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Combination of 3D-GIS and FEM modelling of the 2nd Heinenoord Tunnel, the Netherlands.

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Project

The construction of the 2nd Heinenoord Tunnel in the Netherlands was used in a pilot project for investigating the advantages and disadvantages of using 3D-GIS in complex underground civil engineering projects for the design, cost effective execution, and the recognition and avoiding of risks related to underground construction works. The 2nd Heinenoord Tunnel was built between 1996 and 1999 for slow traffic, to relieve the capacity problems of the existing Heinenoord Tunnel. It was the first tunnel in the Netherlands to be drilled. It is anticipated that in the near future, more and more tunnels will be drilled. A second goal was to try to link the 3D-GIS to a finite element model (FEM). The data flow in the project is shown in figure 1. The location of the tunnel site is shown in figure 2.

Dimensions in GIS

A 2D-GIS (Geographic Information System) uses a two-dimensional database. Therefore, it cannot be used for the construction of an underground model, which by definition is three-dimensional. A 2.5D-GIS also has a two-dimensional database, with the exception that it allows pseudo-3D viewing of surfaces. The space between the surfaces, however, is not described. Hence, this space is by definition considered homogeneous, an assumption seldom true. 3D-GIS uses a fully three-dimensional database, in which every point in space is described. Therefore, the use of 3D-GIS has an essential added value over 2- or 2.5D-GIS.

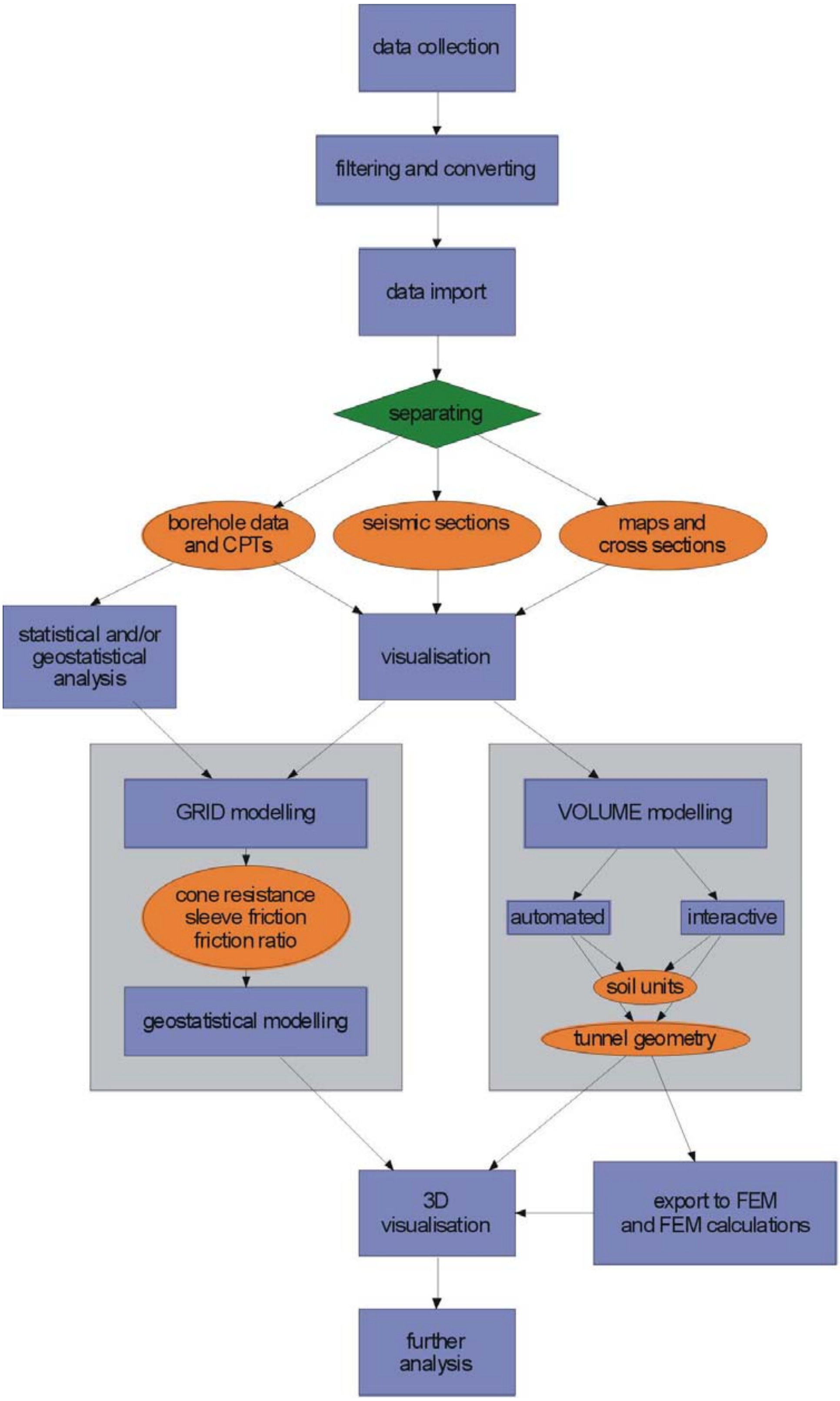


Figure 1. Flow chart showing research methodology.

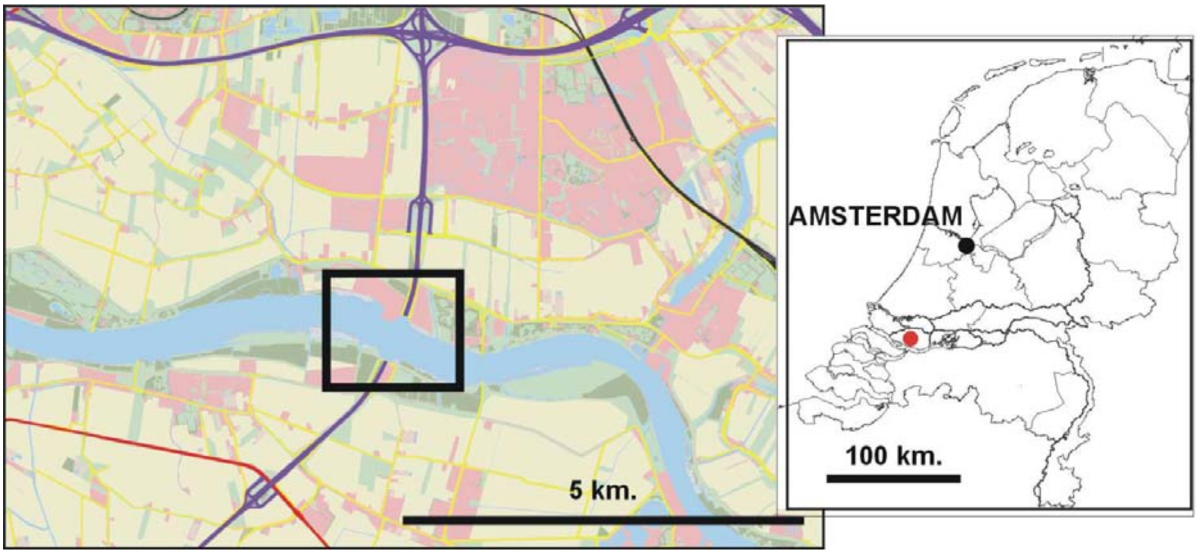


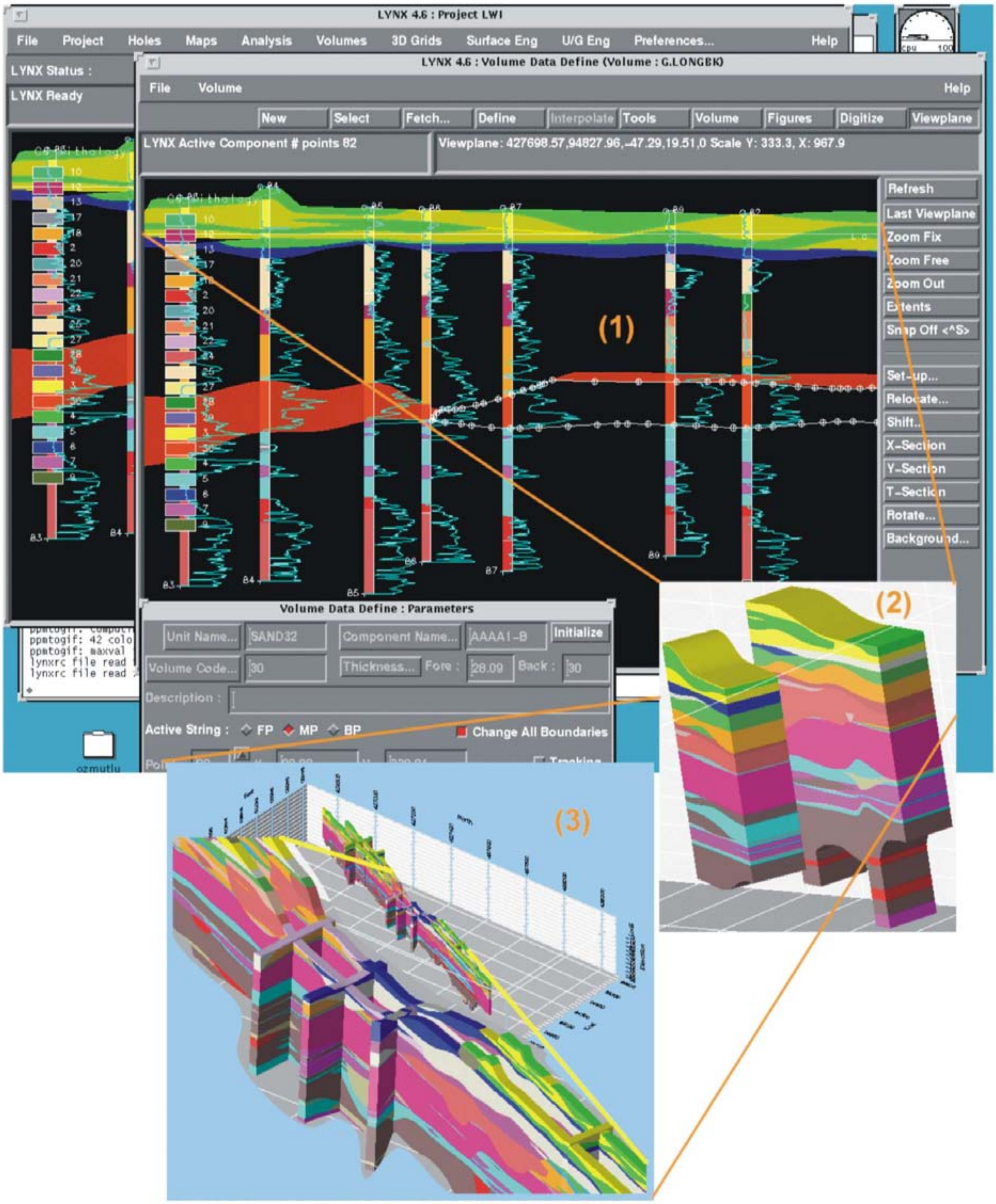
Figure 2. Map showing the location of the Heinenoord Tunnel along the Oude Maas river in the south-western part of the Netherlands.

Data entry, visualisation, and analysis

A variety of data sources was available: borehole data, cone penetration tests (CPT), geotechnical profiles, and seismic data. It is important that the various sources can all be read, viewed, and interpreted at the same time, in order to allow the construction of a litho-stratigraphic model of the subsurface that is consistent with all data sources. Visual inspection of raw data precedes the construction of any model of the underground (figure 3). It is essential for a thorough understanding of the geology. The incorporation of the seismic data presented a problem, because of the different units in which the third dimension is measured: time in the seismic data, opposite to distance in all other sources. Most 3D-GIS are not suited for the interpretation of seismic data; this might better be done in special seismic interpretation software packages. This, however, impedes the simultaneous interpretation of all data sources.

Volumetric or grid-based modelling

From the interpreted data sources, three volumetric (litho-) stratigraphic models were built (small, medium, and large scale). The various scales were chosen to identify the influence of the amount of data available for the model (small scale: large amount of data; large scale: small amount of data).



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■ Change All Boundaries

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Figure 3. Interactive visualisation and modelling process.

Not all stratigraphic layers that were identified in the raw data could be incorporated in the model. This would have yielded an unnecessarily complex model impossible to handle by the FE package. A number of major geo-technical units were derived from the stratigraphic units using rules of thumb, by absence of true field-measured geo-technical data. This implies that a single stratigraphic unit is considered geotechnically homogeneous. This assumption will clearly not always hold, especially in geologically complex settings. Figure 4 shows litho-stratigraphic models at various levels of detail.

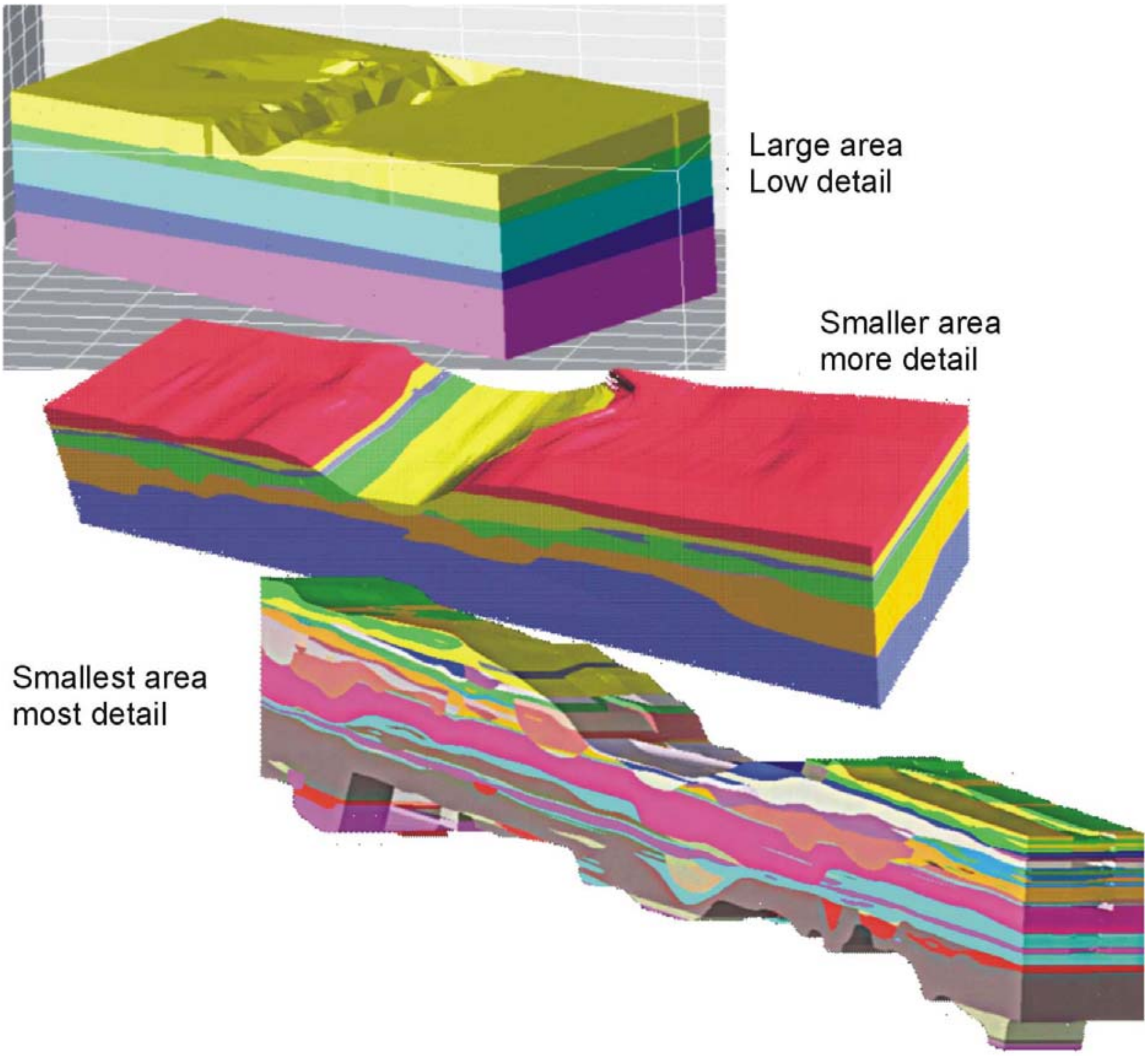
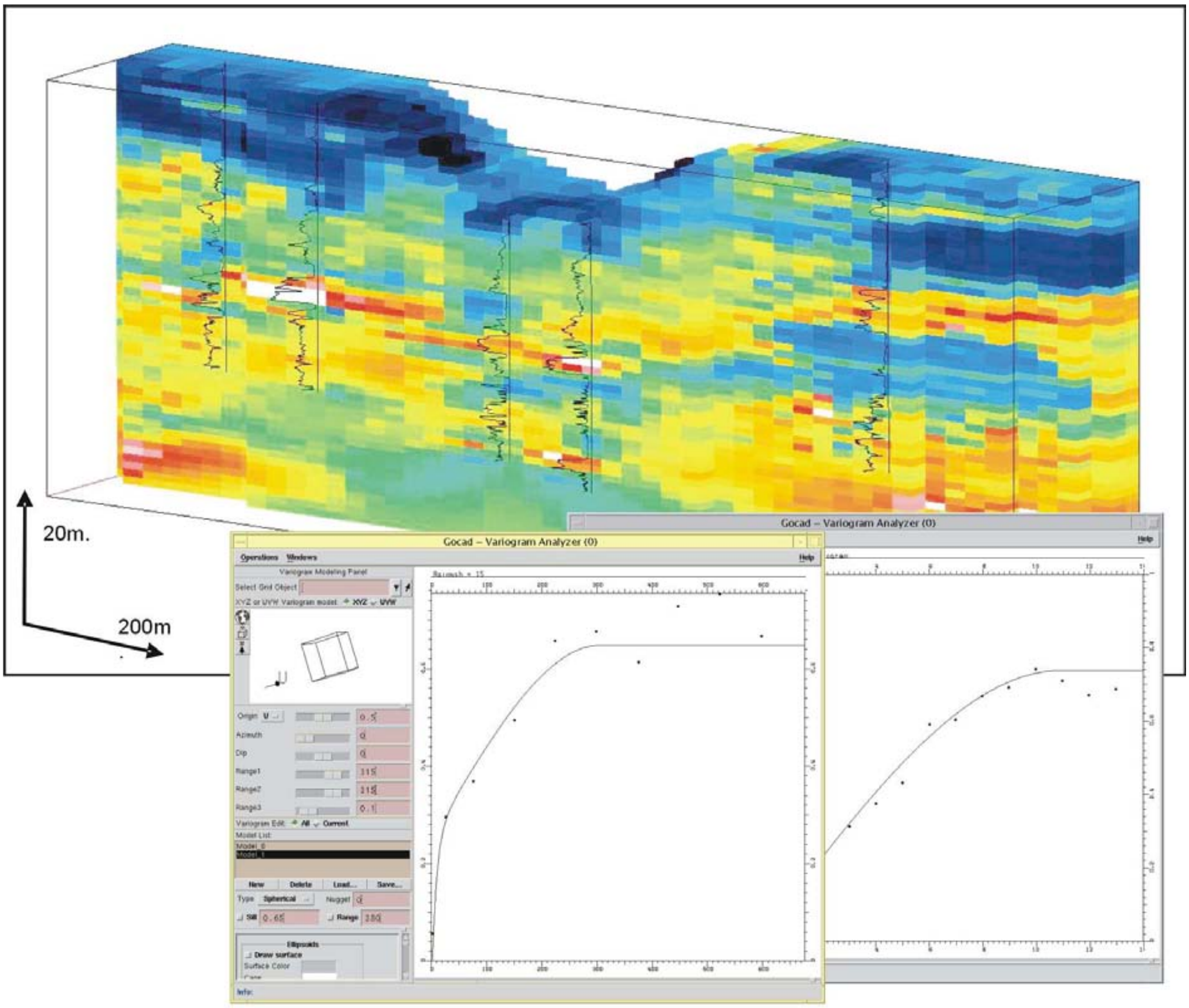


Figure 4. 3D models of litho-stratigraphy at various levels of detail. The incision in the middle of model is the Oude Maas river.

CPT-logs (e.g. cone resistance, sleeve friction, friction ratio, water pressure) also can be used for deriving geo-technical properties, instead of using lithology as a rough approximation of geo-technical properties. This is done by using correlation rules and geo-statistic techniques like Kriging and stochastic simulation. Figure 5 shows horizontal (XY-plane) and vertical (Z-direction) variograms of the cone resistance which was recorded by CPTs. The variogram indicates the amount of correlation that exists between pairs of measured cone resistances in space. The correlation (vertical axis) diminishes with distance (horizontal axis); 0 means perfect correlation. Determination of the spatial correlation is essential for the application of interpolation algorithms. The same figure 5 shows a 3D grid model with simulated cone resistances. High cone resistances are indicated in orange, red and white (gravel and sand), low ones in grey and blue (peat; clay and silt). The lateral variation in the interpolated cone resistance is indicative for the heterogeneity of the modelled units, and, indirectly, for the variation of the soil strength. In this project, however, these results were not further used because of a number of anticipated problems beyond the scope of the project: establishment of the type of correlation between cone resistance and soil strength, and the complexity of the geo-technical model in relation to the construction of the FE model.



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Azimuth 0
Dip 0
Range1 115
Range2 115
Range3 0.1
Type Spherical
Nugget 0
Sill 0.65
Range 280

Figure 5. Horizontal and vertical variograms of cone resistance, and 3D grid showing modelled cone resistance. On the foreground of the grid 5 CPT logs are shown. The depression in the middle of the grid is the Oude Maas River. The cell dimensions are 25×25×1 meter, the entire model box equals 255×1250×55 meter. Note the complex pattern of the modelled cone resistance in relation to the relatively simple litho-stratigraphic model of figure 4.

Finite element (FE) modelling

The volumetric model was brought into the finite element modelling package DIANA. Typical soil strength values were assigned to the various layers. Stresses on the tunnel, induced by the (fictitious) construction of a building on the surface above the tunnel, were then calculated. The vertical displacement caused by the loading is shown in figure 6. The model results were then exported back into the 3D-GIS. These kinds of calculations help to identify potential areas of high risk due to surface loading.

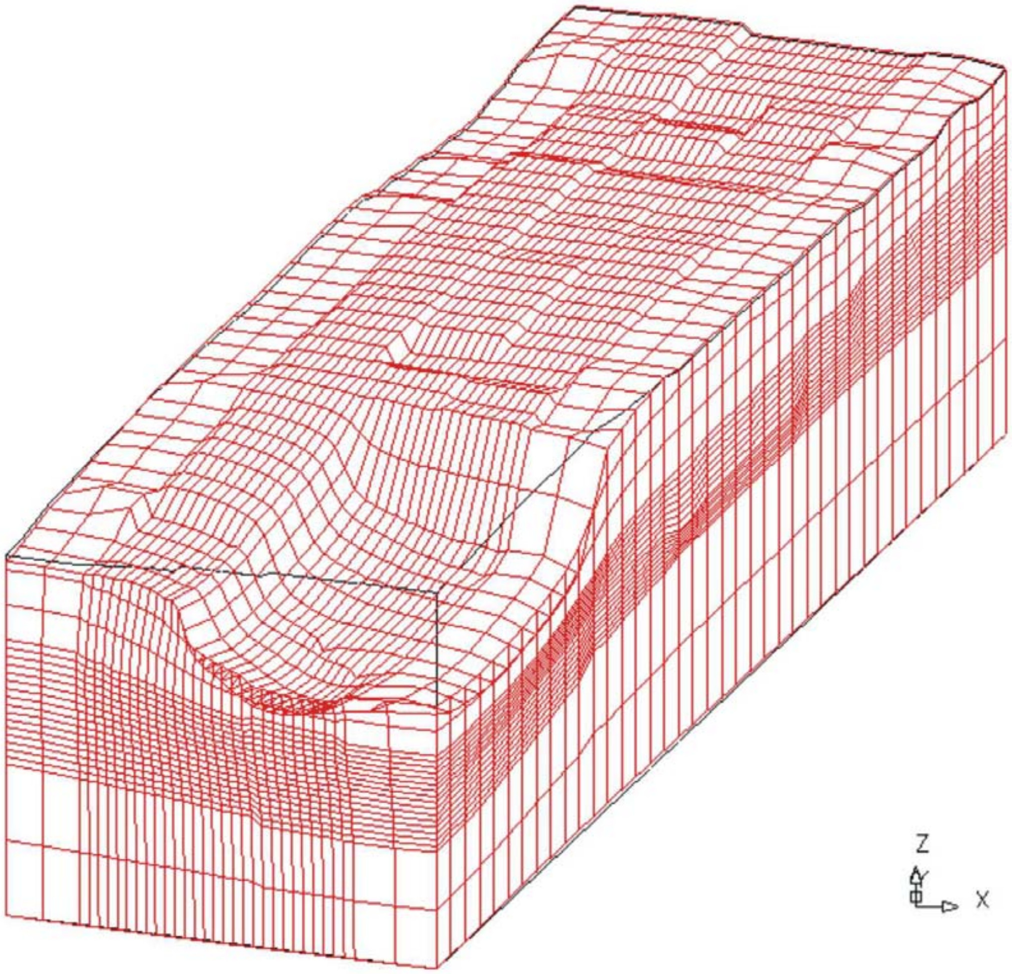

Figure 6. Vertical displacement caused by applying a fictitious load on the surface above the tunnel.

Conclusions

The most important conclusion from the project was that, using current GIS-technology, it is possible to carry out the entire model flow: visualise raw 3D-data, construct a 3D-geotechnic model from various data sources, export the model to a FE package, calculate stresses or displacements in the FE model, and export the data back into the 3D-GIS.

It also turned out important to realise, right from the start, that the geologic model will be used for finite element modelling. A geologic model consisting of a dozen units and several millions of cells is considered average, whereas in an FE model seldom more than about 10 units and about 100,000 cells are used. Sometimes units that are considered important in geotechnical context, such as lenses, are difficult to incorporate into the FE model. Some mesh generators may have problems with this kind of irregular shapes. A considerate definition of unit boundaries and layer parameters may prevent this kind of problems. Constant close co-operation of the interpreting geologist and the FE modeller is therefore important.

Project context, partners, commissioner/client/customer COB, LWI

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