8.1 Summary

In the first part of this thesis, selected aspects of mechanized tunneling process are introduced as a basis for simulating the shield supported tunnel construction process. The literature provides different computational models with various assumptions and modeling schemes. The effectiveness of these models depends on its capability to replicate the real conditions. In this context, the simulation model ekate is used for the process oriented analyses, in which, the shield advancement is realized by means of an automatic steering algorithm. For an automatized process for the generation and execution of finite element simulations, the simulation model has been incorporated into the so-called Tunneling Information Model (TIM), which is a Building Information Modeling (BIM) based product model that has been developed in the context of the German Research Foundation funded Collaborative Research Center 837. The applicability and the effectiveness of the proposed framework to automatically generate a fully 3D finite element model have been demonstrated by means of two reference projects. The presented case studies reveals the merits of the proposed approach and shows that it is feasible to conveniently perform an automatic numerical simulation for a tunneling project with minimum user intervention.

With respect to segmental tunnel lining analysis, traditional analysis methods generally use simplified structural models that attain simplified loading assumptions. Consequently, such models can only serve to provide first-order estimates of the structural forces in tunnel lining. A review of the structural models that are used in design is provided, as well as the various loading assumptions that leads to a range of design structural forces. Throughout the discussion presented in this work, it becomes apparent that more detailed models need to be considered in order to accurately identify the underlying factors that control segmental lining response and to be able to determine which simplifications can be made without influencing the model accuracy. To this end, a detailed analysis of segmental tunnel lining is performed within the simulation model ekate to accurately account for the actual loading on the lining. In addition, the interactions between the segments at the longitudinal and ring joints, are modeled by means of frictional contact to better capture the lining
kinematics. Furthermore, the mutual interactions between the segments along the joints, the interactions of the lining with the grouting material as well as the surrounding ground are accounted for realistically. The consideration of the initially fluid like grouting material and its hydration induced stiffening, as well as the consolidation processes of the saturated soft soils, enhances the capability of the model to provide realistic insights in the spatio-temporal loading on the tunnel linings during the simulation of the mechanized tunneling process.

Finally, extension to the use of the computational framework is demonstrated by advanced applications that are occasionally encountered during tunneling. The simulation model is used to evaluate the tunnel-building interaction. This is of great interest in urban tunneling, especially when historical or other important buildings are influenced. To this end, an approach for the damage assessment of the existing surface structures, considering different level of details of their structural components, is presented. This approach provides a flexible damage assessment concept that can be adopted during the planning phase. For the case of high risk of building damage, additional countermeasures are required. In order to address this issue in the framework of the numerical simulations, a coupled thermo-hydraulic formulation is introduced to model Artificial ground freezing. In addition, the influence of groundwater flow on the freezing arch formation is examined and an optimization solution for the freezing pipes’ position is provided based on the Ant Colony Optimization.

8.2 Conclusion

8.2.1 Segmental Lining Analysis

The simulation model has been used to predict the ground deformation and loading on lining, as well as the normal forces and bending moments induced by the construction process and the surrounding soil. Results from the parametric study in chapter 4 have shown that the model is able to provide detailed insights into the loading during construction with respect to various geotechnical and constructional aspects. It was demonstrated that the steering gap resulted from shield overcut and conicity have a significant influence on the redistribution of stresses in the tunneling vicinity and therefore, the predicted loads and the structural forces. It should be noted that such geometrical parameters can not be considered in the classical lining models. The ground water level and the lateral earth pressure coefficient affect the lining response, in particular the predicted bending moments. In general, based on the model assumptions, these lining forces and deformations are obtained from a simulation procedure that stays in line with the actual construction process.

With respect to joint response, a penalty based frictional contact algorithm was used to describe the contact between consecutive rings and between segments, this provides an explicit representation of lining joints. The proposed computational model was successfully validated by numerical simulations of a single joint and a full ring test. It was shown that the classical contact mechanics can be used successfully to characterize the lining joints.

By the developed segmental lining model in ekate, it was shown that the application of grouting pressure at the tail of the machine provides a hydrostatic state of stresses, which provides sufficient compressive forces in the lining leading to a higher joint stiffness. With the advancement of the shield and the erection of new lining rings, the dissipation of the grouting pressure behind