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摘要集

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目　录

Performance of multicomponent GCLs in high salinity impoundment applications

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Abstract: The interface transmissivity (θ) of two multicomponent geosynthetic clay liners (GCLs) is investigated upon hydration and permeation with a highly saline solution (TDS ≈ 260,000 mg/l; Na^+ ~ 95,000 mg/l; K^+ ~ 12,000 mg/l) at two stress levels (10 kPa and 150 kPa). One GCL had a smooth 0.2 mm-thick coating whereas the second GCL had a textured 1 mm-thick coating. For both GCLs, the interface transmissivity after 2-weeks is shown to be higher than at steady-state. The lower the geomembrane's (GMB) stiffness, the lower interface transmissivity. However, the effect is generally diminished at steady state and higher stress. The effect of GMB stiffness at 10 kPa is shown to be 1.6-times that at 150 kPa. Similarly, the 2-week and steady state interface transmissivity for the textured GMB was higher at 10 kPa than at 150 kPa. Coating texture and coating orientation are shown to have a significant effect on GMB/multicomponent GCL interface transmissivity. A hole in the coating aligned with GMB hole creates an additional flow path at the coating/GCL interface ($\theta_{Geofilm/GCL}$), however most of the flow occurs at the coating/GMB interface ($\theta_{Geofilm/GMB}$).
Keywords: Geosynthetics; Geosynthetic clay liner; Interface transmissivity; Multicomponent GCL; Geofilm

A DEM analysis of geomembrane-lined landfill subject to vertical loading

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Abstract: Particle flow code in three dimensions (PFC^{3D}) is used to investigate the bearing capacity and mechanism of a geomembrane-lined landfill under construction loading. The soils and the geomembranes are simulated by numerous balls and parallel bond, respectively. The initial states and loading processes of geomembrane-lined soil are simulated by PFC^{3D} method. The displacement vector diagram, the velocity vector diagram, the stress and the porosity of soil were analyzed using the numerical models. The simulation results demonstrate that the geomembranes keep the underneath soil particles from being displaced under the applied load and can distribute the load uniformly over a wider area. The interface between soil particles and geomembranes, the displacement vector, the contact force and the deformation of the geomembranes are also analyzed. The results showed that the vertical loading affect strength-strain behavior of geomembranes. The contribution of radial displacements on strain and, consequently, the stress crack and potential failure mechanism of geomembranes were analyzed.
Keywords: Geomembrane; PFC^{3D}; Mechanism; Reinforcement; Vertical loading

Analytical solutions for contaminant diffusion in four-layer sediment-cap system for subaqueous in-situ capping

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Abstract: This paper presents analytical solutions for predicting one-dimensional contaminant diffusion in a four-layer sediment-cap system, which is typically encountered in subaqueous in-situ capping of contaminated sediments. The sediment-cap system is comprised of, from top to bottom, a layer of capping material (e.g., clean sand), a layer of reactive core mat (RCM), a layer of contaminated sediment and a layer of uncontaminated sediment. Two different bottom boundary conditions are considered, i.e., zero-concentration-gradient bottom boundary condition and zero-concentration bottom boundary condition, for which the method of separation of variables is used to obtain the analytical solutions. The extensively verified CST3 (Consolidation and Solute Transport 3) model is used to verify the proposed analytical solutions. Using the verified analytical solutions, parametric studies are conducted to investigate the effect of several important parameters on contaminant transport in the four-layer sediment-cap system. The results indicate that the cap thickness, the contaminated sediment thickness, the uncontaminated sediment thickness, the effect of RCM, and the RCM distribution coefficient have significant impact on contaminant diffusion in the four-layer sediment-cap system. The analytical solutions presented herein can be used to assist the design of subaqueous in-situ capping of contaminated sediments and to verify other numerical models.

Keywords: Geosynthetics; Analytical solutions; Contaminated sediments; Diffusion; In-situ capping; Reactive core mat

Dynamic shear behaviors of textured geomembrane/nonwoven geotextile interface under cyclic loading

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Abstract: Textured geomembrane (GMB) and nonwoven geotextile (GTX) are usually used together in liner systems of MSW landfills, but the low shear strength of GMB/GTX interface is extremely detrimental to the stability of landfills, especially under earthquake loading. To study the dynamic shear strength of the GMB/GTX interface, a series of displacement-controlled cyclic direct shear tests are conducted with a large-scale direct shear machine. Normal stress levels ranging from 100 to 1000 kPa and displacement amplitudes ranging from 5 to 25 mm are considered. To compare the failure mechanism, GMB and GTX specimens are tested in not only hydrated but also dry conditions. Different wave forms and excitation frequencies are also applied to analyze the effects of test conditions. It can be seen that the shear deformation develops totally along the GMB/GTX interface when specimens are fully hydrated, while the internal failure of GTX is induced in dry condition. Equivalent linear analyses reveal that the shear stiffness depends on normal stress and displacement amplitude, while the damping ratio is only affected by displacement amplitude. Variations of shear strength during the shear process indicate that the softening behavior of the GMB/GTX interface is closely related to cumulative displacement and normal stress level. Furthermore, based on test results, a positive correlation is summarized between the shear strength and displacement rate of the interface.

Keywords: Geosynthetics; Geomembrane; Geotextile; Cyclic shear test; Dynamic shear strength

Physical and numerical modelling of strip footing on geogrid reinforced transparent sand

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Abstract: This paper presents the results of laboratory scale plate load tests on transparent soils reinforced with biaxial polypropylene geogrids. The influence of reinforcement length and number of reinforcement layers on the load-settlement response of the reinforced soil foundation was assessed by varying the reinforcement length and the number of geogrid layers, each spaced at 25% of footing width. The deformations of the reinforcement layers and soil under strip loading were examined with the aid of laser transmitters (to illuminate the geogrid reinforcement) and digital camera. A two-dimensional finite difference program was used to study the fracture of geogrid under strip loading considering the geometry of the model tests. The bearing capacity and stiffness of the reinforced soil foundation has increased with the increase in the reinforcement length and number of reinforcement layers, but the increase is more prominent by increasing number of reinforcement layers. The results from the physical and numerical modelling on reinforced soil foundation reveal that fracture of geogrid could initiate in the bottom layer of reinforcement and progress to subsequent upper layers. The displacement and stress contours along with the mobilized tensile force distribution obtained from the numerical simulations have complimented the observations made from the experiments.

Keywords: Geosynthetics; Reinforced transparent soil foundation; Strip footing; Numerical modelling

Experimental study on the permeability and self-healing capacity of geosynthetic clay liners in heavy metal solutions

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Abstract: Geosynthetic clay liners (GCLs), which have a very low permeability to water and a considerably high self-healing capacity, are widely used in liner systems of landfills. In this study, a series of experimental tests were carried out under complex conditions on typical commercial GCLs from China. In particular, the effects of pH values and lead ions (Pb^{2+}) were tested in addition to other factors. The swelling properties of natural bentonite encapsulated between geotextile components in the GCLs were tested first. The swelling capacity was reduced rapidly at pH values < 3 and concentrations of Pb^{2+} >40 mM. Permeability tests on GCLs with different concentrations of lead ions were then performed by using the self-developed multi-link flexible wall permeameter, and data showed that increases in lead ion concentrations greatly improved the permeability. Finally, self-healing capacity tests were conducted on needle-punched GCLs under different levels of damage. Results showed that the GCLs have a good self-healing capacity with small diameter damage holes (2 mm, close to three times the original aperture), but with a damage aperture larger than 15% of the sample area, the self-healing capacity could not prevent leakage; hence, in certain situations it will be necessary to repair the damage to meet the anti-seepage requirement.
Keywords: Geosynthetic clay liners; Bentonite; Permeability coefficient; Self-healing

Hydraulic conductivity of bentonite-polymer composite geosynthetic clay liners permeated with bauxite liquor

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Abstract: The high ionic strength of the porewater in red mud (bauxite liquor from digestion) can suppress swelling of montmorillonite, resulting in geosynthetic clay liners (GCLs) that are too permeable to be effective as liners in red mud disposal facilities. Bentonite-polymer composite GCLs (BPC GCLs) have been developed as more resilient lining materials, and some BPC GCLs have been shown to have very low hydraulic conductivity to bauxite liquors that have extreme ionic strength and pH. In this study, a nationwide investigation was conducted in China to evaluate the characteristics of bauxite liquor in Chinese impoundments, and to evaluate the suitability of GCLs containing granular sodium bentonite or BPCs for containment. Hydraulic conductivity tests were conducted on six BPC GCLs with two characteristic Chinese bauxite liquors that are hyperalkaline (pH > 12) and had ionic strengths of 76.9 mM and 620.3 mM. The BPC GCLs had hydraulic conductivity ranging from 10^{-8}-10^{-12} m/s, which is higher than the hydraulic conductivity of BPC GCLs to deionized water (10^{-12}-10^{-13} m/s), but lower than the hydraulic conductivity of conventional GCLs with granular sodium bentonite GCLs to the same liquors (10^{-7}-10^{-8} m/s). The hydraulic conductivity of the BPC GCLs depends on the chemical properties of the leachate, the polymer loading, and the type of polymer. Microstructural analysis by scanning electron microscopy (SEM) suggests that the hydraulic conductivity of BPC GCLs is controlled by pore-blocking by polymer hydrogel, which is affected by the bauxite liquor.

Keywords: Geosynthetics; Bentonite; Red mud; Bauxite liquor; Geosynthetic clay liner; Hydraulic conductivity; Polymer; Hydrogel

Field behaviors of a geogrid reinforced MSW slope in a high-food-waste-content MSW landfill: A case study

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Abstract: A one-year field monitoring of a geogrid reinforced municipal solid waste (MSW) slope was conducted in the Xingfeng Landfill. Settlement tubes, strain gauges and earth pressure cells were used to measure the vertical settlement, the reinforcement strains and the vertical earth pressures in the reinforced MSW slope, respectively. During the monitoring period, the waste sliding occurred and the fresh MSW was dumped at the top of the reinforced slope. The vertical settlement along the reinforcement was nonlinear and the peak settlement occurred at the central part of the reinforcement. The reinforcement strains and the vertical earth pressures at various positions were affected by the sliding and the waste dumping to differing extents. Along the lengths of the geogrid reinforcements, the reinforcement strains showed single-peak distributions. The peak strains were attained in the central part of the reinforcements and the minimum strains were attained at the tail ends. The vertical earth pressures mainly depend on the overlying loads; however, the distributions of them along the reinforcement were nonlinear. Based on the monitoring results, the slope stability evaluation was conducted. It shows that the internal stability of the reinforced MSW slope might be sufficient, while the external stability was insufficient, meaning that this reinforced project was unsuccessful. Finally, various lessons and design suggestions learned from this unsuccessful project were discussed, which could provide valuable references for the future practice of geosynthetic reinforced MSW.

Keywords: Geosynthetics; Geogrid reinforced MSW slope; Long-term monitoring; Field behaviors; Slope stability

Experimental investigation on methane advection and diffusion in geosynthetic clay liners

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Abstract: Geosynthetic clay liners (GCLs) are widely used in landfill and heap-leach facility cover system for mitigating rainfall infiltration and gas migration into atmosphere. Laboratory tests were conducted to investigate methane diffusion and advection through GCLs. Gas permeability coefficient of GCL for the case with moisture content =47.5% is one and two orders of magnitude greater than the cases with moisture content = 68.5% and 80.9%, respectively, when 20 kPa vertical stress was applied. The batch adsorption tests indicated that adsorption of methane onto bentonite is negligible. The concentration variation for the adsorption of methane onto bentonite can be neglected. However, methane concentration decreased by 14.2% for the test of methane adsorption onto GCL during the first 2–3 days. This is because methane was adsorbed by the geotextiles rather than by the bentonite in GCL. The large porosity and surface area of geotextiles provide lots of micropores for methane adsorption. Analytical model was then developed to analyze the performance of GCL-based liners system with respect to methane transport. The results indicate that methane emission fluxes for the case with SL + GCL are 7.8 and 5.1 times less than the cases with SL + CCL when the moisture contents were 25.9% and 35.1%, respectively. The methane emission fluxes for both of the SL + GCL and SL + CCL can be neglected when they are fully saturated. GCL is recommended to be used in arid and semi-arid regions rather than CCL. GCL is recommended to be used in arid and semi-arid areas rather than CCL. Advection plays a more important role in methane migration through SL + GCL and SL + CCL than that of diffusion. With moisture contents = 25.9% and 32%, methane emission flux attributed to advection accounts for more than 90% of the total emission flux for both cases of SL + GCL and SL + CCL. With the increase of moisture content of SL, the effectiveness of SL in reducing methane emission increases. The saved space for using GCL + SL composite cover compared with using a single SL cover is 0.7 m when the moisture content equals 25.9%, which is 0.5 m greater than the case when moisture content equals 32%. GMB plays a dominant role in inhibiting methane migration and reducing methane emission flux. When moisture content equals 25.9%, the methane emission fluxes for SL + GMB + GCL and SL + GMB + CCL are 343 times and 2643 times less than the cases with SL + GCL and SL + CCL, respectively.

Keywords: Geosynthetics; GCL; Methane; Diffusion coefficient; Permeability coefficient; Adsorption

Combined vacuum and surcharge preloading method to improve Lianyungang soft marine clay for embankment widening project: A case

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Abstract: Increased traffic volume in China has made it necessary to increase road capacities by widening embankments. Some of these widened embankments are located in thick soft ground that requires extra improvement beforehand. This paper presents a case study using the combined vacuum and surcharge preloading method to improve the thick soft clay foundation for an embankment widening project in Lianyungang, China. The soil improvement procedure used the combined vacuum (approximately 85 kPa) and surcharge (4.8 m in height) preloading method, the instrumentation scheme was first described and field monitoring (including the longitudinal crack along the current embankment) was also performed. After the combined vacuum and surcharge preloading, the ground settled more than 1.4 m, the average consolidation degree was more than 90%, and the cone and sleeve resistance of the soft clays increased by approximately 2–10 times. The water content, void ratio, and compression coefficient were significantly reduced while density, compression modulus, and cohesion increased substantially. These findings can be used to guide the design of the combined preloading method of the embankment widening project along the east coast of China.

Keywords: Geosynthetics; Embankment widen; Ground improvement; Combined vacuum and surcharge preloading; Field monitoring; Settlement behavior

Performance issues of barrier systems for landfills: A review☆

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Abstract: The objective of the paper is to give an update in key topics related to performance issues of barrier systems for landfills. The objective of using barrier systems is to minimize the impact of contaminants on the surrounding environment. To achieve this goal puncture protection of the geomembrane must be ensured. An update is first given with respect to this matter. The question of the stability on slope of geosynthetic barrier systems is then discussed and an insight is given in modeling and laboratory measurement of parameters required to perform reliable modeling, especially as regards the case of piggy-back landfills. Geotechnical centrifuge modelling tests are very important for simulation of landfill stability induced by the failure of geosynthetic interfaces and validation of complicated numerical models, especially for the high food waste content landfills. The seismic design or assessment of landfill stability with respect to geosyntheics needs to be investigated. Finally, the question of transfers through bottom barrier systems is addressed, giving an update especially in the analytical solutions developed in the past 10 years in China in this matter. The breakthrough time based design method for landfill liner system was then summarized. The behaviour of double-liner system and its simplified performance based design method should be further investigated in the high food waste landfills with high leachate level.
Keywords: Geosynthetics; Landfills; Barrier system; Transfer; Protection; Stability

Analytical model for coupled consolidation and diffusion of organic contaminant transport in triple landfill liners

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Abstract: A triple-layer composite liner consisting of a geomembrane liner (GMB), a geosynthetic clay liner (GCL) and a compacted clay liner (CCL) is commonly used at the landfill bottom liner system to isolate the contaminated leachates. In this paper, one-dimensional quasi-steady-state small deformation model (SDSS) was developed to investigate the behavior of organic chemicals transport in landfill composite liner system considering coupled effect of consolidation, diffusion and degradation. The first and second type bottom boundary conditions are used to derive the analytical solutions. The generalized integral transform technique (GITT) is adopted to derive the analytical solutions. The effect of consolidation on the performance of GMB/GCL/CCL with intact or leaking GMB is investigated. The triple liner under double drainage boundary condition (DDBC) has better performance compared to the case under single drainage boundary condition (SDBC). This is because the velocity induced by consolidation under DDBC is lower than that under SDBC. The effect of GCL consolidation shows an opposite trend compared to CCL consolidation. Considering GCL consolidation can increase the breakthrough time. The effective diffusion coefficient of GCL can be two magnitude orders smaller after consolidation, which provides a better diffusion barrier for the chemical transport. The effects of adsorption and degradation have been analyzed as well. Increasing the adsorption capacity of a deforming composite liner can increase the steady-state bottom flux, which shows the opposite tendency compared to the case without considering consolidation. This is due to the fact that for the case of a deforming composite liner, the advection induced by consolidation includes a new term due to the solid velocity. This velocity will result in the increase the mass of chemical migration through the composite liner.

Keywords: Geoynthetics; Landfill; Leachate; Composite liner; Analytical solution; Contaminant diffusion; Degradation; Consolidation; Small deformation

A simple design approach to analyse the piled embankment including tensile reinforcement and subsoil contributions

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Abstract: There is not one generally accepted approach for the design of geogrid-reinforced pile-supported (GRPS) embankments. Relevant mechanisms include arching of the embankment material, but also the effect of geogrid reinforcement and potentially a contribution from the underlying subsoil. This paper presents a simple design approach to identify the contribution of all three mechanisms, in which the contribution of multi-layered geogrid reinforcement is also presented. To validate the theoretical predictions for the effect of geogrid reinforcement and the potential contribution of underlying subsoil, a series of three-dimensional finite element analyses are conducted. It is found that a point of 'maximum arching' is increased with the height of embankment. This study also presents that the reinforcement could reduce the ultimate stress on the subsoil. However, this requires significant sag of the reinforcement. It is found that the sag of reinforcement is very sensitive to the span of the reinforcement between piles, but relatively insensitive to the stiffness of the reinforcement. For a case with three layers of geogrid, the upper two grids carry relatively little tension compared to the bottom layer. This in turn leads to an approximate but simple equation of vertical equilibrium which may be of use in design.

Keywords: Geosynthetics; Arching; Reinforcement; Piled embankment; Finite element analyses