《Geotextiles and Geomembranes》

（土工织物与土工膜）

<双月刊>

2019年第47卷第3期

摘要集

中国土工合成材料工程协会秘书处

国际土工合成材料学会中国委员会秘书处

目　录

Fully transient analytical solution for degradable organic contaminant transport through GMB/GCL/AL composite liners

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Abstract: In this study, analytical solution for degradable organic contaminant transport through a composite liner consisting of a geomembrane (GMB) layer, a geosynthetic clay liner (GCL) and an attenuation layer (AL) is derived by the separation of variables method. The transient contaminant transport in the whole composite liner can be well described avoiding some weird phenomena in existing analytical solutions. The results of parametric study show that GCL has significant effect on improving the barrier efficiency especially for scenarios with high leachate head. The biodegradation and adsorption in GCL have significant influence on the contaminant transport through the composite liner when the half-life of contaminant in GCL is less than 5 years. Otherwise, the effect can be neglected.

Keywords: Geosynthetics, Biodegradation, Advection, Diffusion, Composite liner, Analytical solution

Design and construction of lightweight EPS geofoam embedded geomaterial embankment system for control of settlements

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Abstract: This paper presents a research study on a bridge site located along US highway 67 over SH 174 in Cleburne, Texas, where bridge approach slabs have experienced more than 0.4 m (17 in.) of settlement within a span of 16 years after construction. Many treatment methods attempted to mitigate this problem had proven to be in effective. As part of novel rehabilitation works, the top of existing fill soil on the embankment was replaced with lightweight expanded polystyrene (EPS) geofoam blocks to alleviate the approach slab settlements. This paper describes initial design and construction details of the rehabilitation works performed on the embankment system along with a focus on the early performance details. Field monitoring studies were conducted for almost three years to study the bump/settlements under the EPS geofoam embankment system. Short term measured settlement data was analyzed with hyperbolic model to predict the long-term settlements. Numerical finite element studies attempted in this study showed that settlements could be reasonably predicted by modeling these geofoam embankments. Based on the monitoring and modeling studies, the effectiveness of utilizing EPS geofoam as an embankment fill material was addressed to mitigate the differential settlements under a bridge approach slab.

Keywords: Geosynthetics, Bump, Bridge approach, Expanded polystyrene (EPS) geofoam, Embankment settlements, Finite element analysis

Evaluation of moisture reduction in aggregate base by wicking geotextile using soil column tests

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Abstract: This study investigated the distance effect on water reduction by the wicking geotextile in a base course experimentally using three sets of soil column tests. In each set of tests, two soil columns were constructed by compacting well-graded aggregate over a non-wicking woven geotextile and a wicking geotextile. A portion of the geotextile specimen was extended outside of the soil column for evaporation. The changes of the water contents in the soil column were monitored by volumetric water content sensors installed at various depths. The experimental results indicate the capillary drainage by the wicking geotextile effectively reduced water content within the soil column up to a distance from the wicking geotextile (i.e., approximately 200 mm for this specific aggregate with 10% fines). The test results also show that the wicking geotextile could reduce more water content of the aggregate below its optimum water content at a faster rate than the non-wicking geotextile.

Keywords: Geosynthetics, Geotextile, Suction, Wicking, Base course, Water content

Seismic analysis of geosynthetic-reinforced retaining wall in cohesive soils

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Abstract: Although a cohesionless backfill is recommended for geosynthetic reinforced earth retaining walls, cohesive soil have been widely used in many regions across the globe for economic reasons. This type of backfill exposes the soil to the crack formation that leads to reduce the stability of the system. In this paper, to investigate the internal seismic stability of reinforced earth retaining walls with cracks, the discretization method combined with the upper bound theorem of limit analysis are used. The potential failure mechanism is generated using the point-to-point method. Two types of cracks are considered, a pre-existing crack and a crack formation as a part of the failure mechanism. The use of the discretization method allows the consideration of the vertical spatial variability of the soil properties. A pseudo-dynamic approach is implemented which allows the account of the dynamic characteristics of the ground shaking. The presented method is validated using the conventional limit analysis results of an existing study conducted under static conditions. Once the proposed technique to consider the cracks is validated, a parametric study is conducted to highlight the key parameters effects on the lower bound of the required reinforcement strength.

Keywords: Geosynthetics, Earth retaining wall, Limit analysis, Discretization, Pseudo-dynamic approach, Cracks

The role of undrained clay soil subgrade properties in controlling deformations in geomembranes

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Abstract: Strains were evaluated in a 1.5 mm HDPE geomembrane from overlying coarse uniform drainage gravel when placed above six different compacted clayey soils while keeping pressure, protection, loading rate equal. In each case, a protection layer consisting of 400 g/㎡ nonwoven geotextile was placed over the geomembrane. Vertical load of 300 kPa was applied in a relatively short duration. A photogrammetry procedure was used to develop a digital elevation model for each deformed geomembrane surface and the distribution of resulting strain in the geomembrane was evaluated on a percent area basis. The proportion of the overall geomembrane area in which the localised strain exceeded 3% was related to the compacted water content, index soil properties, and undrained shear strength of the six different clayey soils. It was found that an increase in moulding moisture content resulted in increased geomembrane strain in all cases, but the magnitude of the increase in strain varied considerably, depending on the plasticity and silt content of the soil used.

Keywords: Geosynthetics, Geomembrane, Clay liner, Protection layer, Strain, Stress cracking

A novel 2D-3D conversion method for calculating maximum strain of geosynthetic reinforcement in pile-supported embankments

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Abstract: For design of a geosynthetic-reinforced pile-supported (GRPS) embankment over soft soil, the methods used to calculate strains in geosynthetic reinforcement at a vertical stress were mostly developed based on a plane-strain or two-dimensional (2-D) condition or a strip between two pile caps. These 2-D-based methods cannot accurately predict the strain of geosynthetic reinforcement under a three-dimensional (3-D) condition. In this paper, a series of numerical models were established to compare the maximum strains and vertical deflections (also called sags) of geosynthetic reinforcement under the 2-D and 3-D conditions, considering the following influence factors: soil support, cap shape and pattern, and a cushion layer between cap and reinforcement. The numerical results show that the maximum strain in the geosynthetic reinforcement decreased with an increase of the modulus of subgrade reaction. The 2-D model underestimated the maximum strain and sag in the geosynthetic reinforcement as compared with the 3-D model. The cap shape and pattern had significant influences on the maximum strains in the geosynthetic reinforcements. An empirical method involving the geometric factors of cap shape and pattern, and the soil support was developed to convert the calculated strains of geosynthetic reinforcement in piled embankments under the 2-D condition to those under the 3-D condition and verified through a comparison with the results in the literature.

Keywords: Geosynthetics, GRPS embankment, 3-D effect, Maximum strain, Conversion method

Two and three-dimensional numerical analyses of geosynthetic-reinforced soil (GRS) piers

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Abstract: In this study, both two-dimensional (2D) and three-dimensional (3D) numerical analyses were carried out to evaluate the performance of geosynthetic-reinforced soil (GRS) piers. The numerical models were first calibrated and verified against test results available in the literature. A parametric study was then conducted under both 2D and 3D conditions to investigate the influences of reinforcement tensile stiffness, reinforcement vertical spacing, and a combination of reinforcement stiffness and spacing on the performance of GRS piers under vertical loading. Numerical results indicated that the effect of reinforcement spacing was more significant than that of reinforcement stiffness. The use of closely – spaced reinforcement layers resulted in higher global elastic modulus of the GRS pier, smaller lateral displacements of pier facing and volumetric change of the GRS pier, lower and more uniformly-distributed tension in the reinforcement, and larger normalized coefficients of lateral earth pressure. This study concluded that a 2D numerical model gave more conservative results than a 3D model.

Keywords: Geosynthetics, Geosynthetic-reinforced soil, Reinforcement spacing, Finite difference analysis, Pier, Tension, Two-dimensional, Three-dimensional

Quantifying the effects of geogrid reinforcement in unbound granular base

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Abstract: This study presents an effort to quantify the effects of geogrid reinforcement in the unbound granular base through laboratory testing. Two laboratory tests, the large-scale cyclic shear test and the repeated load triaxial test, were employed. The test protocol of the cyclic shear test was developed by modifying that for the triaxial test. The cyclic shear test was performed by applying a series of cyclic shear stresses to the geogrid-aggregate interface under different normal stresses. Two different types of geogrids were used as reinforcement in unbound granular material. Resilient modulus (MR) from the repeated load triaxial test and a term named resilient interface shear modulus (G_i) from the cyclic shear test was used to characterize the effects of geogrid reinforcement in unbound granular base, respectively. The results of triaxial tests showed that the inclusion of geogrid had a negligible effect on the resilient modulus, indicating that the triaxial resilient modulus test may not be effective in evaluating the geogrid reinforcement in unbound granular materials. Compared to the triaxial resilient modulus test, the cyclic shear test showed great potential in identifying the effects of geogrid reinforcement, with an obvious improvement in the degree of interlocking between geogrids and aggregates.
Keywords: Geosynthetics, Geogrids, Resilient modulus, Triaxial test, Cyclic shear test

A simplified model for evaluating the hardening behaviour of sensorenabled geobelts during pullout tests

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Abstract: Geosynthetics reinforced soil structures (GRSSs) have a tendency to be large and high, resulting in high normal pressures on the geosynthetics. As one of the effective tests for investigating the geosynthetics-soil interaction, pullout tests are traditionally conducted under low normal pressures. This paper reports pullout tests on a type of sensor-enabled geobelts (SEGB) with different normal pressures (5 kPa, 100 kPa, 200 kPa and 400 kPa) applied. The self-measurement function of SEGB allows the study of the working process of SEGB in pullout tests. Moreover, a simplified theoretical model is proposed to investigate the hardening behavior of geobelts in pullout tests. Two models are incorporated in the theoretical model: a bilinear model capturing the full stress-strain curve obtained from uniaxial tensile tests and a hyperbolic model simulating the geobelt-sand interaction from direct shear tests. By means of the finite-difference method, the numerical solutions of the theoretical model are obtained. The proposed model is validated by comparing calculated and measured front pullout force-displacement curves of SEGB under different normal pressures. Further, the computation of the strain distribution of SEGB sandwiched in the sand is compared with tested data with different front pullout force levels for the aforementioned normal pressures. The numerical solutions generally agree well with the experimental results for all tested tensile force and strain ranges; therefore, the proposed simplified model is suitable for evaluating large quasi-plastic deformations of geobelts and the associated interaction with surrounding sand.

Keywords: Geosynthetics, Pullout tests, High normal pressure, Quasi-plastic deformation, Sensor-enabled geobelt

A closed-form solution for column-supported embankments with geosynthetic reinforcement

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Abstract: Soil arching effect results from the non-uniform stiffness in a geosynthetic-reinforced and column-supported embankment system. However, most theoretical models ignore the impact of modulus difference on the calculation of load transfer. In this study, a generalized mathematical model is presented to investigate the soil arching effect, with consideration given to the modulus ratio between columns and the surrounding soil. For simplification, a cylindrical unit cell is drawn to study the deformation compatibility among embankment fills, geosynthetics, columns, and subsoils. A deformed shape function is introduced to describe the relationship between the column and the adjacent soil. The measured data gained from a full-scale test are applied to demonstrate the application of this model. In the parametric study, certain influencing factors, such as column spacing, column length, embankment height, modulus ratio, and tensile strength of geosynthetic reinforcement, are analyzed to investigate the performance of the embankment system. This demonstrates that the inclusion of a geosynthetic reinforcement or enlargement of the modulus ratio can increase the load transfer efficiency. When enhancing the embankment height or applying an additional loading, the height of the load transfer platform tends to be reduced. However, a relatively long column has little impact on the load transfer platform.
Keywords: Geosynthetics, Column-supported embankment, Soil arching, Modulus ratio, Stress ratio, Axisymmetric modelling

Local stiffness characteristic of geogrid-stabilized aggregate in relation to accumulated permanent deformation behavior

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Abstract: Accumulated permanent deformation is the primary source of damage in a pavement unbound aggregate base layer. Mechanical stabilization with the help of a geogrid installed in unbound aggregate base provides lateral restraint to the flexible pavement, however, the local stiffness characteristic of geogrid-stabilized aggregate in relation to permanent deformation behavior is not clearly known. This study presents variations in shear modulus properties of geogrid-stabilized and unstabilized aggregate specimens in relation to permanent deformation accumulation. To characterize the local stiffnesses near and far away from geogrid, two pairs of bender elements were inserted in triaxial specimens as shear wave transducers. With the number of load cycles, the variations in the shear wave velocities at two different specimen heights were monitored. The test results show that, after the specimen preparation, the shear modulus near the geogrid was greater than that far away from the geogrid. Further, the shear modulus estimated at both levels of unstabilized specimen was similar to that estimated far away from geogrid in the mechanically stabilized specimen. This study demonstrates that the local stiffness of aggregate can be monitored by using the bender elements in relation to trends in permanent deformation behavior, and suggests the bender element systems can be effectively used to validate the benefits of geogrid stabilization by quantifying local stiffnesses at various levels of accumulated permanent deformation.
Keywords: Geosynthetics, Permanent deformation, Shear wave, Stabilization

Corner reinforced slopes: Required strength and length of reinforcement based on internal stability

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Abstract: This paper develops an analysis procedure for turning corner in Geosynthetic-Reinforced Soil Structures (GRSS's). The procedure includes the calculations of the required strength and length of the reinforcement for internal stability. The calculations are based on the variational limit equilibrium analysis of three-dimensional (3D) stability of slopes. Seismic effects are also considered using the pseudo-static method. Results are presented in a condensed form of design charts, providing a simple tool to determine the required tensile strength and embedment length of the reinforcement. Two examples are given to demonstrate the use of the design charts. Compared with the conventional design based on plane-strain analysis, the presented design procedure yields longer reinforcement for the 3D internal stability of the corners. Generally, 3D design requires longer reinforcement than 2D as the seismic acceleration increases. The trend of obtained result is in good agreement with performance observations related to corners reported in commentary of AASHTO.

Keywords: Geosynthetics, Reinforced soil, Corner, Design, Three dimension, Internal stability

Experimental and theoretical studies on the ultimate bearing capacity of geogrid-reinforced sand

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Abstract: Geosynthetic reinforced soil (GRS) structures have gained popularity in replacing concrete rigid piles as abutments to support medium or small-spanned bridge superstructures in recent years. This study conducted 13 model tests to investigate the ultimate bearing capacity of the GRS mass when sand was used as backfill soil. The GRS mass was constructed and loaded to failure under a plane strain condition. Test results were compared with two analytical solutions available in literature. This study also proposed an analytical model for predicting the ultimate bearing capacity of the GRS mass based on the Mohr-Coulomb failure criterion. The failure surface of the GRS mass was described by the Rankine failure surface. The effects of compaction and reinforcement tension were equivalent to increased confining pressures to account for the reinforcing effects of the geosynthetic reinforcement. The proposed model was verified by the results of the model tests conducted in this study and reported in literature. Results indicated that the proposed model was more capable of predicting the ultimate bearing capacity of the GRS mass than the other two analytical solutions available in literature. The proposed model can be used to predict the ultimate bearing capacity of GRS structures when sand was used as backfill material. In addition, a parametric study was conducted to investigate the effects of friction angle of backfill soil, reinforcement spacing, reinforcement strength, and reinforcement stiffness on the ultimate bearing capacity of the GRS mass calculated with and without compaction effects. Results showed that the ultimate bearing capacity of the GRS mass was significantly affected by the friction angle of backfill soil, reinforcement spacing and strength. Compaction effects resulted in an increase in the ultimate bearing capacity of the GRS mass.

Keywords: Geosynthetics, Geosynthetic reinforced soil, Compaction, Increased confining pressure, Tension, Ultimate bearing capacity

Microscale investigation into mechanical behaviors of heat-bonded nonwoven geotextile using DEM

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Abstract: Heat-bonded nonwoven geotextiles (HBNGs) made from synthetic fibers are widely used in engineering practices. One of the challenges on the way is to link the properties of fibers and the fabric's microstructure to the deformation and failure mechanisms of HBNGs. In this study, a random distribution geometry method was developed to reproduce the complex fibrous structure of HBNG. A piecewise linear model was adopted to reproduce the nonlinear stress-strain relationships of single fibers. The present method has been successfully applied in the simulation of uniaxial and biaxial tensile tests and puncture test. The orientation distribution of fibers and the mechanical behaviors (e.g., deformation, strain localization, force-strain relationship) of HBNG specimen were reasonably simulated. Specifically, the hourglass shape during uniaxial tensile test, the axisymmetric deformation pattern during biaxial tensile test and the trumpet shape during puncture test were all well reproduced. The present method provides an applicable tool to study the complicated mechanical behaviors of HBNG and is also helpful to obtain a better understanding of its deformation and failure mechanisms.
Keywords: Geosynthetics, DEM, Geotextile, Fiber, Tensile test, Puncture test

Magnitude and significance of tensile strains in geomembrane landfill liners

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Abstract: The implications of the tensile stress/strain developed in high density polyethylene (HDPE) geomembranes (GMB) is explored in the context of a reduction in stress crack resistance due to ageing in contact with leachate in a municipal solid waste (MSW) landfill. The experimental evidence of GMB cracking and ultimately failure when subject to excessive tensile strains is discussed to highlight the need to limit the maximum tensile strain sustained by an HDPE GMB to an acceptable level if good long-term performance is to be ensured. The effect of both local GMB indentations induced by gravel in an overlying drainage layer or an underlying clay liner on tensile strain is reviewed. In addition, the tensile strains caused by down-drag in the GMB on side slopes with settlement of the waste are examined. The key research related to tensile strains developed in GMBs from these sources is reviewed and new data presented. It is shown that an appropriate protection layer over the GMB can limit local GMB tensile strains to less than 3% and that the selection of a suitable slope inclination and stiffness of a geotextile reinforcement layer can limit the GMB strains due to down-drag to less than 2% and geotextile strains to less than 4% after long-term waste settlement.

Keywords: Geosynthetics, Geomembranes, Strains, Landfills, Indentations, Side slopes