論 文 内 容 の 要 旨
Abstract of Dissertation

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In design of building, the pile foundations and the rigid footings have routinely been designed to carry the vertical load of the superstructure, resist the horizontal load from wind and wave loads, and the moment load coming from the eccentric vertical or horizontal loads. This study mainly focuses on the following objectives by using the rigid plastic finite element method (RPFEM); 1) The assessment for group effect on ultimate lateral resistance of piles against uniform ground movement; 2) Ultimate bearing capacity of rigid footing under eccentric vertical load; 3) Limit load space of rigid footing under eccentrically inclined load; and 4) Ultimate bearing capacity of rigid footing on sand-over-clay under vertical load:

[1] Firstly, in earthquake engineering, pile foundations have typically been designed to withstand the lateral loading that results from large displacements due to ground movement caused by strong earthquakes during which the distress and failure of superstructures may take place when the lateral load exceeds the ultimate lateral resistance of the piles. The aim of this study is to estimate the ultimate lateral resistance of piles especially in terms of the group effect induced by the pile arrangement. Several experimental and numerical analyses have been conducted on pile groups to investigate the group effect when the groups are subjected to uniform large horizontal ground movement. However, these previous studies usually calculated the ultimate lateral resistance of the pile groups by applying the load to the piles. The present study directly assesses the ultimate lateral resistance of pile groups against ground movement by systematically varying the direction of the ground movement. Although the load bearing ratio of each pile in a pile group, defined as the ratio of the ultimate lateral resistance of each pile in a pile group to that of a single pile, is an important design criterion, it was difficult to assess in past works. This study focuses on the load bearing ratio of each pile against ground movement in various directions. The use of the finite element method (FEM) provides options for simulating the pile-soil system with complex pile arrangements by taking the complicated geometry of the problem into account. The ultimate lateral resistance is examined here for pile groups consisting of a 2x2 arrangement of four piles, as well as two piles, three piles, four piles, and an infinite

number of piles arranged in a row through case studies in which the pile spacing is changed by applying the two-dimensional rigid plastic finite element method (RPFEM). The RPFEM was extended in this work to calculate not only the total ultimate lateral resistance of pile groups, but also the load bearing ratio of the piles in the group. The obtained results indicate that the load bearing ratio generally increases with an increase in pile spacing and converges to almost unity at a pile spacing ratio of 3.0 with respect to the pile diameter. Moreover, the group effect was further investigated by considering the failure mode of the ground around the piles.

[2] Secondly, in geotechnical engineering, the stability of rigid footings under eccentric vertical loads is an important issue. This is because the number of superstructure buildings has increased and the situation of structures being subjected to eccentric vertical loading is occurring more and more frequently. In this study, focus is placed on the ultimate bearing capacity of a footing against the eccentric load placed on two types of soil, namely, sandy soil and clayey soil, using a finite element analysis. For the sandy soil, the study newly introduces an interface element into the footing-soil system in order to properly evaluate the interaction between the footing and the soil, which greatly affects the failure mechanism of the footing-soil system. For the clayey soil, the study improves the analysis procedure by introducing a zero-tension analysis into the footing-soil system. Two friction conditions between the footing and the soils are considered; one models a perfectly rough condition and the other models a perfectly smooth condition. For a two-dimensional analysis of the footing-soil system, the rigid plastic finite element method (RPFEM) is applied to calculate the ultimate bearing capacity of the eccentrically loaded footing. The RPFEM is extended in this work to calculate not only the ultimate bearing capacity, but also the distribution of contact stress along the footing base. The study thoroughly investigates the effect of the eccentric vertical load on the ultimate bearing capacity in the normalized form of V/V_{ult} and e/B where e is the length of the eccentricity and B is the width of the footing. V_{ult} indicates the ultimate bearing capacity for the centric vertical load. The failure envelope in the plane of V/V_{ult} and M/BV_{ult} is further investigated under various conditions for the sandy and clayey soils. M is the moment load induced by the eccentric vertical load. This study examines the applicability of the failure envelope obtained for the eccentric vertical load to the cases where two variables, V and M, are independently prescribed. The obtained results are coincident and indicate the wide applicability of the failure envelope in the normalized V-M plane in practice. Finally, in a comparison with previous researches, the numerical data in the present

study lead to the derivation of new equations for the failure envelopes of both sandy and clayey soils.

(3) Thirdly, the objective of this study was to evaluate the bearing capacity of a rigid footing on the free surface of uniform sandy and clayey soils under the action of eccentric and inclined loading using a finite element analysis by assuming that the soils follow the Drucker-Prager yield function. In the two-dimensional analysis of the footing-soil system, the rigid plastic finite element method (RPFEM) was applied to calculate the ultimate bearing capacity of the eccentric-inclined loaded footing. In the numerical analysis, an interface element was introduced to simulate the footing-soil system with the rigid plastic constitutive equation developed by the authors. The footing was considered to be rigid and rough, as it most often is in reality. This study thoroughly considered the effect of the soil properties on load inclination factors i_γ and i_c in order to investigate the validity of the current design methods. In particular, the effects of the horizontal load in two directions on the ultimate bearing capacity of the footing and the failure envelopes in the V-H-M space were clarified, namely, positive and negative horizontal loads. The results showed that the positive horizontal load had a negative effect on the bearing capacity, while the negative horizontal load had the opposite effect in the presence of eccentrically inclined loading. The failure mode of the footing-soil system was clearly seen in the difference between the two directions of horizontal load. Through a series of numerical analyses, new equations were proposed for load inclination factors i_γ and i_c, and for the failure envelopes in the V-H-M space, taking into account the direction of the horizontal load. The obtained limit load space was proved to be rational in comparison to those given in the literature. Furthermore, the applicability of the limit load space to different computation conditions and independently prescribed moments was examined. Consequently, the failure envelope for each type of soil in the V-H-M space was clearly seen to be unique.

(4) In geotechnical engineering, there are frequently challenged with design of rigid footing on layered soil profiles. This is because that the native soils are often replaced in the top layer of soft clay by cohesionless soil which artificially forms a sand layer overlying clay. The objective of this study was to evaluate the bearing capacity of a rigid footing on the free surface of sand overlying clay under the action of vertical load, using a rigid plastic finite element method (RPFEM). Focus is placed on various factors contributing to the problem; the sand layer internal friction angle ϕ, the sand layer thickness D, and the clay layer shear strength c_u. Failure mode in

two layer was governing by the Drucker-Prager yield function. In the numerical analysis, an interface element was introduced to simulate the footing-soil system with the rigid plastic constitutive equation developed by the authors. Two friction conditions of the footing surface are considered; one models a perfectly rough condition and the other models a perfectly smooth condition. The RPFEM is extended in this study to calculate not only the ultimate bearing capacity, but also the distribution of contact normal stress along the footing base. The improvement of the ultimate bearing capacity of two-layers of sand-clay is intensified by increasing the internal friction angle, the thickness of the sand layer, and the shear strength of the clay layer. According to the obtained results, the maximum improvement was found in a scenario when the failure mode of the footing was within the sand layer. The higher of the sand layer internal friction angle and its thickness are able to support greater bearing capacity under vertical load. In particular, this study newly introduces a simple bearing capacity model based on the limit equilibrium method to investigate the validity of the current design model, which captures the variation in shear resistance from the sand layer with the undrained shear strength of the clay layer. Finally, in a comparison with previous researches, the numerical data in the present study lead to the derivation of new bearing capacity model for two friction conditions.