PERFORMANCE OF PARTICLE IMAGE VELOCIMETRY (PIV) AND CLOSE-RANGE PHOTOGRAPHY ON TOYOURA SAND

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1. INTRODUCTION

High-level precision tools for measuring soil deformation are important in describing soil-foundation interaction. In this concern, particle image velocimetry (PIV) and close-range photography have delivered remarkable results in the order of 1/17,680 to 1/176,800 fractions of field of view (FOV) [1].

The PIV system currently used in Tokyo Institute of Technology employs close-range digital photography in obtaining images of deforming bodies, and the GeoPIV software to implement the PIV analysis. This system is both used in 1g and centrifuge tests, usually with Toyoura sand. No validation experiments, however, were (yet) made to assess its over-all performance. This paper evaluates and quantifies the performance of the said system, specifically in the context of its target object image, the Toyoura sand.

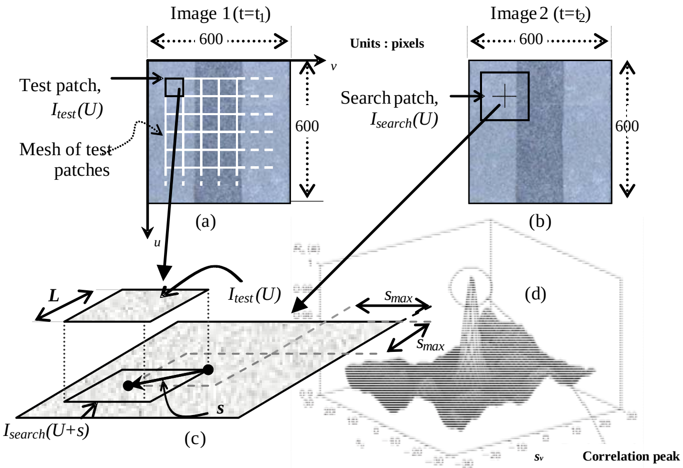

Fig.1 Image manipulation and evaluation of displacement vector in PIV analysis, after White *et al* (2003)

2. EXPERIMENTAL PROGRAM

Precision performance was evaluated by considering a 600x600 pixels image of Toyoura sand (**Fig1**). The analyses were conducted as a non-translating rigid body motion, that is, by comparing the image with itself. Five (5) PIV analyses were carried out wherein the whole image was covered with square test patches with side lengths, ***L*** of 16, 24, 32, 48 and 64 pixels. The scatter of displacement vectors recorded was used to evaluate the precision of the PIV system.

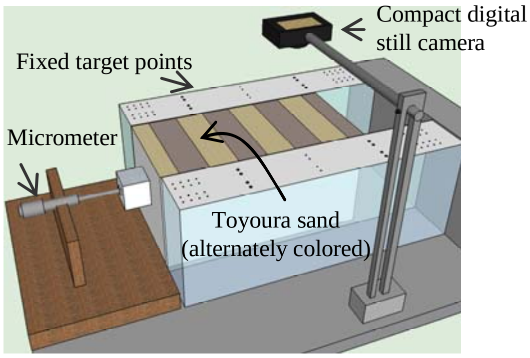

Fig.2 Movement accuracy test set-up for Toyoura

Movement accuracy was evaluated by two approaches. One set of artificial soil movements were prescribed by means of cropping a photo of Toyoura sand and shifting the target area along the horizontal direction in increments of 1, 5, 10, 11, 12, 15, 18 and 20 pixels. This allowed the soil movements to be exactly controlled and to be independent of external influences such as lighting, etc. On the other hand, to introduce the influence of random changes in appearance associated with taking multiple photos of a translating object, a block with Toyoura sand was manually translated using a micrometer below a fixed camera approximately 375mm high (**Fig.2**). A series of images was captured at displacement increments of 25/7, 50/7, 75/7 and 100/7 pixels. The difference in the recorded displacements and their corresponding real displacement relays the movement accuracy of the PIV system. All images were captured using Canon Powershot G7, and were analyzed by the GeoPIV software.

3. RESULTS AND DISCUSSION

Non-translating soil movements. The variation in recorded displacements for zero pixel displacement analyses, which corresponds to the precision of the measurement, is shown in

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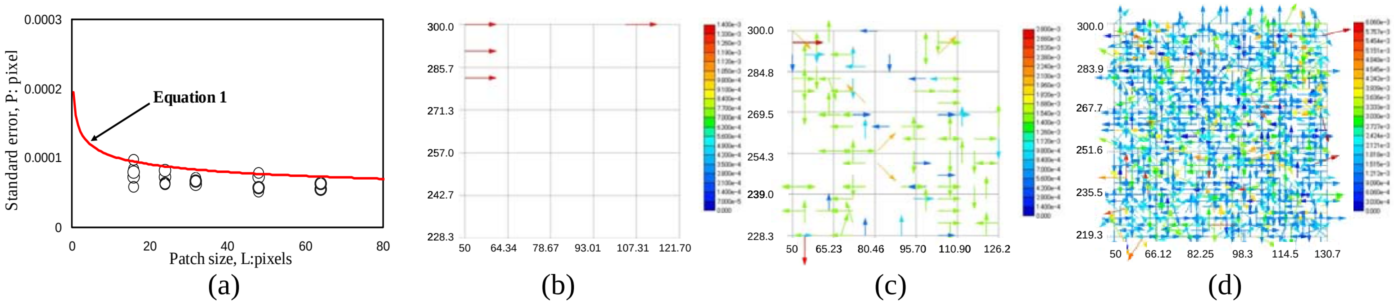

Fig.3 PIV precision validation: **(a)** Measurement standard error against patch size; Example results for scatter of displacement vectors (in mm) for 32 pixels search zone and zero incremental displacement for patch sizes of **(b)** 64x64, **(c)** 32x32 and **(d)** 16x16 pixels.

Fig.3a. The result reiterates from [1] that precision, P_{pixel} increases with patch size, L. **Equation 1** (R^2=0.9553) is an empirically derived equation that gives an upper-bound of the precision errors for the PIV system on hand.

$$P_{pixel} = \frac{0.0002}{L^{0.1879}} \text{, where } 0 < L < \infty \text{; in pixels} \quad (1)$$

Ideally, for rigid body displacement increment of zero pixels, nil vectors are expected. However, smaller PIV patches generated wild vectors, some as big as 0.01 pixel. This is due to a greater number of measurement points, showing more detail of the brightness dependency of neighboring pixels (**Fig.3b-d**).

Translating soil movements. Values of true displacements for translating soil movements were plotted against standard deviation of measurements and discrepancy from true value (**Fig.4**). Results reveal that for highly-controlled movements, precision and accuracy are achieved at roughly the same levels for any value of displacement (**Fig.4a**). However, for movements driven by the micrometer, although precision of measurements were comparable to image-shifted movements (see **Table 1**), the average discrepancy from true value was rather large at around 0.25 pixel compared to 0.001 pixels for highly-controlled displacements. This large discrepancy for manually-applied movements (in the order of 0.035mm for standard resolution of 180pixels/in) is brought partly by the spatial variation between image and object scales, and the uncompensated errors of sub-pixel movements. One interesting observation is the sudden drop in both precision and accuracy at movements around 10 pixels for both cases. However, higher accuracy and precision is seen for movements greater than 10 pixels (>1.4mm).

4. CONCLUSIONS

Measurement precision was achieved at 1/18,240 to 1/1,824,000 fraction of FOV for translating soil displacements. This is a remarkable improvement in accuracy compared to earlier bench-top experiments listed in [2]. Discrepancy from true values was as high as 0.45 pixel for translating soil movements, which is equivalent to 0.063mm displacement in object-space. In general, the PIV system produces more precise and accurate results for large patch sizes, and large displacement increments.

REFERENCES

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[2] White, D. J., and Take, W. A.: "Discussion on application of particle image velocimetry (PIV) in centrifuge testing of uniform clay", *IJPMG* No. 7, 27-31, 2005.

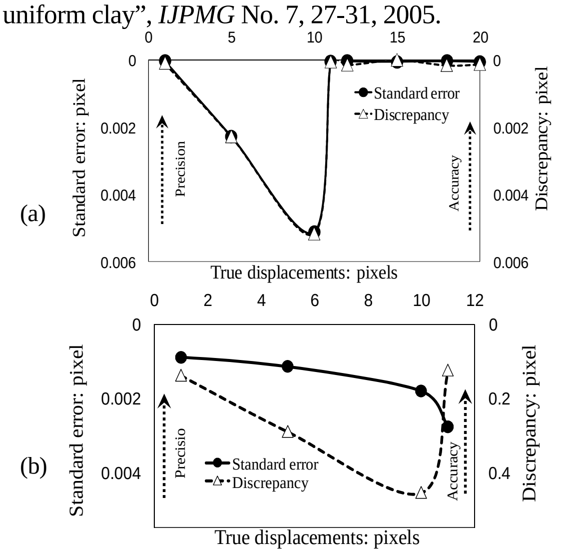

Fig.4 Movement accuracy results: (a) image-shifted displacements, (b) micrometer-driven displacements

Table 1. Summary of results

	Precision (image space) : pixel	
	Max precision	Min precision
Non translating[1]	0.001889303	0.011645095
Translating (Image-shifted)	0.0015408125	0.2145430062
Translating (Micrometer)	0.0738666908	0.2316226930
	Accuracy (image space): pixel	
	Image-shifted	Micrometer
Average[2]	0.0010077130	0.2512674345
Max accuracy	0.0000076324	0.1233650887
Min accuracy	0.0051667182	0.4548667672

[1]Dependent on patch size Resolution: 180pixel/in
[2]Dependent on displacement length