Long-Term Performance of a concrete-lined Tunnel at CERN

Vanessa Di Murro

Department of Engineering

University of Cambridge

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At the world's largest physics centre for nuclear research (CERN) under controlled laboratory conditions, two high-energy particle beams travel close to the speed of light around the most powerful particle accelerator ever built. The accelerator runs through a deep network of underground tunnels and caverns. To forefront the boundaries of experimental physics, CERN physicists rely on civil engineers to keep their systems running efficiently, performing repairs and upgrades when necessary. However, due to ageing of CERN underground infrastructure, certain amounts of cracking and swelling-induced heave have developed at certain sections along the tunnel linings, which could potentially result in structural damage of the existing infrastructure with consequent impact on the performance of physical experiments. Furthermore, the long-term groundwater seepage has caused the deterioration of the drainage system, inducing a change in the flow regime around the tunnel. This inevitably introduced a new loading condition to the lining, which may have affected the tunnel stability with time.

This thesis focuses on the long-term investigation of a horseshoe-shaped concrete-lined tunnel excavated at CERN, in Geneva, in a weak sedimentary rock called the *red molasse*, an irregular and heterogeneous rock mass comprising a sequence of marls and sandstones. Such complex ground conditions in addition to a change in groundwater and tunnel drainage conditions especially after the large seepage flow event in the year 2013 have contributed to additional loading to the tunnel lining and consequently led to cracks, water infiltration and other structural distress after tunnel construction.

To improve the understanding of the long-term tunnel lining performance, a detailed analysis of the field data measurements was undertaken. Both conventional and innovative monitoring technologies were deployed in order to assess the tunnel lining deformation mode with time and also to evaluate the feasibility of different monitoring instrumentation in CERN radioactive environments.

The observed data show that compressive and tensile strains develop at the tunnel crown and tunnel axis respectively, suggesting a vertical tunnel elongation with time as the tunnel lining mechanism of deformation. Yet slow development of strains with time was observed, albeit over a relatively short monitoring period of three years. Additionally, noteworthy peak strain values seem to be localised along the lining when the very weak marl units with swelling properties are encountered.

In order to validate the field data and to assess the ground loading on the tunnel lining, a series of soil-fluid coupled 2D finite element analyses has been conducted with a particular interest in the effect of change of lining permeability into the lining response. The FE findings show that the tunnel lining permeability relative to the surrounding rock plays an important role on the tunnel deformation mode during the long-term. In particular, the layering divisions in the complex molasse region greatly affect the earth pressure distribution on the tunnel lining and hence results in critical tunnel damage (e.g. cracks and heaving at the tunnel invert). The consolidation-induced structural damage in addition to a reduced capacity of the drainage system with time, in turn, creates a new drainage tunnel lining condition around the tunnel circumference which exacerbates further tunnel distress with time.