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Performance-based re-use of tunnel muck as granular material for subgrade and sub-base formation in road construction

Pier Paolo Riviera *, Rossana Bellopede [1], Paola Marini [2], Marco Bassani [3]

Department of Environment, Land and Infrastructures Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Torino, Italy

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ABSTRACT

Large volumes of muck are produced in the Alpine Region and bordering areas as a result of new road and railway construction. For example, in Austria every year approximately 32×10^6 Mg of muck are produced from tunnelling activities. In the near future, many other initiatives along the European corridors will lead to further construction activity, with an inevitable increase in the environmental problems related to the use or disposal of the muck generated. Therefore, there is a clear opportunity for the extensive re-use of muck due to the high demand for granular materials (about 3 billion tonnes in Europe, only 5% of which comes from recycling), the depletion of existing quarries (approximately 24,000 in Europe), and the environmental constraints preventing or delaying the opening of new quarries.

In this scenario, a new approach to the re-use of muck is both necessary and timely. Although many typical defects deriving from its geological nature and/or from the extraction techniques employed may lead to its rejection as an aggregate, these same defects are of less importance in embankment, subgrade and sub-base construction in transportation infrastructures and, indeed, in most cases they can be mitigated by granular or chemical stabilization.

The investigation described here embraces this philosophy. Starting from the chemical physical characterization of seven different mucks derived from tunnelling activities on the Italian side of the Alps, the paper aims to explore the potential benefits deriving from their re use as a construction material. The test methods used all adhere to prescriptive and performance-based construction specifications. Notwithstanding the unfavourable geological origin of some of the considered materials, they all exhibited mechanical properties that would encourage their almost complete re-use in infrastructure construction projects.

1. Introduction

In Europe, the transportation infrastructure system is considered fundamental for the smooth operation of the internal market, the mobility of people and goods, and economic and social cohesion between European countries. In support of this system, the Trans-European Transportation Network (TEN-T) provides roadways, railways, and airports as defined by the European Union in the 1980s. In the 27 EU member countries 5,000,000 km of paved roads, of which 65,100 km are motorways, and 212,800 km of railway lines are included (European Commission, 2005). In Northern Italy, 200 km of new railway tunnels and 200 km of road tunnels of more than 2000 m in length are planned (World's Longest Tunnel Page, 2012), together with new underground lines in the largest urban areas. From 2013 to 2015, the plan for the Italian railway system envisages approximately 2500 km of new infrastructures (Rete Ferroviaria Italiana, 2012).

These new constructions will lead to the excavation of great quantities of granular materials, so the re-use of tunnel mucks, presently considered a waste according to new construction specifications, could make an important contribution to the sustainable, economic and technological development of European society.

A well-performing transportation network requires large volumes of natural resources such as soils and aggregates. The European Aggregates Association indicates that, in 2010, the production of aggregates was of the order of 3680×10^6 Mg, of which recycled aggregates accounted for 186×10^6 Mg (5%) and crushed rock accounted for 1929×10^6 Mg (53%). In Italy there are no figures available for the percentage of recycled aggregates (European Aggregate Association, 2012). Despite the high level of activity associated with the provision of infrastructures and the considerable need for resources, the document on the impact

* Corresponding author. Tel.: +39 011 0905612; fax: +39 011 0905614.
E-mail addresses: pierpaolo.riviera@polito.it (P.P. Riviera), rossana.bellopede@polito.it (R. Bellopede), paola.marini@polito.it (P. Marini), marco.bassani@polito.it (M. Bassani).
[1] Tel.: +39 011 0907738; fax: +39 011 0907699.
[2] Tel.: +39 011 0907625; fax: +39 011 0907699.
[3] Tel.: +39 011 0905635; fax: +39 011 0905614.

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assessment on the European Transport Area (European Commission, 2011a) attached great significance to the employment of environmental resources but paid very little attention to the employment of mineral raw materials (soils and rocks) and their recycling and re-use.

This paper promotes the consideration of tunnel muck as a stable and alternative source of surrogate and soils. For this purpose, seven tunnel mucks with diverse geological origins and produced by different excavation methods were considered. Although certain defects may lead to the rejection of some muck as aggregate material for bound pavement layers (i.e., large size, elongated shape, flakiness), these same defects render the muck more suitable for use in embankments, subgrades and sub-bases of transportation infrastructures where significant large volumes of granular materials are required (see Fig. 1 the typical section of a road). It is worth noting that the granular materials employed in the construction of sub-bases and subgrades contribute to the mitigation of the detrimental effects of climate and dynamic stresses induced by traffic loads, so the unbound granular material employed in their formation should meet with stricter specifications than those used for the selection of embankment materials.

2. Background and literature review

2.1. Re-use of tunnel mucks

The idea of an extensive re-use of tunnel excavated materials originated in the 1990s when the growing environmental and sustainability problems associated with the supply of natural aggregates became one of the most important issues in civil construction (Kwan and Jardine, 1999; Gertsch et al., 2000). In recent years the problem has been exacerbated due to the construction of a number of very long tunnels which have generated significant quantities of muck to be disposed of, with an ensuing consumption of land, and economic and environmental resources (Ritter et al., 2013). This depletion of resources is certainly not sustainable in the long term. Nevertheless, in spite of the large scale impact of the problem, only a limited number of experimental investigations relating to the possibility of using muck as aggregate or soil surrogate have been disseminated in literature.

A number of these studies have focused on the effects of the excavation technique used on the properties of spoils. Grunner et al. (2003) underlined that the usages of excavated materials should be evaluated on the basis of the excavation driving method as this influences the cleanliness and shape of mucks. They noted that the use of the Tunnel Boring Machine (TBM) led to a particle size which was suitable for aggregate, while with classical excavation methods the characteristics of muck depended on the physical state of the original rock mass and on the blasting technology used.

Some attempts have been made to assess the possibility of re-using muck as concrete aggregate especially when the excavation process is carried out by means of the TBM. Using six different

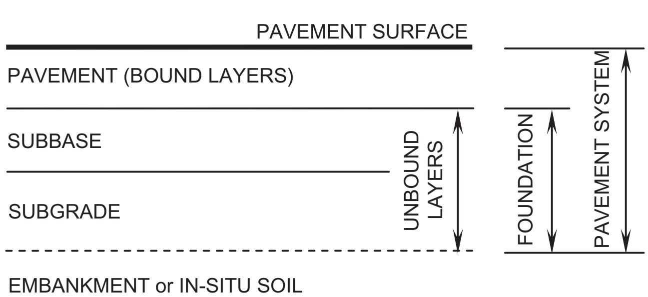

Fig. 1. Principal layers of a road.

TBM mucks, Olbrecht and Studer (1998) obtained a highly-workable concrete characterized by a greater shrinkage and a lower elasticity modulus, approximately equal to 50% of that of conventional concretes. Thalmann-Suter (1999) also pointed out that the recycling of excavated debris begins with the choice of digging method and requires careful and continuous control of the muck produced to ascertain its quality with practice-friendly test methods.

The possible re-use of excavation materials has also been evaluated in Austria where 32×10^6 Mg of muck are produced every year. The research by Resch et al. (2009), supported by the Austrian Research Promotion Agency, highlighted that the re-use of muck depends mostly on the lithological properties of the excavated rock, the demand for mineral raw materials within a defined distance from the tunnel construction site, and the treatments which the tunnel mucks are subjected to after excavation.

In more recent years, some experience with its re-use has been gained with the generation of large volumes of muck during the construction of new tunnels in the Alpine Region. An investigation carried out at the Gotthard Base Tunnel (Lieb, 2009) analysed spoil recycling for the production of high quality concretes and shotcretes. In this case, a specific testing plan was developed to assess the quality of both the raw material and the concrete mixes produced by evaluating workability time, mechanical properties and durability.

In the Danube Lobau tunnel experience (Schröfelbauer et al., 2009) it was observed that gravel and sands obtained from spoils can be used as aggregate for concrete production or as soil for embankments and subgrades. Silt and clay obtained from excavations can be used instead for embankment filling and backfilling (after suitable drying) depending on their plasticity.

Finally, Burdin and Monin (2009), who worked on material extracted from the shafts of the Lyon–Turin high-speed railway, also remarked on all the different usages for excavated material. Depending on spoil characteristics and on the basis of technical specifications for rock classification, they identified three distinct quality classes. In particular, the classification of excavated materials is useful when selecting material for the production of concrete aggregates (class 1), for the production of soil surrogates for embankments (class 2), and finally for disposal into deposit areas (class 3); similar classifications have been considered by previous authors (Lieb, 2009; Resch et al, 2009; Ritter et al., 2013).

Burdin and Monin (2009) also noted that the extensive recycling of excavated debris could lead to significant benefits including a reduction in the area required for deposit, a reduction in the cost of aggregates and embankment materials and, above all, lower CO_2 emissions.

As a result of the literature review, it can be noted that few past experiences focus on the evaluation of muck as a resource in the construction of infrastructures. Only recent papers focus on the recycling of the most valuable part of mucks, which is normally used solely in the production of cement mixtures, while in only a few cases attention is devoted to the total volume of excavated materials.

Finally, various classification systems are considered in literature. They all subdivide the excavated materials on the base of geological exploration results and on laboratory testing by geologists'. It is worth noting that such classification systems do not consider the standards used to assess the performance of concrete, asphalt and granular materials for pavement and embankment applications (with the sole exception of the Los Angeles test).

2.2. Recycling

The common purpose in the management of large quantities of tunnel muck is their recycling in order to provide surrogate gravel