chemical changes inside the concrete



# Time-temperature curves in Europe



Lilla Bommen Tunnel,  
Gothenburg, Sweden; dicon tu,  
30 mm, set in concrete;  
system tested with HC curve;  
180 minutes plus

Tunnel des Bruyères,  
fire drill; structural concrete protected  
with AESTUVER dicon tu fire-resistant  
boards in test area

# Colour options

AESTUVER fire-resistant boards for underground transport systems can have their top layer factory-dyed with concrete paint. This gives them a lasting, weather-resistant colour finish. They are available in a matte finish in red, yellow, brown, anthracite, or green and blue.



# AESTUVER

## Fire-resistant boards for underground transport systems made from glass-fibre reinforced light-weight concrete

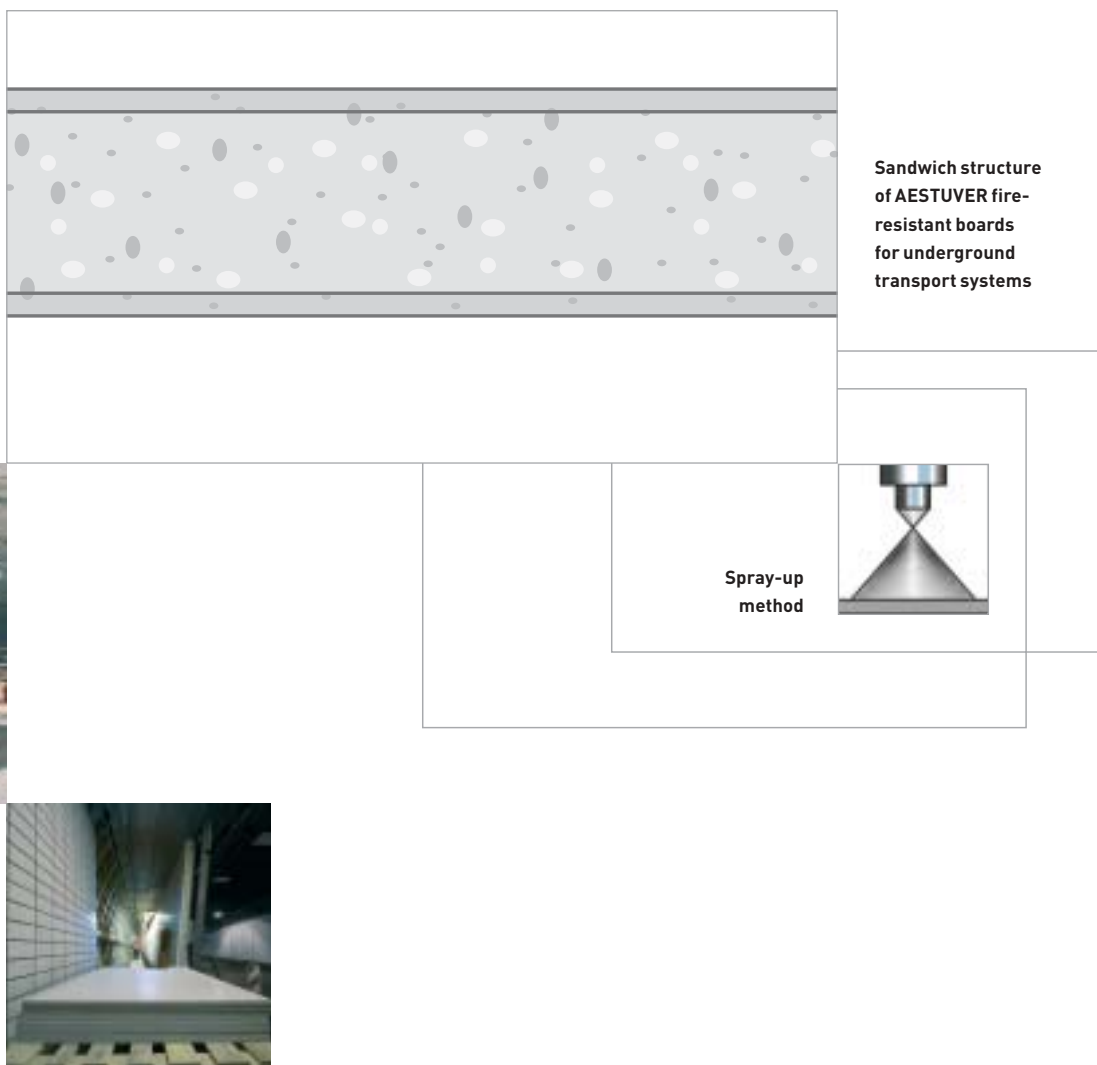


### AESTUVER fire-resistant boards for underground transport systems.

If a fire occurs in a tunnel, the unprotected structural concrete is exposed to rapidly rising temperatures and considerable heat radiation. In particular the high-strength concretes that are increasingly used today will respond with explosive spalling after only a short time. This weakens the load-bearing capacity and stability of the structure, and exposes tunnel users and rescue teams to additional risks. Once the concrete has started to spall, the heat can penetrate deep into the material and change the structural fabric, further reducing its strength and favouring

the development of hairline cracks. The smoke that normally accompanies tunnel fires can thus also penetrate the unprotected concrete much more easily, which may lead to corrosion of the reinforcing steel.

AESTUVER fire-resistant boards fitted to concrete surfaces in underground transport systems reliably protect the concrete against fire-induced stressing up to the conditions of the RWS time-temperature curve, with peak temperatures of up to 1,350 °C (product-specific), also preventing concrete sloughing and spalling.



### Tried and trusted: glass-fibre reinforced light-weight concrete.

For many years, AESTUVER has been a supplier of fire-resistant boards that have been specifically developed for underground transport system applications and have proven to be excellent performers. These boards are used by renowned firms specializing in preventive structural fire engineering solutions because of their reliability and quality, particularly when exposed to permanent or repeated moisture and/or extreme mechanical loads.

AESTUVER fire-resistant boards for underground transport systems are non-combustible, purely mineral, hydraulically bonded fire-resistant boards made from glass-fibre reinforced light-weight concrete (building material class 1 in compliance with DIN 4102).

### The AESTUVER spray-up method.

All fire-resistant boards sold under the trade name AESTUVER are produced using the successful AESTUVER spray-up method. This method allows relatively long glass fibres with their excellent reinforcing properties to be embedded in the concrete.

In the spray-up process, the endless glass fibre is cut into sections of up to 5 cm in length, which are directly blown into the mortar jet. Glass fibre and matrix application is an automatic process, in which uniform layers are produced at a high pressure. Thanks to this technique, AESTUVER fire-resistant boards for underground transport systems feature a dense and regular fibre structure across their entire cross section.

Another advantage of this method is that it produces thin boards with high compressive and tensile bending strength and high abrasion resistance. Smooth and robust surfaces, in conjunction with homogeneous edges, make the board a highly versatile product for a wide range of applications and processing requirements.

# Properties

## Resistant to compression.

AESTUVER fire-resistant boards for underground transport systems derive their high compressive strength from the dense and homogeneous board structure. The matrix-embedded glass fibres further enhance this property.

## Resistant to tensile bending.

The high tensile bending strength of AESTUVER fire-resistant boards for underground transport systems results from the use of long glass fibres which are uniformly distributed throughout the entire board.

## Resistant to abrasion.

AESTUVER fire-resistant boards for underground transport systems owe their abrasion resistance primarily to a uniformly compacted surface. The production process ensures an optimised exposed surface that has almost no visible pores. With its smooth finish, it provides very good protection against wear.

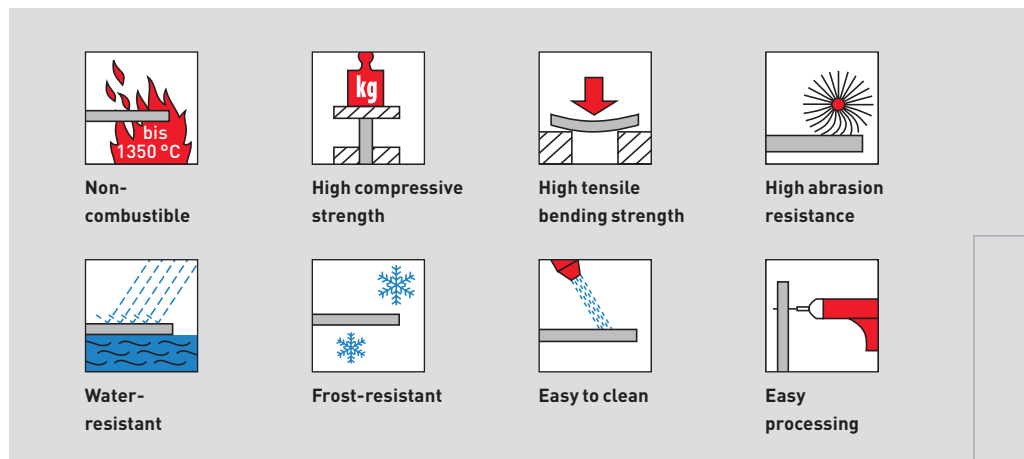
## Water-resistant.

AESTUVER fire-resistant boards for underground transport systems have excellent water-resistance qualities. This advantage results from the cement-bound matrix structure and its low water absorbency.

Even high moisture exposure does not significantly affect the physical properties of AESTUVER fire-resistant boards for underground transport systems. This explains why these boards do not have to be subjected to any additional waterproofing measures.

## Frost- and deicing-salt resistant.

The frost and deicing-salt resistance of AESTUVER fire-resistant boards for underground transport systems has been examined in long-term tests, and the boards have been attested excellent resistance properties.



## Easy cleaning.

Because of their regular, smooth and firm surface, the boards can be cleaned easily and with lasting effect, using different cleaning methods, water- or steam-jet cleaning, and adding cleaning agents (in accordance with recommendations).

## Processing advantages.

Thanks to their excellent mechanical properties, AESTUVER fire-resistant boards for underground transport systems can be used for a wide range of applications. The boards can be processed industrially to produce standard elements and structural systems, and they can likewise be used for individual and tailor-made structural solutions on site. The smooth surface of the boards also provides an ideal base for painting and coating.

AESTUVER fire-resistant boards for underground transport systems can be sawn, milled, drilled, nailed or bolted without any problems. The low dust emission level adds to their excellent mechanical handling characteristics.

## No health risks.

Only fibres with uncritical dimensions (according to WHO) are used in the production of AESTUVER fire-resistant boards for underground transport systems. This makes the boards safe to use, because no fibres are deposited in the respiratory system or the lungs (risk of asbestosis), a known problem with the use of asbestos products.

## Advantages of AESTUVER fire-resistant boards for underground transport systems:

- Conventional cleaning methods may be used, requiring no additional treatment of the boards
- No bonding problems in connection with high-strength concrete
- Protection of movement joints
- MULTI-MONTI® screw anchors allow the protection to be removed for inspection at any time and without causing any damage to the structural system (note screw anchor type approval)
- Resistant to water, frost and de-icing salt; no loss in strength when exposed to moisture

## Fields of application of AESTUVER fire-resistant boards for underground transport systems.

The most common fields of application of AESTUVER fire-resistant boards for underground transport systems are shown on the next pages. Because of their very good processability and material properties, the boards can be a simple and effective solution to a number of other special requirements, including fire protection for expansion joints.

# Protection of structural concrete

## Subsequently mounted protection.

When AESTUVER fire-resistant boards for underground transport systems are subsequently applied to structural concrete, feed-through connectors, e.g. MULTI-MONTI® screw anchors, are used to fit the boards to the tunnel structure. Joint backing strips, 10 mm thick as a minimum, are provided in both longitudinal and transverse directions. These strips protect the board joints against fire penetration, provide additional insulation with the air cushion thus created, and produce a much more uniform surface as they bridge offsets and irregularities. MULTI-MONTI® screw anchors are self-tapping concrete anchors, which can be removed and retightened up to 10 times for quick and low-cost inspection and repair.

## Concreted protection.

When set in concrete, AESTUVER fire-resistant boards for underground transport systems are butted in the form-work. Joints can be additionally sealed to prevent the cement-water mixture from getting underneath the boards. They are backed with strips, 10 mm thick as a minimum, which are made from the same material as the boards. These backing strips are bolted to the boards and can serve as spacers for the reinforcement at the same time. They protect the joints against fire penetration, and have a bonding function for the mechanical board anchoring elements and the concrete.



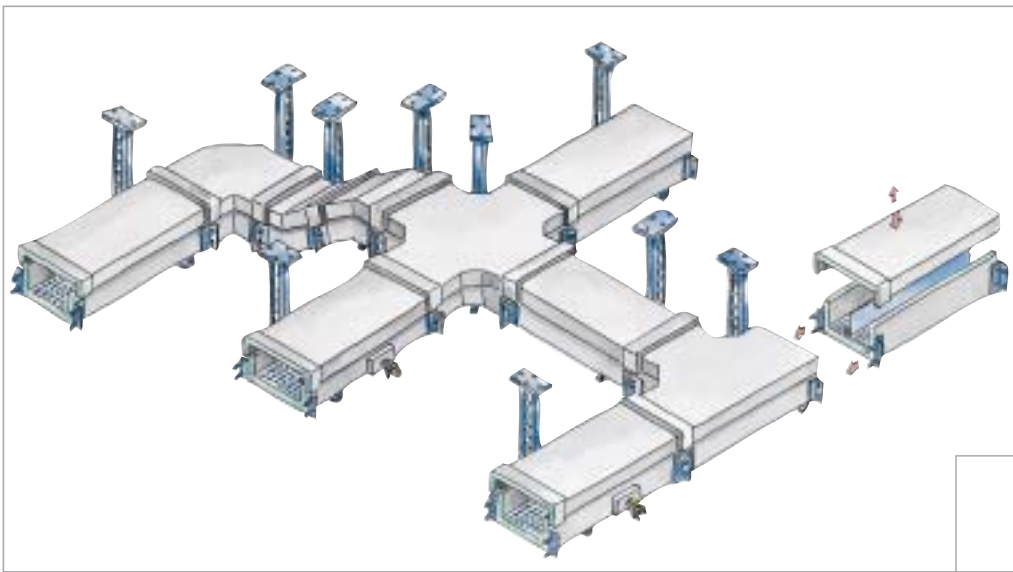
Joint with  
joint backing strips



**It has been shown that the fire safety objective – protection of structural concrete against high-temperature exposure in a fire in compliance with European time-temperature curves – is fully achieved (see time-temperature curves).**

# AESTUVER fire-resistant cable ducts – designed to isolate fires along rescue routes and maintain the integrity of electrical systems

When a fire spreads to cable installations, this normally produces not only dense smoke, it also releases highly toxic gases. Escape and rescue routes can thus turn into deadly traps within a few minutes, and it may become difficult, if not impossible, for rescue teams to do their work.



AESTUVER fire-resistant cable ducts keep rescue routes smoke-free in a fire and help maintain the integrity of systems with vital functions for the safety of underground transport systems. AESTUVER fire-resistant cable ducts have been tested for compliance with DIN 4102, Parts 11 and 12. The official materials testing institute at the IBMB institute of Braunschweig Technical University has subjected the cable ducts to an extensive test programme for that purpose. General building code test certificates and expert reports certify that AESTUVER fire-resistant cable ducts provide a high degree of safety in the event of a fire.



**Berlin central station  
Lehrter Bahnhof  
equipped with AESTUVER  
fire-resistant cable ducts**



**Regional railway station  
Potsdamer Platz, Berlin;  
protected with AESTUVER  
fire-resistant cable ducts**

AESTUVER fire-resistant cable ducts come in two different versions:

- In their fire-resistance class I 30 – I 120 version, AESTUVER fire-resistant cable ducts prevent cable fires from spreading to rescue routes, and they help contain the highly toxic smoke. Cable outlets for either individual cables or cable bundles are included in the overall system test. Custom-fit threaded joints provide for quick and easy high-tensile connection of cable trays.
- In their fire-resistance class E 30 – E 120 version, AESTUVER fire-resistant cable ducts prevent fires from spreading into the duct. This keeps temperatures inside the duct low and avoids the risk of short circuits or power failures. 'E' ducts are legally required wherever the integrity of safety-critical systems has to be maintained in a fire. Such systems could be fire detection installations, smoke and heat extraction facilities, and emergency lighting in underground transport systems.

Moulded parts provide for highly flexible cable routing. Mounted on spacer bars, the perforated tray ensures continuous ventilation inside the cable duct and allows commercially available separator elements to be fitted without any problems. AESTUVER fire-resistant cable ducts are supplied in a pre-fabricated state and made available "just in time" for installation. They can thus be fitted within a very short time. Since AESTUVER fire-resistant cable ducts have removable covers, additional cabling can be installed at any time. This feature also provides for easy system inspection.

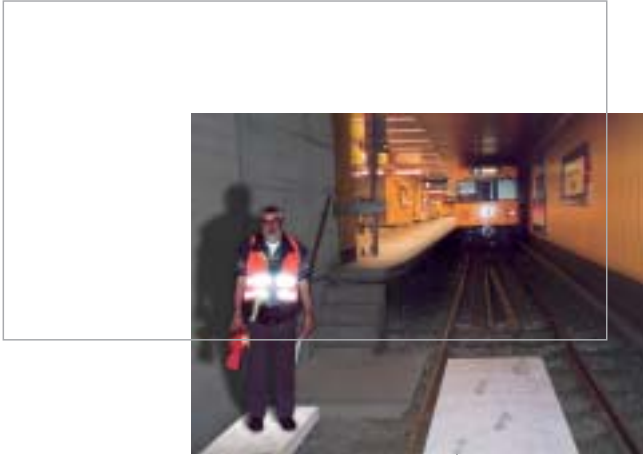


**Suspended AESTUVER  
fire-resistant cable ducts**



# Escape- and rescue-route solutions

Walk-on AESTUVER D+2 fire-resistant boards – used as covering for concrete troughs alongside track bedding, or as timber sleeper covering for safe escape- and rescue-route surfacing.



**Berlin underground railway; covering for timber sleepers**



The walk-on AESTUVER D+2 fire-resistant board has been specifically developed for covering concrete troughs (possibly replacing timber sleepers) or for the safe surfacing of escape and rescue routes along track bedding.

The glass-fibre reinforced light-weight concrete makes the board a light-weight element for easy and quick installation and inspection, which can also be easily cut to size as required on site.

If necessary for specific applications, AESTUVER D+2 fire-resistant boards can come with an anti-slip or afterglow finish.

# Shaft-wall systems for safety-device protection



Tiergartentunnel,  
Berlin

F 90-A  
shaft-wall  
design

AESTUVER fire-resistant boards used as recess covers to protect tunnel safety features, such as distribution boxes, switchgear cubicles or emergency phones, are also available with stainless-steel protection. These slender elements can thus provide class F 90-A fire protection, while meeting the stringent requirements for underground transport facilities.



## Additional protection options (requiring individual testing):

- Ventilation ceilings
- Smoke extraction ducts
- Steel structures
- Enclosures

## Excellent references

The tables below list reference projects in which the following AESTUVER fire-resistant boards have been installed in underground transport systems:

- AESTUVER dicon tu fire-resistant board
- dicon tu

- AESTUVER T
- AESTUVER fire-resistant board
- AESTUVER D+2 fire-resistant board and
- AESTUVER fire-resistant cable ducts (AESTUVER cable ducts come as factory-made elements using AESTUVER fire-resistant boards)

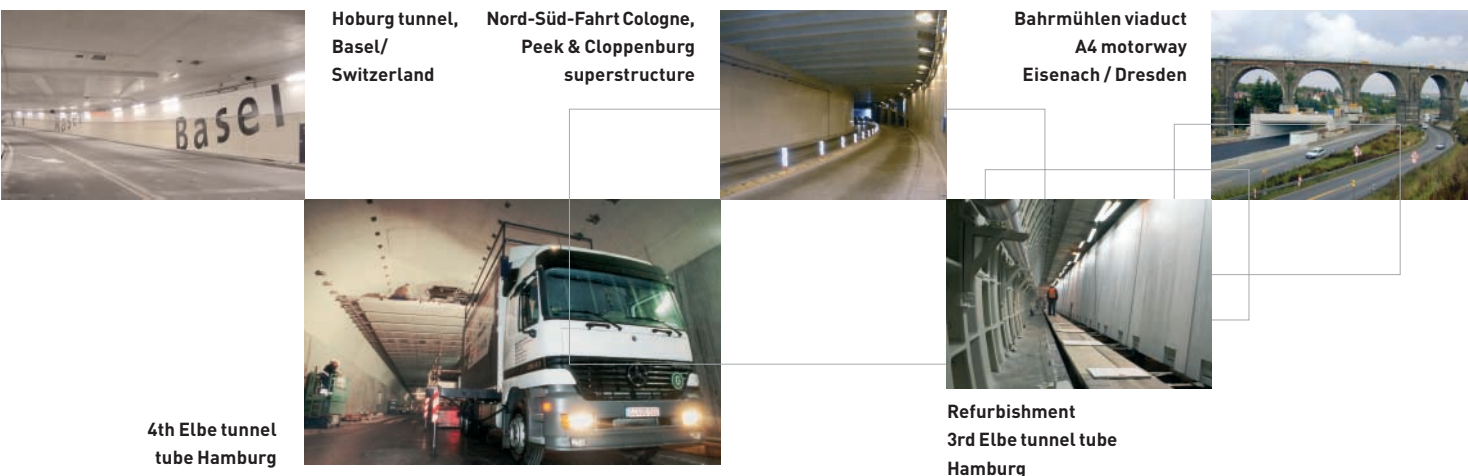
For the specifications of the boards and their attestations, please refer to the respective product data sheets.

### Reference projects: AESTUVER dicon tu fire-resistant board

Tunnel	Place	Year	Type of protection	Requirement	Area
Ruhr-Tunnel	Duisburg-Meiderich	2000	Curved protection for steel tubbings; 20 mm on 20-mm backing	ETK curve	150 m <sup>2</sup>
Nord-Süd-Fahrt superstructure	Cologne	2000	Girder/column protection; protection for bracing steel structure	ZTV curve	6,000 m <sup>2</sup>
Central station Lehrter Bahnhof	Berlin	2000/2001	Protection boarding for walls, ceilings; integrated formwork; hemispherical shells for round columns	ZTV curve	1,000 m <sup>2</sup>
4th Elbe tunnel tube	Hamburg	2001/2002	Smoke extraction ceiling; two-sided protection for steel structure; 2 x 25 mm	ZTV curve	125,000 m <sup>2</sup>
Bahrmühlenviadukt A4 motorway	Chemnitz	2001/2002	Protection boarding for structural concrete; 20 mm on 10-mm joint backing	ZTV curve	2,200 m <sup>2</sup>
Weser tunnel	Dedesdorf	2003	Fire-resistant protection for tubbings above impact walls; 20 mm on 10-mm joint backing	ZTV curve	47,000 m <sup>2</sup>

### Reference projects: AESTUVER dicon tu

Tunnel	Place	Year	Type of protection	Requirement	Area
Nord-Süd-Fahrt / Peek & Cloppenburg superstructure	Cologne	2003	Girder/column protection; fire-resistant protection for structural concrete; fire-resistant protection for load-bearing steel structure	ZTV curve	12,000 m <sup>2</sup>
Moorfleet tunnel	Hamburg	2003	Fire-resistant cable ducts; 2-sided cable duct to maintain functional integrity; 2 x 25 mm	ZTV curve; 1200 °C until minute 95	2,100 m <sup>2</sup>
Lilla Bommen tunnel	Gothenburg Sweden	2004/2005	Concreted tunnel ceiling protection; 30 mm with 10-mm joint backing	HC curve 180 minutes	8,000 m <sup>2</sup>
Refurbishment 1st Elbe tunnel tube	Hamburg	2004	Protection for prefabricated walls next to roadway and inclined sections between wall and ceiling; 20 + 25 mm	ZTV curve	22,000 m <sup>2</sup>
Herrentunnel Lübeck	Lübeck	2004	Fire-resistant protection for tubbings above impact walls; 20 mm on 10-mm joint backing	ZTV curve	25,000 m <sup>2</sup>
Refurbishment 4th Elbe tunnel tube	Hamburg	2006	Protection for prefabricated walls next to roadway (20 + 25 mm) and inclined sections between wall and ceiling (2 x 25 mm)	ZTV curve	22,000 m <sup>2</sup>
Horburg tunnel	Basel Switzerland	2006	Protection for tunnel ceiling and wall strips; 20 mm on 10-mm joint backing	ZTV curve	8,000 m <sup>2</sup>



### Reference projects: AESTUVER T

Tunnel	Place	Year	Type of protection	Requirement	Area
Gotschna tunnel	Klosters Switzerland	2005	Protection of ceiling central ventilation system; 20 mm on 10-mm joint backing	ZTV curve	300 m <sup>2</sup>
Antony tunnel	Paris France	2005	Protection of tunnel ceiling and wall strips; 30 mm on 10-mm joint backing	HCM curve	1,600 m <sup>2</sup>
Nanterre tunnel	Paris France	2005	Protection of tunnel ceiling and wall strips; 30 mm on 30-mm joint backing	HCM curve	800 m <sup>2</sup>

### Reference projects: AESTUVER fire-resistant board

Tunnel	Place	Year	Type of protection	Requirement	Area
Tiergarten B96	Berlin	2005	Wall recess protection; 2 x 25 mm	E 90	approx. 2,500 m <sup>2</sup>

### Reference projects: AESTUVER D+2 fire-resistant board (walk-on type)

Tunnel	Place	Year	Type of protection	Requirement	Length
Berlin underground	Berlin	st. 2004	Escape route between rails	A1 board	1,750 m
Munich underground	Munich	2002	Trough cover	A1 board	200 m
Rail crossing Nürnberg Fürth	Nuremberg Fürth	2003	Escape route/crossing	A1 board	100 m
Cologne underground	Cologne	2005/2006	Trough cover	A1 board	500 m

### Reference projects: AESTUVER cable ducts

Tunnel	Place	Year	Type of protection	Requirement	Length
Central station Lehrter Bahnhof	Berlin	2004/2005	Cable ducts	E 30 + I 30	approx. 7,500 m
Regional station Potsdamer Platz	Berlin	2005	Cable ducts	E 30 + I 30	approx. 2,000 m
North-south rail link	Berlin	2005	Cable ducts	E 90	approx. 7,000 m

Diagram on page 3 from: Verhalten von Beton  
bei Temperaturbelastung; Passiver Brand-  
schutz im Tunnel- und Tiefbau; Harald Pflanzl;  
Zement und Beton Sonderheft  
Kolloquium 2002

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to be missing in this issue  
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