GEOreCIRC – utilization of TBM spoil

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ABSTRACT

A continuously growing focus on reuse and recycling, means an increasing interest to facilitate reutilization of various residual resources in an environmentally satisfactory way. The construction industry is responsible for a substantial generation of excess material, much of which may have several useful areas of use. One such material is the spoil material resulting from tunnel excavation using tunnel boring machines. Both material and environmental properties of the material is of key importance when evaluating the possible areas of reuse. Environmental samples from two recent Norwegian TBM-projects have tested and compared. Overall, the results indicate that the level of contamination in the tested TBM spoil is low. The majority of the samples had concentrations of heavy metals and organic contaminants below the threshold level for contaminated soils according to Norwegian regulations.

KEYWORDS

Recycling, reutilization, tunnelling, TBM, D&B, geochemical, geotechnical, heavy metals, aliphates,

1. INTRODUCTION

During the past years, the overall environmental focus has increased in almost every aspect of life. The EU-commission recently launched a circular economy strategy in an effort to increase recycling and re-use of materials. One important goal of this strategy is to increase the reutilization of various types of geo-resources. However, this requires a thorough understanding of both the physical and environmental properties of the material in question.

With its numerous mountains and valleys, Norway has a long history of tunnelling projects. Such projects often result in large amounts of excess materials. The majority of former tunnelling projects, especially for road and rail development, have been completed using tunnel driving by drill and blast (D&B). However, tunnel excavation using tunnel boring machines (TBM) was utilized in several hydropower projects in the 1970s and 80s (Lunde, 1986), and has recently also been utilized in large tunnelling projects for both hydropower and railroad. A TBM is used to excavate circular tunnels in materials ranging from sand to hard rock. The machine is typically shaped like a long tube, filling most of the foremost part of the tunnel (see Figure 1). A rotating cutting wheel makes up the front of the machine, whilst a transportation system ensures that excess mass is transported backwards and out of the tunnel. There are different types of machines available, depending on the type of tunnel and geological conditions in the area (Jakobsen & Arntsen, 2014).

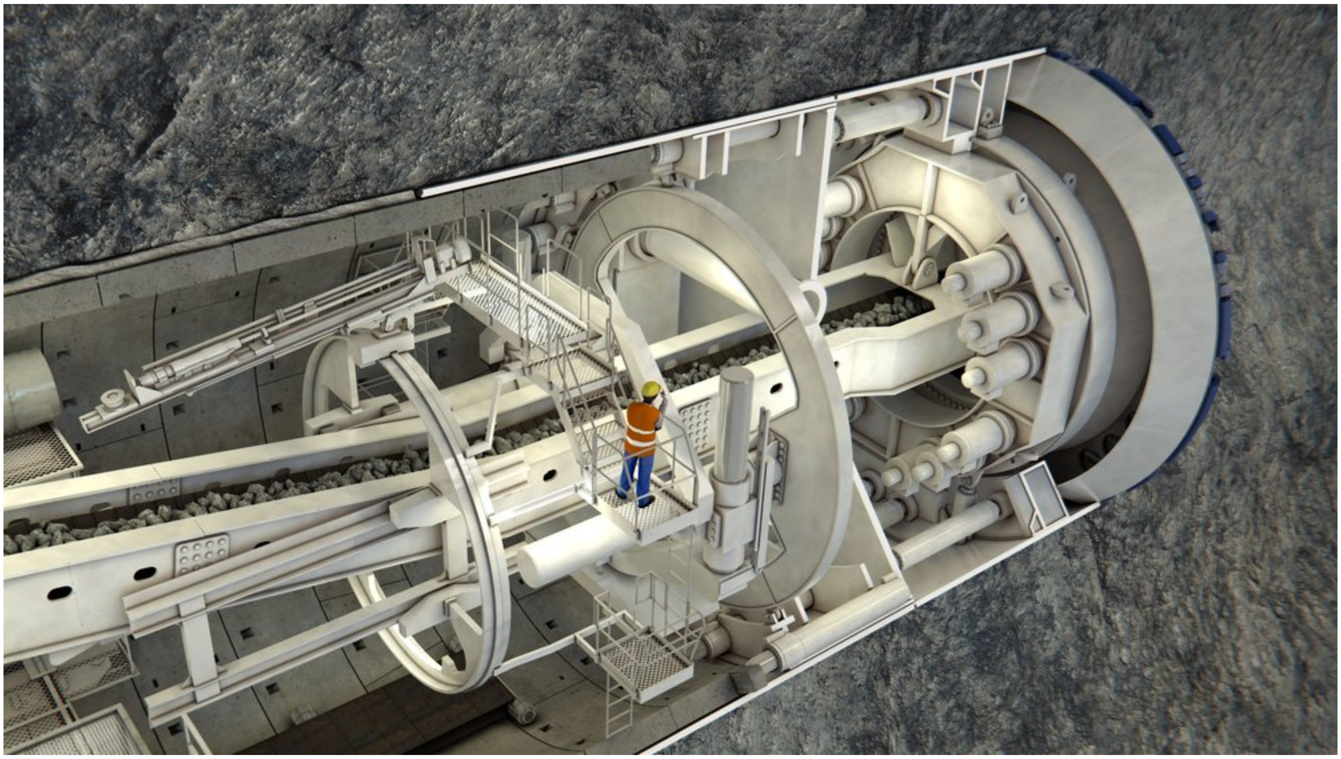

Figure 1. A tunnel boring machine in operation. Illustration from BaneNOR.

There are several key differences between the excess mass produced by D&B and TBM. Most notably, the spoil material from TBM-tunnelling has a rather different particle size distribution compared to spoil from D&B tunnels. As a result of the drilling process, the material consist of a wide range of particle sizes, from fines (particles less than 0.075 mm in diameter) to particles with a diameter up to about 50-60 mm. A typical grain size distribution of TBM spoil, based on several previous Norwegian hydro power projects is shown in Figure 2. These results closely match the preliminary results from the ongoing Norwegian TBM-projects. In TBM spoil, the amount of fines may be up to about 20 %. Such high contents of fines result in uncertainties with respect to the possible utilization of the material, as a large amount of fines will increase the ability for the material to store water. The main uncertainties are therefore related to the water and frost susceptibility of the material. If the material is deposited as a fill material, it is important to stress the need for compaction, to avoid possible settlement under self-weight of the material.

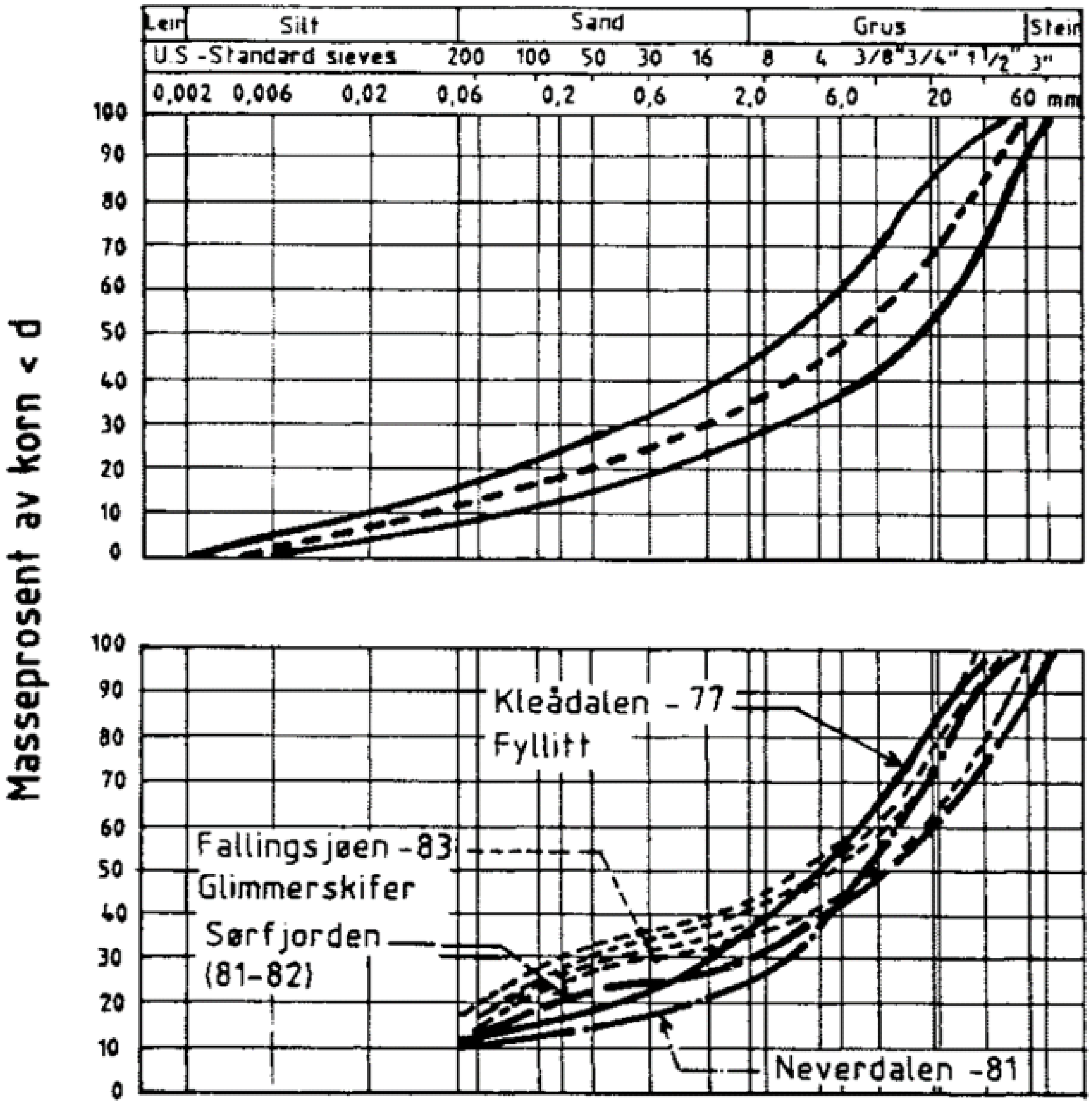

Figure 2. A comparison of grain size distribution curves from several Norwegian TBM-projects. Figure from NGI report 85607-1.

Studies have shown that the amount of voids in between the particles in a material is of key importance for the frost susceptibility of a material (Konrad, J. M., 1999). When a well-graded material like TBM spoil is exposed to sub-zero temperatures, a certain amount of fines will aid the transportation of water to the upper, frozen layer of the soil. As the water is transported towards to surface, the water will freeze and generate growing ice lenses. This will result in the upwards swelling of the material, known as frost heaving (Konrad, J. M., 1999).

The environmental properties of the TBM spoil is of equal importance when considering the possible reuse of the material. Norwegian law states that no pollution is to be spread from one area to another (Norwegian Pollution Act, 1981, § 7-1), requiring close testing and evaluation of any material that is to be reused at a different site. Compared to tunnel excavation with D&B, the use of TBM has several environmental advantages. In contradiction to D&B spoil, the TBM spoil will not contain any residues from explosives. Secondly, most TBMs are electrically powered and in many TBM projects, the transportation of the excavated spoil is conducted by the use of a conveyor system. Consequently, the need for trucks and loaders inside the tunnel is almost abundant.

Combined, this not only results in a reduction in emissions, it also contributes to a better working environment (Tarkoy, P. J., 1995).

Consequently, to give a proper evaluation of the possible areas of reuse for TBM spoil, a thorough determination of both physical and environmental properties of the material is required. Previous investigations of the geotechnical properties of TBM spoil from several Norwegian tunnelling projects, conducted at the Norwegian Geotechnical Institute (NGI), indicate that the material may have several useful areas of application (e.g. see Vassdragsregulantenes forening, 1991; NGI, 1986). Key geotechnical parameters includes the natural water content, grain size distribution as well as stiffness and strength properties of the materials. This is typically determined through the use of standard Proctor, oedometer and plate load tests.

To gain an even better understanding of the properties of TBM spoil, two recent Norwegian TBM-projects have been studied in more detail. In both projects, an extra effort was given to find suitable options for the reuse of the excavated material. The projects are briefly introduced below. This article focuses mainly on the environmental properties of the material. Geotechnical properties of the TBM-spoil will be presented in a future publication.

1.1. The Ulriken project

A single-shield TBM with a diameter of 9.3 m produced by Herrenknecht was used for the excavation of an approximately 7 km long railway tunnel through the Ulriken Mountain just outside of Bergen. A single-shield machine was chosen due to the somewhat changing rock conditions along the tunnel (Herrenknecht, 2017). The project is estimated to generate about 700 000 m^3 of excess mass. A substantial amount of the excavated material has been reutilized to cover areas of polluted seabed in the port of Bergen (Norwegian Environment Agency, 2017).

1.2. The Follo Line project

The Follo Line project includes the construction of the longest railway tunnel in Norway, and is currently the country's largest infrastructure project. A total of four double-shield TBMs with a diameter of about 10 m produced by Herrenknecht are used for the excavation of two tunnels, each almost 20 km long between Oslo and Ski. Double-shield machines were chosen due to the length of the tunnels, the stable geological conditions and hard rock in the area. A double-shield machine offers the ability to mount precast concrete elements to the walls of the newly excavated tunnel as the machine proceeds. A hydraulic trust system pushes against the concrete elements and makes a steady forward advancement of the machine possible (Herrenknecht, 2016). The Follo line project is estimated to generate somewhere between 4 and 5 million m^3 or 10 – 11 million tons of excess mass. As the project includes such vast amounts of material, it has been of great important to ensure reuse of the material. As a result Bane NOR, the Norwegian railroad authority, and Oslo Municipality made an agreement to deposit most of the material in a valley just south of Oslo. The material will create a building platform for a future township, known as Stensrud-Gjersrud (Bane NOR, 2015).

2. METHOD

Sampling for geochemical testing was conducted under similar conditions for both projects. Sampling was done by the use of a hand shovel from a temporary storage site, just outside the tunnel. The amount of time between drilling and sampling is estimated to vary between 12 and 36 h for all samples. For the Follo line project, sampling was done the first week of each month. Every time a total of three samples were collected, each sample consisting of at least 6 subsamples from different points.

Samples from both projects were analyzed by ALS Laboratory Group Norway AS (ALS), using accredited analysis methods in accordance with national or international standards. All samples were analyzed for heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn), mineral oils (aliphatics, C8-C35), benzene, toluene, ethyl benzene, xylenes (BTEX), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). The parameters analyzed for represent a range of possible contaminants associated with natural rock minerals (heavy metals) and machinery used in the tunnelling process (mineral oils, BTEX and PAHs).

Geotechnical testing for the determination of water content, grain size distribution as well as standard Proctor, oedometer and plate load tests will be conducted in accordance with standardized routines.

3. RESULTS

The presented data set includes data from both the Ulriken project (n=66) and the Follo Line Project (n=38). For both projects, the concentration of heavy metals were below the threshold levels for contaminated soils, according to Norwegian regulations (SFT, 2009), in the majority of the samples (figure 1). A few exceptions where samples were classified as lightly contaminated (Tilstandsklasse 2, SFT, 2009) were observed: for As, 1 out of 66 samples (1/66) for Ulriken and 0/38 for Follo; for Cu, 1/66 for Ulriken and 1/38 for Follo; for Cr, 3/66 for Ulriken and 0/38 for Follo; for Ni, 1/66 for Ulriken and 0/38 for Follo; and for Pb, 0/66 for Ulriken and 1/38 for Follo.

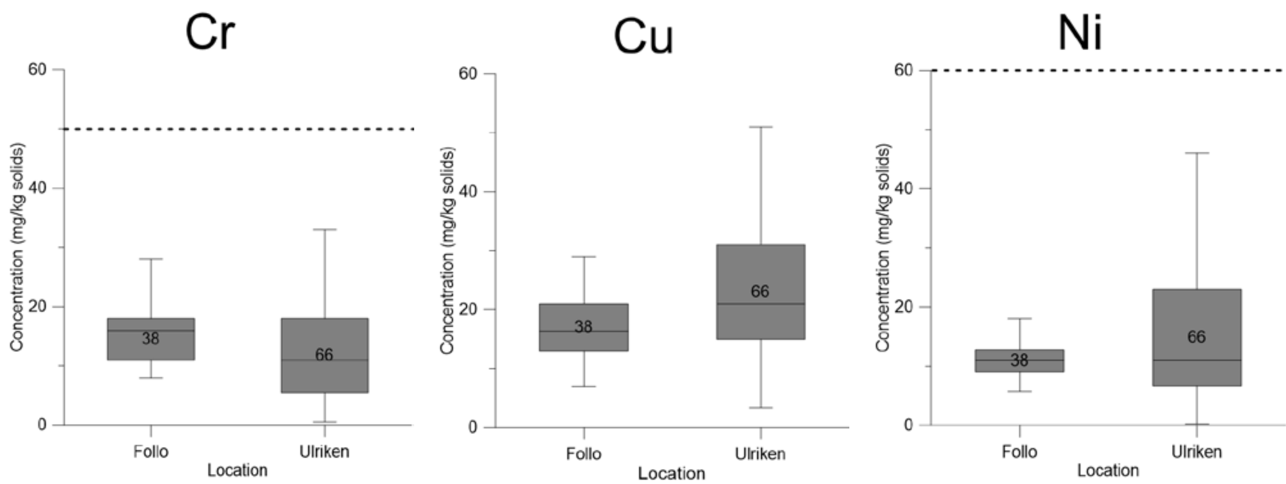

Figure 3. Concentrations of (from left) chromium (Cr), copper (Cu) and nickel (Ni) in TBM from the two projects, Follo and Ulriken. The black, dashed lines indicate threshold levels for contaminated soils in Norway. For Cu, the threshold value is 100 mg/kg and outside of the range of the plot. Concentrations <LOD for the respective methods were treated as LOD/2.

The concentrations of BTEX, PAH and PCB were below the respective limits of detection (LOD) for each method in all samples tested from both Ulriken (n=66) and Follo (n=38).

For almost all of the Ulriken samples (62 out of 66 samples), the concentration of longer chain aliphates (>C12-C35) were below the LOD (10 mg/kg). In 3 of the samples with detectable concentrations, the concentrations were below the threshold value. Only one sample was classified as lightly contaminated (Tilstandsklasse 2, SFT, 2009) with a concentration of 250 mg/kg. Shorter chain aliphates (>C10-C12) were not detected above the LOD (5 mg/kg) in any of the Ulriken samples (n=68). For the Follo samples (n=38) the concentrations of longer chain aliphates (>C12-C35) were 25 ± 16 mg/kg (average ± one standard deviation), but none of the samples exceeded the threshold level for contaminated soils (100 mg/kg). Shorter chain aliphates (>C10-C12) were not detected above the LOD (10 mg/kg).

4. DISCUSSION

Overall, the results indicate that the level of contamination in the tested TBM spoil is low. The majority of the samples had concentrations of heavy metals and organic contaminants below the threshold level for contaminated soils according to Norwegian regulations (SFT, 2009). This is an important insight, as any geo-material with concentrations below this threshold level can be re-utilized without environmental restrictions.

Any traces of aliphates have to originate from the TBM or other machinery in the tunnel. During the drilling process, grease is used to protect and prolong the lifetime of the drill bit. The amount of grease required will depend on the progress of the drilling process – a higher drilling pressure requires less grease. For the Ulriken project, an estimated 6 kg of grease was used per meter drilling. This grease will be rather homogenously distributed into the resulting spoil material and a rough estimate suggests about 0.03 kg grease for each 1000 kg of spoil material, or 30 mg/kg. This number coincides well with the measured average concentration of 26 ± 16 mg/kg. Furthermore, in the 104 samples tested in both projects, only one sample had a concentration of longer chain aliphates (C12-C35) exceeding the threshold level for contaminated soils. This sample however, is not representative of the bulk TBM spoil as it was collected not at the temporary storage site as the other samples, but just below the cutter head of the TBM. Spoil directly below the cutter head could be directly affected by oil leaks from the machinery. As the analysis of the other 103 samples from bulk TBM spoil at the temporary storage sites show, aliphates, both long and short chains, are present in either non-detectable amounts or amounts below the threshold level for contaminated soil. Thus, aliphates in TBM spoil should not be regarded as an environmental concern. TBM spoil directly affected by oil leaks however, should if possible be handled separately.

The heavy metal concentrations exceeding the threshold levels for contaminated soils found in 9 of the 104 samples from both the Ulriken and Follo line project is most likely related to variations in the mineralogy of the local rock masses. Heavy metals are native to a range of natural minerals and will thus vary in the TBM spoil depending on what rock types the TBM is drilling through. The threshold levels referred to (SFT, 2009) were established for contaminated soils and are therefore not really suitable to evaluate the environmental risk related to heavy metals in mineral masses. Minerals generally have a low solubility and will not leach as readily as heavy metals in soil of an anthropogenic origin.

It could be argued that part of the heavy metal content in the TBM spoil could be related to the drill bit of the TBM. It is unlikely however, that this is a significant source as the drill bit is protected against degradation by grease. Also, elevated levels of heavy metals were not detected in the sample taken directly below the cutter head. Heavy metal contamination in TBM spoil should therefore only be a relevant problem if the drilling process goes through sulfide containing minerals that can release heavy metals and low pH water when oxidized.

To summarize, the results from the geochemical sampling suggests that the characteristics of the parent rock material should be the only factor that could influence the re-use of TBM spoil. Based on a thorough study of the bedrock in the area of the tunnel, one may be able to predict environmental properties of the resulting spoil material. For the Follo line project, most of the bedrock consists of Precambrian gneiss rocks with a significant amount of intrusions from the perm period (Asplan Viak, 2011). Similarly, for the Ulriken project, the bedrock consists mostly of different types of gneiss, with fragments of anorthosite, green stone, amphibolite, and glimmer shale (Norconsult, 2013). These rock types generally do not contain significant amounts of sulphides and should not pose any environmental issues.

5. CONCLUSIONS

In order to increase the reutilization of excess and waste material from the construction industry, a thorough determination of the material properties is required. Environmental testing of samples from two recent Norwegian TBM-projects have been compared. The majority of the samples had concentrations of heavy metals and organic contaminants below the threshold level for contaminated soils according to Norwegian regulations.

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