The planning of LEAP-Asia-2025 project and preliminary centrifuge model tests at Zhejiang University

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ABSTRACT: The LEAP-Asia-2025 project investigates the dynamic response of liquefiable grounds under earth dam (or embankment) during shaking, with particular emphasis on the effects of overburden stress and initial static shear stress. This paper outlines the integrated research framework combining element testing, centrifuge model testing, and numerical simulations. To verify the feasibility of the proposed centrifuge testing scheme, preliminary model tests were conducted at Zhejiang University. Full-cross-section and half-cross-section embankment models were examined under sinusoidal input motions with varying peak ground accelerations. The results indicate that the half-cross-section model introduces significant boundary constraints and cannot fully reproduce the response of the full-cross-section configuration, especially in the crest surcharge zone. Deformation analyses further demonstrate the strong influence of input intensity on foundation performance. Based on these findings, a full-cross-section model with reduced dam height and a recommended peak ground acceleration are adopted for the subsequent LEAP-Asia-2025 collaborative test programme.

1 INTRODUCTION OF LEAP-ASIA-2025

LEAP (Liquefaction Experiments and Analysis Projects) is an international collaborative research programme with the primary objective of developing a standardized protocol for the verification, calibration, and validation of numerical simulations used in the analysis of liquefaction problems (Manzari et al., 2014; Kutter et al., 2018; Manzari et al., 2018; Zeghal et al., 2018). In the early discussions of the LEAP initiative, three benchmark problem categories were identified: (1) level ground and sloping ground, (2) retaining structures (e.g., sheet piles or seawalls), and (3) embankments or earth dams. The first two categories have been investigated in previous LEAP projects (Kutter et al., 2019; Tobita et al., 2024; Zhou et al., 2018). Based on discussions at the 8th International Conference on Earthquake Geotechnical Engineering, the LEAP-Asia-2025 project will focus on the dynamic response of liquefiable grounds under earth dam (or embankment) subjected to shaking, with emphasis on the effects of overburden stress and initial static shear stress on soil liquefaction.

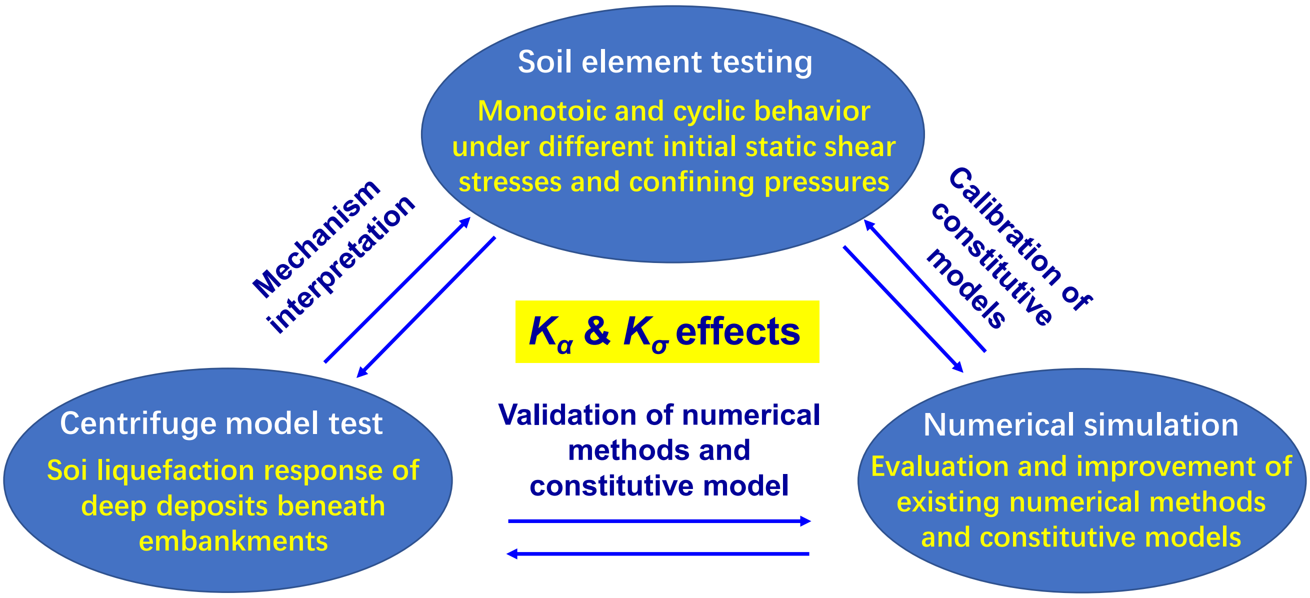

Figure 1. Framework of LEAP-Asia-2025 programme

1.1 Significance of investigating liquefaction of dam foundations

Due to the overburden of the dam, relatively large initial static shear stresses develop in the foundation soil beneath the dam toe. The initial shear stress is considered a primary factor contributing to lateral deformation of the foundation during earthquakes (Maharjan & Takahashi, 2014). Excessive lateral displacement induced by seismic loading may lead to significant structural damage and pose a serious threat to the stability and safety of the dam. However, the capability of existing liquefaction constitutive models to accurately simulate the cyclic response of soils under initial static shear stress remains insufficient and requires further improvement (Tobita, 2024; Kutter, 2019). Therefore, it is necessary to systematically evaluate and compare the predictive performance of different liquefaction constitutive models for soils subjected to complex stress states in the field-scale.

1.2 Research methodology

To address the above issues, the present study integrates soil element testing, centrifuge model testing, and numerical simulations within the LEAP-Asia-2025 framework (Figure 1), with the inspiration from previous LEAP projects (e.g., Tobita et al., 2022; Vargas et al., 2021; Korre et al., 2021; ElGhoraiby et al., 2020; Ziotopoulou, 2018; Hung et al., 2018). Soil element tests are first conducted to investigate the liquefaction behaviour of soils under various combinations of initial static shear stress and confining pressure, and to calibrate constitutive models at the element scale. Subsequently, centrifuge shaking table tests of embankments or dams founded on liquefiable ground are performed to examine the seismic response at the model scale. Finally, types of Class-A, -B, and -C numerical predictions will be carried out to evaluate and validate the performance of different constitutive models in simulating the observed boundary value problem responses. The following section introduces the framework of LEAP-Asia-2025 programme and two sets of preliminary centrifuge model tests conducted at Zhejiang University Framework of LEAP-Asia-2025 programme.

2 SOIL ELEMENT TEST PROGRAMME

A series of soil element tests was preliminarily designed to supplement the existing LEAP element test database, thereby enabling more accurate calibration of model parameters by the numerical modelling teams. The element testing programme mainly consists of two categories: cyclic tests and monotonic tests. The cyclic tests include undrained cyclic triaxial tests with isotropic consolidation (UCTX-ic), undrained cyclic triaxial tests with anisotropic consolidation (UCTX-ac), undrained cyclic triaxial tests with initial static shear stress (UCTX-is), and drained cyclic triaxial tests for the determination of dynamic properties (CTX). The monotonic triaxial shear tests include both drained (CD) and undrained (CU) conditions. The main testing conditions are summarized in Table 1. The detailed experimental procedures will be presented at a future LEAP-related workshops.

Soil element test of LEAP-Asia-2025 have attracted 13 esteemed institutions to join in up to now. The tentative element testing programme is given in

Table 2. The main types of testing equipment include monotonic or cyclic triaxial apparatus and hollow cylindrical torsional shear devices.

Table 1. Soil element test conditions.

Test type	Confining pressure/ (kPa)	Relative density/ (%)	Initial shear stress ratio
UCTX-ic	50,100,200	30,50,70	/
UCTX-ac	50,100,200	30,50,70	/
UCTX-is	100	50,70	0.05,0.1, 0.15
CTX	50,100,200, 400	50,70	/
CU & CD	50,100,200, 400	50,70	/

Table 2. Institutions participating in LEAP-Asia-2025.

Team	University or Institute (Country)
Soil element testing team	George Washington University (US) University of British Columbia (CA) Kyoto University (JP) Waseda University (JP) Utsunomiya University (JP) Nihon University (JP) OYO Corporation (JP) Central Giken Co., Ltd. (JP) University of Canterbury (NZ) Tsinghua University (CN) Dalian University of Technology (CN) Nanjing Tech University (CN) Zhejiang University (CN)
Centrifuge model test team	University of Cambridge (UK) Rensselaer Polytechnic Institute (US) Kyoto University (JP) Ehime University (JP) Penta-Ocean Construction (JP) Public Works Research Institute (JP) Institute of Engineering Mechanics, China Earthquake Administration (CN) China Institute of Water Resources and Hydropower Research (CN) Zhejiang University (CN)
Numerical simulation team	University of British Columbia (CA) The George Washington University (US) Tsinghua University (CN) Dalian University of Technology (CN) Kyoto University (JP) Xiamen University (CN) Zhejiang University (CN)

3 PRELIMINARY CENTRIFUGE MODEL TESTS

Table 2 lists the institutions that have confirmed their participation in soil element testing, centrifuge model test and numerical simulation programmes of LEAP-Asia-2025. As the coordinating institution of LEAP-Asia-2025, Zhejiang University conducted preliminary centrifuge tests in the initial stage to verify the feasibility and robustness of the proposed experimental scheme.

3.1 Experiment specifications

As shown in Figure 2(a), a full-cross-section dam model (Model A) was adopted. The foundation soil was composed of Ottawa sand with a relative density of 70% and a dry density of 1.650 g/cm³. The detailed properties of Ottawa sand have been summarized by Kutter et al. (2019). The dam body material was prepared by sieving Fujian standard sand and reconstituting it to match the gradation of Leighton Buzzard Sand A, with a dry density of 1.717 g/cm³. The uniform and relatively coarse grain size distribution can effectively mitigate capillary effects, thereby helping the embankment remain dry. Arrays of accelerometers and pore water pressure transducers were installed in the zone beneath the crest, where relatively large surcharge-induced stresses developed, and in the zone near the dam toe, where the additional stresses were superimposed on the initial static shear stress, respectively.

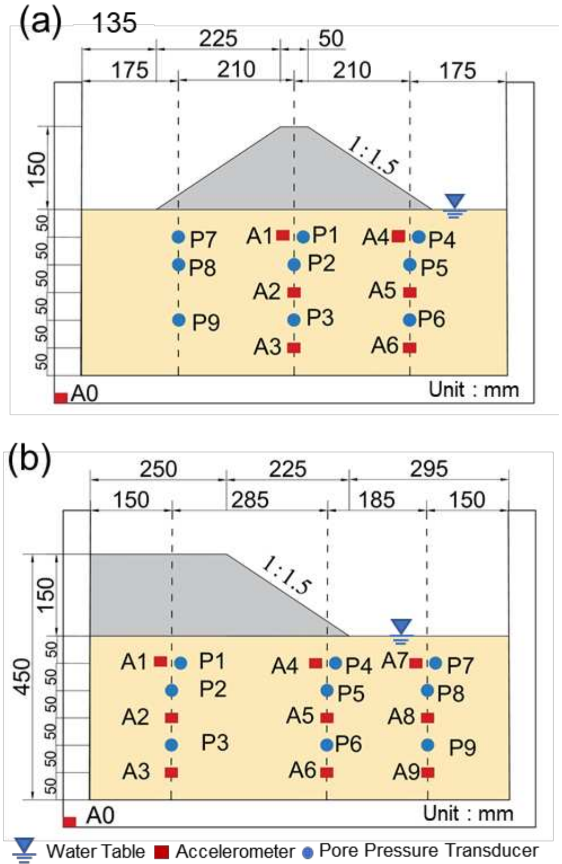

Figure 2. Model geometries and instrumentations: (a) full-cross-section dam model; (b) half-cross-section dam model.

Significant lateral deformation is commonly observed during liquefaction of foundation soils. To provide sufficient free-field width and to minimize boundary constraints imposed by the model container walls on lateral spreading, a half-cross-section dam model (Model B), as shown in Figure 2(b), was designed for comparison. Model B differs from Model A only in geometry, and an additional array of sensors was installed in the free-field region.

All tests were performed under a centrifugal acceleration of 50 g. To select an appropriate intensity of base motion centrifuge model tests, two preliminary experiments conducted at Zhejiang University applied three incremental vibration cycles. The waveform used was a non-uniform amplitude sinusoidal wave, which was commonly used in the LEAP projects (Figure 3). The peak accelerations for the three vibration cycles were 0.15 g, 0.25 g, and 0.35 g, respectively.

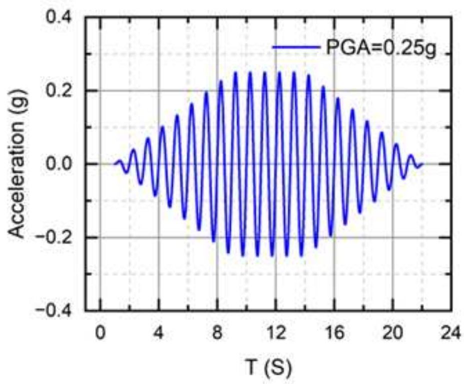

Figure 3. Base input motion with PGA=0.25g.

3.2 Centrifuge model test results

Typical test results are presented herein to illustrate the development of the centrifuge experiment programme.

3.2.1 Responses of excess pore pressure

Figures 4 and 5 compare the excess pore water pressure responses obtained from the two model tests under a shaking input with PGA = 0.15 g. Figure 4 presents the records of transducers P1–P3 located in the zone beneath the crest, where relatively large surcharge-induced stresses developed. The results indicate pronounced differences in pore pressure responses between the two tests in this region. Specifically, the response at P1 in Model A exhibits an evolution pattern of "increase–decrease–increase," which is not observed in Model B. The oscillation amplitude of pore pressure at P2 differs markedly between the two models. Moreover, both the peak and residual excess pore water pressures at all three locations show substantial discrepancies.

Figure 5 shows the records of P4–P6 located near the dam toe, where additional stresses were superimposed on the initial static shear stress. In contrast to the crest region, the excess pore water pressure responses at these locations are in good agreement between the two models, exhibiting similar oscillation patterns as well as comparable peak and residual values, with only minor differences in the dissipation rate.

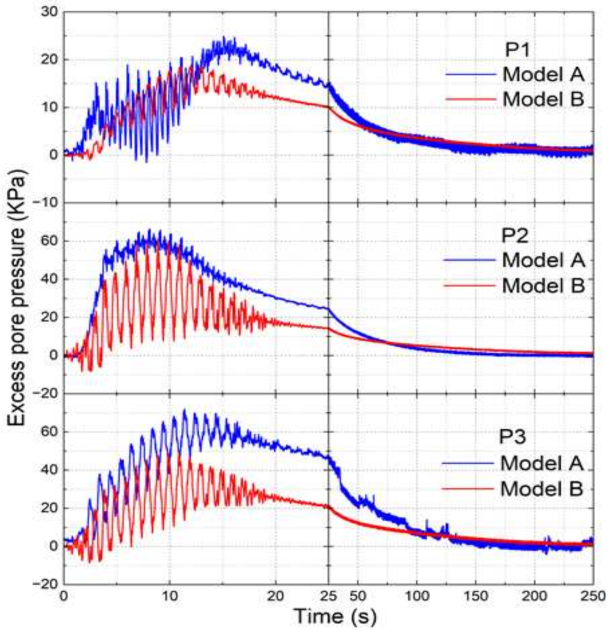

Figure 4. Excess pore water pressure responses at P1–P3

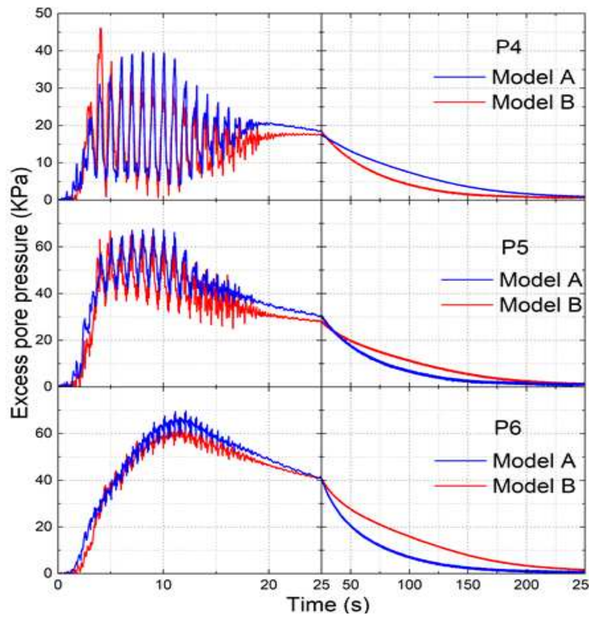

Figure 5. Excess pore water pressure responses at P4–P6

The observed discrepancies could be attributed to differences in boundary conditions. Compared with the full-cross-section model, the half-cross-section model has a large area of contact with the container wall on the left side, resulting in significantly different boundary constraints. Consequently, the pore pressure responses in the crest surcharge zone(P1-P3), which is closer to this boundary, differ substantially between the two models. In contrast, the toe region(P4-P6) subjected to combined surcharge and initial shear stress is less affected by boundary constraints, leading to similar responses in both models.

These results indicate that, for centrifuge shaking table tests, the half-cross-section embankment model cannot fully represent the full-cross-section model. Significant discrepancies are observed in the surcharge zone beneath the crest, whereas the responses in the shear zone near the dam toe are nearly equivalent. Therefore, the full-cross-section dam model was adopted in the subsequent LEAP-Asia-2025 test programme.

3.2.2 Residual deformation after shaking

Figure 6 presents the PIV-derived residual deformation fields of Model A after the three shaking events (in model scale). Under seismic loading, the deformation pattern of the foundation soil is characterized primarily by downward settlement in the surcharge zone beneath the crest, and pronounced lateral displacement in the shear zone near the dam toe. In the latter region, settlement is observed on the side closer to the embankment crest, whereas uplift occurs toward the free-field side.

The objective of the LEAP project is to validate the accuracy of numerical simulations using centrifuge model tests. Excessive damage to the embankment or overly large permanent deformations of the foundation soil in the physical model would be detrimental to the calibration and validation of numerical models. Therefore, the magnitude of foundation deformation needs to be carefully considered in the design of centrifuge test programmes. As shown in Figure 5, large-scale deformations (approximately 12–16 mm in model scale) occurred under the PGA = 0.35 g input motion, whereas the residual deformations under PGA = 0.25 g were relatively moderate. Based on these considerations, PGA = 0.25 g is recommended as the input motion intensity for the subsequent LEAP-Asia-2025 centrifuge test programme.

4 THE PROPOSED CENTRIFUGE MODEL TEST PROGRAMME

Following multiple online meetings and detailed discussions among participating institutions, the results of the two preliminary centrifuge tests were thoroughly reviewed, and the final experimental configuration was established, as shown in Figure 7. The key decisions are summarized as follows: (1) The full-cross-section embankment model was adopted; (2)

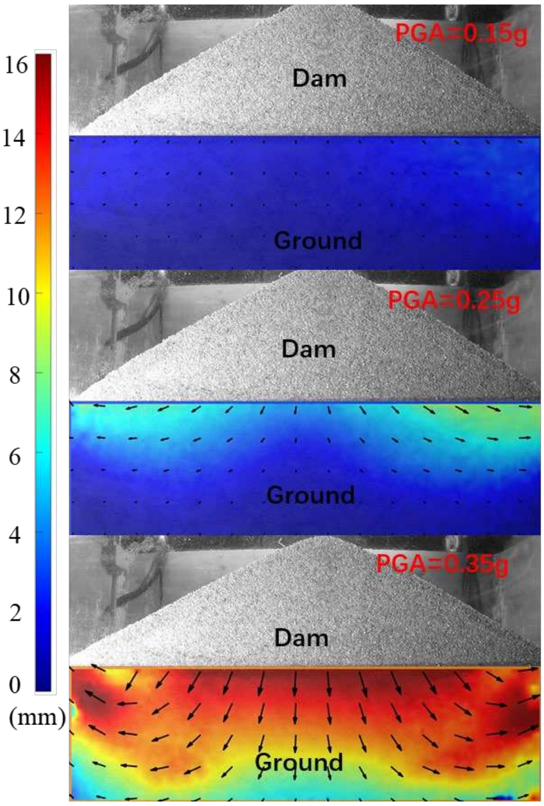

Figure 6. PIV results of residual deformation for Model A (model scale)

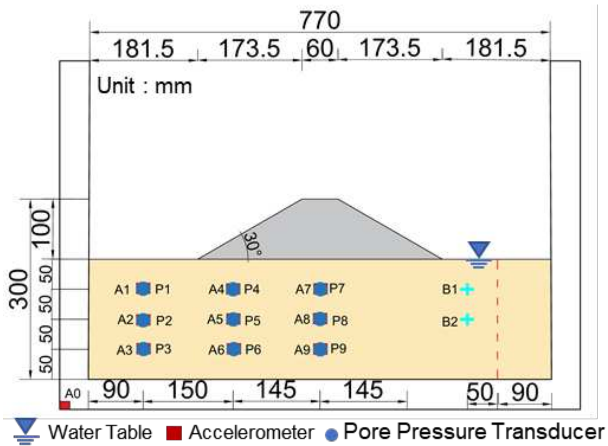

Figure 7. The proposed layout for centrifuge model test.

The dam height was reduced to increase the width of the free-field zones on both sides of the model, thereby mitigating boundary effects; (3) A more moderate input motion with a peak ground acceleration of 0.20 g was recommended for the formal centrifuge tests.

5 CONCLUSIONS

This paper introduces the organizational framework and overall research plan of the LEAP-Asia-2025 project, which aims to investigate the dynamic response of liquefiable ground beneath earth dams through coordinated soil element testing, centrifuge modelling, and numerical simulations. The roles of participating institutions and the integration of experimental and computational efforts are outlined to clarify the collaborative structure of the programme.

Furthermore, two sets of preliminary centrifuge model tests were conducted to evaluate the feasibility and robustness of the proposed experimental configuration. A comparative study between full-cross-section and half-cross-section embankment models was carried out to assess the boundary effects, while different levels of seismic input intensity were applied to examine their influence on ground deformation. The results indicate that the half-cross-section model introduces noticeable boundary constraints, particularly in the crest surcharge zone, whereas the responses in the compression–shear zone near the dam toe are relatively consistent between the two configurations. Based on the experimental observations, including excess pore water pressure development and PIV-derived residual deformation, the final centrifuge testing scheme for LEAP-Asia-2025 was established. The adopted configuration consists of a full-cross-section embankment model and a controlled seismic input motion intensity, ensuring both reliable boundary conditions and deformation levels suitable for subsequent numerical model validation.

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