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摘要集

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目　录

Physical performance of flexible pavement system with and without a Portland-cement-concrete (PCC) slab for geofoam embankments

Emre Akınay [a,*] , Hande Isik Ozturk [b], Abdullah Yasin Büyükaslan [c] , Abdullah Tolga Özer [d]

a Geotech Soil and Foundation Engineering, Kocaeli, Türkiye

b Middle East Technical University, Ankara, Türkiye

c HAVELSAN (Hava Elektronik Sanayi A.S¸.), Ankara, Türkiye

d Gebze Technical University, Gebze, Kocaeli, Türkiye

Abstract: Pavement system design for geofoam block embankments requires special solution due to their low California Bearing Ratio (CBR) values. Hence, the use of a reinforced Portland-cement-concrete (PCC) slab atop the geofoam block assemblage is considered as a practical approach to increase the stiffness of the pavement. On the other hand, the PCC slab has some inherent disadvantages such as construction delay due to curing. A thicker pavement system without a PCC slab can be a potential alternative. Hence, the performance of flexible pavement systems with and without PCC slab were investigated using the accelerated pavement test (APT) program in detail. Two 3.75 m-wide and 10 m-long pavements were constructed in a test bed, and a controlled wheel load was applied using a 3-axle, 37.72-ton truck that traveled with an average speed of 16.5 km/h. The test was terminated, when rutting reached to steady deformation pattern at 1299 passes (3897 axle repetitions), which is equal to 20,264.4 equivalent single axle loads (ESAL). The test program also included plate load tests (PLT) and falling weight deflectometer (FWD) tests. The full-scale APT results showed that flexible pavement systems without a PCC slab for geofoam block embankments can be a viable option.

Keywords: Geofoam, Accelerated pavement test (APT), Falling weight deflectometer (FWD), Numerical modeling

Cold temperature behaviour of polyethylene geomembranes

M. Somuah , F.B. Abdelaal , R. Kerry Rowe *
GeoEngineering Centre at Queen's-RMC, Department of Civil Engineering, Queen's University, Ellis Hall, Kingston, ON, K7L 3N6, Canada

Abstract: Impact and tensile tests were conducted on two high-density polyethylene (HDPE) geomembranes made from unimodal and bimodal resins, as well as a linear low-density polyethylene (LLDPE) geomembrane. This study investigates the ductile-to-brittle transition temperatures (DBTTs), energy-to-break (EtB, defined as the amount of energy required to cause a geomembrane specimen to either partially or fully fracture under impact test conditions). Of the three geomembranes, BMzA15 maintained the highest overall EtB values, followed closely by LxD15, and significantly above MxC15, over a range of temperatures (−60 °C–25 °C). Results showed that DBTT occurred between −16 °C and −27 °C, significantly above the glass transition temperature (Tg) of polyethylene. While higher molecular weight and lower density correlated with lower DBTT, no single resin property consistently predicted impact energy absorption below the DBTT. Additionally, surface flaws as shallow as 5 % of the geomembrane's nominal thickness shifted DBTT upward by nearly 18 °C, and reduced energy-to-break by about 33 %. These findings highlight the need for careful material selection, defect management, and load-rate consideration when selecting geomembranes for applications in cold environments.

Keywords: Geomembranes, Impact resistance, Ductile-to-brittle transition, Subzero temperature

Quantification of shear-induced wear development on textured geomembrane-geotextile interfaces

Gary John Fowmes [a,*], Catalin Alexandru Zaharescu [b], Zhiming Chao [c], Ahmad Mousa [d,**]

a School of Engineering, University of Warwick, CV4 7AL, UK

b Catalin Alexandru Zaharescu, Solmax, UK

c Shanghai Maritime University, Shanghai, 200135, China

d Department of Civil Engineering, Faculty of Science and Engineering, University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo, 315100, China

Abstract: The development of wear on the textured geomembrane interface has a significant influence on the reduction of post-peak interface shear strength. This study aims to examine and quantify the development of shear-driven wear on geosynthetic interfaces. New interfacial parameters are introduced to systematically describe the changes in the surface morphology of a geomembrane during the shearing process by combining quantitative and qualitative digital imaging techniques. Based on the developed surface roughness geometric parameters, an intensive quantitative and stereoscopic analysis of the wear development of the geomembrane surface morphology has been conducted during interfacial shear. The geometric parameters of the textured surface, namely asperity height, top angle, top radius, approach angle, and departure angle, can capture the changes in surface topography of the geomembrane in pre- and post-shearing. The top angle and radius, as well as the approach and departure angles, change significantly during the early stages of shearing (5 mm–20 mm). In general, the changes in the adopted geometric parameters resulted from a shearing rise associated with the increase in normal pressure. Furthermore, they could be used to better define the evolution of wear through complex stress histories that geomembranes frequently experience.

Keywords: Geosynthetics, Geomembrane texturing, Interfaces, Digital imaging, Scanning electron microscope

Stress transfer mechanism of ground reinforcement embankments subjected to lateral rockfall impact

Liang Lu [a,b,*], Haibo Zhu [a,b], Zongjian Wang [c], Chengkun Wu [a,b], Lanxing Li [a,b], Katsuhiko Arai [d]

a School of Civil Engineering, Chongqing University, Chongqing, 400045, China

b State Key Laboratory of Safety and Resilience of Civil Engineering in Mountain Area, Chongqing, 400045, China

c College of River and Ocean Engineering, Chongqing Jiaotong University, Chongqing, 400074, China

d University of Fukui, Fukui, 9108507, Japan

Abstract: The stress transfer mechanism of ground reinforced embankments subjected to lateral rockfall impact is systematically investigated through full-scale tests, finite element simulations, and theoretical analysis, with a particular focus on the stress diffusion angle. The results indicate that the impact-induced stress propagated rapidly and attenuated with increasing distance from the impact point, with transmission most efficient in the direction of impact. Parametric analyses demonstrate that impact energy, reinforcement spacing, and soil friction angle significantly influenced stress dispersion, whereas the height-to-thickness ratio mainly affected wall deformation. It is found that a reinforcement spacing of 0.2 m yielded optimal performance in resisting rockfall impact. Furthermore, it is recommended that the height-to-thickness ratio of the embankment be limited to less than 2 to mitigate wall deformation and prevent rear extrusion under impact. A theoretical model for the stress diffusion angle is derived based on the conical stress diffusion theory, providing an explicit analytical expression for GREs under lateral rockfall impact. The proposed model shows satisfactory agreement with numerical results, with discrepancies below 15 %, thereby validating the reliability of the theoretical solution.

Keywords: Ground reinforced embankments, Rockfall impact, Stress transfer mechanism, Stress diffusion angle, -Full-scale test

Drainage performance for clay slopes with wicking tubes in seasonally frozen regions: Experiment and field monitoring

Zhimin Ma , Chuang Lin * , Guanfu Wang , Decheng Feng , Feng Zhang **
School of Transportation Science and Engineering, Harbin Institute of Technology, 73 Huanghe Road, Nangang District, Harbin, 150090, China

Abstract: In seasonally frozen regions, spring thaw often destabilizes embankment slopes because excess moisture accumulates in the surface layers. Existing drainage systems are constrained by slow response times, particularly under unsaturated conditions. To address these challenges, this study proposes a seasonally frozen slope treatment method based on wicking geotextiles with active drainage capabilities. Comprehensive slope model tests were conducted under natural freeze-thaw and rainfall conditions to comparatively evaluate the drainage performance of wicking geotextiles against conventional alternatives. The results indicated that wicking geotextiles significantly enhanced lateral water migration, rapidly reduced soil moisture content under unsaturated conditions, and effectively prevented moisture accumulation during thawing and rainfall events. Subsequently, field case studies were conducted to assess the practical engineering performance by monitoring slope sections with and without wicking geotextile treatment. It further confirmed the superior drainage efficiency of wicking geotextiles, notably improving slope stability by mitigating moisture-induced shallow landslides during the spring thaw period. This study demonstrates the potential of wicking geotextiles as a practical engineering solution, providing valuable insights into slope stabilization technology in seasonally frozen regions.

Keywords: Seasonally frozen regions, Embankment slope, Wicking geotextiles, Hydrothermal coupling, Drainage performance

Synergistic effects of enzyme-induced carbonate precipitation (EICP) treatment and geogrid reinforcement on mechanical properties of washed recycled sand

Lian Liang , Ming Huang *, Mingjuan Cui , Chaoxian Wang
College of Civil Engineering, Fuzhou University, Fuzhou, 350108, China

Abstract: EICP and geogrids are widely regarded as environmentally sustainable and effective techniques for soil stabilization. This study assesses the feasibility of combining EICP with geogrid reinforcement to improve the mechanical properties of sands. The Brazilian splitting test and particle image velocimetry were employed to investigate the effects of three independent variables—the cementation–enzyme ratio (X_1), median particle size (X_2), and geogrid placement (X_3)—on the mechanical behavior of sand treated with both EICP and geogrid (STEG). Response surface methodology was used to assess variable interactions and optimize parameters for maximum tensile strength. The mechanism of reinforcement was further investigated through measurements of calcium carbonate content, permeability testing, ultrasonic velocity analysis, and scanning electron microscopy (SEM). Results show that the interactions between variables significantly influence the tensile strength and failure patterns of STEG. The optimal parameters (X_1 = 1:1.935, X_2 = 1.211 mm, X_3 = 1.2 cm) achieved a tensile strength of 1.71 MPa. Compared with specimens without geogrids, STEG samples demonstrated higher peak and residual strengths. SEM results revealed substantial calcium carbonate precipitation around geogrids, enhancing interparticle bonding, increasing ultrasonic velocity, and reducing permeability. These findings highlight the potential of combining EICP and geogrids to improve the mechanical properties of cohesionless soils, offering promising applications for subgrade reinforcement.

Keywords: EICP technique, Geogrid reinforcement, Response surface methodology, Tensile strength, PIV technique

Improving the geotextile filter design criteria for internally unstable cohesionless soils

Nicola Moraci a, Stefania Bilardi [a], Maria Clorinda Mandaglio [b,*]

a Department of Civil, Energy, Environmental and Materials Engineering, Mediterranea University of Reggio Calabria, Reggio Calabria (RC), Italy

b Department of Civil Engineering, University of Salerno, Fisciano (SA), Italy

Abstract: The behaviour of a geotextile filter in contact with internally unstable cohesionless soils depends on interaction between filter pore size distribution and base soil particles and on fraction of particles free to move inside soil skeleton. These particles can accumulate at soil-filter interface leading to blinding or remain entrapped within filter pores leading to clogging or pass through geotextile. The openings of geotextile should allow the passing of soil particles not belonging to soil skeleton keeping the same stable to avoid base soil erosion and minimize the geotextile filter clogging and/or blinding. The upper limit of filter characteristic opening size meets requirement of retention criterion while the lower limit of filter avoids blinding and/or clogging phenomena. Among different geotextile filter design criteria for internally unstable cohesionless soils, Moraci (1996) criterion considers as lower limit of filtration opening size the critical diameter of suffusion. In this paper, a database of many soil-geotextile filtration tests, for which this criterion has not yet been tested, was created to assess its reliability, compared to other existing design criteria. Finally, a new methodology proposed recently by the Authors is also applied to evaluate internally unstable cohesionless soil-geotextile filter compatibility to all interfaces analysed in database.

Keywords: Geotextile filter, Internal stability, Characteristic opening size, Critical diameter of suffusion, Design criteria

Experimental and analytical evaluation of enhanced interface efficiency with geocell anchor cages

Aarya Krishna *, Gali Madhavi Latha
Department of Civil Engineering, Indian Institute of Science, Bangalore, 560012, India

Abstract: A new reinforcement concept of Geocell Anchor Cage (GAC) system has been recently proposed by the authors and its benefits in increasing the load carrying capacity and reducing the settlements are established. This paper evaluates the interface shear response of geocell-GACs in comparison to geocells and geocell-grid combinations through large direct shear tests. Results showed that the sand-geocell-GAC interface has shown an increased interface efficiency of 1.5 compared to an interface efficiency of 1.25 computed for the sand-geocell interface at a normal stress of 25 kPa. This difference is slightly reduced at higher normal stresses, but the GACs constantly showed higher interface efficiency compared to geocell and geocell-grid interfaces with sand. Further, interface shear tests were carried out with different geocell pocket sizes to confirm the beneficial effects of GACs and to understand the influence of relative size of geocells and anchor pins. The individual contributions of geocell, geogrid and pins in increasing the interface shear resistance are analytically quantified. Through Particle Image Velocimetry (PIV) analysis of videos captured during shear tests, particle movement and shear zone formations are compared to provide clues to the internal shear mechanisms and interactions involved.

Keywords: UN SDG 9, Industry, Innovation, And infrastructure, Soil reinforcement, 3D printing, Geosynthetics, Geocells, Anchor cages, Interface tests

Sensing performance and mechanism of flexible sensing-enabled CB-CNT/PDMS geosynthetics for soil deformation monitoring

Xinzhuang Cui [a,*], Shibao Lu a, Xu Zhang [a], Qing Jin [a], Shiyuan Sun [a], Hui Li [b]
a School of Civil Engineering, Shandong University, Jinan, 250061, China
b School of Civil Engineering, Chongqing University, Chongqing, 400044, China

Abstract: Conventional soil deformation monitoring technologies often struggle to achieve distributed and high-precision measurements under large-strain conditions (>20 %), which are typical in geotechnical failures. To address this limitation, this study developed a novel flexible sensing-enabled geosynthetics material by incorporating a hybrid conductive filler system composed of carbon black (CB) and carbon nanotubes (CNT) into a polydimethylsiloxane (PDMS) matrix. Key fabrication parameters including the CB/CNT mass ratio, n-hexane dispersant content, and curing temperature were systematically optimized to enhance electrical conductivity and electromechanical response. The optimized composite exhibits excellent strain-sensing performance within the 0–20 % strain range, with a gauge factor (GF) of 2.453, a linear coefficient of determination (R^2) of 0.972, and demonstrates outstanding signal stability and cyclic durability. Microstructural analyses revealed that the synergistic effect between CB and CNT facilitated the formation of a dense and stable conductive network, significantly improving sensing linearity and sensitivity. The feasibility of the material for practical application was validated through model tests on a sand foundation, where it accurately captured deformation patterns under various loading conditions. This work provides a reliable and sensitive flexible sensing solution for real-time monitoring of soil deformation, with broad potential in geotechnical health monitoring and early warning systems.

Keywords: Flexible sensing, CB-CNT/PDMS geosynthetics, Sensing performance, Sensing mechanism, Soil deformation monitoring

Effect of temperature on the long-term interaction mechanism between geogrid and backfill

Huaxin Han [a], Chengzhi Xiao [a,*] , Nan Zhu [b], Jianguang Yin [a], Luqiang Ding [a], Xiangji Ye [c]
a School of Civil and Transportation Engineering, Hebei University of Technology, Tianjin, 300401, China
b Tianjin Port Engineering Institute Co., Ltd. of CCCC First Harbor Engineering Co., Ltd., Tianjin, 300461, China
c CCCC First Harbor Consultants Co., Ltd., Tianjin, 300222, China

Abstract: Variations in backfill temperature affect the long-term interaction behavior between geosynthetic and surrounding soil in geosynthetic-reinforced soil (GRS) walls, which in turn influences their service life. To investigate such behavior, a novel testing apparatus was developed to examine the long-term mechanical response of GRS unit specimens (composed of PP geogrid and either dry sand or clay) and its influence on the lateral earth pressure developing under sustained vertical loading at five controlled temperatures. Test results demonstrated that under constant vertical normal stress applied to the backfill, the horizontal tensile force in the geogrid decreased over time in both unfrozen backfill types, with higher temperatures accelerating the reduction. Rising temperatures also increased strain concentration near the tensile end of the reinforcement. Additionally, the results revealed that existing GRS wall design guidelines based on Rankine earth pressure theory underestimate the horizontal reinforcement tensile force under low temperatures due to inaccurate estimations of lateral earth pressure. Accordingly, a correction factor was proposed to properly predict the lateral earth pressure based on the Rankine earth pressure at different temperatures and times. This study offers valuable insights that could contribute to enhancing the design of GRS walls in regions with extreme climate conditions.

Keywords: Geogrid, Temperature, Creep test, Sand and clay, Long-term interaction mechanism, Lateral earth pressure

Static pullout behavior of a geogrid under cyclic normal loading

Wooseok Shin , Jonghyun Kim , Chungsik Yoo *
School of Civil, Architectural, and Landscape Architecture, Sungkyunkwan University, 2066 Seobu-Ro, Jan-An Gu, Suwon, Gyeong-Gi Do, 16419, South Korea

Abstract: This study investigates the effect of cyclic normal loading on the static pullout behavior of geogrids installed in compacted sandy soils. A series of laboratory pullout tests was performed where geogrid specimens were subjected to cyclic normal loads (CNL) with varying amplitudes. The results show that the geogrid pullout behavior under cyclic normal loading generally falls between those under the static normal stresses corresponding to the cyclic upper and lower normal stresses. For all baseline normal stress levels tested, there is a general trend of increasing peak pullout resistance with increasing CNL amplitude but with a strong dependency of the magnitude of increase on the baseline normal stress level. This observation highlights the importance of considering the cyclic amplitude in relation to baseline normal stress when estimating the pullout resistance of a geogrid under cyclic normal loading. Based on the test results, an equivalent normal stress approach incorporating cyclic amplitude mobilization factor was presented for evaluating the interaction coefficient under cyclic normal loading. The practical implications of the findings were also discussed.
Keywords: Geosynthetics, Geogrid, Pullout test, Pullout resistance, Cyclic normal loading

Centrifuge model tests on Geostrip Reinforced Soil Walls with low-permeable backfills subjected to seepage

B.V.S. Viswanadham, V.V. Turlapati, S.K. Bhattarai
Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, 400 076, India

Abstract: The objective of this study is to employ centrifuge-based physical modeling to investigate the performance of geostrip reinforced soil walls (GSRSWs) constructed with low-permeable backfill subjected to seepage conditions. A 4.5 m radius large beam centrifuge facility at IIT Bombay was used to simulate a prototype GSRSW of height 10 m with a 6° batter angle at 40g. Geostrip - geosynthetic material comprising of a high tenacity polyester tendons core encased in a polymeric sheathing. Firstly, the scaling considerations essential for modeling geostrips in centrifuge model tests are presented. Based on the evolved scaling considerations, polyester based model geostrip reinforcement was developed and used in the present study. Influence of coverage ratio, R_c, was studied, keeping other physical characteristics of GSRSW the same. Results showcased GSRSW with a coverage ratio of 0.10 failed catastrophically after 12 days of seepage conditions with a maximum face movement of 0.377H at the penultimate stage. Increasing coverage ratio to 0.15 prevented a catastrophic failure and resulted in a maximum face movement of 0.035H after a sustained seepage of 30 days. Further, seepage and slope stability analysis were carried out, and the outcomes were found to be corroborate well with physically observed centrifuge test results.
Keywords: Geosynthetics, Geostrip, Reinforced soil wall, Low-permeable backfills, Centrifuge modeling, Seepage