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MEMORANDUM REPORT ARCCB-MR-90029

# LOAD-LINE DISPLACEMENTS FOR THREE-POINT BEND J TESTS USING BOTTOM SURFACE DISPLACEMENTS

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OCTOBER 1990

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1. REPORT NUMBER
ARCCB-MR-90029

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
LOAD-LINE DISPLACEMENTS FOR THREE-POINT BEND J TESTS USING BOTTOM SURFACE DISPLACEMENTS

5. TYPE OF REPORT & PERIOD COVERED
Final

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
J.H. Underwood and M.D. Witherell

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army ARDEC
Benet Laboratories, SMCAR-CCB-TL
Watervliet, NY 12189-4050

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
AMCMS No. 6126.23.H210.0
PRON No. 1A02ZPMRNMSC

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

12. REPORT DATE
October 1990

13. NUMBER OF PAGES
8

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Submitted to Engineering Fracture Mechanics.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
$J_{Ic}$ Tests
Load-Line Displacement
Three-Point Bend
Finite Element

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Finite element calculations show that elastic displacements along the bottom surface of a three-point bend specimen can be used to obtain a close approximation to the load-line displacement at the crack line. The use of load-line displacement for measuring crack growth by unloading compliance is discussed with application to a simplified test procedure for J-integral fracture toughness tests.

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# ACKNOWLEDGEMENT

We are pleased to credit D.J. Corrigan for graphics production.

## INTRODUCTION

The current methods for determining J-integral fracture toughness using unloading compliance with a bend specimen require that both load-line and crack-mouth displacements be measured (refs 1,2). Load-line displacement is fundamental to the methods, because it is a basic component of the strain energy input to the sample and is required to calculate values of applied J. Crack-mouth displacement is the preferred displacement for the unloading-compliance method of measuring crack growth during the tests. However, there is no fundamental limitation to using load-line displacement for the unloading-compliance procedures, thus, simplifying the overall method for determining fracture toughness. In some recent work (ref 3), the advantage of using one displacement for both purposes went beyond simplicity; it avoided the difficult test arrangements which would have been required for two measures of displacement with small, 3-mm thick bend specimens.

The objective here is to describe some finite element displacement measurements along the bottom surface of a bend specimen and show that they give an accurate measure of load-line displacement for the specimen and results suitable for use in J-integral fracture toughness tests.

## RESULTS

Figure 1 shows the configuration of the arc-shaped bend specimen which was modeled using the ABAQUS finite element code. A linear elastic analysis was carried out using eight-node isoparametric plane-stress elements; plane-stress conditions were used because of the global nature of the bottom surface displacements which were of primary interest. Crack tip elements were formed by collapsing one side of the element and moving the midside node in the usual manner. Stress intensity factor, K, was also calculated from the J-integral contours of the code. The specimen had an outer-to-inner radius ratio of 1.27, span-to-depth ratio, S/W, of 4.0, and cord surface offset-to-depth ratio, X/W, of 0.1.

The bottom surface displacements calculated from the finite element model are listed in Table I, along with estimates of the load-line displacement and the differences between the calculated and estimated values of load-line displacement. Results are shown for seven values of offset relative to the load line, 2L/S, and three crack lengths. The displacement, d, from finite element results on the bottom surface is given in a common dimensionless form, dEB/P, and compared with a simple estimate of the displacement at the load line, $\delta$, obtained as follows:

$$\delta EB/P = (dEB/P)\ (S/2L) \qquad (1)$$

where E is elastic modulus and the other parameters are defined in Figure 1. This expression describes the motion of the bottom surface of the specimen as if it were simple rigid body rotation. The results in Table I show that an assumption of rigid body rotation is good for relatively deep cracks and small offsets from the load line. For offsets with $2L/S > 0.85$ and $a/W > 0.6$, Eq. (1) gives a value of load-line displacement within one percent of the actual value from finite element calculations.

It is prudent to verify finite element results to identify any errors hidden in the complexity of the procedure. For example, the load-line displacement for $a/W = 0.6$ for this arc-shaped specimen is $\delta EB/P = 95.73$. This compares well with the respective value for a rectangular specimen, $\delta EB/P = 88.28$ (ref 1). The higher value (by about eight percent) is expected for the arc-shaped specimen because of the diminished cross section away from the load line. A comparison of the arc-shaped results here with arc-shaped results from prior work by the authors (ref 4) shows agreement of K within one percent and agreement of $\delta$ within four percent, providing further verification.

## SUMMARY

Finite element calculations of bottom surface displacement showed that a rigid body rotation expression gives an accurate description of the load-line displacement for the arc-shaped specimen. Since the configuration and the displacements of the arc-shaped specimen were similar to those of the rectangular specimen, bottom surface displacements can be used as a general measure of load-line displacement for bend specimens.

# REFERENCES

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## TABLE I. BOTTOM SURFACE DISPLACEMENTS FOR AN ARC-SHAPED THREE-POINT BEND SPECIMEN

| Crack Length a/W | Center Offset 2L/S | Displacement, *FE Calculations dEB/P | Displacement, Eq. (1) Estimate $\delta EB/P$ | Difference, FE vs. Eq. (1) Percent |
|---|---|---|---|---|
| 0.4 | 1.000 | 43.24 | 43.24 | 0.0 |
|  | 0.988 | 42.76 | 43.28 | 0.1 |
|  | 0.975 | 42.27 | 43.35 | 0.3 |
|  | 0.963 | 41.78 | 43.39 | 0.3 |
|  | 0.950 | 41.30 | 43.47 | 0.5 |
|  | 0.850 | 37.70 | 44.35 | 2.6 |
|  | 0.806 | 36.21 | 44.93 | 3.9 |
| 0.6 | 1.000 | 95.73 | 95.73 | 0.0 |
|  | 0.988 | 94.61 | 95.76 | 0.0 |
|  | 0.975 | 93.48 | 95.88 | 0.2 |
|  | 0.963 | 92.36 | 95.91 | 0.2 |
|  | 0.950 | 91.24 | 96.04 | 0.3 |
|  | 0.850 | 82.44 | 96.99 | 1.3 |
|  | 0.806 | 78.60 | 97.52 | 1.9 |
| 0.8 | 1.000 | 380.2 | 380.2 | 0.0 |
|  | 0.988 | 375.5 | 380.1 | 0.0 |
|  | 0.975 | 370.9 | 380.4 | 0.1 |
|  | 0.963 | 366.2 | 380.3 | 0.0 |
|  | 0.950 | 361.5 | 380.6 | 0.1 |
|  | 0.850 | 324.5 | 381.7 | 0.4 |
|  | 0.806 | 308.0 | 382.1 | 0.5 |

*FE: Finite Element

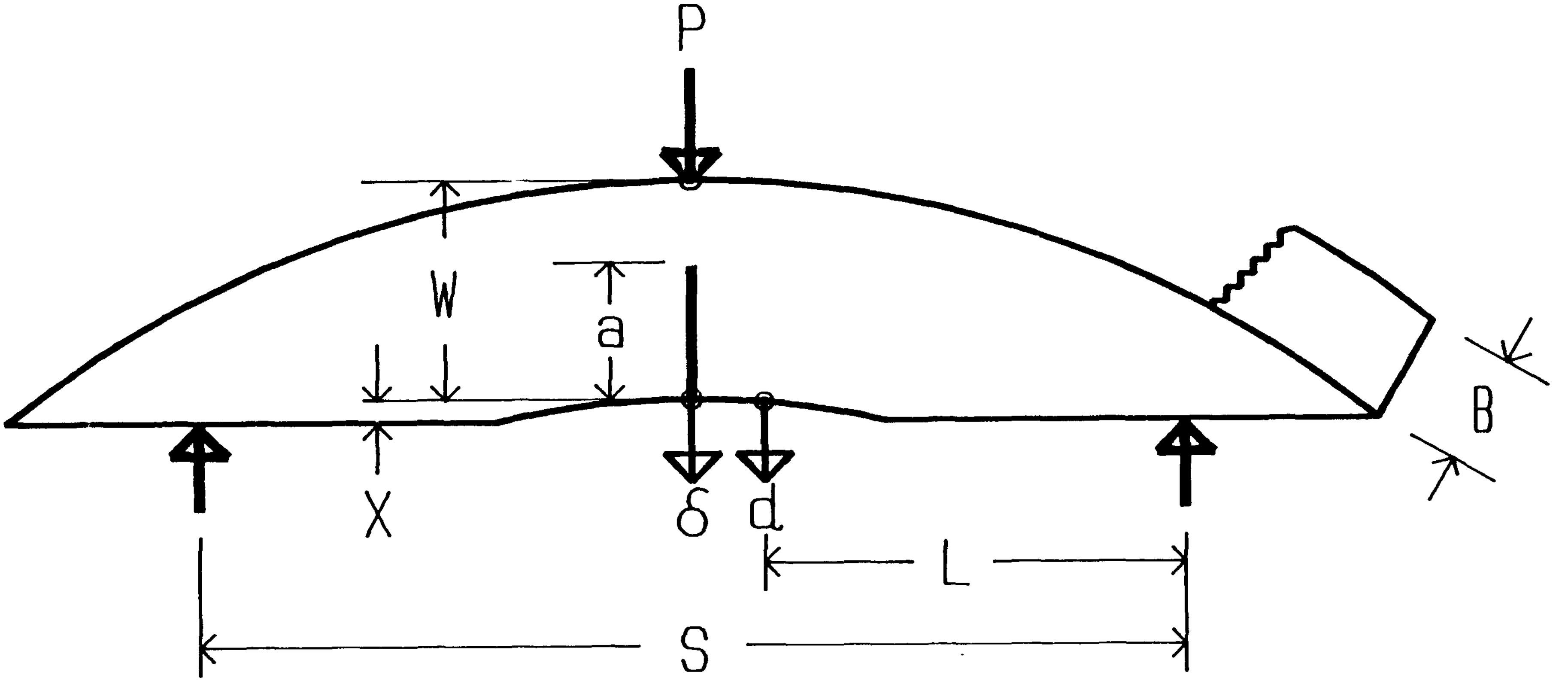

Figure 1. Specimen configuration and nomenclature.

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