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Geomechanics and Tunnelling Article/Report

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Soil conditioning in EPB Shield tunnelling: an overview of laboratory tests

The application of full face mechanized tunneling, mainly with EPB shielded machines, has widely increased in the last years and today it can be considered the key technology when tunneling in soils above and below the water table. The applicability range of EPB machines has widened thanks on one side to the technological and mechanical progresses and on the other to the quality and effectiveness of the conditioning products. No recognized standards are available for laboratory testing of conditioned soil and each research center has developed its own procedures and methods. In this paper, an overview of the most frequently used procedures is shortly presented and discussed.

Konditionierung von EPB-Schild bei Tunnelbau: Ein Überblick der Labortests

Der Einsatz des vollflächigen mechanisierten Tunnelbaus, vor allem mit EPB-Schildmaschinen, hat in den letzten Jahren stark zugenommen und kann heute als Schlüsseltechnologie beim Tunnelbau in Böden über und unter dem Grundwasserspiegel angesehen werden. Der Anwendungsbereich der EPB-Maschinen hat sich auf einer Seite durch den technologischen und mechanischen Fortschritt und auf der anderen durch die Qualität und Wirksamkeit der Konditionierungsprodukte erweitert. Für Labortests von konditioniertem Boden gibt es keine anerkannten Normen und jedes Forschungszentrum hat seine eigenen Verfahren und Methoden entwickelt. In diesem Beitrag wird ein Überblick über die am häufigsten verwendeten Verfahren gegeben und diskutiert.

Keywords: EPB shield, soil conditioning, laboratory tests

1 Introduction

The continuous growth of EPB shield applications has been made possible by an increase in research on different topics, among which soil conditioning is one of the most important. In EPB tunneling, conditioning agents are mixed with soil through nozzles located on the cutter-head, on the bulk wall and along the screw conveyor to change the mechanical and hydraulic behavior of the excavated soil into that of a plastic paste.

The most important goals of conditioning are:

- to help to apply an homogeneous pressure against the tunnel face;

- to minimize water inflow;

- to create an homogenous flow of the excavated soil through the cutter-head, the chamber and the screw conveyor;

- to guarantee that the screw conveyor is always completely full and acts as a plug;

- to minimize both the cutter-head and the screw conveyor torque and wear;

- to prevent clay clogging.

The used frequently conditioning additives are:

- foam, obtained mixing surfactant, water and air used both in choesionless soils and clay. It is the most frequently used and the most important conditioning agent;

- aggregating polymers used to improve the consistency of the muck in choesionless soils mainly when a reduced amount of fine grains are present;

- adsorbing polymers used to reduce the water content in the excavated material when working below the water table;

- anti–clogging, dispersing and lubricating agents used to avoid amalgamation and stickiness of the clay;

- abrasion-preventers used to reduce wear of the metallic parts of the machines;

- bentonite slurry and fillers used to artificially change the natural grain size curve of the soil mainly in choesionless soils;

- water used both in choesionless soils and in clay (frequently in large quantities).

The parameters used to describe the conditioning with foam are the concentration of surfactant in the generation fluid (c_f), the foam expansion ratio (FER) and the foam injection ratio (FIR), defined, at atmospheric pressure, as:

$$c_f = \frac{V_{Sf}}{V_L} \cdot 100 \qquad (1)$$

$$\mathrm{FER} = \frac{V_F}{V_L} \qquad (2)$$

$$FIR = \frac{V_F}{V_S} \cdot 100 \qquad (3)$$

where V_{Sf} is the volume of surfactant, V_L is the volume of the surfactant solution (water + surfactant), V_F is the volume of the foam at atmospheric pressure and V_S is the volume of the excavated soil. Normally, higher FER (10-15) is suggested to be used when tunneling in sand and gravel while in clays lower FER values are suggested (5-8) while the optimal FIR value has to be determined through specific laboratory test [1]. Information on the properties of the foam (mainly the bubble size and its stability in time) can be found in [2-5]. Mooney et al. [2-3], following previous researches of Bezuijen et al. [6], took into account the effect of the pressure in the chamber, showing that an increase of the pressure reduces both FER and FIR.

For a correct conditioning design, i.e. the choice of the chemical products and its amount, laboratory tests are needed and in the following paragraphs, the most used tests for soil conditioning assessment for cohesionless soils and clays are shortly presented and discussed.

2 Tests on cohesionless soil

2.1 Slump test

The most frequently used test is the slump test, derived from concrete technology (EN 12350-2, ASTM C143). This test assesses the workability of the mix in a simple and cheap way and can also be performed in the machine, on the extracted material. A large number of tests with different soils, foams and water contents have been carried out by many researchers and it has been observed that a direct relationship exists among workability and water and foam contents [6-17]. The drop of the cone and its shape are the test results: a value below 10cm is usually considered too low while above 25cm the mix is considered too fluid. To correctly interpret the tests it is necessary also to check the global behavior of the mass and a design chart is useful, as the one shown in Figure 1. The slump test is also frequently used to study how the properties decay with time (Figure 2) [1]. This test is simple to be executed and cheap therefore a large number of conditioning set could be easily compared furthermore a large data base is available and this helps for an optimal assessment.

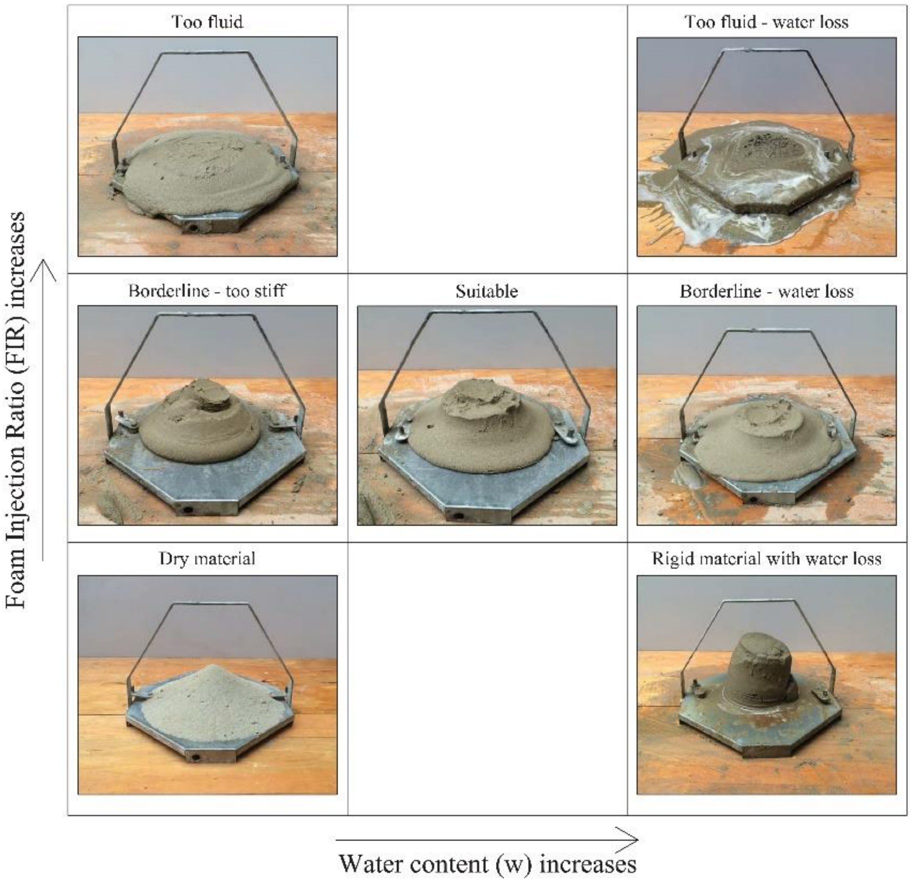

Fig 1 Design chart for conditioning assessment using slump tests [12]

Fig 2 Slump test on the a morenic soil at different times from production (from left: production, 1, 3 and 7 days). It is possible to see the change of behavior with time.

2.2 Permeability test

The permeability of the conditioned soil is important particularly when tunneling below the water table. Budach and Thewes [13] performed permeability tests under constant water head and showed that permeability increases with testing time, due to the removal of the foam from the soil while Borio and Peila [18] proposed a modified permeability test, measuring the time required by a pre-defined amount of water to pass through the soil sample used in the standard device of the permeability test (EN ISO 17892-11). Figure 3 shows that higher foam content increases this time. This test is simple to be executed to compare different conditioning sets. It should be used when large amount of water are expected and no researches are available with high water pressure.

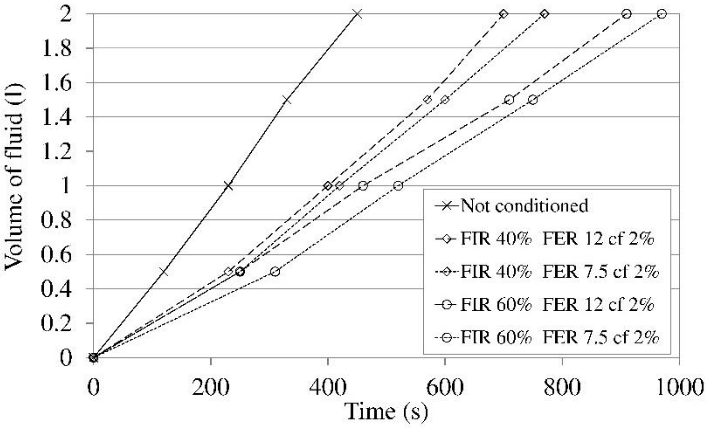

Fig 3 Results of the permeability test on sand (D_{10}=0.08mm; D_{60}=0.2mm; w= 7%): time taken by 2 liters to pass through the sample. A sample well conditioned with FIR=60% it is practically impervious [18]

2.3 Wear tests

The wear of tools, cutter-head and screw conveyor influences the number and duration of maintenance stops. The rock tool wear has been extensively studied and standardized tests have been proposed. Conditioning changes the wear mode, resulting in tools working with a plastic paste which embeds the cutter-head and with the conditioned soil moving along the screw conveyor. Generally recognized tests are not available and researches are working to define indexes able to link the conditioned soil properties with wear.

So far the proposed tests are useful only for comparison of different conditioning sets.

These tests are based on the rotation of metallic elements inside the conditioned soil [19], [20]. Rostami et al. [21] and Jakobsen and Lohne [22] have found that the graph of the wear vs the soil moisture has a bell shape. The effect of soil conditioning on wear has been studied by Jakobsen et al. [23] who proposed a test device where a cross of prismatic bars is rotated in the soil while Barbero et al. [24] used an aluminum disk and measured the lost weight and the torque and Gharahbagh et al. [20] used a different propeller with inclined blades. Onate at al. [25] proposed to use sharp steel blades that are rotated in the soil (Figure 4). Thank to a detailed measurements of the blades shapes before and after the test, these authors obtained a wear index. Even if the initial results of this researchers are promising, definitive conclusions have not been yet obtained.

Many tests have been proposed but no relationships able to link the test results and the expected wear of tools and of the metallic parts of the EPB are available. These tests are useful for a relative comparison of different conditioning sets.

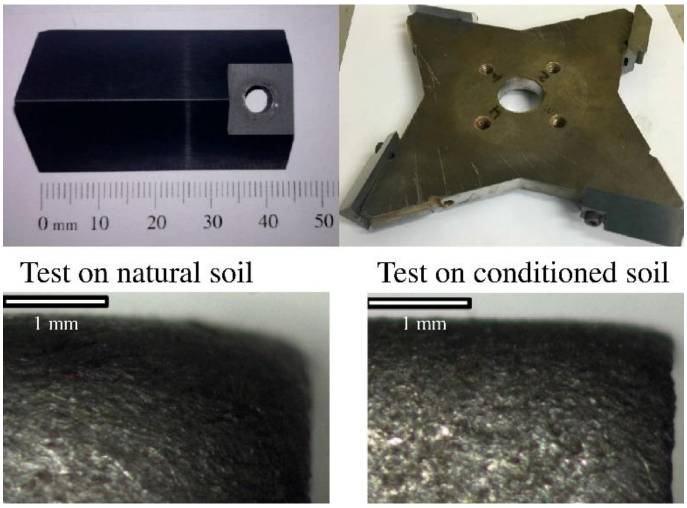

Fig 4 Wear tools used by [25] and picture of the tool cutting edge scanned by video-microscope after the test (magnification: 200×).

2.4 Screw conveyor extraction test

This test evaluates the suitability of conditioned soil to be extracted from a pressurized chamber by a screw conveyor. The first attempt to simulate this condition was done by Merritt and Mair [26] and similar devices have been used by Vinai et al. [10] and Rivas at al. [27] and Li and Tan [28]. The device developed by Vinai et al. [8] is composed of a big tank where the conditioned soil is pressurized and a screw conveyor with an upward inclination of 30° from which it is extracted. The pressure in the soil at the top and at the bottom of the tank and along the screw conveyor and its torque are measured. This test allows to check the feasibility of the extraction of the conditioned soil on a large scale. The conditioning is considered correct when the screw conveyor is able to extract the soil from the tank with a torque that remains more or less constant during the whole test and the pressure registered along the screw conveyor drops in a gradual and consistent fashion toward the outlet. The test is useful to confirm the results of a preliminary slump test campaign to which it should always be combined.

2.5 Shear, rheometer and flow tests

The shear and rheological behavior of the conditioned soil influence the extraction process. To evaluate these parameters both vane test [29-33] and direct shear tests [9, 34] have been performed. Martinelli et al. [34] used a modified undrained direct shear box and demonstrated that a good conditioning reduces the shear strength of the mix. Galli and Thewes [11] studied the rheology of the mix using a rotational rheometry device and obtained results consistent with those of [34]. Recently, Carigi et al. [35] studied the flow of a conditioned soil with cobbles using the test device of Figure 5 and developed assessment indexes. These tests are useful for a comparison of different conditioning sets.

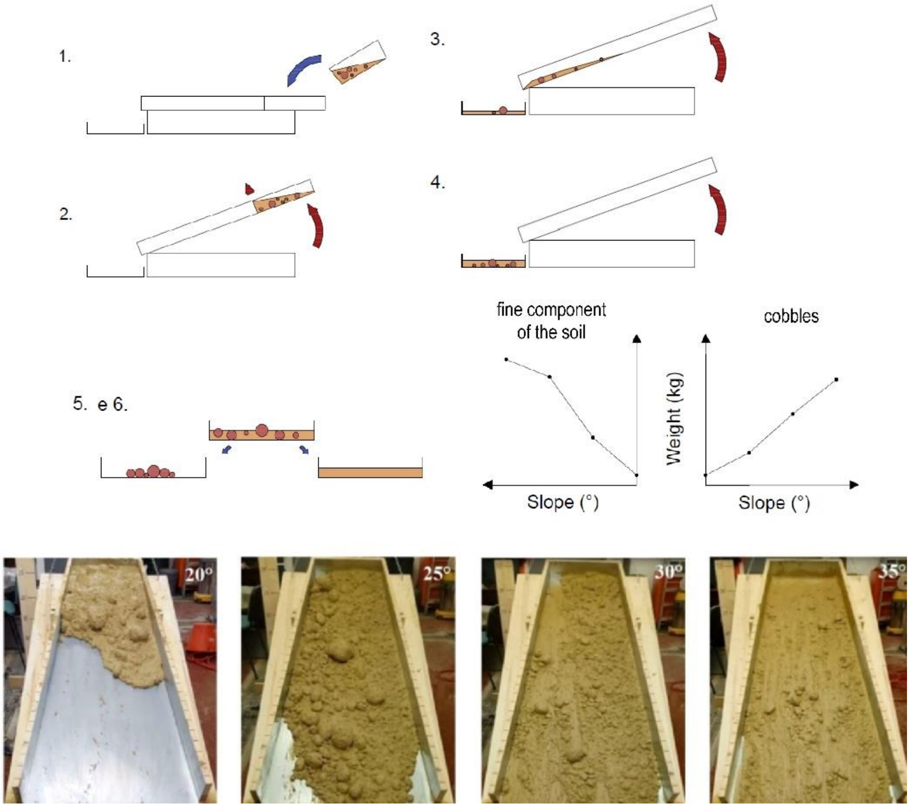

Fig 5 Scheme of the tilt sliding test [35]. The cobbles and the fines are collected at the bottom and weighted for each inclination angle.

2.6 Pressurized tests

Since EPB machines can work with a high pressure up to 6-7 bar, some researchers tested the behavior of the conditioned soil under pressure. In these conditions, the mix changes its behavior because the bubbles reduce their size and, consequently, their effectiveness in reducing the shear strength. Zumsteg et al. [29], Ptomas [30] , Mooney et al. [3], Mori et al. [36] and Meng at al. [31], Yi et al. [33] evaluated the shear strength, the compressibility of the soil and the void index in pressurized chambers.

Large-scale pressure tests were proposed by Thewes and Steep [37] and Martinelli [38]. The latter measured the torque on blades rotating in a pressurized tank filled with soil (Figure 6). Figure 7 shows the results of a test carried out with this device on a sand: the torque for conditioned soil is much lower than that of the wet soil and remains quite constant up to a threshold pressure, after which it increases. This confirms that when the bubble size reduces due to higher pressure the stiffness of the soil increases.

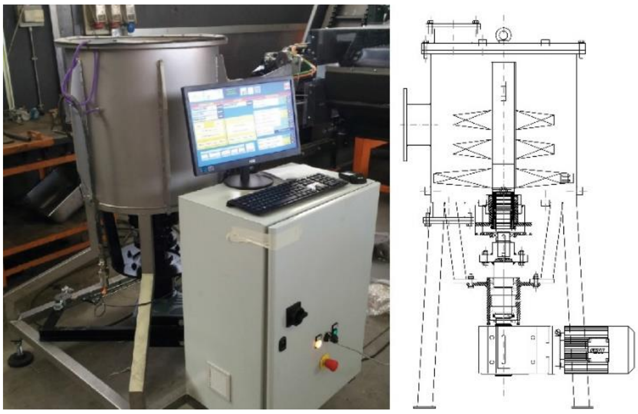

Fig 6 Device used for large scale pressure test [38]. The sizes of the tank are height=613mm, diameter=600mm.

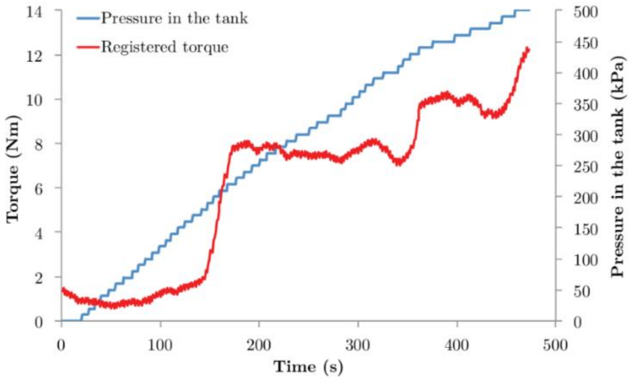

Fig 7 Measured torque on the blades increasing the pressure on a sand (D_{10}=0.1mm; D_{60}=0.2mm) conditioned with FER=15; FIR=80%, c_f=2% and w=20% [38].

To study the mechanical behavior of soil before and after conditioning Martinelli et al. [39] used a large scale triaxial device able to test samples with a diameter of 300mm and a height of 600mm (Figure 8). They observed that the conditioned soil behaves like a fluid at low confinement pressure because foam limits mutual contact between the grains, increasing the pressure the material becomes stiffer and the shear strength increases, the preliminary results of the test performed on the same sand used for the tests of Figure 7 are consistent. This test is a research one and it cannot be used for standard procedures for soil conditioning assessment.

3 Tests on clay

Clay clogging and adhesion are the phenomena that occur when the openings in the cutter-head are plugged and steel surfaces are covered by clay while re-aggregation occurs when the clay clumps create a new mass inside the chamber [40-47]. These phenomena are negative for EPB tunneling. So far, evaluation of the clogging potential is based on the clay properties, such as plasticity and consistency indexes.

Fig 8 Picture of the triaxial test device and example of the sample at failure after the triaxial test with extension unloading [39].

In clay, the most used conditioning agents are foam and, usually a high quantity of water. However, since foam has a reduced effect on clogging, it is usually combined with polymers able to lubricate the clay, to minimize the stickiness and to act as clay dispersing agent [46]. Several test methods have been developed based on powdered clay samples mixed with the conditioning agents. This assumption is acceptable to study problems related to small-scale adhesion but during the excavation both clay chips and clay powder are produced. For this reason, the study of clay conditioning should be developed taking into account both powdered material and clay chips as done by Peila et al. [48] and by Olivera et al. [49-50].

Furthermore it is important to highlight that some of the test methods previously described for the study of cohesionless soils can be also applied to clay, such as the slump test, the screw conveyor extraction test and the vane shear test. However, the slump test does not give any indication about the clogging but it only provides a global overview of the behavior of the conditioned mix (Figure 10) while the screw conveyor extraction test give a clear indication if the soil is properly conditioned or not and if clogging phenomena could occur during the extraction process.

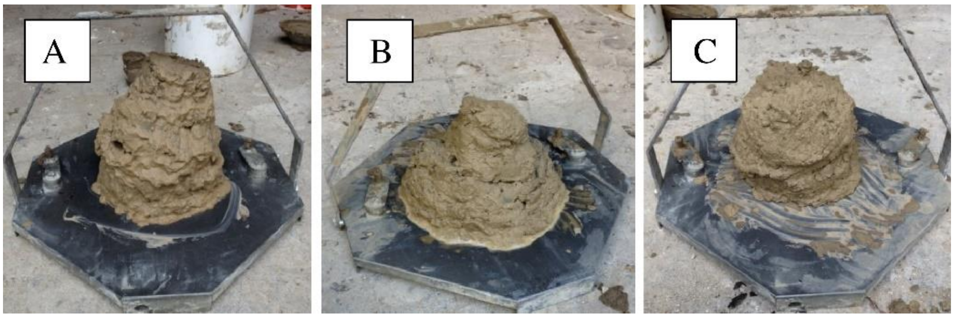

Fig 10 Slump tests of a sticky clay (natural water content=20%; LL=65% and PL=23%) at different conditioning sets: A) Foam (FIR=60% ; FER 5.5) and no added water; B) Foam (FIR=60%; FER 5.5) + 5% of added water with lubricating polymer (c_p=0,1%); C) Foam (FIR=60% ; FER 5.5) + 5% of added water with disaggregant polymer (c_p=0,1%)

3.1 Adhesion tests on powdered clay

The assessment of clogging is usually done measuring the adhesion of the clay on a steel element associated with sliding. Zumsteg and Puzrin [40] evaluated the sliding resistance of a metallic disc rotating into a box filled with soil while Feinendegen et al. [51] used the cone pull-out test. Other authors proposed to measure the amount of clay that remains adhered to the mixing element during clay conditioning. The Hobart mixer has been used by [40], [49] and [50]. For powdered clay tests it is also often used the mini flow test while some researchers combine small slump test and the flow table measuring the height and diameter variation of the cone after a certain number strokes [36].

4 Conclusions

The research carried out in the last ten years on soil conditioning allowed to develop different laboratory tests and to enhance the effectiveness and the quality of the conditioning technology. While some tests are nowadays widely recognized, others are still at a research stage. Moreover, it is important for designers to know the possibility offered by the laboratories and which information can be obtained before starting an EPB tunneling project.

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Bibliography

[1] *Peila, D., Oggeri, C., Borio, L.:* Using the Slump Test to Assess the Behavior of Conditioned Soil for EPB Tunneling. Environ. Eng. Geosci. 15 (2009), S. 167–174.

[2] *Wu, Y., Mooney, M.A., Cha, M.:* An experimental examination of foam stability under pressure for EPB TBM tunneling. Tunn. Undergr. Sp. Tech. 77 (2018), S. 80–93.

[3] *Mooney, M., Wu, Y., Mori L., Bearce R., Cha M.*: Earth Pressure Balance TBM soil conditioning: It's about the pressure. WTC2016, San Francisco (2016), S. 2433-2444.

[4] *Sebastiani, D., Vilardi, G., Bavasso, I., Di Palma, L., Miliziano, S.:* Classification of foam and foaming products for EPB mechanized tunnelling based on half-life time. Tunn. Undergr. Sp. Tech. 92 (2019).

[5] *Tao, L., Chen Z., Cui, J. Wang, H., Fang Y.:* Experimental methods to assess the effectiveness of soil conditioning with foam in fully weathered granite. Advances in Materials Science and Engineering, Hindawi (2019) (article ID 9046704)

[6] *Bezuijen, A., Schaminee, P., Kleinjan, J.:* Additive testing for earth pressure balance shields. 12th European Conf. on Soil Mech. and Geotech. Eng. (1999).

[7] *Quebaud, S., Siba, M., Henry, J.:* Use of Chemical Foam for Improvements in Drilling by Earth-Pressure Balanced Shields in Granular Soils. Tunn. Undergr. Sp. Tech. 13 (1999), S. 173–180.

[8] *Jancsecz, S., Krause, R., Langmaack, L.:* Advantages of Soil Conditioning in Shield Tunneling. Experiences of LRTS Izmir. Cong. Challenges for the 21st Century (1999), S. 865–875.

[9] *Pena, M.:* Soil conditioning for sands. T&T Int. 35 (2003), 40–42.

[10] *Vinai, R., Oggeri, C., Peila, D.:* Soil conditioning of sand for EPB applications : A laboratory research. Tunn. Undergr. Sp. Tech. 23 (2008), S. 308–317.

[11] *Galli, M., Thewes, M.:* Rheological Characterisation of Foam-Conditioned Sands in EPB Tunneling. Int. J. Civ. Eng. 17 (2019), S. 145–160.

[12] *Martinelli, D., Peila, D., Campa, E.:* Feasibility study of tar sands conditioning for earth pressure balance tunnelling. Journal of Rock Mech. and Geotech. Eng. 7 (2015), S. 684–690.

[13] *Budach, C., Thewes, M.:* Application ranges of EPB shields in coarse ground based on laboratory research. Tunn. Undergr. Sp. Tech. 50 (2015), S. 296-304.

[14] *Zhao, B., Liu, D., Jiang, B.:* Soil Conditioning of Waterless Sand–Pebble Stratum in EPB Tunnel Construction, Geotech Geol Eng (2018) 36. S. 2495–2504

[15] *Wangm S., Lu, X., Wang X., He ,Xin X., Ruan, L., Jian, Y.:* Soil improvement of EPBS construction in high water pressure and high permeability sand stratum, Hindawi, Advances in Civil Engineering, 2019 (Article ID 4503219).

[16] *Ye, X., Wang, S., Yang, J., Sheng, D.*: Soil Conditioning for EPB shield tunnelling in argillaceous siltstone with high content of clay minerals: case study, Int. J. of Geomech. (2017), 17.

[17] *Kim, T., Kim, B., Lee, K., Lee I.*: Soil conditioning of weathered granite soil used for EPB Shield TBM: a laboratory scale study, KSCE (2019), 23(4), S. 1829-1828

[18] *Borio, L., Peila, D.:* Study of the Permeability of Foam Conditioned Soils with Laboratory Tests. American J. of Environmental Sciences 6 (2010), S. 365–370.

[19] *Nilsen, B., Raleigh, P.:* New Test Methodology for Estimating the Abrasiveness of Soils for TBM tunneling. RETC 2007, (2007), S. 104–116.

[20] *Gharahbagh, E. A., Rostami, J., Talebi, K.*: Experimental study of the effect of conditioning on abrasive wear and torque requirement of full face tunneling machines. Tunn. Undergr. Sp. Tech. 41 (2014), S. 127–136.

[21] *Rostami, J., Alavi, E., Palomino, A.M., Mosleh, M.:* Development of soil abrasivity testing for soft ground tunneling using shield machines. Tunn. Undergr. Sp. Tech. 28 (2012), S. 245–256.

[22] *Jakobsen, P. D., Lohne, J.:* Challenges of methods and approaches for estimating soil abrasivity in soft ground TBM tunnelling. Wear (2013), S. 166–173.

[23] *Jakobsen, P. D., Langmaack, L., Dahl, F., Breivik, T.:* Development of the Soft Ground Abrasion Tester (SGAT) to predict TBM tool wear, torque and thrust. Tunn. Undergr. Sp. Tech. 38 (2013), S. 398–408.

[24] *Barbero, M., Peila, D., Picchio, A., Chieregato, A., Bozza, F., Mignelli, C.:* Procedura sperimentale per la valutazione dell'effetto del condizionamento del terreno sull'abrasione degli utensili nello scavo con EPB. GEAM 135 (2012), S. 13–19.

[25] *Oñate Salazar, C., Todaro, C., Bosio, F., Bassini, E., Ugues, D., Peila, D.:* A new test device for the study of metal wear in conditioned granular soil used in EPB shield tunneling. Tunn. Undergr. Sp. Tech. 73 (2018), S. 212–221.

[26] *Merritt, A. S., Mair, R. J.:* Mechanics of tunnelling machine screw conveyors: model tests. Géotechnique 56 (2006), S. 605–615.

[27] *Rivas, J., Jiménez, A., Videra, O., Gégout,P., Vallon, F., Pegon,J.:* Reducing the environmental impact of tunnel boring (OSCAR), Technology Innovation in Underground Construction (2009), S. 239–259.

[28] *Li, X., Tan, N.*: Calculation model of the equivalent spiral shear stress of conditioned sand. PLoS ONE (2019), 14(3), e0212923

[29] *Zumsteg, R., Messerklinger, S., Puzrin, A.M., Egli, H., Walliser, A.:* Pressurized vane shear test for soil conditioning. 17th Int. Conf. on Soil Mech. and Geotech. Eng. (2009) S. 275–278.

[30] *Psomas, S.:* Properties of foam/sand mixtures for tunnelling applications. PhD Thesis, University of Oxford, 2001.

[31] *Meng, Q., Qu, F., Li, S.*:Experimental investigations on viscoplastic parameters of conditioned sands in earth pressure balance shield tunnelling. J. of Mech. Science & Technology. (2011), 25 (9). S. 2259-2266

[32] *Copur, H., Avunduk, E., Tolouei, S.:* Possibility of using vane shear testing device for optimizing soil conditioning. WTC 2019, Neaples (2019) S. 1954–1963.

[33] *Yi, Y., Xinggao, L., Xingchun, L.*: Shear Strength and Compression Coefficient for Conditioned Sand Subjected to Earth Chamber Stress Levels, Advances in Materials Science and Engineering - Hindawi (2018) (paper ID 1759151).

[34] *Martinelli, D., Winderholler, R., Peila, D.:* Undrained behaviour of granular soils conditioned for EPB tunnelling – A new experimental procedure. Geomechanics and Tunnelling 10 (2017) S. 81–89.

[35] *Carigi, A., Luciani, A., Martinelli, D., Todaro, C., Peila, D.:* Tilt sliding test to assess the behaviour of conditioned soil with large amount of cobbles. WTC 2019, Neaples (2019).

[36] *Mori, L., Mooney, M., Minsu, C.*: Characterizing the influence of stress on foam conditioned sand for EPB tunnelling. Tunn. Under. Sp. Tech. 71 (2018) S. 454-465

[37] *Thewes, M., Steeb, H.:* Modellbildung für das Stützmedium aus konditioniertem Lockergestein beim Vortrieb mit Erddruckschilden. Interaktionsmodelle für den maschinellenTunnelbau. Ruhr-Universität, Bochum (2014) S. 95–112.

[38] *Martinelli, D.:* Mechanical behaviour of conditioned material for EPBS tunnelling. PhD Thesis, Politecnico di Torino, 2016.

[39] *Martinelli, D., Todaro, C., Luciani, A., Peila, D.:* The use of large triaxial cell for testing conditioned soils for EPBS tunneling. Tunn. Undergr. Sp. Tech. (submitted) (2019).

[40] *Zumsteg, R., Puzrin, A. M.:* Stickiness and adhesion of conditioned clay pastes. Tunn. Undergr. Sp. Tech. 31 (2012), 86–96.

[41] *Hollmann, F. S., Thewes, M.:* Assessment method for clay clogging and disintegration of fines in mechanised tunnelling. Tunn. Undergr. Sp. Tech. 37 (2013), 96–106.

[42] *Thewes, M., Burger, W.:* Clogging of TBM drives in clay – identification and mitigation of risks. WTC 2015, Dubrovnik (2015). 737-742.

[43] *Alberto-Hernandez, Y., Kang, C., Yi, Y., Bayat A.*: Clogging potential of tunnel boring machine (TBM): a review, Int. J., Geotech. Eng. 12:3, S. 316-323

[44] *Thewes, M., Hollmann F.*: Assessment of clay soils and clay-rich rock for clogging of TBMs, Tunn. Undergr. Sp. Tech. 57 (2016), 122-128.

[45] *Tokgöz, N.*: An assessment method for fine-grained sedimentary materials excavated by EPB TBM, Geomechanik und Tunnelbau 9(4) (2016). S.326-337

[46] *Thewes, M.:* Adhäsion Von Tonböden Beim Tunnelvortrieb Mit Flüssigkeitsschilden, *21. Berichte aus Bodenmechanik und Grundbau der Bergischen Universität Wuppertal,* Fachbereich Bauingenieurwesen, Aachen: Shaker Verlag (1999).

[47] *Liu. P., Wang, S., Ge, L., Thewes, M., Xia, Y.*: Changes of Atterberg limits and electrochemical behaviors of clays with dispersants as conditioning agents for *EPB* shield tunnelling, Tunn. Undergr. Sp. Tech. 73 (2018), 244-251

[48] *Peila, D., Picchio, A., Martinelli, D., Dal Negro, E.:* Laboratory tests on soil conditioning of clayey soil. Acta Geotechnica 11 (2016), 1061–1074.

[49] *Oliveira, D., Thewes, M., Diderichs, M., Langmaack, L.:* Proposed methodology for clogging evaluation in EPB machines. WTC2018, Dubai (2018).

[50] *Oliveira, D., Diderichs, M., Thewes, M.:* EPB excavation of cohesive mixed soil: combined methodology for clogging and flow assessment. WTC2019, Naples, (2019).

[51] *Feinendegen, M., Ziegler, M., Spagnoli, G., Fernández-Steeger, T., Stanjek, H.:* A new laboratory test to evaluate the problem of clogging in mechanical tunnel driving with EPBshield. Rock Mechanics in Civil and Environmental Engineering (2010).

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