Simulation of the tunnelling process with DIEKA

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GeoDelft

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Summary of report:

This report is a sub report of the Delft Cluster project "Large deformations in the geotechnics ".
The subject of the main project is to develop a three dimensional finite element (FE) model for soil penetration purposes.
In this report the development and the application of this F.E. model is discussed.
In 1999 a simular calculation is carried out with DIEKA. In the calculation presented in this report
The 3-dimensional Mohr-Coulomb material model is used, instead of the Von Misses model like in 1999.
Very promising results are presented in this report concerning the possibility to simulate the tunnelling process in DIEKA.

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1 Introduction

This report is a sub report of the Delft Cluster (DC) project "Large deformations in the geotechnics ". The subject of the main project is to develop a three dimensional finite element (FE) model for soil penetration purposes. This FE-model will be developed in the FE-code DIEKA.
The topic discussed in this report concerns the 3 dimensional simulation of the tunnelling process with the 3 dimensional constitutive model Mohr Coulomb.
The F.E. model discussed in this report involves front stability, tail void effects and soil deformations. In the next chapters we will present the description and results of the simulation.

2 Description finite element model tunnelling simulation

The F.E. model is developed in the F.E. code DIEKA. DIEKA is a non-commercial code and has no standard pre-processing program to generate the input file. The input file used in these simulations is produced with FEMSYS. FEMSYS is the pre- and post-processing program of DIANA. FEMSYS can not generate a complete input file for DIEKA; the generated file has to be adapted.
The main aim of this part of the investigation is to discover the abilities of DIEKA to model the tunnelling process. Therefore not the accuracy but the abilities of DIEKA are tested.
In 1999 a similar calculation is carried out with this model [GD 1999]. The difference with the model presented in this report is the applied constitutive model. In 1999 the calculation is carried out with the 3 dimensional Von Mises material model. In 2000 the calculation is carried out with the 3 dimensional Mohr Coulomb material model.

2.1 The geometry

The input file used in this calculation is similar to the input file used in 1999.
The geometry used in the calculations is based on the calculations made in the L500 project. Not exactly the same geometry is used but only the dimensions of the TBM and the tunnel segments is used. For easy handling purposes the TBM is assumed to be straight in axial direction, so no decline in diameter in the back of the TBM.
The diameter of the TBM is 8 meter, the length of the machine is 8 meter.
The thickness of the tunnel segments is 0.35 meter. The grout layer is 0.12 meter thick.
The centre of the tunnel is situated at 8 meters below ground level. This shallow depth is used for easy handling as well.

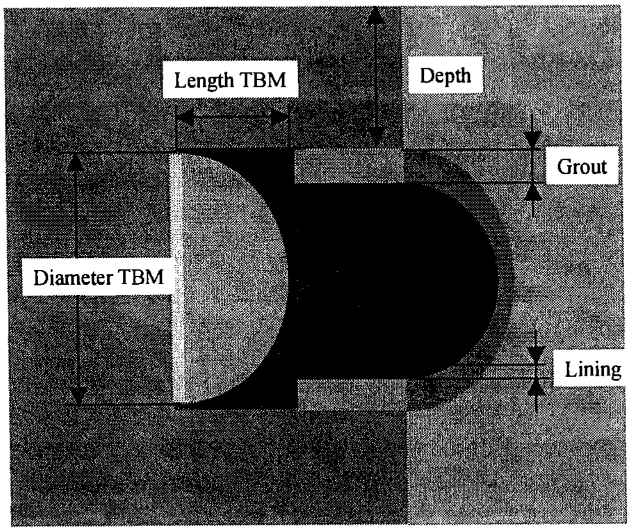


Figure 2.1

2.2 The mesh

The mesh contains large 8 noded elements to save calculation time. This acceptable since we decided that discovering the abilities of DIEKA is the main aim of this investigation.
The mesh is build up out of three parts:

1.- part containing soil
2.-part containing tunnel boring machine
3.- part containing tunnel segments and grout

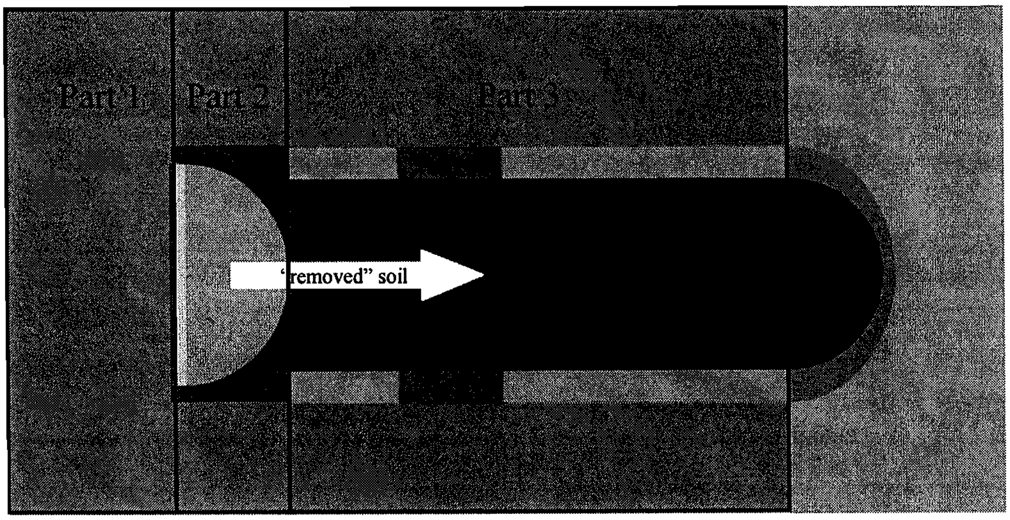


Figure 2.2

The material behaviour of the soil is modelled with the Mohr Coulomb material model.
The tunnel boring machine is not modelled with elements but with the boundary conditions. The tunnel boring machine is assumed to be extremely stiff. Hence the TBM can be modelled with the correct boundary conditions.

The behaviour of the grout is also modelled with the Mohr Coulomb material model. The grout occurs in the model in three phases:
1-liquid phase
2-higher stiffness phase
3-solid phase

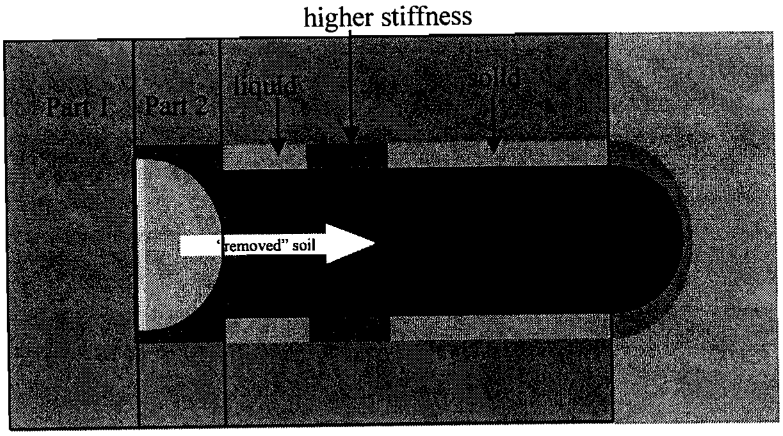


Figure 2.3

The behaviour of the tunnel segments is also modelled with the Mohr Coulomb material model. The segments are assumed to be very stiff.

The complete mesh contains 1216 elements and 1685 nodes. In Figure 2.4 the mesh is shown.

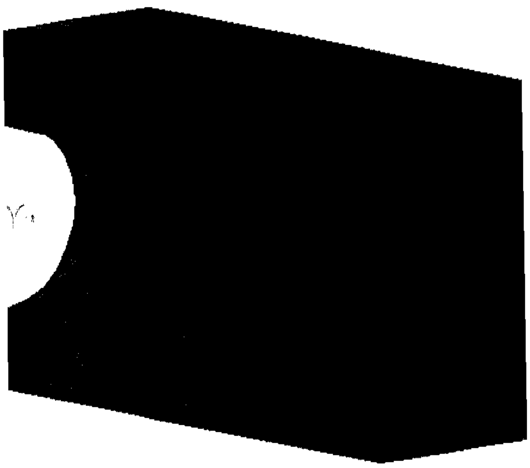


Figure 2.4

2.2.1 Boundary conditions

The geometry of the tunnelling process is cut in half, there is a symmetric plane at the hart of the tunnel. This means that the symmetric boundary conditions must be applied on this plane of symmetry. At this plane the displacements in z-directions are suppressed.
The opposite site of the plane of symmetry is suppressed in z-direction also.

The bottom of the mesh is restricted to move in y-direction, hence the displacements in y-direction are suppressed.

The TBM is modelled with the boundary conditions. This means that the soil can slide frictionless along the TBM and the TBM can not deform in radial direction. To prevent these radial displacements the local axes have to be rotated. This option is called "rotated bases" in DIEKA and is shown in Figure 2.5.

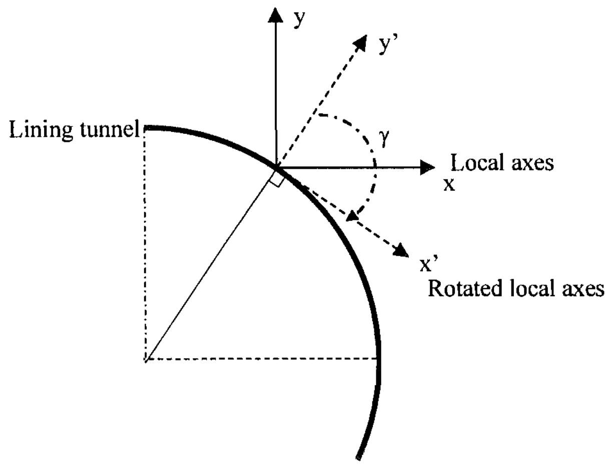


Figure 2.5

According to Figure 2.5 the nodes are suppressed in the y-direction and free in the z- and x-direction.

The inner nodes of the lining of the tunnel have the same boundary conditions as the nodes of the TBM. Hence no-radial movement is possible in the lining. The lining itself is modelled with elements and is very stiff.

The borders of the grout are modelled as Lagransian borders in radial direction. This means that the nodes can move in radial direction so the elements can deform in radial direction. This behaviour can be modelled in DIEKA by the surface option OPT2 for 3 dimensional calculations.
The Langransian direction is determined by the element face which contains the Langransian node, this option is shown in Figure 2.6.

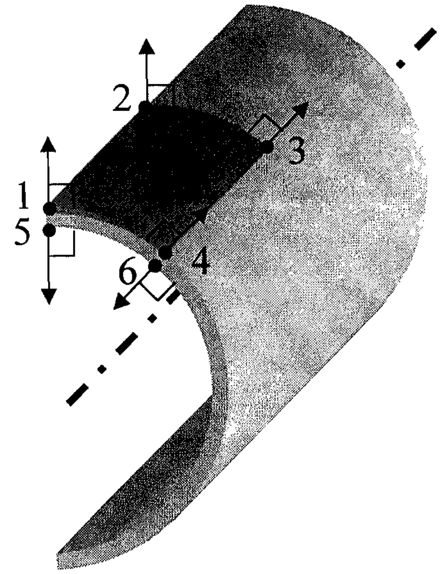


Figure 2.6

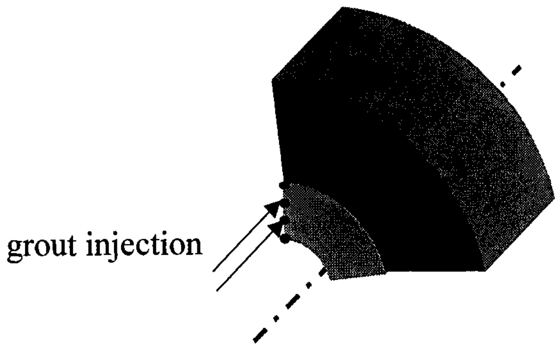


Figure 2.7

New grout flows in at the grout front. This means that the grout flow is controlled by volume. The grout injection can be varied along the grout front. The injection points are along the whole grout front in the calculations presented in this report. The nodes, which are used for the grout injection, do not belong to the soil element or to the lining element.

The construction of tunnel segments in the lining is modelled in the same way as the grout injection. At the lining front lining nodes are used to simulate the installation of new tunnel segments

To simulate the pressure at the boring front loads are applied on the nodes in the front. These loads can be varied to simulate different boring pressures

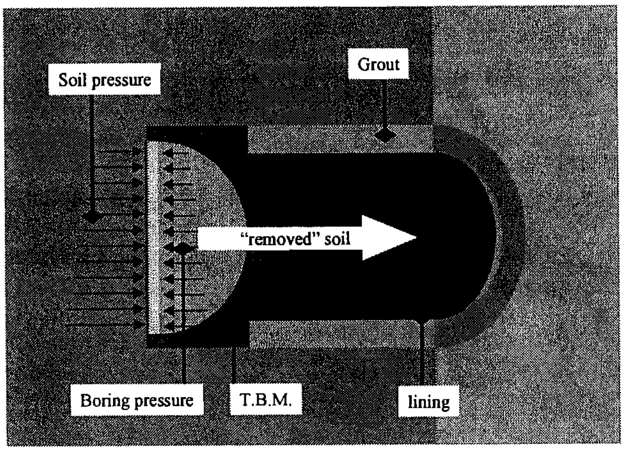


Figure 2.8

3 Results of the calculations

The used constitutive model in this calculation is a non-associated Mohr-Coulomb model. Mohr Coulomb is notorious because of its difficulty to converge in numerical simulations. This is caused by the angles of the yield surface. To reach the convergence criterion very small steps have to be made. This leads to an increase of the computer time and even crashing of the calculation before reaching steady state. In this chapter the results of the calculation is presented. Especially the deformations at ground level have the attention and will be discussed.

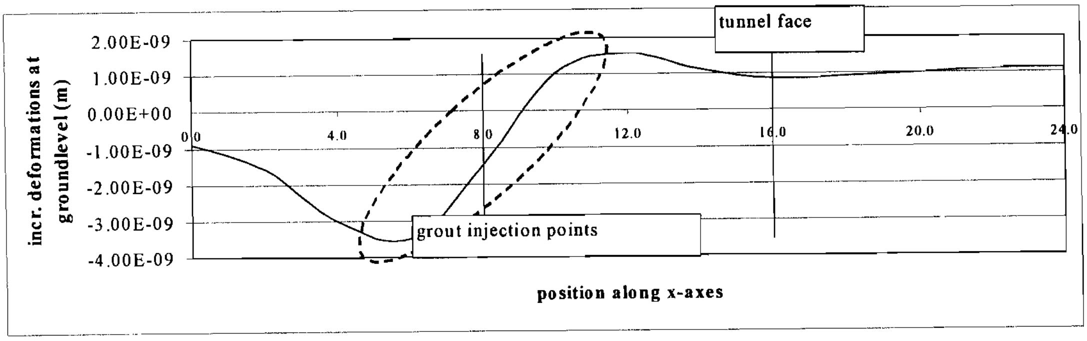


Figure 3.1

In Figure 3.1 the incremental displacement in y-direction at ground level is shown. It can be seen that close to the tunnel face ground is moving in negative y-direction. This indicates that there is instability at the tunnel face. The pressures of the boring fluid are modelled with nodal forces. These pressures are less than the pressure of the soil. The soil moves into the TBM with a higher velocity than planned, soil disappears.
This can be checked by showing the displacements at the front.

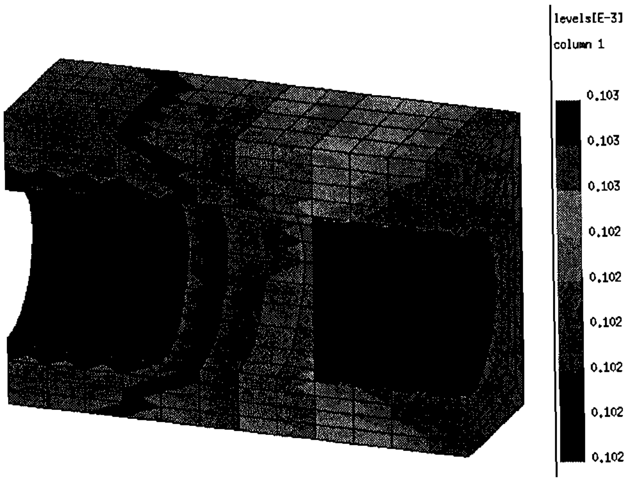
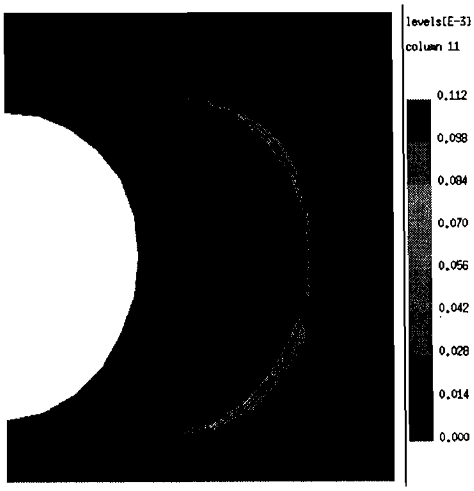


Figure 3.2 displacement in x-direction (m)

Figure 3.2 shows the displacement of the soil in x-direction. The figure confirms the statement that the soil moves with a higher velocity into the TBM than planned. This causes the deformations at ground level.

After the tunnel face the deformations increase, this is caused by the injection of the grout.
By injecting grout with a low volume the soil moves down in negative y-direction. This results in an increase of the deformations caused by the instability at the front.



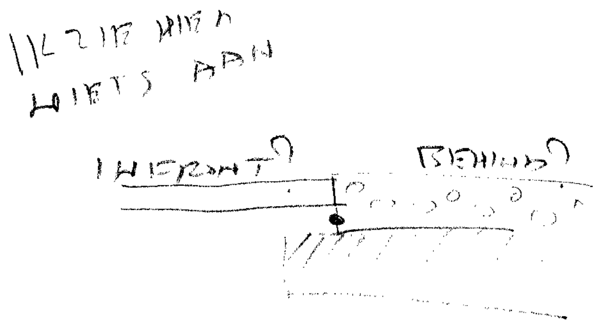


Figure 3.3 plastic strains

In Figure 3.3 the plastic strains are shown. It can be seen that the plasticity occurs, as expected, in the grout layer.

WAT IS BEHIND/IN FRONT

In Figure 3.1 can be seen that boundary effects influence the results. Especially at the grout injection point's boundary effects play an important role. At the grout injection points the nodes of the grout are connected to the nodes of the soil. If the velocity of the grout is lower than velocity of soil there will occur tension stresses behind the grout injection points and pressure points in front of the injection points. This leads to heaving in front of the injection points and settlements behind the grout injection points (dotted area in Figure 3.1).

In the future more calculations can be made with this model. Especially the grout behaviour and the front stability can be modelled in such a way that good predictions of the front stability and the grouting process can be expected. The boundary effect as discussed can be solved by using triple nodes at the grout injection points. The soil nodes and the grout nodes are de-coupled when using triple nodes.

4 Recommendations and modifications of the model

The F.E. as described in chapter 2 and 3 can be modified at certain points to describe the tunnelling process more accurate.
These items of modifications are:

1. injection grout at different places
2. model the behaviour of the grout with a viscous material model
3. allow deformation of the lining
4. model the decline in diameter of the TBM
5. use triple nodes at the grout injection points to avoid boundary effects
6. the use of a more advanced material model
7. [illegible]

ad. 1

In the calculations discussed in this report the grout is injected at al the grout front nodes. In reality this is not the case; the grout is injected at a certain number of injection points. By replacing the position of these injection points in the calculation the effect of the position of the injection point can be determined.

ad. 2

The grout in the presented calculations is modelled with the Von Mises material. This model is not suited to model the behaviour of the grout. In future calculations the behaviour of the grout can be modelled with more suitable material models. DIEKA already has material models, which can describe the behaviour of viscous materials. Investigation of these models must result in a recommendation whether these models are applicable for the modelling of grout.

ad. 3

Deformation of lining is in the current calculation not allowed. In reality the lining can deform. Hence in future calculations of the tunnelling process should involve a deformable lining and the possibility of the tunnel to lift. This can be realised by removing the boundary conditions of the lining.

ad. 4

For easy handling purposes only the decline in diameter of the TBM is neglected. In future calculations this decline in diameter can be modelled in the current model top describe the tunnelling process better.

ad. 5

Boundary effects at the grout injection points influence the results this can be avoided by using triple nodes.

ad. 6

The use of a more advanced material model will lead to better and more accurate results.

A general recommendation is that the element mesh used in this calculation should be refined to get more accurate results.

J

5 References

[GD 1999]
Simulation of the tunnelling process with DIEKA and DIANA
Report GeoDelft, G.J. Schotmeijer, CO-378530/907/26, 1999