Time-Dependent Three-Dimensional Finite-Element Ground Model for Geotechnical Engineering Problems

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The comprehensive modelling of soil-structure interaction requires three-dimensional dynamic design systems, which capture the changes that occur on the geotechnical components during the construction progress. The powerful generation and administration of the complex time-dependent geotechnical model need holistic computational tools for the management, the visualization and the proof of the engineering system. The system introduced allows a time-dependent management of the individual stages of the construction by a dynamic model in consideration of the ground properties, the geotechnical construction elements and the construction processes. An automatic mesh generation enables the generation of hexahedron meshes for the finite-element representation. The implementation of the system was achieved using object oriented modelling techniques and implementation in C++.

Introduction

Modern large scaled buildings are erected on rather complex foundations. Deep excavations in densely built-up areas require retaining walls and other geotechnical construction elements. The planning and design of the pit and the geotechnical engineering is normally performed by the use of different software tools. The stability of the construction is investigated in necessary spots at different

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times independently from each other. An integrated design is not always guaranteed. The following approach enables a holistic computer aided modelling of the ground as well as the geotechnical construction considering the construction time schedule.

Model management for dynamic geotechnical engineering problems

The basic problem connected with geotechnical engineering is the multi-dimensionality in space and time [Diaz 1998, Schönenborn 1999]. Planning work is carried out in several individual phases which differ in their degree of complexity and generally rely on information obtained from preceding phases: Phase 1: Prior clarification of geotechnical conditions for a project (e.g. site investigation etc.), Phase 2: Foundation soil investigations for the multi-stage project (e.g. determination of soil parameters etc.), Phase 3: Detailed investigations for the concretised project (e.g. design, dimensioning and checking of construction elements etc.), Phase 4: Additional clarifications and inspections during construction work (e.g. control of the actual foundation soil based on the excavated material),

The planning process constitutes a highly time-dependent system. The order in which the individual planning phases are carried out prescribes a specific sequence of engineering models. In Phase 1 the preliminary site investigation is conducted on the basis of two-dimensional layout plans and geological information. Once the site investigation has been completed, further information concerning e.g. soil composition, neighbouring structures etc. are added in Phase 2. By combining the information obtained from Phases 1 and 2, a new level of detail is attained for the purpose of dimensioning the construction elements, which may then be represented in layout plans, sectional drawings and 3-D-models. Once the dimensioning stage has been reached (Phase 3) decisions must be made concerning the geotechnical construction based on the available planning information. The necessary starting parameters (e.g. width, materials, number of structural elements etc.) must be specified for this purpose. The parameters obtained during the preliminary design stage subsequently serve as input values for the final dimensioning and analysis of the geotechnical construction. In order to carry out the necessary structural stability and load safety verifications for the selected construction, suitable models are developed in the first instance. These models include all relevant information and basic planning data. For this reason, both simple one- and two-dimensional models as well as complex three-dimensional models are applied. For verification purposes it is necessary to set up and analyse models for all critical construction stages. Only by this means it is possible to guarantee the structural stability of the construction throughout the entire construction period.

For the simulation of different scenarios of the construction state we developed and implemented the research prototype of the GeoTechnical Information System (GTIS). Here are some requirements resulting from the described scenario in geotechnical practice.

- The ground model requires a time-dependent structure to represent all the critical states. This is only possible with a software design using a dynamic data structure.
- The dynamic data structure has to be extended by a spacial access mechanism to reduce the access complexity within the ground model because of the complexity of the ground model in time and space. Therefore we use an octree-data-structure.
- A direct relationship betweenthe ground model objects and the geotechnical construction elements is necessary.
- A construction manager is required for the handling of the different critical construction states.
- Because of the three-dimensional complexity of the ground and geotechnical construction, a finite-element computation is needed for the static proofing of all building states.

The approach for an integrated design is shown in [Diaz 1998], [Schönenborn 1999] and [Meißner u. a. 1996]. A central three-dimensional time-dependent ground model was developed using the methods of the object-oriented modelling. The ground model consists of the following components:

Ground Model: The ground model includes all data of the building ground such as the boundary of the area and information about the ground materials from bored drills (Figure 1 a)). Undisturbed foundation soil is assumed as a starting point for the ground model. By integrating individual

a) b)

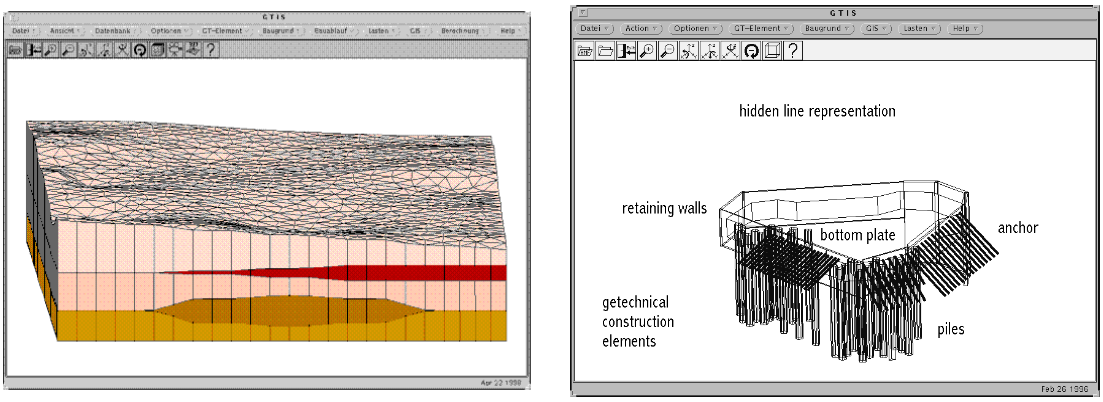

Figure 1: *a) Ground Model b) Geotechnical Construction Model*

changes in soil geology and soil properties (e.g. due to excavation work or soil improvement) during construction, subsequent construction states are generated and stored in the ground model for retrieval as required at a later stage.

Geotechnical Construction Model: The geotechnical construction model contains the geotechnical construction elements designed by the civil engineer. This permits individual construction elements (piles, foundations, retraining walls) to be generated in parameterised form from construction component catalogues and to be combined as required (Figure 1 b)).

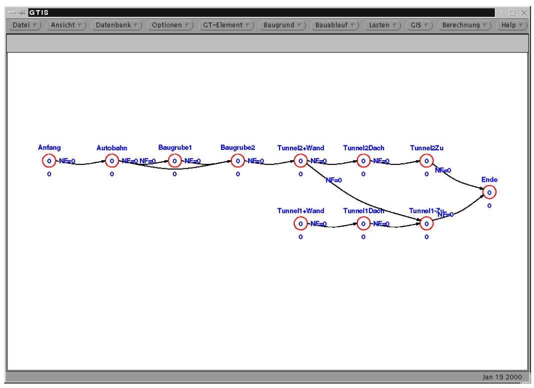

Figure 2: *Construction Sequence Model*

Construction Sequence Model: The construction sequence model permits the definition of the temporal sequence of construction phases. Network planing technology is applied for this aim. Critical and relevant construction states and processes are specified in the network (Figure 2). By this means, it is possible to systematically describe and manage the construction sequence. With the aid of construction sequence control during each construction stage, a valid model comprised of foundation soil, construction and excavated trench is created, which may be further processed for computation, dimensioning or construction purposes. As usual, processes and states which are optionally coupled with geotechnical construction elements may be modelled in the form of network plans, which take account of time and resource factors. Optimisation is possible by network plan variations and computations.

Finite-Element-Model: For all relevant states finite-element models are generated. These models contain all information for the calculation such as elements, nodes, loads, boundary conditions and contact areas.

Finite-Element-Mesh-Generation

For the automatic generation of meshes representing ground and construction following criteria are needful:

- The integral description of the ground is especially reasonable if the calculation is three-dimensional. The complex structure of ground and construction elements should be managed in a CAD-system like in GTIS.

- Hexahedron elements or tetrahedron elements are possible geometric elements for three-dimensions. In the finite-element program used a 20-node hexahedron element is implemented for the simulation of the ground.

- For the convergence of the calculation mesh refinements must be possible in critical areas of the continuum. To discover these critical areas an error estimator is to be used [Meißner und Wibbeler 1990].

- For the simulation by the finite-element method boundary conditions and loads are required. These are assigned automatically to the nodes and elements of the discretised model when it is derived from GTIS.

a) b)

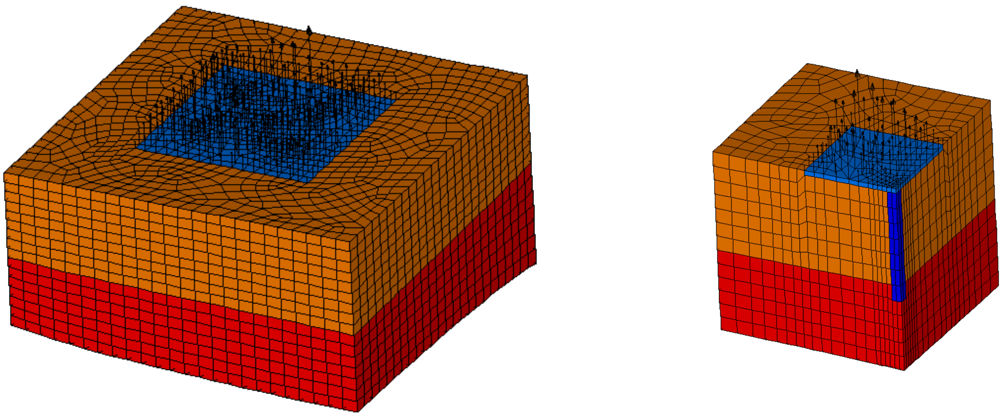

Figure 3: *Finite-Element Mesh a) complete model b) symmetric cut model*

Due to the complexity of the ground and the construction unstructured hexahedron meshes are employed. These are generated with a projection method. This method consists of the following three steps:

Projection: All geometrical information of the geotechnical construction elements are projected on a horizontal layer.

2D-Mesh: Using the information of the horizontal layer, a two-dimensional mesh is produced with quadrangle elements.

Hexahedron Elements: Considering additionally information in depth of the construction elements and the thickness of the ground layers, soils of hexahedron elements are generated for each quadrangle.

Mesh Refinement

Local mesh refinements are necessary in order to obtain convergence for the finite element method. While using the projection technique, refinements of the initial 2D-mesh is not useful. The resulting mesh would contain badly shaped elements. Therefore the initial mesh is generated with a unique mesh density and the refinements are realized in a subsequent step.
For the refinement of hexahedron elements edges of an element have to be split into three parts. For the refinement of arbitrary regions 22 interface-meshes are

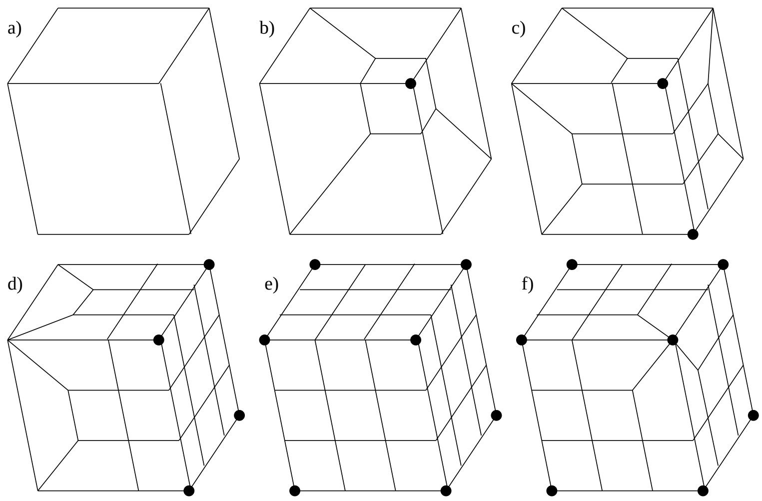

Figure 4: *Refinement of Hexahedron Elements*

necessary [Schneiders u. a. 1996]. Some of these interface meshes can not be generated, like the mesh shown in Figure 4 f) [Mitchell 1996]. To refine convex regions only 5 of these 22 interface-meshes are necessary shown in Figure 4 a) - e). The refinement of non-convex regions is possible by enlarging the refinement region to obtain a convex region. Recursive refinements are possible by using this technique in order to achieve a higher density.

Summary

A holistic computer aided modelling was illustrated for the geotechnical systems with a dynamic sequence of construction processes. A dynamic model management handels the ground properties, the geotechnical construction elements and the construction states. Despite the complexity of the ground and construction models, the three-dimensional software system developed permits an insight into construction details as well as a comprehensive geotechnical proofs in an engineering manner. For the investigation of critical states finite-element models are generated considering automatic mesh generation methods for the three-dimensional, complex geotechnical region.

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Key Words

- object-oriented modelling
- time-dependent geotechnical model
- construction sequence
- finite-element