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Foreword to special issue on geosynthetic-reinforced pile-supported embankments

R. J. Bathurst and J. P. Giroud

Geosynthetic-reinforced pile-supported (GRPS) embankments are a relatively new geotechnical technology with a strong geosynthetics component. The use of these systems to improve the performance of embankments over poor soils has expanded rapidly. Interest in these systems can be seen in the large number of technical papers on the subject that have appeared in the journal literature including Geosynthetics International. It is timely then that the Journal be able to present this special issue on GRPS embankments, which contains a collection of 15 papers on a wide range of topics related to GRPS embankments written by many of the foremost international experts.

We are delighted to have Dr Suzanne J .M. van Eekelen and Dr Jie Han as guest editors of this special issue and to have the opportunity to thank them for their many efforts in assembling this valuable collection of papers for the Journal.

Drs van Eekelen and Han first approached us with the idea of this special issue in 2017 following the very successful First International W orkshop on Geosynthetic-Reinforced Pile-Supported Embankments that was held at T ongji University, Shanghai, China in June of that year. The conference was attended by experts from around the world and Drs van Eekelen and Han made the case that selected papers that were delivered at the workshop should be published in expanded form in the Journal. They also volunteered to produce a state-of-the-art paper on the theme of the special issue. Both Drs van Eekelen and Han are recognized experts on the topic and we immediately accepted their offer and appointed them as guest editors.

Under their supervision all of the papers were subjected to rigorous peer-review by other experts. We congratulate all of the authors who contributed to this special issue and the many reviewers who critically assessed the original manuscripts.

We anticipate that this twelfth in a series of special issues of Geosynthetics International, published since 1995 (Table 1), will become an important reference for engineers and researchers interested in the design, construction and performance of GRPS embankments.

Introduction to Special Issue on Geosynthetic-reinforced pile-supported embankments

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Volume 27, no. 2 of Geosynthetics International is a special issue devoted to geosynthetic-reinforced pile supported (GRPS) embankments. A geosynthetic reinforced pile-supported embankment consists of a reinforced embankment with one or multiple horizontal layers of geosynthetic reinforcement installed at the base of the embankment over a pile foundation in soft soils.

GRPS embankments have become an effective and economic solution for mitigating soft soil – related problems and risks when embankments are constructed on soft soils to support highways, railways, storage tanks, industrial areas, and even buildings. GRPS embankments have been constructed in soft soil areas worldwide because they offer several advantages over alternative solutions, such as short construction time, elimination of staged construction, small post-construction settlement, limited influence on nearby objects, and limited or no maintenance requirements.

A significant amount of research has been conducted by many researchers and engineers in the past three decades to advance this technology by better understanding their behavior through laboratory and field studies including instrumentation and monitoring and numerical analyses, and by improving their design and construction.

The First International Workshop on Geosynthetic-Reinforced Pile-Supported Embankments was held at Tongji University , Shanghai, China from June 14 to 16, 2017 with the objectives: (1) to understand current practices and research in different countries, (2) to seek consensus or identify differences in common issues, (3) to identify topics for future research, and (4) to explore opportunities for future collaborations. The invited international experts participating in this workshop were: C. Xu (chair), X. Bian, R. Chen, S. Liu, R. Rui, F. Xiao, G. Zheng, J. Zheng, and Y. Zhuang from China; J. Han (chair) and J. Collin from USA; S. van Eekelen (chair) from Netherlands; S. Liyanapathirana and L. King from Australia; M. de Souza Soares de Almeida and M.C.F . Almeida from Brazil; M. Blanc from France; S.J. Hao from Malaysia; and B. Reshma from India. Approximately 70 people participated in this workshop. The workshop was organized by Tongji University, funded by the Ministry of the China Changjiang Scholars Fund and the National Natural Science F oundation of China (No. 51478349), and sponsored by the industrial partners: Maccafferi, T encate, Tianan R oad

Engineering Materials, Hock Technology, and NETE.

This special issue on GRPS embankments was prepared after the workshop to include extended papers on work presented at the workshop, manuscripts written by invited experts, and manuscripts received independently by the journal on the same theme. The total number of the manuscripts received was 16, from which 12 technical papers and 2 technical notes were accepted for publication after review. Each manuscript received rigorous peer review by two or more anonymous reviewers in addition to the two guest editors.

This special issue starts with a state-of-the-art paper by the guest editors that covers a wide range of topics including: load distribution, deformations, and their key influence factors (such as cyclic loading, pile layout, and crust effects); long-term field performance; detailed review of design methods; stability; and topics for future research.

We would like to thank the Editor, R.J. Bathurst, and the Chair of the Editorial Board, J. P. Giroud for providing us the great opportunity and excellent guidance to co-edit this special issue. We express our appreciation to C. Xu for his great efforts to organize the First International W orkshop on Geosynthetic-Reinforced Pile-Supported Embankments.

This special issue would not have been possible without the outstanding technical contributions of all the authors and the careful and constructive reviews provided by all the anonymous reviewers who ensured each paper met the high technical and presentation standards of Geosynthetics International.

It was our great pleasure to work with all the authors as guest editors of this Special Issue and to collaborate on our joint state-of-the-art paper.

Geosynthetic-reinforced pile-supported embankments: state of the art

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Abstract: Geosynthetic-reinforced pile-supported embankments have been increasingly used worldwide to support earth structures. A significant amount of research has been conducted by many researchers and engineers in recent years. This paper provides a state-of-the-art review of this technology, and of important developments and results obtained throughout the years that help to better understand the mechanisms that play an important role in the design, construction, and performance of these systems. This paper begins with terminologies and historical developments. It then focuses on load transfer mechanisms and practical design and proposes topics for future research. The supplemental material gives tips for construction details and instrumentation for performance evaluation.
Keywords: Geosynthetics, Reinforcement, Piled embankments, Load transfer platforms, Soil arching, Deformation, Construction, Design, Instrumentation

Long term measurements in the Woerden geosynthetic-reinforced pile-supported embankment

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Abstract: The purpose of this paper is to present long-term measurements in a full-scale study on a basal reinforced piled embankment that make it possible to validate calculations used for the design of the geosynthetic reinforcement (GR). These calculations are normally carried out in two steps. To validate steps 1 and 2 together, it is necessary to measure GR strains. To validate calculation steps 1 and 2 separately, arching *A* needs to be measured, which is the pressure on the pile cap above the GR. An extensive monitoring project was conducted over a period of four years, in a basal reinforced piled embankment on 17 m of soft clay and peat. This study presents the measured GR strains and load distribution including arching, accompanied by measured groundwater levels and deformations. The subsoil support of the geosynthetic reinforcement disappeared quickly, arching developed over the first three months, and an annual cycle in the load distribution became apparent. Arching effects increase during the summer when conditions are relatively dry, resulting in a larger load on the piles and a reduction in the load on the GR. Additionally, the measured changes after an extremely rainy week are presented.
Keywords: Geosynthetics, Piled embankments, Load transfer platforms, Geosynthetic reinforcement, Field monitoring, Full-scale field test, Arching

3D modeling of geosynthetic-reinforced pile-supported embankment under cyclic loading

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Abstract: Mechanical and hydraulic properties of recycled concrete aggregate (RCA) were evaluated for use as backfill in mechanically stabilized earth (MSE) walls. Large-scale drained triaxial tests, direct shear tests and pullout tests were performed to obtain mechanical properties of RCA interacting with various geosynthetics. Long-term filtration (LTF) tests were performed to evaluate hydraulic conductivity of RCA-geotextile systems. Results showed that the RCA had an internal friction angle of 49°, which was within the typical range. The RCA-uniaxial geogrid had the highest interface friction angle of 36° – and the interface friction angles of RCA-biaxial geogrid, RCA-nonwoven geotextile, and RCA-woven geotextile were 32°, 26° and 22°, respectively. Reinforced RCA showed comparable pullout capacity to reinforced sand. No slippage was observed between the RCA and geotextiles or geogrids, and the failures occurred mainly due to rupture of the geotextiles and geogrids during the pullout test. Results of the LTF tests showed that, over a filtration period of 2500 h, the ratio of mean hydraulic conductivity of RCA only to that of RCA-nonwoven geotextile and RCA-woven geotextile systems remained between 0.91 and 3.2, suggesting that the clogging of the geotextiles with RCA was minimal.

Keywords: Geosynthetics, Filtration, Geogrid, Geotextile, Image analysis, Recycled concrete aggregate

Centrifuge model studies on the settlement response of geosynthetic piled embankments

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Abstract: The paper aims at comparing the deformation behaviour of unreinforced embankments, basal reinforced embankments and geosynthetic reinforced embankments with floating and end bearing piles. The floating piles were terminated within the soft foundation soil, while the end bearing piles transfer the loads to a hard stratum. Four series of centrifuge model tests were conducted at gravity g= 40, using the 4.5 m radius large beam centrifuge facility at the Indian Institute of Technology Bombay. The tests were performed at constant pile spacing, and the embankment was constructed using an in-flight sand hopper. The deformations were measured using Linear Variable Differential Transformers (LVDTs). A digital image analysis technique was employed to arrive at the surface displacements, displacement vectors, and displacement contours. The geogrid reinforced embankments resting on end bearing piles and floating piles showed 88% and 44% lesser settlements respectively, compared to the unreinforced embankments. The geogrid reinforcement helps to distribute the load uniformly. A deep-seated slope failure was observed for unreinforced embankments. The piled embankments proved to be a practical solution for construction without prolonged waiting periods for pre-consolidation of the foundation soil.
Keywords: Geosynthetics, Centrifuge models, Digital image analysis, Geogrid-reinforced piled embankments, Geosynthetic applications, Soft clay

Analysis of unreinforced and reinforced shallow piled embankments under cyclic loading

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Abstract: Reinforced piled embankments are being increasingly used for construction over soft ground due to their efficiency in reducing potential settlement, speed of construction, and associated cost. Most of the previous studies focused on developing understanding of the behaviour of thick embankments that are loaded with a static surcharge load. Data on the behaviour of shallow piled embankments under cyclic loadings are scarce. In this study, an experimental programme was undertaken using a fully instrumented testing rig to generate data and improve our understanding of the behaviour of unreinforced and reinforced shallow piled embankments subject to monotonic and cyclic loadings that were applied over a predetermined area of the embankment. The experimental results showed that collapse of soil arching is instantaneous and occurs during the first few cycles of load. However, strength was regained, and recovery of the arching effect was observable during further stages of cyclic loadings due to densification of the embankment material and deformation of the soft subsoil. Inclusion of reinforcement layers was found to enhance the performance of load transfer mechanisms by concentrating stresses on pile caps. The results clearly showed a significant reduction in surface settlement, soft subsoil settlement and heaving with increasing numbers of reinforcement layers.

Keywords: Geosynthetics, Arching of soil, Cyclic loading, Piled embankment, Shallow embankment, Soil heaving, Soil reinforcement, Tensioned membrane

Effectiveness of geosynthetic reinforcement for load transfer in column-supported embankments

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Abstract: Many column-supported embankment (CSE) design methods include geosynthetic reinforcement for vertical load transfer and/or settlement reduction regardless of project conditions. However, geosynthetic reinforcement may not be necessary for all applications, particularly if a sufficiently thick and strong soil layer overlies the compressible soil. A strong soil layer can transfer embankment loads to the columns without much differential settlement at the base of the embankment, limiting the development of tension in the reinforcement. If weak and compressible soil extends to the ground surface and the area replacement ratio is low, differential settlements may be so large that it may not be practically possible to provide enough reinforcement to avoid excessive strain or rupture. This paper describes parametric studies using the Load Displacement Compatibility method to investigate the influences of embankment height, geosynthetic stiffness, column diameter, and thickness of an upper sand layer on geosynthetic strain, differential settlement at the base of the embankment, and load distribution among the CSE components. Results of the parametric study show that site conditions, CSE system geometry, and performance requirements limit the range of circumstances for which geosynthetic reinforcement for settlement reduction is needed, effective, and practically possible.

Keywords: Geosynthetics, Column-supported embankment, Load transfer platform, Soft ground, Load-displacement compatibility

Deformations in trapdoor tests and piled embankments

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Abstract: Fill deformation and surface settlement can be induced by differential settlement at the bottom of the fill in piled embankments. The deformation patterns and the relationship between the surface settlement and the differential settlement at the bottom of the fill have not been well investigated. Two-dimensional single-trapdoor, twin-trapdoor, and multi-trapdoor tests, including four tests with geosynthetic reinforcement, were conducted using elliptical steel rods as an analog to soil. The deformation pattern and influence regions in the single-trapdoor tests were evaluated using the measured deformations. The fill deformations in the trapdoor tests followed the Gaussian distribution. The superposition results of these Gaussian distribution curves of the single-trapdoor tests were compared with the measured deformations in the twin-trapdoor and multi-trapdoor tests. The differences between the measured and calculated results indicate that additional interaction occurred between adjacent trapdoors. The deformation shapes of the fill at the bottom of the geosynthetic-reinforced and unreinforced test sections were different. However, the settlement pattern at the elevation level above 1.5 times the clear spacing of pile caps followed the same Gaussian distribution curve, if the volumetric settlement was the same. A method for predicting the surface settlement of 2D piled embankments is then presented.
Keywords: Geosynthetics, Analog soil, Piled embankment, Trapdoor, Deformation, Settlement, Model test