



Investigation into the effects of two component grout properties on surface settlements



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ABSTRACT

Ground displacement is an inevitable problem in the excavation and construction of tunnels and underground spaces near the surface of the earth. In urban areas, this displacement can affect surface and sub-surface constructs. In fact, there is no possibility of boring underground space and the installation of support systems, simultaneously. Therefore, some ground displacement will happen at the level of the tunnel and eventually this displacement will also lead to surface settlement. Surface settlement becomes more important by reducing the depth of the tunnel. When settlements greater than the limit value are created they can damage surface and subsurface constructs. Therefore, identification of factors affecting the settlement of the tunnel is important and one of these factors is grouting behind the segmental lining of the tunnel. In tunneling by the shield, due to differences in the diameter of cutter head and tail shield, empty space is created around the segmental lining of the tunnel. This void is usually the ratio of the cross sectional area that is being drilled in soil and soft ground and will cause problems such as settlement of surface, displacement and damage to the lining of the tunnel and unsuitable sealing. Therefore, this empty space must be filled immediately after the drilling operation. There are different methods to fill any given empty space. One of them, in excavation by EPB-TBM, is the injection of two component grout with suitable pressure to the back of the segment (simultaneously with moving ahead of the shield of the excavator). Grout used must have the appropriate performance and mechanical properties. There is still no certain standard for the compressive strength of two component grout and the compressive strength of grout proposed is variable with different values in projects and researches. In this study, grout mechanical properties such as compressive strength, modulus of elasticity and Poisson's ratio were studied. Thus, more tests were performed with different proportions of ingredients and finally the effect of each of the components on the properties were examined. Then, to study the effect of the grout properties on surface settlement until introduction of the appropriate amount and compressive strength of two component grout a numerical modeling of Tabriz subway line 2 by FLAC3D software were completed. For this purpose, the results of the laboratory tests for numerical modeling of grout were used in software. Finally, with regard to the obtained numerical results, the conclusion that excessive increased resistance were came and thereby the amount of cement of grout will only result in additional costs and in terms of settlement control has little effect. Therefore, create a grout with resistance as the resistance of the soil is sufficient to fill the empty space and surface settlement control (part of the settlement due to lack of suitable filler material occurs).

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1. Introduction

Growth of the population, the expansion of urbanization and rising living standards lead to traffic problems hence the need for the development of the urban rail transport network increases. Consequently, tunneling in urban areas that mainly consist of soil

materials has become necessary. Hence, with the increased need to build underground projects, it is necessary and essential that tunneling operations be done with minimal impact on urban transportation and construction.

Ground displacement is an inevitable problem in the excavation and construction of the tunnels and the underground spaces near the surface of the earth. In urban areas, this displacement can affect surface and subsurface constructs. Underground space excavation causes the release of in-situ stresses that is only limited by

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the installation of support. In fact, there is no possibility of boring underground space and the installation of support systems, simultaneously. Therefore, some ground displacement will happen at the level of the tunnel and eventually this displacement will also lead to surface settlement. Settlement becomes more important by reducing the depth of the tunnel surface. When the settlements are greater than the limit value they can damage surface and sub-surface constructs. Therefore, identification of the factors affecting the settlement of tunnels is important and one of these factors is grouting behind the segmental lining of the tunnel.

In addition to speeding up the drilling operation, using earth pressure balanced machine (EPBM), reduces the risks of tunnel excavation, especially full face tunnel boring and damage to structures and installations around the tunnel. Nevertheless, there is a concern caused by ground settlement during and after the crossing the shield and the final surface settlement at any point, include aggregation of minor settlements in the drilling cycle. Minor settlement in the drilling process, by basis of the location of the point of the shield, is divided into four main groups (Thewes and Budach, 2009):

1. Settlement before drilling machine
2. Settlement during crossing the shield
3. Settlement caused by empty space at the shield
4. Settlement in the long term

Considering statistical studies, it can be concluded that the maximum settlement among the different stages occurs in case 3. An important factor in controlling the settlement at this stage is the selection of appropriate methods of grouting (Fig. 1).

One of the ways of filling the empty space is the use of two component grout. Two component systems were developed primarily to allow for a very early strength grout so as to provide support to the soil directly behind the TBM Tail Skin. This is achieved by using an accelerator as the second component to speed up the set of the cement based grout. Typically, this mix is a pure grout and does not contain sand or filler. However, bentonite is often used to reduce bleeding in the mix. To control the settlement, the short term compressive strength of two component grout is more important than that of the long term. However, there is still no certain standard for the compressive strength of two component grout and different values have been recommended in projects, papers and researches.

For instance, Phil Anutunes in the mixing technologies team for the compressive strength of two component grout, suggested

quantities such as 0.1–0.3 MPa for one hour, 1.45 MPa for 24 h and 3–1 MPa for 28 days (Fowler et al., 2012). Pellegrini and Perruzza (2009) proposed resistance of more than 0.1 MPa for one hour, more than 0.5 MPa for 24 h and more than 2.5 MPa for 28 days (Pellegrini and Perruzza, 2009). Also based on the TAC grout, Hashimoto et al. (2004) suggested data values in this range. Also, Barnett (2008) offered about 2 MPa for 28 days. According to the mentioned values observed, there is no fixed amount for the compressive strength of two component grout and this value may be changed in accordance with the terms of each project. Consequently, these results and values are obtained by testing and trial and error. However, if a connection between the properties of the excavation area and grout resistance is established then research in this field can be improved. That is the topic discussed in this study and supported by the laboratory studies and numerical modeling.

So far, several studies on ground surface settlement have been conducted with the use of different software. As in all these studies, it is always useful to compare the results of numerical and instrumentation tests. Numerical modeling can be used as a tool for predicting the ground behavior during tunneling operation and its benefits can be noted as the general prediction of ground behavior in various times, places and conditions and also it is low cost.

During the past decades, an increased use of numerical models for the prognosis of the ground behavior, the surface settlements and the loading and deformation of the lining of shield-driven tunnels can be observed. Starting from two-dimensional approaches, see e.g. Finno and Clough (1985), Bernat and Cambou (1998) and Abu-Farsakh and Voyiadjis (1999), several advanced three-dimensional models have been developed in recent years, e.g. by Mansour (1996), Krishna (1998), van Dijk and Kaalberg (1998), Komiya et al. (1999), Dias et al. (2000) and Melis et al. (2002). However, relatively few elaborate and systematic parametric studies that evaluate the influence of the various parameters involved in shield tunneling have been published so far. Finno and Clough (1985) have analysed the effect of the face support pressure of an EPB shield and the influence of the soil stratification on the ground deformations by means of two-dimensional analyses. Using a similar two-dimensional model for tunnel advances in soft soil, Abu-Farsakh and Tumay (1999) have performed parametric studies to determine the effect of the coefficient of earth pressure at rest, the over consolidation ratio, the face pressure and the cover depth on the ground deformations and the excess pore pressures in the soil. Lee and Rowe (1989) have used a two-dimensional finite element model to study the influence of the anisotropy of natural soils on the ground behavior. The three dimensional model

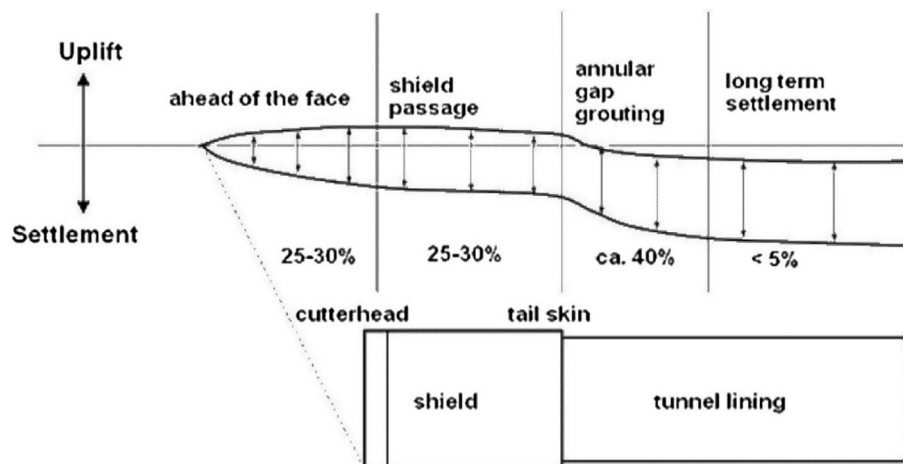


Fig. 1. Schematic development of settlements and percentage of total settlement (Thewes and Budach, 2009).

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