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Editorial

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Physical model testing in geotechnical engineering

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1 Introduction

Several characteristics of natural soils complicate the relationship between their mechanical behaviour and geotechnical construction and maintenance in the field. These characteristics include the presence of three phases (solid particle, water, and air), particle constitutions of various minerals (such as quartz, kaolinite, and montmorillonite), and an exceptionally wide range of particle size from μm-scale (clay particles smaller than 2 μm) to 100-mm scale (such as some gravels and pebbles), with complicated interparticle contact distributions. Field or in-situ testing is the most reliable way to reveal the real conditions for geotechnical engineering (Chen et al., 2021; Xue et al., 2021). However, field testing is sometimes not easy or even not realistic to perform because of resource shortages, time limitations, and difficult operability. To overcome these issues and to reproduce the mechanical or thermo-hydro-mechanical-chemical (THMC) coupled behaviours of geotechnical structures, physical model testing is an efficient and reasonable approach, widely used by academics and engineers around the world (Wang et al., 2018; Guo and He, 2020; Bian et al., 2021; Lei et al., 2021; Tang et al., 2022).

Physical model tests can be categorized into small-scale, large-scale, and full-scale cases. Compared to field testing, physical model testing has advantages of high reproduction of the in-situ condition, a much lower cost, and noticeably higher operability. Physical model testing can help identify the effects of various controllable influencing factors on the performance of engineering cases, thereby providing a connection between the investigation of basic soil behaviour in the laboratory and practical geotechnical engineering applications in the field (Wang et al., 2019; Peng et al., 2022). Following further data processing and analysis, theoretical models and basic designs can be provided for engineering practice (van Eekelen et al., 2013; Wang and Chen, 2019; Tu et al., 2020). Hence, physical model testing serves as an enduring and popular method for academics and engineers to solve complicated geotechnical problems by improving the understanding of such problems.

This special issue contains original research articles in the area of small-scale, large-scale, and full-scale physical model testing for geotechnical engineering, with a focus on the following aspects: (1) physical model development for critical engineering problems, using innovative testing methods (including innovative sensors); (2) clarification of multi-physics behaviour of geotechnical cases using physical model tests; (3) development of theoretical models and basic designs for practical applications in geotechnical engineering through physical model testing.

Several experts in this field were invited to share their up-to-date investigations. The collected articles

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cover various topics as previously listed. Herein, we briefly introduce the articles as follows:

Zheng et al. (2022) present a series of physical model tests to visualize the dynamic progression of backward erosion piping by a Hele-Shaw cell. Various gaps between the upper and lower plates of the cell, and ratios of the flux of water to the gap were controlled. The results indicate that the erosion process can be divided into a piping progression phase and a piping stabilization phase. A higher flux of water induces more branched patterns for the morphologies of erosion, when the gap is not too wide (within 5 mm). Interestingly, as the thickness of the sample increases, the sand grains are easier to dislodge, due to more degrees of freedom. A critical thickness of the sample, above which the erosion geometry may not be affected, still needs to be confirmed.

Chang et al. (2022) investigated the behaviour of a frozen sand–concrete interface under constant normal load and constant normal height boundary conditions using a series of large-scale interface shear tests. Different normal stresses and temperatures were applied. The testing results show that strain softening behaviour is exhibited under negative temperatures. Under a lower temperature or a higher normal stress for both constant normal load and constant normal height boundary conditions, the degree of strain softening behaviour, the elastic shear modulus, the peak and the critical interface shear stress, and the value of the peak ice-cementation are higher. However, the percentage of peak ice-cementation in the peak interface shear stress increases with decreasing temperature or decreasing normal stress.

Based on the geological conditions and disaster cases of the Xinping Tunnel in the China–Laos railway line, Xu et al. (2022) performed a large-scale physical model test to simulate tunnel excavation in sandstone and slate interbedded strata, and to reproduce the water-and-mud disasters. From the testing results, water-and-mud inrush was shown to progress in three stages: seepage stage, high-leakage flow stage, and attenuation stage. When a water-resistant stratum is reduced to a critical safety thickness (corresponding to a pivotal point at which the seepage pressure changes from high to low, and the flow varies from low to high), a water-inrush channel develops. Under the unloading effect due to the excavation and the coupling effect of in-situ stress-seepage, the water-resistant stratum gradually fails. In addition, the variations of the stress and strain, and the seepage pressure and flow of surrounding rock reveal the process of formation and evolution of the disaster, according to the stage-related characteristics of the water-and-mud inrush process.

Another engineering issue related to tunnelling was investigated by Zhang et al. (2022). Several large-scale physical model tests were conducted to unravel the effect of soil on the bearing capacity of a double-lining tunnel structure under internal water pressure in sandy soil and highly weathered rock conditions. The testing results indicate that the contribution of soil to the bearing capacity increases with the increase of the soil elastic modulus. After crack development on the double-lining, the soil contributes more to bearing the internal water pressure, compared to a scenario with no crack on the double-lining. In addition, this response increased for highly weathered rocks. Following the analysis of the physical model testing results, an analytical solution was proposed to further evaluate the contribution of soil to the bearing capacity, considering the soil–double-lining interactions. From comparisons, the analytical solution could be verified by the physical model testing results, with an average error of about 7.9%.

Ren et al. (2022) developed a dynamic numerical model to investigate the effect of a change in groundwater level on the seismic response of geosynthetic-reinforced soil retaining walls (GSRWs). This model was validated by centrifugal shaking-table physical model tests. The results show that when the groundwater level drops, the seismic stability of the GSRW is worse, because the drag forces caused by water flowing from the inside to the outside of the GSRW damage the wall structure, leading to a larger outward deformation. In contrast, the GSRW has the highest seismic stability as the groundwater table rises, preventing the retaining wall from deforming outwards caused by the rising groundwater level. Compared to the low-groundwater level case, the seismic stability of the GSRW is worse for the high-groundwater level case, due to the generation of excess pore water pressure during an earthquake. According to the investigations, coarse-grained soils with good drainage properties are recommended as backfill for GSRWs.

Another study dealing with the seismic response of geotechnical structures under earthquakes is provided by Wei et al. (2022). In this study, a series of 1/4-scale physical model tests were performed to evaluate the seismic responses of a cantilever retaining wall with reinforced and unreinforced backfill, under minor, moderate, and major earthquake loadings. The results indicate that the inclusion of reinforcement improves the integrity of the soil-wall system, mitigates vibration-related damage, and reduces the fundamental frequency of the system and the amplification effect of the input motion. Under both minor and moderate earthquake loadings, the inclusion of reinforcement decreases the seismic earth pressure compared to the unreinforced case. Under major earthquake loading, backfill reinforcement is not fully effective. In such case, the horizontal displacement of the wall is smaller than that of the backfill, with the backfill deforming the wall significantly.

In consideration of the need to reduce cost, mitigate environmental impacts, and improve efficiency during the construction of highway subgrade, Wang et al. (2022) performed a series of full-scale model tests to examine the compaction quality of a gravel subgrade with large-thickness layers (65 and 80 cm) by heavy roller compaction. The results indicate that the dynamic soil stress induced by heavy vibratory rollers was much higher than that from conventional rollers, particularly at deeper depths. Within 6 to 7 passes of the heavy vibratory rollers, the subgrade could be compacted in a uniform manner, with the degree of compaction ranging from 96.0% to 97.2% for the 65-cm layers, and from 94.1% to 95.4% for the 80-cm layers, exceeding the design value of 93%. Compared to conventional compaction thickness, compaction with thicker layers leads to a better bearing capacity. In summary, increasing the thickness of the compaction layer by heavy rollers significantly reduces cost and time burdens, while ensuring a high quality of compaction.

Another study was related to the transportation subgrade. Su et al. (2022) performed a series of multi-stage cyclic triaxial tests and mercury intrusion porosity tests on fine–coarse soil mixtures to model the track-bed materials in French railways at various water contents of fines, coarse grain contents, and deviator stress amplitudes. Regarding the fine matrix fabric when the water content for fines is higher than its plastic limit, the rebounding effect on the resilient modulus is more significant than the hardening effect. This leads to a decrease of the resilient modulus with increasing deviator stress amplitude. In contrast, in terms of the fine aggregate fabric with the water content for fines lower than its plastic limit, the rebounding effect on the resilient modulus is not as great as the hardening effect, resulting in an increase of the resilient modulus with increasing deviator stress amplitude. As the coarse grain content increases, the resilient modulus increases under both saturated and unsaturated conditions, attributed to the reinforcement effect of coarse grains.

With these articles, we believe this special issue provides a fundamental basis for academics and engineers to present and discuss up-to-date progress in the field of physical model testing in geotechnical engineering. By covering several topics and backgrounds such as transportation subgrade, tunnelling, erosion, frozen soil, and seismic analysis in relation to geotechnical structures, we hope this special issue will enhance the understanding of each topic and promote the application of the physical model testing approach to more areas of geotechnical engineering. We also expect the selected articles will bring new ideas to academics and engineers in the relevant areas, and inspire the readers of this journal.

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Author contributions

Zhen-yu YIN conceived and edited the draft manuscript. Han-lin WANG performed the literature review and completed the first draft of the manuscript. Xue-yu GENG revised and edited the final version.

Conflict of interest

Zhen-yu YIN, Han-lin WANG, and Xue-yu GENG declare that they have no conflict of interest.

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Introducing Guest Editor-in-Chief and Guest Editors:

Guest Editor-in-Chief

Prof. Zhen-yu YIN has been an Editorial Board Member of *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)* since 2019. Prof. Zhen-yu YIN is currently Professor of Geotechnical Engineering at The Hong Kong Polytechnic University (China). Prof. YIN received his B.Eng. in Civil Engineering from Zhejiang University (China) in 1997, followed by five years of engineering consultancy at the Zhejiang Jiahua Architecture Design Institute (China). Then, he obtained his MSc and Ph.D. in Geotechnical Engineering at Ecole Centrale de Nantes (France) in 2003 and 2006, respectively. Prof. YIN has published over 230 articles in peer-reviewed international journals with an H-index of 48 according to Web of Science. He is an Associate Committee Member of the Granular Materials Committee of American Society of Civil Engineers, Associate Editor of *European Journal of Environmental* and *Civil Engineering* and *Geotechnique Letters*, and Editorial Board Member of some top journals in the field of soil mechanics and geotechnical engineering (*Canadian Geotechnical Journal*, *International Journal of Geomechanics ASCE*, *Soils and Foundations*, *Acta Geotechnica*, *Transportation Geotechnics*, *Computers and Geotechnics*, *GeoRisk*, etc.).

Guest Editors

Prof. Han-lin WANG has been a Young Scientist Committee Member of *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)* since 2022. Prof. Han-lin WANG was appointed Professor in the College of Civil Engineering, Hunan University (China) in June 2022. He obtained his B.Eng and Ph.D. degrees from Zhejiang University in 2011 and 2017, respectively. During his Ph.D. study, he had one-year joint Ph.D. experience at Ecole des Ponts ParisTech in 2016. Before joining Hunan University, he worked in the University of Macau (China), Cardiff University (UK), and The Hong Kong Polytechnic University (China). Prof. WANG works in the area of high-speed transportation geotechnics. Currently, he serves as an Editorial Board Member (or Early-Career Member) or Guest Editor for four journals: *Transportation Geotechnics*, *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, *Buildings*, and *Transportation Infrastructure Geotechnology*. In addition, he serves as a Committee Member in the TC202 Transportation Geotechnics, International Society for Soil Mechanics and Geotechnical Engineering.

Dr. Xue-yu GENG has been a Reader in Ground Engineering at the University of Warwick (UK) since 2015. She worked in Australia prior to her appointment in the UK. She has conducted both fundamental and applied research in the disciplines of soil dynamics and soil reinforcement. She is a Fellow of the British Geological Society (FGS), Fellow of the Higher Education Academy (FHEA), Chartered Engineering from ICE (CEng), and Member of ICE (MICE). She is also the Editor-in-Chief for the Proceedings of the Institution of Civil Engineering—Geotechnical Engineering, Associate Editor for the Proceedings of the Institution of Civil Engineering—Ground Improvement, and an Editorial Board member for *Transportation Geotechnics*.