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NUMERICAL ANALYSIS OF LAMINATED, ORTHOTROPIC COMPOSITE STRUCTURES

Prepared by

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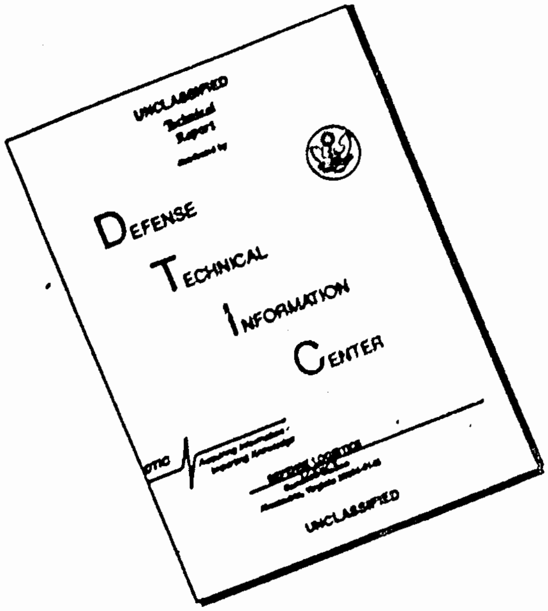

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This report presents the two main lines of investigation which were carried out during the past contract year. One investigation was intended to check-out previously developed finite-element computer programs on a large degree-of-freedom composite material model. This was done by applying the analysis to a recoilless rifle configuration. The finite-element grid and the numerical results for this problem are presented and discussed. The second line of investigation was concerned with developing fracture models for composite materials. Two different models were developed. One model deals with interla-

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minar failure and the other predicts the matrix failure within an individual composite ply. No suitable experimental results are presently available to check out the first model but the second model is found suitable for explaining experimental results dealing with a nonlinear response of certain cylindrical models loaded to failure by internal pressure. These results, obtained from experiments performed at the Ballistic Research Laboratories, show that pronounced nonlinear structural response occurs at a fraction of failure load which suggests that an appreciable degradation of material occurs at relatively low stress levels. It is shown that this phenomenon can be explained by a model that assumes that the shear modulus in the plane of the fibers is reduced by matrix material failure parallel to the fibers.

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I INTRODUCTION

During the first part of this investigation two finite-element models were developed[1,2] for the purpose of analysis of laminar, orthotropic structures in the form of bodies of revolution. The models allow for orthotropic axes to be arbitrarily oriented with respect to the cylindrical coordinates. Because of this, the models allow for three components of displacements including the two components in the meridian plane and the circumferential component. As a result, the models can be used to analyze unbalanced laminar configurations and interlaminar stresses can be predicted. The two models which have been developed differ in the basic finite-element shape which was used. The shape is defined by the cross-section of the elements in the meridian plane.

In the first model[1], a nine degree-of-freedom, straight sided, triangular element was used. In this element, the three components of displacement are defined at each corner of the triangle and a linear displacement variation is assumed inside the element. In the second model[2], a higher order, isoparametric element was used with quadratic displacment variations for two of the meridian displacements and a linear variation for the circumferential component. These elements are triangular with curved sides and mid-side nodes in addition to the corner nodes. Each of these elements possesses fifteen degrees-of-freedom.

A number of numerical examples were analyzed with both of these models to check-out the methods and the associated computer programs. One of these examples was analyzed by both models and was intended to compare the relative accuracy of each method. It was found that, for an equivalent number of total degrees-of-freedom, the results given by both methods were very close[2]. Although the total number of degrees-of-freedom in both models was the same, fewer of the isoparametric elements had to be used. The conclusion from this study was that each of these models was equally accurate and either one could be used for any given problem.

The various examples which were analyzed[1,2] during check-out contained relatively few degrees of freedom. However, both computer programs were designed to handle much larger problems and consequently it was desired to check-out this capability. Since both of these programs are similar in their solution of the global matrix equations, it was decided to apply only one of these programs to a large problem. For this, the model with the straight sided elements[1] was chosen since it permitted a large number of elements to be used for a given total number of degrees-of-freedom. This fact was advantageous in the problem to be analyzed since it permitted more flexibility in modelling the orthotropic plies of the structure. The problem analyzed corresponds to a recoilless rifle configuration made up from a large number of orthotropic, fiberglass plies. The analysis of

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[1] A. R. Zak, "Second Quarterly Report," U.S. Army Contract No. DAAD05-73-C-0197.

[2] A. R. Zak, "Final Report," U. S. Army Contract No. DAAD05-73-C-0197, January, 1974.

this structure and the numerical results will be discussed in the first part of this report.

The second line of investigation was concerned with the failure analysis of laminated structures. Two possible modes of failure were postulated and numerical methods necessary to examine them were developed. These methods are related to the linear finite-element method discussed previously.[1] The first mode of failure to be examined consists of interlaminar cracking. In this model an ultimate shear stress is assigned to the region between the composite plies and the plies are allowed to slip relative to each other when this stress is exceeded. In the second model the failure is assumed to occur inside the matrix of an individual ply. This failure is gradual since the matrix stresses are not uniform and, consequently, higher stressed regions would fail first. The consequence of such failure is a reduction in the effective transverse material properties of the total composite ply.

Each of these failure modes was considered a possible explanation of certain experimental results, which were obtained at the Ballistic Research Laboratories[3]. In these experiments a strong nonlinear response was observed when certain laminated cylindrical specimens were loaded up to the failure level. The cylinders were loaded by time dependent internal pressure and produced a nonlinear strain-pressure history. Both the longitudinal and the circumferential strains were measured and the response was found to be nonlinear even at loads only a fraction of the ultimate value. This suggests that a measurable degradation of the material properties occurs, and the objective was to determine if either one of the failure models could explain this behavior. This study is described in the second part of the report.

II LINEAR STRESS ANALYSIS OF RECOILLESS RIFLE

Finite-Element Model

The cross-section of the recoilless rifle is shown in three parts in Figures 1 to 3. It can be seen that the rifle is composed of two sections of fiber-reinforced composite material joined together by an adhesive layer. The composite material is arranged in helical and hoop plies. The helical plies are arranged in pairs with equal and opposite wrap angle. There are two distance scales used in the radial direction in Figures 1 to 3. One scale is used for the internal surface and another scale, 3.58 times larger, is used for distances inside the cross-section. Consequently, the model looks 3.58 times as thick as the real structure. However, in the finite-element stress analysis, the correct dimensions are used.

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[3] J. N. Majerus, W. F. Donovan and R. W. Greene, "Hot Gas Test Fixture with Minimized End Restraints for Rapidly Pressuring Anisotropic Tube Type Structures," Ballistic Research Laboratores, Memorandum Report No. 2459, March 1975. (AD #B003671L)

In the finite-element model, the structure is divided into 1368 elements and the element boundaries are chosen so as to correspond to the boundaries of the composite material plies. A set of elements was also chosen to correspond to the adhesive layer. The finite-element grid can first be illustrated in the I-J coordinates which is shown in Figures 4 to 6. In this coordinate system, each element is represented by a square. This representation of the finite-element grid is useful in establishing the information for the generation of the actual finite-element model as well as other necessary input data. In Figures 4 to 6, the solid lines illustrate the material block cards and the dotted lines are the elements inside each block. Altogether there were 123 material blocks used. One of these blocks was used to define the adhesive layer and the remaining blocks contained composite, orthotropic material. The computer program[1] allows for the orthotropic axes to differ from block to block. In each block the axes of orthotropy in the meridan plane is constant and the helical orientation of the axes can either be constant or vary by a factor of plus or minus[1]. In Figures 4 to 6, the I-J coordinates are shown for selected nodes in order to illustrate the size of the grid. The actual finite-element grid generated in the program and used in the stress analysis is shown in Figure 7. This grid was generated in the computer and as in the case of Figures 1 to 3, two different plotting scales were used in the radial direction in order to illustrate cross-sectional detail.

The elastic orthotropic properties for the composite material which were used in the analysis are given in Table I below:

Table I

Elastic Orthotropic Material Properties for the Composite Material

E_n = 58.6 GPa

E_s = 13.79 GPa

E_t = 13.79 GPa

ν_{ns} = .25, G_{ns} = 4.82 GPa

ν_{nt} = .25, G_{nt} = 4.82 GPa

ν_{st} = .45, G_{st} = 1.379 GPa

The nomenclature in Table I corresponds to the definitions given in Reference 1. The direction n is chosen along the fibers, s is perpendicular to the fibers and in the plane of the laminar, and t is the remaining orthotropic axis in the transverse direction. The mechanical properties for the adhesive layer were assumed to be isotropic and the Young's modulus and Poisson's ratio used was E = 3.44 GPa and ν = 0.35.

The load applied to the structure was assumed to be composed of an internal pressure acting on the inside surface of the structure. In the chamber section the pressure was assumed to be uniform and equal to 6.895×10^7 Pa. In the barrel section, where the radius is constant, the pressure was continued at the same constant value. In the nozzle throat the pressure was assumed to make a step jump and a uniform pressure of 1.385×10^7 Pa was used on the diverging section of the nozzle. This value was chosen as to balance the total load acting on the structure. The pressure load just described is illustrated in Figure 8. It may be noted that although the pressure distribution at the nozzle and barrel sections is somewhat arbitrary, this will not be a critical factor since the largest stresses are produced in the chamber section and these are mainly a function of the chamber pressure. If the chamber pressure should not be equal to 6.895×10^7 Pa as used in this analysis, the corresponding stresses can be obtained from this analysis by linear scaling.

Numerical Results

Because of the large number of degrees-of-freedom involved in this analysis, a great deal of stress and strain data was generated by the solution. At each nodal point the solution generates three components of displacement and for each element two sets of stresses and strains are calculated. One set is in the cylindrical coordinates and the other is along the axes of orthotropy. Consequently, it is practical to present here only a small amount of this data. In choosing the data for presentation, it was observed that the largest stresses occur in the hoop direction and that they are in the chamber region of the structure. Figures 9 to 11 show the radial hoop stress distribution at three different axial stations defined approximately by $z \approx 139.7$ mm, 223.5 mm and 322.5 mm respectively. Also shown in these diagrams are the stresses in the direction of the glass fibers. The hoop stresses are given by the dotted curves and the stresses in the fiber direction are given by the solid curves. In the case of the hoop plies, the two curves obviously coincide and only the solid curve is seen. Figures 12 to 14 show similar results for the shear stresses in the plane of the orthotropic plies at the same values of z. It can be observed from these figures that there are large variations of the stresses through the thickness and this variation is most pronounced when going from a helical to a hoop ply. As expected, the largest fiber stresses occur in the hoop plies as can be seen from Figures 9 and 10. In Figure 9 two hoop plies exist through the thickness and these produce the two peaks shown. In Figure 10 we also encounter two hoop layers leading to two peaks, and furthermore, there is a pronounced dip in the curves as the adhesive layer is crossed. The results in Figure 11 show stresses through helical plies only, but there is still a large variation due to change in helical angle through the thickness. The largest transverse shear stresses occur in the helical plies and these stresses are also discontinuous from one ply to another.

Other interesting results are the stresses in the adhesive layer. In Figure 15 a plot is given showing the variation of the maximum shear stress, the hoop stress, and the longitudinal stress as a function of the corrdinate z. The failure of the adhesive layer would be governed by the maximum shear stress which can be seen from Figure 15 to be about 6.2×10^7 Pa. Further results are shown in Figure 16 where an axial distribution is shown of the maximum fiber stress and the maximum transverse shear stress through the thickness of the cross-section. It can be seen that a large variation of these stresses exists in both the nozzle and the chamber sections.

In conclusion, it is interesting to note the maximum fiber stress and its location. The maximum fiber stress occurred in element number 927 and its magnitude was 168.7×10^7 Pa. This element is in the hoop ply region and its approximate position is identified in Figure 3. The average coordinates for this element are r = 58.6 mm and z = 202.8 mm.

III NONLINEAR MATERIAL RESPONSE

Experimental Results

Figures 17 and 18 show one set of typical results of an experimental investigation conducted at the Ballistic Research Laboratories[3]. In this study a set of cylindrical fiber reinforced models was subjected to time dependent internal pressure loads which eventually led to total structural failure. The specimens were made from S glass fibers with six plies as shown in Figure 19. The four internal plies were constructed with a 54 degree helix angle and the two outside plies with an 83 degree angle. These angles were alternated in each successive ply in order to produce a balanced structure. The length of each cylinder was 388.62 mm, the inside diameter was 67.56 mm and the ply thicknesses are given in Figure 19.

The cylinders were loaded by burning about 0.09 kg of propellent which produced a time dependent pressure-time curve. The ends of each cylinder were sealed by plugs as shown in Figure 20. These plugs did not apply an appreciable axial load to the cylinder, and as the cylinder expanded some amount of gas was released between the cylinder and the plugs. A detailed description of the experimental apparatus can be found in Reference 3.

The results shown in Figures 17 and 18 contain the strain measurements obtainable from strain gages situated on the external surface of the cylinder. The strains are given as a function of the internal pressure. The strain gages were mounted to measure both the circumferential and longitudinal strains as a function of time, and then these strains were correlated with the recorded pressures. These strains were measured at three different points in the cylinder, two of these being at 12.7 mm from the cylinder ends and the third at the center. All three readings are shown in Figures 17 and 18, and it can be seen that there is a measurable experimental difference between the readings. Some of this difference may be attributed to end effects.

However, only a small amount could be explained by this, since as the subsequent numerical calculations showed, the end effects die down quite rapidly.

The results for both the longitudinal, Figure 17, and the circumferential strains, Figure 18, show a pronounced nonlinear response. Furthermore, the nonlinear effects are more pronounced in the longitudinal strains. This can be illustrated by considering the slope of the response curves for both directions. Because of the variation between the different parts of the cylinder, it is necessary to speak of some average response. This is indicated by the solid lines drawn in Figures 17 and 18, which are approximately the average values of the three strain gage readings. In order to illustrate the relative nonlinearity in the two directions, the slopes of these curves were normalized relative to their initial slope at low pressure loadings, and the results of this are illustrated in Figure 21. The relative amount of nonlinearity can be measured by the deviation of this normalized slope from the value of 1.0, and it can be seen that this effect is most pronounced in the longitudinal direction.

Linear Stress Analysis

As the first step in the nonlinear investigation, a linear stress analysis was performed on the model corresponding to the experimental configuration shown in Figure 19. This was done by using the previously described[1] finite-element program. Because of a symmetry about the center line only one half of the cross-section had to be modelled by the finite-elements. This was done by using 20 nodes over half of the cylinder and 25 nodes in the thickness direction. Each ply was represented by four elements through the thickness. The size of the elements in the longitudinal direction was varied by using smaller elements near the ends of the cylinder. This was done by using two elements 3.17 mm in length followed by two elements 6.34 mm in length. The remaining sixteen elements were divided equally. This grid permitted a good resolution of the end stresses and Figure 22 shows the axial variation of the maximum shear stress σ_{rz}. It can be seen that these stresses are limited to only a very small distance of the ends of the cylinder. The results of this analyses show that the stress conditions are essentially constant over the length of the cylinder. This is expected since the thickness of the cylinder relative to the radius is very small as seen in Figure 19.

Initially there was no guarantee that the orthotropic material properties used in the finite-element analysis would correspond exactly to the experimental model. Consequently, initially a reasonable set of values was chosen and the calculated response was compared to the measured response at low pressure levels. The results of this initial calculation showed insignificant variation of stresses and strains through the thickness of each ply as illustrated in Figure 23 where the fiber σ_{11} is plotted over the thickness of the cylinder. Therefore, in the subsequent calculations each ply was represented by one element in the thickness direction. This permitted a small grid size and, consequently, much faster execution time. After the initial linear calculation the material properties were adjusted as to agree with the experimental data, and these values are given in Table II below:

Table II

Elastic Orthotropic Material Properties for the Test Cylinder

$$E_n = 38.2 \text{ GPa}$$

$$E_s = 9.37 \text{ GPa}$$

$$E_t = 9.37 \text{ GPa}$$

$$\nu_{ns} = 0.25, \quad G_{ns} = 3.3 \text{ GPa}$$

$$\nu_{nt} = 0.25, \quad G_{nt} = 3.3 \text{ GPa}$$

$$\nu_{st} = 0.45, \quad G_{st} = .896 \text{ GPa}$$

The properties in Table II have the same meaning as in Table I.

In the linear calculation, the actual value of the pressure is not important since the load and the stresses are linearly scaled. Table III below contains some of the results obtained by using a pressure of 6.895×10^6 Pa uniformly distributed over the length of the cylinder. The results given are the stresses in the local orthotropic coordinates for each material ply. The plies are numbered starting on the inside of the cylindrical surface. Only four stresses are shown since the remaining two stresses were found to be negligible.

Table III

Calculated Linear Stresses in the Test Cylinder ($\div 10^6$ Pa)

Ply Number	σ_n	σ_s	σ_t	σ_{ns}
1	100.8	4.9	-6.6	-25.47
2	99.7	5.0	-6.0	25.3
3	99.0	4.9	-5.5	-25.2
4	97.9	5.0	-4.9	25.2
5	191.7	-13.5	-3.5	- 6.3
6	189.6	-12.7	-1.0	6.3

It can be seen from Table III that, as expected, the largest stresses are the normal stresses σ_n along the fibers. The highest fiber stresses occur in the two outside plies which have the helical angle of 83 degrees. The next largest stresses are the shear stresses σ_{ns} and they are more predominant in the four inside plies. The remaining two stresses, σ_s and σ_t, are appreciably smaller. These results suggest that the maximum stress existing in the matrix material are shear stresses resulting from σ_{ns}.

Methods of Analysis

A. Interlaminar Slip

One possible failure mode in a laminated, composite structure is the separation of individual plies when interlaminar shear stress exceeds a critical value. If this phenomena would occur in any given strucutre, it would lead to a nonlinear response. In order to analyze this response it would be necessary to use an iterative, numerical approach. The objective was to develop such a method of analysis by using previously developed[1] finite-element computer program as the basis. The results of this study are presented in this section.

The approach which has been developed can be illustrated by considering the four adjacent elements to a node which lies on the interface between material layers as shown in Figure 24a. The first step in the analysis is to check if a prescribed interlaminar shear stress is exceeded at this point in the material. Since the stresses are calculated in the elements, rather than the nodes, the failure at the node shown in Figure 24a is defined in terms of the resultant shear stresses in the four adjacent elements. The resultant shear stresses are calculated in each laminar parallel to the interlaminar plane. The average of this resultant stress over the adjacent elements is then compared against a prescribed failure criterion.

Referring to Figure 24a the elements above the interlaminar plane are called the upper elements and below they are the lower elements. If the shear stress exceeds the failure criterion at a particular node then there will be a relative motion of the upper and lower elements as illustrated in Figure 24b This motion will be characterized by the physical condition that the net forces on the upper and lower elements at the given node which has failed will be zero parallel to the interlaminar plane. The slip displacements are characterized by two components for the upper and two for the lower elements. These components can be transformed into the cylindrical coordinates by the relations

$$\{\delta^U\} = [T]\{\Delta^U\}$$

$$\{\delta^L\} = [T]\{\Delta^L\} \qquad (1)$$

where $\{\delta\}$ is the displacement vector in cylindrical coordinates due to nodal slip, $[T]$ is the transformation matrix, and $\{\Delta\}$ the two slip components. The superscripts U and L refer to the upper and lower elements. Before the slip has occurred the nodal displacements for each element are known and therefore these known displacements are added to the displacements due to the slip as given by Equations (1). Consequently, the net force components on the upper and lower elements can be expressed in the following form

$$\{F^U\} = \{f^U\} + [Y]\{\Delta^U\}$$

$$\{F^L\} \quad \{f^L\} + [Z]\{\Delta^L\} \tag{2}$$

where F represents total force and f is the force due to known displacements. The matrices [Y] and [Z] are known and are related to the stiffness matrices. The forces in Equations (2) are originally in cylindrical coordinates and by suitable transformation it is possible to obtain the two force components in the interlaminar plane. These components can be expressed in the form

$$\{P^U\} = \{A^U\} + [B^U]\{\Delta^U\}$$

$$\{P^L\} = \{A^L\} + [B^L]\{\Delta^L\} \tag{3}$$

The condition for failure at a given node is now specified by the requirement of zero inplane forces

$$\{P^U\} = 0$$

$$\{P^L\} = 0 \tag{4}$$

Equations (3) and (4) represent a set of four algebraic equations in the unknown slip components $\{\Delta^U\}$ and $\{\Delta^L\}$.

In the present method the above analysis is systematically applied to each node. First, each node at which interlaminar failure can occur is identified and checked for failure. If failure criterion is exceeded then slip components are calculated as indicated above.

One calculation at each node is, however, not sufficient. It can be easily seen that if failure occurs at two or more adjacent nodes the calculation of zero forces is not independent at each node. For example, if the condition of zero forces is satisfied at the first node, then when the similar conditions are specified at the adjacent node, the forces at the original node will be changed since they share some of the adjacent elements. Consequently, this calculation for each node is performed more than once in an iterative fashion. In order to perform these calculations, the finite-element computer program from Reference 1 was used and modified by adding subroutines SET and ITERAT. A partial flow chart showing the relative positions of these two subroutines is given in Figure 25. For convenience this flow chart shows only some of the main subroutines which are pertinent to our discussion. The subroutine SET sets some of the data necessary to define the direction and the areas of possible interlaminar cracking. The iteration for satisfying zero interlaminar forces are performed in the subroutine ITERAT and this calculation is repeated a number of times in the loop DO 900 IS = 1, NSLIP. The parameter NSLIP is an inputed variable. As will be illustrated in a numerical example, this iteration does converge rather quickly. At each iteration additional slip components are calculated and added to the original displacements. In order to achieve a smooth convergence it was found desirable to modify the calculation slightly by only adding half of the slip displacements to the original displacements in each calculation cycle. The reason for this modification is that adjacent nodes share some of the elements and therefore these elements have their nodel displacements modified twice during each calculation cycle. Once the zero forces are obtained at each node, the overall equilibrium of the structure is disturbed and the total equilibrium has to be recomputed. This is done in the loop DO 900 INP = 1, NEQL, where again NEQL is an inputed variable. It can be seen that for each calculation of equilibrium the node check for failure and calculation of slip components is performed NSLIP times.

In the modified computer program the input cards are similar to those used in the original linear version[1] except three additional input cards were added. All the input parameters are described in Appendix A. The three additional cards are "Crack Iteration Card", "Crack Direction Card" and "Failure Block Definition Card." The listing of the modified computer program is given in Appendix B.

In order to check out the convergence of this method a simple numerical example was chosen. The example consists of a hollow circular cylinder as shown in Figure 26a. One end of the cylinder is clamped and the other is subject to a shear load of 6.895×10^7 Pa over part of the boundary. The cylinder is composed of four orthotropic layers oriented in the axial direction. The finite-element grid used in the analysis is shown in Figure 26b. In the radial direction the elements are chosen to correspond to the orthotropic layers. In the computer program it is possible to specify shear failure at any arbitrary interlaminar region and in this example the failure was specified to be possible in the center interlaminar plane. More specifically, failure was allowed at nodal points 8, 13, and 18 shown in Figure 26b.

The actual failure, and resultant nodal slip will depend on the magnitude of the failure stress. At first the failure stress was chosen at a low value of 5.5×10^6 Pa. This caused failure at the nodal points 13 and 18 where the original resultant interlaminar shear stresses were 6.2×10^6 Pa and 2.1×10^7 Pa respectively. This means that at the nodal point 18 the ratio of the resultant stress to the failure stress was nearly 4. First the convergence of the nodel equilibrium iteration was examined. This iteration is governed by parameter IS. The measure of how fast this iteration converges are the nodal forces in the plane of failure. In this example it is possible to examine the axial force at node 18 on the upper elements of Figure 23a as a function of IS. This force is given in Table IV as a function of IS together with the initial value.

Table IV

Convergence of the Nodal Equilibrium Iteration

Iteration Number IS	Nodal Force (Newton's)
0	3.86×10^3
1	0.128×10^3
2	0.0004×10^3

It can be seen from Table IV that this iteration step is rapidly convergent.

Consider now the convergence of the iteration on the total equilibrium of the structure. This iteration is governed by the parameter INP. Again it is possible to measure this convergence by the nodal axial force at the node 18. In order to obtain a better feeling for this convergence, the example was also repeated for failure stress of 17.2×10^6 Pa. Consequently, at the node 18 the resultant stress exceeds the failure stress by a factor of approximately 1.25. Table V shows the value of nodal force for both values of the failure stress as a function of the iteration parameter INP.

Table V

Nodal Force (Newton's)

Iteration Number INP	Failure Stress 5.5×10^6 Pa	Failure Stress 17.32×10^6 Pa
1	3.87×10^3	3.87×10^3
2	1.61×10^3	1.06×10^3
3	$.38 \times 10^3$	0.30×10^3
4	$.347 \times 10^3$	0.0084×10^3

It can be seen from Table V that when the failure stress is closer to the actual stress, then the convergence is faster as expected. However, even when the failure stress has been exceeded by a factor of 4, as in the case of 5.5×10^6 Pa failure level, the convergence to 10 percent of the original force is achieved in four cycles.

B. Matrix Material Failure

The results presented in Figure 22 show that the interlaminar stresses in the cylindrical model used in the experimental investigation are very small compared to the other stresses and are confined to a small region near the ends of the cylinder. Consequently, it is not possible that the experimentally observed nonlinear effects could be explained in this case by the interlaminar failure model described in the previous sections. This suggests that another failure mode is occurring inside the orthotropic plies. Since the nonlinear effects were observed at fiber stresses equal to a fraction of the ultimate values, this suggests that fiber failure can be ruled out as the cause and matrix material failure must be considered.

In order to develop a failure model for the matrix, it is recognized that the transverse shear stress is transferred between the fibers and the matrix, and this stress will depend on the position inside the composite material. This can be illustrated by considering a schematic representation of a composite material as shown in Figure 27. In this diagram, a rectangular cube of the material is shown subjected to shear stress σ_{ns} and the fibers are assumed to be randomly packed. In certain region of the material, labelled A, the fibers may be close together and in other region, labelled B, the fibers will be relatively far apart. If the fiber material is assumed to be much more rigid than the matrix, as is the case for the glass reinforced materials, it can be shown that the shear stress in region A will be appreciably larger than in the region B. For idealized materials with regular fiber arrangement, this variation has been calculated analytically[4,5] and numerically[6,7] by other investigators, but in the case of real materials with random packing this is not possible. Therefore, we proceed with an empirical relationship which states that the local matrix shear stress $(\sigma_{ns})_m$ is proportional to the overall shear strain in the composite material γ_{ns} and it can be expressed in the form

$$(\sigma_{ns})_m = K \gamma_{ns} \tag{5}$$

---

[4] J. A. Kies, "Maximum Strains in the Resin of Fiberglass Composites," NRL Report 5752, March 1962.

[5] J. C. Schultz, "Maximum Stresses and Strains in the Resin of a Filament-Wound Structure," Presented at the 18th Annual Meeting of the Reinforced Plastics Conference, SPI, February 1963.

[6] D. F. Adams and D. R. Doner, "Transverse Normal Loading of a Unidirectional Composite," J. Composite Materials, Vol. 1, No. 2, 1967, p. 152.

[7] D. R. Adams and S. W. Tsai, "The Influence of Random Filament Packing on the Transverse Stiffness of Unidirectional Composites," J. Composite Materials, Vol. 3, July 1969, p. 368.

where K is a proportionality parameter and varies throughout the composite material. Some idea of how K can vary can be obtained from the previous studies on idealized materials, and it has been found to be dependent on the fibers and the matrix.[4,5,6,7]

Consider now the problem of matrix failure. Since the various regions of the matrix are subjected to different levels of shear stress, the failure of the material will proceed gradually through the material with the regions most highly stressed failing first. Consequently, for a given shear strain γ_{ns} a certain amount of matrix will fail which in turn will lead to the reduction of the shear modulus G_{ns}. We can express this by the relation

$$G_{ns} = G_{nso} \, P(\gamma_{ns}) \tag{6}$$

where G_{nso} is the original value of the modulus, and the function $P(\gamma_{ns})$ contains the modulus reduction factor which depends on the applied shear strain γ_{ns}, the elastic properties of the components, and the fiber geometry. Once the geometry of the composite material and the ultimate stress are determined we can regard Equation (6) as a function of γ_{ns} only. In view of the fact that the random fiber configuration in real materials prevents deterministic solution, we must regard Equation (6) as an empirical relation to be established experimentally. The objective here is to do this using the experimental results described in the previous section.

As the first step in determining the relation expressed by Equation (6), it is assumed that the shear failure will only occur in the four inner plies where the maximum shear stress occurs as seen in Table III. In the next step a specific value of the function $P(\gamma_{ns})$ in Equation (6) is chosen. The first choice can be denoted by P_1 and therefore the shear modulus is given by

$$G_{ns} = G_{nso} \, P_1 \tag{7}$$

At this point it is not known what internal pressure level p will produce the particular amount of failure corresponding to P_1. Consequently, the pressure is chosen in the form

$$p = cp_o \tag{8}$$

where p_o is a convenient known level of pressure, which in our case we used 6.895×10^6 Pa and c is an unknown factor. Stress analysis is now performed using the pressure p_o. From this analysis we can use either the results for the circumferential or the longitudinal strains to compare to the results obtained by initial calculation for the undamaged material using G_{nso} modulus. In this analysis the longitudinal strains were compared. For this comparison a ratio $\varepsilon_z/\varepsilon_{zo}$ is calculated where

ε_z and ε_{zo} are the strains corresponding to the moduli G_{ns} and G_{nso} respectively. Using the solid line in Figure 17 it is possible to calculate the experimental value for the ratio $\varepsilon_z/\varepsilon_{zo}$ as a function of the pressure. At this stage the calculated and the experimental values are compared and this determines the actual pressure which corresponds to the chosen value of P_1 and also, from Equation (8), the constant c is determined. Knowing this constant, the shear strain corresponding to P_1 is known. By repeating this process for different values of the function $P(\gamma_{ns})$ given by P_2, P_3 etc., a continuous relation can be established defining this function. In the present calculations four values of $P(\gamma_{ns})$ were used which varied from 1/2 up to 1/32. This last value was found to correspond to the experimental data near the failure region, and it was reasonable not to reduce the modulus any further. Figure 27 shows variation of the function $P(\gamma_{ns})$ with the shear strain. Using function $P(\gamma_{ns})$ the circumferential strain was calculated and compared to the experimental results in Figure 18. It can be seen that a good agreement is obtained with the experimental data. The calculated longitudinal response will agree with the solid curve in Figure 17 since this data was used to define $P(\gamma_{ns})$.

In the calculations which lead to the results shown in Figure 28, the shear failure was allowed only in the four inner plies. The failure could also occur, to a much smaller extent, in the two outer plies with the helix angle of 83 degrees. Consequently, the results in Figure 28 can be considered as a first approximation. In order to establish the effect of the failure in the outer plies, the function $P(\gamma_{ns})$ from Figure 28 was used for both plies and stress analysis calculations were repeated allowing both inner and outer plies to fail. The results were only slightly different from those in which only the inner plies failed.

Once the model, which predicts the nonlinear response of this particular cylindrical configuration, has been established, it is possible to use it to examine the effect on the stress levels. One interesting result is the difference in the normal stresses in the fiber direction in the linear and the nonlinear analyses. For example, it is interesting to compare these stresses in the outer plies which carry the highest stresses. Using a pressure value of 27.58×10^6 Pa, which is close to the failure load, the ratio of the fiber stresses from the nonlinear to the linear analysis was found to be approximately 1.1. This means that the actual fiber stresses are about 10 percent higher than those predicted by the linear analysis. By the same token it may be mentioned that the fiber stresses in the inner plies are reduced by the nonlinear effects. These results are illustrated in Table VI where the fiber stresses are shown for the undamaged and the damaged situation for the six plies. Two different sets of damaged data are presented and these correspond to allowing matrix damage in the inner plies only, and then allowing both inner and outer plies to fail.

Table IV

Comparison of Fiber Stress σ_n ($\div 10^6$ Pa) for Undamaged and Damaged Matrix Situations

Ply Number	Undamaged Stress	Inner Plies Damaged Only	Inner & Outer Plies Damaged
1	100.6	97.3	97.2
2	99.7	95.8	95.6
3	99.0	94.9	94.9
4	97.9	93.4	93.3
5	191.7	216.3	216.9
6	189.6	214.0	214.7

It can be seen from Table IV that the damage in the outer plies produces little additional changes in the stresses.

IV CONCLUSIONS

From the analysis of the recoilless rifle configuration we can conclude that the finite-element computer programs[1,2] which have been developed, are capable of detailed stress analysis of rather complex structures. Since the analysis allows for the modelling of each ply as a separate material, the interlaminar stresses, as well as individual ply stresses, are generated by these programs. These programs should be a valuable tool in future engineering analyses of composite material structures.

Two different models for describing failure of composite materials have been developed. One of these models analyzes interlaminar failure and a computer program has been developed for this model. The computer program uses a finite-element method and an iteration scheme for determining where and when failure occurs. Every time failure occurs at any point in the structure, the total equilibrium of the structure is reevaluated. The second failure model is based on matrix failure inside individual plies by transverse shear stresses. In this model the effect of failure is to reduce the transverse shear modulus of the ply. Using this model, the stress calculation can be performed by linear finite-element model by varying the material properties. The results of this model are compared with nonlinear experimental data for cylindrical six ply models. It is found that this model does predict the correct longitudinal and circumferential response.

ACKNOWLEDGEMENT

This work was sponsored by the U.S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, under Contract No. DAAD05-73-C-0197, as part of the Short-Range Man-Portable Antitank Weapons Technology (SMAWT) Program.

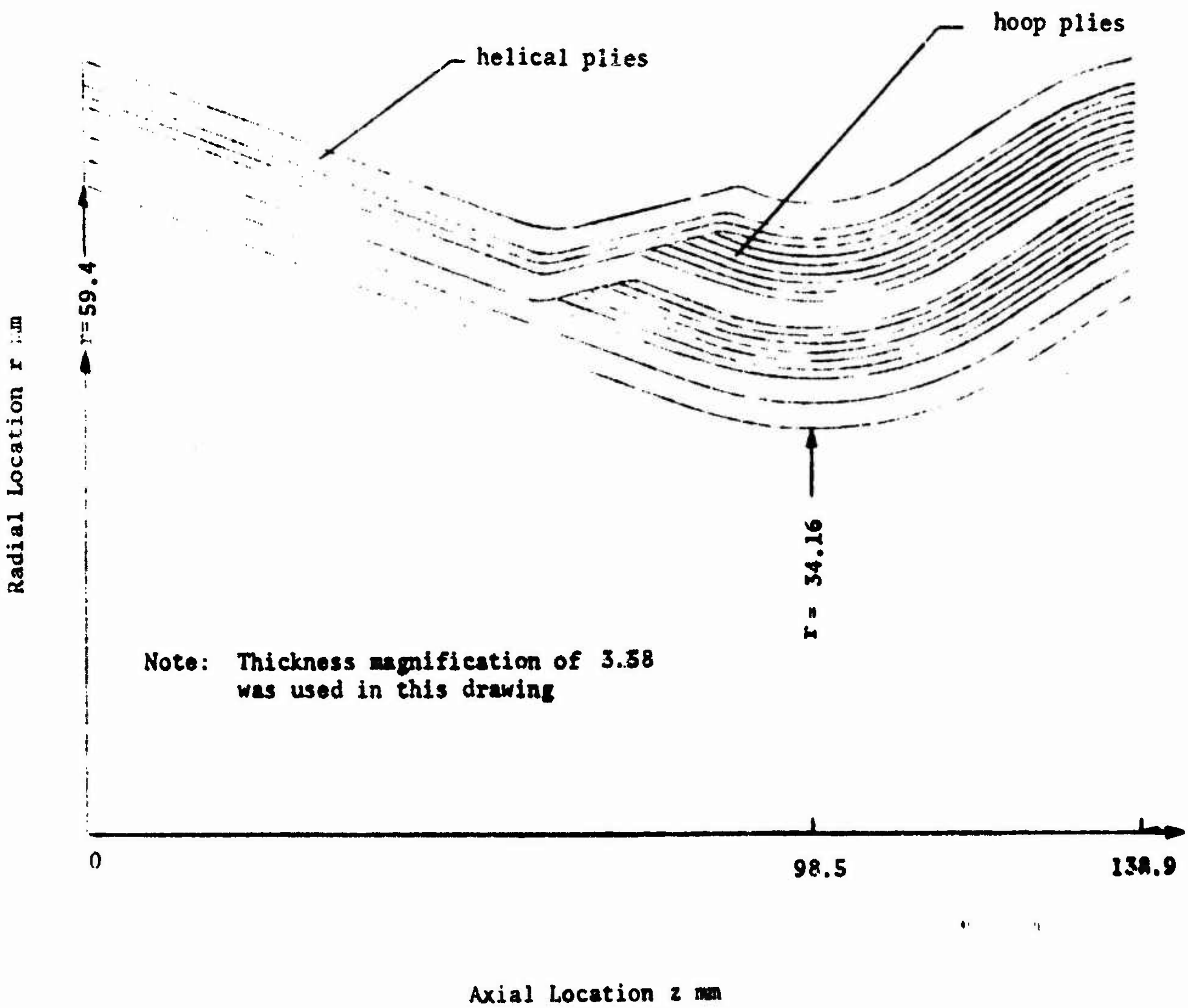


Figure 1. Nozzle section of the recoilless rifle.

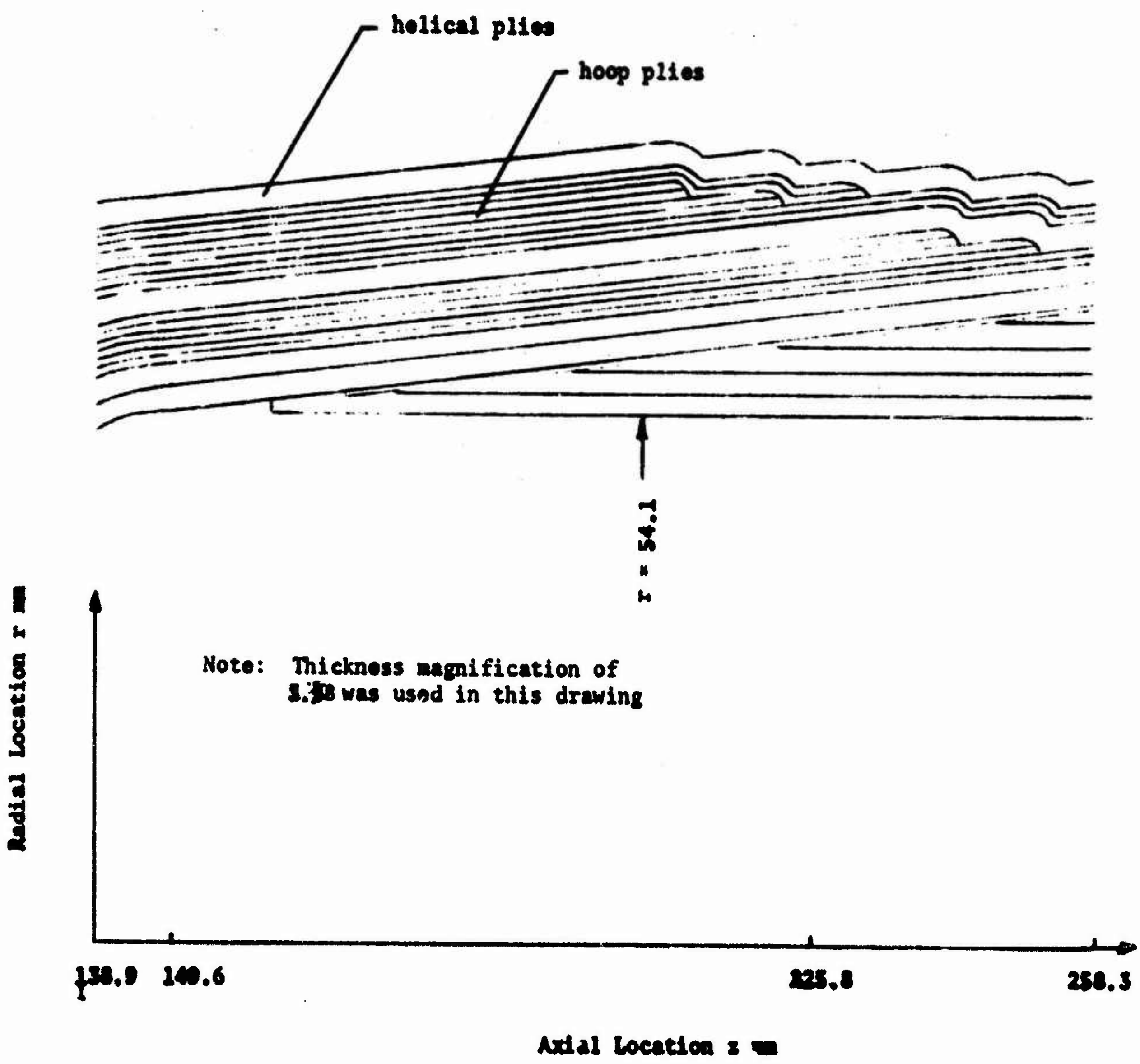


Figure 2. Center section of the recoilless rifle.

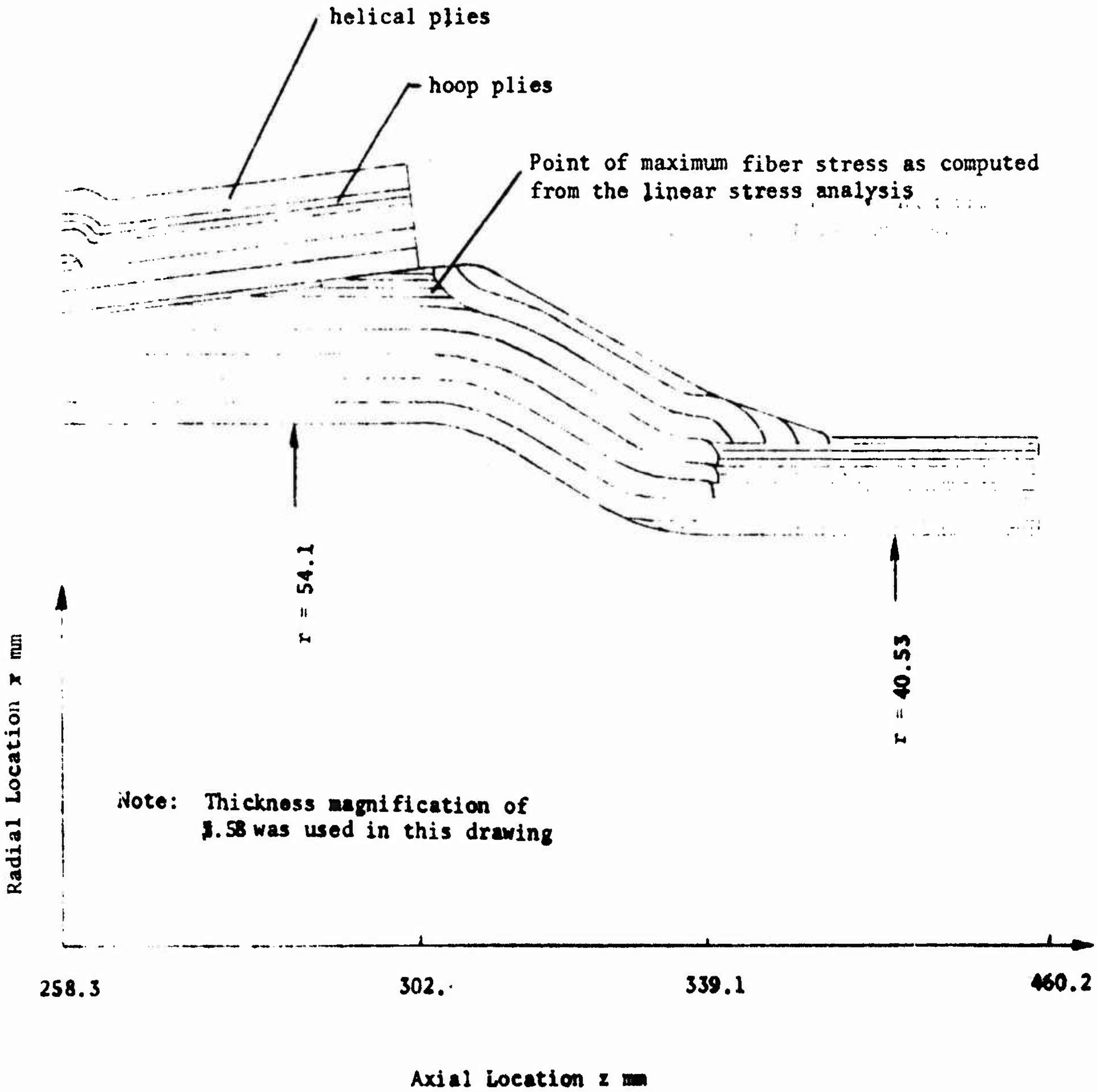


Figure 3. Forward section of the recoilless rifle.

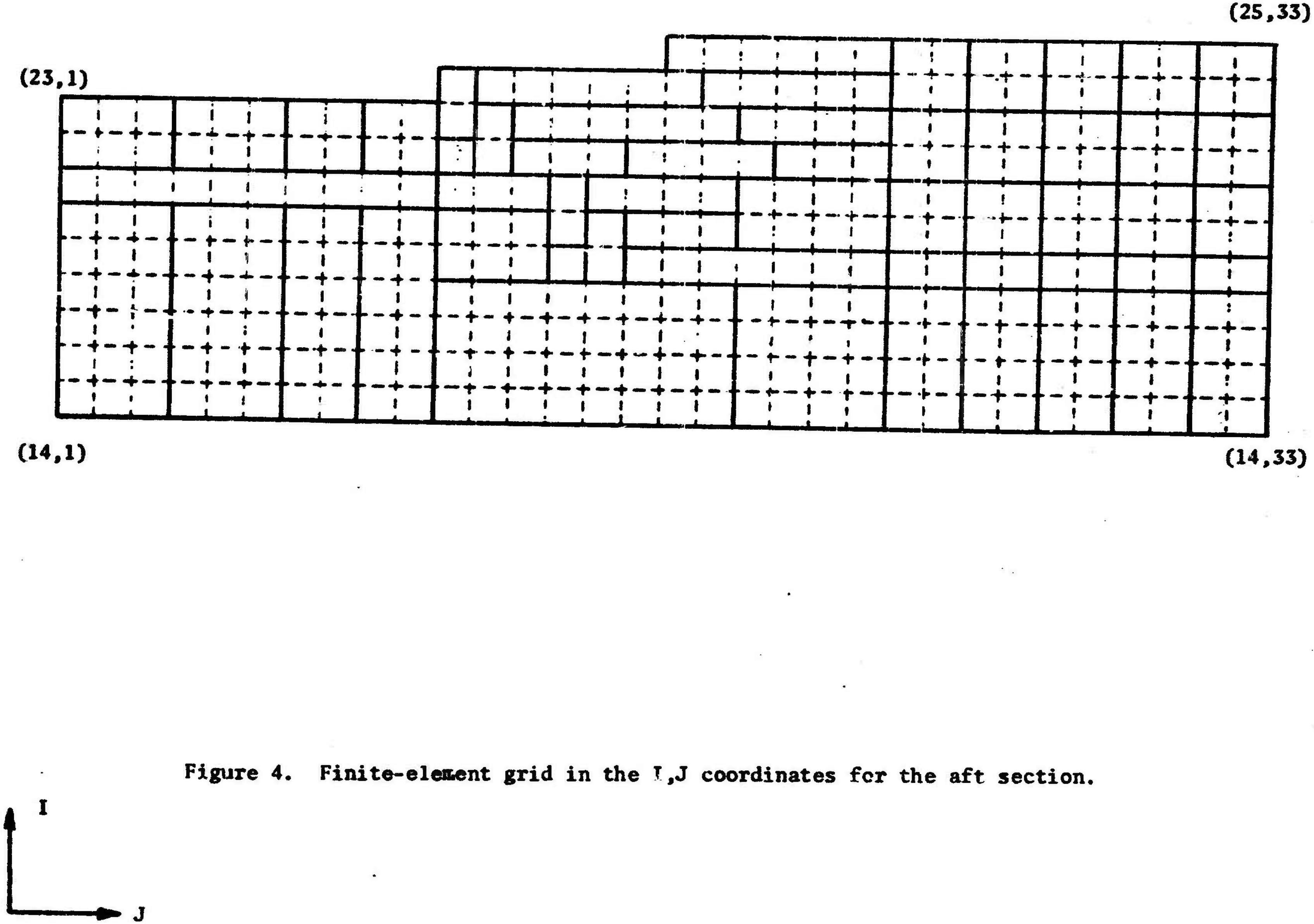


Figure 4. Finite-element grid in the I,J coordinates for the aft section.

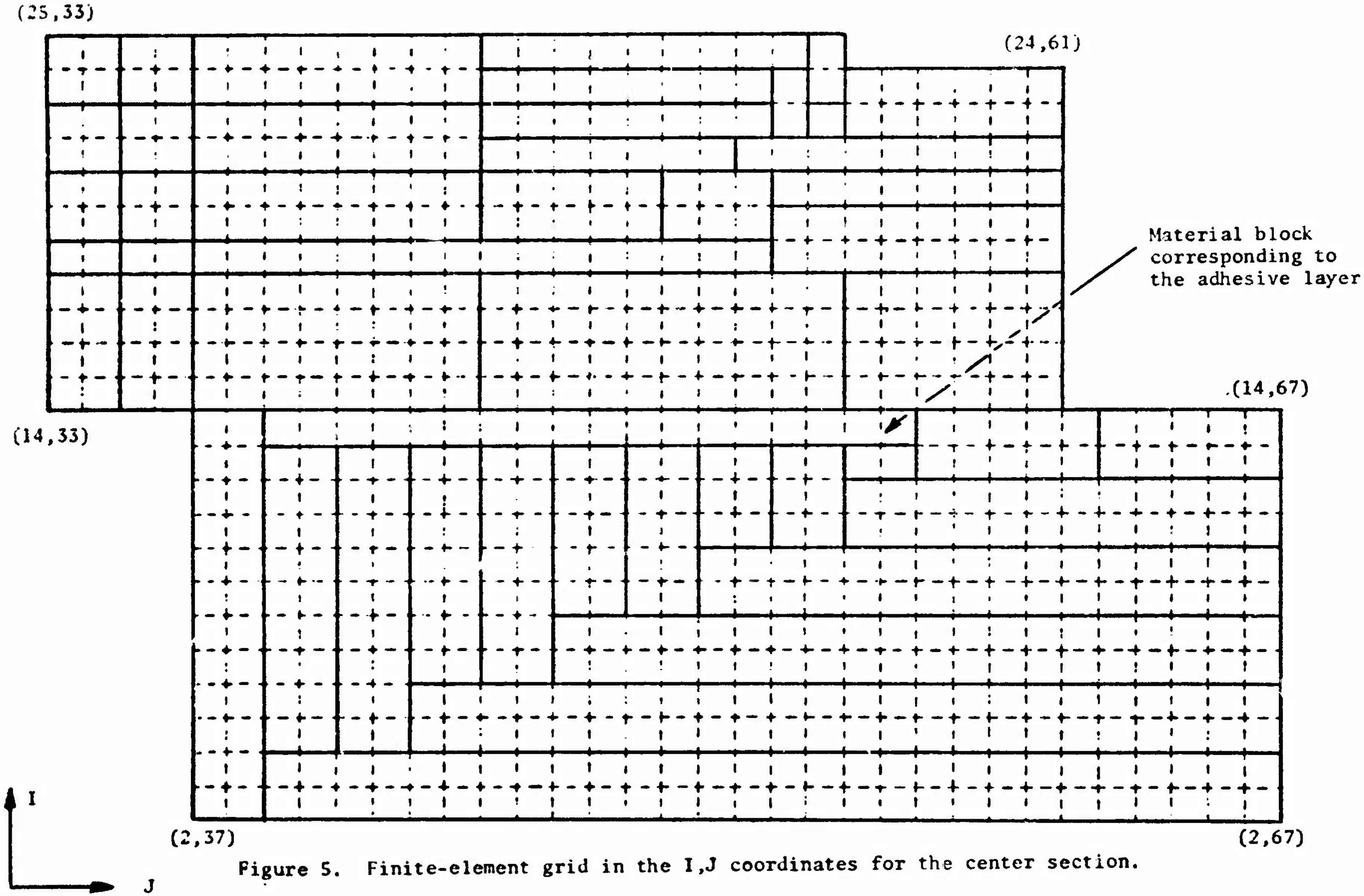


Figure 5. Finite-element grid in the I,J coordinates for the center section.

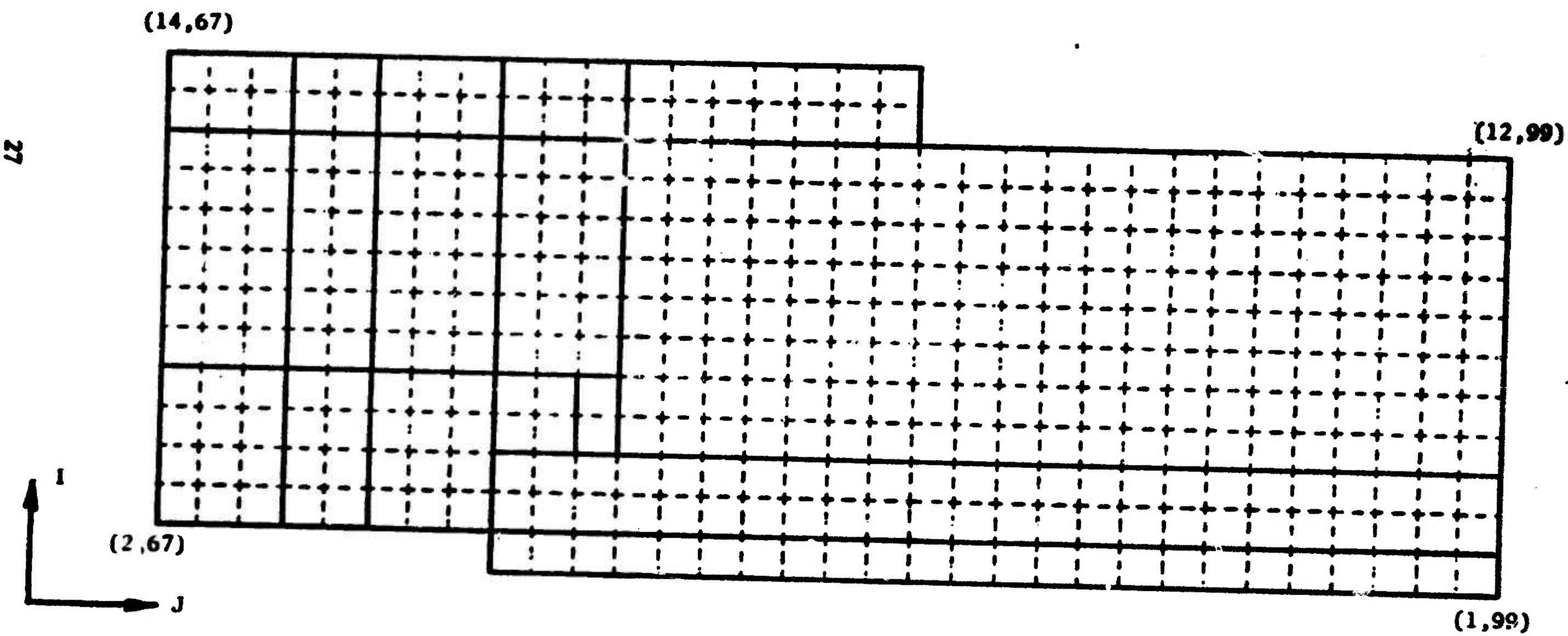


Figure 6. Finite-element grid in the I,J coordinates for the forward section.

Note: Thickness magnification of 20 was used in this diagram.

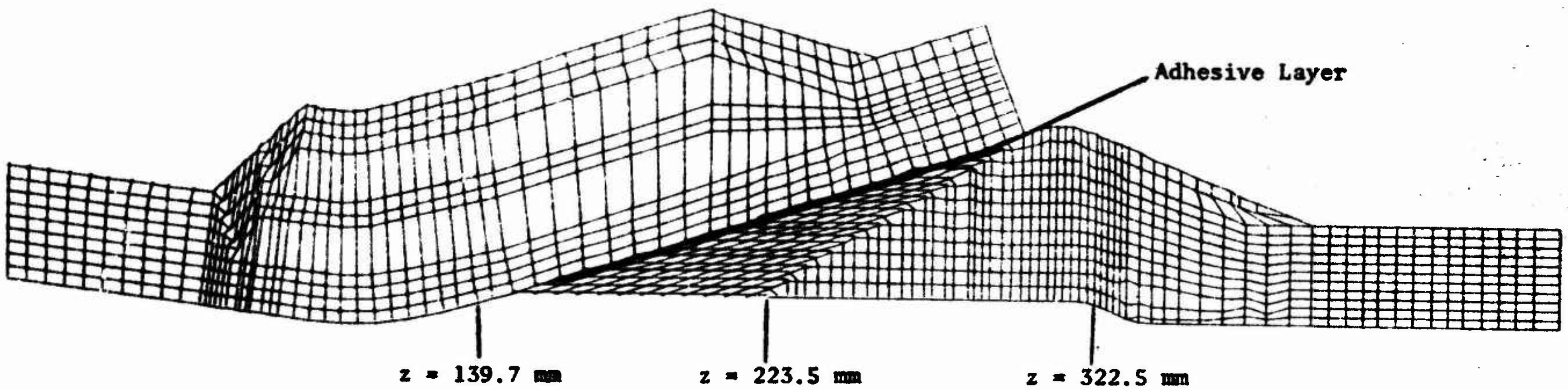


Figure 7. Finite-element grid for recoilless rifle.

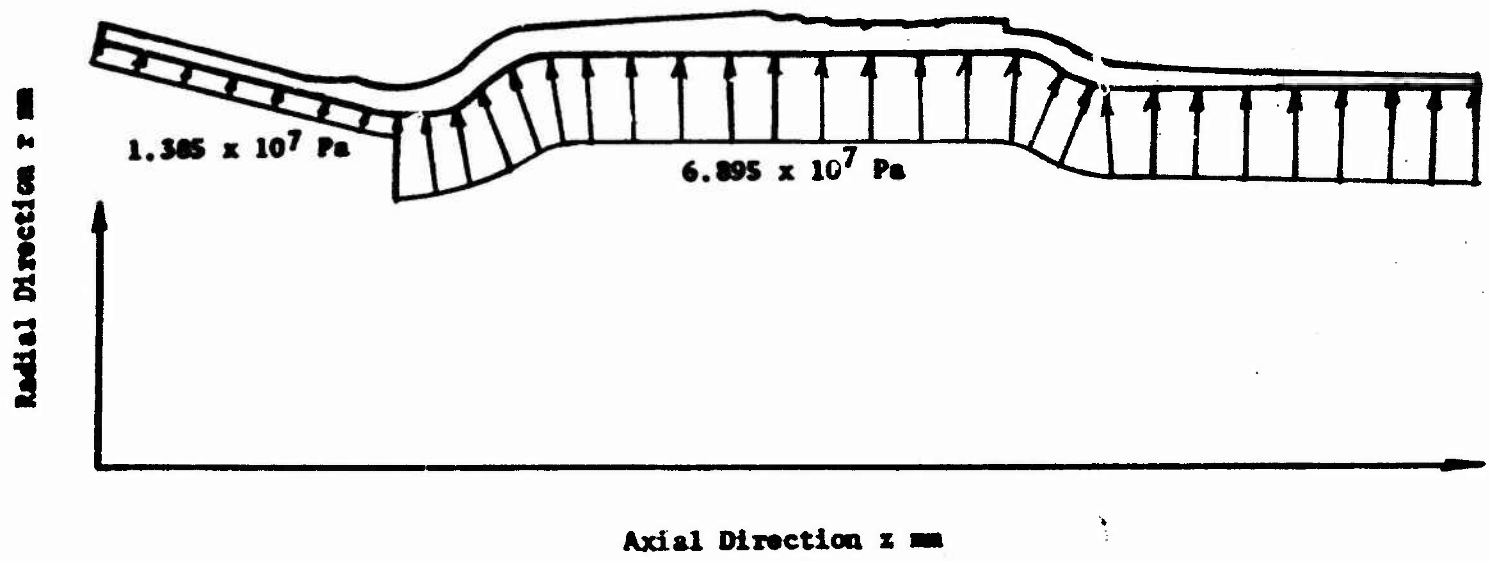


Figure 8. Internal pressure distribution

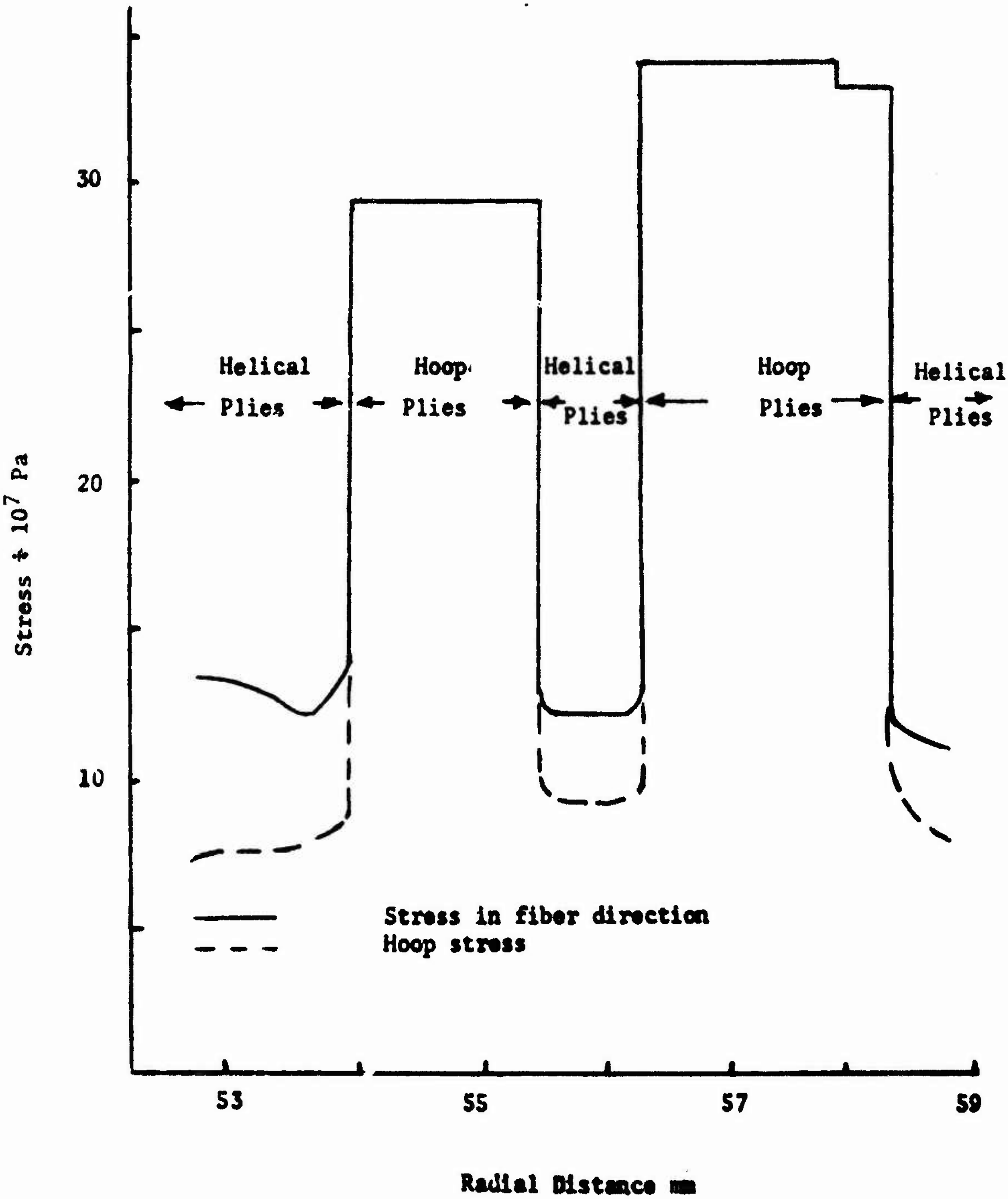


Figure 9. Radial distribution of fiber and hoop stress at axial location z = 139.7 mm.

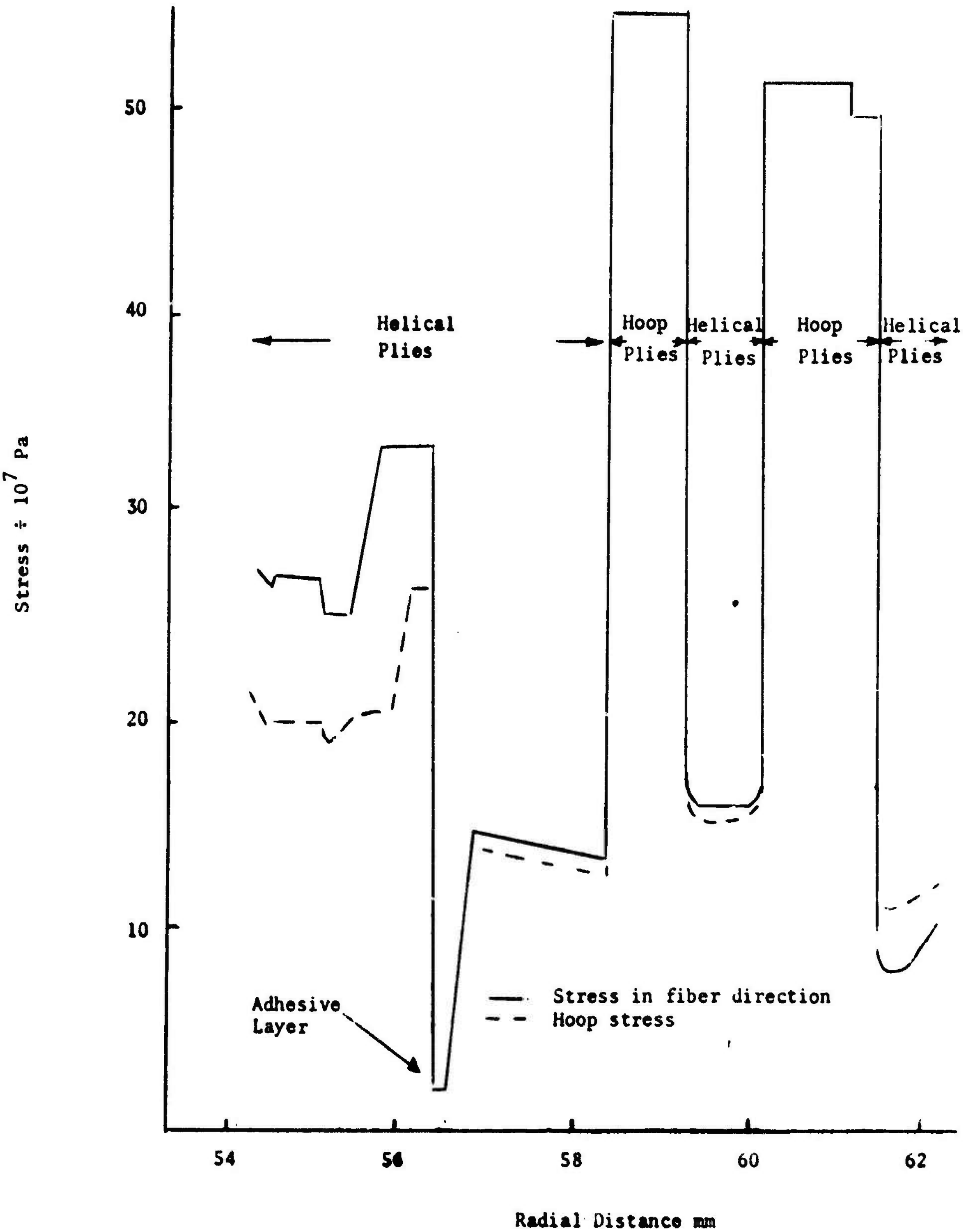


Figure 10. Radial distribution of fiber and hoop stresses at axial location z = 223.5 mm.

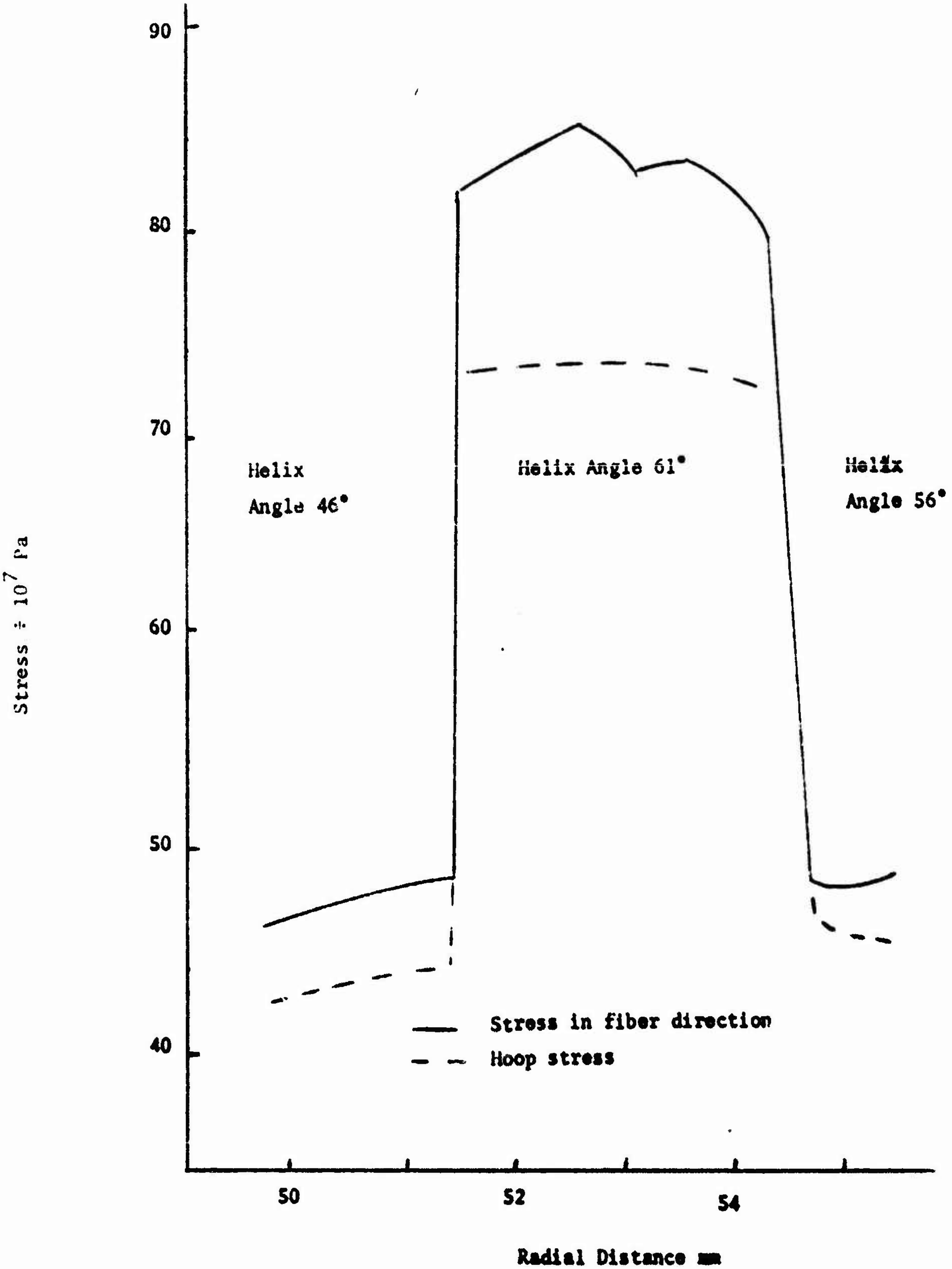


Figure 11. Radial distribution of fiber and hoop stresses at axial location z = 322.5 mm

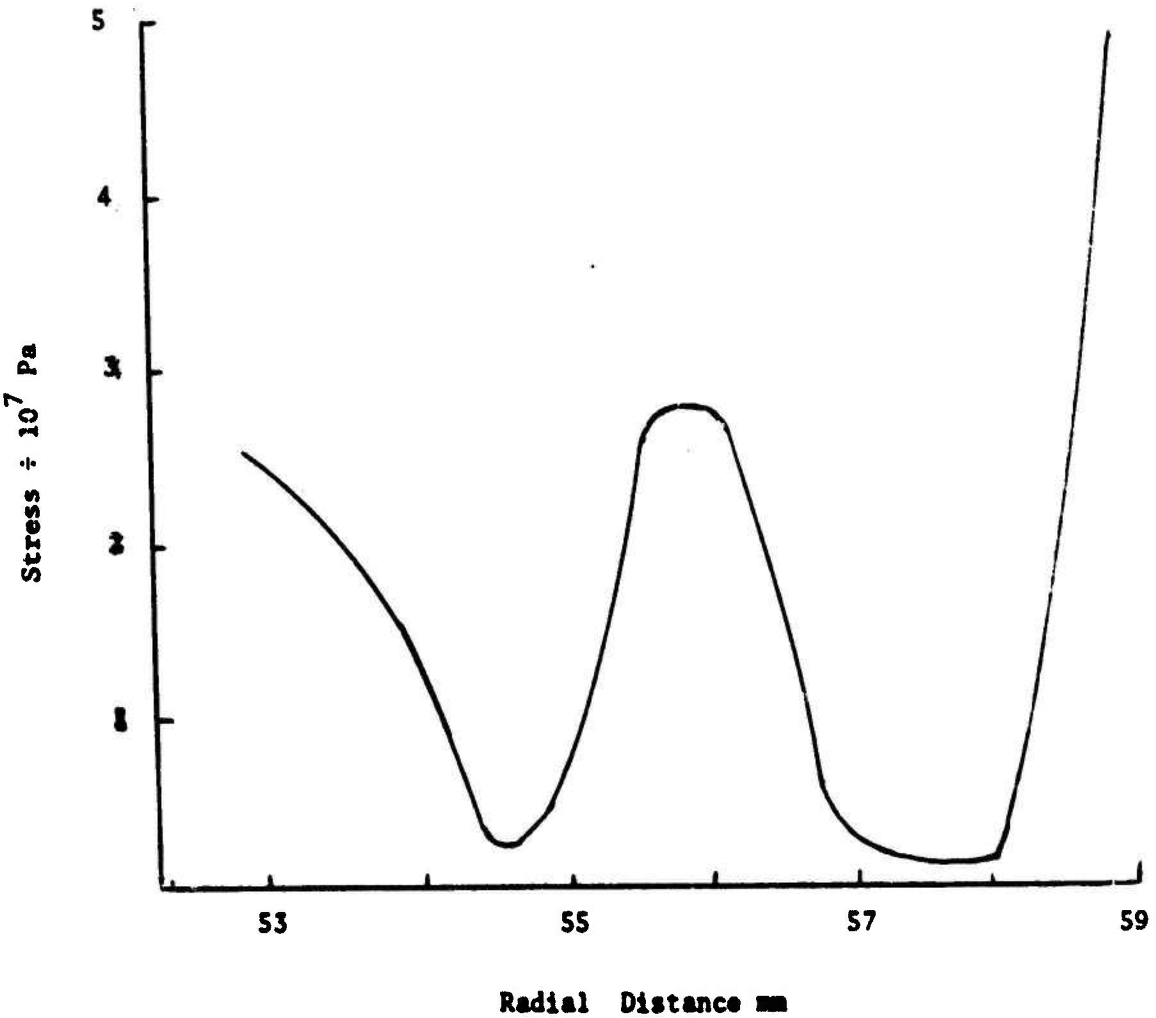


Figure 12. Radial distribution of the magnitude of the shear stress σ_{ns} at axial location z = 139.7 mm.

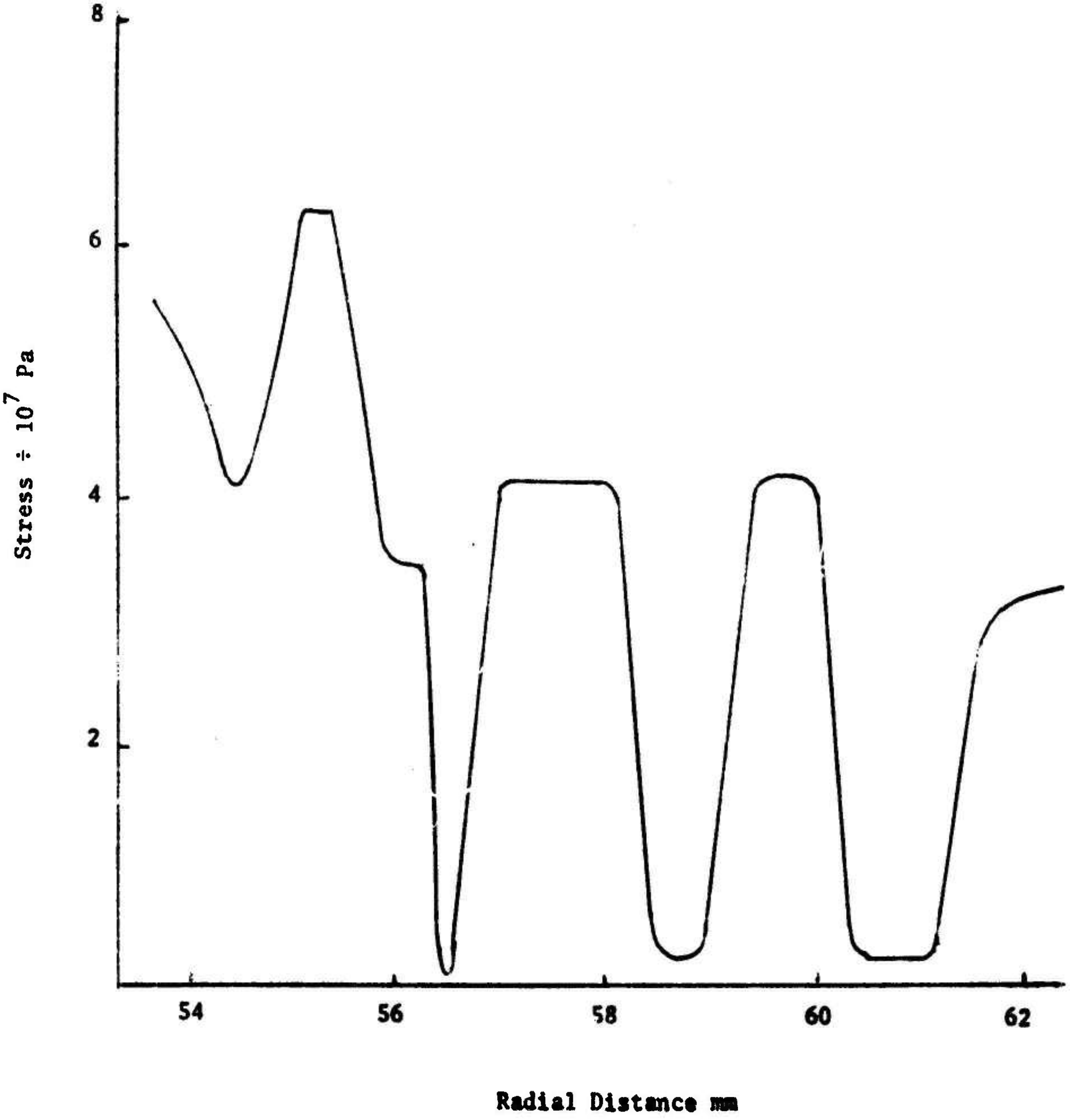


Figure 13. Radial distribution of the magnitude of the shear stress σ_{ns} at axial location z = 223.5 mm.

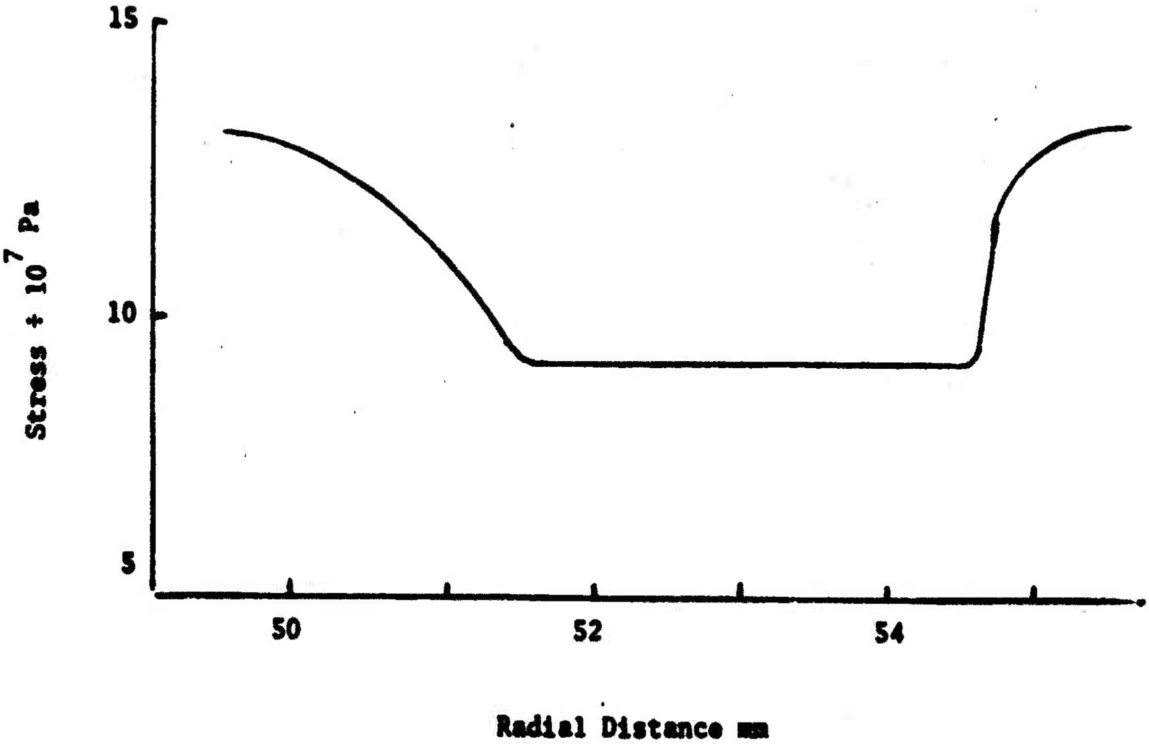


Figure 14. Radial distribution of the magnitude of the shear stress σ_{ns} at axial location z = 322.5 mm.

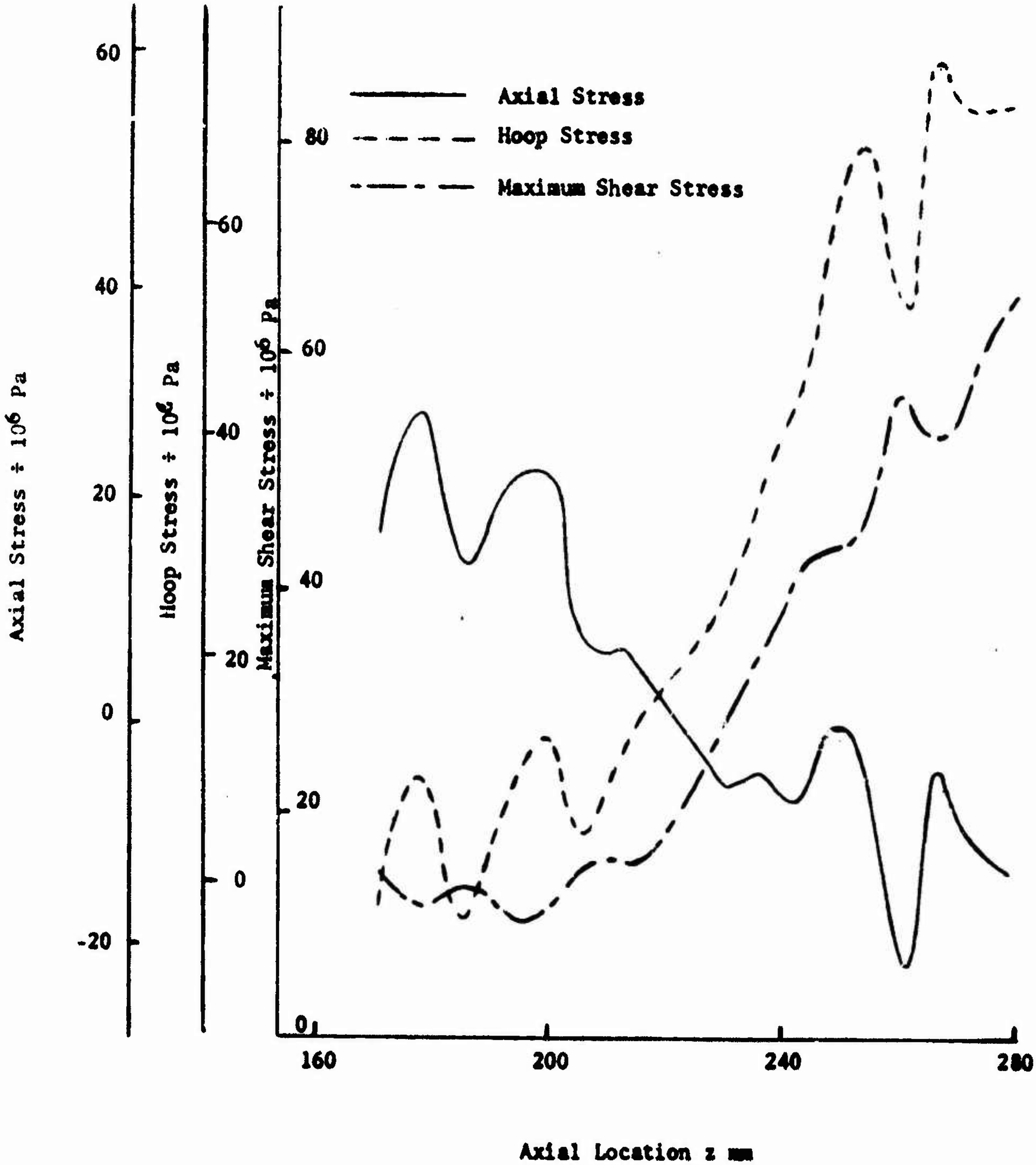


Figure 15. Axial distribution of axial stress, hoop stress, and maximum shear stress in the adhesive layer.

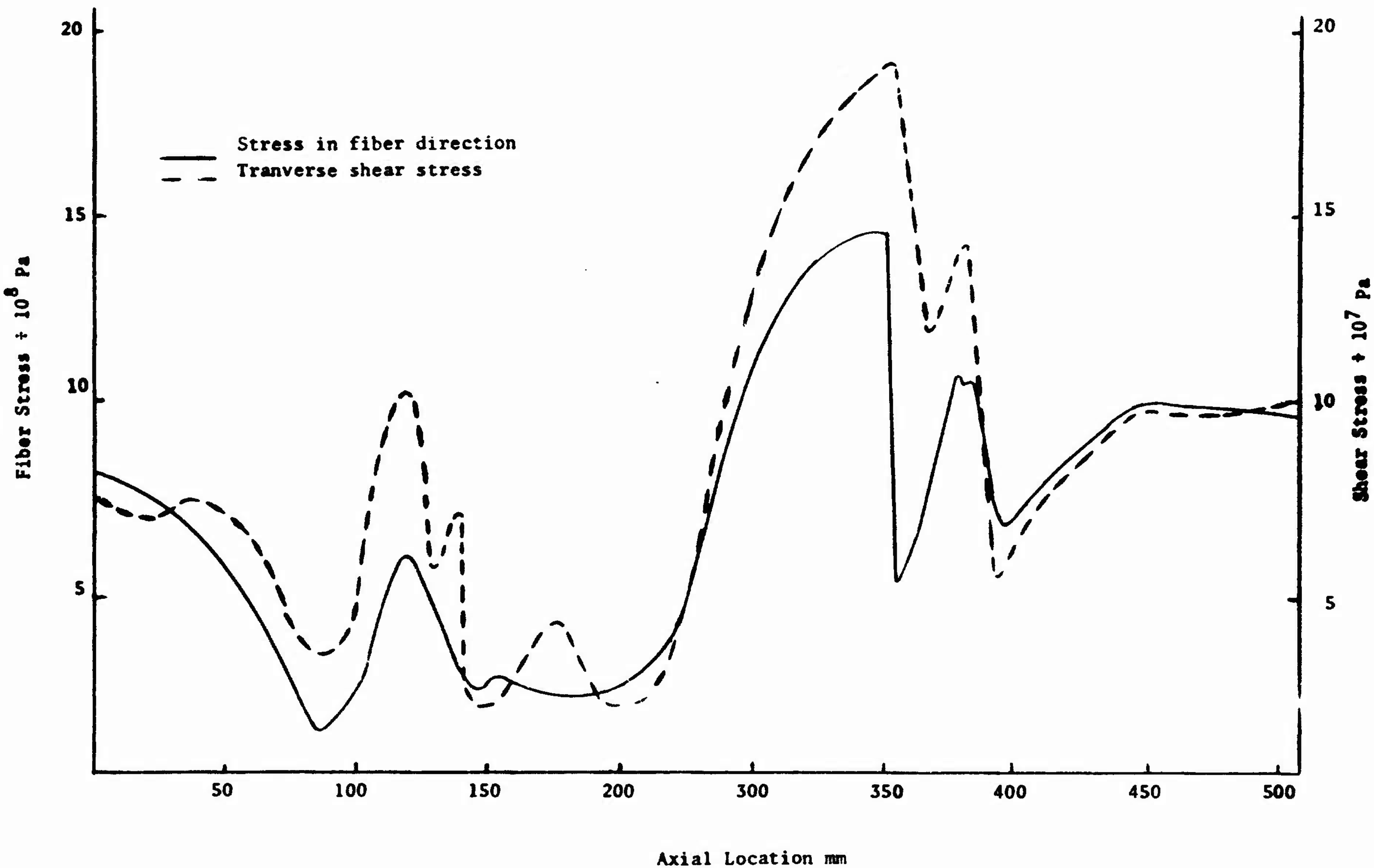


Figure 16. Axial distribution of the maximum fiber stress σ_n and shear stress σ_{ns}.

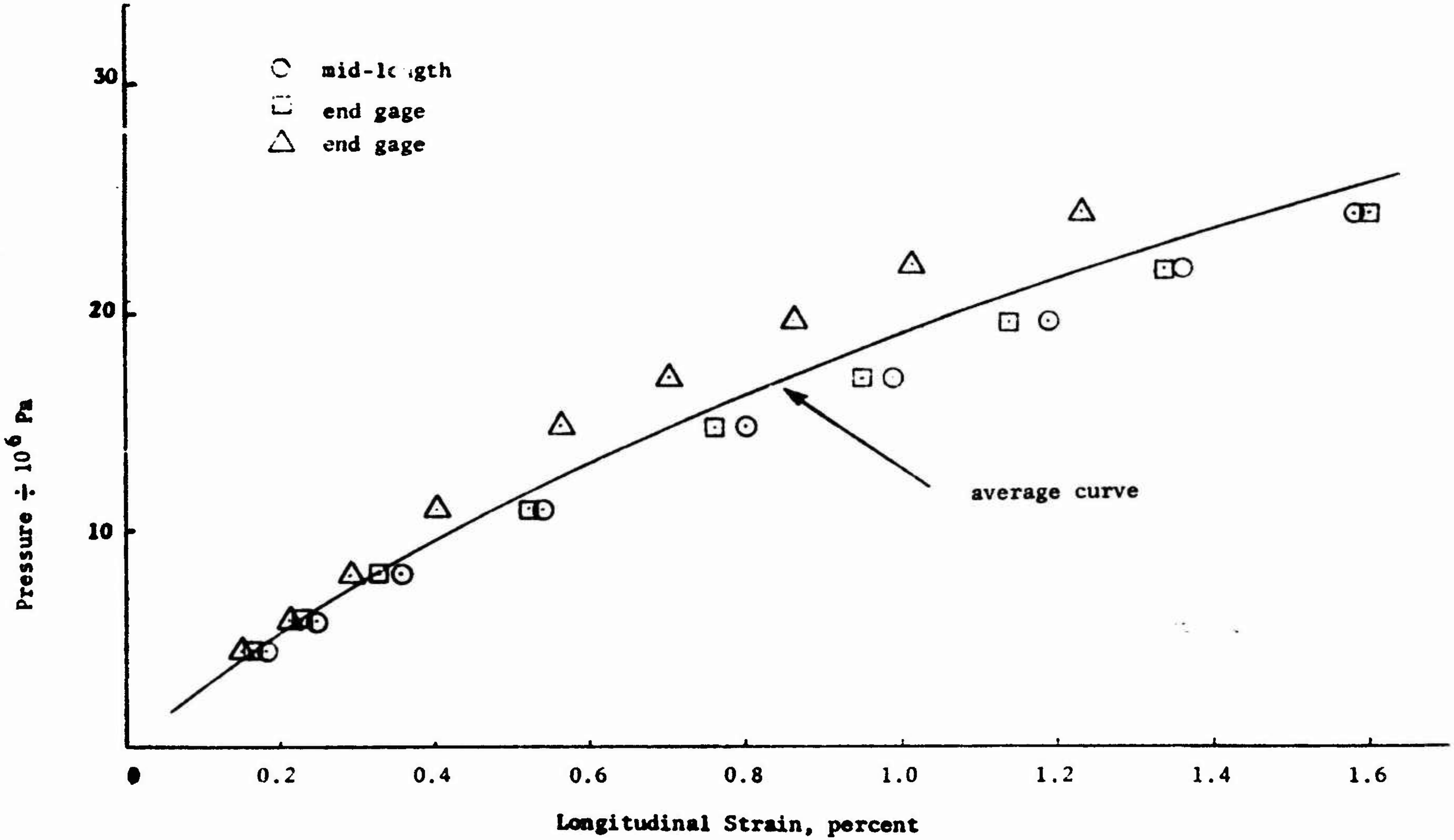


Figure 17. Longitudinal strain measured as a function at internal pressure.

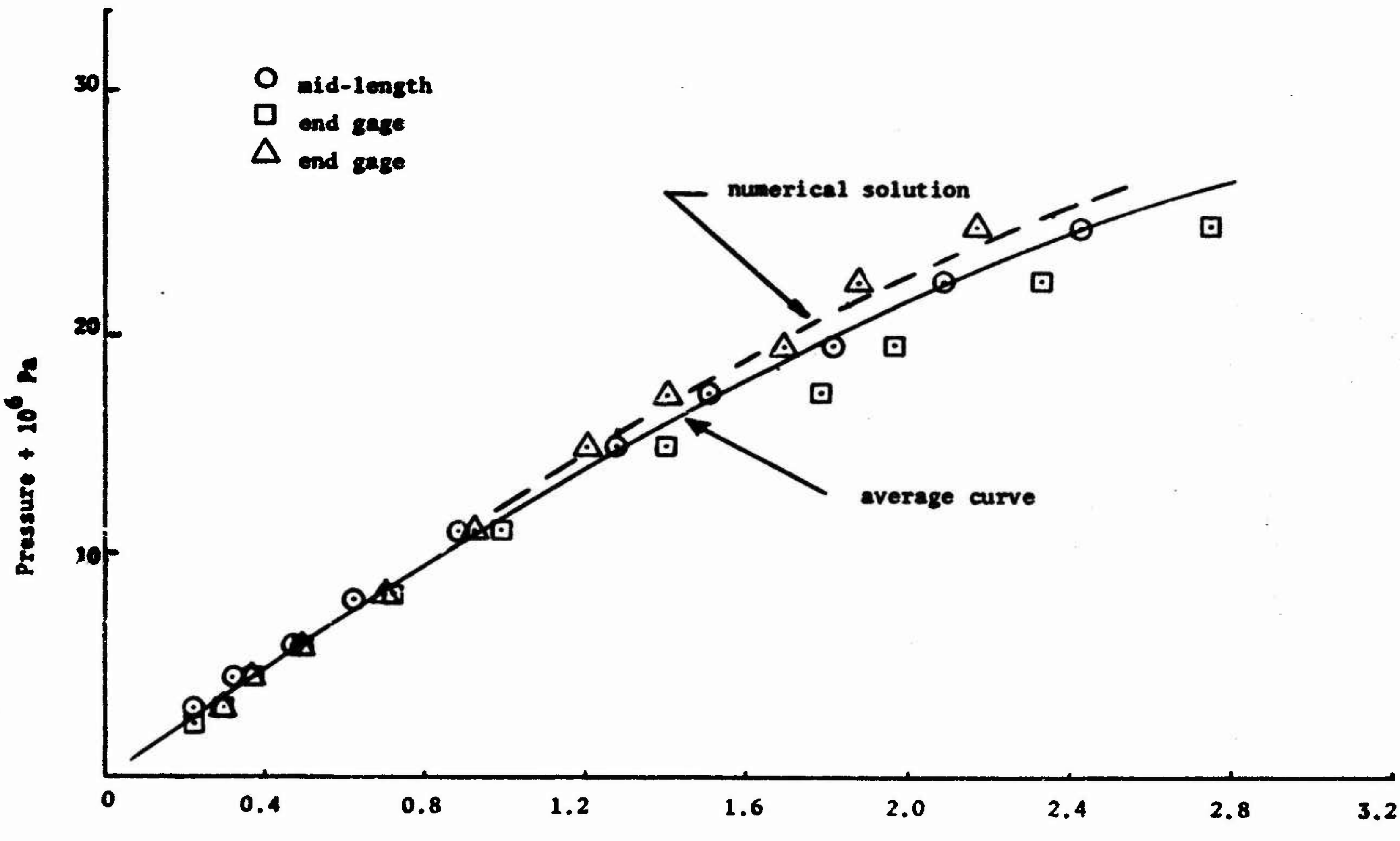


Figure 18. Circumferential strain measured as a function of internal pressure.

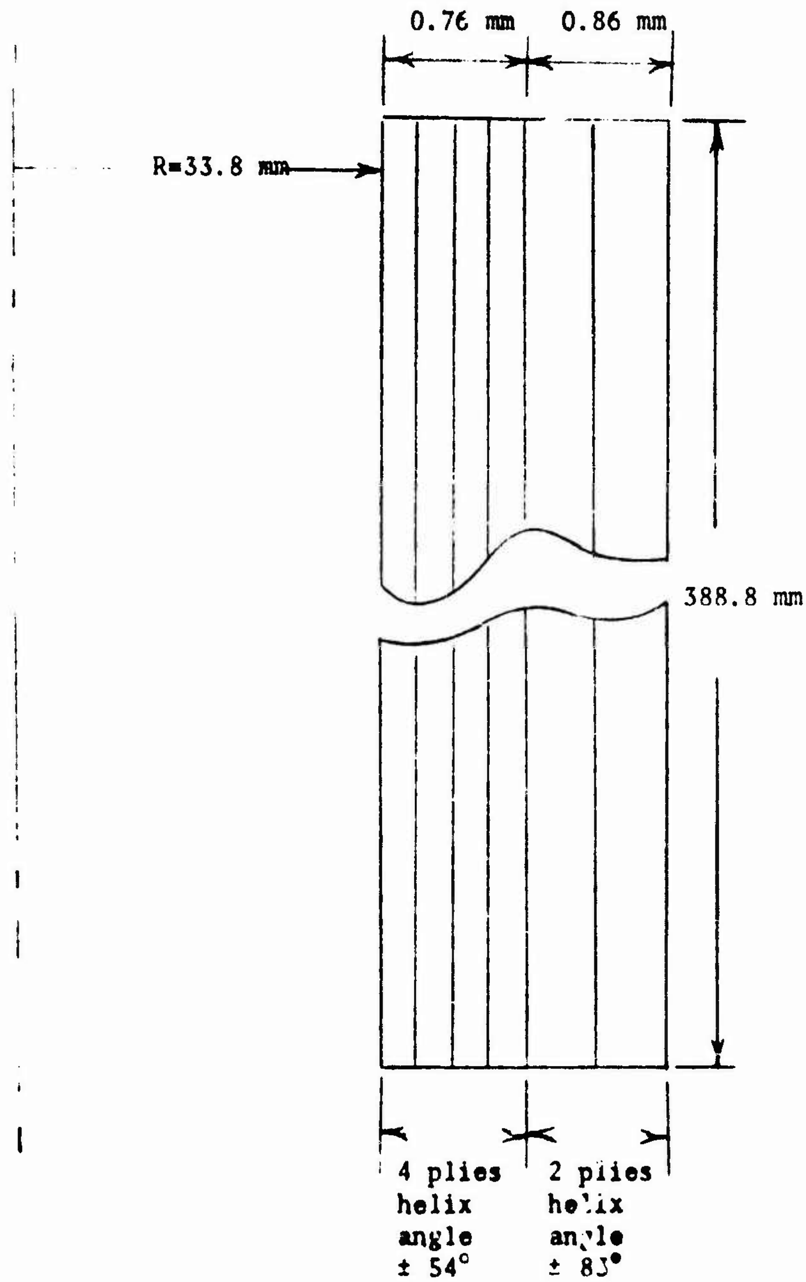


Figure 19. Arrangement of orthotropic plies in the test cylinder.

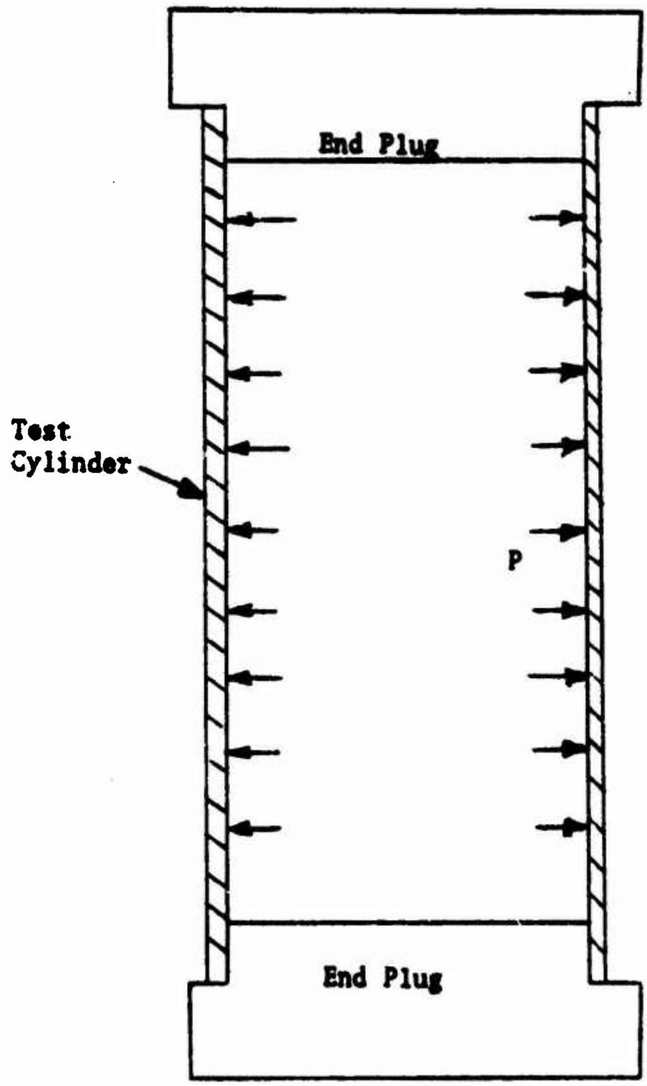


Figure 20. Experimental Test Arrangement.

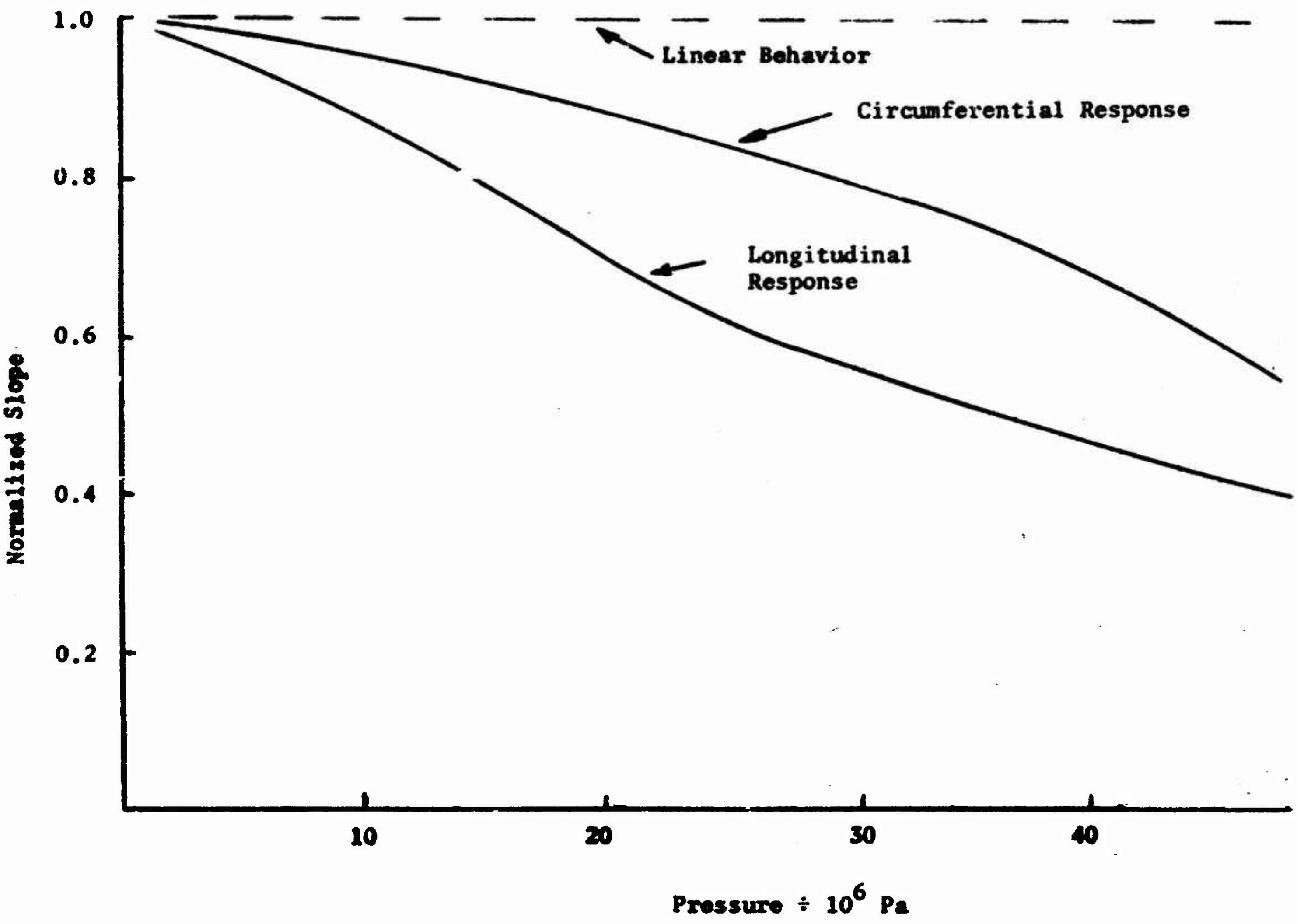


Figure 21. Nondimensional slope variation with pressure

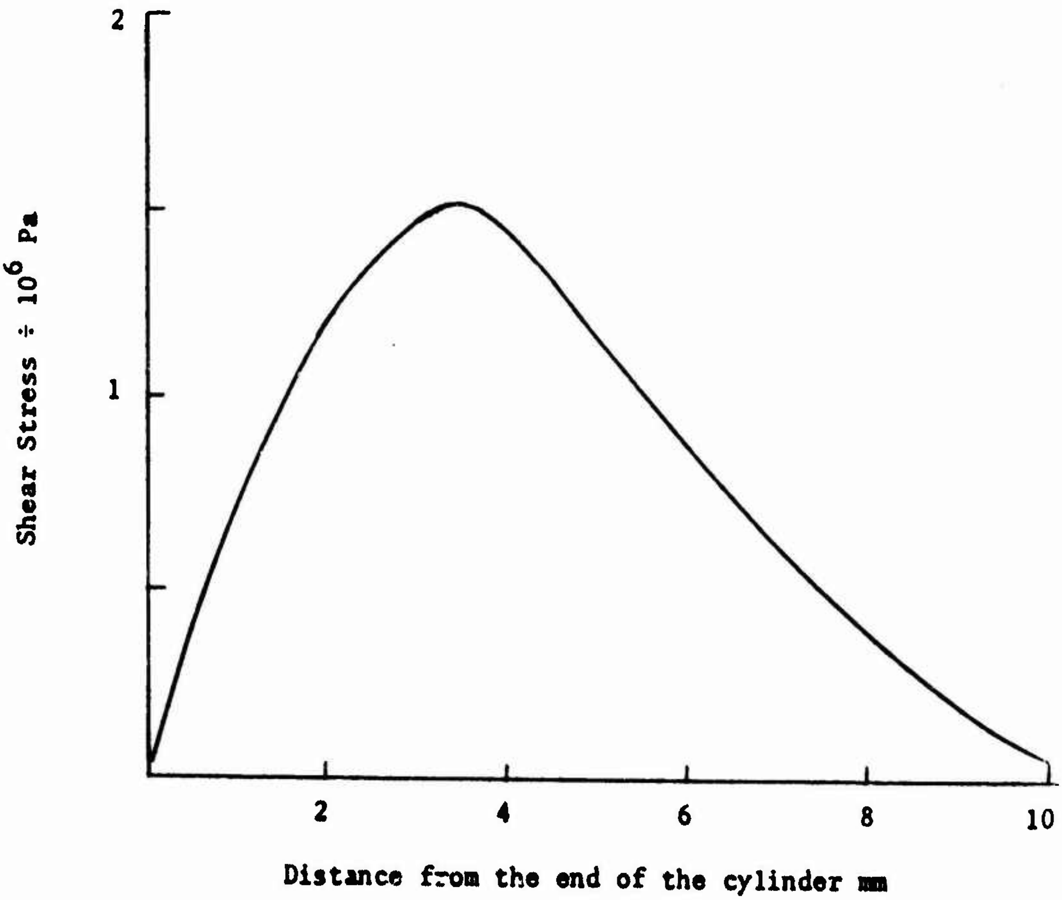


Figure 22. Axial distribution of the shear stress σ_{rz}.

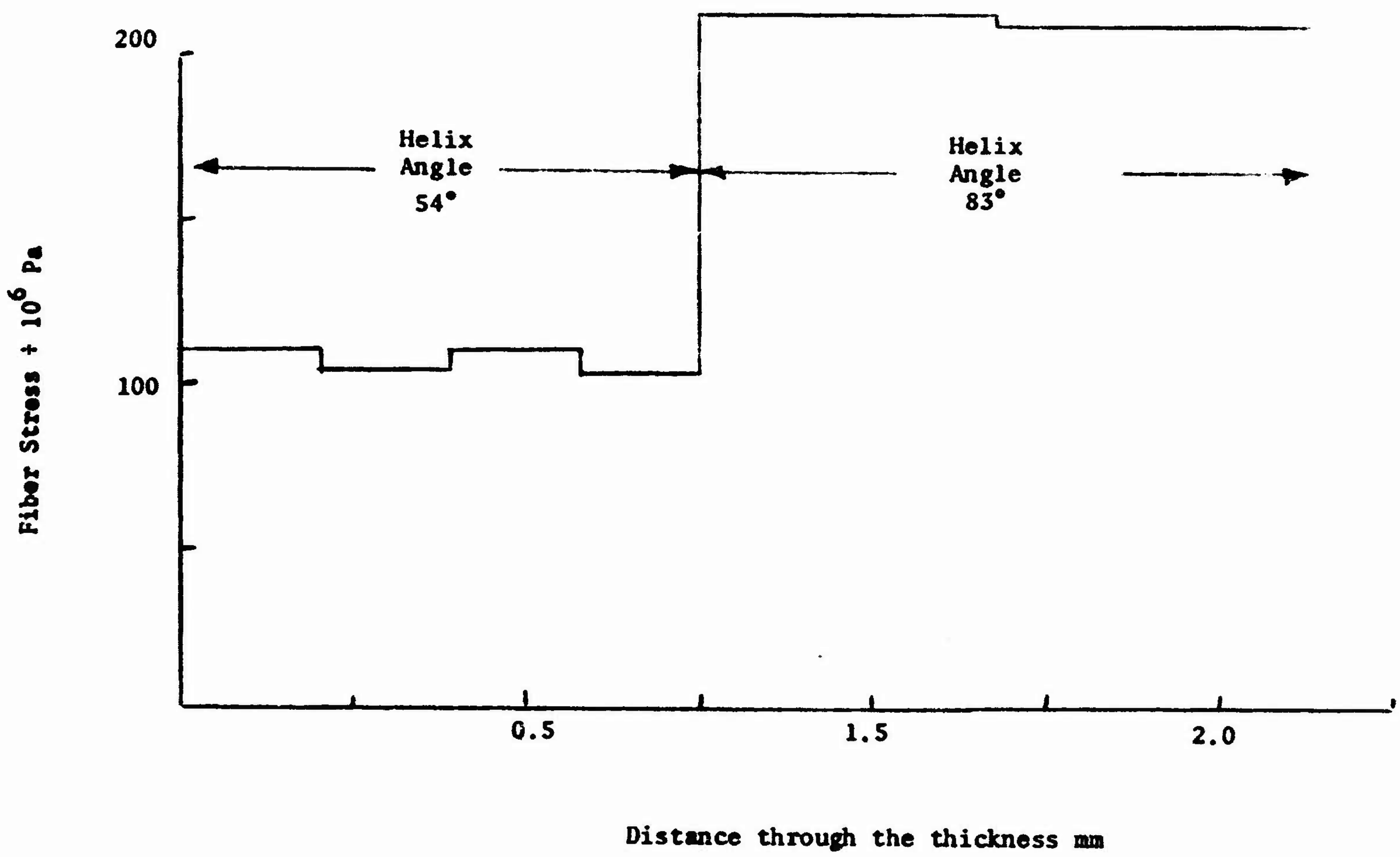


Figure 23. Radial distribution of the fiber stress σ_n calculated by using 4 elements to represent each ply in the thickness direction.

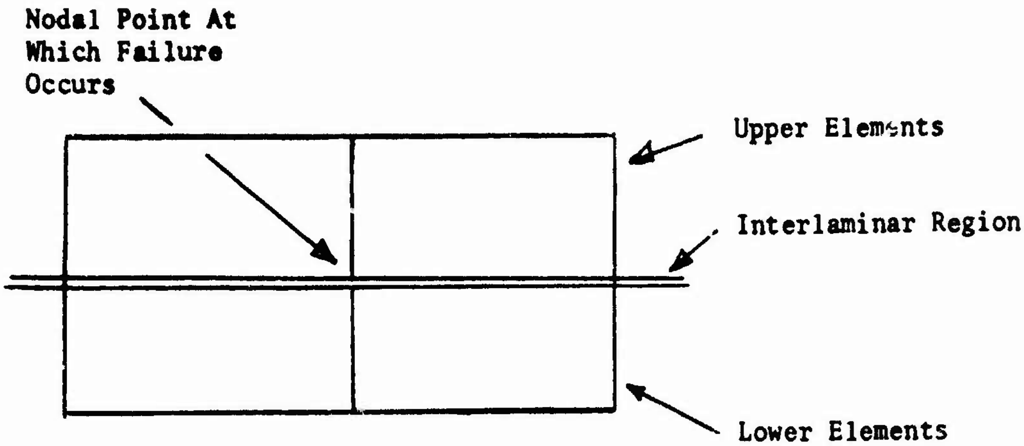


Figure 24a. Nodal Point On Interlaminar Plane

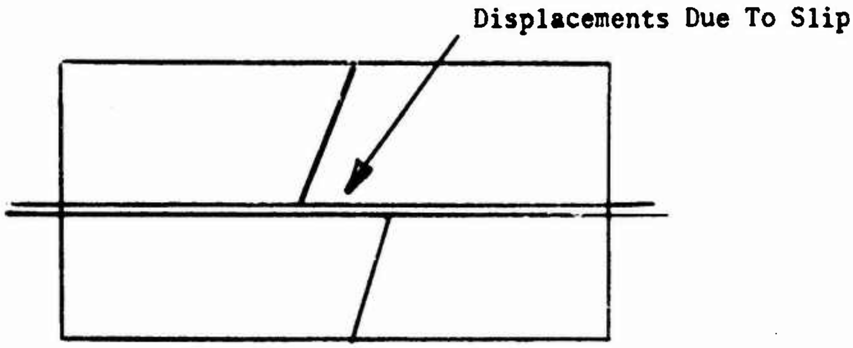


Figure 24b. Relative Slip At The Nodal Point Following Failure

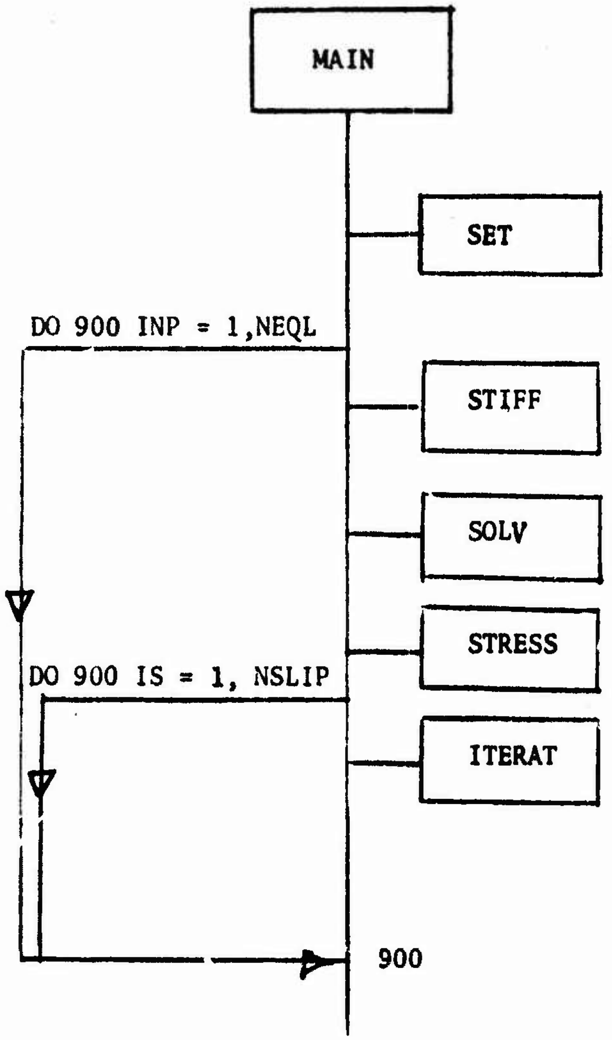


Figure 25. Simplified Computer Flow Chart Showing The Arrangement of The Iterative Schemes

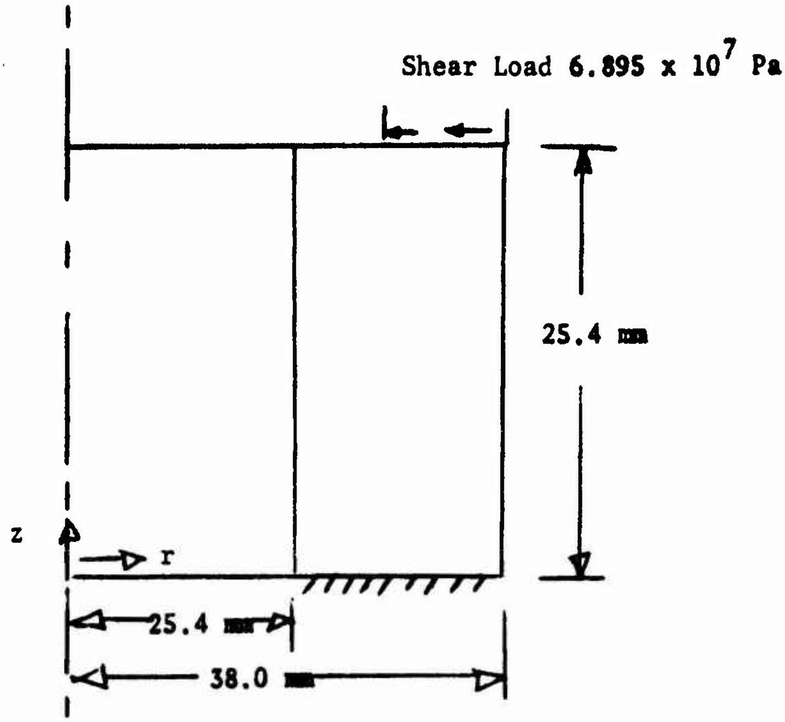


Figure 26a. Cylindrical Configuration Used In The Numerical Example

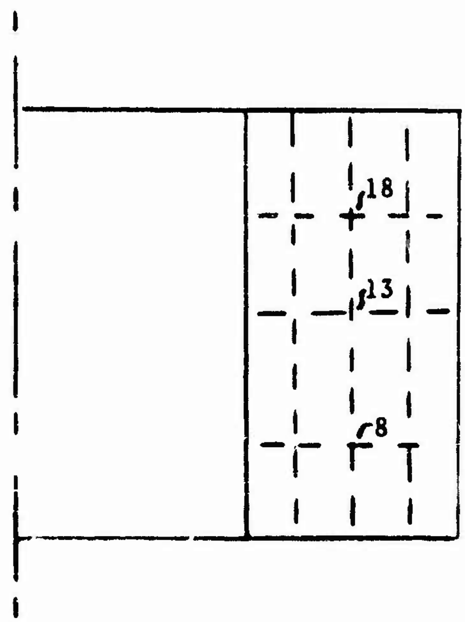


Figure 26b. Finite-Element Grid Used In The Numerical Calculations.

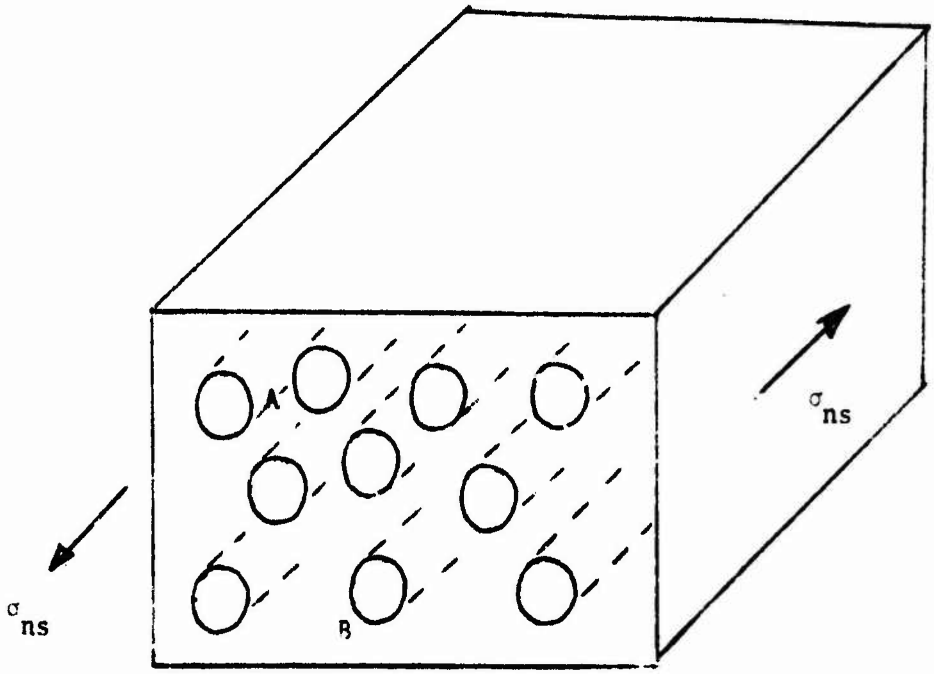


Figure 27. Macroscopic model of composite material subject to shear stress.

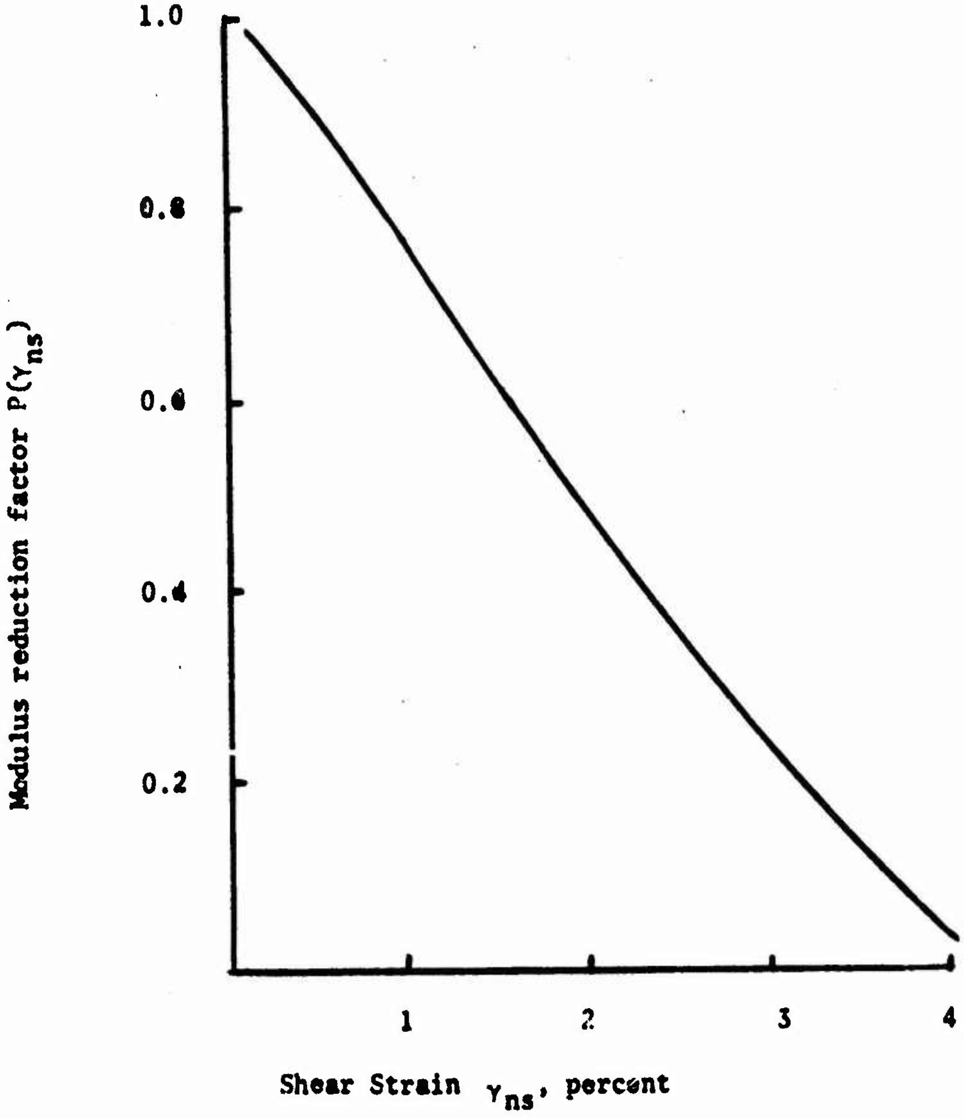


Figure 28. Dependence of shear modulus factor on the shear strain.

APPENDIX A

INPUT CARDS FOR INTERLAMINAR FAILURE FINITE-ELEMENT PROGRAM

TITLE CARD

Format (20A4)
Columns 1-80 TITLE (Title for particular case)

CONTROL CARD

Format (6I5, F5.0, 5I5)

Columns	1-5	NNLA (Number of nonlinear approximations; NNLA=1 for this version of the program)
	6-10	NUMTC (Number of temperature cards; if -2, a constant temperature is specified)
	11-15	NUMMAT (Number of different materials; 6 maximum)
	16-20	NUMPC (Number of boundary pressure cards; 200 maximum)
	21-25	NUMSC (Number of boundary shear cards; 200 maximum)
	26-30	NUMST (Number of boundary shear cards in tangential direction; 200 maximum)
	31-35	TREF (Reference temperature)
	36-40	INERT (This parameter decides if inertia loads will be present, INERT=0 means zero values of axial acceleration, and angular acceleration and velocity for each load increment)
	41-45	NLINC (Number of load increments with time, NLINC≥1)
	46-50	INCI (If INCI=0, then inertia loads for each time increment will be the same as for first increment)
	51-55	INCF (If INCF-0, then surface loads for each time increment will be the same as for first increment)
	56-60	IPLOT (Plot parameter, IPLOT = 1 if plot required)

MESH GENERATION CONTROL CARD

Format (5I5)

Columns	1-5	MAXI (Maximum value of I in mesh; 25 maximum)
	6-10	MAXJ (Maximum value of J in mesh; 100 maximum)
	11-15	NSEG (Number of line segment cards)
	16-20	NBC (Number of boundary condition cards)
	21-25	NMTL (Number of material block cards)

LINE SEGMENT CARDS

The order of line segment cards is immaterial except when plots are requested; in this case, the line segment cards must define the perimeter of the solid continuously. The order of line segment cards defining internal straight lines is always irrelevant.

Format (3(2I3, 2F8.3), I5)

Columns	1-3	I coordinate of 1st point
	4-6	J coordinate of 1st point
	7-14	R coordinate of 1st point
	15-22	Z coordinate of 1st point
	23-25	I coordinate of 2nd point

Columns (continued)

26-28	J coordinate of 2nd point
29-36	R coordinate of 2nd point
37-44	Z coordinate of 2nd point
45-47	I coordinate of 3rd point
48-50	J coordinate of 3rd point
51-58	R coordinate of 3rd point
59-66	Z coordinate of 3rd point
67-71	Line segment type parameter

If the number in column 71 is

0 Point (input only 1st point)
1 straight line (input only 1st and 2nd points)
2 straight line as an internal diagonal (input only 1st and 2nd points)
3 circular arc specified by 1st and 3rd points at the ends of the arc and 2nd point at the mid-point of the arc.
4 circular arc specified by 1st and 2nd points at the ends of the arc with the coordinates of the center of the arc given as the 3rd point (delete I and J for 3rd point).
5 straight line as a boundary diagonal for which I of 1st point is minimum for its row and/or I of 2nd point is minimum for its row (input only 1st and 2nd points).
6 straight line as a boundary diagonal for which I of 1st point and/or 2nd point is maximum for its row (input only 1st and 2nd points).

NOTE: In specifying a circular arc, the points are ordered such that a counterclockwise direction about the center is obtained upon moving along the boundary.

BOUNDARY CONDITION CARDS

Each card assigns a particular boundary condition to a block of elements bounded by I1, I2, J1, J2. For a line I1 = I2 or J1 = J2. For a point I1 = I2 and J1 = J2.

Format (4I5, I10, 5F10.0)

Columns	
1-5	Minimum I
6-10	Maximum I
11-15	Minimum J
16-20	Maximum J
21-30	Boundary condition code
31-40	Radial boundary condition, XR
41-50	Axial boundary condition, XZ
51-60	Tangential boundary condition XT

If the number in Columns 21-30 is

0	XR is the specified R-load and XZ is the specified Z-load and XT is the specified T-load
1	XR is the specified R-displacement and XZ is the specified Z-load and XT is the specified T-load
2	XR is the specified R-load and XZ is the specified Z-displacement and XT is the specified T-load
3	XR is the specified R-displacement and XZ is the specified Z-displacement and XT is the specified T-load
4	XR is the specified R-load and XZ is the specified Z-load and XT is the specified T-displacement
5	XR is the specified R-displacement and XZ is the specified Z-load and XT is the specified T-displacement
6	XR is the specified R-load and XZ is the specified Z-displacement and XT is the specified T-displacement
7	XR is the specified R-displacement and XZ is the specified Z-displacement and XT is the specified T-displacement

NOTE: All loads are considered to be total forces acting on one radian segment.

MATERIAL BLOCK ASSIGNMENT CARD

Each card assigns a material definition number to a block of elements defined by the I, J coordinates.

Format (5I5, 2F10.0, 2I5)

Columns	1-5	Material definition number (1 through 6)
	6-10	Minimum I
	11-15	Maximum I
	16-20	Minimum J
	21-25	Maximum J
	26-35	Material principal property inclination angle BETA in R-Z plane
	36-45	Material principal property inclination angle APLHA in N-T plane
	46-50	IANG (If IANG = 0, then ALPHA is same for total material block. If IANG = 1, the ALPHA varies in sign in the I direction from element to element every NANG elements. This will allow for equal but opposite helical angles.)
	51-55	NANG (Number of elements in the I direction with the same ALPHA)

PLOT TITLE CARD*

Format (20A4)

Columns 1-80 Title (Title printed under each plot)

PLOT GENERATION INFORMATION CARD*

Format (2F10.0)

Columns	1-10	RMAX (Maximum r coordinate of mesh)
	11-20	ZMAX (Maximum z coordinate of mesh)

*NOTE: Use only if IPLOT = 1 (plot required)

TEMPERATURE FIELD INFORMATION CARDS

If NUMTC in columns 6-10 of the CONTROL CARD is greater than 1, the temperature field is given on cards. One card must be supplied for each point for which a temperature is specified.

Format (3F10.0)

Columns	1-10	R coordinate
	11-20	Z coordinate
	21-30	Temperature

If NUMTC in columns 6-10 of the CONTROL CARD is -2, a constant temperature field is specified; the value is given on a single card.

Format (F10.0)

Columns 1-10 Temperature

MATERIAL PROPERTY INFORMATION CARDS

The following group of cards must be specified for each material (maximum of 6).

a. MATERIAL IDENTIFICATION CARD

Format (2I5, 2F10.0)

Columns	1-5	Material identification number
	6-10	Number of temperatures for which properties are given (12 maximum)
	11-20	Mass density of material (if required)
	21-30	Thermal expansion parameter (If 1, free thermal expansions on the material property cards; otherwise, coefficients of thermal expansion are on the material property cards.)

b. MATERIAL PROPERTY CARDS

Format (7F10.0)

Columns	1-10	Temperature
	11-20	Modulus of elasticity, E_N
	21-30	Modulus of elasticity, E_S
	31-40	Modulus of elasticity, E_T

Columns (continued)

41-50 Poisson's ratio, ν_{NS}
51-60 Poisson's ratio, ν_{NT}
61-70 Poisson's ratio, ν_{ST}

Second Card

Format (6F10.0)

Columns 1-10 Shear Modulus G_{NS}
11-20 Shear Modulus G_{ST}
21-30 Shear Modulus G_{TN}
31-40 $\alpha_n T$ or α_n
41-50 $\alpha_S T$ or α_S
51-60 $\alpha_T T$ or α_T

CRACK ITERATION CARD

Format (2I10, F10.3)

Columns 1-10 NSLIP number of iteration steps at each node to satisfy local equilibrium and calculate slip components.
11-20 NEQL number of times that the equilibrium of the total structure is to be recalculated.
21-30 TFAIL the magnitude of the shear failure stress between plies

CRACK DIRECTION CARD

Format (2I10)

Columns 1-10 NCBI number of blocks of nodal points where slip can occur in I direction
11-20 NCBJ number of blocks of nodal points where slip can occur in J direction

FAILURE BLOCK DEFINITION CARDS

Format (4I10)

This card is to be repeated a number of times equal to the sum of NCBI and NCBJ. These cards define blocks of nodes in the I, J coordinates where failure can occur either in the I or J directions.

Columns 1-10 NIMIN minimum I in block
11-20 NIMAX maximum I in block
21-30 NJMIN minimum J in block
31-40 NJMAX maximum J in block

INERTIA LOAD CARD

Format (3F10.0)

Starting with this input card and including the boundary force cards, this data is to be inputted as a block for each load step, that is NLINC times. There are the following exceptions to this:

a) If INERT = 0, then this card is to be omitted completely (no inertia load).

b) If INCI = 0, then this card is not repeated but appears in first block only (the inertia loads are constant for each load step).

c) If INCF = 0, then the following boundary pressure and shear cards are to be given only for the first block and not repeated again (the pressure and shear loads are constant for each load increment).

Columns	1-10	ACELZ (axial acceleration)
	11-20	ANGVEL (angular velocity)
	21-30	ANGACC (angular acceleration)

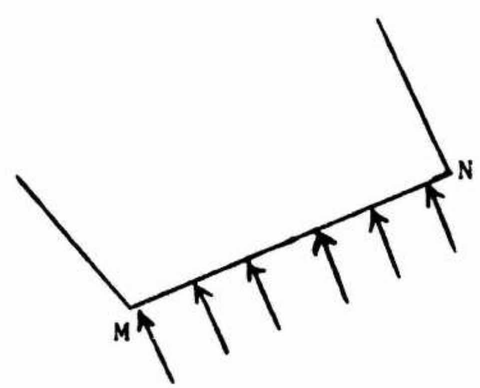
BOUNDARY PRESSURE CARDS

One card is required for each boundary element which is subjected to a normal pressure, that is the number of these cards is NUMPC for each load increment.

Format (3I5, F10.0)

Columns	1-5	Nodal point M
	6-10	Nodal point N
	11-20	Normal pressure

As shown in the figure below, the boundary element must be on the left when progressing from M to N. Surface normal tension is input as a negative pressure.



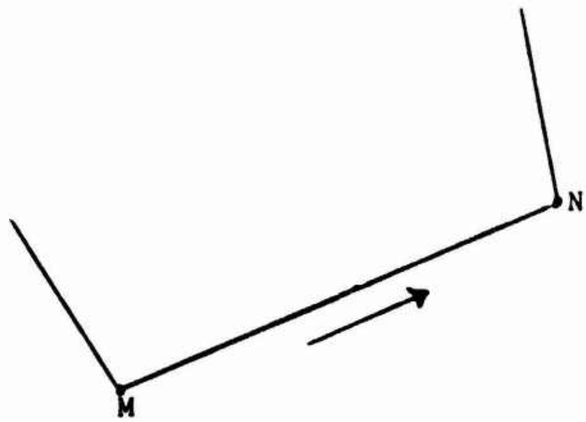
BOUNDARY SHEAR CARDS

One card is required for each boundary element which is subjected to surface shear, that is, the number of these cards is NUMSC for each load increment.

Format (2I5, F10.0)

Columns	1-5	Nodal point M
	6-10	Nodal point N
	11-20	Surface shear,

As shown in the figure below, the boundary element must be on the left when progressing from M to N. The positive sense of the shear is from M to N.

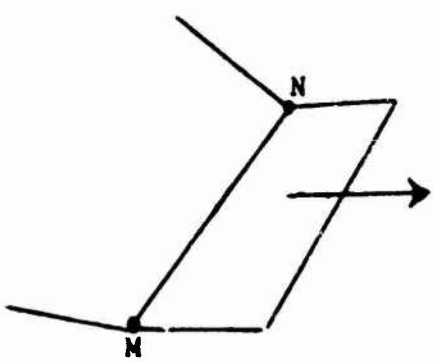


BOUNDARY TRANSVERSE SHEAR CARDS

One card is required for each boundary element whish is subject to transverse shear, that is the number of these cards is NUMSC for each load increment.

Format(2I5, F10.0)

Columns	1-5	Nodal point M
	6-10	Nodal point N
	11-20	Surface transverse shear



APPENDIX B

PROGRAM LISTING FOR INTERLAMINAR FAILURE ANALYSIS

```
C     FINITE ELEMENT STRESS ANALYSIS OF AXISYMMETRIC, LAYERED
C     SOLIDS WITH ORTHOTROPIC, TEMPERATURE-DEPENDENT MATERIAL
C     PROPERTIES USING STRAIGHT SIDED ELEMENTS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/MATP/RO(6),E(12,16,6),EE(16),AOFTS(6)
      COMMON/ARG/RRR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CRZ(6,6),XI(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/SOLVE/ X(888),Y(888),TEM(888),NUMTC,MBAND
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      COMMON/CONVRG/IDONE
      COMMON/PLANE/NPP
      COMMON/RESULT/BS(6,15),D(6,6),C(6,6),AR,BB(6,9),CNS(6,6)
      COMMON/CIT/NEQL   ,NSLIP,ICRACK,ISLIP,INP,NSKIP
      COMMON/DATA1/RTN(200),RST(200),RNN(200)
      COMMON/DATA2/IFAIL(200),TB(200,12),ICP(200),IAD(200,4)
      DIMENSION TITLE(20)
      DIMENSION TD(100,12)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     READ AND WRITE CONTROL INFORMATION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
   50 READ(5,1000,END=920)TITLE,NNLA,NUMTC,NUMMAT,NUMPC,NUMSC,NUMST,TREF
     1,INERT,NLINC,INCT,INCF,IPLOT,ICRACK
      WRITE(6,2000)TITLE,NNLA,NUMTC,NUMMAT,NUMPC,NUMSC,NUMST,TREF,INERT,
     1NLINC
      WRITE(6,4000) ICRACK
 4000 FORMAT(3X,I5)
      NSKIP=0
      NPP=0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     GENERATE FINITE ELEMENT MESH
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  100 CALL MESH
      IF (IPLOT.EQ.1) CALL MPLOT
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     READ AND WRITE TEMPERATURE DATA
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  103 IF(NUMTC.EQ.0) GO TO 440
      IF(NUMTC.GT.0) READ(5,1001) (X(I),Y(I),TEM(I),I=1,NUMTC)
      IF(NUMTC.EQ.-2) CALL TEM2(NUMNP)
```

```
      IF(NUMTC.EQ.-2) GO TO 440
      MPRINT=0
      DO 210 I=1,NUMTC
      IF(MPRINT.NE.0) GO TO 200
      WRITE(6,2001)
      MPRINT=59
  200 MPRINT=MPRINT-1
  210 WRITE(6,2002) X(I),Y(I),TEM(I)
      MPRINT=0
      DO 230 N=1,NUMNP
      IF(MPRINT.NE.0) GO TO 220
      WRITE(6,2003)
      MPRINT=59
  220 MPRINT=MPRINT-1
      CALL TEMP(R(N),Z(N),T(N))
  230 WRITE(6,2004) N,R(N),Z(N),T(N)
  440 MPRINT=0
      DO 460 N=1,NUMEL
      IF(MPRINT.NE.0) GO TO 450
      WRITE(6,2008)
      MPRINT=59
  450 MPRINT=MPRINT-1
      II=IX(N,1)
      JJ=IX(N,2)
      KK=IX(N,3)
      LL=IX(N,4)
C
C     TEM IS TEMPORARY STORAGE FOR ELEMENT TEMPERATURES
C
      TEM(N)=(T(II)+T(JJ)+T(KK)+T(LL))/4.0
  460 WRITE(6,2009) N,(IX(N,I),I=1,5),BETA(N),ALPHA(N),TEM(N)
      DO 470 K=1,NUMEL
  470 T(K)=TEM(K)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     READ AND WRITE MATERIAL PROPERTIES
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  500 CONTINUE
      IF(NUMMAT.EQ.0) GO TO 600
      DO 510 M=1,NUMMAT
      READ(5,1004)  MTYPE,(NT,RO(MTYPE),ADFTS(MTYPE))
      WRITE(6,2010) MTYPE,NT,RO(MTYPE)
      READ(5,1005)((E(I,J,MTYPE),J=1,14),I=1,NT)
      IF(ADFTS(MTYPE).NE.1.) WRITE(6,2011)((E(I,J,MTYPE),J=1,13),I=1,NT)
      IF(ADFTS(MTYPE).EQ.1.) WRITE(6,2012)((E(I,J,MTYPE),J=1,13),I=1,NT)
      DO 510 I=NT,12
      DO 510 J=1,16
  510 E(I,J,MTYPE)=E(NT,J,MTYPE)
```

```
C      SET INTERLAMINAR SLIP DATA
C
       IF(ICRACK.EQ.0) GO TO 509
       CALL SET
  509  CONTINUE
       DO 501 N=1,NUMEL
       DO 501 I=1,12
  501  TS(N,I)=0.0
C***********************************************************************
C***********************************************************************
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C      DETERMINE BANDWIDTH, INITIALIZE ELASTIC-PLASTIC RATIO,
C      AND CONVERT BETA FROM DEGREES TO RADIANS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
       J=0
       DO 710 N=1,NUMEL
       DO 710 I=1,4
       DO 710 L=1,4
       KK=IABS(IX(N,I)-IX(N,L))
       IF(KK.GE.J) J=KK
   710 CONTINUE
       MBAND=3*J+3
       DO 720 N=1,NUMEL
       EPR(N)=1.
       ALPHA(N)=ALPHA(N)/57.29578
   720 BETA(N)=BETA(N)/57.29578
       DO 900 NL=1,NLINC
       WRITE(6,2030) NL
       ACELZ=0.0
       ANGVEL=0.0
       ANGACC=0.0
       IF(INERT .EQ. 0) GO TO 511
       IF(NL .NE. 1 .AND. INCI .EQ. 0) GO TO 511
       READ(5,1030) ACELZ, ANGVEL, ANGACC
   511 CONTINUE
       WRITE(6,2031) ACELZ, ANGVEL, ANGACC
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C      READ AND WRITE PRESSURE AND SHEAR BOUNDARY CONDITIONS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
       IF(NL .NE. 1 .AND. INCF .EQ. 0) GO TO 700
   600 IF(NUMPC.EQ.0) GO TO 630
       MPRINT=0
       DO 620 L=1,NUMPC
       IF(MPRINT.NE.0) GO TO 610
       WRITE(6,2013)
       MPRINT=58
   610 MPRINT=MPRINT-1
       READ(5,1006)  IP(L),JP(L),PR(L)
```

```
  620 WRITE(6,2014) IP(L),JP(L),PR(L)
  630 IF(NUMSC.EQ.0) GO TO 701
      MPRINT=0
      DO 650 L=1,NUMSC
      IF(MPRINT.NE.0) GO TO 640
      WRITE(6,2015)
      MPRINT=58
  640 MPRINT=MPRINT-1
      READ(5,1006)  IS(L),JS(L),SH(L)
  650 WRITE(6,2014) IS(L),JS(L),SH(L)
  701 IF(NUMST.EQ.0) GO TO 700
      MPRINT=0
      DO 680 L=1,NUMST
      IF(MPRINT.NE.0) GO TO 670
      WRITE(6,2025)
      MPRINT=58
  670 MPRINT=MPRINT-1
      READ(5,1006)  IT(L),JT(L),ST(L)
  680 WRITE(6,2014)IT(L),JT(L),ST(L)
  700 CONTINUE
      IF(ICRACK.EQ.0) GO TO 741
      DO 990 INP=1,NEOL
  741 CONTINUE
      DO 721 N=1,NUMEL
  721 IX(N,5)=IABS(IX(N,5))
C
C     FORM STIFFNESS MATRIX
C
      CALL STIFF
C
C     SOLVE FOR DISPLACEMENTS
C
      CALL SOLV
C
C     COMPUTE STRESSES
C
      CALL STRESS
C
C     SLIP ITERATION
C
      IF(ICRACK.EQ.0) GO TO 731
      DO 729 L=1,NSLIP
      IF(L.GT.1) GO TO 723
      DO 723 I=1,NUMEL
      DO 723 J=1,12
      TO(I,J)=TP(I,J)
  723 CONTINUE
      CALL ITERAT
```

```
      IF(L.NE.NSLIP) GO TO 729
      DO 724 I=1,NUMEL
      DO 724 J=1,12
  724 TB(I,J)=TD(I,J)+(TB(I,J)-TD(I,J))*2.
  729 CONTINUE
  731 CONTINUE
  900 CONTINUE
  910 GO TO 50
 1000 FORMAT(20A4/6I5,F5.0,6I5)
 1001 FORMAT(3F10.0)
 1004 FORMAT (2I5,2F10.0)
 1005 FORMAT(7F10.0)
 1006 FORMAT (2I5,F10.0)
 1030 FORMAT(3F10.0)
 2000 FORMAT (2H1 ,20A4/
     1 33H0  NUMBER OF APPROXIMATIONS------I4/
     2 33H0  NUMBER OF TEMPERATURE CARDS---I4/
     3 33H0  NUMBER OF MATERIALS-----------I4/
     4 33H0  NUMBER OF PRESSURE CARDS------I4/
     5 33H0  NUMBER OF SHEAR CARDS---------I4/
     6 33H0  NUMBER OF TORSION CARDS-------I4/
     7 33H0  REFERENCE TEMPERATURE---------E12.4/
     8 33H0  NUMBER OF INERTIA CARDS-------I4/
     9 33H0  NUMBER OF LOAD INCREMENTS-----I4/)
 2001 FORMAT (1H1,13X,1HR,14X,1HZ,14X,1HT)
 2002 FORMAT (3F15.3)
 2003 FORMAT (35H1    N       R          Z              T)
 2004 FORMAT (I5,2F10.4,F10.0)
 2008 FORMAT (74H1   EL    I    J    K   L     MATERIAL    ANGLE BETA    ANGLE A
     1LPHA     TEMPERATURE)
 2009 FORMAT (I5,4I4,I8,F11.1,2F13.3)
 2010 FORMAT (1H1,'MATERIAL IDENTIFICATION NUMBER =',I2/
     11H ,'NO. OF MATERIAL TEMPERATURE CARDS =',I2/
     21H ,'MASS DENSITY =',E15.7)
 2011 FORMAT (1H ,'TEMPERATURE =',E15.7/
     11H ,'MODULUS OF ELASTICITY-EN =',E15.7/
     21H ,'MODULUS OF ELASTICITY-ES =',E15.7/
     31H ,'MODULUS OF ELASTICITY-ET =',E15.7/
     41H ,'POISSON RATIO-NUNS =',E15.7/
     51H ,'POISSON RATIO-NUNT =',E15.7/
     61H ,'POISSON RATIO-NUST =',E15.7/
     71H ,'SHEAR MODULUS-GNS =',E15.7/
     81H ,'SHEAR MODULUS-GST =',E15.7/
     91H ,'SHEAR MODULUS-GTN =',E15.7/
     11H ,'COEFFICIENT OF THERMAL EXPANSION-AN =',E15.7/
     21H ,'COEFFICIENT OF THERMAL EXPANSION-AS =',E15.7/
     31H ,'COEFFICIENT OF THERMAL EXPANSION-AT =',E15.7/)
 2012 FORMAT (1H ,'TEMPERATURE =',E15.7/
```

```
     11H ,'MODULUS OF ELASTICITY-EN =',E15.7/
     21H ,'MODULUS OF ELASTICITY-ES =',E15.7/
     31H ,'MODULUS OF ELASTICITY-ET =',E15.7/
     41H ,'POISSON RATIO-NUNS =',E15.7/
     51H ,'POISSON RATIO-NUNT =',E15.7/
     61H ,'POISSON RATIO-NUST =',E15.7/
     71H ,'SHEAR MODULUS-GNS =',E15.7/
     81H ,'SHEAR MODULUS-GST =',E15.7/
     91H ,'SHEAR MODULUS-GTN =',E15.7/
     11H ,'FREE THERMAL STRAIN-FN =',E15.7/
     21H ,'FREE THERMAL STRAIN-FS =',E15.7/
     31H ,'FREE THERMAL STRAIN-FT =',E15.7/)
2013 FORMAT (30H1 PRESSURE BOUNDARY CONDITIONS/20H    I    J  PRESSURE)
2014 FORMAT (2I5,F10.1)
2015 FORMAT (27H1 SHEAR BOUNDARY CONDITIONS/17H    I    J  SHEAR)
2016 FORMAT (26H  THE SYSTEM CONVERGED IN I2,11H ITERATIONS)
2017 FORMAT (33H  THE SYSTEM DID NOT CONVERGE IN I2,11H ITERATIONS)
2024 FORMAT (43H0 THE AXISYMMETRIC OPTION HAS BEEN SELECTED)
2025 FORMAT(30H1  TORSION BOUNDARY CONDITIONS/17H    I    J  SHEAR)
2030 FORMAT(1H1,'LOAD STEP=',I4)
2031 FORMAT(1H0 ,'AXIAL ACCELERATION  =',E12.4/
     11H0 ,'ANGULAR VELOCITY     =',E12.4/
     21H0 ,'ANGULAR ACCELERATION=',E12.4)
 920 STOP
     END
```

COMMON BLOCK /BASIC / MAP SIZE 3C

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	ANGVEL	8	ANGACC	10	TREF	1[illegible]
28	NUMEL	2C	NUMPC	30	NUMSC	3[illegible]

COMMON BLOCK /MATP / MAP SIZE 24E0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	E	30	EE	2430	AOFTS	24B[illegible]

COMMON BLOCK /ARG / MAP SIZE DC4

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	ZZZ	28	RR	50	ZZ	7[illegible]
798	TT	810	H	840	CRZ	81[illegible]
C90	STC	CA0	EPS	D30	N	DC[illegible]

COMMON BLOCK /NPDATA / MAP SIZE 28C0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	CODE	640	XR	960	Z	FA[illegible]

```
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      SUBROUTINE ANGLE (R,Z,RC,ZC,ANG)
      IMPLICIT REAL*8(A-H,O-Z)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     FIND ANGLE OF INCLINATION BETWEEN 0 AND 2*PI
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      PI=3.1415927
      D1=(Z-ZC)
      D2=(R-RC)
      IF(DABS(R-RC).GT.1.E-8) GO TO 100
      ANG=PI/2.
      IF(D1.GT.1.E-8) RETURN
      ANG=-ANG
      RETURN
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ALLOW CIRCLE TO CROSS AXIS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  100 ANG=DATAN2(D1,D2)
      RETURN
      END
```

SUBPROGRAMS CALLED

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
A0						

SCALAR MAP

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
B0	D1	B8	Z	C0	ZC	(
D8	RC	E0	ANG	E8		

STATEMENT NUMBER MAP

OCATION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT	LOCA
1CC	3	1CC	4	1D4	5	1
200	8	20C	9	222	10	2
242						

IN EFFECT* NOID,BCD,SOURCE,NOLIST,NODECK,LOAD,MAP
IN EFFECT* NAME = ANGLE , LINECNT = 50
ICS* SOURCE STATEMENTS = 13,PROGRAM SIZE = 586
ICS* NO DIAGNOSTICS GENERATED

```
      SUBROUTINE CIRCLE(ANG1,DELPHI,RSTRT,ZSTRT,RC,ZC,I,J)
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      DIMENSION AR(10,20),AZ(10,20)
      EQUIVALENCE (R(1),AR),(Z(1),AZ)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     FIND INTERSECTION OF LINE AND CIRCLE = NEW R AND Z
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      ANG1=ANG1+DELPHI
      RR=DSQRT((RSTRT-RC)**2+(ZSTRT-ZC)**2)
      AR(I,J)=RC+RR*DCOS(ANG1)
      AZ(I,J)=ZC+RR*DSIN(ANG1)
      RETURN
      END
```

COMMON BLOCK /TD / MAP SIZE 100

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	IMAX	50	JMIN	A0	JMAX	C
F4	NMTL	F8	NBC	FC		

COMMON BLOCK /NPDATA / MAP SIZE 28C0

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	AR	0	CODE	640	XR	96
FA0	XZ	15E0	NPNUM	1C20	T	1F4

SUBPROGRAMS CALLED

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
9C	DCOS	A0	DSIN	A4		

SCALAR MAP

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
B8	DELPHI	C0	RR	C8	RSTRT	[illegible]
E0	ZC	E8	I	F0	J	[illegible]

STATEMENT NUMBER MAP

LOCATION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT	LOCA
206	8	206	9	212	10	2[illegible]
292						

```
      SUBROUTINE INTER
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/ARG/RRR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CRZ(6,6),XI(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/PLANE/NPP
      DIMENSION XM(7),R(7),Z(7),XX(9)
      DATA XX/3*.1259391805448,3*.1323941527884,.225,
     1 .696140478028,.410426192314/
      R(7)=(RR(1)+RR(2)+RR(3))/3.
      Z(7)=(ZZ(1)+ZZ(2)+ZZ(3))/3.
      DO 100 I=1,3
      J=I+3
      R(I)=XX(8)*RR(I)+(1.0-XX(8))*R(7)
      R(J)=XX(9)*RR(I)+(1.0-XX(9))*R(7)
      Z(I)=XX(8)*ZZ(I)+(1.0-XX(8))*Z(7)
  100 Z(J)=XX(9)*ZZ(I)+(1.0-XX(9))*Z(7)
      DO 200 I=1,7
  200 XM(I)=XX(I)*R(I)
      DO 300 I=1,10
  300 XI(I)=0.0
      AREA=.5*(RR(1)*(ZZ(2)-ZZ(3))+RR(2)*(ZZ(3)-ZZ(1))+RR(3)*(ZZ(1)
     1  -ZZ(2)))
      IF(NPP.NE.0) GO TO 600
      DO 400 I=1,7
      XI(1)=XI(1)+XM(I)
      XI(2)=XI(2)+XM(I)/R(I)
      XI(3)=XI(3)+XM(I)/(R(I)**2)
      XI(4)=XI(4)+XM(I)*Z(I)/R(I)
      XI(5)=XI(5)+XM(I)*Z(I)/(R(I)**2)
      XI(6)=XI(6)+XM(I)*(Z(I)**2)/(R(I)**2)
      XI(7)=XI(7)+XM(I)*R(I)
      XI(8)=XI(8)+XM(I)*Z(I)
      XI(9)=XI(9)+XM(I)*(R(I)**2)
  400 XI(10)=XI(10)+XM(I)*R(I)*Z(I)
      DO 500 I=1,10
  500 XI(I)=XI(I)*AREA
      RETURN
  600 XI(1)=AREA
      XI(7)=R(7)*AREA
      XI(8)=Z(7)*AREA
      RETURN
      END
```

COMMON BLOCK /ARG / MAP SIZE 0C4

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	ZZZ	28	RR	50	ZZ	
798	TT	810	H	840	CRZ	8

```
      SUBROUTINE ITERAT
C
C     NODAL SLIP IS FOUND BY ITERATION
C
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/ARG/RRR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CRZ(6,6),XI(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/SOLVE/B(72),A(72,36),NUMTC,MBAND
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),F(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/RESULT/BS(6,15),D(6,6),C(6,6),AR,BB(6,9),CNS(6,6)
      COMMON/CIT/NEQL  ,NSLIP,ICRACK,ISLIP,INP,NSKIP
      COMMON/DATA1/RTN(200),RST(200),RNN(200)
      COMMON/DATA2/IFAIL(200),TB(200,12),ICR(200),IAD(200,4)
      COMMON/DATA3/TFAIL,CF
      DIMENSION T(3,2),SQ(4,15,15),PQ(4,15),AU(2,2),AL(2,2),BU(2),BL(2),
     1TNL(3),YM(3,2),ZM(3,2),TNU(3),DM(4,12),FM(2,12),SU(2),SL(2)
      DIMENSION S2(12,3),S3(3,12),S4(3,3),S5(12,3),S6(12,12)
C
C     START LOOP ON NODAL POINTS
      DO 900 NP=1,NUMNP
      IF(ICR(NP).EQ.0) GO TO 900
      AV=0.0
      ANGS=0.0
      TRES=0.0
      DO 7 I=1,4
      DO 6 K=1,15
      PQ(I,K)=C.0
      DO 6 L=1,15
    6 SQ(I,K,L)=0.0
      N=IAD(NP,I)
      IF(N.EQ.0) GO TO 7
      AV=AV+1.
      TRES=TRES+DSQRT(RTN(N )**2+RST(N )**2)
    7 CONTINUE
      IF(IFAIL(NP).EQ.1) GO TO 8
      TRES=DABS(TRES)/AV
      TFAIL=DABS(TFAIL)
      IF(TRES.LT.TFAIL) GO TO 900
      IFAIL(NP)=1
    8 CONTINUE
      DO 10 I=1,4
      N=IAD(NP,I)
```

```
          IF(N.EQ.0) GO TO 10
          ANGS=ANGS+BETA(N)
   10     CONTINUE
          ANGS=ANGS/AV
          DO 11 I=1,3
          DO 11 J=1,2
   11     T(I,J)=0.0
          T(1,1)=DSIN(ANGS)
          T(2,1)=DCOS(ANGS)
          T(3,2)=1.0
          DO 14 I=1,4
          N=IAD(NP,I)
          IF(N.EQ.0) GO TO 14
          CALL QUAD
          IX(N,5)=-IX(N,5)
          DO 100 K=1,4
          II=3*K
          JJ=3*IX(N,K)
          P(II-2)=B(JJ-2)
          P(II-1)=B(JJ-1)
  100     P(II)  =B(JJ)
          DO 231 II=1,3
          DO 231 JJ=1,3
    231   S4(II,JJ)=S(II+12,JJ+12)
          CALL SYMINV(S4,3)
          DO 232 II=1,12
          DO 232 JJ=1,3
    232   S2(II,JJ)=S(II,JJ+12)
          DO 233 II=1,3
          DO 233 JJ=1,12
    233   S3(II,JJ)=S(II+12,JJ)
          DO 240 L=1,12
          DO 240 J=1,3
          S5(L,J)=0.000
          DO 240 K=1,3
    240   S5(L,J) = S5(L,J) + S2(L,K) * S4(K,J)
          DO 241 L=1,12
          DO 241 J=1,12
          S6(L,J)=0.000
          DO 241 K=1,3
    241   S6(L,J) = S6(L,J) + S5(L,K) * S3(K,J)
          DO 235 II=1,12
          DO 235 JJ=1,12
    235   S(II,JJ)=S(II,JJ)-S6(II,JJ)
C
C
          DO 13 II=1,12
          PO(I,II)=P(II)+TB(N,II)
```

```
      DO 13 JJ=1,12
13    SQ(I,II,JJ)=S(II,JJ)
      NS=ICR(NP)
14    CONTINUE
      IF(NS.EQ.2) GO TO 24
      DO 23 K=1,3
      FM(1,K)=0.0
      FM(2,K)=0.0
      DO 21 I=1,2
      NN=3*(I-1)+K
      DO 20 M=1,12
20    FM(1,K)=FM(1,K)+SQ(I,NN,M)*PQ(I,M)
      DO 21 J=1,2
      YM(K,J)=0.0
      DO 21 L=1,3
      NQ=3*(I-1)+L
21    YM(K,J)=YM(K,J)+SQ(I,NN,NQ)*T(L,J)
      DO 23 I=3,4
      NN=3*(I-1)+K
      DO 22 M=1,12
22    FM(2,K)=FM(2,K)+SQ(I,NN,M)*PQ(I,M)
      DO 23 J=1,2
      ZM(K,J)=0.0
      DO 23 L=1,3
      NQ=3*(I-1)+L
23    ZM(K,J)=ZM(K,J)+SQ(I,NN,NQ)*T(L,J)
      GO TO 29
24    DO 28 K=1,3
      FM(1,K)=0.0
      FM(2,K)=0.0
      DO 26 I=1,4,3
      NN=3*(I-1)+K
      DO 25 M=1,12
25    FM(1,K)=FM(1,K)+SQ(I,NN,M)*PQ(I,M)
      DO 26 J=1,2
      YM(K,J)=0.0
      DO 26 L=1,3
      NQ=3*(I-1)+L
26    YM(K,J)=YM(K,J)+SQ(I,NN,NQ)*T(L,J)
      DO 28 I=2,3
      NN=3*(I-1)+K
      DO 27 M=1,12
27    FM(2,K)=FM(2,K)+SQ(I,NN,M)*PQ(I,M)
      DO 28 J=1,2
      ZM(K,J)=0.0
      DO 28 L=1,3
      NQ=3*(I-1)+L
28    ZM(K,J)=ZM(K,J)+SQ(I,NN,NQ)*T(L,J)
```

```
29    CONTINUE
      AU(1,1)=YM(3,2)
      AU(1,2)=-YM(1,2)*T(1,1)-YM(2,2)*T(2,1)
      AU(2,1)=-YM(3,1)
      AU(2,2)= YM(1,1)*T(1,1)+YM(2,1)*T(2,1)
      BU(2)=-FM(1,3)
      BU(1)=-FM(1,1)*T(1,1)-FM(1,2)*T(2,1)
      DET=AU(1,1)*AU(2,2)-AU(2,1)*AU(1,2)
      DO 31 I=1,2
      SU(I)=0.0
      DO 31 J=1,2
31    SU(I)=SU(I)+AU(I,J)*BU(J)/DET
      AL(1,1)=ZM(3,2)
      AL(1,2)=-ZM(1,2)*T(1,1)-ZM(2,2)*T(2,1)
      AL(2,1)=-ZM(3,1)
      AL(2,2)= ZM(1,1)*T(1,1)+ZM(2,1)*T(2,1)
      BL(2)=-FM(2,3)
      BL(1)=-FM(2,1)*T(1,1)-FM(2,2)*T(2,1)
      DET=AL(1,1)*AL(2,2)-AL(2,1)*AL(1,2)
      DO 32 I=1,2
      SL(I)=0.0
      DO 32 J=1,2
32    SL(I)=SL(I)+AL(I,J)*BL(J)/DET
      DO 35 I=1,3
      TNU(I)=0.0
      TNL(I)=0.0
      DO 35 J=1,2
      TNU(I)=TNU(I)+T(I,J)*SU(J)
      TNL(I)=TNL(I)+T(I,J)*SL(J)
35    CONTINUE
      IF(ICR(NP).EQ.2) GO TO 45
      DO 43 I=1,4
      DO 41 J=1,12
41    DM(I,J)=0.0
      DO 43 J=1,3
      NJ=3*(I-1)+J
      IF(I.GT.2) GO TO 42
      DM(I,NJ)=TNU(J)
      GO TO 43
42    DM(I,NJ)=TNL(J)
43    CONTINUE
      GO TO 49
45    DO 48 I=1,4
      DO 46 J=1,12
46    DM(I,J)=0.0
      DO 48 J=1,3
      NJ=3*(I-1)+J
      IF(I.EQ.2.OR.I.EQ.3) GO TO 47
```

```
      DM(I,NJ)=TNU(J)
      GO TO 48
47    DM(I,NJ)=TNL(J)
48    CONTINUE
49    CONTINUE
      DO 62 I=1,4
      N=IAD(NP,I)
      IF(N.EQ.0) GO TO 62
      DO 61 J=1,12
61    TB(N,J)=TB(N,J)+DM(I,J)/2.0
62    CONTINUE
C
900   CONTINUE
      RETURN
      END
```

COMMON BLOCK /ARG / MAP SIZE DC4

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	ZZZ	20	RR	50	ZZ	
798	TT	810	H	840	CRZ	8
C80	SIG	CA0	EPS	D30	N	D

COMMON BLOCK /SOLVE / MAP SIZE 5348

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	A	240	NUMTC	5340	MBAND	53

COMMON BLOCK /BASIC / MAP SIZE 3C

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	ANGVEL	8	ANGACC	10	TREF	
28	NUMEL	2C	NUMPC	30	NUMSC	

COMMON BLOCK /NPDATA / MAP SIZE 2BC0

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	CODE	640	XR	960	Z	F
1C20	F	1F40	XT	2580		

COMMON BLOCK /ELDATA / MAP SIZE 2BC0

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	EPP	640	PR	C80	SH	D
1060	JP	1080	IS	1E00	JS	1E
24E0	JT	2800	ST	2820		

```
      SUBROUTINE MESH
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      DIMENSION AR(10,20),AZ(10,20),NCODE(10,20)
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      EQUIVALENCE (R(1),AR),(Z(1),AZ),(IX(1,1),NCODE)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     MESH CONTROL INFORMATION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      READ (5,1000) MAXI,MAXJ,NSEG,NBC,NMTL
      WRITE(6,2000) MAXI,MAXJ,NSEG,NBC,NMTL
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     INITIALIZE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      ISEG=-1
      PI=3.1415927
      DO 110 J=1,10
      DO 100 I=1,5
      NCODE(I,J)=0
      AR(I,J)=0.
      AZ(I,J)=0.
      JMAX(I)=0
  100 JMIN(I)=MAXI
      IMIN(J)=MAXJ
  110 IMAX(J)=0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     LINE SEGMENT CARDS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  150 ISEG=ISEG+1
  159 IF(ISEG.EQ.NSEG) GO TO 400
      READ(5,1001) I1,J1,R1,Z1,I2,J2,R2,Z2,I3,J3,R3,Z3,IPTION
      WRITE(6,2001)I1,J1,R1,Z1,I2,J2,R2,Z2,I3,J3,R3,Z3,IPTION
      IPTION=IPTION+1
      AR(I1,J1)=R1
      AZ(I1,J1)=Z1
      NCODE(I1,J1)=1
      CALL MNIMX(I1,J1)
      GO TO (150,200,200,300,300,200,200), IPTION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     GENERATE STRAIGHT LINES ON BOUNDARY
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
200   DI= ABS(FLOAT(I2-I1))
      DJ= ABS(FLOAT(J2-J1))
```

```
      AR(I2,J2)=R2
      AZ(I2,J2)=Z2
      NCODE(I2,J2)=1
      CALL MNIMX(I2,J2)
      ISTRT=I1
      ISTP=I2
      JSTRT=J1
      JSTP=J2
      DIFF=DMAX1(DI,DJ)
      ITER=DIFF-1.
      IINC=0
      JINC=0
      IF(I2.NE.I1) IINC=(I2-I1)/IABS(I2-I1)
      IF(J2.NE.J1) JINC=(J2-J1)/IABS(J2-J1)
      KAPPA=1
      IF(I2.NE.I1.AND.J2.NE.J1.AND.IPTION.NE.3) KAPPA=2
      IF(KAPPA.EQ.2) DIFF=2.*DIFF
      RINC=(R2-R1)/DIFF
      ZINC=(Z2-Z1)/DIFF
      WRITE(6,2002) DI,DJ,DIFF,RINC,ZINC,ITER,IINC,JINC,KAPPA
C
C     CHECK FOR INPUT ERROR
C
      IF(KAPPA.NE.2.OR.DI.EQ.DJ) GO TO 210
      WRITE(6,2003)
      GO TO 150
C
C     INTERPOLATE
C
  210 I=I1
      J=J1
      WRITE(6,2004)
      DO 230 M=1,ITER
      IF(ITER.EQ.0.AND.IPTION.EQ.2) GO TO 230
      IF(ITER.EQ.0.AND.IPTION.EQ.6) GO TO 230
      IF(ITER.EQ.0.AND.IPTION.EQ.7) GO TO 230
      IF(KAPPA.EQ.2) GO TO 220
      IOLD=I
      I=I+IINC
      JOLD=J
      J=J+JINC
      AR(I,J)=AR(IOLD,JOLD)+RINC
      AZ(I,J)=AZ(IOLD,JOLD)+ZINC
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
      CALL MNIMX(I,J)
      NCODE(I,J)=1
      GO TO 230
  220 CONTINUE
```

```
      IF(I1.GT.I2.AND.IPTION.EQ.7) GO TO 221
      IF(I1.LT.I2.AND.IPTION.EQ.6) GO TO 221
      IOLD=I
      I=I+IINC
      AR(I,J)=AR(IOLD,J)+RINC
      AZ(I,J)=AZ(IOLD,J)+ZINC
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
      NCODE(I,J)=1
      CALL MNIMX(I,J)
      JOLD=J
      J=J+JINC
      AR(I,J)=AR(I,JOLD)+RINC
      AZ(I,J)=AZ(I,JOLD)+ZINC
      NCODE(I,J)=1
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
      CALL MNIMX(I,J)
      GO TO 230
  221 JOLD=J
      J=J+JINC
      AR(I,J)=AR(I,JOLD)+RINC
      AZ(I,J)=AZ(I,JOLD)+ZINC
      NCODE(I,J)=1
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
      CALL MNIMX(I,J)
      IOLD=I
      I=I+IINC
      AR(I,J)=AR(IOLD,J)+RINC
      AZ(I,J)=AZ(IOLD,J)+ZINC
      NCODE(I,J)=1
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
      CALL MNIMX(I,J)
  230 CONTINUE
      IF(KAPPA.EQ.1) GO TO 150
      IF(I1.GT.I2.AND.IPTION.EQ.7) GO TO 231
      IF(I1.LT.I2.AND.IPTION.EQ.6) GO TO 231
      IOLD=I
      I=I+IINC
      AR(I,J)=AR(IOLD,J)+RINC
      AZ(I,J)=AZ(IOLD,J)+ZINC
      GO TO 232
  231 CONTINUE
      JOLD=J
      J=J+JINC
      AR(I,J)=AR(I,JOLD)+RINC
      AZ(I,J)=AZ(I,JOLD)+ZINC
  232 CONTINUE
      NCODE(I,J)=1
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
```

```
      CALL MNIMX(I,J)
      GO TO 150
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     GENERATE CIRCULAR ARCS ON BOUNDARY
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  300 AR(I2,J2)=R2
      AZ(I2,J2)=Z2
      NCODE(I2,J2) = 1
      CALL MNIMX(I2,J2)
      IF(IPTION.EQ.5) GO TO 320
C
C     FIND CENTER OF CIRCLE
C
      AR(I3,J3)=R3
      AZ(I3,J3)=Z3
      NCODE(I3,J3)=1
      CALL MNIMX(I3,J3)
      SLAC=(Z2-Z1)/(R2-R1)
      SLBF=-1./SLAC
      SLCE=(Z3-Z2)/(R3-R2)
      SLDF=-1./SLCE
C
C     CHECK FOR INPUT ERROR
C
      IF(DABS(SLAC-SLCE).GT..001) GO TO 310
      WRITE(6,2006) R1,Z1,R2,Z2,R3,Z3,SLAC,SLCE
      GO TO 150
  310 R4=R1+(R2-R1)/2.
      Z4=Z1+(Z2-Z1)/2.
      R5=R2+(R3-R2)/2.
      Z5=Z2+(Z3-Z2)/2.
      BBF=Z4-SLBF*R4
      BDF=Z5-SLDF*R5
      RC=(BBF-BDF)/(SLDF-SLBF)
      ZC=SLBF*RC+BBF
      WRITE(6,2007) RC,ZC
      KAPPA=1
      GO TO 330
  320 KAPPA=2
      RC=R3
      ZC=Z3
  330 ISTRT=I1
      ISTP=I2
      JSTRT=J1
      JSTP=J2
      RSTRT=R1
      RSTP=R2
      ZSTRT=Z1
```

```
      ZSTP=Z2
  340 CALL ANGLE(RSTRT,ZSTRT,RC,ZC,ANG1)
      CALL ANGLE(RSTP,ZSTP,RC,ZC,ANG2)
      IF(ANG2.LE.ANG1)  ANG2=2.0*PI+ANG2
C
C     FIND ANGULAR INCREMENT
C
      DI= ABS(FLOAT(ISTP-ISTRT))
      DJ= ABS(FLOAT(JSTP-JSTRT))
      IINC=0
      JINC=0
      IF(ISTRT.NE.ISTP) IINC=(ISTP-ISTRT)/IABS(ISTP-ISTRT)
      IF(JSTRT.NE.JSTP) JINC=(JSTP-JSTRT)/IABS(JSTP-JSTRT)
      LAMDA=1
      IF(IINC.NE.0.AND.JINC.NE.0) LAMDA=2
      DIFF=DMAX1(DI,DJ)
      ITER=DIFF-1.
      IF(LAMDA.EQ.2) DIFF=2.*DIFF
      DELPHI=(ANG2-ANG1)/DIFF
      WRITE(6,2008) ANG1,ANG2,DIFF,DELPHI
C
C     CHECK FOR INPUT ERROR
C
      IF(LAMDA.NE.2.OR.DI.EQ.DJ) GO TO 350
      WRITE(6,2003)
      GO TO 150
  350 IO=ISTRT
      JO=JSTRT
      WRITE(6,2004)
C
C     INTERPOLATE
C
      NPT=IABS(I2-I1)+IABS(J2-J1)-1
      DO 380 M=1,ITER
  359 IF(LAMDA.EQ.2) GO TO 360
      I=IO+IINC
      J=JO+JINC
      CALL MNIMX(I,J)
      NCODE(I,J)=1
      CALL CIRCLE(ANG1,DELPHI,RSTRT,ZSTRT,RC,ZC,I,J)
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
      GO TO 370
  360 I=IO+IINC
      J=JO
      NCODE(I,J)=1
      CALL MNIMX(I,J)
      CALL CIRCLE(ANG1,DELPHI,RSTRT,ZSTRT,RC,ZC,I,J)
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
```

```
      J=J0+JINC
      NCODE(I,J)=1
      CALL MNIMX(I,J)
      CALL CIRCLE(ANG1,DELPHI,RSTRT,ZSTRT,RC,ZC,I,J)
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
  370 I0=I
  380 J0=J
      IF(LAMDA.NE.2) GO TO 390
      I=I0+IINC
      NCODE(I,J)=1
      CALL MNIMX(I,J)
      CALL CIRCLE(ANG1,DELPHI,RSTRT,ZSTRT,RC,ZC,I,J)
      WRITE(6,2005) I,J,AR(I,J),AZ(I,J)
  390 IF(KAPPA.EQ.2) GO TO 150
      ISTRT=I2
      ISTP=I3
      JSTRT=J2
      JSTP=J3
      RSTRT=R2
      RSTP=R3
      ZSTRT=Z2
      ZSTP=Z3
      KAPPA=2
  399 GO TO 340
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     CALCULATE COORDINATES OF INTERIOR POINTS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  400 IF(MAXJ.LE.2) GO TO 430
      J2=MAXJ-1
      DO 420 N=1,500
      RESID=0.
      DO 410 J=2,J2
      I1=IMIN(J)+1
      I2=IMAX(J)-1
      DO 410 I=I1,I2
      IF(NCODE(I,J).EQ.1) GO TO 410
      DR=(AR(I+1,J)+AR(I-1,J)+AR(I,J+1)+AR(I,J-1))/4.-AR(I,J)
      DZ=(AZ(I+1,J)+AZ(I-1,J)+AZ(I,J+1)+AZ(I,J-1))/4.-AZ(I,J)
      RESID=RESID+DABS(DR)+DABS(DZ)
      AR(I,J)=AR(I,J)+1.8*DR
      AZ(I,J)=AZ(I,J)+1.8*DZ
  410 CONTINUE
      IF(N.EQ.1) RES1=RESID
      IF(N.EQ.1.AND.RESID.EQ.0.)GO TO 430
      IF(RESID/RES1.LT.1.E-5) GO TO 430
  420 CONTINUE
  430 WRITE(6,2009) N
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
      CALL POINTS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
 1000 FORMAT (5I5)
 1001 FORMAT (3(2I3,2F8.3),I5)
 2000 FORMAT (30H1  MESH GENERATION INFORMATION//
     1 41H0  MAXIMUM VALUE OF I IN THE MESH--------I3/
     2 41H0  MAXIMUM VALUE OF J IN THE MESH--------I3/
     3 41H0  NUMBER OF LINE SEGMENT CARDS----------I3/
     4 41H0  NUMBER OF BOUNDARY CONDITION CARDS----I3/
     5 41H0  NUMBER OF MATERIAL BLOCK CARDS--------I3///)
 2001 FORMAT (//88H  INPUT   I1  J1    R1       Z1     I2  J2    R2      Z
     2    I3  J3    R3      Z3    IPTION/8X,3(2I4,2F8.4),I6)
 2002 FORMAT (5H  DI=F4.0,5H  DJ=F4.0,7H  DIFF=F4.0,7H  RINC=F8.3,7H  ZI
     1NC=F8.3,7H  ITER=I3,7H  IINC=I3,7H  JINC=I3,8H  KAPPA=I1)
 2003 FORMAT(1X,38H**BAD INPUT--THIS LINE IS NOT DIAGONAL)
 2004 FORMAT (30H    I    J         AR         AZ)
 2005 FORMAT (2I5,2F11.6)
 2006 FORMAT (51H ** BAD INPUT - THESE POINTS DO NOT DEFINE A CIRCLE,/,
     13X,6F12.4,10X,2E20.8)
 2007 FORMAT(19H  CENTER COORDINATE,(F11.6,1X,F11.6,1X))
 2008 FORMAT (7H  ANG1=F9.6,7H  ANG2=F9.6,7H  DIFF=F3.0,9H  DELPHI=F9.6)
 2009 FORMAT (//30H  COORDINATES CALCULATED AFTER I3,11H ITERATIONS)
      RETURN
      END
```

COMMON BLOCK /TD / MAP SIZE 100

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	IMAX	50	JMIN	A0	JMAX	
F4	NMTL	F8	NBC	FC		

COMMON BLOCK /NPDATA / MAP SIZE 28C0

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	AR	0	CODE	640	XR	9
FA0	XZ	15E0	NPNUM	1C20	T	1F

COMMON BLOCK /ELDATA / MAP SIZE 28C0

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	EPP	640	PR	C80	SH	D
DC0	IP	1060	JP	1080	IS	1E
1EA0	IT	24E0	JT	2800	ST	28

SUBPROGRAMS CALLED

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
1DC	MNIMX	1E0	ANGLE	1E4	CIRCLE	1

```
      SUBROUTINE MNIMX(I,J)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      IF(J.LT.JMIN(I)) JMIN(I)=J
      IF(J.GT.JMAX(I)) JMAX(I)=J
      IF(I.LT.IMIN(J)) IMIN(J)=I
      IF(I.GT.IMAX(J)) IMAX(J)=I
      RETURN
      END
```

COMMON BLOCK /TD / MAP SIZE 100

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL
0	IMAX	50	JMIN	A0	JMAX
F4	NMTL	F8	NBC	FC	

SCALAR MAP

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL
A4	I	A8			

STATEMENT NUMBER MAP

ENT LOCATION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT
13A	4	13A	5	15C	6
1C6					

```
TIONS IN EFFECT*  NOID,BCD,SOURCE,NOLIST,NODECK,LOAD,MAP
TIONS IN EFFECT*  NAME = MNIMX  , LINECNT =       50
ATISTICS*    SOURCE STATEMENTS =          9,PROGRAM SIZE =        462
ATISTICS*  NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE MODIFY(NEQ,N,U)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/SOLVE/B(72),A(72,36),NUMTC,MBAND
      DO 10 M=2,MBAND
      K=N-M+1
      IF(K.LE.0) GO TO 5
      B(K)=B(K)-A(K,M)*U
      A(K,M)=0.0
    5 K=N+M-1
      IF(NEQ.LT.K) GO TO 10
      B(K)=B(K)-A(N,M)*U
      A(N,M)=0.0
   10 CONTINUE
      A(N,1)=1.0
      B(N)=U
      RETURN
      END
```

COMMON BLOCK /SOLVE / MAP SIZE 5348

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	A	240	NUMTC	5340	MBAND	53

SCALAR MAP

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
B8	M	C0	K	C4	N	

STATEMENT NUMBER MAP

OCATION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT	LOCA
18C	4	18C	5	198	6	1
1E0	9	1F0	10	200	11	2
248	14	264	15	278	16	2

```
; IN EFFECT*  NOID,BCD,SOURCE,NOLIST,NODECK,LOAD,MAP
; IN EFFECT*  NAME = MODIFY  , LINECNT =       50
TICS*    SOURCE STATEMENTS =        17,PROGRAM SIZE =       660
TICS*  NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE MPLOT
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      REAL*4 X(100),Y(100),TX(2),TY(2),TITLE(20),ZMAX
      READ (5,1000) TITLE,RMAX,ZMAX
      CALL CCP2SY (0.7,0.2,0.2,TITLE,0.0,80)
      CALL CCP1PL (0.7,0.7,-3)
      TX(1)=0.0
      TY(1)=0.0
      TX(2)=RMAX/9.0
      TY(2)=RMAX/9.0
      ZMAX=ZMAX*TY(2)+2.0
      IF (ZMAX.LT.17.0) ZMAX=17.0
      DO 100 J=1,MAXJ
      NSTART=IMIN(J)
      NSTOP=IMAX(J)
      N=0
      DO 101 I=NSTART,NSTOP
      N=N+1
      NP=NPNUM(I,J)
      Y(N)=R(NP)
  101 X(N)=Z(NP)
      CALL CCP6LN (X,Y,N,1,TX,TY)
  100 CONTINUE
      DO 102 I=1,MAXI
      NSTART=JMIN(I)
      NSTOP=JMAX(I)
      N=0
      DO 103 J=NSTART,NSTOP
      N=N+1
      NP=NPNUM(I,J)
      Y(N)=R(NP)
  103 X(N)=Z(NP)
      CALL CCP6LN (X,Y,N,1,TX,TY)
  102 CONTINUE
      CALL CCP1PL (ZMAX,-0.7,-3)
 1000 FORMAT (20A4/2F10.0)
      RETURN
      END
```

COMMON BLOCK /TD / MAP SIZE 100

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	IMAX	50	JMIN	A0	JMAX	

```
      FUNCTION NODE(I,J)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      NODE=0
      DO 100 JJ=1,J
      NSTART=IMIN(JJ)
      NSTOP=IMAX(JJ)
      DO 100 II=NSTART,NSTOP
      NODE=NODE+1
      IF(JJ.EQ.J.AND.II.EQ.I) RETURN
  100 CONTINUE
      RETURN
      END
```

COMMON BLOCK /TD / MAP SIZE 100

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	IMAX	50	JMIN	A0	JMAX	[illegible]
F4	NMTL	F8	NBC	FC		

EQUIVALENCE DATA MAP

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
A0						

SCALAR MAP

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
A4	J	A8	NSTART	AC	NSTOP	[illegible]
B8						

STATEMENT NUMBER MAP

OCATION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT	LOCA
156	4	156	5	15E	6	1[illegible]
17A	9	182	10	18E	11	1[illegible]

IN EFFECT* NOID,BCD,SOURCE,NOLIST,NODECK,LOAD,MAP
IN EFFECT* NAME = NODE , LINECNT = 50
ICS* SOURCE STATEMENTS = 13,PROGRAM SIZE = 508
ICS* NO DIAGNOSTICS GENERATED

```
      SUBROUTINE POINTS
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/MATP/RO(6),E(12,16,6),EE(16),AOFTS(6)
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/SOLVE/ X(888),Y(888),TEM(888),NUMTC,MBAND
      COMMON/TD/ IMIN(20),IMAX(20),JMIN(10),JMAX(10),MAXI,MAXJ,
     1NMTL,NBC
      COMMON/PLANE/NPP
      DIMENSIONAR(10,20),AZ(10,20),MATRIL(200,5),BLKANG(200),
     1BLKALF(200)
      DIMENSION IBNG(130),NBNG(130)
      EQUIVALENCE (R(1),AR),(Z(1),AZ)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * *   * * * * * *
C     ESTABLISH NODAL POINT INFORMATION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      NEL=0
      NODSUM=0
      DO 100 J=1,MAXJ
      NSTART=IMIN(J)
      NSTOP=IMAX(J)
      DO 100 I=NSTART,NSTOP
  100 NODSUM=NODSUM+1
      NELSUM=0
      JJMAX=MAXJ-1
      DO 1.0 JJ=1,JJMAX
      NSTOP=MINO(IMAX(JJ),IMAX(JJ+1))-1
      NSTART=MAXO(IMIN(JJ),IMIN(JJ+1))
      DO 110 II=NSTART,NSTOP
  110 NELSUM=NELSUM+1
      NUMNP=NODSUM
      NUMEL=NELSUM
      DO 120 J=1,MAXJ
      NSTART=IMIN(J)
      NSTOP=IMAX(J)
      DO 120 I=NSTART,NSTOP
      NPNUM(I,J)=NODE(I,J)
      NP=NPNUM(I,J)
      R(NP)=AR(I,J)
  120 Z(NP)=AZ(I,J)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     READ AND ASSIGN BOUNDARY CONDITIONS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
C     INITIALIZE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO 130 I=1,NUMNP
      CODE(I)=0
      IF(R(I).EQ.0..AND.NPP.EQ.0) CODE(I)=1.
      XR(I)=0.
      XZ(I)=0.
      XT(I)=0.0
  130 T(I)=0.
      IF(NBC.EQ.0) GO TO 210
      DO 200 IBCON=1,NBC
      READ(5,1002) I1,I2,J1,J2,ICN,RCON,ZCON,TCON
      DO 200 I=I1,I2
      DO 200 J=J1,J2
      NP=NPNUM(I,J)
      CODE(NP)=ICN
      XR(NP)=RCON
      XT(NP)=TCON
  200 XZ(NP)=ZCON
  210 MPRINT=0
      DO 230 J=1,MAXJ
      NSTART=IMIN(J)
      NSTOP=IMAX(J)
      DO 230 I=NSTART,NSTOP
      NP=NPNUM(I,J)
      IF(MPRINT.NE.0) GO TO 220
      WRITE(6,2000)
      MPRINT=59
  220 MPRINT=MPRINT-1
  230 WRITE(6,2001) I,J,NP,CODE(NP),R(NP),Z(NP),XR(NP),XZ(NP),XT(NP)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ASSIGN MATERIALS IN BLOCKS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO 300 M1=1,NUMEL
  300 IX(M1,5)=0
      DO 310 IMTL=1,NMTL
      READ (5,1000) MTL,(MATRIL(IMTL,IM),IM=2,5),BLKANG(IMTL),
     1BLKALF(IMTL),IBNG(IMTL),NBNG(IMTL)
  310 MATRIL(IMTL,1)=MTL
      ICNG=0
      NCNG=0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ESTABLISH ELEMENT INFORMATION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      JJMAX=MAXJ-1
      N=0
      MTL=1
      KTL=1
```

```
      DO 440 JJ=1,JJMAX
      NSTOP=MINO(IMAX(JJ),IMAX(JJ+1))-1
      NSTART=MAXO(IMIN(JJ),IMIN(JJ+1))
      DO 440 II=NSTART,NSTOP
      NEL=NEL+1
      DO 400 IMTL=1,NMTL
      IF(II.LT.MATRIL(IMTL,2)) GO TO 400
      IF(II.GE.MATRIL(IMTL,3)) GO TO 400
      IF(JJ.LT.MATRIL(IMTL,4)) GO TO 400
      IF(JJ.GE.MATRIL(IMTL,5)) GO TO 400
      KAT=IMTL
      MAT=MATRIL(IMTL,1)
  400 CONTINUE
      IF(KAT.EQ.KTL) GO TO 410
      KTL=KAT
      MTL=MAT
      GO TO 420
  410 IF(II.EQ.NSTART) GO TO 420
      IF(JJ.NE.JJMAX.OR.II.NE.NSTOP) GO TO 440
      M=NEL+1
      IANG=ICNG
      NANG=NCNG
      GO TO 421
  420 I=NPNUM(II,JJ)
      J=I+1
      K=NPNUM(II+1,JJ+1)
      L=K-1
      M=NEL
      IX(M,1)=I
      IX(M,2)=J
      IX(M,3)=K
      IX(M,4)=L
      IX(M,5)=MTL
      BETA(M)=BLKANG(KTL)
      ALPHA(M)=BLKALF(KTL)
      IANG=ICNG
      NANG=NCNG
      ICNG=IBNG(KTL)
      NCNG=NBNG(KTL)
421   NC=2
  430 N=N+1
      IF(M.LE.N) GO TO 440
      IX(N,1)=IX(N-1,1)+1
      IX(N,2)=IX(N-1,2)+1
      IX(N,3)=IX(N-1,3)+1
      IX(N,4)=IX(N-1,4)+1
      IX(N,5)=IX(N-1,5)
      BETA(N)=BETA(N-1)
```

```
      IF(IANG.EQ.1) GO TO 442
      ALPHA(N)=ALPHA(N-1)
      GO TO 443
  442 CONTINUE
      IF(NC.GT.NANG) GO TO 444
      ALPHA(N)=ALPHA(N-1)
      GO TO 443
  444 NC=1
      ALPHA(N)=-ALPHA(N-1)
  443 CONTINUE
      NC=NC+1
      IF(M.GT.N) GO TO 430
  440 CONTINUE
      IF(NUMNP.GT.2000) WRITE(6,2002)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     SET NODAL POINT TEMPERATURE TO REFERENCE TEMPERATURE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(NUMTC.NE.0) RETURN
      DO 500 N=1,NUMNP
  500 T(N)=TREF
 1000 FORMAT (5I5,2F10.0,2I5)
 1002 FORMAT(4I5,I10,3F10.0)
 2000 FORMAT (128H1    I     J     NP          TYPE     R-ORDINATE     Z-ORDINA
     1TE   R LOAD OR DISPLACEMENT  Z LOAD OR DISPLACEMENT  T LOAD OR DISP
     2LACEMENT)
 2001 FORMAT (2I5,I6,I12,F13.6,F14.6,E26.7,E24.7,E24.7)
 2002 FORMAT (35H  LAD INPUT - TOO MANY NODAL POINTS)
      RETURN
      END
```

COMMON BLOCK /BASIC / MAP SIZE 3C

ATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATI
0	ANGVEL	8	ANGACC	10	TREF	1[illegible]
28	NUMEL	2C	NUMPC	30	NUMSC	3[illegible]

COMMON BLOCK /MATP / MAP SIZE 24E0

ATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATI
0	E	30	EE	2430	AOFTS	24B[illegible]

COMMON BLOCK /NPDATA / MAP SIZE 2BC0

ATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATI
0	AP	0	CODE	640	XP	96[illegible]
FA0	XZ	15E0	NPNU	1C20	T	1E4[illegible]

```
      SUBROUTINE QUAD
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      REAL*8 NUSN,NUTN,NUTS,NUNS,NUNT,NUST
      DIMENSION DUMMY(6,6),DUMMY1(6,6)
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/MATP/RO(6),E(12,16,6),EE(16),ADFTS(6)
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/ARG/PRR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CPZ(6,6),XT(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/RESULT/BS(6,15),D(6,6),C(6,6),AR,BB(6,9),CNS(6,6)
      COMMON/PLANE/NPP
      I1=IX(N,1)
      J1=IX(N,2)
      K1=IX(N,3)
      L1=IX(N,4)
      MTYPE=IABS(IX(N,5))
      IX(N,5)=-IX(N,5)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     INTERPOLATE MATERIAL PROPERTIES
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO 100 I=1,12
  100 EE(I)=E(1,I+1,MTYPE)
      DO 110 I=1,6
      DO 110 J=1,6
      CNS(I,J)=0.0
      C(I,J)=0.0
  110 D(I,J)=0.0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     FORM STRESS-STRAIN RELATIONSHIP IN N-S-T SYSTEM
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      NUNS=EE(4)
      NUNT=EE(5)
      NUST=EE(6)
      NUSN=(EE(2)*NUNS)/EE(1)
      NUTN=(EE(3)*NUNT)/EE(1)
      NUTS=(EE(3)*NUST)/EE(2)
      DIV=1.0-NUNS*NUSN-NUST*NUTS-NUNT*NUTN-NUSN*NUNT*NUTS
     1-NUNS*NUTN*NUST
      CNS(1,1)=EE(1)*(1.0-NUST*NUTS)/DIV
      CNS(1,2)=EE(2)*(NUNS+NUNT*NUTS)/DIV
      CNS(1,3)=EE(3)*(NUNT+NUNS*NUST)/DIV
      CNS(2,1)=CNS(1,2)
      CNS(2,2)=EE(2)*(1.0-NUNT*NUTN)/DIV
```

```
      CNS(2,3)=EE(3)*(NUST+NUSN*NUNT)/DIV
      CNS(3,1)=CNS(1,3)
      CNS(3,2)=CNS(2,3)
      CNS(3,3)=EE(3)*(1.0-NUNS*NUSN)/DIV
      CNS(4,4)=EE(7)
      CNS(5,5)=EE(8)
      CNS(6,6)=EE(9)
C     SET UP STRAIN TRANSFORM TO N-S-T SYSTEM
      SINA=DSIN(ALPHA(N))
      COSA=DCOS(ALPHA(N))
      S2=SINA**2
      C2=COSA**2
      SC=SINA*COSA
      D(1,1)=C2
      D(1,3)=S2
      D(1,6)=-SC
      D(2,1)=S2
      D(2,3)=C2
      D(2,6)=SC
      D(3,2)=1.0
      D(4,1)=2.0*SC
      D(4,3)=-2.0*SC
      D(4,6)=C2-S2
      D(5,4)=SINA
      D(5,5)=COSA
      D(6,4)=COSA
      D(6,5)=-SINA
C     SET UP STRAIN TRANSFORMATION TO R-Z-T SYSTEM
      SINB=DSIN(BETA(N))
      COSB=DCOS(BETA(N))
      S2=SINB**2
      C2=COSB**2
      SC=SINB*COSB
      C(1,1)=S2
      C(1,2)=C2
      C(1,4)=SC
      C(2,1)=C2
      C(2,2)=S2
      C(2,4)=-SC
      C(3,3)=1.0
      C(4,1)=-2.0*SC
      C(4,2)=2.0*SC
      C(4,4)=S2-C2
      C(5,5)=SINB
      C(5,6)=-COSB
      C(6,5)=COSB
      C(6,6)=SINB
C     CALCULATE CRZ MATRIX
```

```
      DO 120 I=1,6
      DO 120 J=1,6
      DUMMY(I,J)=0.0
      DO 120 K=1,6
  120 DUMMY(I,J)=DUMMY(I,J)+D(I,K)*C(K,J)
      DO 130 I=1,6
      DO 130 J=1,6
      DUMMY1(I,J)=0.0
      DO 130 K=1,6
  130 DUMMY1(I,J)=DUMMY1(I,J)+CNS(I,K)*DUMMY(K,J)
      DO 140 I=1,6
      DO 140 J=1,6
      DUMMY(I,J)=0.0
      DO 140 K=1,6
  140 DUMMY(I,J)=DUMMY(I,J)+D(K,I)*DUMMY1(K,J)
      DO 160 I=1,6
      DO 150 J=1,6
      CRZ(I,J)=0.0
      DO 150 K=1,6
  150 CRZ(I,J)=CRZ(I,J)+C(K,I)*DUMMY(K,J)
      TT(I)=0.0
      DO 160 M=1,6
      P(M)=0.0
      DO 161 II=1,3
      IF(ADEFTS(MTYPE).EQ.1.) P(M)=CNS(M,II)*EE(II+9)
  161 P(M)=P(M)+(T(N)-TREF)*CNS(M,II)*EE(II+9)
      DO 160 K=1,6
  160 TT(I)=TT(I)+C(K,I)*D(M,K)*P(M)
C
C     FORM QUADRILATERAL STIFFNESS MATRIX
      RRR(5)=(R(I1)+R(J1)+R(K1)+R(L1))/4.
      ZZZ(5)=(Z(I1)+Z(J1)+Z(K1)+Z(L1))/4.
      DO 200 M=1,4
      MM=IX(N,M)
      IF(NPP.NE.0) GO TO 190
      IF(R(MM).EQ.0..AND.CODE(MM).EQ.0.)CODE(MM)=1.
  190 RRR(M)=R(MM)
  200 ZZZ(M)=Z(MM)
      DO 220 II=1,15
      P(II)=0.0
      DO 220 JJ=1,15
  220 S(II,JJ)=0.0
      DO 90 I=1,6
      VOL=0.
      DO 90 J=1,15
   90 BS(I,J)=0.0
      AR=0.0
  240 CALL TRISTF(4,1,5)
```

```
      CALL TRISTF(1,2,5)
      CALL TRISTF(2,3,5)
      CALL TRISTF(3,4,5)
      DO 91 I=1,6
      DO 91 J=1,15
   91 BS(I,J)=BS(I,J)/AR
      RETURN
      END
```

COMMON BLOCK /BASIC / MAP SIZE 3C

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	ANGVEL	8	ANGACC	10	TREF	
28	NUMEL	2C	NUMPC	30	NUMSC	

COMMON BLOCK /MATP / MAP SIZE 24E0

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	E	30	EE	2430	AOFTS	24[illegible]

COMMON BLOCK /NPDATA / MAP SIZE 28C0

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	CODE	640	XR	960	Z	F.
1C20	T	1F40	XT	2580		

COMMON BLOCK /ELDATA / MAP SIZE 28C0

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	EPR	640	PR	C80	SH	D:
1D60	JP	1D80	IS	1E00	JS	1E
24E0	JT	2800	ST	2820		

COMMON BLOCK /ARG / MAP SIZE DC4

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	ZZZ	28	RP	50	ZZ	
798	TT	810	H	840	CPZ	8
C80	SIG	CA0	EPS	D30	N	D

COMMON BLOCK /RESULT / MAP SIZE 7E8

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	D	200	C	3F0	AR	5
6C8						

COMMON BLOCK /PLANE / MAP SIZE 4

```
      SUBROUTINE SET
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/CIT/NEQL   ,NSLIP,ICRACK,ISLIP,INP,NSKIP
      COMMON/DATA1/RTN(200),RST(200),RNN(200)
      COMMON/DATA2/IFAIL(200),TB(200,12),ICR(200),IAD(200,4)
      COMMON/DATA3/TFAIL,CF
C
C     READ NUMBER OF ITERATIONS FOR SLIP,FOR EQUILIBRIUM,COEFFICIENT
C     OF FRICTION AND MAXIMUM ALLOWED INTERLAMINAR SHEAR STRESS
C
      READ(5,1001) NSLIP,NEQL,TFAIL
      DO 10 I=1,NUMNP
      IFAIL(I)=0
   10 ICR(I)=0
C
C     READ PARAMETERS DEFINING DIRECTION OF SLIP
C
      READ(5,1001) NCBI,NCBJ
      IF(NCBI.EQ.0) GO TO 13
      DO 11 N=1,NCBI
      READ(5,1000) NIMIN,NIMAX,NJMIN,NJMAX
      DO 11 I=NIMIN,NIMAX
      DO 11 J=NJMIN,NJMAX
      NPIJ=NPNUM(I,J)
   11 ICR(NPIJ)=1
   13 CONTINUE
      IF(NCBJ.EQ.0) GO TO 14
      DO 12 N =1,NCBJ
      READ(5,1000) NIMIN,NIMAX,NJMIN,NJMAX
      DO 12 I=NIMIN,NIMAX
      DO 12 J=NJMIN,NJMAX
      NPIJ=NPNUM(I,J)
   12 ICR(NPIJ)=2
   14 CONTINUE
C
C     IDENTIFY FOUR ADJACENT ELEMENTS FOR EACH NODE
C
      DO 21 N=1,NUMNP
      DO 21 I=1,4
   21 IAD(N,I)=0
      DO 22 N=1,NUMEL
```

```
      DO 22 I=1,4
      IXX=IX(N,I)
22    IAD(IXX,I)=N
1000  FORMAT(4I10)
1001  FORMAT(2I10, F10.3)
      RETURN
      END
```

COMMON BLOCK /BASIC / MAP SIZE 3C

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA'
0	ANGVEL	8	ANGACC	10	TREF	
28	NUMEL	2C	NUMPC	30	NUMSC	

COMMON BLOCK /NPDATA / MAP SIZE 28C0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA'
0	CODE	640	XP	960	Z	F
1C20	T	1F40	XT	2580		

COMMON BLOCK /ELDATA / MAP SIZE 28C0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	EPR	640	PR	C80	SH	D
1060	JP	1080	IS	1E00	JS	1E
24E0	JT	2800	ST	2820		

COMMON BLOCK /CIT / MAP SIZE 18

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	NSLIP	4	ICRACK	8	ISLIP	
14						

COMMON BLOCK /DATA1 / MAP SIZE 12C0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	PST	640	RNN	C80		

COMMON BLOCK /DATA2 / MAP SIZE 5DC0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	TB	320	ICP	4E20	IAD	51

COMMON BLOCK /DATA3 / MAP SIZE 10

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	CF	8				

```
      SUBROUTINE SOLV
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/SOLVE/B(72),A(72,36),NUMTC,MBAND
      MM=MBAND
      NN=36
      NL=NN+1
      NH=NN+NN
      REWIND 1
      REWIND 2
      NB=0
      GO TO 150
C     REDUCE EQUATIONS BY BLOCKS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     1. SHIFT BLOCK OF EQUATIONS
C
  100 NB=NB+1
      DO 125 N=1,NN
      NM=NN+N
      B(N)=B(NM)
      B(NM)=0.0
      DO 125 M=1,MM
      A(N,M)=A(NM,M)
  125 A(NM,M)=0.0
C
C     2. READ NEXT BLOCK OF EQUATIONS INTO CORE
C
      IF(NUMBLK.EQ.NB) GO TO 200
  150 READ(2) (B(N),(A(N,M),M=1,MM),N=NL,NH)
      IF(NB.EQ.0) GO TO 100
C
C     3. REDUCE BLOCK OF EQUATIONS
C
  200 DO 300 N=1,NN
      IF(A(N,1).EQ.0.0) GO TO 300
      B(N)=B(N)/A(N,1)
      DO 275 L=2,MM
      IF(A(N,L).EQ.0.0) GO TO 275
      C=A(N,L)/A(N,1)
      I=N+L-1
      J=0
      DO 250 K=L,MM
      J=J+1
  250 A(I,J)=A(I,J)-C*A(N,K)
      B(I)=B(I)-A(N,L)*B(N)
      A(N,L)=C
```

```
  275 CONTINUE
  300 CONTINUE
C
C     4. WRITE BLOCK OF REDUCED EQUATIONS ON FORTRAN UNIT 1
C
      IF(NUMBLK.EQ.NB) GO TO 400
      WRITE (1) (B(N),(A(N,M),M=2,MM),N=1,NN)
      GO TO 100
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     BACK-SUBSTITUTION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  400 DO 450 M=1,NN
      N=NN+1-M
      DO 425 K=2,MM
      L=N+K-1
  425 B(N)=B(N)-A(N,K)*B(L)
      NM=N+NN
      B(NM)=B(N)
  450 A(NM,NB)=B(N)
      NB=NB-1
      IF(NB.EQ.0) GO TO 500
      BACKSPACE 1
      READ (1) (B(N),(A(N,M),M=2,MM),N=1,NN)
      BACKSPACE 1
      GO TO 400
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ORDER FORMER UNKNOWNS IN B ARRAY
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  500 K=0
      DO 600 NB=1,NUMBLK
      DO 600 N=1,NN
      NM=N+NN
      K=K+1
  600 B(K)=A(NM,NB)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     WRITE SOLUTION
      MPRINT=0
      DO 710 N=1,NUMNP
      IF(MPRINT.NE.0) GO TO 700
      WRITE (6,2000)
      MPRINT=59
  700 MPRINT=MPRINT-1
  710 WRITE (6,2001) N,B(3*N-2),B(3*N-1),B(3*N)
 2000 FORMAT (13H1 NODAL POINT,18X,2HUR,18X,2HUZ,18X,2HUT)
 2001 FORMAT (I13,3E20.7)
      RETURN
      END
```

```
      SUBROUTINE STIFF
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/ARG/EPPR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CPZ(6,6),XI(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/SOLVE/B(72),A(72,36),NUMTC,MBAND
      COMMON/PLANE/NPP
      COMMON/DATA2/IFAIL(200),TB(200,12),ICR(200),IAD(200,4)
      DIMENSION LM(4),S2(12,3),S3(3,12),S4(3,3),S5(12,3),S6(12,12)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     INITIALIZATION
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      REWIND 2
      ND=36
      ND2=2*ND
      STOP=0.
      NUMBLK=0
      DO 100 N=1,ND2
      B(N)=0.0
      DO 100 M=1,ND
  100 A(N,M)=0.0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     FORM STIFFNESS MATRIX IN BLOCKS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  200 NUMBLK=NUMBLK+1
      NH=NB*(NUMBLK+1)
      NM=NH-NB
      NL=NM-NB+1
      KSHIFT=3*NL-3
      DO 340 N=1,NUMEL
      IF(IX(N,5).LE.0) GO TO 340
      DO 210 I=1,4
      IF(IX(N,I).LT.NL) GO TO 210
      IF(IX(N,I).LE.NM) GO TO 220
  210 CONTINUE
      GO TO 340
  220 CALL QUAD
      IF(VOL.GT.0.) GO TO 230
      WRITE(6,2000) N
      STOP=1.
  230 IF(IX(N,3).EQ.IX(N,4)) GO TO 300
      DO 231 II=1,3
```

```
      DO 231 JJ=1,3
  231 S4(II,JJ)=S(II+12,JJ+12)
      CALL SYMINV(S4,3)
      DO 232 II=1,12
      DO 232 JJ=1,3
  232 S2(II,JJ)=S(II,JJ+12)
      DO 233 II=1,3
      DO 233 JJ=1,12
  233 S3(II,JJ)=S(II+12,JJ)
      DO 240 I=1,12
      DO 240 J=1,3
      S5(I,J)=0.0
      DO 240 K=1,3
  240 S5(I,J) = S5(I,J) + S2(I,K) * S4(K,J)
      DO 241 I=1,12
      DO 241 J=1,12
      S6(I,J)=0.0
      DO 241 K=1,3
  241 S6(I,J) = S6(I,J) + S5(I,K) * S3(K,J)
      DO 234 II=1,12
      DO 234 JJ=1,3
  234 P(II)=P(II)-S5(II,JJ)*P(JJ+12)
      DO 235 II=1,12
      DO 235 JJ=1,12
  235 S(II,JJ)=S(II,JJ)-S6(II,JJ)
      DO 93 I=1,12
      DO 93 J=1,12
   93 P(I)=P(I)-S(I,J)*TB(N,J)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ADD ELEMENT STIFFNESS MATRIX TO BODY STIFFNESS MATRIX
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  300 DO 310 I=1,4
  310 LM(I)=3*IX(N,I)-3
      DO 330 I=1,4
      DO 330 K=1,3
      II=LM(I)+K-KSHIFT
      KK=3*I-3+K
      B(II)=B(II)+F(KK)
      DO 330 J=1,4
      DO 330 L=1,3
      JJ=LM(J)+L-II+1-KSHIFT
      LL=3*J-3+L
      IF(JJ.LE.0) GO TO 330
      IF(ND.GE.JJ) GO TO 320
      WRITE(6,2001) N
      STOP=1.
      GO TO 340
  320 A(II,JJ)=A(II,JJ)+S(KK,LL)
```

```
  330 CONTINUE
  340 CONTINUE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ADD CONCENTRATED FORCES
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO 400 N=NL,NM
      IF(N.GT.NUMNP) GO TO 500
      K=3*N-KSHIFT
      B(K)=B(K)+XT(N)
      B(K-1)=B(K-1)+XZ(N)
  400 B(K-2)=B(K-2)+XR(N)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ADD PRESSURE BOUNDARY CONDITIONS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  500 IF(NUMPC.EQ.0) GO TO 600
      DO 540 L=1,NUMPC
      I=IP(L)
      J=JP(L)
      PP=PP(L)/6.
      DR=(R(J)-R(I))*PP
      DZ=(Z(I)-Z(J))*PP
      RX=2.*R(I)+R(J)
      ZX=R(I)+2.*R(J)
      II=3*I-KSHIFT-1
      JJ=3*J-KSHIFT-1
      IF(II.LE.0.OR.II.GT.ND) GO TO 520
      SINA=0.
      COSA=1.
  510 B(II-1)=B(II-1)+RX*(COSA*DZ+SINA*DR)
      B(II)=B(II)-RX*(SINA*DZ-COSA*DR)
  520 IF(JJ.LE.0.OR.JJ.GT.ND) GO TO 540
      SINA=0.
      COSA=1.
  530 B(JJ-1)=B(JJ-1)+ZX*(COSA*DZ+SINA*DR)
      B(JJ)=B(JJ)-ZX*(SINA*DZ-COSA*DR)
  540 CONTINUE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ADD SHEAR BOUNDARY CONDITIONS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  600 IF(NUMSC.EQ.0) GO TO 701
      DO 640 L=1,NUMSC
      I=IS(L)
      J=JS(L)
      SS=SH(L)/6.
      DZ=(Z(I)-Z(J))*SS
      DR=(R(J)-R(I))*SS
      RX=2.*R(I)+R(J)
      ZX=R(I)+2.*R(J)
```

```
      II=3*I-KSHIFT-1
      JJ=3*J-KSHIFT-1
      IF(II.LE.0.OR.II.GT.ND) GO TO 620
      SINA=0.
      COSA=1.
  610 B(II-1)=B(II-1)+RX*(SINA*DZ+COSA*DR)
      B(II)=B(II)-RX*(COSA*DZ-SINA*DR)
  620 IF(JJ.LE.0.OR.JJ.GT.ND) GO TO 640
      SINA=0.
      COSA=1.
  630 B(JJ-1)=B(JJ-1)+ZX*(SINA*DZ+COSA*DR)
      B(JJ)=B(JJ)-ZX*(COSA*DZ-SINA*DR)
  640 CONTINUE
  701 IF(NUMST.EQ.0) GO TO 700
      DO 680 L=1,NUMST
      I=IT(L)
      J=JT(L)
      RT=ST(L)/6.
      RX=2.*R(I)+R(J)
      ZX=R(I)+2.*R(J)
      XX=DSQRT((R(J)-R(I))**2+(Z(J)-Z(I))**2)
      II=3*I-KSHIFT
      JJ=3*J-KSHIFT
      IF(II.LE.0.OR.II.GT.ND) GO TO 670
      B(II)=B(II)+RT*RX*XX
  670 IF(JJ.LE.0.OR.JJ.GT.ND) GO TO 680
      B(JJ)=B(JJ)+RT*ZX*XX
  680 CONTINUE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     ADD DISPLACEMENT BOUNDARY CONDITIONS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
  700 DO 750 M=NL,NH
      IDM=0
      IF(M.GT.NUMNP) GO TO 750
      IF(CODE(M).GT.3) GO TO 751
      U=XR(M)
      N=3*M-2-KSHIFT
  752 IF(CODE(M)) 740,750,710
  710 IF(CODE(M).EQ.1) GO TO 720
      IF (CODE(M).EQ.2) GO TO 740
      IF(CODE(M).EQ.3) GO TO 730
      GO TO 740
  720 CALL MODIFY(ND2,N,U)
      CODE(M)=CODE(M)+IDM
      GO TO 750
  730 CALL MODIFY(ND2,N,U)
  740 U=XZ(M)
      N=N+1
```

```
      CALL MODIFY(ND2,N,U)
      CODE(M)=CODE(M)+IDM
      GO TO 750
  751 IDM=IDM+4
      U=XT(M)
      N=3*M-KSHIFT
      CALL MODIFY(ND2,N,U)
      U=XR(M)
      N=3*M-2-KSHIFT
      IF(CODE(M).EQ.4) GO TO 750
      CODE(M)=CODE(M)-4
      GO TO 752
  750 CONTINUE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     WRITE BLOCK OF EQUATIONS ON FORTRAN UNIT AND SHIFT UP LOWER BLOCK
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      WRITE (2) (B(N),(A(N,M),M=1,MBAND),N=1,ND)
      DO 800 N=1,ND
      K=N+ND
      B(N)=B(K)
      B(K)=0.0
      DO 800 M=1,ND
      A(N,M)=A(K,M)
  800 A(K,M)=0.0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     CHECK FOR LAST BLOCK
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      IF(NM.LT.NUMNP) GO TO 200
      IF(STOP.NE.0.) STOP
 2000 FORMAT (27H  NEGATIVE AREA ELEMENT NO.,I4)
 2001 FORMAT (46H  BAND WIDTH EXCEEDS ALLOWABLE FOR ELEMENT NO.,I4)
      RETURN
      END
```

COMMON BLOCK /BASIC / MAP SIZE 3C

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATI
0	ANGVEL	8	ANGACC	10	TREF	1E
28	NUMEL	2C	NUMPC	30	NUMSC	34

COMMON BLOCK /NPDATA / MAP SIZE 28C0

CATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATI
0	CODE	640	XR	960	Z	FA(
1C20	T	1F40	XT	2580		

COMMON BLOCK /ELDATA / MAP SIZE 28C0

```
      SUBROUTINE STRESS
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/MATP/RO(6),E(12,16,6),EE(16),AOFTS(6)
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/ARG/RRR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CRZ(6,6),XI(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/CCNVRG/IDONE
      COMMON/SOLVE/B(72),A(72,36),NUMTC,MBAND
      COMMON/PLANE/NPP
      COMMON/RESULT/BS(6,15),D(6,6),C(6,6),AR,BB(6,9),CNS(6,6)
      COMMON/CIT/NEQL   ,NSLIP,ICRACK,ISLIP,INP,NSKIP
      COMMON/DATA1/RTN(200),RST(200),RNN(200)
      COMMON/DATA2/IFAIL(200),TB(200,12),ICR(200),IAD(200,4)
      DIMENSION LM(4),TP(6),TR(3,3),Q(3)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     INITIALIZE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      XKE=0.
      XPE=0.
      MPRINT=0
      ERROR=.005
      IDONE=1
      DO 200 N=1,NUMEL
      IX(N,5)=IABS(IX(N,5))
      CALL QUAD
      DO 100 I=1,4
      II=3*I
      JJ=3*IX(N,I)
      P(II-2)=B(JJ-2)
      P(II-1)=B(JJ-1)
  100 P(II)  =B(JJ)
      DO 11 I=1,12
   11 P(I)=P(I)+TB(N,I)
      DO 110 I=1,3
  110 Q(I)=P(I+12)
      DO 120 I=1,3
      DO 120 J=1,3
  120 TR(I,J)=S(I+12,J+12)
      CALL SYMINV(TP,3)
      DO 130 I=1,3
      P(I+12)=0.0
      DO 130 J=1,3
```

```
      DO 130 K=1,12
  130 P(I+12)=P(I+12)+TR(I,J)*(Q(J)-S(J+12,K)*P(K))
      MTYPE=IABS(IX(N,5))
C
C     MATRIX P NOW CONTAINS 15 DISPLACEMENTS FOR QUADRILATERAL ELEMENT
C
C     CALCULATE AVERAGE STRAINS
C
      DO 140 I=1,6
      EPS(I)=0.0
      DO 140 J=1,15
  140 EPS(I)=EPS(I)+BS(I,J)*P(J)
C
C     CALCULATE AVERAGE STRESSES
C
      DO 151 I=1,6
      SIG(I)=0.0
      DO 151 J=1,6
  151 SIG(I)=SIG(I)+CRZ(I,J)*EPS(J)
      DO 152 I=1,6
  152 SIG(I)=SIG(I)-TT(I)
C
C     CALCULATE STRAINS  IN N-S-T COORDINATES
C
      DO 150 I=1,6
      EPS(I+6)=0.0
      DO 150 J=1,6
      DO 150 K=1,6
  150 EPS(I+6)=EPS(I+6)+D(I,J)*C(J,K)*EPS(K)
C
C     CALCULATE STRESSES IN N-S-T COORDIATES
C
      DO 160 I=1,6
      SIG(I+6)=0.0
      DO 160 J=1,6
  160 SIG(I+6)=SIG(I+6)+CNS(I,J)*EPS(J+6)
      DO 161 M=1,6
      P(M)=0.0
      DO 161 II=1,3
      IF(AREFS(MTYPE).EQ.1.) P(M)=CNS(M,II)*EE(II+9)
  161 P(M)=P(M)+(T(N)-TREF)*CNS(M,II)*EE(II+9)
      DO 162 I=1,6
  162 SIG(I+6)=SIG(I+6)-P(I)
C
C
C     CALCULATE AND STORE INTERLAMINAR STRESSES
C
      IF(ICRACK.EQ.0) GO TO 180
```

```
          RTN(N)=SIG(12)*DCOS(ALPHA(N))+SIG(11)*DSIN(ALPHA(N))
          RST(N)=SIG(12)*DSIN(ALPHA(N))-SIG(11)*DCOS(ALPHA(N))
          RNN(N)=SIG(9)
          IF(INP.NE.NECL.AND.INP.NE.1) RETURN
    180   CONTINUE
C         WRITE STRESSES
C
C         WRITE STRAINS IN PERCENTAGE FORM
C
          DO 300 I=1,12
    300   EPS(I)=100.*EPS(I)
          IF(MPRINT.NE.0) GO TO 210
          WRITE(6,2000)
          WRITE(6,2002)
          MPRINT=19
    210   MPRINT=MPRINT-1
          WRITE(6,2001) N,RRR(5),ZZZ(5),(SIG(I),I=1,12)
          WRITE(6,2003) T(N),(EPS(I),I=1,12)
    200   CONTINUE
   2000   FORMAT(129H1      EL       R        Z        SIGMAR    SIGMAZ    SIGMAC    SIGMA
         1RZ    SIGMAZC   SIGMACR   SIGMAN    SIGMAS    SIGMAT    SIGMANS   SIGMAST
         2 SIGMATN)
   2001   FORMAT(1H0,I5,1X,2F7.4,12F9.0)
   2002   FORMAT(128H0          TEMPERATURE        EPSR      EPSZ      EPSC      EPSR
         1Z      EPSZC     EPSCR     EPSN      EPSS      EPST      EPSNS     EPSST
         2  EPSTN)
   2003   FORMAT(6X,F13.0,2X,12F9.5)
          RETURN
          END
```

COMMON BLOCK /BASIC / MAP SIZE 3C

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	ANGVEL	8	ANGACC	10	TREF	1
28	NUMEL	2C	NUMPC	30	NUMSC	3

COMMON BLOCK /MATP / MAP SIZE 24F0

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	E	30	EE	2430	AOFTS	248

COMMON BLOCK /NPDATA / MAP SIZE 28C0

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCAT
0	CODF	640	XR	960	Z	FA
1C20	T	1F40	XT	2580		

```
      SUBROUTINE SYMINV(A,NMAX)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(NMAX,NMAX)
      DO 300 N=1,NMAX
      D=A(N,N)
      DO 100 J=1,NMAX
  100 A(N,J)=-A(N,J)/D
      DO 210 I=1,NMAX
      IF(N.EQ.I) GO TO 210
      DO 200 J=1,NMAX
      IF(N.NE.J) A(I,J)=A(I,J)+A(I,N)*A(N,J)
  200 CONTINUE
  210 A(I,N)=A(I,N)/D
  300 A(N,N)=1.0/D
      RETURN
      END
```

SCALAR MAP

ION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	NMAX	B8	N	BC	J	

ARRAY MAP

ION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
8						

STATEMENT NUMBER MAP

ION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT	LOCA
4	4	194	5	19C	6	1
0	9	228	10	236	11	2
C	14	344	15	37E		

```
EFFECT*   NOID,BCD,SOURCE,NOLIST,NODECK,LOAD,MAP
EFFECT*   NAME = SYMINV  , LINECNT =       50
  SOURCE STATEMENTS =        16, PROGRAM SIZE =        902
 NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE TEMP(R,Z,T)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/SOLVE/ X(888),Y(888),TEM(888),NUMTC,MBAND
      DIMENSION SMALL(20),ISM(20)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     INITIALIZE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      J=1
      JMAX=16
      IF(NUMTC.LT.JMAX) JMAX=NUMTC
      DO 10 I=1,JMAX
      SMALL(I)=0.
   10 ISM(I)=0
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     FIND THE JMAX CLOSEST POINTS
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DO 50 I=1,NUMTC
      DSQ=(X(I)-R)**2+(Y(I)-Z)**2
      IF(DSQ.GT..1E-4) GO TO 20
      T=TEM(I)
      RETURN
   20 IF(I.EQ.1) SMALL(1)=DSQ
      IF(I.EQ.1) ISM(1)=1
      IF(I.EQ.1) GO TO 50
      IF(SMALL(J).LE.DSQ.AND.J.LT.JMAX) SMALL(J+1)=DSQ
      IF(SMALL(J).LE.DSQ.AND.J.LT.JMAX) ISM(J+1)=I
      IF(SMALL(J).LE.DSQ) GO TO 40
      DO 30 K=1,J
      JB=J-K +1
      IF(JB.EQ.0) GO TO 40
      SMALL(JB+1)=SMALL(JB)
      ISM(JB+1)=ISM(JB)
      SMALL(JB)=DSQ
      ISM(JB)=I
      IF(JB.EQ.1) GO TO 40
      IF(SMALL(JB-1).LE.DSQ) GO TO 40
   30 CONTINUE
   40 IF(J.LT.JMAX) J=J+1
   50 CONTINUE
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C     FIND THE THIRD TEMPERATURE POINT BY AREA TEST
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      JCHK=JMAX-2
      J=0
      I1=ISM(1)
      I2=ISM(2)
   60 I3=ISM(J+3)
      AREA=.5*(Y(I1)*X(I3)-Y(I3)*X(I1)+Y(I3)*X(I2)-Y(I2)*X(I3)+
```

```
      1          Y(I2)*X(I1)-Y(I1)*X(I2))
        D1=(X(I2)-X(I1))**2+(Y(I2)-Y(I1))**2
C       IF D1 IS APPROXIMATELY 0. IT IS ASSUMED THAT THERE EXISTS A
C       DUPLICATION OF INPUT
        IF(D1.GT..1E-3) GO TO 70
        I2=I3
        J=J+1
        GO TO 60
     70 IF(AREA**2.GT..1*D1*SMALL(1)) GO TO 80
        J=J+1
        IF(J.LT.JCHK) GO TO 60
        WRITE(6,2000) I1,I2,I3,J
        T=TEM(I1)
        RETURN
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C       FIND TEMPERATURE INTERCEPT
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     80 DETA=Y(I1)*(TEM(I3)-TEM(I2))+Y(I2)*(TEM(I1)-TEM(I3))
      1       +Y(I3)*(TEM(I2)-TEM(I1))
        DETB=X(I1)*(TEM(I2)-TEM(I3))+X(I2)*(TEM(I3)-TEM(I1))
      1       +X(I3)*(TEM(I1)-TEM(I2))
        DETC=TEM(I1)*(X(I2)*Y(I3)-X(I3)*Y(I2))+TEM(I2)*(X(I3)*Y(I1)-X(I1)*
      1Y(I3))+TEM(I3)*(X(I1)*Y(I2)-X(I2)*Y(I1))
        T=(DETA*P+DETB*Z+DETC)/(2.*AREA)
   2000 FORMAT (28H   ERROR IN TEMPERATURE INPUT,5H   I1=I4,5H   I2=I4,
      15H   I3=I4,4H   J=I4)
        RETURN
        END
```

COMMON BLOCK /SOLVE / MAP SIZE 5348

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	Y	1BCO	TEM	3780	NUMTC	53

SUBPROGRAMS CALLED

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
113						

SCALAR MAP

LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
120	P	128	Z	130	T	1
149	DETA	150	DETB	158	DETC	1
16C	I	170	K	174	JB	1
180	I2	184	I3	188	I1	1

```
      SUBROUTINE TEM2(NUMNP)
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      READ(5,1000) TCONST
      DO 100 N=1,NUMNP
  100 T(N)=TCONST
 1000 FORMAT(F10.0)
      RETURN
      END
```

COMMON BLOCK /NPDATA / MAP SIZE 28C0

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
0	CODE	640	XR	960	Z	F
1C20	T	1F40	XT	2580		

SUBPROGRAMS CALLED

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
9C						

SCALAR MAP

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
A0	N	A8	NUMNP	AC		

FORMAT STATEMENT MAP

OCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCA
80						

STATEMENT NUMBER MAP

OCATION	STATEMENT	LOCATION	STATEMENT	LOCATION	STATEMENT	LOCA
138	5	138	6	154	7	1

```
*IN EFFECT*  ECID,BCD,SOURCE,NOLIST,NODECK,LOAD,MAP
 IN EFFECT*  NAME = TEM2    , LINECNT =      50
ICS*     SOURCE STATEMENTS =        10,PROGRAM SIZE =        392
ICS*  NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE TRISTF (II,JJ,KK)
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER CODE
      COMMON/MATP/RO(6),E(12,16,6),EE(16),AOFTS(6)
      COMMON/BASIC/ACELZ,ANGVEL,ANGACC,TREF,VOL,NUMNP,NUMEL,NUMPC,NUMSC,
     1NUMST
      COMMON/ARG/RRR(5),ZZZ(5),RR(4),ZZ(4),S(15,15),P(15),TT(6),
     1H(6,15),CPZ(6,6),XI(10),ANGLE(4),SIG(18),EPS(18),N
      COMMON/NPDATA/ R(200),CODE(200),XR(200),Z(200),XZ(200),
     1NPNUM(10,20),T(200),XT(200)
      COMMON/ELDATA/ BETA(200),EPR(200),PR(20),SH(20),IX(200,5),IP(20),
     1JP(20),IS(20),JS(20),ALPHA(200),IT(200),JT(200),ST(20)
      COMMON/RESULT/BS(6,15),D(6,6),C(6,6),AR,BB(6,9),CNS(6,6)
      DIMENSION B1(6,9),B2(6,9),B3(6,9),F(6,9),G(9,6),V(9,9)
      DIMENSION BF(3),BFR(3),BFZ(3),TP(9),B(9,9)
      MTYPE=IABS(IX(N,5))
      RR(1)=RRR(II)
      RR(2)=RRR(JJ)
      RR(3)=RRR(KK)
      ZZ(1)=ZZZ(II)
      ZZ(2)=ZZZ(JJ)
      ZZ(3)=ZZZ(KK)
      CALL INTER
      VOL=VOL+XI(1)
      COMM=RR(2)*(ZZ(3)-ZZ(1))+RR(1)*(ZZ(2)-ZZ(3))+RR(3)*(ZZ(1)-ZZ(2))
       DO 10 I=1,6
       DO 10 J=1,9
      B1(I,J)=0.0
      B2(I,J)=0.0
   10 B3(I,J)=0.0
C     FILL B1 MATRIX-CONSTANT TERMS
      B1(1,1)=(ZZ(2)-ZZ(3))/COMM
      B1(1,4)=(ZZ(3)-ZZ(1))/COMM
      B1(1,7)=(ZZ(1)-ZZ(2))/COMM
      B1(3,1)=B1(1,1)
      B1(3,4)=B1(1,4)
      B1(3,7)=B1(1,7)
      B1(2,2)=(RR(3)-RR(2))/COMM
      B1(2,5)=(RR(1)-RR(3))/COMM
      B1(2,8)=(RR(2)-RR(1))/COMM
      B1(4,1)=B1(2,2)
      B1(4,4)=B1(2,5)
      B1(4,7)=B1(2,8)
      B1(4,2)=B1(1,1)
      B1(4,5)=B1(1,4)
      B1(4,8)=B1(1,7)
      B1(5,3)=B1(4,1)
      B1(5,6)=B1(4,4)
```

```
      B1(5,9)=B1(4,7)
C     FILL B2 MATRIX-1/R TERMS
      B2(3,1)=(1/COMM)*((ZZ(3)-ZZ(2))*RR(2)+(RR(2)-RR(3))*ZZ(2))
      B2(3,4)=(1/COMM)*((ZZ(1)-ZZ(3))*RR(3)-(RR(1)-RR(3))*ZZ(3))
      B2(3,7)=(1/COMM)*((ZZ(2)-ZZ(1))*RR(1)+(RR(1)-RR(2))*ZZ(1))
      B2(6,3)=-B2(3,1)
      B2(6,6)=-B2(3,4)
      B2(6,9)=-B2(3,7)
C     FILL B3 MATRIX-Z/R TERMS
      B3(3,1)=(RR(3)-RR(2))/COMM
      B3(3,4)=(RR(1)-RR(3))/COMM
      B3(3,7)=(RR(2)-RR(1))/COMM
      B3(6,3)=(RR(2)-RR(3))/COMM
      B3(6,6)=(RR(3)-RR(1))/COMM
      B3(6,9)=(RR(1)-RR(2))/COMM
      AR=AR+XI(1)
      DO 80 I=1,6
      DO 80 J=1,9
80    BB(I,J)=B1(I,J)*XI(1)+B2(I,J)*XI(2)+B3(I,J)*XI(4)
      DO 81 K=1,6
      DO 81 I=1,3
      BS(K,3*JJ-3+I)=BB(K,I+3)+BS(K,3*JJ-3+I)
      BS(K,3*II-3+I)=BB(K,I)+BS(K,3*II-3+I)
81    BS(K,3*KK-3+I)=BB(K,I+6)+BS(K,3*KK-3+I)
      DO 110 I=1,9
      DO 110 J=1,9
      B(I,J)=0.0
      DO 110 K=1,6
      DO 110 M=1,6
      B(I,J)=B(I,J)+B1(K,I)*CRZ(K,M)*(B1(M,J)*XI(1)
     1+B2(M,J)*XI(2)+B3(M,J)*XI(4))
     2+B2(K,I)*CRZ(K,M)*(B1(M,J)*XI(2)
     3+B2(M,J)*XI(3)+B3(M,J)*XI(5))
     5+B3(K,I)*CRZ(K,M)*(B1(M,J)*XI(4)
     6+B2(M,J)*XI(5)+B3(M,J)*XI(6))
110   CONTINUE
C     ASSEMBLE QUADRILATERAL STIFFNESS MATRIX, S, FROM TRIANGULAR
C     STIFFNESS MATRIX, B.
      IIM=3*II-3
      JJM=3*JJ-3
      KKM=3*KK-3
      DO 120 I=1,3
      DO 120 J=1,3
      S(IIM+I,IIM+J)=B(I  ,J  )+S(IIM+I,IIM+J)
      S(IIM+I,JJM+J)=B(I  ,J+3)+S(IIM+I,JJM+J)
      S(IIM+I,KKM+J)=B(I  ,J+6)+S(IIM+I,KKM+J)
      S(JJM+I,IIM+J)=B(I+3,J  )+S(JJM+I,IIM+J)
      S(JJM+I,JJM+J)=B(I+3,J+3)+S(JJM+I,JJM+J)
```

```
      S(JJM+I,KKM+J)=B(I+3,J+6)+S(JJM+I,KKM+J)
      S(KKM+I,IIM+J)=B(I+6,J  )+S(KKM+I,IIM+J)
      S(KKM+I,JJM+J)=B(I+6,J+3)+S(KKM+I,JJM+J)
      S(KKM+I,KKM+J)=B(I+6,J+6)+S(KKM+I,KKM+J)
  120 CONTINUE
C     ASSEMBLE BODY FORCES MATRIX
      BF(1)=(ZZ(3)*RR(2)-RR(3)*ZZ(2))/COMM
      BF(2)=(ZZ(1)*RR(3)-RR(1)*ZZ(3))/COMM
      BF(3)=(ZZ(2)*RR(1)-RR(2)*ZZ(1))/COMM
      BFR(1)=(ZZ(2)-ZZ(3))/COMM
      BFR(2)=(ZZ(3)-ZZ(1))/COMM
      BFR(3)=(ZZ(1)-ZZ(2))/COMM
      BFZ(1)=(RR(3)-RR(2))/COMM
      BFZ(2)=(RR(1)-RR(3))/COMM
      BFZ(3)=(RR(2)-RR(1))/COMM
C     BODY FORCE IN Z-DIRECTION
      COMM=-ACELZ*RO(MTYPE)
      DO 140 I=1,3
      IIK=3*I-1
  140 TP(IIK)=COMM*(BF(I)*XI(1)+BFR(I)*XI(7)+BFZ(I)*XI(8))
C     BODY FORCE IN R-DIRECTION
      COMM=ANGVEL**2*RO(MTYPE)
      DO 150 I=1,3
      L=3*I-2
  150 TP(L)=COMM*(BF(I)*XI(7)+BFR(I)*XI(9)+BFZ(I)*XI(10))
C     BODY FORCES IN TANG. DIRECTION
      COMM=-ANGACC*RO(MTYPE)
      DO 160 I=1,3
      IIM=3*I
  160 TP(IIM)=COMM*(BF(I)*XI(7)+BFR(I)*XI(9)+BFZ(I)*XI(10))
C     ADD THERMAL EFFECTS
      DO 161 J=1,9
      DO 161 K=1,6
 161  TP(J)=TP(J)+(XI(1)*B1(K,J)+XI(2)*B2(K,J)
     1+XI(4)*B3(K,J))*TT(K)
C     REARRANGE TP INTO P-MATRIX,THE BODY FORCES MATRIX
      K=3*II-2
      L=3*JJ-2
      M=3*KK-2
      DO 170 I=1,3
      J=I-1
      P(K+J)=P(K+J)+TP(I)
      P(L+J)=P(L+J)+TP(I+3)
  170 P(M+J)=P(M+J)+TP(I+6)
      RETURN
      END
```

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