Proceedings, 11th FIG Symposium on Deformation Measurements, Santorini, Greece, 2003.

DEFORMATION DETECTION OF LIGHTWEIGHT CONCRETE BLOCK USING GEODETIC AND NON-GEODETIC METHODS

Halim Setan, Zainal Abidin Md Som & Khairulnizam M.Idris

Center for Industrial Measurement & Engineering Surveying
Faculty of Geoinformation Science & Engineering University Technology of Malaysia
81310 UTM Skudai Malaysia

Abstract

One of the main tasks in deformation monitoring is to investigate the movement or displacement that occurred to any structural object. The measuring techniques and the instruments used for such monitoring are categorized as geodetic and non-geodetic (i.e., geotechnical/structural) methods. A monitoring survey has been conducted in a laboratory to detect the deformation of a light weight concrete block which undergoes load testing. A number of target points on one surface of the concrete block has been monitored by triangulation survey using a total station. Five epochs of measurement have been obtained and each epoch was based on the load applied ranging from 0kN up to 358kN. The investigation is supplemented by data obtained from non-geodetic instrument (i.e., strain gauge). Results from such exercise indicate the practicality of the geodetic method in deformation detection for civil engineering application.

1. Introduction

In general, the deformation measurement methods can be divided into two categories namely the geodetic and non-geodetic. The geodetic method of deformation monitoring of any structural object involves determining the coordinates difference of object points measured from a reference network. The non-geodetic method employs specialized instrumentation which normally used by the geotechnical and structural engineers (Chrzanowski 1986, Teskey 1986). The geodetic method is very useful in giving a global deformation picture of deformation. While the non-geodetic method is benefit by providing measurement data at point where locality is not a problem.

The main aim of geodetic deformations analysis includes (Chrzanowski and Szostak, 1995);

a) geometrical analysis, which describe the geometrical status of deformable object, change in shape and dimensions (rigid body movement) of whole deformable object with respect to a stable reference frame,
b) physical interpretation which describe the state of internal stresses and the relationship between the causative factors and deformations.

Recently, a deformation measurement has been conducted to a lightweight concrete block (Fig 1) in conjunction with it's load test experiment. This research is a collaboration between Center of Industrial Measurement & Engineering Surveying (CIMES) and Laboratory of Material & Structural, Faculty of Civil Engineering UTM. This paper deals with geometrical deformation analysis of axial compression test applies to the lightweight concrete (Figure 1) using geodetic method. The study was supplement by non-geodetic data obtained using strain gauges.

Figure 1: Lightweight Concrete Block

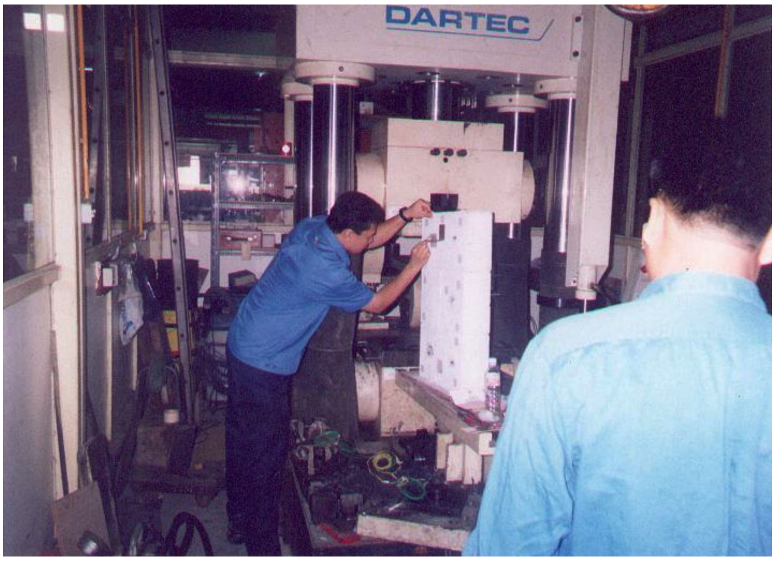

Figure 2: DARTEC Testing Machine

2. Source of deformation data

The concrete block used in this study has undergone an axial compression testing to determine its axial strength (Mokhtazul, 2002b). The axial compression experiment was performed by employing DARTEC testing machine (Fig. 2). An incremental series of loads in kiloNewton (kN) standard were utilized in the testing ranging from 0, 200, 258 300 and 375 kN respectively.

2.1 Geothetic method

The geodetic method of deformation measurement were carried out from a small survey network established within the laboratory (Fig 3). A number of object points were identified and marked with retro-tape target and glued on one side of the concrete block (Fig 4). The survey method utilized a conventional 2D measurements consist of bearing and distance observed using Total Station. A total of five epoch of measurements were observed and each epoch was identify based on the load utilized during the testing (i.e., 0kN, 200kN up to 375kN).

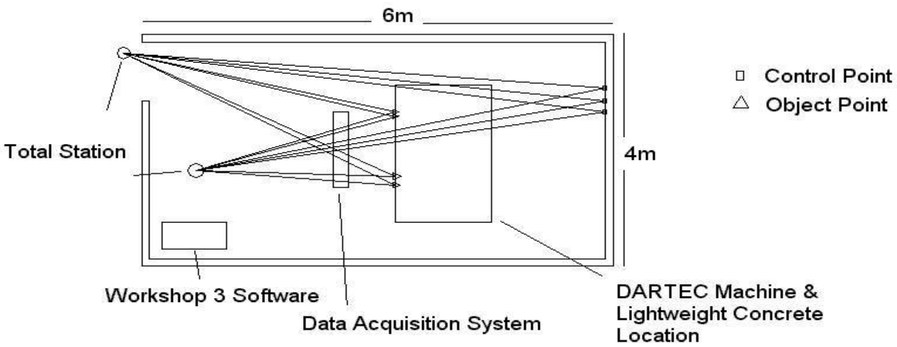

Figure 3: Sketch of the geodetic deformation network established in the laboratory

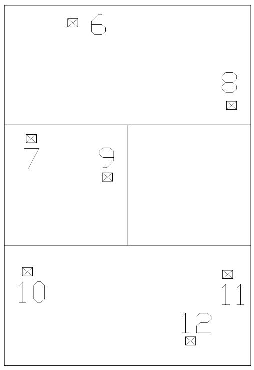

Fig 4: Distribution of object points on the concrete block

2.2 Non – geothetic method

In addition to conventional survey observations measurement by non-geodetic technique was also performed to the lightweight concrete block. The non-geodetic scheme involves strain measurement at a number of points on the concrete block. The instrumentation used in collecting the non-geodetic data is the Data Acquisition System consists of Electrical Resistance Strain (ERS) together with the Linear Variable Displacement Transducer (LVDT) as shown in Figure 5. The Electrical Resistance Strain are connected to high speed multi-channel data logger for measuring strain, load pressure and voltage or thermocouple. All measurements are in real-time mode. Figure 6 shows location of the Electrical Resistance Strain points on the lightweight concrete block.

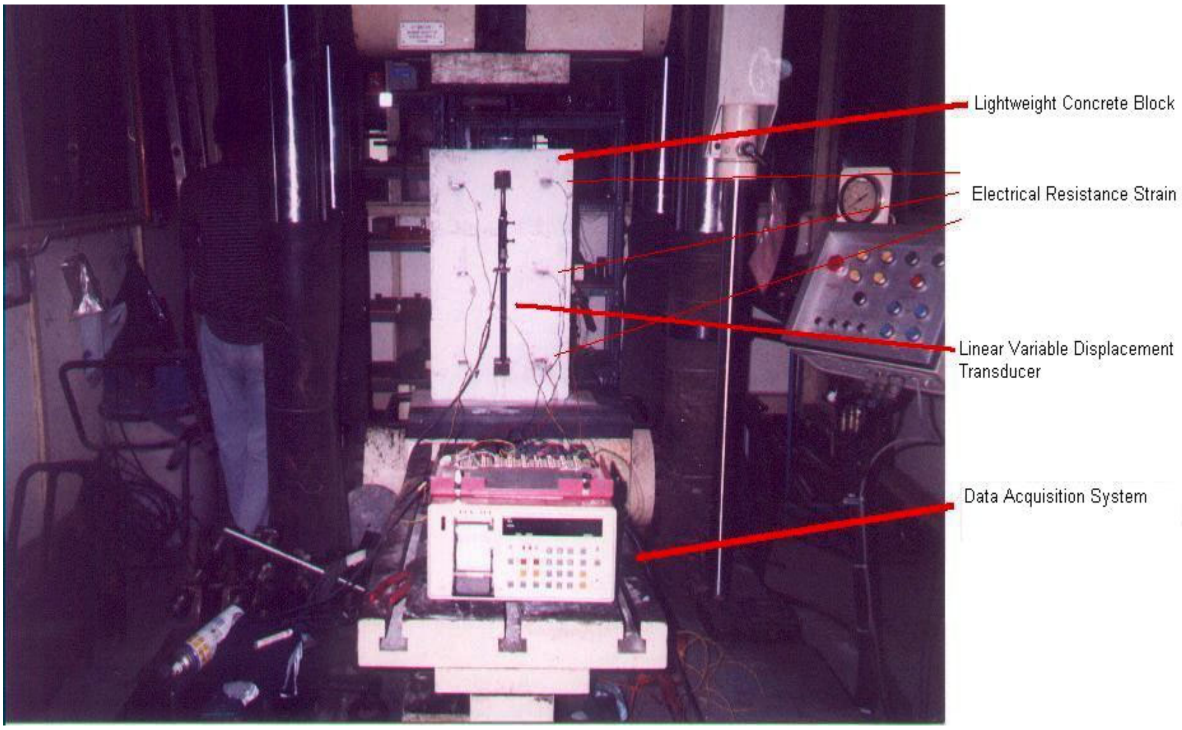

Figure 5: The set-up of Non-Geodetic Instrumentations

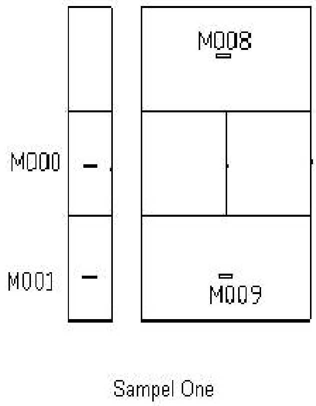

Figure 6: Location of Electrical Resistance Strain (ERS) points

3. Mathematical formulation

3.1 Network adjusment

The measured data (e.g, directions and distances) are being related to the parameter (coordinates) by mathematical relationship called the functional model and expressed as (Cooper, 1987; Harvey, 1990);

$$l = f(x) \qquad [1]$$

$$\hat{v} = A\hat{x} + b \qquad [2]$$

where, $\hat{v}$ is the vector of residuals, $\boldsymbol{A}$ is the design matrix, $\hat{x}$ is the vector of corrections to the approximate value and b is the misclosure vector. The normal equation with a full rank can be written as;

$$N\hat{x} + U = 0 \qquad [3]$$

and solution for $\hat{x}$;

$$\hat{x} = -N^{-1}U = (A^T PA)^{-1} A^T \qquad [4]$$

In general, least square estimation suffers from rank deficiency due to configuration or datum defect. As a solution, datum defect are overcome by means of constraints. Normally, the common choice of datum for the monitoring network are minimum constraint, minimum trace and partial minimum trace. In this particular work, the method of minimum constraint was chosen as datum definition.

3.2 Deformation detection

The deformation detection required in this work was carried out by employing the congruency approach (Caspary 1987). The objective of a congruency test is to detect whether or not the point group in a deformation network has remained stable. The test is based on F-statistic, which requires the computation of pooled variance of the epoch and statistical test. Basically the adopted procedure of congruency testing consists of the following (Caspary, 1987; Halim, 1995);

a) Transformation of the displacement vector and its cofactor matrix for both epoch into a common datum.
b) Determination of stable datum points by congruency testing;

$$\omega = \frac{\Omega}{\left(h \bullet \hat{\sigma}_o^2\right)} = \frac{d_2'^T Q_{d_2}'^+ d_2'}{\left(h \bullet \hat{\sigma}_0^2\right)} \sim F\left(\alpha, h, \partial f\right) \qquad [5]$$

where;

$d_2' =$ displacement vector and its cofactor matrix of the common datum point in both epoch.

$Q_{d_2}' =$ cofactor matrix for displacement vector d_2'.

$\hat{\sigma}_o^2 = \dfrac{\left[\left(\hat{\sigma}_{o1}^2\right)\left(df_1\right) + \left(\hat{\sigma}_{o2}^2\right)\left(df_2\right)\right]}{df}$, pooled variance factor.

$\hat{\sigma}_{o1}^2$, df_1 = aposteriori variance factor and the degree of freedom in epoch 1

$\hat{\sigma}_{o2}^2$, df_2 = aposteriori variance factor and the degree of freedom in epoch 2

$Q_{d_2}'^+ = \left(Q_{d_2}' + GG^T\right)^{-1} - G(G^T GG^T G)^{-1} G^T$, the pseudo inverse.

$h =$ rank $\left(Q_{d_2}'\right) = \left(2n - d\right)$ for 2D network with n number of common point and d number of datum defect.

c) Localization of deformation through single point test, S-transformation and congruency testing.
d) Final testing on all common points by single point test.

$$T_j = \frac{\Omega}{2 \bullet \hat{\sigma}_o^2} = \frac{d_{3j}^T Q_{d_{3j}}^{-1} d_{3j}'}{2 \bullet \hat{\sigma}_o^2} \sim F\left(\alpha, 2df\right) \qquad [6]$$

4. Results and analysis

4.1 Results of the geothetic method

All computations for geodetic method has been solved by utilizing a computer package DEFORM99 developed at the CIMES, University of Technology Malaysia. In DEFORM99, the least square estimation employs minimum constraint datum definition, the deformation detection is using congruency testing and the graphic presentation module is link with AutoCAD.

The deformation detection of the monitoring network consists of 13 points, i.e. 5 reference points (1,2,3,4 and 5) and 7 object points (6,7,8,9,10,11 and 12) were done on a two-epochs basis. Each measurement epoch consists of 22 directions and 15 horizontal distances. A total of five epochs of measurement data were gathered based on the load-test applied to the concrete block (i.e., 0kN, 200kN, 258kN, 300kN and 375kN). Finally, the deformation analysis was only concentrated between the first and the last epochs of measurement (i.e., 0kN and 375kN loads). The summary of the least squares adjustment details are given in Table 1.

	0kN	**375kN**
Datum definition	x_1, y_1	x_1, y_1
No of Observations	37	37
Degrees of Freedom	15	15
Aposteri variance factor	0.448917	0.458043
Global Test	0.245 < 1 < 1.075	0.250 < 1 < 1.097
Critical value Pope Tau & Local test	2.8198 All Passed	2.8198 All Passed

Table 1: Least squares estimation output

The displacement vector of the reference points and the object points of the lightweight concrete are determined by using congruency testing with points 1,2,3,4 and 5 defined as datum and the results is tabulated in Table 2 below.

Object Point	Displacement Vector (m)		
	0kN & 200kN	0kN & 258kN	0kN & 375kN
6	0.001	0.0012	0.0011
7	0.0025	0.0026	0.0044
8	0.0041	0.0065	0.0093
9	0.0046	0.0047	0.008
10	0.0012	0.0121	0.0026
11	0.0012	0.0118	0.0039
12	0.0044	0.0173	0.0075

Table 2 : Displacement Vector

4.2 Results of the non - geothetic method

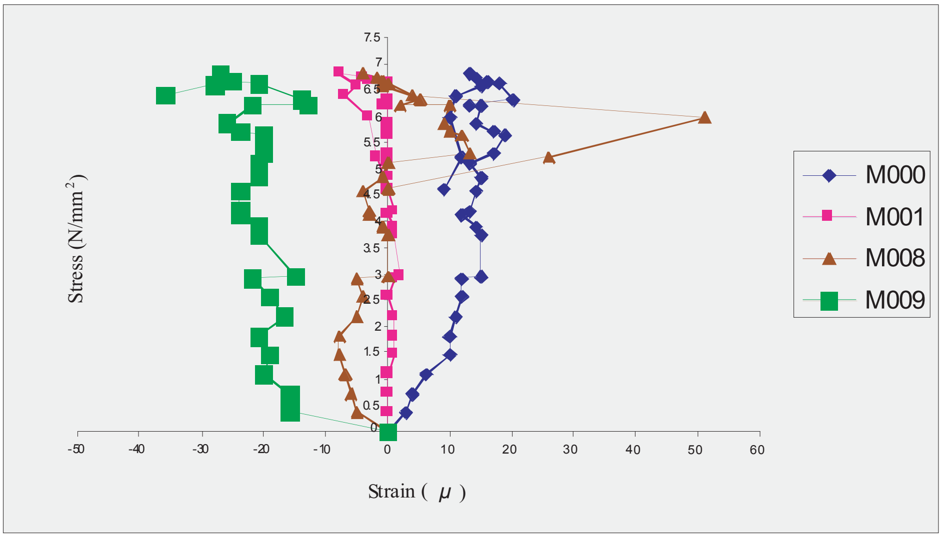

Figure 7: Strain-Stress relationship of the surface of lightweight concrete

The data obtained using non-geodetic technique (i.e., strain gauges) are able to provide a supplement view on deformation and the behavior of the lightweight concrete block. This information is the form of strain-stress relationship as shown in Fig 7. Strains are found critical at the top and bottom of the block (M008 and M009) and reduce strain at the side of the block (M000 and M001). This is happening because the unit block expanded when it was constructed.

5. Conclusion

The ability of surveyors to provides other profession such as civil engineer, a graphical presentation of displacement vector of the monitoring object is very meaningful. For example, results of this particular monitoring works (Fig 8) were given to civil engineering colleagues. Such results will then enable them to visualize the movement trend of the lightweight concrete block which undergone the axial compression testing.

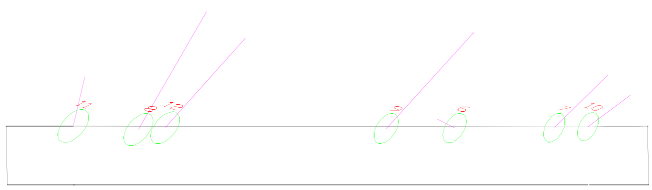

Figure 8: Displacement vector of object points on the concrete block

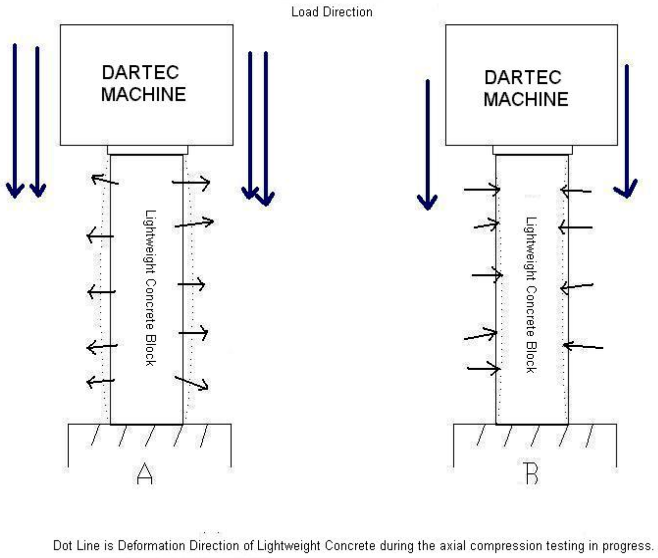

Figure 9: Direction of concrete block during the test

Theoretically, due to axial compression the lightweight concrete will expand in the way shown graphically in Fig. 9 (picture A). On the other hand, if the movement of the concrete block occurs as in picture B it implies that either the geodetic monitoring results was wrong, or there could be wrong in designing the concrete block or mislaid of the concrete block on the DARTEC machine. Therefore, results obtained in this work is agreed to what is expected by judging the deformation vector obtained by geodetic method as indicated in Fig 8.

Acknowledgement

This work is part of a research project sponsored by the Ministry of Science and Technology, Malaysia under IRPA Program (Vote 74156).

References

Bruce R. Harvey (1990). "Practical Least Square and Statistics for Surveyor." School of Geomatic Engineering, The University of New South Wales. *Monograph* 13

Chrzanowski, A. (1986). "Geotechnical and other non-geodetic method in deformation measurement. " In: *Proceedings of the Deformation Measurement Workshop*. Oct 31 – Nov 1, Ed: Yehuda Bock, Massachusetts Institute of Technology, Cambridge, MA. pp. 112-152

Chrzanowski, A., Chen, Y.Q. & Secord, J.M (1986). "Geometrical Analysis of Deformation Surveys." In: *Proceedings of the Deformation Measurement Workshop*. Oct. 31 – Nov. 1, Ed: Yehuda Bock, Massachusetts Institute of Technology, Cambridge, MA pp 170 – 206

Cooper, M.A.R. (1987). "*Control Surveys in Civil Engineering*.' London: William Collins Sons & Co. Ltd

Chrzanowski, A. & Szostak-Chrzanowski, A. (1995). "Identification of Dam Mechanism." The MWA International Conference on Dam Engineering, Kuala Lumpur, August 1995.

Caspary, W. F. (1987). "Concept of Network and Deformation Analysis." School of Surveying, The University New South Wales, Monograph 11.

Halim Setan (1995). "Functional and Stochastic Models for Geometrical Detection of Deformation In Engineering: A Practical Approach." *PhD Thesis*, City University.

Ranjit Singh (1999). "The Adjustment and Analysis of a Monitoring Network for the Purpose of Geometrical Deformation Detection." *MSc Thesis*, University of Technology Malaysia.

Teskey, W.F. (1986). "Integrated analysis of deformation." In*: Proceedings of Deformation Measurement Workshop*. Oct 31 – Nov 1, Ed: Yehuda Bock, Massachusetts Institute of Technology, Cambridge, MA pp. 221-233