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3D INELASTIC ANALYSIS METHODS FOR HOT SECTION COMPONENTS*

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INTRODUCTION

Accomplishments are described for the 2-year program, to develop advanced 3-D inelastic structural stress analysis methods and solution strategies for more accurate and cost effective analysis of combustors, turbine blades and vanes. The approach was to develop a matrix of formulation elements and constitutive models. Three constitutive models were developed in conjunction with optimized iterating techniques, accelerators, and convergence criteria within a framework of dynamic time incrementing. Three formulations models were developed; an eight-noded mid-surface shell element, a nine-noded mid-surface shell element and a twenty-noded isoparametric solid element. A separate computer program has been developed for each combination of constitutive model-formulation model. Each program provides a functional stand alone capability for performing cyclic nonlinear structural analysis. In addition, the analysis capabilities incorporated into each program can be abstracted in subroutine form for incorporation into other codes or to form new combinations.

OBJECTIVES

The objective of this research was to develop analytical tools capable of economically evaluating the cyclic time-dependent plasticity which occurs in hot section engine components in areas of strain concentration resulting from the combination of both mechanical and thermal stresses. The techniques developed are capable of accommodating large excursions in temperatures with the associated variations in material properties including plasticity and creep.

The overall objective of this research program was to develop advanced 3-D inelastic structural/stress analysis methods and solution strategies for more accurate and yet more cost-effective analysis of combustors, turbine blades, and vanes. The approach was to develop a matrix of formulation elements and constitutive models, three increasingly more complex formulation models and three increasingly more complex constitutive models.

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CONSTITUTIVE MODELS

The three constitutive models were developed in conjunction with optimized iteration techniques, accelerators, and convergence criteria within a framework of dynamic time incrementing. These consist of a simple model, a classical model, and a unified model. The simple model performs time-independent inelastic analyses using a bilinear stress-strain curve and time-dependent inelastic analyses using a power-law creep equation. The second model is the classical model of Professors Walter Haisler and David Allen (Reference 1) of Texas A&M University. The third model is the unified model of Bodner, Partom, et al. (Reference 2). All models were customized for a linear variation of loads and temperatures with all material properties and constitutive models being temperature dependent.

FORMULATION MODELS

The three formulation models developed are an eight-noded mid-surface shell element, a nine-noded mid-surface shell element and a twenty-noded isoparametric solid element. Both of the shell elements are obtained by "degenerating" 3D isoparametric solid elements and then imposing the necessary kinematic assumptions in connection with the small dimension of the shell thickness (References 3 and 4). The eight-noded element uses Serendipity shape functions and the nine noded element uses Lagrange shape functions. The eight-noded element uses Gaussian quadrature for numerical integration, with nodal and surface stresses being obtained by extrapolation/mapping techniques. Lobatto quadrature is being used with the nine-noded element to effectively provide for direct recovery of the stresses and strains at the surfaces and node points. The eight-noded element has an excellent combination of accuracy and economy in the normal element aspect range encountered when modeling most hot section components. The nine-noded Lagrangian formulation overcomes the shear locking problem experienced when the element size-versus-thickness-aspect ratio becomes very large. The twenty-noded isoparametric element uses Gaussian quadrature.

COMPUTER PROGRAMS

A separate computer program has been developed for each combination of constitutive model-formulation model. Each program provides a functional, stand alone capability for performing cyclic nonlinear structural analysis. In addition, the analysis capabilities incorporated into each program can be abstracted in subroutine form for incorporation into other codes or to form new combinations. These programs will provide the structural analyst with a matrix of capabilities involving the constitutive models-formulation models from which he will be able to select the combination that satisfies his particular needs. The program architecture employs state-of-the-art techniques to maximize efficiency, utility, and portability. Among these features are the following:

(i) User Friendly I/O

- o Free format data input

- o Global, local coordinate system, (Cartesian, Cylindrical, Spherical)
- o Automatic generation of nodal and elemental attributes
- o User-controlled optional print out

  Nodal Displacements

  Nodal Forces

  Element Forces

  Element Stresses and Strains

(ii) Programming Efficiency

- o Dynamic core allocation
- o Optimization of file/core utilization
- o Blocked column skyline out-of-core equation solver

(iii) Accurate and Economical Solution Techniques

- o Right-hand side pseudoforce technique
- o Accelerators for the iteration scheme
- o Convergence criteria based on both the local inelastic strain and the global displacements

The ability to model piecewise linear load histories was also included in the finite element codes. Since the inelastic strain rate could be expected to change dramatically during a linear load history, it is important to include a dynamic time-incrementing procedure.

Three separate time step control criteria are used. These are the maximum stress increment, maximum inelastic strain increment, and maximum rate of change of the inelastic strain rate. The minimum time step calculated from the three criteria is the value actually used. Since the calculations are based on values readily available from the previous time step, little computational effort is required.

TEST CASES

These formulation models and constitutive models have been checked out extensively against both theory and experiment. Figure 1 shows the correlation between Bodner's model in the eight-noded and mid-surface shell element (MSS8) and both experiment and other predictions (Reference 5). Figures 2 through 6 illustrate the predictability of the classical Haisler-Allen model. Figure 7 shows a comparison of both Bodner's model and the simple model to both experiment and independent predictions (Reference 6).

SOURCE CODE INFORMATION

These nine programs, both source (Fortran 77) and compiled, have been installed and checked out on the NASA-Lewis CRAY-1 machine. The interactive deck generator has been installed on the NASA-Lewis AMDAHL machine.

Table 1 shows the lines of source code for each of the nine computer programs. These numbers do not include the interactive deck generators.

TABLE 1. LINES OF SOURCE CODE

		Elements		
		20-Noded	8-Noded	9-Noded
Constitutive Models	Simple	8300	13,800	17,900
	Haisler-Allen	9200	16,300	19,000
	Bodner	7300	13,800	17,600

Since these programs use dynamic core allocation, they can be recompiled to size for any specific machine. They are presently loaded for 10^7 bytes of core. At this size, the maximum problem would be approximately 4000 nodes and 1000 elements, and 24000 degrees of freedom.

REFERENCES

1. Allen, D.H., and Haisler, W.E., "A Theory of Thermoplastic Materials," Computers and Structures, Vol. 13, pp. 129-135, 1981.

2. Bodner, S.A., Partom, I., and Partom, Y., "Uniaxial Cyclic Loading of Elastic-Viscoplastic Material," ASME J. Appl. Mech., Vol. 46, p. 805, 1979.

3. Chang, T.Y. and Sawamiphakdi, K., "Large Deformation Analysis of Shells by Finite Element Method," Comp. and Struct., Vol. 13, pp. 331-340, 1981.

4. Chang, T.Y. and Sawamiphakdi, K., "Nonlinear Finite-Element Analysis of Shells with Large Aspect Ratio," presented at the Nonlinear Structural Analysis Workshop, NASA-Lewis Research Center, April 19 and 20, 1983.

5. Stouffer, D.C., "A Constitutive Representation for IN100," Air Force Materials Laboratory, AFWAL-TR-81-4039, 1981.

6. Bodner, S.R., "Representation of Time Dependent Mechanical Behavior of Rene' 95 by Constitutive Equations," Air Force Materials Laboratory, AFML-TX-79-4116, 1979.

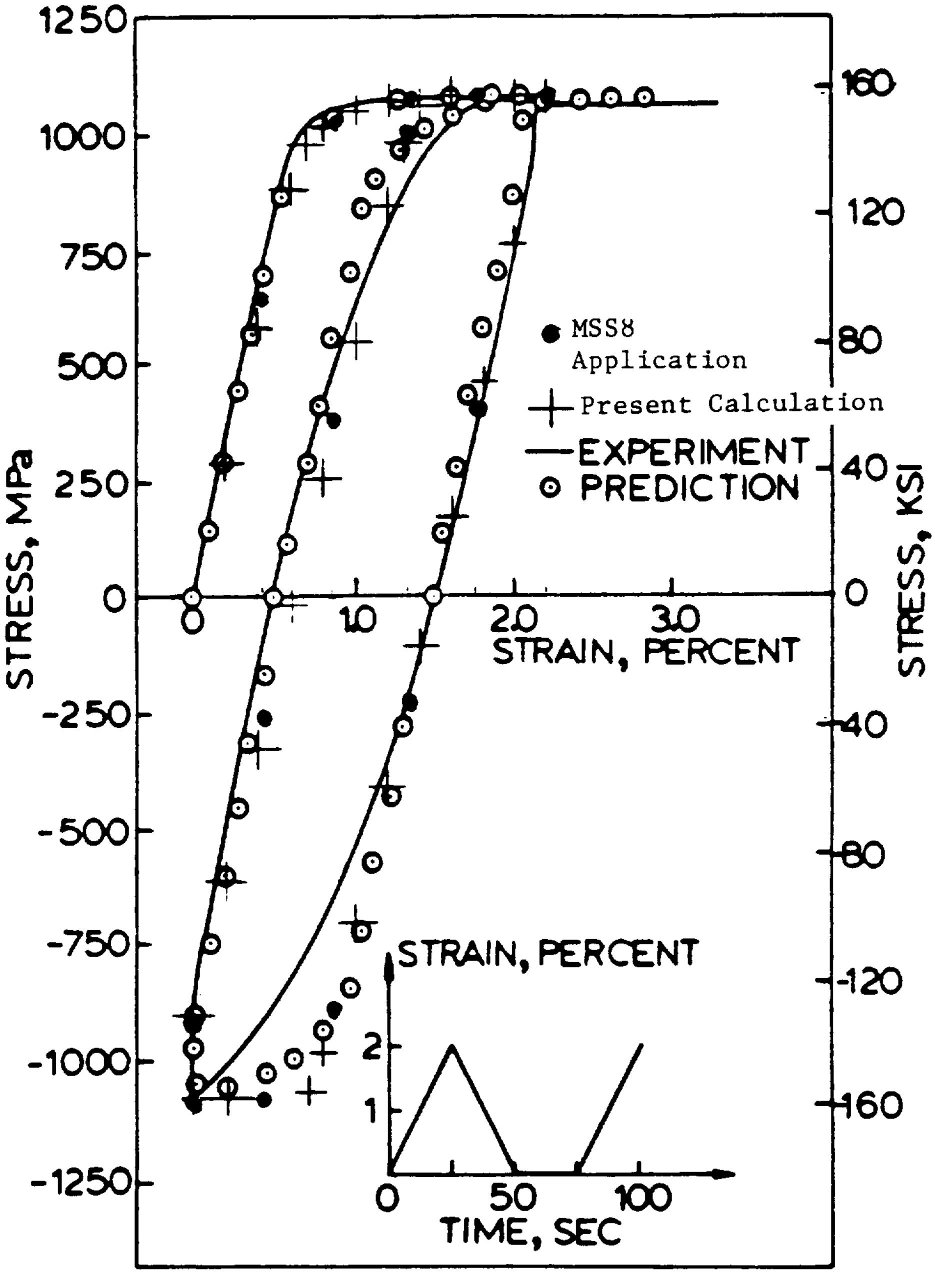

Figure 1. Displacement Controlled Cycling Results.

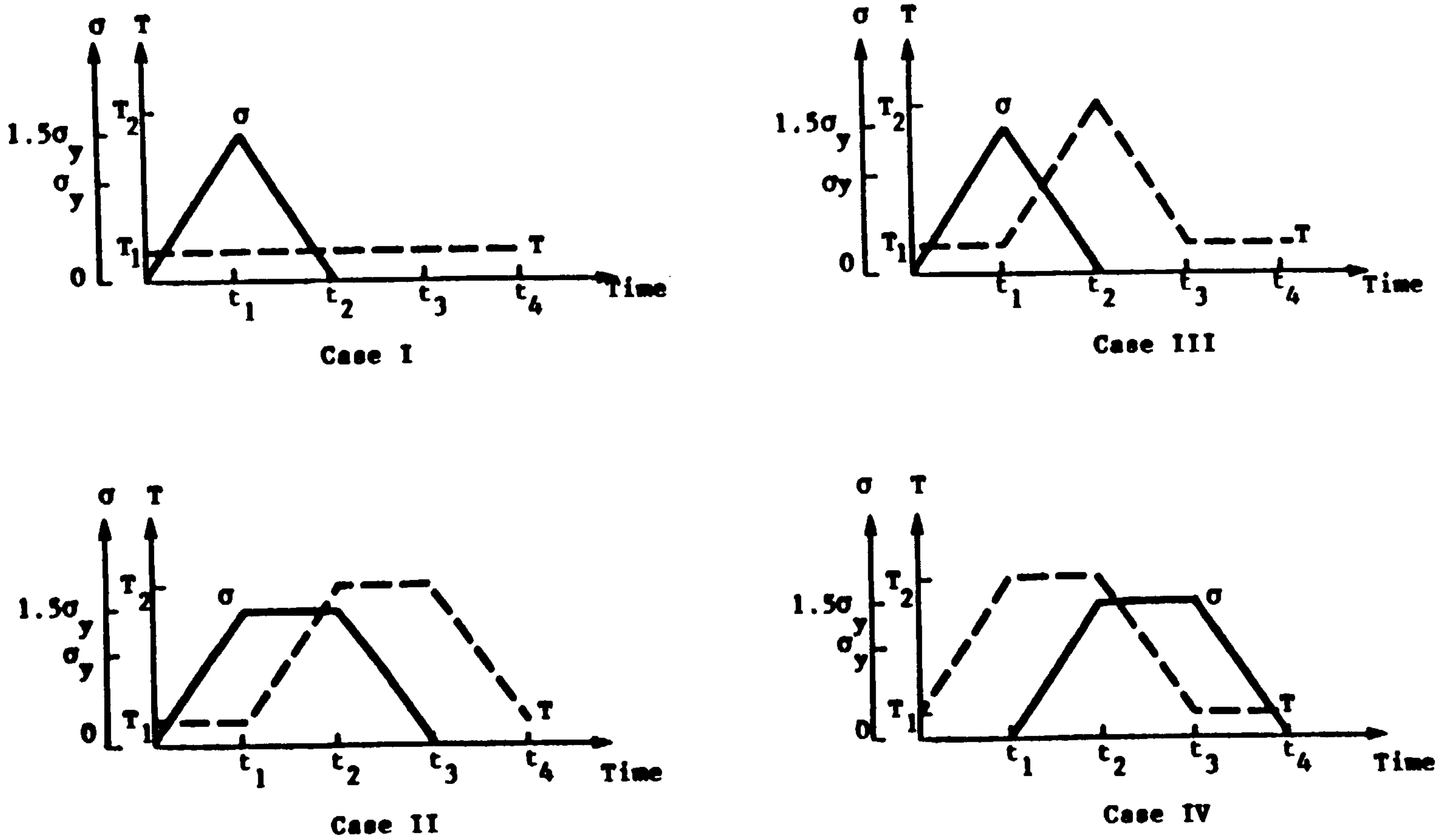

Figure 2. Load Histories for Plasticity Example.

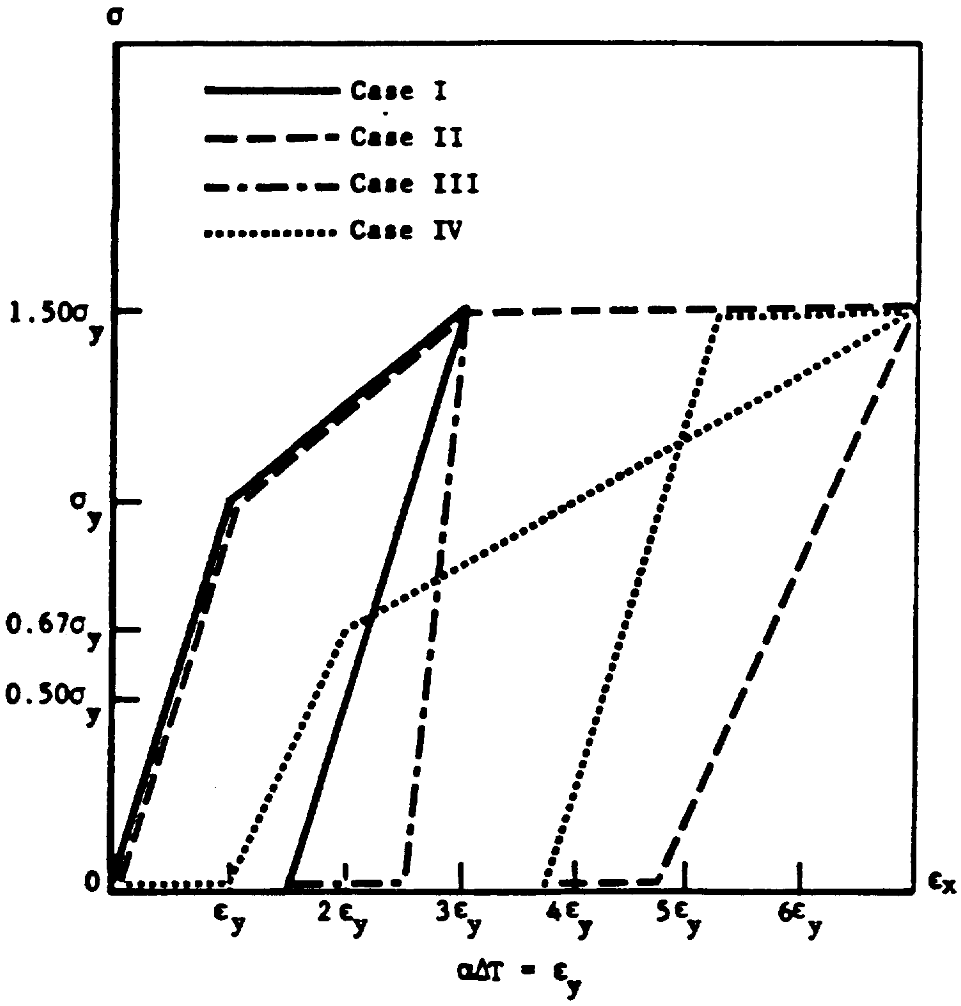

Figure 3. Results of Plasticity Example.

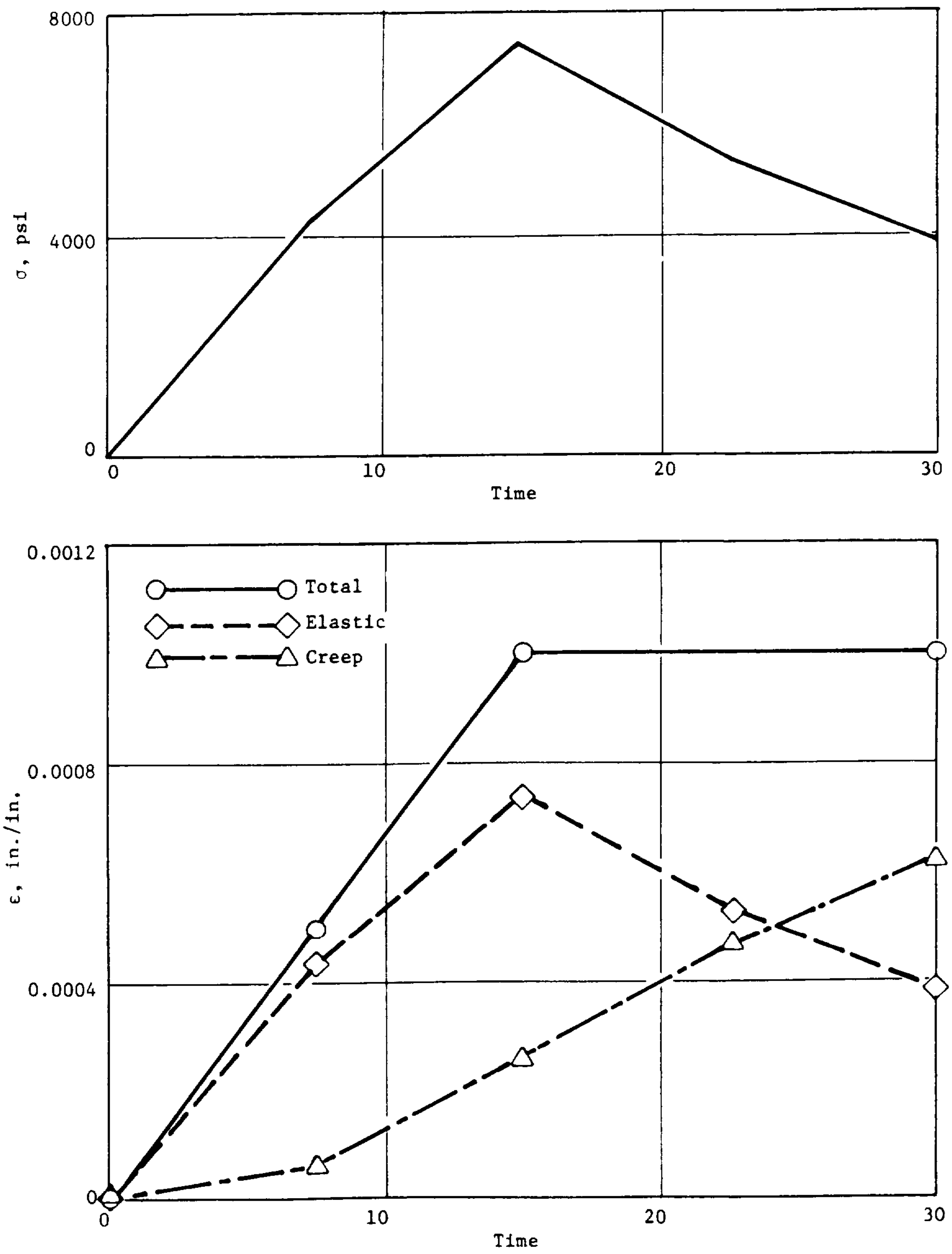

Figure 4. Strain Controlled Creep.

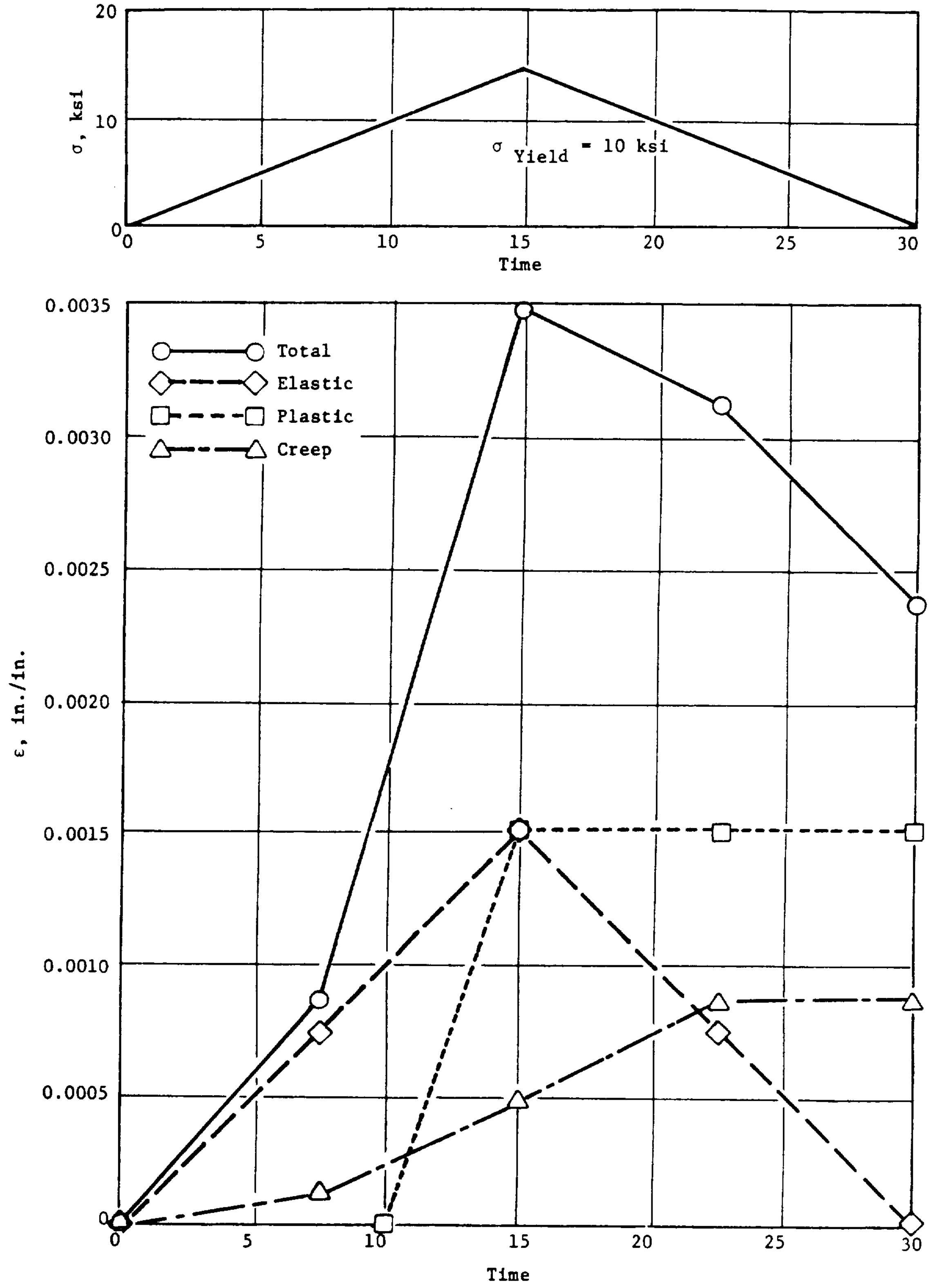

Figure 5. Stress Controlled Cycling with Combined Plasticity and Creep.

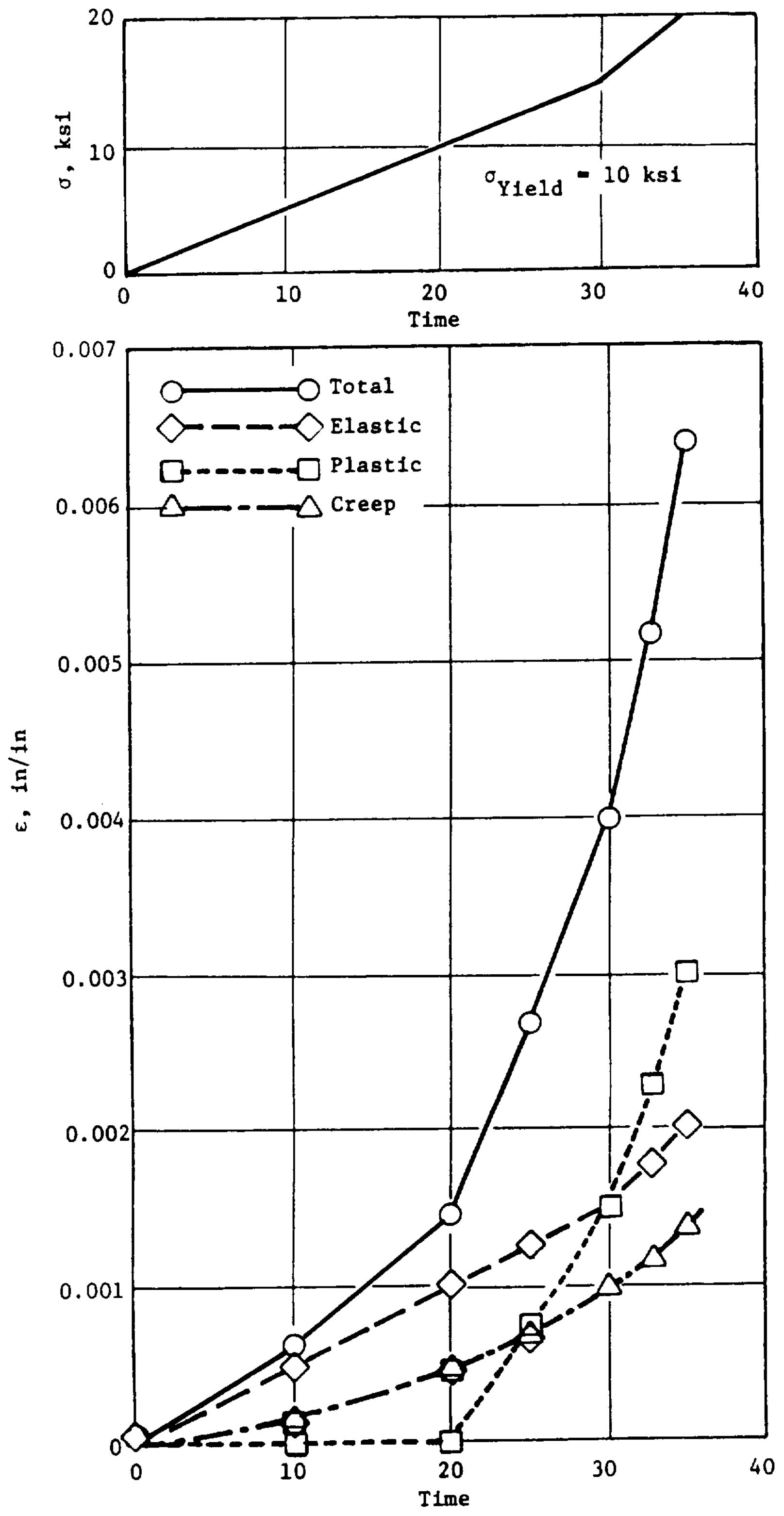

Figure 6. Stress Controlled Combined Plasticity and Creep.

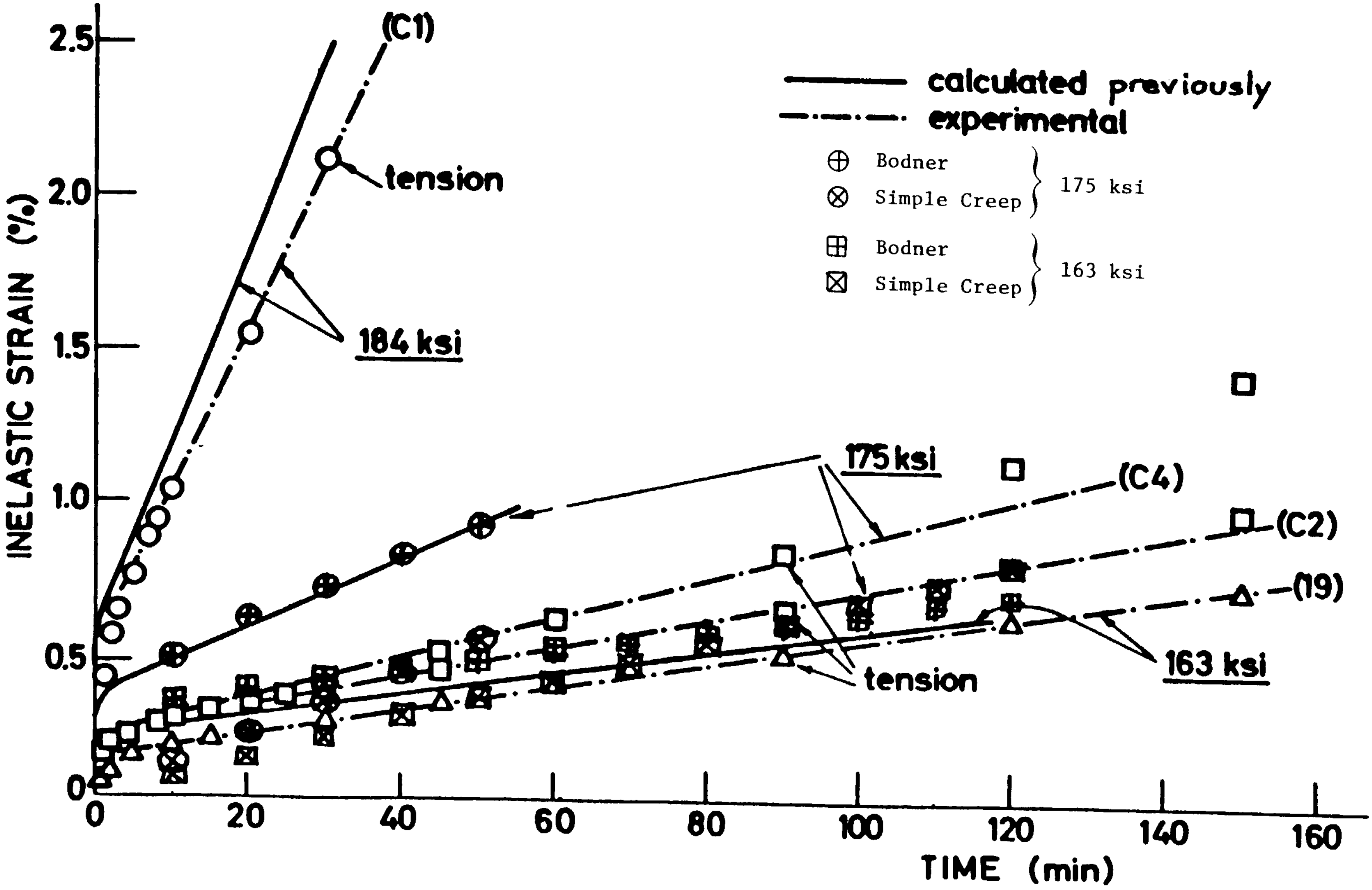

Figure 7. Comparison of Bodner Mode to Simple Creep.