33. A Study on Estimation of Fracture Toughness (J-integral Estimations) for Concrete

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1. INTRODUCTION

It is impossible to directly apply linear elastic fracture mechanics on estimation of fracture toughness for concrete. This is because the existence of a non-linear zone (resulting from mainly micro-cracking) in front of the notch tip can not be neglected.

So non-linear fracture mechanics parameters have been applied to estimation of fracture toughness on specimens of small size. As one representative parameter, the J-integral value can be mentioned. For estimating J-integral value there are the experimental method by Begley-Landes, the semi-analytical method using Rice's formula, or the indirect estimation based on analyses of fracture models. Regarding micro-cracking zone in concrete as pseudo-plastic zone, it is useful to discuss the applicability of above methods for concrete just as for metals. In some literatures, associated studies were reported.

The purpose of this study is to investigate the above-mentioned J-integral estimation for concrete.

2. VARIOUS J-INTEGRAL ESTIMATIONS

The method by Begley-Landes is based on the concept that J-integral value is the difference of potential energy by variation of crack length and is the estimation using tangential gradients of a curve plotting the potential energy obtained by load-displacement curves for specimens with different notch-depths against notch-areas. One example is shown in Fig.1 .

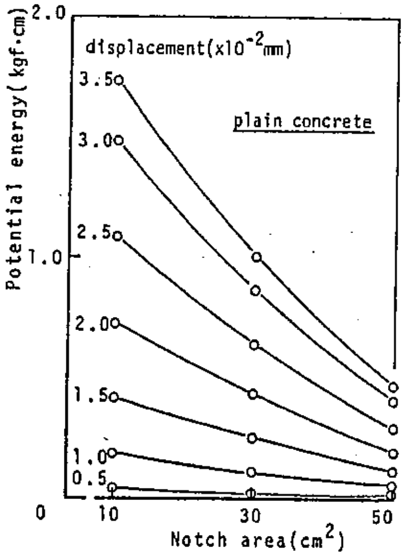

Fig.1 Method by Begley-Landes

The method by Rice is the estimation based on the following formula which was induced by him for a notched beam provided that the notch is deep and the load-displacement curve depends only on the ligament length.

$$J = \frac{2}{B \times b} \int_0^{\Delta_C} P \, d\Delta_C \quad \text{------ (1)}$$

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where B: beam width, b: ligament length, P: load, $\Delta_C = \Delta - \Delta_0$: displacement resulting from notch (Δ_0: displacement for un-notched beam) .

As an indirect estimation in this study the applicability of Dugdale model on concrete (reported before [Ref.1]) is assumed and J-integral value based on its analyses is estimated.

3.EXPERIMENTAL METHOD

Fracture toughness tests were conducted with center-point bending (span-depth ratio = 3) for notched beams of 100x100x400 mm. Notches were precast using an acrylic sheet of 1.0 mm thickness. The ratios of notch depth to beam depth were three kinds, namely 0.1, 0.3, 0.5 . Specimens were naturally dried in air for 7 days after 21 days curing in water of 20°C . To measure displacement under a loading point, angle-shaped metals were fixed with epoxycal adhesive agent on the both sides of the specimen. The method for measurement is shown in Fig.2 . The relation between load and displacement of the specimen was automatically recorded using a X-Y recorder. Materials and mix proportions for mortar and concrete are indicated in Tables 1 and 2 respectively.

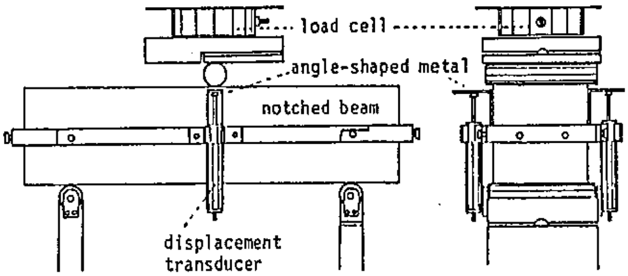

Fig.2 Method for Measurement

4.EXPERIMENTAL RESULTS

Fig.3 shows load-displacement curves and various J-integral value-displacement relations of specimens with three kinds of mix proportions. Each measured value is the mean value of three specimens. The marks ● and ○ represent cracking and maximum load points respectively. The areas under load-displacement curves (potential energy) were numerically integrated to obtain J-integral values in the methods by Begley-Landes and by Rice. In the estimation based on Dugdale model analyses, J-integral value was uniquely and analytically determined by measuring ratios of external force (nominal flexural stress) to tensile strength.

Table 1 Materials Used

cement	ordinary portland	
sand	Ohi river sand specific gravity maximum size F.M.	 =2.62 =5.0mm =2.85
gravel	Ohi river gravel specific gravity maximum size F.M.	 =2.65 =15.0mm =6.50

Table 2 Mix Proportions

series	proportion	direct tensile* strength(kgf/cm^2)	Young's modulus (x10^5 kgf/cm^2)
mortar-a	water-cement ratio=65% sand-cement ratio =2.0 (Toyoura standard sand)	19.9	2.09
mortar-b	water-cement ratio=50% volume fraction of sand =0.5	27.8	2.49
plain concrete	water-cement ratio=50% volume fraction of sand =0.3 volume fraction of gravel =0.4	32.8	3.36

* $\sigma_t = 1.81\ \sigma_s^{0.794}$ [Ref.2] , σ_t;direct tensile strength, σ_s;splitting strength

The cracking points were detected by the following methods.

(1) predicting crack extension length analytically from increase rate of compliance in a repeated load-displacement curve (the estimated and measured length of crack extension showed good agreement).

(2) plotting residual displacement and compliance against crack extension (Fig.4).
(3) estimating cracking points by extrapolated values of residual displacement and compliance at no crack extension.

As conjectured from Fig.3, the J-integral value-displacement curves exhibit similar behaviour until cracking point. Specimens made of larger fracture toughness materials increase the rising gradient and give larger J-integral values at the same displacement. Considerable difference appeared between J-integral values estimated at maximum load point by the estimation based on Dugdale model analyses and by the other two methods. This is because the increase rates of J-integral value decrease at the after-

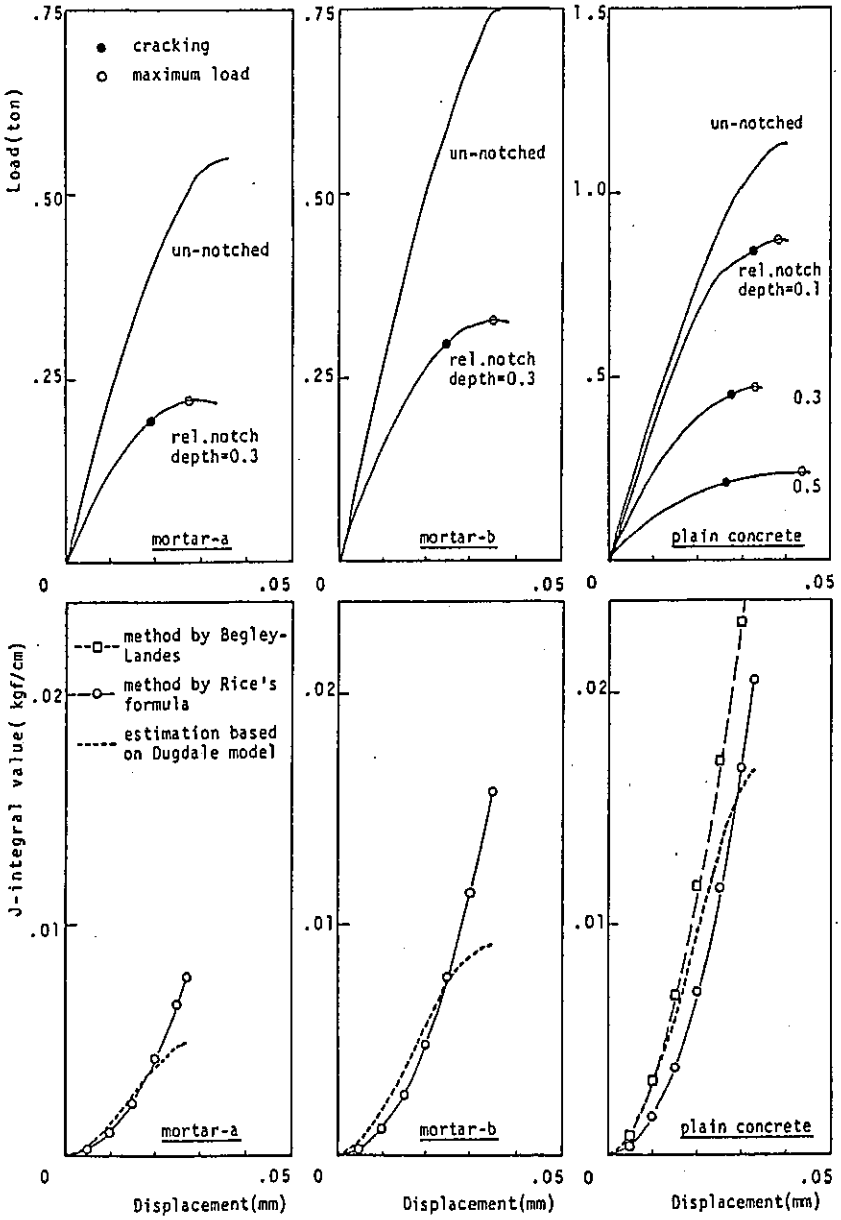

Fig.3 Load-Displacement and Various J-integral Value-Displacement Curves

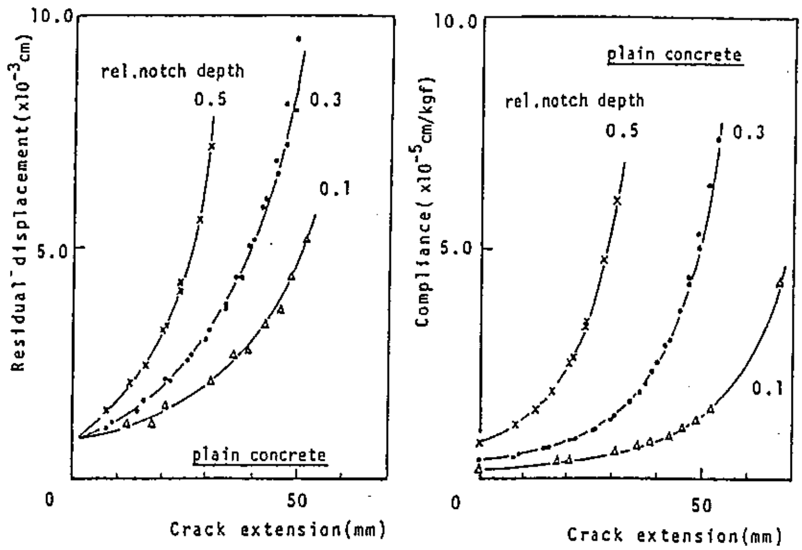

Fig.4 Method for Detecting Cracking Points

cracking area on which the extension of displacement increases quickly in the former method with only the amount of load considered in the estimation, and this turning point seems to nearly agree with cracking point. This means that conversely in case of the latter methods, selection of estimating points has great influence on obtained J-integral values.

5.CONCLUSIONS

From the above results, within the range of the present experiments the following views were derived.

(1) For indirect imformation of non-linear behaviours near the notch tip J-integral value-displacement curves are effective. The specimens made of larger fracture toughness materials increase the rising gradient and give larger J-integral value at the same displacement.

(2) J-integral value-displacement curves exhibit similar behaviour among the method by Begley-Landes, by Rice and the estimation based on Dugdale model analyses until cracking points. The J-integral values estimated at cracking point by these three methods showed good agreement.

(3) Considerable difference between J-integral values estimated at maximum load point by the estimation based on Dugdale model analyses and the other two methods arised. It seems that in case of the latter, the selection of estimating points has great influence on obtained J-integral values and detecting cracking point is a quite important subject for J-integral estimation.

REFERENCES

1) K.Kishitani et al.,"A Study on Fracture Toughness for Concrete", Cement Association Annual, Vol.38, 1984.
2) N.Watanabe et al.,"A Study on Tensile Strength for Concrete", Cement Association Annual, Vol.38, 1984.