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Ground settlements and tilting of buildings due to tunneling - evidence from geodetic surveys in the Athens Metro

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The excavation of tunnels produce ground settlements ("ground loss") which result in subsidence, tilting and occasionally damage to overlying structures. The above is known since many decades ago (Terzaghi, 1942) and till now systematic recording of ground deformation is a common practice for decision making about the development of the excavation or about measures for ground and/or structures stabilization. In this study we summarize geodetic monitoring data from tilting of two brick chimneys in the Technopolis area and ground subsidence at Sepolia area during the construction of the Athens Metro in 1997 and 2003, respectively.

Evidence of ground/structures deformation at the Athens Metro excavation

Tilting of chimneys at Technolopis (Gazi) area

The geological conditions of the Athens Metro consist of the local flysch, which is deformed and foliated and in its upper parts is highly weathered. An up to 70m wide tunnel influence zone (zone of extension of the settlement trough above the tunnel axis) was predicted on the surface. This zone includes Technopolis site dominated by three historical brick chimneys (Figure 1).

Systematic monitoring of the chimneys aimed to detect any movements of the order of a few mm during the tunnel excavation in depth as Papastamos et al. (2015) described in detail. Horizontal dislocation of the top of the chimneys provided evidence about chimneys' tilting, a critical parameter for decision making about the progress of the construction. Maximum amount of tilting was recorded to be 7.5‰ for K1, while the value of the remnant tilting was of the order of 5‰. Despite the fact that 2‰ tilting is regarded to be a threshold for the structural integrity of buildings of different types (Harris et al. 1999; Burland et al. 2001), the Gazi chimneys, survived a much larger amount of tilting without damage. The explanation is that chimneys' geometrical and structural characteristics enabled them to behave as isolated, slender structures subjected only to rigid-body rotation around the vertical axis. The distortion of the chimneys is apparently free from differential settlements which are the most common cause of structural damage.

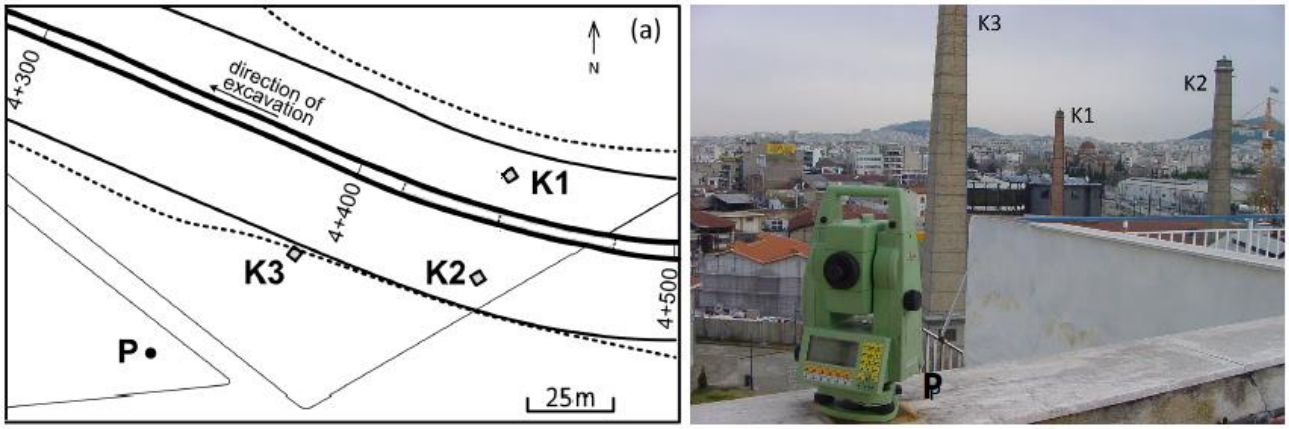

Figure 1: Left: Location map of the Technopolis area on which the tunnel and its influence zone are shown. The location of the three chimneys K1, K2 and K3, and of the monitoring point P are also shown. Right: View of the three chimneys from the fixed monitoring point P.

Ground subsidence at Sepolia area

Extension of the Athens Metro from Sepolia to Ag. Antonios met the Athenian schist and alluvia (locally overlying) and the excavation technique applied was mechanical excavation using a TBM.

The monitoring project of the ground and structures was based on systematic leveling of hundreds of control points on the ground surface and buildings within the assumed area of influence above the tunnel opening. The recorded total ground subsidence, shown in Figure 2, forms contours with higher values reaching 24mm above the tunnel axis, a pattern that confirms the Gaussian trough model. However, the pattern of ground subsidence indicates that the settlement trough is not uniform, both at the transversal direction and along the tunnel axis. This is due to three independent reasons: *first*, local conditions, as for instance natural voids in the ground altering the state of stresses at the opening vicinity, *second*, tunnel construction details involving time of installation of the lining, pause of excavations etc.;

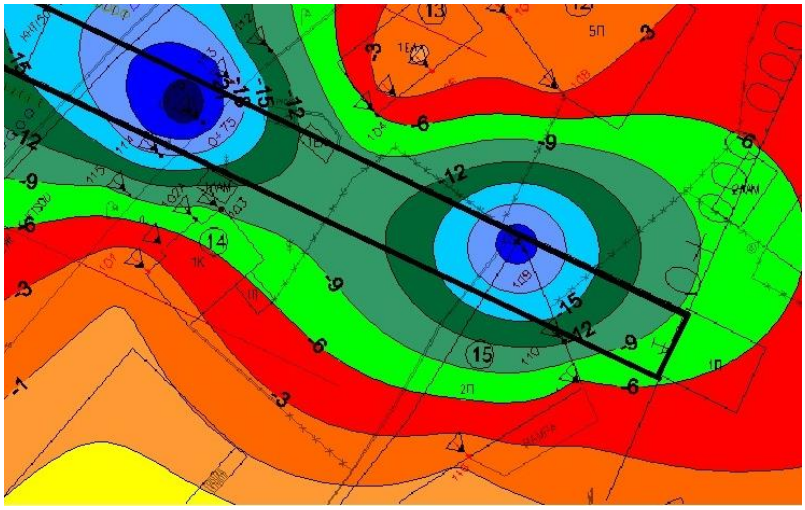

Figure 2: Total ground subsidence observed during the excavation of line 2 of the Athens Metro (at Sepolia area) in contour form. Subsidence ranges up to 24mm. Tunnel is marked by a rectangular.

and *third*, the state of the ground surface, being either a greenfield or built, with the later state consisting of a mixed system of ground and structure increasing the natural stiffness of the ground and consequently diminishing the surface subsidence.

Conclusions

Geodetic monitoring data from two brick chimneys in the Technopolis area during the construction of the Athens Metro suggest that the chimneys suffered a high amount of tilting though without any damage. Later, geodetic monitoring data from the ground subsidence at Sepolia area during tunneling for the Athens Metro reveal that the profile of the settlement trough on the ground surface was not uniform, both at the transversal direction and along the tunnel axis.
The interpretation of the monitoring records of the above projects led to the conclusion that they both deviate from idealized cases, subsequently verifying that urban excavation remains a challenge for geologists and engineers and geodetic monitoring is an invaluable tool tightly linked to safety in constructions.

Acknowledgements

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