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摘要集

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Thermo-hydraulic numerical modelling of in-soil conditions in reinforced soil walls

A. Moncada[1], I. P. Damians[2,3], S. Olivella[4] and R. J. Bathurst[5]
1 PhD Candidate, Department of Civil and Environmental Engineering (DECA), and International Centre for Numerical Methods in Engineering (CIMNE), Universitat Politècnica de Catalunya·BarcelonaTech (UPC), Barcelona, Spain, E-mail: anibal.moncada@upc.edu(Orcid:0000-0001-5054-0513)
2 Associate Research Professor, Department of Civil and Environmental Engineering (DECA), and International Centre for Numerical Methods in Engineering (CIMNE), Universitat Politècnica de Catalunya·BarcelonaTech (UPC), Barcelona, Spain (Orcid:0000-0002-0333-7296)
3 VSoL® R&D Responsible, VSL International Ltd, Barcelona, Spain, E-mail: ivan.puig@upc.edu(Orcid:0000-0002-0333-7296)
4 Professor, Department of Civil and Environmental Engineering (DECA), and International Centre for Numerical Methods in Engineering (CIMNE), Universitat Politècnica de Catalunya·BarcelonaTech (UPC), Barcelona, Spain, E-mail: sebastia.olivella@upc.edu (Orcid:0000-0003-3976-4027)
5 Professor and Research Director, Department of Civil Engineering, GeoEngineering Centre at Queens's RMC, Royal Military College of Canada, Kingston, Ontario 7K7 7B4, Canada, E-mail: bathurst-r@rmc.ca (corresponding author) (Orcid:0000-0002-5176-5287)

Abstract: The role of temperature and relative humidity in long-term mechanical and chemical degradation of polyester fibres due to hydrolysis and creep is well documented. This study presents the results of a thermo-hydraulic 2D finite-element model used to estimate the magnitude and distribution of in situ temperature, relative humidity, and degree of saturation in the backfill of reinforced soil walls(RSWs) due to changes in atmospheric boundary conditions. Boundary conditions for in-air temperature, relative humidity and daily precipitation were taken from weather databases for continental, Mediterranean, desert, and tropical climates. Scenarios with different water tables, and permeable or impermeable zones around the reinforced soil zone were analyzed. Numerical outcomes show that mean in-soil temperature values can be related to the mean annual atmospheric value for each geographical location, with relevant fluctuations limited to the first 3 m of distance from the vertical and horizontal boundaries. In-soil relative humidity values depended on the climate dataset and the permeability of the zones adjacent to the reinforced soil. The results of this study and lessons learned are a valuable precursor for future studies of coupled thermo-hydro-mechanical modelling of polyester geosynthetic RSWs under in situ operational conditions.
Keywords: Geosynthetics, Finite-element modelling, Atmospheric conditions, Temperature, Relative humidity

GMX/GDC strength loss mechanisms

J. Lin[1], T. D. Stark[2], A. Idries[3] and S. Choi[4]

1 Doctor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, USA (Orcid:0000-0002-5773-8087)

2 Doctor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, USA, E-mail: tstark@illinois.edu (corresponding author)

3 Master, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, USA

4 Student, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, USA

Abstract: This paper provides insight into the causes of post-peak strength loss for textured geomembrane (GMX) and nonwoven geotextile (NGT) interfaces. The NGT can be part of a geosynthetic drainage composite (GDC) or a stand-alone NGT. The study used ring shear tests where one of the two interface materials was replaced after reaching a residual strength condition and the test was restarted to measure the change in interface strength. The interface strength loss from peak to large displacement (LD) strength primarily comes from three mechanisms: (1) geomembrane wear, (2) breakage and combing of fibers in the NGT, and (3) reduction of the hook and loop effect between GMX asperities and fibers of the NGT. The source of interface strength loss from LD strength to the residual value mainly comes from breakage and continuous combing of NGT fibers parallel to the direction of shear in ring shear tests. Scanning electron microscopy photographs of the GMX and NGT before and after shearing confirm wear and smoothing of GMX asperities and the combing of NGT fibers in the direction of shear.

Keywords: Geosynthetics, Textured geomembrane, Drainage composite, Geotextile, Asperity, Ring shear, Hook and loop interaction, Geotextiles, geomembranes & geogrids, Shear strength

Probabilistic analysis for the reinforced fill over void problem

R. J. Bathurst[1] and F. M. Naftchali[2]
1 Professor and Research Director, Department of Civil Engineering, GeoEngineering Centre at Queen's-RMC, Royal Military College of Canada, Kingston, ON, Canada,
E-mail: bathurst-r@rmc.ca(corresponding author)
2 PhD student, Department of Civil Engineering, GeoEngineering Centre at Queen's-RMC, Queens University, Kingston, ON, Canada, E-mail: 18fmn@queensu.ca

Abstract: Analytical and numerical solutions for the problem of geosynthetic-reinforced fills over a void have been the subject of investigation for the last four decades. A common feature of this prior work is that all methods have treated the analytical solutions as deterministic. While the treatment of some input parameters must be taken as deterministic, there are other parameters that have uncertainty. Furthermore, the underlying mechanistic models for load and resistance terms in the limit state equations for the reinforced fill over a void problem can be expected to have different accuracy. This paper revisits the problem of geosynthetic-reinforced fills over voids from a probabilistic point of view for reinforcement tensile strain, tensile strength, and geosynthetic stiffness limit states. Particular attention is paid to the method used to select the isochronous stiffness of the reinforcement and the associated uncertainty in the magnitude of that value. The paper demonstrates how the factor of safety from deterministic past practice can be linked quantitatively to the reliability index used in contemporary probabilistic design. Finally, the paper demonstrates the advantage of using product-specific constant-load creep test results to maximise margins of safety for strength and stiffness limit states in both deterministic and probabilistic frameworks.
Keywords: Geosynthetics, Reinforced fill, Void, Sinkhole, Cavity, Limit states, Deterministic analysis, Probabilistic analysis, Factor of safety, Deformation, Strain, Tensile strength, Stiffness, Reliability index, Probability of failure, Level of understanding, Model bias, Isochronous load–strain behaviour, Creep, Hyperbolic stiffness model

Durability of geogrid in a sloped reinforced soil wall after 25 years in service

V. S. Quinteros[1] and R. J. Fannin[2]
1 Senior Specialist, Advanced Modelling, Norwegian Geotechnical Institute, Oslo, Norway (Orcid:0000-0002-4895-1580)
2 Associate Professor, Professor of Civil Engineering, University of British Columbia, Canada, E-mail: jonathan.fannin@ubc.ca

Abstract: The durability of geogrid reinforcement exhumed after 25 years from a sloped wall structure was examined through a comparison of the material properties of exhumed samples with technical data for the original product type. Visual and microscopic inspections found no evidence of installation damage. Analysis of strain increments in rapid loading creep tests to 10 000 h showed excellent agreement between the exhumed and original materials. The results of this study lend confidence in the use of isochronous load–strain–time data for predicting the long-term strain of geosynthetic-reinforced soil structures in design to a serviceability limit state.
Keywords: Geosynthetics, Geogrid, Field exhumation, Laboratory tests, Durability

Dynamic properties of frozen rubber-reinforced expansive soils under confining pressure

Z. Yang[1], Z. Cheng[2], Y. Cui[3], X. Ling[4] and W. Shi[5]
1 Professor, Department of Civil Engineering, Qingdao University of Technology, Qingdao, China, E-mail: yzhnqd@qut.edu.cn
2 PhD in Geotechnical Engineering, Department of Environmental Science and Engineering, Ocean University of China, Qingdao, China, E-mail: czj_qut@foxmail.com
3 PhD in Geotechnical Engineering, Department of Environmental Science and Engineering, Ocean University of China, Qingdao, China, E-mail: cyx9656@foxmail.com (corresponding author)
4 Professor, Department of Civil Engineering, Harbin Institute of Technology, Harbin, China; Qingdao University of Technology Qingdao, China, E-mail: xianzhang_ling@263.net
5 Professor, Department of Civil Engineering, Qingdao University of Technology, Qingdao, China, E-mail: susan@qut.edu.cn

Abstract: In recent years, waste rubber has been increasingly utilized to enhance the performance of expansive soil foundations. This study aims to investigate the influence of rubber powder on the dynamic characteristics of frozen rubber-reinforced expansive soils (RRES) in permafrost regions. Temperature-controlled dynamic triaxial tests were conducted on RRES samples, varying rubber content, freezing temperatures, and confining pressures. The key findings are as follows: (1) A modified Hardin model with freezing temperature and rubber content as correction factors was established, which was verified to be useful for describing the dynamic stress-strain relationship. (2) Under the confining pressure, the dynamic shear modulus decreases with increasing rubber content. When the rubber content changes from 5% to 10%, the dynamic shear modulus decreases by about 20 MPa; the change becomes less obvious after the content exceeds 20%, and the RRES tends to show the characteristics of rubber. (3) As the rubber content increases, the damping ratio rises and shows the phenomenon of increasing and then decreasing with increasing confining pressure, and reaching a maximum at 0.4 MPa. (4) A prediction model for the maximum dynamic shear modulus with rubber content, freezing temperature and confining pressure is proposed.
Keywords: Geosynthetics, Frozen rubber-reinforced expansive soils, Confining pressure, Freezing temperature, Rubber content, Dynamic properties, UN SDG 11: Sustainable cities and communities

Modeling geogrid-stabilized aggregate base courses considering local stiffness enhancement

Y.-H. Byun[1], I. I. A. Qamhia[2], M. Kang[3], E. Tutumluer[4] and M. H. Wayne[5]

1 Associate Professor, School of Agricultural Civil & Bio-Industrial Engineering, Kyungpook National University, Buk-gu, Daegu, Korea, E-mail: yhbyun@knu.ac.kr (corresponding author)

2 Senior Research Scientist, Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign, Urbana, Illinois, USA, E-mail: qamhia2@illinois.edu

3 Assistant Professor, Civil Engineering Department, University of St. Thomas, St. Paul, Minnesota, USA, E-mail: kang4575@stthomas.edu

4 Abel Bliss Professor, Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign, Urbana, Illinois, USA, E-mail: tutumlue@illinois.edu

5 Director of Application Technology and Engineering, Tensar International Corporation a division of CMC, Alpharetta, GA, USA, E-mail: mark.wayne@cmc.com

Abstract: Lateral restraint is the primary stabilization mechanism associated with the interlocking of aggregate particles in the geogrid apertures. This paper presents findings from a laboratory study which quantifies the local stiffness enhancement of aggregates through micromechanical interlocking provided by two different types of geogrids. These findings are applied to model the resilient response characteristics of geogrid-stabilized base course composite systems. Using three pairs of bender elements as shear wave transducers, horizontal stiffness profiles were determined above mid-heights of aggregate specimens. For two types of geogrids with square- and triangular-shaped apertures, the shear modulus profiles decreased moving away from the geogrid location. Based on a relationship for aggregates, resilient modulus was estimated from the shear modulus. Considering the variations in resilient moduli with distance from the geogrid location, the local stiffness enhancements provided by the two geogrid types were assigned to modulus profiles of a geogrid-stabilized aggregate base course in flexible pavement mechanistic analysis and modeling. The modeling results demonstrate the effect of geogrid base stabilization on the computed pavement resilient responses for both geogrid types. The sublayering approach which properly considers modeling of the geogrid influence zone could be effectively used in mechanistic analysis of a geogrid-stabilized pavement system.

Keywords: Geosynthetics, Aggregates, Base course, Geogrid, Layered elastic analysis, Shear wave

Assessment of the stress crack resistance of multilayered textured HDPE geomembranes

F. B. Abdelaal[1], M. Zafari[2] and R. K. Rowe[3]
1 Assistant Professor, GeoEngineering Centre at Queen's-RMC, Queen's University, Kingston, ON, Canada, E-mail: fady.abdelaal@queensu.ca
2 PhD student, GeoEngineering Centre at Queen's-RMC, Queen's University, Kingston, ON, Canada, E-mail: mohsen.zafari@queensu.ca
3 Professor and Canada Research Chair in Geotechnical and Geoenvironmental Engineering, GeoEngineering Centre at Queen's-RMC, Queen's University, Kingston, ON, Canada, E-mail: kerry.rowe@queensu.ca (corresponding author)

Abstract: The stress crack resistance (SCR) of different multilayered textured geomembranes (GMBs) immersed in synthetic municipal solid waste leachate at 55°C and 85°C for 50 months was assessed using their smooth edge or smooth equivalent GMBs made from the same formulation as textured GMBs. The difference between the actual thickness of the smooth edge and the nominal thickness of the GMB was shown to result in SCR values that do not reflect the true SCR of the GMB resin when assessed based on the current ASTM standard test procedure. As such, adjustments to the current test method are presented to limit its effect on SCR, especially when comparing the performance of different GMBs based on SCR. Additionally, due to variations in formulation and thickness of the textured and smooth portions of GMB rolls, a new double-notching technique was examined to assess the SCR of the textured portion. Using this technique on samples from textured and smooth portions at different incubation times showed similar initial and stabilised SCR values but different SCR degradation rates for the two different parts of the same GMB roll. Relying solely on SCR values obtained from the smooth edge/smooth equivalent GMB may thus underestimate or overestimate the degradation of multilayered textured GMBs.
Keywords: Geosynthetics, Municipal solid waste landfills, Landfill liners, Multilayered geomembranes, Textured geomembranes, Stress crack resistance, UN SDG 6: Clean water and sanitation, UN SDG 9: Industry, innovation and infrastructure, UN SDG 11: Sustainable cities and communities, UN SDG 15: Life on land

Permeability mechanism of PVC-P geomembranes based on low-field NMR technology

X. L. Zhang[1], Y. Y. Wu[2], C. J. Yin[3] and X. Y. Gu[4]

1 Associate Professor, School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, China, E-mail: zhangxianlei@ncwu.edu.cn (corresponding author) (Orcid:0000-0002-7740-3938)

2 PhD student, College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing, China, E-mail: 190202020002@hhu.edu.cn (Orcid:0000-0002-5181-8852)

3 Postgraduate student, School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, China, E-mail: yinchunjie1205@163.com

4 Postgraduate student, School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, China, E-mail: guxiaoyu47@163.com

Abstract: The permeability of plasticised polyvinyl chloride (PVC-P) geomembranes (GMBs) is of significant importance to the safe operation of impermeable structures and even entire projects. To avoid the drawbacks of the traditional method of adopting the permeability coefficient to characterise permeability, this paper presents a mathematical model of porosity and seepage discharge based on the results of the vertical permeability test and porosity obtained from low-field nuclear magnetic resonance (NMR) tests. This paper also explores the applicability of porosity to evaluate permeability combined with the dynamic distribution of pores and pore radius. The results show that low-field NMR technology with 1 H (isotope of hydrogen) atoms as the probe can accurately measure the distribution of pores and pore radius in the PVC-P GMB. The proportion of micropores (Mic), mesopores (Mes) and macropores (Mac) and the shrinkage or development of pore radius are primarily responsible for the variation of porosity. Porosity is closely correlated with seepage discharge, and the constructed model can accurately predict seepage discharge. Furthermore, porosity can provide technical support for the evaluation of the permeability of PVC-P GMBs and the selection of appropriate GMBs for engineering design.

Keywords: Geosynthetics, PVC-P geomembrane, Low-field NMR

Modular polymer stormwater collection structure response to one-week design-truck load

R. W. I. Brachman[1], A. Zarpeima[2] and J. M. LeBlanc[3]
1 Professor, GeoEngineering Centre at Queen's–RMC, Queen's University, Kingston ON, Canada, E-mail: brachman@queensu.ca (corresponding author)
2 Graduate student, GeoEngineering Centre at Queen's–RMC, Queen's University, Kingston ON, Canada, E-mail: arian.zarpeima@queensu.ca
3 Former graduate student, GeoEngineering Centre at Queen's–RMC, Queen's University, Kingston ON, Canada, E-mail: 11jml21@queensu.ca

Abstract: Full-scale physical modelling was used to evaluate the response of modular polymer stormwater collection structures when subjected to design-truck loading that was sustained for 1 week (i.e. a parked vehicle) and when buried with minimum soil cover. Surface loading was applied on a steel load pad that simulates one-half of the AASHTO design-truck single-axle that was held constant for 1 week to assess the stability of the buried system and demand on the platen and column components of the modules to allow independent load rating of the buried structure. No collapse or limiting state occurred. The 1-week creep buckling resistance was found to be nearly four times the factored column demand to 1-week loading for both module types. New insight into the time-dependent behaviour of the soil–structure system was gained by comparing the buried response to creep tests conducted on isolated columns and platens. The response of the buried soil–structure system was less severe than unconstrained creep. Column loads were found to not increase with time. Bending deflections increased by 1.04 to 1.26 times when buried rather than by 3.0 to 3.4 times for unconstrained creep as platen creep when buried was greatly restrained by the soil.

Keywords: Geosynthetics, Soil–structure interaction, Buried polymer structure, Physical modelling, Creep

Combined bearing capacity of footings on geogrid-reinforced granular fill over soft clay

M. Fatehi[1], B. Yaghoobi[2], M. Payan[3], I. Hosseinpour[4] and R. Jamshidi Chenari[5]

1 MSc Graduate, Department of Civil Engineering, Faculty of Engineering, University of Guilan, Rasht, Iran, E-mail: fatehi.mahtab@gmail.com

2 M.Sc. Graduate, Department of Civil Engineering, Faculty of Engineering, University of Guilan, Rasht, Iran, E-mail: behnaz.yaghoobi.98@gmail.com

3 Assistant Professor, Department of Civil Engineering, Faculty of Engineering, University of Guilan, Rasht, Iran, E-mail: payan@guilan.ac.ir

4 Assistant Professor, Department of Civil Engineering, Faculty of Engineering, University of Guilan, Rasht, Iran, E-mail: imanhp@guilan.ac.ir

5 Senior Geotechnical Engineer, TREK Geotechnical Inc., Winnipeg, Manitoba, Canada; Formerly Research Fellow, Department of Civil Engineering, GeoEngineering Centre at Queen's-RMC, Royal Military College of Canada, Kingston, Canada,
E-mail: jamshidi_reza@yahoo.com (corresponding author)

Abstract: The current study investigates the ultimate bearing capacity of obliquely/ eccentrically loaded shallow strip foundations resting on a geogrid-reinforced granular fill with limited thickness over a very soft to soft clay layer. To this end, the lower bound theorems of the finite element limit analysis (FELA) and second-order cone programming (SOCP) are effectively exploited to simulate the underlying clay deposit, geogrid layer, and granular fill along with the inclined/eccentric loading exerted on the overlying footing. The accuracy of the adopted formulations is rigorously examined through several comparisons with the results of a well-established analytical approach in the literature. A comprehensive parametric study is then conducted to properly examine the influences of the geosynthetic layer characteristics and soft clay properties on the overall bearing capacity and failure envelope of the strip footing subjected to wide ranges of inclined and eccentric loadings. The results show that placement of a geogrid-reinforced granular fill layer over the soft clayey soil significantly increases the bearing capacity of the shallow foundation. The ultimate tensile strength of the reinforcement layer and the cohesion of the underlying very soft to soft clay deposit are also observed to have considerable effects on the size of failure envelopes.

Keywords: Geosynthetics, Reinforcement, Soft clay, Lower bound, Finite element limit analysis (FELA)

Study on performance of geocell-reinforced red clay subgrade

X. W. Luo[1], Z. Lu[2], J. B. Zhang[3] and H. L. Yao[4]

1 Associate Professor, State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China, E-mail: xwluo@whrsm.ac.cn (corresponding author)

2 Professor, State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China, E-mail: zlu@whrsm.ac.cn

3 Professor of Engineering, CCCC Second Highway Consultants Co., Ltd., Wuhan, China, E-mail: zhangjingbo@ccccltd.cn

4 Professor, State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China, E-mail: hlyao@whrsm.ac.cn

Abstract: Three comparative treatment plans are used to study the effect of red clay subgrade reinforced with geocell. Multiple subgrade test methods including Benkelman beam, portable falling weight deflectometer, dynamic cone penetrometer and standard vehicle load tests are adopted in the field tests. Test results show that the application of geocell in red clay subgrade can enhance the overall stiffness and strength of the subgrade. The mechanism of geocell in the subgrade is studied. Geocell can provide added confinement to the subgrade soil. Compared with the red clay subgrade without geocell reinforcement, for the red clay subgrade reinforced with 0.1 m-high geocell and 0.05 m-high geocell, the rebound modulus increases by 65% and 33%, the dynamic modulus increases by 69% and 38% and the penetration decreases by 51.7% and 40.4%, respectively. A hard shell layer is formed in the subgrade when it is reinforced with geocell. The geocell-reinforced layer mainly plays the role of stress diffusion. It not only can reduce the additional stress in the subgrade but can also diminish the influence of the depth of the vehicle load.

Keywords: Geosynthetics, Reinforcement, Benkelman beam, Portable falling weight deflectometer, Dynamic cone penetrometer

A nonlinear analytical model for consolidated geotextile-encased sand columns

H.-J. Kim[1], P. R. Dinoy[2], H.-J. Kim[3], V. A. Corsino Jr[4], Y.-S. Joung[5] and J.-Y. Park[6]

1 Professor, Department of Civil Engineering, Kunsan National University, Gunsan, Republic of Korea, E-mail: kimhj@kunsan.ac.kr (Orcid:0000-0003-1365-6992)

2 Researcher, Renewable Energy Research Institute/Department of Civil and Environmental Engineering, Kunsan National University, Gunsan, Republic of Korea, E-mail: peter_rey@kunsan.ac.kr (corresponding author) (Orcid:0000-0002-5884-1748)

3 Graduate student, Department of Civil and Environmental Engineering, University of California, Davis, CA, USA, E-mail: hyki@ucdavis.edu

4 Graduate student, Department of Civil and Environmental Engineering, Kunsan National University, Gunsan, Republic of Korea, E-mail: vacorsino@kunsan.ac.kr

5 Graduate student, Department of Civil and Environmental Engineering, Kunsan National University, Gunsan, Republic of Korea, E-mail: jos0428@kunsan.ac.kr

6 Graduate student, Department of Civil and Environmental Engineering, Kunsan National University, Gunsan, Republic of Korea, E-mail: wnsdyd0808@kunsan.ac.kr

Abstract: A nonlinear model for consolidated geotextile-encased sand columns (GESACs) was formulated. The model is based on a power law and predicts the stress–strain curve of a consolidated GESAC based on the superposition rule, wherein the stress–strain curve of the unconsolidated GESAC is superposed by the stress–strain curve of the soil alone in a consolidated triaxial test. A uniaxial compression test was conducted to study the failure mechanism of the GESAC. In addition, unconsolidated and consolidated triaxial tests on loose GESACs were conducted to investigate the effect of initial stresses on the shear behavior of GESACs. To further investigate the interaction between the soil and geotextile, and to assess the GESAC model, finite-element simulations were conducted. The results showed that internal lateral stresses developed in the GESAC due to the confining effect of the geotextile, which increased the circumferential tension force on the geotextile while the *p*–*q* path of the GESAC approached the critical state line and followed the line when the shear strength of the soil was mobilized. The model was verified based on data on dense consolidated GESACs found in the literature and the measured and predicted results showed good agreement.

Keywords: Geosynthetics, Geotextile-encased sand column (GESAC), Nonlinear analytical model, Stress–strain behavior, UN SDG 9: Industry, innovation and infrastructure, UN SDG 11: Sustainable cities and communities

Response of sensor-enabled piezoelectric geobelt reinforced soil pullout friction signals

Y. Rao[1], Z. Liu[2], G. Ding[3], Z. Gao[4], J. Wang[5], H. Wang[6] and X. Wu[7]

1 Graduate student, College of Civil Engineering and Architecture, Wenzhou University, Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province, International Cooperation Base for Science and Technology on Ultra-soft Soil Engineering and Smart Monitoring, Wenzhou, China, E-mail: raoyu20@163.com (Orcid:0000-0003-4754-9175)

2 Graduate student, College of Civil Engineering and Architecture, Wenzhou University, Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province, International Cooperation Base for Science and Technology on Ultra-soft Soil Engineering and Smart Monitoring, Wenzhou, China, E-mail: liuzhiming680@163.com

3 Professor, College of Civil Engineering and Architecture, Wenzhou University, Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province, International Cooperation Base for Science and Technology on Ultra-soft Soil Engineering and Smart Monitoring, Wenzhou, China, E-mail: zl6895xy@163.com

4 Graduate student, College of Civil Engineering and Architecture, Wenzhou University, Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province, International Cooperation Base for Science and Technology on Ultra-soft Soil Engineering and Smart Monitoring, Wenzhou, China, E-mail: gaoziyang2022@163.com (corresponding author) (Orcid:0000-0002-9057-212X)

5 Professor, College of Civil Engineering and Architecture, Wenzhou University, Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province, International Cooperation Base for Science and Technology on Ultra-soft Soil Engineering and Smart Monitoring, Wenzhou, China, E-mail: wangjunx9s@163.com

6 Graduate student, Zhejiang Provincial Department of Transportation, Wenzhou, China, E-mail: wanghangyu777@163.com

7 Graduate student, Zhejiang Provincial Department of Transportation, Wenzhou, China, E-mail: wuxiuyong556@163.com

Abstract: Geosynthetics are widely used in soil reinforcement engineering, the failure modes of which are typically pullout modes. However, current research on monitoring the pullout damage experienced by reinforced soil is limited. Accordingly, in this study, the stress variation laws and signal output characteristics of a sensor-enabled piezoelectric geobelt (SPGB) that can capture the tensile vibration signals of reinforced soil under various tensile failure conditions were examined. It was found that the SPGB captured the response signals under different soil environments, confining pressures, and shear rates. During the pullout

friction process, a spike was generated, and the displacement corresponding to the position of the spike increased with an increase of the pullout friction rate. In the clay environment, the spike voltage was related to the confining pressure, while in the sand environment, there was no obvious relationship between the spike voltage and the confining pressure. In the gravel environment, the output voltage of the SPGB fluctuated greatly, due to the embedment of gravel particles, and many negative voltages of large amplitude appeared. The results of this study verify the promising application potential of SPGBs for the integration of soil reinforcement and monitoring, which is significant for further applications of SPGBs in engineering.
Keywords: Geosynthetics, Sensor-enabled piezoelectric geobelt (SPGB), Sensor-enabled geosynthetic (SEG), Reinforced soils, Pullout friction, UN SDG 11: Sustainable cities and communities

Extrapolating residual GMX/GDC interface strength from direct shear tests

J. Lin[1], T. D. Stark[2] and A. Idries[3]

1 1 Graduate Research Assistant of Civil and Environmental Engineering, Newmark Civil Engineering Laboratory, University of Illinois, Urbana, IL, USA, E-mail: jialel2@illinois.edu

2 Professor of Civil and Environmental Engineering, Newmark Civil Engineering Laboratory, University of Illinois, Urbana, IL, USA, E-mail: tstark@illinois.edu (corresponding author)

3 Graduate Research Assistant of Civil and Environmental Engineering, Newmark Civil Engineering Laboratory, University of Illinois, Urbana, IL, USA,
E-mail: aidries2@illinois.edu

Abstract: Residual interface strength is mobilized along sideslopes of geosynthetic lined areas, such as landfill sideslope. Unfortunately, only the large displacement (LD) interface strength is measured in frequently used direct shear tests, which overpredicts the residual interface strength by about 40% because of limited continuous shear displacement and new geomembrane being introduced during the test. Commercial laboratories usually conduct direct shear tests in accordance with ASTM D5321-02 or ASTM D6243-13, which can only measure the LD interface strength. This paper suggests a method to estimate the residual interface strength from direct shear test results, which provides a better estimate of field interface strengths. The shear stress–displacement relationship from ring shear tests fits a power function, which can be used to extrapolate direct shear test results to the residual strength. This paper shows the power function can predict reasonable residual interface strengths from the shear stress– displacement relationship measured in direct shear tests. This method allows estimation of the residual strength data when only direct shear test results are available and prevents overprediction of the factor of safety (FoS) during slope stability evaluations.

Keywords: Geosynthetics, Textured geomembrane, Drainage composite, Direct shear test, Residual shear strength, Ring shear, Large displacement shear strength

Equivalent analytical models for assessment of landfill composite liners

H. Xie[1], W. Xu[2], L. Wang[3], H. Yan[4] and J. Wu[5]
1 Professor, Center for Balance Architecture, Zhejiang University, Hanghzou, China, E-mail: xiehaijian@zju.edu.cn
2 Postgraduate, College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China, E-mail: 22112095@zju.edu.cn
3 Postgraduate, Center for Balance Architecture, Zhejiang University, Hanghzou, China, E-mail: leonwang0416@zju.edu.cn
4 Research Fellow, College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China, E-mail: yanhuaxiang@zju.edu.cn (corresponding author)
5 Research Fellow, Center for Balance Architecture, Zhejiang University, Hanghzou, China, E-mail: wujiawei@zju.edu.cn

Abstract: An equivalent analytical model based on time moments is proposed to estimate the properties of landfill composite liners. The service performance of landfill liners composed of a geomembrane layer (GMBL), a geosynthetic clay layer (GCL), and an attenuation layer (AL) and a GMBL, compacted clay layer (CCL), and AL were equivalently analyzed. The equivalent analysis and quantitative correlation of contaminants at the bottom of the GMBL/GCL/AL and GMBL/CCL/AL systems were considered according to the relative concentration (C_N), instantaneous flux (J_I) and accumulative flux (J_A). The relative concentration (C_N) was found to be the most conservative equivalent index. The thickness equivalent relation of the AL for the different composite liners was consequently obtained using the pure diffusion equivalent model and the advection–diffusion equivalent model. It was found that the pure diffusion thickness equivalent relationship was a simplified linear correlation and independent of time. The quadratic polynomial equivalent equations of AL thickness for different service times were obtained by the group method of data handling. The results showed that GCL-based composite liner had a better environmental protection performance than the CCL-based composite liner. When the thickness of the GMBL/CCL/AL composite liner was fixed, the corresponding equivalent thickness of AL in the GMBL/GCL/AL composite liner decreased with an increase in the leachate head and the wrinkle length for the same value of C_N.
Keywords: Geosynthetics, Equivalency analysis, Contaminant transport, Landfills, Composite materials

Vacuum consolidation of dredged slurry improved by horizontal drainage-enhanced geotextile

J. Wang[1], R. Anda[2], H. Fu[3], X. Hu[4], X. Li[5] and Y. Cai[6]

1 Professor, College of Civil Engineering and Architecture, Wenzhou University; Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province; Zhejiang Engineering Research Center of Disaster Prevention and Mitigation for Coastal Soft Soil Foundation; Zhejiang Collaborative Innovation Center of Tideland Reclamation and Ecological Protection, Wenzhou, China, E-mail: wangj19802022@163.com

2 Lecturer, College of Civil Engineering and Architecture, Wenzhou University; Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province; Zhejiang Engineering Research Center of Disaster Prevention and Mitigation for Coastal Soft Soil Foundation; Zhejiang International Science and Technology Cooperation Base of Ultra-soft Soil Engineering and Smart Monitoring, Wenzhou, China, E-mail: adrila@163.com

3 Professor, College of Civil Engineering and Architecture, Wenzhou University; Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province; Zhejiang Collaborative Innovation Center of Tideland Reclamation and Ecological Protection; Wenzhou Key Laboratory of Traffic Piezoelectric Engineering Technology, Wenzhou, Zhejiang, China, E-mail: fuhongtao2012@163.com (corresponding author)

4 Professor, College of Civil Engineering and Architecture, Wenzhou University, China, E-mail: 316620400@qq.com

5 Professor, College of Civil Engineering and Architecture, Wenzhou University, China, E-mail: ac-lxb@wzu.edu.cn

6 Laboratory Technician, College of Civil Engineering and Architecture, Wenzhou University, China, E-mail: 11293875@qq.com

Abstract: the vacuum consolidation behavior of dredged slurry improved by horizontal drainage-enhanced geotextile (HDeG) application was investigated. For comparison, vacuum consolidation tests using a prefabricated vertical drain (PVD) and layered prefabricated horizontal drains (PHDs) were conducted. Based on the test results, it was found that by using HDeG, the consolidation rate of the dredged slurry was significantly increased. Thus, the effectiveness of the HDeG method was verified. The nonwoven geotextile sheet of HDeG could provide a sufficient vacuum pressure and drainage and therefore greatly shorten the drainage path. The HDeG-induced consolidation settlement generally matched the calculated 1D consolidation settlement well using a representative coefficient of consolidation. The analysis of scanning electron microscopy images shows that after the vacuum consolidation test, the porosity of the PHD filter (vacuum PHD treatment) was only 11% (21.1% of the initial porosity), while the porosity of the PHD filter of the HDeG was 22.16% (42.6% of the

initial porosity), suggesting that the geotextile effectively reduced the apparent clogging of the drains.
Keywords: Geosynthetics, Vacuum preloading, Horizontal drainage-enhanced geotextile, Prefabricated horizontal drain, Prefabricated vertical drain

Response of shallow foundations in tire derived aggregate

A. A. Yarahuaman[1] and J. S. McCartney[2]
1 PhD candidate, Department of Structural Engineering, University of California San Diego, La Jolla, CA, USA, E-mail: ayarahua@ucsd.edu
2 Professor, Department of Structural Engineering, University of California San Diego, La Jolla, CA, USA, E-mail: mccartney@ucsd.edu (corresponding author)

Abstract: This study investigates the quasi-static bearing stress-settlement response of shallow foundations in monolithic tire derived aggregate (TDA) layers having a total thickness of 3 m using a large-scale container and loading system. Tests were performed on footings having a range of widths, embedment depths, shapes, and loading inclinations. In tests where tilting was restricted, a clear bearing capacity was not observed for settlements up to 1.2B, where B is the footing width, but in tests where tilting was permitted bearing capacity was observed between settlements of 0.2B to 0.7B. Surface settlements indicate a dragdown response of the TDA adjacent to the footing extending out to more than 3B from the footing center, while settlement plates beneath the footing indicate a zone of influence of induced settlements of 14% at a depth of 4B. While bearing capacity theories for frictional geomaterials provided a reasonable prediction of the bearing capacity of footings in TDA for most tests, the corresponding settlements may be excessive for engineering applications. Accordingly, a correlation was developed between the theoretical bearing capacity and bearing stress at a settlement of 0.1B. A test with sustained loading indicates slight creep settlements with some stress dependency with magnitudes consistent with past studies.
Keywords: Geosynthetics, Tire derived aggregate, Footings/foundations, Bearing capacity, Large-scale testing

Ultimate bearing capacity of geosynthetic reinforced soil abutment centrifuge model tests

C. Zhao[1], C. Xu[2,3], Y. Yang[4,5], Q. Wang[6], C. Du[7] and G. Li [8]
1 PhD candidate, Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai, China, E-mail: 1910368@tongji.edu.cn
2 Professor, Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai, China
3 Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, Shanghai, China, E-mail: c_axu@tongji.edu.cn (corresponding author)
4 Associate Professor, Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai, China
5 Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, Shanghai, China, E-mail: 2011yang@tongji.edu.cn
6 PhD candidate, Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai, China, E-mail: qm_wang@tongji.edu.cn
7 PhD student, Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai, China, E-mail: qm_wang@tongji.edu.cn
8 PhD student, Department of Geotechnical Engineering, College of Civil Engineering, Tongji University, Shanghai, China, E-mail: ligeye@tongji.edu.cn

Abstract: Five centrifuge models of geosynthetic reinforced soil (GRS) abutments with segmental block facing were loaded in the acceleration field under plane strain condition. Influencing factors including reinforcement tensile strength, setback and bearing area width were considered and analysed. Results show that the abutment with stronger reinforcement remained stable under the maximum loading capacity. However, abutments with weaker reinforcement showed excessive vertical strain, local deformation or even collapse. The ultimate bearing capacity increased with the lengthening of setback but decreased due to a larger bearing area. The rupture of reinforcements was observed and considered as the cause of the failures. Compared with the measured ultimate bearing capacity, the values calculated by the semi-empirical formula of design guidelines were significantly conservative. The failure surface of failed abutment developed from the rear edge of the bearing area to the middle height of the abutment at an angle of nearly $45° + \varphi/2$. The setback and the bearing area width affected the form and position of the failure surface. The difference between the potential failure surface predicted by available methods and the measured failure surfaces has been discussed, and suggestions for the design and ultimate bearing capacity prediction of GRS abutments with segmental block facing are provided.
Keywords: Geosynthetics, Geosynthetic reinforced soil (GRS) abutment, Ultimate bearing capacity, Failure surface, Centrifuge test

Response of anchor foundations in geogrid reinforced sand under combined loads

S. Mukherjee[1] and G. L. Sivakumar Babu[2]
1 Research Scholar, Department of Civil Engineering, Indian Institute of Science, Bengaluru, India, E-mail: msougata@iisc.ac.in
2 Professor, Department of Civil Engineering, Indian Institute of Science, Bengaluru, India, E-mail: gls@iisc.ac.in (corresponding author)

Abstract: The use of geogrid reinforcement has proven to be an effective measure to improve the anchor uplift capacity. However, previous studies are limited to analyzing the axial pullout capacity of plate anchors. In comparison, the anchor foundations employed in field are compelled to resist both uplift and lateral forces. In most cases, the foundation's safety against lateral forces dictates the design criteria for tall structures. Therefore, improving the foundation's lateral load-bearing capacity is of utmost importance. This paper presents a three-dimensional numerical analysis of anchor foundations in geogrid-reinforced sand under uplift and lateral forces. The results highlight the benefits of geogrid reinforcement on the anchor's response to uplift and lateral loads. The geogrid reinforcement is modelled using cable elements capturing the actual apertures responsible for tensile force mobilization along the geogrid ribs. A significant reduction in the displacements of the anchor foundation is observed in geogrid-reinforced sand, both in horizontal and vertical directions, when combined loads are applied on the anchor. However, the maximum reduction is found in the case of vertical uplift forces for higher values of the applied load. The practical implication of this study is demonstrated using a performance-based design example of transmission tower foundations in geogrid-reinforced sand.
Keywords: Geosynthetics, Geogrid, Anchor foundation, Numerical modelling, Uplift and lateral force, Transmission tower

Uniaxial compression test of cement-solidified dredged slurry columns encased with geogrid

C. C. Qiu[1,2], G. Z. Xu[3], G. Q. Gu[4], W. Z. Song[5] and D. H. Cao[6]
1 Associate Professor, School of Civil Engineering, Yancheng Institute of Technology, Yancheng, Jiangsu, China
2 Coastal City Low Carbon Construction Engineering Technology Research Center, Yancheng, Jiangsu, China, E-mail: craigqiu@163.com
3 Professor, School of Architecture and Engineering, Yancheng Polytechnic College, Yancheng, Jiangsu, China, E-mail: guizhongxu@163.com (corresponding author)
4 Associate Professor, School of Civil Engineering, Yancheng Institute of Technology, Yancheng, Jiangsu, China, E-mail: gqgu@ycit.edu.cn
5 Senior Engineer, Shanghai MCC20 Construction Corporation Limited, Shanghai, China, E-mail: song.wenzhi@hotmail.com
6 Senior Engineer, Yancheng Architectural Design & Research Institute Co., Ltd, Yancheng, Jiangsu, China, E-mail: 229872879@qq.com

Abstract: This study investigated the performance of unreinforced and geogrid-encased cement-stabilized dredged slurry columns by uniaxial compression tests to simulate the extreme case where the surrounding soil offers no confinement. The objective was to understand the strength characteristics and visualize the deformation damage patterns of the columns with respect to the water content, cement content, length-to-diameter ratio, and geogrid strength. The results show that the unreinforced specimens exhibited strain-softening behavior, whereas geogrid encasement induced strain-hardening, with high-strength geogrids showing superior strain-hardening capacity. Notably, regardless of geogrid strength, encasement enhanced the resistance to deformation and ductility of the columns. Increasing the cement content, reducing the water content, and decreasing the length-to-diameter ratio all contributed to higher peak strength in both unreinforced and geogrid-encased specimens. Geogrid encasement provides confinement that enhances peak strength. The influence of geogrid encasement on peak strength becomes more pronounced at lower cement contents, higher water contents, and higher length-to-diameter ratios. Geogrid encasement also affects failure modes, altering the predominant inclined shear failure observed at the top of unreinforced specimens. Specimens encased with geogrids of higher tensile strength exhibit enhanced integrity and deformation resembling compression strut buckling, with a symmetrically inclined failure trend at the top and bottom.
Keywords: Geosynthetics, Compressive strength, Columns, Dredged slurry, Uniaxial compression test