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Tunnels and Underground Cities: Engineering and Innovation meet Archaeology, Architecture and Art – Peila, Viggiani & Celestino (Eds)

Excavation of connecting tunnels in Centrum Nauki Kopernik underground train station on line II in Warsaw

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ABSTRACT: The construction of the three connecting tunnels between the east side and the west side of the Centrum Nauki Kopernik underground train station, adjacent to the Vistula river, has a long and complex history, as they cross beneath one of Warsaw's main road arteries (Wislostrada). After the attempt to excavate the first tunnel, the face of the tunnel collapsed on the night of August 13, 2012, and a volume of about 10,000 cubic meters of liquid mass (water, silty soil and sand) entered and flooded the west side of the station, which was filled with more than seven meters of material. Fortunately, the workers managed to escape, but machines and equipment were lost. This paper deals with how the tunnels were completed, by adopting soil improvement, jet grouting, GRP bars, ground freezing and a careful choice of work steps.

1 INTRODUCTION

The Centrum Nauki Kopernik station on Line II of the Warsaw Underground is located alongside the Vistula river (Figure 1). This station hereinafter is referred to as station C13.

The station consists of three parts: the east and west part, and three connecting tunnels 40 meters long with a large cross section (170 m^2). It includes the rails along the sides and the platform along the centre. The reason for the underground connection of two shafts with a tunnel is the presence of a road tunnel (Wisłostrada, hereinafter called WS), which must be underpassed by the new metro line (Figure 2).

The existing tunnel (Wisłostrada) was built many years before on diaphragm walls and barrettes, so some foundation structures interfere with the underground tunnel. The challenge was to build the connectors without stopping the traffic of vehicles along the highway above. All works took place in very difficult geological and groundwater conditions due to the presence of Vistula alluvial deposits with poor mechanical characteristics. The soil profile consists of relatively loose sands on top, and silts overlying high plasticity Pliocene clays highly disturbed by the effects of the repeated over-sliding of glacial moraine deposits.

The station is located entirely on the west side bank of the Vistula River: the eastern boundary of the station shaft is less than 10 m from the river bank. The station has been constructed with top-down methodology, with diaphragm walls (1.40 m thick) supported by the slabs that have been constructed during the lowering excavation. After the construction of each slab supported by the soil in the bottom, the excavation has been carried out under the slab until the level of the next slab to be constructed. The maximum excavation depth reaches a level of 24 metres. The two side tunnels have an internal diameter of about 7 meters and their shape is perfectly circular to allow, after their completion, the TBM's passage.

The three tunnels were to be excavated in clayey soil using conventional methods. Instead, the soil turned out to be of sandy materials below groundwater. In essence, it is as if the tunnels were excavated in the river's sub bed, in the presence of flowing water. A further major

Figure 1. The Centrum Nauki Kopernik station and the Vistula river.

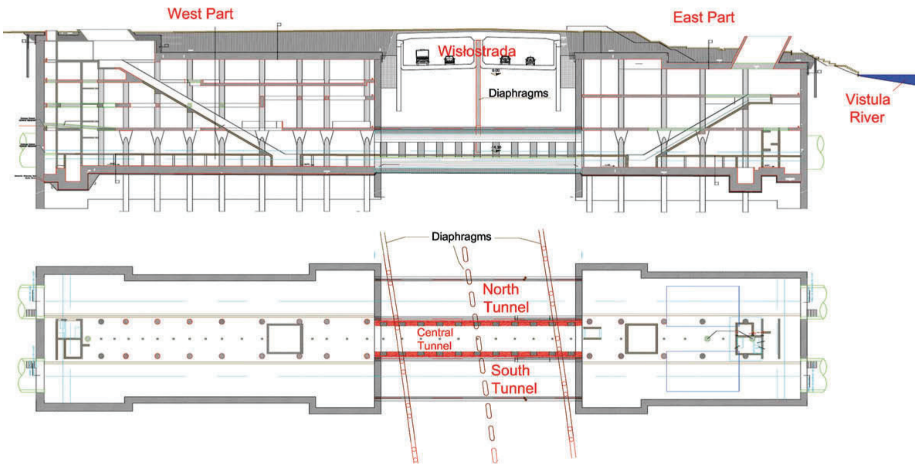

Figure 2. The two parts of the station and the connecting tunnels.

complication was due to the presence of the of WS tunnel foundations made by diaphragm walls, which would have been dismantled during tunnels excavation and in the presence of normal vehicle traffic. This paper focuses on the several excavation attempts that were implemented to complete the connector.

2 EXCAVATION ATTEMPTS

Several attempts to construct the three tunnels were carried out. The first attempt followed the original design that was based on a geological profile that turned out to be inaccurate. Only clay was expected along the tunnel path, but this was not the case.

2.1 *The First Attempt –Steel pipe umbrella (Canopy Piles)*

The original construction scheme entailed the excavation and lining of the two side tunnels (for the tracks), followed by the excavation and lining of the central tunnel (for the platform), connected to the two side tunnels by arches.

The excavation of the two side tunnels would have to be supported by steel pipe umbrella except for the sides bordering the central tunnels and Fiber Reinforced Plastic tubes (hereinafter called FRP tubes) at the face. On the sides of the two tunnels bordering the central tunnel, the design required FRP tubes instead of steel ones, to allow the subsequent excavation of the central tunnel, whose final lining was to have been supported by the final lining of the two side tunnels (Figure 3).

After the first core drilling on the diaphragm walls of the entrance of the north tunnel on the west side, on February 2, 2012, a massive flow of sand and water occurred from the hole into the shaft (Figure 4).

There was no clay soil behind the wall, as expected, but something else. The need to proceed with geological surveys along the tunnel path became clear. Beforehand the surveys could not be executed in order not to close the high flow road WS. The hole was plugged and a new investigation campaign begun.

2.2 *The Geological Survey of the Path*

Once the east and west parts of the station were excavated, it was possible to perform a geological survey of the tunnel path, with horizontal and sub-horizontal borings, starting from the station diaphragm walls and without having to close the busy WS tunnel above.

As a result of this survey, it appeared that the level of the clayey soil was lower than expected and that the top of the tunnel sections were in sandy material below ground water.

The decision was made to perform a soil improvement, but since the interventions could not be implemented from the WS tunnel in order not to close it, a new design including columns of jet grouting on top of the tunnel was drawn up (Figure 5).

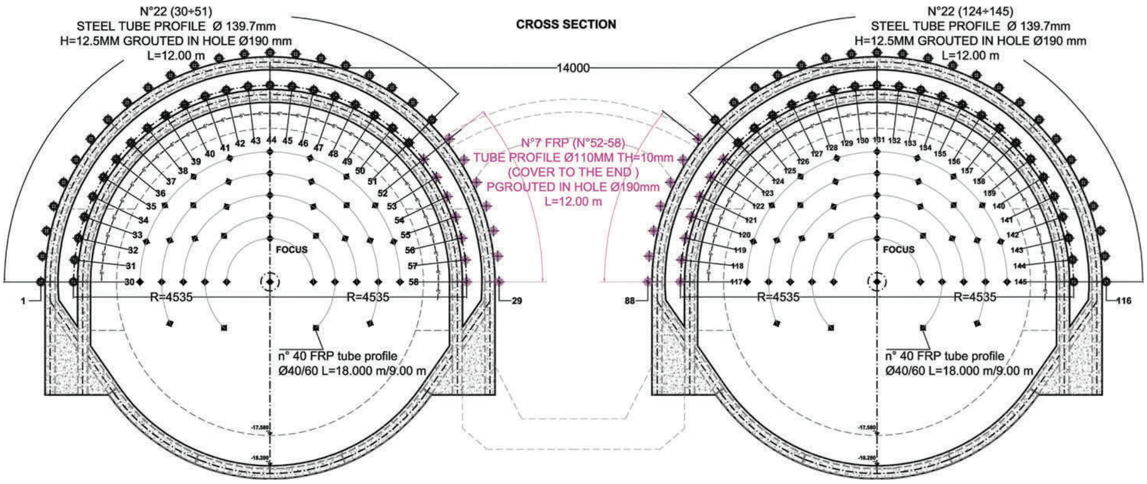

Figure 3. Original design of the two side tunnels to be excavated.

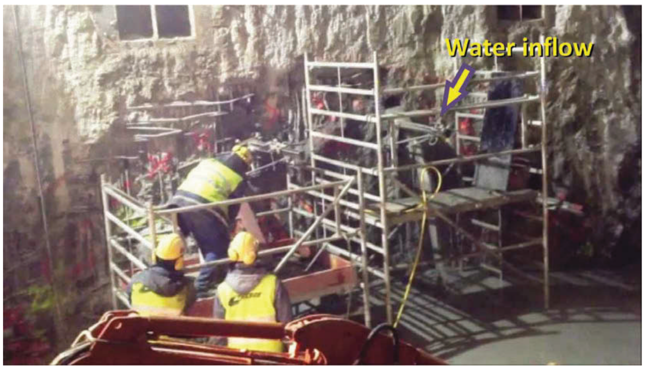

Figure 4. Water inflow.

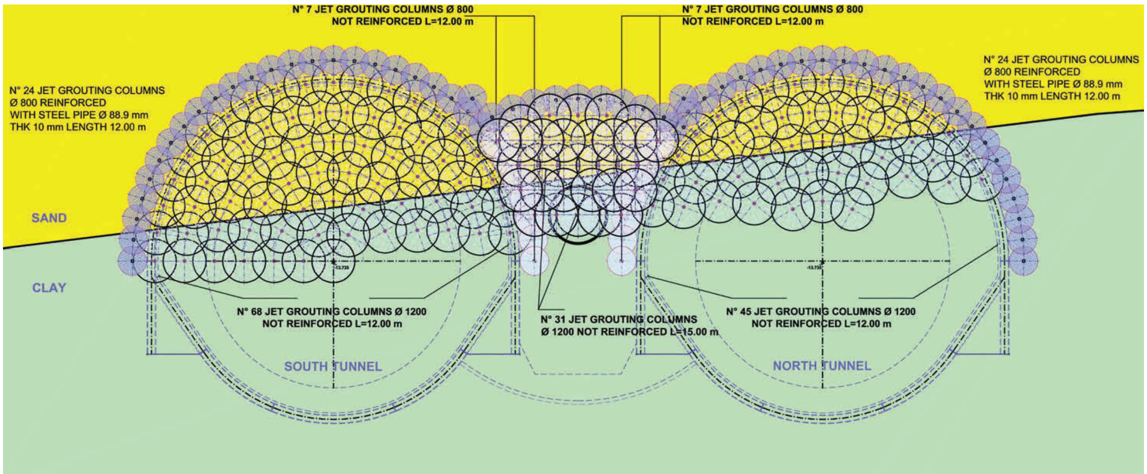

Figure 5. Updated design with columns of jet grouting.

2.3 *The Second Attempt – Jet Grouting*

The new work schedule planned the north tunnel excavation first, followed by the south tunnel. The central tunnel would have been the last one. Excavation would have been done from both the east and west heading of each tunnel, up to the central diaphragm walls supporting the WS tunnel.

Jet grouting and the steel pipe umbrella started on the diaphragm walls of the north tunnel's west side with a big machine, then the big machine moved to the east side of the station, to the other face of the north tunnel, and a smaller one arrived in the west side. Afterwards, the east face of the other two tunnels was dealt with. The remaining face of the south tunnel in the east side would have been the last.

During the soil improvements carried out at the east side, the excavation of the north tunnel started from the west side, following the phases shown in Figure 6.

After the demolition of the station's diaphragm walls, the first excavation step was finished. The diaphragm walls supporting the WS tunnel were also demolished and the primary lining was applied, consisting of steel ribs, wire mesh, struts on the invert and shotcrete.

The second excavation step began and continued without problems. Every 75 cm, a layer of shotcrete was applied to the face of the tunnel during the primary lining of the previously excavated portion of tunnel. On the evening of August 13, 2012, the excavation arrived at the fifth steel rib of the second excavation step (Figure 6). The workers applied the shotcrete to the face of the tunnels in order to stabilize them, and went to dinner at 10:30 PM.

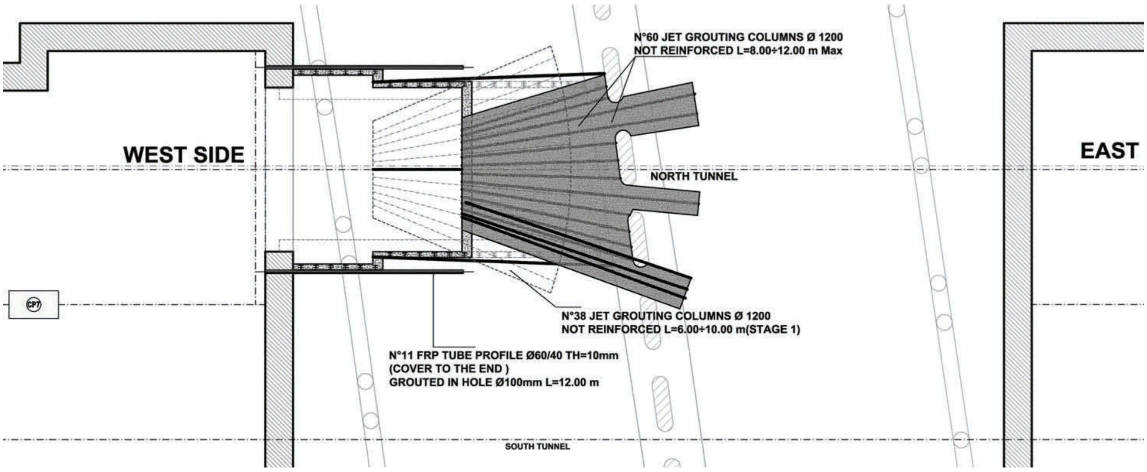

Figure 6. Plan view of an excavation phase of North tunnel from west side.

2.4 *The Collapse of the Tunnel Face*

At 10:45 PM, a foreman saw that something strange was happening. Some water was inflowing from the top and from the face of the tunnel. He immediately sounded the alarm, and a team of workers ran down into the station, at the tunnel face. At 11:00 PM they began to spray another layer of shotcrete on the face of the tunnel, but because the sprayed shotcrete was swelling and cracking in some areas on the face, the action taken was interrupted and all the workers attempted to place material against the face to contain it (Figure 7).

At the same time, because the face was continuing to move despite the containment action, the workers also managed to save equipment and machines using the gantry crane, but were unable to finish this operation because the immediate evacuation of the station was ordered.

To avoid the feared collapse of the west side of the station, the flooding in progress was intentionally accelerated by pumping water from the Vistula river in order to balance the external pressure of the soil on the walls (Figure 9). Access to the WS tunnel was forbidden for safety reasons.

Many machines were lost in the station (Figure 10). Fortunately, no one was injured.

2.5 *The Concrete Filling Under the WS Tunnel*

After non-destructive fact-finding surveys, it was determined that there was a deposit of solid material, mostly sand, of approx. 6,500 cubic meters inside the station, and a loss of the equivalent amount of material beneath the road slab of the Wisłostrada tunnel. The cavity underneath the WS tunnel was filled with water up to approximately 2 meters from the bottom of the slab. The road slab thus was not supported by natural subsoil, and was suspended in risky equilibrium between the lateral diaphragm walls.

Figure 7. The collapse of the tunnel face.

Figure 8. Water, sand and clay inflow from the tunnel.

Figure 9. The station before the event and after the intentional flooding.

Figure 10. One of the buried machines.

In order to fill the cavity with concrete, there was an initial campaign with a massive injection of concrete, self-levelling, with mixes designed to cure underwater. The second campaign for deep consolidation was obtained with a low-pressure injection of cement mixes followed by chemical mixes, using manchette tubes.

The second campaign stopped and was not completed because the grouting lifted the road slab up to 20 cm in some points.

2.6 *The Third and Final Attempt – Soil Freezing*

Soil freezing was the final solution adopted to improve the soil (see Capata et al. 2015, Balossi Restelli et al. 2016).

Divers inspected the bottom of the station and found a large pile of sand which obstructed the tunnel entrance, so the station was carefully emptied of inflow material. The pile of sand was carefully removed, layer by layer, and a reinforced concrete wall was built by underpinning methodology. Horizontal and vertical freezing probes were installed. The excavation phases were quite complex.

The Figure 11 shows some design phases for the north tunnel (similar to those for the south and the central tunnels).

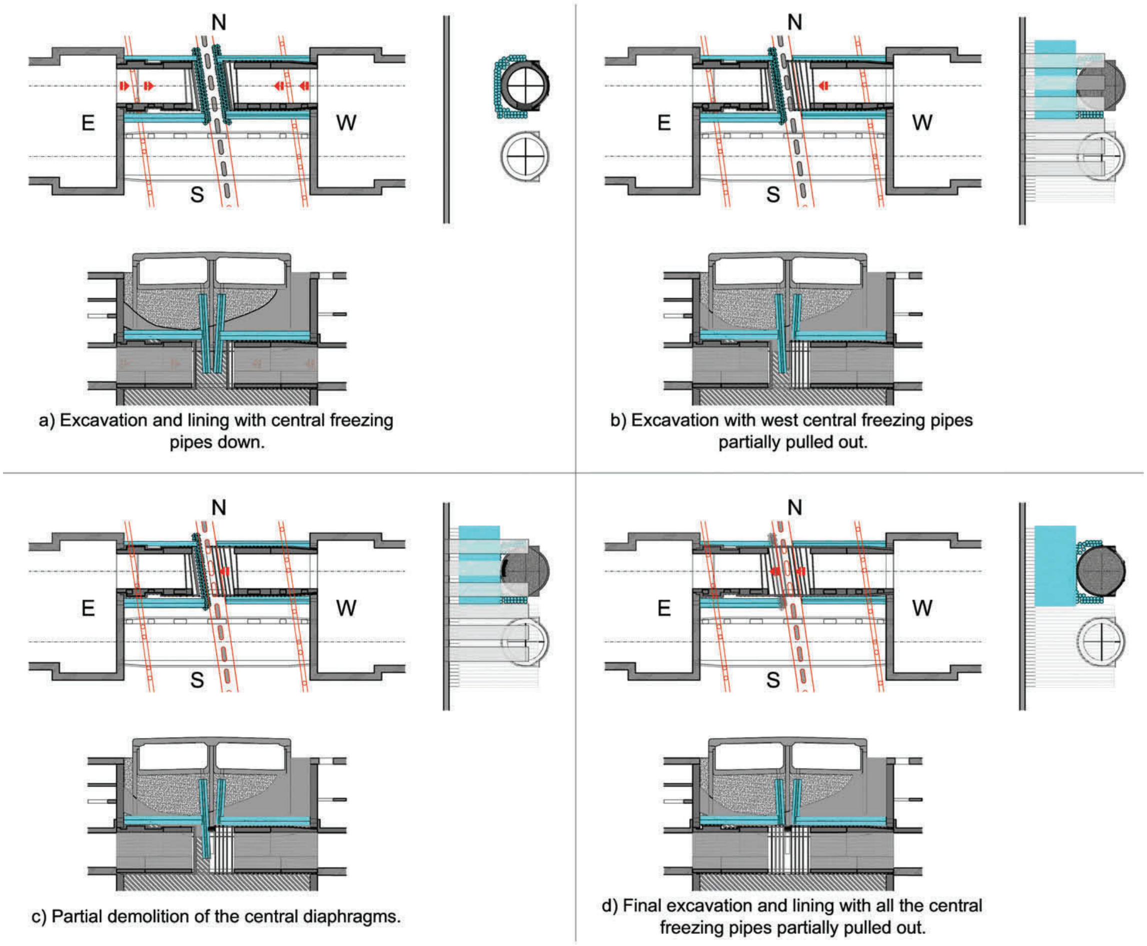

Figure 11. Excavation and lining phases.

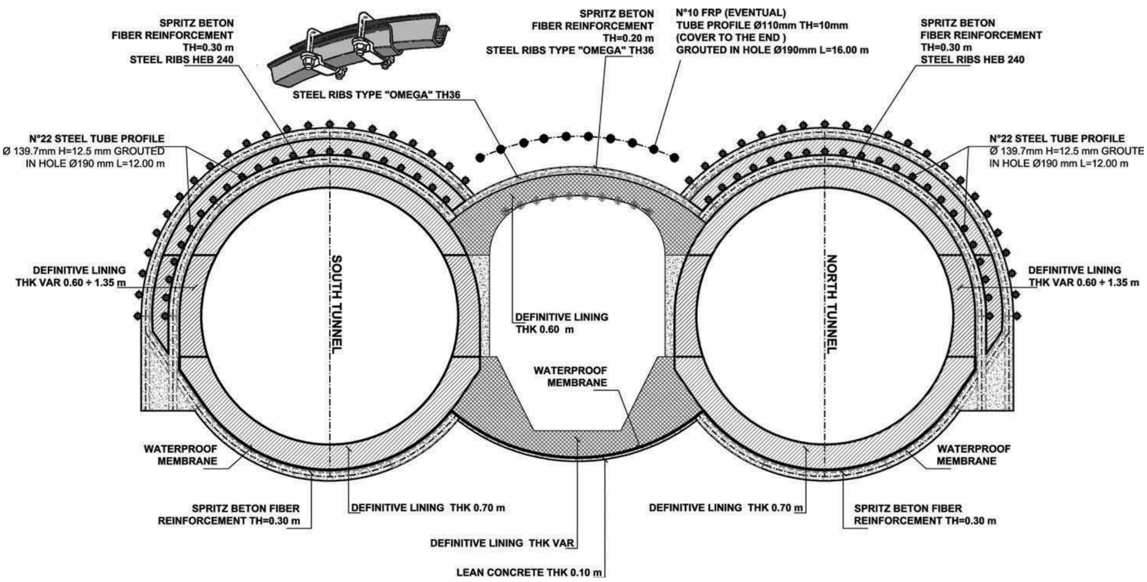

Figure 12. Central tunnel with adjustable Omega Type steel ribs.

The horizontal probes were put in place all around the tunnel section, and vertical probes were placed at the sides of the central diaphragm walls supporting the WS tunnel. The excavations were carried out from the two headings and stopped near the diaphragm walls. The two sections were lined and after the vertical probes were partially pulled up, the central section was excavated and lined.

The two side tunnels were completed and then the central tunnel was excavated adopting, in the primary lining, steel ribs bearing on the steel ribs of the side tunnels, uncovered during the excavation. The central ribs were welded on the side tunnels' ribs and, at the end of the excavation cycle, the side tunnels' piers were cut. Omega-type steel ribs (Figure 12) were chosen to compensate for the variability of the several lengths of arc.

3 CONCLUSIONS

The first attempt failed due to the presence of sand and water along the excavation path, the second attempt probably failed because the water was in motion and washed away the injected grout. In both cases, the failures are attributable to the water that negatively affected the consistency of the soil and the consolidation attempt.

The third attempt, the freezing of the soil, worked well because the same water, whose presence was harmful in the two previous attempts, was successfully used as a support system in an ice form.

4 EPILOGUE

As shown in Figure 13, it took 33 months to complete the excavation and structural works of the station:

- 9 months for flooding,
- 5 months for freezing,
- 18 months of effective works

Six of the 18 months were used for the tunnel during the 3rd attempt (Figure 14) and the work was completed 15 days in advance of the last milestone.

It took more than two and a half years to complete the tunnels, but, thanks to the efforts of the people who worked to solve the serious issues of this work in order to safeguard people, structures and equipment as far as possible, the tunnels were finished. Figure 15 and Figure 16 show some pictures of the tunnels during the works and how it appears today.

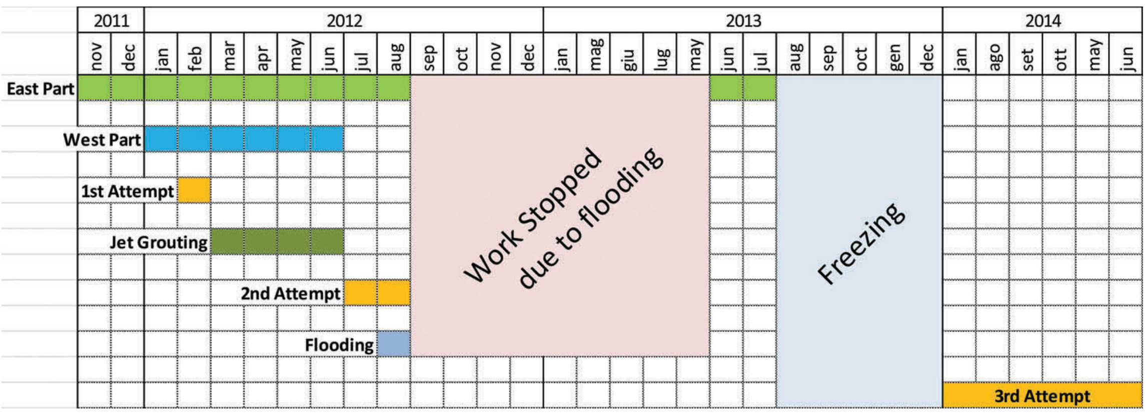

Figure 13. Chronology of events.

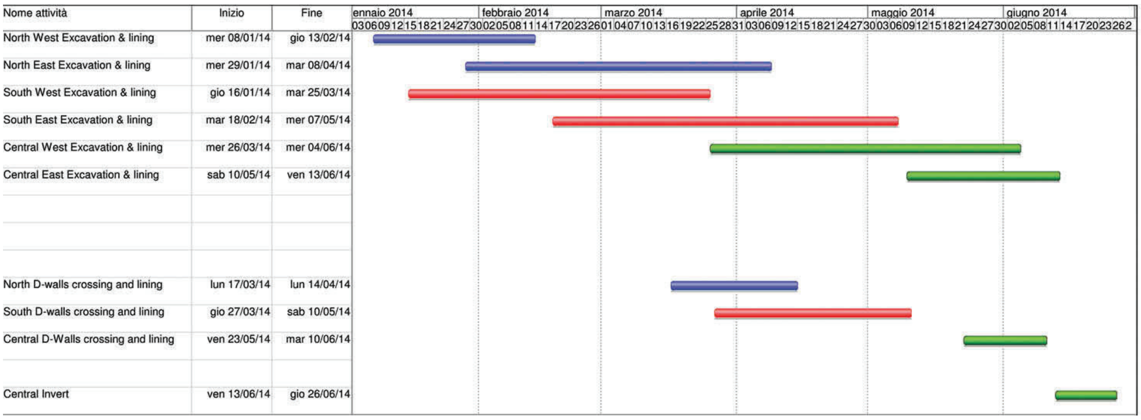

Figure 14. The chronological of the 3rd attempt in detail.

Figure 15. At top, a side tunnel; at centre, the central tunnel; at bottom, a panoramic photo of the three tunnels.

Figure 16. At left, a side tunnel; at centre, at right, the central tunnel.

REFERENCES

Capata, V., Lombardi, A., & Bizzi, F. 2015. Line II of Warsaw Underground: the excavation of tunnel connector (Centrum Nauki Kopernik station). *Infrastructure Conference Proceedings – ICE Publishing*

Balossi Restelli, A., Rovetto, E. & Pettinaroli, A. 2016. Combined Ground Freezing Application for the Excavation of Connection Tunnels for Centrum Nauki Kopernik Station—Warsaw Underground Line II. *ITA-AITES World Tunnel Congress 2016 (WTC 2016) - Proceedings of a meeting held 22–28 April 2016*, San Francisco, California, USA