論文　Application of Digital Image Correlation Method to Hardening Shrinkage Behavior of Resin Concrete

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レジンコンクリートの硬化収縮挙動を対象としたデジタル画像相関法の適用に関する研究

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ABSTRACT: Application of the digital image correlation method[1)] (hereinafter, DCM) that is a noncontact measuring technique to hardening shrinkage of resin concrete was investigated. Hardening shrinkage of resin concrete was measured by DCM and was compared with that determined by the wire strain gauge. The test result showed the length of base line in DCM effected spatial variance in measurement. However, that could be controlled by increasing the base line to three times of maximum size of coarse aggregate. In addition, shrinkage behavior restrained by the steel mold was observed to confirm boundary conditions in the numerical analysis. As a result, it was found that DCM is effective technique to determine boundary conditions in the numerical simulation.

Keywords: Digital image correlation method,　Resin concrete,　Hardening shrinkage

1. INTRODUCTION

Recently some measuring techniques using digital image are developed actively. In the concrete engineering field, the infrared rays thermography which investigate a defect in concrete structures and the high precision digital image for crack distribution have been put practical use. However, the measuring technique that can determine spatial strain continuously has not been received practical application. So the authors propose the application of digital image correlation method (DCM) to strain measurement of concrete. DCM is a noncontact measuring technique, which has some features: 3D measuring, wide scope and real time scanning etc. Some practical applications on DCM has been reported in mechanical engineering[1)], agriculture[2)] and medical field[3)]. It is expected for DCM to apply to site investigation like as maintenance of infrastructures, because the digital image for DCM can be taken by a handy

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camera. However, there are few application reports in civil engineering Field[4)]. Therefore in this report, the application of the digital image correlation method to concrete was investigated.

2. MEASURING SCHEME OF DCM

The measuring scheme of DCM is shown in **Fig. 1**. Before deformation, a minute subset composed of some pixels which have brightness value is set in the digital image. After deformation, some subsets for scanning are set up around the original position and correlation of brightness R between original and deformed image is determined from **Eq.(1)**.

$$R = \sum_{i,j} (q_{ij} - p_{ij})^2 \qquad (1)$$

Where, p_{ij}, q_{ij}: brightness value of pixel in original and deformed image.

Then distribution of R is formulated into parabolic surface **Eq.(2)** and the new position of the subset at where coordinates (x,y) makes R minimum is solved from **Eq.(2).**

$$R_{(x,y)} = ax^2 + bx + cy^2 + dy + exy + f \qquad (2)$$

Where, a-f : constant obtained from method of least squares.

Fig.2 shows basic concept of curve approximation. Because distribution of correlation is formulated into a continuous function, regardless of pixel size, high precision measurement can be achieved.

As a result, displacement of subset is determined from difference of coordinates between original and new position. In addition, setting up a base line in the measuring area, linear strain can be obtained from the displacement of both ends of the base line, and influence of rotation and shear deformation can be controlled by reducing scanning interval.

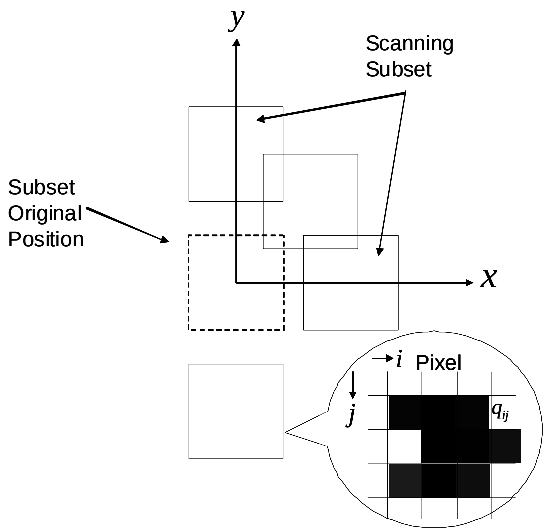

Fig.1 Basic scheme of DCM

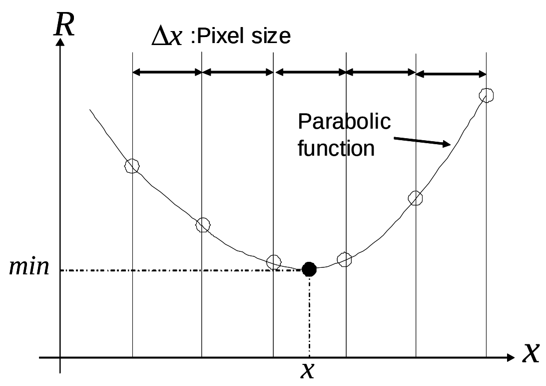

Fig.2 Concept of curve approximation for sub-pixel measurement

3. COMPARISON WITH WIRE STRAIN GAUGE

In order to investigate capability and accuracy of DCM, the comparison with wire strain gauge was made.

Table 1 Properties of Materials

Material	Specification	Density g/cm^3	Absorption %
Resin	Unsaturated polyester resin	1.12	—
Accelerator	Octenoic acid,coblt solt	1.14	—
Agent	Methyl ethyl ketone peroxide	1.16	—
Filler	Slag powder	3.35	—
Fine aggregate	Sand	2.54	1.2
Coarse aggregate	Crushed stone	2.65	0.8

Table 2 Mixture proportion

Unit mass	Resin	Accele-rator	Agent	Filler	Fine aggregate	Coarse aggregate
kg/m^3	290	0.3＊	1.5＊	400	1105	442

＊Percentage to resin

3.1 Experimental Outline

In this study, a resin concrete was adopted due to its remarkable shrinkage. Property of materials and mixture proportion are shown in **Table 1** and **2**. **Fig.3** gives the section of specimen. Resin concrete was cast into two layers and the wire strain gauge attached on chloroprene rubber(10 × 80 × 1mm) embedded at the middle of specimen. The gauge length of wire strain gauge was 30mm long: three times as large as maximum size of coarse aggregate. The position of digital camera was adjusted at where one pixel in the digital image corresponds to 0.1mm in length on the surface of specimen. Hence, 300 pixels in the image indicates a length of 30mm on the specimen, which agrees with the gauge length of embedded strain gauge. To make brightness clear blast furnace slag powder was sprayed on the specimen. Then the digital image was taken every one minutes during shrinkage.

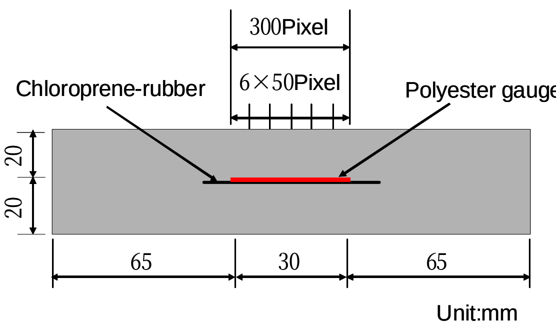

Fig.3 Cross section of specimen

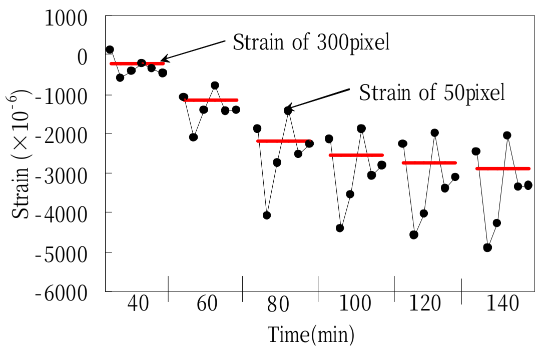

Fig.4 Influence of base line

3.2 Result and discussion

Fig.4 shows shrinkage strain of the resin concrete measured by DCM. In the figure, dot and line indicates measurement with the base line which was 50 pixels long (5mm) and lateral bar denotes that with 300 pixels base line. There is wide spatial variance in the case when the base line is 50 pixels long. However, its distribution is not changed during measurement. Therefore it is considered that, thickness of resin paste was fluctuated in space due to dispersion of coarse aggregate, then hardening shrinkage of resin paste was localized. The comparison of DCM with embedded strain gauge is shown in **Fig.5** in the case when their base line is same length: three times of maximum size of the coarse aggregate. In the figure, close agreement between DCM and embedded strain gauge can be observed. It is considered enlarging the length of base line made distribution of strain uniform. Hence, similarly in the case of a wire strain gauge, it is also important for DCM to take the length of base line into consideration; but influence of coarse aggregate will be controlled by adopting the base line which has more than three times as large as maximum size of coarse aggregate.

4 APPRICATION OF DCM

As a property of DCM there is wide scope scanning as remarked above; DCM can determine displacement and strain where any measuring instrument: displacement meter and wire strain gauge can not be attached. So the authors tried applying DCM to confirm boundary conditions in a numerical simulation.

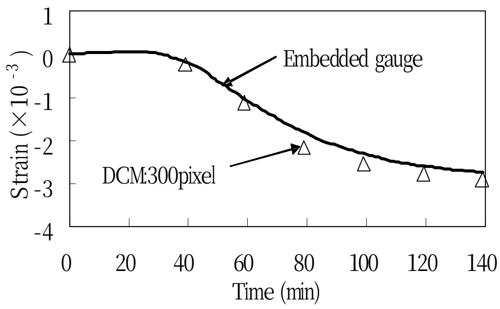

Fig.5 Comparison DCM v.s. wire strain gauge

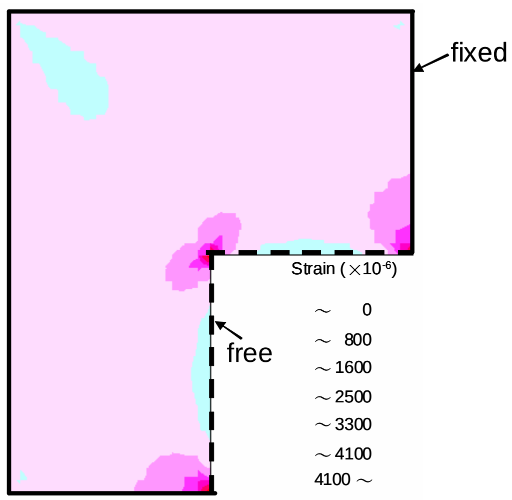

Fig.6 Distribution of principal strain from FEM

4.1 Outline of numerical simulation

Shrinkage behavior in infinity plate with a square window was chosen as the object and strain distribution in 1/4 region around the window was calculated by FEM. As boundary conditions, displacement of the plate was fixed in both *x* and *y* direction and at the edge of open space displacement was assumed free. Hardening shrinkage of resin concrete was reproduced as volumetric change with temperature descent. In **Fig.6**, distribution of principal strain calculated by FEM analysis, it is found that tensile strain is concentrated at the corner of window and strain along the boundary of analysis region is almost small.

4.2 Experimental works

Experimental specimen which reproduces boundary conditions above analysis. In order to restrain the displacement and the slip at the edge of steel mold, a wood screw was arranged and a frictionless sheet was inserted into the edge of open space to keep displacement free. Outline of specimen is shown in **Fig.7**.

In measurement a resin paste was adopted to enlarge its shrinkage. Mixture proportion is shown in **Table3** and property of materials used is shown in **Table1**. The treatment of specimen and the setup of digital camera were similar to **3.1**. The digital image was taken every 30 second.

4.3 Experimental result and discussion

Summative displacement in x and y direction are shown in **Fig.8** and **9.** It is found that near the steel mold displacement in x direction is not restrained; but in y direction it is restrained adequately. Therefore arranging wood screw along the mold has effect to restrain the displacement of concrete in its orthogonal direction. Similarly, at the edge of free end, large displacement was observed in both x and y direction, then effect of frictionless sheet was confirmed. If these information about boundary condition are taken into numerical simulation, precision of analysis will be improved.

5 CONCLUSIONS

In order to investigate application Digital Image Correlation Method(DCM) to concrete, comparison with wire strain gauge and

Table3 Mixture proportion (kg/m^3)

Resin	Accele-rator	Agent	Filler
728	2.2	10.8	1091

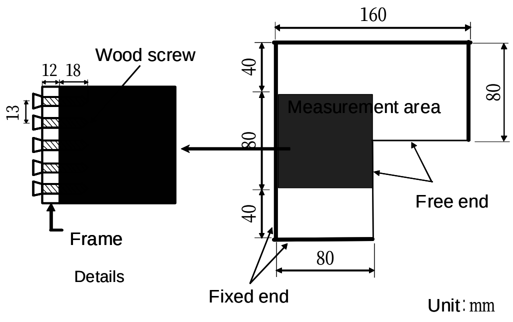

Fig.7 Outline of specimen

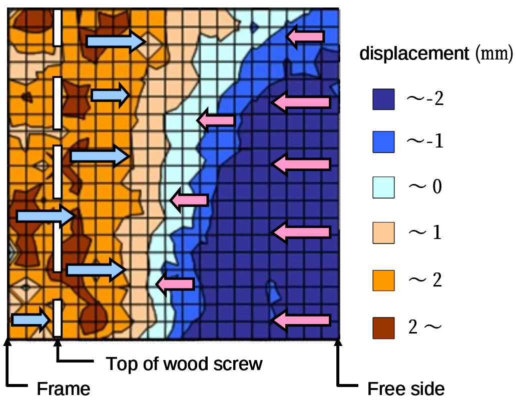

Fig.8 Displacement in x-direction

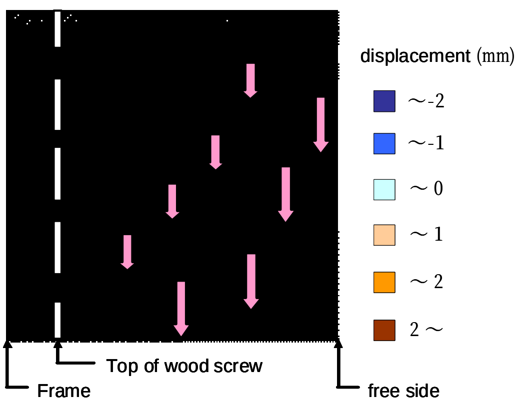

Fig.9 Displacement in y-direction

confirmation of boundary conditions in numerical analysis were conducted. The conclusions obtained from this investigation are lined up:

(1) The strain measured by DCM was affected by dispersion and size of aggregate, but that could be inhibited by enlarging the length of base line more than three times as large as maximum size of aggregate.

(2) The displacement near the steel mold could be determined by using DCM.

Experimental results from DCM can be applied to boundary conditions in numerical simulation; it is efficient scheme to improve precision of numerical analysis.

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