

Continuous Displacement Measurement of Soil Mass Using White Light Digital Image Analysis in Frequency Domain

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Abstract— The displacement and deformation of soil mass is the important index in civil engineering. In this paper, white light digital image analysis in frequency domain is introduced to measure the continuous displacement of soil mass. This method has the characteristics of whole-field, non-contact measurement and the measuring system is very simple. CCD camera is used to record the images of soil mass before and after deformation. The images are digitalized and then analyzed to obtain the displacement of the specimen by using frequency domination correlation arithmetic. Comparing the experimental result with the theoretical value of displacements, the usability of this method for measuring the displacement and deformation is certified.

Keywords- soil mass; continuous displacement; white light digital image analysis in frequency domain; digital images; translation experiment.

I. INTRODUCTION

In civil engineering, the displacement and deformation of soil mass is always the important index in civil engineering which affects the success of the project and the security of life and property. Therefore, the measuring method for its displacement and deformation attracts the interest of the researchers[1-2].

The analysis methods for measuring displacement of soil mass include numerical method[3] and experiment method[4].

There are two major measurement methods which are commonly used which are strain gauge and displacement meter[5-6]. The advantage of two methods is that they can be used to measure the displacement and deformation of soil mass in real time and have the rapid data transmission. Meanwhile, the disadvantage of them is also obvious. First of all, it is necessary to make the measuring instrument touch the measured soil, or the instrument should be installed in the measured field. The operation progress is complex. They cannot be used in some dangerous areas;

Moreover, two methods can only be used to measure some particular points, therefore can not meet the requirement of full-field measurement and have relatively low measurement precision; Finally, the measuring instrument of two methods can only be used only one time and must be bought again next. Therefore, though these methods are suitable for a wide range, some disadvantages such as low precision, high cost and the unable whole-field measurement always affect the safety of construction engineering.

In this paper, white light digital image analysis in frequency domain [7-8] is introduced to measure the continuous displacement of soil mass. It is based on white speckle method and coherent analysis in frequency domain and has the advantages of the whole-field measurement, non-destructive measurement without coherent light source method. The method has simple light path, convenient operation, only needs a computer and a CCD camera to finish the whole record progress. The method has been already used to study the mechanical characteristics of concrete [9-10]. Therefore, the method is applicable to measure displacement and deformation of the soil mass.

II. PRINCIPLE OF WHITE LIGHT DIGITAL IMAGE ANALYSIS IN FREQUENCY DOMAIN

CCD camera is used to record gray images before and after deformation and analyze them in computer to obtain the displacement information. A small region in images is considered that the displacements of the small region are equal. Let δ denote the gray distributions of one point. $\delta_0(x, y)$ is the location before deformation of specimen, $\delta_1(x, y)$ is the corresponding location after deformation and $\delta_1(x, y) = \delta_0(x + u, y + v)$ as shown in Fig. 1. d is the displacement vector, θ is included angle between d and x axle.

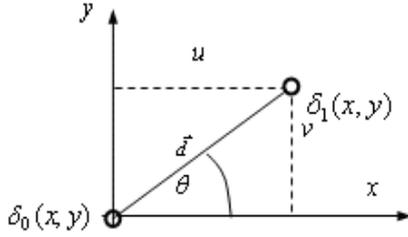


Figure 1. small region before and after deformation

g is the sum of light intensity before and after deformation and then,

$$g(x, y) = \delta_0(x, y) + \delta_0(x + d \cos \theta, y + d \sin \theta) \quad (1)$$

According to Eq. 1, fourier transformation is used to obtain the spectrum:

$$G(X, Y) = 2G_0(X, Y)(1 + \exp(-i\pi(2\vec{r} \cdot \vec{d}))) \quad (2)$$

Where,

$$G_0(X, Y) = \mathfrak{F}\{\delta_0(x, y)\}$$

$$= \iint \delta_0(x, y) \exp(-2\pi i(xX + yY)) dx dy = 1'$$

$\mathfrak{F}\{\}$ is fourier transformation, (x, y) is the coordinate on object plane, (X, Y) is the coordinate on spectrum plane. $\delta_0(x, y)$ and $G_0(X, Y)$ denote the gray distribution of small region in images and its Fourier transformation respectively. \vec{r} is the coordinate vector on spectrum plane.

The distribution of light intensity on spectrum plane can be obtained:

$$I = G^*G = 4 \cos^2[\pi(\vec{r} \cdot \vec{d})] \quad (3)$$

According to Eq.3, when $\pi(\vec{r} \cdot \vec{d}) = n\pi$, I can be its maximum; when $\pi(\vec{r} \cdot \vec{d}) = (n-1/2)\pi$, I is the minimum.

A series of parallel fringes can be shown in the form of image.

$$\vec{r} \cdot \vec{d} = \begin{cases} n & \text{bright fringe} \\ n - \frac{1}{2} & \text{dark fringe} \end{cases} \quad (4)$$

$$(n = 0, \pm 1, \pm 2, \dots)$$

It is considered that the displacement of every point in small region is equal. N and $N' = N + 1$ denote fringe values of adjacent fringes and then,

$$r_N \cdot d = N, r_{N+1} \cdot d = N + 1.$$

So $d = (N + 1) - N / (r_{N+1} - r_N)$ and

$$d = \frac{1}{\Delta r} \quad (5)$$

where Δr is the fringe separation.

Clearly, the displacement vector is vertical to the fringe direction and its magnitude can be obtained according to Eq. 5.

The imaging lens in CCD is used when images are recorded, so the real displacement d_T is

$$d_T = \frac{d}{M} = \frac{1}{M \Delta r} \quad (6)$$

where M is image multiple.

According to domination transformation theory, then,

$$\Delta r = \frac{1}{Lccd} \Delta K \quad (7)$$

where $Lccd$ is target dimension of CCD, ΔK is pixel number between the fringes.

Substitute Eq. 7 into Eq. 6 and then,

$$d_T = \frac{Lccd}{M \cdot \Delta K} \quad (8)$$

u, v are the components of d_T on x, y axle respectively.

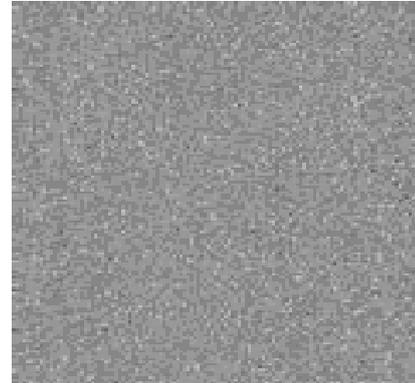
III. EXPERIMENTS

A rectangular soil mass is selected as the specimen whose dimension is 25cm length, 20cm width and 2cm height. The specimen is fixed on the translation stage and CCD camera is placed in front of the specimen.

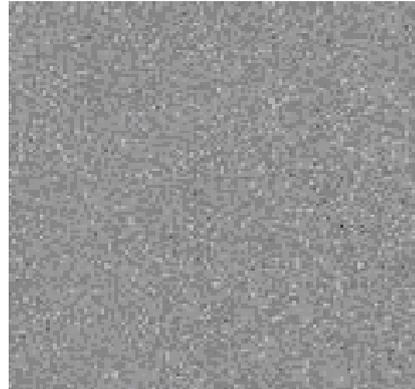
Firstly, CCD camera is used to record the image of the specimen before translation. Every 1mm translation, the images of the specimen after translation are recorded. The images of the specimen are input into the computer and the displacement information can be obtained by use of white light digital image analysis in frequency domain.

IV. EXPERIMENT RESULTS

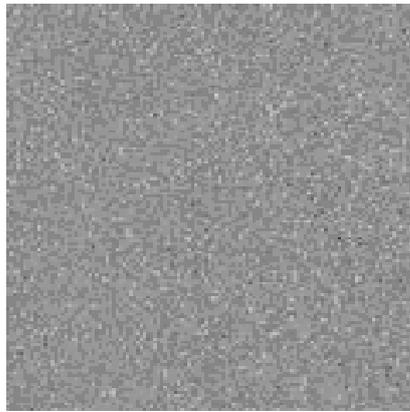
The images recorded by CCD camera are shown in Fig. 2. Because of too many images, only the four images are shown.



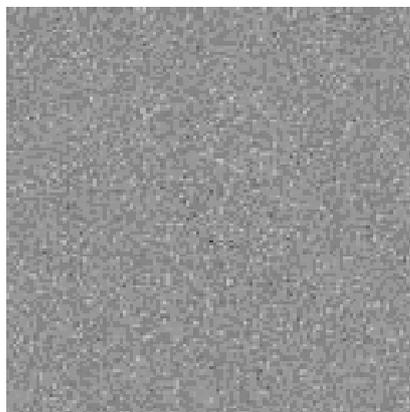
(a) before translation



(b) 1mm translation



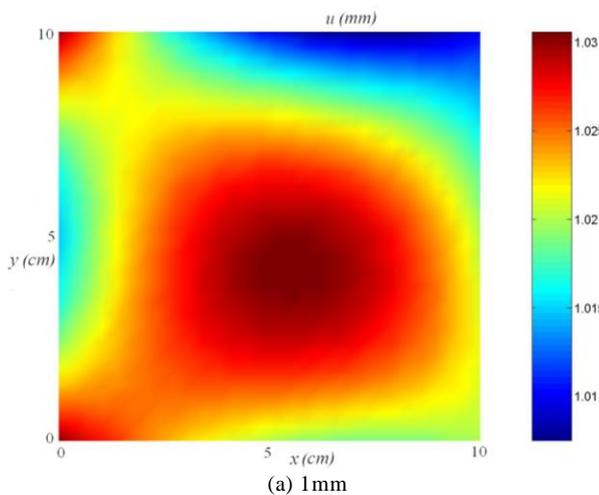
(c) 5mm translation



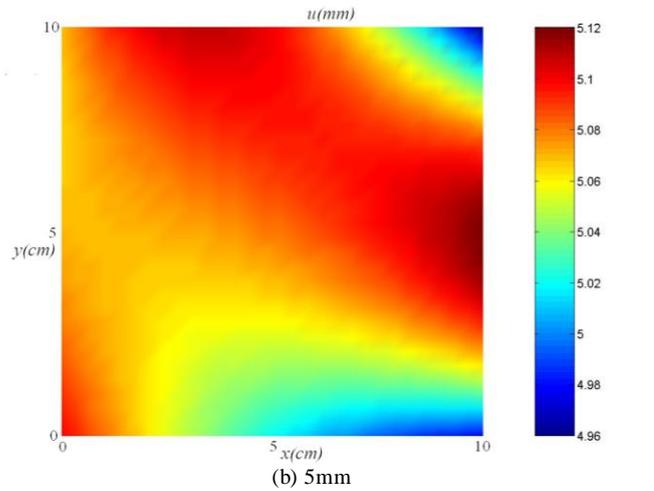
(d) 10mm translation

Figure 2. the images recorded by CCD camera

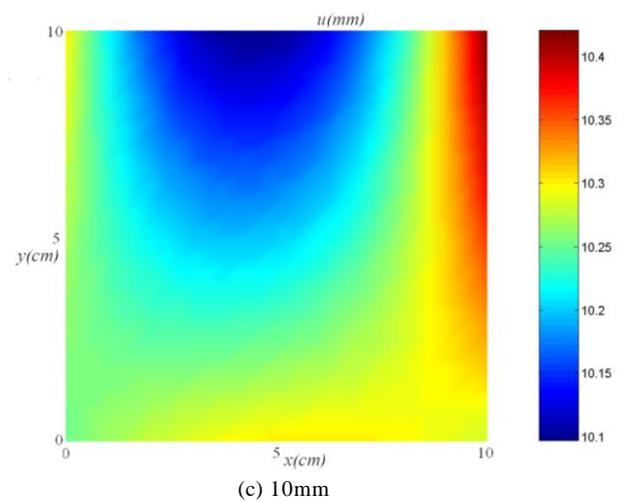
A rectangle field whose length and width are 10cm is chosen as the measured area and the continuous displacements which are shown in Fig. 3 can be obtained by using white light digital image analysis in frequency domain.



(a) 1mm



(b) 5mm



(c) 10mm

Figure 3. the experimental results of translation

Different color represents the values of displacement. The experimental results show that the maximum error is less than 5% and small enough, which certifies the accuracy of the experimental results.

V. CONCLUSIONS

The displacement and deformation of soil mass are the important index in civil engineering. In this paper, white light digital image analysis in frequency domain is introduced to measure the continuous displacement of soil mass. This method has the characteristics of whole-field, non-contact measurement and the measuring system is very simple. The method is introduced to measure the continuous displacement of soil mass. The experimental results show that the maximum error is less than 5% and small enough, which certifies the accuracy of the experimental results. This translation experiment proves that white light digital image analysis in frequency domain can be used to measure the displacement and deformation of soil mass and further applied in the practical civil engineering.

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