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Tunnel spoil classification and applicability of lime addition in weak formations for muck reuse

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ABSTRACT

Tunnel construction planning requires careful consideration of the spoil management part, as this involves environmental, economic and legal requirements. In this paper a methodological approach that considers the interaction between technical and geological factors in determining the features of the resulting muck is proposed. This gives indications about the required treatments as well as laboratory and field characterisation tests to be performed to assess muck recovery alternatives. While this reuse is an opportunity for excavations in good quality homogeneous grounds (e.g. granitic mass), it is critical for complex formation. This approach has been validated, at present, for three different geo-materials resulting from a tunnel excavation carried out with a large diameter Earth Pressure Balance Shield (EPB) through a complex geological succession. Physical parameters and technological features of the three materials have been assessed, according to their valorisation potential, for defining re-utilisation patterns. The methodology proved to be effective and the laboratory tests carried out on the three materials allowed the suitability and treatment effectiveness for each muck recovery strategy to be defined.

1. Introduction

Tunnels and underground structures play a fundamental role in transportation, water access and sewage management in cities or across mountainous regions. Excavations are also necessary for mining and quarrying activities that provide raw materials for manufacturing. Several publications (Godard, 2004; Kovari, 2004; Parker, 2004) detail tunnelling benefits and drawbacks. Amongst tunnelling processes, muck management is gaining increasing attention. Muck management requires consideration starting from the feasibility study phase and through the excavation process, since it has several environmental, technical, economic and legal impacts.

Tunnelling in the world results in billions of tons of debris that requires management and, when not reused, this large quantity of soil and rock becomes a waste product that must be handled according to the best available environmental practices required by a quality tunnel design (Oggeri and Ova, 2004). An interesting case history dealing with environmental requirements and monitoring activities for the reutilisation of tunnel muck is described by Haid and Hammer (2009), where cross-linked responsibilities of client, contractor, authorisation bodies and other stakeholders for the management of spoils derived by the excavation of a German railway tunnel with an EPB shield are described.

Material reuse or recycle have two main environmental benefits: (1) reduced waste disposal, (2) a reduction in raw materials extracted.

Recent initiatives highlight these benefits: the SARMa project (Blengini et al., 2012; "The SARMa project", 2009) included sustainable production and recycling of aggregates, the DRAGON project ("DRAGON project", 2013), currently undergoing, analysed the possibility of increasing the amount of excavated mineral resources from tunnelling that can be used by other industries, and the REMUCK project, focused on the development of innovative methods for excavation waste recycling management (Oggeri and Ronco, 2010; Bellopede and Marini, 2011; Bellopede et al., 2011; Riviera et al., 2014).

The use of muck as sub-product is subject to several considerations, in particular:

- In-Country legal framework: each Country has specific guidelines for spoil management that, for European Countries, should also fulfil the requirements specified in the Waste Framework Directive 2008/98/EC, as discussed by Entacher et al. (2011);
- Technical features of the excavated material vs. reuse/recycle requirements (mainly from the technological and environmental points of view);

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- Costs of spoil treatment vs. "traditional" alternatives (spoil disposal and utilisation of virgin raw materials);
- Actual utilisations (alternatives, available quantities, reactive nearby markets).

Although waste minimisation is invoked by concerned stakeholders, its application is still limited due to lack of knowledge as far as costs, quality, quantity and suitability of such materials are concerned (Kwan and Jardine, 1999).

Environmental impact assessment approaches adapting existing methodologies such as multi-criteria analysis, carbon-foot printing and Life Cycle Assessment (LCA) of competing scheme have been proposed for the measurement and mitigation of environmental impacts associated to earthworks (O'Riordan and Phear, 2012). Several examples of reuse and recycle can be found in technical literature (Bellopede and Marini, 2011; Bellopede et al., 2011; Büchi and Thalmann, 1994; Camposinhos et al., 2009; Gertsch et al., 2000; Kwan and Jardine, 1999; Resch et al., 2009; Saathof and Ketelaars, 1999; Thalmann et al., 2003, 2005; Tokgöz, 2013). The most common are: (good quality muck) aggregates, raw material for industrial production; (fair quality muck) material for embankments, road construction; (low quality muck) refilling material for voids or land reclamation.

For each potential application, engineering practice and technical norms impose an in-depth qualification phase to be carried out through laboratory tests for specific technical parameters assessment, according to the technical requirements. As an example, it is possible to refer to StGotthard plant in Bodio, where at least 10 tests have been carried out in order to ensure the quality of processed materials from granitic and gneissic rock formations, as reported by Oggeri and Ronco (2010).

The aim of this paper is to propose a methodology for providing guidance for the possible scenarios to be considered when a tunnel excavation is being planned. Moreover, a case history concerning muck condition assessment for a large tunnelling project involving geo-materials of varying properties is discussed.

2. Methodology description

Tunnelling is carried out by means of various excavation methods depending on the ground conditions and on the tunnel features. The close relationships between geological conditions, excavation method and muck features have already been proposed for estimating the Rock Mass Rating according to Tunnel Boring Machine (TBM) performance parameters and muck features (Sun et al., 2008). Thalmann-Suter (1997), after describing the influence of geology and excavation method on the final muck, proposed a procedure for the suitability assessment of tunnel spoils for aggregate production in case of hard rock tunnelling. On the basis of possible combinations between suitable methods and grounds, the material produced after the excavation process ("muck" or "spoil") presents a wide variety of physical and geotechnical properties. These include the physical properties of grain size distribution, grain shape, bulk density, water content, abrasivity, and viscosity. Geotechnical properties include residual cohesion, friction strength, hydraulic conductivity, and consistency. Concerning the choice of the excavation method when full face mechanised tunnelling is adopted, in the past slurry shields or hydroshields were associated with the excavation in coarse, granular formations, whereas Earth Pressure Balance (EPB) Shields were used for fine cohesive materials. However, the technical development of tunnel boring machines and the introduction of new excavation techniques (for example the soil conditioning) allow modern TBM to tackle mixed ground conditions where alternation of granular soil, cohesive soil and even rock formation are encountered. Therefore, in this proposed methodology the full face mechanised excavation is presented according to the kind of geo-material that is to be excavated, overcoming the differentiation between Slurry shields and EPB shields that could not take into account the hybrid systems that are nowadays utilised.

The developed schemes gave a synthetic overview of the possible muck types arising from civil tunnelling works (Table 1) and of their possible applications (Table 2). When a possible application is identified, a full characterisation of the material according to usual technical prescriptions is required. Table 3 gives an overview of the mechanical and physical parameters concerned for different destinations mentioned in Table 2. Fig. 1 shows typical examples of different tunnel spoils. Muck from drilling and blasting operations (Fig. 1a) is characterised by the presence of a wide range of grain size, from very fine material (visible in the top half part) to very coarse cobbles (visible on the bottom of the excavation face). Full face TBM excavation in hard rock gives a more homogeneous muck (Fig. 1b), with similar size chips (their dimension is related to the disk spacing) and powdered material. The excavation in soft rock-hard soil with the utilisation of soil conditioning technique leads to the production of a mud where cobbles and lumps of soil are surrounded by a fine soil fraction, which is lubricated by the conditioning agent (Fig. 1c). Eventually, the mechanised excavation in coarse soil returns a bulk material (Fig. 1d) that can be assimilated to loose soil. While other classifications are possible, based on petrography, mineralogy, grain size distribution or other geotechnical data, the proposed system concerns the actual features of the tunnel spoils, considering their possible behaviour on a phenomenological approach.

Eventually the assumption for the utilisation of this categorisation is that all prescribed environmental tests have been carried out on representative muck samples and that the presence of pollutants has been excluded, since contaminated soils have no recovery option and require disposal as a special waste, possibly after treatment.

The general item concerning the muck management is articulated in three main aspects, respectively regarding the technical issues (this paper falls into this field), the legal rules and the economic-environmental possible advantages. The technical field concerns the modes that produce the muck and the consequent ability to modify it by adopting suitable treatment plants, in order to select, ameliorate and control the final product and its characteristics. The legal field covers the definition of the context where the matter is regulated also by means of specific physical or chemical requirements allowing the material itself to be adapted to the final use or destination. The economic and environmental field considers the possibility of adding value to a material that is produced as a consequence of a different project, with the basic aim to reduce the impact arising from simple disposal and from a quarrying activity to produce raw materials for the completion of the initial work (the tunnel and its connections).

3. Application of the methodology

This section describes a detailed assessment on the muck produced by the excavation of a large-diameter tunnel bored with an Earth Pressure Balance Shield (EPB-TBM) using additives for soil conditioning. The tunnel is excavated in a complex formation crossing soft rocks, such as argillites, (soil F1), claystones, and highly clayish sandstones (soil F2). Within F1, some zones containing ophiolitics and basaltic boulders, characterised by a high strength (soil F3), can be found. For spoil handling improvement purposes, following a technical practice also described by Haid and Hammer (2009), a small quantity of CaO (between 0.5% and