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摘要集

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目　录

Chemical durability of bituminous geomembranes (BGMs) in heap leach pad applications

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Abstract: The degradation behaviour of a 4.8 mm thick elastomeric bituminous geomembrane (BGM) immersed in pH 0.5, 9.5, and 11.5 synthetic mining solutions is examined over 26 months at 22, 40, 55 and 70°C. The low pH solution simulates the leach solutions found in copper, nickel, and uranium heap leach pads while the two high pH solutions simulate the chemistry and pH found in gold and silver heap leaching facilities. The mechanical, rheological, and chemical properties are examined at different incubation times to assess the degradation in the BGM at different temperatures. It is shown that the degradation rates of all properties are faster in pH 11.5 and 9.5 than in pH 0.5. Additionally, the BGM started to exhibit degradation in its mechanical properties even with a slightly degraded bitumen coat in all the mining solutions at elevated temperatures. The time to nominal failure of the BGM is predicted at different field temperatures using Arrhenius modelling. Due to the relatively fast degradation in the mechanical properties of the BGM, especially at temperatures above 50°C, the tensile strains in the BGM in the field should be limited so it can meet the required liner design life of heap leaching applications.
Keywords: Geosynthetics, Bituminous geomembrane, Durability, Heap leach pads, Mining

New insights into geotribology of non-dilative interfaces from novel experimental studies

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Abstract: The paper presents new insights into the particle kinematics and tribological aspects and their effects on the non-dilative interface shear response from novel experimental investigations. A custom-designed apparatus that enables image analysis of particulate-continuum materials interactions from the bottom of the interface plane while shearing was developed. The effect of influential factors on the frictional mechanism, particle kinematics, and subsequently on the friction coefficient was investigated by performing experiments on three types of sands at different normal stresses with a transparent acrylic sheet and smooth geomembrane. The results demonstrated that the frictional response of the acrylic sheet and geomembrane was comparable, indicating that their particle kinematics at the interface could be similar. However, the critical normal and peak shear stresses differed due to the materials' hardness. The image and micro-topographical analysis of the tested interfaces revealed that the box fixity, particle shape, and normal stress influence particle kinematics and shear-induced surface changes. The fixed box has shown restricted particle movements compared to the conventional box. Angular and smooth spherical particles exhibited lesser kinematics despite a huge difference in the shape and shear-induced surface changes. Rough spherical particles have larger displacements and shear-induced surface changes than smooth spherical particles.

Keywords: Geosynthetics, Friction, Non-dilative interfaces, Geotribology, Micro-topographical analysis

Cyclic response of stereoscopic geogrid–sand interface under static and cyclic loading

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Abstract: The investigation of cyclic shear response on a geosynthetic–soil interface is important for reinforced soil structures. A stereoscopic geogrid with a thickened transverse-rib thickness increases the interaction with the soil compared with a planar geogrid. In this study, three-dimensional printing technology was used to produce stereoscopic geogrids with transverse-rib thicknesses of 5, 10, 15 and 20 mm. The influences of different cyclic shear displacement amplitudes (1, 3, 6 and 10 mm) and normal stresses (20, 40 and 60 kPa) on the direct shear tests under static and cyclic loading at the stereoscopic geogrid–sand interface were investigated. The results indicate that the maximum shear stress can be improved by the stereoscopic geogrid at larger cyclic shear displacement amplitudes. The effect of transverse-rib thickness on the fitted curves of the normalised interface shear stiffness and damping ratio was reversed. The cyclic shear process altered the relationship between apparent cohesiveness and transverse-rib thickness. The peak stress ratio of the stereoscopic geogrid–sand interface is proposed as a function of the transverse-rib thickness and maximum dilation angle.
Keywords: Geosynthetics, Interfaces, Shear strength, Transverse-rib thickness, Stress–dilatancy relationship

Dynamic stress attenuation characteristics of geocell-reinforced railway subgrade

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Abstract: The dynamic stresses in many subgrades for old railways exceed the bearing capacity of the fillers. The geocell has been used to reinforce weak subgrades and achieve a quick attenuation in the dynamic stress. In this study, a series of field tests were conducted to investigate the dynamic stress attenuation characteristics in a weak subgrade reinforced with a geocell. A coupled finite element-discrete element model was developed to analyze the mechanism of the stress attenuation from a multiscale perspective. The results indicated that increasing the geocell height or decreasing the weld distance resulted in an increase in the attenuation rate. There was a threshold for the weld distance, below which its impact on the stress attenuation rate became negligible. When the weld distance was small, the dynamic stress attenuation was attributed to the geocell induced lateral confinement for the infilled soil. With the weld distance increasing, the deformation of the geocell increased and the membrane effect was further mobilized, which contributed to the dynamic stress attenuation. Based on the field test and numerical results, a design method was proposed to determine the reinforcement parameters of geocell-reinforced subgrade, aimed at improving dynamic stress attenuation and preventing subgrade distress.
Keywords: Geosynthetics, Dynamic stress attenuation, Field testing, FEM–DEM coupling, Design methods

Bearing capacity of footings on geosynthetic-reinforced soils under combined loading

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Abstract: In this study, the ultimate bearing capacity of shallow strip footings resting on a geosynthetic-reinforced soil mass subjected to inclined and eccentric combined loading is rigorously examined through the well-established method of lower bound limit analysis (LA) in conjunction with finite element (FE) and second-order cone programming (SOCP). Lower bound limit analysis formulation is modified to consider the ultimate tensile force of the geosynthetic layer in the soil mass so as to account for both pullout (sliding) and rupture (structural) modes of reinforcement failure. The effects of several parameters, including the embedment depth (u) and the ultimate tensile strength (T_u) of the geosynthetic layer along with load inclination angle (α) and load eccentricity (e), on the bearing capacity ratio (BCR) and failure envelopes of the overlying shallow foundation are examined and discussed. The results generally show a marked increase in the ultimate bearing capacity of the surface footing against combined loading with the inclusion of a single geosynthetic layer. Results also reveal that a second intermediate reinforcement might be required to bear a dual performance against both vertical concentric and combined loading scenarios so as to more effectively support the footing.
Keywords: Geosynthetics, Bearing capacity, Reinforced soils, Shallow foundations, Finite element limit analysis, Combined loading

Breakthrough time assessment of liner system for MSW landfills with high leachate heads

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Abstract: This paper presents a design method for liner systems of municipal solid waste (MSW) landfills with high leachate heads based on the breakthrough time of an indicative contaminant (Chloride). The performance of liner systems with varying thicknesses of compacted clay liner and attenuation layer was assessed. The single composite liner consisting of a geomembrane and a 0.75-thickness compacted clay liner can meet the 50-year breakthrough time requirement of the liner system for cases with the thickness of the attenuation layer > 3 m and the average height of waste H_D < 60 m. The double liner system consisting of two geomembranes with one single 0.3 m-thickness compacted clay liner, as proposed in the Chinese landfill standards, cannot meet the 50-year breakthrough time requirement of the liner system, especially for large-scale landfills (e.g. H_D > 60 m). The double composite liner with two composite liners consisting of a geomembrane and a 0.3 m-thickness compacted clay liner can be used for a landfill with an average height of over 60 m. Different liner systems for other cases with different average design heights of waste and

the thickness of the attenuation layer were proposed. They can be easily used for MSW landfills with high leachate heads.
Keywords: Geosynthetics, High leachate head, Liner system, Indicative contaminant, Performance design

Leakage through a circular geomembrane hole overlain and underlain by silty sand tailings

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Abstract: Experiments are conducted to investigate leakage through circular GMB holes overlain and underlain by both tailings with various hole diameters and GMB thicknesses. Finite element analyses are performed to explore the effect of hydraulic conductivities (k) of subgrade (underliner) and tailings above the GMB (overliner) on water head contours dissipation. An analytical solution is developed for predicting leakage through circular GMB hole overlain and underlain by both tailings. Results show that the effect of subgrade on leakage is highly dependent on the ratio of k between the underliner and the overliner. If the ratio >100, no head loss occurs in the subgrade; if the ratio <0.01, all the head loss occurs in the subgrade. With the deposition of fines from overliner into subgrade, a low permeable filter cake is formed on the subgrade surface, notably increasing the impact of underliner on leakage. With the increasing ratio of k between underliner and overliner from 0.01, 0.1, 1, 10, and to 100, the ratio of leakage relative to a highly permeable subgrade increases from 0.01, 0.1, 0.56, 0.93, and to 1. An intimate interface contact can be achieved when the GMB is underlain by silty sand tailings as subgrade (foundation) material.
Keywords: Geosynthetics, Geomembrane, Holes, Tailings, Subgrade, Leakage

Antioxidant-stabilizer depletion of 4 HDPE geomembranes with high HP-OIT in MSW leachate

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Abstract: The antioxidant-stabilizer depletion of four 1.5-mm HDPE geomembranes from the same manufacturer each with a different resin and additive package is examined in air and a synthetic municipal solid waste leachate at a range of temperatures (40–95°C) for 7.5 years. Two were formulated for high temperatures and used polyethylene of raised temperature resistance (PE-RT) resins while two used more conventional HDPE geomembrane formulations. The depletion of protective antioxidants and stabilizers was monitored using standard and high-pressure oxidative induction time (OIT) tests and the notably different depletion times for both OIT tests implied they were detecting different groups of AO-S. Although both PE-RT GMBs showed significantly slower AO-S depletion at 85°C in air compared to the conventional PE GMBs, only one PE-RT GMB maintained this status in 85°C leachate, highlighting the limitation of air aging tests (and importance of fluid immersion tests). The importance of running immersion tests long enough to reveal the residual HP-OIT value is stressed. The roles of stabilizer mobility and solubility in polyethylene and their suspected involvement in residual HP-OIT behavior are also illustrated.
Keywords: Geosynthetics, High temperature HDPE geomembranes, PE-RT, Antioxidant depletion, HP-OIT, Long-term performance, Accelerated aging, UN SDG 6: Clean water and sanitation, UN SDG 12: Responsible consumption and production

Lateral force–displacement relationships for shallowly buried pipe reinforced by geocells

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Abstract: Geocell reinforcements are proposed as a thrust countermeasure for shallowly buried pipeline bends and tees. The proposed method is easy to construct and has shorter construction time than the use of conventional concrete blocks since it does not require curing. Lateral loading tests were conducted on plates reproducing pipe bends or tees to verify their effectiveness while understanding deformation mechanisms. In addition to changing the plate width and geocell pocket size, additional experiments were conducted with different geocell reinforcement dimensions, geocell tensile stiffnesses and tensile properties of the seams. An equation for predicting the force–displacement relationship was developed as part of the proposed design method. The experimental results showed that the sides of the reinforced ground were not fully integrated when the width of the geocell reinforcement was large relative to the plate width. It was also found that the maximum force hardly decreased, although the displacement increased slightly due to the reduction of the tensile stiffness of the geocells and the tensile force at the geocell seams. Moreover, a hyperbolic approximation of the force–displacement relationship of the geocell reinforcement was developed and the calculated values agreed well with the experimental values.
Keywords: Geosynthetics, Geosynthetic-reinforced soils walls & slopes, Pipes & pipelines, Model tests

Filtration behaviour of staple fibre geotextiles under unequal biaxial tensile strains

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Abstract: Gradient ratio tests were conducted to investigate the filtration behaviour of staple fibre needle-punched nonwoven geotextiles subjected to unequal biaxial tensile strains. Three groups of biaxial tensile strains were designed, with the ratios of the strain in the machine direction to that in the cross-machine direction set to 1, 2, and 4, respectively. The strains in the machine direction in the three groups were the same, ranging from 10% to 30%. The tested filtration properties included the gradient ratio (GR), permeability of the soil-geotextile system, mass of soil loss, and permittivity of the pure geotextiles. Comparisons were made between the filtration properties of staple fibre (SN) geotextiles and continuous filament (CN) geotextiles. It is shown that for a certain strain ratio, the GR value at the time of test termination increases with increasing strain, and the permeability of the soil-geotextile system, soil loss, and permittivity of the pure geotextiles decrease with increasing strain. The soil loss and permittivity under equal biaxial tensile strains tend to be higher than those under unequal biaxial tensile strains. The CN geotextiles have better retention capability and more clogging potential for the tested soils than the SN geotextiles for a similar mass per unit area.
Keywords: Geosynthetics, Filters and drains, Strain, Gradient ratio test, Clogging

Investigating the effect of temperature and water freezing on the response of geogrid composite

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Abstract: Geosynthetics can be exposed to varying temperature and moisture conditions when embedded in soil, which can affect their mechanical properties. However, existing testing standards do not account for extreme environmental conditions such as low temperatures and ice formation. The aim of this study was to understand the effect of temperature variation and ice formation on the tensile properties of dry and wet geosynthetics by conducting single-rib tensile tests on a wicking geogrid composite in a temperature chamber. Tensile stress–strain curves were obtained at various temperatures for dry samples (−40°C to 40°C) and wet samples (0°C to −40°C). It was found that, with a decrease in temperature, the tensile strength and stiffness of dry and wet samples increased while the ultimate strain decreased. The freezing of water in wet samples also accelerated the rates of increase in ultimate strength and decrease in ultimate strain. The failure mode of the geogrid composite also changed with temperature, occurring at the middle junction at higher temperatures and closer to the end junctions with a fibrous appearance at lower temperatures. These findings provide insights into the significance of varying environmental conditions on geosynthetic properties.
Keywords: Geosynthetics, Geogrid composite, Wet conditions, Tensile properties, Temperature effects

Centrifuge modelling of the progressive failure of geosynthetic-reinforced embankments

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Abstract: Understanding the failure mechanism of geosynthetic-reinforced embankments on soft foundations is crucial for ensuring safety in design. This study aimed to investigate the failure mechanism and stability of embankments reinforced with varying layers and lengths of geosynthetic reinforcements utilising centrifuge testing and numerical modelling. The results show that a foundation under construction exhibits a progressive shear failure coupled with a tensile failure of the geosynthetic reinforcement. The plastic shear strain in the soft clay layer initiates at the centreline, shoulder and embankment toe and propagates both forward and backward until a critical slip surface develops. The tensile failure of the geosynthetic was observed at the embankment centre. Comparatively, implementing two shorter layers of geosynthetics proved more advantageous for overall stability than using a single layer with the entire length. By analysing the strain distribution in the foundation, the deformation modes of the embankment reinforced by different numbers of geosynthetic layers were clarified. It was found that increasing the number of geosynthetic layers extended the active

shear zone in soft clay.

Keywords: Geosynthetics, Embankment, Centrifuge model test, Progressive failure, Deformation

Investigation on dynamic performance of soilbag cushion using shaking table tests

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Abstract: Soilbag cushion is one of the promising base isolation methods to reduce seismic energy transfer from ground to building structure. In this study, a series of shaking table tests were conducted comparatively on foundation models with soilbag cushion and sand cushion to evaluate their dynamic performance. The test results indicate that soilbag cushion could significantly reduce acceleration response and accumulated settlement compared to sand cushion. And the relatively smaller amplitude of dynamic lateral earth pressure measured on contact surface of soilbags within soilbag cushion also indicates its stability during oscillation. The advantages of soilbag cushion for energy dissipation and damping are more easily highlighted under the condition of high-acceleration, high-frequency or high uniformly distributed load. The dynamic performance of soilbag cushion is dependent on embedded depth and thickness. It is most effective for soilbag cushion to be arranged near the rigid footing of building structures; it is suggested that the number of layers of soilbag cushion be controlled on the premise of the designed ratio of the thickness to the width of soilbag cushion ranging from 0.125 to 0.4 for low- or middle-rise masonry buildings in practical engineering.
Keywords: Geosynthetics, Shaking table test, Soilbags, Acceleration, Dynamic lateral earth pressure, Settlement

Evaluating stability of rigid-column-supported and geosynthetic-reinforced embankments

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Abstract: Field observations and centrifuge tests indicate that progressive column bending failure accompanies most instabilities of rigid-column-supported and geosynthetic-reinforced (RCGR) embankments. However, recognized guidelines specifically for evaluating the overall stability of such systems featuring bending failure remain limited. A general methodology to calculate the factor of safety (FS) for RCGR embankments using the limit equilibrium method is presented in this article. The focus is on deep-seated slope failures, wherein rigid columns progressively fracture due to subsoil overstressing. The concentric arches model, along with tensioned geosynthetic analysis, informs the determination of vertical and horizontal loads on the column heads. The column's resisting moment stems from its flexural and compression resistance. A mobilization factor for the net thrust on each column is defined to capture the progressive failure. The methodology involves an iterative computational procedure to identify the critical slip surface and the FS using the Fellenius' method. The solution was validated using three case studies, including both centrifuge models and field tests, as well as finite-element analysis. The results indicate that the soil mass

contributes the most to resisting sliding and overall stability, followed by columns and geosynthetics. In addition, axial force mainly provides the resisting moment of columns.
Keywords: Geosynthetics, Limit equilibrium methods, Columns, Embankments, Foundations, Bending failure

Semi-analytical model for axisymmetric transport of contaminant through flawed geomembrane

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Abstract: Geomembrane (GM) is a kind of cost-efficient material for pollutant barriers in landfills, while defects can occur during the installation or service periods, resulting in a mixed-type boundary condition (MTBC) at the top surface of the underlying soil layer (SL). In this study, a novel boundary transform method is employed to handle the MTBC problem of axisymmetric transport of organic contaminant through defected GM, and a semi-analytical solution is derived to evaluate the concentration profiles in the spatiotemporal domain. The proposed solution is in the cylindrical coordinates that can incorporate the diffusion and dispersion processes, as well as the concentration condition in the GM defect. The discretization method, integral transforms and corresponding inverse transforms are applied to obtain the semi-analytical solution, which is demonstrated to be effective compared to the numerical results. The model is applied to predict the migration characteristics of organic contaminant in several cases, followed by discussions to evaluate the influencing roles of defect rate, anisotropic coefficient, and segment number. Results indicate that the existence of defects substantially reduces the barrier capacity of the GM layer, and the contaminant migration time varies in several orders of magnitude for different MTBCs.
Keywords: Geosynthetics, Geomembrane, Axisymmetric transport of contaminant, Mixed-type boundary condition, Discretization method

Effect of oxidative ageing on stiffness improvement factor for HDPE and PET geogrids

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Abstract: The effect of thermal-oxidative ageing on in-isolation and in-soil stiffness is investigated for two high-density polyethylene (HDPE) and two polyester (PET) geogrids when incubated in an oven at 90°C. It is shown that the in-isolation and in-soil stiffness of three out of the four geogrids decreased during the 4-month ageing time with a faster degradation of the two PET geogrids. In contrast, one of the HDPE geogrids examined with thicker rib showed slower degradation compared to the PET counterparts. It is also shown that a geogrid might have a higher unaged stiffness, but less aged stiffness compared to another geogrid made of the same polymer type. It is suggested that the ageing approach used in this study could be adopted for the selection of geogrids based on their long-term stiffness for structures such as reinforced embankments or mechanically stabilized earth walls that require a long service life. Moreover, results indicate that the stiffness improvement factor for PET geogrids decreases with ageing time. On the contrary, the stiffness improvement factor of the HDPE geogrid increases with time and hypothetically might keep increasing followed by a sudden drop to zero at full degradation of the geogrid.
Keywords: Geosynthetics, Geogrid, Soil reinforcement, In-isolation stiffness, In-soil stiffness, Stiffness improvement factor, HDPE, PET, Degradation, Thermal-oxidative ageing, Oven ageing, UN SDG 11: Sustainable cities and communities

Influence of roots on the hydro-mechanical performance of a drainage geocomposite

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Abstract: Geosynthetics are increasingly used in geotechnical works in association with vegetation, whose function has been typically considered as an improvement for the works themselves, especially due to the mechanical and hydraulic effects the root system provides. Within this context, the paper presents an experimental study performed to evaluate the long-term performance of geosynthetics, specifically drainage geocomposites, exposed to the influence of roots. Two species of plant were selected for their fast-growing and pervasive roots, Vetiver and Bamboo, and planted in a thin layer of growing medium, which buried the geosynthetic specimens. After a period of plant growth, the specimens affected by roots ('rooted specimens') were exhumed, and submitted to tensile and drainage capacity laboratory tests, to determine their mechanical and hydraulic behaviour. The laboratory test results were compared with those obtained on virgin specimens of drainage geocomposite, under undisturbed conditions ('reference specimens'). The results show a decrease in drainage capacity for rooted specimens, more pronounced in the case of the highest density of roots into the drainage core. Concerning the tensile behaviour, no significant variations emerged in rooted specimens, although a slight increase in tensile strength, together with a modest decrease in elongation at maximum load, could be observed.
Keywords: Geosynthetics, Drainage geocomposite, Roots, Water flow, Tensile properties

Observations on tensile testing of intact and slitted geotextiles through image analysis

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Abstract: Geotextiles are widely used as reinforcing elements in many geotechnical engineering applications such as mechanically stabilized earth walls, reinforced soil slopes, capping of high-water content clays in landfills, reinforced embankments for railways and roadways, and so on. The ultimate strength of geotextile is obtained from the load-displacement plot; however, the failure mechanism evaluation of local displacement is crucial to understand the serviceability state. In the present study, the image-based deformation measurement technique is used to evaluate the local displacement within geotextile at different locations during the wide-width tensile test. Further, the load-displacement plots are obtained for different geotextiles and a comparison is made between the measured displacements from the instruments and through an image-based deformation measurement technique. Additionally, the strength of geotextiles with imbibed defects at different orientations and corresponding failure patterns is investigated. The imbibed defect in geotextile is in the form of slits having orientations varied as vertical, horizontal, and inclined with respect to the loading direction. It has been observed that geotextile with vertical slit has the highest strength, followed by geotextile with inclined and horizontal slits. The present study results provide insight into the variation in the strength and displacement field of geotextiles having defects.
Keywords: Geosynthetics, Image-based deformation measurement technique, Wide-width tensile test, Failure pattern, Imbibed defect

Behavior of back-to-back mechanically stabilized earth walls as railway embankments

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Abstract: Twelve physical model tests were carried out to investigate the role of the type and arrangement of reinforcements on the behavior of back-to-back mechanically stabilized earth walls (BBMSEWs) supporting railway tracks. Six metal-strip reinforced BBMSEW models and six geogrid reinforced models were prepared with different reinforcement arrangements and then were vertically loaded to failure using wooden railway sleepers. The findings indicated that the reinforcement stiffness played a more prominent role in improving the bearing capacity than the pull-out capacity. The connection of two opposing walls with continuous reinforcements and the complete separation of them from each other were found to be the best and worst reinforcement arrangements, respectively, for improving the bearing capacity and reducing wall deformation in BBMSEWs. The respective use of these two arrangements mobilized the maximum and minimum forces in the reinforcements. Moreover, the creation of a proper connection between the opposing walls using continuous inextensible reinforcements or those with a sufficient overlap length were found to be efficient solutions to preventing the propagation of a failure plane across the back-to-back MSE walls.
Keywords: Geosynthetics, Back-to-back MSE walls, Railway embankments, Physical model test