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摘要集

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目　录

A novel transient gravimetric monitoring technique implemented to GCL osmotic suction control

A.S. Acikel[a], A. Bouazza[b], W.P. Gates[c], R.M. Singh[d], R.K. Rowe[e,*]

a Formerly Monash University, Melbourne, Australia

b Monash University, Melbourne, Australia

c Deakin University, Burwood, Australia

d Norwegian University of Science & Technology (NTNU), Trondheim, Norway

e Queen's University, Kingston, Canada

Abstract: A modified osmotic suction control technique for monitoring apparent transient weight changes was successfully adapted to the wetting and drying paths of geosynthetic clay liners (GCLs). Reasonable control was possible, enabling suction equilibrium to be achieved without disruption to the test. The results provide unique insight into the time-dependent changes in water retention properties and the semi-permeable membrane behaviour of the bentonite component in GCLs. The stages of suction equilibrium, related to the tri-modal pore structure of GCLs and the point of capillary break, could also be monitored. While the osmotic method has been traditionally used to control matric suction (up to 10 MPa) in soils, the overall results presented in this paper indicate that its application for total suction control in GCLs is largely due to the membrane behaviour of their bentonite component. Furthermore, because of capillary break between the GCL and the osmotic solution at the water entry (or residual) suction value of a GCL, an upper limit of 2.8 MPa suction is recommended for the application of the osmotic method to measure the water retention properties of GCLs.

Keywords: Geosynthetic clay liner; Membrane behaviour; Microstructure; Osmotic method; Time dependency

Effectiveness of geogrid reinforcement in improvement of mechanical behavior of sand-contaminated ballast

Javad Sadeghi (PhD) [a,*], Ali Reza Tolou Kian (PhD) [a], Hossein Ghiasinejad (PhD) [b], Mosarreza Fallah Moqaddam (MS) [a], Sepehr Motevalli (MS) [a]

a School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran

b School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran

Abstract: Vertical stiffness and shear strength of ballasts are significantly degraded when contaminated with sands. There is a lack of solutions/studies related to strengthening ballast against sand contamination. Addressing this limitation, a comprehensive laboratory investigation was made on effectiveness of geogrid reinforcement for improvement of mechanical properties of sand-contaminated ballast. To this end, large-scale direct shear tests as well as plate load tests were conducted on geogrid-reinforced ballast samples prepared with different levels of sand contamination. The obtained results indicate that geogrid reinforcement considerably improves shear strength and vertical stiffness of contaminated ballast. A bandwidth was obtained for contamination levels in which ballast reinforcement is effective. Through examining geogrid with different aperture sizes and locations in the ballast layer, the best performance conditions of geogrid reinforcement were derived. The results were used to propose an effective method of ballast reinforcement and an efficient ballast maintenance approach in sandy areas.

Keywords: Ballast; Geogrid; Shear strength; Plate load test; Sand contamination; Railway track

Deterministic and probabilistic assessment of margins of safety for internal stability of as-built PET strap reinforced soil walls

Richard J. Bathurst [a,*], Yoshihisa Miyata [b], Tony M. Allen [c]
a Department of Civil Engineering, GeoEngineering Center at Queen's-RMC, Royal Military College of Canada, Kingston, ON, K7K 7B4, Canada
b Department of Civil and Environmental Engineering, National Defense Academy, 1-10-20 Hashirimizu, Yokosuka, 239-8686, Japan
c State Geotechnical Engineer, Washington State Department of Transportation, State Materials Laboratory, P.O. Box 47365, Olympia, WA, 98504-736, USA

Abstract: The paper demonstrates deterministic and reliability-based assessment of strength limit states (tensile resistance and pullout) and the service limit state for soil failure for mechanically stabilized earth (MSE) walls constructed with polyester (PET) strap reinforcement. The general approach considers the accuracy of the load and resistance models that appear in each limit state equation plus uncertainty in the estimate of nominal load and resistance values at time of design. Reliability index is computed using a closed-form solution that is easily implemented in a spreadsheet. Three PET strap MSE wall case studies are used to demonstrate the reliability-based assessment approach and to compare margins of safety using different load and resistance model combinations. In some walls using the Coherent Gravity Method to compute loads, the recommended nominal factors of safety for tensile strength and pullout limit states were not satisfied. However, reliability analyses showed that the walls satisfy recommended minimum target reliability index values for the limit states investigated, usually by large amounts. The most critical limit state is the soil failure limit state which is used in the Simplified Stiffness Method to keep the reinforced soil zone at working stress conditions assumed for geosynthetic MSE walls under operational conditions.
Keywords: Mechanically stabilized earth (MSE) walls; Polyester (PET) strap reinforcement; Tensile strength; Pullout strength; Soil failure (service) limit state; Reliability-based design

Liquefaction resistance of fibre-reinforced silty sands under cyclic loading

Soheil Ghadr [a,*], Alireza Samadzadeh [a], Hadi Bahadori [a], Arya Assadi-Langroudi [b]
a Civil Engineering Department, Urmia University, Urmia, Iran
b Engineering and Computing, University of East London, Royal Docklands, London, UK

Abstract: Whether the so-called double porosity in soils with a loose and natural packing state is a concept with real-world implications is a fundamental yet controversial question in the study of cyclic undrained shear behaviour of fibre-reinforced silty sands. An attempt is made here to clarify the question by means of particle-level modelling combined with 41 undrained cyclic triaxial shear tests. The study shows that the initial Random Loose Packing changes to Random Close Packing and then Close Packing with silt content increments. The transition from random to close packing occurs at a threshold silt content which is relatively lower in coarser sands. For sands with <40% silt content, the rate of pore pressure growth with loading-unloading cycles increase with silt content increment. Reverse trend applies to silty sands with >40% silt content. Irrespective of fine content, fibre tend to sit deep into the silt pellets and encrust the macro-pore spaces. Generally, increasing fibre content leads to an increase in the average number of contacts per particle, dilation and easier dissipation of excess pore water pressure, a decrease in contact forces and improved liquefaction resistance. For sands with >40% silt content, effectiveness of fibre reinforcement diminishes with increasing sand median size.
Keywords: Liquefaction; Silty sand; Fibre; Cyclic; Shear; Packing

Microstructures within and outside the smear zones for soft clay improvement using PVD only, Vacuum-PVD, Thermo-PVD and Thermo-Vacuum-PVD

Dennes T. Bergado [a], Salisa Chaiyaput [b,*], Suthasinee Artidteang [c], Trong Nghia Nguyen [d]

a Emeritus Professor, Geotechnical and Earth Resources Engineering, School of Engineering and Technology, Asian Institute of Technology, Klongluang, Pathumthani 12120, Thailand

b Department of Civil Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand

c Department of Public Works and Town and Country Planning, Bangkok 10400, Thailand

d Faculty of Civil Engineering, Open University Ho Chi Minh City, Ho Chi Minh City, Viet Nam

Abstract: Previous investigators have found increasing rates odf consolidation with increasing degrees of soft clay improvement using PVD only, Vacuum-PVD, Thermo-PVD and Thermo-Vacuum-PVD). This paper utilized scanning electron microscope (SEM) to evaluate and compare the microstructures of the clay specimens obtained from within the smear zone of both undisturbed and reconstituted samples in small consoledometer as well from within and outside the smear zone of reconstituted samples in large consolidometer. Before improvement, both reconstituted and undisturbed specimens showed anisotropic microstructures. In reconstituted specimen, face to face preferred orientations are revealed parallel to the horizontal plane. Meanwhile, in the undisturbed specimen, some degree of random edge to face mixed with face to face orientations were displayed. After improvement, the microstructures of Thermo-Vacuum-PVD revealed high levels of edge to face orientation in the vertically dominated smear zone, followed by Thermo-PVD, Vacuum-PVD, and PVD only. Moreover, the microstructures of specimens in the horizontally dominated outside of smear zone exhibited mainly face to face orientation and progressively mixed with edge to face orientation. The increasing intensities of edge to face microstructures were successfully correlated with increasing flow parameters and measured shear strengths corresponding to the increasing levels of improvement.

Keywords: Consolidation; Scanning electron microscope (SEM); Prefabricated vertical drain (PVD); Soft clay improvement

Effect of geogrid reinforcement on soil - structure − pipe interaction in terms of bearing capacity, settlement and stress distribution

Selçuk Bildik [a,*], Mustafa Laman [b]
a Nisantasi University, Istanbul, Turkey
b Liverpool University, England, United Kingdom

Abstract: In this study, the contribution of single and multiple layers of geogrids to bearing capacity and stress behavior was determined by laboratory experiments. The effects of parameters such as the depth of the first geogrid, the vertical spacing between the geogrid layers and the number of geogrid layers on the bearing capacity and settlement behavior of soil and stress distribution on geogrid and pipe by using strain gauges have been investigated. The results of experiments were given in dimensionless form of bearing capacity ratio (BCR), settlement reduction factor (SRF) and stress capacity ratio (SCR). As a result of experiments, the contribution of the geogrid on the soil-structure-pipe interaction has been observed together with the stress distribution on the geogrid contributed to the efficient use of the appropriate geogrid capacity.
Keywords: Geogrid; Model tests; Buried pipes; Strain gauges; Stress distribution

Analytical solutions for geosynthetic-reinforced cohesive subgrade spanning trench voids

Fu-quan Chen *, Yu-jian Lin, Shi-xuan Chen
College of Civil Engineering, Fuzhou University, No.2 Xueyuan Road, Fuzhou, 350116, China

Abstract: Geosynthetic-reinforced structures are required for constructing roads in the presence of trench voids. In this study, we propose a novel method with respect to the geosynthetic-reinforced cohesive subgrade spanning trench or column voids. Using this method, we can estimate the geosynthetics deformation w and strain ε by considering various load patterns, the upper interface friction of geosynthetics, the subgrade subsidence, and further investigate the effect of the soil cohesion and the filling in voids on the geosynthetics. Moreover, the node tension bar model was employed with respect to the geosynthetics in the subsided area and the settlement area. The present results were in good agreement with the previous experimental and numerical results. Extensive parametric studies have also been conducted. Thus, the invert parabolic load pattern is the most unfavourable load pattern. Affected by the soil-geosynthetic relative displacement and subgrade soils, w and ε are off by at least 10%. With the loss of fillings in void, w and ε are increased up to 590% and 300%. Reducing the stiffness of geosynthetics leads to increasing w and ε by up to 55% and 250%. In addition, the larger void width results in maximum 260% and 150% increases in w and ε.
Keywords: Geosynthetics; Geosynthetic-reinforced subgrade; Voids; Cohesive backfills; Node method

Effect of specimen preparation on the swell index of bentonite-polymer GCLs

Christian Wireko [a], Binte Zainab [b], Kuo Tian [b,*], Tarek Abichou [a]
a Department of Civil and Environmental Engineering, Florida A&M University- Florida State University College of Engineering, 2525 Pottsdamer St., Tallahassee, FL, 32310-6064, USA
b Department of Civil, Environmental, and Infrastructure Engineering, George Mason University, Fairfax, VA, 22030, USA

Abstract: Experiments were conducted to investigate how specimen preparation (crushing and sieving) affects the swell index (SI) of bentonite-polymer (B–P) composites and the relationship between SI and hydraulic conductivity of B–P GCLs. Seven B–P and one N–B GCLs were used in this study. Tests were conducted using DI water and synthetic municipal solid waste incineration ash leachates. Specimens were prepared using the ASTM D5890 and two alternative methods prior to SI testing. For both Na–B and B–P composites, <100% of the specimen passed through the #100 sieve regardless of the amount of crushing performed using a mortar and pestle. SIs and loss on ignitions (LOI) of the portion of the B–P composites passing #100 sieve were comparable to the Na–B, whereas the B–P specimen retained on #100 sieve had very high SIs and LOIs. These observations indicate that crushing and sieving of the B–P composites lead to segregation of polymer. A stronger correlation (R2 =0.90) was observed between SI and hydraulic conductivity, only when SI tests were conducted with B–P without any crushing and sieving, suggesting that SI tests should conduct with B–P composites retrieved from the GCLs without sieving to provide a better prediction of hydraulic compatibility.
Keywords: Geosynthetic clay liners; Swell index; Loss on ignition; Linear polymer; Crosslinked polymer; Hydraulic conductivity

Vertical cyclic loading response of geosynthetic-encased stone column in soft clay

Ling Zhang, Zeyu Xu *, Shuai Zhou
College of Civil Engineering, Hunan University, Changsha, 410082, China

Abstract: Dynamic responses of the geosynthetic-encased stone column (GESC) supported embankment under traffic loads have become a hot topic. This study investigates the responses of GESC improved ground under vertical cyclic loading. A series of laboratory tests in a designed model test tank have been carried out with different loading parameters (varied loading amplitudes and frequencies), different column dimensions (varied encasement lengths and column diameters). In the tests, the soil-column stress distribution, accumulated settlement of loading plate, excess pore water pressure in the surrounding soil and lateral bulging of the stone column are monitored. Experimental results indicate that the vertical stress on the stone column increases with the increment of encasement length, and decreases with the increment of column diameter, loading amplitude and loading frequency. The increasing stress on the surrounding soil leads to a greater accumulated settlement of the loading plate and excess pore water pressure, while the increasing stress on the column leads to larger lateral bulging of the column. Excess pore water pressure dissipates effectively through vertical and horizontal drainage channels provided by the stone column and the sand bed. The geosynthetic encasement prevents the clay from obstructing the drainage channel by filtration and guarantees the drainage effect.

Keywords: Geosynthetic-encased stone columns; Cyclic loading; Model tests; Excess pore water pressure

Combined effects of ammonium permeation and dry-wet cycles on the hydraulic conductivity and internal properties of geosynthetic clay liners

Ta Thi Hoai [a,b,*], Toshifumi Mukunoki [c]
a Graduate School of Science and Technology, Kumamoto University, Japan
b VNU University of Science, Vietnam National University, Hanoi, Viet Nam
c Faculty of Advanced Science and Technology, Kumamoto University, Japan

Abstract: The hydraulic conductivity of geosynthetic clay liners (GCLs) permeated with deionized water (S0) and NH_4^+ solutions, with concentrations of 100 mg/L (S100) and 1000 mg/L (S1000), was examined under six dry-wet cycles. The internal properties of virgin, desiccated, and healed GCLs were analyzed and quantified using X-ray computed tomography images. The hydraulic conductivity of the GCLs permeated with S0 and S100 underwent a negligible change during the six dry-wet cycles, whereas that of S1000 increased by almost three orders of magnitude after two desiccations. Each desiccation, after permeating with S0 and S100, generated a completely different macro-crack pattern; however, generation of macro-cracks at the same locations from dry cycles 2 to 6 and an abundance of micro-cracks were typical for S1000. This implies the severe deterioration of bentonite due to multi-desiccations and chemical compatibility with S1000. Moreover, the swell index of bentonite exposed to S1000 was reduced by approximately half, after six dry-wet cycles. Despite the lower volume percentage of macro-cracks for S1000 compared to S0 and S100, the swelling capacity of this bentonite was insufficient to fully heal these cracks. Hence, the swelling properties of bentonite dominate crack volume with regard to determining the hydraulic conductivity of GCLs.
Keywords: Geosynthetic clay liners; Hydraulic conductivity; Ammonium permeation; Dry-wet cycles; Crack self-healing; X-ray computed tomography images

Effect of added polymer on the desiccation and healing of a geosynthetic clay liner subject to thermal gradients

Bowei Yu [a,*], Abbas El-Zein [a], R. Kerry Rowe [b]
a School of Civil Engineering, University of Sydney, Australia
b GeoEngineering Centre at Queen's-RMC, Dept of Civil Engineering, Queen's University, Kingston, Canada

Abstract: The desiccation and subsequent hydraulic conductivity of both a standard (GCL_A) and polymer-enhanced (GCL_B) Na-bentonite GCL hydrated from a well-graded sandy subsoil under 20 kPa, then subjected to a thermal gradient, and finally rehydrated and permeated with distilled water or 0.325 mol/L Na^+ synthetic brine are reported. With moderate temperature of 40 ◦C applied to the top of the liner, GCL_B experienced less cracking than GCL_A, but this advantage disappeared when temperatures increased. Both desiccated specimens of GCL_A and B showed significant self-healing when permeated with distilled water and their hydraulic conductivities quickly reduced to around 10^{-11}m/s at 20 kPa upon rehydration. However, when GCL_B desiccated specimens were permeated with the synthetic brine, their hydraulic conductivities were found to be one to two orders of magnitude higher than corresponding values obtained with distilled water. On the other hand, GCL_A (with no polymer treatment) maintained its hydraulic conductivities at the same level obtained with distilled water. It is concluded that caution should be exercised in using polymer-bentonite in applications in which GCLs are subjected to significant thermal gradients unless there is data to show they are resistant to thermal effects.
Keywords: Geosynthetics; GCLs; Temperature; Brine; Desiccation; Self-healing; Hydraulic conductivity

Load sharing characteristics of rigid facing walls with geogrid reinforced railway subgrade during and after construction

Ung Jin Kim [a], Dae Sang Kim [b,*]
a Transportation System Engineering, University of Science and Technology (Korea), #176, Cheoldo Bangmulgwan-ro, Uiwang, Gyeongi-do, South Korea
b Advanced Railroad Civil Engineering Division, Korea Railroad Research Instiute, #176, Cheoldo Bangmulgwan-ro, Uiwang, Gyeongi-do, South Korea

Abstract: Reinforced subgrade for railways (RSR) is a construction method in which reinforced subgrade is constructed first and a rigid facing wall later to minimize the residual settlement after the service of a roadbed. The RSR was designed and constructed at Osong railway test line in Korea. In this study, load sharing capacities from the reinforced subgrade to the rigid facing wall of it were evaluated through long-term measurement, extending 22 months from the start of roadbed construction to the completion of track construction. Under the condition of 0.4 m geogrid vertical spacing installation, the load sharing proportion of horizontal earth pressure of the rigid facing wall was 9%–22% in the lower part, and lesser in the upper part. The strain of geogrid during construction was 0.607%, which was relatively lower than the designed geogrid tensile strain of 5%. The change in geogrid strain after construction was closely correlated with temperature change in the soil.
Keywords: RSR; Load sharing; Field measurement; Geogrid; Long-term behavior

Irrigated composite liner designs for fast hydration and prevention of thermal desiccation of geosynthetics clay liners

Bowei Yu [a,*], Abbas El-Zein [b]
a School of Civil Engineering, University of Sydney, Australia
b School of Civil Engineering, USYD, University of Sydney, Australia

Abstract: In composite liners made of geomembrane (GMB)-geosynthetics clay liners (GCLs), maintaining bentonite in the GCL in a suitably hydrated state is critical for their performance. Hydration of GCL from subsoil, following industry best practice, is time consuming and conditional on suitable water chemistry in subsoil. In addition, under thermal gradients, dehydration occurs, with moisture migrating downwards to the subsoil, leading to the development of cracks in the bentonite and hence loss of performance.

Two novel ideas are proposed in this paper, namely hydration of GCLs by artificial irrigation and hydraulic separation of the liner system from the underlying subsoil. Three new composite liner designs allowing for actively irrigating a geosynthetic clay liner (GCL) through a geocomposite layer were investigated. In two of the three designs, the hydraulic connection between the GCL and the subsoil was broken by placing an additional GMB between them. The new designs were tested in column experiments under 20 kPa overburden pressure and temperatures of up to 78 ◦C applied to the top of the liner. The performances of the new designs were compared to that of a standard GCL-GMB design where GCL was allowed to hydrate from a well-graded sandy subsoil. Three scenarios for the staging of hydration and thermal load application were investigated.

Under active hydration of the composite liners, it took less than 14 days for the GCLs to reach a gravimetric water content ω of 110–130%, compared to 49 days taken to reach ω~95% under hydration from the subsoil. GCLs in the new designs in which the hydraulic connection with the subsoil was broken, remained well-hydrated (ω>100%) after 14 days of heating and no cracks appeared in the bentonite. On the other hand, the GCL in the conventional design experienced severe desiccation under the same conditions. The new designs hence offer a viable solution to the problem of slow hydration and/or thermal desiccation of GCLs.

Keywords: Geosynthetics; Geosynthetic clay liners; Geomembranes; Bentonite; Desiccation; Hydration; Composite liners; Irrigation

Shear strength and failure mechanism of needle-punched geosynthetic clay liner

Shi-Jin Feng *, Ji-Yun Chang, Hong-Xin Chen, Yang Shen, Jia-Liang Shi
Key Laboratory of Geotechnical and Underground Engineering of the Ministry of Education, Department of Geotechnical Engineering, Tongji University, Shanghai, 200092, China

Abstract: The internal shear strength of a geosynthetic clay liner (GCL) within composite liner systems is crucial for the stability of landfills and should be carefully considered in the design. To explore the shear strength and failure mechanism of the extensively used needle-punched GCL, a series of displacement-controlled direct shear tests with five normal stress levels (250–1000 kPa) and eight displacement rates (1–200 mm/min) were conducted. The shear stress to horizontal displacement relationships exhibits well-defined peak shear strengths and significant post-peak strength reductions. The monitoring results of the thickness change indicate that the degree of volumetric contraction is related to the reorientation of fibers and dissipation of pore water pressure. Furthermore, the peak and residual shear strengths both depend on the displacement rate because of the rate-dependent tensile stiffness of needle-punched fibers and shear strength of the soil/geosynthetic interface. Through additional tests and lateral comparison, it was discovered that the shear behavior of sodium bentonite, degree of hydration, and pore water pressures all affect the shear mechanisms of the NP GCL. In particular, the failure mode transfers from fiber pullout to fiber rupture with the increase in water content as the hydrated bentonite particles facilitate the stretching of needle-punched fibers.
Keywords: Geosynthetics; Geosynthetic clay liner; Needle-punched; Bentonite; Direct shear test

Suction and crack propagation in GCLs subjected to drying and wetting in $CaCl_2$-solutions

Wolfgang Lieske [a,*], Florian Christ [a], Wiebke Baille [a], Gemmina Di Emidio [b], Torsten Wichtmann [a]

a Chair of Soil Mechanics, Foundation Engineering and Environmental Geotechnics, Ruhr-Universität Bochum, Germany

b Laboratory of Geotechnics, Department of Civil Engineering, Ghent University, Belgium

Abstract: The current study addresses the cracking and self-healing capacity of Geosynthetic clay liners (GCLs) subjected to drying and wetting in a divalent salt solution. Commercially available GCLs, initially saturated under a load of 3.92 kPa, were stepwise dried for different durations in an oven at 30 ◦C and rewetted afterwards in deionised water and divalent salt solutions (CaCl2) of different molarities (0.05 mol/l, 0.5 mol/l and 0.05 mol/l prehydrated). The evolution of cracks and their patterns were studied by analysing X-ray images. In parallel, the water retention behavior was tested on the raw bentonite using micro-cells and a chilled-mirror hygrometer. The morphology of the crack patterns in the GCLs was highly affected by the pore fluid, which was reasoned by reduced tensile strength caused by the salt induced aggregation. The ability to retain water at a given suction was found to be higher for the samples subjected to CaCl2-solutions in comparision to the sample saturated with deionised water. However, a calculation of the osmotic suction caused by the additional CaCl2 in the porewater shows that the matric suction of the samples subjeted to CaCl2 decreases. The crack intensitiy factor (CIF) followed a similar trend and three different drying regimes were identified.

Keywords: GCL; $CaCl_2$-Solutions; Drying

Characterization of geogrid mechanical and chemical properties from a thirty-six year old mechanically-stabilized earth wall

Ben Leshchinsky [a,*], Ryan Berg [b], Willie Liew [c], Morgan Kawakami-Selin [d], Jaxom Moore [e], Sophie Brown [f], Bernard Kleutsch [f], Kira Glover-Cutter [f], Mark Wayne [c]
a Oregon State University, 319 Snell Hall, Corvallis, OR, 97331, USA
b Ryan Berg and Associates, 2192 Leyland Cove, Woodbury, MN, 55125, USA
c Tensar Int. Corp, 2500 Northwinds Pkwy, Suite 500, Alpharetta, GA, 30009, USA
d Oregon State University, 201 Snell Hall, Corvallis, OR, 97331, USA
e Oregon State University, 110 Kearney Hall, Corvallis, OR, 97331, USA
f Oregon Department of Transportation, 555 13th St. NE, Suite 2, Salem, OR, 97301, USA

Abstract: The mechanical properties of geosynthetic reinforcements are known to be time-, environment- and stress-dependent. Characterization of these reinforcement properties is often assessed under controlled laboratory settings and extrapolated to the design life of geosynthetic-reinforced soil structures. However, despite the wide application of geosynthetic reinforcement in earth retaining structures, there is limited evaluation of how mechanical properties of geosynthetic materials change in situ on constructed works; and primarily limited to case studies within the first decade following construction. This study describes the change in mechanical properties of geogrids retrieved from the facing of the wrapped-face of one of the oldest geosynthetic-reinforced mechanically-stabilized earth (MSE) walls in the United States, constructed in 1983 in a relatively harsh, coastal environment. Laboratory characterization of mechanical and chemical properties of the geogrid are presented, and compared to properties of archived samples, as well as samples from another structure exhumed 8 and 11 years after its respective construction. The laboratory test results demonstrate that the geogrid mechanical and chemical properties have not significantly changed in the 35+ years of service. While the data from this study represents a limited set of conditions, these results demonstrate that geogrids may perform well long after construction.
Keywords: Geosynthetics; Geogrids; Reinforced soil; Creep; Durability

Case history on failure of a 67 M tall reinforced soil slope

Ryan R. Berg [a,*], James G. Collin [b], Thomas P. Taylor [c], Chester F. Watts [d]
a Ryan R Berg & Associates, 2190 Leyland Alcove, Woodbury, MN, 55125-3504, USA
b The Collin Group, 7445 Arlington Road, Bethesda, MD, 20184, USA
c Ground Improvement Systems, LLC, 114 South Collins Street, Arlington, TX, 76011, USA
d Director of Geohazards & Unmanned Systems Research Center, Reed Hall, Box 6939, Radford University, Radford, VA, 24142, USA

Abstract: Construction of this 67 m high RSS was completed in December 2006. After seven years in-service, a tension crack was observed at the top of the slope. In March 2015 this RSS structure catastrophically collapsed. This RSS structure collapsed in a compound failure mode; as the failure plane passed beneath, partially behind, and partially through the reinforced soil mass. The failure plane beneath the RSS was along a shale-claystone interface. The failure surface partially behind the RSS was along sandstone bedrock with water-seeping bedding planes dipping out of the rock mass. The failure surface through the upper portion of the RSS is where the geogrid reinforcement was overwhelmed by stresses originating from underlying deformation. The RSS collapse occurred after 8.3 years in-service as the shear strength along the shale-claystone interface decreased and approached the fully softened strength. The primary causative factors of this failure are: (i) an insufficient subsurface investigation program and interpretation of data for design and detailing; (ii) insufficient specifications and construction plan details for both foundation preparation and rock backcut benching; (iii) insufficient foundation preparation and rock backcut benching during construction; and (iv) adaptations to the design made during construction.
Keywords: Reinforced soil slope; Geogrid; Failure; Compound failure plane; Case history

Ultimate bearing capacity of strip footing resting on soil bed strengthened by wraparound geosynthetic reinforcement technique

Muhammad Nouman Amjad Raja [a,b,*], Sanjay Kumar Shukla [a,c,d]
a Geotechnical and Geoenvironmental Engineering Research Group, School of Engineering, Edith Cowan University, Perth, Australia
b School of Engineering, Civil Engineering Department, University of Management and Technology, Lahore, Pakistan
c School of Building and Civil Engineering, Fiji National University, Suva, Fiji
d VR Siddhartha Engineering College, Vijayawada, India

Abstract: In the recent past, the wraparound geosynthetic reinforcement technique has been recommended for constructing the geosynthetic-reinforced soil foundations. This paper presents the development of an analytical expression for estimating the ultimate bearing capacity of strip footing resting on soil bed reinforced with geosynthetic reinforcement having the wraparound ends. The wraparound ends of the geosynthetic reinforcement are considered to provide the shearing resistance at the soil-geosynthetic interface as well as the passive resistance due to confinement of soil by the geosynthetic reinforcement. The values of ultimate load-bearing capacity determined by using the developed analytical expression agree well with the model footing load test values as reported in the literature.
Keywords: Geosynthetic reinforcement; Strip footing; Ultimate bearing capacity; Wraparound technique

Analyzing the deformation and failure of geosynthetic-encased granular soil in the triaxial stress condition

Fei Song [a,b,*], Yangtao Jin [a], Huabei Liu [c,**], Jie Liu [d]

a Institute of Geotechnical Engineering, School of Highway Engineering, Chang'an University, Xi'an, 710064, PR China

b Key Lab of Geomechanics and Geotechnical Engineering of Ministry of Water Resources, Changjiang River Scientific Research Institute, Wuhan, 430010, PR China

c School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan, 430074, PR China

d Xinjiang Transportation Planning Surveying and Design Institute, Urumqi, 830006, PR China

Abstract: The equivalent strength and stiffness of geosynthetic-encased soil are two important parameters for analysis of cellular geosynthetic-reinforced foundations and earth structures. However, limited analytical approaches exist for the estimation of these parameters, and this limitation hinders their applications in geotechnical engineering practice. In this study, an analytical method is proposed for the prediction of the stress-strain response of geosynthetic-encased soil by employing the soil response in the triaxial stress condition and the theory of thin cylinders. This method has the advantages of theoretical rigorousness and convenience for use and can consider soil nonlinearity, soil dilatancy, soil plasticity and soil-geosynthetic interaction. Different types of yield criteria for soils can be readily incorporated into the proposed method. The proposed method is validated against the results of triaxial compression tests on geosynthetic-encapsulated sand. The good agreement between the predicted stress-strain curves and the measured curves demonstrates the effectiveness of the method. In addition, design tables and parametric studies are provided by employing the formulated analytical method for application purposes.

Keywords: Geosynthetics; Geosynthetic-encased granular soil; Equivalent stiffness; Apparent cohesion; Analytical method; Triaxial stress condition

Evaluation of silt curtain in the reduction of suspended solids

Eduardo Paniguel Oliveira [a], Rafael Brito de Moura [a], Caio Pompeu Cavalieri [b], Rafael de Oliveira Tiezzi [a,*]

a Institute of Science and Technology, Federal University of Alfenas (UNIFAL-MG), Rodovia José Aurélio Vilela, 11999 (BR 267 Km533), Poços de Caldas, MG, Brazil

b Institute for Technological Research (IPT), Avenida Prof. Almeida Prado, nº 532, Cidade Universitária, 05508-901, São Paulo, SP, Brazil

Abstract: Turbidity curtains, also called as turbidity barriers and silt curtains, were designed to contain plumes of suspended solids in water bodies. The high concentration of suspended solids in the raw water impacts on the costs of its treatment. Water with higher turbidity requires more coagulants in water treatment and needs a sludge management. In order to reduce turbidity in the water intake, the present study used a central composite rotational design (CCRD) for a set of 2 in-line turbidity curtains in a laboratory hydraulic flume. Three factors were analyzed: the grammage of the first barrier, the grammage of the second barrier and the solids application rate. The experimental design was made of 18 experiments. Furthermore one blank test was performed. The analyses of variance revealed which factors were significant for each answer. The first curtain efficiency was related positively with the first grammage and negatively with the second curtain grammage. The second curtain efficiency was related positively with the second grammage and application load, and negatively related with the first grammage. The system retention mass was influenced positively by the application load.

Keywords: Silt curtain; Turbidity curtain; Turbidity barrier; Geotextile