TRANSPARENT SIMULANT SOIL FOR LASER IMAGING APPLICATIONS

INTRODUCTION

Various moving boundary problems in geotechnical engineering, such as the interpretation of *in situ* tests, the estimation of soil resistance during pile driving, or the assessment of the extent of the smear zone around wick drains/samplers require some model of the three-dimensional failure surface developed in the soil. This is not possible with conventional non-intrusive imaging methods due to the opaque nature of natural soils.

Numerical simulations or, more commonly, analytical methods are used to identify the extent of the zone where high soil strains are mobilised during penetration of a rigid object. The use of transparent "soil simulant" materials, exhibiting similar mechanical behaviour to real soils, allows direct visual observation of soil flow and failure around rigid moving/rotating objects in three dimensions. When combined with imaging technologies, they allow the accurate measurement of progressive soil deformations during scaled modelling of moving boundary problems, with minimal influence from soil disturbance or boundary effects.

TRANSPARENT SIMULANT SOIL MIXTURE

To match the geotechnical properties and behaviour of the simulant soil with natural clay, this research utilises LNM Silica (commercially known as LAPONITE RD®) which is an artificial smectite clay that closely resembles the natural hectorite clay mineral (Ruzicka and Zaccarelli 2011). LNM Silica hydrates in solution to form a thixotropic transparent gel, which exhibits (at maximum recommended concentration) an undrained shear strength S_u~0.4kPa, water content w~1200% and similar geotechnical behaviour to soft, normally consolidated marine clays (Wallace and Rutherford 2015).

Higher strengths can be achieved by adding the temporary anticoagulation agent TSPP to the pore fluid during mixing (Beemer *et al*. 2016), which gives up to a six-fold increase in undrained shear strength to S_u~2.4kPa and a three-fold reduction in the moisture content to w~400%. Estuarine Australian clays, such as the Ballina clay extensively tested in the CGSE, exhibit a higher undrained shear strength of S_u~20kPa and reduced moisture content w~110% (Pineda *et al*. 2016). Interestingly though, the failure characteristics of natural, structured Ballina clay (which is of interest here) are very similar to those of LNM Silica mixtures. This is depicted in Fig. 1, which presents the results of vane shear tests on various materials, obtained with a torque-spring vane shear apparatus in the laboratory.

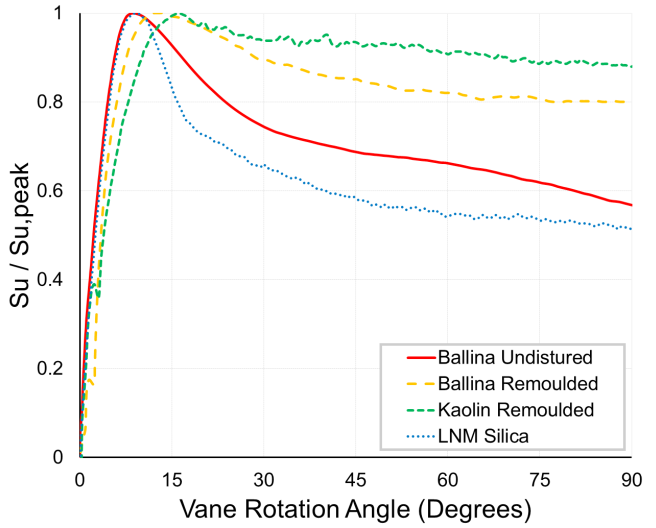

Figure 1: Comparison of normalised pre- and post-failure response for real and artificial soil materials.

This project trialled various methods to mechanically and/or chemically increase the strength and reduce the water content of transparent mixtures so that they match the properties measured in Australian natural clays. The influence of alternate pore fluid compositions on the undrained shear strength was also investigated, via addition of ionic salts and biopolymers at various concentrations. For example, addition of potassium chloride to increase the electrical conductivity of the pore fluid to 35 mS/cm resulted in a maximum vane shear strength of S_u~5kPa, without significantly compromising the transparency or similarity of pre- and post-failure behaviour to Ballina clay.

Innovative consolidation methods are also being investigated to mechanically increase the strength and stiffness of LNM Silica mixtures. To accelerate consolidation, in-flight equipment is being trialled at the University of Western Australia centrifuge facilities, while porous cells of large height-to-diameter ratio have been designed and manufactured at the University of Newcastle. These methods aim to overcome challenges related to the high compressibility (C_c>17) and low hydraulic conductivity (K_{sat} < 10^{-8} m/s) that characterise non-preloaded LNM Silica mixtures (Wallace and Rutherford 2015).

LASER-AIDED PARTICLE IMAGE VELOCIMETRY

The deformation of transparent simulant soil during laboratory tests can be measured with Particle Image Velocimetry (PIV) techniques. This requires the addition of highly reflective microspherical particles to the transparent material, albeit at low concentrations so as not to alter its mechanical properties. By illuminating a discrete plane of the material using a sheet of laser light, the in-plane particle movements can be captured at high-resolution using macrophotography techniques. Post-processing of the images with the GeoPIV-RG software developed by CGSE staff (Stanier *et al*. 2015), allows determination of the deformation field that develops during penetration or rotation of a rigid object in the transparent material. This concept is illustrated in Fig. 2.

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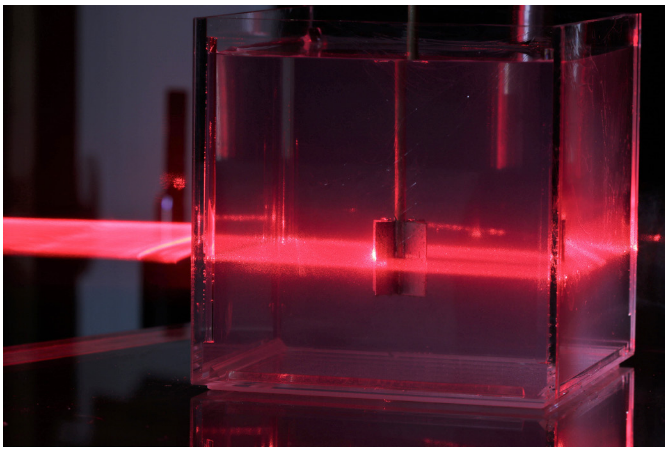

Figure 2: Use of laser-aided imaging to capture transparent soil deformations during vane shear tests.

Comparing the displacement fields obtained using laser-aided PIV with those from simulations of undrained vane rotation with the finite element method provides insight to the mode of failure during vane shear tests (Fig. 3). Excellent agreement between the numerical and experimental results is demonstrated in Fig. 4, which compares the normalised radial displacements along a hypothetical section that traverses the failure surface. Minor discrepancies beyond the edge of the blades are attributed to the influence of shear softening and progressive failure effects, which are not accounted for in the numerical simulations.

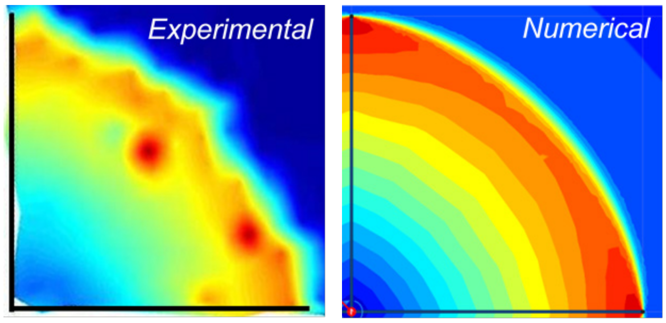

Figure 3: Qualitative comparison of post-peak displacement fields obtained via laser imaging and numerical simulations.

CONCLUDING REMARKS

Results from the experiments presented has led to a more refined method to infer the undrained shear strength of natural soft clays from field vane tests. The current method used in Australian Standards will be improved by accounting for the exact geometry of the strain field that is mobilised during vane rotation, as well as the disturbance effects that arise during insertion of the vane.

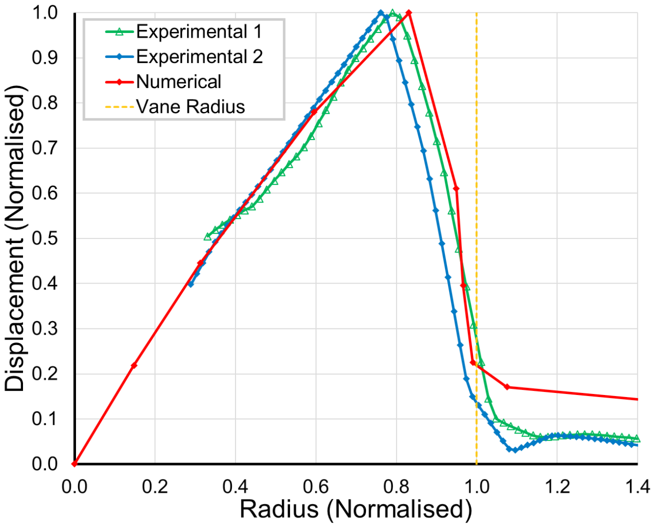

Figure 4: Comparison of normalised radial displacements obtained via laser-aided PIV and numerical simulations.

This experimental framework can be applied to the investigation of a broad range of other geotechnical engineering problems involving three-dimensional soil flow, failure and disturbance around rigid moving objects such as CPT and fall cones, dilatometer blades, piles, mandrels, and samplers. The development of a synthetic soil mixture with mechanical properties and failure characteristics similar to those of natural clays offers the opportunity to peer inside Australian soils, and literally visualise how we can improve testing and construction methods. The recently established laser-imaging laboratory at the University of Newcastle will facilitate future research on this topic.

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