UPGRADING OF AGEING CERN UNDERGROUND INFRASTRUCTURE TO FULFIL THE SPACE REQUIREMENTS OF NEW FACILITIES AT CERN

A. Martínez Sellés†, E. Carlier, V. Di Murro[1], B. Goddard, E. Gschwendtner, F. Magnin, R. F. Morton, J. A. Osborne, CERN, 1211 Geneva 23, Switzerland
[1]also at CSIC, University of Cambridge, Cambridge, United Kingdom

Abstract

Particle accelerator technology is constantly being developed, and new equipment and machines replace the former ones to keep pushing the energy and intensity frontiers. Therefore, in order to meet the space requirements of new equipment, the infrastructure often needs to be modified, and given its rigid nature, this presents a challenge for the civil engineers to provide the needed space without compromising the safety and serviceability of the structures. In this paper, two underground works are presented: a new cross-passage tunnel for the AWAKE experiment completed in 2014 and the future SPS Beam Dump. The challenges that must be faced are: (a) to make sure that the movements of the adjacent structures remain within admissible limits, (b) to design and execute the works such that the life span of the structure is not reduced, (c) To ensure the effectiveness of existing and new drainage systems during and after the works. For these purposes, in the frame of future tunnel asset management, the use of novel and conventional monitoring techniques plays a crucial role as it can predict in real time potential tunnel deformations, which can lead, in the worst scenario, to tunnel failure.

INTRODUCTION

Tunnels are an indispensable part of the accelerator complex at CERN. As multi-generation structures, they usually host different sensitive equipment along their service life, therefore, their long-term stability as well as the effectiveness of their drainage is of central importance. When the infrastructure needs to be modified, tunnel design and construction methods must take into account the interaction of the new structure with the existing linings and waterproofing systems to ensure compatibility and adequate transmission of the forces. In order to minimise the impact on the existing structures during the modification works, it may be necessary to install temporary support and carry out structural monitoring.

AWAKE EXPERIMENT

In 2014, CERN undertook the construction of a cross passage between two existing tunnels, TCV4 and TT41, in order to provide the required space for the installation of the AWAKE experiment (Fig. 1). The connection tunnel (TT43) was constructed in the Molassic geological zone, which is typically good ground for tunnelling but can be prone to heaving or swelling when exposed to moisture [1]. Hence, the design and construction methodology ensured that significant water was not directly introduced to the ground.

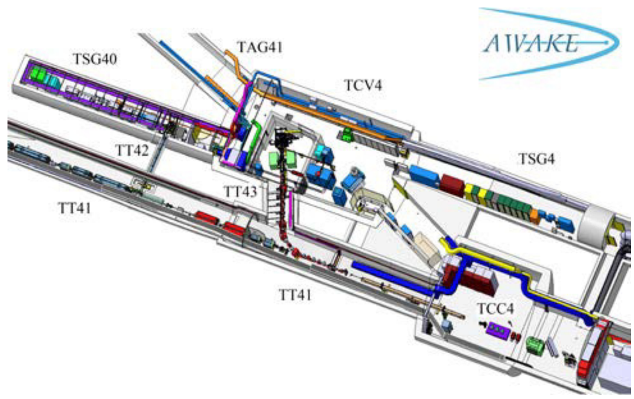

Figure 1: Layout AWAKE experiment [2].

Assessment of the Existing Structures

The purpose of the assessment of existing structures is to determine potential temporary support for the existing tunnels (TT41 and TCV4) during the construction of the new tunnel (TT43). Such additional support could have consisted of pre-tensioned rock bolts or simple propping.

The initiated stresses were checked against the admissible concrete strength to demonstrate that the existing lining could be broken out in the temporary condition with little or no temporary support. If this case could not be demonstrated to be adequate, additional support or sequencing around the breakout would be considered. Only the more critical serviceability condition was analysed, as tunnel linings usually require very large amounts of deformation before they are considered to have structurally failed.

In assessing the stresses around the opening, which is approximately circular to maximise its efficiency, the following was considered [3]:

- Out of plane bending in the lining immediately above and below the opening: due to an uneven redistribution of stresses in the lining, this tends to bend inwards. This can generally be considered as a flat slab applying a triangular area of load above and below the opening subject to out of plane bending.
- Tensile tangential stresses around the opening due to the divergence of the stress flow lines over the opening: assessed using the hole in the plate model (Kirsch's solution). The stresses are calculated at a distance d/3 from the opening crown level, to be added to the bending stresses.

† alex.martinez@cern.ch

- Compressive tangential stresses at the axis level of the opening due to the convergence of the stress flow lines.

In assessing the stresses at the breakout both the self weight only and the maximum ground load cases were considered.

In order to minimise the transmission of loads from the new structure to the existing ones, TT43 tunnel was not structurally linked with the existing tunnels, thus allowing differential movements between them. Furthermore, no anchors or any other connection method was put in place.

The longitudinal section of the new TT43 tunnel and its relative size with respect to the existing TT41 and TCV4 tunnels is shown in Fig. 2.

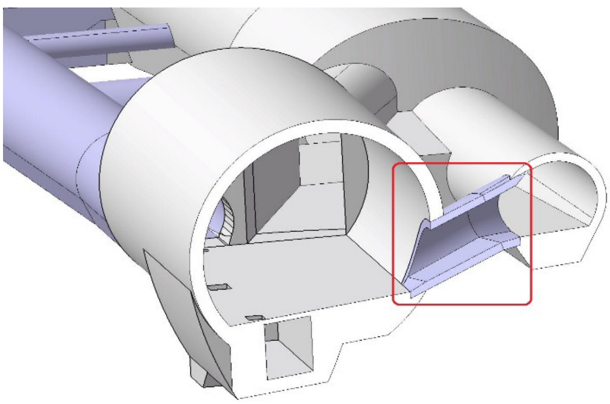

Figure 2: Cross section AWAKE area.

Drainage of the System

The new TT43 tunnel was wrapped in a drainage layer membrane, which was overlapped with the drainage of the existing TT41 and TCV4 structures. This allows the groundwater to flow along the drainage membranes to be driven to a central slotted drain. The configuration of the drainage system is shown in Fig. 3.

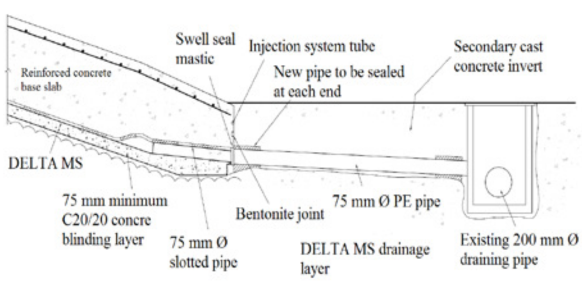

Figure 3: Drainage interface.

Since the new TT43 tunnel is not linked structurally to the existing ones, the potential relative movements between them could lead to the development of weak points in the areas where the drainage of the new tunnel meets the existing one. As a contingency measure, an injectable tube was installed in all the construction joints, allowing the possibility to inject waterproof mortar/resin in the event of water infiltration.

SPS BEAM DUMP

CERN wishes to develop an in-line beam-dump facility at Point 5 of the SPS tunnel. The beam dump is elevated to be on the axis of the SPS beam (Fig. 4). The main activity within the civil engineering package of this project consists in widening the tunnel opening in the shaft and tunnel eye lining to accommodate the required transport route.

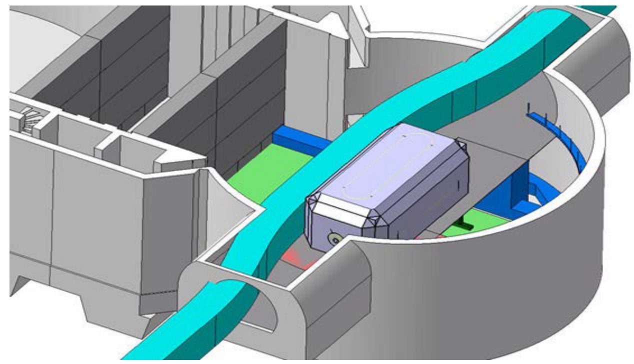

Figure 4: Beam dump and required transports volume.

Ground Conditions

The molasse, a weak sedimentary rock through which the tunnel eye will be excavated, has an underlying bed of soft marl that can swell when exposed to water. However, due to few publications on the swelling characteristics of the marls, the maximum capacity to swell has been assumed. This will result in a conservative design capable of absorbing the maximum load transmitted by the swelling layer to the invert. [4-6].

Design Principle

In order to design the tunnel eye enlargement, the following steps will be taken into account:

- Definition of the geometry of the new widened shaft opening, tunnel and connection;
- Temporary works solution to support all the structural elements during the works;
- Permanent works solution for the structures to resist the overburden ground and water loading, as well as the swelling pressure from the rock;
- Assessment of potential damage to existing lining left in place and surrounding structures.
- Definition of a monitoring plan for the existing tunnel lining and surrounding structures and action plan in the event monitoring trigger levels are realised.

Proposed Structural Envelope

The proposed shape for the enlarged tunnel eye is shown in Fig. 5. As portions of the existing structure remain, the construction method could have a significant impact on the existing structures functionality within the new combined structure.

Therefore, the design firm proposed the following construction method, which has a significant bearing on the design:

ISBN 978-3-95450-182-3

- Remove the existing secondary lining from the tunnel crown to the invert in one-meter wide stripes to allow redistribution of the hoop forces around the cut band and maintain support to the remaining existing secondary lining.
- Retain the existing waterproofing behind the secondary lining allowing for a minimum 300 mm overlap to the new waterproofing.
- Remove the existing primary lining in small sections and reconstruct the primary lining to the proposed shape. Including the new section of invert.
- Remove the 200mm thick slab above the "eggbox" waterproofing system.
- Construct the new enlarged secondary lining. Installing new waterproofing system.
- Construct the new invert and waterproofing, connecting to existing waterproofing.

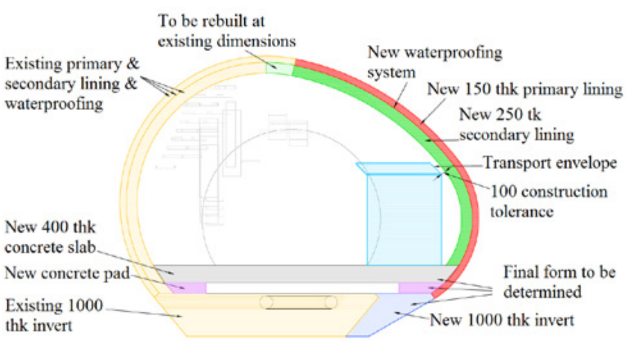

Figure 5: Cross section enlarged tunnel eye.

Waterproofing

The new waterproofing shall be designed to be a cavity membrane system, which manages the water path and ensures safe collection and disposal of any water ingress. This system will provide the most robust connection to the existing system. The following design steps shall be considered:

1. Design layout of waterproofing and locations for lapping onto existing to ensure a controlled and manageable water path to drainage systems.
2. Determine lap details to existing systems to optimise the manageability of water paths.

Temporary Support Tunnel Eye

As the existing tunnel eye is a two lining system with a primary lining with significant structural capacity, it is quite possibly supporting the entire ground load while the interior lining is only supporting any water pressure.

The tunnel enlargement will require one side of the tunnel lining to be removed. In the temporary state where there is effectively an incomplete ring, additional support will be required to maintain structural stability of the tunnel

The use of temporary propping is likely to complicate the construction sequence by imposing spatial constraints on the work, whereas the use of rock bolts to provide temporary support has been discarded due to its impact on the existing waterproofing system.

The following temporary support design procedure will be adopted:

- Establish load requirement for the temporary props using a suitable safety factor as the loading of the existing lining.
- Determine stresses in the lining on using props and compare against lining capacity.
- Construction sequence to demonstrate constructability of remaining works

Secondary Support Design

The secondary lining will be designed to resist all the loads in the long term, implying a conservative assumption that the primary lining will degrade to a point where it will not take any load.

The long term loads include the stresses created by the ground (rock and water) and potential upwards pressure due to the swelling of the marl layer, which has the potential to induce swelling pressures in the invert. The top of the marl layer coincides with the invert level of the tunnel eye

Two solutions to cope with the upwards swelling pressures are being considered:

- Design a gap between the existing primary invert and new secondary invert. The gap will allow for the swelling deformation to occur and to not load the secondary lining. While the primary lining (existing 1m thick un-reinforced concrete) will crack and partially resist the ultimate limit state (ULS) load by arching.
- Design a fixed slab sufficiently reinforced to resist the upwards pressures and limit the deformation up to admissible values. Such a fixed slab would remain stable during the heavy transports activities. In this case, the machine supports should be designed to accommodate any unwanted deformations induced by swelling pressures.

MONITORING

In order to predict structural movements and to assure the stability of the existing tunnels while excavating the TT43 cross-passage, a short-term monitoring plan was proposed. Three monitoring systems were tested to record the movements and deformations of TT41 tunnel: conventional tape extensometer readings, laser scanning and a new photogrammetric movement detection technique, which was developed at University of Cambridge and is called CSattAR. The results show very little movements suggesting that the tunnel lining experienced less than 3 mm of convergence, as predicted by designers [7]. A short and long-term monitoring plan for the SPS Beam Dump project will be proposed as well.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the SMB-SE group at CERN for allowing me the opportunity to participate in the projects presented in this paper, and to ATKINS and CSIC for contributing to make a success of the construction of the TT43 tunnel.

REFERENCES

[1] GADZ, “AWAKE electron gun tunnel, avis géotechnique”, Geneva, Switzerland, January 2014.

[2] AWAKE, `http://awake.web.cern.ch/awake/.`

[3] R. Colombero *et al.,* “AWAKE electron gun tunnel, basis of design”, ATKINS, London, United Kingdom, March 2014.

[4] J. F. Mathier *et al.,* “Projet LHC, synthèse géologique et géotechnique”, GADZ, Geneva, Switzerland, July 1993.

[5] J. F. Mathier *et al.,* “CERN BA5 bâtiment 899, sondages et étude géotechnique”, GADZ, Geneva, Switzerland, November 1978.

[6] R. Pandya *et al*., “SPS in-line beam dump, tunnel eye widening - phase 2 design report”, ATKINS, London, United Kingdom, January 2017.

[7] M. Alhaddad *et al*., “Photogrammetric and conventional deformation monitoring of an existing tunnel while a new cross-passage tunnel is excavated through its concrete lining for AWAKE project at CERN”, in *Proc. 6th ISHMII workshop on Civil Structural Health monitoring (CSHM-6),* Belfast, United kingdom.

ISBN 978-3-95450-182-3