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Particle Image Velocimetry Analysis on the Sinking of Shallow Foundation in 2D

P. Pizette[1] and N-E. Abriak[2]
[1,2]IMT Lille Douai, Univ. Lille, EA 4515 - LGCgE - Laboratoire de Génie Civil et géoEnvironnement, départment Génie Civil & Environnemental, F-59000 Lille, France
E-mail: patrick.pizette@imt-lille-douai.fr

ABSTRACT: This paper focuses on the development of punching device dedicated to study the failure of 2D analogue soil. In order to follow the kinematic behaviours of soil, Particle Image Velocimetry (PIV) analysis has been developed and tested in the case of the shallow foundations. The results show that the field of the soil displacement under the foundation can be followed via the PIV method. In particular, the image analysis results are qualitatively in good agreement with the Prandlt scheme.

KEYWORDS: Schneebeli's material, Shallow foundation, PIV.

1. INTRODUCTION

The settlement, the bearing capacity and the soil failure behaviour are main data to design a building structure as for example the foundations. In parallel with the analytical and numerical approaches, the experimental bi-dimensional approaches have been developed since the 1950s to study the typical behaviour of soil in interaction with geotechnical structure.

In particular, scale models with Schneebeli's material have been widely used for example to reproduce the active and passive earth pressures, the soil nailing, the foundation loadings, the tunnel structures, the kinematics of silo discharge, etc.. This Schneebeli's material, name usually given as from the name of the researcher who first used (Schneebeli, 1956), is composed of rods stacked up following to their axis (named also Taylor-Schneebeli model medium). This layout of the rods enables only plane strains thereby reproducing the typical behaviour of soil in 2D. This 2D approach also allows making links between the global behaviour of the granular media and the local parameters at the grain scale (Abriak, 1998) (Misra and Poorsolhjouy, 2013). With the major development of the image analysis technics since 2000s, the behaviour of soils has become accessible in 3D via for example the micro-tomography applied on the laboratory devices (Hall et al., 2012). However, the Schneebeli's approach remains used in particular for the structure (Dolzhenko, 2002) (Jenck et al., 2009) and theory studies (Misra and Poorsolhjouy, 2013) and also thanks to the news development in image analysis methods carried out on the Schneebeli's materials (Sibille and Froiio, 2007), (Richefeu et al., 2012).

Particle Image Velocimetry (PIV) is a photogrammetry method of flow visualization used in the fields of research and education. PIV allows the instantaneous velocity of fluid to be measured by following tracer particles seeded therein. In this paper, PIV analysis tracking has been carried out on the Schneebeli's material in the case of superficial foundation loading. The aims of this study are to show the potential uses of PIV method for the granular media in 2D in the case of shallow foundation and to set up a base for image analysis with the perspective of a further more detailed experimentation program.

2. MATERIAL AND EXPERIMENTAL DEVICE

2.1 Schneebeli's material

First introduced by G. Schneebeli, rods stacked up following to their axis reproduce a bi-dimensional analogue granular medium by complying with the Mohr-Coulomb's criteria (Schneebeli, 1956).

In this study, the rods are cylindrical with 60 mm in length. As shown in Figure 1-a), three various diameters have been used with a fairly distribution of each diameter (3, 4 and 5 mm). The matter of the cylinders is duralumin. The friction local angle (grain-grain friction) is approximately 18° and the intrinsic friction angle is approximately 26°-28° (Abriak, 2006).

2.2 Punching apparatus

A dedicated punching apparatus was developed in order to simulate the loading of a foundation until the punching shear failure.

As shown in Figure 2, four steel extruded bars are used to form the rectangular frame allowing the analogue granular matter to be contained.

A loading system is simply composed of a vertical steel cylindrical shank with 30 mm in diameter guided by a Teflon bushing and of a load plate fixed on the top of the cylindrical shank allowing weights to be set down. At each stage of the loading, the settlement and the applied stress are measured. Note that a more sophisticated loading system is under development with a pneumatic piston. This system would allow the axial displacement of the loading cylindrical shank to be controlled during a punching.

To model the foundation, two strategies were tested. The first consists to simply assemble the wooden battens until the required length (for example shown in the Figure 1-b). Figure 1-c illustrates the second with a spread footing foundation. In this case, the use of strato-conception machine allows several types of foundation shapes to be obtained easily.

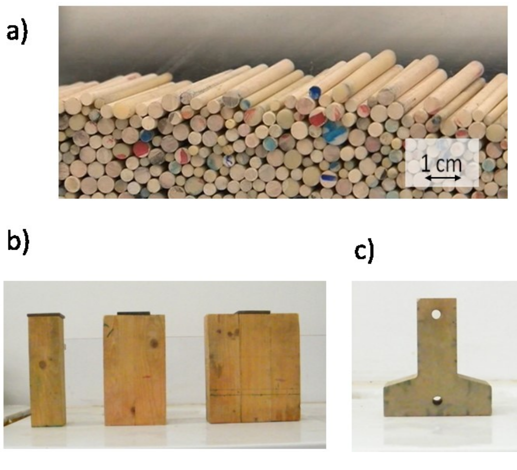

Figure 1 a) Schneebeli's material b) Examples of foundation scale model (length 60, 110 and 160 mm) c) Scale model of spread footing foundation manufactured by strato-conception machine

The foundation is positioned between the granular matter and the load cylindrical shank with either a knuckle or a clamping. As the granular medium has a low density (the density of the duralumin is equal to 2900 kg/m3), the foundation is wooden to simulate the entire problem via a scale model, i.e. the soil, the foundation and the load effect of the structure building.

We consider that the distance between the frame and foundation is sufficient to have a semi-infinite condition.

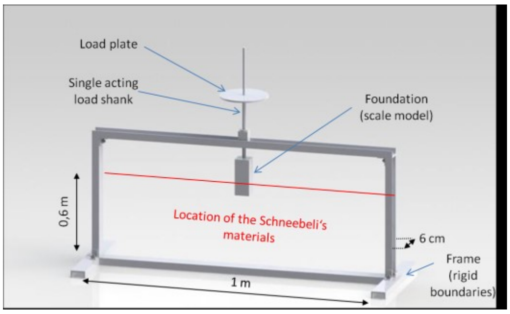

Figure 2 General view of the punching apparatus

2.3 Image acquisitions

The images of the punching of the analogue soil by the foundation were acquired by digital camera or high-speed digital camera.

The location of the camera has been fixed in order to avoid an image distortion (minimal distance from the device) and to align the camera horizontally and vertically on the interesting part of the granular matter, i.e. under the foundation. To illustrate the punching mechanism, a coloured square grid is drawing on the analogue granular matter at the initial stage to help the following of the displacement patterns (each square measure approximately 25 × 25 mm^2).

The Figure 3 shows an example of punching sequence in the case of foundation with 160 mm in width at four stages of the load.

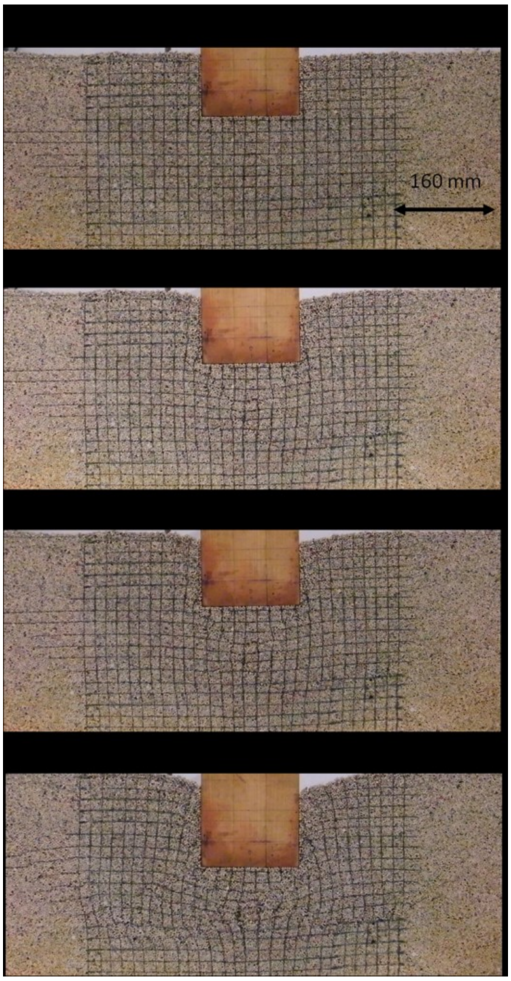

Figure 3 Image acquisitions of the soil punching (initial depth D_f of foundation is 100 mm)

In particular, the stage (*t3*) corresponds at the moment after the punching shear failure. Note that for each initial stage (*t0*), the analogue granular matter was systematically expanded by hand to have an initial packing as loose as possible.

In the case of post-treatment with PIV, high-speed camera was used to capture the foundation motion and soil displacement. Especially, an IMPERX IPX-VGA 210 was employed thereby achieving 210 frames per second with 640×480 pixels resolution. Note that this camera gave directly grayscale images (8-bit grayscale).

3. IMAGE ANALYSIS

3.1 Image pre-processing

Several preliminary stages are required in order to treat the image sequences before the PIV analysis. In this work, the FIJI open source software was used to both the pre-processing and the PIV analysis. The following stages were applied in order to obtain binary images:

- The interested area should be delimited by removing the not required data on the images as for example the frame of the device.
- The background of the images could be treated by removing smooth continuous backgrounds via a rolling ball algorithm (the radius of curvature should be at least as large as the radius of the diameter of rods)
- Is not by default, each image must be converted to 8-bit grayscale.
- One additional operation may be applied in order to obtain a binary image. By make a zoom on one of the faces of rods, white and black threshold is carried out in the zoom selection to distinguish the centre of each grain. Dilate or erode operations may be carried out to ameliorate the threshold. Note that this operation is not turned out to be necessary: the PIV may be applied directly on 8-bit grayscale image.

3.2 Particle Image Velocimetry analyses

The using of digital image analyzing is widely developed in particular to extract information from the images. A manually analysis done manually on our rods would be time consuming and influenced by a personal bias. To go to an automatized processing, Particle Image Velocimetry (PIV) plugin was applied on your image acquisitions.

Both for a first approach and to evaluate the feasibility for our rods in the case of the punching, we use the PIV ImageJ plugin developed originally for the Traction Force Microscopy (TFM) applications (Qinqzong, 2011). Two images following one another were extracted from the punching test, thus the preprocessing described above were applied to obtain a binary image which allow the distinction between the faces of the rods to be drawn . The preprocessing is a delicate stage because some information could be lost during the threshold operations. The iterative PIV operations which were performed in this study use the template-matching cross-correlation type. Compare to a basic cross-correlation basic PIV, this PIV iterative method consists to decrease several time the size of the interrogation window during an iteration to increase the accuracy of the PIV.

A typical result of the PIV plugin has been shown in Figure 4 in the case of the foundation described in 2.3 (the foundation is 160 mm in length and 100 mm in-depth). The vectors represent the displacement field coloured as a function of the displacement magnitude. In particular, the results show that the PIV analysis clearly highlights the field of the displacement in several areas of soil. Thus, the results of the PIV are in good agreement with the image observations of the shear localization observed in the untreated images (see Figure 3).

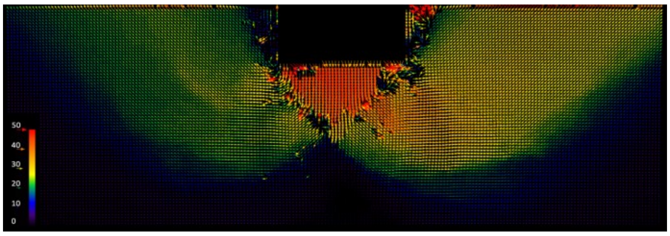

Figure 4 PIV analysis exhibits the slip – line field in the case of foundation punching

3.3 Punching mechanism

As shown in Figure 5-a, the Prandtl mechanism consists to describe the flow of the soil under a foundation in three distinct zones. These zones are represented in the case of our PIV analysis in the Figure 5-b.

These Figures show that the experimental tendencies via the PIV have been qualitatively in agreement with the Prandtl mechanism. The area I under the foundation is a triangular form with a vertical translation. Note that the value of angle depends on the intrinsic friction angle of the analogous granular matter but also of the roughness of the footing of the foundation. The area II exhibits a lateral movement of the analogue soil corresponding to the radial shear zone. At last, the area III corresponds to the backflow of the soil led by the punching. Note that the last area IV does not show any sizeable influence on the soil (quasi motionless).

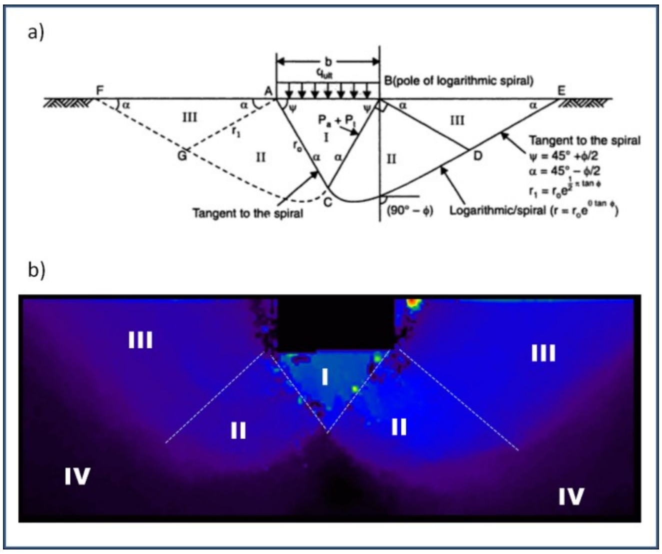

Figure 5 a) Prandtl system (from Venkatramaiah, C. (1993)) - b) Flow areas and displacement magnitude field obtained by the PIV analysis

4. CONCLUSION

We have presented the potential to use of particle image velocimetry applied to bi-dimensional analogue materials in the particular case of shallow foundation bearing capacity. A dedicated apparatus has been developed to punch the analogue soil. The results showed that the PIV analysis provided valuable information of failure mechanism under foundation. These PIV results can be exploited in order to compare the image data with other approaches like for example FEM simulations, kinematics models (Van Baars, 2014), etc.

The future work should be carried out both by experimental and numerical methods. For the experimental method, the load mechanism could be improved to control the displacement during the loading and the image analysis could be developed in order to catch the rotation of the rods (Richefeu et al, 2012).

For the numerical method, the main idea should be to model the foundation and the soil by discrete element method (Pizette and Rémond, 2014) (Govender et al, 2015) in order to study both the link between the global and local behaviours of soils and the interaction between the soil and the footing given both by numerical and experimental approaches.

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