# Tunnel Fire Protection
## Lost formwork system with PROMATECT®-H

www.promat-tunnel.com



The photographs on pages 2, 3 and 6 of this brochure are reproduced courtesy of the Taisei Corporation.

## This brochure describes the use of Promat fire protection lining boards installed on the tunnel project on The Palm Jumeirah.

# 1. Project background

The Palm Jumeirah development on the coast of Dubai is a man-made island in the shape of a palm tree extending into the Arabian Gulf.

The project was launched in 2001 with reclamation starting the same year. Approximately 100 million cubic meters of sand were placed to form the The Palm Jumeirah, which consists of a main trunk with a total of 17 fronds extending each side, all being encircled by a Crescent, which forms a breakwater. The island extends 5 kilometres into the Arabian Gulf area and is 5 kilometres wide.

The Crescent is connected to the trunk by a 1.4 kilometre long cut and cover, sea-crossing tunnel. In addition to vehicular traffic, a mono rail system is being constructed from the Gateway station for the entire length of the island's trunk to the Atlantis station with two intermediate stations. On completion, The Palm Jumeirah which is envisaged to be one of the world's premier living and tourism destinations, will contain a total of approximately 1540 villas in a number of distinctive styles. There will also be 20 shoreline apartment buildings of 13/14 levels containing a mixture of 1, 2 and 3 bedroom units, totalling approximately 2500 apartments. In addition to this there will be 4 large marinas and over 30 of the world's top hotels.

# 2. Companies involved

**NAKHEEL – PROPERTY DEVELOPER**
The project developer for The Palm Jumeirah is Nakheel, the Middle East's leading property development company.

As the developer of more than $30 billion of real estate in Dubai, Nakheel has been instrumental in turning Dubai into one of the fastest growing cities in the world, and a world class destination for business and tourism. In addition to The Palm Jumeirah, Nakheel is developing two other palm shaped islands, The World – 300 islands in the shape of the world – and Dubai Waterfront, the world's largest waterfront development and a number of large scale inland developments.

**PARSONS BRINCKERHOFF - PROJECT MANAGEMENT CONSULTANTS**
One of the leading transportation engineering companies in the world providing design, construction and programme management world-wide and specialising in transit systems, tunnels, bridges and airports.

**PARSONS DE LEUW CATHER - SUPERVISING CONSULTANTS**
Internationally renowned consultants on roads and highways, transportation systems, bridges and tunnels.

**TAISEI CORPORATION - DESIGN AND BUILD MAIN CONTRACTOR**
One of the largest Japanese construction and engineering companies working on major projects world-wide. Taisei appointed Halcrow International Partnership as their design partners.

“*We ordered PROMATECT®-H boards in October 2005, with a schedule of required deliveries to meet our construction programme through to mid-2006.*

*The boards were received on, or before, our required dates. The boards were well packed and protected and no transit damage was experienced. We decided to set up a dedicated storage/workshop area on site, where we could prepare the boards prior to installation. This area was manned by a team of men who prepared and cut the boards. The same team was also responsible for installation. Promat sent two engineers to site during our first few days of the project to give advice to our installation team. Promat continued with periodic on-site advice during the project.*

*The PROMATECT®-H boards were supplied accurately cut and finished within the required dimensional tolerances. Our installation team found the boards easy to handle and place, as proved by the improved production and installation rate. The key point of the installation was the curved section, where each row of boards was placed on plywood in the workshop area and cut in one go. This resulted in minimising the gap between the boards as a result of Promat's and Taisei's idea. The finished lining to the tunnel provided a pleasant appearance with minimised gaps between boards.*”

Mr Akihiko Mochizuki, Project Manager for Taisei Corporation.
Main Contractor, The Palm Jumeirah tunnel project.

# 3. Technical specification and requirements for fire protection of structural concrete

### 3.1. REASONS TO PROTECT A CONCRETE TUNNEL AGAINST FIRE

Concrete tunnels are vulnerable to elevated temperatures caused by fire. Tests have shown thatwhen the temperature of the reinforcement reaches 300°C, the bond between the rebar and concrete will be significantly reduced, leading to irreparable sagging and possible collapse of the total structure. Moreover, when concrete is exposed to fire temperatures as experienced in tunnels, concrete spalling often occurs.

Spalling is an umbrella term, covering different damage phenomena that may occur to a concrete structure during fire. These phenomena are caused by different mechanisms: pore pressure, thermal gradient, internal thermal micro-cracking, cracking around reinforcement bars and strength loss due to chemical transitions. In different combinations of these mechanisms, possible spalling phenomena include violent spalling, progressive gradual spalling, explosive spalling, corner spalling and post-cooling spalling [1]*.

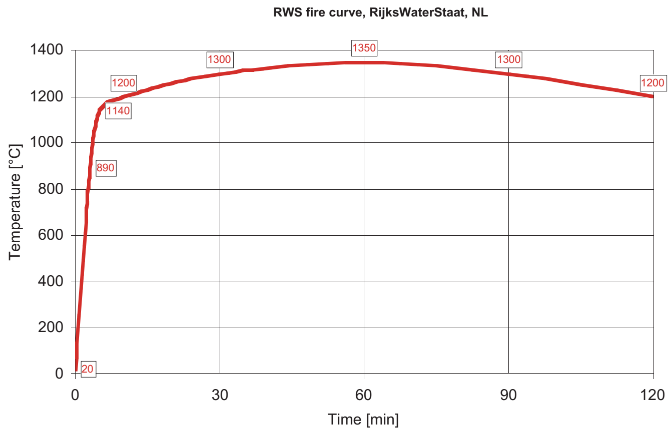
The Palm Jumeirah tunnel is constructed using a C40 concrete grade, which was cast in place. If left unprotected, such concrete would typically suffer from violent spalling if it was exposed to a typical tunnel fire, which creates temperatures up to 1200°C within only 5 minutes. Violent spalling is the separation of small or larger pieces of concrete from the cross section, during which energy is released in the form of popping off of the pieces and small slices with a certain speed, and also a popping or cracking sound. This type of spalling is caused by pore pressure and thermal gradients [1]*.

* Refer to 'References List' on page 22.

Severe concrete spalling after fire exposure in tunnel

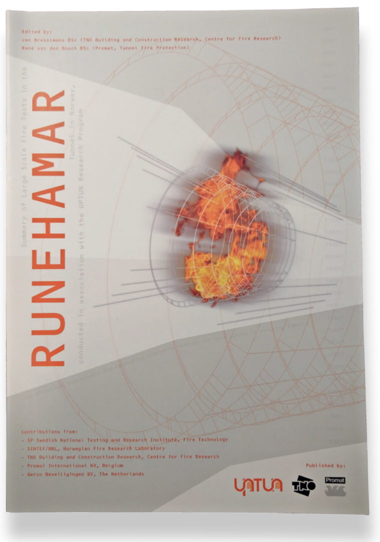
## 3.2. DEFINITION OF DESIGN FIRE CURVE

In the late 1970's the Dutch Ministry of Transport, Rijkswaterstaat (RWS), contemplated the structural safety of their immersed tunnels in case a large fire would occur. In co-operation with TNO Centre for Fire Safety in the Netherlands, a series of small-scale tests were carried out, which resulted in the time-temperature curve as we now know as the RWS fire curve.




RWS fire curves, 120 minutes as applied in The Palm Jumeirah tunnel

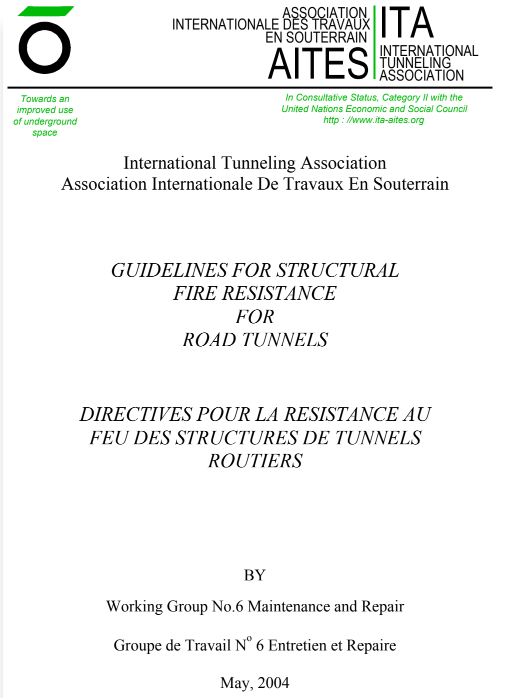
The worst case scenario was defined as a 50m³ petrol tanker that would catch fire in the tunnel, creating a pool-fire size of some 150m² and lasting 120 minutes. Such a fire would create a heat release rate of 300MW. Years later, the accuracy of this fire curve was confirmed by the Eureka tests, BRE and the Memorial Tunnel tests in the USA. In the frame of a Swedish national and a European research program on tunnel safety (UPTUN), comprehensive large scale fire tests have been carried out in the abandoned Runehamar road tunnel in the western part of Norway in September 2003. In the 4 tests that were conducted during this project, the RWS curve was confirmed to be the right choice as a design fire curve for tunnels. Even with very limited fire loads temperatures reached up to 1250-1350°C.




It should be noted that all combustible materials, which were used in these tests, are not listed as hazardous/dangerous. Products like petrol, paints, resins etc were not used as combustibles. A fire in a truckload of pallets (test 1) made the gas-temperatures rise up to 1365°C. A small truckload of plastic cups in cardboard boxes (test 4) created gas-temperatures of over 1200°C.

| Test nr. | Description of the fire load in Runehamar tests | Total weight (kg) |
|---|---|---|
| 1 | 360 wood pallets measuring 1200 x 800 x 150mm<br>20 wood pallets measuring 1200 x 1000 x 150mm<br>74 PE plastic pallets measuring 1200 x 800 x 150mm | 10911 |
| 2 | 216 wood pallets<br>240 PUR mattresses measuring 1200 x 800 x 150mm | 6853 |
| 3 | Furniture and fixtures (tightly packed plastic and wood cabinet doors<br>upholstered PUR arm rest, upholstered sofas, stuffed animals,<br>potted plant (plastic), toy house of wood, plastic toys).<br>10 large rubber tyres (800kg) | 8500 |
| 4 | 600 corrugated paper carton with interiors (600 x 400 x 500mm)<br>and 15% of total mass of unexpanded polystyrene (PS) cups<br>(18000 cups) and 40 wood pallets (1200 x 1000 x 150mm) | 3120 |

Working Group 6 of the ITA (International Tunnelling Association), focussing on Maintenance and Repair of tunnels, has adopted the complete Runehamar report as mentioned under [2]*. They included the Runehamar report in their final document [3]*, thus acknowledging the conclusion that the RWS curve is the right choice as a design fire curve for tunnels. Based on the information opposite and conducted research from all over the world, the developer decided to apply the highest and safest available standards for fire protection of tunnels to the The Palm Jumeirah tunnel: the RWS requirements.



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*GUIDELINES FOR STRUCTURAL FIRE RESISTANCE FOR ROAD TUNNELS*

*DIRECTIVES POUR LA RESISTANCE AU FEU DES STRUCTURES DE TUNNELS ROUTIERS*

BY

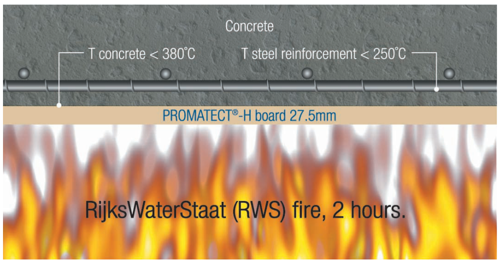
Working Group No.6 Maintenance and Repair

Groupe de Travail N° 6 Entretien et Repaire

May, 2004

### 3.3. THERMAL PERFORMANCE CRITERIA

The Dutch Ministry of Transport, Rijkswaterstaat (RWS), in close co-operation with TNO, Centre for Fire Research in The Netherlands has issued a test procedure for fire protection of tunnels [4]*.




As described in section 6.1 of this procedure, the thermal performance should comply with the following criteria: When spalling is not decisive during the 2 hours heating period the following temperature values shall not be exceeded:

- 380°C for each measuring point in the interface concrete/protective material;
- 250°C for each measuring point at 25mm above the bottom of the concrete slab (thermocouples fixed to the under side of the reinforcement). During the 2 hours heating period, the material must not fall down as a result of failure of the offered fixing system.

* Refer to 'References List' on page 22.

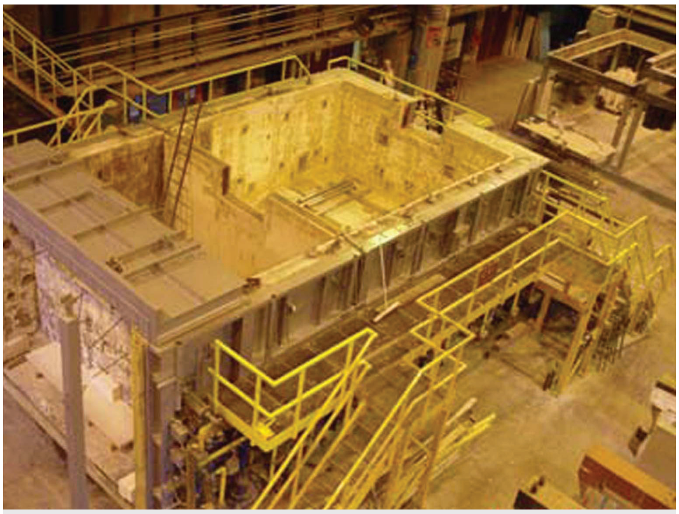
# 4. Promat technical offer

### 4.1. THERMAL PERFORMANCE OF PROMATECT®-H BOARDS

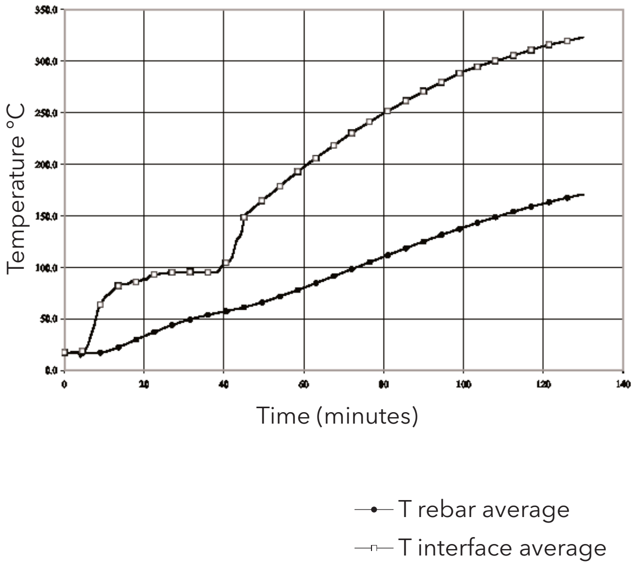
Promat conducted several fire tests at TNO Centre for Fire Research which proved that the system meets the specifications as defined in the RWS test procedure. The conclusion of these tests is that 27,5mm PROMATECT®-H boards will provide sufficient insulation to the concrete structure to meet the RWS requirements as listed in paragraph 3.3.

The graphs below indicate the thermal performance of 27,5mm PROMATECT®-H boards when applied for concrete protection [5]*. As can be seen, the recorded temperatures on the interface (approximately 320°C) and the reinforcement (165°C) are well below the RWS criteria of 380°C and 250°C respectively.

* Refer to 'References List' on page 22.



TNO Efectis Netherlands: largest RWS-fire capable furnace in Europe




#### 4.1.1. PROMATECT®-H CEILING SYSTEM, LOST FORMWORK METHOD

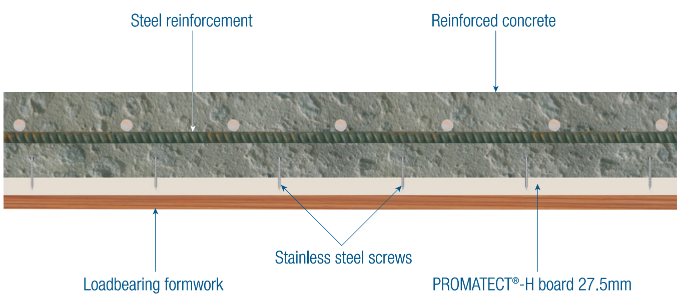
In this project the PROMATECT®-H boards in the ceiling were applied using the lost formwork method. Basically this system consists of the following installation steps:

**1. The boards are laid on the load-bearing formwork**

The PROMATECT®-H boards will be laid with the smooth face down **(see drawing A)**, as this will provide the fair faced finish after completion of the tunnel.

It is very important to align the first row of boards preferably alongside a ruler or a strip of plywood, which is screwed to the formwork. The rest of the boards are laid next to each other, with butted joints, utilising the previous row as the next ruler. No special treatment on the joints is required **(see photographs B, C and D)**.

Where the tunnel is designed with sloped sections, so called haunches, the edges of the boards are simply cut under an angle and installed butt-jointed **(see photograph E)**.




A - Principle of lost formwork

In order to minimise tolerances by cutting on the job site, there are two options. One is to lay the boards on the formwork, draw the cutting line (for example at the end of a section) and cut all boards in one go alongside a ruler on the formwork. The second option is to pre-cut the boards in a dedicated workshop on site. This second method was used by Taisei and has proven its accuracy, based on the minimised gaps between the boards.

The boards can either be installed using staggered joints or straight joints. Experience from contractors has learned that the staggered joint method results is less gaps in between the boards, as this method allows to compensate for certain tolerances, whereas the straight joint method does not allow for much compensation. For The Palm Jumeirah tunnel, Taisei chose to lay the boards with straight joints.

The locations of the screws are marked on the boards, using a template and a spray-can with red paint (see par. 5.1.), **(photograph F)**.

### 2. The first layer of reinforcement is installed

Prior to the installation of the stainless steel screws, the first layer of reinforcement is installed on the stools (spacer blocks creating concrete cover). In this way the screws are always protected from people stepping on them **(see photograph G)**.

### 3. Stainless steel screws are partly inserted in the PROMATECT®-H boards

The 50mm long screws (as detailed on page 13) are inserted to a depth of 20mm, through the openings in the reinforcement; the remaining 30mm sticks out of the board creating the anchorage to the concrete after it has been poured **(see drawing H next page)**. Several methods are available on the market for ease of installation of the stainless steel screws **(see photographs I and J next page)**:

- Battery-driven drilling machines can be equipped with depth guiding devices to ensure the correct drilling depth of 20mm.
- Screws can be supplied on a plastic strip, which is fed into the drilling machine, increasing the installation speed.
- Battery-driven drilling machines can be equipped with a tube through which the screw can be dropped down onto the surface of the board. The installer can remain standing upright while installing the screws.

### 4. The concrete is poured

Before the concrete is poured, the PROMATECT®-H boards can be hosed down to remove the accumulated site debris and to humidify the boards to prevent that water is extracted from the concrete mixture. Excessive water should be removed from the surface of the boards prior to the pouring of the concrete **(see photograph K next page)**. During vibration of the concrete, the machinery being used should be kept away from the surface of the PROMATECT®-H boards.

### 5. After the concrete is sufficiently cured the formwork will be extracted

As there is no adhesion between the concrete and the formwork, it will be easy to extract the formwork and it remains clean **(see photograph L next page)**. The following advantages of the PROMATECT®-H lost formwork system have been reported by contractors over the years:

Formwork savings:

- The shuttering material only has to have load-bearing properties. There is no need to apply phenol coated plywood boards as the PROMATECT®-H boards will be laid on top of the formwork. The formwork elements just have to be installed properly (flush).


B - Fixed strip of plywood serves as a ruler for the first row of boards


C - The boards are laid with the smooth face down


D - The joints are butted, no special treatment of the joints are required


E - The boards are cut under an angle at the haunches

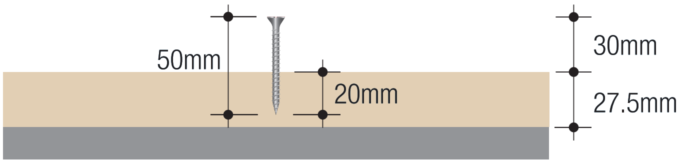

F - The screw locations are pre-marked on the boards


G - First layer on reinforcement installed, prior to inserting the screws

- As the concrete will not be in direct contact with the formwork, there is no need for de-moulding oil (no slippery surfaces). The plywood sheets will remain clean and can be re-used.
- Formwork can be installed at a distance of up to 90mm from the side walls. The PROMATECT®-H boards can span that distance, depending on the expected load. At this location, care should be taken with the vibrating action during pouring of the concrete. Extraction of the formwork is much easier as it will not get stuck between the walls.
- As there is no adhesion between the concrete and the formwork, it is easy to extract the formwork

Ease of installation:

- Joints in between boards only have to be butt-jointed. No special treatment such as filler or mastic is necessary from a fire performance point of view. The cement water will not run through the joints. Where gaps of more than 1mm occur, mastic can be used to seal the gap in order to prevent the cement water leaking through the gap, causing an unsightly stain.
- The vertical wall panels can also be installed using the lost formwork system
- Curves in the tunnel can easily be dealt with by cutting the boards on the formwork
- Openings in the PROMATECT®-H lining (for manholes and end-walls) can easily be made by installing a phenol coated formwork panel instead. Afterwards standard size PROMATECT®-H boards will close the opening by post-fixing the board into the opening.
- PROMATECT®-H boards provide a heavy-duty floor surface. The abrasion resistance is such that the surface can withstand the exposure to people walking and working on top of it, even in wet conditions. Also, the weight of bundles of reinforcement steel and pallets in excess of one tonne will not cause any damage to the boards.
- Rapid installation method. Installation rates for the PROMATECT®-H boards of 150m² per man per day have been reported on European tunnel projects.
- The installation of the system does not interfere with other construction activities.
- Extensive experience is available with this system in immersed and cut and cover tunnels Tunnel services and special shapes:
- Anchor systems (i.e. jet-fans) can be fixed on the boards, prior to casting the concrete
- Services, pipes, tubes etc. can be included
- After the formwork is extracted, services can be installed on the PROMATECT®-H lining from below. Anchors can be installed through the boards into the concrete, thus providing a continuous fire protective layer.
- Special shapes in the concrete structure can easily be made (i.e. beams)




H - Principle of screw insertion

I - Insertion of the screws

J - Screw installed and protected by reinforcement

K - The pouring of the concrete

L - Extracted formwork. Flush finish of the ceiling

Other:

- As the PROMATECT®-H boards are installed in the very early stages of the construction of the tunnel, it provides fire protection during the construction phase.
- The PROMATECT®-H lost formwork system provides a flush finish of the ceiling. No obstacles like anchor-heads.

Promat

# PROMATECT®-H
## Lost formwork system at The Palm Jumeirah, Dubai, UAE

Wall panels can also be installed using the lost formwork method

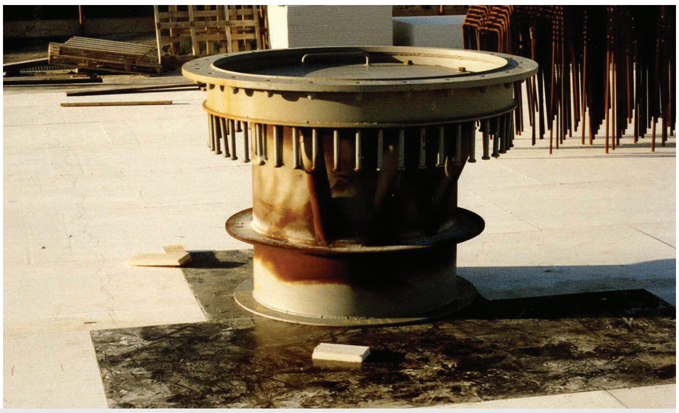
Regular load bearing plywood can be used instead of phenol coated

Cutting the boards on the formwork eliminates tolerances

Distance between formwork and wall, easing the extraction of the formwork

Anchors for services are installed through boards into the concrete, thus creating a continuous fire protective layer

Special shapes in the concrete can easily be made

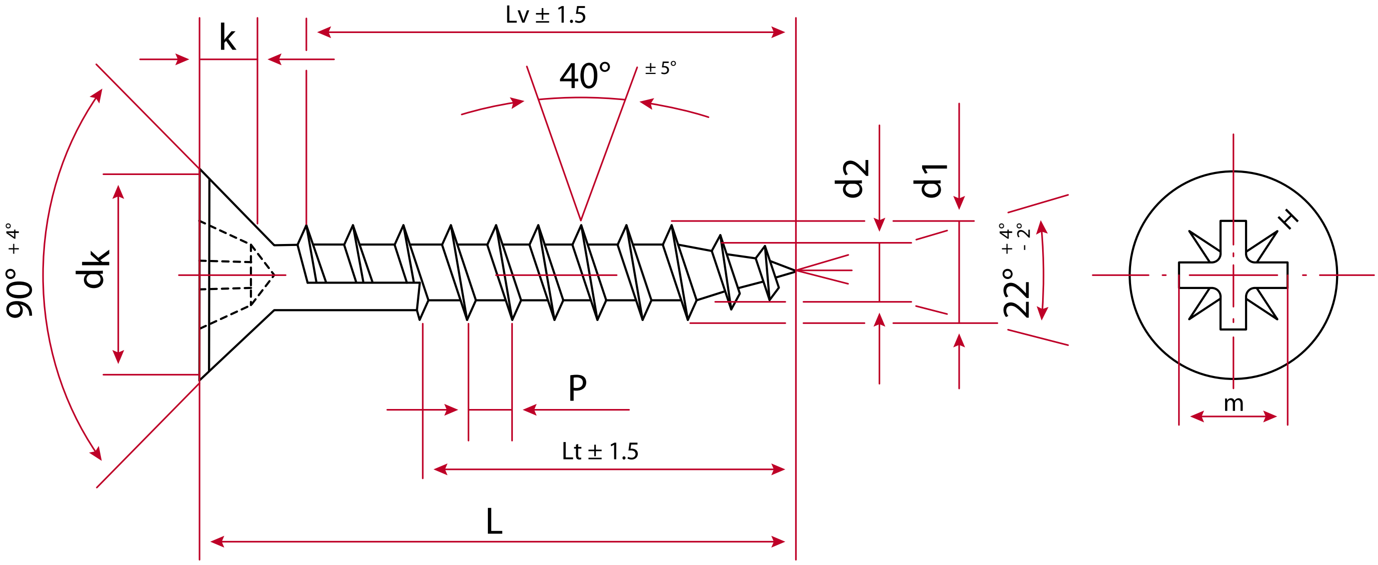


Openings for manholes can easlily be made by using phenol coated plywood panels

## 4.1.1.a. SCREW MODEL DESCRIPTION

The applied screws for the lost formwork system are 5.0 x 50mm chipboard screws, with a countersunk (CSK) head type and a pozidrive-2 connection. These screws were applied in a stainless steel grade A2 (1.4567). See par. 4.1.3 for more details on this.

Dimensional details of this particular screw can be found in the below table and drawing.




The design of a screw has major influence on the mechanical performance and fire performance, in combination with PROMATECT®-H boards. Among others, properties like shaft-diameter versus thread-diameter, sharpness of the tip and distance of the winding (thread) will influence the stickability of the screws and the performance of the final system.

The above mentioned screw type has been tested to its pullout resistance when partially (20mm) inserted into dry as well as water saturated (worst case) 27,5mm PROMATECT®-H boards [6]*. Even when tested in water saturated conditions the minimum-recorded screw pullout strength was in excess of 500N, which was satisfactory for the client. In dry conditions the maximum-recorded screw pullout strength exceeded 725N. Similar screws as described above have also been used in a lost formwork system in a fire test at TNO where PROMATECT®-H boards have been exposed to the RWS fire curve for 120 minutes, without any mechanical or thermal failure [7]*.

| Code | Description | Dimension (mm) | Tolerance |
|---|---|---|---|
| **L** | Length | 50 | - |
| **Lv** | Length of winding | 44 | +/- 1,5mm |
| **Lt** | Length of serrated winding | 29 | +/- 1,5mm |
| **d1** | Threat diameter | 5,0 | +0,2 -0,35mm |
| **d2** | Shaft diameter | 3,05 - 3,45 | - |
| **dk** | Head diameter | 9,7 | +0 -0,5mm |
| **p** | Winding distance | 2,5 | +/- 10% |
| **k** | Connection depth, Pozidrive-2 | 2,6 - 3,0 | - |
| **m** | Connection width | 5,3 | - |

* Refer to 'References List' on page 22.

### 4.1.1.b. TUNNEL EXPANSION JOINTS

The expansion joints are kept watertight by means of a rubber profile which is embedded in the concrete. During the lifetime of the tunnel an expansion joint can create a gap of up to a maximum of 35mm as a result of thermal movement of the tunnel. This could potentially cause a thermal leak in case of fire as the PROMATECT®-H boards will follow the movement of the structural concrete it is mounted on. In order to address this, cover strips of the same PROMATECT®-H 27,5mm material are installed behind the joints and are fixed with stainless steel screws to one side. In this way a potential gap in between the boards, at the location of the expansion joint, is always closed and the fire performance is secured.

Detail of an expansion joint and cover strip allowing movement

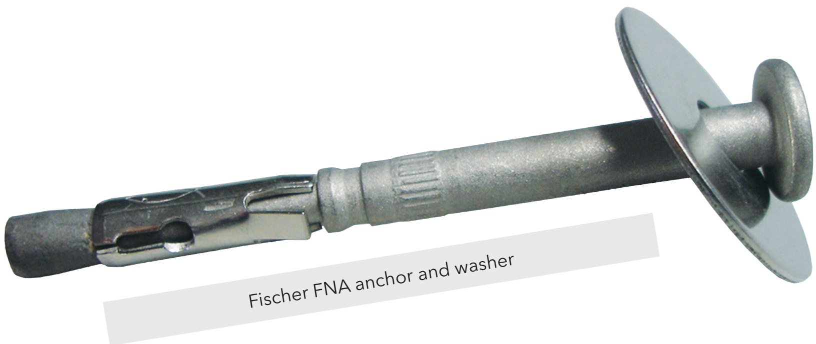
### 4.1.2. PROMATECT®-H WALL SYSTEM, POST-FIXED METHOD

Just like the ceiling system, the wall panels can also be installed as a lost formwork system. The boards are temporarily connected to the vertical formwork by means of 4 screws per panel. The anchorage of the PROMATECT®-H board to the concrete is again done by means of partially inserted screws.

For the Palm Jumeirah tunnel it was decided to install the wall panels after the walls had been constructed. The boards were installed by means of stainless steel anchors, creating fire protection over a height of 1200mm on the wall. The boards were anchored to the concrete, butt jointing one board next to the other. The reason for protecting the top section of the wall is that the bending moment in the roof introduces compression stresses into the upper part of the wall. Research has proven that concrete that is exposed to compression stress is more vulnerable to fire exposure (spalling), as opposed to neutral (non-loaded) or tensioned concrete.

### 4.1.2.a. ANCHOR MODEL DESCRIPTION

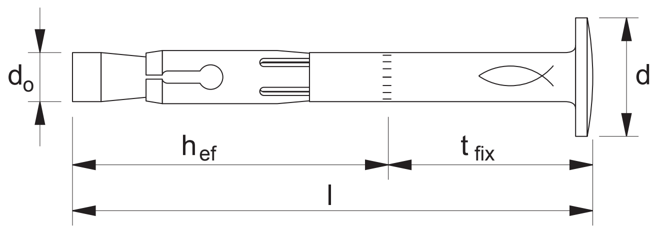
The selected anchor type is the Fischer FNA 6x30/30 A4. These anchors were applied in a stainless steel grade A4 (1.4401). See par. 4.1.3 for more details on this. The FNA anchors are installed in combination with a circular washer, diameter 30mm, thickness 1,2mm stainless steel grade A4 and a hole diameter of 7,5mm. This FNA anchor, including the washer, was tested at TNO, Centre for Fire Research in RWS fire conditions for 120 minutes in combination with the 27,5mm PROMATECT®-H boards and passed the test, without any mechanical or thermal failure [5]*.



Fischer FNA anchor and washer

* Refer to 'References List' on page 22.

| Code | Description | Dimension (mm) |
|---|---|---|
| $d_o$ | Anchor diameter | 6 |
| l | Length | 68 |
| $h_{ef}$ | Effective anchorage depth | 30 |
| $t_{fix}$ | Effective length | 30 |
| d | Diameter of nailhead | 13 |




fischer FIXING SYSTEMS

The aforementioned anchor type, including the washer, has also been tested for its pull-through resistance when installed in dry and water saturated (worst case) 27,5mm PROMATECT®-H boards [8]*.

Even when tested in water saturated conditions the recorded anchor pull-through strength was in excess of 2400N, which was satisfactory for the client. In dry conditions the recorded anchor pull-through strength exceeded 3300N.

In general, when selecting anchors for the installation of fire protective boards in tunnels, following items should be considered:

- Preferably M6 in diameter, to avoid heat sink into the concrete in case of fire
- Made of stainless steel. Grade in function of local tunnel environment (see par. 4.1.3.)
- Of appropriate length to secure the panel, depending on the panel thickness
- Expansion action of the anchorage shall be within the concrete and not in the PROMATECT®-H panel.
- Can be supplied with a nut and washer head to facilitate removal of the PROMATECT®-H panels where required.
- Suitable for use in the tension zone of concrete (cracked concrete).
- Suitable for use where the bolts will be subject to positive and negative pressure fluctuation.

### 4.1.3. CORROSION RESISTANCE OF FIXATION MATERIALS, STAINLESS STEEL GRADES

As described in par. 4.1.1.a. and 4.1.2.a. the fixation materials for the installation of the PROMATECT®-H boards are made out of stainless steel.

| Item | Group Material | | DIN | AISI | Chemical composition | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | C | Si | Mn | S | Cr | Mo | Ni | Cu |
| **Post fixedwall: Fischer anchor FNA 6x30/30** | A4 | 1.4401 | X4CrNiMo17-12-2 | 316 | 0,04 | 0,50 | 1,00 | 0,015 | 17,50 | 2,25 | 12,00 | - |
| **Lost formwork ceiling: screw 5x50mm** | A2 | 1.4567 | X3CrNiCu 18-9-4 | 304 Cu | 0,03 | 0,50 | 1,00 | 0,015 | 18,00 | - | 9,00 | 3,50 |

The above mentioned stainless steel grades were also used for the fire tests and mechanical tests. In general, the corrosion resistance of fixing materials for fire protective boards in a tunnel should be checked with the fixing supplier as to the suitability of application in the specific environmental conditions of the tunnel project it is meant for.

* Refer to 'References List' on page 22.

### 4.2. DYNAMIC LOAD EXPOSURE ON THE FIRE PROTECTIVE LINING

When the tunnel is in operation and traffic passes through the tunnel, the tunnel lining gets exposed to air pressure/de-pressure fluctuations (dynamic loads) especially from trucks.

The de-pressure loads in particular can cause integrity problems to fire protective linings. Several tests were conducted at the Technical University of Braunschweig, Germany in order to judge the behaviour of both the lost formwork system (ceiling) as well as the post-fixed system (wall) [9]*.

### 4.2.1 DYNAMIC LOAD ON LOST FORMWORK SYSTEM (CEILING)

When concrete is poured on the surface of PROMATECT®-H boards, the boards will absorb some cement water creating additional adhesion of the boards to the concrete surface.

This effect results in an increased stickability of the boards, as these are not relying on the screws only. However, during the lifetime of the tunnel the adhesion effect of the cement water could decrease, as a result of movement of the tunnel tube and temperature differences. In that case the boards are again relying on the pullout strength of the screws, when the lining gets exposed to dynamic loads.

In order to simulate this worst case scenario, dynamic load tests were conducted using a polyethylene foil at the interface, in between the PROMATECT®-H boards and the concrete, to avoid the adhesion effect [9]*. The whole system was exposed to dynamic loads of up to +/-3 KPa, which is approximately 3 times the load expected in practice. No mechanical failures or any damage to the boards were recorded. The deflection between the screws was less than 1/15.000 of the span.

### 4.2.2. DYNAMIC LOAD ON POST-FIXED SYSTEM (WALL)

27,5mm thick PROMATECT®-H boards were also tested to dynamic loads when post-fixed to a concrete slab, using 3,8 anchors per $m^2$, in combination with a 30mm circular washer [9]*. This average of 3,8 anchors per m2 is even less than the 4,5 to 5 anchors per m2 which are applied in practice. The system was exposed to respectively 3, 4 and 5 KPa. The maximum deflection at 5 KPa was recorded at 1/1.500 of the span between the anchors. No mechanical failures or any damage to the boards were recorded.

### 4.3. SURFACE QUALITY AND CLEAN-ABILITY

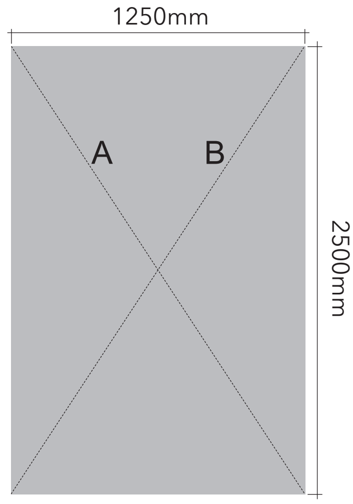
The standard appearance of PROMATECT®-H is a white to off-white colour, having diffuse light reflectance properties, suitable for tunnel linings. When properly maintained the surface can be cleaned by means of professional washing equipment. The abrasion resistance of the surface is such that it will withstand the cleaning action of the brushes.

### 4.4. DIMENSIONAL TOLERANCES OF PROMATECT®-H BOARDS

The dimensions of each tunnel section in the ceiling area are approximately 16 x 25 meters. If the dimensional and squareness tolerances on the PROMATECT®-H boards were too large, gaps would occur while laying the boards on the formwork as the tolerances will add up.

In order to avoid this effect, PROMATECT®-H boards are cut to tight tolerances in the factory, such that gaps between the boards will be minimised.

| Item | Specification | Tolerance |
|---|---|---|
| **Thickness** | Nominal 27,5mm | Minimum 27,0mm<br>Maximum 30,0mm |
| **Length and width** | L x W = 2500x1250mm | +/- 1,0mm on L and W |
| **Squareness** | Difference in diagonal lengths | A - B < 1,5mm |
| **Straightness of edges** | Maximum theoretical gap in between two boards | < 1,5mm |




### 4.5. REPAIR OF MINOR DAMAGES

PROMATECT®-H boards, when installed in a lost formwork system, provide a heavy-duty floor surface. The abrasion resistance is such that the surface can withstand the exposure to people walking and working on top of it, in all weather conditions. However, in practice, minor damage can occur on the jobsite. In case minor surface damages or gaps in between the boards in excess of 2mm would occur, these would be filled with PROMATECT®-T compound, prior to casting the concrete. This material comes as a dry, white to off white powder made from calcium-aluminium silicates and additives. It will just be mixed with water and is then applied with a spatula.

The PROMATECT®-T compound was tested to RWS conditions for a duration of 120 minutes [10]*. A gap of 10mm width was left open in between two PROMATECT®-H panels of 27,5mm thick. Also two holes of 10mm diameter were drilled into the panels. Both the gap and the holes were filled with the PROMATECT®-T compound, which did not show any integrity failures during and after the fire test. The average interface temperature at the joint (behind the PROMATECT®-T compound) after 120 minutes of RWS fire exposure was 335°C, which is well below the interface criteria of 380°C according to RWS requirements.

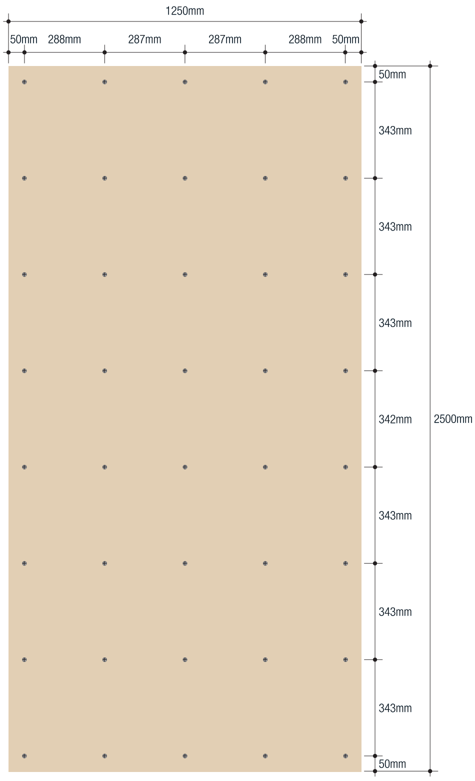
See the technical data sheet for more details and installation and application instructions [11]*.

* Refer to 'References List' on page 22.

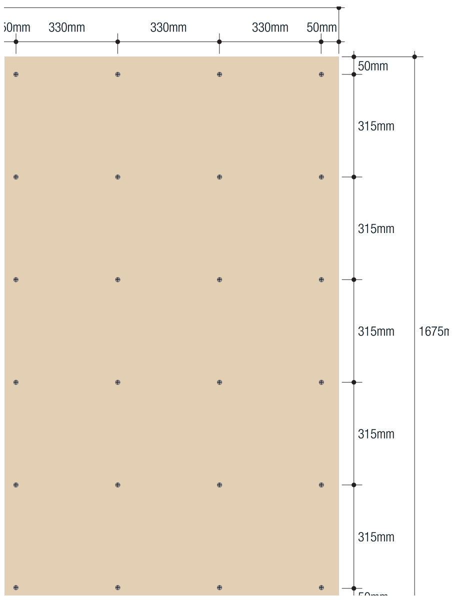
# 5. Installation guide and experiences

### 5.1. CEILING APPLICATION

12 screws per m$^2$ were applied during the fire test at TNO, The Netherlands [7]*. In order to ensure the same fire performance in practice, the exact same set-up as duringthe fire test should always be followed, including fixing materials.




The screw pattern of a full size board of 2500 x 1250mm looks as detailed below, providing an average of 12,8 screws per m$^2$:




In The Palm Jumeirah tunnel the PROMATECT®-H boards were supplied in dimensions of 2500 x 1250mm. The locations of the screws were marked on the boards, using a template and a spray-can with red paint.

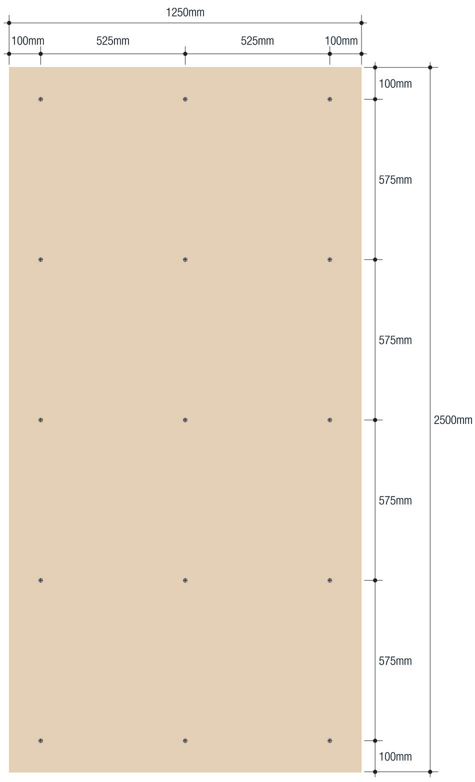
The majority of the boards are laid on the formwork in its standard full size dimension. Some panels had to be cut to size in order to cover the whole surface of the formwork and to connect to the walls and construction joints.

Where cut to size panels are used, the following criteria should be followed:

- The minimum amount of screws should be 12 screws per m$^2$.
- The edge distance should be 50mm
- The screws for cut pieces should be evenly distributed over the surface of the panel. That means that the spacing distances in X and Y direction should be optimised and be as close as possible.

The drawing opposite is an example of a screw pattern on a cut to size panel of 1675 x 1090mm, in which all criteria are followed. The surface area of the panel is 1,83m$^2$ which means that the minimum amount of screws should be 22. In this case the total amount is 24 screws and the edge distance of 50mm is followed. The spacing distances are optimised and are almost equal (315 and 330mm).

### 5.2. WALL APPLICATION




Post-fixed installation of PROMATECT®-H boards require 4,5 to 5 anchors per m$^2$. The anchors will be installed using a circular washer of 30mm diameter, as described in par. 4.1.2.a.

The anchor pattern of a full size board of 2500 x 1250mm looks as follows, having an average of 4,8 anchors per m$^2$:

The majority of the boards are installed against the wall in standard (full size) dimensions. Some panels have to be cut to size in order to connect to the ends of the tunnel element.


Spray can to mark screw location using template

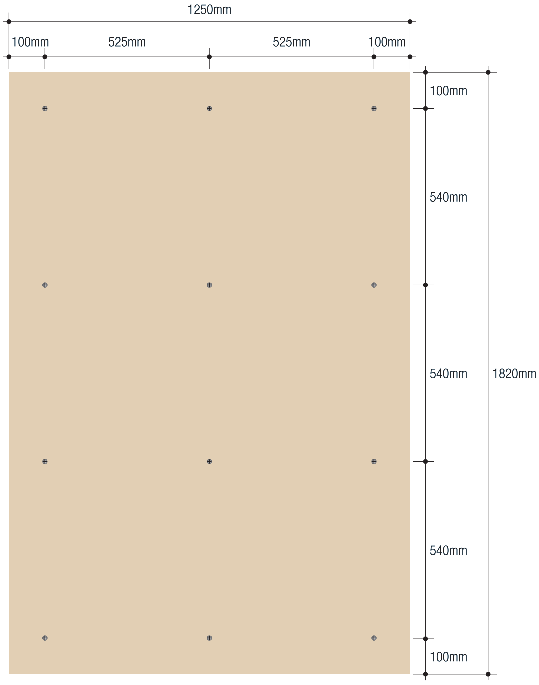

Template for screw location

In case of cut to size panels, the following criteria should be followed:

- The minimum amount of anchors should be 4,5 anchors per $m^2$.
- The edge distance should be 100mm.
- The anchors for cut pieces should be evenly distributed over the surface of the panel. That means that the spacing distances in X and Y direction should be optimised and be as close as possible.

The drawing opposite is an example of an anchor pattern on a cut to size panel of 1820 x 1250mm, in which all criteria are followed.

The surface area of the panel is 2,28$m^2$ which means that there should be a minimum of 11 anchors. In this case, the total amount is 12 anchors and the edge distance is 100mm. The spacing distances are optimised and are almost equal (525 and 540mm).




# 6. Project references in lost formwork application

Throughout the world, Promat boards have been applied to protect over 120 tunnels against the most severe tunnel fires. Amongst others, the PROMATECT®-H lost formwork system as used in The Palm Jumeirah tunnel was also installed in following reference projects:

| Project name | Year of installation | Country | City | Tunnel use |
|---|---|---|---|---|
| Aquaduct Abcoude | 2005 | The Netherlands | Abcoude | Train |
| Roer Tunnel | 2005 | The Netherlands | Roermond | Road |
| Gotha Tunnel | 2003 | Sweden | Gothenburg | Road |
| Viaduct Schiphol Airport | 2002 | The Netherlands | Amsterdam | Road |
| Caland Tunnel | 2002 | The Netherlands | Rotterdam | Road |
| High Speed Line | 2002 | The Netherlands | Rotterdam | High speed train |
| Seitwende Tunnel | 2002 | The Netherlands | The Hague | Road |
| Elbe Tunnel 4th Tube (ramps) | 2001 | Germany | Hamburg | Road |
| 2nd Benelux Tunnel | 2001 | The Netherlands | Rotterdam | Road |
| City Northern Bypass Tunnel | 1998 | Australia | Perth | Road |
| Tunnel North River | 1989 | The Netherlands | Hendrik Ido Ambacht | Road |
| Harbour Tunnel CANA | 1989 | USA | Boston | Road |

Promat

# PROMATECT®-H
# Lost formwork system at The Palm Jumeirah, Dubai, UAE


Aquaduct Abcoude, The Netherlands


Roer tunnel, The Netherlands

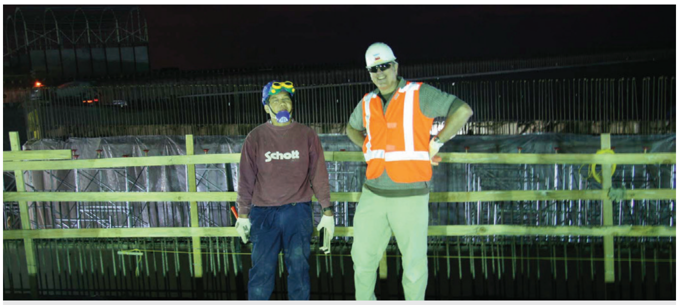

Gotha tunnel, Sweden


Project builders


City Northern Bypass tunnel, Perth, Australia


Project builders


Harbour tunnel CANA, USA


Project builders


Seitwende tunnel, The Netherlands


Project builders

# 7. Acknowledgement and reference list

## REFERENCE LIST

*[1] SPALLING OF CONCRETE AND FIRE PROTECTION OF CONCRETE STRUCTURES*

A. J. Breunese and J. H. H. Fellinger

TNO Building and Construction Research, Centre for Fire Research, Delft/Rijswijk, The Netherlands

*[2] SUMMARY OF LARGE SCALE FIRE TESTS IN THE RUNEHAMAR TUNNEL IN NORWAY, CONDUCTED IN ASSOCIATION WITH THE UPTUN RESEARCH PROGRAM*

Jan Brekelmans, TNO Building and Construction Research, Centre for Fire Research,

René van den Bosch, Promat Tunnel Fire Protection

*[3] GUIDELINES FOR STRUCTURAL FIRE RESISTANCE FOR ROAD TUNNELS*

ITA, International Tunnelling Association, Working Group No.6 Maintenance and Repair, May, 2004

*[4] FIRE PROTECTION FOR TUNNELS, Part 1: Fire Test Procedure,*

*1998-CVB-R1161 (rev. 1)*

TNO Building and Construction Research, Centre for Fire Research, Delft/Rijswijk, The Netherlands

*[5] DETERMINATION OF THE BEHAVIOUR OF A CONCRETE SLAB PROTECTED WITH CALCIUM SILICATE BOARD TYPE PROMATECT®-H UNDER RWS FIRE CONDITIONS, 2004-CVB-R0115 (Rev.1).*

TNO Building and Construction Research, Centre for Fire Research, Delft/Rijswijk, The Netherlands

*[6] SCREW PULLOUT OF PROMATECT®-H IN DRY AND WATER SATURATED CONDITION*

PRTC, Promat Research and Technology Centre, 30 November 2005

*[7] DETERMINATION OF THE BEHAVIOUR OF A CONCRETE SLAB PROTECTED WITH CALCIUM SILICATE BOARD TYPE PROMATECT®-H UNDER RWS FIRE CONDITIONS, B-85-191(E)*

TNO Building and Construction Research, Centre for Fire Research, Delft/Rijswijk, The Netherlands

*[8] PULL THROUGH TEST ON PROMATECT®-H 27,5 MM OF FISCHER FIXATIONS AT060131*

PRTC, Promat Research and Technology Centre, 2 February 2006

*[9] TESTING OF DYNAMIC LOAD CYCLES IN 27,5 MM PROMATECT®-H BOARDS (German)*

6432/328-Pm/br Technical University Braunschweig, 25 July 1989

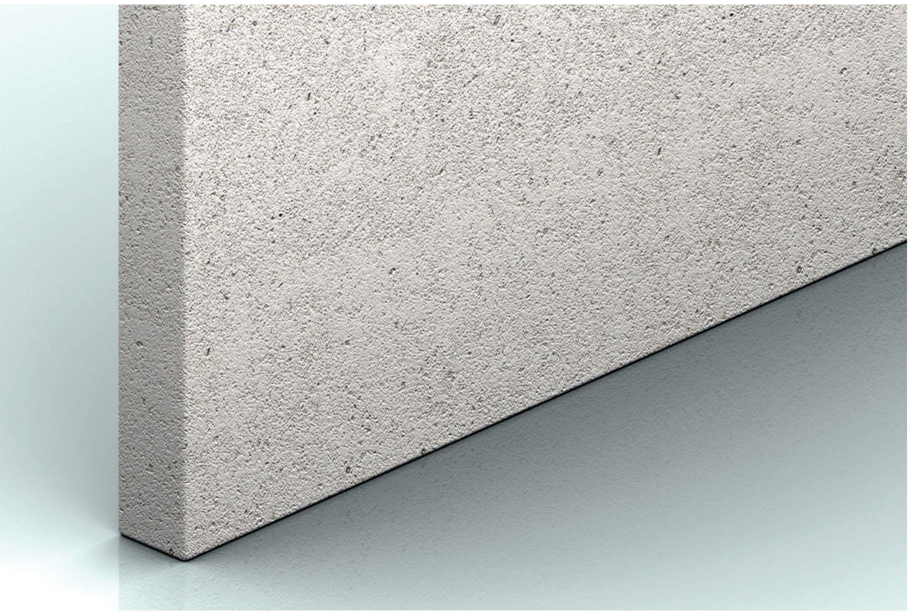
*[10] DETERMINATION OF THE BEHAVIOUR OF A CONCRETE SLAB PROTECTED WITH CALCIUM SILICATE BOARD TYPE PROMATECT®-H UNDER RWS FIRE CONDITIONS, 2004-CVB-R0114 (Rev.1).*

TNO Building and Construction Research, Centre for Fire Research, Delft/Rijswijk, The Netherlands

*[11] TECHNICAL DATASHEET PROMATECT®-T COMPOUND*

October 2003

# 8. Technical data sheet PROMATECT®-H for The Palm Jumeirah tunnel



## Introduction

PROMATECT®-H is a non-combustible matrix engineered mineral board reinforced with selected fibres and fillers. It is formulated without the use of formaldehyde.

PROMATECT®-H is off-white in colour and has a smooth finish on one face with a sanded reverse face. The board can be left undecorated or easily finished with paints.

PROMATECT®-H is resistant to the effects of moisture and will not physically deteriorate when used in damp or humid conditions. Performance characteristics are not degraded by age or moisture.

## Advantages

- Resistant to the effects of moisture
- Not physically deteriorate when used in damp or humid conditions
- Performance characteristics are not degraded by age or moisture.

## Applications

- Tunnel lining, concrete floor and wall upgrading
- M&E services enclosure
- Access panels and hatches, fire doors
- Structural steel protection
- Membrane ceilings
- Cladding to steel ducts, self-supporting ducts

## Fire protection thickness

Fire protection thickness requirements are often specified in the owner operator's engineering codes of practice.

Alternatively, please consult Promat

## General technical properties

| | | |
|---|---|---|
| **Product generic description** | non-combustible, fire resisting calcium silicate board | |
| **Combustibility** | DIN 4102, Part 1<br>BS 476, Part 4<br>EN 13051-1:A1<br>(Classification Report WFR-Gent 11527C) | Non-combustible |
| **Board format (length x width)** | mm | 1250 x 2500 |
| **Tolerance on length and width** | mm | ± 1 |
| **Board thickness** | mm | 27,5 |
| **Tolerances on thickness** | mm | Minimum 27,0<br>Maximum 30,0 |
| **Tolerances on squareness** | mm | Difference in diagonal length:<br>A - B < 1,5 |
| **Straightness of edges** | mm | Maximum gap in between 2 boards <1,5 |
| **Density (nominal, oven dry)** | $Kg/m^3$ | 870 ± 15% |
| **Density (nominal, 23°C, 50% RH)** | $Kg/m^3$ | 940 ± 15% |
| **Alkalinity (approximate)** | pH | Approximately 12 |
| **Thermal conductivity λ** | W/m°K | Approximately 0.175 (at 20°C) |
| **Water absorption** | $g/cm^3$ | Approximately 0.57 |
| **Moisture diffusion resistance** | μ | ca. 20 |
| **Typical moisture content (at EMC*)** | % | 5 - 10 |
| **Surface conditions** | Front face: smooth, unsanded<br>Back face: embossed or sanded<br>Colour: off-white | |
| **Storage** | Store on flat surface, in a dry area. | |

## Typical mechanical properties

| | | |
|---|---|---|
| **Bending strength (longitudinal direction)** | N/mm² | 7.0 |
| **Tensile strength (longitudinal direction)** | N/mm² | 4.5 |
| **Compressive strength (perpendicular to the surface)** | N/mm² | 9.3 |
| **Screw pull out resistance: screw into board surface - 20mm deep** | HECO-FIX PLUS 5,0 X 50 mm:<br>Dry drilled – dry tested:<br>Maximum value 727 N<br>Minimum value 630 N<br>Dry drilled – wet tested:<br>Maximum value 559 N<br>Minimum value 509 N | |
| **Anchor pull through resistance (board thickness = 27,5mm)** | Fischer FNA 6x30/30 A4, with 30mm circular washer A4:<br>Dry: 3368 N<br>Wet: 2456 N | |

* EMC: Equilibrium moisture content.

### Processing & machining

When machining the product with power tools, do not breathe dust and respect the regulatory occupational exposure limits for total inhalable and respirable dust. Wear safety goggles. Avoid contact with skin and eyes. Use dust extraction. In case of insufficient ventilation, wear suitable respiratory equipment to avoid health effects.

### Waste disposal

Refer to local legislation

If not available: the board is not classified as a dangerous substance and no special provisions are required regarding the carriage and disposal of the product to landfill. They can placed in an on-site skip with other general building waste.

### Quality assurance

Promat products are manufactured to stringent quality control systems to assure that our customers receive materials made to the highest standards.

Operating to these standards means that all activities, which have a bearing upon quality, are set out in written procedures.

Systematic and thorough checks are made on all materials and their usage. Test equipment is subjected to regular checks and is referred back to national standards.

The information given in this data sheet is based on actual tests and is believed to be typical of the product. No guarantee of results is implied however, since conditions of use are beyond our control.

# Notes

# Notes

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