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Life cycle assessment of a geosynthetic-reinforced soil bridge system – A case study

Karmen Fifer Bizjak *, Stanislav Lenart
Slovenian Building and Civil Engineering Institute, ZAG, Ljubljana, Dimičeva 12, 1000, Ljubljana, Slovenia

Abstract: Road infrastructures are a very important component of the world's total transportation network. Investment in its construction and maintenance is significant on a global scale. The paper presents some results from an environmental study of a geosynthetic-reinforced soil integrated bridge system. The Pavlovski potok stream in Slovenia was used as a demonstration case for this study. It is the first GRS bridge system with full-height rigid (FHR) facings in Europe. It was constructed at the end of 2014. The goal of these analyses was to compare two different types of bridges: the new GRS bridge system, which is comprised of a simple girder partially structurally integrated to FHR facings of GRS bridge abutments and a conventional reinforced concrete road bridge. The results of an environmental life cycle assessment (LCA) show that the GRS bridge system has a much lower environmental impact than an equivalent bridge conventionally built with reinforced concrete.

Keywords: Geosynthetics; Road; Life cycle assessment; Geosynthetic-reinforced soil; Integrated bridge system; Environment

Exploring the effects of geotextiles in the performance of highway filter drains

L.A. Sañudo-Fontaneda [a, b,*], S.J. Coupe [b], S.M. Charlesworth [b], E.G. Rowlands [c]

a Department of Construction and Manufacturing Engineering, University of Oviedo, Polytechnic School of Mieres, Calle Gonzalo Gutierrez Quiros s/n, 33600, Mieres, Asturias, Spain

b Centre for Agroecology, Water and Resilience (CAWR), Coventry University, Ryton Gardens, Wolston Lane, Ryton-on-Dunsmore, CV8 3LG, Coventry, UK

c Carnell Group Ltd. Gothic House, Market Place, ST19 5DJ, Penkridge, United Kingdom

Abstract: Highway Filter Drains (HFD) are one of the most utilised drainage systems for roads, being considered as an environmental solution for sustainable drainage in transport infrastructures. However, little research has been done to understand their performance, representing a significant knowledge gap. This article therefore determines the hydraulic and clogging response of 3 different HFD designs in the laboratory; one standard design with British Standard Type B aggregate, and 2 new designs including a geotextile located at 50mm and 500mm depth from the surface of the HFD structure in order to assess the effect of the geotextile. The laboratory models were initially subjected to 9 rainfall scenarios with 3 rainfall intensities (2.5, 5 and 10 mm/h) and 3 storm durations (5, 10 and 15 min). Subsequently, the equivalent of 2-years' worth of pollutants were added to test possible clogging issues under the highest intensity rainfall event, corresponding to a 1 in 1 year return period for the West Midlands, UK. No clogging issues were found in any of the models although the majority of the sediments were concentrated in the first 50mm of the HFD profile, with higher percentages (> 90% of the sediment added) in those models with an upper geotextile. Location of the geotextile significantly influenced (p-value= 0.05) the hydraulic performance of the HFD.

Keywords: Geosynthetics; Clogging; Geotextile; Highway filter drains; Road safety; Sustainable Drainage Systems (SuDS)

Experimental evaluation of the effect of compaction near facing on the behavior of GRS walls

S.H. Mirmoradi *, M. Ehrlich
Dept. of Civil Engineering, COPPE, Federal University of Rio de Janeiro, RJ 21945-970, Brazil

Abstract: Experimental studies have been carried out to evaluate the effect of the compaction condition at the back of block facing on the behavior of geosynthetic reinforced soil (GRS) walls. Three GRS walls with 1.2m high were constructed at the COPPE/UFRJ Geotechnical Laboratory. The walls were well-instrumented in order to monitor the values of the reinforcement load, toe horizontal load, horizontal facing displacement, horizontal stress at the back of the block facing, and vertical displacement on the top of the walls. The behavior of the walls has been investigated at the end of construction and during the surcharge application (post-construction). At the end of the loading, the toes of the walls were gradually released to also verify the influence of the different toe restraints. The results clearly show the effect and call attention to the importance of the compaction conditions near the facing on the behavior of GRS walls.
Keywords: Geosynthetics; GRS walls; Compaction condition; Experimental study; Working stress conditions

Preloading using fill surcharge and prefabricated vertical drains for an airport

Jun Wang [a, c, d], Ziquan Fang [a, c, d], Yuanqiang Cai [b, c, d,*], Jinchun Chai [e], Peng Wang [a, c, d], Xueyu Geng [f]

a College of Architecture and Civil Engineering, Wenzhou University, Chashan University Town, Wenzhou 325035, China

b College of Civil Engineering and Architecture, Zhejiang University of Technology, Hangzhou 310014, China

c Innovation Center of Tideland Reclamation and Ecological Protection, Wenzhou University, Wenzhou, Zhejiang 325035, China

d Key Laboratory of Engineering and Technology for Soft Foundation and Tideland Reclamation, Wenzhou University, Zhejiang, Wenzhou 325035, China

e Department of Civil Engineering and Architecture, Saga University, 1 Honjo-machi, Saga-city, Saga 840-8502, Japan

f School of Engineering, University of Warwick, Coventry, CV4 7AL, United Kingdom

Abstract: This paper presents the field measurements and analysis of a preloading project with the installation of prefabricated vertical drains (PVDs) in Wenzhou, China. At the site, PVDs were installed to a depth of 22m from the ground surface with a spacing of 1.5m in a triangular pattern. The preloading fill thickness was 6m with a unit weight of approximately 18 kN/m^3. After a total elapsed time of 310 days, approximately 3m thick fill was removed. The measured preloading settlement was approximately 1.5 m. The measurements and analytical results indicated that the soil layer with PVD improvement reached almost 100% primary consolidation when part of the fill was removed. After partial unloading, the PVD-improved zone was in an over-consolidated state. After the runway was opened for traffic, a settlement increment of approximately 7mm was monitored over a period of 11 months. Analysis indicated that the settlement was mainly due to the consolidation of soil layers below the PVD-improved zone and post-surcharge secondary consolidation of the PVD-improved zone. The values of the parameters related to PVD improvement were back-estimated from the field measurements. These findings can be used to guide the design of PVDs improvement along the east coast of China.

Keywords: Geosynthetics; Surcharge preloading; Ground treatment; Runway; Consolidation; Field monitoring

Load-settlement response of shallow square footings on geogrid-reinforced sand under cyclic loading

Jia-Quan Wang [a], Liang-Liang Zhang [a], Jian-Feng Xue [b,*], Yi Tang [a]
a College of Civil and Architectural Engineering, Guangxi University of Science and Technology, Liuzhou, 545006, China
b School of Engineering and IT, University of New South Wales, Campbell, 2612, ACT, Australia

Abstract: To study the settlement and dynamic response characteristics of shallow square footings on geogrid-reinforced sand under cyclic loading, 7 sets of large scale laboratory tests are performed on a 0.5m wide square footing resting on unreinforced and geogrid reinforced sand contained in a 3m ×1.6m ×2m (length ×width ×height) steel tank. Different reinforcing schemes are considered in the tests: one layer of reinforcement at the depth of 0.3B, 0.6B and 0.9B, where B is the width of the footing; two and three layers of reinforcement at the depth and spacing both at 0.3B. In one of the two double layered reinforcing systems, the reinforcements are wrapped around at the ends. The footings are loaded to 160 kPa under static loading before applying cyclic loading. The cyclic loadings are applied at 40 kPa amplitude increments. Each loading stage lasts for 10 min at the frequency of 2 Hz, or until failure, whichever occurs first. The settlement of the footing, strain in the reinforcement and acceleration rate in the soil have been monitored during the tests. The results showed that the ultimate bearing capacity of the footings was affected by the number and layout of the reinforcements, and the increment of bearing capacity does not always increase with the number of reinforcement layers. The layout of the reinforcement layers affected the failure mechanisms of the footings. Including more layers of reinforcement could greatly reduce the dynamic response of the foundations under cyclic loading. In terms of bearing capacity improvement, including one layer of reinforcement at the depth of 0.6B was the optimum based on the test results. It is found that fracture of geogrid could occur under cyclic loading if the reinforcement is too shallow, i.e. for the cases with the first layer of reinforcement at 0.3B depth.

Keywords: Geosynthetics; Cyclic loading test; Square footing; Geogrid-reinforced foundation; Dynamic response

Geosynthetic-sheet pile reinforced foundation for mitigation of earthquake and tsunami induced damage of breakwater

Babloo Chaudhary [a,*], Hemanta Hazarika [b], Akira Murakami [a], Kazunori Fujisawa [a]
a Div. of Environmental Science & Technology, Kyoto University, Kyoto 606-8502, Japan
b Department of Civil Engineering, Kyushu University, Fukuoka 819-0396, Japan

Abstract: Earthquake and tsunami impose great threats on the stability of a breakwater. Foundation of the breakwater is weakened by these forces, and it may result in collapse of the breakwater. Lateral flow of seabed soils take place beneath the breakwater, and excess pore water pressure is generated in the foundation by an earthquake that precedes tsunami. These factors may lead to excessive settlement and horizontal displacement of the breakwater. Tsunami introduces additional instability to the deformed breakwater. Due to water level difference between seaside and harborside of the breakwater during a tsunami, seepage occurs through its foundation, and it may cause pipping of seabed soils. Tsunami induced scouring of mound is also a big problem for the stability of the breakwater foundation. Finally, these result in failure of the breakwater foundation. Due to failure of its foundation, the breakwater may collapse and cannot block the tsunami. It results in entering of the tsunami in coastal areas. In order to make a breakwater resilient against earthquake and tsunami induced damage, reinforcing countermeasures were developed for foundation of a breakwater. Geogrid, gabions and sheet piles were used for reinforcing a foundation model. The effectiveness of the model is evaluated through physical modeling for mitigating the earthquake and tsunami induced damage. Shaking table tests were performed to determine the effectiveness of the reinforced model under different earthquake loadings. Tsunami overflow test was conducted on the same deformed model in order to see the effects of tsunami on the model. Comparisons were made between the unreinforced and reinforced foundations, and it was observed during the tests that the reinforced foundation performed well in reducing the damage of the breakwater brought by the earthquake and tsunami. Overall, this study is useful for practice engineering, and the reinforced foundation model can be adopted for designing a breakwater foundation to reduce damage triggered by an earthquake and tsunami in the future.
Keywords: Geosynthetics; Breakwater; Earthquake; Tsunami; Foundation; Bearing capacity; Countermeasures; Geogrid; Settlement

Investigation of load transfer mechanisms in granular platforms reinforced by geosynthetics above cavities

Minh-Tuan Pham [a, b, c], Laurent Briançon [a,*], Daniel Dias [b], Abdelkader Abdelouhab [d]

a Université de Lyon, INSA-Lyon, GEOMAS, 34 Avenue des Arts 69621, Villeurbanne, Cedex, France

b Laboratory 3SR, Grenoble Alpes University, CNRS UMR 5521, Grenoble, France

c GEOPET, Ho Chi Minh City University of Technology, 268 Ly Thuong Kiet Street, Ho Chi Minh City, Viet Nam

d TEXINOV, 56 Route de Ferrossière, 38110 Saint-Didier-de-la-Tour, France

Abstract: Geosynthetic-reinforced soils constitute an interesting solution for bridging cavities. Many methods have been developed to analyze the stability of soil-geosynthetic-cavity systems, but none of them is able to take into account all the complexities of these mechanisms. Many researchers have assumed mechanisms developed in the reinforced granular platform when cavities appear, such as load transfer and expansion of materials. However, they are not fully understood because many factors can influence the design, such as the cavity opening processes, the type, and the density of the soil. In this study, a new laboratory apparatus is developed to simulate two different cavity opening procedures (trapdoor and progressive opening) for different geometric configurations. A series of tests is conducted for three granular soils with two different geosynthetic sheets. By measuring the shape of the surface soil settlement and the geosynthetic deflection, the expansion coefficient is calculated. A novel tactile pressure sensor is used to observe the load transfer during the cavity opening. The experimental data are analyzed and the influence of the experimental conditions (geometric and soil properties and the opening procedure) are also discussed. Correspondingly, elicited findings can be used to propose recommendations to improve the existing design methods.

Keywords: Geosynthetics; Cavity; Soil arching; Physical modeling; Tactile pressure sensors.

An observational method for consolidation analysis of the PVD-improved subsoil

Wei Guo [a, b], Jian Chu [c], Wen Nie [c,*]

a State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, China

b School of Civil Engineering, Tianjin University, 135 Yaguan Road, Jinnan District, Tianjin 300350, China

c School of Civil & Environmental Engineering, Nanyang Technological University, 50 Nanyang Ave, 639798, Singapore

Abstract: Surcharge preloading together with prefabricated vertical drains (PVD s) have been widely used to improve properties of thick clay deposits. To assess the performance of soil improvement works, the average degree of consolidation needs to be estimated. A curve fitting formula is proposed in this paper to simulate the degree of consolidation versus a non-dimensional time factor relationship. The proposed formula fits the theoretical consolidation solutions well with a regression coefficient R^2 larger than 0.9996 and an error of less than 1.2%. Based on the formula, a modified Asaoka's observational method is proposed to predict the ultimate settlement and calculate the coefficient of consolidation using field settlement monitoring data. The effectiveness of the proposed observational method has been verified using some well-documented case histories. Comparisons between the proposed method and the Asaoka's method indicate that the proposed method will give a less than 1.0% higher ultimate settlement than that by the Asaoka's method and the proposed method is able to predict the c_h value with the consideration of both vertical and horizontal flow through the ratio of time factor in horizontal and vertical direction v_{hv}.

Keywords: Geosynthetics; PVD; Consolidation; Asaoka's method; Ground improvement

Numerical study on maximum reinforcement tensile forces in geosynthetic reinforced soil bridge abutments

Yewei Zheng [a,*], Patrick J. Fox [b], John S. McCartney [a]

a Department of Structural Engineering, University of California San Diego, La Jolla, CA, 92093-0085, USA

b Department of Civil and Environmental Engineering, Pennsylvania State University, University Park, PA, 16802, USA

Abstract: This paper presents a numerical study of maximum reinforcement tensile forces for geosynthetic reinforced soil (GRS) bridge abutments. The backfill soil was characterized using a nonlinear elasto-plastic constitutive model that incorporates a hyperbolic stress-strain relationship with strain softening behavior and the Mohr-Coulomb failure criterion. The geogrid reinforcement was characterized using a hyperbolic load-strain-time constitutive model. The GRS bridge abutments were numerically constructed in stages, including soil compaction effects, and then loaded in stages to the service load condition (i.e., applied vertical stress=200 kPa) and finally to the failure condition (i.e., vertical strain=5%). A parametric study was conducted to investigate the effects of geogrid reinforcement, backfill soil, and abutment geometry on reinforcement tensile forces at the service load condition and failure condition. Results indicate that reinforcement vertical spacing and backfill soil friction angle have the most significant effects on magnitudes of maximum tensile forces at the service load condition. The locus of maximum tensile forces at the failure condition was found to be Y-shaped. Geogrid reinforcement parameters have little effect on the Y-shaped locus of the maximum tensile forces when no secondary reinforcement layers are included, backfill soil shear strength parameters have moderate effects, and abutment geometry parameters have significant effects.

Keywords: Geosynthetics; Geosynthetic reinforced soil; Bridge abutment; Numerical modeling; Internal stability; Tensile force

Stabilization of soft clay using short fibers and poly vinyl alcohol

Mehdi Mirzababaei [a,*], Arul Arulrajah [b], Suksun Horpibulsuk [c], Amin Soltani d, Navid Khayat [e]

a School of Engineering and Technology Central Queensland University, 120 Spencer Street, Melbourne, Victoria, 3000, Australia

b Department of Civil and Construction Engineering, Swinburne University of Technology, Hawthorn, Victoria, 3122, Australia

c School of Civil Engineering, Center of Excellence in Innovation for Sustainable Infrastructure Development, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand

d School of Civil, Environmental and Mining Engineering, The University of Adelaide, Adelaide, SA, 5005, Australia

e Department of Civil Engineering, Islamic Azad University, Ahvaz branch, Ahvaz, Iran

Abstract: In this study, the effect of the combined addition of fibers and a nontraditional polymer on the mechanical behavior of a clay was investigated. Poly vinyl alcohol, PVA, used as a solution with concentrations of 0.1%, 0.3%, 0.5%, 1.0% and 1.5% and 1, 2, 3, 4 Butane Tetra Carboxylic Acid, BTCA was added as a crosslinking agent at concentration rates of 0.1%, 0.3% and 0.5%, respectively. Short polypropylene fibers were added to the clay at proportionate quantities of 0.25% and 0.50% of the dry weight of the soil. Clay samples were prepared for unconfined compressive strength (UCS) tests at two different initial void ratio values, denoting relatively stiff and markedly soft states. UCS tests were conducted on both 1-day and 14-day cured samples. The results confirmed significant UCS improvements with combined fiber reinforcement and PVA-BTCA stabilization when samples were cured for 14 days. It was also observed that fiber reinforcement outperformed PVA-BTCA stabilization for clays with the lower initial void ratio. PVA-BTCA stabilization was however found to be superior to fiber reinforcement in clays with a relatively higher initial void ratio. The effect of fiber reinforcement and PVABTCA stabilization on the stability of soils subjected to excessive wetting was also evaluated using soaking tests. Stabilization with PVA and BTCA was found to enhance the stability of soaked samples significantly. The results of soaking tests proved that BTCA made PVA-stabilized samples more durable when exposed to soaking.

Keywords: Geosynthetics; Fiber reinforcement; Chemical stabilization; Expansive clay; Polymer; UCS

Stress-controlled direct shear testing of geosynthetic clay liners I: Apparatus development

Shahin Ghazizadeh, Christopher A. Bareither *
Civil & Environmental Engineering, Colorado State University, Fort Collins, 80523, CO, USA

Abstract: The use of geosynthetic clay liners (GCLs) in waste containment applications can induce long-term normal and shear stresses as well as expose GCLs to elevated temperatures and non-standard hydration solutions. Considering the importance of GCL internal shear strength to the design and integrity of waste containment barrier systems, innovative laboratory testing methods are needed to assess shear behavior of GCLs. There were two main objectives of this study: (i) develop a stress-controlled direct shear apparatus capable of testing GCLs exposed to elevated temperatures and hydrated in non-standard solutions; and (ii) assess internal shear behavior of GCLs under varying experimental conditions (e.g., stress, temperature, solution). These two objectives were partitioned into a two-paper set, whereby Part I (this paper) focuses on the shear box design and Part II focuses on an assessment of shear behavior. The direct shear apparatus includes a reaction frame to mitigate specimen rotation that develops from an internal moment within needle-punched reinforced GCLs. Rapid-loading shear tests were conducted to assess functionality of the apparatus and document baseline shear behavior for a heat-treated and a non-heat treated needle-punched GCL with comparable peel strength. These two GCLs failed at comparable applied shear stress; however, the heat-treated GCL yielded lower shear deformation and failure occurred via rupture of reinforcement fiber anchors, whereas the non-heat treated GCL yielded larger shear deformation and failure via pullout of reinforcement fibers.
Keywords: Geosynthetics; Direct shear; Geosynthetic clay liner; Mining; Shear strength

Stress-controlled direct shear testing of geosynthetic clay liners II: Assessment of shear behavior

Shahin Ghazizadeh, Christopher A. Bareither *
Civil & Environmental Engineering, Colorado State University, Fort Collins, CO, 80523, USA

Abstract: This paper is the second of a two-paper set on stress-controlled direct shear testing of geosynthetic clay liners (GCLs). Design of the apparatus, preliminary experiments, and shear deformation mechanisms in heat-treated and non-heat treated needle-punched (NP) GCLs were discussed in Part I. The objective of Part II (this paper) was to evaluate the effects of physical factors (i.e., peel strength and initial normal stress, σ_{ni}), environmental factors (i.e., temperature and hydration solution), and creep on the internal shear behavior of NP GCLs. In addition, failure conditions of GCLs in the stress-controlled direct shear tests were compared to displacement-controlled direct shear tests to verify results. An increase in internal shear strength developed from increased GCL peel strength or increased normal stress. Elevated temperatures were observed to decrease internal shear strength for both non-heat treated and heat-treated NP GCLs. Specimens hydrated with a calcium-rich synthetic mining solution experienced increased internal shear strength due to cation exchange in the bentonite, whereas specimens hydrated with a highly alkaline synthetic mining solution experienced decreased internal shear strength. Creep tests revealed an increase in time-to-failure with decrease in applied shear stress. Finally, stress states at failure from stress-controlled and displacement-controlled shear tests corresponded to a unique failure envelope, which validates the efficacy of using stress-controlled direct shear tests to assess internal shear behavior and shear strength of NP GCLs.

Keywords: Geosynthetics; Chemistry; Creep; Geosynthetic clay liner; Shear strength; Temperature