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Authors	S. Hayasaka, N. Chijiwa, M. Iwanami
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Development of a New Simple Method to Evaluate the Remaining Pre-Stress in PC Structures

S. Hayasaka
Tokyo Institute of Technology, Tokyo, Japan, hayasaka.s.aa@m.titech.ac.jp,

N. Chijiwa
Tokyo Institute of Technology, Tokyo, Japan, chijiwa@cv.titech.ac.jp,

M. Iwanami
Tokyo Institute of Technology, Tokyo, Japan, iwanami@cv.titech.ac.jp

Abstract

The number of aged infrastructures is increasing rapidly in Japan, although the budget of maintenance is reducing. Developing more rational maintenance techniques is strongly required. Pre-stressed Concrete (PC) structures have been widely used because of its economic efficiency. If their PC cable is corroded by salt attack or poor grouting operation, introduced pre-stress is decreased with section loss of PC cable. As pre-stress loss may lead sudden failure of the structure in the worst scenario, monitoring remaining pre-stress is important for safety. There are several methods to detect the defect positions of PC cable, for example, drilling the hole, X-ray transmission and impact echo. A method of measuring working stress in PC structures is also developing. However those methods need special equipment and skills, and their searching area is limited. This research aims to propose a new simple method to roughly detect the defect position of the PC cable by evaluating the remaining pre-stress in PC structures. The proposed method utilizes the volume expansion of concrete due to water absorption and detects the defect position through examining remaining pre-stress by the trend of the volumetric change.

In the elemental experiment with a small scale specimen kept under the uniaxial stressed condition, the expansive strains of specimen surface are measured just after spraying water. The result is that, 20 micro difference between the strain in the pre-stressed direction and the strain in perpendicular to the pre-stressed direction is observed. In case of no pre-stressed condition, the volume expansion by spraying water is approximately same in the both direction. The result of the elemental experiment was confirmed by multi-scale analytical system (DuCOM-COM3). This analysis result also showed approximately same trends of the result of elemental experiment. These results demonstrate feasibility of our proposed new simple evaluating method by means of measuring the trend of volumetric change on concrete surface. The difference in the volume expansion under different stress conditions is not so large, but it can be a clue to detect the defect position of PC cable by evaluating the restraining effect of residual pre-stressing force in PC structures.

1. Introduction

Pre-stressed Concrete (PC) structures have been widely used because of its economic efficiency. If their PC cable is corroded by salt attack or poor grouting operation, introduced pre-stress is decreased with section loss of PC cable. As pre-stress loss may lead sudden failure of the structure in the worst scenario, monitoring remaining pre-stress is important for safety. There are several methods to detect the defect positions of PC cable, for example, drilling the hole, X-ray transmission and impact echo [1]. A method of measuring working stress in PC structures is also developing [2]. However those methods need special equipment and skills, and their searching area is limited. This research aims to propose a new simple method to roughly detect the defect position of PC cable by evaluating the restraining effect of residual pre-stressing force in PC structures.

2. Mechanisms of proposed new simple evaluating method

Healthy PC structures are kept under pre-stressed condition by PC cables. This pre-stress restrains the volumetric changes of concrete in the direction of the pre-stress. The restraining effect of the concrete disappears finally when some defects occur in PC cables. These pre-stressed or no pre-stressed conditions can be judged by the volume expansion of concrete due to water absorption. In the direction of pre-stress, if the volume expansion of concrete members is restrained, the PC structure is in healthy condition. When the volume expansion of concrete is comparatively larger than that of healthy condition, it means that the PC structure loses pre-stress. The proposed method utilizes the volume expansion of concrete due to water absorption and detects the defect position of PC cable through examining remaining pre-stress by the trend of the volumetric change.

3. Elemental experiment and analysis

Elemental experiment and analysis confirmed the restraining action by pre-stress of volumetric expansion of concrete on a small prism specimen. The strains in the axial direction (same direction as compressive stress) and the strain in perpendicular to axial direction are measured for catching the restraining effect of volumetric expansion due to water absorption.

3.1 Experimental method

100×100×200mm specimen made by W/C=55% concrete was prepared. After 7 days sealed curing at 20 °C, the specimen was set in 60°C and RH=10% room till starting of experiment. 30mm waterproof strain gauges were attached for measuring the expansion strain of concrete surface. The strain gauges were put on the concrete surface (**Figure 1**). Uniaxial stress was applied sustainably as pre-stress to 100×100mm surface of specimen. This uniaxial stress was 30% of compressive strength, 35.3N/mm^2. The value of 30% was determined for observing restraining effect on clearly without introducing micro cracks in the specimen. A specimen surface attached strain gauges was kept wet for 20 minutes by spraying water.

3.2 Analysis method

A numerical analysis with 'DuCOM-COM3' [3] system is conducted to understand the behavior of specimen deeply. DuCOM-COM3 system is the integrated FE analytical system composed of DuCOM system and COM3 system. DuCOM is an integrated thermos-hygral analysis model that includes cement hydration in concrete mixture, micro-pore structure of formation and mass transport models for concrete ranging from the 10^{-3} to 10^{-9} meter scales of micro-pores, while COM3 is a 3D finite element analysis platform for structural concrete with and without cracks. As a result, the linked system is capable of predicting changes in concrete material properties from casting to dismantling of entire structures and taking this material development into account for predicting the response of structural concrete. Through such integration, the long-term structural response under actual ambient conditions can be simulated in a more realistic manner.

In the simulation, the modeled specimen is kept under the same temperature and same humidity condition with experiment. The strain in axial direction and the strain perpendicular to axial direction on the concrete surface were calculated from the relative displacement of the nodes which are 15mm distance from center of the side surface. Uniaxial stress is 30% of compressive stress on pre-stressed condition. Volumetric expansion of concrete due to water absorption is simulated by raising water vapor pressure in surface nodes and opposite of driving force of drying shrinkage.

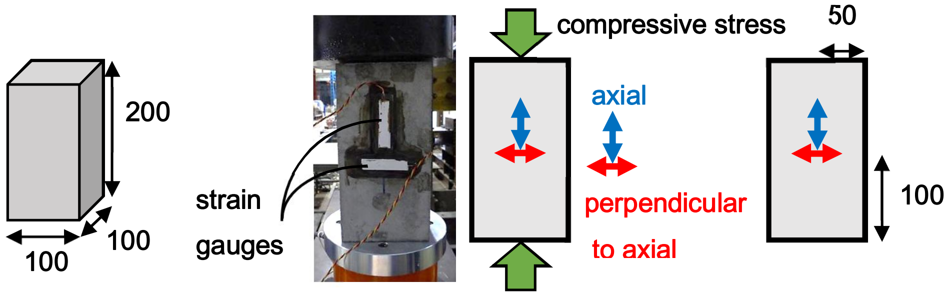

Figure 1: Specimen size, appearance of experiment and attached positions of specimen surface [mm]

3.3 Results of elemental experiment and analysis

Figure 2, 3 show the results of elemental experiment and analysis. Their original points of time is starting time of spraying water to one surface of specimen. In vertical axis of those figures, positive number means expansive strain.

In the experimental result under pre-stressed condition, 20 micro difference between the strain in the pre-stressed direction and the strain in perpendicular to the pre-stressed direction is observed. The axial strain of pre-stressed condition decreases by creep due to uniaxial stress after 5 micro expansion. In case of no pre-stressed condition, the volume expansion by spraying water is approximately same in the both direction. Both trends mean that uniaxial stress restrains volume expansion of concrete.

Analytical results show approximately same trends as experimental results. Under pre-stressed condition, the axial strain does not show sharp increase at starting of spraying water because of loading surface fixed in the direction of pre-stress by loading plate. The axial strain increases gradually with water absorption for 20 minutes. Under no pre-stressed condition, we can see initial increase in strain of the both direction due to water absorption. However the axial strain is only half of expansion of perpendicular to the axial direction strain, and no increase is observed after the first sharp increase in strain. A major cause of this trend is volume constraint due to aspect ratio the axial to perpendicular to the axial length of model of specimen.

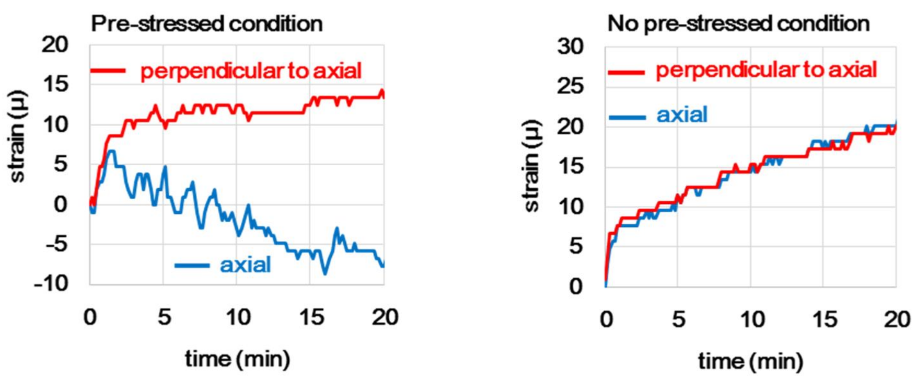

Figure 2: Results of elemental experiment

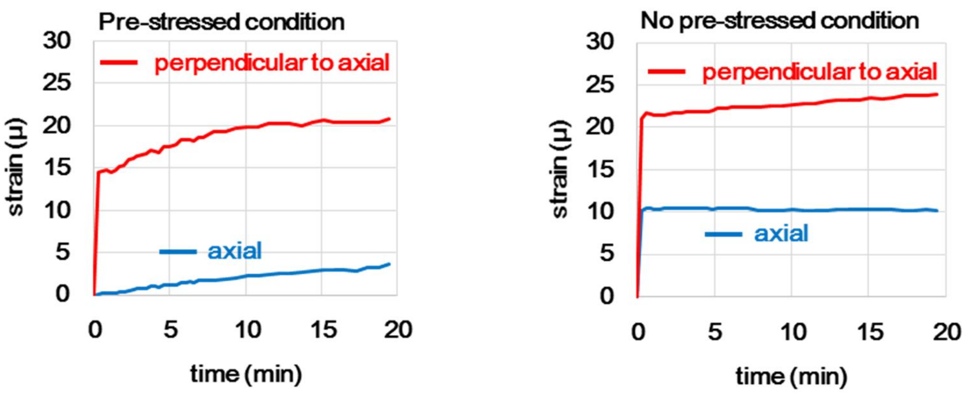

Figure 3: Results of analysis

4. Conclusions

By simulating pre-stressed condition, experimental and analysis results confirm that pre-stress restrains volumetric expansion of concrete due to water absorption in the direction of pre-stress. These results demonstrate feasibility of our proposed new simple method to evaluate the remaining pre-stress in PC structure by means of measuring the trend of volumetric change of concrete. The difference in the volume expansion under different stress conditions is not so large, but it can be a clue to detect the defect position of PC cable.

5. Future works

For confirming the validity of this method, elemental experiment and analysis focusing dominant parameters of specimens, for example W/C, size, aspect ratio, existence of steel bars, wetting and drying state and compressive stress as pre-stress are necessary. On the basis of results of elemental experiment, models of PC structure member specimens introduced pre-stress by PC cable are designed and measured the trend of strain in the both direction. In addition, we need to conduct same experiment to elemental experiment and confirm applicability of our proposed evaluating method on actual PC structures by evaluating the remaining pre-stress in PC structures.

6. References

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