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Experiences with using parametric 3D modelling in geotechnical engineering

Expériences d'utilisation de la modélisation 3D paramétrique en géotechnique

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ABSTRACT: In recent years, geotechnical engineers at NGI and Geovita AS have adopted new ways of creating and using parametric 3D/BIM models in their engineering design. The models are used through the life cycle of the project, from idea to construction to as-built documentation. This new way of working has successfully been adopted on several ongoing, major infrastructure projects in Norway. All models for underground structural design, such as retaining walls, soil improvement, rock support etc., are developed through parametric modelling. The models mature throughout the project and adding information in the models makes them fully functioning BIM-models which can be used directly by the contractors. The use of parametric design greatly improves communication and multi-disciplinary design, reduces risk of collision and errors, and can lead to significant time and cost savings in projects compared to a manual geotechnical design. This article shows the possibilities of parametric modelling in geotechnical engineering and will hopefully inspire more geotechnical engineers to open this digital toolbox.

RÉSUMÉ: Ces dernières années, les ingénieurs en géotechnique du NGI et de Geovita AS ont adopté de nouvelles approches pour créer et utiliser des modèles paramétriques 3D/BIM dans leur processus de design d'ingénierie. Ces modèles sont utilisés tout au long du cycle de vie des projets, de l'idée à la construction, jusqu'à la documentation finale. Cette nouvelle manière de travailler a été intégrée avec succès à plusieurs projets d'infrastructures majeurs en Norvège, pour lesquels tous les modèles de design des infrastructures souterraines, comme les murs de soutènement, l'amélioration des sols, le support rocheux, sont développés à l'aide de la modélisation paramétrique. Les modèles évoluent tout au long du projet, et l'ajout d'informations dans les modèles BIM les rend entièrement fonctionnels et permet leur utilisation directe par les entrepreneurs. L'utilisation de la conception paramétrique améliore considérablement la communication et la conception multidisciplinaire, réduit les risques de collisions et d'erreurs, et peut entraîner des économies de temps et de coûts significatives dans les projets, comparativement à une conception géotechnique manuelle. Cet article présente les possibilités de la modélisation paramétrique en géotechnique et vise à encourager davantage d'ingénieurs en géotechnique à ouvrir cette boîte à outils numérique.

Keywords: Parametric modelling; BIM; automation.

1 INTRODUCTION

Focusing on infrastructure projects and geotechnical engineering, the subsurface in urban areas is becoming more congested, increasing complexity for new developments. BIM (Building Information Modelling) is increasingly being used in subsurface engineering (Gondar et al., 2019; Satyanaga el al., 2023), also for specific applications such as soil nailing (Nappa et al., 2019). In general, underground construction is moving towards more digitized workflows (Huang et al., 2021).

Geotechnical engineers should be prepared for the drawing-free projects that are coming and adopt to a more model-based design workflow following the principles of BIM.

A few years ago, NGI and Geovita AS began improving our design workflows largely enabled using parametric 3D-modelling tools and the development of scripts to automate the 3D modelling tasks.

2 3D MODELLING WORKFLOWS

2.1 The past workflow

Both companies have been 3D-modelling for several years. This was often static 3D-modelling in AutoCAD, which often gave very large and hence slow models. Since there often is late changes in the projects, these models were established at the end of the design phase to avoid too much re-work in the projects. And even if these models were only produced once, production of these models was very time consuming.

Late modelling also resulted in the lack of possibility for interdisciplinary class detection, which again could result in undetected conflicts and reasons for higher costs. The modelling was also mainly done for the geotechnical-structures, and not for the soil layering except for the bed rock surface.

2.2 Present workflow

Basis for the change in workflow was to find more suitable software, which would enable more dynamic models. Both companies ended up with using Leapfrog Works (Seequent) for modelling geology/soil/soil layering and the combination of Rhino and Grasshopper (Robert McNeel & Associates) for modelling geo-structures.

These software gives the possibility to establish the geotechnical models early in the projects, and the models will then evolve with the projects. The level of the model is of course always communicated with a given LOD- or MMI-value. The establishment of these models has several advantages:

- They are improving the communication about uncertainties (more about this later).
- They are basis for the calculations of the geotechnical engineer, which saves time in the calculation process.
- The early establishing of these models ensures better interdisciplinary clash control.
- They will early give a picture of both cost and carbon footprint.
- They are basis for execution for the contractors, both as models and as geodata.

Since we are using dynamic modelling, the always present changes in the projects will only result in a minimum of extra work, will cut the cost dramatically and makes new, updated models extremely quick.

3 PARAMETRIC MODELLING

Parametric design is something that has been in use for quite some time within other fields such as e.g., architecture and construction industry, but is still relatively new in the geotechnical world.

In short, parametric design is a new way of defining work tasks and planning throughout the entire construction process. In the CAD software Rhino there is a built-in framework for visual programming called Grasshopper. This works in such a way that you create a work process by "visually" connecting different components (or parameters) with nodes.

As an example: the work process can be "set out piles along an axis" and the components in this case will be e.g., "create a reference point", "set diameter of piles", "set pile length", "set centre distance between piles", "set number of piles further along the axis" and "construct cylinder object". Connecting these components then creates a kind of network, or a script, which together performs the desired work process. Updating a single component, e.g., "moving the reference point for the cylinder", will automatically cause all piles along the axis to move to the new reference point. This is what is called parametric modelling – that a dynamic network of interconnected components enables a complex work routine that is updated seamlessly with each update of a single component. As a bonus, you can reuse the same work routine over and over on project after project. This saves a lot of time and requires increased quality of each modelling task and delivery.

3.1 Sheet pile wall with tie-back anchors

As an example, for use in the geotechnical design, we take a closer look at a construction pit. We are in an early planning phase and the only thing we have received from the project is a line of proposals for the placement of the basement wall. In addition, we have a terrain model and a rock model. With these input parameters and a pre-defined script that creates sheet pile walls, see Figure 1, we get a 3D model of the construction pit within a few seconds.

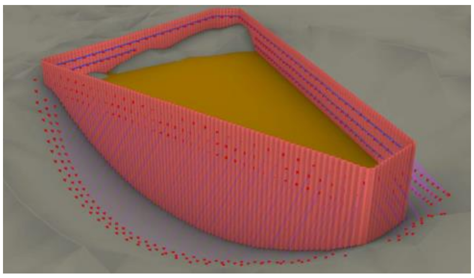

Figure 1. Sheet pile wall with tie-back anchors.

In addition to a script for generating sheet pile walls, we have developed scripts for different types of retaining structures (such as diaphragm walls, Berliner wand etc.), struts, tie-back-anchors, beams, lime-cement columns, jet grouting etc. All these scripts are re-used, which gives a huge time-saving on new projects.

Back to the example above, if we now want to add tie-back-anchors in the model of our construction pit, we simply add it by serially connect the sheet piling script with a new script that generates anchor braces. The model with the anchors and the bed rock surface is given in the figure below. What is very important to point out here and which is essential for the models to be dynamic, is that these scripts must be connected. The reason for this is that if you move or change the original line, defining the basement, then both the sheet pile walls and the anchors are moved according to the new position.

3.2 Settlement analysis

The software is also used for performing an analytical settlement calculation over a larger area to assess the impact on the surroundings because of our planned construction pit.

The procedure involves creating a grid that covers the area you want to assess. A direction vector is then calculated and the distance from each cell in the grid to the construction pit. At the intersection between vector line and cell, three points are taken out (far, middle and nearest). In each of these three points, in each cell, the depth to rock and the depth is divided into segments with e.g. 0.5 m thickness. Soil parameters are calculated in the same way for each depth segment with Python code components in Grasshopper. Based on this, one can then perform a 1D settlement calculation (Janbu, 1970) in each individual point with a time component through approximation of the degree of consolidation from Terzaghi and Fröhlich (1936).

With this script it is possible to visualize the effect on the surrounding area because of the construction site. In Figure 2, one can see that the calculations indicate an influenced area up to 340 m from the construction pit.

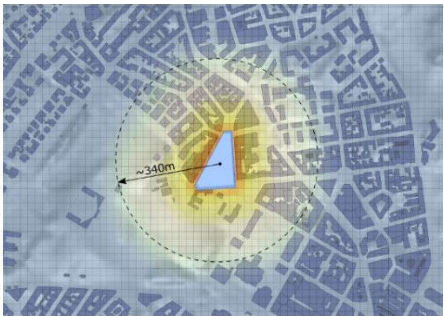

Figure 2. Calculation of influence area.

The effect of the construction work can also be calculated for points on each building object around the pit, see Figure 3. Resulting potential for damage to surrounding buildings can be visualized as damage classes.

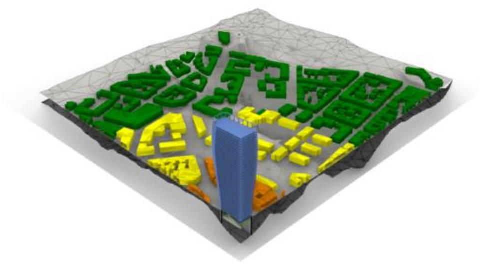

Figure 3. Visualization of potential damage on buildings.

3.3 Ground improvement with deep soil mixing

Parametric modelling is also used for establishing models for ground improvement with deep soil mixing.

There are several methods to improve the strength and stiffness of the ground, using vibration, impact, or by mixing a binder material into the soil. In this modelling example, we will focus on deep soil mixing, known in Norway as lime-cement-columns. With this method a binder, typically lime and cement, is mixed into the soil using air pressure and a rotational tool. These columns can be approx. 20 to 30 m long and commonly have a diameter of 600 to 800 mm. Columns are installed in various patterns such as grids, ribs, panels or single column, depending on the purpose and structural function of the ground improvement.

Large construction projects in soft-clay areas may have several tens of thousands of these columns installed to improve constructability and reduce ground risk. The modelling of the deep soil mixing with parametric modelling gives not only dynamic models, but the models are also basis for the execution by the contractor.

In our given example we connect another script, producing the lime-cement-columns to our construction pit, and we will then quickly get the result shown in Figure 4. Of course, we could now easily change parameters in the model.

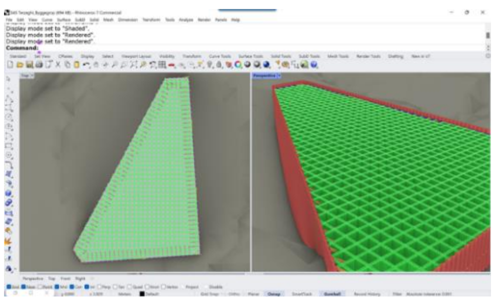

Figure 4. Excavation pit with lime-cement-columns.

3.4 Quantity take-off and sustainability

In all the scripts producing the models, we have also implemented a system for defining the properties of the objects which are summed up in geotechnical Psets, easily readable in the IFC-files we make in Rhino/Grasshopper. This is not only details about the structural element, but can also be details about tolerances, material properties, execution etc.

As the models develops through the project, this also means that we easily can see how the cost, emissions, etc. develops with changes in the models.

3.5 Visualization of uncertainty

Geotechnical engineering has a lot of uncertainties. The geotechnical engineer has often information about the soil conditions in points, but between these points the knowledge is uncertain.

One way to communicate to project stakeholders in the BIM model that geotechnical point information is interpolated and extrapolated to create continuous surfaces, such as the bedrock model, is to visualize on the surface mesh the closest distance from the mesh cell centre to the nearest borehole. Applying a colour map where green is “close” and “red” is further away yields a triangulated bedrock rendering as shown in Figure 5. This method does not quantify the uncertainty, e.g. a standard deviation, but is merely used as a simple visual communication tool in the BIM model.

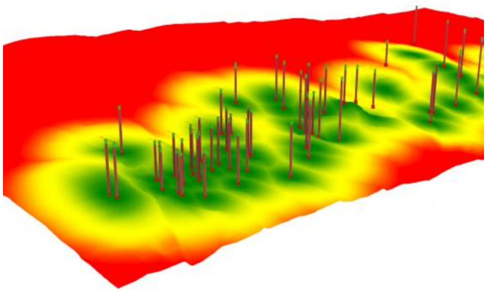

Figure 5. Visualization of pseudo-uncertainty based the distance of each mesh cell to the nearest borehole.

These models can further be part in a collaboration software which then easily can communicate the uncertainty to other participants in the project. Are your planned new building placed in the middle of a red area, then you have acquired a project with a high level of uncertainty, geotechnically speaking.

4 CONCLUSIONS

This paper describes how NGI and Geovita have adopted parametric 3D modelling to deliver examples of geotechnical analysis, BIM models and how to effectively communicate geotechnical uncertainty to projects stakeholders in the BIM model. The use of parametric design has greatly improved our engineering and project workflow, especially for larger infrastructure projects such as road and railway developments. The dynamic 3D models are updated continuously throughout the project and yields significant timesaving when the 3D geometry generation is automated using Grasshopper-scripts. Parametric modelling can be applied a wide range of geotechnical problems, including analysis of settlement and generating quantity take-offs for construction works. The authors highly recommend design and engineering firms within the geotechnical domain to adopt this way of working.

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