コンクリート工学年次論文報告集　10-2　1988

論　文

[1152]　CT試験における歪軟化特性の推移の評価手法に関する研究

METHOD TO EVALUATE TRANSITION OF STRAIN SOFTENING IN COMPACT TENSION TEST OF CONCRETE

Noriaki NOMURA*, Masanori IZUMI* and Hirozo MIHASHI*

1. INTRODUCTION

Strain softening plays a strong role in a numerical analysis of the material breakdown process caused by cracking behavior of a concrete structure. The shape of strain softening diagram greatly influences the whole behavior of structure as expressed by a complete load-displacement curve (1,2,3). Roelfstra and Wittmann(1) have developed the method to estimate the parameters of bilinear strain softening diagram by means of least square approximation of an experimental load-displacement and calculated one.

We have made fundamental discussion on this powerful method with potential abilities and represented the revised technique of the parameter estimation(3). This paper describes an advanced method to estimate parameters varying in the ligament of a compact tension(CT) test specimen.

2. BILINEAR MODEL OF STRAIN SOFTENING

The ordinary parameters of bilinear model of strain softening for the fictitious crack model(4,5) are, (f_t, s_1, w_1, w_2) as shown in Fig.1. Here, (s_1, w_1) is called a break point, which has little physical meaning but only geometrical meaning of strain softening diagram. In the present method, both progresses of the whole behavior, as expressed by a load-displacement curve, and microscopic behavior represented by a strain softening diagram, have to be considered in the parameter estimation algorithm. In view of monitoring the progressive behavior, we have defined the bilinear strain softening diagram by other parameters, (f_t, C_1, s_1, C_2). Here, C_1 and C_2 are the initial compliance and the second compliance respectively.

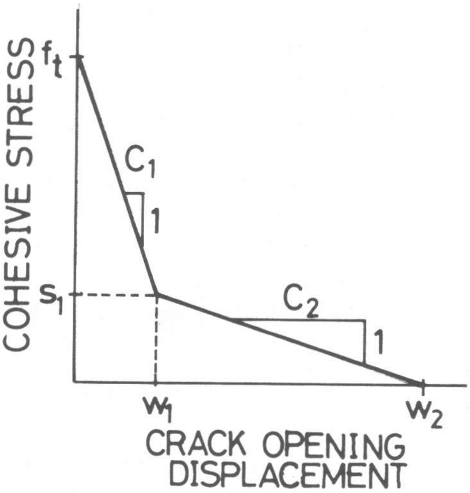

Fig.1 Parameters of Bilinear Strain Softening Model

---

*Department of Architecture, Faculty of Engineering, Tohoku University

3. TRANSITION OF STRAIN-SOFTENING IN LIGAMENT

When material surrounding cracking zone in ligament remains elastic in material breakdown process, the integration of microscopic mechanical behavior in ligament results in the macroscopic characteristics of a complete load-displacement curve. In contrast, the parameter estimation technique is to predict average mechanical characteristics in the ligament in view of meso-level(6).

However, it is not apparent that microcracks distribute uniformly in the ligament of an actual fracture test. There may be transition or variation in microcrack process along the ligament. Unless the transition is negligible, we have to use a parameter estimation algorithm capable of estimating the change in parameters of strain softening in the ligament.

If we provided different bilinear strain softening diagrams for all the discrete nodes to which the fictitious crack model was applied, and estimate the sets of parameters, we could determine the transition of strain softening. However, this extreme method would fail because there are too many unknowns to solve a system equation.

Fig.2 represents a complete load-displacement curve which is simulated with uniform bilinear strain softening diagram in the ligament of a CT

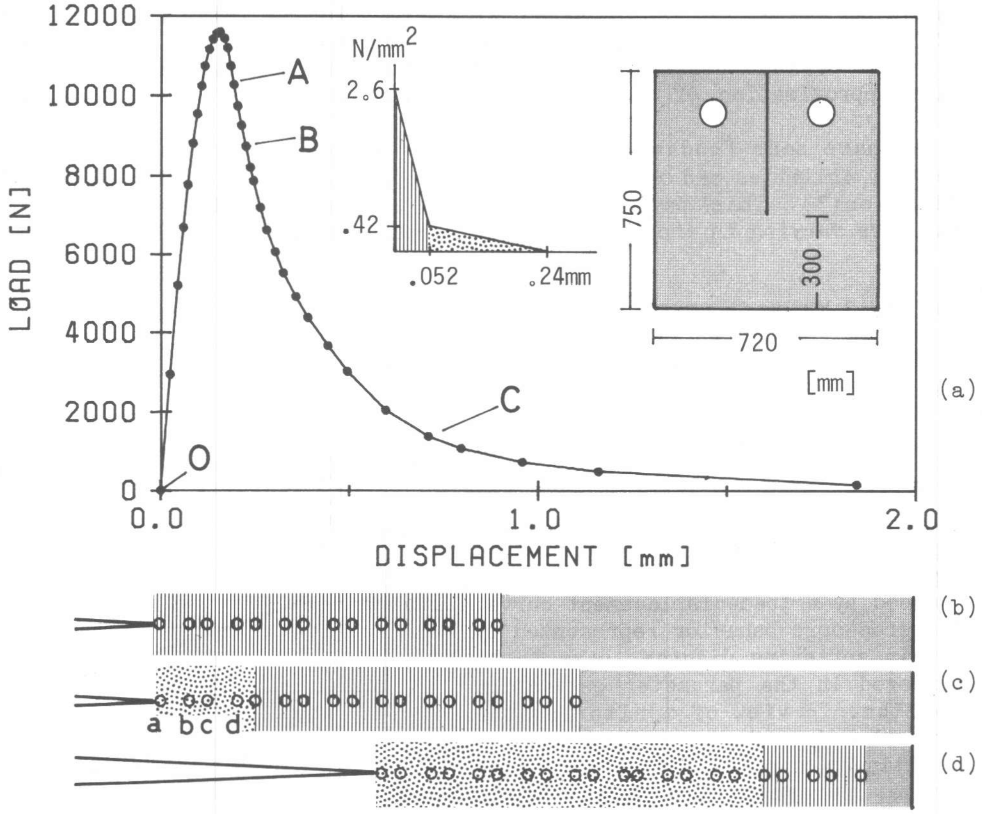

Fig.2 (a) Simulated Load-Displacement Curve of CT Specimen.
(b),(c) and (d) State of Strain Softening corresponding to Point A, B and C respectively.

specimen, and some states of strain softening in the ligament. The state of strain softening shown in Fig.2(b) produces the load-displacement curve from the point 0 to A. Since no node comes to the second compliance of bilinear strain softening diagram, it is impossible to estimate s_1 and C_2, through the section of load-displacement curve between 0 and A. In the subsequent state in Fig.2(c) several nodes lie in the second compliance. Consequently, the section between 0 and A can be utilized to estimate the complete parameters of nodes a, b, c and d, and two parameters f_t and C_1, of other nodes.

Based on the observation of the load-displacement curve and the state of strain softening, we arrive at one of strategies to estimate the transition of strain softening, in which the least square approximation is applied continuously to appropriate successive windows of load-displacement curve. Through a step of calculation a set of parameters can be estimated for the moving window. The window is not provided in advance but controlled dynamically by the combination of the least square algorithm and the fictitious crack calculation.

For demonstration, we have applied the present method to the artificial load-displacement curve of a CT test which is simulated with non-uniform strain softening characteristics, i.e. with constant f_t, s_1, and w_1, and linearly varying w_2. Fig.3 represents the estimated results in terms of f_t, s_1, w_1 and w_2. Results by using the algorithm that estimates constant parameters in a ligament(METHOD I) are shown as well. Few

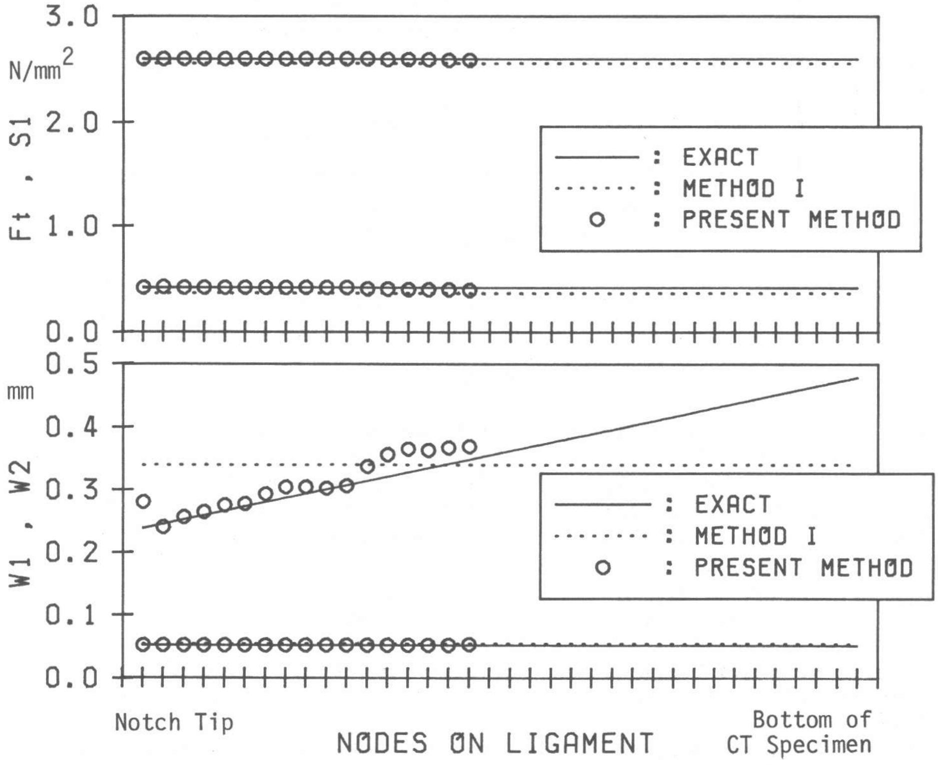

Fig.3. Parameters Estimated. (Eighteen nodes controlled the range of window in the estimation.)

significant differences in parameters of f_t, s_1 and w_1 among the two method appear. Whereas the parameter estimation method I yields the averaged value of w_2 in the ligament, the present method can estimate the varying w_2 corresponding to the exact distribution. The load-displacement curve simulated using the varying parameters fits to the target curve better than the other, as shown in Fig.4.

5. CONCLUDING REMARKS

The present method can evaluate the varying parameters of strain softening diagram for the idealized example of load-displacement curve. Although an actual experimental data containing occasionally local irregularity can affect the convergence of solution and the stability in the least square calculation, the method is applicable in principal to the actual data. We expect that the results will suggest the information concerned with the microcrack process of concrete material.

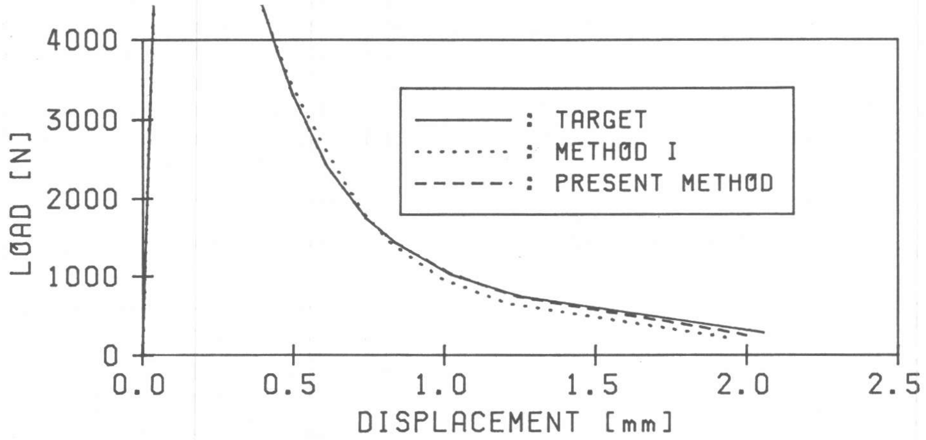

Fig.4. Tail Part in Load-Displacement Curves.

REFERENCES

1) Roelfstra, P.E. and Wittmann F.H.:"Numerical Method to Link Strain Softening with Failure of Concrete," in Frac. Toughness and Frac. Energy of Concr., Ed. by F.H. Wittmann, Elsevier, 1986, pp.163-175.
2) Rots, J.G.:"Strain-Softening Analysis of Concrete Fracture Specimens," in Frac. Toughness and Frac. Energy of Concr., Ed. by F.H. Wittmann, Elsevier, 1986, pp.137-148.
3) Nomura, N. and Izumi, M.:"Fundamental Study on Estimation Problem in Strain Softening of Constitutive Law of Concrete,(in Japanese)" Proc. of the JCI, Vol.9, No.2, 1987, pp97-102.
4) Petersson, P-E.:"Crack Growth and Development of Fracture zones in Plain Concrete and Similar Materials," Lund Institute of Technology., Report TVBM-1003, 1981.
5) Hillerborg, A.:"Analysis of One Single Crack," in Frac. Mech. of Concr., Ed. by F.H. Wittmann, Elsevier, 1983, pp.223-249.
6) Wittmann, F.H.:"Structure of Concrete with respect to Crack Formation," in Frac. Mech. of Concr., Ed. by F.H. Wittmann, Elsevier, 1983, pp.43-74.