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Stability assessment of 3D reinforced soil structures under steady unsaturated infiltration

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Abstract: Internal stability assessment of geosynthetic-reinforced soil structures (GRSSs) has been commonly carried out assuming plane-strain conditions and dry backfills. However, failures of GRSSs usually show three-dimensional (3D) features and occur under unsaturated conditions. A procedure based on the kinematic limit-analysis method is proposed herein to assess 3D effects and the role of steady unsaturated infiltration on the required geosynthetic strength for GRSSs. A suction stress-based framework is used to describe the soil stress behavior under steady unsaturated infiltration. Based on the principle of energy-work balance, the required geosynthetic strength is determined. A comparison analysis with the prior research is conducted to verify the developed method. Two kinds of backfills, i.e., high-quality backfill and marginal backfill, are considered for comparison in this work. It is shown that accounting for 3D effects and the role of unsaturated infiltration considerably reduces the required geosynthetic strength. The 3D effects are primarily affected by the width-to-height ratio of GRSSs, and the contribution of unsaturated infiltration is mainly influenced by the soil type, flow rate, GRSS's height, and location of the water table.

Keywords: Geosynthetics; 3D reinforced soil structures; Steady unsaturated infiltration; Suction stress

Coupled consolidation via vertical drains in unsaturated soils induced by time-varying loading based on continuous permeable boundary

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Abstract: Considering continuous permeable boundary and coupled radial-vertical flow in this paper, a generalized semianalytical solution for the consolidation enhanced by vertical drains (VDs) in unsaturated soils under timevarying loading is proposed. Firstly, the continuous permeable boundary is introduced into the axisymmetric consolidation model. Afterwards, the coupled controlling governing equations of excess pore pressures (EPPs) are solved by mathematical methods such as the decoupling technology, the Laplace transformation and inversion. Then, the validity of the current solution is verified by special cases with double-permeable boundary conditions (BCs) and instantaneous loading. The case analyses eventually were carried out, and the results show that the smear effects slow down the consolidation process but that is not obvious when the smear parameter is great than five. The effect of vertical flow on consolidation becomes insignificant when the ratio of radial to vertical permeability coefficient is greater than five; conversely, when its value is less than five, the above effect increases with the enhancement of the permeability properties at the top (or bottom) boundary. Moreover, the new solution can be applied to time-varying loadings, and different distributions of top and bottom boundary permeability.

Keywords: Unsaturated soils; Continuous permeable boundary; Radial-vertical flow; Time-varying loadings; Semi-analytical solution

Internal stability analysis of geocell-reinforced slopes subjected to seismic loading based on pseudo-static approach

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Abstract: Seismic stability analysis of geocell-reinforced slopes (GRSs), considering shear and moment strength in addition to tensile resistance for geocells, is a novel topic for which scarce studies are found in the literature. Despite few available studies, an analytical approach is presented in this study to investigate the seismic internal stability of GRSs, employing the pseudo-static method based on a limit state approach. Results are given in terms of conventional design charts representing the required total strength and critical length of geocells. The results show that with increasing the horizontal seismic acceleration (k_h), the internal stability degenerates since the required strength and critical length of geocells increase. For GRSs subjected to greater k_h, the effect of increasing the vertical seismic component (k_v) on increasing the required strength and length of geocells is more considerable than those subjected to lower k_h values. Parametric analyses are conducted, under various seismic conditions, to investigate the effect of increasing the geocell height and raising the number of geocell layers, leading to the reduction in the required strength and length of geocells. Such effects are found to be dependent on the parameters such as the intensity of seismic excitation, material properties and geometry of slope.

Keywords: Geocell reinforced slopes; Seismic stability analysis; Pseudo-static; Limit equilibrium method (LEM)

A simplified model for the analysis of piled embankments considering arching and subsoil consolidation

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Abstract: An analytical model is presented for the design of geosynthetic-reinforced and pile-supported (GRPS) embankments in this paper. The originality of the proposed solution lies in the fact that it allows considering the influence of the subsoil consolidation on the soil arching and geosynthetic strain. A nonlinear function is implemented to describe the subsoil behavior with the consolidation process in a closed-form solution. A simplified approach is then presented to link the arching development with the subsoil consolidation. The arching theory is combined with the tensioned membrane theory and the soil-structure interaction mechanisms to provide a simple and suitable design approach that enables a realistic approximation for designing soil–geosynthetic systems. The analytical model is capable of performing an ultimate and serviceability limit state design of GRPS embankments. While current methods cannot fully address the important effects of the subsoil consolidation, the analytical results suggested that arching and differential settlements increase with an increase of the subsoil consolidation degree. The analytical model is compared to field measurements and five other design standards for several full-scale field tests to study its validity. The results showed a satisfactory agreement between the proposed model and measured data, and generally better results are obtained as compared with other design methods.
Keywords: Pile-supported embankment; Geosynthetics; Soil arching; Consolidation; Limit state design; Soil-structure interaction; Ground reaction curve

Pullout resistance of geogrid and steel reinforcement embedded in lightweight cellular concrete backfill

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Abstract: Lightweight Cellular Concrete (LCC) has been increasingly used as backfill material for retaining walls, ground improvement, and pavements due to its low self-weight, quick installation, and high compressive strength as compared with soils. This paper presents a series of pullout tests performed in the laboratory to investigate the pullout resistance of geogrid (extensible reinforcement) and steel strip (inextensible reinforcement) embedded in LCC. Pullout displacements and pullout forces were monitored using displacement transducers (DT) and a load cell during the pullout process. This study investigated the effects of age, normal stress, fly ash, the presence of a cold joint, and re-pullout on the pullout resistance and calculated the pullout resistance factors F^* for geogrid and steel strip embedded in LCC. Test results show that for the geogrid embedded in LCC, the maximum pullout force increased as the normal stress increased. For the steel strip embedded in LCC, the maximum pullout force was independent of the normal stress and increased as the age and the cement to fly ash ratio increased. Test results also show that the presence of a cold joint did not reduce the pullout resistance, while the re-pullout test had lower pullout resistance compared to the original pullout test for the same specimen. The pullout resistance factors F^* for steel strips were greater than those for geogrids and these factors decreased as the normal stress increased.

Keywords: Geosynthetics; Age; Geogrid; Lightweight cellular concrete; Pullout resistance ; Steel strip

Effect of armour unit layers and placement mode in the determination of stability of geotextile sand container (GSC) breakwaters

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Abstract: Geosynthetic Sand Containers (GSCs) are increasingly harnessed for their coastal protection capabilities. Recent studies point to its efficacy to be used even as armour units of breakwaters. The current investigation aims at understanding the effect of armour unit layers and placement modes in altering the stability of GSC breakwaters. Single-layered and double-layered GSC structures with slope parallel and perpendicular placement are tested for stability against wave conditions of the Mangaluru coast. A 1:30 scaled monochromatic wave flume model study is adopted to detail the damage levels and stability of various GSC breakwaters. It is observed that the stability of structure increased by up to 17% when supplemented with double layers. Structure tends to be stable with increasing armour units size and fill percentage. Larger bags stacked to double layers is found to be the most stable configuration. 80% filled, slope parallel placement exhibited the least stability. The paper dealt with all factors affecting structure stability and deduced stability nomograms helpful for coastal engineers to design GSC breakwaters.
Keywords: Geotextiles; Coastal protection; Breakwaters; Stability curves; Damage levels

Evaluating long-term benefits of geosynthetics in flexible pavements built over weak subgrades by finite element and Mechanistic-Empirical analyses

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Abstract: Finite element (FE) models were developed to evaluate the benefits of geosynthetic reinforcement in flexible pavements built over weak subgrades. The parametric study was conducted to evaluate the effect of different variables such as base thickness, geosynthetic type, geosynthetic stiffness, and double-geogrid layers. FE analyses were performed for 100 load cycles, and the permanent deformation (PD) was used to calibrate the empirical parameters in MEPDG equations for each layer, which were used to extrapolate PD data for the service life of pavements. The PD curves for unreinforced and similar reinforced sections were used to evaluate the Traffic Benefit Ratios (TBR) at different rut depths. The results showed that the inclusion of one geogrid/geotextile layer at the base-subgrade interface could significantly reduce pavement rutting. The use of geogrid is more effective than geotextile in reducing pavement rutting. The derived TBR values range from 1.91 to 8.9 for one geogrid layer and from 1.71 to 5.92 for one geotextile layer. The TBR values increase with increasing the rutting depth and geosynthetic stiffness. The TBR value demonstrates an optimum at a base thickness of 10 in. The results demonstrated the superior benefits of using double geogrid layers compared to single-layer cases.

Keywords: Finite element analysis; Flexible pavement; MEPDG; Rutting; Geosynthetics; Traffic benefit ratio

Centrifuge modeling of geosynthetic-reinforced soil retaining walls subjected to the combined effect of earthquakes and rainfall

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Abstract: Local fine-grained soils were usually used as backfill for geosynthetic-reinforced soil retaining walls (GSRWs). However, there are few studies on the seismic response in this case, especially under the influence of rainfall. In this study, three centrifuge shaking table tests were performed at 30 gravities to investigate the performance of GSRWs subjected to the combined effect of earthquakes and rainfall. Two stages were designed in this study. In the first stage, three conditions were simulated, i.e., post-rainfall earthquake (Test-1), rainfall and earthquake occurring simultaneously (Test-2), and post-earthquake rainfall (Test-3). The results show that if there was enough time for rainwater seepage, the suction force generated in unsaturated GSRW enhanced the soil strength. When GSRW was subjected to heavy rainfall and no time for seepage, the deformation of the GSRW was largest due to the high excess pore water pressure of local saturated soil in GSRW. In the second stage, seismic failure models of GSRWs with different water contents were studied. Under the excitation of a series of continuous earthquakes, a large tensile crack was formed in the unsaturated GSRW, whereas no cracks were found in the saturated GSRW, but its panel demonstrated a large bulging deformation.

Keywords: Reinforced retaining walls; Centrifuge modeling; Shaking table tests; Rainfall; Earthquake; Acceleration amplification coefficient

Centrifuge model studies on desiccation cracking behaviour of fiber-reinforced expansive clay

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Abstract: In this study, randomly distributed fiber reinforcement on the desiccation cracking behavior of expansive clay was investigated. Modeling considerations for the desiccation cracking behavior of unreinforced and fiber-reinforced clay was established using dimensional analysis. A custom-designed setup consisting of a specimen container, heating assembly, and digital image acquisition system was designed, calibrated, and used in the present study. A series of desiccation cracking tests were performed on unreinforced and fiber-reinforced expansive clay in a balanced beam geotechnical centrifuge. The test setup performance was evaluated by conducting tests at varying gravity levels and performing modeling of models. Digital image analysis and particle image velocimetry techniques were used to obtain qualitative information about the cracking of clay under the influence of fiber reinforcement and the varying thickness of the clay layers. The specimens reinforced with fibers exhibited improved cracking resistance than unreinforced clay specimens. The results indicate that the desiccation cracking of clays can be successfully modeled in a geotechnical centrifuge, highlighting the fact that this study is the first-ever such study. This knowledge can be used to study the behavior of critical geotechnical structures, especially clay barriers of landfill cover subjected to desiccation cracking.

Keywords: Geosynthetics; Fiber-reinforced soil; Fibers; Centrifuge modeling; Expansive soils; Reinforced soils

Experimental evaluation of the performance of a geotextile for a pressure-grouted soil nail

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Abstract: A new idea that adopts a geotextile instead of a latex membrane to improve the performance of a pressure- grouted soil nail, was proposed. First, based on the self-developed device, a series of cement slurry filtration tests were carried out to study the influence of the water-cement ratio, slurry volume, and grouting pressure on the geotextile's filtration performance. The variations in filtration time and water-cement ratio, derived from the changes in the aforementioned influencing factors, during pressure grouting were obtained. Second, corresponding penetration tests for the surrounding sands after filtration tests were conducted, and the strength improvement due to infiltration of cohesive substances was subsequently evaluated. Third, uniaxial compression tests were carried out for cement blocks before and after the filtration tests. The grout bulb strength (cement block) was largely increased because the water-cement ratio in the grout bulb was significantly reduced during filtration of the geotextile. This study can help optimize the design of pressure-grouted soil nails using geotextiles.

Keywords: Geotextile; Pressure-grouted soil nail; Water-cement ratio; Slurry volume; Grouting pressure

Hydraulic conductivity requirement of granular and geotextile filter for internally stable soils

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Abstract: A filter media satisfying the hydraulic conductivity requirements allows unimpeded seepage without generation of surplus pressure head and decrease of flow rate. This paper proposes design criteria for the hydraulic conductivity requirements of a filter based on governing flow equations. The results have shown that the hydraulic conductivity requirements of pressure head and flow rate are satisfied with a single condition of hydraulic conductivity of filter greater than or equal to the hydraulic conductivity of soil times the hydraulic gradient in soil. The proposed model is developed for saturated conditions and is also applicable for partially saturated conditions. The developed model is validated based on the experimental evaluations of sandy soil with three granular filters and two needle punched non-woven geotextile filters. The developed design criterion applies to internally stable soils with granular and geotextiles filters and offers an improvement in the standards and current design guidelines for protective filters.
Keywords: Hydraulic conductivity; Permeability; Filter; Geotextile; Geosynthetics; Filtration

Hydraulic and physicochemical properties of dense thin bentonite layers permeated with variably mixed alkaline solutions of KOH and $CaCl_2$ at various temperatures (25–75 °C) for 3 years

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Abstract: Hydraulic conductivity tests were performed using mixed alkaline solutions of KOH and $CaCl_2$ (pH~12) on thin Na-bentonite layers under various temperature conditions (25–75 °C) for 3 years. For dense thin Na-bentonite (dry density of 1.12 Mg/m^3) in a mixed alkaline solution of 0.03 M KOH and 0.03 M $CaCl_2$, the hydraulic conductivities at 50 °C and 75 °C were approximately 10 times higher than that at 25 °C. The bentonite samples permeated with the mixed solution at 50 °C and 75 °C achieved almost complete cation exchange of Na ions by Ca and K ions. However, only slight cation exchange occurred in the bentonite specimens permeated at 25 °C, regardless of the type of permeant. The free swell index of the reacted bentonite permeated with a mixed solution of 0.03 M KOH and 0.03 M $CaCl_2$ significantly decreased at 50 °C and 75 °C compared with that at 25 °C. X-ray diffraction analysis revealed that the decreases in the relative intensities of the peaks of accessory minerals, such as opal-cristobalite/tridymite, quartz, and feldspar, were enhanced at 50 °C and 75 °C.

Keywords: Bentonite barrier; Alkaline solution; Hydraulic conductivity; Cation exchange; Coupled thermal–hydraulic–chemical process

Consolidation considering increasing soil column radius for dredged slurries improved by vacuum preloading method

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Abstract: Soil column is often investigated in the improvement of dredged slurries. Different from the smear zone, the soil column forms gradually and has extremely low permeability. This study presents an analytical solution for soil consolidation considering the increasing radius of the soil column and time-dependent discharge capacity. Based on the solution, the influence of the radius' increase on the consolidation behavior is found significant when the soil column has low permeability and large final radius, and the increase of formation time can lead to the increase of consolidation speed and final consolidation degree.

Keywords: Dredged slurries; Vacuum preloading method; Reduction of discharge capacity decay; Increasing soil column radius