



# Warsaw WARSAW METRO LINE 2

**LEFT AND TOP OF THE PAGE.** The construction works carried out in 2017-2019 on line 2 of the Warsaw metro included the completion of 2.2 km tunnels in natural excavation for each tube.

**BELOW.** Line 2 runs under some areas of the Polish capital enclosing ancient buildings that date back to pre-war times.



and 10 m, in clean sandy soil, under water table.

### Geological conditions and design approach

Along the whole route the soil to be excavated and the soil above the tunnels were mainly granular. They belonged to the Quaternary period and were of sedimentary origin. The water table is 3 m deep from the ground level. Only the bottom part of the excavated front was silty and made of clay. Several buildings, in the area along the Strzelecka street, are in a critical structural condition and consequently more subject to possible damage. The local authorities in charge of the design were proposed a "classic" solution using sub-horizontal drilling carried out from the ground level under the foundations

of the buildings in order to install sleeved grouting pipes for subsequent grouting. The difficulties in obtaining the working areas, as well as the issues and the time required to get the permits for temporary occupation of private properties and traffic routes, were not compatible with the general planning of the construction works. It was therefore decided to limit soil improvement to 5 ancient buildings with a very fragile structure and in difficult conditions. This solution minimized the impact of the works on the urban area, reducing the risk of damage to the buildings located along the alignment of the tunnels. The final decision, also due to budget and management choices, was to limit soil improvement to the area located under the foundation of five buildings, and try to make an

accurate excavation by TBM EPB closed mode, with some solutions and procedures devised with the help of Mapei technicians.

### Specific solutions for surface settlement reduction

Due to the peculiarity of the buildings above the tunnel alignment, the operation in closed mode and the accurate control of the earth pressure were key parameters to be kept under strict observation to minimize the surface settlements.

Another fundamental aspect to be accurately controlled to minimize the loss of volume and, therefore, the settlement on the surface, was the annular gap backfilling injection. The volume and pressure control of the injection had to be carefully managed. The injected volume had to reach at least the theoretical value, with pressures of about 0.5 bars exceeding the earth pressure applied to the tunnel face. The soil, properly conditioned to achieve good TBM performance and a proper pressure transmission to the tunnel face, showed a too liquid behavior on the TBM belt, due to the lack of finer fraction and the saturated conditions of the sandy soil. Beyond the logistic problems related to the muck management from the tunnel belt up to the truck transportation, a too liquid behavior might have caused difficulties in the earth pressure control. In fact, a too liquid muck, in the presence of pressure in the excavation chamber, may flow along the screw conveyor by extrusion, pushed by the earth pressure. The liquid consistency of

## MAPEI PRODUCTS WERE SUCCESSFULLY USED FOR TUNNELING WORKS

The extension of the Warsaw Metro Line 2 in 2014 was certainly a further step in the development of the public transport system in the capital of Poland and it is included in the Odcinek II expansion program of public infrastructure. Line 2 was intended to become the main connection between downtown and the north-east areas of the city, reducing the distance between the residential districts and the city center. The particular geological conditions and the shallow overburden required particular care when building the new

metro line.

The construction works carried out in 2017-2019 included the completion of 3 stations and 2.2 km tunnels in natural excavation for each tube. Excavations involved the use of two TBMs (EBP type), accurately refurbished after the excavation of the same metro line under the historical city center. The section between C-18 Trocka station and C-15 Dworzec Wilenski station runs along a curved path with shallow overburden under the Targówek and the Praga District, with buildings that survived the Se-

cond World War. The critical stretch for the excavation was the last part, the section from C16 Szwedzka station and the dismantling chamber, which was temporary created in the holding track in station C15. From this station 2 tubes run under the historical area, the right one under Strzelecka street and the left one running for roughly 500 m under a row of ancient buildings, with different elevation and with 2,5 m basement deep. The overburden between the top of TBM excavation and the lower level of the basement ranged from 7





**LEFT.** The excavations involved the use of two TBM EPB machines, accurately refurbished after the excavation of the same metro line under the historical city center.

**BELOW.** Visual aspect of the muck before the use of MAPEDRILL M1 (left) and after the use of MAPEDRILL M1 (right).

**RIGHT.** The station of Szwedzka after completion of the works.

CBS SYSTEM 1, an admixture used to ensure the A component a workability of 3 days. The proportion between MAPEQUICK CBS SYSTEM 3 (accelerator) and the A component was reduced. These modifications brought to a reduction of about 2 seconds of the gel time and to a higher viscosity of the backfilling grout. The modified mix design was studied and tested by Mapei experts at the mixing plant prior to its actual production, to evaluate the most suitable mix design for the specific situation.

The injection parameters were also modified in order to minimize the possible fall of soil in the void and to compensate the loss of injected volume due to possible permeation of the grout in the sandy soil. The injection pressure was increased up to almost 1 bar exceeding the earth pressure. The total injected volume per ring was also increased in order to keep the pressure level required to minimize the settlement.

**TBM excavation performances**

With the application of these measures and products during excavation works, earth pressure was kept regularly on the right range. It was checked that the volume of excavated ground never exceeded the theoretical values, which made it was possible to avoid settlement around the area of the cutter head. On the other hand, the volume of grout filled in the gap behind the lining at the tail skin was always higher than the designed value.

The first of two underground routes began to be excavated on October 2017 with TBM S644, which drilled the left tunnel towards the C15 Station and successfully completed the critical passage on December 2017. Then, following alignment under Str-



the muck caused difficulties in the pressure management and, therefore, in the minimization of the surface settlement. The solution adopted was the injection in the excavation chamber of MAPEDRILL M1, a soil conditioning polymer with water absorption and lubricating properties. The use of about 0.3 – 0.4 kg of MAPEDRILL M1 per cubic meter of soil, brought to an effective control of the soil consistency. By observing the TBM data during the use of the polymer, any uncontrolled fluctuation of earth pressure was visible. Although the muck was drier than before, the cutterhead torque and the TBM performances remained the same.

The injection of MAPEDRILL M1 and its fast reaction time allowed the treatment of the soil close to the screw

conveyor inlet, without affecting the consistency of the conditioned soil close to the cutter head.

**Backfilling grout injection improvement**

Due to the non-cohesive nature of the soil, every step of the excavation foreseeing an unsupported situation had to be reduced to a minimum. For this reason, the standard mix design of the A component of the two-component backfill grout, studied in the Mapei R&D laboratory during the site preparation, was modified. The proportions between the two components, were modified too, in order to reduce the gel time. To achieve this without affecting the performances of the grout, cement was increased on the A component mix, together with a slight increase of MAPEQUICK



zelecka street, TBM S760 passed the same route between October 2017 and January 2018. Both underground passages, about 1150 m long stretch, which included the 550 m under ancient buildings and Strzelecka street with shallow overburden, were achieved with average daily advances of 18.75 m and 18.5 m respectively, with peaks of 33 m per day. The recorded volume loss was less than 0.30% instead of 0.44 % and the total settlement under the urban areas was lower than one centimeter.

Following a customary procedure for this kind of underground projects in urban areas, a monitoring system was installed to check settlements and deformation during the TBMs performances. The system was able to continuously register data, providing automatic and manual measurements. The behavior of the

buildings was analysed during the passage of the two TBMs and proved to be similar. The settlement occurred in a similar way, both in terms of kinematics and values. The measurements underlined the success of the EPB technology in urban areas under sensitive buildings. The careful attention paid to the excavation parameters, such as earth pressure, muck extraction control, backfilling injection pressure and volume, played a crucial role in the minimization of the settlements.

Good practice, together with the use of a specific soil conditioning product such as MAPEDRILL M1, as well as the adjustment of the mix design and injection procedure of the backfilling grout, combined with good TBM crew skills and careful supervision, made possible to respect the admissible settlements limits, without the

use of an extensive grouting campaign below the buildings. The synergy between contractors and suppliers was crucial to ensure the sharing of know-how with the common target of a safe and effective TBM excavation, while guaranteeing the expected results and good production rates.

**MAPEDRILL M1**

Liquid polymer to be employed in mechanized tunnelling and drilling

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**TECHNICAL DATA**  
**Warsaw metro - Line 2,**  
 Warsaw (Poland)  
**Period of construction:**  
 2010-ongoing  
**Period of the Mapei**  
**intervention:** 2017-2019  
**Intervention by Mapei:**

supplying products for backfilling grout injection and soil conditioning  
**Client:** AGP Metro  
**Main contractor:** Astaldi SpA  
**Mapei coordinators:** Enrico Dal Negro, Alessandro

Boscaro, Andrea Picchio, Enrico Barbero, UTT Division, Mapei SpA (Italy); Mikolaj Alexandrowicz, Mapei Polska (Poland).

**MAPEI PRODUCTS**  
 Products for underground

**works:** Mapedrill M1, Mapequick CBS System 1, Mapequick CBS System 3, Polyfoamer FP/CC, Mapebent CBS 4, Mapeblox T, Mapeblox PKG

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