International Journal of Geosynthetics and Ground Engineering (2024) 10:58
https://doi.org/10.1007/s40891-024-00569-9

EDITORIAL

Guest Editorial for the Special Issue on “Geosynthetic-Reinforced Sustainable Transport Infrastructures”

Fernanda Bessa Ferreira[1] · Sanjay Nimbalkar[2]

Accepted: 25 May 2024

Geosynthetics have been increasingly used in civil engineering applications due to their numerous benefits, including the cost-effectiveness, reliability and sustainability. In transport infrastructure projects, geosynthetics can serve a variety of functions including filtration, drainage, separation, barrier, stabilisation and reinforcement, hence contributing to improved stability and longevity of the system. This Special Issue encompasses fifteen papers that address the development and use of innovative geosynthetic solutions to enhance the short- and long-term performance of transport infrastructures, such as pavements, railway tracks, embankments and earth retaining structures. The papers in this collection present comprehensive laboratory, analytical, numerical and field studies involving the most recent geosynthetic products and associated technologies. A summary of each paper is provided below.

Article 30 focuses on three-dimensional (3D) finite element modelling of basal reinforced deep mixed (DM) column-supported (BRCS) embankment situated on soft clay. The numerical simulations were performed using the PLAXIS 3D software. The embankment fill and DM columns were simulated using the Mohr-Coulomb (MC) model, which follows a linear elastic-perfectly plastic constitutive relationship. On the other hand, the soft soil was modelled with a Modified Cam Clay (MCC) model, which follows an incremental hardening/softening elastoplastic constitutive relationship. A geogrid element, capable of withstanding tensile forces only, was used to model a geotextile layer. The numerical model was validated using the results of laboratory tests conducted on a small-scale embankment model built in a mild steel tank with dimensions of 1.5 m (length, L) × 0.3 m (width, W) × 0.85 m (height, H). Once the model was validated, a parametric study was performed to identify the major parameters influencing the response of the BRCS embankment. The stress ratio (M) of the soft soil, tensile strength of geotextile (T), diameter (d) of the DM column, number of DM column (N), and Young’s Modulus (E) of DM column were identified as the major parameters. In contrast, strength parameters (λ and κ) of soft soil and length (l) of floating DM column were found to have minor effect on the response of BRCS embankment.

Article 31 examines the pullout response of metallic and synthetic strips in conventional and alternative fill materials, specifically lateritic soil (LS), crushed sand (CS) and recycled sand (RS) derived from construction and demolition waste (CDW). The study involved a comprehensive geotechnical characterisation of the fill materials, as well as standard pullout tests of the reinforcement elements. The design parameters derived from the laboratory tests were then compared with values obtained through standard procedures established by relevant design manuals. The obtained results showed that similar pullout resistance can be mobilised in alternative CDW fill materials, compared to natural materials, particularly in applications involving reinforcements subjected to relatively low normal stresses and under appropriate drainage conditions. The granular nature of CS and RS coupled with their dilation behaviour led to mobilisation of higher vertical stress levels around the reinforcement, compared to the case where the LS was used. The presence of ribs in the metallic strips oriented perpendicular to the pullout direction significantly affected stress mobilisation, pointing out their essential role in enhancing pullout resistance. For the synthetic strips, higher stresses were attributed to the installation in pairs and the surface roughness.

✉ Fernanda Bessa Ferreira
fbf@fe.up.pt

Sanjay Nimbalkar
Sanjay.Nimbalkar@uts.edu.au

1 CONSTRUCT, Faculty of Engineering, University of Porto, R. Dr. Roberto Frias, Porto 4200-465, Portugal

2 School of Civil and Environmental Engineering, University of Technology Sydney, Ultimo, NSW 2007, Australia

Published online: 05 June 2024

In Article 33, the inclusion of distinct types of geogrids for improved performance of ballasted tracks is investigated by means of laboratory tests and 3D discrete element modelling (DEM). A series of large-scale direct shear tests and impact tests was carried out to assess ballast behaviour in terms of stress–strain responses and stress concentration using stress sensing sheets. A micromechanical analysis was then performed to evaluate the influence of geogrid on contact force distribution, coordination number and orientation of contacts, which could not be captured through laboratory experiments. The results indicated that the use of geogrids can effectively enhance ballast behaviour by increasing its shear strength and reducing the dilation during shearing. The DEM simulations further revealed that the inclusion of geogrid resulted in increased coordination number, reflecting an increased degree of interlocking among particles. In addition, contact forces in geogrid-reinforced ballast were redistributed and reoriented, aligning more towards the horizontal shearing direction to support the applied shear loads. From a practical perspective, this study demonstrates that geogrids can significantly contribute towards more sustainable and efficient railway infrastructure, offering valuable insights into optimising track stability and longevity.

Article 34 presents a comprehensive analysis of the behaviour of geocell-reinforced pavement and identifies the key factors affecting its performance. This is accomplished through a combination of experimental and numerical approaches. The experimental approach involved testing full-scale models of reinforced and unreinforced pavement sections in a tank with dimensions of 2.0 m (L) × 2.0 m (W) × 1.8 m (H) under repeated loading. The geocell was made up from high-density polyethylene (HDPE) sheets forming a honeycomb structure when expanded. The height and weld distance (pocket size) of the geocell layer were 150 and 330 mm, respectively. In turn, the numerical approach consisted of simulating both unreinforced and reinforced pavement sections using the three-dimensional finite element software PLAXIS 3D. In the experimental approach, river sand and aggregates were utilised for the subgrade, subbase (granular subbase, GSB) and base (wet mix macadam, WMM) layers. In the numerical analysis, the sandy subgrade, GSB and WMM layers were represented using the MC model. Besides, a parametric study was conducted considering two different materials for the subgrade layer (sand and clayey soil) and three different types of base material (WMM, sand and fly ash). The clayey subgrade soil was simulated using the hardening soil (HS) model. The study highlights that reinforced pavement sections constructed with a base layer of fly ash exhibit superior performance compared to sections with bases made of WMM and sand materials, showcasing reduced rut depth and lower stresses at the subgrade level.

In Article 35, a discrete approach was used to develop a two-dimensional (2D) finite element model, implemented in MATLAB, for analysing the performance of full-height panel mechanically stabilised earth (MSE) walls with pond ash backfill. The Duncan-Chang hyperbolic model was adopted to simulate the response of the backfill material. Geogrid reinforcements were modelled using linear elastic elements, while zero-thickness interface elements were utilised to simulate the backfill-facing and backfill-geogrid interfaces based on a MC model. The model was validated considering a reference geosynthetic-reinforced continuous panel MSE wall with H of 6 m and a rigid base. The findings indicated that, regardless of the stiffness of the reinforcement material, pond ash backfill performed better than sand for the given facing type and geometry. Through a sensitivity analysis, it was determined that variations in the angle of internal friction (ϕ), unit weight (γ_s), elastic modulus number (k_e), and elastic modulus exponent (n) of the pond ash significantly affected wall displacements, connection loads, and reinforcement strains. Consequently, limiting values for model parameters were computed based on the sensitivity analysis to meet specified design requirements.

Article 36 delves into the utilisation of CDW as an eco-friendly backfill for geosynthetic-reinforced MSE walls through a combination of experimental and numerical methods. The experimental approach involved a detailed physical, chemical, strength, and crushing characterisation of different fractions of the CDW material. Specifically, the mixed CDW was divided into five distinct fractions: CDW F1 (80–10 mm), i.e. fraction 1 with particle sizes ranging from 80 to 10 mm, CDW F2 (20–4.75 mm), CDW F3 (10–1 mm), CDW F4 (4.75–0.075 mm), and CDW F5 (< 0.075 mm). The numerical approach entailed the simulation of a MSE wall using PLAXIS 2D. The non-linear elastic behaviour of the CDW was represented using a hyperbolic model. It was found that two specific fractions of CDW material, namely CDW F3 (gravel sized) and CDW F4 (sand sized) were suitable as backfill for geosynthetic-reinforced MSE walls, resulting in reductions of the horizontal deformation of the wall facing by 23% and 86%, respectively, in comparison with conventional backfill material.

A case study of a 42-m high geosynthetic-reinforced soil (GRS) retaining structure constructed with marginal backfill available on site is presented in Article 37. The GRS structure was designed and built as part of the Northern Marmara Motorway Project, Kurtkoy - Akyazi Section (Turkey). Since the facing of the structure was designed as a wraparound flexible facing with an inclination of 70° and geogrid reinforcement was employed, locally available marginal soils (about 605,000 m^3) obtained from a tunnel excavation could be used as the backfill material. The environmental benefits, including the reduction in CO_2 emission resulting from the use of marginal backfill in lieu of select backfill material excavated from a quarry were pointed out. In particular, it was estimated that the CO_2 emission due to the hauling and quarry operations was reduced from 7,630,000 kg to 477,000 kg by adopting the aforementioned environmentally friendly solution.

Article 38 examines the performance of steel slag and CDW as potential backfill materials for GRS applications. The study adopted a combined experimental-numerical approach to analyse the behaviour of these waste materials. Consolidated undrained cyclic triaxial tests were conducted on unreinforced and reinforced sand, slag and CDW specimens with dimensions of 75 mm (diameter, *D*) × 150 mm (*H*). Both slag and CDW exhibited cyclic behaviour similar to that of sand but showed elevated excess pore pressure owing to slightly higher fines content. The inclusion of a biaxial geogrid with aperture size of 23 mm × 23 mm improved the cyclic strength of both slag and CDW. The study also employed the FLAC 2D finite difference package to further explore the practical implementation of slag and CDW in GRS walls under railway loading. The GRS wall components were modelled using linear elastic (LE) constitutive law. An advanced constitutive model termed as the plastic-hardening (PH) model was also used for the backfill materials for comparison purposes. The LE model was found to overestimate the GRS wall performance compared to the PH model. The numerical simulations also showed that using slag or CDW as backfill resulted in a significant reduction in wall deflection compared to that obtained with conventional materials.

In Article 39, a combined analytical-numerical approach was employed to evaluate the advantages of using geotextile in unpaved roads constructed over marginal subgrade under quasi-static and repetitive loading conditions. The analytical approach involved a limit equilibrium-based analysis, considering the 3D load-dispersion of stresses across the aggregate layer and the shape of the equivalent wheel contact. A finite element analysis using PLAXIS 3D software was then conducted to incorporate the influence of deformations. Both the subgrade and aggregate layer were represented using the MC model. The study demonstrated that the inclusion of a geotextile at the interface between the aggregate layer and the subgrade significantly reduced the surface rutting and vertical displacements of the unpaved road. By implementing a coupled stress-deformation approach in PLAXIS 3D, a step-by-step design methodology for unreinforced unpaved roads was developed.

Article 40 demonstrates the applicability of 3D printing technique for manufacturing customised geocells, particularly low strength geocells for reduced scale model tests, while contributing to a better understanding of their mechanical properties. The study involved the fabrication of honeycomb-shaped geocells of 100 mm pocket size using 3D printed polypropylene (PP) sheets through ultrasonic welding. A series of wide-width tensile tests on 3D printed PP sheets, shear strength and peel strength tests on geocell junctions, and direct shear tests on sand-geocell interfaces were then performed. Particle Image Velocimetry (PIV) analysis was carried out through video capturing during interface shear tests to understand the micro-level shear mechanisms at the soil-geocell interface. The results indicated that geocells fabricated by 3D printing technology have similar tensile and interface shear response as that of commercially available geocells. Moreover, it was found that PIV analysis can effectively be used to observe the mobilisation of passive resistance and dilation in interface shear tests involving geocells and correlate them to the different stages of sand-geocell interface shear response.

In Article 41, a new method is proposed for determining the effective modulus of soft subgrades stabilised using locally available soil material combined with geogrids. The laboratory program involved testing relatively soft subgrades with California bearing ratio (CBR) values of 2, 5, and 7%. The prepared subgrade material consisted of locally available granular material with CBR values of 8, 14, and 20%. To stabilise the subgrade layer, geogrids with varying tensile stiffness (ranging from low to high) were used, including polypropylene (PP30) and polyethylene terephthalate (PET100) geogrids. The geogrid layer was placed at the interface between the existing and the prepared subgrade. A series of model pavement experiments were carried out in a large-size test chamber with dimensions of 1.5 m (*L*) × 1.5 m (*W*) × 1.0 m (*H*) under static loading. The results showed a significant improvement in performance for subgrades with low CBR values and high stiffness geogrids. Furthermore, an economic analysis was performed, which revealed that PP30 geogrid-stabilised subgrades were approximately 50% cheaper compared to cement-stabilised subgrades. Additionally, a comparative cost analysis between cement and geogrid materials alone showed a cost reduction of about 77% when considering the latter.

Article 42 presents a bibliometric review of reinforced soil or mechanically stabilised earth (MSE) walls, aiming to present relevant literature to assist geotechnical engineers in examining the conceptual, intellectual, and descriptive framework of studies on MSE walls. A thematic/keyword cluster categorisation was performed to catalog and organise the numerous applications analysed and published over the last four decades, in order to demonstrate the main traditional applications, current utility and latest developments in this area. The overview of studies, concepts, and trends presented in this paper may be useful in enhancing the selection of appropriate subjects, approaches, and key variables in the field of MSE walls, while assisting researchers in outlining potential future research directions.

The findings of the 3D finite element analysis on the pullout behaviour of plate anchors in reinforced soft clay can be found in Article 46. A 3D model was created in PLAXIS 3D software, with dimensions of 1 m (*L*) × 1 m (*W*) × 1 m (*H*) and appropriate boundary conditions, to replicate the writers' previous physical model experiment. A square plate anchor with a size (*B*) of 0.1 m was positioned at different embedment depth ratios (*H*/*B*) ranging from 1 to 6. The Soft Soil (SS) model and Hardening Soil model with small-strain stiffness (HS_{small}) were utilised to predict the pullout response of the anchor under monotonic and cyclic loading conditions. The results emphasised the advantages of incorporating geotextile in enhancing anchor stability and resistance to vertical pullout and cyclic disturbances. When the embedment ratio (*H*/*B*) was 2, anchors in reinforced soil displayed a 45% increase in pullout resistance under monotonic loading and a 29% increase under cyclic loading. Ultimately, the addition of geotextile not only improved the pullout capacity, but also significantly modified the response of the anchors.

The main aim of Article 47 is to illustrate and quantify the sustainability benefits of incorporating geosynthetics in roadway design. To this end, six roadway projects covering different geosynthetic applications were assessed, each involving at least two alternative designs: one with and the other without geosynthetics. For each roadway project, the sustainability benefits achieved using geosynthetics were evaluated by performing carbon audits for the alternative designs. From the comparison between the conventional approaches and the design alternatives involving geosynthetics, it was found that the geosynthetic design alternatives consistently proved more sustainable, resulting in savings in the total carbon footprint that ranged from 16.3 to 44.44 tCO_2e per lane-km (or 11.6 to 50.11% reduced footprint in relation to conventional approaches). The analyses presented in this paper demonstrate that the inclusion of geosynthetics in roadways is one of the most promising applications of geosynthetics in addressing the global sustainability requirements.

Article 57 focuses on the design of geocells for unpaved rural and forest roads. Geocell-reinforced soil design methods available in the literature are reviewed and categorised based on the respective approach and associated outputs (e.g. increase in confining pressure, bearing capacity, and base layer thickness). A general base scenario was considered to enable the comparison between different design methods. A parametric analysis was then carried out to better understand the effect of relevant parameters on the outputs of each method. Overall, this paper aims to provide actual, simple, and systematised information to assist practitioners in the design of geocell reinforcement for unpaved roads, targeting more sustainable and resilient roads supporting increased traffic loads, while reducing maintenance operations and extending the infrastructure lifespan.

The Guest Editors would like to thank the authors for submitting their high-quality papers to this Special Issue and extend their best wishes for continued success in their research endeavours. The time and effort of the anonymous reviewers, whose constructive feedback was instrumental in shaping the quality of final papers are kindly acknowledged. The Guest Editors also wish to extend their heartfelt appreciation to Prof. Sanjay Kumar Shukla, the Editor-in-Chief, for his valuable support during the preparation of this Special Issue.

We sincerely anticipate that the papers included in this collection will benefit researchers and practitioners alike, and anyone who is interested in the most recent research advancements in geosynthetics for the development of efficient and sustainable transport infrastructure.