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GEOTECH 2.0: A New Age of Geotechnical Engineering

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ABSTRACT

In this keynote lecture, the pressing challenges facing today's geotechnical engineering, particularly regarding the unpredictability of soil and rock properties, are explored. The multifaceted nature of uncertainty and complexity in geotechnical solutions is examined, with emphasis placed on the need for precision, realism, economy, and sustainability. Emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins, and Metaverse are leveraged, showcasing their transformative potential in addressing these challenges. Through a comprehensive review of recent studies and real-life case studies, the benefits and disadvantages of these technologies in geotechnical applications are highlighted. A central focus is placed on the introduction of a novel Deep Learning-Physics-Informed Neural Network (PINN) approach for predicting the axial capacity of drilled shafts, which integrates empirical data with geotechnical principles. The findings underscore the promise of emerging technologies to revolutionize geotechnical engineering and usher in a new era of precision and sustainability.

1. INTRODUCTION

How far are today's geotechnical solutions precise, realistic, economical, and sustainable? This question lies at the heart of contemporary geotechnical engineering, a discipline grappling with the inherent unpredictability of its primary medium. The challenges associated with soil and rock are numerous, but they revolve predominantly around the central issue of uncertainty.

Uncertainty in geotechnical engineering arises from challenges on both micro and macro scales. On a macro scale, the fluctuations in soil properties vertically and horizontally across a site present significant hurdle. These fluctuations, influenced by factors such as geological formations and environmental conditions, contribute to spatial variability that is difficult to predict and model accurately. Meanwhile, on a micro-scale, the heterogeneous nature of soils poses another layer of complexity. At this level, soils exhibit variations in properties such as composition, moisture content, and stress history, creating intricacies that traditional methods struggle to capture effectively. Understanding and modeling this micro-level heterogeneity is crucial for predicting soil behavior under different loading conditions and ensuring the stability and safety of structures.

Addressing these challenges requires a multi-faceted approach that leverages emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins, and the Metaverse. By incorporating data from both micro and macro scales, these technologies may offer precise, realistic, and sustainable geotechnical solutions. AI algorithms, for instance, can analyze vast datasets encompassing both micro and macro-scale information to identify patterns and make predictions that account for the inherent variability of soils.

In recent years, the field of geotechnical engineering has witnessed a paradigm shift driven by the rapid advancement of emerging technologies. With the rise of Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins, and the Metaverse, a new age of geotechnical engineering is on the horizon. These cutting-edge technologies offer unprecedented opportunities to overcome longstanding challenges and revolutionize the way we understand, analyze, and mitigate risks associated with the Earth's subsurface.

2. EXPERIMENTAL RESULTS

The keynote lecture will delve into the main findings of several most recent studies in the literature on uncertainty and complexity resources, summarizing their profound impact on today's geotechnical engineering solutions. Through a comprehensive review, attendees will gain insights into the multifaceted challenges posed by the inherent unpredictability of soil and rock properties. Moreover, the lecture will highlight the innovative use of AI, IoT, Digital Twins, and the Metaverse in overcoming some of these challenges. In addition, to that some interesting results of using several emerging technologies in real-life case studies and the benefits and disadvantages of using such technologies. For instance, A novel approach of using Deep Learning-Physics-Informed Neural Network (PINN) in predicting the axial capacity of drilled shafts will be presented in comparison with the traditional data-driven machine learning models. The experimental work will highlight how the statistical robustness offered by data- driven machine learning models over theoretical methods could be misleading and how they tend to capture statistical correlations rather than underlying physical processes. Alternatively, the PINN that integrates the fundamental geotechnical principles directly into the machine learning process will be proposed.

3. FINDINGS

The case studies presented have shown how emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins, and the Metaverse can assist in overcoming many fundamental challenges in geotechnical engineering, including uncertainty, geospatial variability, and complexity, signaling the advent of a new age in geotechnical engineering. However, it is imperative to address the black box and data-driven nature of such tools to achieve robust and theoretically correct solutions. Models like the Physics-Informed Neural Network (PINN), with their dual focus on empirical data and geotechnical principles, introduce a novel paradigm that may lead to a more reliable framework for predicting soil behavior. Future research will likely extend this approach to larger datasets and more complex geotechnical applications, ensuring that machine learning tools not only predict with high statistical performance but also align with the fundamentals of geotechnical knowledge.

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