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ORVIRT.PC: A 2-D Finite-Element Fracture Analysis Program for a Microcomputer

J. W. Bryson

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreements DOE 40-551-75 and 40-552-75

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FOREWORD

The work reported here was performed at Oak Ridge National Laboratory (ORNL) under the Heavy-Section Steel Technology (HSST) Program, C. E. Pugh, Program Manager. The program is sponsored by the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC). The technical monitor for the NRC is Milton Vagins.

This report is designated HSST Program Technical Report 83. Prior reports in this series are listed below:

1. S. Yukawa, *Evaluation of Periodic Proof Testing and Warm Prestressing Procedures for Nuclear Reactor Vessels*, HSSTP-TR-1, General Electric Company, Schenectady, N. Y. (July 1, 1969).
2. L. W. Loechel, *The Effect of Testing Variables on the Transition Temperature in Steel*, MCR-69-189, Martin Marietta Corporation, Denver, Colo. (November 20, 1969).
3. P. N. Randall, *Gross Strain Measure of Fracture Toughness of Steels*, HSSTP-TR-3, TRW Systems Group, Redondo Beach, Calif. (November 1, 1969).
4. C. Visser, S. E. Gabrielse, and W. VanBuren, *A Two-Dimensional Elastic-Plastic Analysis of Fracture Test Specimens*, WCAP-7368, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (October 1969).
5. T. R. Mager and F. O. Thomas, *Evaluation by Linear Elastic Fracture Mechanics of Radiation Damage to Pressure Vessel Steels*, WCAP-7328 (Rev.), Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (October 1969).
6. W. O. Shabbits, W. H. Pryle, and E. T. Wessel, *Heavy-Section Fracture Toughness Properties of A533 Grade B Class 1 Steel Plate and Submerged Arc Weldment*, WCAP-7414, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (December 1969).
7. F. J. Loss, *Dynamic Tear Test Investigations of the Fracture Toughness of Thick-Section Steel*, NRL-7056, Naval Research Laboratory, Washington, D.C. (May 14, 1970).
8. P. B. Crosley and E. J. Ripling, *Crack Arrest Fracture Toughness of A533 Grade B Class 1 Pressure Vessel Steel*, HSSTP-TR-8, Materials Research Laboratory, Inc., Glenwood, Ill. (March 1970).
9. T. R. Mager, *Post-Irradiation Testing of 2T Compact Tension Specimens*, WCAP-7561, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (August 1970).
10. T. R. Mager, *Fracture Toughness Characterization Study of A533, Grade B, Class 1 Steel*, WCAP-7578, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (October 1970).

11. T. R. Mager, *Notch Preparation in Compact Tension Specimens*, WCAP-7579, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (November 1970).

12. N. Levy and P. V. Marcal, *Three-Dimensional Elastic-Plastic Stress and Strain Analysis for Fracture Mechanics, Phase I: Simple Flawed Specimens*, HSSTP-TR-12, Brown University, Providence, R.I. (December 1970).

13. W. O. Shabbits, *Dynamic Fracture Toughness Properties of Heavy Section A533 Grade B Class 1 Steel Plate*, WCAP-7623, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (December 1970).

14. P. N. Randall, *Gross Strain Crack Tolerance of A533-B Steel*, HSSTP-TR-14, TRW Systems Group, Redondo Beach, Calif. (May 1, 1971).

15. H. T. Corten and R. H. Sailors, *Relationship Between Material Fracture Toughness Using Fracture Mechanics and Transition Temperature Tests*, T&AM Report 346, University of Illinois, Urbana, Ill. (August 1, 1971).

16. T. R. Mager and V. J. McLaughlin, *The Effect of an Environment of High Temperature Primary Grade Nuclear Reactor Water on the Fatigue Crack Growth Characteristics of A533 Grade B Class 1 Plate and Weldment Material*, WCAP-7776, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, Pa. (October 1971).

17. N. Levy and P. V. Marcal, *Three-Dimensional Elastic-Plastic Stress and Strain Analysis for Fracture Mechanics, Phase II: Improved Modelling*, HSSTP-TR-17, Brown University, Providence, R.I. (November 1971).

18. S. C. Grigory, *Tests of 6-in.-Thick Flawed Tensile Specimens, First Technical Summary Report, Longitudinal Specimens Numbers 1 through 7*, HSSTP-TR-18, Southwest Research Institute, San Antonio, Tex. (June 1972).

19. P. N. Randall, *Effects of Strain Gradients on the Gross Strain Crack Tolerance of A533-B Steel*, HSSTP-TR-19, TRW Systems Group, Redondo Beach, Calif. (June 15, 1972).

20. S. C. Grigory, *Tests of 6-Inch-Thick Flawed Tensile Specimens, Second Technical Summary Report, Transverse Specimens Numbers 8 through 10, Welded Specimens Numbers 11 through 13*, HSSTP-TR-20, Southwest Research Institute, San Antonio, Tex. (June 1972).

21. L. A. James and J. A. Williams, *Heavy Section Steel Technology Program Technical Report No. 21, The Effect of Temperature and Neutron Irradiation Upon the Fatigue-Crack Propagation Behavior of ASTM A533 Grade B, Class 1 Steel*, HEDL-TME 72-132, Hanford Engineering Development Laboratory, Richland, Wash. (September 1972).

22. S. C. Grigory, *Tests of 6-Inch-Thick Flawed Tensile Specimens, Third Technical Summary Report, Longitudinal Specimens Numbers 14 through 16, Unflawed Specimen Number 17*, HSSTP-TR-22, Southwest Research Institute, San Antonio, Tex. (October 1972).

23. S. C. Grigory, *Tests of 6-Inch Thick Tensile Specimens, Fourth Technical Summary Report, Tests of 1-Inch-Thick Flawed Tensile Specimens for Size Effect Evaluation*, HSSTP-TR-23, Southwest Research Institute, San Antonio, Tex. (June 1973).

24. S. P. Ying and S. C. Grigory, *Tests of 6-Inch-Thick Tensile Specimens, Fifth Technical Summary Report, Acoustic Emission Monitoring of One-Inch and Six-Inch-Thick Tensile Specimens*, HSSTP-TR-24, Southwest Research Institute, San Antonio, Tex. (November 1972).

25. R. W. Derby, J. G. Merkle, G. C. Robinson, G. D. Whitman, and F. J. Witt, *Test of 6-Inch-Thick Pressure Vessels. Series 1: Intermediate Test Vessels V-1 and V-2*, ORNL-4895, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (February 1974).

26. W. J. Stelzman and R. G. Berggren, *Radiation Strengthening and Embrittlement in Heavy Section Steel Plates and Welds*, ORNL-4871, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (June 1973).

27. P. B. Crosley and E. J. Ripling, *Crack Arrest in an Increasing K-Field*, HSSTP-TR-27, Materials Research Laboratory, Inc., Glenwood, Ill. (January 1973).

28. P. V. Marcal. P. M. Stuart, and R. S. Bettes, *Elastic-Plastic Behavior of a Longitudinal Semi-Elliptic Crack in a Thick Pressure Vessel*, HSSTP-TR-28, Brown University, Providence, R.I. (June 1973).

29. W. J. Stelzman, R. G. Berggren, and T. N. Jones, *ORNL Characterization of Heavy-Section Steel Technology Program Plates 01, 02 and 03*, NUREG/CR-4092 (ORNL/TM-9491), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (in preparation).

30. Canceled.

31. J. A. Williams, *The Irradiation and Temperature Dependence of Tensile and Fracture Properties of ASTM A533, Grade B, Class 1 Steel Plate and Weldment*, HEDL-TME 73-75, Hanford Engineering Development Laboratory, Richland, Wash. (August 1973).

32. J. M. Steichen and J. A. Williams, *High Strain Rate Tensile Properties of Irradiated ASTM A533 Grade B Class 1 Pressure Vessel Steel*, Hanford Engineering Development Laboratory, Richland, Wash. (July 1973).

33. P. C. Riccardella and J. L. Swedlow, *A Combined Analytical-Experimental Fracture Study of the Two Leading Theories of Elastic-Plastic Fracture (J-Integral and Equivalent Energy)*, WCAP-8224, Westinghouse Electric Corporation, Pittsburgh, Pa. (October 1973).

34. R. J. Podlasek and R. J. Eiber, *Final Report on Investigation of Mode III Crack Extension in Reactor Piping*, Battelle Columbus Laboratories, Columbus, Ohio (December 14, 1973).

35. T. R. Mager, J. D. Landes, D. M. Moon, and V. J. McLaughlin, *Interim Report on the Effect of Low Frequencies on the Fatigue Crack Growth Characteristics of A533 Grade B Class 1 Plate in an Environment of High-Temperature Primary Grade Nuclear Reactor Water*, WCAP-8256, Westinghouse Electric Corporation, Pittsburgh, Pa. (December 1973).

36. J. A. Williams, *The Irradiated Fracture Toughness of ASTM A533, Grade B, Class 1 Steel Measured with a Four-Inch-Thick Compact Tension Specimen*, HEDL-TME 75-10, Hanford Engineering Development Laboratory, Richland, Wash. (January 1975).

37. R. H. Bryan, J. G. Merkle, M. N. Raftenberg, G. C. Robinson, and J. E. Smith, *Test of 6-Inch-Thick Pressure Vessels. Series 2: Intermediate Test Vessels V-3, V-4, and V-6*, ORNL-5059, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (November 1975).

38. T. R. Mager, S. E. Yanichko, and L. R. Singer, *Fracture Toughness Characterization of HSST Intermediate Pressure Vessel Material*, WCAP-8456, Westinghouse Electric Corporation, Pittsburgh, Pa. (December 1974).

39. J. G. Merkle, G. D. Whitman, and R. H. Bryan, *An Evaluation of the HSST Program Intermediate Pressure Vessel Tests in Terms of Light-Water-Reactor Pressure Vessel Safety*, ORNL/TM-5090, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (November 1975).

40. J. G. Merkle, G. C. Robinson, P. P. Holz, J. E. Smith, and R. H. Bryan, *Test of 6-In.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-7*, ORNL/NUREG-1, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (August 1976).

41. J. A. Davidson, L. J. Ceschini, R. P. Shogan, and G. V. Rao, *The Irradiated Dynamic Fracture Toughness of ASTM A533, Grade B, Class 1 Steel Plate and Submerged Arc Weldment*, WCAP-8775, Westinghouse Electric Corporation, Pittsburgh, Pa. (October 1976).

42. R. D. Cheverton, *Pressure Vessel Fracture Studies Pertaining to PWR LOCA-ECC Thermal Shock: Experiments TSE-1 and TSE-2*, ORNL/NUREG/TM-31, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (September 1976).

43. J. G. Merkle, G. C. Robinson, P. P. Holz, and J. E. Smith, *Test of 6-In.-Thick Pressure Vessels. Series 4: Intermediate Test Vessels V-5 and V-9 with Inside Nozzle Corner Cracks*, ORNL/NUREG-7, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (August 1977).

44. J. A. Williams, *The Ductile Fracture Toughness of Heavy Section Steel Plate*, Hanford Engineering Development Laboratory, Richland, Wash., NUREG/CR-0859 (September 1979).

45. R. H. Bryan, T. M. Cate, P. P. Holz, T. A. King, J. G. Merkle, G. C. Robinson, G. C. Smith, J. E. Smith, and G. D. Whitman, *Test of 6-in.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-7A Under Sustained Loading*, ORNL/NUREG-9, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (February 1978).

46. R. D. Cheverton and S. E. Bolt, *Pressure Vessel Fracture Studies Pertaining to a PWR LOCA-ECC Thermal Shock: Experiments TSE-3 and TSE-4 and Update of TSE-1 and TSE-2 Analysis*, ORNL/NUREG-22, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (December 1977).

47. D. A. Canonico, *Significance of Reheat Cracks to the Integrity of Pressure Vessels for Light-Water Reactors*, ORNL/NUREG-15, Oak Ridge Natl. Lab., Oak Ridge, Tenn. (July 1977).

48. G. C. Smith and P. P. Holz, *Repair Weld Induced Residual Stresses in Thick-Walled Steel Pressure Vessels*, NUREG/CR-0093 (ORNL/NUREG/TM-153), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (June 1978).

49. P. P. Holz and S. W. Wismer, *Half-Bead (Temper) Repair Welding for HSST Vessels*, NUREG/CR-0113 (ORNL/NUREG/TM-177), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (June 1978).

50. G. C. Smith, P. P. Holz, and W. J. Stelzman, *Crack Extension and Arrest Tests of Axially Flawed Steel Model Pressure Vessels*, NUREG/CR-0126 (ORNL/NUREG/TM-196), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (October 1978).

51. R. H. Bryan, P. P. Holz, J. G. Merkle, G. C. Smith, J. E. Smith, and W. J. Stelzman, *Test of 6-in.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-7B*, NUREG/CR-0309 (ORNL/NUREG-38), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (October 1978).

52. R. D. Cheverton, S. K. Iskander, and S. E. Bolt, *Applicability of LEFM to the Analysis of PWR Vessels Under LOCA-ECC Thermal Shock Conditions*, NUREG/CR-0107 (ORNL/NUREG-40), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (October 1978).

53. R. H. Bryan, D. A. Canonico, P. P. Holz, S. K. Iskander, J. G. Merkle, J. E. Smith, and W. J. Stelzman, *Test of 6-in.-Thick Pressure Vessels, Series 3: Intermediate Test Vessel V-8*, NUREG/CR-0675 (ORNL/NUREG-58), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (December 1979).

54. R. D. Cheverton and S. K. Iskander, *Application of Static and Dynamic Crack Arrest Theory to TSE-4*, NUREG/CR-0767 (ORNL/NUREG-57), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (June 1979).

55. J. A. Williams, *Tensile Properties of Irradiated and Unirradiated Welds of A533 Steel Plate and A508 Forgings*, NUREG/CR-1158 (ORNL/Sub-79/50917/2), Hanford Engineering Development Laboratory, Richland, Wash. (July 1979).

56. K. W. Carlson and J. A. Williams, *The Effect of Crack Length and Side Grooves on the Ductile Fracture Toughness Properties of ASTM A533 Steel*, NUREG/CR-1171 (ORNL/Sub-79/50917/3), Hanford Engineering Development Laboratory, Richland, Wash. (October 1979).

57. P. P. Holz, *Flaw Preparations for HSST Program Vessel Fracture Mechanics Testing; Mechanical-Cyclic Pumping and Electron-Beam Weld-Hydrogen Charge Cracking Schemes*, NUREG/CR-1274 (ORNL/NUREG/TM-369), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (May 1980).

58. S. K. Iskander, *Two Finite Element Techniques for Computing Mode I Stress Intensity Factors in Two- or Three-Dimensional Problems*, NUREG/CR-1499 (ORNL/NUREG/CSD/TM-14), Computer Sciences Div., Union Carbide Corp. Nuclear Div., Oak Ridge, Tenn. (February 1981).

59. P. B. Crosley and E. J. Ripling, *Development of a Standard Test for Measuring K_{Ia} with a Modified Compact Specimen*, NUREG/CR-2294 (ORNL/Sub-81/7755/1), Materials Research Laboratory, Glenwood, Ill. (August 1981).

60. S. N. Atluri, B. R. Bass, J. W. Bryson, and K. Kathiresan, *NOZ-FLAW: A Finite Element Program for Direct Evaluation of Stress Intensity Factors for Pressure Vessel Nozzle-Corner Flaws*, NUREG/CR-1843, (ORNL/NUREG/CSD/TM-18), Computer Sciences Div., Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tenn. (March 1981).

61. A. Shukla, W. L. Fourney, and G. R. Irwin, *Study of Energy Loss and Its Mechanisms in Homalite 100 During Crack Propagation and Arrest*, NUREG/CR-2150 (ORNL/Sub-7778/1), University of Maryland, College Park, Md. (August 1981).

62. S. K. Iskander, R. D. Cheverton, and D. G. Ball, *OCA-1, A Code for Calculating the Behavior of Flaws on the Inner Surface of a Pressure Vessel Subjected to Temperature and Pressure Transients*, NUREG/CR-2113 (ORNL/NUREG-84), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (August 1981).

63. R. J. Sanford, R. Chona, W. L. Fourney, and G. R. Irwin, *A Photoelastic Study of the Influence of Non-Singular Stresses in Fracture Test Specimens*, NUREG/CR-2179 (ORNL/Sub-7778/2), University of Maryland, College Park, Md. (August 1981).

64. B. R. Bass, S. N. Atluri, J. W. Bryson, and K. Kathiresan, *OR-FLAW: A Finite Element Program for Direct Evaluation of K-Factors for User-Defined Flaws in Plate, Cylinders, and Pressure-Vessel Nozzle Corners*, NUREG/CR-2494 (ORNL/CSD/TM-165), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (April 1982).

65. B. R. Bass and J. W. Bryson, *ORMGEN-3D: A Finite Element Mesh Generator for 3-Dimensional Crack Geometries*, NUREG/CR-2997, Vol. 1 (ORNL/TM-8527/V1), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (December 1982).

66. B. R. Bass and J. W. Bryson, *ORVIRT: A Finite Element Program for Energy Release Rate Calculations for 2-Dimensional and 3-Dimensional Crack Models*, NUREG/CR-2997, Vol. 2 (ORNL/TM-8527/V2), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (February 1983).

67. R. D. Cheverton, S. K. Iskander, and D. G. Ball, *PWR Pressure Vessel Integrity During Overcooling Accidents: A Parametric Analysis*, NUREG/CR-2895 (ORNL/TM-7931), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (February 1983).

68. D. G. Ball, R. D. Cheverton, J. B. Drake, and S. K. Iskander, *OCA-II, A Code for Calculating Behavior of 2-D and 3-D Surface Flaws in a Pressure Vessel Subjected to Temperature and Pressure Transients*, NUREG/CR-3491 (ORNL-5934), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (February 1984).

69. A. Sauter, R. D. Cheverton, and S. K. Iskander, *Modification of OCA-I for Application to a Reactor Pressure Vessel with Cladding on the Inner Surface*, NUREG/CR-3155 (ORNL/TM-8649), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (May 1983).

70. R. D. Cheverton and D. G. Ball, *OCA-P, A Deterministic and Probabilistic Fracture-Mechanics Code for Application to Pressure Vessels*, NUREG/CR-3618 (ORNL-5991), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (May 1984).

71. J. G. Merkle, *An Examination of the Size Effects and Data Scatter Observed in Small Specimen Cleavage Fracture Toughness Testing*, NUREG/CR-3672 (ORNL/TM-9088), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (April 1984).

72. C. E. Pugh et al., *Heavy-Section Steel Technology Program — Five-Year Plan FY 1983–1987*, NUREG/CR-3595 (ORNL/TM-9008), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (April 1984).

73. D. G. Ball, B. R. Bass, J. W. Bryson, R. D. Cheverton, and J. B. Drake, *Stress Intensity Factor Influence Coefficients for Surface Flaws in Pressure Vessels*, NUREG/CR-3723 (ORNL/CSD/TM-216), Oak Ridge National Laboratory, Oak Ridge, Tenn. (February 1985).

74. W. R. Corwin, R. G. Berggren, and R. K. Nanstad, *Charpy Toughness and Tensile Properties of Neutron Irradiated Stainless Steel Submerged-Arc Weld Cladding Overlay*, NUREG/CR-3927 (ORNL/TM-9309), Oak Ridge National Laboratory, Oak Ridge, Tenn. (September 1984).

75. C. W. Schwartz, R. Chona, W. L. Fourney, and G. R. Irwin, *SAMCR: A Two-Dimensional Dynamic Finite Element Code for the Stress Analysis of Moving CRacks*, NUREG/CR-3891 (ORNL/Sub/79-7778/3), University of Maryland, College Park, Md. (November 1984).

76. W. R. Corwin, G. C. Robinson, R. K. Nanstad, J. G. Merkle, R. G. Berggren, G. M. Goodwin, R. L. Swain, and T. D. Owings, *Effects of Stainless Steel Weld Overlay Cladding on the Structural Integrity of Flawed Steel Plates in Bending, Series 1*, NUREG/CR-4015, ORNL/TM-9390, Oak Ridge Natl. Lab., Oak Ridge, Tenn., April 1985.

77. R. H. Bryan, B. R. Bass, S. E. Bolt, J. W. Bryson, D. P. Edmonds, R. W. McCulloch, J. G. Merkle, R. K. Nanstad, G. C. Robinson, K. R. Thoms, and G. D. Whitman, *Pressurized-Thermal-Shock Test of 6-in.-Thick Pressure Vessels. PTSE-1: Investigation of Warm Prestressing and Upper-Shelf Arrest*, NUREG/CR-4106 (ORNL-6135), Oak Ridge Natl. Lab., Oak Ridge, Tenn. (May 1985).

78. R. D. Cheverton, D. G. Bal , S. E. Bolt, S. K. Iskander, and R. K. Nanstad, *Pressure Vessel Fracture Studies Pertaining to the PWR Thermal-Shock Issue: Experiments TSE-5, TSE-5A and TSE-6*, NUREG/CR-4249 (ORNL-6163), Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn. (June 1985).

79. R. D. Cheverton, D. G. Ball, S. E. Bolt, S. K. Iskander, and R. K. Nanstad, *Pressure Vessel Fracture Studies Pertaining to the PWR Thermal-Shock Issue: Experiment TSE-7*, NUREG/CR-4304 (ORNL-6177), Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn. (in preparation).

80. R. H. Bryan, B. R. Bass, S. E. Bolt, J. W. Bryson, J. G. Merkle, R. K. Nanstad, and G. C. Robinson, *Test of 6-in.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-8A — Tearing Behavior of Low Upper-Shelf Material*, NUREG/CR-XXXX (ORNL-6187), Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn. (to be published).

81. R. D. Cheverton and D. G. Ball, *A Parametric Study of PWR Pressure Vessel Integrity During Overcooling Accidents, Considering Both 2-D and 3-D Flaws*, NUREG/CR-XXXX (ORNL/TM-9682), Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., Oak Ridge, Tenn. (in preparation).

82. E. C. Rodabaugh, *Comments on the Leak-Before-Break Concept for Nuclear Power Plant Piping Systems*, NUREG/CR-4305 (ORNL/Sub/82-22252/3), E. C. Rodabaugh Associates, Inc., Hilliard, Ohio (in preparation).

ORVIRT.PC: A 2-D FINITE-ELEMENT FRACTURE ANALYSIS PROGRAM FOR A MICROCOMPUTER

J. W. Bryson

ABSTRACT

ORVIRT.PC (Oak Ridge VIRTual crack extension. Personal Computer) is a two-dimensional (2-D) finite-element fracture analysis program for an IBM PC/AT or PC/XT microcomputer. The code is based primarily on the techniques used in the ORMGEN-ADINA-ORVIRT fracture analysis system. ORVIRT.PC is a stand-alone program capable of performing 2-D linear-elastic stress and fracture-mechanics analyses. Thermal loadings may be analyzed in addition to mechanical loadings. Crack-face tractions may also be considered. Eight-noded isoparametric elements that combine both performance and ease of modeling are employed in the program. Special crack-tip elements that allow for an inverse square root variation in the near tip stress and strain fields may be used at the crack tip. Detailed user instructions describe both preparation of input data and program operation. Sample problems are presented that demonstrate good agreement with known solutions.

1. INTRODUCTION AND SUMMARY

This report describes the finite-element computer program ORVIRT.PC (Oak Ridge VIRTual crack extension. Personal Computer) and provides user instructions. ORVIRT.PC is a stand-alone finite-element program that executes on an IBM PC/AT or PC/XT and is capable of performing two-dimensional (2-D) linear thermoelastic stress and fracture-mechanics analyses. Special crack-tip elements that allow for an inverse square root variation in the near tip stress and strain fields may be used at the crack tip.

ORVIRT.PC is based primarily on the techniques used in the ORMGEN-ADINA-ORVIRT[1-3] fracture analysis system.* An enhanced version[3,4] of the deLorenzi virtual crack extension development[5] is employed in the code. Because pressurized thermal shock[6,7] of light-water reactor vessels is a major concern of the HSST Program, a thermal loading capability[4] has been added to the original deLorenzi development. The virtual crack extension technique used here can be shown[3] to reduce identically to the J-integral for 2-D problems. In addition, it offers an advantage in application

*ORMGEN-ADINA-ORVIRT addresses linear or nonlinear fracture in 2- or 3-D crack configurations and has been extensively used and thoroughly validated by research members in the Heavy-Section Steel Technology (HSST) Program at the Oak Ridge National Laboratory.

over the latter when thermal loadings are considered because all integrals to be performed are area integrals, as opposed to a mix of contour and area integrals for the J-integral. Although the technique is applicable in principle to the elastoplastic problem, limitations imposed by the microcomputer environment make its inclusion impractical at this time.

Routines that greatly facilitate data preparation are available in the program. Eight-noded isoparametric quadrilateral elements are employed everywhere in the modeling, including the crack-tip region. These elements give essentially the same accuracy for linear-elastic analyses as the collapsed-wedge elements used in the mainframe ORMGEN-ADINA-ORVIRT system[1-3] and are much easier to model.

The motivation for developing ORVIRT.PC was to provide an accurate 2-D stand-alone fracture analysis capability for linear thermoelastic applications. The program performs its own stress analysis, and, thus, access to a large structural code such as ADINA[2] is not necessary. A very efficient frontal solver introduced by Irons[8] and presented in detail by Owen and Fawkes[9] is employed in the equation solution subroutine.

Comparisons of ORVIRT.PC results with known solutions indicate very good agreement. Typical run times on an IBM PC/AT are 20 to 22 min for a problem approaching the maximum allowable dimensions of 135 elements and 450 nodes. The program takes ~60% longer to execute on an IBM PC/XT.

2. STRESS ANALYSIS

ORVIRT.PC performs linear-elastic plane-stress or plane-strain analyses. Eight-noded isoparametric quadrilateral elements with curved sides and a quadratic variation of displacement are used in the program (Fig. 1). Either a 2 by 2 or 3 by 3 Gauss integration rule may be employed (see Fig. 2). Stresses are calculated and printed for the Gauss point positions shown in Fig. 2. Eight-noded isoparametric elements were chosen for ORVIRT.PC because they are versatile and well tried and tested and are good performers. Practical experience indicates that greater accuracy can be achieved by using fewer of these complex elements in place of a larger number of simpler elements. Also, user input and modeling are greatly simplified in an attempt to provide a user-friendly fracture analysis tool.

ORVIRT.PC employs modified versions of subroutines presented in the finite-element texts by Owen and Fawkes[9] and Hinton and Owen.[10] An extremely efficient frontal solver described and listed in both Refs. 9 and 10 is used in its entirety in ORVIRT.PC. The frontal equation technique

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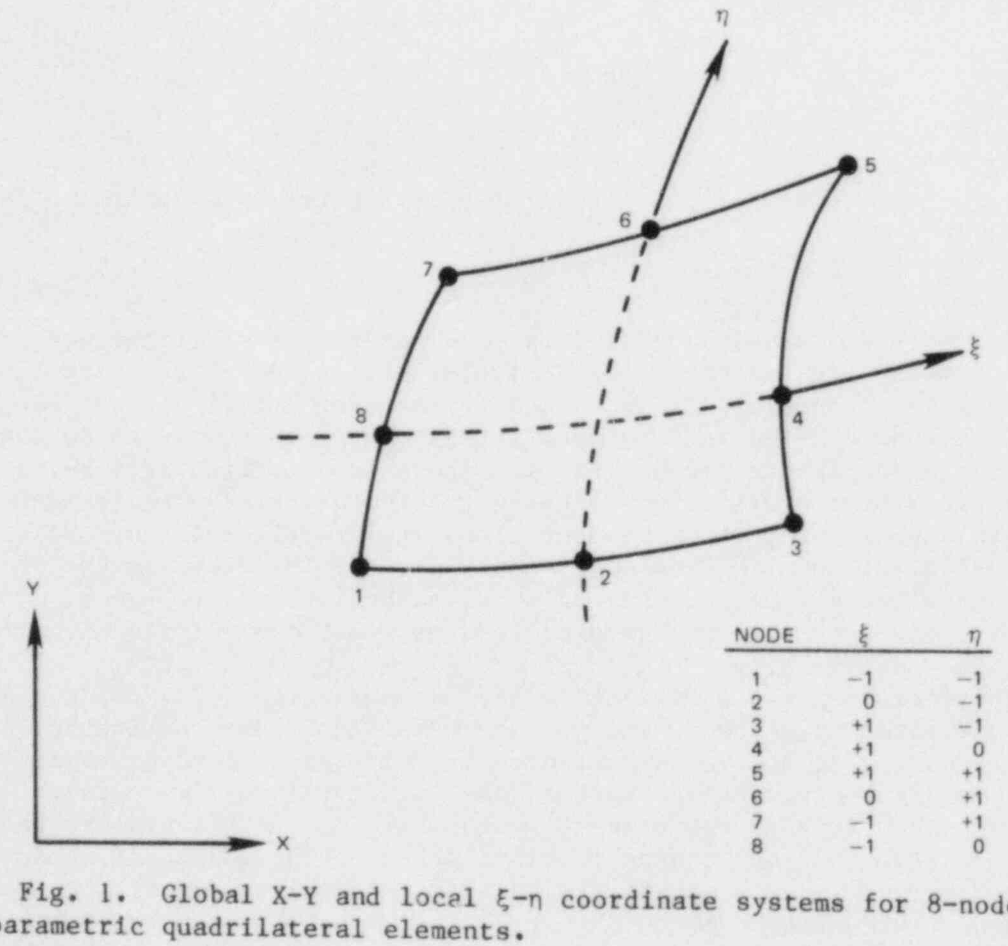
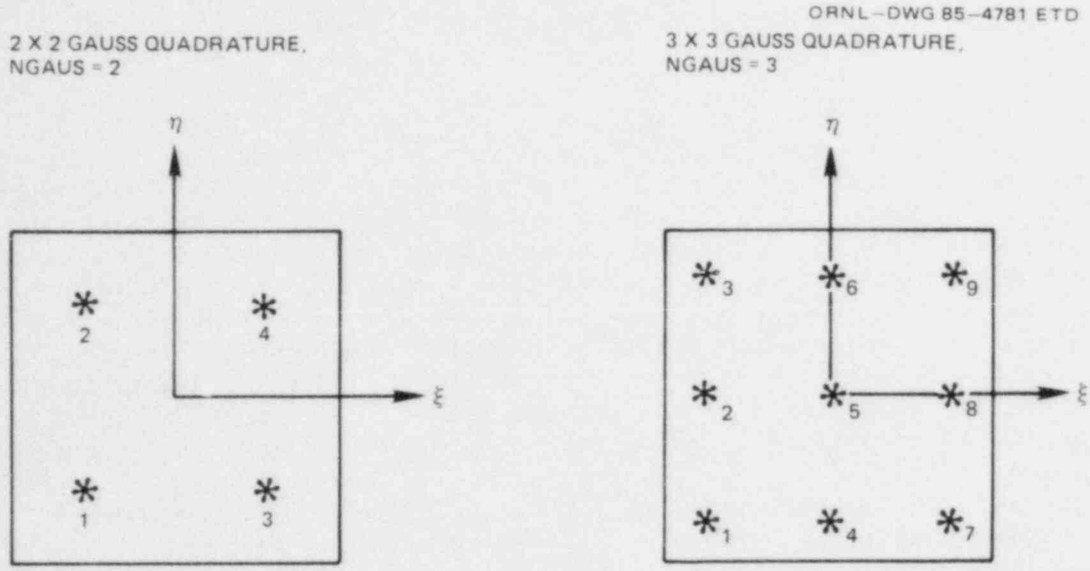


NODE	ξ	η
1	−1	−1
2	0	−1
3	+1	−1
4	+1	0
5	+1	+1
6	0	+1
7	−1	+1
8	−1	0

Fig. 1. Global X-Y and local ξ-η coordinate systems for 8-noded isoparametric quadrilateral elements.



G. P.	ξ	η
1	−0.5774	−0.5774
2	−0.5774	+0.5774
3	+0.5774	−0.5774
4	+0.5774	+0.5774

G. P.	ξ	η
1	−0.7746	−0.7746
2	−0.7746	0
3	−0.7746	+0.7746
4	0	−0.7746
5	0	0
6	0	+0.7746
7	+0.7746	−0.7746
8	+0.7746	0
9	+0.7746	+0.7746

Fig. 2. Either 2- or 3-point rules may be employed for numerical integration.

was originated by Irons[8] and differs from banded solver techniques in that equations are assembled and variables eliminated at the same time. The complete structural stiffness matrix is never formed as such because, after elimination, the reduced equation is immediately written to the hard disk. The frontal technique, is, therefore, particularly suitable for microcomputer applications because both core storage requirements and the total number of arithmetic operations are greatly reduced. Unlike banded solvers, the ordering of elements is very important in the frontal technique although the ordering of nodal numbering is irrelevant. Therefore, the elements must be numbered in a systematic manner to minimize the front width.[8,10]

The following types of loading may be considered: (1) point loads, (2) distributed-edge loads, and (3) thermal loads. Any combination of these loads may be applied simultaneously, or several loading conditions may be applied in succession to the same structural configuration. Distributed-edge loads do not have to be constant but can vary along the element edge. Thermal loading consists of inputting values of ΔT at node points. As a further simplification, gravity loads and other body force loadings are not included.

ORVIRT.PC is dimensioned for a maximum of 450 nodes and 135 elements. Up to five different materials may be considered; however, as will be explained in Sect. 3, the crack-tip zone must consist of a single material.

3. FRACTURE ANALYSIS

After deLorenzi,[5] ORVIRT.PC employs a virtual crack extension technique that has been modified to include the effects of thermal strains.[3,4] The method requires calculation of the released energy G* corresponding to a virtual crack advance in a cracked body subjected to surface tractions F_α, body force f_α, and temperature distribution T (Fig. 3). Points of configuration I (prior to crack advance) are mapped into configuration II (after crack advance) by the mapping

$$\overline{x}_\alpha = x_\alpha + \Delta x_\alpha \ , \tag{1}$$

where x_α, $\overline{x}_\alpha$ correspond to coordinates in configurations I, II, respectively, and Δx_α is the incremental change in coordinates throughout the body accompanying a virtual crack extension Δa at the crack tip.

Using index notation, it can be shown[3,5] that the energy release parameter G* becomes

$$G^* = \int_V \left(\sigma_{\alpha\beta} \frac{\partial u_\alpha}{\partial x_\delta} - W\delta_{\delta\beta}\right) \frac{\partial \Delta x_\delta}{\partial x_\beta} \, dV + \int_V \left(\sigma_{\alpha\beta} \frac{\partial \theta_{\alpha\beta}}{\partial x_\delta} - f_\alpha \frac{\partial u_\alpha}{\partial x_\delta}\right) \Delta x_\delta \, dV - \int_S t_\alpha \frac{\partial u_\alpha}{\partial x_\beta} \Delta x_\beta \, dS \ , \tag{2}$$

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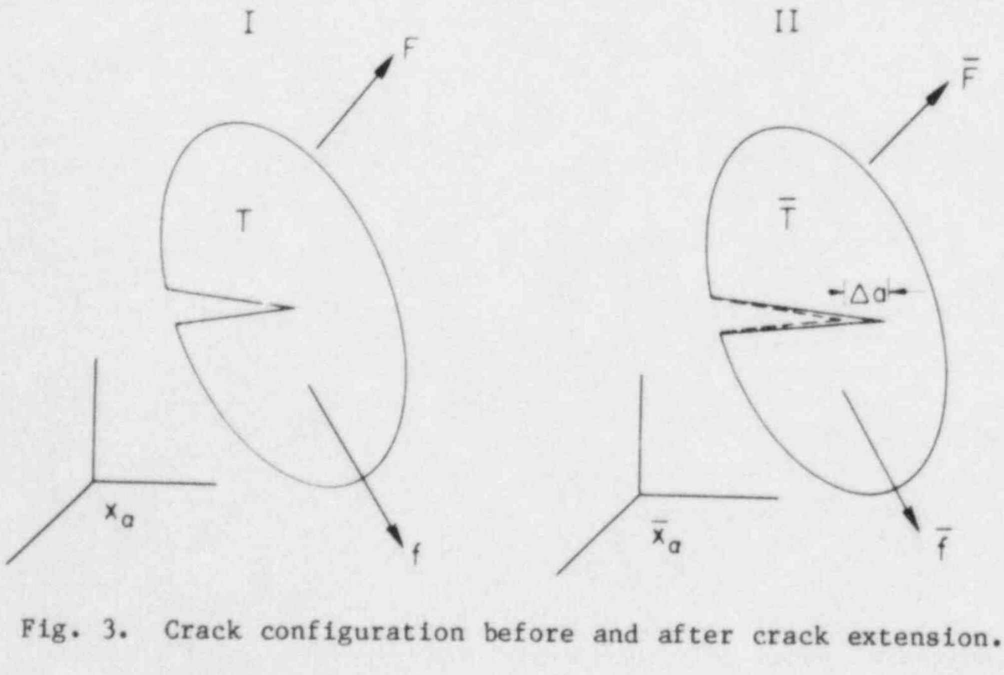

Fig. 3. Crack configuration before and after crack extension.

where

x_α = cartesian coordinate system,
V = volume,
S = surface of the cracked body,
$\sigma_{\alpha\beta}$ = stress tensor,
u_α = displacement vector,
W = strain energy density,
f_α = body force vector,
t_α = surface traction vector,
$\theta_{\alpha\beta}$ = strains of free thermal expansion,
$\delta_{\alpha\beta}$ = Kronecker's delta,
Δx_α = mapping function defined above,

and α, β, δ take on the range 1, 2, 3, and the summation convention for repeated indices is used. The strain energy density W is given by

$$W = \int \sigma_{\alpha\beta} \, d\varepsilon'_{\alpha\beta} \ ,$$
$$\varepsilon'_{\alpha\beta} = \varepsilon_{\alpha\beta} - \theta_{\alpha\beta} \ , \tag{3}$$

where the mechanical strain components $\varepsilon'_{\alpha\beta}$ are defined in terms of the total strains $\varepsilon_{\alpha\beta}$ and the strains of free thermal expansion $\theta_{\alpha\beta}$.

The energy release rate G is given by

$$G = G^*/\Delta A \ , \tag{4}$$

where ΔA is the area increment covered by the virtual crack extension. The mode I stress-intensity factor K_I is related to G by

$$K_I = \begin{cases} \sqrt{GE} & \text{plane stress} \\ \sqrt{\dfrac{GE}{1 - \upsilon^2}} & \text{plane strain} \ , \end{cases} \tag{5}$$

where E is the elastic modulus and υ is Poisson's ratio.

Obviously, there are an infinite number of mappings Δx_α for any given virtual crack extension Δa. However, if a mapping such that $\Delta x_\alpha = 0$ outside a "crack-tip zone" is chosen, then the right side of Eq. (2) must be integrated only over this crack-tip zone. In particular, ORVIRT.PC utilizes the mapping shown in Fig. 4 where $0 \leq \Delta x \leq \Delta a$ in an outer annulus of elements referred to as Region 1, and $\Delta x = \Delta a$ inside this annulus in a so-called Region 2. Note that for 2-D problems, $\Delta x_2 = \Delta x_3 = 0$ and $\Delta x_1 = \Delta x$. It can be seen that the first term on the right-hand side of

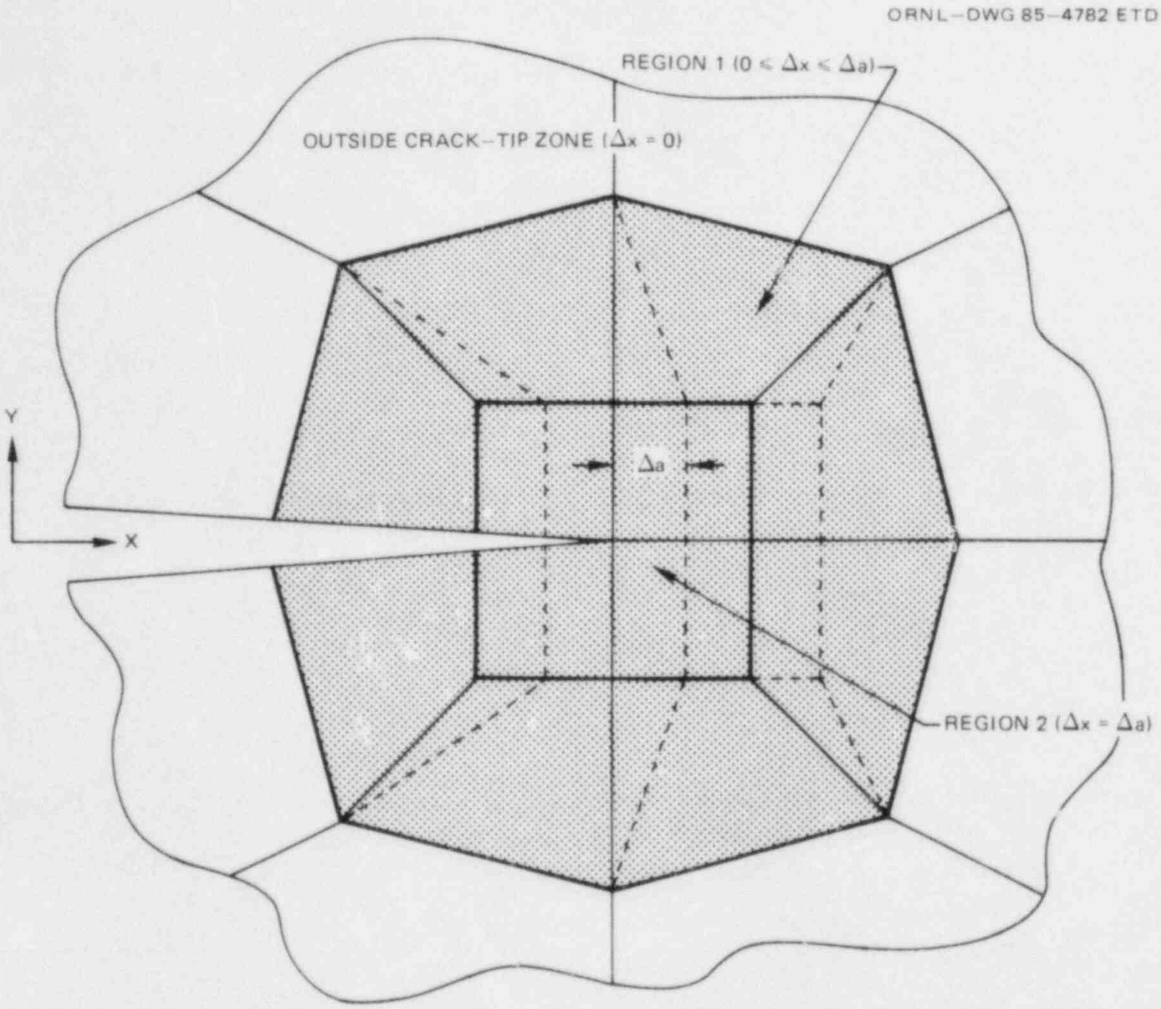

Fig. 4. ORVIRT.PC performs calculations only over the "crack-tip zone" (shaded). Outside the crack-tip zone, $\Delta x = 0$.

Eq. (2) is identically zero everywhere except within Region 1, while the second term must be integrated over the entire "crack-tip zone," that is, Regions 1 and 2. The third term only comes into play for crack-face pressure loading. ORVIRT.PC constrains a user to model the crack in the Y = 0 plane as shown in Fig. 4; hence, dS becomes dx, and the third term is a straightforward definite integral over the surface of elements within the crack-tip zone (Regions 1 and 2) that have an applied crack-face pressure.

It is important that a user understand the above strategy to correctly prepare the input data. Equation (2) is a path-independent integral; however, it is recommended that a user perform more than one "perturbation" or mapping when performing a fracture analysis. Deviations in G or K_I between different perturbations should be <0.1%, and a failure to meet this condition indicates that the problem may not be set up properly or that a finer mesh may be required.

The virtual crack extension development presented in Eq. (2) is only valid for a homogeneous crack-tip zone; that is, ORVIRT.PC cannot be used to analyze fracture configurations where the crack-tip zone consists of more than one material. Chen and Wu[11] have demonstrated the appropriate modifications to the J-integral for a crack at the interface of different materials. It is certainly conceivable that an appropriate perturbation or mapping could be defined that would enable ORVIRT.PC to handle such a situation. This would, nonetheless, require some additional modifications to the program.

ORVIRT.PC automatically generates special crack-tip elements in which the midside nodes nearest the crack tip are moved to quarter-point positions. This introduces the appropriate inverse square root variation in stress and strain along element edges that meet at the crack tip. While some may argue for the use of collapsed-wedge elements[12] at the crack tip, the quadrilateral quarter-point element employed in ORVIRT.PC gives essentially the same accuracy for linear-elastic analyses and is much easier to model. In fact, experience indicates that accurate solutions can be obtained with ORVIRT.PC by the sole use of refined meshes of conventional isoparametric quadrilateral elements at the crack tip.

Finally, it may not be obvious to a user that the virtual crack extension development used here offers a computational advantage over a J-integral calculation. In fact, for purely mechanical loading, the latter is probably more straightforward in application and programming. However, when thermal loads are present, the J-integral (Fig. 5) requires both a contour integral calculation through defined Gauss points and an

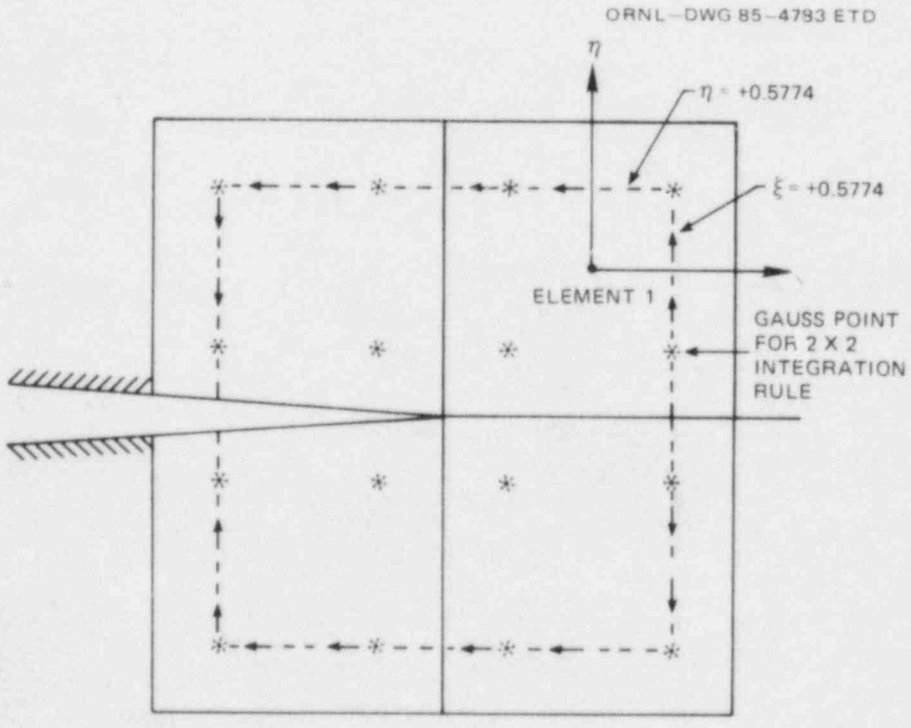

Fig. 5. J-integral contour path through "corner" elements.

area integral[13] inside this selected contour similar to the second term in Eq. (2). Integration is now required over part of an element instead of over the entire element as in the virtual crack extension formulation. This creates problems for finite-element techniques utilizing Gauss quadrature, and some kind of scaling or approximation is required. An alternative approach is to choose the contour to pass through nodal points; however, stresses must now be determined at the nodal points and this generally involves some kind of averaging scheme from all elements that meet at a common node. Also, an additional problem in the J-integral calculation, whether or not thermal loads are present, is how one handles "corner elements" like element 1 in Fig. 5, where the contour changes from the $\xi = +0.5774$ direction to the $\eta = +0.5774$ direction within an element. Owen and Fawkes[9] present an approximate scheme for handling this kind of situation; however, a user must be very careful to input the element connectivities in the specific format required.

For these reasons, the virtual crack extension development[3,5] is employed in ORVIRT.PC. Further, it represents a much cleaner formulation with regard to application than the J-integral and requires no approximations in the integration. It should be restated, however, that the two approaches must give identical results; it is only in the ease of application and programming that the virtual crack extension technique is preferred.

4. COMPARISONS WITH KNOWN SOLUTIONS

Comparisons of ORVIRT.PC calculations with known or accepted solutions are presented in the following for four different crack configurations. Although the geometries analyzed are relatively simple, finite dimensions have been chosen such that the "shape factor" for the particular problem is significantly different from unity; that is, each of the four flaw geometries represents a challenging problem for numerical analysis. The results of the comparisons demonstrate that high accuracy is obtainable with ORVIRT.PC.

Each problem was analyzed using a 3 by 3 Gauss integration rule. From the known solutions, loads and material properties were selected such that $K_I = 100$;* thus, percentage differences between ORVIRT.PC results and known solutions are readily obtained. Sample input data for the problem discussed in Sect. 4.1 are provided in Appendix B, while a complete printout of an ORVIRT.PC analysis of the same problem is given in Appendix C.

4.1 Center Cracked Plate Subjected to a Uniform Tensile Stress

Figure 6 taken from Rooke and Cartwright[14] indicates that the known solution for a geometry having $h/b = 0.5$ and $a/b = 0.5$ is $K_I = 1.94\ \sigma \sqrt{\pi a}$; thus, for $K_I = 100$, the applied tensile stress is 9.1965 if $a = 10$. The finite-element discretization and boundary conditions employed in the ORVIRT.PC analysis are shown in Fig. 7. For the given loading, ORVIRT.PC computed $K_I = 101.0$ for a 1.0% difference from the accepted solution.

4.2 Edge Crack in a Finite-Width Sheet Subjected to Three-Point Bending

Rooke and Cartwright[14] give $K_I = (1.405)\ (6M\sqrt{\pi a}/b^2)$, where $M = Pl/2$ for three-point bending of a crack configuration in which $l/b = 2$ and $a/b = 0.5$ (Fig. 8). The finite-element mesh, boundary conditions, and applied loading are shown in Fig. 9. For $a = 10$ and an applied loading $P/2 = 21.164$, ORVIRT.PC gives $K_I = 99.2$ for a 0.8% difference from the known solution.

4.3 Pressurized Tube with Crack-Face Pressure

The recognized solution[14] for a tube having $R_1/R_2 = 0.5$ and $a/(R_2 - R_1) = 0.5$ is $K_I = 1.172\ K_0$ where $K_0 = 2pR_2^2\sqrt{\pi a}/(R_2^2 - R_1^2)$ (Fig. 10).

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*For brevity and ease of report preparation, units have been omitted in the following discussion. It is understood that the results are applicable for any consistent set of units.

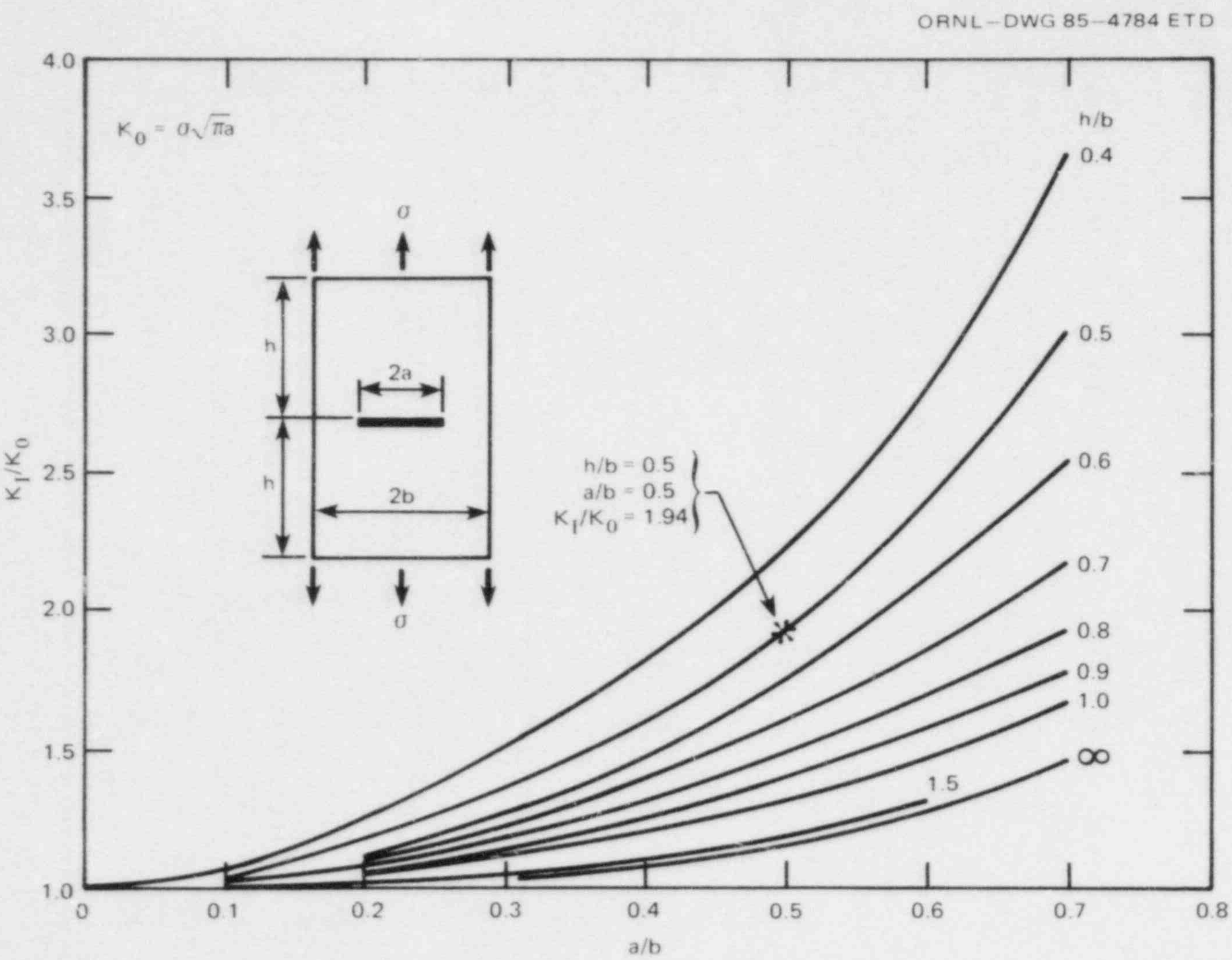

Fig. 6. K_I for a center cracked plate subjected to uniform tensile stress.

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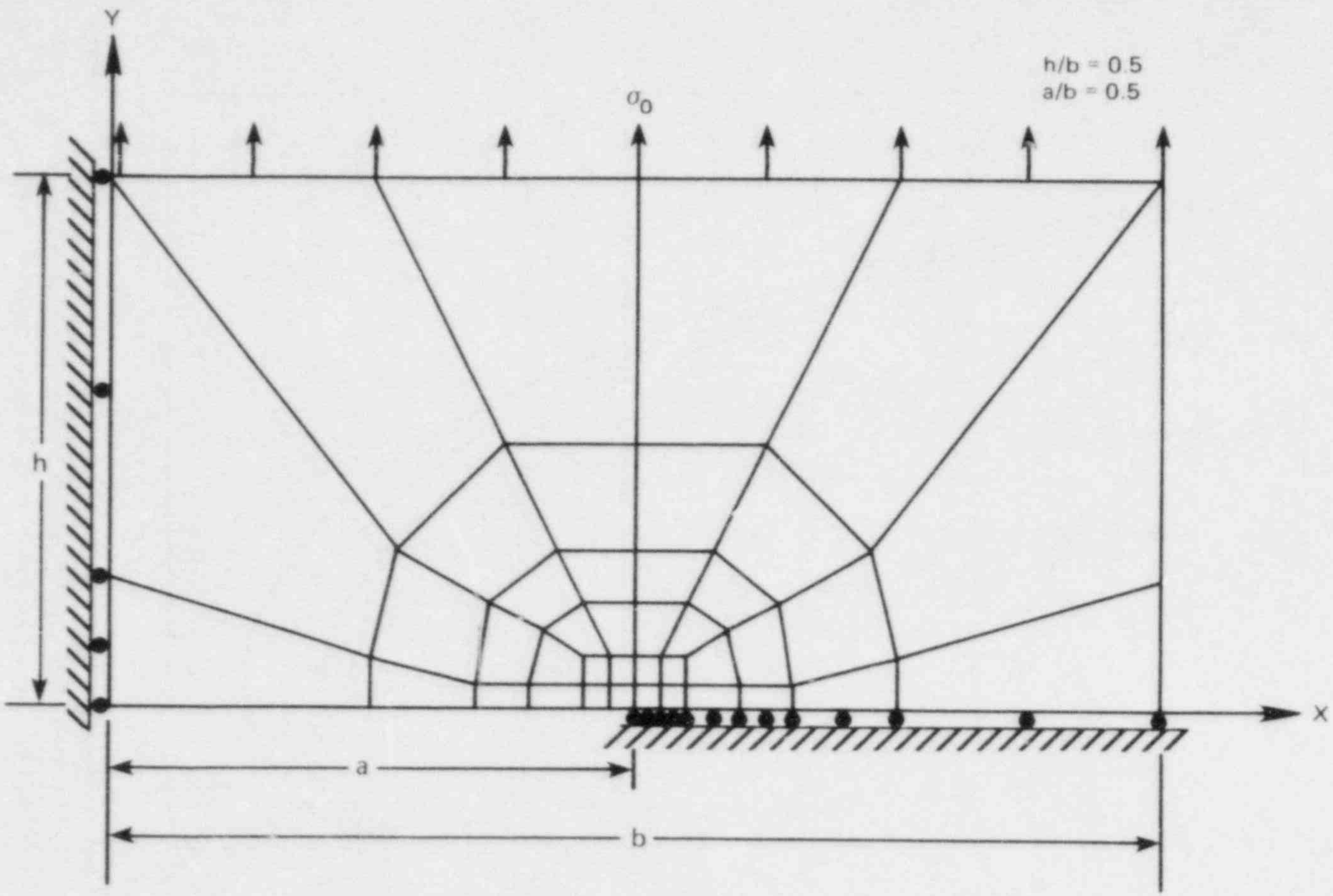

Fig. 7. Finite-element mesh employed for center cracked plate subjected to uniform tensile stress.

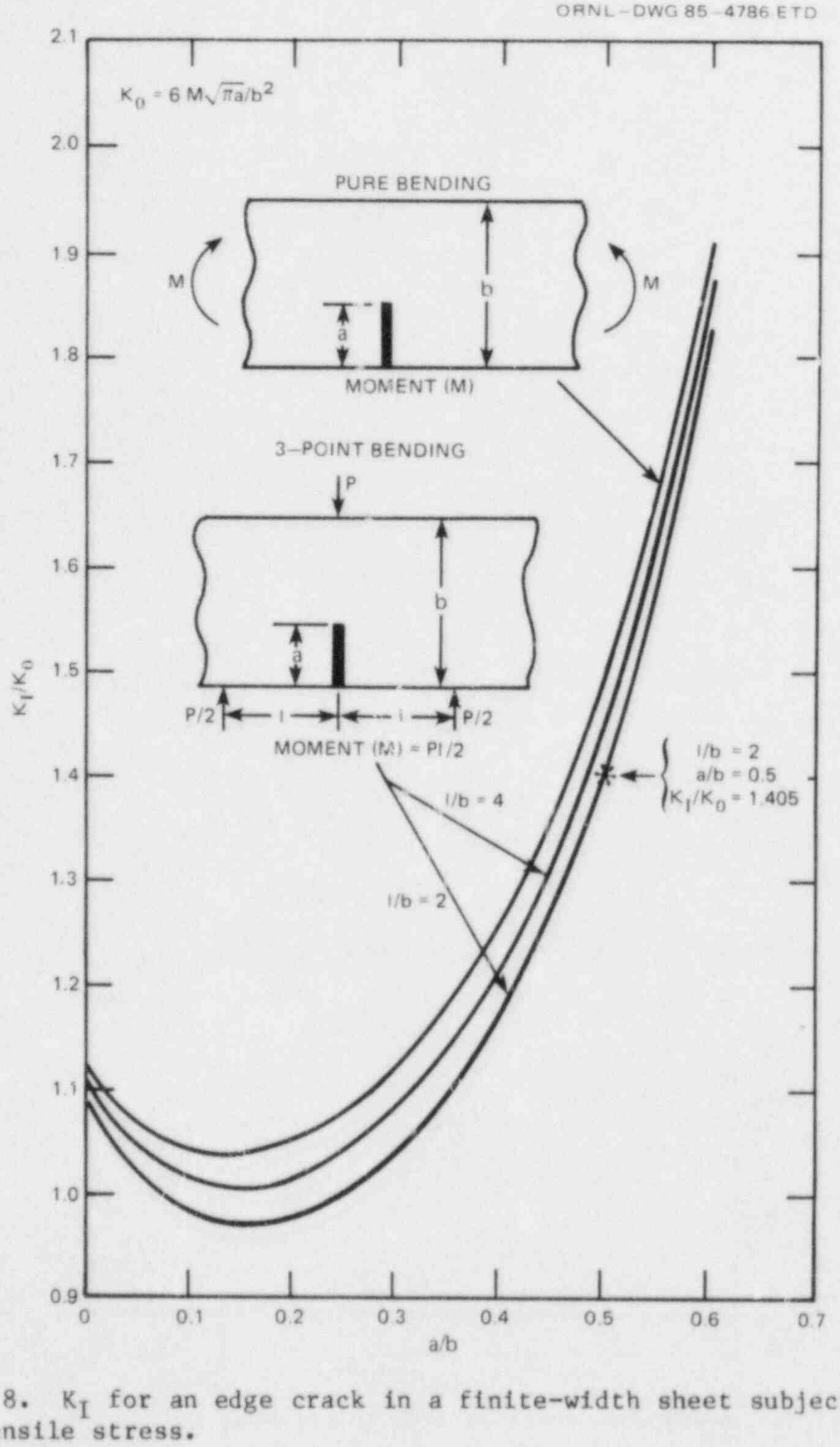

Fig. 8. K_I for an edge crack in a finite-width sheet subjected to uniform tensile stress.

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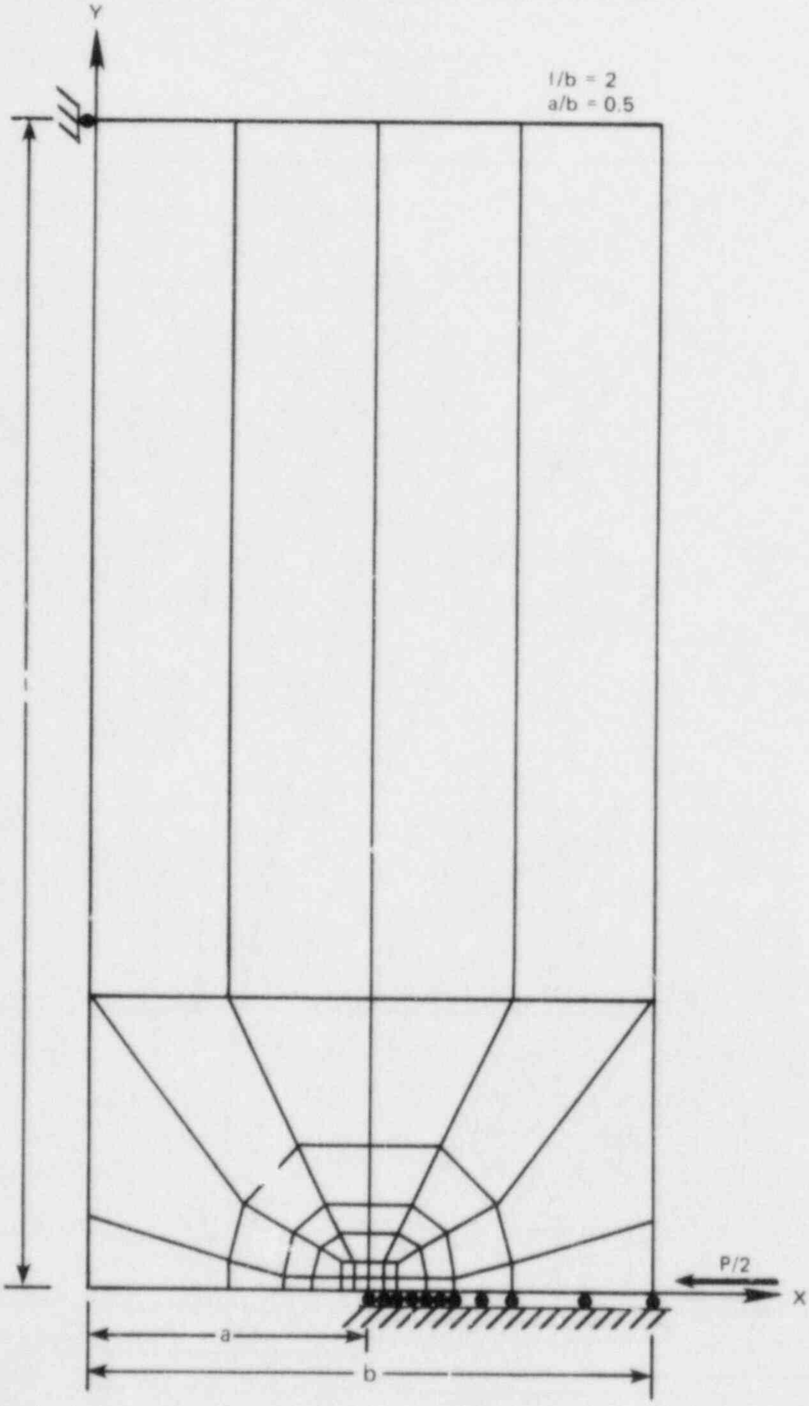

Fig. 9. Finite-element mesh employed for edge crack in a finite-width sheet subjected to three-point bending.

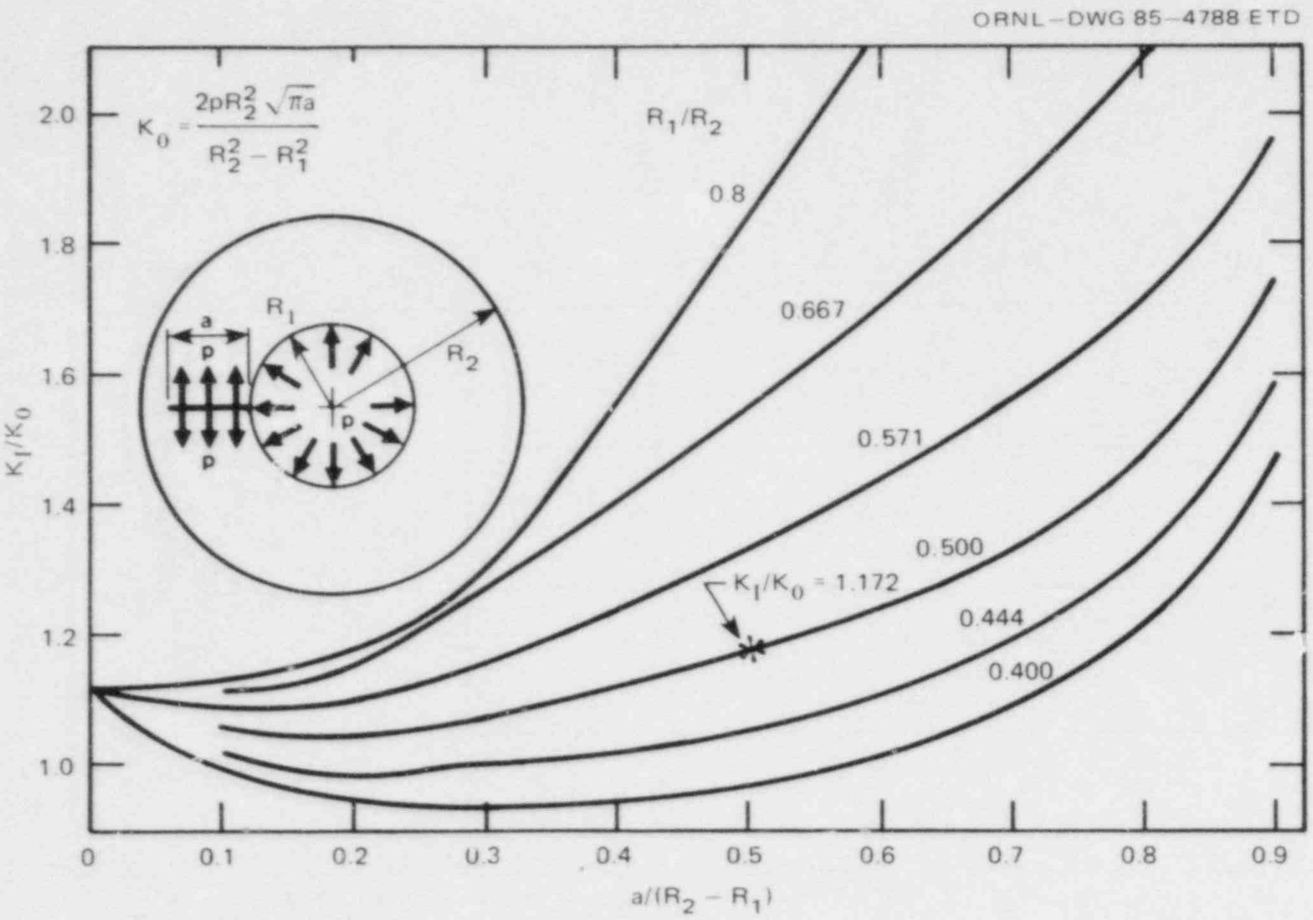

Fig. 10. K_I for a pressurized tube with crack-face pressure.

The finite-element modeling and imposed boundary conditions for the ORVIRT.PC analysis are shown in Fig. 11. For $a = 10$ and $p = 5.7086$, ORVIRT.PC gives $K_I = 98.6$, which represents a 1.4% deviation from the known solution.

4.4 Center Cracked Plate, Parabolic Temperature Distribution

The last sample problem demonstrates an application of ORVIRT.PC for thermal loading. Figure 12 shows the finite-element model used for a center cracked plate having $a/b = 0.25$ and $h/b = 3$. The plate, initially stress free at $T_o = 0$, is exposed to a parabolic temperature distribution $T = \Delta T(x/b)^2$ that gives rise to a known[13] mode I stress-intensity factor,

$$K_I = 0.557E\ \alpha\Delta T\sqrt{a}\ .$$

For $a = 10$ and $\Delta T = 200$, $K_I = 100$ if $E\alpha = 0.2839$. Using these values, ORVIRT.PC computes $K_I = 99.9$ for a 0.1% deviation from the known solution.

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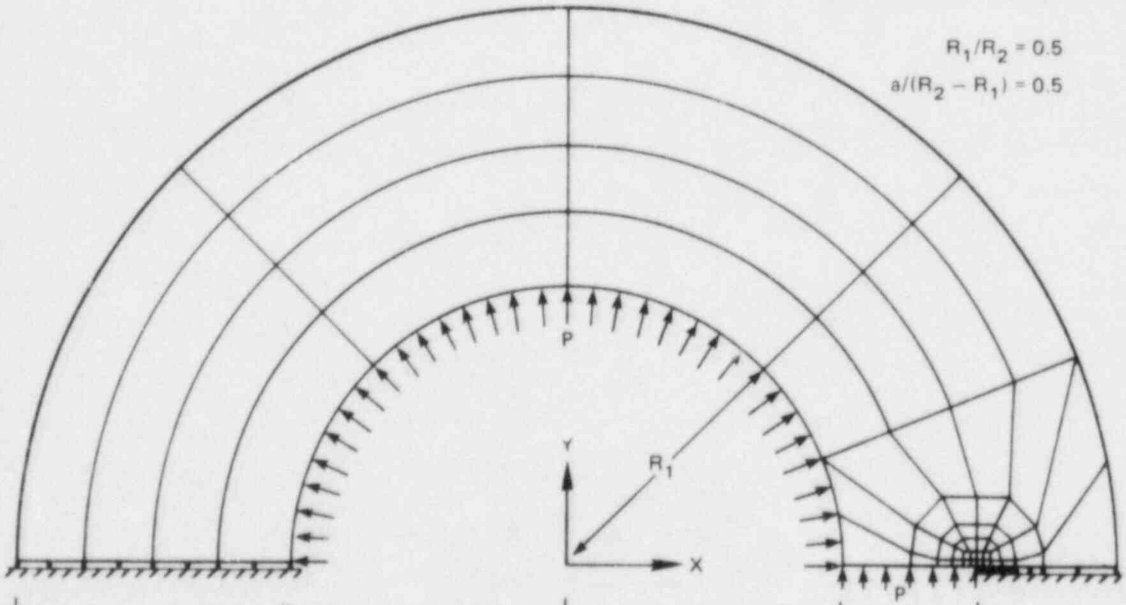

Fig. 11. Finite-element mesh employed for pressurized tube with crack-face pressure.

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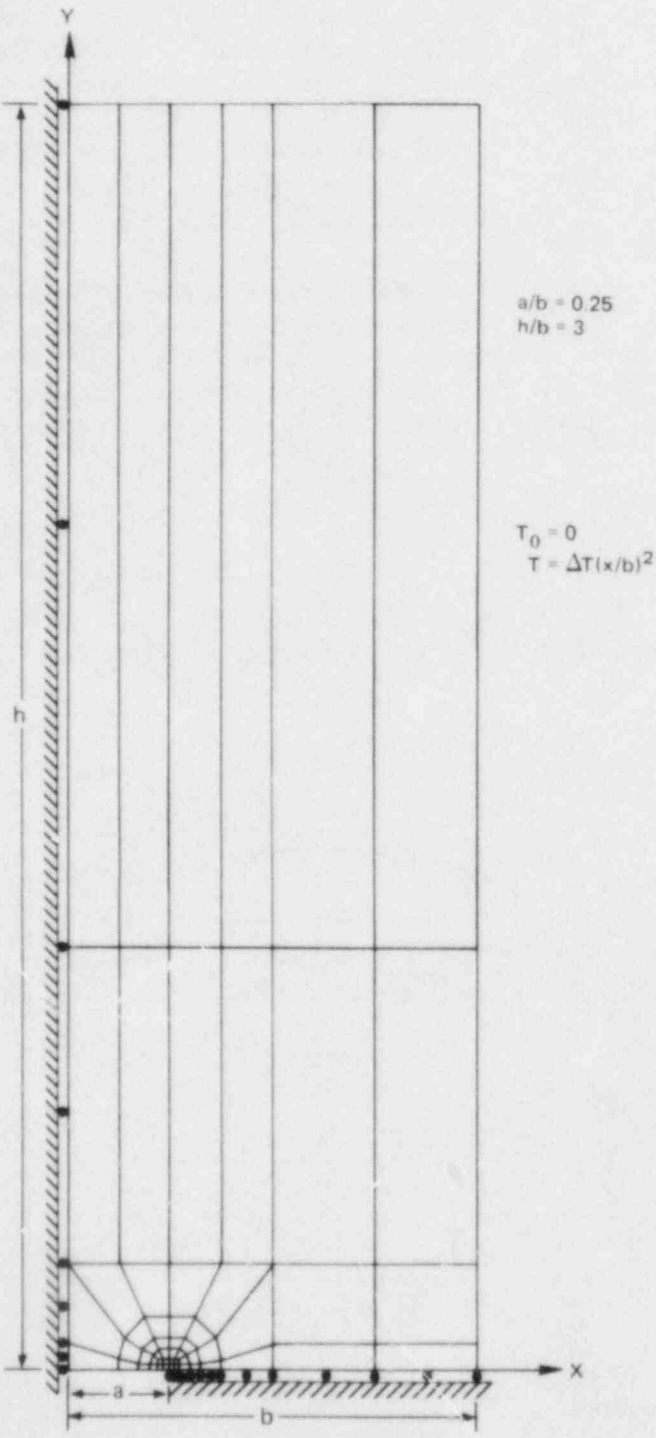

Fig. 12. Finite-element mesh employed for center cracked plate subjected to a parabolic temperature distribution.

5. PROGRAM OPERATION

The system requirements for executing ORVIRT.PC are

1. IBM PC/AT or PC/XT, 512K minimum memory, minimum 10MB hard disk capacity;
2. 80287 or 8027 math coprocessor;
3. IBM Professional Fortran Compiler, Version 1 or 2; and
4. 132 column printer.

Executing program ORVIRT.PC consists of installing the IBM Fortran Compiler routines, copying the ORVIRT.PC program diskette to the hard disk, preparing an input file FORT5, and running the program. All routines and files should reside in the root directory of the hard disk. All I/O is performed to the hard disk, and disk drives A and/or B are used only to initially load the programs. A complete stress and fracture-mechanics analysis is written to the output file FORT6. The step-by-step procedure for program execution is as follows:

1. Install IBM Professional Compiler, Version 1 or 2 according to the instructions in the compiler manual. Make sure that a CONFIG.SYS file that includes the statements FILES=10 and BUFFERS=10 is created.
2. Copy the load module ORVIRT.EXE to the hard disk by inserting the ORVIRT.PC diskette in disk drive A and typing COPY A:ORVIRT.EXE C:<cr> where <cr> is a carriage return.
3. Create the input file FORT5 using an appropriate editor or word processor. Note that the filename has no extension.
4. Execute the program by typing ORVIRT/R 10000<cr>.
5. Examine the output with either the command TYPE FORT6<cr> or TYPE FORT6>PRN<cr>. The former scrolls the output on a console while the latter prints on a 132-column printer.

ORVIRT.PC is written in FORTRAN 77, using 64 bit, double precision, real words. The 80287 and 8087 math coprocessors maintain 80 bits of accuracy for mathematical operations, and the data are rounded only when the resultant is stored back in memory.

Typical run times for ORVIRT.PC on an IBM PC/AT are 5 min for small problems to 20 min for problems approaching the maximum allowable dimensions of 135 elements and 450 nodes; the program takes ~60% longer to execute on an IBM PC/XT. Problem size and run time for each of the four example problems presented in Chap. 4 are given below:

				Run time (min)	
Problem	Nodes	Elements	DOF	IBM PC/AT	IBM PC/XT
4.1	141	40	264	5.4	8.9
4.2	155	44	296	6.1	9.8
4.3	197	56	371	7.3	12.3
4.4	197	56	368	8.4	13.9

ACKNOWLEDGMENTS

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REFERENCES

1. B. R. Bass and J. W. Bryson, *Applications of Energy Release Rate Techniques to Part-Through Cracks in Plates and Cylinders, Volume 1. ORMGEN-3D: A Finite Element Mesh Generator for 3-Dimensional Crack Geometries*, NUREG/CR-2997/V1 (ORNL/TM-8527/V1), Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., December 1982.

2. K. J. Bathe, *ADINA — A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis*, Report 82448-1, Massachusetts Institute of Technology, Cambridge, Mass., September 1975 (revised December 1978).

3. B. R. Bass and J. W. Bryson, *Applications of Energy Release Rate Techniques to Part-Through Cracks in Plates and Cylinders, Volume 2. ORVIRT: A Finite Element Program for Energy Release Rate Calculations for 2-Dimensional and 3-Dimensional Crack Models*, NUREG/CR-2997/V2 (ORNL/TM-8527/V2), Union Carbide Corp. Nuclear Div., Oak Ridge Natl. Lab., February 1983.

4. B. R. Bass and J. W. Bryson, "Energy Release Rate Techniques for Combined Thermo-Mechanical Loading," *Int. J. Fract.* 22, R3-R7 (1983).

5. H. G. deLorenzi, "On the Energy Release Rate and the J-Integral for 3-D Crack Configuration," *Int. J. Fract.* 19, 183–93 (1982).

6. R. D. Cheverton and D. G. Ball, "A Reassessment of PWR Pressure Vessel Integrity During Overcooling Accidents, Considering 3-D Flaws," *J. Pressure Vessel Technol.* 106, 375–82 (November 1984).

7. R. H. Bryan et al., *Pressurized-Thermal-Shock Test of 6-in.-Thick Pressure Vessels. PTSE-1: Investigation of Warm Prestressing and Upper-Shelf Arrest*, NUREG/CR-4106 (ORNL-6135), Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., April 1985.

8. B. M. Irons, "A Frontal Solution Program," *Int. J. Num. Meth. Eng.* 2, 5–32 (January–March 1970).

9. D. R. J. Owen and A. J. Fawkes, *Engineering Fracture Mechanics: Numerical Methods and Applications*, Pineridge Press Ltd., Swansea, Wales, 1983.

10. E. Hinton and D. R. J. Owen, *Finite Element Programming*, Academic Press Inc., New York, 1977.

11. W.-H. Chen and C.-W. Wu, "On the J-Integral for a Pressurized Crack in Bonded Materials," *Int. J. Fract.* 16, R47–R51 (1980).

12. R. S. Barsoum, "Triangular Quarter-Point Elements as Elastic and Perfectly-Plastic Crack Tip Elements," *Int. J. Numer. Methods Eng.* 11, 85–98 (January 1977).

13. R. A. Ainsworth, B. K. Neale, and R. H. Price, *Fracture Behavior in the Presence of Thermal Strains*, Report RD/B/N4152, Central Electricity Generating Board, Research Division, Berkeley Nuclear Laboratories, November 1977.

14. D. P. Rooke and D. J. Cartwright, *Compendium of Stress Intensity Factors*, The Hillingdon Press, Her Majesty's Stationery Office, London, 1976.

Appendix A

ORVIRT.PC USER INSTRUCTIONS

<u>CARD SET 1</u> — TITLE CARD (12A6), one card

Cols. 1–72	TITLE	Title of the problem

<u>CARD SET 2</u> — CONTROL CARD FOR STRESS ANALYSIS (8I5), one card

Cols. 1–5	NPOIN	Total number of nodal points, 450 maximum
6–10	NELEM	Total number of elements, 135 maximum
11–15	NVFIX	Total number of restrained boundary points where one or more degrees of freedom are restrained, 100 maximum
16–20	NCASE	Total number of load cases to be analyzed
21–25	NTYPE	Problem type parameter 1 — plane stress 2 — plane strain
26–30	NMATS	Total number of different materials, 5 maximum
31–35	NGAUS	Order of integration formula for numerical integration, either 2 or 3
36–40	NFRAC	Fracture analysis index 0 — stress analysis only 1 — fracture analysis

NOTES:

1. Only 8-noded, isoparametric, quadrilateral elements are permitted (see Fig. 1).
2. Either 2- or 3-point Gauss quadrature rules may be employed (see Fig. 2). Stresses will be calculated and printed at Gauss points only.

<u>CARD SET 3</u> — ELEMENT CARDS (10I5), one card for each element

Cols. 1–5	NUMEL	Element number
6–10	MATNO(NUMEL)	Material property number
11–15	LNODS(NUMEL,1)	1st nodal connection number
16–20	LNODS(NUMEL,2)	2nd nodal connection number
.	.	.
.	.	.
.	.	.
46–50	LNODS(NUMEL,8)	8th nodal connection number

NOTES:

1. If NFRAC=1 (see CARD SET 2), identify a quarter-point quadrilateral crack-tip element by assigning a negative material property

number to MATNO(NUMEL). A positive material property number for an element at the crack tip indicates that conventional elements are to be employed.

2. The nodal connection numbers must be listed counterclockwise, starting from any corner node (Fig. 1). This, of course, implies that the global X-Y coordinate system must be a right-handed one. Elements in Region 1 of the crack-tip zone, however, require a special numbering convention (Fig. 13). Also, for crack-tip elements, nodal connection numbers must begin with the crack-tip node; in other words, LNODS(NUMEL,1) must be the crack-tip node.

3. Only 8-noded, quadrilateral elements are permitted. Triangular elements formed by collapsing quadrilateral elements are not allowed.

<u>CARD SET 4</u> — NODAL COORDINATES (I5,2F10.5), one card for each node whose coordinates are to be input

Cols.	1–5	IPOIN	Nodal point number
	6–15	COORD(IPOIN,1)	X-coordinate of node
	16–25	COORD(IPOIN,2)	Y-coordinate of node

NOTES:

1. The coordinates of the highest numbered node must be input whether or not it is a corner-point node.

2. The total number of cards in this set will generally be less than NPOIN (see CARD SET 2) because for straight element sides it is only necessary to specify corner-node coordinates; midside nodal coordinates are automatically determined if on a straight side. Quarter-point node coordinates are automatically generated for crack-tip elements.

<u>CARD SET 5</u> — RESTRAINED NODE CARDS (I5,3X,2I1,2F10.5), one card for each restrained node, total of NVFIX cards (see CARD SET 2).

Cols.	1–5	NOFIX(IVFIX)	Restrained node number
	9	IFPRE(IVFIX,1)	X-displacement restraint 0 — no restraint 1 — displacement restrained
	10	IFPRE(IVFIX,2)	Y-displacement restraint 0 — no restraint 1 — displacement restrained
	11–20	PRESC(IVFIX,1)	Prescribed value of X-displacement
	21–30	PRESC(IVFIX,2)	Prescribed value of Y-displacement

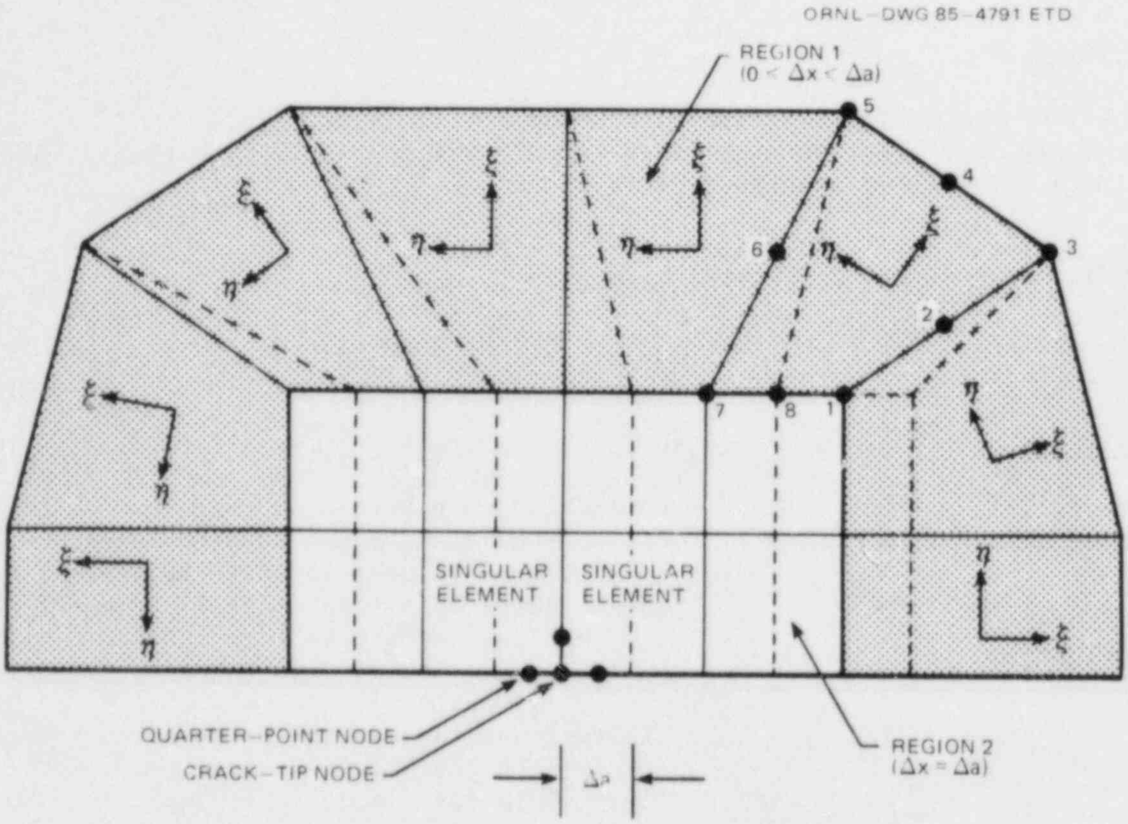

Fig. 13. Elements in Region 1 of the crack-tip zone that require the numbering convention where node 1 is always at $\xi = -1$ and $\eta = -1$ with respect to local coordinates. No special convention is required for elements in Region 2, except for crack-tip singularity elements in which node numbering must commence with crack-tip node.

CARD SET 6 — MATERIAL PROPERTIES (I5,4F10.5), one card for each different material, total of NMATS cards (see CARD SET 2).

Cols. 1—5	NUMAT	Material identification number
6—15	PROPS(NUMAT,1)	Elastic modulus
16—25	PROPS(NUMAT,2)	Poisson's ratio
26—35	PROPS(NUMAT,3)	Material thickness
36—45	PROPS(NUMAT,4)	Coefficient of thermal expansion

NOTES:

1. Material properties are assumed to be isotropic.
2. For plane strain, leave PROPS(NUMAT,3) blank. The program automatically assigns a unit thickness.

CARD SET 7 — LOAD CASE TITLE CARD (12A6), one card

Cols. 1—72	TITLE	Title of the load case

CARD SET 8 — LOAD CONTROL CARD (3I5), one card

Cols. 1—5	IPLOD	Point load control parameter 0 — no applied nodal point loads 1 — nodal point loads to be input
6—10	IEDGE	Distributed edge load control parameter 0 — no distributed edge loads 1 — distributed edge loads to be input
11—15	ITEMP	Thermal loading control parameter 0 — no thermal loading 1 — thermal loads to be input

NOTES:

1. Distributed edge loads need not be constant but can vary along the element edge.
2. Gravity and other body-force loadings are not available.

CARD SET 9 — NODAL POINT LOAD CARDS (I5,2F10.3), one card for each loaded nodal point

Cols. 1—5	LODPT	Node number
6—15	POINT(1)	Load component in X-direction
16—25	POINT(2)	Load component in Y-direction

NOTES:

1. The last card should be that for the highest numbered node whether or not it is loaded.
2. If IPLOD=0 in CARD SET 8, omit this set.

CARD SET 10 — DISTRIBUTED EDGE LOAD CARDS

10(a) CONTROL CARD (I5), one card

Cols. 1—5	NEDGE	Number of element edges on which distributed loads are to be applied

10(b) ELEMENT FACE TOPOLOGY CARD (4I5)

Cols. 1—5	KELEM	Element number with which the element edge is associated
6—10	NOPRS(1)	List of counterclockwise nodal points forming the element face on which the distributed load acts
11—15	NOPRS(2)	
16—20	NOPRS(3)	

10(c) DISTRIBUTED LOAD CARDS (6F10.3)

Cols. 1—10	PRESS(1,1)	Value of normal component of distributed load/unit length at node NOPRS(1)
11—20	PRESS(2,1)	Value of normal component of distributed load/unit length at node NOPRS(2)
21—30	PRESS(3,1)	Value of normal component of distributed load/unit length at node NOPRS(3)
31—40	PRESS(1,2)	Value of tangential component of distributed load/unit length at node NOPRS(1)
41—50	PRESS(2,2)	Value of tangential component of distributed load/unit length at node NOPRS(2)
51—60	PRESS(3,2)	Value of tangential component of distributed load/unit length at node NOPRS(3)

NOTES:

1. Subsets 10(b) and 10(c) must be input a total of NEDGE times. The element edges can be considered in any order.
2. Positive normal components act into an element while positive tangential components act counterclockwise.
3. If IEDGE=0 in CARD SET 8, omit this card set.

CARD SET 11 — THERMAL LOAD CARDS (I5,F10.3)

Cols. 1—5	NODPT	Node number
6—15	TEMPE (NODPT)	ΔT at node

NOTES:

1. Although not recommended, only corner-node values of ΔT are required to be input; the program will automatically perform a linear interpolation for ΔT at midside nodes and quarter-point nodes. The card

set must terminate with the highest numbered node whether or not it is a corner node.

2. IF ITEMP=0 in CARD SET 8, omit this card set.

OMIT THE REMAINING CARD SETS IF NFRAC=0 (see CARD SET 2).

CARD SET 12 — CONTROL CARD FOR FRACTURE ANALYSIS (4I5,F10.4), one card

Cols. 1—5	NPERT	Number of perturbations for which a fracture analysis will be performed
6—10	MATIP	Material property identification number for elements in crack-tip zone
11—15	NSYMM	Model symmetry factor 1 — entire crack-tip region modeled 2 — one-half of crack-tip region modeled
16—20	IFACE	Crack-face pressure index 0 — no crack-face pressure 1 — normal pressure loading applied to the crack face
21—30	CREXT	Value of virtual crack extension

NOTES:

1. The crack must lie in the Y = 0 plane.

2. Although the development presented here is path independent, more than one perturbation is recommended. K-values obtained for different perturbations should typically agree to 0.1%. A failure to meet this condition indicates that a more refined mesh may be required.

3. Only one material type is permitted in the crack-tip zone. The virtual crack extension development employed here is valid only for a homogeneous material in the crack-tip zone. More than one material, however, is permitted outside the crack-tip zone.

4. The normal pressure loading on the crackface need not be constant but can vary along the crackface. Tangential components of crackface pressure, however, are not permitted.

5. The virtual crack extension should be substantially less than a typical dimension of a crack-tip element, a recommended value is 0.001. Input a positive value for crack extension in the positive X-direction and a negative value for crack extension in the negative X-direction.

CARD SET 13 — PERTURBATION TOPOLOGY CARDS (see Fig. 13)

13(a) REGION 1 CONTROL CARD

Cols. 1—5	NLIS1	Number of elements in perturbed Region 1 where $0 < \Delta x < \Delta a$, 16 maximum

13(b) REGION 1 TOPOLOGY (16I5), one card

Cols. 1–5	LIST1(1)	Read NLIS1 Elements in perturbed Region 1, maximum of 16 Elements
6–10	LIST1(2)	
.	.	
.	.	
.	.	
75–80	LIST1(16)	

READ THE NEXT TWO SETS, 13(c) AND 13(d), ONLY IF ITEMP=1 IN CARD SET 8.

13(c) REGION 2 CONTROL CARD

Cols. 1–5	NLIS2	Number of elements in perturbed Region 2 where $\Delta x = \Delta a$, 48 maximum

13(d) REGION 2 TOPOLOGY (16I5), one, two, or three cards

Cols. 1–5	LIST2(1)	Read NLIS2 elements in perturbed Region 2, maximum of 48 Elements
6–10	LIST2(2)	
.	.	
.	.	
.	.	
75–80	LIST2(16)	

2nd card, if necessary

Cols. 1–5	LIST2(17)
6–10	LIST2(18)
.	.
.	.
.	.
75–80	LIST2(32)

3rd card, if necessary

Cols. 1–5	LIST2(33)
6–10	LIST2(34)
.	.
.	.
.	.
75–80	LIST2(48)

NOTES:

1. See Fig. 13 for definition and description of Regions 1 and 2. Elements in Region 1 must have the nodal connectivity shown.

2. The element topology for Region 2 is required only if thermal loads are present; otherwise, omit CARD SETS 13(c) and 13(d).

READ THE NEXT CARD SET ONLY IF IFACE=1 (see CARD SET 12).

CARD SET 14 — CRACK-FACE PRESSURE CARDS

14(a) CONTROL CARD (I5), one card

Cols. 1—5	NLIS3	Number of elements in the crack-tip zone with crack-face pressure

14(b) ELEMENT FACE TOPOLOGY CARD (4I5)

Cols. 1—5	KELEM	Element number with which the element edge is associated
6—10	NOPRS(1)	List of counterclockwise nodal points forming the element face on which the normal crack-face pressure acts
11—15	NOPRS(2)	
16—20	NOPRS(3)	

14(c) CRACK-FACE PRESSURE CARDS (3F10.3)

Cols. 1—10	PRESS(1,1)	Value of normal crack-face pressure load at node NOPRS(1)
11—20	PRESS(2,1)	Value of normal crack-face pressure load at node NOPRS(2)
21—30	PRESS(3,1)	Value of normal crack-face pressure load at node NOPRS(3)

NOTES:

1. Subsets 14(b) and 14(c) must be input a total of NLIS3 times. The element edges can be considered in any order.
2. If IFACE=0 in CARD SET 8, omit this card set.

REPEAT CARD SETS 13 AND 14 IN ACCORDANCE WITH NPERT IN CARD SET 12.

REPEAT CARD SETS 7 TO 14 FOR EACH LOAD CASE IN ACCORDANCE WITH NCASE IN CARD SET 2.

Appendix B

SAMPLE INPUT DATA (File FORT5)

Sample input data are provided below for the first sample problem, 4.1, presented in Chap. 4. The finite-element mesh for this problem showing node and element numbers is also presented (Fig. 14).

```
CENTER CRACKED PLATE SUBJECTED TO A UNIFORM TENSILE STRESS
  141   40    18     1     1     1     3     1
    1    1    41    40    39    26     1     2     3    27
    2    1    43    42    41    27     3     4     5    28
    3    1    45    44    43    28     5     6     7    29
    4    1    47    46    45    29     7     8     9    30
    5    1    49    48    47    30     9    10    11    31
    6   -1    13    32    51    50    49    31    11    12
    7   -1    13    14    15    33    53    52    51    32
    8    1    15    16    17    34    55    54    53    33
    9    1    17    18    19    35    57    56    55    34
   10    1    19    20    21    36    59    58    57    35
   11    1    21    22    23    37    61    60    59    36
   12    1    23    24    25    38    63    62    61    37
   13    1    79    78    77    64    39    40    41    65
   14    1    81    80    79    65    41    42    43    66
   15    1    83    82    81    66    43    44    45    67
   16    1    85    84    83    67    45    46    47    68
   17    1    87    86    85    68    47    48    49    69
   18    1    89    88    87    69    49    50    51    70
   19    1    51    52    53    71    91    90    89    70
   20    1    53    54    55    72    93    92    91    71
   21    1    55    56    57    73    95    94    93    72
   22    1    57    58    59    74    97    96    95    73
   23    1    59    60    61    75    99    98    97    74
   24    1    61    62    63    76   101   100    99    75
   25    1   115   114   113   102    77    78    79   103
   26    1   117   116   115   103    79    80    81   104
   27    1   119   118   117   104    81    82    83   105
   28    1    87   106   119   105    83    84    85    86
   29    1    89   107   121   120   119   106    87    88
   30    1    91   108   123   122   121   107    89    90
   31    1    93    94    95   109   123   108    91    92
   32    1    95    96    97   110   125   124   123   109
   33    1    97    98    99   111   127   126   125   110
   34    1    99   100   101   112   129   128   127   111
   35    1   139   138   137   130   113   114   115   131
   36    1   141   140   139   131   115   116   117   132
   37    1   121   133   141   132   117   118   119   120
   38    1   123   124   125   134   141   133   121   122
   39    1   125   126   127   135   139   140   141   134
   40    1   127   128   129   136   137   138   139   135
    1          0.0         0.0
    3          5.0         0.0
    5          7.0         0.0
    7          8.0         0.0
    9          9.0         0.0
   11          9.5         0.0
   13         10.0         0.0
   15         10.5         0.0
   17         11.0         0.0
   19         12.0         0.0
   21         13.0         0.0
   23         15.0         0.0
   25         20.0         0.0
   39          0.0         2.5
   41          5.0         1.0
   43          7.0         0.5
   45          8.0         0.5
```

```
  47        9.0       0.5
  49        9.5       0.5
  51       10.0       0.5
  53       10.5       0.5
  55       11.0       0.5
  57       12.0       0.5
  59       13.0       0.5
  61       15.0       1.0
  63       20.0       2.5
  77        0.0      10.0
  79        5.5       3.0
  81       7.25       2.0
  83       8.25       1.5
  85        9.0       1.0
  87        9.5       1.0
  89       10.0       1.0
  91       10.5       1.0
  93       11.0       1.0
  95      11.75       1.5
  97      12.75       2.0
  99       14.5       3.0
 101       20.0      10.0
 113        5.0      10.0
 115        7.5       5.0
 117        8.5       3.0
 119        9.0       2.0
 121       10.0       2.0
 123       11.0       2.0
 125       11.5       3.0
 127       12.5       5.0
 129       15.0      10.0
 137       10.0      10.0
 139       10.0       5.0
 141       10.0       3.0
   1   10
  13   01
  14   01
  15   01
  16   01
  17   01
  18   01
  19   01
  20   01
  21   01
  22   01
  23   01
  24   01
  25   01
  26   10
  39   10
  64   10
  77   10
   1   30000.         0.3       1.0       0.0
UNIFORM TENSILE STRESS
   0    1    0
   4
  25  113  102   77
  -9.1965    -9.1965    -9.1965
  35  137  130  113
  -9.1965    -9.1965    -9.1965
  40  129  136  137
  -9.1965    -9.1965    -9.1965
  34  101  112  129
  -9.1965    -9.1965    -9.1965
   2    1    2    0      0.001
   8
   9   21   31   30   29   28   16    4
   8
  10   22   32   38   37   27   15    3
```

ORNL-DWG 85-4792 ETD

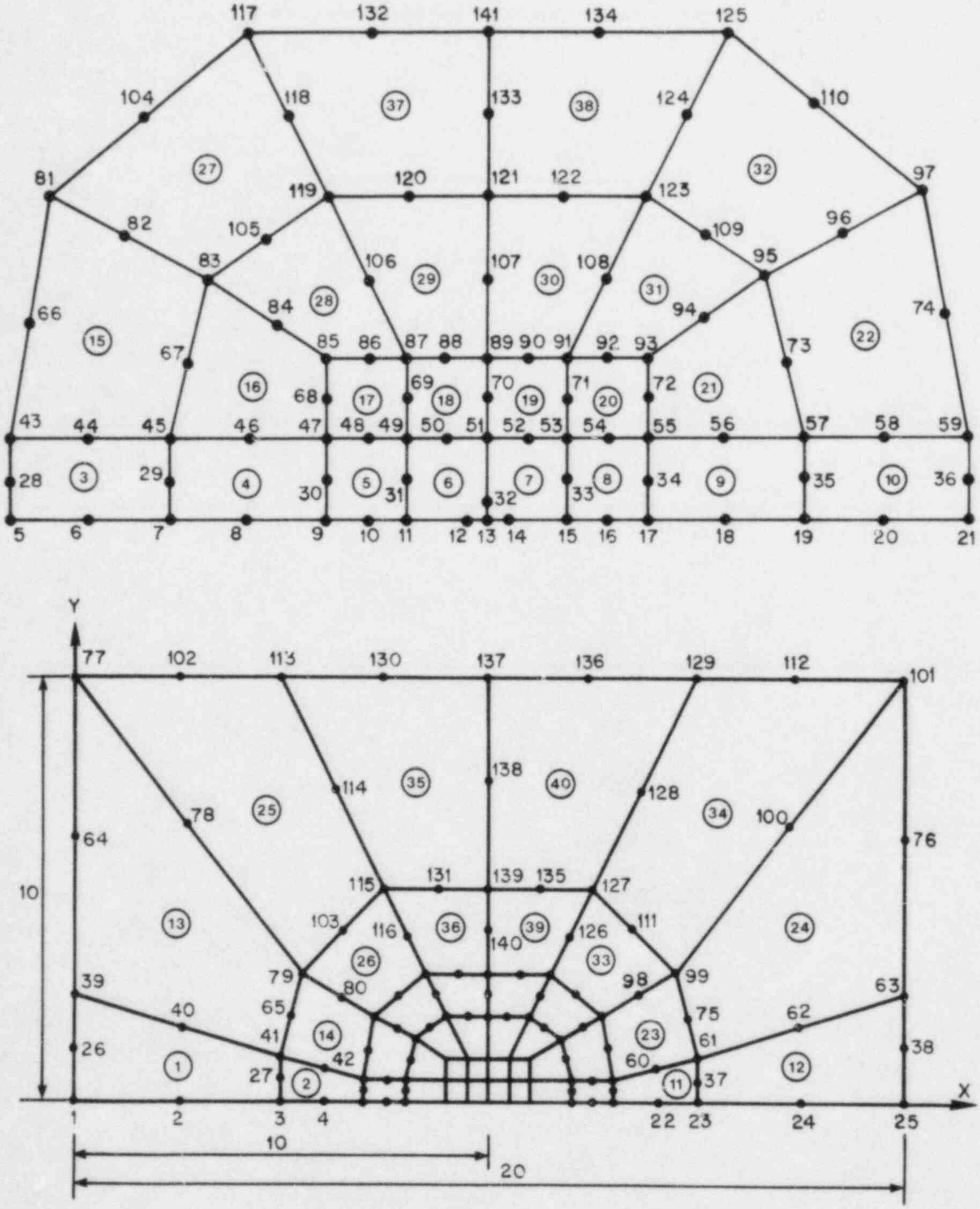

Fig. 14. Finite-element mesh employed for sample problem 4.1.

Appendix C

SAMPLE ORVIRT.PC OUTPUT (File FORT6)

A complete printout is provided below for sample problem 4.1.

```
CENTER CRACKED PLATE SUBJECTED TO A UNIFORM TENSILE STRESS


NUMBER OF NODAL POINTS............(NPOIN) =  141
NUMBER OF ELEMENTS................(NELEM) =   40
NUMBER OF RESTRAINED NODES........(NVFIX) =   18
NUMBER OF LOAD CASES..............(NCASE) =    1
PLANE STRESS OR PLANE STRAIN......(NTYPE) =    1
NUMBER OF MATERIALS...............(NMATS) =    1
GAUSS QUADRATURE RULE.............(NGAUS) =    3
FRACTURE ANALYSIS INDEX...........(NFRAC) =    1

ELEM PROP                     NODE NUMBERS
   1    1    41    40    39    26     1     2     3    27
   2    1    43    42    41    27     3     4     5    28
   3    1    45    44    43    28     5     6     7    29
   4    1    47    46    45    29     7     8     9    30
   5    1    49    48    47    30     9    10    11    31
   6   -1    13    32    51    50    49    31    11    12
   7   -1    13    14    15    33    53    52    51    32
   8    1    15    16    17    34    55    54    53    33
   9    1    17    18    19    35    57    56    55    34
  10    1    19    20    21    36    59    58    57    35
  11    1    21    22    23    37    61    60    59    36
  12    1    23    24    25    38    63    62    61    37
  13    1    79    78    77    64    39    40    41    65
  14    1    81    80    79    65    41    42    43    66
  15    1    83    82    81    66    43    44    45    67
  16    1    85    84    83    67    45    46    47    68
  17    1    87    86    85    68    47    48    49    69
  18    1    89    88    87    69    49    50    51    70
  19    1    51    52    53    71    91    90    89    70
  20    1    53    54    55    72    93    92    91    71
  21    1    55    56    57    73    95    94    93    72
  22    1    57    58    59    74    97    96    95    73
  23    1    59    60    61    75    99    98    97    74
  24    1    61    62    63    76   101   100    99    75
  25    1   115   114   113   102    77    78    79   103
  26    1   117   116   115   103    79    80    81   104
  27    1   119   118   117   104    81    82    83   105
  28    1    87   106   119   105    83    84    85    86
  29    1    89   107   121   120   118   106    87    88
  30    1    91   108   123   122   121   107    89    90
  31    1    93    94    95   109   123   108    91    92
  32    1    95    96    97   110   125   124   123   109
  33    1    97    98    99   111   127   126   125   110
  34    1    99   100   101   112   129   128   127   111
  35    1   139   138   137   130   113   114   115   131
  36    1   141   140   139   131   115   116   117   132
  37    1   121   133   141   132   117   118   119   120
  38    1   123   124   125   134   141   133   121   122
  39    1   125   126   127   135   139   140   141   134
  40    1   127   128   129   136   137   138   139   135

NODAL POINT COORDINATES
NODE        X          Y
   1      0.000      0.000
   2      2.500      0.000
   3      5.000      0.000
   4      6.000      0.000
   5      7.000      0.000
   6      7.500      0.000
   7      8.000      0.000
   8      8.500      0.000
   9      9.000      0.000
  10      9.250      0.000
  11      9.500      0.000
  12      9.875      0.000
  13     10.000      0.000
  14     10.125      0.000
  15     10.500      0.000
  16     10.750      0.000
  17     11.000      0.000
  18     11.500      0.000
  19     12.000      0.000
  20     12.500      0.000
  21     13.000      0.000
  22     14.000      0.000
  23     15.000      0.000
  24     17.500      0.000
  25     20.000      0.000
  26      0.000      1.250
  27      5.000      0.500
  28      7.000      0.250
  29      8.000      0.250
  30      9.000      0.250
  31      9.500      0.250
  32     10.000      0.125
  33     10.500      0.250
  34     11.000      0.250
  35     12.000      0.250
  36     13.000      0.250
```

37	15.000	0.500
38	20.000	1.250
39	0.000	2.500
40	2.500	1.750
41	5.000	1.000
42	6.000	0.750
43	7.000	0.500
44	7.500	0.500
45	8.000	0.500
46	8.500	0.500
47	9.000	0.500
48	9.250	0.500
49	9.500	0.500
50	9.750	0.500
51	10.000	0.500
52	10.250	0.500
53	10.500	0.500
54	10.750	0.500
55	[illegible]	0.500
56	11.500	0.500
57	12.000	0.500
58	12.500	0.500
59	13.000	0.500
60	14.000	0.750
61	15.000	1.000
62	17.500	1.750
63	20.000	2.500
64	0.000	6.250
65	5.250	2.000
66	7.125	1.250
67	8.125	1.000
68	9.000	0.750
69	9.500	0.750
70	10.000	0.750
71	10.500	0.750
72	11.000	0.750
73	11.875	1.000
74	12.875	1.250
75	14.750	2.000
76	20.000	6.250
77	0.000	10.000
78	2.750	6.500
79	5.500	3.000
80	6.375	2.500
81	7.250	2.000
82	7.750	1.750
83	8.250	1.500
84	8.625	1.250
85	9.000	1.000
86	9.250	1.000
87	9.500	1.000
88	9.750	1.000
89	10.000	1.000
90	10.250	1.000
91	10.500	1.000
92	10.750	1.000
93	11.000	1.000
94	11.375	1.250
95	11.750	1.500
96	12.250	1.750
97	12.750	2.000
98	13.625	2.500
99	14.500	3.000
100	17.250	6.500
101	20.000	10.000
102	2.500	10.000
103	6.500	4.000
104	7.875	2.500
105	8.625	1.750
106	9.250	1.500
107	10.000	1.500
108	10.750	1.500
109	11.375	1.750
110	12.125	2.500
111	13.500	3.000
112	17.500	10.000
113	5.000	10.000
114	6.250	7.500
115	7.500	5.000
116	8.000	4.000
117	8.500	3.000
118	8.750	2.500
119	9.000	2.000
120	9.500	2.000
121	10.000	3.000
122	10.500	3.000
123	11.000	2.000
124	11.250	2.500
125	11.500	3.000
126	12.000	4.000
127	12.500	5.000
128	13.750	7.500
129	15.000	10.000
130	7.500	10.000
131	8.750	5.000
132	9.250	3.000
133	10.000	2.500
134	10.750	3.000
135	11.250	5.000
136	12.500	10.000
137	10.000	10.000
138	10.000	7.500
139	10.000	5.000
140	10.000	4.000
141	10.000	3.000

RESTIAINED NODLS

NODF	CODE	FIXED VALUES	
1	10	0.0000	0.0000
13	01	0.0000	0.0000
14	01	0.0000	0.0000
15	01	0.0000	0.0000
16	01	0.0000	0.0000
17	01	0.0000	0.0000
18	01	0.0000	0.0000
19	01	0.0000	0.0000
20	01	0.0000	0.0000
21	01	0.0000	0.0000
22	01	0.0000	0.0000
23	01	0.0000	0.0000
24	01	0.0000	0.0000

25	01	0.0000	0.0000
26	10	0.0000	0.0000
39	10	0.0000	0.0000
64	10	0.0000	0.0000
77	10	0.0000	0.0000

MATERIAL PROPERTIES

NUMBER	YOUNG	POISSON	THICK	ALPHA
1	0.3000E+05	0.3000E+00	0.1000E+01	0.0000E+00

MAXIMUM FRONTWIDTH ENCOUNTERED = 60

UNIFORM TENSILE STRESS　　　　LOAD CASE = 1

NODAL POINT LOADS....................(IPLOD) = 0

DISTRIBUTED EDGE LOADS.............(IEDGE) = 1

THERMAL LOADS.........................(ITEMP) = 0

NO. OF LOADED EDGES = 4

LIST OF LOADED EDGES AND APPLIED LOADS

25	113	102 77			
-9.197	-9.197	-9.197	0.000	0.000	0.000
35	137	130 113			
-9.197	-9.197	-9.197	0.000	0.000	0.000
40	129	136 137			
-9.197	-9.197	-9.197	0.000	0.000	0.000
34	101	112 129			
-9.197	-9.197	-9.197	0.000	0.000	0.000

DISPLACEMENTS

NODE	X-DISP.	Y-DISP.
1	0.000000E+00	0.148542E-01
2	-0.137787E-02	0.141916E-01
3	-0.382212E-02	0.121597E-01
4	-0.445728E-02	0.109502E-01
5	-0.502925E-02	0.949700E-02
6	-0.529721E-02	0.866006E-02
7	-0.554798E-02	0.772800E-02
8	-0.579071E-02	0.666791E-02
9	-0.600401E-02	0.541900E-02
10	-0.614196E-02	0.468423E-02
11	-0.625126E-02	0.377932E-02
12	-0.632332E-02	0.183890E-02
13	-0.634664E-02	0.000000E+00
14	-0.583290E-02	0.000000E+00
15	-0.525256E-02	0.000000E+00
16	-0.505459E-02	0.000000E+00
17	-0.491305E-02	0.000000E+00
18	-0.468231E-02	0.000000E+00
19	-0.451304E-02	0.000000E+00
20	-0.437575E-02	0.000000E+00
21	-0.426693E-02	0.000000E+00
22	-0.411645E-02	0.000000E+00
23	-0.400614E-02	0.000000E+00
24	-0.394631E-02	0.000000E+00
25	-0.388823E-02	0.000000E+00
26	0.000000E+00	0.151180E-01
27	-0.328268E-02	0.122524E-01
28	-0.463778E-02	0.953461E-02
29	-0.506168E-02	0.775954E-02
30	-0.533905E-02	0.544177E-02
31	-0.531047E-02	0.380288E-02
32	-0.550747E-02	0.851093E-03
33	-0.511409E-02	0.352167E-03
34	-0.484677E-02	0.259233E-03
35	-0.448434E-02	0.169865E-03
36	-0.425592E-02	0.130388E-03
37	-0.397629E-02	0.154985E-03
38	-0.374567E-02	-0.203899E-03
39	0.000000E+00	0.153144E-01
40	-0.113404E-02	0.145098E-01
41	-0.279421E-02	0.123329E-01
42	-0.350880E-02	0.110689E-01
43	-0.425432E-02	0.956694E-02
44	-0.440083E-02	0.872476E-02
45	-0.459358E-02	0.778426E-02
46	-0.469442E-02	0.671360E-02
47	-0.472146E-02	0.544957E-02
48	-0.469452E-02	0.470079E-02
49	-0.463039E-02	0.394346E-02
50	-0.455662E-02	0.283462E-02
51	-0.460717E-02	0.187435E-02
52	-0.470119E-02	0.113922E-02
53	-0.473933E-02	0.807759E-03
54	-0.473107E-02	0.624763E-03
55	-0.467370E-02	0.524820E-03
56	-0.453799E-02	0.412387E-03
57	-0.441264E-02	0.345532E-03
58	-0.430488E-02	0.298244E-03
59	-0.421350E-02	0.263271E-03
60	-0.402137E-02	0.312620E-03
61	-0.389588E-02	0.309409E-03
62	-0.364702E-02	0.377766E-03
63	-0.334839E-02	-0.379211E-03
64	0.000000E+00	0.158126E-01
65	-0.137993E-02	0.121668E-01
66	-0.324523E-02	0.943886E-02
67	-0.375845E-02	0.756950E-02
68	-0.420070E-02	0.546997E-02
69	-0.413171E-02	0.393436E-02
70	-0.418009E-02	0.230356E-02
71	-0.438016E-02	0.124366E-02
72	-0.443080E-02	0.820526E-03
73	-0.416139E-02	0.753885E-03
74	-0.394027E-02	0.698329E-03
75	-0.354453E-02	0.760238E-03
76	-0.129933E-02	-0.511774E-04
77	0.000000E+00	0.163503E-01
78	0.406290E-03	0.149846E-01
79	-0.129442E-02	0.119712E-01

80	-0.179053E-02	0.107334E-01
81	-0.238485E-02	0.930472E-02
82	-0.271059E-02	0.838690E-02
83	-0.304809E-02	0.736710E-02
84	-0.339345E-02	0.649606E-02
85	-0.376458E-02	0.551371E-02
86	-0.374484E-02	0.482042E-02
87	-0.373952E-02	0.408560E-02
88	-0.376884E-02	0.334983E-02
89	-0.383072E-02	0.265989E-02
90	-0.393113E-02	0.208494E-02
91	-0.404133E-02	0.164455E-02
92	-0.411672E-02	0.134683E-02
93	-0.416178E-02	0.113732E-02
94	-0.395698E-02	0.118980E-02
95	-0.377223E-02	0.124094E-02
96	-0.362348E-02	0.123139E-02
97	-0.348837E-02	0.122351E-02
98	-0.322761E-02	0.123708E-02
99	-0.297553E-02	0.123382E-02
100	-0.908655E-03	0.140154E-02
101	0.123776E-02	0.780076E-03
102	0.157252E-02	0.156055E-01
103	-0.742830E-03	0.107638E-01
104	-0.194693E-02	0.829745E-02
105	-0.276091E-02	0.661756E-02
106	-0.308320E-02	0.506278E-02
107	-0.325350E-02	0.327828E-02
108	-0.355108E-02	0.202354E-02
109	-0.348658E-02	0.171801E-02
110	-0.302182E-02	0.190234E-02
111	-0.215017E-02	0.211511E-02
112	0.147602E-02	0.232947E-02
113	0.301733E-02	0.137513E-01
114	0.128243E-02	0.118756E-01
115	-0.132596E-03	0.958551E-02
116	-0.832439E-03	0.851060E-02
117	-0.161181E-02	0.731011E-02
118	-0.203907E-02	0.663709E-02
119	-0.252740E-02	0.589850E-02
120	-0.261220E-02	0.482018E-02
121	-0.276119E-02	0.380910E-02
122	-0.295389E-02	0.296779E-02
123	-0.314195E-02	0.233084E-02
124	-0.278224E-02	0.258487E-02
125	-0.244725E-02	0.280159E-02
126	-0.182022E-02	0.313474E-02
127	-0.121452E-02	0.336316E-02
128	0.443126E-03	0.361933E-02
129	0.188470E-02	0.379479E-02
130	0.354999E-02	0.109663E-01
131	-0.309958E-03	0.775519E-02
132	-0.172727E-02	0.596119E-02
133	-0.233070E-02	0.427413E-02
134	-0.219300E-02	0.361762E-02
135	-0.870028E-03	0.453329E-02
136	0.274060E-02	0.555810E-02
137	0.349666E-02	0.804817E-02
138	0.116189E-02	0.714511E-02
139	-0.530467E-03	0.600697E-02
140	-0.121419E-02	0.540391E-02
141	-0.193635E-02	0.469095E-02

REACTIONS

NODE	X-REAC.	Y-REAC.
1	0.102623E+02	0.000000E+00
13	0.000000E+00	-0.118711E+02
14	0.000000E+00	-0.354350E+02
15	0.000000E+00	-0.139905E+02
16	0.000000E+00	-0.152266E+02
17	0.000000E+00	-0.929658E+01
18	0.000000E+00	-0.204046E+02
19	0.000000E+00	-0.832702E+01
20	0.000000E+00	-0.185378E+02
21	0.000000E+00	-0.953320E+01
22	0.000000E+00	-0.197979E+02
23	0.000000E+00	-0.136482E+02
24	0.000000E+00	-0.158624E+02
25	0.000000E+00	0.400090E+01
26	0.273178E+02	0.000000E+00
39	0.170722E+02	0.000000E+00
64	-0.263887E+02	0.000000E+00
77	-0.282636E+02	0.000000E+00

STRESSES

ELEM	G.P.	X-COORD.	Y-COORD.	X-STRESS	Y-STRESS	XY-STRESS	Z-STRESS	MAX P.S.	MIN P.S.	ANGLE
1	1	4.4365	1.0373	-0.14921E+02	0.83253E-01	-0.16561E+01	0.00000E+00	0.26387E+00	-0.15101E+02	6.224
	2	4.4365	0.5845	-0.17488E+02	0.44343E-01	-0.90347E+00	0.00000E+00	0.90776E-01	-0.17535E+02	2.942
	3	4.4365	0.1318	-0.20717E+02	-0.19280E+00	-0.13985E+00	0.00000E+00	-0.19185E+00	[illegible]	0.390
	4	2.5000	1.5528	-0.13636E+02	0.30890E+00	-0.10773E+01	0.00000E+00	0.39165E+00	[illegible]	4.392
	5	2.5000	0.8750	-0.17461E+02	0.21767E+00	-0.73439E+00	0.00000E+00	0.24813E+00	[illegible]	2.375
	6	2.5000	0.1972	-0.21660E+02	0.14099E-01	-0.40944E+00	0.00000E+00	0.21831E-01	-0.21668E+02	1.082
	7	0.5635	2.0682	-0.12190E+02	0.63872E+00	-0.30431E+00	0.00000E+00	0.64593E+00	-0.12197E+02	1.358
	8	0.5635	1.1655	-0.17296E+02	0.32610E+00	-0.16788E+00	0.00000E+00	0.32770E+00	-0.17297E+02	0.546
	9	0.5635	0.2627	-0.22632E+02	-0.55787E-01	-0.64002E-01	0.00000E+00	-0.55606E-01	-0.22633E+02	0.162
2	1	6.7746	0.4936	-0.12459E+02	0.63714E-01	-0.10664E+01	0.00000E+00	0.15387E+00	-0.12543E+02	4.833
	2	6.7746	0.2782	-0.14406E+02	0.15733E-01	-0.56926E+00	0.00000E+00	0.38170E-01	-0.14427E+02	2.257
	3	6.7746	0.0627	-0.16154E+02	0.26594E-01	-0.89545E-01	0.00000E+00	0.27090E-01	-0.16155E+02	0.317
	4	6.0000	0.6655	-0.13554E+02	0.12900E+00	-0.16512E+01	0.00000E+00	0.32544E+00	-0.13753E+02	6.785
	5	6.0000	0.3750	-0.15560E+02	0.80525E-01	-0.85832E+00	0.00000E+00	0.12749E+00	-0.15607E+02	3.132
	6	6.0000	0.0845	-0.17530E+02	0.42793E-01	-0.84171E-01	0.00000E+00	0.43197E-01	-0.17531E+02	0.274
	7	5.2259	0.8373	-0.14388E+02	0.22006E+00	-0.18018E+01	0.00000E+00	0.43903E+00	-0.14607E+02	6.929
	8	5.2259	0.4718	-0.16621E+02	0.11399E+00	-0.83054E+00	0.00000E+00	0.15511E+00	-0.16662E+02	2.834
	9	5.2259	0.1064	-0.18912E+02	-0.96975E-02	0.12127E+00	0.00000E+00	-0.89195E-02	-0.18913E+02	-0.368
3	1	7.8873	0.4436	-0.92043E+01	0.12357E+00	-0.14282E+01	0.00000E+00	0.33733E+00	-0.94180E+01	8.513
	2	7.8873	0.2500	-0.11518E+02	0.51278E-01	-0.73148E+00	0.00000E+00	0.97345E-01	-0.11564E+02	3.608
	3	7.8873	0.0564	-0.14032E+02	-0.81403E-01	-0.42660E-01	0.00000E+00	-0.81272E-01	-0.14032E+02	0.175
	4	7.5000	0.4436	-0.10696E+02	0.92163E-01	-0.12549E+01	0.00000E+00	0.23621E+00	-0.10840E+02	6.548
	5	7.5000	0.2500	-0.12695E+02	0.73147E-01	-0.72116E+00	0.00000E+00	0.11375E+00	-0.12736E+02	3.222
	6	7.5000	0.0564	-0.14896E+02	-0.62590E-02	-0.19532E+00	0.00000E+00	-0.36973E-02	-0.14898E+02	0.751
	7	7.1127	0.4436	-0.12225E+02	-0.65370E-01	-0.85240E+00	0.00000E+00	-0.59075E-02	-0.12285E+02	3.990

	8	7.1127	0.2500	-0.13911E+02	-0.31112E-01	-0.46168E+00	0.00000E+00	-0.14415E-01	-0.13927E+02	1.985
	9	7.1127	0.0564	-0.15797E+02	-0.57242E-01	-0.11882E+00	0.00000E+00	-0.56345E-01	-0.15798E+02	0.432
4	1	8.8873	0.4436	-0.18797E+01	0.31218E+00	-0.33705E+01	0.00000E+00	0.29038E+01	-0.90713E+01	37.557
	2	8.8873	0.2500	-0.58280E+01	0.31393E+00	-0.16204E+01	0.00000E+00	0.71523E+00	-0.72293E+01	13.909
	3	8.8873	0.0564	-0.10753E+02	0.14268E+00	0.73176E-01	0.00000E+00	0.14313E+00	-0.10754E+02	-0.385
	4	8.5000	0.4436	-0.46730E+01	0.32655E+00	-0.27594E+01	0.00000E+00	0.15501E+01	-0.58965E+01	23.913
	5	8.5000	0.2500	-0.82405E+01	0.26892E+00	-0.14445E+01	0.00000E+00	0.50744E+00	-0.84791E+01	9.376
	6	8.5000	0.0564	-0.12385E+02	0.38237E-01	-0.18607E+00	0.00000E+00	0.41023E-01	-0.12388E+02	0.858
	7	8.1127	0.4436	-0.79201E+01	0.16146E+00	-0.15340E+01	0.00000E+00	0.44284E+00	-0.82015E+01	10.394
	8	8.1127	0.2500	-0.10707E+02	0.44431E-01	-0.65429E+00	0.00000E+00	0.84102E-01	-0.10747E+02	3.470
	9	8.1127	0.0564	-0.14071E+02	-0.24564E+00	0.16897E+00	0.00000E+00	-0.24357E+00	-0.14073E+02	-0.700
5	1	9.4436	0.4436	0.11366E+02	0.75392E+01	-0.13403E+02	0.00000E+00	0.22992E+02	-0.40865E+01	-40.938
	2	9.4436	0.2500	0.61980E+01	0.47418E+01	-0.63166E+01	0.00000E+00	0.11620E+02	-0.88849E+00	-41.712
	3	9.4436	0.0564	-0.74104E+01	-0.58779E+00	0.12131E+01	0.00000E+00	-0.37852E+00	-0.76197E+01	-9.788
	4	9.2500	0.4436	0.66630E+01	0.30877E+01	-0.94033E+01	0.00000E+00	0.14447E+02	-0.46963E+01	-39.618
	5	9.2500	0.2500	0.22123E+01	0.16572E+01	-0.44179E+01	0.00000E+00	0.63614E+01	-0.24919E+01	-43.203
	6	9.2500	0.0564	-0.10679E+02	-0.23054E+01	0.10104E+01	0.00000E+00	-0.21852E+01	-0.10799E+02	-6.784
	7	9.0564	0.4436	0.26910E+01	0.10728E+01	-0.52852E+01	0.00000E+00	0.72287E+01	-0.34648E+01	-40.648
	8	9.0564	0.2500	-0.10424E+01	0.10093E+01	-0.24012E+01	0.00000E+00	0.25946E+01	-0.26277E+01	33.433
	9	9.0564	0.0564	-0.13216E+02	-0.15863E+01	0.92580E+00	0.00000E+00	-0.15131E+01	-0.13290E+02	-4.523
6	1	9.9880	0.0120	0.12803E+03	0.11008E+03	-0.10767E+03	0.00000E+00	0.22710E+03	0.11009E+02	-42.618
	2	9.8609	0.0314	0.97087E+01	-0.24378E+01	-0.94940E+01	0.00000E+00	0.14906E+02	-0.76349E+01	-28.697
	3	9.6007	0.0507	0.14029E+01	0.60486E+00	-0.32329E+00	0.00000E+00	0.15175E+01	0.49034E+00	-19.506
	4	9.9686	0.1391	0.45501E+02	0.89847E+02	-0.53512E+02	0.00000E+00	0.12560E+03	0.97508E+01	33.746
	5	9.8125	0.1875	0.22615E+02	0.23282E+02	-0.24300E+02	0.00000E+00	0.47251E+02	-0.13543E+01	44.607
	6	9.5814	0.2359	0.14778E+02	0.79552E+01	-0.11819E+02	0.00000E+00	0.23667E+02	-0.93717E+00	-36.947
	7	9.9493	0.3993	0.11855E+02	0.63985E+02	-0.26617E+02	0.00000E+00	0.75174E+02	0.66636E+00	22.800
	8	9.7641	0.4186	0.12718E+02	0.29854E+02	-0.22816E+02	0.00000E+00	0.45658E+02	-0.30859E+01	34.709
	9	9.5620	0.4380	0.16295E+02	0.11662E+02	-0.19857E+02	0.00000E+00	0.33971E+02	-0.60129E+01	-41.673
7	1	10.0120	0.0120	0.18541E+03	0.37094E+03	0.48124E+02	0.00000E+00	0.38268E+03	0.17367E+03	-13.710
	2	10.0314	0.1391	0.25757E+02	0.12069E+03	-0.10892E+02	0.00000E+00	0.12192E+03	0.24523E+02	6.462
	3	10.0507	0.3993	0.86853E+01	0.77451E+02	-0.16790E+02	0.00000E+00	0.81331E+02	0.48050E+01	13.018
	4	10.1391	0.0314	0.85240E+02	0.12280E+03	0.20156E+02	0.00000E+00	0.13157E+03	0.76471E+02	-23.511
	5	10.1875	0.1875	0.34436E+02	0.91224E+02	0.61450E+01	0.00000E+00	0.91881E+02	0.33779E+02	-6.106
	6	10.2359	0.4186	0.14487E+02	0.74192E+02	-0.10122E+01	0.00000E+00	0.74209E+02	0.14469E+02	0.971
	7	10.3993	0.0507	0.53604E+02	0.60886E+02	0.50400E+01	0.00000E+00	0.63463E+02	0.51028E+02	-27.077
	8	10.4186	0.2359	0.33059E+02	0.62505E+02	0.77892E+01	0.00000E+00	0.64438E+02	0.31125E+02	-13.941
	9	10.4380	0.4380	0.17414E+02	0.63894E+02	0.10961E+02	0.00000E+00	0.66349E+02	0.14959E+02	-12.625
8	1	10.5564	0.0564	0.38877E+02	0.48622E+02	0.21261E+01	0.00000E+00	0.49066E+02	0.38434E+02	-11.787
	2	10.5564	0.2500	0.33273E+02	0.55538E+02	0.70251E+01	0.00000E+00	0.57569E+02	0.31242E+02	-16.127
	3	10.5564	0.4436	0.22348E+02	0.60857E+02	0.10580E+02	0.00000E+00	0.63572E+02	0.19632E+02	-14.394
	4	10.7500	0.0564	0.32763E+02	0.42213E+02	0.11346E+01	0.00000E+00	0.42347E+02	0.32628E+02	-6.751
	5	10.7500	0.2500	0.29984E+02	0.46481E+02	0.53212E+01	0.00000E+00	0.48048E+02	0.28416E+02	-16.413
	6	10.7500	0.4436	0.21884E+02	0.49153E+02	0.81637E+01	0.00000E+00	0.51410E+02	0.19627E+02	-15.456
	7	10.9436	0.0564	0.27633E+02	0.39088E+02	0.15353E+01	0.00000E+00	0.39291E+02	0.27431E+02	-7.503
	8	10.9436	0.2500	0.27680E+02	0.40710E+02	0.50094E+01	0.00000E+00	0.42413E+02	0.25977E+02	-18.779
	9	10.9436	0.4436	0.22406E+02	0.40735E+02	0.71394E+01	0.00000E+00	0.43188E+02	0.19953E+02	-18.960
9	1	11.1127	0.0564	0.25560E+02	0.36813E+02	0.11212E+01	0.00000E+00	0.36924E+02	0.25449E+02	-5.635
	2	11.1127	0.2500	0.23711E+02	0.36843E+02	0.34085E+01	0.00000E+00	0.37675E+02	0.22879E+02	-13.717
	3	11.1127	0.4436	0.20700E+02	0.36525E+02	0.56919E+01	0.00000E+00	0.38359E+02	0.18866E+02	-17.865
	4	11.5000	0.0564	0.21048E+02	0.30493E+02	0.51040E+00	0.00000E+00	0.30520E+02	0.21020E+02	-3.085
	5	11.5000	0.2500	0.20105E+02	0.30775E+02	0.22994E+01	0.00000E+00	0.31249E+02	0.19631E+02	-11.658
	6	11.5000	0.4436	0.18000E+02	0.30708E+02	0.40845E+01	0.00000E+00	0.31908E+02	0.16800E+02	-16.366
	7	11.8873	0.0564	0.17077E+02	0.25975E+02	0.53806E+00	0.00000E+00	0.26008E+02	0.17045E+02	-3.448
	8	11.8873	0.2500	0.17040E+02	0.26509E+02	0.18286E+01	0.00000E+00	0.26850E+02	0.16699E+02	-10.559
	9	11.8873	0.4436	0.15840E+02	0.26694E+02	0.31154E+01	0.00000E+00	0.27525E+02	0.15009E+02	-14.928
10	1	12.1127	0.0564	0.15836E+02	0.24274E+02	0.52400E+00	0.00000E+00	0.24306E+02	0.15804E+02	-3.540
	2	12.1127	0.2500	0.15278E+02	0.24611E+02	0.15734E+01	0.00000E+00	0.24869E+02	0.15020E+02	-9.316
	3	12.1127	0.4436	0.14491E+02	0.24880E+02	0.25998E+01	0.00000E+00	0.25494E+02	0.13877E+02	-13.296
	4	12.5000	0.0564	0.13788E+02	0.21645E+02	0.20599E+00	0.00000E+00	0.21651E+02	0.13782E+02	-1.501
	5	12.5000	0.2500	0.13430E+02	0.21924E+02	0.11799E+01	0.00000E+00	0.22084E+02	0.13269E+02	-7.764
	6	12.5000	0.4436	0.12843E+02	0.22133E+02	0.21310E+01	0.00000E+00	0.22599E+02	0.12377E+02	-12.322
	7	12.8873	0.0564	0.11886E+02	0.19504E+02	0.55358E-01	0.00000E+00	0.19504E+02	0.11885E+02	-0.416
	8	12.8873	0.2500	0.11728E+02	0.19723E+02	0.95390E+00	0.00000E+00	0.19835E+02	0.11615E+02	-6.710
	9	12.8873	0.4436	0.11340E+02	0.19873E+02	0.18296E+01	0.00000E+00	0.20249E+02	0.10965E+02	-11.605
11	1	13.2254	0.0627	0.10321E+02	0.17960E+02	0.19780E+00	0.00000E+00	0.17965E+02	0.10316E+02	-1.482
	2	13.2254	0.2782	0.10450E+02	0.18178E+02	0.10043E+01	0.00000E+00	0.18307E+02	0.10321E+02	-7.284
	3	13.2254	0.4936	0.10171E+02	0.18275E+02	0.17869E+01	0.00000E+00	0.18651E+02	0.97949E+01	-11.899
	4	14.0000	0.0845	0.84047E+01	0.14966E+02	0.38470E+00	0.00000E+00	0.14989E+02	0.83823E+01	-3.344
	5	14.0000	0.3750	0.82092E+01	0.14968E+02	0.10036E+01	0.00000E+00	0.15113E+02	0.80634E+01	-8.270
	6	14.0000	0.6655	0.76623E+01	0.14864E+02	0.16074E+01	0.00000E+00	0.15206E+02	0.73203E+01	-12.029
	7	14.7746	0.1064	0.65078E+01	0.11969E+02	0.28976E+00	0.00000E+00	0.11984E+02	0.64925E+01	-3.029
	8	14.7746	0.4718	0.60674E+01	0.11826E+02	0.76064E+00	0.00000E+00	0.11924E+02	0.59686E+01	-7.399
	9	14.7746	0.8373	0.53092E+01	0.11587E+02	0.12217E+01	0.00000E+00	0.11817E+02	0.50798E+01	-10.633
12	1	15.5635	0.1318	0.37366E+01	0.10171E+02	0.28120E+00	0.00000E+00	0.10183E+02	0.37243E+01	-2.498
	2	15.5635	0.5845	0.36668E+01	0.10258E+02	0.12257E+01	0.00000E+00	0.10478E+02	0.34463E+01	-10.201
	3	15.5635	1.0373	0.36578E+01	0.10363E+02	0.22009E+01	0.00000E+00	0.11021E+02	0.30000E+01	-16.641
	4	17.5000	0.1972	0.22345E+01	0.50589E+01	0.16463E+00	0.00000E+00	0.50695E+01	0.22242E+01	-3.324
	5	17.5000	0.8750	0.22447E+01	0.54351E+01	0.87045E+00	0.00000E+00	0.56571E+01	0.20226E+01	-14.310
	6	17.5000	1.5528	0.20273E+01	0.57420E+01	0.15834E+01	0.00000E+00	0.63253E+01	0.14440E+01	-20.223
	7	19.4365	0.2627	-0.10494E+00	-0.28080E+01	0.19638E+00	0.00000E+00	-0.90749E-01	-0.28222E+01	4.134
	8	19.4365	1.1655	-0.39252E-02	-0.22733E+01	0.56669E+00	0.00000E+00	0.12972E+00	-0.24069E+01	13.270
	9	19.4365	2.0682	-0.27502E+00	-0.18501E+01	0.93228E+00	0.00000E+00	0.15782E+00	-0.22830E+01	24.905
13	1	4.8301	3.4936	-0.31288E+01	0.25404E+01	-0.59318E+01	0.00000E+00	0.62801E+01	-0.68685E+01	32.229
	2	4.6583	2.4790	-0.62595E+01	0.17131E+01	-0.43410E+01	0.00000E+00	0.36204E+01	-0.81669E+01	23.720
	3	4.4865	1.4643	-0.12250E+02	0.61919E-01	-0.26576E+01	0.00000E+00	0.61108E+00	-0.12799E+02	11.675
	4	2.7218	5.9647	-0.41617E+01	0.52682E+01	-0.36599E+01	0.00000E+00	0.84164E+01	-0.10135E+02	40.702
	5	2.6250	4.1250	-0.23293E+01	0.32289E+01	-0.29814E+01	0.00000E+00	0.45256E+01	-0.36260E+01	23.506
	6	2.5282	2.2853	-0.10647E+02	0.64708E+00	-0.21088E+01	0.00000E+00	0.11008E+01	-0.11100E+02	11.119
	7	0.6135	8.4357	-0.13298E+02	0.83009E+01	-0.92133E+00	0.00000E+00	0.13463E+01	0.81447E+01	-10.136
	8	0.5917	5.7710	-0.35950E+01	0.51827E+01	-0.78658E+00	0.00000E+00	0.55064E+01	0.32713E+01	22.368
	9	0.5699	3.1064	-0.75021E+01	0.16383E+01	-0.66711E+00	0.00000E+00	0.16867E+01	-0.75506E+01	4.152
14	1	7.0214	1.9373	-0.39137E+01	0.18338E+01	-0.64888E+01	0.00000E+00	0.60567E+01	-0.81366E+01	33.056
	2	6.9137	1.3345	-0.68292E+01	0.10304E+01	-0.42168E+01	0.00000E+00	0.28647E+01	-0.86634E+01	23.509
	3	6.8059	0.7318	-0.10663E+02	-0.64920E-01	-0.18522E+01	0.00000E+00	0.24946E+00	-0.10977E+02	9.633
	4	6.3327	2.3028	-0.42568E+01	0.18409E+01	-0.64609E+01	0.00000E+00	0.59362E+01	-0.83520E+01	32.369
	5	6.1875	1.6250	-0.74717E+01	0.10753E+01	-0.43056E+01	0.00000E+00	0.28682E+01	-0.92646E+01	22.607
	6	6.0423	0.9472	-0.11455E+02	0.69163E-01	-0.20749E+01	0.00000E+00	0.43138E+00	-0.11817E+02	9.902
	7	5.6441	2.6682	-0.44076E+01	0.18147E+01	-0.63049E+01	0.00000E+00	0.57342E+01	-0.83272E+01	31.868
	8	5.4613	1.9155	-0.79326E+01	0.10376E+01	-0.42170E+01	0.00000E+00	0.27087E+01	-0.96038E+01	21.618
	9	5.2786	1.1627	-0.12107E+02	0.62600E-01	-0.20695E+01	0.00000E+00	0.40489E+00	-0.12450E+02	9.392
15	1	8.1091	1.4373	-0.52203E+00	0.33709E-01	-0.80494E+01	0.00000E+00	0.97058E+01	-0.68570E+01	38.203
	2	8.0123	1.0282	-0.27759E+01	0.20405E-01	-0.51953E+01	0.00000E+00	0.55406E+01	-0.62760E+01	32.873
	3	7.9155	0.6191	-0.71474E+01	-0.61754E-01	-0.23475E+01	0.00000E+00	0.64540E+00	-0.78546E+01	16.764
	4	7.7218	1.6091	-0.17286E+01	0.27434E-01	-0.74292E+01	0.00000E+00	0.82658E+01	-0.72510E+01	36.625
	5	7.6250	1.1250	-0.42729E+01	0.16776E-01	-0.49460E+01	0.00000E+00	0.44743E+01	-0.70696E+01	29.486
	6	7.5282	0.6409	-0.87052E+01	-0.43379E-01	-0.21632E+01	0.00000E+00	0.46635E+00	-0.92149E+01	13.265
	7	7.3345	1.7809	-0.28831E+01	0.21740E-01	-0.72211E+01	0.00000E+00	0.68466E+01	-0.74932E+01	34.907
	8	7.2377	1.2209	[illegible]	0.12710E-01	-0.48654E+01	0.00000E+00	[illegible]	-0.73950E+01	[illegible]
	9	7.1409	0.6627	-0.10287E+02	-0.20639E+00	-0.11743E+01	0.00000E+00	0.96791E-01	-0.10590E+02	9.697

16	1	8.9123	0.9936	0.34779E+01	0.64750E+01	-0.11156E+02	0.00000E+00	0.16233E+02	-0.62802E+01	41.175
	2	8.9014	0.7782	0.35692E+01	0.47222E+01	-0.88047E+01	0.00000E+00	0.12969E+02	-0.46779E+01	43.127
	3	8.8905	0.5627	0.10826E+01	0.21368E+01	-0.59581E+01	0.00000E+00	0.75910E+01	-0.43716E+01	42.472
	4	8.6109	1.1655	0.20049E+01	0.48713E+01	-0.98972E+01	0.00000E+00	0.13439E+02	-0.65624E+01	40.880
	5	8.5625	0.8750	0.72784E+00	0.33643E+01	-0.73075E+01	0.00000E+00	0.94715E+01	-0.53793E+01	39.887
	6	8.5141	0.5845	-0.24691E+01	0.11775E+01	-0.43678E+01	0.00000E+00	0.40873E+01	-0.53789E+01	33.671
	7	8.3095	1.3373	0.53876E+00	0.38875E+01	-0.86234E+01	0.00000E+00	0.10998E+02	-0.65713E+01	39.506
	8	8.2236	0.9718	-0.19919E+01	0.21762E+01	-0.57004E+01	0.00000E+00	0.61615E+01	-0.59773E+01	34.959
	9	8.1377	0.6064	-0.60706E+01	-0.79228E-01	-0.25220E+01	0.00000E+00	0.84104E+00	-0.69909E+01	20.047
17	1	9.4436	0.9436	0.74149E+01	0.20007E+02	-0.18086E+02	0.00000E+00	0.32862E+02	-0.54399E+01	35.403
	2	9.4436	0.7500	0.98424E+01	0.15482E+02	-0.17150E+02	0.00000E+00	0.30042E+02	-0.47182E+01	40.332
	3	9.4436	0.5564	0.11405E+02	0.10697E+02	-0.15696E+02	0.00000E+00	0.26751E+02	-0.46487E+01	-44.353
	4	9.2500	0.9436	0.60856E+01	0.12911E+02	-0.15088E+02	0.00000E+00	0.24968E+02	-0.59709E+01	38.627
	5	9.2500	0.7500	0.69153E+01	0.92528E+01	-0.13524E+02	0.00000E+00	0.21658E+02	-0.54900E+01	42.530
	6	9.2500	0.5564	0.68805E+01	0.53348E+01	-0.11441E+02	0.00000E+00	0.17575E+02	-0.53596E+01	-43.068
	7	9.0564	0.9436	0.55540E+01	0.84745E+01	-0.12805E+02	0.00000E+00	0.19902E+02	-0.58734E+01	41.747
	8	9.0564	0.7500	0.47859E+01	0.56830E+01	-0.10612E+02	0.00000E+00	0.15856E+02	-0.53869E+01	43.790
	9	9.0564	0.5564	0.31535E+01	0.26322E+01	-0.79014E+01	0.00000E+00	0.10799E+02	-0.50129E+01	-44.055
18	1	9.9436	0.9436	0.26410E+01	0.38907E+02	-0.17147E+02	0.00000E+00	0.45731E+02	-0.41827E+01	21.700
	2	9.9436	0.7500	0.31355E+01	0.44430E+02	-0.18148E+02	0.00000E+00	0.51273E+02	-0.37066E+01	20.657
	3	9.9436	0.5564	0.47681E+01	0.50295E+02	-0.20999E+02	0.00000E+00	0.58502E+02	-0.34384E+01	21.386
	4	9.7500	0.9436	0.44623E+01	0.31687E+02	-0.18815E+02	0.00000E+00	0.41297E+02	-0.51480E+01	27.057
	5	9.7500	0.7500	0.70012E+01	0.33013E+02	-0.19452E+02	0.00000E+00	0.43406E+02	-0.33925E+01	28.117
	6	9.7500	0.5564	0.10678E+02	0.34680E+02	-0.21940E+02	0.00000E+00	0.47687E+02	-0.23282E+01	30.661
	7	9.5564	0.9436	0.62535E+01	0.24366E+02	-0.19211E+02	0.00000E+00	0.36549E+02	-0.59291E+01	32.380
	8	9.5564	0.7500	0.10837E+02	0.21495E+02	-0.19485E+02	0.00000E+00	0.36367E+02	-0.40749E+01	37.352
	9	9.5564	0.5564	0.16559E+02	0.18966E+02	-0.21610E+02	0.00000E+00	0.39405E+02	-0.38809E+01	43.406
19	1	10.0564	0.5564	0.38144E+01	0.58231E+02	-0.17438E+02	0.00000E+00	0.63339E+02	-0.12942E+01	16.328
	2	10.0564	0.7500	0.11716E+01	0.51060E+02	-0.16063E+02	0.00000E+00	0.55785E+02	-0.35531E+01	16.390
	3	10.0564	0.9436	0.79834E+00	0.44570E+02	-0.14164E+02	0.00000E+00	0.48753E+02	-0.33852E+01	16.455
	4	10.2500	0.5564	0.10306E+02	0.64850E+02	-0.51320E+01	0.00000E+00	0.65328E+02	0.98275E+01	5.329
	5	10.2500	0.7500	0.55149E+01	0.58397E+02	-0.66887E+01	0.00000E+00	0.59230E+02	0.46820E+01	7.098
	6	10.2500	0.9436	0.29932E+01	0.52626E+02	-0.77211E+01	0.00000E+00	0.53799E+02	0.18199E+01	8.681
	7	10.4436	0.5564	0.13604E+02	0.60823E+02	0.62651E+01	0.00000E+00	0.61640E+02	0.12787E+02	-7.431
	8	10.4436	0.7500	0.66645E+01	0.55089E+02	0.17768E+01	0.00000E+00	0.55154E+02	0.65994E+01	-2.099
	9	10.4436	0.9436	0.19944E+01	0.50037E+02	-0.21873E+01	0.00000E+00	0.50136E+02	0.18951E+01	2.601
20	1	10.5564	0.5564	0.14669E+02	0.55697E+02	0.58988E+01	0.00000E+00	0.56528E+02	0.13838E+02	-8.021
	2	10.5564	0.7500	0.88903E+01	0.51296E+02	0.28744E+01	0.00000E+00	0.51490E+02	0.86963E+01	-3.860
	3	10.5564	0.9436	0.47521E+01	0.47387E+02	0.62698E+00	0.00000E+00	0.47396E+02	0.47428E+01	-0.842
	4	10.7500	0.5564	0.16602E+02	0.48952E+02	0.67915E+01	0.00000E+00	0.50320E+02	0.15234E+02	-11.388
	5	10.7500	0.7500	0.10944E+02	0.46607E+02	0.44126E+01	0.00000E+00	0.47145E+02	0.10406E+02	-6.949
	6	10.7500	0.9436	0.69265E+01	0.44755E+02	0.28105E+01	0.00000E+00	0.44962E+02	0.67188E+01	-4.226
	7	10.9436	0.5564	0.18596E+02	0.42411E+02	0.74935E+01	0.00000E+00	0.44573E+02	0.16434E+02	-16.091
	8	10.9436	0.7500	0.13059E+02	0.42123E+02	0.57599E+01	0.00000E+00	0.43222E+02	0.11959E+02	-10.811
	9	10.9436	0.9436	0.91620E+01	0.42326E+02	0.48032E+01	0.00000E+00	0.43008E+02	0.84803E+01	-8.077
21	1	11.1095	0.5627	0.18589E+02	0.38084E+02	0.67137E+01	0.00000E+00	0.40173E+02	0.16501E+02	-17.279
	2	11.0986	0.7782	0.13549E+02	0.38642E+02	0.59365E+01	0.00000E+00	0.39976E+02	0.12215E+02	-12.661
	3	11.0877	0.9936	0.86137E+01	0.39190E+02	0.48846E+01	0.00000E+00	0.39939E+02	0.78644E+01	-8.791
	4	11.4859	0.5845	0.16343E+02	0.31830E+02	0.49914E+01	0.00000E+00	0.33299E+02	0.14874E+02	-16.403
	5	11.4375	0.8750	0.12390E+02	0.33037E+02	0.49968E+01	0.00000E+00	0.34182E+02	0.11244E+02	-12.414
	6	11.3891	1.1655	0.79225E+01	0.33952E+02	0.46579E+01	0.00000E+00	0.34760E+02	0.71141E+01	-9.846
	7	11.8623	0.6064	0.14538E+02	0.27540E+02	0.42134E+01	0.00000E+00	0.28786E+02	0.13292E+02	-16.474
	8	11.7764	0.9718	0.11167E+02	0.29110E+02	0.46342E+01	0.00000E+00	0.30236E+02	0.10040E+02	-13.659
	9	11.6905	1.3373	0.68923E+01	0.30205E+02	0.46524E+01	0.00000E+00	0.31099E+02	0.59981E+01	-10.879
22	1	12.0845	0.6191	0.13587E+02	0.25301E+02	0.36780E+01	0.00000E+00	0.26360E+02	0.12528E+02	-16.064
	2	11.9877	1.0282	0.10674E+02	0.27019E+02	0.42712E+01	0.00000E+00	0.28068E+02	0.96249E+01	-13.796
	3	11.8909	1.4373	0.63314E+01	0.28138E+02	0.44728E+01	0.00000E+00	0.29019E+02	0.54457E+01	-11.154
	4	12.4718	0.6409	0.12023E+02	0.22191E+02	0.31450E+01	0.00000E+00	0.23085E+02	0.11129E+02	-15.870
	5	12.3750	1.1250	0.95906E+01	0.23889E+02	0.38149E+01	0.00000E+00	0.24843E+02	0.86365E+01	-14.043
	6	12.2782	1.6091	0.57835E+01	0.25039E+02	0.41323E+01	0.00000E+00	0.25888E+02	0.49342E+01	-11.615
	7	12.8591	0.6627	0.10611E+02	0.19697E+02	0.28222E+01	0.00000E+00	0.20503E+02	0.98060E+01	-15.924
	8	12.7623	1.2218	0.85380E+01	0.21362E+02	0.35329E+01	0.00000E+00	0.22271E+02	0.76291E+01	-14.427
	9	12.6655	1.7809	0.51386E+01	0.22519E+02	0.39226E+01	0.00000E+00	0.23363E+02	0.42943E+01	-12.147
23	1	13.1941	0.7318	0.92718E+01	0.18190E+02	0.27059E+01	0.00000E+00	0.18946E+02	0.85150E+01	-15.626
	2	13.0863	1.3345	0.73651E+01	0.19591E+02	0.35930E+01	0.00000E+00	0.20569E+02	0.63874E+01	-15.223
	3	12.9786	1.9373	0.44200E+01	0.20451E+02	0.39243E+01	0.00000E+00	0.21361E+02	0.35109E+01	-13.043
	4	13.9577	0.9472	0.72089E+01	0.15895E+02	0.22571E+01	0.00000E+00	0.16452E+02	0.67517E+01	-13.867
	5	13.8125	1.6250	0.57763E+01	0.16525E+02	0.34063E+01	0.00000E+00	0.17514E+02	0.47877E+01	-16.183
	6	13.6673	2.3028	0.33248E+01	0.16663E+02	0.41027E+01	0.00000E+00	0.17824E+02	0.21639E+01	-15.799
	7	14.7214	1.1627	0.53845E+01	0.14177E+02	0.19305E+01	0.00000E+00	0.14582E+02	0.49793E+01	-11.854
	8	14.5387	1.9155	0.42060E+01	0.14252E+02	0.33094E+01	0.00000E+00	0.15244E+02	0.32139E+01	-16.689
	9	14.3559	2.6682	0.22006E+01	0.13884E+02	0.42138E+01	0.00000E+00	0.15304E+02	0.78043E+00	-18.222
24	1	15.5135	1.4642	0.34573E+01	0.10516E+02	0.31949E+01	0.00000E+00	0.11752E+02	0.22573E+01	-21.150
	2	15.3417	2.4790	0.32983E+01	0.11137E+02	0.33092E+01	0.00000E+00	0.12347E+02	0.20882E+01	-20.047
	3	15.1699	3.4936	0.89835E+00	0.11287E+02	0.37204E+01	0.00000E+00	0.12482E+02	-0.29655E+00	-17.806
	4	17.4718	2.2853	0.92626E+00	0.44729E+01	0.29089E+01	0.00000E+00	0.61064E+01	-0.70725E+00	-29.116
	5	17.3750	4.1250	0.93288E+00	0.68533E+01	0.27992E+01	0.00000E+00	0.79671E+01	-0.18100E+00	-21.699
	6	17.2782	5.9647	-0.84960E+00	0.86964E+01	0.26531E+01	0.00000E+00	0.93842E+01	-0.15374E+01	-14.534
	7	19.4301	3.1064	0.14692E+00	0.20009E+01	0.14764E+01	0.00000E+00	0.28172E+01	-0.66938E+00	-28.938
	8	19.4083	5.7710	0.20849E+00	0.50228E+01	0.12485E+01	0.00000E+00	0.53273E+01	-0.96032E-01	-13.737
	9	19.3865	8.4357	-0.13197E+01	0.75637E+01	0.82553E+00	0.00000E+00	0.76397E+01	-0.13958E+01	-5.264
25	1	6.9547	5.3635	0.20572E+01	0.81946E+01	-0.97458E+01	0.00000E+00	0.15343E+02	-0.50916E+01	36.263
	2	6.0492	4.6762	0.12109E+00	0.63262E+01	-0.82868E+01	0.00000E+00	0.12072E+02	-0.56249E+01	34.737
	3	5.1436	3.9889	-0.15621E+01	0.34442E+01	-0.67920E+01	0.00000E+00	0.81796E+01	-0.62975E+01	34.484
	4	5.8555	7.2873	0.40514E+01	0.72690E+01	-0.67067E+01	0.00000E+00	0.12557E+02	-0.12367E+01	36.256
	5	4.5000	7.0000	0.56637E+01	0.71116E+01	-0.54871E+01	0.00000E+00	0.11922E+02	0.85301E+00	41.242
	6	3.1445	6.6127	0.79134E+01	0.65534E+01	-0.39091E+01	0.00000E+00	0.10647E+02	0.28201E+01	-43.682
	7	4.7564	9.4111	0.15651E+02	0.98269E+01	-0.14531E+01	0.00000E+00	0.17493E+02	0.94844E+01	-13.260
	8	2.9508	9.3238	0.16989E+02	0.90861E+01	-0.16110E+01	0.00000E+00	0.17305E+02	0.87704E+01	-11.090
	9	1.1453	9.2365	0.18399E+02	0.89551E+01	-0.89491E+00	0.00000E+00	0.18483E+02	0.88711E+01	-5.366
26	1	8.2349	3.1000	-0.52555E+00	0.93270E+01	-0.11888E+02	0.00000E+00	0.17269E+02	-0.84671E+01	33.745
	2	7.7200	2.6691	-0.31562E+00	0.66792E+01	-0.10407E+02	0.00000E+00	0.14160E+02	-0.77977E+01	35.714
	3	7.2032	2.2381	-0.21715E+01	0.29420E+01	-0.79835E+01	0.00000E+00	0.98008E+01	-0.79803E+01	36.040
	4	7.8169	1.8309	0.40432E+00	0.90484E+01	-0.10837E+02	0.00000E+00	0.16188E+02	-0.67156E+01	33.423
	5	7.1875	3.2500	-0.61681E+00	0.61575E+01	-0.96384E+01	0.00000E+00	0.12987E+02	-0.74459E+01	35.319
	6	6.5581	2.6691	-0.70681E+01	0.25139E+01	-0.80431E+01	0.00000E+00	0.82174E+01	-0.87921E+01	35.432
	7	7.3968	4.5619	0.15752E+01	0.86242E+01	-0.94244E+01	0.00000E+00	0.15164E+02	-0.49643E+01	34.750
	8	6.6550	3.8309	-0.22737E+00	0.55113E+01	-0.87523E+01	0.00000E+00	0.11953E+02	-0.65180E+01	35.926
	9	5.9131	3.1000	-0.30231E+01	0.18270E+01	-0.76529E+01	0.00000E+00	0.74298E+01	-0.86263E+01	36.208
27	1	8.8528	3.0500	0.86312E+00	0.12757E+02	-0.13291E+02	0.00000E+00	0.21371E+02	-0.77505E+01	32.947
	2	8.5405	1.8345	0.88715E+00	0.93027E+01	-0.11712E+02	0.00000E+00	0.17540E+02	-0.73498E+01	35.119
	3	8.2282	1.6191	0.31892E-01	0.45411E+01	-0.95844E+01	0.00000E+00	0.12132E+02	-0.75595E+01	38.381
	4	8.6373	2.4155	0.73315E-01	0.11512E+02	-0.12849E+02	0.00000E+00	0.19857E+02	-0.82721E+01	33.003
	5	8.2500	2.1250	0.85863E-01	0.84267E+01	-0.11030E+02	0.00000E+00	0.16048E+02	-0.75358E+01	34.644
	6	7.8627	1.8345	-0.71777E+00	0.43507E+01	-0.87293E+01	0.00000E+00	0.10906E+02	-0.72733E+01	36.906
	7	8.4218	2.7809	-0.50844E+00	0.10145E+02	-0.12472E+02	0.00000E+00	0.18381E+02	-0.87440E+01	33.437
	8	7.9595	2.4155	-0.63991E+00	0.71697E+01	-0.10430E+02	0.00000E+00	0.13402E+02	-0.78725E+01	34.738
	9	7.4972	2.0000	-0.15561E+01	0.33853E+01	-0.79502E+01	0.00000E+00	0.92398E+01	-0.74108E+01	36.168

28	1	9.3841	1.1064	0.46572E+01	0.17553E+02	-0.17103E+02	0.00000E+00	0.29381E+02	-0.71732E+01	38.672
	2	9.1796	1.0845	0.45270E+01	0.12553E+02	-0.14736E+02	0.00000E+00	0.23813E+02	-0.67330E+01	37.383
	3	8.9750	1.0627	0.43057E+01	0.75887E+01	-0.12005E+02	0.00000E+00	0.18064E+02	-0.61673E+01	41.107
	4	9.1796	1.4718	0.28125E+01	0.16029E+02	-0.15147E+02	0.00000E+00	0.25947E+02	-0.71[illegible]E+01	33.215
	5	8.9375	1.3750	0.28974E+01	0.11785E+02	-0.13207E+02	0.00000E+00	0.21276E+02	-0.6593[illegible]E+01	35.702
	6	8.6954	1.2782	0.26406E+01	0.74951E+01	-0.10960E+02	0.00000E+00	0.16294E+02	-0.61578E+01	38.756
	7	8.9750	1.8373	0.16644E+01	0.13458E+02	-0.13837E+02	0.00000E+00	0.22602E+02	-0.74797E+01	33.459
	8	8.6954	1.6655	0.16162E+01	0.94535E+01	-0.12185E+02	0.00000E+00	0.18335E+02	-0.72651E+01	36.086
	9	8.4159	1.4936	0.10169E+01	0.52271E+01	-0.10217E+02	0.00000E+00	0.13554E+02	-0.73101E+01	39.179
29	1	9.9373	1.1127	0.22014E+01	0.37239E+02	-0.15836E+02	0.00000E+00	0.43336E+02	-0.38955E+01	21.056
	2	9.7218	1.1127	0.30361E+01	0.29963E+02	-0.16916E+02	0.00000E+00	0.38119E+02	-0.51198E+01	25.741
	3	9.5064	1.1127	0.34801E+01	0.21386E+02	-0.17764E+02	0.00000E+00	0.32326E+02	-0.74600E+01	31.627
	4	9.9155	1.5000	0.22912E-01	0.32775E+02	-0.13717E+02	0.00000E+00	0.37761E+02	-0.49632E+01	19.976
	5	9.6250	1.5000	0.11730E+01	0.26617E+02	-0.14763E+02	0.00000E+00	0.33384E+02	-0.55933E+01	24.623
	6	9.3345	1.5000	0.20007E+01	0.19386E+02	-0.15581E+02	0.00000E+00	0.28535E+02	-0.71888E+01	30.422
	7	9.8936	1.8873	-0.15037E+01	0.28342E+02	-0.12703E+02	0.00000E+00	0.33017E+02	-0.[illegible]704E+01	20.203
	8	9.5282	1.8873	-0.23310E+00	0.22626E+02	-0.13752E+02	0.00000E+00	0.29078E+02	-0.66848E+01	25.134
	9	9.1627	1.8873	0.75546E+00	0.15970E+02	-0.14574E+02	0.00000E+00	0.24803E+02	-0.80773E+01	31.218
30	1	10.4936	1.1127	0.58482E+00	0.45661E+02	-0.33686E+01	0.00000E+00	0.45911E+02	0.33447E+00	4.250
	2	10.2782	1.1127	0.10489E+01	0.44935E+02	-0.82506E+01	0.00000E+00	0.46435E+02	-0.45101E+00	10.303
	3	10.0627	1.1127	0.40776E+00	0.40525E+02	-0.12931E+02	0.00000E+00	0.44332E+02	-0.33991E+01	16.404
	4	10.6655	1.5000	-0.28538E+00	0.39257E+02	-0.26411E+01	0.00000E+00	0.39433E+02	-0.46101E+00	3.804
	5	10.3750	1.5000	-0.21230E+00	0.38969E+02	-0.68833E+01	0.00000E+00	0.40144E+02	-0.13864E+01	9.680
	6	10.0845	1.5000	-0.10659E+01	0.35593E+02	-0.11002E+02	0.00000E+00	0.38641E+02	-0.41143E+01	15.487
	7	10.8373	1.8873	-0.12255E+01	0.33818E+02	-0.27068E+01	0.00000E+00	0.34026E+02	-0.18332E+01	4.390
	8	10.4718	1.8873	-0.14022E+01	0.33724E+02	-0.65767E+01	0.00000E+00	0.34915E+02	-0.25932E+01	10.264
	9	10.1064	1.8873	-0.24004E+01	0.30892E+02	-0.10369E+02	0.00000E+00	0.33857E+02	-0.53659E+01	15.960
31	1	11.0250	1.0627	0.72616E+01	0.39040E+02	0.40943E+01	0.00000E+00	0.39559E+02	0.67426E+01	-7.225
	2	10.8204	1.0845	0.57449E+01	0.42951E+02	0.20576E+01	0.00000E+00	0.43064E+02	0.56315E+01	-3.156
	3	10.6159	1.1064	0.33444E+01	0.44257E+02	-0.44520E+00	0.00000E+00	0.44262E+02	0.33395E+01	0.623
	4	11.3046	1.2782	0.59875E+01	0.34538E+02	0.41824E+01	0.00000E+00	0.35139E+02	0.53874E+01	-8.165
	5	11.0625	1.3750	0.41688E+01	0.37358E+02	0.21234E+01	0.00000E+00	0.37533E+02	0.40337E+01	-3.642
	6	10.8204	1.4718	0.15945E+01	0.38462E+02	-0.38564E+00	0.00000E+00	0.38466E+02	0.15905E+01	0.599
	7	11.5841	1.4936	0.51345E+01	0.30992E+02	0.39577E+01	0.00000E+00	0.31584E+02	0.45423E+01	-8.510
	8	11.3046	1.6655	0.27718E+01	0.32934E+02	0.17587E+01	0.00000E+00	0.33036E+02	0.26696E+01	-3.326
	9	11.0250	1.8373	-0.22134E+00	0.33520E+02	-0.85611E+00	0.00000E+00	0.33542E+02	-0.24304E+00	1.453
32	1	11.7718	1.6191	0.46602E+01	0.28989E+02	0.38030E+01	0.00000E+00	0.29569E+02	0.40796E+01	-8.681
	2	11.4595	1.8345	0.24718E+01	0.31135E+02	0.18198E+01	0.00000E+00	0.31250E+02	0.23567E+01	-3.618
	3	11.1472	2.0500	-0.63357E+00	0.31458E+02	-0.78051E+00	0.00000E+00	0.31477E+02	-0.65254E+00	1.392
	4	12.1373	1.8345	0.40546E+01	0.25840E+02	0.37250E+01	0.00000E+00	0.26459E+02	0.34352E+01	-9.440
	5	11.7500	2.1250	0.19457E+01	0.27999E+02	0.19238E+01	0.00000E+00	0.28141E+02	0.18045E+01	-4.200
	6	11.3627	2.4155	-0.10994E+01	0.28444E+02	-0.50750E+00	0.00000E+00	0.28453E+02	-0.11082E+01	0.984
	7	12.5028	2.0500	0.34137E+01	0.23331E+02	0.36476E+01	0.00000E+00	0.23978E+02	0.27667E+01	-10.058
	8	12.0405	2.4155	0.13022E+01	0.25379E+02	0.13205E+01	0.00000E+00	0.2553[illegible]E+02	0.11500E+01	-4.532
	9	11.5782	2.7809	-0.17534E+01	0.25790E+02	-0.43866E+00	0.00000E+00	0.25797E+02	-0.17604E+01	0.912
33	1	12.7968	2.2381	0.28811E+01	0.21199E+02	0.36804E+01	0.00000E+00	0.21911E+02	0.21693E+01	-10.946
	2	12.2800	2.6691	0.10763E+01	0.23165E+02	0.19461E+01	0.00000E+00	0.23335E+02	0.90613E+00	-4.997
	3	11.7631	3.1000	-0.19324E+01	0.23735E+02	-0.48204E+00	0.00000E+00	0.23744E+02	-0.19415E+01	1.076
	4	13.4419	2.6691	0.19475E+01	0.17813E+02	0.39818E+01	0.00000E+00	0.18757E+02	0.10043E+01	-13.327
	5	12.8125	3.2500	0.60738E+00	0.19882E+02	0.21135E+01	0.00000E+00	0.20111E+02	0.37837E+00	-6.184
	6	12.1831	3.8309	-0.17840E+01	0.20655E+02	-0.37910E+00	0.00000E+00	0.20662E+02	-0.17904E+01	0.968
	7	14.0869	3.1000	0.11239E+01	0.14965E+02	0.41832E+01	0.00000E+00	0.16131E+02	-0.42249E-01	-15.576
	8	13.3450	3.8309	0.34564E-01	0.16984E+02	0.21841E+01	0.00000E+00	0.17260E+02	-0.24236E+00	-7.226
	9	12.6032	4.5619	-0.19910E+01	0.17782E+02	-0.39371E+00	0.00000E+00	0.17790E+02	-0.19988E+01	1.140
34	1	14.8564	3.9889	-0.11260E+00	0.12208E+02	0.36136E+01	0.00000E+00	0.13189E+02	-0.10943E+01	-15.198
	2	13.9508	4.6762	-0.65038E+00	0.14610E+02	0.24880E+01	0.00000E+00	0.15006E+02	-0.10458E+01	-9.030
	3	13.0453	5.3635	-0.17849E+01	0.14908E+02	0.81777E+00	0.00000E+00	0.14947E+02	-0.18249E+01	-2.798
	4	16.8555	6.6127	-0.90279E+00	0.94904E+01	0.25237E+01	0.00000E+00	0.10071E+02	-0.14832E+01	-12.952
	5	15.5000	7.0000	-0.21073E+01	0.10914E+02	0.23106E+01	0.00000E+00	0.11311E+02	-0.25052E+01	-9.770
	6	14.1445	7.3873	-0.38530E+01	0.10762E+02	0.18429E+01	0.00000E+00	0.10992E+02	-0.40835E+01	-7.103
	7	18.8547	9.2365	-0.51656E+00	0.73835E+01	0.10129E+01	0.00000E+00	0.75113E+01	-0.64436E+00	-7.191
	8	17.0492	9.3238	-0.17251E+01	0.87828E+01	0.11970E+01	0.00000E+00	0.89175E+01	-0.18598E+01	-6.417
	9	15.2436	9.4111	-0.32311E+01	0.92693E+01	0.11789E+01	0.00000E+00	0.[illegible]295E+01	-0.33413E+01	-5.341
35	1	9.6865	5.5635	-0.15990E+01	0.13548E+02	-0.85874E+01	0.00000E+00	0.[illegible]24E+02	-0.54755E+01	24.295
	2	8.6091	5.5635	-0.38678E+00	0.11779E+02	-0.91749E+01	0.00000E+00	0.16[illegible]4E+02	-0.53121E+01	28.228
	3	7.5318	5.5635	0.44659E+00	0.87464E+01	-0.10254E+02	0.00000E+00	0.15[illegible]9E+02	-0.64658E+01	33.984
	4	9.5774	7.5000	-0.14566E+01	0.11355E+02	-0.54667E+01	0.00000E+00	0.1[illegible]20E+02	-0.34721E+01	20.239
	5	8.1250	7.5000	0.21730E+01	0.10458E+02	-0.57404E+01	0.00000E+00	0.13394E+02	-0.76354E+00	27.093
	6	6.6726	7.5000	0.55875E+01	0.88439E+01	-0.61851E+01	0.00000E+00	0.13612E+02	0.81990E+00	37.626
	7	9.4682	9.4365	-0.32873E+00	0.94397E+01	-0.24478E+01	0.00000E+00	0.10019E+02	-0.90781E+00	13.309
	8	7.6409	9.4365	0.46824E+01	0.89114E+01	-0.26283E+01	0.00000E+00	0.10170E+02	0.34236E+01	25.591
	9	5.8135	9.4365	0.95750E+01	0.79881E+01	-0.27903E+01	0.00000E+00	0.11682E+02	0.58806E+01	-37.063
36	1	9.8182	3.2254	-0.27567E+01	0.20386E+02	-0.10366E+02	0.00000E+00	0.24350E+02	-0.67210E+01	20.928
	2	9.1936	3.2254	-0.13896E+01	0.16531E+02	-0.11444E+02	0.00000E+00	0.22105E+02	-0.69635E+01	25.970
	3	8.5691	3.2254	-0.30318E+00	0.11740E+02	-0.11972E+02	0.00000E+00	0.19119E+02	-0.76825E+01	31.649
	4	9.7746	4.0000	-0.18255E+01	0.18284E+02	-0.92626E+01	0.00000E+00	0.21900E+02	-0.54417E+01	21.326
	5	9.0000	4.0000	-0.12618E+01	0.14881E+02	-0.10297E+02	0.00000E+00	0.19893E+02	-0.62737E+01	25.954
	6	8.2254	4.0000	-0.92646E+00	0.10718E+02	-0.10922E+02	0.00000E+00	0.17273E+02	-0.74812E+01	30.970
	7	9.7309	4.7746	-0.11347E+01	0.16047E+02	-0.85897E+01	0.00000E+00	0.19604E+02	-0.46924E+01	22.498
	8	8.8064	4.7746	-0.11213E+01	0.12925E+02	-0.96179E+01	0.00000E+00	0.17811E+02	-0.60073E+01	26.931
	9	7.8818	4.7746	-0.13008E+01	0.91605E+01	-0.10331E+02	0.00000E+00	0.15510E+02	-0.76501E+01	31.574
37	1	9.8809	2.1127	-0.20528E+01	0.26618E+02	-0.12172E+02	0.00000E+00	0.31089E+02	-0.65232E+01	20.167
	2	9.4718	2.1127	-0.65199E+00	0.21396E+02	-0.13116E+02	0.00000E+00	0.27505E+02	-0.67619E+01	24.977
	3	9.0627	2.1127	0.43170E+00	0.15116E+02	-0.13820E+02	0.00000E+00	0.23422E+02	-0.78752E+01	31.010
	4	9.8591	2.5000	-0.26205E+01	0.24349E+02	-0.11281E+02	0.00000E+00	0.28445E+02	-0.67168E+01	19.957
	5	9.3750	2.5000	-0.10806E+01	0.19728E+02	-0.12274E+02	0.00000E+00	0.25415E+02	-0.67668E+01	24.857
	6	8.8909	2.5000	0.18072E+00	0.14180E+02	-0.13033E+02	0.00000E+00	0.21974E+02	-0.76133E+01	30.881
	7	9.8373	2.8873	-0.29018E+01	0.22115E+02	-0.10725E+02	0.00000E+00	0.26084E+02	-0.68704E+01	20.306
	8	9.2782	2.8873	-0.12741E+01	0.17889E+02	-0.11777E+02	0.00000E+00	0.23491E+02	-0.68752E+01	25.435
	9	8.7191	2.8873	0.10345E+00	0.12829E+02	-0.12599E+02	0.00000E+00	0.20581E+02	-0.76485E+01	31.603
38	1	10.9373	[illegible].1127	-0.16115E+01	0.31634E+02	-0.25685E+01	0.00000E+00	0.31831E+02	-0.18088E+01	4.392
	2	10.5282	[illegible].1127	-0.17563E+01	0.31795E+02	-0.62673E+01	0.00000E+00	0.32928E+02	-0.28888E+01	10.243
	3	10.1191	[illegible].1127	-0.27684E+01	0.29065E+02	-0.10311E+02	0.00000E+00	0.31952E+02	-0.56547E+01	16.083
	4	11.1091	2.5000	-0.20812E+01	0.28750E+02	-0.22754E+01	0.00000E+00	0.28917E+02	-0.22482E+01	4.198
	5	10.6250	2.5000	-0.21405E+01	0.28988E+02	-0.5773[illegible]E+01	0.00000E+00	0.30024E+02	-0.31761E+01	10.173
	6	10.1409	2.5000	-0.29814E+01	0.26622E+0[illegible]	-0.93079E+01	0.00000E+00	0.29302E+02	-0.56621E+01	16.075
	7	11.2809	2.8873	-0.24467E+01	0.26092E+02	-0.21577E+01	0.00000E+00	0.26254E+02	-0.26090E+01	4.299
	8	10.7218	2.8873	-0.24521E+01	0.26358E+02	-0.55162E+01	0.00000E+00	0.27378E+02	-0.34722E+01	10.477
	9	10.1627	2.8873	-0.31764E+01	0.24228E+02	-0.89030E+01	0.00000E+00	0.26867E+02	-0.58148E+01	16.507
39	1	11.4309	3.2254	-0.26364E+01	0.24163E+02	-0.[illegible]0964E+01	0.00000E+00	0.24326E+02	-0.27994E+01	4.446
	2	10.8064	3.2254	-0.25341E+01	0.24655E+02	-0.52791E+01	0.00000E+00	0.25644E+02	-0.35211E+01	10.611
	3	10.1818	3.2254	-0.32603E+01	0.22385E+02	-0.84939E+01	0.00000E+00	0.24943E+02	-0.58184E+01	16.760
	4	11.7746	4.0000	-0.28451E+01	0.20916E+02	-0.17959E+01	0.00000E+00	0.21051E+02	-0.29801E+01	4.298
	5	11.0000	4.0000	-0.26563E+01	0.21447E+02	-0.45847E+01	0.00000E+00	0.22290E+02	-0.34989E+01	10.418
	6	10.2254	4.0000	-0.31623E+01	0.19663E+02	-0.73945E+01	0.00000E+00	0.21849E+02	-0.53485E+01	16.470
	7	12.1182	4.7746	-0.31117E+01	0.17874E+02	-0.16674E+01	0.00000E+00	0.18006E+02	-0.32433E+01	4.515
	8	11.1936	4.7746	-0.28670E+01	0.18423E+02	-0.41498E+01	0.00000E+00	0.19222E+02	-0.36555E+01	10.765
	9	10.2691	4.7746	-0.32267E+01	0.16958E+02	-0.67456E+01	0.00000E+00	0.19005E+02	-0.52735E+01	16.879

40	1	12.4682	5.5635	-0.26058E+01	0.14362E+02	-0.54608E+00	0.00000E+00	0.14380E+02	-0.2623[illegible]	1.841
	2	11.3909	5.5635	-0.22618E+01	0.14638E+02	-0.36369E+01	0.00000E+00	0.15388E+02	-0.30112E+01	11.683
	3	10.3135	5.5635	-0.21648E+01	0.14091E+02	-0.68203E+01	0.00000E+00	0.16574E+02	-0.46472E+01	20.000
	4	13.3274	7.5000	-0.27955E+01	0.12013E+02	0.13618E+00	0.00000E+00	0.12014E+02	-0.27967E+01	-0.527
	5	11.8750	7.5000	-0.19670E+01	0.12610E+02	-0.19635E+01	0.00000E+00	0.12870E+02	-0.22268E+01	7.538
	6	10.4226	7.5000	-0.14515E+01	0.12165E+02	-0.40970E+01	0.00000E+00	0.13303E+02	-0.25896E+01	15.522
	7	14.1865	9.4365	-0.67159E+01	0.88495E+01	0.11487E+01	0.00000E+00	0.89338E+01	-0.68002E+01	-4.198
	8	12.3591	9.4365	-0.56394E+01	0.95110E+01	-0.12262E+00	0.00000E+00	0.95120E+01	-0.56404E+01	0.468
	9	10.5318	9.4365	-0.49147E+01	0.90000E+01	-0.13945E+01	0.00000E+00	0.91384E+01	-0.50530E+01	5.667

NUMBER OF PERTURBATIONS............(NPERT) = 2

CRACK TIP ZONE MATERIAL............(MATIP) = 1

MODELLING SYMMETRY FACTOR..........(NSYMM) = 2

CRACK FACE PRESSURE INDEX..........(IFACE) = 0

VIRTUAL CRACK EXTENSION............(CREXT) = 0.10000E-02

LOAD CASE 1, PERTURBATION 1

PERTURBED ELEMENTS, REGION 1......(LIST1) = 9 21 31 30 29 28 16 4

ENERGY RELEASE RATE........................ = 0.33976E+00

MODE I K-FACTOR............................ = 0.10096E+03

LOAD CASE 1, PEBTURBATION 2

PERTURBED ELEMENTS, REGION 1......(LIST1) = 10 22 32 38 37 27 15 3

ENERGY RELEASE RATE........................ = 0.33984E+00

MODE I K-FACTOR............................ = 0.10097E+03

Appendix D

INPUT ERROR DIAGNOSTICS

ORVIRT.PC employs modified versions of data-checking routines listed in Refs. 9 and 10. Any detected input errors are assigned the following error codes.

Error	Interpretation
1	NPOIN ≤ 0
2	NPOIN greater than the possible maximum number of nodes
3	NPOIN must be less than or equal to 450
4	NELEM must be greater than 1 and less than or equal to 135
5	NVFIX must be less than or equal to 100
6	NCASE improperly specified
7	NTYPE improperly specified
8	NMATS improperly specified
9	Not used
10	NGAUS must be 2 or 3
11	NFRAC must be 0 or 1
12	Not used
13	Not used
14	MATNO improperly specified
15	LNODS has a zero entry
16	LNODS has a negative entry or an entry greater than NPOIN
17	A node number may not be repeated within an element
18,19	A node number in the list of nodal points does not appear in the element connectivities
20	An unused node number is specified as a restrained node
21	The maximum allowable front width = 120 has been exceeded (see Ref. 10)
22,23,24	Improperly specified boundary condition

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13. ABSTRACT (200 words or less)

ORVIRT.PC (Oak Ridge VIRTual crack extension.Personal Computer) is a 2-D finite element fracture-analysis program for an IBM PC/AT microcomputer. The code is based to a large extent on the techniques used in the ORMGEN-ADINA-ORVIRT fracture-analysis system. ORVIRT.PC is a stand-alone program capable of performing 2-D linear elastic stress and fracture-mechanics analyses. Thermal loadings may be analyzed in addition to mechanical loadings. Crack-face tractions may also be considered. Eight-noded isoparametric elements which combine both performance and ease of modelling are employed in the program. Special crack-tip elements which allow for an inverse square root variation in the near-tip stress and strain fields are used at the crack tip. Detailed user instructions are provided which describe both preparation of input data and program operation. Sample problems are presented which demonstrate good agreement with known solutions.

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Flaws
Fracture analysis
Microcomputer software
Stress Analysis

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