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Feasibility study of tar sands conditioning for earth pressure balance tunnelling

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A B S T R A C T

This paper presents the results of laboratory test on the feasibility of soil conditioning for earth pressure balance (EPB) excavation in a tar sand, which is a natural material never studied in this respect. The laboratory test performed is based on a procedure and methods used in previous studies with different types of soils, but for this special complex material, additional tests are also conducted to verify particular properties of the tar sands, such as the tilt test and vane shear test usually used in cohesive materials, and a direct shear test. The laboratory test proves that the test procedure is applicable also to this type of soil and the conditioned material can be considered suitable for EPB excavations, although it is necessary to use a certain percentage of fine elements (filler) to create a material suitable to be mixed with foam. The test results show that the conditioned material fulfils the required standard for an EPB application.

1. Introduction

Earth pressure balance (EPB) shield machines have been used for tunnelling excavation in many different types of soils thanks to the use of soil conditioning agents. These agents modify the properties of the soil into that of a plastic paste, thus permitting the homogeneous flow of the excavated soil from the tunnel face through the bulk chamber and the screw conveyor, the optimal control of the face pressure, the creation of spoil suitable to be transported on a conveyor belt, the prevention of water inflow, the reductions of the cutter head and screw conveyor torque and of the friction between metallic parts and the soil and, finally, the reduction of wear (Merritt and Mair, 2006; Vinai et al., 2007; Borio et al., 2010; Thewes and Budach, 2010; Herrenknecht et al., 2011; Barbero et al., 2012; Peila, 2014). Several studies have investigated the possibility of conditioning and the chemical materials to be used in different types of soils, mainly subdivided into three groups: cohesionless soils (sand and gravel), silts and clays, and rock masses. The various researches have set up different laboratory procedures for these achievements before and after soil conditioning, as stated in Peila (2014) and Thewes and Budach (2010) for cohesionless soils, in Thewes and Burger (2005), Zumsteg et al. (2012) and Hollmann and Thewes (2013) for clay, in Peila et al. (2013) and Martinelli et al. (2015) for rock mass.

All these researches suggested that before the EPB shield starts to work, it is strongly recommended to carry out laboratory tests to check if the soil can or cannot be conditioned and to provide an estimate of the conditioning agent types (mainly foam and polymers) and sets. Sometimes the use of fillers is required in order to artificially modify the particle size distribution of the natural soil, thus allowing the conditioning agents to work properly. These fillers are usually bentonite or carbonate submillimetric particles mixed in the soil as slurries.

Excavation through layers of tar sands, which are sandy soils containing a variable amount of hydrocarbons, is a rare but very critical case in some areas in the world, such as in the Metro of Los Angeles, and it has never been studied with reference to the EPB tunnelling conditioning process. Understanding the conditioning of this type of complex material at laboratory scale assumes an interesting scientific and technical aspect. This assessment can be done using as a reference the same procedure used for other types of soils, but taking into account the specificity of this natural material (the hydrocarbon content and its interference with the conditioning agents, influence of temperature, etc.).

The mechanical behaviour of the tar sand is temperature-dependent and its rheology is influenced by the tar content and properties, which can interact with the conditioning material in different ways. Moreover, the infusion of tar reduces the permeability of the material transforming the sand, which can usually be easily mixed with the foam (Milligan, 2000; Merritt et al., 2003; Peila et al., 2007; Vinai et al., 2007; Thewes and Budach, 2010; Zumsteg et al., 2013a, b) into a stronger material similar to a

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Fig. 1. Picture of the soil tested in the laboratory. It is possible to see the sand aggregated in blocky elements.

cold-mix asphalt mixture (Anochie-Boateng and Tutumluer, 2009, 2012). This aspect can be problematic in the conditioning process, since the reduced capability of the material to absorb and to be mixed with liquids and foam prevents the creation of a material suitable for EPB tunnelling, and this is the main goal of the research.

2. Laboratory test

The test methods and interpretation schemes usually used have been updated and improved in this research, and the test procedure has been applied to tar sand samples to check its feasibility.

2.1. Soil tested

The soil tested in the laboratory is a natural sand with a relevant tar infusion (Fig. 1). It was initially tested for bitumen content (AASHTO T 308-10, 2010) which was found to be equal to 13%, while the water content is 1.4%. After separating the bitumen from the sand by burning it in a furnace, washed sieve analysis tests were conducted to determine particle size distributions, as shown in Fig. 2 (ASTM D422-07, 2007). The sand is uniformly graded from fine to medium with particle sizes ranging from 0.01 mm to 5 mm.

2.2. Test procedure

The laboratory studies were carried out on the natural tar sands following an already established procedure (Peila, 2014), but, for this special case, as the temperature at tunnel depth is expected to be up to 45 °C, tests were conducted also on heated material. At this temperature, the natural material becomes more fluid and the cementation effect of the grains is reduced due to the partial melting of the tar in the mass (Fig. 3).

The first step of the research consists of determining the best conditioning parameters through a slump test, which can be assessed by a fall to the cone of the magnitude of 15–20 cm, and a reduced release of water and foam from the mass is required. A comparative table for the qualitative assessment of the mix was developed by Peila et al. (2009), as reported in Fig. 4.

The most important parameters to investigate and assess soil conditioning are: (i) the foam injection ratio (*FIR*), representing the percentage in volume of foam added to the soil; (ii) the foam expansion ratio (*FER*), representing the ratio between the obtained volume of foam and the volume of generation fluid (water + foaming agent); (iii) the percentage of free water added to the material (w_{add}); and (iv) the slurry injection ratio (*SIR*), representing the percentage in volume of slurry/filler added to the soil.

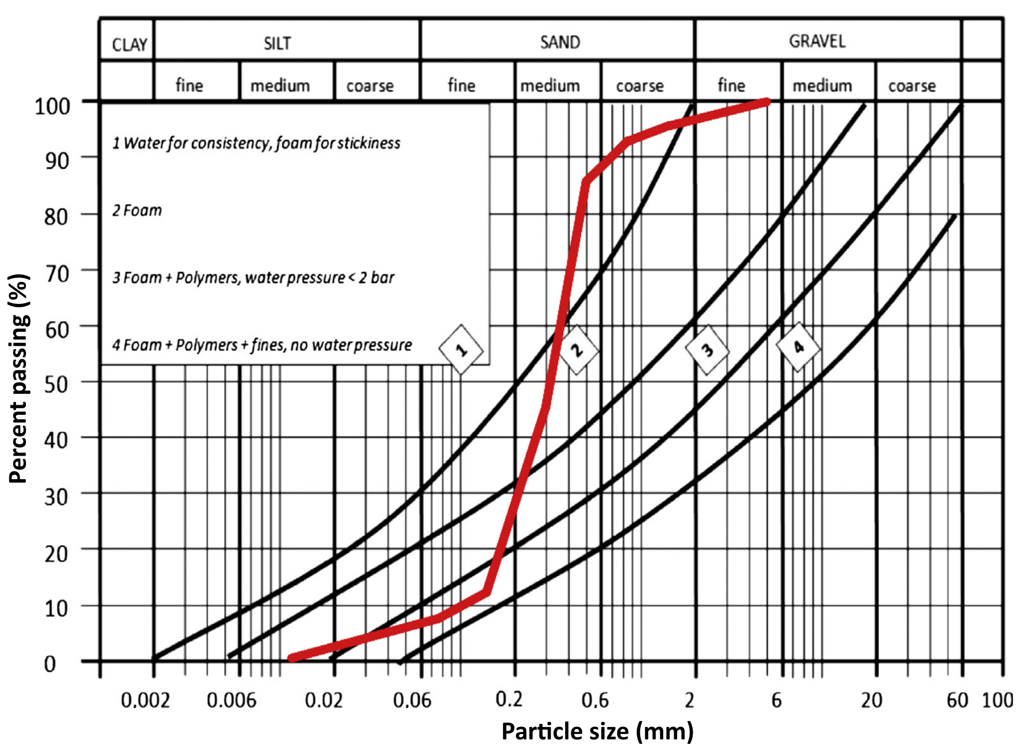

Fig. 2. Particle size distribution of the sand compared with the range of application of EPB (1 bar = 100 kPa) (Herrenknecht et al., 2011).