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AUTOMATIC CONTROL OF SECONDARY FLEXURE IN UNIAXIAL TENSILE TEST OF CONCRETE

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ABSTRACT

When a uniaxial tensile test is performed to investigate tension softening behavior of concrete, a secondary flexure occurs inevitably because of the heterogeneous nature of concrete, even in the case of no eccentricity in the applied load. The secondary flexure causes a significant reduction in the observed peak load, and then makes the estimated observed tensile strength unreliable. Therefore, the prevention of the flexure occurrence is essential to obtain reliable experimental results. In order to meet this requirement, the authors have developed a unique test procedure, which consists of a manually operated adjusting gear system. Although the system has provided successful and informative results, it also has an intrinsic drawback, i.e. human related malfunction. The main objective of this study is to establish and to qualify automation for the prevention of the secondary flexure, using computer-controlled DC motors instead of manual operations. Consequently, the application of the automatic system on the uniaxial tensile test not only provides better test results but also reduces long time efforts.

KEYWORDS

Uniaxial tension, tension softening, secondary flexure, automatic control, test method, concrete

INTRODUCTION

The information of tension softening process is essential to analyze fracture behavior and to estimate concrete properties. One of the best ways to investigate the tension softening process is testing under uniaxial tensile loading because of simultaneous investigation of tensile strength and softening curves from single specimen. Additional tests or calculations, for instance the inverse analysis, are not required for the uniaxial tensile test. The authors had developed and reported a unique test procedure of uniaxial tensile test for concrete [1]. This test procedure provides solutions for four common problems of the test, such as unstable fracture, secondary flexure, multiple cracks and overlapping cracks. First, the problem of unstable fracture can be avoided by employing a deformation-controlled loading process with an appropriate measuring length. Second, a secondary flexure caused by heterogeneous nature of concrete as well as unpredicted flexures due to load eccentricity are eliminated by equalizing reciprocally opposite lateral elongations. For this purpose, a specifically designed manual-operated adjusting gear system was developed. Next, multiple cracks are prevented by the application of primary notches on the middle of two identical laterals of a specimen. At last, overlapping cracks are avoided by adopting additional notches, called a guide notch, on the middle of other sides (cast and bottom laterals).

The prevention of the secondary flexure is the most significant among these four problems because the flexure, if it occurs, reduces the measured peak load up to 20%. Nevertheless, many researchers have paid little attention on the importance of the effect of the secondary flexure [2,3] or have sometimes failed in the prevention of it mainly because of insufficient experimental apparatus [4,5]. Thus, the main issue of this study is to establish the test procedure to prevent the secondary flexure in uniaxial tensile test of concrete.

MANUALLY OPERATED ADJUSTING GEAR SYSTEM

A secondary flexure is denoted as the induced flexure (namely lateral flexing) originated fundamentally in the heterogeneous material aspect of concrete. Even when there is no eccentricity in the applied load, the secondary flexure will occur. General causes of the secondary flexure are the effects of local softening at the weakest zone of a specimen and of non-symmetrical arrest of propagating cracks by aggregates. The secondary flexure produces strain gradient, making one half portion softened but the opposite half contracted relatively within the cracked section. The cohesive stresses in the softened zone decrease a little to compare with tensile strength, while the stresses at the opposite side are reduced much due to superposition of compressive stress by the flexure, as illustrated in Figure 1. Therefore, the peak load, which is the resultant force of these tensile stresses along the cross section, decreases considerably.

In order to control the secondary flexure, a specifically designed adjusting gear system was attached as illustrated in Figure 2. When a certain side of a testing specimen is elongated more than the opposite side, the longer side is contracted by manual turns of the adjusting gear on that side until balancing elongations, while the opposite side gear should be released completely. If the elongation of a certain side becomes longer than the opposite when the opposite side gear have already been tightened, the tightened side should be released until the balance. Without this release, the deformation of a specimen is too restricted to express a real softening phenomenon. When the measuring length of deformation is 70 mm and the maximum limit of the deformation is 0.35 mm, the four side deformations are monitored by a digital strain meter with the resolving power of 1 $\mu\varepsilon$. For the manual operation, it is inevitably required to use a human labor for continuous monitoring and controlling.

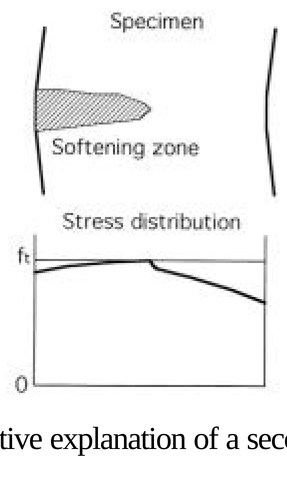


Figure 1: An illustrative explanation of a secondary flexure

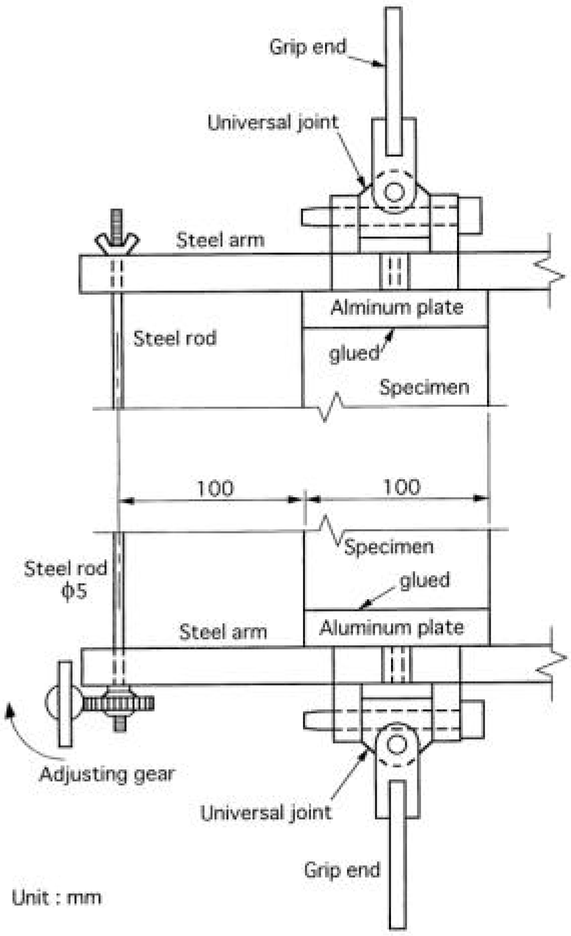
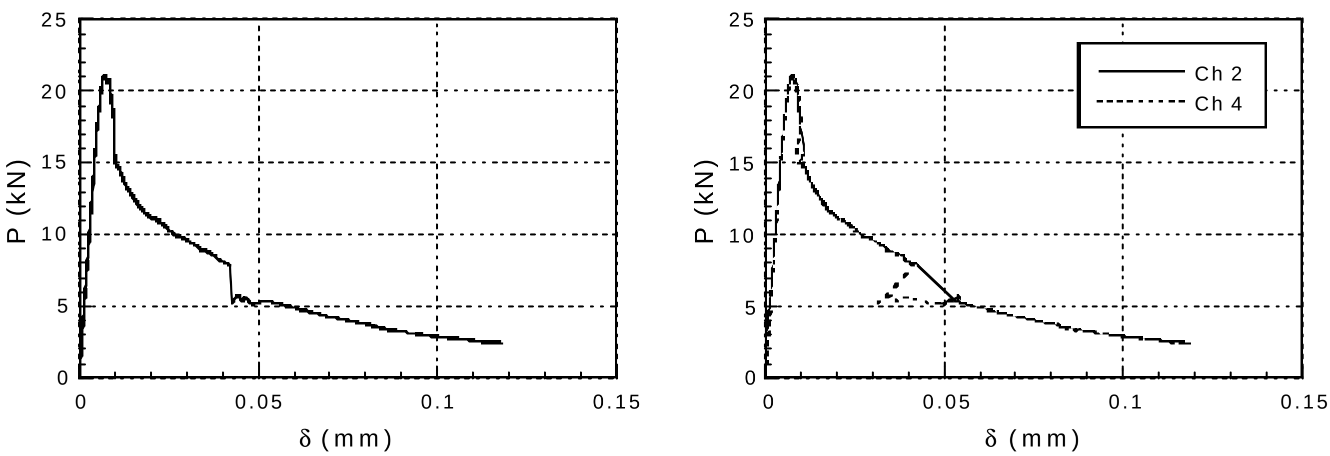


Figure 2: Apparatus to prevent secondary flexure



(a) average deformation (b) individual deformation of ch-2 and ch-4

Figure 3: Load-deformation curves by manual control

PROBLEM OF MANUAL OPERATION

Although the test procedure, mentioned in the previous section, shows great improvements of the uniaxial tensile test and provides much reliable information of tensile behavior of concrete, it has an inevitable weakness– employment of human operators as a kind of a controller. Outputs could sometimes be different even if ideally identical concrete specimens were tested because the controlling patterns of human operators would be varied with respect to operator's skill and character, or date and time of testing. Fig. 3 shows the worst test result due to the mistake in the manual control. The radical drop at around δ=0.04 mm on the load-deformation (P-δ) curve in 3 (a) and corresponding contorted individual P-δ curves in 3 (b) might not be caused by the testing material itself but by the human mistake in controlling the adjusting gear. Thus, in order to establish fundamental and scientific basis for the test procedure, the kind of any uncontrolled and unpredicted factors should be excluded, and thus the development of an automatic adjusting gear system is required.

AUTOMATIC ADJUSTING GEAR SYSTEM

In order to improve manual operation, an automatic control system was developed. One DC 6V and 60 rpm motor controlled by a computer program is attached to each adjusting gear. The schematic diagram and photograph of the automatic system are shown in Figure 4 and 5, respectively. Figure 4

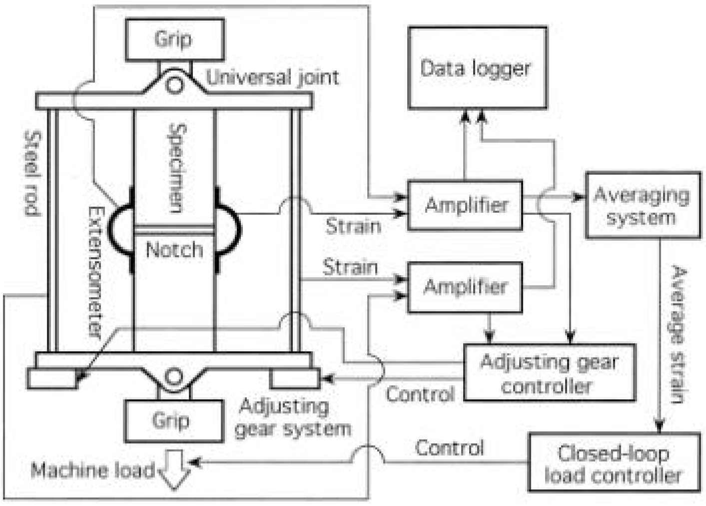


Figure 4: Controlling and recording system

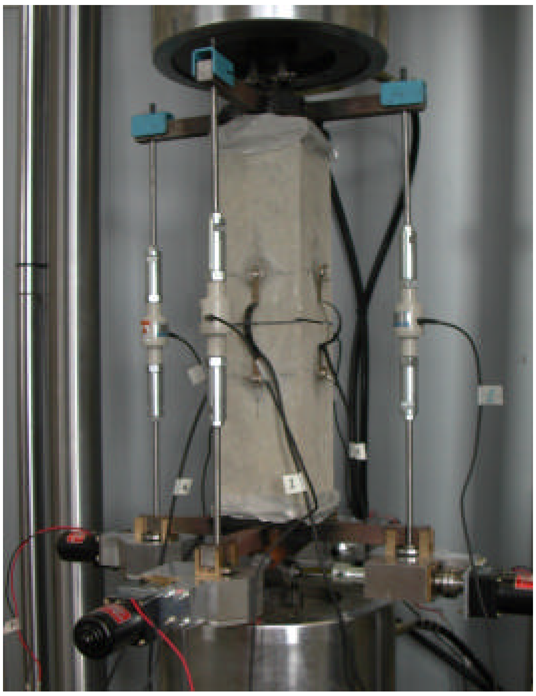


Figure 5: Experimental set-up

and 5 show upper and lower grips of loading machine, a prismatic specimen with notches, extensometers crossing the notches, load-cells connecting to rods and the adjusting gear system with motors. The only difference between the manual and the automatic system is the type of the adjusting gear controller in the Figure 5. The controller was human labor for the manual system, while that was a set of motors (See Figure 5) and a computer system. Both four side strains of the specimen and four strains of steel rods in the gear system are reflected for the control. The DC motor employed rotates clockwise or counterclockwise without speed variations. The computer program that controls the rotation of motors was written in the BASIC language, and the time duration of one cycle is 0.04 second. The algorithm of the computer program is shown in Figure 6. The motors begin to round when the deformation difference (Dif) exceeds a threshold (D), and an adjusting gear is judged whether it is

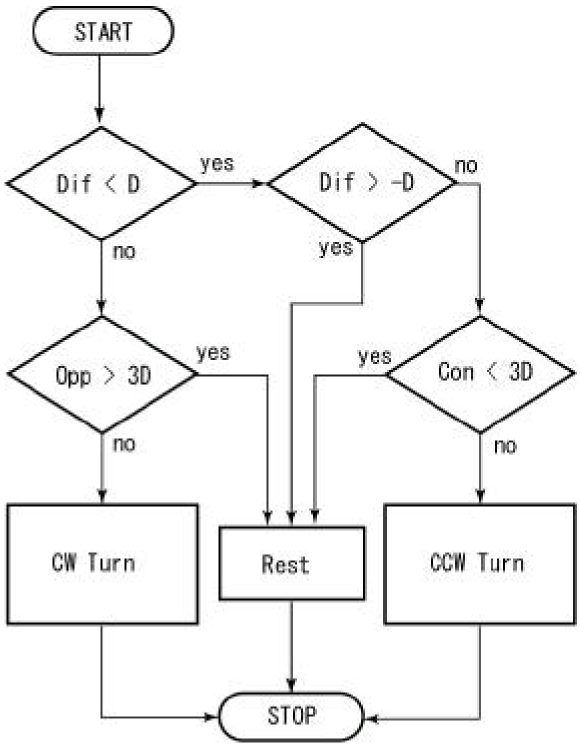
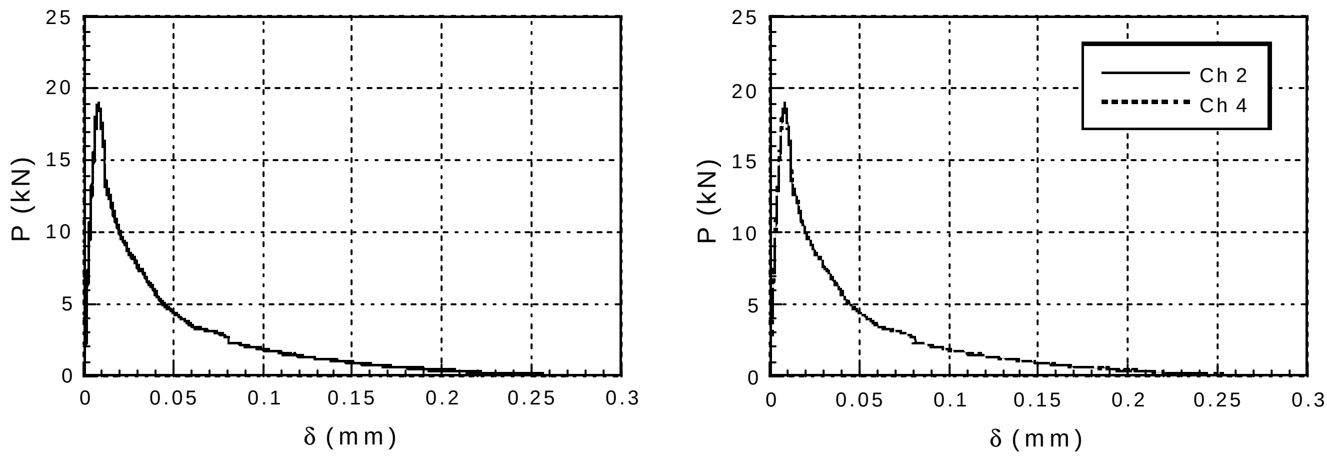


Figure 6: Flow-chart of controlling program



(a) for average (b) for ch-2 and ch-4

Figure 7: Load-deformation curves by automatic control

tightened or not by the comparison with the rod strain and other threshold (3D). The algorithm of the motor control consists of one turn and several time-unit-rests and the rest time is inversely proportional to the level of deformation difference. The rest is indispensable because of the delay in the response of the concrete specimen to the operation, especially at the load descending branch after peak load.

RESULTS AND DISCUSSIONS

Figure 7 are examples of P- δ curves obtained by the automatic control system. 7 (a) shows the relation with respect to the average deformation of four laterals, while 7 (b) to the individual deformation of ch-2 and 4. It is shown that the smooth and better curves are obtained by the automatic system in comparison with those obtained by the manual adjusting system. Both curves in 7 (b) are coincide all over the range. Thus, the automatic adjusting gear system enables to provide more reliable test results than manual operation.

CONCLUSIONS

An automatic adjusting gear system, which consists of four DC motors and a computer program, to control the secondary flexure in uniaxial tensile test of concrete is developed. The system shows a great improvement in controlling the secondary flexure and observing the tension softening behavior in comparison with the manual-operated system. Therefore, the automatic system provides an optimistic future in the field of the uniaxial tensile testing in concrete.

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