学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Bearing capacity of a shallow foundation on several types of ground with cavity under dry and unsaturated conditions based on Rigid Plastic Finite Element Method
(剛塑性有限要素解析に基づいた、様々な地盤および水理条件下における空洞が発達した地盤上の直接基礎の支持力評価)

Ensuring the stability and load-bearing capacity of shallow foundations is critical for the safety and durability of various structures. However, when these foundations are situated on ground containing voids like underground karst features or voids from natural or human-induced processes, their behavior becomes considerably more intricate. Understanding the interaction between shallow foundations and such cavity-prone ground is essential for engineers and geotechnical practitioners in designing resilient and dependable structures. This study aims to investigate the bearing capacity of shallow foundations on ground with cavities, considering various soil properties to delineate zones of influence on the foundation and consequently design robust foundations for challenging soil conditions. Through this research, we have conducted a thorough analysis of the Ultimate Bearing Capacity utilizing a numerical analysis code developed within our research group, known as the Rigid Plastic Finite Element Method (RPFEM). This endeavor seeks to offer valuable insights to enhance the design and performance of shallow foundations while elucidating the influence zones in regions susceptible to subsurface cavities.

In this study, the investigation is structured into three distinct steps, each aimed at illuminating different aspects of the problem. (1) Initially, an analysis of the Ultimate Bearing Capacity (UBC) under dry conditions is conducted, focusing on undrained scenarios to comprehend how the foundation behaves when there is no water flow within the soil. (2) Subsequently, we delved into the analysis of the UBC under unsaturated conditions, acknowledging the influence of moisture content on soil strength and its implications for foundation performance. (3) Finally, experimental methods were employed to complement theoretical analyses, offering empirical validation and deeper insights into the complex interactions between shallow foundations and ground containing cavities. Through this systematic approach, the goal is to provide a comprehensive understanding of the bearing capacity of shallow foundations in challenging soil environments characterized by the presence of subsurface cavities.

(1) In the analysis conducted under dry conditions, which encompasses various soil types such as cohesive and intermediate soils, the results are presented using dimensionless 2D charts. These charts feature normalized horizontal axis X and vertical axis Y, which are horizontal and vertical distances of the cavity to the footing normalized to the parameters R and H respectively. R and H represent the horizontal and vertical extents of the boundaries of the failure surface beneath the footing in the absence of the soil cavity. By examining geometric factors like footing width B and cavity characteristics (shape, size, and location), the study illustrates that the farther the cavity is, the lesser its impact on the

footing's performance. The distribution of normalized bearing capacity across the (X, Y) space elucidates the expansion and variation of the influence zone. Equations incorporating the aforementioned geometric parameters and soil shear strengths are proposed and validated using literature data, with adjustments made according to the different soil types involved.

(2) The analysis conducted under unsaturated conditions examined the geometric parameters of the footing and the cavities, similar to the approach taken in the dry conditions analysis. The primary focus was on evaluating the effects of matric suction and instability of the cavity itself on the overall performance of the footing under these specific conditions. Given the recent advancements in unsaturated soils mechanics and the prevalence of foundations existing in unsaturated conditions throughout their lifespan, predicting the behavior of the footing-cavity system under such hydraulic conditions is considered crucial. The Soil-Water Characteristic Curve (SWCC) model utilized was the van Genuchten model due to its simplicity and effectiveness. The results of the seepage analysis unveiled various distributions of porewater pressure heads depending on the cavity location. Despite similarities in the conclusions drawn from the Ultimate Bearing Capacity (UBC) analysis compared to the dry conditions, there was a notable expansion observed in the zone of influence. Furthermore, failure mode analyses highlighted the differences and influence of matric suction in the unsaturated conditions. Equations describing the influence zone incorporating geometric parameters and soil shear strength parameters are also provided.

(3) The experimental approach encompassed a laboratory-scale simulation method to replicate the presence of a cavity and its effects on the ultimate bearing capacity of the footing. The experiments included generating cavities from their initial state and studying their respective impacts. Model footing tests were performed on unsaturated sandy soil containing a simulated cavity. The cavity was created using a readily available commercial balloon, which was inserted into the model soil and then expanded. Following the deflation of the balloon, the unsaturated soil was vertically loaded using a circular model footing with a diameter of B = 30 mm. Through the experimental results, the validity of the numerical analyses, particularly under unsaturated conditions, was successfully confirmed.

In light of our comprehensive study, which findings elucidated the impact and range the ultimate bearing capacity of a shallow foundation situated on ground containing cavities under different soil and hydraulic conditions. It is imperative that construction practitioners and regulatory bodies recognize the potential impact of subsurface voids on the stability of foundations. Our findings underscore the need for applying straightforward formulas based on the soil types, geometry and hydraulic conditions to assess the stability level when a cavity is discovered. Such solutions are scarce in the current literature and such solution is proposed in the current work. Moreover, these results are anticipated to offer practical insights, including identifying areas that require investigation for the presence of cavities.