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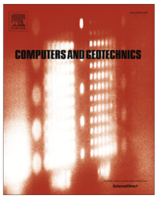

Research Paper

Computational simulation of time-dependent behavior of soil–structure interaction by using a novel creep model: Application to a geosynthetic-reinforced soil physical model

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ABSTRACT

In this paper, a model geosynthetic-reinforced soil retaining walls (GRS-RW) is tested by vertically loading it through a rough footing on the top near the retaining wall and the results are simulated by a sophisticated nonlinear Finite Element Method (FEM) having a novel rate dependent constitutive model for both the backfill material and the geosynthetic reinforcement. Usually, polymer geosynthetic reinforcement is known to exhibit more-or-less rate-dependent stress–strain or load–strain behavior due to their viscous properties. The geomaterials (i.e., clay, sand, gravel and soft rock) also exhibit viscous properties. The viscous behavior of geometrials are quite different from that of the polymer based geosynthetic-reinforcements. It has been revealed recently that viscous behavior of sand is a kind of temporary effect, which vanishes with time. So the rate-dependent deformation of backfill reinforced with polymer geosynthetic reinforcement becomes highly complicated due to interactions between the elasto-viscoplastic properties of backfill and reinforcement. In the present study, a scaled model geosynthetic-reinforced soil retaining wall is tested with a vertically loaded rough rigid footing. The results of the model test are simulated by using an appropriate elasto-viscoplastic constitutive model of both sand and geogrid embedded in a nonlinear plane strain FEM.

1. Introduction

Design life of geosynthetic-reinforced soil retaining walls (GRS-RW) usually depends on the creep deformation of the geosynthetic-reinforcements. The design-life of a geosynthetic-reinforced soil retaining wall is estimated from the creep and relaxation behavior of the geosynthetic-reinforcements using some kind of empirical formula. Geosynthetic-reinforced soil retaining walls (GRS-RW) exhibit more-or-less rate-dependent deformation due to the viscous properties of backfill and geosynthetic reinforcement. Interactions between the rate-dependent behaviors of soil and reinforcement make this issue very complicated. The behavior of backfill soil (here it is sand) is more complex than the polymer type geosynthetic reinforcement. The sand exhibits a new kind of response to the change in the strain rate termed here as temporary effect [41] whereas the geosynthetic reinforcement exhibits an Isotach type of viscous behavior. In this paper, both of the backfill material and the geosynthetic reinforcement are modeled within the three-component elasto-viscoplastic framework and the GRS-RW model test result is simulated using these sophisticated models.

In the present study, a unique scaled model test is carried out with detailed measurement of the development of the stress patterns under the footing placed on the top of the retaining wall. The tensile stresses inside the reinforcements were also measured. A sophisticated plane strain elasto-viscoplastic FE analysis was performed incorporating non-linear three-component models of sand and polymer reinforcement to simulate results obtained from a loading test on a scaled-down GRS-RW model. Although the FE code [33] was developed by the author earlier but it was applied only for one-dimensional case of analysis (one element, one gauss-point analysis). In this paper, the non-linear three-component models of sand and polymer reinforcement are applied to a full-scale boundary value problem along with the unique model test with internal stress and force history measurements.

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2. Literature review

Geosynthetic-reinforced soil retaining walls (GRS-RW) have a very long history. Many researchers contributed to the research of this very cost-effective alternative of gravity retaining walls. A limited review of the subject is carried out with in the defined scope of this paper. Ling et al. [15] developed an apparatus capable of measuring the strength and deformation properties of geotextiles under unconfined conditions and under the confinement of a membrane or a soil. Three non-woven geotextiles manufactured in different materials and by different bonding processes were used in this study, and their stress-confinement effects were also measured. It was concluded that the in-membrane test was sufficient for evaluating the load-deformation properties of geotextile. Cai and Bathurst [1] simulated the behavior of two carefully constructed and monitored large-scale geosynthetic reinforced soil retaining walls by finite element models. A modified form of hyperbolic constitutive model that included a dilation parameter was adopted to model the behavior of the granular soil. Wall performance was predicted well in this study. Cai and Bathurst [2] computed the dynamic response of a geosynthetic reinforced soil retaining wall by Finite Element Method (FEM). The cyclic shear behavior of the backfill soil was described by a hyperbolic stress–strain relationship with Masing hysteretic unload-reload behavior. They pointed out the influence of dynamic load on various aspects of the retaining wall. Rowe and Taechakumthorn [29] conducted a numerical study of the behavior of geosynthetic-reinforced embankments constructed on soft rate-sensitive soil with and without prefabricated vertical drains (PVDs). They concluded that the combined use of the geosynthetic reinforcement and PVDs enhances embankment performance substantially. Zarnani and Bathurst [45] used FLAC numerical code to simulate the results of an experimental program of reduced-scale wall models constructed with a seismic geofoam buffer inclusion and loaded using a large shaking table. They captured the trend in earth forces with increasing base acceleration for all six models and in most cases, quantitative dynamic load–time response of the numerical simulations was in good agreement with measured values. Liu and Won [16] conducted extensive finite-element analyses considering the viscous properties of geosynthetic reinforcements to investigate the load distributions in geosynthetic reinforcements of GRS walls under operational condition. Construction sequence was simulated and a creep analysis of 10 years was subsequently conducted on each model wall. The effects of wall parameters, including backfill soil, reinforcement length, reinforcement spacing, reinforcement stiffness, and creep rate of reinforcement were investigated. Lee et al. [13] simulated by FEM three full-scale geosynthetic-reinforced soil walls that were seismically loaded by a shaking table. They found that seismic wall displacement decreases with decreasing reinforcement spacing. They also discussed the factors responsible for comparison discrepancy. Ling et al. [15] simulated the dynamic behavior of four full-scale reinforced soil retaining walls subjected to earthquake loading by Finite Element procedure. The soil behavior was modeled using a unified general plasticity model, which was developed based on the critical state concept and that considered the stress level effects over a wide range of densities using a single set of parameters. The geosynthetic model was based on the bounding surface concept and it considered the S-shape load–strain behavior of polymeric geogrids. The FEM results simulated the shake-table test results reasonably well. Liu et al. [17] investigated the reinforcement load and the deformation mode for geosynthetic-reinforced soil (GRS) walls subject to seismic loading by Finite Element Method using marginal backfill soils (plasticity index, PI > 6). It was found that under strong seismic loading reinforced soil walls with marginal backfills exhibited a distinctive “two-wedge” deformation mode. Peng et al. [27] used a three-component visco-elsto-plastic model to simulate a physical model test on geogrid-reinforced sand retaining wall. It was shown that the aforementioned FEM could well simulate the deformation and strength behaviors of geogrid-reinforced sand retaining wall under the change of loading rate. Li et al. [14] simulated plane-stain-compression (PSC) tests on the geogrid-reinforced sand specimen by a nonlinear Finite Element Method (FEM) analysis technique. The viscous properties of sand and polymer geogrid were described in the framework of a unified nonlinear three-component elasto-viscoplastic model. It was shown that the developed FEM analysis technique could simulate the stress–strain behavior of geogrid-reinforced sand well, especially for rate-dependent behavior, creep deformation and stress relaxation. Liu [18] investigated the displacements of segmental GRS walls at the end of construction and after 10 years of creep under constant gravity loading. He found out that between the two main components of lateral facing displacement, the deformation of reinforced soil zone was largely governed by reinforcement spacing and reinforcement stiffness, while the influence of reinforcement length was negligible. Moghaddas et al. [20] conducted laboratory-model tests on strip footings supported on unreinforced and geocell-reinforced sand beds under a combination of static and repeated loads. Plastic deformation was limited by geocells more under repeated loading than under a similar static loading, with the reduction being greatest when more reinforcement was present and when the loading rate was fastest. Mohamed et al. [21] simulated a series of centrifuge tests on geosynthetic-reinforced soil (GRS) two-tier wall models with various offset distances by finite element (FE) analysis. The study demonstrated favorable agreement between FE and the centrifuge model in locating the failure surface. The FE results showed that as the offset distance increased, the reinforcement tensile load and wall deformation decreased in both the upper and lower tiers, suggesting the attenuation of interaction between the two tiers. The maximum tensile loads of all reinforcement layers at the wall failure predicted using FE analysis and LE method assuming uniform distribution of reinforced tensile loads were comparable to the results of the centrifuge tests.

The effects of loading rate due to material viscosity on the stress–strain behavior of sand (not due to delayed dissipation of excess pore water) are often very important in geotechnical engineering practice. A number of researchers (e.g., [22,4,12,19,6,41,11,23,24,42]) reported significant loading rate effects observed in laboratory stress–strain tests on sand under drained conditions; i.e., effects of strain rate and its change on the stress–strain relation, creep deformation and stress-relaxation during otherwise monotonic loading (ML) at a constant strain rate.

Within the framework of the general non-linear three-component model (Fig. 1), Di Benedetto et al. [6] and Tatsuoka et al. [41] proposed a set of stress–strain models to simulate the effects of material viscosity on the stress–strain behavior of geomaterial (i.e., clay, sand, gravel and softrock). They showed that the viscous property of clean sand (i.e., uniform sand) is different from that of clay in that the viscous effect decays with an increase in the irreversible strain and proposed a specific model to describe the above (i.e., the TESRA model explained below). In this paper, it is shown that this model can be smoothly implemented in a FE code. Then, shear stress–shear (or axial) strain relations from typical drained plane strain compression (PSC) tests on clean sands (i.e., Toyoura and Hostun sands) were simulated by the FE code [33] embedded with the TESRA model.