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A numerical modelling technique for geosynthetics validated on a cavity model test

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ABSTRACT

Numerical modelling approaches can aid in designing geotechnical constructions involving geosynthetics. However, the reliability of numerical results depends on how the model is developed, the constitutive model, and the set of parameters used. By comparing the numerical results with experiment, the present work verifies a numerical modelling technique developed to model multilayered geosynthetic lining systems for landfills. The numerical modelling technique involves strain softening at interfaces and allows the axial stiffness of the geosynthetics to evolve as a function of strain. This work focuses on a two-dimensional finite-difference model, which is used to simulate three types of experimental tests: conventional uniaxial tensile tests, direct shear tests, and a large-scale test that was used to assess the overall mechanical behaviour of a reinforced geosynthetic system that spanned over a cavity. This reinforced geosynthetic system consisted of a 50 kN/m polyvinyl alcohol geogrid reinforcement embedded in a layer of sand, a geosynthetic clay liner, a high-density polyethylene geomembrane, and a non-woven needle-punched geotextile. The uniaxial tensile tests, direct shear tests, and the large-scale test were numerically modelled and the numerical results were compared with experimental results. The results of the numerical modelling technique presented very closely match the results of the three experimental tests, which indicates that the numerical model correctly predicted the measured data.

1. Introduction

Geotechnical constructions that involve geosynthetics, such as landfills, are traditionally designed by using limit equilibrium methods (Giroud and Beech, 1989; Koerner and Hwu, 1991). However, these methods cannot be used to assess the integrity (e.g., strain or tensile forces) (Long et al., 1995) of the construction components and do not consider whether stresses are compatible with strains and displacements (Villard et al., 1999). As an alternative, such constructions may be designed by using numerical modelling methods (Fowmes et al., 2008); these methods not only account for the above-mentioned aspects but also account for the multiple interactions between geosynthetics.

Numerical modelling techniques are becoming ever more sophisticated because today's software allows designers to consider the key aspects of the mechanical characteristics of geosynthetics (e.g., the nonlinear stiffness) and of the interfaces (e.g., strain softening). However, the reliability of such numerical results depends on the numerical modelling technique used, which in turn rests upon how the model is developed, the constitutive model, and the set of parameters used.

Whichever numerical modelling technique is used, questions exist with respect to (i) the relevance of the numerical modelling technique and therefore (ii) the reliability of the numerical results. Consequently, to answer such questions, numerical results should be confirmed by comparing them with experimental data. In the context of landfills, and particularly for piggy-back landfill expansions where a new landfill is built over an older one, such

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Notations

K_s	Interface shear stiffness
K_n	Interface normal stiffness
c	Cohesion
$\varnothing_{peak}$	Peak friction angle
$\varnothing_{res}$	Residual friction angle
γ	Sand unit weight
E	Sand elastic modulus
ν	Sand Poisson ratio
D_{min}	Minimum diameter of sand particles
D_{max}	Maximum diameter of sand particles

Abbreviations

GMB	Geomembrane
GGR	Geogrid
GTX	Geotextile
GCL	Geosynthetic clay liner
PVA	Polyvinyl alcohol
HDPE	High-density polyethylene
UTT	Uniaxial tensile test
DST	Direct shear test
LSTA	Large-scale test apparatus

verification is essential because of the interactions between the various materials, such as clay, sand, gravel, geosynthetic, and waste (Tano and Olivier, 2014).

Unfortunately, limited studies that addressed the comparison of the experimental behaviour of multilayered geosynthetic lining systems with that predicted by numerical models are available (Fowmes et al., 2008). To the best of our knowledge, only three studies (Villard et al. (1999), Fowmes et al. (2008) and Zamara et al. (2014)) compare experimental results of multilayered geosynthetics with numerical results of models of landfill lining systems.

This work aims to verify a numerical modelling technique by comparing it with three experimental tests: a tensile test, a direct-shear test, and a large-scale large test. These tests were developed to assess the mechanical behaviour of a reinforced geosynthetic lining system.

Prior to discussing the details of the verification process, the previous studies of Villard et al. (1999), Fowmes et al. (2008) and Zamara et al. (2014) are further discussed in the following section. The benefits and limitations of these studies provide a framework for the present study and lead us to develop a new modelling technique.

2. Background

Villard et al. (1999) applied finite-element modelling to describe a veneer cover of a landfill and to better understand the distribution of forces and strains within a geotextile (GTX) and geomembrane (GMB) placed at the bottom and on side slopes of the landfill. The forces within the GTX were measured by force sensors positioned at the top of the slope. A cable-type displacement (extensometer wires) was used to measure the geosynthetic displacements and then the strains were calculated from the differential displacements obtained between two consecutive measurement marks on the geosynthetic. The numerical model used the Mohr–Coulomb failure criterion with single shear strength to model the interfaces and assumed a linear elastic behaviour for the various geosynthetics. The numerical results (displacements, strains and tensions) were then compared with the measured results obtained at the instrumented site.

Although Villard et al. (1999) considered that their model produced results that were, on the whole, satisfactorily consistent with experiment, discrepancies appeared between trends and between the strains, forces, and displacements obtained numerically and by experiment. As an example, the strains calculated by applying the numerical model to the section of slope where the GTX was not covered by the granular layer were constant whereas the experimentally determined strains increased along this slope. The authors attribute these discrepancies to differences in displacement measurements. Moreover, at the top of the geosynthetic, the simulated displacements differed from the measured displacements. Villard et al. (1999) concluded that these differences were probably due to the system that fastened the geosynthetic to the top of the slope interfering with the measurements. In addition, the calculated and measured strains at the nonloaded part of the slope differed significantly, which the authors attributed to faulty operation of the measuring devices or to insufficient stabilization time.

Fowmes et al. (2008) used a finite-difference method to numerically model the mechanical behaviour of a two-layered geosynthetic (GTX and GMB) lining system subjected to downdrag forces from synthetic waste in a large-scale test. The relative displacement of the GMB and of the GTX was measured by using extensometer wires, and the forces within the GMB were measured by using tensile load cells. The numerical model used the Mohr–Coulomb failure criterion with a displacement-dependent limiting shear strength (i.e., strain softening) to model the behaviour of the interfaces between the geosynthetics. Fowmes et al. (2008) used a constant 2% strain secant modulus to model the various geosynthetics. However, they noticed that the use of a 2% modulus in the design could lead to an overestimate of the material stiffness for strains in excess of 2%. To verify the numerical modelling technique, the results of the numerical calculations (strains and relative shear displacements at interfaces) were compared with measurements.

Fowmes et al. (2008) concluded that some discrepancies existed between the measured and the numerically modelled results, which they attributed to simplifications in modelling the axial behaviour of the geosynthetics and in the constitutive model used to represent the synthetic waste. In fact, the displacements of the GMB were underestimated by the numerical model, as revealed by comparison with the large-scale test. This underestimation thus led to the underestimation of the extension of the GMB. They attributed this discrepancy to the fact that the 2% strain secant modulus used underestimated the tensile strength at the relevant strains in their investigation. Overall, Fowmes et al. (2008) concluded that their numerical model (strain-softening characteristics of interfaces) and application methodology were valid.

More recently, Zamara et al. (2014) used the numerical model developed by Fowmes et al. (2008) for strain-softening behaviour at interfaces to investigate the mechanical performance of a multilayer-lining (GTX and GMB) system on a landfill slope. This site was monitored, which allowed the measured displacements and strains of the geosynthetics to be compared with the numerical results.

Zamara et al. (2014) claim that their model replicates the behaviour of the GTX at the lower part of the slope. However, the correlation between (i) the measured displacements and strains and (ii) the modelled displacements and strains was faulty. For example, the numerical model gave compressive strains for the toe section throughout the cell-filling stages, whereas tension in this section was measured on site. The authors concluded that this discrepancy is related to significant displacement of the GMB at the

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