Force chain visualisation in the geotechnical centrifuge by means of photoelasticity

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ABSTRACT: The photo-elastic technique provides a tool to visualise the force chain network and its changes by means of variations in brightness in a birefringent material. Despite previous works with a focus on the geomechanics of granular materials, there are no applications in the geotechnical centrifuge, missing the opportunity of taking advantage of the augmented inter-granular stresses that result from the increased acceleration field. The objective of this work is twofold: to examine the potential advantages and limitations of the proposed modelling approach, providing guidance on the conditions under which its application is justified; and to demonstrate that the photoelastic technique can be effectively implemented in a centrifuge model. First, we evaluate the alternatives to implement the photoelastic technique in the centrifuge. Then, we study the evolution of the force chain network at different acceleration levels and explore the pull-out of a caisson at different velocities. The recorded evolution of the force chain network provides new insights into the tip-to-shaft transition in the caisson bearing capacity. The models explored in this work provide an example of how the use of the photoelastic technique enables a deeper understanding of the complex interactions between soil and geotechnical structures in centrifuge modelling.

1 INTRODUCTION

Photoelastic experiments offer valuable insight into grain-scale mechanisms, helping to explain the macroscopic behaviour of granular materials and their interaction with geotechnical structures (Dijkstra and Broere, 2010, Leśniewska et al., 2020)

In this study, a series of photoelastic tests is carried out in a geotechnical centrifuge. The applicability of photoelasticity in centrifuge modelling is first examined through tests on a uniformly loaded sample of transparent granules, used to assess how increasing acceleration influences the development of the force-chain network.

Additionally, the method's ability to capture soil–structure interaction is evaluated through a caisson pullout test performed at different pullout velocities.

2 MATERIALS AND METHODS

The Polydimethylsiloxane (PDMS) granules with average diameter of 2.5 mm are used as a birefringent material in photoelastic tests and mixed with a liquid (mixture of water and glicerine) with comparable refractive indexes. Because the density of PDMS grains is low (0.97 – 1.05 g/cm3), additional surcharge must be applied on top of the sample, in a form of a layer of 3.0 mm steel beads enclosed in a flexible plastic net, to initiate the development of the force chain network. Its total weight is either 450g (for pullout velocity of 0.2 mm/s) or 520 g (for other velocities).

The sample is placed in the model container and has the dimensions: 14.8 x 28.6 x 2.0 cm. The photoelastic setup consists of a monochromatic light source, a photoelastic sample placed between two sets of plane polarization filters with quarter-wave plates, and a recording camera, as shown in Figure 1. Schematic of the centrifuge photoelastic setup.

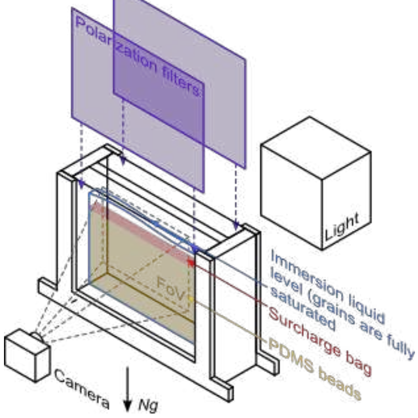

Figure 1. Schematic of the centrifuge photoelastic setup.

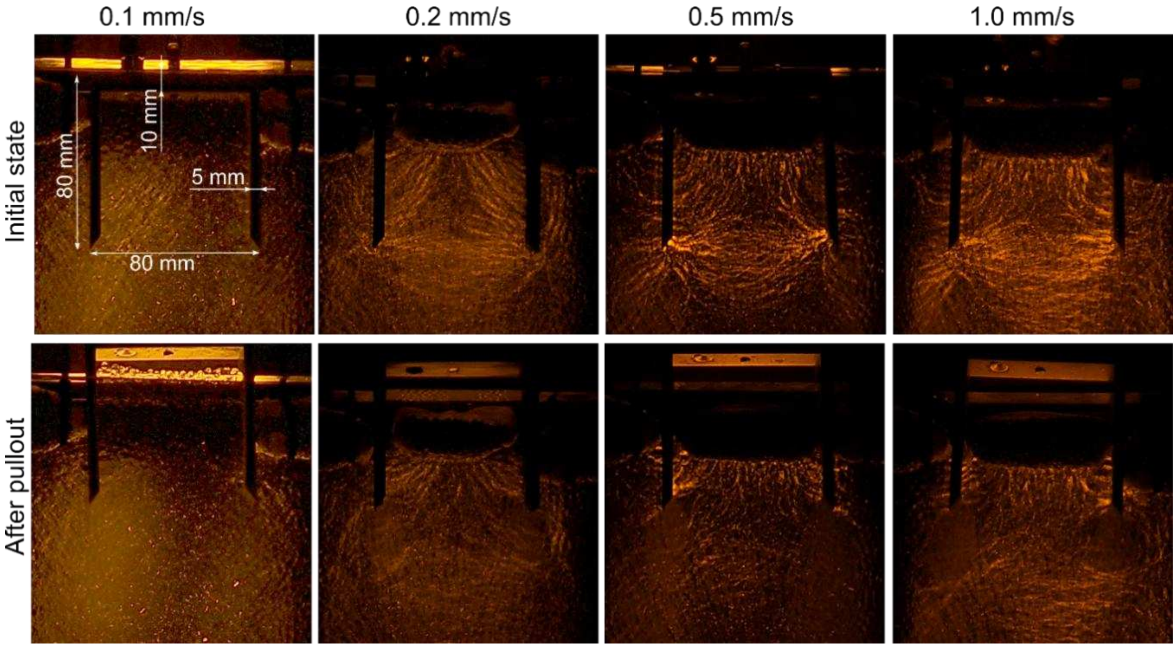

Figure 2. Results of photoelastic tests: caisson pullout considering different velocities.

The experiments are performed in the 1.2 m radius and 9 g-ton geotechnical centrifuge at TU Delft. The suction caisson is 3D printed with PETG (Polyethylene Terephthalate Glycol-modified), see Figure 2Figure 2. Results of photoelastic tests: caisson pullout considering different velocities.The caisson is pulled-out of the model through a rope, connected to the actuator.

3 RESULTS AND DISCUSSION

The photoelastic images obtained before and after caisson's pullout, considering different pullout velocities are presented in Figure 2. Results of photoelastic tests: caisson pullout considering different velocities.

The structure of the initial force-chain network depends on the applied surcharge. As a result, it differs between the test conducted at a pull-out velocity of 0.2 mm/s, where the surcharge is lower, and those at 0.5 and 1.0 mm/s, where the surcharge is nearly doubled. Consequently, it is important to select the surcharge level appropriately so that force-chain development is initiated.

As shown in the images, the force-chain network that develops around the caisson is strongly influenced by the pullout process. The primary concentrations of force chains initially form near the caisson tips. With increasing displacement, they gradually weaken and eventually vanish, giving rise to circular zones of loosely packed grains. Simultaneously, horizontal force chains originating from the grains adjacent to the caisson shaft become brighter and more pronounced. This evolution illustrates a clear tip-to-shaft transition in the mobilised bearing capacity of the structure.

4 CONCLUSIONS

The results of this research demonstrate that photoelastic methods can be successfully applied in geotechnical centrifuge modelling. The caisson pull-out example provides new insights into the stress distribution near the suction caisson and its evolution with increasing pull-out displacement.

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