Proceedings of the 11th ICPMG 2026
11th International Conference on Physical Modelling in Geotechnics
8-12 June 2026, Zurich, Switzerland

Physical Modelling of Basal-Reinforced Piled Embankments: Five Key factors and Project Insights

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ABSTRACT: Physical model tests of basal reinforced piled embankments (BRPEs) face challenges in representing prototype behaviour and producing useful results. This study identifies five key factors for successful BRPE modelling: boundary effects, soil stress levels, subsoil behaviour, basal reinforcement modelling, and measurement strategies. Within the PEBSTER project, small- and large-scale tests with basal steel mesh reinforcement (SR) investigated soil arching and fill deformation. Measurements included total pile loads, stresses above and below the SR, and three-dimensional strains of both SR and soil. Comparison with the Concentric Arches model shows good agreement for soil arching and SR deformation, confirming its suitability for design applications.

1 INTRODUCTION

Many research projects on basal reinforced piled embankments (BRPEs) used physical modelling, providing valuable insights. This paper discusses five key factors that are important for physical modelling of BRPEs and describes their implementation in the small- and large-scale tests of the PEBSTER project (Piled Embankments with Basal Steel Reinforcement).

2 BOUNDARY EFFECTS

Physical BRPE models typically represent the embankment centre, with model boundaries treated as symmetry axes. However, soil-wall friction and limited model dimensions introduce additional support that may interfere with soil arching.

In the small-scale PEBSTER model, a lubricated rubber liner reduced wall friction, yet approximately 35 % of the applied vertical load was lost to the boundaries. In the large-scale model, Figure 1 shows that the central piles attracted the highest load, while edge and corner piles were affected by friction along one or two adjacent walls. Consequently, only the central piles can be considered approximately undisturbed, highlighting the importance of a sufficiently large pile layout to limit boundary effects.

The small-scale tests used piles with a diameter of 0.10 m and a centre-to-centre spacing of 0.55 m, resulting in an area replacement ratio of 2.6 %. In the large-scale test, the piles had a diameter of 0.2445 m and a spacing of 1.25 m, corresponding to a pile area ratio of 3.0 %.

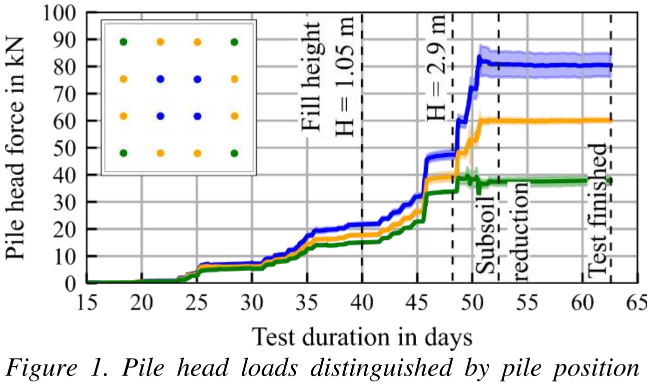

Figure 1. Pile head loads distinguished by pile position within the large-scale test setup.

3 SOIL STRESS LEVEL

Realistic soil stresses are essential in BRPE modelling, as soil arching efficiency is stress dependent. In the PEBSTER small-scale tests, surcharge loads were gradually applied up to 100 kPa. In the large-scale test, the embankment height of 2.9 m led to approximately 47 kPa at the reinforcement level. Both approaches are considered to ensure realistic stresses in the BRPE models.

4 MODELLING SUBSOIL BEHAVIOUR

Adequate modelling of the soft subsoil stiffness below the BR is essential, as the reduction and loss of support over time affects reinforcement behaviour. In the small-scale tests, a saturated foam cushion simulated subsoil compression. Drainage was controlled and measured using a pressure transducer and weighing system. In the large-scale test, a two-step method was used: first, compressible crumb rubber modelled low subsoil stiffness, then incremental lowering of a stiff plate, while measuring the total load on the plate modelled the subsoil consolidation. Although this method realistically simulated the subsoil reaction, it did not allow precise measurement of vertical compressions and stresses in the subsoil.

5 BASAL REINFORCEMENT

The BR benefits from edge fixation to limit horizontal displacement, while allowing vertical settlement. Geosynthetic reinforcement (GR) typically need a stiff frame, whereas steel reinforcement (SR) has higher axial and bending stiffness, reducing this need. In the model tests, SR was installed without a frame. Larger vertical deformations occurred at edges and corners, showing cantilever-like behaviour, but SR behaviour between piles agreed well with analytical calculations. In the large-scale model, plastic vertical deflections at the edges were approximately three times larger than those observed between the piles.

6 SENSOR PLACEMENT

Soil arching (A) in BRPEs is best measured directly above the piles and above the reinforcement, enabling the validation of soil arching models. In addition, it is useful to measure the total load on the piles, below the reinforcement. Together, these measurements allow to determine the load transferred via the reinforcement to the piles. Figure 2 compares the measured and calculated soil arching A for the large-scale test in relation to the embankment height, that increased up to the final height of 2.9 m. The analytical Concentric Arches (CA) model calculation closely matches the measured soil arching.

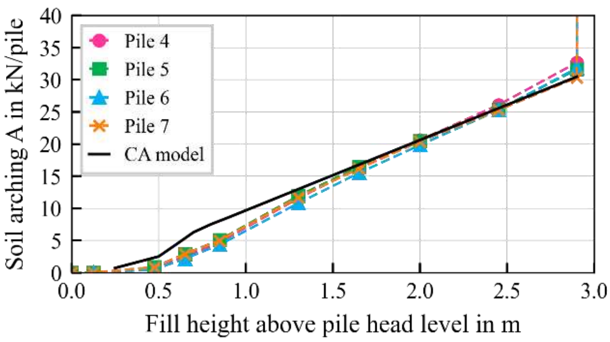

Figure 2. Soil arching A measured above the centre piles in the large-scale test, compared with CA model calculations.

In the model tests, three-dimensional deformations of the SR were measured using distributed fibre optic strain sensors installed directly on the reinforcement.

The SR showed a smooth, rounded deformation profile above the piles, unlike the sharper bending commonly observed for GR. The sand layer placed between pile heads and the SR, prevents sharp bending and potential damage to the SR. Comparison with CA model predictions in Figure 3 shows good agreement for the deformation between the piles, confirming that both the deformation mechanism and magnitude were realistically captured in the large-scale test.

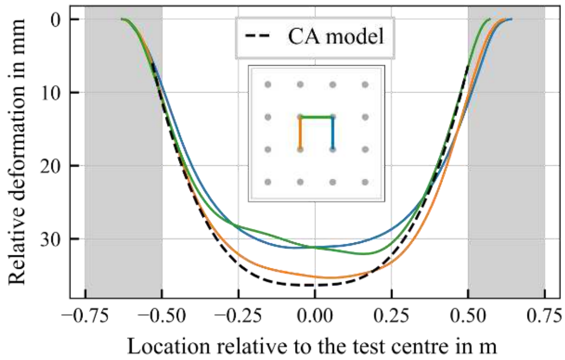

Figure 3. Vertical SR deformations measured between the centre piles of the large-scale model at full embankment height (2.90 m) and after lowering the stiff plate by 25 mm, compared with CA model calculations.

ACKNOWLEDGEMENTS

The authors are grateful for the funding from the European Union’s Horizon 2020 research and innovation program under Grant Agreement No. 101006512 for the GEOLAB project PEBSTER, the TKI-PPS funding of the Dutch Ministry of Economic Affairs and financial support from Keller.

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