Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-1229

Enhancing Geotechnical Design and Construction: Integrating BIM in Large-Scale Deep Excavation Projects

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ABSTRACT: This paper explores the integration of Building Information Modeling (BIM) within the realm of geotechnical design, focusing on a large-scale deep excavation project currently in progress. The Project involves an 800 long and 170 m deep excavation pit, with 10 m high benches sloped at 1H:6V. The excavation is being carried out in granite rock mass, which is intersected by various volcanic dykes, lineaments and faults. It encompasses all related slope stabilization works, such as installation of tensioned strand anchors and the integration of monitoring devices, under stringent BIM requirements set by the employer. The BIM model plays a pivotal role in coordinating the design and construction, particularly given the Project's scale, which includes approximately 39,000 untensioned rock dowels and 4,500 tensioned strand anchors. All BIM models are stored on the Autodesk Construction Cloud (ACC) platform, serving as a central hub for model reviews and issue coordination. Automated clash detection ensures seamless integration. The geological underground model is integrated with the BIM model, establishing a connection to geological data. Furthermore, 2D sections extracted from the BIM model are utilized for finite element analysis (FEA) of the slopes. The rock support determined through the FEA is subsequently incorporated into the BIM model. Custom scripts automate various time-consuming processes, such as placing anchors and updating their coordinates. The contractor depends on 2D CAD drawings automatically extracted from the BIM model, which contain all necessary data, such as anchor coordinates and types. The ultimate goal is to utilize the BIM model after project completion and transfer it to the employer as a Digital Twin for operational use. This paper highlights the critical role of BIM in enhancing the efficiency and accuracy of geotechnical design and construction processes, demonstrating its potential in geotechnical projects while discussing current software limitations.

KEYWORDS: BIM, geotechnics, large excavations, slope stability, automation, computational design.

1 INTRODUCTION

The increasing complexity of large-scale geotechnical projects demands more integrated and data-driven approaches for design and construction. Building Information Modeling (BIM), widely adopted in structural and architectural disciplines, is gaining traction in geotechnics, where its potential remains underexplored. BIM offers powerful tools and workflows that support projects of this nature, delivering significant advantages in design, execution, and decision making.

This paper presents the application of BIM in a major deep excavation project, highlighting how BIM methods and tools supported geotechnical analysis, design coordination, construction documentation, and change management.

2 PROJECT BACKGROUND

The large-scale deep excavation pit (hereinafter referred to as “the Project”) is situated in an arid, mountainous desert region. Construction is currently in progress, with around 50% of the total rock excavation completed at the time of writing (see Figure 1). The pit is carved into a natural depression along a mountain ridge and measures approximately 800 m in length and up to 170 m in depth. The excavation slopes are subdivided into multiple 10 m high benches with 2 m wide berms. The bench faces are inclined at a slope angle of 80 degrees (1H:6V).

Unlike a conventional rectangular layout, the excavation features a highly contoured geometry and forms an overall V-Shaped cross-sectional profile. This complex shape is driven by structural and architectural requirements.

AFRY Austria GmbH has been engaged as the designer on behalf of an experienced international contractor responsible for the execution of the main excavation works, including all associated slope stabilization measures and the required instrumentation and monitoring, under assignment by the employer. At project initiation, the contractor was provided by the employer with a detailed geometric definition of the excavation layout and available results from geological and geotechnical investigations. However, no comprehensive slope stability analysis had been conducted in previous design stages to verify the structural integrity and stability of the steep, high slopes.

Figure 1. Construction progress photograph of the slope.

The site is characterized by complex and challenging geological, environmental, and seismic conditions. A major north–south trending fault zone intersects the excavation pit centrally. This fault zone is approximately 35 m wide and comprises highly weathered syenogranite with multiple sub-faults, classified as poor-quality rock mass. The regional geology includes intrusive igneous formations, predominantly brownish syenogranite and greyish monzogranite, intersected by numerous dykes with horizontal and vertical thicknesses ranging from 1 to 5 meters. The dykes are generally oriented E-W and NE-SW with steep dips of 70° to 85°. In addition, a dense network of structural lineaments consisting of highly fractured and decomposed rock was identified.

The key geomechanical parameters of the major lithological units are summarized in Table 1.

Table 1. Summary of intact rock parameters (uniaxial compressive strength (UCS), Young’s modulus (Ei) and Geological Strength Index for dry conditions (GSI).

Rock Unit	UCS [MPa]	E_i [MPa]	GSI [-]
Syenogranite	50	13,000	55-65
Monzogranite	55	14,000	55-65
Dyke	50	14,000	50-60
Fault	7	3,500	25
Lineaments	30	10,000	35-50

Based on the developed geological/geotechnical subsurface model a comprehensive slope stability analysis was performed. These analyses accounted for structural loading from the planned superstructure, acting on multiple berm levels, as well as seismic loading corresponding to a design-level earthquake with a return period of 2,475 years. The seismic action was defined through a site-specific probabilistic seismic hazard assessment, which yielded a horizontal peak ground acceleration of 0.284 g.

The applied analysis methodology combined both two-dimensional and three-dimensional approaches and included the following:

- Kinematic Analysis using Dips, RocPlane, Swedge, RocTopple, and RocSlope2 (Rocscience Inc, 2024), to assess the potential for structurally controlled failures such as planar, wedge, and toppling failures. This analysis was based on the orientation and spatial distribution of discontinuities in relation to the slope geometry.
- Finite Element Analysis (FEA) using RS2 and RS3 (Rocscience Inc, 2024), to numerically simulate stress-strain behavior and deformation within the slope, particularly in deeper-seated failure zones. Both isotropic FEA – assuming uniform and direction-independent material properties – and anisotropic FEA – accounting for direction-dependent stiffness and discontinuity effects – were conducted to capture the influence of jointed granite rock mass characteristics.
- Discrete Element Analysis (DEA) using UDEC^{TM} (Itasca Consulting Group Inc, 2023) to model the rock mass as an assembly of individual blocks separated by discontinuities. This method allowed for the simulation of complex failure mechanisms, including block separation, sliding, and rotation, which are particularly relevant in highly jointed or blocky rock formations and cannot be adequately represented using continuum-based methods.

To ensure sufficient slope stability under static, pseudo-static, and dynamic loading conditions, a comprehensive and locally optimized support system was developed in an iterative process for the entire excavation. The system comprises the following key components:

- Tensioned strand anchors, consisting of 7- and 10-strand tendons (15.7 mm diameter) with design loads of 1,170 kN and 1,670 kN respectively. Anchors were installed with reinforced concrete block heads (1.1×1.1×0.75 m), at lengths between 40 to 85 m, and in grid patterns varying from 6×6 m to 3×3 m depending on local stability requirements. The total installed anchor length exceeds 290,000 m (approx. 4,500 anchors).
- Untensioned rock dowels, with diameters ranging from 25 to 40 mm and lengths between 12 and 15 m, were used to stabilize shallow slope instabilities, including local wedge and block failures. These were installed in a regular 2×2 m pattern, totaling approximately 480,000 m in length (approx. 39,000 dowels).
- Perforated drainage pipes, each up to 20 m long, were installed to relieve water pressure during periods of precipitation or snowmelt. Installed in a 6×6 m pattern, the total drainage length amounts to approximately 120,000 m (approx. 8,000 pipes).
- A heavily reinforced concrete plate, 75 cm thick, 80 m long, and 10 m high, was constructed across each berm to span the central fault zone. It is anchored into the rock mass using tensioned strand anchors installed at 3×3 m intervals to ensure structural continuity across the weak zone.
- Slope surface protection, adapted to the degree of weathering, includes either a 20 cm layer of shotcrete reinforced with two layers of welded wire mesh, or high-tensile twisted rectangular steel mesh anchored with rock dowels, to prevent weathering-induced surface degradation and shallow failures.

Given the irregular excavation geometry, marked by step changes, recesses, kinks, and multi-level transitions and the complexity of installing more than 40,000 anchoring and 8,000 drainage elements within a constrained construction schedule, the implementation of a comprehensive Building Information Modeling (BIM) strategy was essential. BIM enabled:

- Efficient coordination among disciplines and project stakeholders
- Automated clash detection and constructability reviews
- Streamlined generation of construction drawings and quantity take-offs
- Centralized integration and visualization of geological, geotechnical, and structural data

From the designer's perspective, the integration of all relevant data into a centralized BIM environment significantly enhanced the design as well as construction process, facilitating iterative optimization and improved decision-making.

Apart from the technical complexity, the Project is subject to strict BIM requirements defined by the employer. These requirements define the specifications for the creation, exchange, and management of information throughout the Project's lifecycle. They specify both the geometric and non-geometric information to be included in the models.

3 BIM INTEGRATION IN GEOTECHNICAL DESIGN

3.1 *Geological Modeling*

The geological model for the Project was developed using Leapfrog Works (Seequent, 2024), a specialized 3D geological modeling software designed for subsurface characterization based on various available geological data. Unlike traditional explicit modeling methods, Leapfrog employs an implicit modeling approach, which relies on mathematical interpolation techniques to generate continuous geological surfaces from discrete data points, such as lithological contacts recorded in boreholes or from mapped structures.

All available geological and geotechnical site data, including borehole logs, surface mappings, geophysical surveys, and geological maps, but also topographical data and civil infrastructure geometry, were imported into the modeling environment. The software integrates these datasets to construct 3D geological surfaces and volumes that represent key subsurface features such as lithological units, faults, dykes, aquifers, and structural lineaments. Once the initial model is generated, it undergoes a manual validation and refinement process by an experienced geologist to ensure geological plausibility and consistency with field observations and conceptual understanding.

An important advantage of Leapfrog's dynamic modeling framework is its ability to incorporate new data throughout the design and construction phase. As additional boreholes are drilled, slope faces are exposed, or monitoring data becomes available, the model can be updated in near real-time to reflect the evolving understanding of the subsurface conditions.

The resulting 3D geological model provides a comprehensive spatial visualization of the underground conditions, including the distribution of rock types, structural discontinuities, and geomechanical parameters, which are essential for geotechnical design and slope stability assessment. An example of the current state of the geological model is illustrated in Figure 2.

For integration into the broader project environment, the Leapfrog model is exported in Industry Foundation Classes, IFC (buildingSMART International, 2017) format and uploaded to the Autodesk Construction Cloud®, ACC (Autodesk Inc, 2023). This allows seamless interoperability with BIM workflows and enables multidisciplinary teams to access, coordinate, and utilize the geological model for further design development.

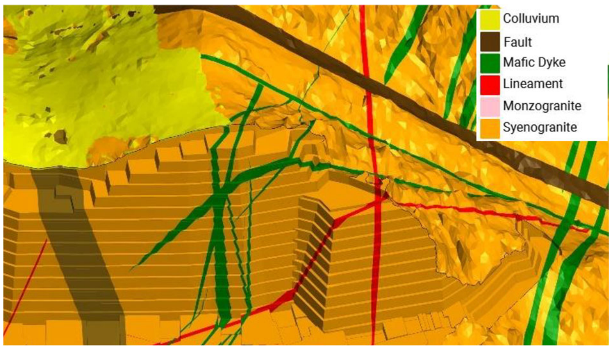


Figure 2. 3D view of the geological underground model (Leapfrog)

3.2 *Geotechnical Analysis*

The geotechnical design approach for ensuring slope stability was based on detailed two-dimensional cross-sectional analyses, which were subsequently validated through corresponding three-dimensional simulations. Over 35 representative cross sections were created at geologically and geometrically critical locations across the entire excavation area. These sections, exported directly from the BIM model, served as the basis for advanced 2D numerical analyses.

The analyses encompassed a comprehensive range of loading scenarios, including static, pseudo-static (with seismic effects represented as equivalent static forces), and fully dynamic conditions. Appropriate constitutive models (e.g. Generalized Hoek-Brown Criterion) were employed to capture the mechanical behavior of the rock mass, incorporating rock properties, joint set orientations, and discontinuities. The Geological Strength Index (GSI) was used to derive rock mass parameters from laboratory-derived intact rock values, accounting for structural degradation due to jointing and weathering. Disturbance zones were defined to reflect strength and stiffness reductions caused by blasting and excavation-induced damage. All numerical simulations were based on a staged construction sequence, realistically modeling the sequential excavation steps and timely installation of slope support systems.

Each two-dimensional analysis was refined through an iterative process to ensure compliance with the required factor of safety (≥1.5 for static and ≥1.1 for seismic loading), while also verifying that the resulting deformations and strain levels remained within acceptable limits. Figure 3 shows a representative analysis setup featuring the anisotropic material model, including geological units and the applied support measures. The corresponding deformation response and calculated factor of safety for the same model, analyzed using RS2 (Rocscience Inc, 2024), are illustrated in Figure 4.

To validate the 2D findings and assess three-dimensional effects, selected slope sections were further analyzed using 3D FEA. These analyses confirmed that displacements and stress concentrations were adequately captured and controlled. In parallel, the results of the kinematic analyses for various slope orientations were combined with the numerical findings to define the required layout of the support measures.

Based on the overall analysis, geotechnical engineers prepared detailed sketches specifying the extent, grid spacing, inclination, lengths, and diameters of anchors and dowels. These specifications were then handed over to the BIM modeling team, who integrated the support elements into the 3D model of the excavation pit. Each component was enriched with structured data to support construction planning and execution.

To manage the complexity of modeling and documenting over 40,000 anchors, automated scripts were employed. These scripts placed each anchor in the model at its exact spatial location with the correct orientation, inclination, and length, ensuring consistency between the geotechnical design and the digital construction model.

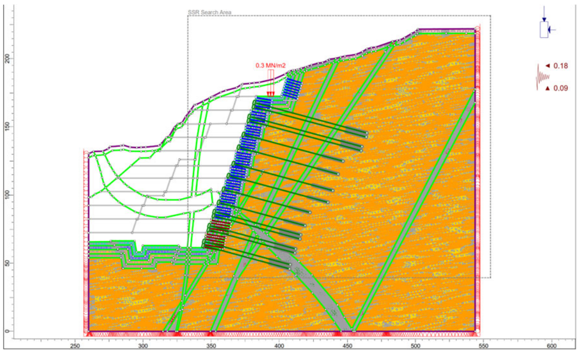


Figure 3. Anisotropic model illustrating geological units, applied loads, staged excavation sequence, and anchor layout.

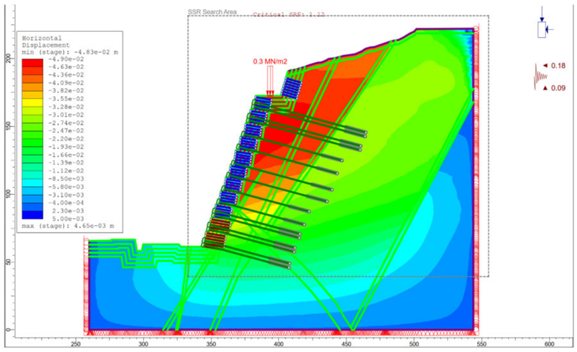


Figure 4. Deformation plot and calculated factor of safety from 2D slope stability analysis using RS2 (Rocscience).

3.3 *Data Transfer to BIM*

To ensure seamless integration between geological modeling and BIM workflows, geological surfaces and volumes generated in Leapfrog Works are exported both as point clouds (e.g., CSV or DXF formats) and as IFC files. These formats enable interoperability across various BIM platforms, including Revit® and Civil 3D® (Autodesk Inc, 2023).

Before export, it is ensured that the geological model is aligned with the project's global coordinate system to ensure spatial consistency. Once exported, the IFC file can contain both the geometric representation of geological units and associated metadata, such as lithological classifications and geotechnical parameters.

In Revit, the IFC geometry is primarily used for visualization and coordination purposes. In Civil 3D, the exported point data can be further processed to generate surfaces and cross-sections for detailed analysis.

The alignment process ensures that geological features-such as faults, dykes, and lithological boundaries correspond accurately with the excavation layout and the design of slope support systems. This integration allows multidisciplinary teams to access and utilize geological data directly within the BIM model, supporting design coordination, clash detection, and construction planning.

4 DESIGN COORDINATION AND DOCUMENTATION

Following the geotechnical analysis, the design was implemented into the BIM environment to support construction planning and documentation. All rock support elements, including anchors and monitoring devices were modeled in Revit, see Figure 5. Given the large volume of elements, custom scripts were developed and deployed to automate their placement and parameterization, significantly reducing manual effort and minimizing human errors.

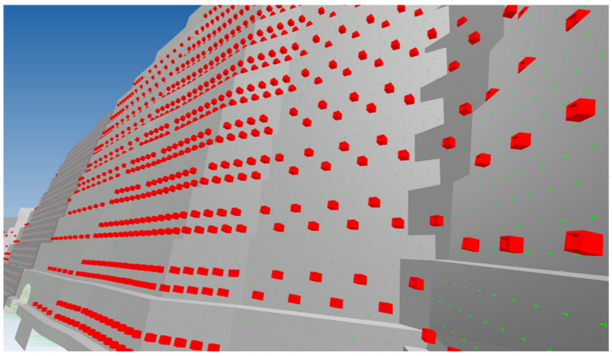
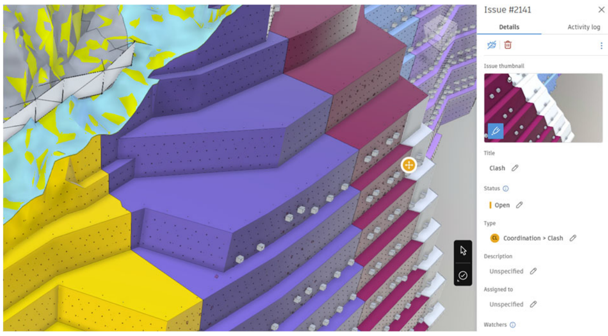


Figure 5. Screenshot of BIM model showing a front view of the slope.

To ensure a clash-free model, Navisworks® (Autodesk Inc, 2023) was used to perform automated clash detection. Each element was assigned a parametric buffer zone to take construction tolerances into account, allowing for more realistic spatial coordination and reducing the risk of conflicts during construction. As part of the Project's BIM requirements, specific clash checks between different element categories were mandated. The resulting clash reports were generated and submitted regularly to the Project's BIM management team.

All models, including the geological model developed in Leapfrog, were uploaded to the ACC platform. This centralized environment enabled interdisciplinary model reviews, issue tracking, and collaborative design coordination. Project stakeholders could access the models, review design elements, and comment on potential issues in real time. Figure 6 illustrates how clash detection and issue management are handled within the ACC platform, providing a visual overview of how conflicts between elements are identified, tracked, and resolved during the coordination process.



Title
Clash

Status
Open

Type
CL Coordination > Clash

Description
Unspecified

Assigned to
Unspecified

Figure 6. Issue coordination within ACC platform.

One of the primary uses of the BIM models was the generation of construction documentation, such as drawings and quantity schedules. These outputs were automatically derived from the model and included critical information such as element coordinates, types, material properties, and installation details. Similarly, element lists were generated to support procurement and construction planning. Any changes made to the model were automatically reflected in the associated drawings and schedules, ensuring consistency between design and documentation and reducing the risk of discrepancies on site.

A sample of the automatically generated 2D construction drawings, including anchor layout and installation details, is shown in Figure 7, illustrating how model data is directly translated into site-ready documentation

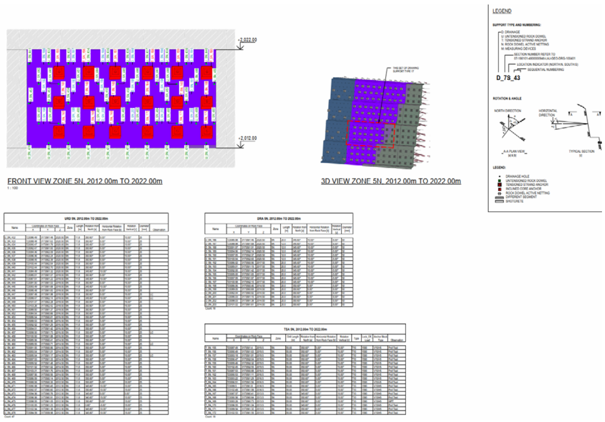


Figure 7. 2D drawing automatically generated from the BIM model.

5 MONITORING AND FEEDBACK INTEGRATION

5.1 *Instrumentation*

An essential component of the slope support design for the Project is the installation of geotechnical instrumentation and the continuous monitoring of slope behavior. This monitoring plays a critical role in ensuring construction safety and validating the design assumptions. Instrumentation provides early detection of displacements or changes in slope behavior, enabling timely implementation of mitigation measures or evacuation procedures before a failure occurs.

Even with a state-of-the-art design, slope behavior may deviate from predictions due to stress redistribution or unforeseen geological conditions. Real-time monitoring allows for the assessment of the effectiveness of installed support systems and enables validation of numerical models and design assumptions. If deviations from expected behavior are detected, the design can be adaptively refined during construction to prevent overstressing of support elements or failure risks.

Depending on the anticipated slope behavior and site-specific conditions, a comprehensive array of instruments is installed, including vibrating wire in-place inclinometers, multiple-point borehole extensometers, optical targets (survey prisms), load cells on anchors, joint meters, ground-based interferometric radar, vibrating wire piezometers, seismographs, and a meteorological station.

Figure 8 illustrates the monitoring devices that are installed at one part of the excavation (in total 1,500 devices are currently installed), each of which continuously transmits real-time data to the centralized online platform Proqio.com (Encardio-Rite Group, 2024).

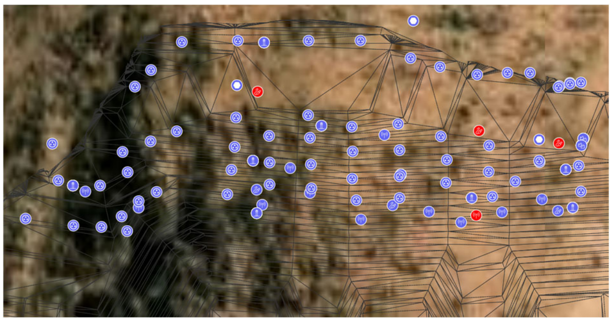


Figure 8. Plan view of the project site showing the installed instrumentation devices (blue dots); approximately 50% of the excavation has been completed.

5.2 *Monitoring Platform*

The online monitoring platform serves as the central interface for collecting and visualizing data from all installed devices. It enables the definition of alert thresholds for each instrument, facilitates the automated generation of plots (e.g., displacement profiles from inclinometers or optical targets, see Figure 9, or load trends in anchor load cells), and supports cross-correlation of various sensor types. This assists geotechnical and geological experts in interpreting the slope's behavior holistically.

Based on the monitoring data, weekly and monthly reports are compiled. In case of anomalies or exceedance of alert thresholds, corrective measures, such as the installation of additional tensioned strand anchors, are immediately reassessed using finite element (FEA) and discontinuum (DEA) analysis methods.

Simultaneously, the geological underground model, the excavation progress, support installation records, and visual inspection reports are updated in the BIM model. This integrative approach ensures that all available data sources are correlated, improving data reliability and enhancing the understanding of actual slope performance.

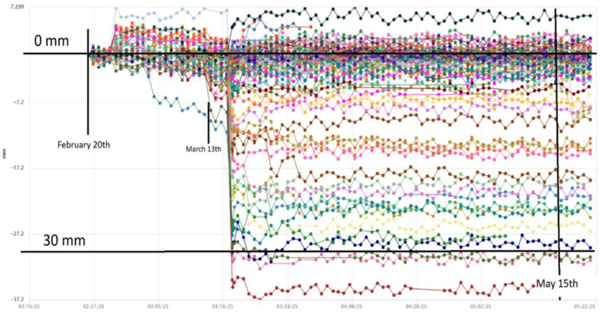


Figure 9. Temporal progression of vertical deformation measured by optical targets in a designated excavation pit area.

5.3 *Data Integration*

While direct integration of real-time monitoring data into the BIM environment is currently limited due to platform separation, however, the insights derived from monitoring are actively used to update the BIM model. Any required design adaptations based on monitoring feedback are communicated immediately to the contractor's on-site team to enable rapid implementation. In parallel, the BIM model and all associated design drawings are revised accordingly and shared with the employer for review and approval. This ensures that any changes in the excavation or support strategy are fully coordinated and transparently documented within the digital project environment.

6 AS-BUILT VERSUS DESIGN COMPARISON

Throughout construction, the actual excavation progress is regularly captured using drone-based photogrammetry. Comparing the as-built excavation geometry with the design model is essential for verifying accuracy and compliance. Overbreak beyond the theoretical excavation profile, caused, for example, by unfavorable joint orientations or blasting inaccuracies, can impact the local stability in hanging or over steepened slopes, reduce the bearing capacity due to geometric changes, and affect long-term durability. As a result, any significant deviations must be assessed through updated geotechnical analyses based on the actual excavation geometry. Even minor discrepancies can influence anchor performance and overall stability.

The drone scans are processed using photogrammetry software and then aligned with the Project's coordinate system and processed into 3D models. These models are then compared with the design BIM models to identify deviations and discrepancies.

A range of methods is used for this comparison, from visual inspection of the 3D models to detailed drawing-based analyses focused on specific areas of interest, see Figure 10. When significant deviations are identified, they are documented and reviewed by the design team. In some cases, the geotechnical analysis is updated to reflect the actual geometry, and support measures are adjusted accordingly. This feedback loop ensures that the design remains aligned with actual site conditions throughout construction.

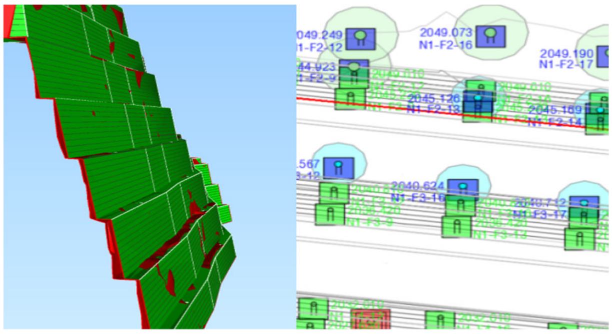


Figure 10. Left: Design (green) versus as-built (red) excavation surfaces. Right: Anchor placement deviations, bubble size indicates magnitude.

7 CONSTRUCTION SUPPORT AND CHANGE-MANAGEMENT

During construction, certain elements, such as anchors or instrumentation devices, often need to be relocated or adjusted due to unforeseen site conditions or geological variations.

When such changes are necessary, the contractor submits a request referencing the specific element by its unique identifier. The design team evaluates the proposed relocation and updates the element's position within the BIM model to reflect the new site conditions. Especially in areas with high element density, multiple locations are explored to identify a feasible position that maintains constructability and avoids conflicts. A clash check is performed to ensure that the new location does not interfere with other elements or structural components.

In these cases, the advantages of working within an accurate 3D model environment become especially clear. Unlike traditional 2D drawings, the 3D BIM model provides spatial awareness and context (as shown in Figure 11), allowing the design team to assess potential conflicts and constraints more effectively. This leads to faster decision-making and more reliable placement of elements.

Once a suitable location is confirmed, the element's information, such as coordinates and orientation, is automatically updated in the BIM model. The revised data is then issued to the site team for implementation. This process ensures that new, clash-free locations can be identified efficiently and with precision, minimizing delays and maintaining alignment between design and field conditions.

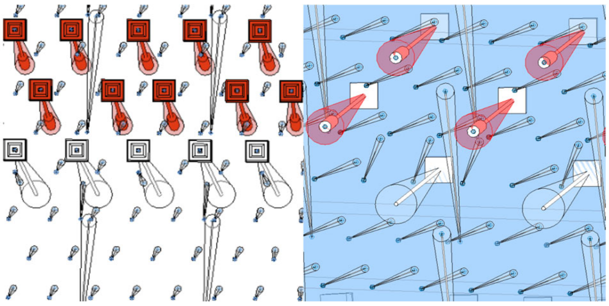


Figure 11. Optimized placement of additional anchors in clash-free locations enabled by the BIM model.

8 BENEFITS AND LIMITATIONS

8.1 *Efficiency Gains*

The integration of BIM significantly improved the design and coordination across different teams and project phases. Automated clash detection, centralized model access, and issue tracking reduced the need for manual checks and repetitive communication. The use of custom scripts for anchor placement and data updates accelerated design iterations and minimized human error. As a result, design decisions could be made faster, and construction activities proceeded with fewer interruptions and less rework.

A major contributor to these gains was the use of an accurate and information-rich 3D model. It enabled intuitive visualization of complex excavation geometries and extensive support systems, allowing the team to quickly understand spatial relationships and construction constraints. Furthermore, essential information such as anchor coordinates, types, and installation details could be extracted directly from the model, reducing the risk of inconsistencies and streamlining the generation of construction documentation.

8.2 *Accuracy Improvements*

By integrating geological, geotechnical, and structural data into a unified BIM environment, the project team was able to maintain a high level of accuracy throughout the design and construction process. Early integration of geological data proved critical for minimizing downstream design changes. The use of 3D geological models ensured that support systems were tailored to actual subsurface conditions. The ability to visualize and analyze complex geometries in 3D provided a level of spatial understanding that would not have been possible with traditional 2D methods.

8.3 *Limitations*

Despite the clear benefits, limitations were also encountered:

- To determine the necessary support measures and factors of safety in a highly constrained schedule, initial slope stability analyses must be conducted in two dimensions (2D). Fully integrated three-dimensional (3D) analyses remain highly time-consuming and computationally demanding. Therefore, they are typically used only for subsequent verification, rather than initial design.
- Current geotechnical software offer limited support for data exchange with the BIM model. RS2 accepts 2D data imports via DXF format, which transfers only geometric information and does not include non-geometric data such as material properties. RS3 offers improved compatibility by supporting the import of 3D solid geometry, allowing for better integration with BIM models. However, it still lacks the ability to incorporate non-geometric data. As a result, full interoperability between geotechnical analysis tools and BIM platforms remains a challenge, often requiring manual input and coordination across software environments.
- Integration of monitoring data into the BIM model remains largely visual, with no direct link between BIM elements and sensor outputs. However, it is worth noting that other platforms on the market do offer more advanced support for sensor connectivity, enabling sensor data to be directly linked to model elements.
- The practical use of BIM on-site was constrained by construction equipment limitations and the need for simplified outputs, such as printed 2D drawings and exported lists of elements, for field teams.

These challenges highlight the need for further development of BIM tools tailored to geotechnical applications and improved interoperability between platforms.

9 CONCLUSIONS

The integration of Building Information Modeling (BIM) into large-scale geotechnical projects, illustrated by this deep excavation case study, has substantially improved design quality, enabled precise bills of quantities for material procurement, increased construction efficiency, strengthened cost control, facilitated comparisons between planned and actual progress, and enhanced interdisciplinary coordination. By consolidating geological, geotechnical, and structural data within a single digital environment, BIM provided accurate 3D visualizations, streamlined data exchange, and automated workflows, thereby supporting complex decision-making among the designer, contractor, and employer.

Despite clear benefits, limitations remain, particularly in software interoperability and real-time data integration. BIM proved to be a powerful enabler for managing complexity, reducing errors, and maintaining alignment between design and as-built conditions. The use of custom scripts, clash detection, and model-based documentation further increased reliability and reduced design iterations.

This project underscores the transformative potential of BIM in geotechnics and highlights the need for continued development of BIM-enabled tools, improved interoperability, and deeper integration of monitoring data to support future digital workflows in underground and slope engineering.

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