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Physical Modelling in Geotechnics

Volume 2

Editors

Andrew McNamara
Sam Divall
Richard Goodey
Neil Taylor
Sarah Stallebrass
Jignasha Panchal

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Andrew McNamara, Sam Divall, Richard Goodey, Neil Taylor,
Sarah Stallebrass & Jignasha Panchal

City, University of London, UK

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Preface

The International Conference on Physical Modelling in Geotechnics is held under the auspices of Technical Committee 104 (*TC104: Physical Modelling in Geotechnics*) of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). Early workshops on physical modelling were held in Manchester, California and Tokyo in 1984 and, as the physical modelling community grew, the first international conference was held only 30 years ago in Paris in 1988. The possibilities offered by physical modelling became apparent around the world and the conference has developed into a quadrennial event that regularly attracts researchers from over 30 countries. The last meeting of the global community was in Perth, Western Australia; a veritable feast to sate the appetite of the hungry faithful, under the very capable leadership of Professor Christophe Gaudin. Regional conferences have also become established following the first Eurofuge held at City, University of London in 2008 followed by European regional conferences at TU Delft and IFSTTAR, Nantes and Asian regional conferences at IIT Bombay and Tongji University, Shanghai. These conferences bring together a community of great innovators; the most practical and capable engineers, in an exciting and specialist field.

TC104 selected London as the destination for the 9th International Conference (ICPMG 2018) which was held at City, University of London, in July 2018. The United Kingdom is a hotspot for physical modelling activity; centrifuges are established at Cambridge University, City, University of London, University of Dundee, University of Nottingham and University of Sheffield.

The conference coincided with the 4th Andrew Schofield Lecture, established by TC104 and named after Professor Andrew Schofield, the great pioneer of geotechnical centrifuge modelling. As the highest honour that can be bestowed upon a member of our community it is fitting that the lecture was delivered by Professor Neil Taylor of City, University of London and Secretary General of ISSMGE; a former doctoral student of Professor Schofield.

The conference programme was a physical modelling extravaganza divided into plenary and parallel sessions running over four days, 17th–20th July. Four keynote lectures were given in the areas of seismic behaviour, design optimisation, new facilities and environmental engineering representing significant areas of interest of the assembled audience. Themed lectures in the areas of education, new technology, urban infrastructure and offshore engineering addressed a key aim of TC104 in showcasing research opportunities to industry who attended a specific half day event. A total of 138 oral presentations were made from 230 papers submitted, originating from over 30 countries, and included in the conference proceedings in 22 chapters. All papers that were not presented orally were presented as posters. The conference gave delegates an opportunity to experience exciting and historic aspects of London that are normally inaccessible to those visiting the city. A welcome reception was held at the historic Skinners' Hall, home to one of the Great Twelve City livery companies and delegates enjoyed a sumptuous gala dinner at the spectacular Middle Temple Hall dating from 1573; one of the four Inns of Court exclusively entitled to call their members to the English Bar as barristers. A pleasant afternoon and evening was spent on a visit to Greenwich on the River Thames, home to the Meridian Line, the famous Cutty Sark, the Royal Observatory, the National Maritime Museum and the Old Royal Naval College.

Physical modelling has come of age and advances in all areas of technology, from digital imaging to computing, electronics and materials offer exciting opportunities to push boundaries well beyond the early experimental work. Visionary and adventurous physical modellers developed the basic techniques and important scaling laws that are the backbone of our work today. Such research made possible important contributions to the understanding of complex soil/structure interaction problems long before numerical modelling was capable of even attempting to establish such insight. Present day physical modellers are just as ambitious and adventurous as their forefathers and are anxious to build ever larger facilities and undertake increasingly complex experimental work. To this end, plans are underway for a 1000 g/tonne 'megafuge' capable of modelling the very largest of geotechnical structures. Physical modelling enjoys increasing popularity as a powerful means of exploring geotechnical problems. However, it rarely finds favour over numerical modelling in the eyes of industry where results of experimental studies are required soon after commissioning the work; regardless of accuracy and at minimal cost. Current work that focuses on exploring the interface between physical modelling and numerical modelling is a particularly exciting development and has the potential to yield important new knowledge applicable to both fields.

The organisation of a major international conference is a massive undertaking. My thanks go to the Local Organising Committee and the International Advisory Board and to everyone who participated in the very thorough review process. Particular thank are due to my colleagues, Sam Divall, Richard Goodey, Jignasha

Panchal, Sarah Stallebrass and Neil Taylor at City, University of London who rolled up their sleeves to help with all aspects of the conference; but notably in managing and editing the huge volume of poorly formatted papers. For anyone reading this far, please do not alter the template when writing your conference papers.

Andrew McNamara

Chair, Technical Committee 104 on Physical Modelling in Geotechnics, 2014 – 2018

International Society for Soil Mechanics and Geotechnical Engineering

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A two-dimensional laser-scanner system for geotechnical processes monitoring

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ABSTRACT: Complex geotechnical processes such as debris or tailings flows, rain-induced landslides, foundation instability, and soil-structure interaction require advanced laboratory techniques, including remote-sensing technology. The purpose of this paper is to describe the implementation of a laboratory-scale LIDAR-type system installed on an environmental flume for geotechnical applications under 1-g conditions. A two-dimensional laser scanner device, which is commonly used in mining operations to measure conveyor-belt volumes, was adapted to move axially along the flume. The scanner measures cross-sectional elevation data on any physical model constructed in the flume to produce a digital elevation model. The flume is an instrumented chamber comprising sprinklers to simulate precipitation (controlled intensity and flow rate), a hydraulic system to induce rise in groundwater level, and a jack to vary model inclination, if required. A calibration protocol and post-processing code were developed to efficiently handle the scanner-recorded elevation data. To test and validate the experimental setup, tailings flow experiments were performed. Results show that laboratory-scale laser sensor technology is a useful and robust tool for physical modelling.

1 INTRODUCTION AND BACKGROUND

Laser-assisted, remote-sensing technology is currently a widely used tool for engineering process monitoring at different scales, e.g., landslide or fault mapping and building information modelling, BIM (Abellán, Vilaplana, & Martinez 2006, Hunter et al. 2011, Kim et al. 2016, Xiong et al. 2013). In addition, two-dimensional laser scanner devices are used in the mining industry in several countries to determine the volume of material transported on conveyor belts (SICK, 2015). In research, laser-scanner systems have been employed to evaluate structural engineering processes like beam deflection and metal frame connections (Cabaleiro et al. 2014, Gordon & Lichti 2007). Furthermore, two-dimensional laser scanners have been recently applied in hydraulic and coastal engineering studies to monitor the evolution of free-surface profiles of regular and irregular waves (Blenkinsopp et al. 2012, Harry et al. 2012, Harry et al. 2011, Streicher et al. 2013).

This article describes the laboratory implementation of a two-dimensional laser scanner system for geotechnical process monitoring. The described system delivers laboratory-scale digital elevation models based upon elevation data obtained from physical models constructed in an instrumented environmental flume.

A number of previous studies describe the use of instrumented chamber flumes to physically simulate landslide processes, particularly those that are rain-induced (Barazzetti et al. 2013, Chen et al. 2010, Fang et al. 2012, Jia et al. 2009, Ling & Ling 2012, Moriwaki et al. 2004). Precipitation of artificially-induced rain is normally generated on the soil physical models via sprinklers uniformly distributed across the flume. To monitor geotechnical processes, these studies use various instruments, including inclinometers, vibrating-wire cell pressures, high-resolution/high-velocity cameras, infrared cameras, and dynamic sensors.

For example, Chen et al. (2010) set a chamber between two sprinklers that spray upward, which allow them to study soil failure and debris flow. On the other hand, Fang et al. (2012) simulate natural-slope failures by varying the slope dip; in their case, the failure is in fact reached once the precipitation event is reproduced. Moriwaki et al. (2004) also present a variable-dip, full-scale slope model, that yields debris flow; their sprinkler system is set in the laboratory ceiling to distribute precipitation uniformly.

In addition to describing the laser scanner system, this article presents the main features of the environmental flume where the scanner is mounted.

2 METHODS

2.1 *Laser scanner*

The two-dimensional laser scanner device used was a Bulkscan® LMS511 laser volume flowmeter (SICK

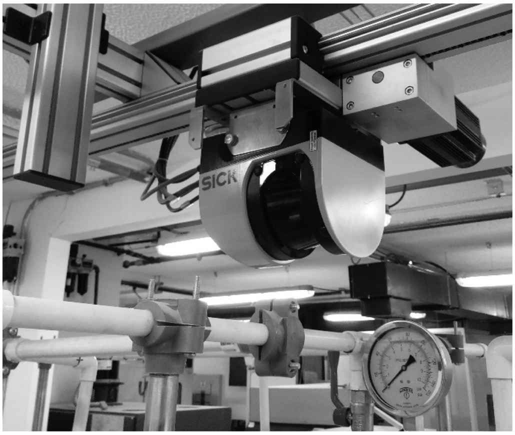

Figure 1. Bulkscan® LMS511 laser scanner.

AG, Waldkirch, Germany; see Fig. 1). This scanner is frequently employed in the mining industry to measure bulk materials on conveyor belts or in piles via the time-of-flight principle and multi-echo technology (SICK, 2015). If required, the laser-scanned data captured by this instrument also allows calculation of level, centre of gravity, and loading position, as well as belt monitoring. The scanner uses infrared, eye-safe laser on a two-dimensional plane with aperture angle of 190°, acquiring elevation data on polar coordinates with 0.5° resolution, equivalent to 12.72-mm resolution at the flume's bottom. The scanner works with an operating range from 0.5 to 20 m, at scanning frequencies varying from 35 to 75 Hz. According to the manufacturer, for conveyor-belt applications, the scanner can effectively measure volumes at up to 30 m/s of conveyor-belt speed.

The laser scanner was installed at the top of the environmental flume located at Pontificia Universidad Javeriana's Geotechnical Laboratory. Instead of the typical conveyor-belt operating method, in the laboratory the target physical model remains stationary in the flume while the scanner moves along the main axis of a flume. For this purpose, the laser scanner was mounted on an aluminium frame (Colsein-Item, Colombia) specifically designed for the moving operation of the scanner (see Fig. 2). The frame withstands acceleration/deceleration and cruise vibrations produced by the scanner during travel. The scanner was controlled via a servo-motor, an electronic interface, and a data acquisition system.

2.2 *Environmental flume*

The environmental flume was constructed with support from the Geophysical Institute and the Department of Civil Engineering of Pontificia Universidad Javeriana. The flume comprises both permanent instruments (including the laser scanner) and project-specific instruments.

The flume features a hydraulic system composed by three sprinklers at the top and a drainage system at base level, and the latter can also act as inlet to yield bottom-up pressure, if required. The hydraulic system is equipped with manometers for pressure control during both rain simulations and bottom-up pore pressure generation. In addition, it includes a hydraulic pump to regulate the flow rate in the system, as well as several valves to control pressures in the sprinklers and at base level.

The flume also includes a jack system on one end, which allows control of the inclination of the models constructed in the flume. This feature is particularly important for slope stability studies under 1-g conditions.

Project-specific instruments that may be coupled to the flume include pore-pressure transducers, pressure cells, and strain sensors for real-time process monitoring.

Figure 2. Environmental flume and laser-scanner mounting frame.

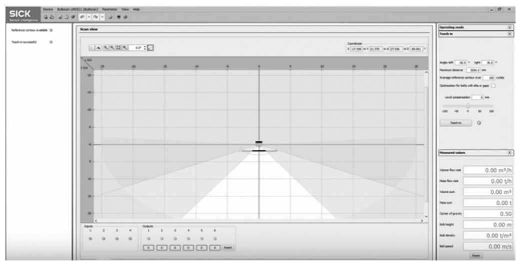

Figure 3. Screenshot of SOPAS Engineering Tool V3 during operation.

2.3 *Scanned data acquisition and post-processing*

The scanner's data acquisition system is the freeware program SOPAS Engineering Tool V3 (SICK AG, Waldkirch, Germany) which is the main computer interface of the system (see Fig. 3).

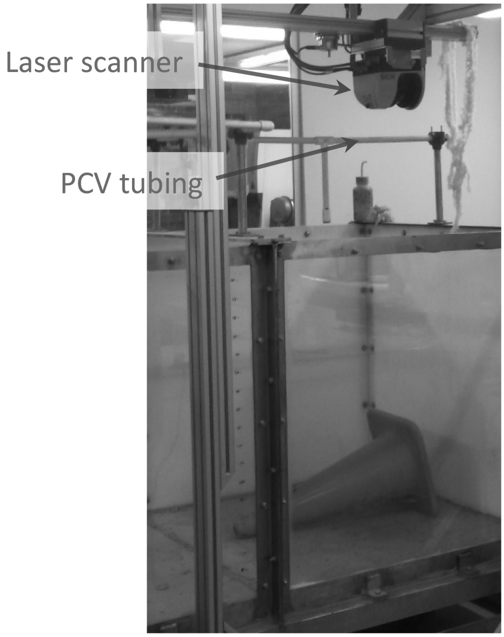

Figure 4a. Traffic cone to be scanned.

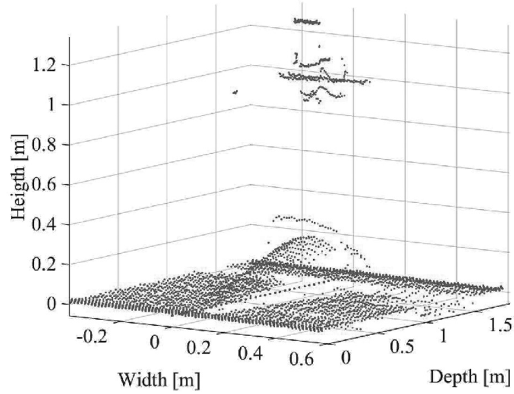

Figure 4b. Traffic-cone elevation data points acquired using the laser scanner system. Data points above 1.0 of height are PVC tubing.

Because the laser scanner records elevation data in polar coordinates, it was decided to translate the data into Cartesian coordinates. Also, because the amount of output data is rather large, post-processing may be tedious. Hence, a MATLAB code was developed for converting the coordinates of every data point while handling the data efficiently.

The code written also required to define the servomotor position vector for determining the along-the-axis Cartesian coordinate. Thus, the code has the capability to determine height, width, and depth (length) of the scanned physical model with a length resolution depending on the chosen time-step, and a resolution of 0.5° at polar coordinates.

During code writing and validation, several laser-scanning tests were performed using simple objects of known geometry (traffic cones, boxes, etc.; see Fig. 4).

2.4 *Sprinklers calibration*

Calibration of the sprinklers was undertaken via a facile procedure using plastic cups set on a grid of 1×1 m, separated every 0.1 m from each other. The plastic cups were placed over a stowage whose height with respect to the flume floor was variable, from 0.1 m to 0.5 m, with steps of 0.1 m (see Fig. 5). The purpose of testing the sprinklers was to measure the influence area of induced precipitation depending on the height of fall of the water, by determining the amount of collected water in each plastic cup.

The artificial-rain calibration test was performed by opening the valve of the central sprinkler for 40 seconds, while trying to keep the pressure system on 80 psi (about 550 kPa). Once the test was finished, the height of the water in each cup was measured with a caliper. The weight on every cup was indirectly determined using a previously-prepared calibration curve for one typical plastic cup. Such curve correlated the height of water with measured water weight as shown in Figure 5. For convenience, the calibration curve was fit to a second-degree polynomial regression.

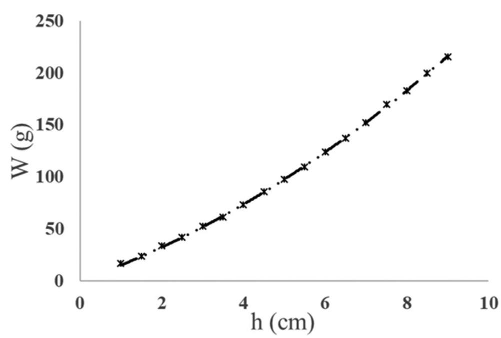

Figure 5. Sprinklers calibration. Top: plastic-cup grid. Bottom: Calibration curve (measured relationship between weight and height of water in the plastic cups).

2.5 *Tailings flow tests*

A series of tailings flow experiments were designed and prepared as part of an ongoing investigation aimed at studying the fundamental flow behaviour of such

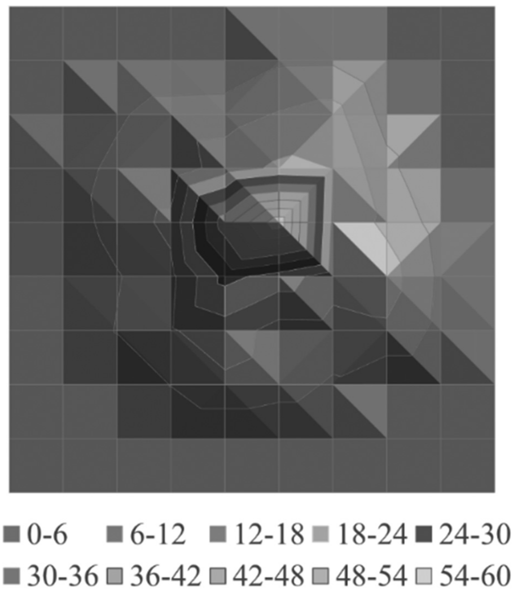

Figure 6. Areal distribution of induced-rain precipitation below the central sprinkler (units: cm^3/s).

non-newtonian fluid. Filtered tailings produced at a recently-opened gold mine in the Antioquia region of Colombia were used to simulate uncontrolled flow in the laboratory.

The tailings were 73.4% silt-, 23.7% sand-, and 2.9% clay-sized particles. The measured average properties of the tailings were $G_s = 2.77$, $LL = 31.7\%$, $LP = 17.9\%$, and the solid concentration of the tailings water-based paste tested was 70%.

An aluminium-and-acrylic box, with dimensions $0.3 \times 0.3 \times 0.5$ m, provided with a 0.1 m-wide 0.3 m-high gate, was constructed and installed inside the flume. This box contained the paste until the gate was opened to yield flow on a flat aluminium surface.

3 RESULTS

3.1 *Sprinklers*

As the stowage elevation changes and the sprinklers tests are performed, the areal distribution of precipitation also changes. One contour plot of induced-rain distribution for water falling from a height of 1 m is shown in Figure 6. It can be seen that the distribution of water in the surface is not as uniform as it might be expected. In fact, the water concentrates in the central part of the grid, as compared with the sprinklers' manufacturer predictions (see Fig. 7).

3.2 *Tailings flow tests*

Figure 8 shows the results from one tailings flow experiment, as well as the digital elevation model reconstructed from laser-scanned data. A total of 187,676 data points were collected to create the digital surface.

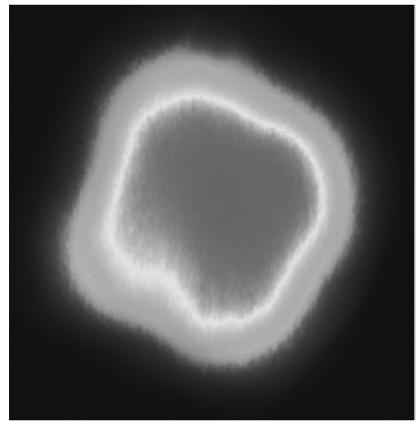

Figure 7. Sprinkler manufacturer's catalogue "shadow". ('Spraying Systems Co. Catalog 75', n.d.).

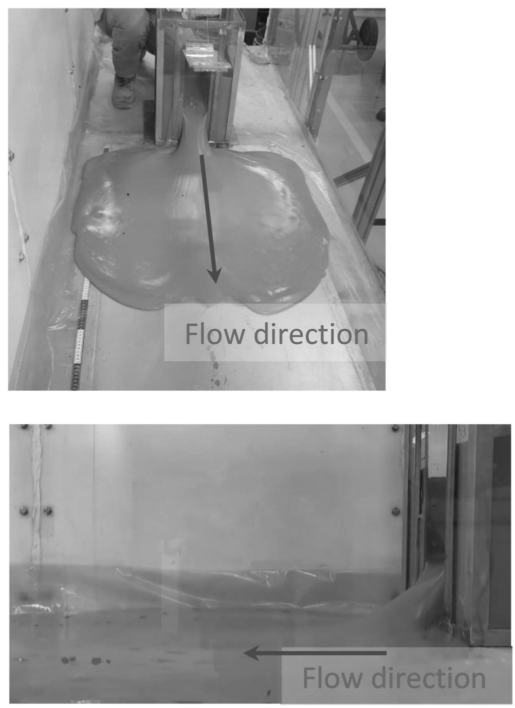

Figure 8a. Tailings flow experiment: photo and video screenshot of the experiment.

These data are currently being used to calibrate and validate computational fluid mechanics simulations of these tailings flows.

4 CONCLUSIONS

Results confirm that laboratory-scale laser sensor technology is a useful and robust tool for physical modelling. Particularly, two-dimensional laser-scanner systems are powerful tools for monitoring geotechnical engineering processes.

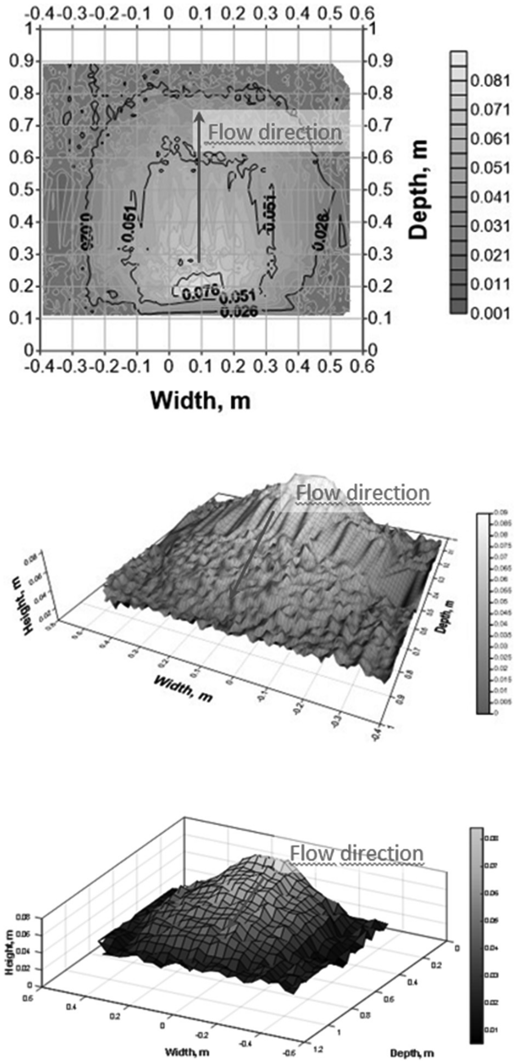

Figure 8a. Tailings flow experiment: laser-scanner-derived digital elevation model (187,676 data points). Top and centre: elevation contours and DEM plot using SURFER®; Bottom: DEM plot using MATLAB®.

By coupling the scanner with an environmental flume and instrumentation, it is possible to simulate geotechnical processes while controlling rain-precipitation parameters and eventually slope dip and pore pressures, all factors affecting geotechnical stability.

The scanner/flume monitoring system will allow future work focusing on experimental modelling of geotechnical processes, as well as validation or calibration of computational models.

ACKNOWLEDGEMENTS

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