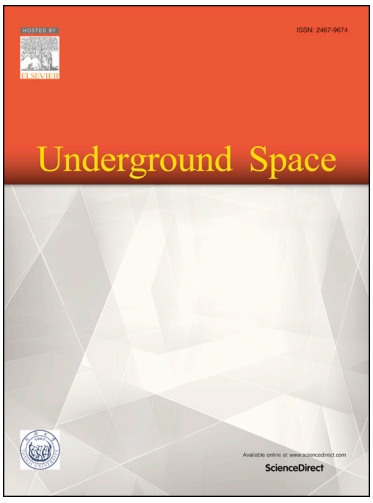

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A hypoplastic particle finite element model for cutting tool–soil interaction simulations: Numerical analysis and experimental validation

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Abstract

This study presents numerical and experimental models for the analysis of the excavation of soft soils by means of a cutting tool. The computational model is constructed using an Updated Lagrangean (UL) velocity-based Finite Element approach. A hypoplastic formulation is employed to describe the constitutive behavior of soft soils. Large displacements and deformations of the ground resulting from the cutting tool–soil interaction are handled by means of the Particle Finite Element method, characterized by a global re-meshing strategy and a boundary identification procedure called α-shape technique. The capabilities and performance of the proposed model are demonstrated through comparative analyses between experiments and simulations of cutting tool–soft soil interactions. The experiments are performed using an excavation device at Ruhr-Universität Bochum (RUB), Germany. The main details concerning the setup and calibration and evolution of the measured draft forces are discussed. Selected computational results characterizing the cutting tool–soft soil interaction including the topology of the free surface, void ratio distribution ahead of the tool, spatio-temporal evolution of the reaction forces and abrasive wear behavior are evaluated.

Keywords: Velocity-based Finite Elements formulation, hypoplasticity, large deformations, Particle Finite Elements, cutting tool–soil interaction, excavation experiments

1. Introduction

Earth Pressure Balance (EPB) shield tunneling is a suitable alternative when dealing with mechanized soft soil excavations in complex geotechnical conditions and strict operational constraints. EPB Tunnel Boring Machines (TBMs) control the face support pressure by regulating the flow of excavated material through the screw conveyor [1]. For coarse-grained soils, foam-conditioning agents [2, 3] are injected ahead of the cutting face for the improvement of the soil mixture properties [1].

During the tunnel face excavation with an EPB machine, a complex interaction develops between the soft ground of the face and the excavation tools mounted at the front of the cutter wheel (see Figure 1). The excavated material, already conditioned with foaming agents, undergoes a transition from a solid-like to a fluid-like behavior. The systematic and comprehensive treatment of the underlying physics behind this material transformation and the soil–structure interaction problem in general, is still an open research topic. Different numerical methodologies [4, 5] have been proposed for the investigation of TBM mechanized excavations in soft grounds.

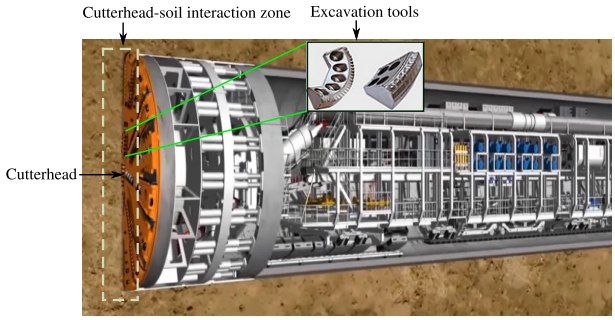

Figure 1: Machine-driven excavations in soft soils: relevant components involved in the cutterhead–soil interaction.

The interaction between the excavation tools mounted at the cutting wheel and the tunnel face can be compared to the problem of soil cutting often encountered in earth-moving operations and soil tillage. During soft soil tillage operations, the ground is broken and loosened [6]. Analytical tillage models have been proposed in [7, 8, 9] for the estimation of the tool total force required for the soil mass to fail. In [7], by assuming a complete failure of the soil, a single force equation taking into account the soil strength (in terms of cohesion and friction angle parameters), self-weight of the failed mass, tool–soil interface friction and any surcharge applied on the free surface was proposed.

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