Geosynthetics, J. Kuwano & J. Koseki (eds)
 ISBN 90 5966 044 7

Thermoplastic lined tunnels for transport and storage of waste and potable water

Lueghamer, A.
Technical Manager, AGRU Technology in plastics GmbH, Austria

Keywords: high density polyethylene (HDPE), concrete protective liner (CPL), Deep Tunnel Sewerage System (DTSS)

ABSTRACT: This paper discusses the implementation of thermoplastic lining in underground systems for the storage and transport of waste and potable water. In this application area, where high requirements are given in regards to durability, lifetime expectancy, flow characteristics, corrosion resistance, mechanical integrity and leak tightness, lining with thermoplastic materials have become a unique solution. On one of the biggest municipal projects worldwide, constructed in Singapore called DTSS (Deep Tunnel Sewerage System), a major large diameter and deep tunnel system was built to collect all city and industrial wastewater from the north and eastern region of the island state. The main tunnel was built by using the tunnel boring machines in a depth of up to 50 m with a diameter ranging from 3.3 m up to 6 m. Thermoplastic (HDPE) Lining, using special liner types with mechanical sure grip embedding into the concrete, was installed in the tunnel to ensure full corrosion and mechanical protection for the concrete structure during operation as a minimum service lifetime of > 100 years was required. Because of the large diameters and the deep location of the tunnel underground, special lining methods and formwork systems have been developed. A major challenge has been the installation speed for the lining as well as the stringent conditions resulting from the existing environment in the tunnel system. Before and during the construction of the system, major investigations have been done to evaluate the capability of installing such lining system and the performance of the thermoplastic corrosion protection under such conditions.

1 INTRODUCTION

For underground tunnel structures used to store and transport potable, drinking or waste water it has become an essential requirement to protect the inside surface. The protection of the inside surface in any kind of underground installed systems is necessary to ensure full water proofing, good flow characteristics, high chemical and abrasion resistance. Past experience has shown that unprotected concrete surfaces (Pictures 1 and 2) as well as chemical based linings such as coatings, sprayed linings and cured in-place-systems are not providing the required life duration and performance, which are required for such investment intensive infrastructure which is essential for cities and also industrial compounds.

Lining with thermoplastic material based on mechanical bonding in the concrete substrate is providing many superior properties for such applications (Figure 1).

Picture 1. Underground sewer pipes damaged by corrosion and abrasion.

Picture 2. Underground sewer pipes damaged by corrosion and abrasion.

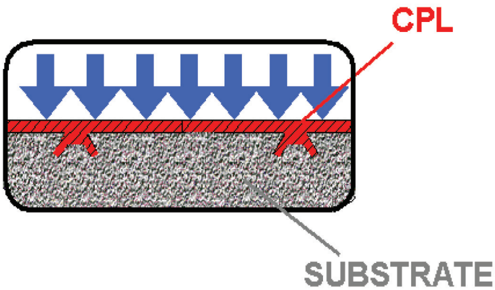

Figure 1. System sketch of mechanical bonded thermoplastic lining.

HDPE has been proven as one of the most durable materials for the protection of concrete surfaces. The main advantages of this lining type are:

- very good chemical resistance
- high abrasion resistance (Figure 2)
- high puncture resistance (Figure 3)
- high flexibility (Tables 1a and 1b)
- very good mechanical and long term properties
- smooth surface/low friction values

Especially in waste water transport systems the chemical and abrasion resistance of the inside surface layer plays a major role for the durability of the installed system. HDPE offers excellent performance whereby long term studies based on actual testing verify practical experience in the field for more than 40 years (Figure 4).

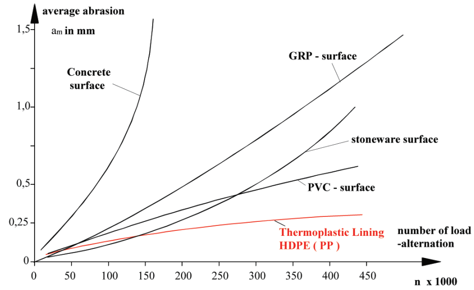

Figure 2. Abrasion resistance of various materials [1].

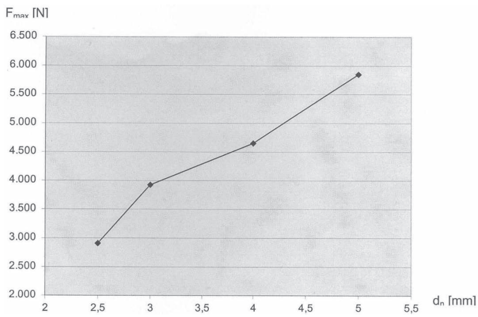

Figure 3. Puncture resistance of HDPE CPL depending on the thickness (acc. to OENORM EN ISO 6603-2).

Table 1a. Earthquake statistics Columbia (1998).

Material	HDPE	Cast	PVC	Cement
Affected Pipe length [m]	115.182	1.030	99.956	221.947
Damaged Pipe system [%]	0.0%	0.3%	27.3%	71.7%

Table 1b. Earthquake statistics Kobe (1995).

Material	HDPE	Cast	Steel
Affected Pipe length [m]	1.458	12.204	21.338
Damage	0.0	630	25.821

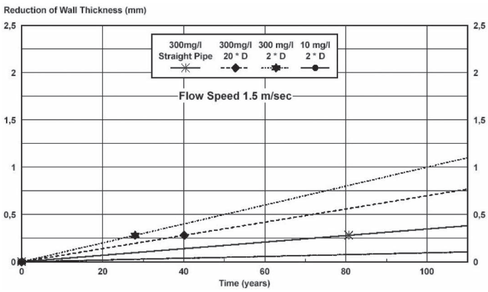

Figure 4. Abrasion behavior of HDPE related to operation time.

HDPE offers high flexibility in underground installations. Compared to other materials HDPE is

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able to bridge cracks in the substrate (Picture 3) and therefore provides full performance in case of settlements or movements of the system in seismic active areas.

Picture 3. Destructive test of CPL lined concrete pipe to verify movement compatibility of HDPE lining.

A further benefit of this lining system is that it is embedded into the concrete by mechanical anchors. The anchors are out of the same material as the liner itself and they are formed for the most available products during manufacturing of the liner. Depending on the anchor design the bonding strength between the applied CPL and the concrete is determined. The bonding strength of the lining system is measured by various test procedures whereby the long term performance is the most important criteria for the system durability. With the existing available CPL types which are suitable for concrete protective lining, a pull out strength up to 65 tons/m^2 and a back pressure resistance up to 1.5 bar are reached.

The main advantage of thermoplastic lining in the application is the direct embedding into the wet concrete substrate. This enables to introduce the corrosion protection system already during the construction. Using this technology can significantly reduce total installation time.

Depending on the application conditions various CPL types are available:

- high temperature resistant CPL
- CPL thickness from 2.0 mm up to 12 mm
- Multilayer CPL with signal layer
- CPL with self cleaning (Bionic) surface

This variety of products enables to design the inside lining of tunnels to reach the best performance.

2 BRIEF PROJECT REVIEW

A major project, located in Singapore, for the construction of a complete new sewer system was done in the past few years. This new sewer system was designed to transport all city and industrial waste to a central water treatment station (Picture 4). In the first phase the north tunnel has been built and the south tunnel system is planned to be constructed after year 2008.

Picture 4. Layout of the Deep Tunnel Sewer System in Singapore [2].

Before DTSS, the collection of wastewater was localized to a treatment plant. There are many treatment plants operating in the state. With DTSS, the existing minor and trunk sewers are connected through the construction of so called “Link Sewers”, by passing the existing treatment plants. In future this will free up valuable land now occupied by the local treatment plants.

To construct the link sewer, in diameters up to 3 m in diameter and a total length of 98 km, open trench construction method and mostly micro tunnelling with the installation of precast pipes was chosen by the contractors. To provide the necessary corrosion resistance and leak tightness, all link sewer pipes were lined with HDPE – CPL installed in the precast factory.

The main tunnel system, installed 30–50 m below ground level with a total length of 48 km and the inside diameters of 3.3 m up to 6.0 m, required the lining of the inside surface by thermoplastic lining to ensure:

- Full water proofing
- Chemical resistance of tunnel surface against waste water
- Corrosion protection of the Concrete structure
- High resistance against the abrasive waste water
- Improved flow characteristics
- High life time of the total system
- Maintenance free operation of the system

Because of the used construction method and to reach system performance as required from the client, the tunnel was built in a two-layer-design (Figure 5).

2.1 *Tunnel construction*

For the construction of the tunnel the system was divided in totally 6 sections (each section between 5.3 to 12.5 km long). Each section has been contracted to a different design and build contractor. EPB TBM’s were engaged in all sections to construct the tunnels.

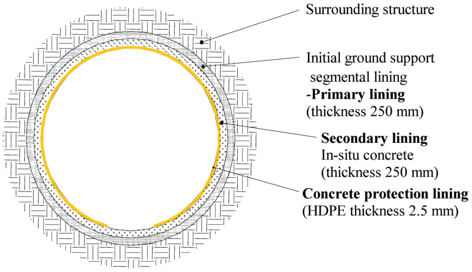


Figure 5. System sketch of tunnel layout [3].

In the area of the access manholes the first section of the tunnel (tunnel section to insert TBM) was constructed using NATM method. As a primary lining in the tunnel to carry the static loads of the tunnel and to reach full water proofing against the ground water pressure (up to 4 bar), concrete segments (thickness 250 mm) were installed (Picture 5).

Picture 5. Segmental lined tunnel section.

On each side of a tunnel section large access manholes (up to 30 m in diameter and 50 m depth) are located. These manholes were used to supply all needed material and equipments into the tunnel section. Also some smaller intermediate manholes have been installed in defined distances of the sections.

After finishing the main tunnel these manholes have been also lined with CPL and used as access shafts and Vortex chambers (see Picture 6).

2.2 *Tunnel lining*

To protect the tunnel (primary lining) against any influence from the transported wastewater and to reach full water proofing, a secondary lining was installed. As required by the client the secondary lining was a layer of concrete without reinforcement and a thickness of around 25 cm installed by cast In-situ method. For each contract, different methods of casting the 330° membrane protected arch first and coming back to

Picture 6. Construction of Vortex Chamber in Access Manhole.

cast the invert while others were casting the invert first and the arch as the second pass. One contractor has even cast the arch and the invert in one cycle.

Ensuring that in case of infiltration of ground water from the outside, a full mechanical embedded concrete lining system with high pull out resistance as well as good drain ability behaviour was required. Large ground water pressure behind the liner in case the primary lining is leaking (e.g. caused by settlements) during operation can be in this way released into the tunnel itself and avoid displacement of the CPL for the concrete.

The secondary lining was installed into the tunnel by applying special hydraulic formworks (Picture 7). The main design features of the used formwork systems were:

- Easy and safe installation of the thermoplastic lining
- High vibration capacity for safe and continuous compaction of the concrete
- Fast casting cycles
- Suitable to be used on existing bends in the tunnel

Picture 7. Hydraulic formwork before installation into the tunnel section.

Various types such as telescopic formworks up to 37.5 m in length have been applied.

Because of the lost time during construction of the tunnel it was the aim to reduce the construction schedule for the secondary lining. Also the application of 2 formworks working parallel in the tunnel from the centre of the section towards the main shafts has been used to reduce the total installation time. All CPL have been prefabricated outside the tunnel to the required size of the casting section whereby the prefabrication cycle was adjusted according to the casting cycle (Figure 6).

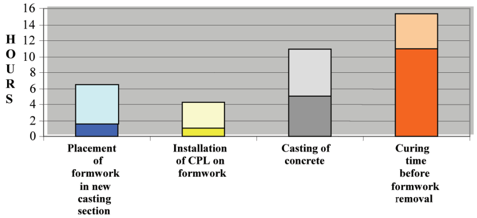


Figure 6. Casting cycle for secondary lining.

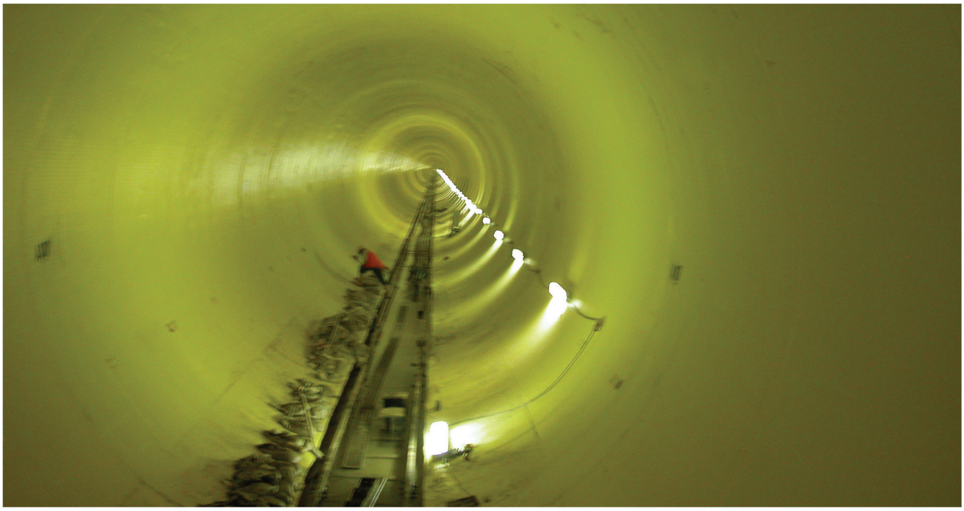
A special designed transport system to move the liner into the tunnel and install it to the formwork was required whereby it was essential to protect the lining system against mechanical damage during installation.

For the casting special concrete (using additives to ensure high flow capacity) with a strength of ~ 50 MPa was required, whereby the size of aggregates have been chosen with 10 or 20 mm depending on the used lining system. To ensure that no honey comp or segregation of the concrete – especially on the large diameter and long casting length – was risked, the concrete was injected in intervals at fixed positions on the circumference of the tunnel. Beside the concrete type and casting sequence also the fixation and tensioning of the thermoplastic lining on the formwork system has been a key factor for the success of the installation.

On the 6 m tunnel section of the project (the largest diameter in the tunnel) casting lengths per day up to 37 m/section (~1000 m/month) have been reached. As required by the client, each section of the tunnel was lined with thermoplastic liner in different light colours (Picture 8). This feature enables easier inspection and verification of the tunnel sections during operation. Since August 2005 the main part of the DTSS system is in operation.

3 CONCLUSIONS

The execution of the DTSS project in Singapore, which was from its size and design requirement the first major project worldwide, has shown that the application of thermoplastic lining is a practical and presently the best method for corrosion protection of concrete structures. Past experience has proven that only lining with thermoplastic material provides the necessary lifetime and system performance for such critical infrastructure. Most cities around the world have problems with existing waste and potable water systems (leaking, capacity, maintenance), which must be addressed to ensure future operation. Thermoplastic lining applied by relining methods or for new constructions therefore will play a major factor.



Picture 8. Final installed secondary lining with full embedded HDPE CPL in yellow colour.

ACKNOWLEDGEMENT

The author wants to give special thanks to Mrs. Seow Kiak Ang (Deputy Director) from PUB Singapore for the contribution to this paper.

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