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Method for Predicting Bending Failure of DCM Columns under Embankment Load

要旨

Deep Cement Mixing (DCM) columns have been used extensively for improving soft clayey deposit for embankment constructions. For stability analysis, the current design method assumes a slip circle failure surface shearing through the columns and the soils and using a weighted average shear strength. However, the results from laboratory centrifuge model test and numerical analysis indicate that in many cases, the DCM columns fail by bending. Some researchers have proposed methods for estimating the maximum bending moment in the single column under embankment loading or maximum embankment loading for bending failure of DCM columns. However, those methods either have limitations in correctly considering the internal shear stresses or not applicable for the case of group DCM column improvement. A new design method for evaluating the bending failure of column for the group DCM columns improved ground under embankment load has been proposed in this study considering main factors affecting the bending moment in the DCM column.

Firstly, bending failure mechanism of DCM columns in soft ground under embankment load has been investigated by verified three dimensional (3D) finite element analyses (FEA). The key factors studied were (1) area improvement ratio by the columns, α, (2) length of the column, L, (3) compressibility of soft ground, λ (slope in e-ln(p') plot of virgin compression, where, e is void ratio and p' is consolidation pressure), (4) undrained shear strength of the ground, su, and (5) height of the embankment, H.

It has been found that maximum bending moment in the column under the toe of the embankment increases with reduction of α and su, and increasing the λ and H. Regarding the length of the column, in case of end bearing column, for the cases investigated where the strength of soft soil increased with depth, the increase in the thickness of the soft soil did not cause considerable increase of maximum bending moment. While for floating column cases, under a condition of fixed thickness of soft soil, the maximum bending moment increased with the reduction of the length of the column.

Then to consider the effects of all these factors in predicting the maximum bending moment in the columns under the toe of an embankment, the normalized maximum bending moment (Mn), and the ratio (Pn) of load (pem) to undrained shear strength ratio (su) have been introduced.

For end bearing columns, the relations between Mn and Pn has been proposed for different stiffness index (Ir) of soil, which is the ratio of shear modulus (G) to the undrained shear strength (su) of the soft deposit. With known soft soil properties and loading conditions, from $Pn - Mn$ relationship, the maximum bending moment can be predicted. Then for cases of floating columns a correction factor has been proposed to convert the maximum bending moment of end bearing case to the floating column case. The effectiveness of the proposed method has been validated through the application to three centrifuge model tests and four field cases results reported in the literature. It is recommended that the proposed method can be used for design embankment on DCM column improved soft clayey deposit.