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# SETTLEMENT MEASUREMENT OF SOFT SOIL BY CLOSE RANGE PHOTOGRAMMETRY AND PARTICLE IMAGE VELOCIMETRY TECHNIQUE

Khairun Nissa Mat Said, Ahmad Safuan A. Rashid* & Nor Zurairahetty Mohd Yunus

*Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru Malaysia*

*Corresponding Author: *ahmadsafuan@utm.my*

**Abstract:** This paper represent the result of soft soil settlement under rigid footing by a small scale physical testing. The measurement was intended to show the deformation of a soil under a design load by the use of digital imagery. Initially, the ultimate bearing capacity was determined in order to obtain the design load of the soft ground model. The settlement under the design load was measured by an image of the exposed surface of a soil model that was captured when the loading is applied to the footing and analysed by the Particle Image Velocimetry, PIV technique. At the very same time, the settlement was measured by linear vertical displacement transducer, LVDT. The settlements results by PIV and LVDT measurements were 0.18 mm and 0.35 mm respectively. The discrepancy of both measurement techniques are as LVDT was used to determine the vertical settlement occurred at the center of rigid footing. As for, the PIV approach was applied to measure the settlement of the entire soil model at 2D plane. As a conclusion, the PIV technique that used in the small scale testing helps to directly interpret the deformation behavior occurred in the ground model.

**Keywords:** *Particle Image Velocimetry, Settlement of soft soil*

## 1.0 Introduction

Settlement and deformations of soil are fundamental properties in understanding the behavior of soil especially on cohesive soil. Historically, several techniques have been used to measure the settlements and deformations of soil either using a small scale physical testing, full scale testing or finite element method. Small scale physical test has been preferred to observe the behavior of the soil in order to avoid high costs associated with in-situ testing. Thus, the developments of various image based techniques such as X-rays (Kirpatrik *et al*., 1968), holographic interferometry (Wood *et al*., 1974), and

Particle Image Velocimetry (Adrian 1991, White *et al*. 2003, Ni Q *et al*., 2010, Juneja *et al*., 2013) has been helpful to measure the planar soil deformation by small scale studies and with proper limitation can be used to simulate the real soil condition.

In geotechnical area, Particle Image Velocimetry, PIV is one of the advance techniques that is frequently used in determining the soil deformation under small scale modelling test. The PIV technique provides an accurate, precise and resolute measurement result, (White, 2003, White *et al*., 2005). PIV was also called as the block-matching method by Guler *et al*., (1999) and digital image correlation (DIC) by Lui *et al*., (2004). PIV was originally developed to determine the velocity of fluid flow seeded with small particles for migrated space of fluid mechanics field according to White *et al*., (2002). The small particles provide indistinguishable texture for operating image process in tracking the fluid movement. Meanwhile in the geotechnical field, the uniform texture of clay soil can be enhanced by adding coloured flock material whilst the natural grained texture of sand can be used directly or dyed for fine sand, (White *et al*., 2003, Slominski *et al*., 2006, Juneja *et al*., 2013).

Several studies have been done to investigate the deformation of soft soil by using PIV technique (White *et al*. 2003, Slominski *et al*. 2006, Rashid 2011, Juneja *et al*. 2013). The studies have shown successful deformation measurements through PIV technique. It emphasizes the use of the PIV technique in ultimate state designs where the high strain occurred on the soil model. However, none of them explained the settlements and ground movements at much lower strains where it is possible when the settlement occurs within the tolerable limit under working load.

Thus, this paper shows the settlement and deformation behavior of the soft soil beneath the rigid footing at the lowest strain when the design load was applied on the model ground.

## 2.0 Materials and Methods

### *2.1 Material and Specimen Preparation*

Table 1 shows the material properties of the clay that has been used to conduct this study.

Table 1: Material Properties

| *Parameter* | *Clay* |
|---|---|
| Classification (USCS) | CL |
| Specific Gravity, SG | 2.64 |
| Atterberg Limit | |
| PL(%) | 57 |
| LL(%) | 32 |
| PI(%) | 25 |

The soft ground model was made by using clay with a 57% liquid limit. At first, the slurry soil mix was produced at two times the liquid limit to ensure the soil was workable enough to be pouring into the testing chamber. Then, the soil was consolidated under continuous incremental stress by 2.12 kPa, 3.125 kPa, 6.25 kPa, 12.5 kPa and 50kPa. The sequence of the stress was increased after it met 90% degree of consolidation. After that the pressure was reduced to 5kPa to obtain an over consolidation ratio of 10. Usually, nine days are required to complete all consolidation stages.

The testing equipment that has been used throughout the experimental consists of testing chamber, loading device and loading plate. The testing chamber has a dimension of 400 mm x 150 mm x 430 mm in width, long and height respectively. The front view of the testing chamber comprised of flexible transparent Perspex window. The testing chamber also was equipped with a drainage path at the top and bottom part to allow access water to flow out during consolidation stages. Meanwhile, the loading plate has a dimension of 80 mm x 150 mm in width and long respectively. The loading tests were carried out under two phases i.e. Phase I: Determine design load by strain controller and Phase II: Determine the settlement of model ground by dead load system (DLS).

Loading test was performed once the soft ground model has undergone the consolidation stages. The bearing capacity test was conducted to determine the ultimate bearing capacity of soft ground model by strain control system as shown in Figure 1. Then, the settlement was measured by applying allowable bearing capacity on top of the rigid footing. The settlement measurement was carried out for 24 hours by using dead load system as shown in Figure 2. At the same time, settlement of ground model was captured continuously *(see section 2.2).*

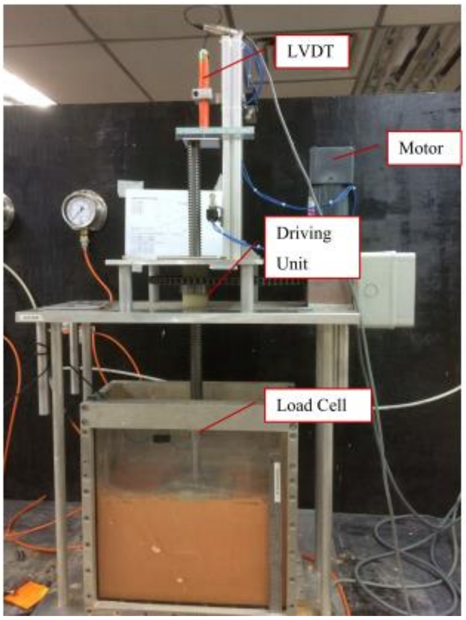



Figure 1: Strain Controller for bearing capacity test

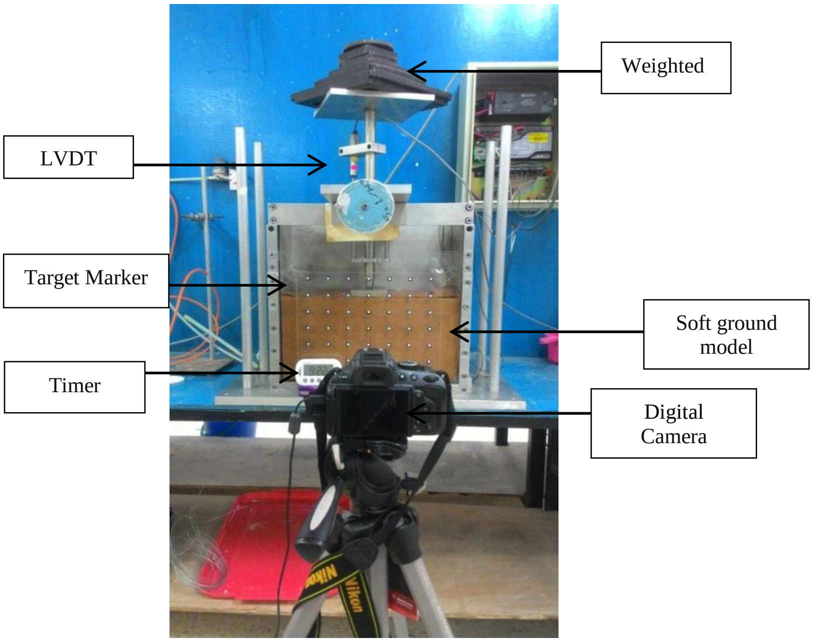


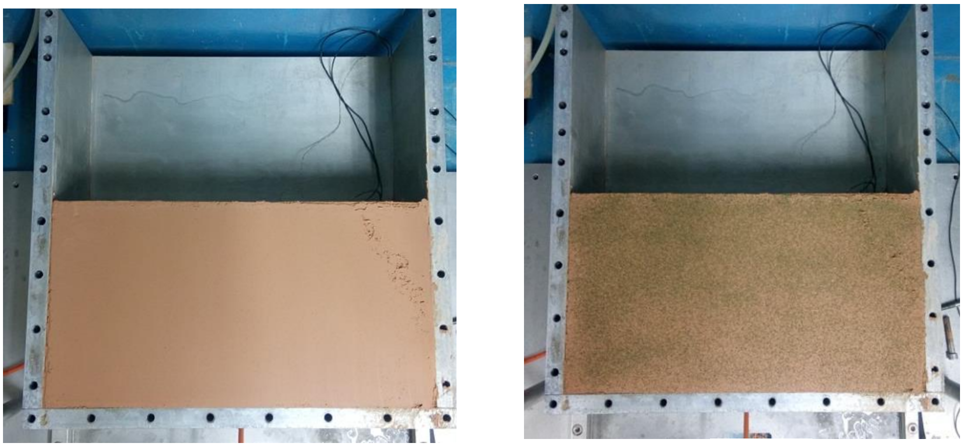

Figure 2: Dead load system for settlement

## *2.2 Small Scale 1g Physical Testing*

### *2.2.1 Close Range Photogrammetry*

Close Range Photogrammetry was applied during measurement of settlement. Figure 2 shows the complete set of the equipment and arrangements used for the measurement which consists of the ground model with flock material, a digital camera, target markers and a timer. In this experiment, the digital image was captured using Nikon D5100 model with image pixel of 4,928 x 3,264. The interval of the capture were selected at 1s, 2s, 4s, 15minutes, 30minutes, 1hour, 2hour, 4hour, 8hour, 12hour and 24hour. Initially, once the consolidation stages were completed the open surface of the soft model ground was spread with flock to enhance the texture for image processing purposes. Figure 3 show the flock material used for enhanced clay texture known as *"Mid Green Fine Turf Javis Premier Range JFT2"*. Figure 4 shows the difference of clay texture with flock material. A thin Perspex plate with 42 target markers was attached to the outside Perspex window of the testing chamber for digital image calibration purposes.

Figure 3:Flock Material



(a) (b)

Figure 4: Texture of clay (a) uniform texture on clay (b) clay with flock material

### *2.2.2 PIV Analysis*

PIV analysis was performed using GeoPIV where it can be loaded in MATLAB. This software was developed for the application of image analysis. Captured images were then transferred into the GeoPIV software for analysis. From the recorded digital images of plane of interest, displacements were computed using a Matlab base module incorporating PIV and GeoPIV as developed by White and Take (2002). Figure 5 shows the stepwise procedure in which PIV analysis was conducted on a series of digital images. While Figure 6 show the Matlab interface during running GeoPIV.

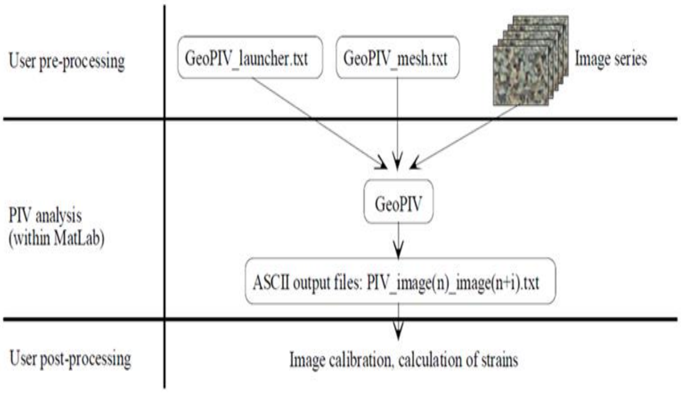



Figure 5:GeoPIV Software usage White *et al* (2002)

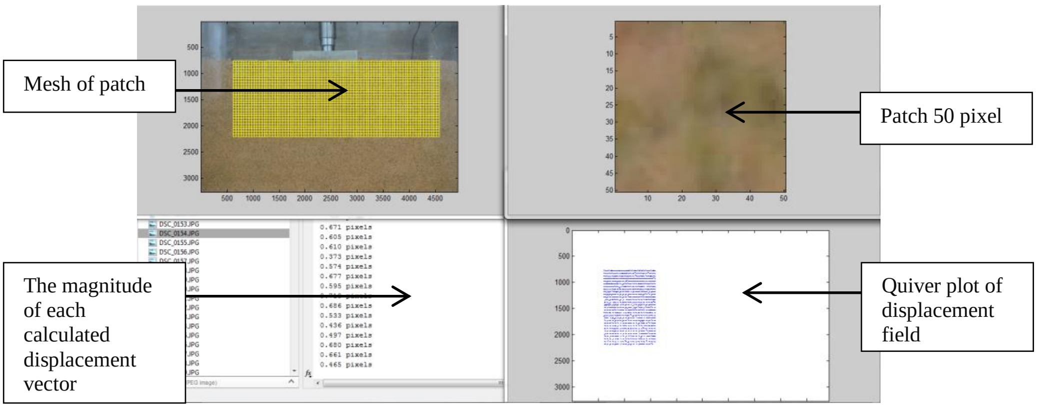



Figure 6: Interface during GeoPIV analysis

# 3.0 Results and Discussion

## *3.1 Ultimate and Allowable Bearing Capacity*

Figure 7 show the stress – displacement/footing width curve. It shows that ultimate bearing capacity, $q_{ult}$ of the model ground was 42 kPa at 0.04 displacement/footing widths. The ultimate bearing capacity of soft soil was calculated using Equation 1 theoretically establish by Mayerhoff (1953). From the experimental result, the strength of the soil measured by the hand vane shear was determined as 8 kPa. The theoretical value of $N_c$ and $S_c$ was 5.14 and 1.1038 respectively. This obtained a theoretical ultimate bearing capacity, $q_{ult}$ value as 45.3 kPa. The discrepancy value between both experimental and theoretical of about 7% might be contributed during manual handling of the small scale physical testing. Then, the allowable bearing capacity, $q_{all}$ was obtained as 14kPa which is $\frac{1}{3}$ of the ultimate bearing capacity.

$$q_u = cN_cS_c$$

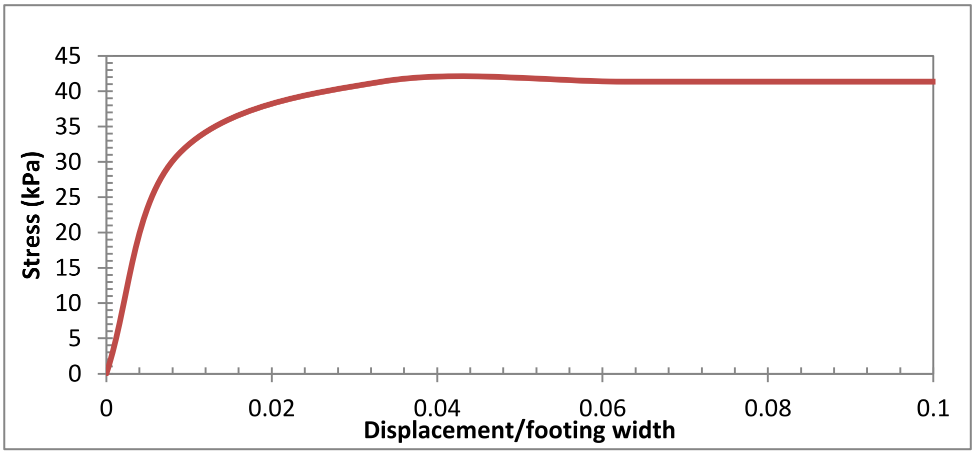



Figure 7: stress – displacement/footing curve

## 3.2 Settlement Measurement

### 3.2.1 Settlement – Time Curve

Figure 8 shows the settlement – time curve of soft soil beneath rigid footing at $q_{all}$=14kPa which is approximate to the 17 kg dead load applied on top of rigid footing. It is shown that the maximum settlement by LVDT at the center of the rigid footing for 24 hours was 0.35 mm. Based on the figure, the measurement of LVDT shows two gradual vertical displacement within 24 hours which are at 0s to 32000s and 40000s to 80000s. To enable good understanding of the displacement of the entire ground model Figure 9 and Figure 10 show the settlements contour and deformation behaviour of the ground model at 2D plane by PIV technique.

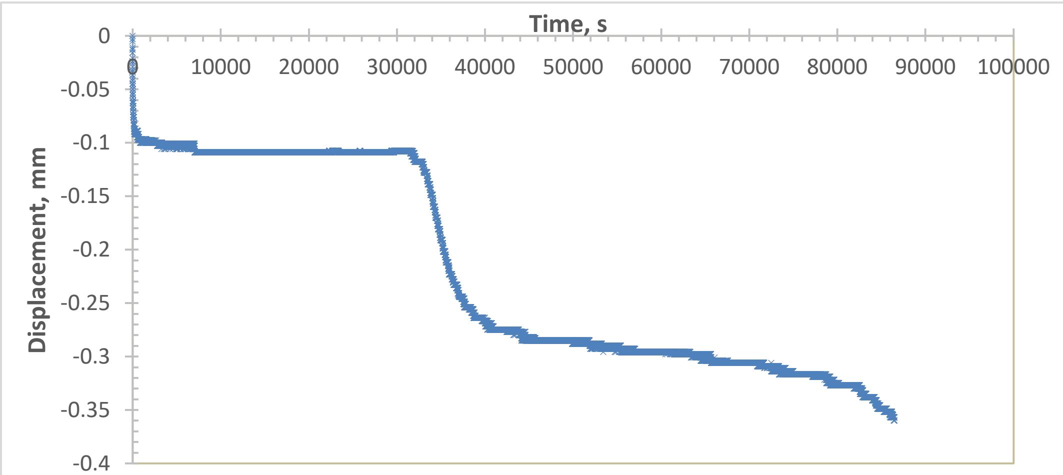



Figure 8: Settlement – Time Curve

### 3.2.2 Settlement Contour and Deformation Behavior by PIV Analysis

Up to 24 hours of the testing, 57 images were captured and used for PIV analyses through Matlab. Figure 9 shows the corresponding settlement contour beneath the rigid footing. The highest contour value was shown at 0.18021 mm. It was concluded as the maximum settlement occurs beneath the rigid footing at the 24 hour mark. Meanwhile, Figure 10 shows the ground model deformation. The deformation of the ground model shows small and uniform displacement occurs beneath the rigid footing. The vector also aligns perfectly vertical without bulging at top edge of the footing. The vector showed same magnitude and indicate that the displacement is the same at all interest areas.

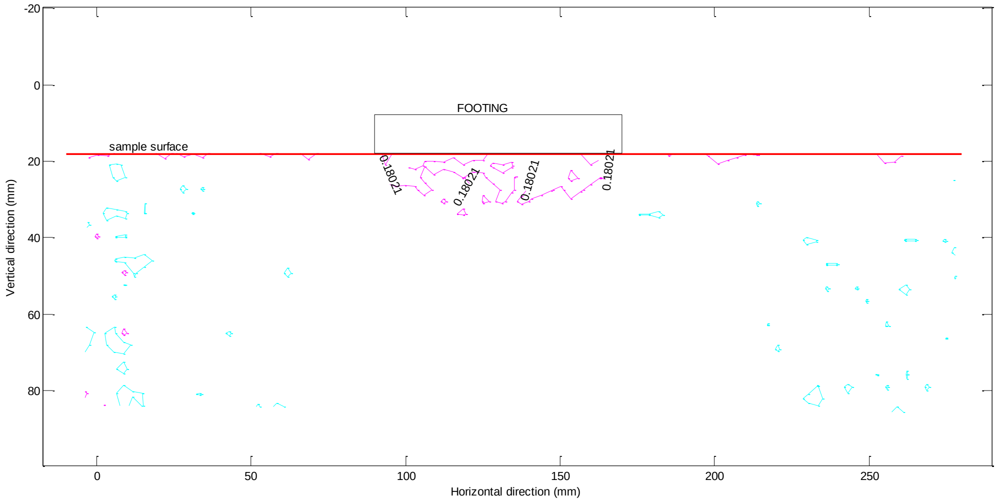



Figure 9: Settlement Contour by PIV

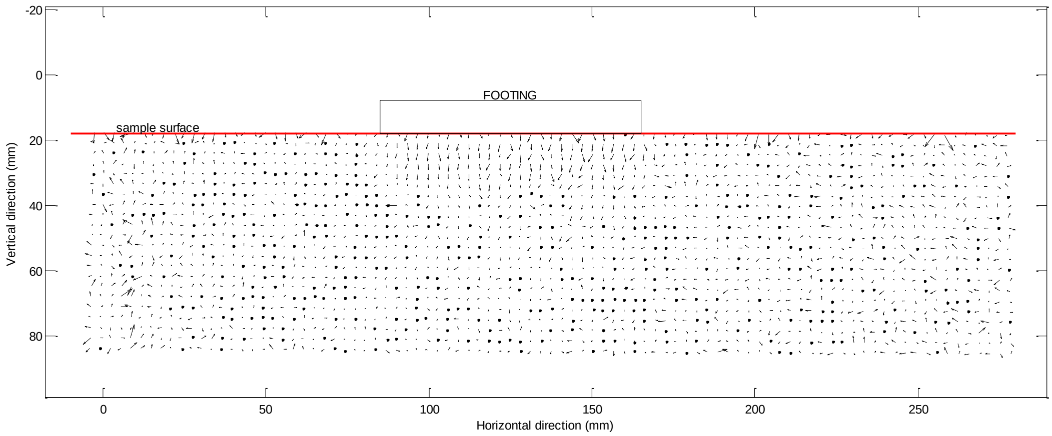



Figure 10: Deformation vector by PIV

## 4.0 Conclusions

Based on the experimental results presented herein, the following conclusion can be drawn;

1. Settlement of ground model measured by Linear Vertical Transducer, LVDT is 0.350mm. However, settlement obtained through PIV analyses is 0.1802mm.
2. It can be seen that the ground model deformed uniformly under the design load from PIV analyses.

3. The settlement and deformation of entire ground model from small scale physical modeling can be better understood by PIV technique as compared to the LVDT that is only utilized for single point vertical displacement measurement at the center of the rigid footing.
4. This study proved that Particle Image Velocimetry, PIV technique is an effective optical method to simulate ground deformations at the lowest strain without performing a real test.

## 5.0 Acknowledgements

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