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Pressurized TBM-shield tunneling under the subsidence sensitive grounds of Oslo: Possibilities and limitations

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ABSTRACT

The marine clay deposits covering the bedrock under the Norwegian capital Oslo are very sensitive to pore pressure reduction. Existing tunnels under the city are draining the ground to varying extents, which have led to settlement damages to buildings and infrastructure. Oslo is the fastest growing capital in Europe, and there is great demand for underground excavations for trains, roads, subways, power cables, water, and wastewater. It will be very important to limit drainage into new tunnels during the construction phase and in the permanent state. This paper discusses the possibilities and limitations of pressurized (closed-mode) TBM-shield tunneling as an alternative to traditional drill and blast (or open-mode TBM excavation) with pre-excavation grouting. Earth pressure balance and slurry shield machines with gasketed precast concrete segmental linings, which are normally used in soil and soft rock tunneling, may give superior drainage control compared to non-pressurized (open) methods; but these machines have challenges with high wear when used in hard rock. The use of traditional hard rock single-shield machines built with the option to convert into closed-static-mode is another, and probably a more realistic alternative, which should be considered in order to better control drainage during the construction phase.

1. Introduction

It is well established that drainage as a result of underground infrastructure and building pit construction in the city of Oslo, can cause surface subsidence. Porewater pressure reduction in the marine clay deposits covering the city leads to compaction, which for buildings with soil foundations, results in settlements that can go on for decades and give massive damages. This is not a direct problem for buildings with bedrock pile foundations, but settlements of the surrounding ground lead to problems for the local infrastructure (roads, tramlines, walkways, sewage and water pipes, etc.) in between the buildings (Fig. 1). Rapid population growth in Oslo raises the demand for new underground transportation and technical infrastructure such as the Fornebu metro line, new central metro tunnels, new train tunnels, tunnels for power cables, tunnels for water transfer and waste water. Future projects may benefit from the possibilities of pressurized TBM-shield excavation in order to reduce and better control drainage in the construction phase. Gasketed single-shell concrete segmental linings, which are typically used in combination with these TBM machines, will also leave behind a permanent waterproof undrained structure. The maximum overburden is seldom more than ca. 100 m, and normally below ca. 50 m for tunnels in Oslo, and this type of segment lining has proven its function under these water pressures. As opposed to the drained structure of many tunnels in Oslo, the undrained structure can better preserve the natural hydrogeological situation without the use of artificial methods (i.e. the use of water infiltration wells to counteract porewater pressure reduction above tunnels). This paper covers some of the possibilities and limitations, in an Oslo-focused context, for the excavation method in question.

2. Geological setting

The geology of the Oslo region involves a transition from Precambrian basement rocks to Cambro-Silurian sedimentary rocks, which were later intruded by Permian volcanic and plutonic rocks. A thin layer of conglomerates is found on top of the basement rocks, overlain by thicker alternating shale and limestone layers (Fig. 2). These layers were later folded and faulted during the Caledonian orogenesis. The fold axis direction was ca. NE-SV and orthogonal to the thrust faulting (compression) direction, which was ca. NV-SE. In Carboniferous - Permian time extension led to the formation of N-S trending faults, and volcanic and plutonic rocks cut through the rock

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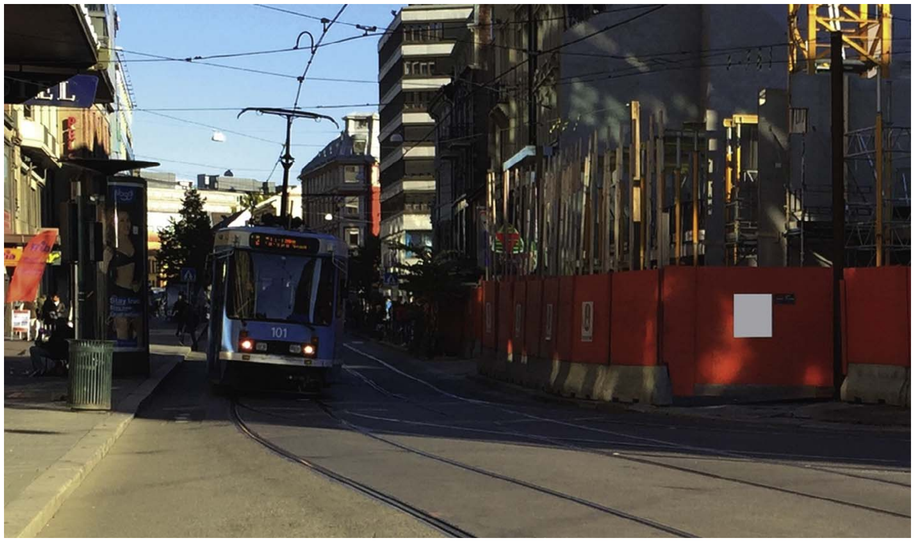

Fig. 1. Settlements induced by construction activity causes problems for the tramline in the street of Storgata (October 2015). Photo: Ø. Dammyr.

mass and formed larger massifs on top of or within the Cambro – Silurian rocks. These rocks today form the elevated terrain of "Nordmarka", a much loved recreational area for the people in Oslo. As a result of this activity, many smaller (meter scale) and wider (10+ meter scale) intrusion dykes are found within the Cambro – Silurian rocks. Thinner dykes are typically composed of diabase and meanite, whilst the thicker ones are composed of syenite.

The Cambro-Silurian sediments are today exposed around the city of Oslo. Weaker fault rocks and shales have often been eroded to a lower level than the stronger limestone layers, leaving deep trenches that were later filled with marine sediments during/after the last glaciation in Holocene. The terrain has risen more than 200 m since then and washout of salt in these clays has resulted in many areas where the clay structure is extremely weak (quick clays), and may collapse (becomes liquid) if stirred or overloaded. The rock surface is typically uneven, and depths from the terrain to the rock surface can vary significantly over short distances. Fig. 3 shows a shale-limestone outcrop, and a flatly lying syenite intrusion below shale at the face of the Løren road tunnel during construction.

3. Tunneling experience in Oslo

There is extensive experience from tunneling in the rock formations under the central city of Oslo and the surroundings. Tunnels for subways, roads, trains, power lines, water and wastewater have been excavated using conventional drilling and blasting (D & B). During the 1970s a 40 km network of smaller diameter (3–3.5 m) sewer tunnels were also excavated through the Cambro-Silurian sediments with the use of open TBMs. The conditions for TBM advancement rate and cutter wear in the Cambro-Silurian rocks are generally considered to be favorable, whilst the Permian rocks are somewhat tougher to bore (Tables 1 and 2).

Degree of fracturing and fracture-orientation in relation to the tunnel drive is a major component that can influence TBM advancement rate. Degree of fracturing should be expected to vary, but is generally thought to be favorable. Fig. 4 shows part of a geological log from the Løren road tunnel. The RQD value varies between 60 and 80, and the number of fracture sets is typically 3, sometimes with additional sporadic fractures. Q – values outside fracture and fault zones typically vary between ca. 1 and 10 for tunnels in Oslo (author's experience). The log of Fig. 4 also shows grout consumption for each of the overlapping grout umbrellas, which were performed systematically during tunneling.

3.1. Rock mass stability

Rock mass surface weathering, low rock overburden with large variations over short distances, and crushed/fault zones are typical concerns for tunnel planners in Oslo. Most of Oslo's transport infrastructure lies relatively close to the surface, and there is often a need to plan tunnel alignments through potentially weathered rock mass. Norway also has areas (including the Oslo area) that have been influenced by deep weathering, typically relating to fault and fracture zones. During the Mesozoic, the climate was tropical and weathering products can still be found deep (+ 100 m) in the rock mass. Other engineering geological challenges are related to intrusion dykes and their adjacent rock mass, which can be fractured/crushed and highly permeable, and lava tuff layers (found in some formations) where alteration products such as swelling clay materials can give rise to stability issues. It has normally been possible to achieve a stable, self-bearing rock mass only with the help of traditional rock reinforcement such as rock bolts and shotcrete. In fault zones and in areas where the rock overburden is low, or the tunnels are close to the surface or other infrastructure, the use of ribs of reinforced shotcrete has normally been sufficient. In parts of future tunnels and caverns close to the surface and/or close to operating infrastructure, more rigid/stiffer excavation support, such as pipe umbrellas in combination with sequential short blast rounds (1–2 m) and cast concrete at the face might have to be used. In order to optimize tunnel alignments, future projects may also have shorter sections planned through soil.

Due to strict requirements relating to vibrations, typically resulting from blasting and machine scaling of tunnels, techniques such as drill and split or TBM may be considered advantageous. Drill and split is at the time of writing in use at the new Follo-line railway project (2 × 19,5 km train tunnels) for passing of road tunnels and oil storage caverns in the Ekeberg-hill (Ekebergåsen).

Alum (potassium aluminum sulfate) shale makes up the lower sedimentary shale layer in the Oslo area. This highly organic black shale was deposited in oxygen poor waters and has a high content of heavy minerals such as uranium, and other minerals such as sulfur. It is considered as the primary source of the radioactive gas Radon (intermediate decay product of Uranium) in many houses in Oslo, which above a certain concentration gives a risk towards the development of lung cancer. If alum shale is exposed to oxygen several chemical processes initiate. In the processes sulfuric acid is precipitated, which can attack concrete and steel (important consideration for tunnel linings and reinforcement). Another alteration product is gypsum, which requires more space and can lead to swelling pressures as large