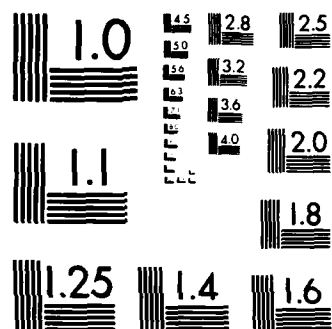


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**MORE ON COMPLIANCE OF THE  
THREE-POINT BEND SPECIMEN**

**JOHN H. UNDERWOOD**

**JOSEPH A. KAPP**

**FRANCIS I. BARATTA**

**MAY 1985**

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| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>Fracture Test Methods<br>Load-Line Displacement<br>Bend Specimen                                                                                                                                                                |                                     |                                                                                                                  |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>Comparison and analysis of load-line displacement for the three-point bend specimen was performed. Expressions were developed for displacement as a function of crack length and for crack length as a function of displacement. |                                     |                                                                                                                  |

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## INTRODUCTION

In a recent publication (ref 1) load-line displacement analysis was presented for the three-point bend specimen often used for fracture testing: the rectangular specimen with span to width ratio,  $S/W = 4$ . In that recent work, an apparent omission of the effect of shear displacement was noted in published results for the bend specimen. The purpose here is to describe some additional analysis and to point out an apparent inaccuracy in the effect of crack related displacement in published results for the specimen.

## DISCUSSION

A general expression for the dimensionless load-line displacement, taken from reference 1, is

$$EB\delta/P = S^3/4W^3 + 3.12 S/4W + 6S^2/4W^2 \cdot f(a/W) \quad (1)$$

where, as usual,  $P$  is load,  $E$  is elastic modulus,  $\delta$  is total load-line displacement, and  $a$  is crack length. The concern here is with  $f(a/W)$ , which describes the variation with crack length of the displacement due to the crack. As described in reference 1, Tada et al (ref 2) give the following expression for  $f(a/W)$ :

$$f_2(a/W) = [a/W(1-a/W)]^2 [5.58 - 19.57(a/W) + 36.82(a/W)^2 - 34.94(a/W)^3 + 12.77(a/W)^4] \quad (2)$$

Comparison is made here with another expression by Wu (ref 3), as follows:

$$f_3(a/W) = 3[-0.3645 (a/W)^5 + 1.326 (a/W)^4 - 2.710 (a/W)^3 + 3.874 (a/W)^2 - 8.614 (a/W) - 2.268 + 6.018 \ln(1+2a/W) - 1.015 \ln(1-a/W) + \frac{2.829 (a/W)^2 - 4.437 (a/W) + 2.268}{(1+2a/W)(1-a/W)^2}] \quad (3)$$

---

References are listed at the end of this report.

Wu obtained this expression using the classic Irwin method (ref 4), integrating the K expression as follows:

$$EB\delta/P = (EB\delta/P)_{a=0} + \int_0^{a/W} (KBW^{1/2}/P)^2 d(a/W) \quad (4)$$

The K expression, which is a function of  $a/W$ , was obtained from ASTM Method E-399 (ref 5).

Figure 1 shows plots of Eq. (1) using the Tada et al expression (ref 2) for  $f(a/W)$ , Eq. (2), and using the Wu expression (ref 3) for  $f(a/W)$ , Eq. (3). The dimensionless parameter used for the ordinate of the plots was chosen (ref 6) so that both the  $a/W = 0$  and  $a/W = 1$  limits of the parameter are known and finite. Note that at  $a/W = 0.5$ , the compliance based on the Wu expression is five percent higher than that based on the Tada et al expression.

Three additional sets of compliance results are shown in Figure 1; finite element results (ref 6) and collocation results (ref 7) for the  $S/W = 4$  rectangular bend specimen, and K expression integration by the present authors. The finite element displacements are at the crack mouth location but in the direction of the applied load. The collocation displacements are at the load point. The integration procedure used was that indicated in Eq. (4), and it was performed on the K results of Brown and Srawley (ref 8). Although the finite element results in particular include some scatter, it is clear that these three independent sets of data support Wu's results. It appears that the Tada et al expression, Eq. (2), for load-line displacement due to the crack is incorrect, which agrees with the statement indicated in (ref 9) that some displacements quoted in Tada et al may be in error.



## RESULTS

Table I lists numerical data from the results described above, as well as from ASTM Method E-813 (ref 10), from the results of Bucci et al (ref 11), Server (ref 12), and from a wide-range compliance expression by the present authors. Comparison of the results from References 2, 10, 11, and 12 with the combined results of References 3, 6, and 7, shows the following for  $a/W = 0.5$ . The compliance based on the Tada et al analysis is three to five percent below that from References 3, 6, and 7; the compliance from ASTM Method E-813 is ten to twelve percent below that from References 3, 6, and 7; the Bucci et al and Server results\* are one to three percent above that from References 3, 6, and 7.

Based on the above comparison, a wide-range compliance expression was fitted to the three sets of results of References 3 and 7, and the K integration of the present authors. The resulting expression is:

$$\frac{EB\delta}{P} \left( \frac{1-a/W}{S/W} \right)^2 = 1.193 - 1.980 a/W + 4.478 (a/W)^2 - 4.443 (a/W)^3 + 1.739 (a/W)^4 \quad (5)$$

which fits both the K integration results by Wu (ref 3) and those performed here within  $\pm 0.5$  percent for the range  $0.4 < a/W < 0.6$ . Equation (5) fits all three sets of results within  $\pm 1.1$  percent over the entire range of  $a/W$ ,  $0 < a/W < 1.0$ .

---

\*In the Bucci et al and the Server K integration compliance analyses, a constant of 4 was used in the equation analogous to Eq. (1), rather than the 3.12 used here. This would cause the Bucci et al and the Server results for  $a/W = 0.5$  to be 1.6 percent higher than that based on a constant of 3.12.

An inverse compliance expression was also fit to the three sets of results of References 3, 7, and the K integration here, using the form proposed by Saxena and Hudak [13]:

$$\delta' = \frac{1}{1 + (EB\delta/P)^{1/2}} \quad (6)$$

$$a/W = f(\delta') = 1 - 3.82 \delta' + 7.85 \delta'^2 - 384 \delta'^3 + 3852 \delta'^4 - 12050 \delta'^5 \quad (7)$$

which fits all three sets of results within  $\pm$  two percent over the range  $0.4 < a/W < 1.0$ .

#### CONCLUSIONS

The compliance expression of Eq. (5) is believed to be accurate within one percent for the entire range of  $a/W$ , and the inverse compliance expression of Eqs. (6) and (7) is believed to be accurate within two percent for  $0.4 < a/W < 1.0$ . The expressions should be generally useful for fracture testing, including fracture toughness and fatigue crack growth rate measurements.

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TABLE I. COMPARISON OF COMPLIANCE FOR THE THREE-POINT RECTANGULAR BEND SPECIMEN WITH  $S/W = 4.0$

$$\frac{EB\delta}{P} \frac{1-a/W}{S/W} \quad (2)$$

| a/W | Eq. (1)<br>Using<br>Ref. 2 | Eq. (1)<br>Using<br>Ref. 3 | Ref. 6<br>Finite<br>Element | Ref. 7<br>Collocation | Ref. 10<br>E813 | Ref. 11<br>K<br>Integration | Ref. 12<br>K<br>Integration | Present Work     |         |
|-----|----------------------------|----------------------------|-----------------------------|-----------------------|-----------------|-----------------------------|-----------------------------|------------------|---------|
|     |                            |                            |                             |                       |                 |                             |                             | K<br>Integration | Eq. (5) |
| 0   | -                          | 1.195                      | -                           | -                     | -               | 1.256                       | -                           | 1.195            | 1.193   |
| 0.1 | -                          | 1.029                      | -                           | -                     | -               | 1.076                       | -                           | 1.026            | 1.036   |
| 0.2 | -                          | 0.946                      | -                           | 0.953                 | -               | 0.980                       | .976                        | 0.940            | 0.944   |
| 0.3 | 0.880                      | 0.901                      | 0.894                       | 0.900                 | -               | 0.928                       | .923                        | 0.896            | 0.896   |
| 0.4 | 0.846                      | 0.880                      | 0.897                       | 0.880                 | -               | 0.902                       | .896                        | 0.876            | 0.878   |
| 0.5 | 0.835                      | 0.877                      | 0.858                       | 0.867                 | 0.783           | 0.895                       | .887                        | 0.872            | 0.876   |
| 0.6 | 0.840                      | 0.885                      | 0.868                       | -                     | 0.805           | 0.903                       | .892                        | 0.881            | 0.883   |
| 0.7 | 0.846                      | 0.899                      | 0.857                       | -                     | 0.827           | -                           | .892                        | -                | 0.895   |
| 0.8 | 0.845                      | 0.917                      | -                           | -                     | -               | -                           | -                           | -                | 0.912   |
| 0.9 | 0.860                      | 0.937                      | -                           | -                     | -               | -                           | -                           | -                | 0.940   |
| 1.0 | -                          | 0.988                      | -                           | -                     | -               | -                           | -                           | -                | 0.987   |

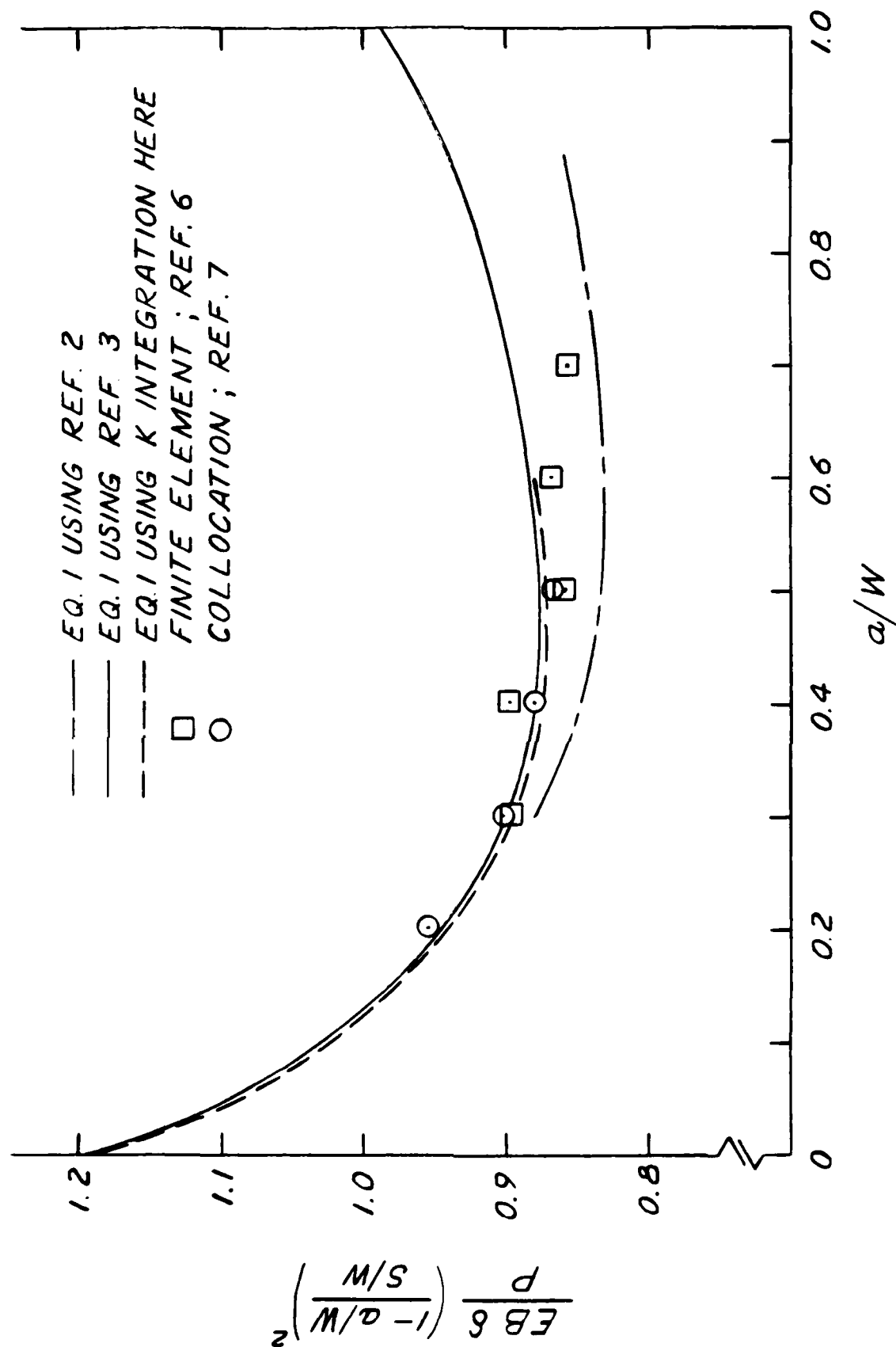


Figure 1. Comparison of load-line displacement for three-point bend specimen with  $S/W = 4.0$ .

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