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Numerical Modeling of Reinforced Soil Walls Using Multiphase Approach and Hyperbolic Constitutive Model

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1- Introduction

The increasing importance and vast use of reinforced soils demand more precise simulation of their behavior. The distinct nature of composing elements of reinforced soil with different mechanical behaviors might make the numerical simulation too complex. To overcome the issue, "homogenization methods" is introduced enabling us to analyze the behavior of the media as one homogenous composite material. These methods are in contrast to the "direct" or "distinct" methods that try to model all the elements comprising the reinforced media separately. While direct simulations in reinforced media are complex and demanding, using homogenization methods leads to fewer model elements and prevents the model from numerical instability caused by stress/strain concentrations. Thus, these methods provide simpler and faster numerical modeling for reinforced media with repeated layers of reinforcing elements in a periodic manner.

2- Literature Review

The "Multiphase approach" is considered as a new framework in homogenization methods, comprising of the assumption that the composite medium is made by the superposition of continuous individual media called phases. Each point of the geometry in a multiphase material is comprised of "matrix" phase (representative of the element which covers most of the space, e.g. soil) and "reinforcement" phase (representative of reinforcement inclusions) with their own kinematics.

So far, in most studies that have been conducted on the multiphase approach, the behavior of both the soil and the reinforcement inclusions is considered as linear elastic-perfectly plastic. Although this simplified behavior model might be a good assumption for inclusions behavior, it cannot simulate the soil behavior well enough. Therefore, more advanced constitutive models are needed to model the nonlinear behavior of soil in reinforced media. In this theoretical and analytical study, the hyperbolic constitutive model also known as Duncan-Chang model is implemented in the multiphase model to simulate soil behavior. The Duncan-Chang constitutive model is an elastic model providing a suitable estimation of the non-linear behavior of soils especially at low-stress levels using mathematical equations.

The aim of this article is to investigate the implementation of the hyperbolic constitutive model into the multiphase approach formulations and to assess the resulting developed model. The behavior of a monitored full-scale reinforced soil wall was simulated using the developed two-phase model in order to evaluate the accuracy and performance of the model. In this study, the inclusions of the reinforced soil wall are considered as tensile planar (two-dimensional) elements behaving as linear elastic-perfectly plastic materials. The wall was constructed and instrumented by the Public Works Research Institute (PWRI) in Tsukuba, Japan. It was constructed directly on a concrete floor inside a test pit with the height of 6 m. The wall was constructed using six primary and five secondary geosynthetic layers, each 3.5 and 1.0 m long. The geosynthetic layers were bolted to the modular concrete blocks using the nuts and metal frame. The wall face consisted of a total of 12 concrete blocks with 50 cm high and 30 cm wide, except for the top and bottom blocks which were 45 and 55 cm high. The horizontal displacement of the wall face, the elongation of geogrid layers, the lateral stress behind the wall as well as the vertical stress at the bottom of the wall were all measured. The backfill used was a silty sand, reinforced with polyethylene (HDPE) geogrid layers. It is also worth noting that the reinforced soil wall was studied under its own weight and no surcharge was applied on the backfill surface of the wall.

3- Methodology

The wall was numerically modeled using FLAC 2D. The wall was analyzed incrementally in 0.5m steps (consisting 12 steps), and its behavior was investigated in each step accordingly. In each step, the numerical results were compared with each other after performing a direct numerical modeling using Duncan-Chang model as well as a two-phase modeling using the developed model. Then, the results were also compared with the measured data in terms of face horizontal displacement, normal stress on the concrete platform (under the reinforced soil walls), horizontal stress behind the wall face and axial force in primary geogrids. Finally, to investigate the effect of the constitutive model on the predicted behavior of reinforced soil wall, numerical results were compared with the ones reported by Seyedi Hosseininia who analyzed the same wall using the two-phase model developed with linear elastic-perfectly plastic Mohr-Coulomb constitutive model.

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It is worth mentioning that all the numerical analyses were performed with the hypothesis of perfect bonding between phases, i.e. the identical displacement field of matrix and reinforcement phases. Also, all interface elements were assumed to be glued to the surrounding media.

4- Concluding Remarks

Combining all the numerical results and the comparisons made with measured data obtained from the monitored full-scale reinforced soil wall, the suitable accuracy of the developed two-phase model has been confirmed. The following conclusions can be made:

1. Given the suitable accuracy of the direct simulation of the wall using Duncan-Chang constitutive model, it can be stated that the model, presents proper simulations of the reinforced soil wall in case of direct simulation despite its simplicity.
2. Considering the similarities between the results of direct and homogeneous (two-phase) numerical simulations, it can be concluded that the results of two-phase numerical simulation of reinforced soil wall are similar to those of direct simulations. Thus, the analysis method (homogeneous or direct) is almost ineffective on the wall's simulated behavior.
3. In the two-phase simulation of the wall, the constitutive model related to the matrix phase (the soil part of the composite media) has a considerable effect on the results. The use of Duncan-Chang constitutive model for the matrix phase leads to better simulation of the wall behavior than using the Mohr-Coulomb criteria.
4. Since the overall displacements of the wall face that came out of the numerical results is in accordance with the real measured values, it can be argued that the perfect bonding assumption is acceptable and does not have much impact on the movement of the wall face. However, relative displacements of the wall face from the bottom of the wall is overestimated due to the assumption that all interface elements in numerical models were glued to the surrounding media. In this case, the behavior of the wall backfill is similar to the active state, and as a result, the horizontal stress behind the wall face is considerably underestimated.

Given the suitable accuracy of the results of the developed two-phase model, it can be concluded that the two-phase analysis approach developed with Duncan-Chang constitutive model is a useful tool to efficiently model reinforced soil walls, offering suitable predictions of the wall behavior especially at no surcharge condition and low-strain levels.

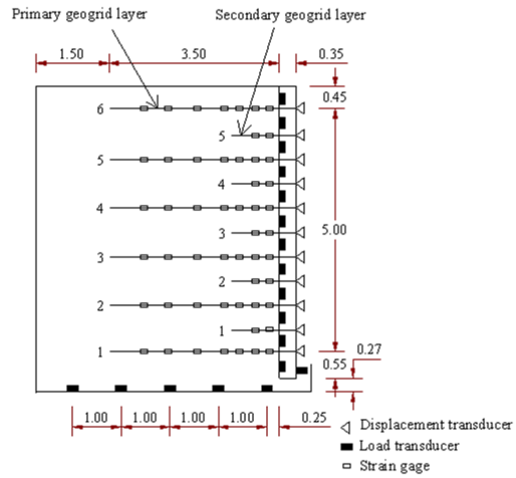

Figure 1. PWRI wall and instrumentation

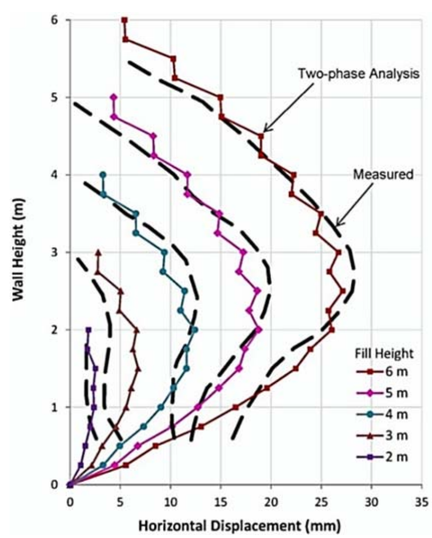

Figure 2. Comparison of measured versus simulated deformatiosn of wall using two-phase approach