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3D Modeling Techniques and Applications of Geological Cross-Section Maps: A Case Study of the Shimen Interconnecting Pipeline Tunnel

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Abstract: This study proposes a semi-automated workflow integrating ArcGIS, Python, and Leapfrog Geo to convert traditional 2D geological cross-section maps into detailed 3D models, using the Shimen Interconnecting Pipeline Tunnel as a case study. The approach enhances spatial visualization and interdisciplinary communication, and the resulting models can be imported into PLAXIS for tunnel deformation and support analysis. The study also emphasizes that model quality depends on the completeness of field data and recommends establishing standardized geological databases and automated conversion tools to improve model consistency and applicability.

Keywords: ***Tunnel geological mapping, 3D modeling, Leapfrog.***

Introduction

Traditional tunnel geological documentation relies on manual drafting of geological maps and excavation profiles, which often fail to convey the spatial relationships of rock mass structures, hindering interpretation and interdisciplinary collaboration. With the rise of Building Information Modeling (BIM), and its extension into Tunnel Information Modeling (TIM), engineering workflows are evolving toward integrated, automated, and real-time design verification (Werkgarner et al., 2024; Barbieri et al., 2024; Rich et al., 2023). This study proposes a workflow combining ArcGIS, Python, and Leapfrog Geo to convert 2D tunnel geological maps into 3D geological models. Using the Shimen Water Conveyance Tunnel as a case study, the approach enhances visualization, improves communication across disciplines, and supports more efficient design and construction decisions.

3D modeling of geological cross-section

Project summary

The tunnel begins at the western access road of the Shimen Dam and extends southwestward to Guanxi Town in Hsinchu County, traversing Mt. Taiping and Mt. Shimen along its alignment. The total length of the tunnel is approximately 3.3 km. The geological longitudinal profile along the tunnel route is shown in Figure 1 (MOEA, 2023). The tunnel passes through the Shihdi Formation (St, mainly shale, gray part in Figure 1) and the Nanchuang Formation (Nc, mainly fine sandstone, green part in Figure 1) and intersects the Shimen Fault near its midpoint. The estimated length of the fault fracture zone is approximately 500 m.

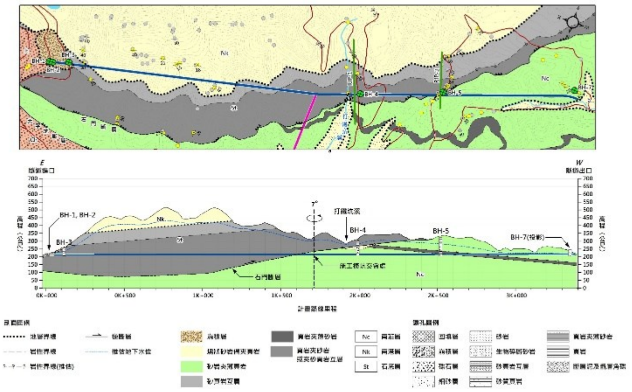

Figure 1, Geological profile of the tunnel.

3D spatial positioning of geological cross-section maps

This study is based on the geological cross-section map of the tunnel segment from chainage 0K+000 to 0K+200 (Figure 2). Geological data, including stratigraphic boundaries, fractured zone distribution, and groundwater inflow locations—were digitized and archived, then imported into ArcGIS software. The centerline of tunnel crown was georeferenced, corrected, and converted into point and linear features in .SHP(ZM) format. Subsequently, the digitized data were projected into 3D space according to the actual tunnel cross-sectional shape (inverted D-type) and dimensions (clear span of 5.6m and height of 5.6m).

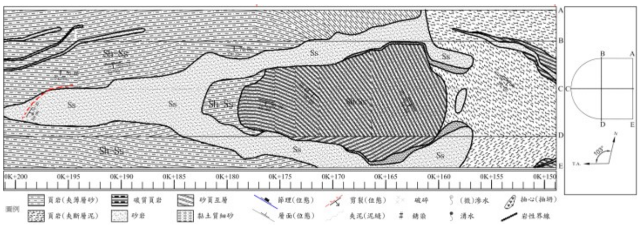

Figure 2, Geological cross-section map (0k+150 to 0k+200).

3D geological modeling

Based on the spatial distribution of data in the tunnel cross-section model (Figure 3), geologists interpreted stratigraphic sequences, filtered and grouped linear features, and preliminarily generated implicit surfaces for each formation. Contact relationships—such as erosion, pinch-out, and faulting—were analyzed to progressively build a complete lithological sequence.

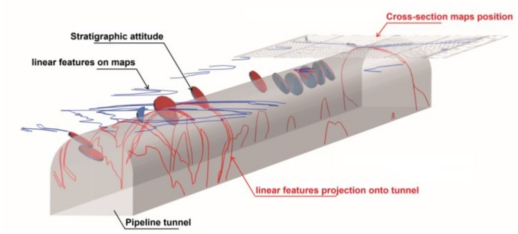

Figure 3, 3D tunnel cross-section model.

By applying the edited implicit surfaces to the blank tunnel model, geological units—including surrounding rock, excavation zones, and key structural blocks—are segmented and assigned geotechnical properties based on field surveys and lab-derived mechanical parameters (Figure 4), forming a 3D tunnel model.

Refined model blocks from Leapfrog Geo can be imported into PLAXIS to build stratified models for finite element analysis, supporting simulations of tunnel deformation (e.g., crown settlement, radial convergence), initial support, and lining reliability. Using Leapfrog's 2D section analysis, selected geological profiles are exported in .DXF format and directly imported into PLAXIS 2D to reconstruct stratigraphy for mesh geometry. For PLAXIS 3D, implicit surfaces are exported as standard formats (e.g., .OBJ or .STL) to define 3D geological bodies.

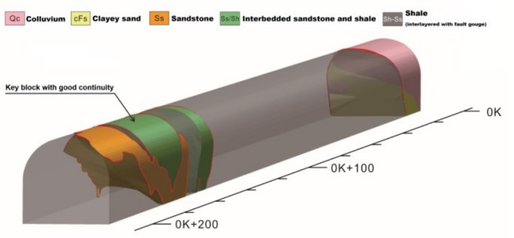

Figure 4, 3D geological model of the tunnel.

Discussion and suggestions

This study presents a 3D digital workflow for tunnel geological data, integrating ArcGIS, Python, and Leapfrog Geo to efficiently convert traditional geological cross-section maps into detailed 3D models. The process automates coordinating transformation and projection, and applies implicit modeling to generate continuous geological surfaces, significantly reducing modeling time and manual errors while enhancing interdisciplinary communication and decision-making. The resulting 3D model supports dynamic updates, allowing geologists to rapidly iterate based on new excavation data and forward exploration, enabling early prediction of rock mass conditions and support requirements. The model can be imported into PLAXIS for structural and deformation analysis, helping engineers work with realistic geological conditions and improving the accuracy of simulation results. Two main challenges remain: (1) reliance on the quality of field geological records, where missing or inaccurate data can reduce model reliability; and (2) the need for case-specific adjustments due to variations in tunnel designs and mapping styles. To address this, the study recommends standardizing geological data protocols and creating automated conversion tools to ensure consistency.

Conclusion

This study introduces a semi-automated 3D geological modeling workflow for tunnels, integrating ArcGIS, Python, and Leapfrog Geo to convert planar geological data into detailed 3D models with engineering parameters. The approach improves modeling speed and accuracy, allows dynamic updates with new geological inputs, and enhances adaptability during design and construction, promoting interdisciplinary integration and more efficient tunnel engineering practices.

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