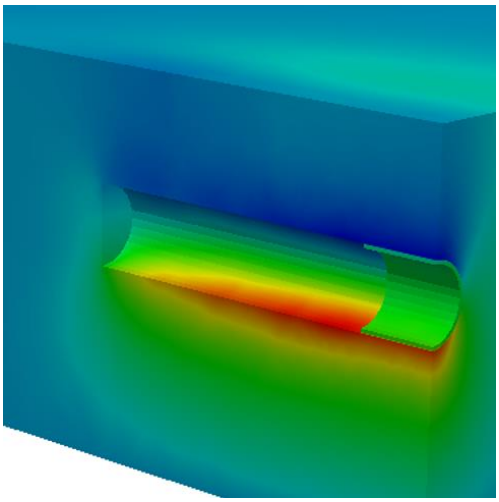
Development of a FEM code for 3D tunnel simulation

Project summary



Client:	SWS Engineering Spa
Partner:	-
Year:	2015-2017
Service:	Scientific Software Development
Sector:	Geomechanical Engineering
Project in numbers:	5340 line of code, 2.000.000+ number of elements
Coding language:	Fortran90
Other details:	Drucker-Prager, Mohr Coulomb, Cam Clay Constitutive material law.

Abstract

The aim of the project is to develop a 3D Finite Element code specifically tailored for the numerical simulation of a tunnel excavation process. The code has been developed according to the specific requirements of the client. The code allows for an effective and fast simulation of a tunnel excavation in heterogeneous media, predicting the effects on the ground surface (land subsidence, surface differential displacements, building damages) and the local stress concentrations along the excavation path.

The development of this code has been a part of the Smart Tunneling Project, financed by SWS Engineering e the Provincia Autonoma di Trento.

Project description

In recent years, the number of new tunnels is worldwide constantly increasing. Several reasons motivate the construction of new tunnels: new subway lines and other urban transportation systems, new high-speed railway lines, new facilities for water supplies, just to name a few.

The design and the construction of tunnels set relevant issues, especially for shallow tunnels in urban environment. The main problems concern the evaluation and the control of ground settlements, the assessment of the deformations and the stability of the excavation front, the analysis of loads and stresses in the lining. A correct analysis of all these aspects is of paramount importance, first to avoid economic, environmental and social risks, second to avoid interruption in the drilling process with consequent time increasing.

Numerical simulations, in particular 3D modelling, are a fundamental tool to predict the mechanical behavior of the soil/rock and the interaction between the soil/rock and the tunnel.

To address the aforementioned aspects, M3E developed a specific software especially tailored for tunnel problems. The software combine the experience gained by the team in the field of geomechanics with the experience in numerical linear

algebra. The result is an efficient instrument, ideal for geotechnical companies interested in accurate simulation of tunnel excavation.

The software is composed by two parts, which are briefly presented, namely:

- Tunnel Generator (TG)
- Tunnel Simulator (TS)

Tunnel Generator

The TG is a parametric pre-processor software. Its goal is the creation of the 3D finite element grid for the simulation of the tunnel excavation. Few simple input data are required (DTM surface, stratigraphy, longitudinal axis of the tunnels and progressive tunnel sections). The software automatically generates the Finite Element domain, by means of tetrahedral elements.
The key feature of the software relies in the parametric architecture, that avoids the use of a CAD engine and allows for an easy and fast domain generation. Since the code has been fully developed by M3E, the software can be tailored according to the customer's requirements.

Main features:

- General stratigraphy of the soil/rock defined by points and/or surfaces.
- General horizontal and vertical variation of the tunnel's axis defined by points.
- General tunnel section defined by parameters (radius, length, etc.) or by points.
- Multiple tunnel.
- Optimized mesh algorithm and user defined size of elements.
- Efficient algorithm that extremely reduces the time needed for the domain creation and for the mesh generation.

Tunnel Simulator

The TS is a non-linear finite element software, especially developed to simulate the excavation of tunnels. The perforation of the tunnel is simulated step by step: first the soil/rock is removed, then frontal and lateral pressures are applied, and finally the elements corresponding to the reinforcement of the tunnel are activated. The program is based on the following libraries:

- M3E_GeoStruct Library, a finite element library developed by M3E for geomechanical problems.
- M3E_LinSolver Library, a linear solver library developed by M3E for solving large sparse linear systems on high performance computers.

Since the code has been fully developed by M3E, the software can be tailored according to the customer's requirements. The code can compute the evolution of displacements, deformations and stresses depending on the progression of the tunnel excavation.

Main features:

- General procedure to define the progress of the excavation.
- General procedure to define the pressure applied to the faces of the tunnel.
- Simulation of the liner.
- Several constitutive laws (Elastic, Elasto-plastic, Hypoelastic).
- Fully parallelized code

Reference

[1]Lu, X. L., F. D. Li, and M. S. Huang. "Numerical simulation of the face stability of shield tunnel under tidal condition." Tunneling and Underground Construction. 2014. 742-750.

[2]Zhao, Kai, et al. "3D simulation of TBM excavation in brittle rock associated with fault zones: The Brenner Exploratory Tunnel case." Engineering Geology 181 (2014): 93-111.

[3]Hasanpour, Rohola, Jamal Rostami, and Bahtiyar Ünver. "3D finite difference model for simulation of double shield TBM tunneling in squeezing grounds." Tunnelling and Underground Space Technology 40 (2014): 109-126.

Project outcome

The outcome of the project was a software library to simulate the evolution of stress and displacements in a fully 3D setting due to the excavation of tunnels.