Tunnelling and Underground Space Technology 77 (2018) 249–260

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Geotechnical characterisation of a weak sedimentary rock mass at CERN, Geneva

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ARTICLE INFO

Keywords:
Geotechnical characterisation
Molasse
Sandstone
Marl
Tunnelling
CERN

ABSTRACT

The European Organisation for Nuclear Research (CERN) in Geneva has extensive underground facilities, which were built over the past 70 years in a weak layered sedimentary rock called the *red molasse*. CERN has thus been continuously exploring its underground space and has gathered extensive geotechnical data from both laboratory and field tests. The data shows that the *red molasse* is composed of marls and sandstones forming 6 different geotechnical units with different geotechnical characteristics. The strength-stiffness relationship of the *red molasse* is lower than other molasses from other regions, and that the marls are significantly more ductile than the sandstones. Moreover, the intermediate rock units (sandy marls and marly sandstones) have similar strength but a different stiffness, a distinction which is not represented in the standard strength classification system. Although all rock units were subjected to the same diagenesis, one rock unit is found to be very weak with soil-like properties. A mineralogy analysis shows that this unit is composed of high plasticity clay, whilst the other marls units are composed of medium-high and low plasticity clay. The field tests show rapid and progressive transitions between the different rock units, which makes field prediction difficult. This paper presents an overview of the geotechnical data gathered by CERN as well as the geotechnical characterisation of the site The geotechnical characterisation presented in this paper also compares laboratory tests with field tests.

1. Introduction

Switzerland is composed of three distinct geological regions – the Alps, the Jura and the molassic plateau (Fig. 1). Whereas the Alps are predominately composed of strong sedimentary and crystalline rocks and the Jura of medium-strong limestones, the Swiss plateau is comprised of a weak to medium-strong sedimentary rock called molasse. Although the term *molasse* originates from the Switzerland, it is used for any orogenic deposits of similar genesis irrespective of their location (Hoek et al., 2005).

The *red molasse* at CERN is composed of sequential layers of marls and sandstones from the Miocene tertiary period and by the diagenesis of Alpine detritus in a soft water basin (Swiss Geological Survey, 2013). The sedimentation of the Alpine detritus, controlled by the geological activity, resulted in the formation of clay, silt and sand lenses with substantial spatial variation. This makes any site prediction very difficult. The molasse at CERN is around 300 m deep (CERN, 1972) and has an anisotropic stress field resulting from the tectonic thrust of the Alps. This paper presents the laboratory and field exploration of the *red molasse* and discusses its mechanical characteristics.

2. Brief history of CERN's underground facilities

CERN was founded in 1952 in Geneva, Switzerland, as a particle physics laboratory and the first particle accelerator was built in 1957 – the *Synchrocyclotron* (SC). It was only in 1976 that CERN went underground with the *Super Proton Synchrotron* (SPS), which is a 7-km-long circular tunnel at a depth of 40 m. Fig. 2 shows a schematic description of the underground facilities at CERN in which the smaller circular tunnel is the SPS tunnel. The machinery was housed in caverns and the access was provided by shafts. Since then, CERN has extended multiple times. In 1988, the *Large Electron-Positron Collider* (LEP) was built. It is a 27-km-long circular tunnel, making it the largest underground construction in Europe and one of Europe's longest tunnels at that time. Ten years later, The LEP was converted to the *Large Hydron Collider* (LHC) and additional caverns and access shafts were constructed,

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https://doi.org/10.1016/j.tust.2018.04.003
Received 5 November 2017; Received in revised form 14 March 2018; Accepted 3 April 2018
Available online 11 April 2018
0886-7798/

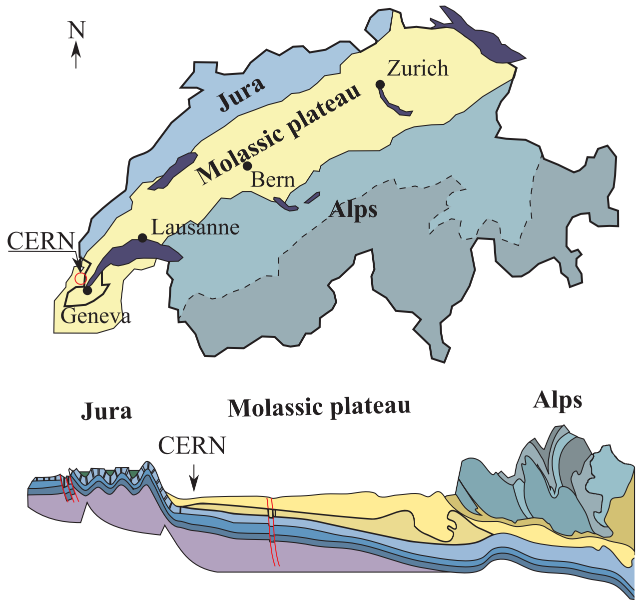

Fig. 1. Schematic description of the Swiss geology.

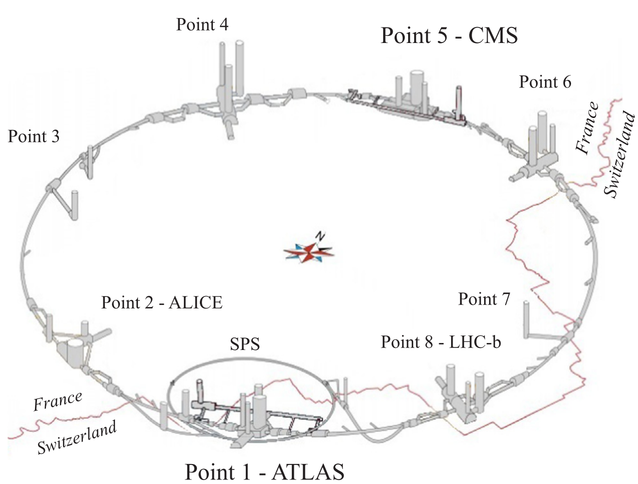

Fig. 2. Schematic description of the underground facilities at CERN.

including ATLAS (Point 1) and CMS (Point 5). Fig. 3 shows a photograph of the ATLAS cavern UX15 during construction, which is the largest cavern at CERN with excavated dimensions of L 55 × W 35 × H 40 metres. Shortly after, ALICE (Point 2) and LHCb (Point 8) were constructed adding new caverns and tunnels to the existing facilities. In 2015, the High Luminosity (HiLumi) project began with the construction of additional caverns, tunnels and shafts and will be operational by 2021.

3. Geotechnical exploration

The geotechnical investigations have been carried out for each new construction and were based on exploration boreholes from which samples were collected for laboratory testing. The boreholes were also used for site testing. The geotechnical characterisation presented in this paper is based on these investigations, and focusses on Point 1 (ATLAS) and Point 5 (CMS) since they offer the most extensive data as well as being at the two opposite positions of the CERN facilities. However, the geological conditions at Point 1 (ATLAS) and Point 5 (CMS) are slightly different. Point 1 (ATLAS) is located near Geneva airport where the bedrock roof is shallow (around 5 m) and Point 5 (CMS) is located next

Fig. 3. Excavation of the cavern UX15 at Point 1 (ATLAS).

to the Jura chain mountain where the bedrock roof is deeper (around 50 m). ATLAS was initially planned at Point 5 but was moved to Point 1 due to the more competent rock mass as it houses large caverns. The borehole logs show that the *red molasse* is primarily composed of layers of sandstone and marl with variable thickness. Fig. 4 shows an extract of the borehole C1 at Point 1 (ATLAS) and translated to English for this paper.

The term *sandstone* refers to cemented sandy or silty rocks and the term *marl* refers to clayey rocks. The borehole shows thick layers of sandstone separated by medium-thick, or even thin, layers of marl. However, thicker layers of marl are observed in other boreholes. This *red molasse* relates to 'Type III' molasse (Marinos et al., 2013) and it is characterised by systematic alternations of sandstone and marl of different grain-size grading with a thickness ranging from a few centimetres to a few metres, and few discontinuities. The *red molasse* is weak and fractured at shallow depths with rock quality designation *RQD* (Deere, 1963) values as low as 0. It is weathered and can have trenches at the surface (GADZ, 2016a), which are filled with quaternary fluvio-glacial soil units and are hazardous for tunnelling. The molasse is massive at depth with *RQD* values in the range of 70 to 100. The molasse can also contain some natural hydrocarbons GADZ (2016a), which affect the mechanical properties of discontinuities (Lombardi, 1979).

3.1. Rock units

Two types of rock are identified – marls and sandstone – and divided into 6 sub-units, 3 for each rock type. The description of these units is as follows.

The marls are micro-fissured rocks with various amounts of clay (40–60% of illite, 20–25% of chlorite), calcite and quartz (Fig. 5). They have smooth to slickensided closed and poorly-cemented joints with a spacing smaller than 60 mm. These marls are subjected to swelling, slaking upon contact with air and water, and spalling. According to the international rock classification (ISRM, 1981), the marls are very weak *R*1 to weak *R*2 rocks. Three sub-units were identified as follows.

– *1. Very weak marl* is mostly *motley* marl made from the diagenesis of high-plasticity clays (Figs. 5 and 6). It is characterised by numerous closed, polished, discontinuous and multi-directional micro-fissures, which give the rock isotropic characteristics. Its mineralogy gives it a low stiffness and ductile behaviour. This marl is subjected to swelling, slaking upon contact with air, and spalling.
– *2. Weak marl* is composed of *laminated* or *platty* marl and is composed of 45–60% of clay, 15–30% of micro-crystalline quartz, and 20–30% of calcareous minerals (Fig. 5). The Atterberg limits (Fig. 6)