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APPLICATION OF GEOMEMBRANES TO UNDERGROUND STRUCTURES: WATERPROOFING OF THE BAIXA/CHIADO SUBWAY STATION IN LISBON

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ABSTRACT

The paper describes installation of a polyvinylchloride waterproofing geomembrane in the deepest station of Lisbon's subway. Due to high piezometric load, a drainage system was provided behind the membrane.

INTRODUCTION

Waterproofing of road, railway and subway tunnels by synthetic geomembranes has been evolving in the last 20 years, so that many new projects for underground structures now include geomembrane systems providing reliable prevention to water infiltration in the support structure.

A synthetic geomembrane system can construct a barrier to chemical attacks and to deterioration caused by water infiltrating the concrete structure, and also to attacks by gas present in the surrounding ground. Since all underground structures are subject to permanent piezometric load, a drainage system must be provided behind the geomembrane liner: collection and discharge of water present behind the liner avoids infiltration into the structure by capillary seepage or seepage through accidental damage in the geomembrane, and relieves underpressures acting on the waterproofing system.

The Baixa / Chiado Subway Station in Lisbon, Portugal, located under the Chiado hill, 45 m below ground level, is the deepest station in the whole subway system of the city of Lisbon. The station will consist of two very large galleries and one entrance, central connection of all subway traffic, of two side boarding platforms and one central boarding platform, and will have two exits with escalators.

The station is one of the most important underground engineering projects accomplished in clay and sand soils. The average piezometric load in the Miocene formations acting on the station will cause permanent submersion of its concrete structure. To prevent chemical attacks, and damages caused by infiltration water, to the concrete structure, to the interior decoration and to all enclosed structures, the owner decided to construct a drained waterproofing system between the primary shotcrete support and the final concrete structure, in the station and its accesses.

Design and installation of the waterproofing system, and manufacturing and supply of the impermeable liner, were accomplished by the CARPI Group. Civil works were executed by Tecnasol/FGE.

THE WATERPROOFING SOLUTION

The waterproofing solution adopts a low permeability, drained PolyVinylChloride (PVC) geomembrane system, as follows:

Type 1) - on the two large galleries: the waterproofing system is installed on the vault and on the walls
Type 2) - on the accesses and on the communication galleries between the two large galleries: the waterproofing system is installed on the vault, on the walls and on the invert.

In both cases, the waterproofing system is installed over the primary support of the excavation, a shotcrete layer, before the final reinforced concrete structure is constructed, as shown in Figure 1. Installation of the waterproofing liner was accomplished with the same procedure on the vault and walls for both Type 1 and Type 2, such as described herein. Works started in 1996 and will be completed in 1997.

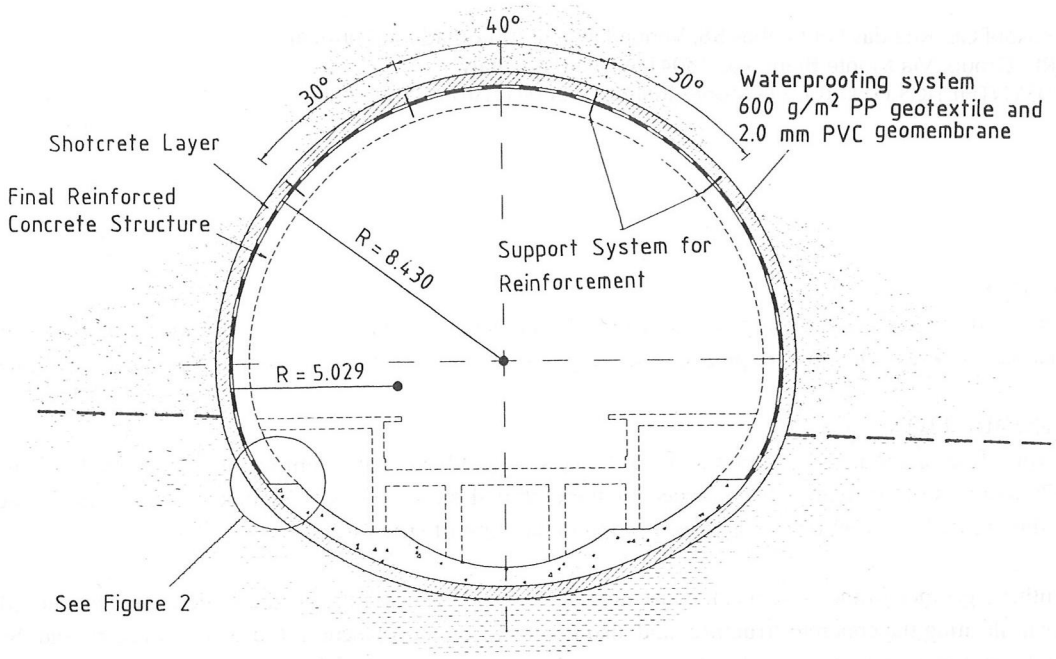

Figure 1. Waterproofing system Type 1

TYPE 1) - WATERPROOFING OF THE GALLERIES

The installed system consists of a drainage collection and discharge system, of a drainage and transition layer, and of a waterproofing liner.

The drainage collection and discharge system consists in High Density Polyethylene (HDPE) microperforated longitudinal conduits, and in transversal PVC pipes discharging into the galleries' main drain.

The drainage and transition layer consists of a nonwoven polypropylene (PP) geotextile, areic mass 600 g/m^2. The geotextile facilitates in-plane flow of water, present behind the liner, towards the collection system, and it provides support and antipuncture protection for the impermeable geomembrane.

The waterproofing liner is a 2.0 mm thick PVC geomembrane, a geomembrane type most commonly used on this kind of applications. The geomembrane adopted for the Baixa / Chiado installation has a different colour on each side, to allow easy detection of any damage occurring during supply, storage or installation.

Drainage Collection and Discharge System

During construction of the gallery, the water table is lowered, so designing the capacity of the drainage layer behind the liner and of the drainage collection system is never an easy task. It may be assumed that

water flow through the temporary shotcrete layer will be small but, however, it is good practice to install longitudinal collectors of high transmissivity.

The drained water is conveyed through the drainage geotextile to the longitudinal collectors. As concentration of concrete reinforcement (at the springing of the invert in the tunnels) does not allow placement of a round drainage pipe, a flat collector is installed, made of microperforated textured HDPE, 33 x 3 cm. Water collected by the longitudinal drains is discharged by rigid PVC pipes, diameter 60 mm, placed transversally at 6.7 m center, on each side, for each concreting section, to the main drainage system of the galleries. Figure 2 illustrates the described drainage scheme.

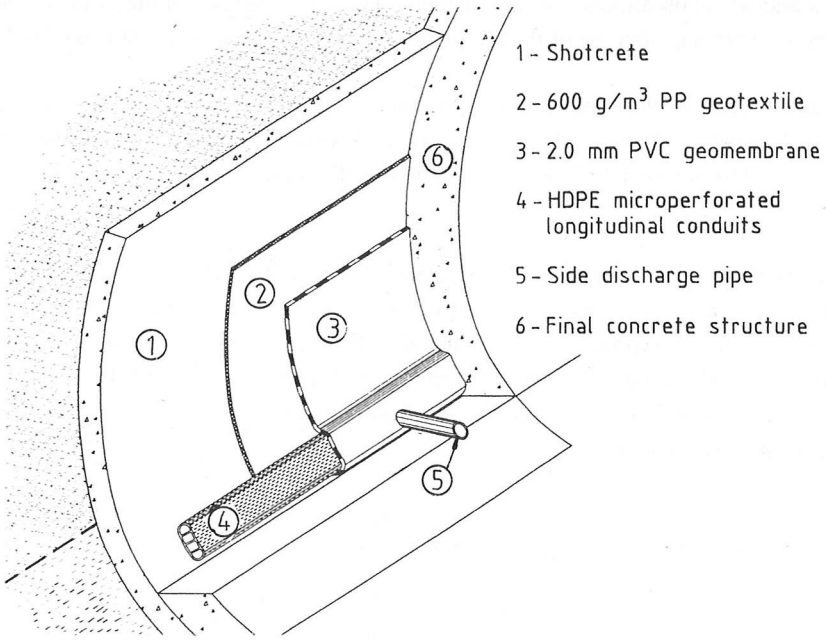

Figure 2. Waterproofing Type 1): conceptual drainage scheme

Drainage and Transition Layer

A high in-plane transmissivity transition geotextile is installed over the shotcrete layer constituting the primary support. The geotextile provides the required drainage capability, and a regularization and anti-puncture protection for the waterproofing geomembrane, against the fairly rough surface of the shotcrete layer.

The chosen nonwoven, continuous filament, 600 g/m^2 PP geotextile has mechanical resistance characteristics three times superior to other nonwoven geotextiles, and it is therefore capable to efficiently sustain mechanical stresses such as applied by a rough substrate.

The geotextile is anchored to the shotcrete by steel impact anchors, approximately 4 for each square meter. All anchors are fitted with PVC disks and/or strips for subsequent anchorage of the waterproofing liner.

Waterproofing Liner

Experience acquired in underground applications of geosynthetics indicates a flexible PVC geomembrane, manufactured by extrusion, and homogeneous in its whole thickness, as the most suitable waterproofing material. Recent practice suggests the use of a two-colour membrane, that is of a membrane incorporating a control layer of different colour, by which any damage to the liner during installation can be visually and easily detected.

The PVC geomembrane installed at Baixa / Chiado is a flexible, non-rotting membrane especially conceived for underground applications, and manufactured in 2.05 m wide sheets. The membrane is manufactured by coextrusion of a basic gray membrane and of a light membrane, approximately 0.3 mm thick, for a total thickness of 2.0 mm. Both layers have the same composition, guaranteeing that the geomembrane liner has homogeneous characteristics in its whole mass. Adequate mechanical resistance, and resistance to the chemical aggression of microorganisms which are present in the underground water of Lisbon area, is thus assured.

Temporary anchorage of the liner, necessary before placement of the final concrete inner ring, is provided by the PVC disks and/or strips attached to the anchors. The PVC geomembrane is heat-welded on these disks and/or strips, number and spacing of these attachments being such as to provide a reliable anchorage.

Adjacent membrane sheets overlap and are heat-welded by the hot air, double track automatic method, which allows non-destructive testing in the air channel between the two weld tracks. A continuous waterproof barrier is thus constructed, which is subsequently permanently anchored by the reinforced concrete structure.

TYPE 2) - WATERPROOFING OF THE ACCESSES AND COMMUNICATION GALLERIES

In these area, the waterproofing system is installed on the vault and on the walls with the procedure described for Type 1). The waterproofing liner is installed also on the invert, where it is protected by a 6 cm concrete slab. To avoid damage during placement of the reinforcement and during concreting of the slab, a 500 g/m^2 nonwoven geotextile coupled to a 0.2 mm PolyEthylene membrane is installed over the liner. Figure 3 illustrates the system.

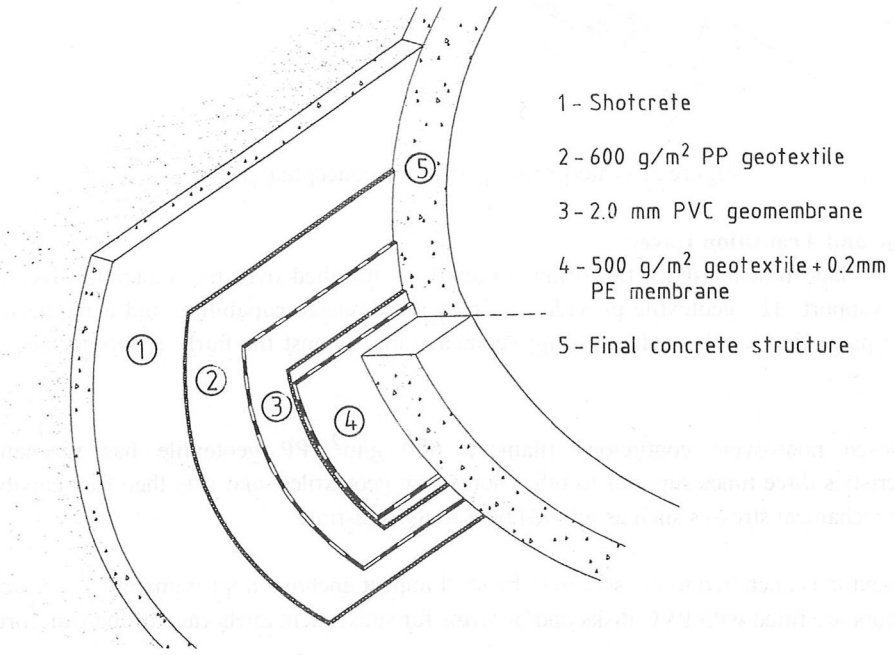

Figure 3. Waterproofing Type 2)

In correspondence of waterproofing Type 2), at intersections with the galleries of the station, the geomembrane liner is welded along the perimeter of the connections, and any seepage water is conveyed by the drainage system of the galleries.

QUALITY CONTROLS

After an underground waterproofing system has been completed and the structure is in service, inspection and repairs are impossible. Quality and durability of the system must therefore be verified by an adequate Quality Control Plan. All workers involved in civil construction must also be made aware of the damages that their activities may cause to the membrane system.

The QC Plan applied at Baixa / Chiado includes controls on materials, on procedures for support preparation and for installation, and special arrangements during civil works subsequent to installation of the waterproofing liner, according to the following phases.

Materials Supply

Quality controls are performed to verify compliance of the supplied materials to the technical characteristics required by contract specifications.
The characteristics in the quality certificate supplied by the manufacturer are compared to the required characteristics. A 1 x 1 m sample is sent to an Official Laboratory for compliance testing, mandatory for final acceptance of the waterproofing system.

In order to allow ascertaining of characteristics of the material at any location of the waterproofed area, for each batch of supplied material (geomembrane and geotextile) four samples, at least 1 x 1 m, of the geomembrane and of the geotextile are randomly collected by the Control Inspector and by the waterproofing contractor in different locations of the waterproofed area. These samples are given to the Owner.

In case any doubts should arise on the identity of the materials, or results of compliance testing should be unsatisfactory, these samples would be sent by the Owner to an Official Laboratory chosen by them for further investigation.

Materials Acceptance

Each geotextile roll has an identification label with trade name and corresponding technical form.
Each PVC geomembrane roll has an identification label with trade name and corresponding technical form, with dimensions of roll, in meters, thickness of the geomembrane, date and place of manufacturing, and number of batch.
The Acceptance Supervisor accepts the rolls only when they comply with the specifications.

Materials Storage

Storage conditions must guarantee integrity of the accepted materials, protecting them against various types of attacks to which either the geotextile or the geomembrane can be susceptible (rain, mud, still waters, U. V., shocks, vandalism, theft), through specified storage and handling precautions.

Support Acceptance

A joint visit by the Control Inspector, the general contractor and the waterproofing contractor is made prior to acceptance of the support shotcrete surface. The visit aims to ascertain if any regularizing of the surface is necessary, and to identify all protruding reinforcement or other existing irregularities which must be eliminated to provide a support suitable for geomembrane installation. This phase also aims to define procedures to perform conveyance of all water resurgence, necessary before installation of the waterproofing system, and to close the pressure relief pipes installed during the construction of the gallery.

Installation

Installation is accomplished according to:

- installation plan, including numbers of all sheets, their size and location, and all procedures for installation control, for testing of welds, for any repair
- general plan of works, prepared with the general contractor, to account for all subsequent civil works, so that concreting of the final ring takes place within 20 days after installation of the geomembrane. This precaution aims to avoid possibility of underpressures build-up on the membrane and on the anchorages, due to infiltration water, and it also assures that the waterproofing geomembrane specialists are present during civil works to avoid that any damage on the geomembrane is caused by inexperienced workers
- weld control. As geomembrane rolls are 2.05 m wide, welding of adjacent rolls must be reliable to construct a continuous liner. PVC membranes can easily be heat welded, and welds can be reliably controlled. In case a weld is deemed unsatisfactory or there are doubts on its efficiency, a geomembrane strip, at least 10 cm wide, is welded over the entire unaccepted area.

Most welds are made by automatic welding machine, manual welding being accomplished only at particular locations where automatic welding is not possible. Control of automatic welds is made by injecting air at a pressure of 2 bar in the 10 mm test channel between the two welds, each at least 12 mm wide. If the pressure is maintained within 2 bar, or does not decrease more than 20 %, for the next 5 minutes (pressure does not fall below 1.6 bar), the weld is accepted. Daily controls are generally made on 10 % of the executed welds, by the Owner's safety control responsible. In case any of the tested welds fail, welds executed after the last accepted one are tested 100 %. Manual welds, both those between sheets and those used for cover strips, are controlled 100 %, by a metal wedge inserted at the exterior border of the weld, to allow detection of any unwelded or partially welded area.

Special Arrangements

A QC plan must include adaptation of the designed waterproofing system to each specific case. All sites are different, and each requires accurate evaluation and prevention of risks to avoid insuccess. At Baixa / Chiado, special arrangements after installation of the waterproofing system include

- protection of the longitudinal drainage system by a PVC membrane, to avoid clogging during concreting
- before each concreting section, transversal discharge pipes are covered by individual concreting, to avoid their being squeezed by the weight of final concreting
- an additional geomembrane strip is rolled as a precaution at the intersections of accesses and communication tunnels, to be deployed and welded to the geomembrane of the other sections
- weight of the reinforcement requires installation of support rods in the shotcrete ring. Consequently, watertight collars must be installed at each membrane crossing, equipped with PVC fittings welded to the main liner
- at the end of the formworks, the general contractor installs a rubber strip to protect the geomembrane and to avoid contact with metal elements in the construction joints.

EFFICIENCY

Before installation of formworks for concreting, efficiency of the liner is verified by visual inspection of the whole waterproofed area. Any anomalies must be repaired immediately, in accordance with the waterproofing contractor. After concreting, efficiency can only be evaluated by testing the perimeter drainage system. To verify efficiency of the drainage system, after each concreting section, water is injected to check communication between the transversal pipes and the longitudinal pipe. If water does not flow from the new transversal pipe, this means that it is clogged, and it must be cleaned of the concrete that has penetrated in it.

CONCLUSIONS

Temporary acceptance will be made after all quality controls have been performed and any detected anomalies have been repaired. After temporary acceptance has been made and the Official Laboratory has

sent to the general contractor (Owner) the certificates assessing compliance of the material, works will be declared accepted.

In the meanwhile, when the piezometric levels are re-established in the galleries, efficiency of the system will be verified in real scale. In underground works such as the one which is being executed at Baixa / Chiado, the consciousness and teamed efforts of all workers involved in the construction must rely on the technical skill of a very experienced waterproofing contractor.

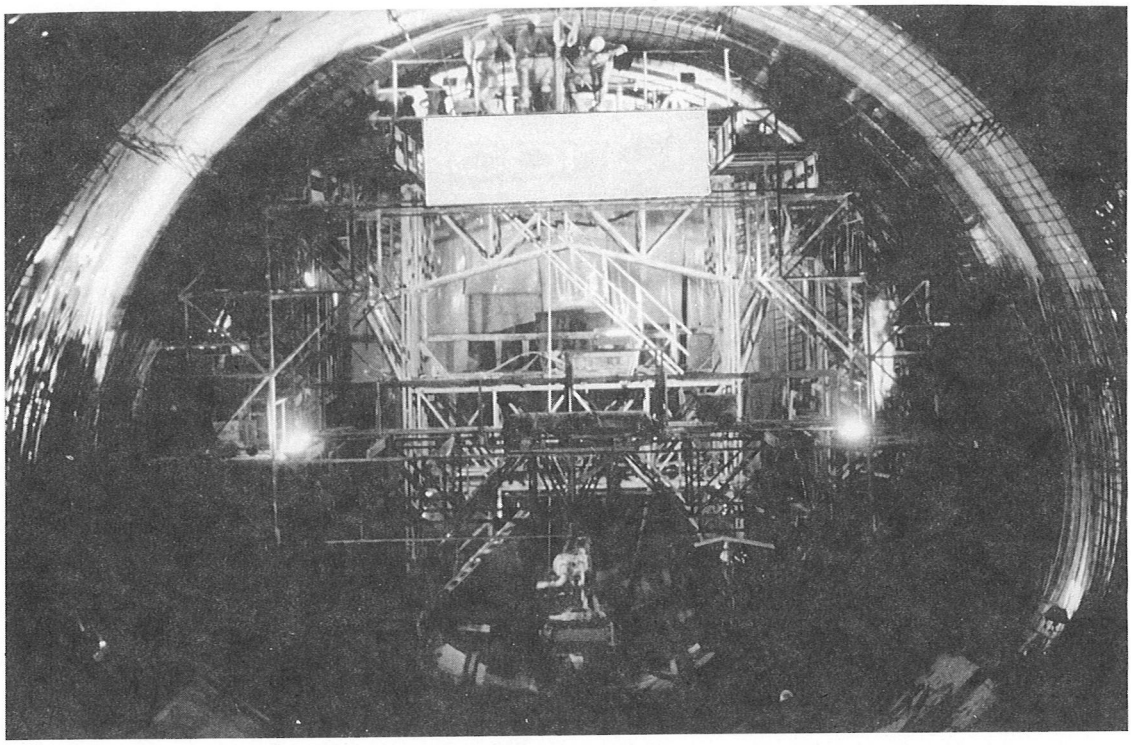

Figure 4. Works in progress at Baixa / Chiado

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