Tensile analyses of creep in plastics using the finite element method

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TENSILE ANALYSES OF CREEP IN PLASTICS
USING THE FINITE ELEMENT METHOD

by

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(Department Chairman)

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Tensile Analyses of Creep in Plastics using the F.E. Method

ABSTRACT

The deformation, stress relaxation, stress recovery, creep rupture, creep buckling, and creep ratchetting aspects of creep are discussed with the emphasis on deformation of a plastic due to a tensile load.

Two problems were run using the ABAQUS Finite Element Program: an axisymmetric steel pressure vessel with elliptical end caps, and a plastic rectangular beam in tension.

The pressure vessel model was used to check the ABAQUS program against the literature. A graphical comparison of the stress results showed that the program showed the proper relationships and magnitudes to confirm agreement.

The plastic rectangular beam problem showed an error less than 10% in total deflection and negligible error in the stress calculations.
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NOMENCLATURE

c C  Creep strain

c C  Creep strain rate

T  Total strain

E  Elastic strain

C ij  Creep strain tensor

σ  Stress

σ e  Equivalent stress

S ij  Stress deviator tensor

T  Temperature (°F or °C) (for superposition °K)

TR  Reference temperature (°K)

A , C  Constants

R  Gas law constant

ΔH  Activation energy

aT  Temperature strain

x(n)  Parameters for optimization

E App  Apparent modulus

t  Time

AT  t/t0 , Time shift factor
I INTRODUCTION

The objective of this work is to learn how to use a finite element program to analyze the creep behavior of plastics. As the study progressed, it was evident that the analysis of plastics is a very difficult subject. The material properties are greatly affected by temperature, molding conditions, time, and the environment. Of these effects, the molding conditions are the most difficult to deal with. If all others remain the same, varying the geometry causes the material properties to change by as much as 50 percent.

One of the reasons for the wide variation in the material properties of plastics used for structural designs is the small reinforcing material (usually glass fibers) which has a tendency to orient itself due to the flow front or the velocity profile. This makes it very difficult to predict the orientation of the fibers for a given mold design. To complicate the subject, if one uses the same geometry and changes the location of the gates in the mold, one gets different fiber orientations.

One of the most obvious examples of the velocity orientation problem is when a rib is being filled in a mold. If the material fills the rib first and then continues to flow to fill the rest of the mold, the random orientation at the root of the rib will now orient itself to the velocity profile near the wall of the mold. If the location of the gate is changed so that the rib finishes filling at the same time as the rest of the mold the random fiber orientation will be preserved.

ABAQUS is a relatively new and powerful nonlinear finite element code with its popularity being passed on by "word of mouth". It appears to be used more in Europe than in the United States. At the start of this project, the objective was to be able to run any geometry and loading condition, but as information from the literature and experience running the ABAQUS finite element program grew, it was evident that this was not going to be possible for a five credit project. Attempting to do a static tensile analysis, problems with iterations and creep slope became road blocks with the program. After considerable work and discussions with many people, I was able to get the program to iterate repeatedly for the tensile problem (15" x 2" x .25" rectangular bar fixed at one end).

For this work, the creep behavior of plastics that can be treated as a homogeneous material will be discussed. This discussion will avoid the load cases that produce bending stress profiles. The reason for avoiding the bending problems is that a model must have many elements through the bending plane because of the dependence of creep on stress level. There is a stress relieving process similar to plasticity going on across the bending plane which must be allowed for. If one was to model a flat plate in bending, one would have to use many solid elements through the thickness. At the present time it does not look cost justifiable to run such a model.
Tensile Analyses of Creep in Plastics using the F.E. Method

II THEORY/LITERATURE REVIEW

When one picks up a book discussing creep, whether it's a general design manual or a reference book, the models usually discussed are the Maxwell and Voight models. The Maxwell model is the spring and dashpot in series and the Voight model is the spring and dashpot in parallel. These models are not adequate to represent the character of real materials. For this reason, the texts usually discuss some combinations of these two models which allow more flexibility in characterizing the response of real materials.

The time dependence of real material properties can best be understood by studying Figures 1 thru 5. The primary and secondary stages of creep only, will be used for the analytical portion of this work.

Figure 1 shows that in a very short time (less than one hour for plastics) from initial loading, the strain rate goes from a very steep rate to a modest rate with the temperature held constant. The next observation that one could make is that the modest rate stays constant during what is called the second stage of creep. The third stage is identified by the increasing strain rate to failure.

Figure 2 shows how a typical creep curve would change if it were plotted starting at different initial stress levels, while holding the temperature constant. This figure shows that the strain rate increases and the time to rupture decreases with increasing initial stress.

Figure 3 shows that the stress caring capacity of the material goes up the faster the load is applied.

Figure 4 shows that the strain rate increases and the time to rupture decreases if the stress is held constant and the initial temperature is increased.

Figure 5 shows the typical way creep rupture data is plotted for determining time to failure.

There are many different concerns that must be discussed before one can decide what aspect of creep one should be concerned with. The creep deformation problem is the one that will be discuss in some depth. Stress relaxation, stress recovery, creep rupture, creep buckling, and creep ratchetting will be discussed briefly at the end of this section.

From ones observations of Figures 1 thru 5 it is seen that the creep strain \( \epsilon^c \) is a function of stress, temperature and time and can be represented by the following relationship

\[
\epsilon^c = F(\sigma, T, t) \tag{1}
\]

where the effects of stress, temperature and time are treated as separable. Treating these terms as separable allows one to sum the effects of many terms.

When the data for Figures 1 thru 5 were taken, the stress and/or temperature were constant. Most problems require variable stress and temperature, so it appears that one has two choices for
handling this formulation[7]*:

1. State Formulation: The response of the material depends on the present state explicitly.

2. Memory Theory: The material remembers its past explicitly and responds to the present in a manner that reflects its past history.

The majority of the literature, especially that written for numerical work, uses the State Formulation idea.[1]

For this study, the State Formulation and the following form of creep relation (Bailey-Norton Law) [7] [2] were chosen:

\[ \varepsilon_c = A \sigma^m t^n \]  \hspace{1cm} (2)

where "A" "m" and "n" are constants that are functions of temperature. "A" and "m" are positive and "n" is a fraction (with the Abaqus Finite Element program a further restriction on "n" is that (n-1) be in the range -1 < (n-1) ≤ 0). This law is only good for modeling primary and secondary creep because the function adding tertiary creep would be a doubly curved function, for which a variable raised to a power shows poor correlation.

There are other equations forms that could be used if necessary or one could add more terms to the equations to better correlate the data. Some of these equations are shown on page 5.

In a variable stress problem, the interest is in the slope of the strain, or the strain rate. If the derivative of the Bailey-Norton Law, Eq. 2, is taken with respect to time, but the time derivative of stress is not considered (one of the shortcomings of the State Formulation method) the following relation is

\[ \varepsilon_c = \frac{\partial \varepsilon_c}{\partial t} = A \sigma^m n t^{n-1} \]  \hspace{1cm} (3)

which is known as the time hardening method[7]. Because the stress derivative was not taken, this limits the solution to stress changes of long duration.

If the Bailey-Norton equation is solved for time and substituted into the above equation, the resulting equation is the so called strain hardening equation[7].

\[ \varepsilon_c = A^{1/n} n \sigma^{m/n} (\varepsilon_c^{(n-1)}/n) \]  \hspace{1cm} (4)

Even though equations (3) and (4) are derived from the same equation, the solution will be different because of the procedural differences in the way one steps through the stress changes. The graphic representation of the time hardening method is shown in Figure 6 and the strain hardening method is shown in Figure 7. For ease in seeing the difference, Figure 8 is a

*Numbers in square brackets refer to the References on page 32.
superimposed view of Figure 7 on Figure 6. As one can see, using the same stresses applied at the same time can leave one at two different end points depending on which hardening method one chooses. The question then becomes which one should one use? From the statements in the available literature, the strain hardening equation more closely matches the experimental data, but the time hardening equation is easier to deal with and seems to converge more rapidly in the finite element programs.[7]

The first and most important step in starting to do an analysis of a structure in the time domain is to get creep or relaxation data on the material of interest. If one wanted to predict what the stress or deflection would be in say 3 years, one would have to take 3 years worth of data. This is not convenient, so many authors recommend taking creep data for short time frames, but at many different temperatures. This temperature data can then be superpositioned using one of the time temperature superposition relations to construct a base curve. The two superposition equations that are popular are the W-L-F equation and the Arrhenius equation. The W-L-F equation was developed for regions above the glass transition temperature but can be used if it fits ones data.

\[
 \log_{10} A_T = \frac{-8.86 (T - T_R)}{101.6 + T - T_R} \tag{5}
\]

The Arrhenius equation can be used for representing the creep data below the glass transition temperature.

\[
 \ln A_T = \frac{\Delta H}{R (T - T_R)} \tag{6}
\]

Now that the creep data is available, it has to be fit to some equation type so it can be used in a numerical solution scheme. Creep strain means strain due to creep only, so the first thing that needs to be done is to take the static deflection out of the data. Next one has to fit the data to an equation form like the ones shown below. These equations have been tried by different experimentalists to match their data and are listed here as a starting point for one to begin. These were obtained from a study to show the degree of correlation of the different equations to the same test data. The first two were also referenced by another study representing polypropylene and polyethylene.
\[ \varepsilon^c = A \sigma^m t^n \quad [14] \quad \text{polypropylene} \] (7)

\[ \varepsilon^c = \sigma^m \sinh^{-1} C t^n \quad [14] \quad \text{polyethylene} \] (8)

\[ \varepsilon^c = \sigma^m \tan^{-1} C t^n \] (9)

\[ \varepsilon^c = \sigma^m \varepsilon_{ct} \] (10)

\[ \varepsilon^c = \sigma^m e^{ct} \] (11)

To finish the description of the behavior of plastic materials, a short discussion on stress relaxation, stress recovery, creep rupture, creep buckling and creep ratchetting will follow.

Stress relaxation is the phenomenon that occurs when the displacement, after load application, is held constant. In this case because of the creep, the material no longer exerts the same force because the molecular chains have actually slipped with respect to each other causing the stress to relieve.

Stress recovery is the opposite type of problem. After some period of time with a constant force applied, the force is suddenly released and the material tries to return to it's original position but it doesn't do it instantaneously. A typical stress recovery problem is shown in Figure 9. This figure shows that as long as one does not strain the part beyond the "zero point" of either the load or the unload curve, these curves should be shifted along the time axis to identify the response. As shown at point e, the "zero point" has been exceeded for the unload curve so the unload starts over with a new "zero point" reference defined.

Creep rupture is the study of the material in the tertiary stage (third stage). Because the material is very unstable in this range, usually a curve such as the one shown in Figure 10 is used to predict failure.

Fatigue of materials at elevated temperature is a complicated problem. For plastics this can be serious at room temperature. The problem here is the interaction between deterioration due to fatigue and the fact that creep rupture occurs at any hold time that occurs in loading cycles. In this type of creep one has to be careful to distinguish between continuous cycles, cycling with hold times during which creep occurs, and cycling with hold times where relaxation occurs. The main point to remember is that more damage is done the longer the load is held at higher stresses.

Creep ratchetting is what happens when a material has a sustained mechanical load and a cyclic temperature load is applied. This response occurs if the yield point of the material is exceeded. Instead of plastically yielding and returning to an elastic response, an increment of plastic strain
occurs during each cycle. This creep ratcheting also can occur with a load such that tension is sustained with a fluctuating bending load superimposed. In these cases the material actually changes size or shape each cycle.

Creep buckling is a phenomenon that causes the buckling to occur at some critical time after the load is applied instead of instantaneously.
III  **FINITE ELEMENT METHOD FOR CREEP**

It is difficult to find solutions to creep problems using the techniques of direct integration and finite differences. One reason for this might be that as the analysts started to become interested in creep problems in the early 1970s, the finite element method was a natural for handling this type of problem.

The finite element method can be based on a displacement function or a force function. The commercially available programs are mainly displacement based. The aircraft and aerospace industries usually use a program based on a force function to obtain better accuracy on stresses. The displacement function can be any function that leads to a square stiffness matrix which can be inverted. If polynomials are used, the greater the number of terms included in the expression, the closer the solution will be to the exact solution.

The equation that represents the total strain as the sum of the elastic strain, the creep strain, and the temperature strain is:

\[
\{\varepsilon^T\} = \{\varepsilon^E\} + \{\varepsilon^C\} + \{\varepsilon^T\}
\]  

(12)

The procedure that is taken in using the finite element method to solve for total strain is as follows:[7]

Step 1: Let \(\{\varepsilon^C\}\) due to creep at time zero equal 0. This gives the displacements and stress at the start of the run.

Step 2: Make the assumption that the stresses remain constant over a small interval of time and calculate the delta strain due to creep. The stress deviator tensor is used instead of the stress tensor because creep experimental data has been shown to be independent of the hydrostatic pressure. The effective stress \(\sigma_e\) and strain \(\varepsilon_e\) are brought into the equation so that formulation will reduce to the correct uniaxial case.

\[
\Delta \varepsilon_{ij}^C = (3/2) \left( \frac{d \varepsilon_e^C}{dt} \right) \left( \frac{S_{ij}}{\sigma_e} \right) \Delta t
\]  

(13)

\[
\varepsilon_{e}^C = \varepsilon_{e}^C(\sigma_e, T, t)
\]  

(14)

Step 3: Use the creep strain increments in step 2 to calculate the new strains at the end of the time interval.

\[
\varepsilon(t + \Delta t) = \varepsilon(t) + \Delta \varepsilon_{ij}^C
\]  

(15)

Step 4: Find the stresses and compare them with the stress at time \(t\). If they are bigger than some preset percentage, repeat steps 2 and 3 with a smaller increment of time.
Step 5: If the stresses are smaller than the preset percentage, then add the results and begin another time increment and repeat steps 2 and 3. Continue this process until the end of the time interval has been reached or until steady state has been achieved.

Appendix V is a copy of the ABAQUS input and output. Cards 3, 4, 35, and 57 to 76 on page 54 are the only ones different from a regular statics run.

Cards 3 and 4 are used to set the initial conditions for the model. The temperature option is the important one that should always be considered for plastics, because the materials are temperature dependent. This problem was run at constant temperature so the other cards that need to be added are not necessary in this problem. ABAQUS makes it very easy to handle temperature changes because one just makes the changes as a new time step when they occur.

Card 35 is used to select either the internally supplied creep law, or ones own fortran written creep law. The creep law used for this run is shown on the page 74. There are 3 sections to the computer output, each one starts numbering with page one. The user written subroutines are placed in their own section (section 2) and for this problem it is only one page long. This creep law subroutine is input as a separate record when one submits ones job. Parameters are transferred by a common statement within the program to ones user written creep law, and are identified on page 11 of this report.

Card 57, on page 55, identifies the start of time after the static initial conditions have been calculated. It allows one to change the default maximum number of increments in a time step, which was changed to 200 from the default of 10. One can also change the default number of recycles (iterations) within an increment. It was changed from 6 to 50 in this problem, but was not necessary once the problem was well defined. Card 58 is the title for this time step.

Cards 59 and 60 are the critical cards that tell the program a creep problem is being run. The title of this card, visco, makes this time step different from a dynamic, frequency, or temperature problem. The PTOL parameter controls the accuracy of the equilibrium equations at each increment and should be set at least two orders of magnitude lower than the load.[2] The MTOL parameter has the same effect as PTOL but is applied to moments. The CETOL parameter controls the accuracy of the creep integration. This value should be set to the maximum difference in the creep strain increment calculated for the creep strain rates based on the conditions before and after the time increment. This is usually calculated by dividing an acceptable stress error by a typical elastic modulus.[2] Card 60 then inputs four time values in the following order, the suggested initial time increment, the total time period for this step, the minimum time increment allowed and a maximum time increment allowed.

Cards 61 to 65 control the output one wants and how often. For creep work I recommend using a large number for the frequency of printing the output, such as 50 as shown in this example,
or one will end up with stresses and displacements for every time increment. Card 66 defines the end of the time step.

Cards 67 to 76 are the same as cards 59 to 66 but card 70 changes the time parameters discussed for card 60 for the next time step.

The data shown on pages 54 to 73 of the input section are printouts of ones input deck in a more readable table format. The data shown on pages 75 to 133 of the output section is the displacement and stress data separated into time steps. The last four pages are the summary of resources used, and the dayfile printed for this job by the cyber 175 computer.
IV AN APPLICATION TO PLASTICS

My first problem was to get experience running the program and verify it against some work in the literature. The only example run using the finite element method, that showed any results, was a steel pressure vessel study of three geometry configurations of the end bells.[5] My model of the problem was very expensive to run and cost $420 per run (18 sec. of CPU time on a cyber 176 with Control Data Corp.).

I chose the ellipse shape and used a fortran program shown in Appendix III to write the node locations cards for input into the ABAQUS program. To verify that ABAQUS was giving the correct results, I compared the graphic results from the literature (Figure 11) to the graphic results from ABAQUS (Figure 12). After studying these figures it is seen that the magnitudes and stress profiles are very close. Take for example the 3 hour stress contour curve shown in Figure 11 compared to the step 3 stress contour curve of Figure 12. The 785 psi. stress level in Figure 11 comes in from the outer surface away from the end cap, to the inner surface and humps out again at the start of the ellipse. Stress contour #7 of Figure 12 does the same thing and is labeled as a stress of 800 psi., which is only a 2% error in magnitude. From this graphic comparison, I made the assumption that the model was correct and ABAQUS was capable of handling the creep problem.

The second problem chosen for analysis was a 15 in. long by 2 in. high by .25 in. thick plastic rectangular bar fixed at one end and tension loaded at the other. Creep data for the material of interest is shown in Figure 13. The creep strain curves shown in Figure 14 are the result of removing the static deflection data from the creep data of Figure 13.

After looking at equation types 1 thru 5 on page 5, the equation type 1 best fit the data and was easier to work with. Because one term was not accurate enough for the 0 thru 10 hour time span of concern, a second term was added and an optimizer routine called OPTIVAR was used to find a best fit for the exponents of the equation. The input to OPTIVAR is show in Appendix I.

The OPTIVAR program was chosen because it was the only program readily available at Xerox to use for determining the exponents to a non-linear equation. The non-linear regression routines in the fortran libraries are set up for polynomials with constant exponents.

The creep data feed into OPTIVAR is from the curves shown in Figure 14. OPTIVAR calculated the coefficients that are shown by the following equations.
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\[ e^C = A_1 \sigma^{m_1} t^{n_1} + A_2 \sigma^{m_2} t^{n_2} \]  
\[ e^C = x(1) \sigma^{x(2)} t^{x(3)} + x(4) \sigma^{x(5)} t^{x(6)} \] (16) (17)

These two equations are the same. The first one is in standard notation and the second is showing the term for term substitution directly under the first. For example, \( x(1) \) is \( A_1 \); \( x(2) \) is \( m_1 \) and so on.

Output from OPTIVAR is shown in Appendix II and the results are repeated here:

\[ \begin{align*}
x(1) &= .79628 \times 10^{-7} \\
x(2) &= .98856 \\
x(3) &= .32006 \\
x(4) &= .74506 \times 10^{-8} \\
x(5) &= .11685 \times 10^1 \\
x(6) &= .29094
\end{align*} \]

The ABAQUS finite element program requires input of the creep strain rate. The obvious step was to differentiate equation 16 and input it into the program. This didn’t work. The program was having trouble stepping away from time zero.

Bengt Karlson and E. Sorensen (authors of ABAQUS) recommended letting the subroutine calculate the strain rate for each delta time step, which resulted in the same equation but in incremental notation, as input to ABAQUS.

\[ \Delta e^C = \left\{ A_1 \left[ \sigma^{m_1} (t + \Delta t)^{n_1} + A_2 \sigma^{m_2} (t + \Delta t)^{n_2} - \epsilon(t) \right] / \Delta t \right\} \] (18)

For the above equation, the ABAQUS parameter labels for the user written subroutine (shown on page 74 in Appendix V) are as follows:

\[ \Delta e^C = \text{ERATE} \quad \sigma = \text{SINV2} \quad t = \text{TIME} \quad \Delta t = \text{DTIME} \quad \epsilon(t) = \text{EQUIVE} \]

This helped but there was still a problem getting the program to step away properly from zero time. The solution finally was to take a very small time step away from zero and then iterate to the final time in a second time period. This worked well and the 750 pound load case input to ABAQUS is shown in Appendix V. The graphical results for the 500 pound load cases is shown in Appendix IV. The only reason Appendix IV and V are not of the same load case is for ease of copying. The 750 pound load case could be read after copying.
V  DISCUSSION OF RESULTS

The hand calculation for the static results at time zero were calculated by the equations:

\[ \delta = \frac{PL}{AE} = \frac{P(15)}{(.5)(363000)} \quad (19) \]

\[ \sigma = \frac{P}{A} = P/.5 \quad (20) \]

The apparent modulus \( E_{App} \) for the 10 hour creep hand calculation were calculated by going to Figure 13 at the 10 hour point for the three different stresses and using the following relation:

\[ E_{App} = \frac{\text{stress}}{\text{total strain after 10 hr.}} \quad (21) \]

The results for the three stress cases are shown in Table I.

The apparent modulus was then substituted in for \( E \), in equation 19, and the deflection after 10 hours was calculated. The results of the three load cases at two different times are shown in the following Table II.

\begin{table}
\begin{center}
\textbf{TABLE I}
PLASTIC BAR IN TENSION

Total strains after 10 hr.

<table>
<thead>
<tr>
<th>STRESS psi.</th>
<th>STRAIN in/in</th>
<th>( E_{App} ) psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0.0015</td>
<td>333,333</td>
</tr>
<tr>
<td>1000</td>
<td>0.0029</td>
<td>344,827</td>
</tr>
<tr>
<td>1500</td>
<td>0.0044</td>
<td>340,909</td>
</tr>
</tbody>
</table>
\end{center}
\end{table}
**TABLE II**

**PLASTIC BAR IN TENSION**

F.E. vs Hand Calculations

<table>
<thead>
<tr>
<th>LOAD TIME</th>
<th>HAND CALC.</th>
<th>ABAQUS</th>
<th>%CREEP*</th>
<th>%ERROR</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb. hr.</td>
<td>δ in. σ psi</td>
<td>δ in. σ psi</td>
<td>hand abaqus.</td>
<td></td>
</tr>
<tr>
<td>250 0</td>
<td>0.02066 500</td>
<td>0.020633 500</td>
<td>.02066 500</td>
<td>.020633 500</td>
</tr>
<tr>
<td>250 10</td>
<td>0.02250 500</td>
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The error shown in Table II for initial displacement is less than .2% for all three loads. The error for predicting creep displacement was less than 1.8% for all three load cases. This is very good for plate elements used to model a beam. The only reason for using plate elements was in preparation for the next load case of interest, that of bending. Because of the stress relieving nature of creep in bending, this problem would require many elements through the thickness.

The amount of deflection due to creep is represented under the column %CREEP. These results should have been better than this and a possible reason for the error is lack of available creep data below the one hour time frame. The creep rate from initial strain to the one hour point is not clearly defined in the literature. The program needed to start at an initial time increment of 1.6E-09 in order to step away from zero time.

*%CREEP is the amount of displacement due to creep with respect to the static load displacement.
VI CONCLUSIONS & RECOMMENDATIONS

The creep analysis of plastics is an involved and error prone process. The hardest data to find on a plastic is the creep information for the period of time longer than one hour. The testing of a plastic for creep data is not any easier. Because of the large strains over time, one needs two methods of recording the displacement, a very sensitive device for taking the reading for less than one hour, and a method of recording the displacements after a month or year. One then has to take the readings over many different stress levels and temperatures.

The next problem is that structural plastics are usually non-isotropic. This means the data has to be recorded in different directions, at different densities, for many fiber concentrations and orientations.

If the material is non-isotropic, the next step is to run an analysis assuming isotropic behavior and study the stress results to determine how the part is behaving. For the next run, place the correct material properties in the areas identified (flexural if bending or tensile if tension, 30% glass filled etc.).

I would recommend using the finite element approach for isotropic constant stress profile problems such as pressure vessels and tensile applications. To use the finite element method for bending problems one needs to use high order elements and use more elements across the plane of bending.

For a complicated casting one would have to use many solid elements through the thickness. To keep a decent aspect ratio, the model would end up being too large, and therefore costly, to run.

Before attempting to do problems that involve bending, one should look carefully at the stress profiles and make sure the finite element technique handles this problem correctly.
Tensile Analyses of Creep in Plastics using the F.E. Method

TYPICAL CREEP CURVE

Figure 1

---

1. Primary stage 1
2. Secondary stage 2
3. Tertiary stage 3

strain

time

$e_o$
TYPICAL CREEP DATA
STRAIN vs. TIME
Constant Temperature [7]

Figure 2
TYPICAL CREEP DATA
STRESS vs. STRAIN
Constant Temperature [7]
Figure 3

stress

strain
Tensile Analyses of Creep in Plastics using the F.E. Method

TYPICAL CREEP DATA
STRAIN vs. TIME
Constant Stress
Figure 4

increasing Temperature

Stress = Const.
TYPICAL CREEP DATA
STRESS vs. RUPTURE TIME [7]

Figure 5

typical creep data
stress vs. rupture time
Tensile Analyses of Creep in Plastics using the F.E. Method

TIME HARDENING [7]
Figure 6

Creep Strain

Stress

Time
STRAIN HARDENING [7]
Figure 7

Creep Strain

Stress

Time
COMBINATION OF Figure 6 & 7

Figure 8
Tensile Analyses of Creep in Plastics using the F.E. Method

STRESS RECOVERY [7]
Figure 9

creep strain
creep strain
creep strain +

0.
0.
time

0.

Figure 9
CREEP RUPTURE [7]
Figure 10
Tensile Analyses of Creep in Plastics using the F.E. Method

END BELLS LITERATURE RESULTS [5]

Figure 11

Fig. 13. Idealization of the pressure vessel with an elliptical end closure. P. 388

Fig. 16. Effective stress contours at time = 0 for the pressure vessel with an elliptical end closure. P. 38

Fig. 19. Effective stress contours at time = 3.0 hours for the pressure vessel with an elliptical end closure. P. 39
END BELLS ABAQUS RESULTS

Figure 12
Tensile Analyses of Creep in Plastics using the F.E. Method

Figure 12 cont.

END BELLS ABAQUS RESULTS
Tensile Analyses of Creep in Plastics using the F.E. Method

END BELLS ABAQUS RESULTS

Figure 12 cont.

END BELLS ABAQUS RESULTS

Figure 12 cont.
Tensile Analyses of Creep in Plastics using the F.E. Method

FLEXURAL CREEP AT 73 deg. F for Lexan FL-900 resin* [12]

Figure 13

*1/4 wall thickness, 1.0 specific gravity [12]
Figure 14

CREEP STRAIN

- 1000 psi
- 1500 psi
- 500 psi

creep strain
1x0.001

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.001377 static strain at 500 psi
.002755 static strain at 1000 psi
.004132 static strain at 1500 psi
Tensile Analyses of Creep in Plastics using the F.E. Method

REFERENCES


Tensile Analyses of Creep in Plastics using the F.E. Method

INPUT TO OPTIVAR
APPENDIX I
Tensile Analyses of Creep in Plastics using the F.E. Method

DIMENSION X(5),XSTRT(6),RMAX(6),RMIN(6),PHI(1),PSI(1),W(48)
N=6
NCONS=0
NEQUS=0
NPENAL=5
DATA RMAX/1.,1.,1.,1.,1.,1./
DATA RMIN/-1.,-1.,-1.,-3.,-3.,-3./
DATA XSTRT/.0000000, .977,.33709,.000000077,.977,-1.100/
CALL SEEK(N,NCONS,NEQUS,NPENAL,RMAX,RMIN,XSTRT,X,PHI,PSI,NVIOL,1W)
CALL ANSWER(U,NCONS,NEQUS)
STOP
END
SUBROUTINE UREAL(X,U)
REAL X(1),ECRH(5),ECRM(6),ECRL(6)
EH2= .0001678
EH3= .0002678
EH4= .0006178
EH5= .001318
EM2= .000452
EM3= .000452
EM4= .0003952
EM5= .0008452
EM6= .0015452
EL2= .0000226
EL3= .0001226
EL4= .0002226
EL5= .0004226
EL6= .0009226
T=1
DO 10 M=2,5,1
ECRH(M)=X(1)*1580.*T**X(3)+X(4)*1500.*T**X(6)
T=T*10.
10 CONTINUE
T=1
DO 20 N=2,6,1
ECRM(N)=X(1)*1888.*T**X(3)+X(4)*1888.*T**X(6)
T=T*10.
20 CONTINUE
T=1
DO 30 I=2,6,1
ECRL(I)=X(1)*58B.*T**X(3)+X(4)*500.*T**X(6)
T=T*10.
30 CONTINUE
U1=((EH2-ECRH(2))**2+(EH3-ECRH(3))**2+(EH4-ECRH(4))**2+
C(EH5-ECRH(5))**2)*.5*2
U2=((EM2-ECRM(2))**2+(EM3-ECRM(3))**2+(EM4-ECRM(4))**2+
C(EM5-ECRM(5))**2+(EM6-ECRM(6))**2)*.5*2
U3=((EL2-ECRL(2))**2+(EL3-ECRL(3))**2+(EL4-ECRL(4))**2+
C(EL5-ECRL(5))**2+(EL6-ECRL(6))**2)*.5
U=U1+U2+U3
RETURN
END
SUBROUTINE CONST(X,NCONS,PHI)
DIMENSION X(1),PHI(1)
RETURN
END
SUBROUTINE EQUAL(X,PSI,NEQUS)
DIMENSION X(1),PSI(1)
RETURN
END
Tensile Analyses of Creep in Plastics using the F.E. Method

OUTPUT FROM OPTIVAR
APPENDIX II
Tensile Analyses of Creep in Plastics using the F.E. Method

**DIRECT SEARCH OPTIMIZATION USING SEEK WITH PENALTY FUNCTION OPTIM5**

**INTERMEDIATE OUTPUT EVERY IPRINT(TH) CYCLE.**

**IPRINT = 1**

**INPUT DATA IS PRINTED OUT FOR IDATA=1 ONLY.**

**IDATA = 1**

**NUMBER OF INDEPENDENT VARIABLES**

**N = 6**

**NUMBER OF INEQUALITY (.GE.) CONSTRAINTS**

**NCONS = 0**

**NUMBER OF EQUALITY CONSTRAINTS**

**NEQUS = 0**

**FRACTION OF RANGE USED AS STEP SIZE**

**F = 9.99999998E-02**

**STEP SIZE FRACTION USED AS CONVERGENCE CRITERION.**

**G = 9.99999998E-02**

**MAXIMUM NUMBER OF MOVES PERMITTED**

**MAXM = 300**

**PENALTY FUNCTION USED IS OPTIM5**

**TOLERANCE ON CONSTRAINTS.**

**ZERO = 1.00000000E-09**

**STOPPING TOLERANCE FOR FINAL optimum.**

**TOL = 1.00000000E-04**

**PENALTY MULTIPLIER.**

**R = 1.800008888E+81**

**ESTIMATED UPPER BOUND ON RANGE OF X(I).**

**RMAX(I) =**

-1.00000000E+01 .10000000E+01 .10000000E+01 .10000000E+01 .10000000E+01 .10000000E+01

**ESTIMATED LOWER BOUND ON RANGE OF X(I).**

**RMIN(I) =**

-1.00000000E+01 -1.00000000E+01 -1.00000000E+01 -3.00000000E+01 -3.00000000E+01

**STARTING VALUES OF X(I).**

**XSTRT(I) =**

0.88888888E-07 .97777777E+00 .33709000E+00 .77000002E-08 .97777777E+00 .11000000E+01

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### Tensile Analyses of Creep in Plastics using the F.E. Method

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Tensile Analyses of Creep in Plastics using the F.E. Method

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END BELL
FORTRAN PROGRAM FOR
GRID LOCATION
APPENDIX III
Tensile Analyses of Creep in Plastics using the F.E. Method

Real $A, B, TH, X, Y, Q$
Integer $R$

$Q = 0.011375$
$A(1) = 0.159$
$B(1) = 0.1124$

$TH(1) = 180$
$TH(2) = 174$

$I = 1$
$I \leq 8$
$I = I + 1$

$A(I + 1) = A(I) + Q$
$B(I + 1) = B(I) + Q$

$I = 1$
$I \leq 16$
$I = I + 1$

$TH(I) = (TH(I))^{TT/180}$

$R = 0$

$I = 1$
$I \leq 16$
$I = I + 1$

$R = R + 17$

Write $R, A(K)$

$R = R + 16$

$K = 1$
$K \leq 9$
$K = K + 1$

STOP

$J = 1$
$J \leq 16$
$J = J + 1$

$X = \frac{1}{B(K)} + \left(\frac{\tan^2(TH(J))}{A(K)}\right)^{\frac{1}{2}}$

$Y = x \tan(TH(J))$

Write $R + J, X, Y$
Tensile Analyses of Creep in Plastics using the F.E. Method

REAL A(9), B(9), TH(16), X, Y, Q
INTEGER R
Q = 0.11375
A(1) = .159
B(1) = .1124
DO 10 I = 1, 8, 1
  A(I+1) = A(I) + Q
  B(I+1) = B(I) + Q
TH(1) = 180
TH(2) = 174
TH(3) = 170
TH(4) = 165
TH(5) = 158
TH(6) = 151
TH(7) = 144
TH(8) = 136
TH(9) = 130
TH(10) = 124
TH(11) = 116
TH(12) = 111
TH(13) = 106
TH(14) = 101
TH(15) = 97
TH(16) = 94
DO 60 I = 1, 16, 1
  TH(I) = TH(I) * 3.1416 / 180
R = 0
DO 30 K = 1, 9, 1
  DO 20 J = 1, 16, 1
    X = ((1/(1/B(K)**2 + (TAN(TH(J))**2)/(A(K)**2)))**0.5)*(1. - 2.)
    Y = TAN(TH(J))*X
  WRITE(6, 40) R + J, X, Y
  40 FORMAT (I3, ' ', F7.5, ' ', F6.5, ' ', 8)
  20 CONTINUE
R = R + 17
WRITE(6, 50) R, A(K)
  50 FORMAT (I3, ' ', '0', ' ', F6.5, ' ', 0)
R = R + 16
RETURN
END
Tensile Analyses of Creep in Plastics using the F.E. Method

PLASTIC BAR
GRAPHICAL RESULTS
500 POUND LOAD
APPENDIX IV
Tensile Analyses of Creep in Plastics using the F.E. Method
Tensile Analyses of Creep in Plastics using the F.E. Method

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STATIC DEFLECTION

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Tensile Analyses of Creep in Plastics using the F.E. Method
Tensile Analyses of Creep in Plastics using the F.E. Method
Tensile Analyses of Creep in Plastics using the F.E. Method
Tensile Analyses of Creep in Plastics using the F.E. Method

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CREEP DEFLECTION

STEP 3  INCREMENT 34
Tensile Analyses of Creep in Plastics using the F.E. Method
PLASTIC BAR
ABAQUS INPUT & OUTPUT
750 POUND LOAD
APPENDIX V
Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method

A B A J U S

THIS PROGRAM HAS BEEN DEVELOPED BY

MISSOTT, KARLSSON & SURENSEN, INC.
35 SOUTH ANGELL STREET
PROVIDENCE, R.I. 02906

FOR ASSISTANCE OR ANY OTHER INFORMATION CALL
401-961-0920
Tensile Analysis of Creep in Plastics using the F.E. Method

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**ABASUS INPUT**

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**CARD 1**
* T: 3600 T: 360 T: 360
* C: 0.001 C: 0.001 C: 0.001
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**CARD 20**
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**CARD 30**
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**CARD 70**
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**CARD 80**
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DATE 03/04/97  TIME 15:23:51  PAGE 2
Tensile Analysis of Creep in Plastics using the F.E. Method

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Tensile Analysis of Creep in Plastics using the F.E. Method
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Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method
### Tensile Analysis of Creep in Plastics using the F.E. Method

#### Creep Analysis Description

**Material** - FOR ELSET EAD

**Plastic**
- **Young’s Modulus**: 1030000
- **Density**: 1.333

#### Creep - ELECTRIC GENERATION with CREEP LAM DEFINED in USER SUBROUTINE

#### Element Sets

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### Text:

**Tensile Analysis of Creep in Plastics using the F.E. Method**

[Further text and mathematical equations are present, but not fully legible in the scanned image.]
Tensile Analysis of Creep in Plastics using the F.E. Method

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Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method

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Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method

STEP 2: STATIC ANALYSIS

ZERO TIME

FIRST TIME INCREMENTS
TIME INCREMENT IS 1.00
TIME UNITS IS 1.00

THE CONVERGENCE TOLERANCE MEASURED ARE -
TOLERANCE ON INCREMENTAL FORCE COMPONENTS 0.00
TOLERANCE ON INCREMENTAL MOMENT COMPONENTS 0.00

THE MINIMUM NUMBER OF INCREMENTS IN THIS STEP IS 10
THE MAXIMUM NUMBER OF ITERATIONS PER INCREMENT IS 1

THE RESPONSE IN THIS STEP IS LINEAR WITH THE STIFFNESS MATRIX PONDER DURING THE FIRST INCREMENT
ENERGY PRINTOUT FLAGGED FOR EVERY 1 INCREMENTS OF THIS STEP

ELEMENT PRINT

THE FOLLOWING IS PRINTED FOR EACH END AT EVERY 1 INCREMENT

STRESS COMPONENTS
STRESS INVARINATS
TOTAL STRAIN COMPONENTS
PLASTIC STRAIN COMPONENTS
CREEP STRAIN COMPONENTS
TOTAL INPLASTIC STRAIN
ENERGY DENSITIES

NODE PRINT

THE FOLLOWING IS PRINTED FOR EACH NODE AT EVERY 1 INCREMENT


**Tensile Analysis of Creep in Plastics using the F.E. Method**

**TOTAL DISPLACEMENTS**

**RELATIVE FORCES**

**CURRENT MAGNITUDE OF CONCENTRATED LOADS**

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**BOUNDARY CONDITIONS**

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**CONCENTRATED LOADS**

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TENSILE BEAM IN CREEP 1500 PSI

STEP 2 VISCO ANALYSIS

CREEP 0 TO 1.0E-27 HOURS

AUTOMATIC TIME CONTROL. WITH -
A SUGGESTED INITIAL TIME INCREMENT OF 1.000E-09
AND A TOTAL TIME PERIOD OF 1.000E-12
THE MINIMUM TIME INCREMENT ALLOWED IS 1.000E-07
THE MAXIMUM TIME INCREMENT ALLOWED IS

THE SIZE OF THE TIME INCREMENT IS CONTROLLED AT -
THE PARAMETER C10132 1.377E-05

THE CONVERGENCE TOLERANCE MEASURES ARE -
TO LEASE ON INDIVIDUAL FORCE COMPONENTS 2.20
TO LEASE ON INDIVIDUAL MOMENT COMPONENTS 3.33

THE MAXIMUM NUMBER OF INCREMENTS IN THIS STEP IS 200
THE MAXIMUM NUMBER OF ITERS PER INCREMENT IS 50

ENERGY PRINTOUT SWITCHED FOR EVERY 50 INCREMENTS OF THIS STEP.

ELEMENT PRINT

THE FOLLOWING IS PRINTED FOR ELSET END AT EVERY 50 INCREMENT

STRESS COMPONENTS
STRESS INVARINTS
TOTAL STRAIN COMPONENTS
PLASTIC STRAIN COMPONENTS
CREEP STRAIN COMPONENTS
TOTAL INELASTIC STRAINS
ENERGY DENSITIES
**Analysis of Creep in Plastics using the F.E. Method**

**Node Print**

The following is printed for resets ALL at every 450 increment:

**Total Displacements**

**Reaction Forces**

**Current Magnitude of Concentrated Loads**

### Boundary Conditions

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### Concentrated Loads

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Tensile Analysis of Creep in Plastics using the F.E. Method

STEP 3 VISCO ANALYSIS

Creep 1.3x10^-7 to 10 days

Automatic Time Control with:
- A suggested initial time increment of 1.00E-04
- A total time period of 16.0
- The minimum time increment allowed is 1.00E-14
- The maximum time increment allowed is 10.0

The size of the time increment is controlled by:
- The parameter CTEL 1.00E-05

The convergence tolerance measures are:
- Tolerance on individual force components 0.220
- Tolerance on individual moment components 0.33

The maximum number of increments in this step is 200
The maximum number of iterations per increment is 50

Energy printout flagged for every 50 increments of this step

Element Print

The following is printed for each element at every 50 increments:

Stress Components
Stress Invariants
Total Strain Components
Plastic Strain Components
Creep Strain Components
Total Inelastic Strains
Energy Densities
**Tensile Analysis of Creep in Plastics using the F.E. Method**

**N U D E  P R I N T**

The following is printed for nodes at every 50 increment.

<table>
<thead>
<tr>
<th>TOTAL DISPLACEMENTS</th>
<th>REACTIONS FORCES</th>
<th>CURRENT MAGNITUDE OF CONCENTRATED LOADS</th>
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**BOUNDARY CONDITIONS**

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<th>AMP.</th>
<th>MAGNITUDE</th>
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**CONCENTRATED LOADS**

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Tensile Analysis of Creep in Plastics using the F.E. Method

**Problem Size**

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<td>Number of Degrees of Freedom is</td>
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<td>Minimum first in element</td>
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Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method

**Static Analysis**

User specified increments of 1.00 for a time period of 1.00

**Equilibrium Tolerances** -
- Tolerance on individual force components: 2.00
- Tolerance on individual moment components: 3.00

**Small Displacement Theory Will Be Used**

Maximum number of increments allowed in this step is 10
Maximum number of iterations allowed per increment is 1

Increment number: 1 Attempt number: 1
Time increment = 1.00

Time completed during this step: 1.00, time increment completed is 1.00, fraction of step is 1.00

**Element Output for Elset**

**Element 39 Point 1**

Stress Components:
- 1.500E+03 -5.130E-10 6.21E-09
- Stress Invariants - Times:
  - 1.500E+03 TRESCA 1.500E+03 EQU. PRESS -500.
- Principal Stresses:
  - 5.130E-10 0
  - 1.500E+03
- Total Strain Components:
  - 4.13E-03 -1.33E-03 4.27E-14

**Element 39 Point 2**

Stress Components:
- 1.500E+03 4.94E-10 5.63E-09
- Stress Invariants - Times:
  - 1.500E+03 TRESCA 1.500E+03 EQU. PRESS -500.
- Principal Stresses:
  - 0
  - 4.94E-10 1.33E-10 1.500E+03
- Total Strain Components:
  - 4.13E-03 -1.03E-03 4.27E-14

**Element 39 Point 3**

Stress Components:
- 1.500E+03 -7.49E-10 5.71E-09
Tensile Analysis of Creep in Plastics using the F.E. Method

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STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS

1.500E+03 1.500E+03 EQU.PRESS -500.

-4.50E-12 6.0 1.500E+03
4.132E-03 -1.033E-03 5.63E-14

ELEMENT 30 POINT 4
STRESS COMPONENTS
1.500E+03 5.493E-09 6.29E-09
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS
0. 5.493E-09 1.500E+03
9.132E-03 -1.033E-03 2.61E-14

ELEMENT 40 POINT 1
STRESS COMPONENTS
1.500E+03 1.555E-09 3.601E-09
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS
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9.132E-03 -1.033E-03 2.61E-14

ELEMENT 40 POINT 2
STRESS COMPONENTS
1.500E+03 5.493E-09 2.57E-09
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS
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ELEMENT 40 POINT 3
STRESS COMPONENTS
1.500E+03 8.331E-10 5.569E-09
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS
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9.132E-03 -1.033E-03 5.85E-14

ELEMENT 40 POINT 4
STRESS COMPONENTS
1.500E+03 4.460E-09 4.27E-09
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS
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9.132E-03 -1.033E-03 2.61E-14

ELEMENT 79 POINT 1
STRESS COMPONENTS
1.500E+03 -7.967E-10 -1.324E-09
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS
-7.967E-10 0. 1.500E+03
9.132E-03 -1.033E-03 4.11E-14

ELEMENT 71 POINT 2
STRESS COMPONENTS
1.500E+03 -3.472E-10 -2.114E-09
Tensile Analysis of Creep in Plastics using the F.E. Method

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STEP 1 INCREMENT 1

ELEMENT 101 POINT 1
STRESS COMPONENTS
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS

ELEMENT 102 POINT 2
STRESS COMPONENTS
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS

ELEMENT 103 POINT 3
STRESS COMPONENTS
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS

ELEMENT 104 POINT 4
STRESS COMPONENTS
STRESS INVARIANTS - MISES
PRINCIPAL STRESSES
TOTAL STRAIN COMPONENTS

ELEMENT 117 POINT 1
STRESS COMPONENTS

Creep Analysis

Using the Finite Element Method

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**Method**

**Step 1 Increment 1**

**Time 10.2446**

**Phase**

**Plastic** 0.

**Creep** 0.
**Tensile Analysis of Creep in Plastics using the F.E. Method**

**TOTAL STRAIN COMPONENTS**

<table>
<thead>
<tr>
<th>Element</th>
<th>Strain Components</th>
<th>Principal Stresses</th>
<th>Total Strain Components</th>
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### Tensile Analysis of Creep in Plastics using the F.E. Method

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<table>
<thead>
<tr>
<th>Step</th>
<th>Increment</th>
<th>Load (kN)</th>
<th>Strain (με)</th>
<th>Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.0</td>
<td>0.2</td>
<td>50</td>
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<tr>
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**Tensile Analysis**

**Creep Tests**

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<th>Time: 02:14</th>
<th>Page 7</th>
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<td>Increment</td>
<td>Load (kN)</td>
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<tr>
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<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
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</table>

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**Reaction Forces**

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<tr>
<th>Force (kN)</th>
<th>Direction</th>
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<tr>
<td>10</td>
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<tr>
<td>15</td>
<td>Horizontal</td>
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</tbody>
</table>

---

**Notes:**

- The tests were conducted under controlled environmental conditions.
- The material used was high-density polyethylene.
- Strain readings were taken at regular intervals.
- Stress values were calculated using load data and cross-sectional area measurements.

---

**Conclusion:**

The creep behavior of the tested material met the specified performance criteria. Further research is recommended to explore the long-term effects of creep under varying loads and environmental conditions.
### Tensile Analysis of Creep in Plastics using the F.E. Method

#### Step 1 Increment 1

<table>
<thead>
<tr>
<th>Node</th>
<th>X Component</th>
<th>Y Component</th>
<th>X Component</th>
<th>Y Component</th>
<th>X Component</th>
<th>Y Component</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>-107.3</td>
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<td>92</td>
<td>-179.7</td>
<td>-123.7</td>
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<tr>
<td>174</td>
<td>-179.7</td>
<td>12.72</td>
<td>183</td>
<td>-157.3</td>
<td>-46.01</td>
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#### Concentrated Forces

<table>
<thead>
<tr>
<th>Node</th>
<th>X Component</th>
<th>Y Component</th>
<th>X Component</th>
<th>Y Component</th>
<th>X Component</th>
<th>Y Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>93.75</td>
<td>0</td>
<td>82</td>
<td>187.5</td>
<td>0</td>
<td>123</td>
</tr>
<tr>
<td>184</td>
<td>187.5</td>
<td>0</td>
<td>209</td>
<td>93.75</td>
<td>0</td>
<td>123</td>
</tr>
</tbody>
</table>
Tensile Analysis of Creep in Plastics using the F.E. Method

**TENSILE ANALYSIS OF CREEP IN PLASTICS USING THE F.E. METHOD**

**STEPS**

1. **STEPS**
   - **CREEP** in **1.00E-07 HOURS**

**DISCUSSION**

- **AUTOMATIC CONTROL WITH**: SUGGESTED **INCREMENT** OF 1.00E-08 and a **TOTAL TIME PLANNED** of 1.00E-07.
- **MAXIMUM TIME INCREMENT ALLOWED** is 1.00E-12.
- **MAXIMUM TIME INCREMENT ALLOWED** is 1.00E-07.

1. **THE MAXIMUM DIFFERENCE IN CREEP STRAIN INCREMENT** between the beginning and the end of an increment is 1.377E-09.

2. **THE STEP WILL USE EXPLICIT TIME INTEGRATION (FORWARD DIFFERENCES)**, **SWITCHING TO IMPLICIT INTEGRATION (BACKWARD DIFFERENCES)** IF THIS SEEMS NECESSARY.

- **EQUILIBRIA TOLERANCES**
  - **TOLERANCE** on individual **FORCE COMPONENTS**: 0.20
  - **TOLERANCE** on individual **MOMENT COMPONENTS**: 3.33

- **SMALL DISPLACEMENT THEORY WILL BE USED**

1. **MAXIMUM NUMBER OF INCREMENTS ALLOWED IN THIS STEP IS** 200
2. **MAXIMUM NUMBER OF ITERATIONS ALLOWED PER INCREMENT IS** 50

1. **INCREMENT NUMBER** 1 ATTEMPT NUMBER 1
2. **TIME INCREMENT**: 1.00E-09

**ITERATION 1: CONVERGENCE**

- **MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.**
  - RESIDUAL NODE
    - 1 3.320E-11 164
    - 2 -4.576E-12 44

- **MAXIMUM DISPLACEMENT INCREMENT ASSOCIATED WITH EACH D.O.F.**
  - DISPLACEMENT NODE
    - 1 4.032E-06 205
    - 2 -1.386E-07 169

**TIME COMPLETED DURING THIS STEP**: 1.00E-09, **TIME INCREMENT COMPLETED IS**: 1.00E-09. **FRACTION OF STEP IS**: 1.00E-09.
Tensile Analysis of Creep in Plastics using the F.E. Method

Iteration 1: Convergent Solution

Maximum residuals associated with each D.O.F.:

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum residuals at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.393E-11</td>
</tr>
<tr>
<td>2</td>
<td>-4.857E-12</td>
</tr>
</tbody>
</table>

Time completed during this step: 4.003E-09
Time increment completed is: 2.402E-09
Fraction of step is: 4.003E-09

Total creep time is: 4.003E-09

Iteration 1: Convergent Solution

Maximum displacement increment associated with each D.O.F.:

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum displacement increment at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.339E-06</td>
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<tr>
<td>2</td>
<td>4.540E-08</td>
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</tbody>
</table>

Increment number: 3
Attempt number: 1
Time increment: 3.600E-09

Iteration 1: Convergent Solution

Maximum residuals associated with each D.O.F.:

<table>
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<tr>
<th>D.O.F.</th>
<th>Maximum residuals at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.445E-11</td>
</tr>
<tr>
<td>2</td>
<td>-4.444E-12</td>
</tr>
</tbody>
</table>

Time completed during this step: 7.500E-09
Time increment completed is: 3.500E-09
Fraction of step is: 7.500E-09

Total creep time is: 7.500E-09

Iteration 1: Convergent Solution

Maximum displacement increment associated with each D.O.F.:

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum displacement increment at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.192E-06</td>
</tr>
<tr>
<td>2</td>
<td>-4.041E-08</td>
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</tbody>
</table>

Increment number: 4
Attempt number: 1
Time increment: 5.400E-09

Iteration 1: Convergent Solution

Maximum residuals associated with each D.O.F.:

<table>
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<tr>
<th>D.O.F.</th>
<th>Maximum residuals at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.393E-09</td>
</tr>
<tr>
<td>2</td>
<td>1.339E-09</td>
</tr>
</tbody>
</table>

Time completed during this step: 1.339E-09
Time increment completed is: 5.400E-09
Fraction of step is: 1.339E-09

Total creep time is: 1.339E-09
Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method

Element Output for ELSE END

Element 37 Point 1
Stress Components
1.500E+03 4.920E-11 2.945E-12
Stress Invariants - Viscous
1.500E+03 TRESA 1.500E+03 Equ. Press -500.
Principal Strains
0. 4.724E-11 1.500E+03
Total Strain Components
9.133E-03 -1.034E-03 2.367E-17
Creep Strains - Magnitude
9.240E-07 Equivalent 9.240E-07 Shelling 0.
ELASTIC STRAINS - MAGNITUDE 9.44E-07 COMPONENTS 4.24E-07 9.92E-07 1.405E-16

ELEMENT 19 POINT 2
STRESS COMPONENTS 1.50E+03 2.93E-11 1.69E-11
STRESS INVARANT - MISES 1.50E+03 TRESSCA 1.50E+03 EQU.PRESS 9500.
PRINCIPAL STRESSES 0. 0. 6.27E-11 1.50E+03
TOTAL STRAIN COMPONENTS 4.133E-03 -1.13E-03 4.33E-16
CREEP STRAINS - MAGNITUDE COMPONENTS 4.24E-07 -8.21E-07 3.22E-16
INELASTIC STRAINS - MAGNITUDE COMPONENTS 9.92E-07 1.405E-16

ELEMENT 19 POINT 3
STRESS COMPONENTS 1.50E+03 -3.45E-11 9.40E-11
STRESS INVARANT - MISES 1.50E+03 TRESSCA 1.50E+03 EQU.PRESS 9500.
PRINCIPAL STRESSES 0. 0. 3.15E-11 1.50E+03
TOTAL STRAIN COMPONENTS 4.133E-03 1.133E-03 3.35E-16
CREEP STRAINS - MAGNITUDE COMPONENTS 9.94E-07 -4.42E-07 3.75E-16
INELASTIC STRAINS - MAGNITUDE COMPONENTS 9.92E-07 1.405E-16

ELEMENT 19 POINT 4
STRESS COMPONENTS 1.50E+03 -3.54E-11 1.79E-11
STRESS INVARANT - MISES 1.50E+03 TRESSCA 1.50E+03 EQU.PRESS 9500.
PRINCIPAL STRESSES 0. 0. 5.693E-11 1.50E+03
TOTAL STRAIN COMPONENTS 4.133E-03 1.03E-03 1.20E-16
CREEP STRAINS - MAGNITUDE COMPONENTS 9.94E-07 4.42E-07 3.42E-16
INELASTIC STRAINS - MAGNITUDE COMPONENTS 9.92E-07 1.405E-16
ELEVENT ENERGIES & KINETIC COMPONENTS 9.92E-07 1.405E-16

ELEMENT 20 POINT 1
STRESS COMPONENTS 1.50E+03 5.37E-12 6.22E-11
STRESS INVARANT - MISES 1.50E+03 TRESSCA 1.50E+03 EQU.PRESS 9500.
PRINCIPAL STRESSES 0. 0. 7.27E-12 1.50E+03
TOTAL STRAIN COMPONENTS 4.133E-03 1.03E-03 4.33E-16
CREEP STRAINS - MAGNITUDE COMPONENTS 9.84E-07 4.42E-07 2.19E-16
INELASTIC STRAINS - MAGNITUDE COMPONENTS 9.84E-07 4.42E-07

ELEMENT 20 POINT 2
STRESS COMPONENTS 1.50E+03 2.31E-11 -1.00E-11
STRESS INVARANT - MISES 1.50E+03 TRESSCA 1.50E+03 EQU.PRESS 9500.
PRINCIPAL STRESSES 0. 0. 2.547E-11 1.50E+03
TOTAL STRAIN COMPONENTS 4.133E-03 1.03E-03 6.74E-17
CREEP STRAINS - MAGNITUDE COMPONENTS 9.84E-07 4.42E-07 1.37E-16
INELASTIC STRAINS - MAGNITUDE COMPONENTS 9.84E-07 4.42E-07 1.37E-16

Tensile Analysis of Creep in Plastics using the F.E. Method
### Element 40 Point 3

<table>
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<th>Stress Components</th>
<th>Stress Invariants</th>
<th>Principal Stresses</th>
<th>Total Strain Components</th>
<th>Creep Strains - Magnitude Components</th>
<th>Inelastic Strains - Magnitude Components</th>
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<th>Creep Strains - Magnitude Components</th>
<th>Inelastic Strains - Magnitude Components</th>
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### Element 79 Point 1

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### Element 79 Point 3

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<td>CREEP STRAINS - MAGNITUDE</td>
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<tr>
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<tr>
<td>PRINCIPAL STRESSES</td>
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<td>CREEP STRAINS - MAGNITUDE</td>
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<td>EQUIVALENT</td>
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<thead>
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<th>STRESS COMPONENTS</th>
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<td>COMPONENTS</td>
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<tr>
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<tbody>
<tr>
<td>STRESS INVARIANTS - Mises</td>
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<tr>
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<td>COMPONENTS</td>
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<td>9.84E-07</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>-------------------</td>
<td>-------</td>
<td>--------------------</td>
</tr>
<tr>
<td>119</td>
<td>1</td>
<td>1.500E+03 6.746E-11</td>
<td>1.500E+03</td>
<td>1.500E+03</td>
</tr>
<tr>
<td>119</td>
<td>2</td>
<td>1.500E+03 6.496E-11</td>
<td>1.500E+03</td>
<td>1.500E+03</td>
</tr>
<tr>
<td>119</td>
<td>3</td>
<td>1.500E+03 6.245E-11</td>
<td>1.500E+03</td>
<td>1.500E+03</td>
</tr>
<tr>
<td>119</td>
<td>4</td>
<td>1.500E+03 6.371E-11</td>
<td>1.500E+03</td>
<td>1.500E+03</td>
</tr>
<tr>
<td>120</td>
<td>1</td>
<td>1.500E+03 6.371E-11</td>
<td>1.500E+03</td>
<td>1.500E+03</td>
</tr>
</tbody>
</table>

**Inelastic Strains - Magnitude**

**Element Energies**
- Kinetic: 0
- Strain: 0.145
- Plastic: 0
- Creep: 6.91E-05
### Tensile Analysis

**Element 193 Point 1**
- **Stress Components**
  - Maximum Stress: 4.14 ksi
  - Minimum Stress: 0.0 ksi
  - Equivalent Stress: 4.14 ksi
  - Creep Stress: 0.0 ksi

**Stress Invariants**
- First Invariant: 1.54 ksi
- Second Invariant: 0.0 ksi
- Third Invariant: 0.0 ksi

**Principal Stresses**
- Maximum Stress: 4.14 ksi
- Minimum Stress: 0.0 ksi
- Equivalent Stress: 4.14 ksi

**Creep Stresses**
- Maximum Stress: 0.0 ksi
- Minimum Stress: 0.0 ksi
- Equivalent Stress: 0.0 ksi

**Element 193 Point 2**
- **Stress Components**
  - Maximum Stress: 4.14 ksi
  - Minimum Stress: 0.0 ksi
  - Equivalent Stress: 4.14 ksi
  - Creep Stress: 0.0 ksi

**Stress Invariants**
- First Invariant: 1.54 ksi
- Second Invariant: 0.0 ksi
- Third Invariant: 0.0 ksi

**Principal Stresses**
- Maximum Stress: 4.14 ksi
- Minimum Stress: 0.0 ksi
- Equivalent Stress: 4.14 ksi

**Creep Stresses**
- Maximum Stress: 0.0 ksi
- Minimum Stress: 0.0 ksi
- Equivalent Stress: 0.0 ksi

**Element 193 Point 3**
- **Stress Components**
  - Maximum Stress: 4.14 ksi
  - Minimum Stress: 0.0 ksi
  - Equivalent Stress: 4.14 ksi
  - Creep Stress: 0.0 ksi

**Stress Invariants**
- First Invariant: 1.54 ksi
- Second Invariant: 0.0 ksi
- Third Invariant: 0.0 ksi

**Principal Stresses**
- Maximum Stress: 4.14 ksi
- Minimum Stress: 0.0 ksi
- Equivalent Stress: 4.14 ksi

**Creep Stresses**
- Maximum Stress: 0.0 ksi
- Minimum Stress: 0.0 ksi
- Equivalent Stress: 0.0 ksi

---

**Creep in Plastics using the P.E. Method**

---

**Creep Analysis**

---

**Creep Method**

---

**Creep Calculation**

---

**Creep Equation**

---

**Creep Test**

---

**Creep Results**

---

**Creep Graph**

---

**Creep Chart**

---

**Creep Data**

---

**Creep Report**

---
### Analysis

#### Creep in Plastics

**DEQ POINT OUTPUT SET ALL**

**TOTAL DISPLACEMENT**

<table>
<thead>
<tr>
<th>NODE X - COMPONENT Y - COMPONENT</th>
<th>NODE X - COMPONENT Y - COMPONENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 0 0 1 11.1259E-03 7.2599E-04</td>
<td>3 0 0 3.1596E-03 9.3096E-04</td>
</tr>
<tr>
<td>4 0 0 1.1254E-03 1.4672E-03</td>
<td>6 0 0 7.6733E-03 1.0618E-03</td>
</tr>
<tr>
<td>7 0 0 1.2314E-03 1.0701E-03</td>
<td>9 0 0 1.2438E-02 1.0337E-03</td>
</tr>
<tr>
<td>11 0 0 1.3419E-03 1.0730E-03</td>
<td>12 0 0 2.1640E-02 1.0334E-03</td>
</tr>
<tr>
<td>14 0 0 1.4414E-02 1.0732E-03</td>
<td>15 0 0 1.0216E-02 1.0333E-03</td>
</tr>
<tr>
<td>19 0 0 1.0283E-02 8.9524E-02</td>
<td>21 0 0 1.0281E-02 8.9525E-02</td>
</tr>
<tr>
<td>24 0 0 1.0282E-02 8.9524E-02</td>
<td>27 0 0 1.0281E-02 8.9524E-02</td>
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<tr>
<td>29 0 0 1.0282E-02 8.9525E-02</td>
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<td>68 0 0 1.0282E-02 8.9524E-02</td>
<td>68 0 0 1.0282E-02 8.9524E-02</td>
</tr>
</tbody>
</table>
Tensile Analysis of Creep in Plastics using the F.E. Method

<table>
<thead>
<tr>
<th>Step</th>
<th>Load</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>Element 1</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>Element 2</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>Element 3</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>Element 4</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>Element 5</td>
</tr>
<tr>
<td>6</td>
<td>350</td>
<td>Element 6</td>
</tr>
<tr>
<td>7</td>
<td>400</td>
<td>Element 7</td>
</tr>
</tbody>
</table>

...
### Tensile Analysis of Creep in Plastics using the F.E. Method

#### Reaction Forces

<table>
<thead>
<tr>
<th>Node</th>
<th>X Component</th>
<th>Y Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-167.2</td>
<td>-249.5</td>
</tr>
<tr>
<td>164</td>
<td>171.7</td>
<td>105.1</td>
</tr>
</tbody>
</table>

#### Calculated Forces

<table>
<thead>
<tr>
<th>Node</th>
<th>X Component</th>
<th>Y Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>93.75</td>
<td>0</td>
</tr>
<tr>
<td>154</td>
<td>167.5</td>
<td>0</td>
</tr>
<tr>
<td>209</td>
<td>137.75</td>
<td>0</td>
</tr>
<tr>
<td>123</td>
<td>167.5</td>
<td>0</td>
</tr>
</tbody>
</table>
STEP 3 CREEP 1.0E-07 TO 1.0E-05 HOURS

ANALYSIS

AUTOMATIC CONTROL
0. SUGGESTED INITIAL TIME INCREMENT IS 1.600E-09
AND A TOTAL TIME DIMOF 10
THE MAXIMUM TIME INCREMENT ALLOWED IS 1.600E-09
THE MAXIMUM TIME INCREMENT ALLOWED IS 10.0

THE MAXIMUM DIFFERENCE IN CREEP STRAIN INCREMENT
AMONG THE BEGINNING AND THE END OF AN INCREMENT IS 1.377E-05

THE STEP WILL USE EXPLICIT TIME INTEGRATION (FORWARD DIFFERENCES)
SWITCHING TO IMPLICIT INTEGRATION (BACKWARD DIFFERENCES) IF THIS SEEMS NECESSARY

EQUILIBRIUM TOLERANCES
TOLERANCE ON INDIVIDUAL FORCE COMPONENTS .220
TOLERANCE ON INDIVIDUAL MOMENT COMPONENTS 3.33

SMALL DISPLACEMENT THEORY WILL BE USED
MAXIMUM NUMBER OF INCREMENTS ALLOWED IN THIS STEP IS 200
MAXIMUM NUMBER OF ITERATIONS ALLOWED PER INCREMENT IS 50

INCREMENT NUMBER 1 ATTEMPT NUMBER 1
TIME INCREMENT = 1.600E-09

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.
RESIDUAL MAXIMUM OCCURS AT
D.O.F. NODE
1 3.274E-11 164
2 -4.242E-12 125

MAXIMUM DISPLACEMENT INCREMENT ASSOCIATED WITH EACH D.O.F.
INCREMENT MAXIMUM OCCURS AT
D.O.F. DISPLACEMENT NODE
1 7.24E-08 205
2 -2.496E-09 164

TIME COMPLETED DURING THIS STEP 1.0E-09
TIME INCREMENT COMPLETED IS 1.600E-09, FRACTION OF STEP IS 1.500E-10

TOTAL CREEP TIME IS
1.0E-07
### Tensile Analysis of Creep in Plastics using the F.E. Method

<table>
<thead>
<tr>
<th>Time Step</th>
<th>Creep Time to 24 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increment Number</td>
<td>2 Attempt Number</td>
</tr>
</tbody>
</table>

#### Iteration 1 Convergent Solution

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.O.F.</td>
<td>Maximum</td>
</tr>
<tr>
<td>1</td>
<td>5.5E+01</td>
</tr>
<tr>
<td>2</td>
<td>-9.5E+01</td>
</tr>
</tbody>
</table>

Time completed during this step: 4.000E-09, Time increment completed is 2.430E-09, Fraction of step is 4.000E-10

Total creep time is 6.0E+08

| Increment Number | 3 Attempt Number | Increment Time = 3.600E-09 |

#### Iteration 2 Convergent Solution

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.O.F.</td>
<td>Maximum</td>
</tr>
<tr>
<td>1</td>
<td>5.5E+01</td>
</tr>
<tr>
<td>2</td>
<td>-9.5E+01</td>
</tr>
</tbody>
</table>

Time completed during this step: 7.600E-09, Time increment completed is 3.000E-09, Fraction of step is 7.600E-10

Total creep time is 1.0E+08

| Increment Number | 4 Attempt Number | Increment Time = 5.400E-09 |

#### Iteration 3 Convergent Solution

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.O.F.</td>
<td>Maximum</td>
</tr>
<tr>
<td>1</td>
<td>5.5E+01</td>
</tr>
<tr>
<td>2</td>
<td>-9.5E+01</td>
</tr>
</tbody>
</table>

Time completed during this step: 13.000E-09, Time increment completed is 5.400E-19, Fraction of step is 1.300E-09

Total creep time is 1.0E+08
Tensile Analysis of Creep in Plastics using the F.E. Method

INCREMENT NUMBER 5  ATTEMPT NUMBER 1
TIME INCREMENT = 9.100E-09

ITERATION 1 CONVERGENT SOLUTION
MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.
D.O.F.   MAXIMUM OCCURS AT
RESIDUAL NODE
1  3.547E-11  164
2  -4.539E-12  42

TIME COMPLETED DURING THIS STEP 2.112E-09
TIME INCREMENT COMPLETED IS 8.100E-09, FRACTION OF STEP IS 2.112E-09
TOTAL CREEP TIME IS 1.221E-07

INCREMENT NUMBER 6  ATTEMPT NUMBER 1
TIME INCREMENT = 1.215E-09

ITERATION 1 CONVERGENT SOLUTION
MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.
D.O.F.   MAXIMUM OCCURS AT
RESIDUAL NODE
1  3.653E-11  164
2  -4.616E-12  43

TIME COMPLETED DURING THIS STEP 3.325E-09
TIME INCREMENT COMPLETED IS 1.215E-09, FRACTION OF STEP IS 3.325E-09
TOTAL CREEP TIME IS 1.333E-07

INCREMENT NUMBER 7  ATTEMPT NUMBER 1
TIME INCREMENT = 1.623E-09

ITERATION 1 CONVERGENT SOLUTION
MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.
D.O.F.   MAXIMUM OCCURS AT
RESIDUAL NODE
1  3.553E-11  164
2  -4.492E-12  125

TIME COMPLETED DURING THIS STEP 5.142E-09
TIME INCREMENT COMPLETED IS 1.523E-09, FRACTION OF STEP IS 5.142E-09
TOTAL CREEP TIME IS 1.855E-07
**Analysis Version 4-4-84**

**Tensile Analysis of Creep in Plastics using the F.E. Method**

**Creep 1500 PSI Creep 1.0E-07 to 10 Hours**

<table>
<thead>
<tr>
<th>INCREMENT NUMBER</th>
<th>ATTEMPT NUMBER</th>
<th>TIME INCREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>2.73E-08</td>
</tr>
</tbody>
</table>

**Iteration 1 Convergent Solution**

- **Maximum Residuals Associated with Each D.O.F.**
  - **Node:** 4
  - **Residual Node:**
    - 1: 3.36E-11
    - 2: -4.63E-12

- **Maximum Displacement Increment Associated with Each D.O.F.**
  - **Node:** 4
  - **Displacement Node:**
    - 1: 3.01E-07
    - 2: -2.93E-08

**Time Completed During This Step:** 7.88E-08, **Time Increment Completed:** 2.73E-08, **Fraction of Step:** 7.88E-09

**Total Creep Time:** 1.78E-07

<table>
<thead>
<tr>
<th>INCREMENT NUMBER</th>
<th>ATTEMPT NUMBER</th>
<th>TIME INCREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2</td>
<td>4.10E-08</td>
</tr>
</tbody>
</table>

**Iteration 2 Convergent Solution**

- **Maximum Residuals Associated with Each D.O.F.**
  - **Node:** 4
  - **Residual Node:**
    - 1: 3.36E-11
    - 2: -4.63E-12

- **Maximum Displacement Increment Associated with Each D.O.F.**
  - **Node:** 4
  - **Displacement Node:**
    - 1: 1.16E-06
    - 2: 3.14E-08

**Time Completed During This Step:** 1.19E-07, **Time Increment Completed:** 4.10E-08, **Fraction of Step:** 1.19E-08

**Total Creep Time:** 2.19E-07

<table>
<thead>
<tr>
<th>INCREMENT NUMBER</th>
<th>ATTEMPT NUMBER</th>
<th>TIME INCREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>8.15E-08</td>
</tr>
</tbody>
</table>

**Iteration 3 Convergent Solution**

- **Maximum Residuals Associated with Each D.O.F.**
  - **Node:** 4
  - **Residual Node:**
    - 1: 3.50E-11
    - 2: -5.14E-12

- **Maximum Displacement Increment Associated with Each D.O.F.**
  - **Node:** 4
  - **Displacement Node:**
    - 1: 1.49E-06
    - 2: 5.03E-08

**Time Completed During This Step:** 1.41E-07, **Time Increment Completed:** 8.15E-08, **Fraction of Step:** 1.41E-08

**Total Creep Time:** 2.61E-07
Tensile Analysis of Creep in Plastics using the F.E. Method

Iteration 1 Convergent Solution
Maximum Residuals Associated with Each D.O.F.

<table>
<thead>
<tr>
<th>Element</th>
<th>Maximum Residuals</th>
<th>Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.729E-11</td>
<td>104</td>
</tr>
<tr>
<td>2</td>
<td>-4.512E-12</td>
<td>120</td>
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</table>

Time completed during this step: 2.73E-08, Time increment completed: 7.226E-08, Fraction of step: 2.73E-08

Total creep time: 7.73E-07

Increment number: 12, Attempt number: 1
Time increment: 1.304E-07

Iteration 2 Convergent Solution
Maximum Residuals Associated with Each D.O.F.

<table>
<thead>
<tr>
<th>Element</th>
<th>Maximum Residuals</th>
<th>Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.120E-11</td>
<td>144</td>
</tr>
<tr>
<td>2</td>
<td>-7.712E-12</td>
<td>120</td>
</tr>
</tbody>
</table>

Time completed during this step: 4.120E-07, Time increment completed: 1.344E-07, Fraction of step: 4.120E-08

Total creep time: 5.120E-07

Increment number: 13, Attempt number: 1
Time increment: 2.076E-07

Iteration 3 Convergent Solution
Maximum Residuals Associated with Each D.O.F.

<table>
<thead>
<tr>
<th>Element</th>
<th>Maximum Residuals</th>
<th>Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.733E-11</td>
<td>104</td>
</tr>
<tr>
<td>2</td>
<td>-4.343E-12</td>
<td>120</td>
</tr>
</tbody>
</table>

Time completed during this step: 5.196E-07, Time increment completed: 2.076E-07, Fraction of step: 6.196E-08

Total creep time: 7.196E-07
TENSILE BEAM IN CREEP 1500 PSI
CREEP 1.0E-07 TO 13 HOURS

INCREMENT NUMBER  14 ATTEMPT NUMBER 1
TIME INCREMENT = 3.114E-07

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>MAXIMUM OCCURS AT RESIDUAL NODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.702E-11 164</td>
</tr>
<tr>
<td>2</td>
<td>-4.376E-12 64</td>
</tr>
</tbody>
</table>

TIME COMPLETED DURING THIS STEP 9.310E-07, TIME INCREMENT COMPLETED IS 3.114E-07, FRACTION OF STEP IS 9.310E-08
TOTAL CREEP TIME IS 1.331E-06

INCREMENT NUMBER 15 ATTEMPT NUMBER 1
TIME INCREMENT = 4.671E-07

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>MAXIMUM OCCURS AT RESIDUAL NODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.620E-11 164</td>
</tr>
<tr>
<td>2</td>
<td>-4.476E-12 64</td>
</tr>
</tbody>
</table>

TIME COMPLETED DURING THIS STEP 1.398E-07, TIME INCREMENT COMPLETED IS 4.671E-07, FRACTION OF STEP IS 1.398E-07
TOTAL CREEP TIME IS 1.494E-06

INCREMENT NUMBER 16 ATTEMPT NUMBER 1
TIME INCREMENT = 7.006E-07

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>MAXIMUM OCCURS AT RESIDUAL NODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.693E-11 164</td>
</tr>
<tr>
<td>2</td>
<td>-4.537E-12 129</td>
</tr>
</tbody>
</table>

TIME COMPLETED DURING THIS STEP 2.093E-07, TIME INCREMENT COMPLETED IS 7.006E-07, FRACTION OF STEP IS 2.093E-07
TOTAL CREEP TIME IS 2.199E-06
Tensile Analysis of Creep using the F.E. Method

INCREMENT NUMBER 17 ATTEMPT NUMBER 1
TIME INCREMENT = 1.051E-06

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F. MAXIMUM DISPLACEMENT INCREMENT ASSOCIATED WITH EACH D.O.F.
D.O.F. MAXIMUM OCCURS AT D.O.F. MAXIMUM OCCURS AT
RESIDUAL DISPLACEMENT NODE
1 3.567E-11 164 1 4.936E-06 41
2 -4.376E-12 125 2 1.674E-07 5

TIME COMPLETED DURING THIS STEP 3.150E-06, TIME INCREMENT COMPLETED IS 1.051E-06, FRACTION OF STEP IS 3.150E-07
TOTAL CREEP TIME IS 3.150E-06

INCREMENT NUMBER 18 ATTEMPT NUMBER 1
TIME INCREMENT = 1.976E-06

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F. MAXIMUM DISPLACEMENT INCREMENT ASSOCIATED WITH EACH D.O.F.
D.O.F. MAXIMUM OCCURS AT D.O.F. MAXIMUM OCCURS AT
RESIDUAL DISPLACEMENT NODE
1 3.411E-11 164 1 5.646E-06 205
2 -4.335E-12 84 2 -1.975E-07 169

TIME COMPLETED DURING THIS STEP 4.726E-06, TIME INCREMENT COMPLETED IS 1.976E-06, FRACTION OF STEP IS 4.726E-07
TOTAL CREEP TIME IS 4.726E-06

INCREMENT NUMBER 19 ATTEMPT NUMBER 1
TIME INCREMENT = 2.365E-06

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F. MAXIMUM DISPLACEMENT INCREMENT ASSOCIATED WITH EACH D.O.F.
D.O.F. MAXIMUM OCCURS AT D.O.F. MAXIMUM OCCURS AT
RESIDUAL DISPLACEMENT NODE
1 3.593E-11 164 1 8.411E-06 41
2 -4.350E-12 125 2 2.134E-07 5

TIME COMPLETED DURING THIS STEP 7.091E-06, TIME INCREMENT COMPLETED IS 2.365E-06, FRACTION OF STEP IS 7.091E-07
TOTAL CREEP TIME IS 7.091E-06
Tensile Analysis of Creep in Plastics using the F.E. Method

Iteration 1 Convergent Solution

Maximum residuals associated with each D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum occurs at residual node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.547E-11</td>
</tr>
<tr>
<td>2</td>
<td>-4.65E-12</td>
</tr>
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</table>

Time completed during this step: 1.00E-05

Time increment completed: 3.547E-06

Fraction of step: 1.064E-06

Total creep time is: 1.00E-05

Iteration 2 Convergent Solution

Maximum residuals associated with each D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum occurs at residual node</th>
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<tr>
<td>1</td>
<td>3.39E-11</td>
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<td>2</td>
<td>-4.47E-12</td>
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</table>

Time completed during this step: 5.54E-05

Time increment completed: 5.323E-06

Fraction of step: 1.596E-06

Total creep time is: 1.00E-05

Iteration 3 Convergent Solution

Maximum residuals associated with each D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum occurs at residual node</th>
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</thead>
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<tr>
<td>1</td>
<td>2.349E-11</td>
</tr>
<tr>
<td>2</td>
<td>-3.215E-07</td>
</tr>
</tbody>
</table>

Time completed during this step: 7.94E-05

Time increment completed: 2.374E-06

Fraction of step: 2.374E-06

Total creep time is: 4.404E-05
Tensile analysis of creep in plastics using the F.E. Method

Increment Number: 23  Attempt Number: 1
Time Increment: 1.147E-06

Iteration 1: Convergent Solution

Maximum Residuals Associated with Each D.O.F.
D.O.F.  Maximum Occurs at Residual Node
1  3.332E-11  164
2  4.333E-12  84

Maximum Displacement Increment Associated with Each D.O.F.
D.O.F.  Maximum Occurs at Displacement Node Increment
1  1.177E-05  123
2  3.53E-07  149

Time Completed During This Step: 3.591E-05  Time Increment Completed: 1.147E-06  Fraction of Step is: 3.591E-05
Total Creep Time is: 3.601E-05

Increment Number: 24  Attempt Number: 1
Time Increment: 1.746E-05

Iteration 1: Convergent Solution

Maximum Residuals Associated with Each D.O.F.
D.O.F.  Maximum Occurs at Residual Node
1  3.547E-11  164
2  4.917E-12  94

Maximum Displacement Increment Associated with Each D.O.F.
D.O.F.  Maximum Occurs at Displacement Node Increment
1  1.223E-05  41
2  4.146E-07  5

Time Completed During This Step: 5.397E-05  Time Increment Completed: 1.746E-05  Fraction of Step is: 5.397E-05
Total Creep Time is: 5.397E-05

Increment Number: 25  Attempt Number: 1
Time Increment: 2.694E-05

Iteration 1: Convergent Solution

Maximum Residuals Associated with Each D.O.F.
D.O.F.  Maximum Occurs at Residual Node
1  3.493E-11  164
2  4.462E-12  94

Maximum Displacement Increment Associated with Each D.O.F.
D.O.F.  Maximum Occurs at Displacement Node Increment
1  1.306E-05  205
2  4.306E-07  159

Time Completed During This Step: 8.080E-05  Time Increment Completed: 2.694E-05  Fraction of Step is: 8.080E-05
Total Creep Time is: 8.080E-05
Tensile Analysis of Creep in Plastics using the F.E. Method

Iteration 1 Convergent Solution

Maximum Residuals Associated With Each D.O.F. 

Maximum Displacement Increment Associated With Each D.O.F.

<table>
<thead>
<tr>
<th>Increment Number</th>
<th>Time Increment = 9.040E-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.411E-11</td>
</tr>
<tr>
<td>2</td>
<td>-9.533E-12</td>
</tr>
</tbody>
</table>

Time Completed During This Step: 6.630E-05, Time Increment Completed Is 6.630E-05, Fraction of Step Is 1.618E-05

Total Creep Time Is: 1.618E-05

Increment Number: 28, Attempt Number: 1, Time Increment = 9.090E-05

Iteration 1 Convergent Solution

Maximum Residuals Associated With Each D.O.F. 

Maximum Displacement Increment Associated With Each D.O.F.

<table>
<thead>
<tr>
<th>Increment Number</th>
<th>Time Increment = 9.090E-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.929E-11</td>
</tr>
<tr>
<td>2</td>
<td>-6.930E-12</td>
</tr>
</tbody>
</table>

Time Completed During This Step: 2.727E-05, Time Increment Completed Is 9.090E-05, Fraction of Step Is 2.727E-05

Total Creep Time Is: 2.727E-05
**Tensile Analysis of Creep in Plastics using the F.E. Method**

### Iteration 1 Convergent Solution

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Node</td>
<td>Displacement Node</td>
</tr>
<tr>
<td>1: 3.593E-11, 144</td>
<td>1: 2.613E-05, 41</td>
</tr>
<tr>
<td>2: -4.970E-12, 84</td>
<td>2: 2.946E-05, 5</td>
</tr>
</tbody>
</table>

**Time Completed During This Step**: 6.136E-04, **Time Increment Completed**: 2.946E-05, **Fraction of Step**: 6.136E-05

**Total Creep Time**: 6.136E-04

### Iteration 1 Convergent Solution

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Node</td>
<td>Displacement Node</td>
</tr>
<tr>
<td>1: 3.593E-11, 144</td>
<td>1: 2.613E-05, 41</td>
</tr>
<tr>
<td>2: -4.970E-12, 84</td>
<td>2: 2.946E-05, 5</td>
</tr>
</tbody>
</table>

**Time Completed During This Step**: 6.204E-04, **Time Increment Completed**: 3.068E-05, **Fraction of Step**: 9.204E-05

**Total Creep Time**: 6.204E-04

---

**Increment Number**: 1, **Attempt Number**: 1, **Time Increment**: 2.204E-04

---

**Increment Number**: 30, **Attempt Number**: 1, **Time Increment**: 2.046E-04

---

**Increment Number**: 31, **Attempt Number**: 1, **Time Increment**: 3.068E-04

---

**Increment Number**: 24, **Attempt Number**: 1, **Time Increment**: 2.204E-04
Tensile Analysis of Creep in Plastics using the F.E. Method

Iteration 1 Converged Solution

Maximum Residuals Associated with Each D.O.F.: 1

Maximum Displacement Increment Associated with Each D.O.F.: 1

TIME COMPLETED DURING THIS STEP 1.33E-03
TIME INCREMENT COMPLETED IS 1.002E-04, FRACTION OF STEP IS 1.33E-04
TOTAL CREEP TIME IS 1.33E-03

Increment Number 33 Attempt Number 1
Time Increment = 1.002E-04

Iteration 2 Converged Solution

Maximum Residuals Associated with Each D.O.F.: 1

Maximum Displacement Increment Associated with Each D.O.F.: 1

TIME COMPLETED DURING THIS STEP 2.071E-03
TIME INCREMENT COMPLETED IS 1.035E-03, FRACTION OF STEP IS 2.071E-04
TOTAL CREEP TIME IS 2.071E-03

Increment Number 34 Attempt Number 1
Time Increment = 1.035E-03

Iteration 3 Converged Solution

Maximum Residuals Associated with Each D.O.F.: 1

Maximum Displacement Increment Associated with Each D.O.F.: 1

TIME COMPLETED DURING THIS STEP 3.106E-03
TIME INCREMENT COMPLETED IS 1.06E-03, FRACTION OF STEP IS 3.106E-04
TOTAL CREEP TIME IS 3.106E-03
**Tensile Analysis of Creep in Plastics using the F.E. Method**

**Iteration 1 Convergent Solution**

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.O.F. Maximum Occurs at Residual Node</td>
<td>D.O.F. Maximum Occurs at Displacement Node</td>
</tr>
<tr>
<td>1: 0.557E-11</td>
<td>1: 0.15E-05</td>
</tr>
<tr>
<td>2: -0.775E-12</td>
<td>2: 2.17E-05</td>
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</tbody>
</table>

Time completed during this step: 2.359E-02, time increment completed is 7.83E-03, fraction of step is 2.359E-02

Total creep time is 2.359E-02

**Iteration 2 Convergent Solution**

<table>
<thead>
<tr>
<th>Maximum Residuals Associated with Each D.O.F.</th>
<th>Maximum Displacement Increment Associated with Each D.O.F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.O.F. Maximum Occurs at Residual Node</td>
<td>D.O.F. Maximum Occurs at Displacement Node</td>
</tr>
<tr>
<td>1: 0.557E-11</td>
<td>1: 0.25E-05</td>
</tr>
<tr>
<td>2: -0.641E-12</td>
<td>2: 3.19E-05</td>
</tr>
</tbody>
</table>

Time completed during this step: 3.53E-02, time increment completed is 1.17E-02, fraction of step is 3.53E-02

Total creep time is 3.53E-02

**Tensile Creep in 1000 PSI Creep 1.05E-07 to 10 Hours**

<table>
<thead>
<tr>
<th>Increment Number</th>
<th>Attempt Number</th>
<th>Time Increment</th>
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</thead>
<tbody>
<tr>
<td>48</td>
<td>1</td>
<td>4.24E-05</td>
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<tr>
<td>39</td>
<td>1</td>
<td>7.46E-03</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>1.17E-02</td>
</tr>
</tbody>
</table>

Date: 03/31/03, Time: 16:24:14, Page: 35, Step: 3 Increment: 37
Tensile Analysis of Creep in Plastics using the F.E. Method

Increment Number 41 Attempt Number 1
Time Increment = 1.700E-02

Iteration 1 Convergent Solution
Maximum residuals associated with each D.O.F.
D.O.F. Maximum occurs at
Residual node
1 3.401E-11 144
2 -4.201E-12 144

Time completed during this step: 1.700E-02
Time increment completed is 1.700E-02, fraction of step is 1.000E+00
Total creep time is 1.700E+02

Increment Number 42 Attempt Number 1
Time Increment = 2.000E-02

Iteration 1 Convergent Solution
Maximum residuals associated with each D.O.F.
D.O.F. Maximum occurs at
Residual node
1 4.101E-11 144
2 -4.201E-12 144

Time completed during this step: 2.000E-02
Time increment completed is 2.000E-02, fraction of step is 1.000E+00
Total creep time is 2.000E+02

Increment Number 43 Attempt Number 1
Time Increment = 3.000E-02

Iteration 1 Convergent Solution
Maximum residuals associated with each D.O.F.
D.O.F. Maximum occurs at
Residual node
1 5.401E-11 144
2 -5.201E-12 144

Time completed during this step: 3.000E-02
Time increment completed is 3.000E-02, fraction of step is 1.000E+00
Total creep time is 3.000E+02
Tensile Analysis of Creep in Plastics using the F.E. Method

Increment Number: 44  Attempt Number: 1
Time Increment = 5.971E-02

Iteration 1 Convergent Solution

Maximum Residuals Associated with Each D.O.F.
- D.O.F.: MAXIMUM OCCURS AT RESIDUAL NODE
1: 3.776E-11 144
2: -4.604E-12 43

Time Completed During This Step: .197  Time Increment Completed is 5.971E-02, Fraction of Step is 1.791E-02
Total Creep Time is .119

Increment Number: 45  Attempt Number: 1
Time Increment = 8.756E-02

Iteration 1 Convergent Solution

Maximum Residuals Associated with Each D.O.F.
- D.O.F.: MAXIMUM OCCURS AT RESIDUAL NODE
1: 3.456E-11 164
2: -4.712E-12 43

Time Completed During This Step: .269  Time Increment Completed is 8.756E-02, Fraction of Step is 2.637E-02
Total Creep Time is .269

Increment Number: 46  Attempt Number: 1
Time Increment = 1.34

Iteration 1 Convergent Solution

Maximum Residuals Associated with Each D.O.F.
- D.O.F.: MAXIMUM OCCURS AT RESIDUAL NODE
1: 3.546E-11 134
2: -4.712E-12 43

Time Completed During This Step: .434  Time Increment Completed is 1.34, Fraction of Step is 4.030E-02
Total Creep Time is .434
INCREMEN T NUMBER 47 ATTEMPT NUMBER 1
TIME INCREMENT = .202

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.

D.O.F. MAXIMUM OCCURS AT
RESIDUAL NODE

TIME COMPLETED DURING THIS STEP .609
TOTAL CREEP TIME IS .609

INCREMEN T NUMBER 48 ATTEMPT NUMBER 1
TIME INCREMENT = .302

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.

D.O.F. MAXIMUM OCCURS AT
RESIDUAL NODE

TIME COMPLETED DURING THIS STEP .407
TOTAL CREEP TIME IS .417

INCREMEN T NUMBER 49 ATTEMPT NUMBER 1
TIME INCREMENT = .453

ITERATION 1 CONVERGENT SOLUTION

MAXIMUM RESIDUALS ASSOCIATED WITH EACH D.O.F.

D.O.F. MAXIMUM OCCURS AT
RESIDUAL NODE

TIME COMPLETED DURING THIS STEP 1.36
TOTAL CREEP TIME IS 1.36

...
Tensile Analysis of Creep in Plastics using the F.E. Method
**Tensile Analysis of Creep in Plastics using the P. E. Method**

<table>
<thead>
<tr>
<th>Element</th>
<th>Point</th>
<th>Stress Components</th>
<th>Stress Invariants</th>
<th>Principal Stresses</th>
<th>Total Strain Components</th>
<th>Creep Strains</th>
<th>Elastic Strains</th>
<th>Kinetic Energy</th>
<th>Creep</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>1</td>
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</tbody>
</table>

- **Creep Strains**
  - Element 79: Point 1: 1.302E-02

- **Elastic Strains**
  - Element 79: Point 1: 1.302E-02

- **Kinetic Energy**
  - Element 79: Point 1: 1.302E-02
Tensile Analysis of Creep in Plastics using the F.E. Method

**Element 10 Point 2**
- Stress Components: 1.50E+03, 2.20E-11, 1.940E-12
- Principal Stresses: 0, 2.57E-11, 1.940E-03
- Total Strain Components: 4.317E-03, 1.126E-03, 1.650E-17
- Creep Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09
- Inelastic Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09

**Element 10 Point 4**
- Stress Components: 1.500E+03, 7.422E-12, 2.336E-12
- Principal Stresses: 0, 1.091E-11, 1.500E-03
- Total Strain Components: 4.317E-03, 1.126E-03, 1.650E-17
- Creep Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09
- Inelastic Strains - Magnitude: 1.152E-04, 1.260E-05, 2.395E-09

**Element 10 Point 5**
- Stress Components: 1.500E+03, 7.422E-12, 2.336E-12
- Principal Stresses: 0, 1.091E-11, 1.500E-03
- Total Strain Components: 4.317E-03, 1.126E-03, 1.650E-17
- Creep Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09
- Inelastic Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09

**Element 11 Point 1**
- Stress Components: 1.500E+03, 3.762E-11, 2.676E-11
- Principal Stresses: 0, 4.002E-11, 1.500E-03
- Total Strain Components: 4.317E-03, 1.126E-03, 1.756E-16
- Creep Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09
- Inelastic Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09

**Element 12 Point 1**
- Stress Components: 1.500E+03, 1.354E-11, 1.695E-11
- Principal Stresses: 0, 1.314E-11, 1.500E+03

**Tensile Stress in Creep 1000 psi**
- Creep: 1.0E+07 to 11 hours
- Total Strain Components: 4.317E-03, 1.126E-03, 3.462E+10
- Creep Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09
- Inelastic Strains - Magnitude: 1.552E-04, 1.260E-05, 2.395E-09
TOTAL STRAIN COMPONENTS  4.12E+03 -1.12E+03 -5.63E+01
CREEP STRAINS - MAGNITUDE  1.652E-04 EQUIVALENT 1.82E+04 SWELLING 0.
                            1.652E-04 9.26E-05 3.005E-17
INELASTIC STRAINS - MAGNITUDE  1.652E-04 COMPONENTS  1.652E-04 -9.26E-05 -3.005E-17

ELEMENT 119  POINT 3
STRESS COMPONENTS  1.050E+03 6.52E+11 -4.27E-12
STRESS INVARANTS - MISSES  1.500E+03 TRES CA 1.500E+03 EQU PRESS -500.
PRINCIPAL STRESSES  0.  4.36E+11 1.500E+03
TOTAL STRAIN COMPONENTS  4.317E-03 -1.12E+03 -3.191E-17
CREEP STRAINS - MAGNITUDE  1.652E-04 EQUIVALENT 1.156E-04 SWELLING 0.
                            1.652E-04 9.26E-05 2.730E-18

ELEMENT 119  POINT 4
STRESS COMPONENTS  1.050E+03 6.330E+11 -6.71E-11
STRESS INVARANTS - MISSES  1.500E+03 TRES CA 1.500E+03 EQU PRESS -500.
PRINCIPAL STRESSES  0.  6.43E+11 1.500E+03
TOTAL STRAIN COMPONENTS  4.317E-03 -1.12E+03 -4.136E-16
CREEP STRAINS - MAGNITUDE  1.652E-04 EQUIVALENT 1.652E-04 SWELLING 0.
                            1.652E-04 9.26E-05 -2.435E-17

ELEMENT 120  POINT 1
STRESS COMPONENTS  1.050E+03 6.74E+11 3.51E-11
STRESS INVARANTS - MISSES  1.500E+03 TRES CA 1.500E+03 EQU PRESS -500.
PRINCIPAL STRESSES  0.  6.91E+11 1.500E+03
TOTAL STRAIN COMPONENTS  4.317E-03 -1.12E+03 2.657E-16
CREEP STRAINS - MAGNITUDE  1.652E-04 EQUIVALENT 1.652E-04 SWELLING 0.
                            1.652E-04 9.26E-05 1.393E-17
INELASTIC STRAINS - MAGNITUDE  1.652E-04 COMPONENTS  1.652E-04 -9.26E-05 -1.393E-17

ELEMENT 120  POINT 2
STRESS COMPONENTS  1.500E+03 -7.155E-12 -6.623E-11
STRESS INVARANTS - MISSES  1.500E+03 TRES CA 1.500E+03 EQU PRESS -500.
PRINCIPAL STRESSES  -1.633E+12 0.  1.500E+03
TOTAL STRAIN COMPONENTS  4.317E-03 -1.12E+03 -4.350E-16
CREEP STRAINS - MAGNITUDE  1.652E-04 EQUIVALENT 1.652E-04 SWELLING 0.
                            1.652E-04 9.26E-05 -2.432E-17

ELEMENT 120  POINT 3
STRESS COMPONENTS  1.630E+03 -3.355E-11 7.135E-12
STRESS INVARANTS - MISSES  1.630E+03 TRES CA 1.630E+03 EQU PRESS -500.
PRINCIPAL STRESSES  -3.274E+11 0.  1.630E+03

Tensile Analysis of Creep in Plastics using the F.E. Method
### Total Strain Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Strain</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creep Strains - Magnitude</td>
<td>1.50E+03</td>
<td>1.12E+03</td>
</tr>
<tr>
<td>Creep Strains - Magnitude</td>
<td>1.65E+04</td>
<td>1.65E+04</td>
</tr>
</tbody>
</table>

### Inelastic Strains - Magnitude

<table>
<thead>
<tr>
<th>Component</th>
<th>Strain</th>
<th>Value</th>
</tr>
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Tensile Analysis of Creep in Plastics using the F.E. Method

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 53.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
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  - KINETIC ENERGY: 0
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  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

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  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
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  - KINETIC ENERGY: 0
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  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
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  - KINETIC ENERGY: 0
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  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
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  - KINETIC ENERGY: 0
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  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0

- TENSILE STUDY TOTALS
  - STRAIN ENERGY: 2.2
  - KINETIC ENERGY: 0
  - PLASTIC DISPLACEMENT: 29.3
  - VISCOS DISPLACEMENT IN DAMPERS, ETC. 0
TENSILE Vs. CREEP 1500 PSI CREEP 1 DAY - 72 HOURS

NOE ELECT OUTPUT SET ALL

TOTAL DISPLACEMENTS

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**Creep Test Data**

| Date 03/14/71 | Time 08:24:14 | Page 47 |

**Tensile Test Data**

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<th>Temperature</th>
<th>Load</th>
<th>Strain</th>
<th>Time</th>
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<td>0.001</td>
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<td>0.002</td>
</tr>
<tr>
<td>123</td>
<td>4,200 psi</td>
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<tr>
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<tr>
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**Creep Test Results**

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<th>Stress (ksi)</th>
<th>Strain (in. / in.</th>
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<td>0.002</td>
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**Concentrated Forces**

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<th>X-Component</th>
<th>Y-Component</th>
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**Reaction Forces**

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<td>-25.70</td>
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**Analysis Notes**

- The analysis was performed using the finite element method to evaluate the creep behavior of the material under specified conditions.
- The creep test results show a linear increase in strain with time, indicating a constant creep rate.
- The concentrated forces and reaction forces were calculated to ensure structural integrity under the applied loads and strains.
Tensile Analysis of Creep in Plastics using the F.E. Method

Tensile Test: 1500 psi
Creep: 1.00-3.57 to 10 hours

Node X - Component Y - Component

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Increment Number: 51  Attempt Number: 1
Time Increment = 1.02

Iteration 1 Convergent Solution

Maximum Residuals Associated with Each D.O.F.

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<th>Maximum Residuals at Node</th>
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Maximum Displacement Increment Associated with Each D.O.F.

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<th>D.O.F.</th>
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Time Completed During This Step: 1.06
Total Creep Time: 1.06

Increment Number: 52  Attempt Number: 1
Time Increment = 1.53

Iteration 1 Convergent Solution

Maximum Residuals Associated with Each D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum Residuals at Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.729E-11</td>
</tr>
<tr>
<td>2</td>
<td>-4.690E-12</td>
</tr>
</tbody>
</table>

Maximum Displacement Increment Associated with Each D.O.F.

<table>
<thead>
<tr>
<th>D.O.F.</th>
<th>Maximum Displacement at Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.245E-04</td>
</tr>
<tr>
<td>2</td>
<td>1.940E-05</td>
</tr>
</tbody>
</table>

Time Completed During This Step: 4.59
Total Creep Time: 4.59

Increment Number: 53  Attempt Number: 1
Time Increment = 1.91
Tensile Analysis of Creep in Plastics using the F.E. Method.
### Tensile Analysis

#### Element Output File Example

<table>
<thead>
<tr>
<th>Element</th>
<th>Point</th>
<th>Stress Components</th>
<th>Principal Stresses</th>
<th>Creep Strains</th>
<th>Inelastic Strains</th>
</tr>
</thead>
</table>
**Tensile Analysis of Creep in Plastics using the FE Method**

<table>
<thead>
<tr>
<th>Element</th>
<th>Point</th>
<th>Stress Components</th>
<th>Stress Invariants</th>
<th>Principal Stresses</th>
<th>Total Strain Components</th>
<th>Creep Strains</th>
<th>Inelastic Strains</th>
<th>Magnitude</th>
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<tbody>
<tr>
<td>41</td>
<td>1</td>
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<td>7.031e-12</td>
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<td>1.604e+03</td>
<td>1.522e+04</td>
<td>3.045e-04</td>
<td>1.569e-17</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>7.031e-12</td>
<td>1.525e+04</td>
<td>1.604e+03</td>
<td>1.522e+04</td>
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<td>1.569e-17</td>
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<td>7.031e-12</td>
<td>1.525e+04</td>
<td>1.604e+03</td>
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<td>1.522e+04</td>
<td>3.045e-04</td>
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**Date:** 13/14/09  **Time:** 13:24:14  **Page:** 51  **Step:** 3  **Increment:** 66
Tensile Analysis of Creep in Plastics using the F.E. Method

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>POINT</th>
<th>STRESS COMPONENTS</th>
<th>SCA</th>
<th>TOTAL STRESS COMPS</th>
<th>CREEP STRESSES</th>
<th>INELASTIC STRESSES</th>
<th>INERTIA</th>
<th>ELEMENT ENERGIES</th>
<th>PLASTIC</th>
<th>CREEP</th>
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<tr>
<td>E4</td>
<td>A</td>
<td>1.96E+3</td>
<td>1.23E+1</td>
<td>1.77E+11</td>
<td>1.61E+11</td>
<td>1.50E+3</td>
<td>1.50E+3</td>
<td>0</td>
<td>1.45E+3</td>
<td>2.14E+2</td>
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<tr>
<td>E5</td>
<td>B</td>
<td>1.80E+3</td>
<td>1.50E+1</td>
<td>1.25E+11</td>
<td>1.75E+11</td>
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<td>1.50E+3</td>
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<td>E6</td>
<td>C</td>
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<td>1.60E+11</td>
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<td>1.50E+3</td>
<td>0</td>
<td>1.45E+3</td>
<td>2.14E+2</td>
</tr>
</tbody>
</table>

Note: The table above presents the stress analysis results for different elements and points, including stress components, total stress components, creep stresses, inelastic stresses, inertia, and element energies. The data is formatted to show the magnitude of each component. The values indicate the direction and magnitude of stress on the materials, which is crucial for understanding the behavior under creep conditions.
### Analysis of Creep in Plastics using the F.E. Method

#### Tensile Stress in Creep 10,001 PSI

**Creep:** 1.3E-07 to 1.2 Hours

<table>
<thead>
<tr>
<th>Stress Invariants</th>
<th>Aises</th>
<th>Tresca</th>
<th>Eou Press</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>500.</td>
</tr>
</tbody>
</table>

**Principal Strains:**

- 0.00E+00

**Total Strain Components:**

- 4.43E-03

**Creep Strains - Magnitude Components:**

- 3.04E-04

**Elastic Strains - Magnitude Components:**

- 3.04E-04

#### Element 09 Point 4

<table>
<thead>
<tr>
<th>Stress Components</th>
<th>Aises</th>
<th>Tresca</th>
<th>Eou Press</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>500.</td>
</tr>
</tbody>
</table>

**Principal Strains:**

- 0.00E+00

**Total Strain Components:**

- 4.43E-03

**Creep Strains - Magnitude Components:**

- 3.04E-04

**Elastic Strains - Magnitude Components:**

- 3.04E-04

#### Element 119 Point 1

<table>
<thead>
<tr>
<th>Stress Components</th>
<th>Aises</th>
<th>Tresca</th>
<th>Eou Press</th>
<th>Step</th>
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<tbody>
<tr>
<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>500.</td>
</tr>
</tbody>
</table>

**Principal Strains:**

- 0.00E+00

**Total Strain Components:**

- 4.43E-03

**Creep Strains - Magnitude Components:**

- 3.04E-04

**Elastic Strains - Magnitude Components:**

- 3.04E-04

#### Element 117 Point 2

<table>
<thead>
<tr>
<th>Stress Components</th>
<th>Aises</th>
<th>Tresca</th>
<th>Eou Press</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>500.</td>
</tr>
</tbody>
</table>

**Principal Strains:**

- 0.00E+00

**Total Strain Components:**

- 4.43E-03

**Creep Strains - Magnitude Components:**

- 3.04E-04

**Elastic Strains - Magnitude Components:**

- 3.04E-04

#### Element 119 Point 3

<table>
<thead>
<tr>
<th>Stress Components</th>
<th>Aises</th>
<th>Tresca</th>
<th>Eou Press</th>
<th>Step</th>
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</thead>
<tbody>
<tr>
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<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>500.</td>
</tr>
</tbody>
</table>

**Principal Strains:**

- 0.00E+00

**Total Strain Components:**

- 4.43E-03

**Creep Strains - Magnitude Components:**

- 3.04E-04

**Elastic Strains - Magnitude Components:**

- 3.04E-04

#### Element 117 Point 4

<table>
<thead>
<tr>
<th>Stress Components</th>
<th>Aises</th>
<th>Tresca</th>
<th>Eou Press</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1500E+03</td>
<td>1500E+03</td>
<td>1500E+03</td>
<td>500.</td>
</tr>
</tbody>
</table>

**Principal Strains:**

- 0.00E+00

**Total Strain Components:**

- 4.43E-03

**Creep Strains - Magnitude Components:**

- 3.04E-04

**Elastic Strains - Magnitude Components:**

- 3.04E-04
Tensile Analysis of Creep in Plastics using the F.E. Method

TENSILE AGED IN CREEP 13000 PSI CREEP 1.15E-4 TO 15 HOURS

STRESS INVARIANTS - MISES 1.50E+03 TRESCA 1.50E+03 EQU. PRESS 500.
PRINCIPAL STRESSES 0.000000 EQU. PRESS 500.
TOTAL STRAIN COMPONENTS 4.437E-02 4.437E-02 4.437E-02
CREEP STRAINS - AMOUNT 3.645E-04 EQUIVALENT 3.645E-04 SHELLING 0.
ELEMENT ENERGIES: KINETIC 0.

ELEMENT 123 POINT 1
STRESS INVARIANTS - MISES 1.50E+03 TRESCA 1.50E+03 EQU. PRESS 500.
PRINCIPAL STRESSES 0.000000 EQU. PRESS 500.
TOTAL STRAIN COMPONENTS 4.437E-02 4.437E-02 4.437E-02
CREEP STRAINS - AMOUNT 3.645E-04 EQUIVALENT 3.645E-04 SHELLING 0.

ELEMENT 129 POINT 2
STRESS INVARIANTS - MISES 1.50E+03 TRESCA 1.50E+03 EQU. PRESS 500.
PRINCIPAL STRESSES 0.000000 EQU. PRESS 500.
TOTAL STRAIN COMPONENTS 4.437E-02 4.437E-02 4.437E-02
CREEP STRAINS - AMOUNT 3.045E-04 EQUIVALENT 3.045E-04 SHELLING 0.

ELEMENT 120 POINT 3
STRESS INVARIANTS - MISES 1.50E+03 TRESCA 1.50E+03 EQU. PRESS 500.
PRINCIPAL STRESSES 0.000000 EQU. PRESS 500.
TOTAL STRAIN COMPONENTS 4.437E-02 4.437E-02 4.437E-02
CREEP STRAINS - AMOUNT 3.045E-04 EQUIVALENT 3.045E-04 SHELLING 0.

ELEMENT 120 POINT 4
STRESS INVARIANTS - MISES 1.50E+03 TRESCA 1.50E+03 EQU. PRESS 500.
PRINCIPAL STRESSES 0.000000 EQU. PRESS 500.
TOTAL STRAIN COMPONENTS 4.437E-02 4.437E-02 4.437E-02
CREEP STRAINS - AMOUNT 3.045E-04 EQUIVALENT 3.045E-04 SHELLING 0.

ELEMEN 121 POINT 1
TENSILE TEST IN CREEP 1500 PSI  
CREEP 1.00E-07 TO 1.0 HOURS

STRESS COMPONENTS - MISES  
1.500E+03 2.47E-11 3.073E-11
PRINCIPAL STRESSES  
0.  2.47E-11 1.500E+03
TOTAL STRAIN COMPONENTS  
4.437E-03 1.139E-03 5.330E-17
CREEP STRAINS - MAGNITUDE  
3.045E-04 EQUIVALENT 3.045E-04 SLEWING 0.
INELASTIC STRAINS - MAGNITUDE  
3.045E-04 COMPONENTS 3.045E-04 -1.522E-04 2.414E-17

ELEMENT 159 POINT 2
STRESS COMPONENTS - MISES  
1.500E+03 2.08E-12 1.997E-11
PRINCIPAL STRESSES  
0.  2.08E-12 1.500E+03
TOTAL STRAIN COMPONENTS  
4.437E-03 1.119E-03 1.529E-13
CREEP STRAINS - MAGNITUDE  
3.045E-04 EQUIVALENT 3.045E-04 SLEWING 0.
INELASTIC STRAINS - MAGNITUDE  
3.045E-04 COMPONENTS 3.045E-04 -1.529E-04 1.528E-17

ELEMENT 159 POINT 3
STRESS COMPONENTS - MISES  
1.500E+03 3.536E-11 -1.119E-11
PRINCIPAL STRESSES  
0.  3.536E-11 1.500E+03
TOTAL STRAIN COMPONENTS  
4.437E-03 1.165E-03 7.906E-17
CREEP STRAINS - MAGNITUDE  
3.045E-04 EQUIVALENT 3.045E-04 SLEWING 0.
INELASTIC STRAINS - MAGNITUDE  

ELEMENT 159 POINT 4
STRESS COMPONENTS - MISES  
1.500E+03 1.339E-11 6.889E-12
PRINCIPAL STRESSES  
0.  1.339E-11 1.500E+03
TOTAL STRAIN COMPONENTS  
4.437E-03 1.165E-03 5.330E-17
CREEP STRAINS - MAGNITUDE  
3.045E-04 EQUIVALENT 3.045E-04 SLEWING 0.
INELASTIC STRAINS - MAGNITUDE  
ELEMENT ANALYSES KINETIC  
0.  STRAIN 1.145 PLASTIC 0. CREEP 2.141E-02

ELEMENT 150 POINT 1
STRESS COMPONENTS - MISES  
1.500E+03 -2.836E-12 1.114E-10
PRINCIPAL STRESSES  
0.  -2.836E-12 1.500E+03
TOTAL STRAIN COMPONENTS  
4.437E-03 1.165E-03 6.413E-16
CREEP STRAINS - MAGNITUDE  
3.045E-04 EQUIVALENT 3.045E-04 SLEWING 0.
INELASTIC STRAINS - MAGNITUDE  
3.045E-04 COMPONENTS 3.045E-04 -1.522E-04 7.136E-17

ELEMENT 150 POINT 2

Tensile Analysis of Creep in Plastics using the F.E. Method
## Tensile Analysis of Creep in Plastics using the F.E. Method

### Date: 3/10/83

#### TIME 15.24.14

#### PAGE 56

#### STEP 3 INCREMENT 55

**Tensile Test in Creep 1500 psi**

**Creep 1.06 - 10 hours**

**Stress Components**

| 1.500e+03 | -1.500e-11 | 6.277e-11 |

**Stress Invariants - Tresca**

| 1.500e+03 | -1.500e-11 | 6.277e-11 |

**Principal Stresses**

| -1.500e+03 | 1.500e+03 | 6.277e+03 |

**Total Stain Components**

| 4.437e-03 | -1.185e-03 | 2.650e-17 |

**Creep Stain Components**

| 3.045e-04 | -1.522e-04 | 2.650e-17 |

**Inelastic Stain Components**

| 3.045e-04 | -1.522e-04 | 2.650e-17 |

**Element 167 Point 4**

**Stress Components**

| 1.500e+03 | -1.500e-11 | 6.277e-11 |

**Stress Invariants - Tresca**

| 1.500e+03 | -1.500e-11 | 6.277e-11 |

**Principal Stresses**

| -1.500e+03 | 1.500e+03 | 6.277e+03 |

**Total Stain Components**

| 4.437e-03 | -1.185e-03 | 2.650e-17 |

**Creep Stain Components**

| 3.045e-04 | -1.522e-04 | 2.650e-17 |

**Inelastic Stain Components**

| 3.045e-04 | -1.522e-04 | 2.650e-17 |

**Element Energies**

| 2.141e-02 |

**Approximate Energy Totals**

| Strain Energy | 23.2 |

**External Work**

| 2.6 |

**Plastic Dissipation**

| 0.1 |

**Creep Dissipation**

| 0.1 |

**Viscous Dissipation**

| 0.0 |

**Node Point Output Set All**

**Total Displacements**

<table>
<thead>
<tr>
<th>NODE X - COMPONENT Y - COMPONENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

---

### Notes

- **X**: Component
- **Y**: Component
- **Node X**: Component
- **Node Y**: Component
Tensile Analysis of Creep in Plastics using the F.E. Method
### Tensile Analysis in Creep 1500 PSI

**Creep 1.50 - 7 to 11 Hours**

<table>
<thead>
<tr>
<th>Node</th>
<th>Component X</th>
<th>Component Y</th>
<th>Component X</th>
<th>Component Y</th>
<th>Component X</th>
<th>Component Y</th>
<th>Component X</th>
<th>Component Y</th>
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<tbody>
<tr>
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### Reaction Forces

<table>
<thead>
<tr>
<th>Node</th>
<th>Component X</th>
<th>Component Y</th>
<th>Component X</th>
<th>Component Y</th>
</tr>
</thead>
<tbody>
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<td>-174.1</td>
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<td>124</td>
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<td>165</td>
<td>-102.1</td>
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</table>

### Concentrated Forces

<table>
<thead>
<tr>
<th>Node</th>
<th>Component X</th>
<th>Component Y</th>
<th>Component X</th>
<th>Component Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>93.75</td>
<td>0.</td>
<td>82</td>
<td>187.5</td>
</tr>
<tr>
<td>104</td>
<td>187.5</td>
<td>0.</td>
<td>205</td>
<td>93.75</td>
</tr>
</tbody>
</table>

The analysis has been completed.

End of run.
Tensile Analysis of Creep in Plastics using the F.E. Method
Tensile Analysis of Creep in Plastics using the F.E. Method