EVALUATION OF THE ULTIMATE LATERAL CAPACITY OF RIGID SPIRAL SINGLE AND COUPLED PILES IN SANDY GROUND

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(砂地盤におけるスパイラル状の鉛直杭と斜杭を組み合わせた杭基礎の水平抵抗特性とその評価に関する研究)

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論　文　内　容　の　要　旨

Energy demand has been growing ceaselessly worldwide year by year. Meanwhile, the human concerns the ecosystem of the world due to the higher consumption of limited resources. This concern leads toward solutions to sustainable power production and its environmental maintenance. Because of the exhaustive nature of fossil fuel, the downside of nuclear power as a source of energy, many countries have set a goal to boost the use of renewable energy systems in the coming decades. One of those countries is Mongolia. The government of Mongolia targets to have renewable energy account for 30% of the country's energy mix by 2030. This commitment will be crucial to the harvest of electrical power from solar photovoltaic (PV) systems, wind turbines, hydropower. Correspondingly, the construction of a solar PV system has been increasing dramatically in recent years. Considering their aerodynamic susceptibility induced by hurricanes, significant studies related to the durability of structure and foundations have been conducted.

One of the capable foundation solutions is the spiral pile in the solar PV system because of its higher capability against the uplift load caused by wind force. The challenge for researchers and engineers is to find out the rational design for spiral pile foundation considering its dissimilarity in shape compared with conventional ones. A spiral pile investigated in this research is made by twisting flat-bar with controlling effective pitch-width ratio. In the design of pile foundation, the proper evaluation model for the lateral capacity of the pile is one of the principles. Moreover, the evaluation model considering the shape of the pile is essential. The current traditional theories neglected the pile shape complexity that considering the nonlinearity effect associated with three-dimensional 3D soil-pile interaction in the course of lateral movement. Hence, the rational and optimized design of the spiral pile foundation of a solar PV system is vital, considering the shape is unique.

Consequently, the primary objectives of this dissertation are introduced as follows. The first is to propose a novel simplified model for estimating the lateral resistance of spiral piles in the sandy ground, which considers the shape factors, rear-passive earth pressure, rotation point. The second is to investigate the reinforcement of a single spiral pile by tilted battered pile under lateral loading conditions. Extensive experimental studies have been done to find out effective reinforcement. The angle of the battered pile with the vertical pile is the most crucial parameter for design effective reinforcement. In addition, a simplified model for evaluating the lateral capacity of the coupled spiral piles is proposed using a novel simplified model for a single spiral pile in this research. The third is the extensive statistical studies that have been carried out to verify the proposed model for a single spiral pile. Accordingly, to achieve those missions, this dissertation includes six chapters, as follows:

Chapter I leads the readers to the background of this research. It calls attention to the current solar PV system development in Mongolia. A brief introduction on the potential of the solar PV and wind speed of the

projected area has been described. The objectives that linked the scenario of the research program are outlined. Additionally, the original contributions of this study are introduced.

Chapter II summarizes the wind load characteristics on solar panels and traditional theories that can evaluate laterally loaded pile foundations subjected to lateral static loading. Furthermore, by considering the limit equilibrium for coupled piles, the method for evaluating the bearing capacity of the helical pile has been reviewed. The method for helical pile has been adapted for the spiral pile caused the lack of study on the axial performance of spiral piles. It highlights the following aspects: wind load characteristic on the solar panel, the factors affecting p-y curves of laterally loaded piles, the evaluation methods for lateral soil resistance, and the methods of predicting the bearing capacity of helical piles.

Chapter III, an experimental 1g model test carried out in the laboratory scale, was described thoroughly in single and coupled piles. The attaching procedure and model of strain gauges and transducers on the model pile used in this research were explained. In addition, the equivalent second moment of area was evaluated using a four-point bending test due to its inconstant behavior along the spiral pile length. The obtained equivalent result has been utilized for designing the prototype pile. Kumamoto sand (K-7) was used as a ground medium for experimental tests. Moreover, physical characteristic tests, such as particle size distribution, density test, and friction angle by triaxial CD test, have been conducted. In addition, the procedure of the half-size chamber test for visual analysis was introduced briefly.

Chapter IV discusses the experimental 1g model test results for laterally loaded pile, including ultimate lateral capacity and bending moment profile before and after reinforcement. A parametric study using the laboratory test has been done to consider the dissimilarity of the pile shape considering the projected area, slenderness ratio, the relative density of the ground medium in single and coupled piles. In addition, the effective angle between vertical and battered pile for reinforcing a single spiral pile was obtained empirically. To conclude the effectiveness of reinforcement, the normalized ultimate lateral capacity was investigated.

Chapter V introduces simplified prediction models for single and coupled spiral piles in the homogeneous sandy soil. The projected area has been considered using sinusoidal and cosinusoidal characteristics to propose a precise prediction model for a single spiral pile. Ready-to-use shape factors for the spiral pile were provided. Moreover, the coefficient of rear-passive earth pressure is provided by considering ultimate frontal soil pressure and ultimate rear passive pressure. A proper evaluation method for evaluating frontal pressure is investigated and selected. The pile length and depth of pile rotation were considered using visual analysis (Half-size chamber). Also, the ready-to-use coefficient of rear-passive earth pressure, angle of pile rotation were given, respectively. In addition, a statistical study was conducted for verification between the novel prediction model and preceding models such as Broms (1964), Petrasovits and Award (1972), Awad-allah, and Yasufuku (2015) in the case of a single pile. After verifying the prediction model, the ultimate lateral capacity of the coupled piles was evaluated considering the novel proposed model and bearing capacity of the helical pile. The method for bearing capacity of the helical pile was adapted for the spiral shape of the pile. Validation of the predicted lateral capacity of the coupled piles was carried out using the experimental test result.

In chapter VI, the summary, conclusions, primary outcomes of the dissertation, and recommendations for further research missions under this topic are discussed in detail at the end.