Computational Modeling in Mechanized Tunneling: From numerical simulation to computational steering

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The ever-increasing power and efficiency of modern computer technology and the considerable progress in computational mechanics have stimulated the development of numerical models in tunneling which are widely used for tunnel design. Over the long term, the use of these models will increase the efficiency of today's tunnel engineering work flows.

The mechanized tunneling is a well established and flexible technology in particular in urban areas, which allows for tunnel advances in a wide range of soils and difficult conditions such as high ground water pressures, soft soils or small cover depths. In soft, partially or fully saturated ground conditions, the tunnel construction process causes short and long term ground deformations resulting from the disturbance of the virgin stress state of the soil and the changing pore water conditions due to the heading face support, the shield skin friction and the gap grouting. In each stage of the construction process, interactions between the construction process, the soil and existing building infrastructure in urban areas, resulting in ground deformations and possible damage of existing buildings, need to be evaluated to limit the risk of damage on existing buildings and to decide on appropriate mitigation measures. To this end, realistic, numerical models that consider the interactions between the TBM tunneling process, the soil and existing surface structures and their foundations during the complete construction process are required.

In the presentation, recent advances in the process-oriented computational simulation of shield supported tunnel excavation in partially and fully saturated soft soils in urban areas is presented. The finite element model takes into account all relevant components involved in shield tunneling such as the TBM, the hydraulic jacks, the frictional contact between the shield skin and the soil and the supporting measures at the face and the tail gap, respectively, and their interactions. In the presentation, various specific aspects of large scale analysis of the TBM process in soft, partially and fully saturated soils are addressed. The simulation of the advancing process for arbitrary alignments requires a continuous adaption of the finite element mesh in the vicinity of the tunnel face in conjunction with a steering algorithm for the TBM advance and appropriate algorithms for the transfer of internal variables. A new technique to automatize the process of mesh generation utilizing a hybrid mesh approach in which a new computational mesh in the vicinity of the tunnel face will be automatically generated within the advancing process, is introduced. With regards to consideration of temporary face support, in addition to more standard hydro- and earth-balance pressure shields also the modeling compressed air support and artificial soil freezing are briefly addressed.
Additional computational aspects addressed in the presentation are concerned with the modeling of pile foundations by means of applying contact formulations onto pile elements, which may be arbitrarily embedded within the soil elements and the analysis of the interactions between the piles and the construction process. In addition, several parallelization techniques have been investigated to reduce the computing times in large scale tunneling simulations. A parallelization concept for distributed memory computers by means of the Trilinos libraries is presented as well as an openCL-based implementation for GPGPU systems. A comparative study reviews the parallel efficiency of different linear solvers and assembling procedures for the finite element model with respect to both speedup and applicability for the simulation of highly demanding numerical models in geotechnics and tunneling.

The integration of construction process and numerical simulation in tunneling represents a major challenge to current research in the field of Computational Engineering. The key concept of this integration is "Computational Steering" where the interactive modification of parameters during the runtime of a simulation is required. This enables the engineers on the construction site to modify the input parameters of the simulated process and study its reaction 'on-the-fly'. Therefore, a surrogate model based on an Artificial Neural Network Model, which is trained by means of the full scale computational model for a certain tunneling section, has been developed. First results obtained by means of this meta model are presented in comparison with the original response of the finite element model.