In modern urban systems, especially in cities, there is a well established tendency to go underground for the construction of new rail and road transit ways. Together with these works there is an ever-growing development of specialised service areas such as underground stations, car parks, garages and facilities that are linked by tunnels or subways. In those areas characterised by persistent snowfalls until late in the season, where the consequent accumulation of snow might threaten transport structures, anti-avalanche tunnels with canopy are created, which remain under snow for a long time and need waterproof protection.

The concrete structures designed to protect these spaces must in turn be protected, before being buried, with a waterproofing membrane to prevent water from penetrating the concrete and corroding the reinforcing rods. This operation is carried out on top of the exposed part of the structure to create a barrier in direct contact with the ground.

For proper water drainage it is necessary to also lay draining belts made of suitable panels and perforated tubes. When planning waterproofing protection for tunnels, one must take into account, as already done for the underground works (see Foundations), the fact that the durability of the waterproofing must be the same as the rest of the protected works since it would be quite difficult to carry out repairs at a later date on surfaces that are not accessible.

It is therefore necessary to choose materials with proven performance and good resistance to perforation to withstand the weight of static loads and site traffic.

For some years INDEX has introduced to the market such highly reliable membranes as TESTUDO SPUNBOND POLIESTERE and PROTEADUO POLIESTERE.
INTRODUCTION

Problems
The waterproofing coverings of tunnels and underground works are usually subject to physical actions of impact: during the application phase as a result of site traffic, and subsequently due to the action of the material which will be placed over the waterproof layer. During its operational life, the waterproofing is mainly subject to static load and to the stress induced by the cracks that form in the laying surface due to the shrinkage of concrete and the effects of fatigue caused by the joining lines of prefabricated panels as a result of the vibration caused by the traffic of motor vehicles.

During the earth covering operations, the covering is subject to abrasion and traction in case of vertical parts covered with drylined membranes.

The waterproof coverings are chemically attacked by underground water, including the water polluted by humic acids, fertilisers and soil micro-organisms.

The covering often serves functions other than that of a cover for the area beneath. One of these is that of being a parking facility (see Technical Specifications no. 8). It is usual to lay hot bituminous conglomerate or poured asphalt directly onto the waterproof covering, which must withstand the thermal shock deriving from applying the layers mentioned above.

In this last case the covering will be exposed in winter to frost-defrost cycles and to the chemical attack of the saline solutions from the use of road salts.

Finally, in case of a seismic event, the cover will be stressed by the differential movements of the layers of concrete in which it is inserted (see Technical Specifications no. 5 bis).

Based on the stress to be incurred, the waterproof covering must be:

• fully bonded to the works to be protected to minimise water seepage in the event of accidental perforation and to resist the parallel forces due to differential movements in the layers of concrete the covering is inserted into and the earth movements on the vertical walls.

• applied thickly: for total adherence the covering must be 4 mm thick to overcome the superficial roughness of the laying structure and such unavoidable problems as small stones and other granular materials which are always present in tunnel-like structures.

• applied thickly: to withstand the abrasive action of the granules detached by friction from the cement surfaces upon which the covering was applied in case of SEISMIC event.

• reinforced with elastic reinforcements featuring a high mechanical resistance to the fatigue from fissures opening and closing in the laying surface onto which the surface is bonded.

• strengthened with reinforcing materials which give the best continuous strength, compatibly with the adhesion to the waterproofing mass, and in order to obtain a waterproofing layer featuring a uniform mechanical behaviour and puncture resistance in all thicknesses.

• inherently puncture resistant. This must take place before the covering is protected by a successive layer and subject to accidental site dynamic punching that may cause leaks that are hard to identify.

• resistant to chemical and biological agents present in the soil and in the other adjacent layers.

• root resistant in all thicknesses, including the overlaps, in case the covering (see Technical Specifications no. 10) is in contact with the soil of a roof garden or where the works are to be covered with earth in which thick vegetation might subsequently grow.

• applicable in single or multi-layered bondable sheets in a way that, when incorporating other functions in the covering (such as anti-piercing function), the waterproofing element may always be reinforced.

• sufficient in its coefficient of friction with concrete, in seismic areas, to avoid excessive sliding between the works and waterproof cover (see Technical Specifications no. 5 bis) in the foundations during high intensity shocks and to ensure stability during low intensity shocks.

• in case of paved covers, resistant to the thermal shock and the hot punching due to laying operations and the rolling of the bituminous paving.
The tunnel of the Atlantique TGV line (Train Grand Vitesse = High Speed Train) runs completely underground for some kilometers except for some areas where it runs above ground and the waterproofing cover concerns a surface of 150,000 m².

The vertical lining is constructed from prefabricated elements. These support the covering made of prefabricated beams covered by reinforced concrete with a joint every 9÷10 m.

As there is no water bearing table, the waterproof covering with INDEX membrane was used on the covering and continued on the vertical side for about 1 m where it joins with the vertical drainage consisting of a large fibre non woven draining fabric about 2 cm thick, coupled with a non woven filtering fabric about 150 g/m².

At the foot of the vertical part the vertical drainage is joined to perforated drainpipes.

The joining lines of the lining panels are sealed with mastics and, for the vertical part of the tunnels covered with soil, these are protected with heat bonded 20÷30 cm testudo strips.

Also the horizontal connector line between the vertical lining and the horizontal beam which runs at the foot of the work, near the drainpipe, is protected by a strip of TESTUDO bonded along the joint where the vertical and horizontal sections meet.

The waterproofing element of the covering consists of a 5 mm TESTUDO SPUNBOND POLIESTERE 25 membrane torch bonded on a coat of adhesion bituminous INDEVER primer, or alternatively ECOVER water primer, protected by a puncture resistant layer. Initially this protective layer was made up of a bare non-woven polyester fabric; subsequently it was replaced by the planners with a reinforced membrane made of “non woven” polyester fabric, self-protected with MINERAL TESTUDO slate granules bonded to the previous layer and thus acting as protective and waterproofing element.

In those areas where the normal slow train passes over the tunnel, the covering was further reinforced by the addition of another layer of MINERAL TESTUDO, which as usual is heat bonded, on which the ballast was laid directly. Since the work had to be totally covered with soil in the area concerned by the planting of thick vegetation, the building management used membranes treated with the antirrot additive, phenoxy-fatty acid ester.

The specification layout can be summarised as follows:

**Primer.** All the surface onto which the covering will be stuck will be painted with a coat of 300 g/m² of INDEVER adhesion bituminous primer, or alternatively ECOVER water primer.

**Waterproofing membrane.** Once dried, on the whole horizontal surface and continuing on the vertical part for at least 1 m, an elastoplastomeric polymer distilled bitumen waterproofing membrane, 5 mm thick, type TESTUDO SPUNBOND POLIESTERE 25, based on distilled bitumen, plastomers and elastomers, reinforced with spunbond non woven fabric will be torch bonded.

There will be 10 cm sheet lateral overlaps and 15 cm lateral overlaps for the end joints, carefully torch bonded.

An elastoplastomeric polymer distilled bitumen waterproofing membrane with the upper face self-protected with slate granules of a weight of 4.5 kg/m², based on distilled bitumen, plastomers and elastomers, reinforced with spunbond non-woven polyester fabric, type MINERAL TESTUDO SPUNBOND POLIESTERE will be fully torch-bonded across the overlaps of the previous layer.

The sheets will be overlapped for 10 cm and the joints will be carefully torch-bonded.

A specific antirrot additive, phenoxy-fatty acid ester, will be added to the waterproofing mass.
**Station under public garden**

The waterproofing system is identical to that designed for the TGV tunnel, with the only difference that, in the part of the wall in contact with the ground, a gutter was built to carry the water to the drains.

The collection tank was also covered with the system described above.

**Batch with covering under poured asphalt**

Primer. All the surface onto which the covering will be stuck will be painted with a coat of 300 g/m² of INDEVER adhesion bituminous primer, or alternatively ECOVER water primer.

- **Waterproof covering with TESTUDO SPUNBOND POLIESTERE 25** elastomeric membrane. Once dried, on the whole covering and the vertical part upstream, an elastoplastomeric polymer distilled bitumen waterproofing membrane, 5 mm thick, type TESTUDO SPUNBOND POLIESTERE 25, based on distilled bitumen, plastomers and elastomers, reinforced with spunbond non woven fabric will be torch bonded. The sheets applied with 10 cm heat-bonded overlaps will be turned and torch bonded on the retaining wall downstream all the way to the head.

Alternatively:

- **Single-layer waterproof covering with PROTEADUO POLIESTERE 25 multi-layer composite membrane.** Once dried, on the whole covering and the vertical part upstream, a multi-layer polymer distilled bitumen waterproofing membrane, 5 mm thick, type PROTEADUO POLIESTERE 25, based on distilled bitumen, plastomers and elastomers, reinforced with spunbond non woven fabric stabilised with fibreglass will be torch bonded. The sheets applied with 10 cm heat-bonded overlaps will be turned and torch bonded on the retaining wall downstream all the way to the head.
A membrane is generally used to cover the covering and the vertical part uphill, which will also be fitted with vertical pebbled drainage from which the water is collected through drainpipes.

The specification layout can be summarised as follows:

**Primer.** All the surface onto which the covering will be stuck will be painted with a coat of 300 g/m² of INDEVER adhesion bituminous primer, or alternatively ECOVER water primer.

- **Waterproof covering with TESTUDO SPUNBOND POLIESTERE 25 elastomeric membrane.** An elastoplastomeric polymer distilled bitumen waterproofing membrane, 5 mm thick, type TESTUDO SPUNBOND POLIESTERE 25, based on distilled bitumen, plastomers and elastomers, reinforced with spunbond non woven fabric will be torch bonded to the whole covering and the vertical part upstream. The sheets applied with 10 cm heat-bonded overlaps will be turned and torch bonded on the retaining wall downstream all the way to the head.

In particularly cold mountainous areas, as an alternative to TESTUDO SPUNBOND POLIESTERE 25, the PROTEADUO POLIESTERE 25 membrane may be applied with the same methods. The laying operations are summarised below:

- **Waterproof covering with PROTEADUO POLIESTERE 25 multi-layer composite membrane.** A multi-layer polymer distilled bitumen waterproofing membrane, 5 mm thick, type PROTEADUO POLIESTERE 25, based on distilled bitumen and elastomers, composite reinforcement made of spunbond non woven fabric stabilised with fibreglass will be torch bonded to the whole covering and the vertical part upstream. The sheets applied with 10 cm heat-bonded overlaps will be turned and torch bonded on the retaining wall downstream all the way to the head.
### Technical Specifications

#### TUNNELS

**Vertical draining layer**
Sheets made of non-woven draining fabric about 2 cm thick coupled with a non-woven filtering fabric sized about 150 gr/m² were mechanically fixed at the top and on one side, all the way down to cover the drainpipe.

**Drainpipes**
On the TGV tunnels, drainpipes were used with transversal cracks, while in the tunnel for the underground system, porous pipes made of cement conglomerate were used.

**Protection in the backfill phases**
1-2 cm panels made of compressed cellulosic fibre were installed to protect the part of the vertical covering of the TGV tunnel before the backfill operations.

- **Backfill operation**
  Although the membranes used have an extremely high resistance to puncture, the backfill operations must be carried out carefully, making sure that the dumper always rests on the ground it pushes forward, by using first the earth without large stones, onto which the site mixed pebbles can be used; it is always advisable to apply a layer to the vertical parts covered with the waterproofing cover for protection and mechanical protection purposes. If only the mechanical protection is required, panels of expanded polystyrene or compressed fibres can be used.

### LAYING DETAILS

**Flat joint (TGV-Atlantique)**
On the covering of the TGV tunnel there is a transversal joint every 9-10 m. Across each joint an aluminum plate 20÷25 cm in width was laid, nailed on side only. The waterproofing layer then covered the joint.

**Connection between vertical waterproof covering (TGV-Atlantique)**
The MINERAL TESTUDO sheet for the end area running for 40÷50 cm on the vertical part was not bonded but covered the end of the non-woven filtering fabric.

**Pontage of the panel joining lines**
A strip of TESTUDO SPUNBOND 25, 25÷30 cm wide was torch bonded to the joining lines of the vertical lining panels, while a strip of the same material about 50 cm in width was bonded across the joining line in contact with the vertical panels as well as the horizontal beam of the excavation foot.

**Vertical draining layer**
Sheets made of non-woven draining fabric about 2 cm thick coupled with a non-woven filtering fabric sized about 150 gr/m² were mechanically fixed at the top and on one side, all the way down to cover the drainpipe.

**Drainpipes**
On the TGV tunnels, drainpipes were used with transversal cracks, while in the tunnel for the underground system, porous pipes made of cement conglomerate were used.
**MINERAL TESTUDO SPUNBOND POLIESTERE 16**

Elastoplastomeric polymer-bitten membrane, with EC marking conforming to UNI EN 13707 and UNI EN 14695, with a base of oxidised bitumen, additives and solvents with solid content (UNI EN ISO 2343) of 40% and cup viscosity of DIN/4 at 23°C (UNI EN ISO 2431) of 12 - 17 s.

**PROTEADUO POLIESTERE 25 - 5 mm**

Multi-layer composite polymer distilled bitumen waterproofing membrane, 5 mm thick (EN 1849-1), made up of an upper layer in elastoplastomeric polymer distilled bitumen with ring and ball softening point (EN 1427) of 150°C, a lower layer in elastoplastomeric polymer distilled bitumen with elastic recovery (NF XP 84-369) of 300% and a stabilised composite reinforcement in polyester non-woven fabric stabilised with glass-fibre impregnated with elastoplastomeric polymer distilled bitumen. The membrane will have Euroclass E reaction to fire (EN 13501-1), with maximum tensile force (EN 12311-1) L/T of 1,000/900 N/50 mm, elongation at max. tensile force (EN 12311-1) L/T of 50/50%, tear resistance (EN 12310-1) L/T of 250/250 N, heat dimensional stability (EN 1107-1) L/T -0.5/+0.5%, cold bend (EN 1109) of -15°C and shape stability to heat (EN 1110) of 120°C.

The membrane, EN 14695 certified for laying under bituminous conglomerate or under poured asphalt on concrete surfaces subject to traffic, will be resistant to compacting of the conglomerate in conformity with EN 14692, resistant to the laying of molten asphalt in conformity with EN 14693 and resistance to poured asphalt in conformity with EN 14694. It will have adhesion strength (EN 13596) of 0.4 N/mm², shear strain of 0.15 N/mm² and compatibility for thermal conditioning (EN 14691) of over 80%.

**INDEVER**

Quick drying adhesion bituminous primer suitable for preparing surfaces for the heat bonding of polymer bitumen membranes, such as INDEVER, with a base of oxidised bitumen, additives and solvents with solid content (UNI EN ISO 3251) of 40% and cup viscosity of DIN/4 at 23°C (UNI EN ISO 2431) of 12 - 17 s.

**ECOVER**

Adhesion bituminous primer, suitable for preparing surfaces for the heat bonding of bitumen polymer membranes, such as ECOVER, with a water bituminous emulsion base, with solid content (UNI EN ISO 3251) of 37%.

**TESTUDO SPUNBOND POLIESTERE 25**

Elastoplastomeric polymer distilled bitumen waterproofing membrane, 5-mm thick (EN 1849-1), measured on the selvedge, with EC marking conforming to UNI EN 13707 and UNI EN 14695, based on distilled bitumen, plastomers and elastomers, with composite reinforcement consisting of spunbond non-woven polyester fabric. The membrane will have Euroclass E reaction to fire (EN 13501-1), with maximum tensile force (EN 12311-1) L/T of 1,000/900 N/50 mm, elongation at max. tensile force (EN 12311-1) L/T of 50/50%, tear resistance (EN 12310-1) L/T of 250/250 N, heat dimensional stability (EN 1107-1) L/T -0.5/+0.3%, cold bend (EN 1109) of -15°C and shape stability to heat (EN 1110) of 120°C.

The membrane, EN 14695 certified for laying under bituminous conglomerate or under poured asphalt on concrete surfaces subject to traffic, will be resistant to compacting of the conglomerate in conformity with EN 14692, resistant to the laying of molten asphalt in conformity with EN 14693 and resistance to poured asphalt in conformity with EN 14694. It will have adhesion strength (EN 13596) of 0.4 N/mm², shear strain of 0.15 N/mm² and compatibility for thermal conditioning (EN 14691) of over 80%.

**WATERPROOF COVERING**

**PRIMER**

**ECOVER**

Adhesion bituminous primer, suitable for preparing surfaces for the heat bonding of bitumen polymer membranes, such as ECOVER, with a water bituminous emulsion base, with solid content (UNI EN ISO 3251) of 37%.

**INDEVER**

Quick drying adhesion bituminous primer suitable for preparing surfaces for the heat bonding of polymer bitumen membranes, such as INDEVER, with a base of oxidised bitumen, additives and solvents with solid content (UNI EN ISO 3251) of 40% and cup viscosity of DIN/4 at 23°C (UNI EN ISO 2431) of 12 - 17 s.
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