

Applications of LLM in Geotechnical Engineering: Use it or lose

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GEOPROFESSIONAL BUSINESS ASSOCIATION

In the ever-evolving landscape of the geoprofessional industry, artificial intelligence continues to drive innovation, efficiency, and curiosity. This article is the final in a six-part series written to educate Geoprofessional Business Association (GBA) members on the implications of AI on the geoprofessions. The article was prepared by GBA Business Technology Committee member, Enrique Farfan, PhD, PE, ENV SP, of HDR.

OpenAl has raised a total of \$11.3B in funding. Google, on the other hand, will

invest \$100 billion in Al. Elon Musk's xAl has secured a \$6B investment for Al development; Meta plans to invest up to \$40B to develop its version of OpenAl.

The engineering consultant industry in the U.S. generates \$208B in annual revenues, while the AI market's current value is estimated to be

\$184B and could reach \$1.8 trillion by 2030.

Generative AI has been in the news, with many examples of how this technology can transform industries, processes, and businesses. The primary sectors transformed by generative AI are customer service, healthcare, legal services, and business processes.

One application of AI that is very captivating is the story of AlphaFold. This AI system was developed by Google DeepMind and can predict the 3D structure of proteins based on their amino acid sequences, solving a long-standing challenge in biology. It uses deep learning to achieve remarkable accuracy, comparable to experimental methods like X-ray crystallography, but much faster and cheaper. Since its breakthrough in the 2020 CASP (Critical



Assessment of Structure Prediction) competition, AlphaFold has revolutionized areas like drug discovery and understanding diseases related to protein structure. DeepMind also released a public database containing predictions for nearly all known proteins, greatly accelerating research in the biological sciences.

AlphaFold was featured in the

December 2021 edition of Science magazine as a breakthrough of the year. So, the question is – how can generative AI benefit the field of geotechnical engineering? Applications of classic AI in geotechnical engineering have been attempted and developed by many scientists and engineers with different degrees of success. Examples of these applications are presented in the first edition of this series of articles dedicated to AI in geotechnical engineering (refer to the GBA NEWS website article dated April 12, 2024).

The article titled "Why Al Models for Predicting Soil Liquefaction Have Been Ignored, Plus Some That Shouldn't Be" by Brett W. Maurer and Morgan D. Sanger examines the reasons behind the lack of adoption of Al-based models for predicting soil liquefaction in geotechnical engineering. Despite the growing number of Al models in the literature, they have not gained traction among practitioners. The authors identify several shortcomings of these models, such as the lack of comparison to state-ofpractice (SOP) models, deviation from best practices in model development, and

presentation in overly complex or inaccessible ways. Additionally, many AI models are not made available for practical use, further hindering their application.

If you train the model with images, it can generate new images. If you train the model with molecules, it will generate new molecules.

raster geotiff and shape files using the application PyTorch, a machine learning library for Python.

In the latest Goldman Sachs report titled "Gen AI: too much spend, too little benefit?" dated June 25, 2024, they noticed that while there has been a massive \$1 trillion investment in AI capital expenditures, the returns remain uncertain. There are diverging views on AI's potential economic impact, with estimates ranging from a modest 0.5% to a more optimistic 9% increase in U.S. productivity. However, AI adoption is fraught with challenges, requiring robust data infrastructure, advanced chips, and immense power to function effectively. Additionally, there is skepticism surrounding Al's costeffectiveness, as the costs of implementation may outweigh the perceived benefits in the short term. Lastly, the longterm outlook raises questions: Are we inflating an AI bubble, or will this technology

drive substantial productivity gains over time?

A simplified view of the capabilities of generative AI to start understanding the potential applications of this

technology in civil engineering can be summarized as follows:

If you train the model with images, it can generate new images. If you train the model with molecules, it will generate new molecules.

A large language model (LLM) can be the perfect assistant for a geotechnical engineer enhancing our capabilities. The LLM can enhance a geotechnical engineer's capabilities like an exoskeleton.

Here are some of the LLM applications that you can apply to your everyday:

On the other hand, a new plugin for QGIS (the open version for ArcGIS) developed by Brendan Ashworth uses AI to allow users via API to automatically vectorize linework from raster maps. The app can trace entire features in a map with two clicks, saving countless hours that will require doing it by hand. In a video published on his LinkedIn account, Ashworth mentions that to get a good performance of the applications, he needed to train the neural network with 1.1 million parameters. The AI was trained using

1. Data Analysis & Calculations

- Explaining and applying formulas related to soil mechanics (e.g., Terzaghi's bearing capacity theory, Mohr-Coulomb failure criterion).
- Helping with spreadsheet automation for repetitive engineering tasks.
- Assisting in writing code in different computer languages like Python or R.

2. Literature Review & Research

- Summarizing geotechnical papers, standards, or reports to extract key points.
- Assisting with finding relevant articles, papers, and reference materials on various geotechnical topics.
- Suggesting key textbooks, articles, or research material on specific geotechnical problems or topics (e.g., foundations, soil liquefaction, geosynthetics).

3. Soil Classification & Description

- Providing guidance on soil classification systems such as USCS (Unified Soil Classification System) or AASHTO (American Association of State Highway and Transportation Officials), including grain size distribution, plasticity, etc.
- Assisting in understanding laboratory and field test results, such as sieve analysis, Atterberg limits, or SPT (Standard Penetration Test) results.

4. Report Writing & Documentation

• Helping draft or review technical reports, including site investigation

reports, foundation recommendations, or geotechnical analyses.

- Assisting in drafting proposals or technical memos for clients or stakeholders.
- Proofreading and improving the clarity and technical accuracy of engineering documents.

5. Software Guidance

- Providing guidance on the use of geotechnical software (e.g., PLAXIS, GeoStudio, Rocscience tools) based on user manuals or general principles.
- Explaining methods to model specific geotechnical problems in simulation software.

6. Project Planning & Site Investigation

- Offering advice on designing and planning site investigation campaigns, including selecting proper drilling methods, sampling techniques, and in-situ tests (SPT, CPT, etc.).
- Providing recommendations for geotechnical instrumentation, monitoring techniques, and interpreting field data.

7. Environmental & Sustainability Considerations

 Assisting with environmental impact assessment for geotechnical works, such as evaluating ground contamination or environmental concerns related to excavation. Offering guidance on sustainable practices in geotechnical engineering, such as the use of recycled materials or minimizing environmental impact.

8. Foundation Design

- Assisting in the preliminary design of shallow and deep foundations, including footing, pile, and mat foundations.
- Providing theoretical support for the design and analysis of retaining structures (gravity walls, sheet pile walls, reinforced soil, etc.).

9. Slope Stability Analysis

- Explaining methods to assess the stability of natural or man-made slopes (limit equilibrium methods, finite element methods).
- Assisting in analyzing slope stability using standard geotechnical parameters (cohesion, angle of internal friction, pore water pressure).

10. Seismic & Dynamic Analysis

- Providing insights into earthquake engineering and the impact of seismic loads on geotechnical structures.
- Assisting with liquefaction analysis or soil-structure interaction under dynamic loading conditions.

11. Geotechnical Problem-Solving

 Suggesting solutions to practical geotechnical problems, such as settlement issues, ground improvement techniques (e.g., vibrocompaction, grouting), or groundwater control methods.

 Offering guidance on foundation challenges due to difficult soil conditions, such as expansive soils or collapsible soils.

12. Learning and Professional Development

- Providing learning resources and explanations on advanced geotechnical concepts for continuing education.
- Suggesting industry trends, certification courses, and updates to remain up-to-date in geotechnical engineering.

13. Code Compliance & Standard References

- Offering general advice on international codes and standards, such as Eurocode 7, AASHTO LRFD, and ASTM standards.
- Helping engineers interpret design guidelines, such as allowable stress design (ASD) or load and resistance factor design (LRFD).

14. Risk Analysis & Geotechnical Hazard Assessment

- Assisting in identifying geotechnical hazards like landslides, subsidence, or erosion.
- Offering insights into geotechnical risk management, including strategies for mitigating identified risks.

15. Collaboration & Communication

- Helping prepare presentations for stakeholders, clients, or team members on geotechnical findings and recommendations.
- Assisting in translating technical jargon into more understandable terms for non-engineers.

LLM can provide guidance, clarity, and support in all these areas, making geotechnical engineering tasks more efficient and accurate.

Here are some examples that you can try with ChatGPT that illustrate its capabilities:



Example 1: Reading from old drawings:

> From the attached figure, which corresponds to an old drawing showing the front sections of a building, what are the roof's dimensions?

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From the drawing provided, the roof's dimensions can be inferred from the "West Elevation" and "East Elevation" views.

- The length of the roof is marked as 22'-0" (22 feet).
- The depth of the roof overhangs from the walls on both the West and East sides. It extends
 4'-0" (4 feet) beyond the walls on the West elevation and 3'-0" (3 feet) on the East elevation.

Therefore, the roof dimensions are 22 feet in length and have a varying overhang depth of 4 feet on the West side and 3 feet on the East side. The total width is not explicitly stated, but based on the drawing, these overhangs suggest it covers the structure width of approximately 8'-6" (from the east elevation).

Let me know if you'd like further analysis or clarifications!

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Example 2: Developing a mind map for a geotechnical topic. This example requires using an external (free) application (markmap).

> Create a mind map of foundation settlements. List topics and central ideas, main branches, and sub-branches.

- > Generate the mind map in markdown format.
 - B Here's the mind map for Foundation Settlement in Markdown format:



•••

Copy the output (the markmap code)

Open the webpage markmap.js.org and copy the code generated by ChatGTP:



Example 3: Provide outline for calculation reports:

> Provide an outline for a pile group foundation calculations report:

Pile Group Foundation Calculations Report 1. Introduction

- 1.1 Purpose of the Report
 - Brief description of the objectives (e.g., to calculate the capacity and settlement of a pile group foundation for a specific project).
- 1.2 Project Overview
 - Location, type of structure, and foundation system required.
- 1.3 Scope of Work
 - Description of the pile group design process, including calculations for load capacity, settlement, and structural integrity.

2. Geotechnical Investigation

- 2.1 Soil Profile
 - \circ $\;$ Overview of soil conditions (e.g., soil types, layers, and depths).
 - 2.2 Soil Properties
 - Shear strength, bearing capacity, cohesion, angle of internal friction, etc.
 - 2.3 Groundwater Conditions
 - \circ Depth of the water table and its influence on pile behavior.

• 2.4 Site Investigation Results

• Borehole data, Standard Penetration Test (SPT) results, or Cone Penetration Test (CPT) results.

3. Pile Group Description

- 3.1 Pile Type and Material
 - Type (e.g., driven piles, bored piles) and materials (concrete, steel, timber).
- **3.2 Pile Dimensions**
 - Length, diameter, cross-sectional area.
- 3.3 Pile Spacing and Layout
 - Arrangement of piles in the group (e.g., square, triangular) and spacing between piles.
 - 3.4 Number of Piles in the Group
 - Total number of piles and their arrangement.

4. Load Analysis

- 4.1 Applied Loads
 - Dead loads, live loads, wind loads, seismic loads, etc.
 - 4.2 Load Distribution
 - Distribution of axial and lateral loads between piles in the group.
- 4.3 Load Combinations
 - Governing load combinations as per design codes (e.g., ultimate and serviceability limit states).

5. Capacity of Individual Piles

- 5.1 Axial Capacity
 - End bearing and skin friction (adhesion) calculations.
 - Use of formulas like Meyerhof, Terzaghi, or empirical methods.
- 5.2 Lateral Load Capacity
 - Lateral load capacity estimation using p-y curves or other methods.
- **5.3 Uplift Capacity (if applicable)**
 - Calculation of uplift resistance.

• 5.4 Pile Group Efficiency

• Calculation of group efficiency using factors like interaction between piles.

6. Pile Group Capacity

• 6.1 Vertical Load Capacity of Pile Group

- Summation of individual pile capacities with consideration for group effects (e.g., reduction due to pile-soil interaction).
- 6.2 Lateral Load Capacity of Pile Group
 - Estimation based on pile-soil interaction and pile arrangement.
- 6.3 Moment Capacity
 - Evaluation of the pile group's ability to resist bending moments.
- 6.4 Group Settlement
 - Calculation of settlement based on methods like elastic theory, load transfer models, or empirical correlations.
- 6.5 Pile Cap Design
 - Design of the pile cap to distribute loads across the pile group.

7. Settlement Analysis

- 7.1 Elastic Settlement
 - Calculation of settlement using elastic modulus and pile spacing.
- 7.2 Consolidation Settlement
 - Estimation of long-term settlement due to consolidation of the surrounding soil.
- 7.3 Differential Settlement
 - Assessment of potential differential settlement within the pile group.
 - 7.4 Allowable Settlement
 - Comparison of calculated settlement with allowable limits based on structural requirements.

8. Safety Factors and Code Compliance

8.1 Safety Factors for Load Capacity

- Application of safety factors for ultimate and serviceability limit states.
- 8.2 Code Compliance
 - Reference to applicable design codes (e.g., Eurocode 7, AASHTO, BS 8004).
- 8.3 Design Assumptions
 - Listing of assumptions made in the analysis (e.g., load distribution, soil homogeneity).

9. Conclusion and Recommendations

• 9.1 Summary of Calculated Results

- Key findings such as pile group capacity, settlement values, and safety margins.
- 9.2 Recommendations
 - Design recommendations, construction considerations, and any necessary remedial actions (if applicable).

• 9.3 Further Investigations (if required)

• Suggestions for additional testing or analysis based on uncertainties or specific site conditions.

10. Appendices

• A1. Calculation Sheets

- Detailed hand calculations or computer-generated results.
- A2. Soil Investigation Reports
 - Full geotechnical investigation report.
- A3. Design Code References
 - List of codes, standards, and regulations used.

• A4. Figures and Diagrams

• Pile group layout, pile cap design, and any other relevant drawings or diagrams.

Example 4: Get tips on Excel

> Provide a guideline to create an Excel spreadsheet to estimate the consolidation of a clay layer using Terzaghi theory:

Overview of Terzaghi's Consolidation Theory

Terzaghi's consolidation theory provides a way to estimate settlement over time as excess pore water pressure dissipates. The key variables are the **degree of consolidation (U)**, **time factor (Tv)**, **coefficient of consolidation (Cv)**, **layer thickness**, and **time**.

Step-by-Step Guideline to Create the Spreadsheet

1. Spreadsheet Setup

- Columns Needed:
 - Time (t) in days, months, or years.
 - Thickness of the clay layer (H).
 - Coefficient of Consolidation (Cv).
 - Degree of consolidation (U).
 - Calculated settlement (S).
 - Cumulative settlement over time.
 - Iterative calculation for time factor (Tv) and settlement.

2. Input Parameters Section

Create a section at the top of your spreadsheet for the input parameters:

Parameter	Symbol	Units	Value
Thickness of the Clay Layer	Н	meters (m) or feet (ft)	[User Input]
Coefficient of Consolidation	Cv	m²/year or ft²/year	[User Input]
Applied Load	ΔΡ	kPa or psf	[User Input]
Compression Index	Сс	unitless	[User Input]
Pre-consolidation Pressure	Рс	kPa or psf	[User Input]
Initial Void Ratio	eo	unitless	[User Input]
Initial Thickness of the Clay Layer	∙ H₀	meters or feet	[User Input]
Time Steps	t	days or years	[Calculated/Iterative]

This section will hold user-defined values that can be referenced in your calculations.

3. Time Factor (Tv) Calculation

• The **Time Factor** (**Tv**) is a non-dimensional number calculated using:

$$Tv = \frac{C_v \cdot t}{H_d^2} Tv$$

Where:

- **Cv** = Coefficient of consolidation (m^2 /year or ft²/year).
- **t** = Time (days, months, or years).
- **Hd** = Drainage path (half the thickness for double drainage, full thickness for single drainage).
- In your spreadsheet, calculate the **Time Factor** for each time step. Create a time column (t) and calculate **Tv** for each time step using the formula above.

4. Degree of Consolidation (U) Calculation

• The degree of consolidation (U) is related to the time factor and is typically derived from:

$$U = 1 - \sum \left(\frac{8}{\pi^2} \exp\left(\frac{-n^2 \pi^2 T_v}{4}\right)\right)$$

For simplicity, a commonly used approximation for degree of consolidation (U) is:

$$U \approx \frac{\sqrt{T_v}}{2}$$
 (for small values of Tv)

In your spreadsheet:

• Calculate **U** for each time step based on **Tv**.

5. Settlement Calculation (S)

• Final Settlement (S₀) is calculated using:

$$S0 = \frac{C_c \cdot H_0 \cdot \Delta P}{1 + e_0} S0$$

Where:

- **Cc** = Compression index.
- **H**_o = Initial thickness of the clay layer.

- \circ **\Delta P = Applied load**.
- $\mathbf{e_0} = \text{Initial void ratio.}$
- In your spreadsheet:
 - Calculate **S**₀ based on input parameters.
- The **Settlement at Time t** (St) is given by:

$$St = U \cdot S_0 St$$

Where U is the degree of consolidation at a particular time t.

• Calculate St (settlement at each time step) by multiplying U by the final settlement So.

6. Cumulative Settlement Calculation

• For each time step, the cumulative settlement **S_total** can be calculated by summing the settlement values from previous time steps or directly using the **St** values for the corresponding time.

7. Formatting the Spreadsheet

• Row Setup Example:

Time (t)	Tv	Degree of Consolidation	Settlement	Cumulative Settlement	
		(U)	(St)	(S_total)	
1 day	[Calculated]	[Calculated]	[Calculated]	[Cumulative Sum]	
1 week	[Calculated]	[Calculated]	[Calculated]	[Cumulative Sum]	
1 month	[Calculated]	[Calculated]	[Calculated]	[Cumulative Sum]	

• You can create time intervals (daily, weekly, monthly) as needed for accurate analysis.

8. Graphical Representation

- **Create a graph** showing **time (t)** on the x-axis and **cumulative settlement (S_total)** on the y-axis. This will give a visual representation of the settlement over time.
- Optionally, add a graph of **Degree of Consolidation (U)** vs. **Time Factor (Tv)**.

Additional Tips

- Use named ranges for key parameters like **Cv**, **H**, and **So** so you can easily reference them in formulas.
- Include checks for common errors, like dividing by zero or negative time values.
- Add comments or notes to key cells to explain the formulas used.

> Create the Excel spreadsheet with the equations

	Time (days)	Thickness of Clay Laye	Time Fact	
1	1	10	0.01	0.0001
2	7	10	0.01	0.0007
3	30	10	0.01	0.003
4	90	10	0.01	0.009
5	180	10	0.01	0.018
6	365	10	0.01	0.037
hav Dow Let r	re created the Excel synload Consolidation me know if you need	oreadsheet for you. Yo Calculations Spreadsh further adjustments or	ou can download it us eet r additional informatio	ing the following lin on! [›-]

ChatGPT creates the ready-to-use spreadsheet for you to download:

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	А		в	с	D	E	F	G	н	1	J K
1	Time (days)		Cv (m²/day)	Hd (m)	Tv	Degree of Consolidat	ic Final Settlement (S _o)	Settlement at Time	(S ₁ Cumulative Settleme	nt	
2		1			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Thickness of Clay Layer (H, m)	10
3		7			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Coefficient of Consolidation (Cv, m ²)	(day) 0.01
4		30			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Applied Load (ΔP, kPa)	50
5		90			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Compression Index (Cc)	0.25
6		180			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Pre-consolidation Pressure (Pc, kPa)	100
7		365			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Initial Void Ratio (e _o)	0.8
8		730			#VALUE!	#VALUE!	#VALUE!	#VALUE!	#VALUE!	Initial Thickness of Clay Layer (Ho, m	10
9											
10											
11											

You can explore other ideas that can enhance your capabilities, such as:

- Compare two design codes and provide a list of differences
- Review a design report using a LLM
- Generate Python or R programs
- Ask questions about modeling a slope stability problem using Geostudio
- Ask questions about using PLAXIS
- Ask to summarize a paper or report
- Role Play (see <u>last issue of</u> <u>this series</u>)

The possibilities are infinite and depend on your imagination. The uses of LLM will depend on individuals and companies that are willing to change and innovate. This Geotechnical Engineer 2.0 will have many advantages to tackle the everyday tasks and concentrate on the most important parts of the design.

Al is revolutionizing how we interact with technology, transforming industries, and reshaping the future of computers to analyze data, perform analysis, visualize, create content, and interpret our world. The future of AI in the field of geotechnical engineering is still to be discovered. The application of LLM could improve and revolutionize the way geotechnical problems are solved and approached; here is a glimpse into potential application in the geotechnical engineering field:

- 1. Site Characterization and Data Analysis
 - 2. Predictive Modeling
 - 3. Real-time Monitoring
 - 4. Risk Assessment
 - 5. Optimization of Designs
 - 6. Automated Reporting
 - Enhanced Simulations
- 8. Integration with other engineering fields
- 9. Remote sensing and drones
- 10. Augmented Reality (AR) and Virtual Reality (VR)
- 11. Data Mining

7.

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Though AI offers immense possibilities, it's vital to approach this technology cautiously without closing the doors to its potential use. Depending solely on AI without our intervention may result in oversights. A balanced blend of human know-how and AIguided perspectives is key to optimal outcomes using this new technology. The future of AI in the geotechnical engineering field is promising. Use it or Lose!

Previous Articles in the Series

- Al Unveiled: The Wizardry Behind Chatbots and Intelligent Systems
- How Large Language Models Work: In a nutshell
- The Ghost in the Machine: Hallucinations
- Superprompts: How to Talk with the Genie and Keep it in the Bottle
- Role-Play Your Way: How to Talk with Terzaghi

ABOUT THE AUTHOR



Enrique Farfan is a Geotechnical and Structural Engineer with a Ph.D. in Engineering and a Master's in Civil Engineering from the University of New Mexico. His expertise spans across various projects in mining, energy, water resources, and transportation, including work on dams, levees, canals, waterfront structures, bridges, foundations, and seismic analysis. Enrique has

implemented diverse design solutions using customized computer programs and database implementations. During his graduate years, he developed an interest in fuzzy logic, optimization, inverse problems, neural networks, and computer programming. Now, he enjoys exploring the fascinating universe of AI and its applications.