論 文

[2140] MEASUREMENT OF INELASTIC FLEXURAL DEFORMATION AT A CRACK IN A BEAM

Tamon Ueda* and Muhammad Akram Tahir**

1. INTRODUCTION

Deflection of a flexurally cracked beam is usually estimated by assuming averaged flexural stiffness over cracked zone like in the Branson's formula. Actual stiffness along beam axis, however, varies greatly. Rotation at a crack is quite different from that between cracks. How to estimate the rotation at a crack has not been commonly known yet because there is lack of experimental data largely due to difficulty in measurement of the rotation at a crack.

Recently a kind of optical metrology, "laser speckle technique", has been applied to measurement of concrete displacement [1]. In laser light natural roughness of surface, like concrete surface, produces speckle, which is very strong contrast of light. When speckle is photographed, the image of a speckle is a pin hole on a film. If the film is double-exposed before and after movement of the concrete surface, the speckle images on the film cause an interferometry phenomenon, called Young's fringe. Magnitude and direction of the movement of the concrete surface can be measured from spacing and direction of the Young's fringe [1][2].

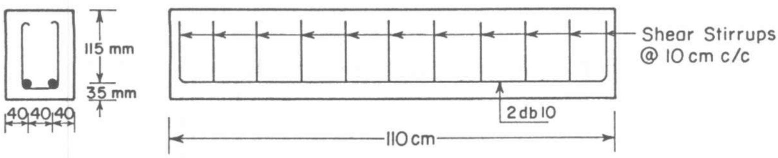
The laser speckle technique enables to measure displacement at any point in a plane. When displacement needs to be measured at a very small interval or when location of measuring displacement is uncertain, the laser speckle technique becomes a powerful tool. The measurement of rotation at a flexural crack, which is considered to be localized at the crack, is the case in which the measurement at a very small interval is vital.

2. OUTLINE OF EXPERIMENT

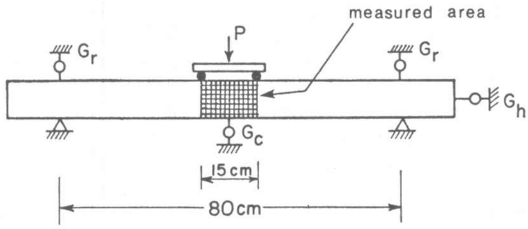
The specimen tested is shown in Fig.1. The concrete cylinder strength was 20MPa and the yield strength of deformed bar was 276MPa. The specimen was loaded with a displacement control testing machine in a dark room. The laser speckle technique was applied to measure displacement of concrete surface (150x150mm) at central part of the span. The grid of 6mm spacing was printed on the specimen's surface before loading, so that points for measurement could be specified easily. Loading was stopped at every 150-200μm of the vertical deflection of the specimen at center in order to take pictures of speckle as well as to measure the deflection at the span center and

* Department of Civil Engineering, University of Tokyo, Tokyo, Japan
** Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan

rigid body movements by dial gages as shown in Fig.1. The measured displacement by the laser speckle technique is an increment of the displacement. Therefore total displacement is to be computed by summing all the increments.



(a) Detail of the Beam Tested



(b) Set up of the Test

FIG.1 Test specimen

3. TEST RESULTS AND DISCUSSION

There was only one flexural crack in the beam which appeared at the span center. The cracking moment was 0.9kN-m and the beam was loaded up to 3.4 kN-m, which is less than the predicted flexural strength of 4.15kN-m. Actually failure of the beam was not reached.

Fig.2 shows the relationship between external moment and deflection at the center of span. The deflection measured by the laser speckle technique is very close to that measured by the dial gage. This fact indicates that the laser speckle technique is reliable to measure the

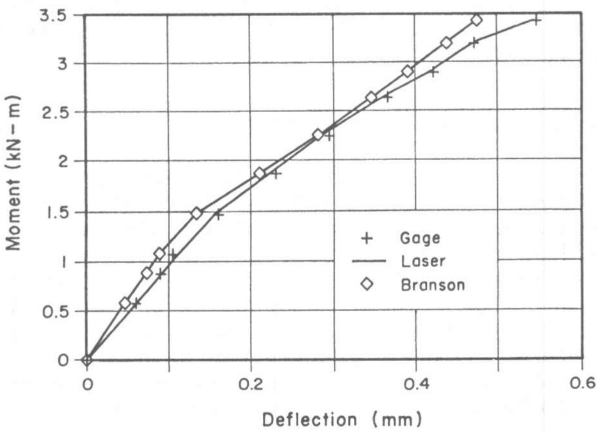


FIG.2 Relationship between moment and total deflection

vertical deflection of the beam. It can be seen in Fig.2 that those measured deflections are greater than the deflection predicted by the Branson's formula.

One of the advantages with the laser speckle technique is that measurement at a small interval is possible. Fig.3 indicates variation of the total deflections measured at the same height along the beam axis at three moment levels, 1.15, 2.25 and 3.4kN-m. The points to measure deflection were taken at an interval of 6mm, but only some points are indicated in Fig.3. The deflected configurations measured along horizontal lines of different heights were observed to be nearly the same.

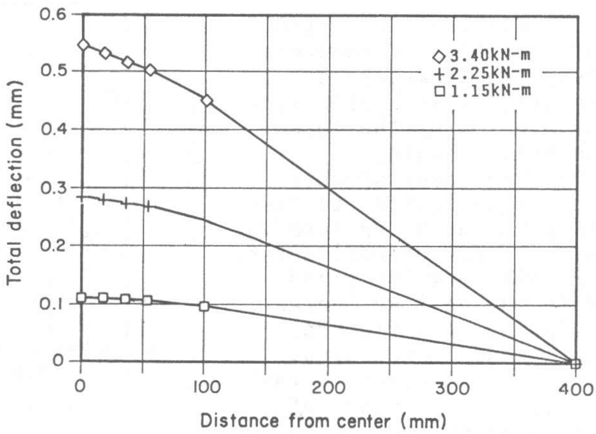


FIG.3 Distribution of total deflection

Inelastic deflection can be estimated by subtracting calculated elastic deflection from the total deflection. Elastic modulus of concrete was calculated by the ACI equation, $E_c=4730\sqrt{f_c'}$ (MPa). The distribution curves of inelastic deflections along the beam axis are given in Fig.4. It can be said that the deflected configurations are almost linear, which means that most of the inelastic component of the deflection is caused by the inelastic rotation right at cracked section. The range of inelastic rotation seems to be widened for a great moment because a knee point can be seen on the top curve in Fig.4.

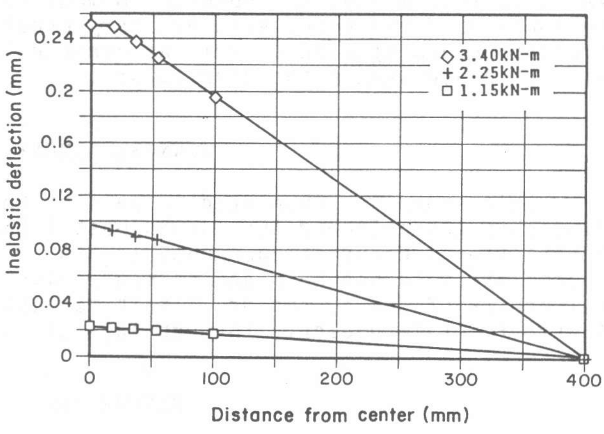


FIG.4 Distribution of inelastic deflection

Inelastic rotations were calculated from the measured deflection distribution curves by taking differences in slope of the curves as shown in Fig.5. The calculated inelastic rotations indicate the applicability of the laser speckle technique.

4. CONCLUDING REMARKS

(1) Flexural deflection of a reinforced concrete beam can be measured accurately with precision of 0.001mm by the laser speckle technique.
(2) The laser speckle technique enables to take measurement at an interval of a couple of millimeter, so that very localized deformation like inelastic rotation at a flexural crack can be measured.
(3) It was observed that inelastic component of flexural deflection in the tested beam was caused by very localized deformation, called inelastic rotation right at a flexural crack.

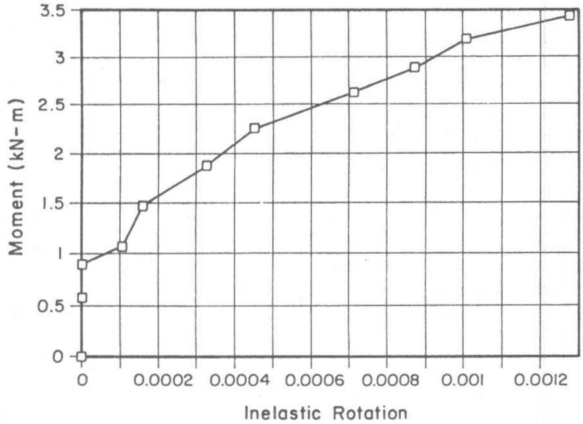


FIG.5 Relationship between moment and inelastic rotation at a crack

To know the relationship between moment and rotation (or moment and curvature) at a flexural crack is very important to estimate flexural deflection. Since the observed crack spacing was unusually large in this study, the observed moment-rotation relationship may not be applied to the cases with ordinary crack spacing. The results with ordinary crack spacing as well as crack height-rotation relationship will be presented in the near future.

ACKNOWLEDGMENT

This study was supproted in part by the research grants from Deutscher Akademischer Austauschdienst (DAAD) and Japan International Cooperation Agency (JICA). The authors greatly appreciate valuable help and comments given by Dr. Hideyuki Horii, University of Tokyo, and Mr. Tirath Manojya Pallewatta, Asian Institute of Technology, through this study.

REFERENCES

1) Jacquot, P. and Rastogi, P. K.: Speckle Metrology and Holographic Interferometry Applied to the Study of Cracks in Concrete, Fracture Mechanics of Concrete, edited by F. H. Wittmann, Elsevier Science Publications B. V., Amsterdam, 1983, pp. 113-155.
2) Ichinomiya, T.: Analytical Model of Fracture Process Zone and Observation by Laser Speckle Method, Master Thesis, submitted to University of Tokyo, March 1989 (in Japanese).