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# 摘要集

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# 目　录

# Effects of rockfall shape on deformation performance of ground reinforced embankments subjected to lateral impact

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**Abstract:** Ground reinforced embankment (GRE) is an economical and efficient protection measure against rockfalls. In various design guidelines of ground reinforced embankments, the impact force of the rockfall is the principal factor, which is significantly affected by rockfall shape. This article conducts real scale tests and numerical tests to observe the external deformation behavior and the internal dynamic response of GREs subjected to lateral impact. Five shapes of the rockfalls corresponding to three contact types are set up in the tests. The experimental results show that the impact surface shapes of the rockfalls govern the penetration deformation patterns of the embankments, and the deformation extent of the disturbed soils. For different contact types between rockfalls and construction materials, the failure mode of the geosynthetics and the displacement distribution of the disturbed soils are distinguishing. The disturbed soils can be divided into two parts, the part surrounds the rockfall mainly expands laterally, and the rest is extruded and slips backward. Basically, the sharpness of the rockfall results in the deeper penetration and the smaller impact force. The influence of the rockfall shape needs to be carefully considered in the design of ground reinforced embankments.

**Keywords:** Geosynthetics, Ground reinforced embankment, Rockfall shape, Deformation performance, Real scale test, MatDEM

# Field evaluation of moisture-suction regime and modulus of geosynthetic-reinforced soil wall with geo-composite side-drain

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**Abstract:** Geosynthetic-reinforced soil (GRS) walls built on hillslopes are more increasingly incorporated with geo-composite side drain in order to prevent the side-seepage entering the fill. This study evaluates the long-term moisture, pore-water pressure, and shear modulus, of a 6.5 m-high geogrid-reinforced soil wall in western Thailand. Through extensive field monitoring and in-situ spectral analysis of surface wave (SASW) tests, conducted during the Years 2018–2019, as well as laboratory tests, several key findings emerge. Free-free resonant frequency (FFR) testing of non-reinforced samples reveals the role of soil wetting and drying history and hysteresis in the stiffness-moisture relationship. In-situ pore-water pressure was found to be highest below the road surface near the wall face, decreasing with depth due to underdrainage, with values ranging from –27 to 5 kPa. The intersection of the side drainage board with the underdrain bottom layer shows the highest water content. In-situ and laboratory-derived soil-water retention curve (SWRC) were found to differ at greater depths. In unsaturated conditions, the in-situ small strain modulus of GRS appeared insensitive to suction stress below 10 kPa but was slightly affected under positive pore-water pressure, with multiple linear regression modeling indicating a dependency of stiffness on depth and pore-water pressure.

**Keywords:** Geosynthetics-reinforced soil wall, Geogrids, Suction, Moisture content, Unsaturated soils, Small-strain modulus

# Effects of bag characteristics and channel side slope on incipient motion of a single Geobag under river current loading

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**Abstract:** Geobag stability has not been extensively studied under river current loading. In this study, the impacts of geobag characteristics (shape, bag material, and fill ratio of sand) and channel side slope (flat and 1V:2H) on a single geobag's stability were systematically investigated in a physical model to form the solid foundation for the research of group geobags. Overall, a geobag with a higher fill ratio, combined with the more flexible cloth material, was found to be the most stable. Critical Shields parameters were estimated between 0.0018 and 0.019, and the cross-sectional averaged flow velocity at incipient motion ranged from 0.49 m/s to 1.08 m/s. A shape factor was introduced to better describe the relationship between geobag characteristics and their stability on both riverbed configurations. Both the fill ratio and the bed side slope had higher importance on the geobag's stability compared to the relative depth, bag shape, and angle of flexibility.
**Keywords:** Geobag, Erosion protection, Open channel, Incipient motion, Shape factor, Stability

# Experimental study on dewatering and reinforcement of dredged slurry treated by PHDs-PVDs under step vacuum preloading

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**Abstract:** Nowadays, the utilization of prefabricated vertical drains (PVDs) or prefabricated horizontal drains (PHDs) in combination with vacuum preloading (VP) has emerged as a prevalent and effective strategy for treating dredged slurry. Nevertheless, both of these methods possess certain inherent limitations. In this study, three groups of parallel model experiments are conducted to compare the effectiveness of PVDs, PHDs and PHDs-PVDs under step VP in treating dredged slurry. Firstly, the water discharge, settlement and pore water pressure are monitored during the experiments. Then, the shear strength and water content of the soil at various locations after experiments are measured and the soil profiles at different cross sections are gauged. Additionally, soil excavation is conducted to evaluate the deformation characteristics of PHDs and PVDs. Finally, a scanning electron microscopy analysis is to assess the clogging of filter membranes. The results indicate that the proposed method can combine the advantages of both PHDs and PVDs, effectively enhancing the treatment effectiveness of the slurry. These findings elucidate the dewatering and reinforcement mechanism of PHDs-PVDs-VP and provide valuable insights for its practical engineering application.

**Keywords:** Consolidation, Prefabricated vertical drains, Prefabricated horizontal drains, Vacuum preloading, Dredged slurry treatment

# Hydraulic conductivity of bentonite-polymer geosynthetic clay liners to aggressive solid waste leachates

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**Abstract:** Hydraulic conductivity of conventional mock sodium bentonite (Na-B) and bentonite-polymer (B-P) geosynthetic clay liners (GCLs) were evaluated with three synthetic leachates that are chemically representative of aggressive leachates from coal combustion product (CCR) (I = 3179 mM), mining waste (MW) (I = 2127 mM, pH= 2.0), and municipal solid waste incineration ash landfill (MSWI) (I = 2590 mM). The mock B-P GCLs were created by dry mixing bentonite with branched, linear, or crosslinked polymer. The polymer loading of mock B-P GCLs ranged from 3 to 15%. Comparative tests were also conducted with Na–B GCLs. The mock Na–B GCLs cannot maintain low hydraulic conductivity to aggressive CCR, MW, and MSWI leachates. Mock B–P GCLs with10% branched polymer had low hydraulic conductivity (< $1.0 \times 10^{-10}$ m/s) to synthetic MW and MSWI leachates at 20 kPa effective confining stress, whereas the hydraulic conductivity of mock B-P GCLs with 10% linear or crosslinked polymer ranged from $1.5\times10^{-9}$ to $1.4\times10^{-7}$ m/s. As the effective stress increased, the B-P GCLs branched polymer showed a faster decreasing trend than that of Na-B and B-P GCLs with linear or crosslinked polymer.

**Keywords:** Bentonite-polymer (B-P), Geosynthetic clay liners (GCLs), Polymer type, CCR leachate, MSWI leachates, MW leachate

# Investigation of load transfer mechanisms in reinforced cohesive soil embankments in case of subsidence using DEM

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**Abstract:** Cavity formations by soil dissolution or underground collapses are at the origin of large surface subsidence that constitutes a risk of damage or failure for infrastructures. Soil reinforcement with geosynthetics positioned at shallow depth is an economical and functional solution to reduce the induced surface settlements. Previous research has mainly focused on the load transfer mechanism and the arching effect in cohesionless reinforced backfills when the cavity opens. Experimental and numerical studies dealing with cohesive soils are very rare, although this situation is commonly found in practice. To overcome this lack of knowledge, a numerical study based on Discrete Element Modelling is carried out to better understand the load transfer mechanisms that are mobilized in cohesive embankments prone to underground cavity opening. The results are compared with experimental data obtained on a small-scale laboratory model in terms of vertical and horizontal displacements of both soil and geosynthetics. The numerical results focus on the collapse mechanisms of the cohesive embankment, the load transfer mechanisms, the shape of the vertical load distribution acting on the geosynthetic layer, the strain and traction forces within the geosynthetic sheet.
**Keywords:** Subsidence, Geosynthetics, Numerical modelling, Laboratory experiment

# Experimental and theoretical studies on deformation characteristics of Geosynthetic-Reinforced Soil (GRS) abutments induced by vertical loads

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**Abstract:** This study conducted five centrifuge model tests to investigate the deformation characteristics of the Geo-synthetics Reinforced Soil (GRS) abutments under vertical loads, considering the setback distance ab and beam seat width *B* as two major influencing factors. Test results show that a linear correlation existed between the maximum lateral facing displacements $D_L$ and the maximum settlements at the top of the GRS abutments $D_v$. The $a_b$ and the *B* had different effects on the deformation characteristics of the GRS abutments as well as the relationship between the $D_L$ and the $D_v$. The total volumetric strains of the GRS abutments were smaller than 0.3% for all the cases investigated in this study, indicating that it was reasonable to use the assumption of zero-volume change for the deformation calculation of the GRS abutments. This study proposed an improved semi-empirical method to describe the relationship between the $D_L$ and the $D_v$. Centrifuge test results and data collected from the literature were used to validate the improved method. It was concluded that the improved method had the advantage of considering the effects of the $a_b$ and the *B* separately and therefore significantly improved the prediction accuracy of the deformations of the GRS abutments.

**Keywords:** Geosynthetics, Geosynthetic reinforced soil (GRS), Abutment, Centrifuge model test, Deformation characteristic, Volumetric deformation, Theoretical method

# Behavior of surface loaded clay foundation reinforced by GESCs with lateral geosynthetic cushion under freeze-thaw cycles

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**Abstract:** The efficiency of geosynthetics has been proven in stone column-reinforced foundations. In this paper, loading tests were conducted on three stone column-reinforced foundations, experiencing four freeze-thaw cycles. The effects of geosynthetic encasement and lateral reinforcement were investigated on the behavior of ordinary stone column (OSC) – reinforced and geosynthetic encased stone column (GESC) – reinforced foundation. The results showed that particles of OSCs spread into foundation soil during freezing and thawing, and top of OSCs were replaced by foundation soil. The temperature gradient along the depth in OSC-reinforced foundation was smaller than in GESC-reinforced foundations, resulting in a lower negative pore pressure at the beginning of freezing. However, it was found that geosynthetic encasement helped maintain the integrity of GESCs, and increased the stress concentration ratio (SCR) during thawing, which led to a lower excess pore pressure in GESC-reinforced foundations. The lateral reinforcement was also found to not only reduce the differential settlement between GESCs and soil during thawing, but also restrain the frost heave during freezing. The tensile membrane effect of lateral reinforcement redistributed the stress and the overburden pressure throughout the freeze-thaw process. More water moved upwards during freezing in the OSC-reinforced foundation, leading to a larger amount of frost heave. However, the moisture migration became complex in the OSC-reinforced foundation, as OSCs were damaged by freeze-thaw cycles..

**Keywords:** Stone column-reinforced foundation, Geosynthetic encasement, Lateral reinforcement, Freeze-thaw cycles, Moisture migration

# Large-scale experimental and ANN modeling for dynamic interaction between vibrating and statically loaded foundations on geogrid-reinforced soil beds

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**Abstract:** The present investigation includes experimental and ANN-based intelligent modeling to explore the dynamic interference effect of closely positioned vibrating foundations placed on unreinforced and geogrid-reinforced soil beds. Large-scale field block vibration tests are conducted on isolated and interacting block footings placed on prepared foundation beds at IIT Kanpur, India. The dynamic interaction of various combinations of two-footing assemblies is examined where one footing (active footing) is excited with dynamic loadings, and the other (passive footing) carries static loadings. The tests involve three eccentric force settings for four distinct footing combinations at different clear spacings and reinforcement conditions. The responses of both footings are recorded at different loading frequencies. The interaction effect is presented in terms of the transmission ratio plotted against the frequency ratio. Additionally, an Artificial Neural Network (ANN) model is developed using the recorded field datasets to anticipate the dynamic interference effect. The predicted outcomes of the ANN model demonstrate promising agreement with the experimental findings reported in the literature, indicating the reliability and robustness of the intelligent model.

**Keywords:** Geosynthetics, Dynamic interference, Vibrating foundation, Block vibration test, Intelligent modeling

# Theoretical and experimental studies on air-inflated rubber dam anchored on sidewall of the rigid base

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**Abstract:** A theoretical study was conducted to investigate the cross-sectional configurations and the tensile forces of an air-inflated rubber dam anchored on the sidewall of the rigid base. A series of large-scale model tests were conducted using rubber dam models with a cross-sectional perimeter of 1.0 m and a length of 8.5 m. The results obtained from the analytical solutions agree well with those obtained from model tests. It is found that there is an optimum height of the rubber dam, especially for larger anchor depth with the increase of the inflated air pressure. The smaller the anchoring depth the higher the optimum inflated air pressure. The contact length between the rubber dam and the rigid base gradually decreases with the increasing inflated air pressure. The greater the anchor depth, the faster the contact length decreases to zero. Generally, the tensile force linearly increases with the increase of the normalized air pressure and the decrease of the anchor depth.
**Keywords:** Geosynthetics, Rubber dam, Geomembrane tube, Weir, Water-retaining

# Study of design parameters for staged-filled slurry treated by prefabricated horizontal drains under vacuum preloading

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**Abstract:** The method of using Prefabricated Horizontal Drains (PHDs) placed in layers under vacuum preloading can significantly speed up consolidation of staged-filled soil slurry. The PHDs can settle with the soil slurry and maintain their shape/pattern and dewatering capacity largely in comparison with Prefabricated Vertical Drains (PVDs). This study presents a field trial focused on treating dredged sediments using PHDs under vacuum preloading for land reclamation purposes. The staged filling involved in the field trial is analyzed using a finite strain consolidation model based on the piecewise-linear finite-difference method. Then, the effects of horizontal and vertical spacings of PHDs on settlement and vacuum consolidation rate are evaluated, considering various combinations of variables for staged-filled soil. It is found that for soils with low compressibility, the consolidation rate is primarily affected by the vertical spacing of PHD layers. For soils with higher compressibility, the consolidation rate is more significantly affected by the horizontal spacing of PHDs, and the final settlement after vacuum preloading is mainly influenced by the vertical spacing of PHD layers. This study provides practical recommendations for cost-effective design of horizontal and vertical spacings of PHDs in efficiently treating soil slurry with different compressibility and initial conditions.

**Keywords:** Staged-filled slurry, Prefabricated horizontal drain, Vacuum consolidation, Field test, Numerical simulation

# A new large-scale shear apparatus for testing geosynthetics-soil interfaces incorporating thermal condition

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**Abstract:** Geosynthetics-soil interfaces are exposed to varying temperatures coupled with complex stress states. Quantifying the mechanical response of the interface considering this combined influence of temperature and complex stress is always a huge challenge. This study proposes a new displacement and stress-loading static and dynamic shear apparatus that is capable of testing the geosynthetics-soil interfaces with high and low-temperature controlling function. The apparatus satisfactorily simulates monotonic and cyclic direct shear tests, and creep shear tests on geosynthetics-soil interfaces at temperatures ranging from -30℃ to 200℃. To validate the functionality of this device, a series of temperature-controlled experiments were conducted on different types of interfaces (sand-geogrid interfaces, sand-textured geomembrane interfaces, sand-smooth geomembrane interfaces). The experimental results indicate that the apparatus can simulate static, dynamic, and creep shear loading on geosynthetics-soil interfaces in high and low temperature environments, and these can be measured reliably. It also manifests that temperature has a non-negligible influence on all mechanical interface responses. These findings highlight the significance and potential of the proposed apparatus and its practical implications.

**Keywords:** Temperature-controlled interface shear apparatus, Geosynthetics-soil interface, Monotonic shear test, Cyclic shear test, Creep shear test

# 3D DEM investigation of shear behavior and interaction mechanism of woven geotextile-sand interfaces

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**Abstract:** This paper presents a numerical study on the investigation of microscopic mechanism governing the interaction of woven geotextile and angular sand employing the 3D discrete element method (DEM). The surface texture and tensile properties of the geotextile were simulated using overlapping spherical particles, and the angular sand was simulated using rigid blocks. The DEM models were fully calibrated based on previous experimental data. The shear and dilation zones of sand near the interface were quantitatively determined based on particle displacement gradients. Analysis of contact forces was conducted to explain the microscopic mechanism behind the macroscopic strength evolution. The influence of geotextile surface roughness on the shear strength of the geotextile-sand interface is also discussed. The results show that the failure mode of the woven geotextile-sand interface is a combination of particle sliding failure along the geotextile surface and shear failure of the sand within the shear zone above the interface. There is a rapid redistribution of contact forces prior to reaching peak shear resistance, and the average normal contact force within the shear zone remains relatively constant after the peak shear stress is achieved. A completely developed shear zone stabilizes soil deformation, typically after achieving the peak shear resistance.

**Keywords:** Woven geotextile, Interface, DEM, Interaction mechanism, Shear behavior

# Analytical assessment of pullout capacity of reinforcements in unsaturated soils

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**Abstract:** The effective interaction mechanisms in the pullout resistance of reinforcements include skin friction mobilized at the soil-solid surface, soil-soil shear resistance, and compressive resistance created against transverse elements. The third component is obtained from passive lateral pressure (LPM) or bearing capacity (BCM) methods. An analytical solution is proposed to determine the pullout capacity of geocell, geogrid, and strengthened geogrids embedded in ordinary and unsaturated soils. For unsaturated soils, the effective stress approach was employed. The solution-predicted results were compared with those obtained from large-scale pullout tests reported in the literature. Results indicated that considering LPM for 2D and 3D reinforcements better agrees with experimental results. The mobilized frictional rib-soil interfaces and the soil-soil shear resistance components generally contribute more to the pullout capacity of the geocell and geogrid, respectively. For the extensibility represented by mpi and flexibility of geocell denoted by $\alpha_{pi}$, the values of $m_{pi}$ = 1, 0.7, and 0.3 for the first, second, and third row of geocell, $\alpha_{pi}$ = 0.4 for the first row of geocell and 0.25 for the second and subsequent rows are suggested to be considered. Parametric studies showed that the optimum transverse rib spacing is over 50 times the equivalent rib thickness ($B_{eq}$).

**Keywords:** Geogrid and geocell, Pullout resistance, Analytical solution, Lateral earth pressure, Bearing capacity method, Unsaturated soil

# Centrifuge model tests on performance of MSE walls with different facing types

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**Abstract:** The role of wall facing is crucial in the design of MSE walls. This study employed two centrifuge model tests specifically designed to analyze walls with two distinct facing types: full-height panel facing and modular block facing. Additionally, surcharge loads were applied to these MSE walls to simulate real-world conditions. The findings from these tests revealed that MSE walls with full-height panel facing exhibited superior performance under the combined effects of self-weight and surcharge loads. The measured maximum horizontal displacements in walls with full-height panel facing and modular block facing were about 55% and 85% of those predicted from current design guidelines at EOS3, respectively. The influence of the surcharge loads on the reinforcement loads was found to be substantial for both wall types, especially for the case of model wall with modular block facing, where the reinforcement loads in the upper half of the wall increased by about 30% from EOS2 to EOS3. The insights garnered from this study contribute to a deeper and more nuanced understanding of the impact of facing types on the practical construction and design of MSE walls, offering valuable guidance for future engineering applications.
**Keywords:** Geosynthetics, MSE walls, Centrifuge model test, Full-height facing panel, Modular block facing

# Modifying ASTM E96 to assess water vapour transmission rates of geomembranes at high temperatures

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**Abstract:** This paper presents a novel methodology for assessing water vapour transmission rates (WVTRs) through geomembranes across a wide temperature range, from 20℃ to 90℃. This expands upon the existing ASTM E96 standard, limited to temperatures up to 32 ◦C. The study focused on 1.5 mm thick high-density polyethylene (HDPE) and polyvinyl chloride-ethylene interpolymer alloy (PVC-EIA) geomembranes. The WVTR results—0.15 g/m$^2$h at 25℃ for PVC-EIA and 0.02 g/m$^2$h at 30℃ for HDPE—align closely with values reported in existing literature for similar geomembranes at lower temperatures, validating the methodology proposed in this study. Under elevated temperatures, the WVTR of PVC-EIA increased significantly to 4.7 g/m$^2$h at 90℃, while HDPE showed a slower increase, reaching only 0.4 g/m$^2$h at the same temperature. This disparity is attributed to polymer composition and behaviour differences under high temperatures. This study's methodology provides a dependable approach for accurately measuring WVTR, including high temperatures relevant to various applications where such data is currently lacking.

**Keywords:** Geosynthetics, Geomembranes, Water vapour transmission rate, High temperature

# DEM modeling of installation damage of geogrids under rockfill compaction condition

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**Abstract:** To investigate the installation damage of geogrids during roller compaction under rockfill condition, a three-dimensional discrete element model for roller compaction of geogrid-reinforced rockfill was established. The rockfill was modeled by irregular rigid block elements, while the geogrids were modeled by bonding basic ball elements. The model parameters were then calibrated by triaxial consolidated-drained and tensile tests. The displacements of the geogrids in three perpendicular directions, and the strength of the geogrids was analyzed. Additionally, the effects of compaction parameters on the installation damage of the geogrids were studied. The results showed that deformation of the geogrids was relatively small in the roller-driving direction but significant in the roller-axis and settlement directions. The damage modes of the geogrids could be mainly classified into three types: rib fracture, rib end fracture, and node fracture. The installation damage of the geogrid was derived mainly from its uneven deformation and fracture, and after roller compaction the strength distributions at different locations of the geogrid layer showed a normal distribution. Furthermore, the installation damage of the geogrids increased with increasing excitation force and compaction passes but decreased with increasing over- lying rockfill thickness, roller velocity, and excitation frequency.

**Keywords:** Discrete element method, Rockfill, Particle shape, Geogrids, Installation damage, Roller compaction

# Seismic analysis of geosynthetic-reinforced soil walls in tiered configuration

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**Abstract:** Research on geosynthetic-reinforced soil (GRS) walls in tiered configurations is increasing gaining attention, with numerical methods being predominantly used in the past. In recent years, there has been a growing trend in conducting shaking table tests to further explore this area. However, traditional limit equilibrium (LE) methods are more preferred for design purposes. This study utilized a modified top-down approach, which is based on LE and pseudo-static methods to investigate the horizontal seismic force on the distribution of required tension along each reinforcement layer. The approach is initially extended from static analysis to seismic analysis for multitiered GRS walls. Parametric analyses are conducted to study the impacts that horizontal seismic coefficient, reinforcement length and spacing, internal friction angle of soil, height ratio of upper/lower tier, offset distance have on the internal stability of two-tiered GRS walls. Meanwhile, influences of wall batter and number of tiers on the critical offset distance for different seismic coefficients are assessed. Results indicate that the internal stability differs between the upper and lower tiers under seismic conditions, particularly with higher seismic forces, where the lower tier requires greater reinforcement tension to enhance its stability. Additionally, the critical offset distance grows with the increase in seismic coefficient, and it is sensitive to the internal friction angle of soil and the height ratio.

**Keywords:** Geosynthetics, Reinforced soil retaining wall, Tiered configuration, Limit equilibrium, Pseudo-static, Log-spiral failure mechanism