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STRESS AND STRAIN DISTRIBUTION IN THE VICINITY OF INTERFERENCE FIT FASTENERS

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MERLE ALLEN

J. A. ELLIS

GENERAL DYNAMICS/CONVAIR AEROSPACE DIVISION

TECHNICAL REPORT AFFDL-TR-72-153

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STRESS AND STRAIN DISTRIBUTION IN THE VICINITY OF INTERFERENCE FIT FASTENERS

MERLE ALLEN
J. A. ELLIS

FOREWORD

This report was prepared by General Dynamics, Convair Aerospace Division, Fort Worth Operation, Post Office Box 748, Fort Worth, Texas 76101, under United States Air Force contract F33615-73-C-3026. The contract was initiated under Project No. 1467, "Structural Analysis Methods," Task. No. 146702, "Thermal Elastic Analysis Methods." The program was administered by the Air Force Flight Dynamics Laboratory (AFFDL). Mr. Gene E. Maddux, AFFDL/FBR, was the Project Engineer. The analysis reported was performed during the period 29 August 1972 to 20 October 1972 under the direction of Mr. Merle G. Allen of the Structural Dynamics Group, Structures and Materials Technology Section, Structures and Design Department. The manuscript was released by the authors in November 1972 for publication as an AFFDL Technical Report.

The authors wish to express their appreciation to Dr. O.E. Wheeler, formerly with the Structures and Materials Technology Section and now with Bucyrus-Erie Company, for proposing the analyses reported herein and suggesting the method of producing the interference; to Mr. O.N. Thompson, Structures and Materials Technology Section, for supplying test data and though provoking criticism; to Dr. R.M. Richard, Professor of Civil Engineering, University of Arizona, for his suggestions and aid in utilizing the digital analysis procedure and to members of the digital computing laboratory for their invaluable aid in implementing analyses procedures and expediting computer runs to get the job done within a short calendar time span.

This technical report has been reviewed and is approved.

Francis J. Janik Jr

FRANCIS J. JANIK, JR
Chief, Solid Mechanics Branch
Structures Division

ABSTRACT

A body of detailed stress and strain distributions in the vicinity of interference fit fasteners has been analytically obtained and is presented. These data, obtained on simple installations, present trends which may be used by designers in determining how or whether to use interference fit fasteners.

The analysis was performed with a finite element digital procedure which has the nonlinear constitutive behavior programmed and interrelates internal loading and deformations. Preparations for the analysis of thirty six conditions included analyzing a test article for which good correlations are shown.

Stress and strain distributions are presented for conditions which include two fastener hole sizes, two levels of interference fit, three plate materials (steel, titanium and aluminum) and three levels of uniaxial loading.

The results indicate that the radial strains in that part of the plate which is strained beyond the yield point are sensitive to the value of plastic modulus of the material. Also, the fastener diameters may be any size provided that the insertion is adjusted accordingly.

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SECTION I

INTRODUCTION

The use of interference fit fasteners in airplane construction extends back prior to World War II days when tapered pins were used in push-pull tubes. In the early 1960 time frame, their use was incorporated into numerous types of joints on several aircraft types. As in-service experience was accumulated and the benefits to be gained were experimentally verified, their usage rate grew until the present where virtually all large aircraft manufactured in this country and abroad incorporate interference fit fasteners. As an example, the F-111 uses approximately 8500 per ship in sizes up to one-half inch diameter and the C-5A uses approximately 700,000 in sizes up to seven sixteenths inch diameter. Available documentation indicates the Concorde uses in excess of 100,000 in sizes up to one-half inch.

The benefits for ductile joint materials is primarily extension of fatigue life. Emphasis is placed on ductile because if the material is brittle, the prestress due to the interference fit can cause failure. Other benefits include a more uniform distribution of stress throughout the joint and elimination of fastener free play. The disadvantages include increased costs of hole preparation and quality control.

The increase in use of interference fit fasteners is due nearly entirely to confidence in the application generated by empirical evidence and not to any appreciable extent to analytical considerations. The lag of analytical treatment behind experimental data is due to the complexity of the basic load deflection interactions and to the fact that effective interference fits strain the joint material into the inelastic range.

The purpose of this report is to help fill the analysis void by presenting a body of data for interference fit fasteners analytically obtained. The data consists of stress and strain distributions in a plate in the vicinity of a fastener. In the analysis, no load is reacted through the joint and the plate is large enough (five by eight inches, 0.10 inch thick with the hole centered) that it may be considered infinite for all practical purposes.

Thirty-six conditions have been analyzed. These consist of using three materials for the plate (while holding the fastener material constant), two hole sizes, two levels of interference and three static loads on the plate. The plate materials were aluminum (2024-T851), titanium (annealed 6Al-4V) and steel (D6ac heat treated to 220-240 psi). The fastener material was 5 Cr-Mo-V steel. Hole sizes were one-fourth (1/4) and three-eights (3/8) inch diameters. The load conditions were interference fit only, interference fit plus an applied uniaxial load resulting in a gross area stress of thirty-five percent of yield and interference fit plus an applied uniaxial load resulting in a gross area stress of seventy percent of yield. (An exception occurred with the titanium plate with the lower level of interference because the plate separated from the bolt when the seventy percent uniaxial load was applied. Hence, the load was reduced to fifty percent to avoid separation.) The two levels of interference were such that if the bolt did not deform and all the deformation occurred in the plate, the tangential strains at the hole interface would have been 0.010 and 0.020 inch per inch. Because the bolt does deform, the plate strains were somewhat less. However, it will be shown by the data that most of the total deformation occurs in the plate.

The analysis methods used are briefly discussed in Section II. These methods have been applied to a test specimen on which test results were available and the analyses/test results are compared in Section III. Section IV contains details of the production conditions and Section V contains conclusions and recommendations. The body of analysis results is presented in the Appendices I, II and III for the aluminum, titanium and steel plates, respectively. Each appendix contains 176 figures. Because of this large quantity, they are not included in the list of figures. Instead, figure indexes are supplied on foldouts following the appendices. It is believed these indices will be more convenient for the reader interested in details, since otherwise approximately 50 pages would have been required just to list the figures.

SECTION II

ANALYSIS METHOD

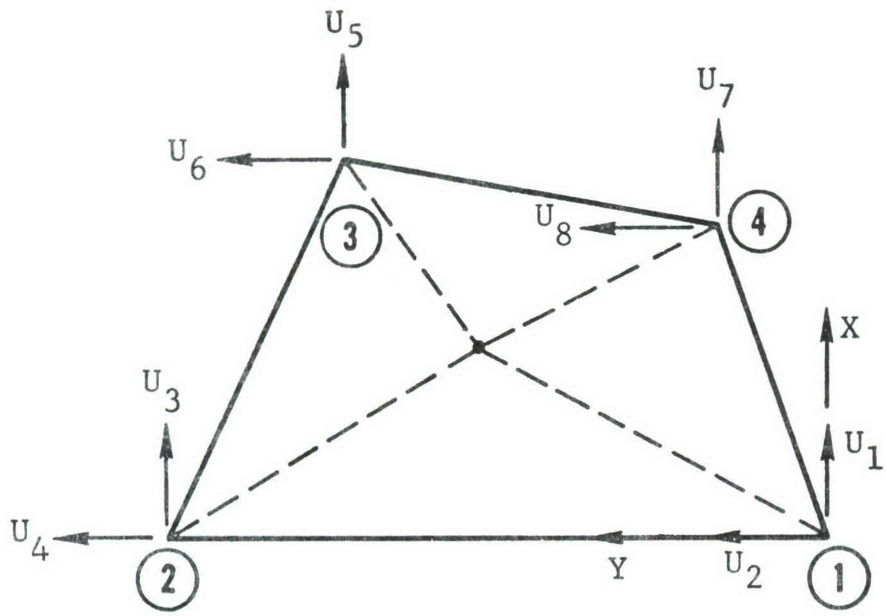
An automated finite element digital procedure has been used to perform the analysis reported herein. This section only summarizes the method since it is presented in reference 1. However, a finite element has been added to those available so it is discussed and the technique used to obtain the interference using finite elements is presented.

The nonlinear constitutive behavior, a dominant feature of the interference fit fastener systems, is a basic part of the input data. This nonlinear behavior is programmed into each element so that the element stiffness is a function of the state of strain and the load-deflection relationship is nonlinear and interdependent. Proportional loading is used in the subject method, consistent with its contemporaries, and the accuracy of the results is controllable by using more load increments at the expense of more computations.

The primary difference in this procedure and its contemporaries is that the latter usually solve linear equations for each load increment (piecewise linear approach), modifying the element stiffnesses after each step. The subject procedure casts the equations in differential form and integrates numerically for each load increment. The equations are of first order and are nonlinear and ordinary. The fourth order Range-Kutta scheme with Simpson rule coefficients is used for integration to obtain deflections.

For the biaxially stressed element, the concept of isotropic hardening and a generalized stress are used to evaluate an effective modulus and Poisson's ratio, which vary continuously from their initial values during elastic straining action to their asymptotic values during intense plastic straining action. The surface of plasticity for the element closely approximates the von Mises surface when the generalized stress is set equal to the von Mises stress and the strain distribution is essentially identical to that obtained by the Prandtl-Reuss incremental flow theory.

The principle finite element used for the analysis reported herein was a quadrilateral membrane composed of four constant stress (linear deformation) type triangular elements. The four triangles are assembled as indicated in Figure II-1 to form the quadrilateral. The displacement degrees of freedom for the



The element stress of each of the four constant stress triangles is calculated and then averaged to obtain the quad plate element stress.

Figure II-1 **Quadrilateral Membrane Finite Element from an Assembly of Four Triangular Elements**

center grid are automatically eliminated from the stiffness matrix for the quadrilateral element before it is added to the structure matrix.

After calculating deflections for each load increment, the element strains are easily obtained. Secant properties are then used to calculate element stresses. Quadrilateral element stresses are obtained by averaging the four triangular element stresses.

In applying finite elements to the analysis of interference fit fastener systems, a problem arises in appropriately representing the interference. Prestress or predeformations cannot be used. The former cannot be used because the distribution of interference between the plate and bolt is unknown before the analysis is performed. The latter cannot be used because the bolt and plate must be allowed to deform as the plate is loaded uniaxially.

This problem has been overcome by replacing the bolt with an internally pressurized ring. The elastic stiffness of the ring was adjusted to be the same as the bolt which it replaced. Under the action of uniaxial load the plate hole tends to become oval but the bolt inside the hole tends to keep it round. Replacing the bolt with the ring allows the bolt effects on the plate to be retained while also allowing the ring to be pressurized internally to produce the desired interference. This analysis predicts the effects of the bolt on the plate (not the plate on the bolt). Hence, this approximation is considered satisfactory.

The relationship used for the cylinder modulus was

$$\bar{E} = \frac{E}{(1-2\nu)(1+\nu)} \left(\frac{a^2 + r^2}{r^2 - a^2} - \nu \right) \tag{II-1}$$

where E is the bolt modulus
ν is Poisson's ratio
a is the inner cylinder radius
r is the hole radius

Equation II-1 was derived by considering the bolt as being approximated by a solid disk in plain strain. The elastic stiffness of this disk is presented in reference 2, page 282. The stiffness of a ring in plain stress is presented in reference 3, page 57. The solid disk stiffness and ring stiffness were set equal to produce the results in equation II-1 above.

The pressure inside the ring, required to produce the desired interference, is

$$P = \frac{r^2 - a^2}{2a^2 r} \, \bar{E} \, \bar{U} \qquad \text{(II-2)}$$

where $\bar{U}$ is the desired radial interference. This expression was also obtained from reference 3, page 56.

SECTION III

ANALYSIS CREDIBILITY

At the initiation of the analysis task, a test program had made available a small amount of data consisting of strains in a round plate with an interference fit fastener in the center. Therefore, this test specimen became the subject of a finite element analysis as a first step in determining the required grid density and value of other parameters necessary to yield engineering accuracy.

The test specimen consisted of a round plate eight inches in diameter with a three-eighth inch hole in the center. The plate was 0.25 inch thick and fabricated from D6ac steel heat treated to 220/240 ksi. Two finite element patterns (Figures III-1 and III-2) were used for analysis. Advantage was taken of the symmetry conditions and only one quadrant was represented; hence, the tangential deformations along each radial edge were constrained. Note that in both idealizations (one element per 15 degrees, Figure III-1 and one element per 10 degrees, Figure III-2) there are two bands of finite elements inside the hole. These two bands represent the ring replacing the steel fastener as discussed in Section II. Pressure was applied as mechanical loads at the inside grid ring inside the bolt and caused the bolt to expand which stressed the plate.

For a trial condition, an interference fit consisting of 0.35 inch bolt insertion was used for both idealizations and analysis was performed. For the integration, four load increments (50, 75, 90 and 100 percent) were used in order to insure accuracy. The value of plastic modulus was very small, being 30,000 psi. The resulting bolt hole radial deformation was the same for both idealizations, being 0.00320 inch. Since the total radial interference was 0.00365 inch, approximately 88 percent of the total was absorbed by the plate. This corresponds to 67 percent for the elastic case which may be obtained analytically from the expressions on pages 57 and 58 of reference 3.

The results of using both element patterns are presented in Table III-1. Any differences in the two are insignificant.

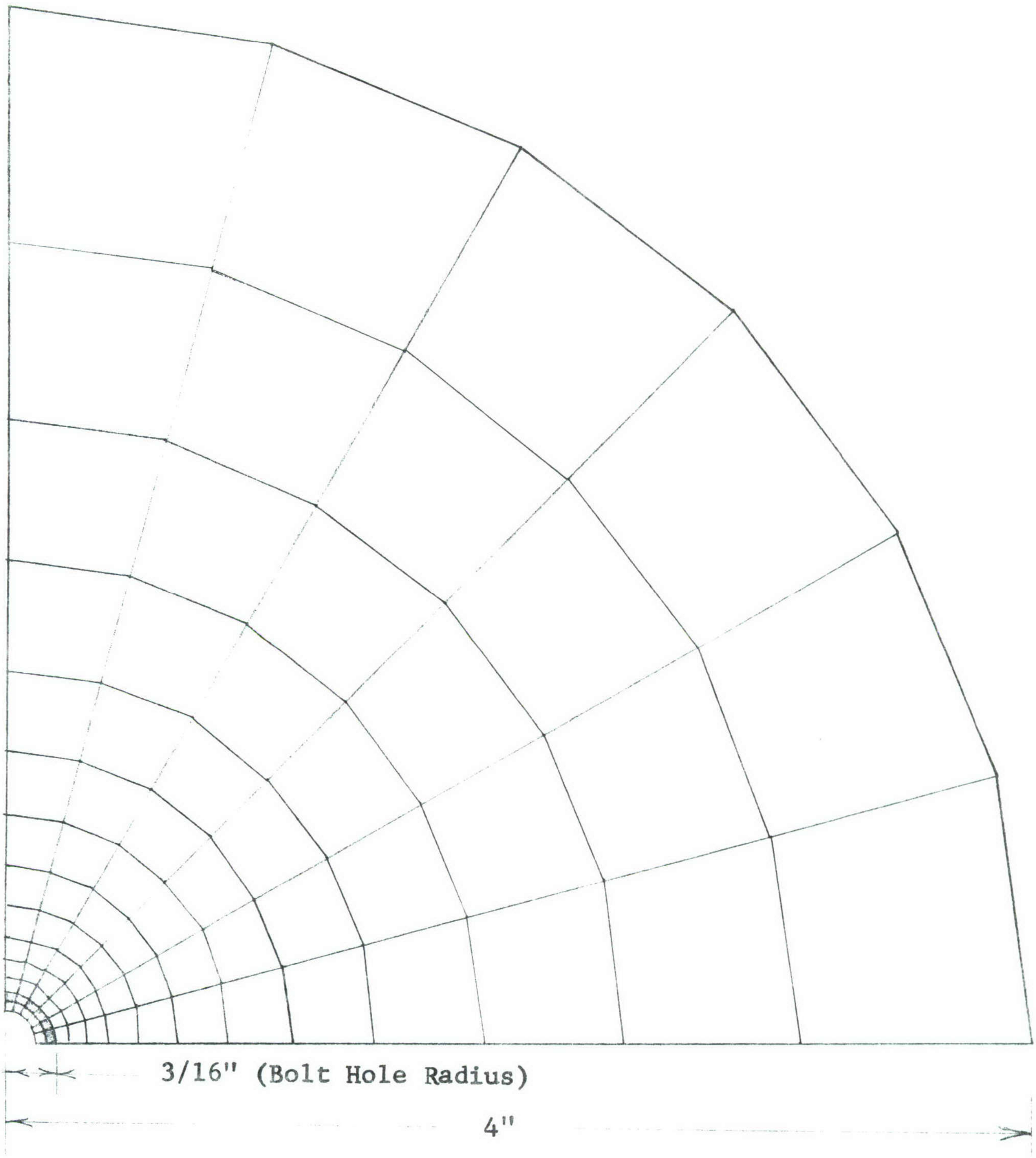


Figure III-1 Idealization of Test Specimen with Finite Elements at 15 Degrees

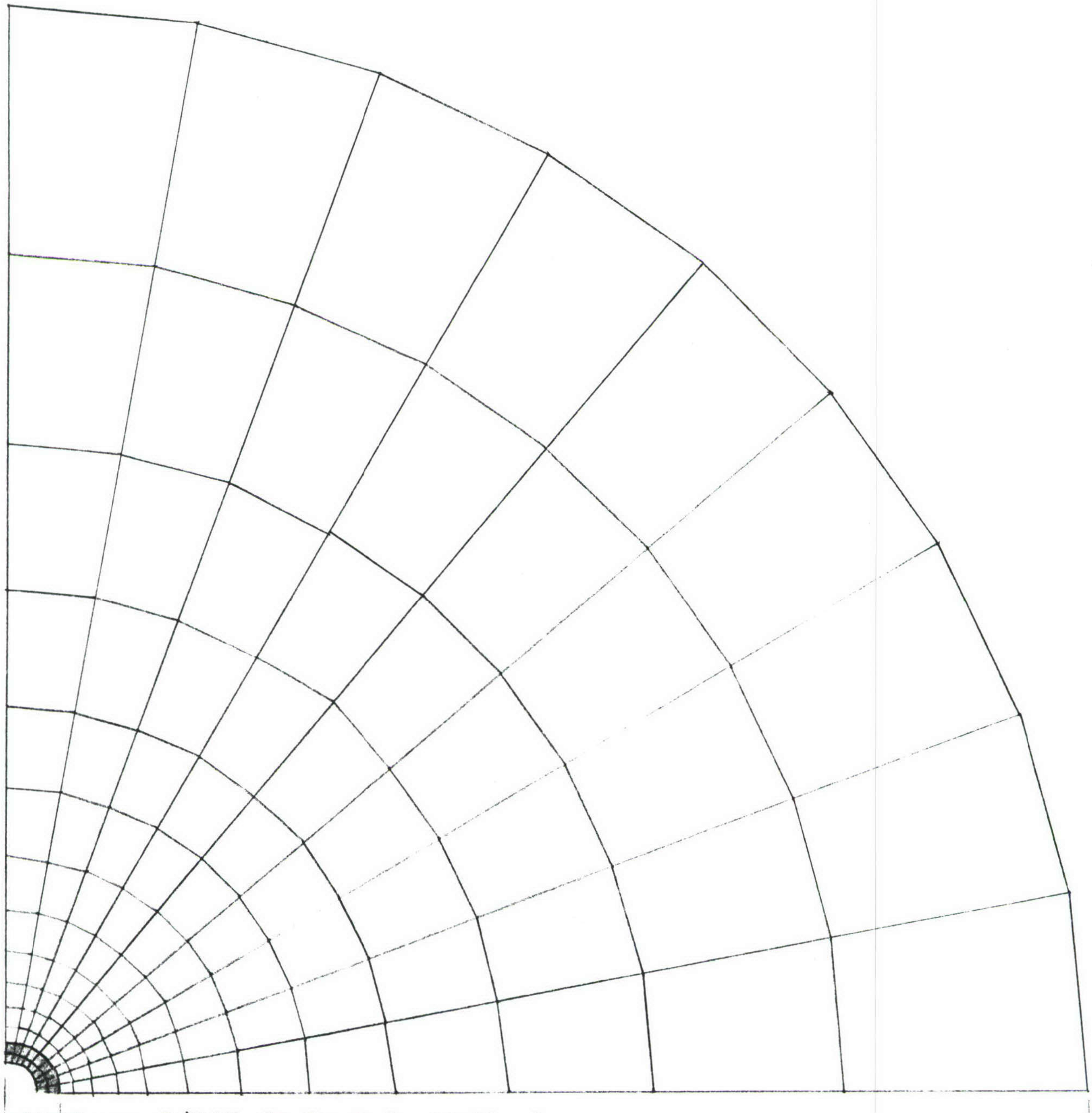


Figure III-2 Idealization of Test Specimen with Finite Elements at 10 Degrees

Table III-1 Finite Element Analysis Results for Idealizations Using Elements 10 and 15 Degrees Wide

Finite Element Numbers		Radius in Inches	Radial Strains $\times 10^3$		Tangential Strains $\times 10^3$		Radial Stresses (Lbs/inch$^2 \times 10^{-3}$)		Tangential Stresses (Lbs/inch$^2 \times 10^{-3}$)	
10 Degrees	15 Degrees		10 Degrees	15 Degrees	10 Degrees	15 Degrees	10 Degrees	15 Degrees	10 Degrees	15 Degrees
19-27	13-18	0.21475	-35.5	-35.7	10.7	10.7	-242	-242	-45	-45
28-36	19-24	0.27715	-4.00	-4.00	4.07	4.08	-88	-88	91	92
37-45	25-30	0.35765	-2.39	-2.39	2.45	2.45	-53	-53	55	55
46-54	31-36	0.46150	-1.43	-1.43	1.47	1.48	-32	-32	33	33
55-63	37-42	0.59555	-0.855	0.857	0.889	0.891	-19	-19	20	20
64-72	43-48	0.76855	-0.510	-0.511	0.538	0.539	-11	-11	12	12

Next, the two inside bands of elements in the plate, adjacent to the hole, were replaced with four bands in both the 10 and 15 degree grid patterns. This refined the grid pattern in and adjacent to the plastic zone. The same four load increments and plastic modulus were used as before. Again, the results were the same for both the 10 and 15 degree simulations and the radial deformation was insignificantly lower, being 0.00319 inches. The radial and tangential strains resulting from the coarse and refined grids are plotted for comparison in Figure III-3. It will be noted that the plate strains in the plastic zone resulting from the refined grid are slightly lower than those from the coarse grid. Using the radius and radial deformation the tangential strain at the edge of the hole may be calculated as 0.0171 inch per inch. This point may be added to Figure III-3 and either set of finite element calculated tangential strains extrapolated to it. (This has not been done in the subject illustration.)

Since the 15 degree grid pattern was as accurate as the 10 degree pattern and yet was more economical to compute, the 10 degree pattern was discarded at this point.

Two parameters were then explored consisting of the number of load increments and the non-linear stress-strain curve relationship as defined analytically. In addition to the four load increments, previously defined, six increments (60, 75, 85, 90, 95 and 100 percent) were used. The use of six increments did not change the results. This implied that perhaps one increment (100 percent) would also produce accurate answers and be computationally more economical. One load increment was then used and the same results were obtained as for the cases using four and six. Hence, one load increment was used for all subsequent conditions including the production conditions.

The non-linear stress-strain curve is defined analytically through use of a parameter n (Reference 1). Its effect, and correlation with the material characteristics, is illustrated in Figure III-4. As may be seen from the figure, the higher values of n correlate more closely with the material characteristics. However, it was discovered that using values above five would cause some slight unbalances to occur across those finite elements which occupy the plastic zone surrounding the hole. Using a value of ten caused an unbalance in the radial direction of approximately three percent of the applied load. (Equilibrium was satisfied in the tangential direction.)

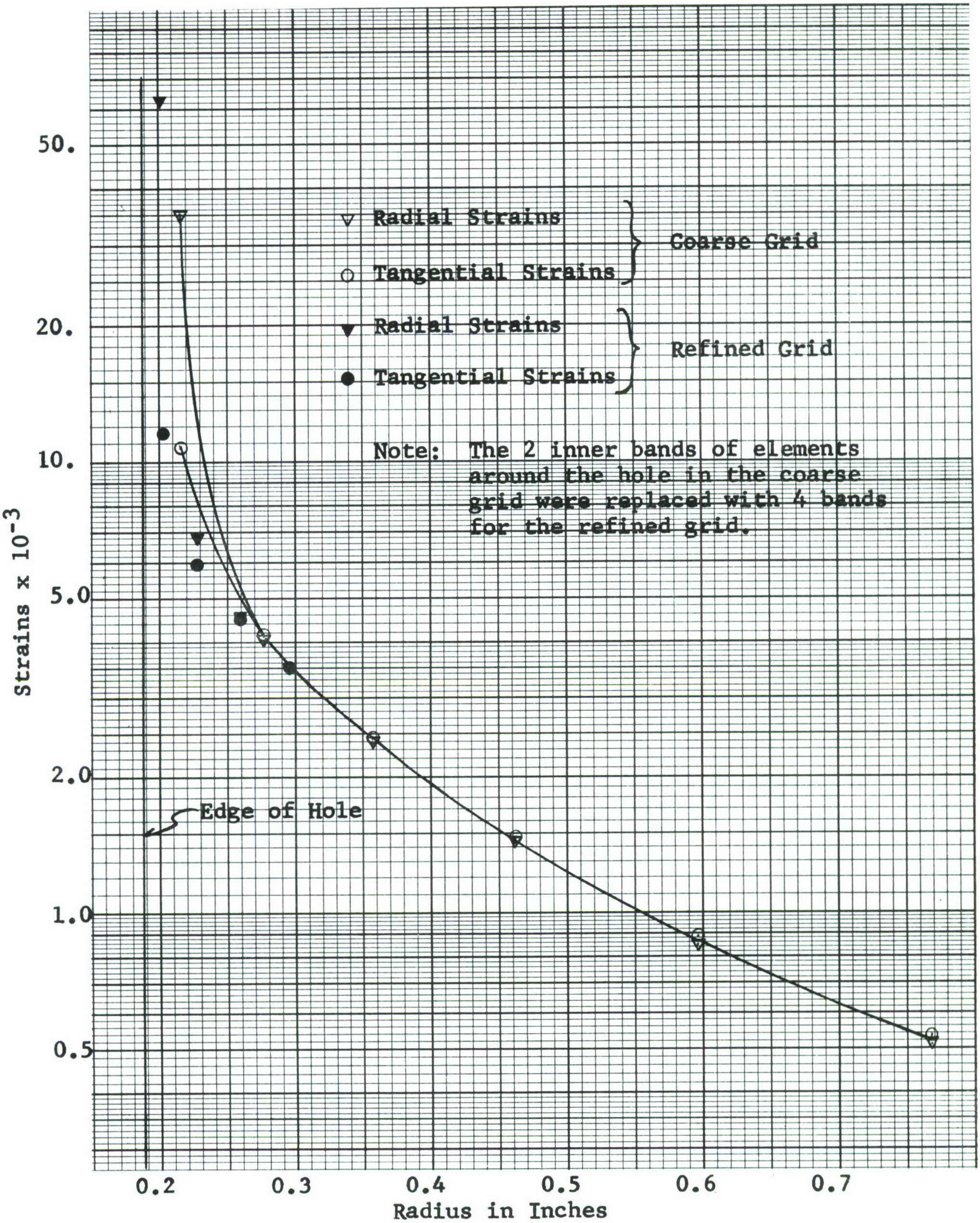


Figure III-3 Finite Element Calculated Strains for Coarse and Refined Grids

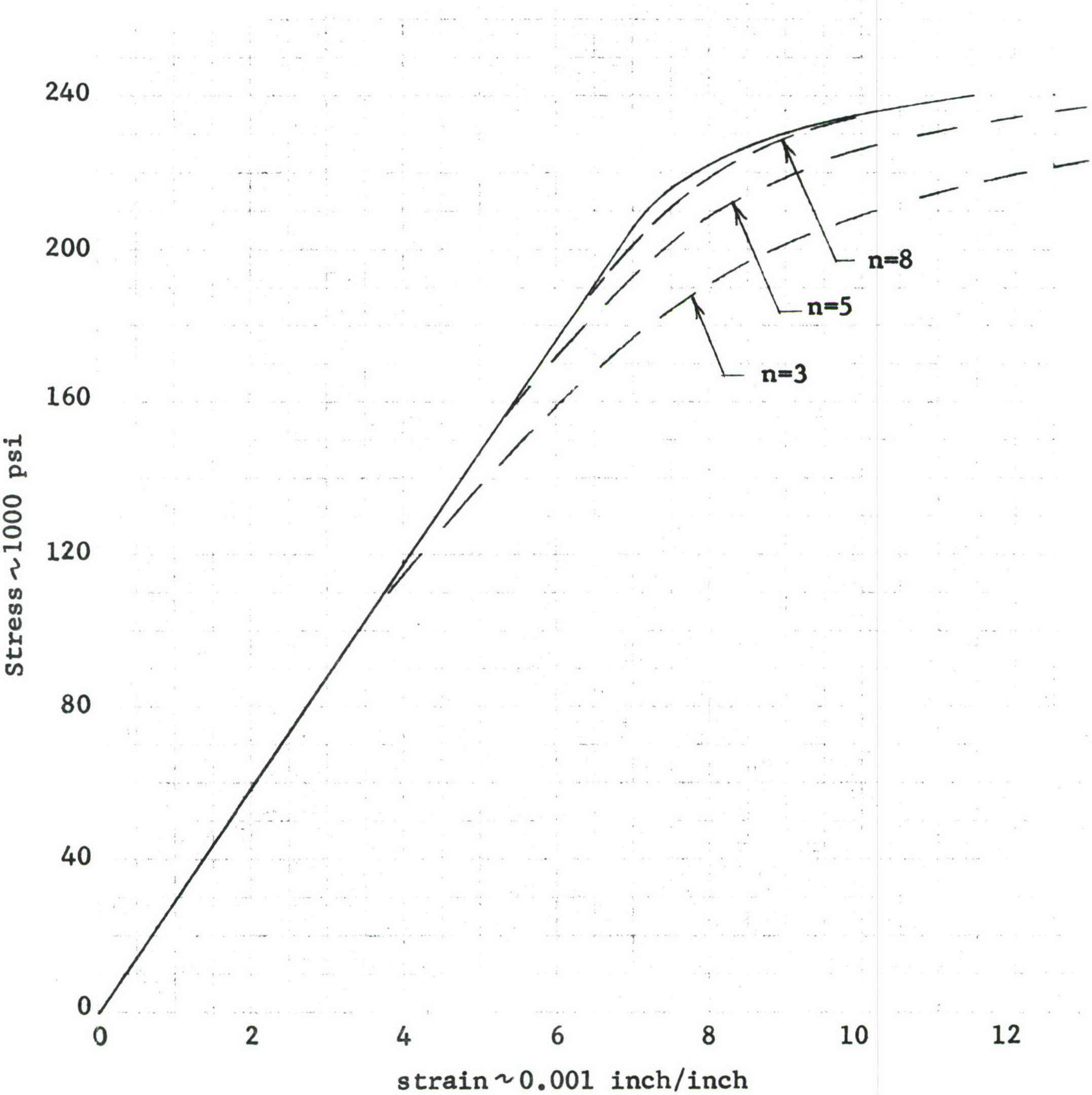


Figure III-4 Effect of Parameter n on Stress - Strain Curve for D-6ac Steel at Room Temperature

Since computation was being performed in single precision on an IBM system, a temporary change to double precision was made. The same unbalances were obtained in double precision for the higher values of n. (These unbalances are now attributed to the sharpness of the "corner" of the stress-strain curve.)

Because equilibrium was satisfied when a value of five was used and no strains were expected in the vicinity of the "corner", the value of five for n was selected and used for all subsequent analysis. Double precision was used for a small number of production conditions until the change could be made to single precision in which most of the production analyses were performed.

Two test conditions were then selected for analysis; a bolt insertion of 0.45 and 0.30 inches, because these corresponded rather closely with the parameters to be used in the production cases. The testing, on the eight inch diameter plate previously discussed, had been performed using strain gages and also using grid lines. The strain gages had been installed along 90 degree radial lines, with two rows for tangential strains 90 degrees apart and two rows for radial strains also 90 degrees apart. In the grid line method, a copper strip was plated on the disc and scribed. Only radial deformations are measured using grid lines and tangential strains are then calculated by dividing by the radial distance.

The experimental tangential strains resulting from a bolt insertion of 0.45 inch are shown in Figure III-5. Three finite element analysis results are superimposed for comparison. The first analysis results were obtained by analytically calculating the pressure as indicated in Section II. This resulted in a plate radial deformation of 0.00414 inches or about 88 percent of the total. The grid line test had indicated that the radial deformation was only 0.00350 inches. Because of this, the bolt pressure was linearly reduced with the results that the calculated radial deformation was 0.00367 inches. For both these analyses conditions, 3×10^6 was used for the value of plastic modulus. In order to determine the effects of the plastic modulus and also because no good definition of plastic modulus could be found for D6ac steel, a third computation was made using 6×10^6. This resulted in a calculated plate hole radial deformation of 0.00356 inches. These three analyses results are shown in Figure III-5.

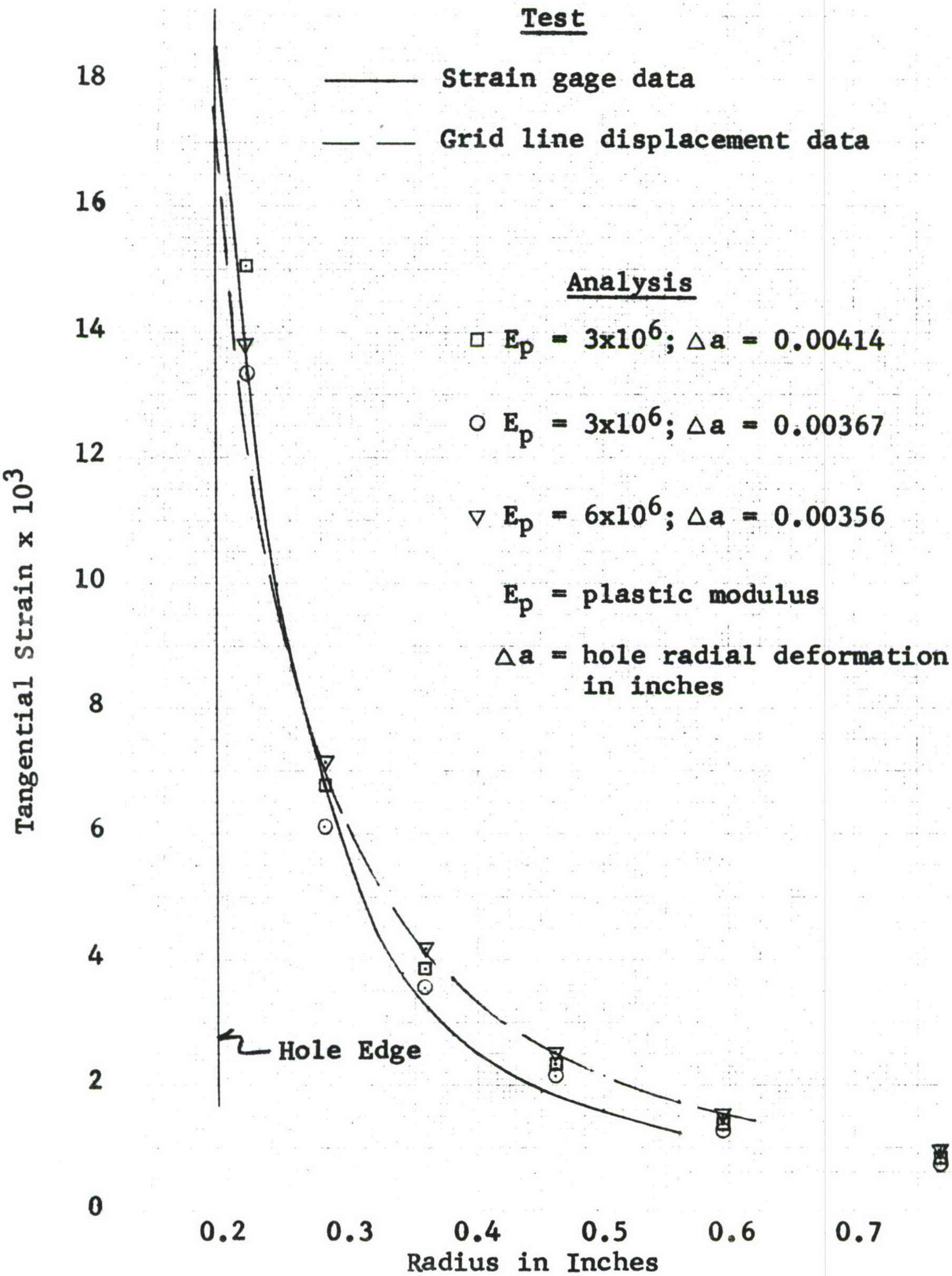


Figure III-5 Analysis/Test Comparison of Tangential Strains for 0.45 Inch Bolt Insertion

Test results obtained from strain gages for both tangential and radial strains resulting from a bolt insertion of 0.45 inches are shown in Figure III-6. These are compared with calculated results from the latter two conditions described above. Note that the level of plastic strain has a pronounced effect on the calculated radial deformations in the plastic zone with the higher value correlating more closely with test. It should be indicated that the hole radial deformation from this test was 0.00333 inch. This deformation was obtained by extrapolating to the hole edge the tangential strains obtained from strain gages and multiplying by the hole radius. This consideration makes the analysis/test comparison even more favorable.

Test results from both strain gages and grid lines for a 0.30 bolt insertion are shown in Figure III-7. Analysis results are superimposed for comparison. The calculated hole deformation was 0.00214 inch; in comparison to 0.00202 inch obtained by extrapolating both the grid line and strain gage data as in the case for 0.45 insertion.

After performing the above described analyses and viewing the analyses/test comparisons, the analytical approach was deemed qualified to predict trends which was the objective of the production conditions.

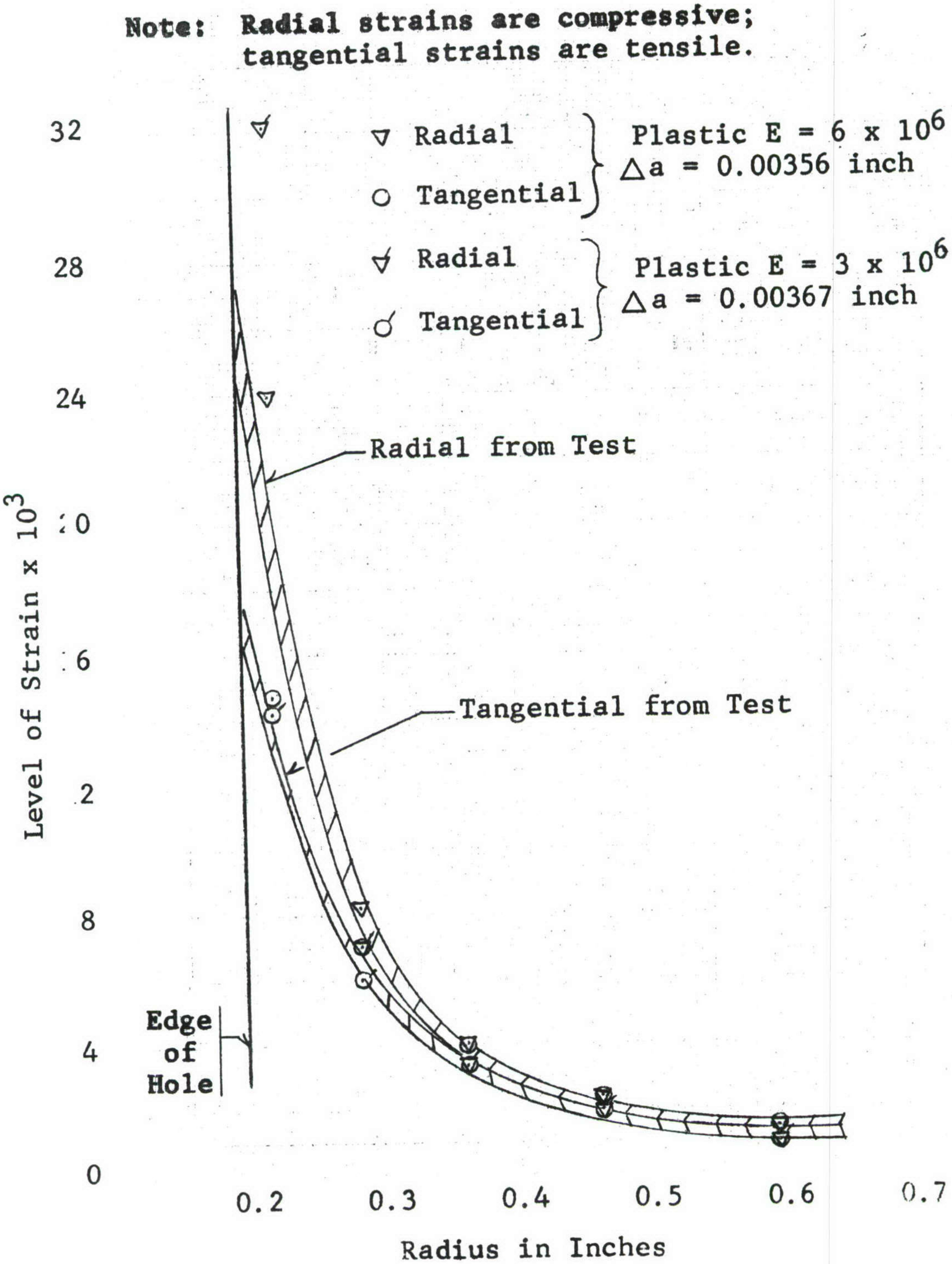


Figure III-6 Analysis/Test Comparison of Radial and Tangential Strains for 0.45-Inch Bolt Insertion

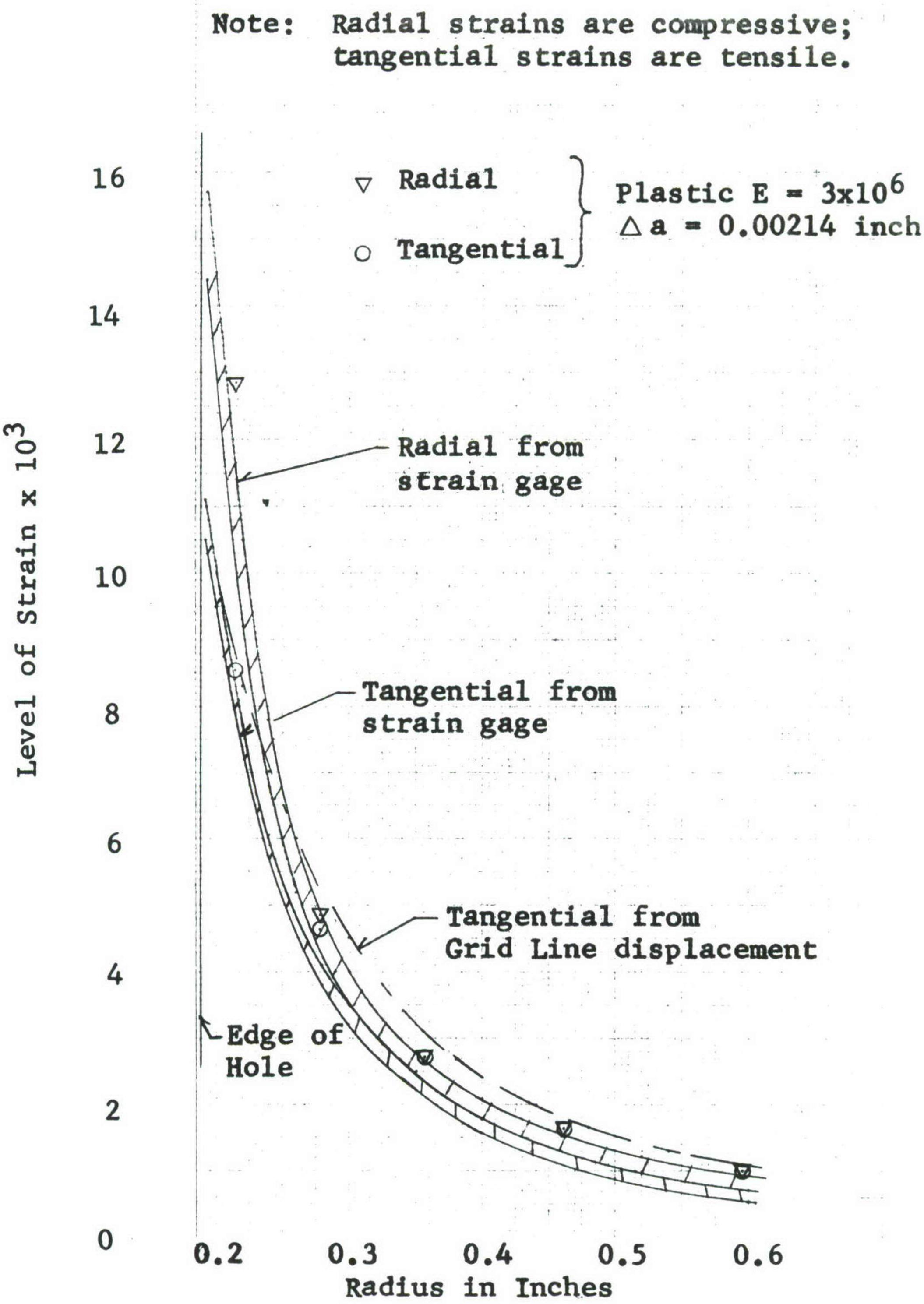


Figure III-7 Analysis/Test Comparison of Radial and Tangential Strains for 0.30 Inch Bolt Insertion

SECTION IV

DISCUSSION OF PRODUCTION CONDITIONS

The analysis subject for the production conditions was a rectangular plate measuring five by eight inches of 0.10 inch gage. Two finite element representations were used because of the two bolt hole sizes. Figure IV-1 shows the representation used for the plate with the 3/8 inch diameter hole and Figure IV-2 shows the representation used for the plate with the 1/4 inch diameter hole. One fourth of the plate is included in the representations which takes advantage of the double symmetry condition. The plate was constrained against longitudinal translation by fixing those longitudinal coordinates along the centerline which forms the bottom edge of the quadrant in Figures IV-1 and IV-2. Lateral translation was constrained along the centerline forming the left edge of the quadrant in the subject figures.

The one element per 15 degree arrangement which proved satisfactory in Section III was reused in this representation. Also, the aspect ratio of the quadrilateral elements surrounding the hole are essentially unchanged. These dimensions were selected because the resulting stresses and strains are nearly the same as in an infinite plate, yet the plate lends itself to modeling with finite elements. Also, the dimensions will allow economical testing by any interested individual.

Because of the voluminous nature of the analyses results, they are presented in the appendices. The presented data consists of stresses and strains in numerical and contour form, both prepared by the Stromberg-Carlson 4020 plotter. The numerical form consists of printing the numerical level of the stress or strain on each finite element in the representation. The contours consist of isolines which represent constant levels of stress or strain. Because the highest stress and strain levels and gradients occur in the vicinity of the fastener only that region adjacent to the fastener is included in the plots. For the plate with the 3/8 inch hole, a region extending from the hole edge to a radial distance of 1.442 inches from the hole center is included for the plots. This region is illustrated in Figures IV-1 and IV-3, the latter of which identifies the finite elements by number. The region of the plate surrounding the 1/4 inch hole measures 0.866 inch radially from the hole center and is illustrated in Figures IV-2 and IV-4.

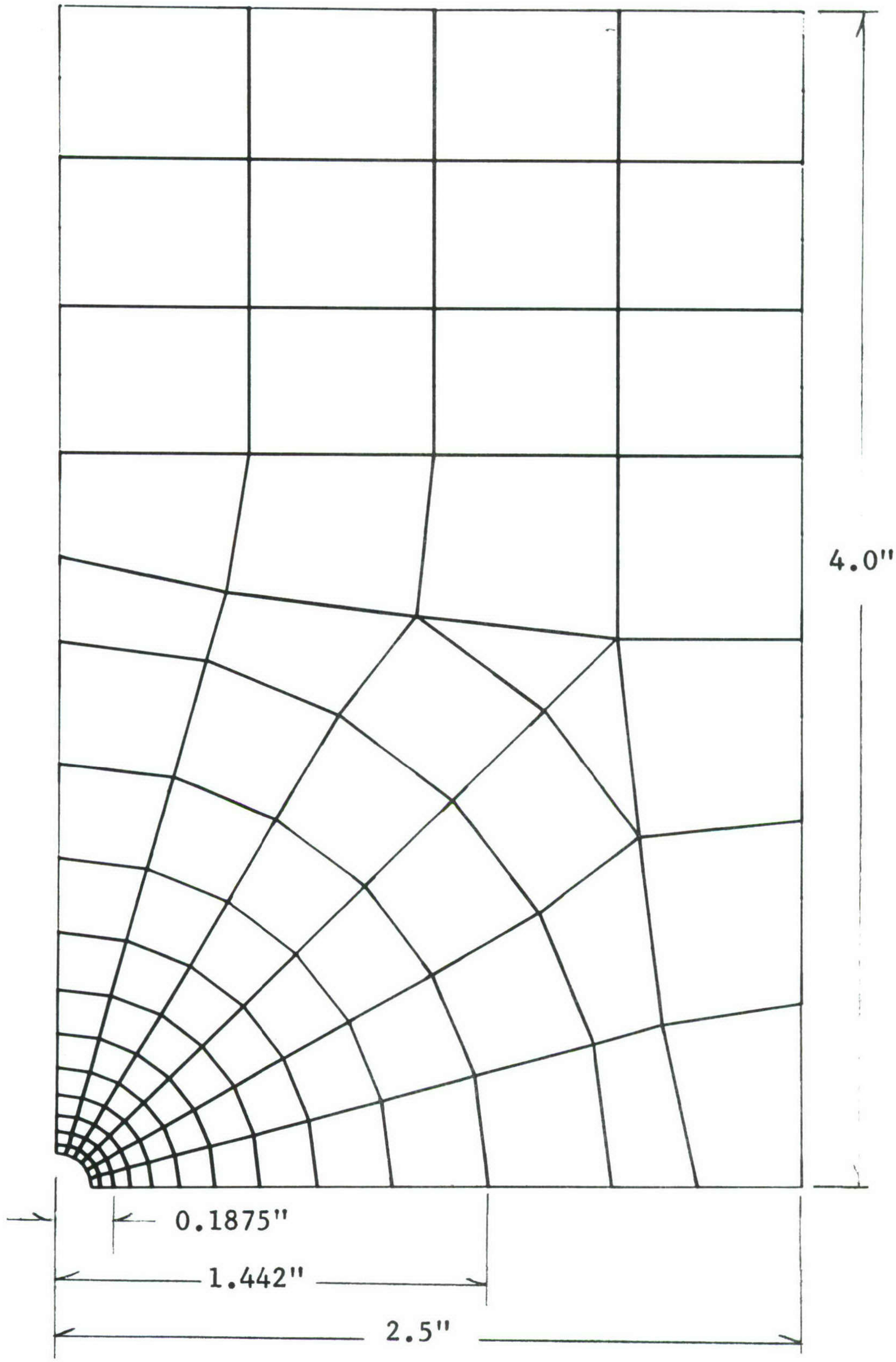


Figure IV-1 Finite Element Representation Used for the Plate with 3/8 Inch Diameter Hole

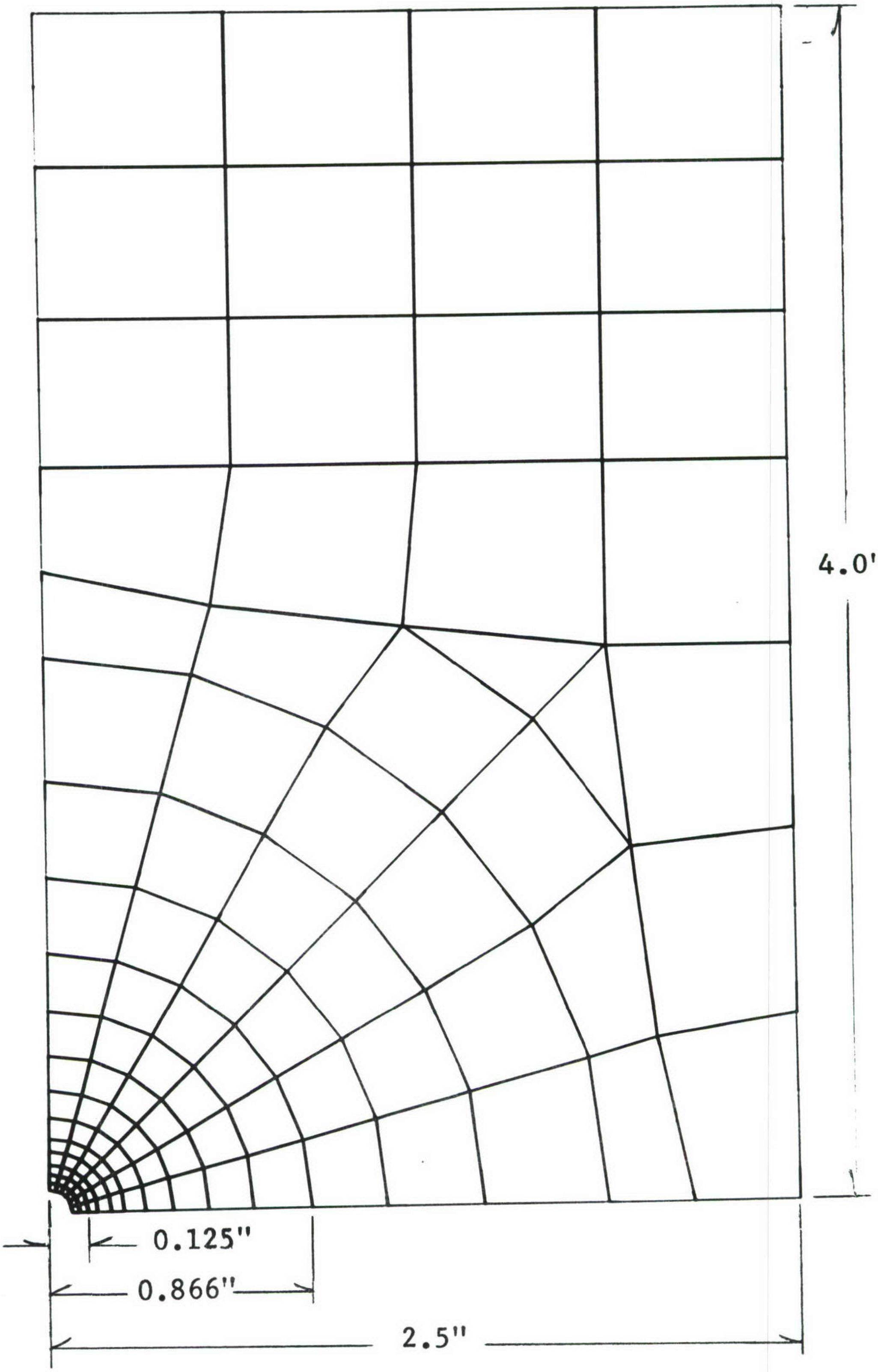


Figure IV-2 Finite Element Representation Used for the Plate with 1/4 Inch Diameter Hole

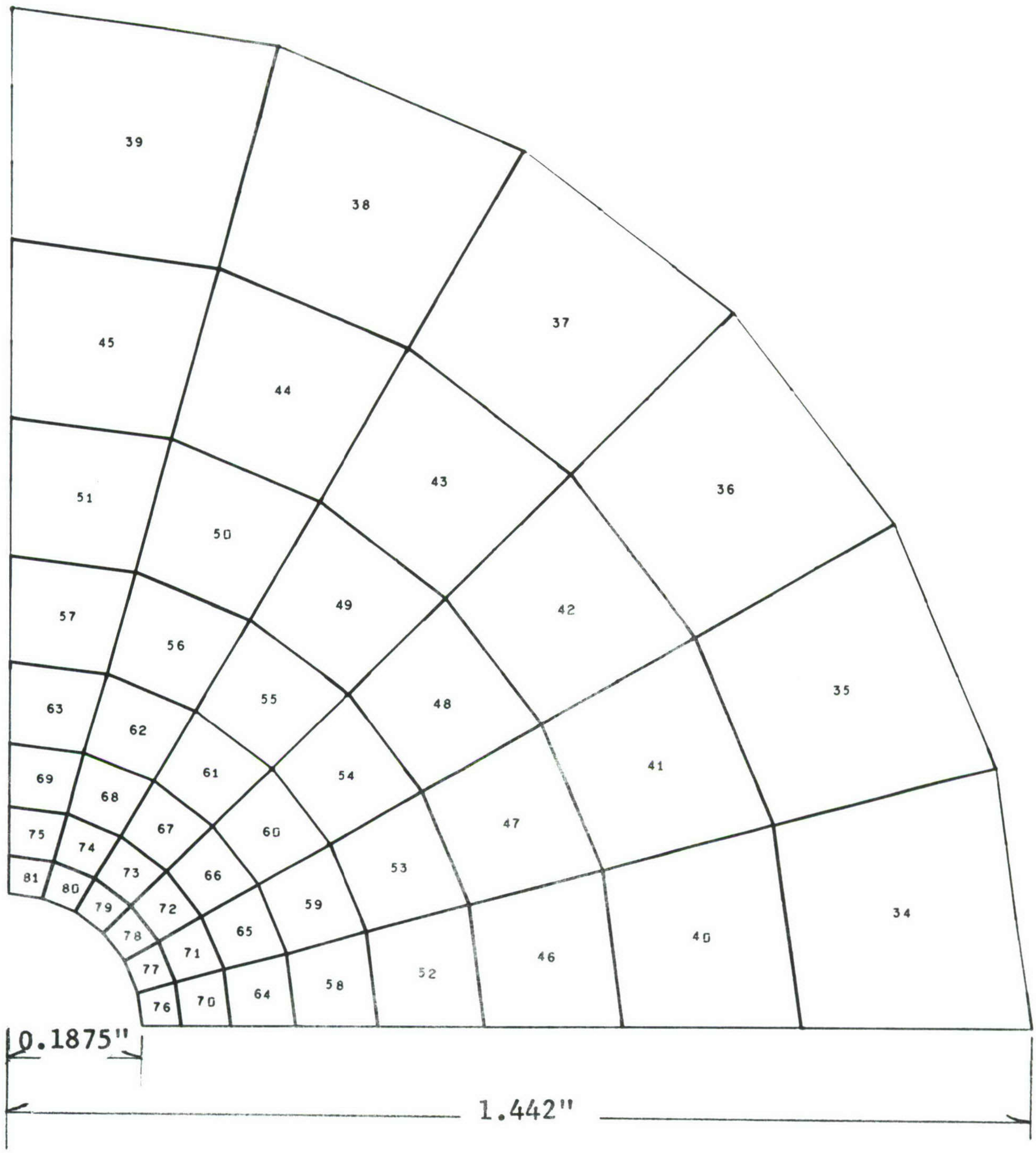


Figure IV-3 Region of Plate Surrounding the 3/8 Inch Hole Used to Present Stresses and Strains

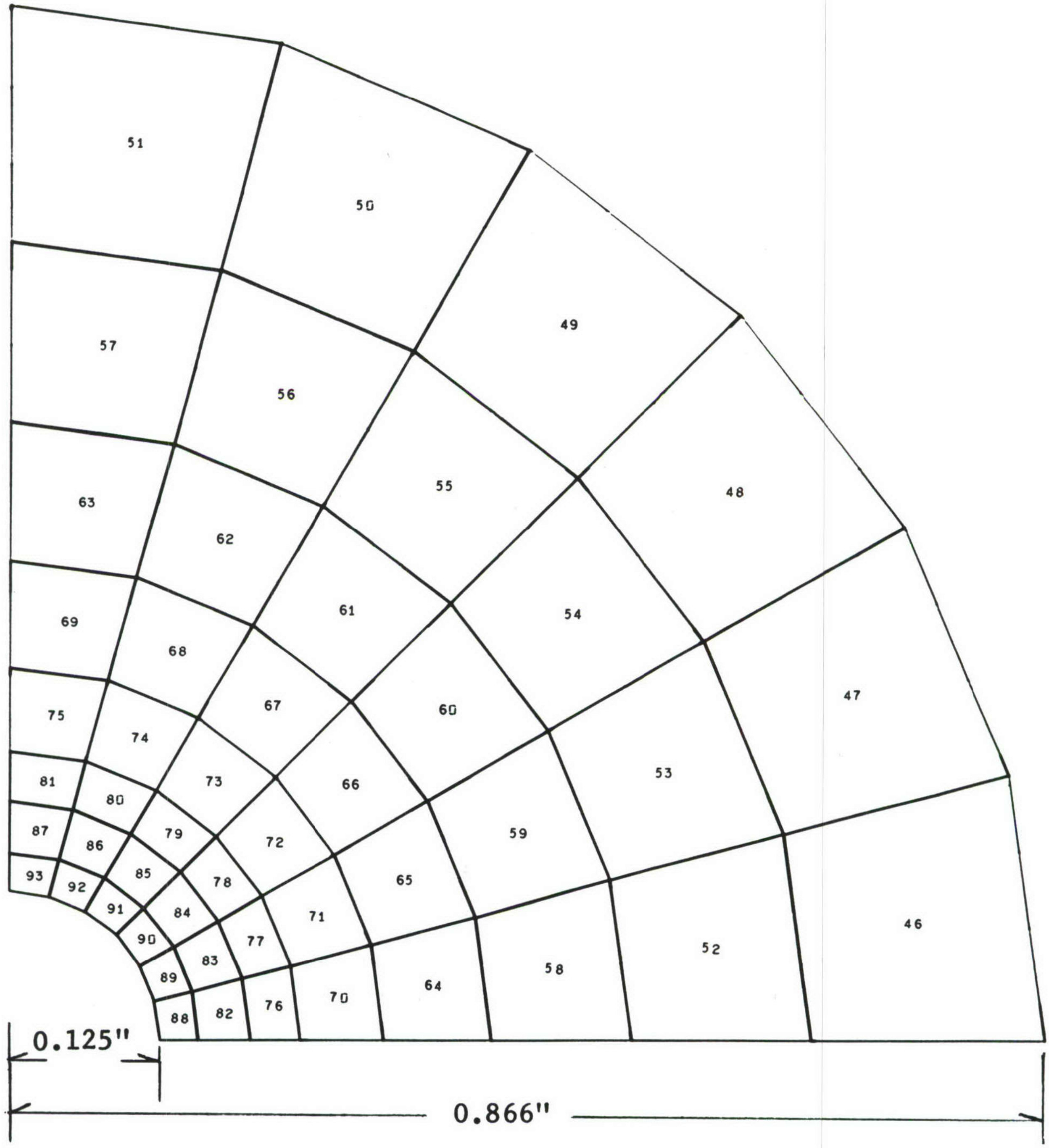


Figure IV-4 Region of Plate Surrounding the 1/4 Inch Hole Used to Present Stresses and Strains

A total of thirty-six conditions have been analyzed, twelve each for aluminum, titanium and steel. For all cases a steel bolt was used. The conditions are defined and numbered for the aluminum plate in Table IV-1. In the table, the diametral interference is total, being the sum of change in diameter of the bolt and plate due to the interference.

The condition numbers for titanium and steel are the same as aluminum except that the letter designation is changed to "T" and "S", respectively. Also, a uniaxial load of 50 percent of gross area yield was used for the titanium plate at the lower levels of interference fit in lieu of the 70 percent because the latter was sufficient to cause separation of the bolt and plate.

The applied uniaxial load was measured as a percent of that gross area stress which would cause yielding to occur in a plate without a hole. The yield point was defined as 50,000 psi stress for aluminum, 210,000 psi stress for steel and 130,000 psi stress for titanium. For all plates, the uniaxial load was applied in a direction parallel to the longitudinal axis and distributed evenly as an edge force along the width.

The uniaxial stress-strain curves used for aluminum and steel are shown in Figures IV-5 and IV-6, respectively. The uniaxial stress-strain curve used for titanium was taken from Reference 4, page 5-85. The value of Poisson's ratio used for each of the three materials was 0.33 for aluminum, 0.31 for titanium, and 0.32 for steel. These values were all obtained from Reference 4, pages 3-44, 5-75, and 2-12, respectively.

The plate hole deformations as a result of the interference fit and applied uniaxial load are computed as a part of the analysis. These deformations are shown in Tables IV-2, IV-3 and IV-4 for the aluminum, titanium and steel conditions, respectively. The grid points at which the deformations were calculated are illustrated in Figure IV-7.

Appendices I, II and III present the results for the aluminum, titanium and steel plates, respectively. Following the appendices is an index of figures for the appendix contents.

Table IV-1 Definition of Analysis Conditions for Aluminum Plate

Condition Number*	Hole Diameter (Inches)	Diametral Interference (Inches)	Uniaxial Load (Percent of Yield)
A1	3/8	0.00375	0
A2	3/8	0.00375	35
A3	3/8	0.00375	70**
A4	3/8	0.00750	0
A5	3/8	0.00750	35
A6	3/8	0.00750	70
A7	1/4	0.00250	0
A8	1/4	0.00250	35
A9	1/4	0.00250	70**
A10	1/4	0.00500	0
A11	1/4	0.00500	35
A12	1/4	0.00500	70

* The numerical part of the condition number is the same for all materials; the letter part is "A" for aluminum, "S" for steel and "T" for titanium.

** A uniaxial load of 50 percent was used for this condition for the titanium plate because at the 70 percent level the plate separated from the bolt.

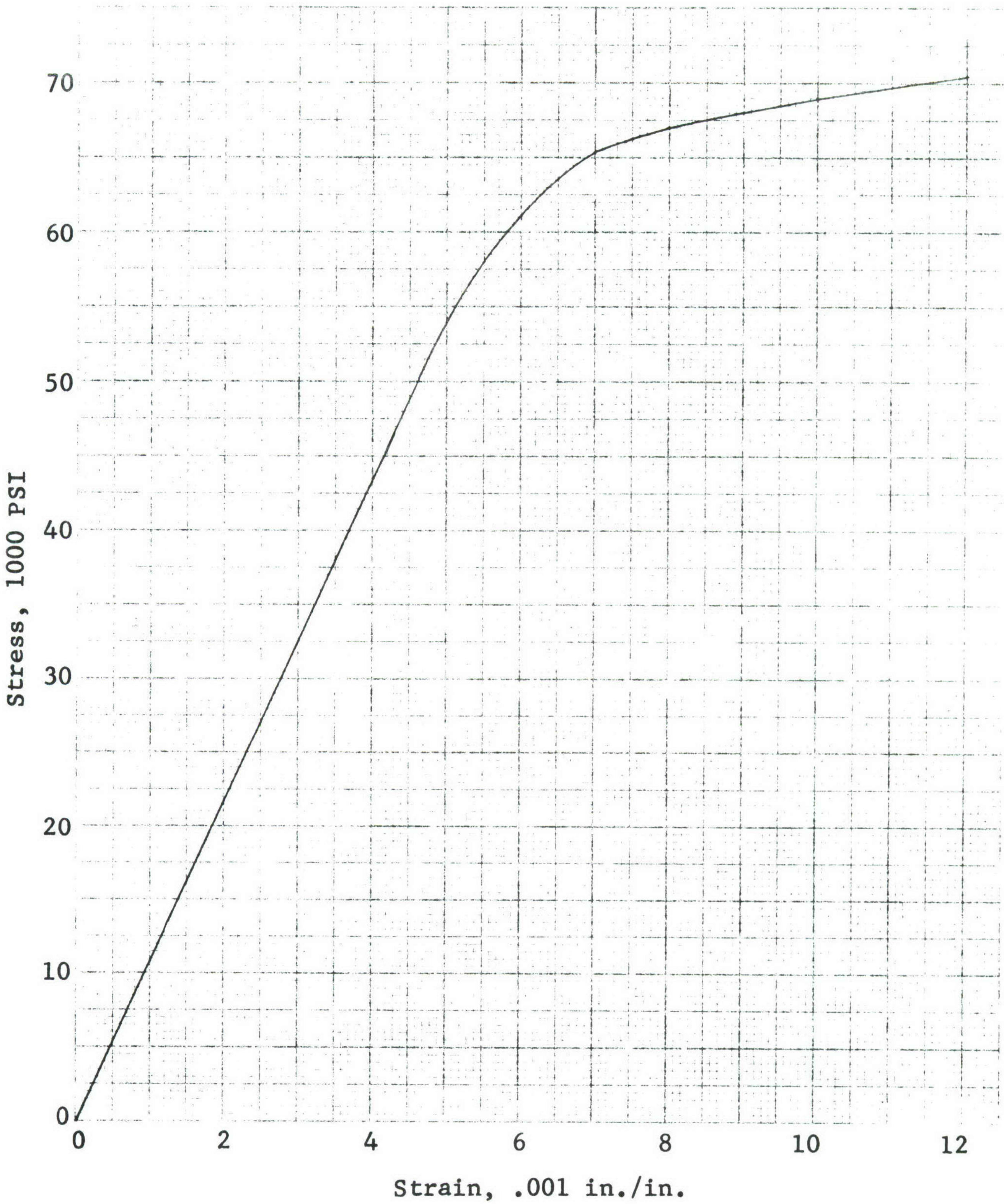


Figure IV-5 Typical Compression Stress-Strain Curve at Room Temperature for 2024-T851 Aluminum Alloy Plate

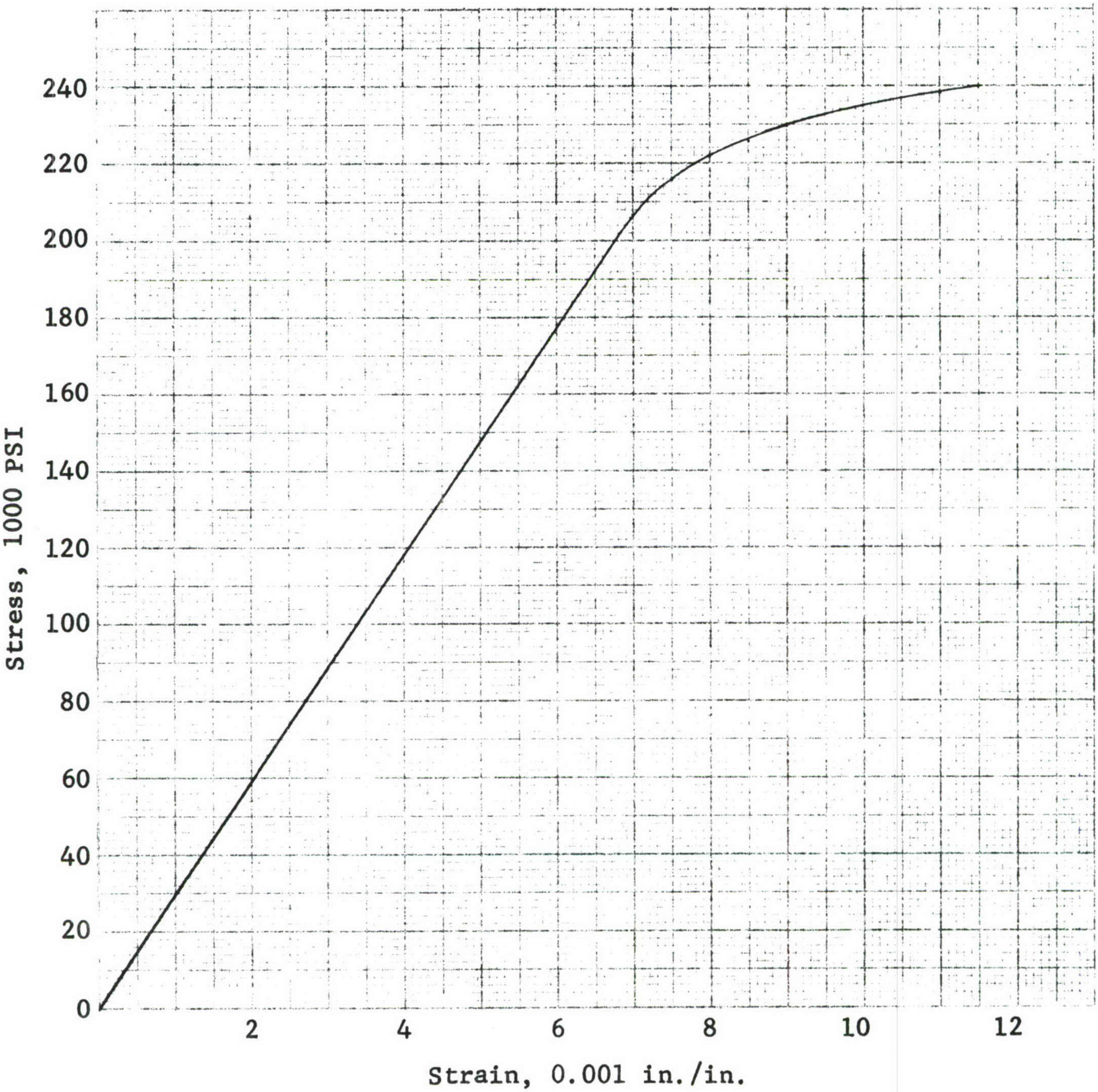


Figure IV-6 Typical Compression Stress-Strain Curve at Room Temperature for D-6ac Steel Forgings (Longitudinal)

Table IV-2 Aluminum Plate Hole Deflections

COND. NO.	DIRECTION	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7
A1	x	.00172	.00167	.00149	.00122	.00087	.00044	0
	y	0	.00044	.00087	.00122	.00149	.00167	.00172
A2	x	.00164	.00159	.00145	.00121	.00087	.00045	0
	y	0	.00045	.00089	.00127	.00158	.00178	.00185
A3	x	.00154	.00151	.00140	.00120	.00088	.00046	0
	y	0	.00045	.00091	.00133	.00169	.00193	.00201
A4	x	.00357	.00346	.00311	.00254	.00180	.00092	0
	y	0	.00092	.00180	.00254	.00311	.00346	.00357
A5	x	.00352	.00341	.00308	.00253	.00181	.00093	0
	y	0	.00092	.00181	.00257	.00316	.00354	.00366
A6	x	.00347	.00337	.00305	.00253	.00182	.00093	0
	y	0	.00092	.00183	.00260	.00323	.00363	.00376
A7	x	.00107	.00103	.00092	.00075	.00054	.00028	0
	y	0	.00028	.00054	.00075	.00092	.00103	.00107
A8	x	.00102	.00099	.00089	.00074	.00054	.00028	0
	y	0	.00028	.00055	.00078	.00097	.00110	.00115
A9	x	.00096	.00094	.00087	.00074	.00055	.00029	0
	y	0	.00028	.00056	.00082	.00103	.00119	.00124
A10	x	.00221	.00214	.00191	.00156	.00111	.00058	0
	y	0	.00058	.00111	.00156	.00190	.00214	.00221
A11	x	.00218	.00211	.00189	.00155	.00112	.00058	0
	y	0	.00058	.00112	.00158	.00194	.00218	.00226
A12	x	.00215	.00209	.00188	.00155	.00112	.00059	0
	y	0	.00058	.00113	.00160	.00198	.00224	.00232

Table IV-3 Titanium Plate Hole Deflections

COND. NO.	DIRECTION	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7
T1	x	.00163	.00158	.00142	.00116	.00082	.00042	0
	y	0	.00042	.00082	.00116	.00141	.00158	.00163
T2	x	.00143	.00140	.00131	.00112	.00084	.00044	0
	y	0	.00043	.00088	.00129	.00164	.00189	.00197
T3	x	.00133	.00132	.00126	.00111	.00085	.00045	0
	y	0	.00044	.00090	.00135	.00175	.00203	.00213
T4	x	.00345	.00334	.00300	.00245	.00174	.00089	0
	y	0	.00089	.00174	.00245	.00300	.00334	.00345
T5	x	.00337	.00328	.00296	.00243	.00173	.00088	0
	y	0	.00090	.00178	.00253	.00311	.00348	.00360
T6	x	.00312	.00307	.00284	.00241	.00176	.00091	0
	y	0	.00090	.00182	.00266	.00338	.00385	.00400
T7	x	.00101	.00098	.00088	.00071	.00051	.00027	0
	y	0	.00027	.00051	.00071	.00088	.00098	.00101
T8	x	.00089	.00088	.00081	.00070	.00052	.00028	0
	y	0	.00027	.00054	.00080	.00101	.00117	.00122
T9	x	.00084	.00083	.00079	.00069	.00053	.00028	0
	y	0	.00028	.00056	.00083	.00108	.00125	.00131
T10	x	.00231	.00206	.00183	.00150	.00107	.00056	0
	y	0	.00056	.00107	.00150	.00183	.00206	.00213
T11	x	.00207	.00201	.00180	.00148	.00107	.00056	0
	y	0	.00057	.00110	.00155	.00192	.00216	.00223
T12	x	.00194	.00189	.00174	.00148	.00109	.00057	0
	y	0	.00057	.00112	.00164	.00207	.00238	.00248

Table IV-4 Steel Plate Hole Deflections

COND. NO.	DIRECTION	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Node 7
S1	x	.00148	.00143	.00129	.00105	.00075	.00038	0
	y	0	.00038	.00075	.00105	.00129	.00143	.00148
S2	x	.00125	.00124	.00116	.00101	.00075	.00040	0
	y	0	.00041	.00084	.00124	.00159	.00183	.00191
S3	x	.00099	.00101	.00103	.00098	.00078	.00043	0
	y	0	.00044	.00093	.00145	.00194	.00229	.00241
S4	x	.00315	.00305	.00274	.00223	.00159	.00081	0
	y	0	.00081	.00159	.00223	.00273	.00305	.00314
S5	x	.00296	.00289	.00264	.00220	.00160	.00083	0
	y	0	.00084	.00167	.00240	.00300	.00339	.00352
S6	x	.00271	.00268	.00253	.00219	.00163	.00085	0
	y	0	.00086	.00176	.00261	.00336	.00385	.00401
S7	x	.00093	.00090	.00080	.00065	.00046	.00024	0
	y	0	.00024	.00046	.00065	.00080	.00090	.00092
S8	x	.00079	.00078	.00072	.00063	.00047	.00025	0
	y	0	.00026	.00052	.00077	.00099	.00114	.00119
S9	x	.00063	.00064	.00065	.00061	.00049	.00027	0
	y	0	.00028	.00058	.00090	.00120	.00142	.00149
S10	x	.00196	.00189	.00169	.00138	.00098	.00051	0
	y	0	.00051	.00098	.00138	.00169	.00189	.00195
S11	x	.00184	.00180	.00163	.00136	.00099	.00052	0
	y	0	.00053	.00104	.00148	.00185	.00210	.00218
S12	x	.00170	.00168	.00156	.00135	.00101	.00053	0
	y	0	.00055	.00109	.00161	.00207	.00238	.00248

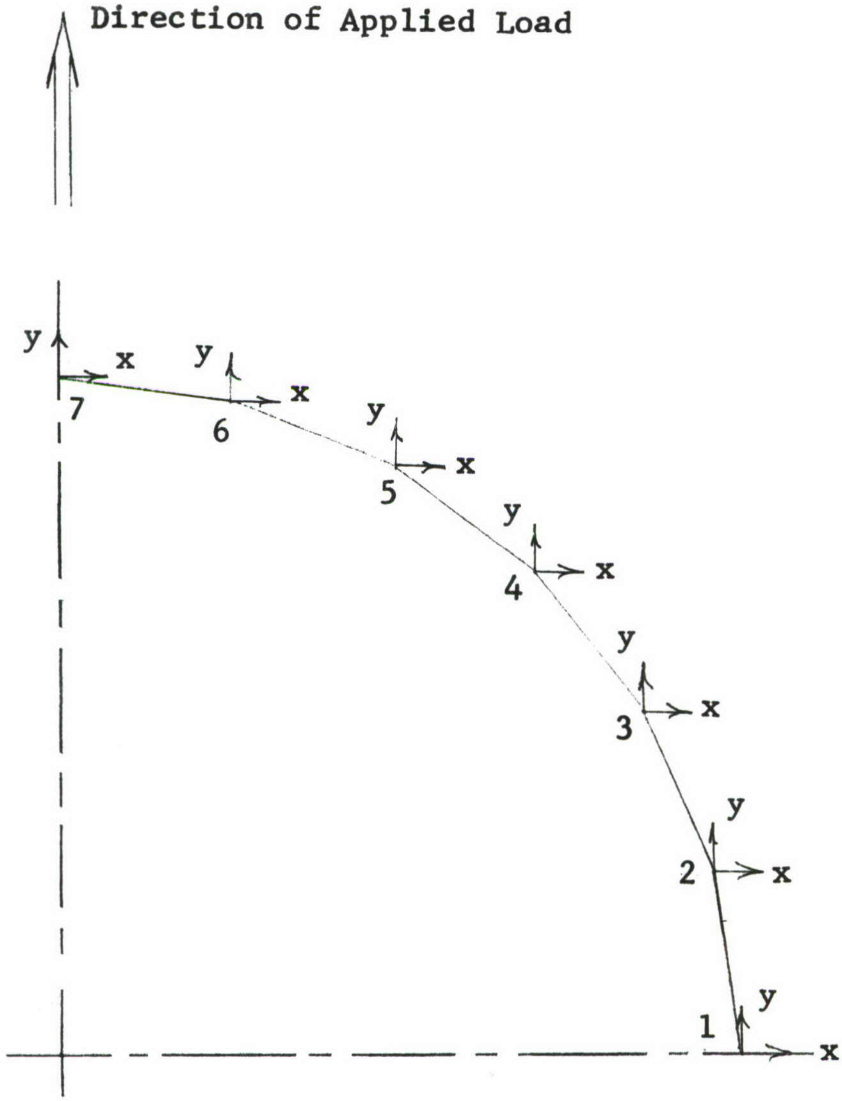


Figure IV-7 Nomenclature and Sign Convention for Nodal Deflections Adjacent to Hole

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A body of data has been generated and is presented. The data consists of stress and strain distributions in the vicinity of interference fit fasteners with and without uniaxial load applied. The resulting trends may be used as guide line information for designers in deciding whether or how to use interference fit fasteners on new aircraft structural systems. Analysis and test strains have been favorably compared in Section III for the case of interference fit without uniaxial load. These Section III results should increase the confidence level of the designer in using both the trends and levels predicted in the body of data.

The Section III results indicate that varying the numerical level of the plastic modulus of the material has a pronounced effect on the radial strains in that region of the material stressed beyond the yield point. (The terminology "plastic modulus" is used here to indicate the slope of that part of the uniaxial stress-strain curve which is beyond the yield zone.) Increasing the plate plastic modulus has the effect of stiffening that part of the plate which is strained beyond the elastic range. For a prescribed level of interference, the stiffened plate will be deformed less (than the unstiffened plate) and the bolt more with the changes in each being negligibly small. The radial deformations (u) and tangential strains (u/r) in the plate are thus essentially unchanged at the hole edge. Because the "plastic" portion of the structure is stiffened, the radial strains in that area are reduced which, in turn, increases the radial and tangential strains in the elastic portion. The values of plastic modulus used to produce the results presented in this report are representative of the specified materials; however, plastic modulus values can vary widely for different members of the same family of materials.

For all analysis conditions, two fastener hole sizes were used; 1/4 and 3/8 inch diameter. However, the bolt insertion length was adjusted so that if the bolt had been rigid and all the work due to insertion had deformed the plate, the plate tangential strains at the hole edge would have been 0.010 and 0.020 inch per inch for the two interference levels used regardless of the hole size. The resulting stresses and strains in the plates for the same conditions, except differing hole sizes, are essentially the same. These results show that the hole diameter may be varied within any practical range for the joint without changing the stresses or strains if the insertion is adjusted accordingly.

For all the analysis reported herein, the bolt was replaced with a ring which had equivalent elastic spring stiffness. The ring was then pressurized to produce the interference effect. For interference fit only, the pressure inside the plate hole would have been sufficient since this is what the plate "feels" from the bolt. However, under the effects of uniaxial load, the ring stiffness is required inside the hole because the pressure exerted by the bolt varies around the circumference as the hole changes to an elliptical shape.

To calculate the equivalent ring stiffness, the bolt was assumed to be in plain strain. This produced a ring which was slightly too stiff. A plain stress assumption could have been made for the bolt but this would have produced a ring too flexible because the bolt is in a three dimensional state of stress which is neither plain strain nor plain stress but is in between. In using the slightly too stiff ring, the plate always absorbed a slightly larger percentage of the total interference than the test results indicated (documented in Section III). This means that the analysis used more "effective" insertion and is the primary reason for including the hole deflections in this report (Tables IV-2, IV-3 and IV-4). It also means that for the plate under uniaxial load, the analysis should predict a plate hole slightly more "rounded" than tests would predict.

Three recommendations are made. For any future analyses, the ring stiffness should be adjusted slightly downward by tempering with test results and/or first performing a three dimensional analysis of the bolt to determine its radial stiffness under pressure. Two dimensional analyses of interference fit fasteners should be performed to determine edge effects and effects of transferring load through the fastener. This latter is actually a three dimensional problem but a large number of three dimensional conditions would be prohibitively expensive. The two dimensional analysis is relatively cost effective and would produce good approximations for thin gage materials.

APPENDIX I

ALUMINUM PLATE RESULTS

This appendix presents the results of the finite element analysis for the aluminum plate with the steel bolt inserted. The results consist of stresses and strains in the vicinity of interference fit fasteners. The analysis conditions are discussed in Section IV and Figures IV-3 and IV-4 illustrate the regions of the plates for which results are presented.

The figures are presented in pairs. The first consists of a numerical level of stress or strain superimposed on each finite element. The second consists of isolines or contours representing constant levels of stress or strain. Results are presented in the same sequence as the analysis conditions A1 through A12, defined in Table IV-1. Radial and tangential stresses and strains are presented for each condition. For those cases where no uniaxial load is applied, these stresses are the principal stresses, hence, no other data is presented. For those cases where uniaxial load is applied, radial-tangential shear strains are presented plus other stresses consisting of radial-tangential shear stress, and the three principal stresses; first, second and shear. The figures are otherwise self-explanatory.

Note: The numbers printed for stress and strain have been truncated back (as opposed to rounded off). The printed stresses are in units of 1000 pounds/inch squared; the printed strains are in units of 0.001 inches/inch. The numbers should be interpreted as being representative of the level at the element center. Negative stresses and strains are compressive, positive stresses and strains are tensile.

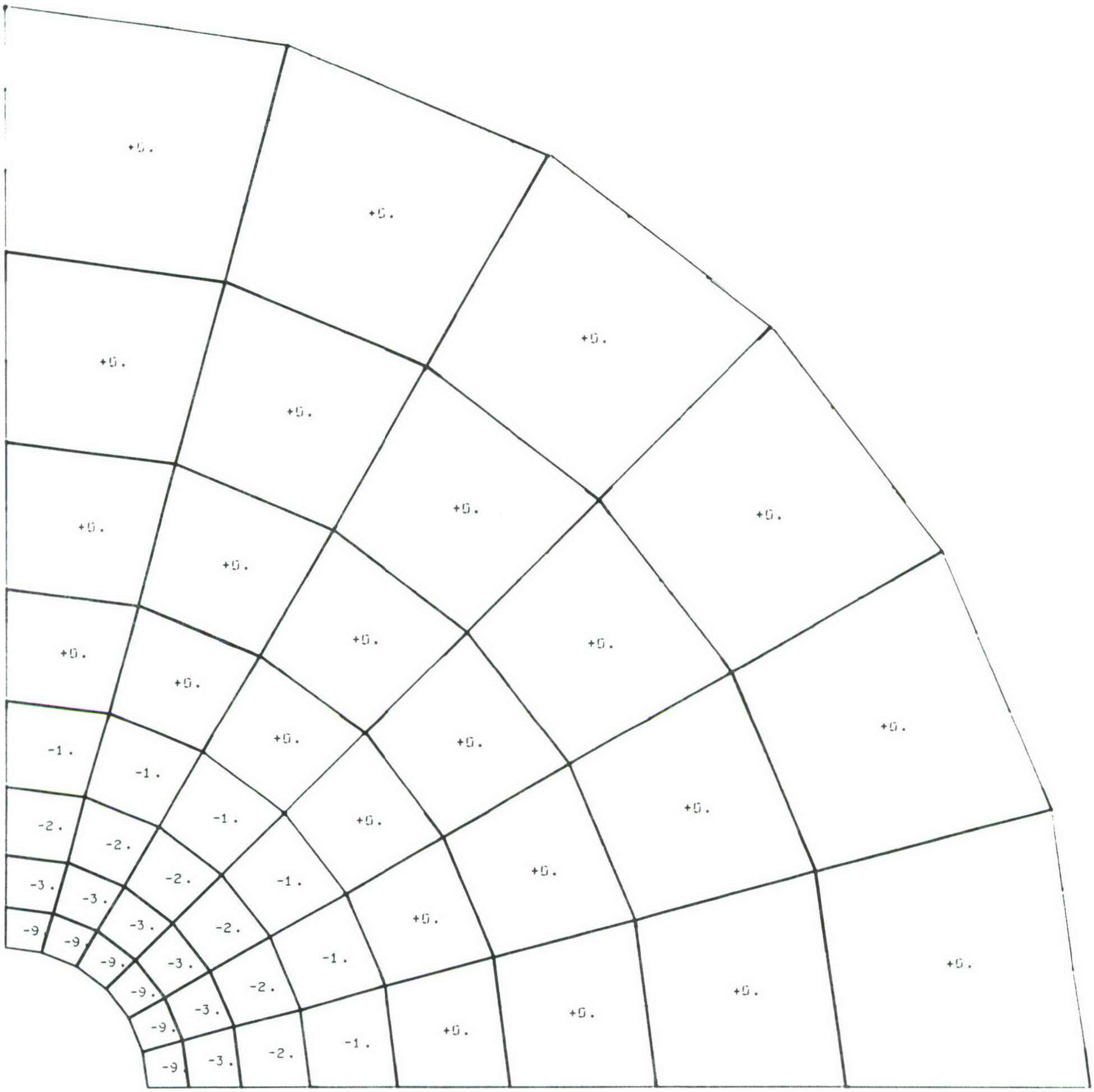


Figure AI-1 Radial Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

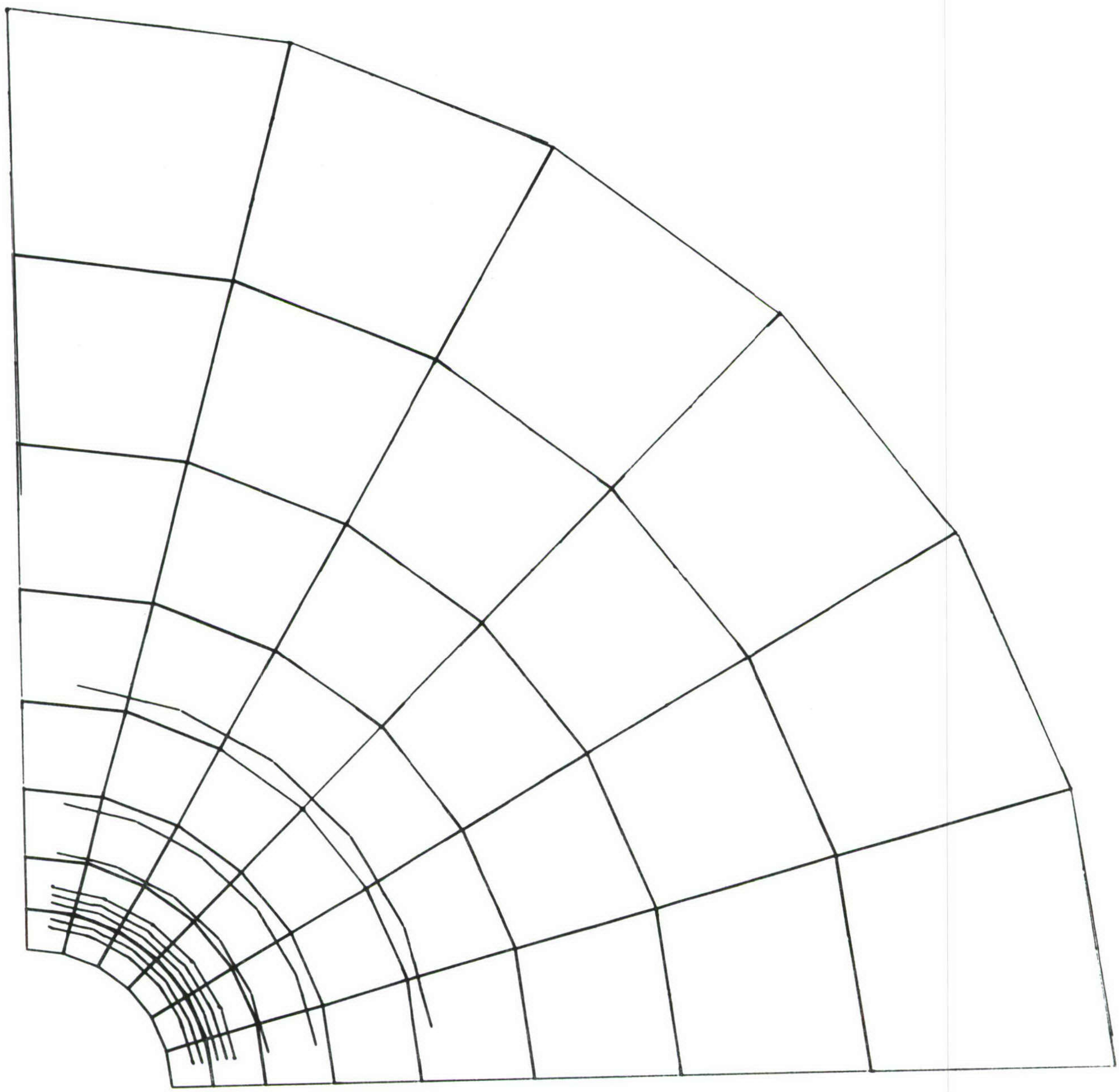


Figure AI-2 Radial Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

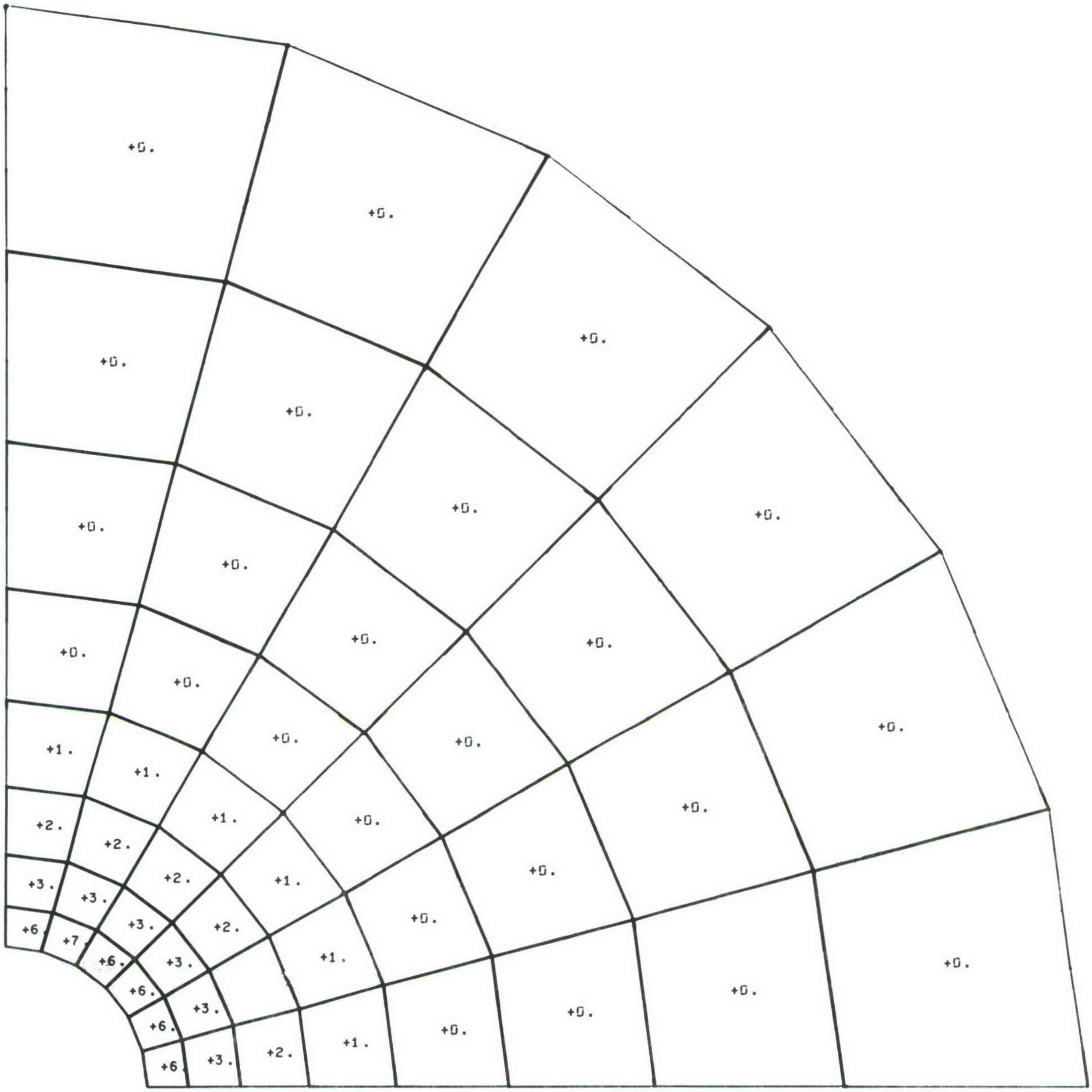


Figure AI-3 Tangential Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

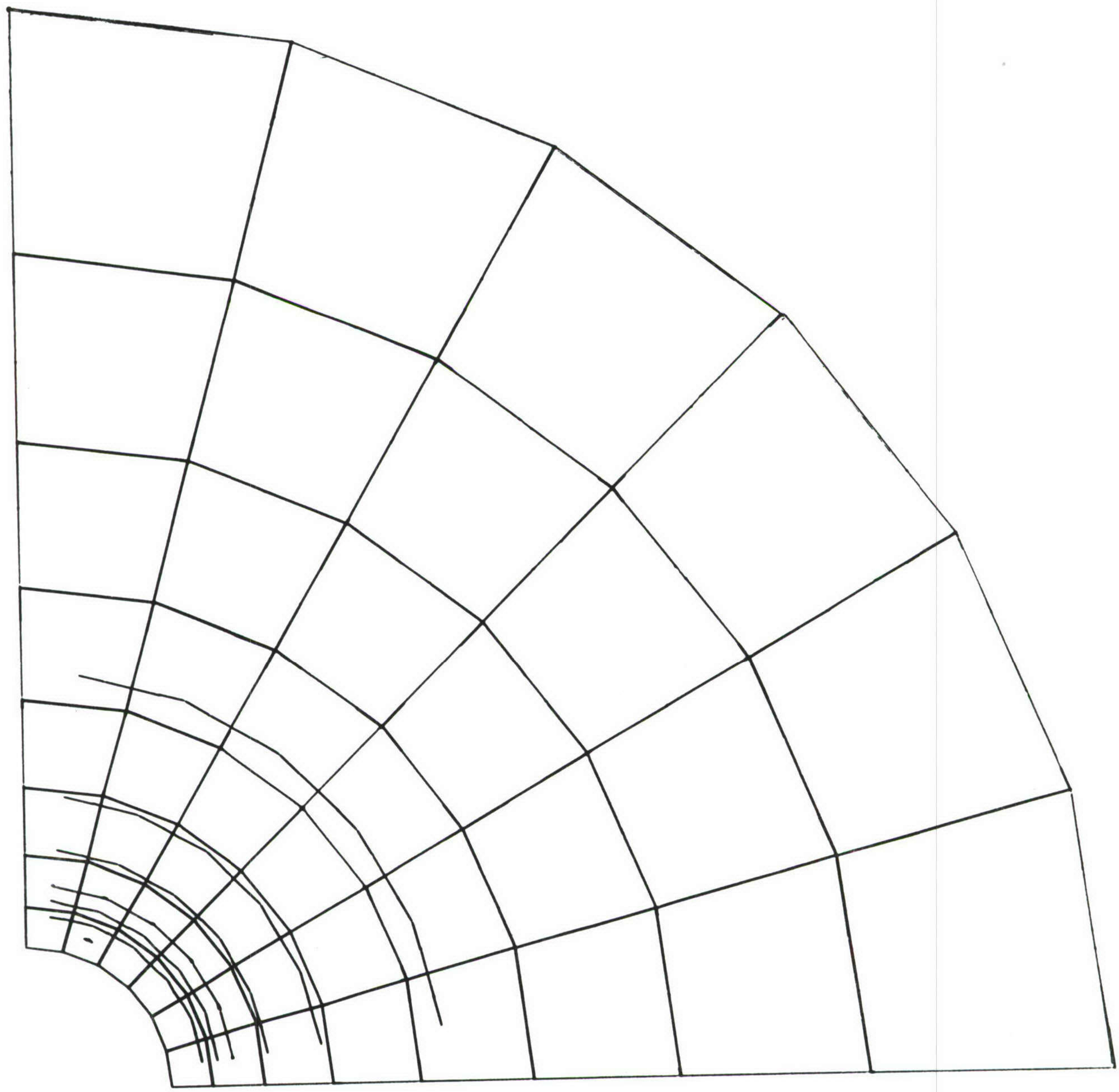


Figure AI-4 Tangential Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

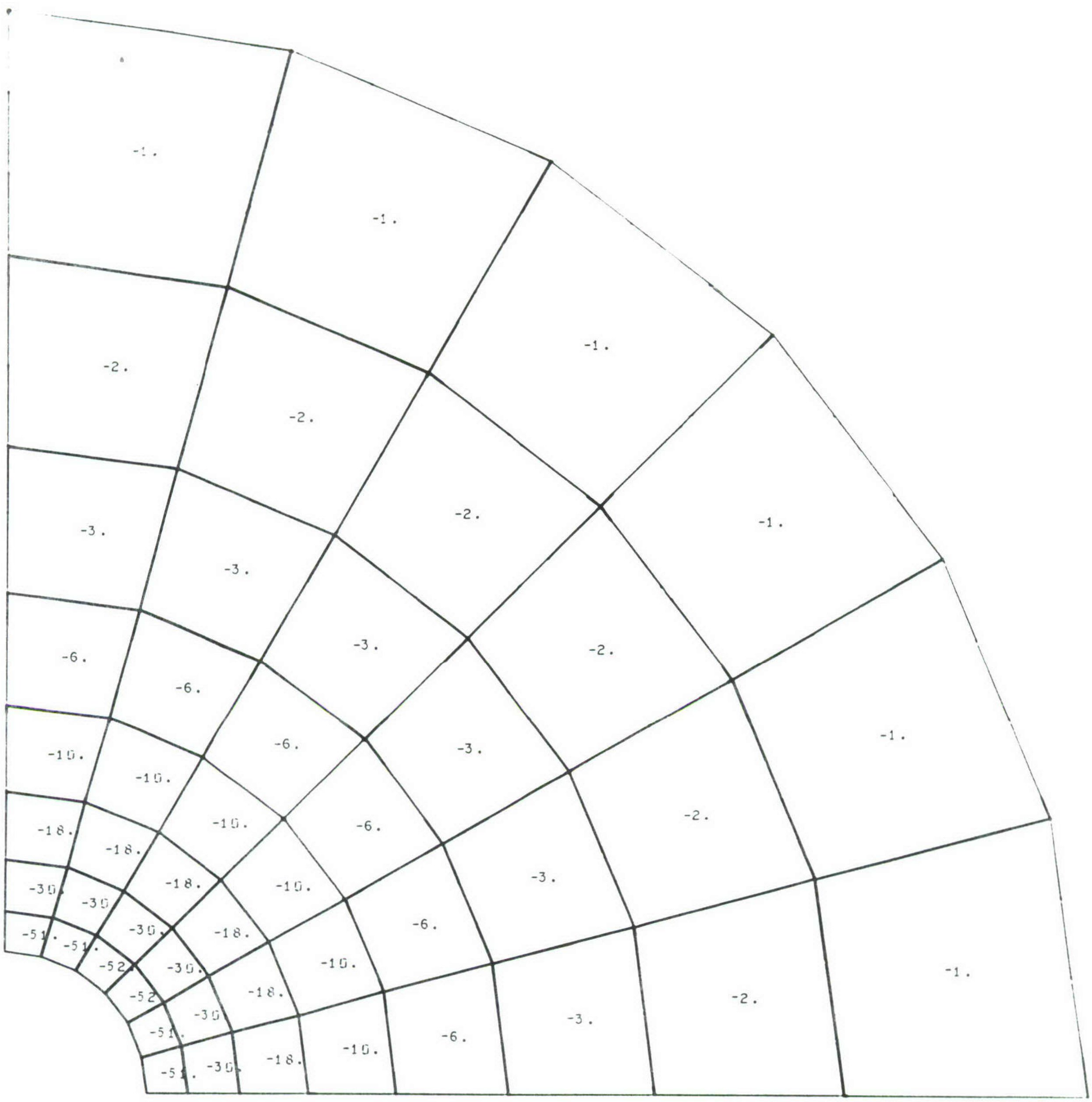


Figure AI-5 Radial Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load

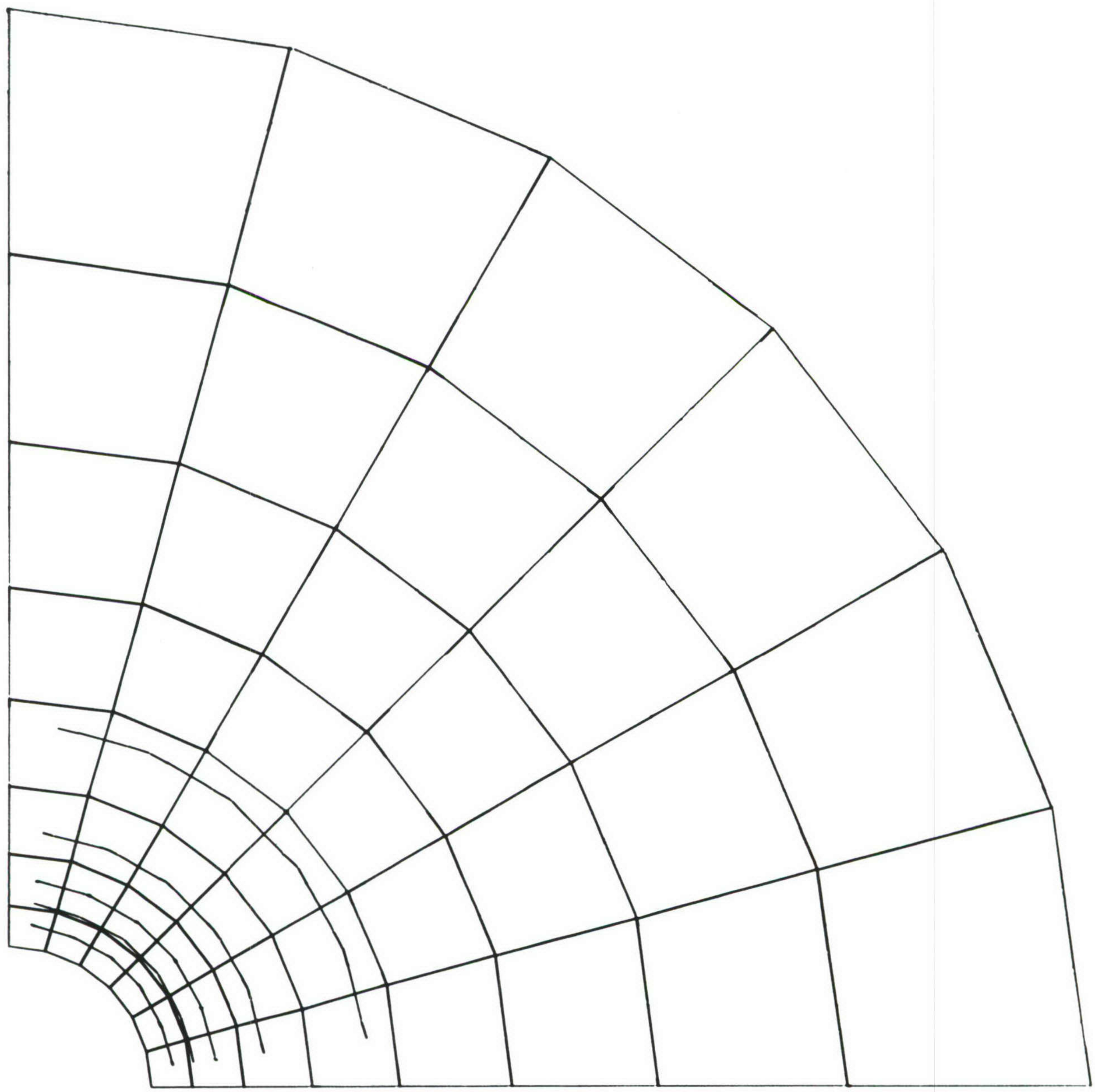


Figure AI-6 Radial Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load

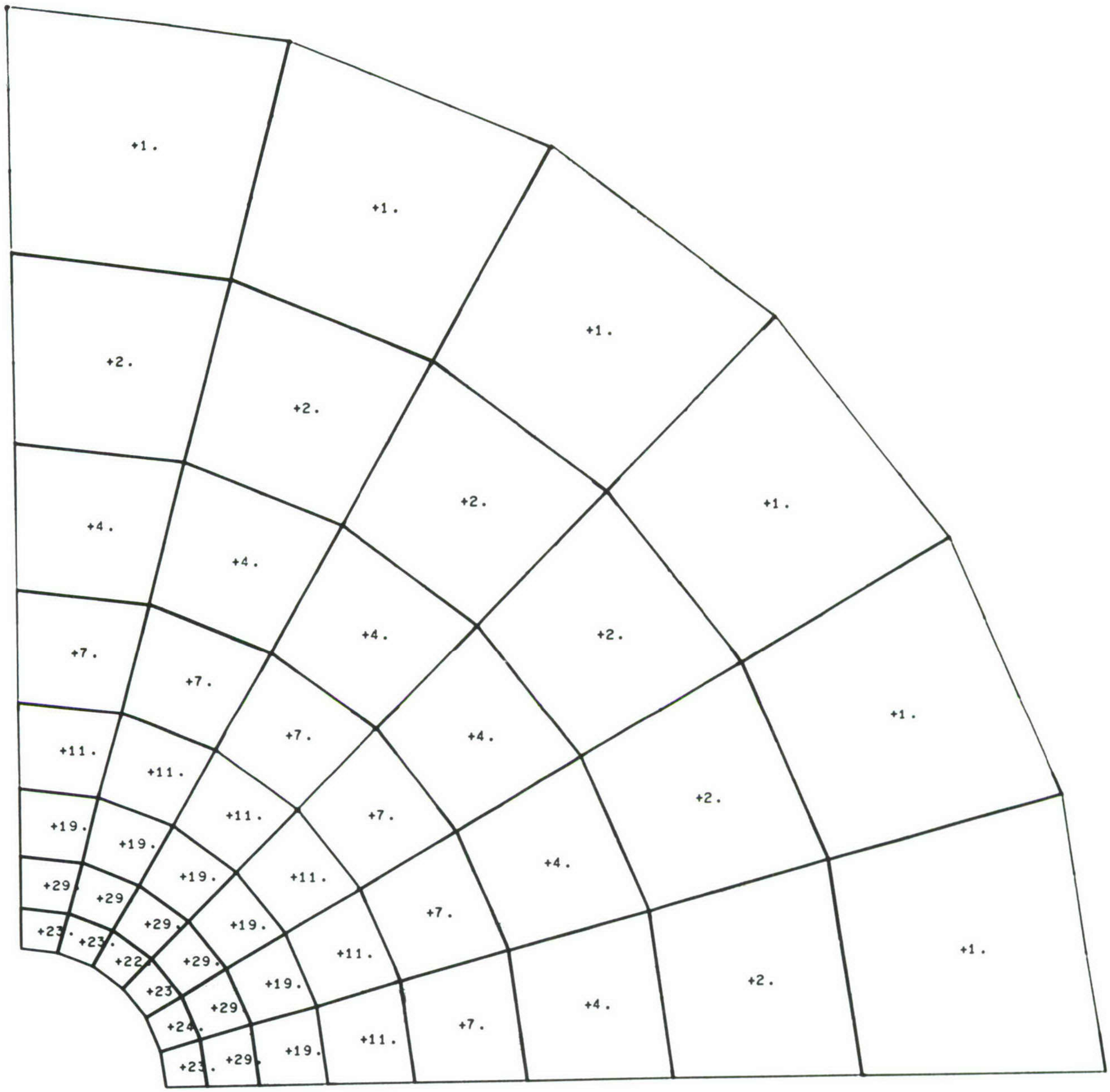


Figure AI-7 **Tangential Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load**

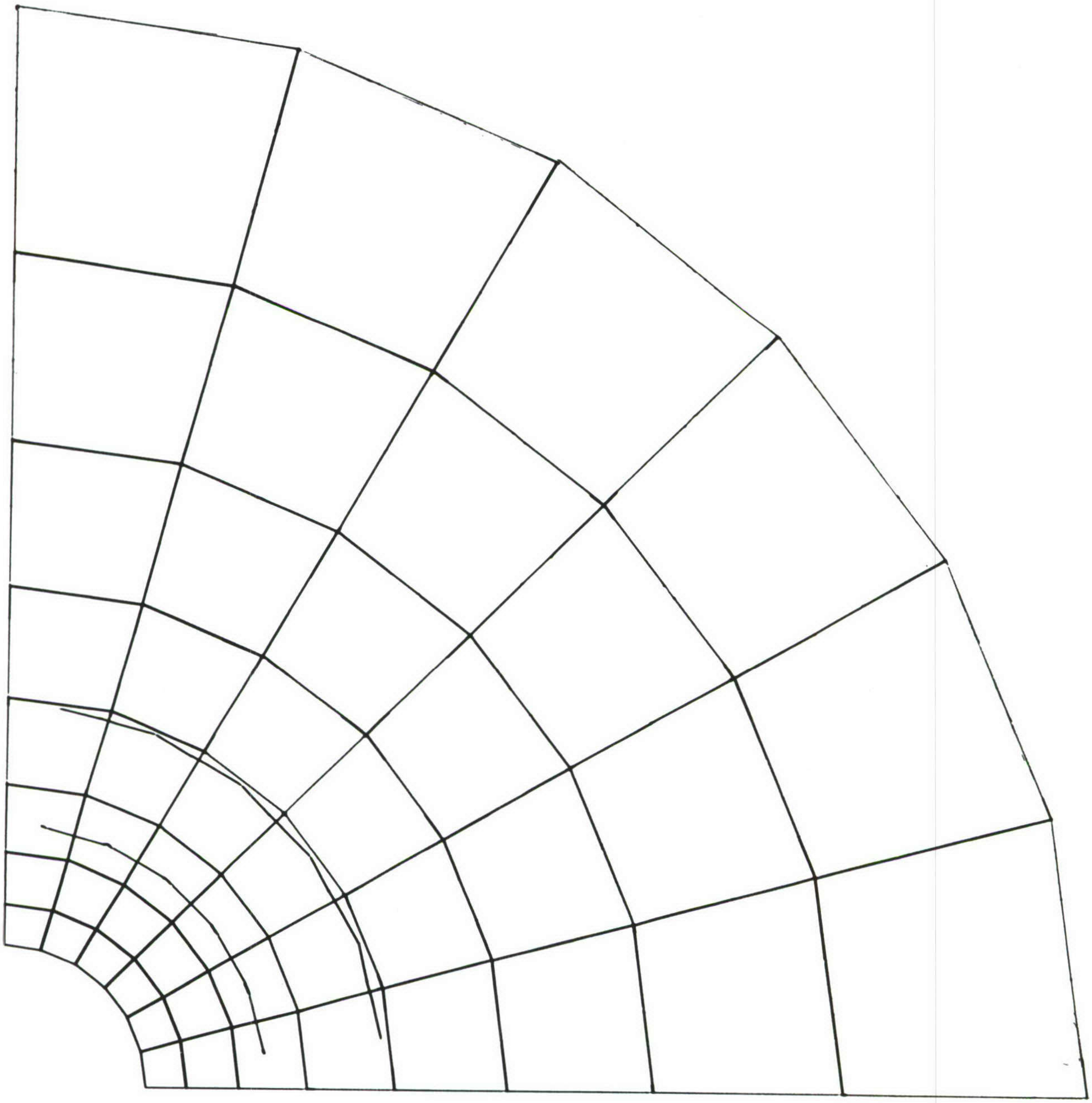


Figure AI-8 Tangential Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load

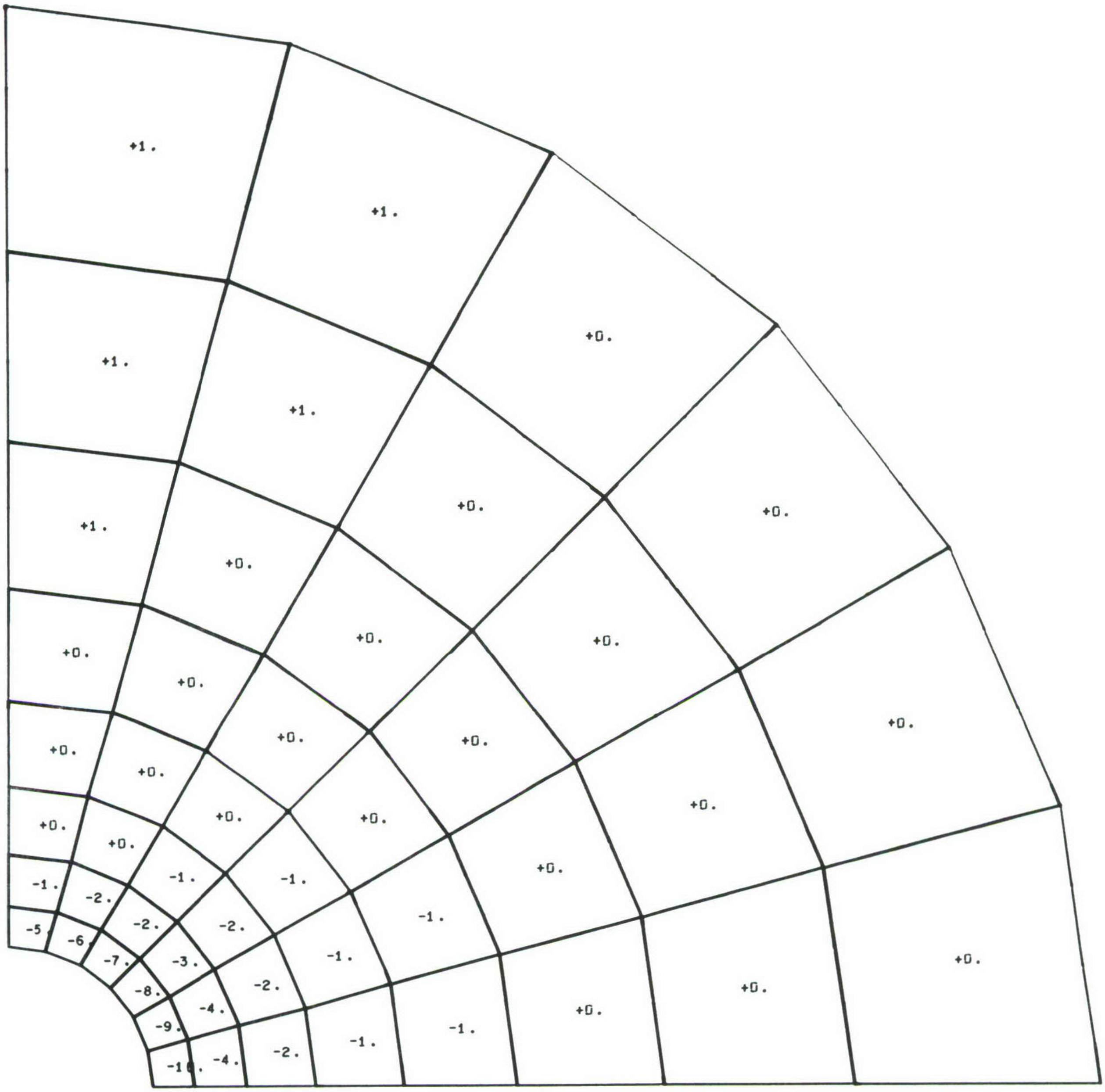


Figure AI-9 Radial Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

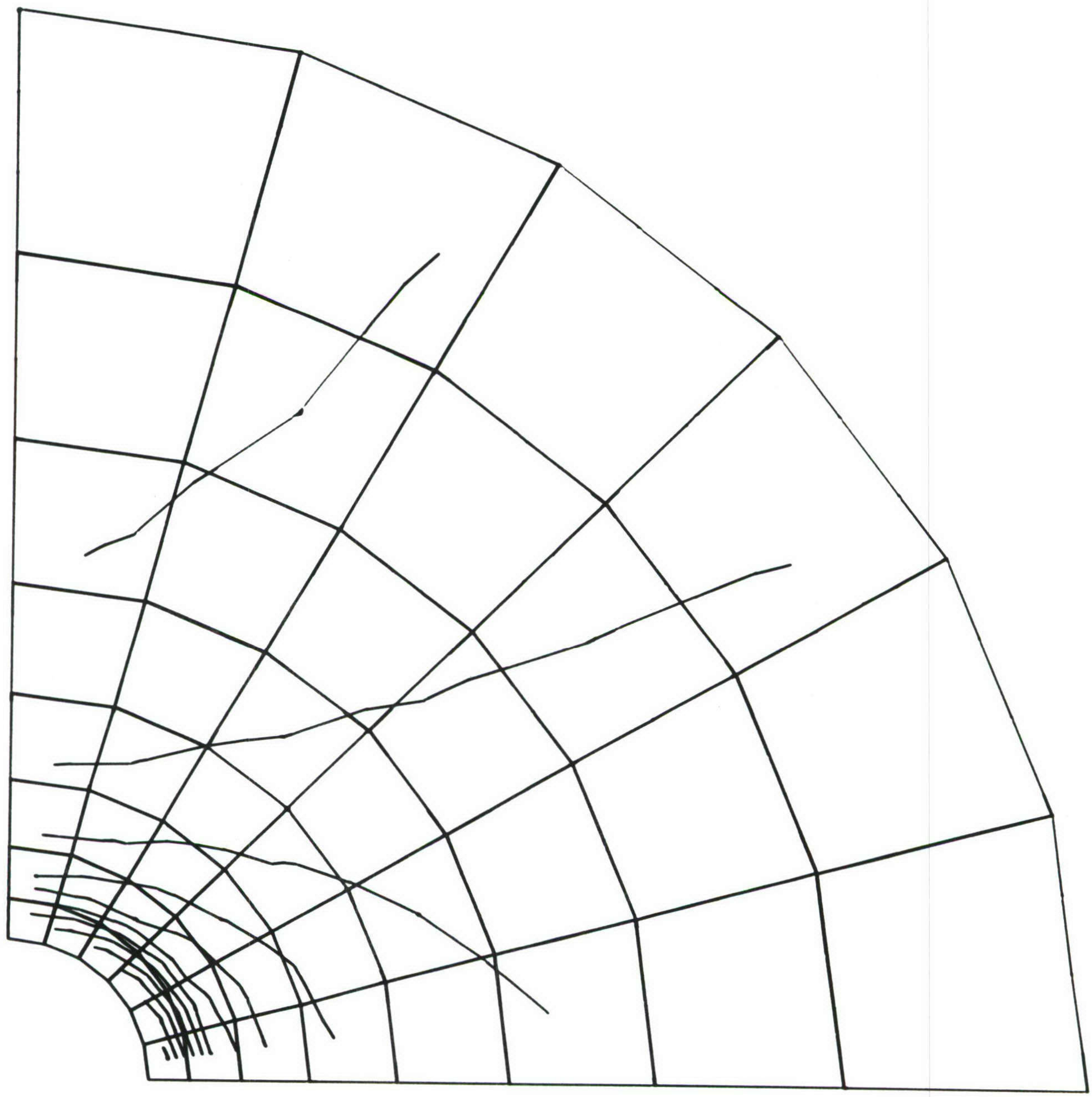


Figure AI-10 Radial Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference, 35% Uniaxial Load

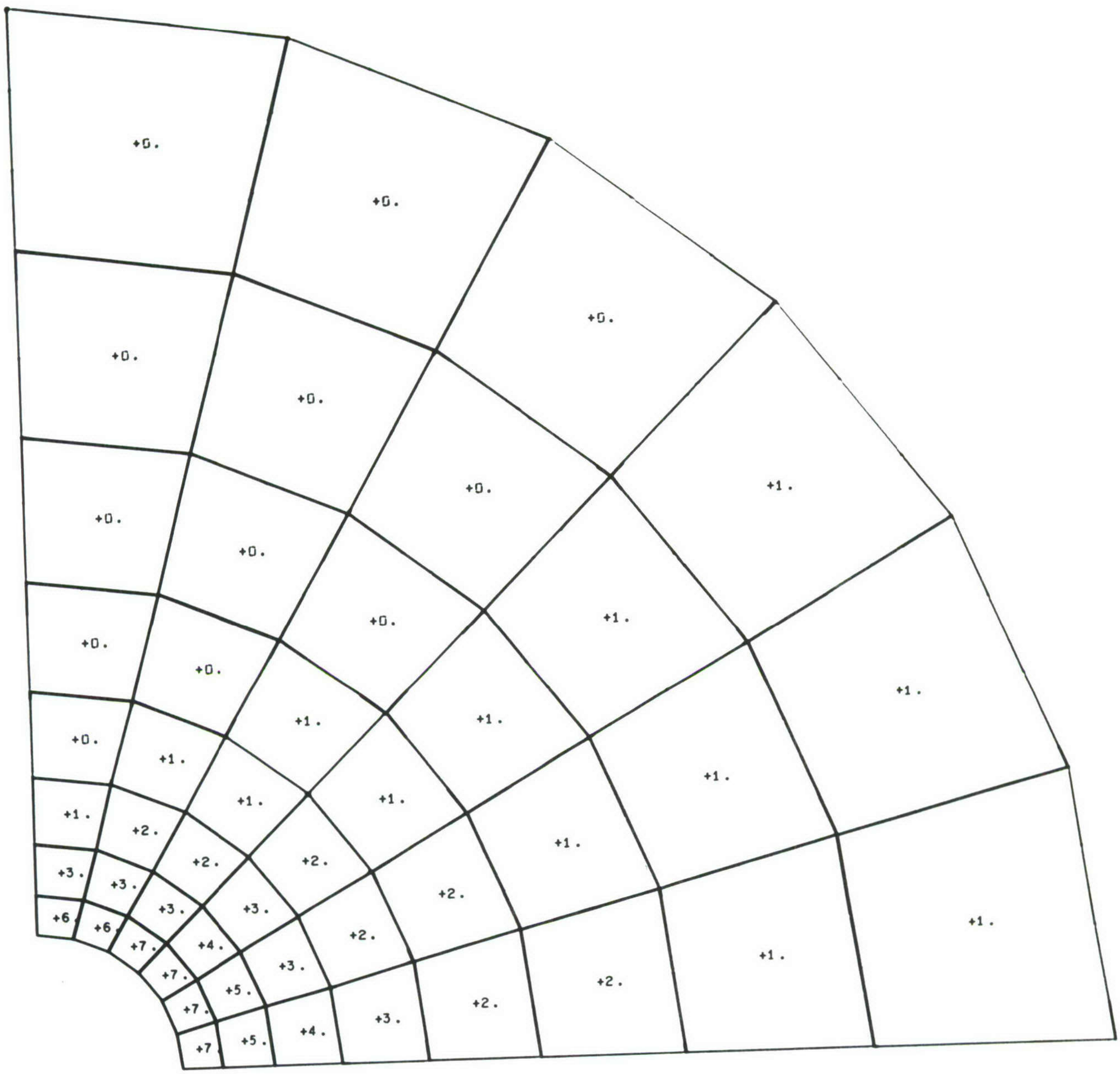


Figure AI-11 Tangential Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

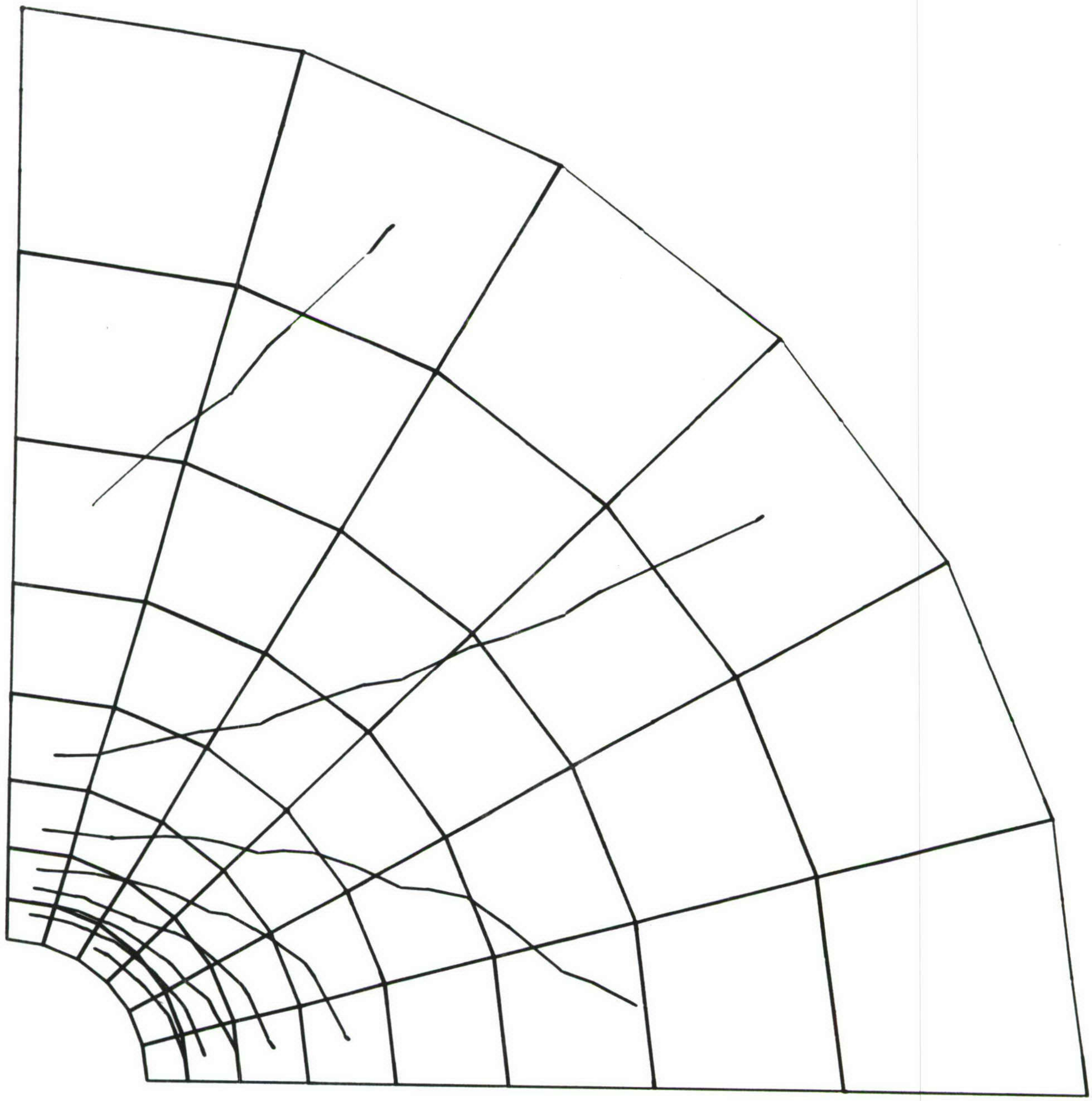


Figure AI-12 Tangential Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

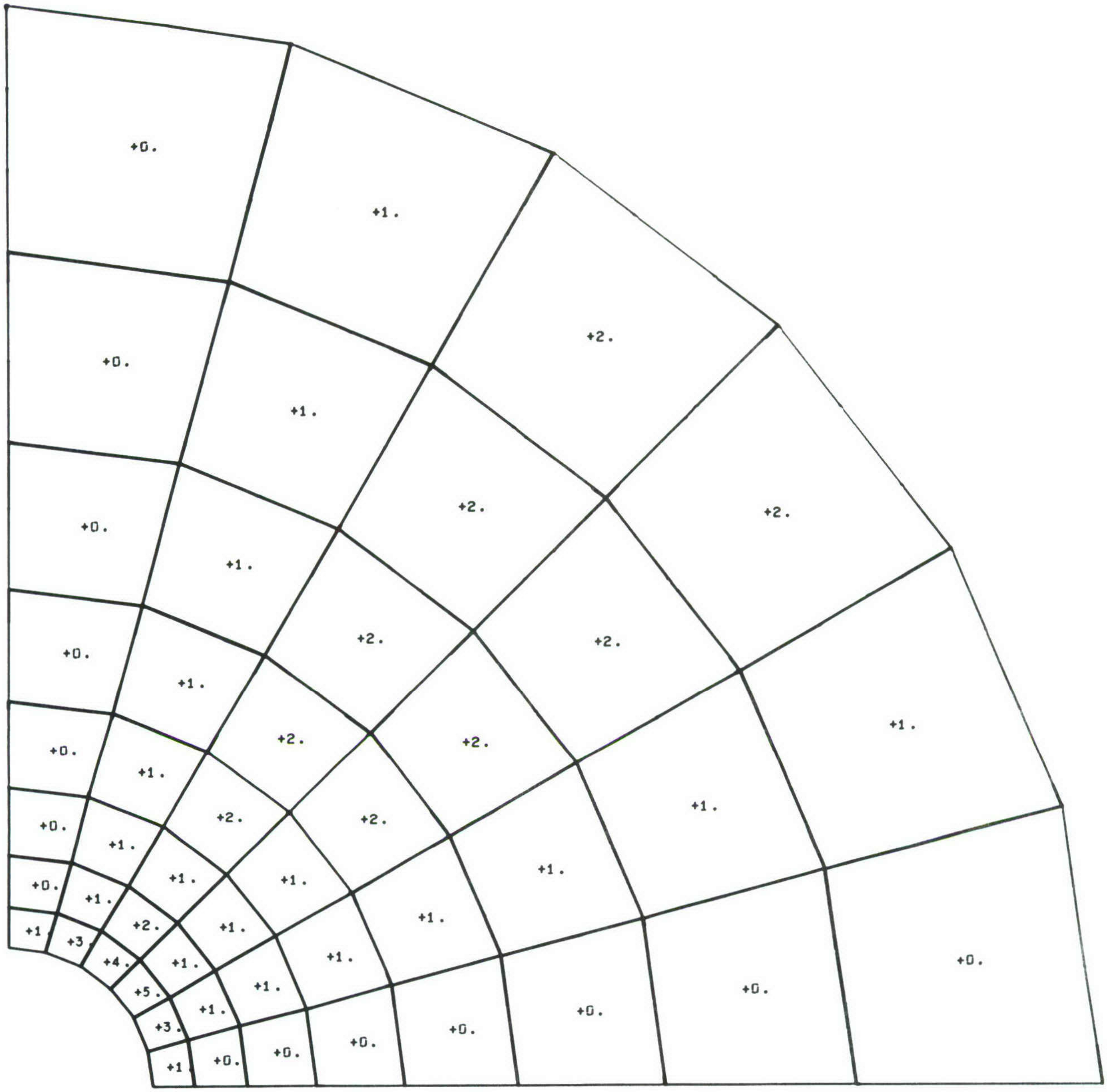


Figure AI-13 Radial-Tangential Shear Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

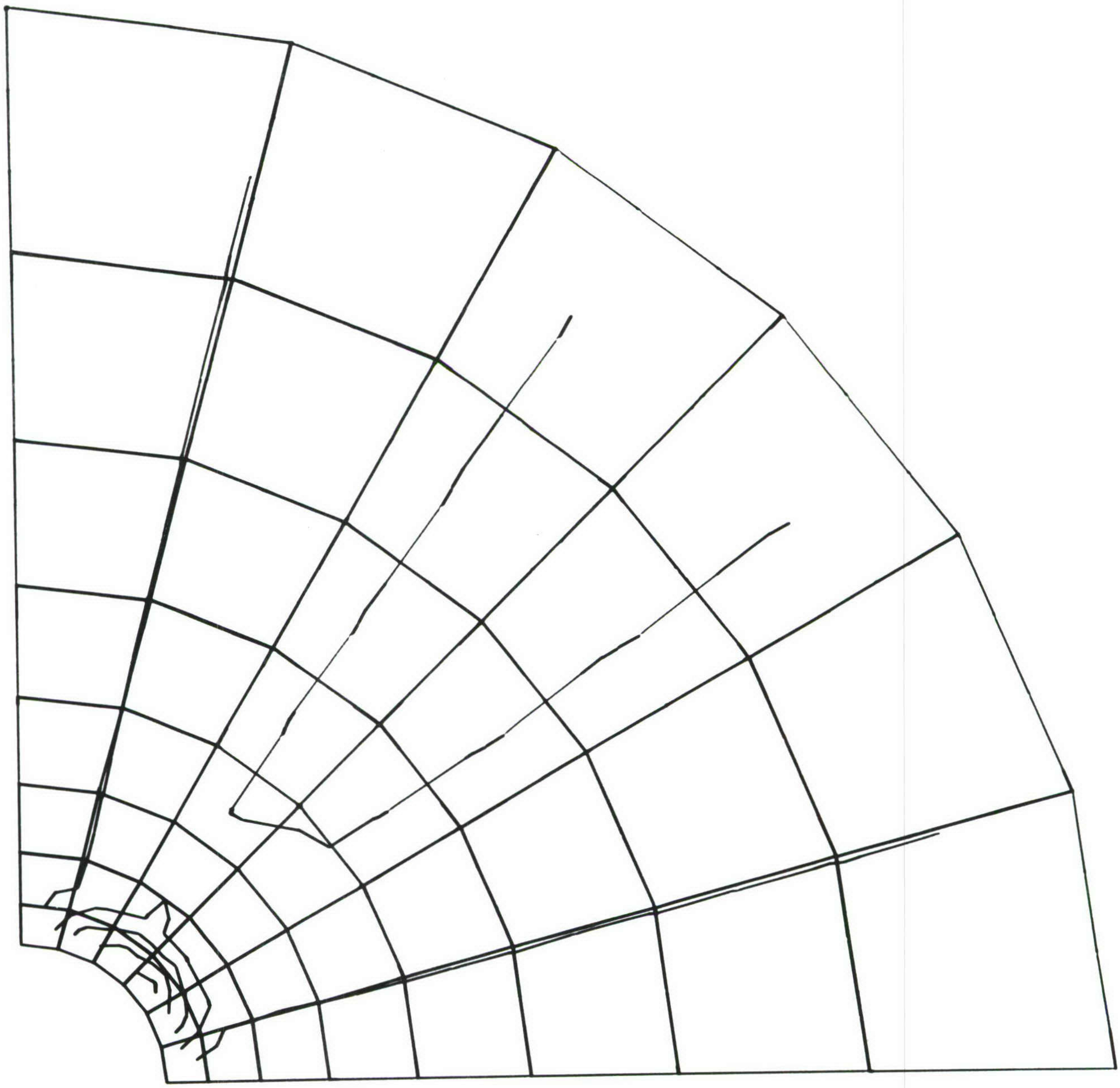


Figure AI-14 Radial-Tangential Shear Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

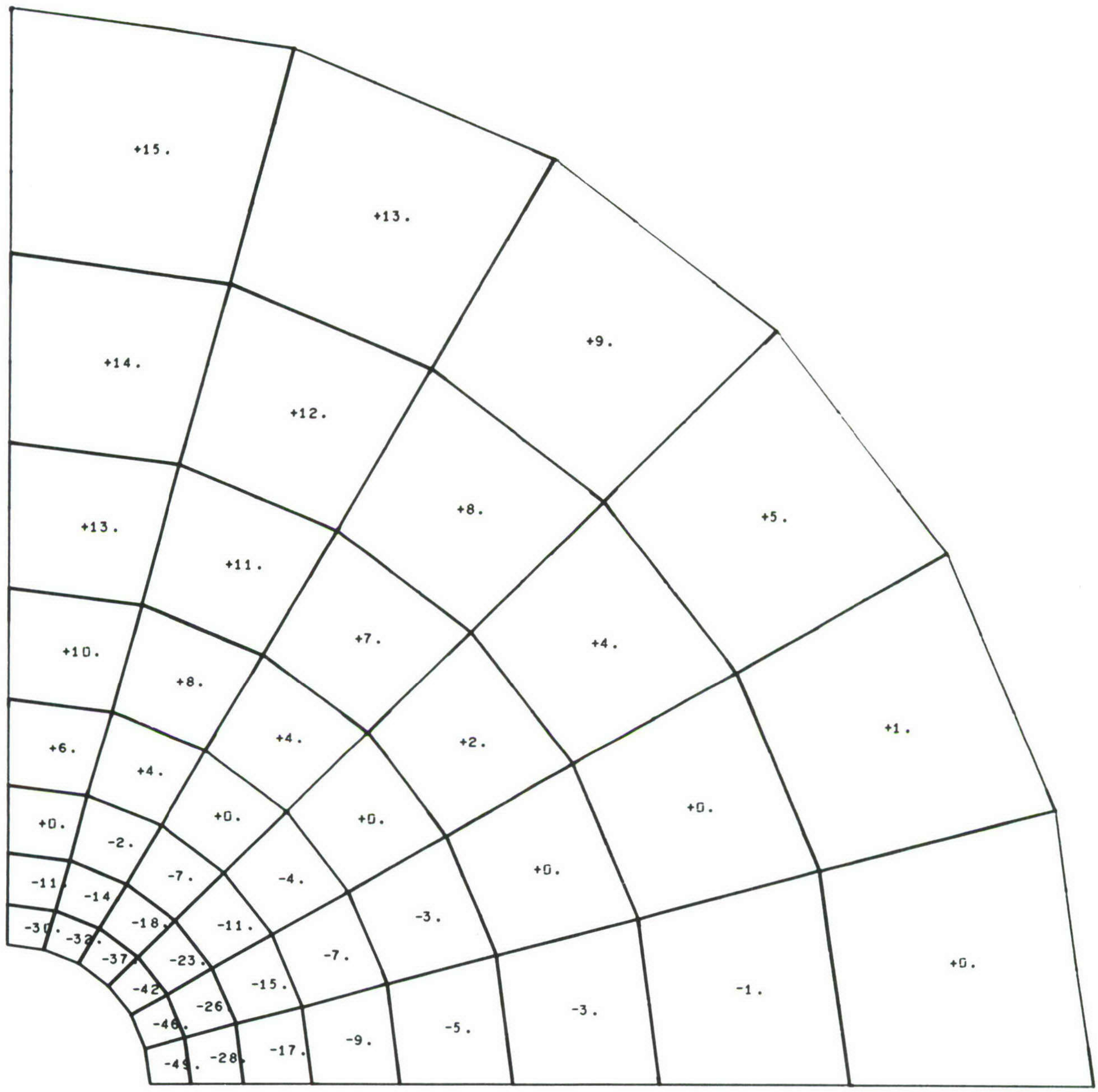


Figure AI-15 Radial Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

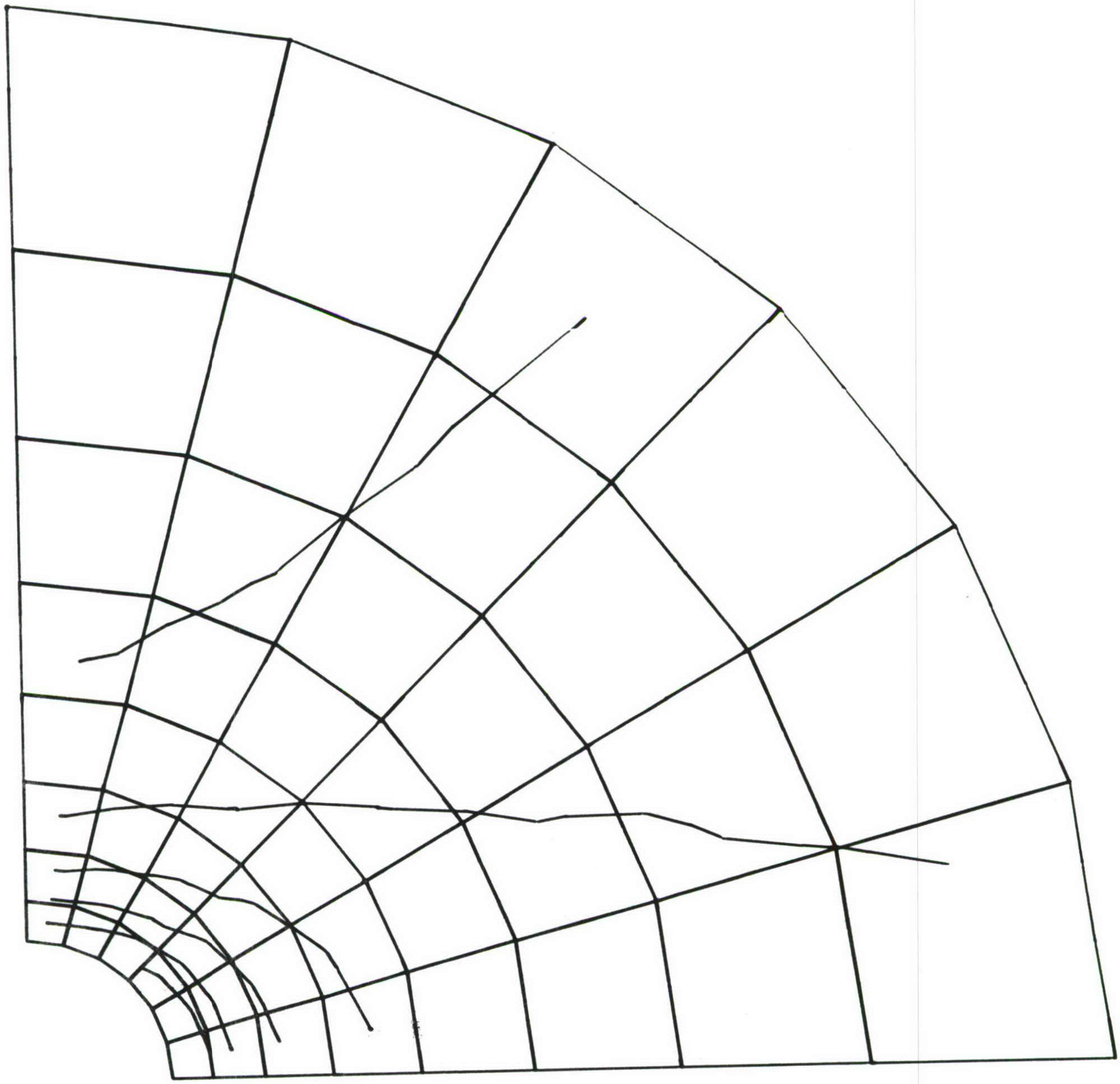


Figure AI-16 Radial Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

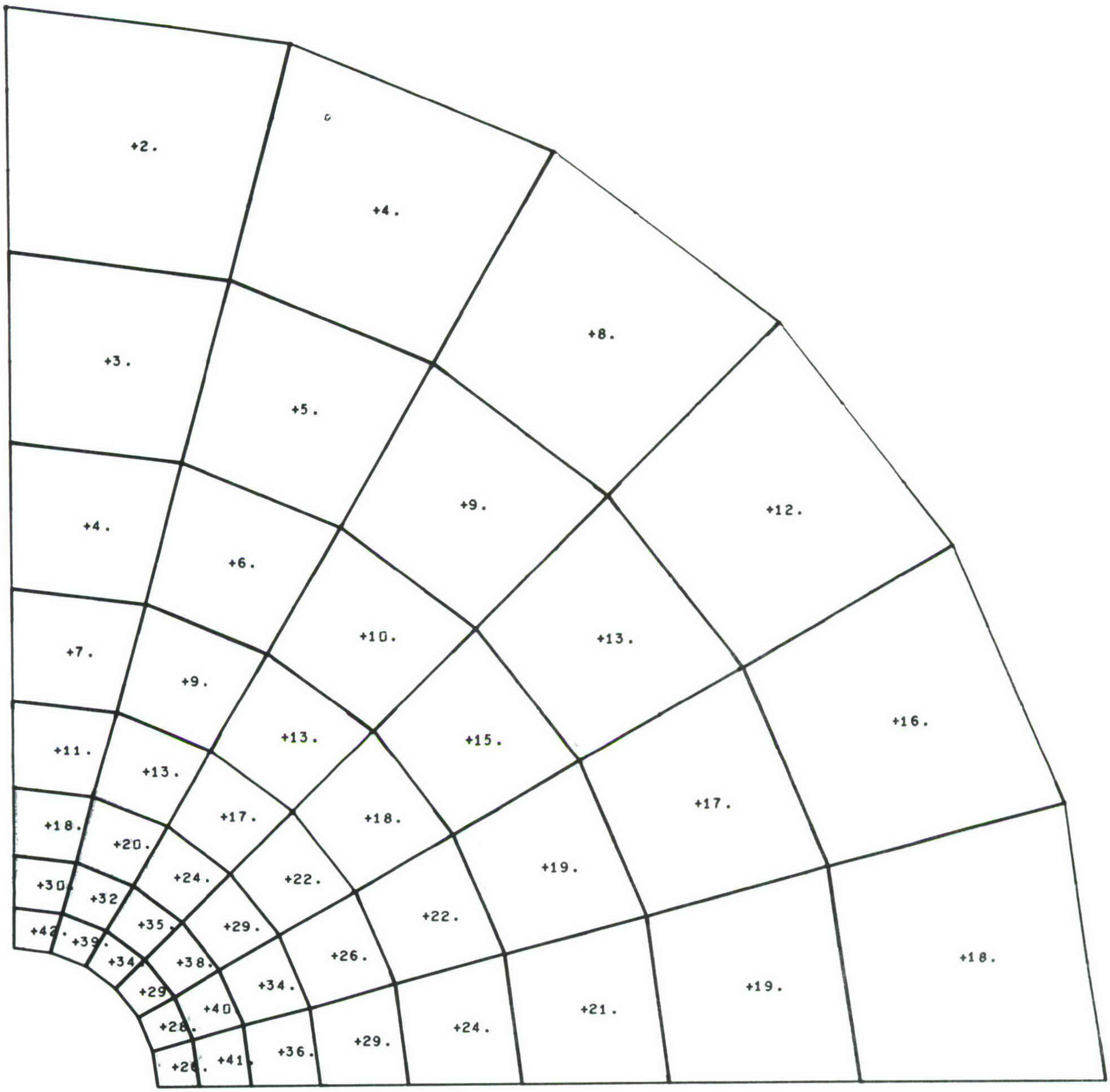


Figure AI-17 Tangential Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

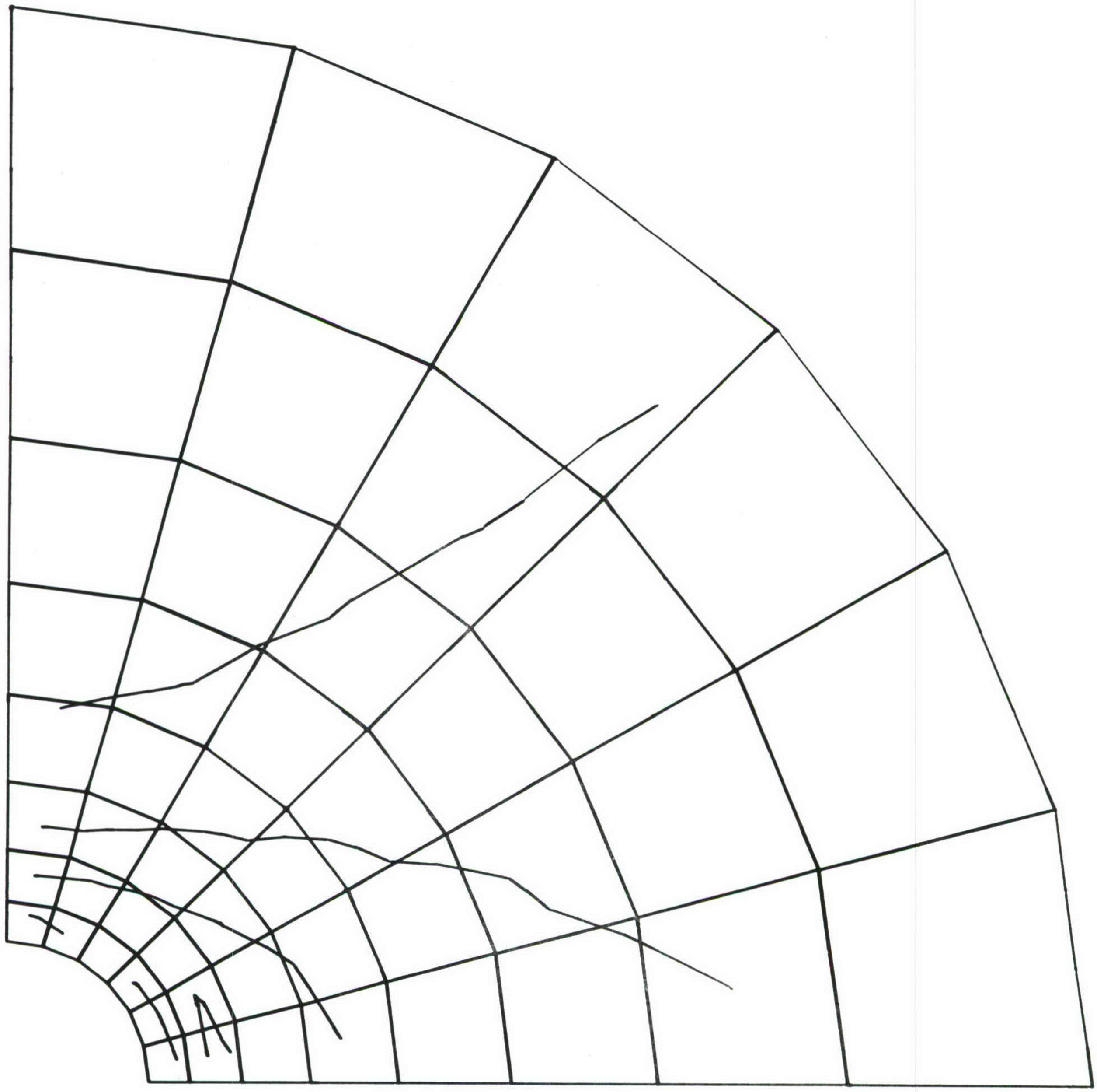


Figure AI-18 Tangential Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

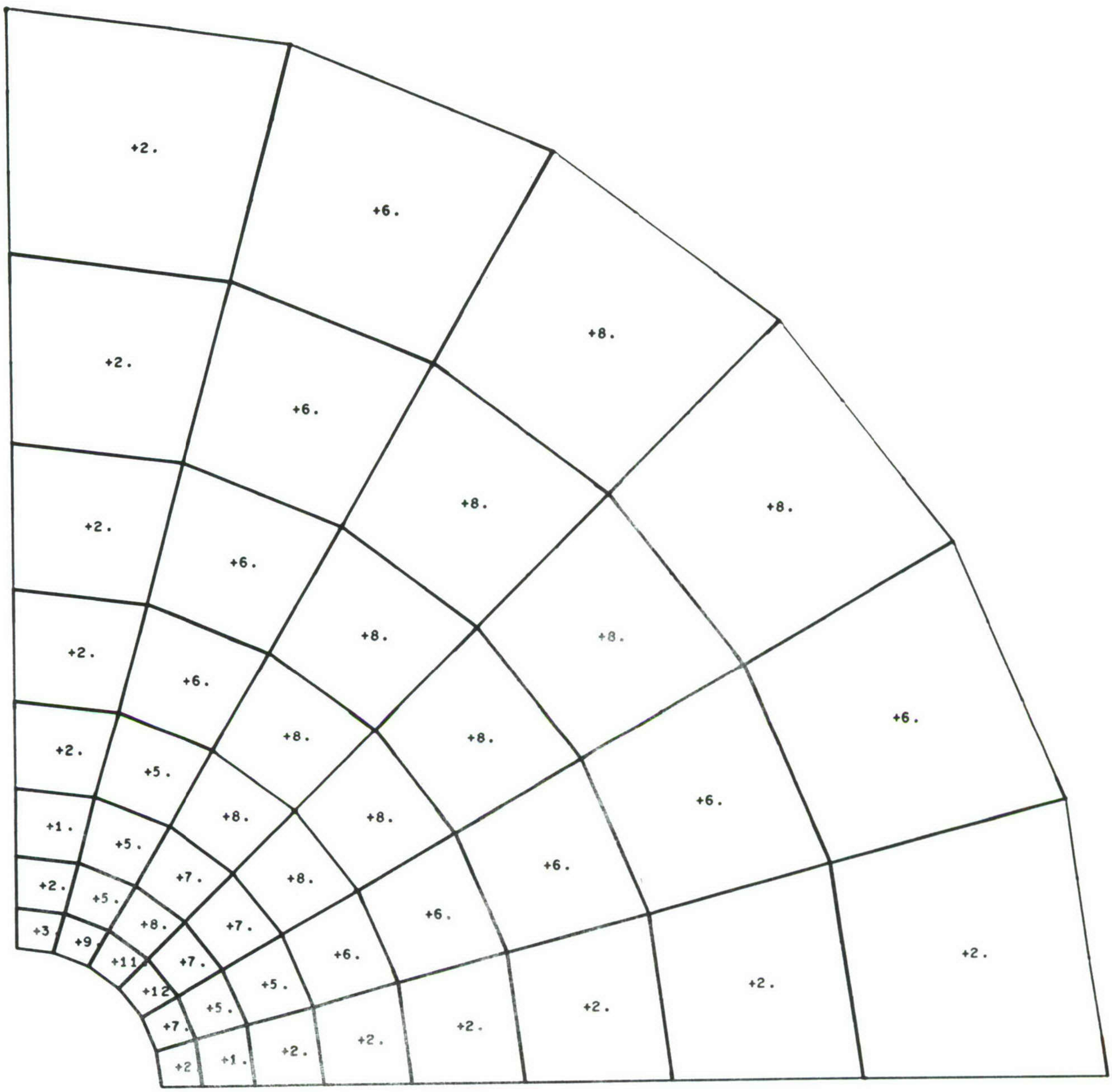


Figure AI-19 Radial-Tangential Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

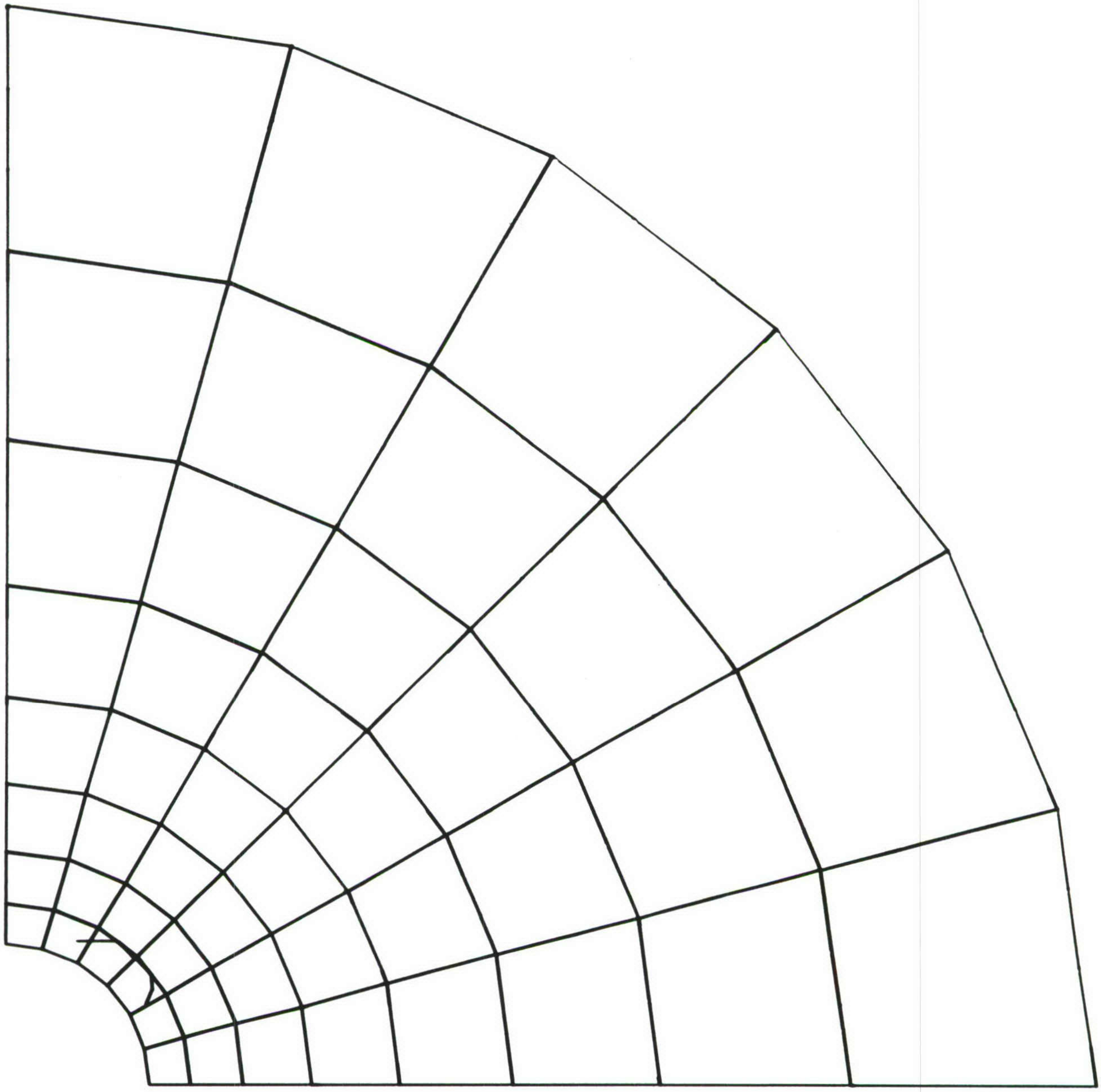


Figure AI-20 Radial-Tangential Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

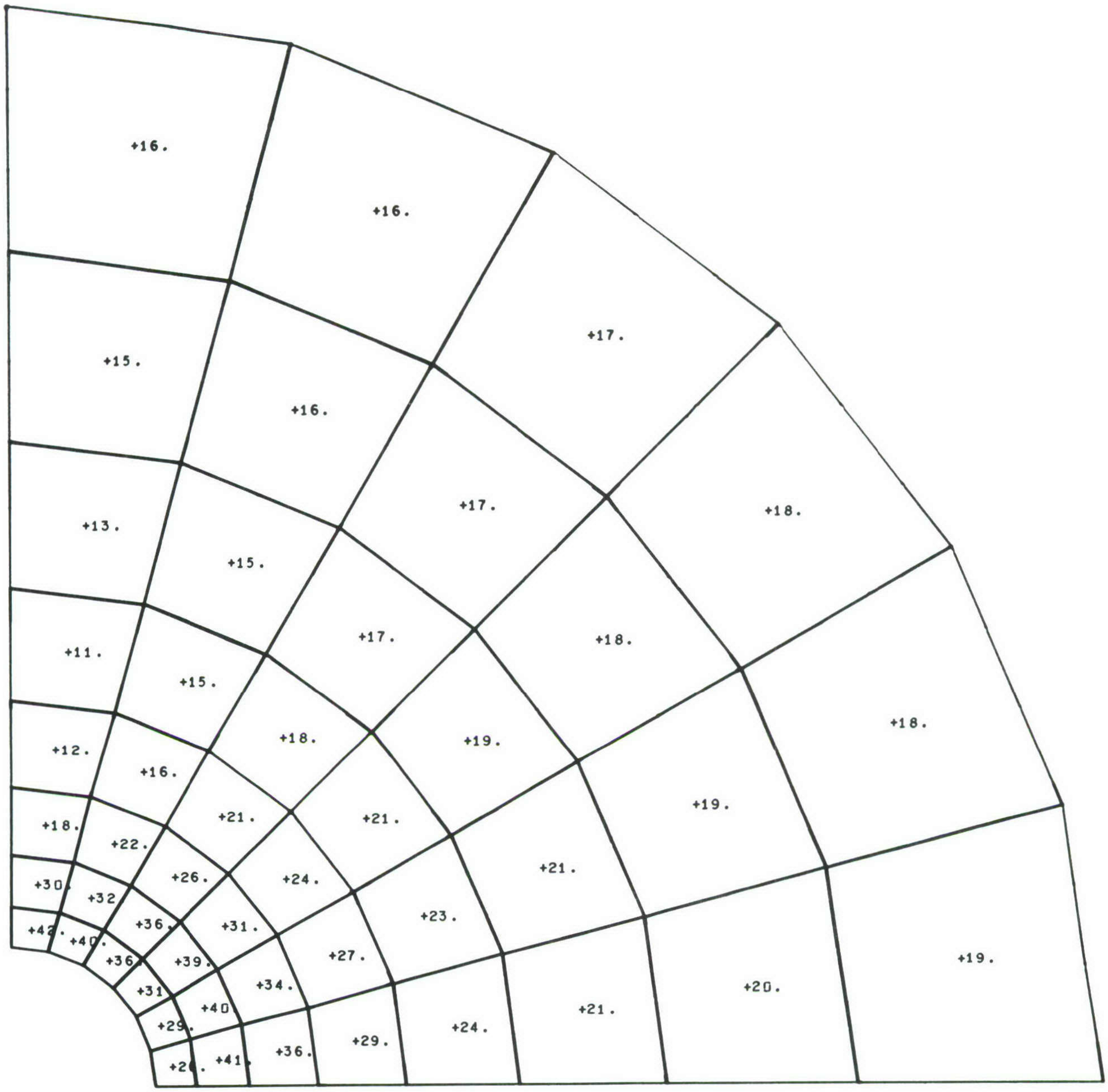


Figure AI-21 First Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

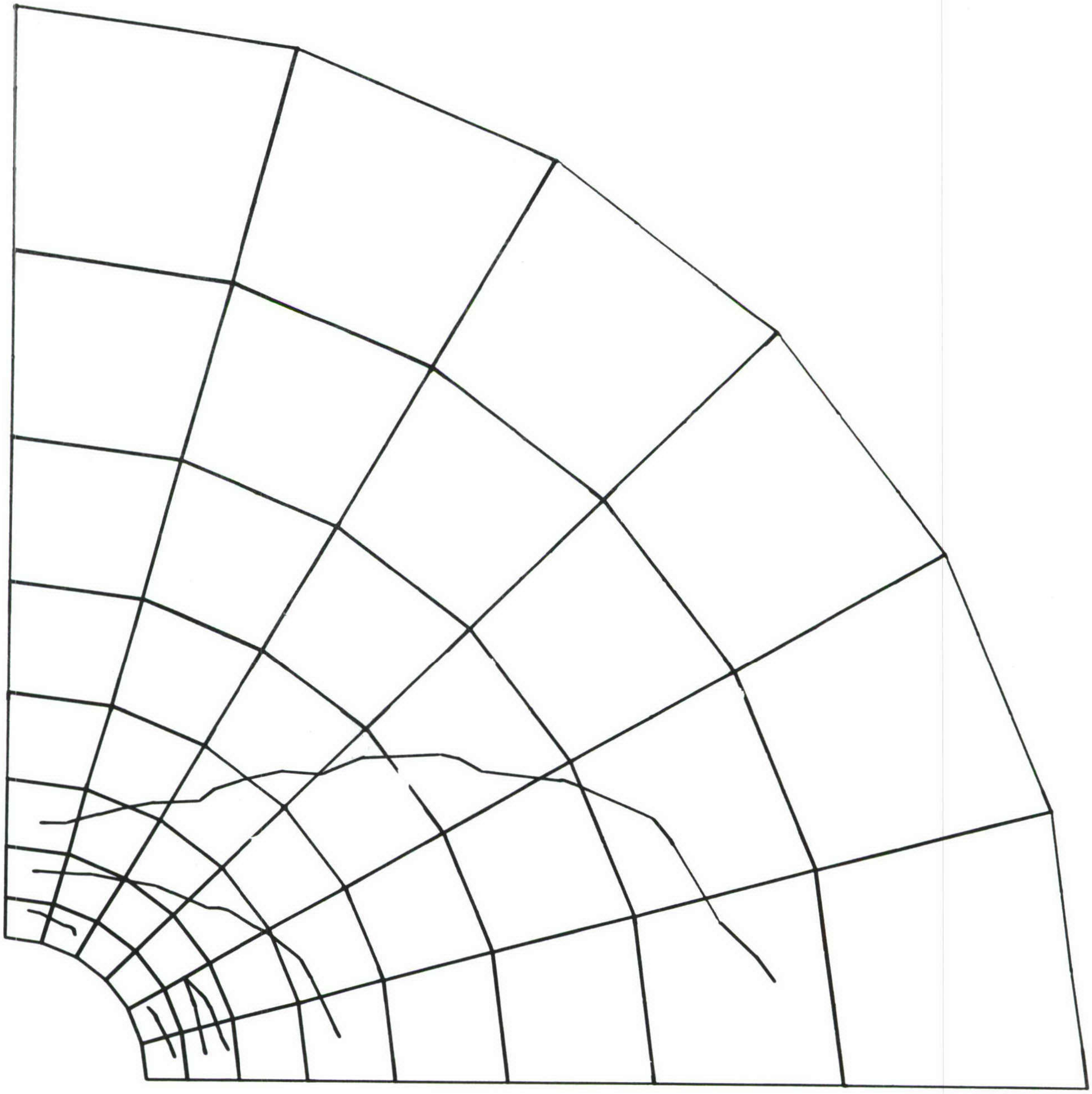


Figure AI-22 First Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

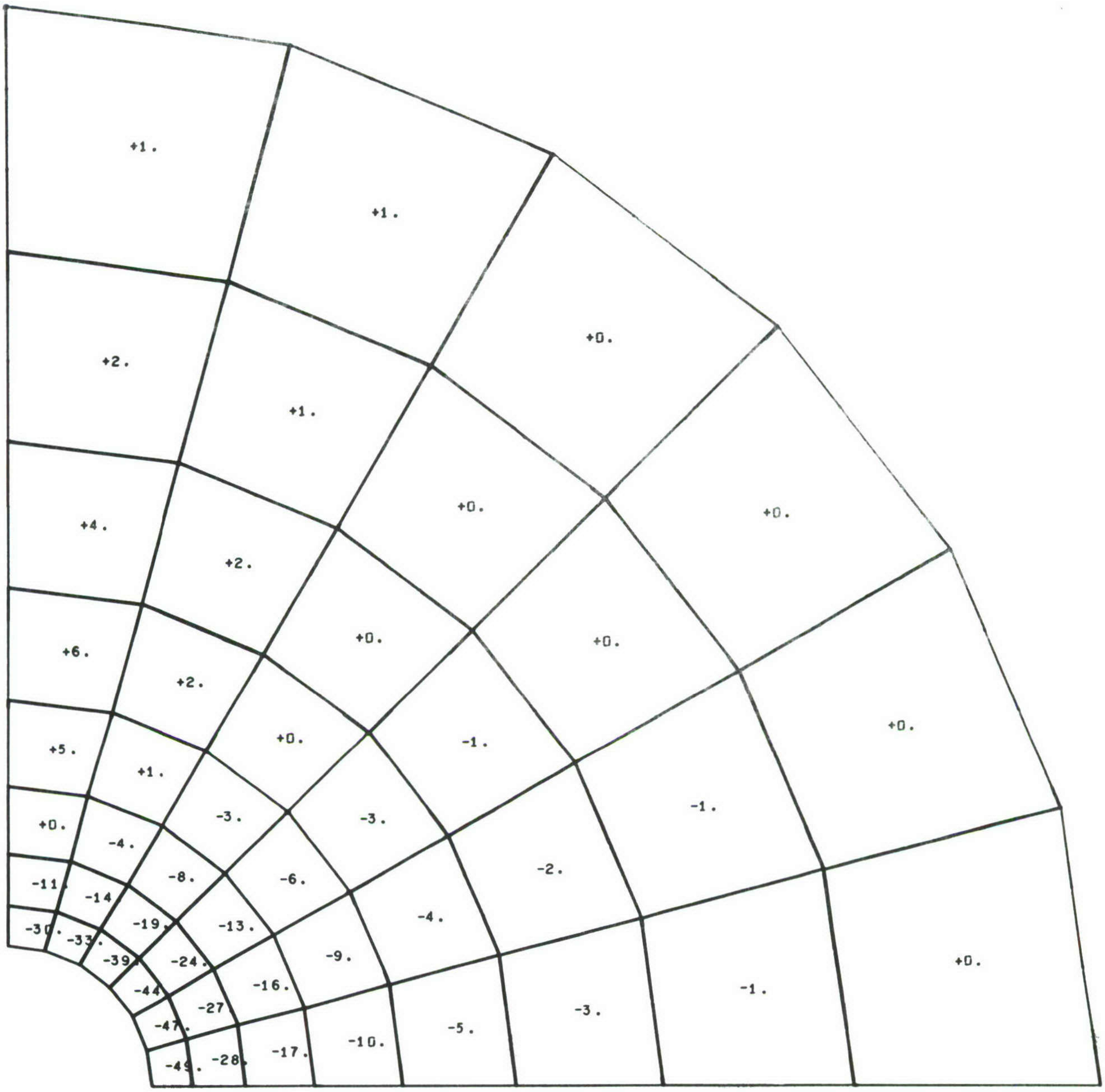


Figure AI-23 Second Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

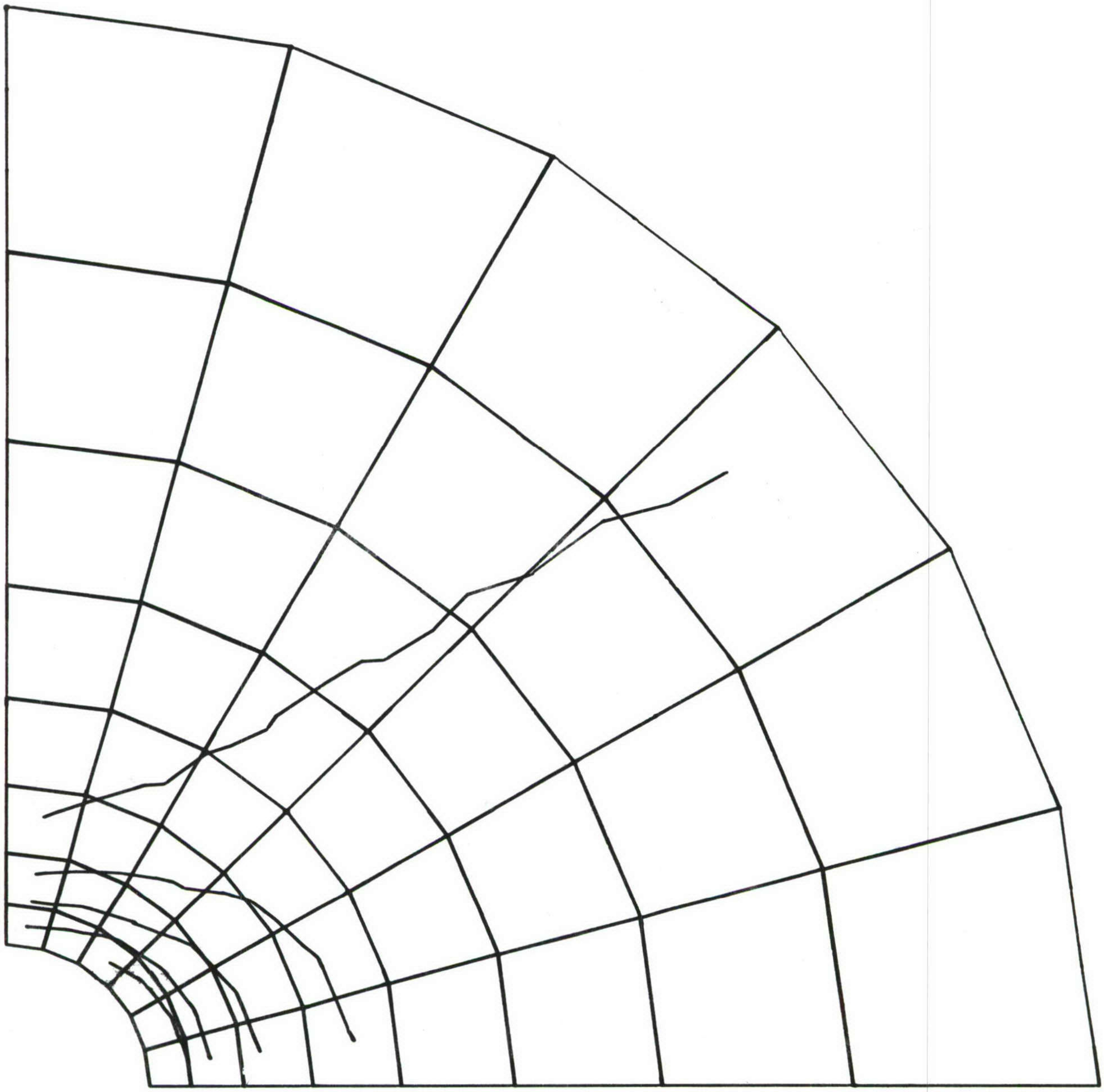


Figure AI-24 Second Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

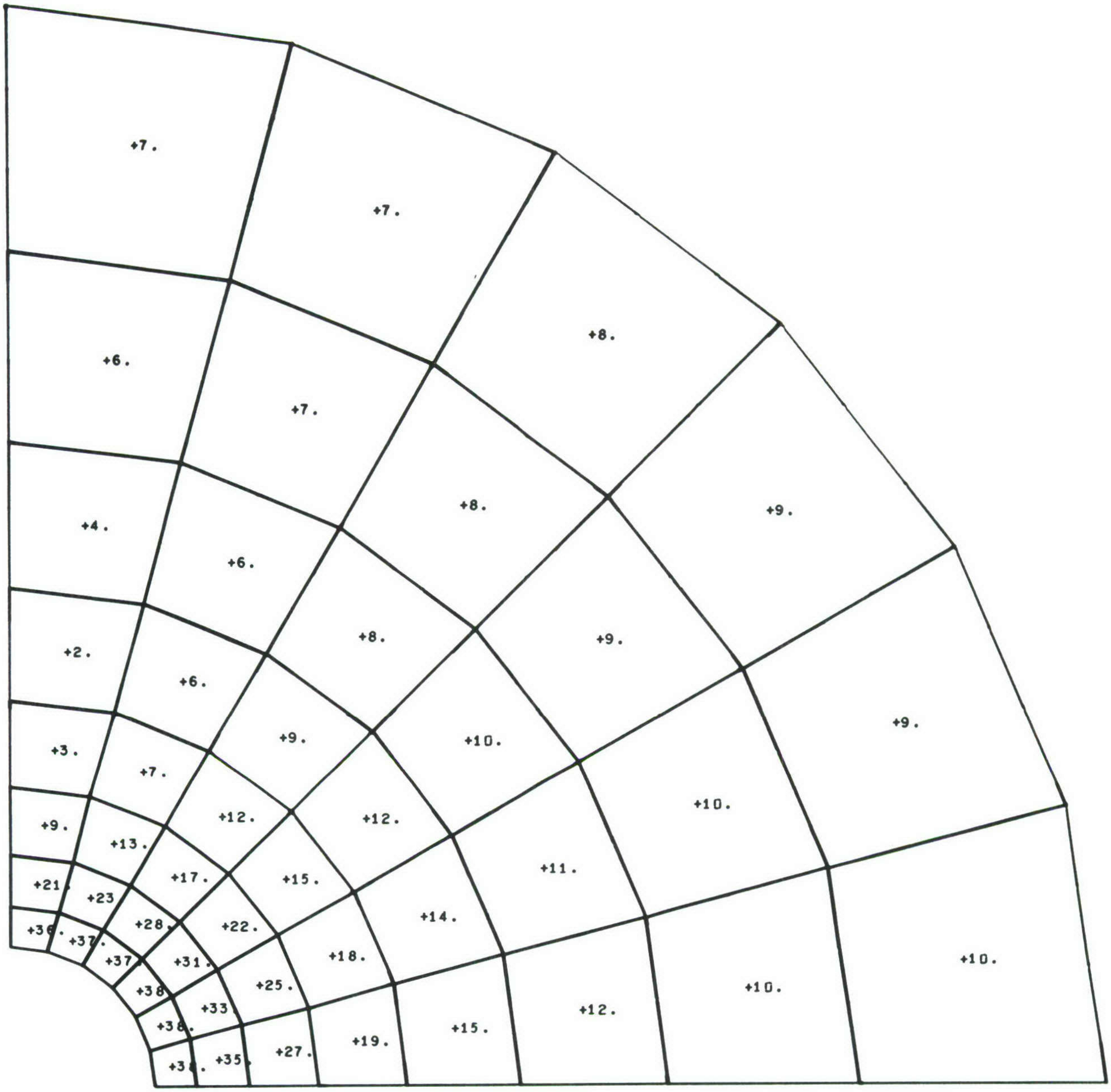


Figure AI-25 Principal Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

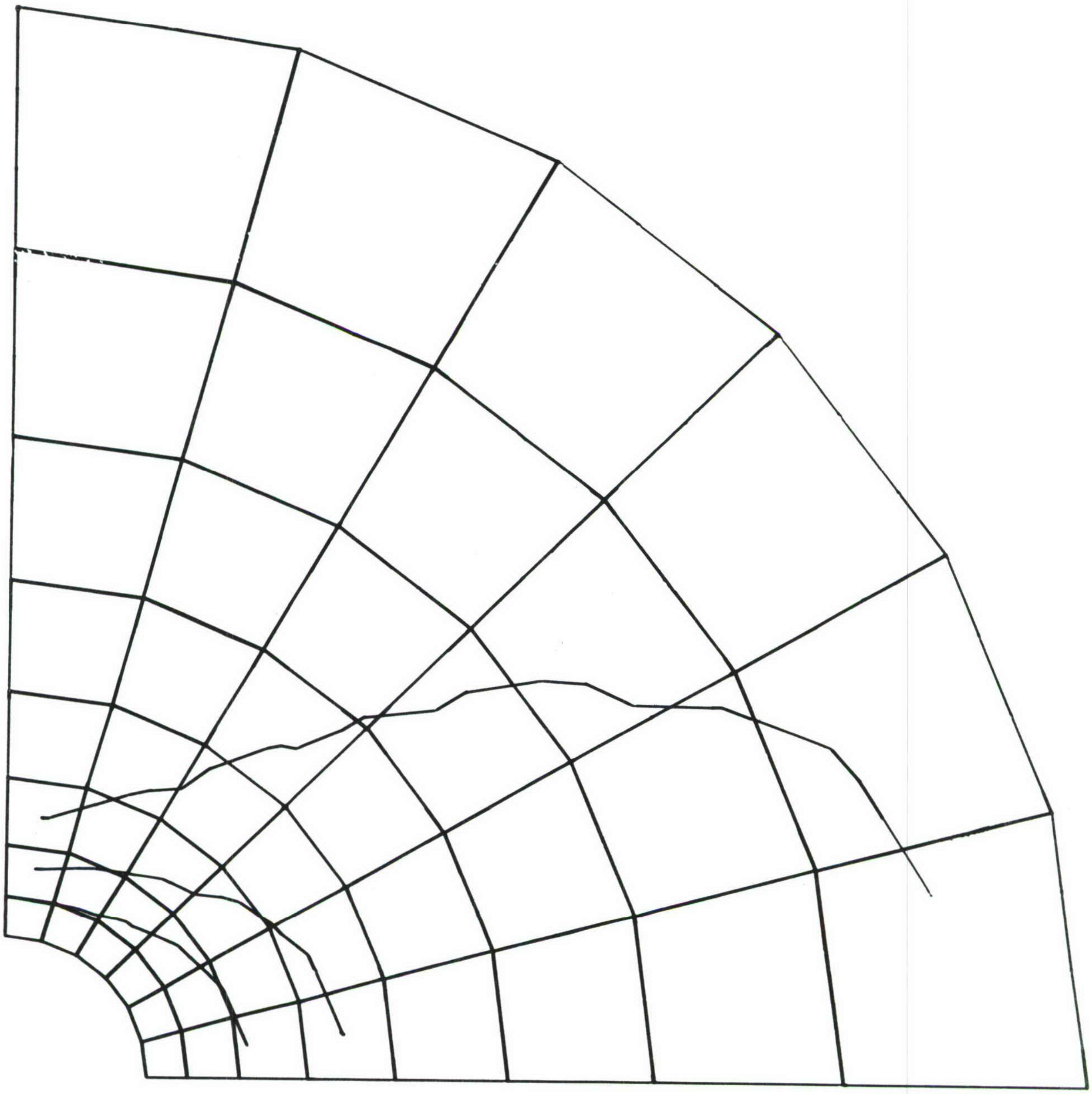


Figure AI-26 Principal Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

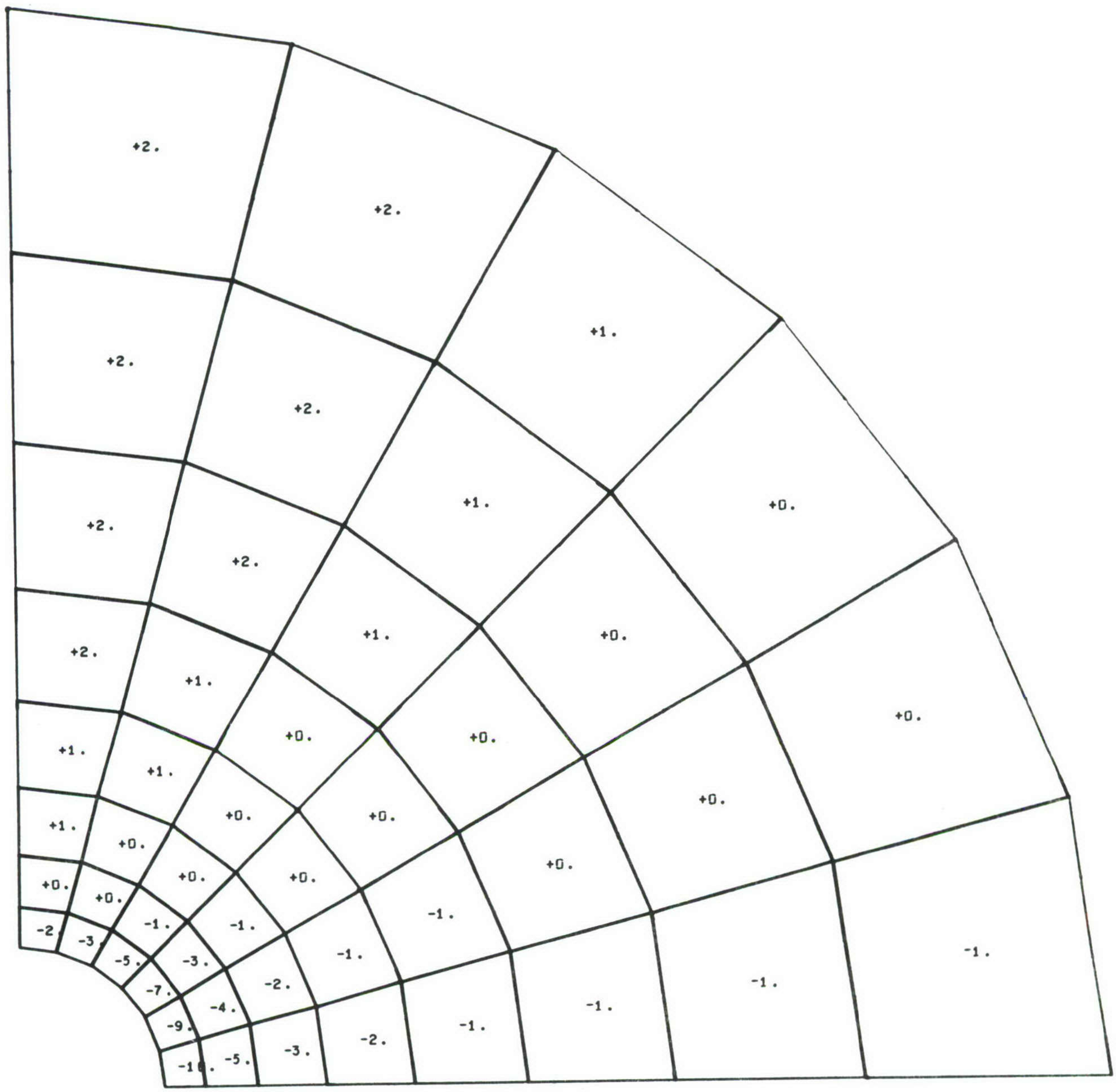


Figure AI-27 Radial Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

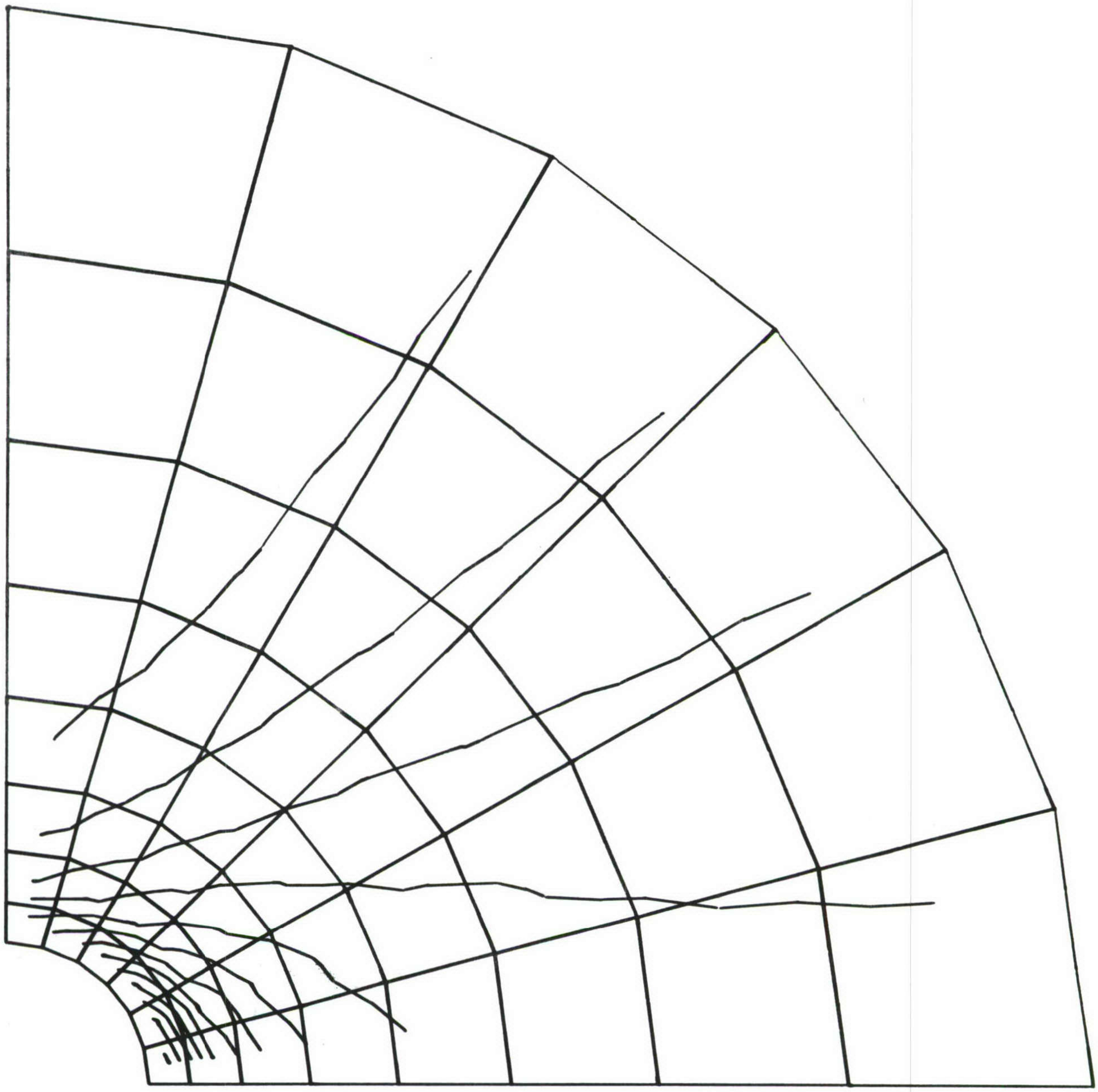


Figure AI-28 Radial Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

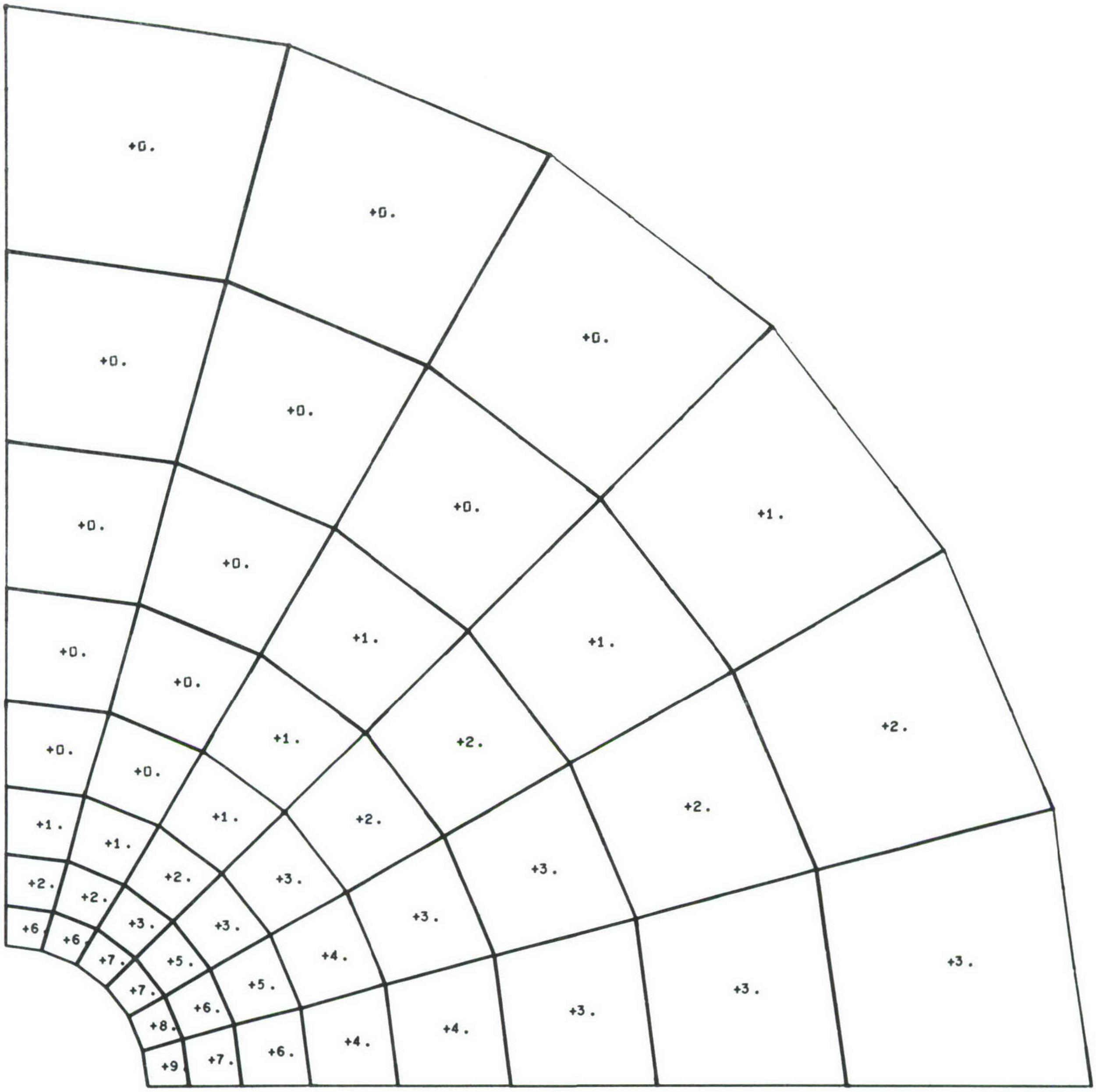


Figure AI-29 Tangential Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

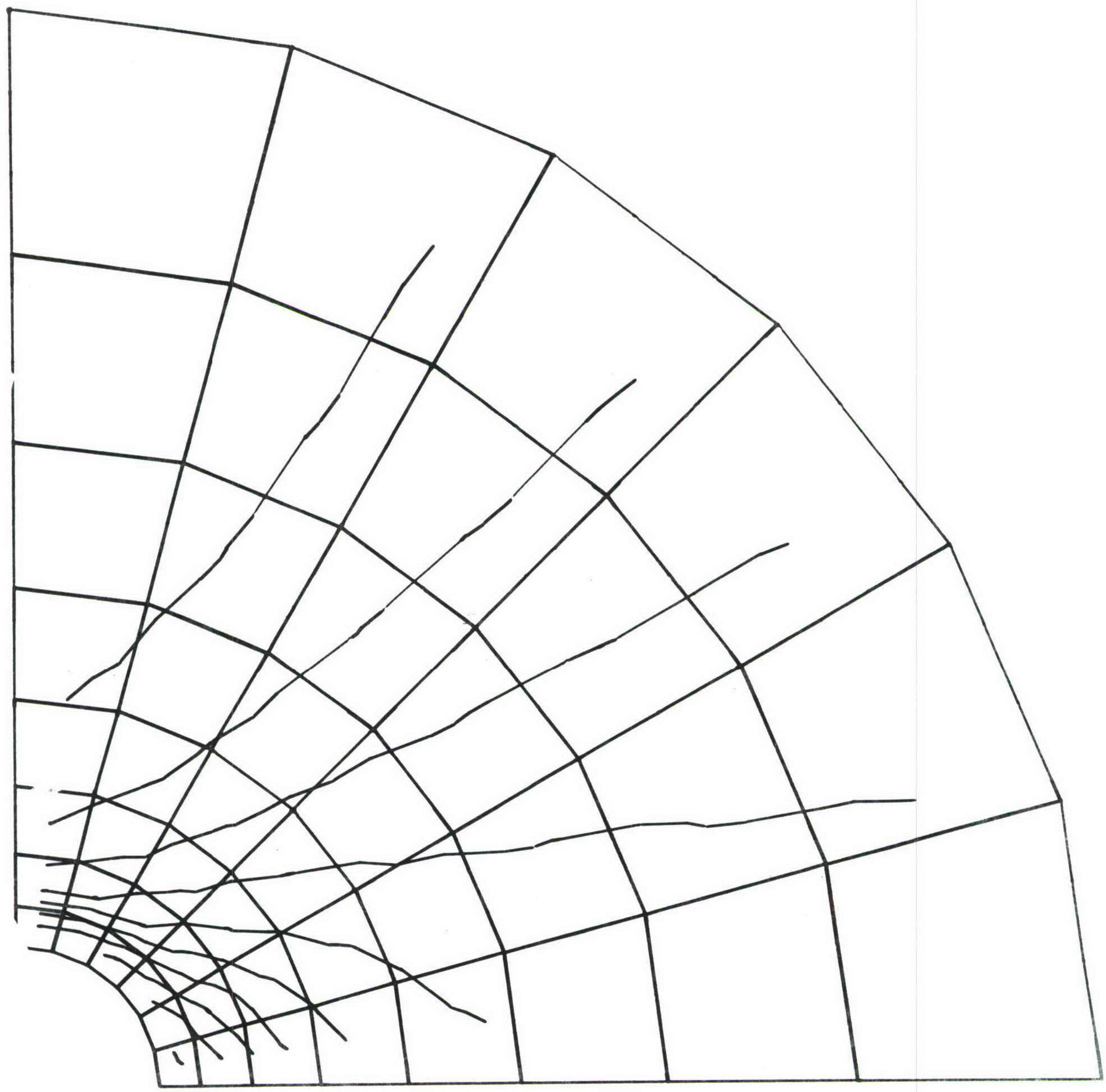


Figure AI-30 Tangential Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

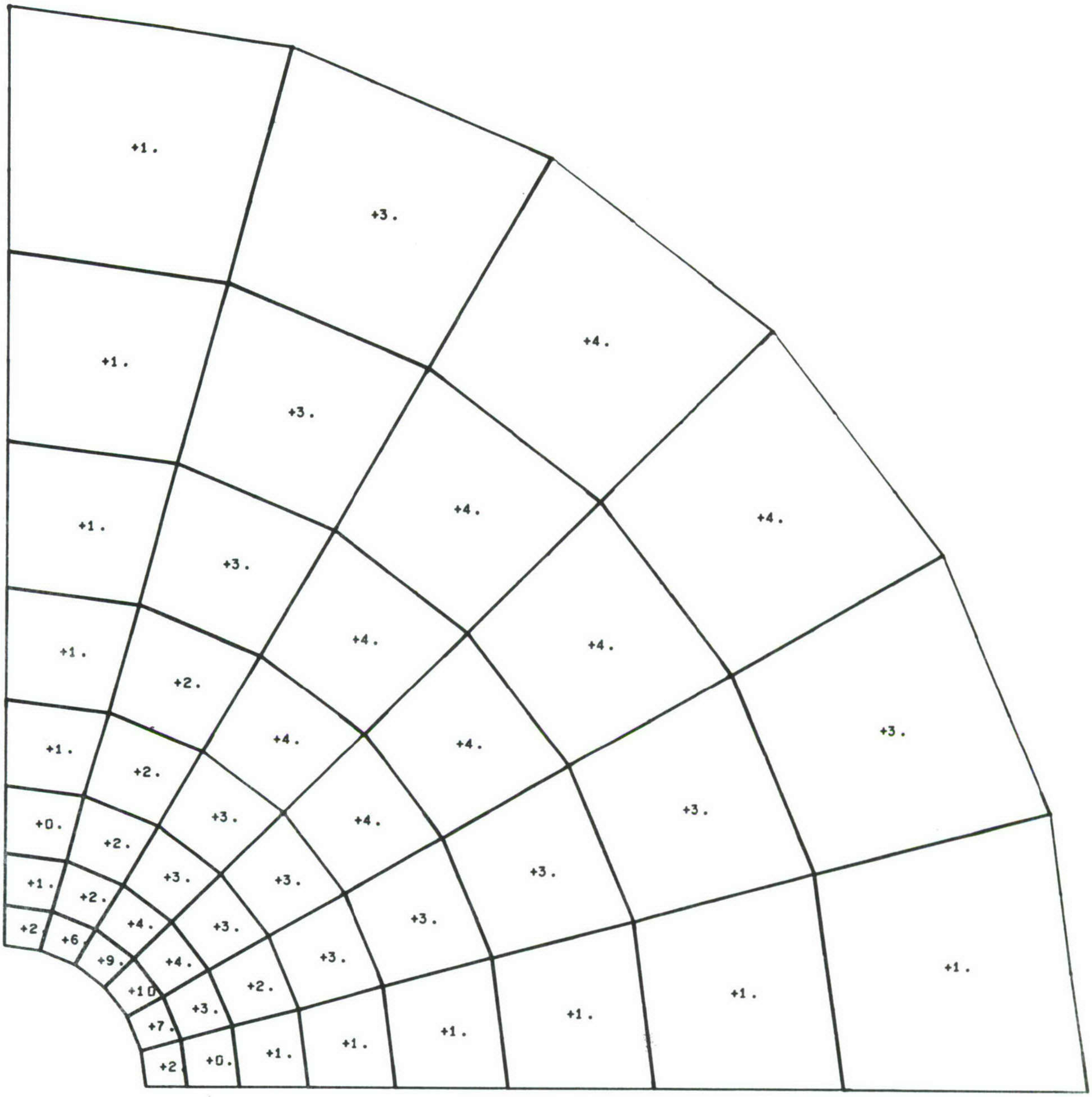


Figure AI-31 Radial-Tangential Shear Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

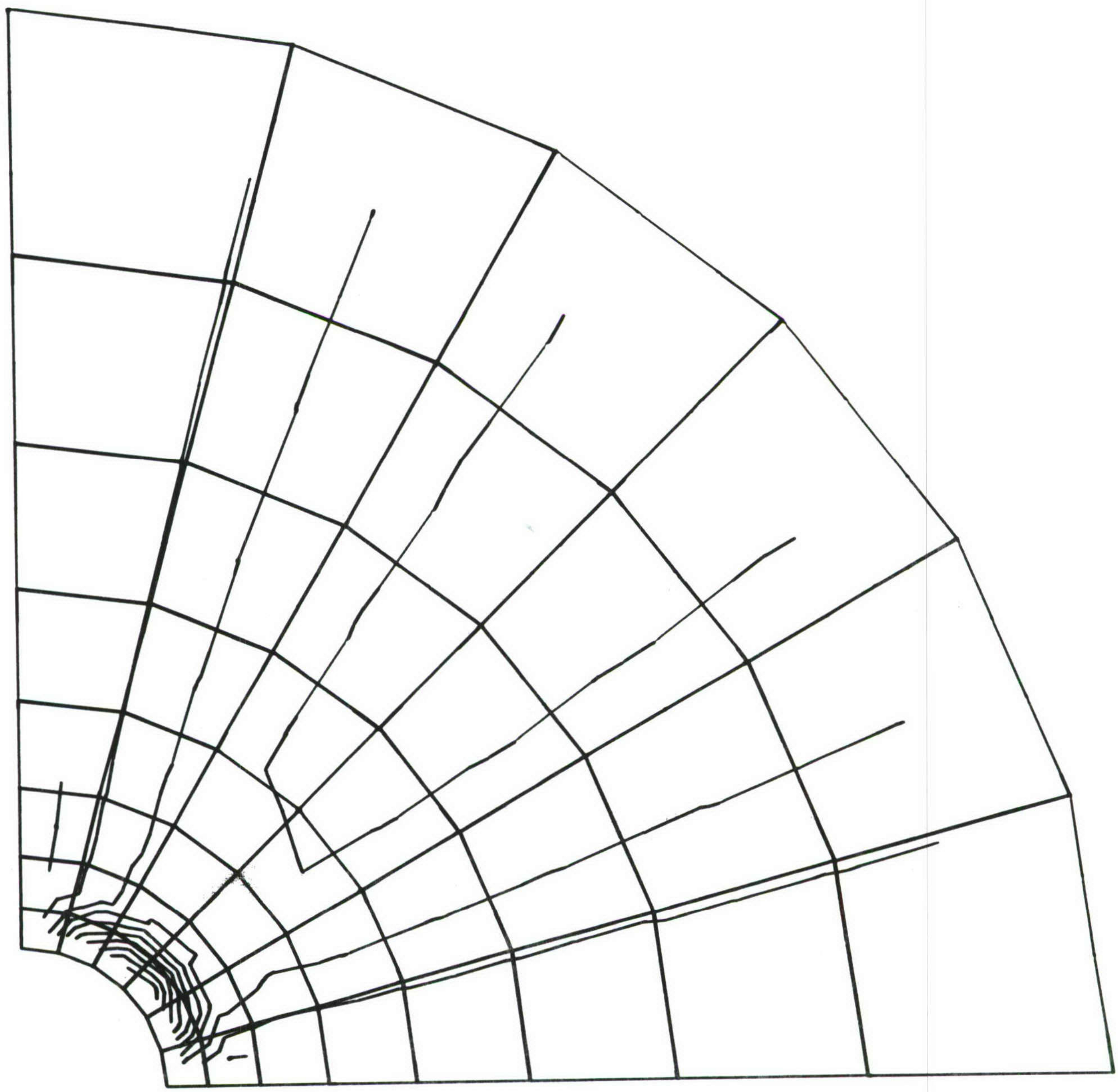


Figure AI-32 Radial-Tangential Shear Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

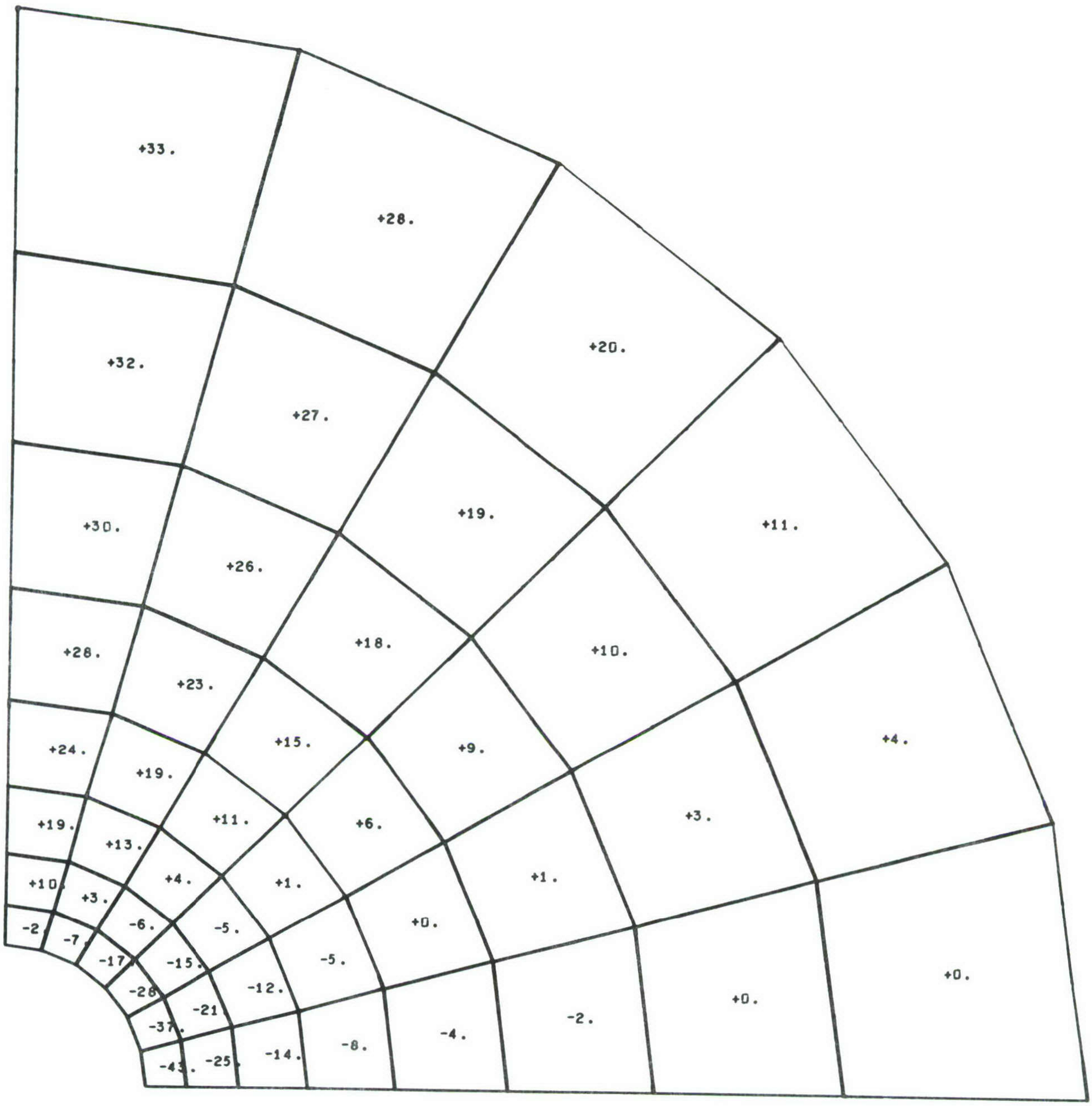


Figure AI-33 Radial Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

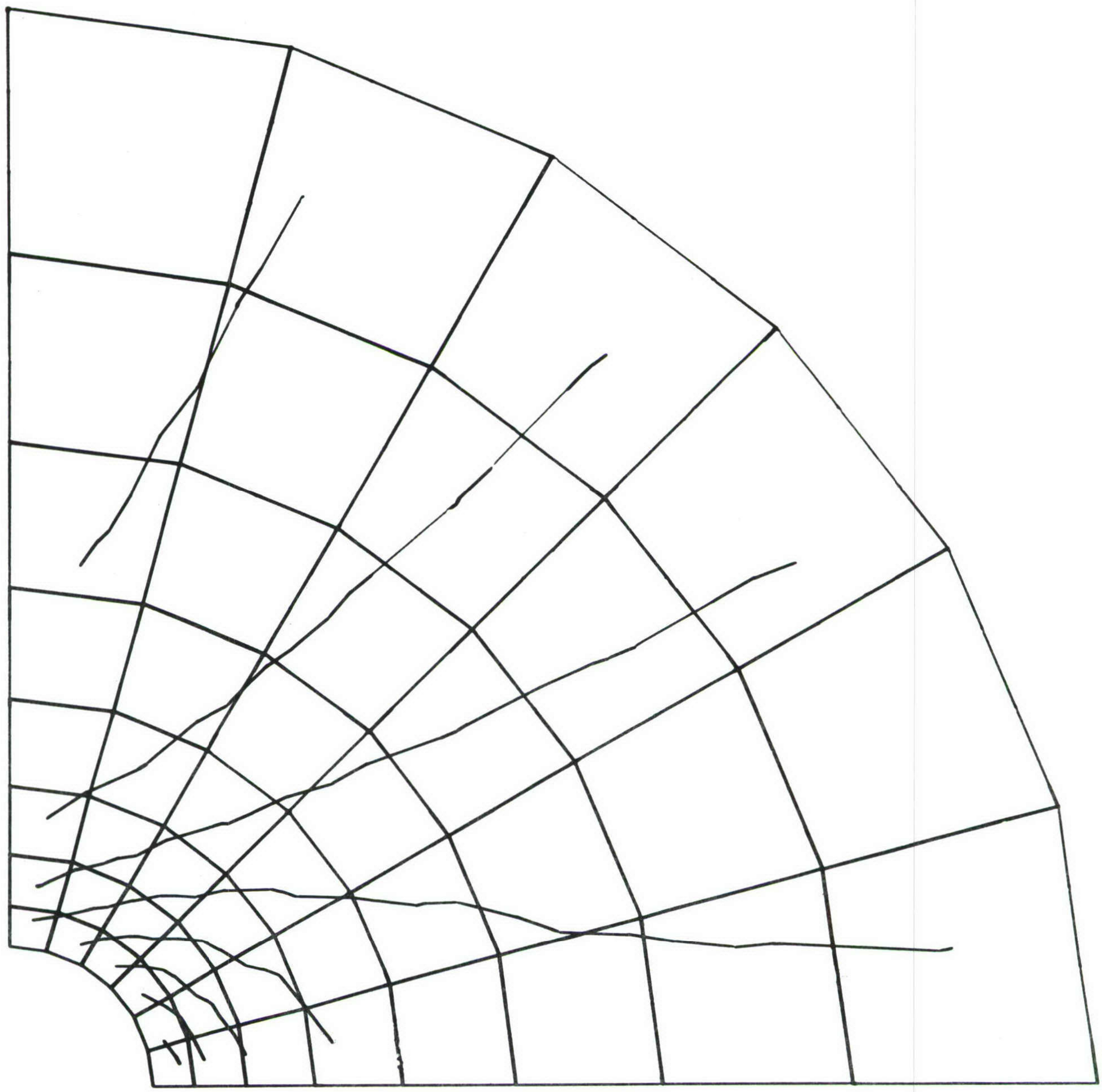


Figure AI-34 Radial Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

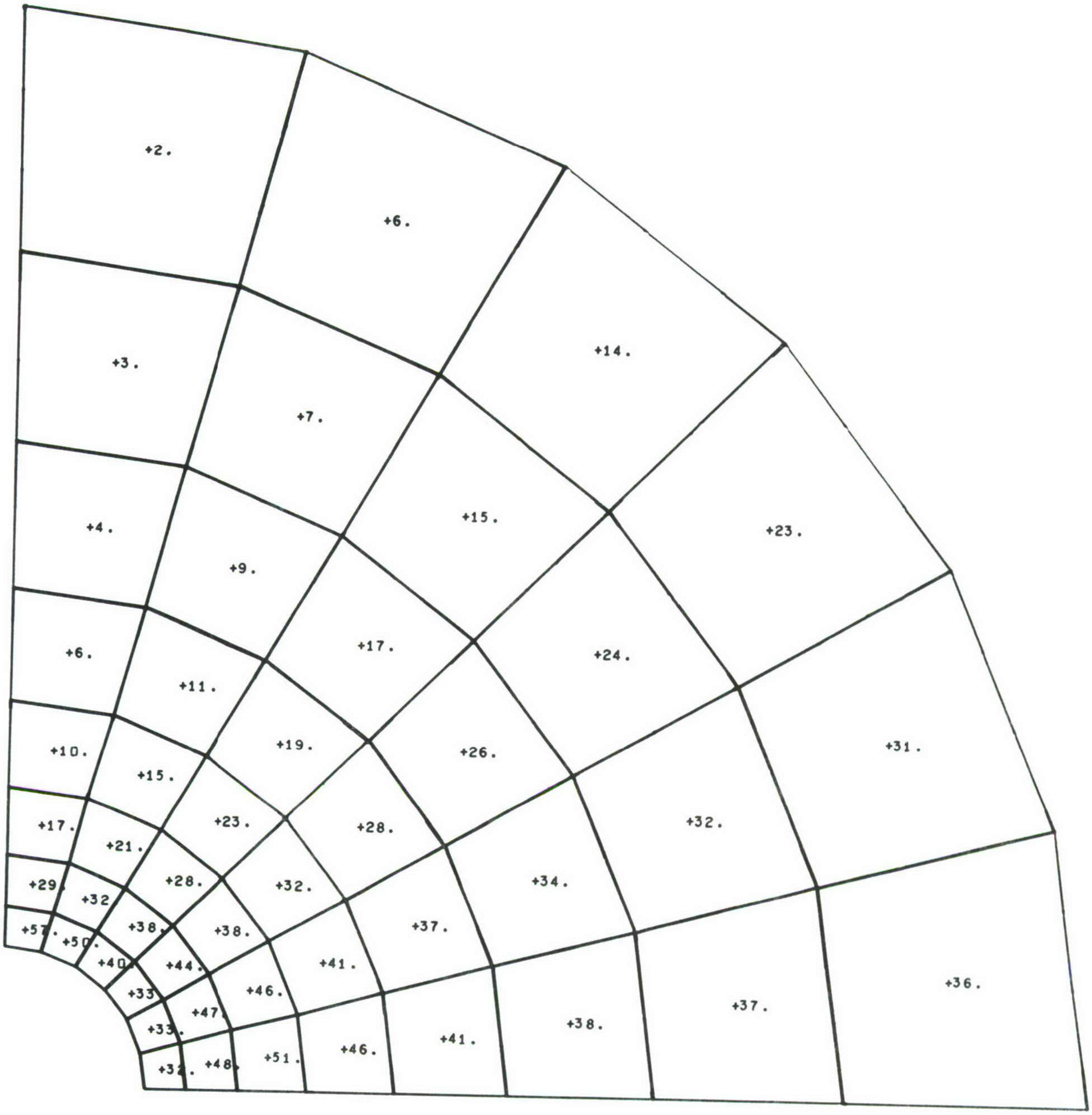


Figure AI-35 Tangential Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

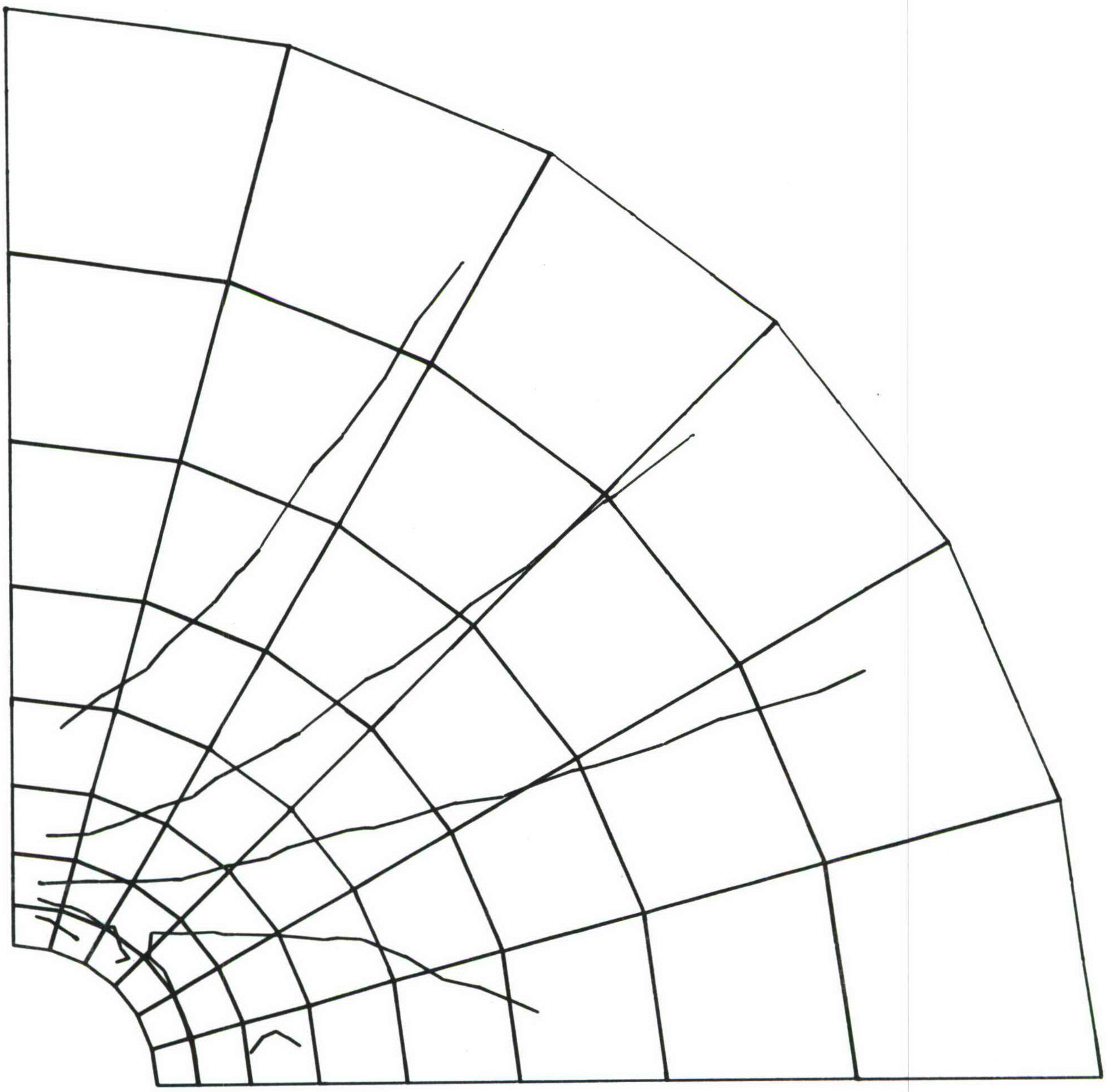


Figure AI-36 Tangential Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

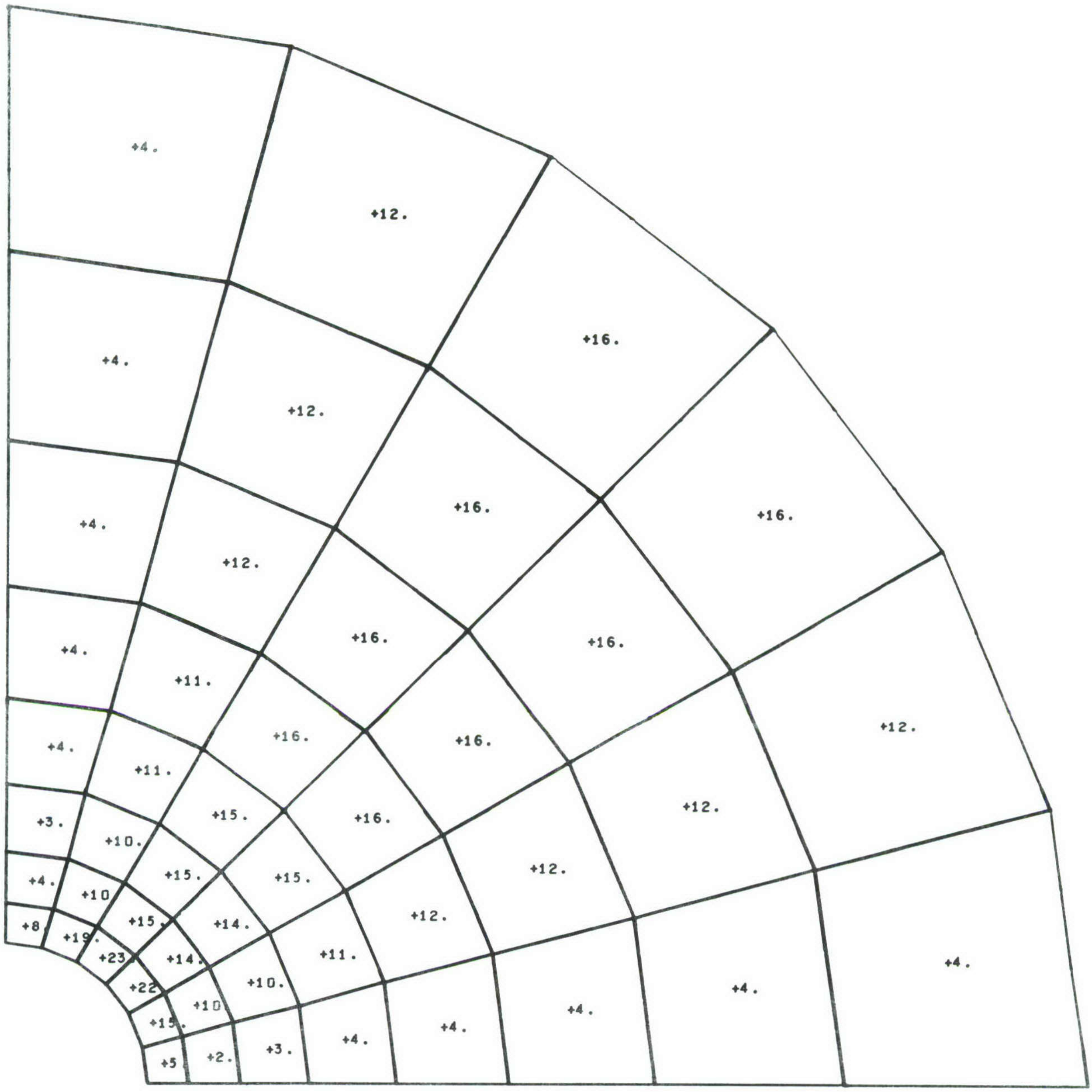


Figure AI-37 Radial-Tangential Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

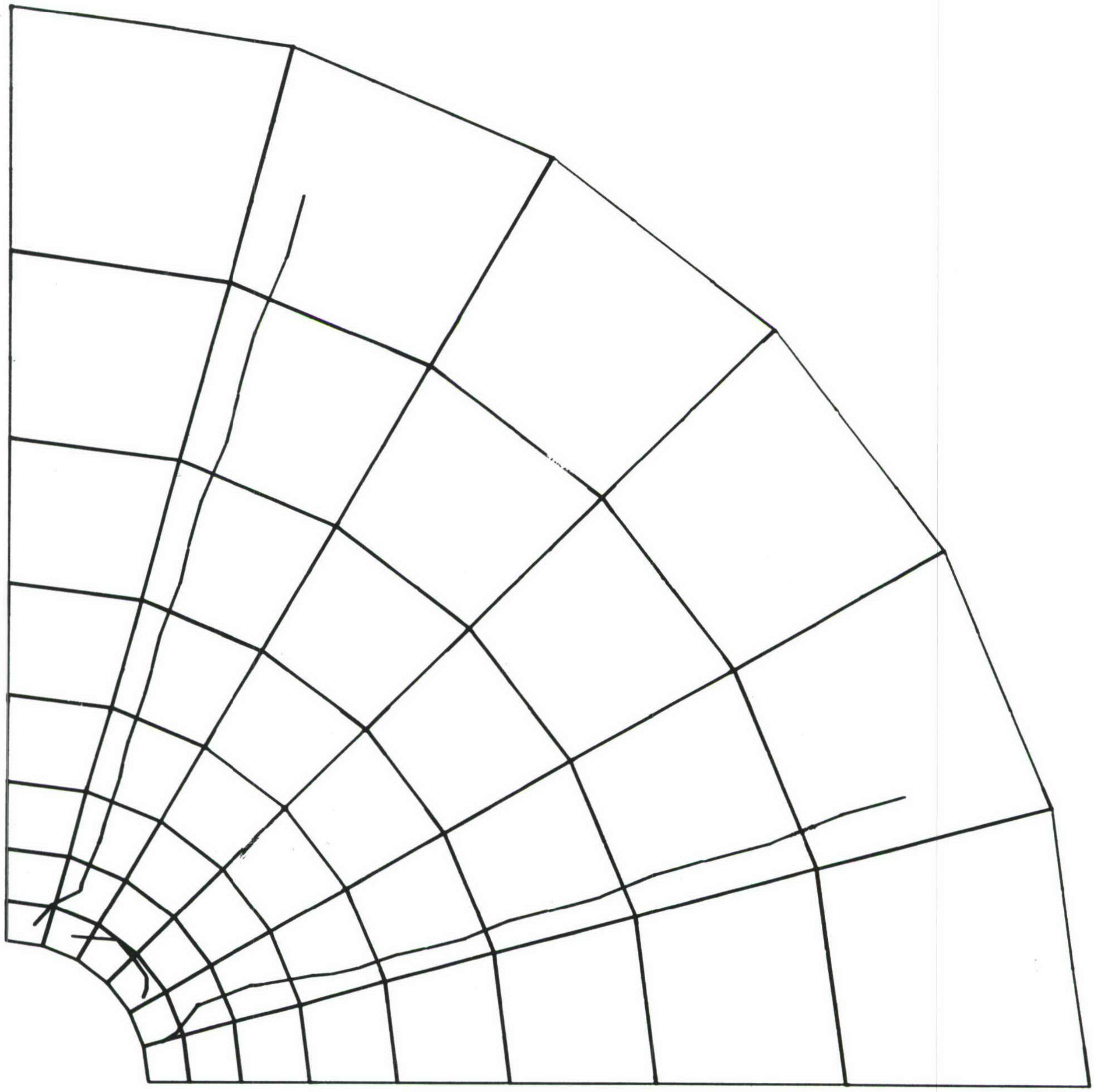


Figure AI-38 Radial-Tangential Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

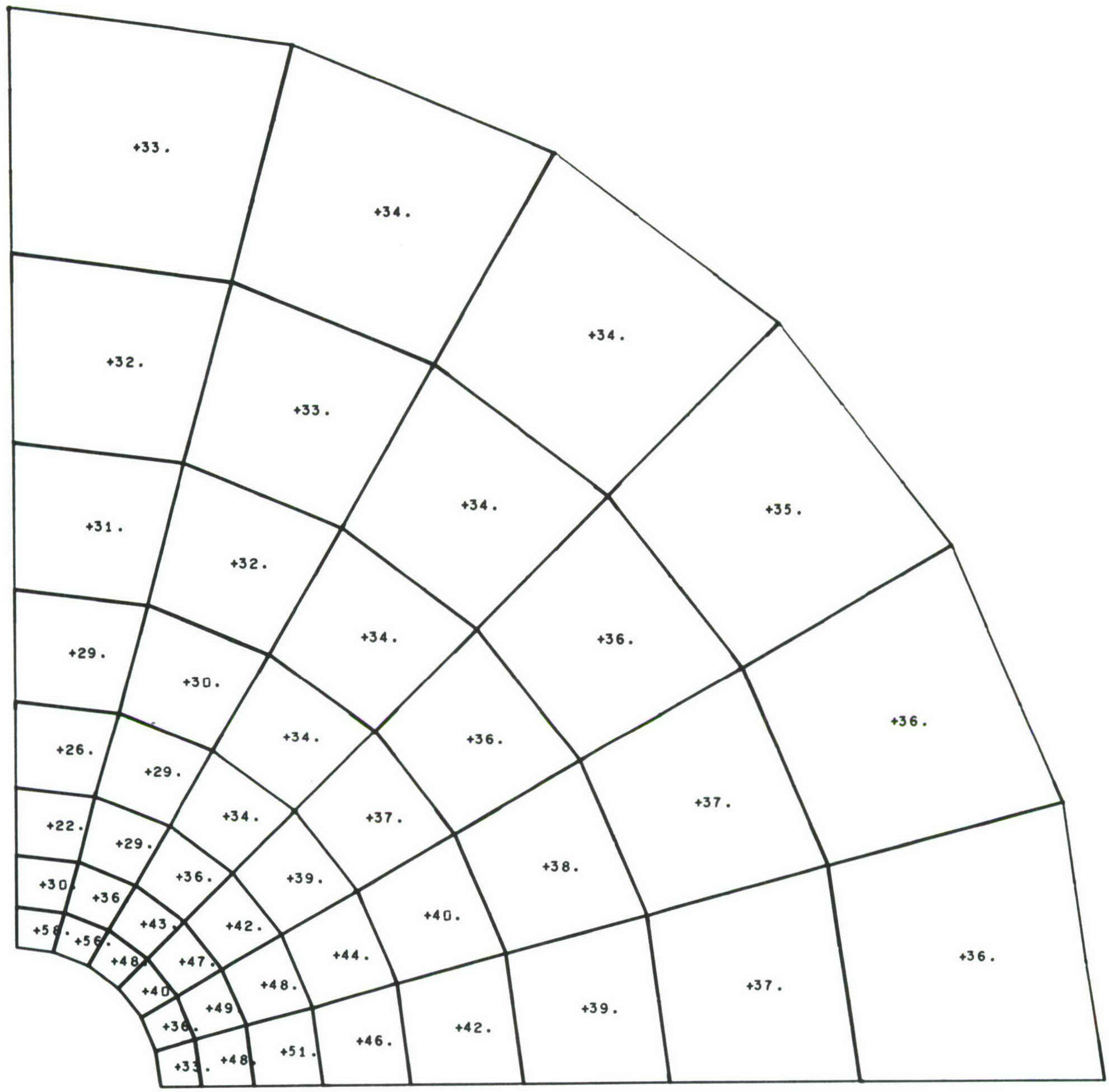


Figure AI-39 First Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

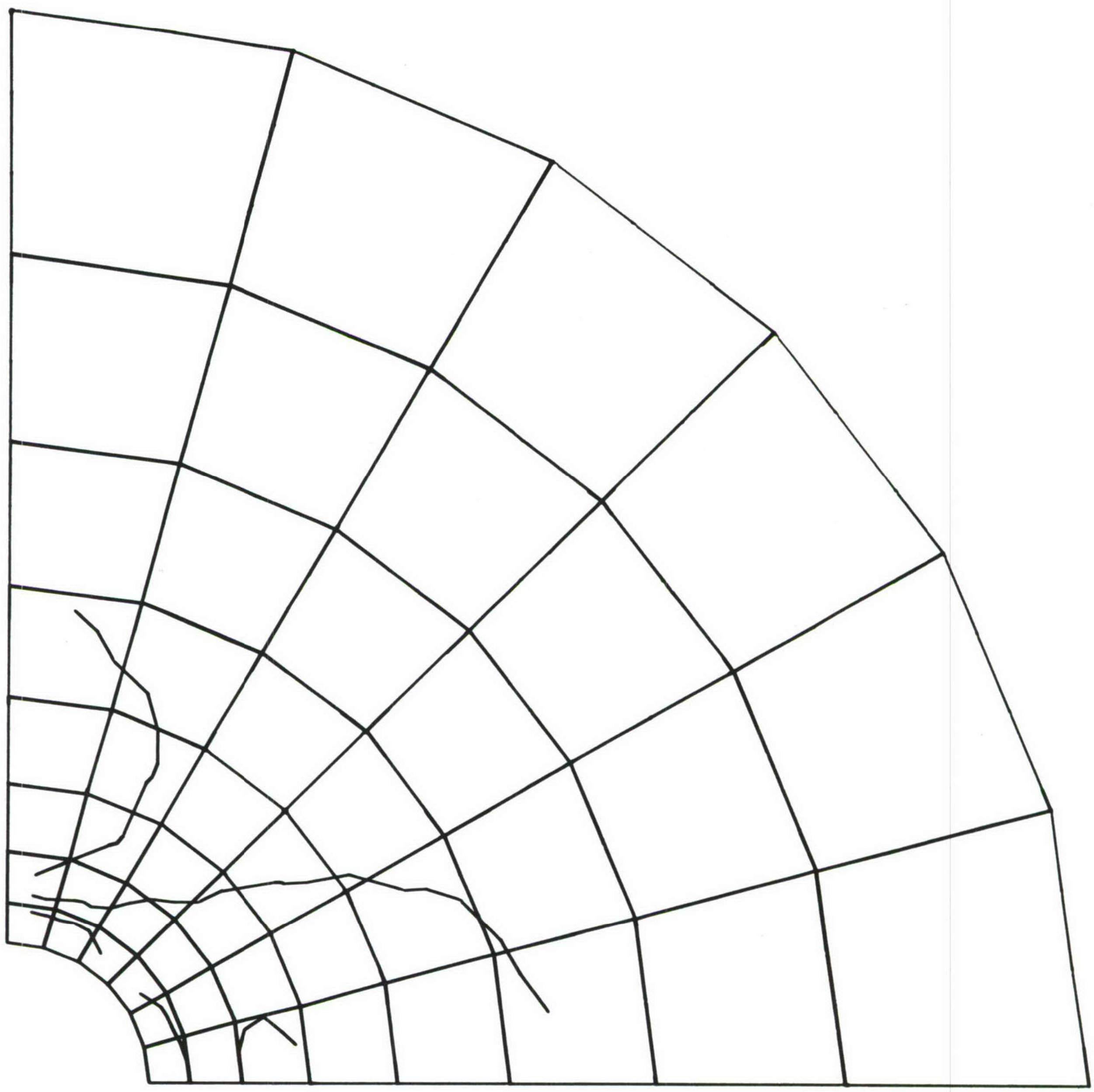


Figure AI-40 First Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

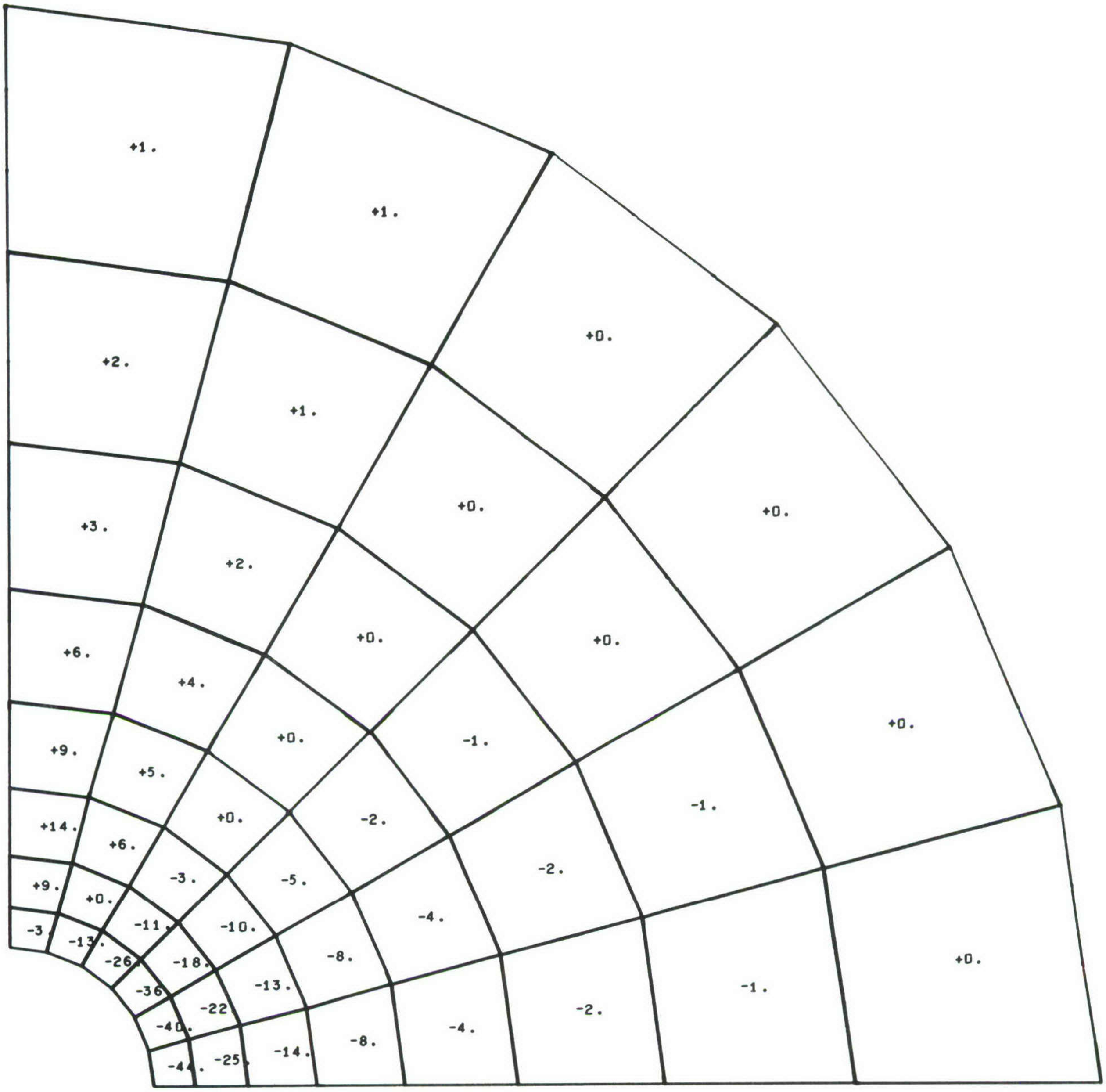


Figure AI-41 Second Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

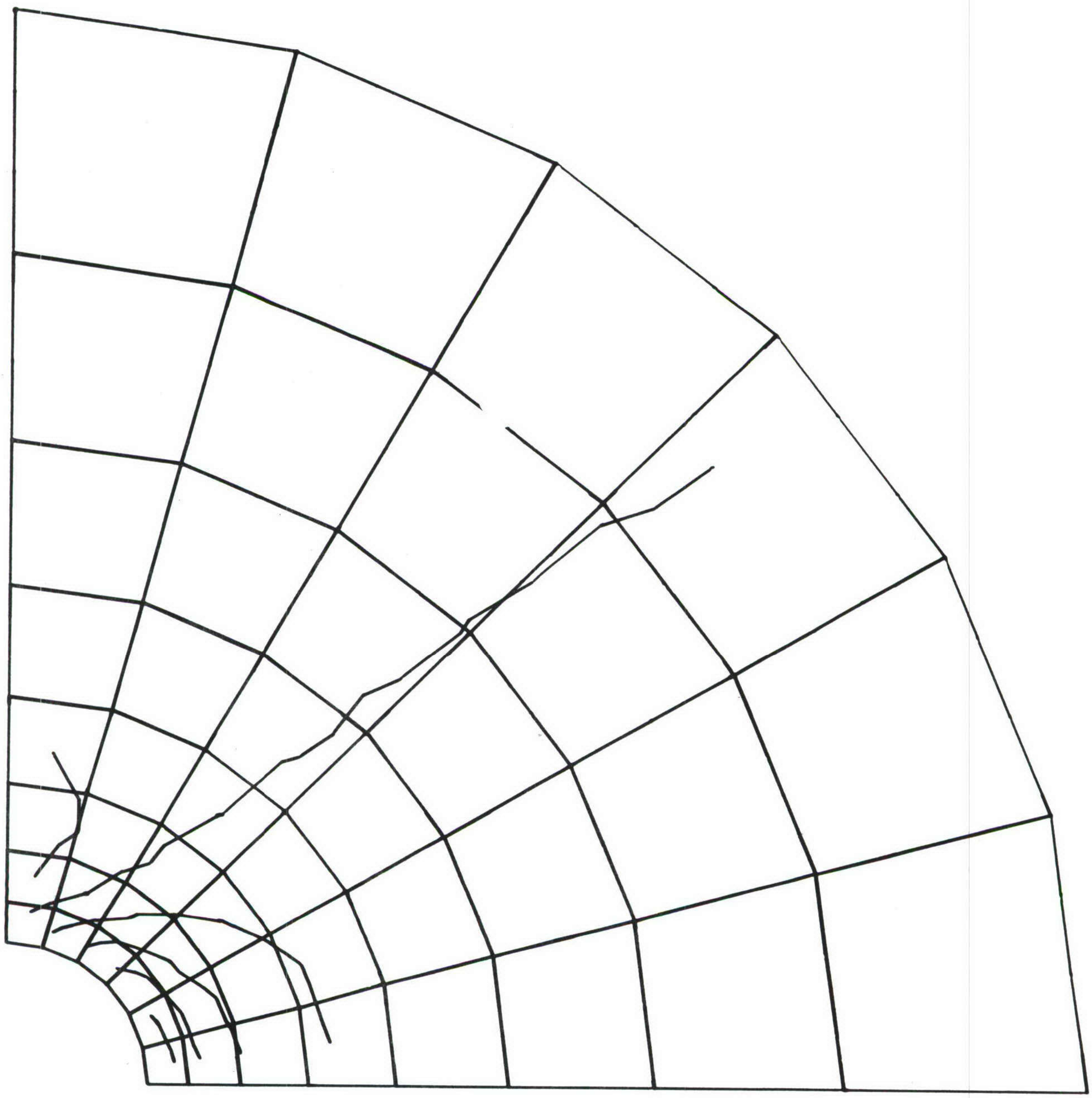


Figure AI-42 Second Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

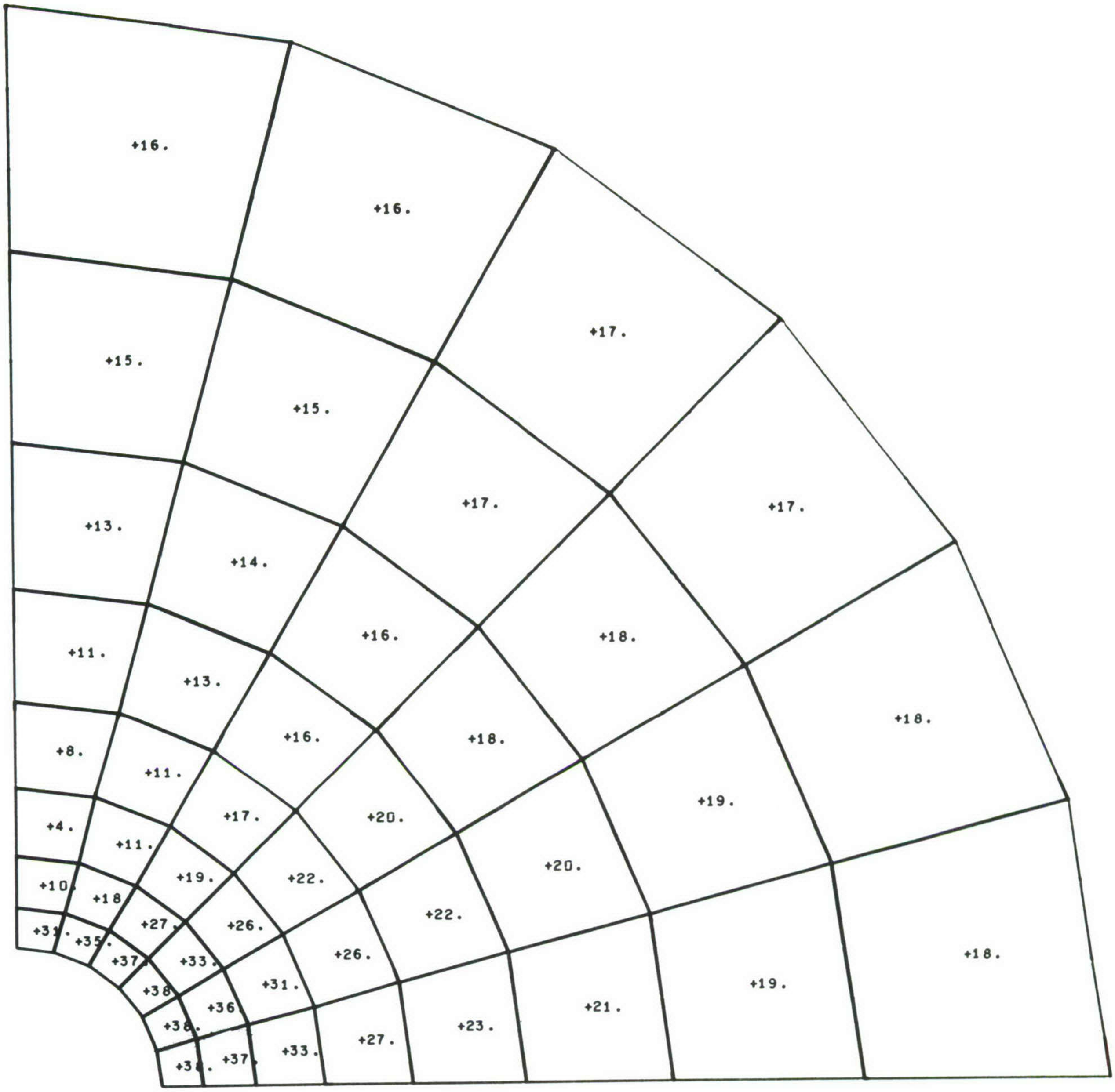


Figure AI-43 Principal Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

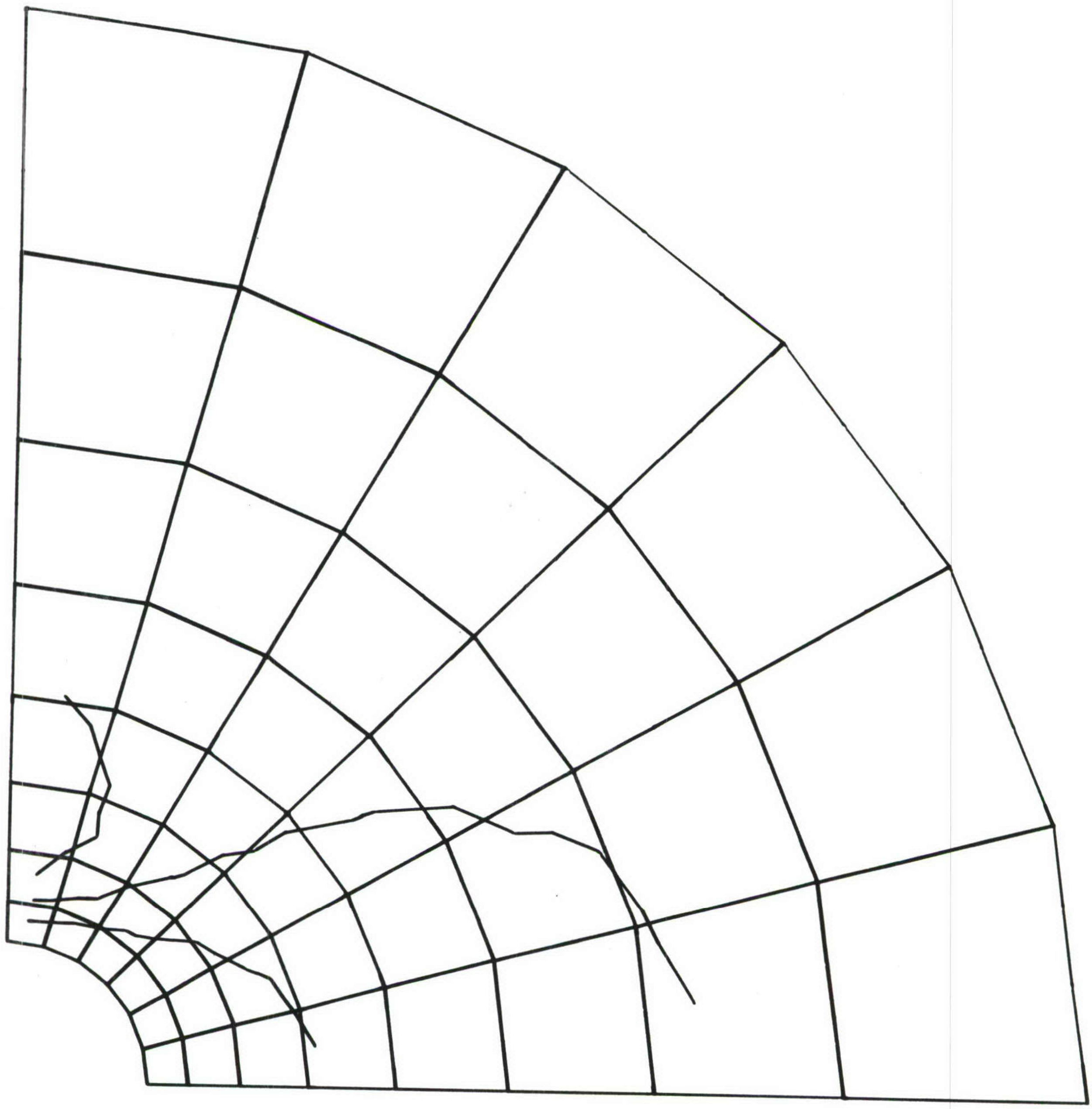


Figure AI-44 Principal Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

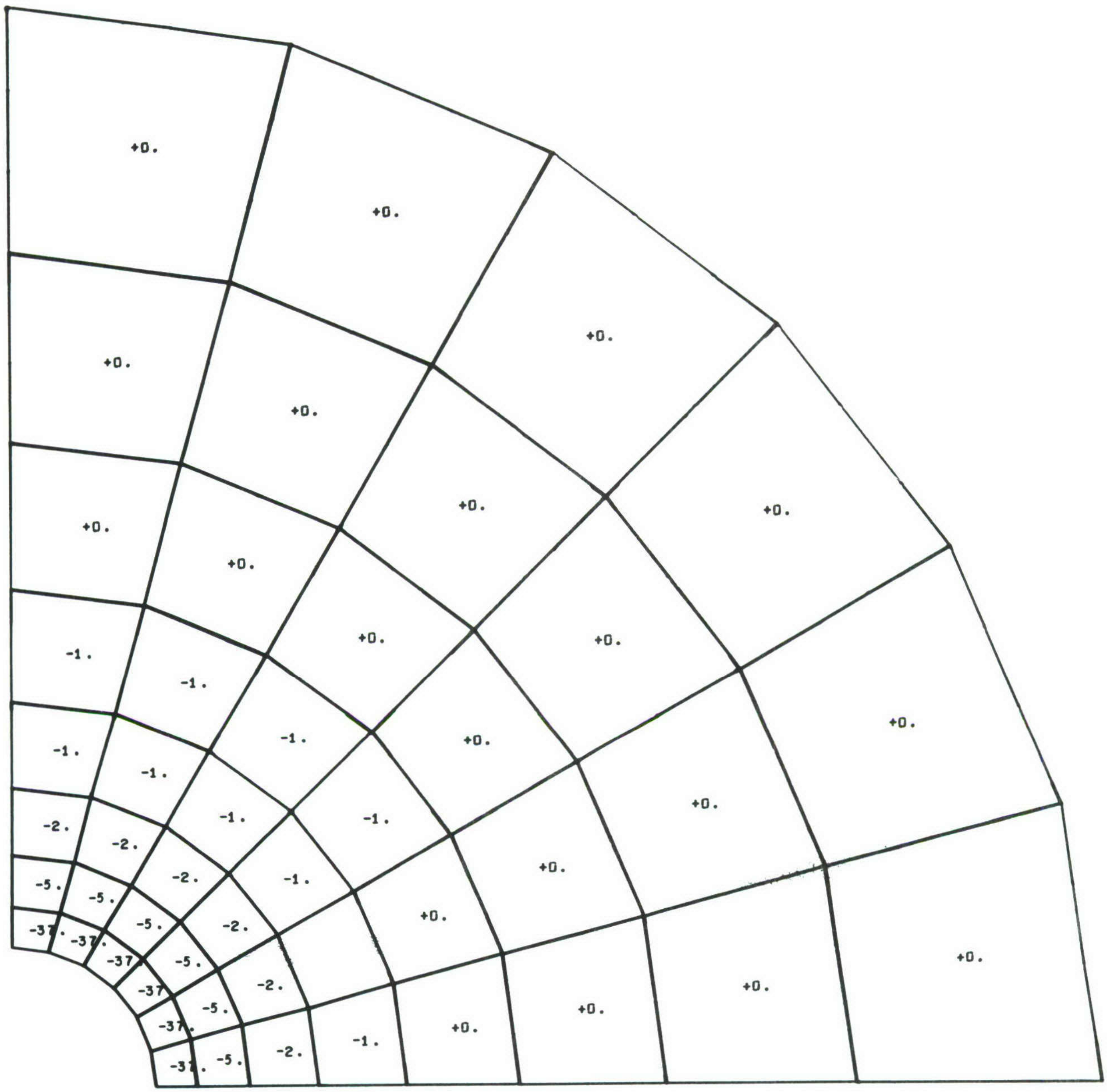


Figure AI-45 Radial Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

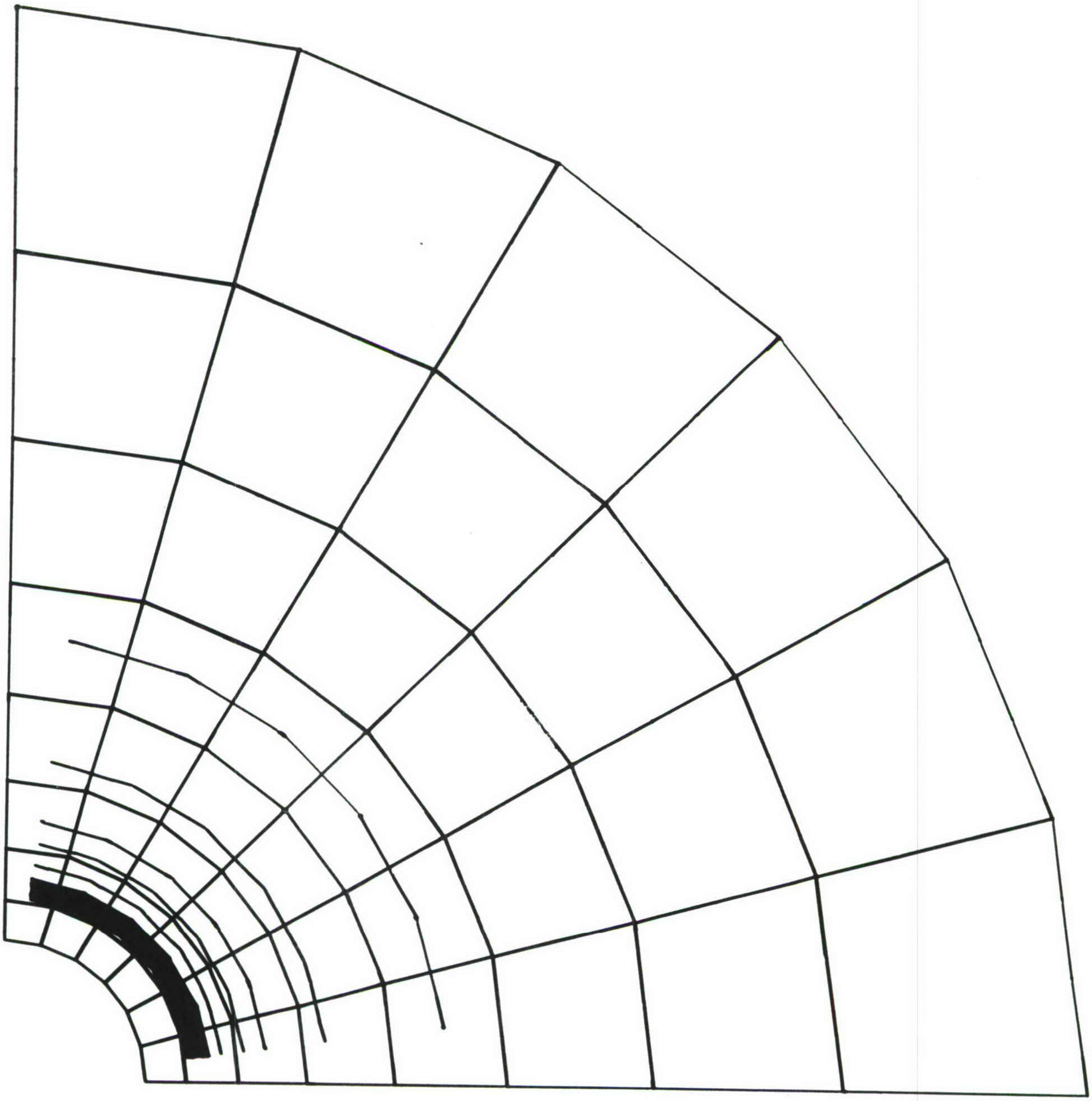


Figure AI-46 Radial Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

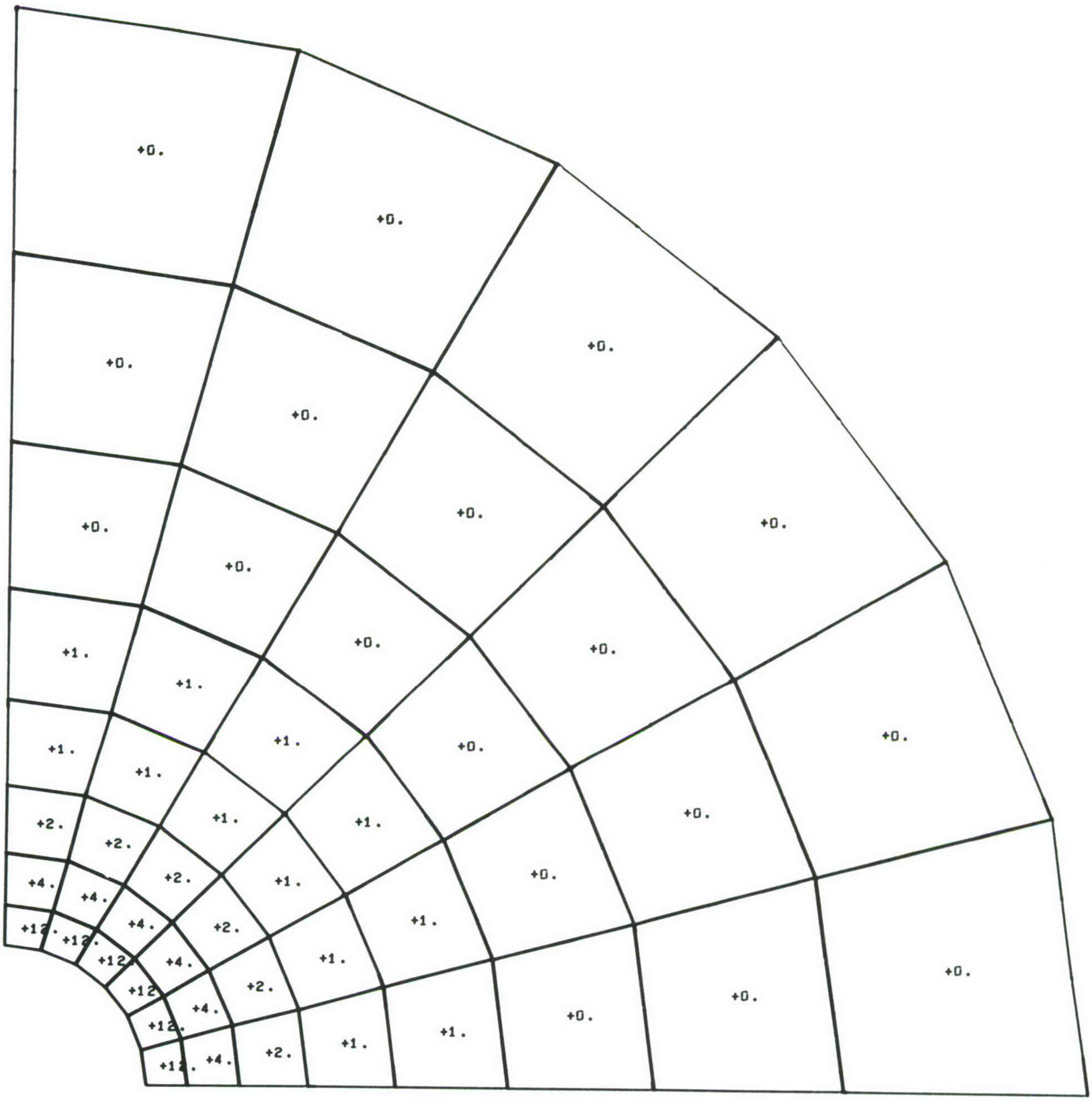


Figure AI-47 Tangential Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

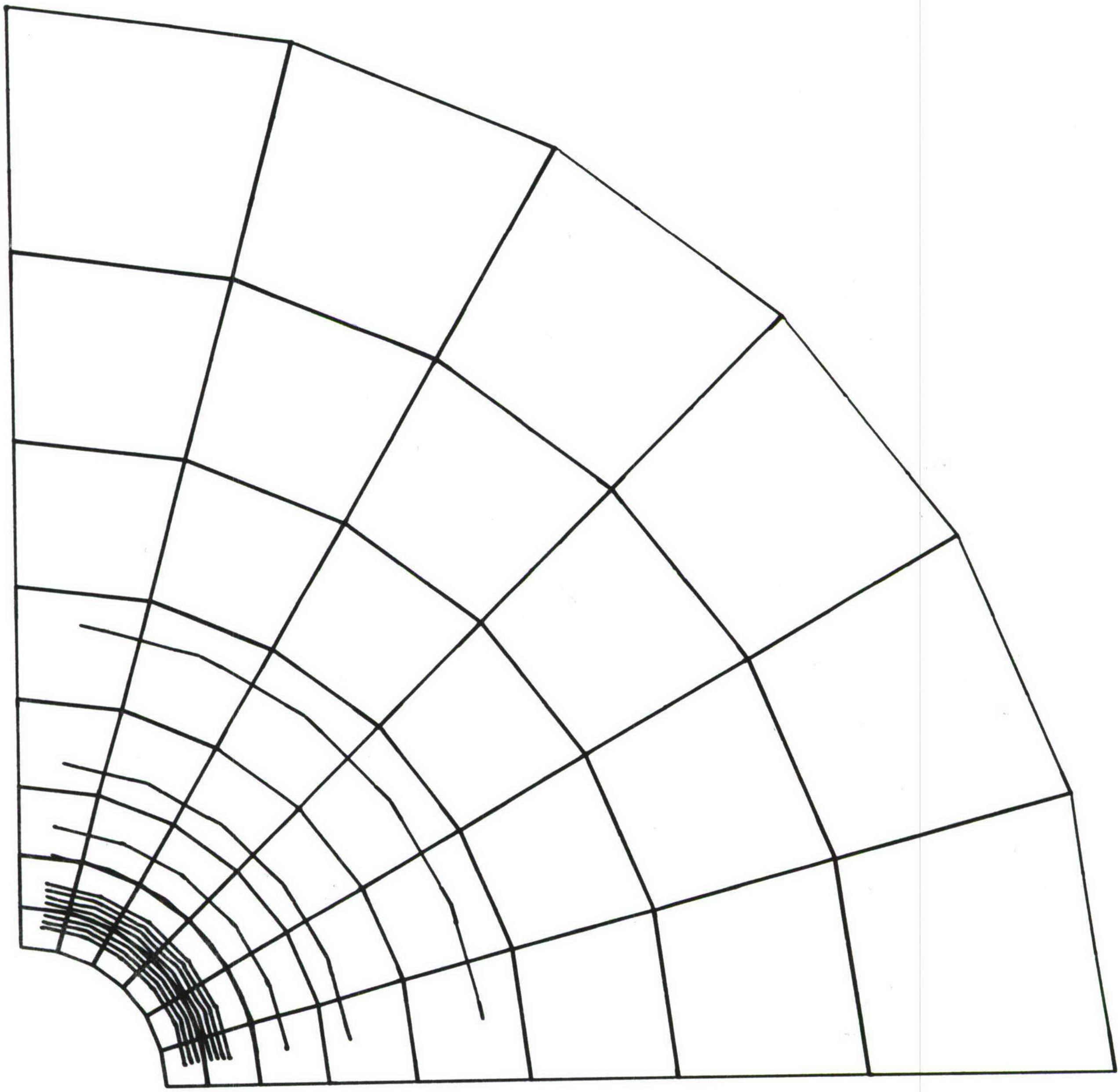


Figure AI-48 Tangential Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

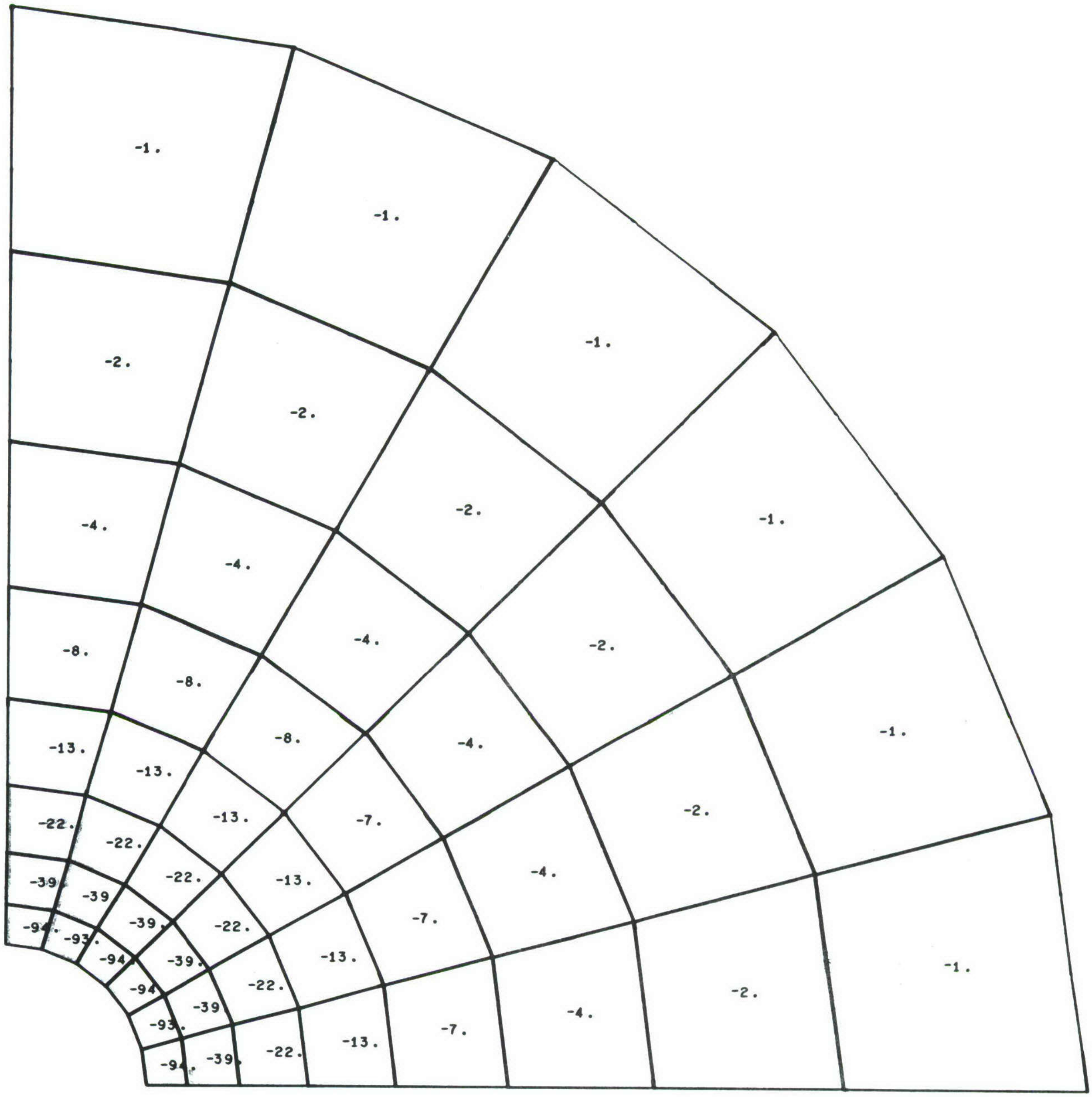


Figure AI-49 Radial Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

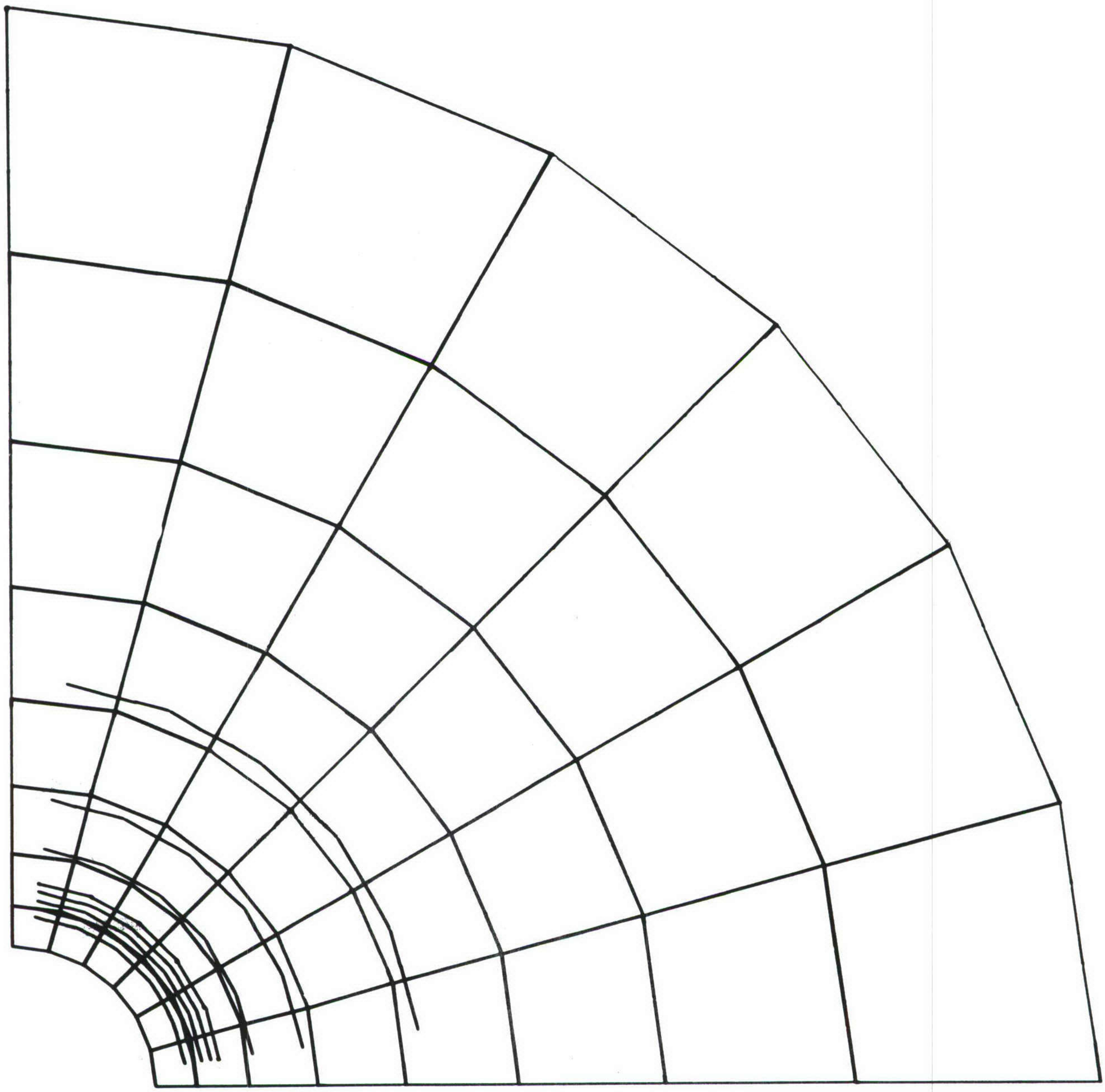


Figure AI-50 Radial Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

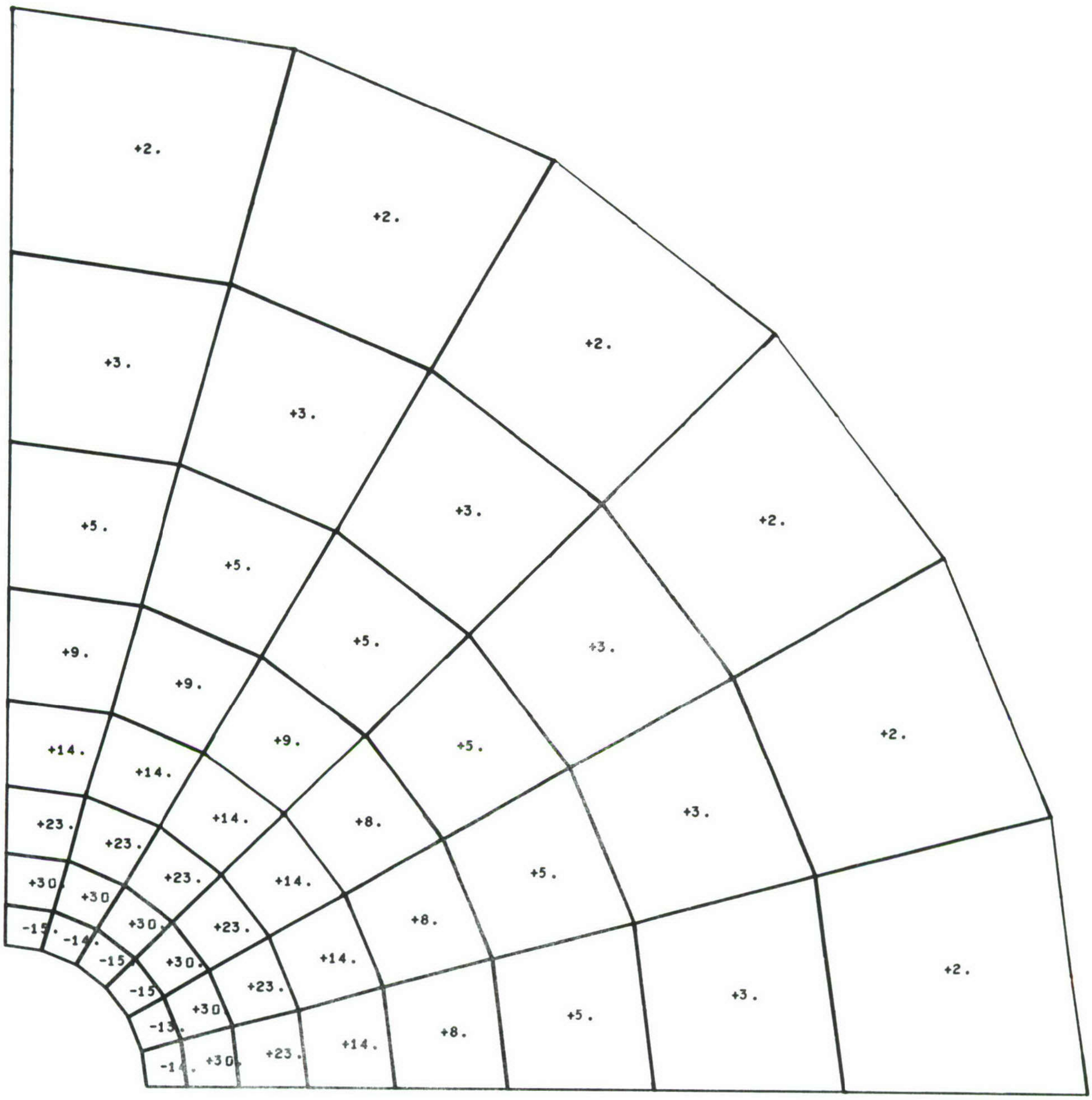


Figure AI-51 Tangential Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

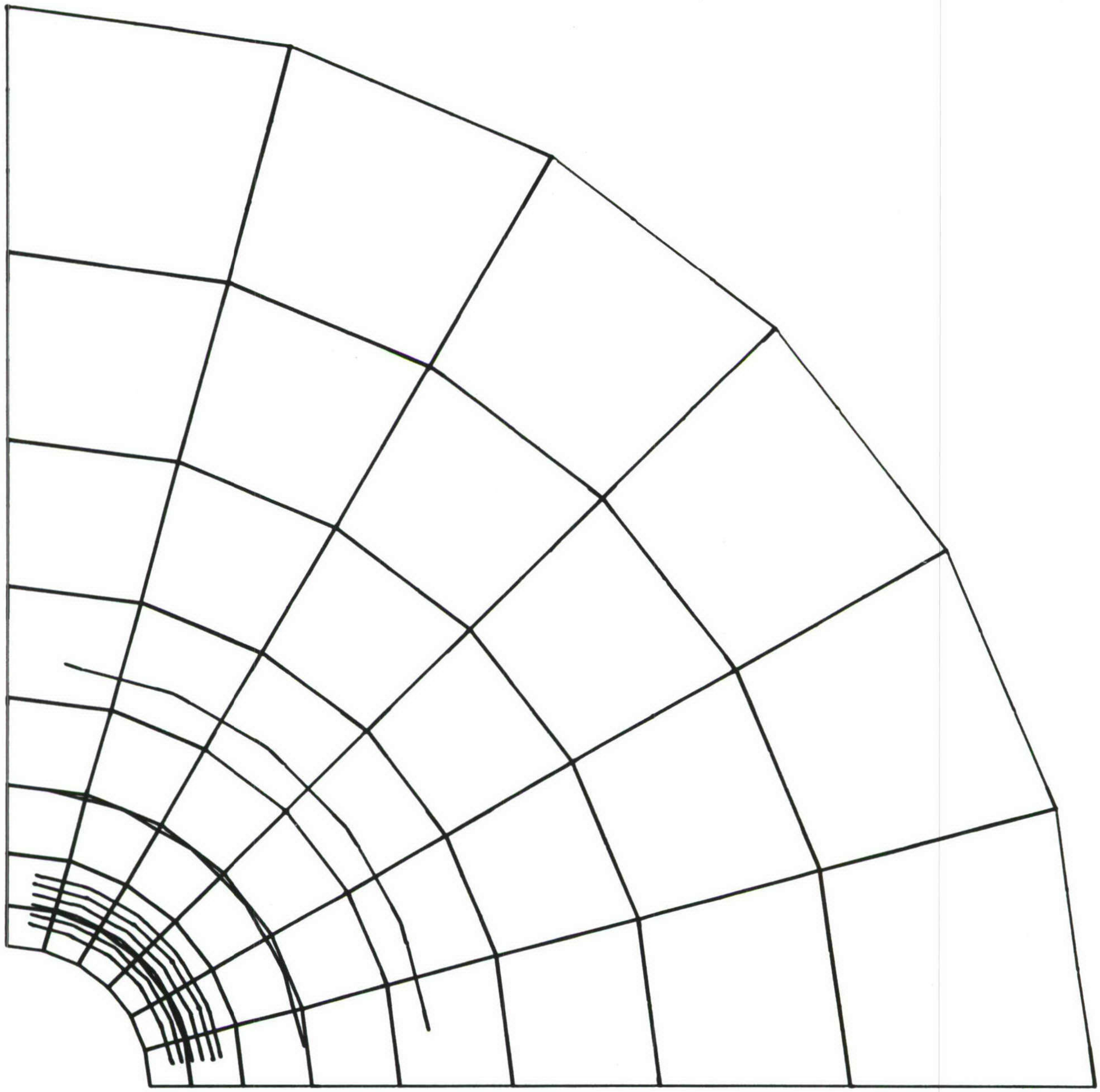


Figure AI-52 Tangential Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

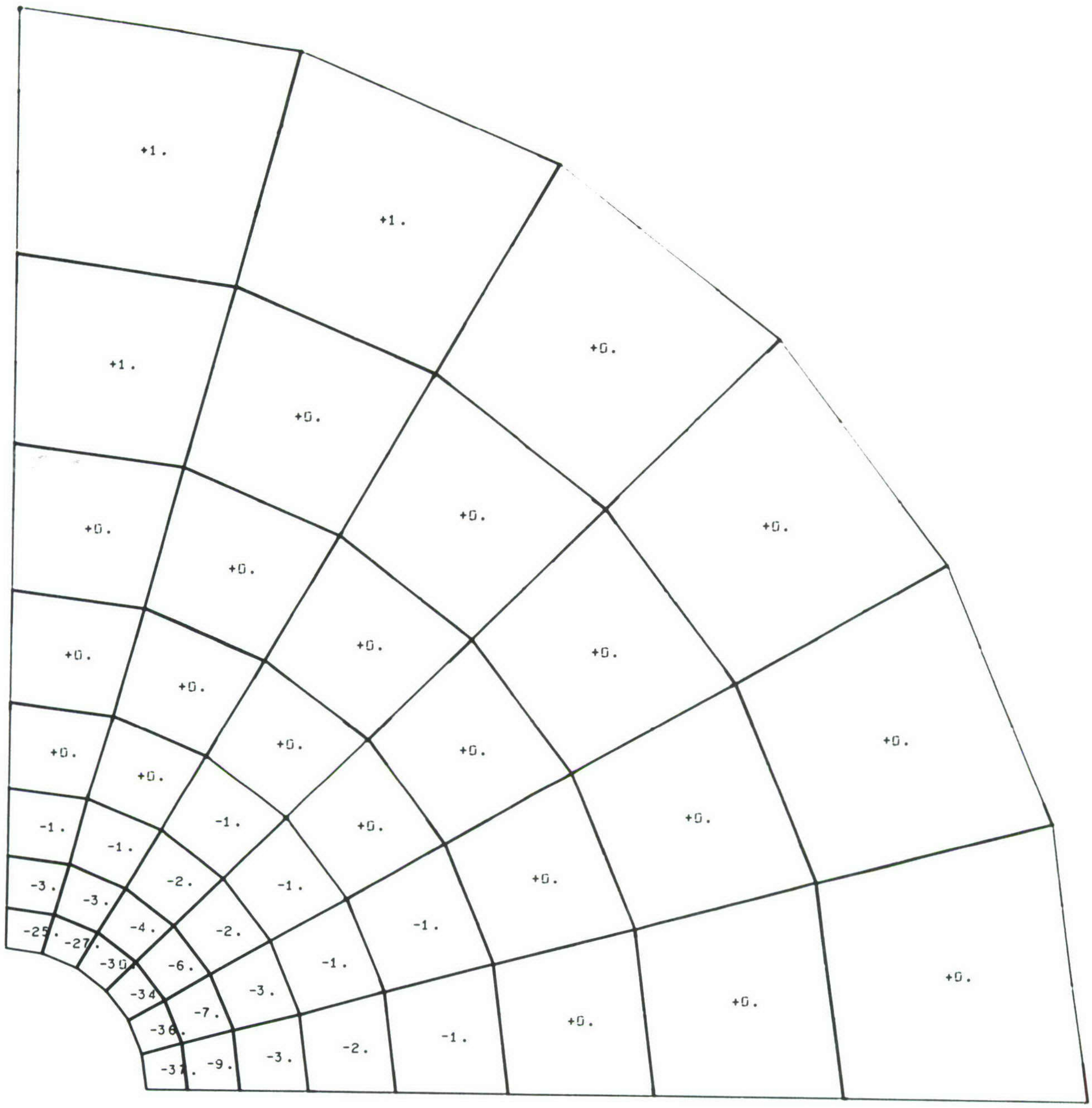


Figure AI-53 Radial Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

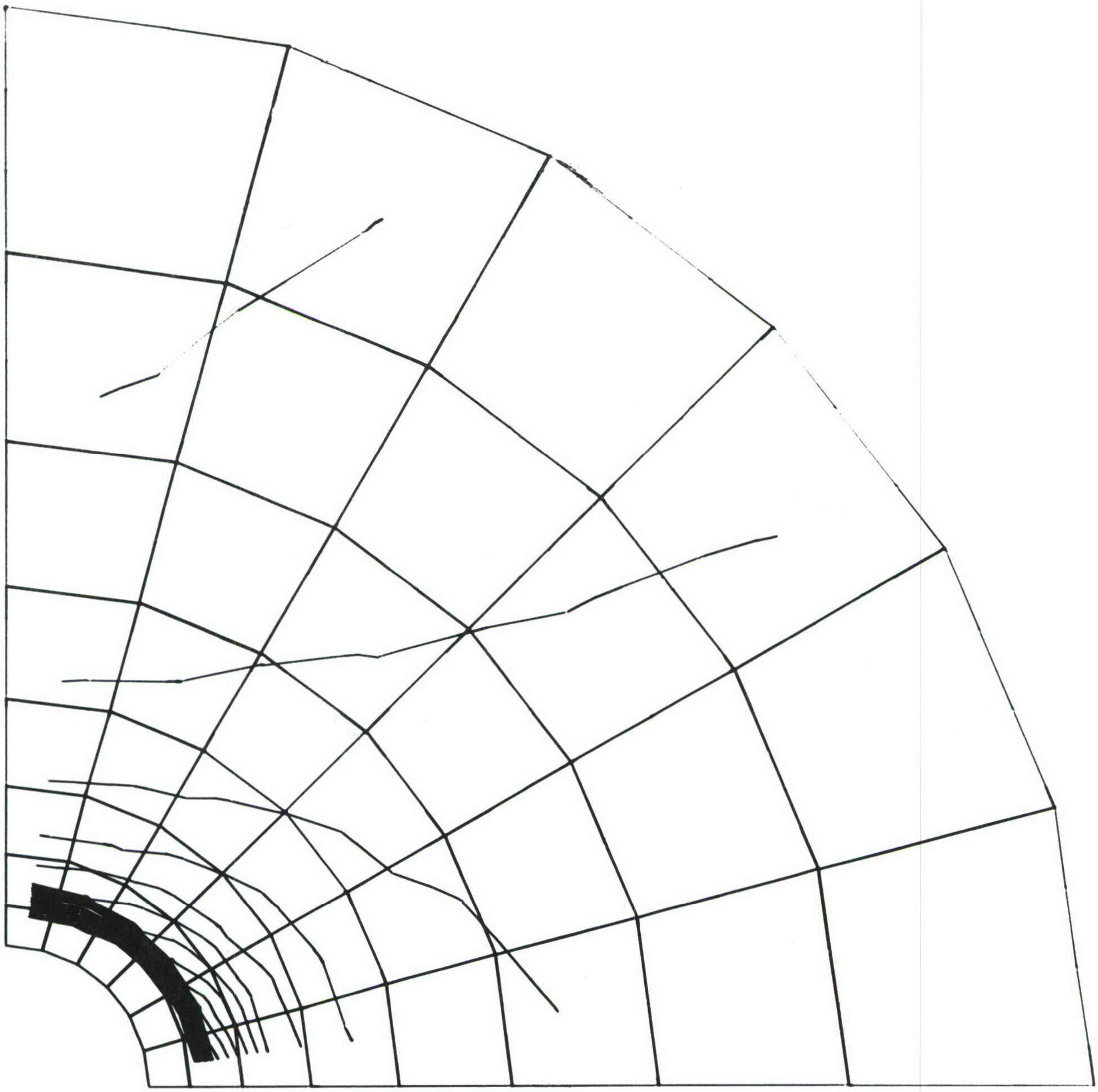


Figure AI-54 Radial Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

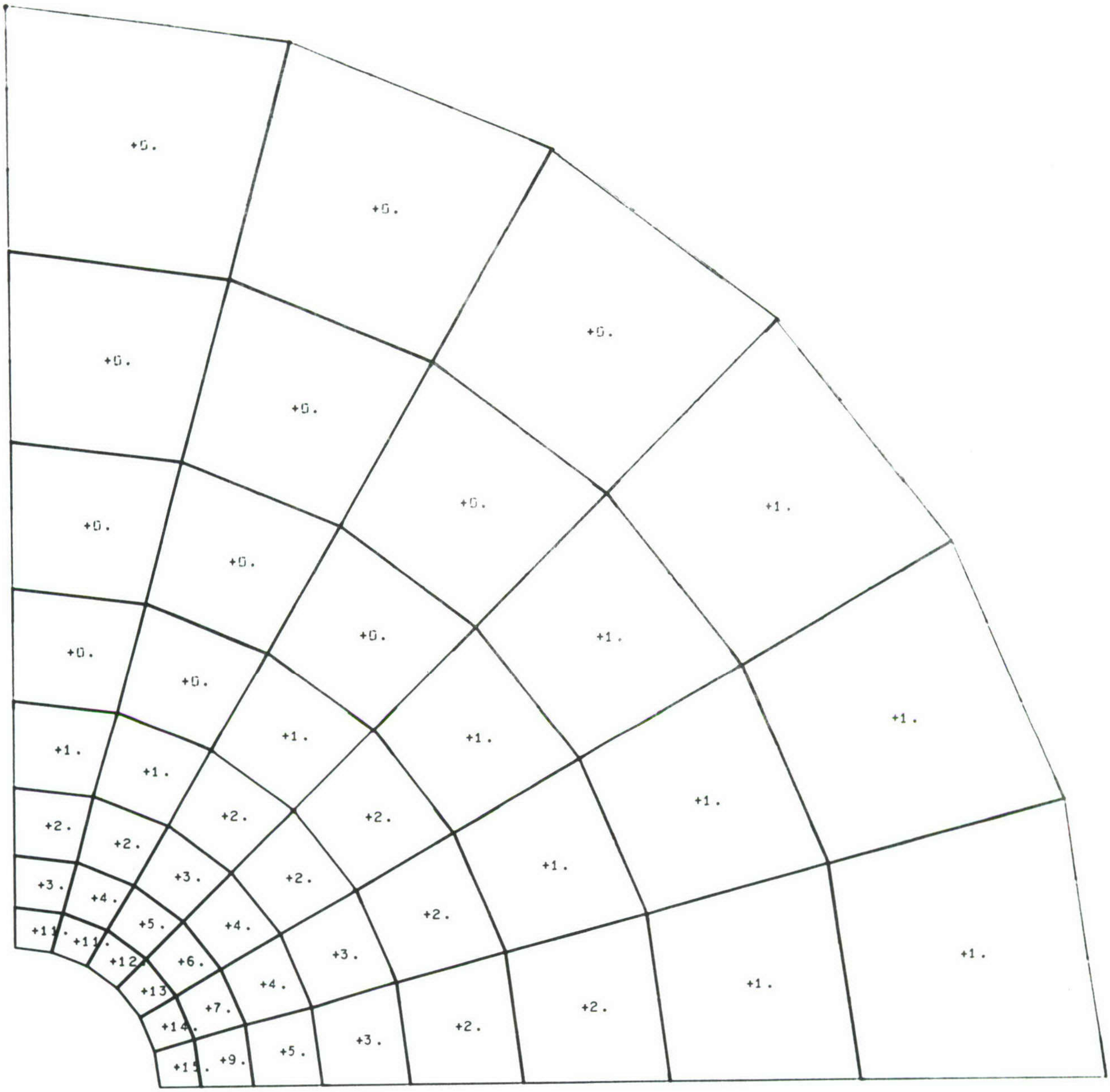


Figure AI-55 Tangential Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

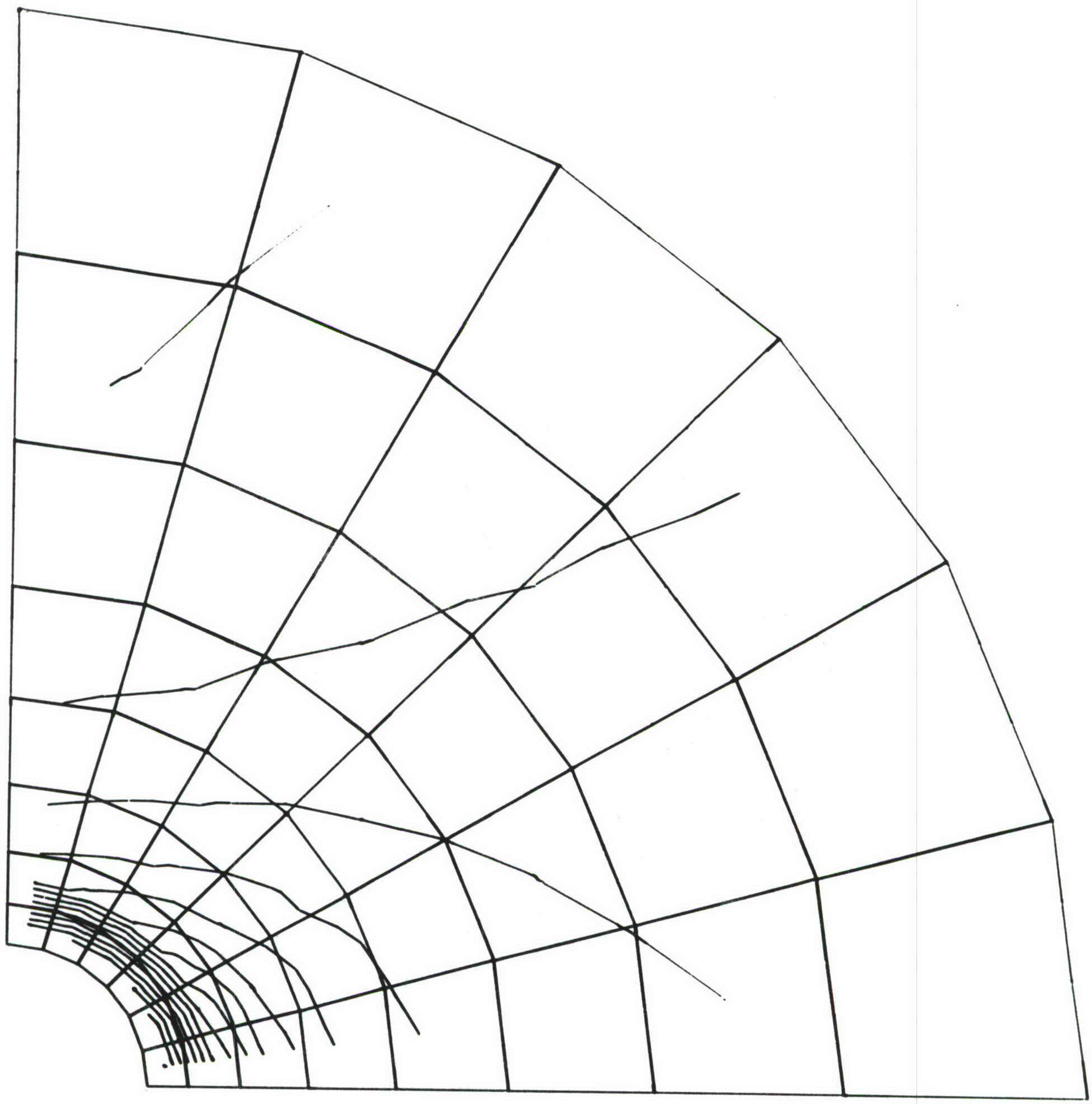


Figure AI-56 Tangential Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

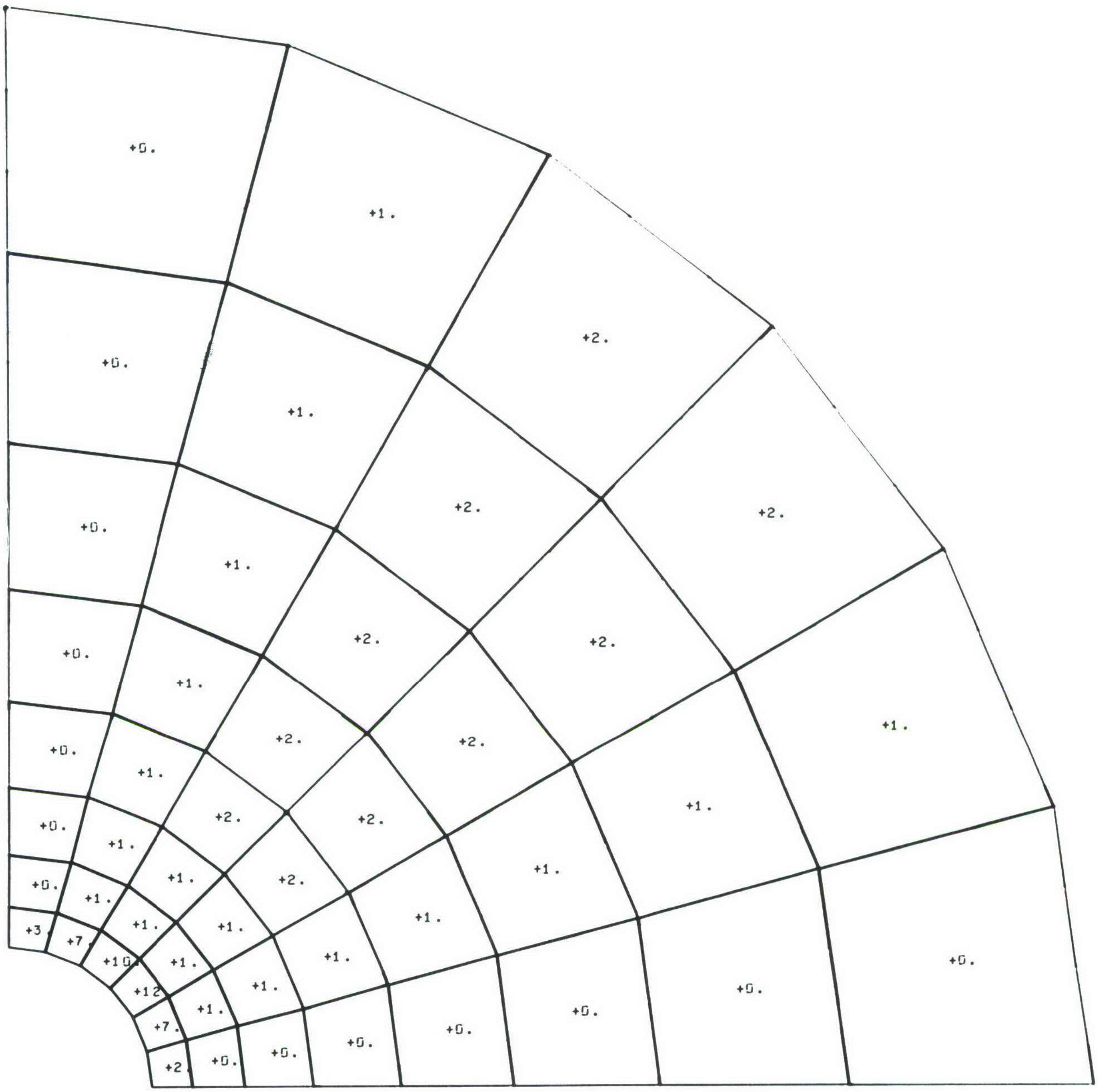


Figure AI-57 Radial-Tangential Shear Strain Values for Alumimum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

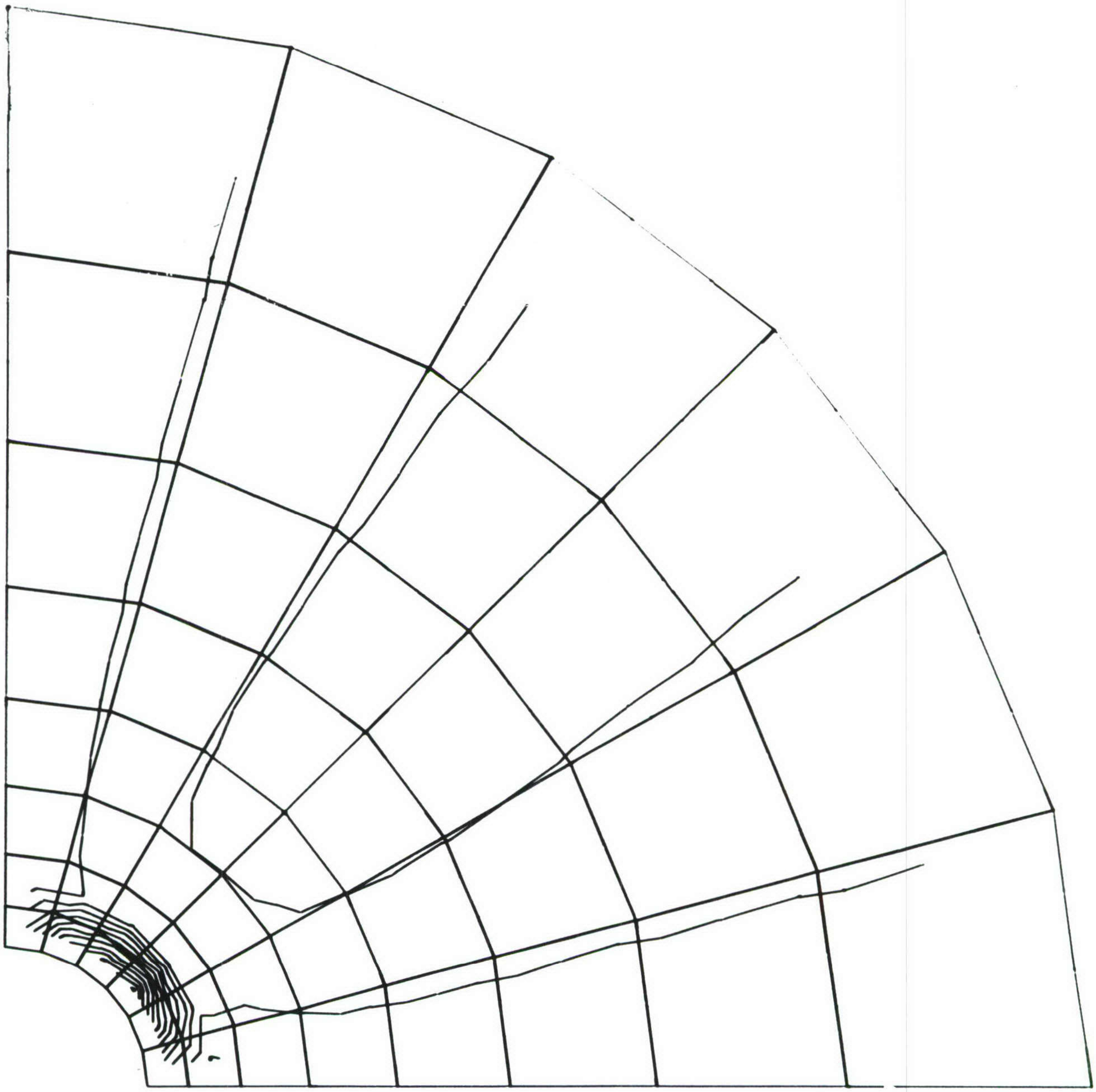


Figure AI-58 Radial-Tangential Shear Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

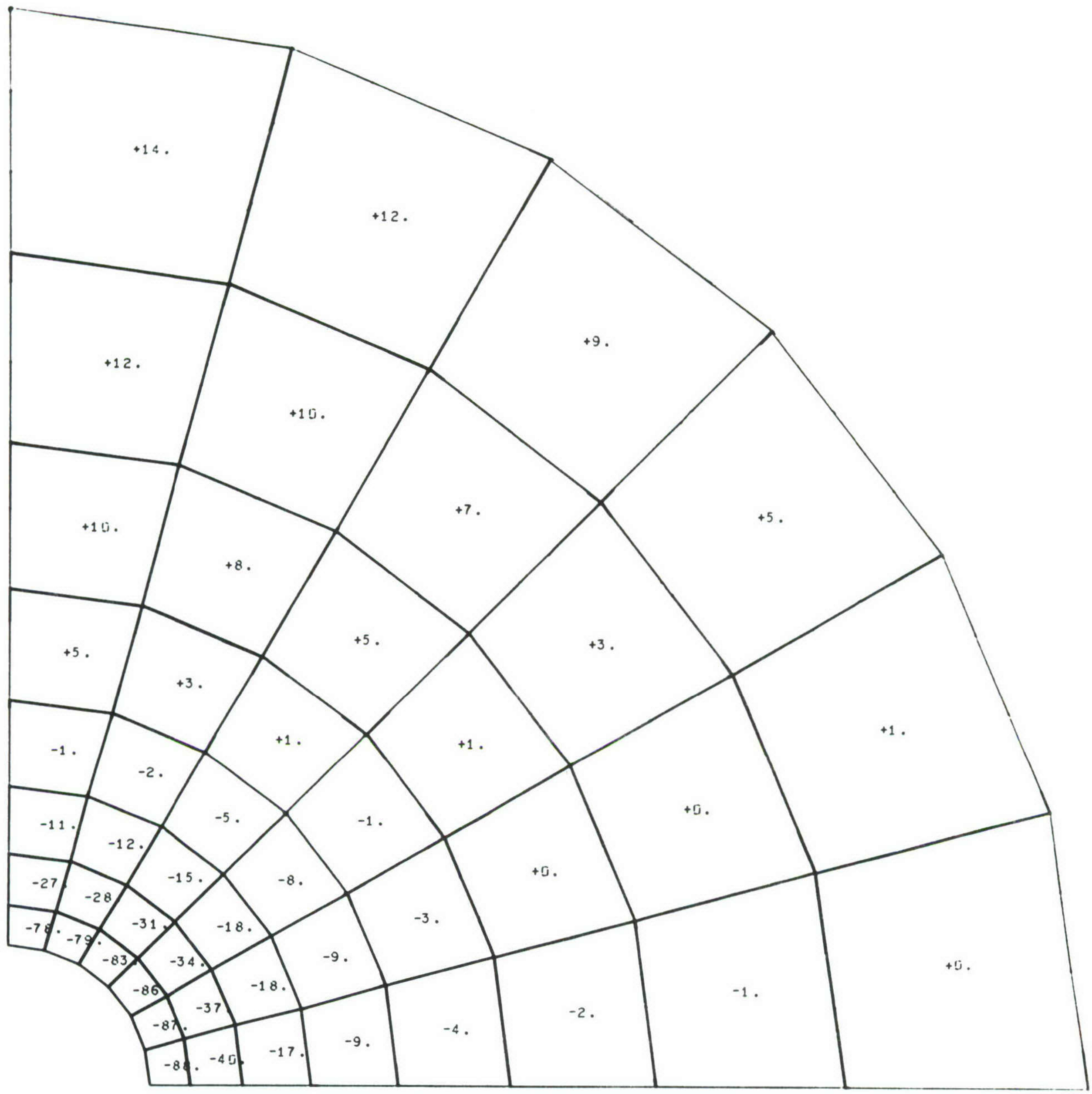


Figure AI-59 Radial Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

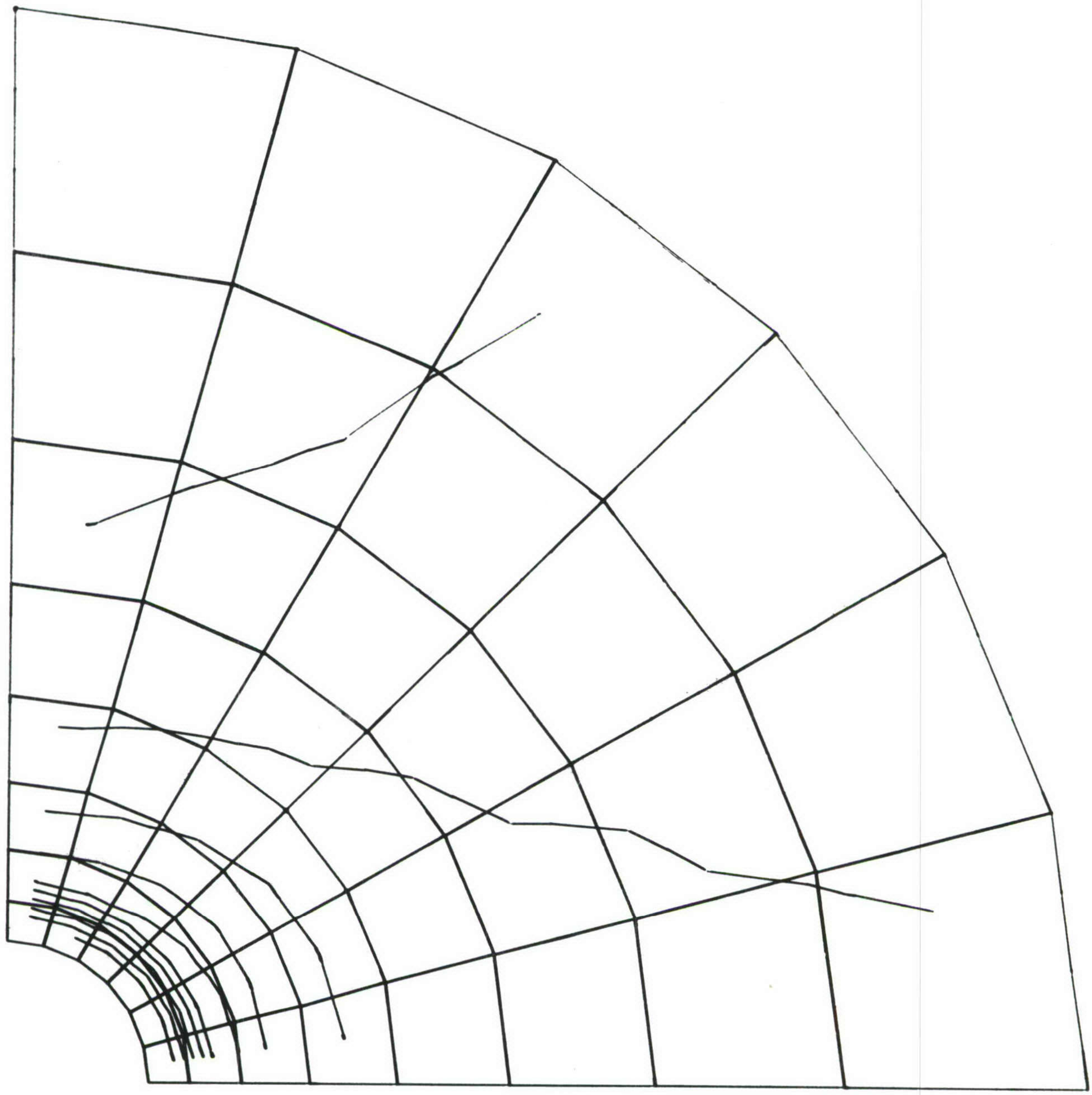


Figure AI-60 Radial Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

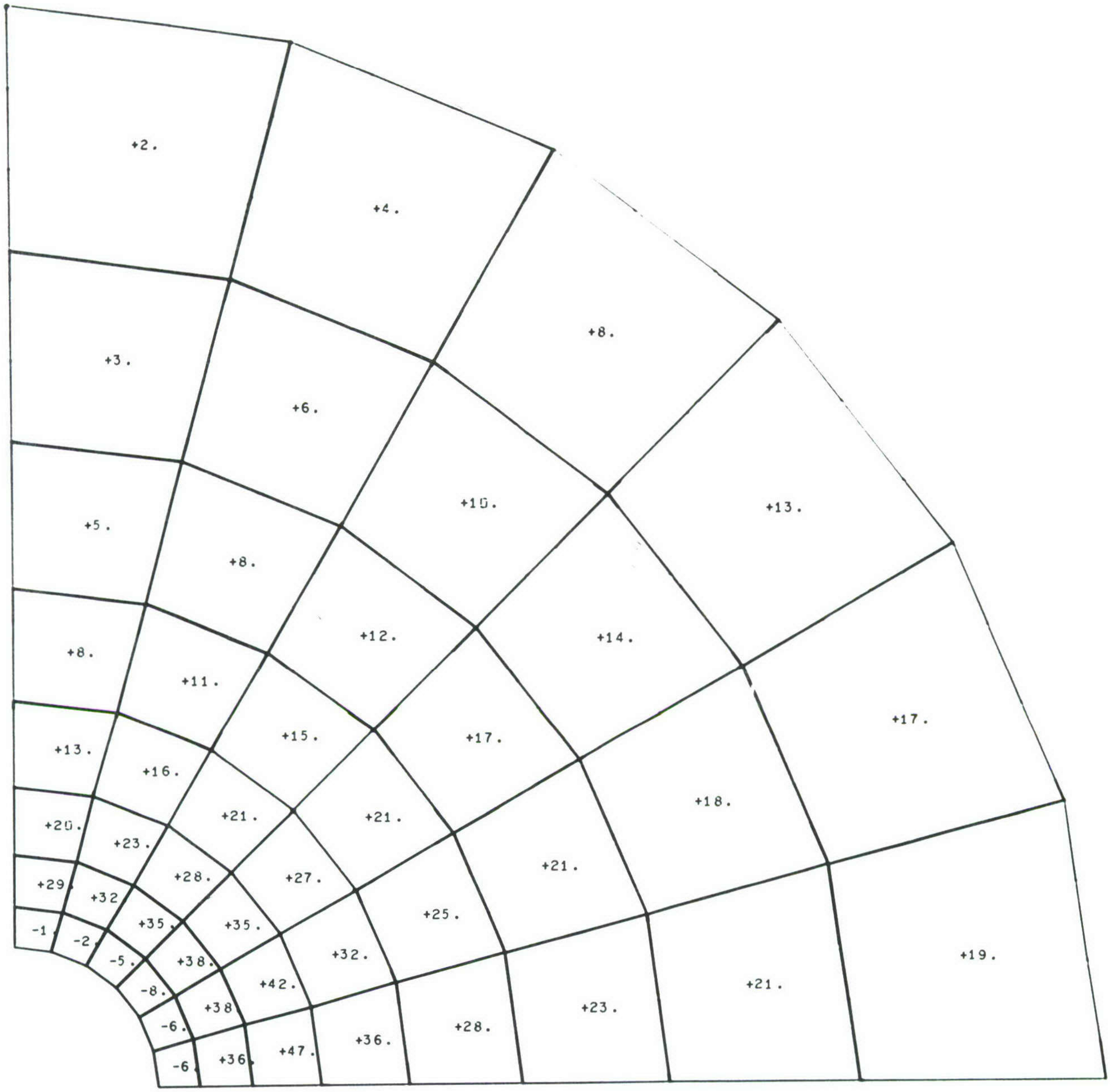


Figure AI-61 Tangential Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

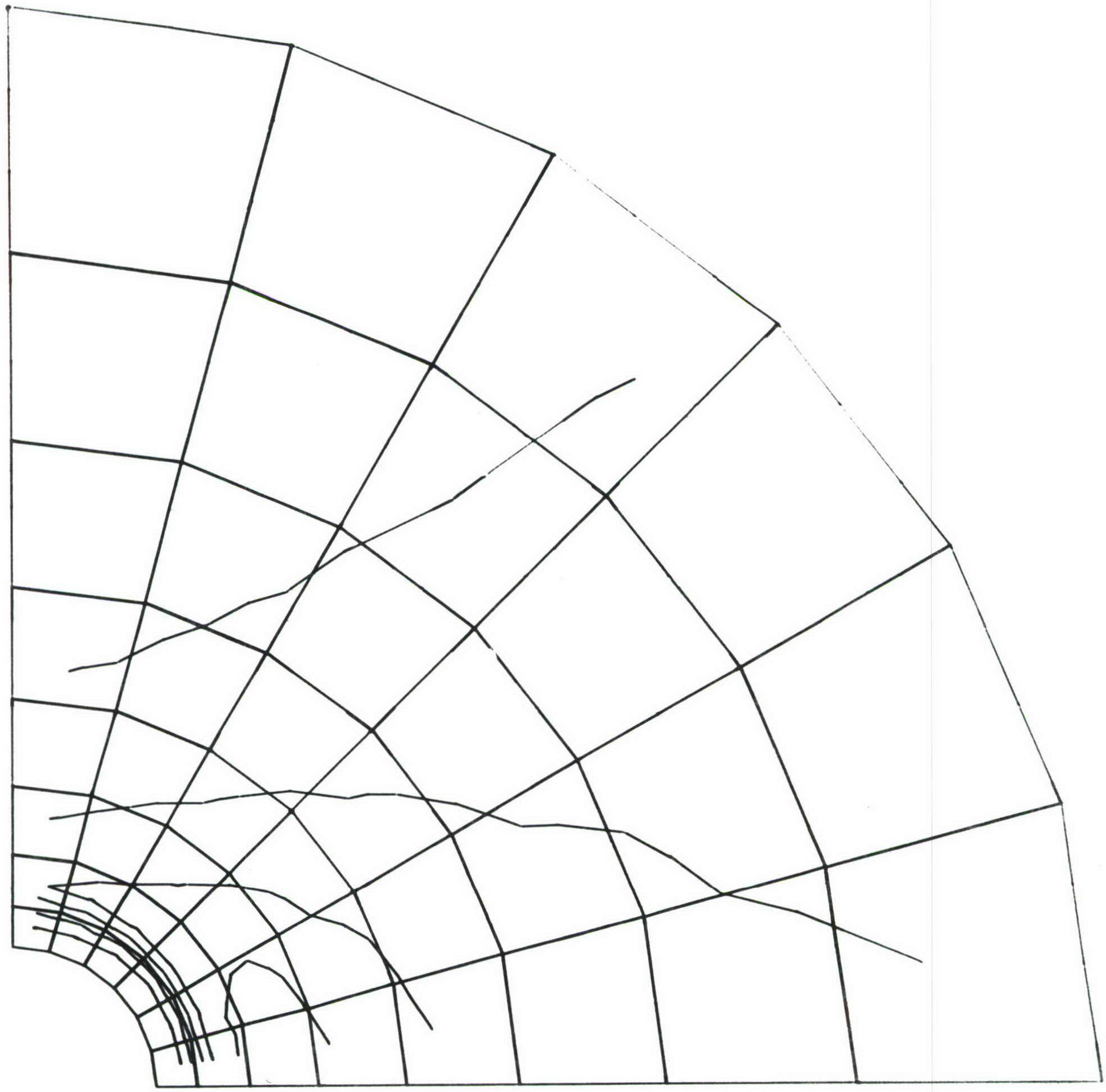


Figure AI-62 Tangential Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

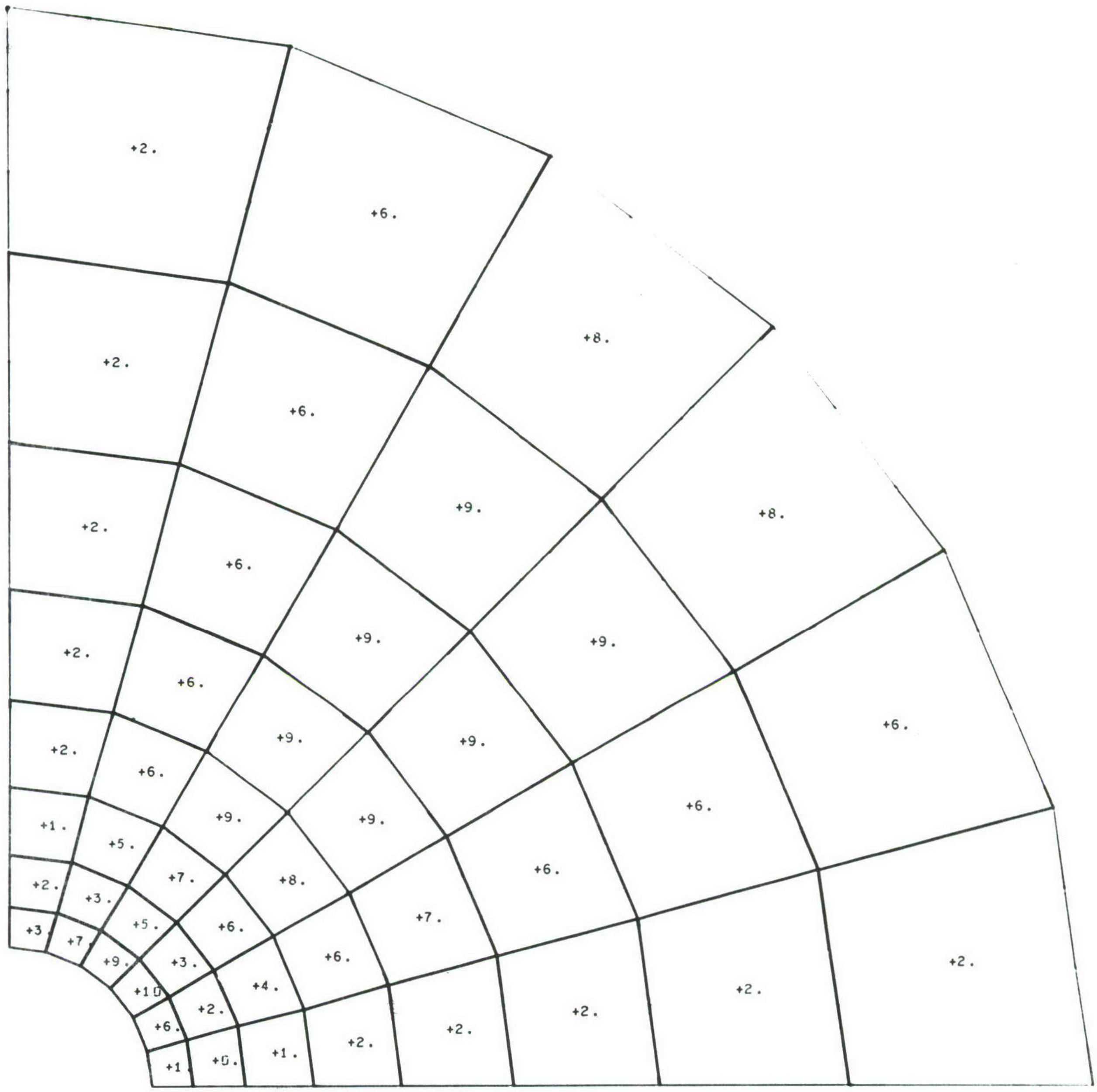


Figure AI-63 Radial-Tangential Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

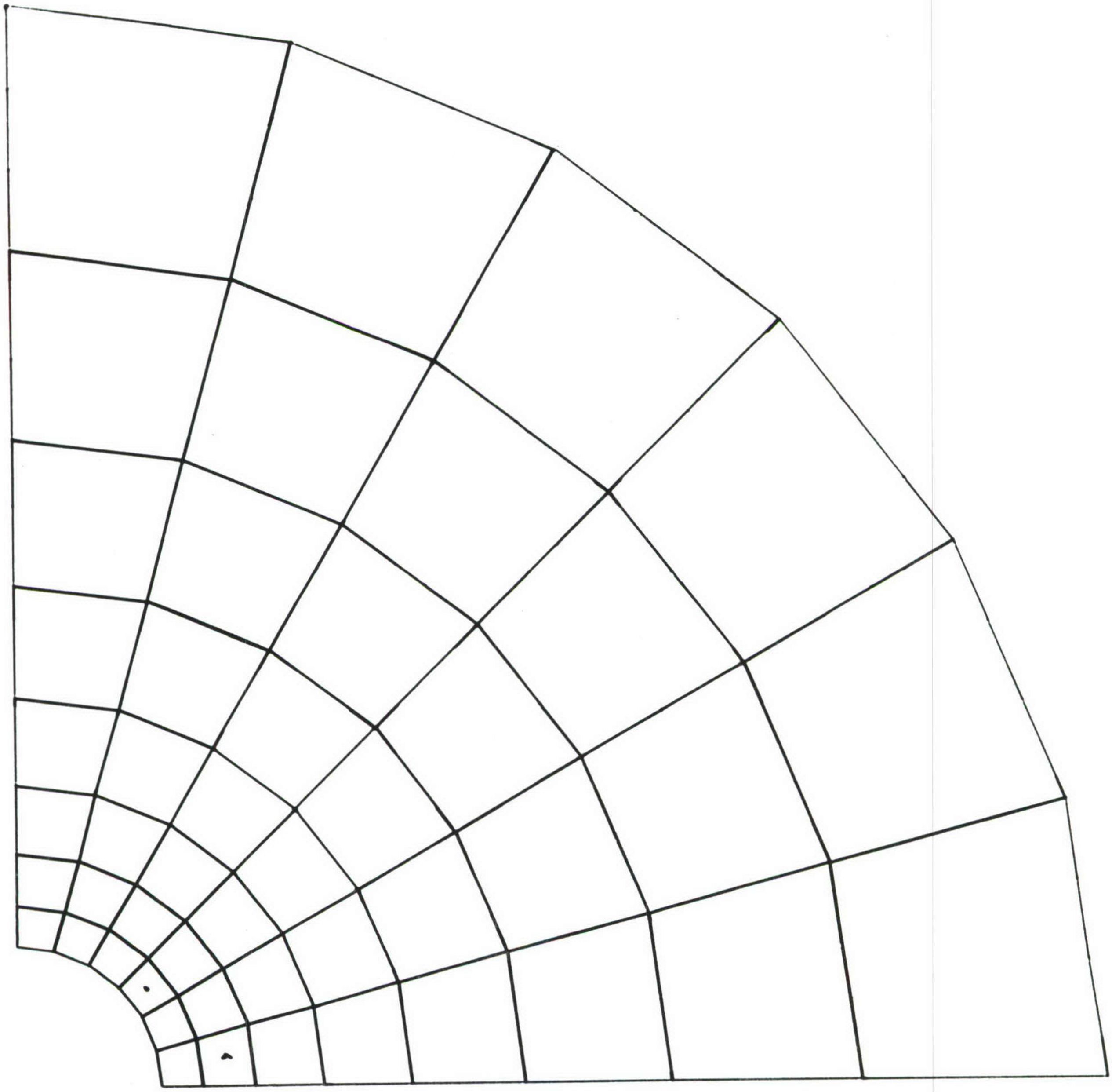


Figure AI-64 Radial-Tangential Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

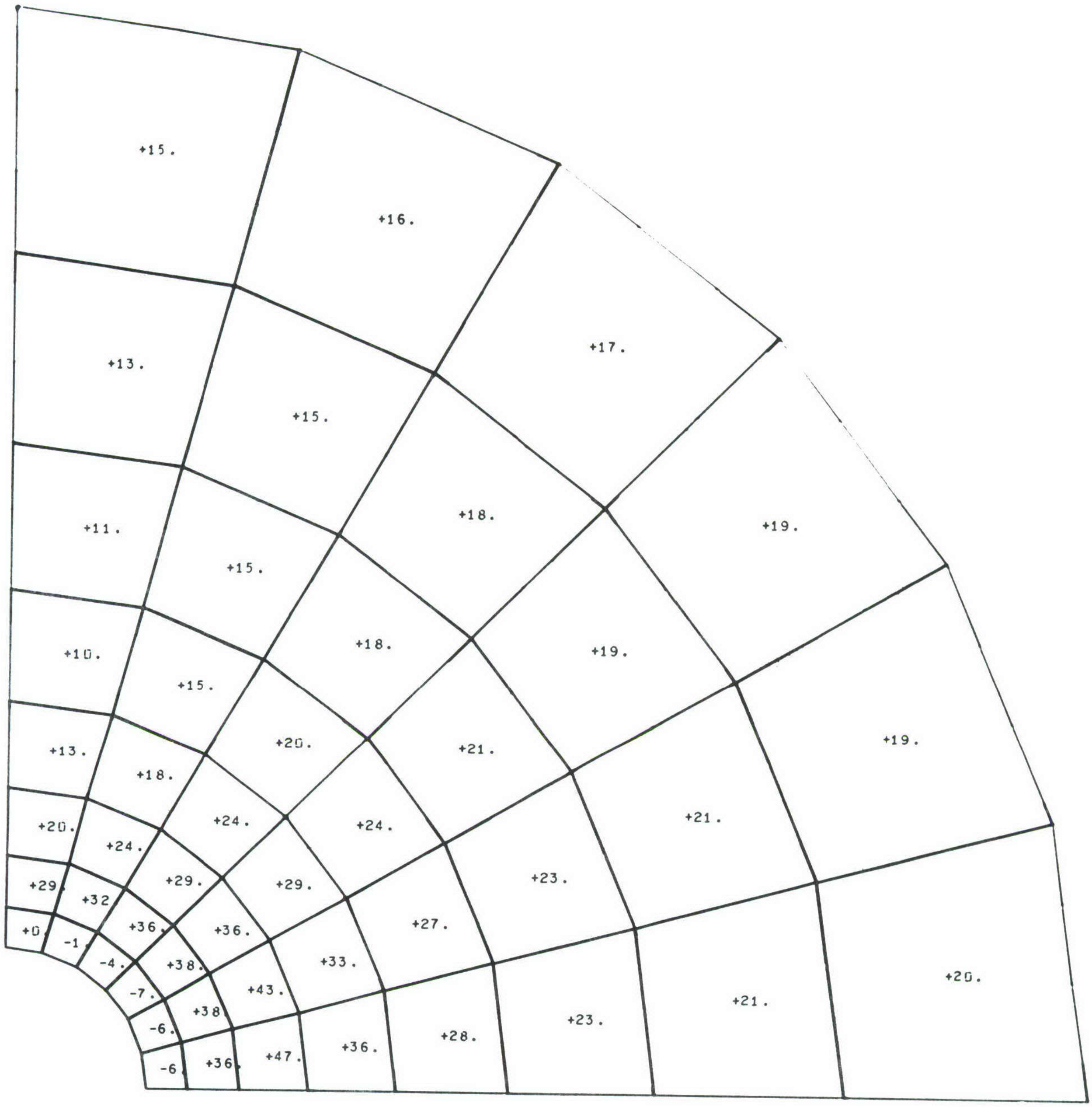


Figure AI-65 First Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

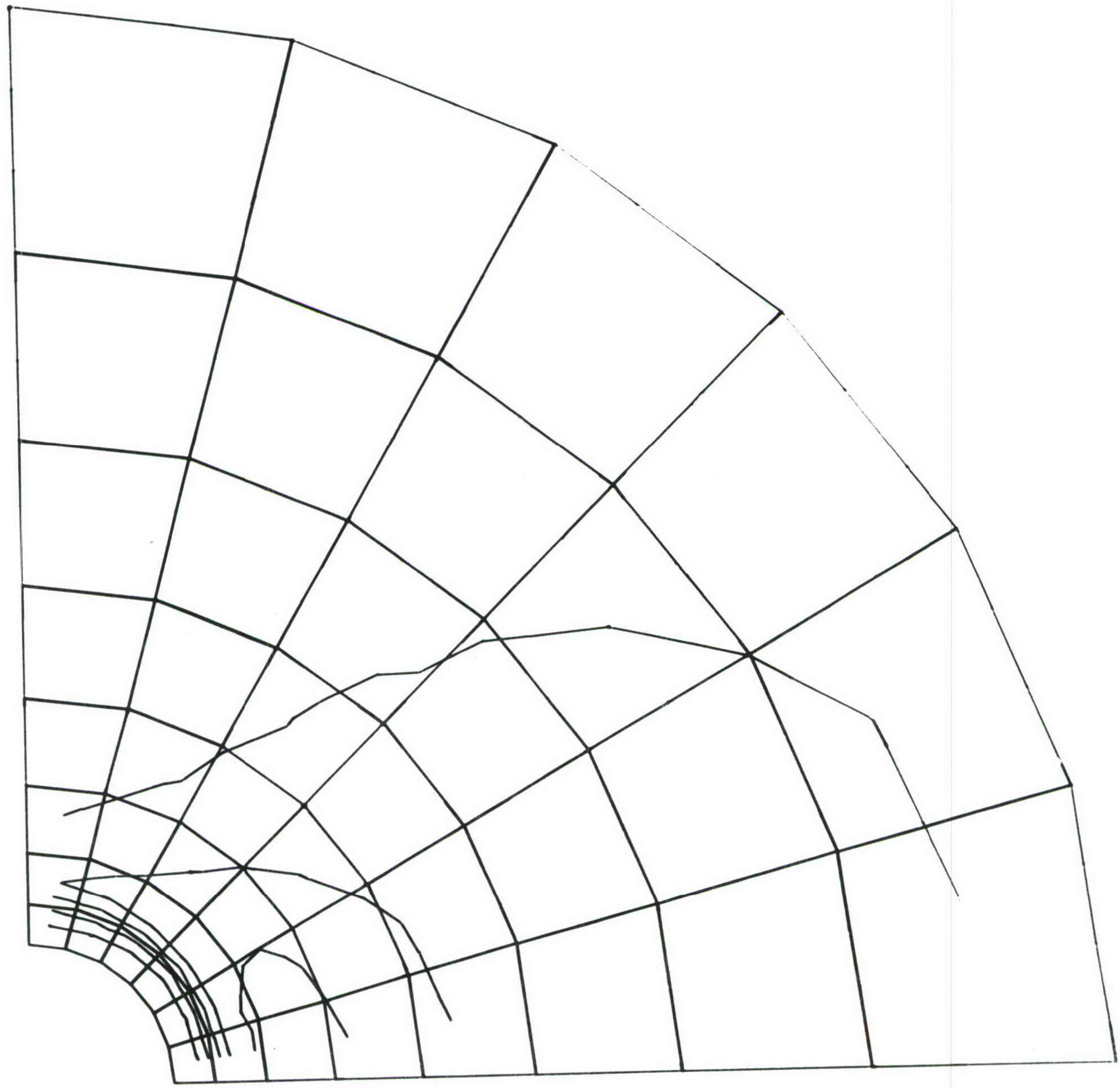


Figure AI-66 First Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

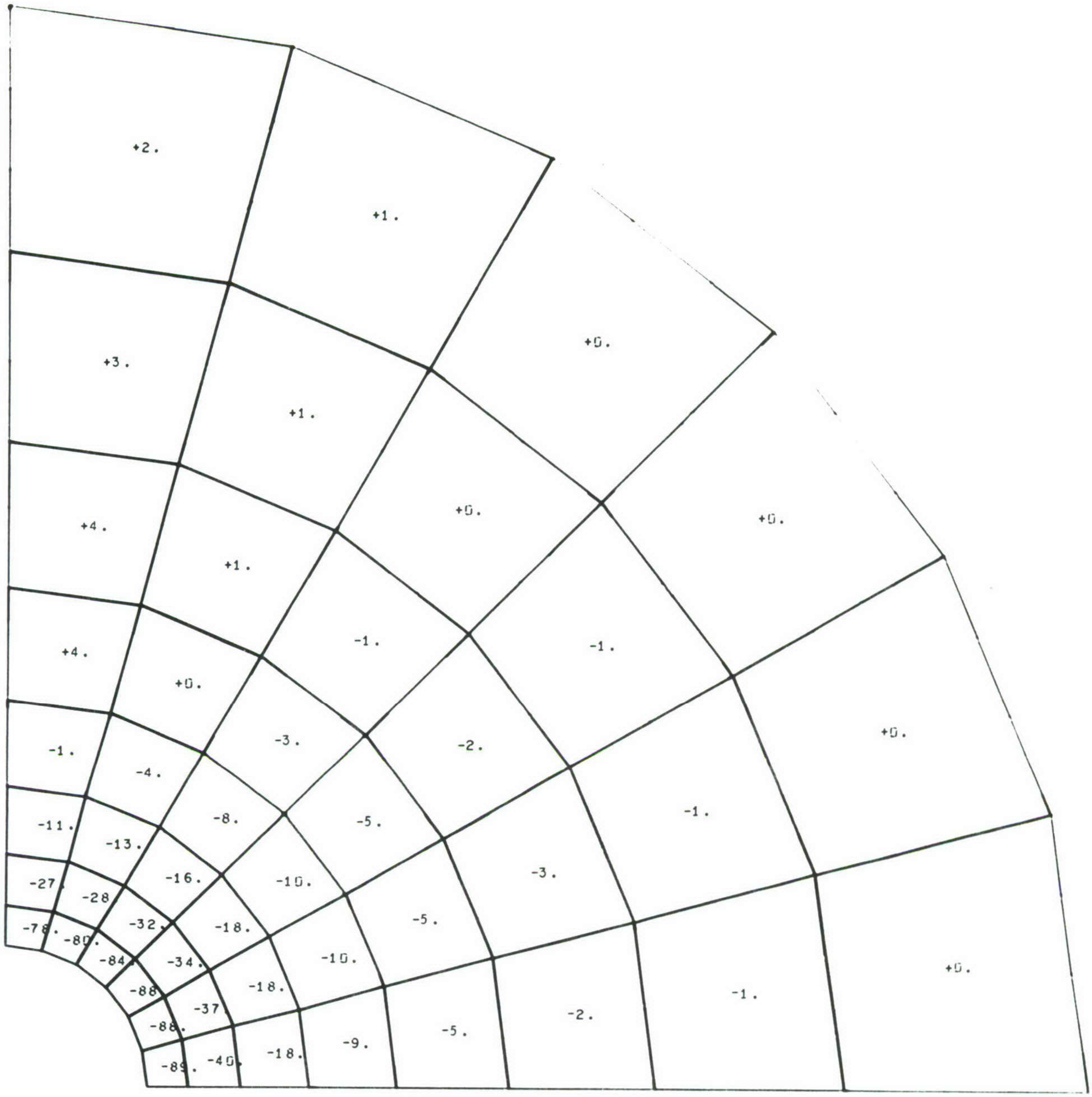


Figure AI-67 Second Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

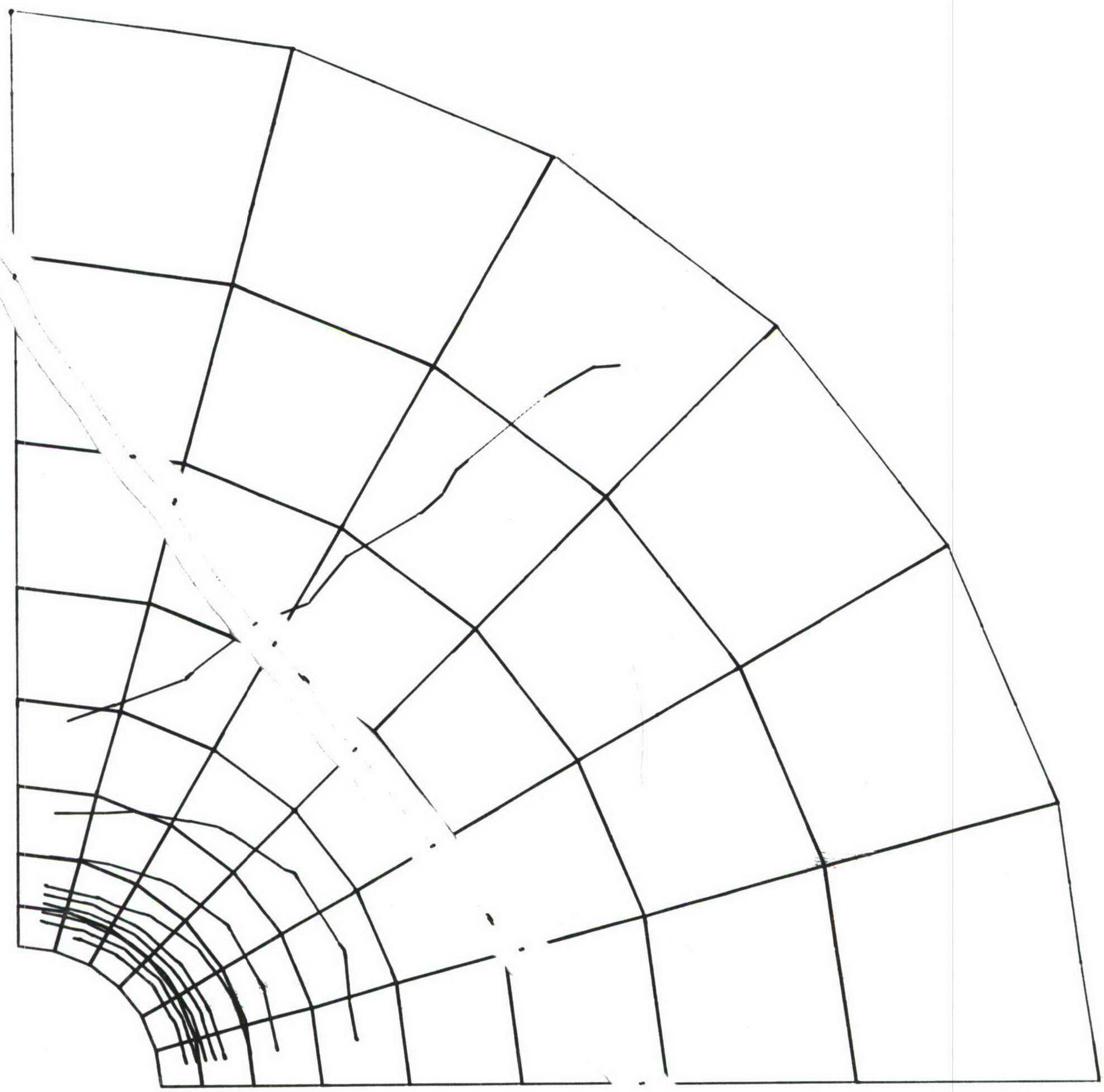


Figure AI-68 Second Principal Stress Cont[illegible] for Aluminum Plate with 3/16 Inch Hole Radius; 0.[illegible]75 Inch Radial Interference; 35% Uniaxi[illegible] Load

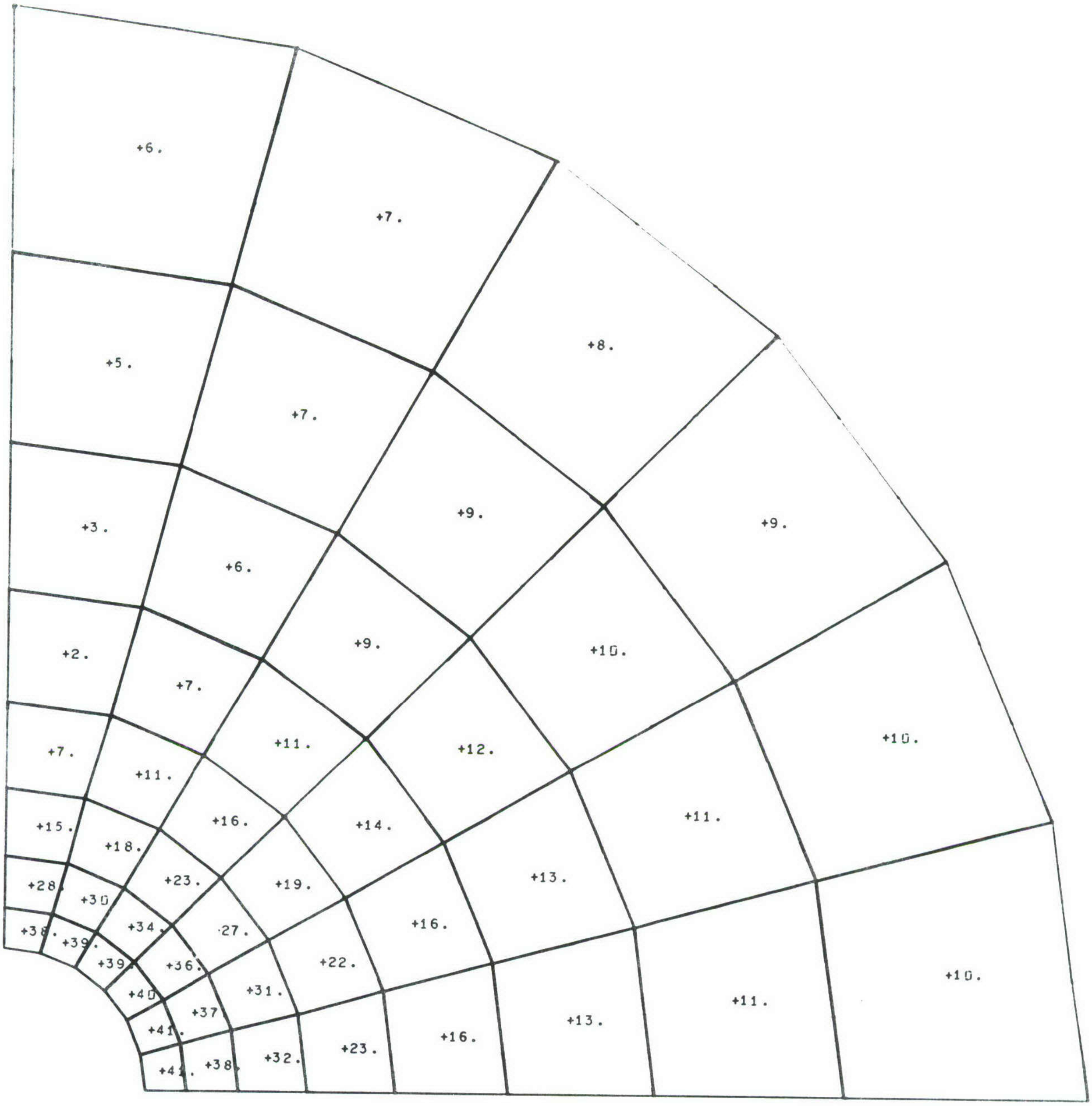


Figure AI-69 Principal Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

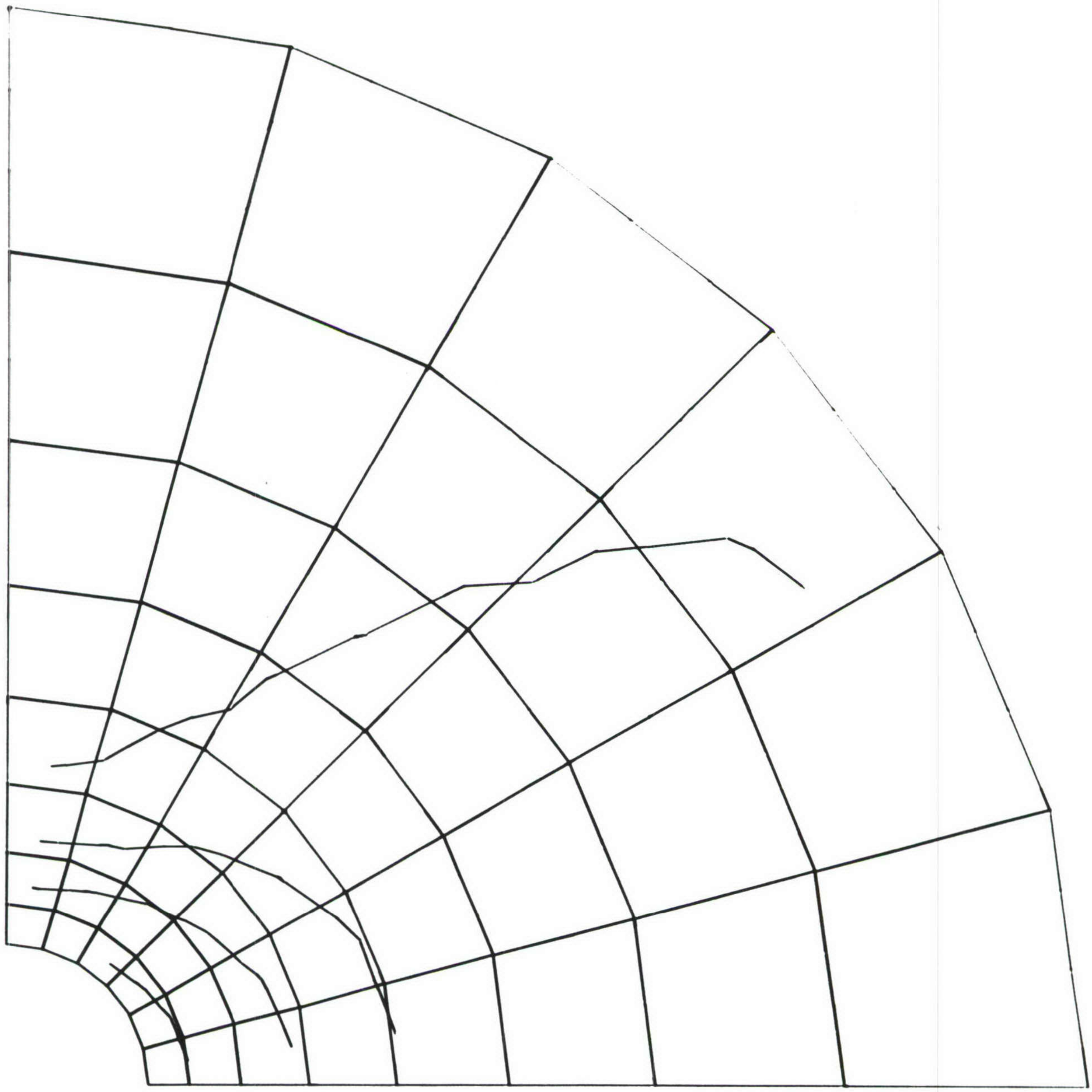


Figure AI-70 Principal Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

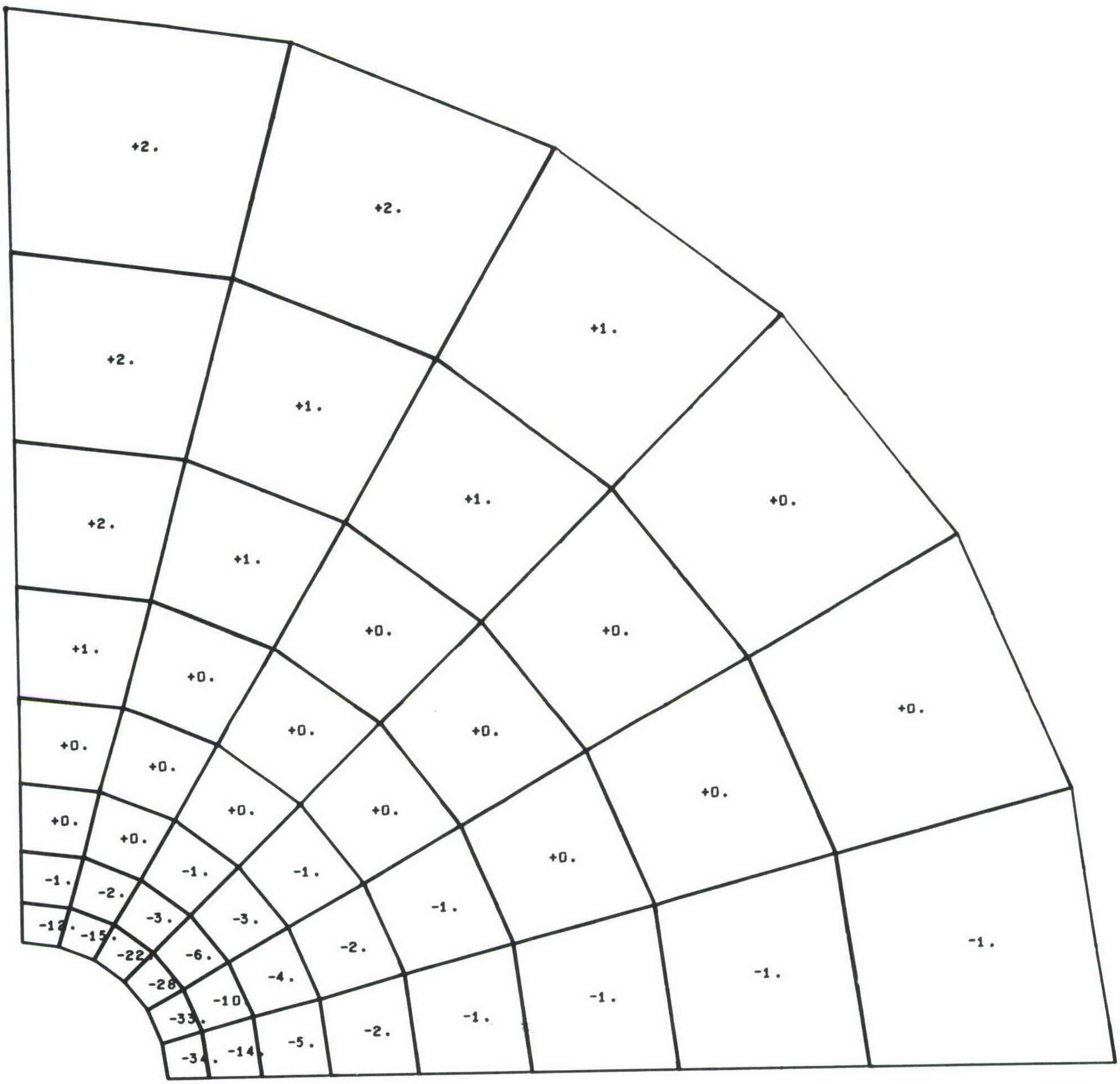


Figure AI-71 Radial Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

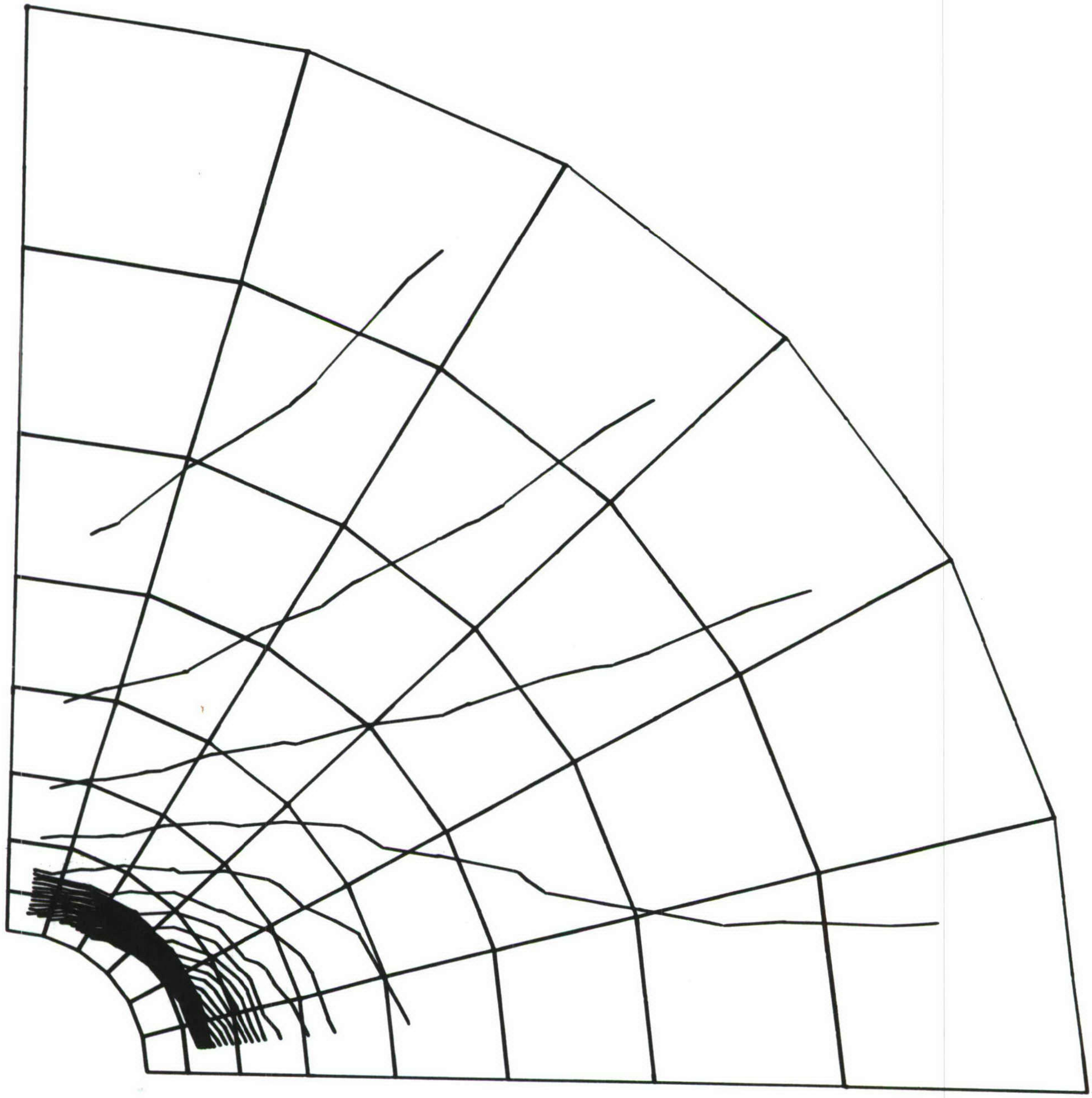


Figure AI-72 Radial Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

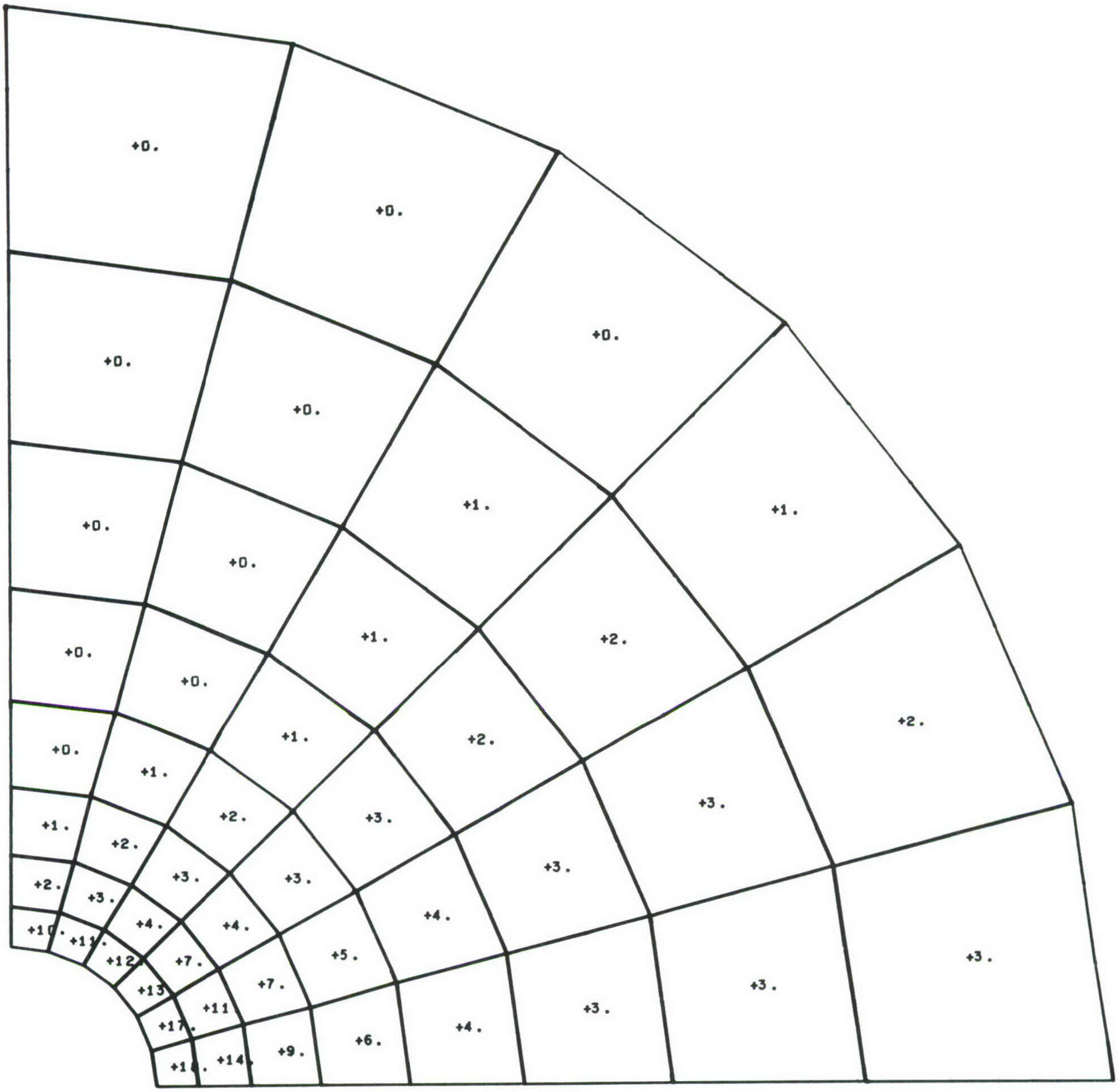


Figure AI-73   Tangential Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

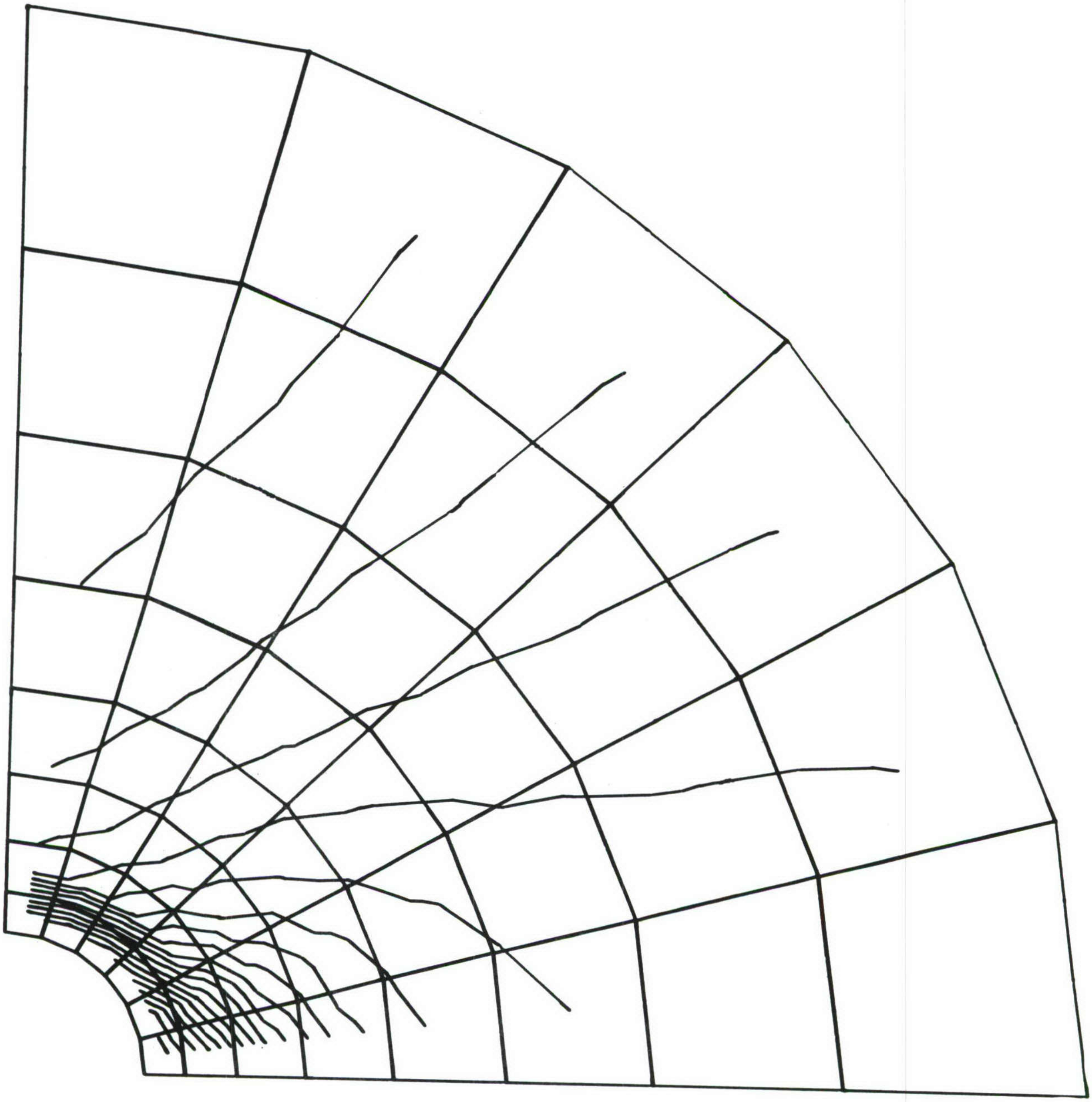


Figure AI-74 Tangential Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

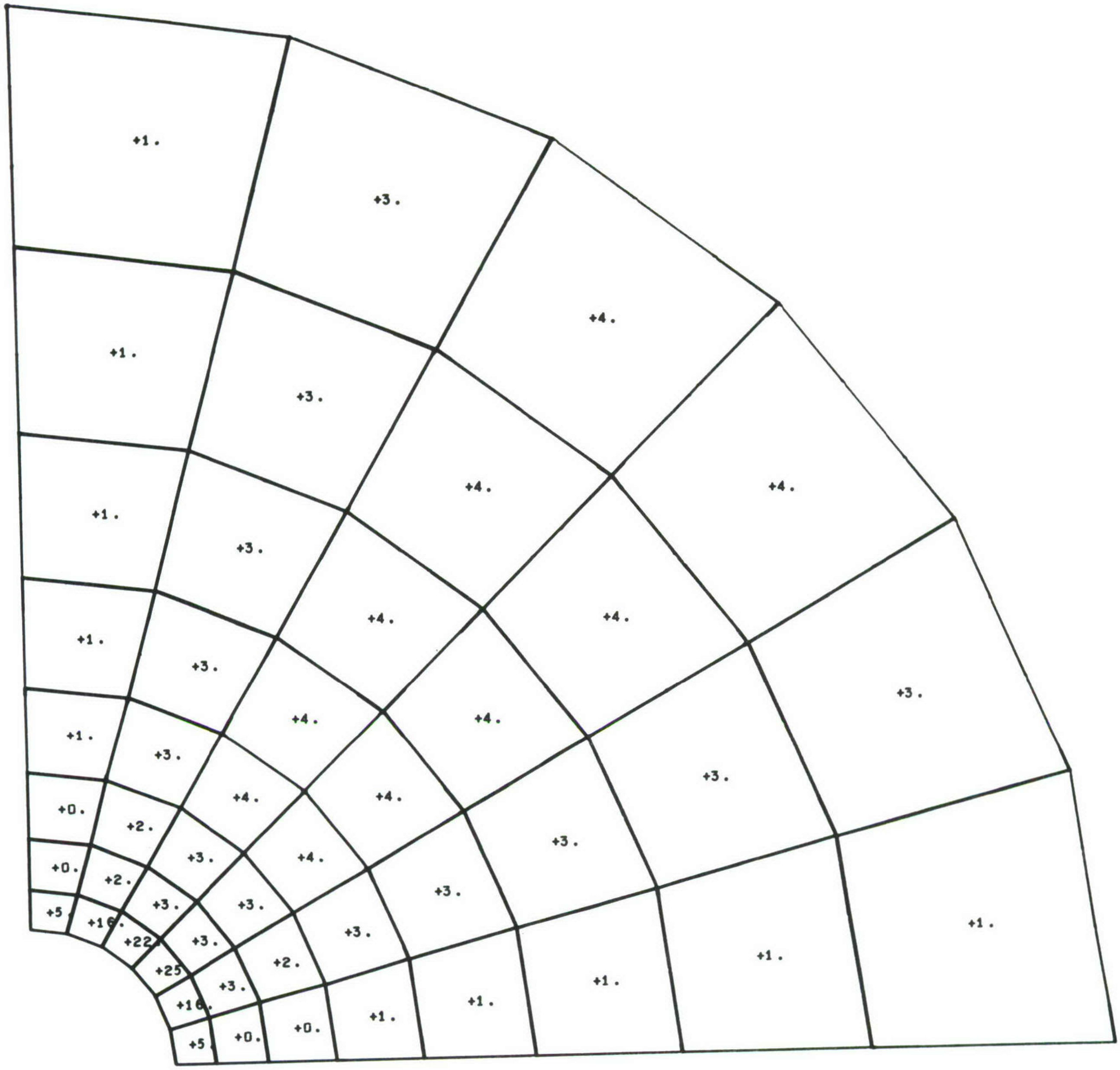


Figure AI-75 Radial-Tangential Shear Strain Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

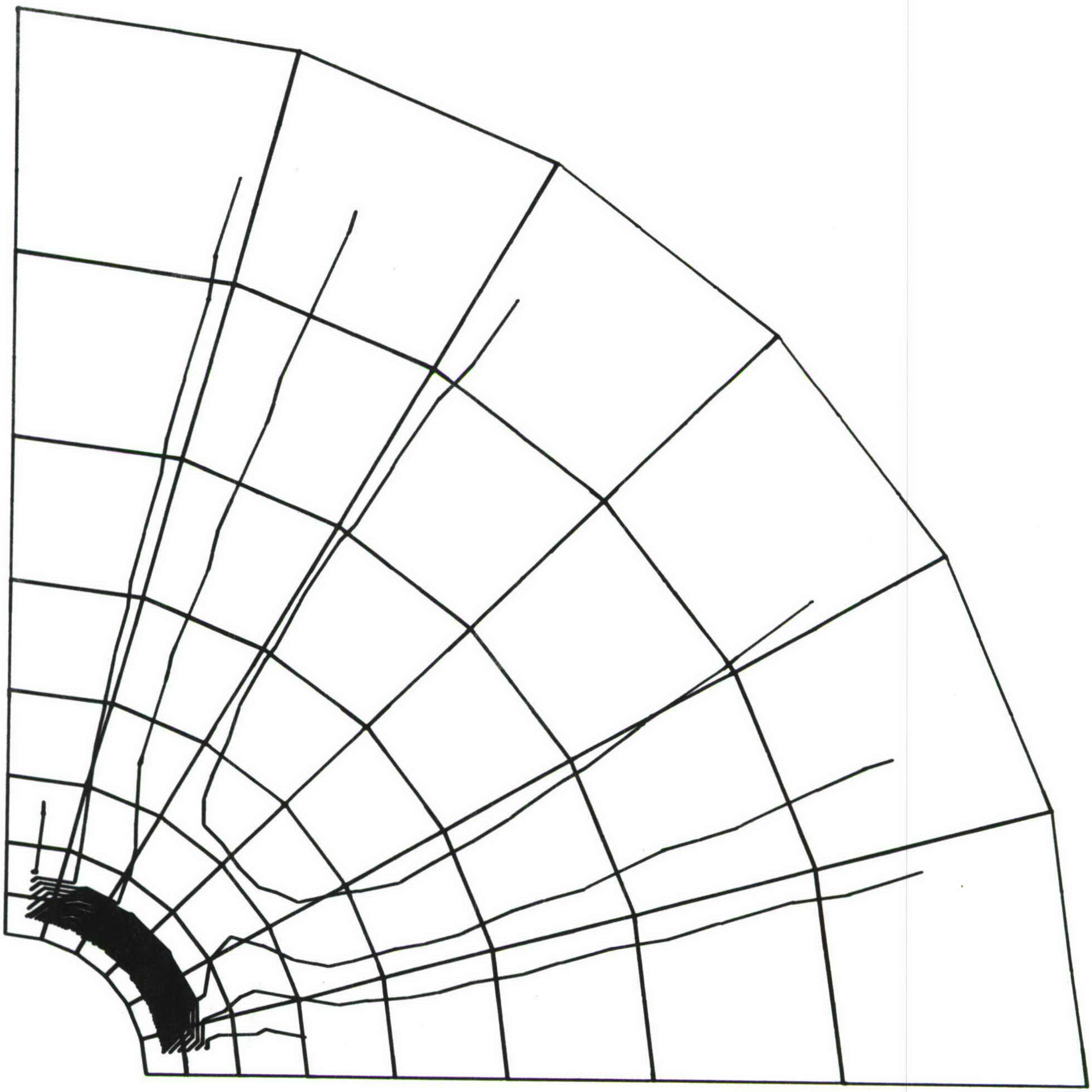


Figure AI-76 Radial-Tangential Shear Strain Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

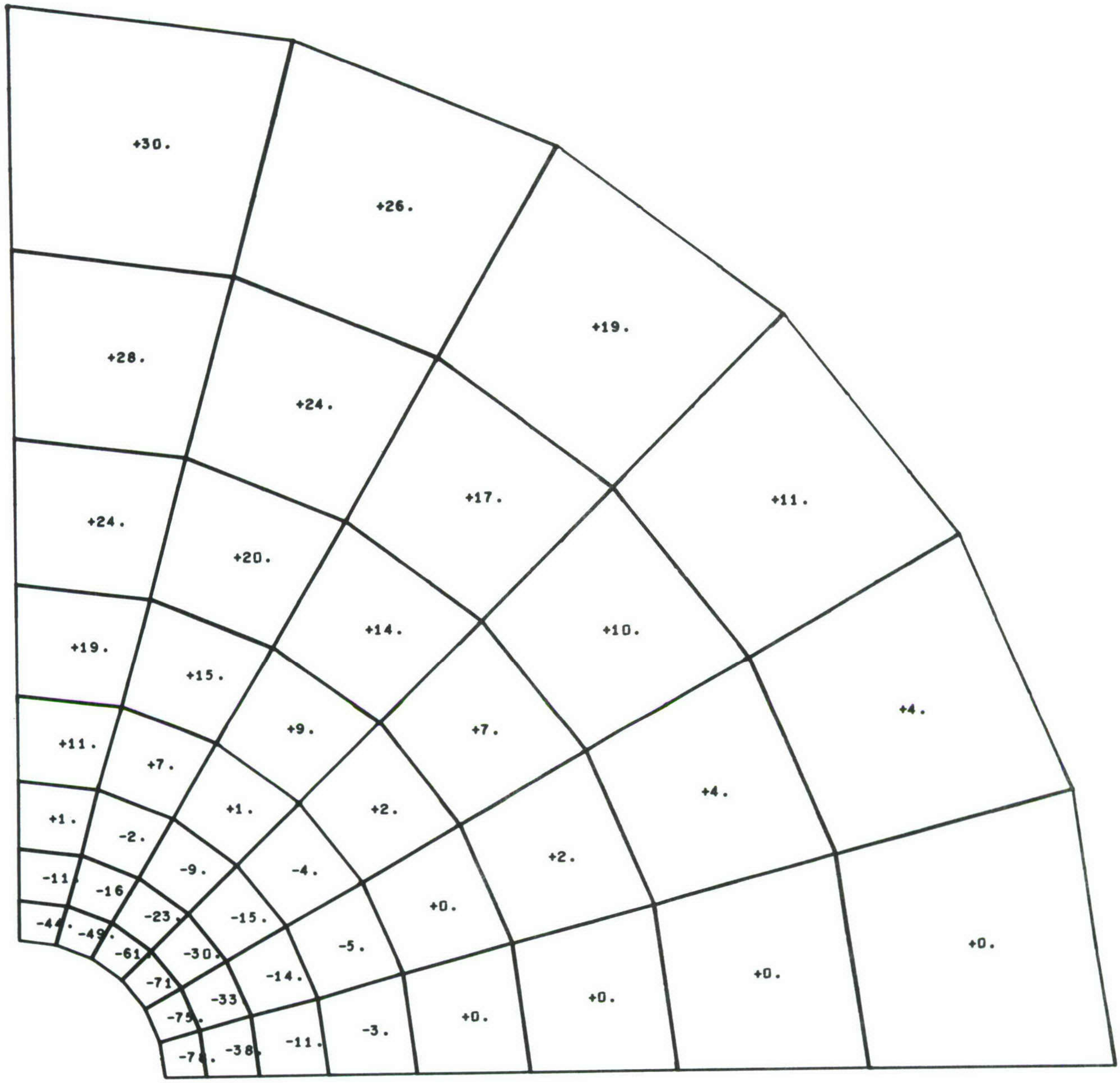


Figure AI-77 Radial Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

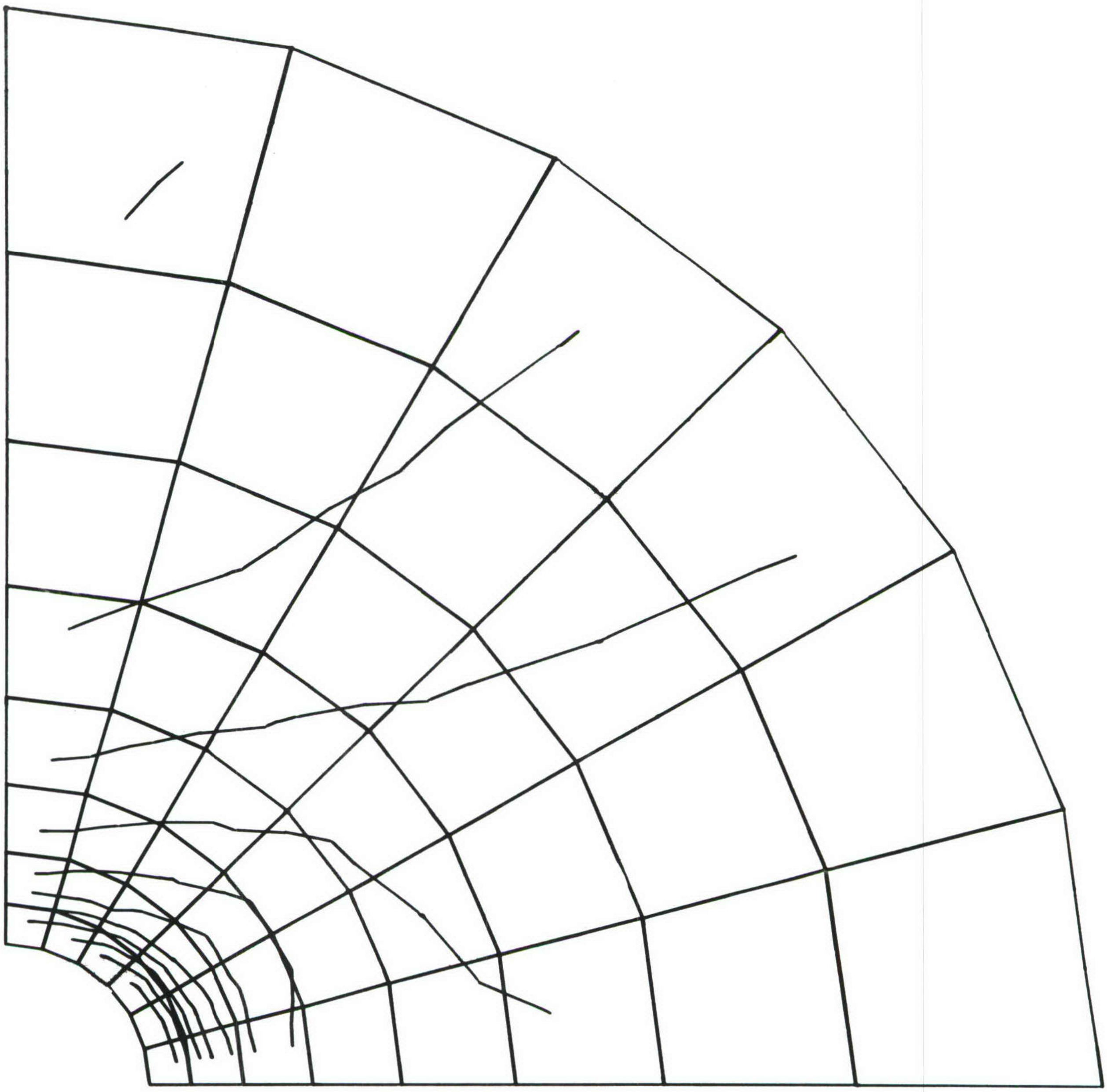


Figure AI-78 Radial Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

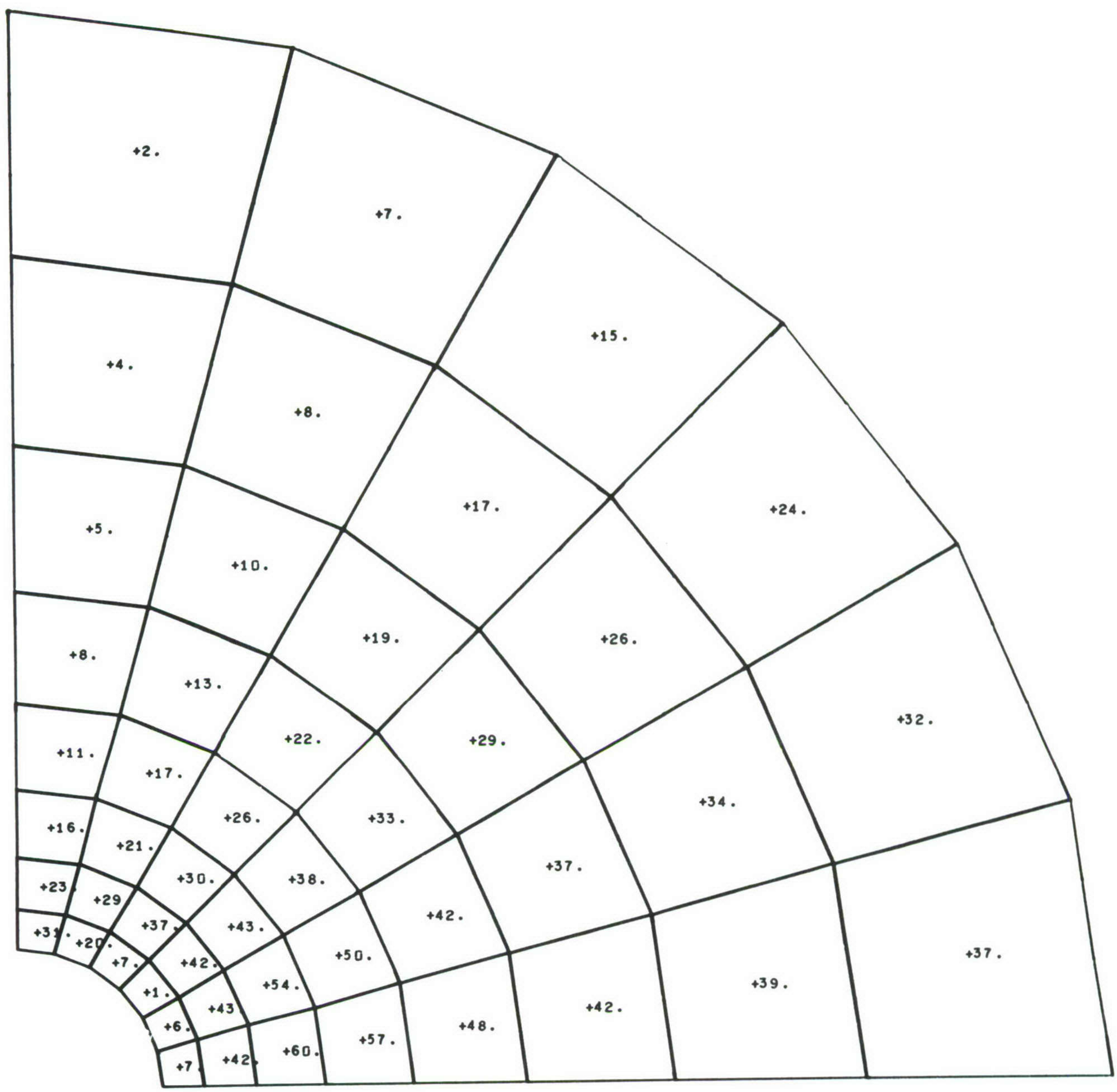


Figure AI-79 Tangential Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

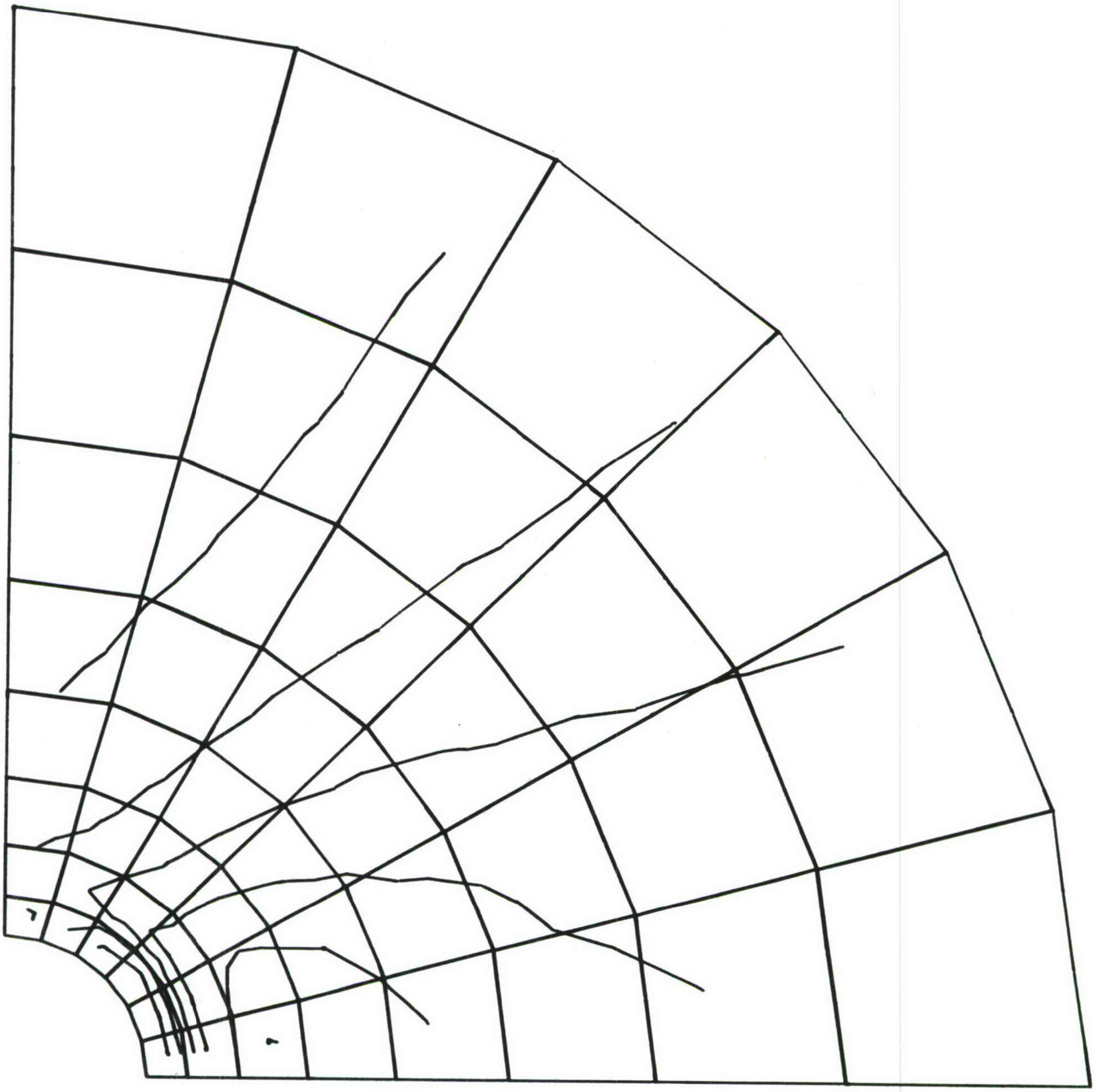


Figure AI-80 Tangential Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

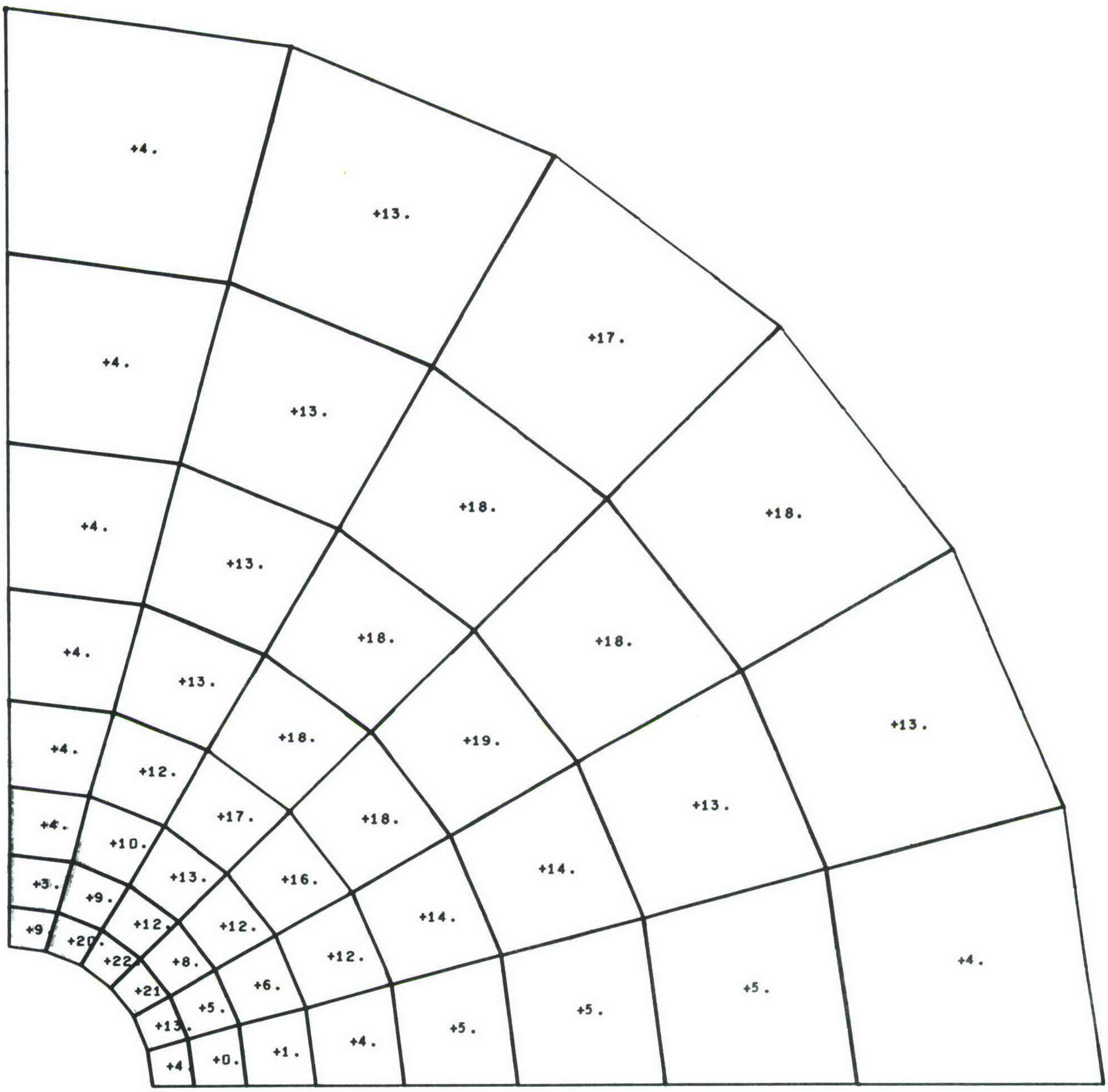


Figure AI-81 Radial-Tangential Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

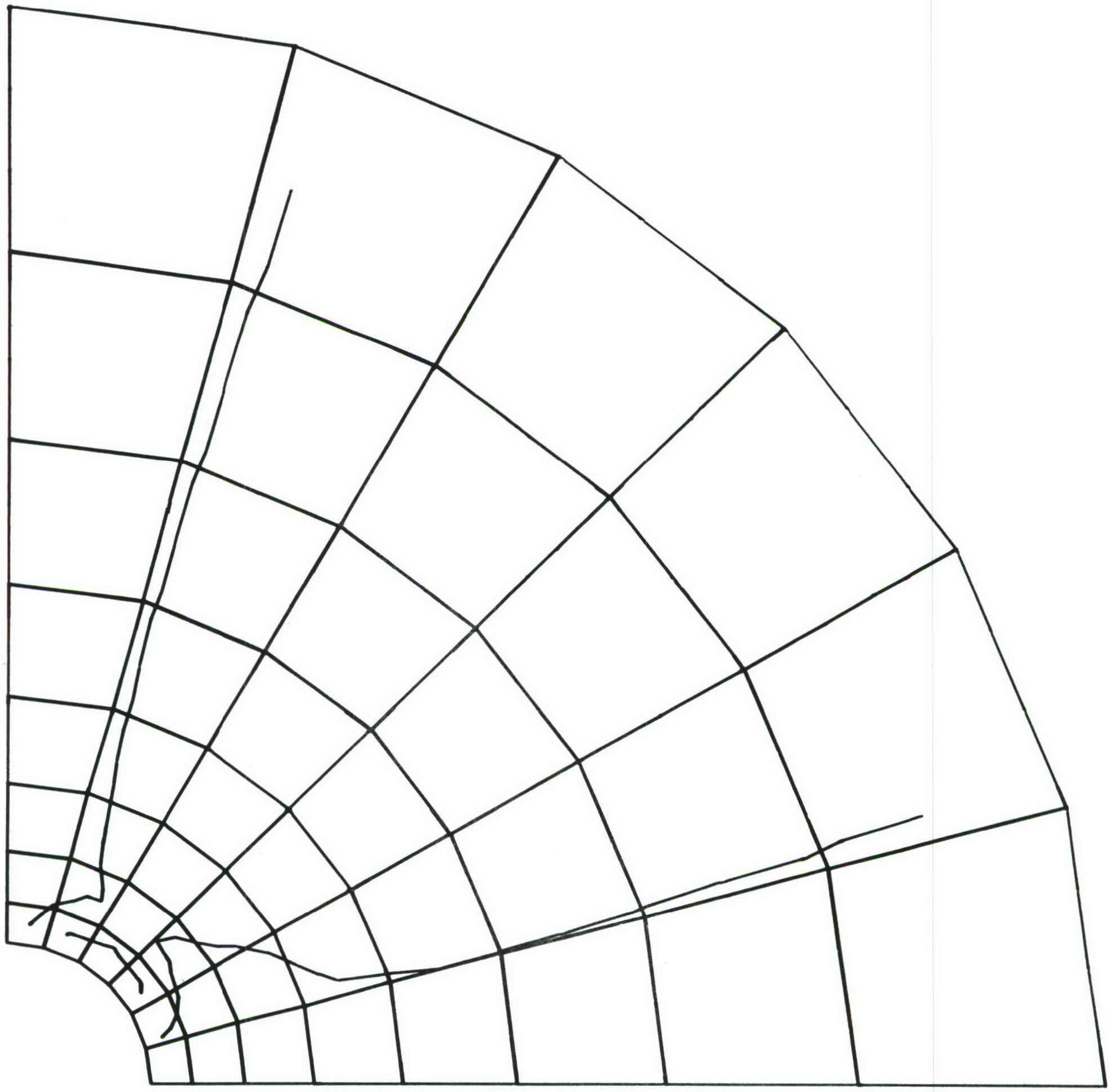


Figure AI-82 Radial-Tangential Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

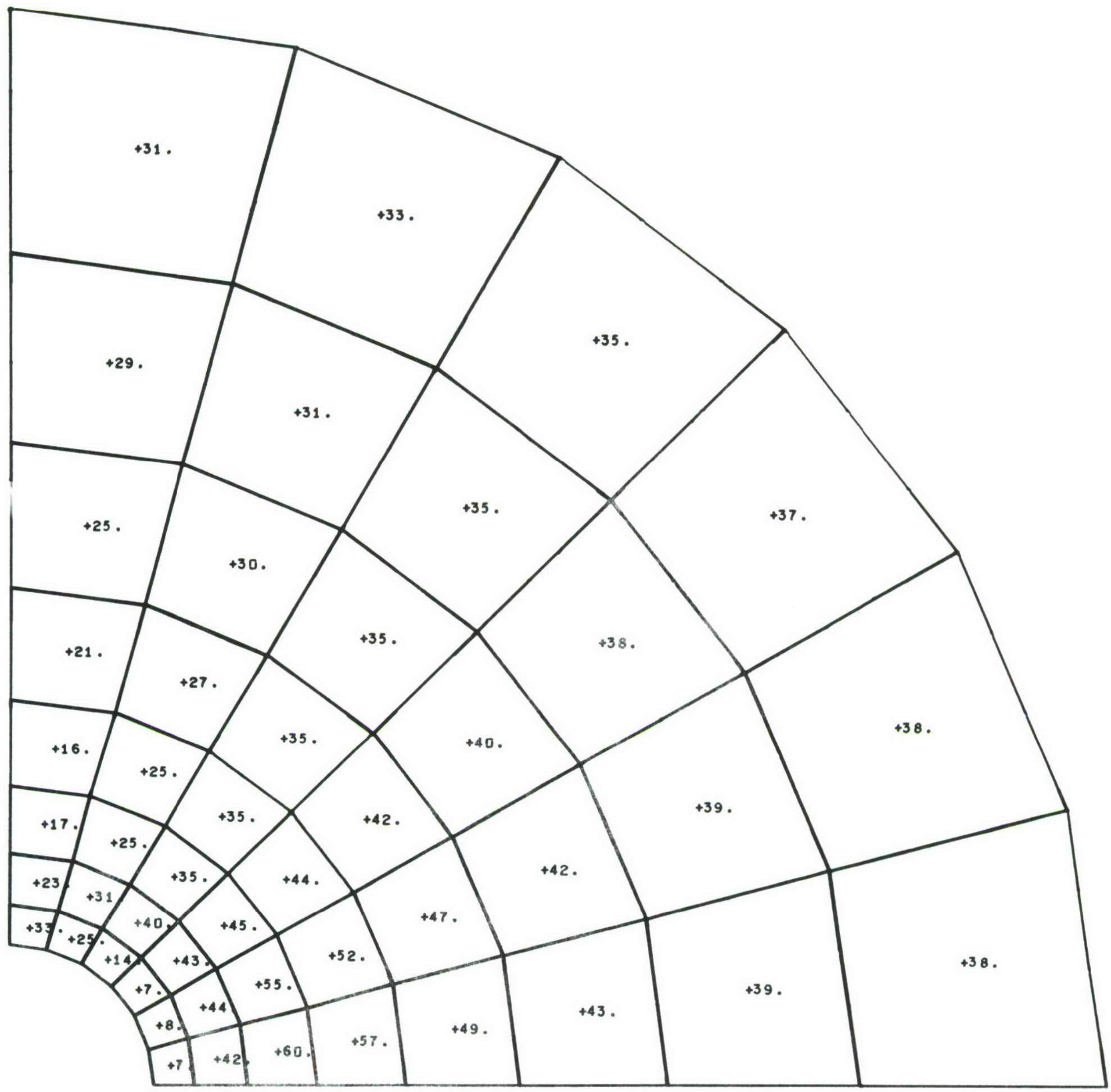


Figure AI-83 First Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

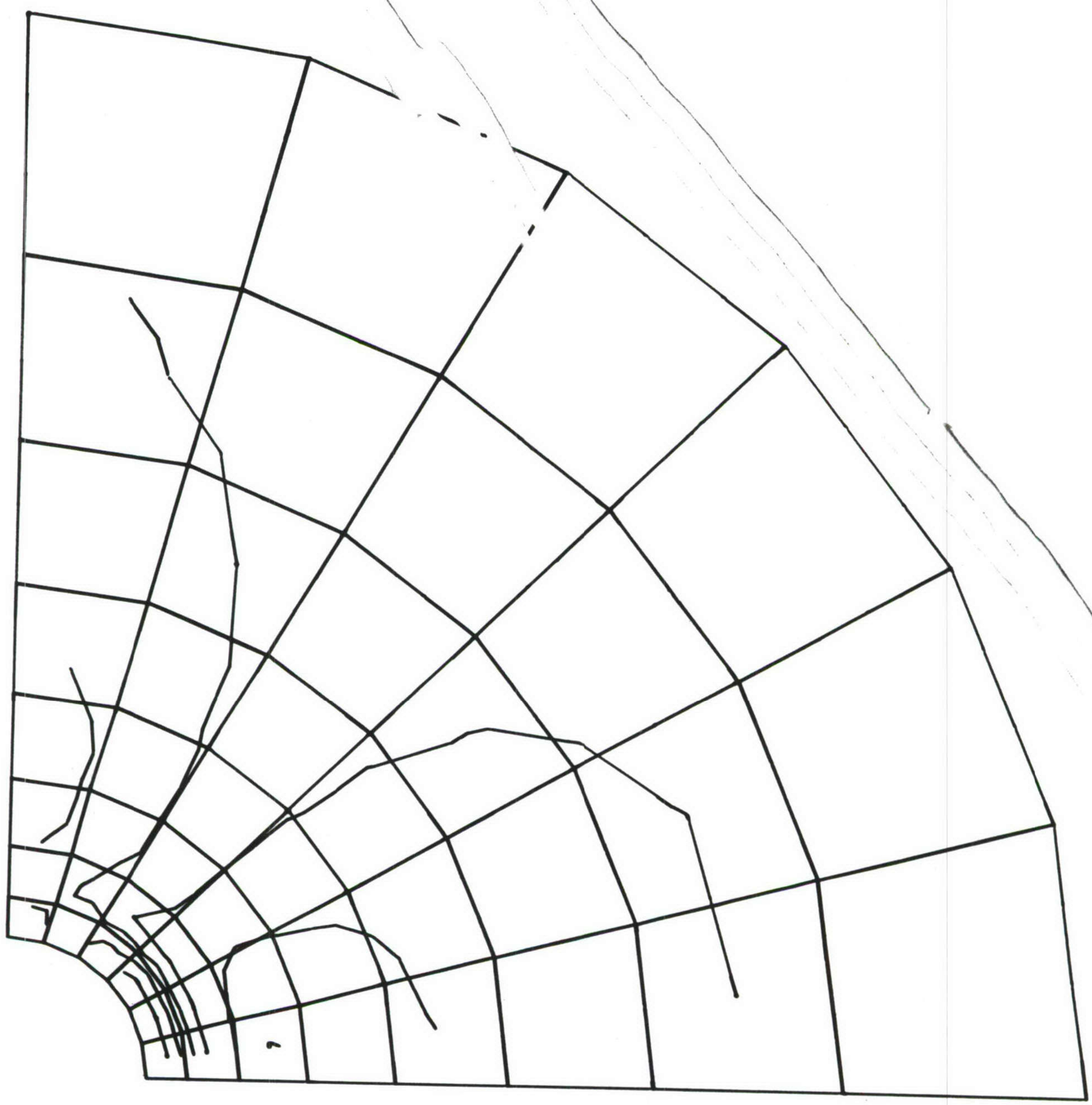


Figure AI-84 First Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

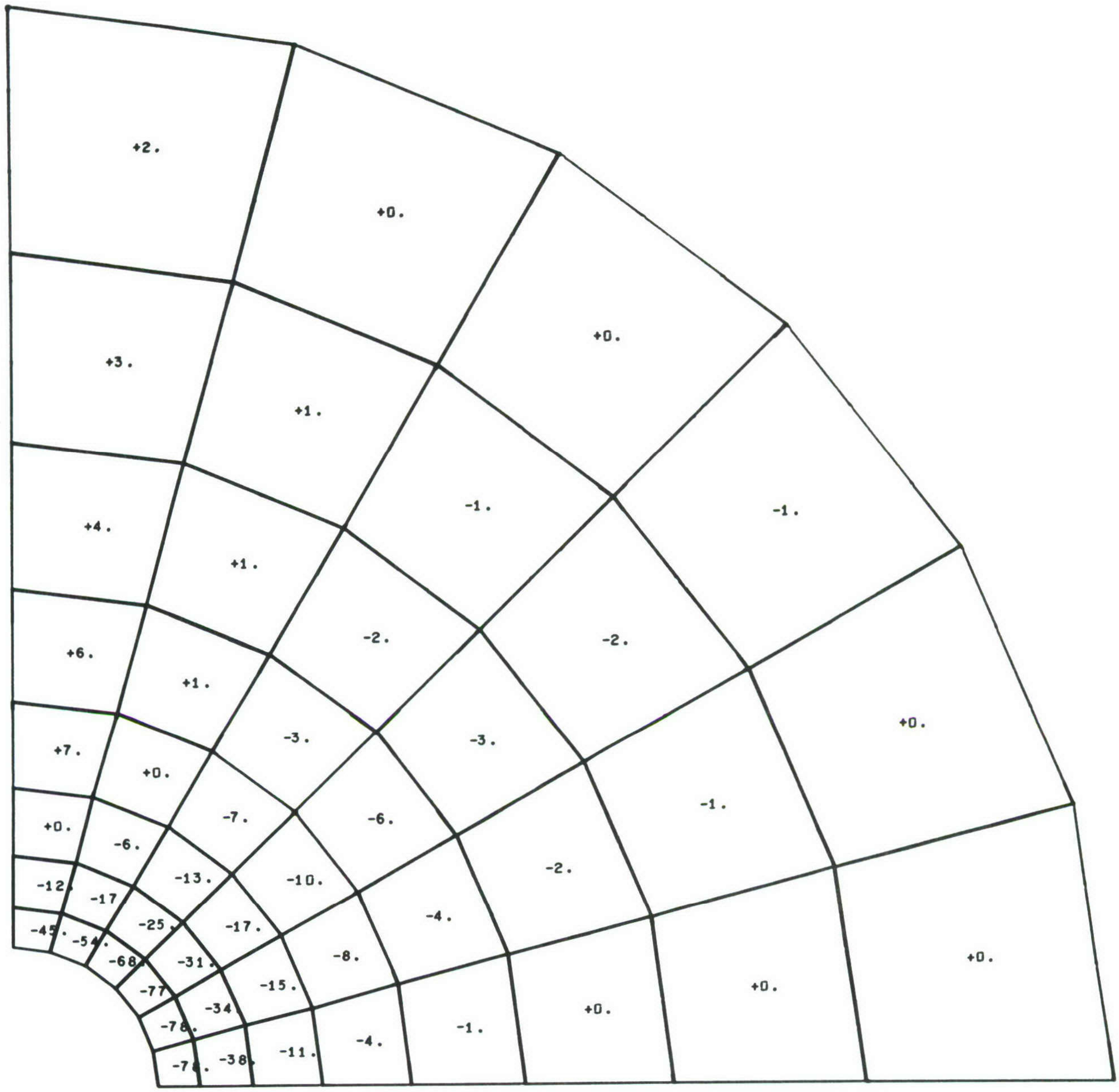


Figure AI-85 Second Principal Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

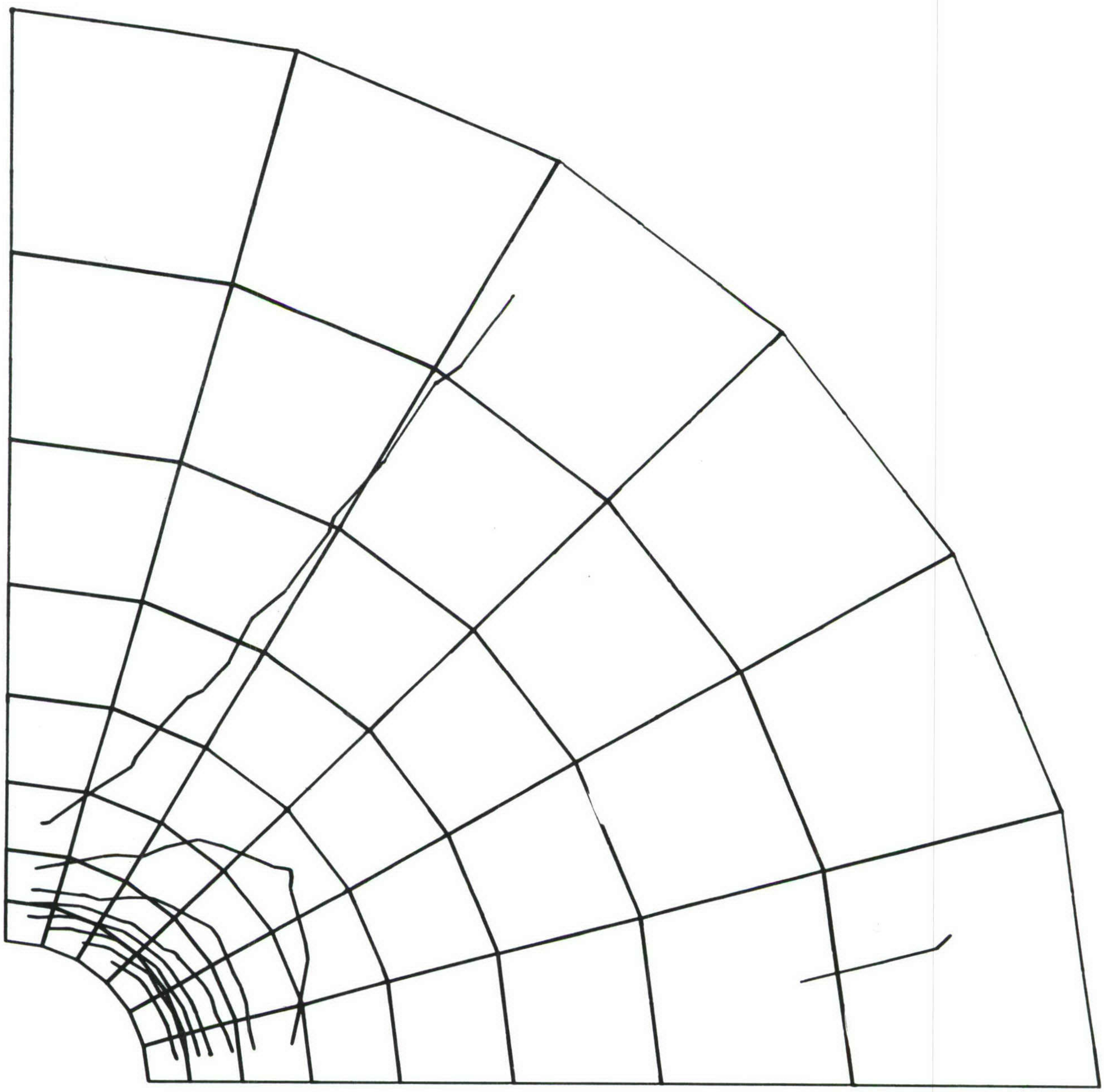


Figure AI-86 Second Principal Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

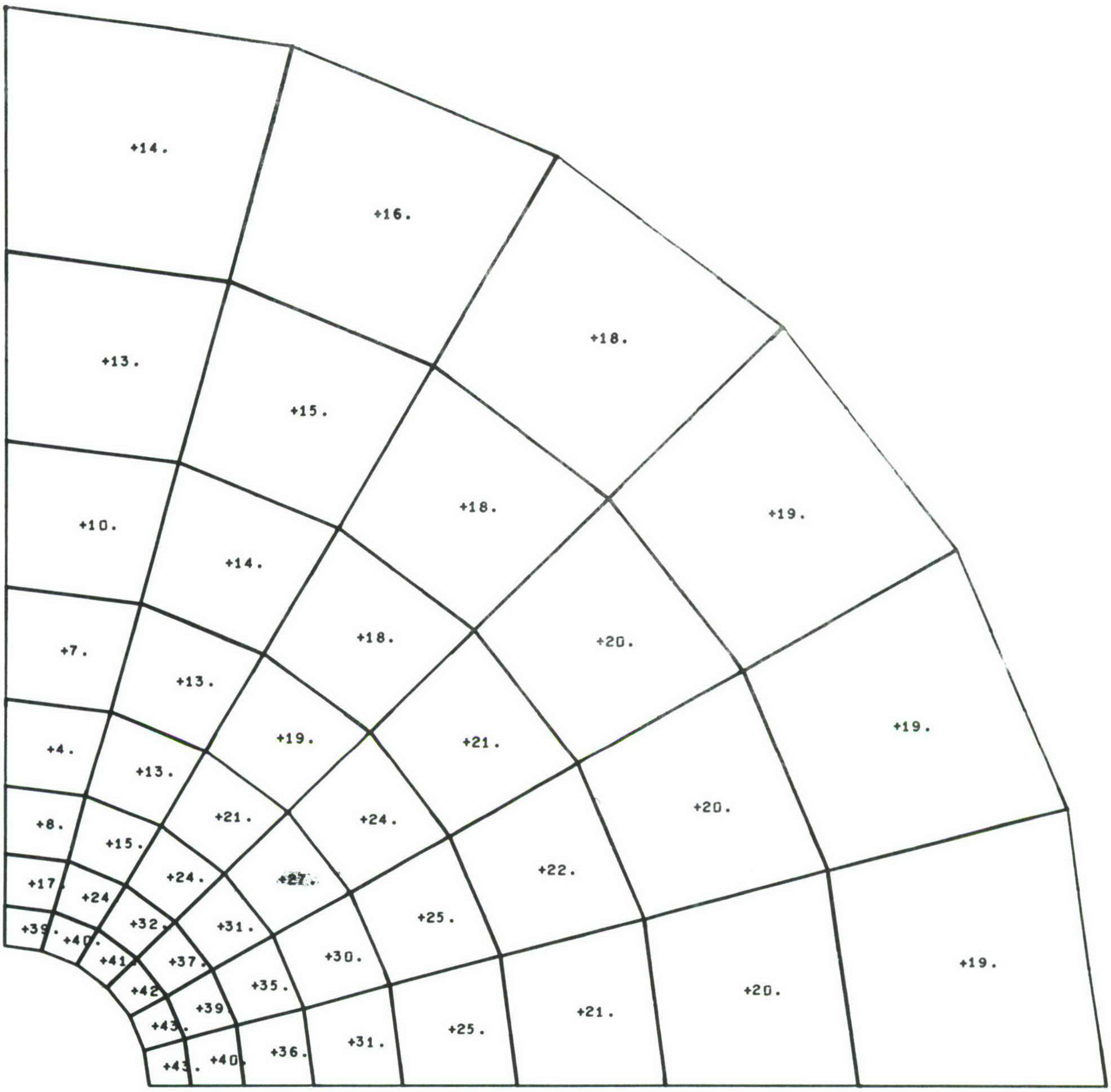


Figure AI-87 Principal Shear Stress Values for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

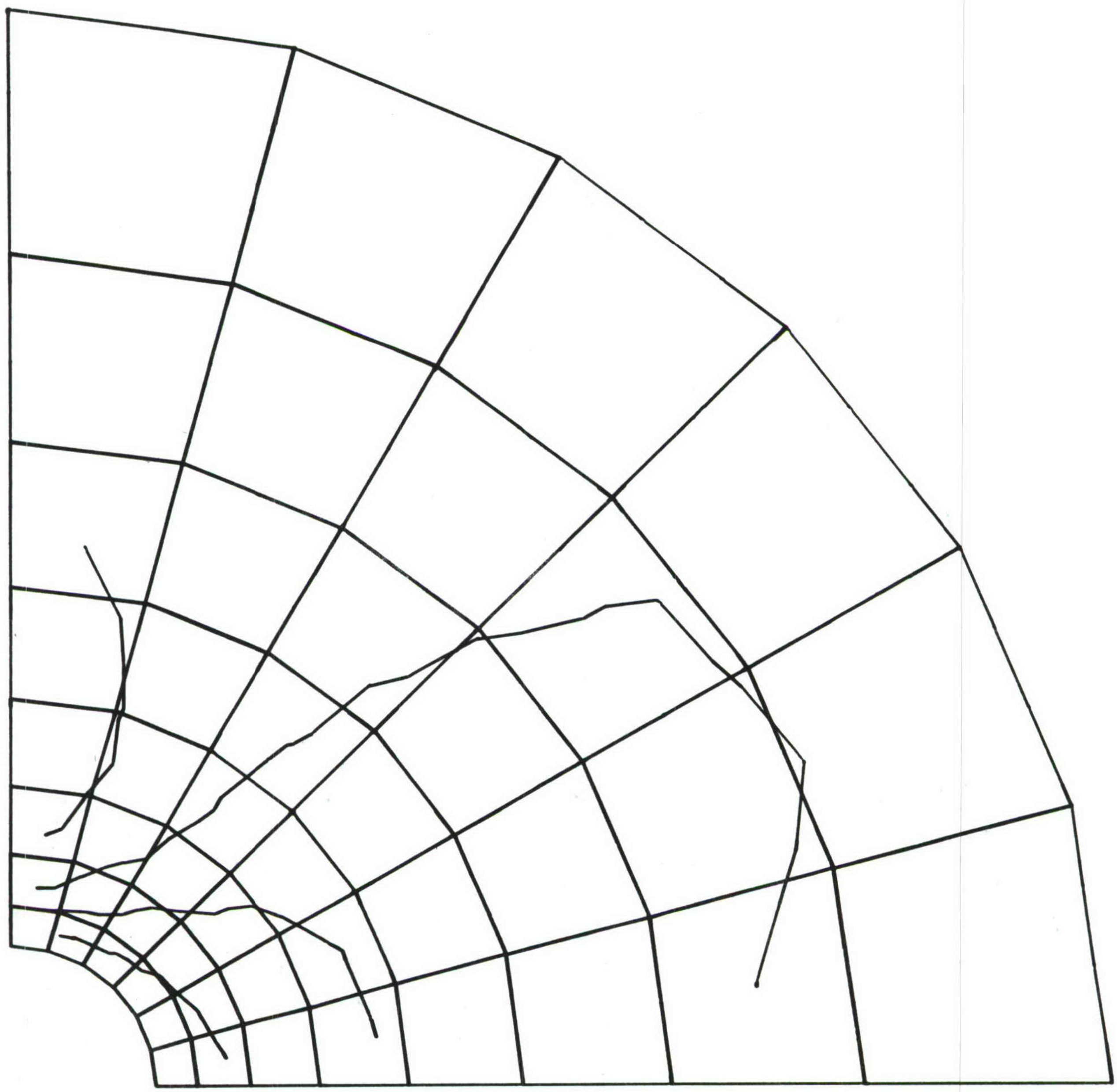


Figure AI-88 Principal Shear Stress Contours for Aluminum Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

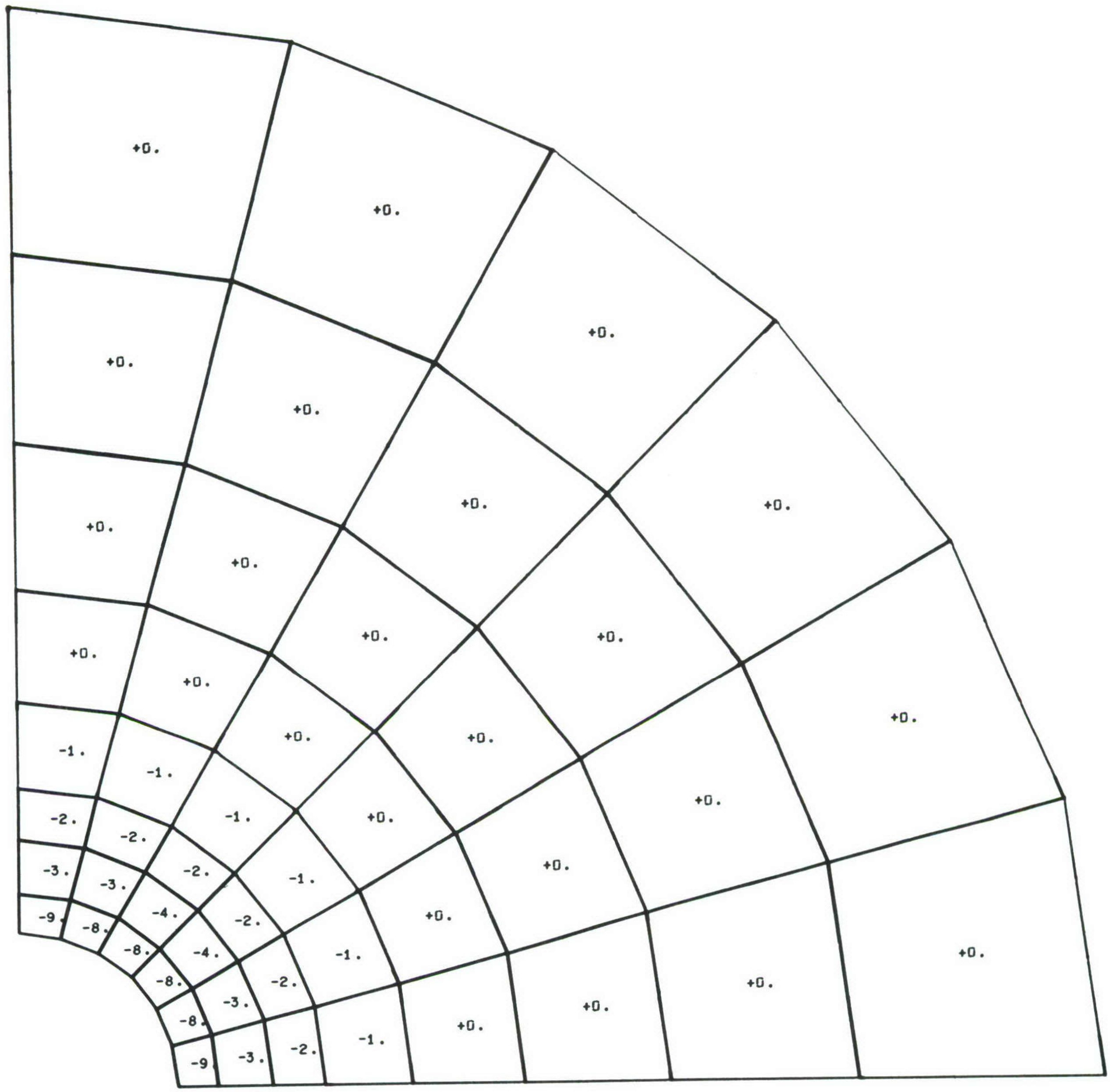


Figure AI-89 Radial Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

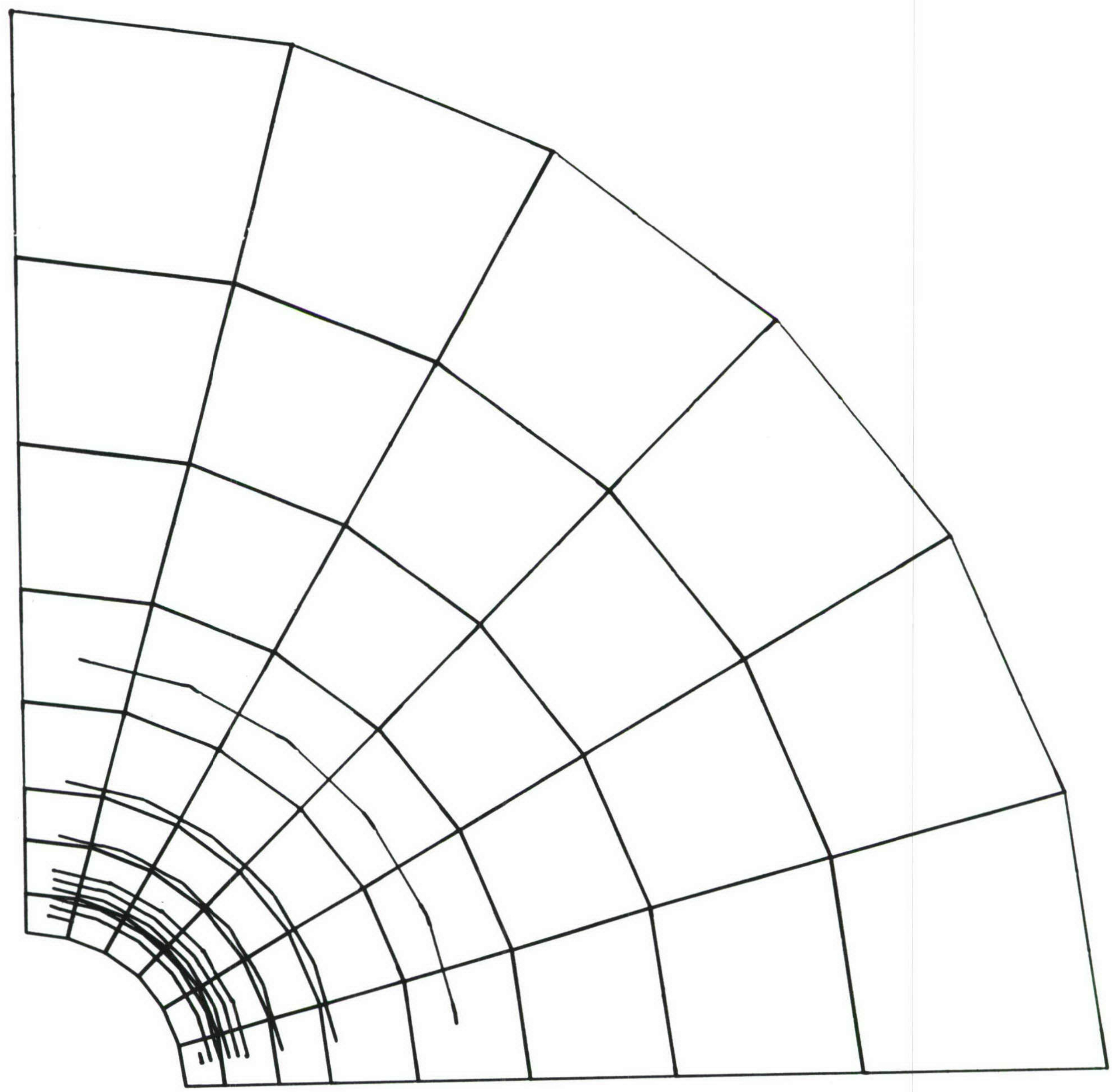


Figure AI-90 Radial Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

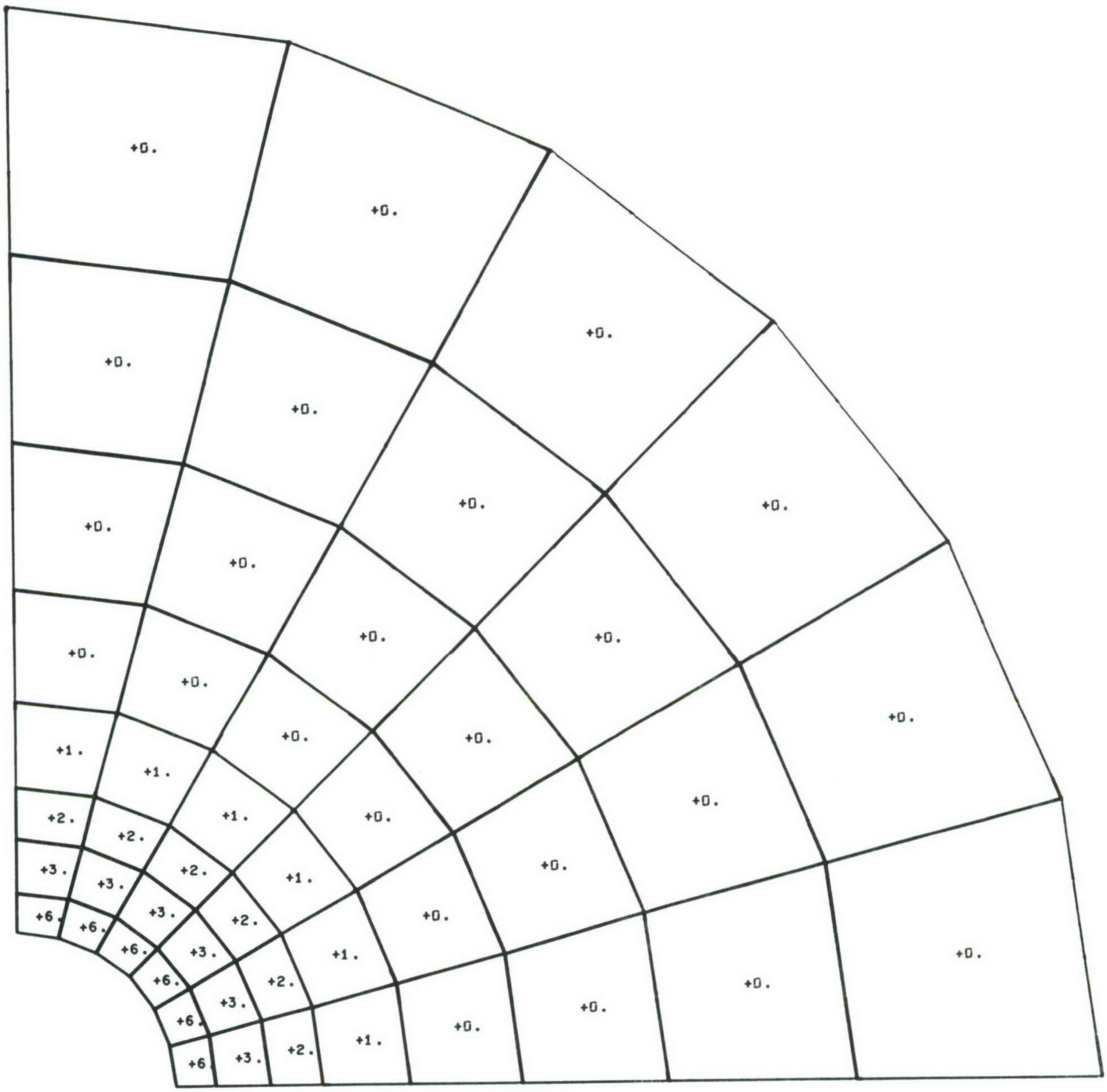


Figure AI-91 Tangential Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

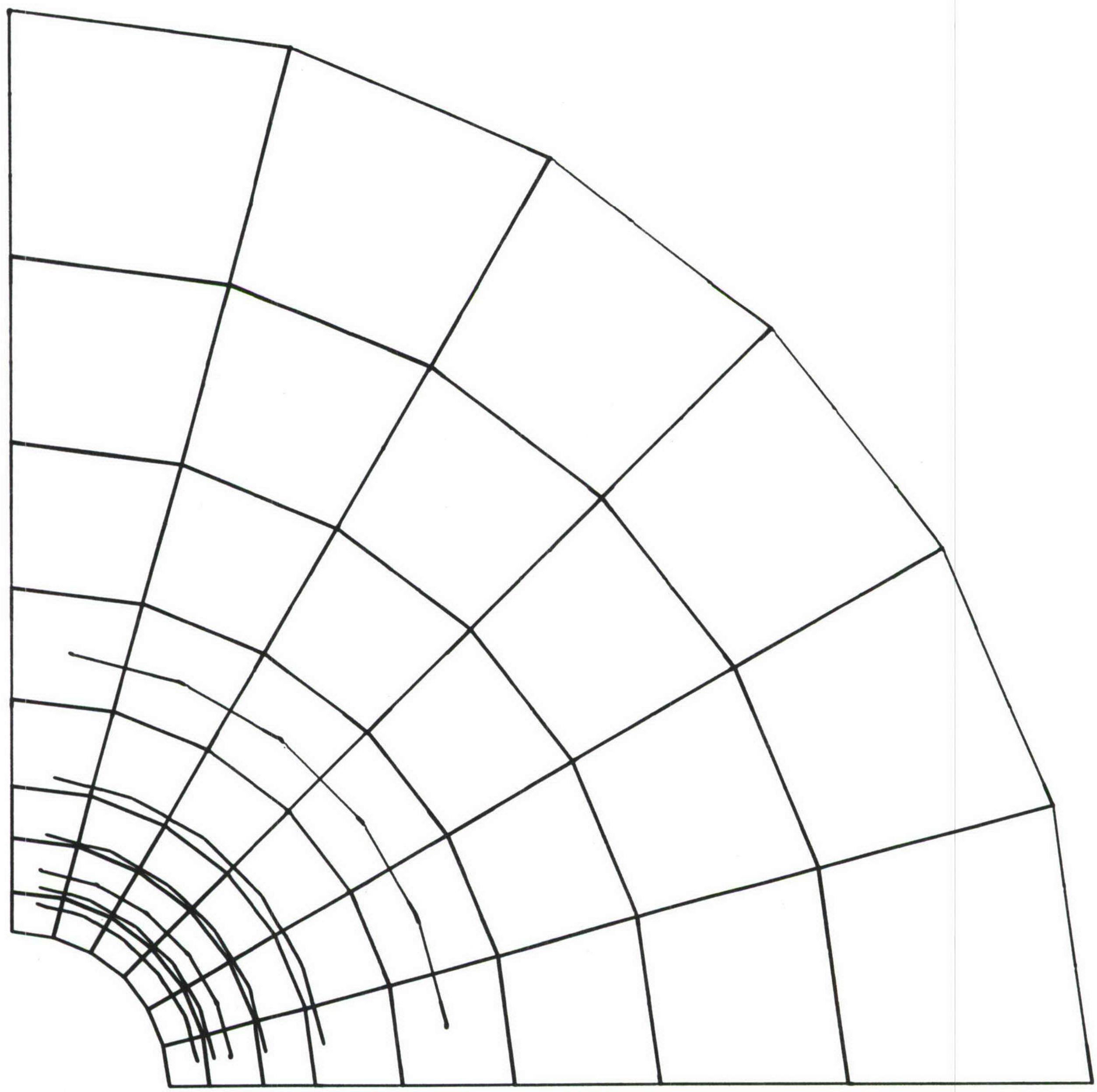


Figure AI-92 Tangential Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

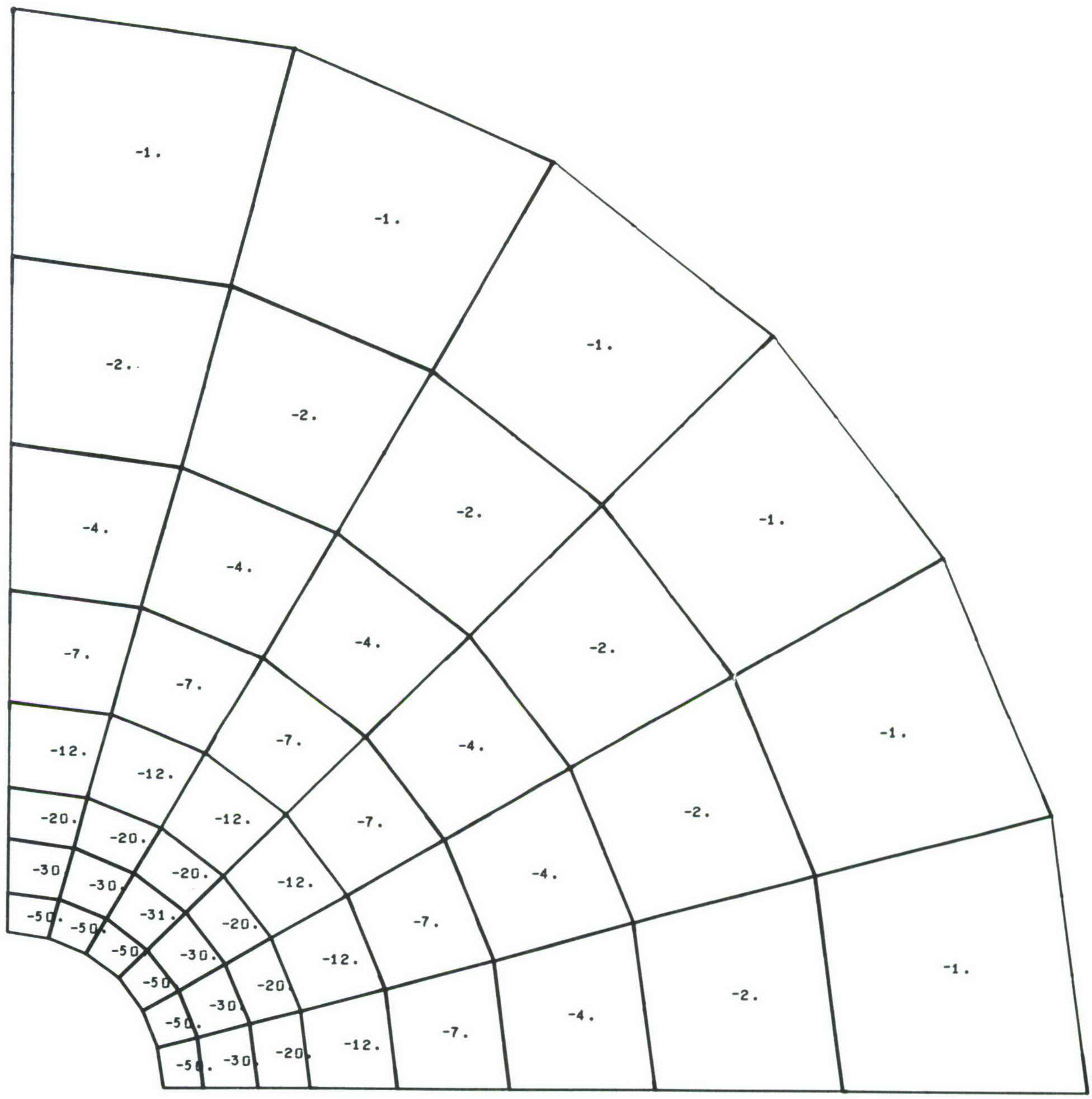


Figure AI-93 Radial Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

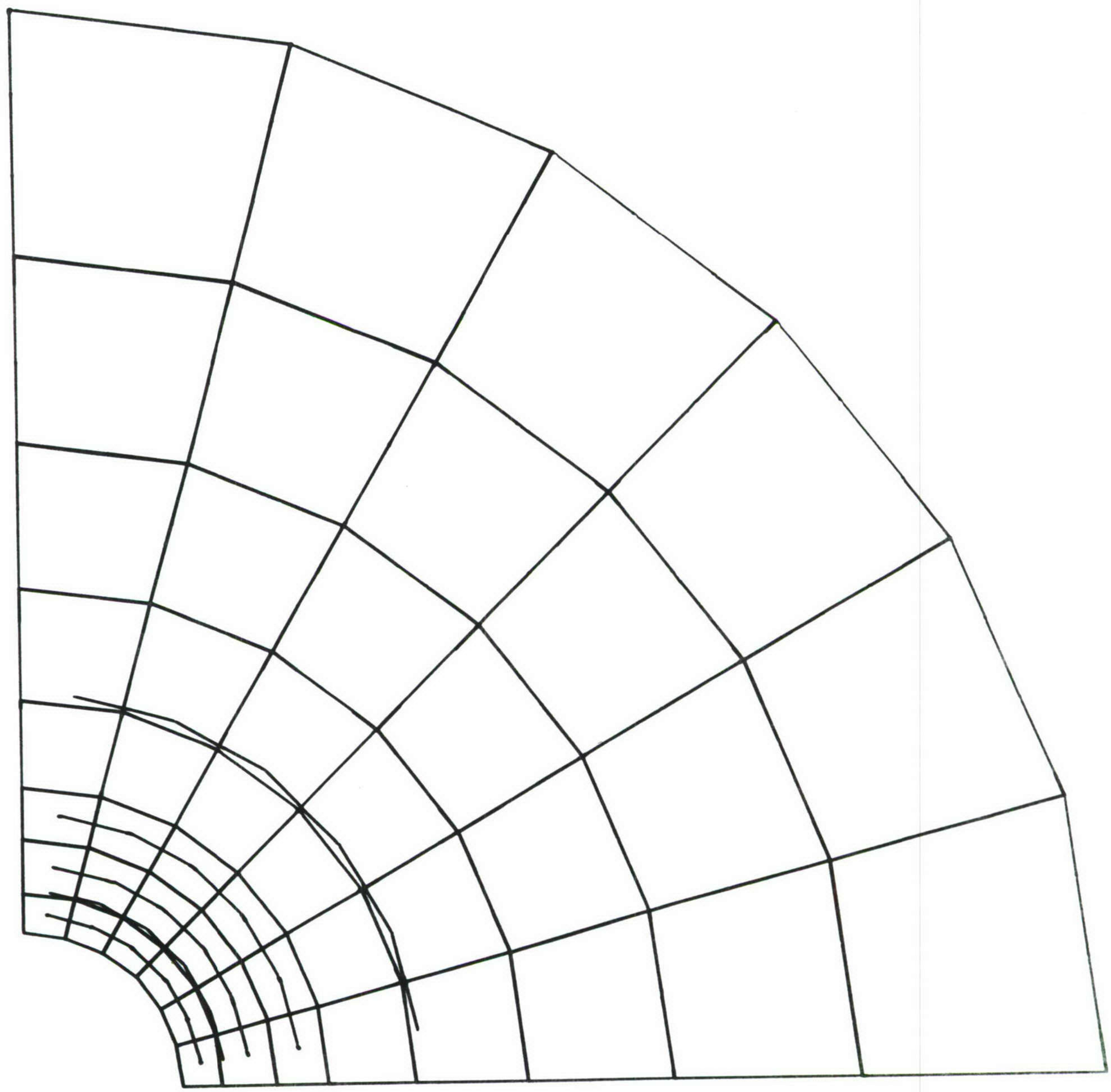


Figure AI-94 Radial Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

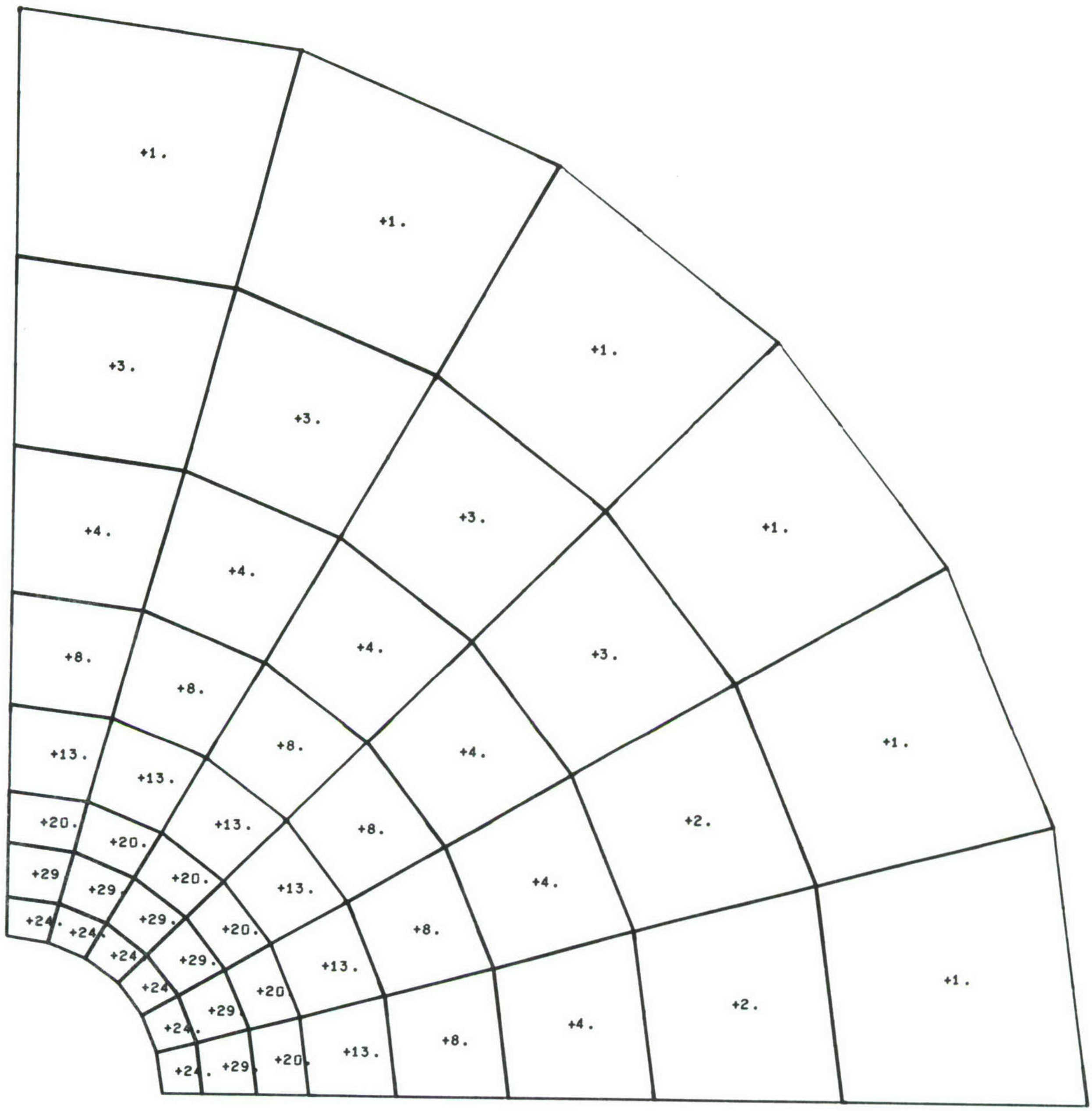


Figure AI-95 Tangential Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

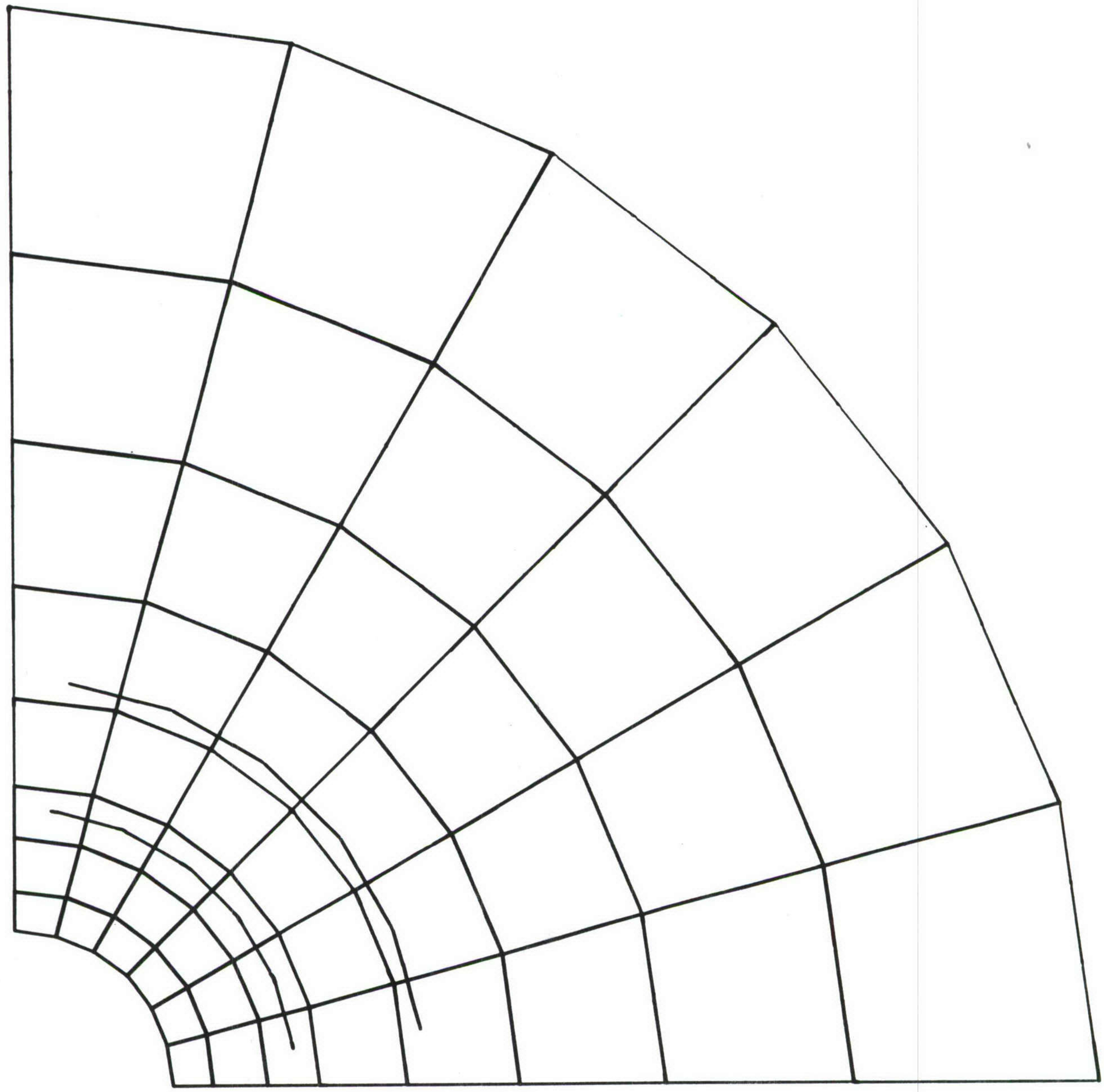


Figure AI-96 Tangential Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

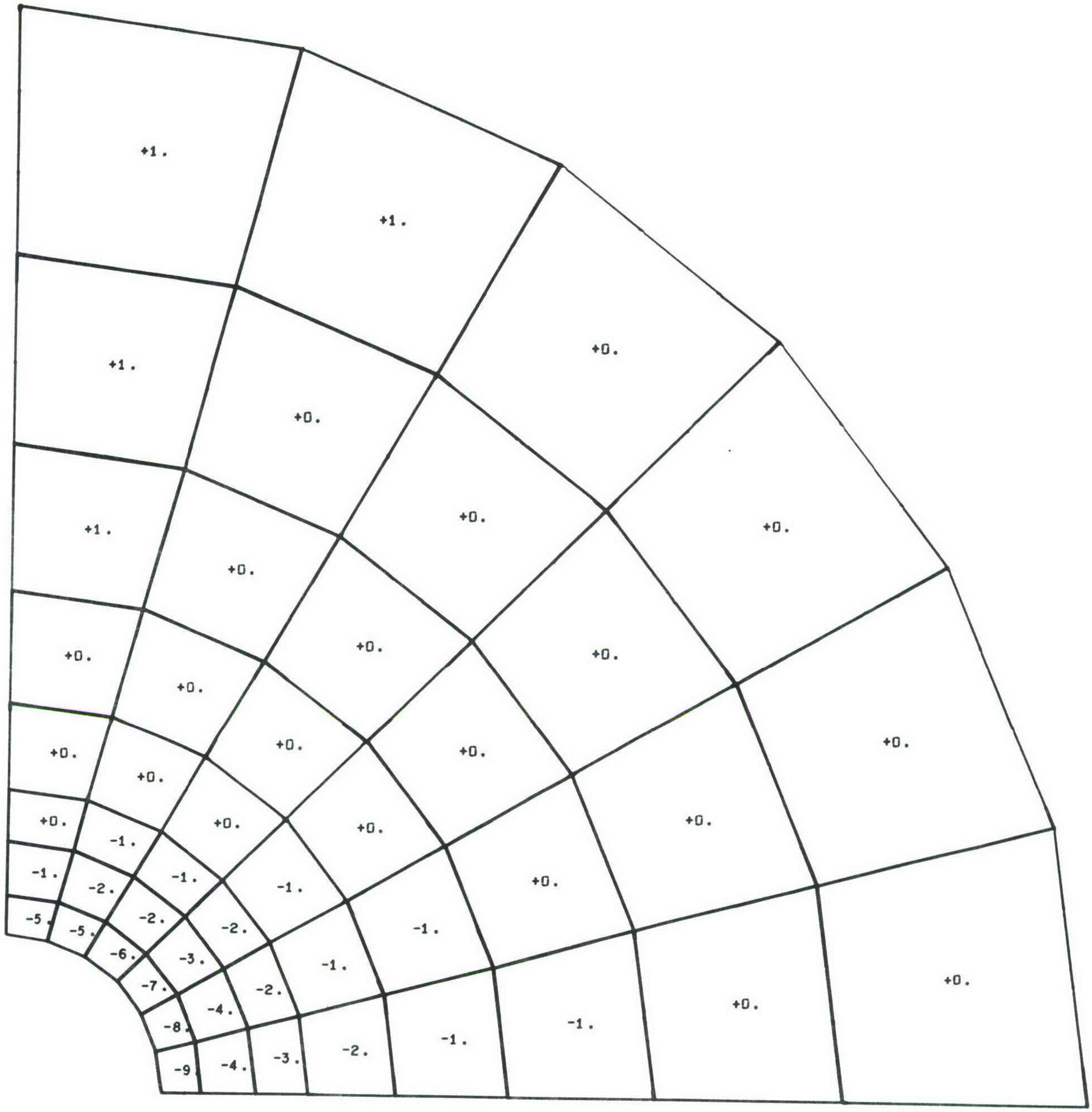


Figure AI-97 Radial Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

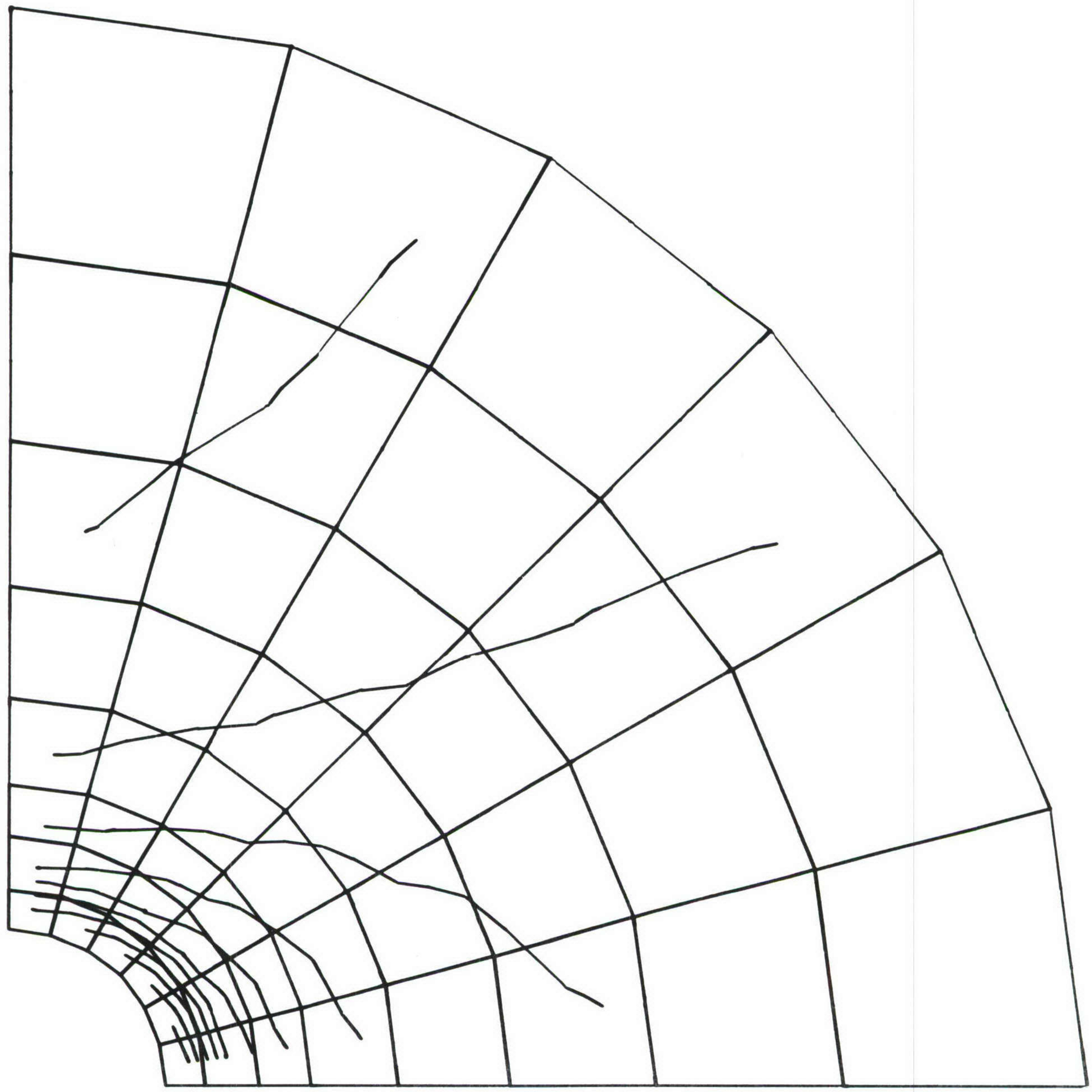


Figure AI-98 Radial Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

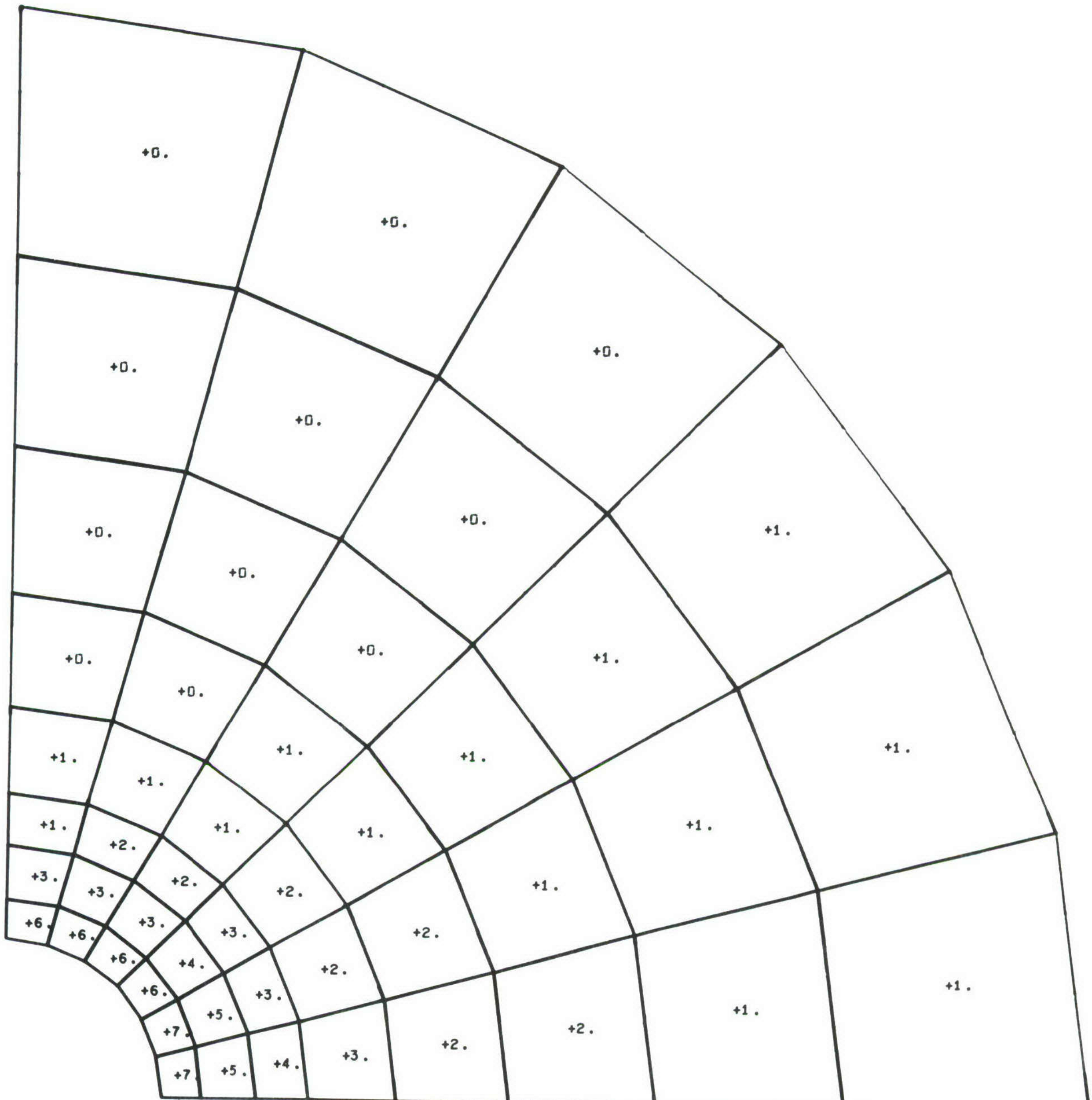


Figure AI-99 Tangential Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

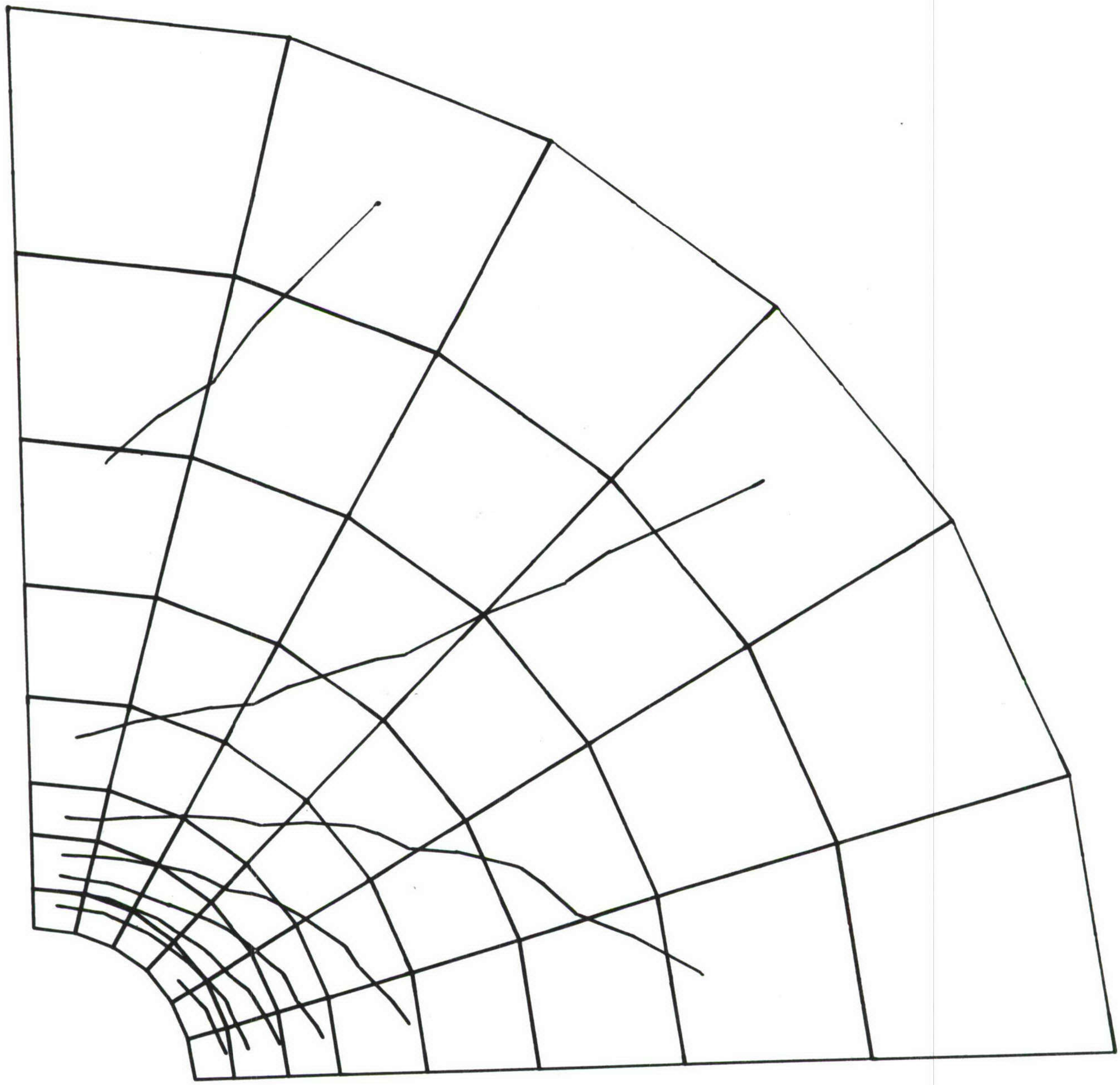


Figure AI-100 Tangential Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

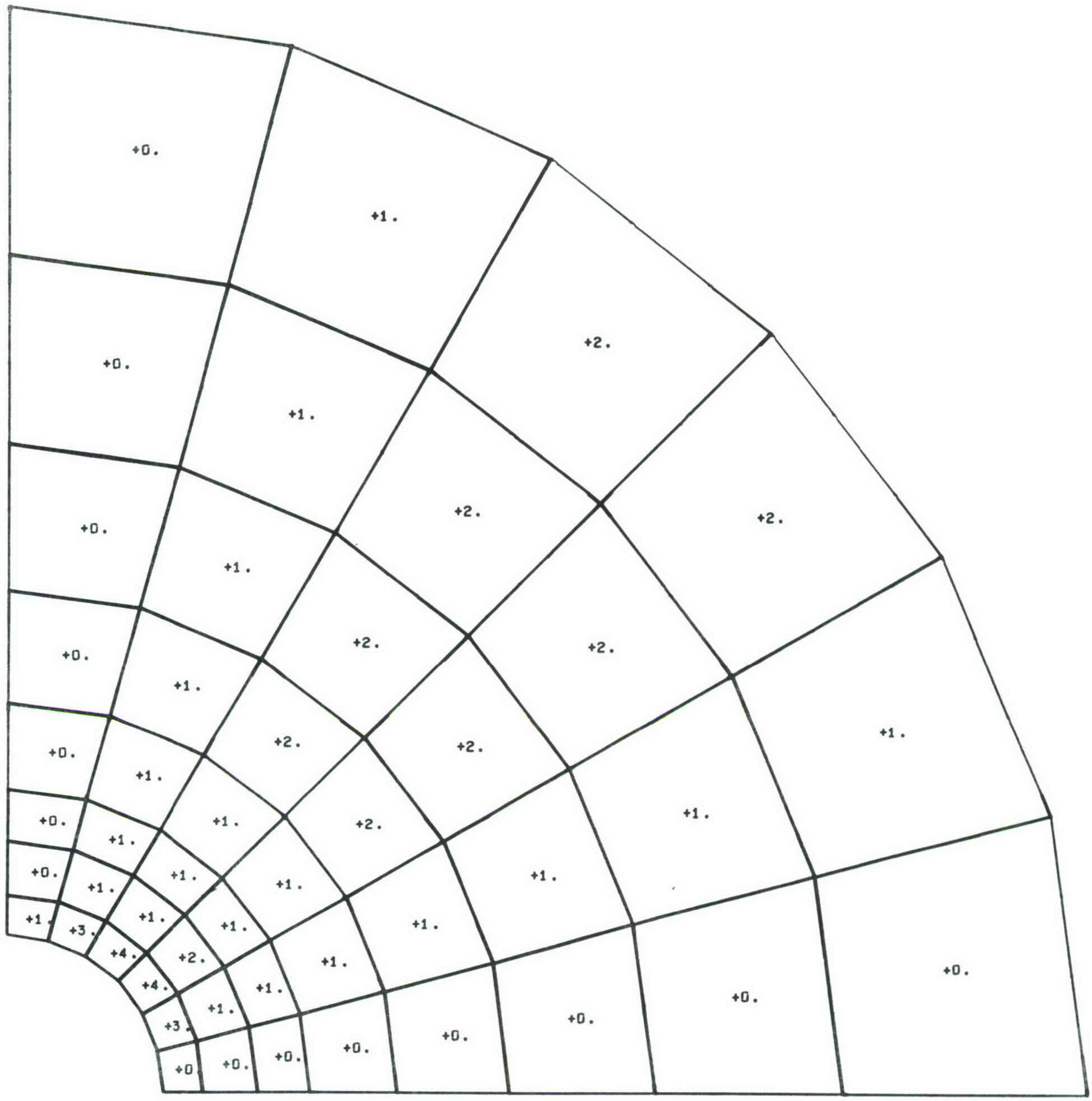


Figure AI-101   Radial-Tangential Shear Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

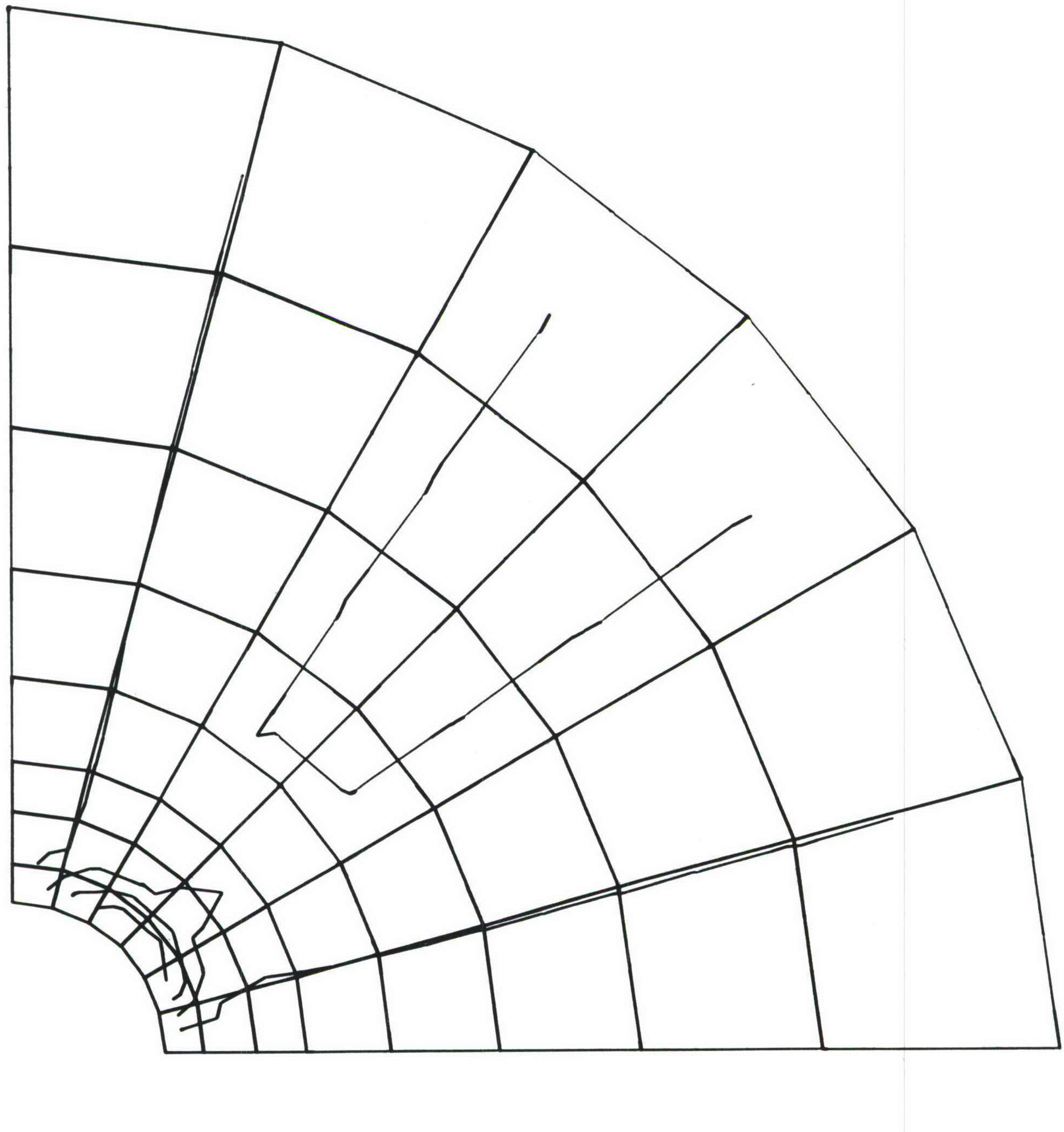


Figure AI-102 Radial-Tangential Shear Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

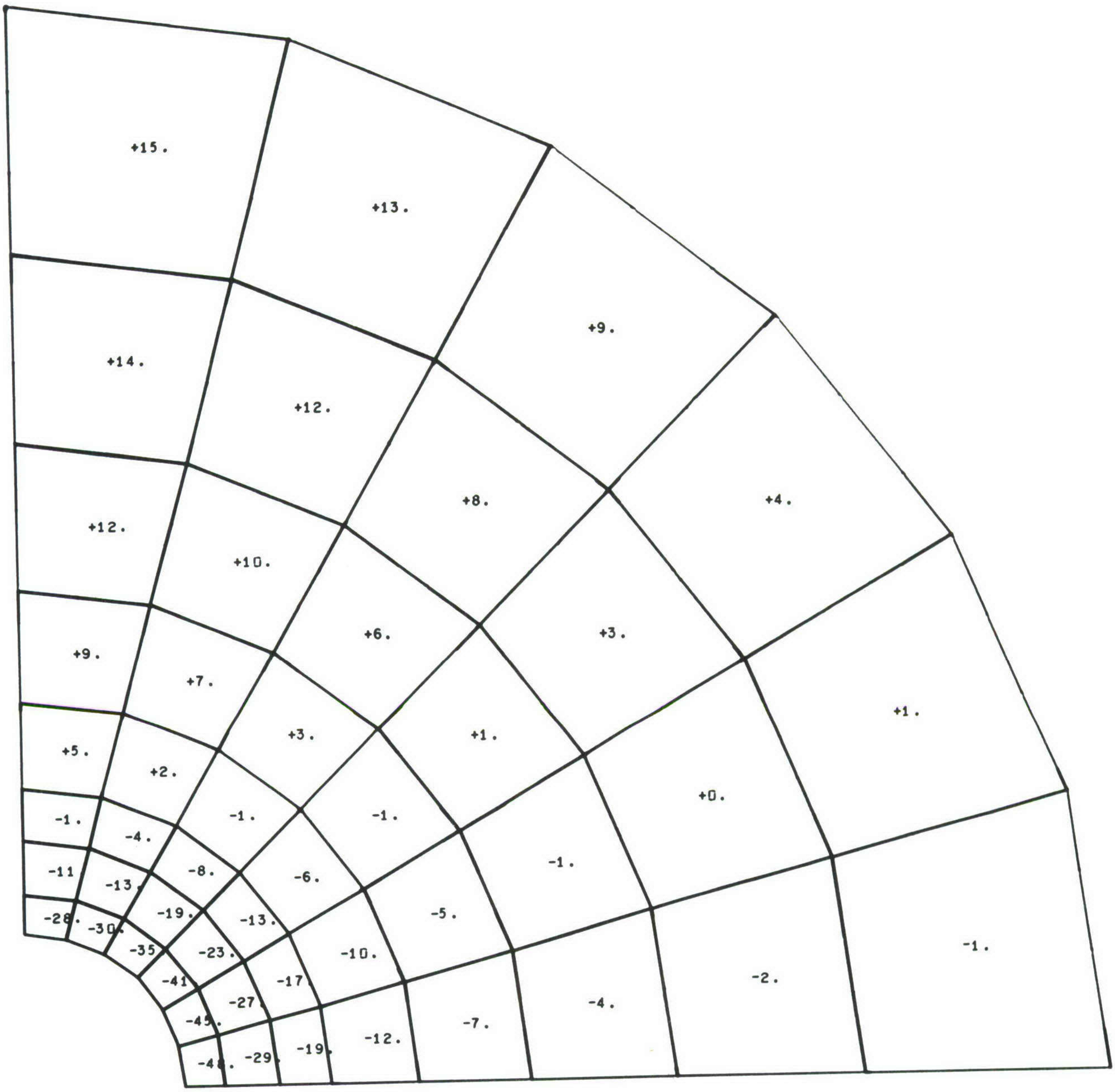


Figure AI-103 Radial Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

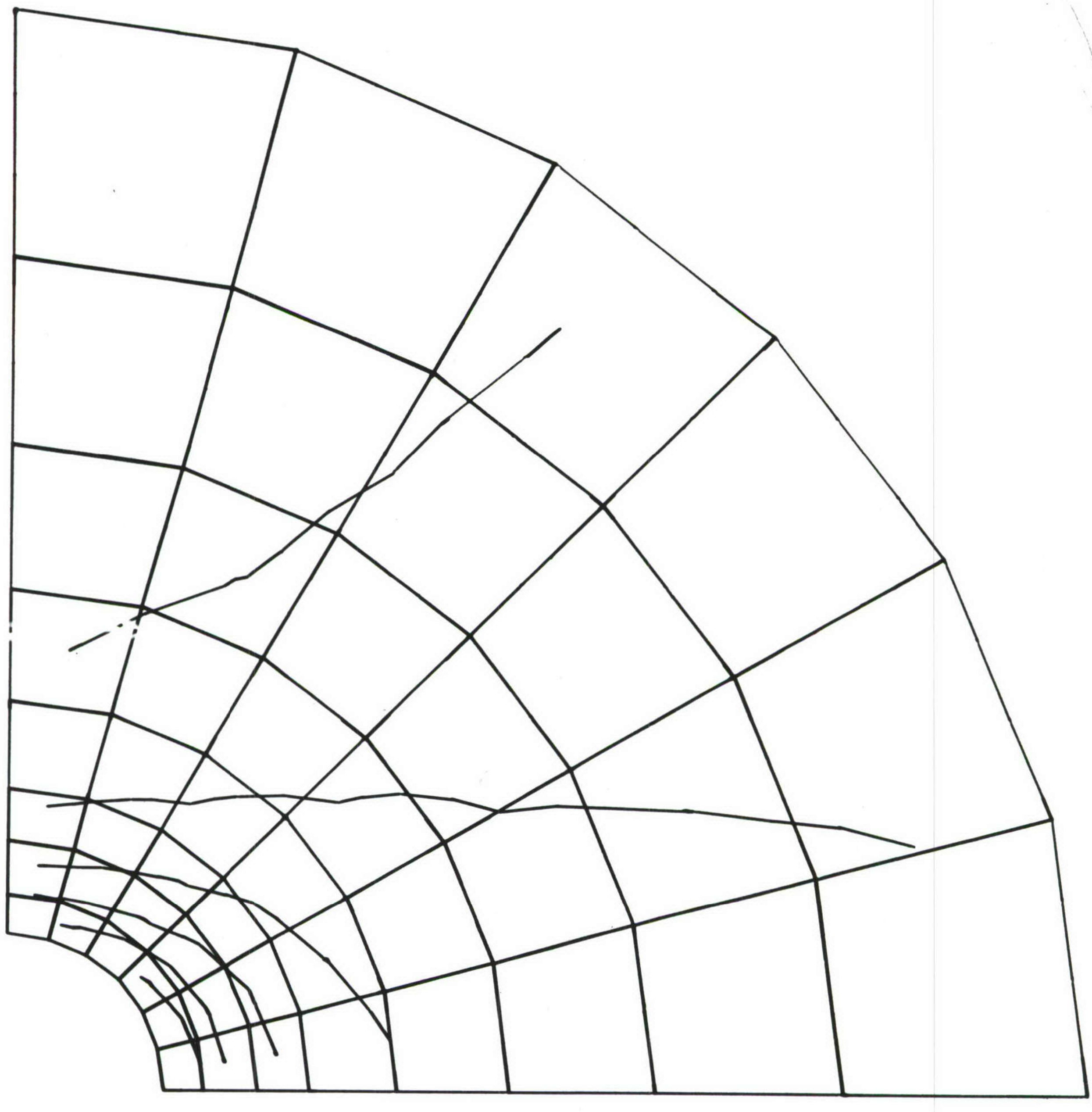


Figure AI-104 Radial Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

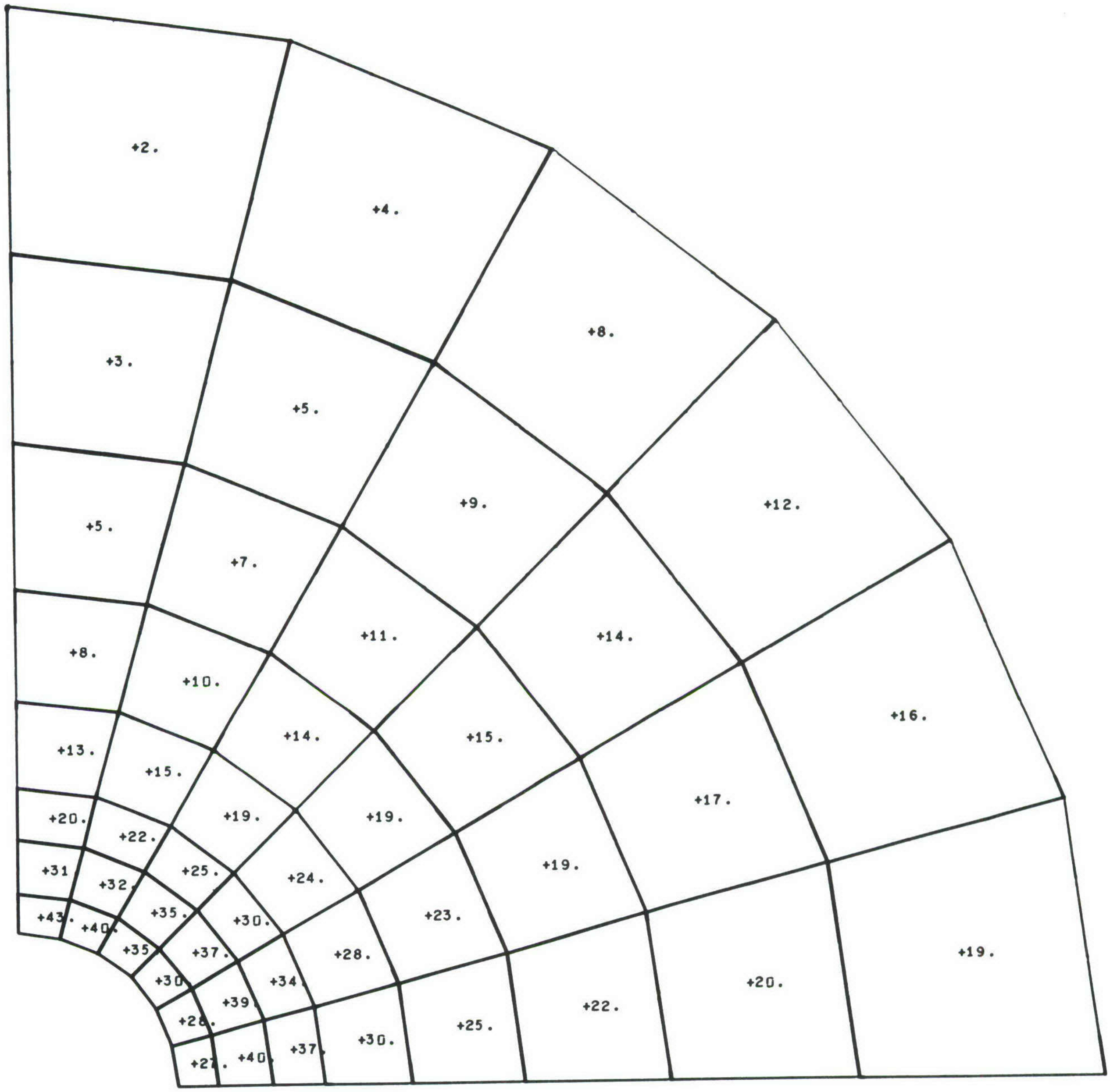


Figure AI-105 Tangential Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

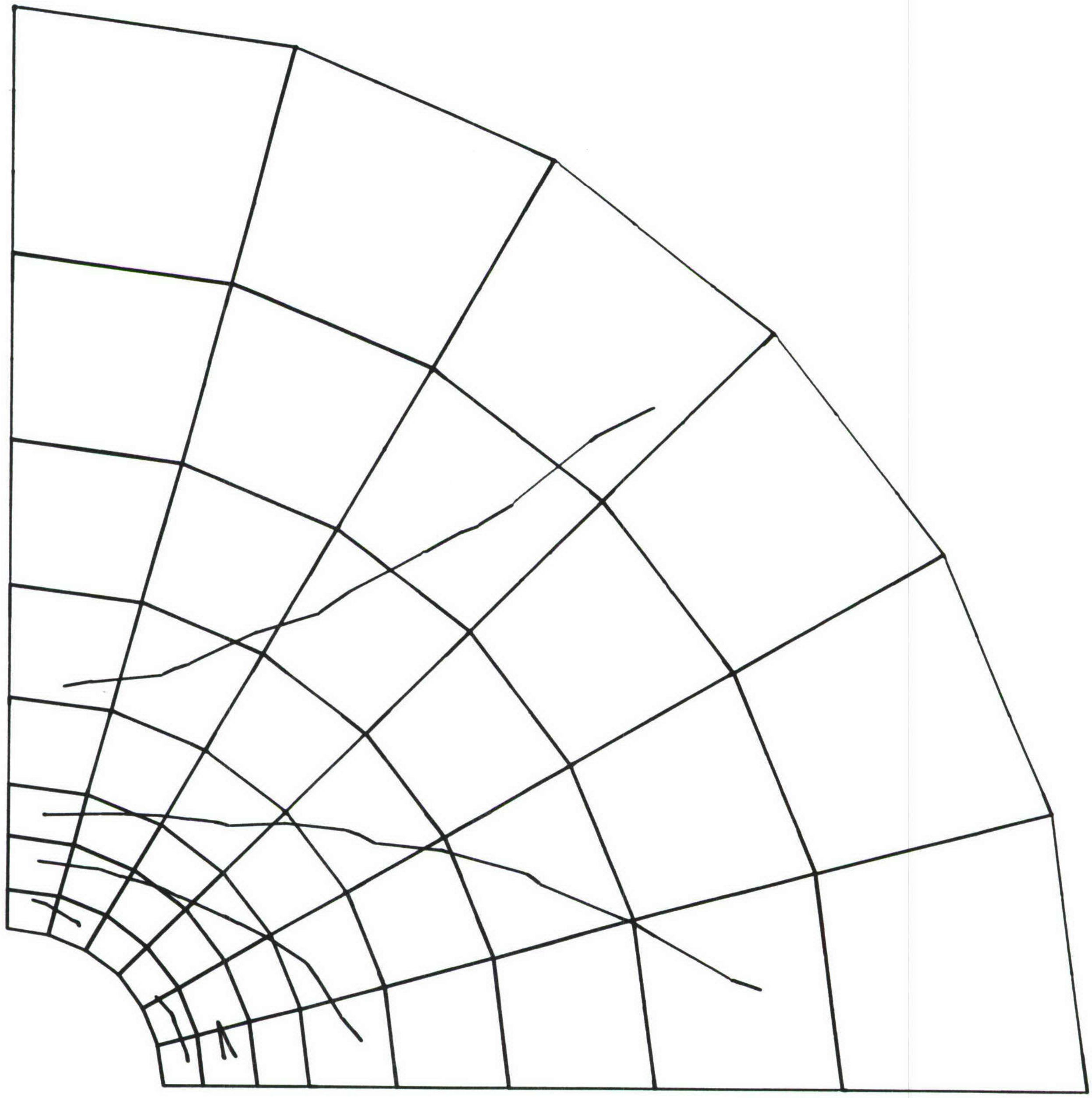


Figure AI-106 Tangential Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

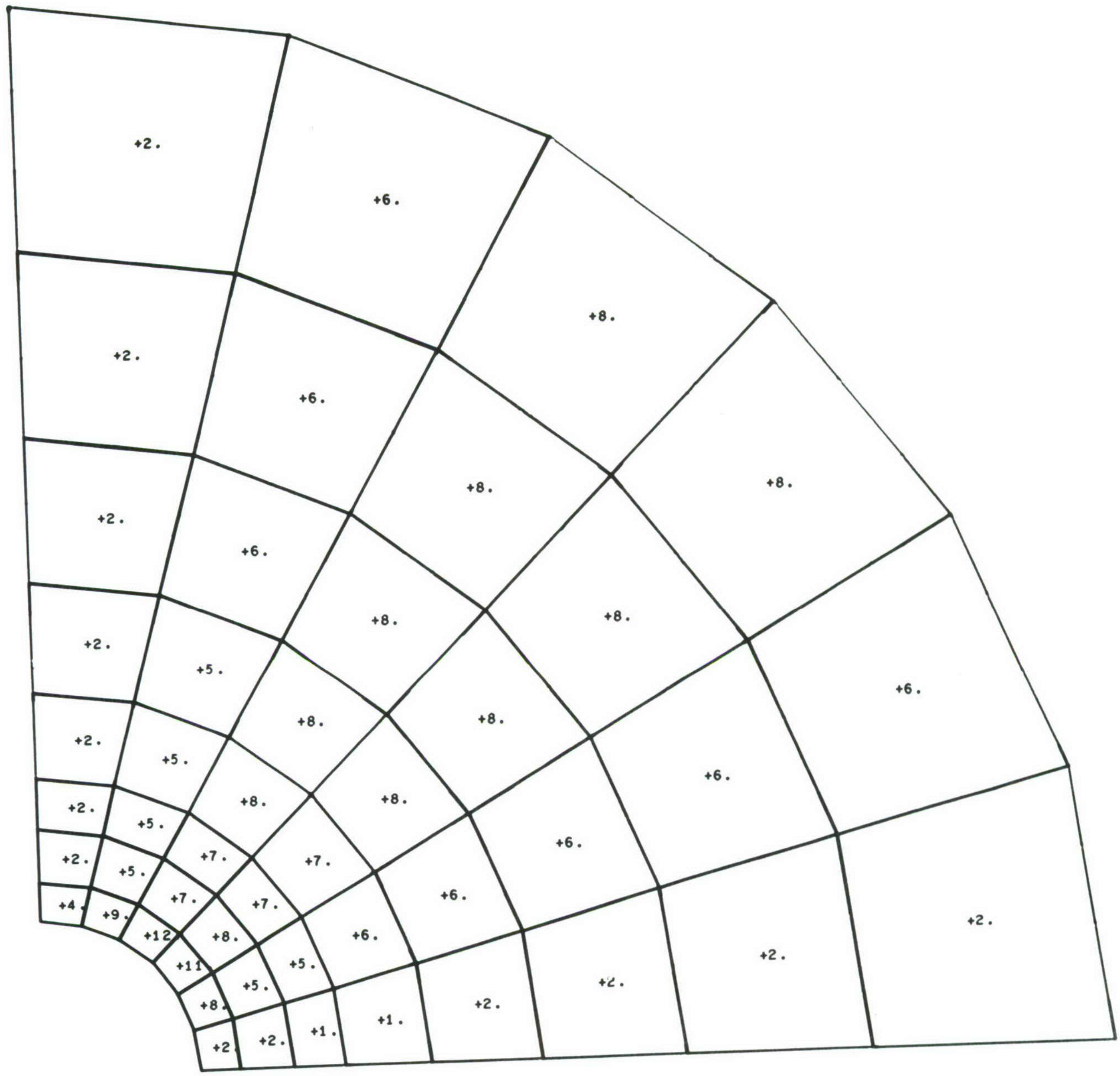


Figure AI-107 Radial-Tangential Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

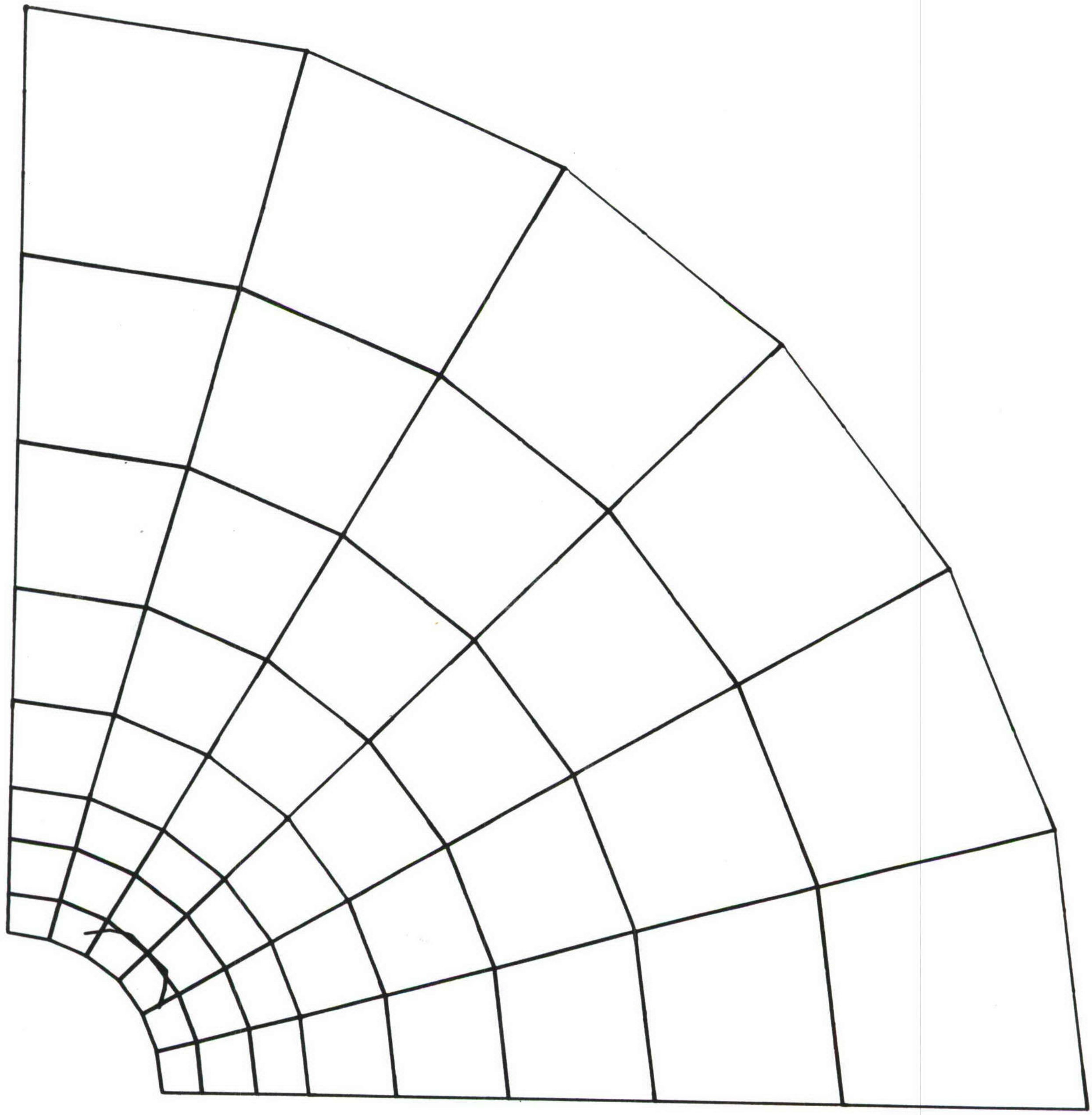


Figure AI-108 Radial-Tangential Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

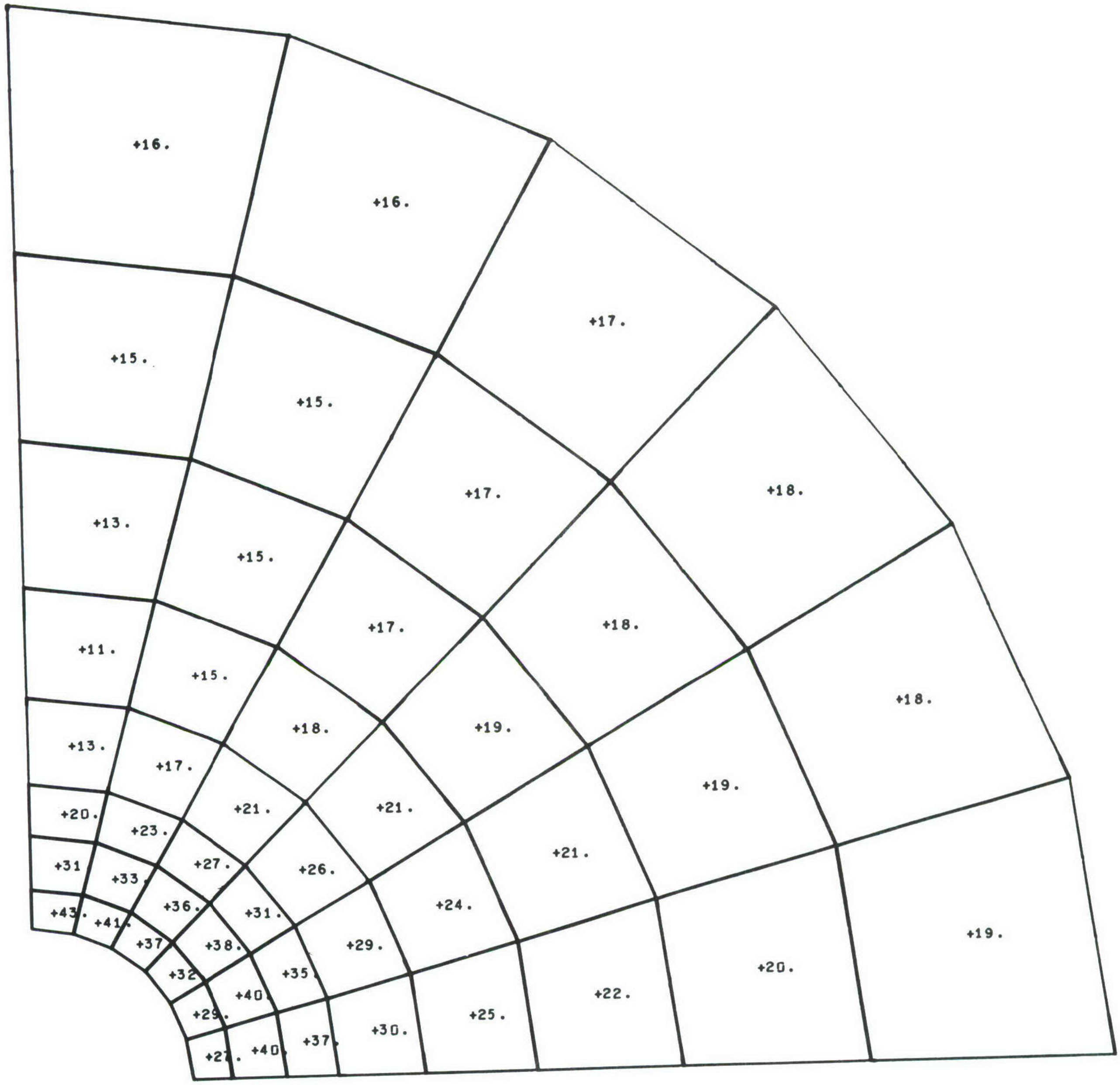


Figure AI-109 First Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

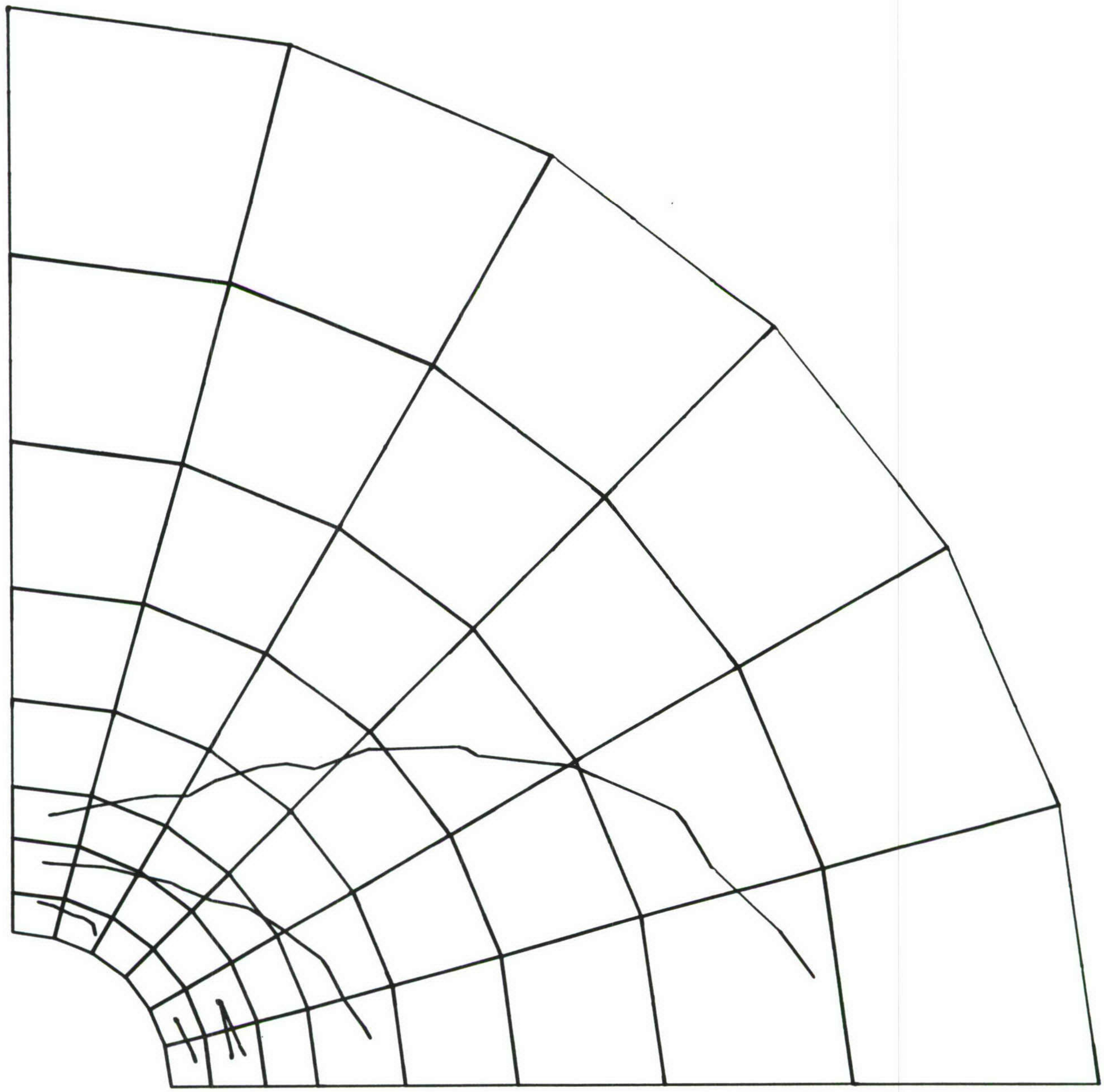


Figure AI-110 First Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

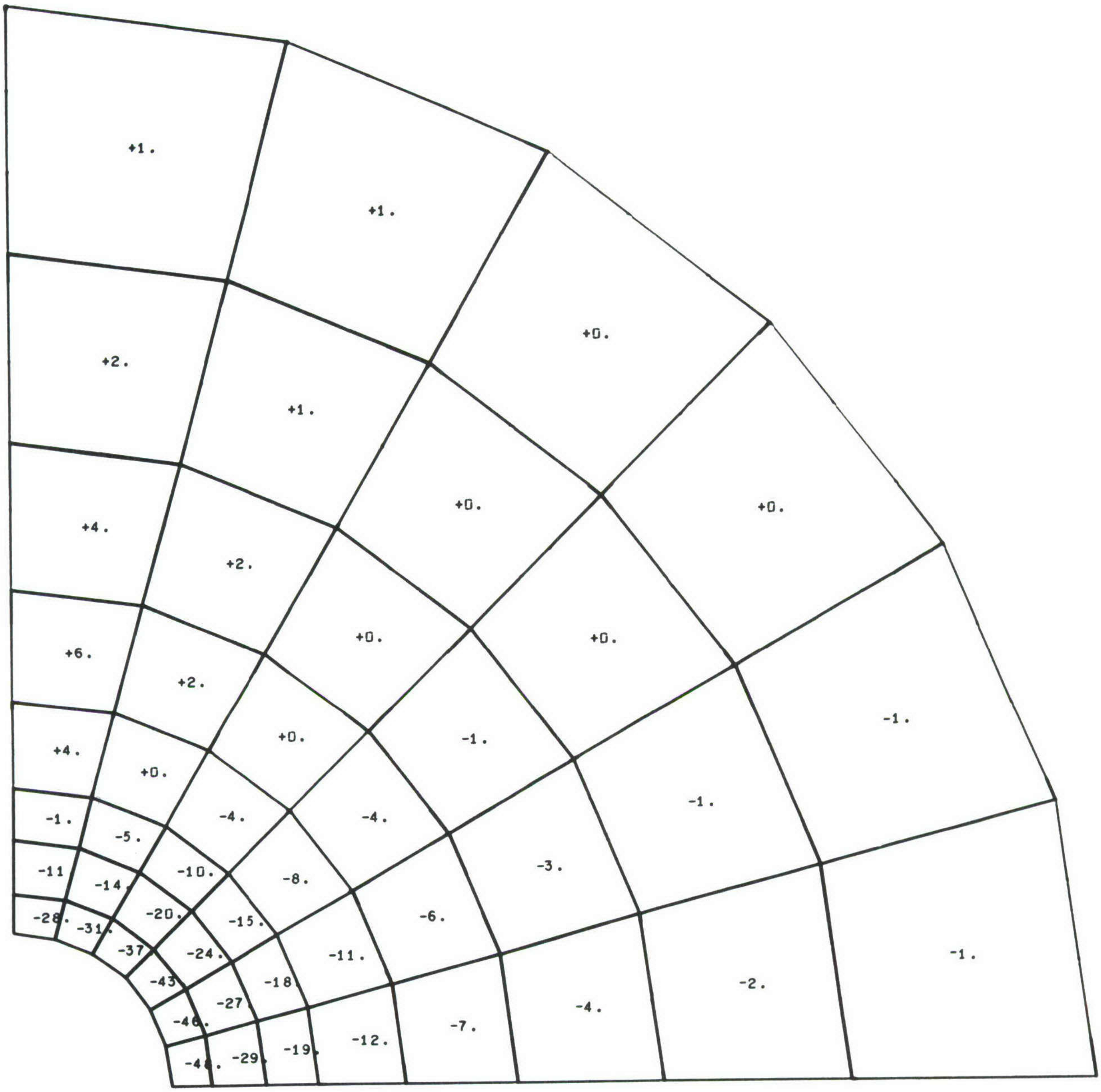


Figure AI-111 Second Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

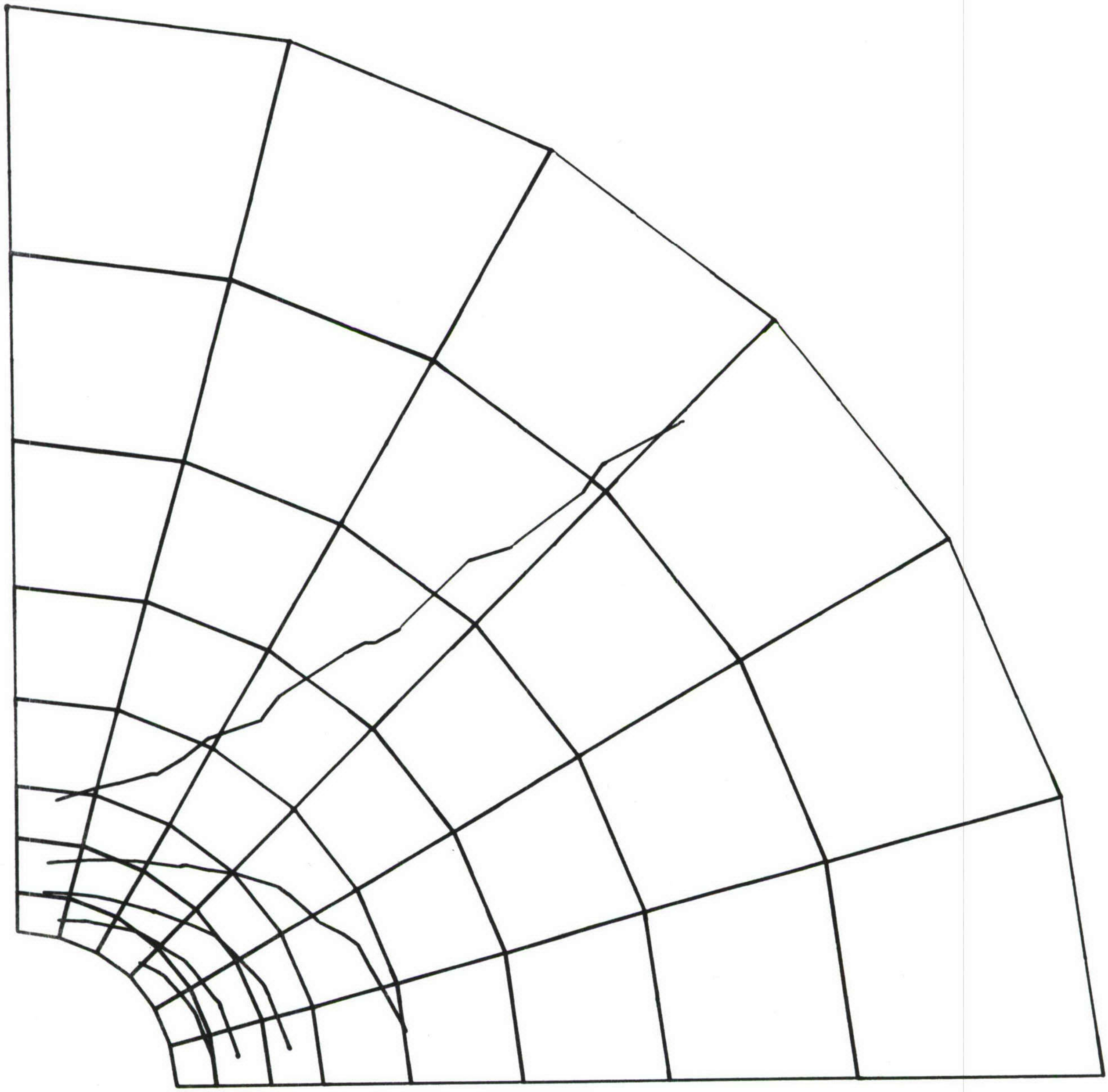


Figure AI-112 Second Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

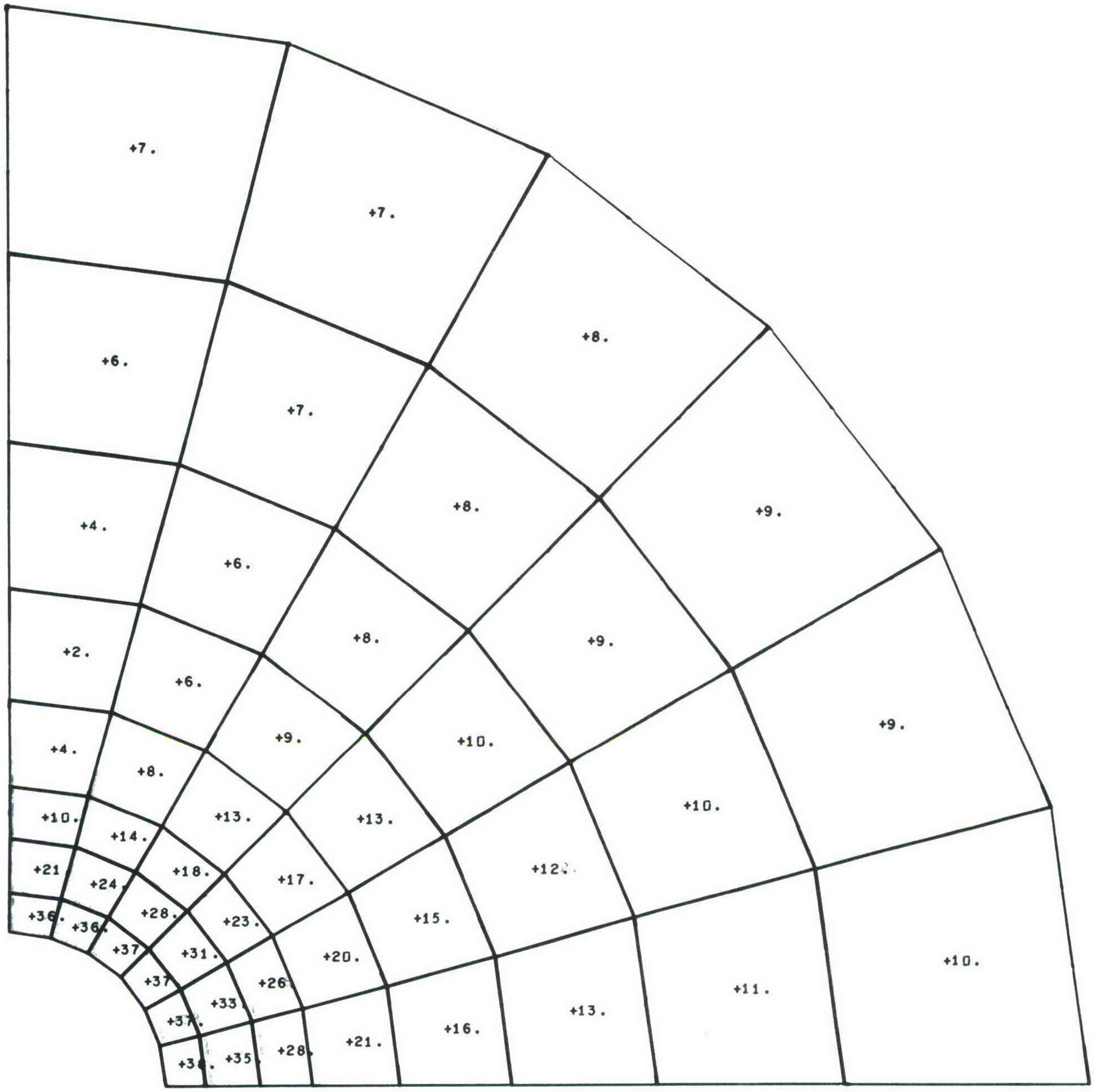


Figure AI-113 Principal Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

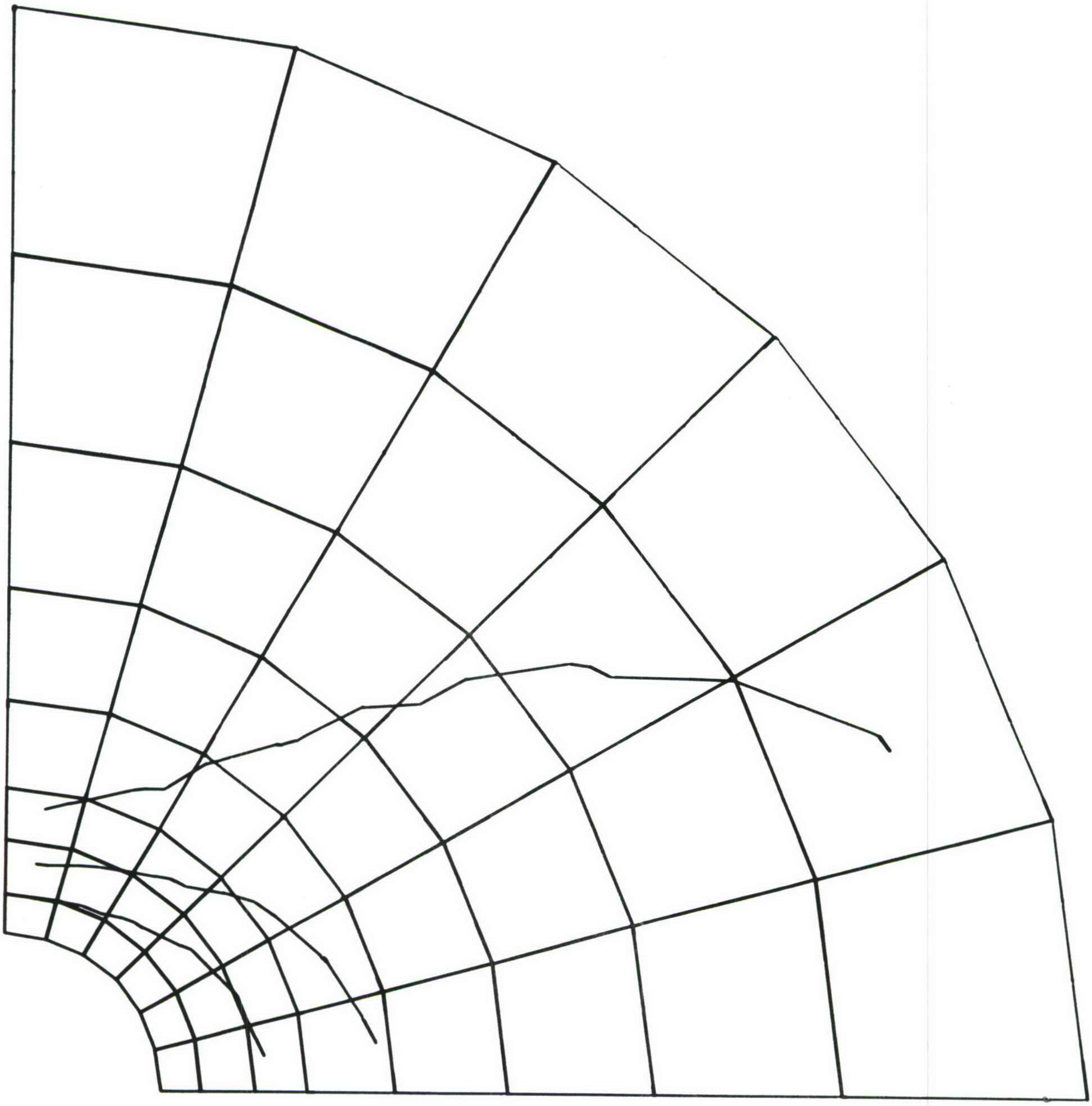


Figure AI-114 Principal Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

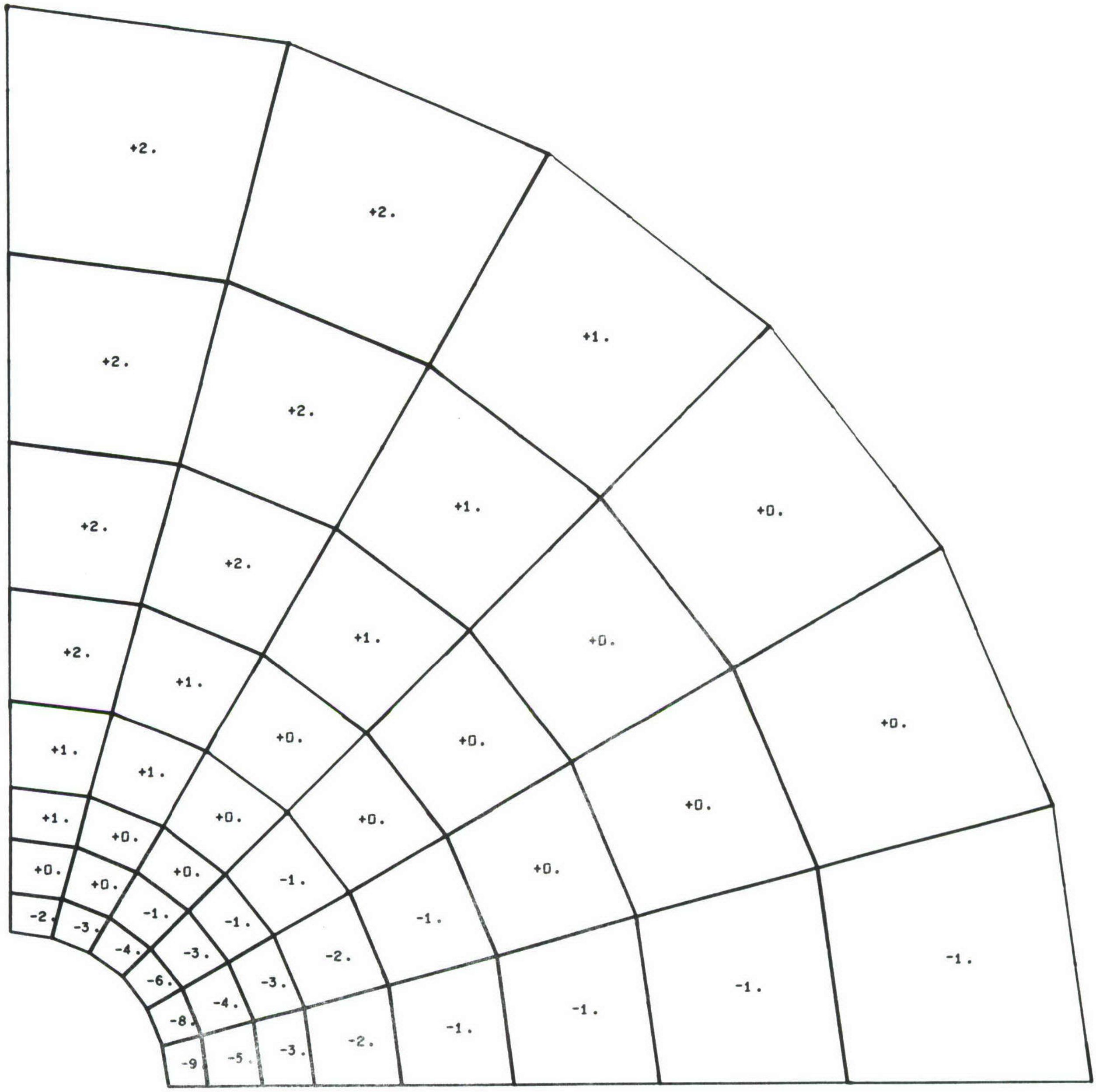


Figure AI-115 Radial Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

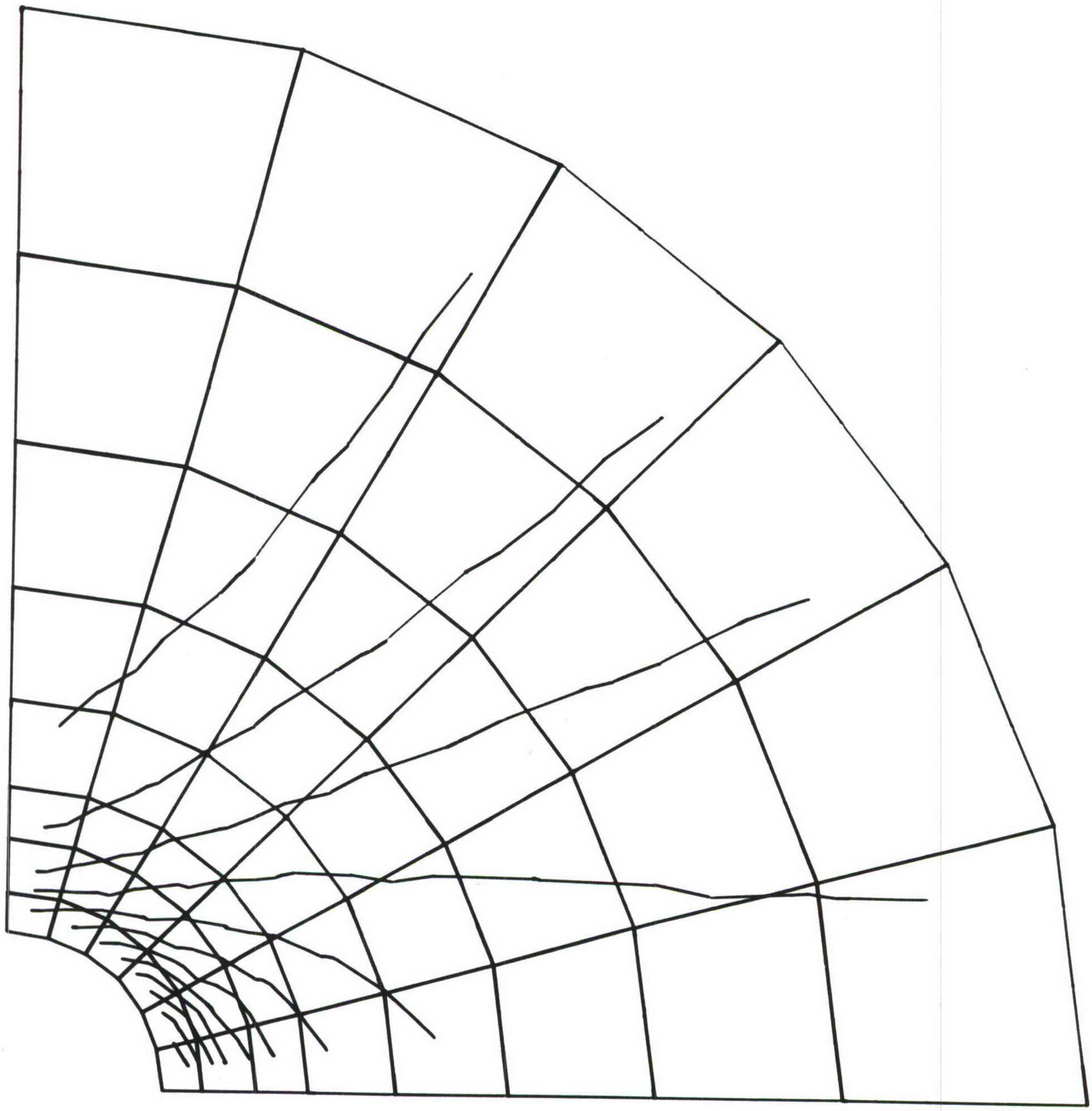


Figure AI-116 Radial Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

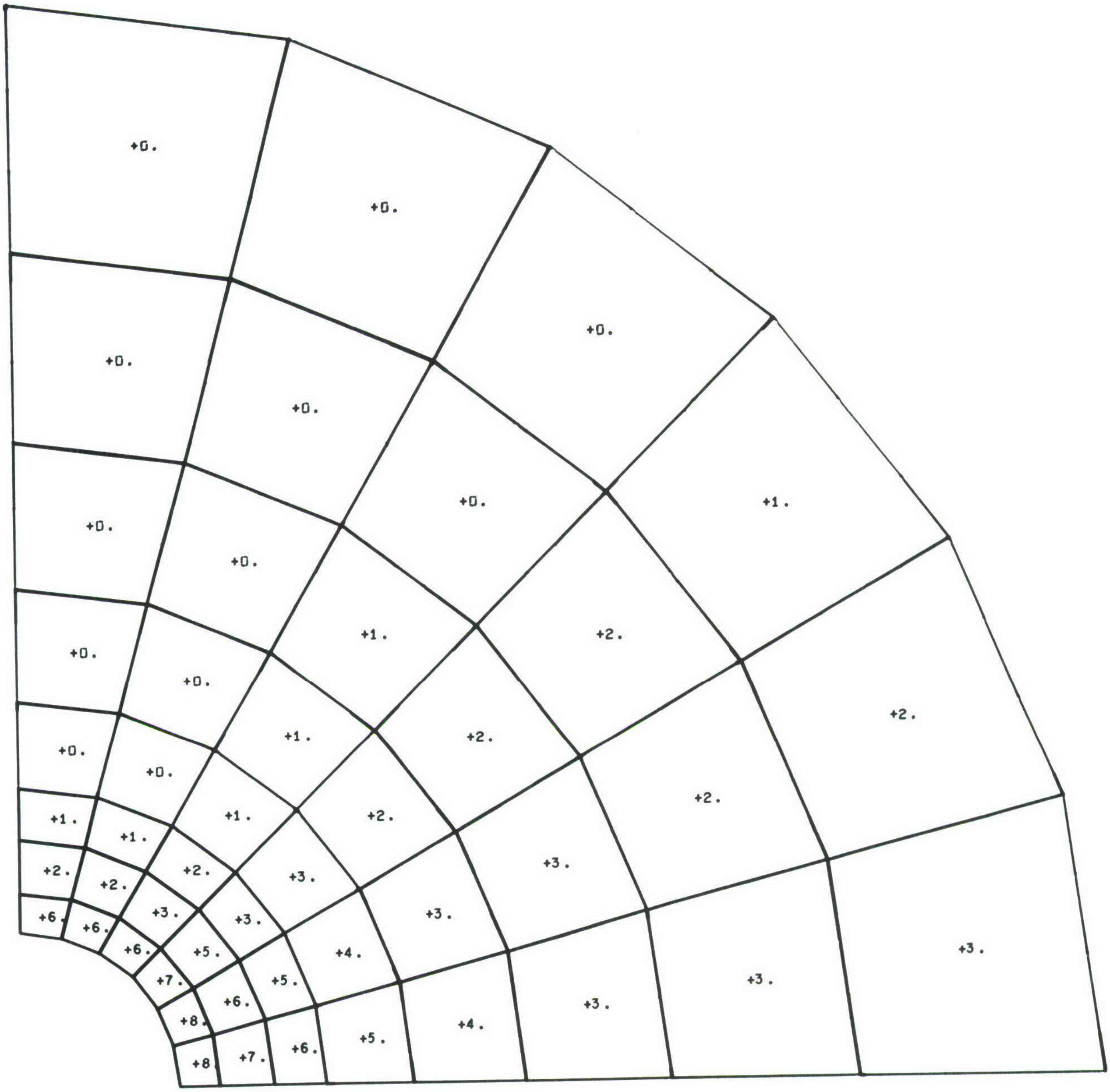


Figure AI-117 Tangential Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

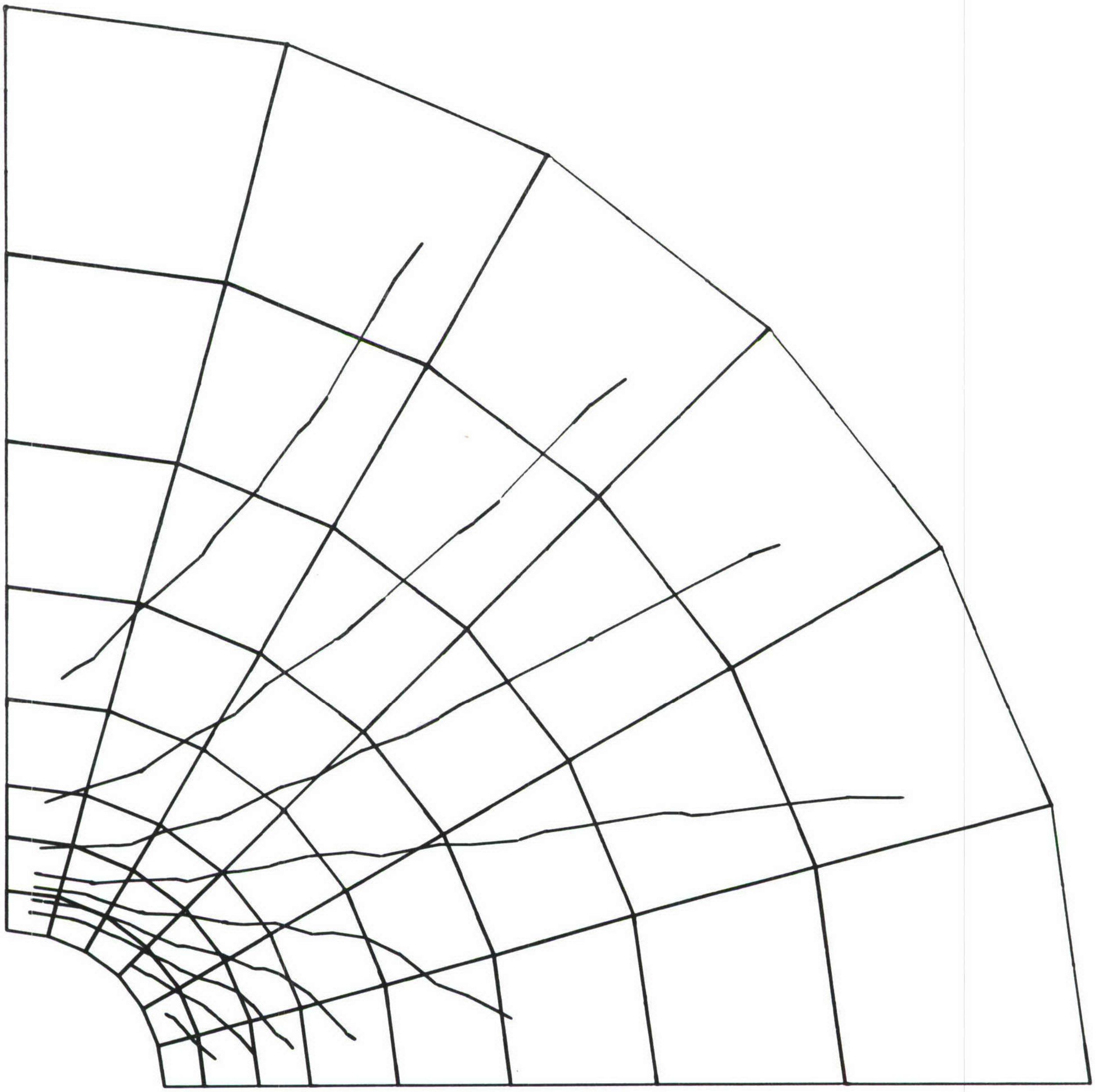


Figure AI-118 Tangential Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

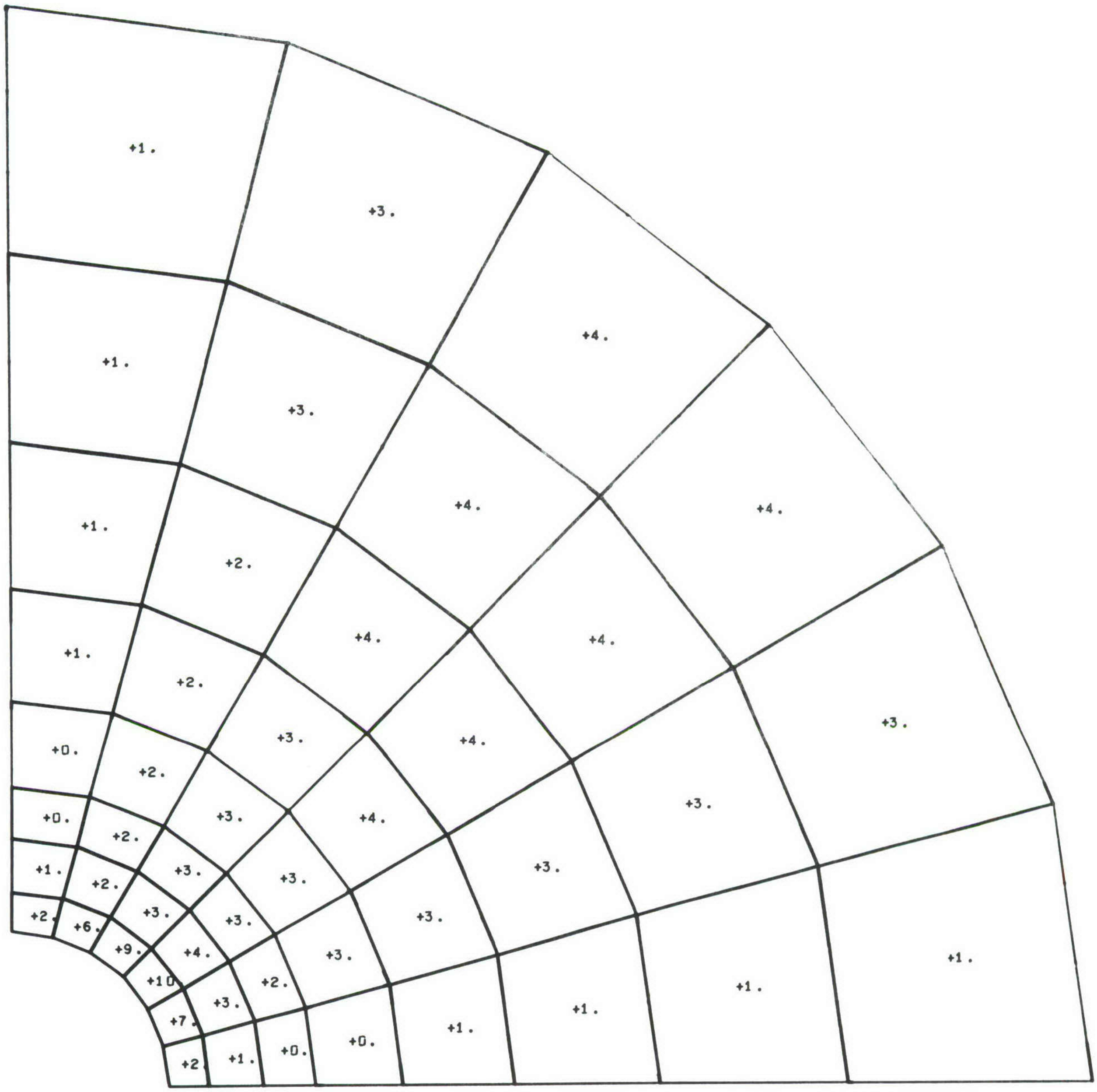


Figure AI-119 Radial-Tangential Shear Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

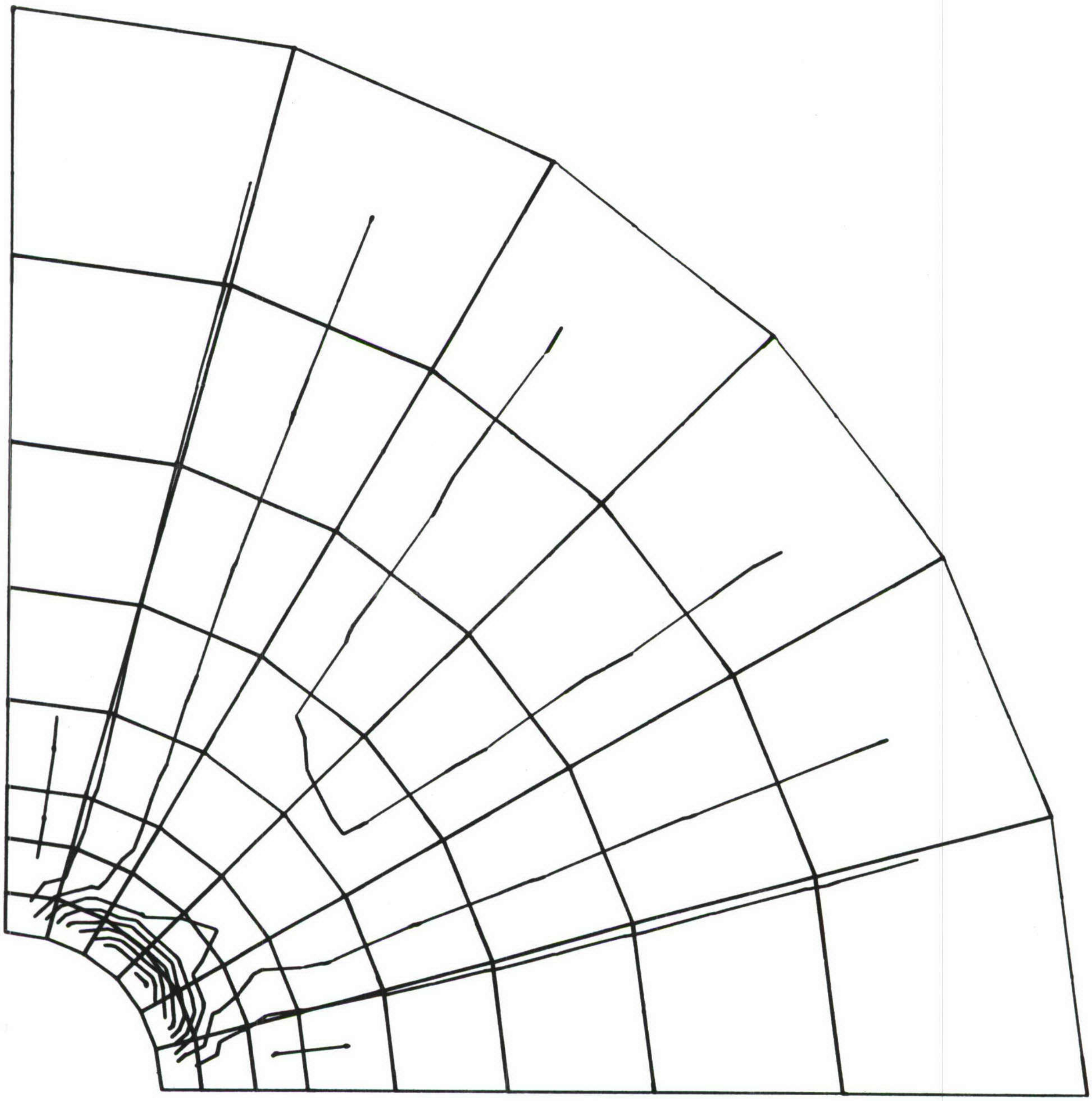


Figure AI-120 Radial-Tangential Shear Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

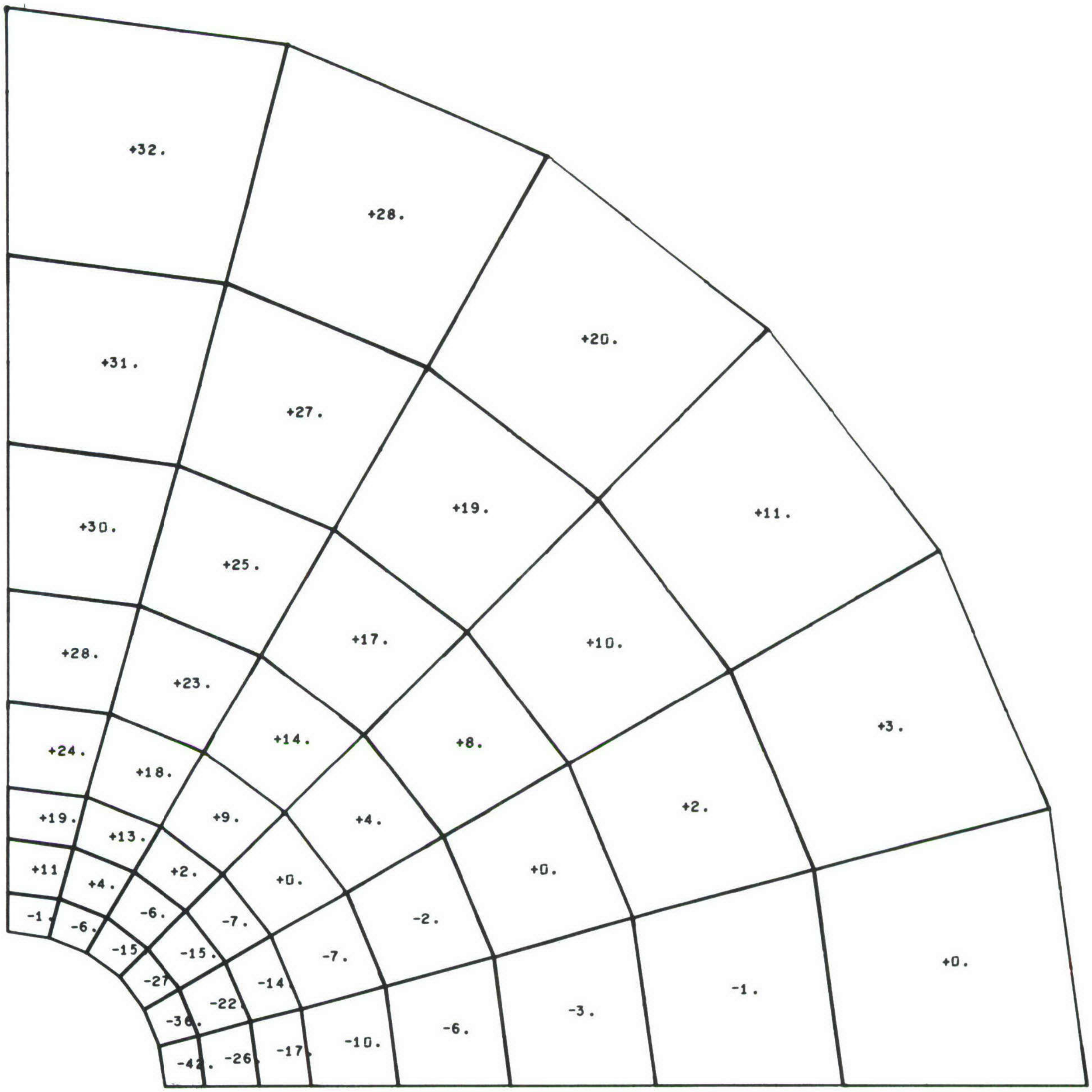


Figure AI-121 Radial Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

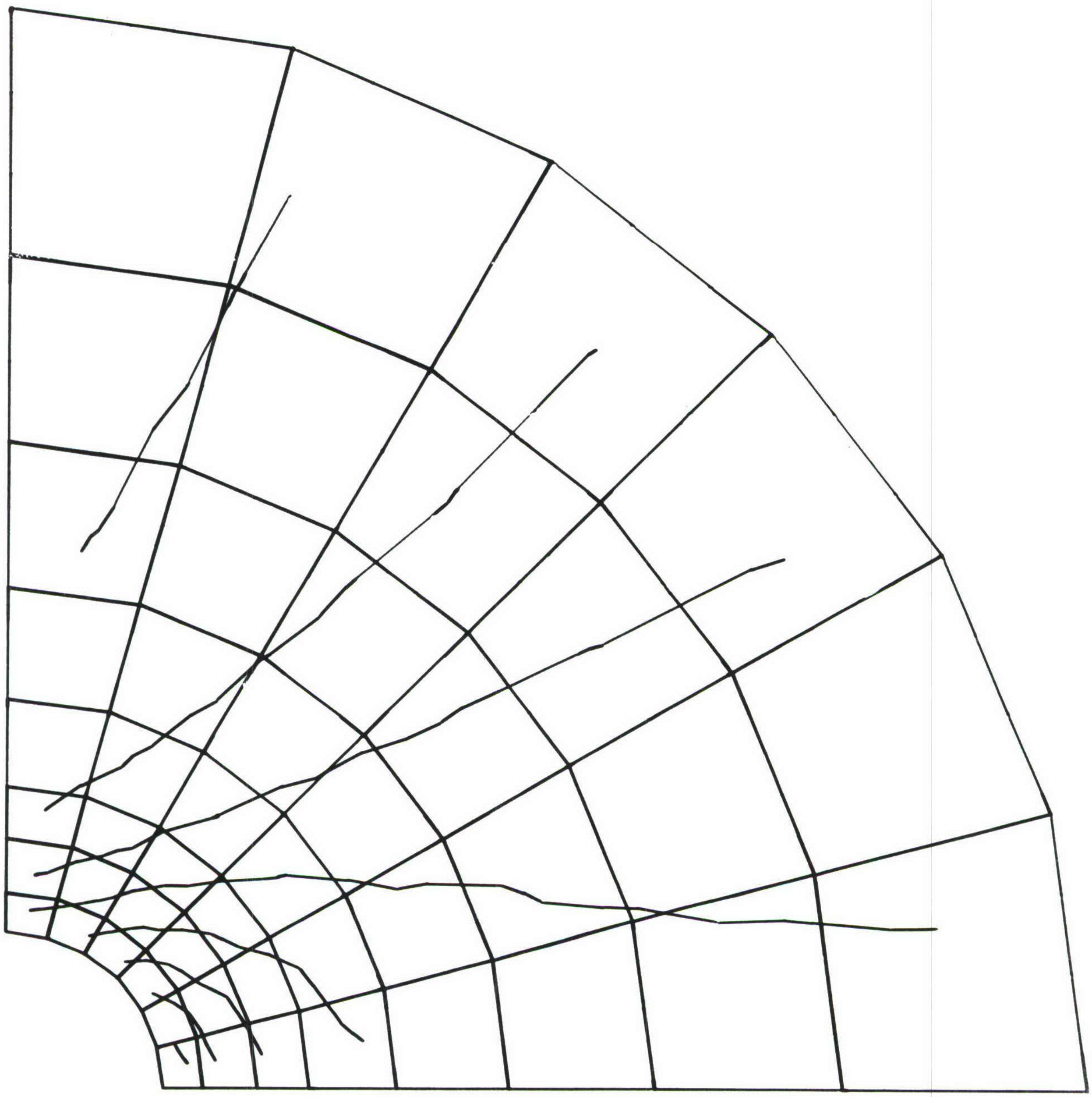


Figure AI-122 Radial Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

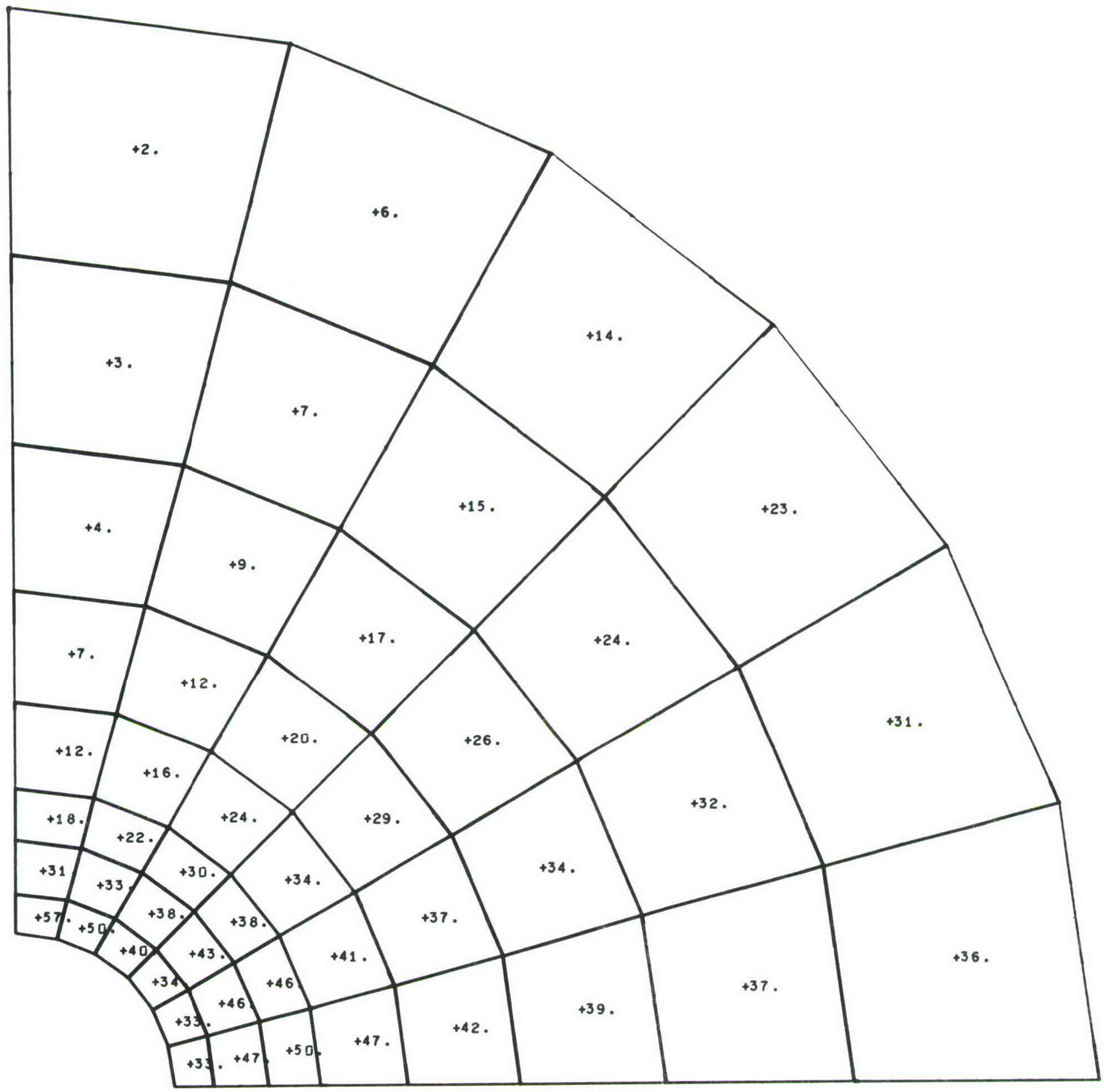


Figure AI-123 Tangential Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

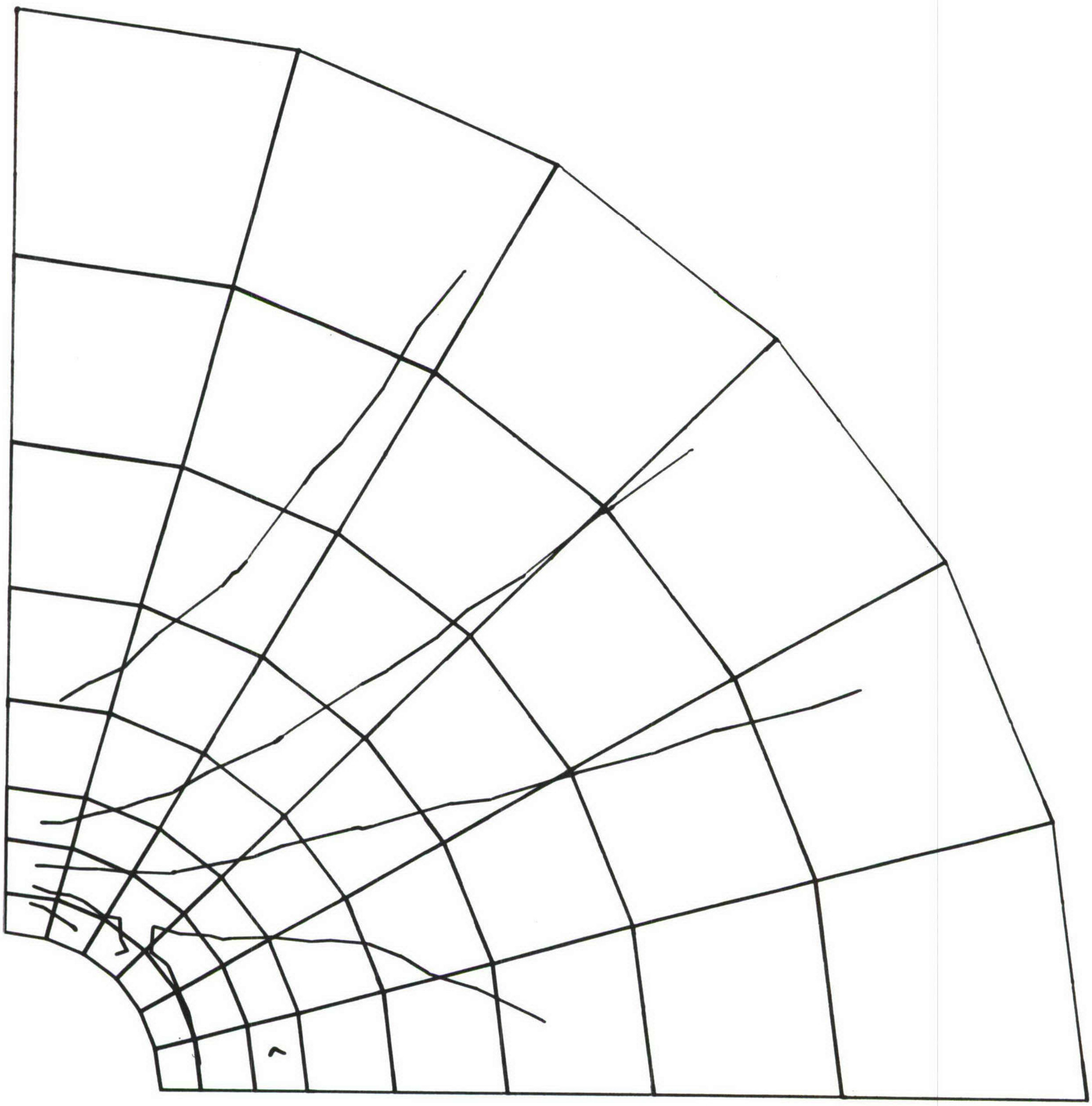


Figure AI-124 Tangential Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

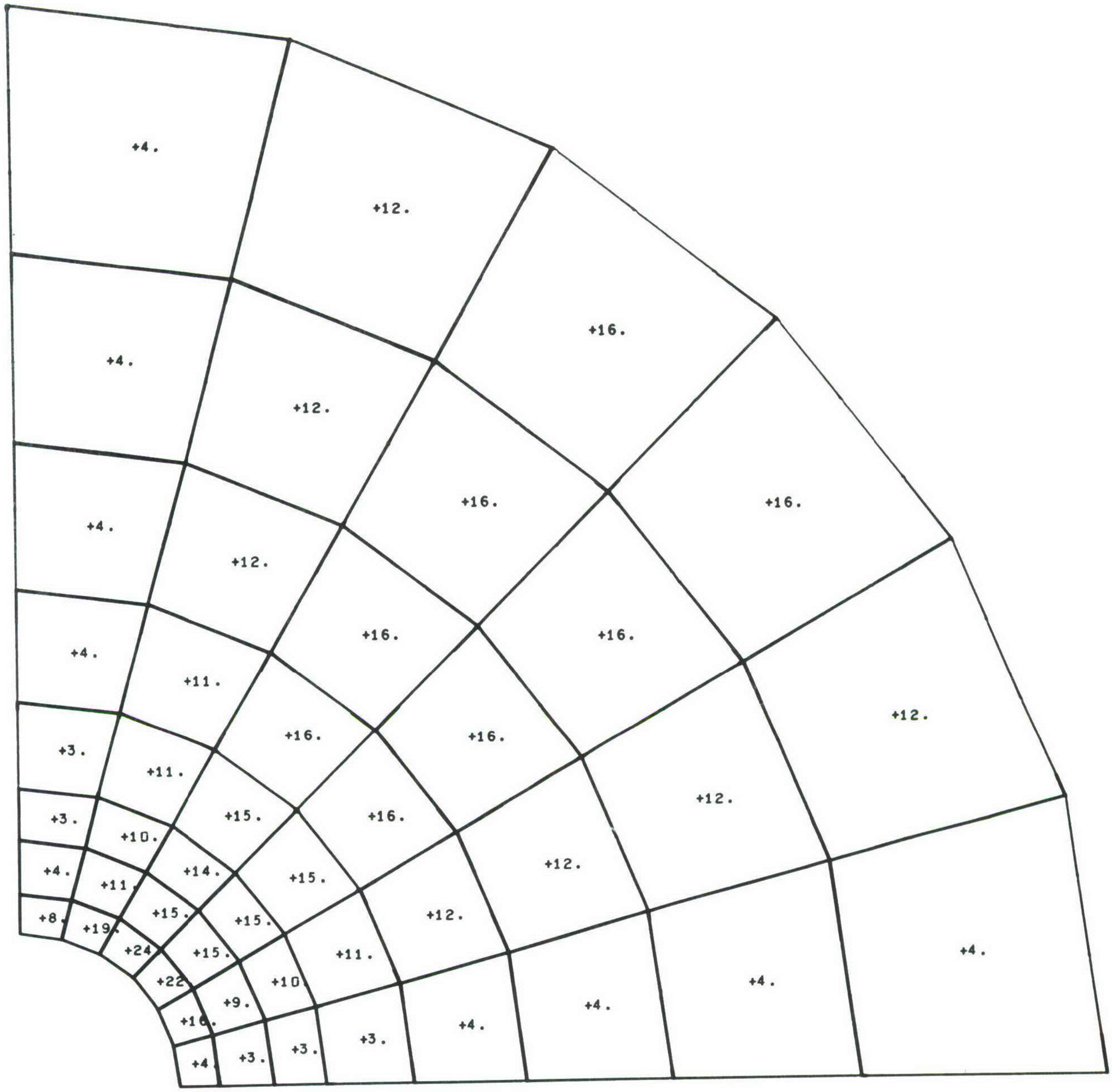


Figure AI-125 Radial-Tangential Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

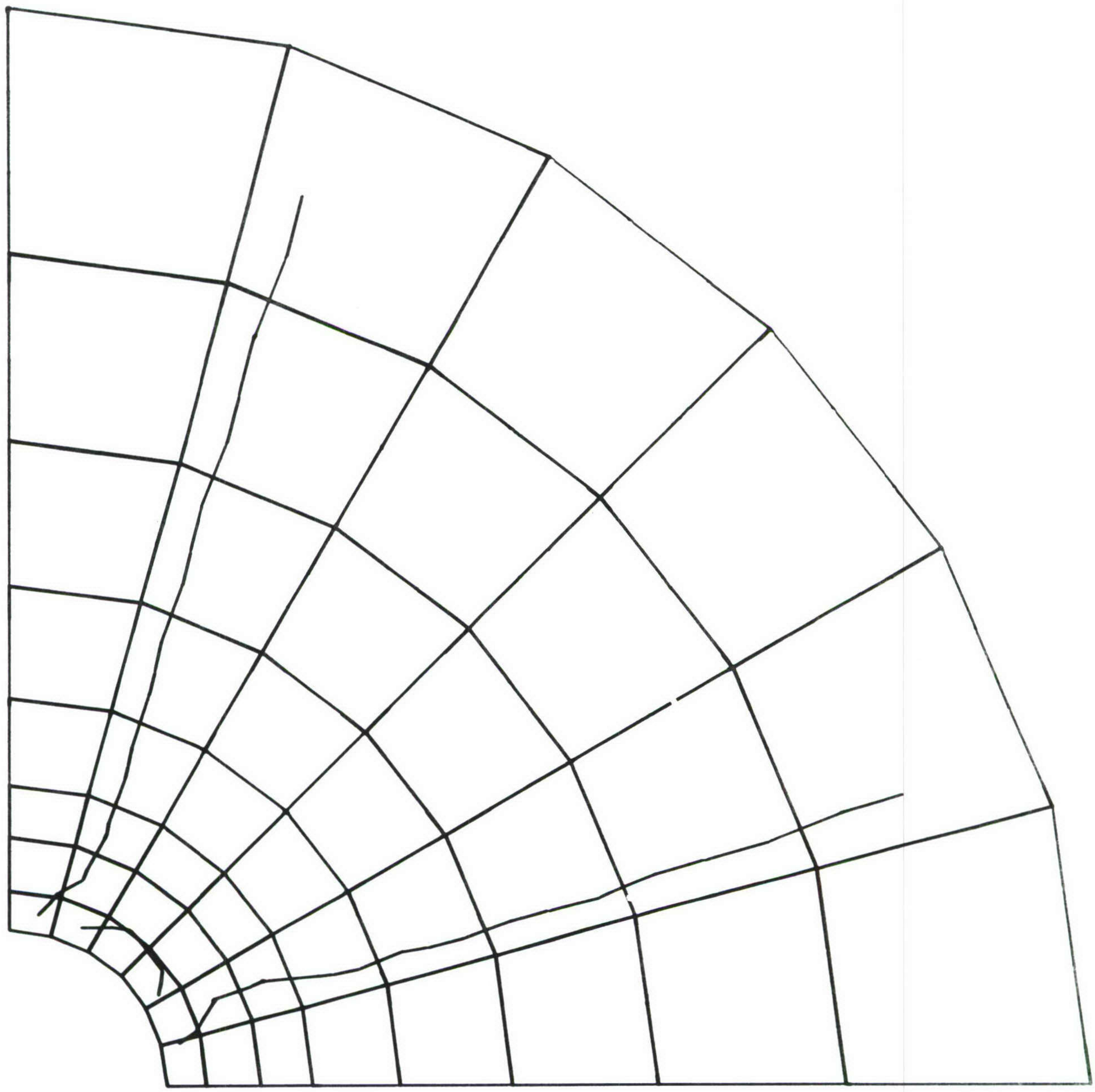


Figure AI-126 Radial Tangential Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

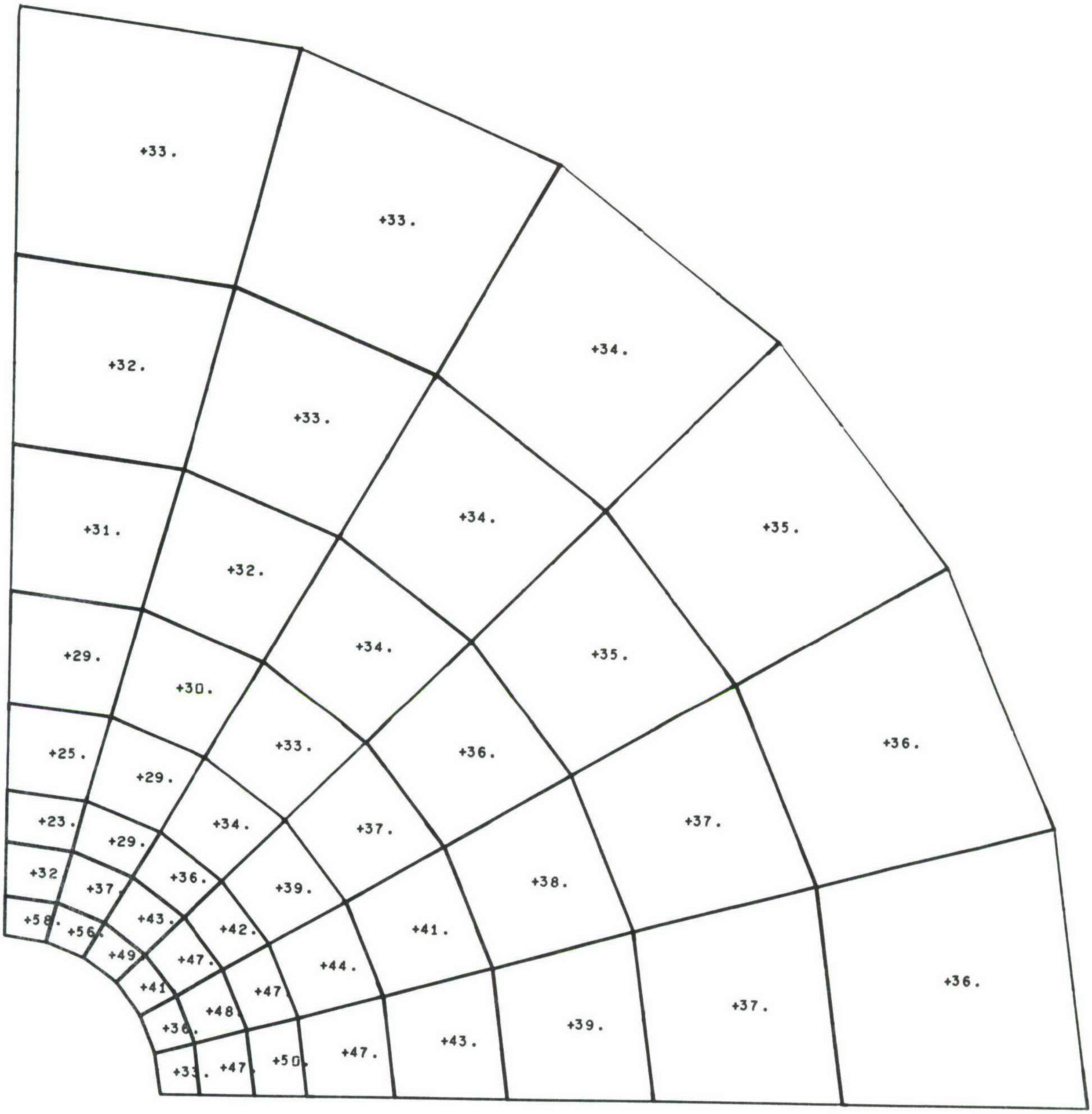


Figure AI-127 First Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

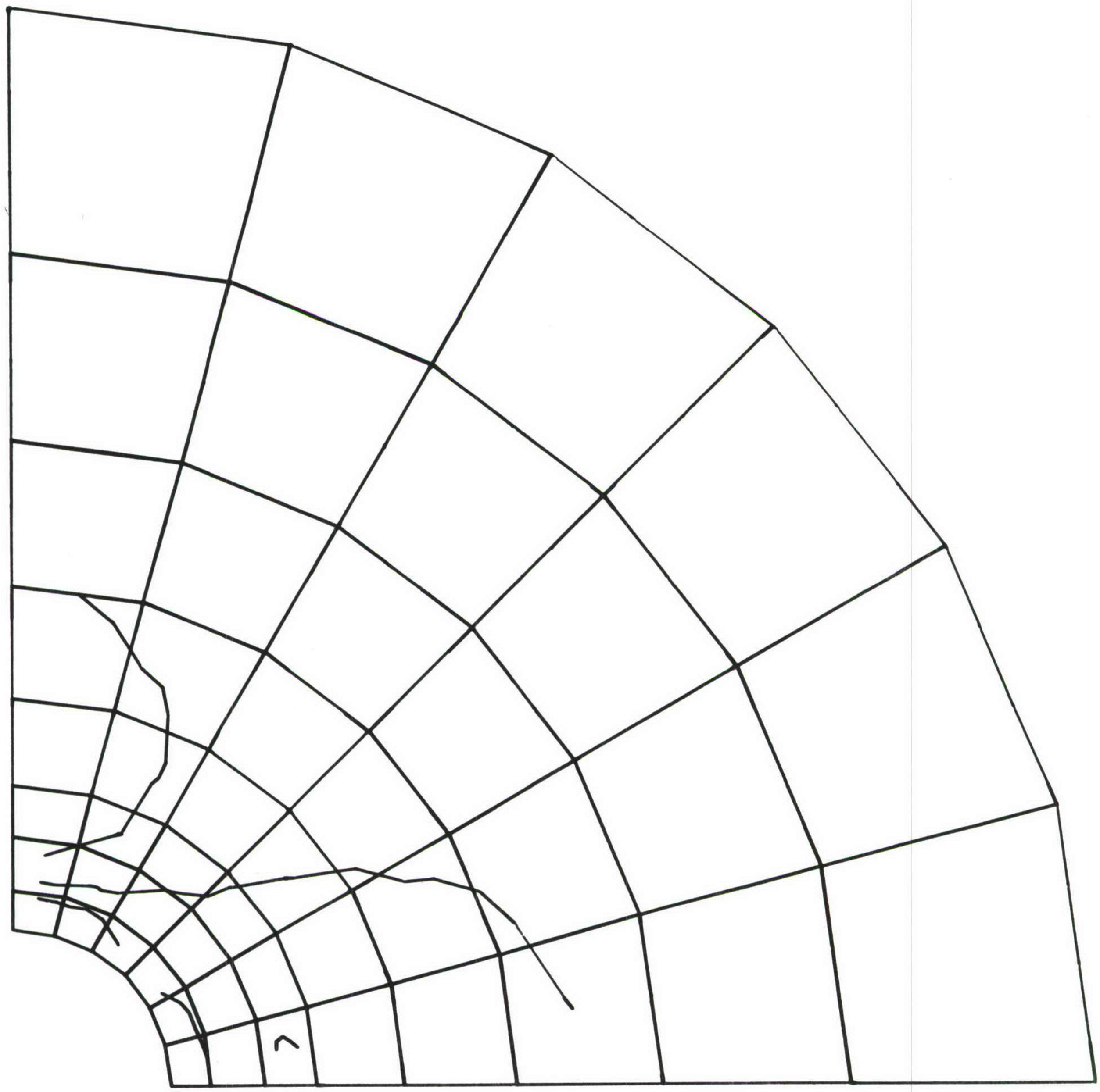


Figure AI-128 First Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

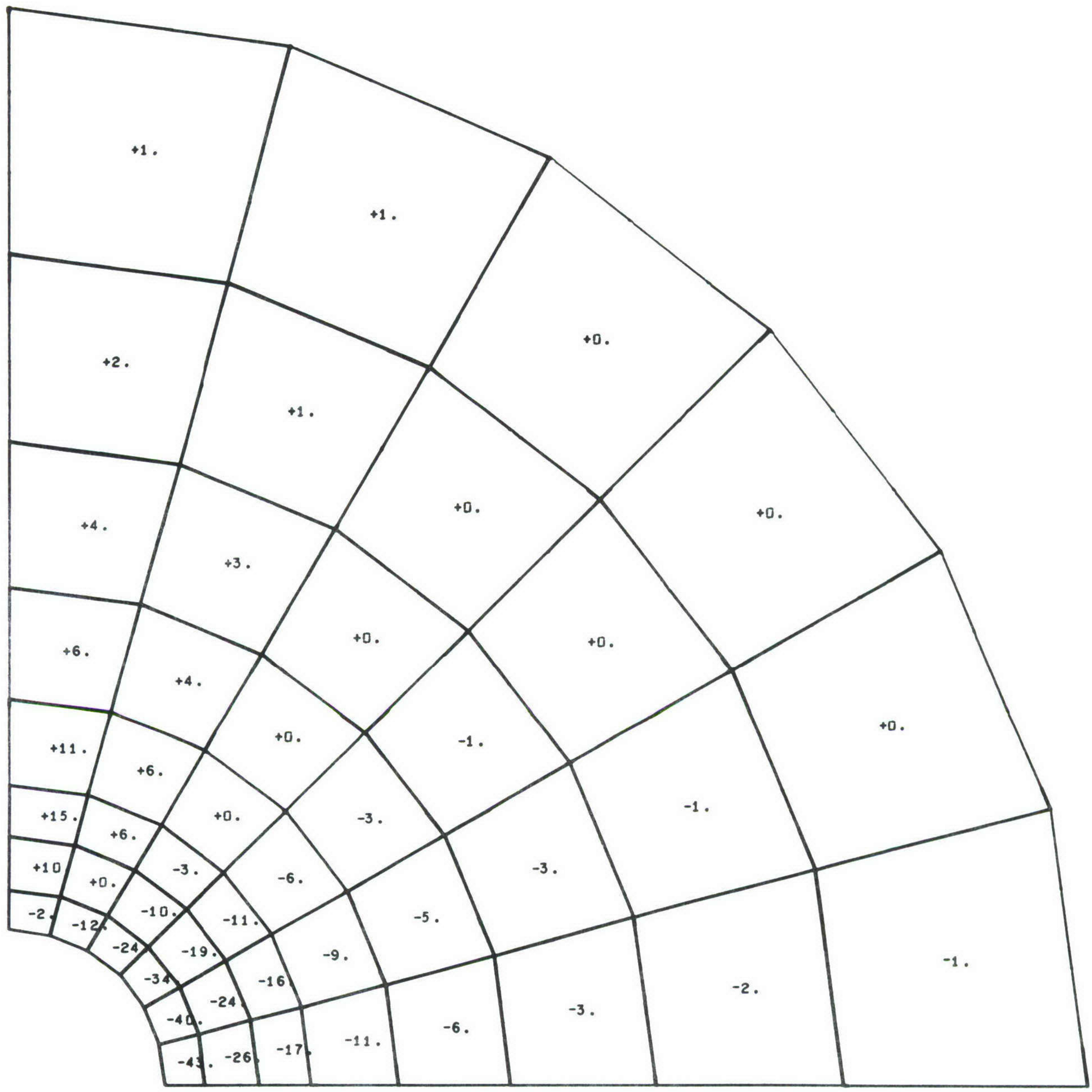


Figure AI-129 Second Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

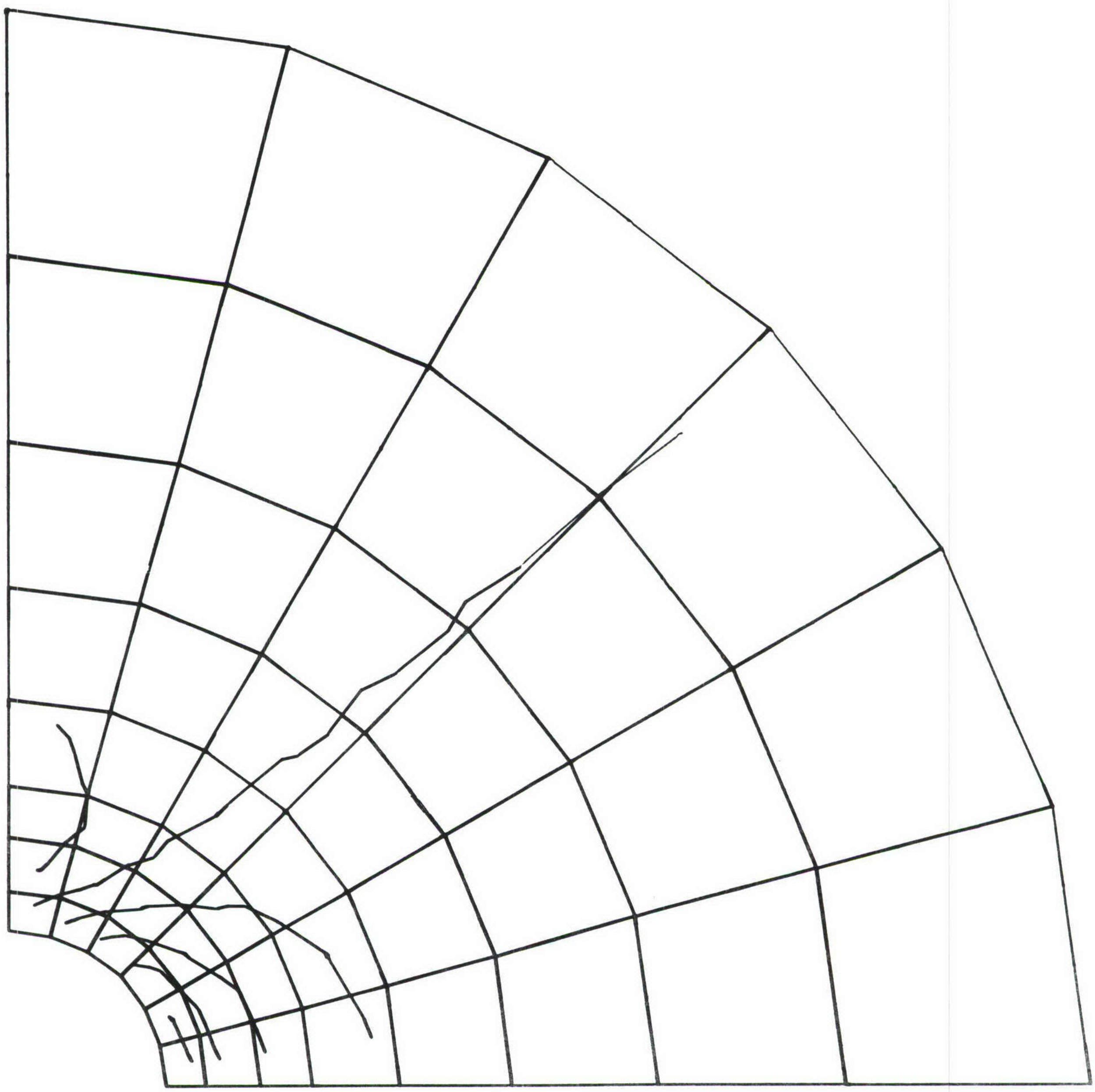


Figure AI-130 Second Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

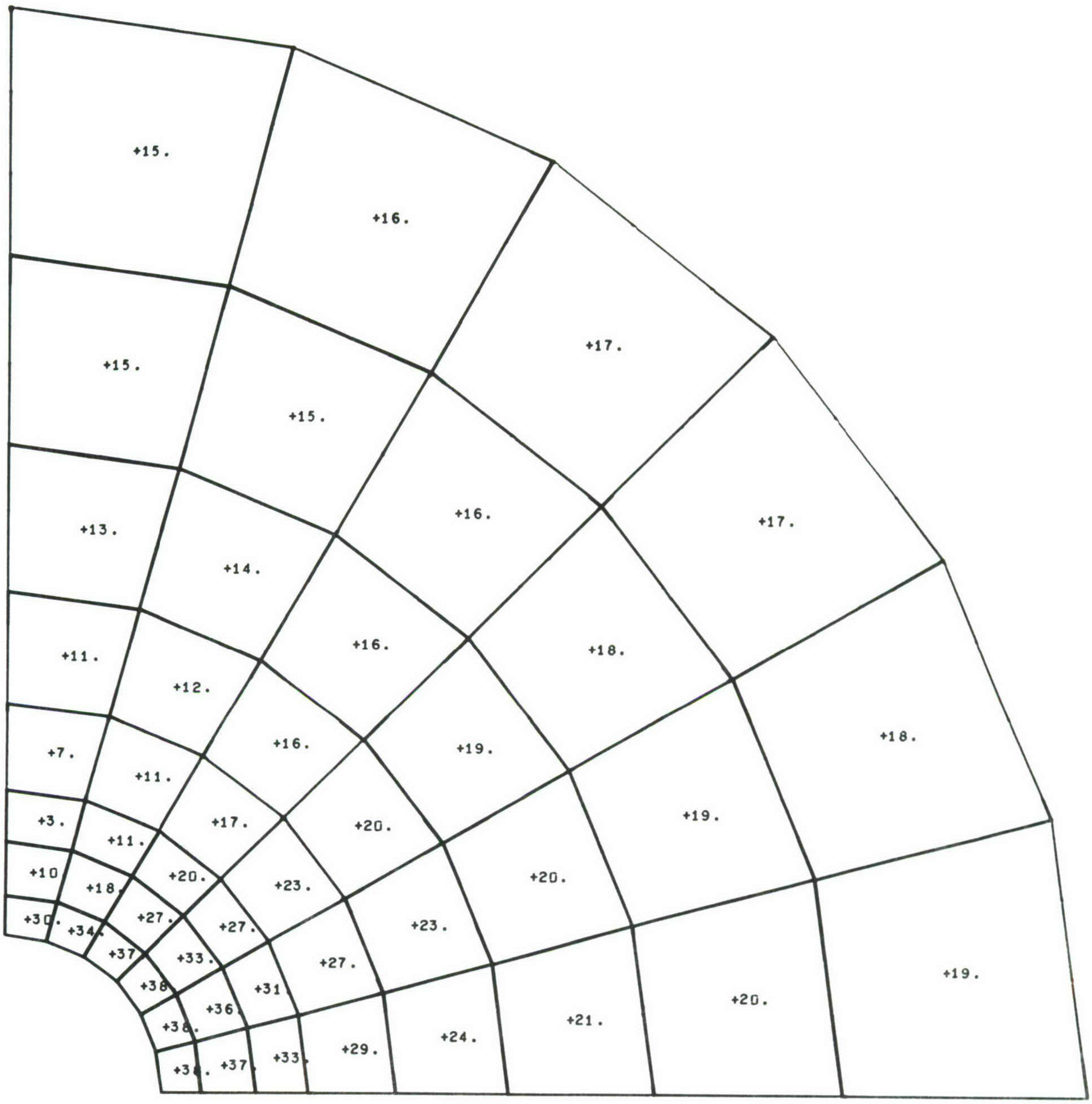


Figure AI-131 Principal Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

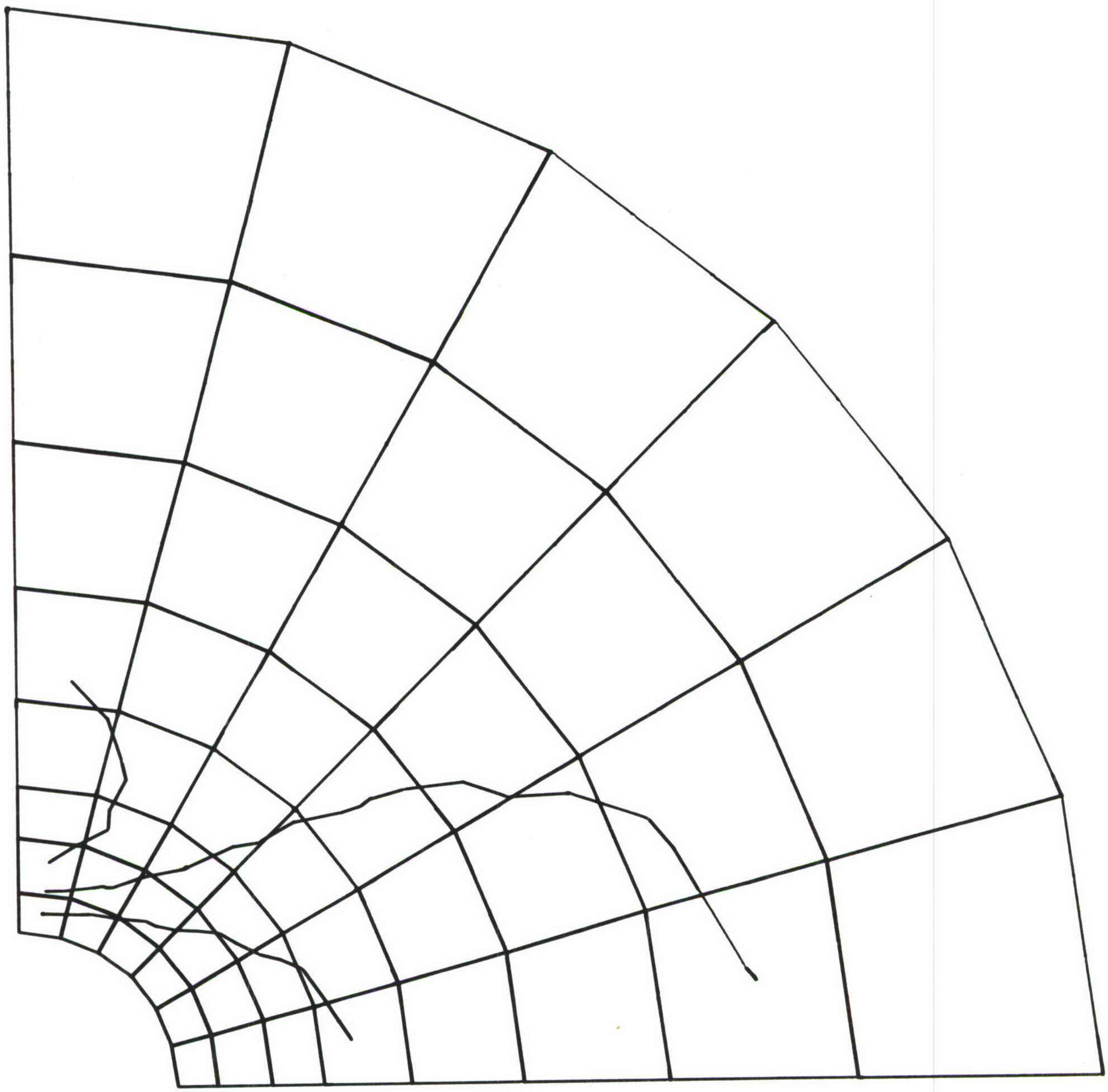


Figure AI-132 Principal Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

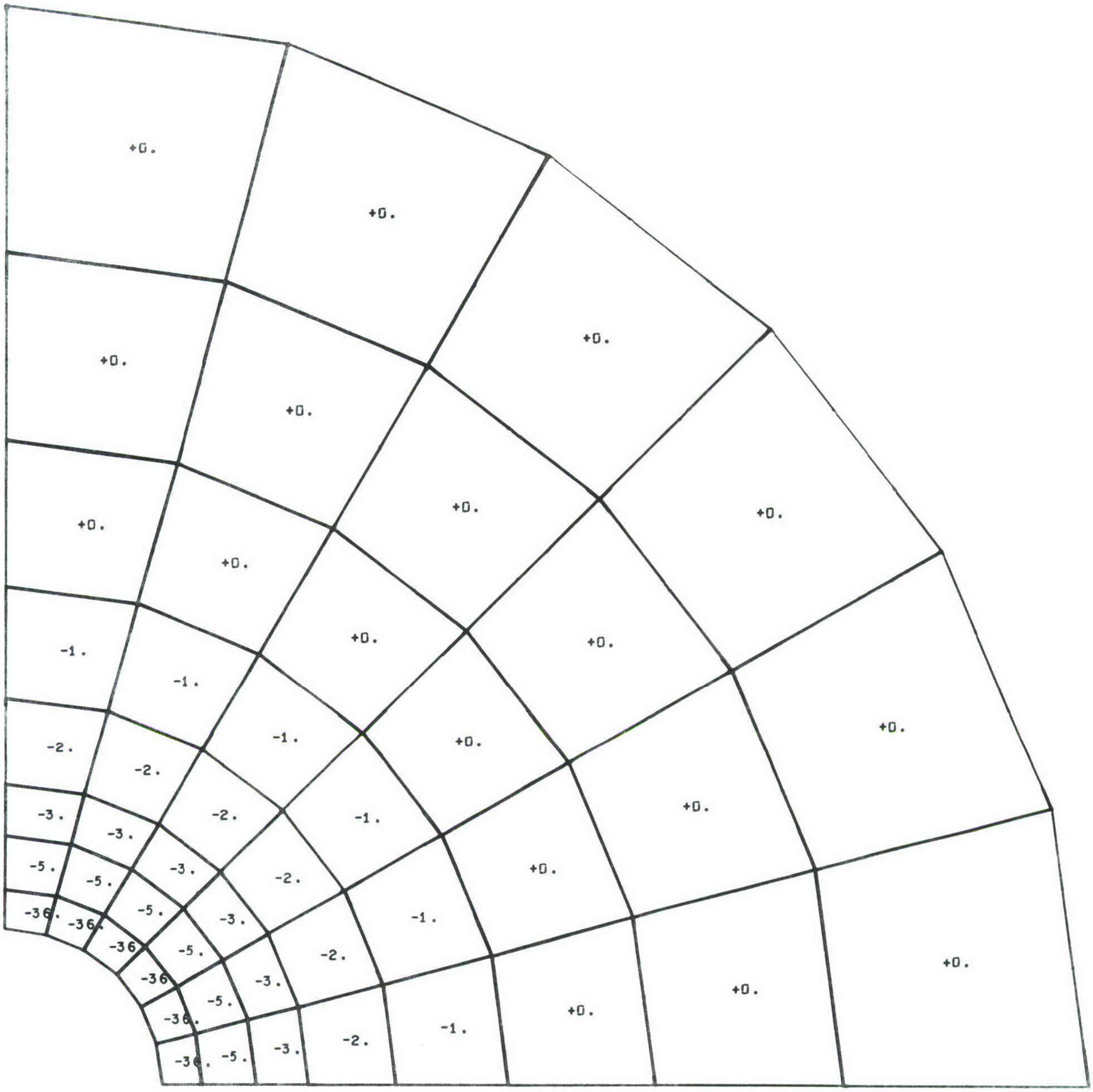


Figure AI-133 Radial Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

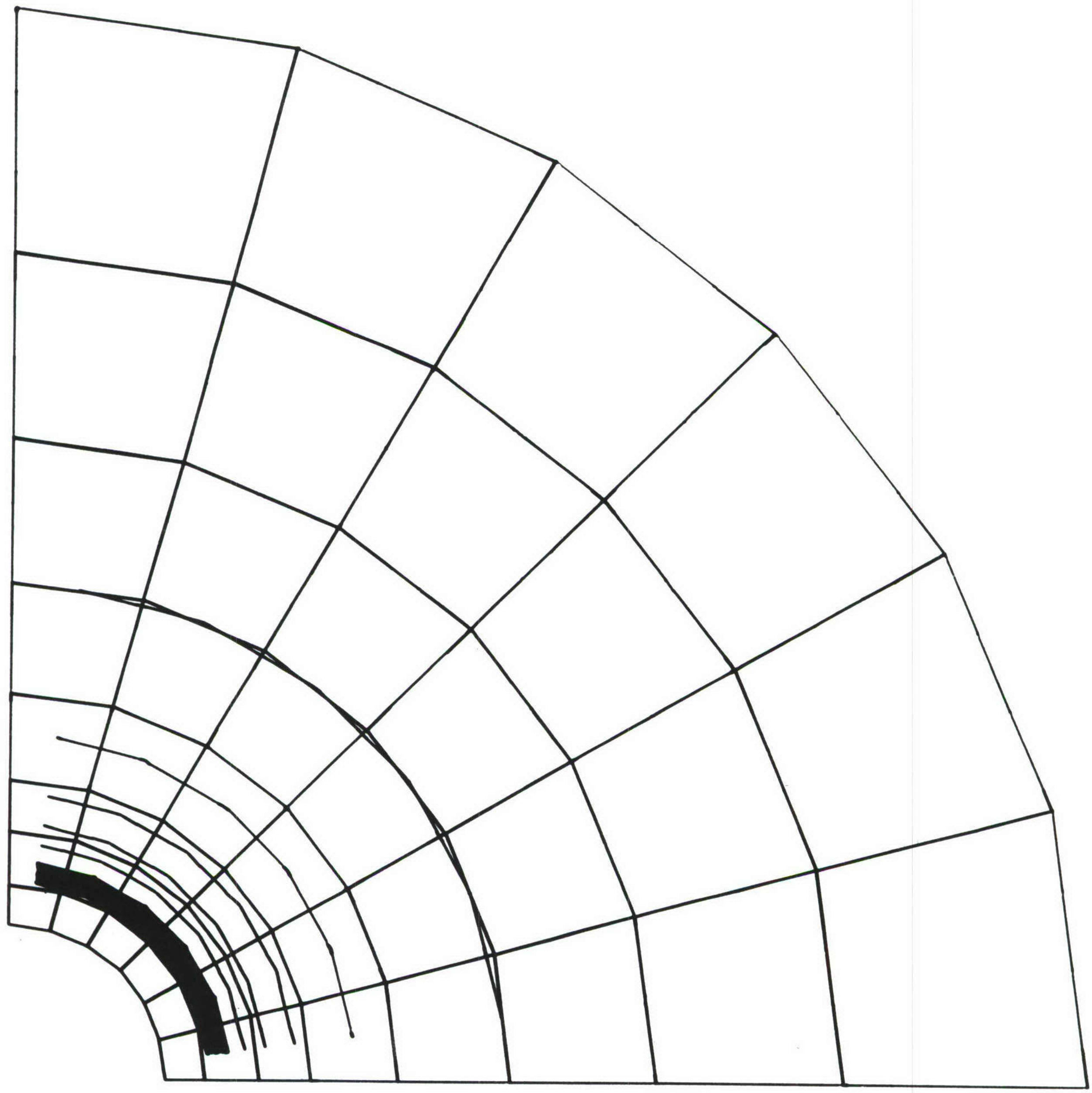


Figure AI-134 Radial Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

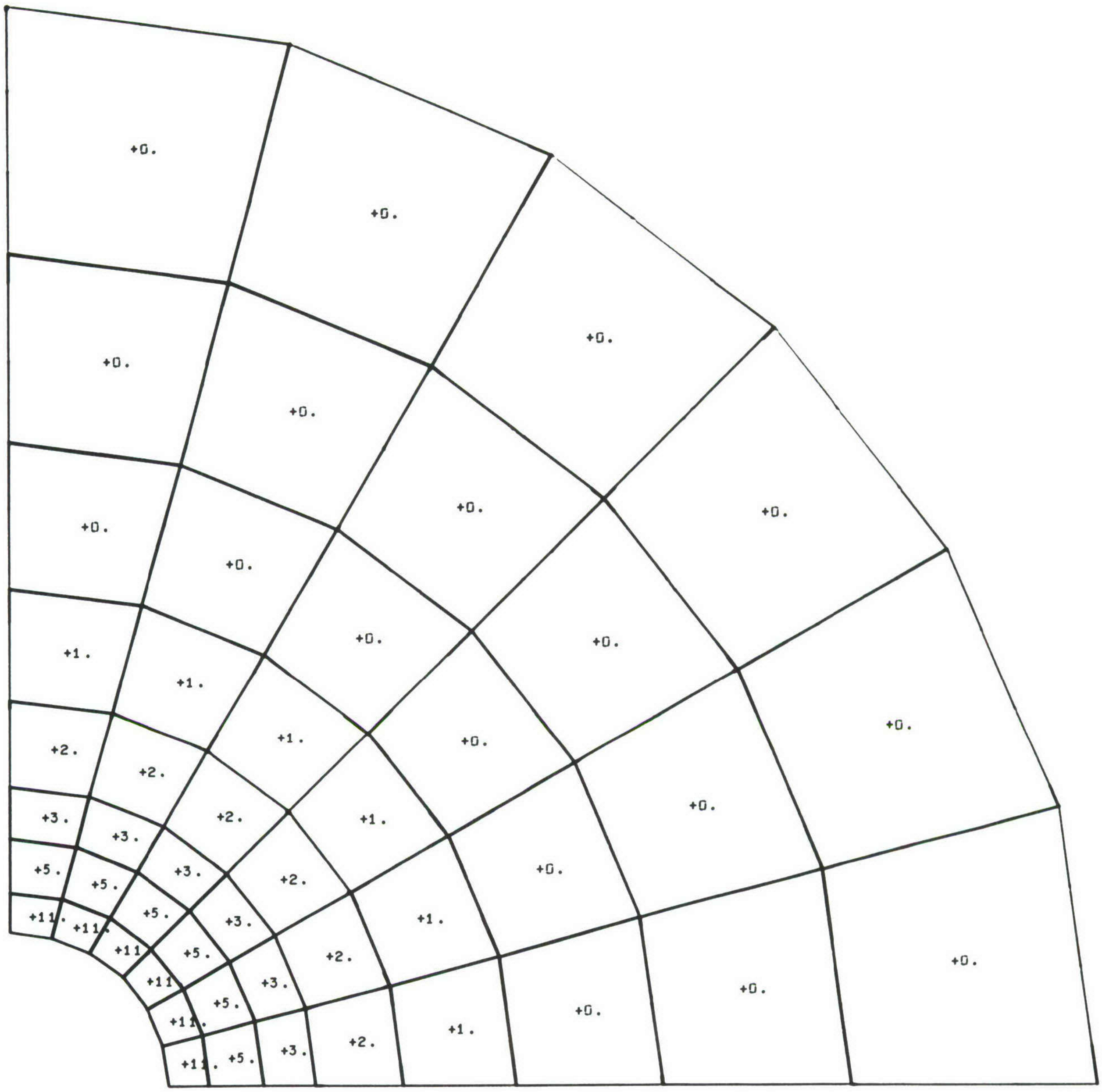


Figure AI-135 Tangential Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

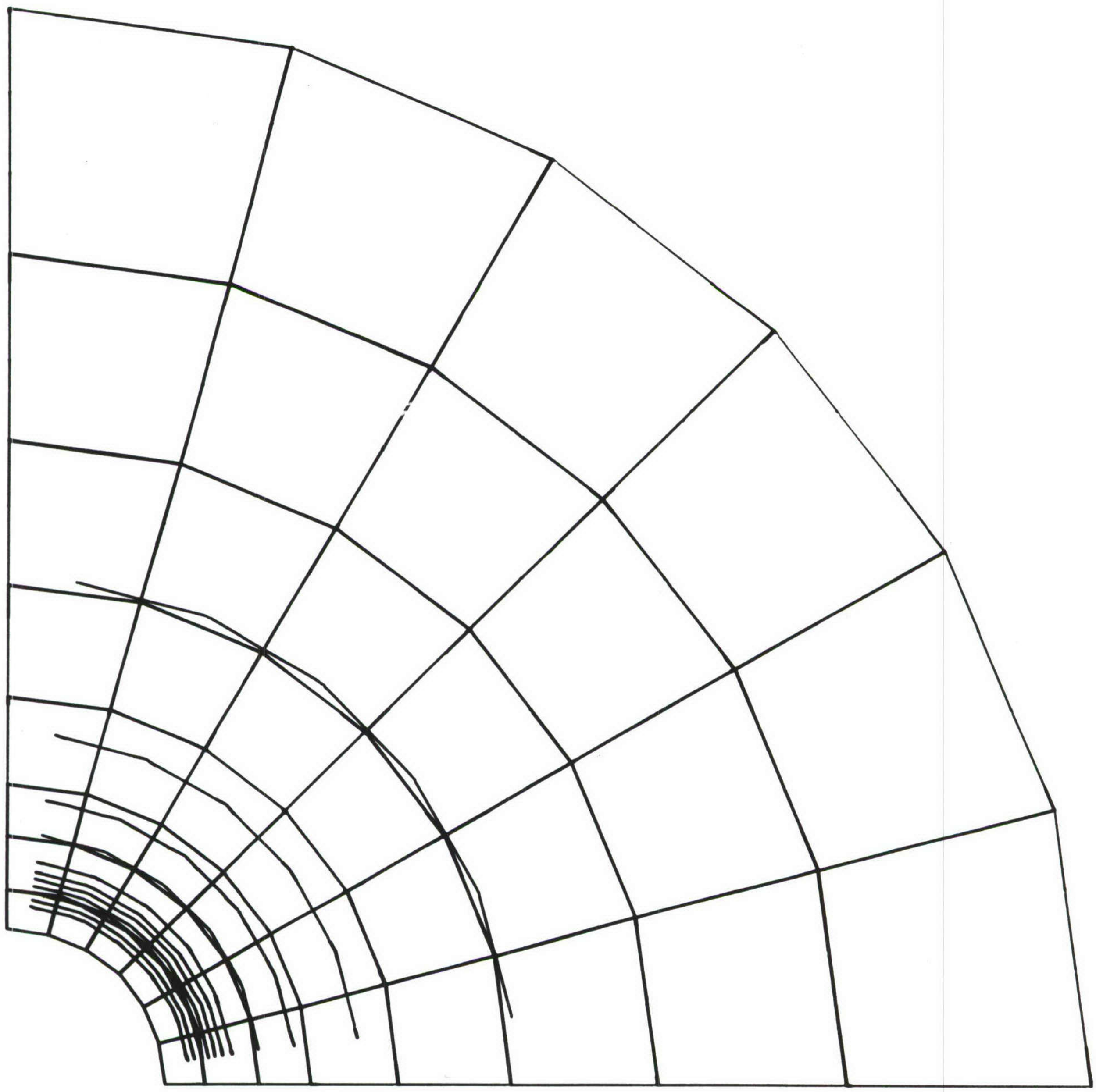


Figure AI-136 Tangential Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

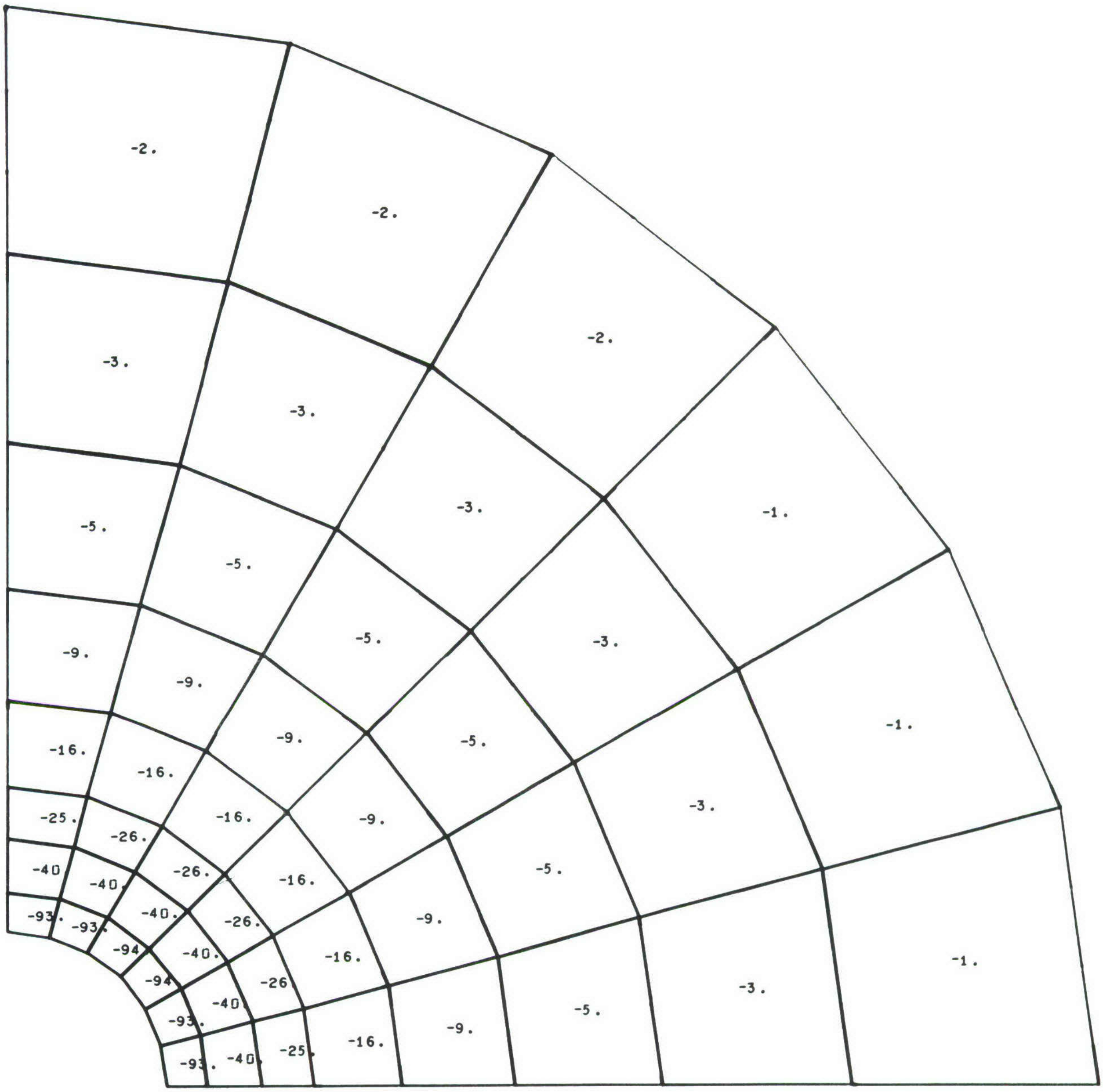


Figure AI-137 Radial Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

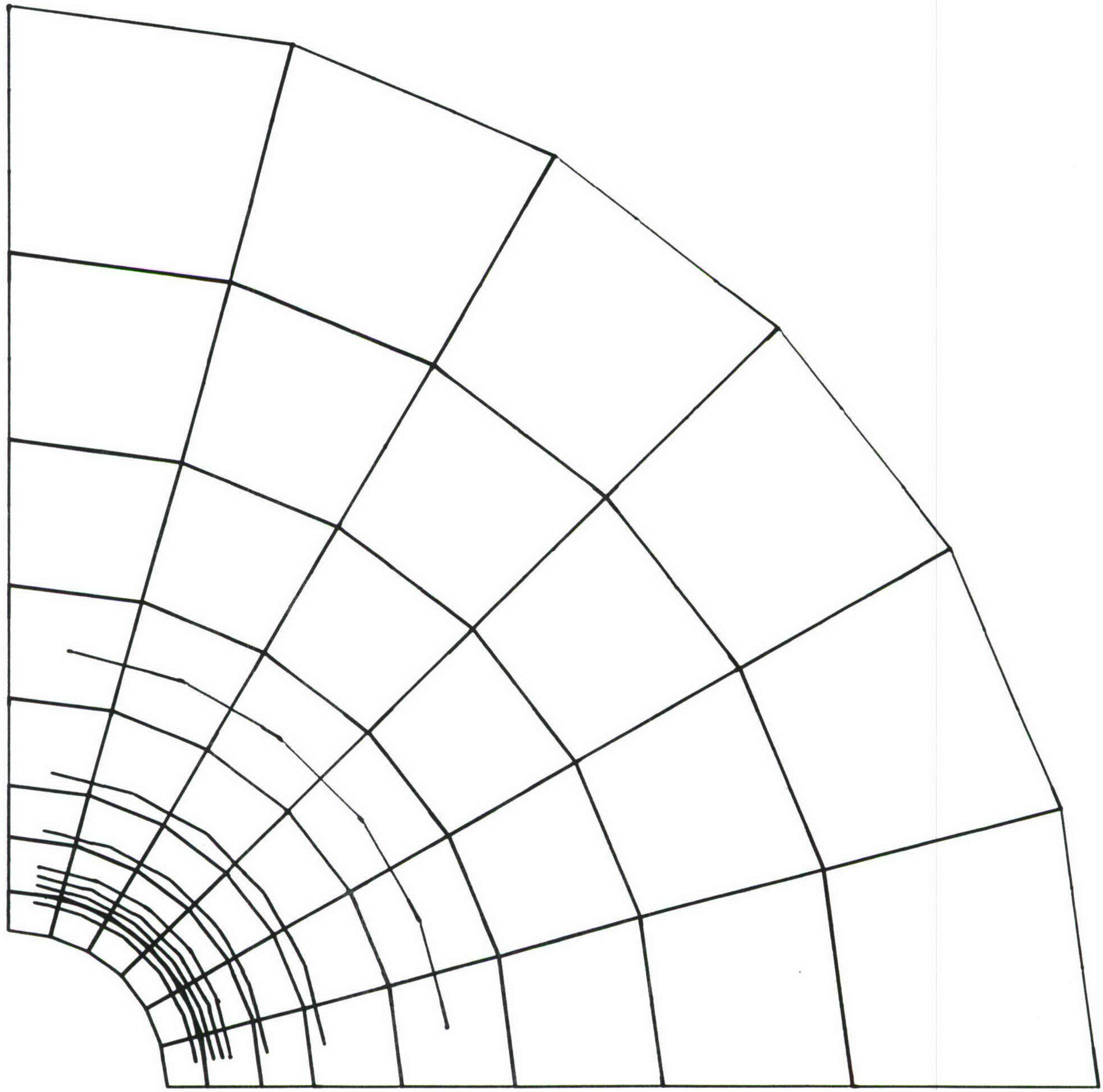


Figure AI-138 Radial Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

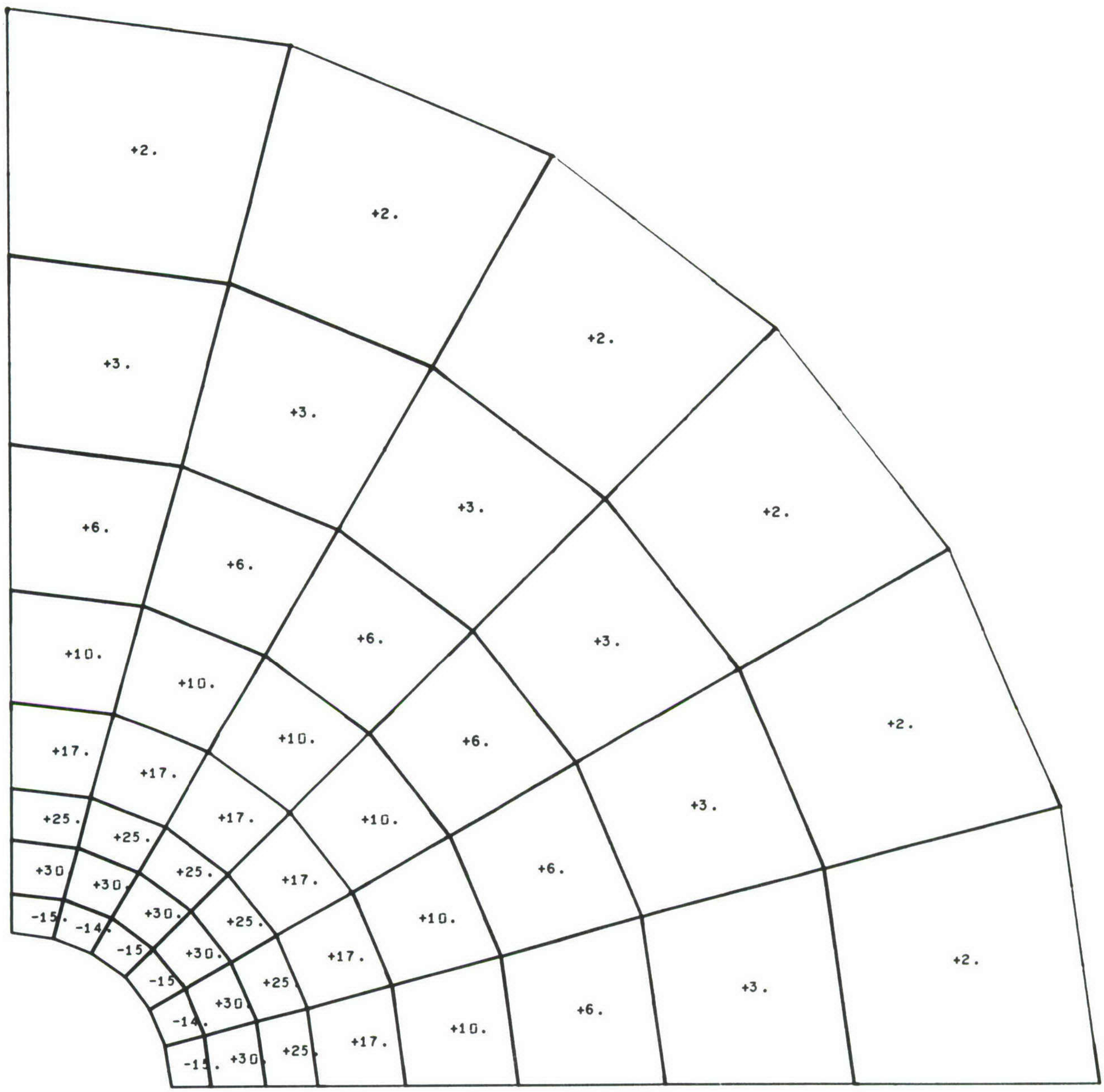


Figure AI-139 Tangential Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

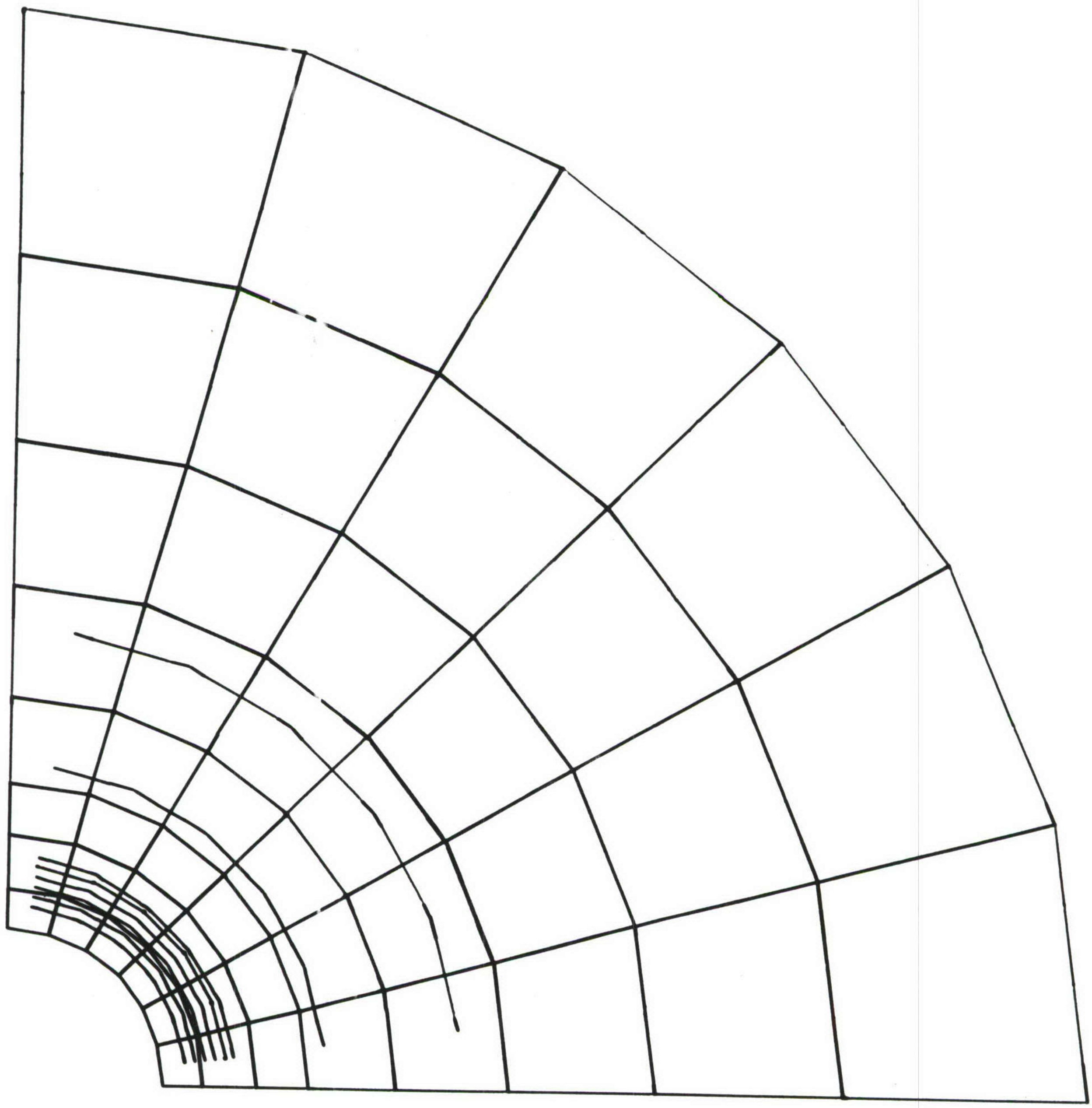


Figure AI-140 Tangential Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

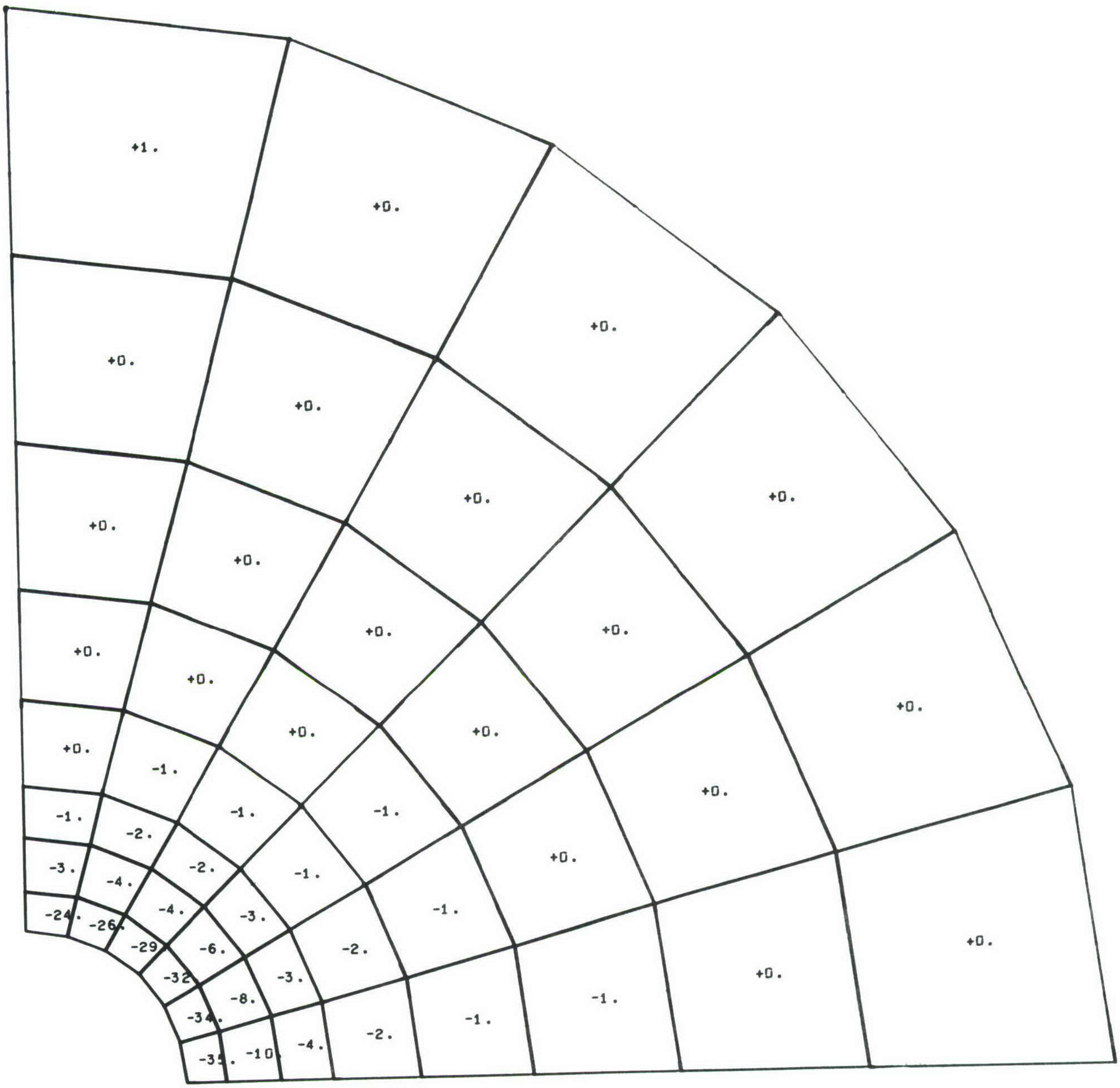


Figure AI-141 Radial Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

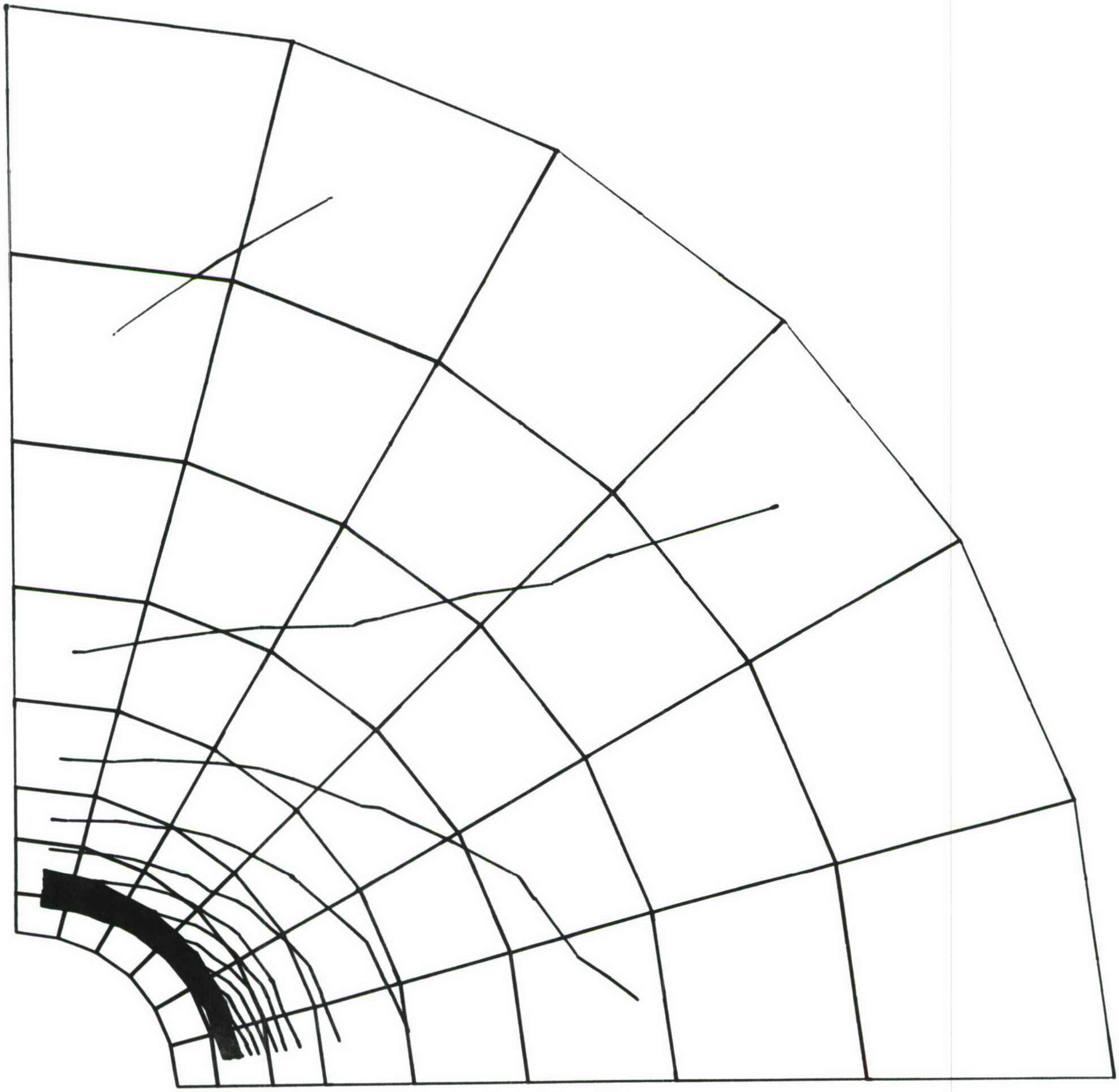


Figure AI-142 Radial Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

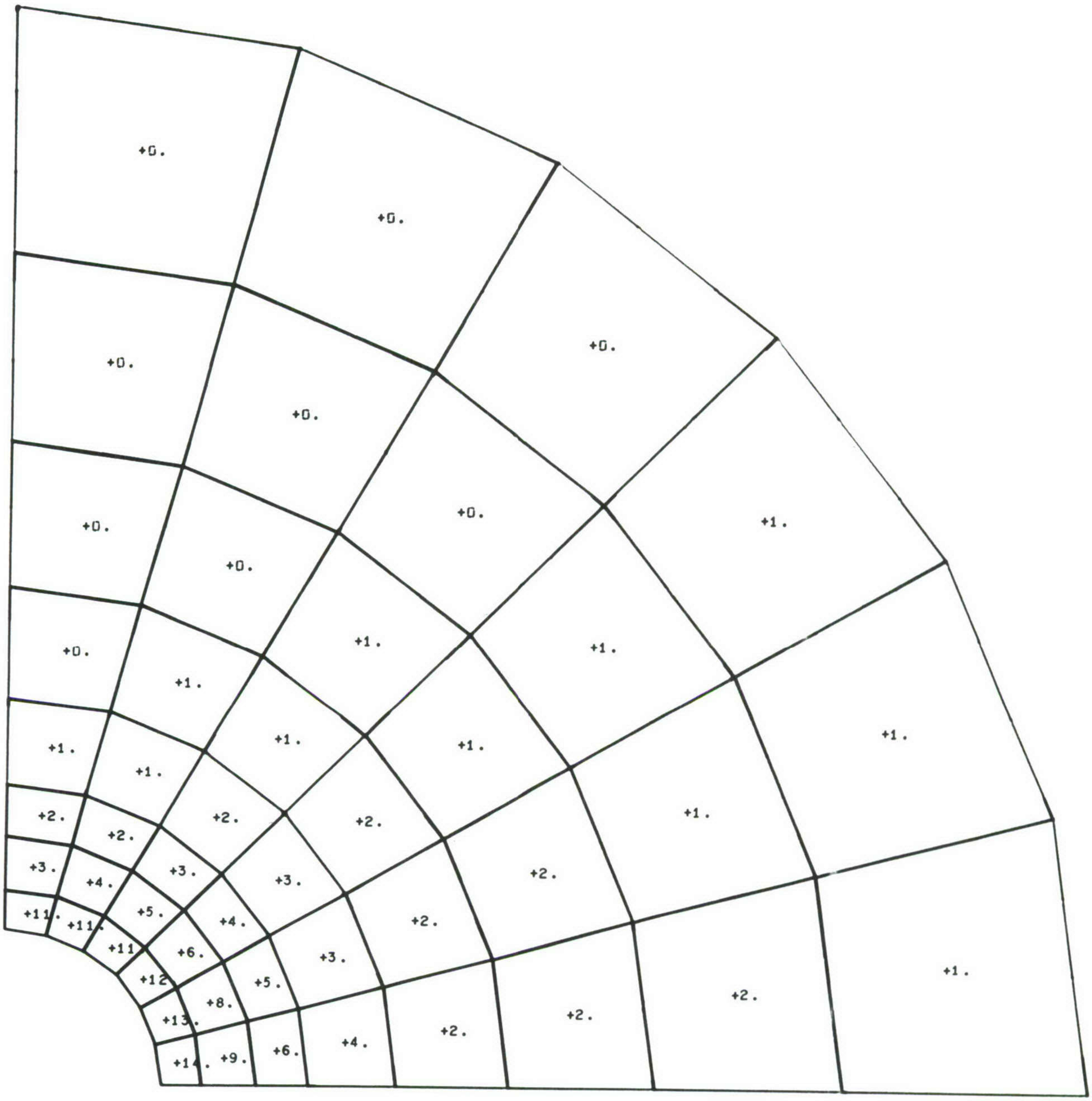


Figure AI-143 Tangential Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

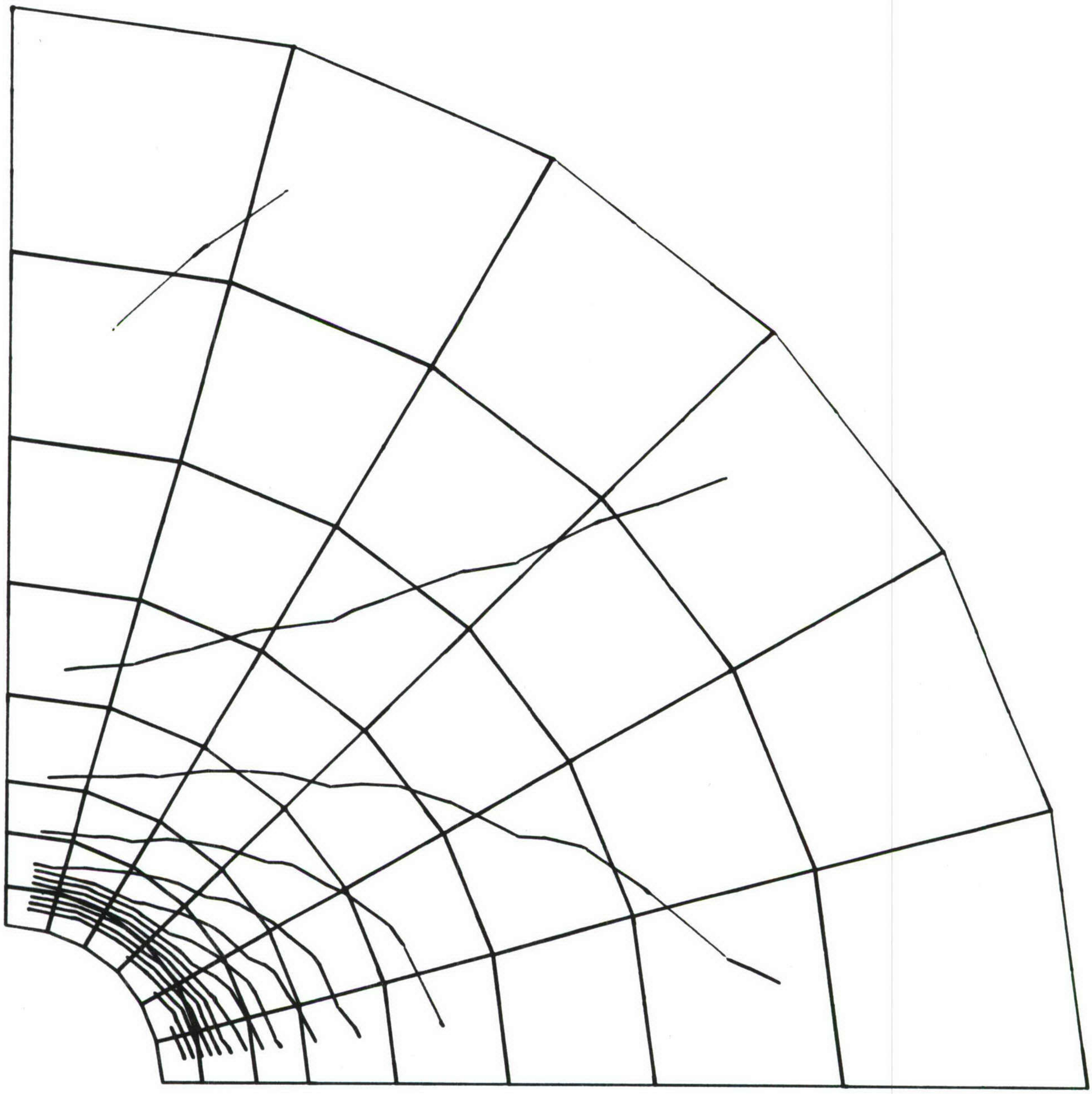


Figure AI-144 Tangential Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

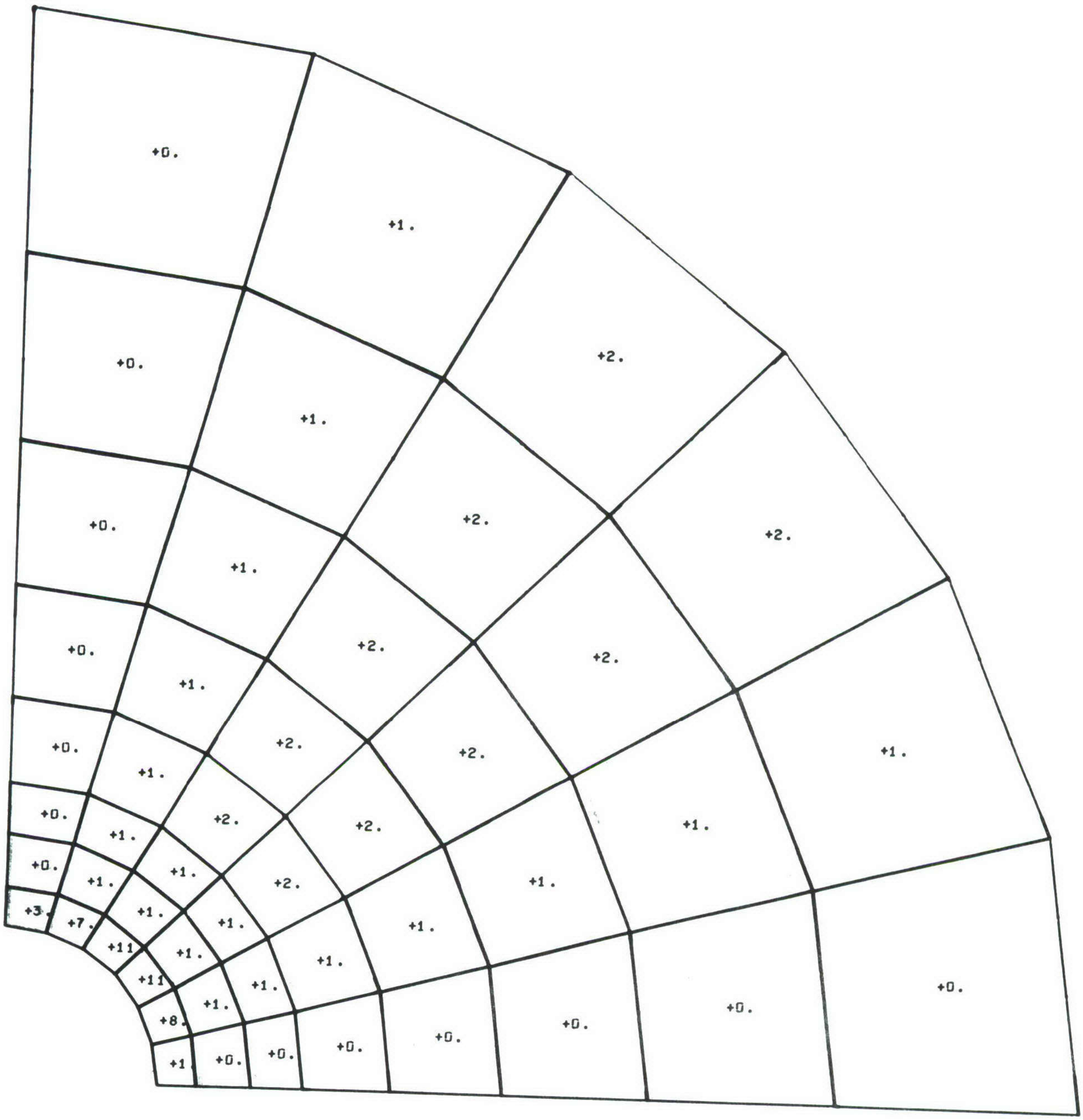


Figure AI-145 Radial-Tangential Shear Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

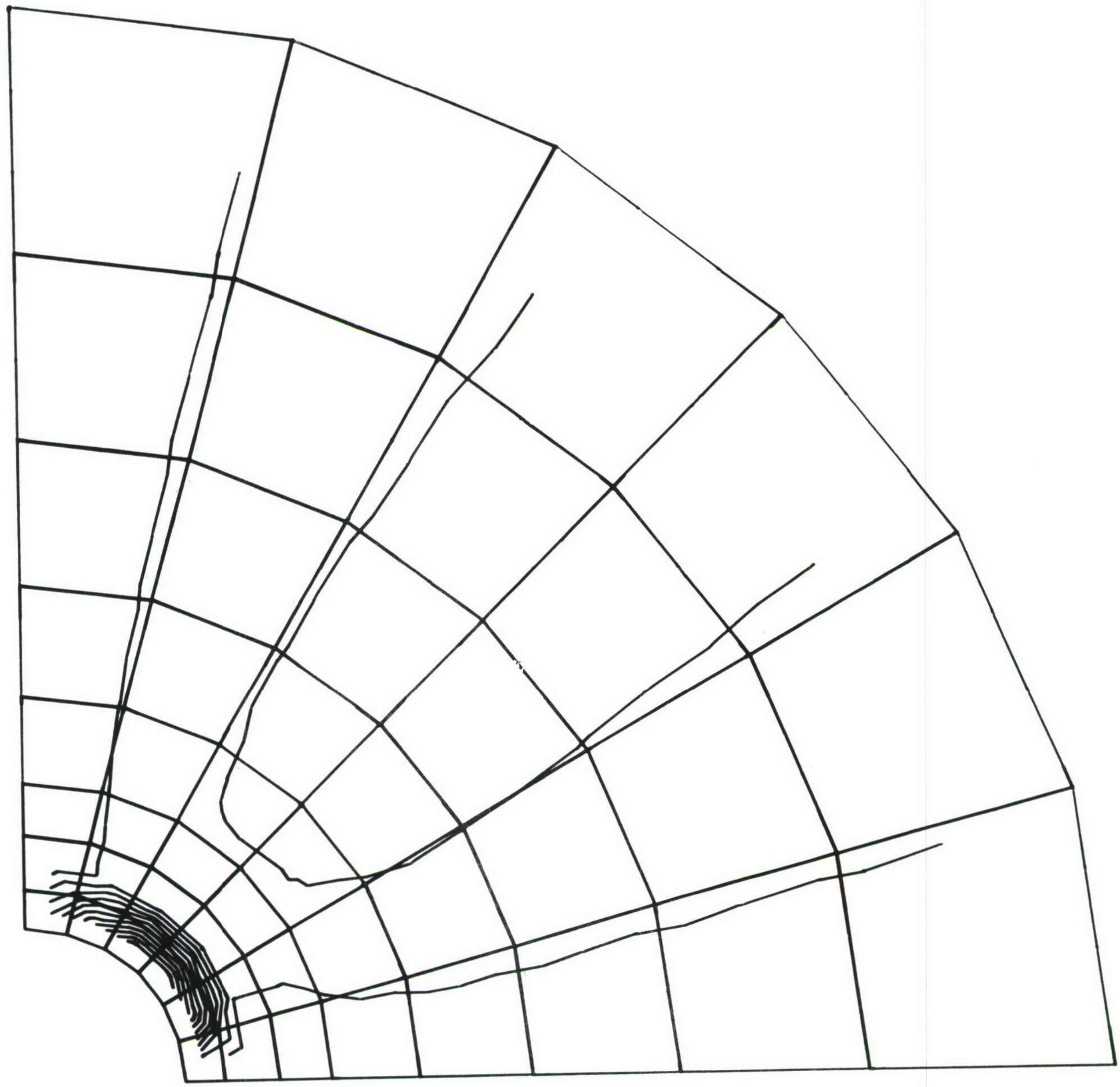


Figure AI-146 Radial-Tangential Shear Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

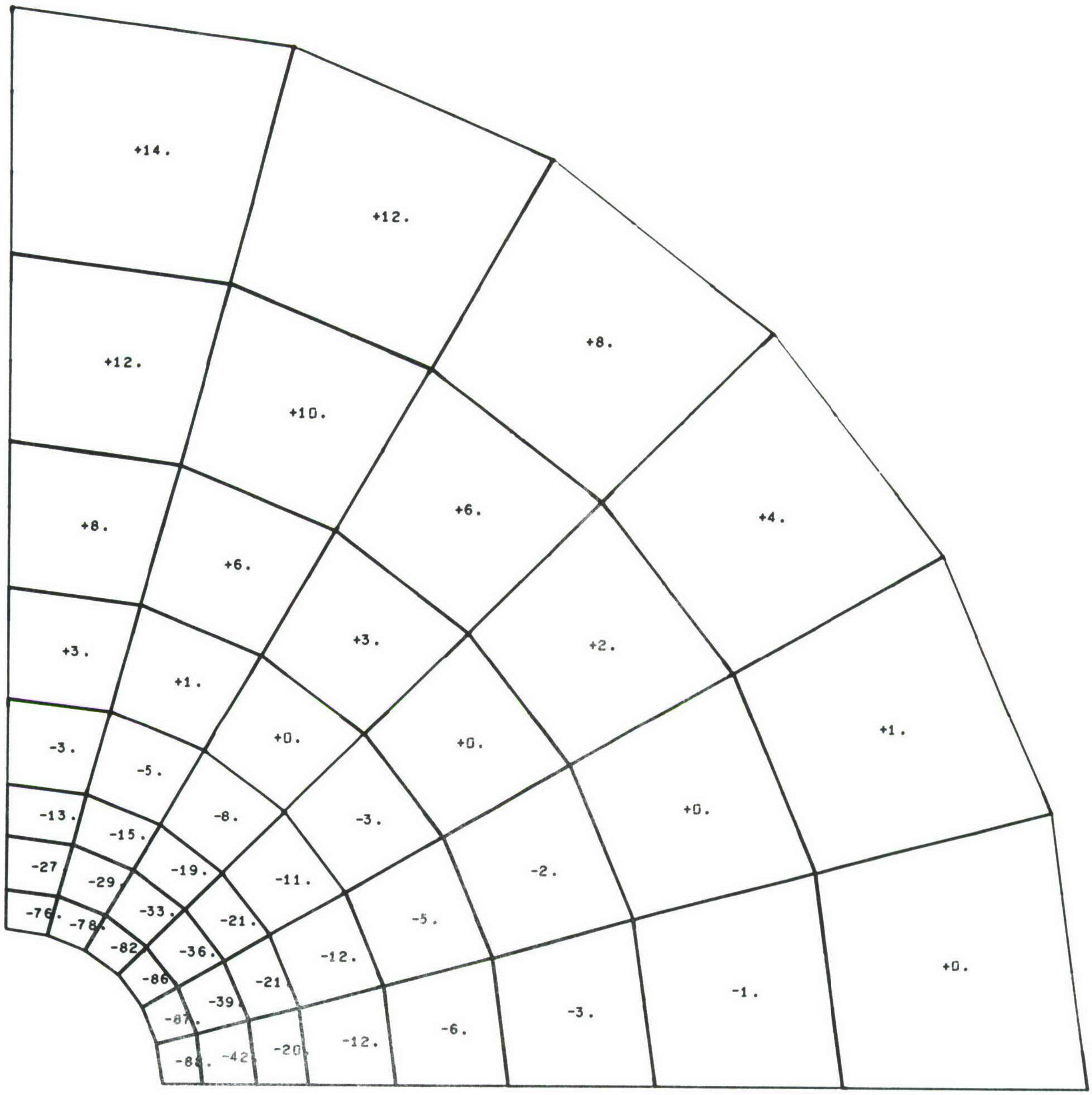


Figure AI-147 Radial Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

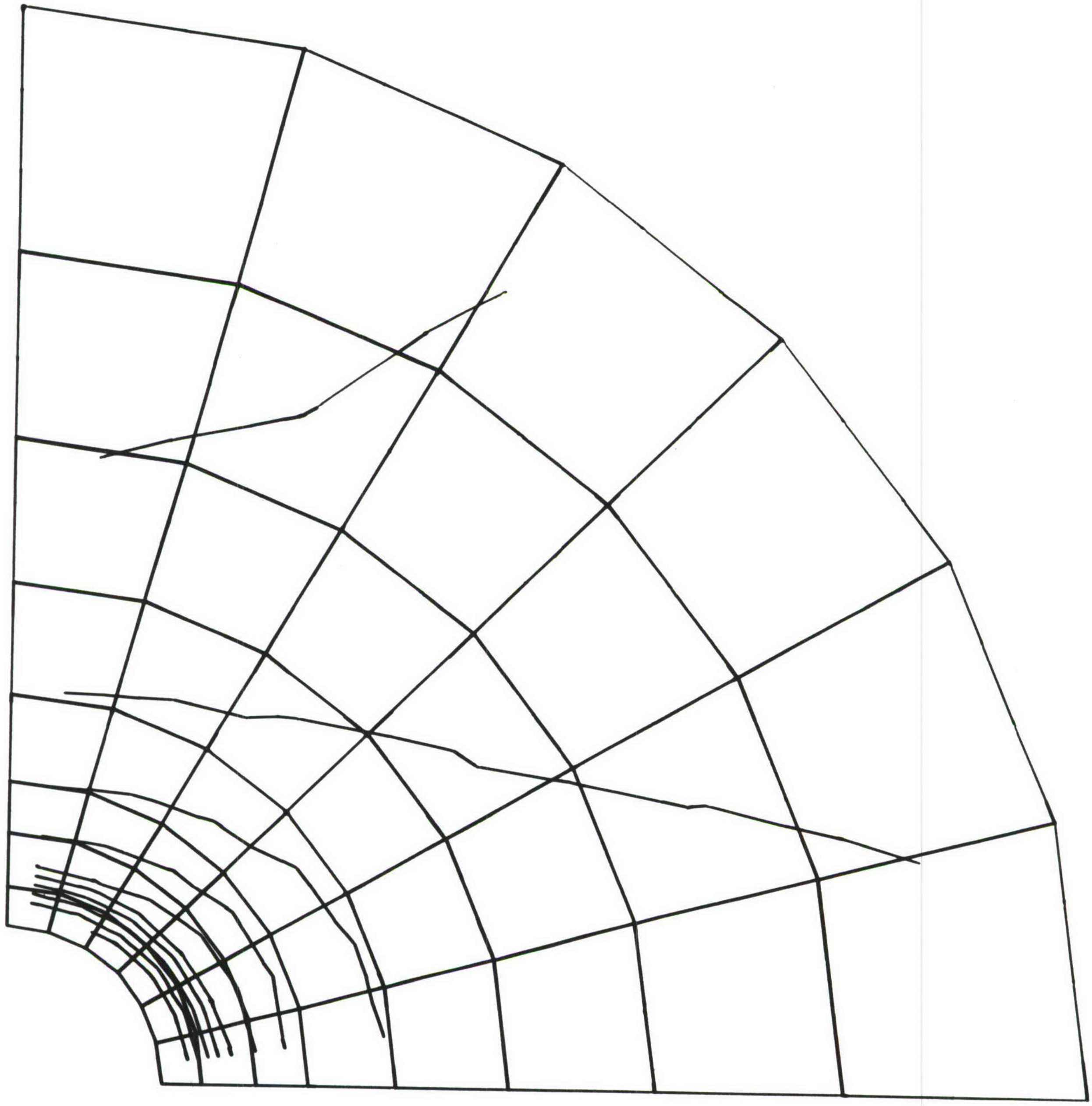


Figure AI-148 Radial Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

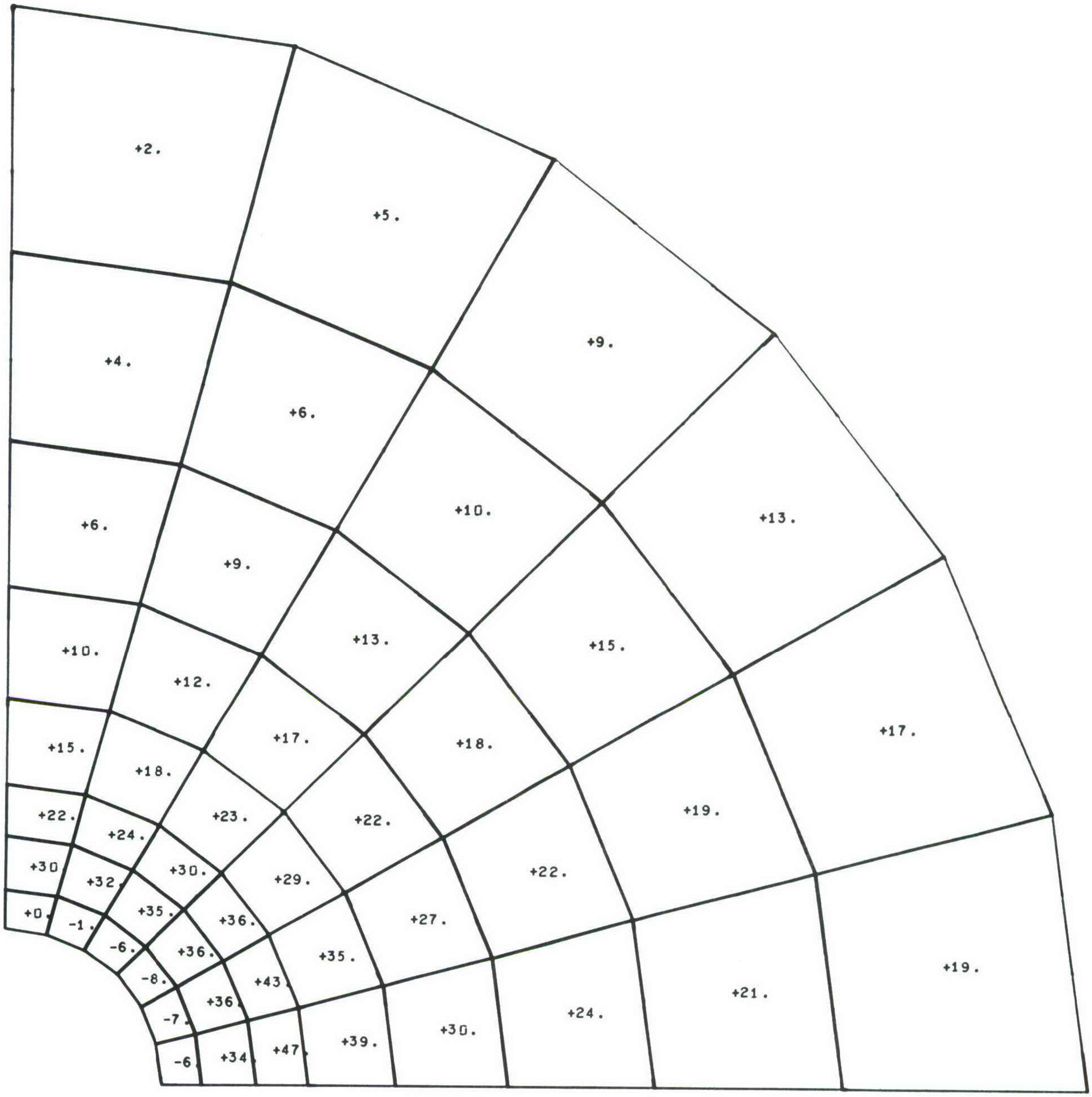


Figure AI-149 Tangential Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

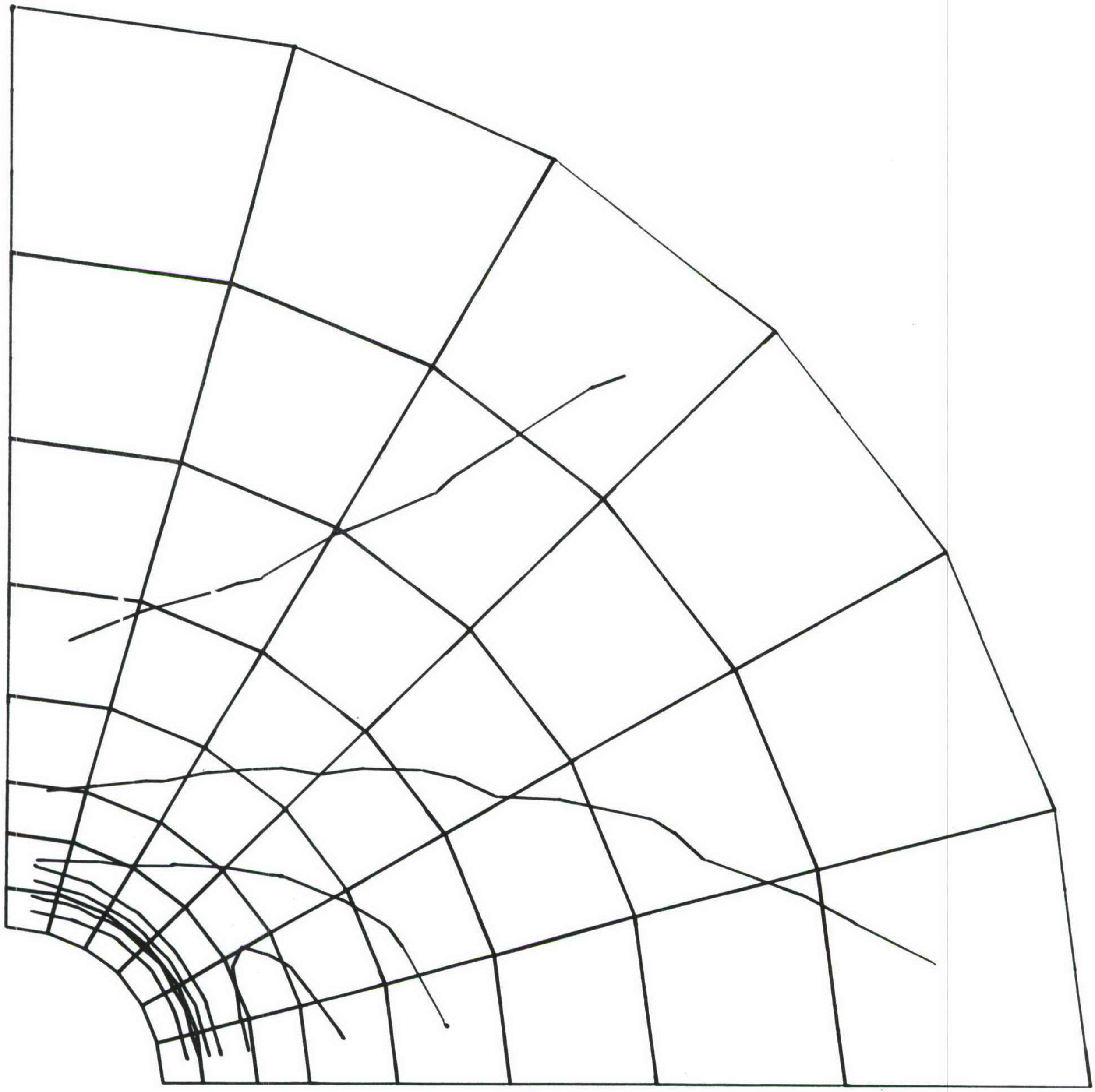


Figure AI-150 Tangential Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

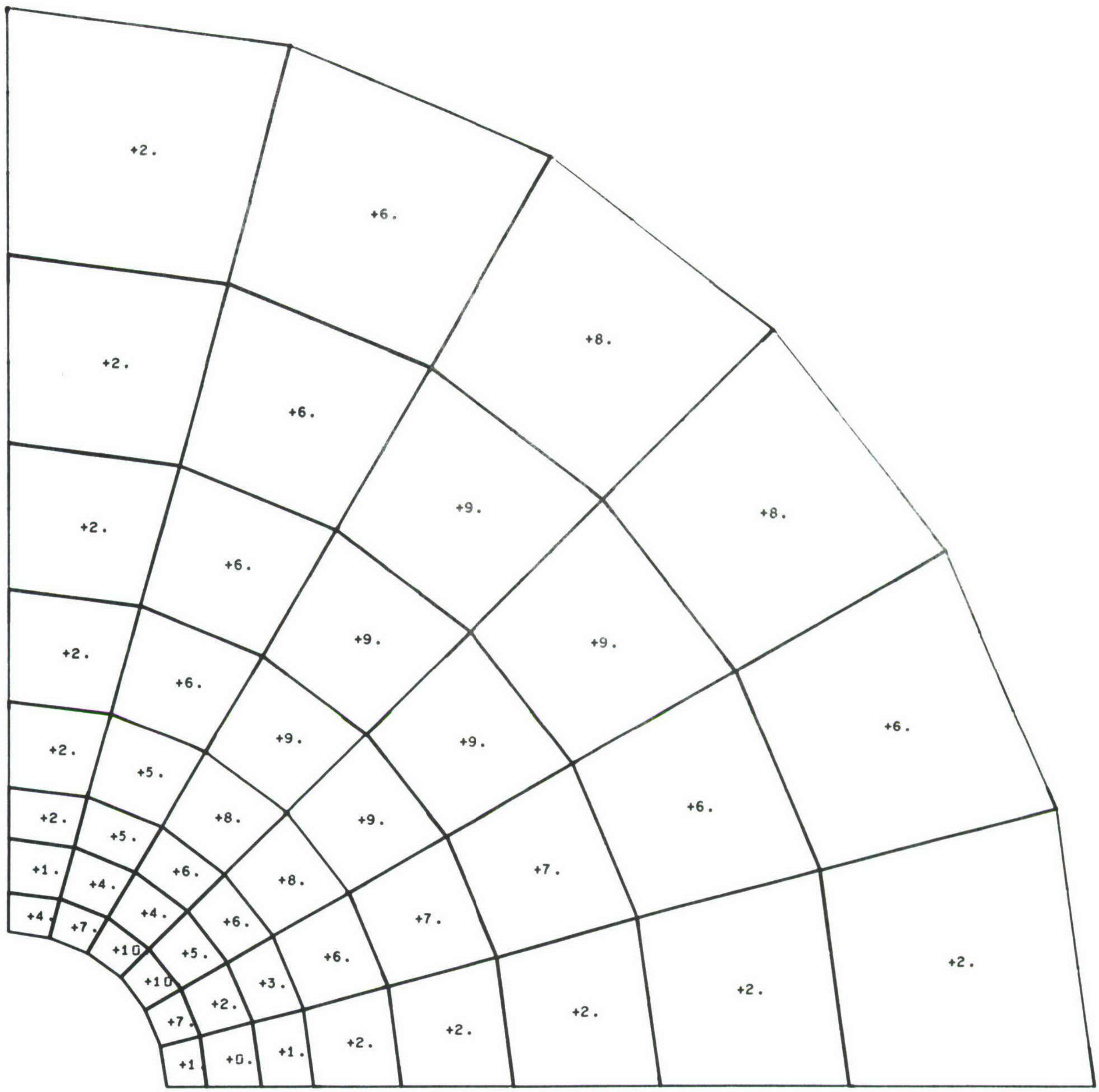


Figure AI-151 Radial-Tangential Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

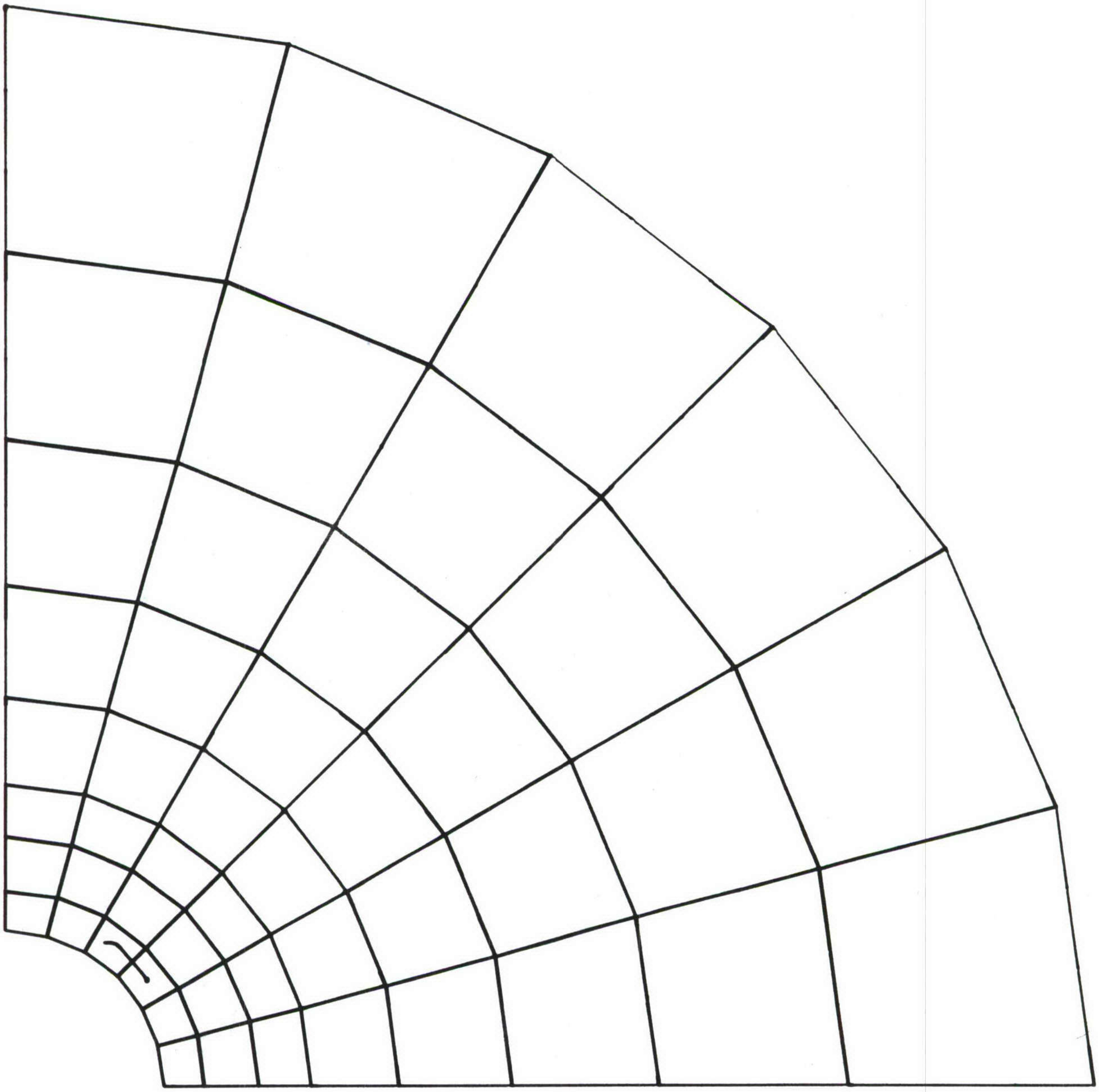


Figure AI-152 Radial Tangential Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

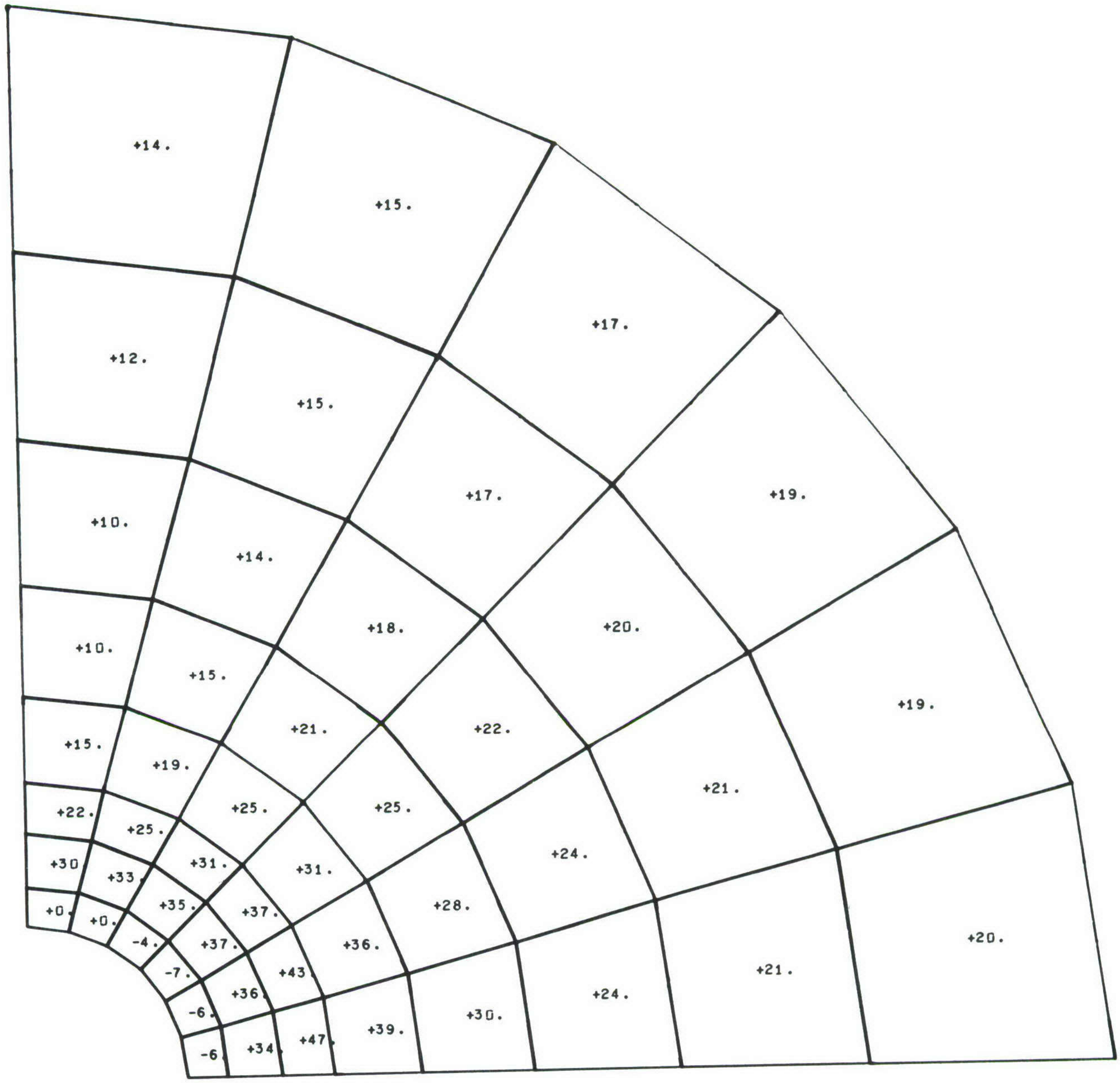


Figure AI-153 First Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

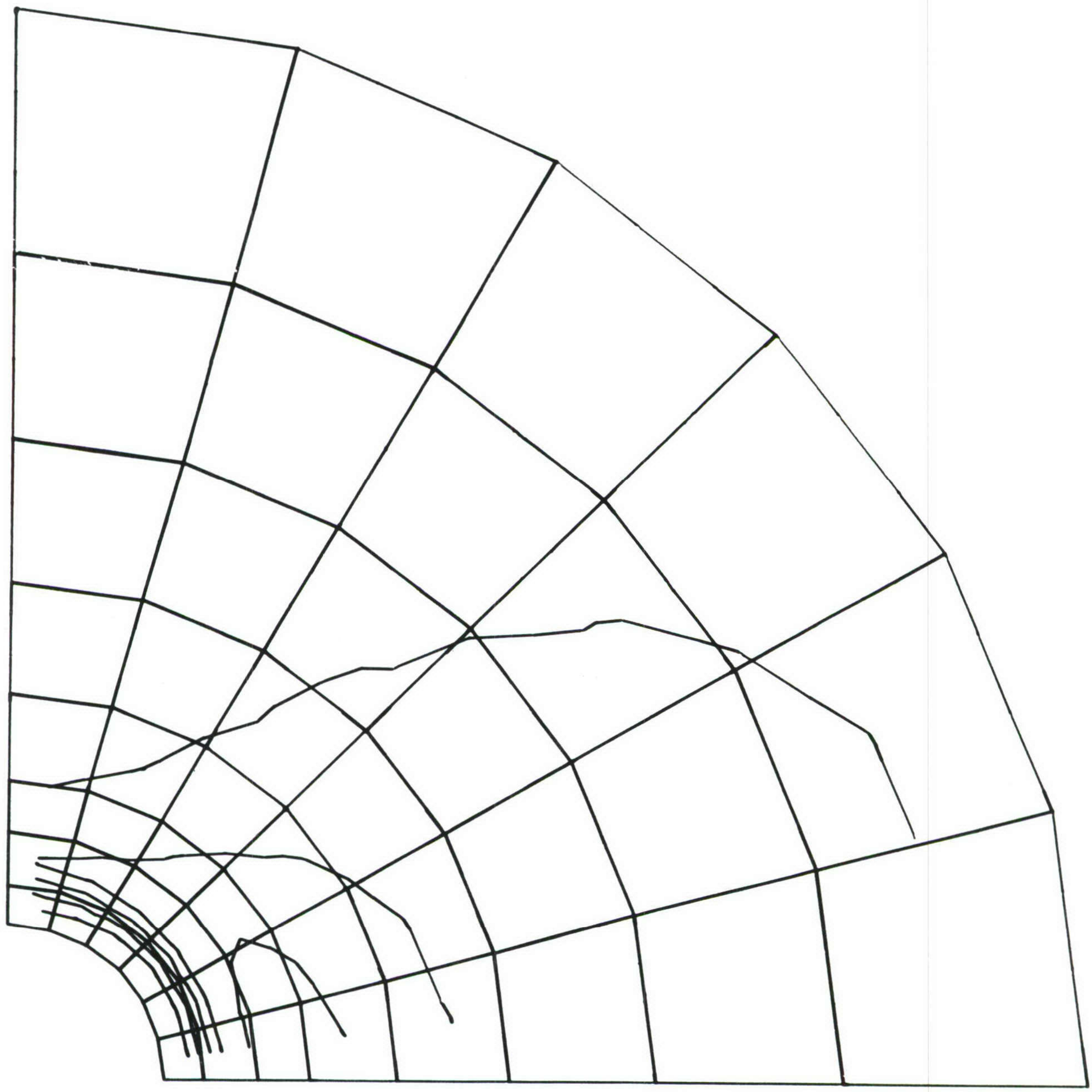


Figure AI-154 First Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

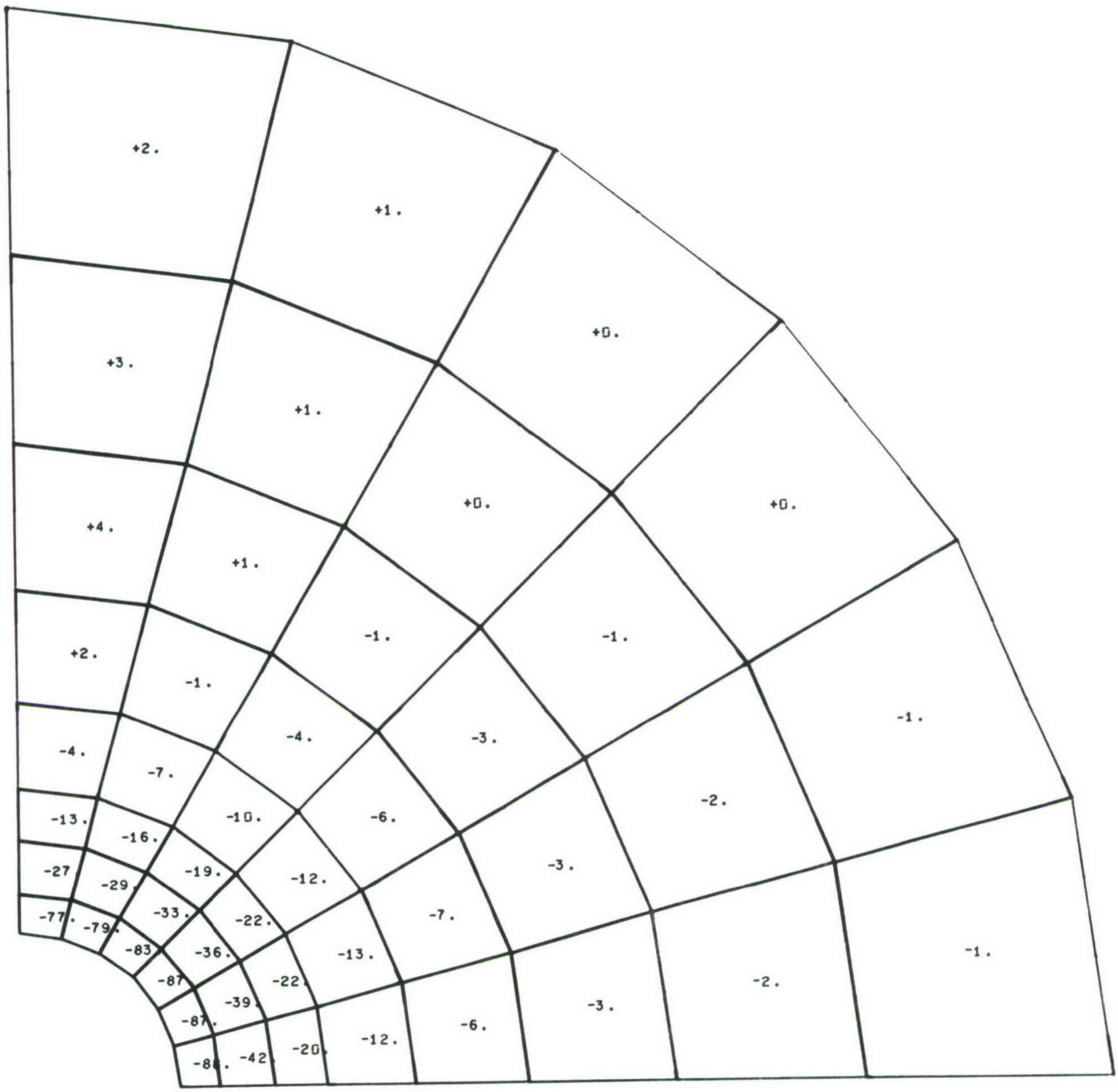


Figure AI-155 Second Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

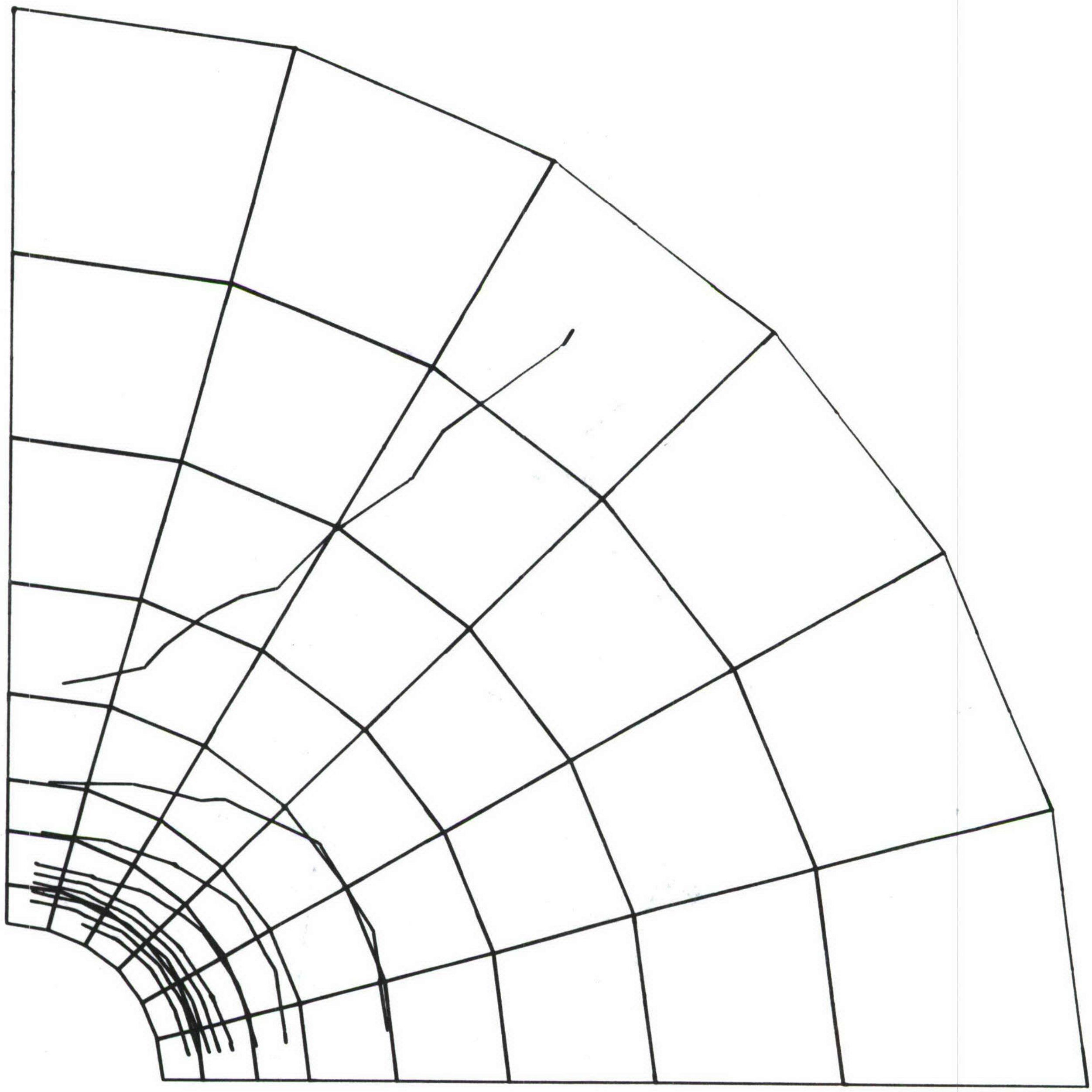


Figure AI-156 Second Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

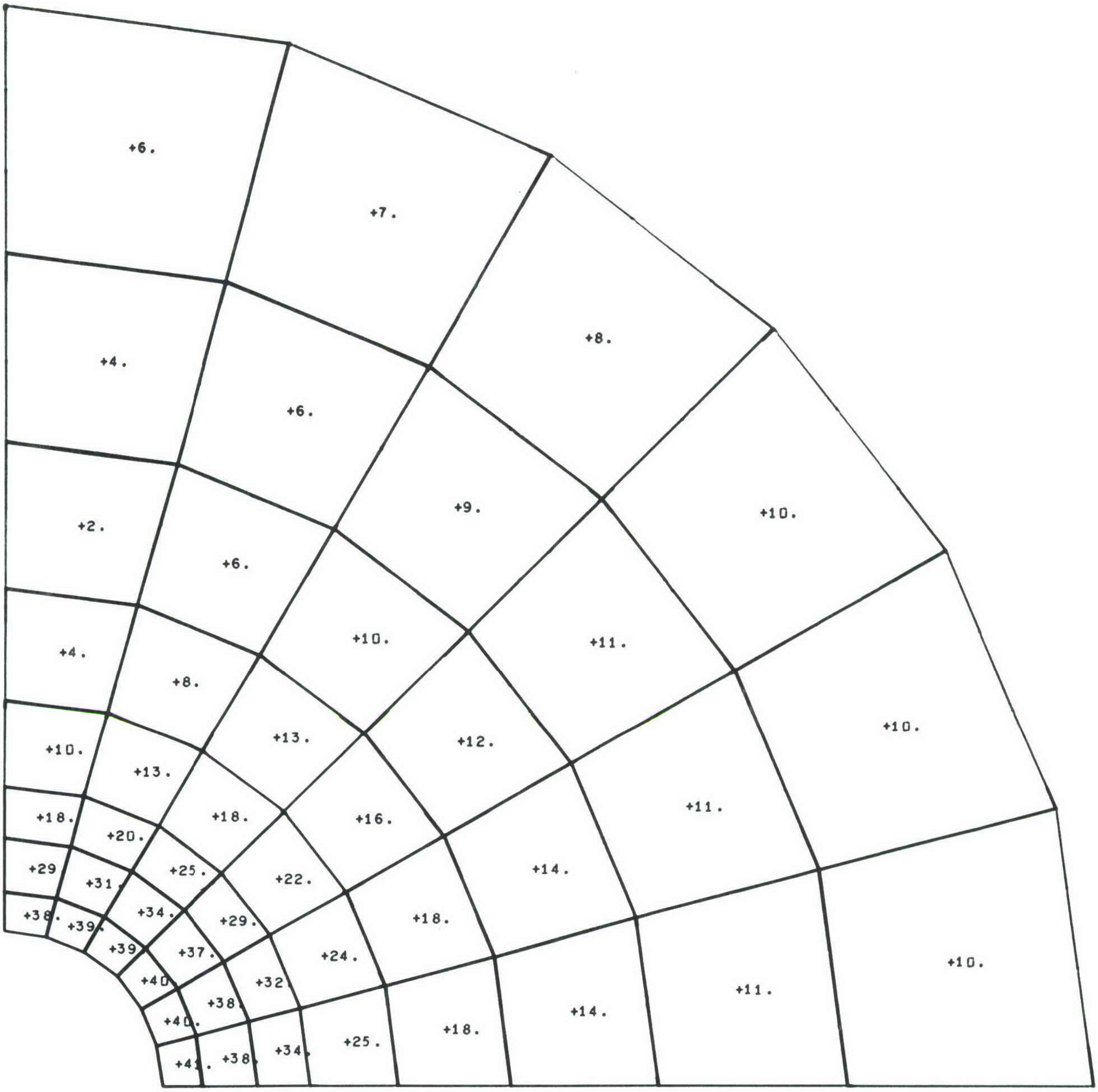


Figure AI-157 Principal Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

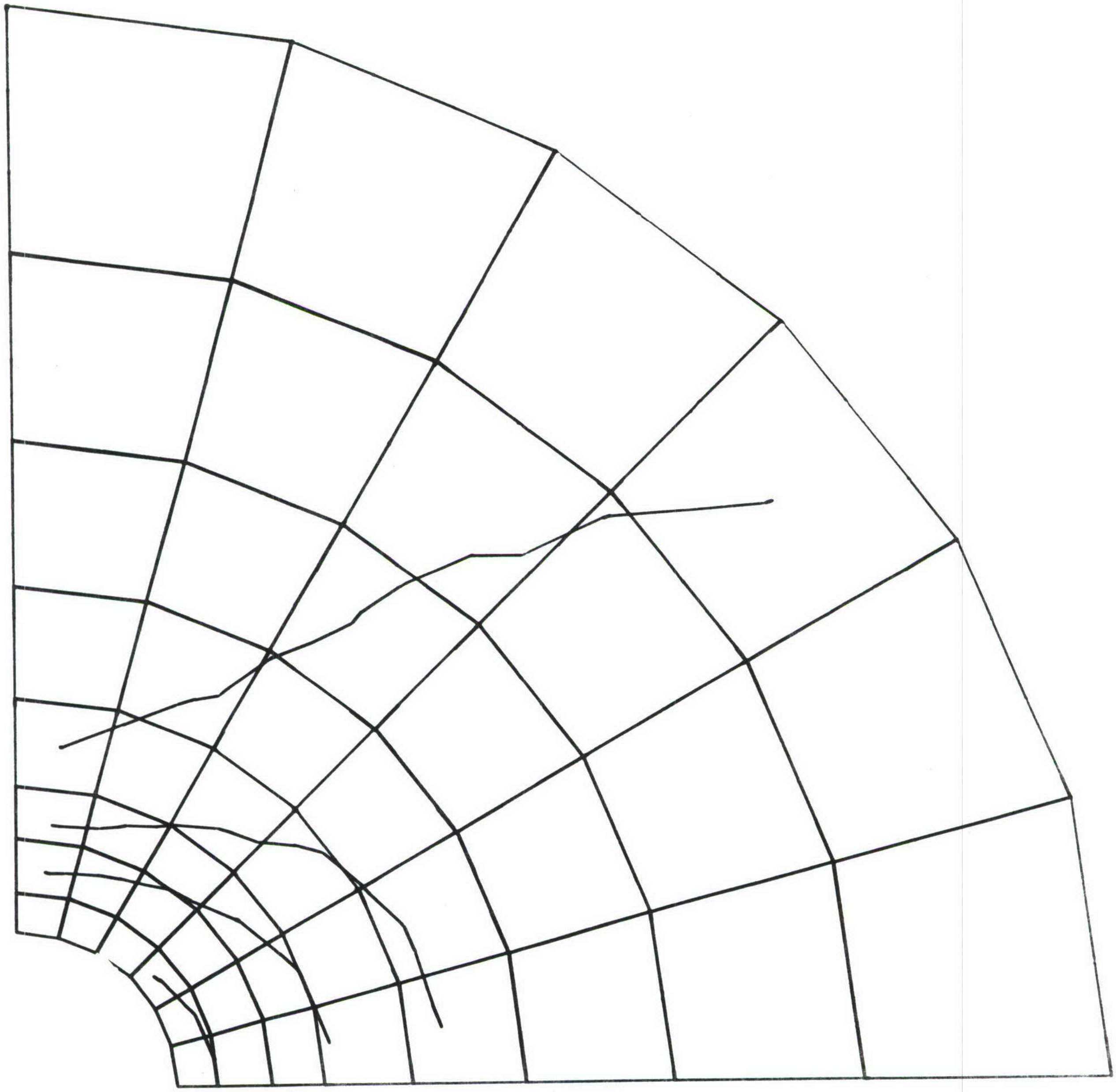


Figure AI-158 Principal Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

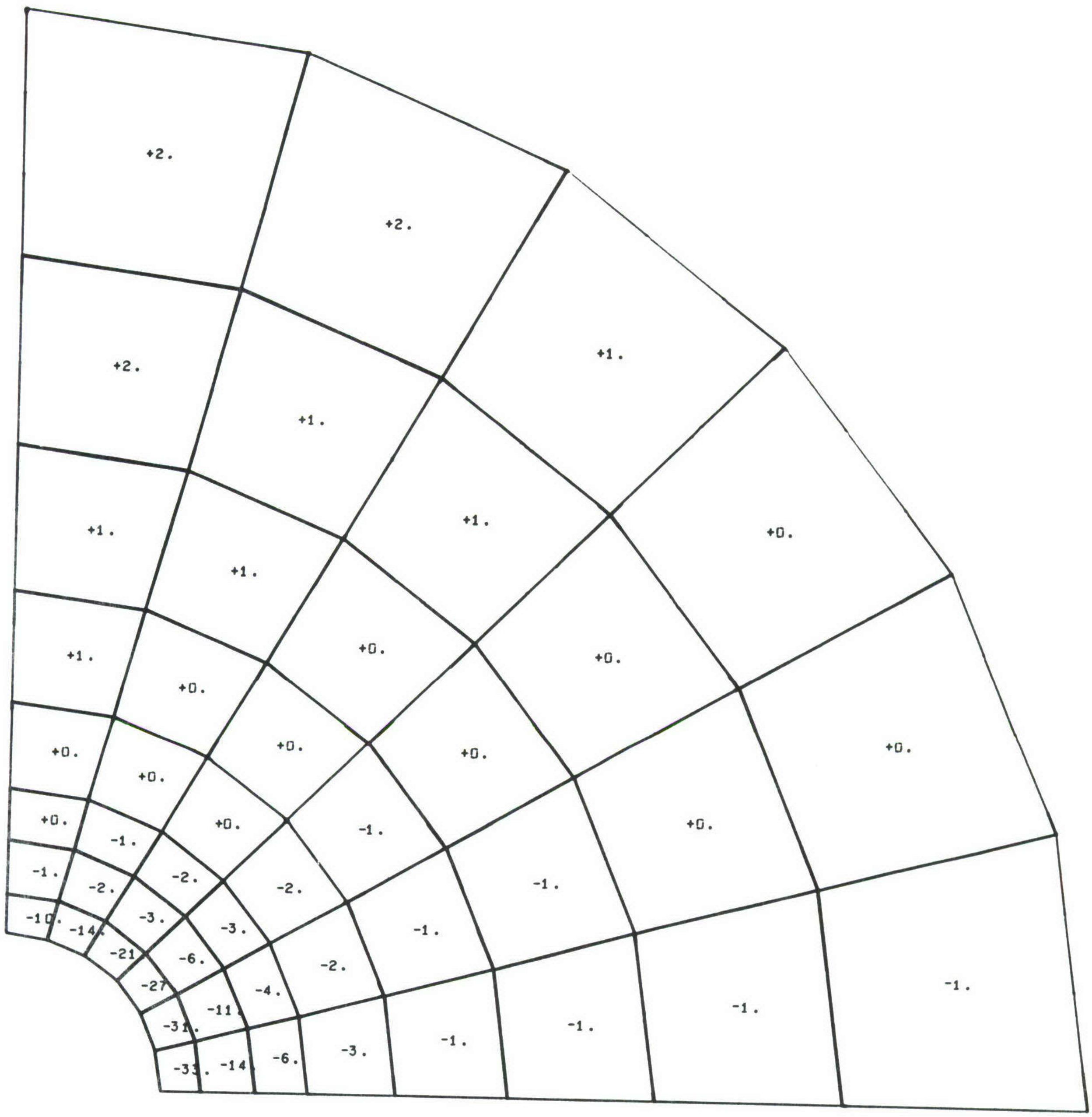


Figure AI-159 Radial Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

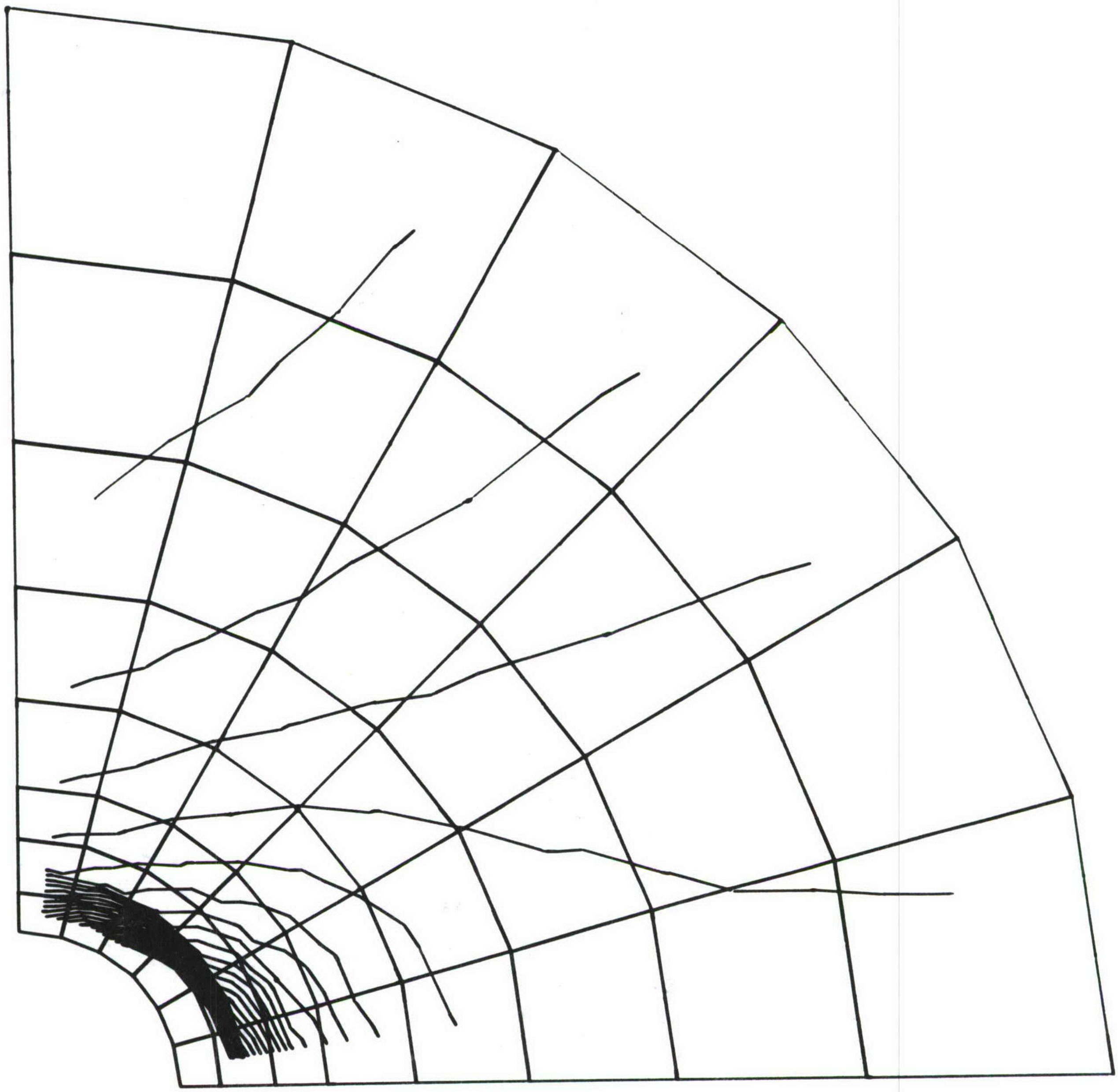


Figure AI-160 Radial Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

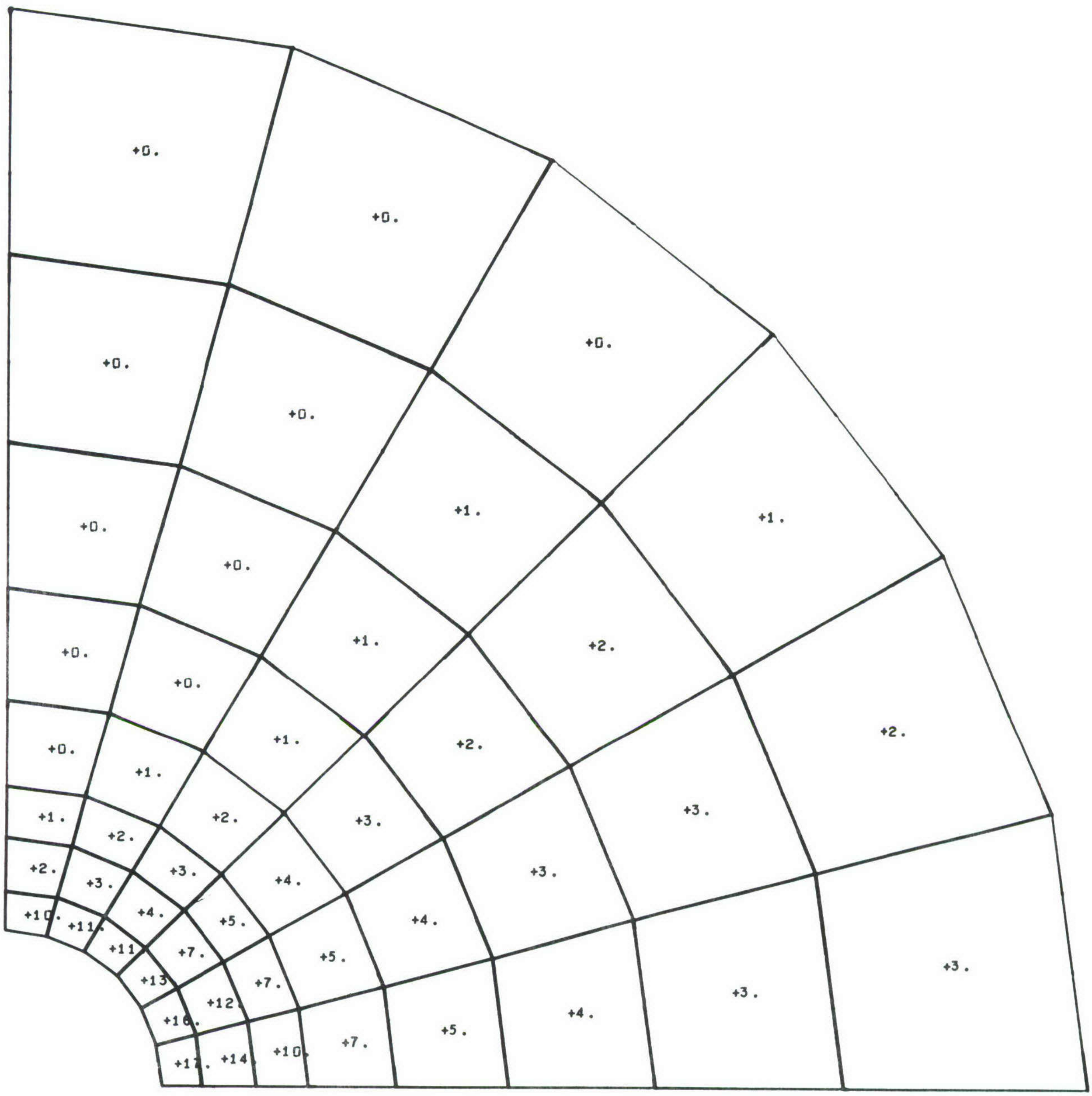


Figure AI-161 Tangential Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

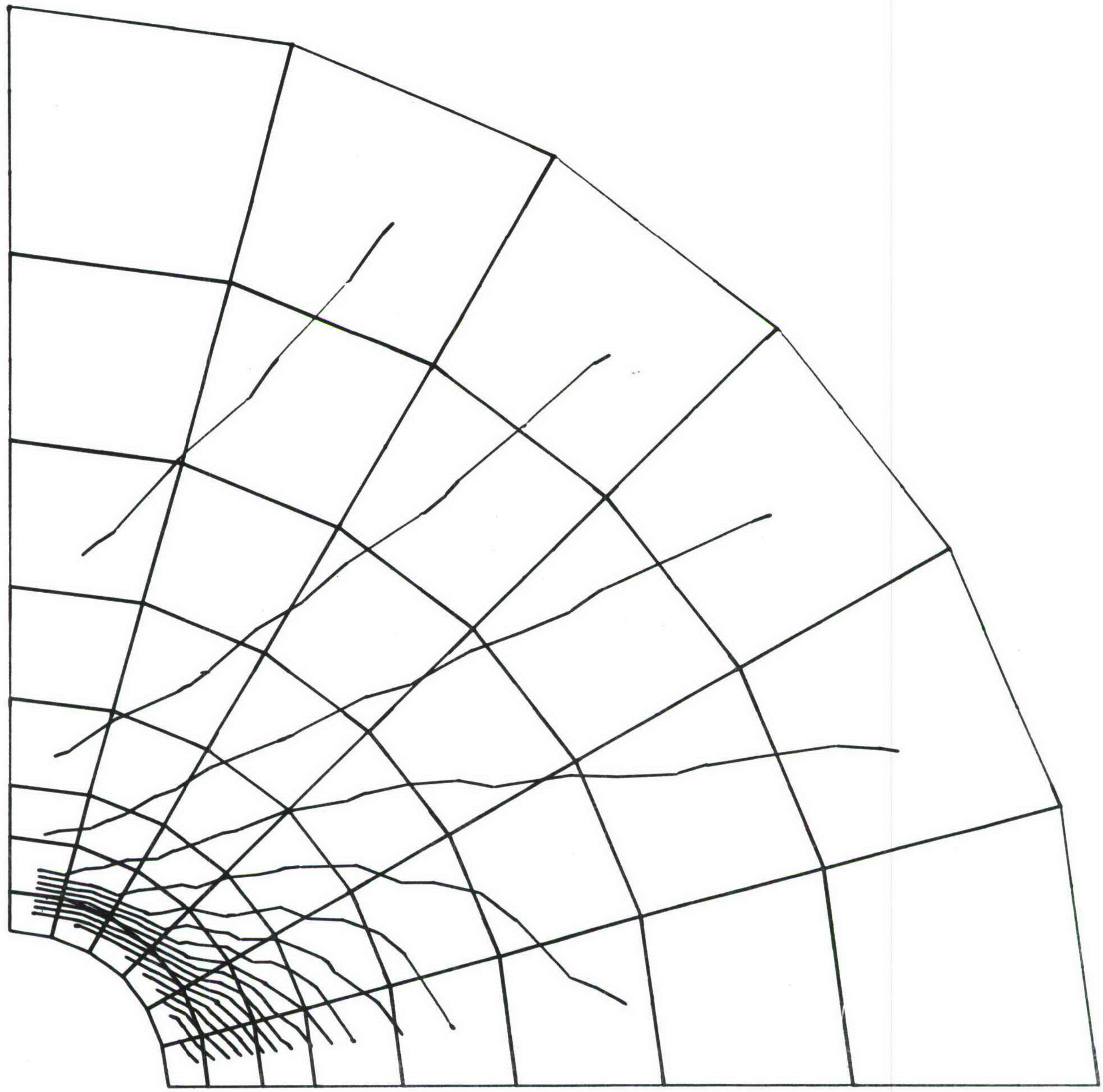


Figure AI-162 Tangential Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

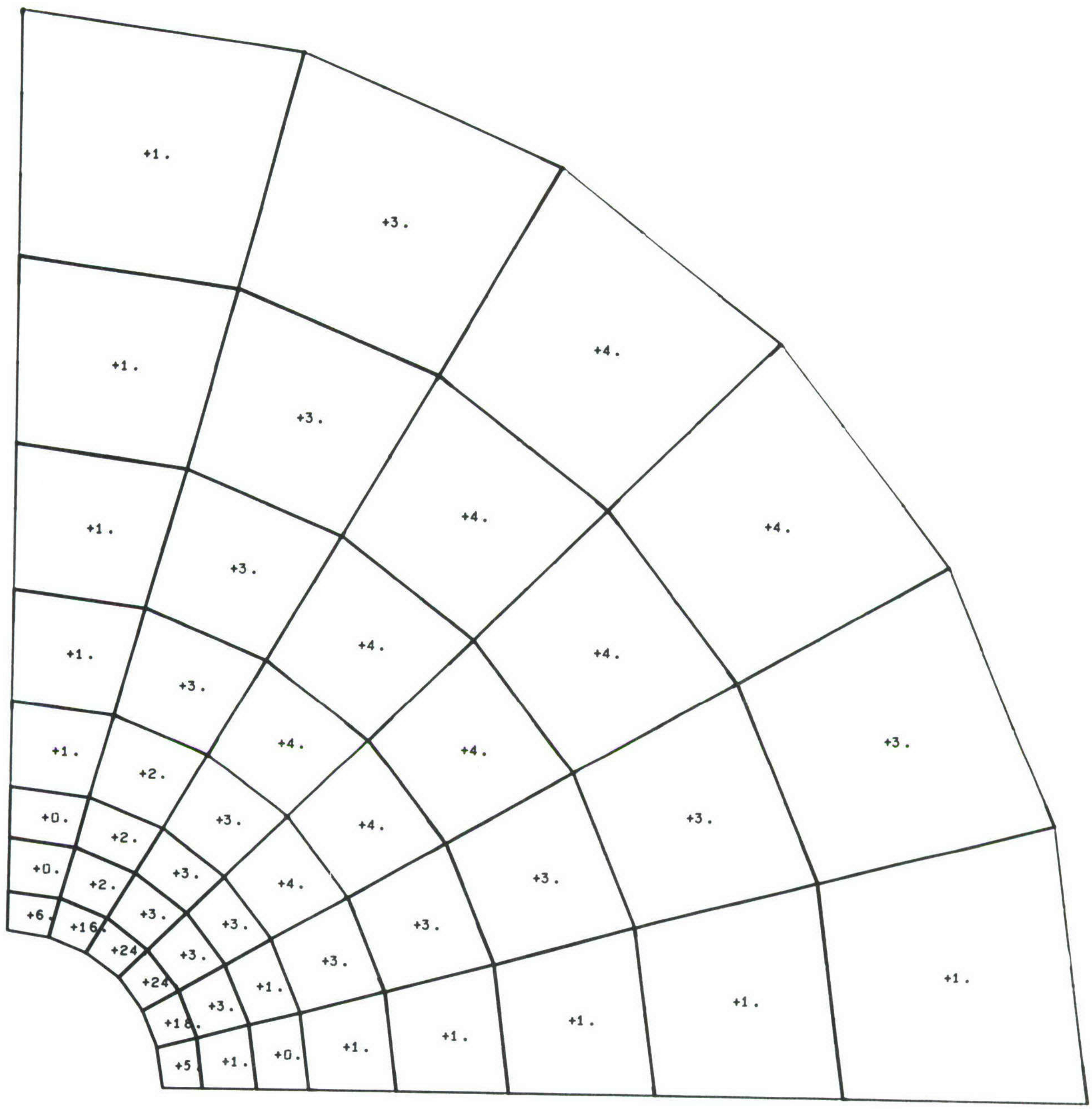


Figure AI-163 Radial-Tangential Shear Strain Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

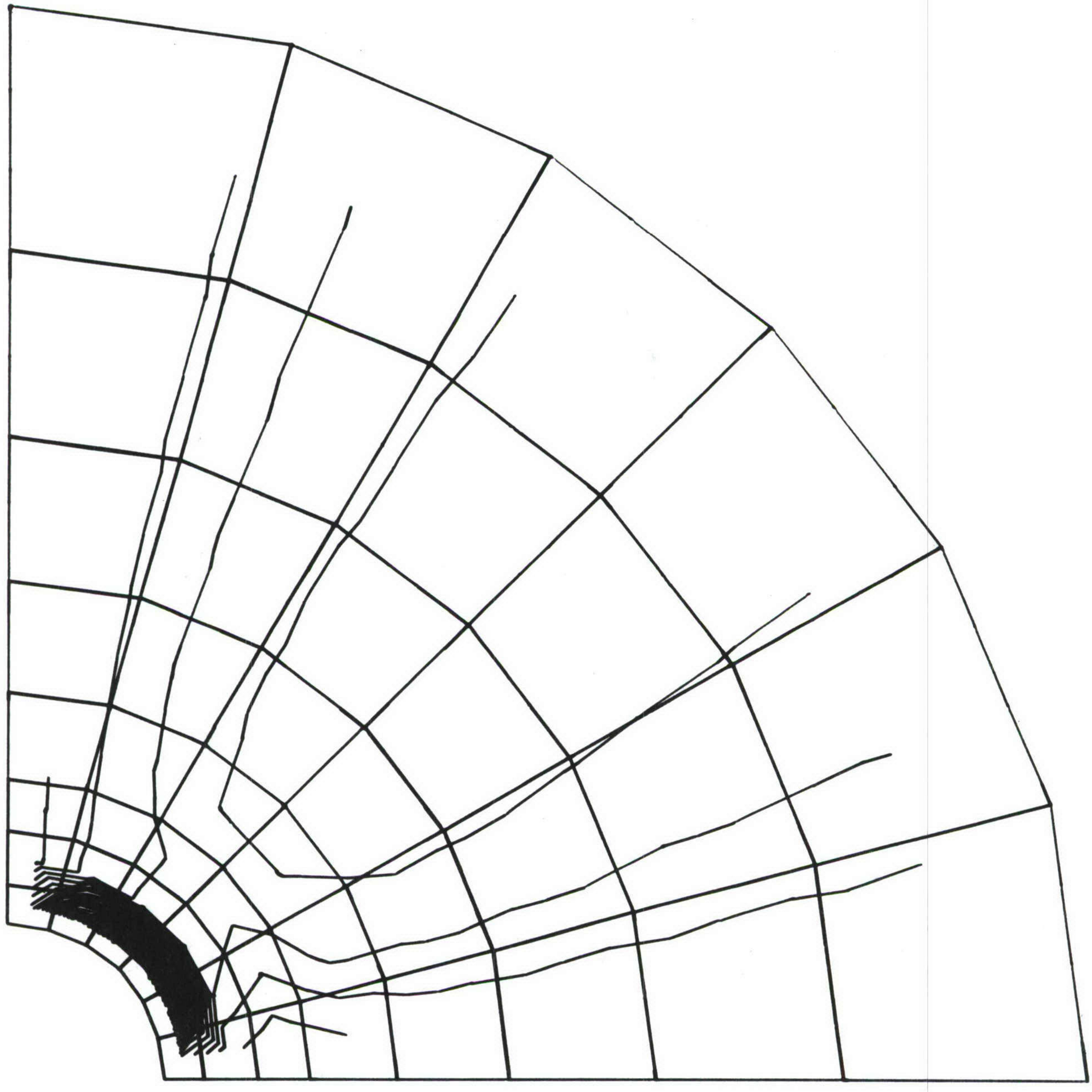


Figure AI-164 Radial-Tangential Shear Strain Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

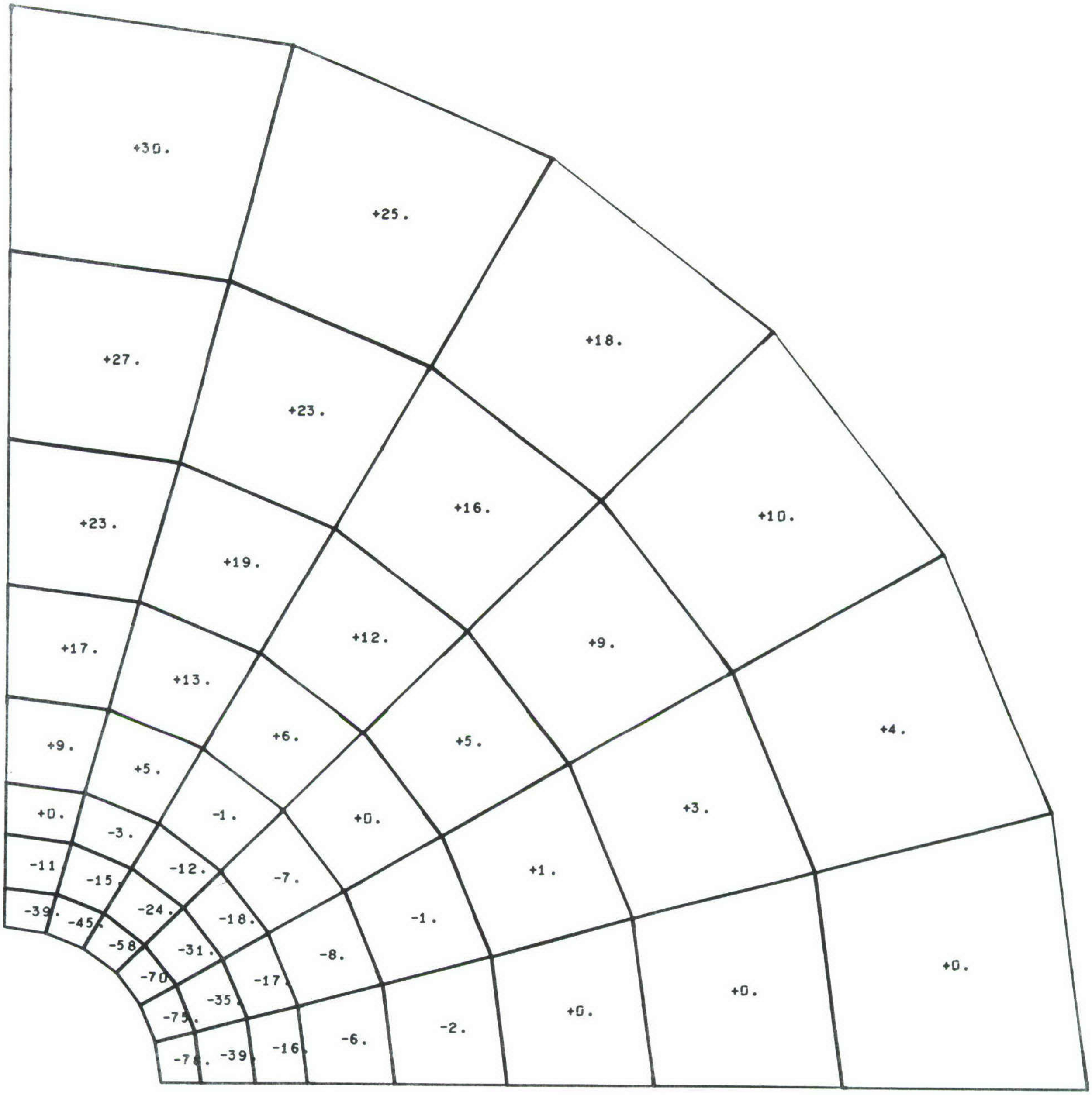


Figure AI-165 Radial Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

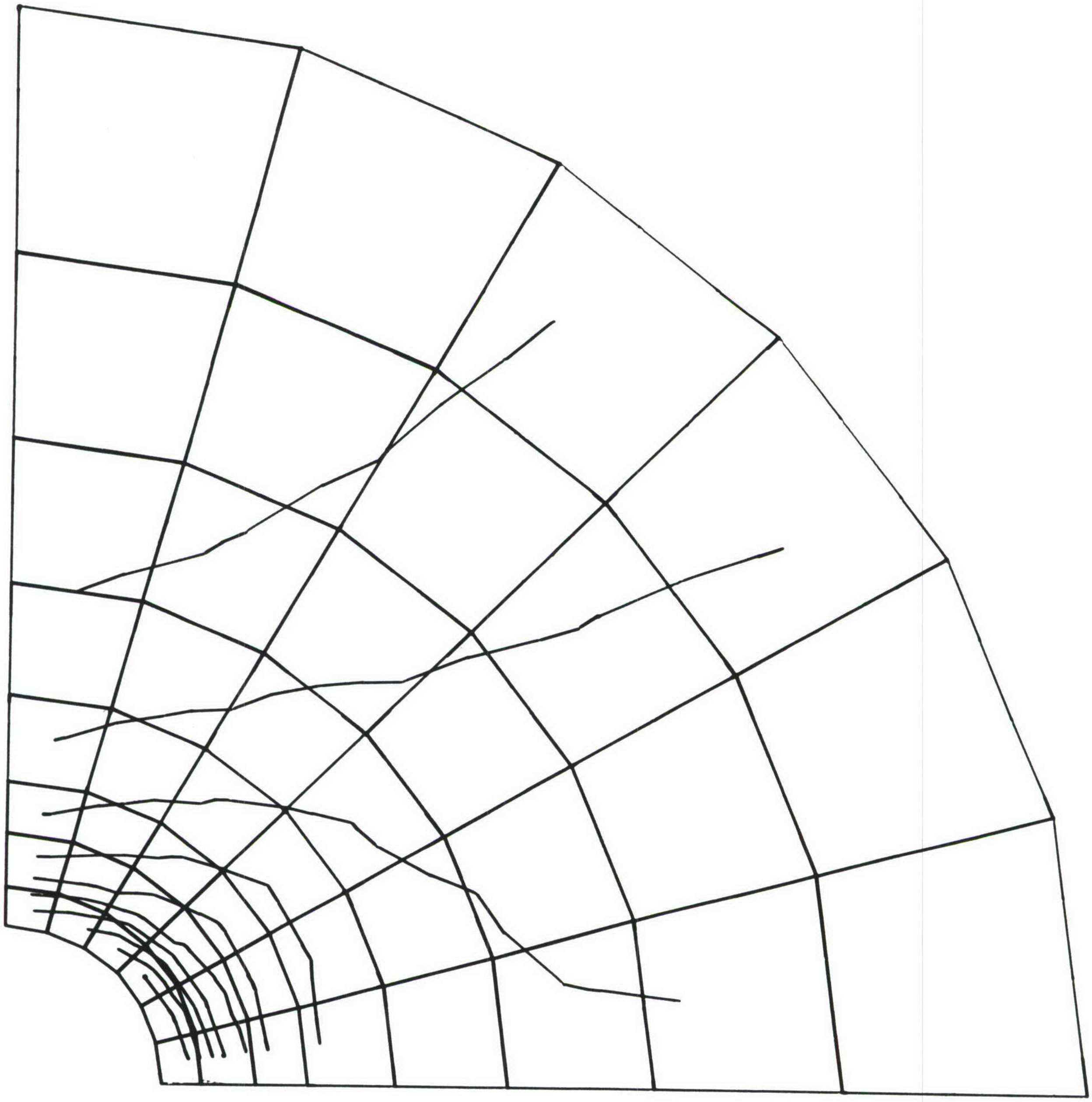


Figure AI-166 Radial Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

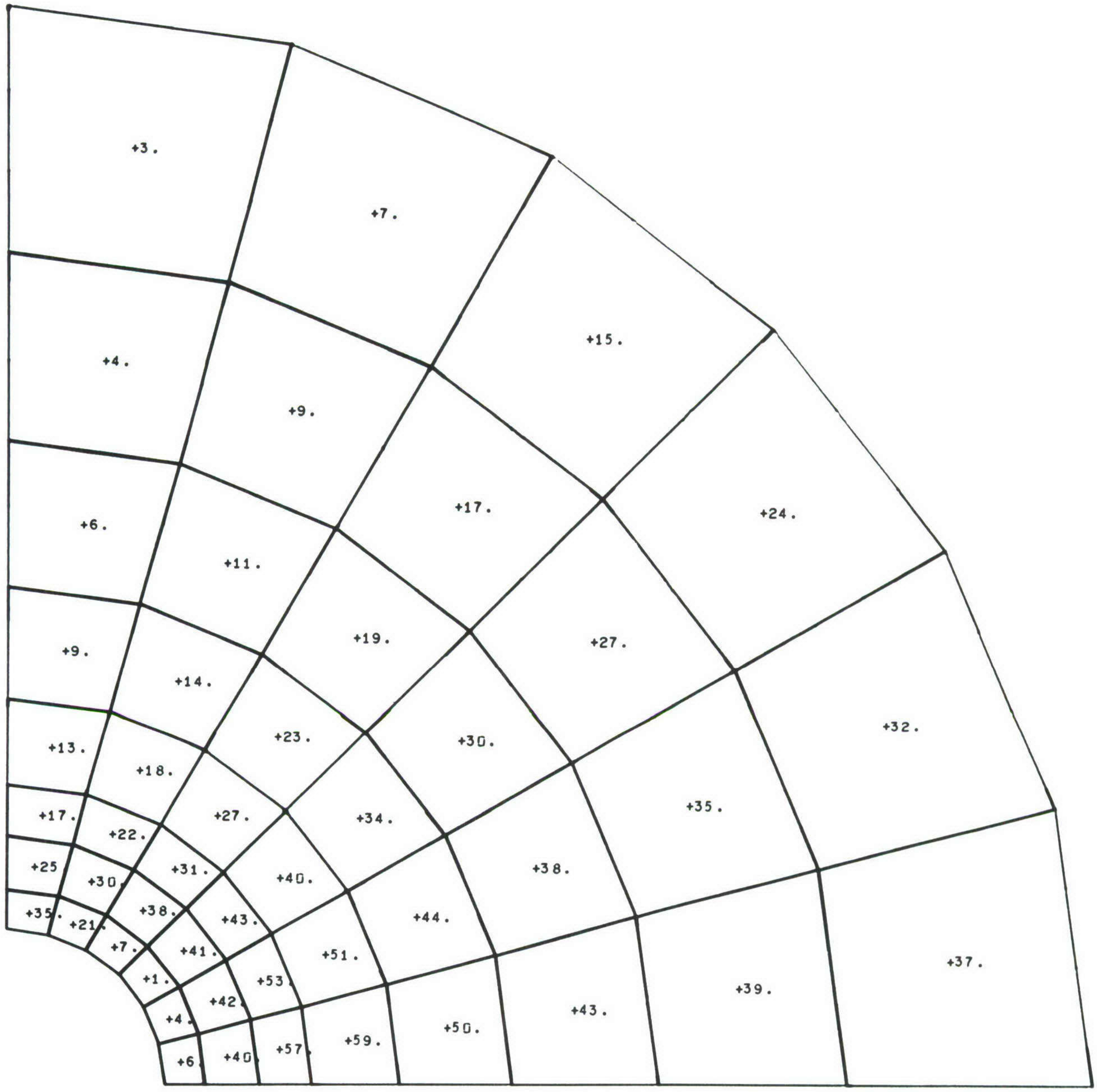


Figure AI-167 Tangential Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

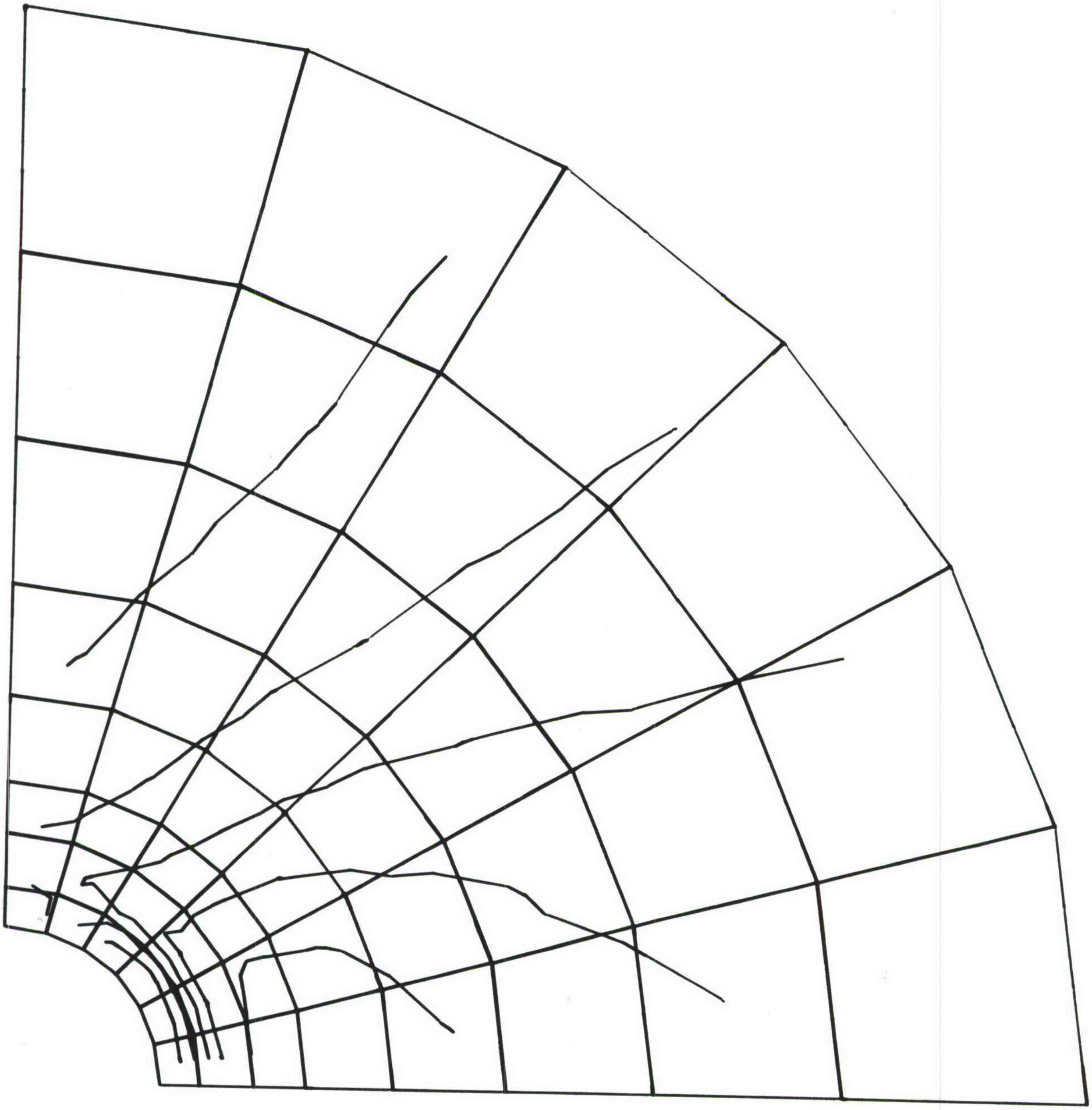


Figure AI-168 Tangential Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

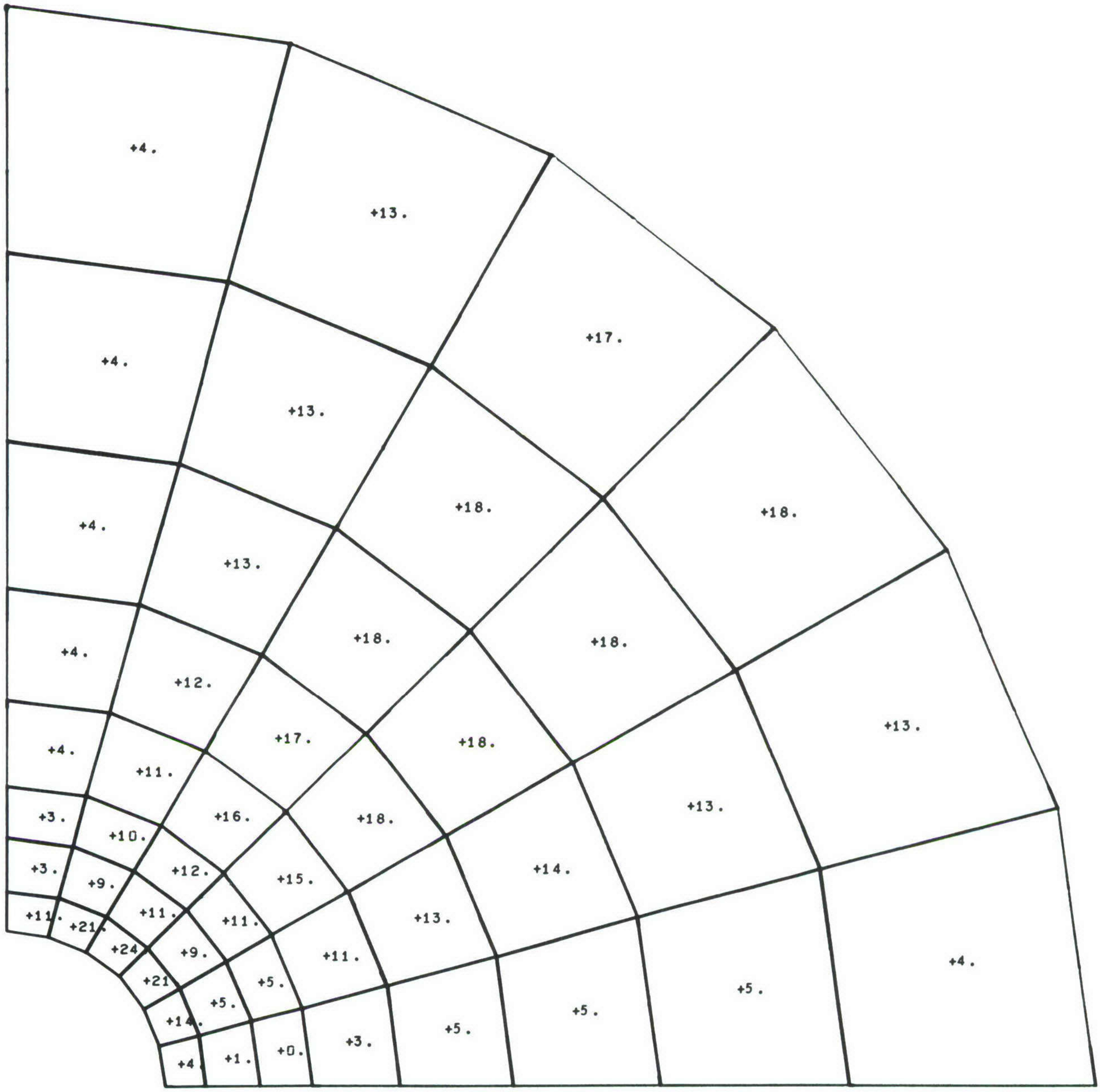


Figure AI-169 Radial-Tangential Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

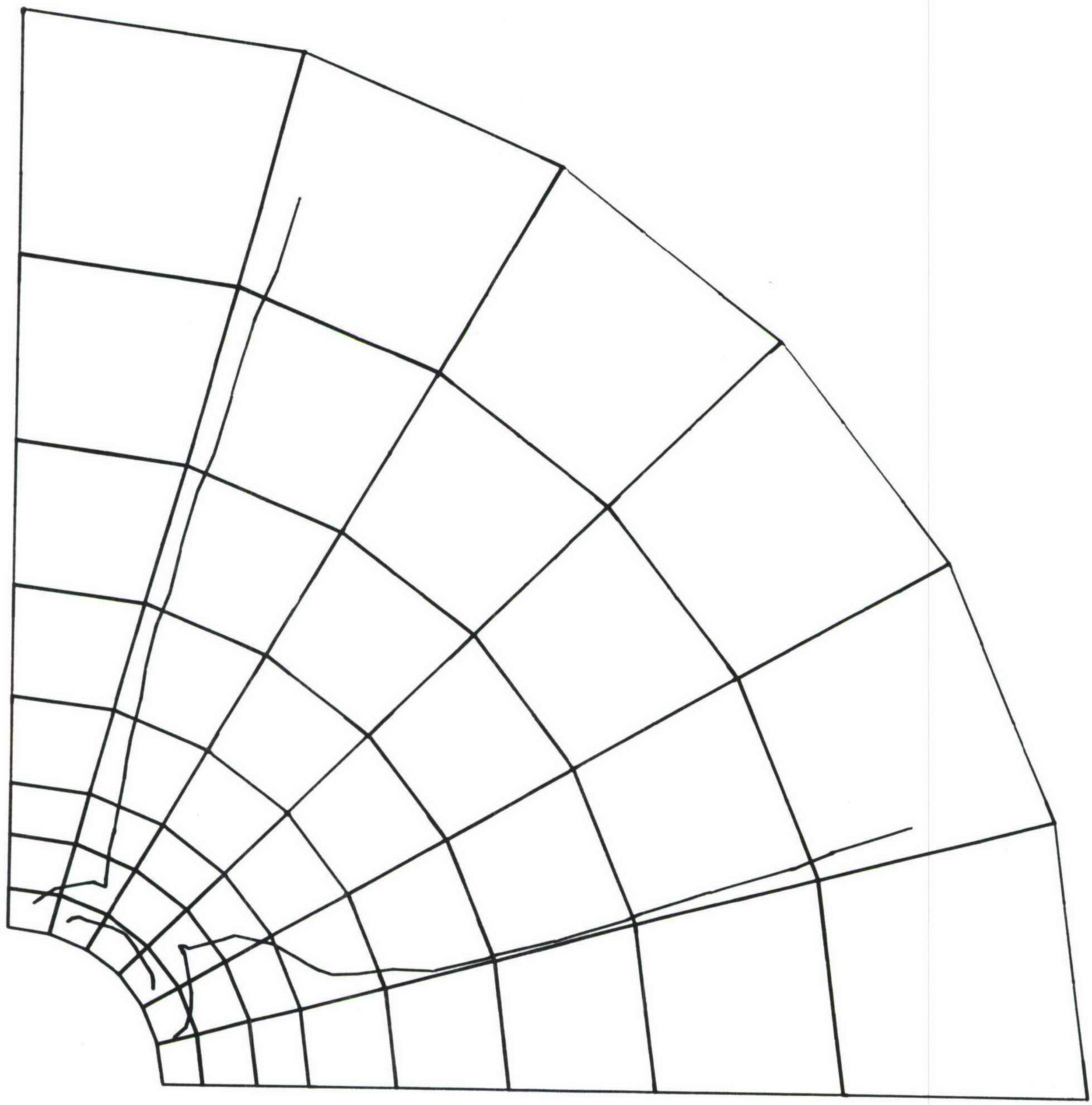


Figure AI-170 Radial-Tangential Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

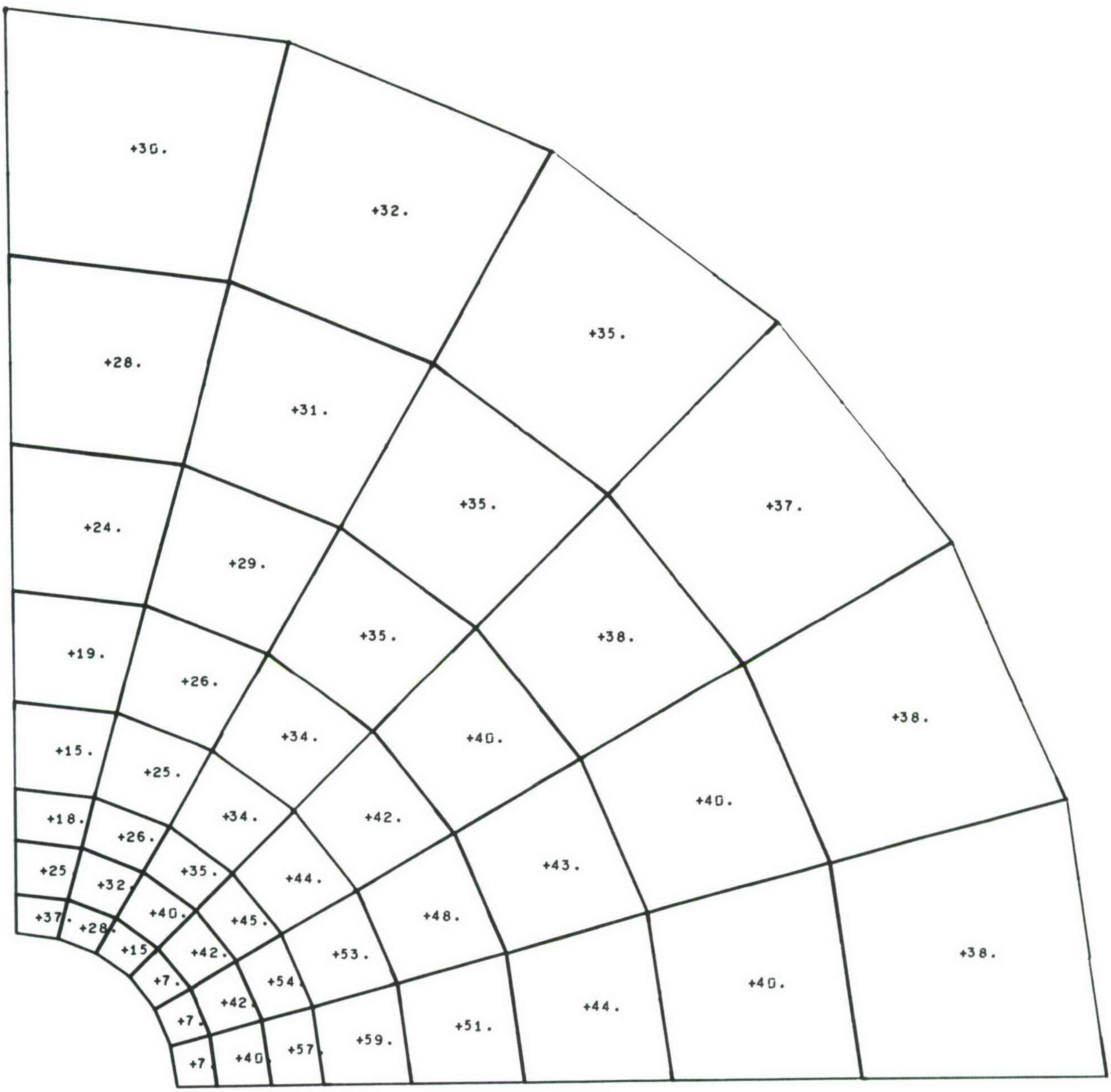


Figure AI-171 First Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

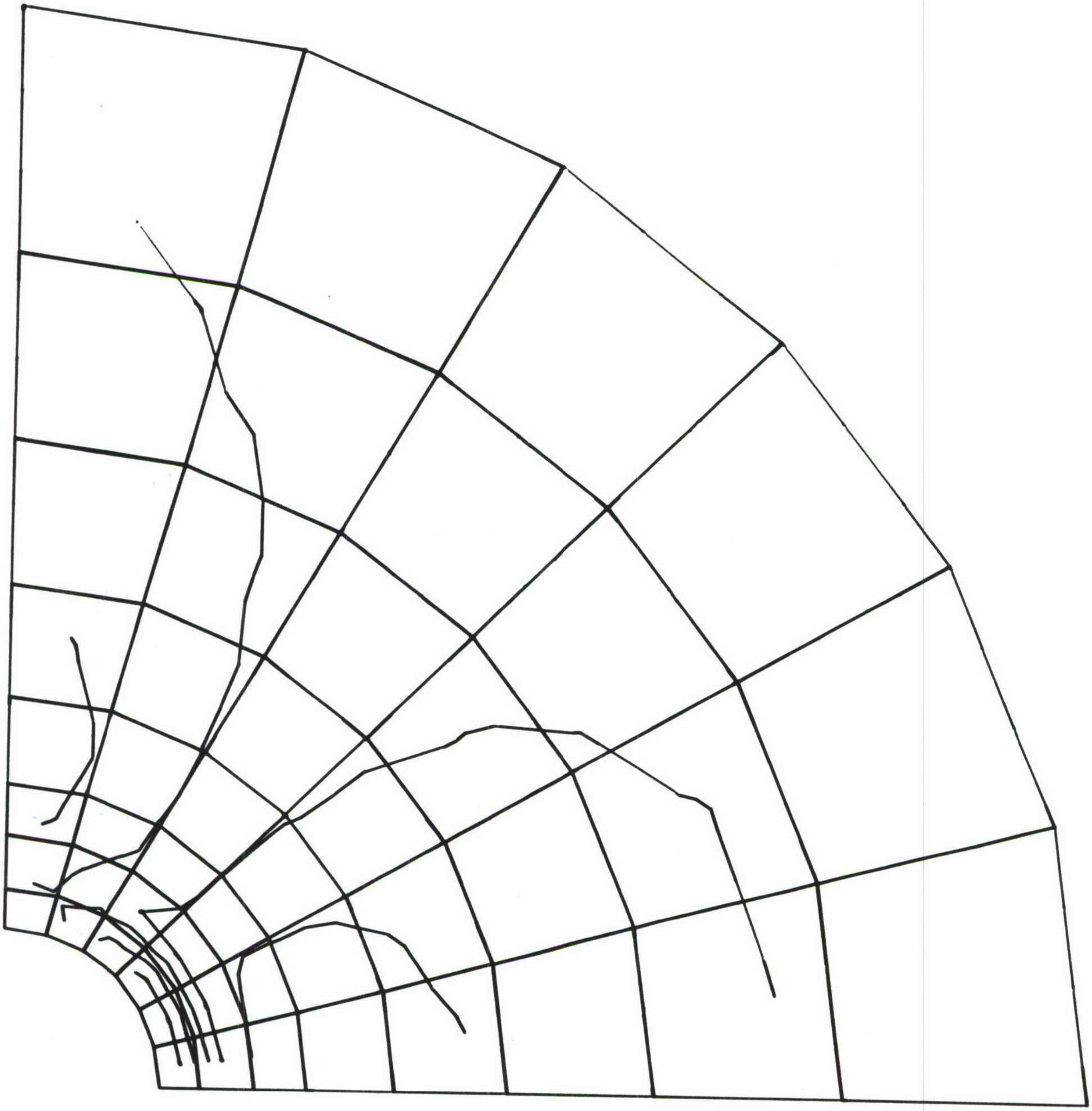


Figure AI-172 First Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

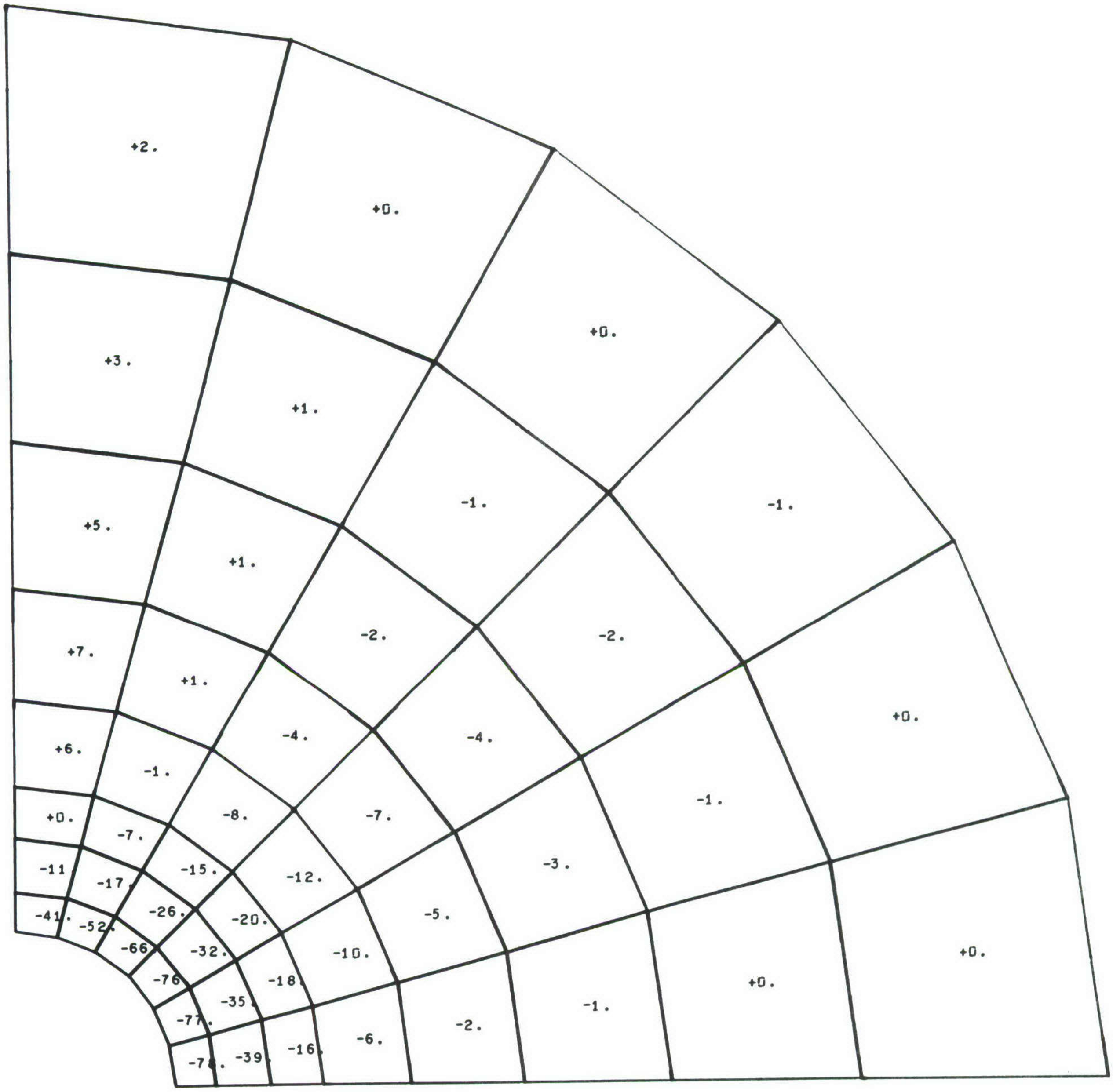


Figure AI-173 Second Principal Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

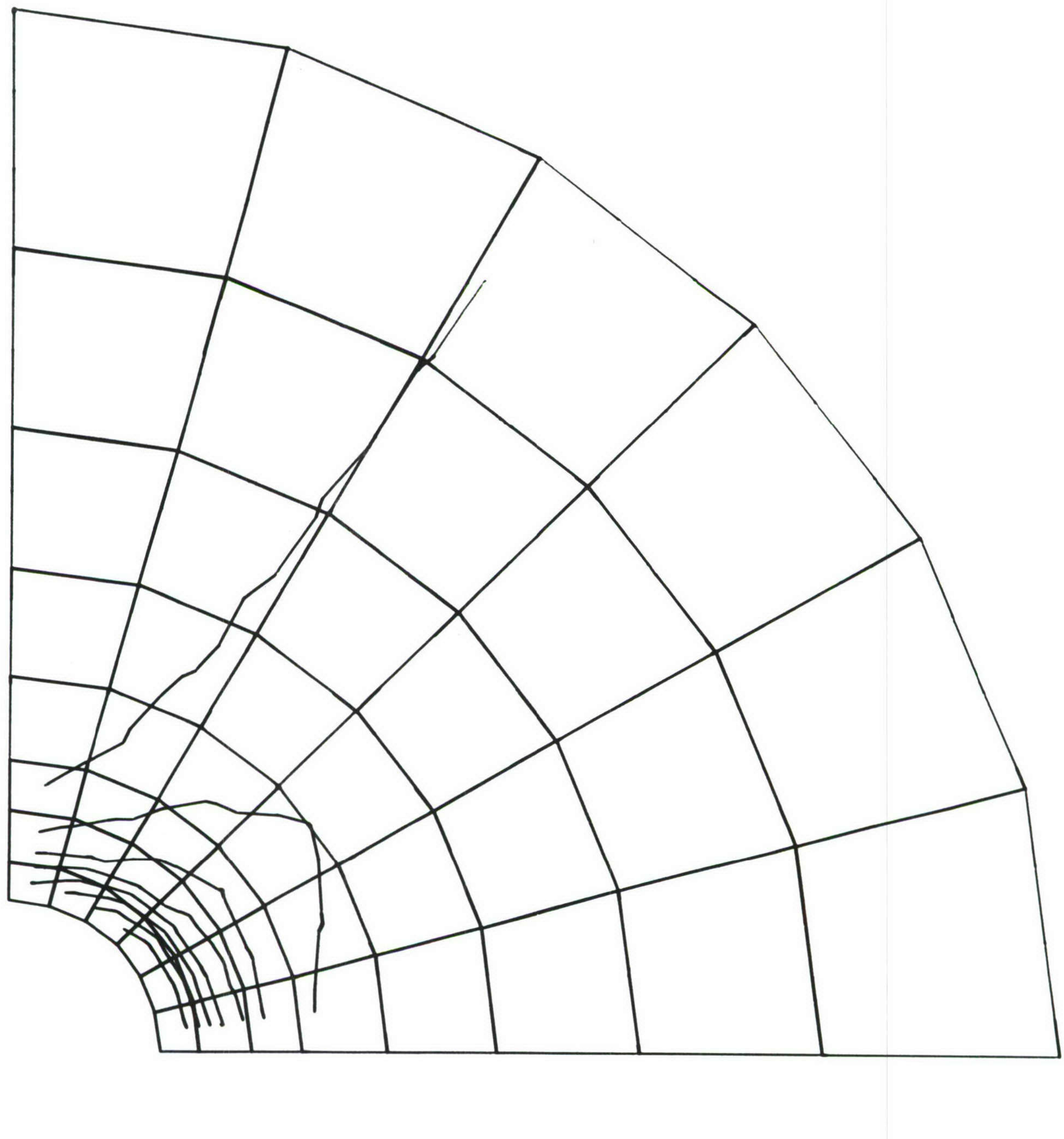


Figure AI-174 Second Principal Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

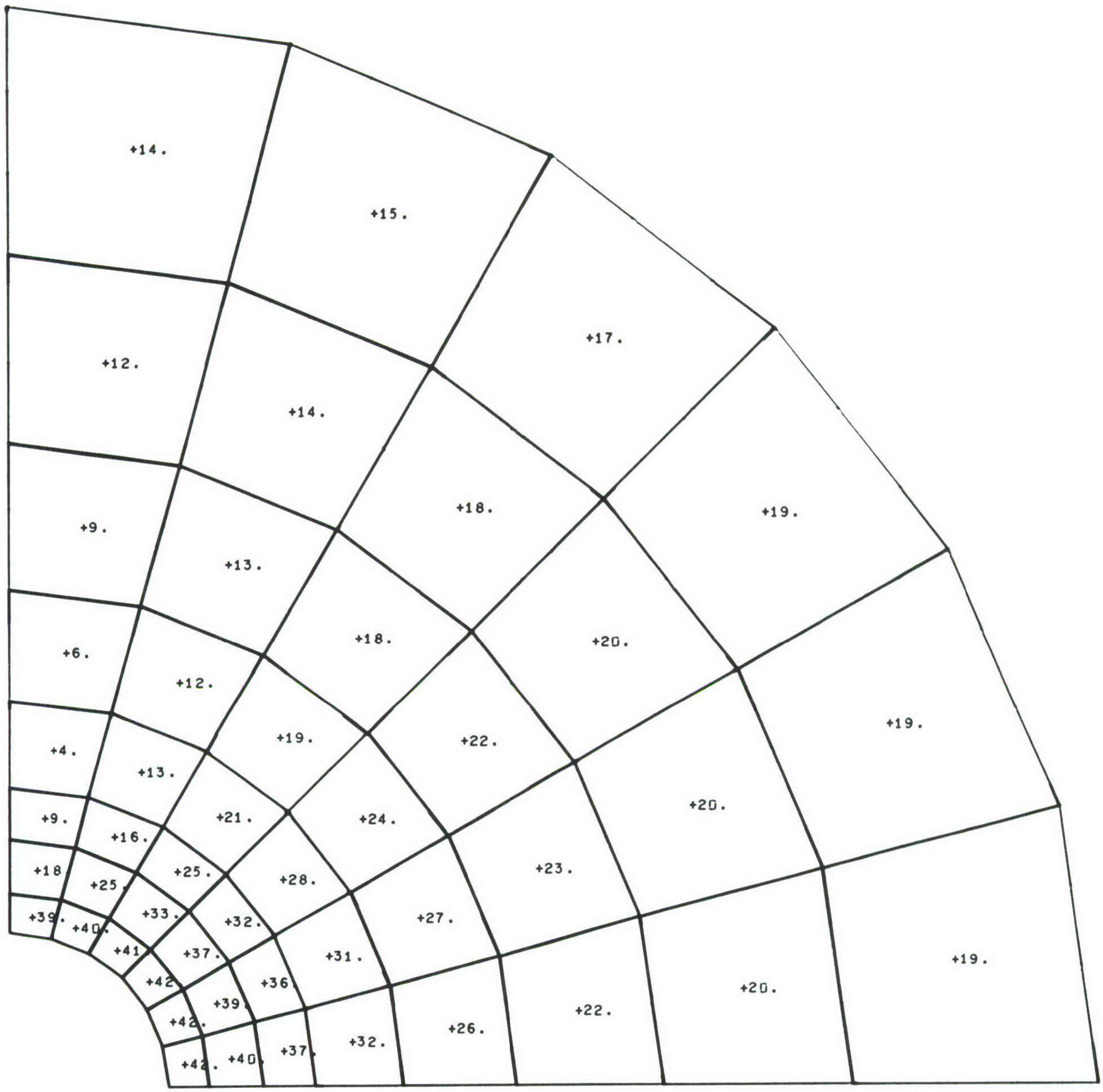


Figure AI-175 Principal Shear Stress Values for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

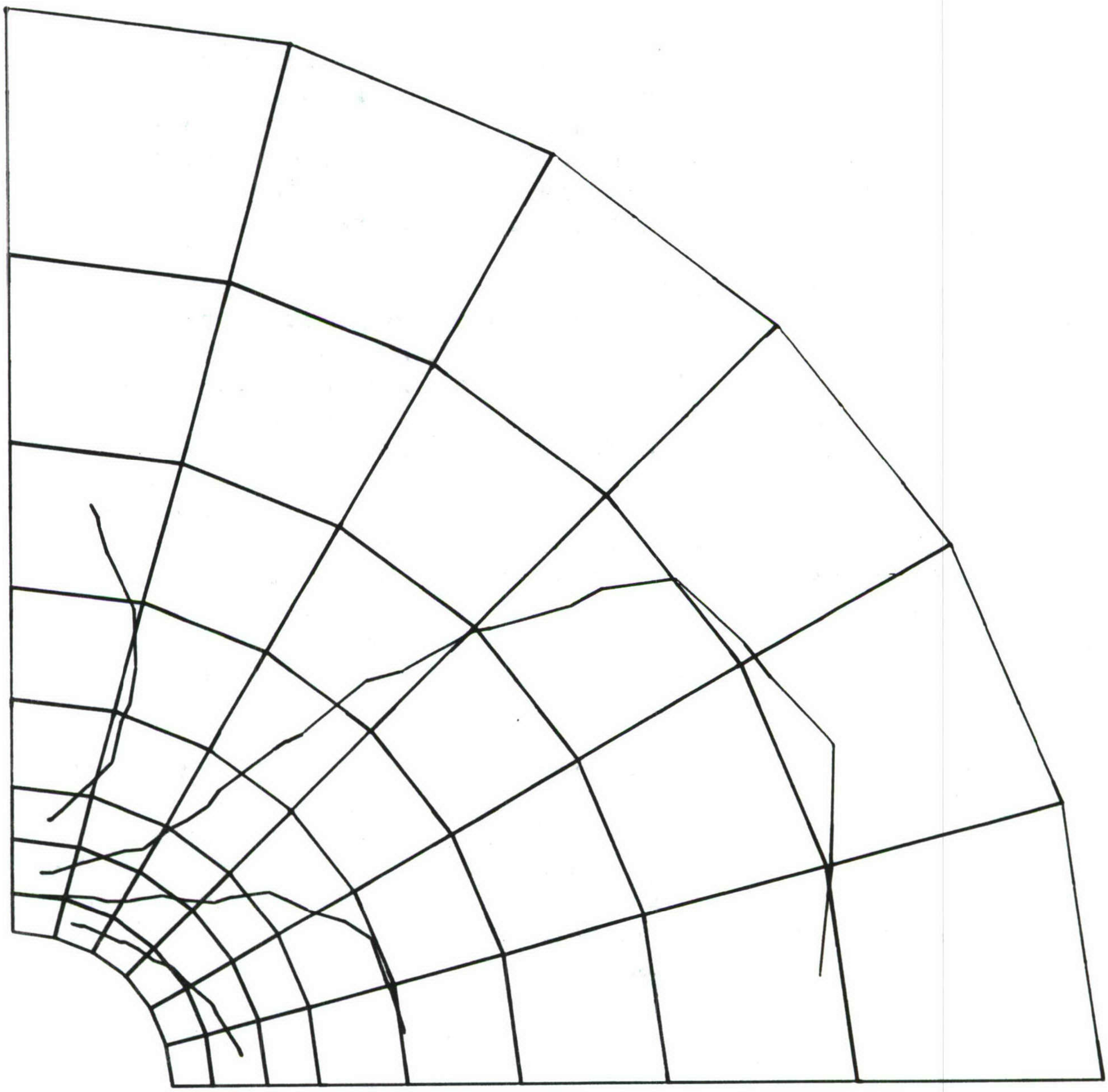


Figure AI-176 Principal Shear Stress Contours for Aluminum Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

APPENDIX II

TITANIUM PLATE RESULTS

This appendix presents the results of the finite element analysis for the titanium plate with the steel bolt inserted. The results consist of stresses and strains in the vicinity of interference fit fasteners. The analysis conditions are discussed in Section IV and Figures IV-3 and IV-4 illustrate the regions of the plates for which results are presented.

The figures are presented in pairs. The first consists of a numerical level of stress or strain superimposed on each finite element. The second consists of isolines or contours representing constant levels of stress or strain. Results are presented in the same sequence as the analysis conditions T1 through T12, defined in Table IV-1. Radial and tangential stresses and strains are presented for each condition. For those cases where no uniaxial load is applied, these stresses are the principal stresses. Hence, no other data is presented. For those cases where uniaxial load is applied, radial-tangential shear strains are presented plus other stresses consisting of radial-tangential shear stress, and the three principal stresses; first, second and shear. The figures are otherwise self-explanatory.

Note: The numbers printed for stress and strain have been truncated back (as opposed to rounded off). Also, the stresses printed are in units of 1000 pounds/inch squared; the strains printed are in units of 0.001 inches/inch. The numbers should be interpreted as being representative of the level at the element center. Negative stresses and strains are compressive, positive stresses and strains are tensile.

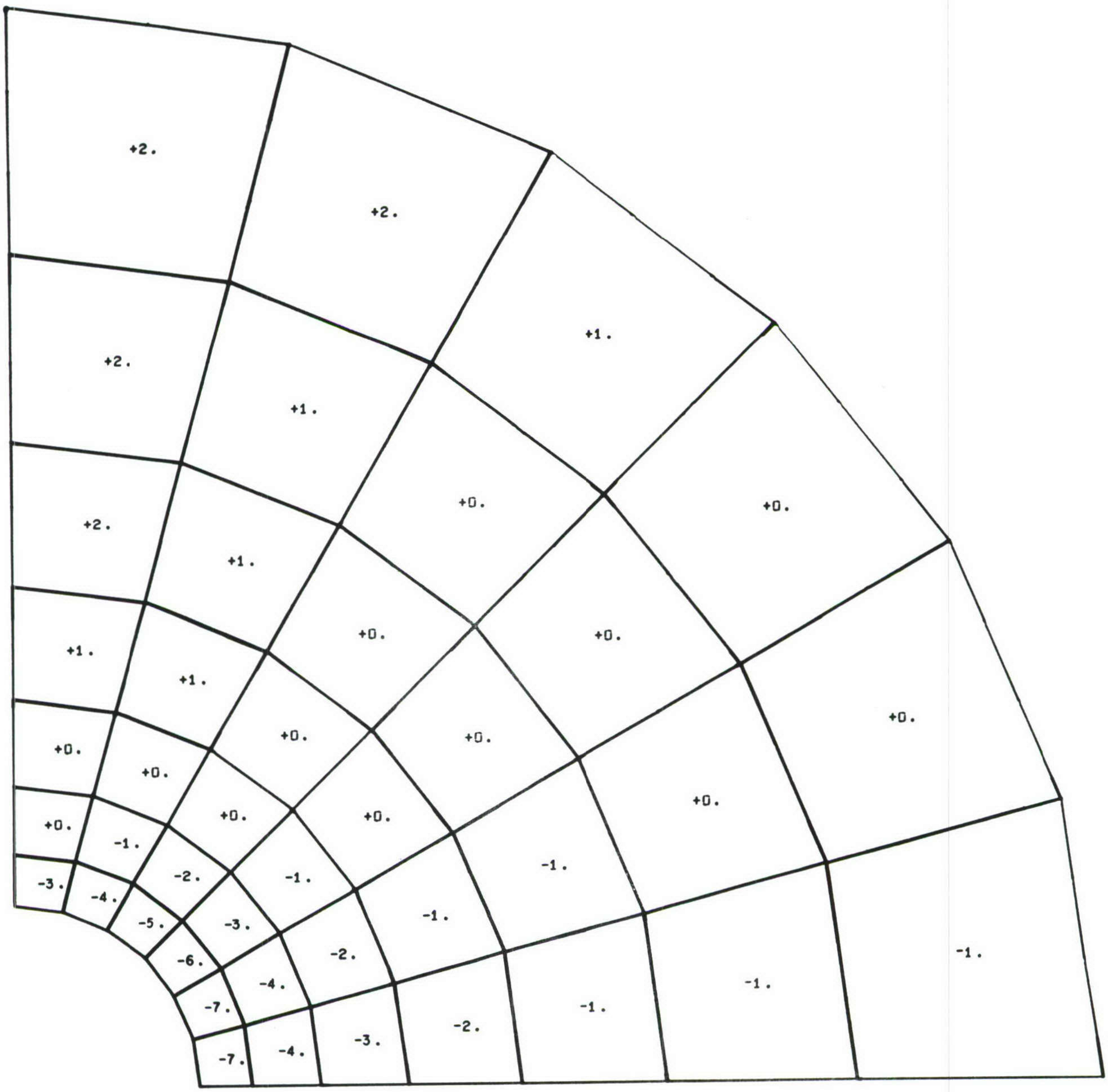


Figure AII-1 Radial Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

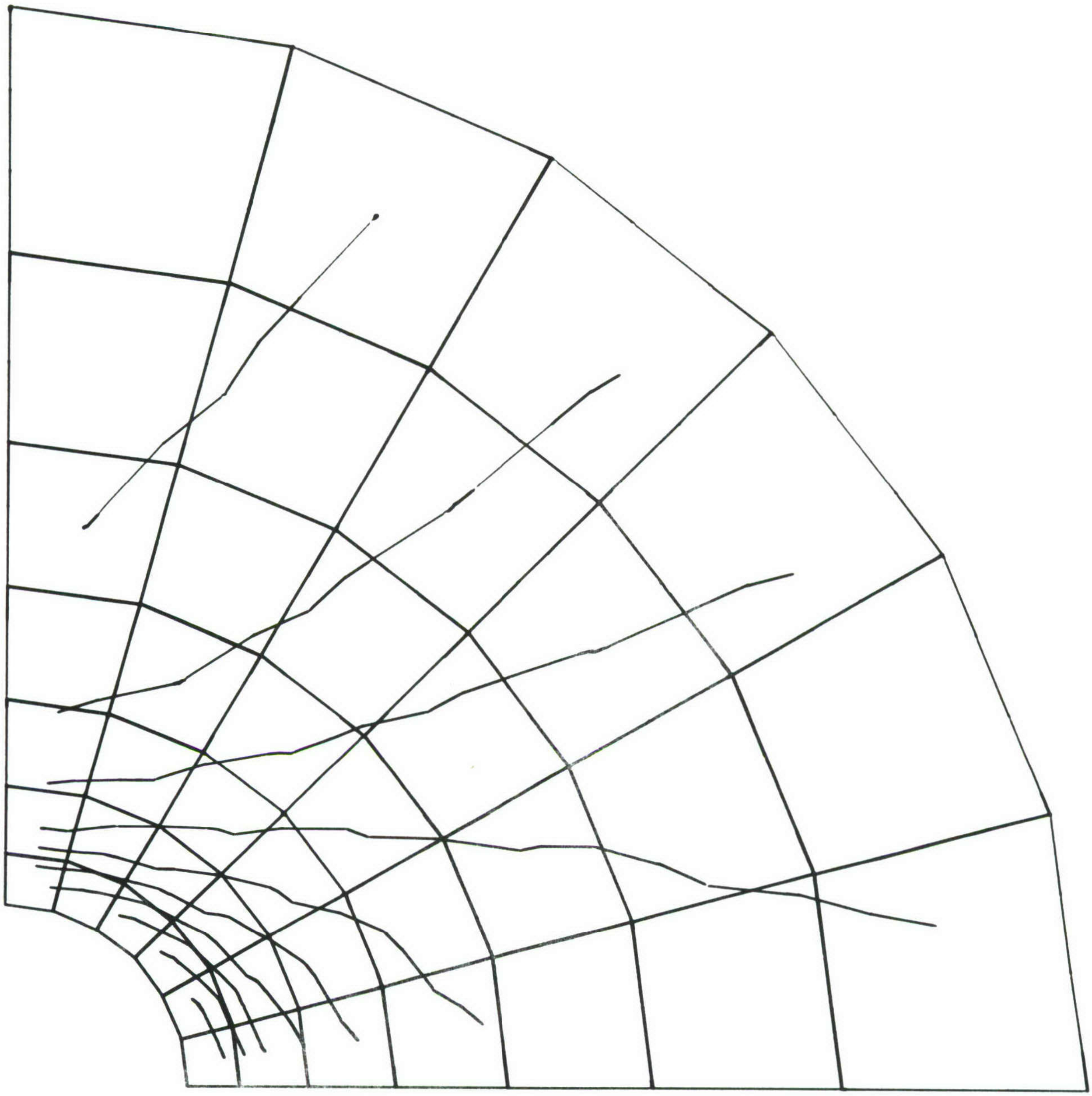


Figure AII-2 Radial Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

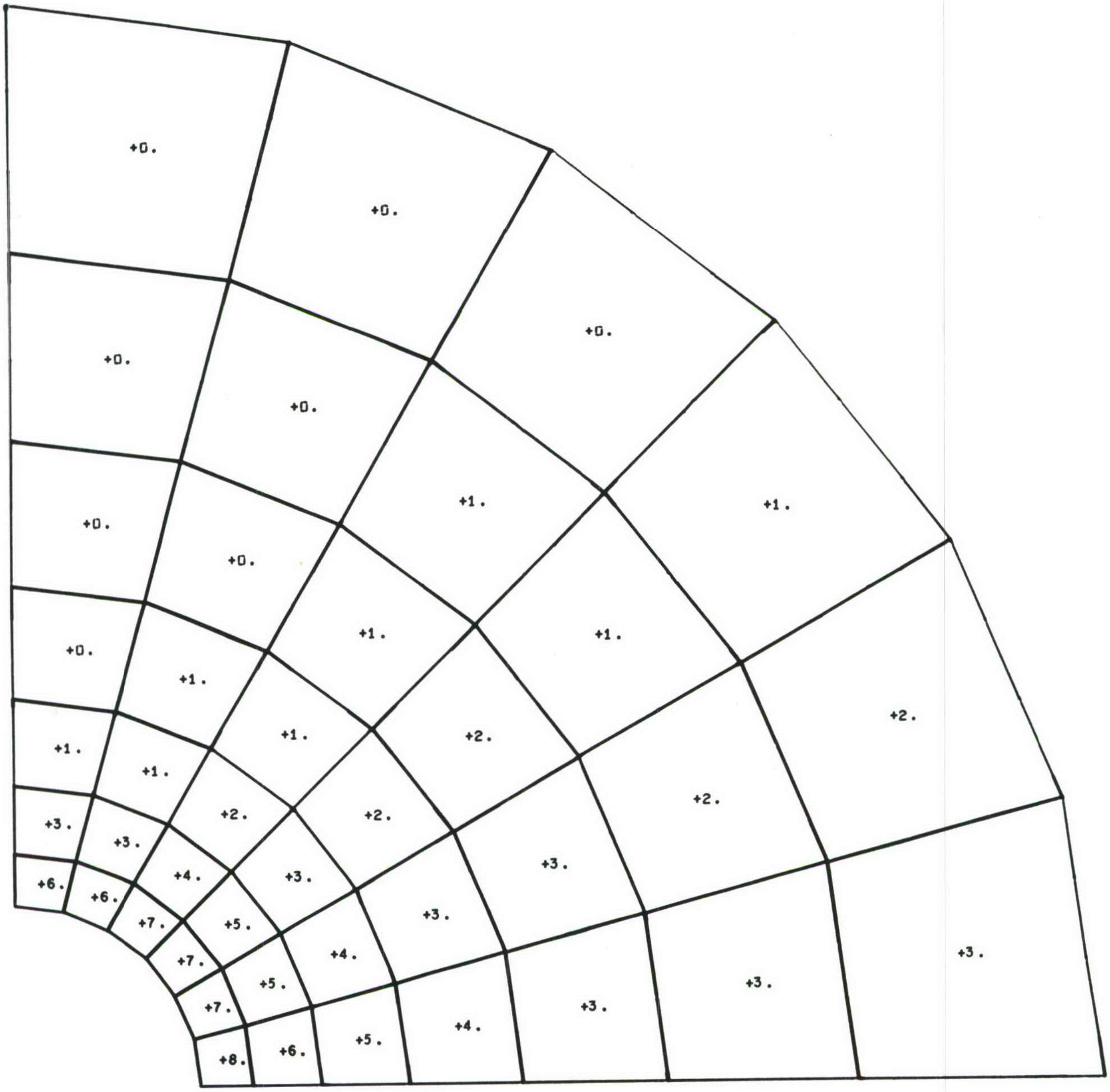


Figure AII-3 Tangential Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

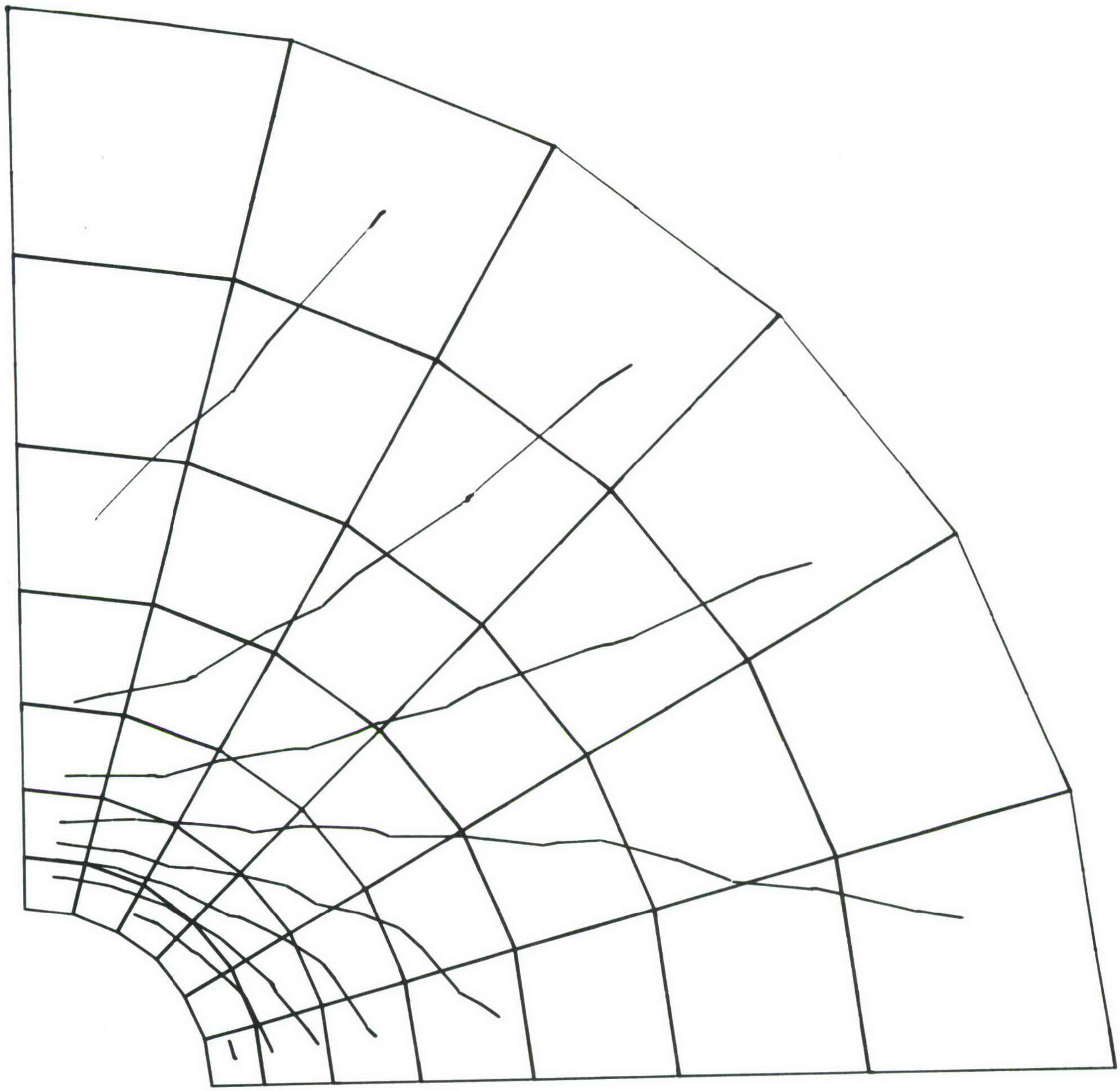


Figure AII-4 Tangential Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

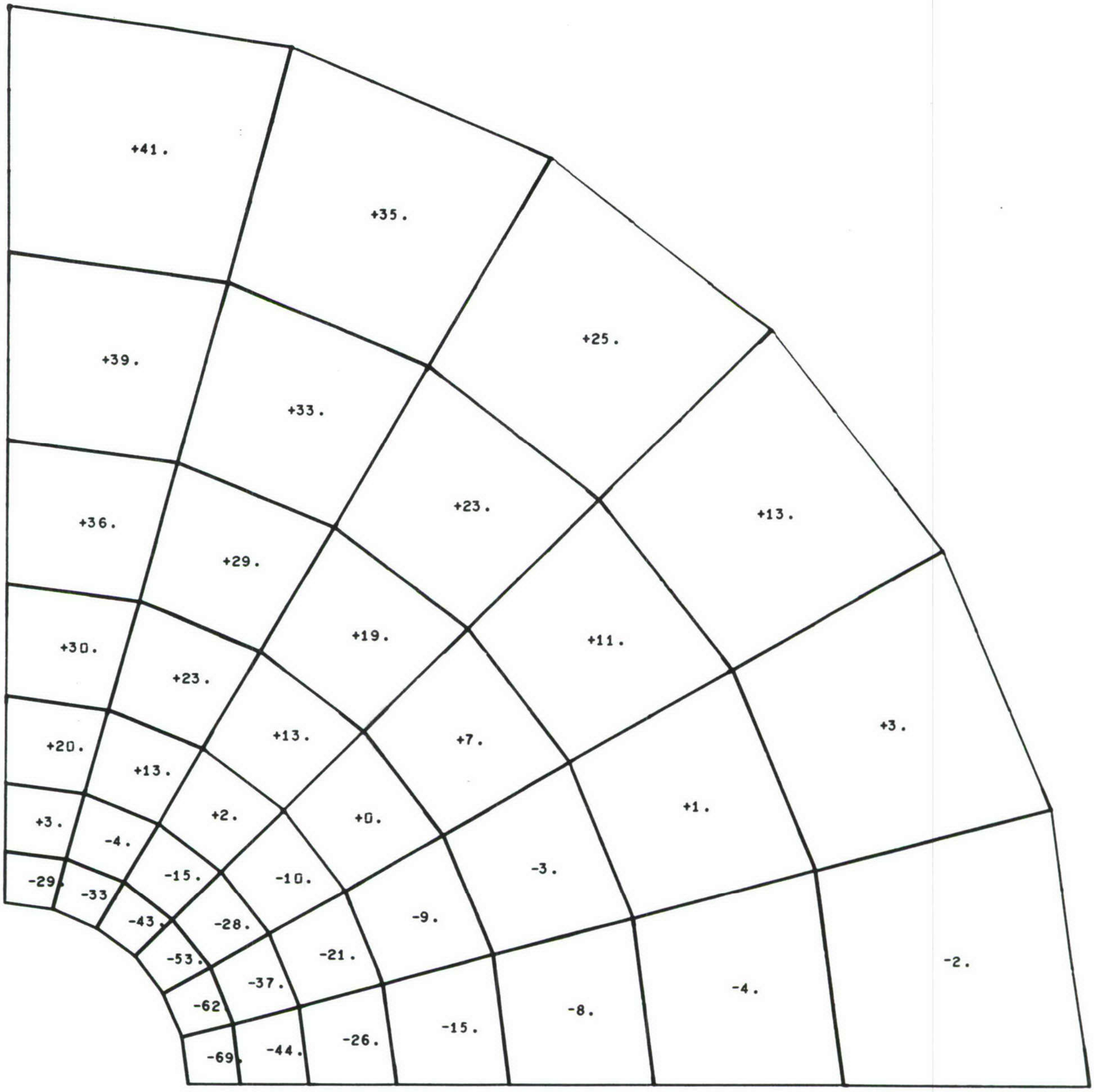


Figure AII-5 Radial Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

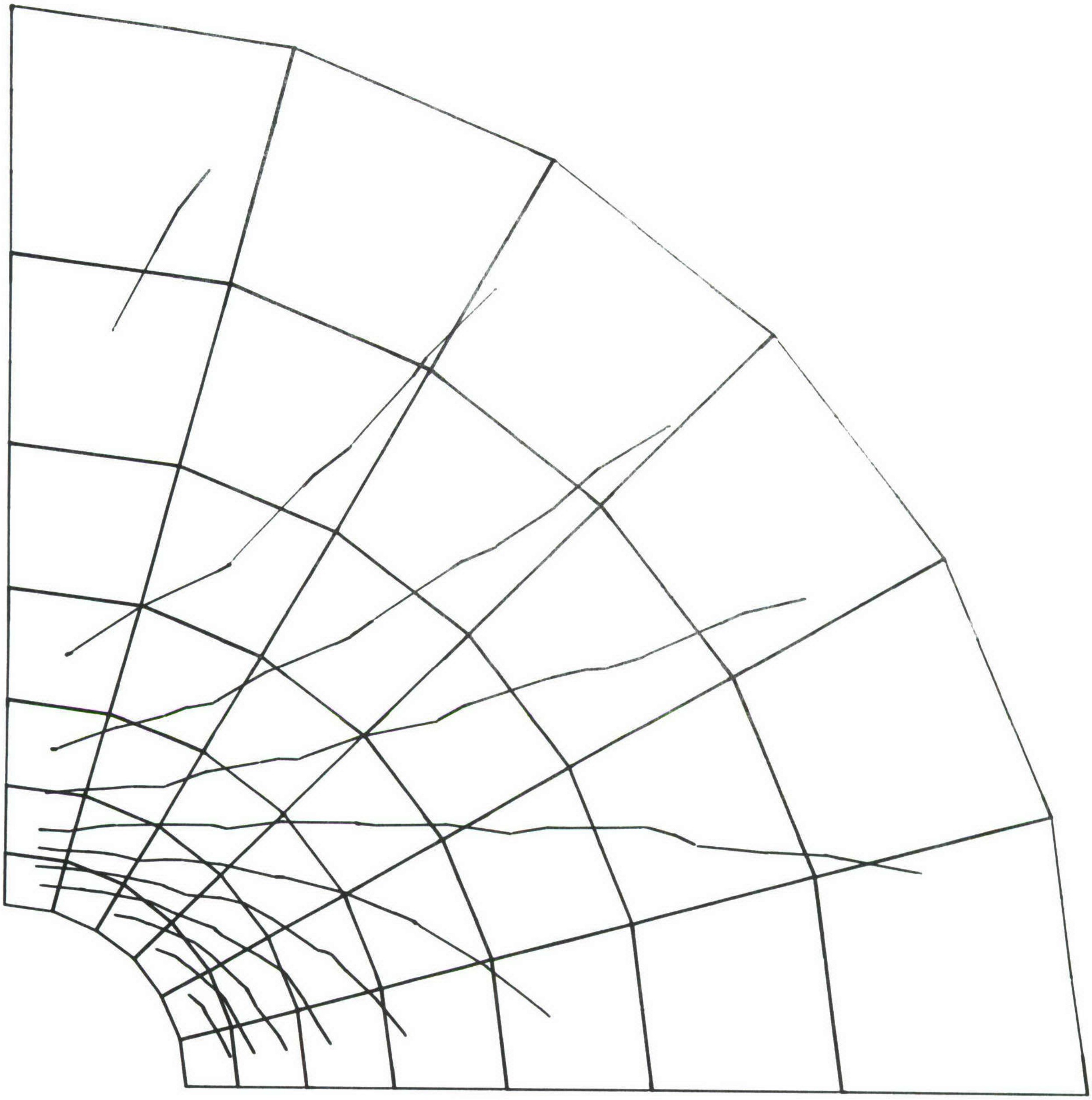


Figure AII-6 Radial Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

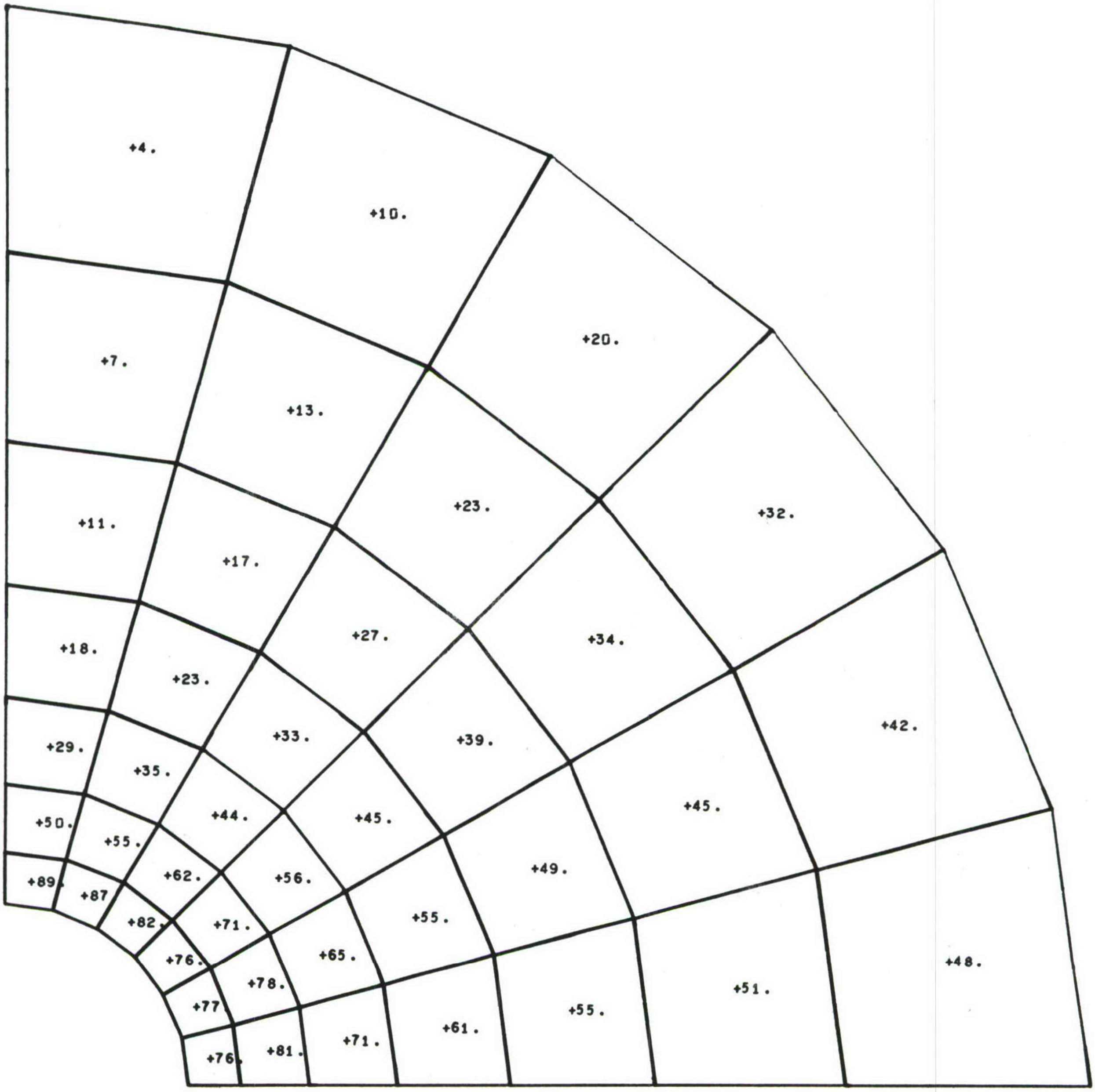


Figure AII-7 Tangential Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

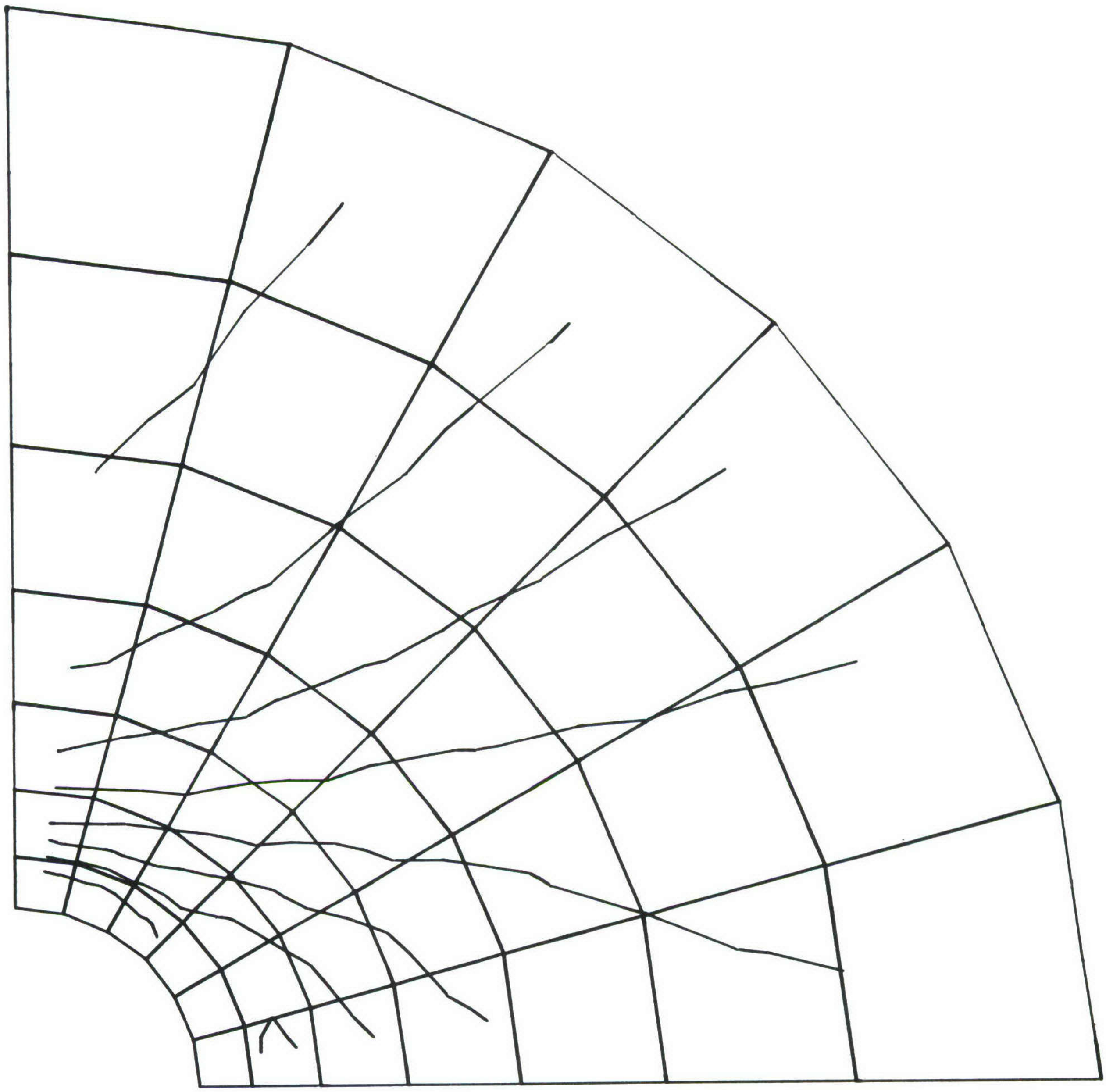


Figure AII-8 Tangential Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

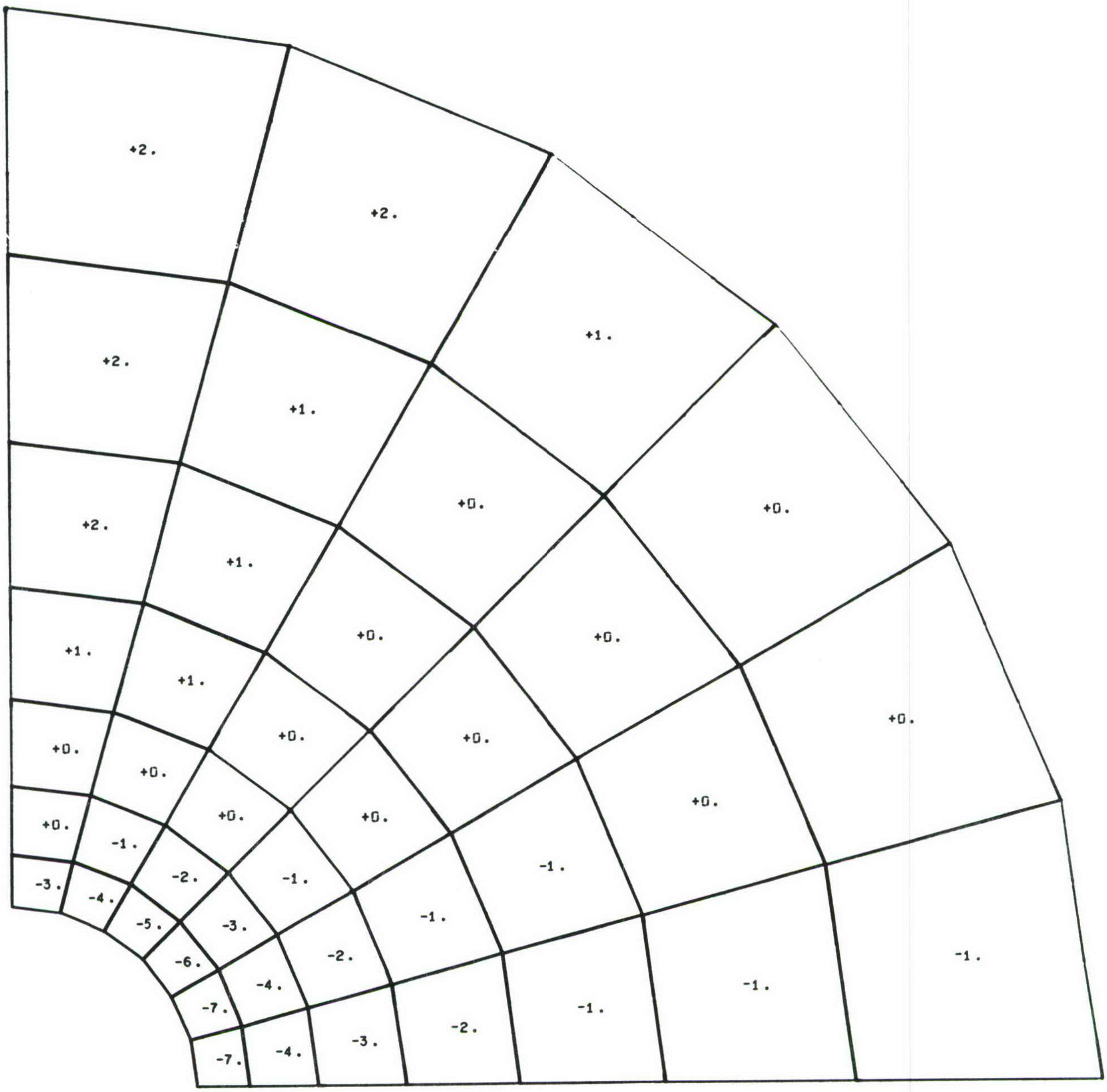


Figure AII-9 Radial Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

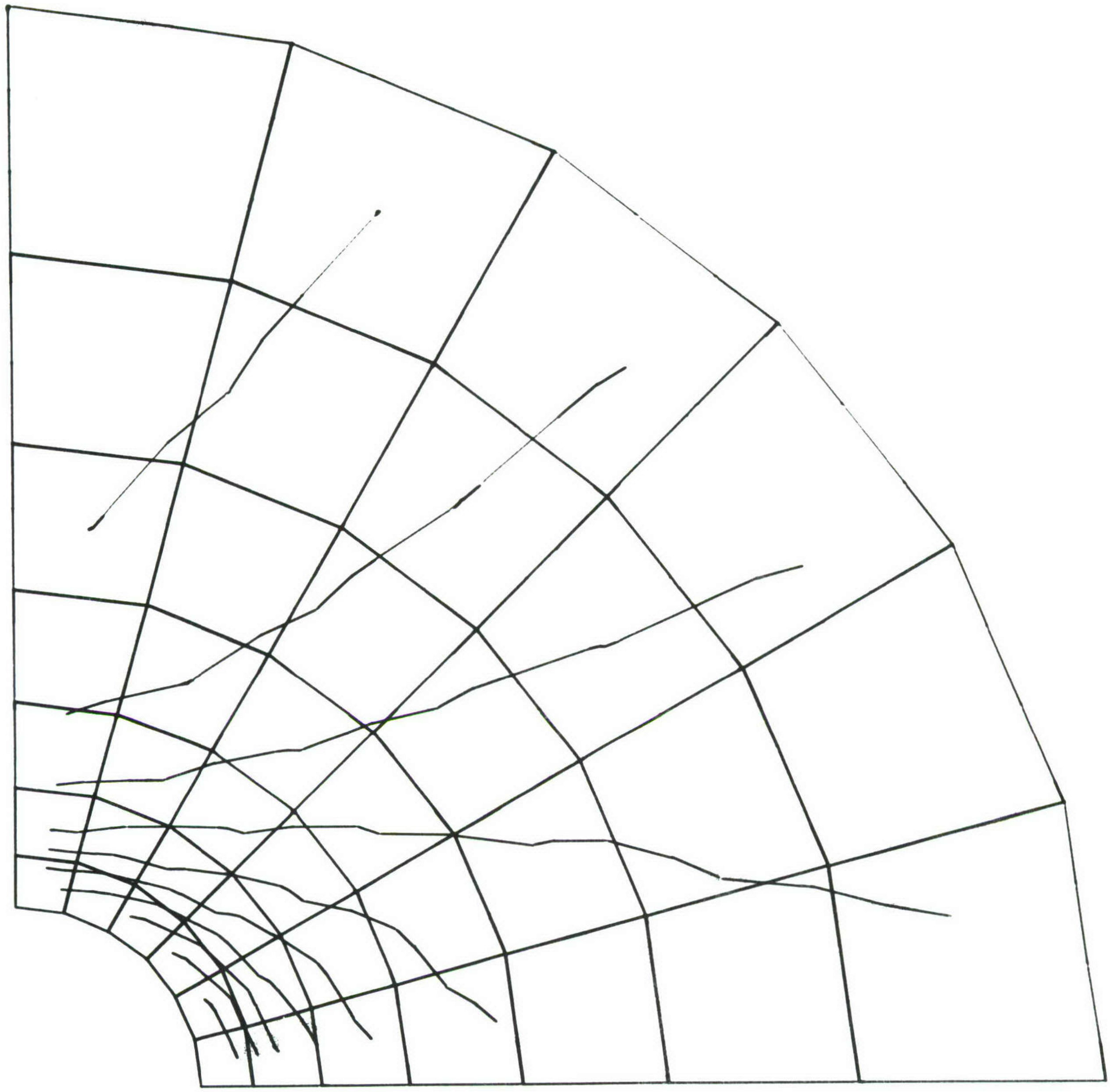


Figure AII-10 Radial Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

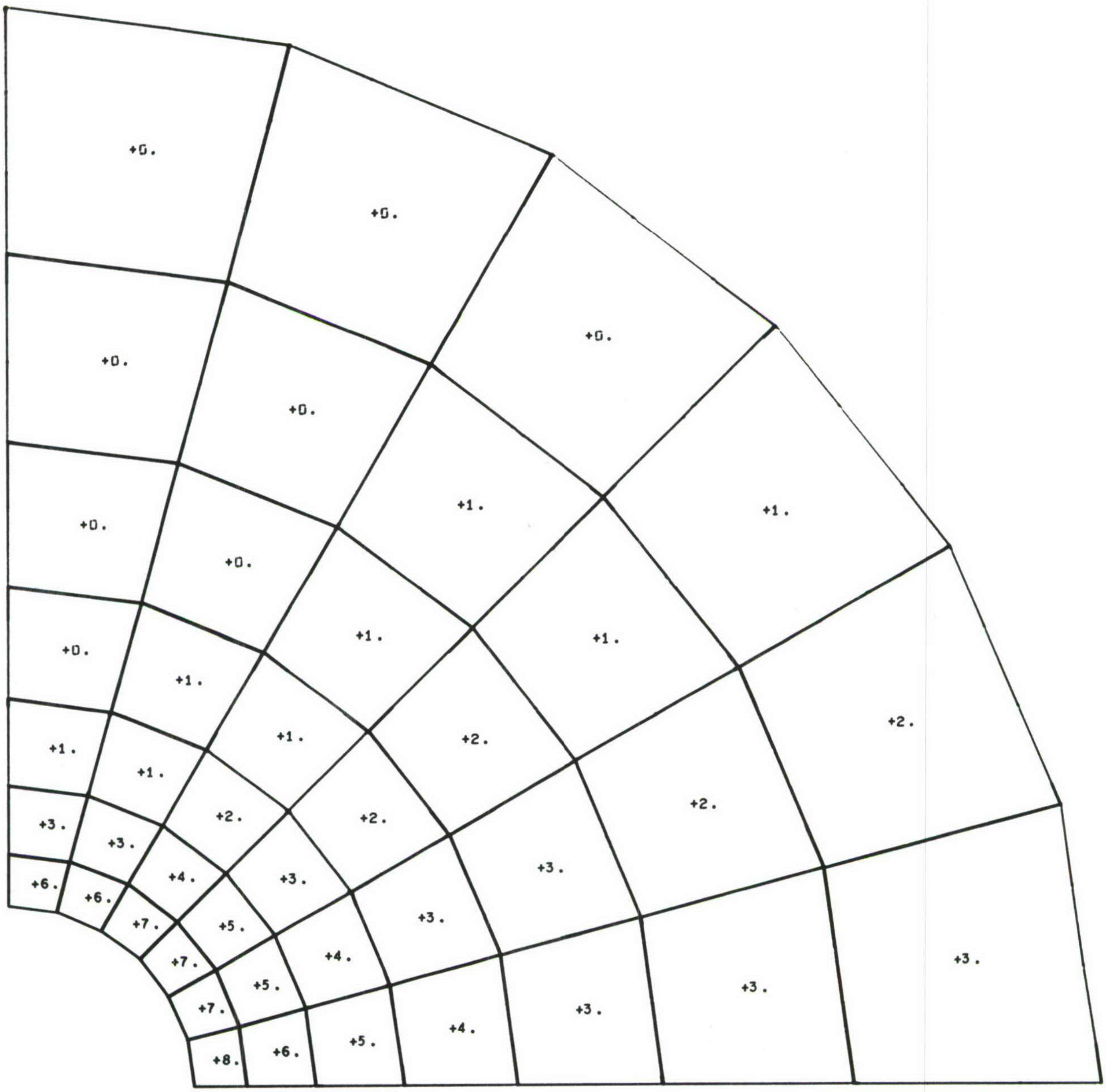


Figure AII-11 Tangential Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

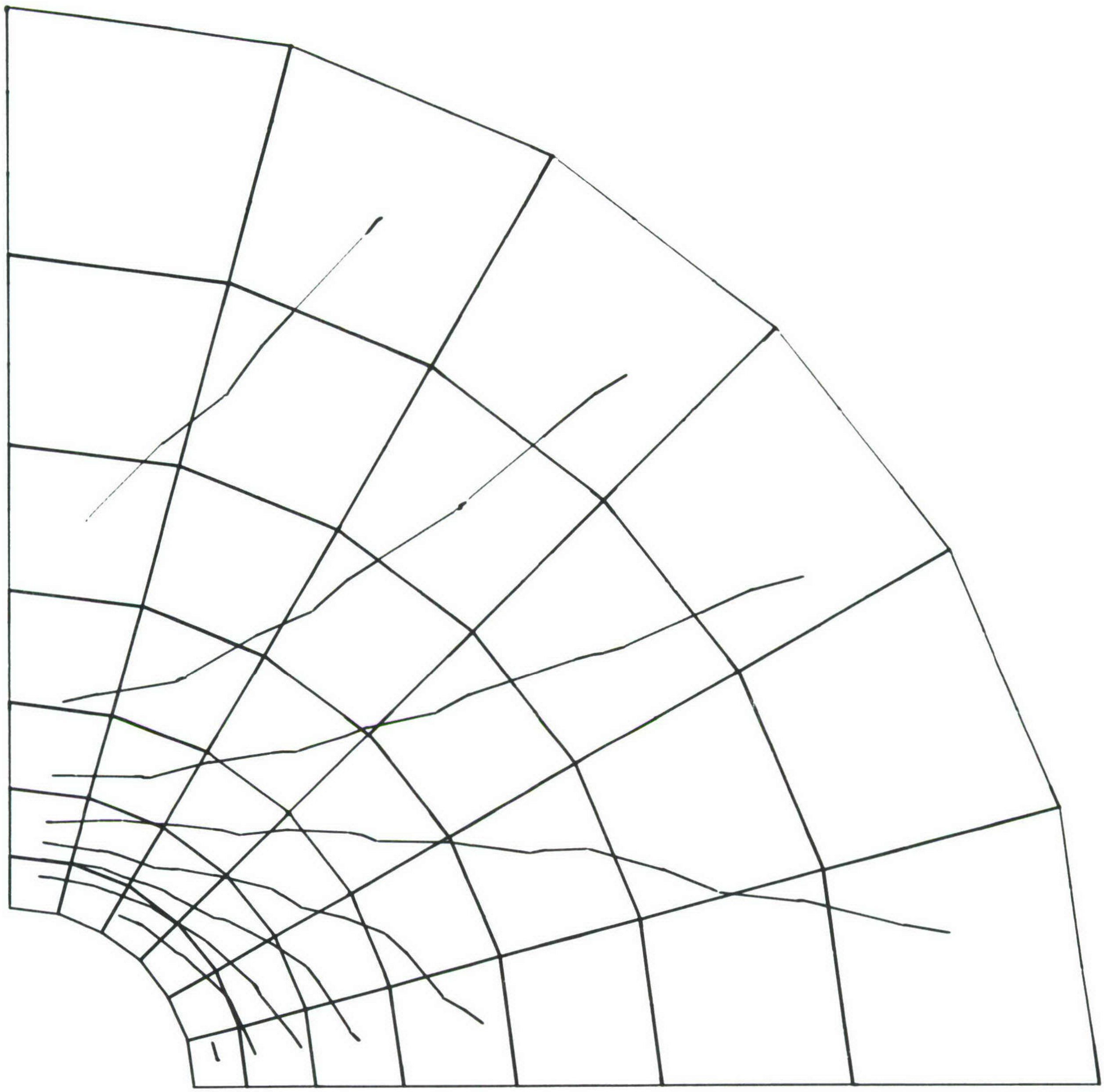


Figure AII-12 Tangential Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

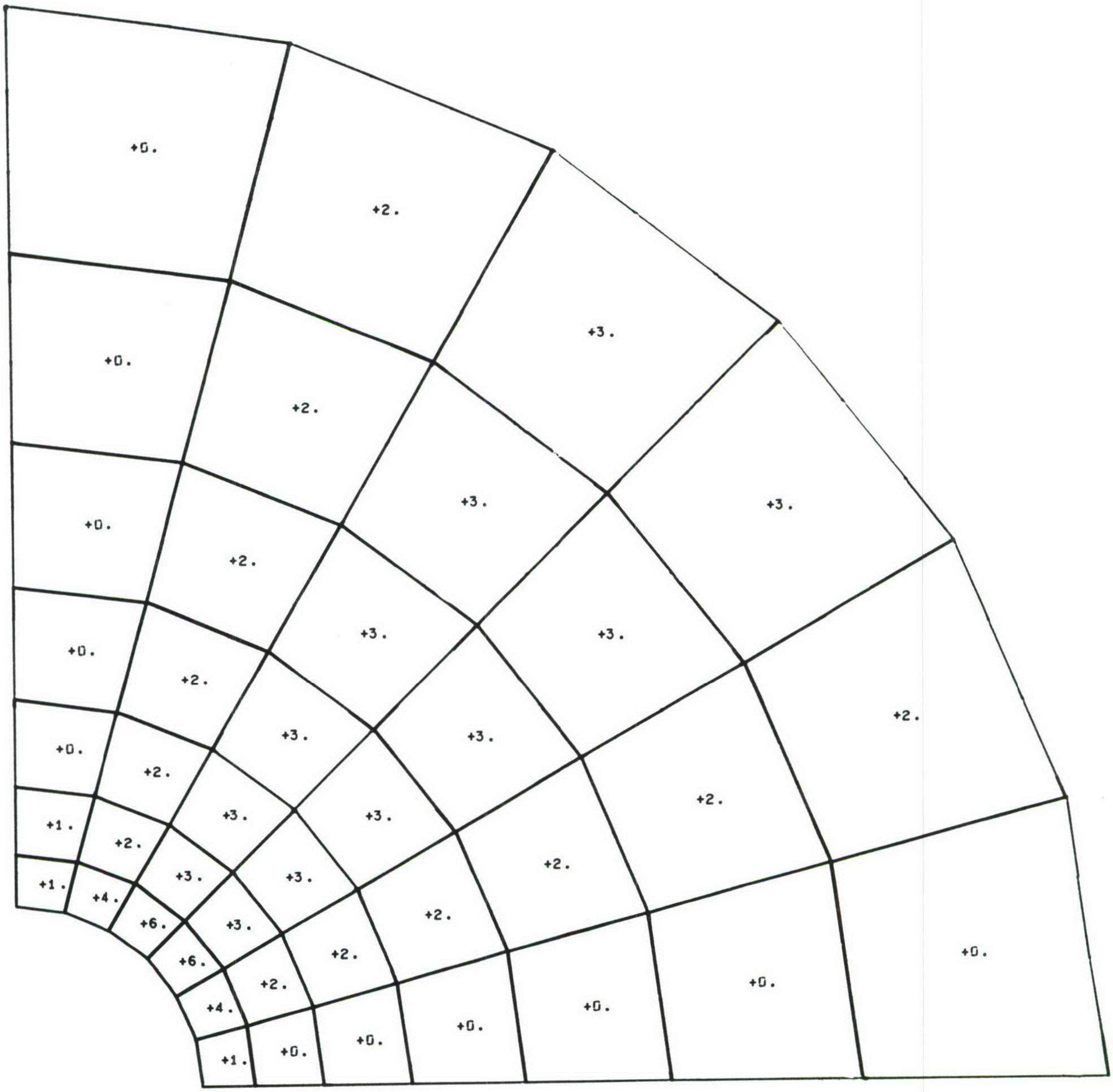


Figure AII-13 Radial-Tangential Shear Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

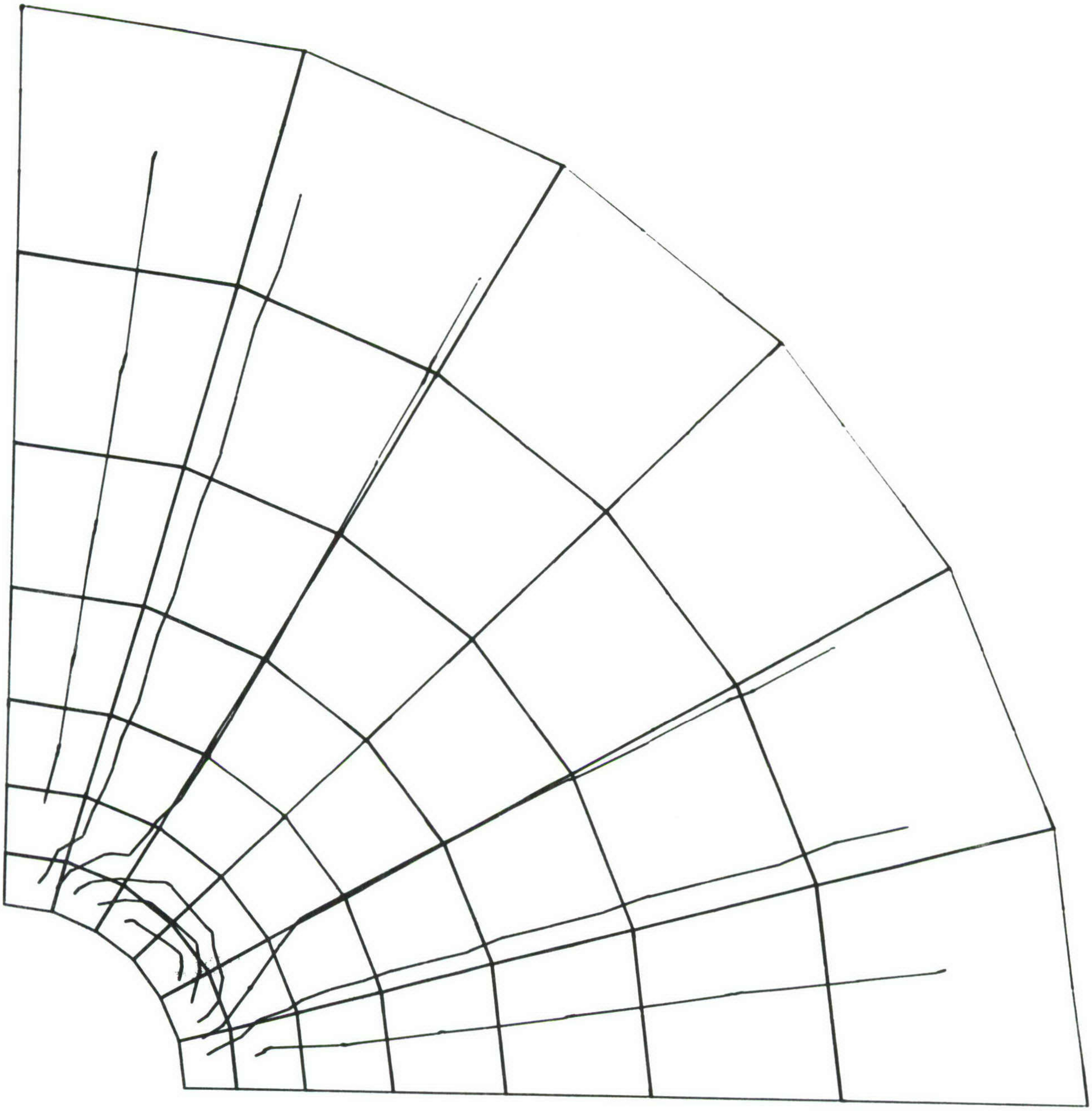


Figure AII-14 Radial-Tangential Shear Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

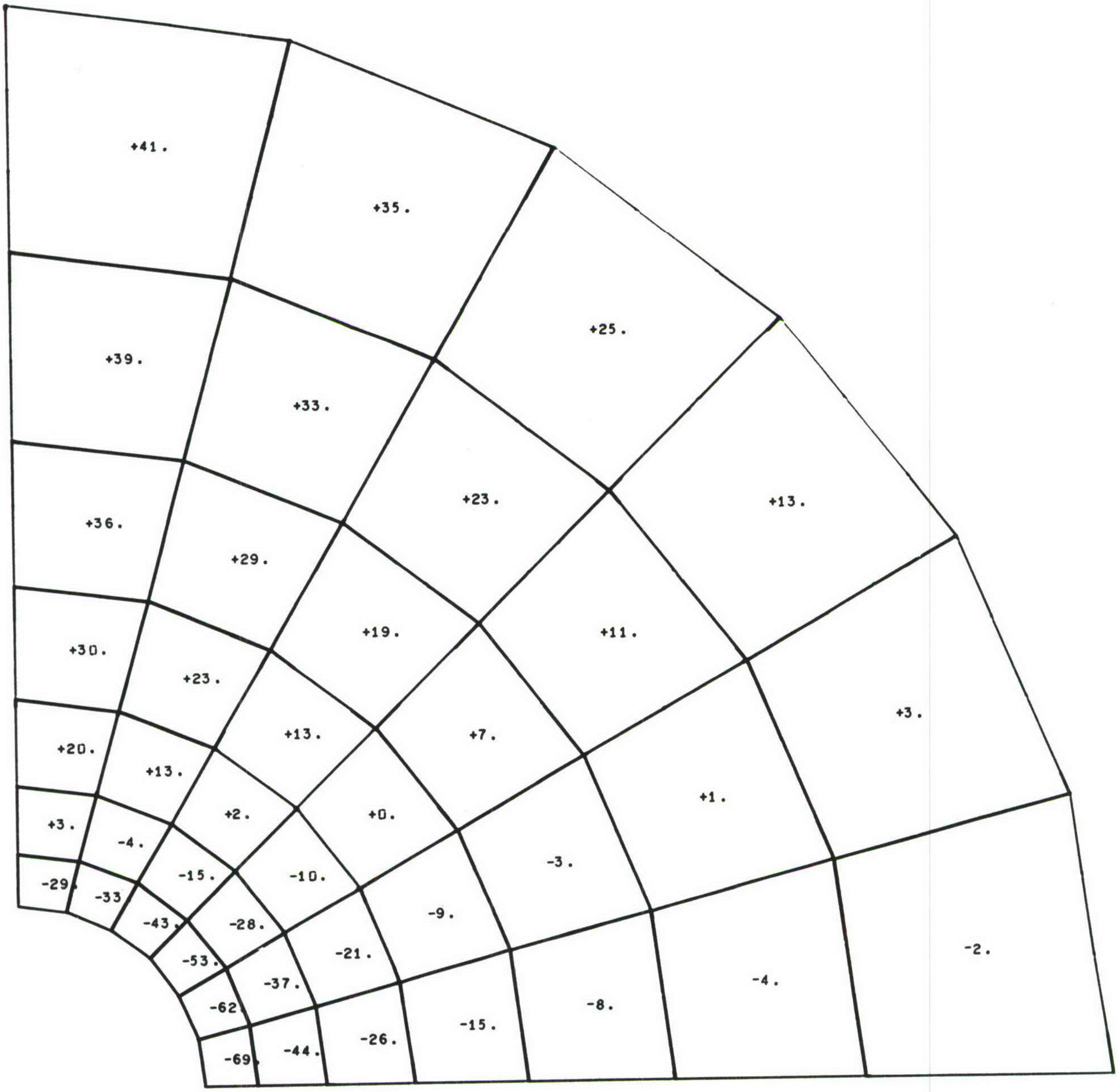


Figure AII-15 Radial Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

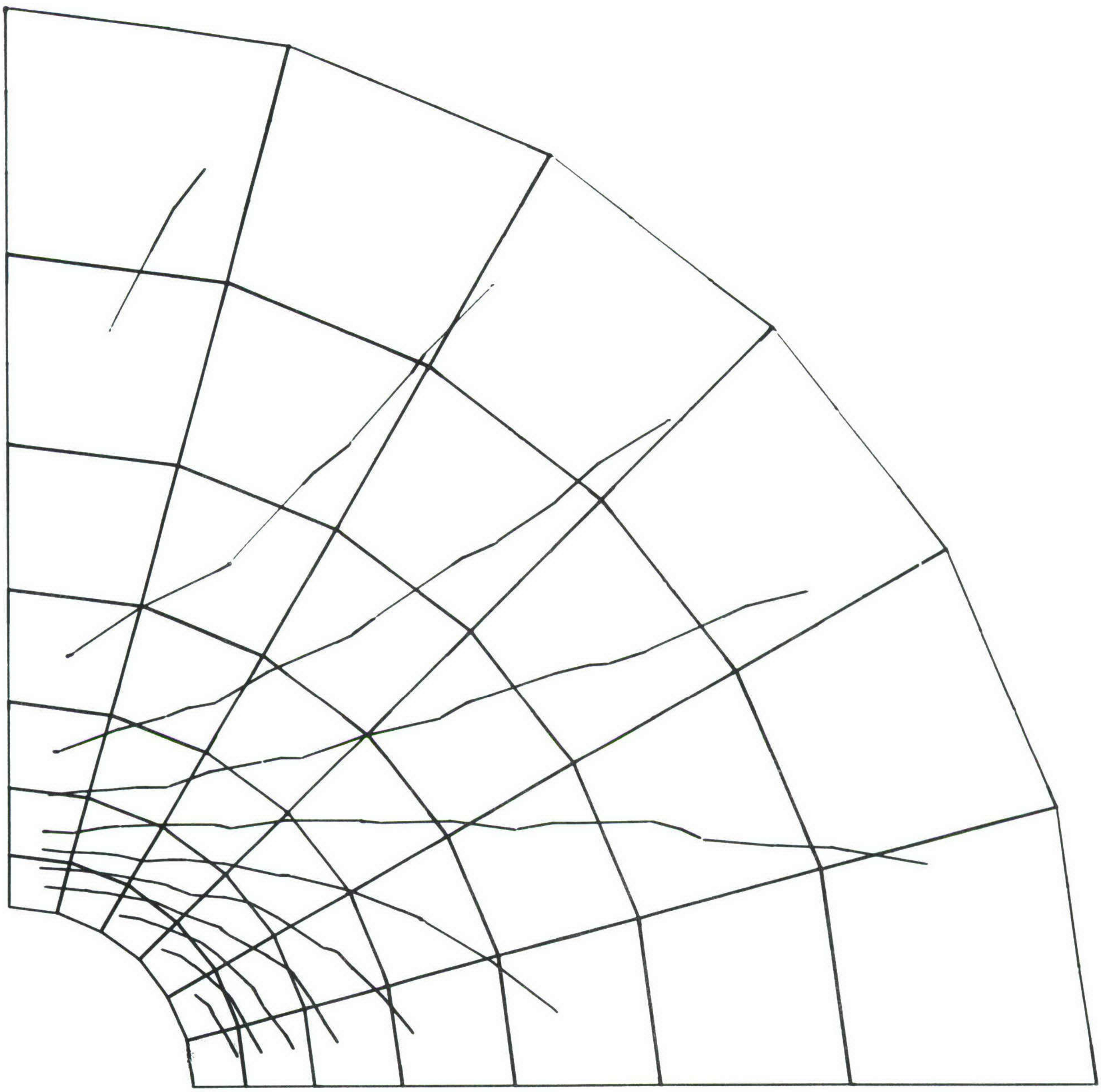


Figure AII-16 Radial Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

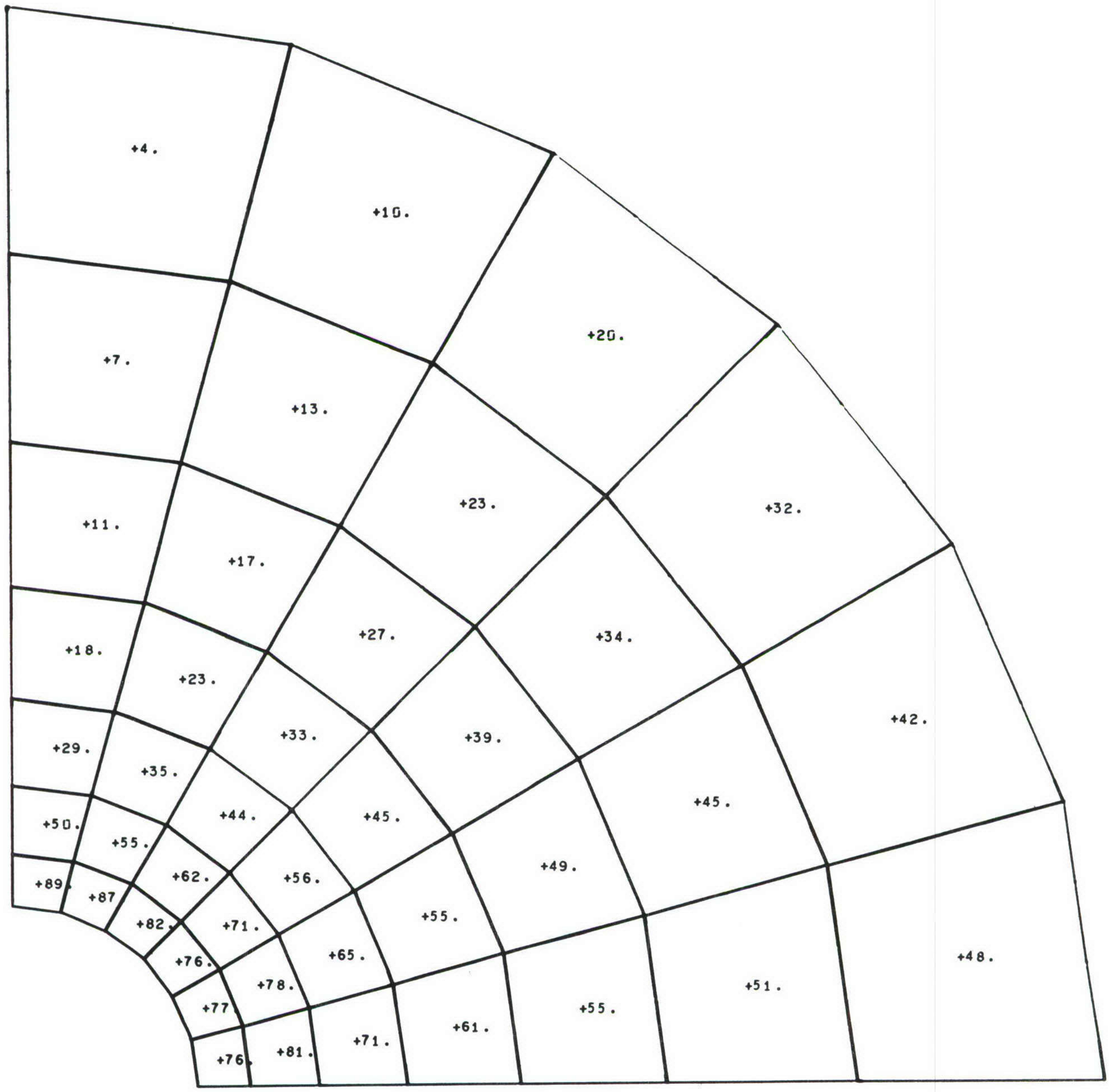


Figure AII-17 Tangential Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

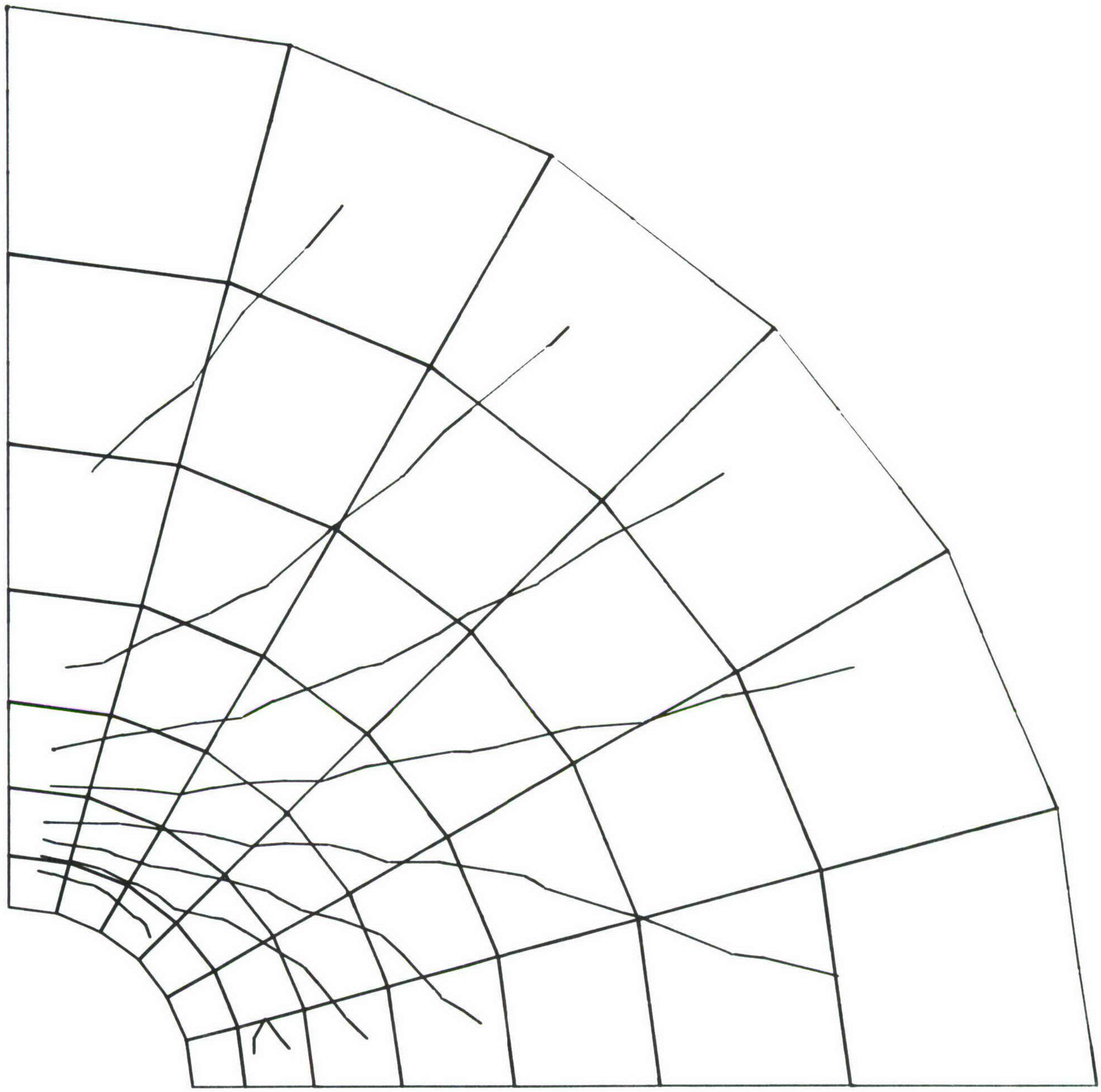


Figure AII-18 Tangential Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

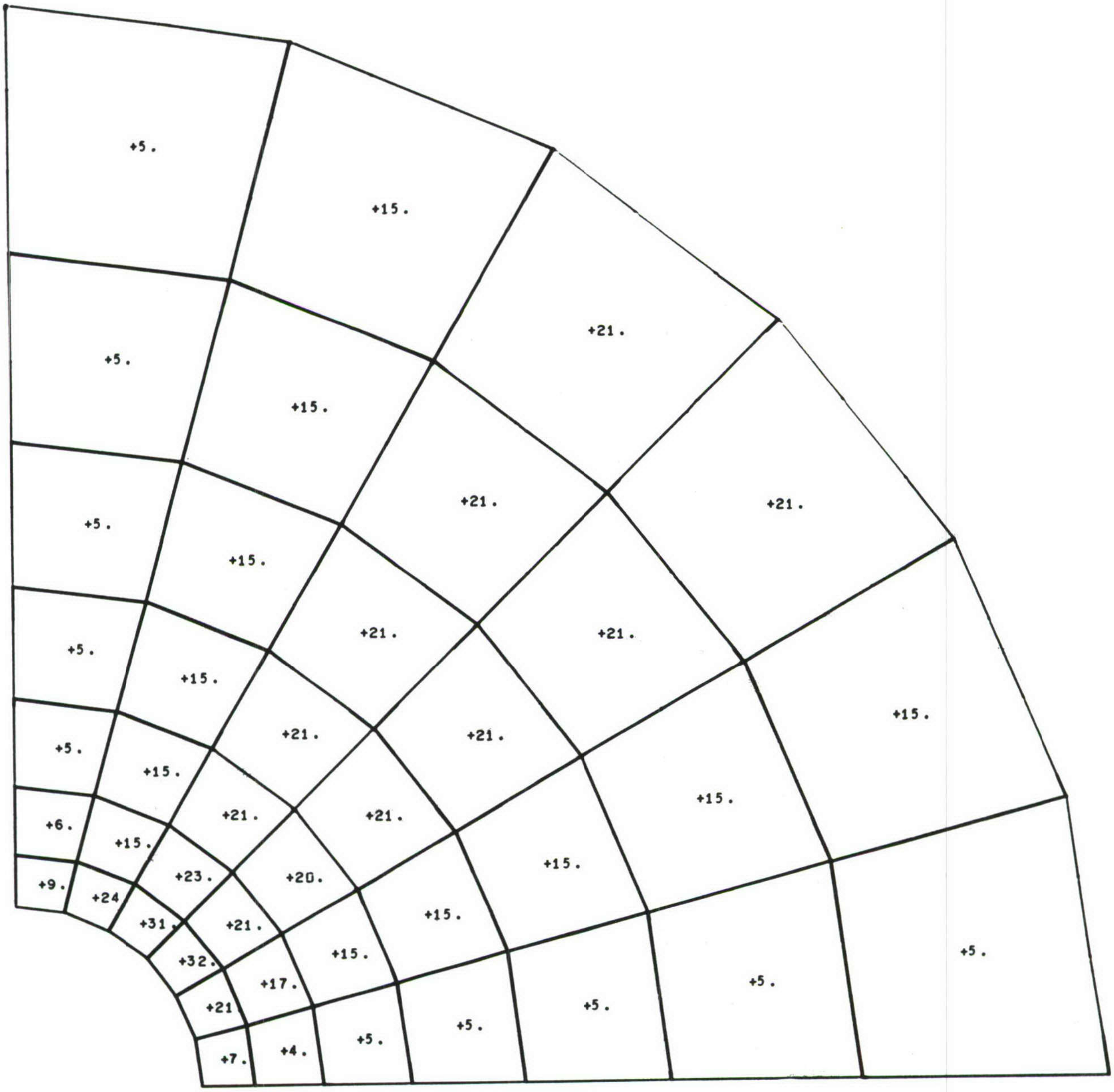


Figure AII-19 Radial-Tangential Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

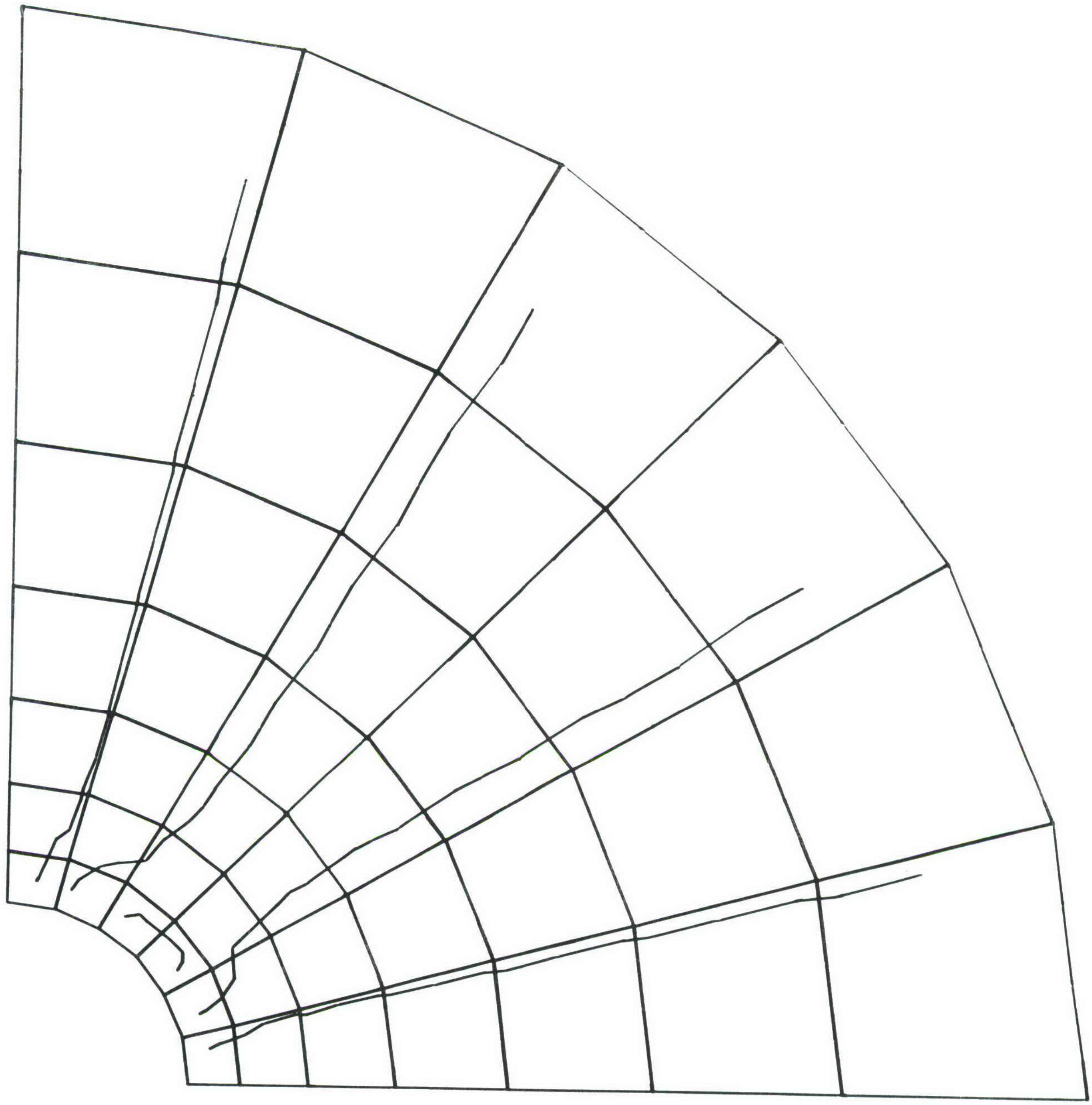


Figure AII-20 Radial-Tangential Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

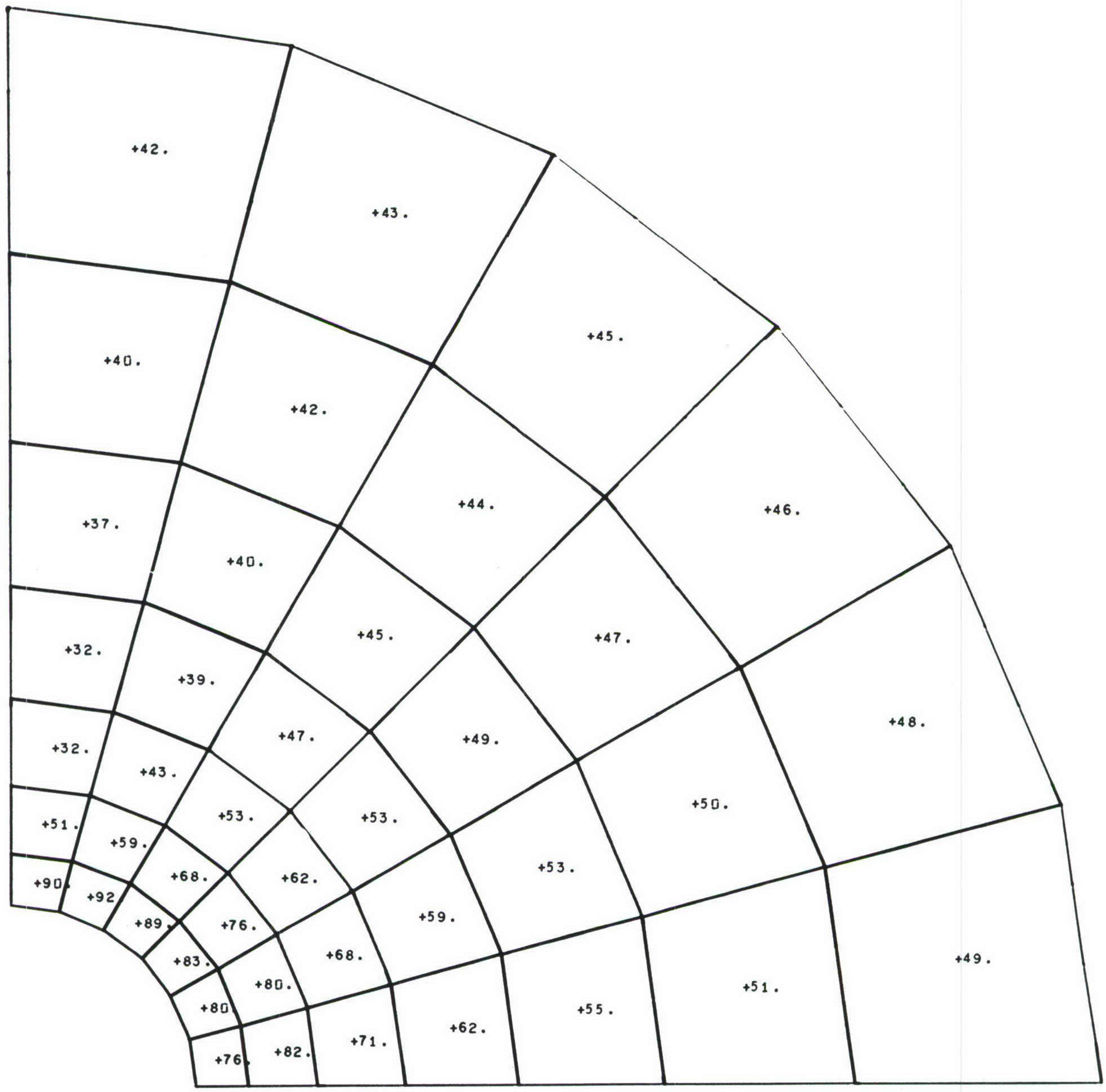


Figure AII-21 First Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

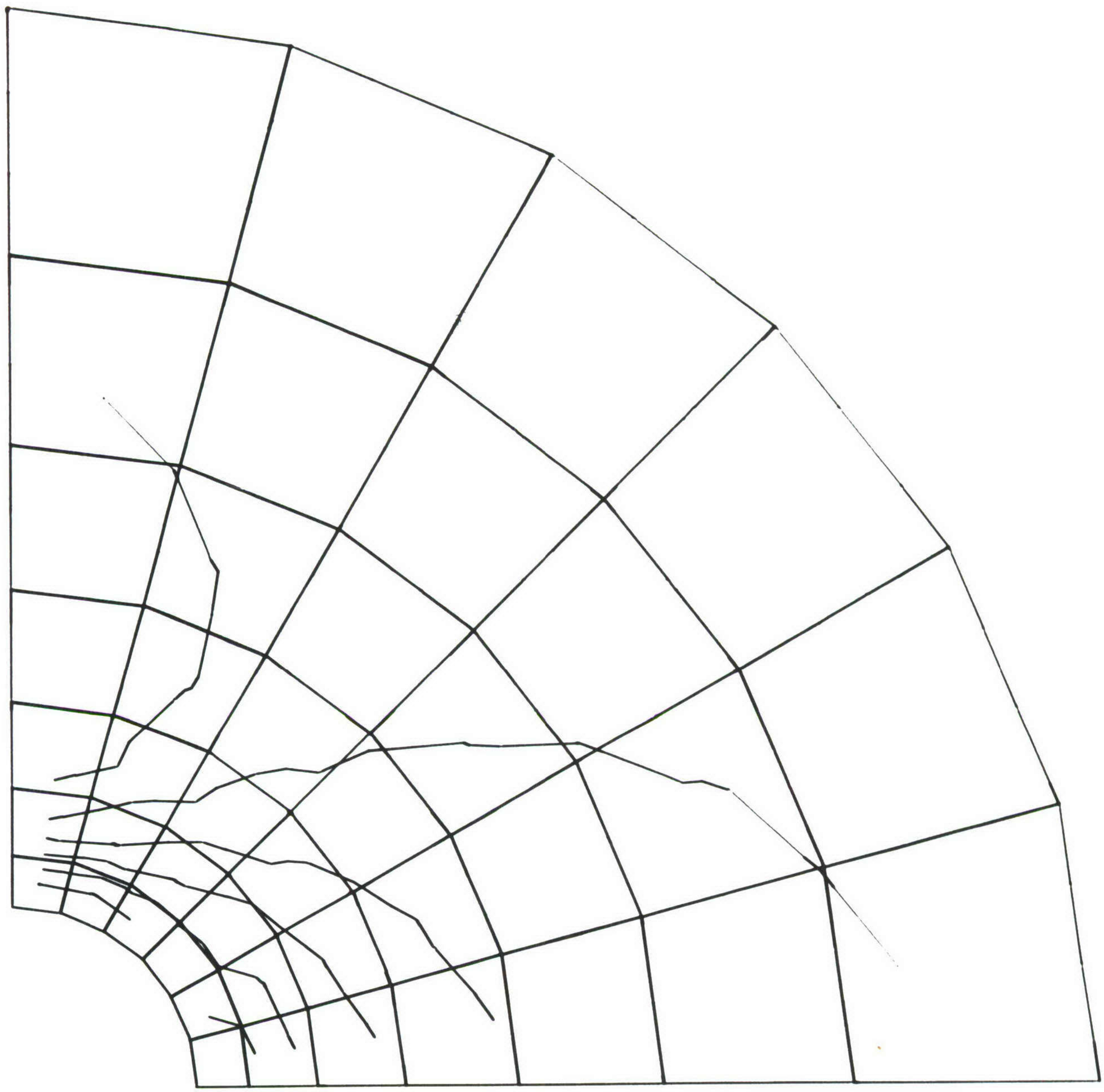


Figure AII-22 First Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

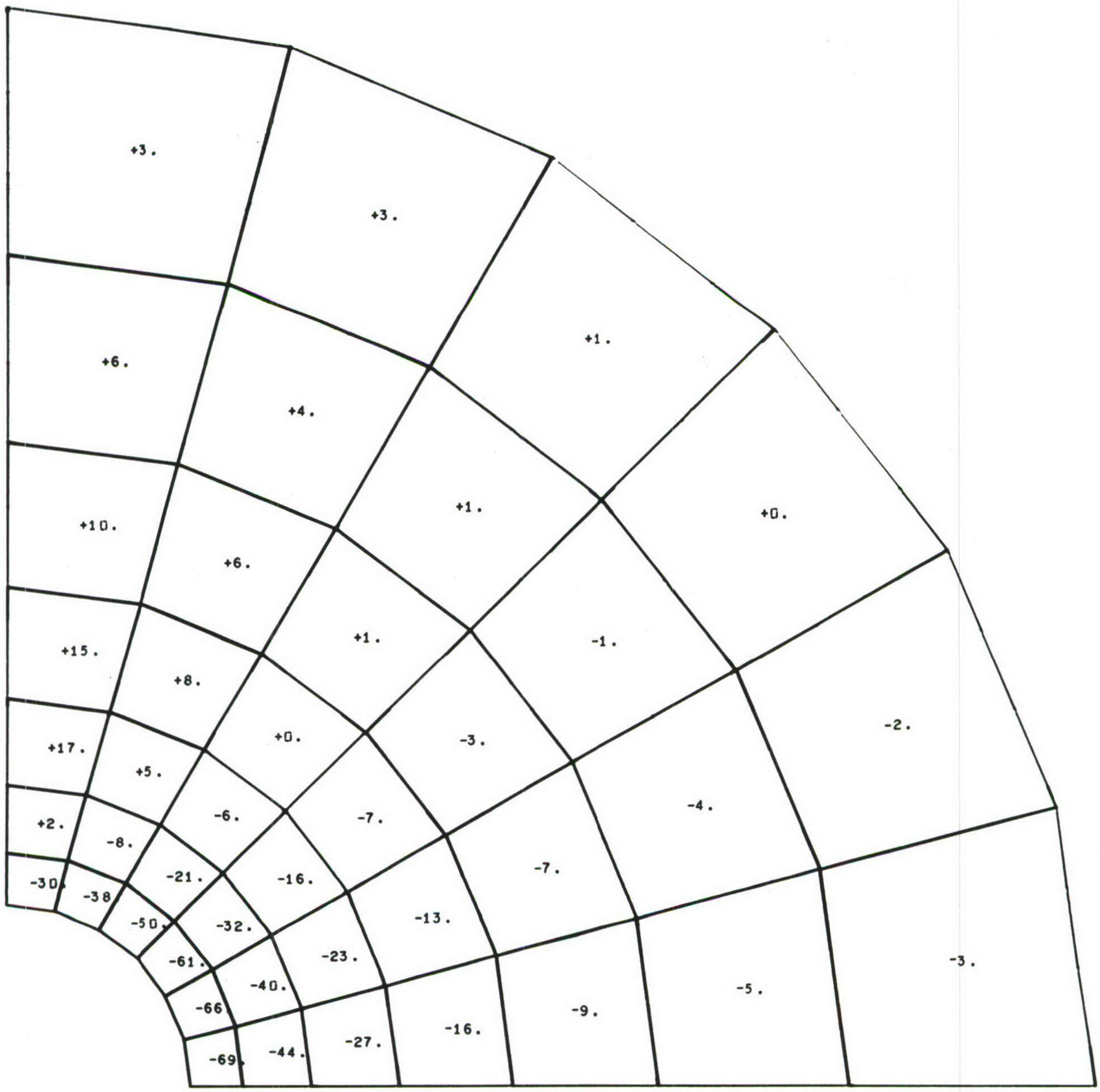


Figure AII-23 Second Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

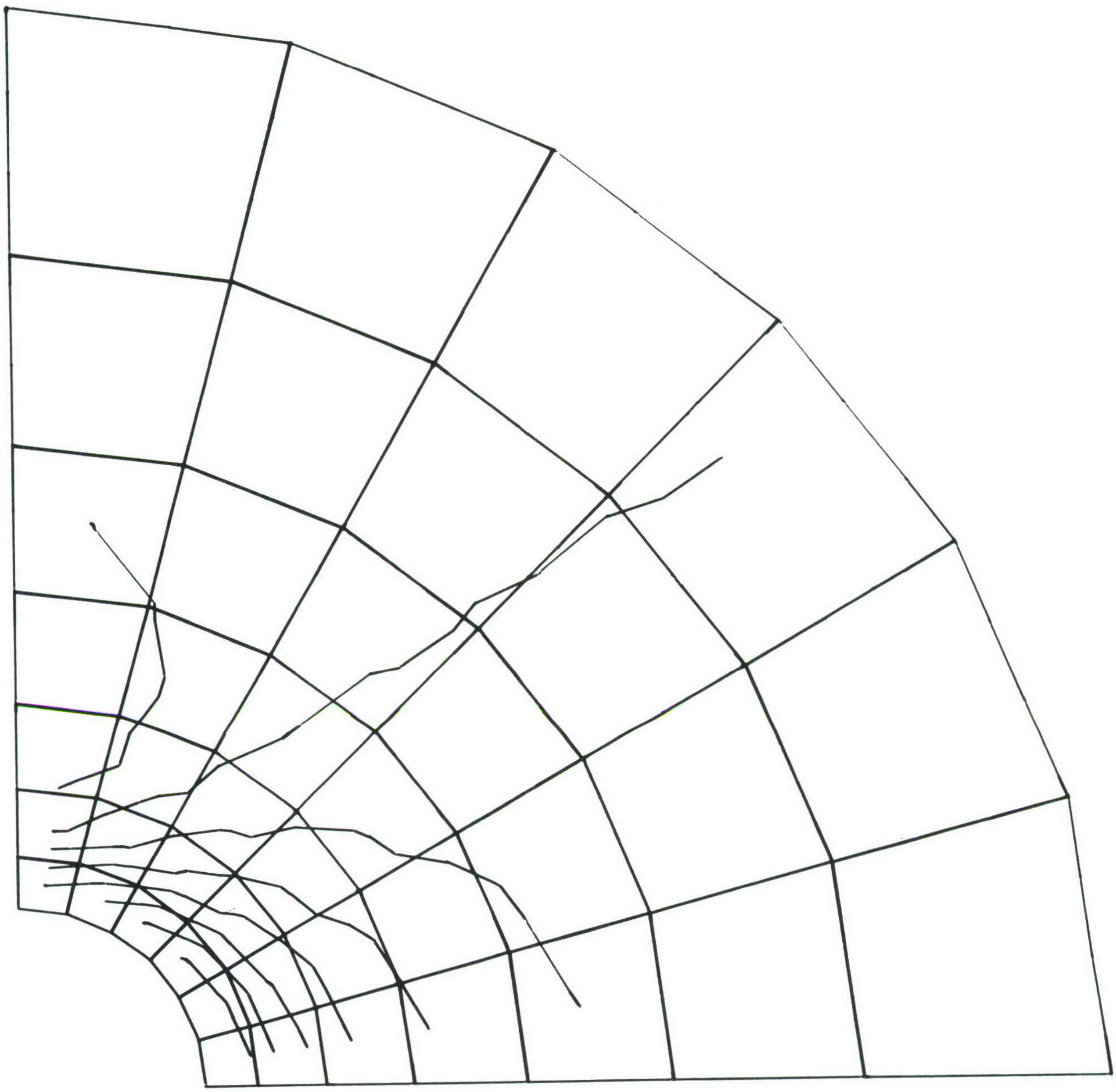


Figure AII-24 Second Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

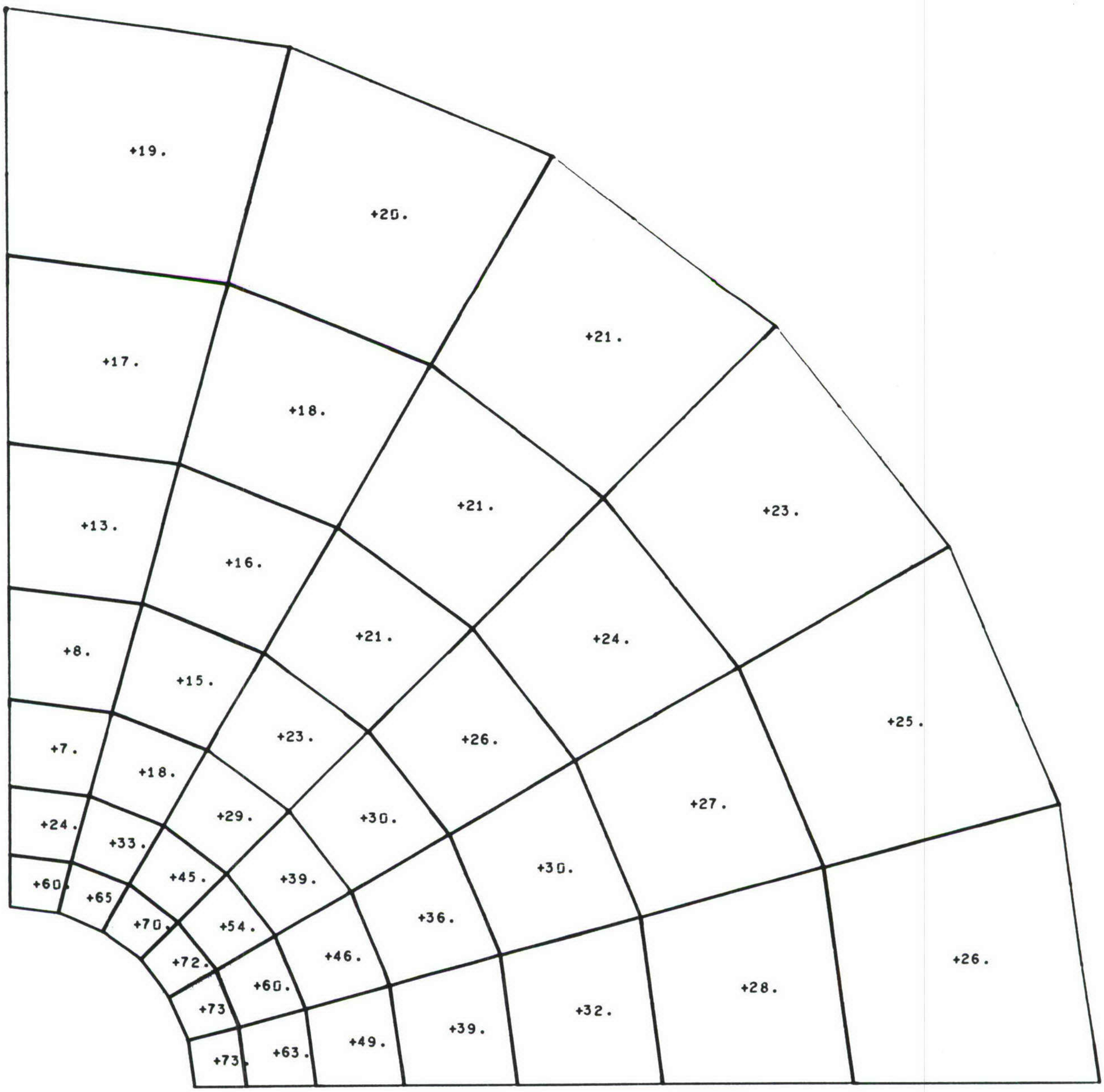


Figure AII-25 Principal Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

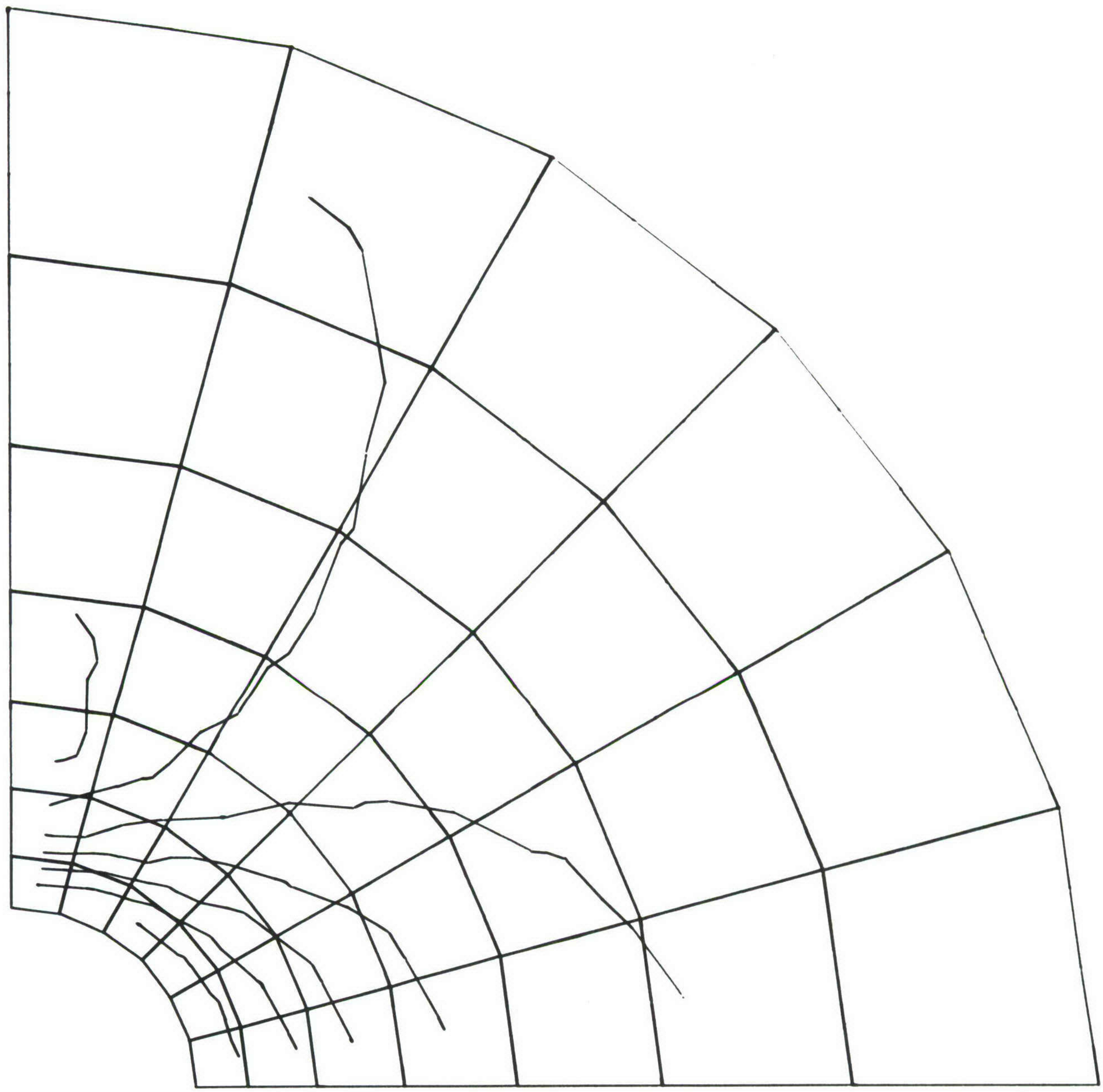


Figure AII-26 Principal Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

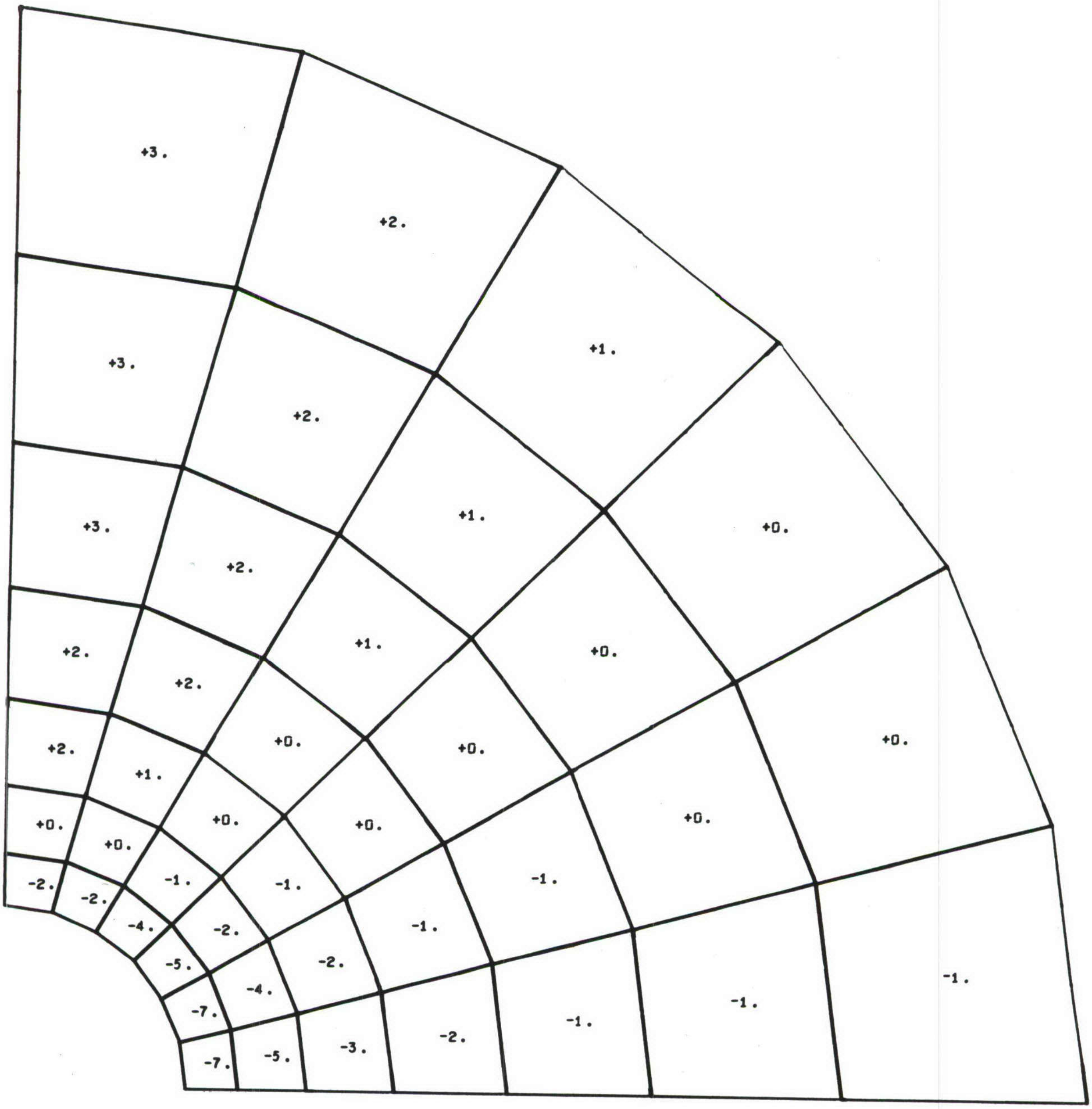


Figure AII-27 Radial Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

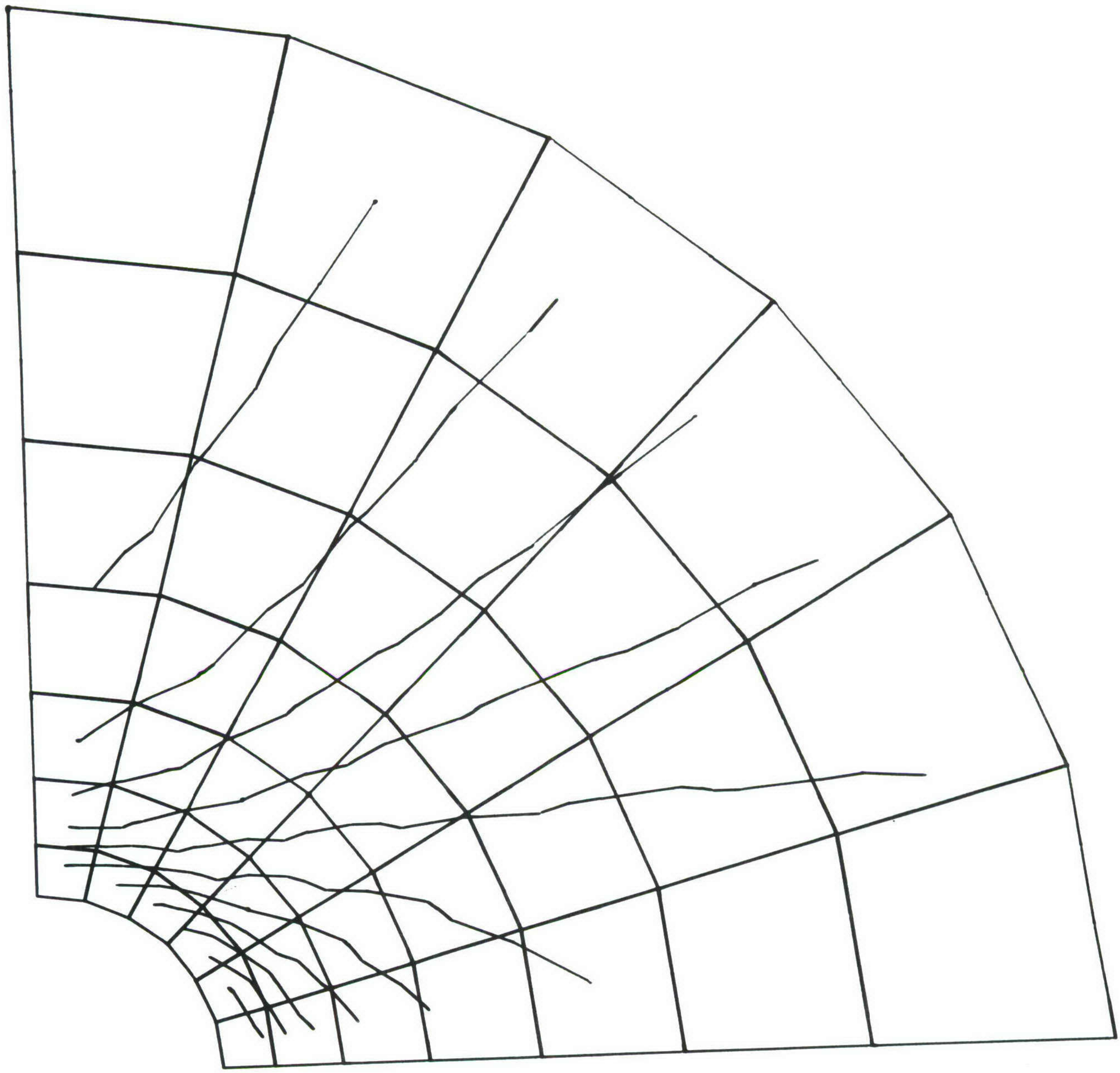


Figure AII-28 Radial Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

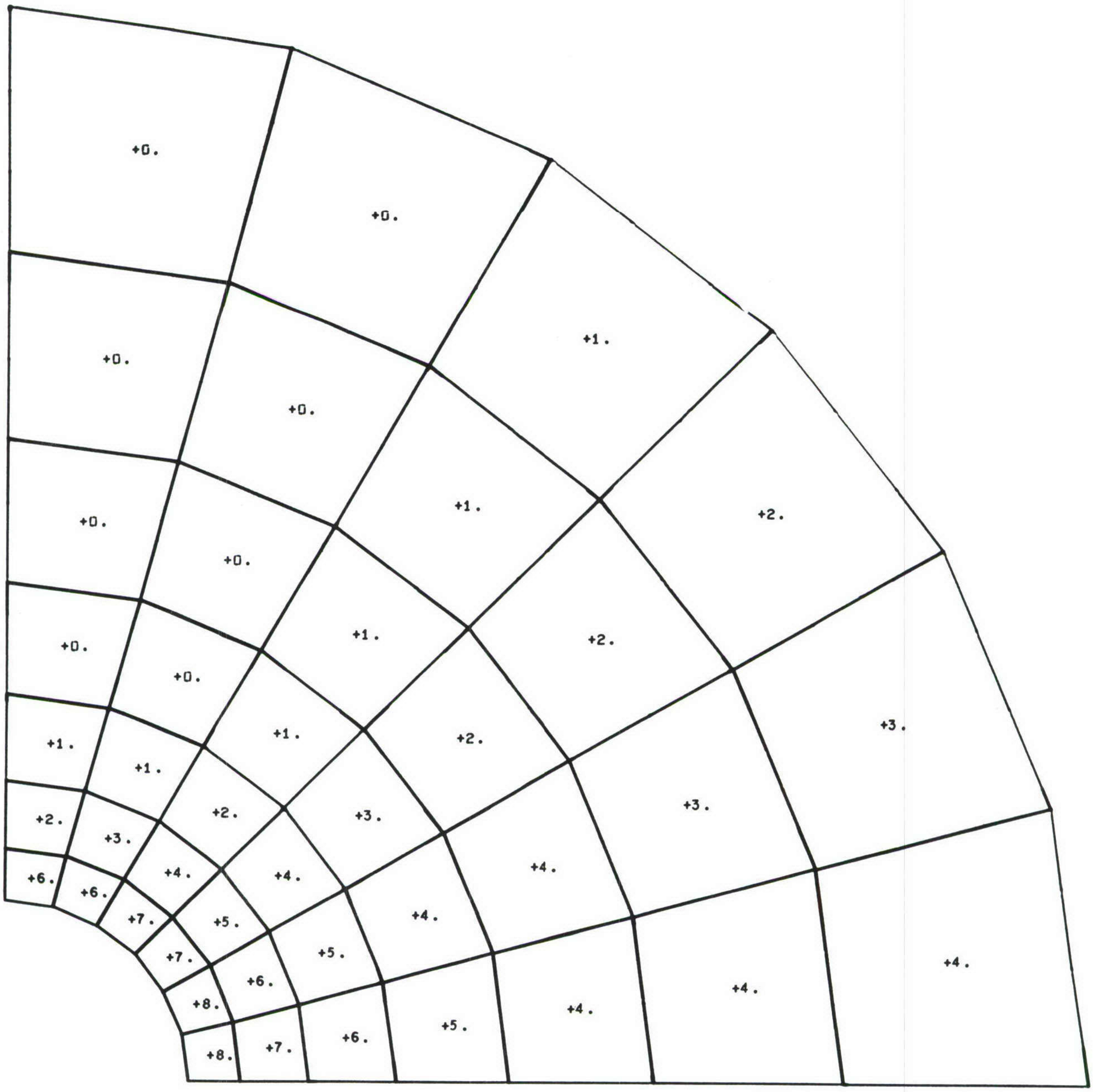


Figure AII-29 Tangential Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

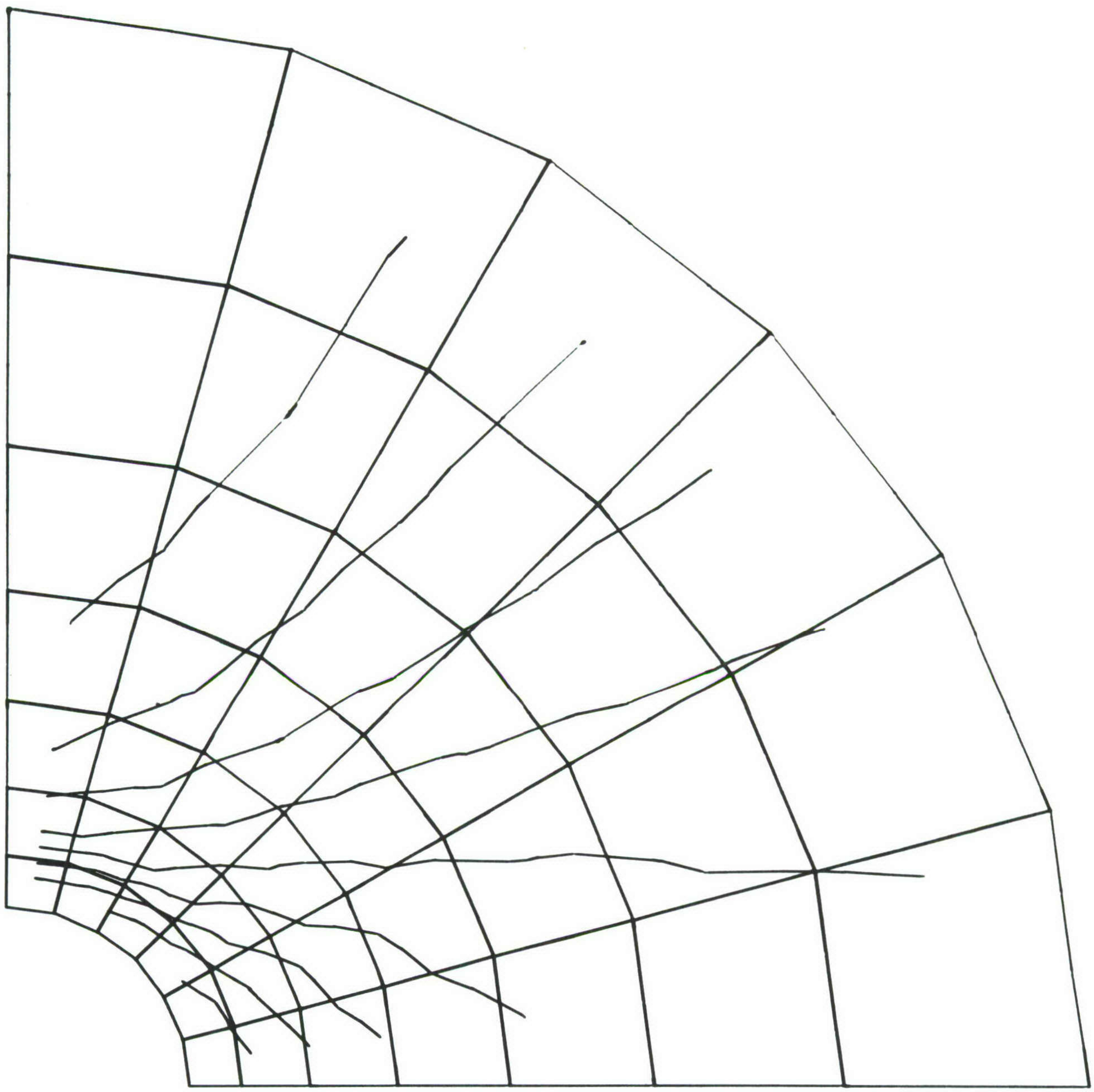


Figure AII-30 Tangential Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

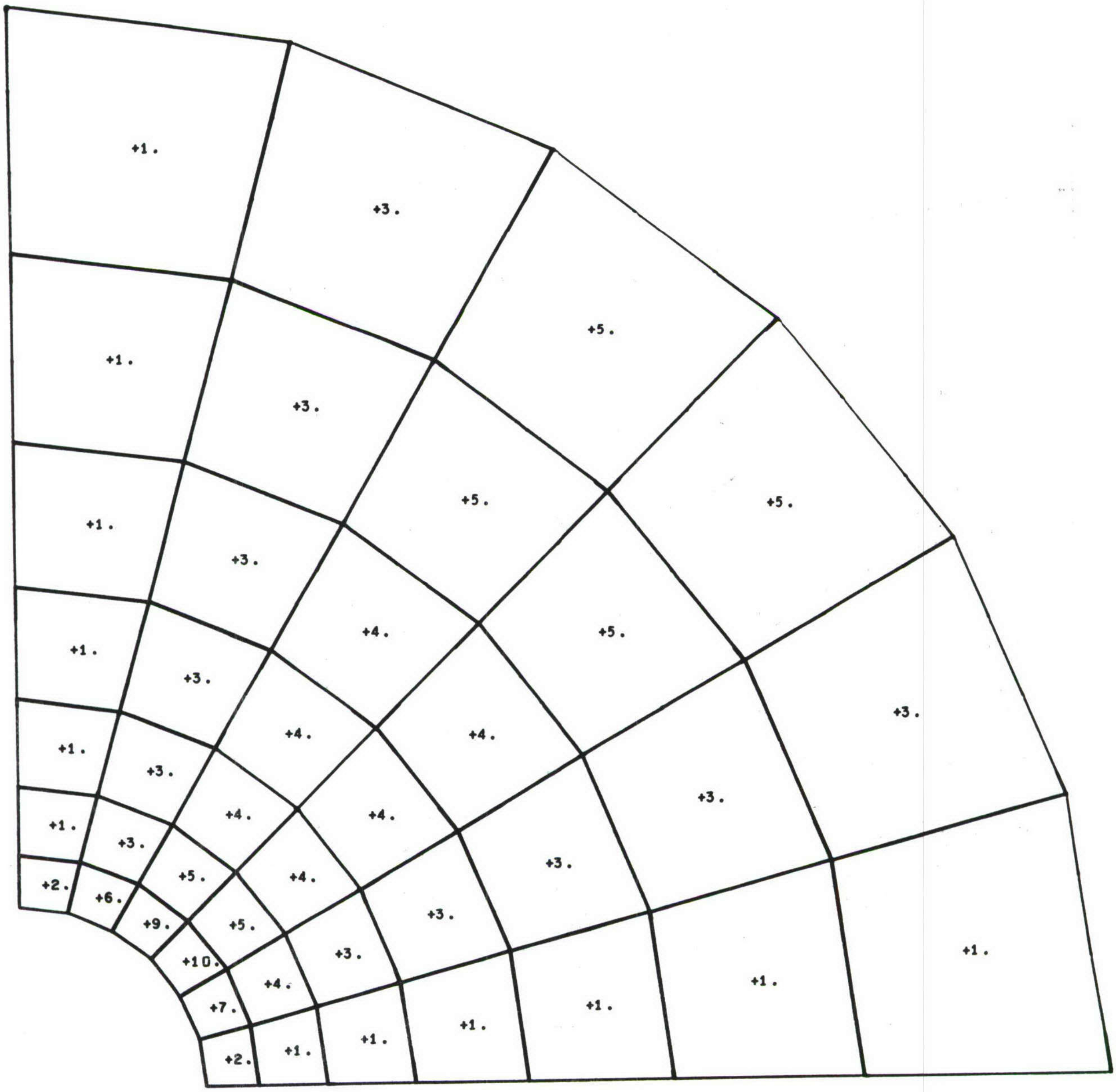


Figure AII-31 Radial-Tangential Shear Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

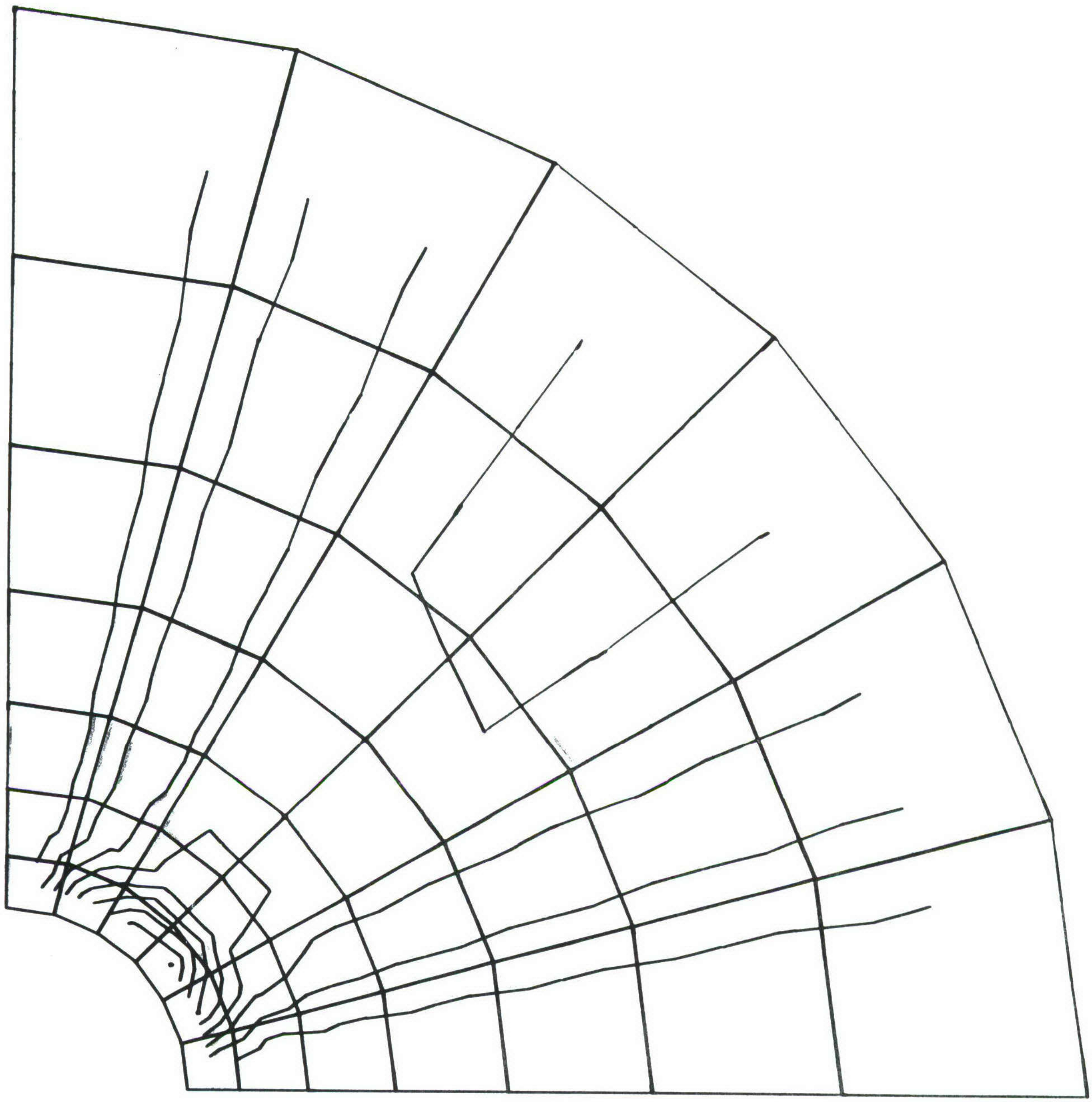


Figure AII-32 Radial-Tangential Shear Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

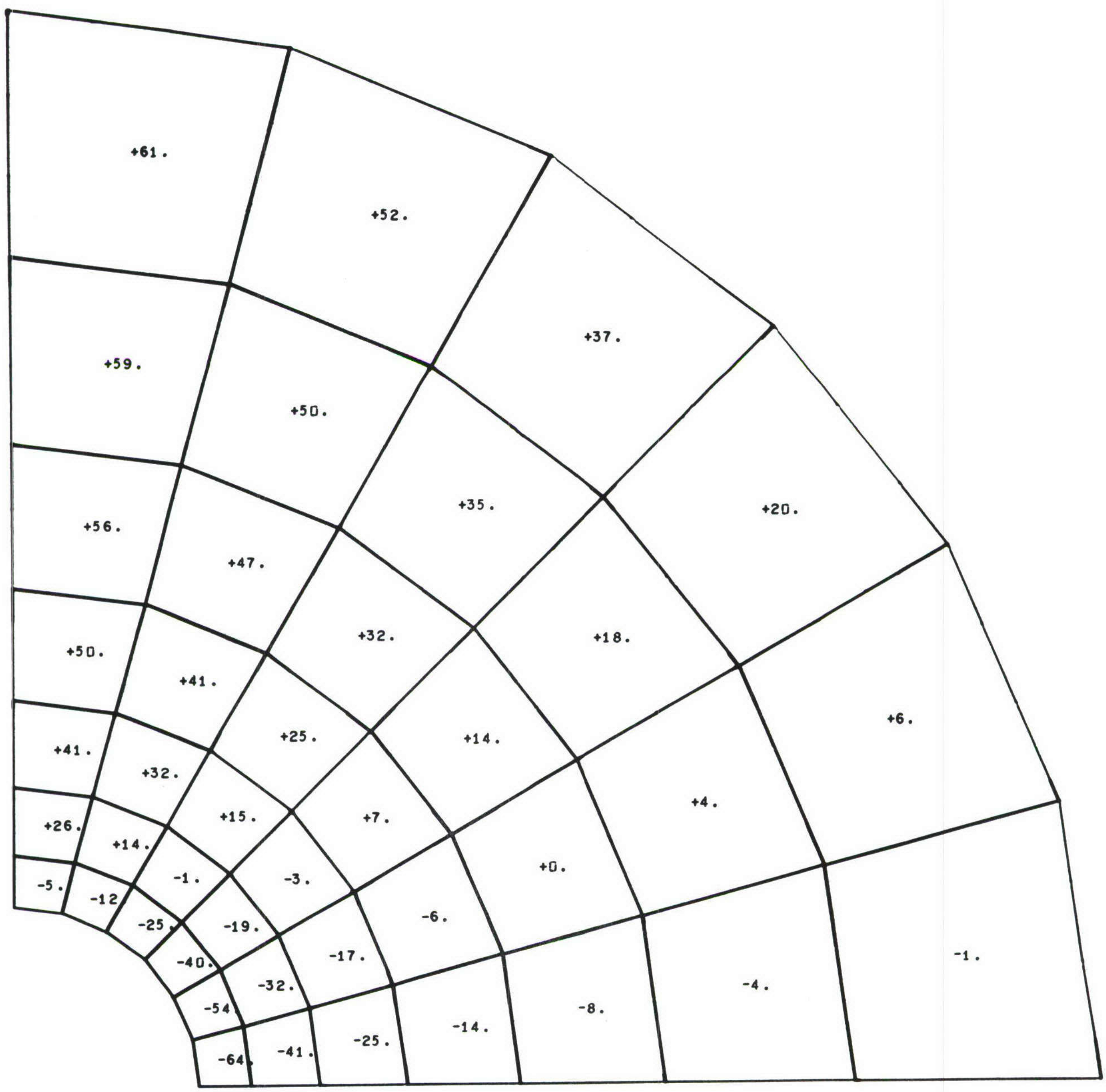


Figure AII-33 Radial Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

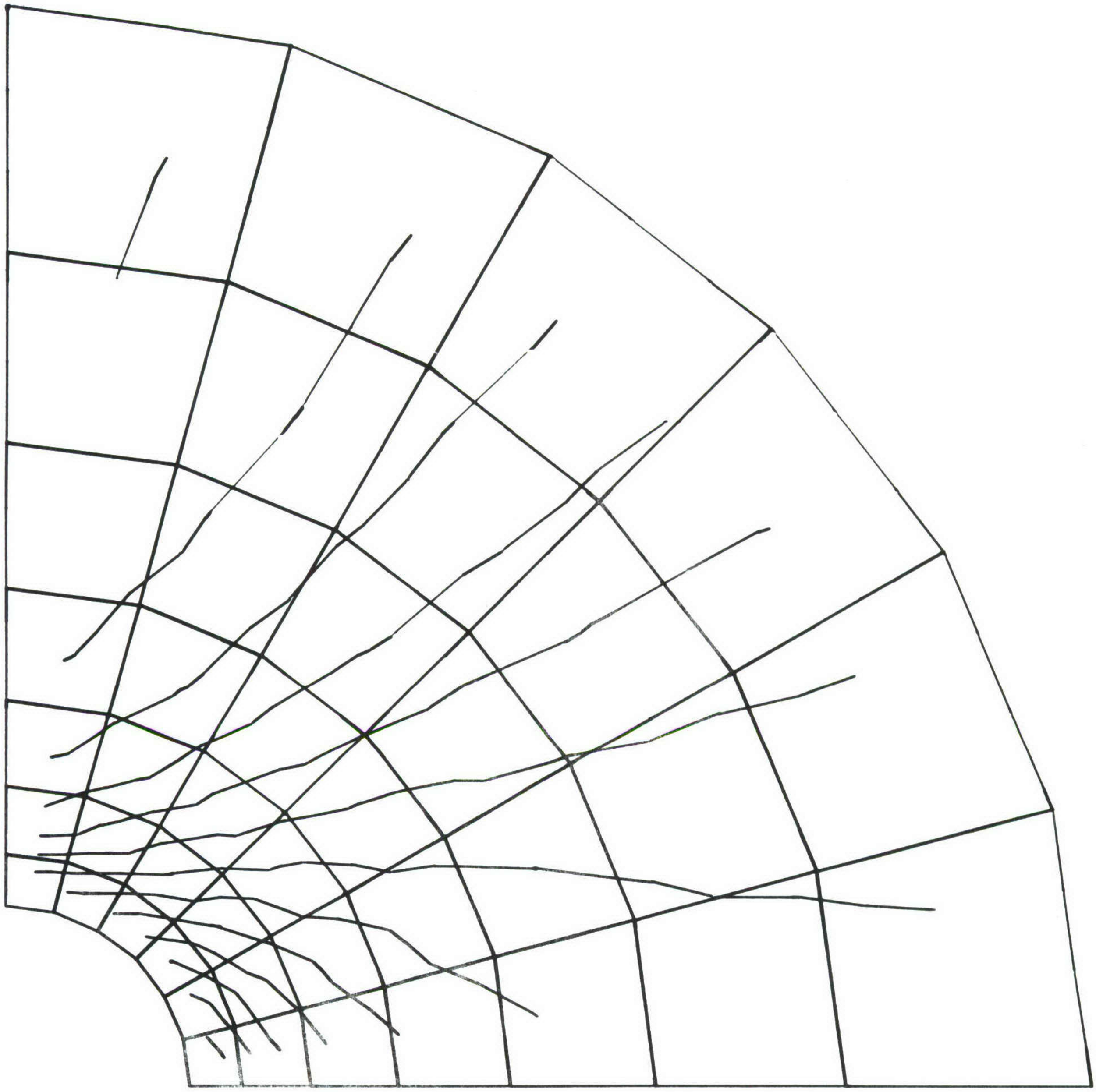


Figure AII-34 Radial Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

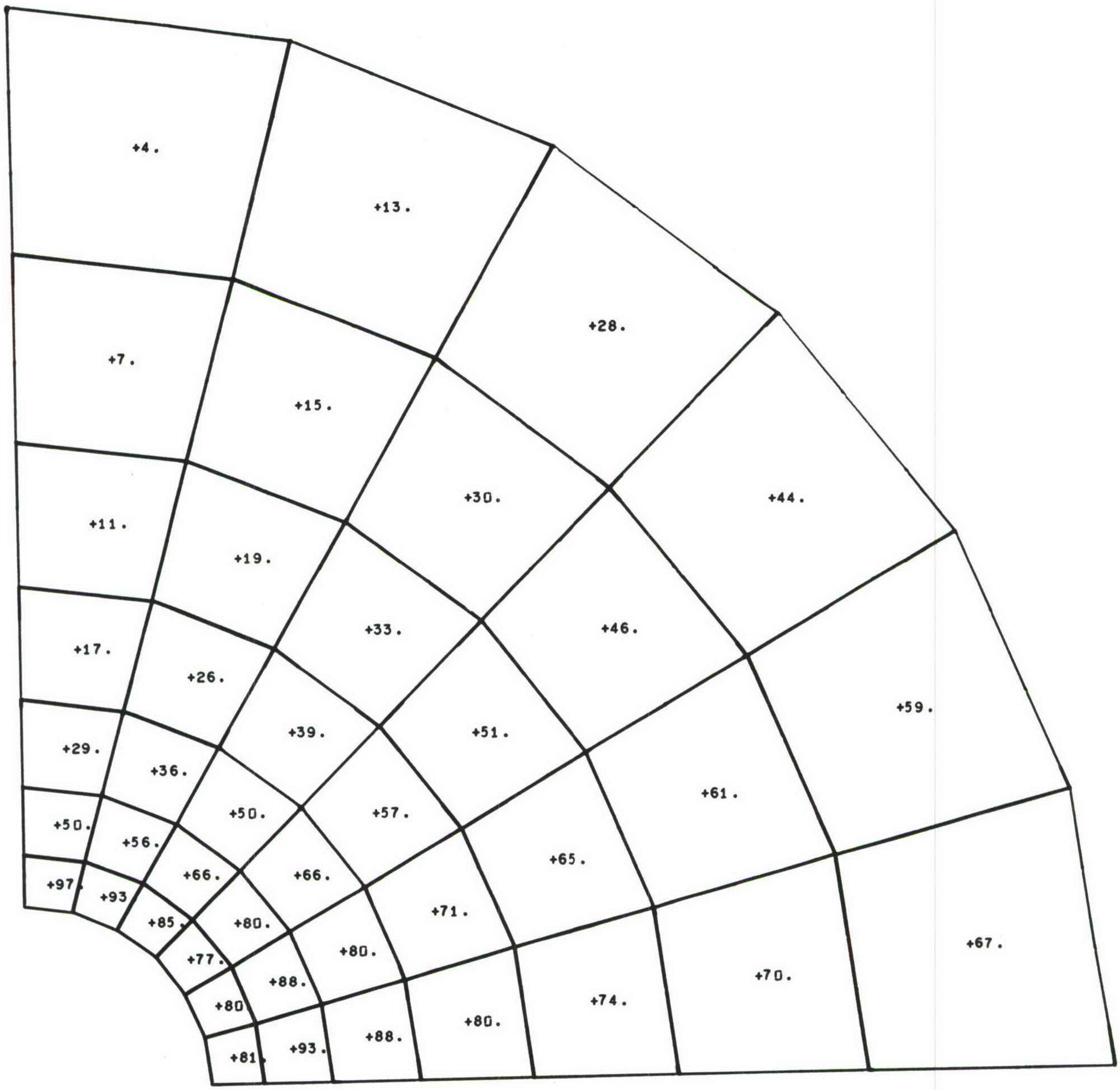


Figure AII-35 Tangential Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

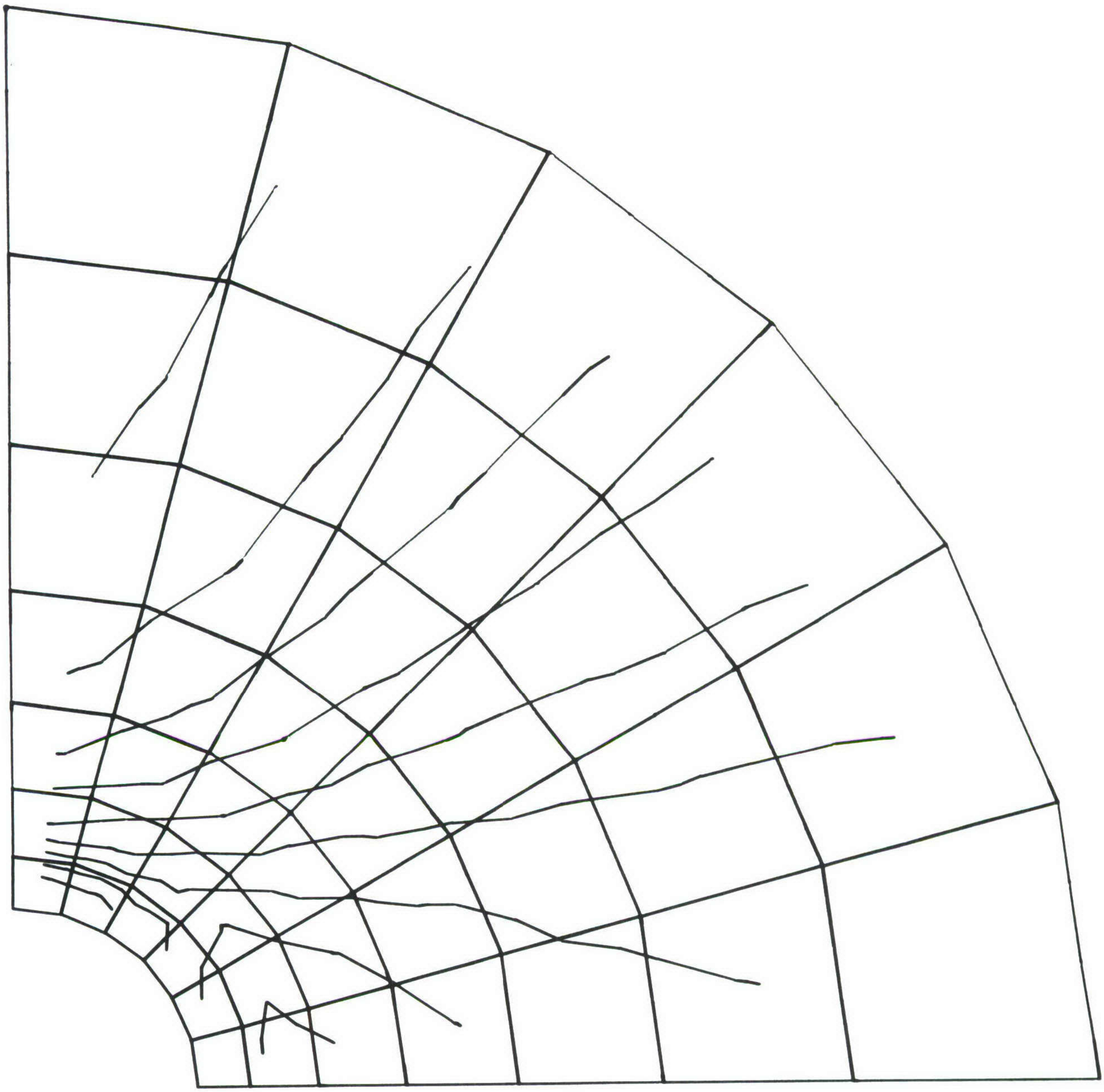


Figure AII-36 Tangential Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

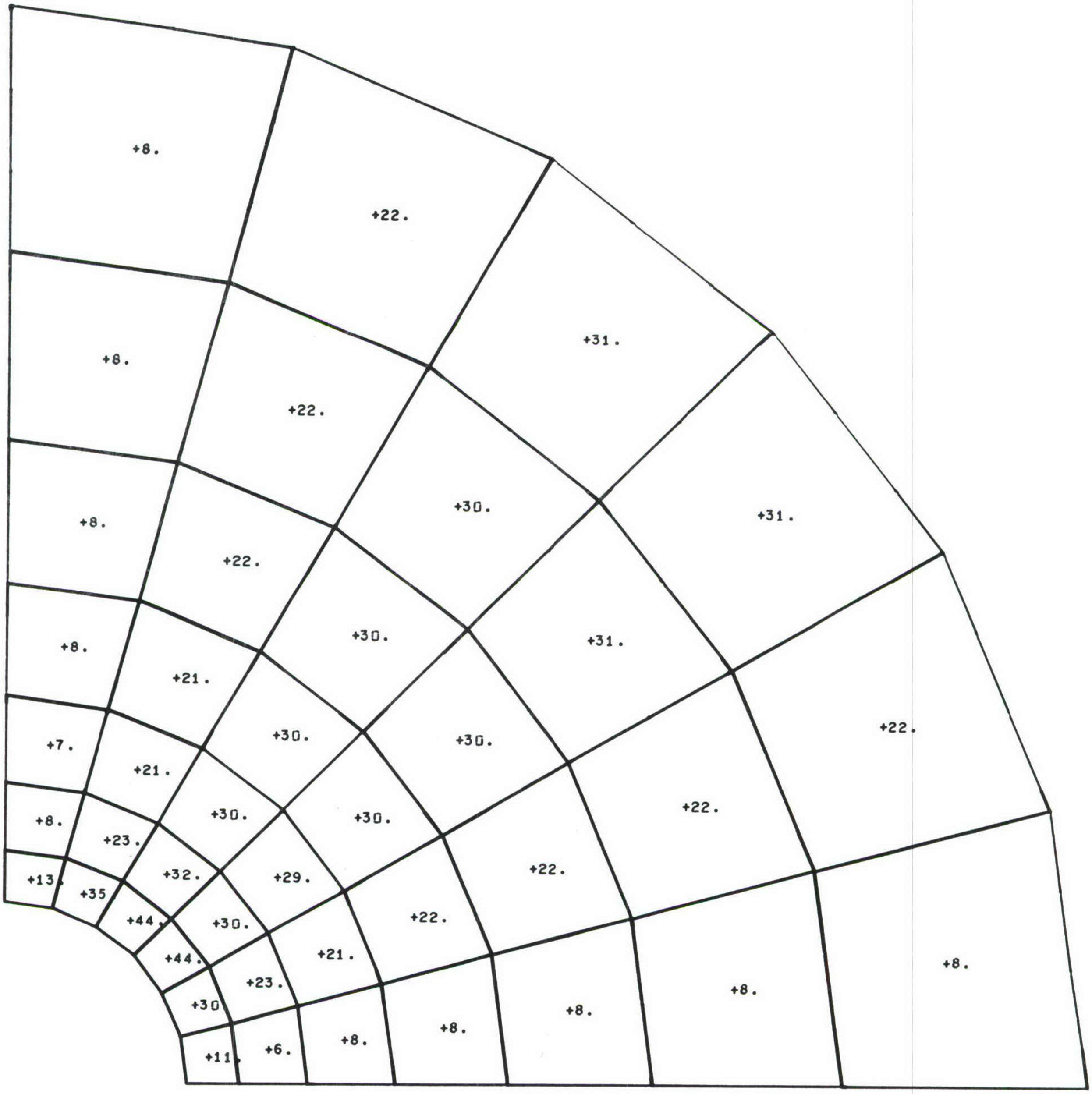


Figure AII-37 Radial-Tangential Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

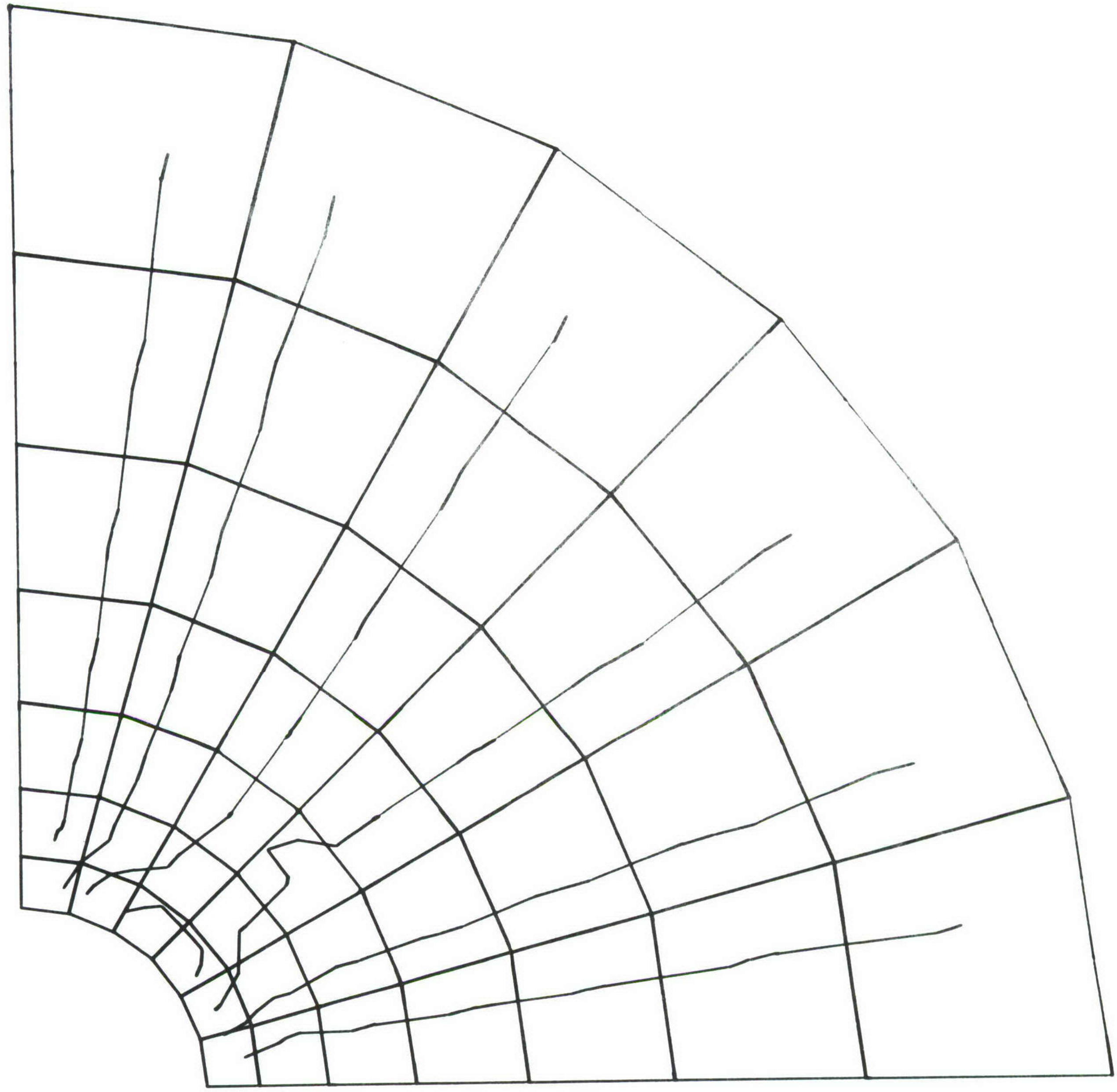


Figure AII-38 Radial-Tangential Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

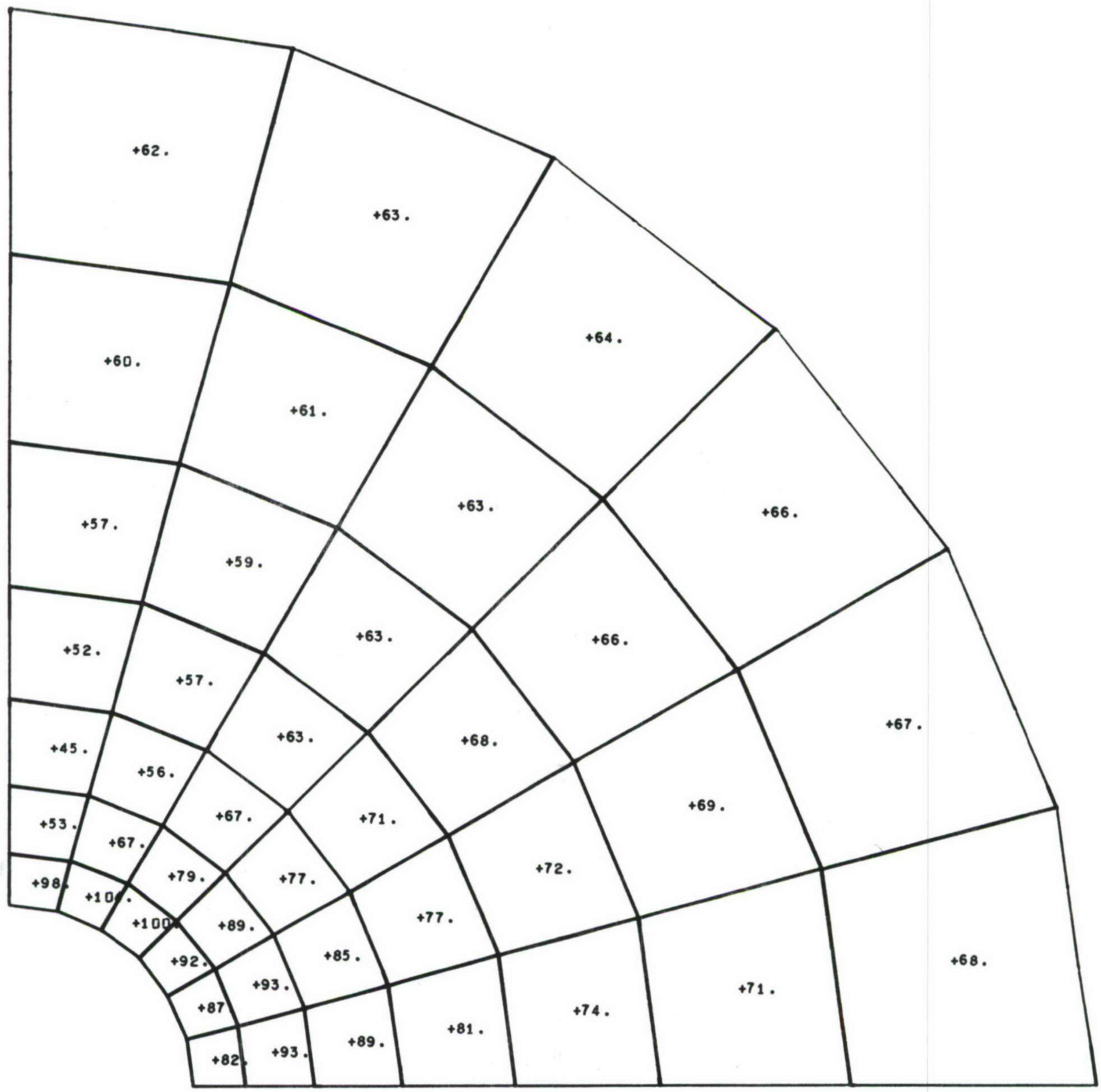


Figure AII-39 First Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

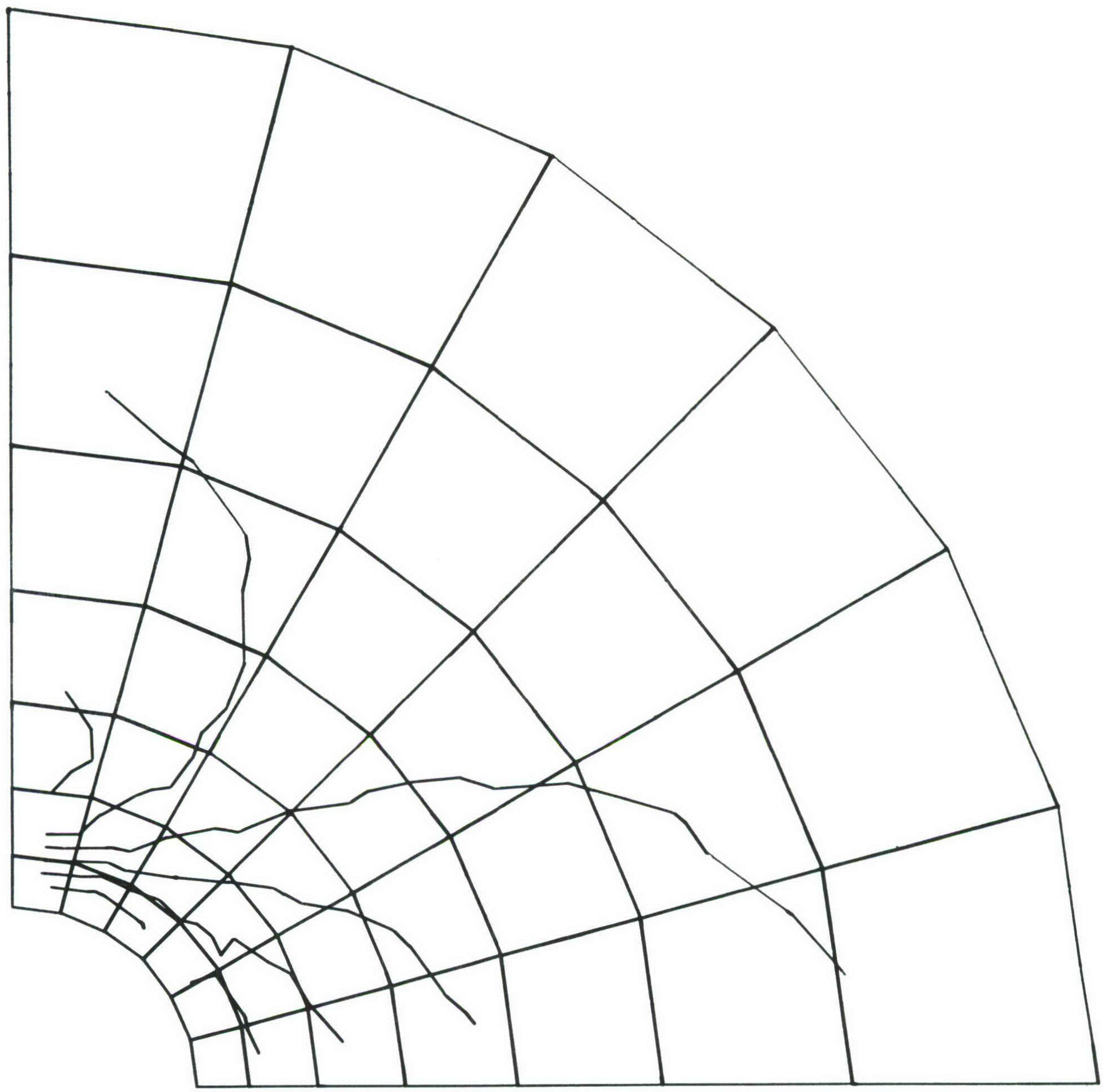


Figure AII-40 First Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

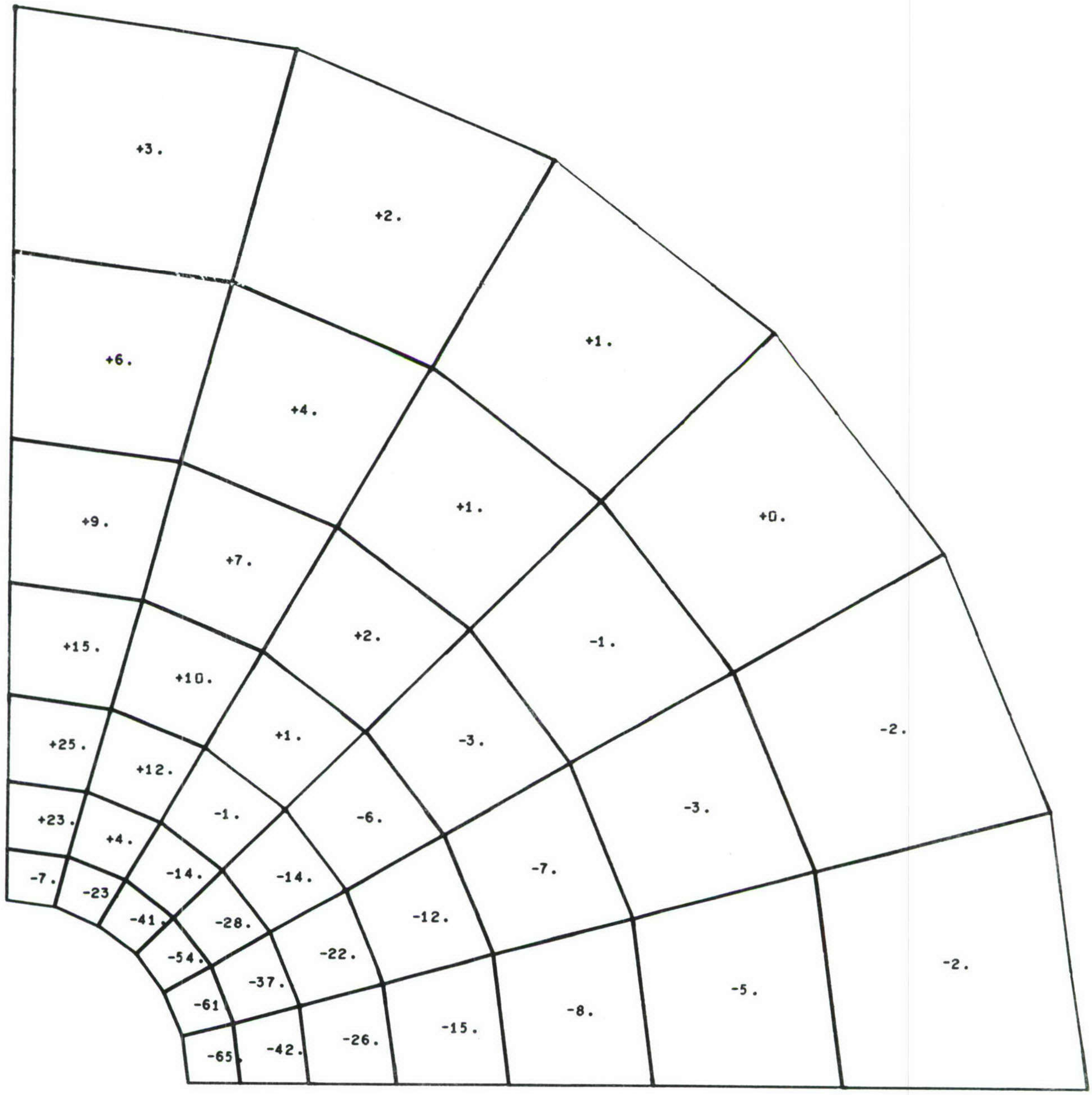


Figure AII-41 Second Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

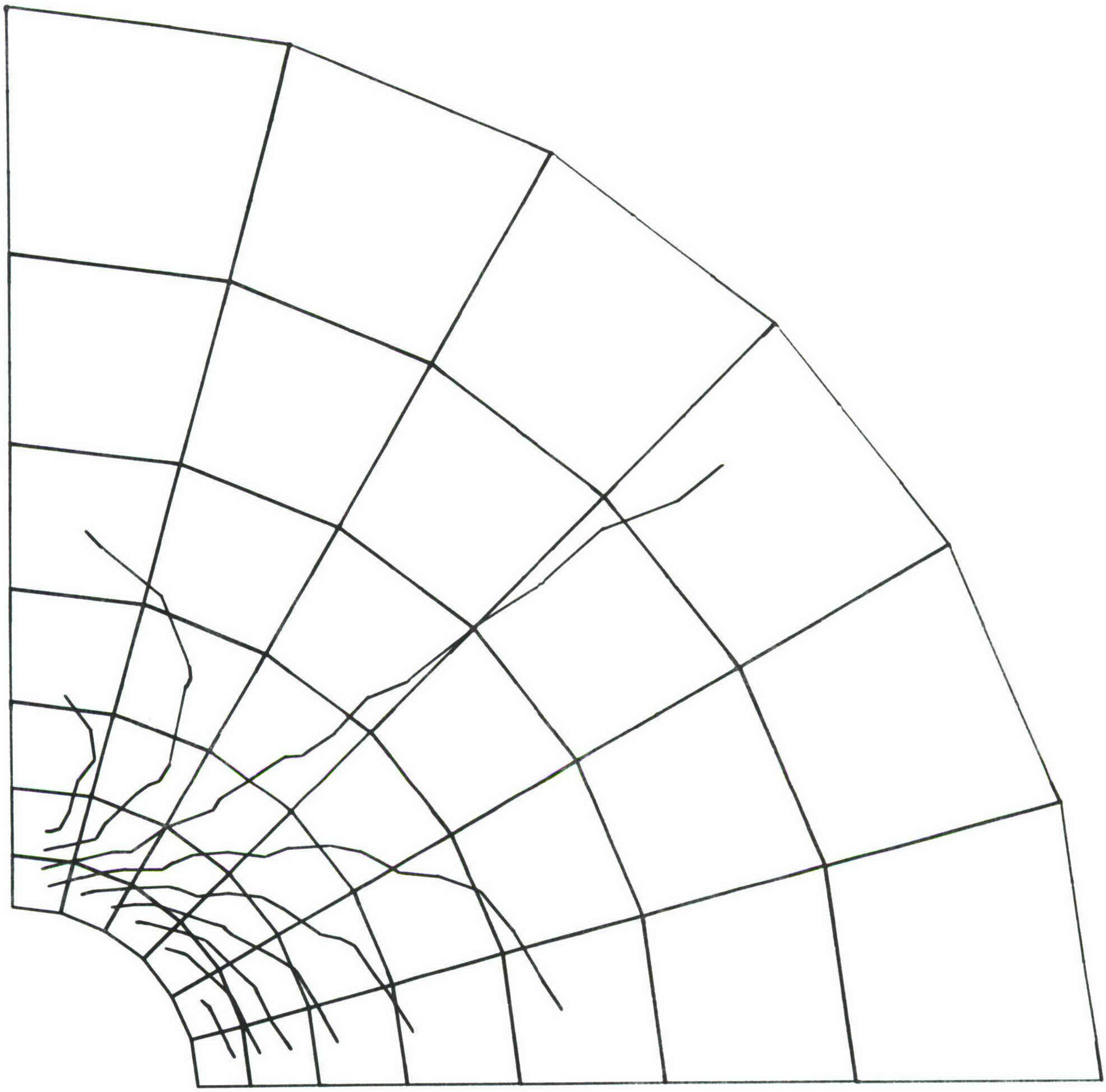


Figure AII-42 Second Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

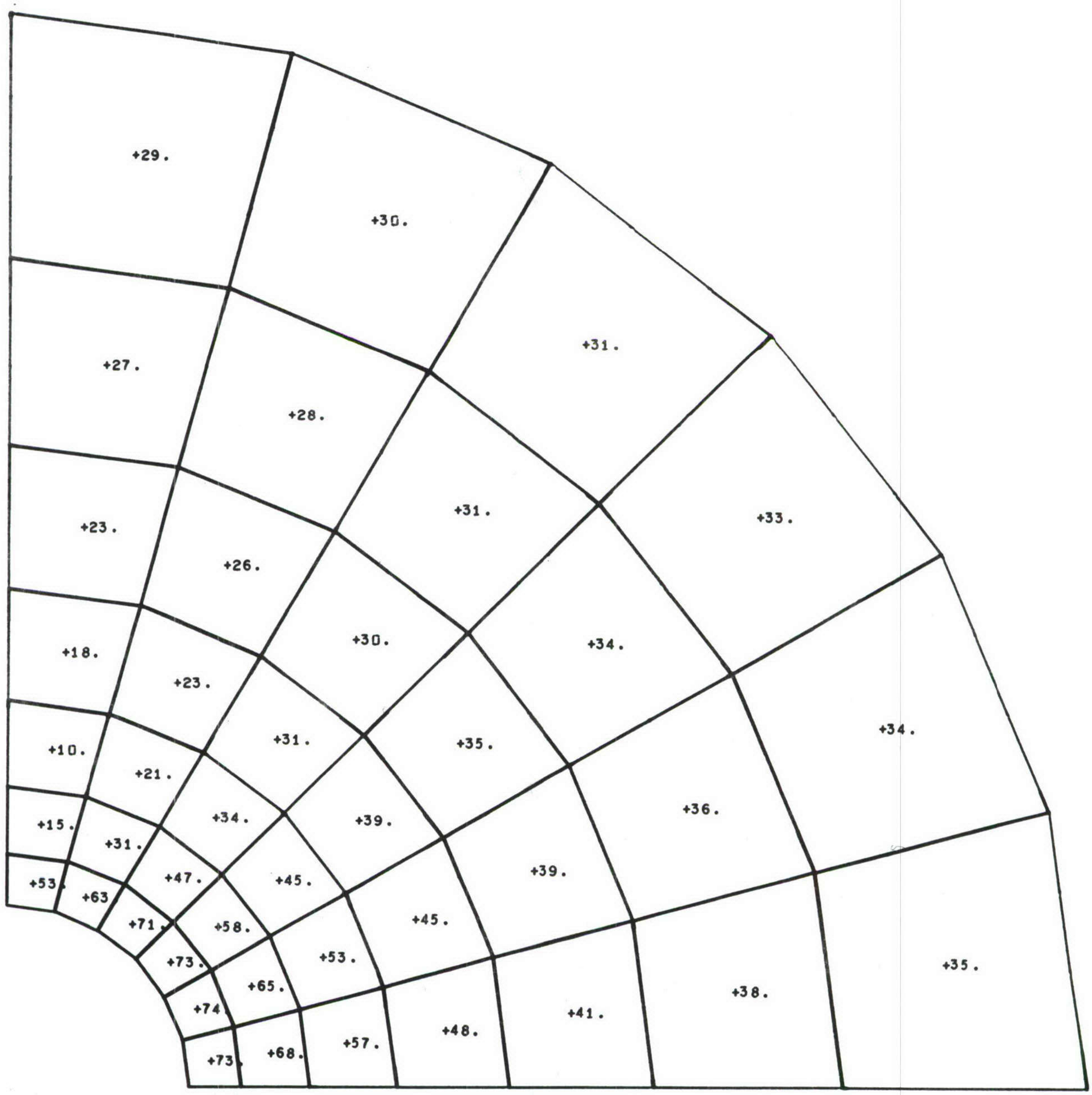


Figure AII-43 Principal Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

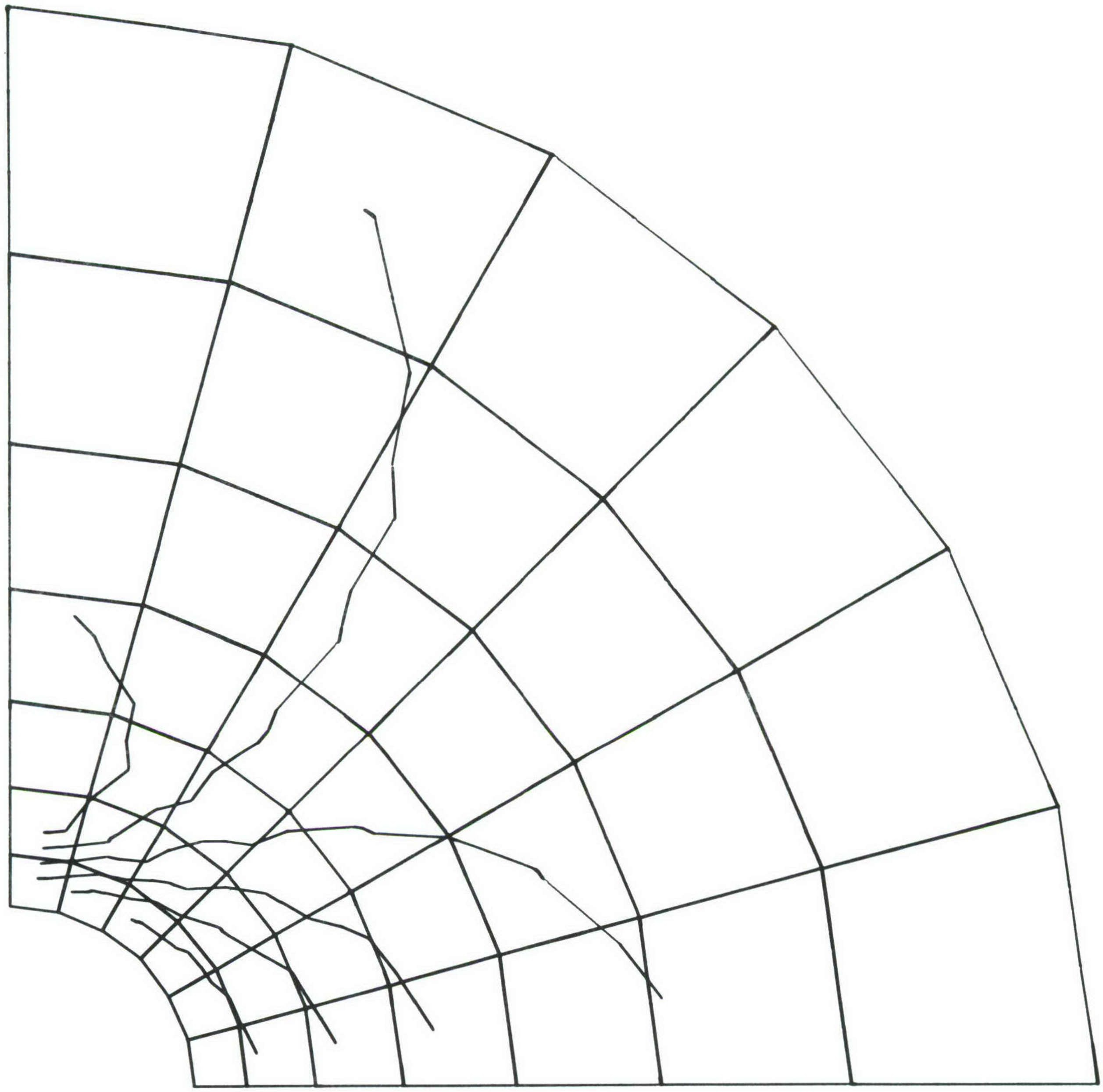


Figure AII-44 Principal Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 50% Uniaxial Load

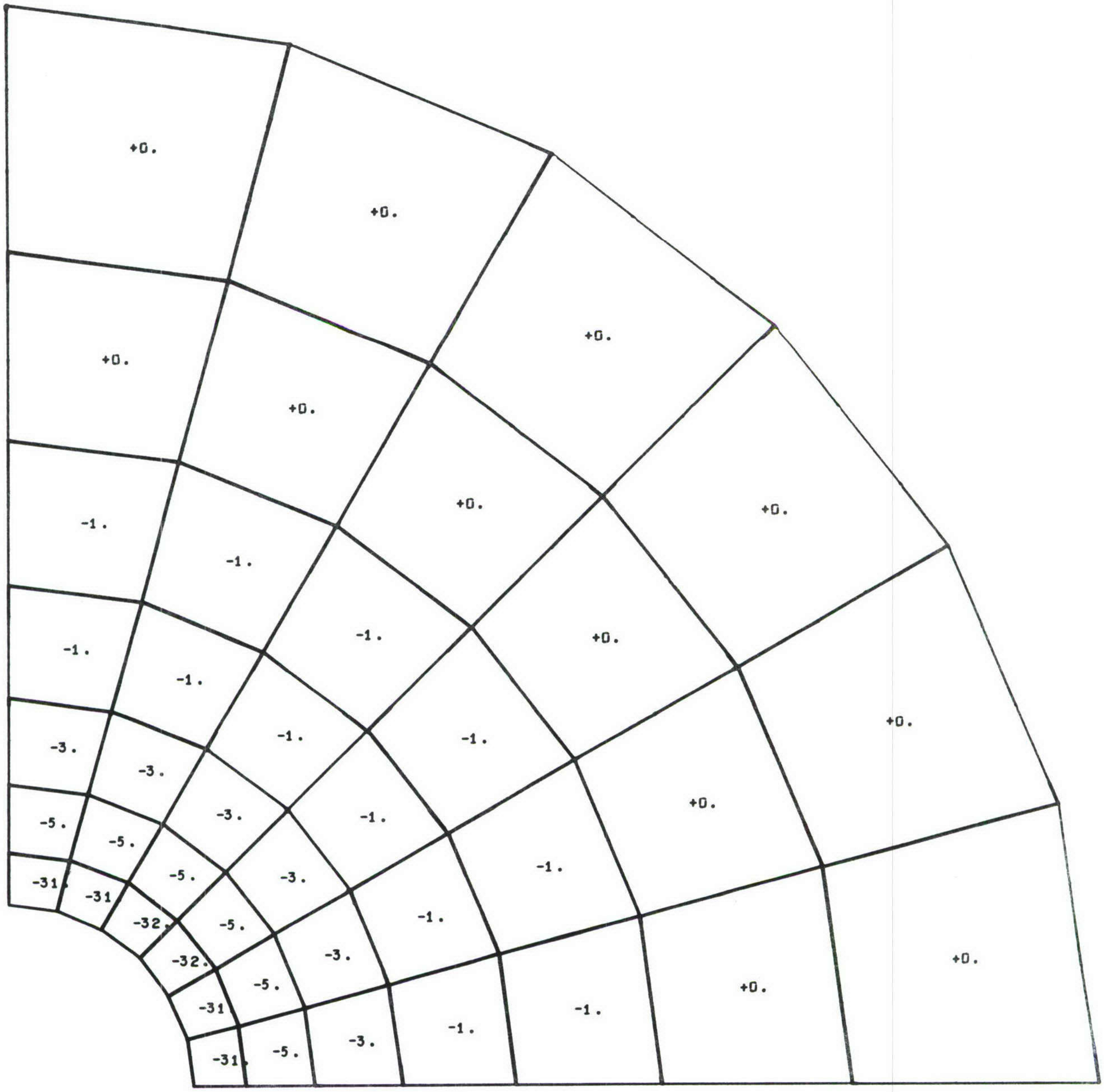


Figure AII-45 Radial Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

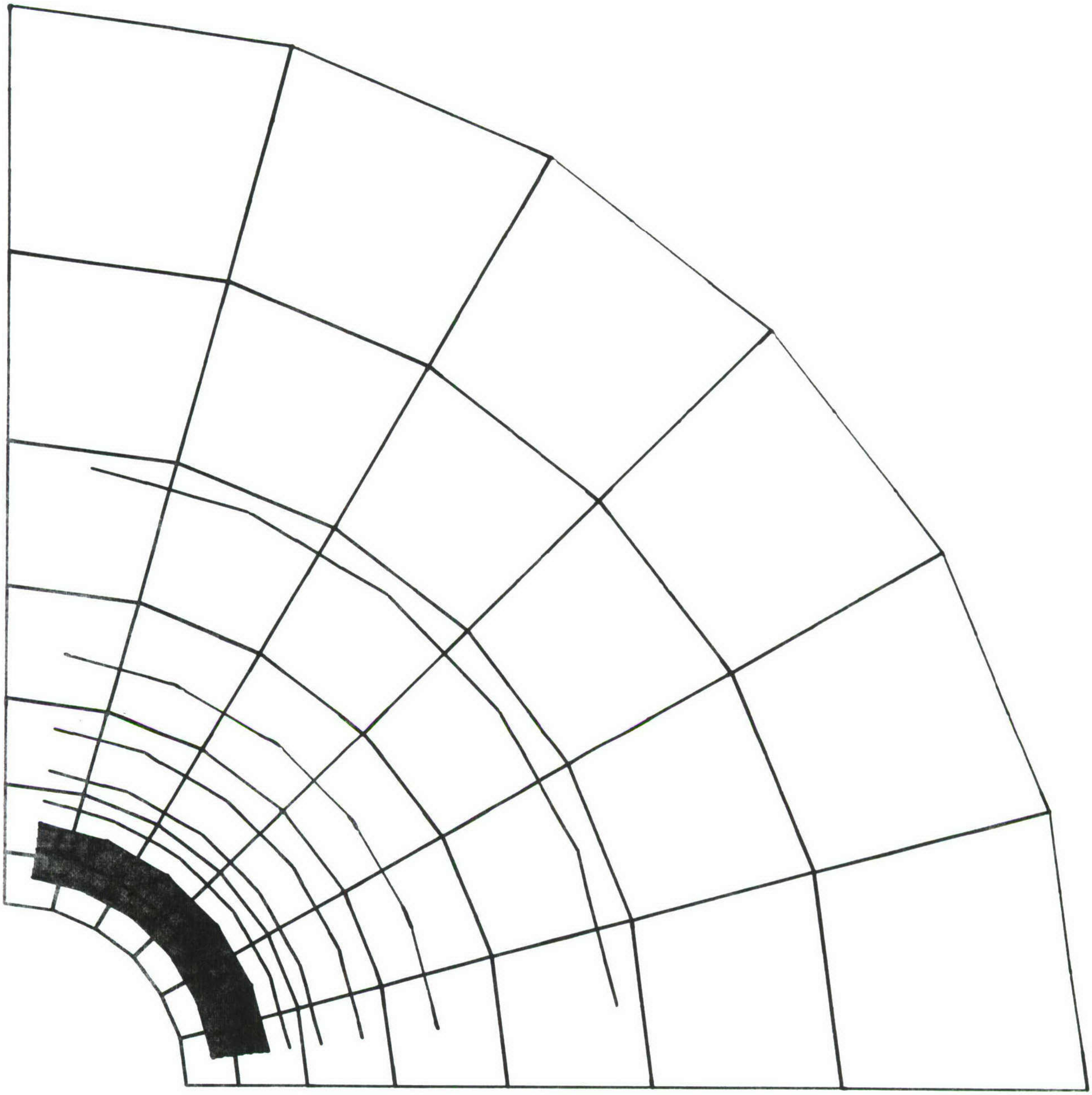


Figure AII-46 Radial Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

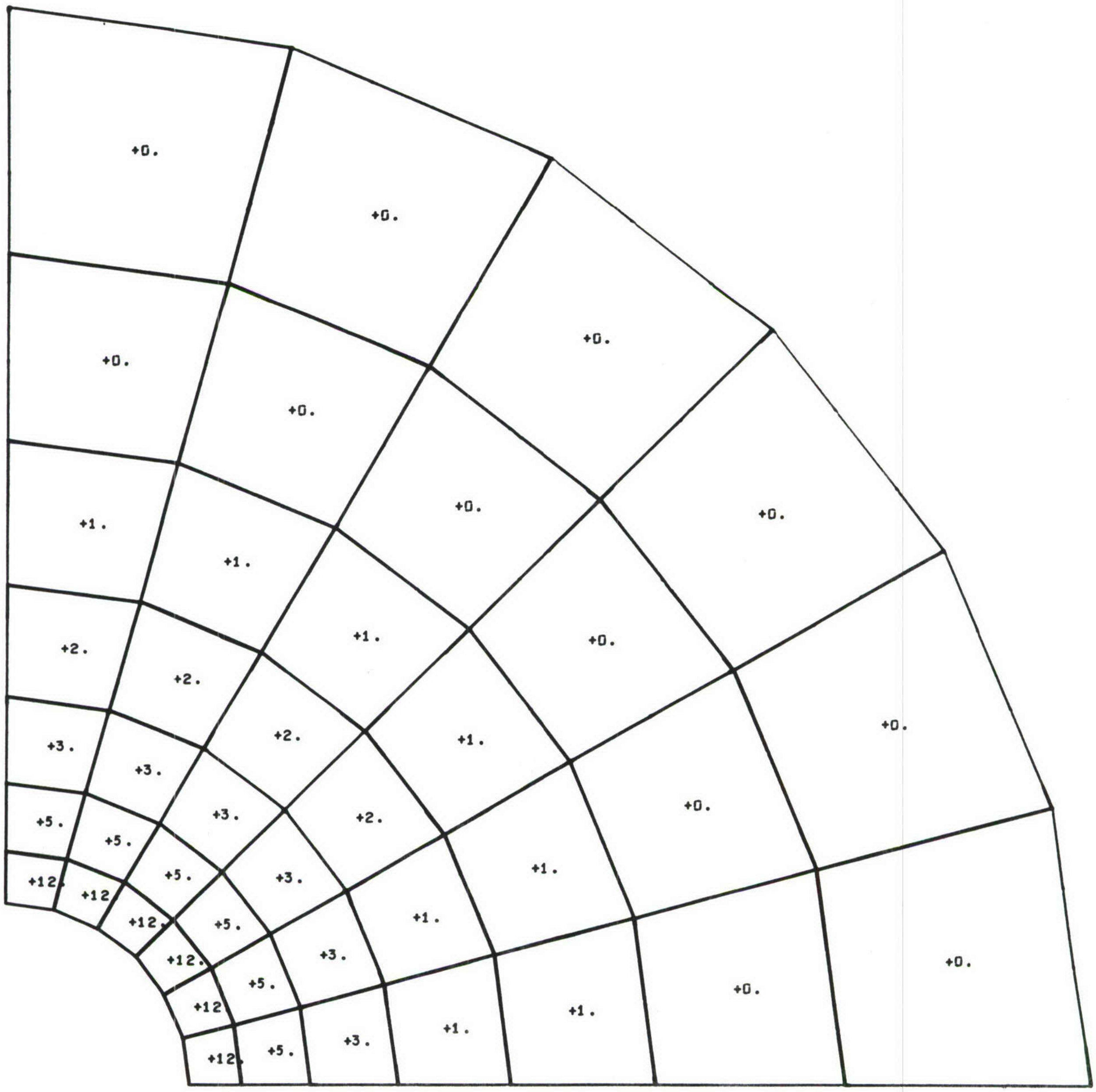


Figure AII-47 Tangential Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

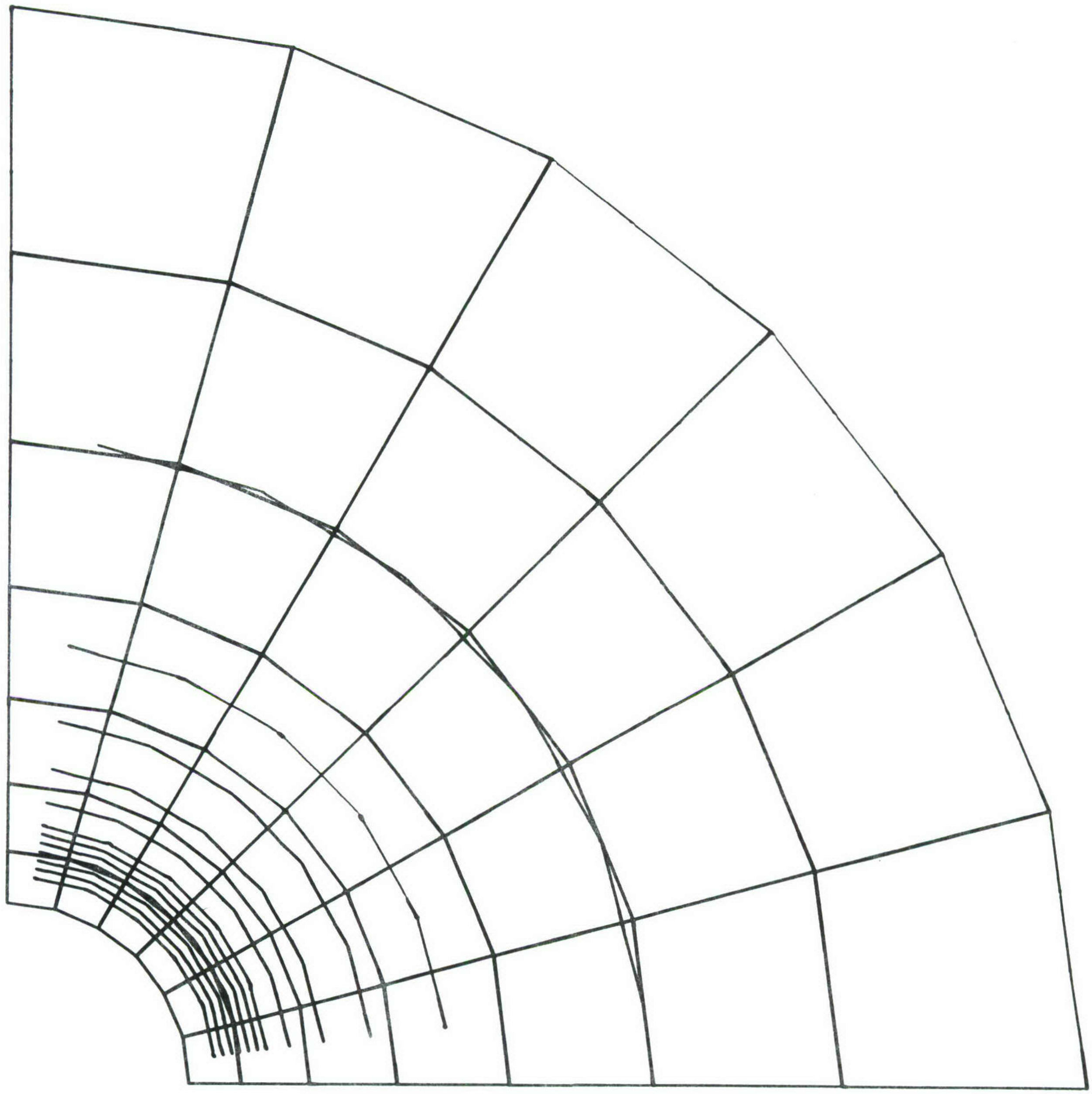


Figure AII-48 Tangential Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

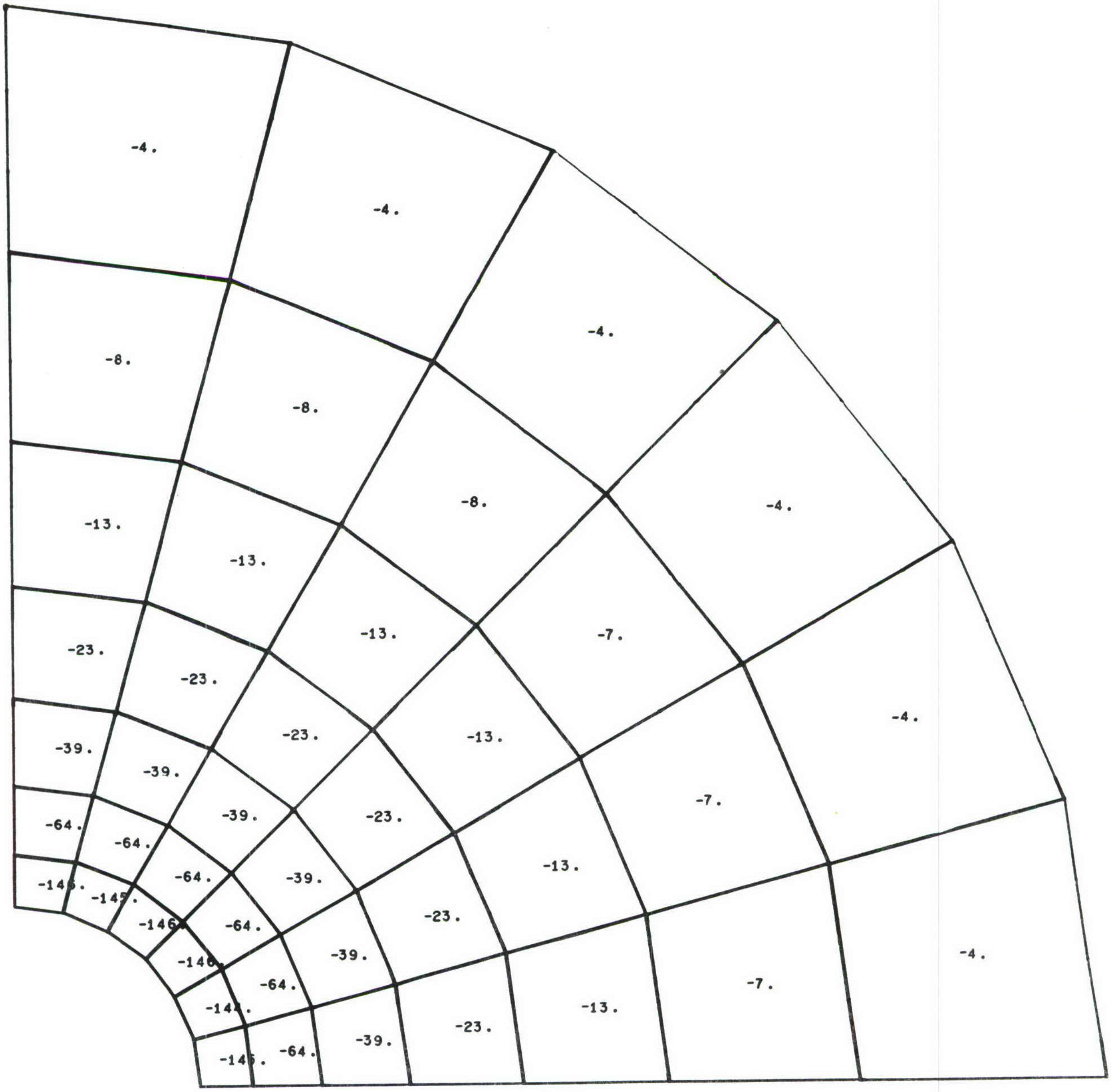


Figure AII-49 Radial Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

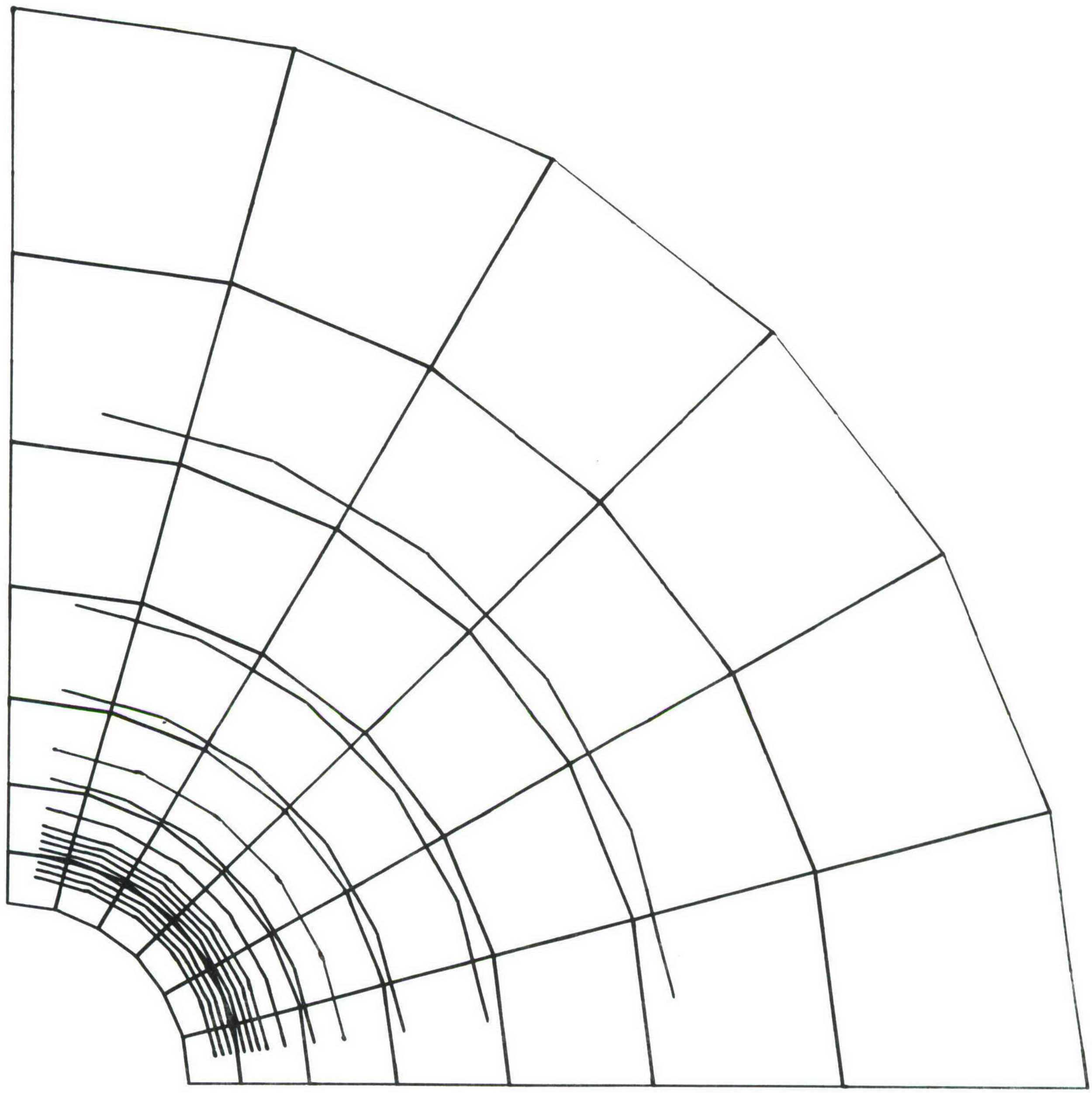


Figure AII-50 Radial Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

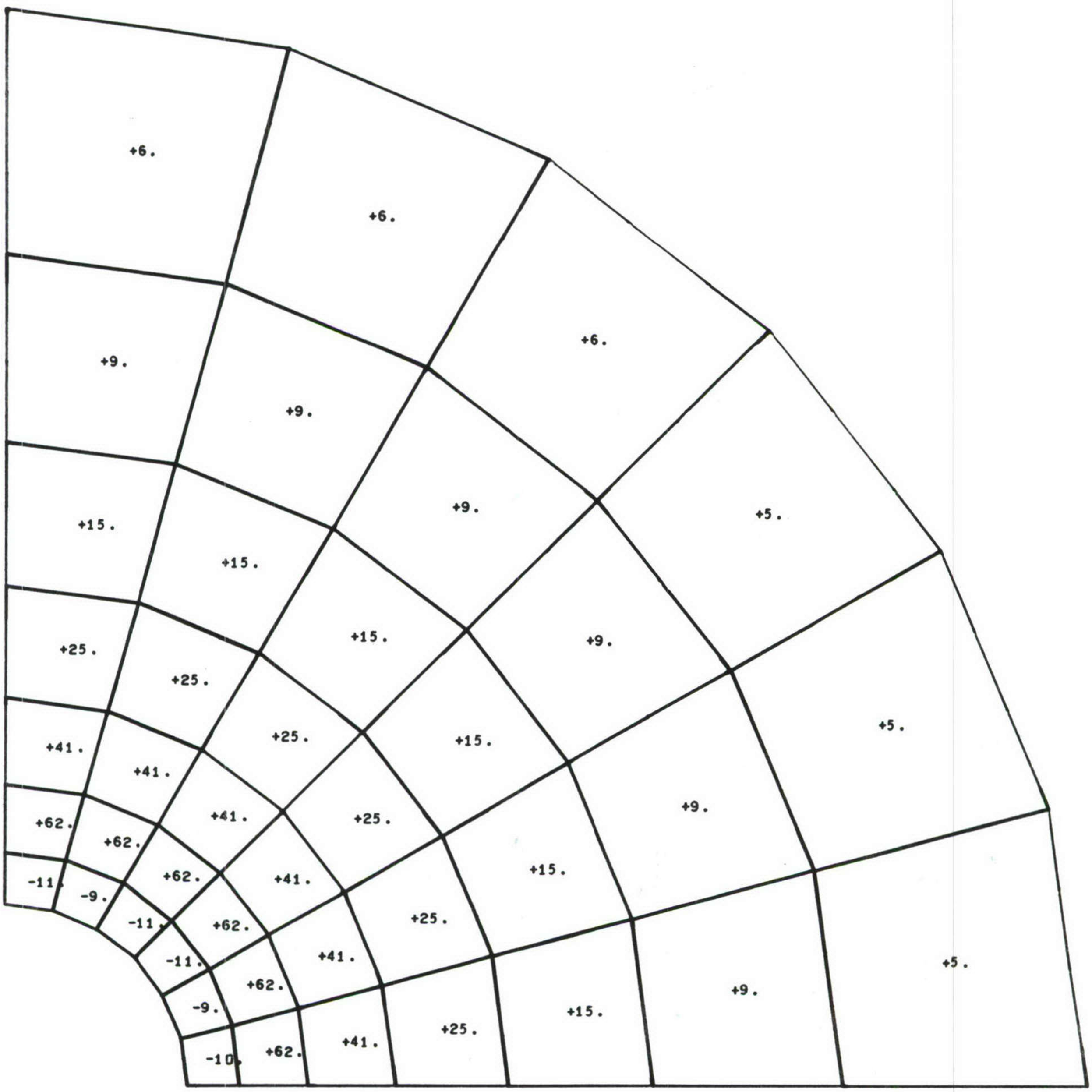


Figure AII-51 Tangential Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

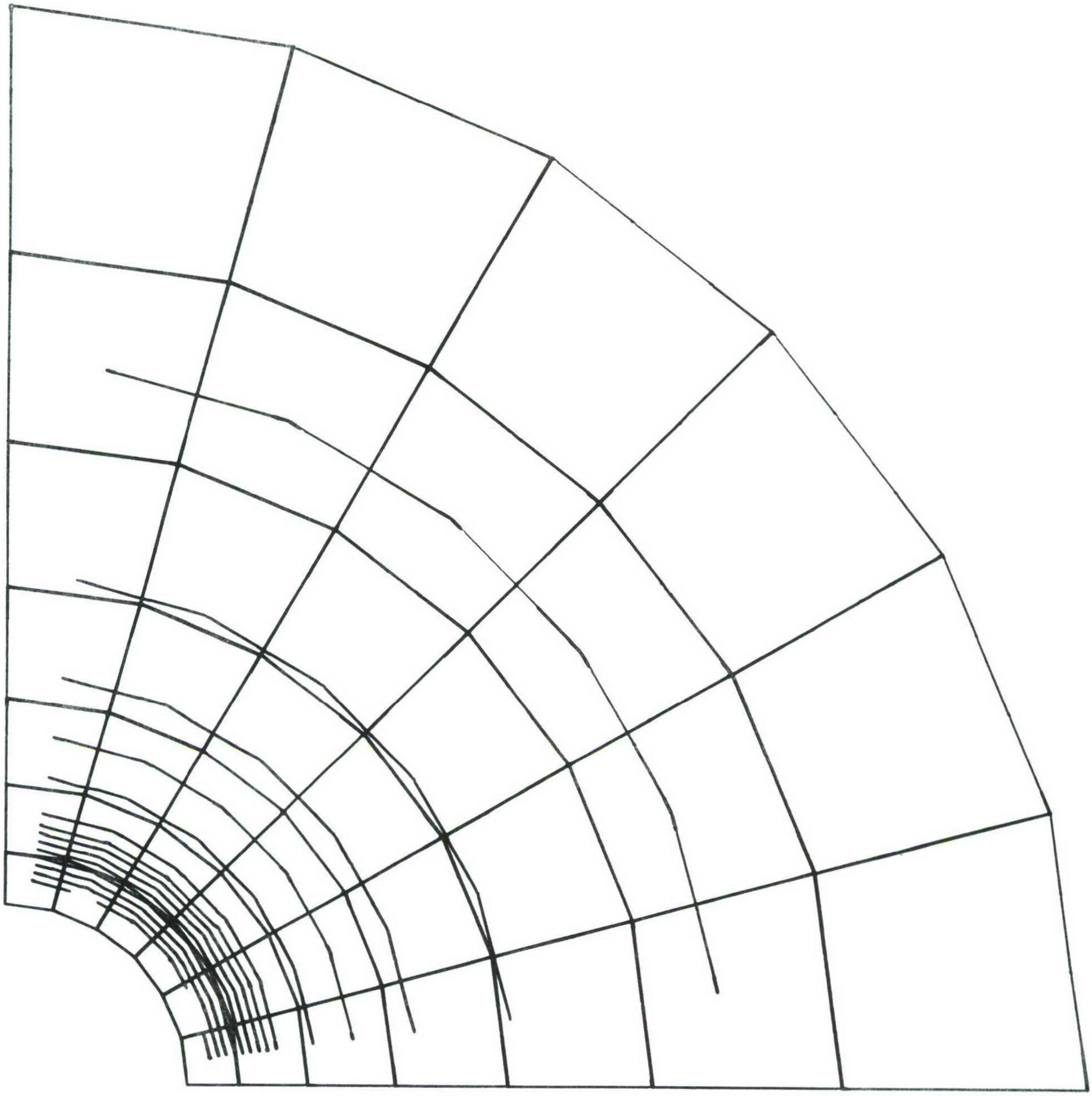


Figure AII-52 Tangential Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

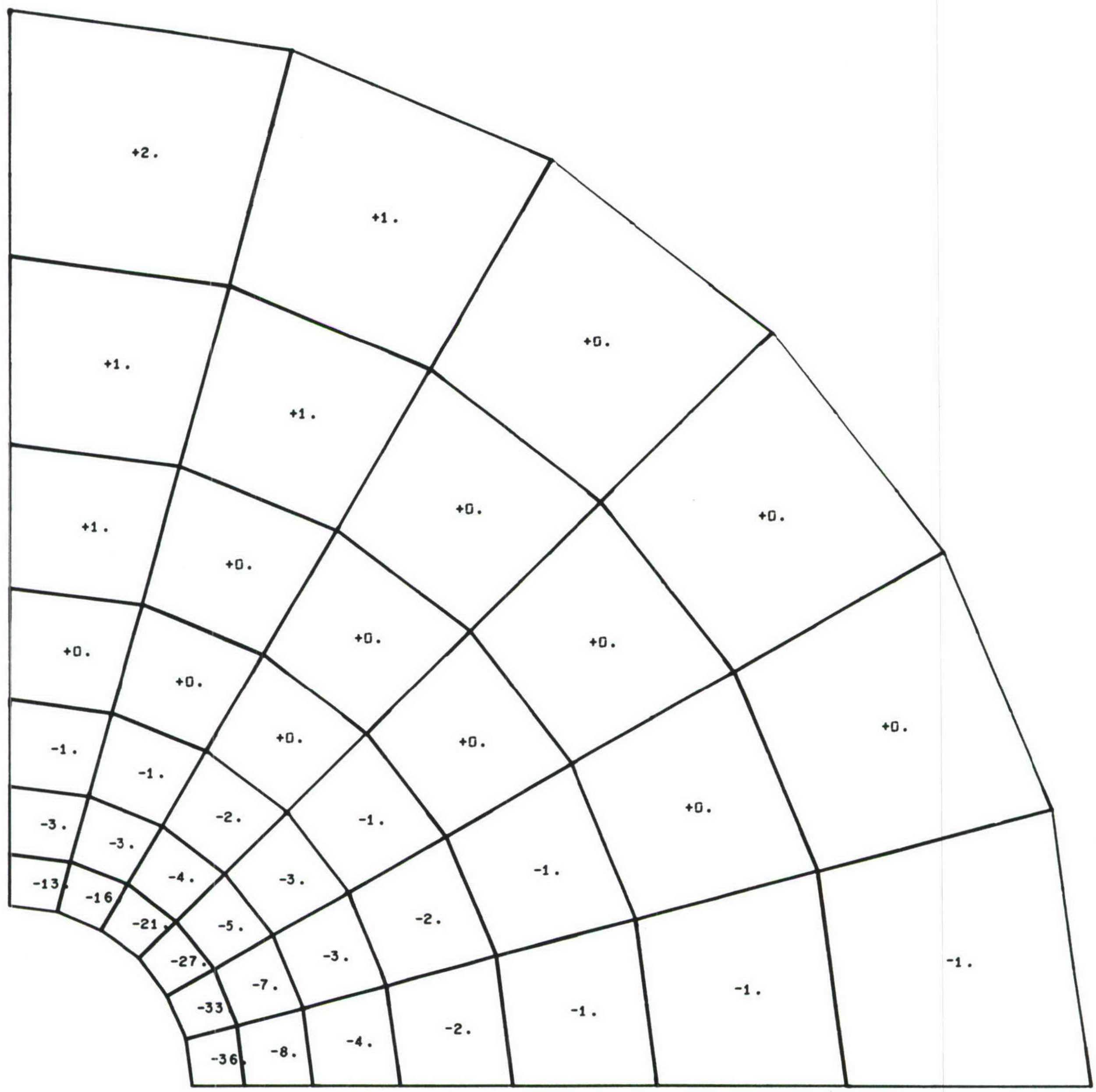


Figure AII-53 Radial Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

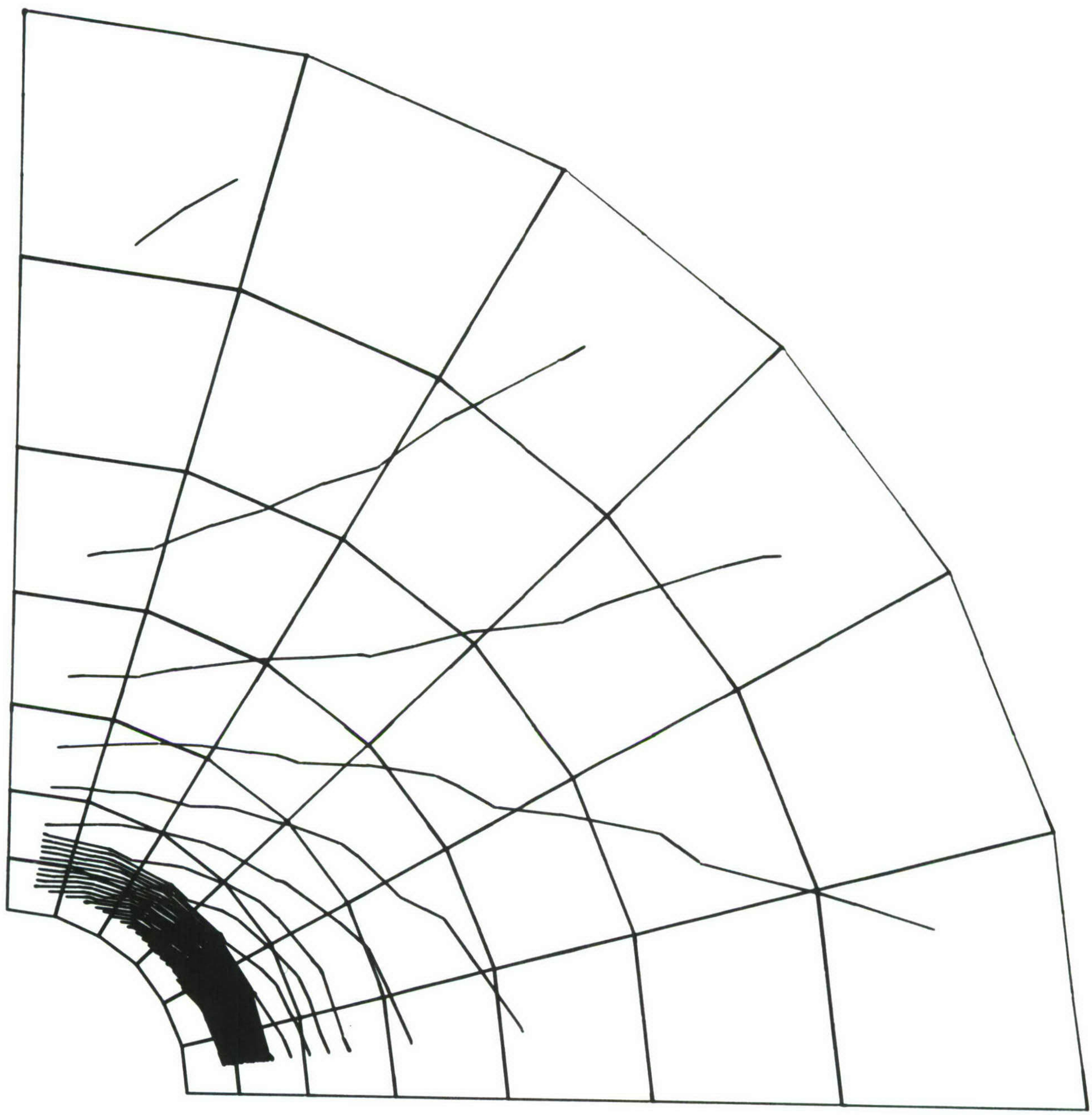


Figure AII-54 Radial Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

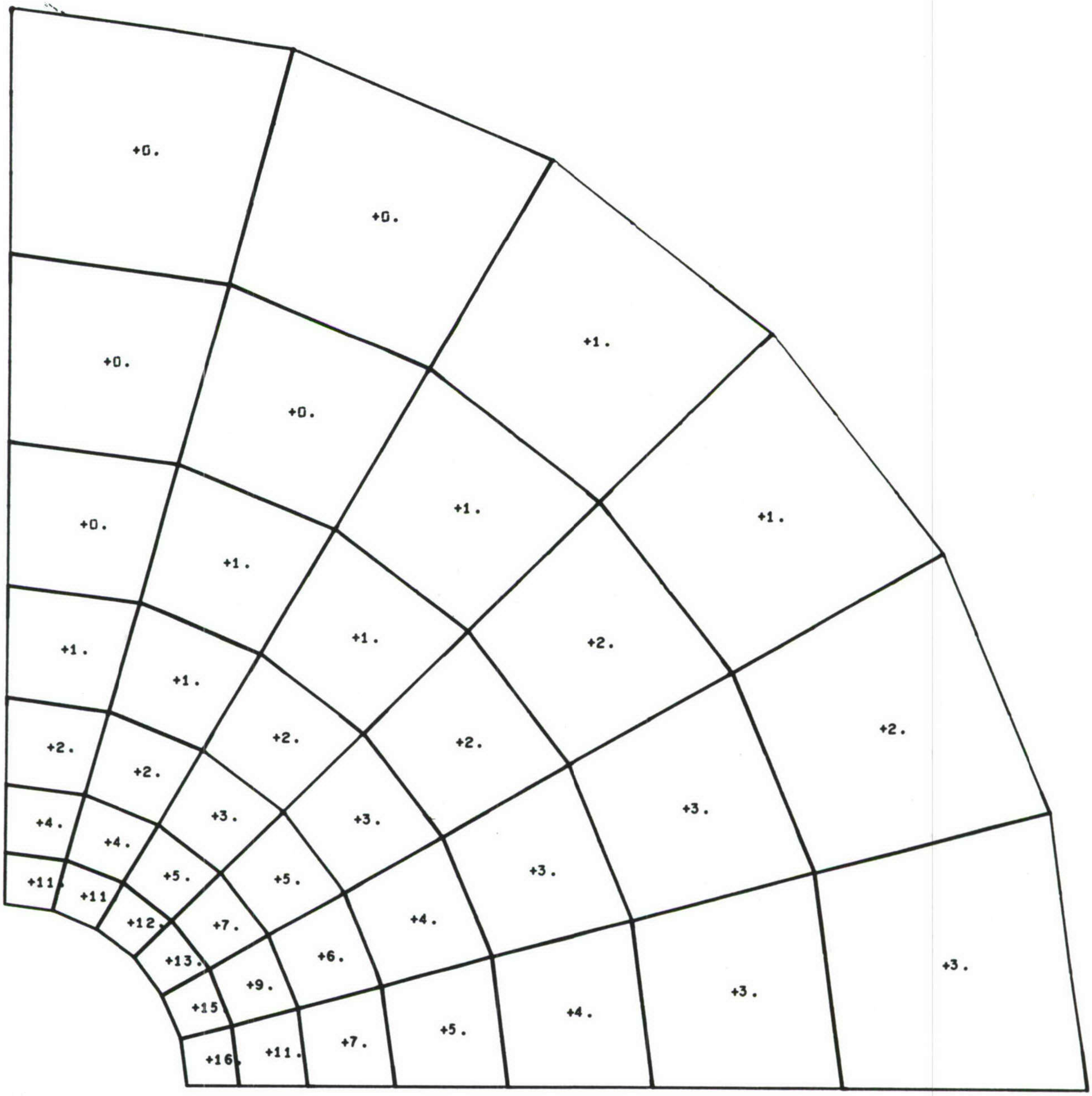


Figure AII-55 Tangential Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

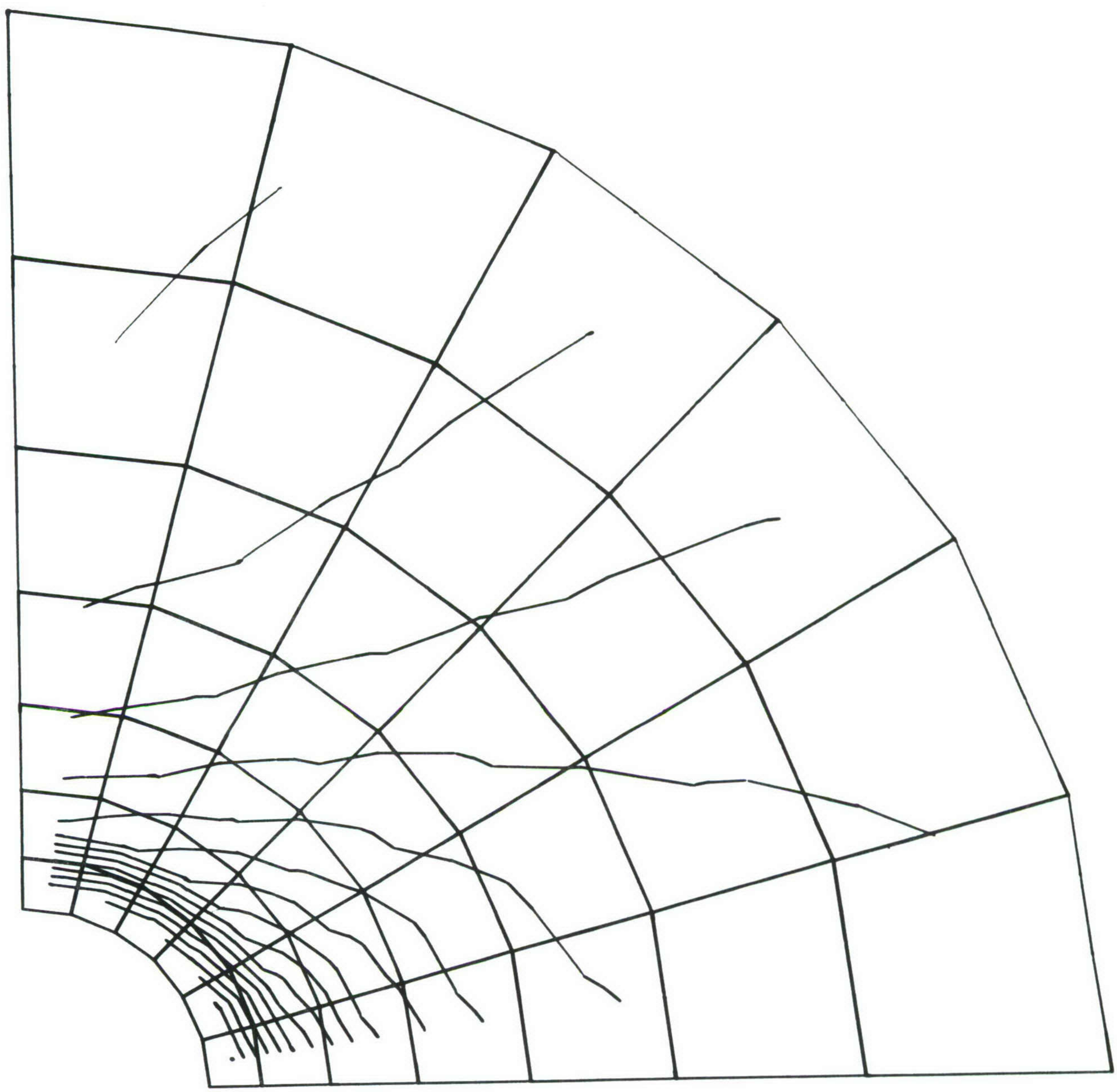


Figure AII-56 Tangential Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

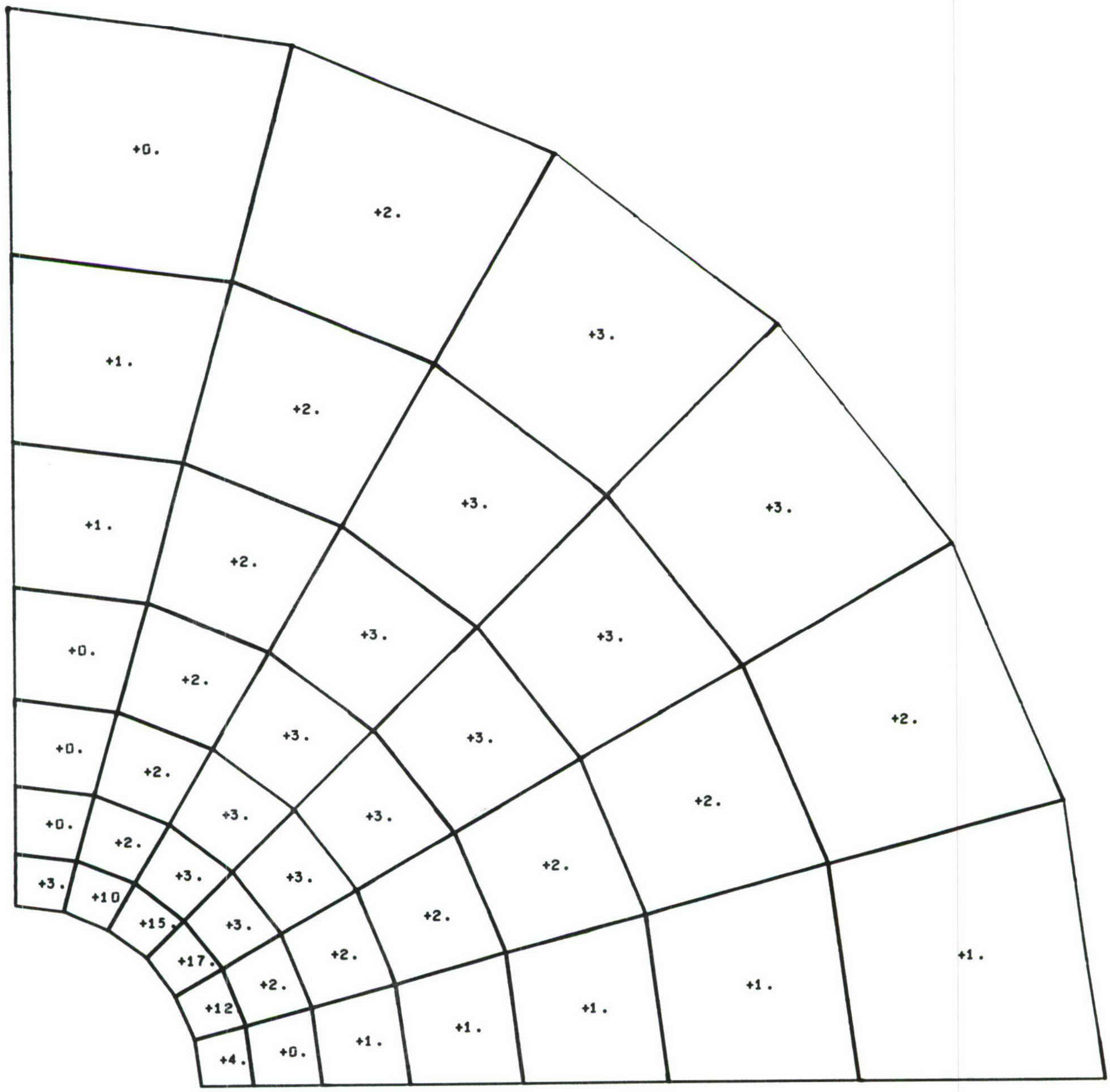


Figure AII-57 Radial-Tangential Shear Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

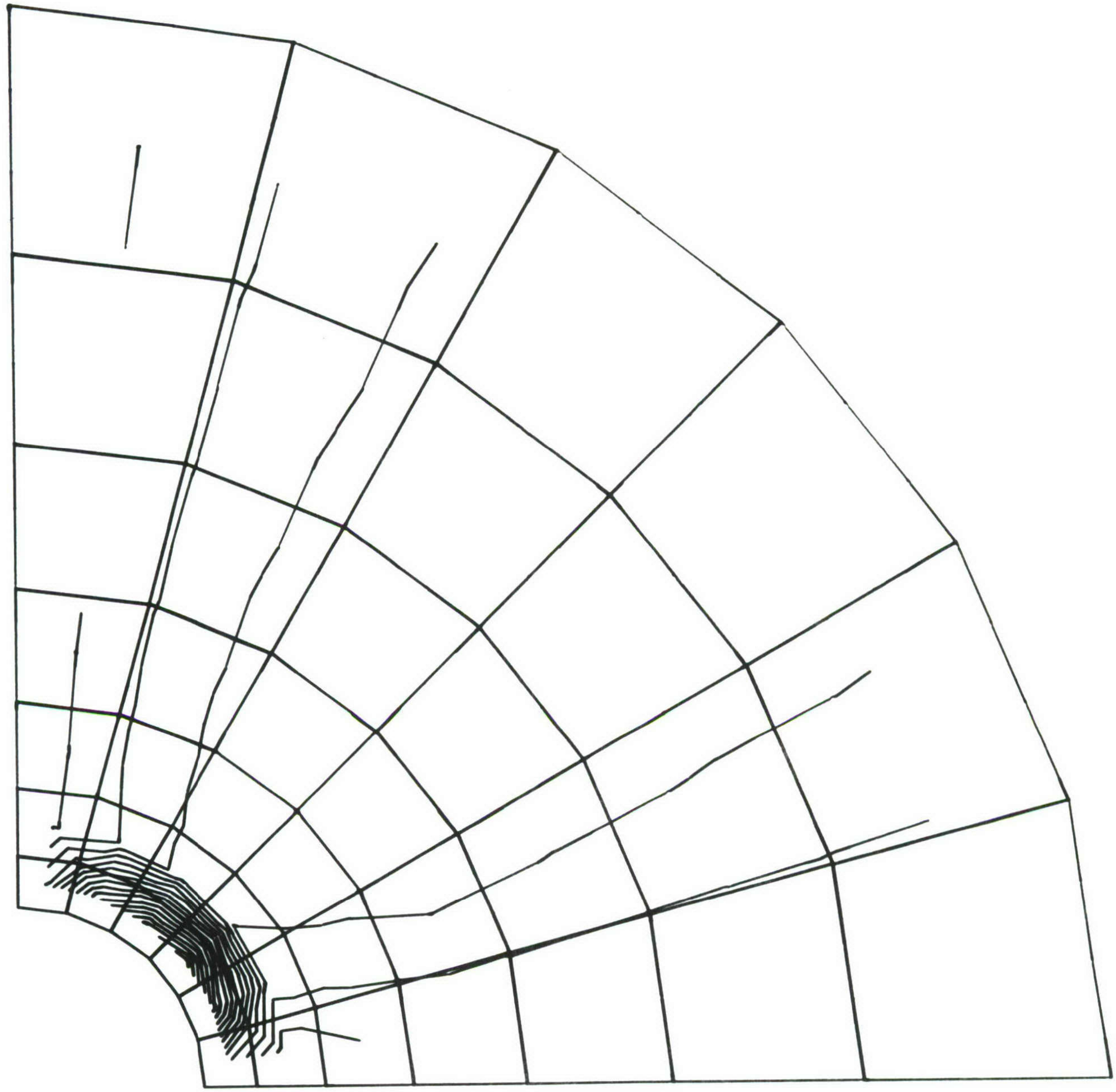


Figure AII-58 Radial-Tangential Shear Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

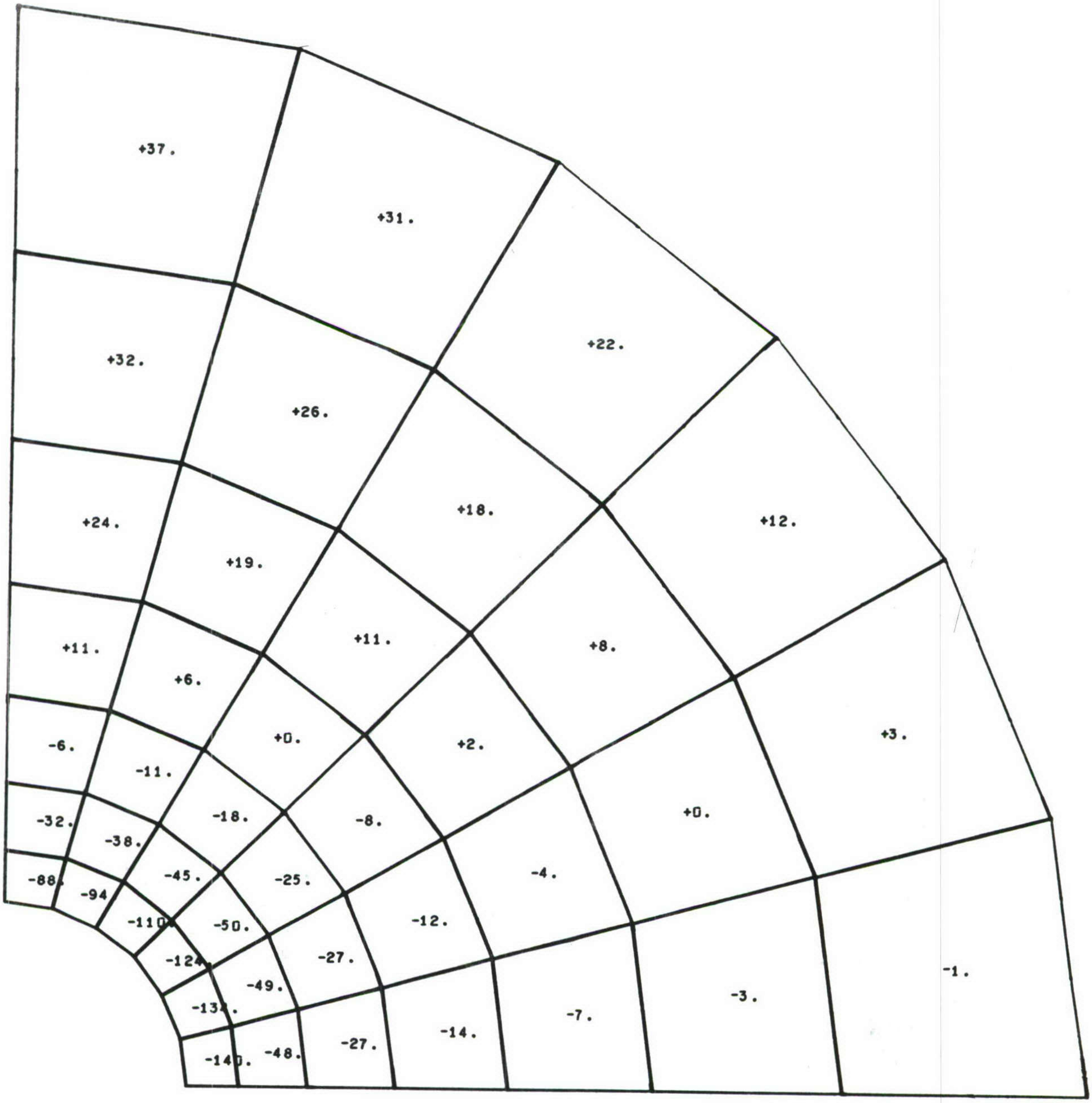


Figure AII-59 Radial Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

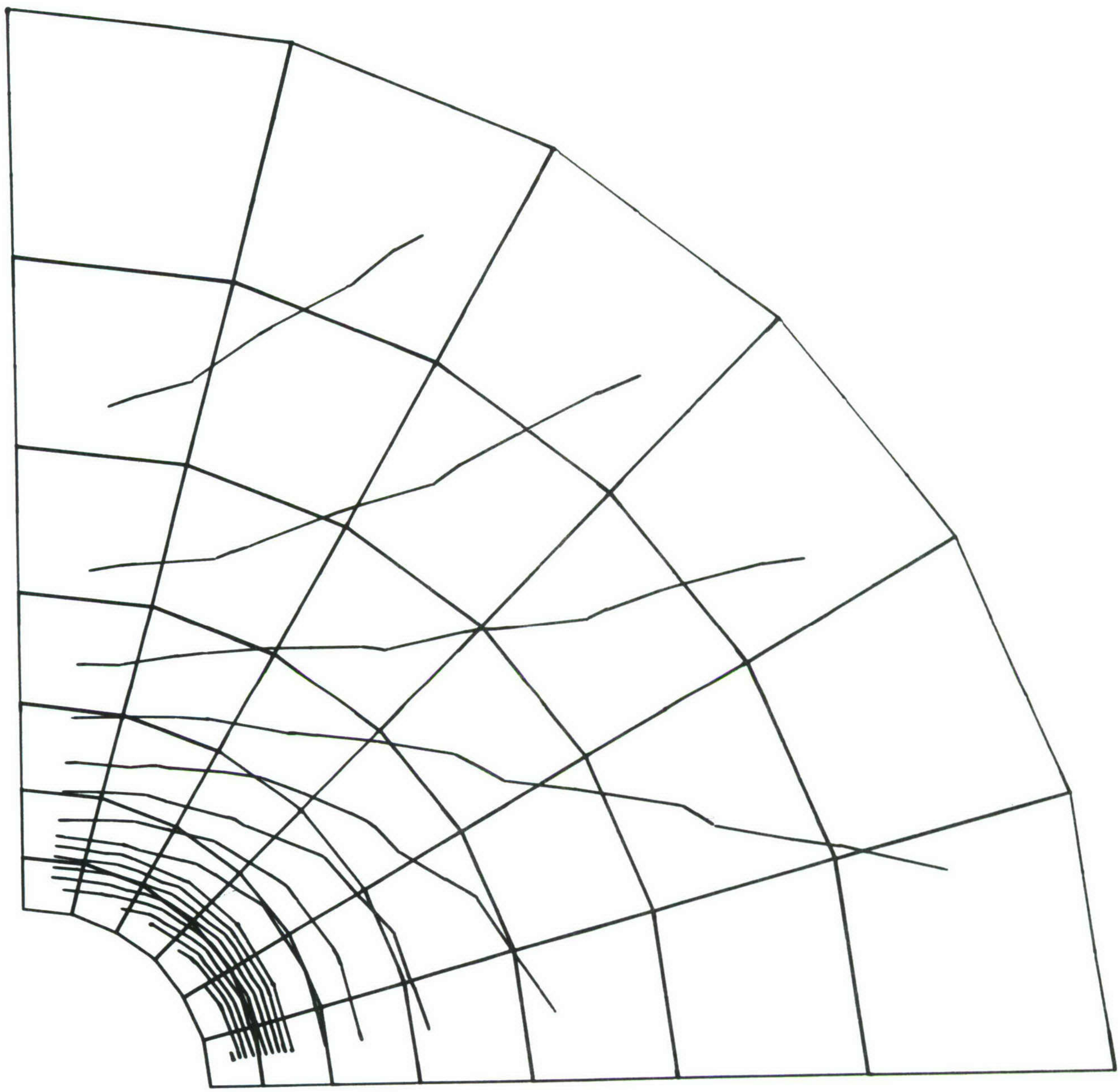


Figure AII-60 Radial Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

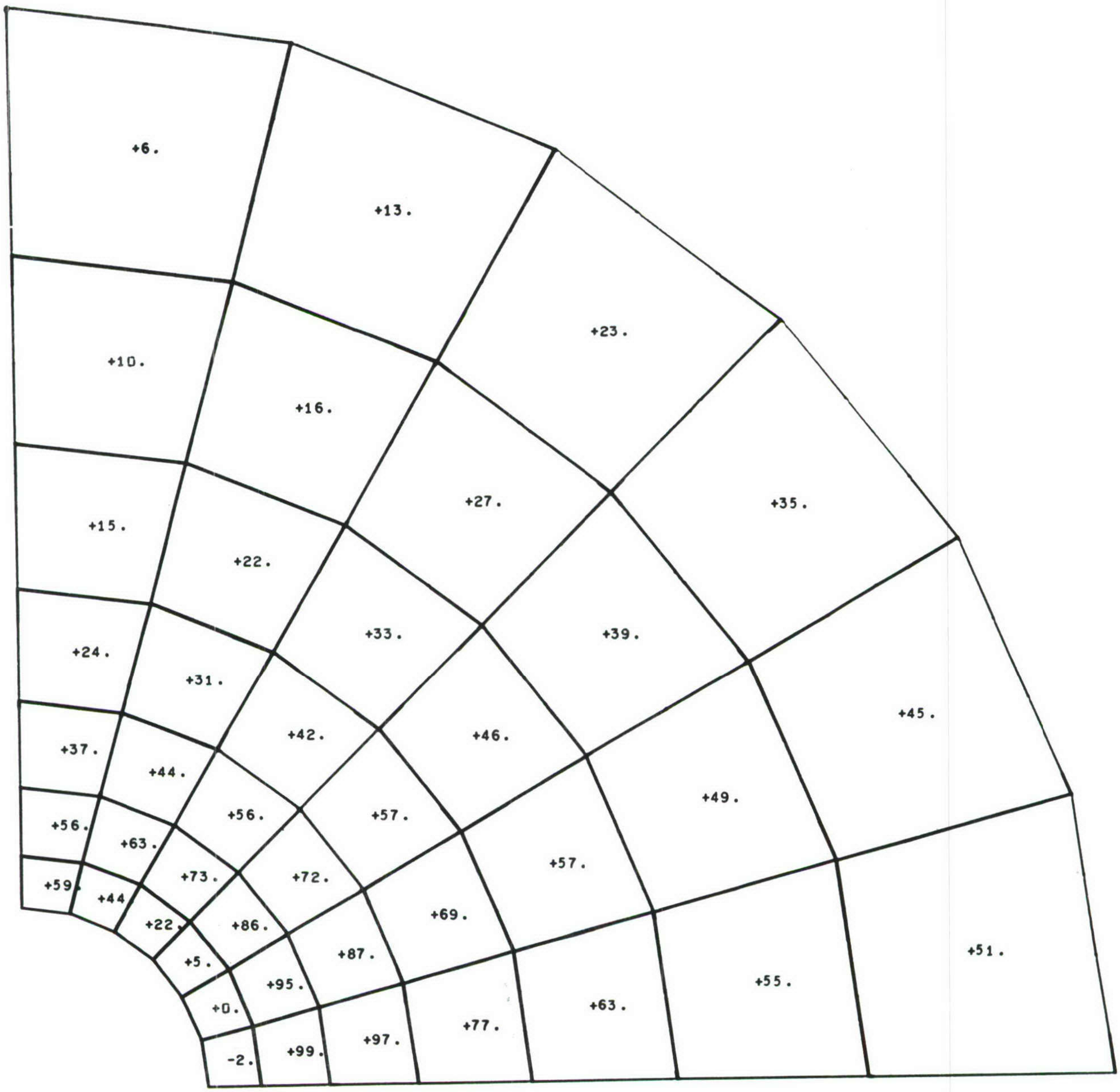


Figure AII-61 Tangential Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

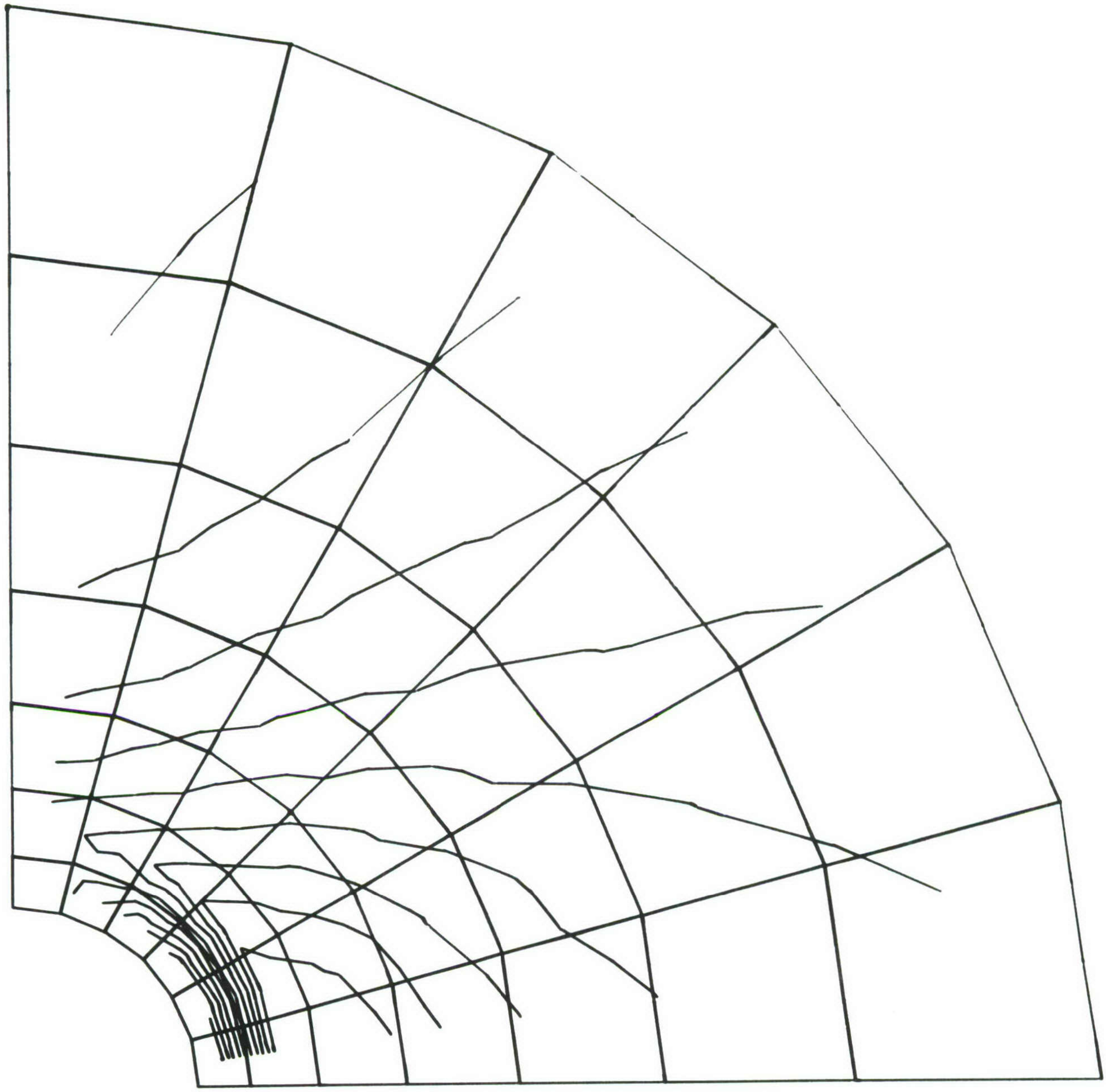


Figure AII-62 Tangential Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

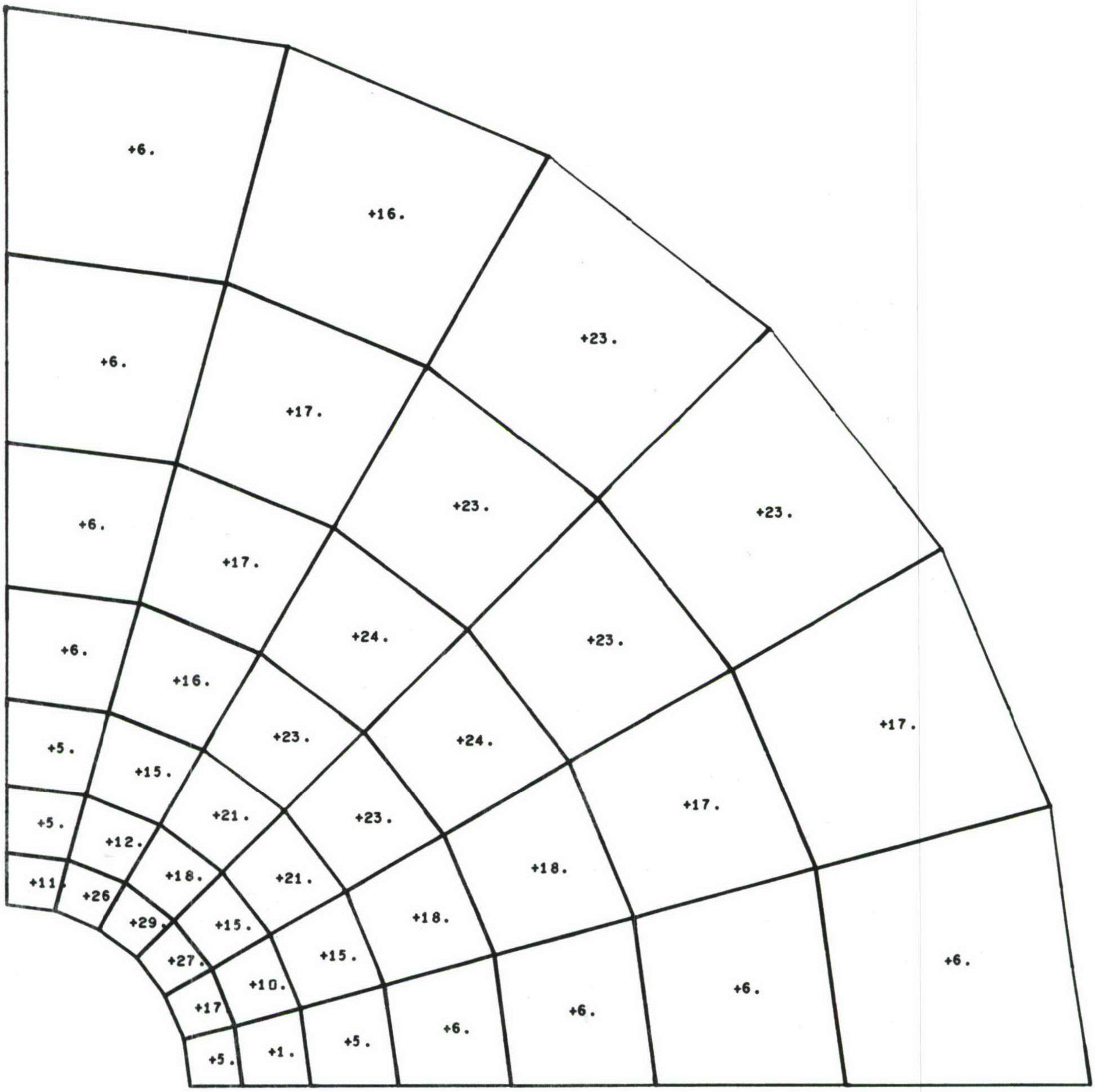


Figure AII-63 Radial-Tangential Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

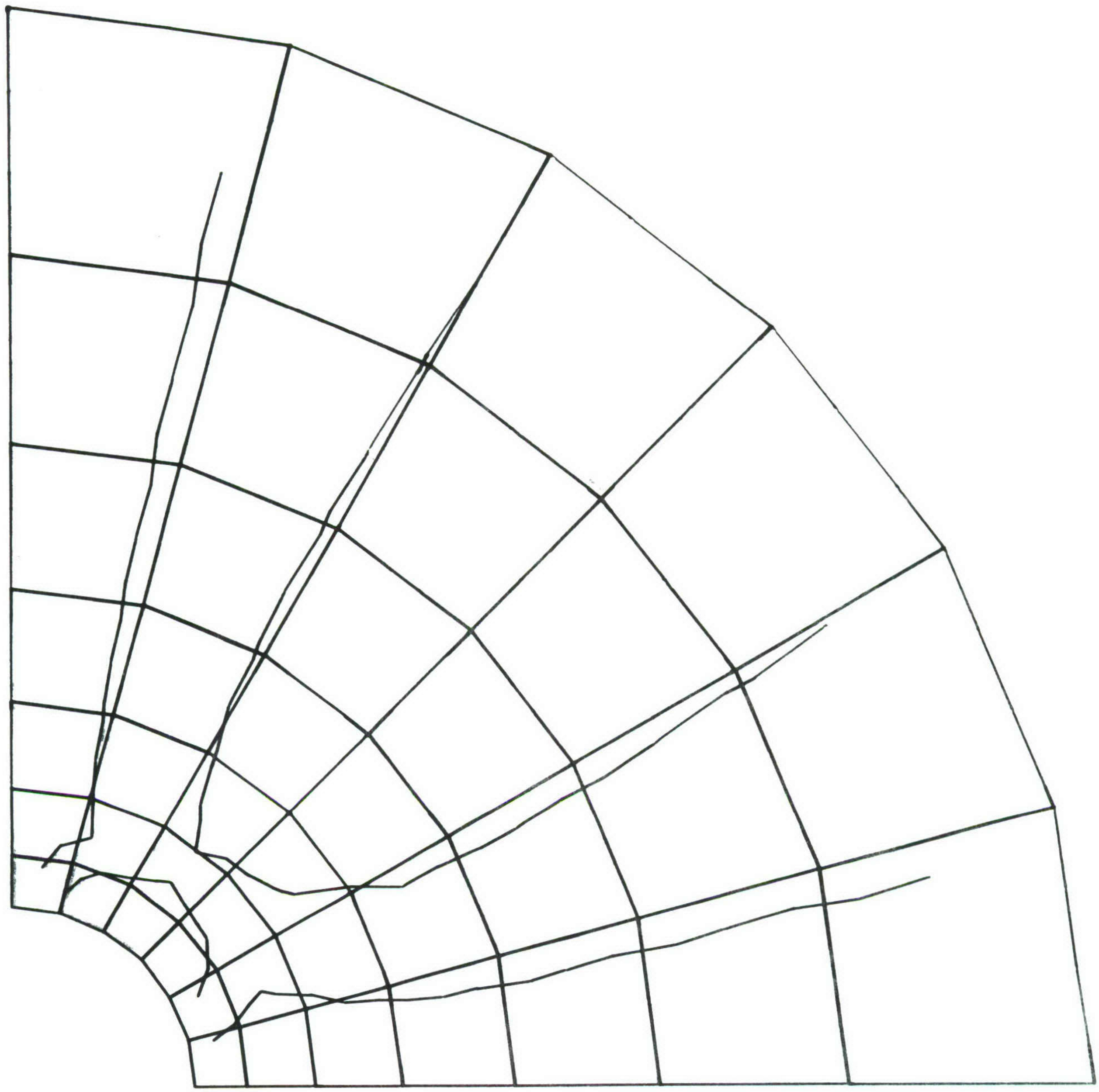


Figure AII-64 Radial-Tangential Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

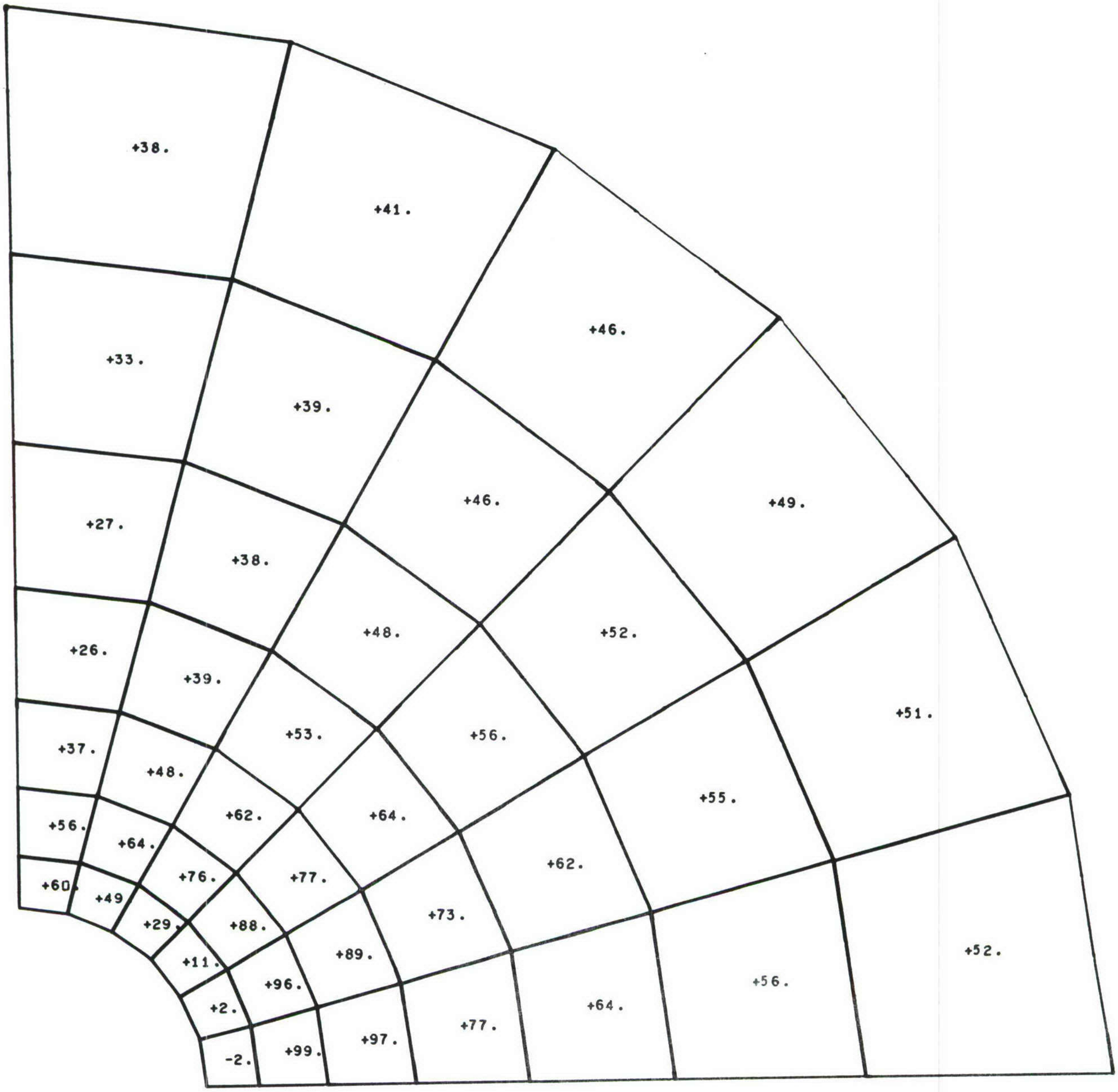


Figure AII-65 First Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

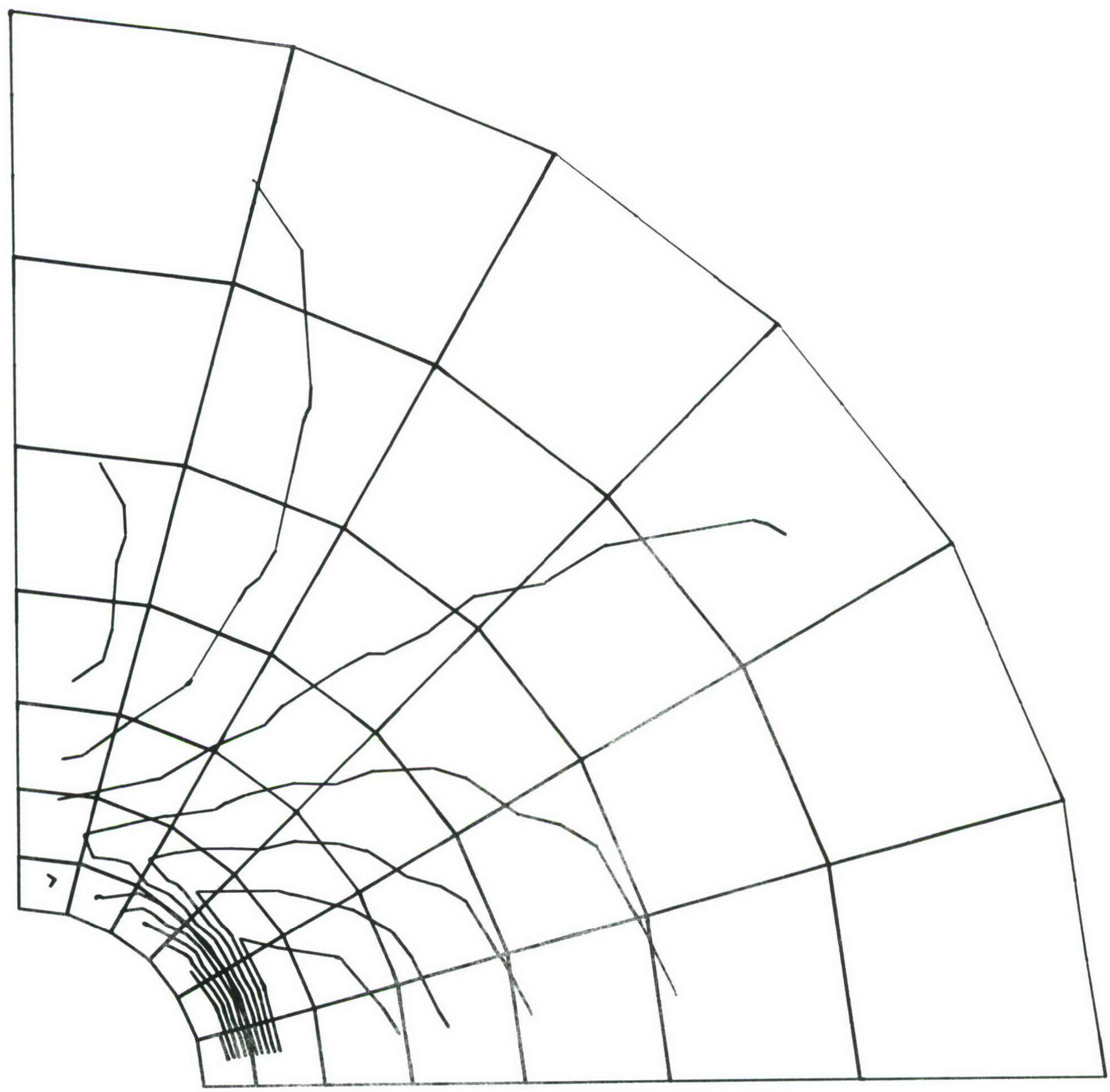


Figure AII-66 First Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

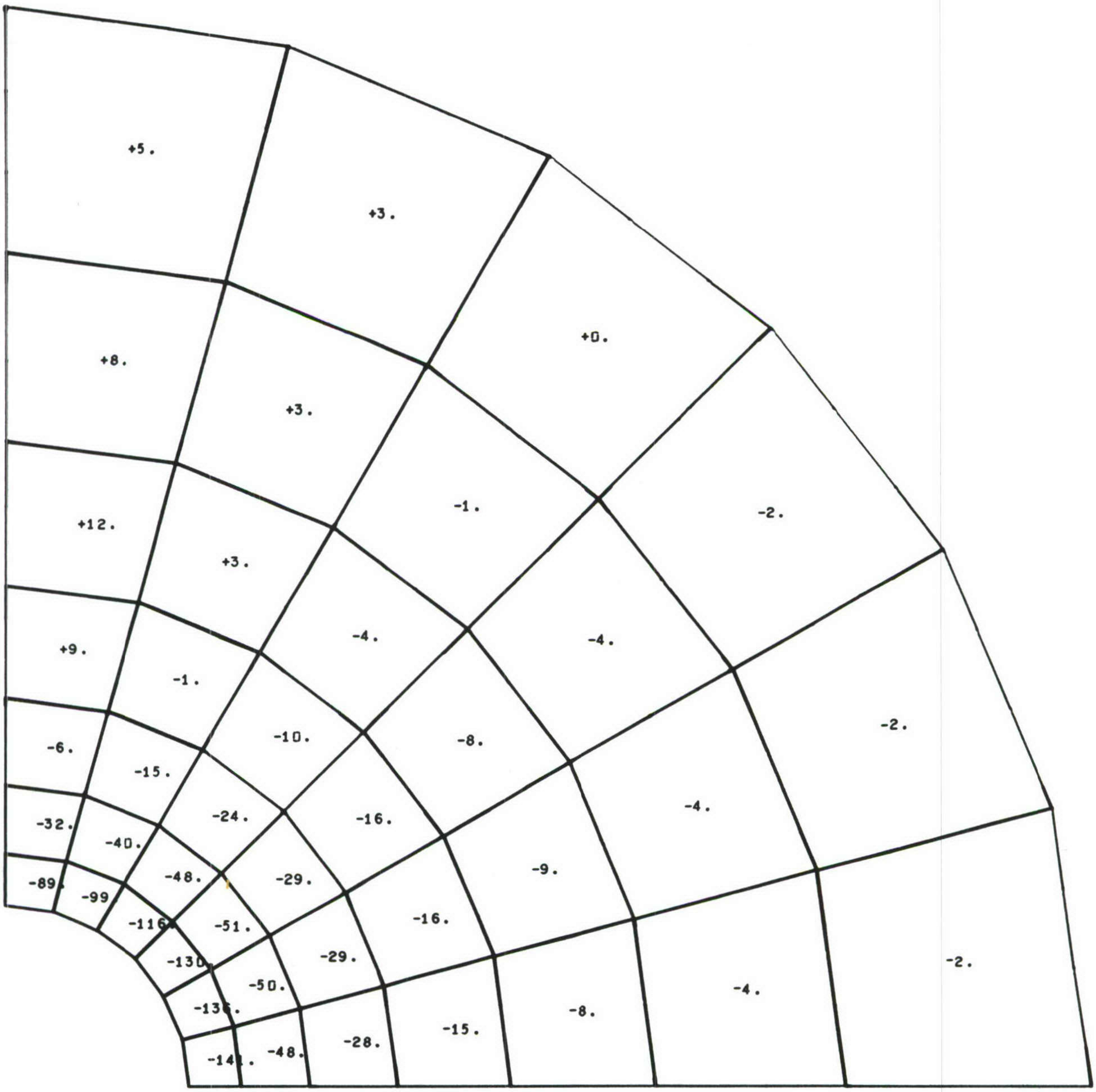


Figure AII-67 Second Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

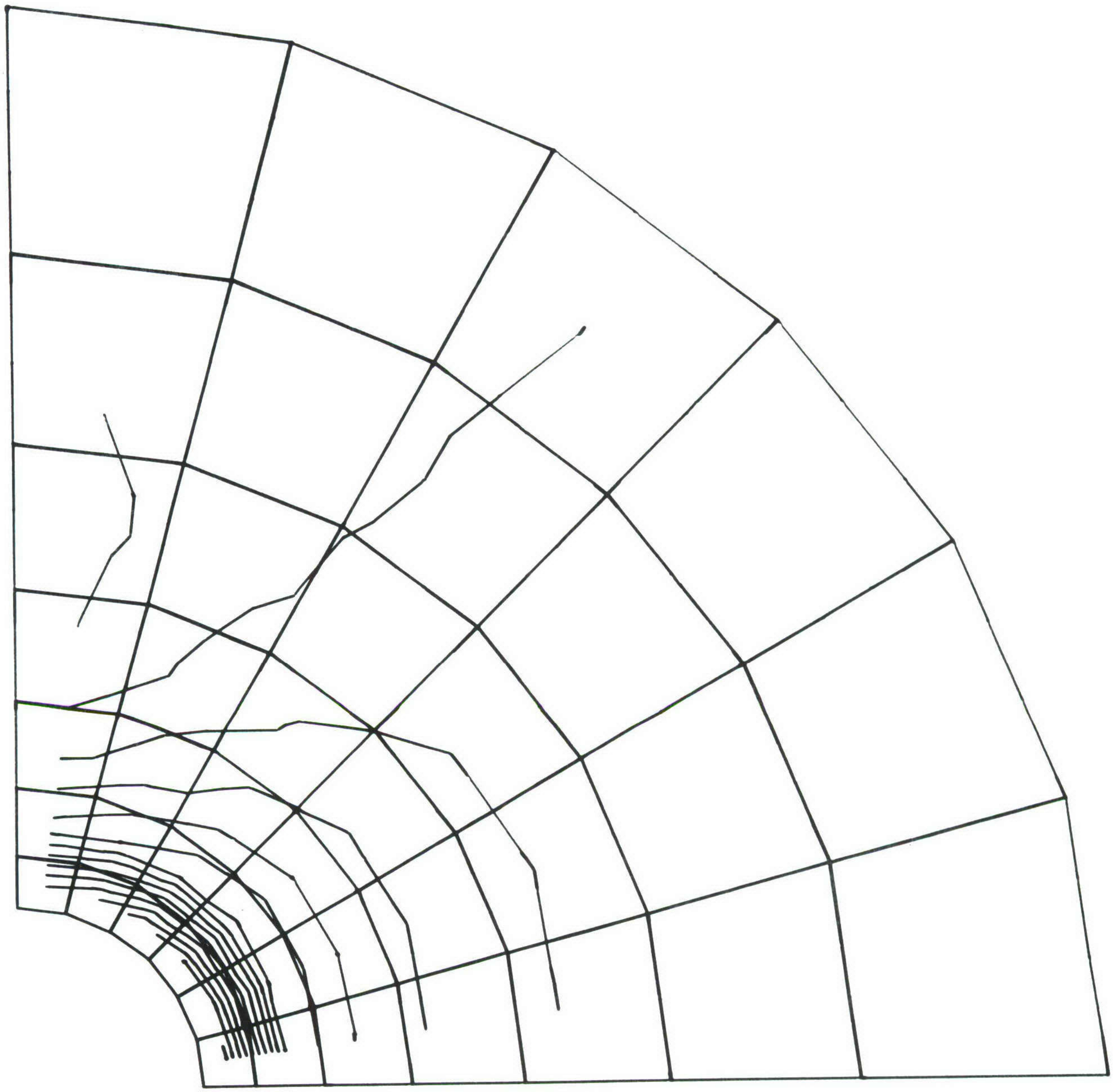


Figure AII-68 Second Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

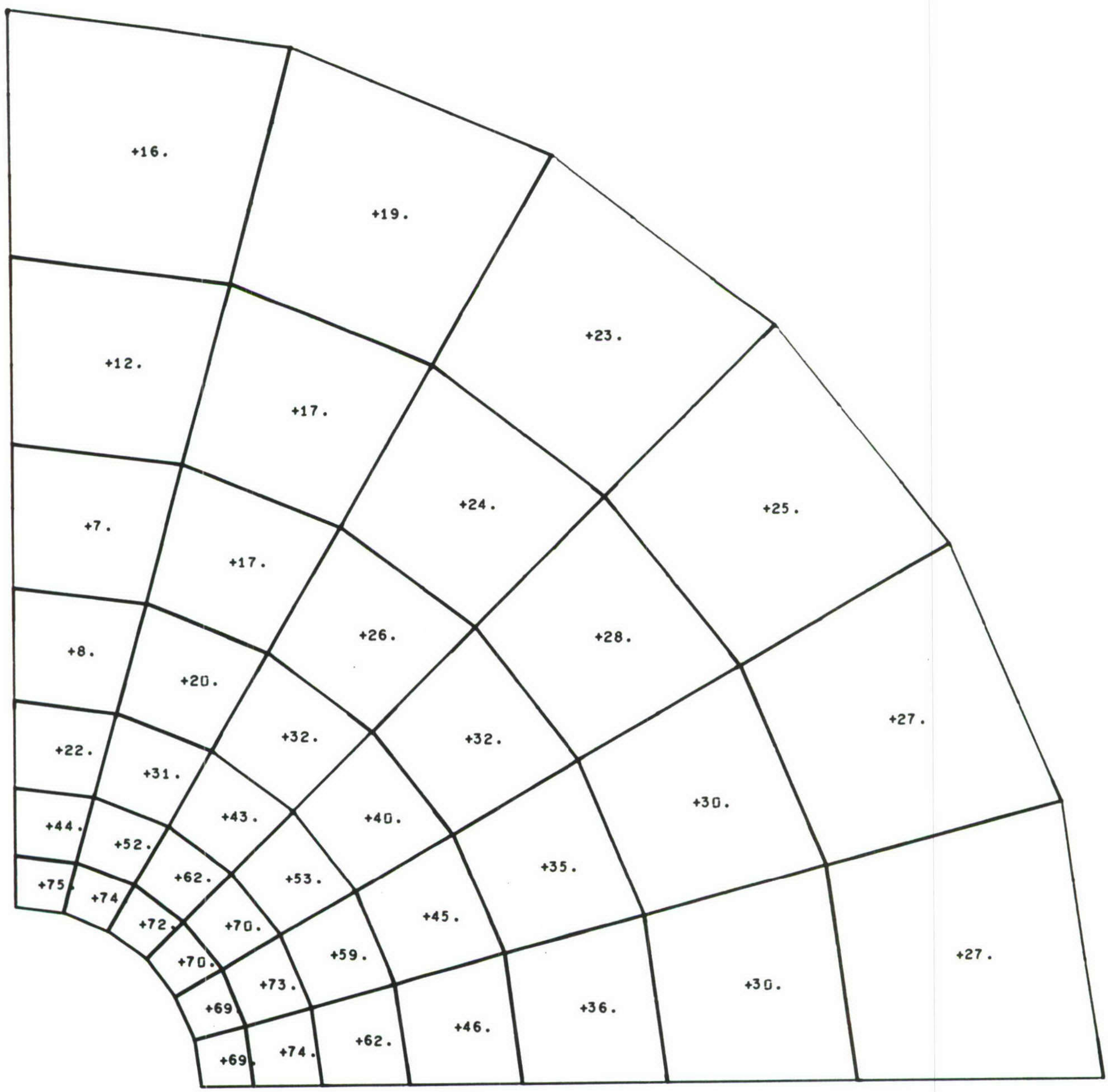


Figure AII-69 Principal Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

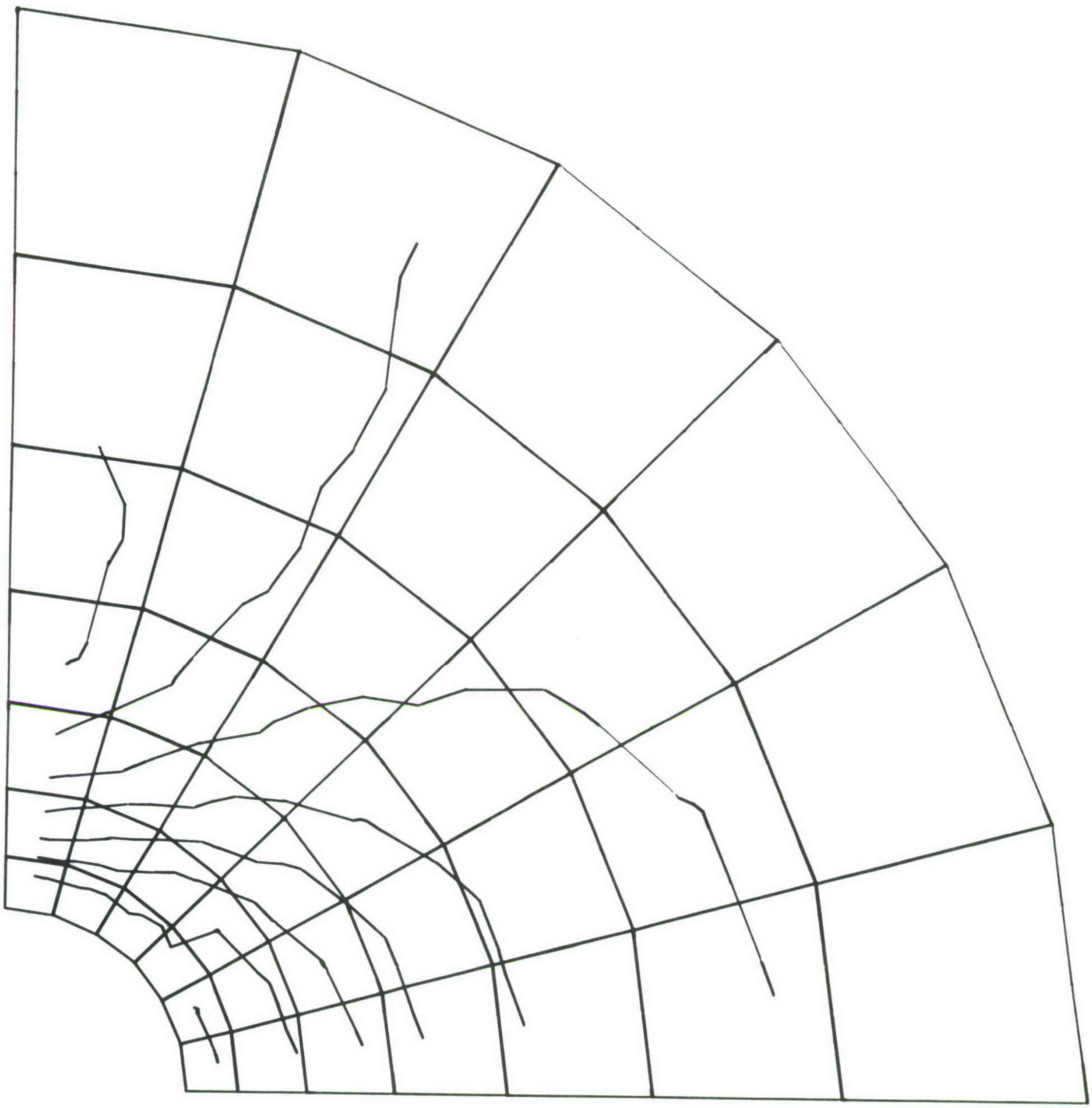


Figure AII-70 Principal Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

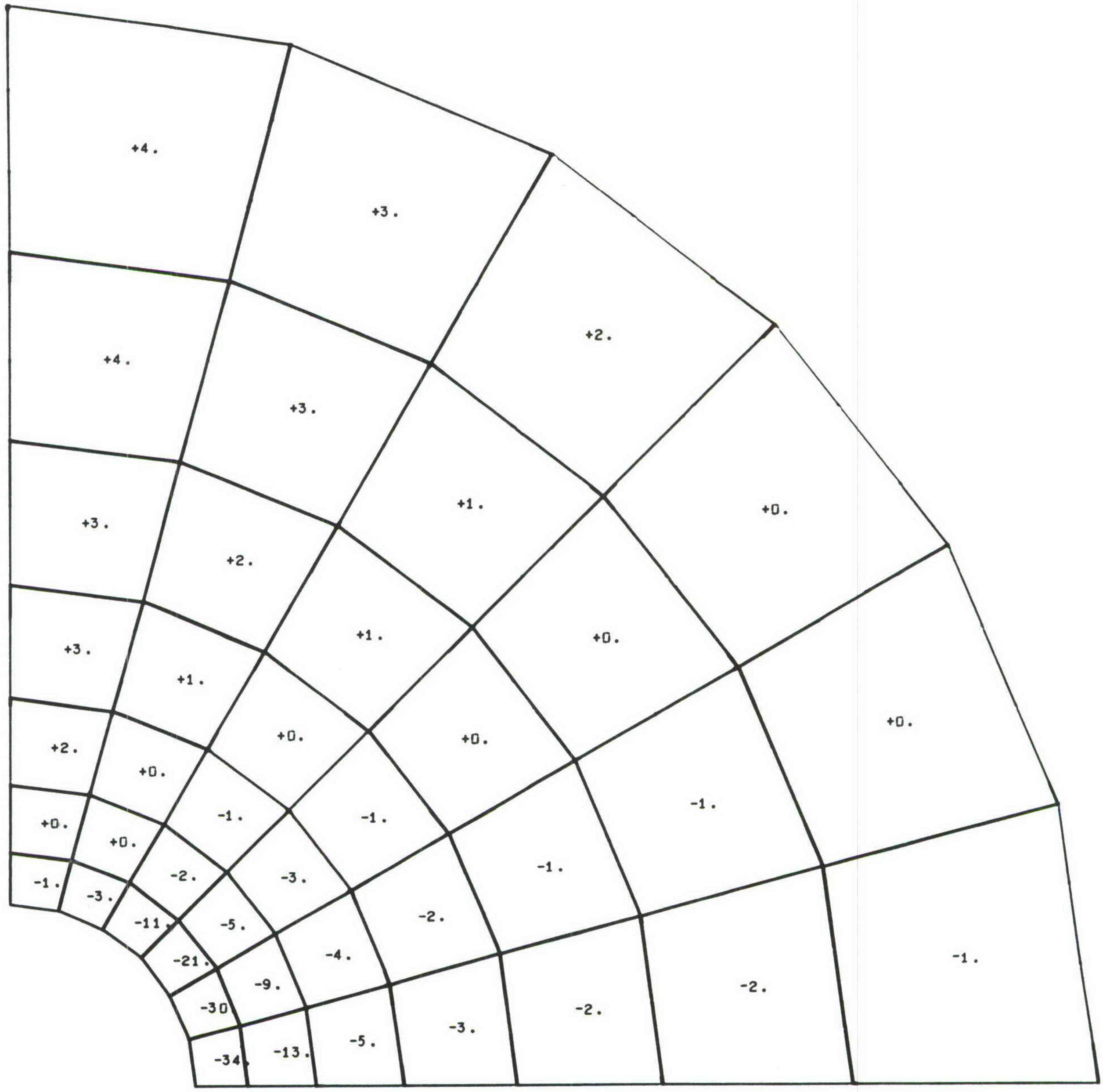


Figure AII-71 Radial Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

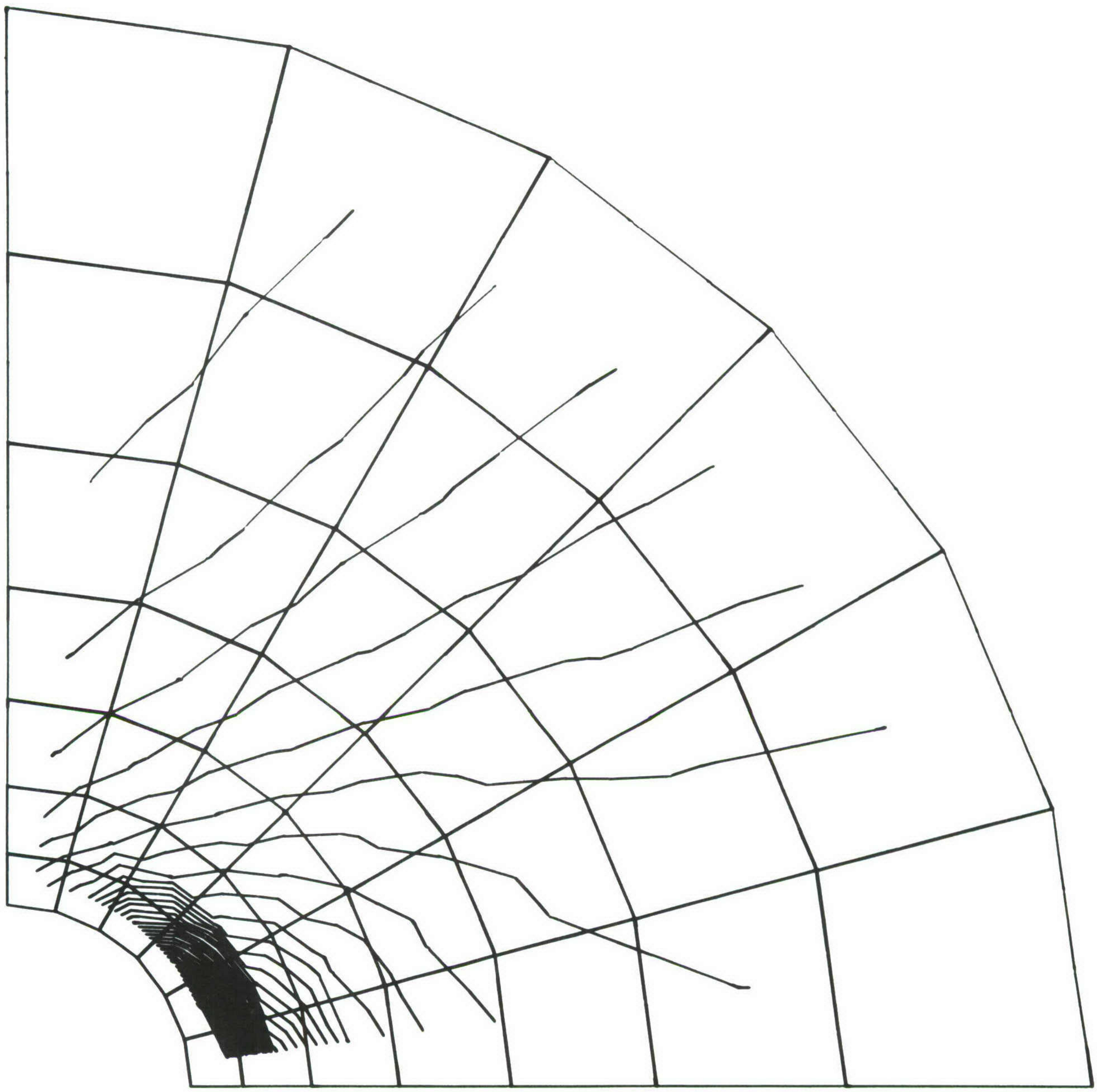


Figure AII-72 Radial Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

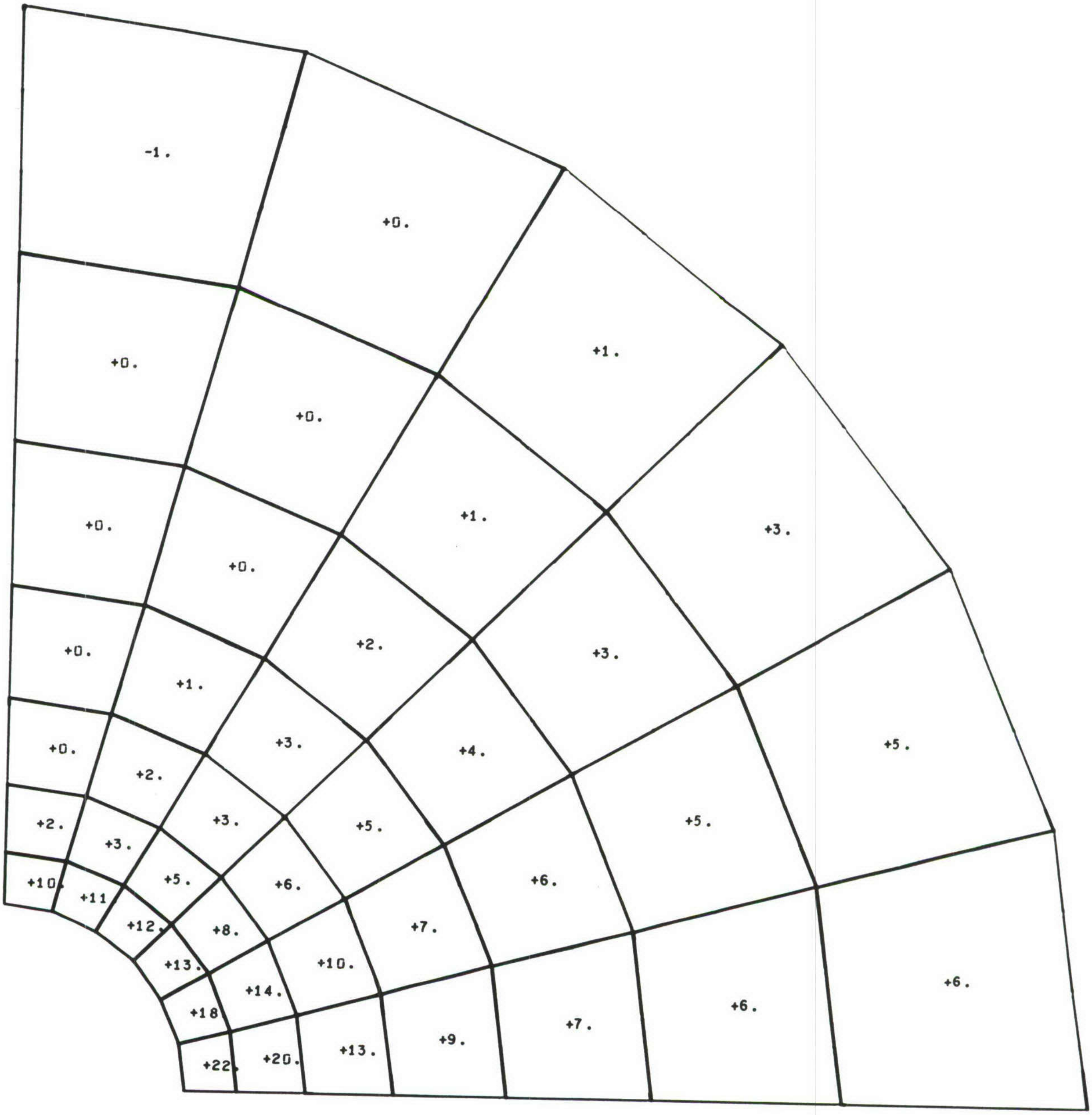


Figure AII-73 Tangential Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

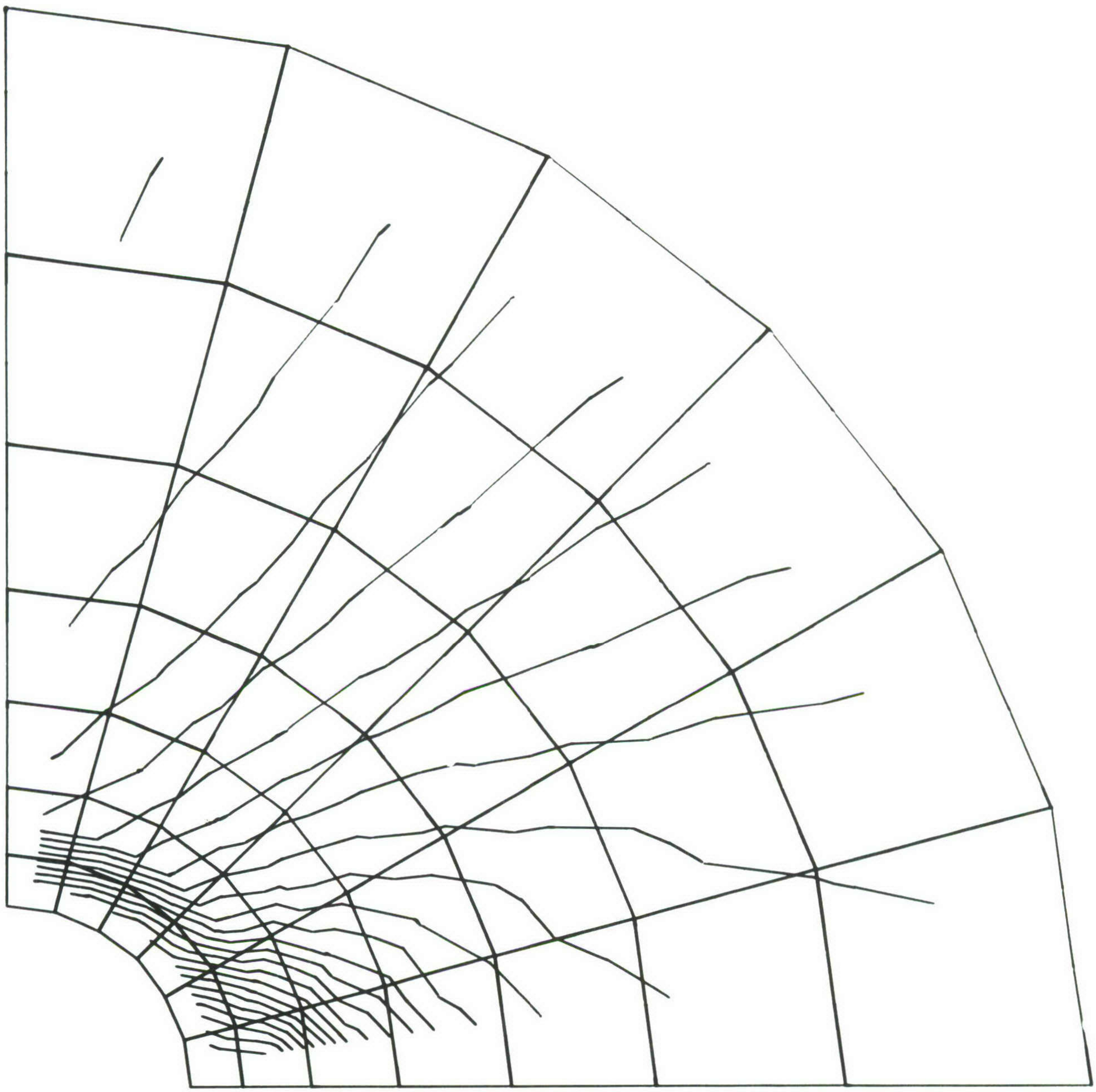


Figure AII-74 Tangential Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

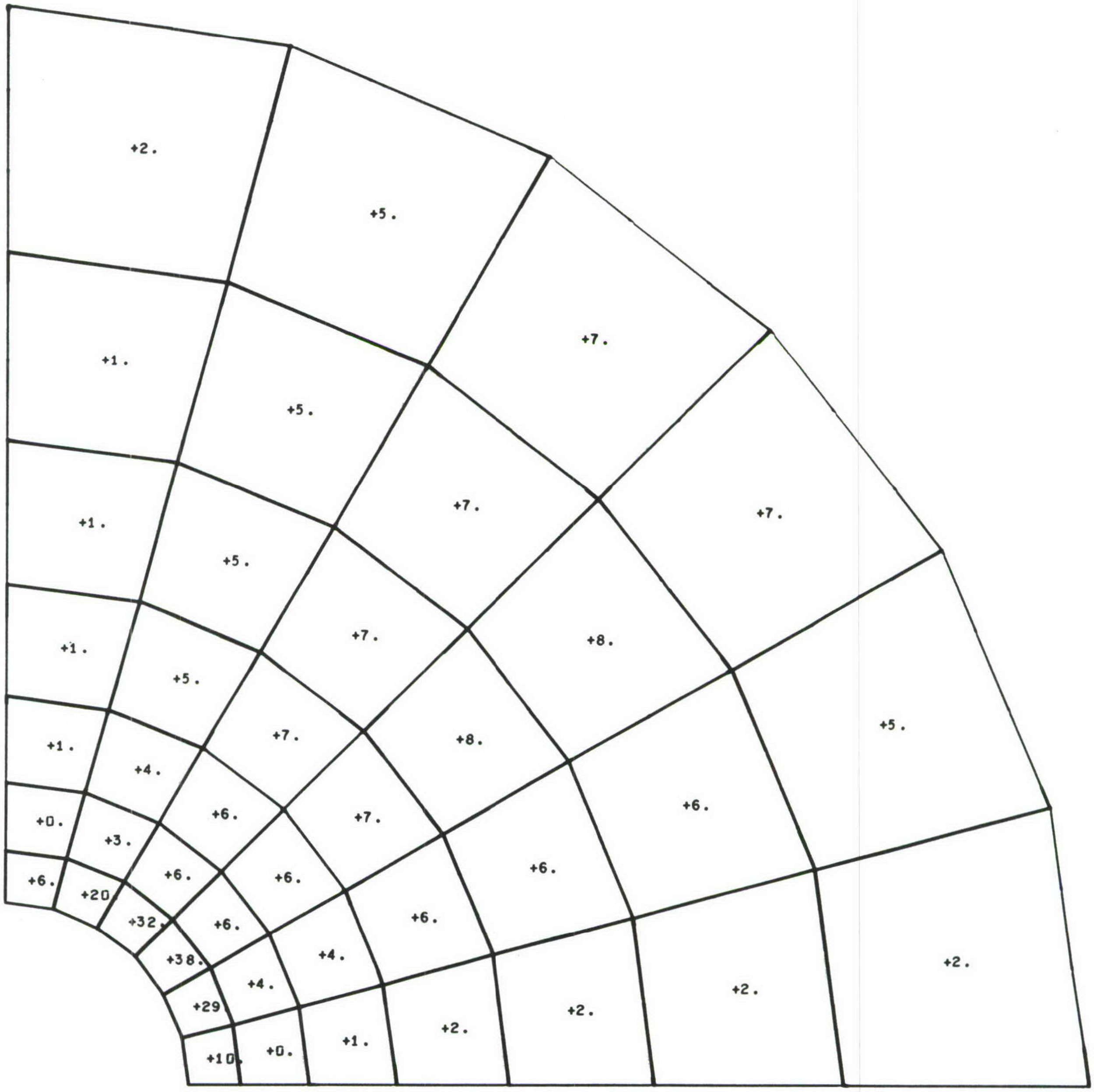


Figure AII-75 Radial-Tangential Shear Strain Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

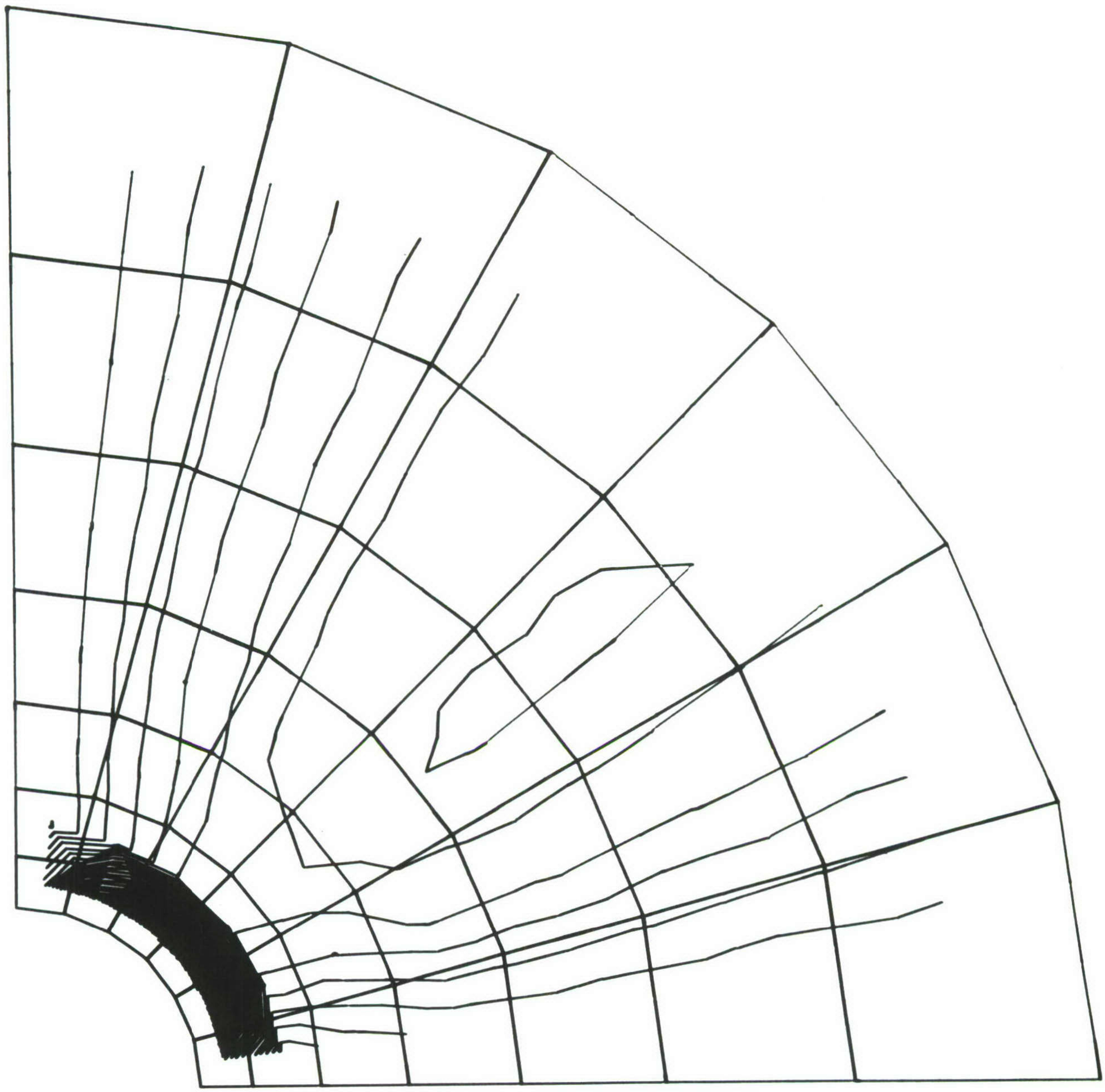


Figure AII-76 Radial-Tangential Shear Strain Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

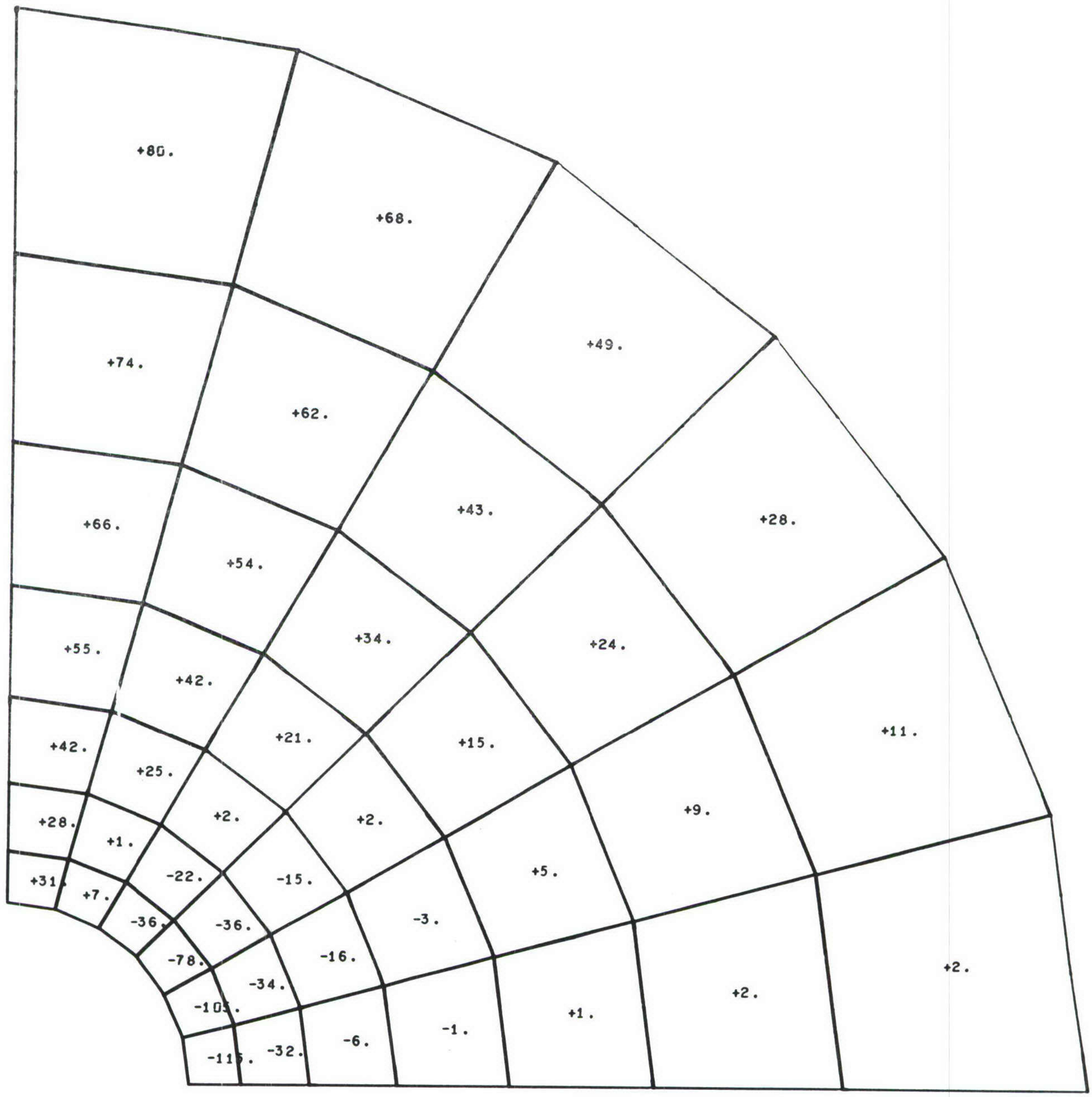


Figure AII-77 Radial Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

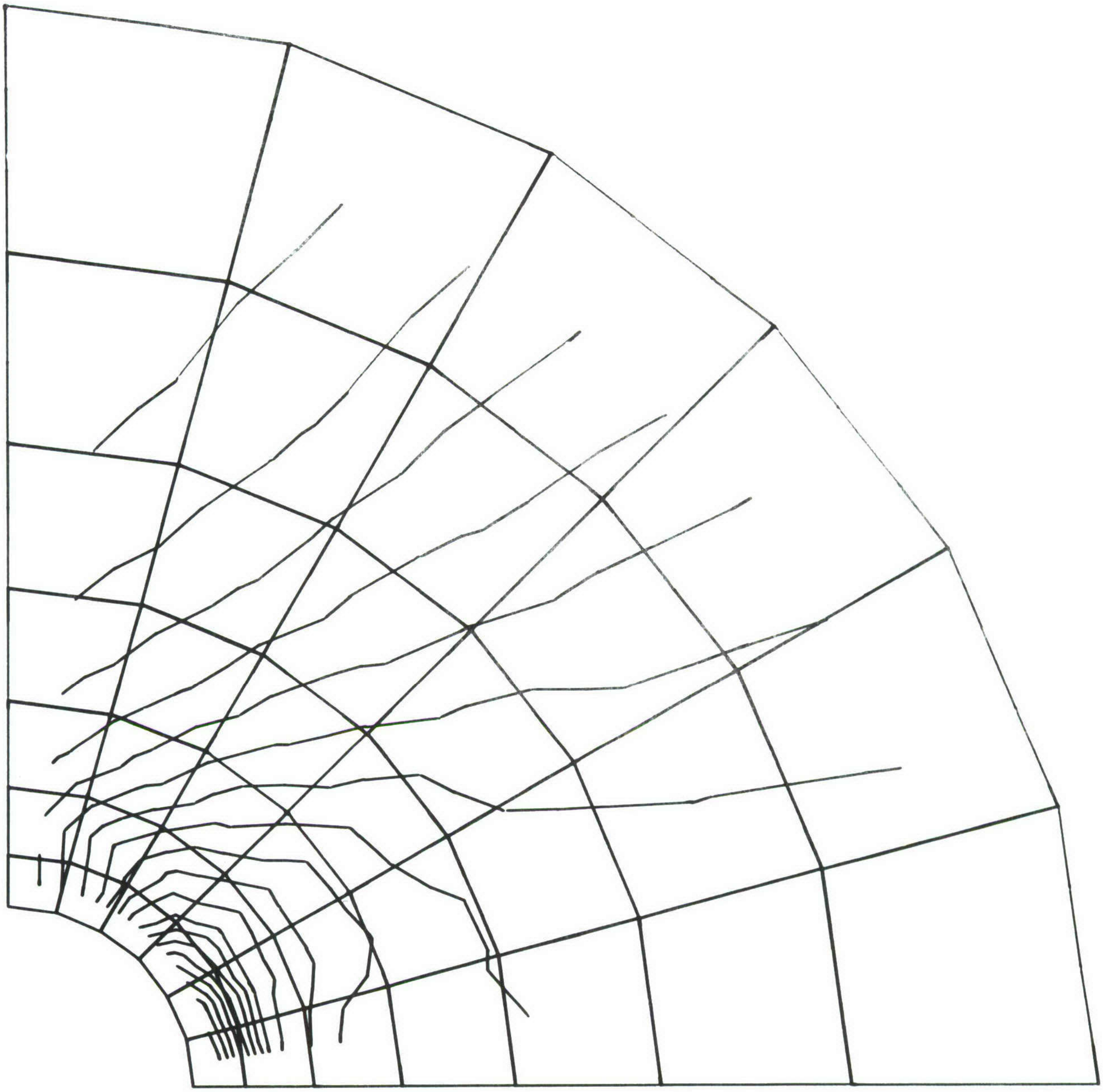


Figure AII-78 Radial Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

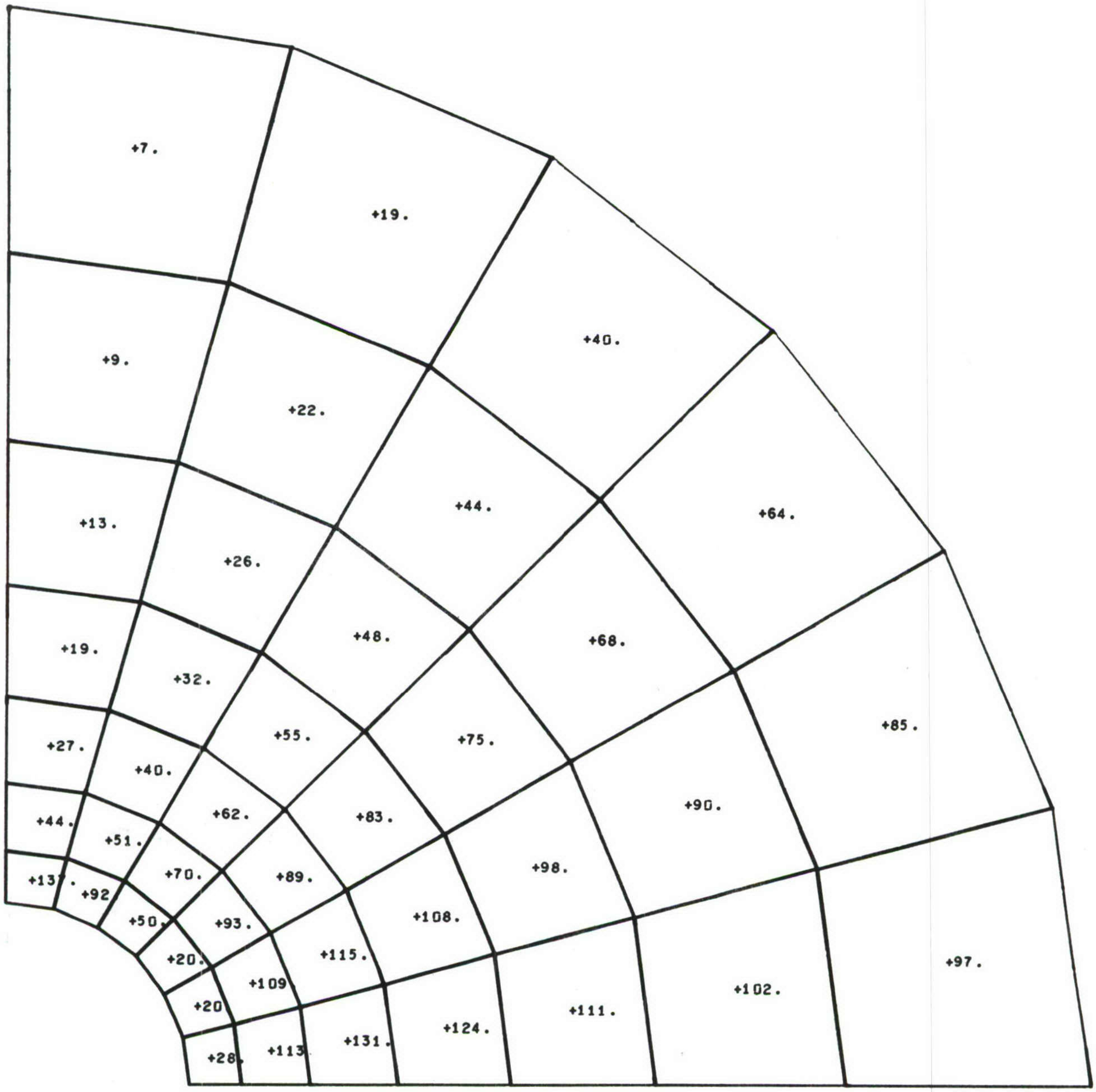


Figure AII-79 Tangential Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

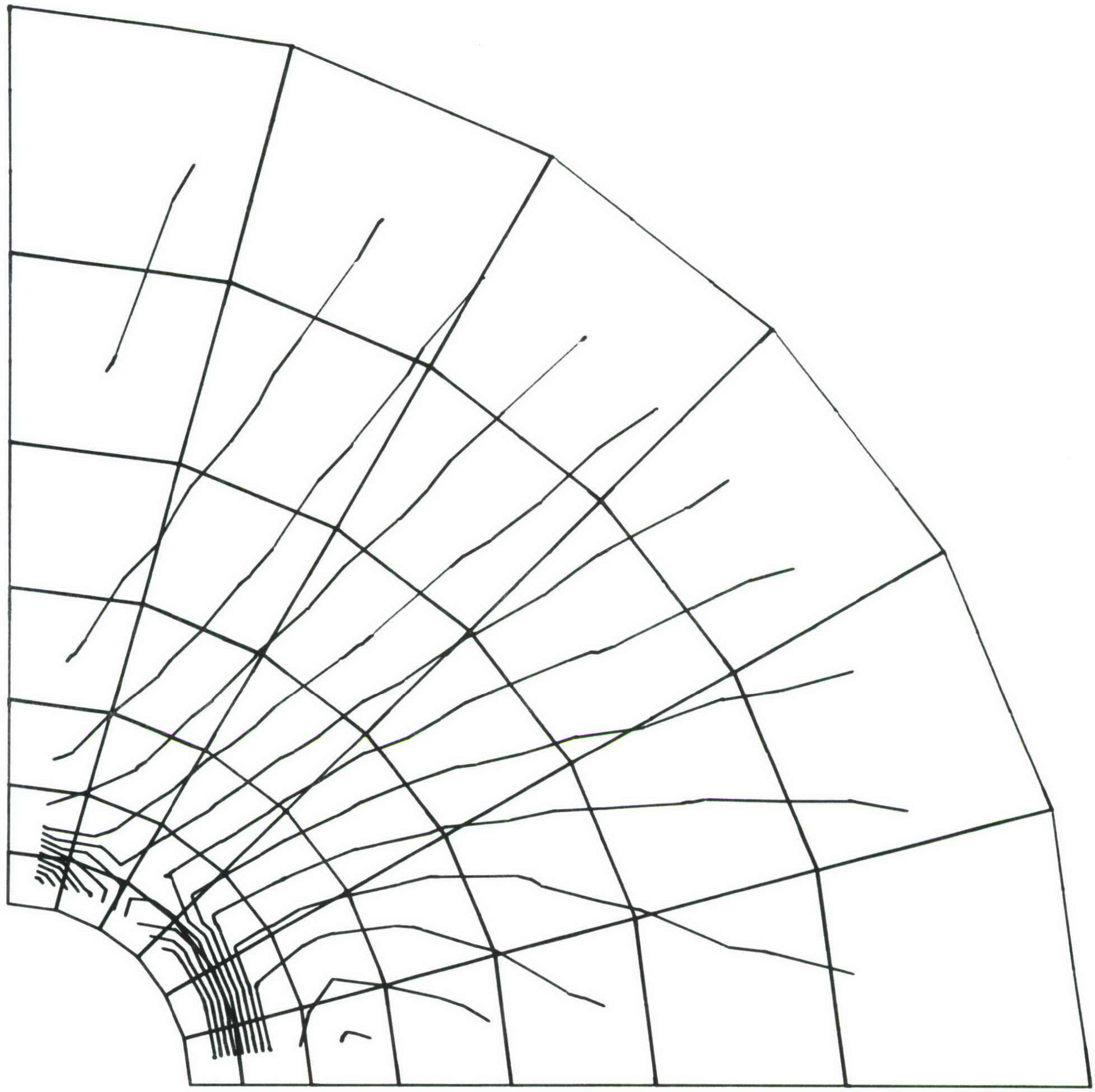


Figure AII-80 Tangential Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

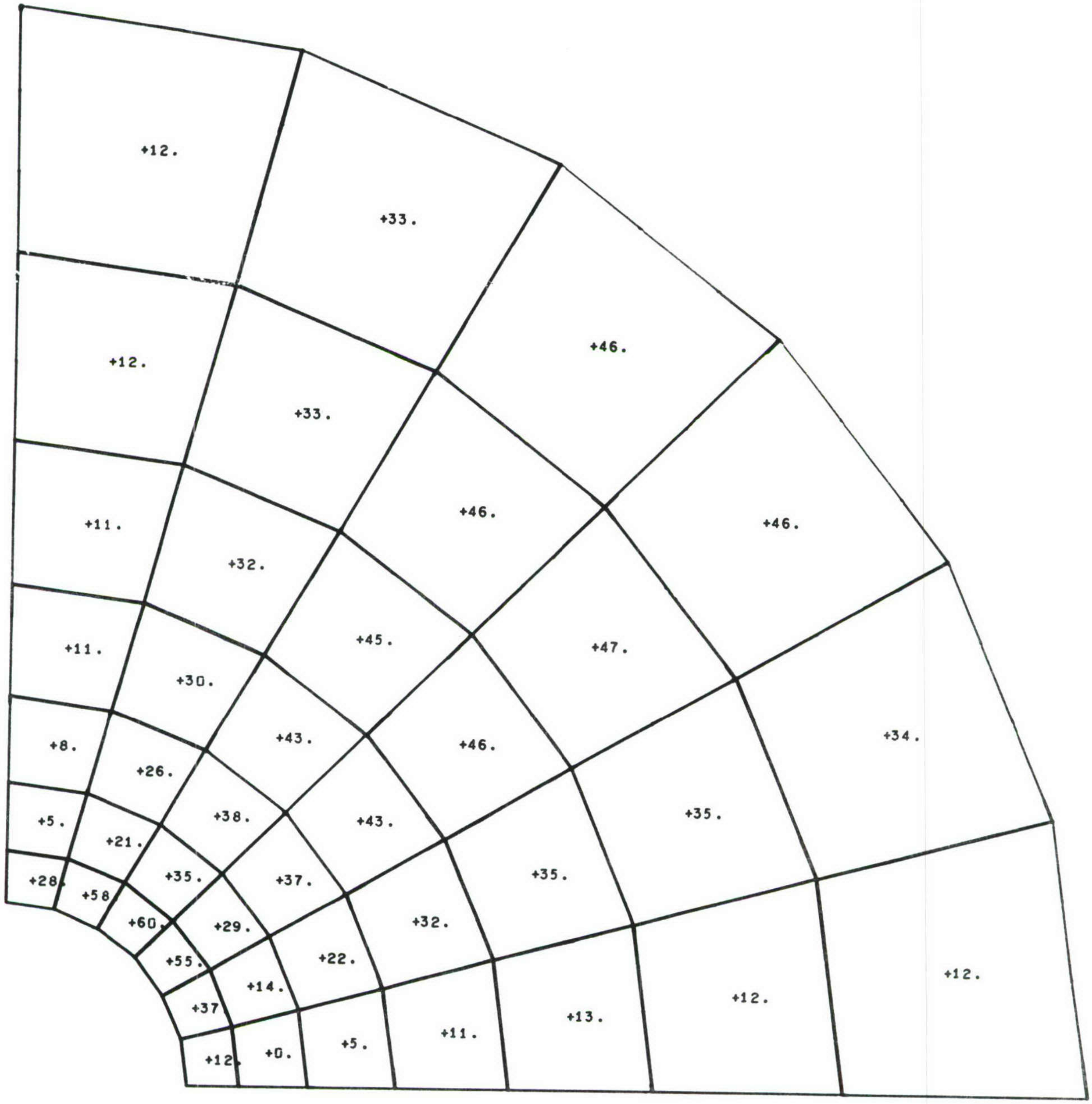


Figure AII-81 Radial-Tangential Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

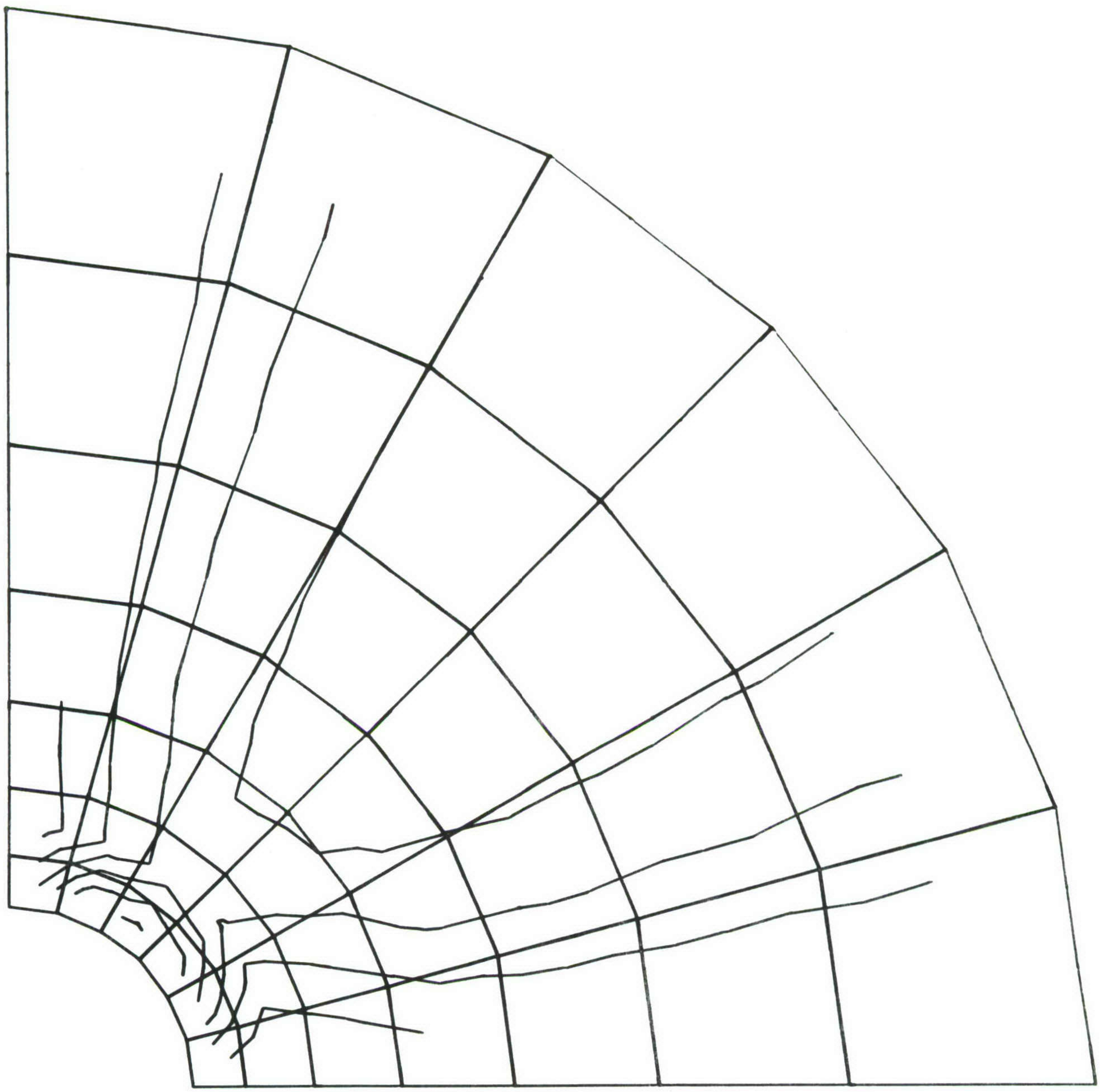


Figure AII-82 Radial-Tangential Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

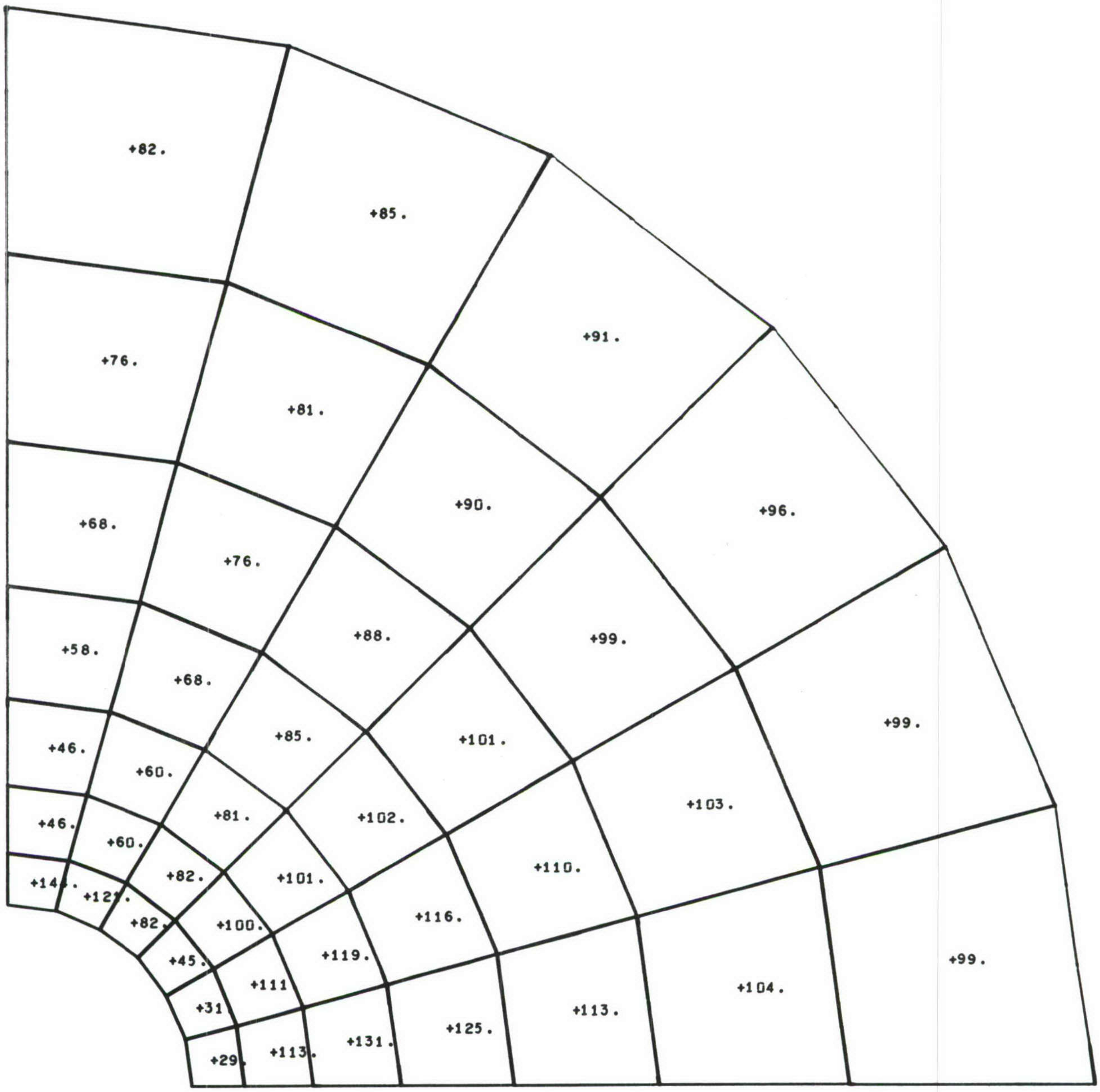


Figure AII-83 First Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

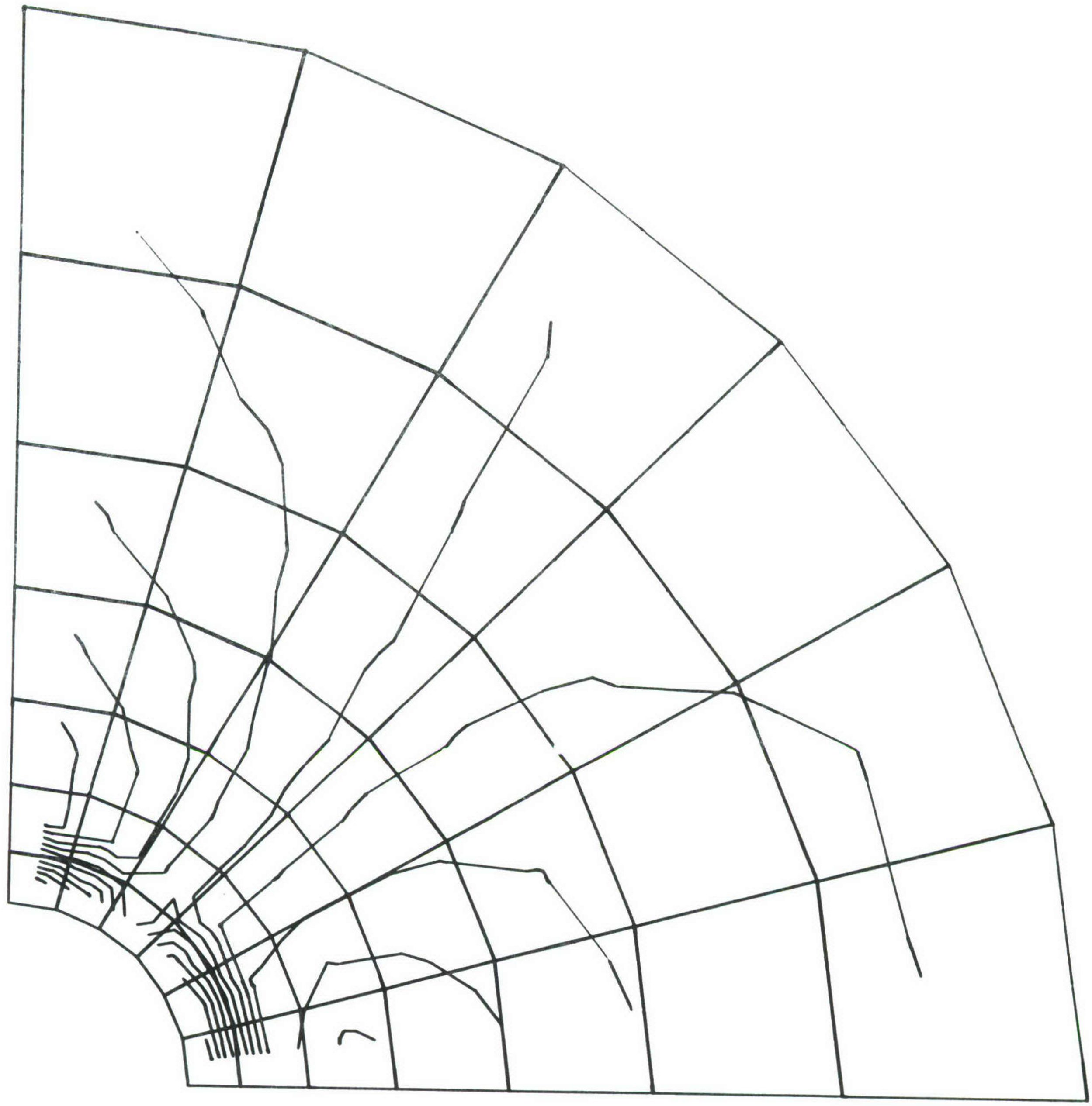


Figure AII-84 First Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

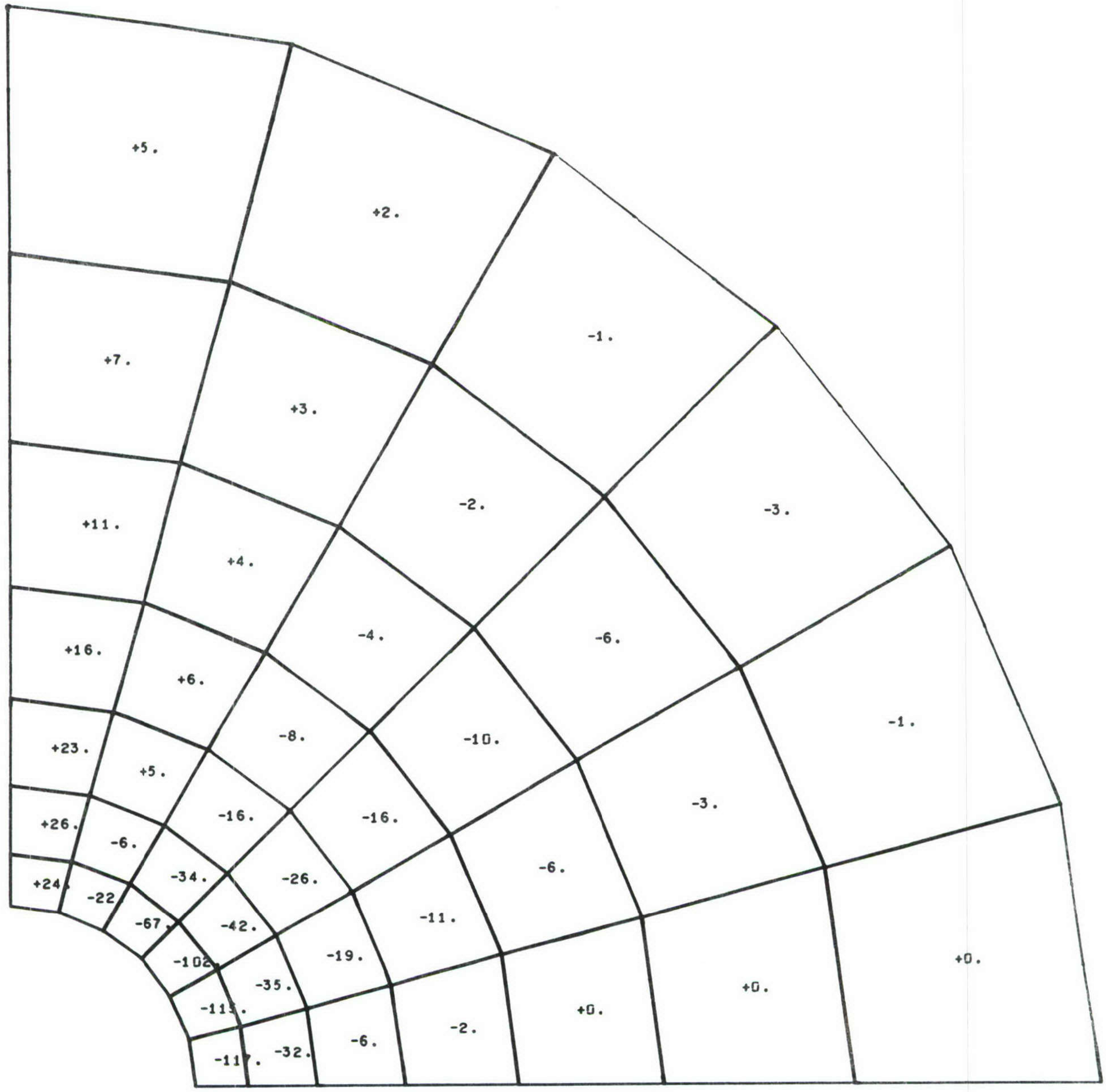


Figure AII-85 Second Principal Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

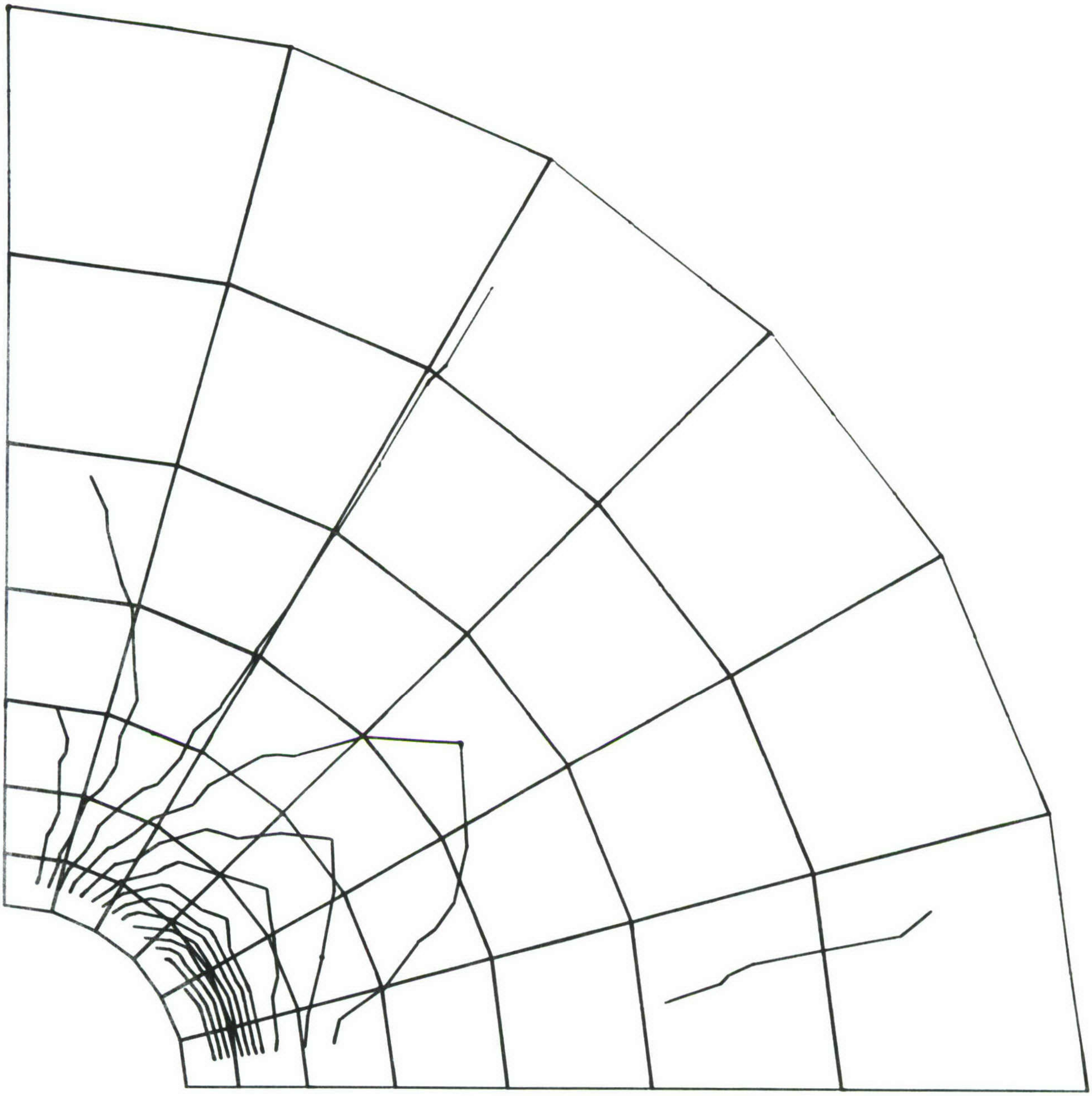


Figure AII-86 Second Principal Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

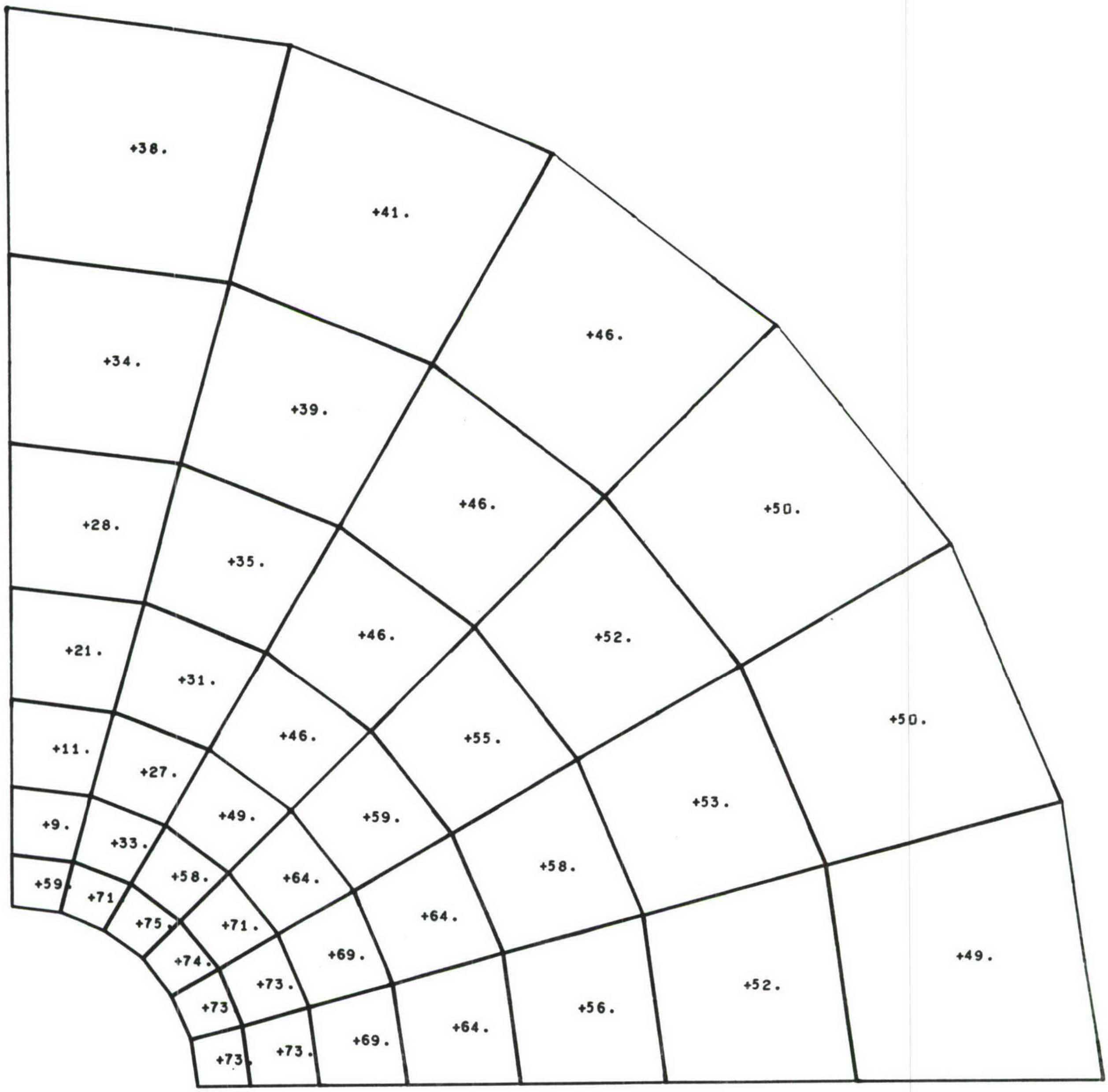


Figure AII-87 Principal Shear Stress Values for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

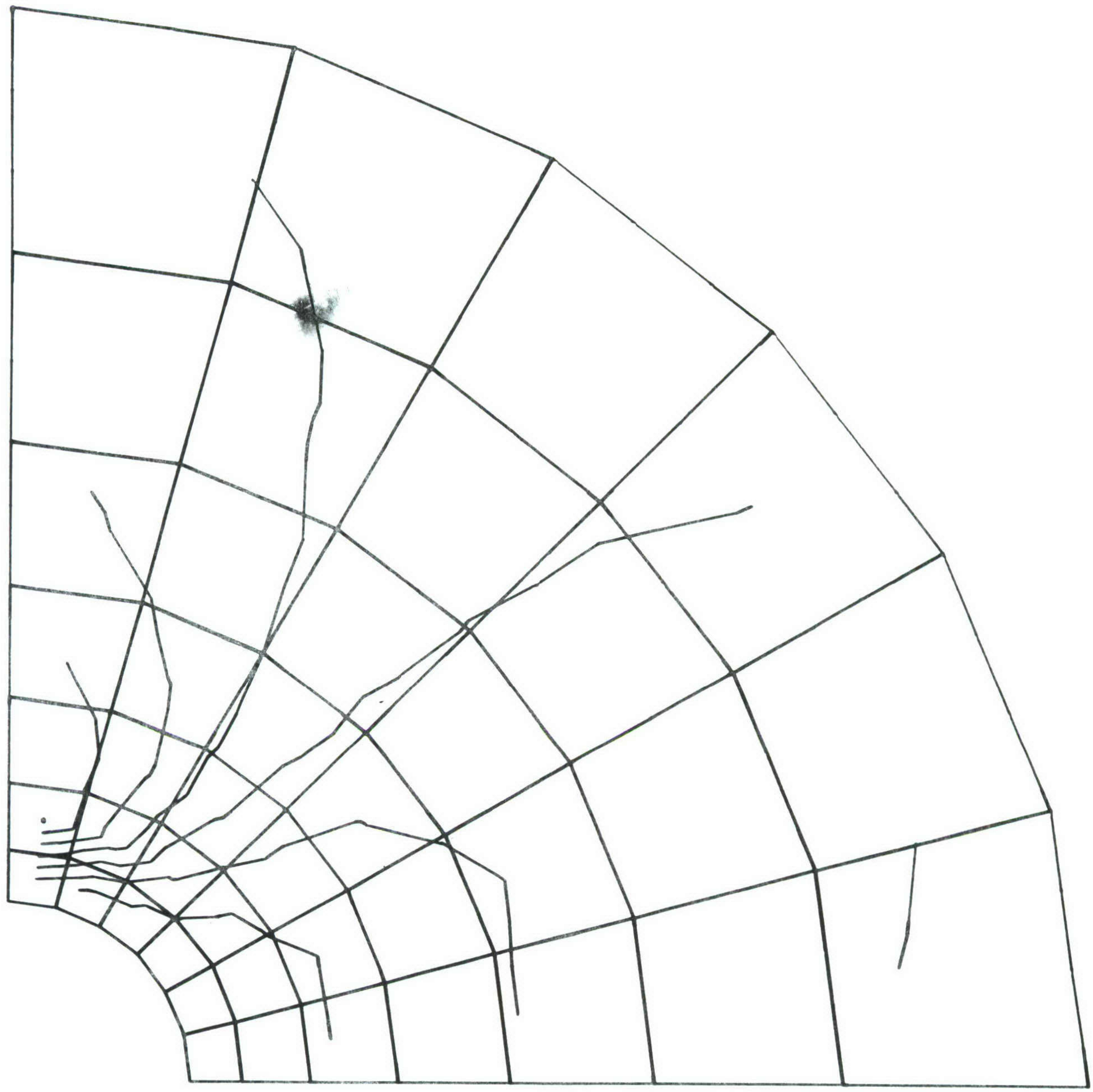


Figure AII-88 Principal Shear Stress Contours for Titanium Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

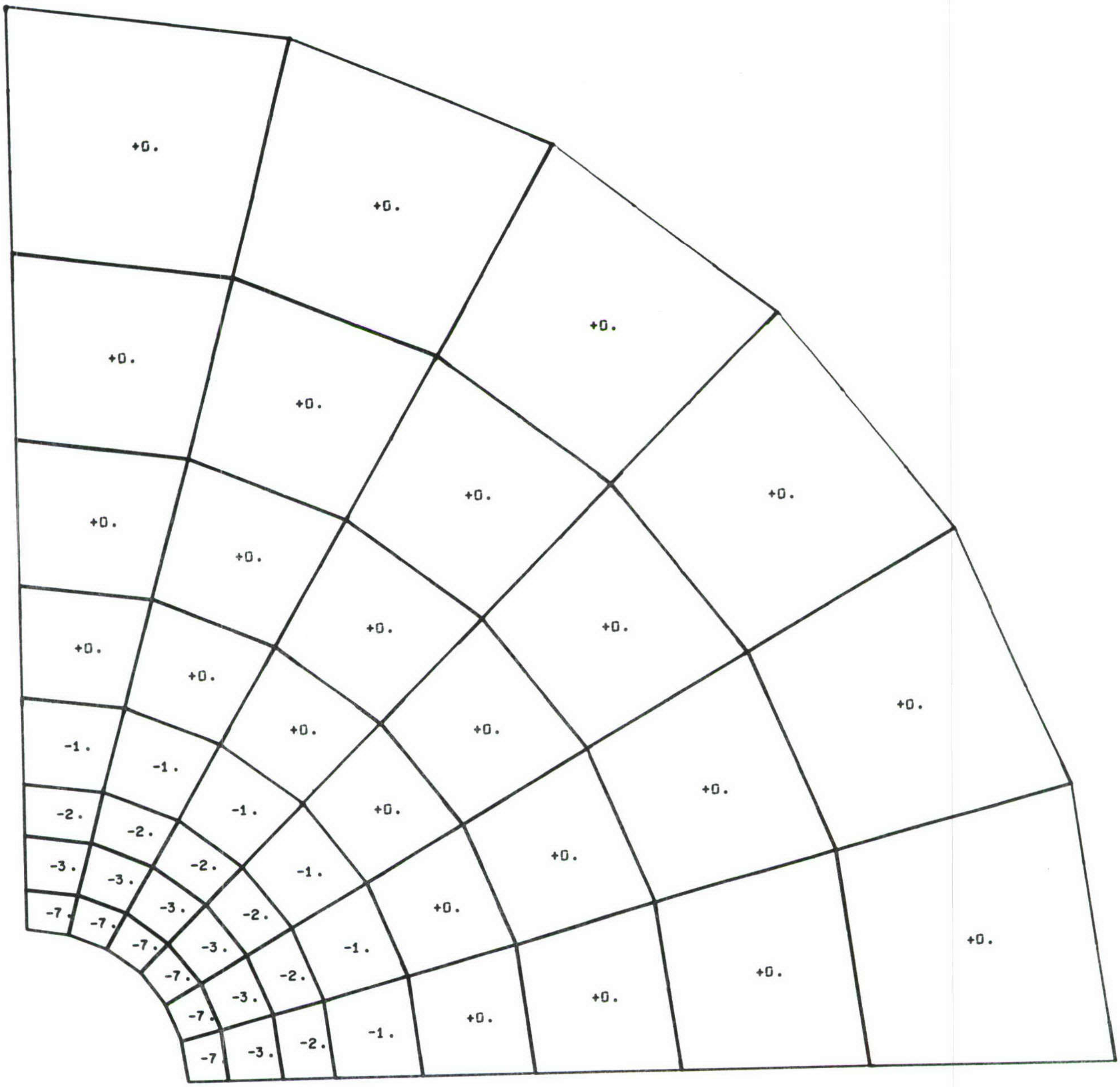


Figure AII-89 Radial Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

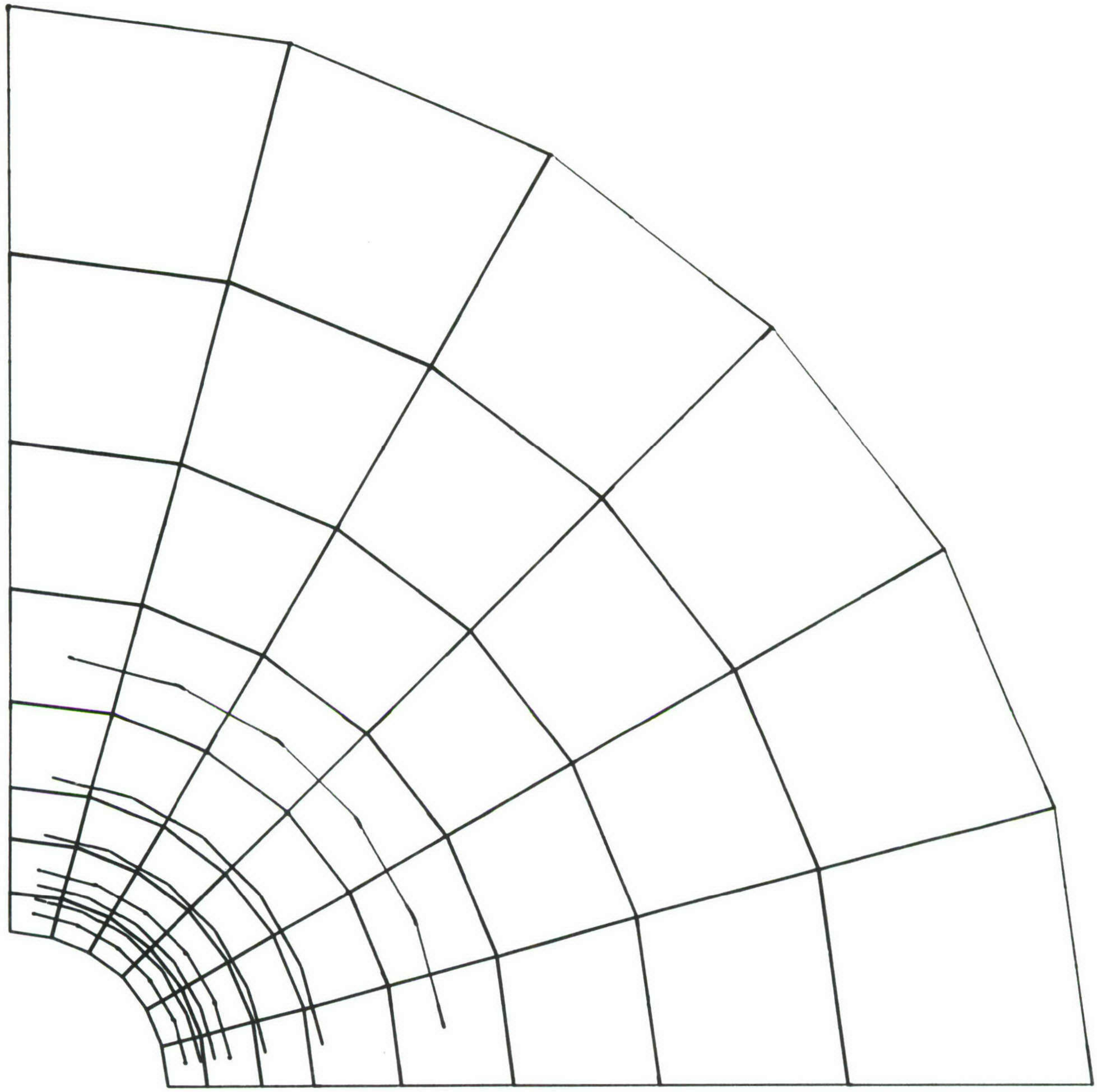


Figure AII-90 Radial Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

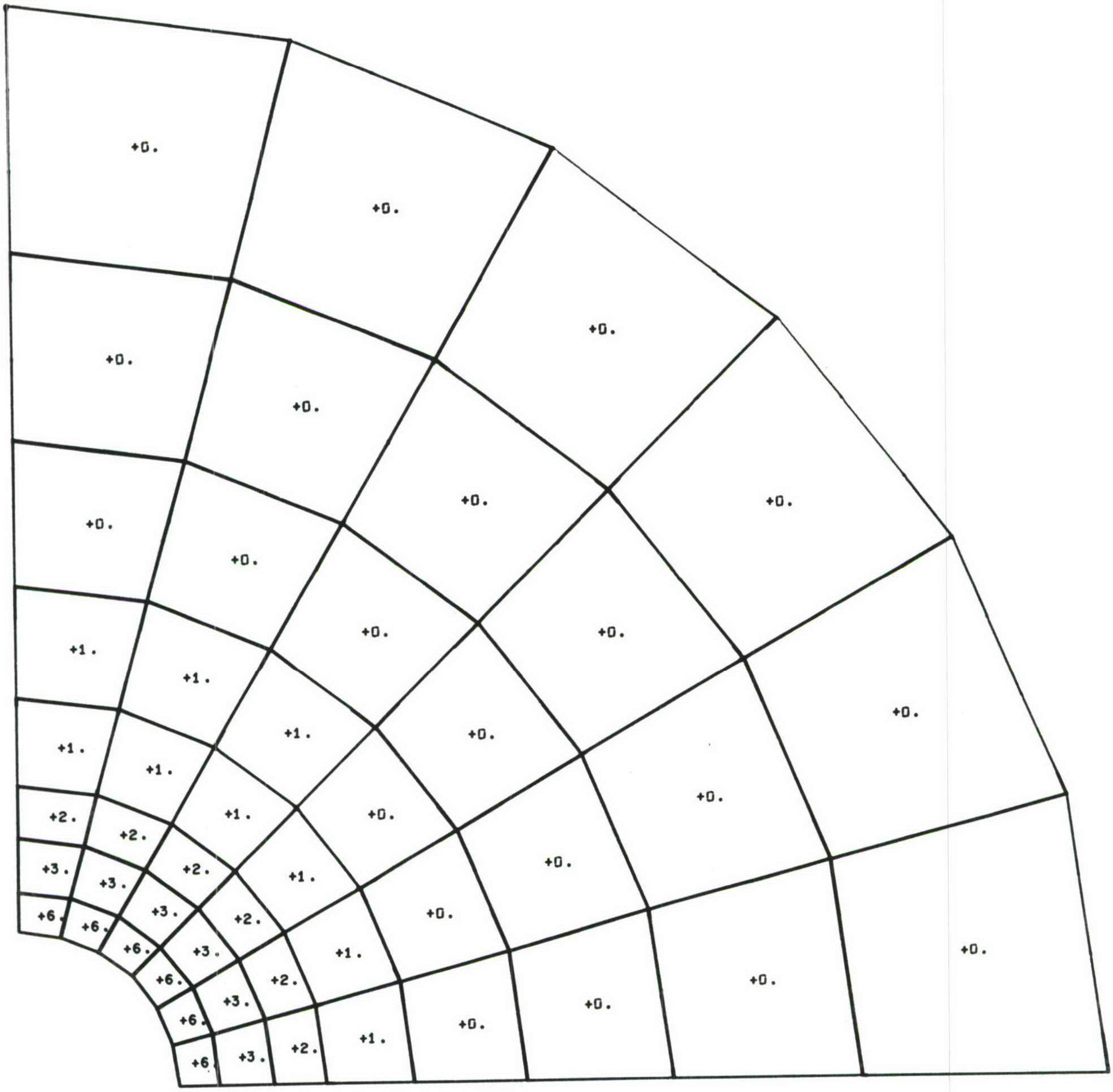


Figure AII-91 Tangential Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference: No Uniaxial Load

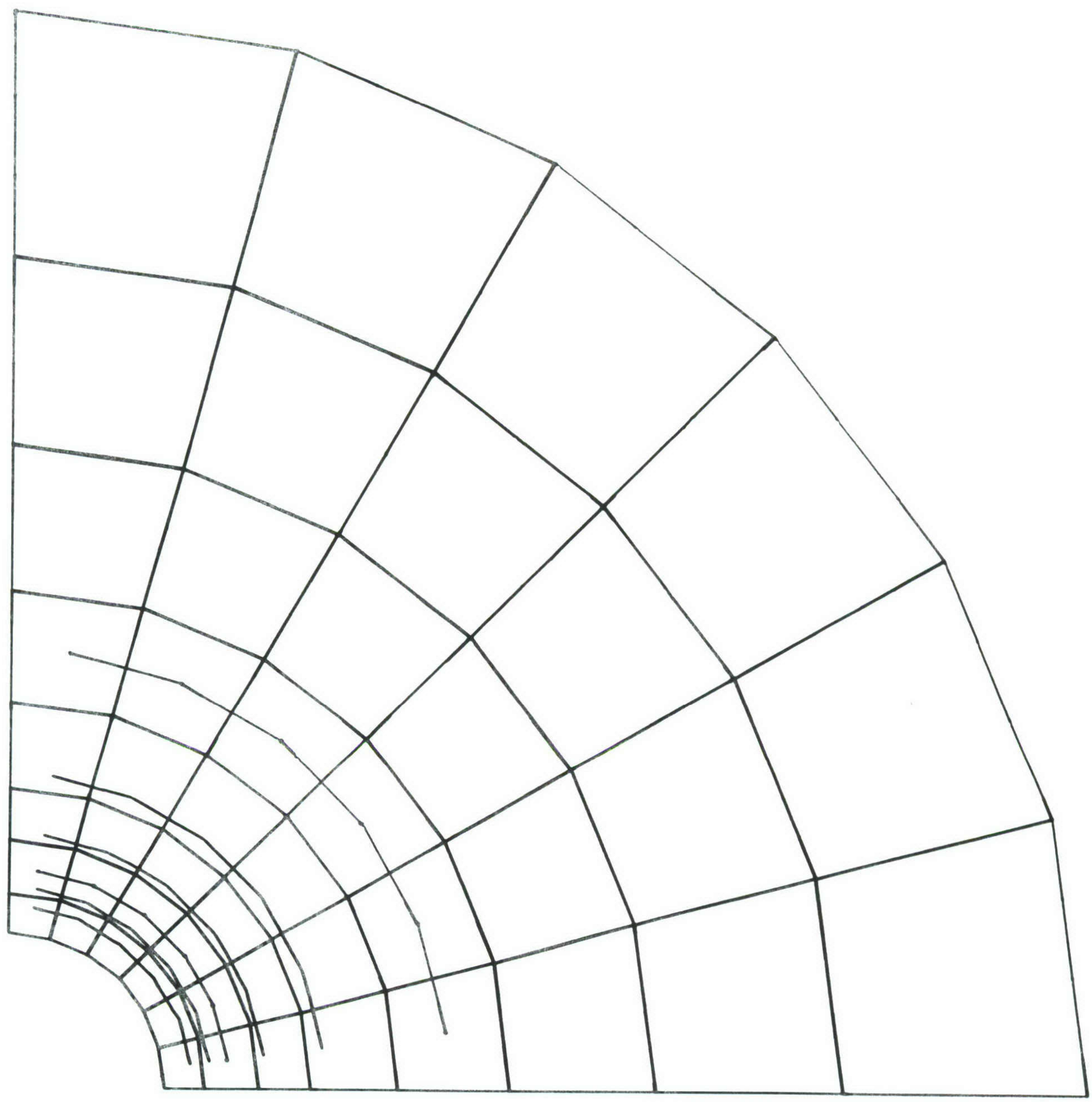


Figure AII-92 Tangential Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

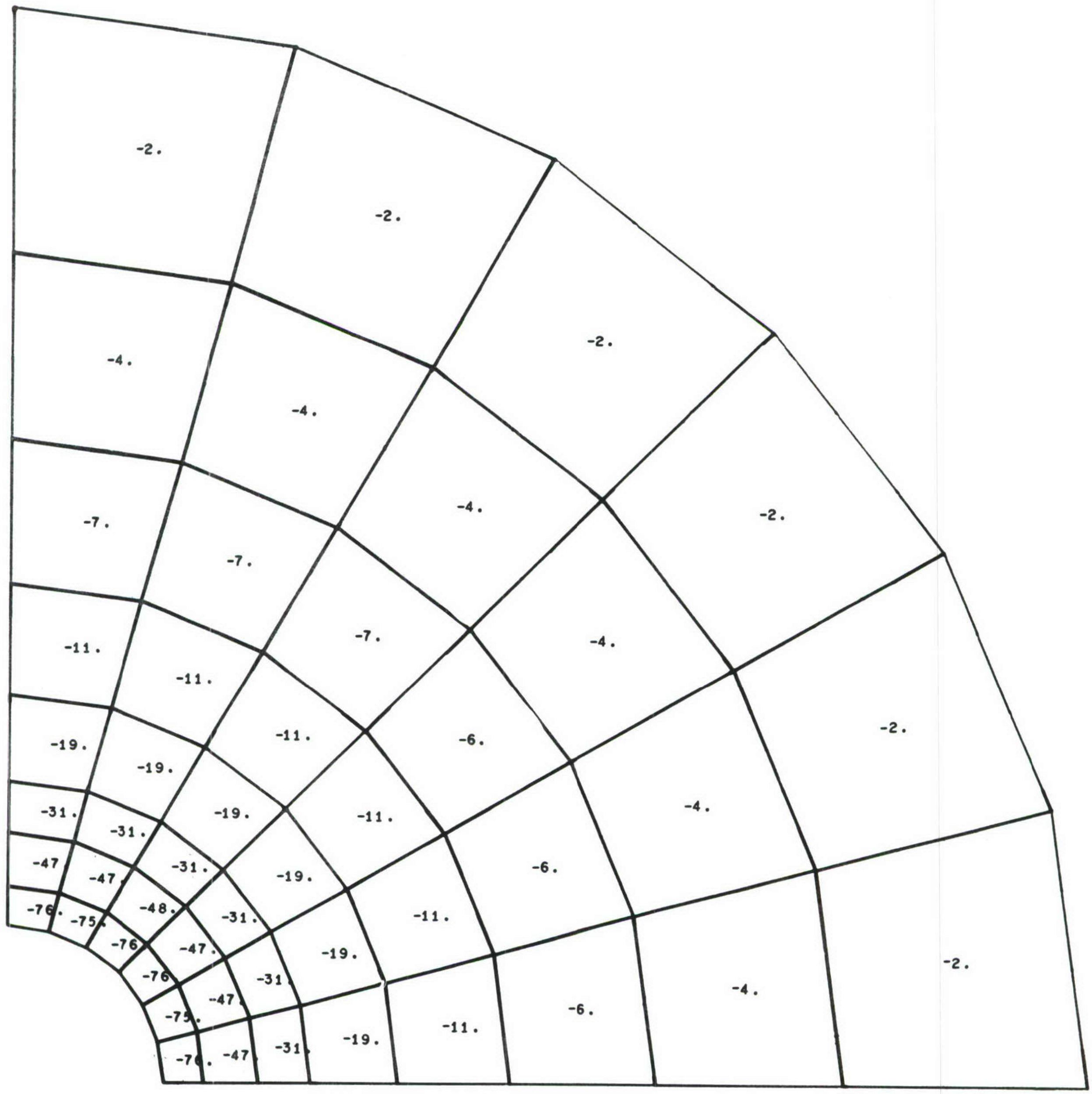


Figure AII-93 Radial Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

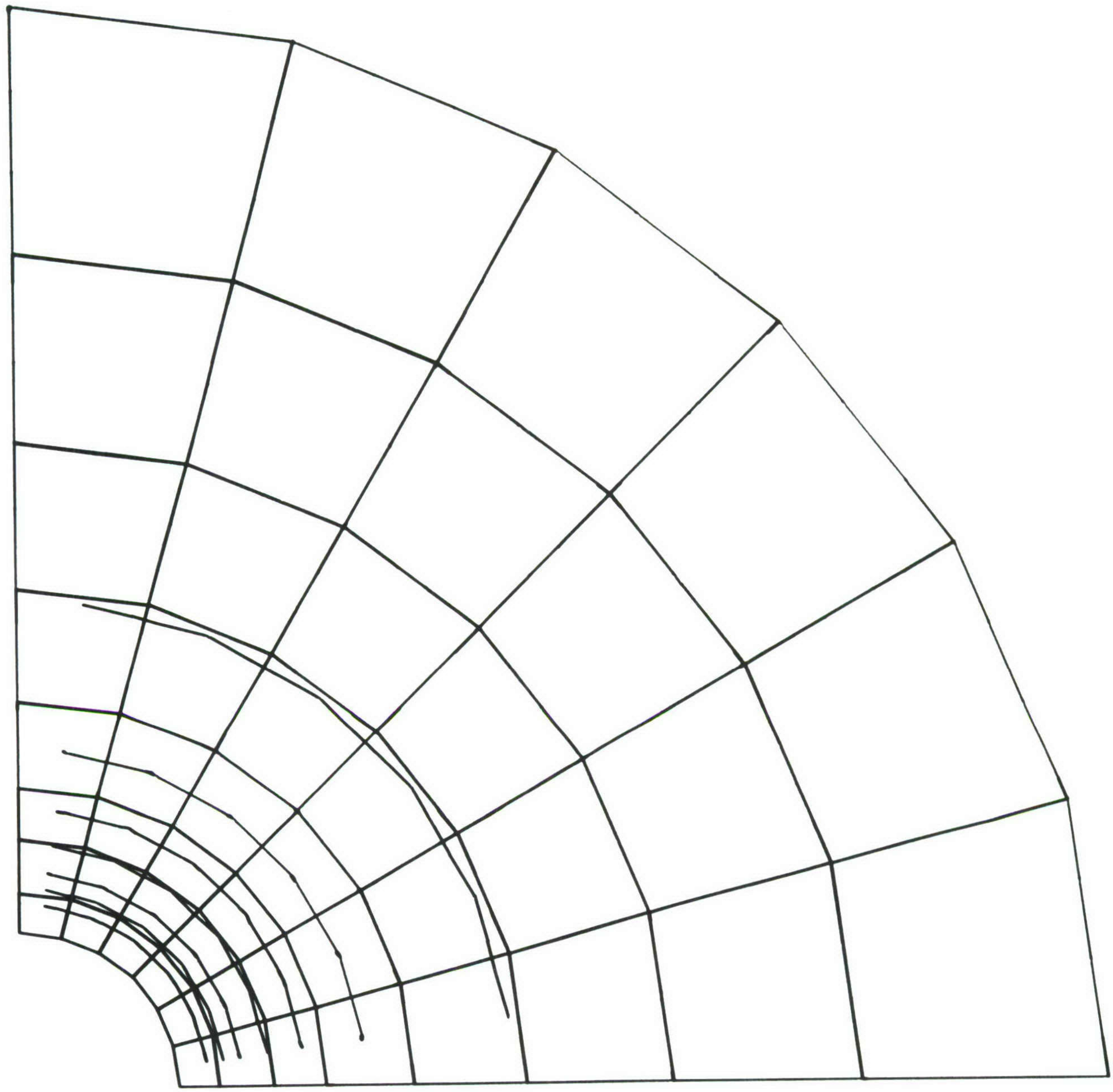


Figure AII-94 Radial Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference: No Uniaxial Load

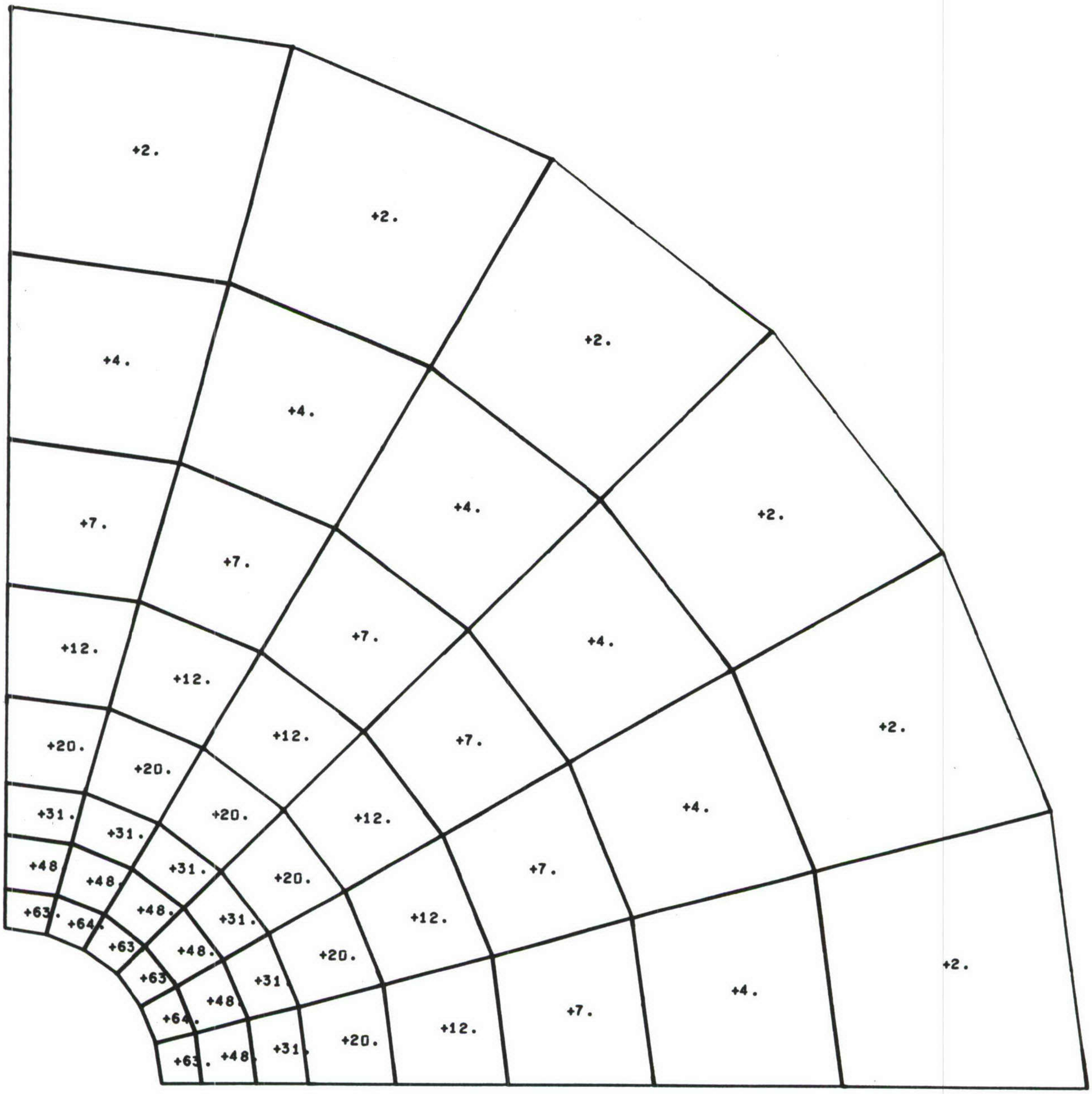


Figure AII-95 Tangential Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

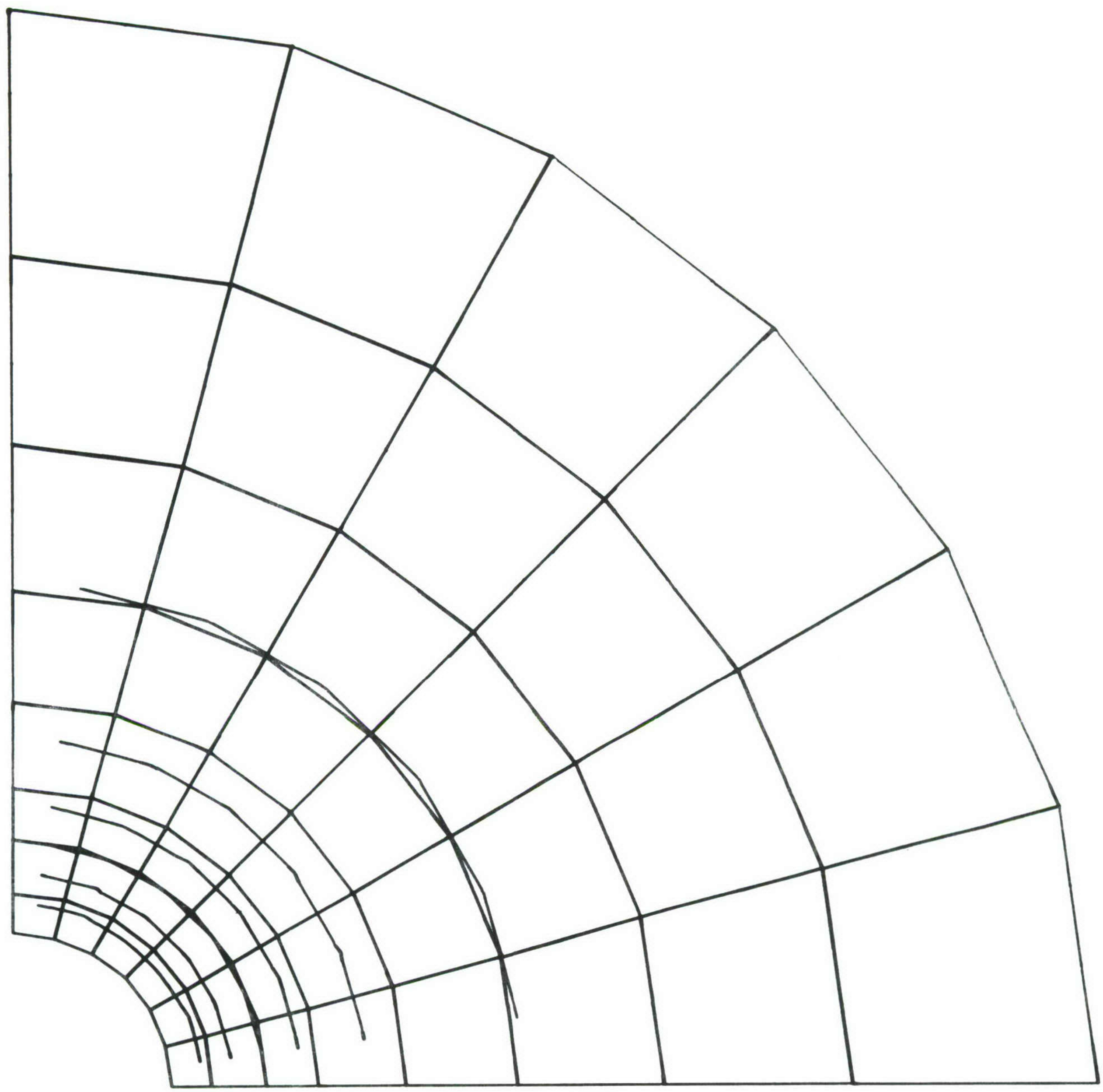


Figure AII-96 Tangential Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

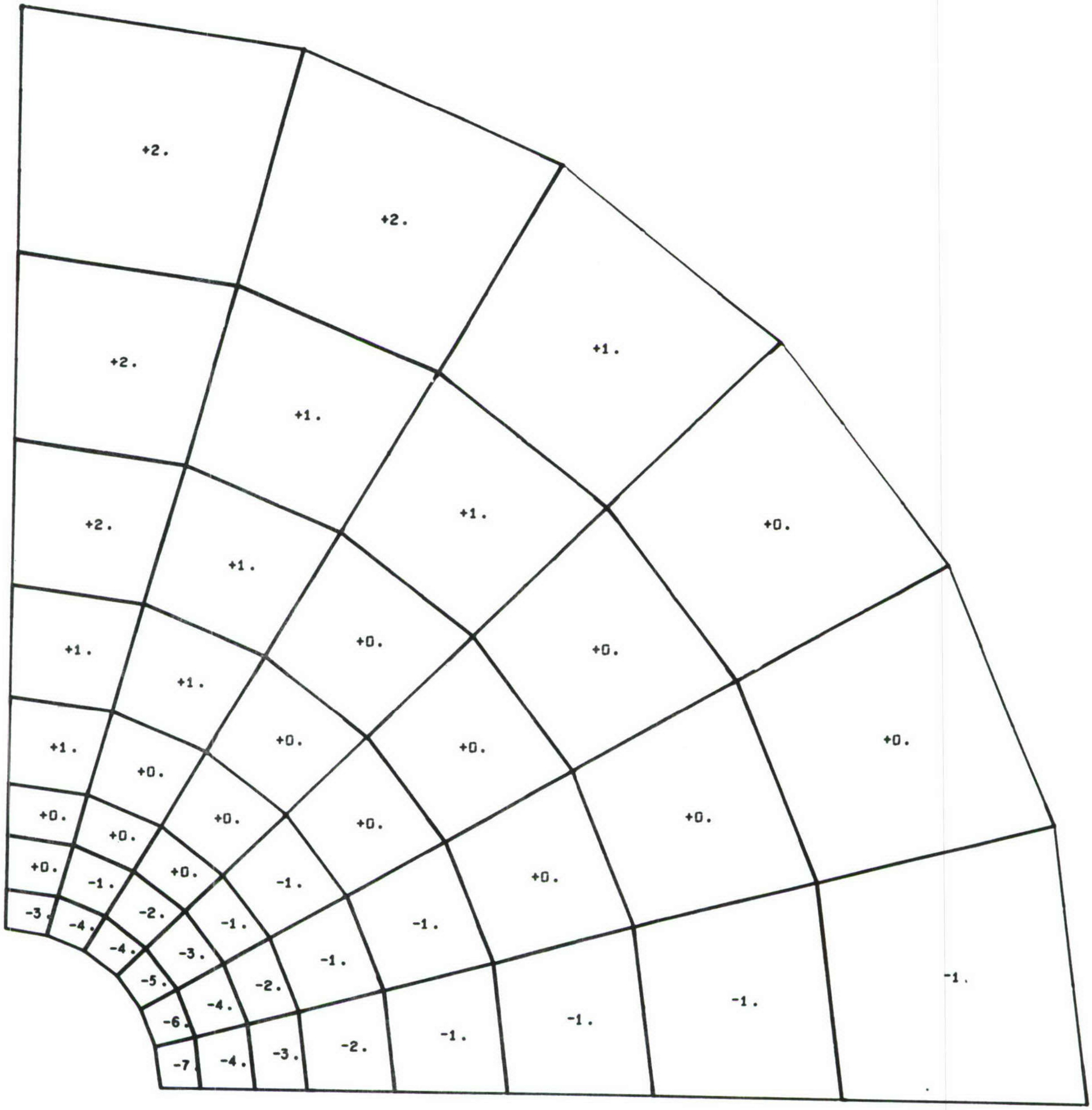


Figure AII-97 Radial Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

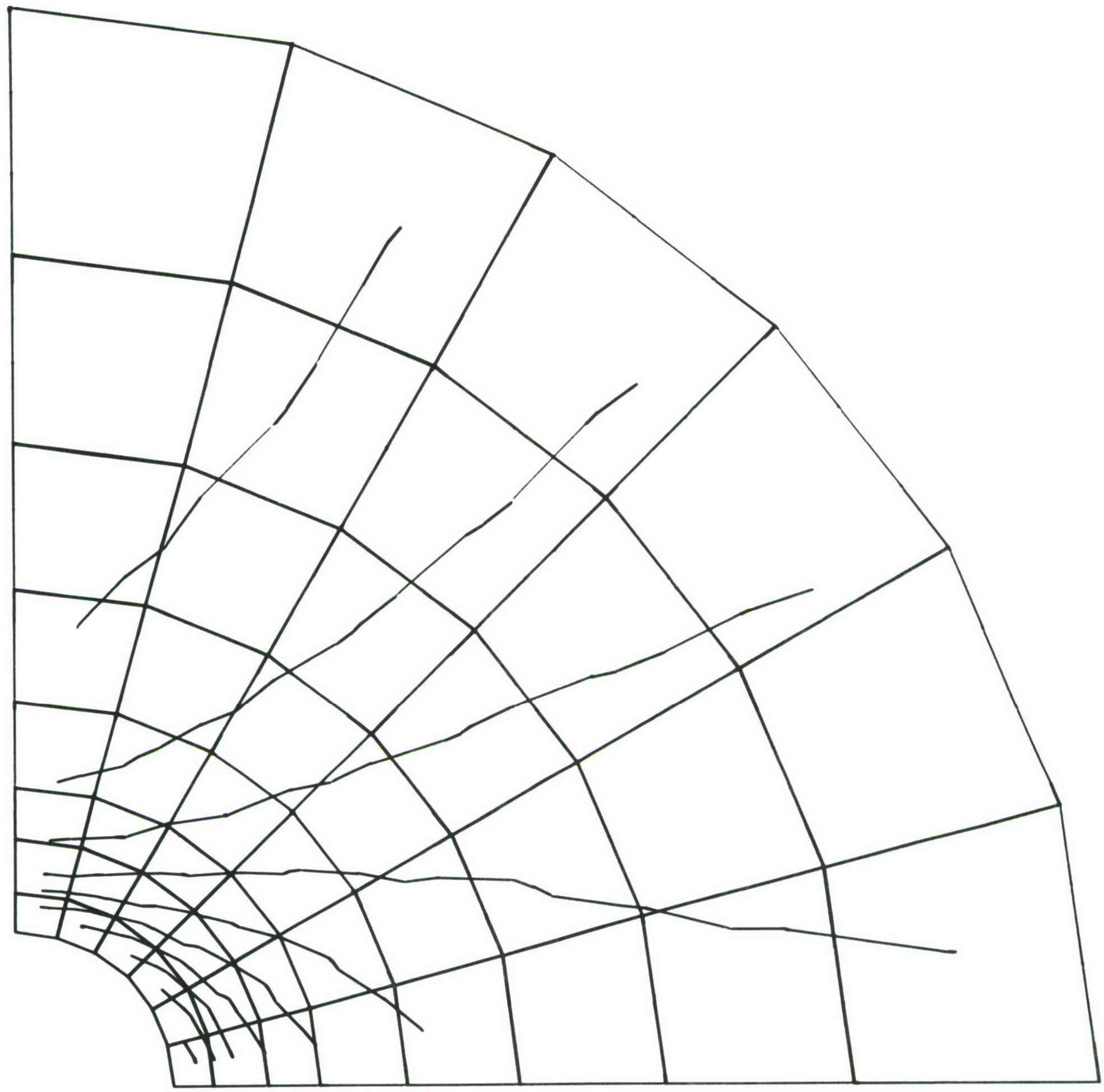


Figure AII-98 Radial Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

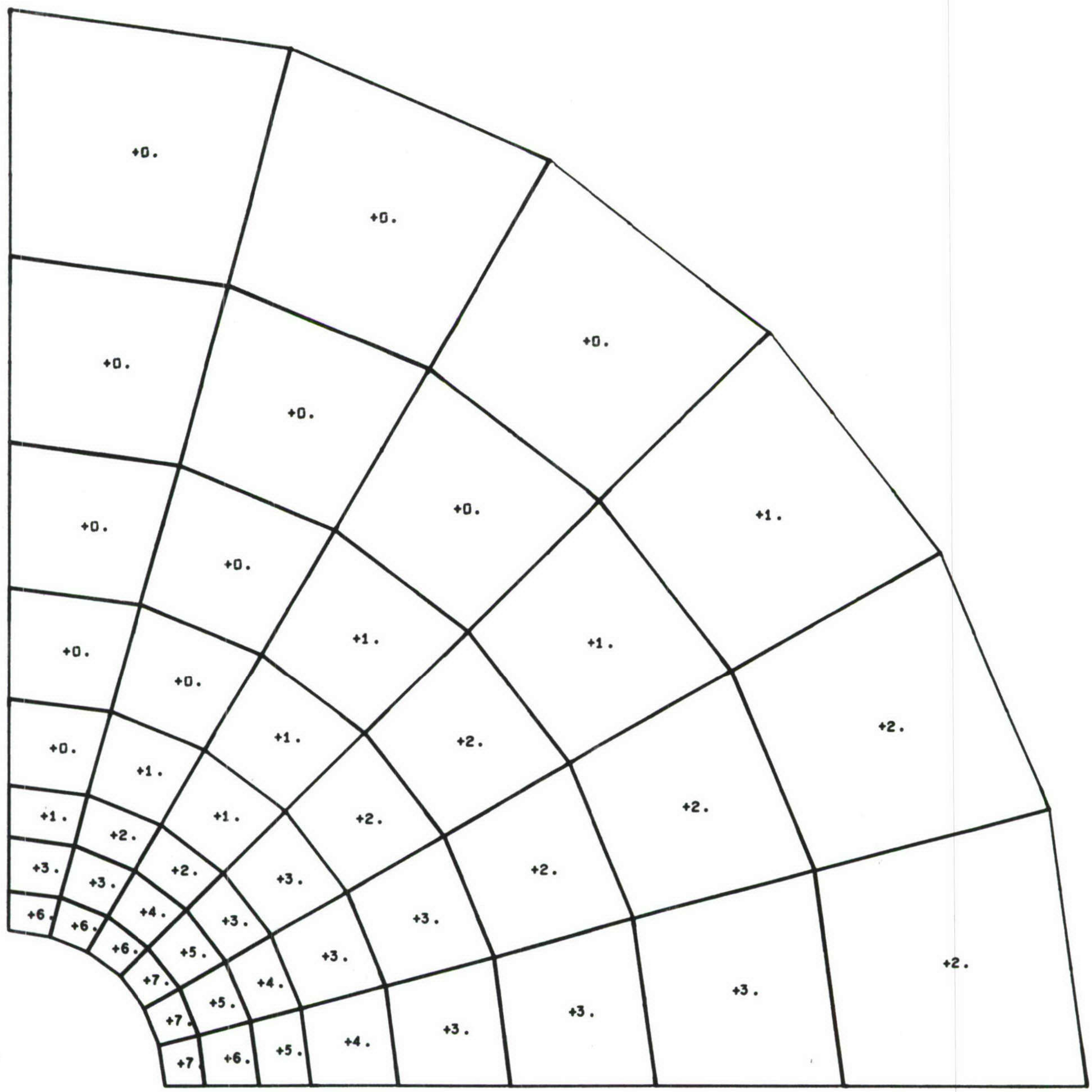


Figure AII-99 Tangential Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

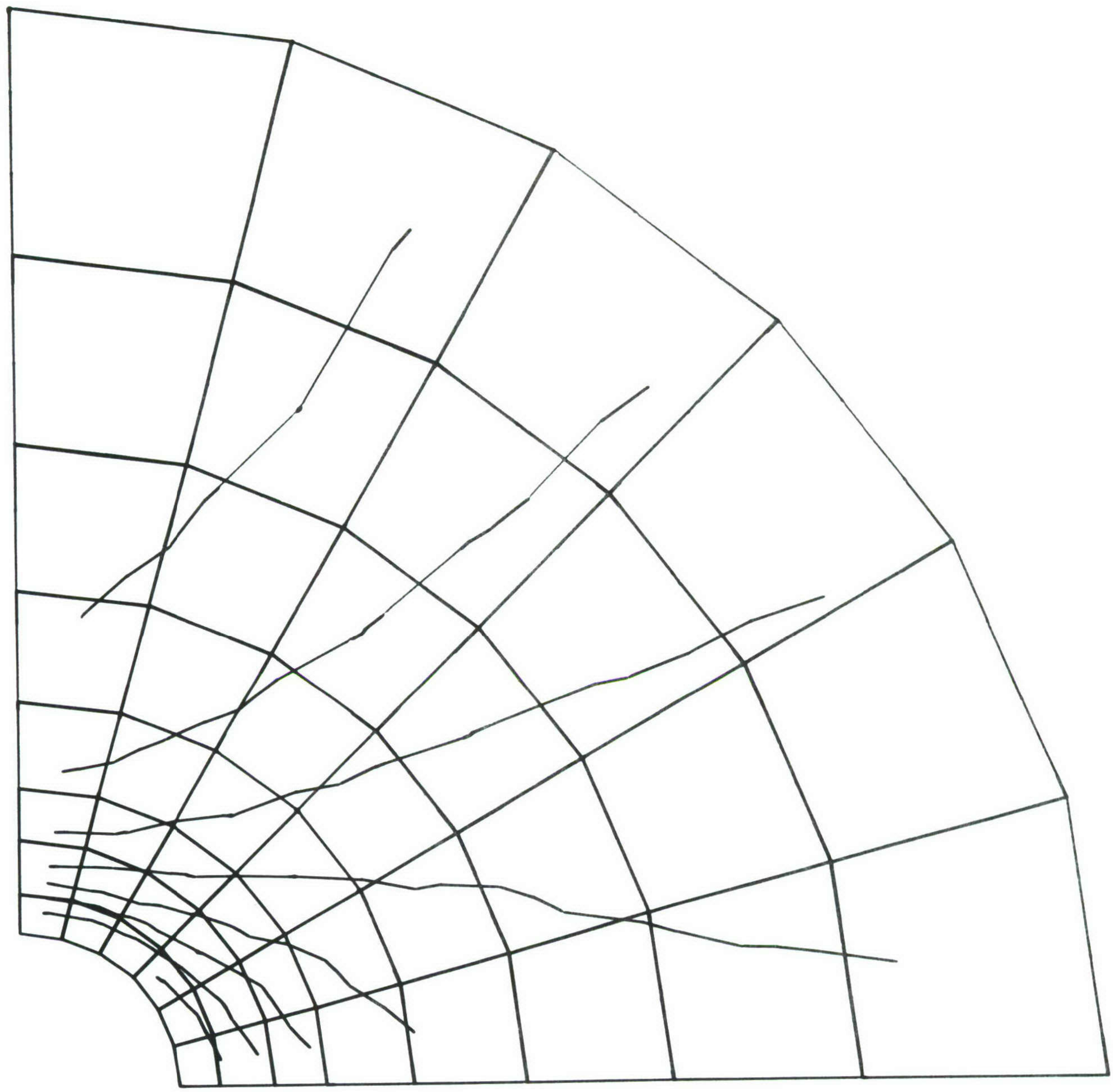


Figure AII-100 Tangential Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

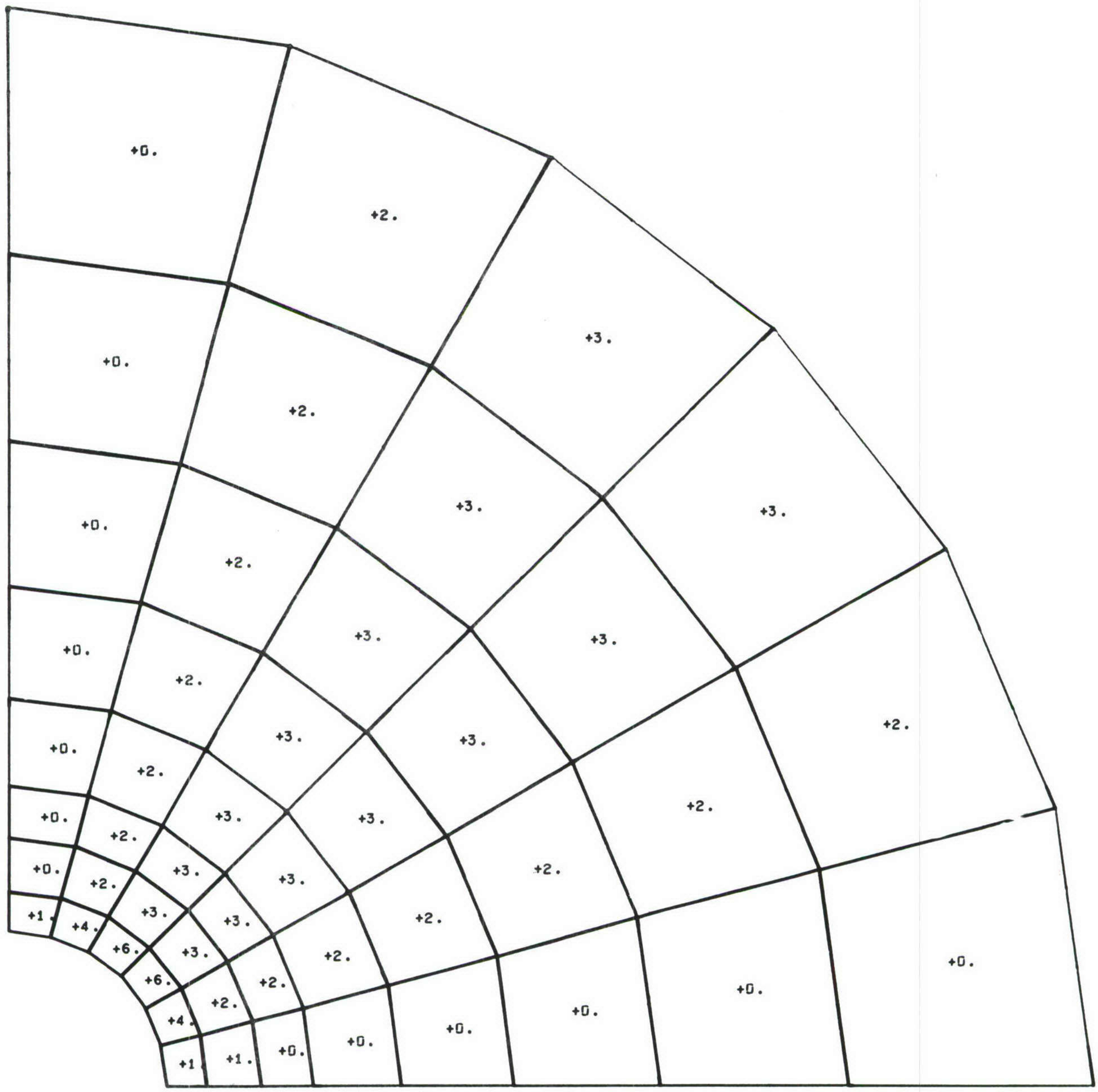


Figure AII-101 Radial-Tangential Shear Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

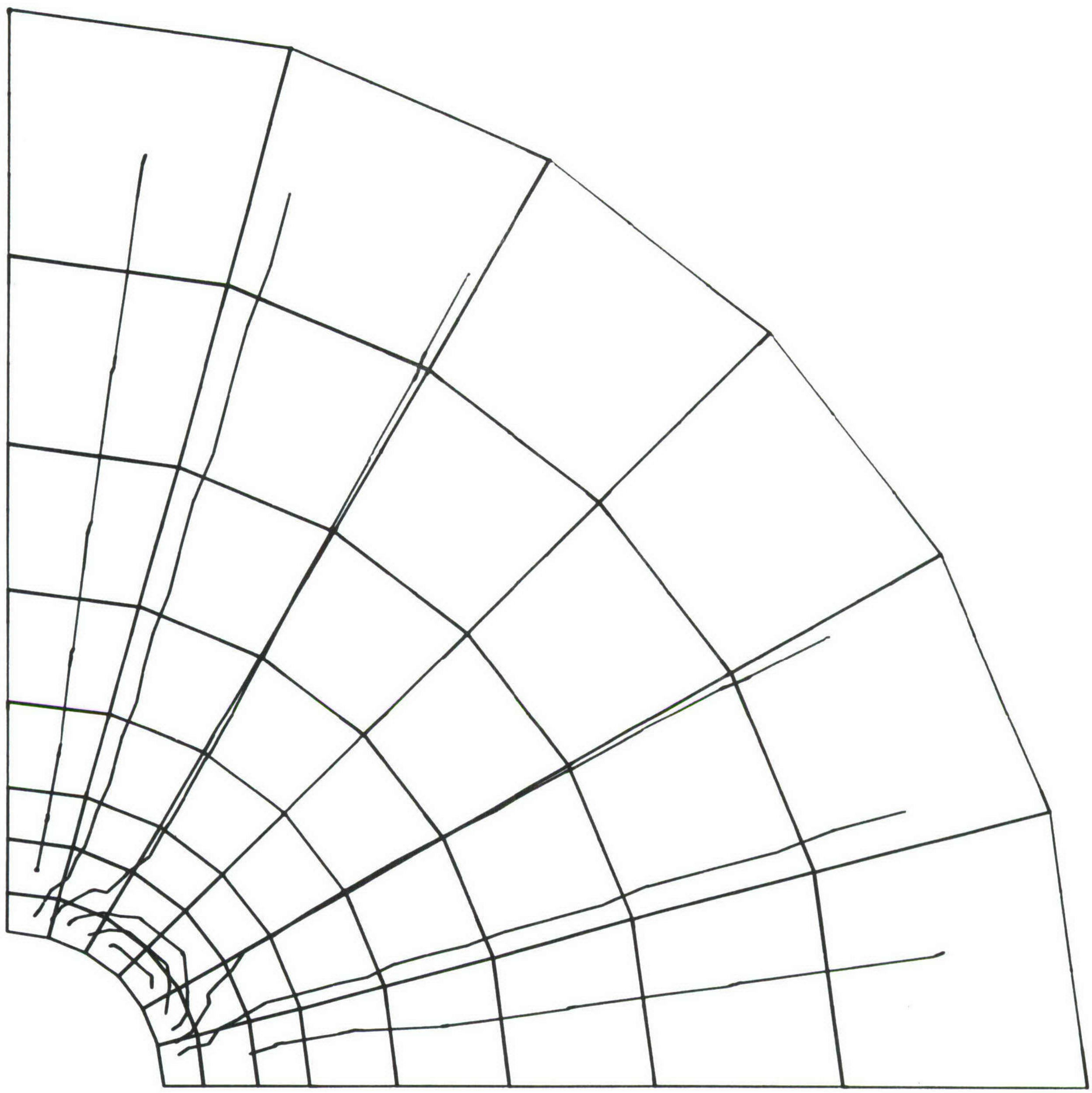


Figure AII-102 Radial-Tangential Shear Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

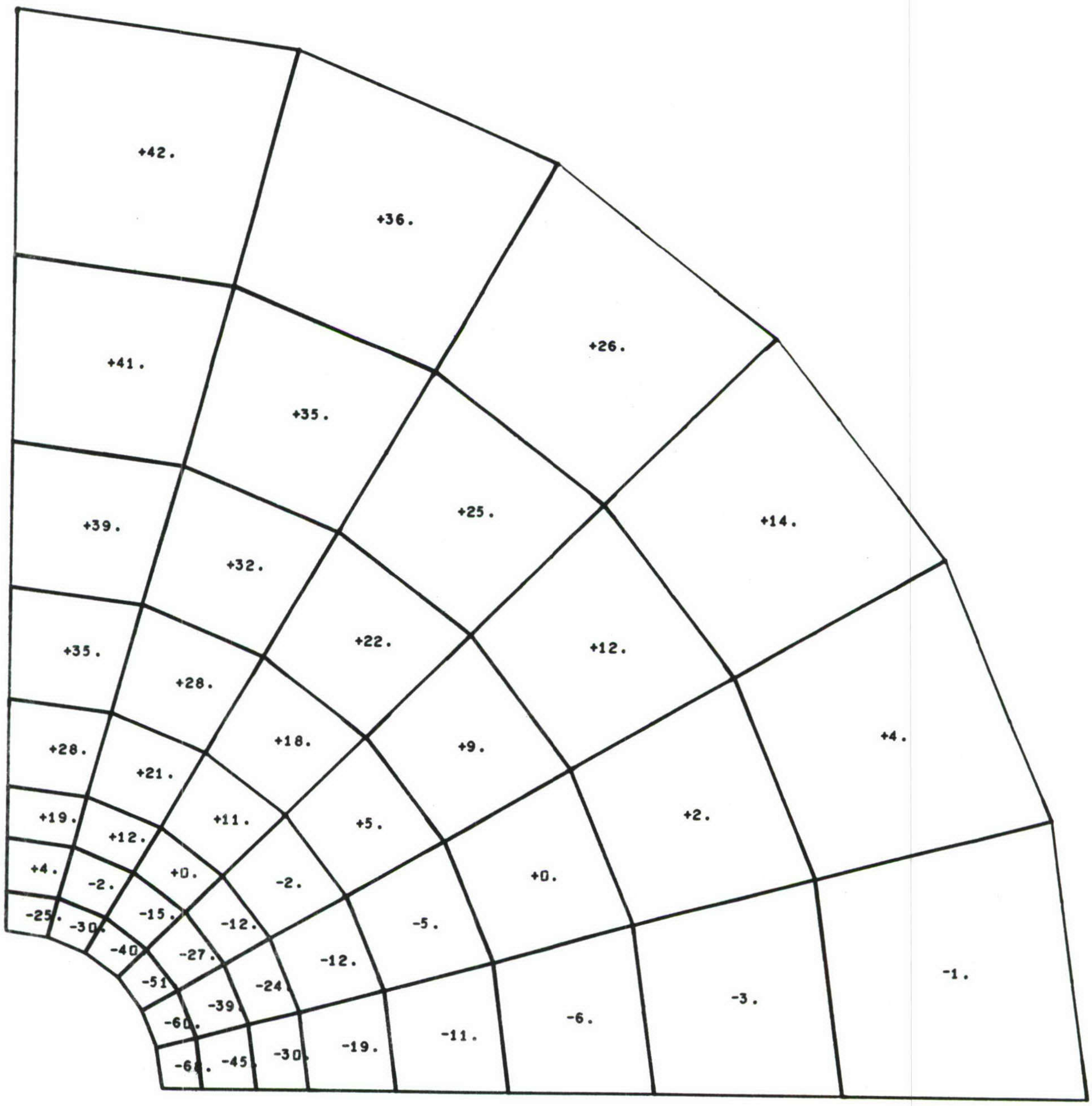


Figure AII-103 Radial Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

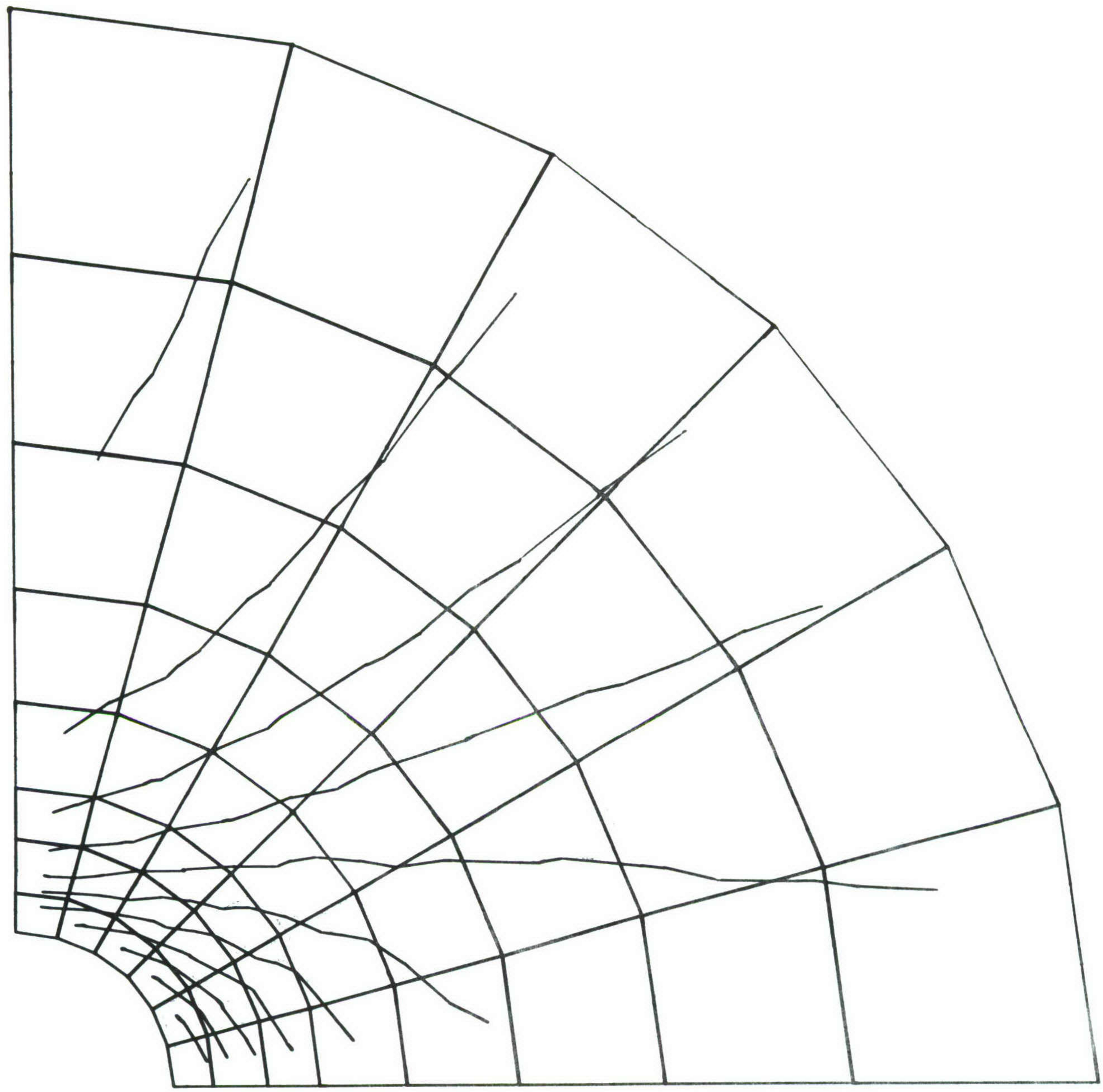


Figure AII-104 Radial Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

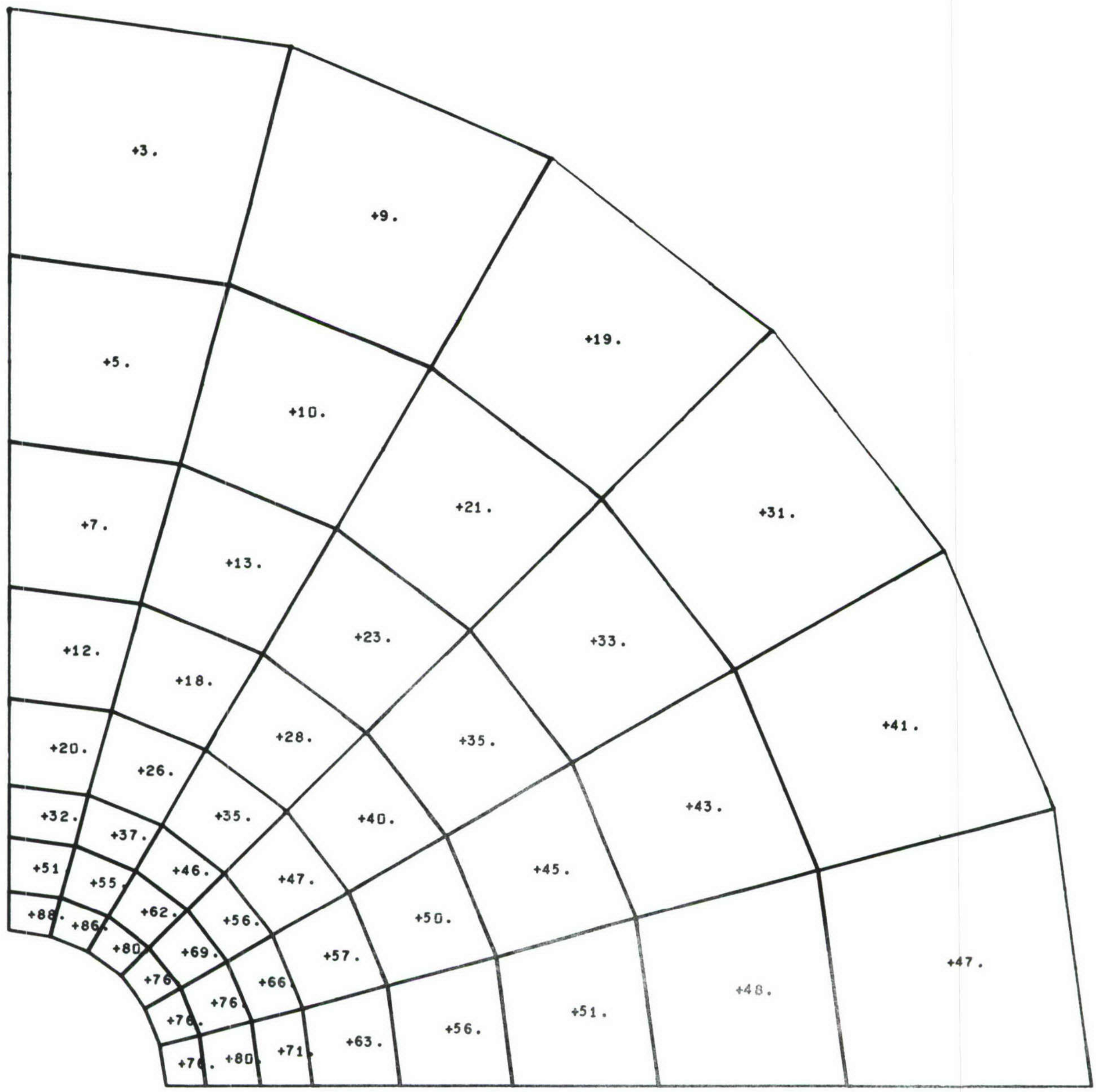


Figure AII-105 Tangential Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

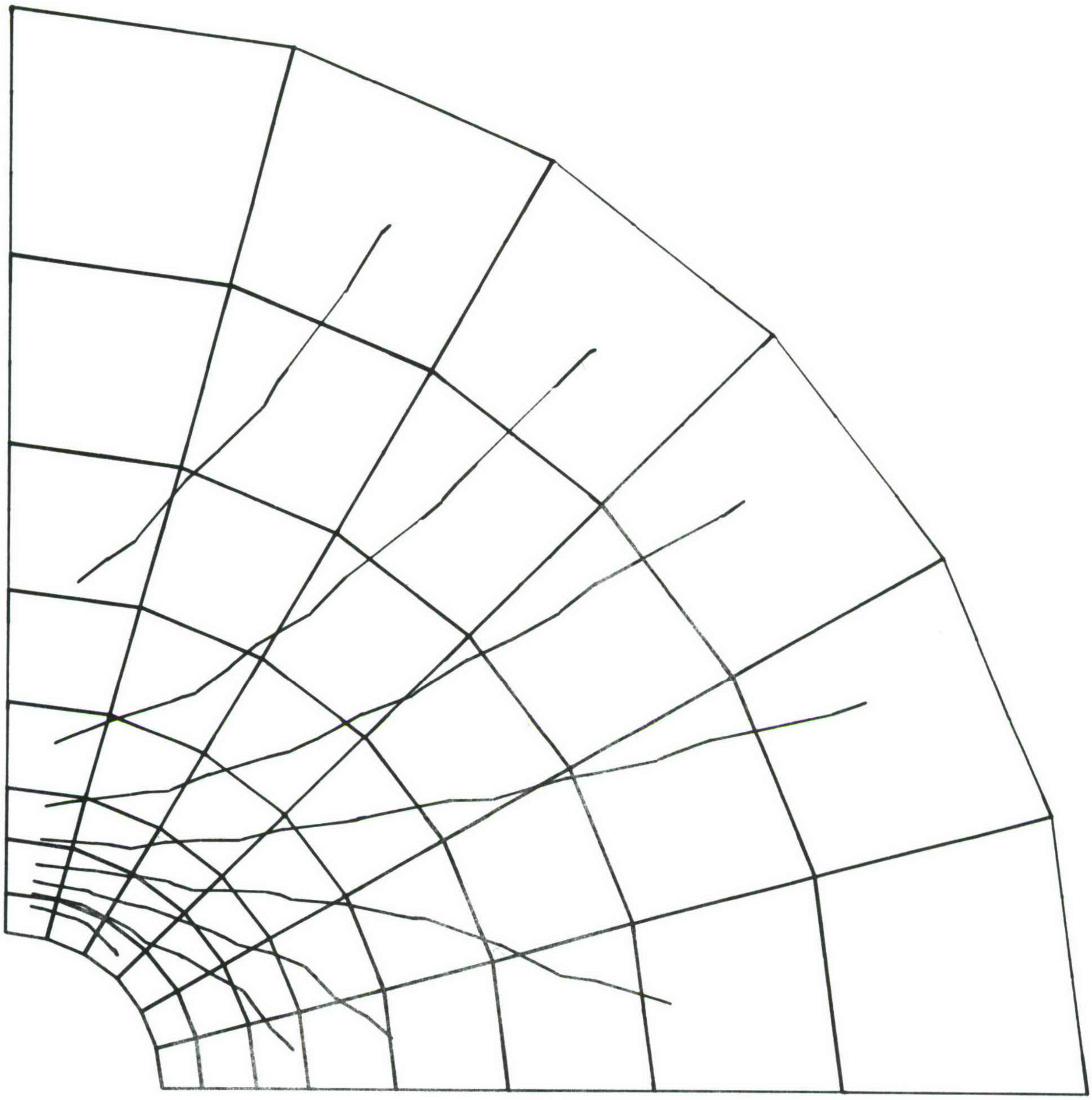


Figure AII-106 Tangential Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

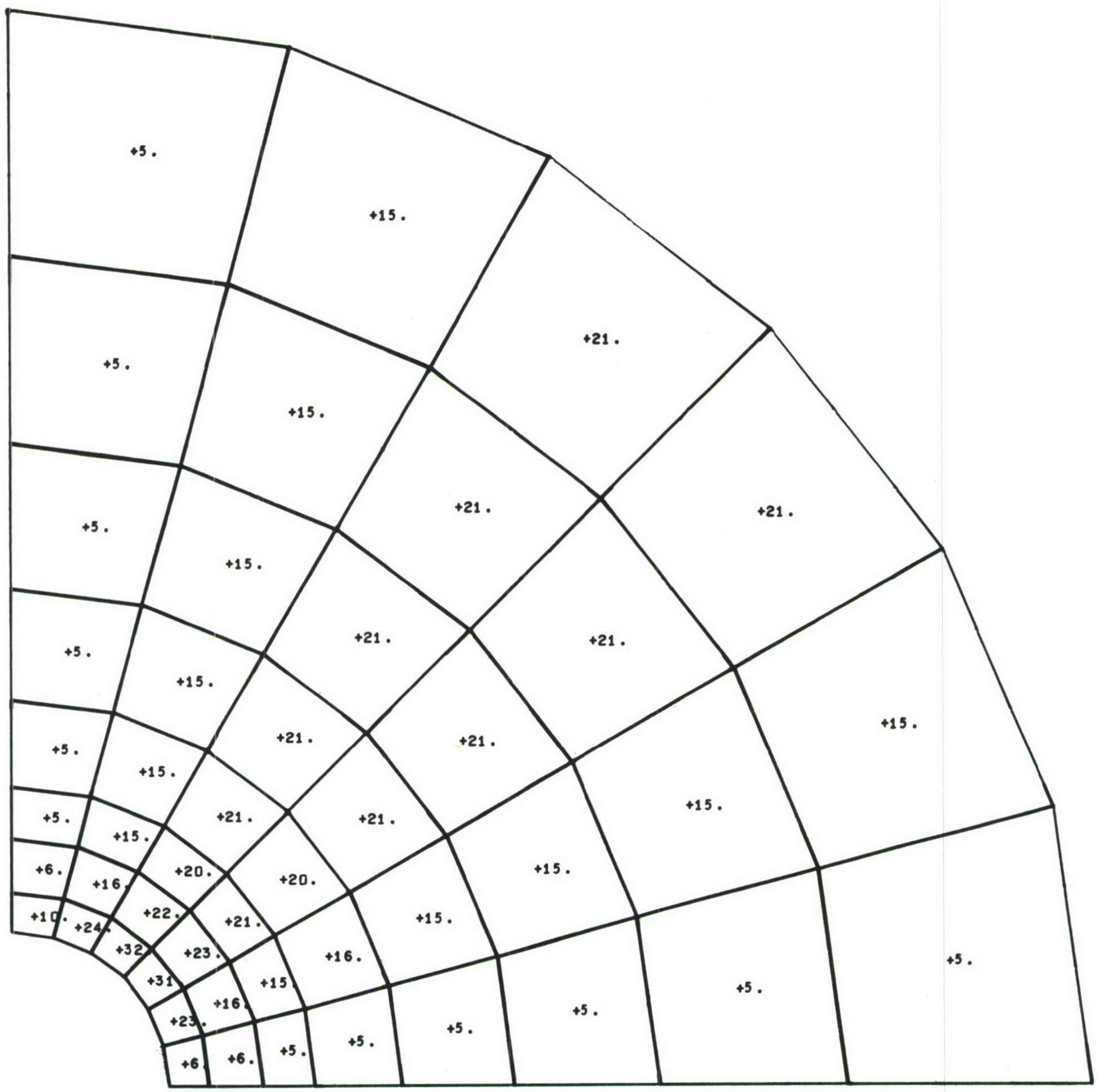


Figure AII-107 Radial-Tangential Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

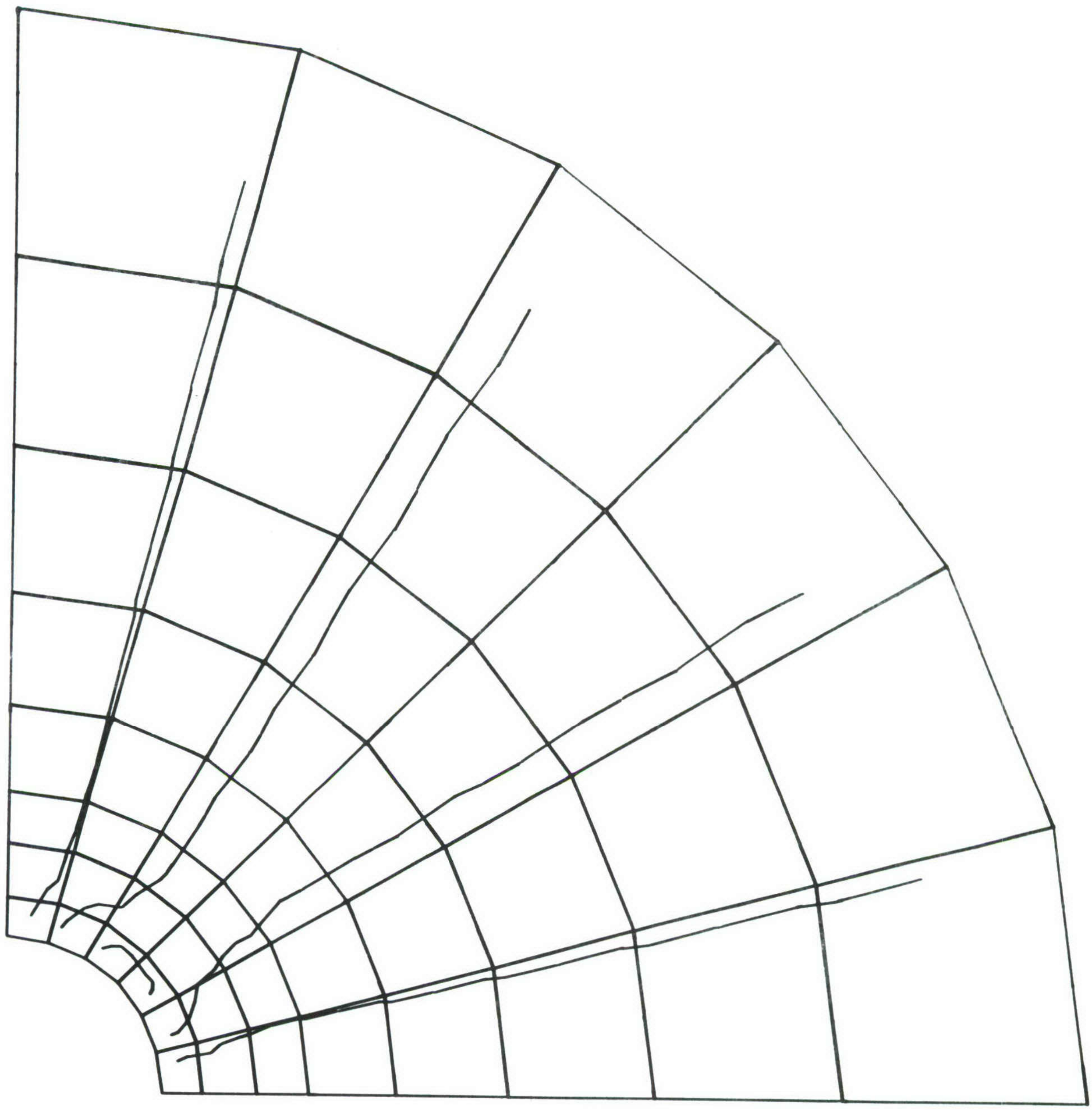


Figure AII-108 Radial-Tangential Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

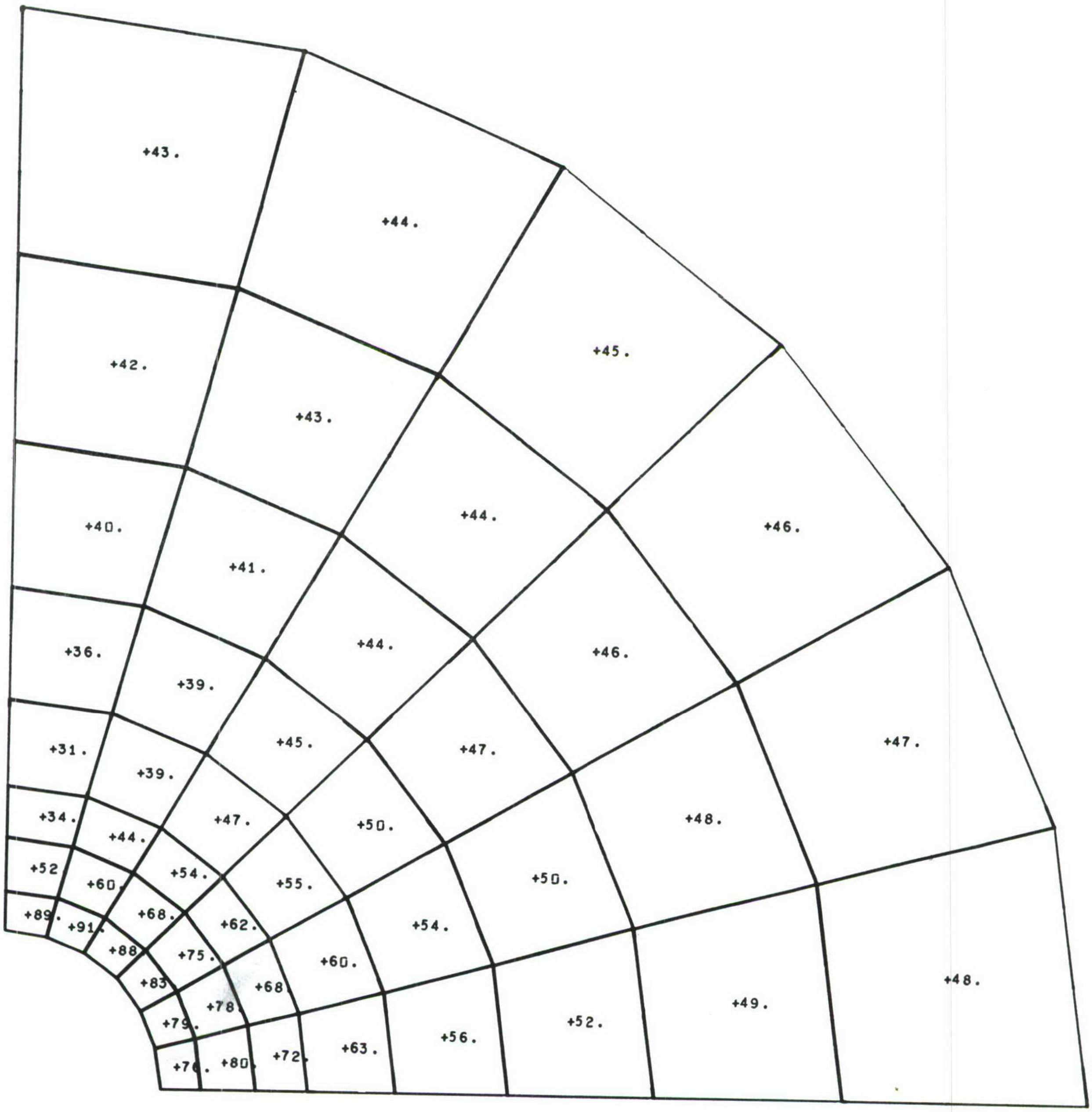


Figure AII-109 First Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

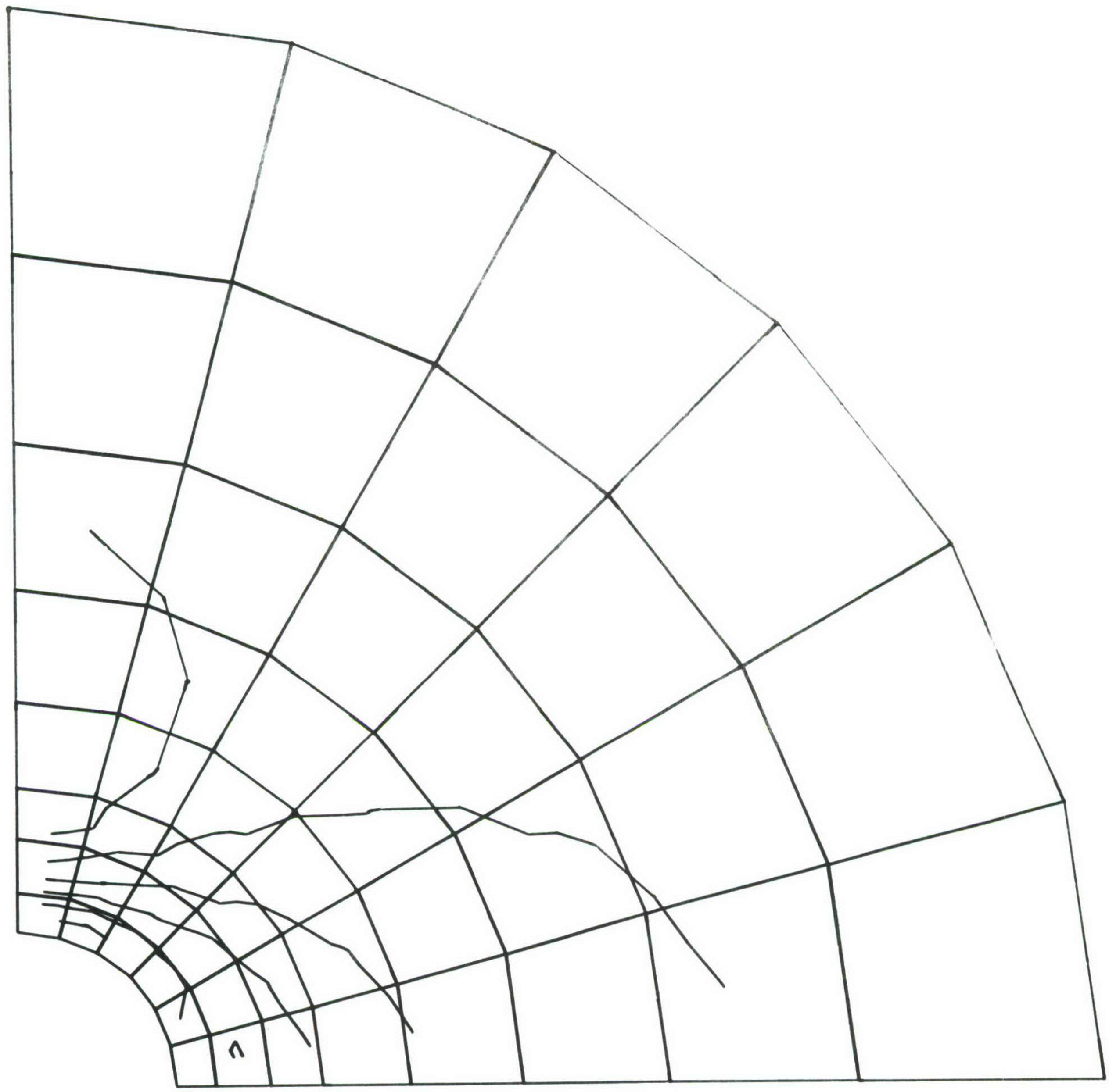


Figure AII-110 First Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

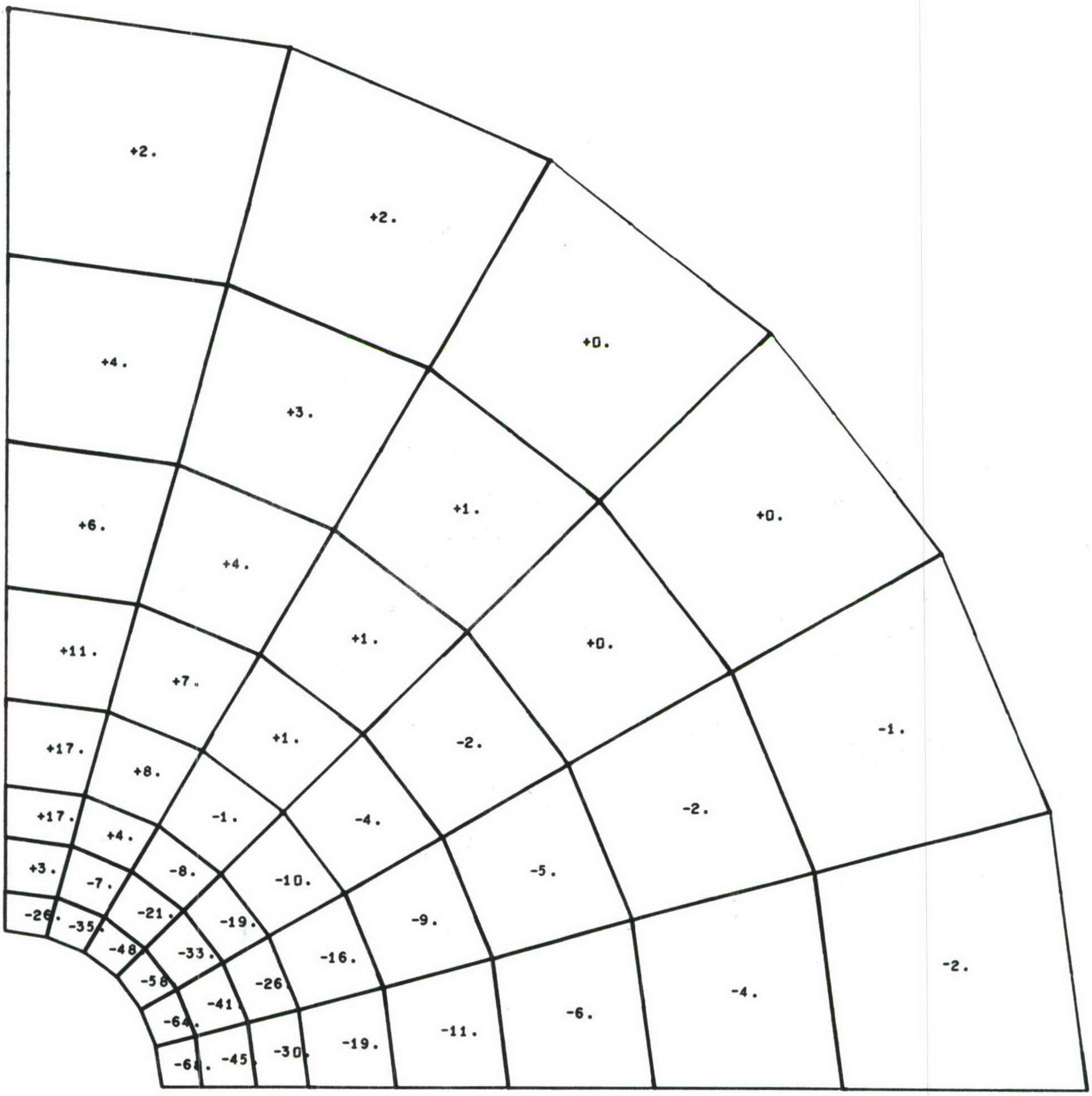


Figure AII-111 Second Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

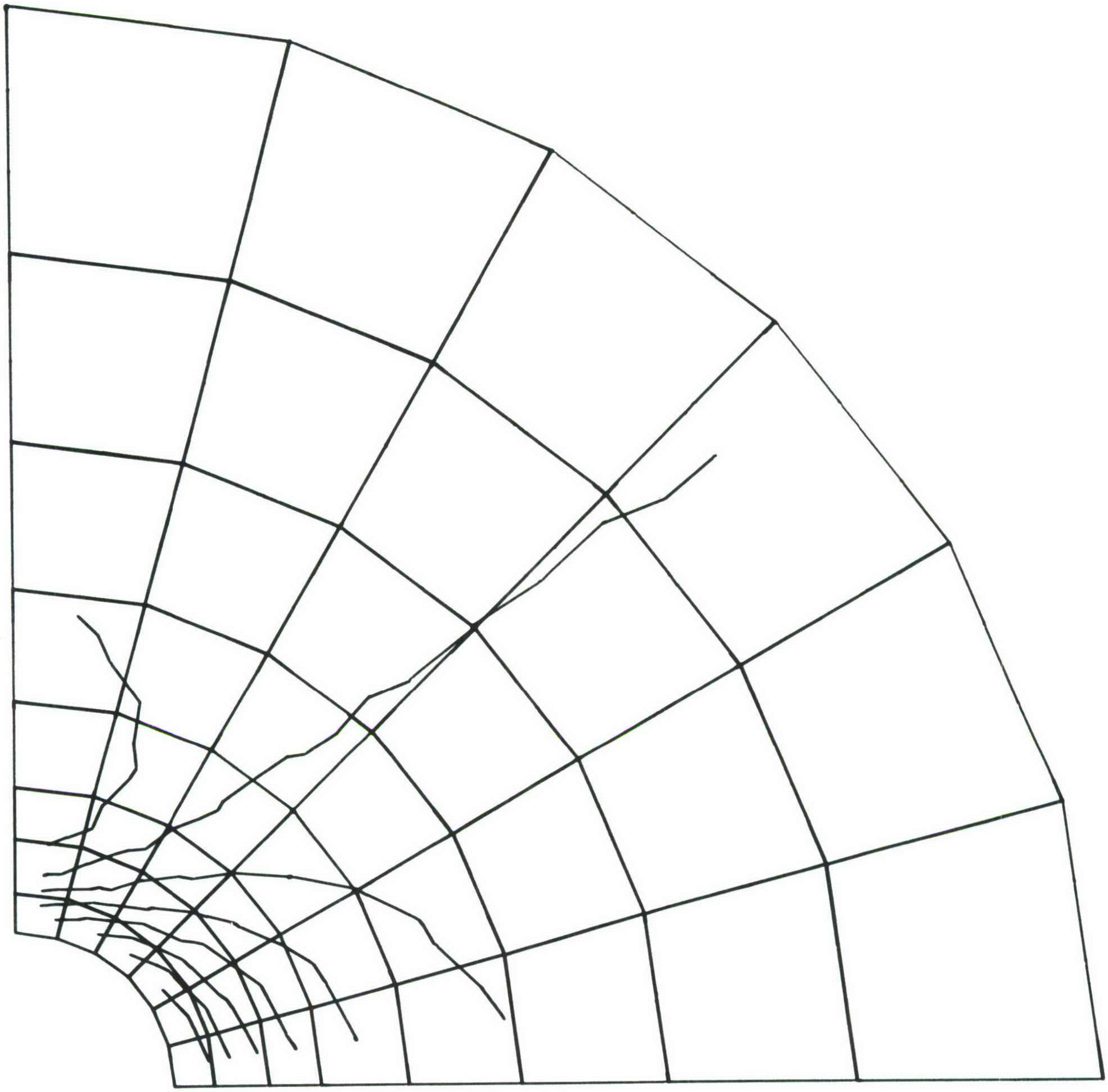


Figure AII-112 Second Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

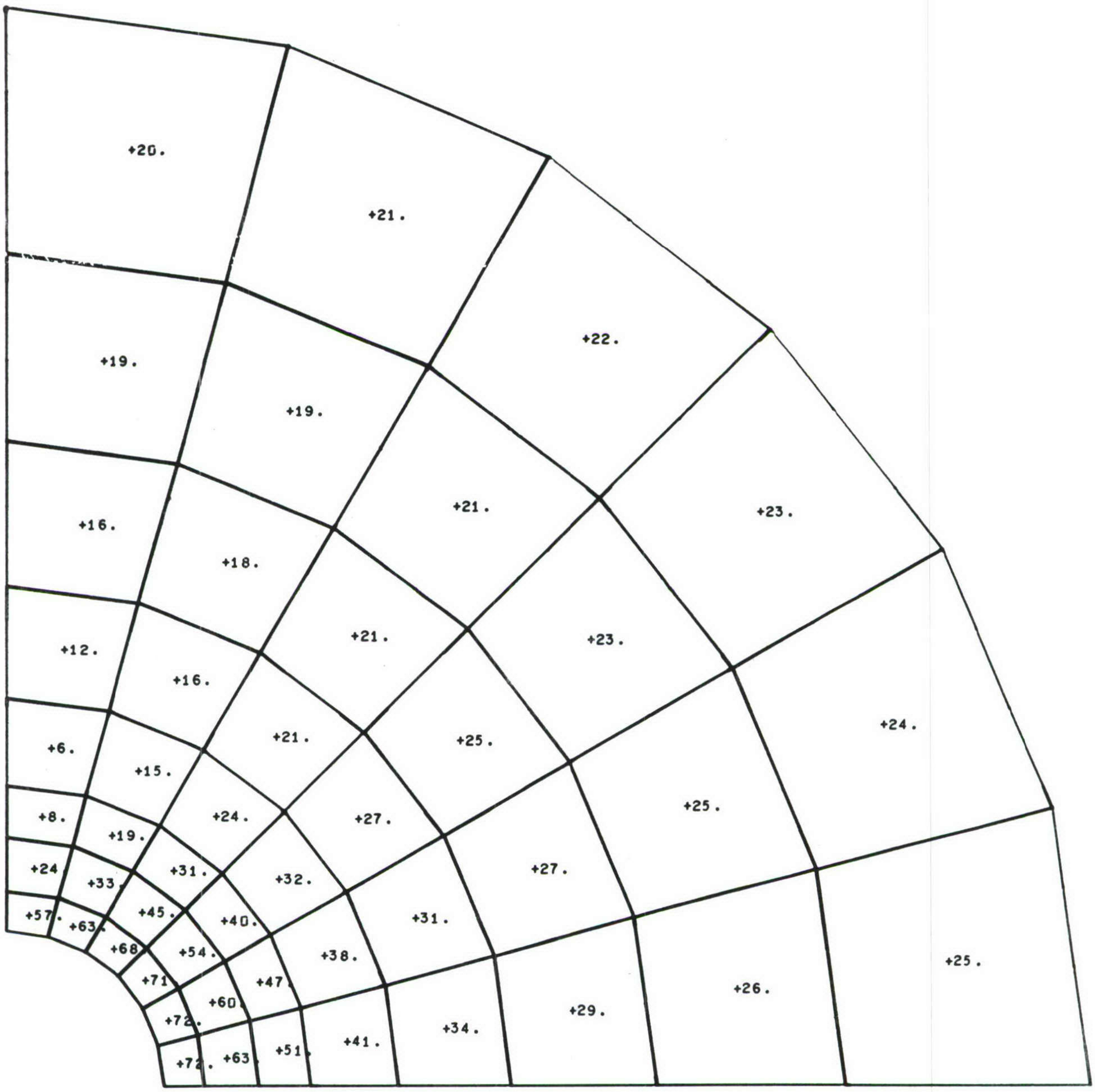


Figure AII-113 Principal Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

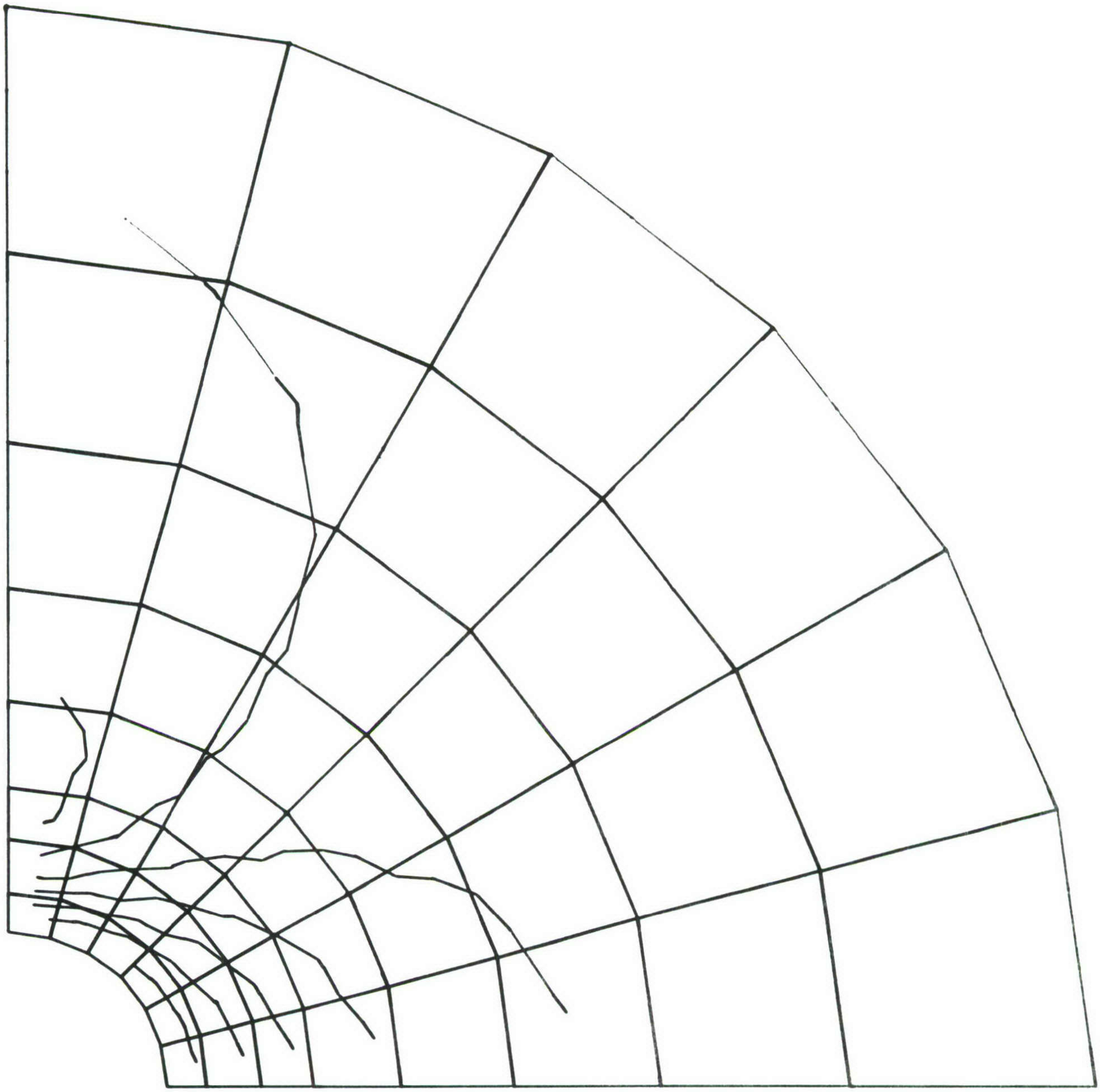


Figure AII-114 Principal Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

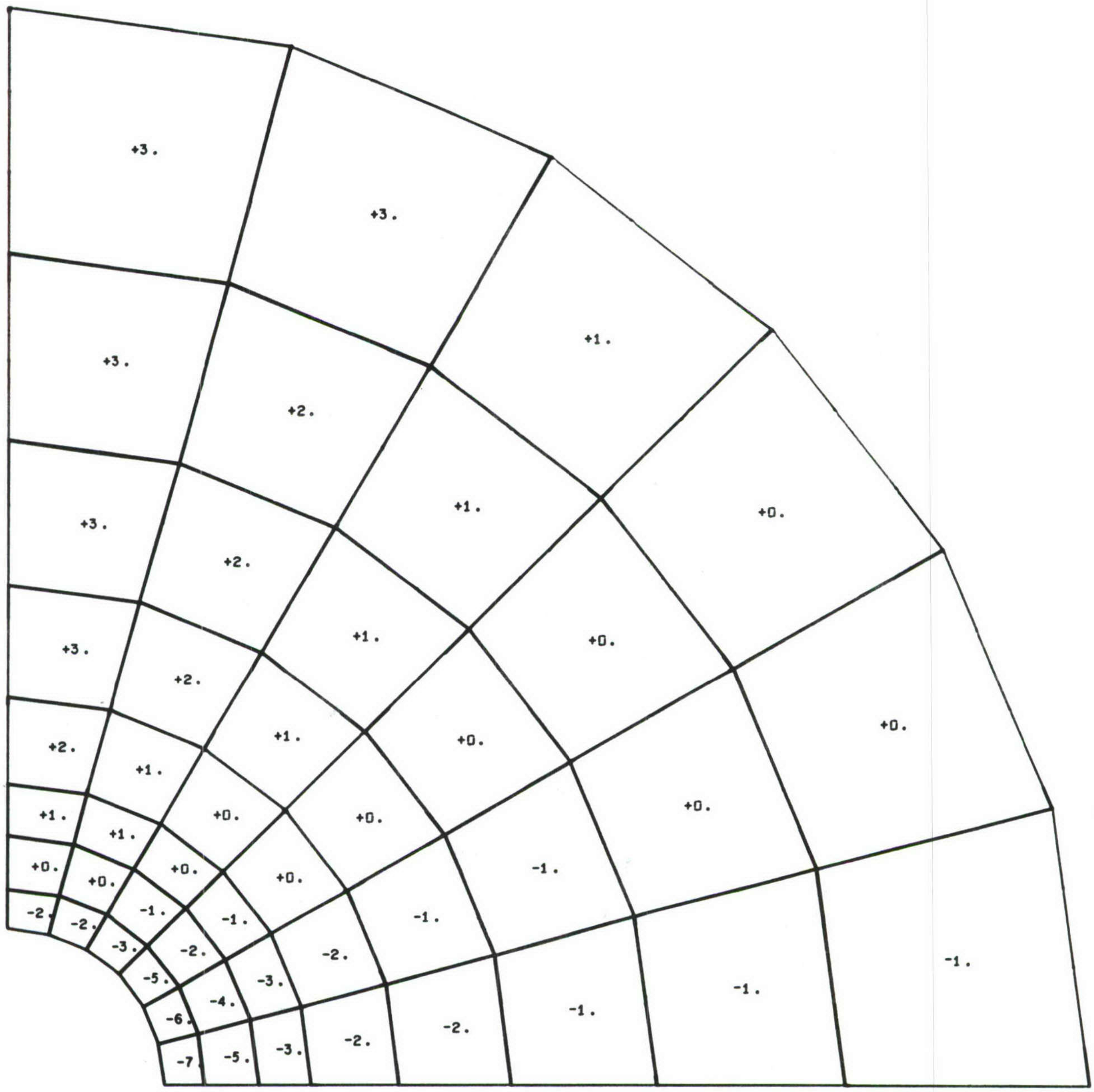


Figure AII-115 Radial Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

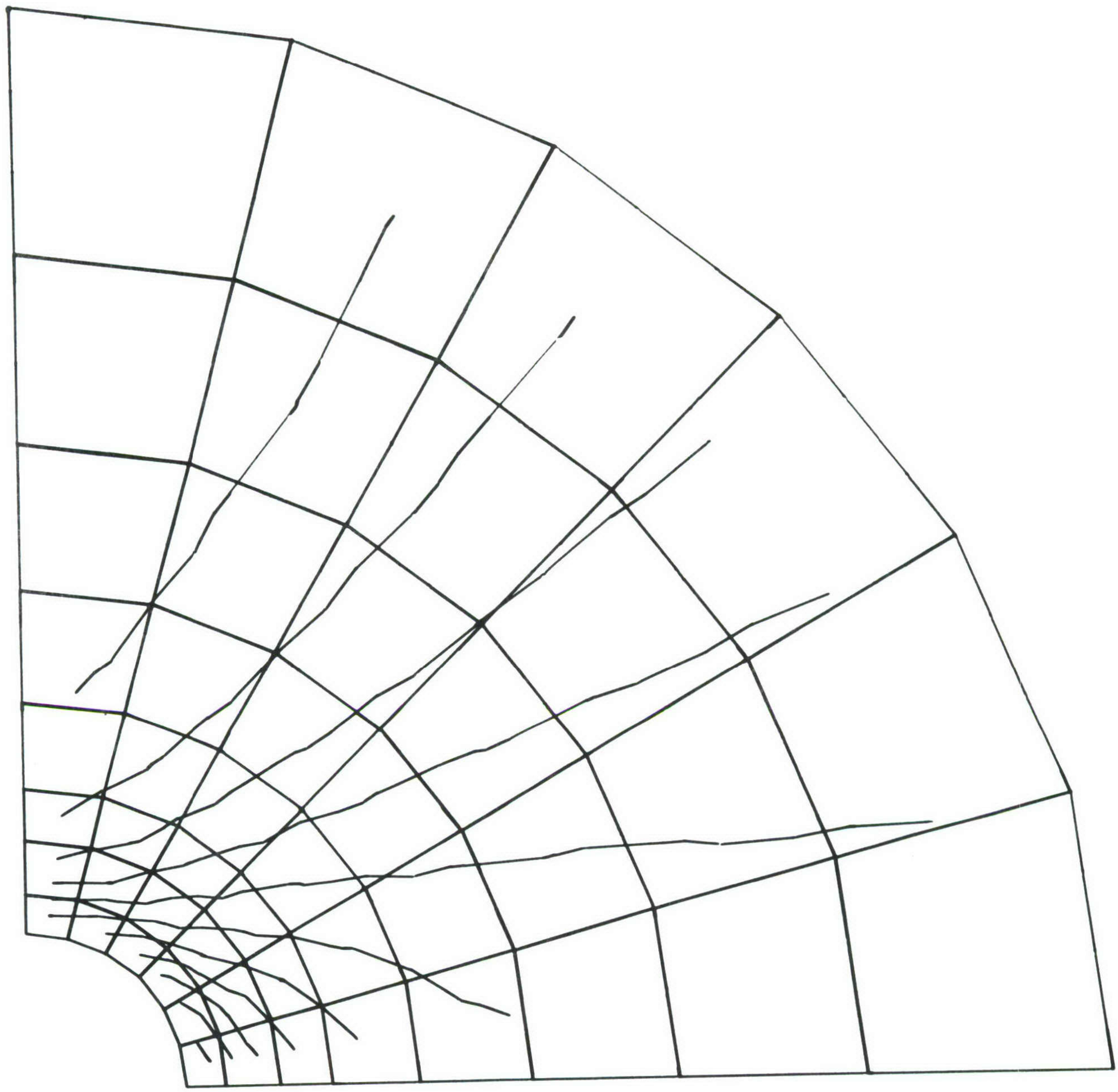


Figure AII-116 Radial Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

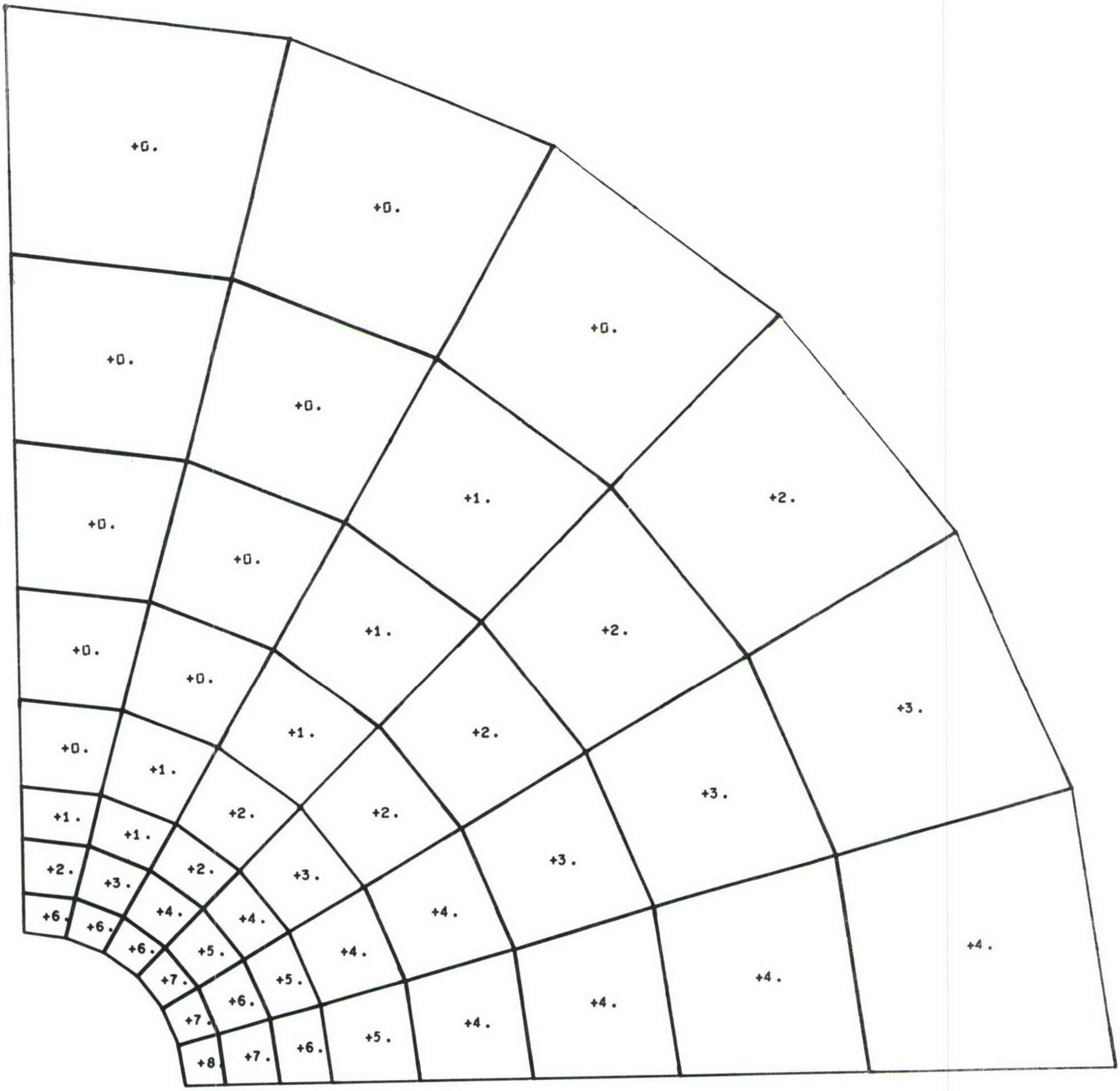


Figure AII-117 Tangential Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

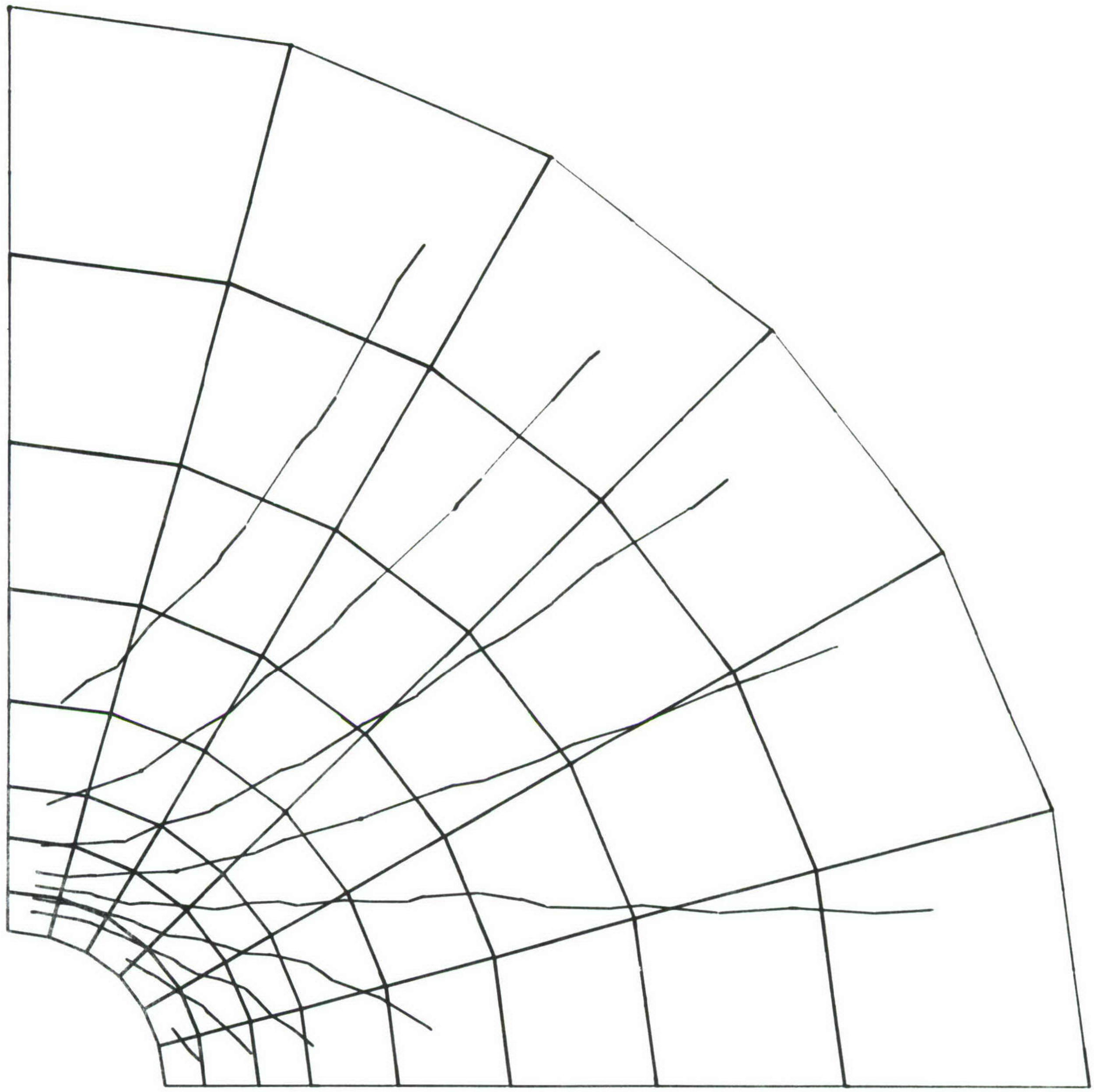


Figure AII-118 Tangential Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

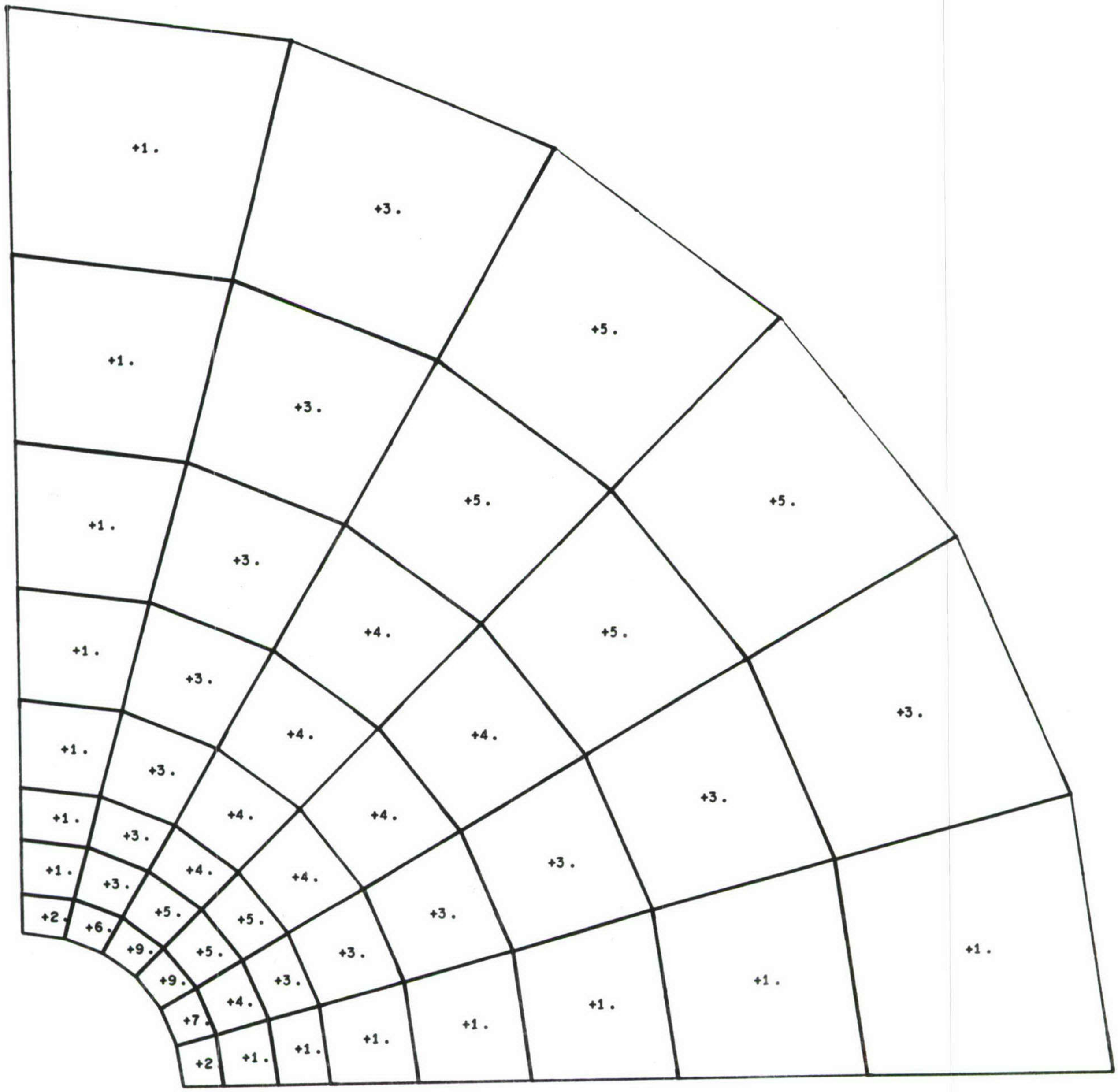


Figure AII-119 Radial-Tangential Shear Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

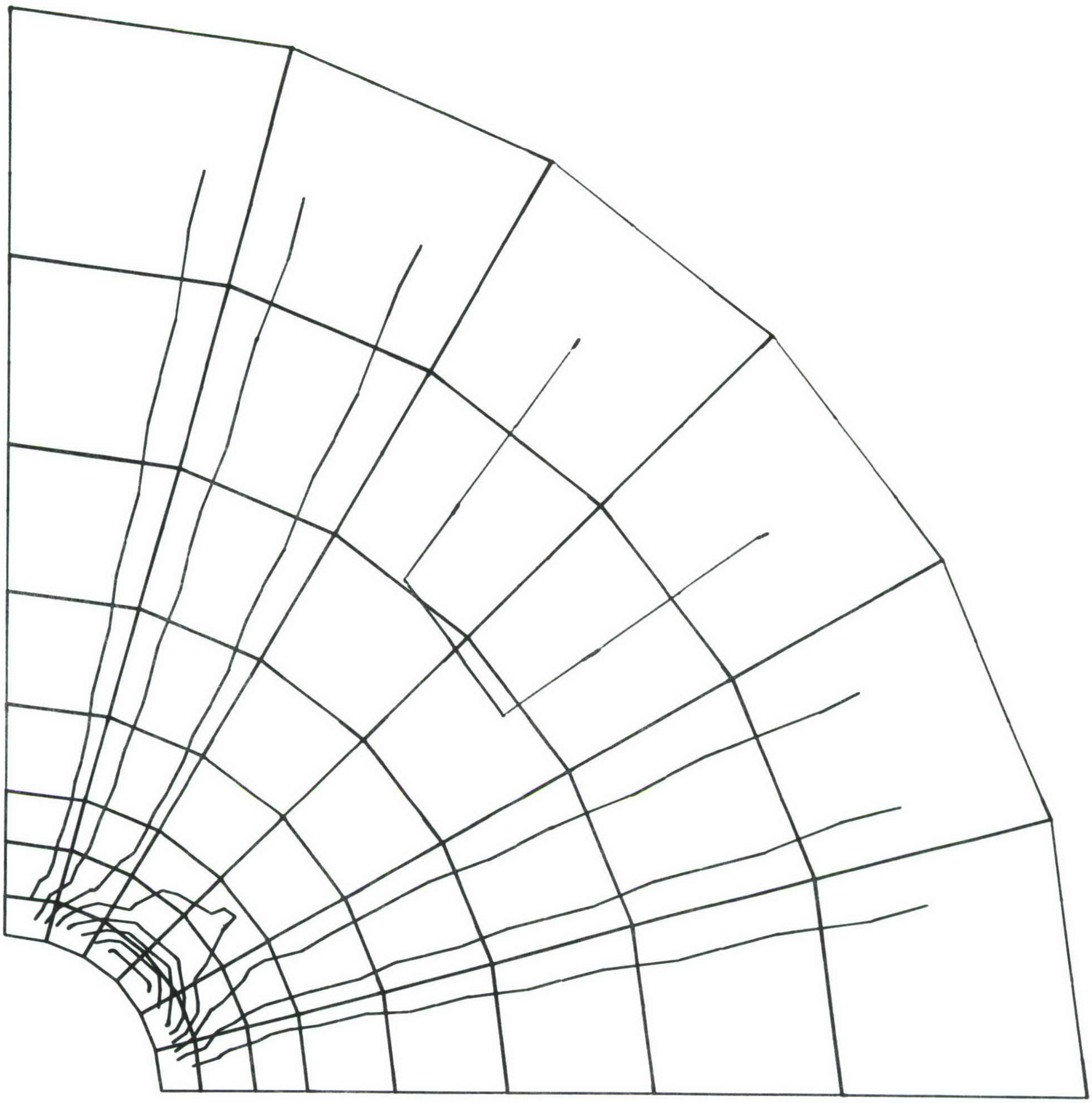


Figure AII-120 Radial-Tangential Shear Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

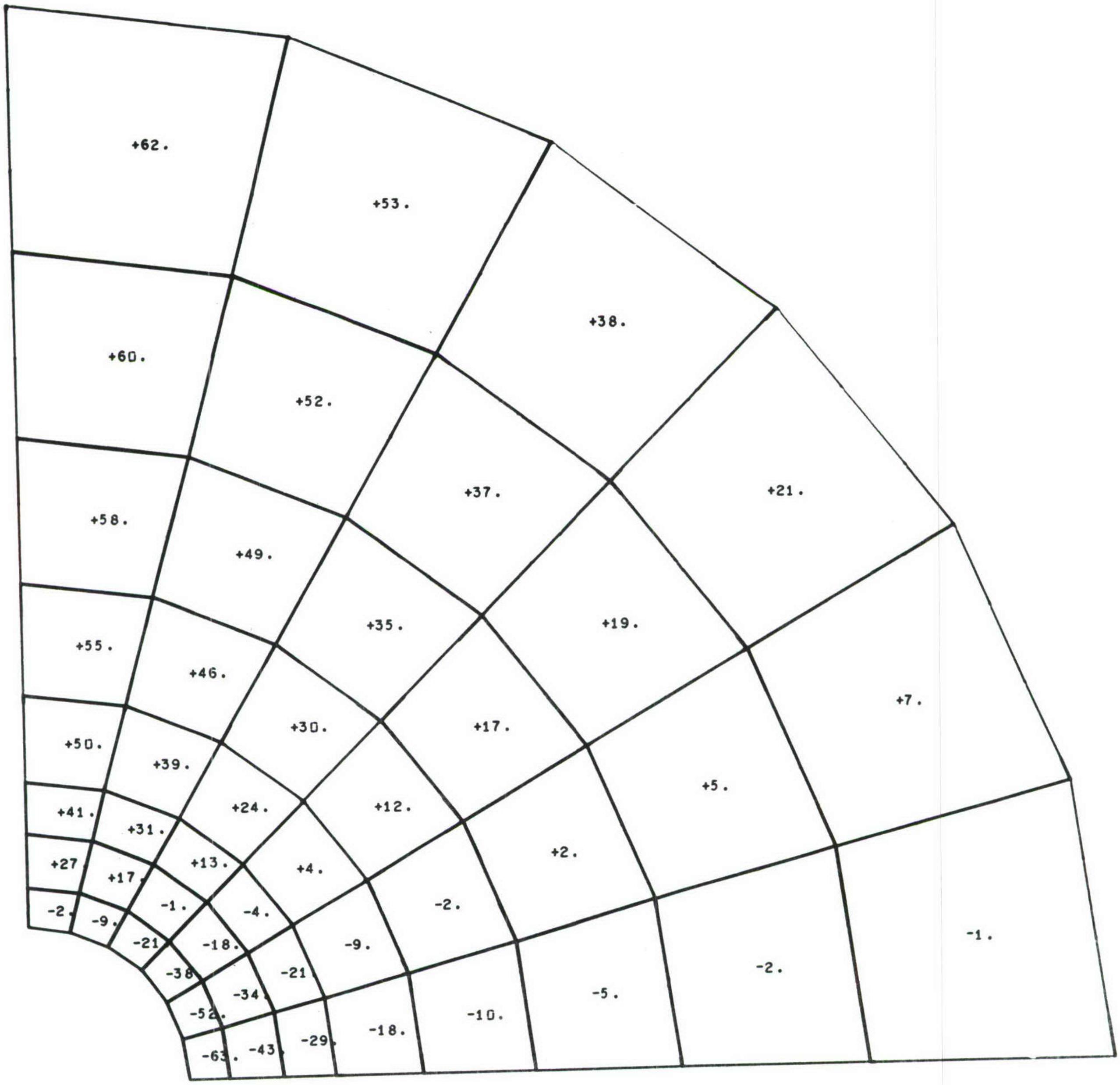


Figure AII-121 Radial Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

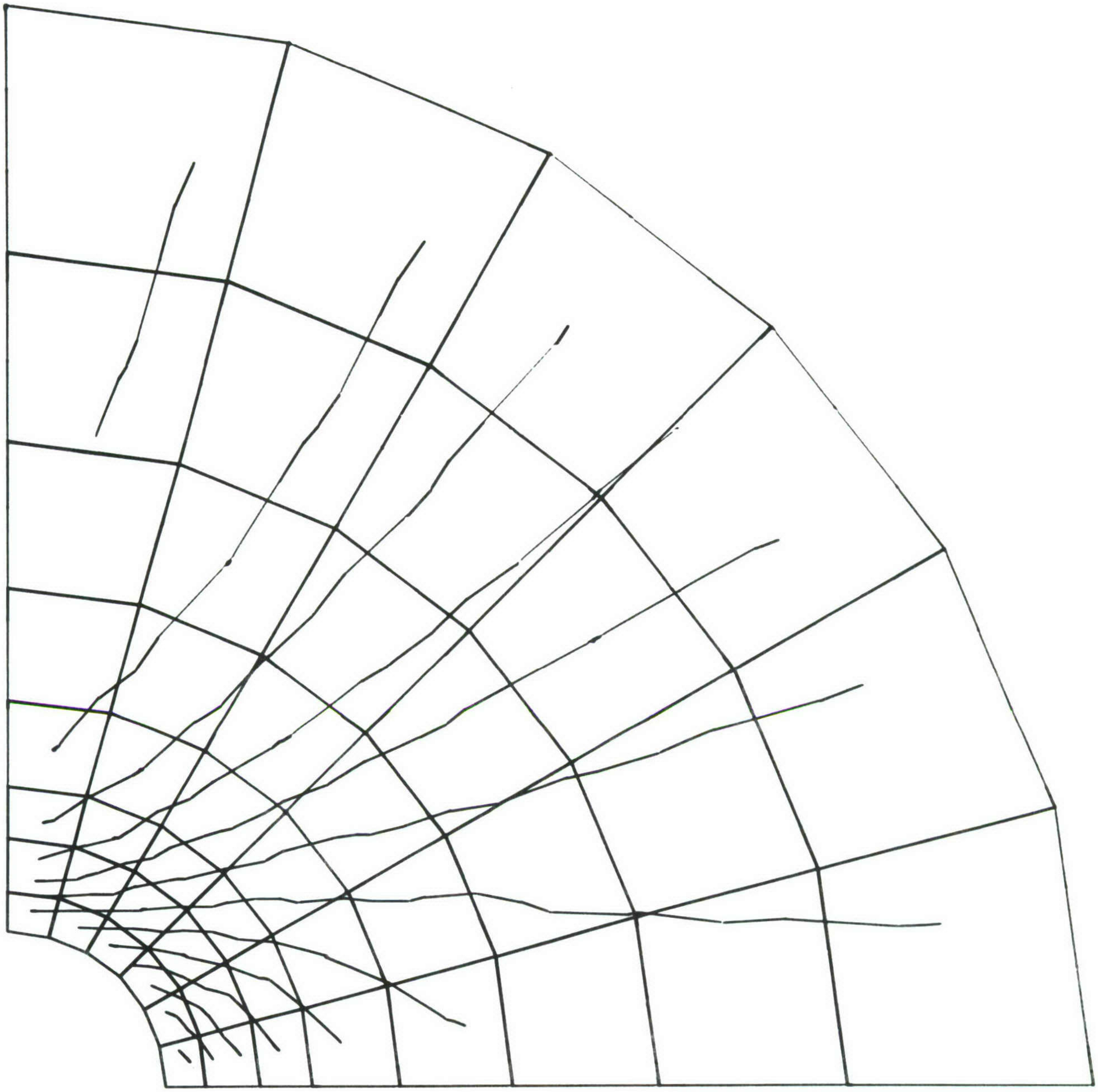


Figure AII-122 Radial Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

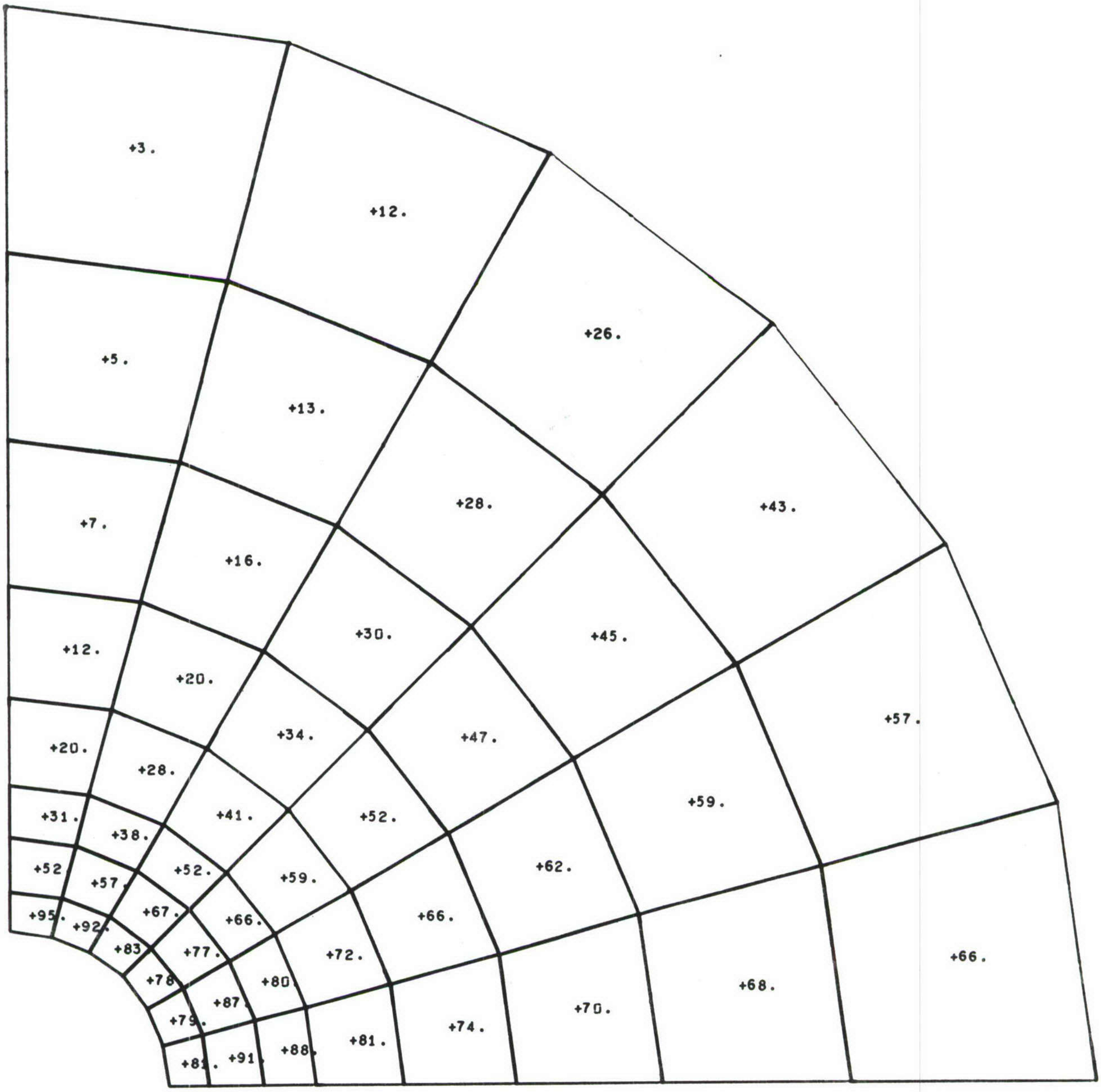


Figure AII-123 Tangential Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

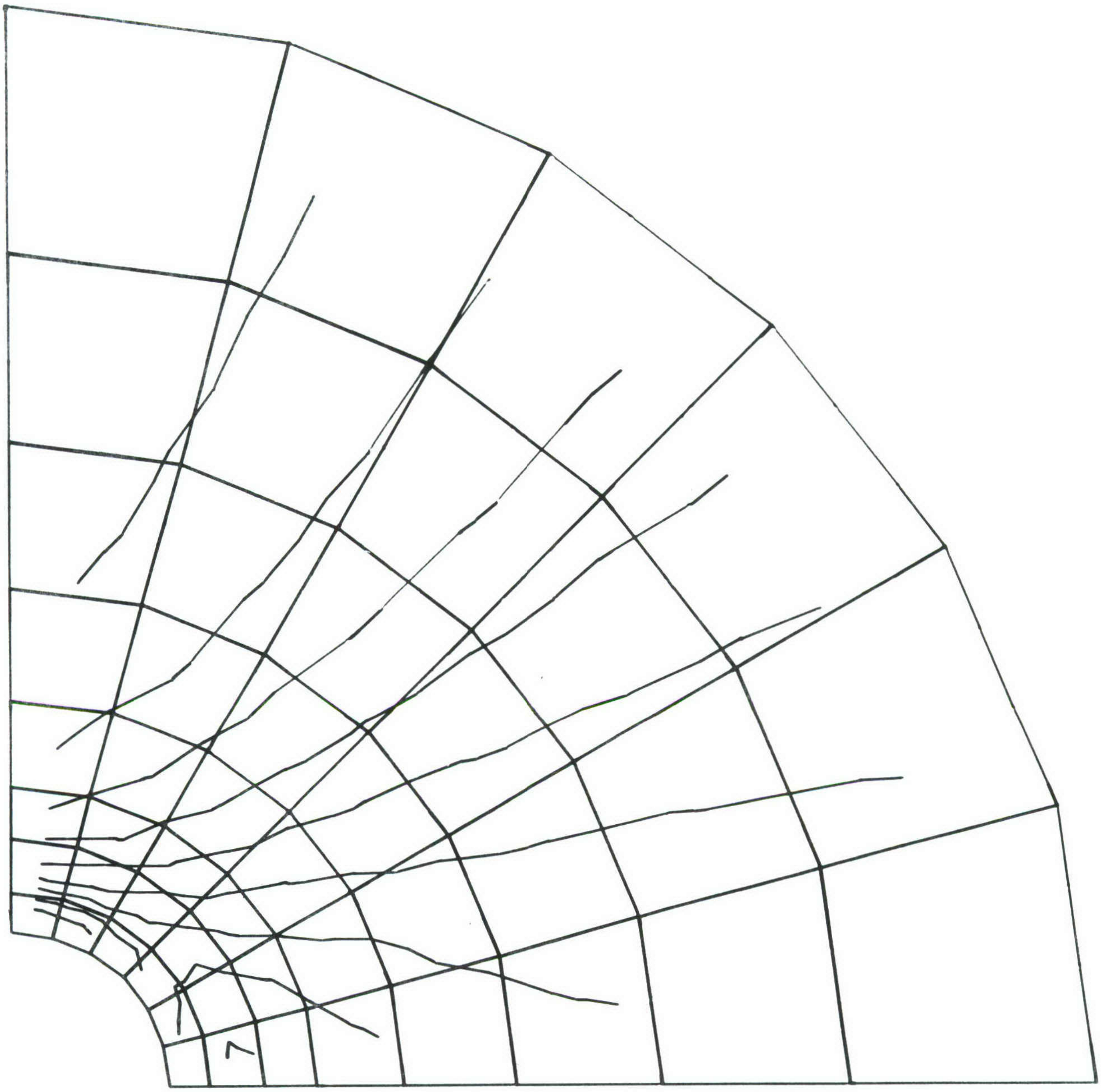


Figure AII-124 Tangential Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

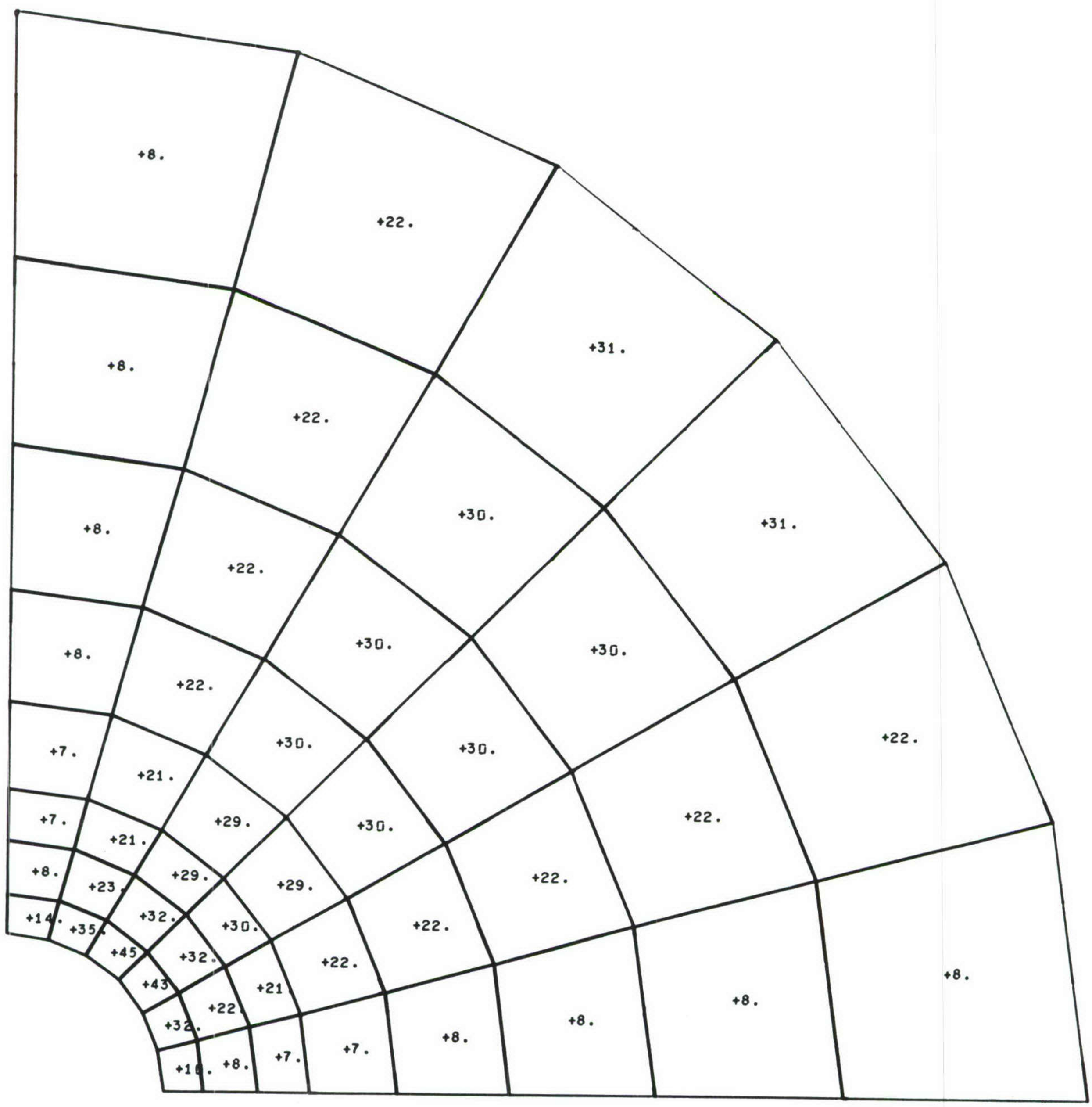


Figure AII-125 Radial-Tangential Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

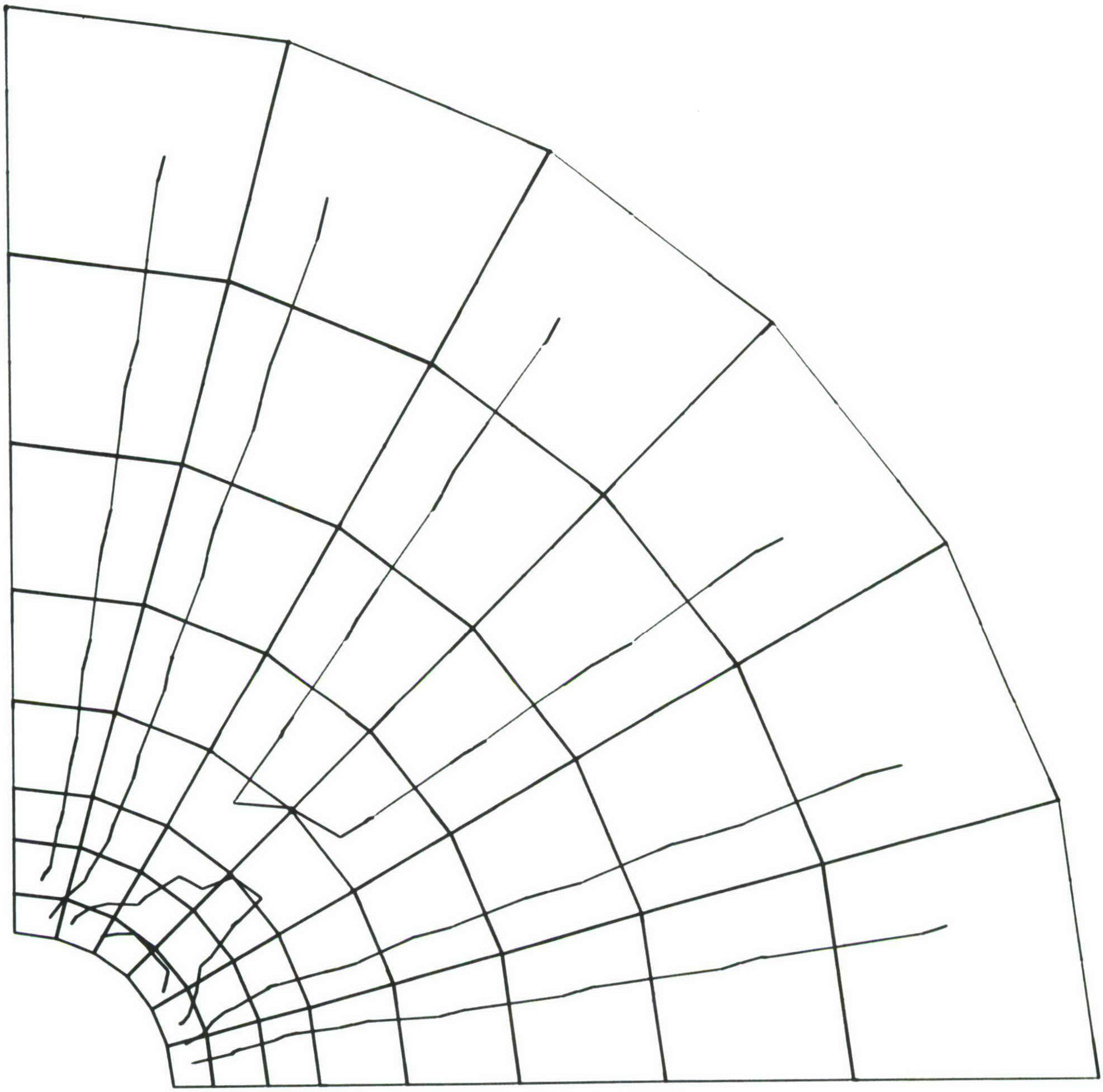


Figure AII-126 Radial Tangential Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

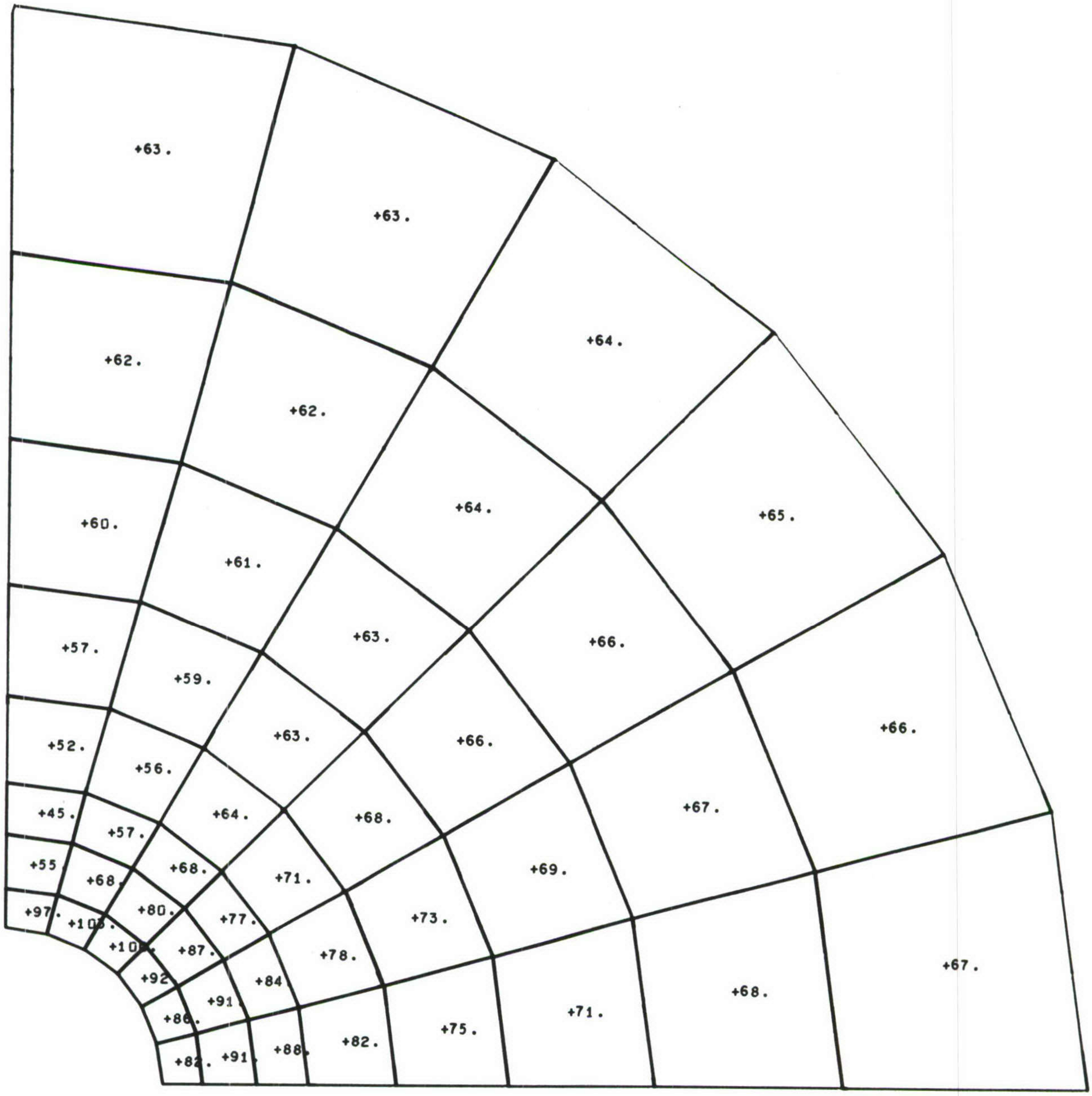


Figure AII-127 First Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

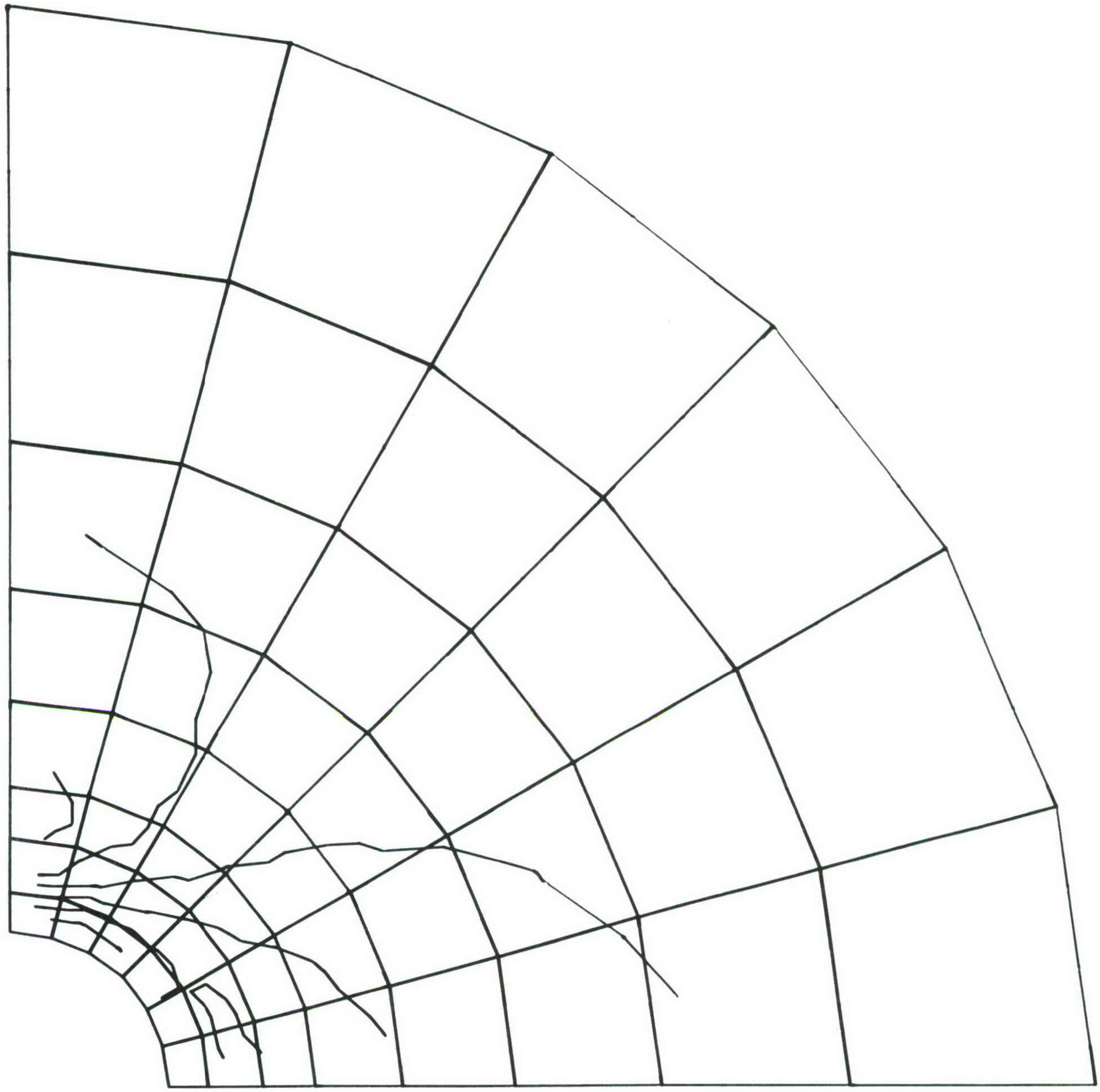


Figure AII-128 First Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

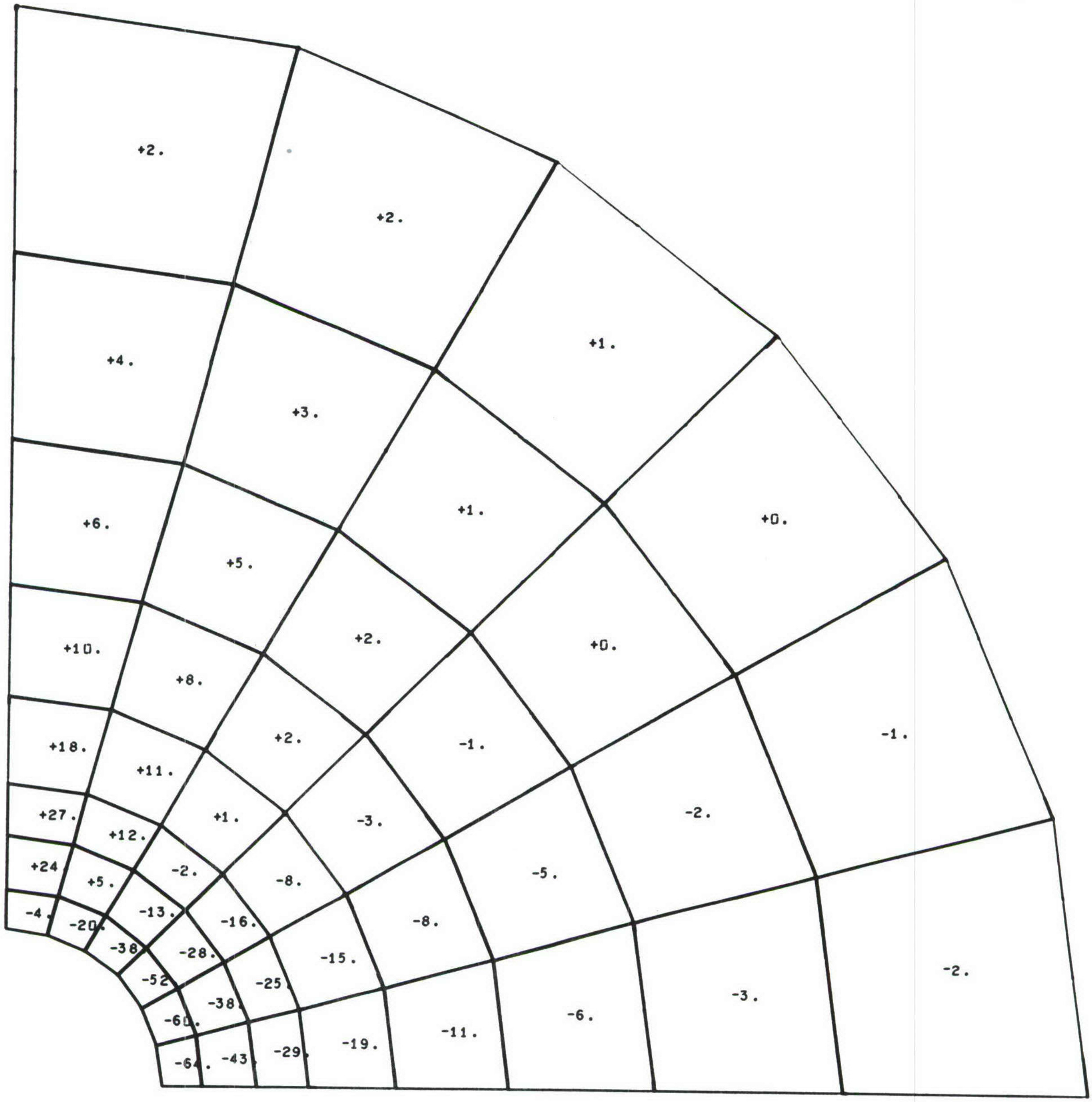


Figure AII-129 Second Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

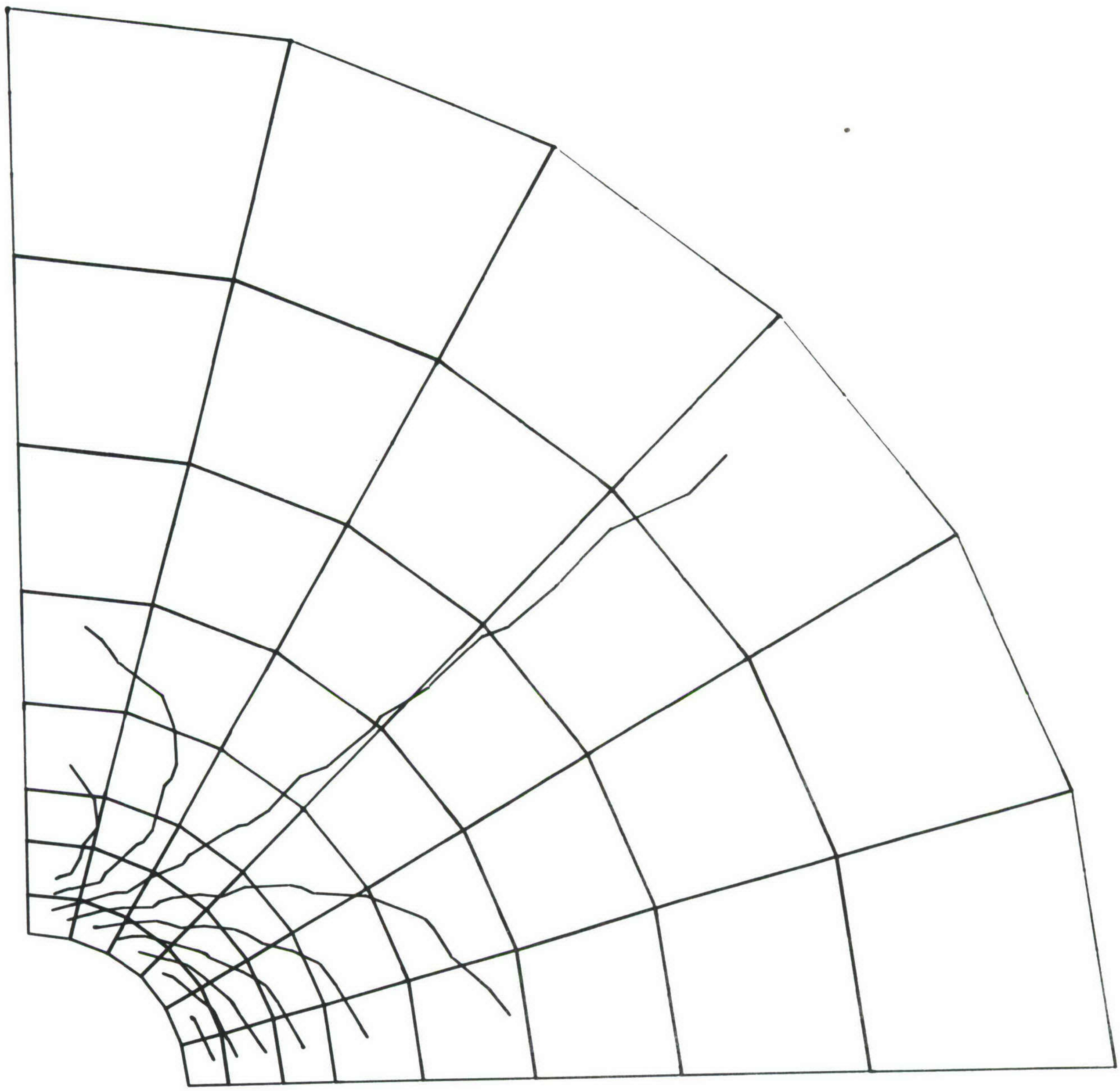


Figure AII-130 Second Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

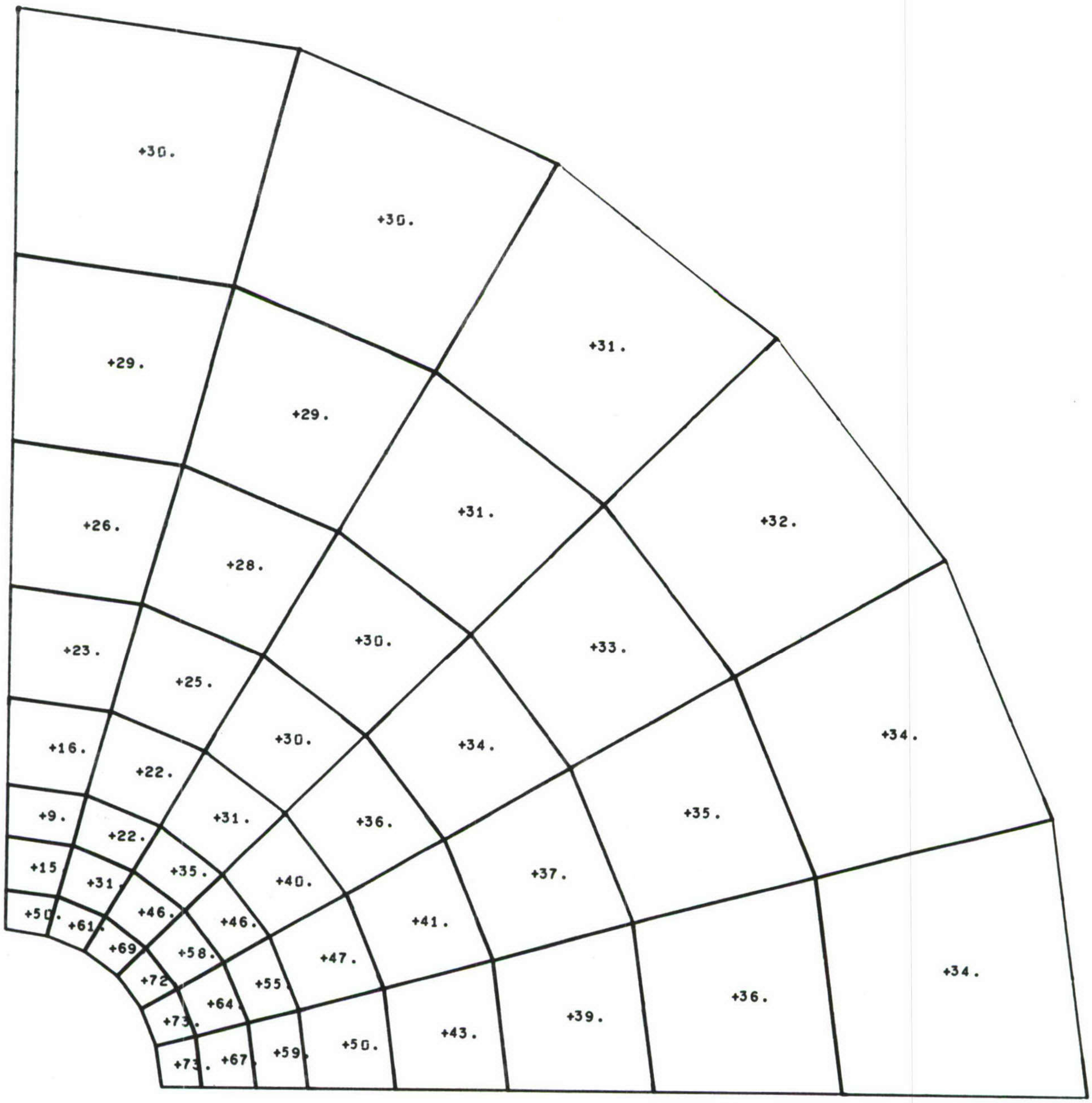


Figure AII-131 Principal Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

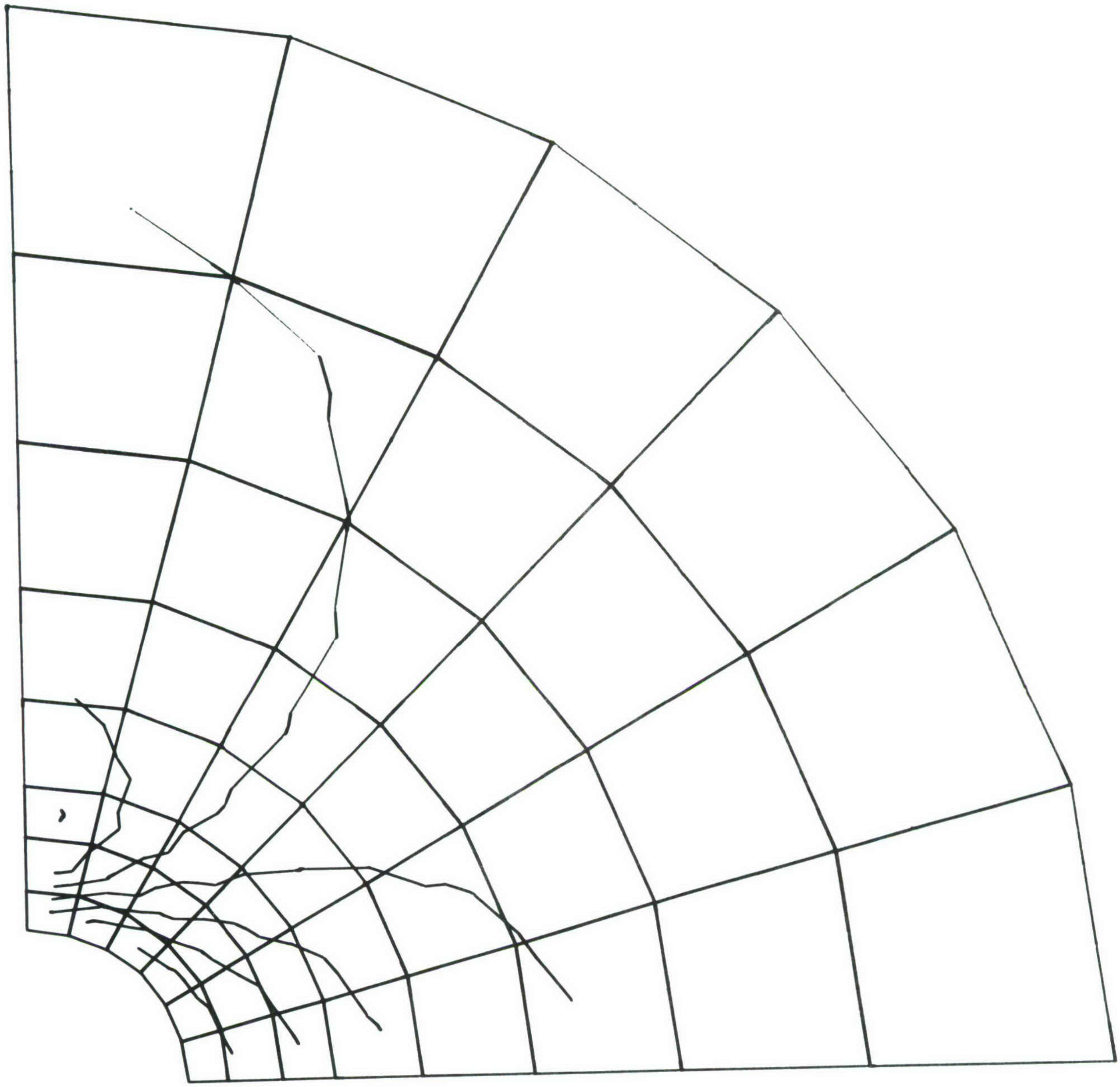


Figure AII-132 Principal Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 50% Uniaxial Load

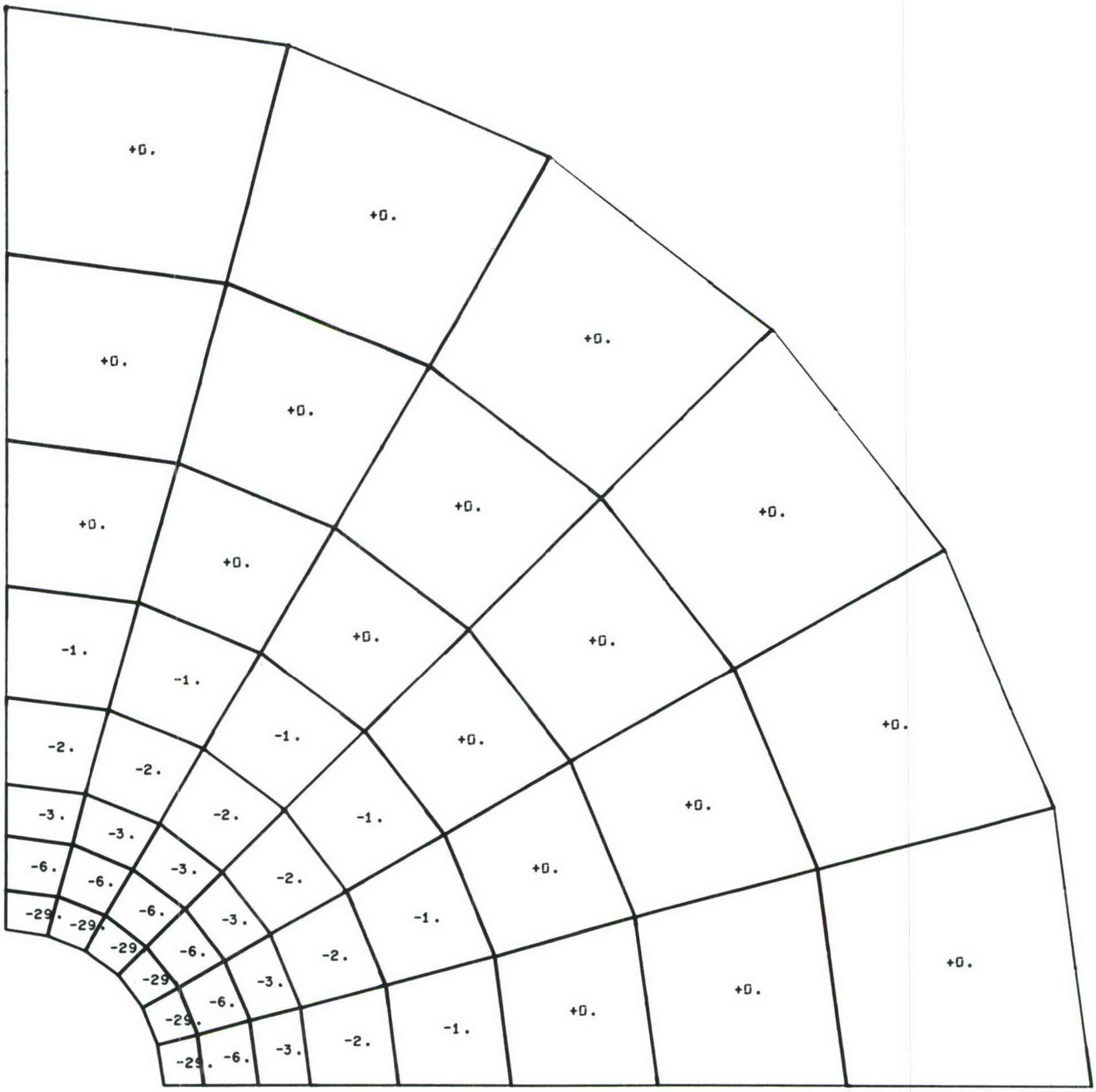


Figure AII-133 Radial Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

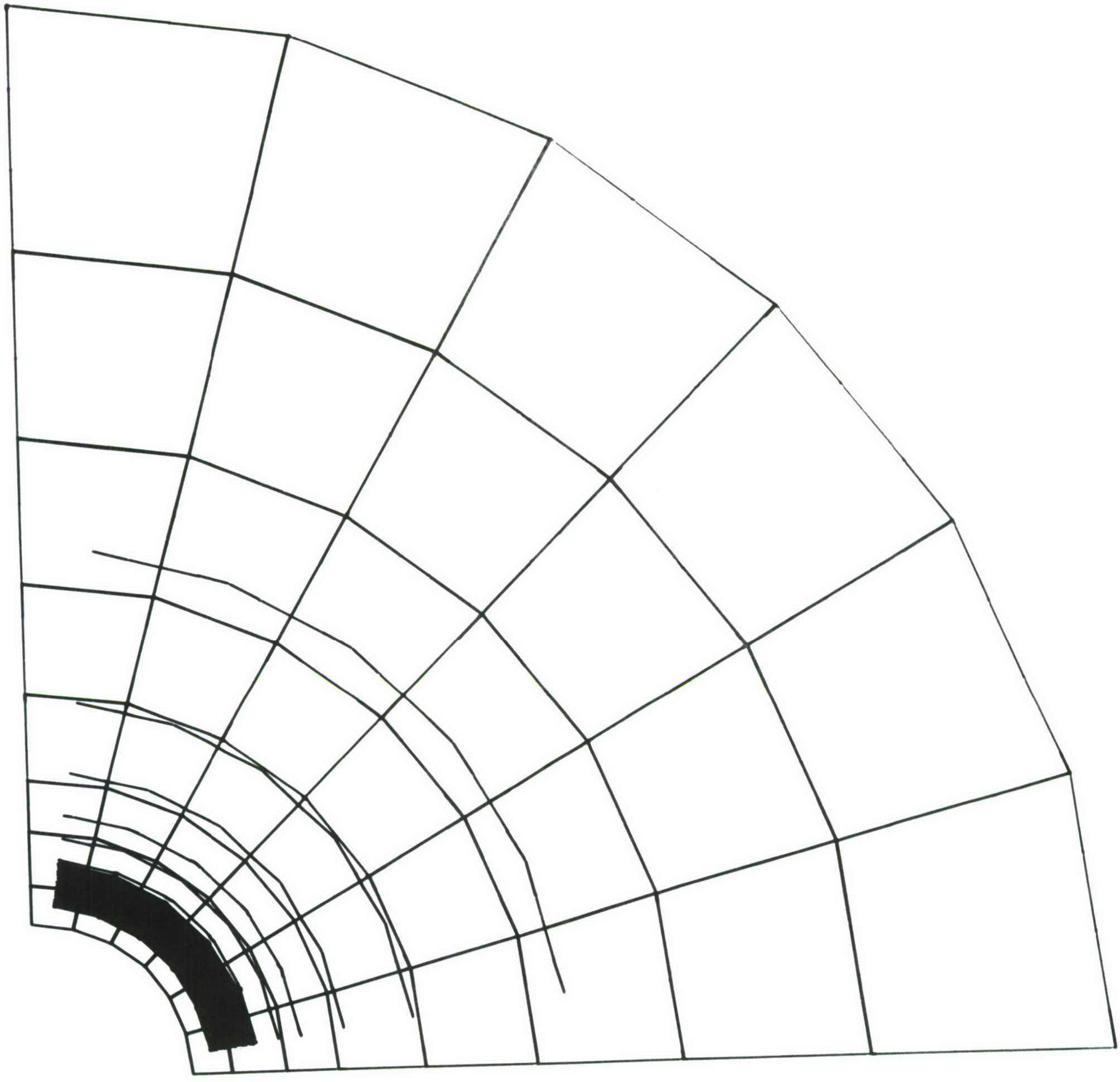


Figure AII-134 Radial Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

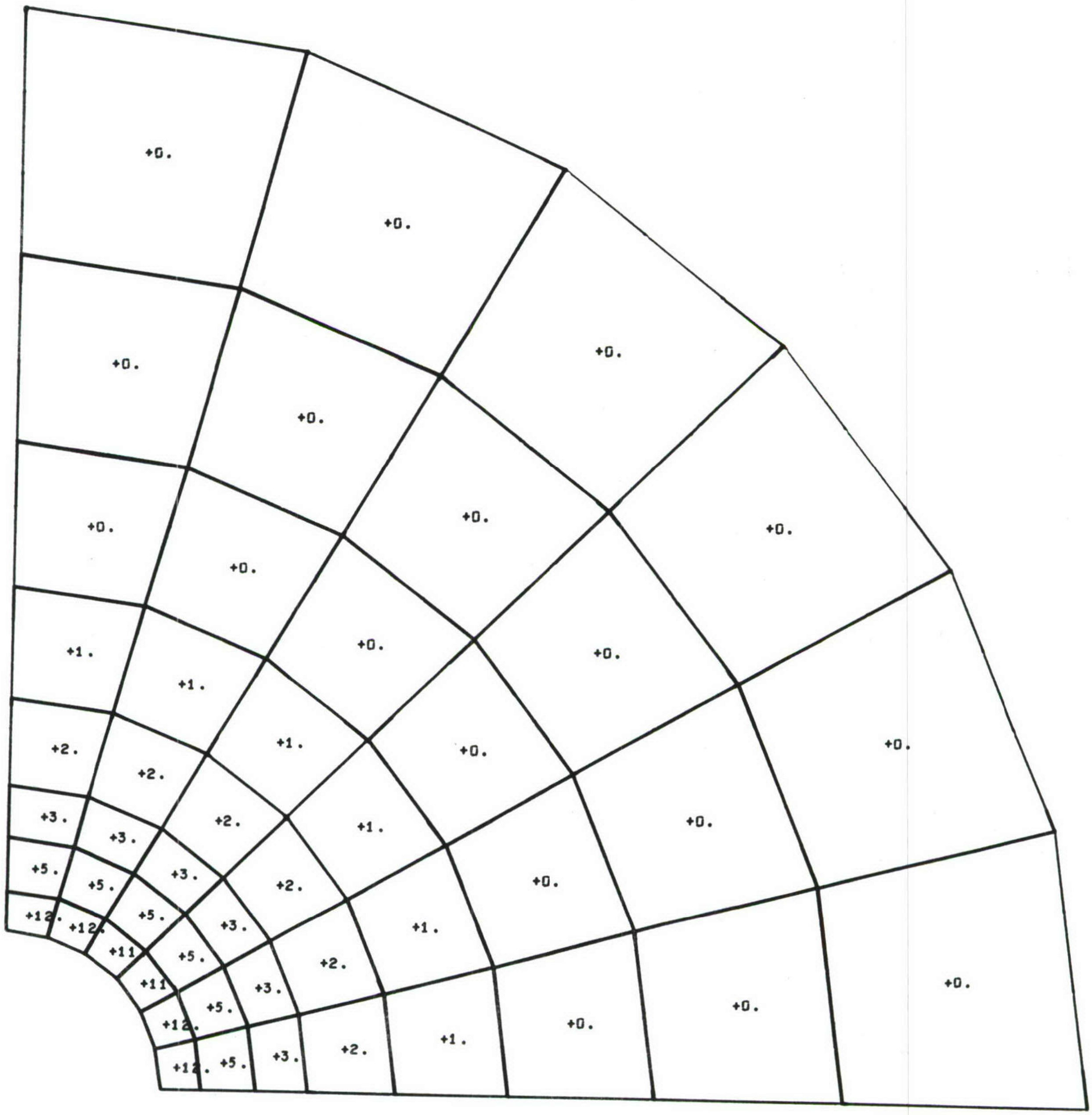


Figure AII-135 **Tangential Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load**

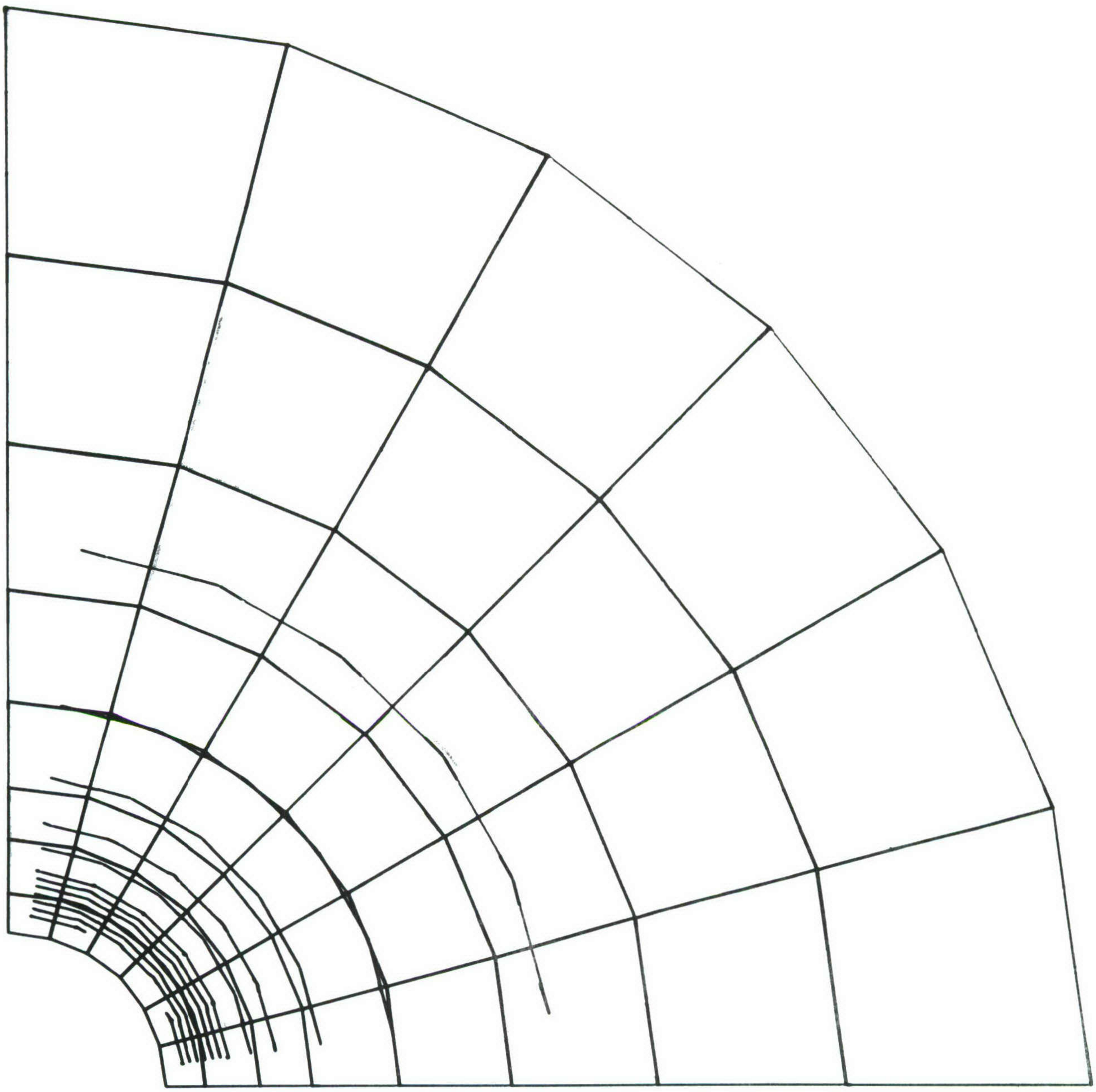


Figure AII-136 Tangential Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

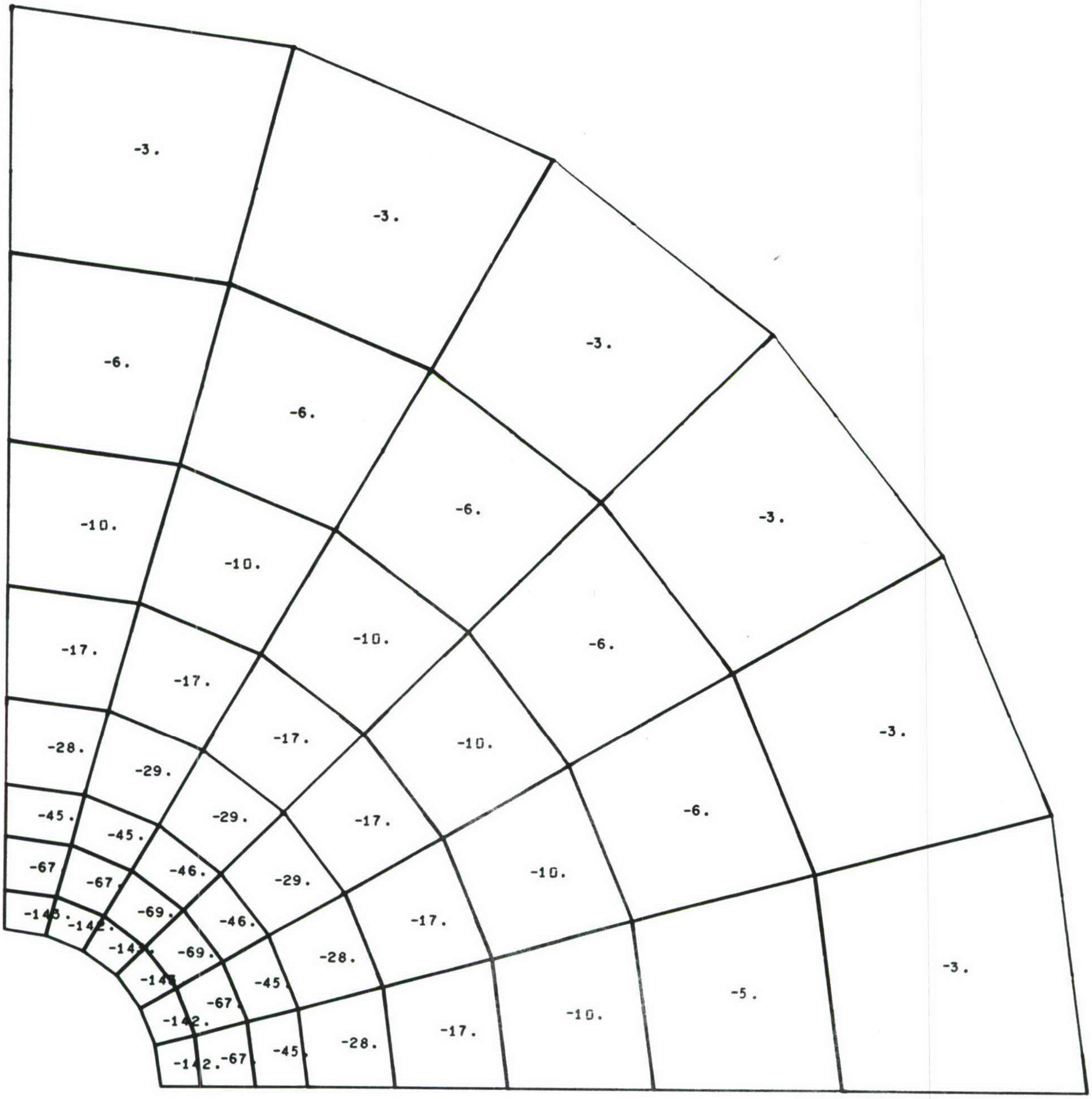


Figure AII-137 Radial Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

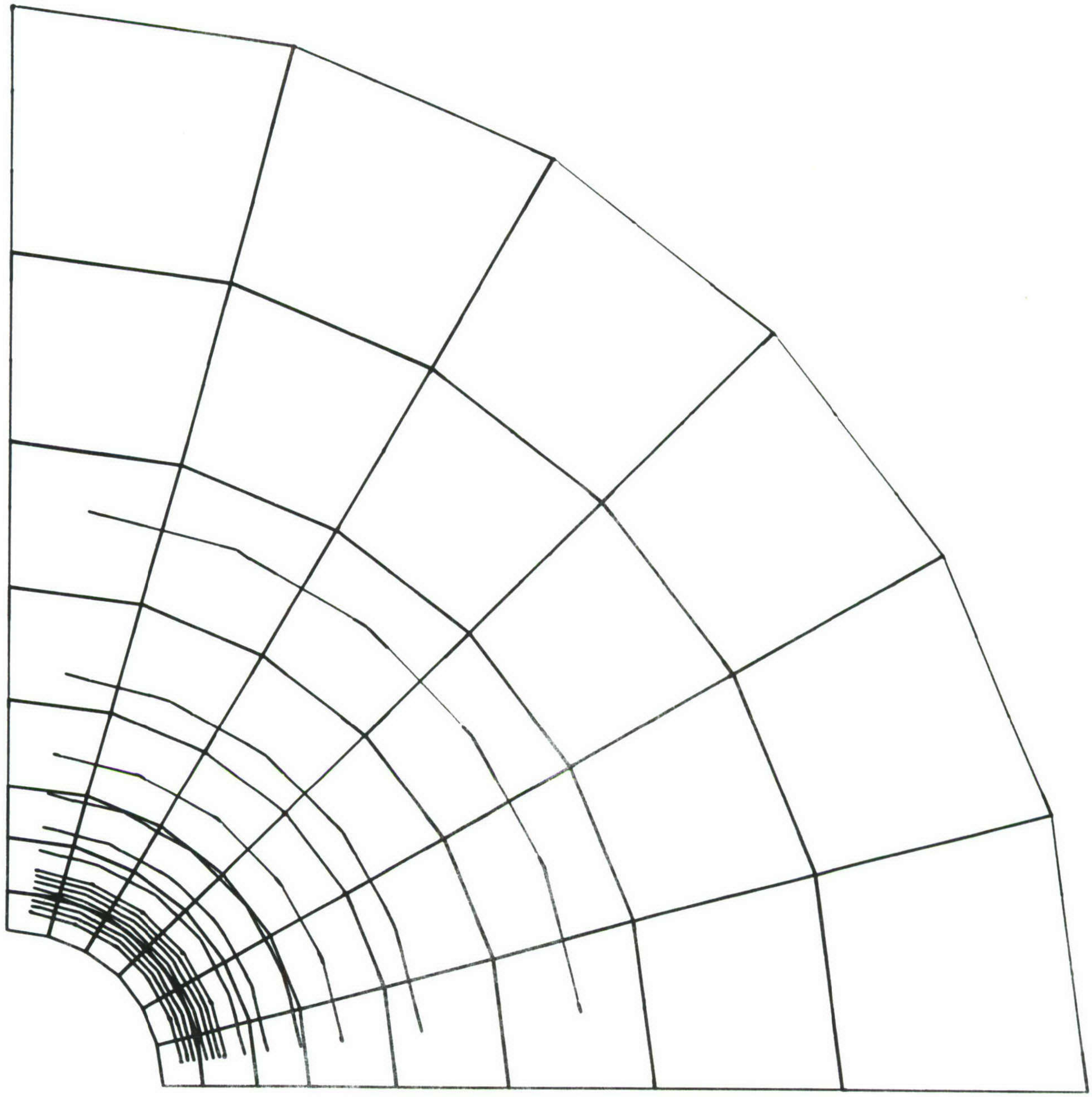


Figure AII-138 Radial Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

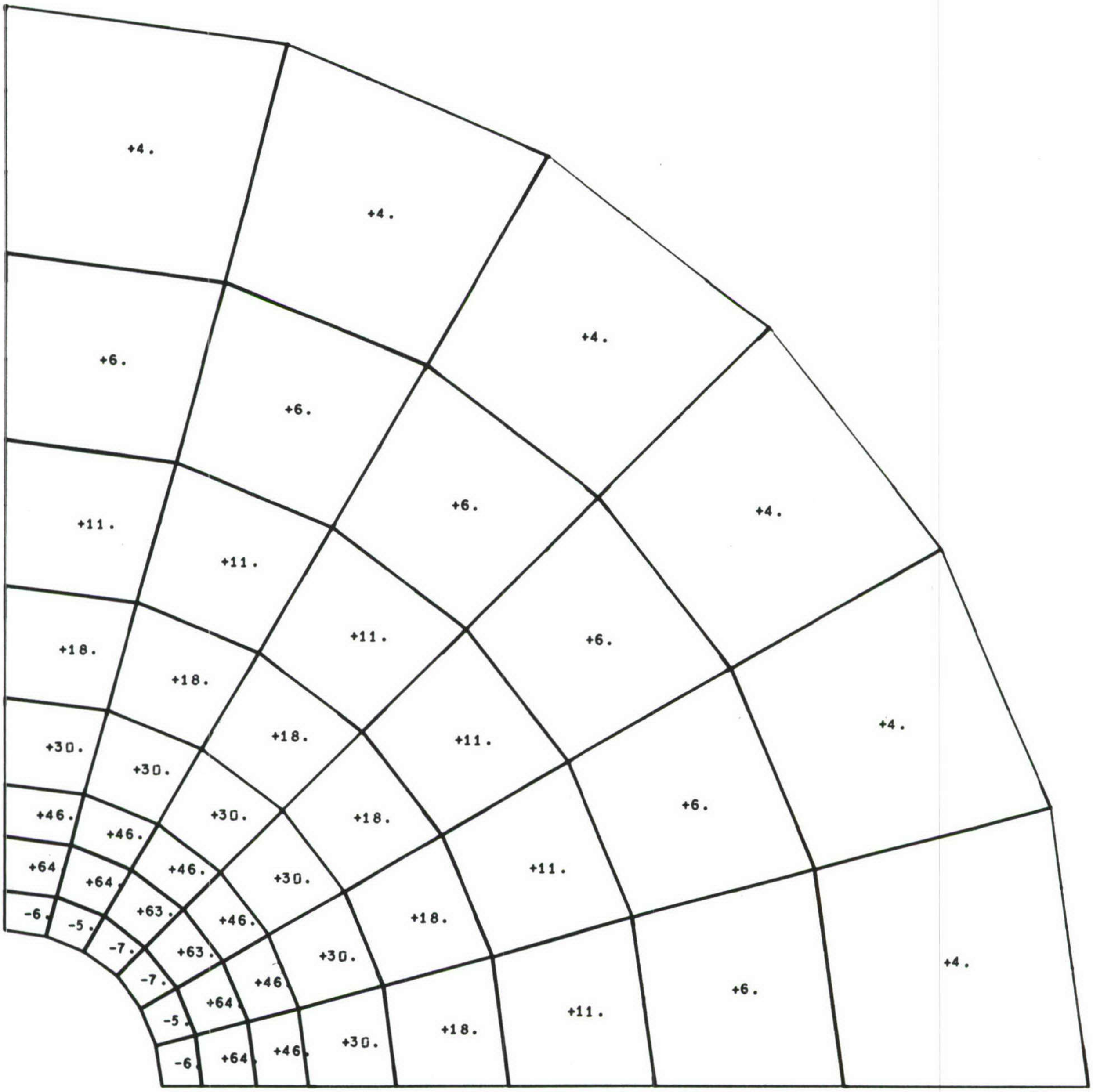


Figure AII-139 Tangential Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

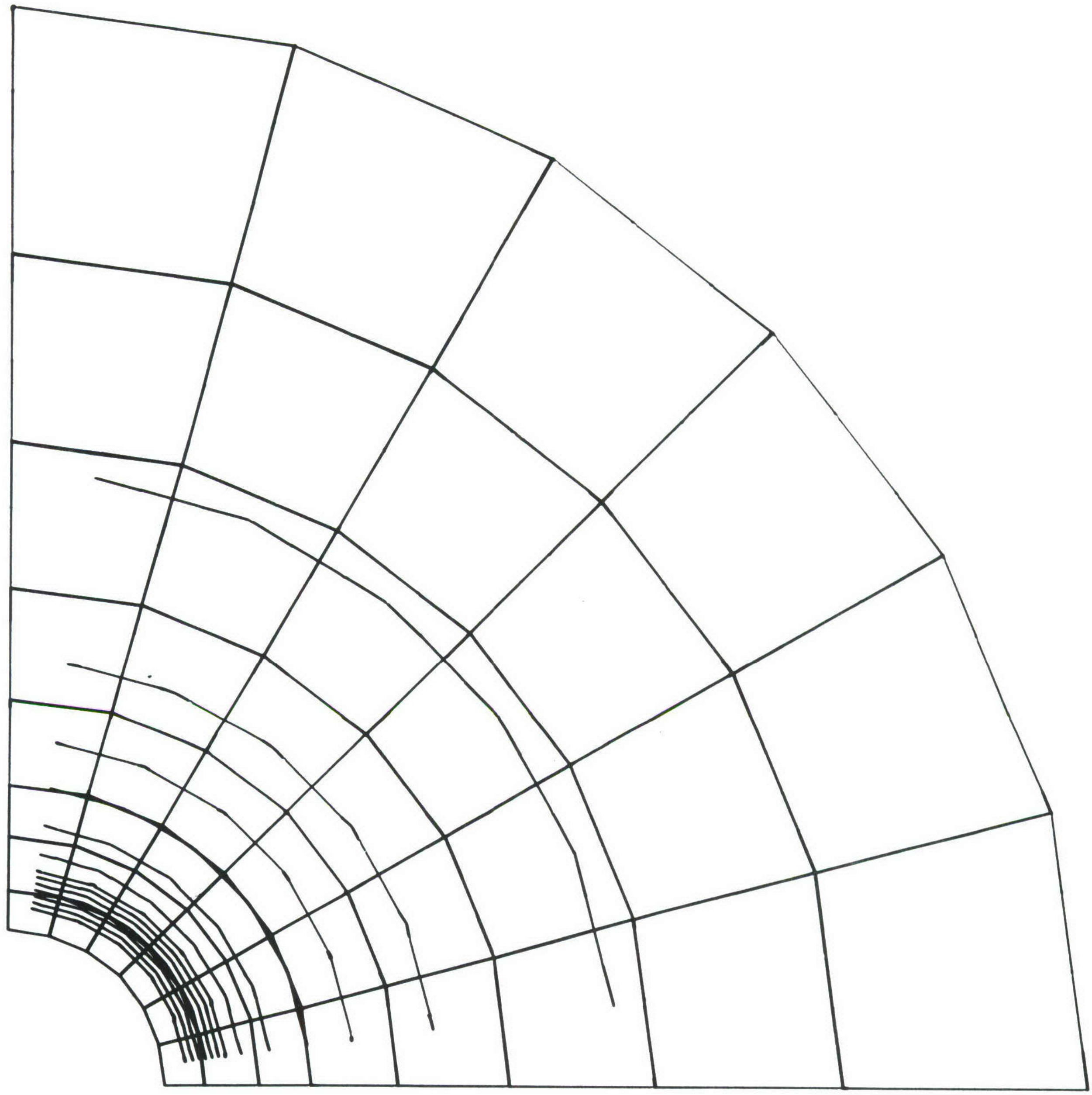


Figure AII-140 Tangential Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

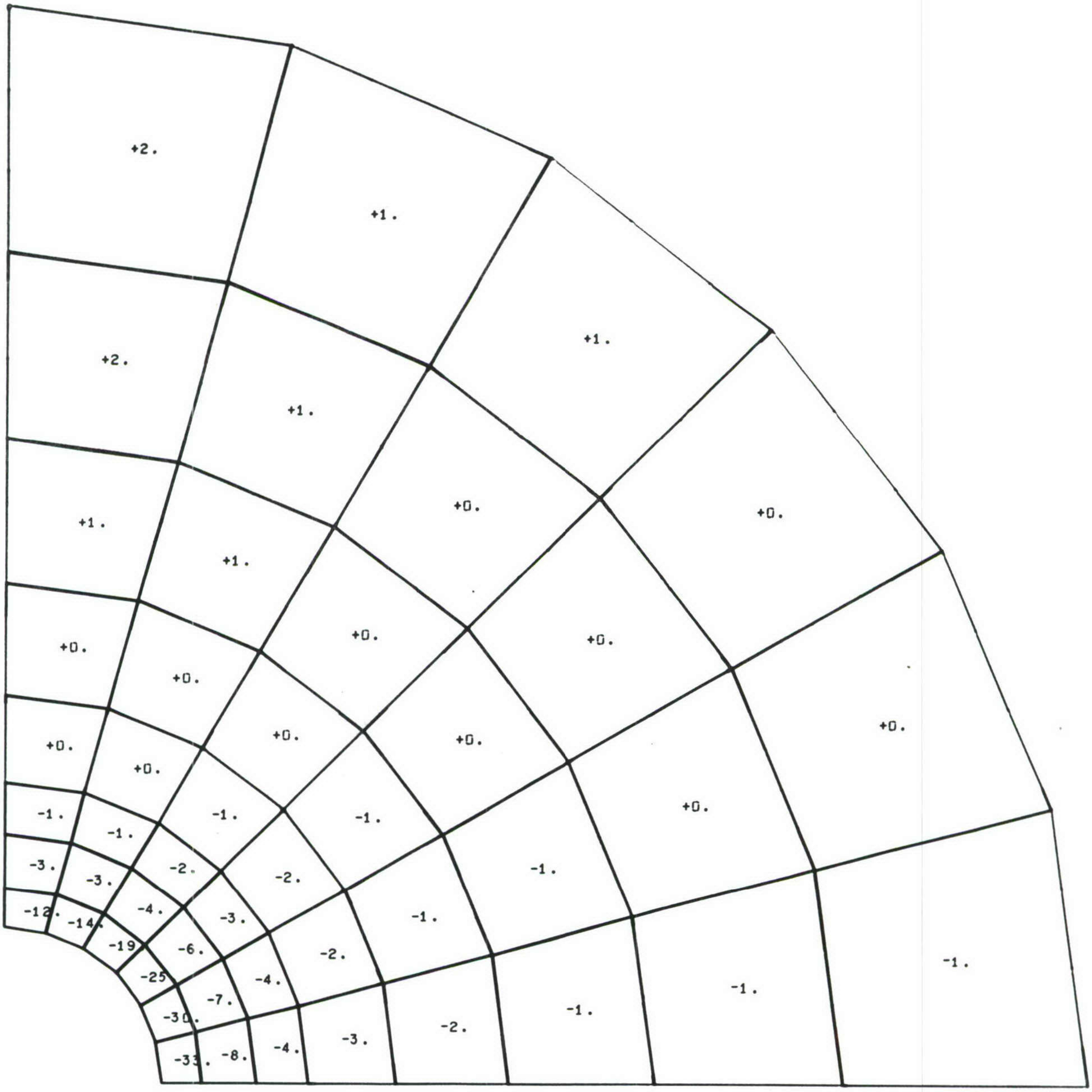


Figure AII-141 Radial Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

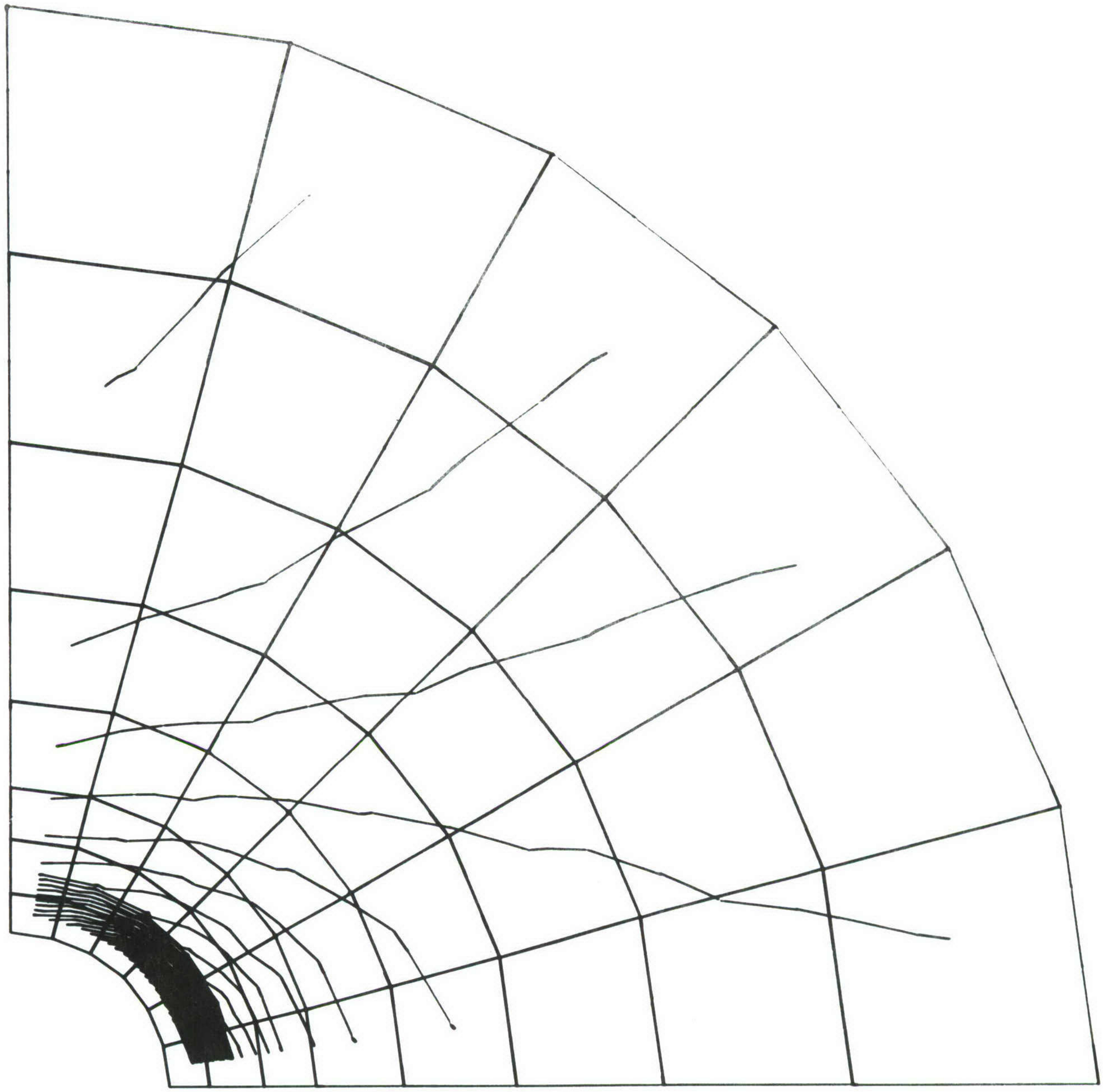


Figure AII-142 Radial Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

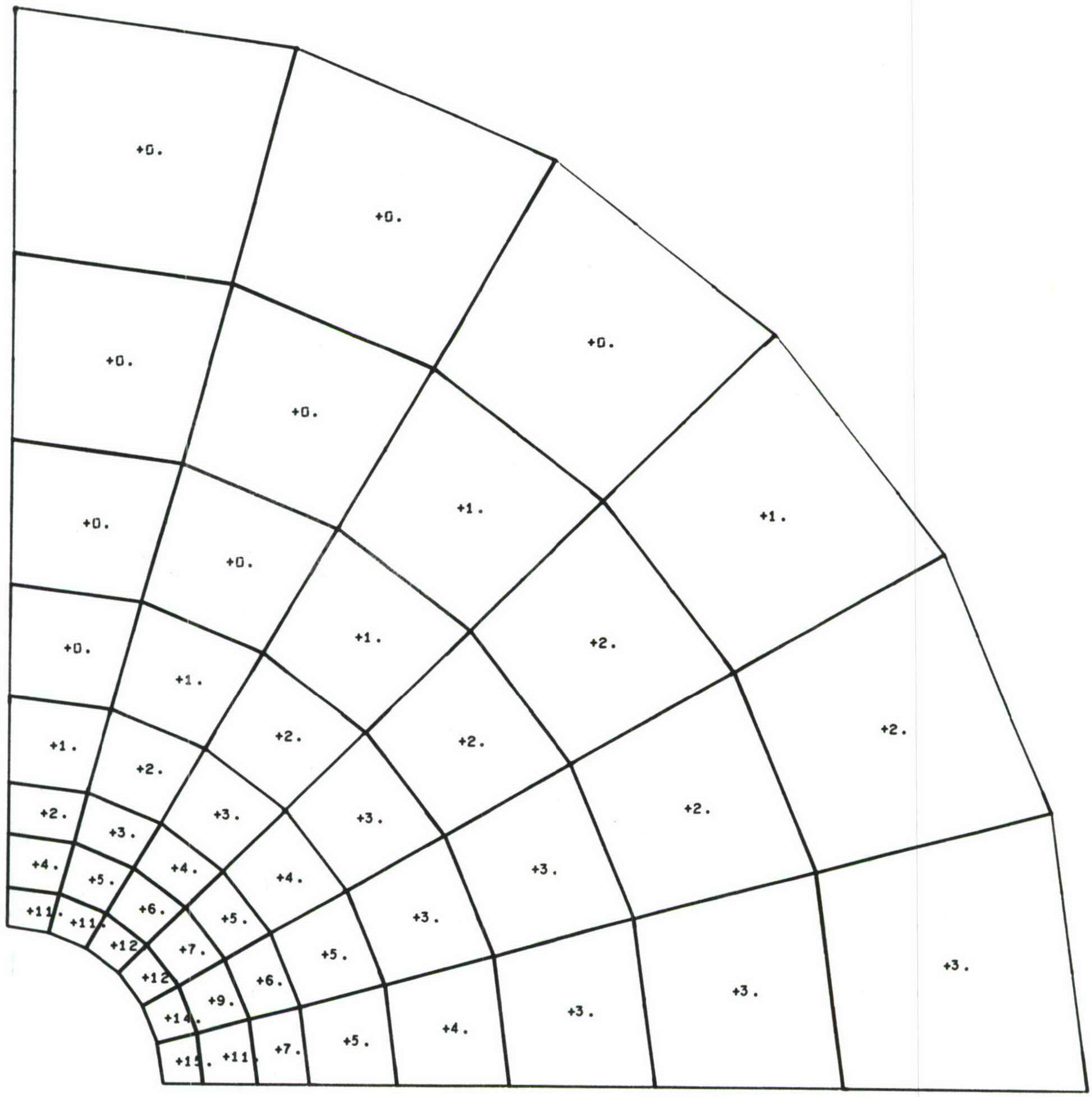


Figure AII-143 Tangential Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

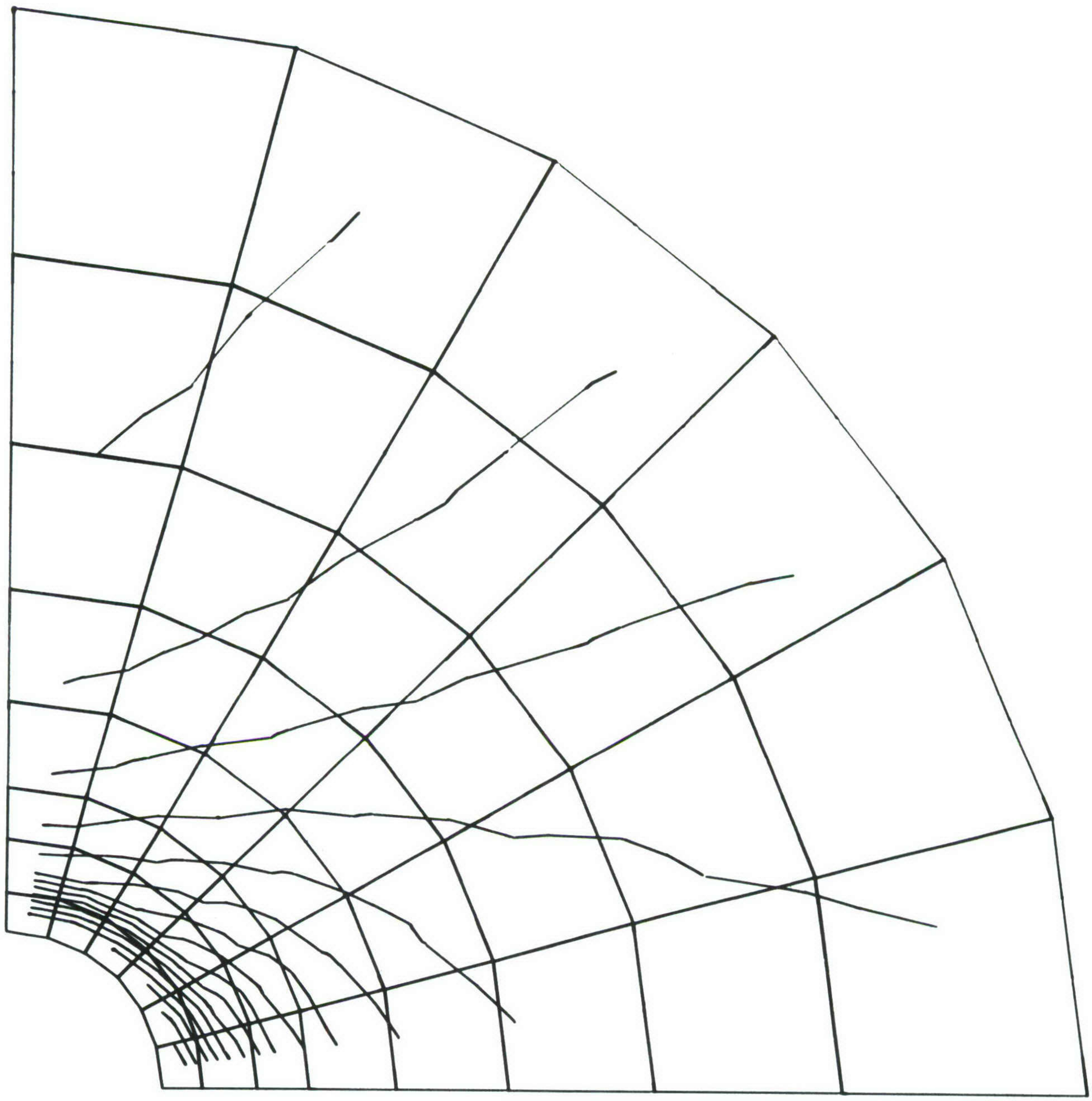


Figure AII-144 Tangential Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

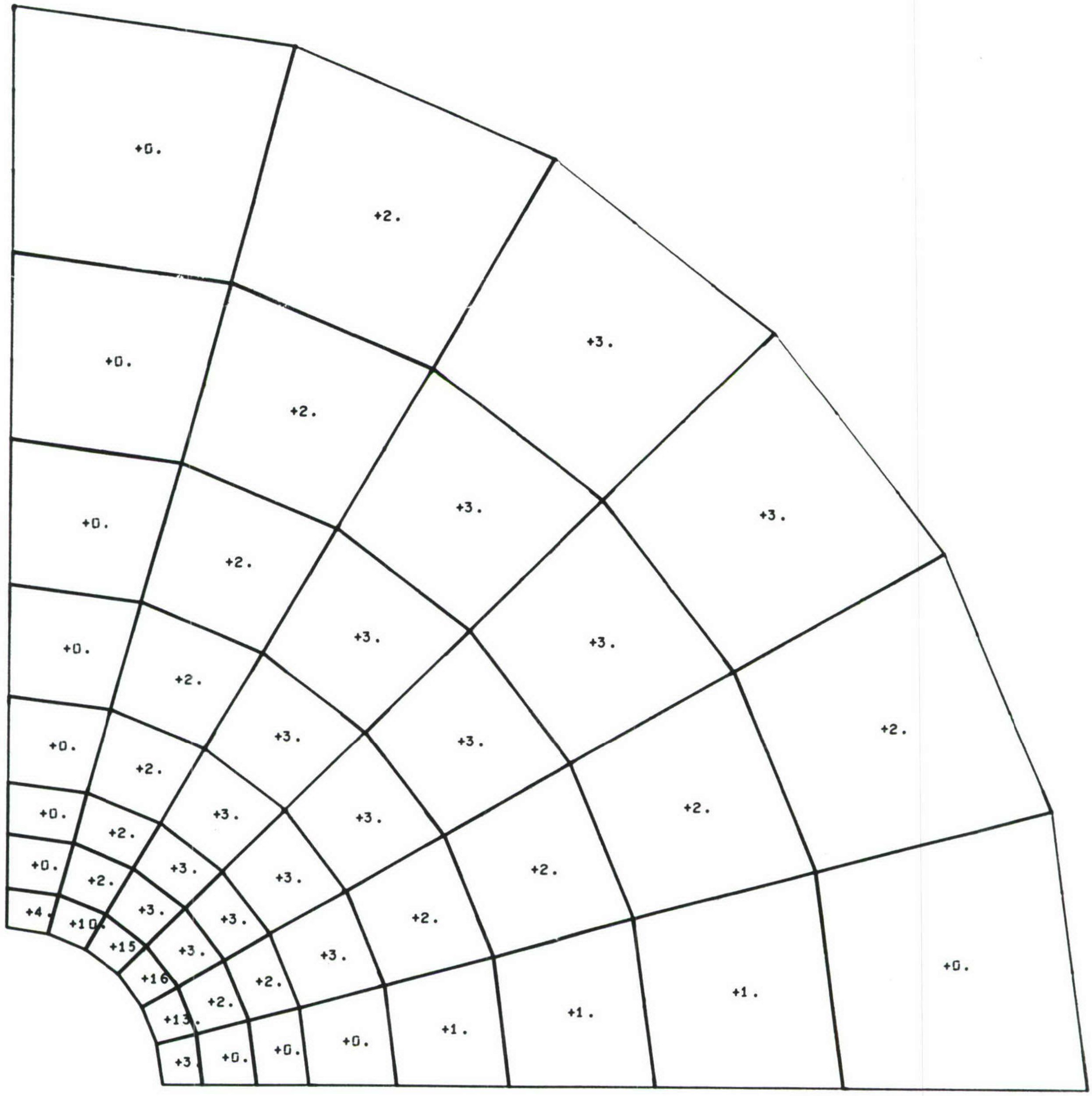


Figure AII-145 Radial-Tangential Shear Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

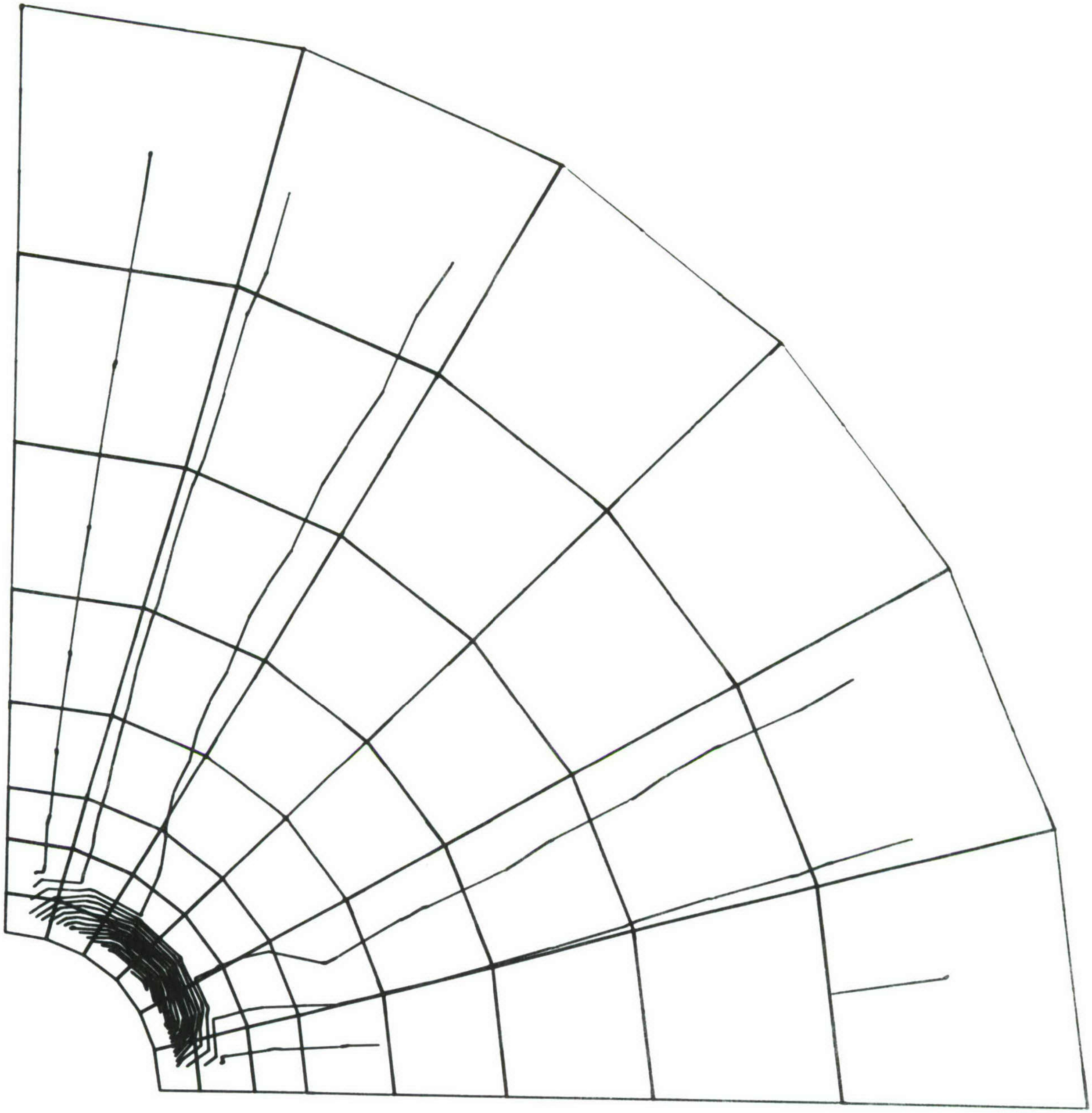


Figure AII-146 Radial-Tangential Shear Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

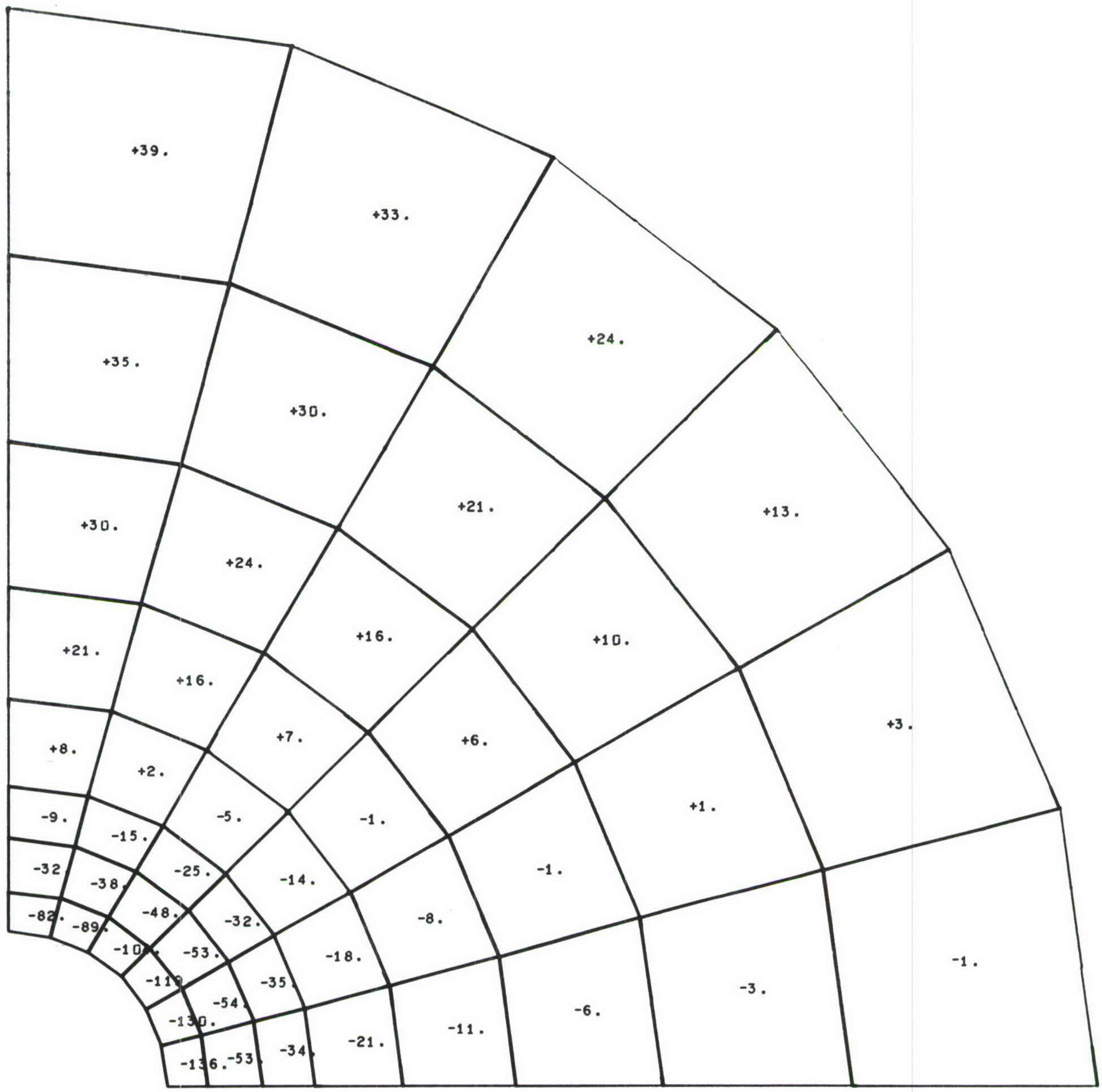


Figure AII-147 Radial Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

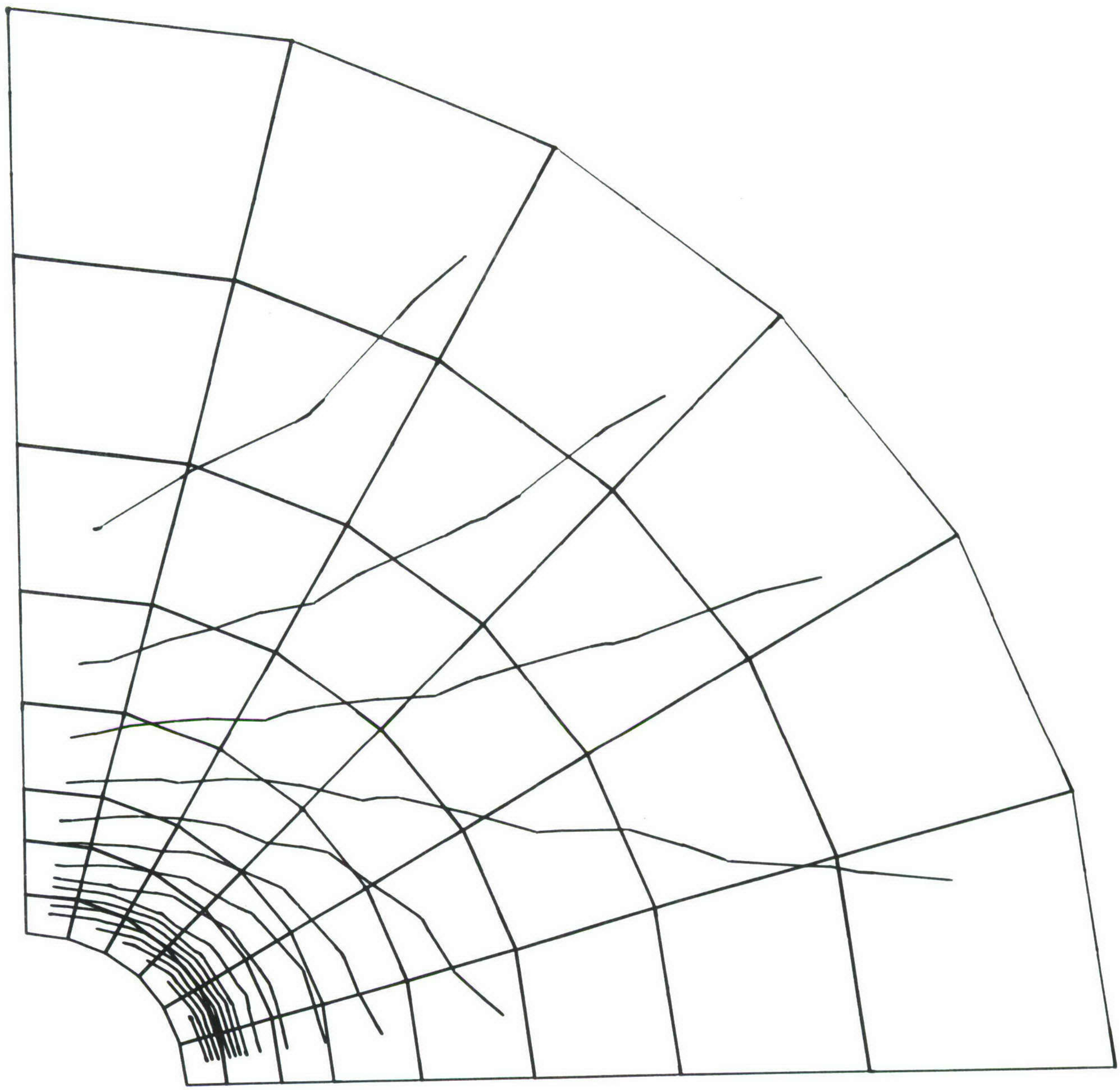


Figure AII-148 Radial Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

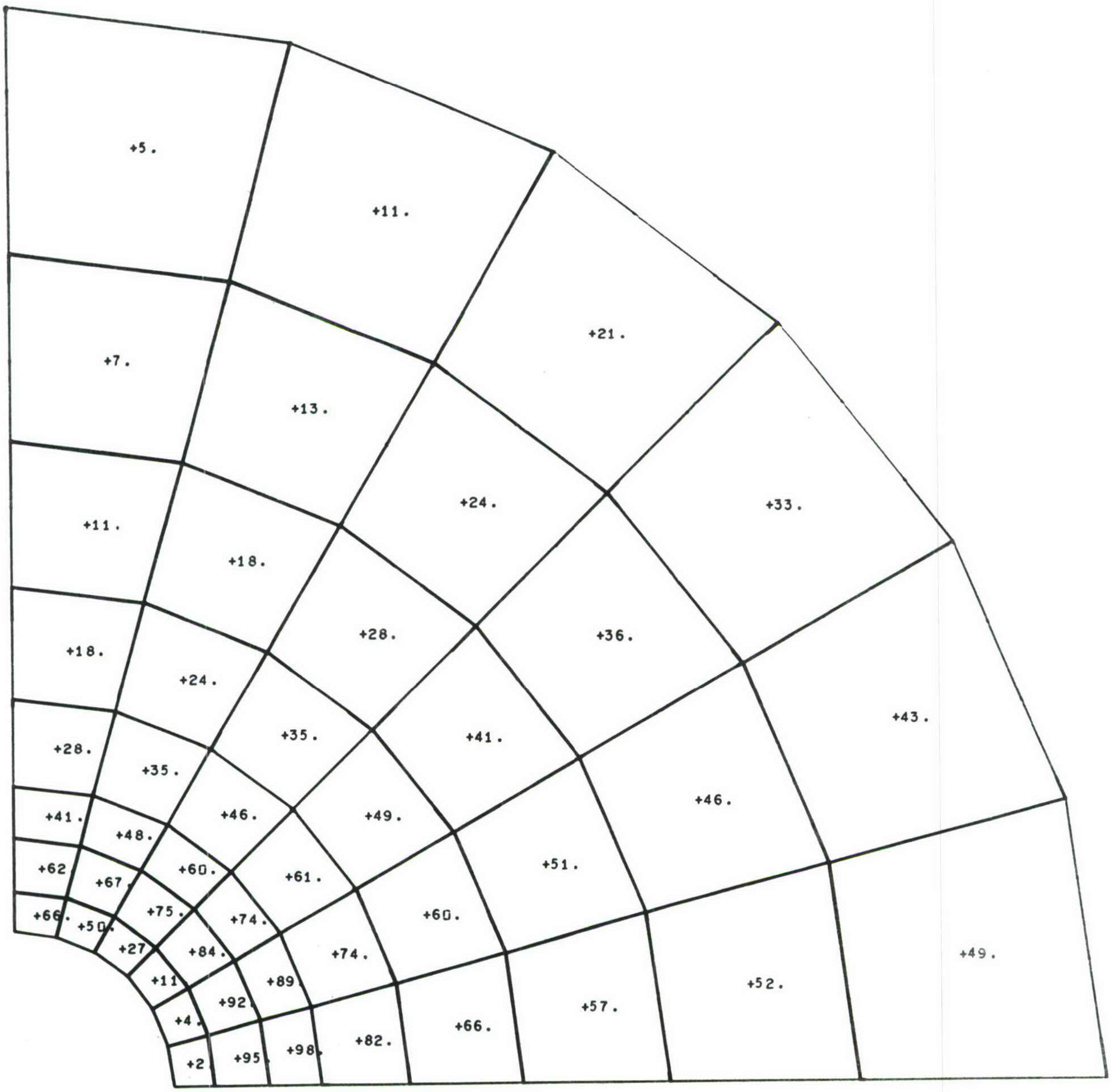


Figure AII-149 Tangential Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

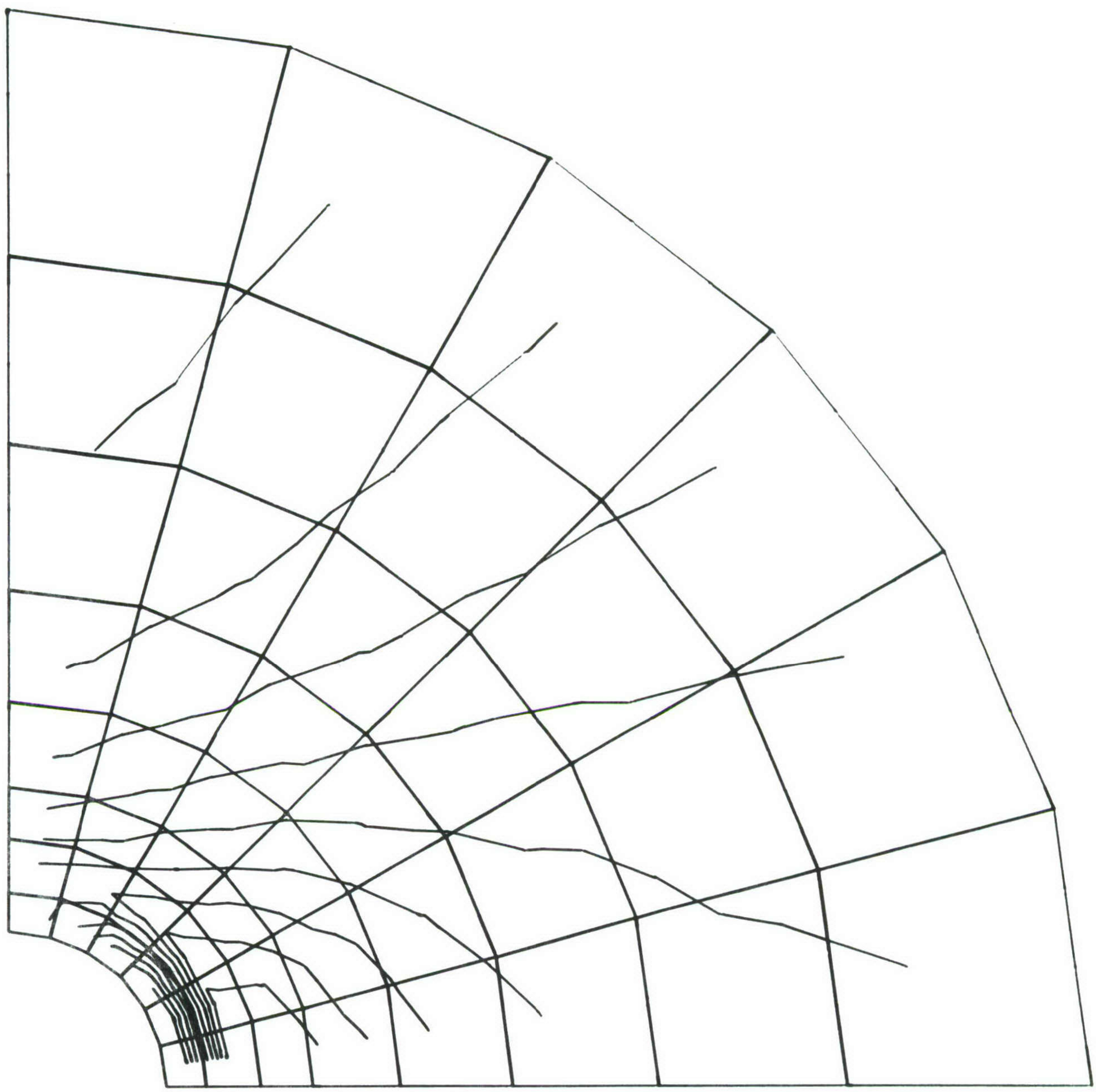


Figure AII-150 Tangential Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

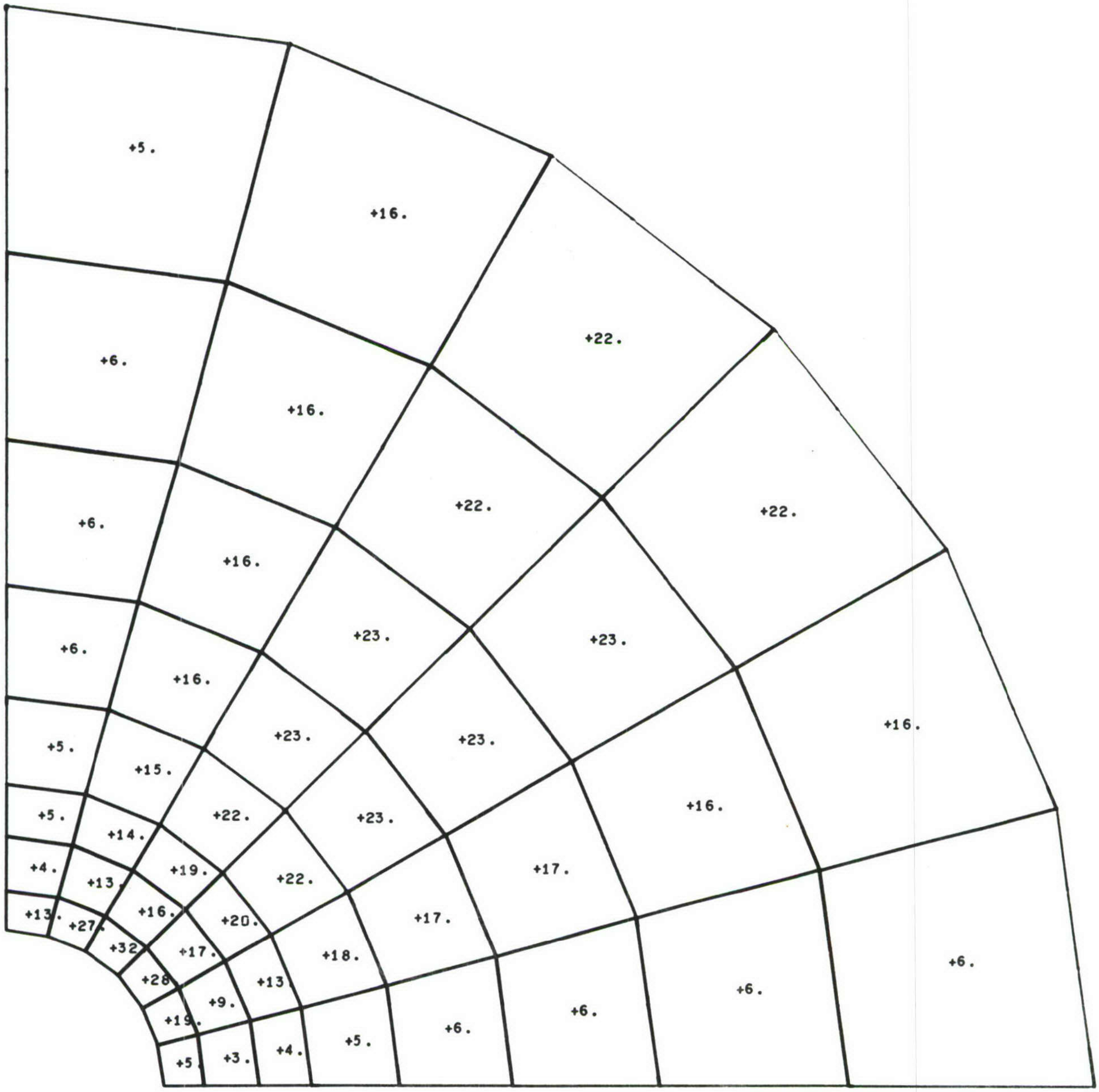


Figure AII-151 Radial-Tangential Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

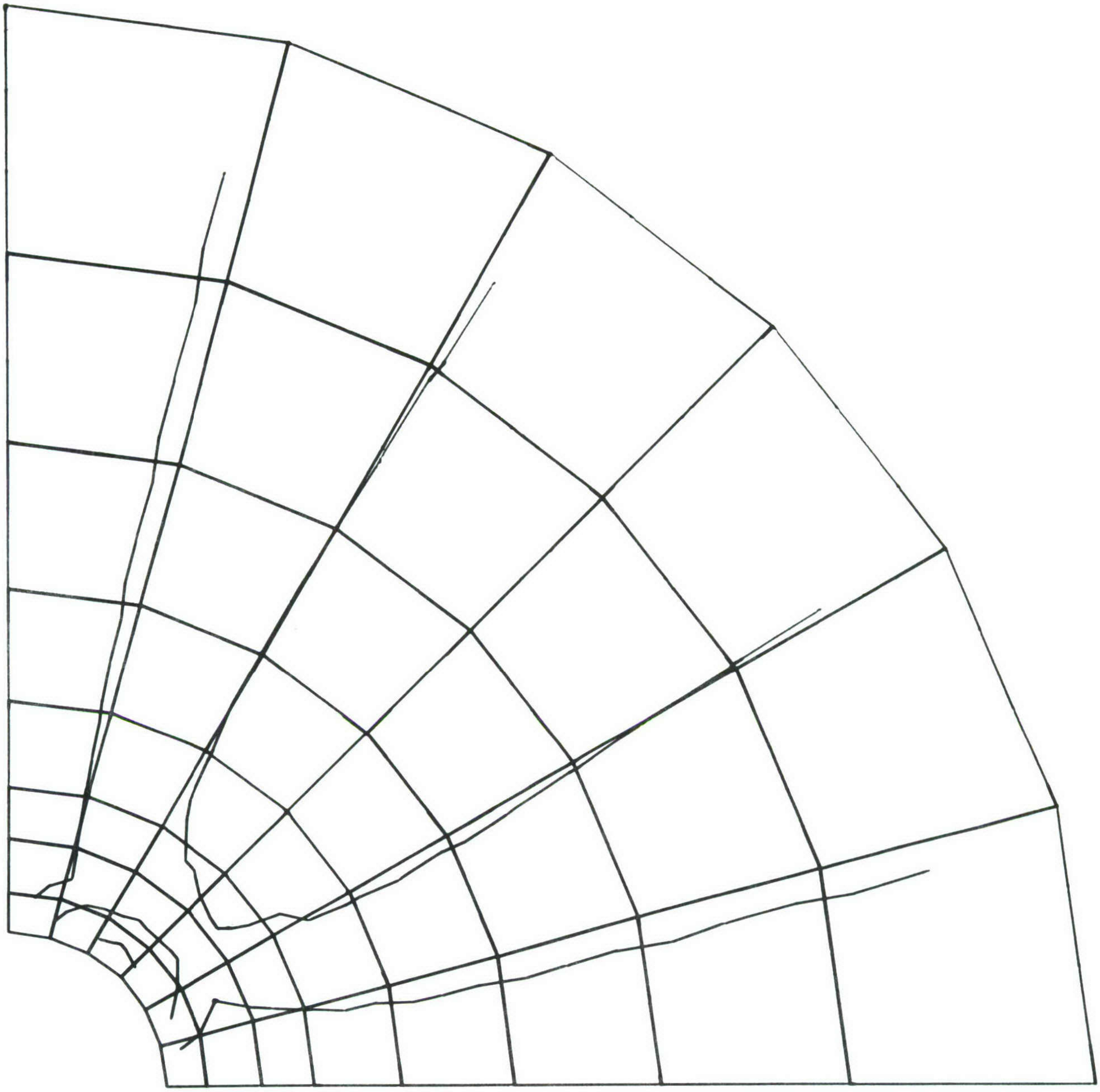


Figure AII-152 Radial-Tangential Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

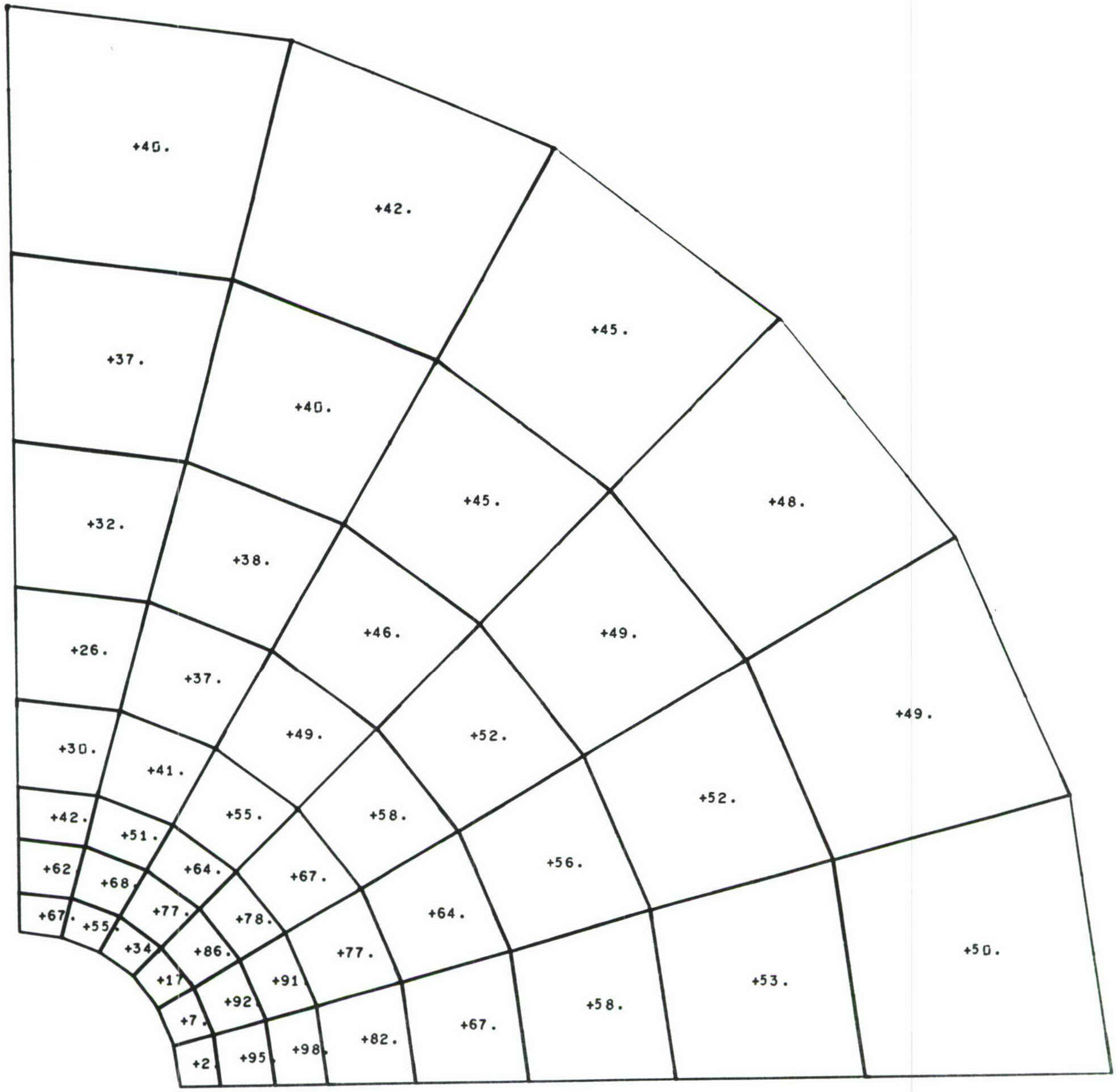


Figure AII-153 First Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

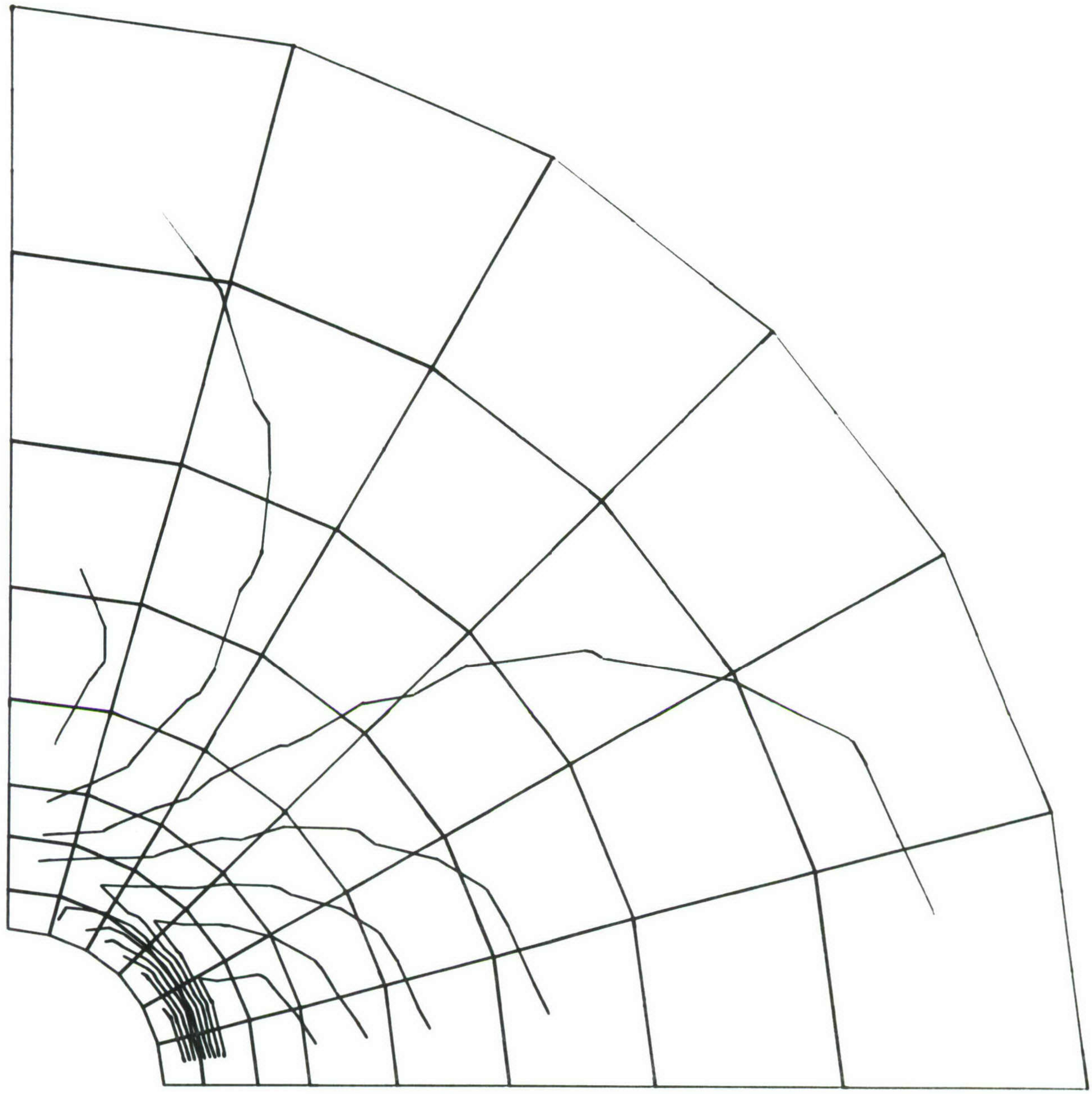


Figure AII-154 First Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

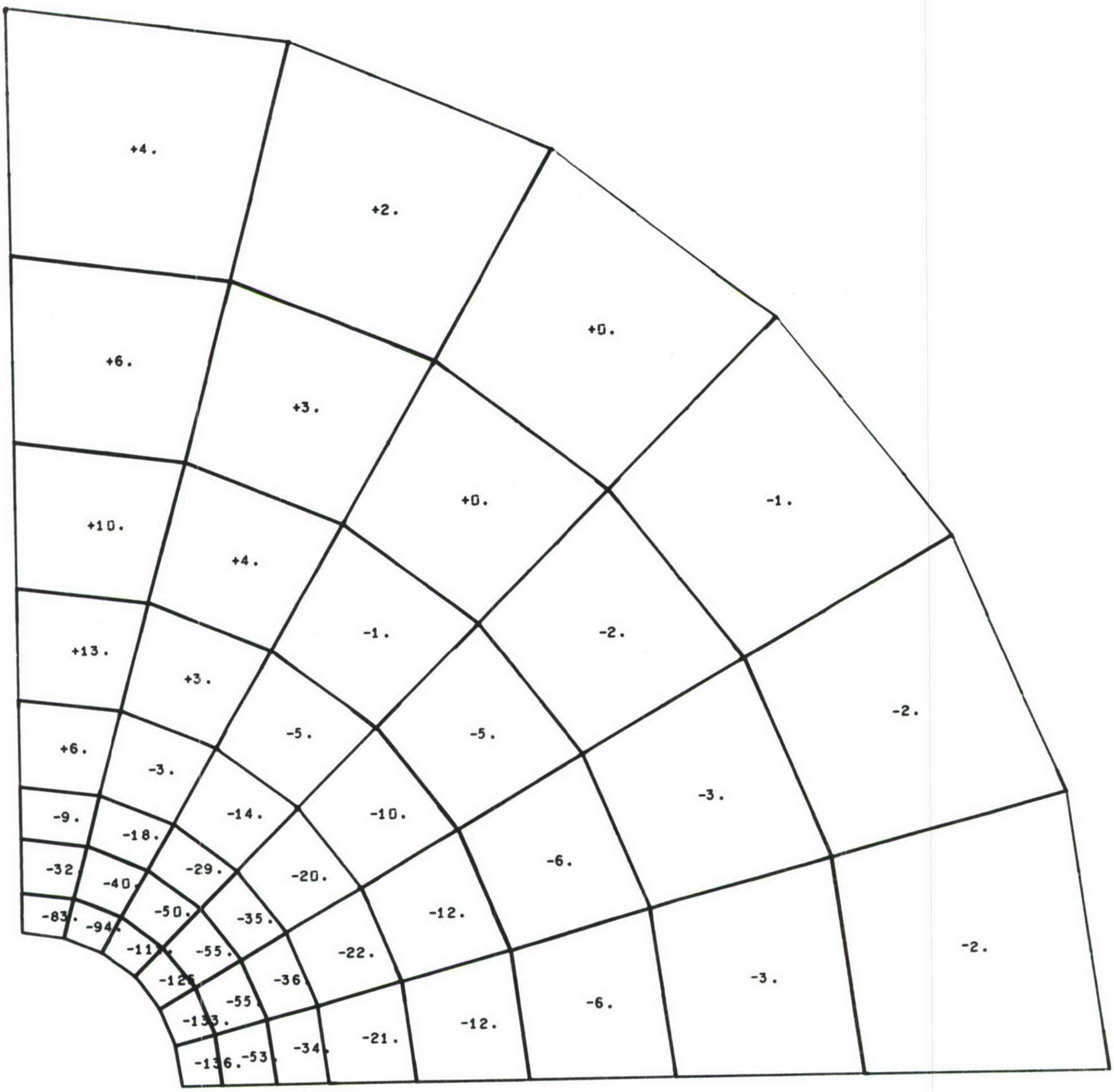


Figure AII-155 Second Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

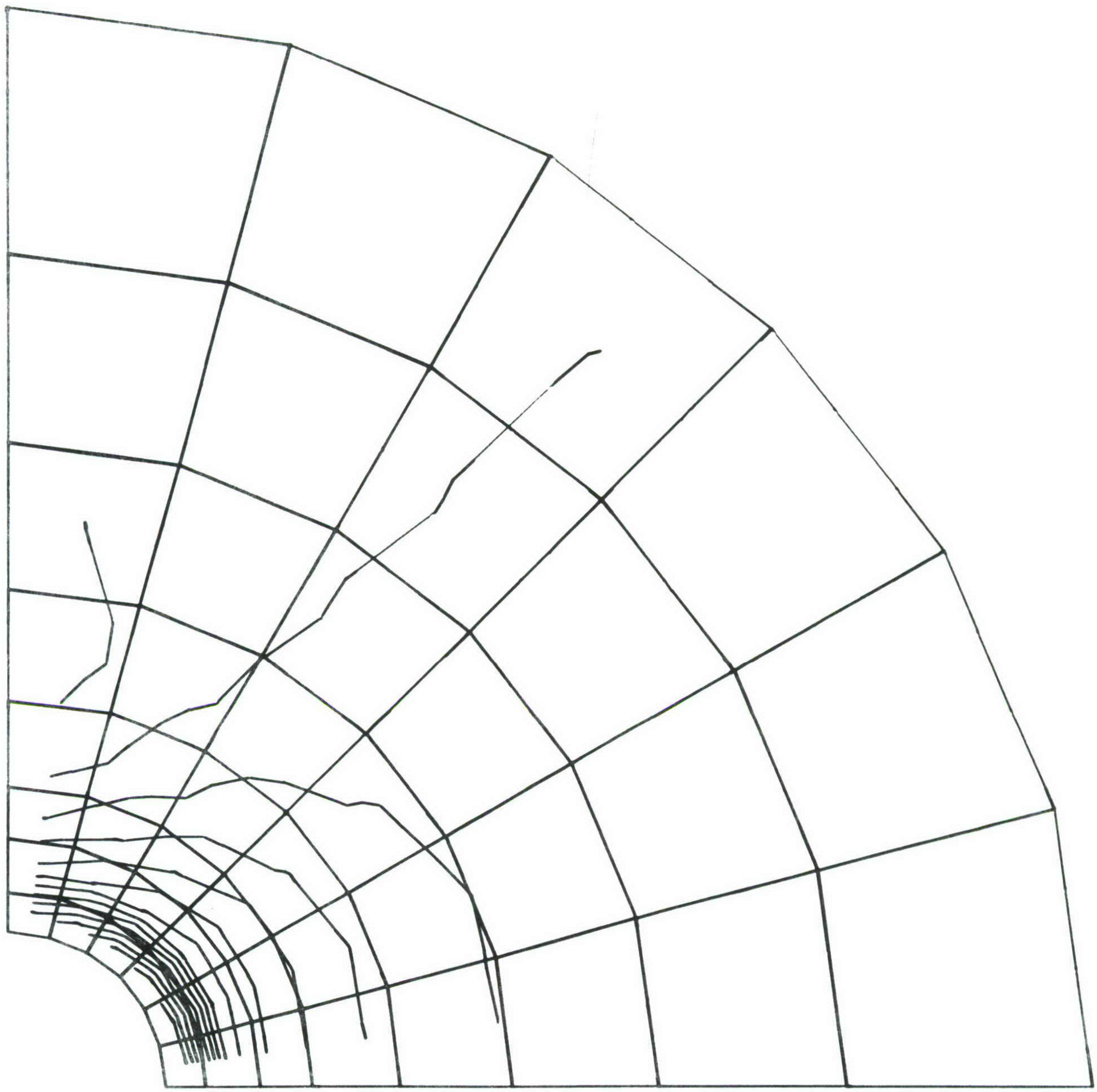


Figure AII-156 Second Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

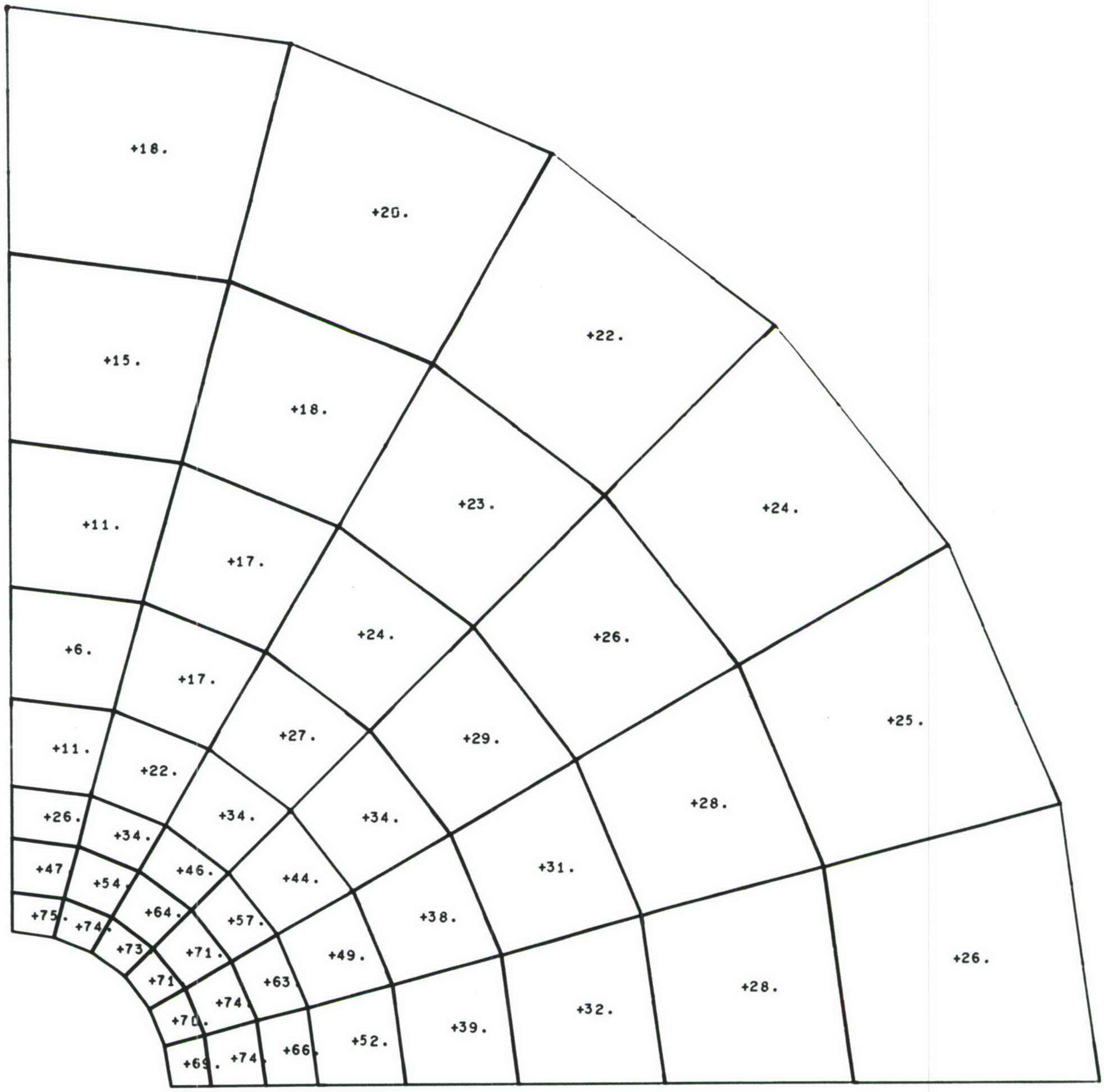


Figure AII-157 Principal Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

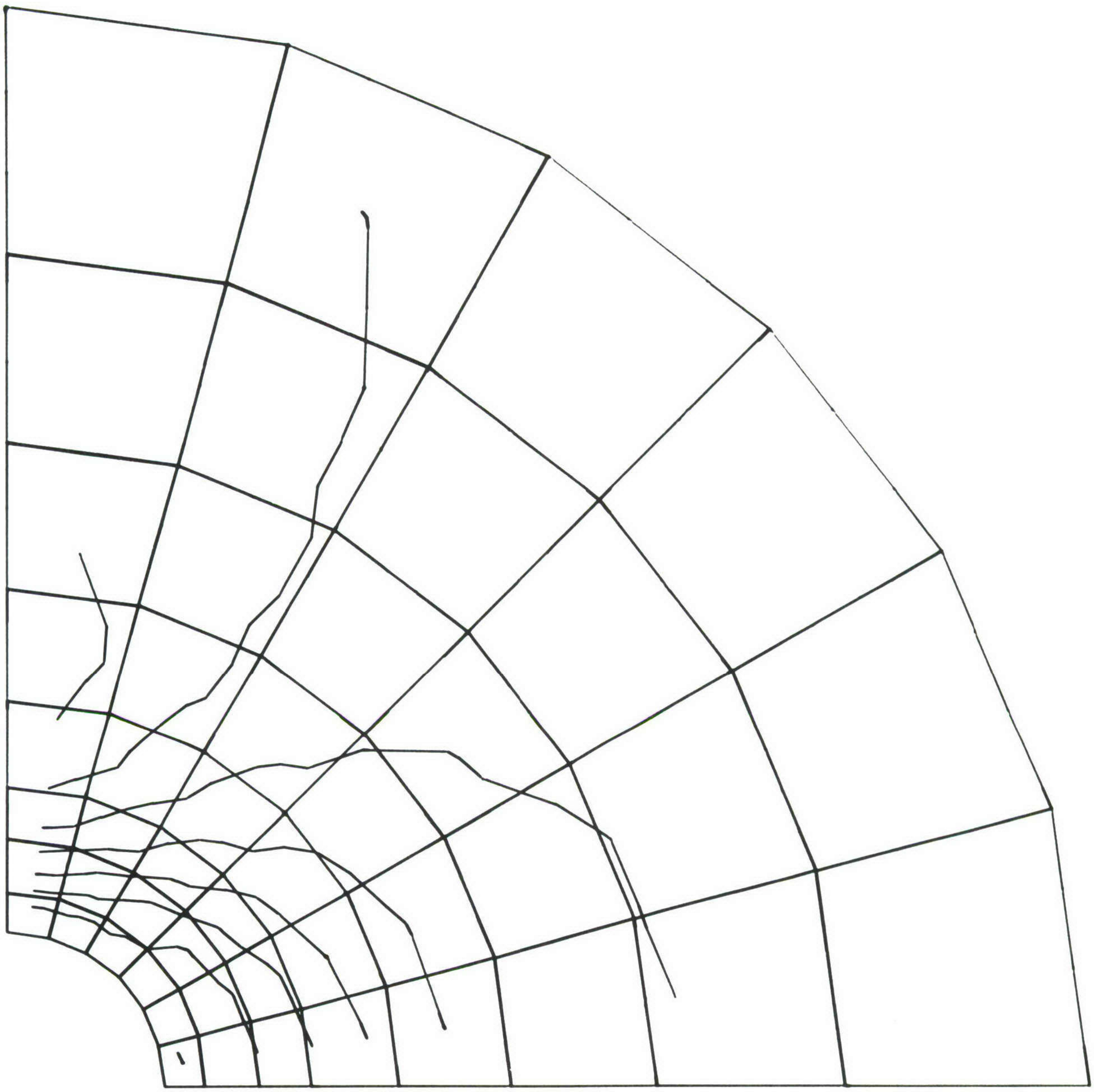


Figure AII-158 Principal Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

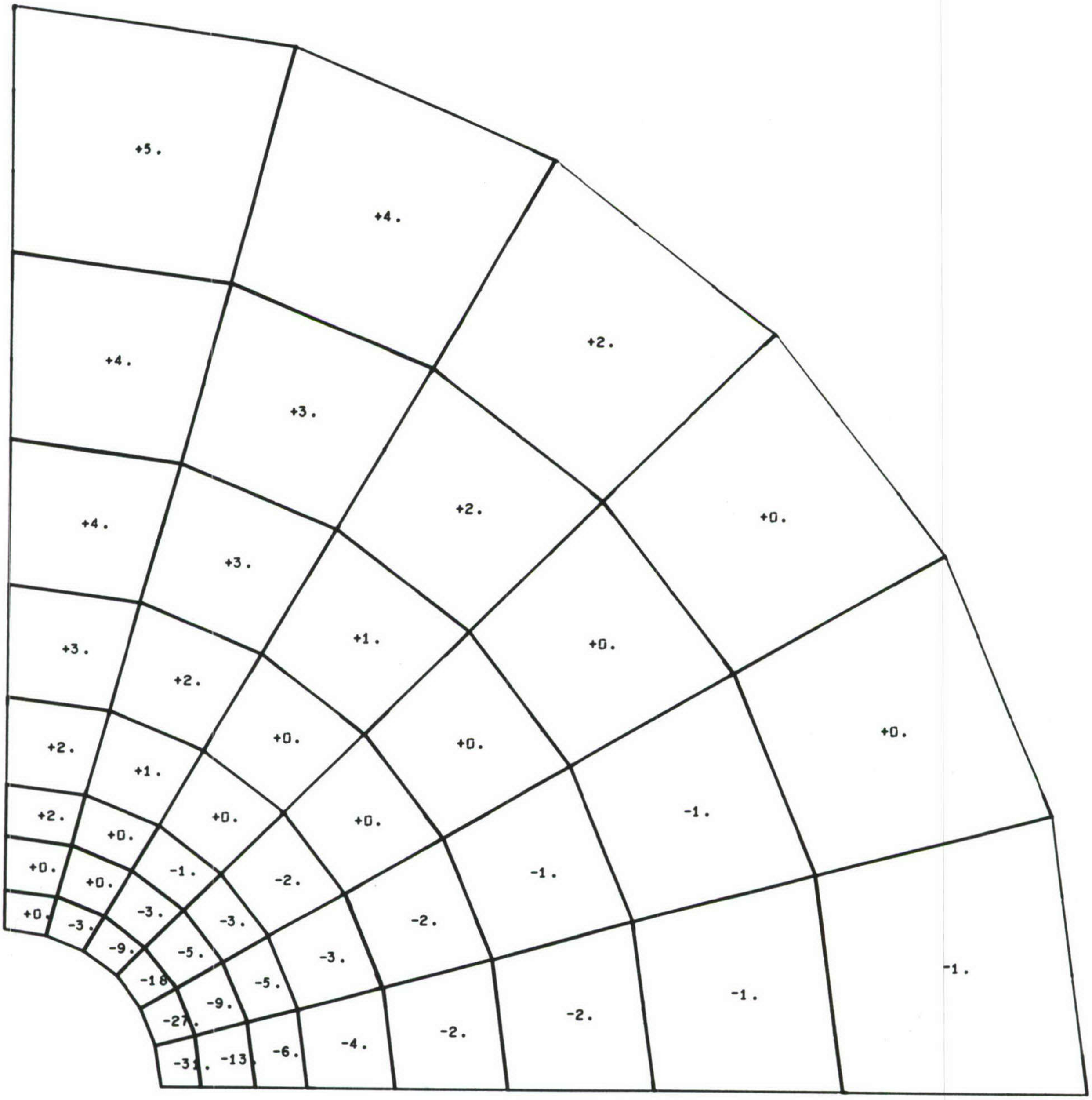


Figure AII-159 Radial Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

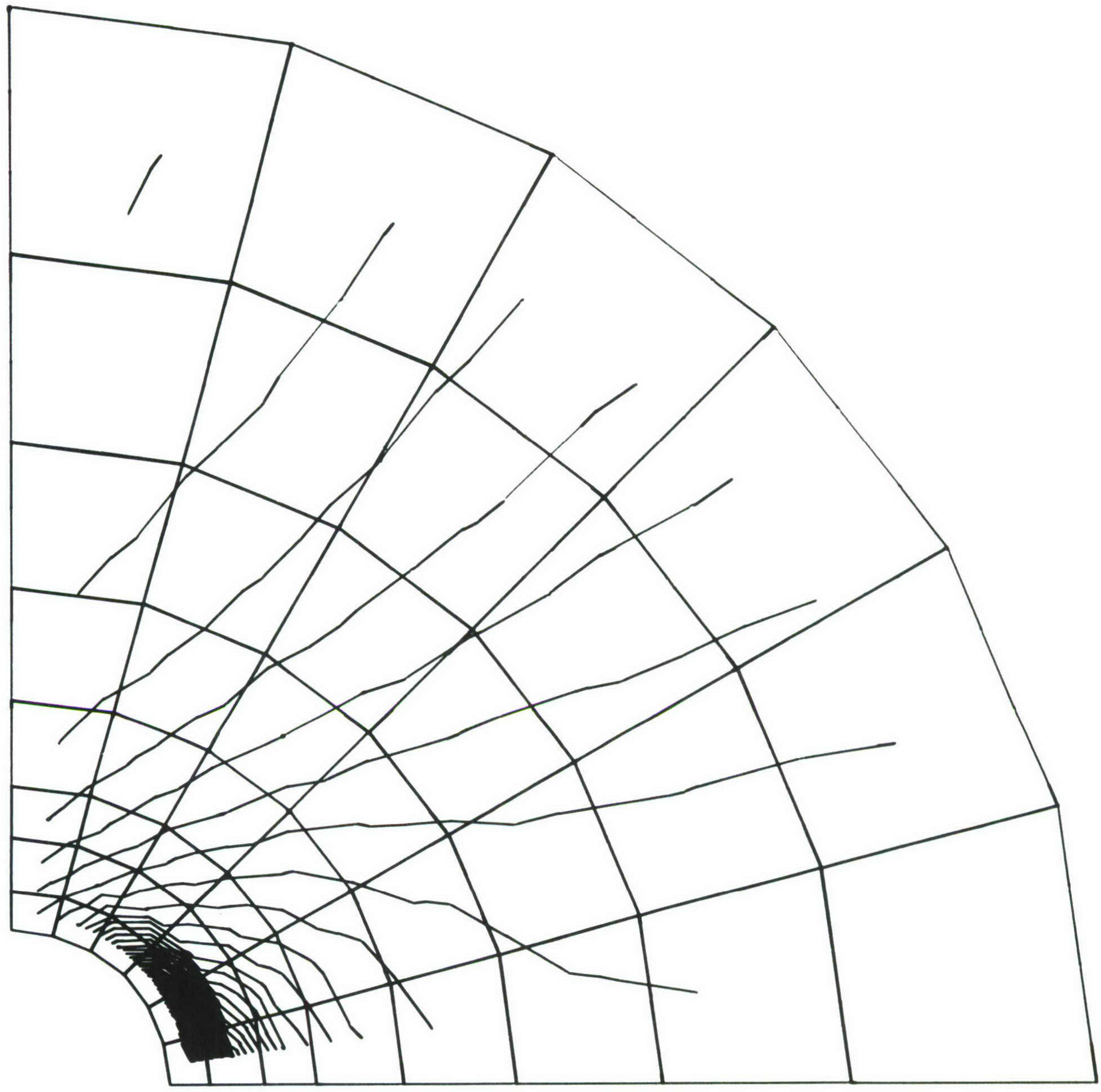


Figure AII-160 Radial Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

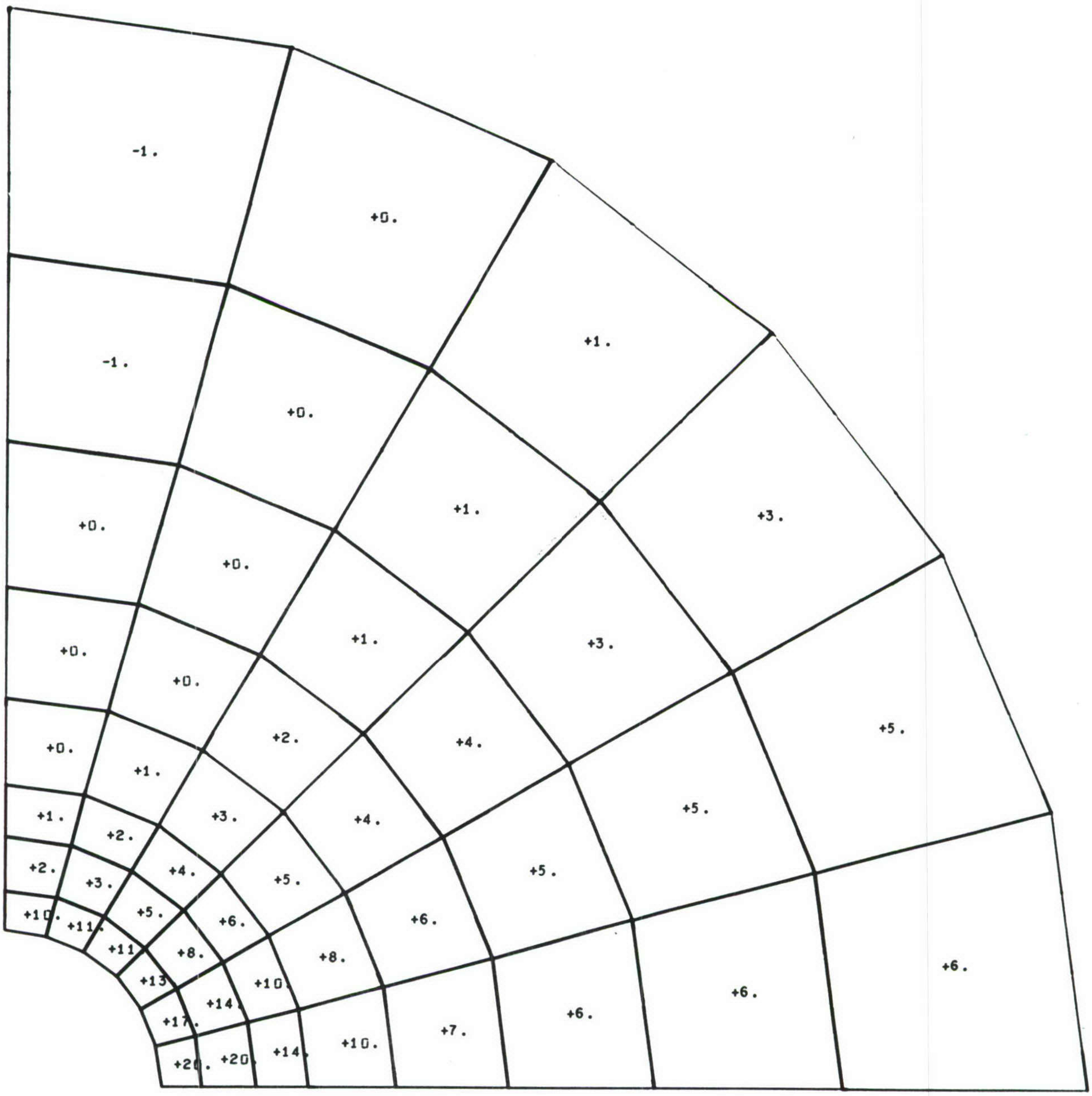


Figure AII-161 Tangential Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

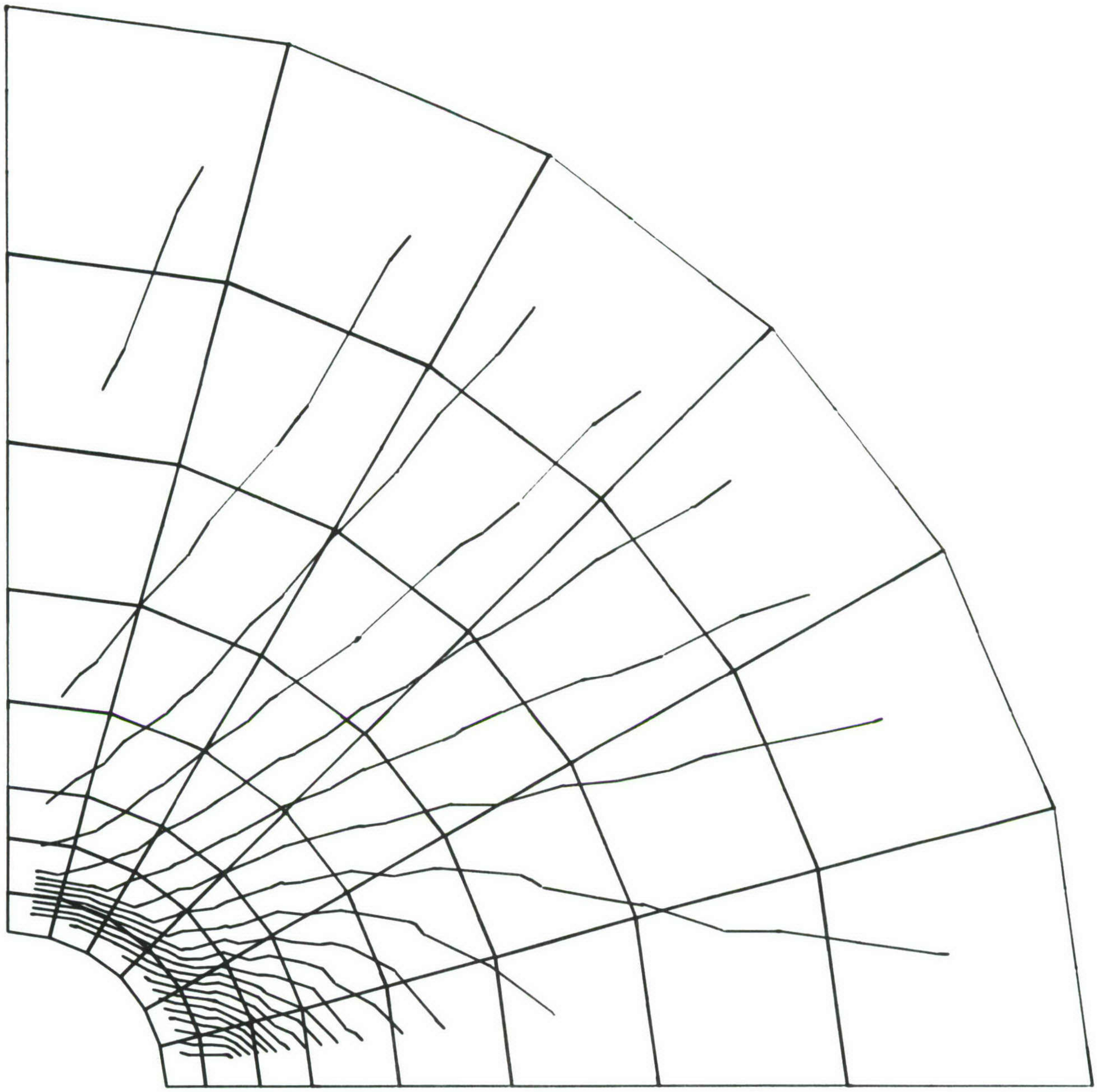


Figure AII-162 Tangential Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

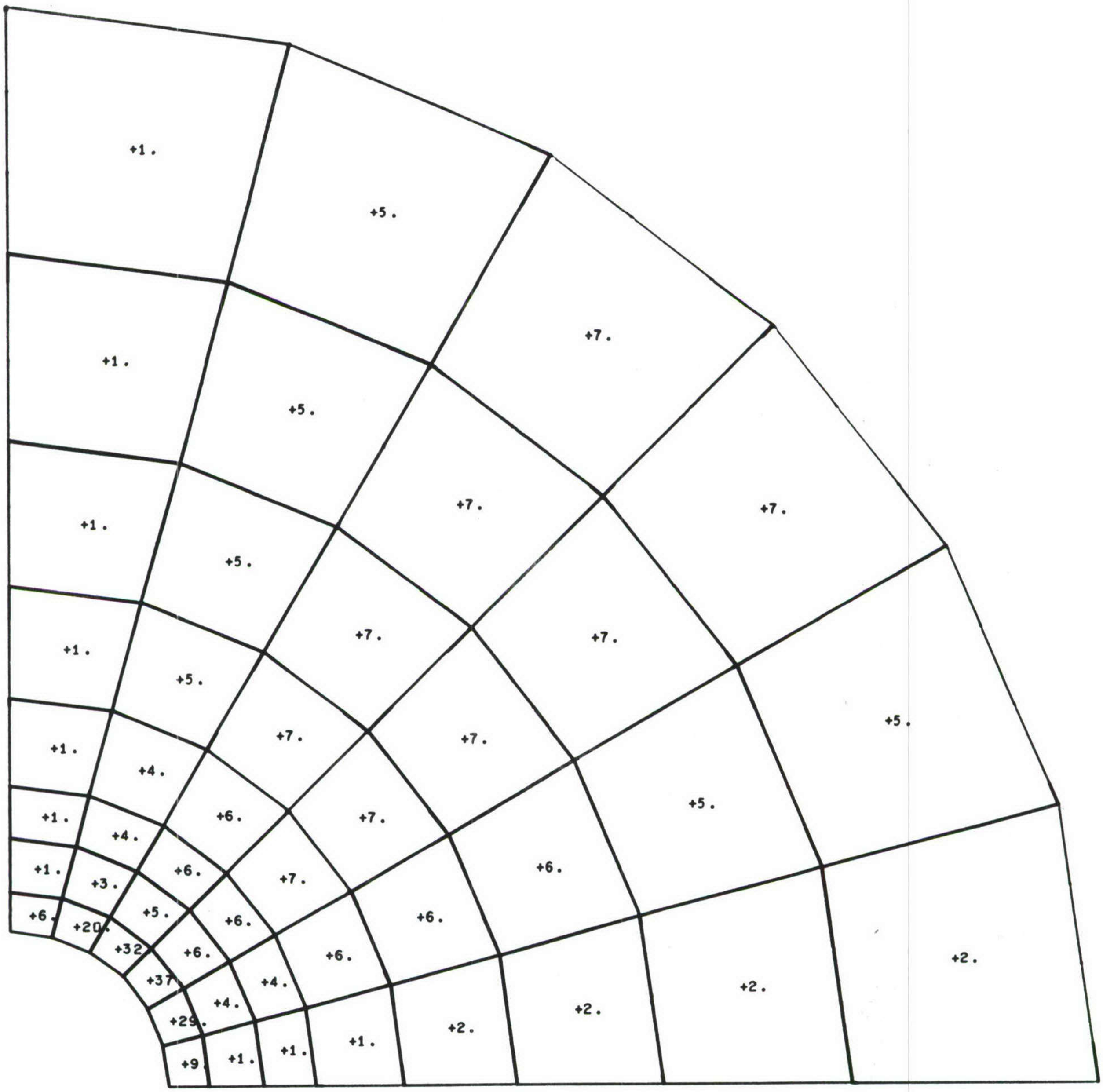


Figure AII-163 Radial-Tangential Shear Strain Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

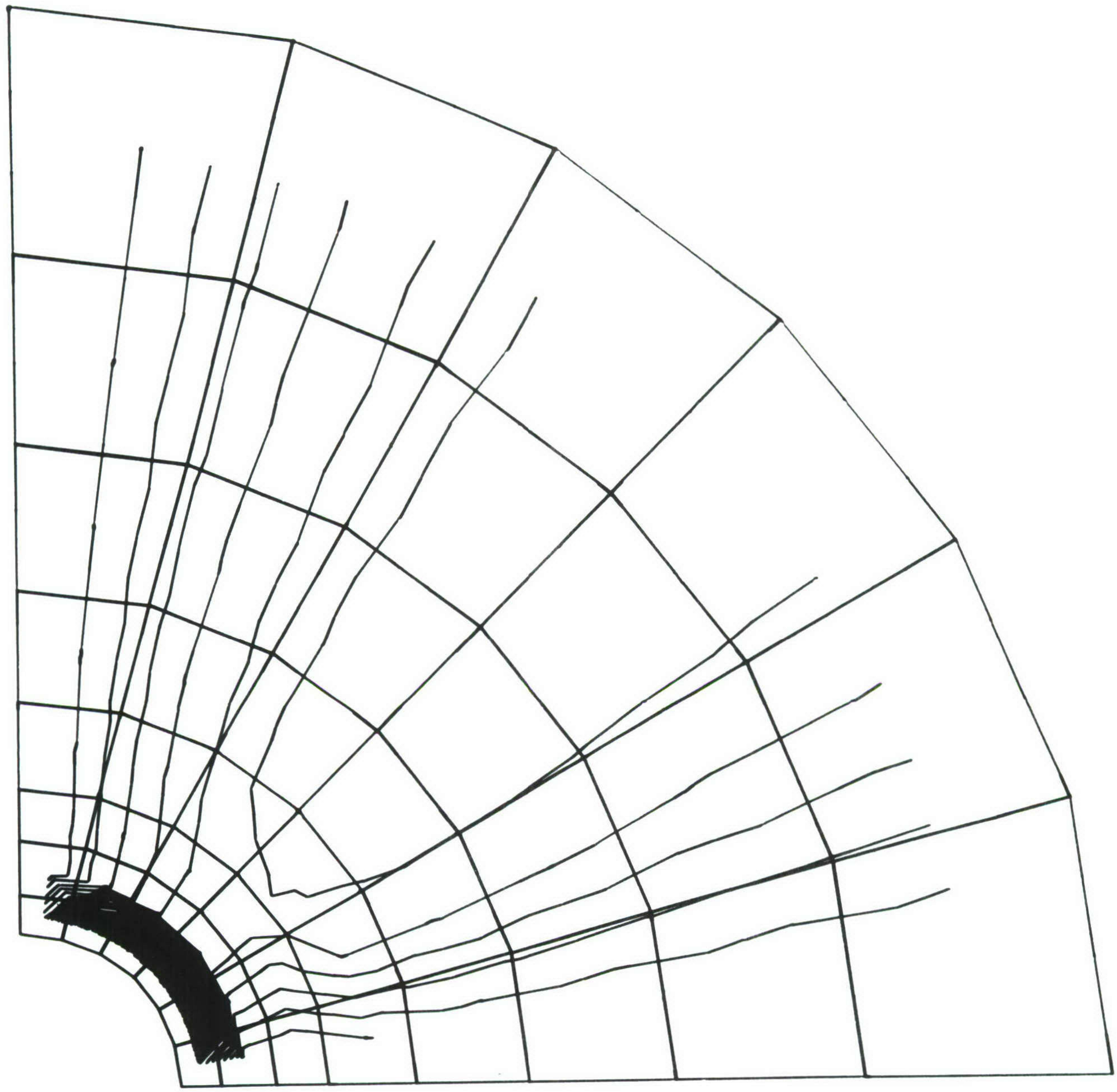


Figure AII-164 Radial-Tangential Shear Strain Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

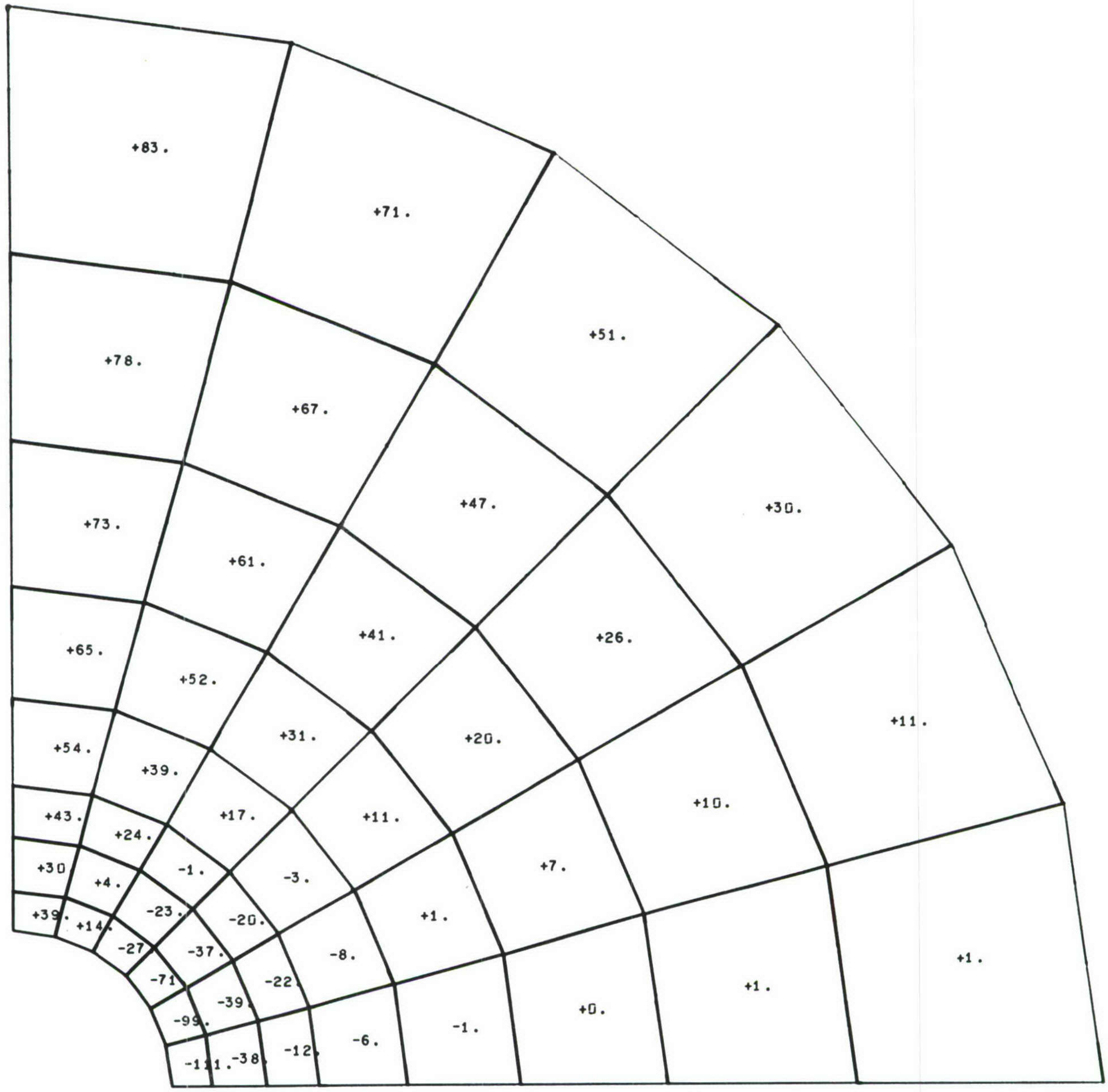


Figure AII-165 Radial Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

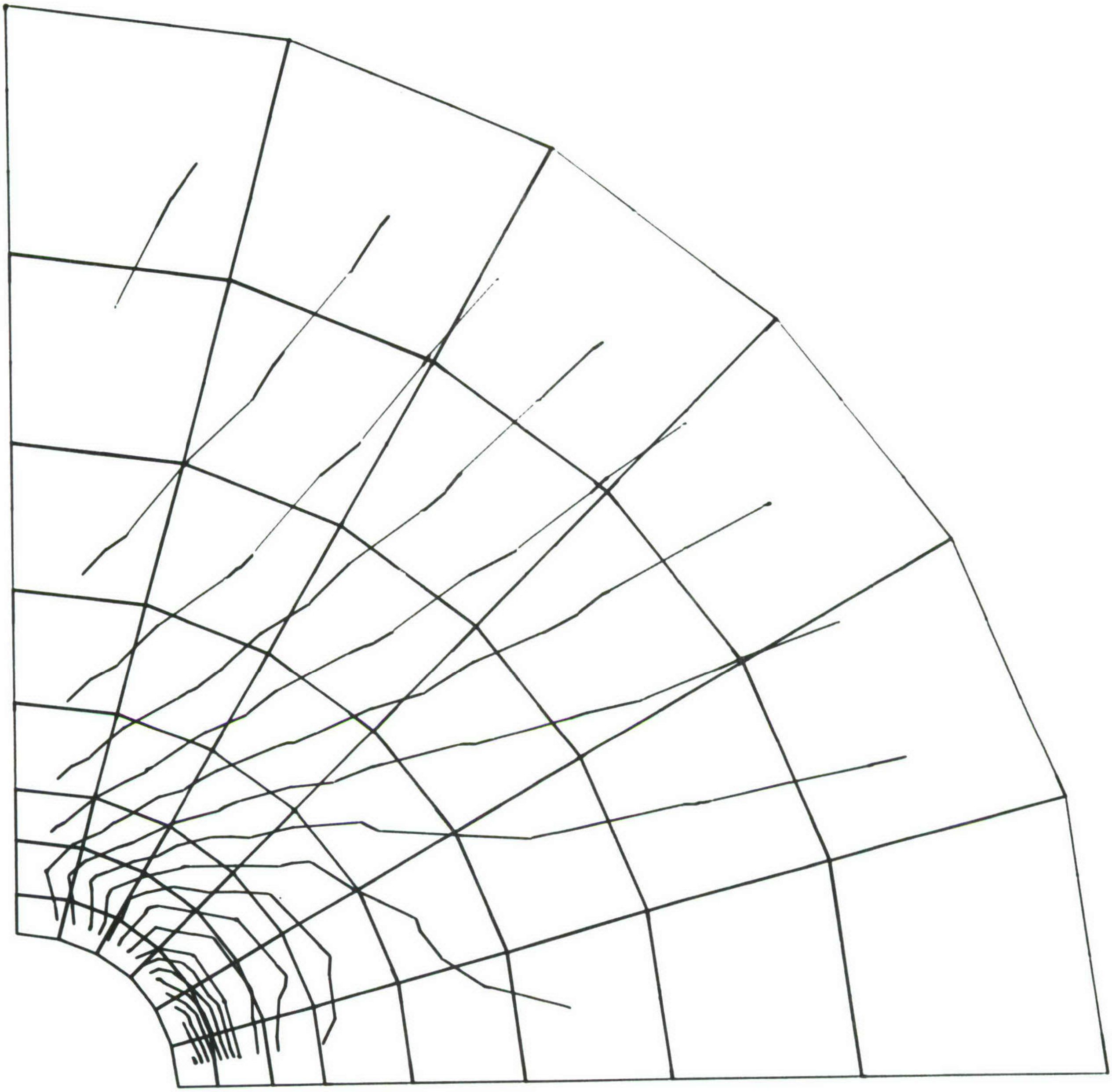


Figure AII-166 Radial Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

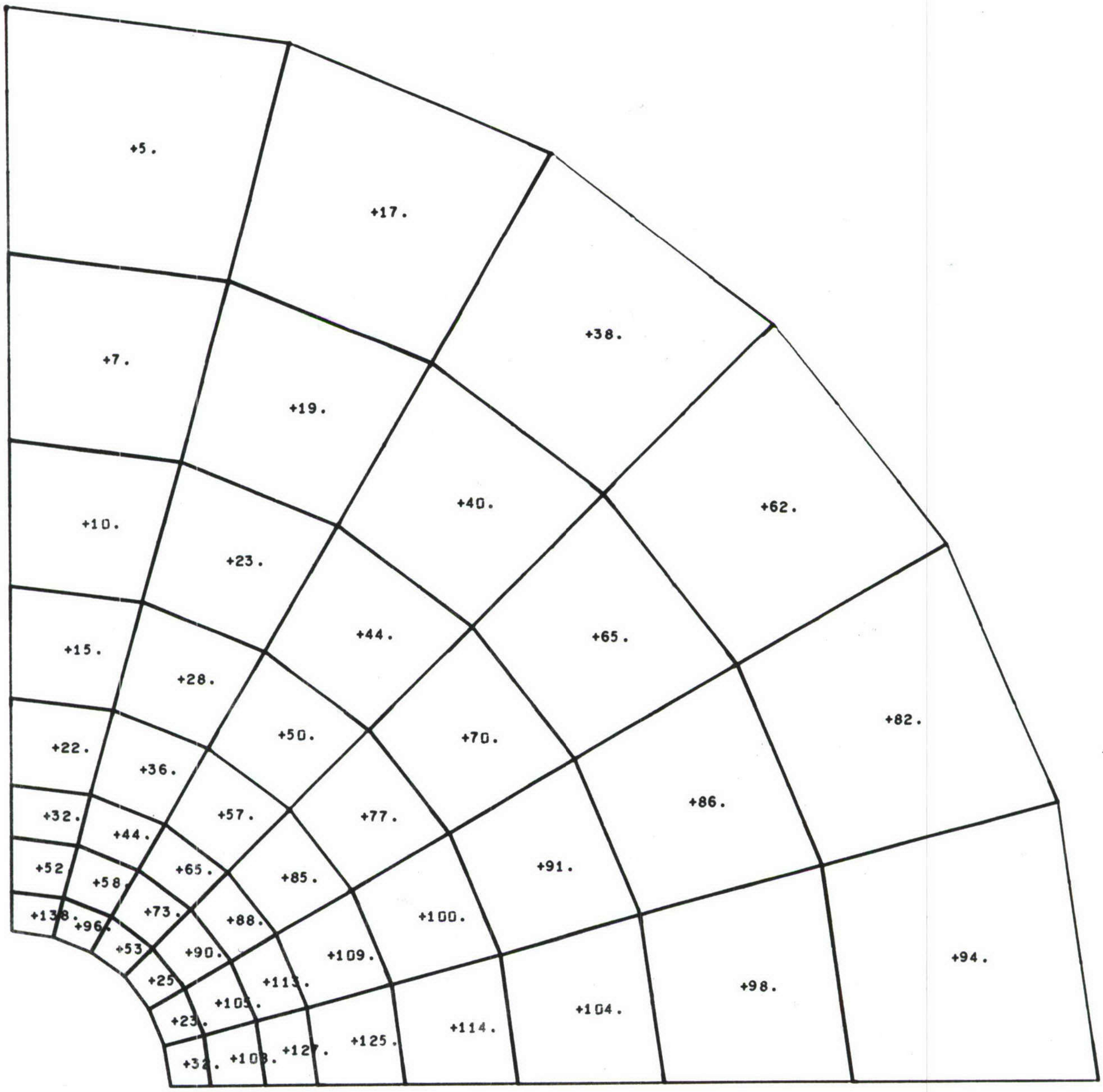


Figure AII-167 Tangential Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

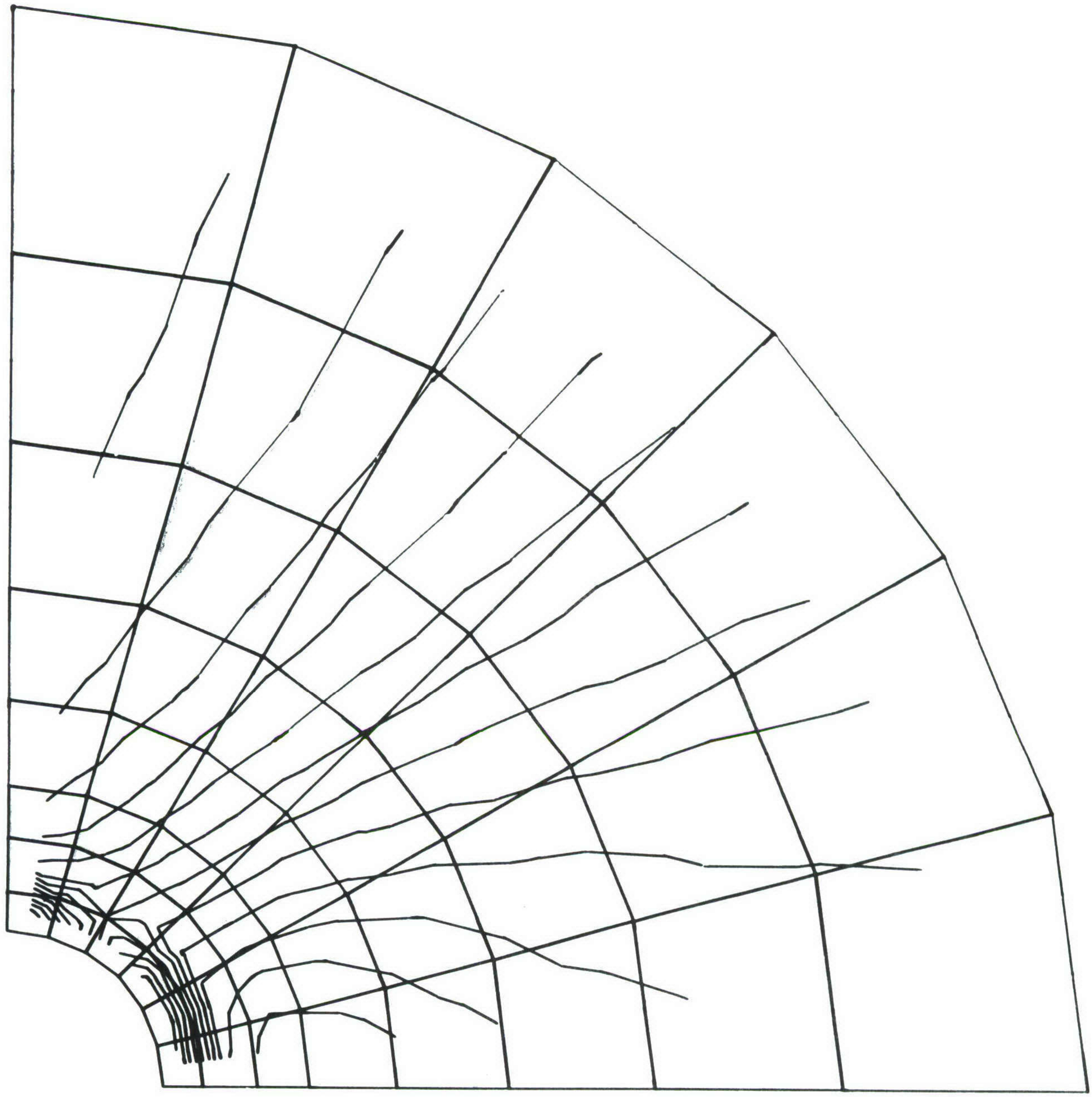


Figure AII-168 Tangential Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

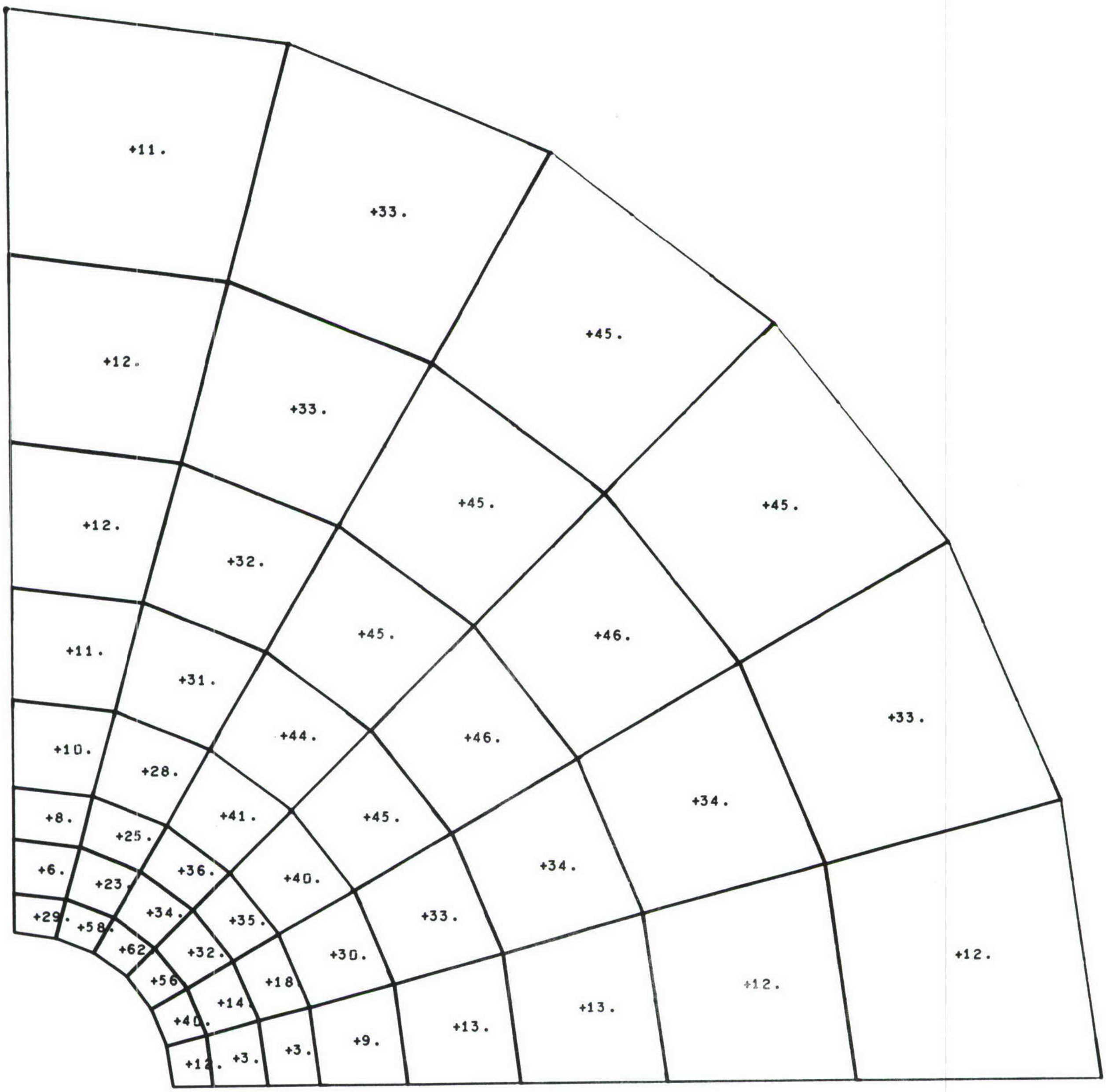


Figure AII-169 Radial-Tangential Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

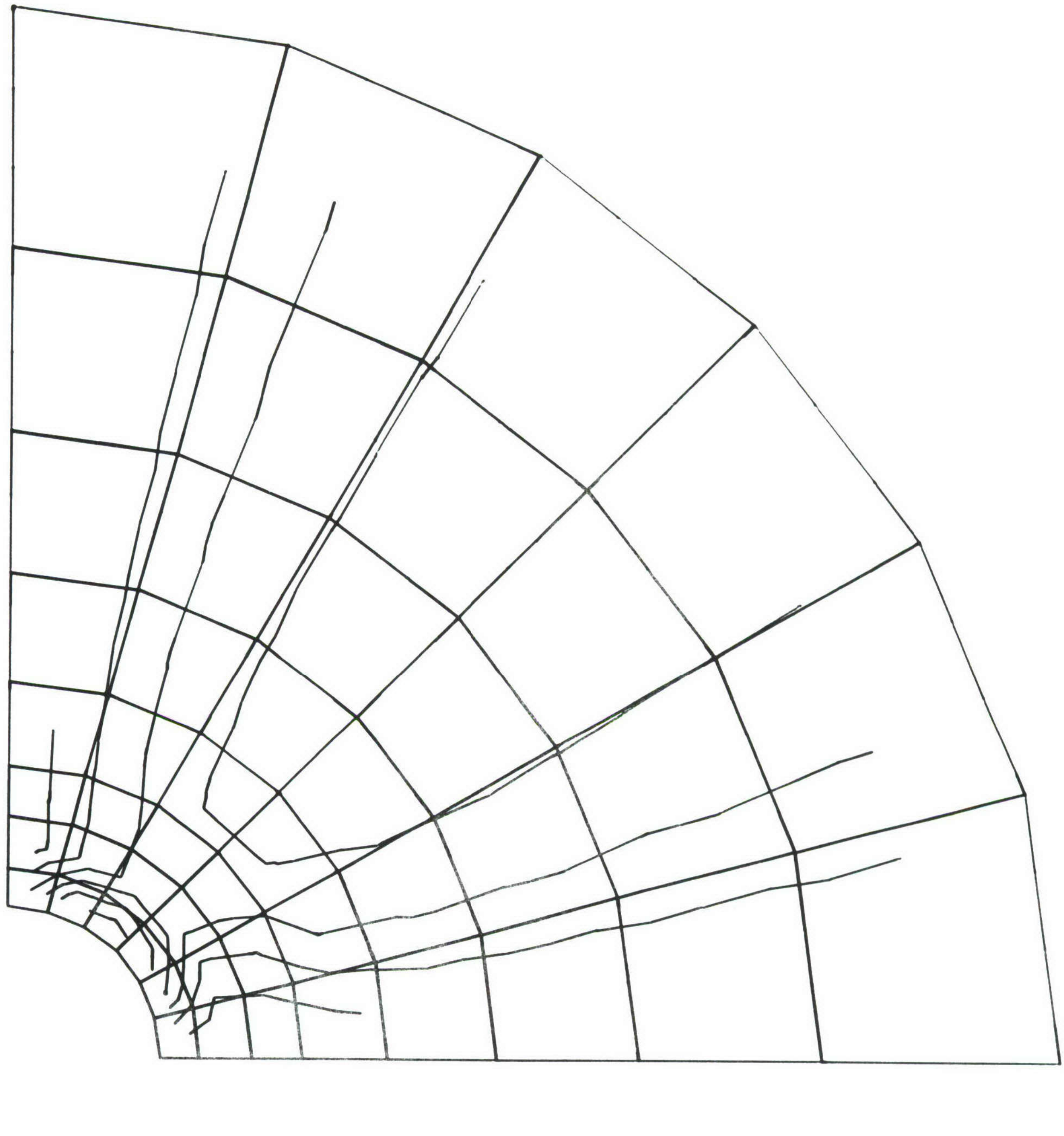


Figure AII-170 Radial-Tangential Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

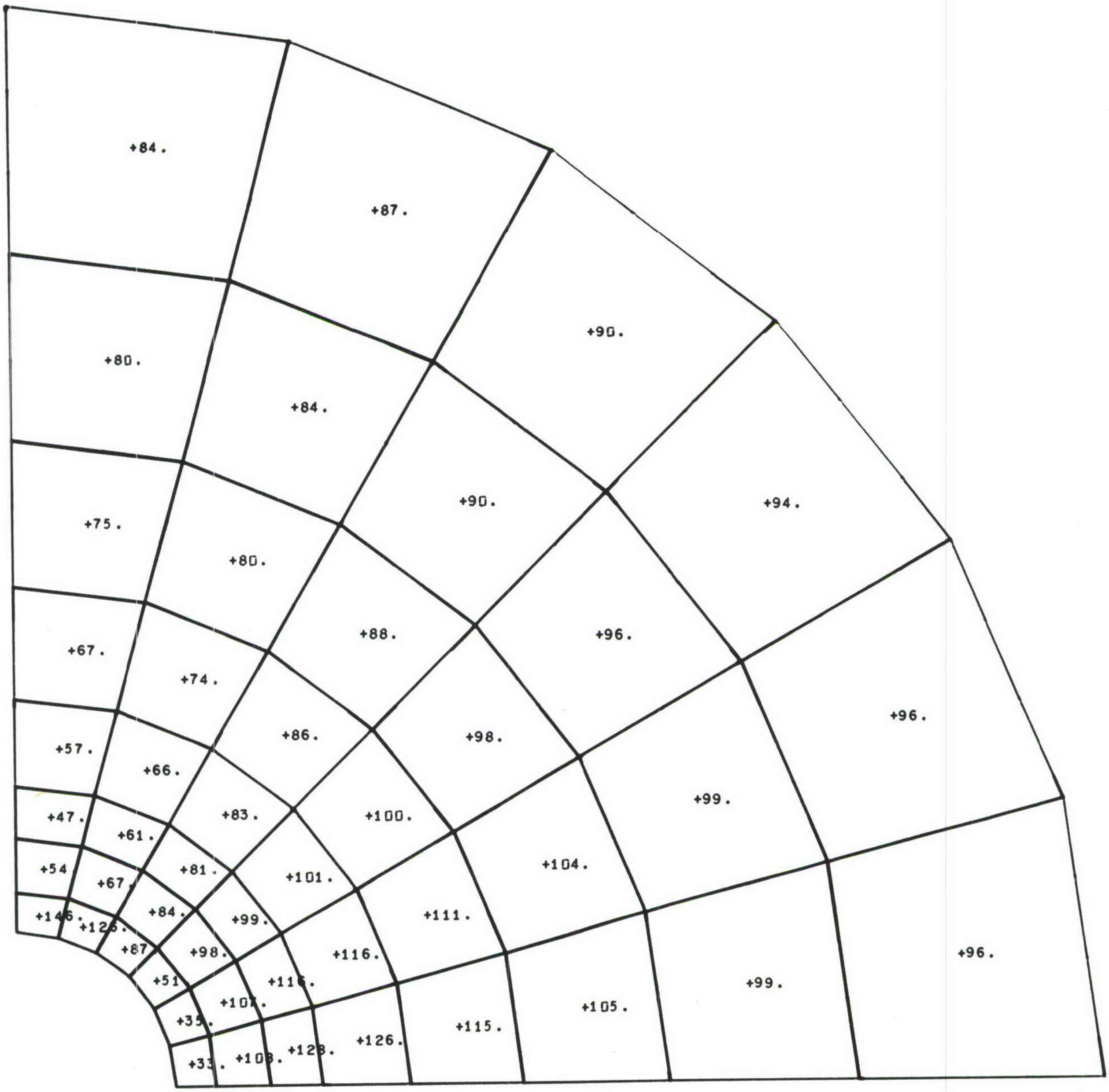


Figure AII-171 First Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

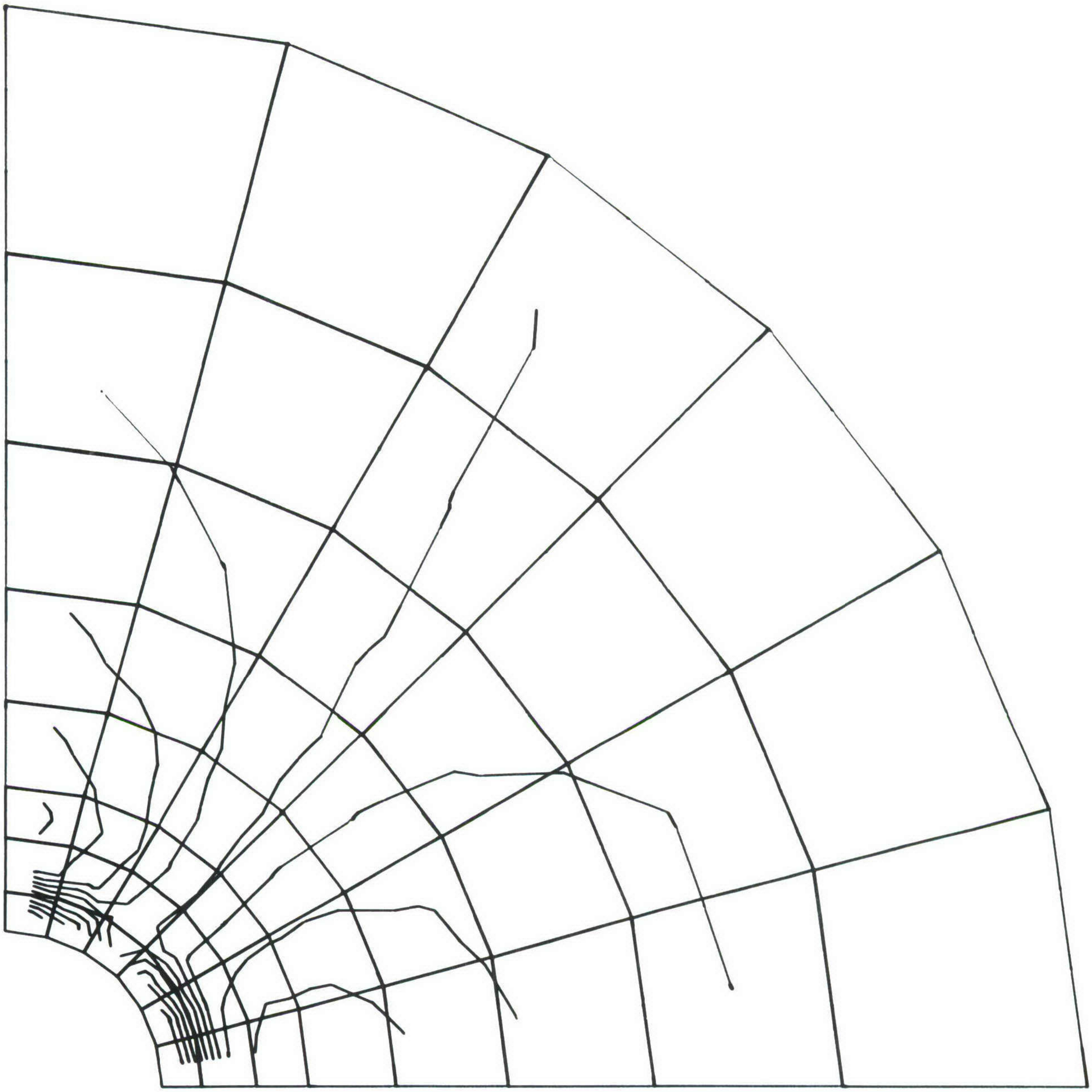


Figure AII-172 First Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

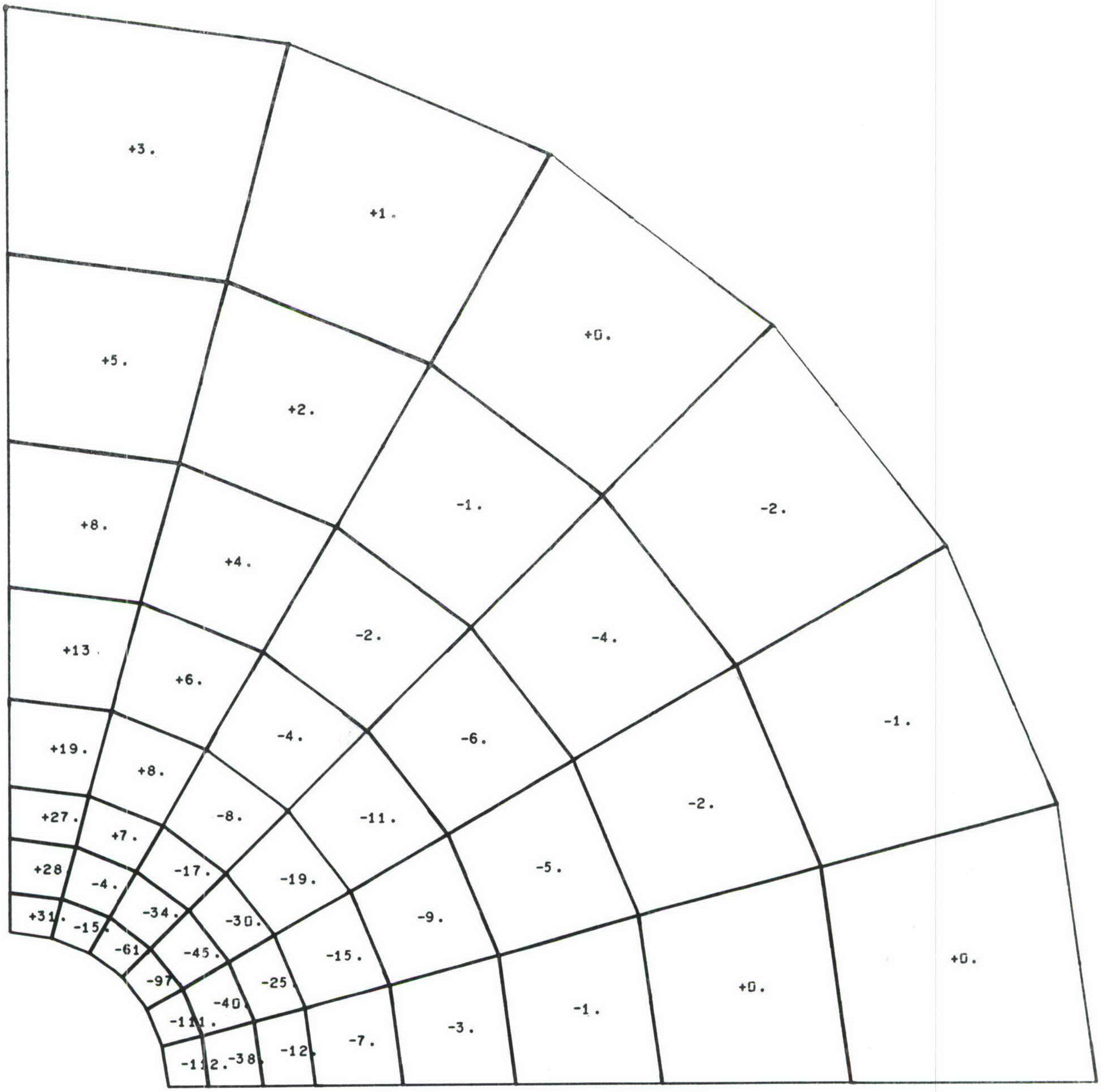


Figure AII-173 Second Principal Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

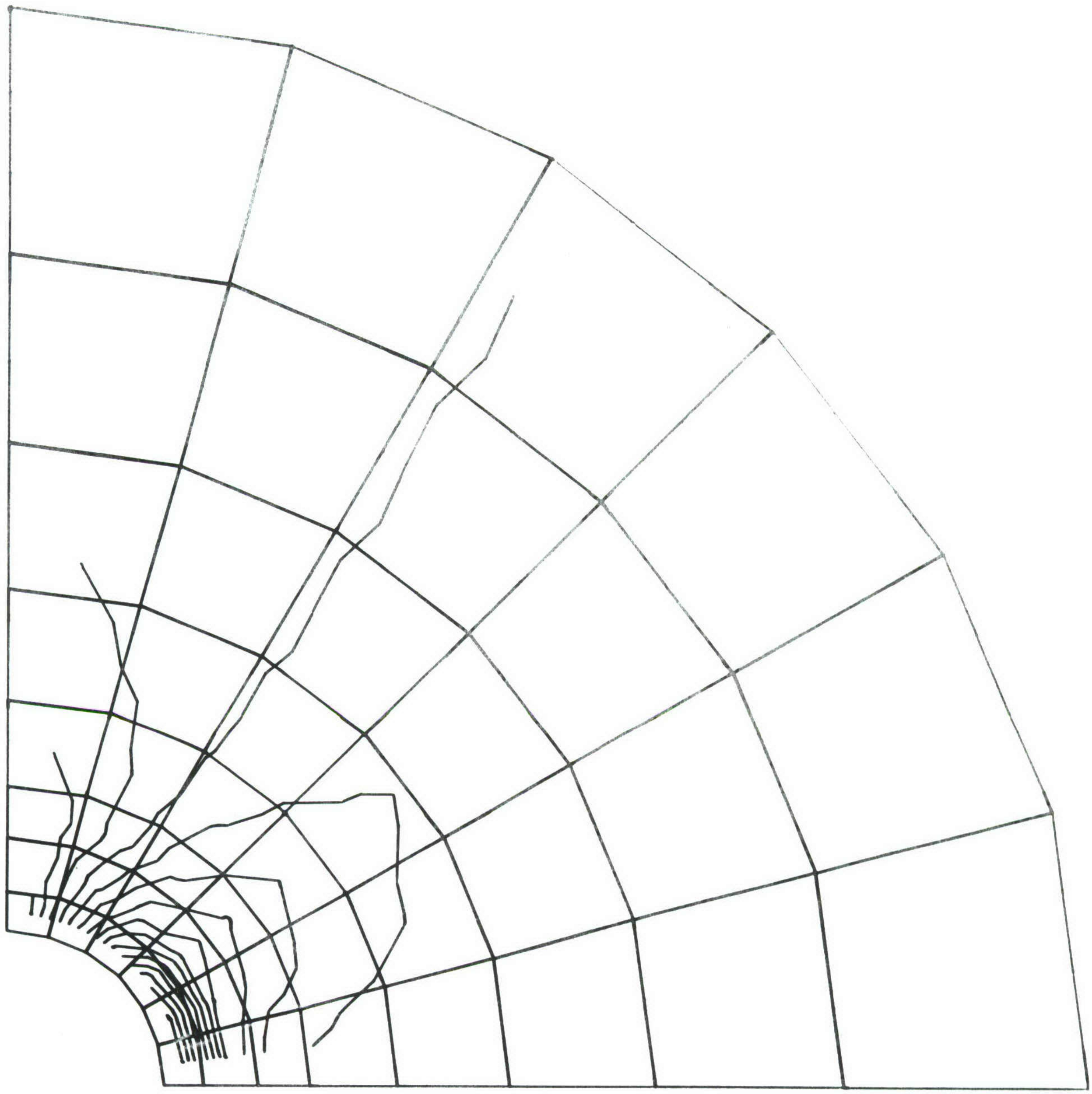


Figure AII-174 Second Principal Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

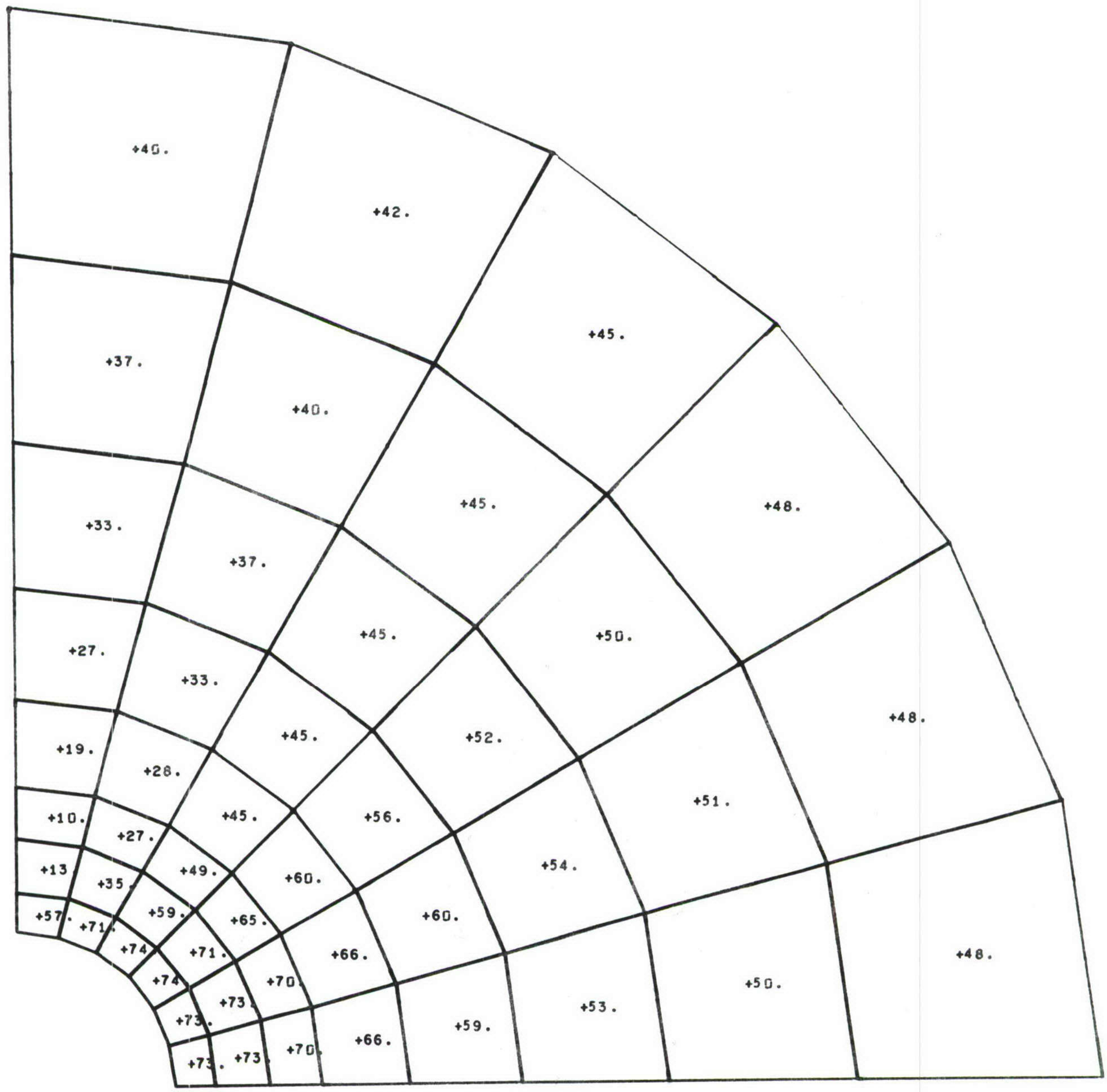


Figure AII-175 Principal Shear Stress Values for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

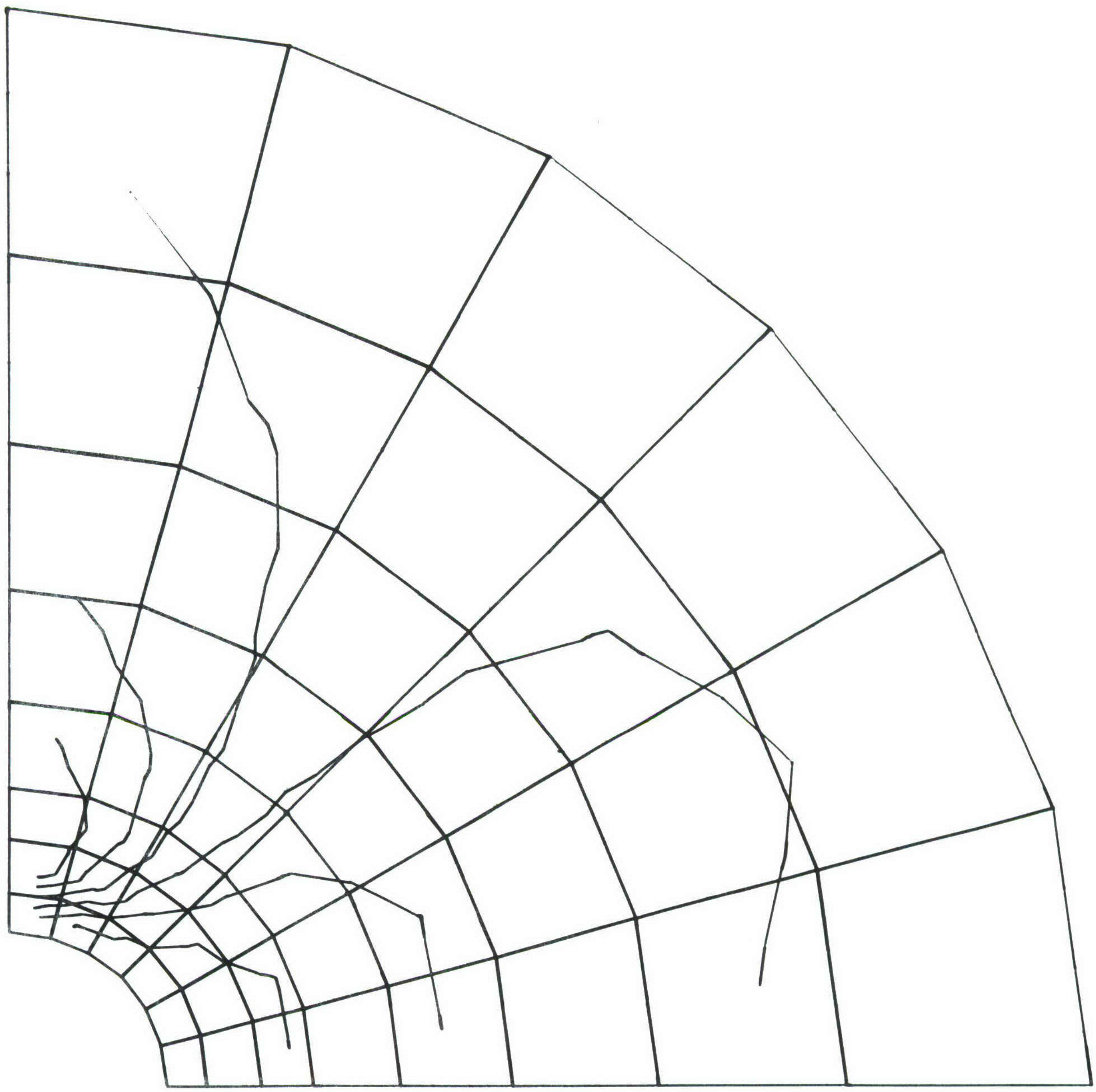


Figure AII-176 Principal Shear Stress Contours for Titanium Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

APPENDIX III

STEEL PLATE RESULTS

This appendix presents the results of the finite element analysis for the steel plate with the steel bolt inserted. The results consist of stresses and strains in the vicinity of interference fit fasteners. The analysis conditions are discussed in Section IV and Figures IV-3 and IV-4 illustrate the regions of the plates for which results are presented.

The figures are presented in pairs. The first consists of a numerical level of stress or strain superimposed on each finite element. The second consists of isolines or contours representing constant levels of stress or strain. Results are presented in the same sequence as the analysis conditions S1 through S12, defined in Table IV-1. Radial and tangential stresses and strains are presented for each condition. For those cases where no uniaxial load is applied, these stresses are the principal stresses. Hence, no other data is presented. For those cases where uniaxial load is applied, radial-tangential shear strains are presented plus other stresses consisting of radial-tangential shear stress, and the three principal stresses; first, second and shear. The figures are otherwise self-explanatory.

Note: The numbers printed for stress and strain have been truncated back (as opposed to rounded off). Also, the stresses printed are in units of 1000 pounds/inch squared; the strains printed are in units of 0.001 inches/inch. The numbers should be interpreted as being representative of the level at the element center. Negative stresses and strains are compressive, positive stress and strains are tensile.

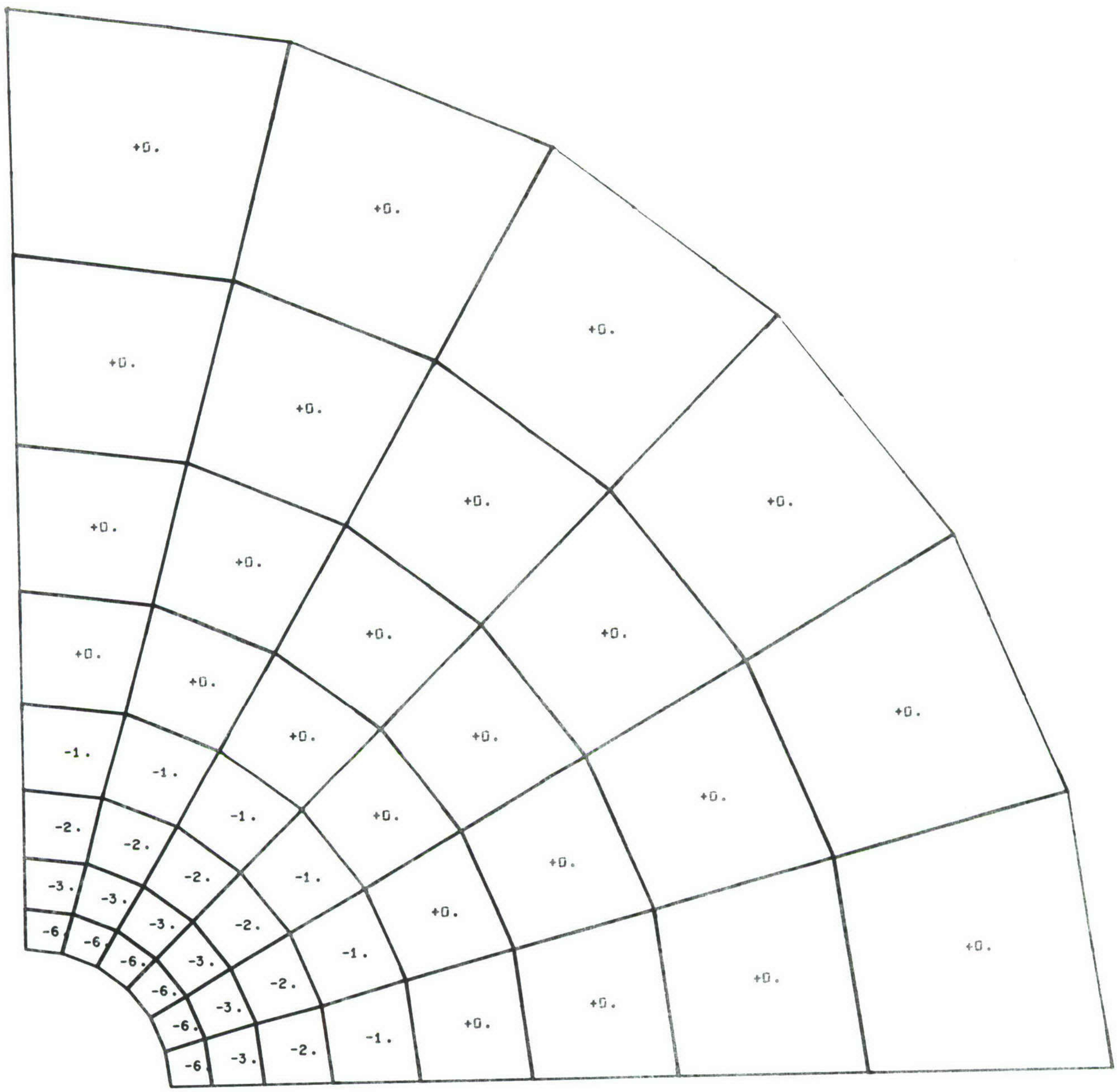


Figure AIII-1 Radial Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

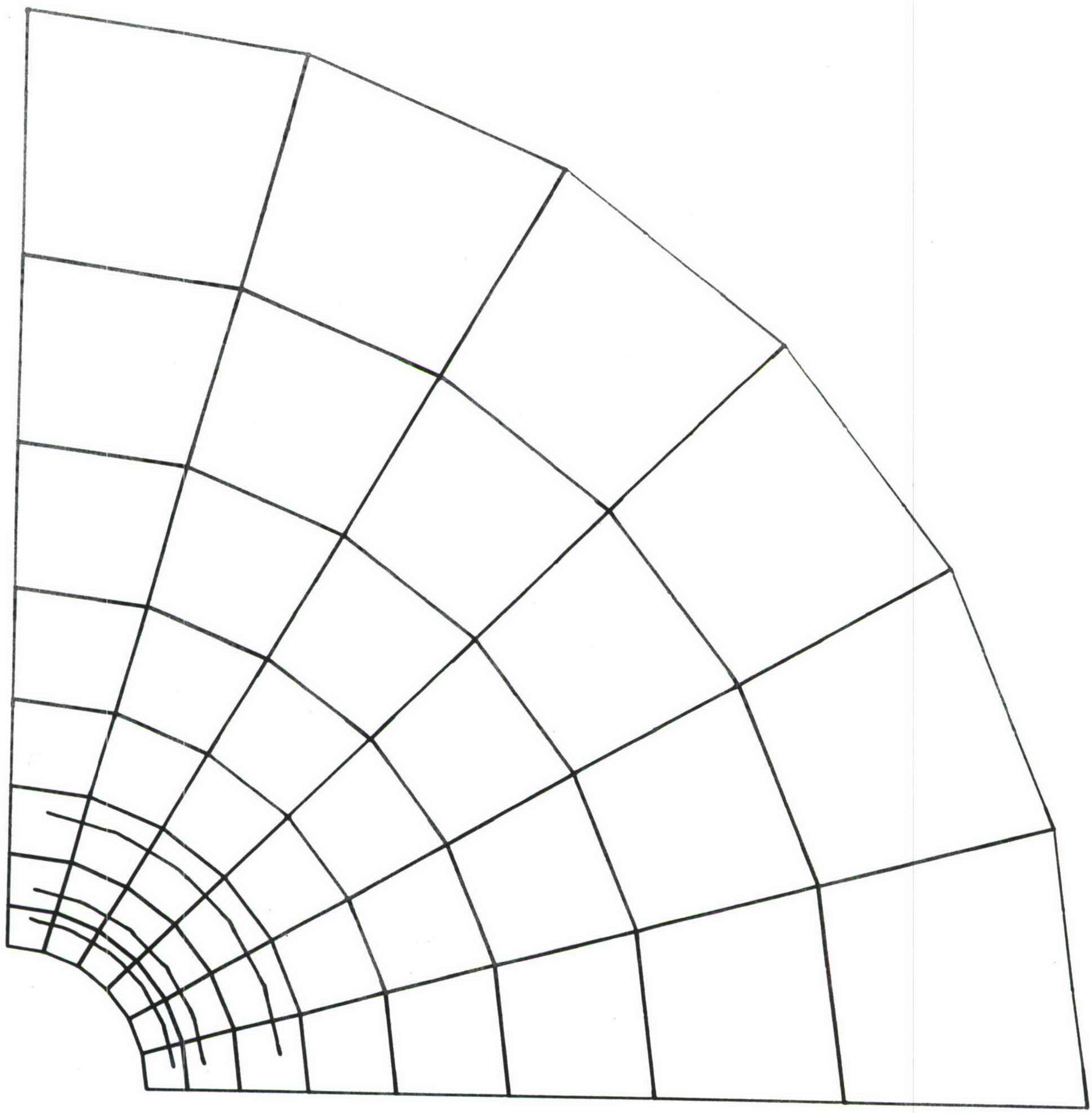


Figure AIII-2 Radial Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

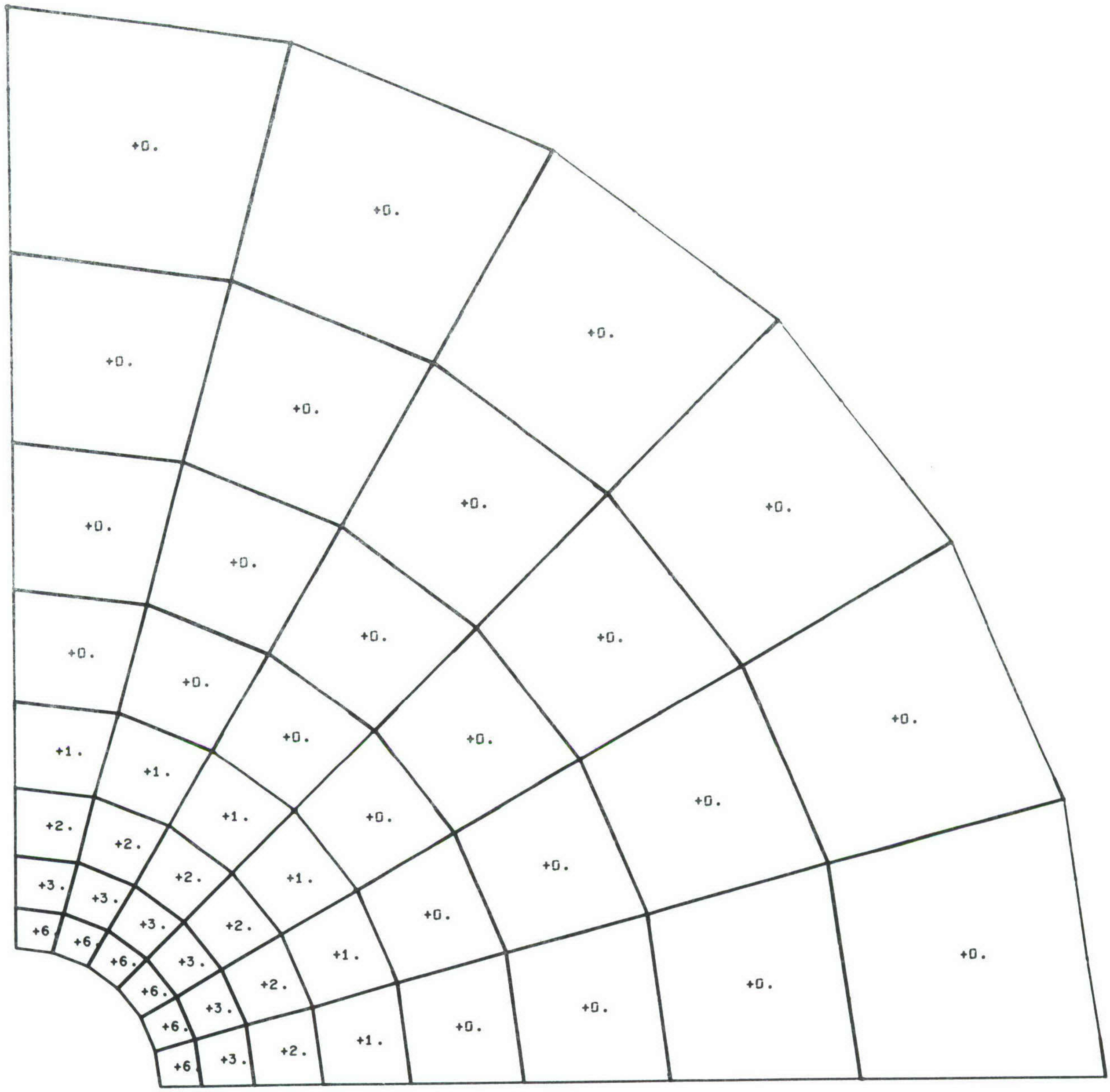


Figure AIII-3 Tangential Strain Values For Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

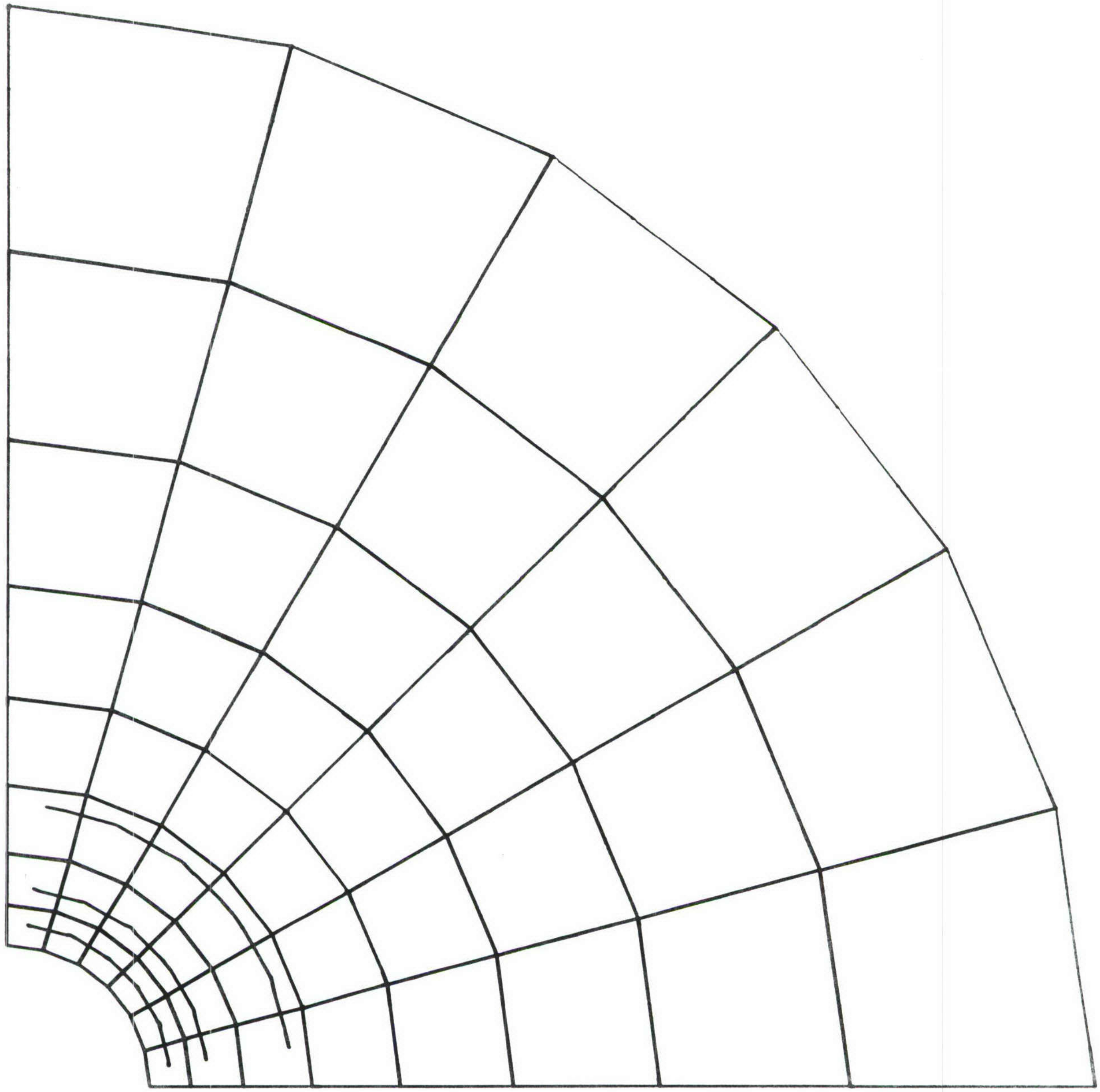


Figure AIII-4   Tangential Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

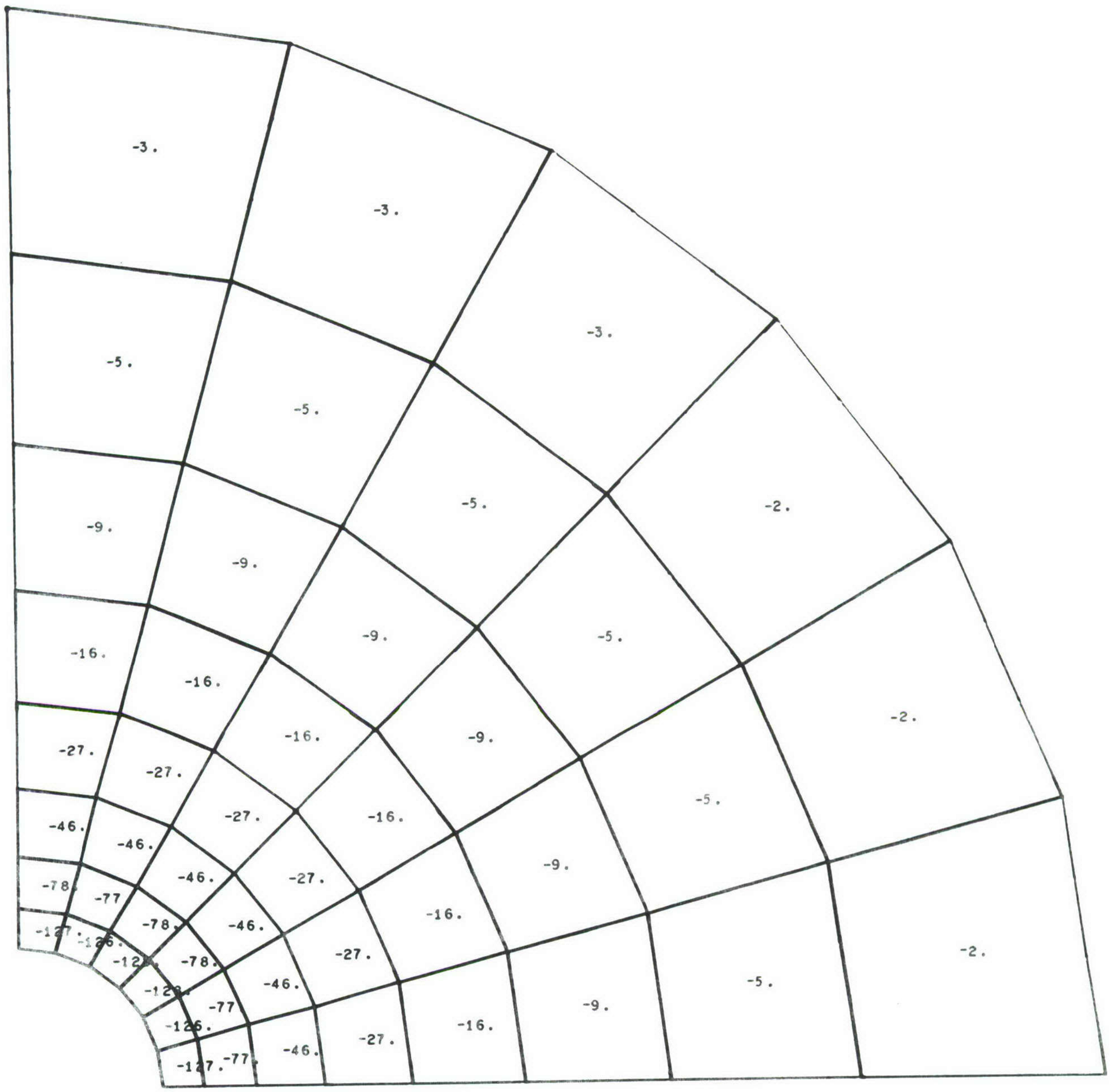


Figure AIII-5 Radial Stress Values for Steel Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load

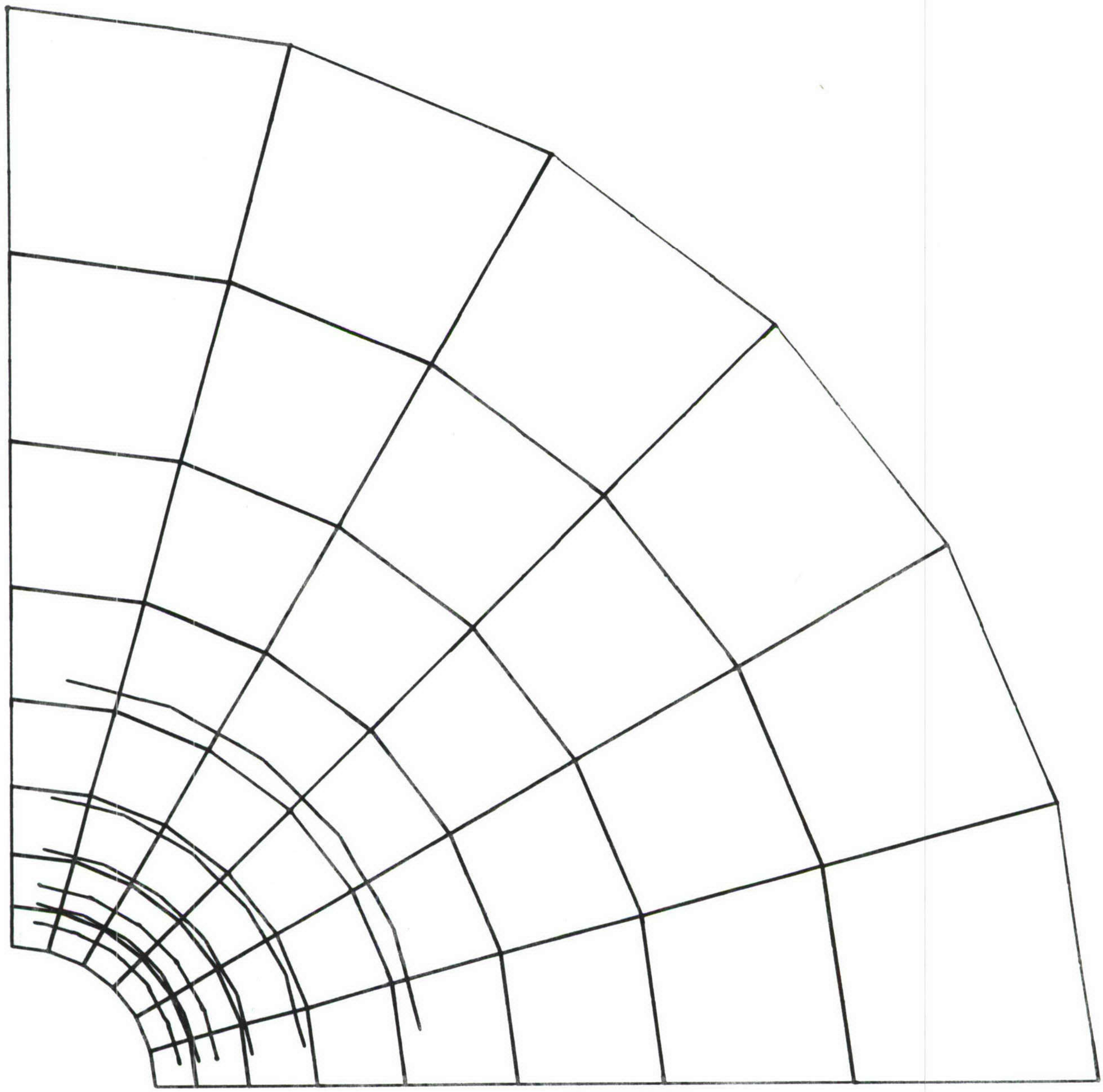


Figure AIII-6 Radial Stress Contours for Steel Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load

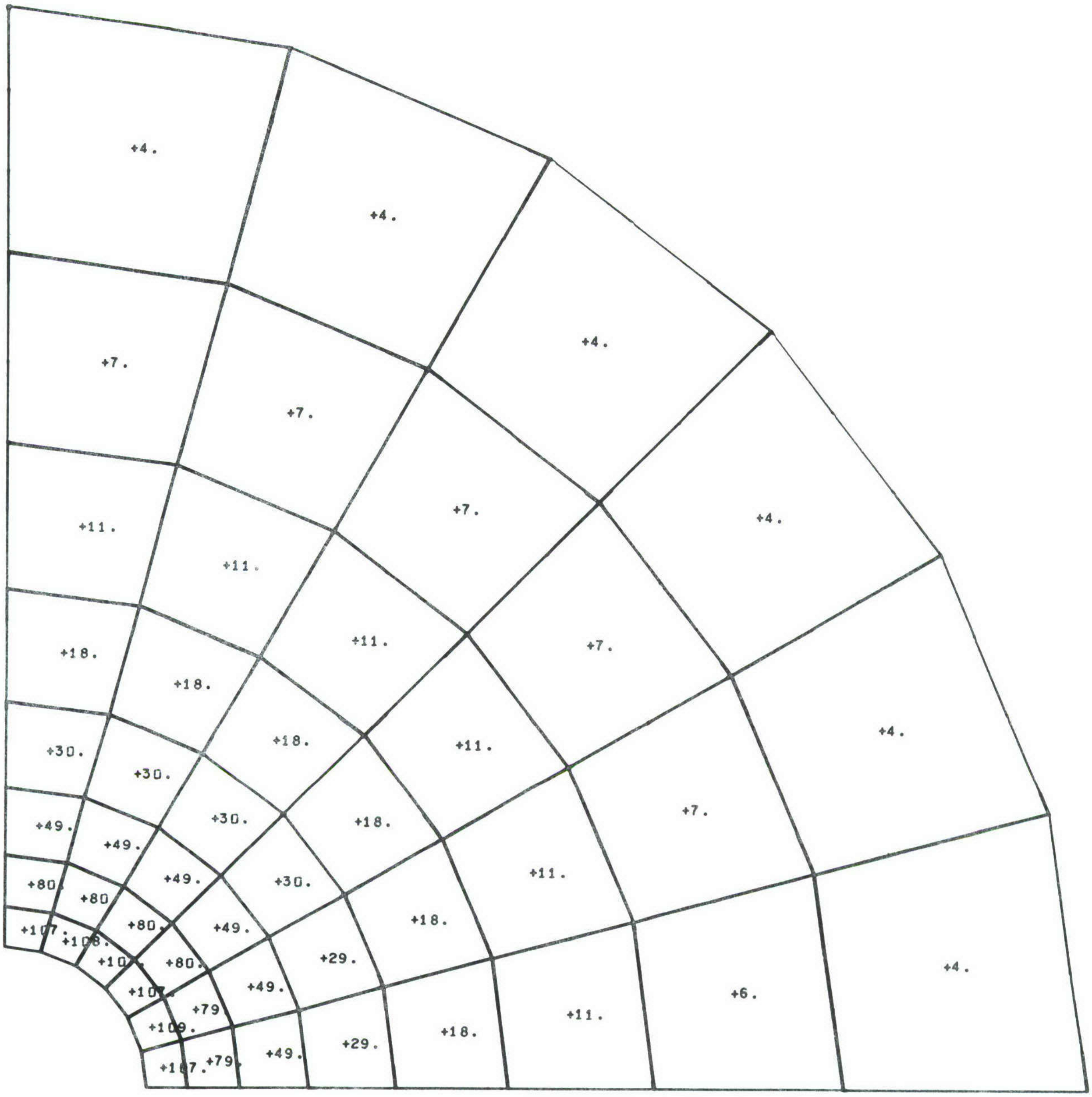


Figure AIII-7 Tangential Stress Values for Steel Plate with 3/16 Inch Hole Radius; .001875 Inch Radial Interference; No Uniaxial Load

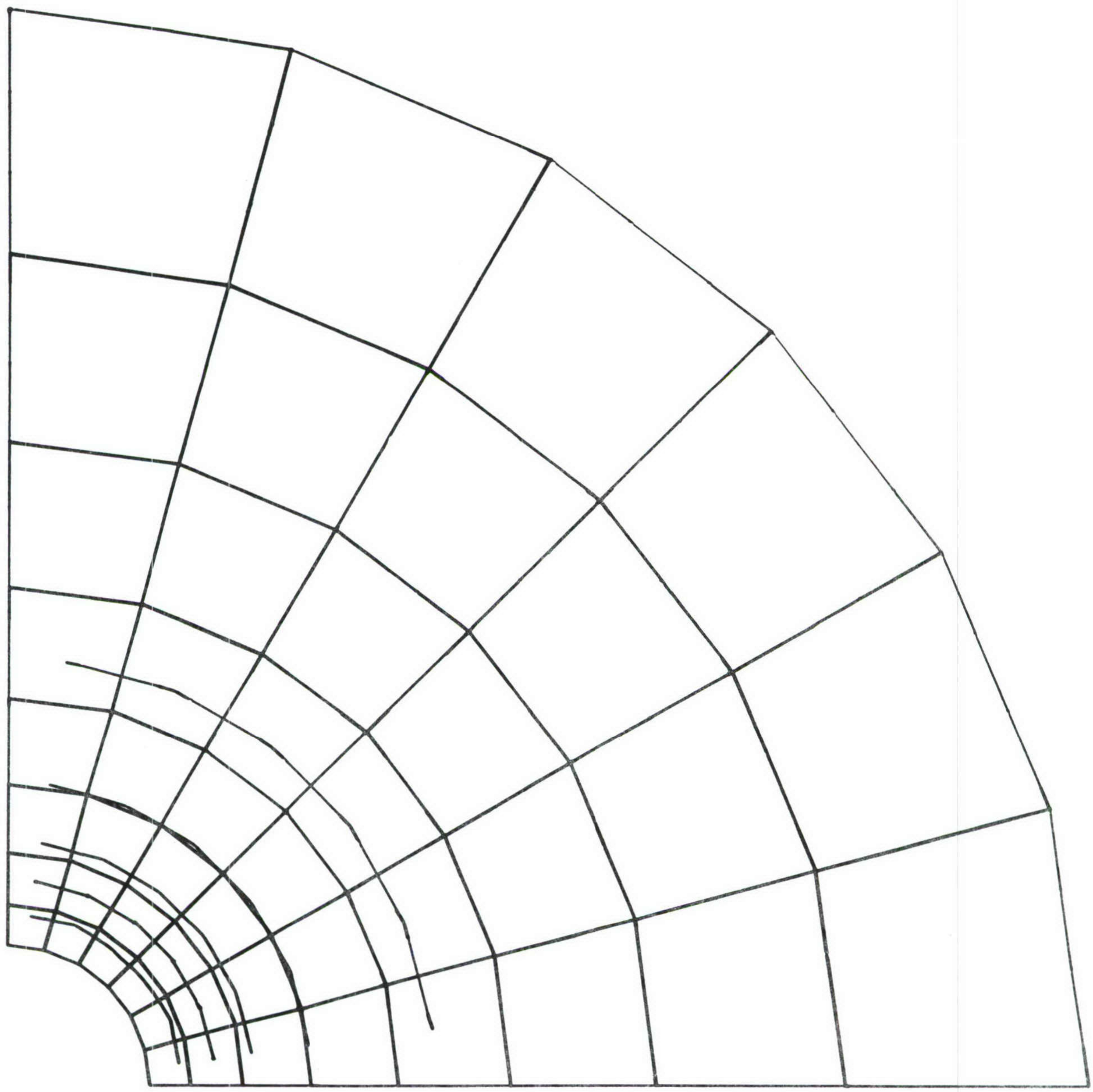


Figure AIII-8 Tangential Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; No Uniaxial Load

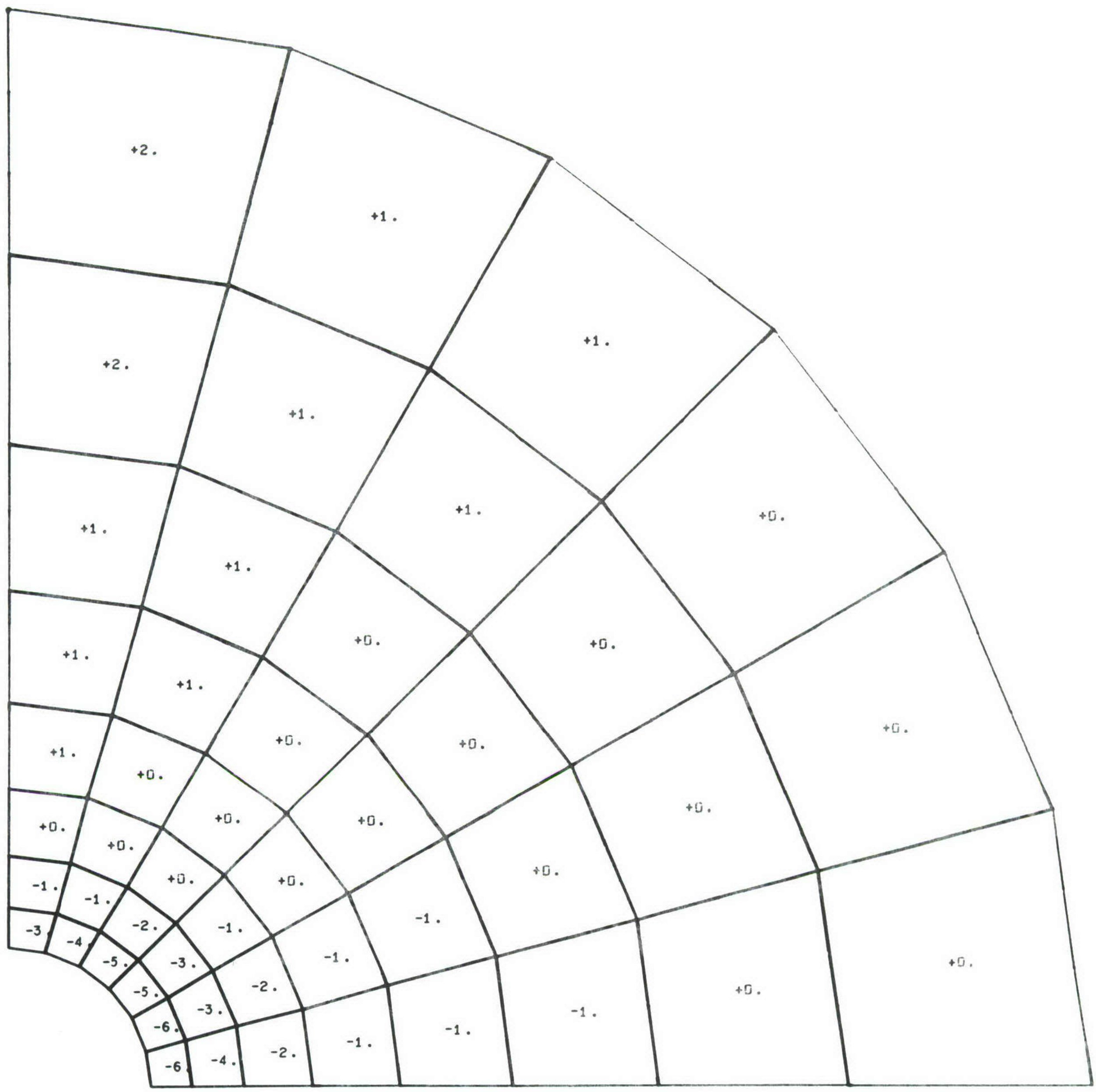


Figure AIII-9 Radial Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

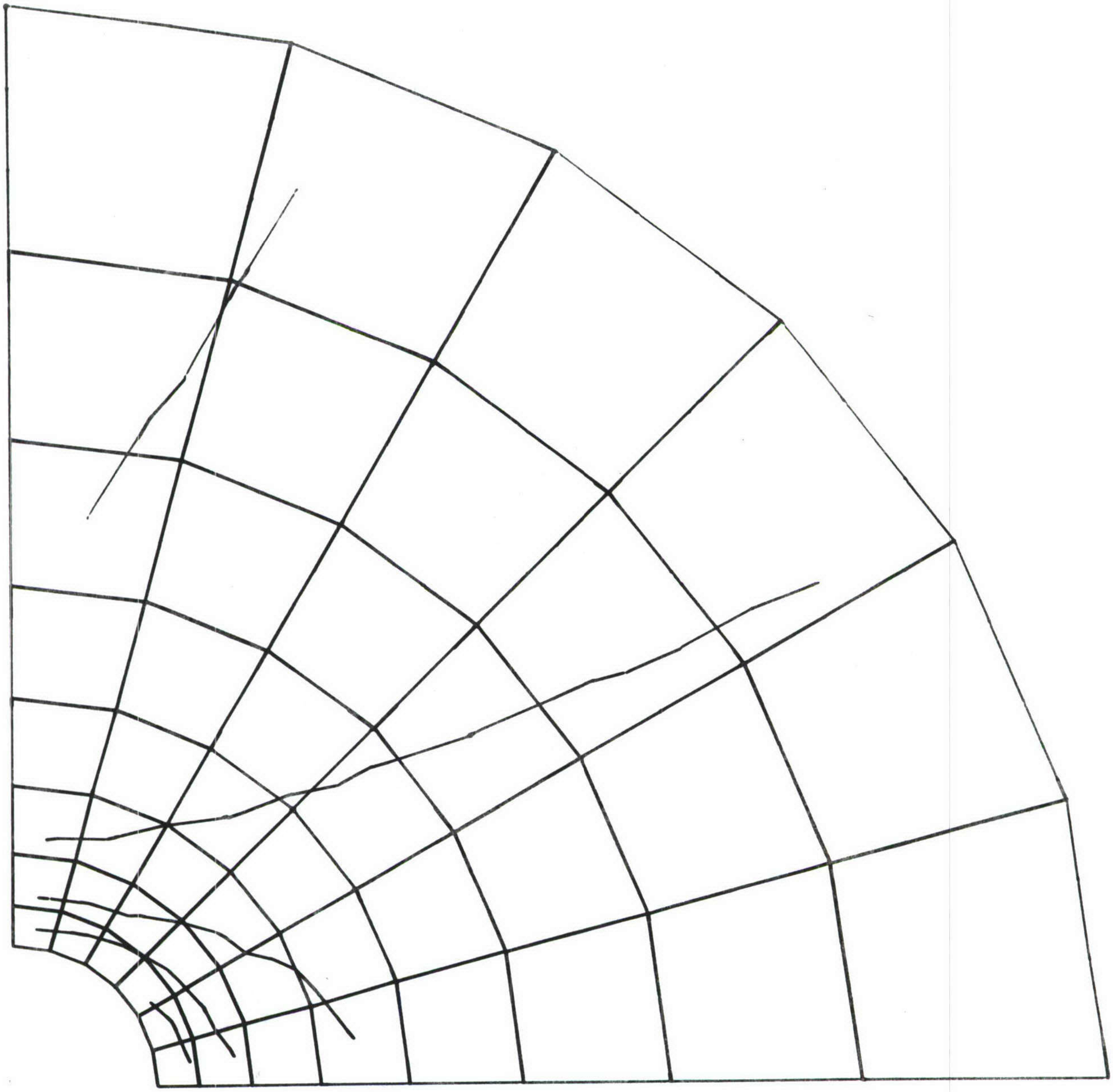


Figure AIII-10 Radial Strain Contours for Steel Plate with 3/16 Inch Hole Radius 0.001875 Inch Radial Interference, 35% Uniaxial Load

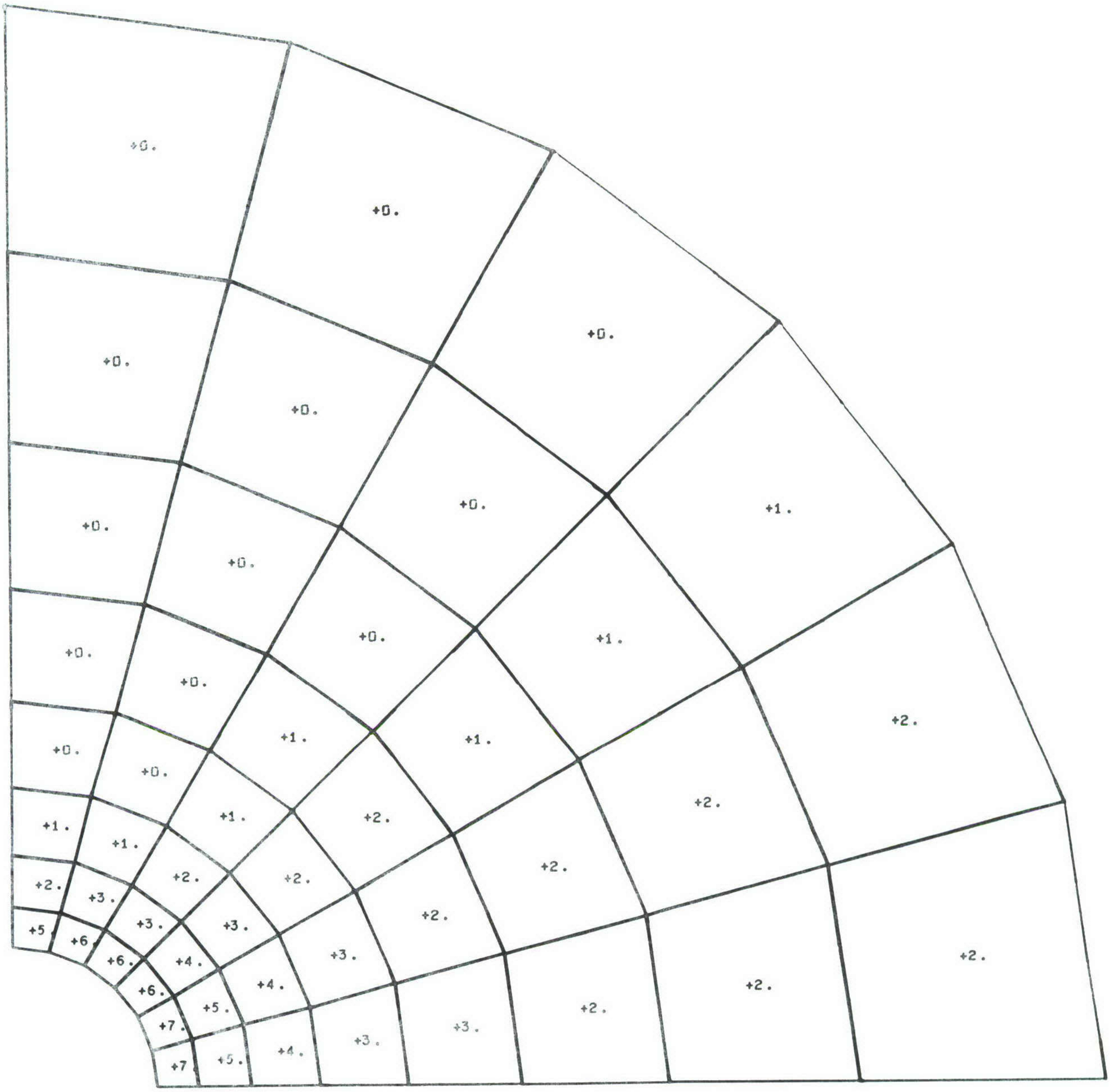


Figure AIII-11 Tangential Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

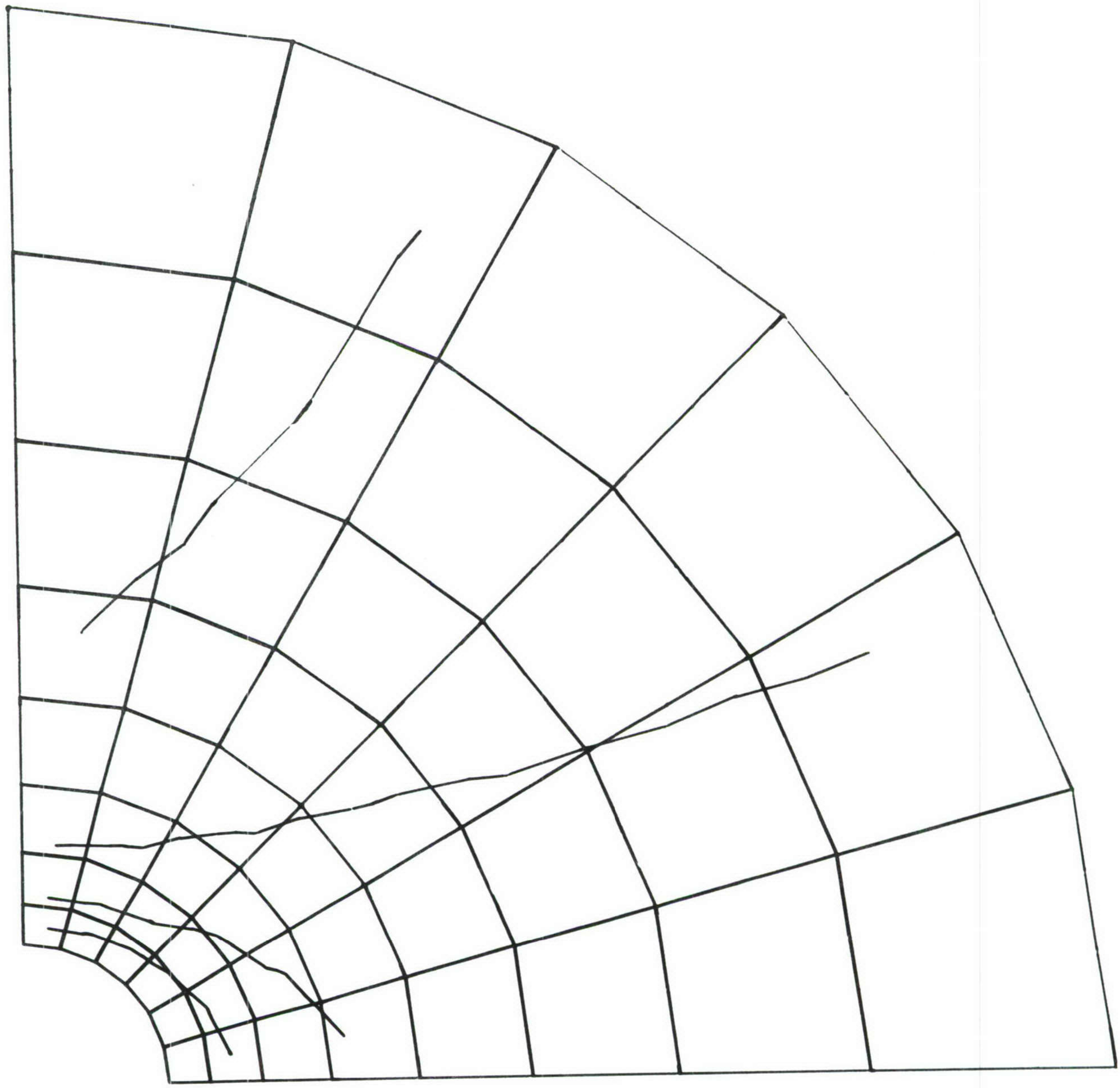


Figure AIII-12 Tangential Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

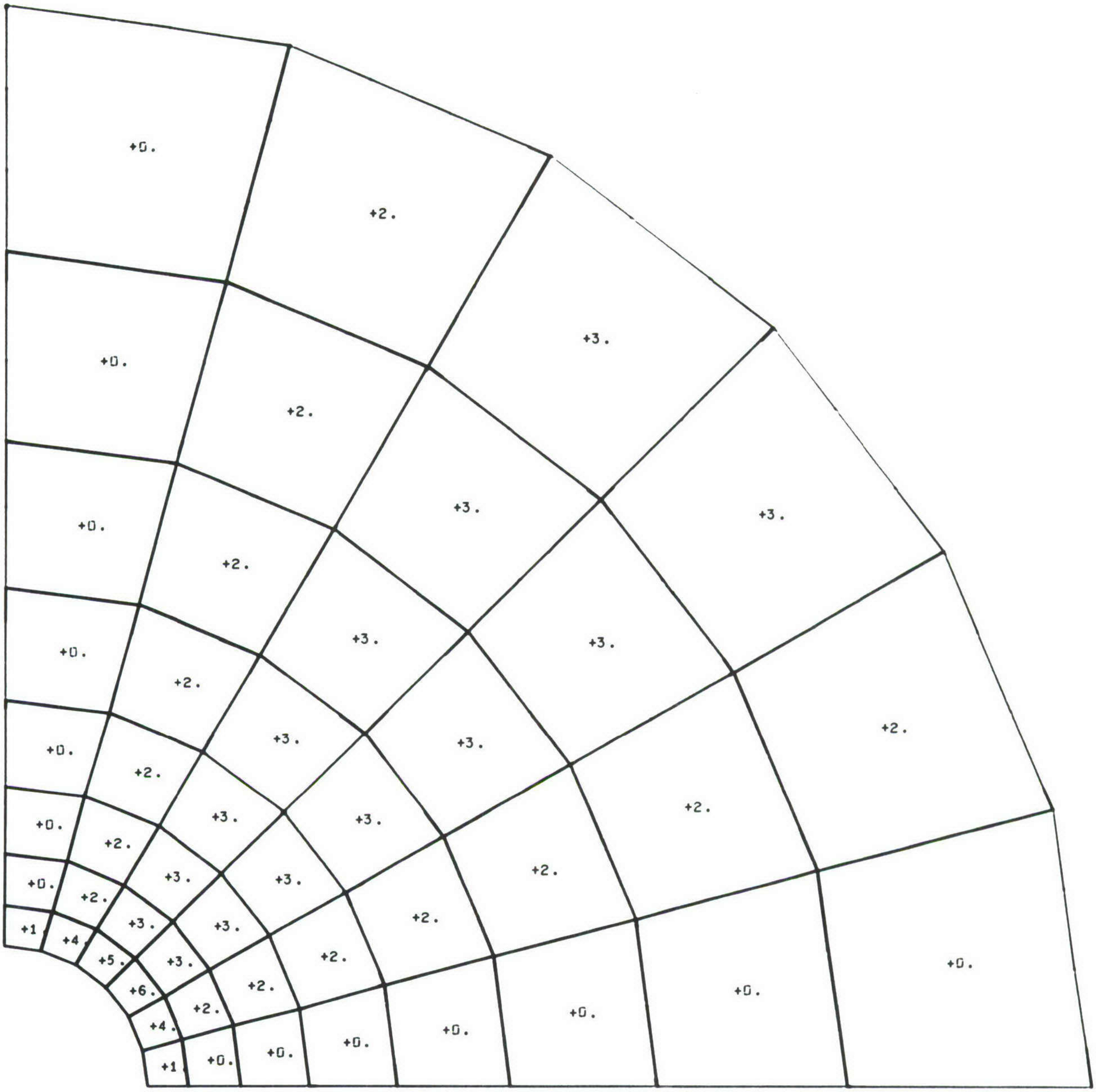


Figure AIII-13 Radial-Tangential Shear Strain Values for Steel Plate with 3/16 Inch Hole Radious; 0.001875 Inch Radial Interference; 35% Uniaxial Load

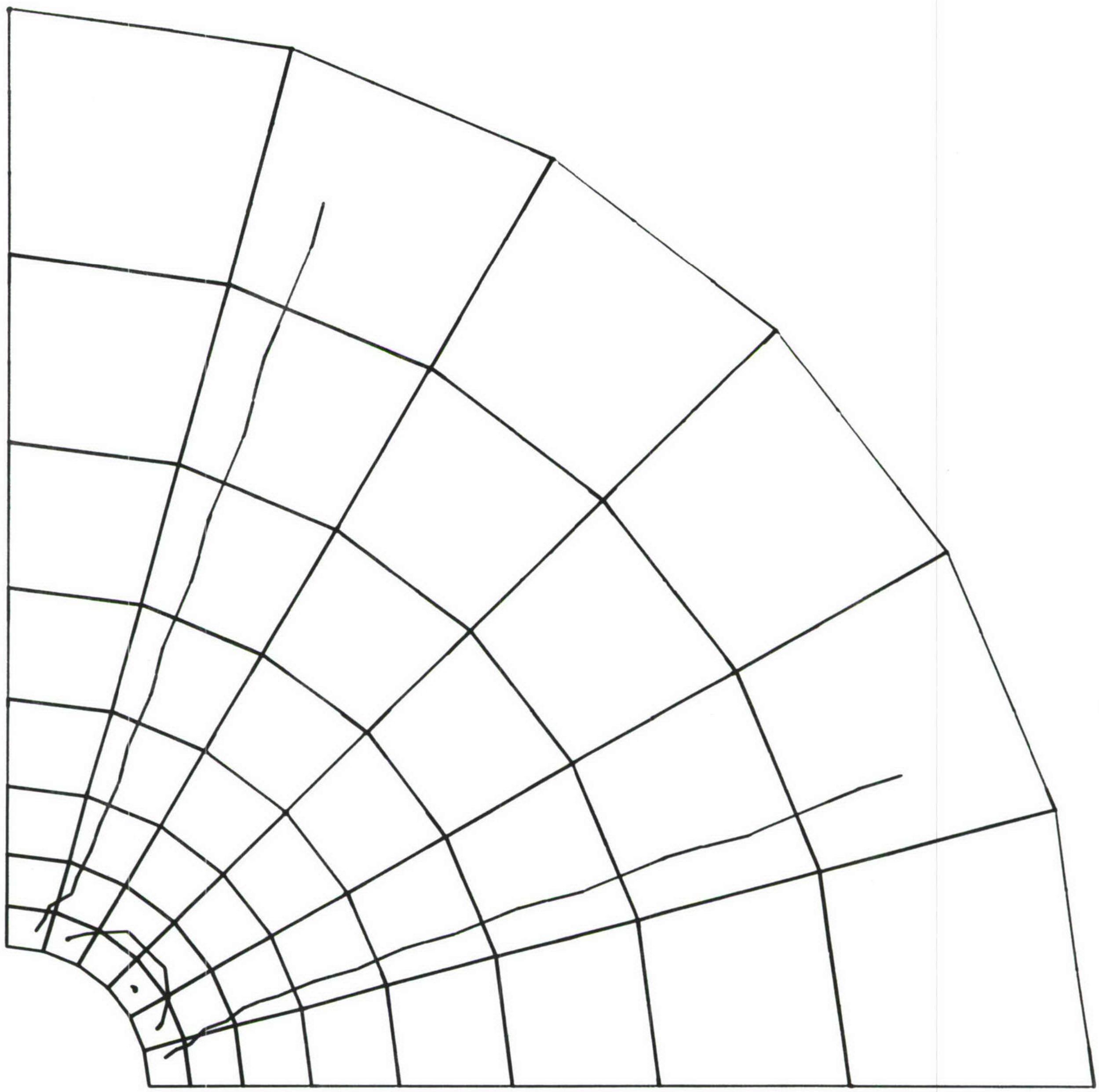


Figure AIII-14 Radial-Tangential Shear Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

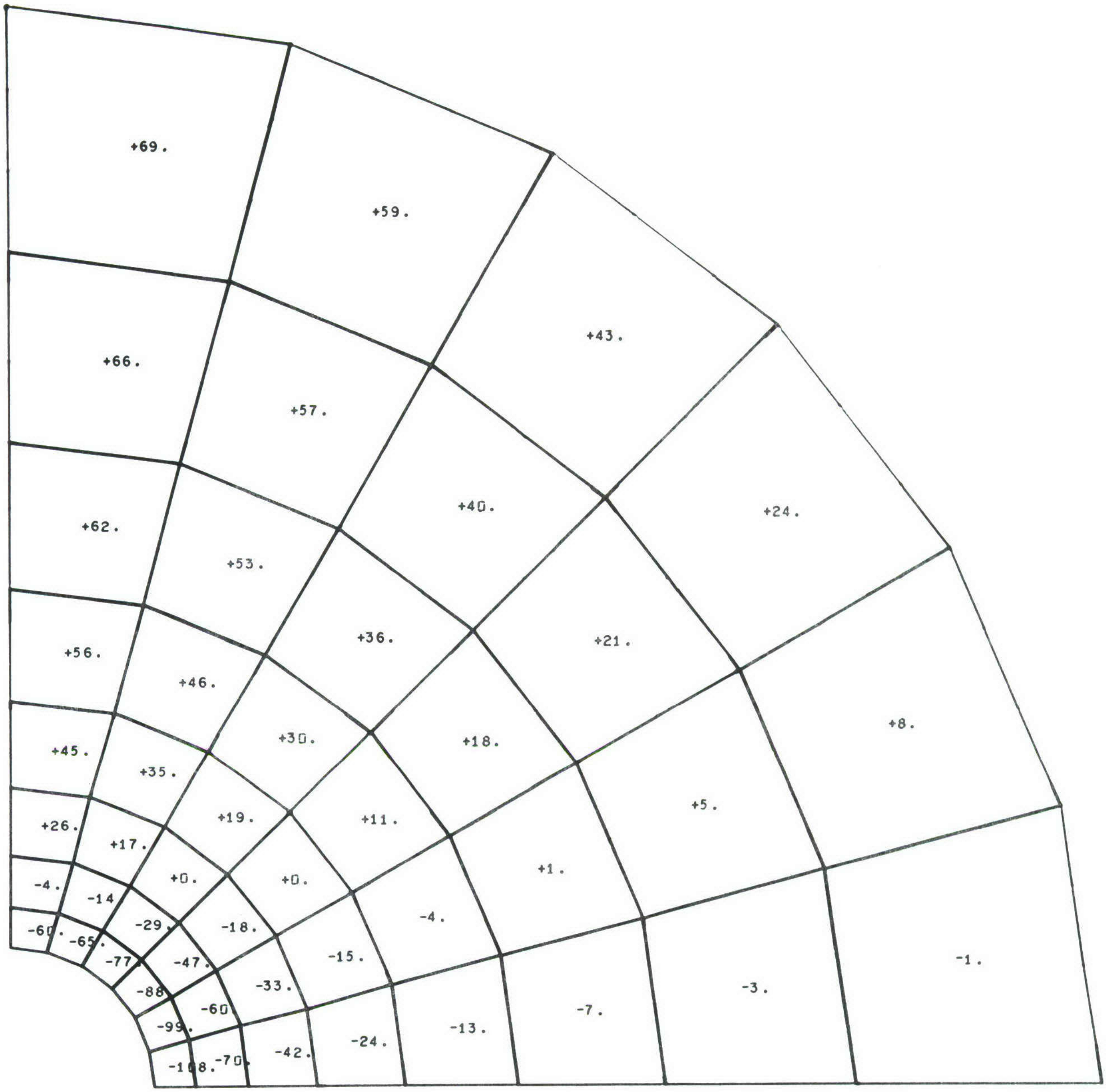


Figure AIII-15 Radial Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

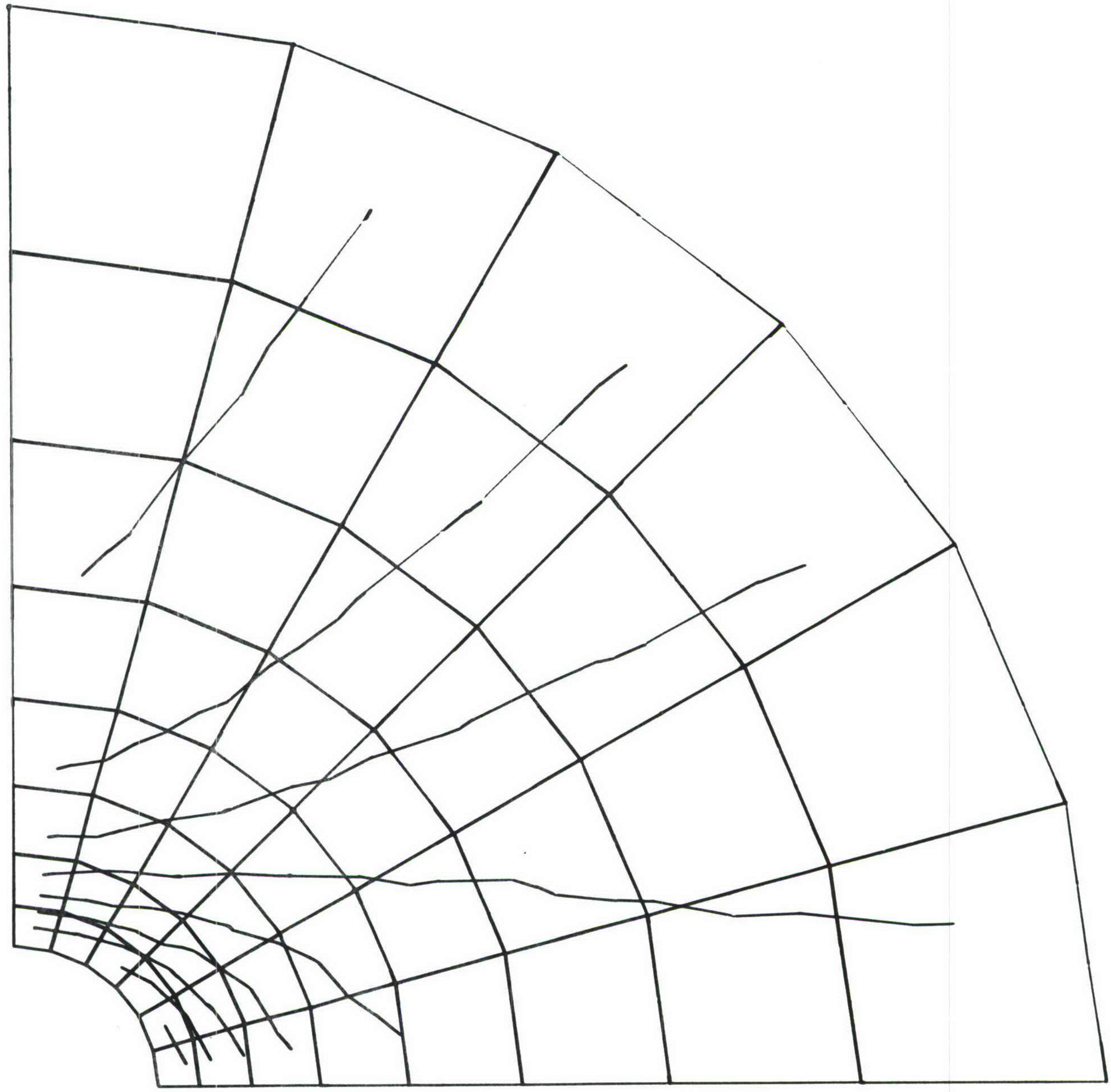


Figure AIII-16 Radial Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

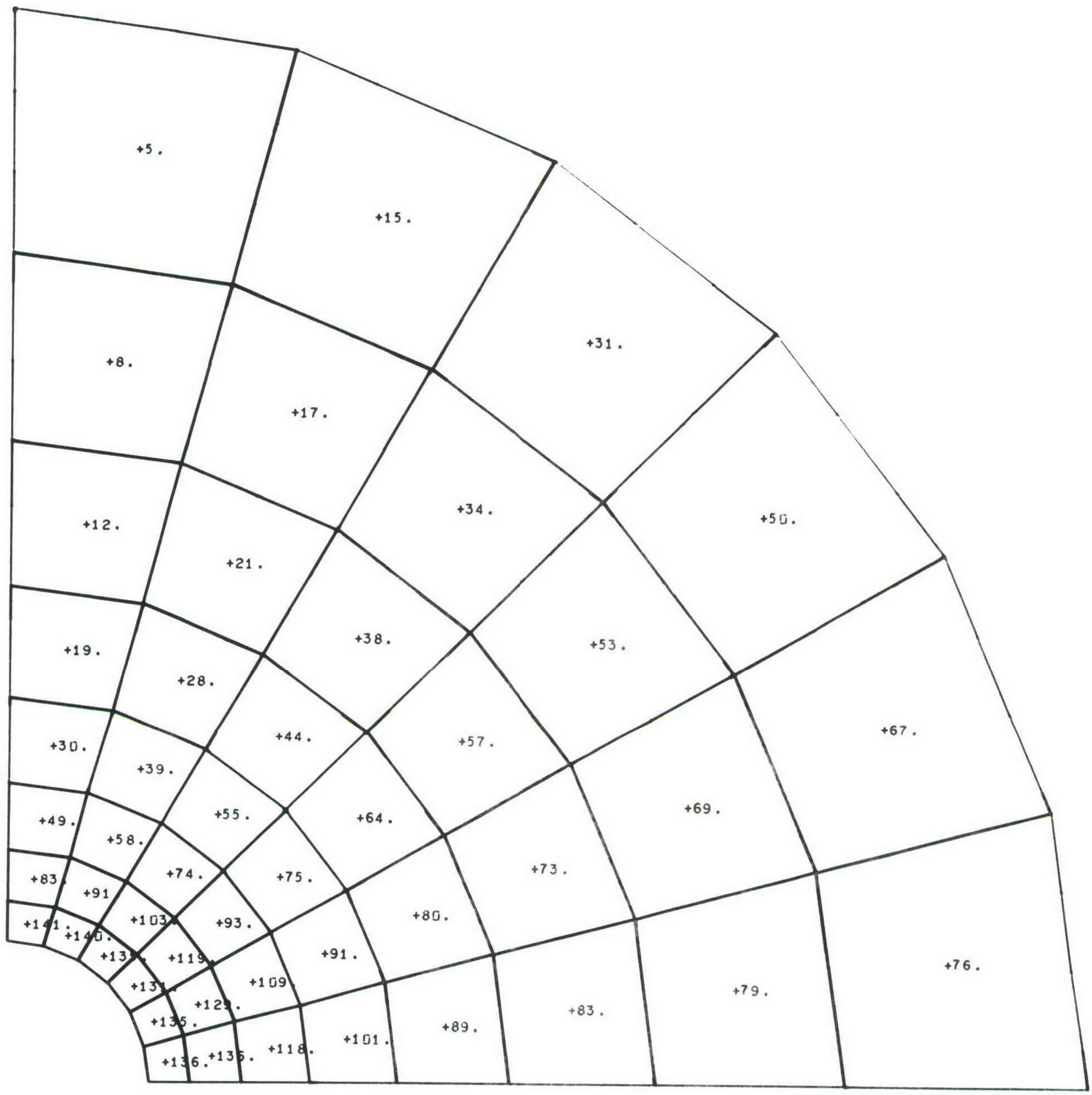


Figure AIII-17 **Tangential Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load**

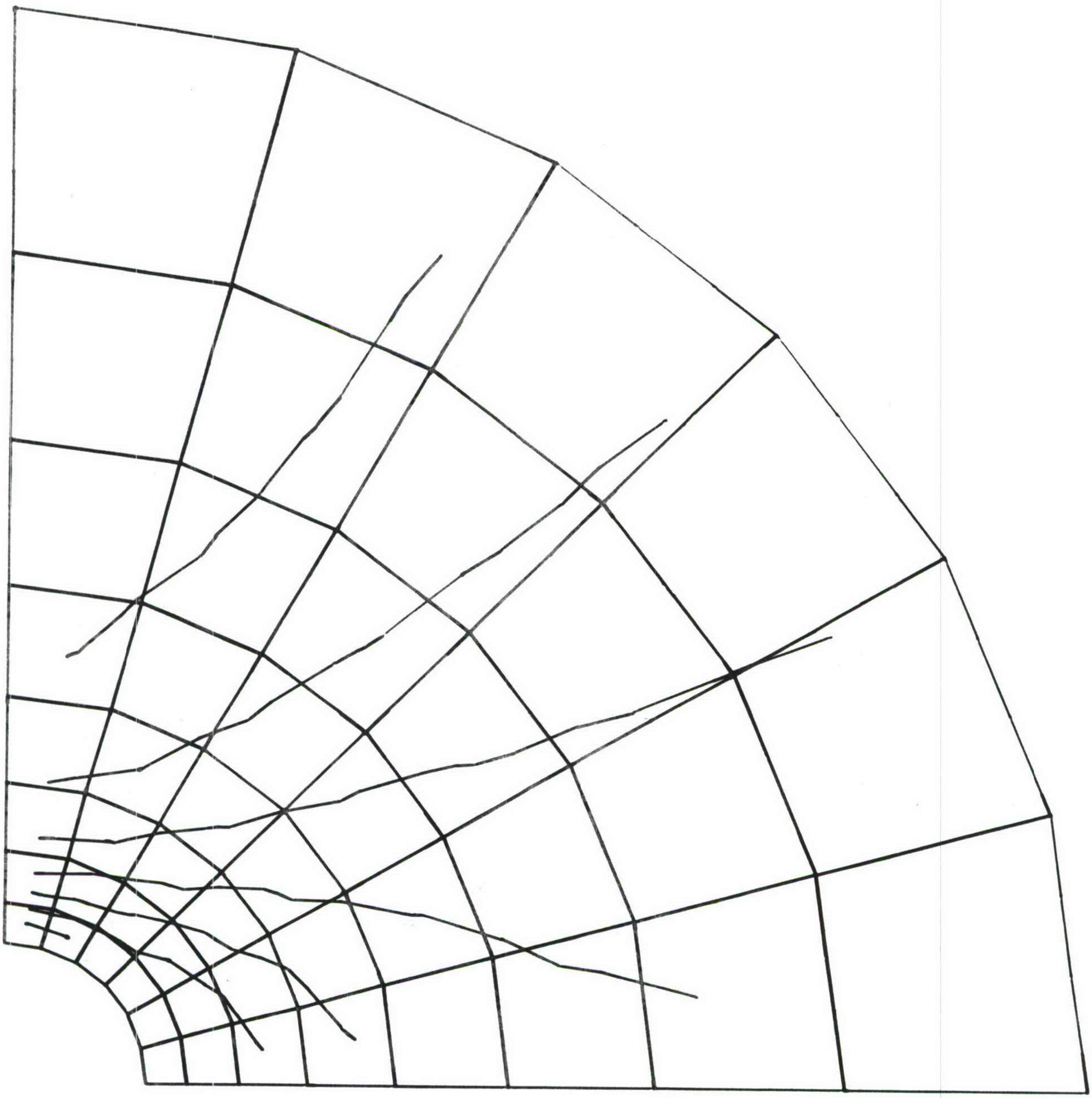


Figure AIII-18 Tangential Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

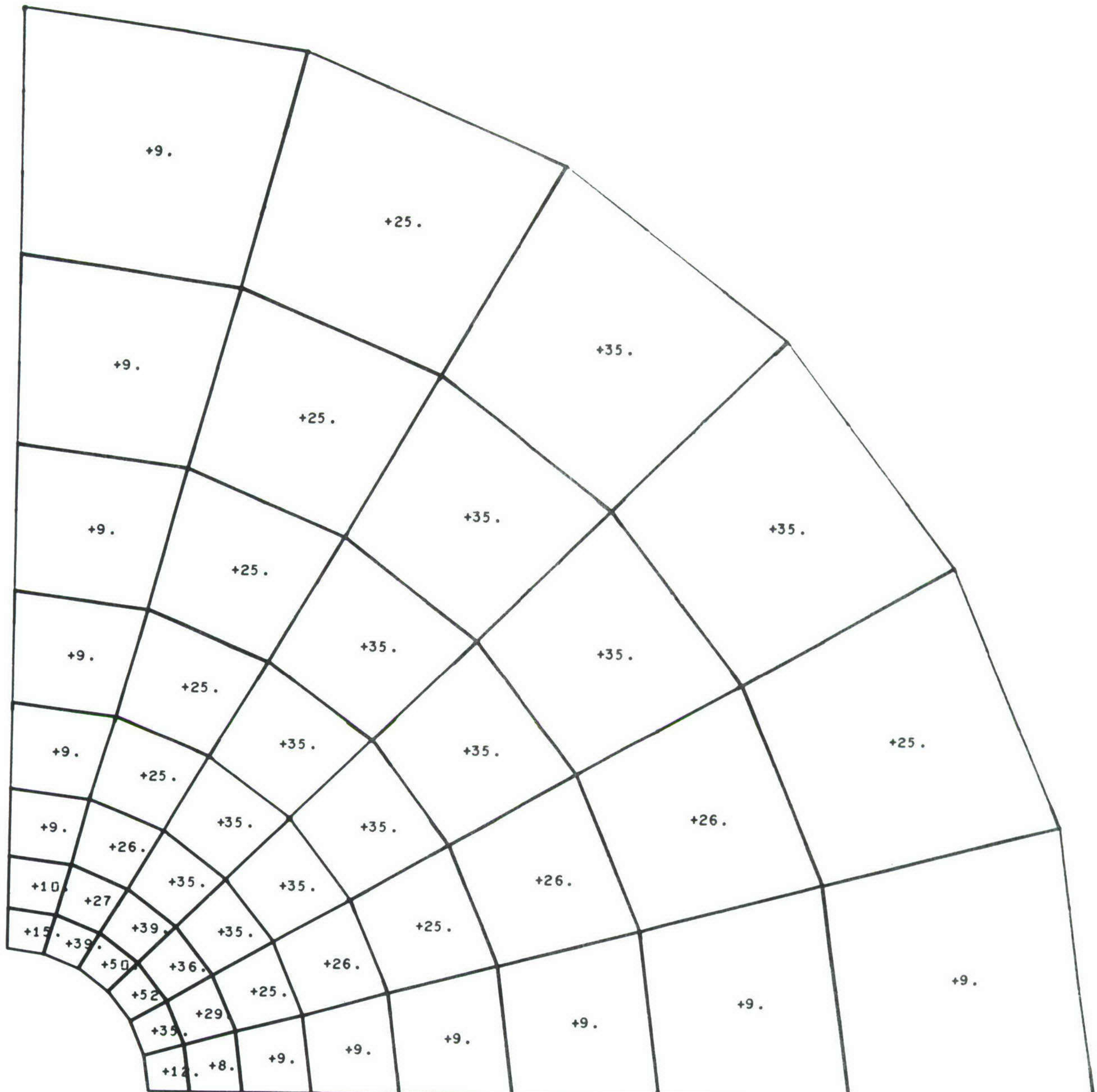


Figure AIII-19 Radial-Tangential Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

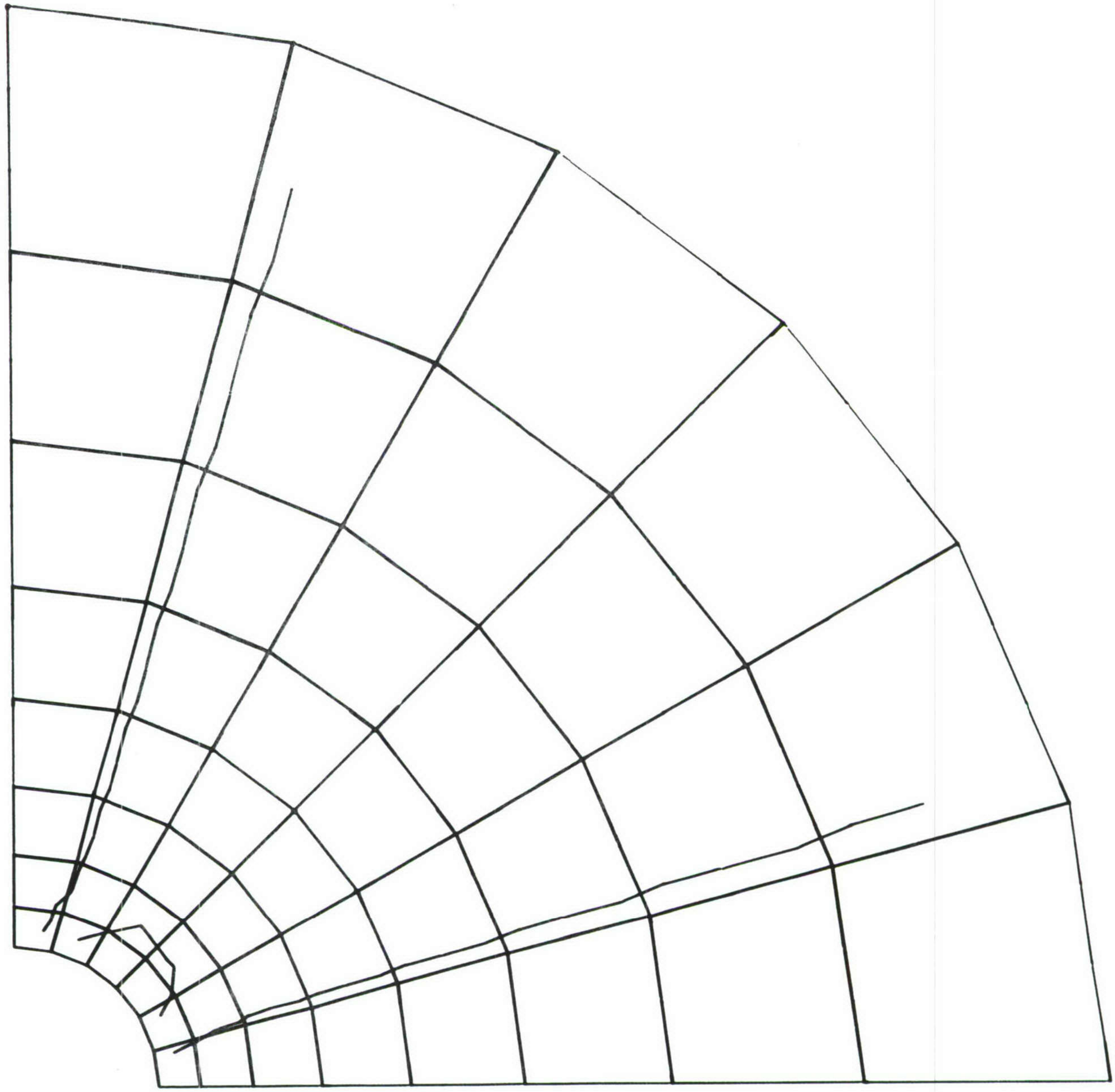


Figure AIII-20 Radial-Tangential Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

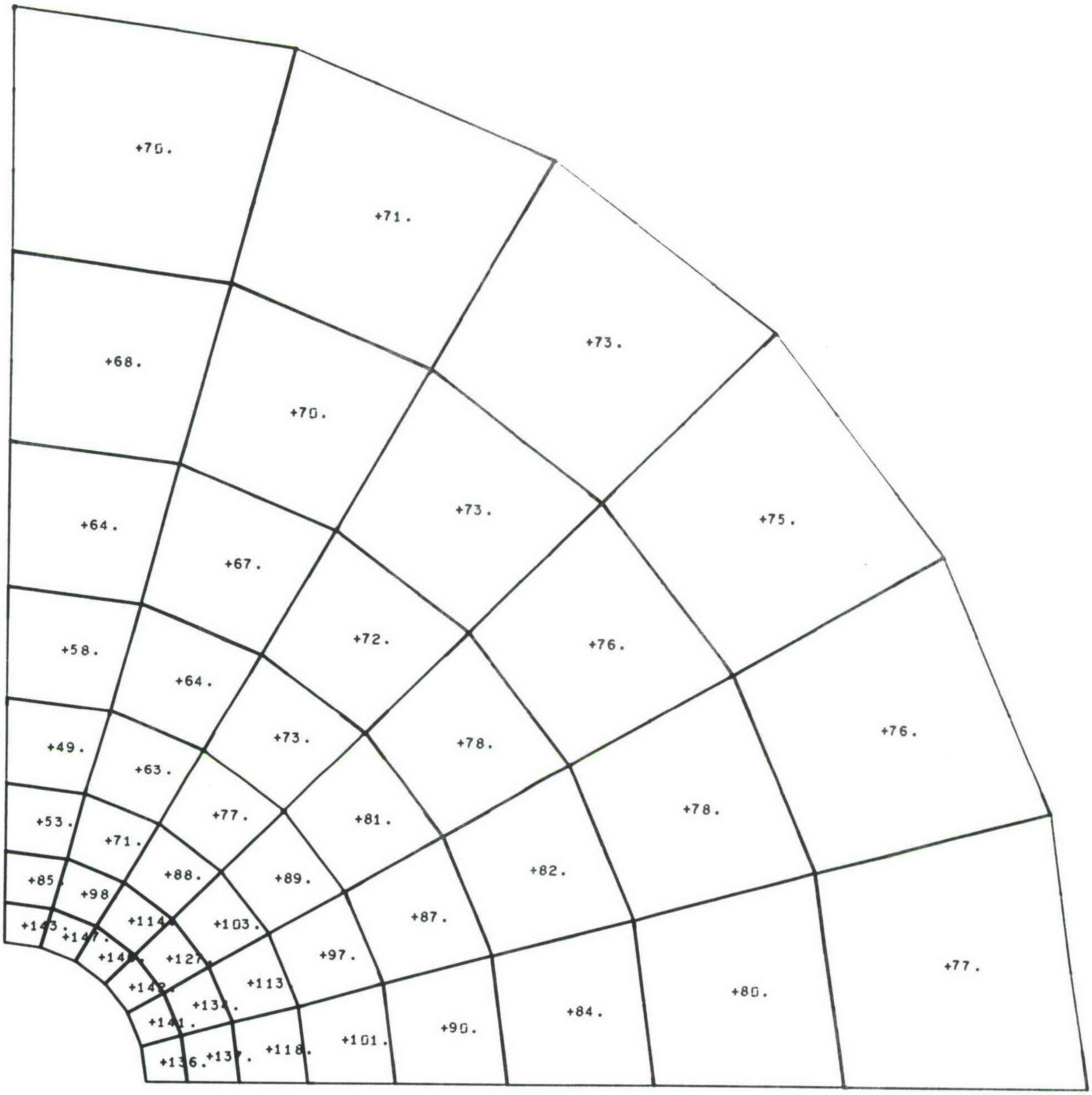


Figure AIII-21 First Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

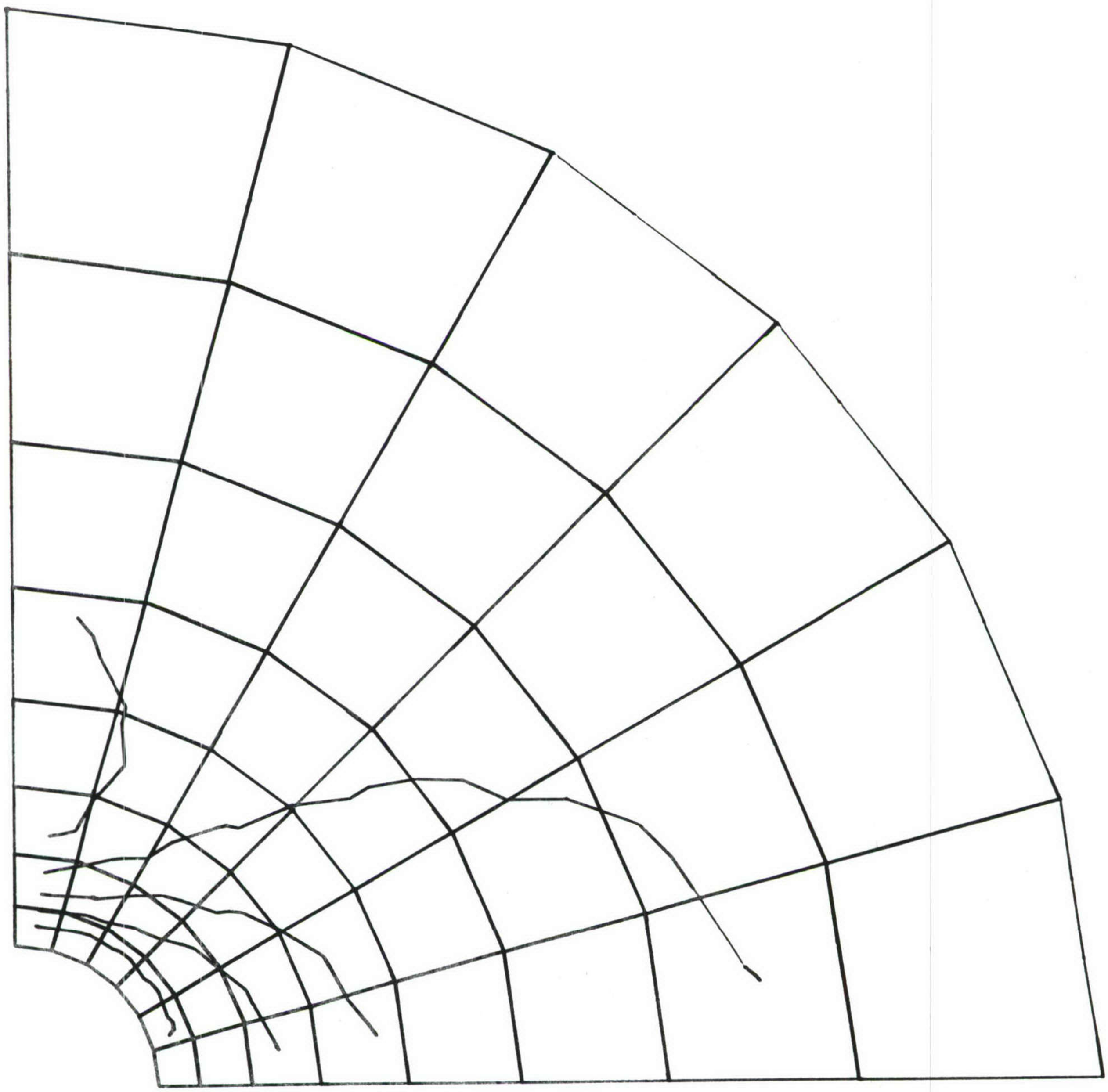


Figure AIII-22 First Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

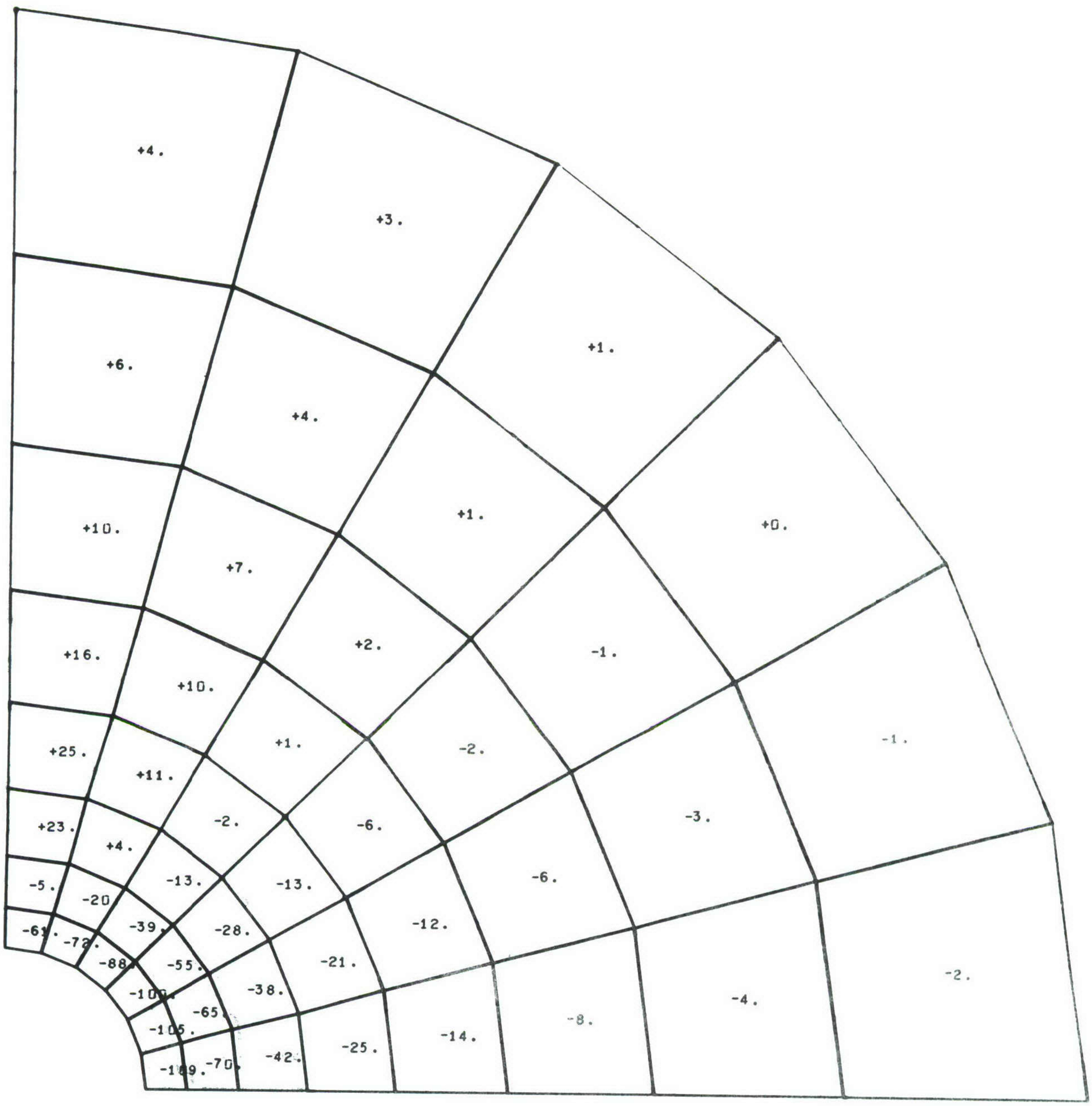


Figure AIII-23 Second Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference 35% Uniaxial Load

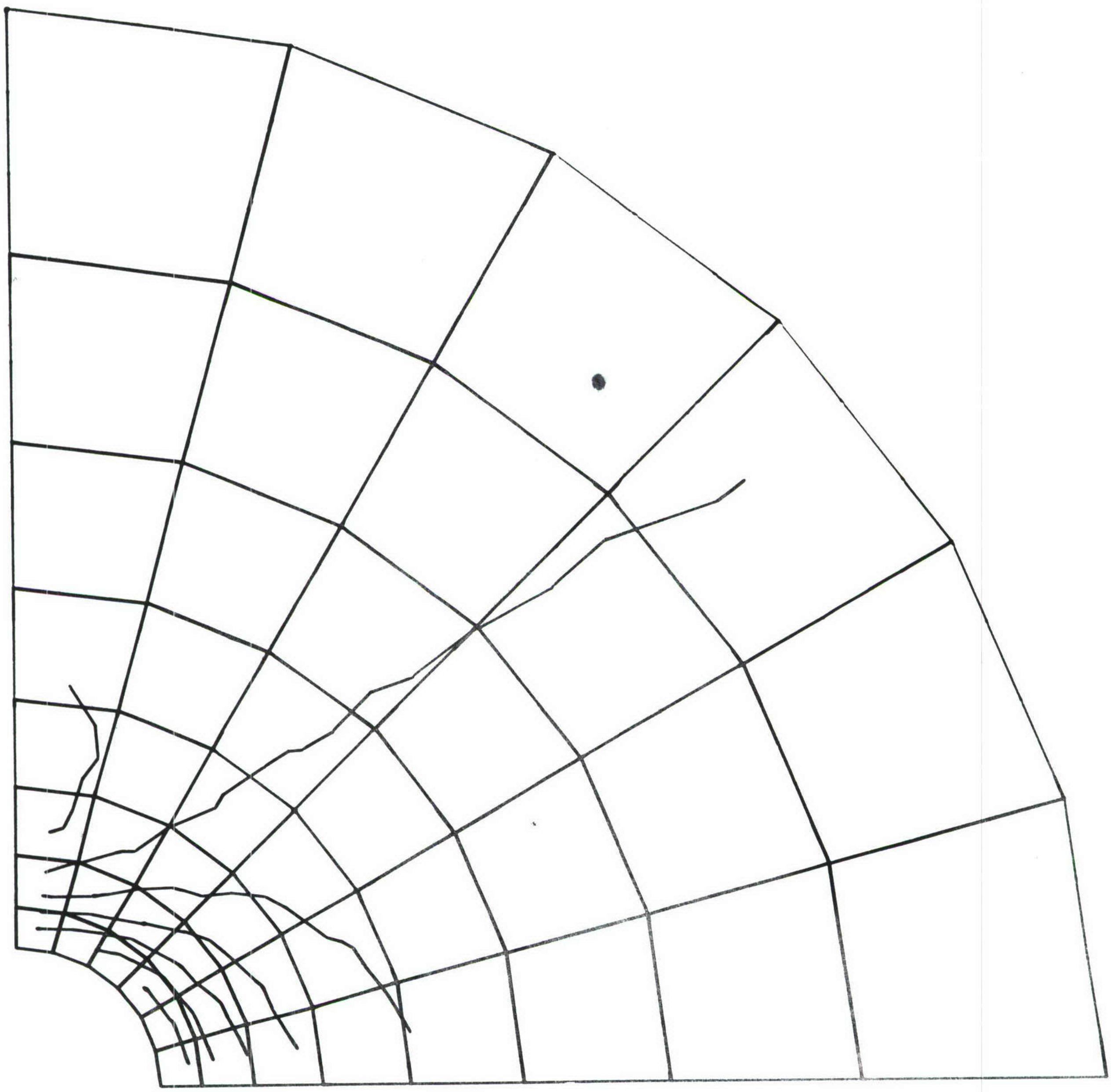


Figure AIII-24 Second Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

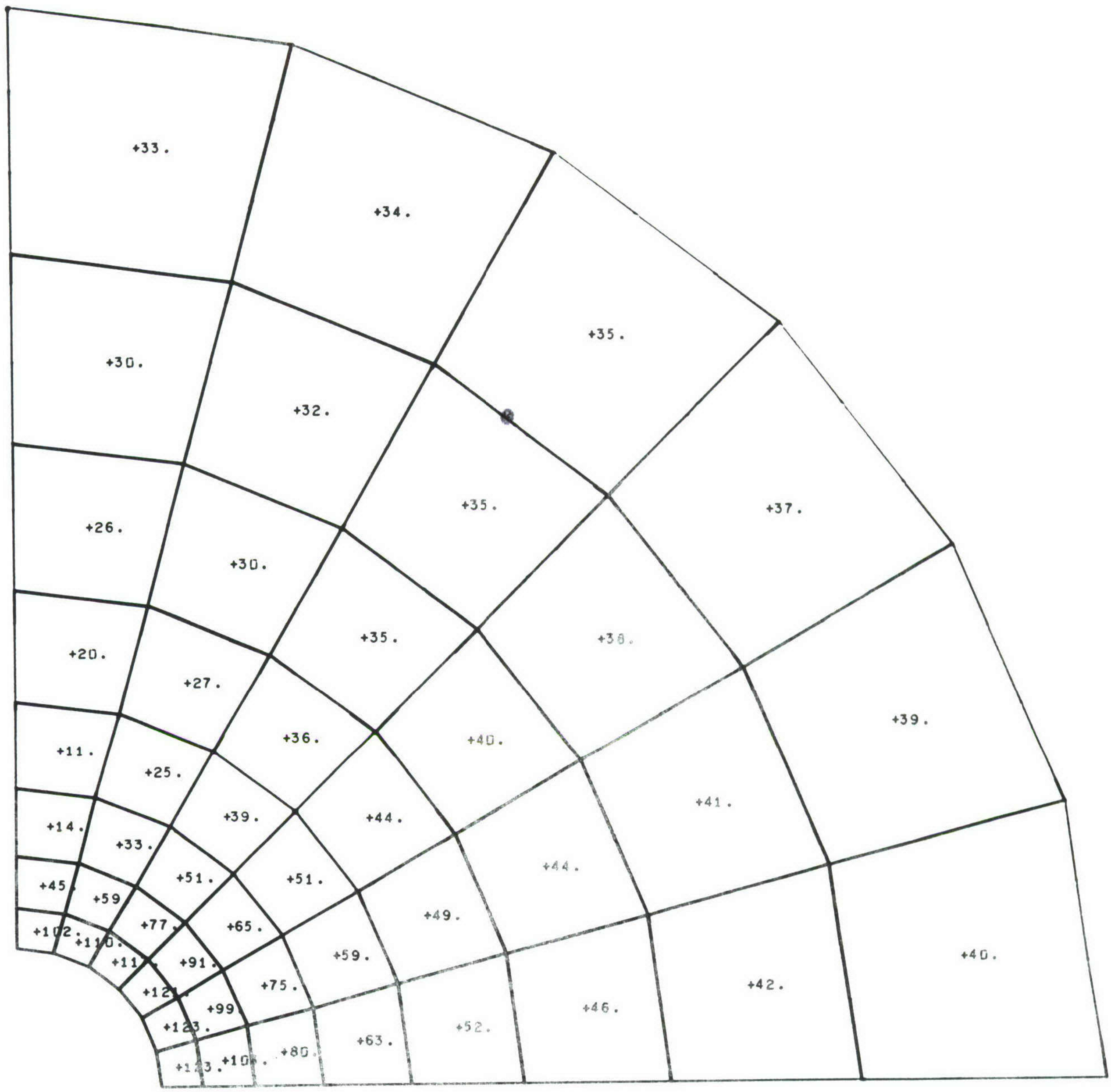


Figure AIII-25 Principal Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

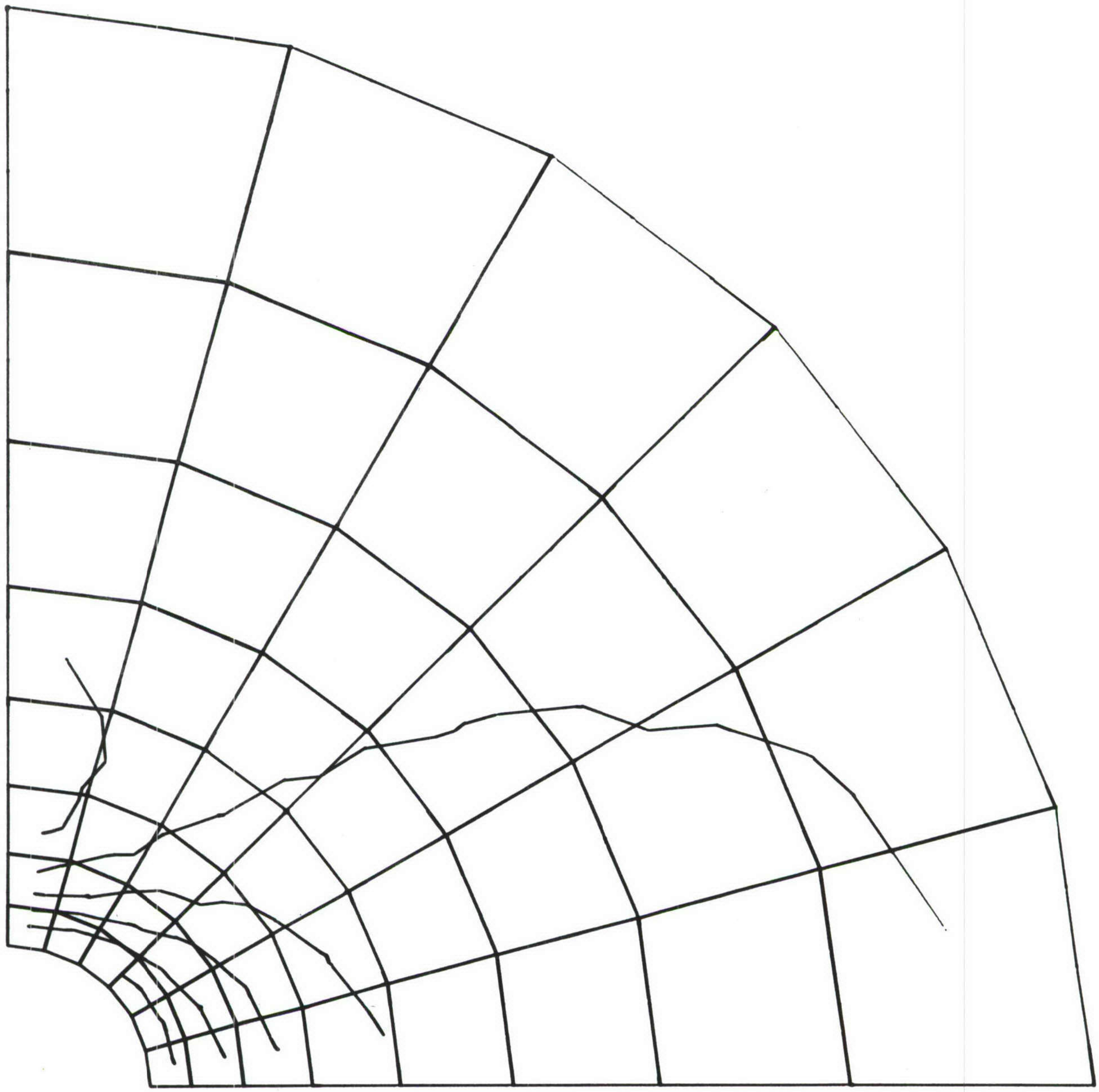


Figure AIII-26 Principal Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 35% Uniaxial Load

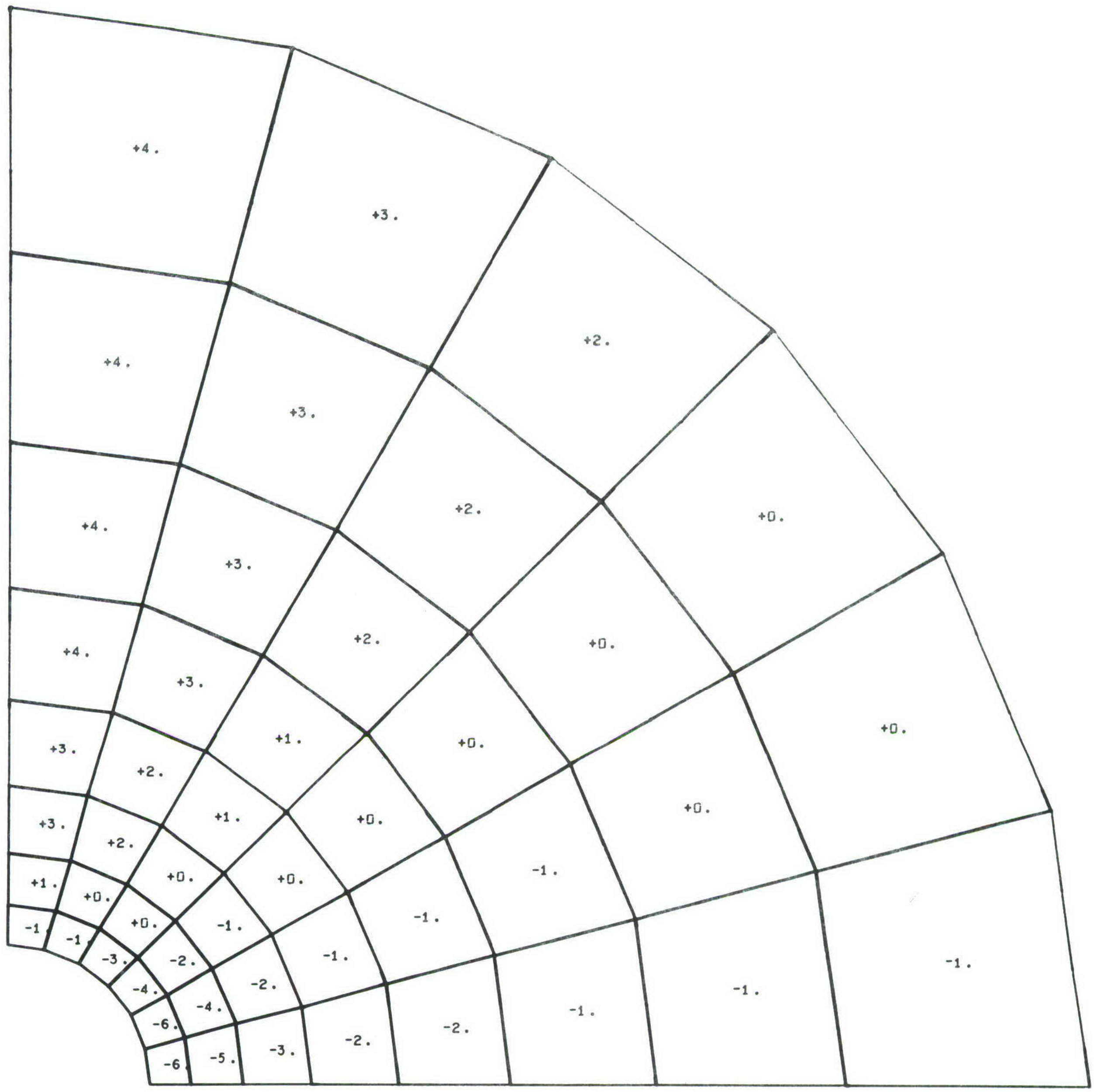


Figure AIII-27 Radial Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

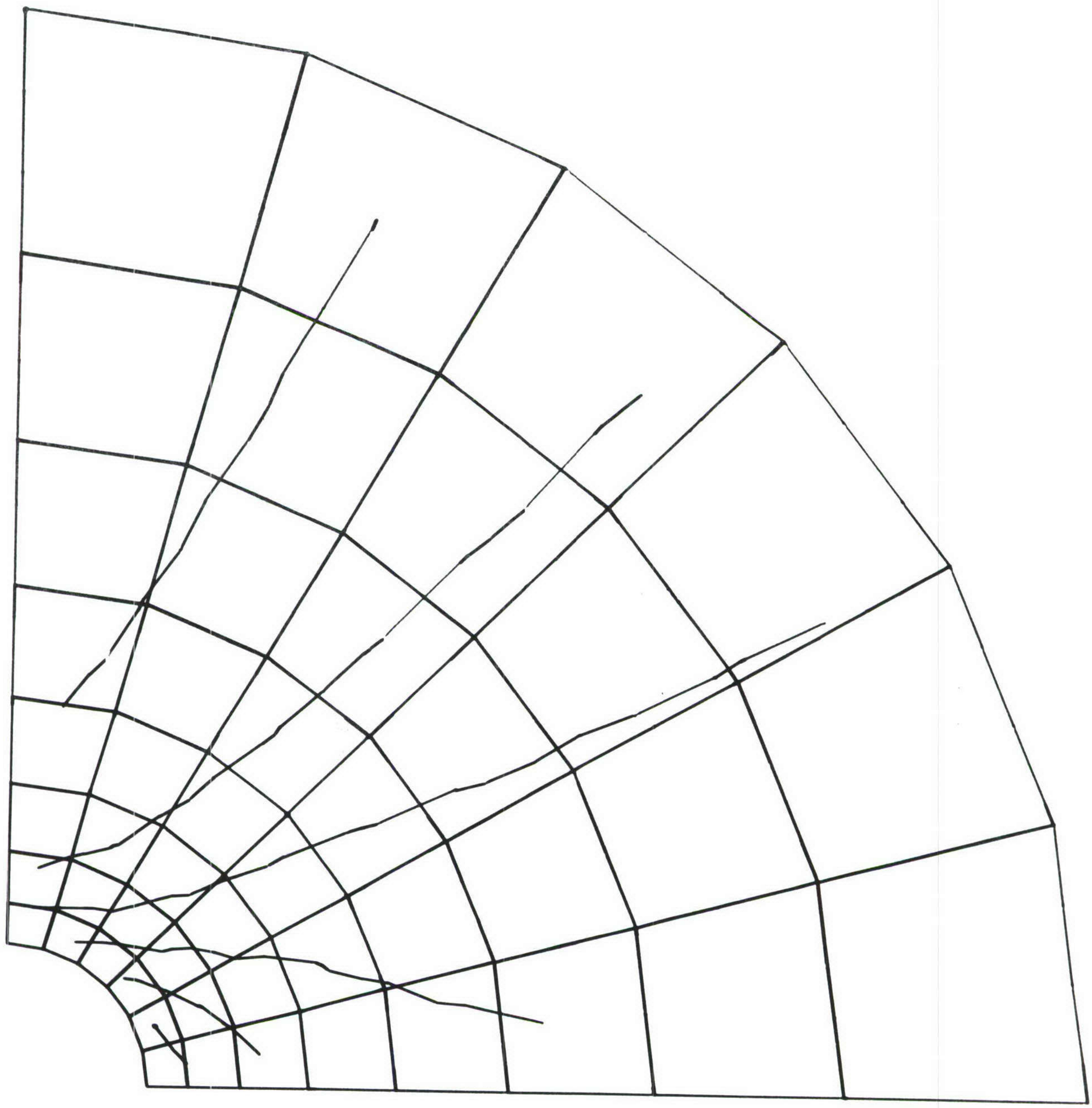


Figure AIII-28 Radial Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

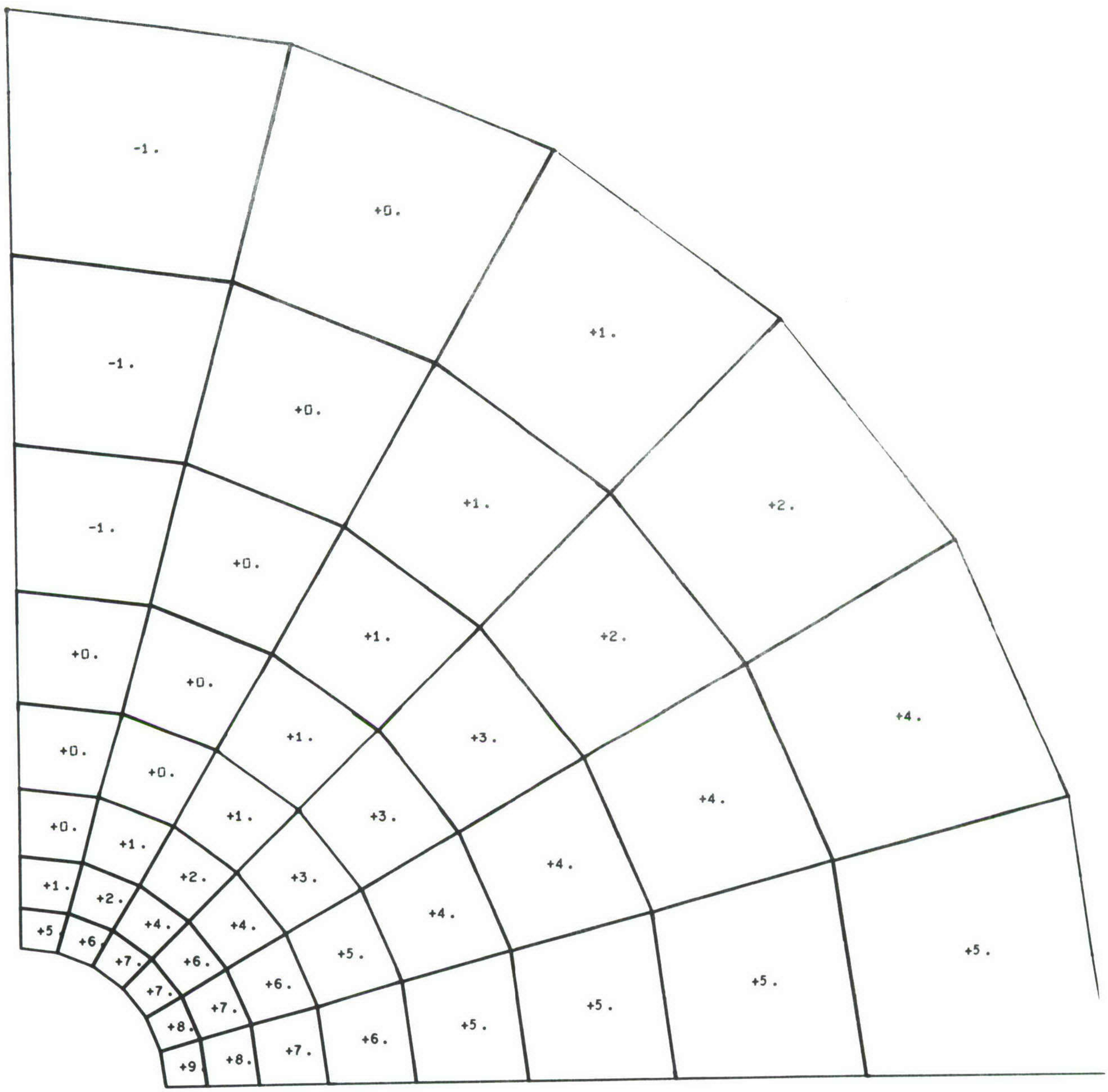


Figure AIII-29 Tangential Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

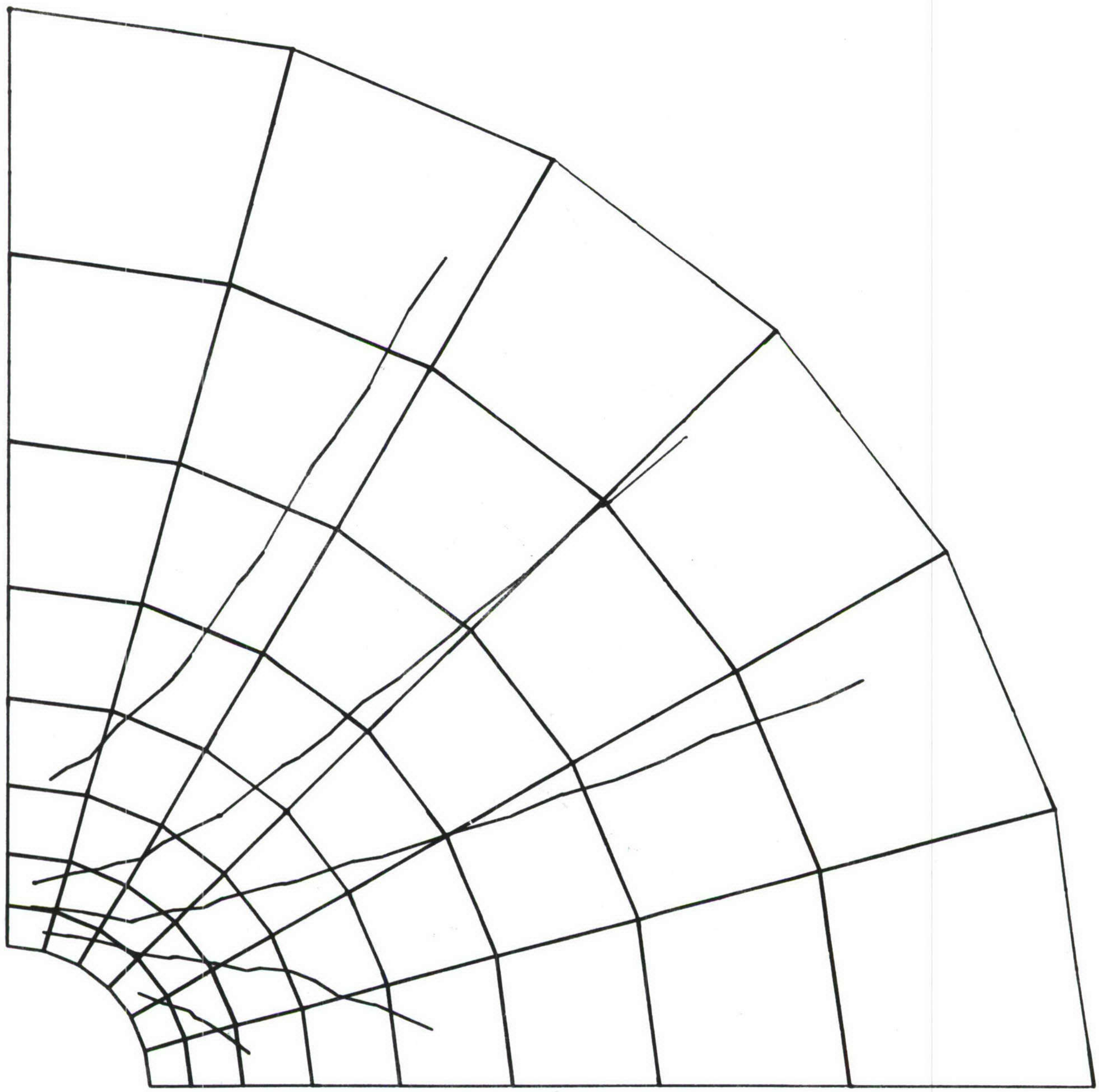


Figure AIII-30 Tangential Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

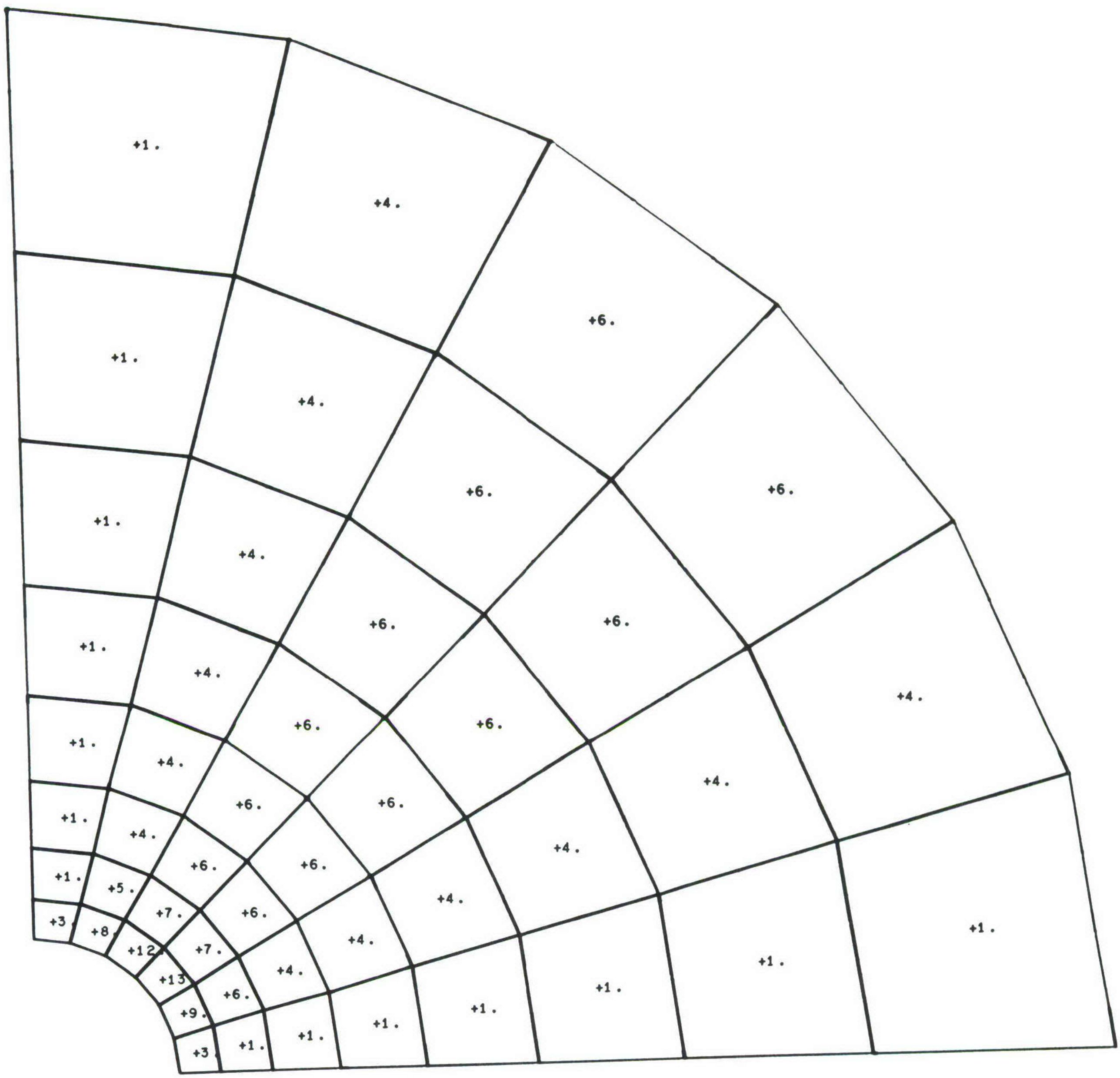


Figure AIII-31 Radial-Tangential Shear Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

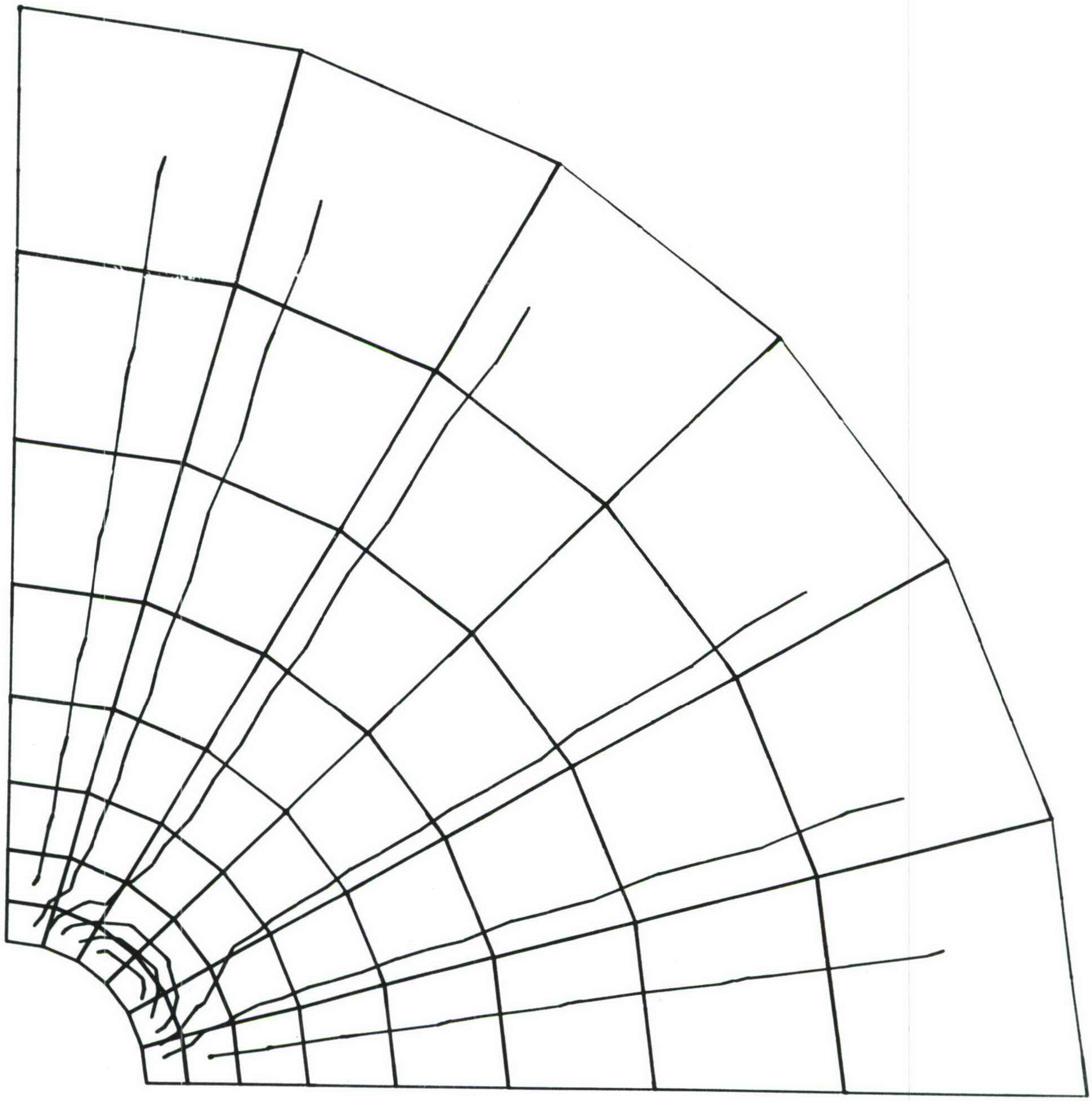


Figure AIII-32 Radial-Tangential Shear Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

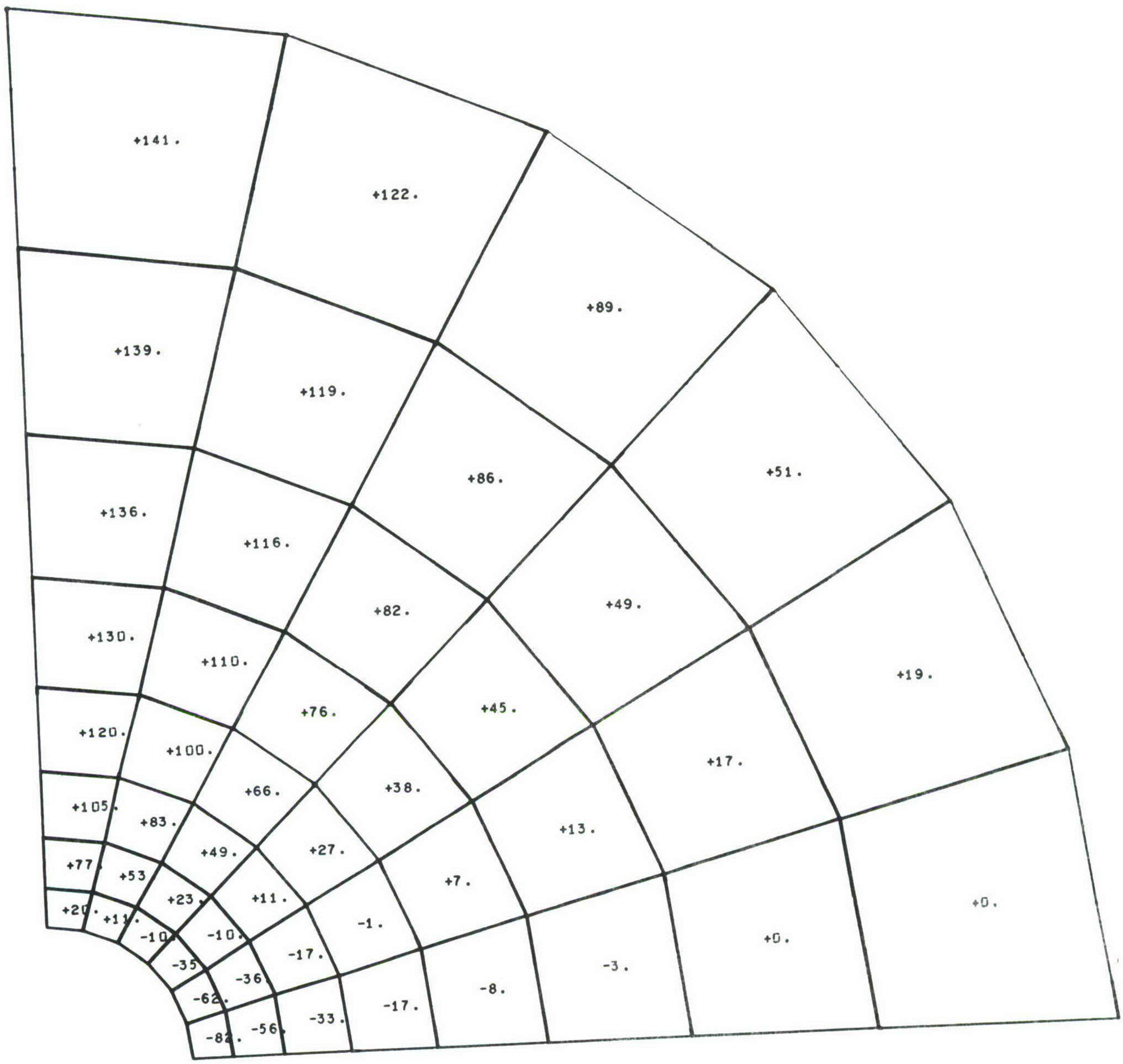


Figure AIII-33 Radial Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

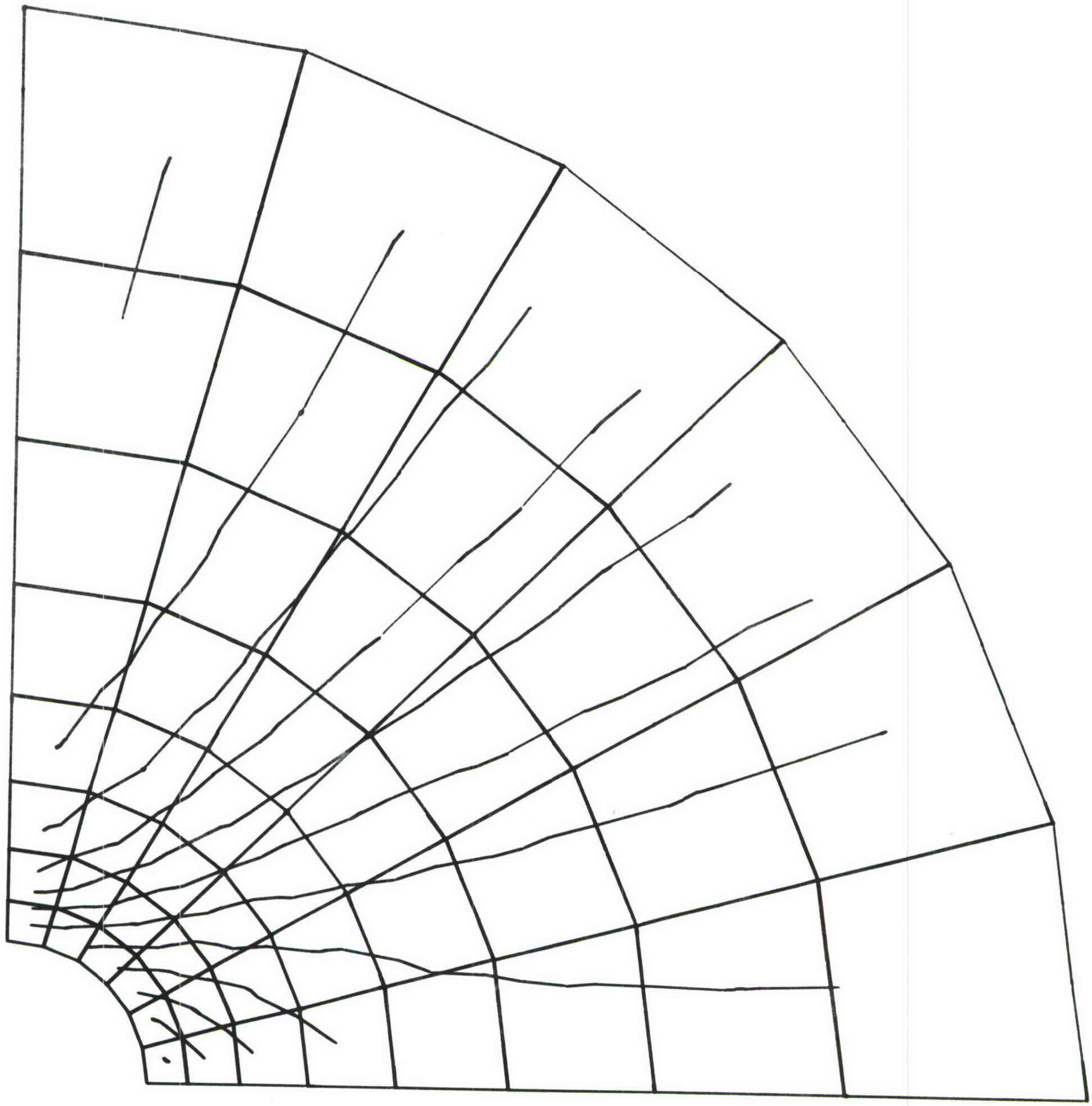


Figure AIII-34 Radial Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

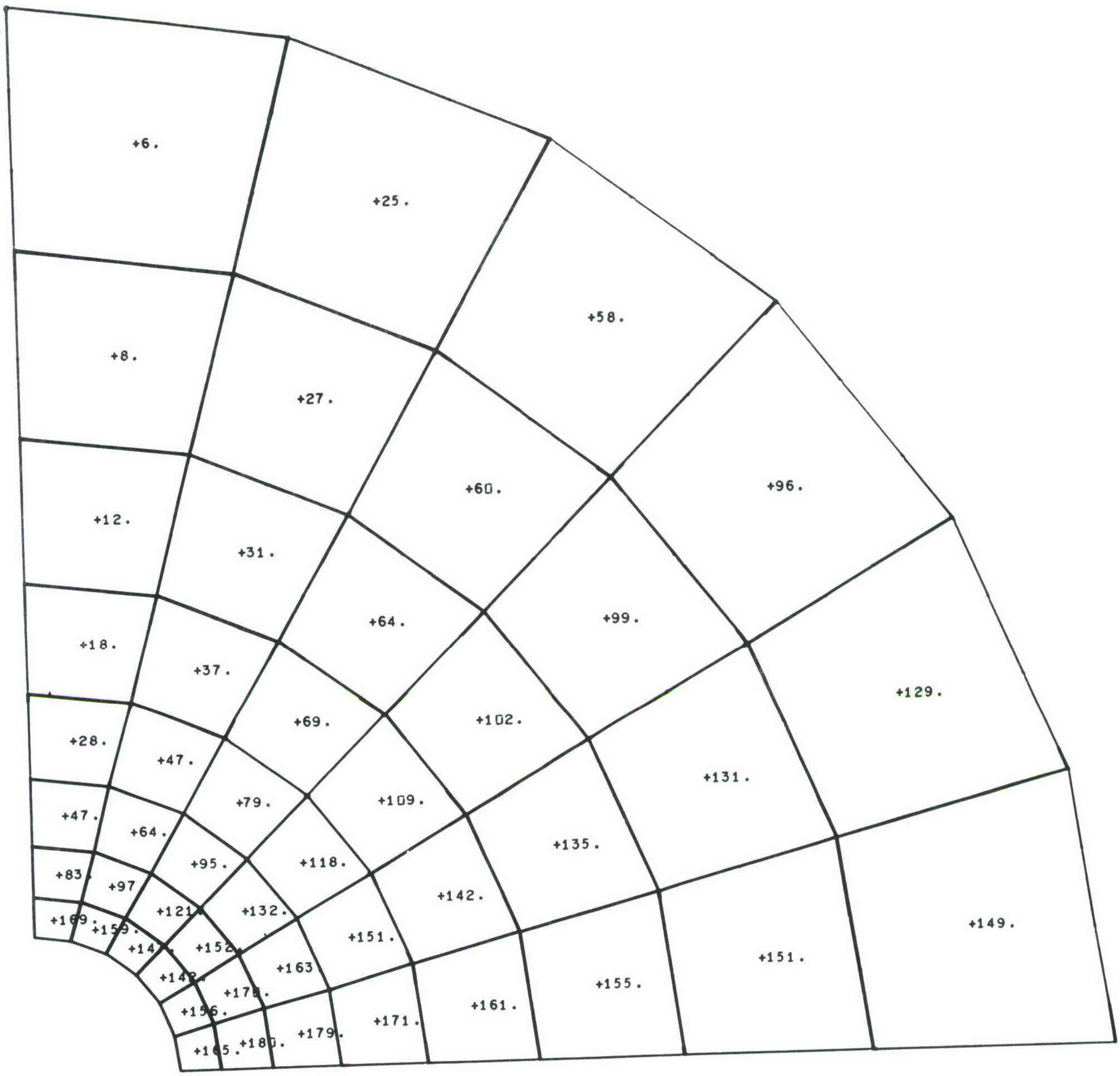


Figure AIII-35 Tangential Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

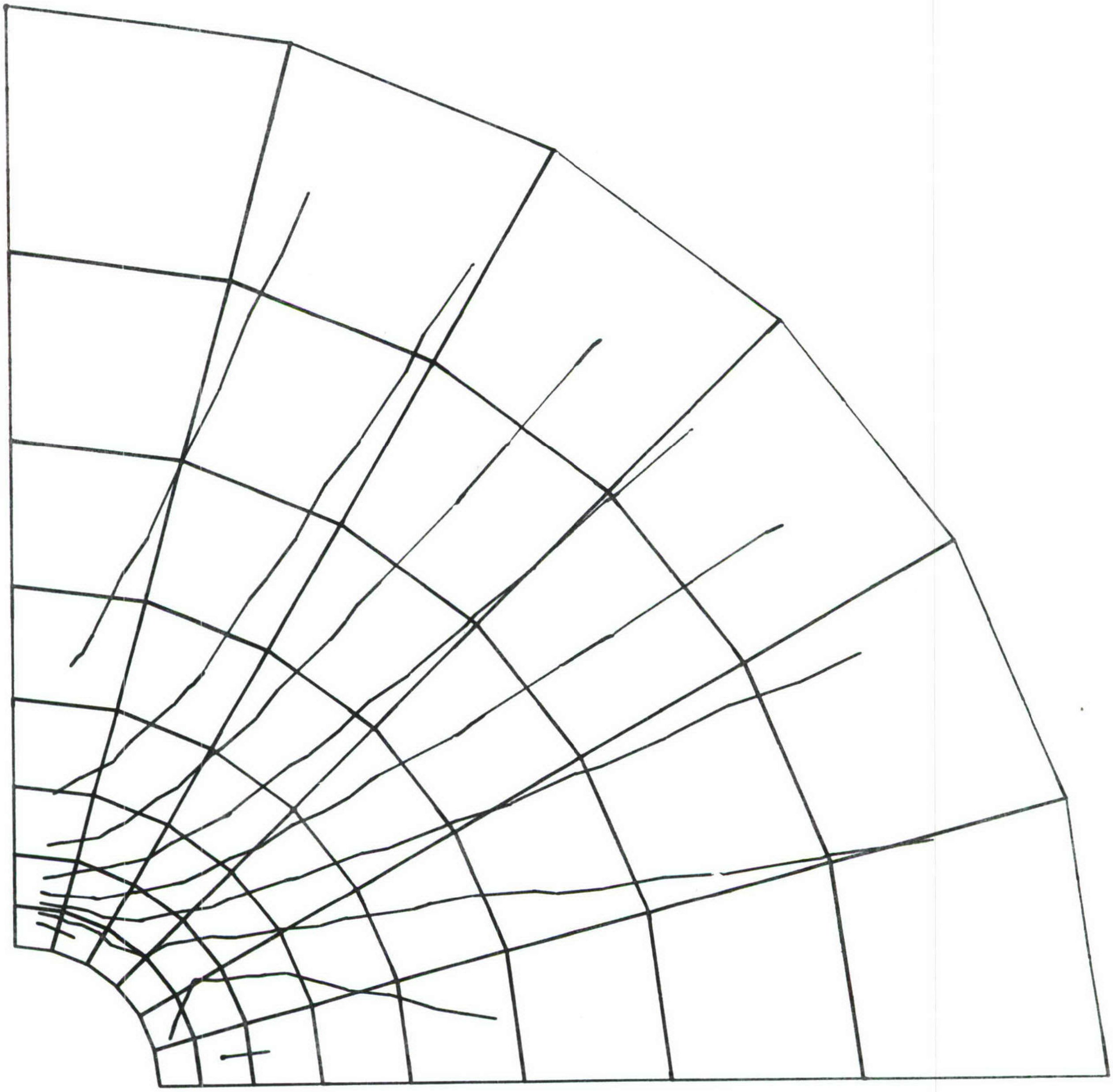


Figure AIII-36 Tangential Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

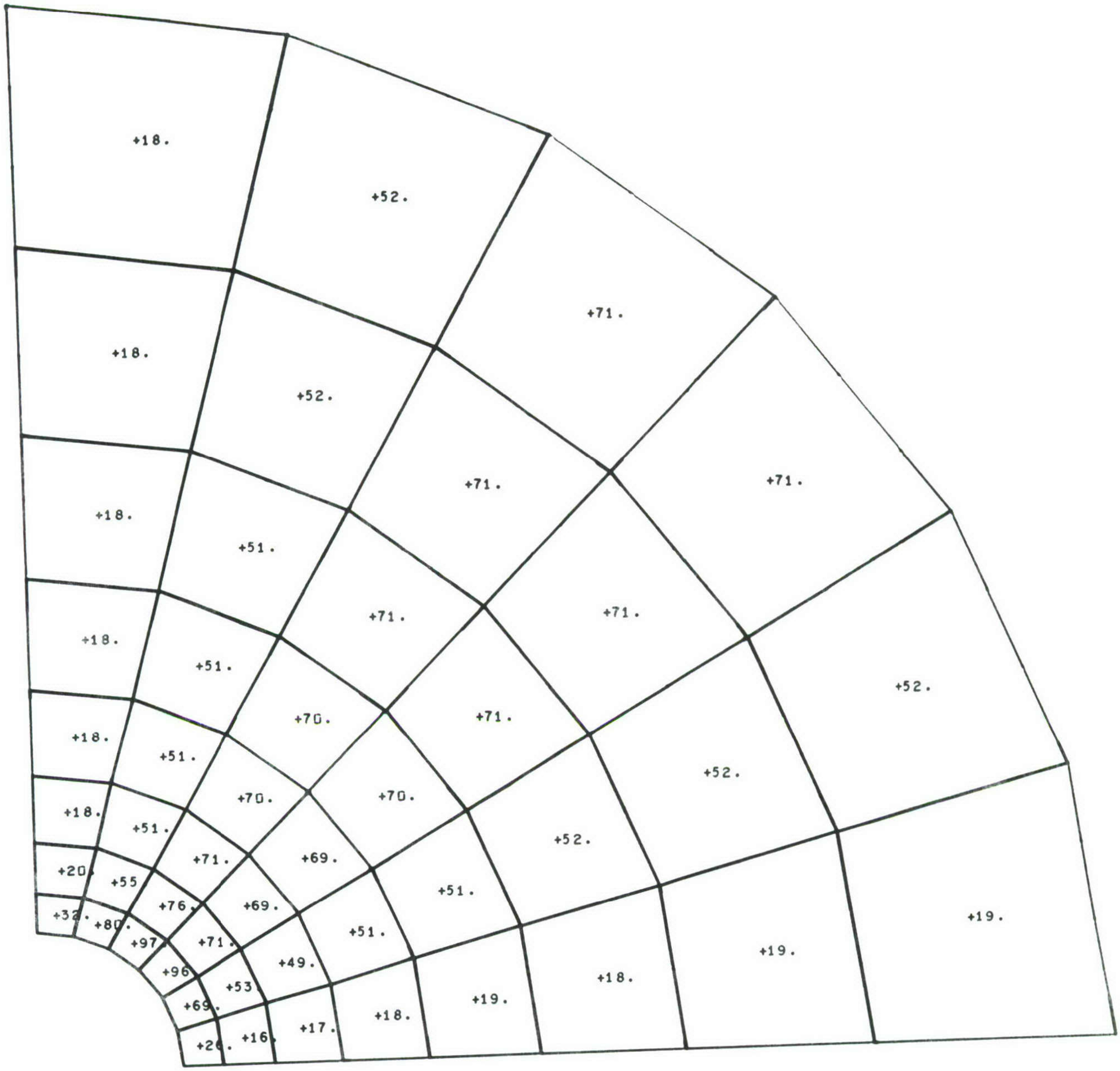


Figure AIII-37 Radial-Tangential Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

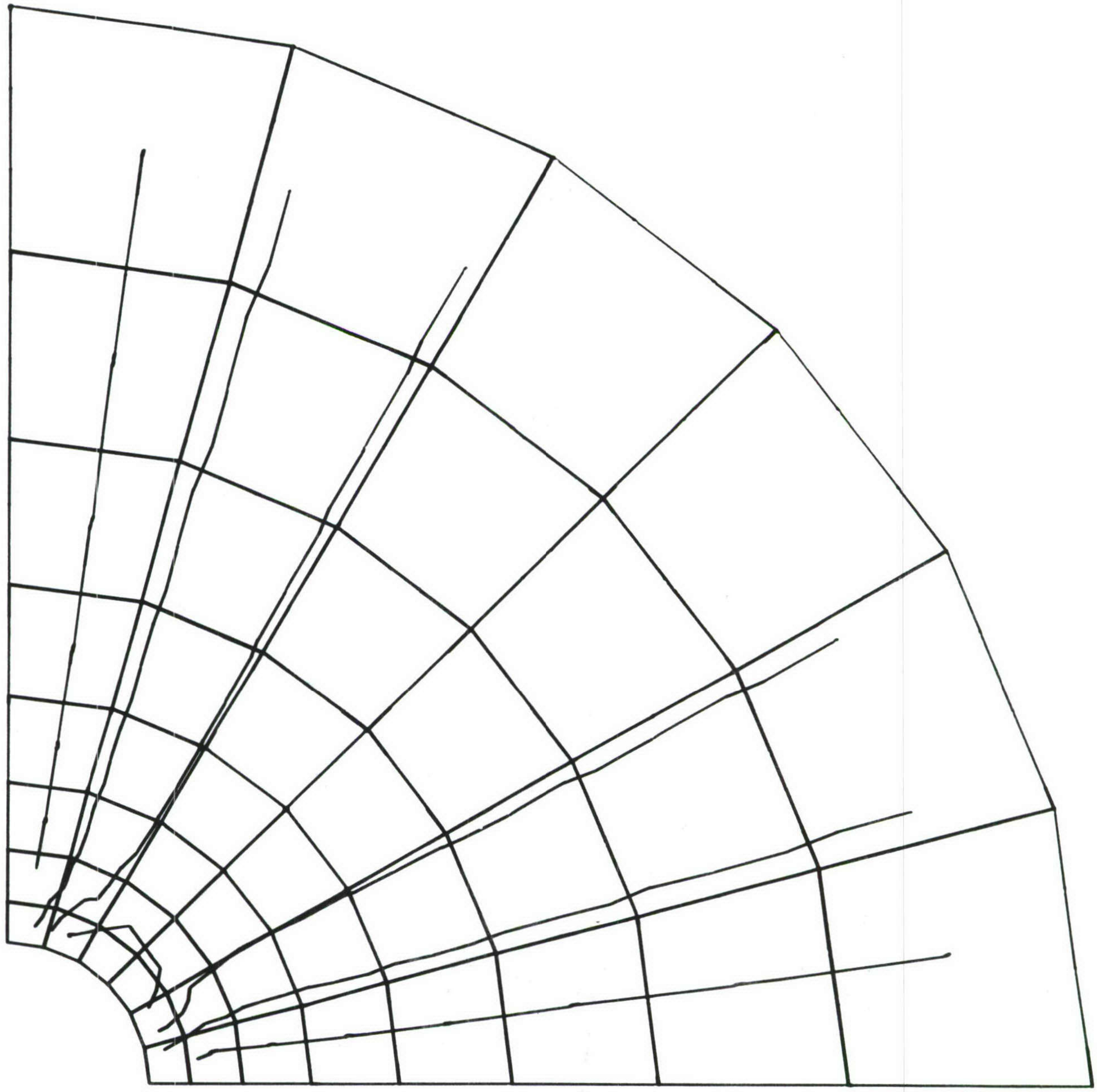


Figure AIII-38 Radial-Tangential Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference: 70% Uniaxial Load

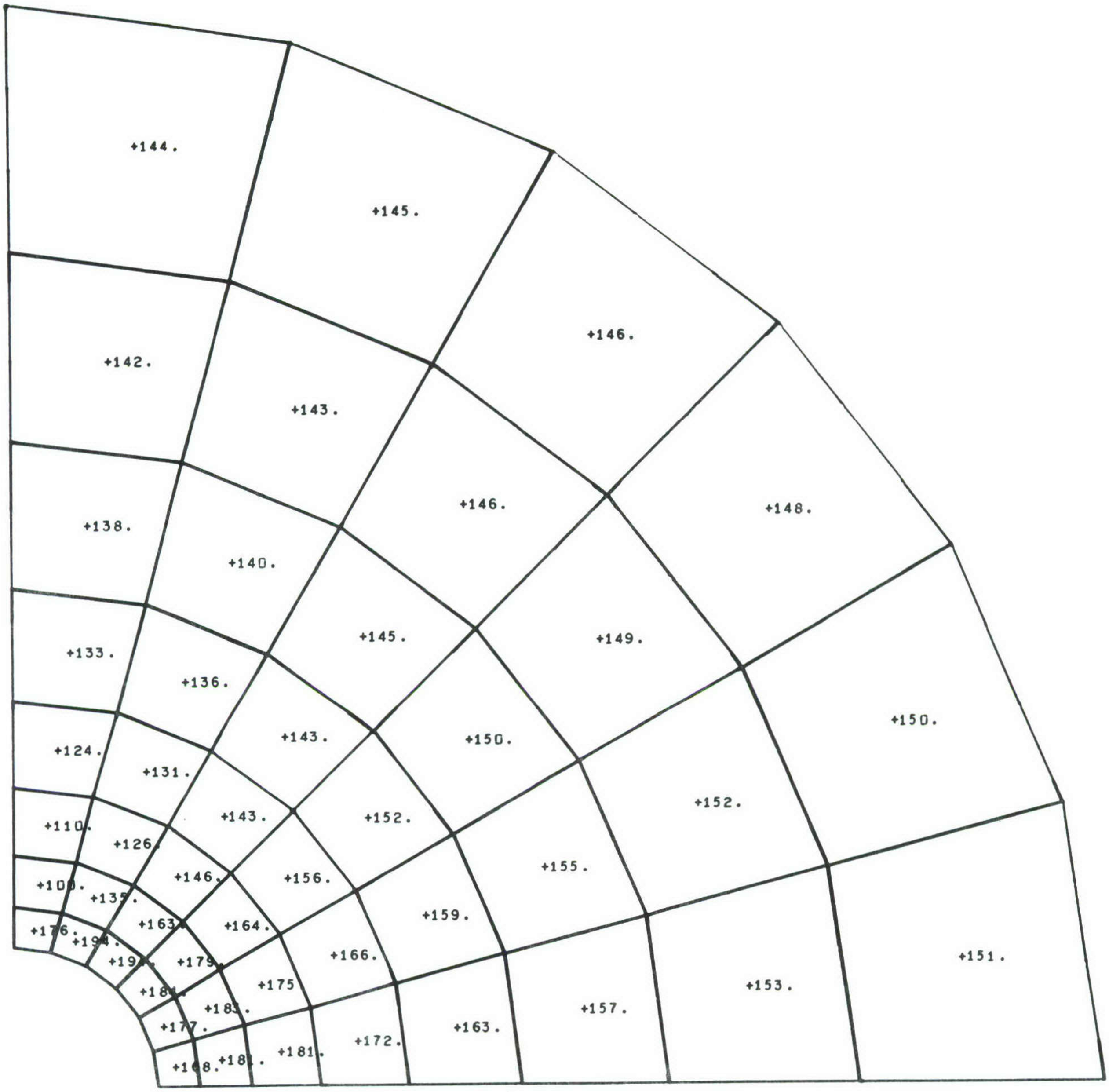


Figure AIII-39 First Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

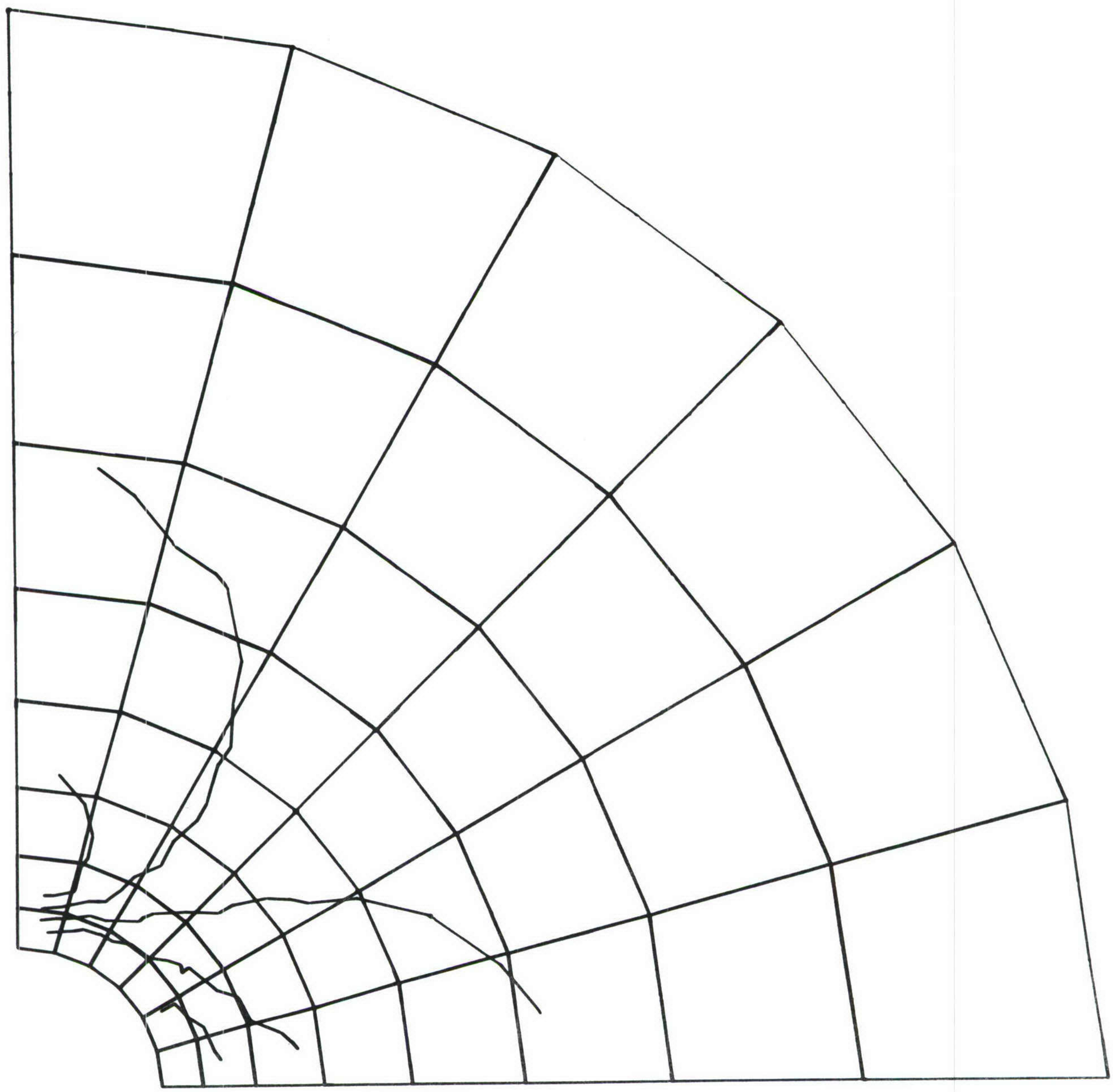


Figure AIII-40 First Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

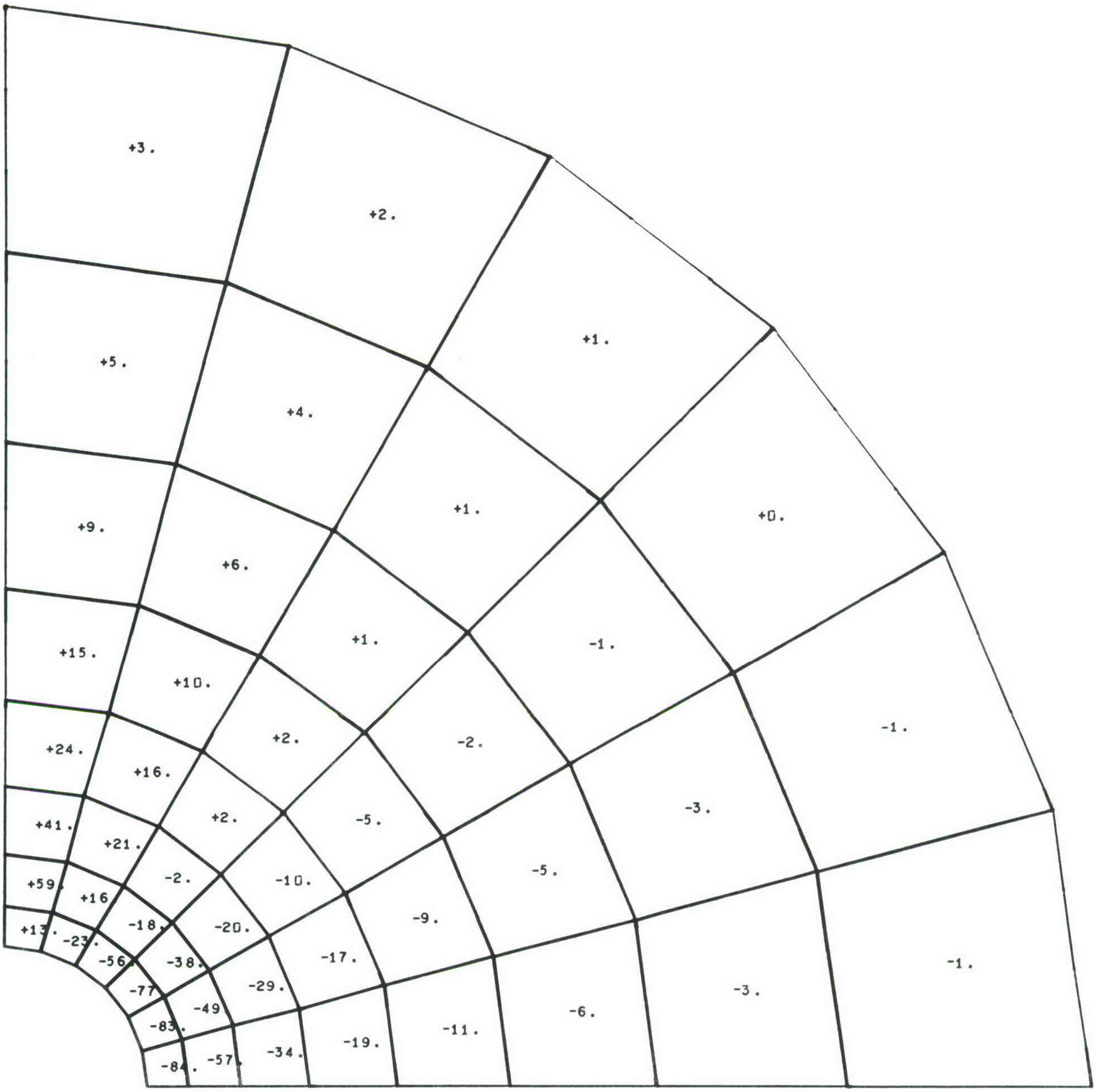


Figure AIII-41 Second Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

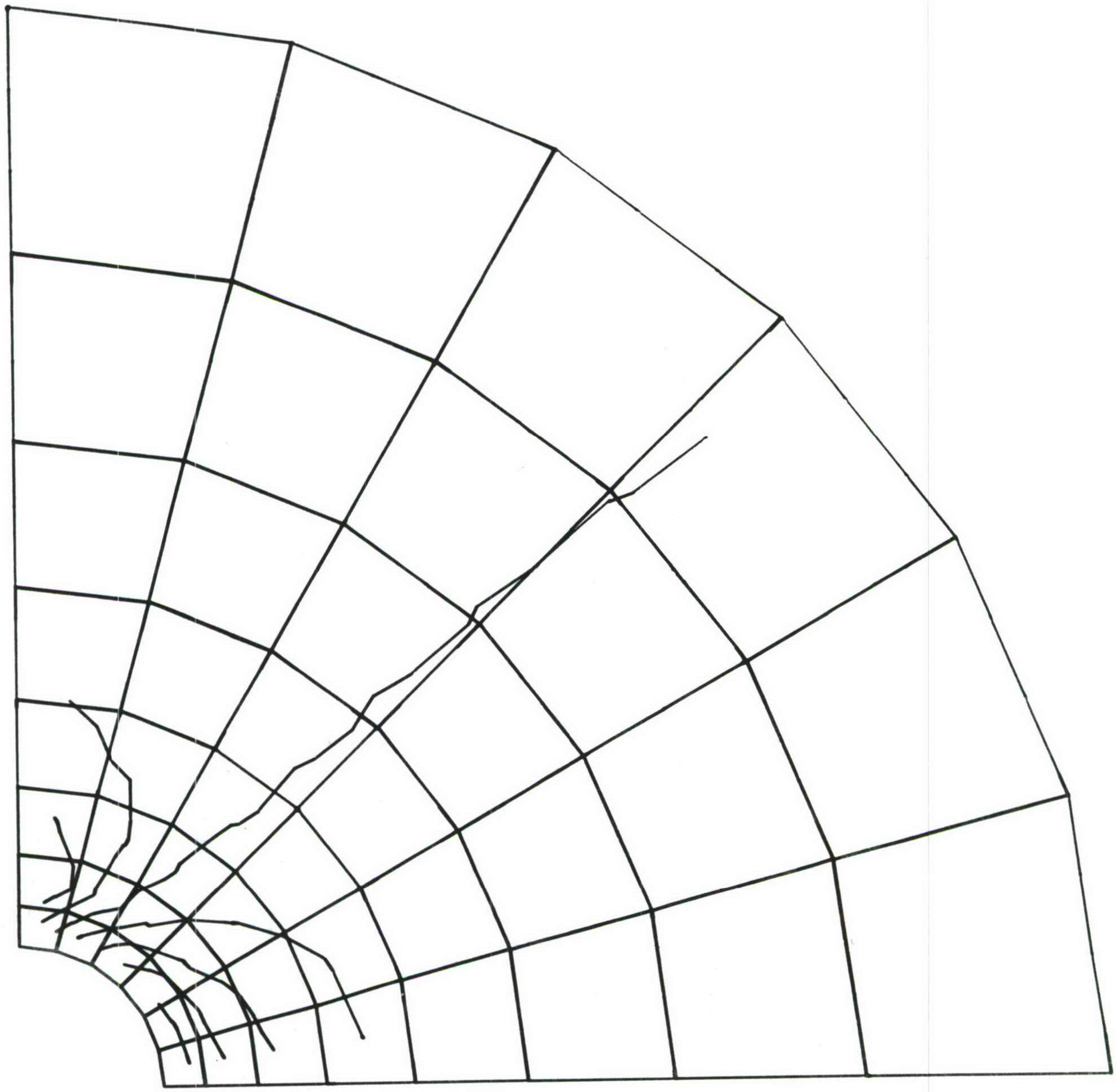


Figure AIII-42 Second Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

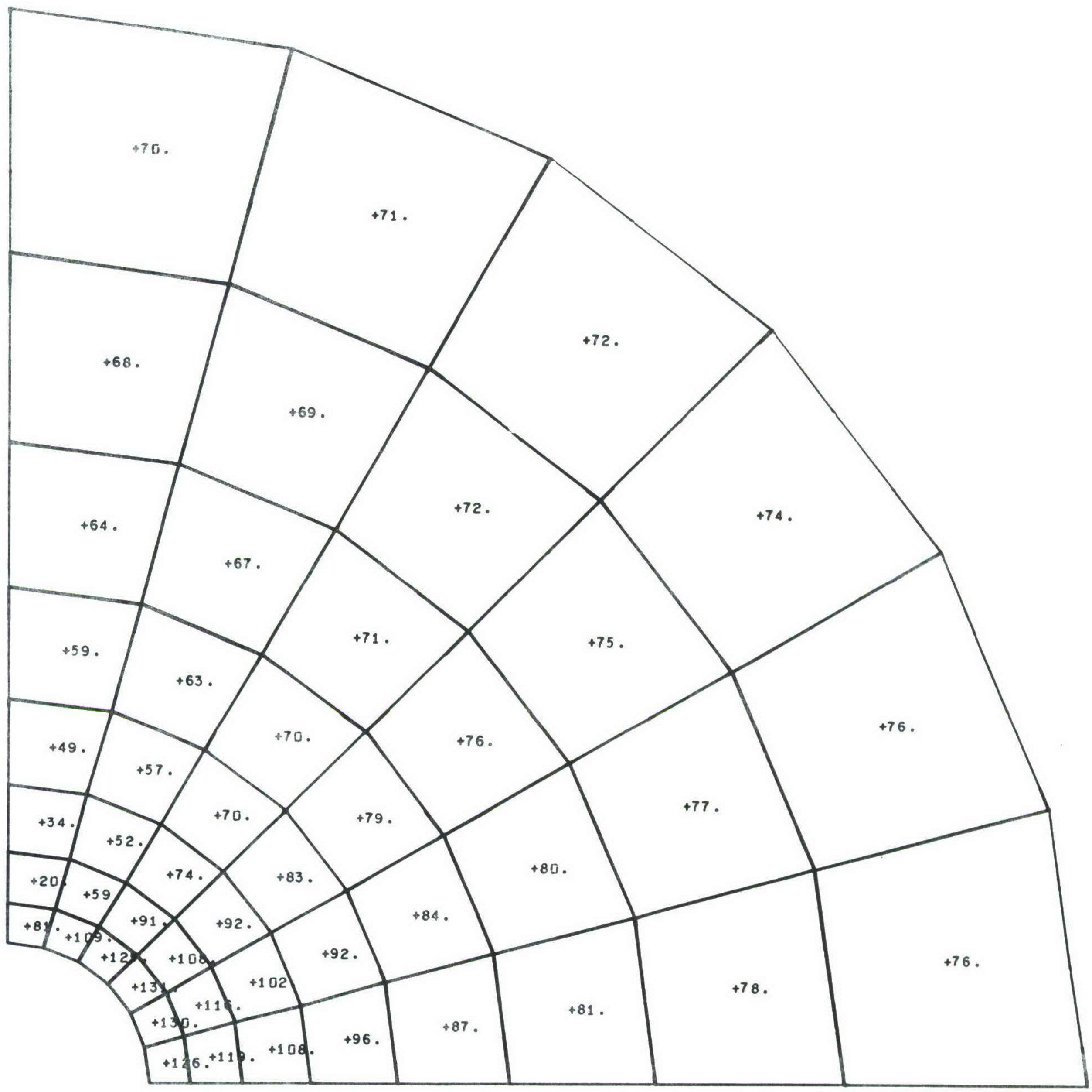


Figure AIII-43 Principal Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

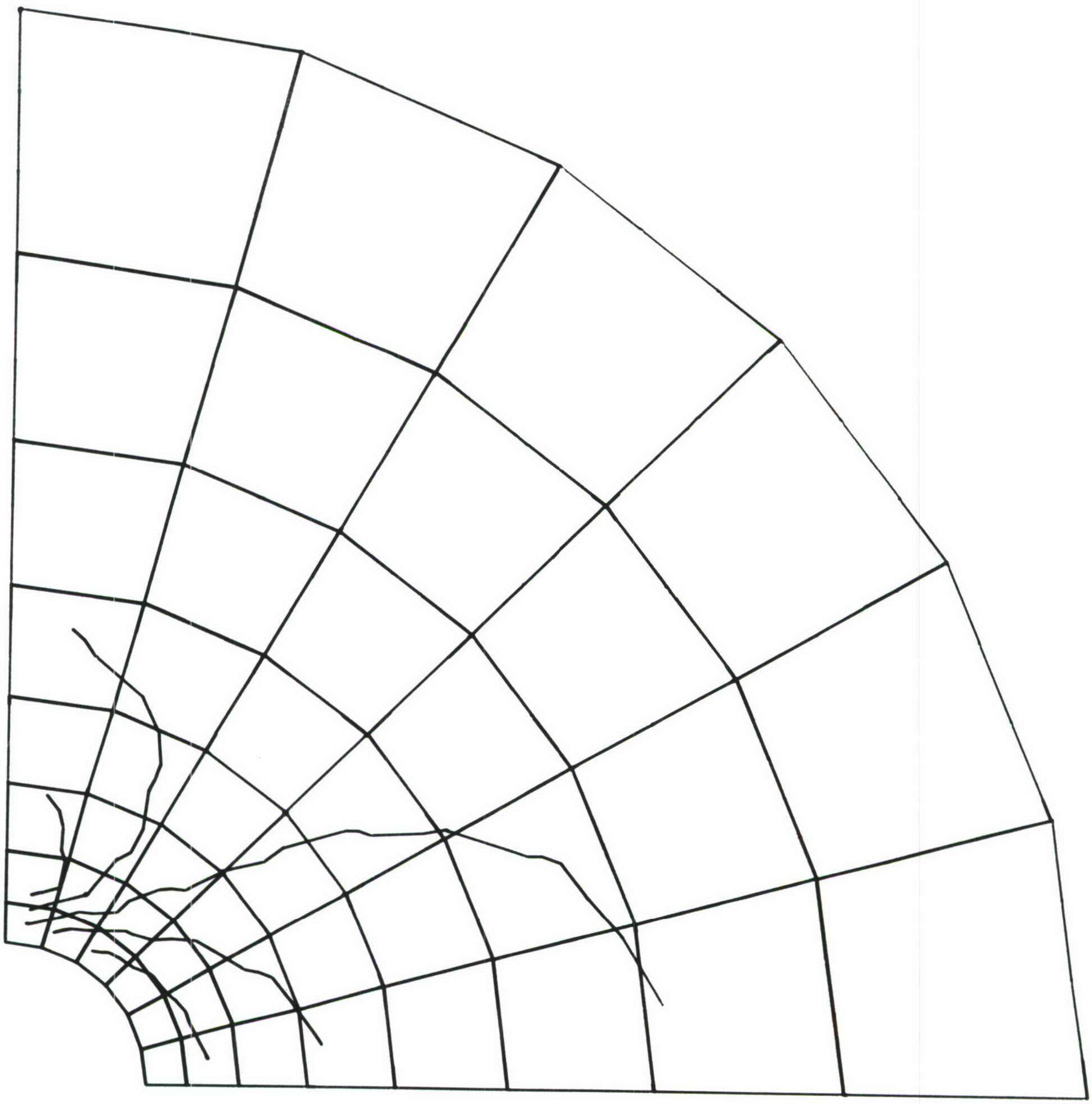


Figure AIII-44 Principal Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.001875 Inch Radial Interference; 70% Uniaxial Load

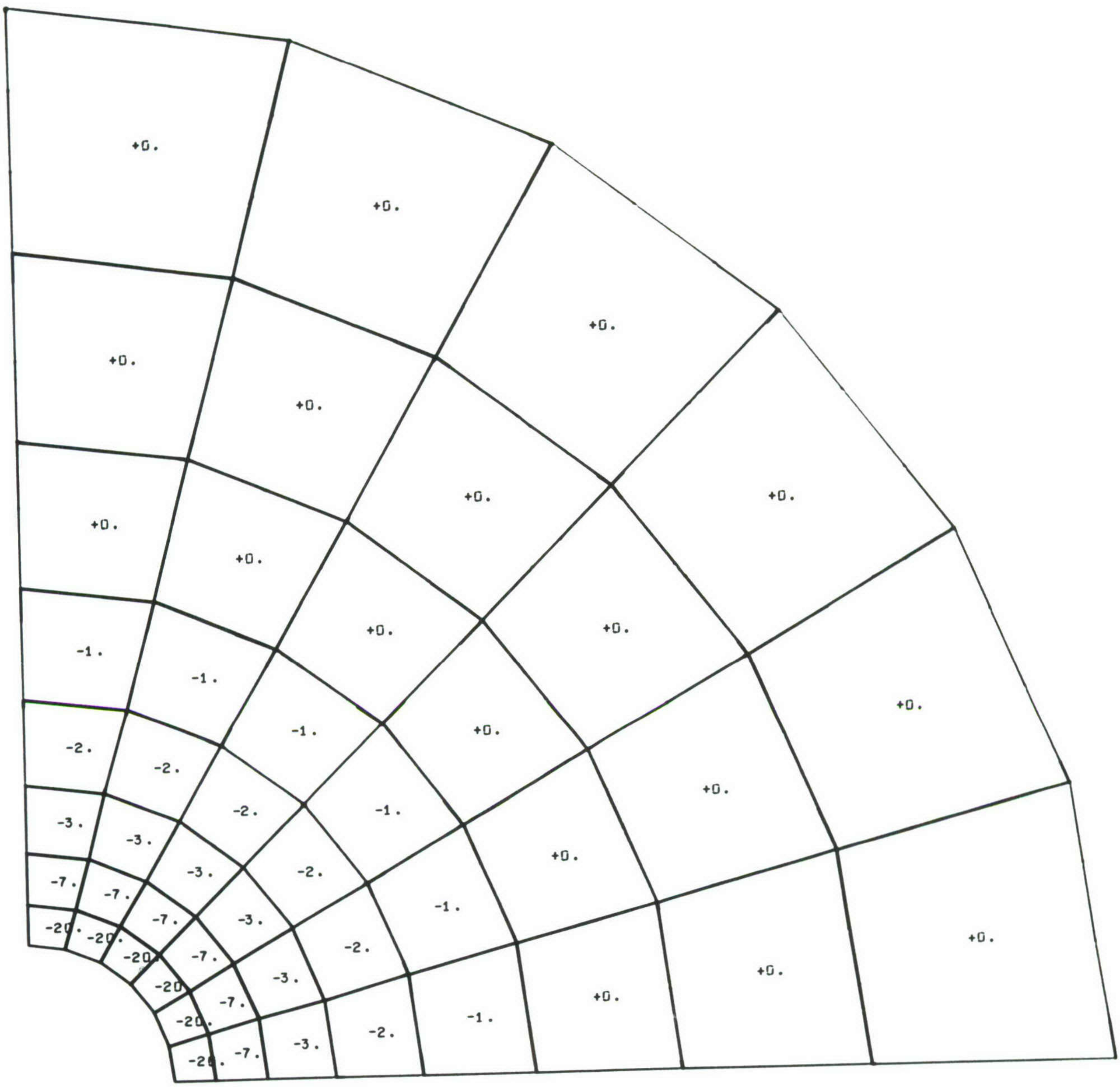


Figure AIII-45 Radial Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

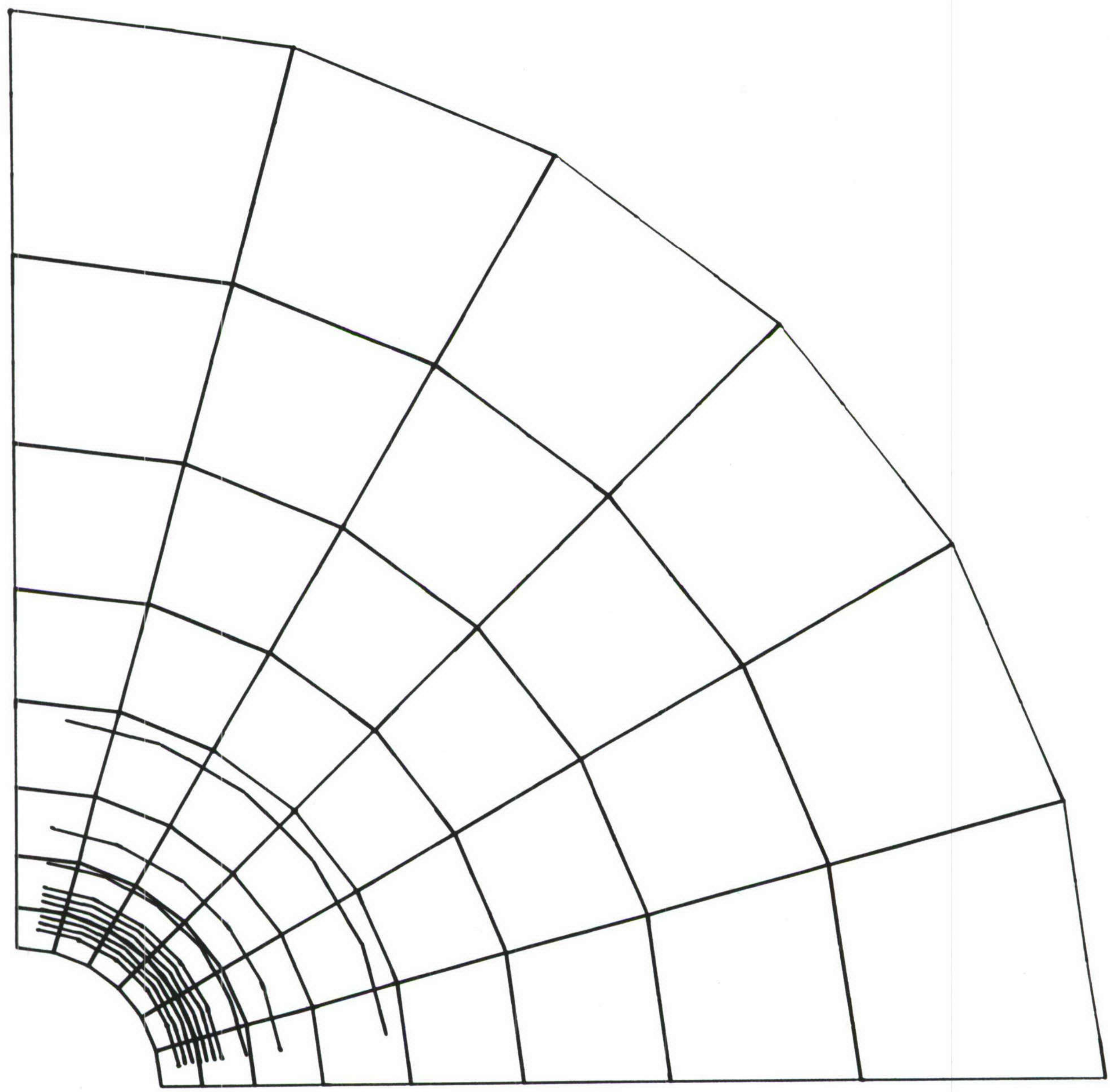


Figure AIII-46 Radial Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

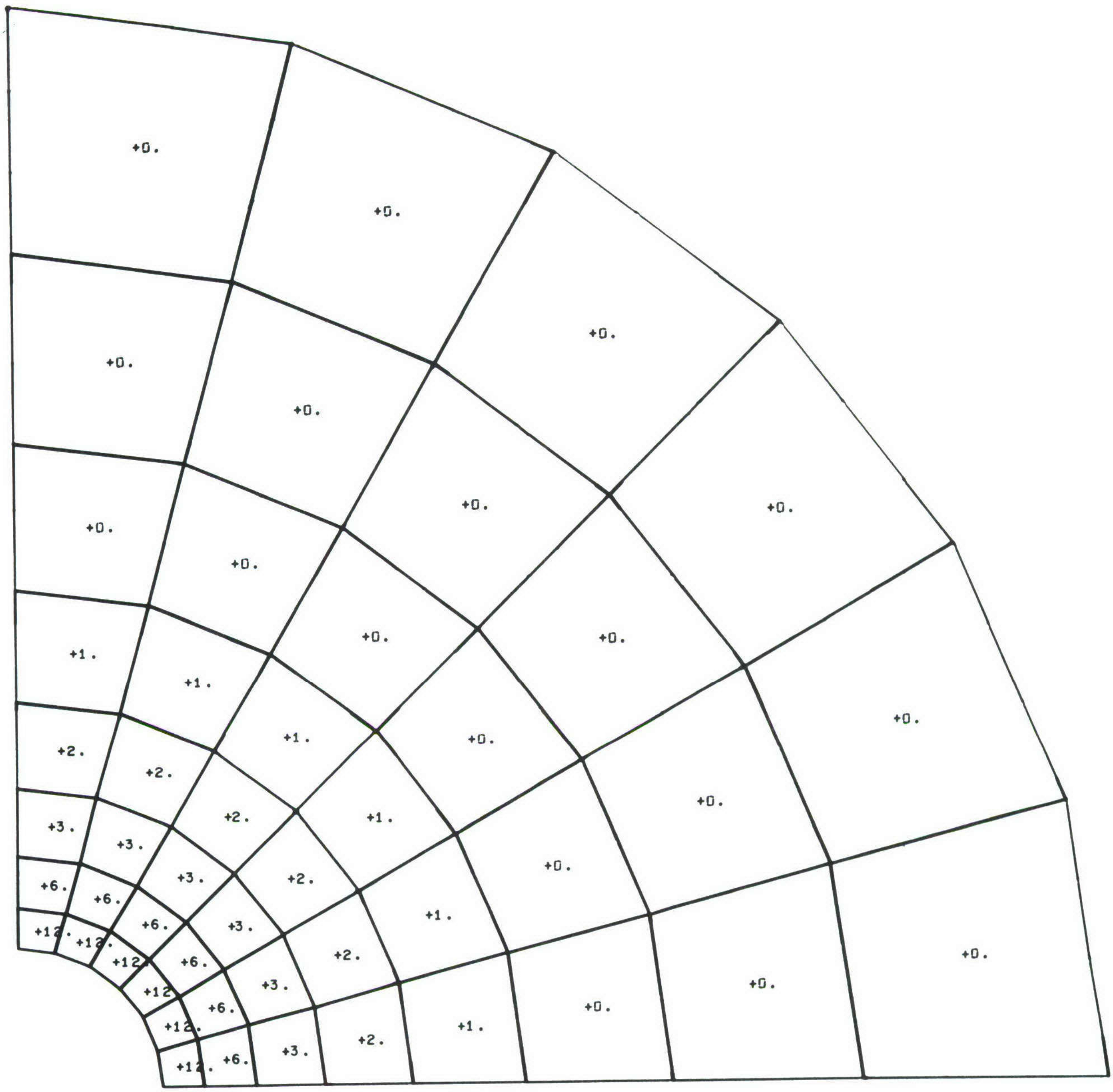


Figure AIII-47 Tangential Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

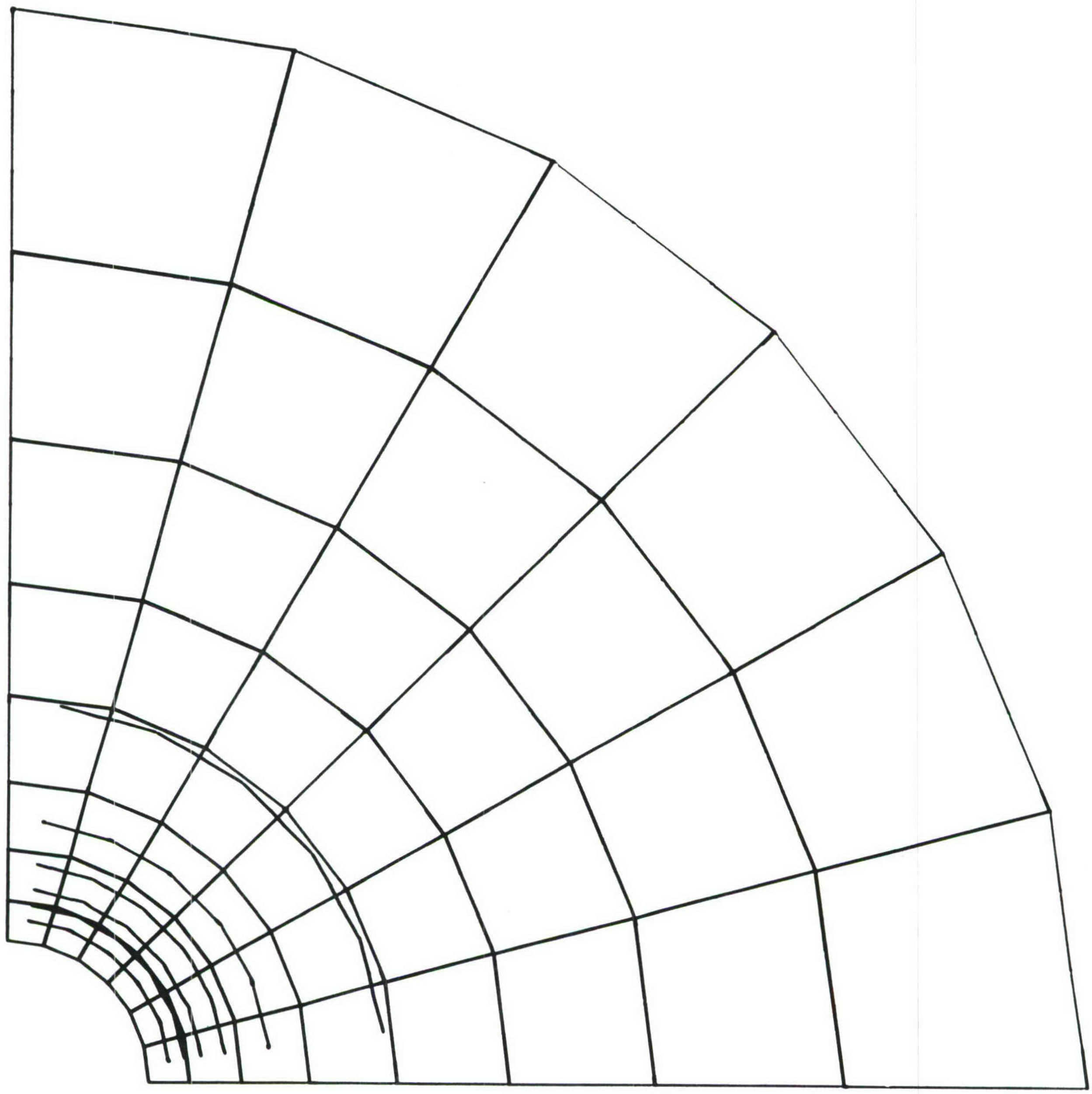


Figure AIII-48 Tangential Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

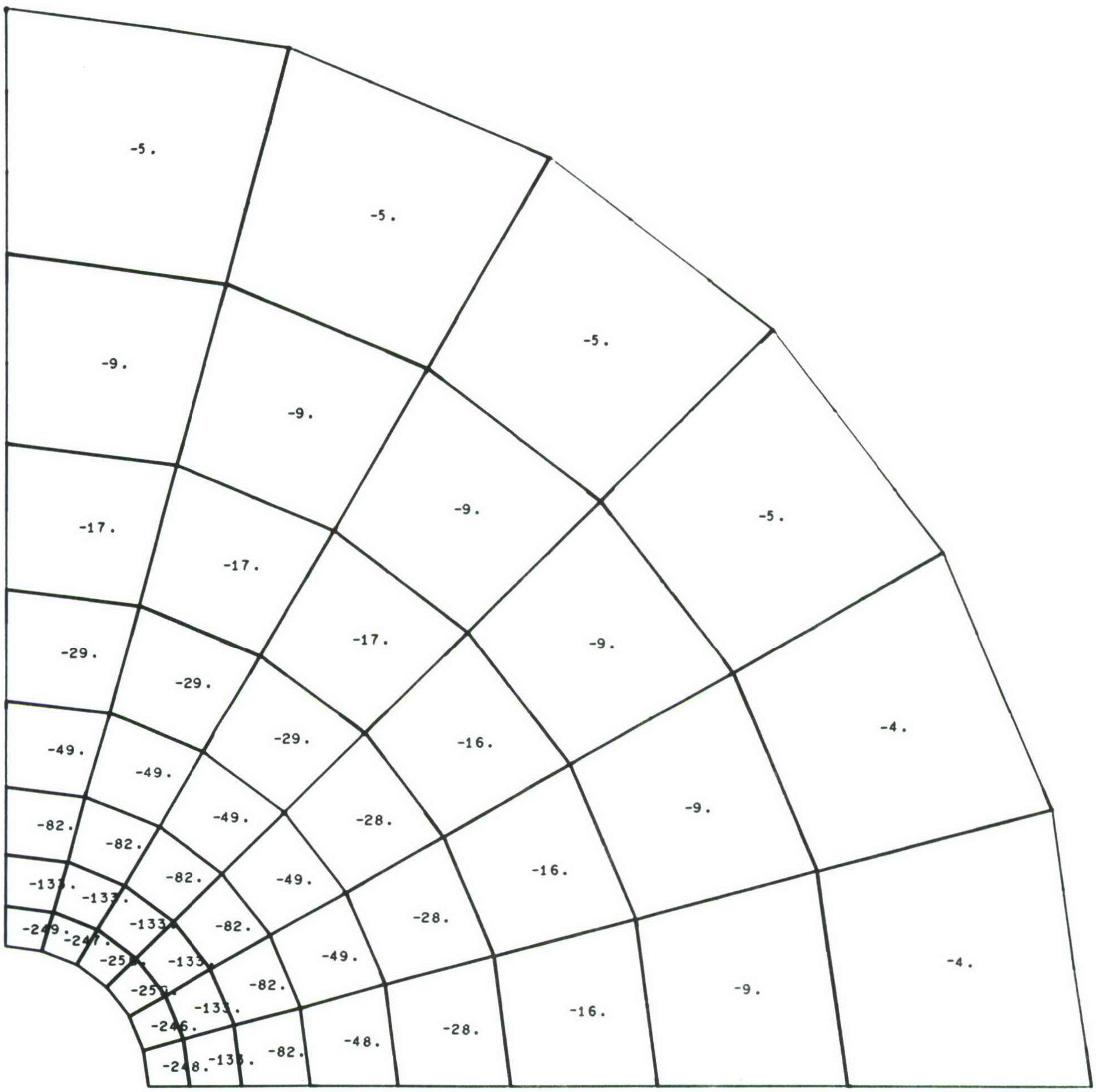


Figure AIII-49 Radial Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

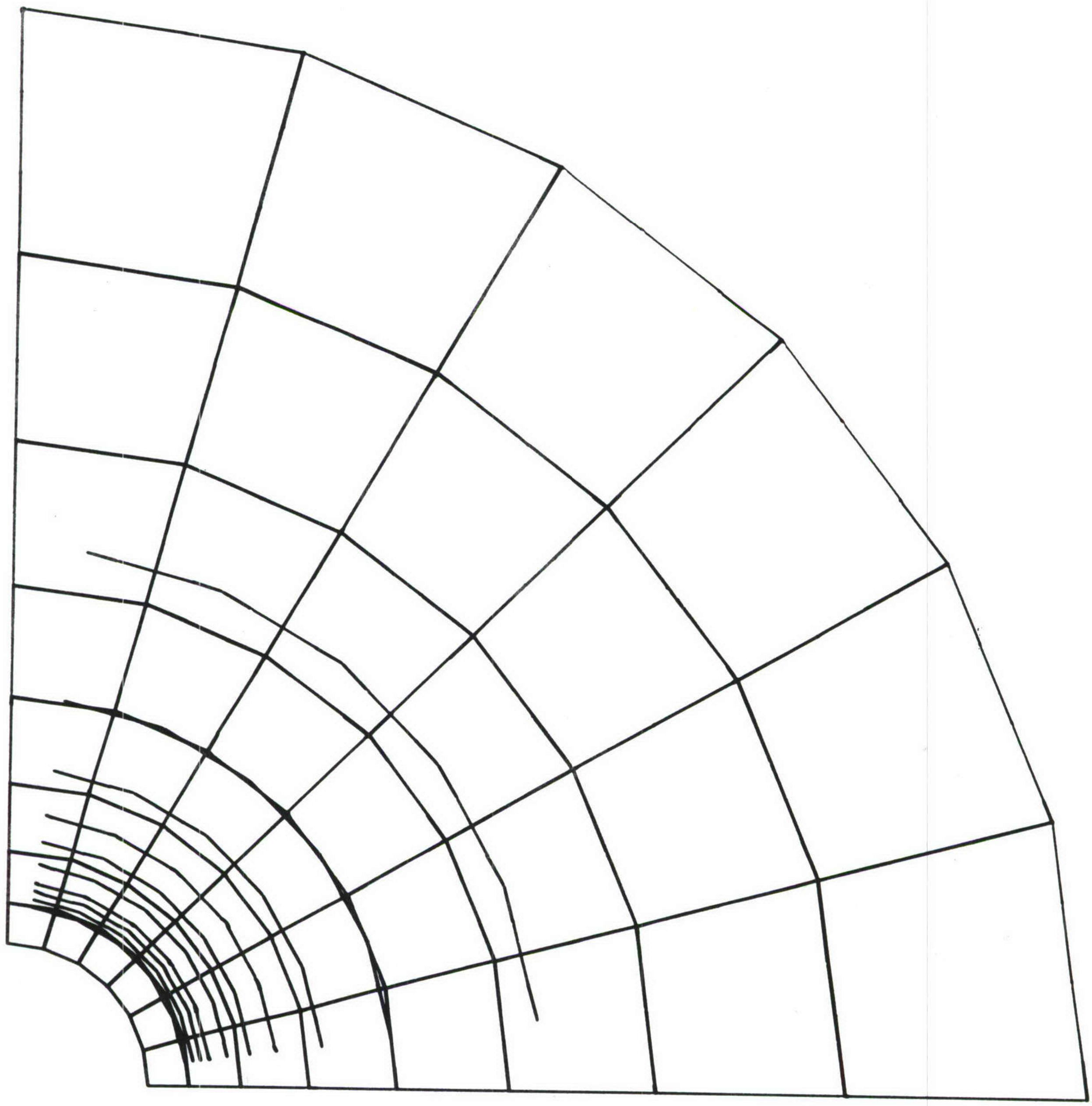


Figure AIII-50 Radial Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

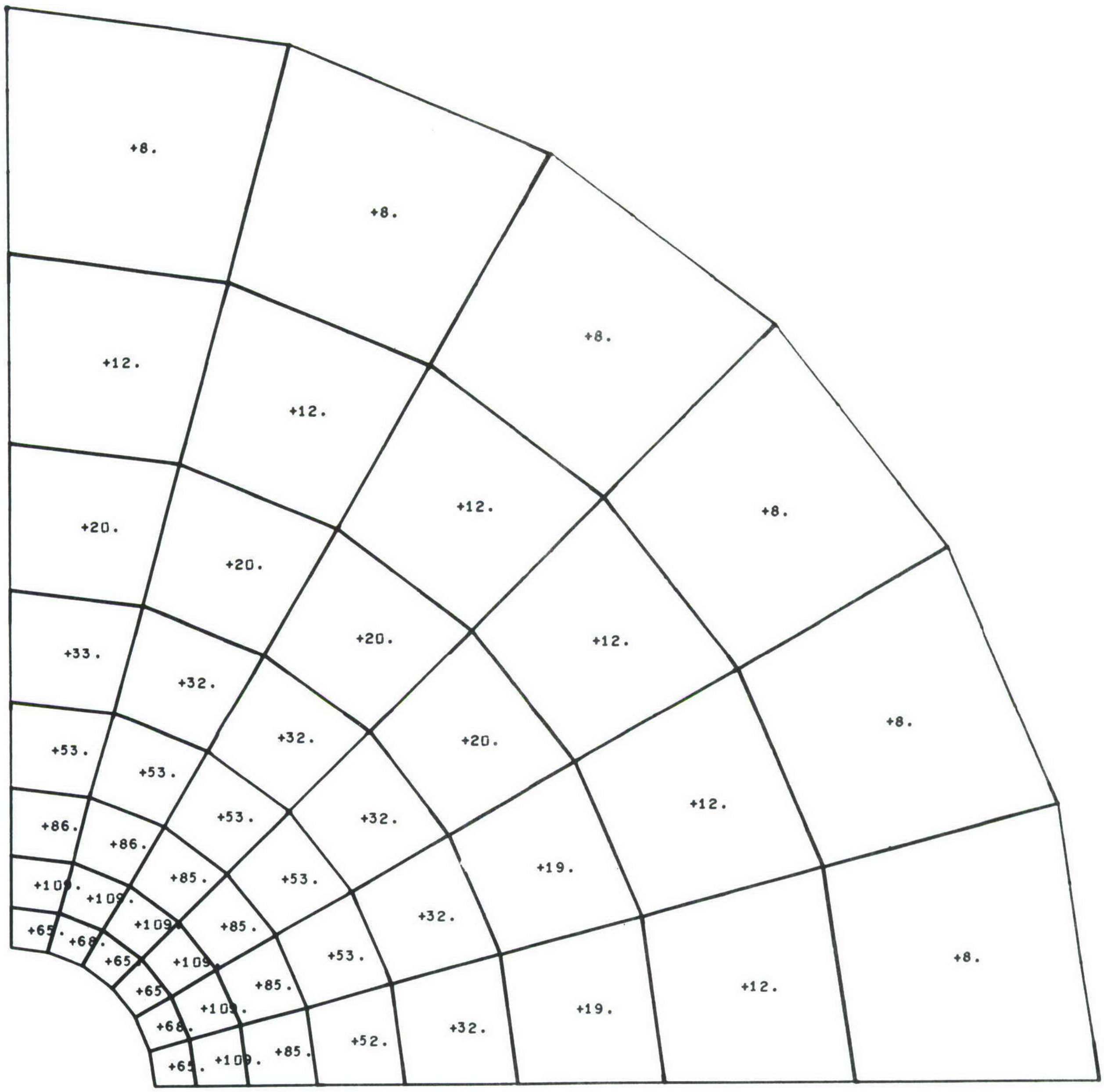


Figure AIII-51 Tangential Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

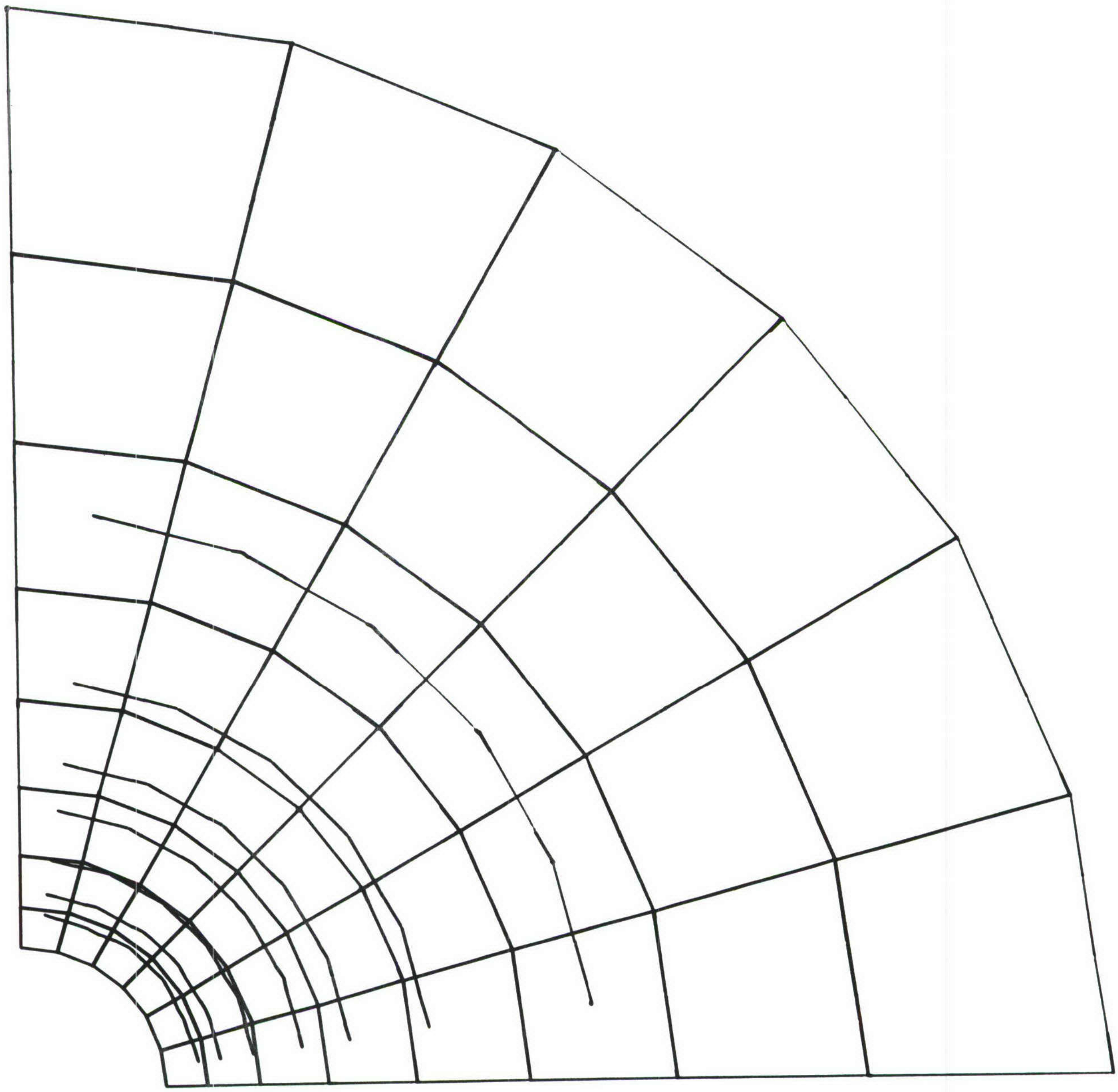


Figure AIII-52 Tangential Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; No Uniaxial Load

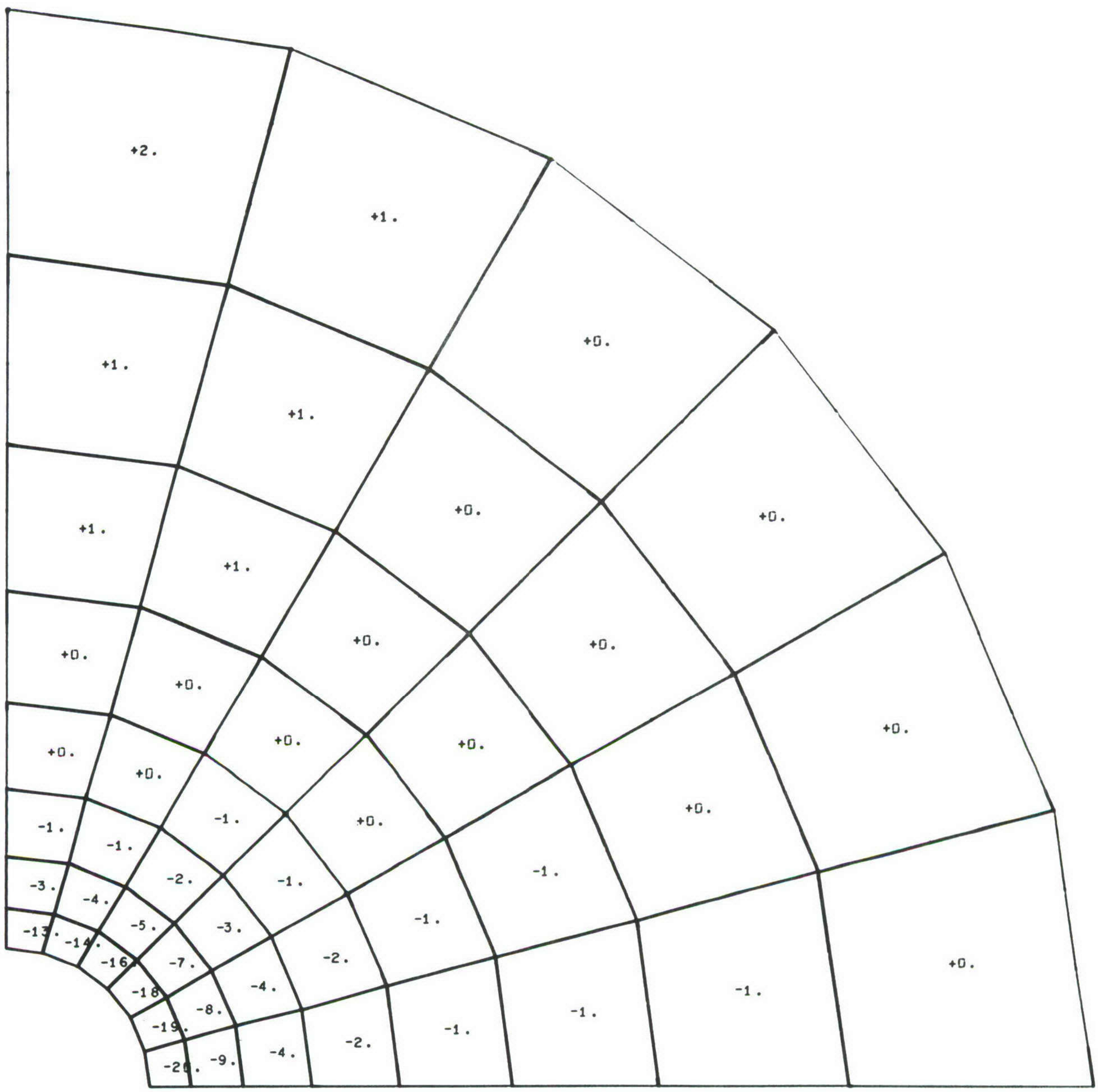


Figure AIII-53 Radial Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference 35% Uniaxial Load

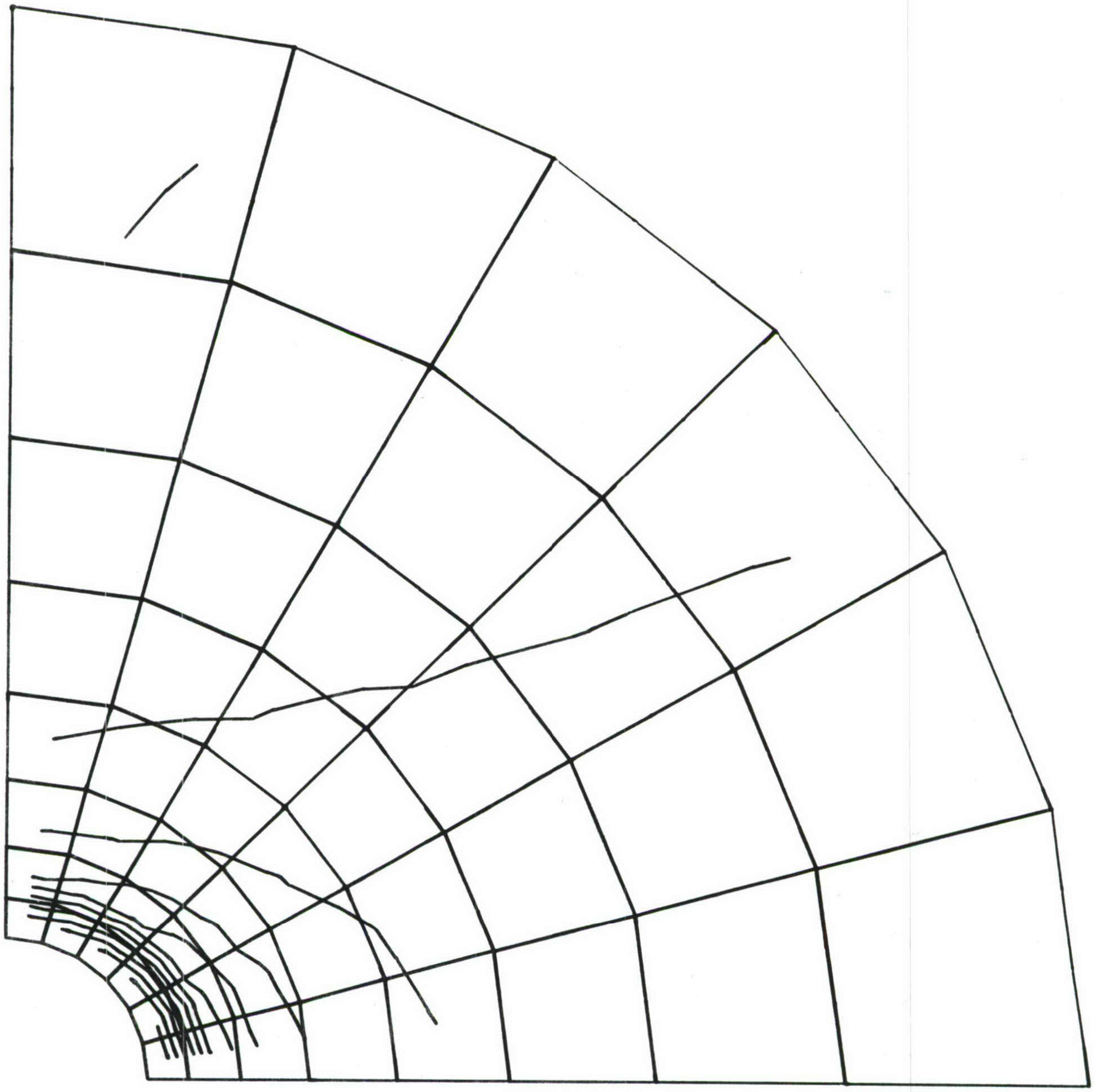


Figure AIII-54 Radial Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

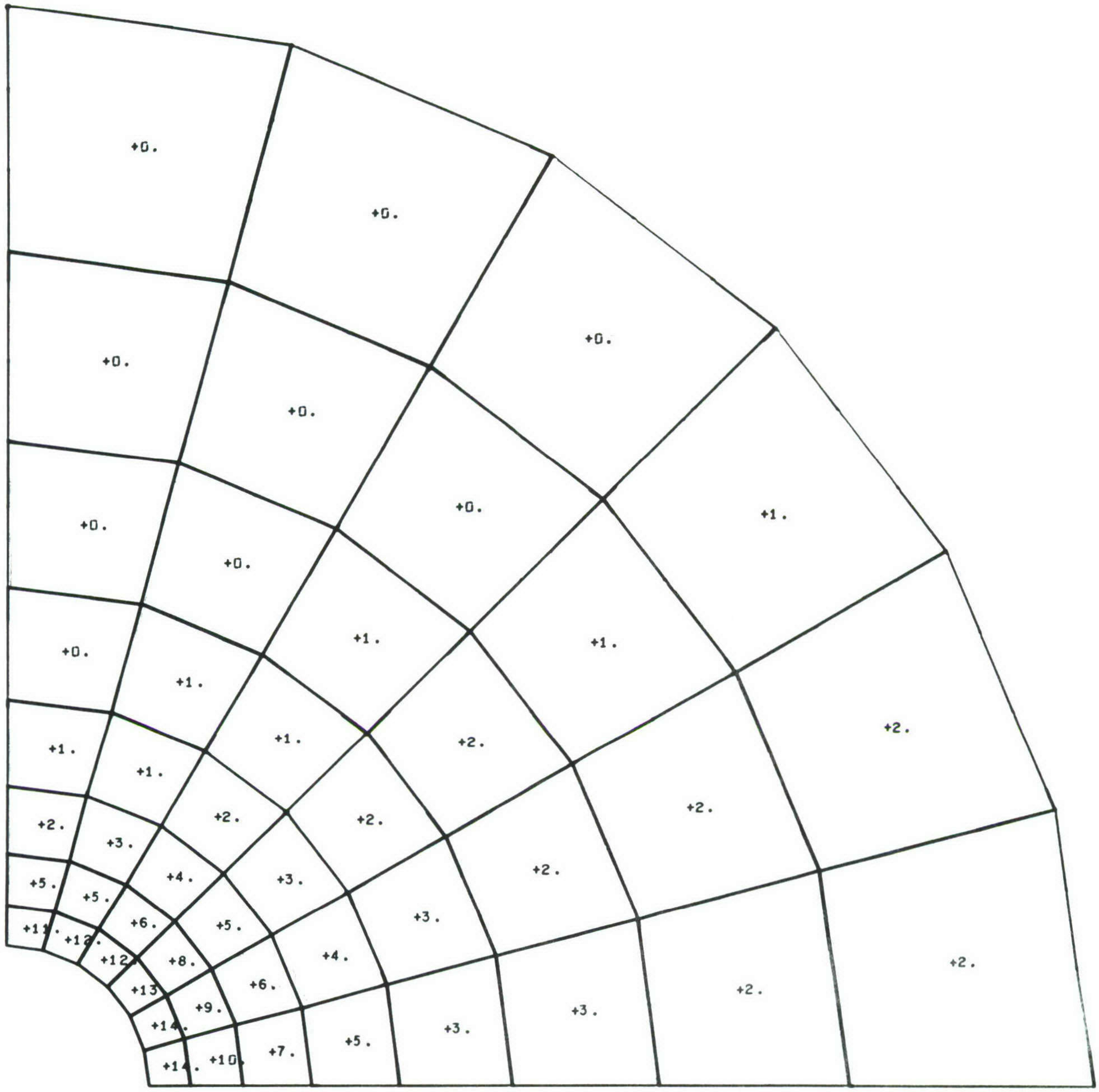


Figure AIII-55 Tangential Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

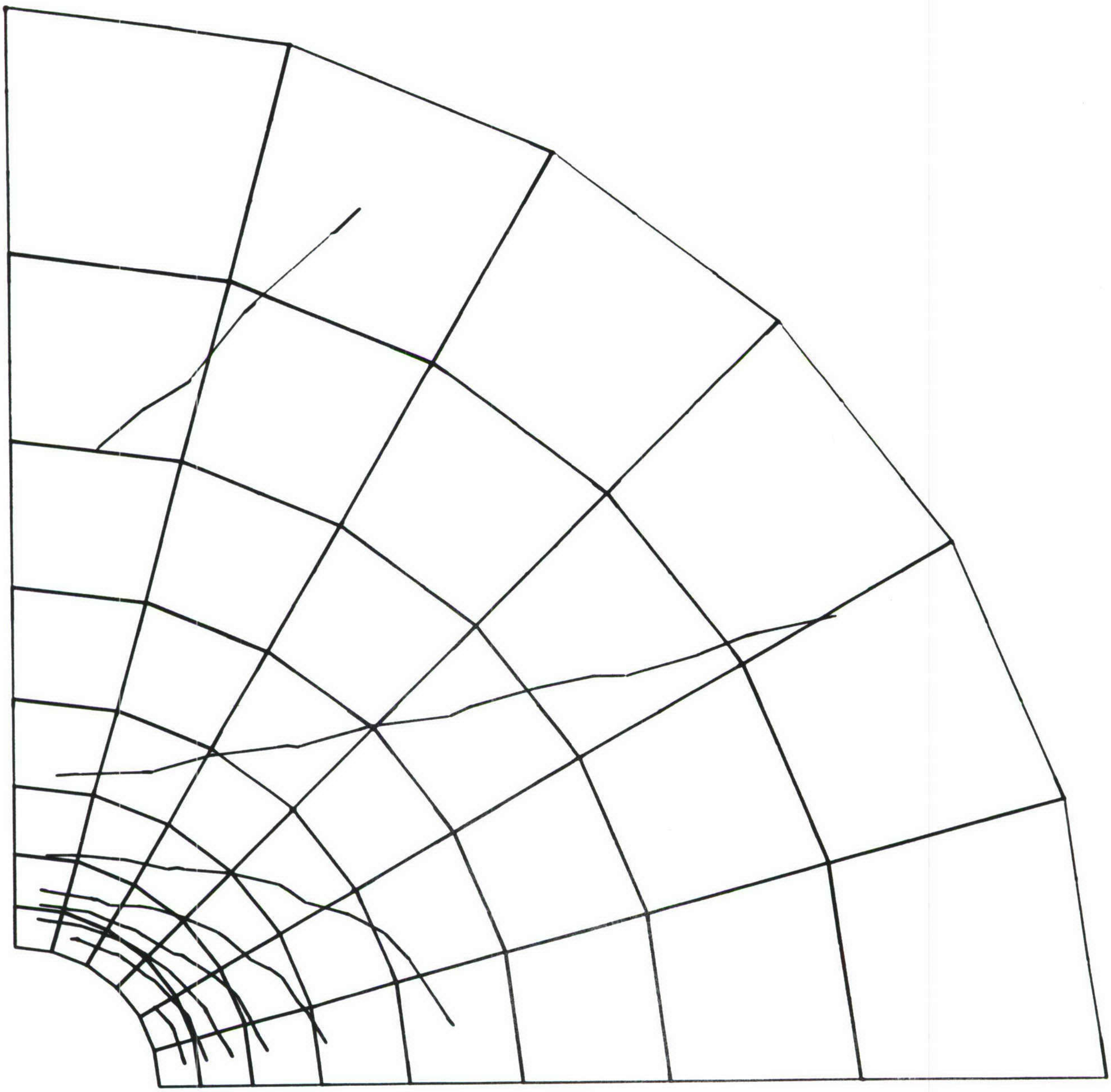


Figure AIII-56   Tangential Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

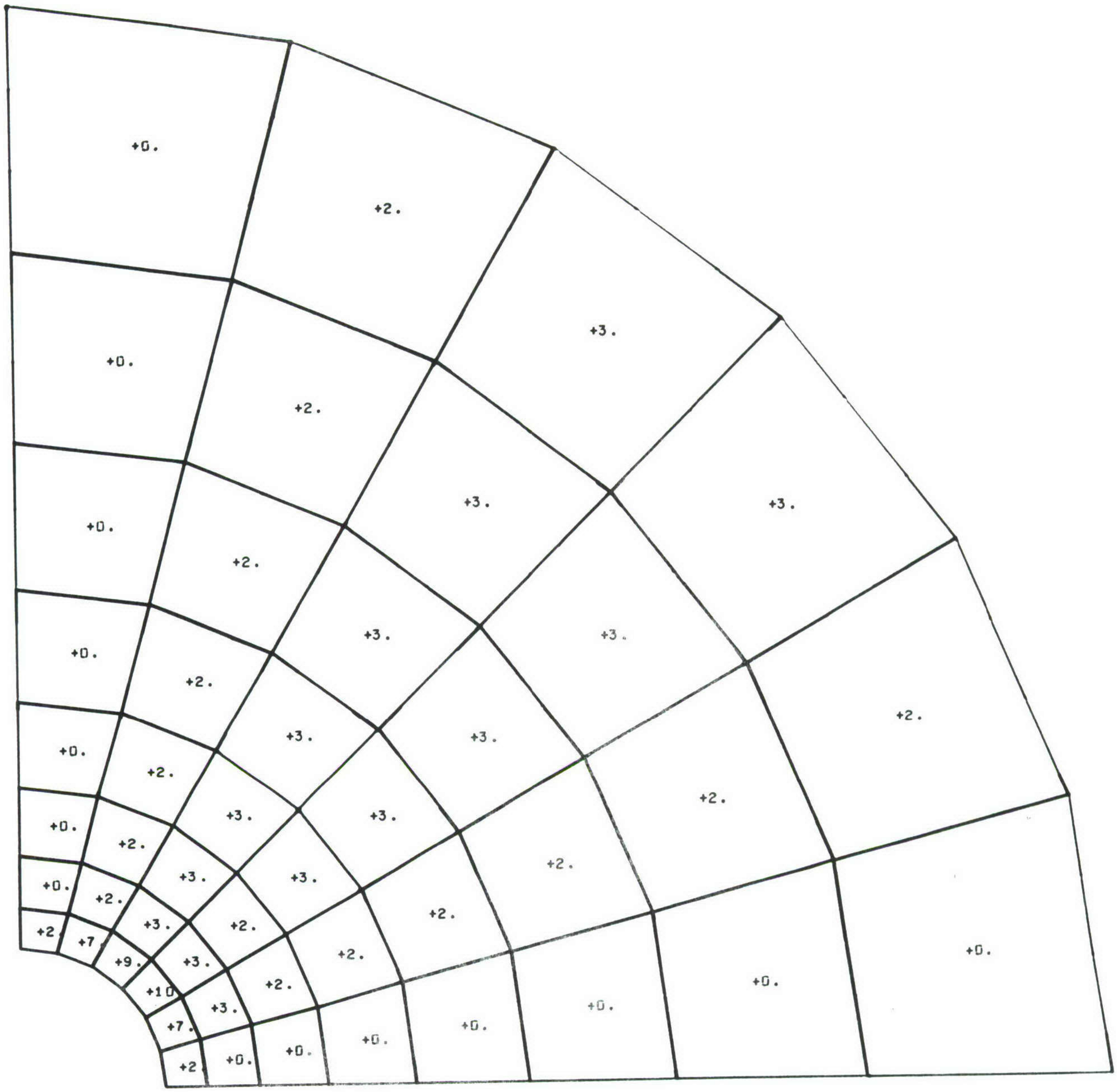


Figure AIII-57 Radial-Tangential Shear Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

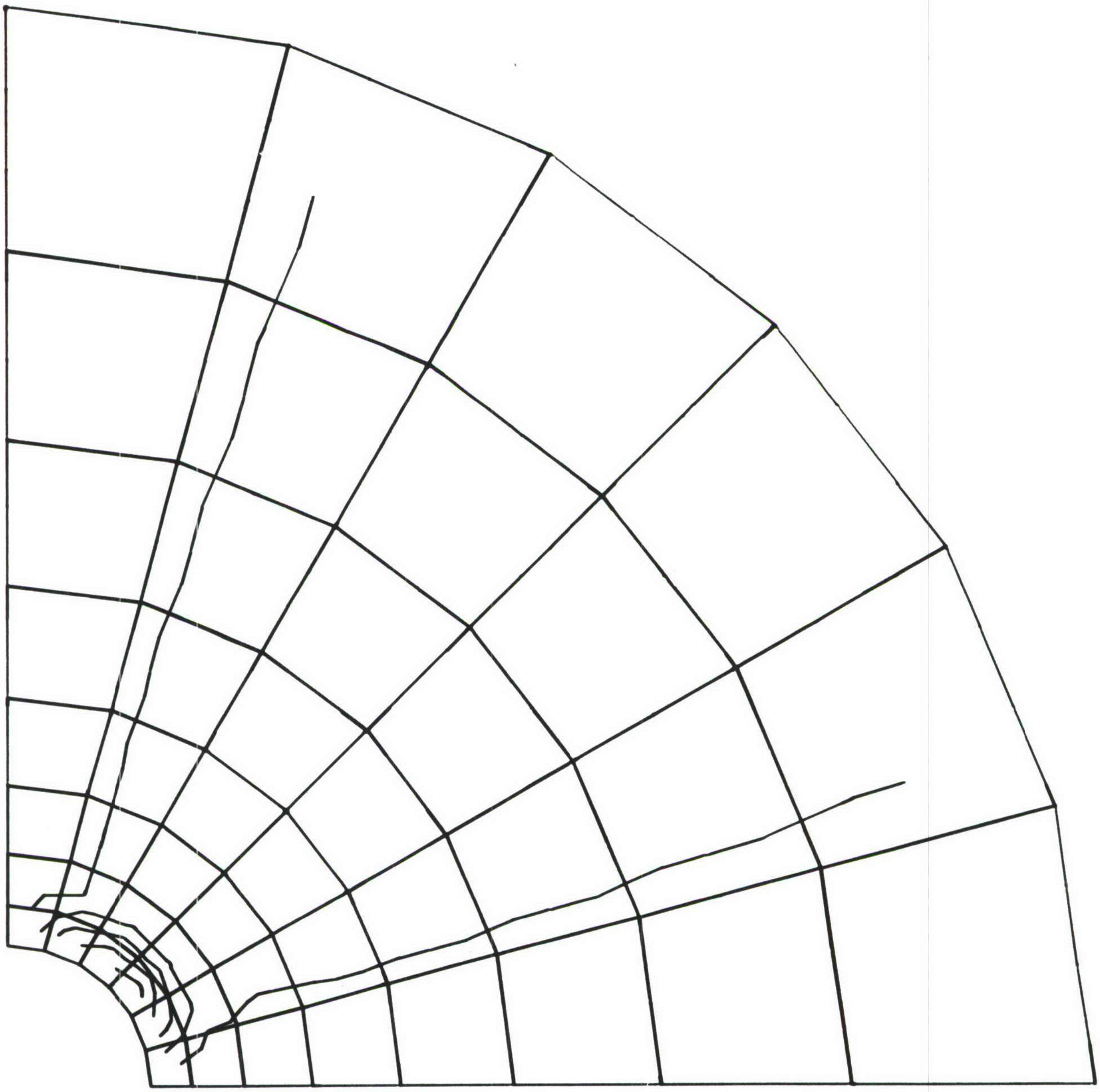


Figure AIII-58 Radial-Tangential Shear Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

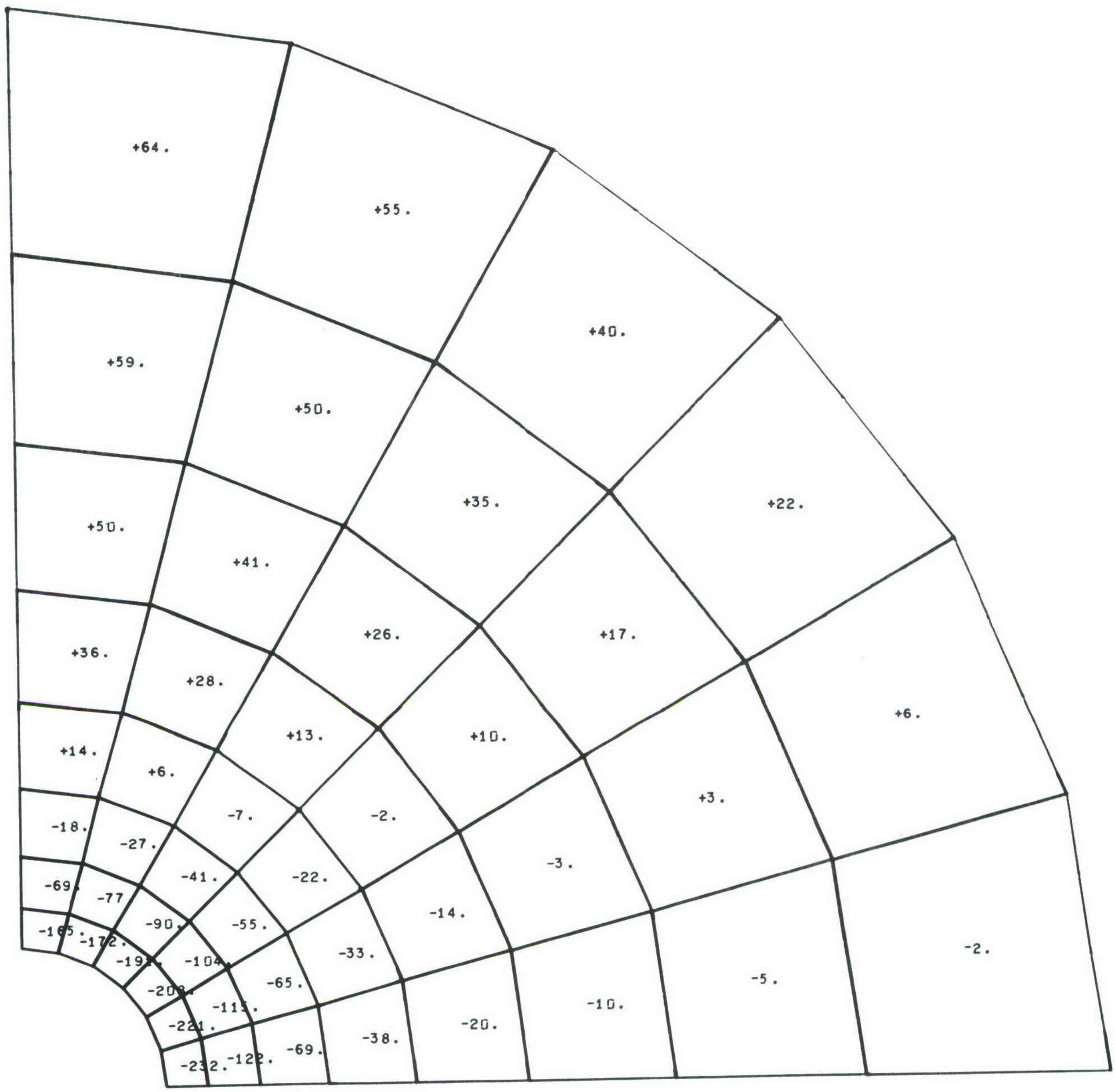


Figure AIII-59 Radial Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

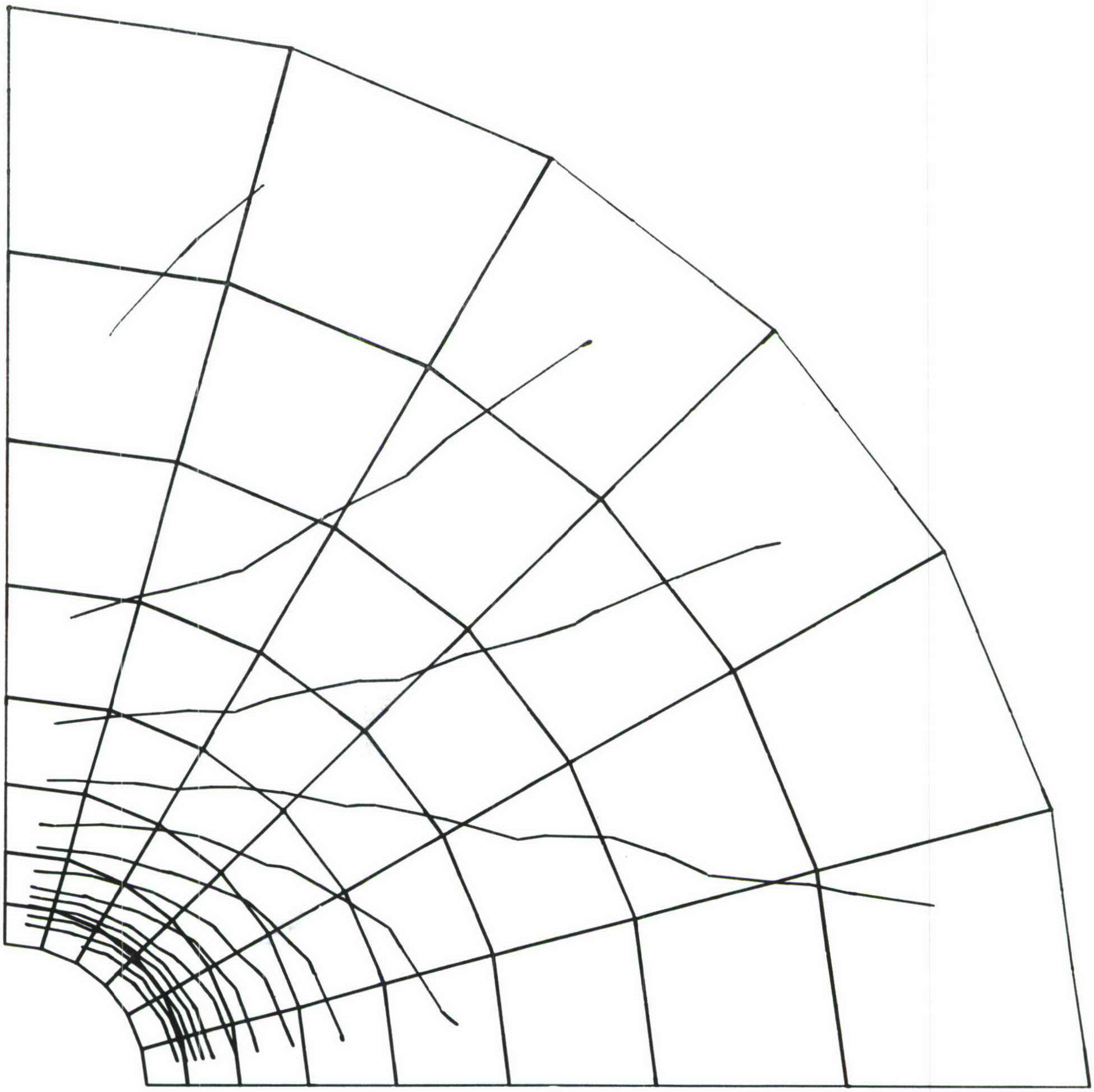


Figure AIII-60 Radial Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

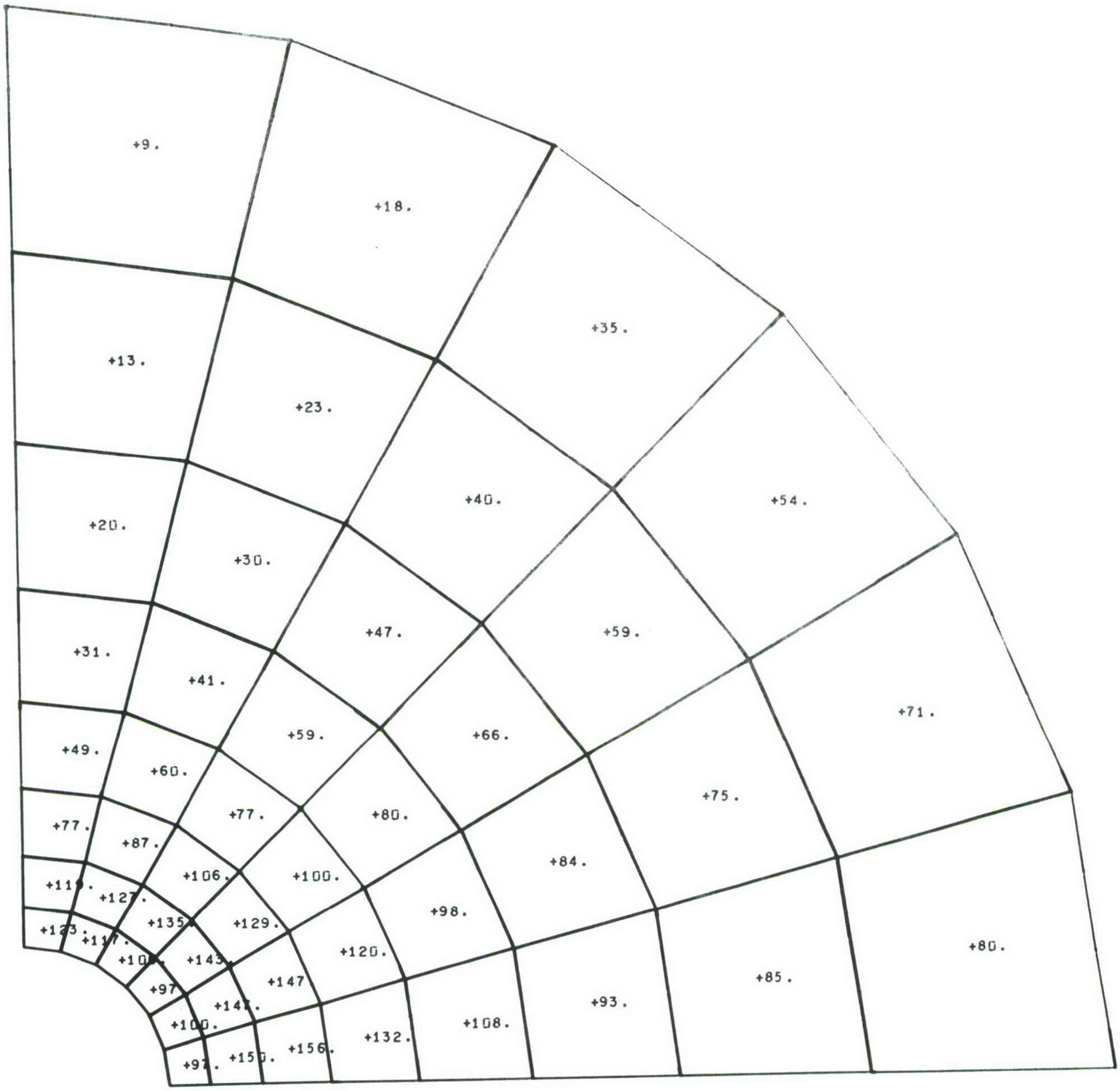


Figure AIII-61 Tangential Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

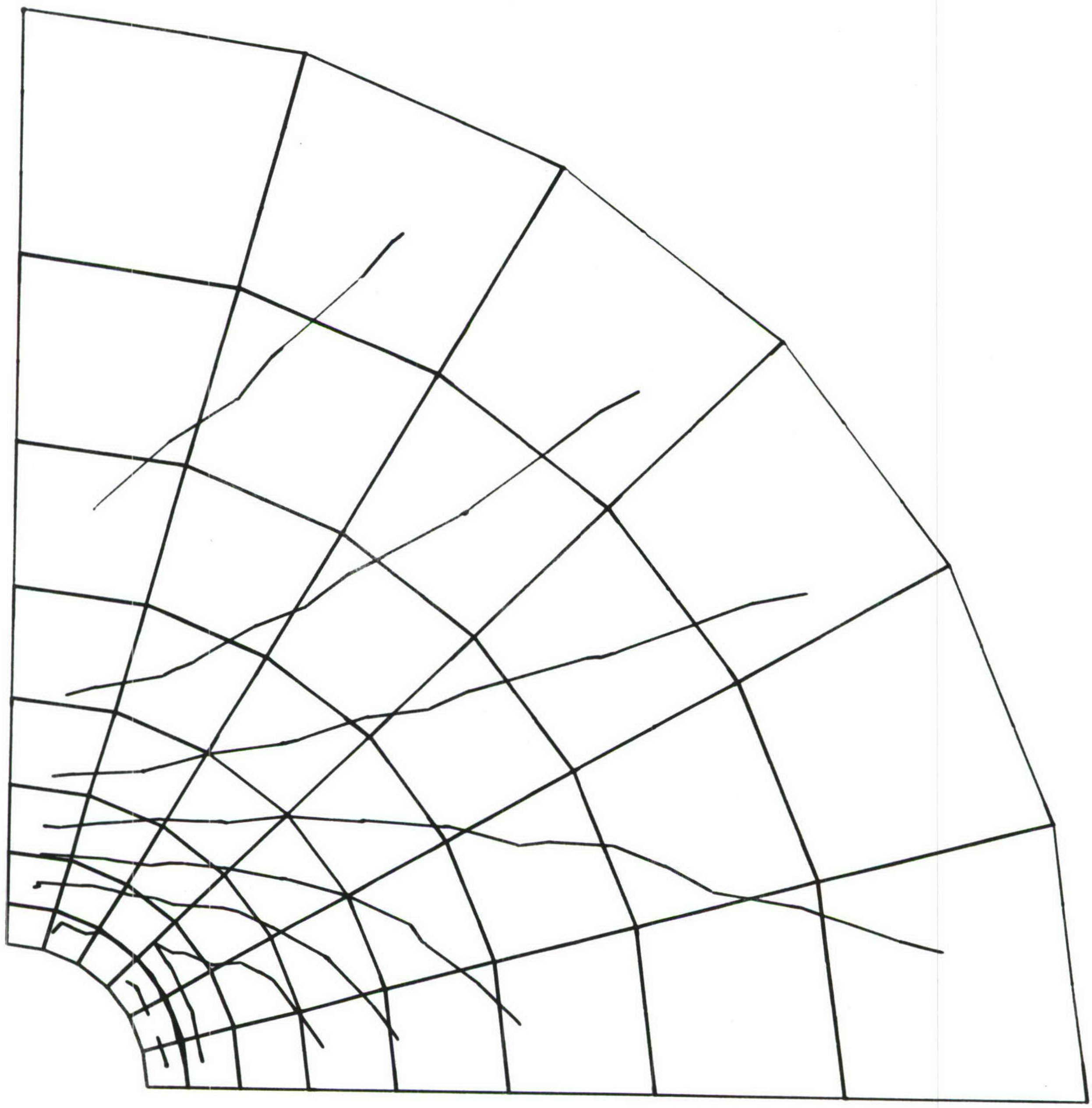


Figure AIII-62 Tangential Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

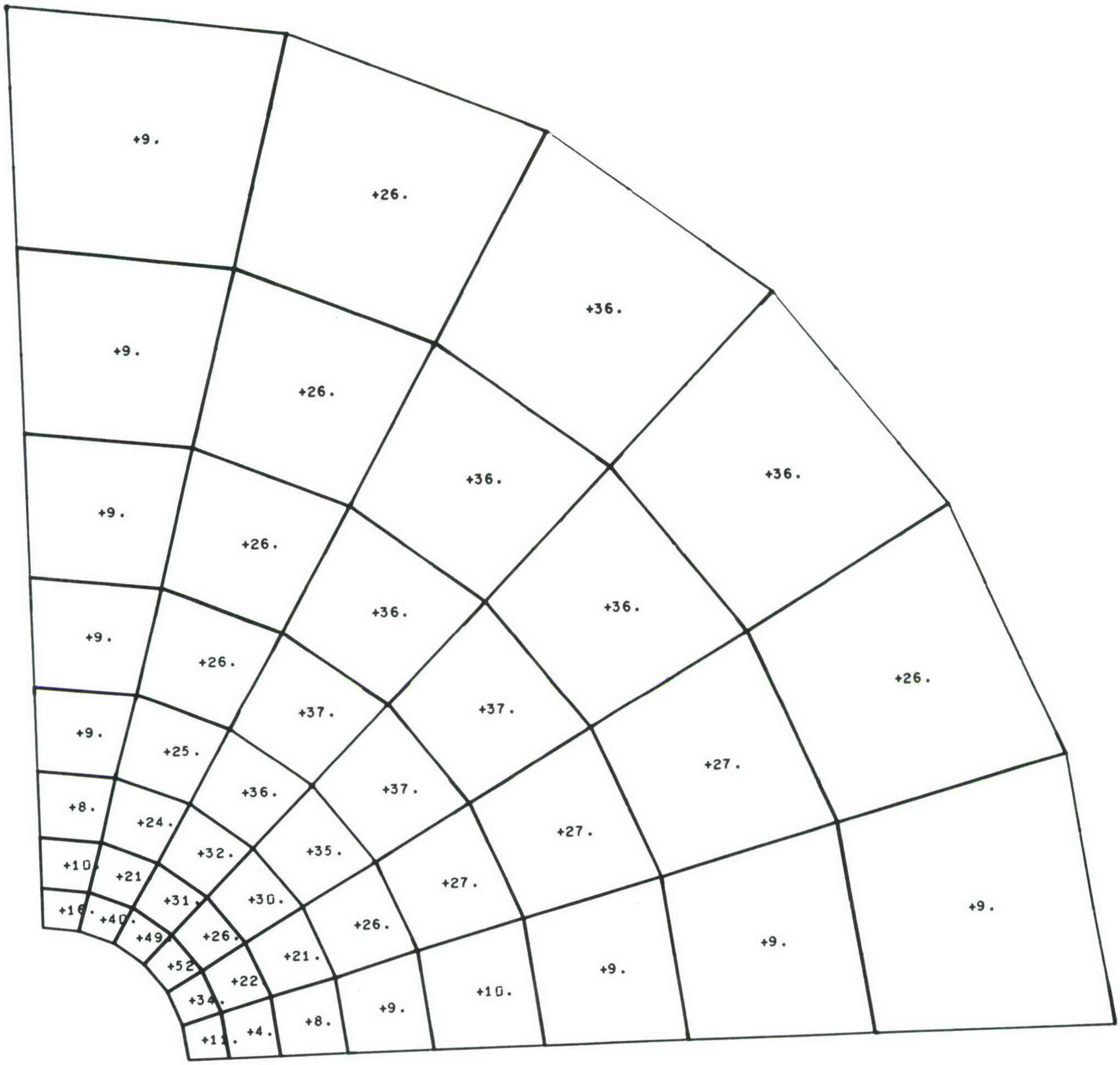


Figure AIII-63 Radial-Tangential Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

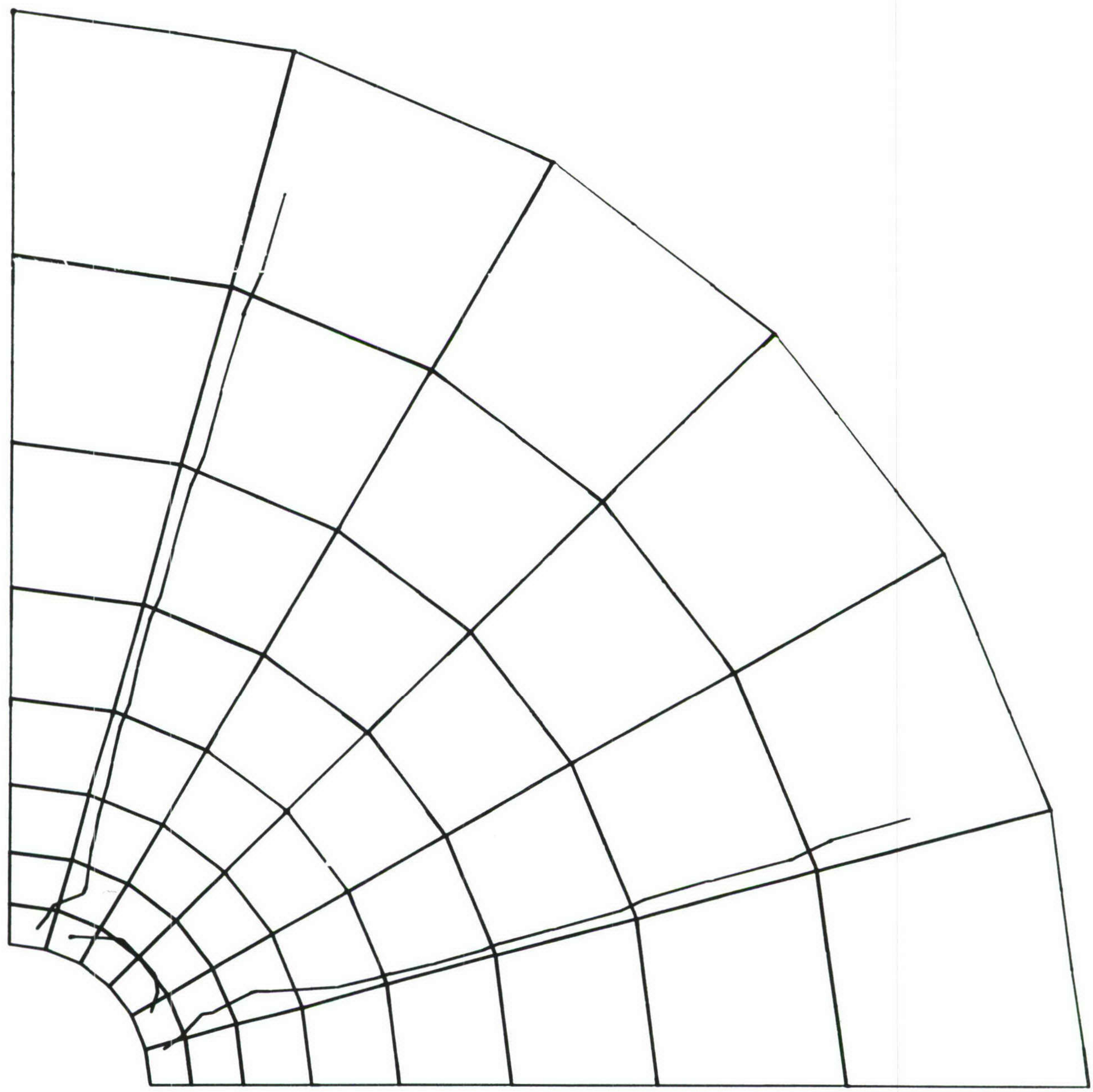


Figure AIII-64 Radial-Tangential Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

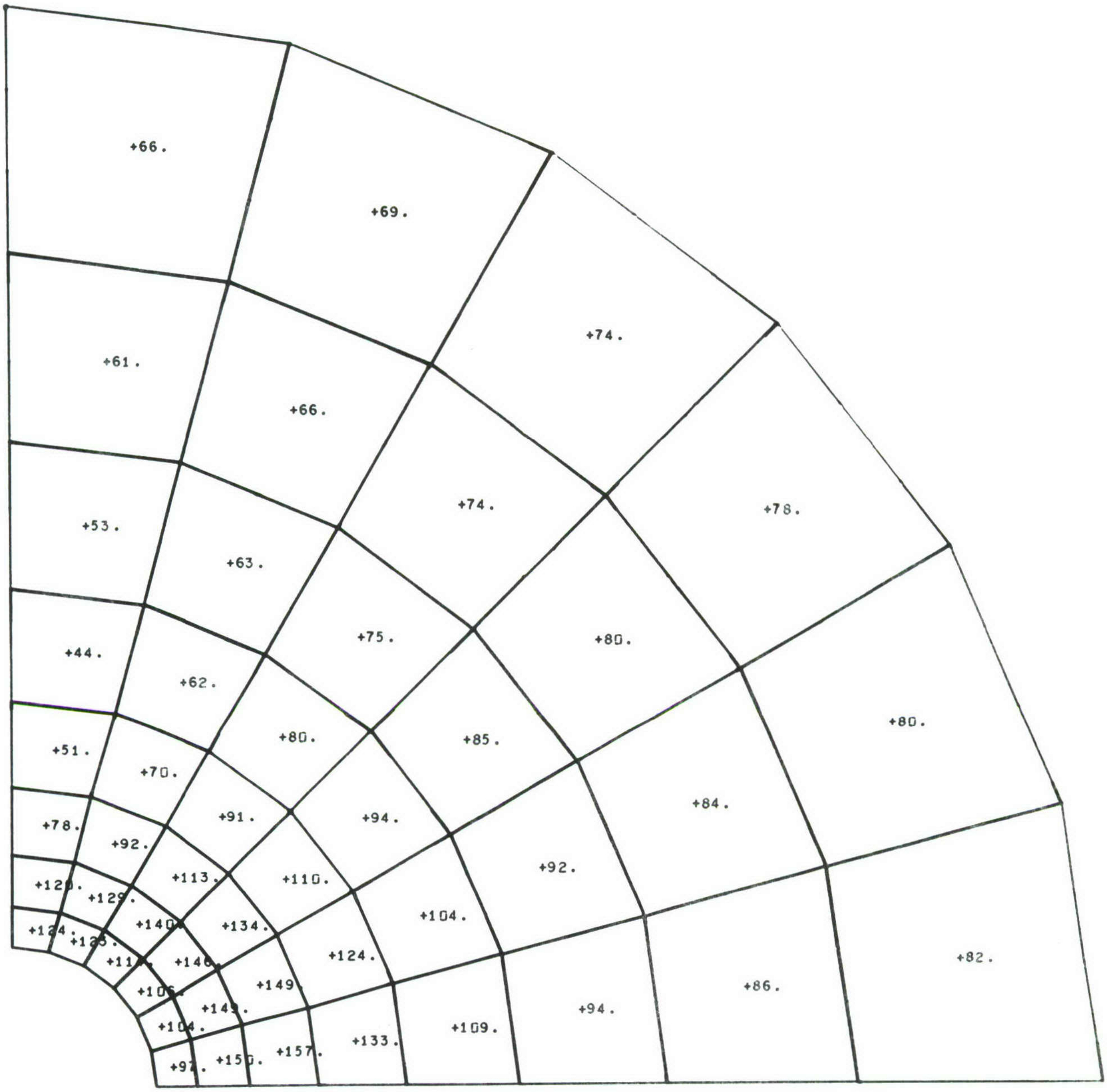


Figure AIII-65 First Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

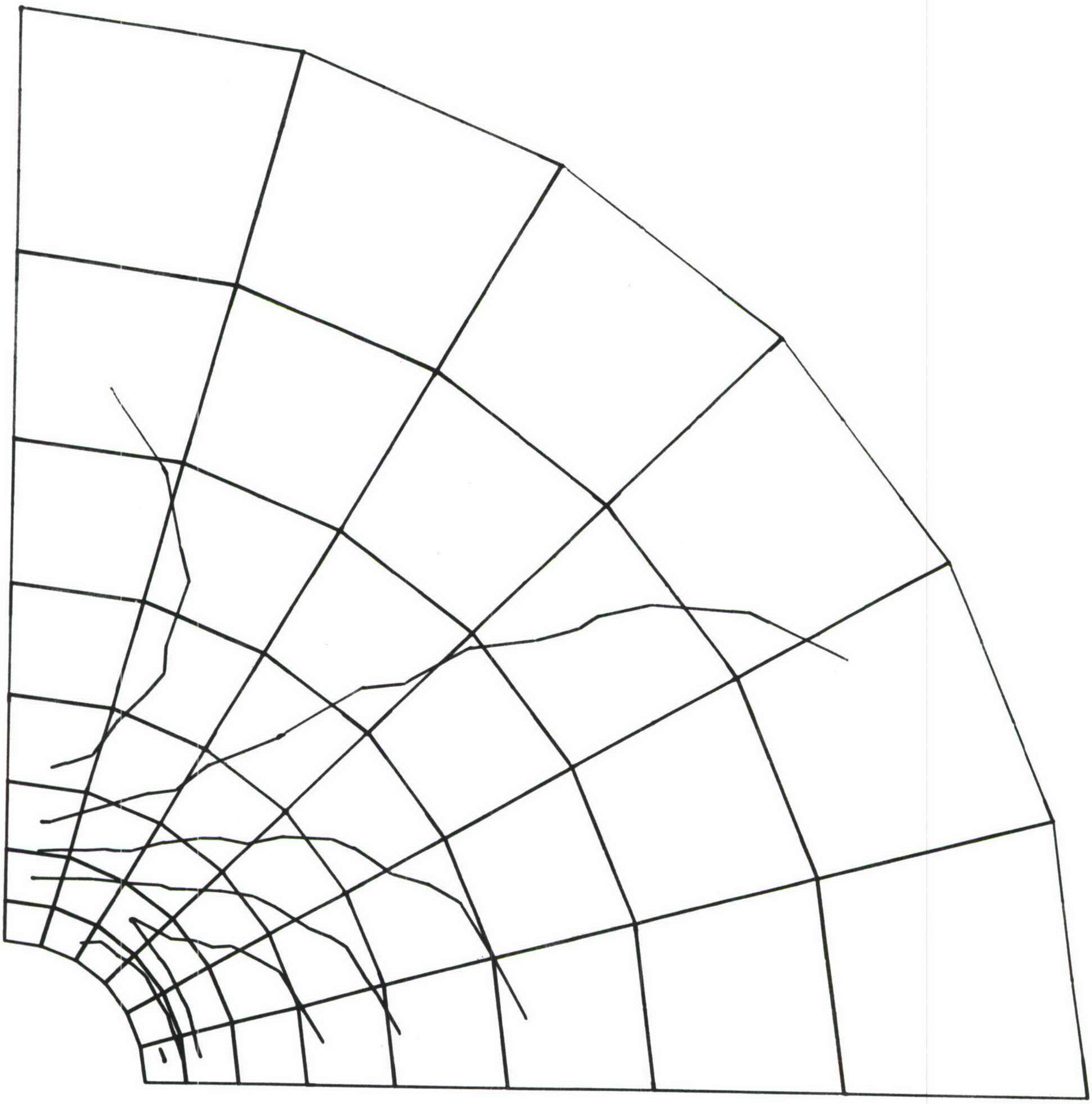


Figure AIII-66 First Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

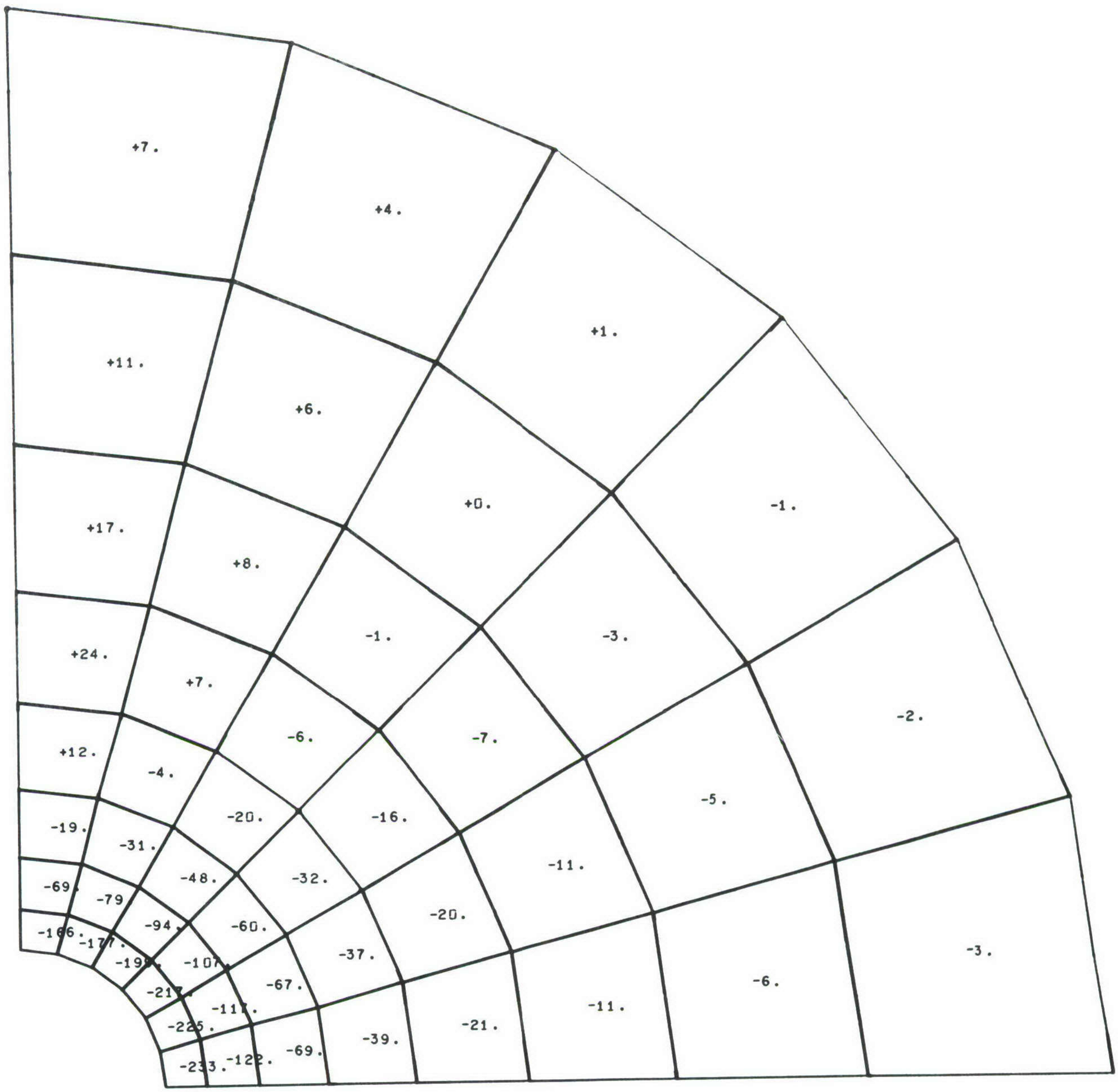


Figure AIII-67 Second Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

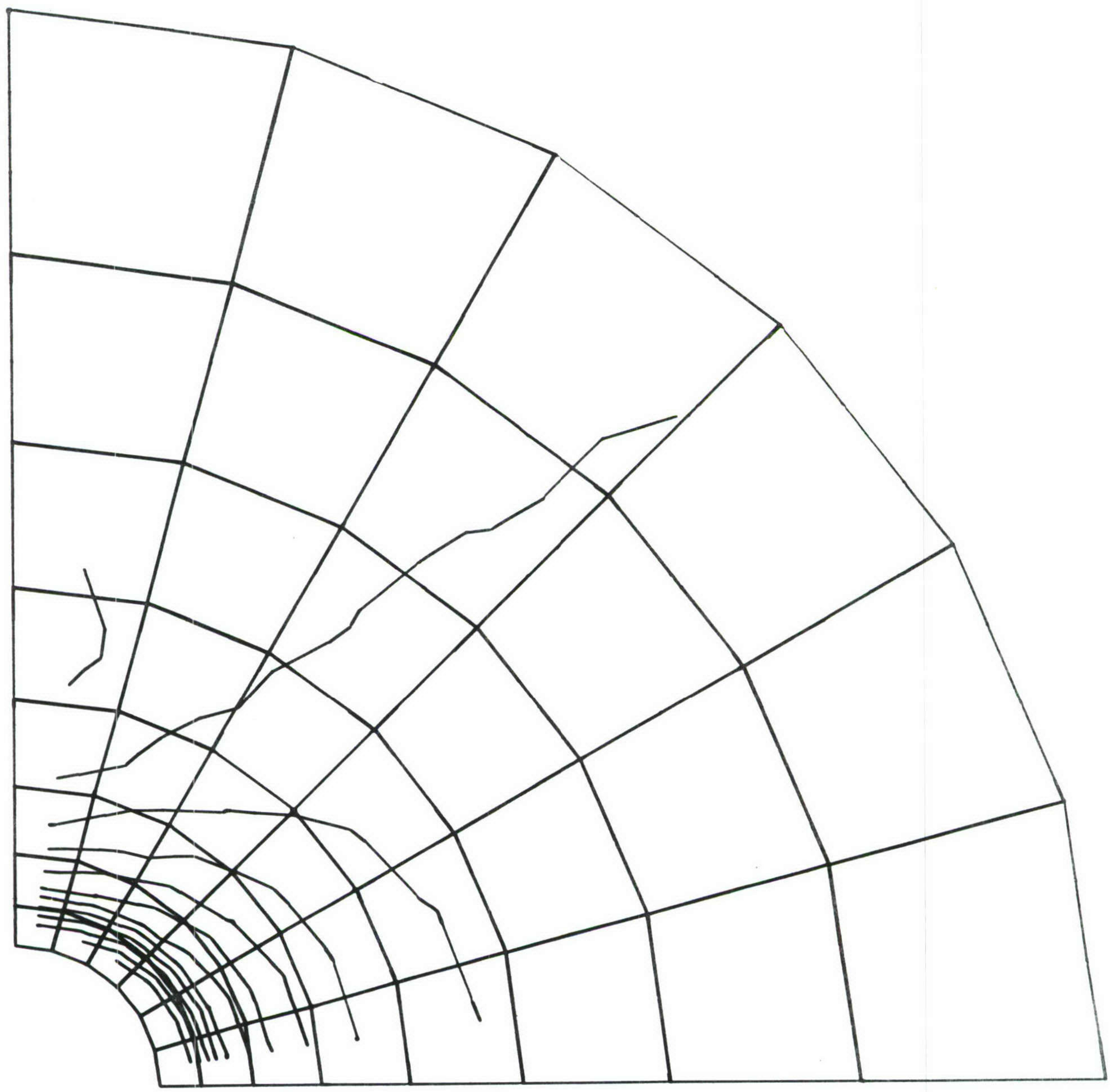


Figure AIII-68 Second Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

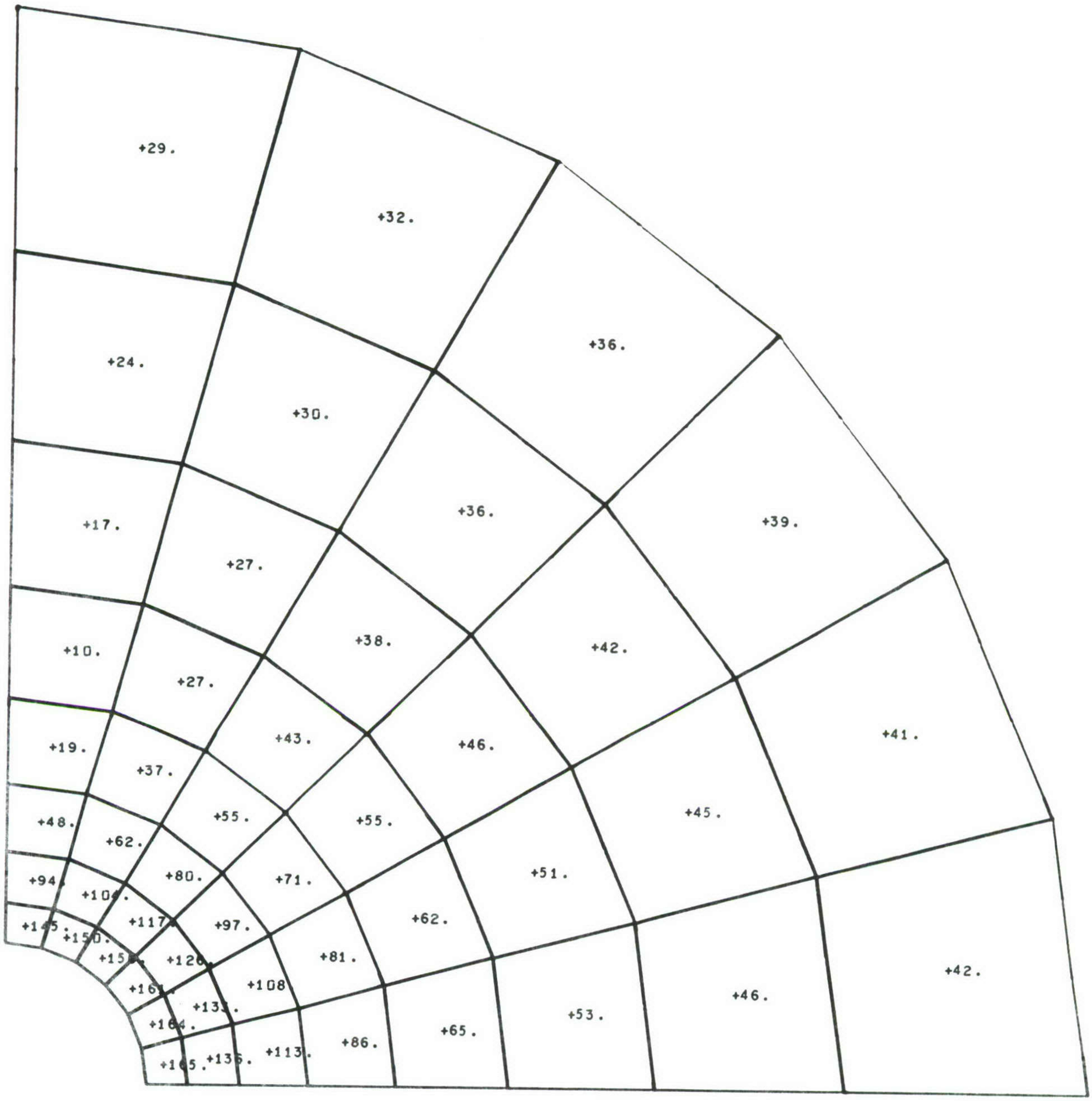


Figure AIII-69 Principal Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

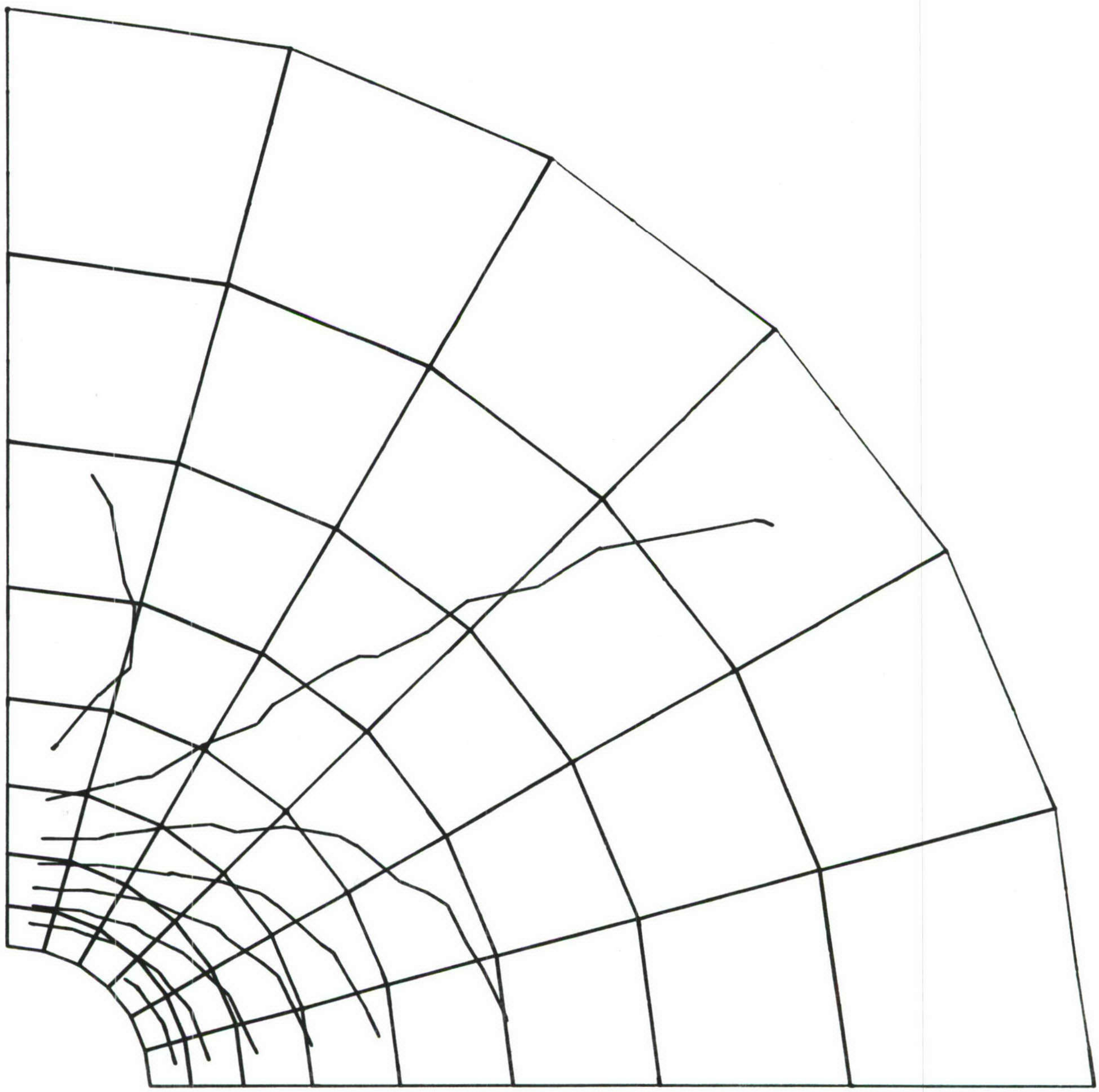


Figure AIII-70 Principal Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 35% Uniaxial Load

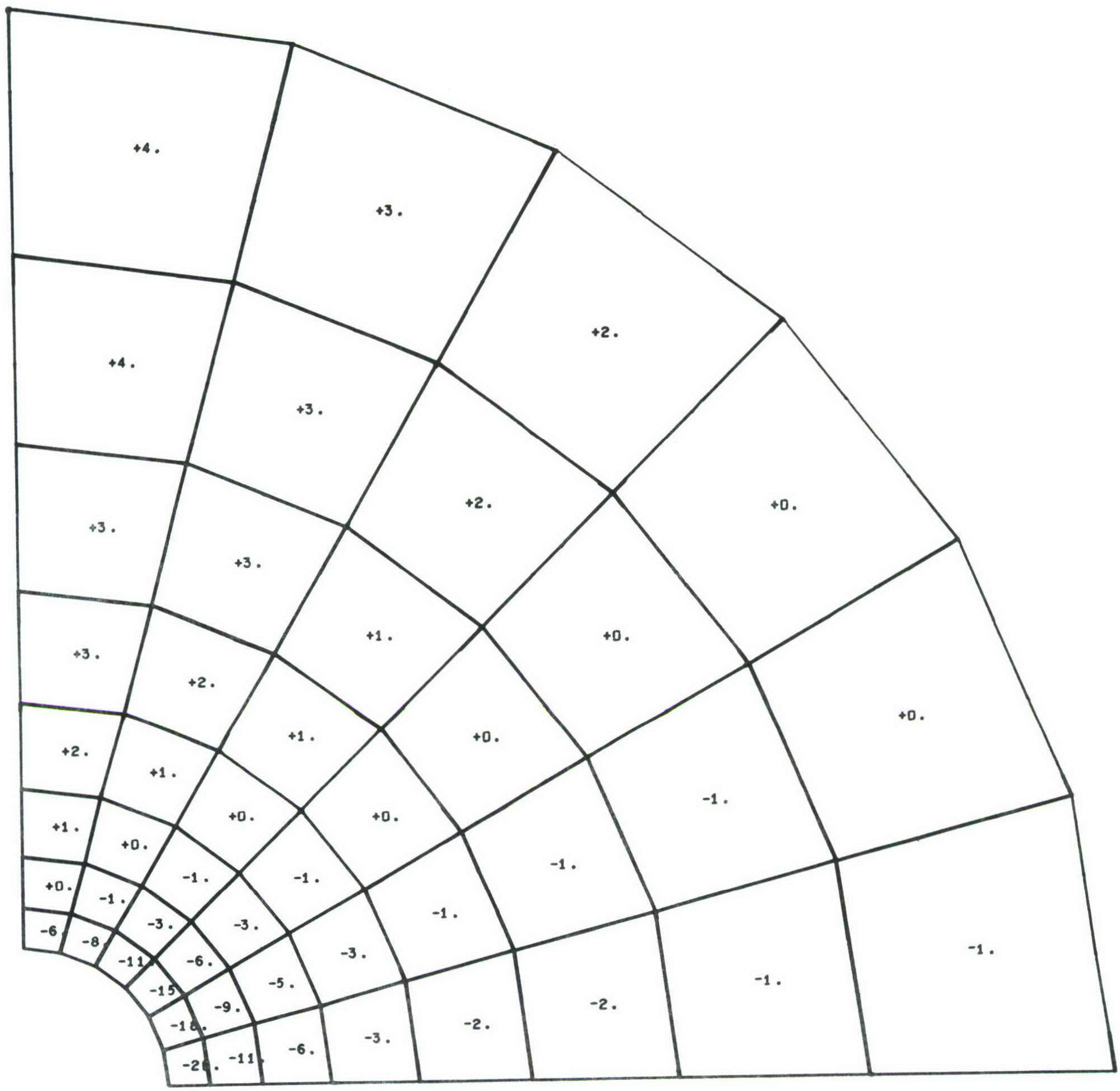


Figure AIII-71 Radial Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

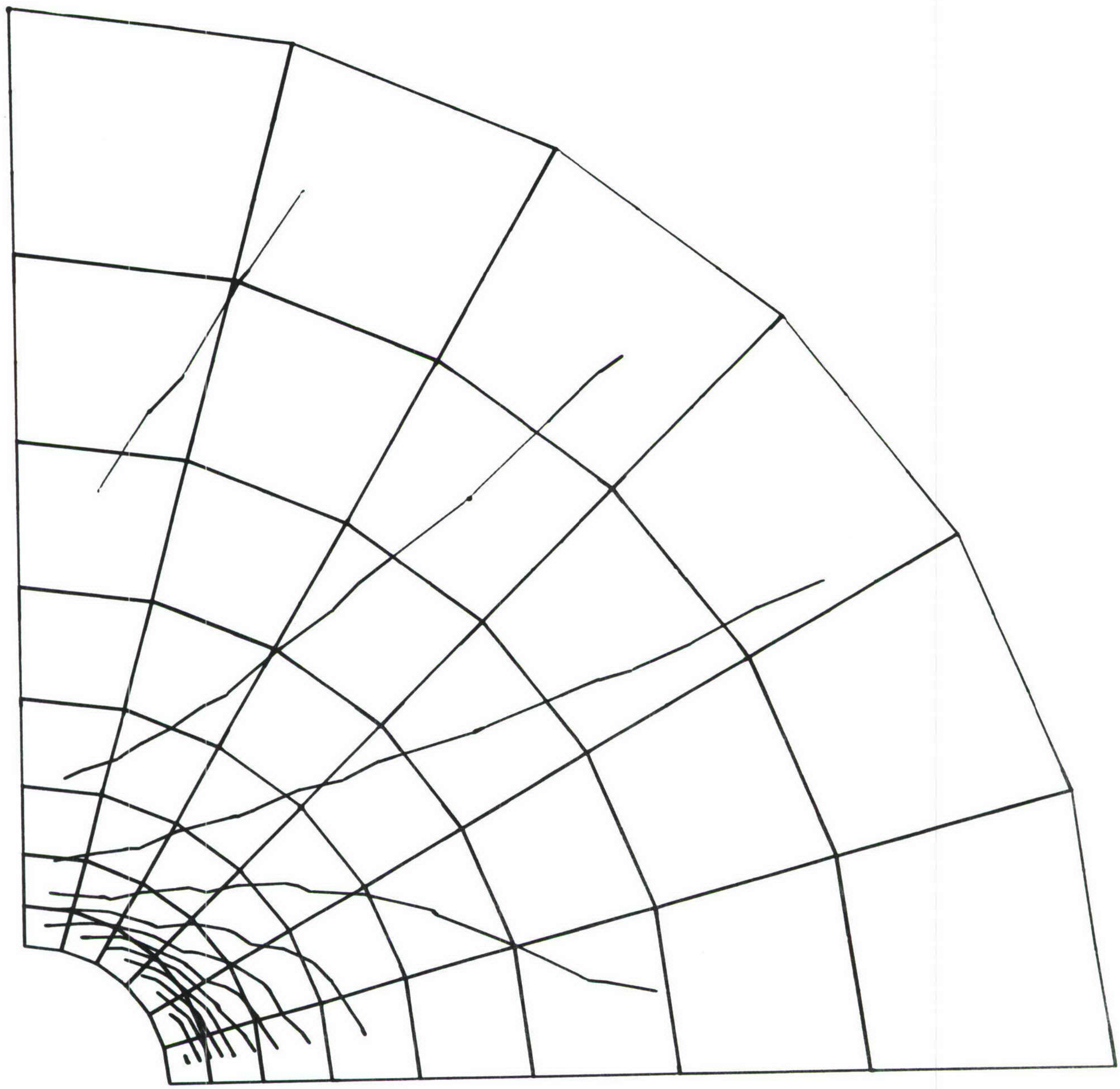


Figure AIII-72 Radial Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

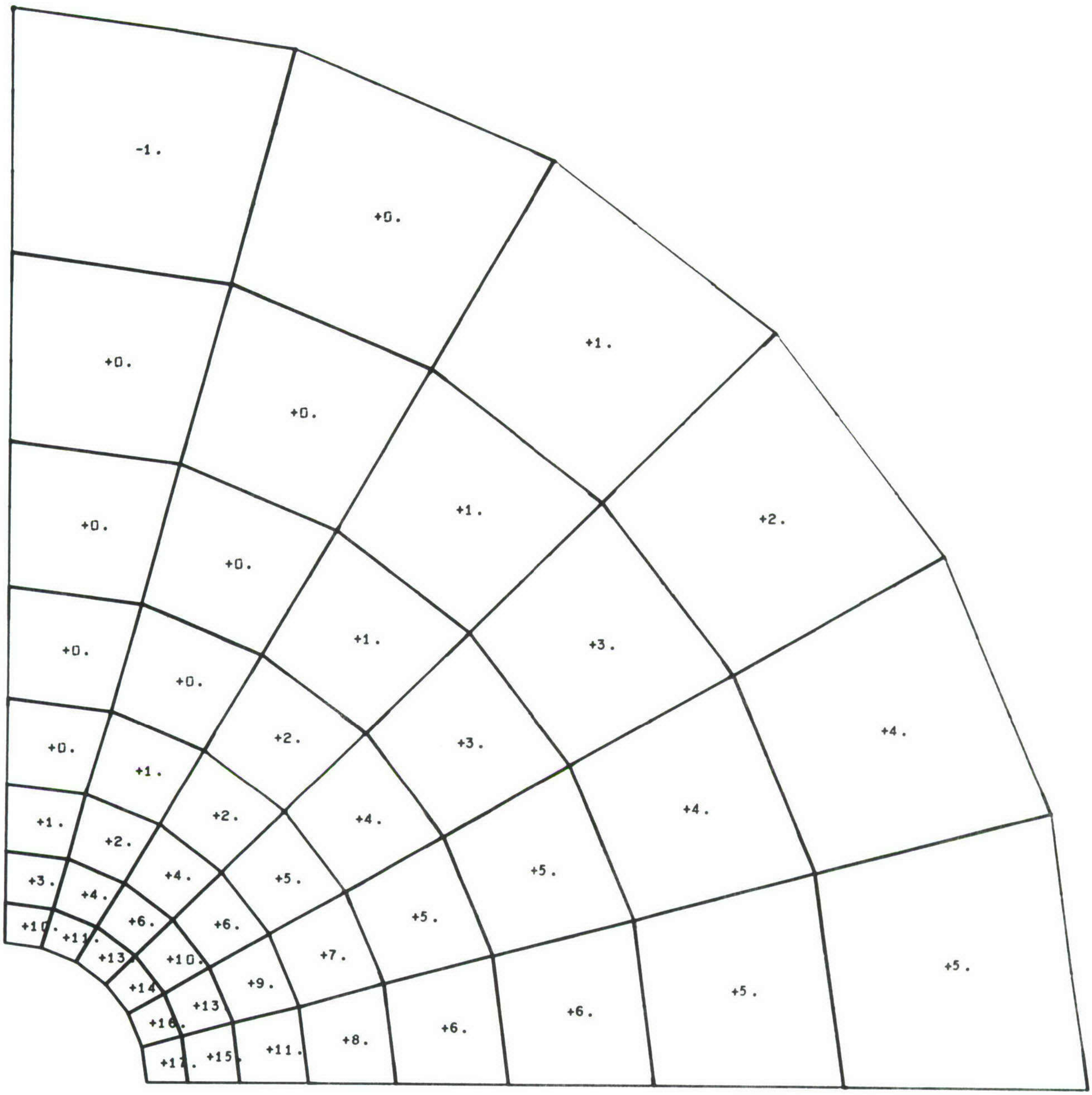


Figure AIII-73 Tangential Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

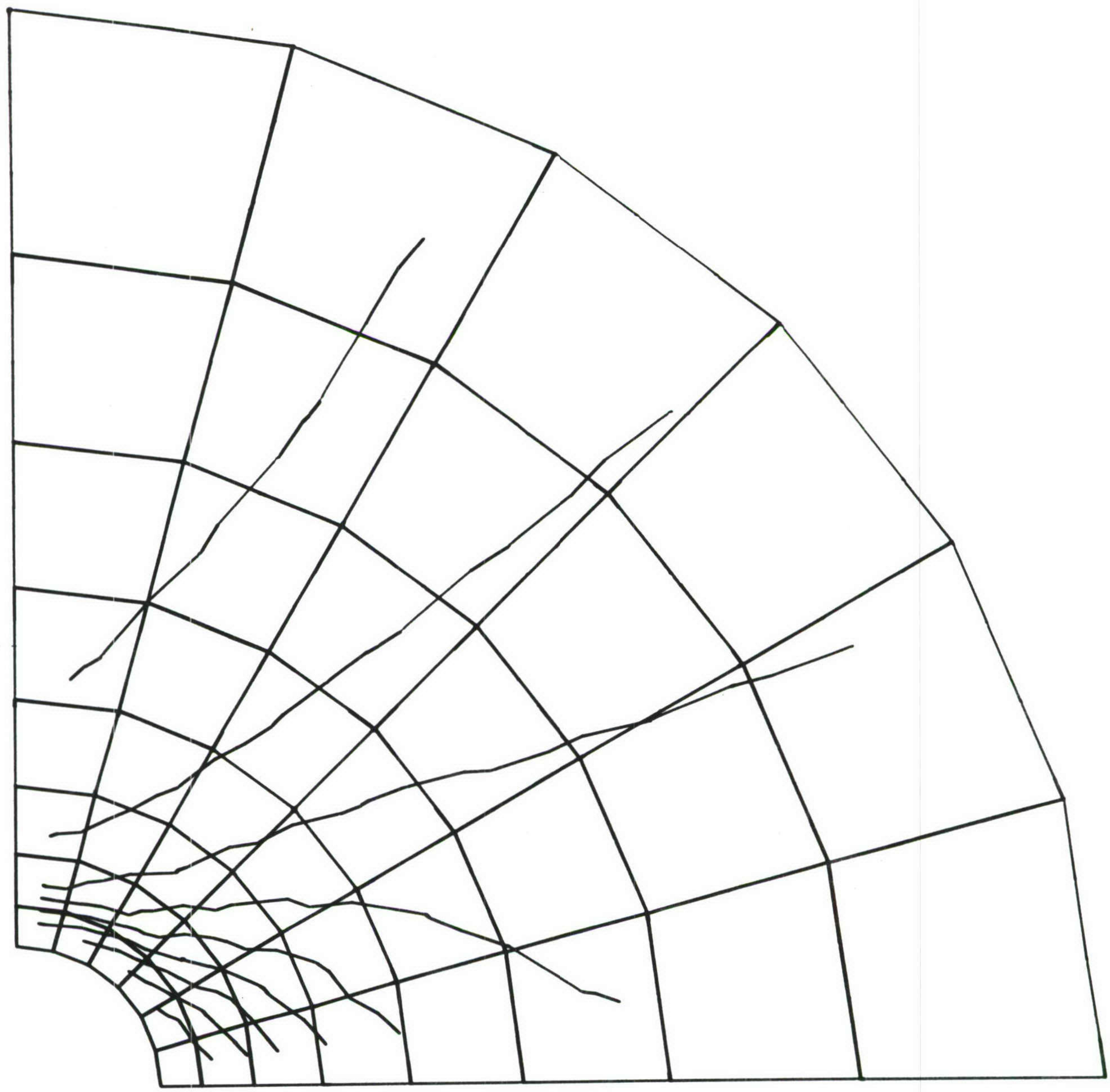


Figure AIII-74 Tangential Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

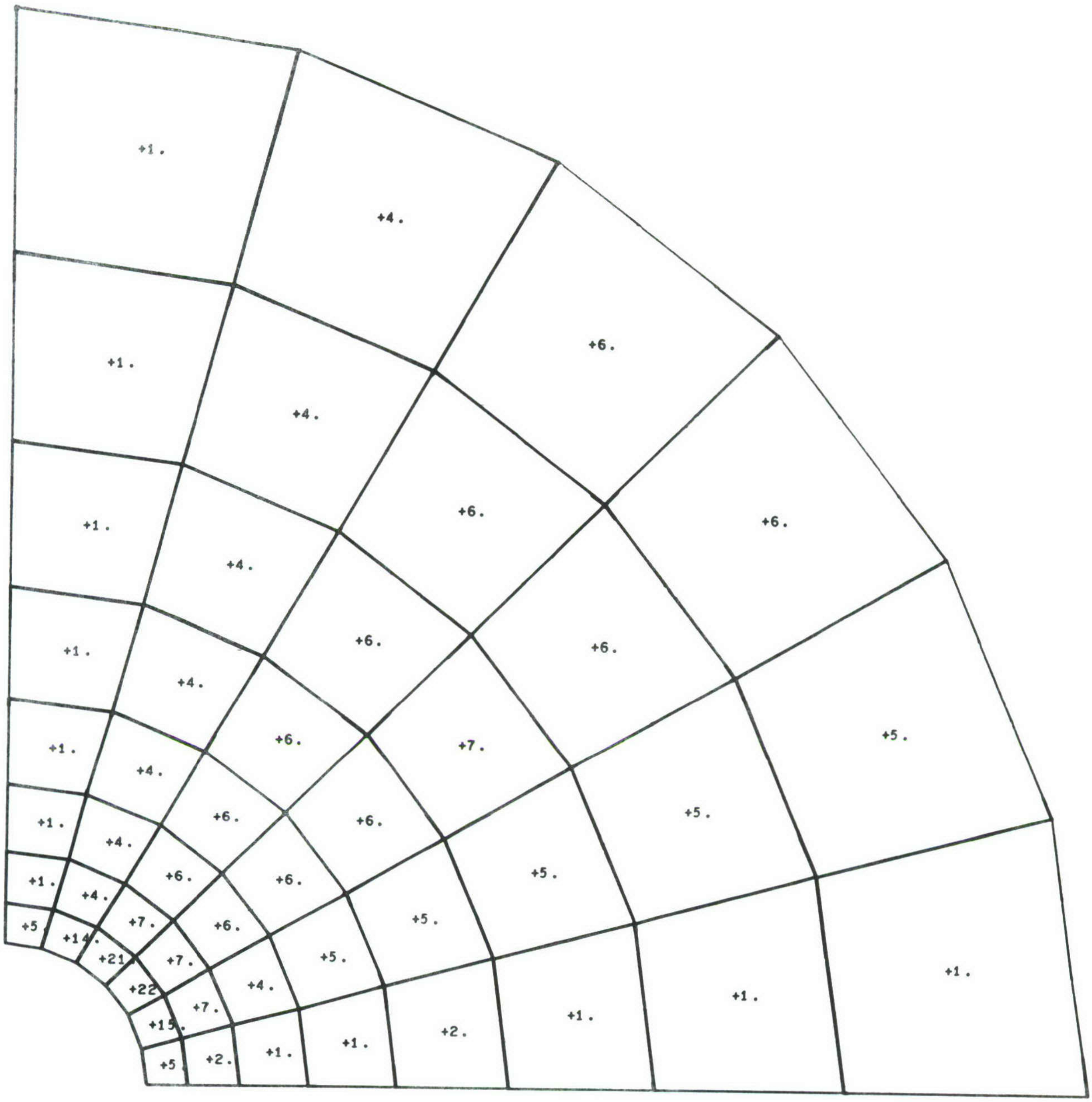


Figure AIII-75 Radial-Tangential Shear Strain Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

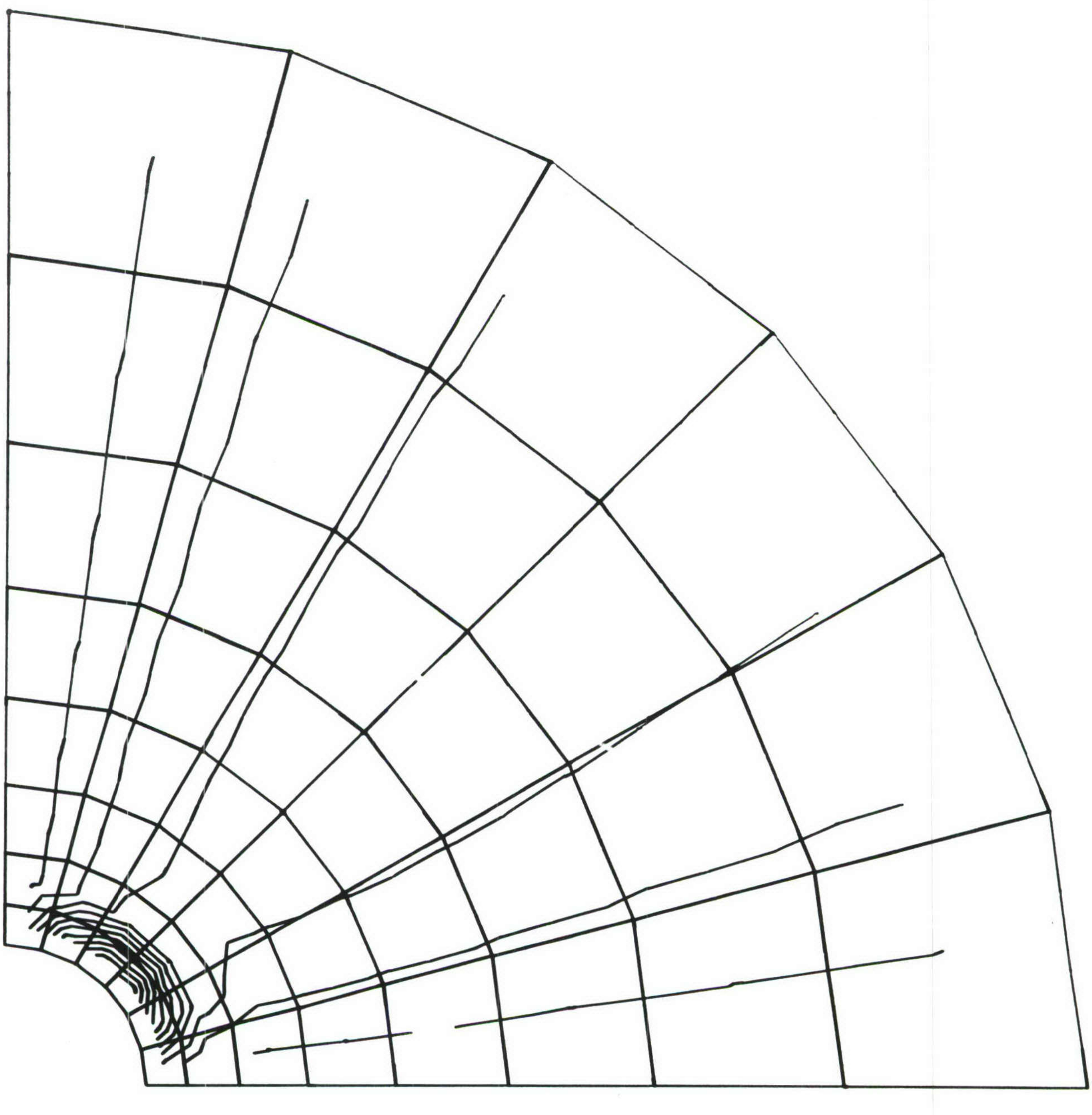


Figure AIII-76 Radial-Tangential Shear Strain Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

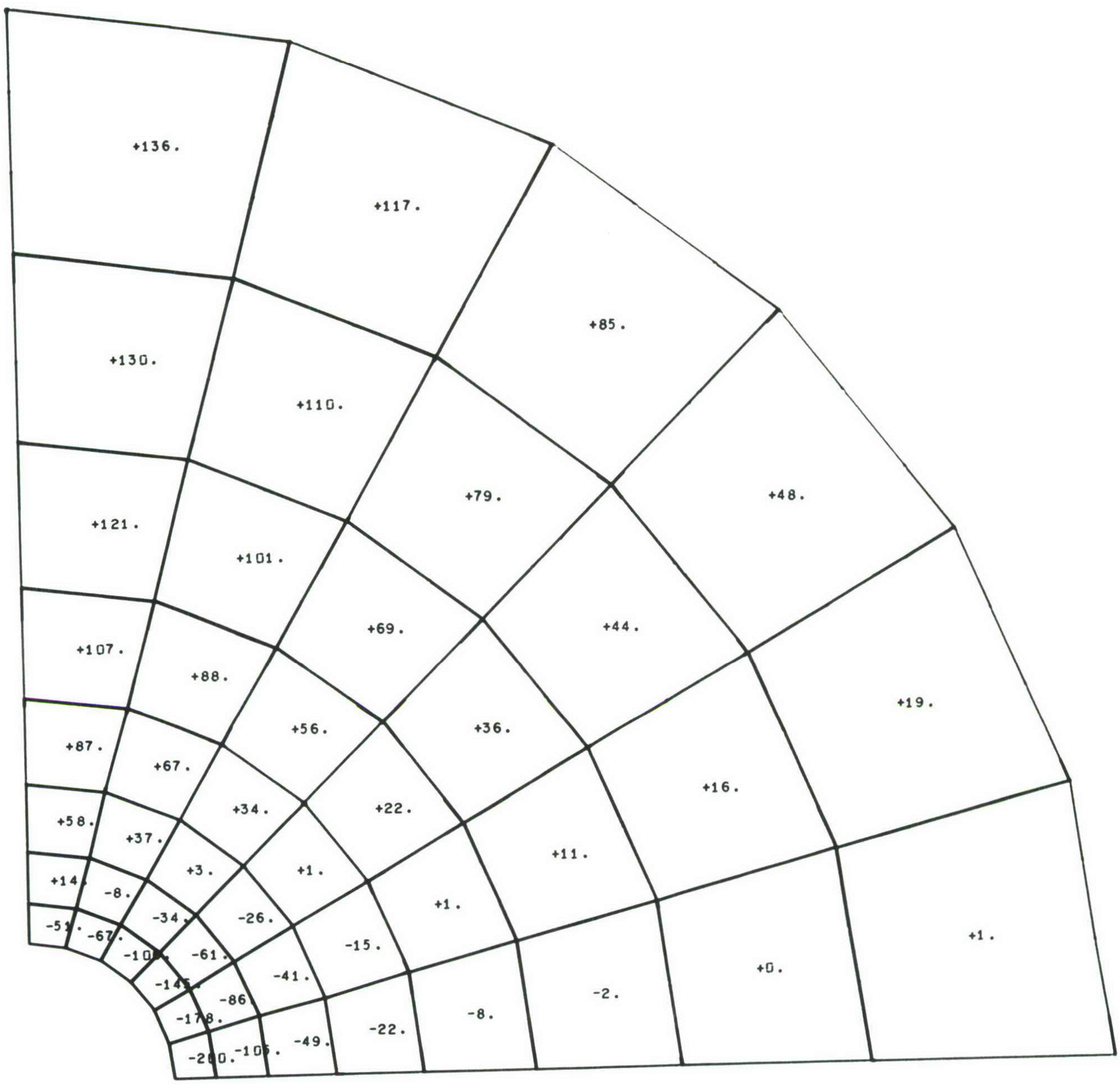


Figure AIII-77 Radial Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

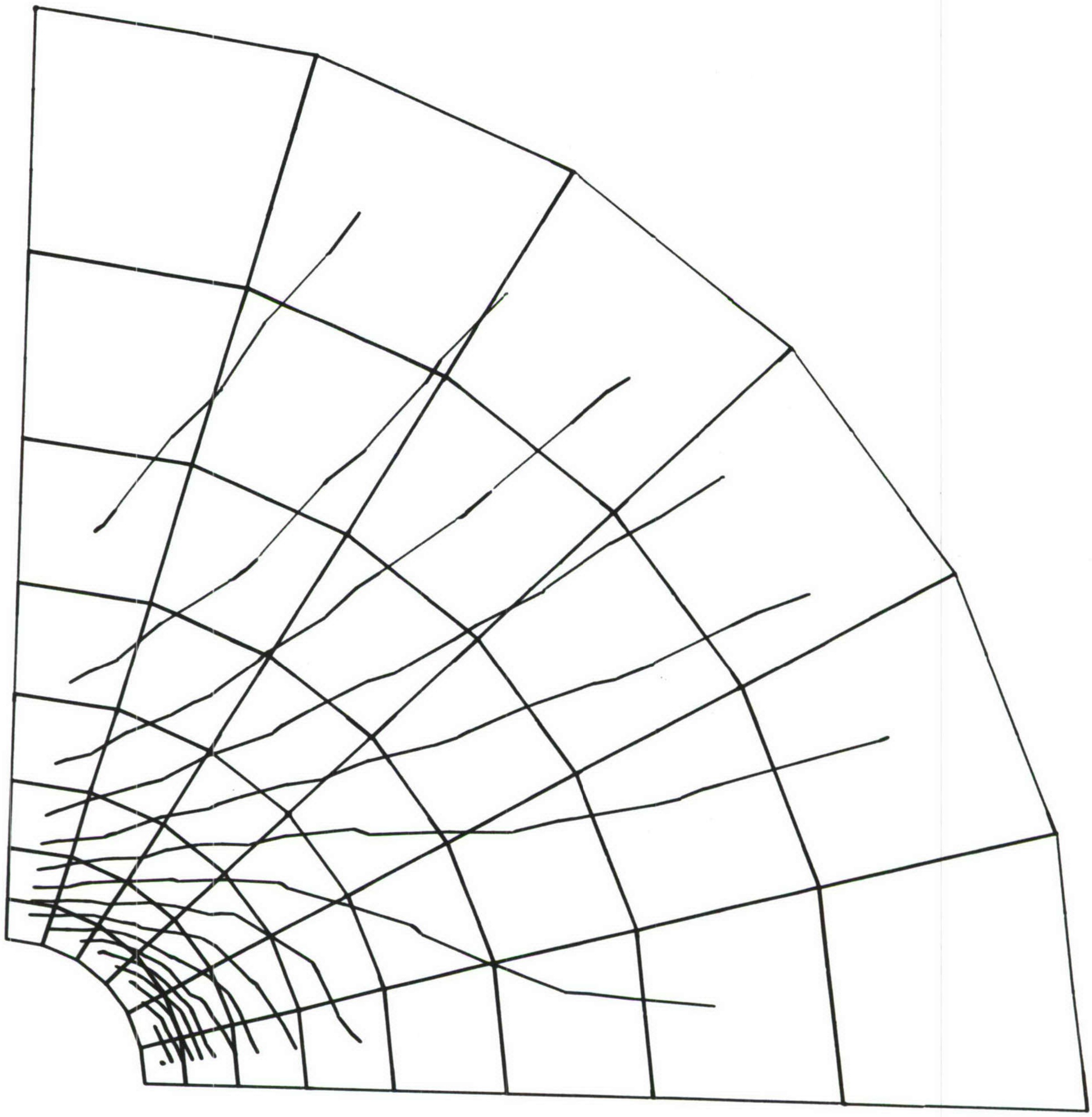


Figure AIII-78 Radial Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

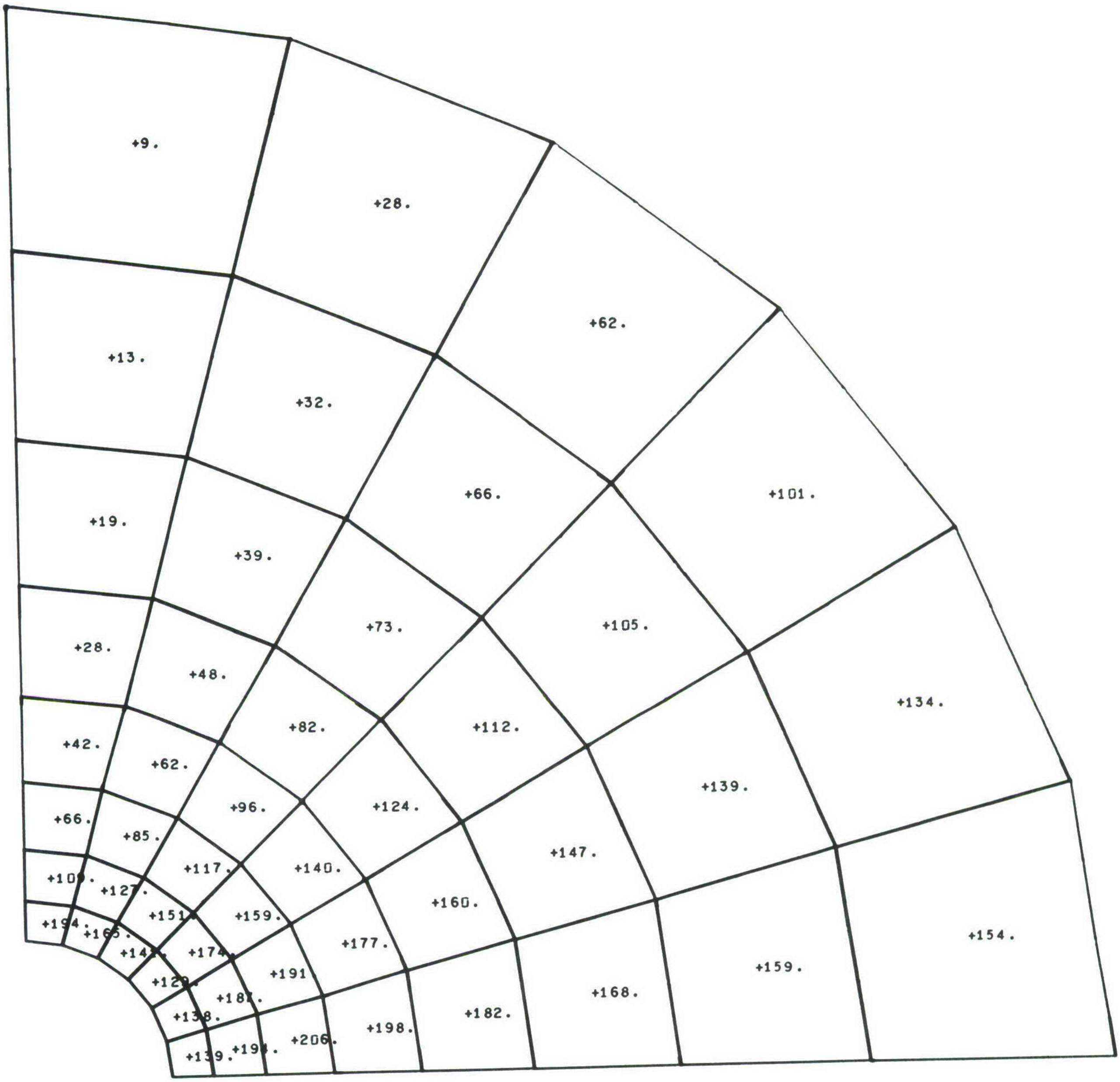


Figure AIII-79 Tangential Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

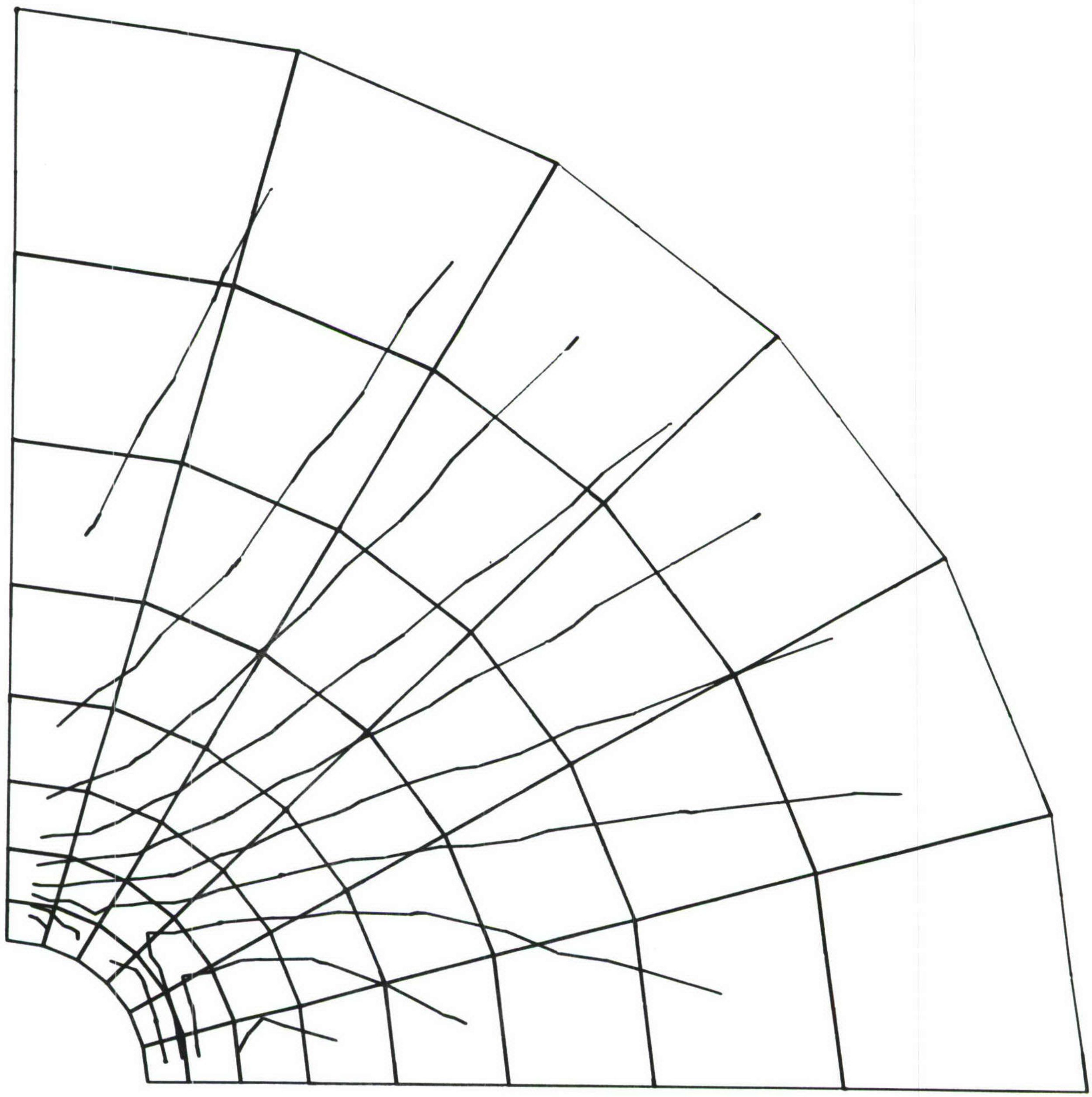


Figure AIII-80 Tangential Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

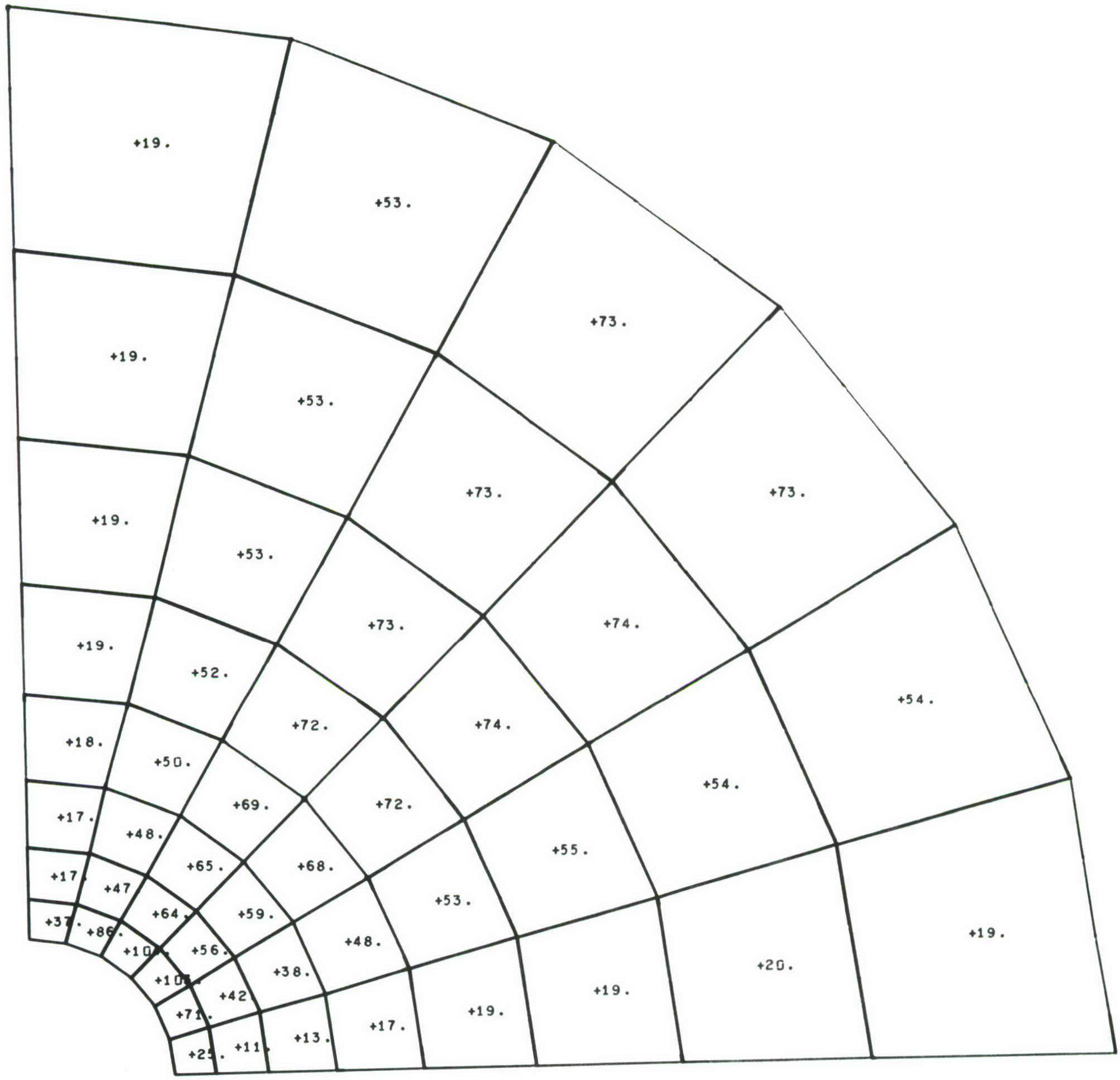


Figure AIII-81 Radial-Tangential Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

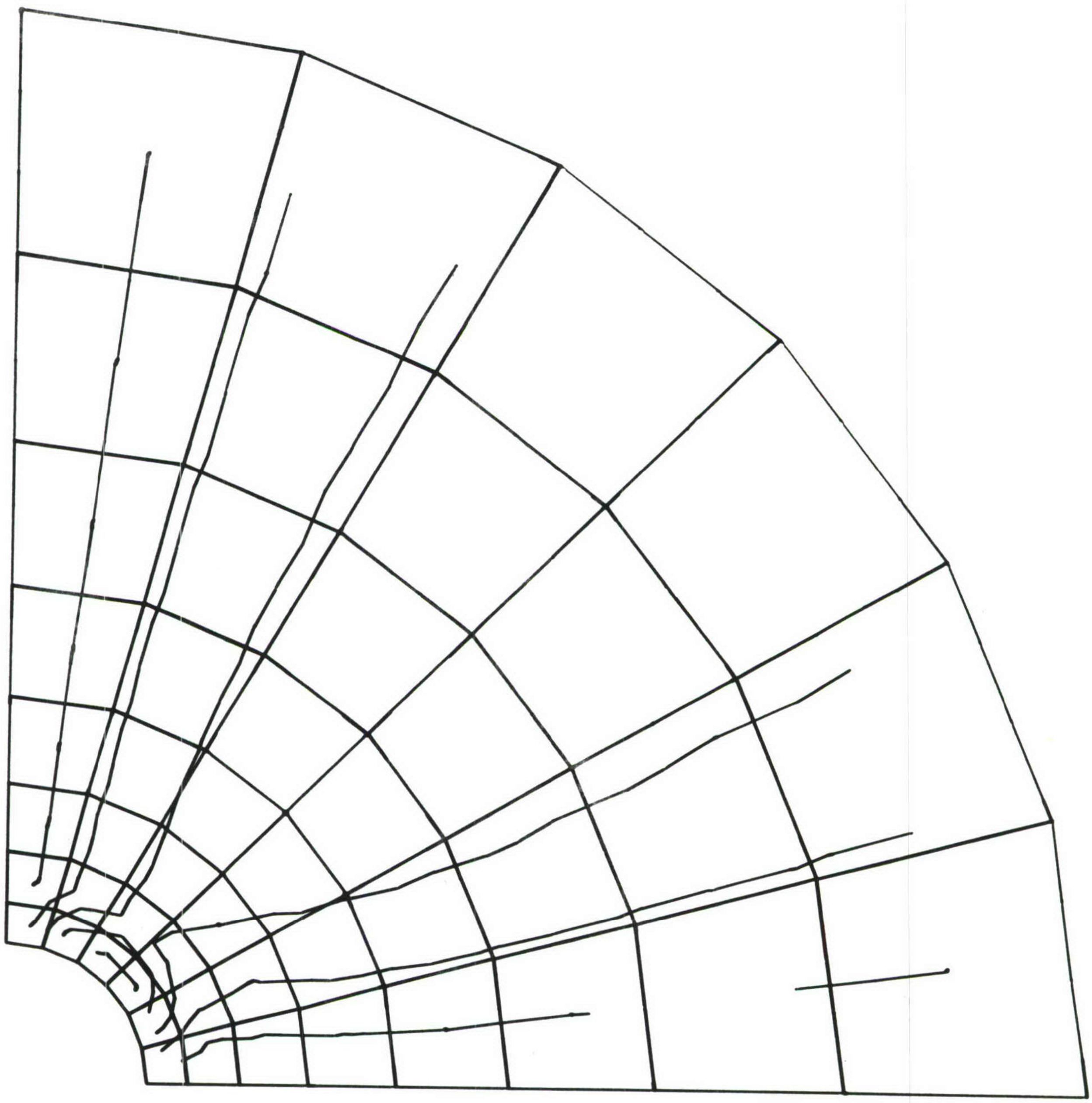


Figure AIII-82 Radial-Tangential Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

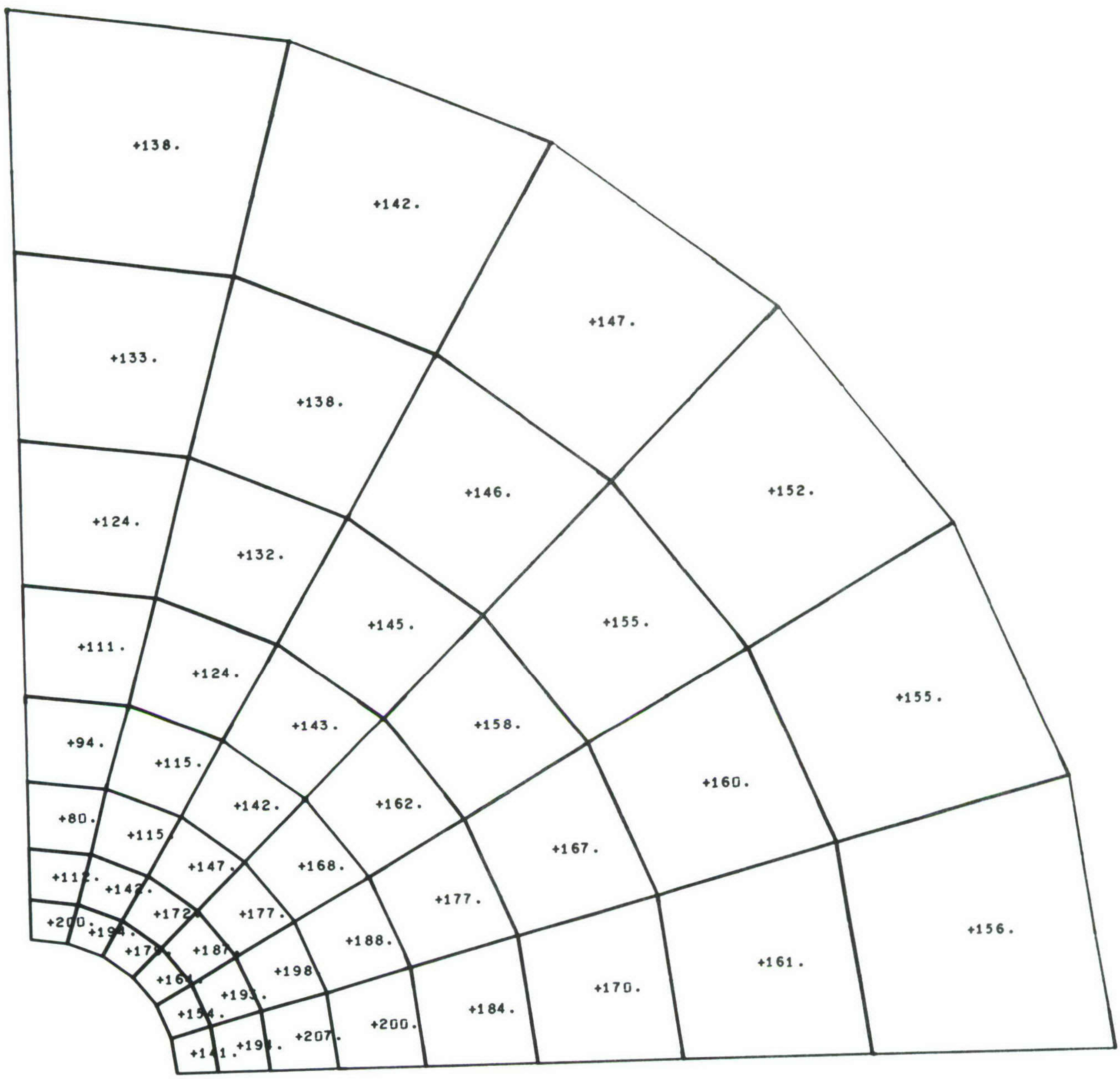


Figure AIII-83 First Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

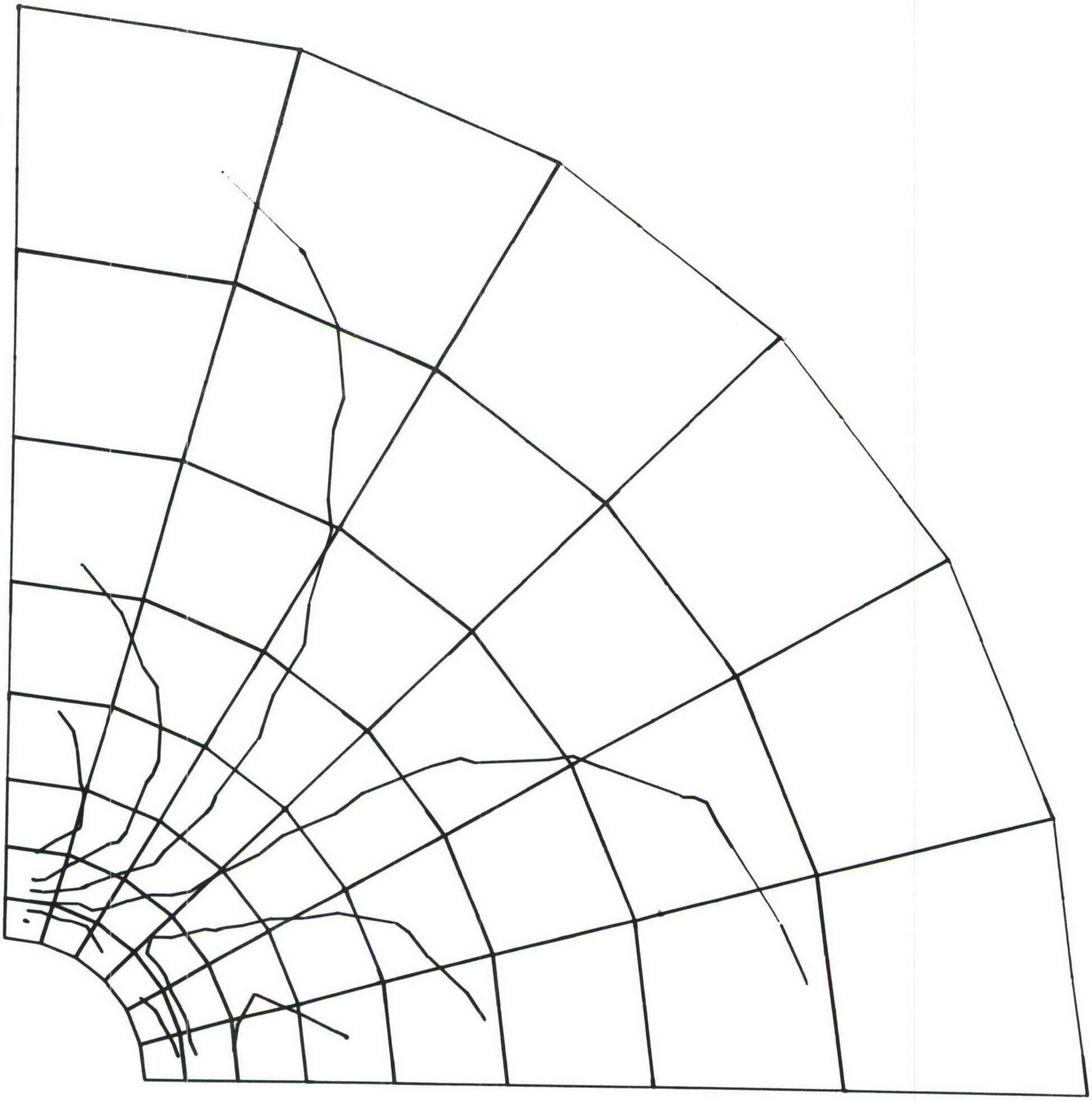


Figure AIII-84 First Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

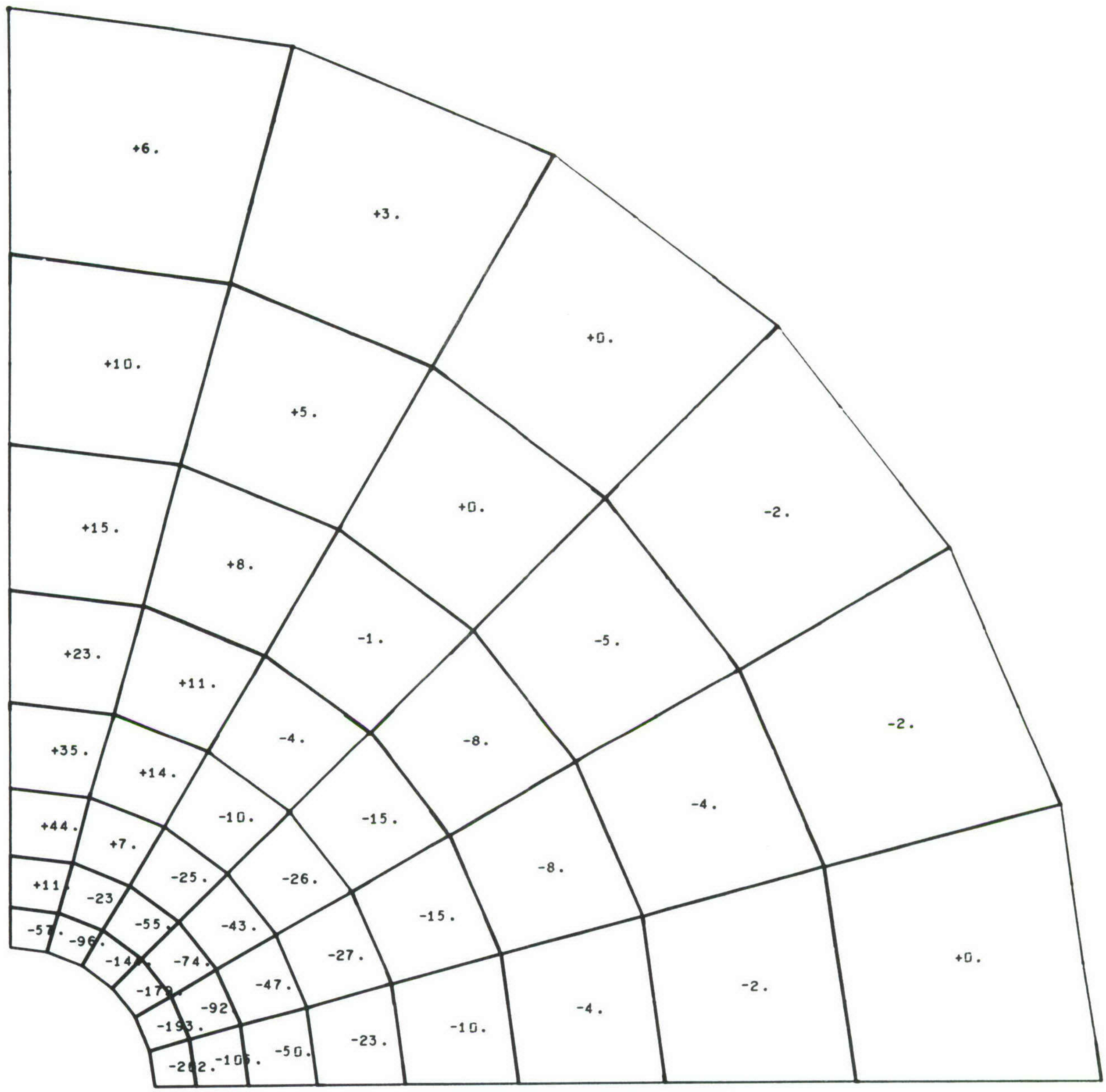


Figure AIII-85 Second Principal Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

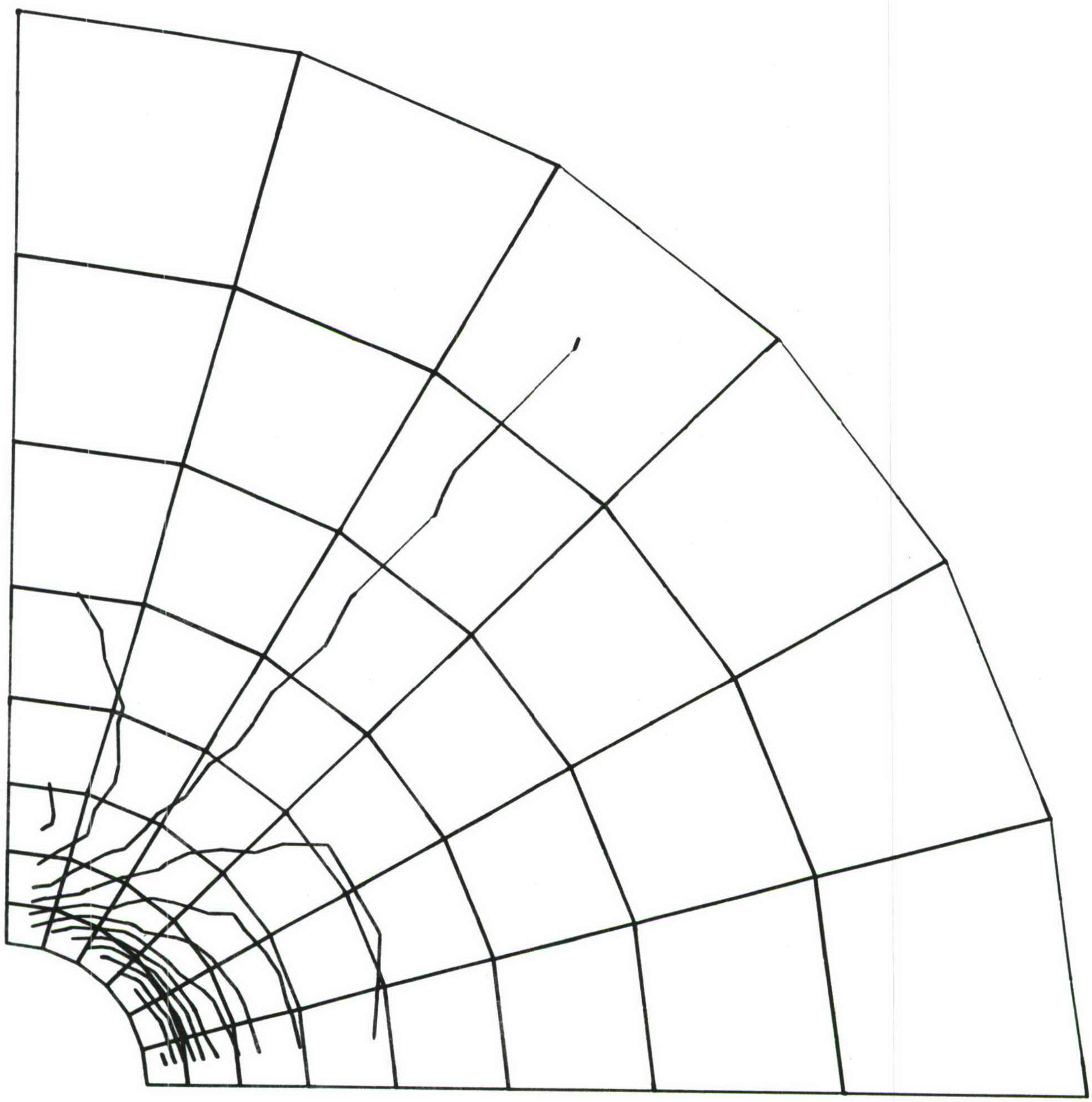


Figure AIII-86 Second Principal Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

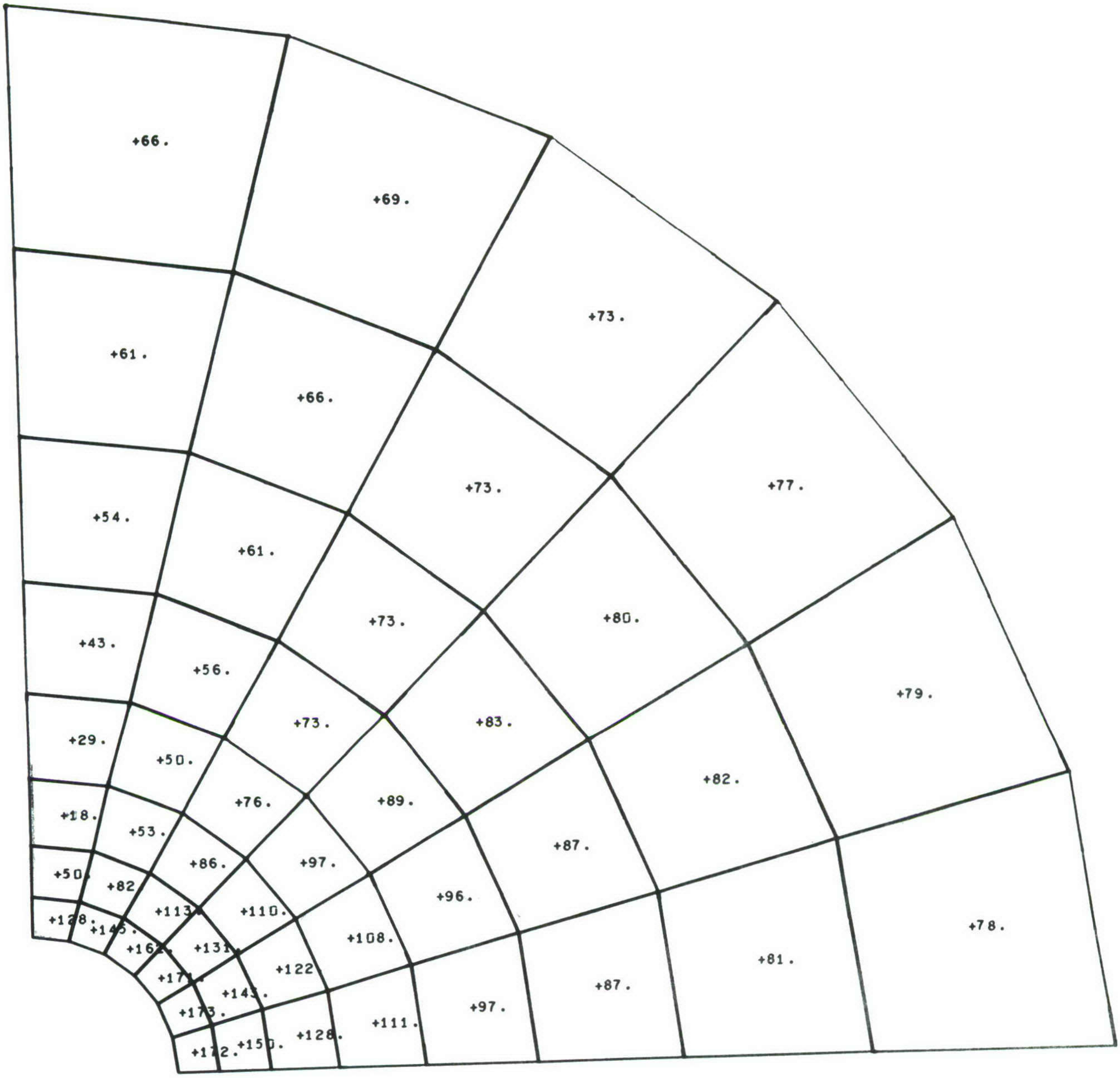


Figure AIII-87 Principal Shear Stress Values for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

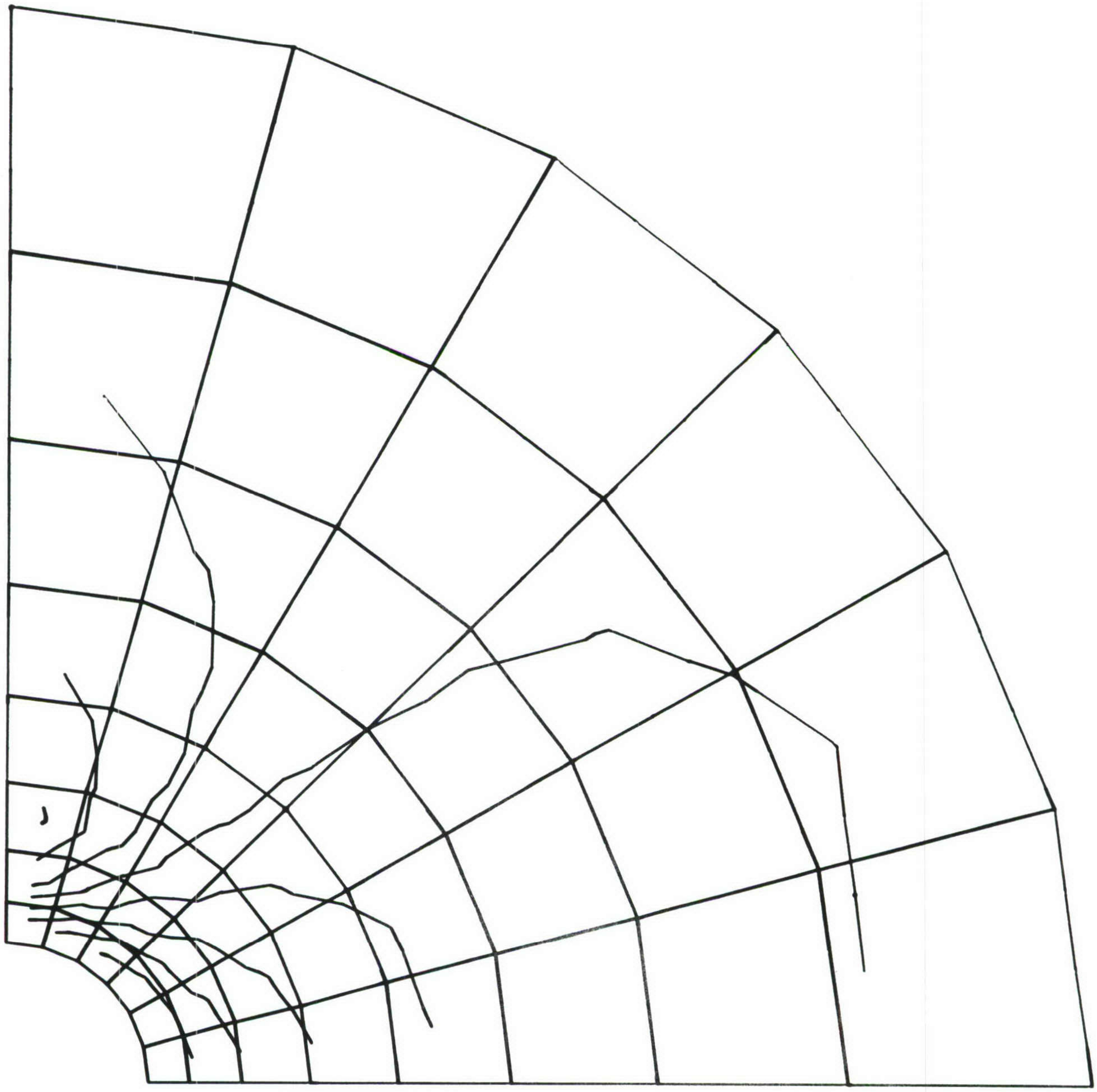


Figure AIII-88 Principal Shear Stress Contours for Steel Plate with 3/16 Inch Hole Radius; 0.00375 Inch Radial Interference; 70% Uniaxial Load

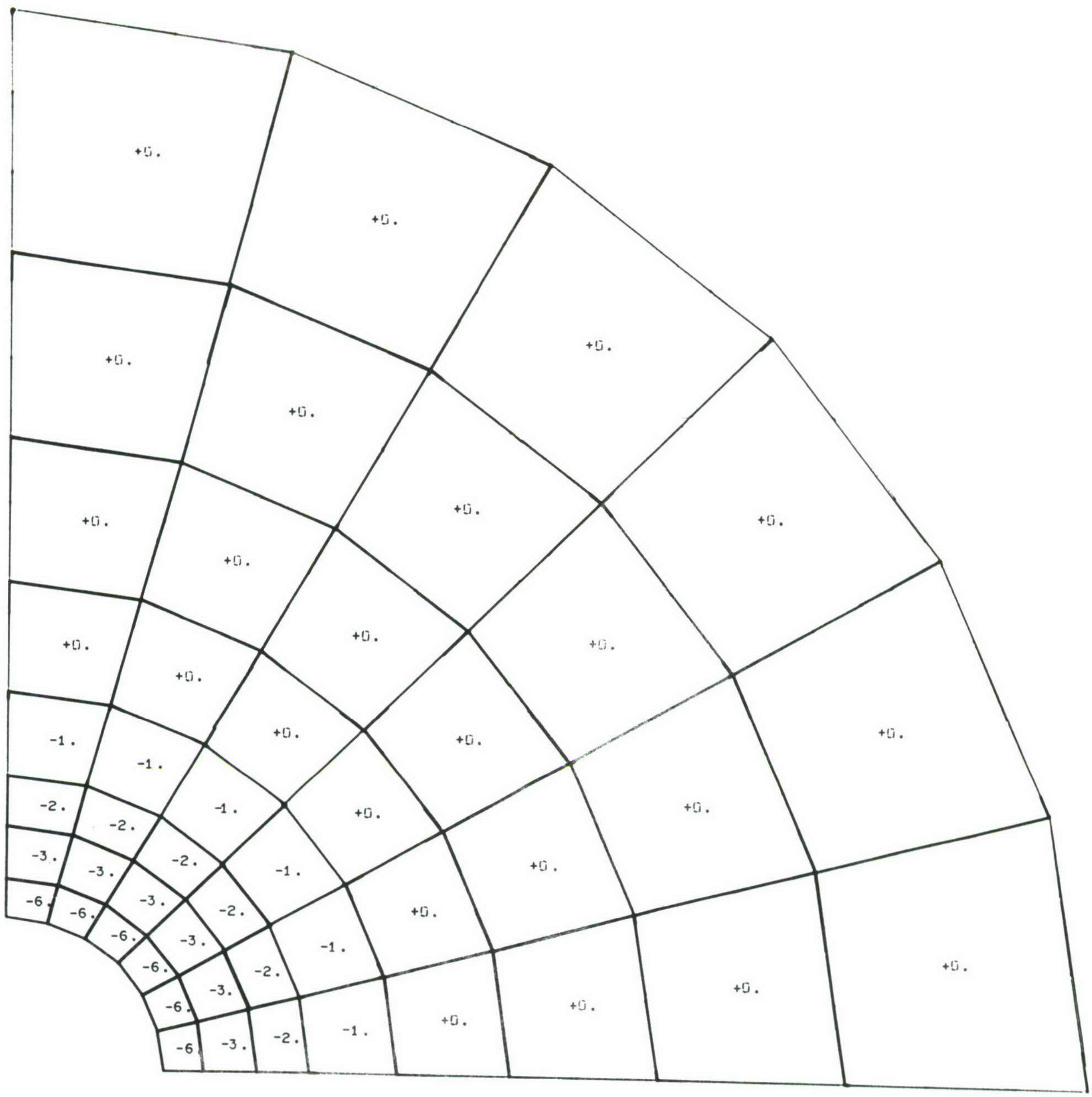


Figure AIII-89 Radial Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

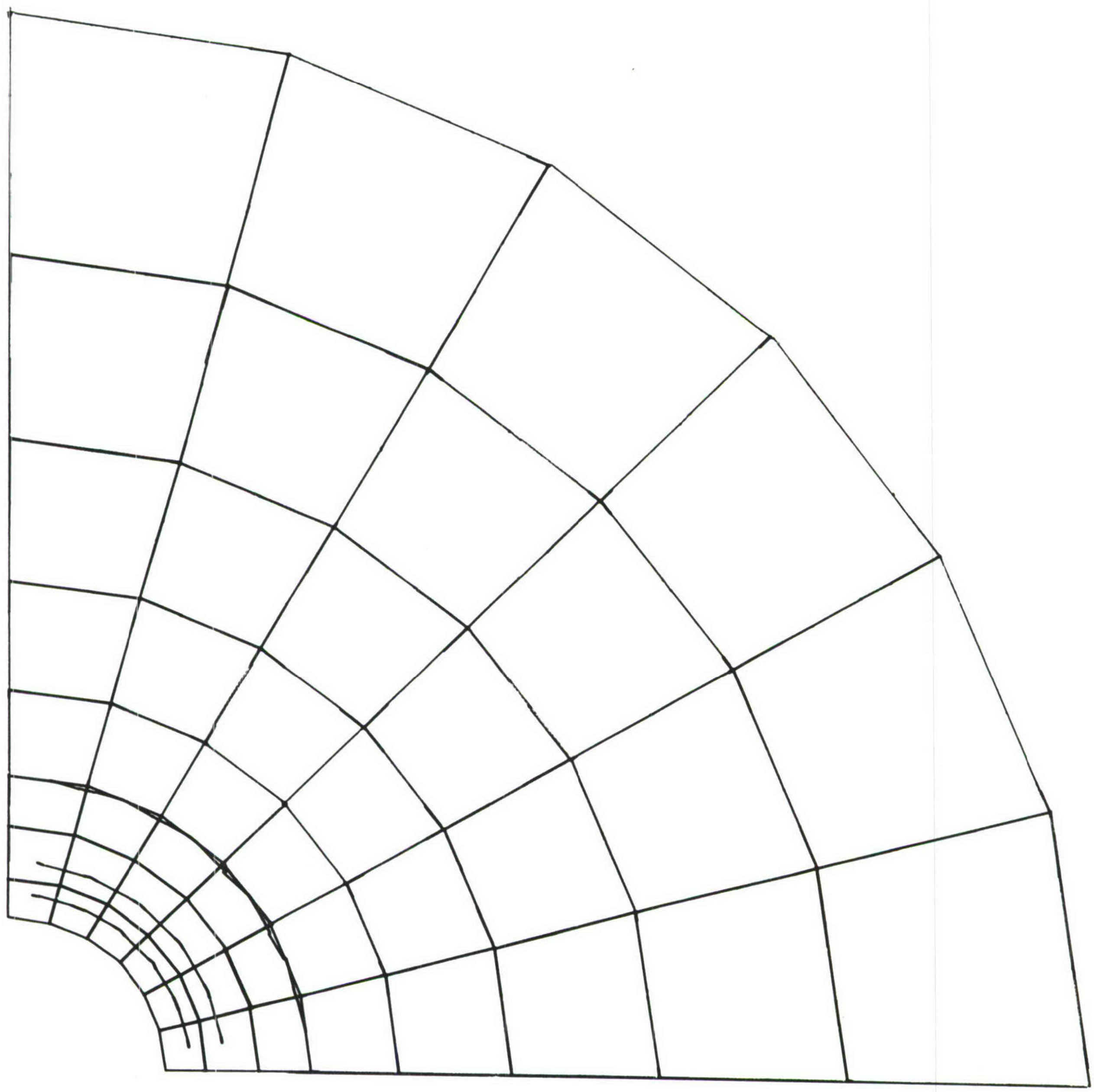


Figure AIII-90 Radial Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

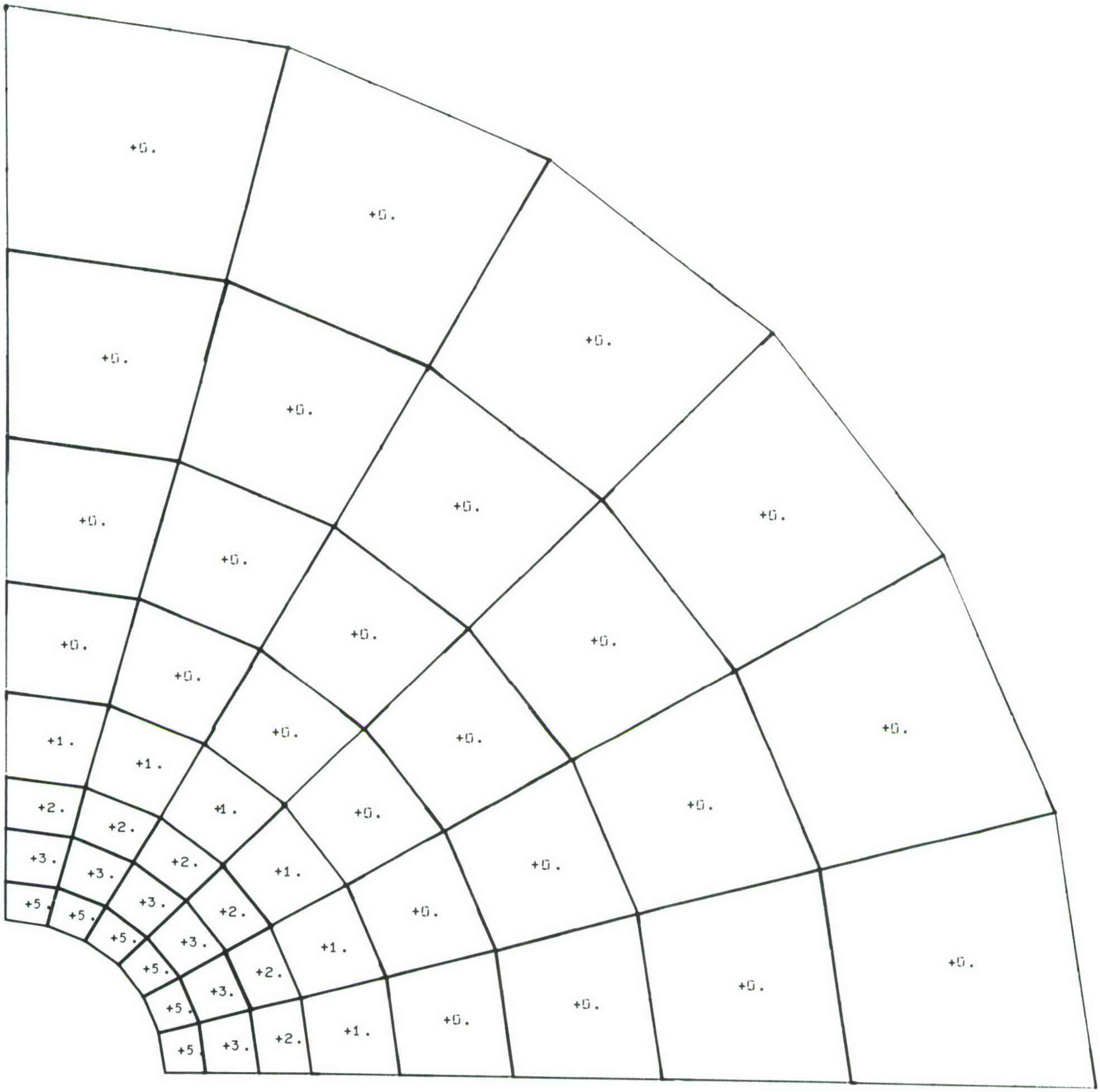


Figure AIII-91 Tangential Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

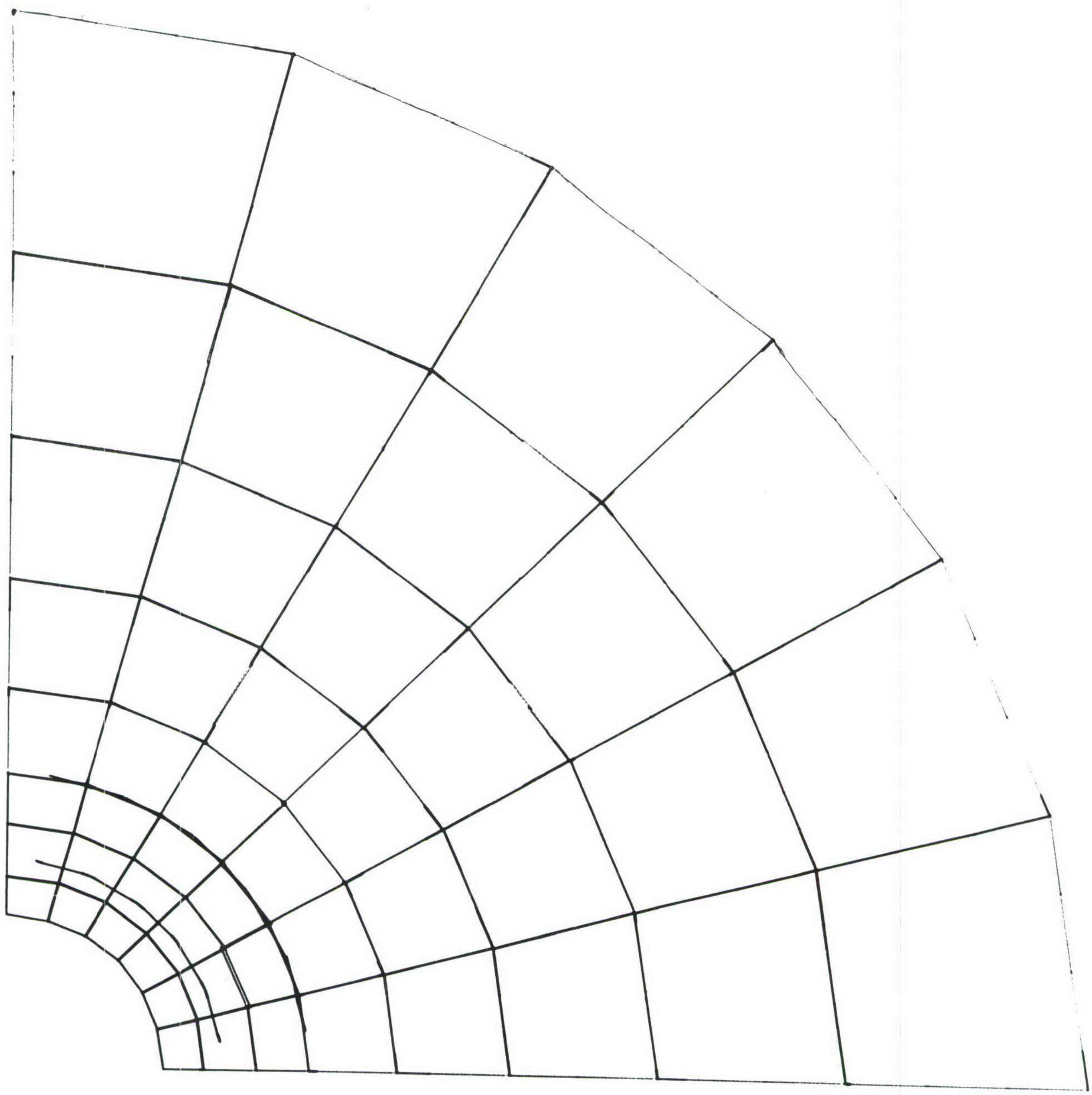


Figure AIII-92 Tangential Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

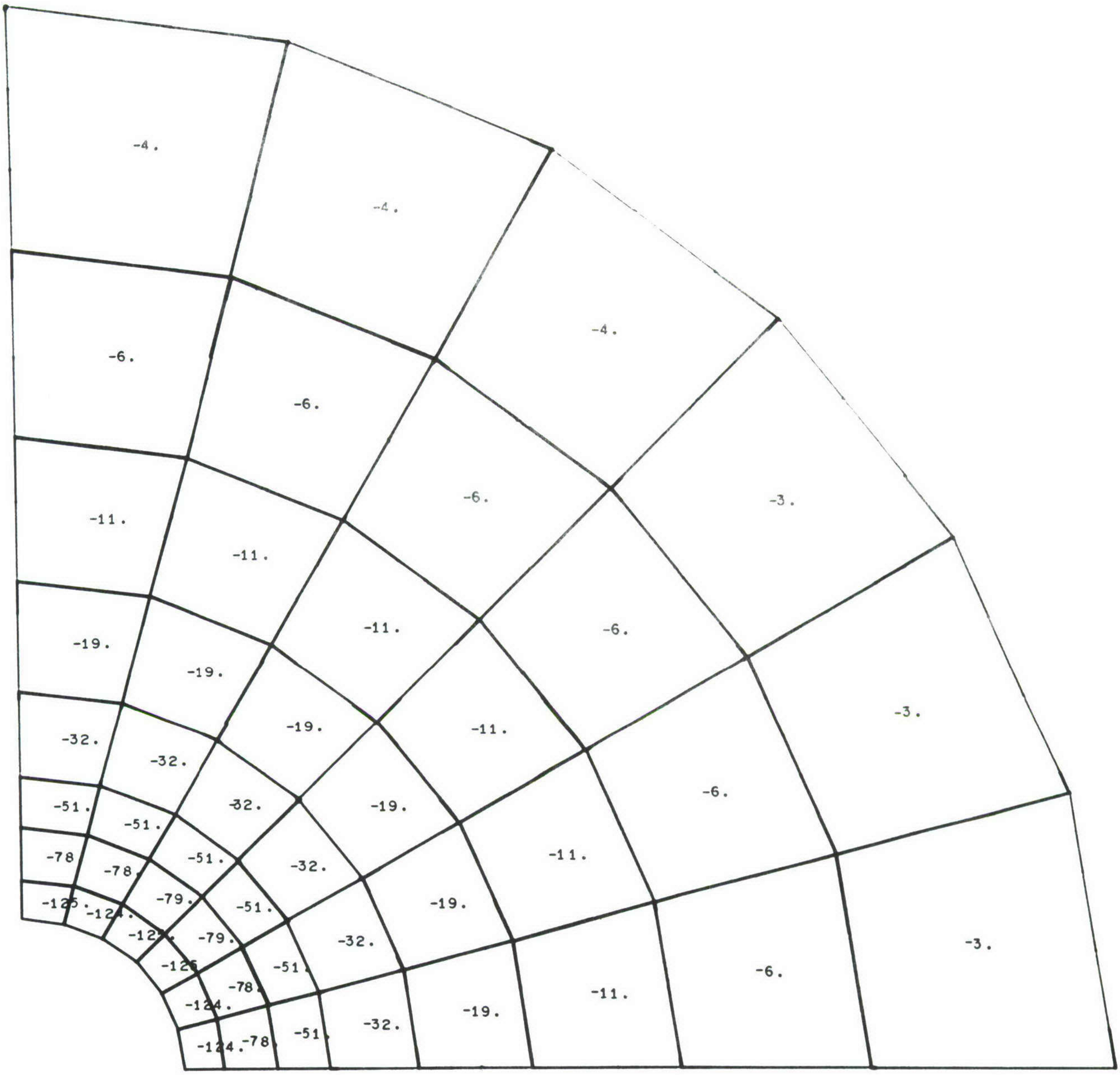


Figure AIII-93 Radial Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

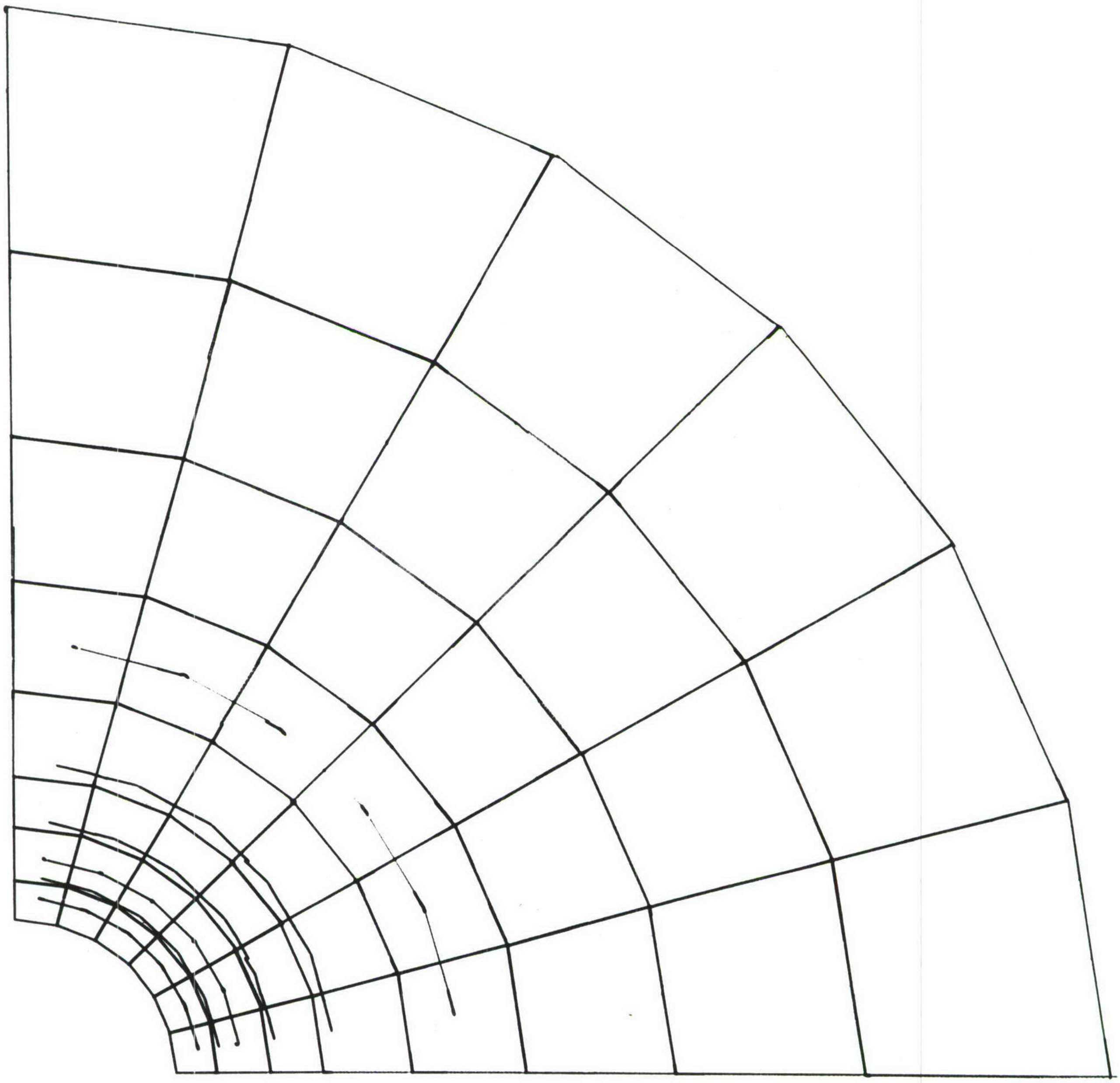


Figure AIII-94 Radial Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

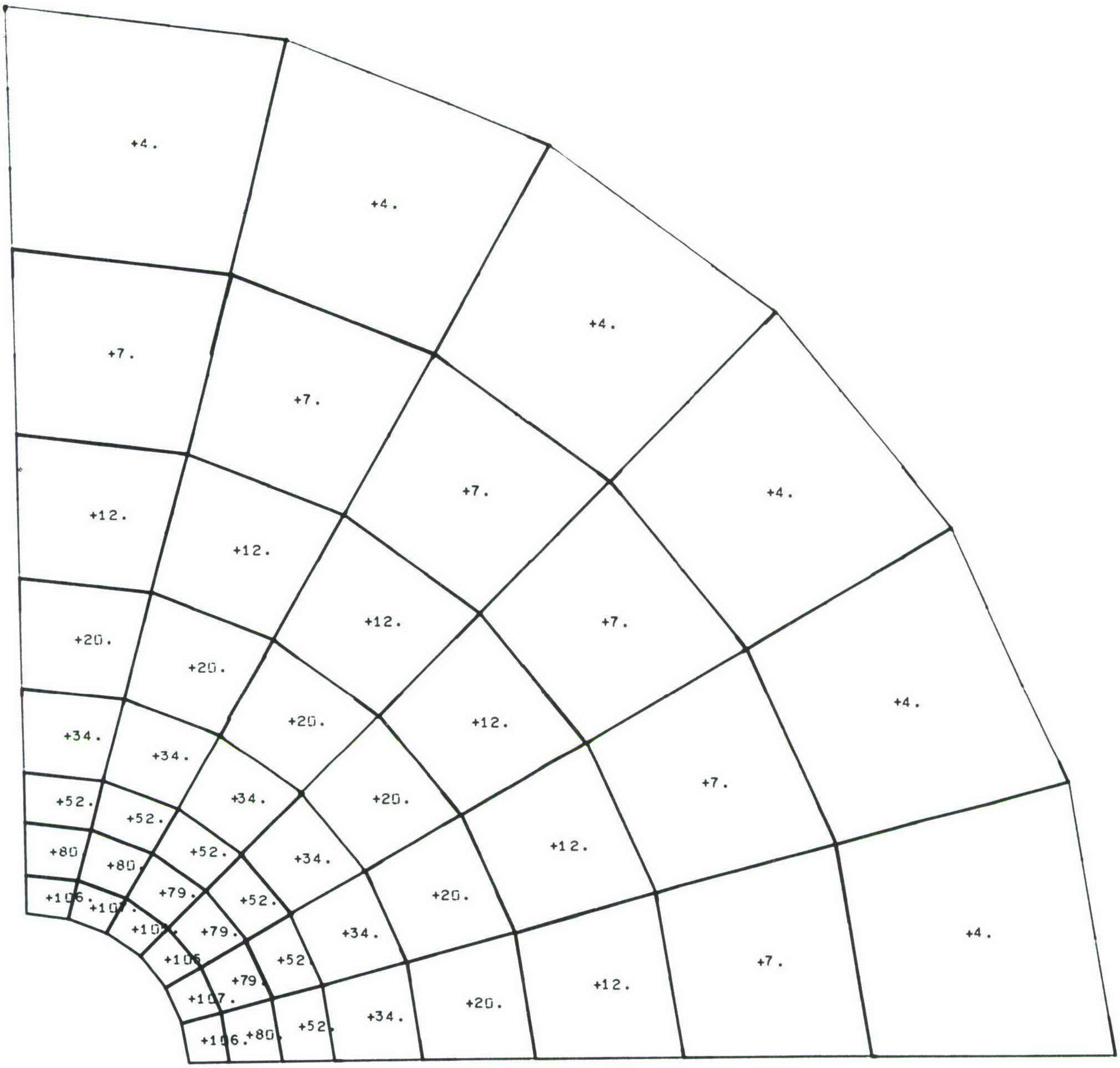


Figure AIII-95 Tangential Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

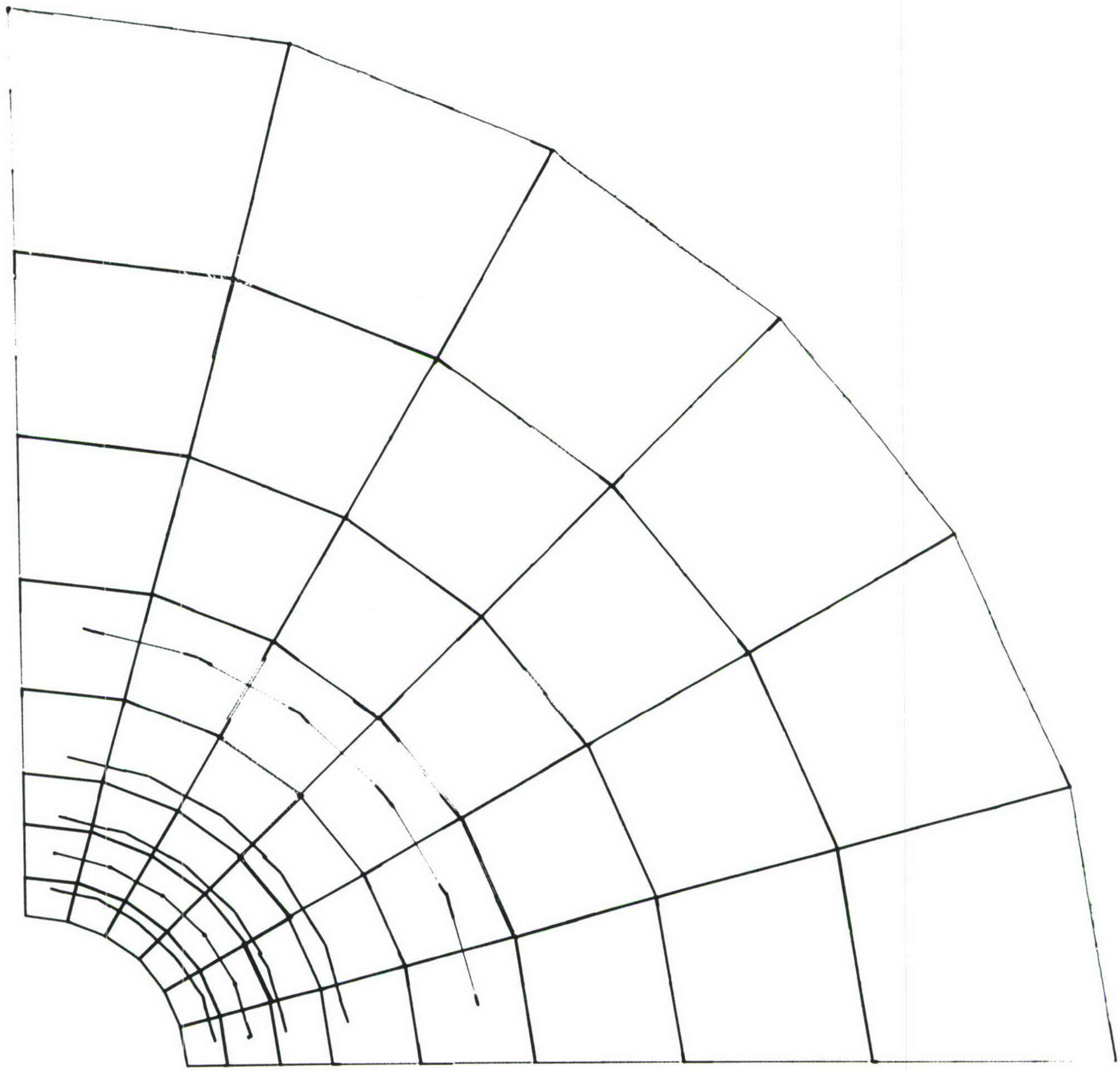


Figure AIII-96 Tangential Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; No Uniaxial Load

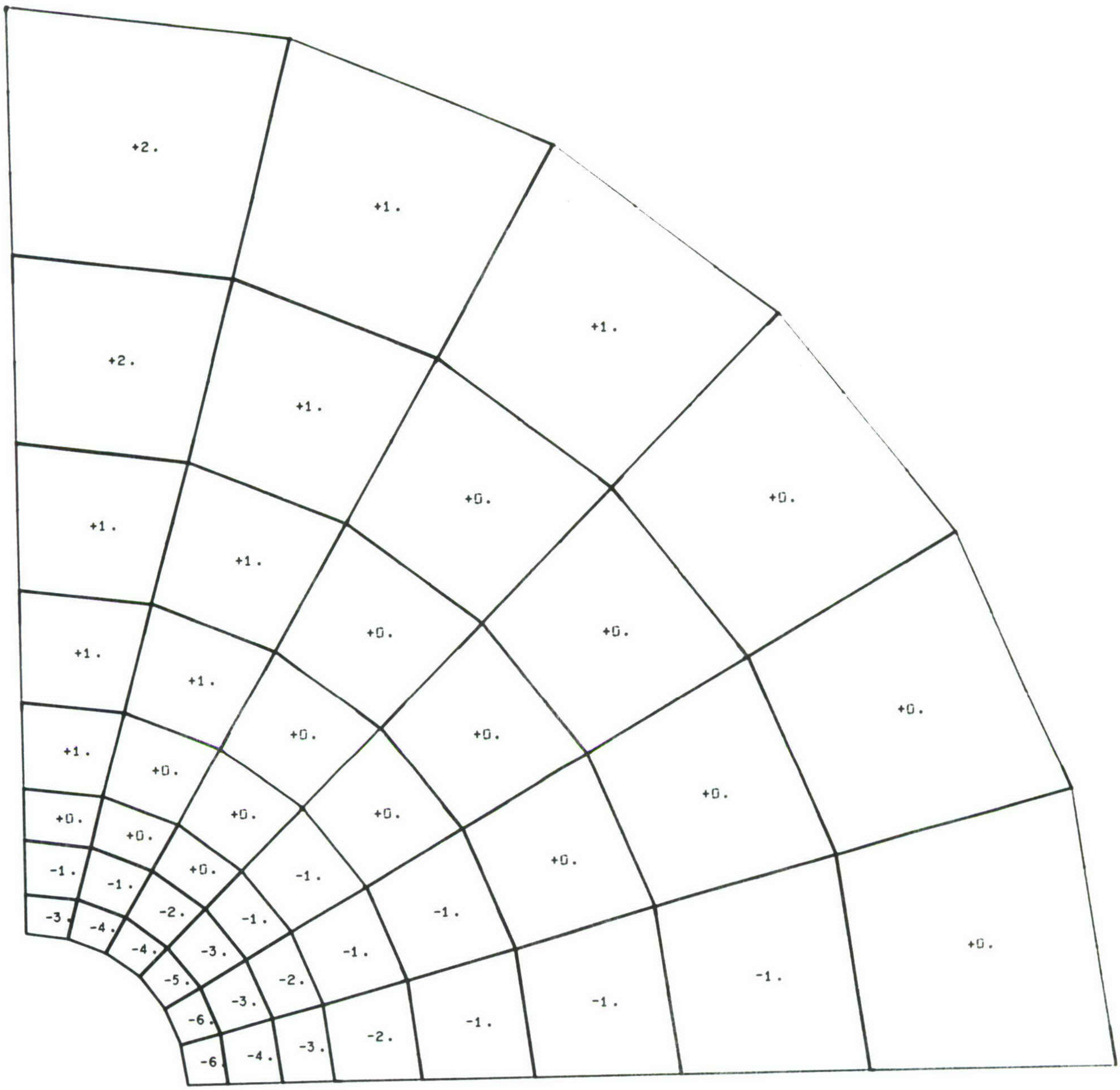


Figure AIII-97 Radial Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

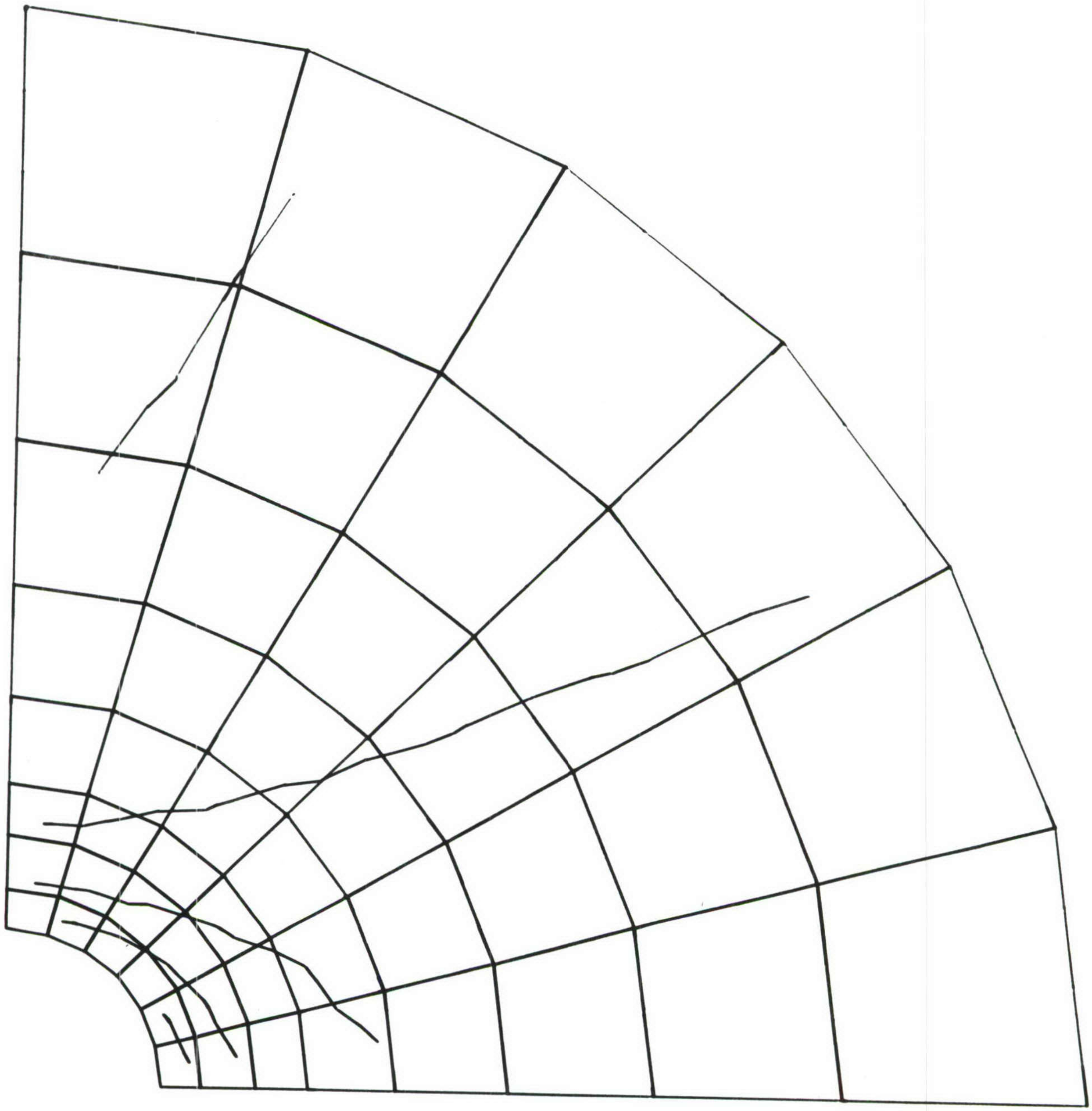


Figure AIII-98 Radial Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

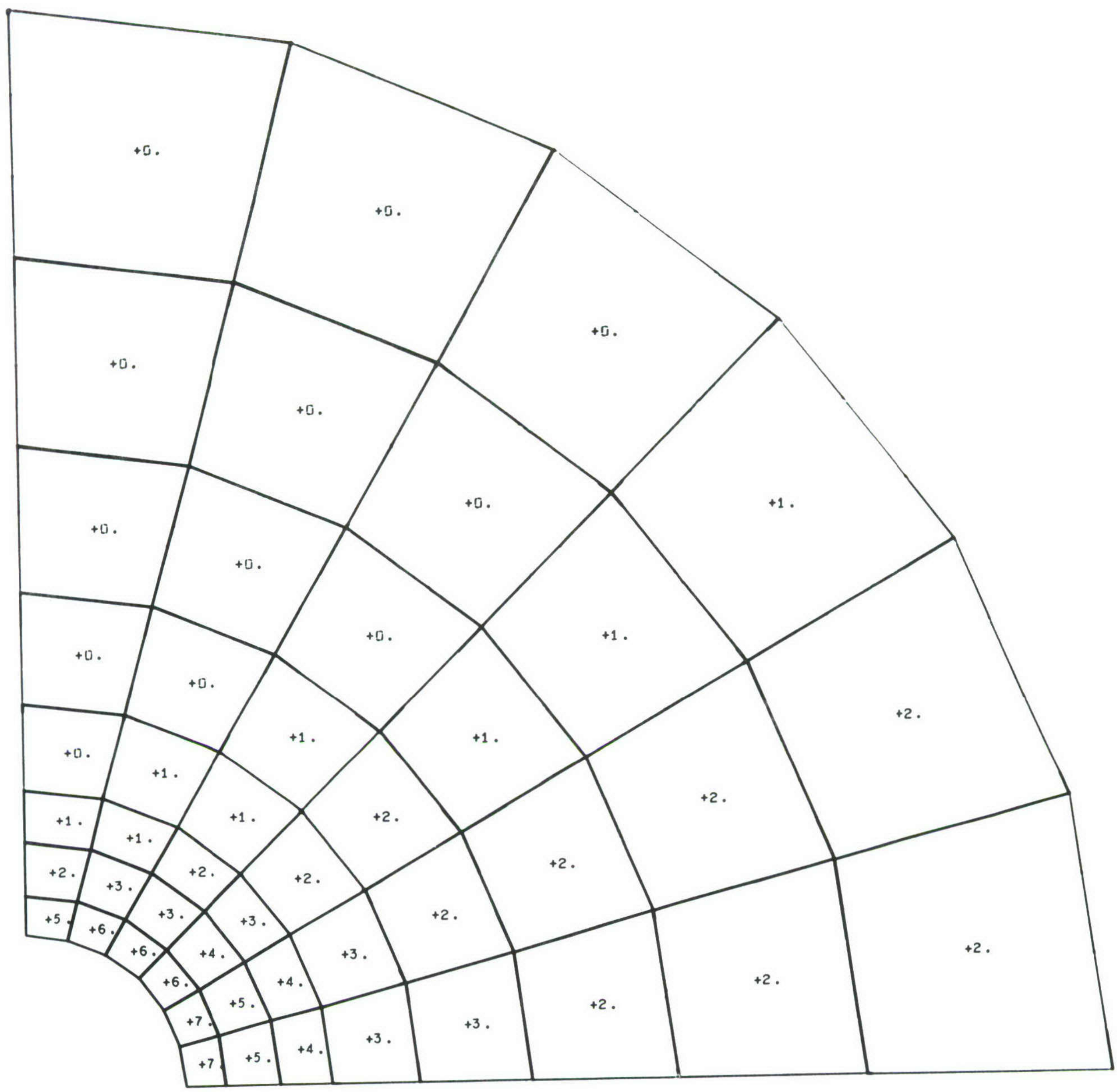


Figure AIII-99 Tangential Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

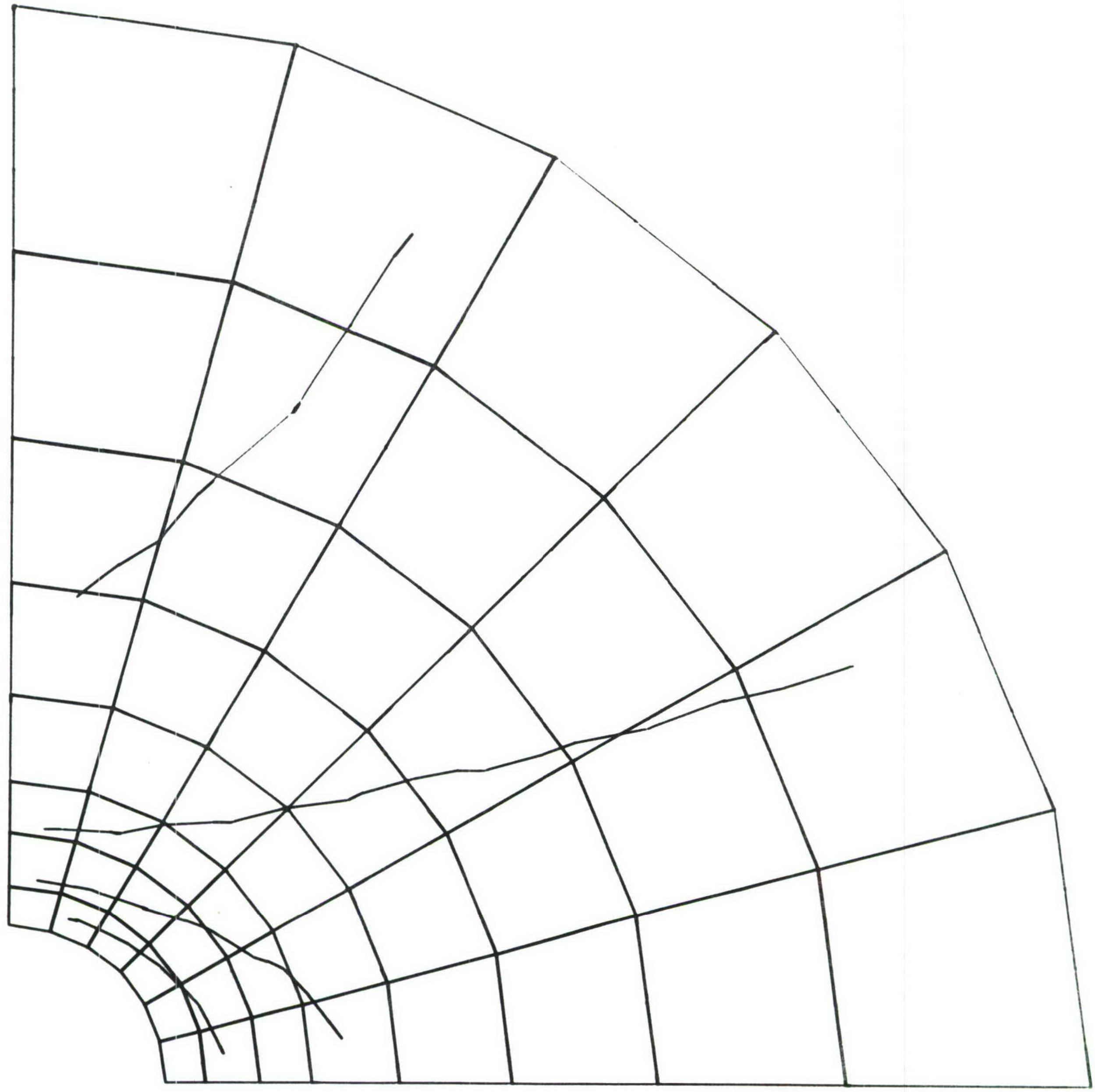


Figure AIII-100 Tangential Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

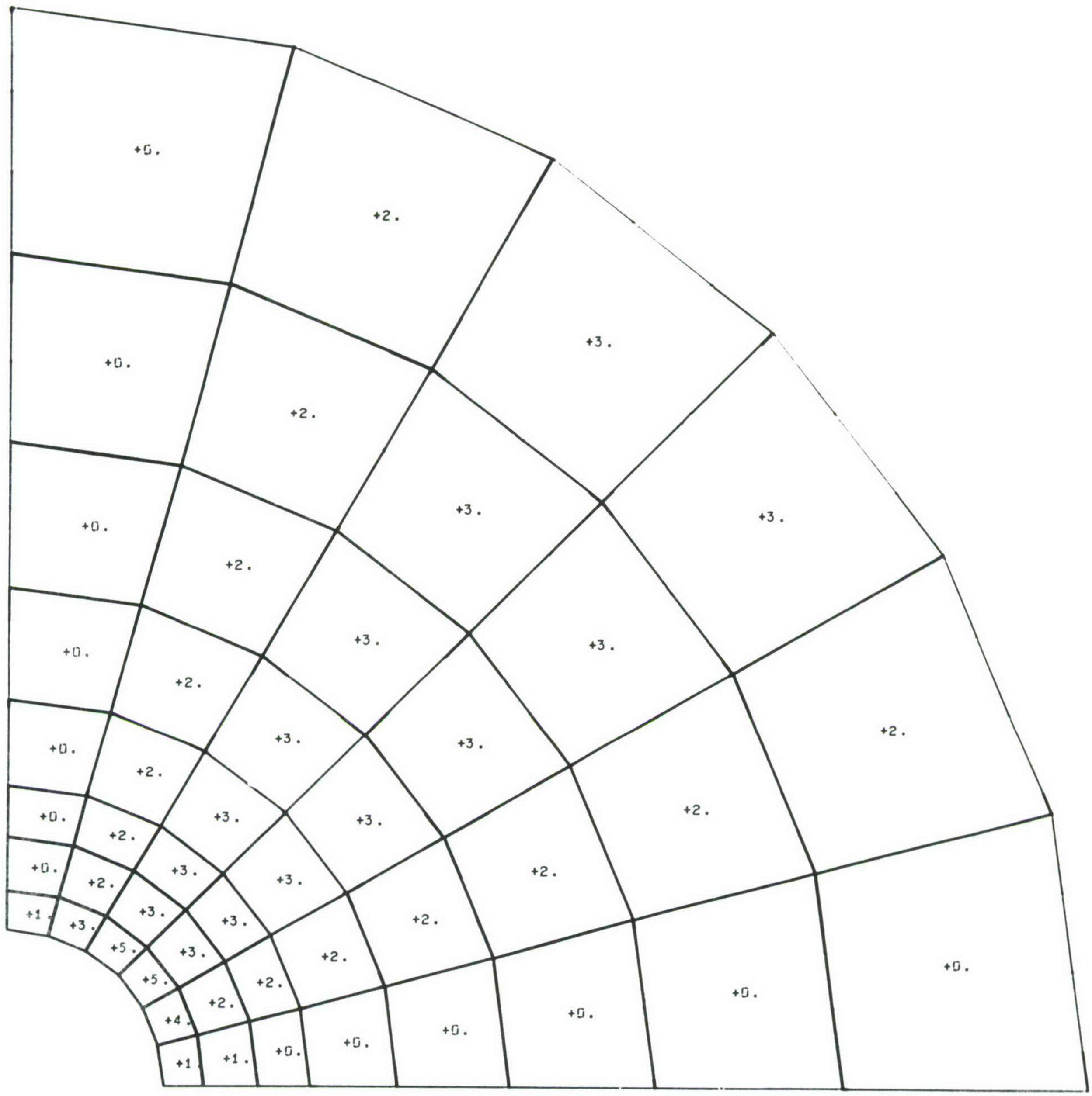


Figure AIII-101 Radial-Tangential Shear Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

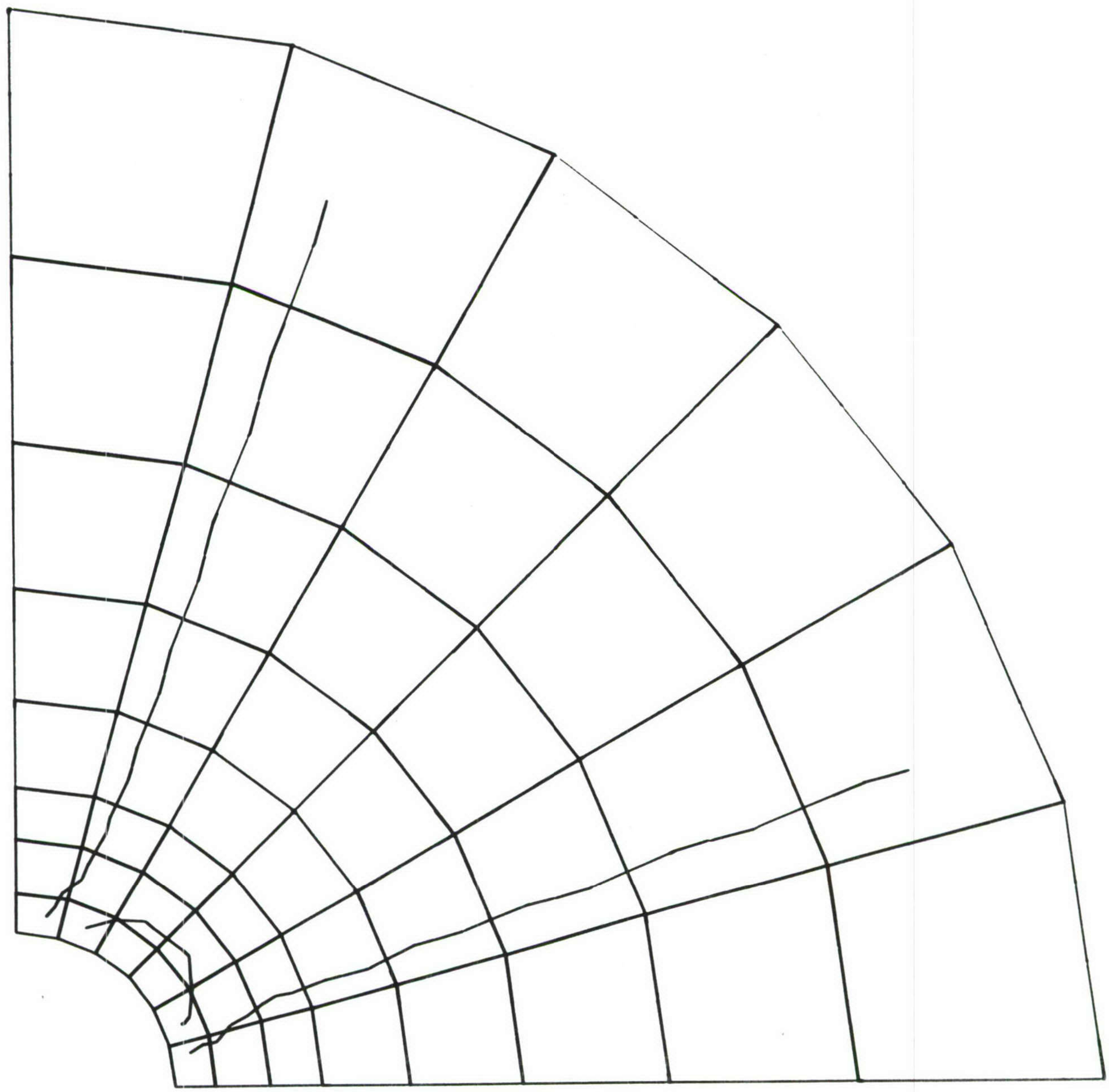


Figure AIII-102 Radial-Tangential Shear Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

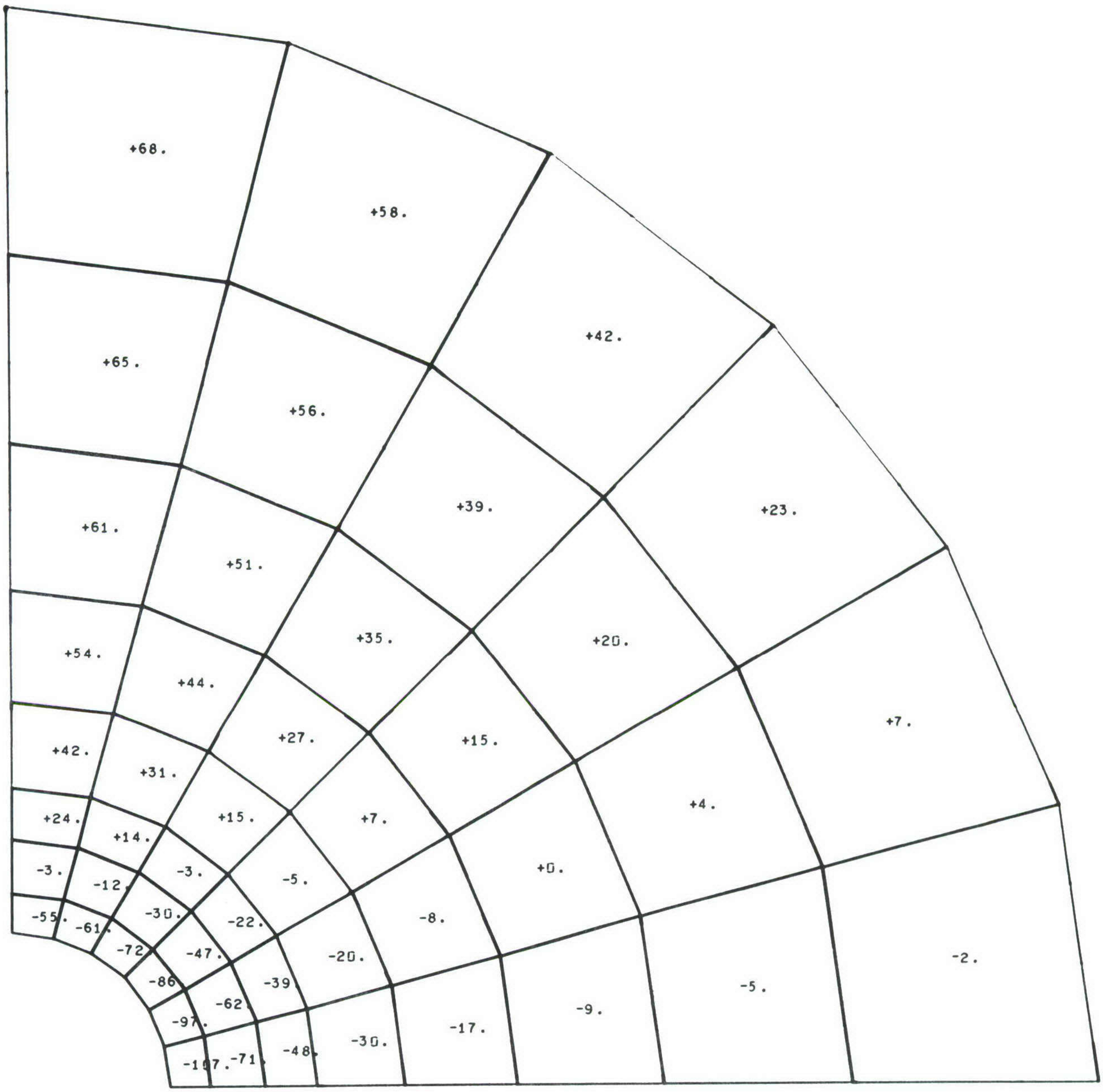


Figure AIII-103 Radial Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

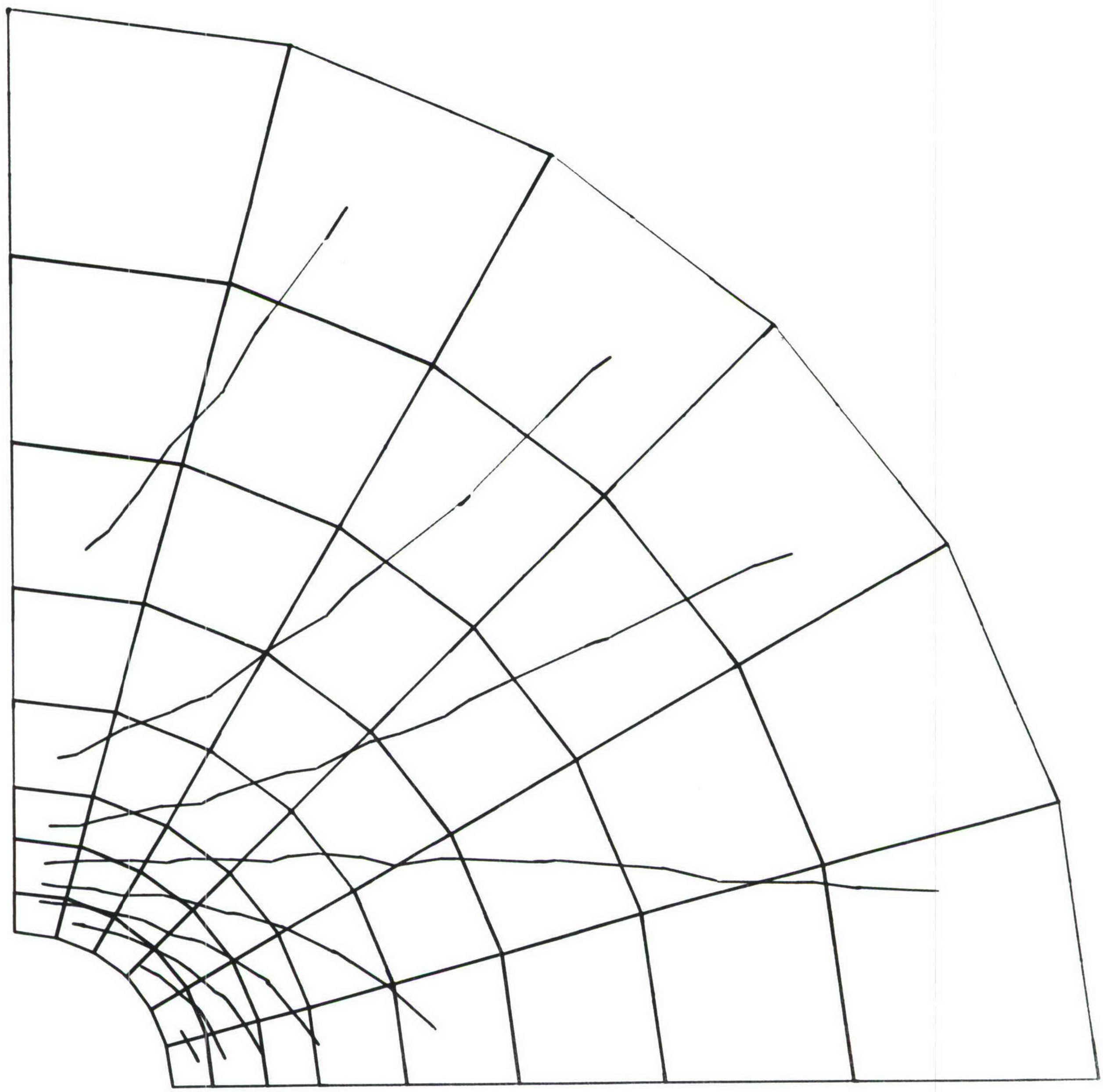


Figure AIII-104 Radial Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

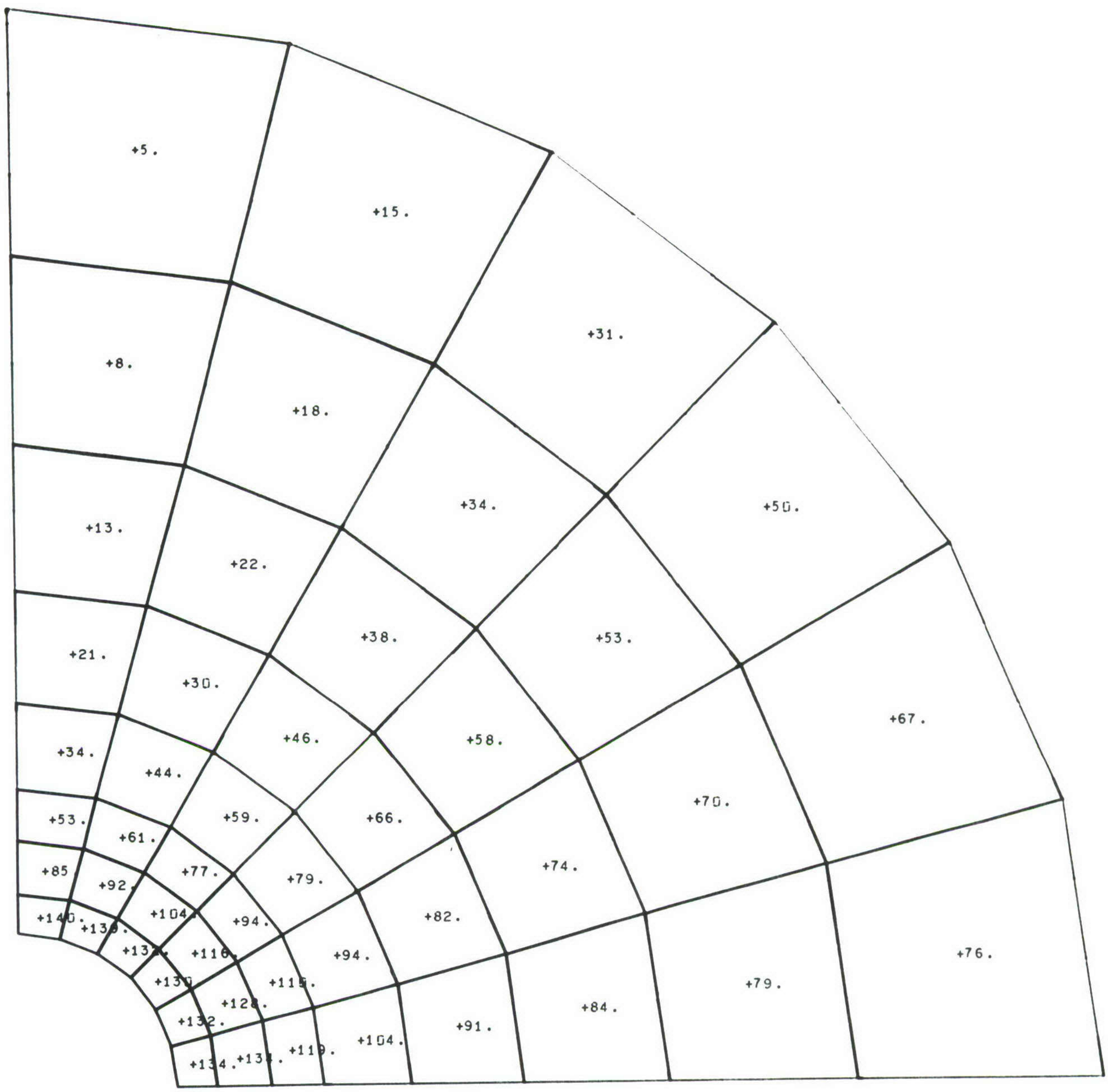


Figure AIII-105 Tangential Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

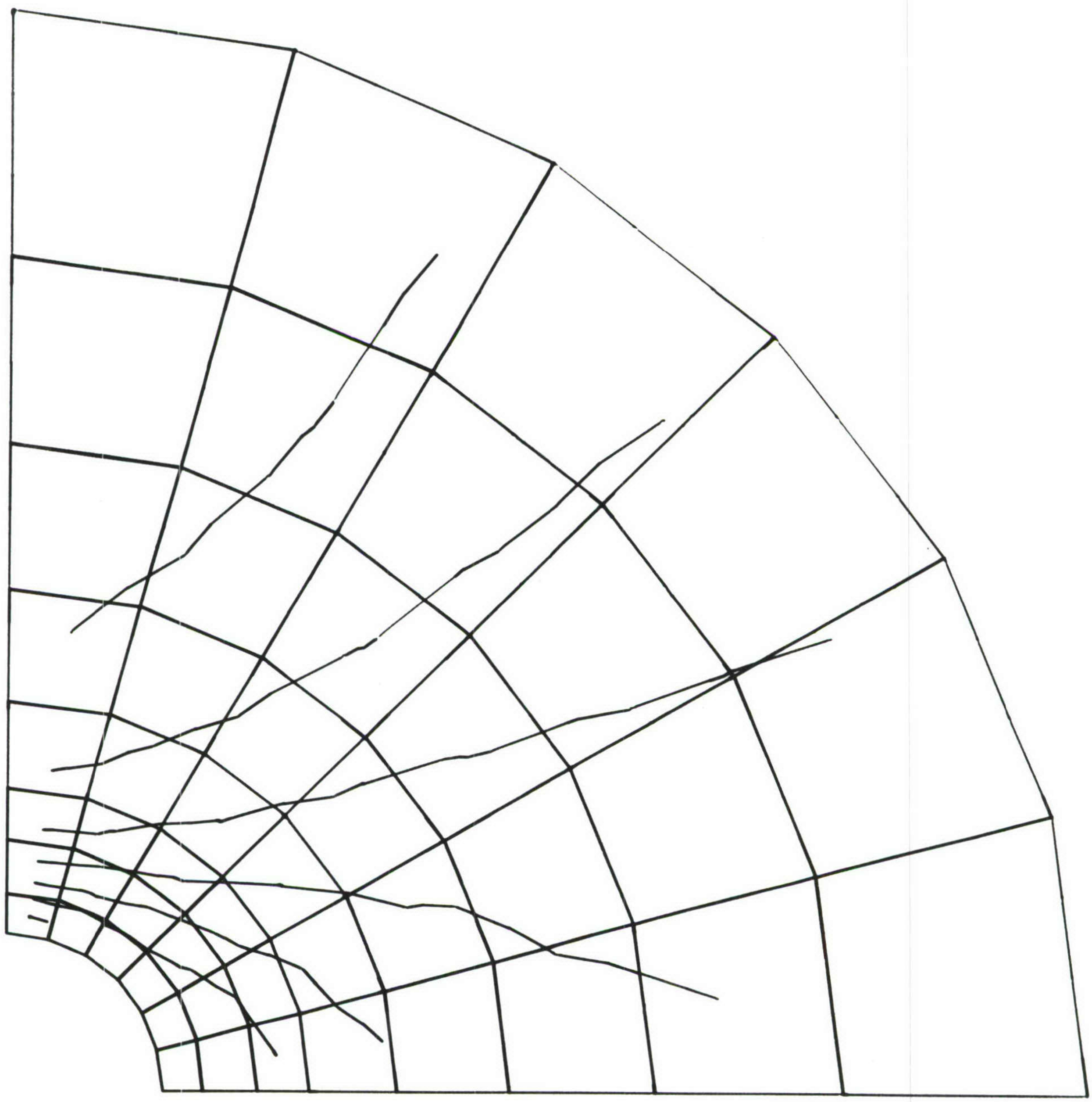


Figure AIII-106 Tangential Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

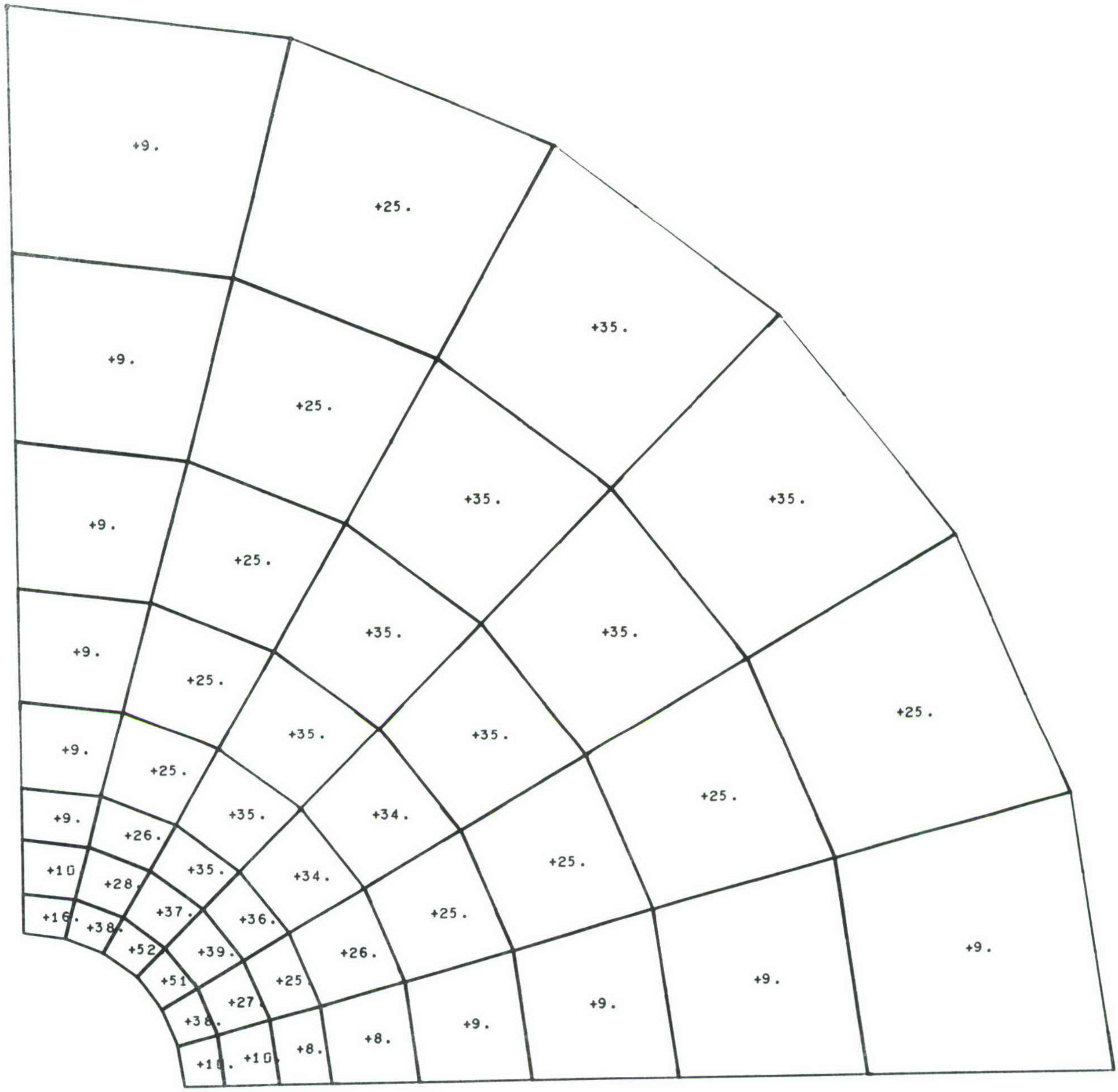


Figure AIII-107 Radial-Tangential Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

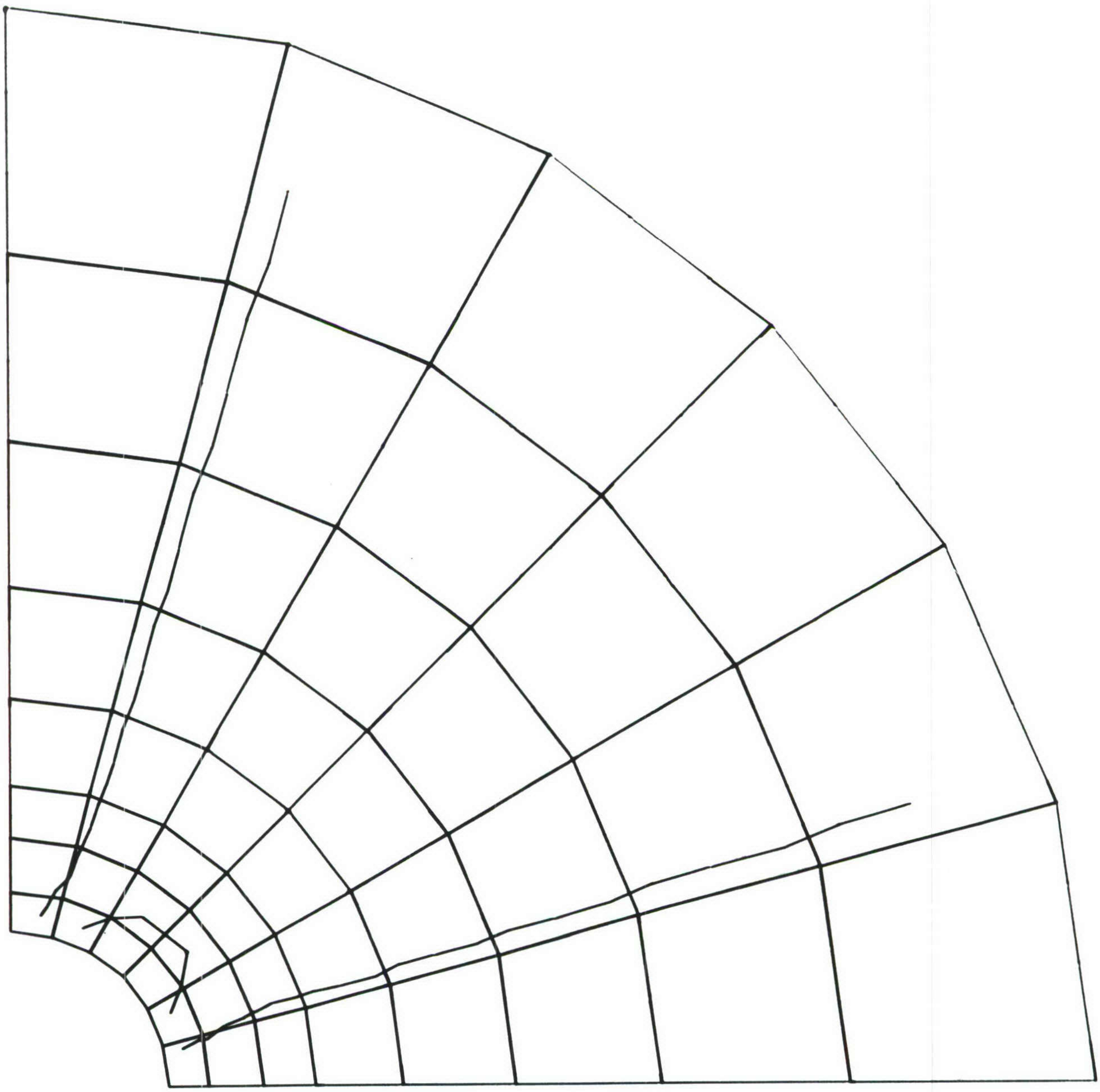


Figure AIII-108 Radial-Tangential Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

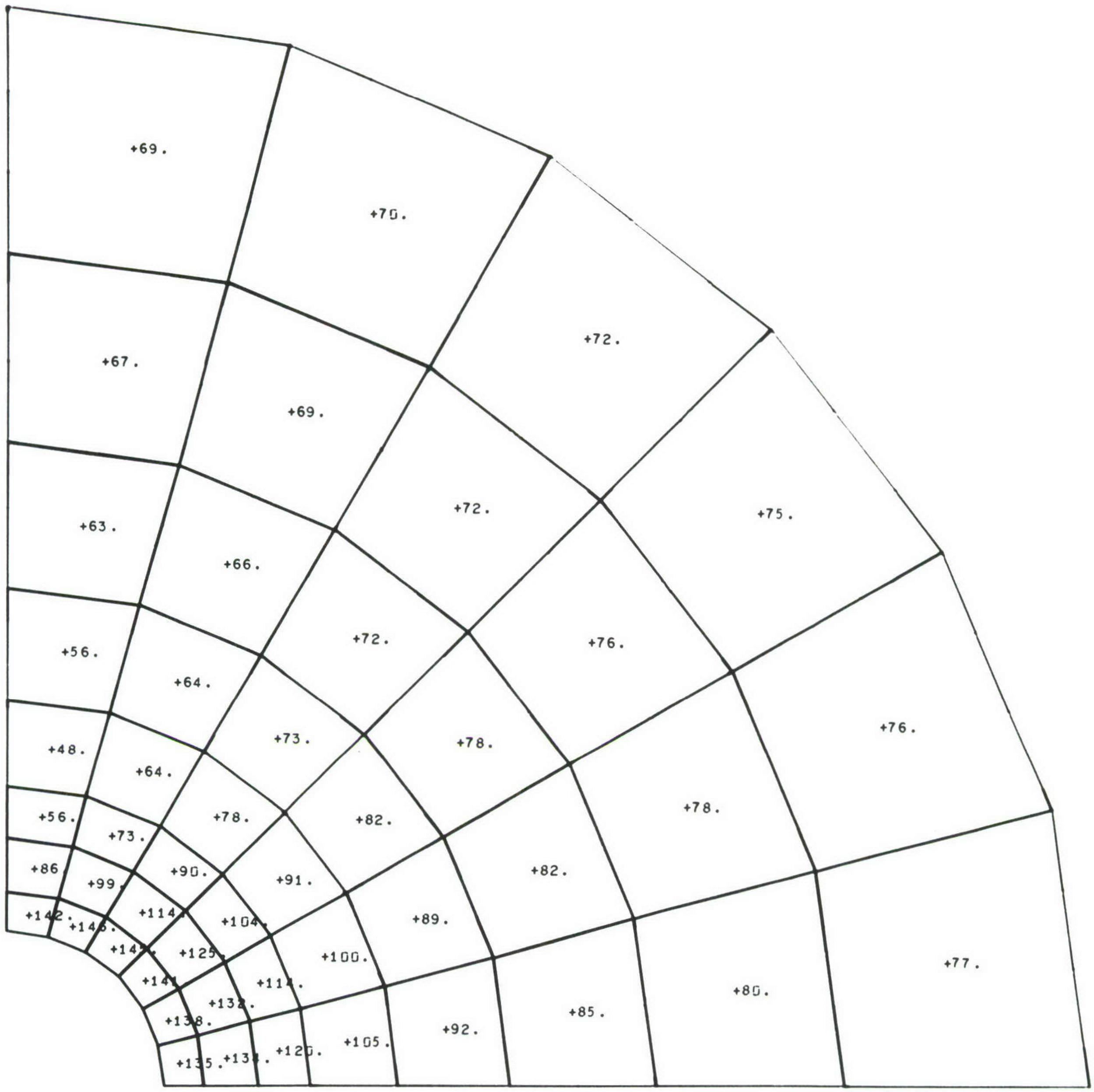


Figure AIII-109 First Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Intereference; 35% Uniaxial Load

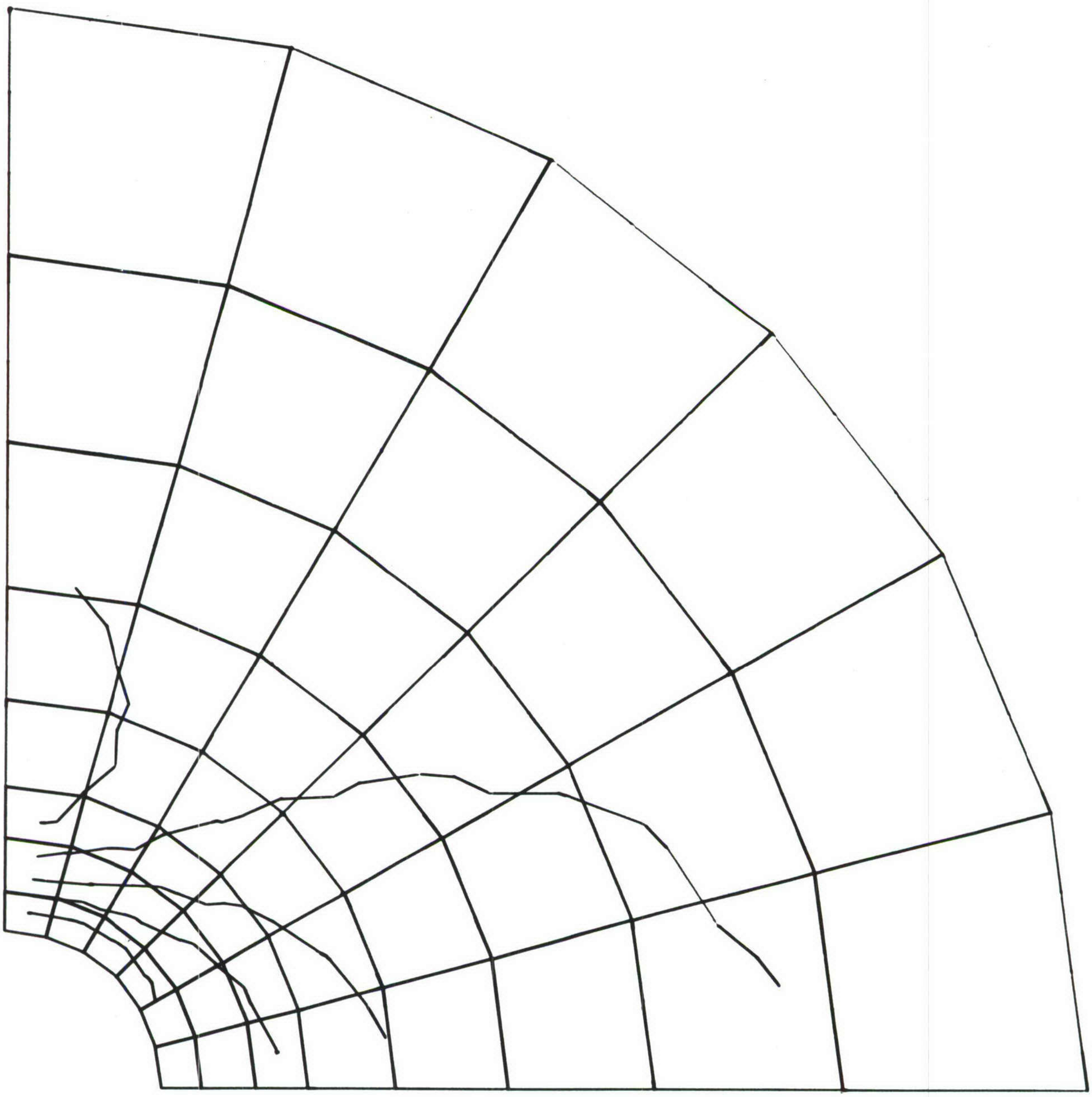


Figure AIII-110 First Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

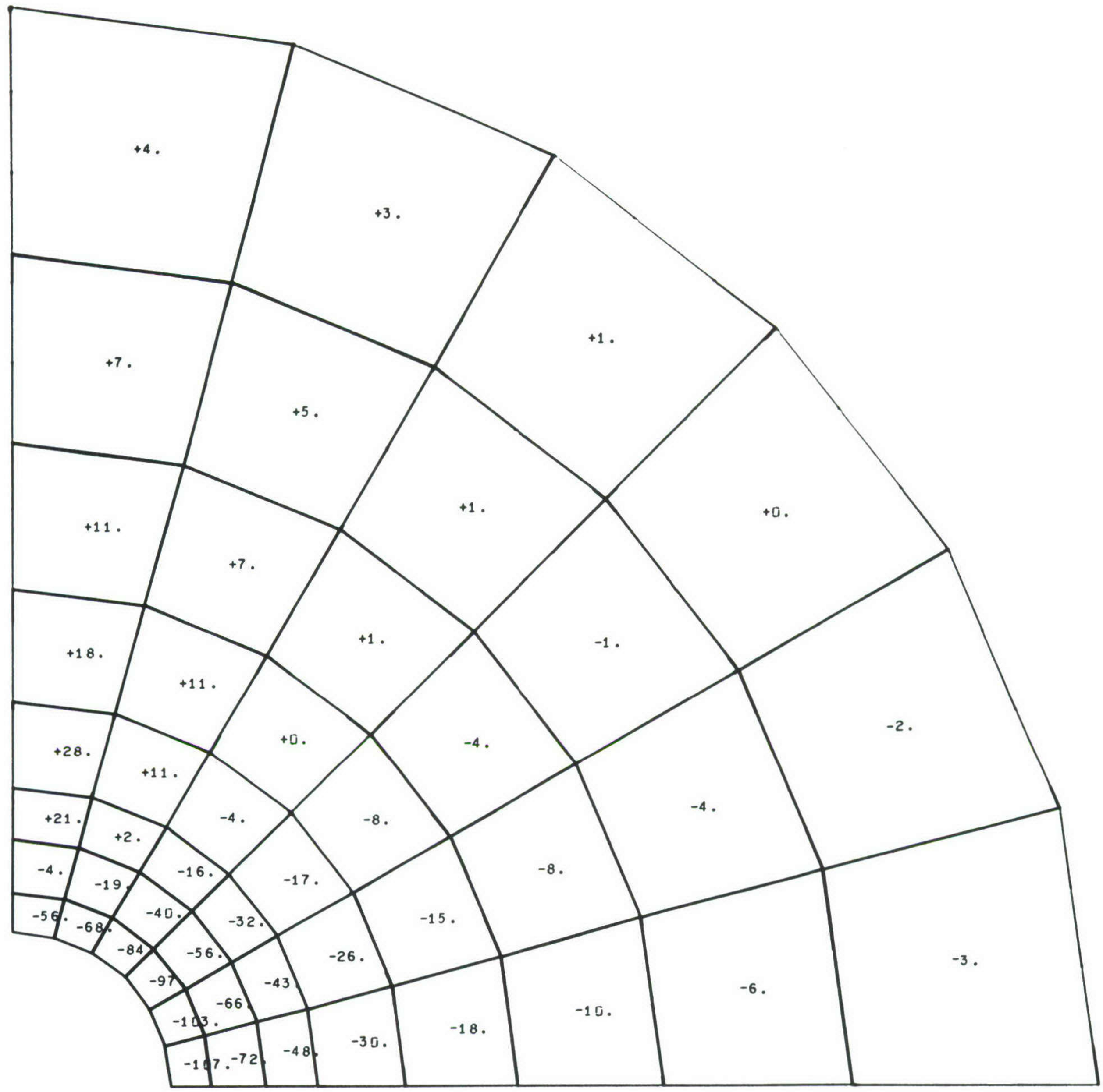


Figure AIII-111 Second Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

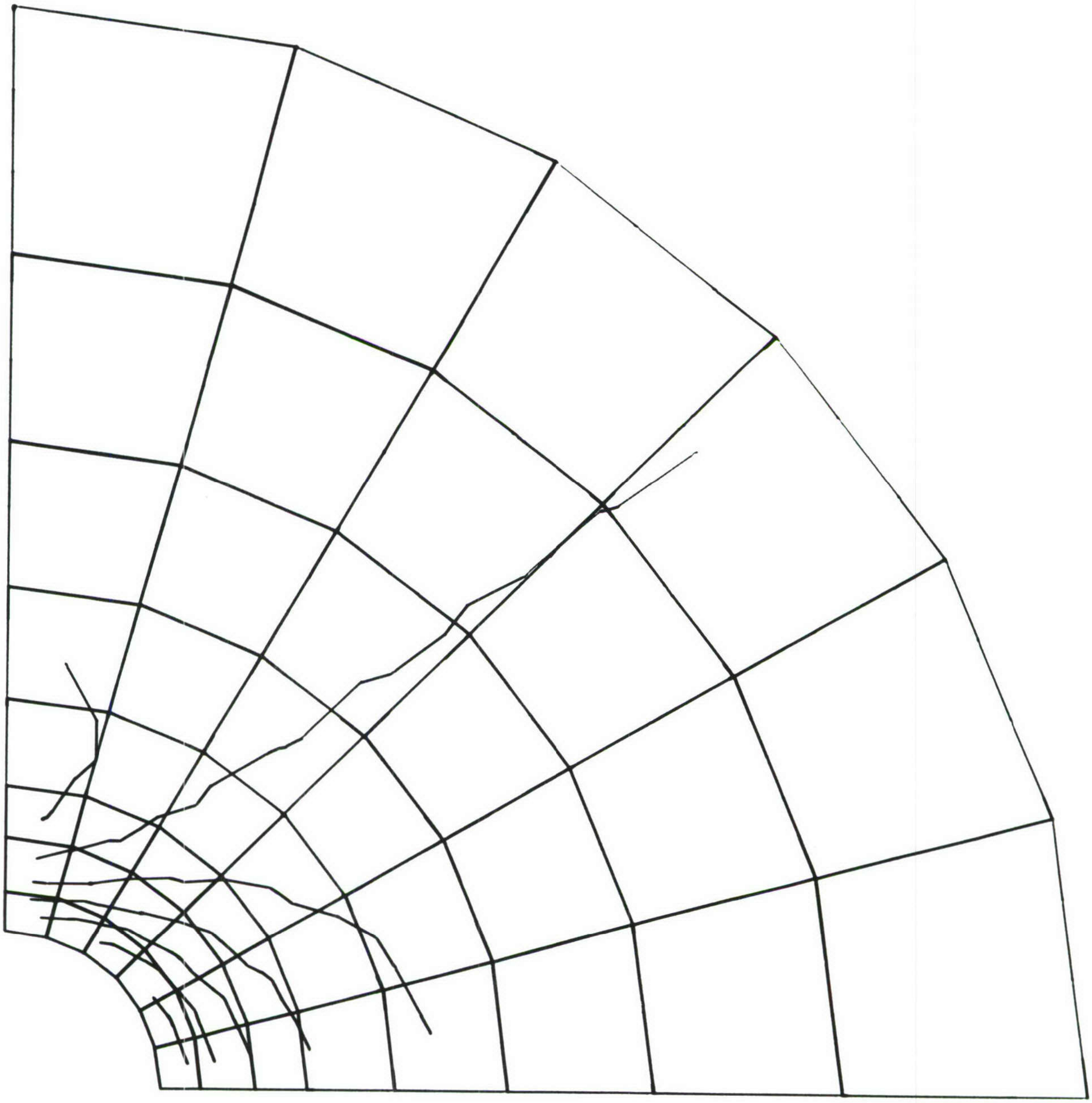


Figure AIII-112 Second Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

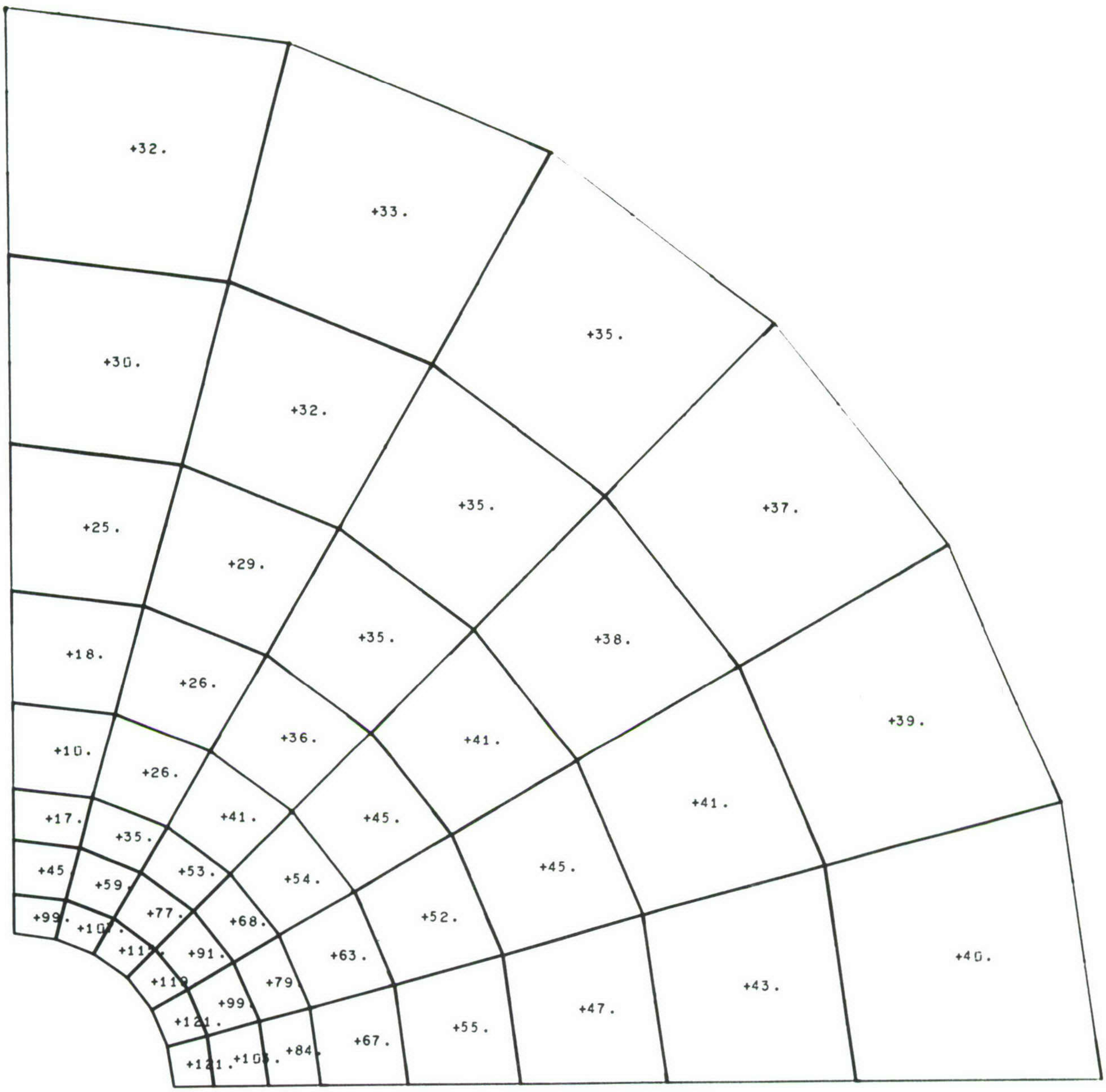


Figure AIII-113 Principal Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

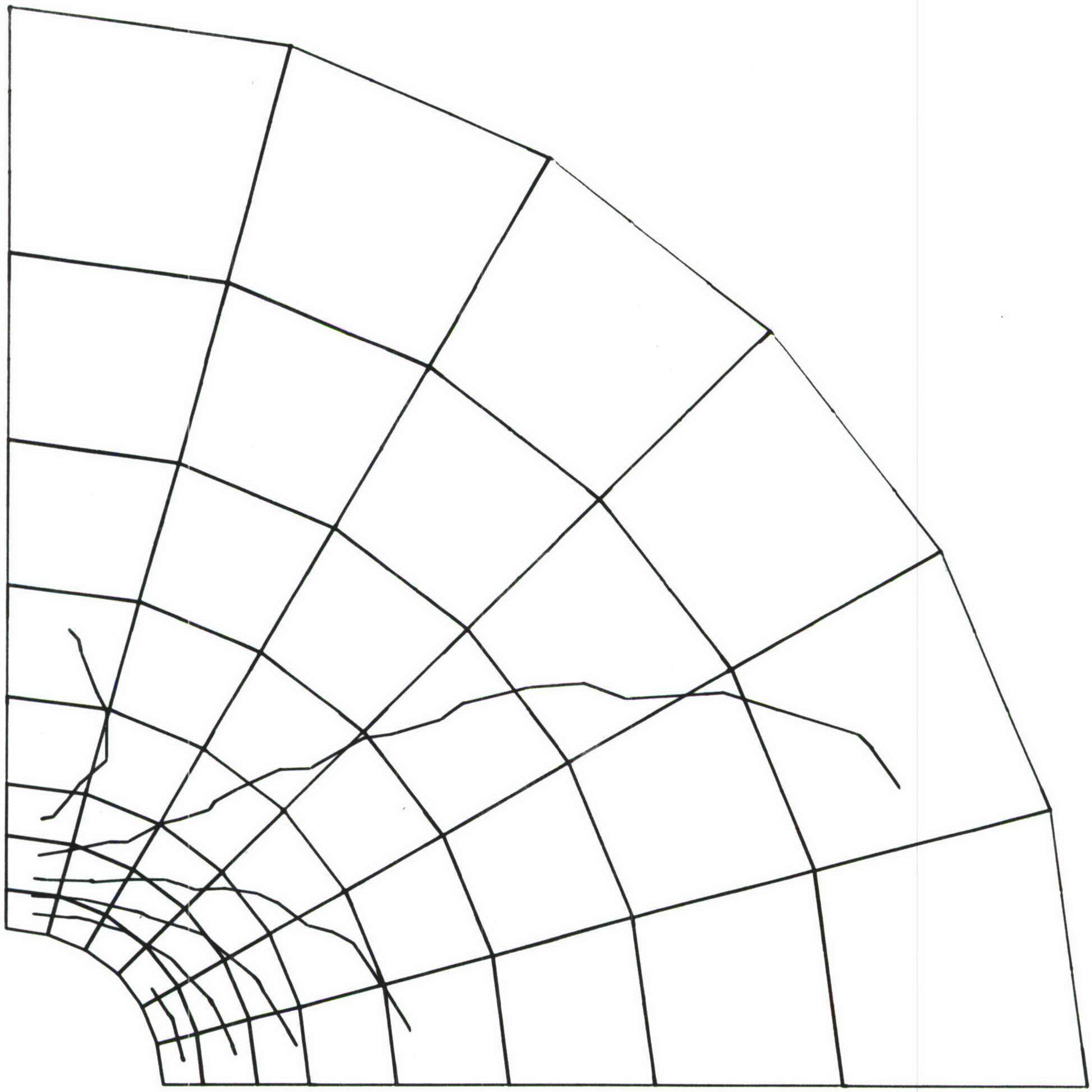


Figure AIII-114 Principal Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 35% Uniaxial Load

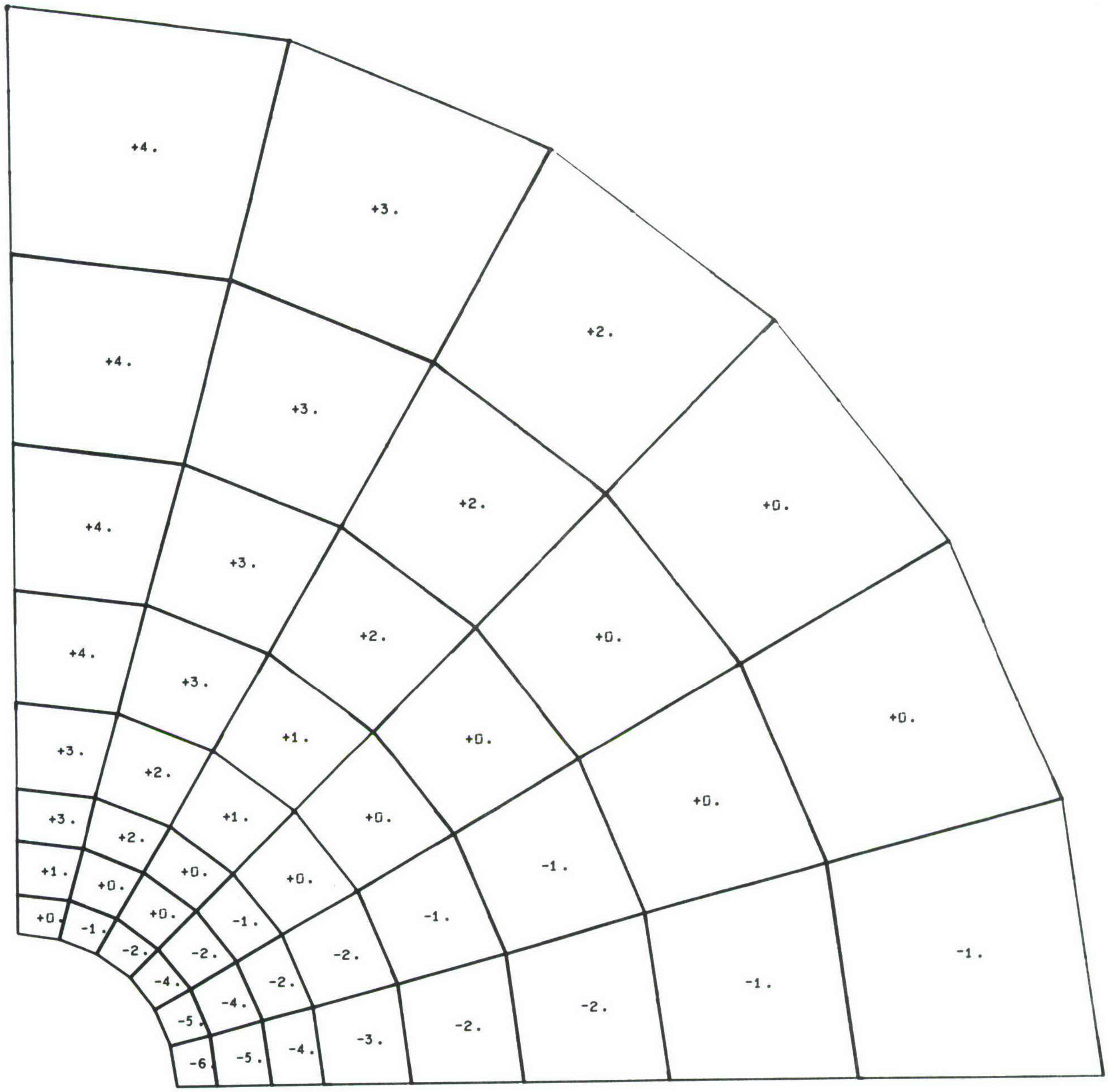


Figure AIII-115 Radial Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

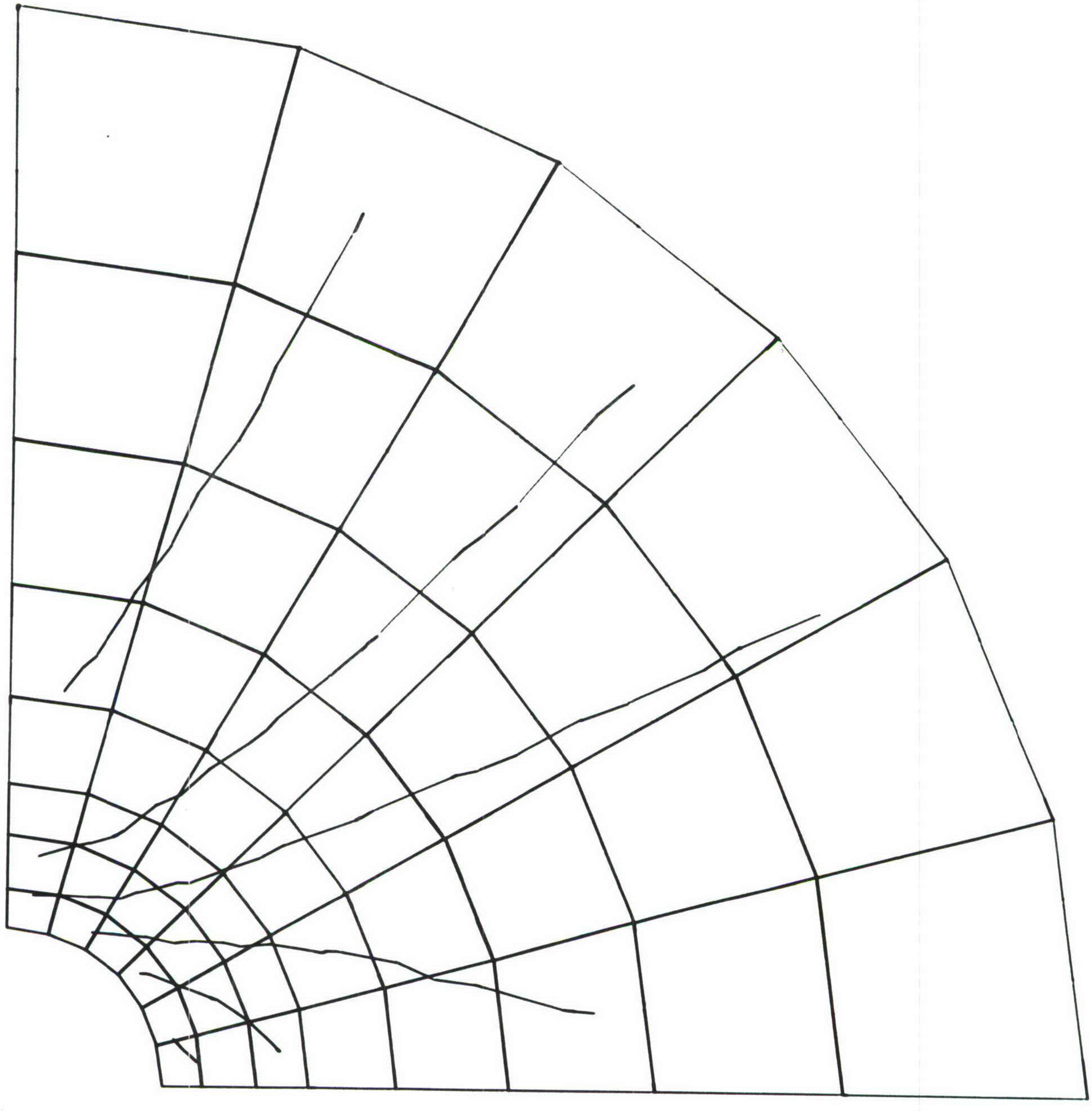


Figure AIII-116 Radial Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

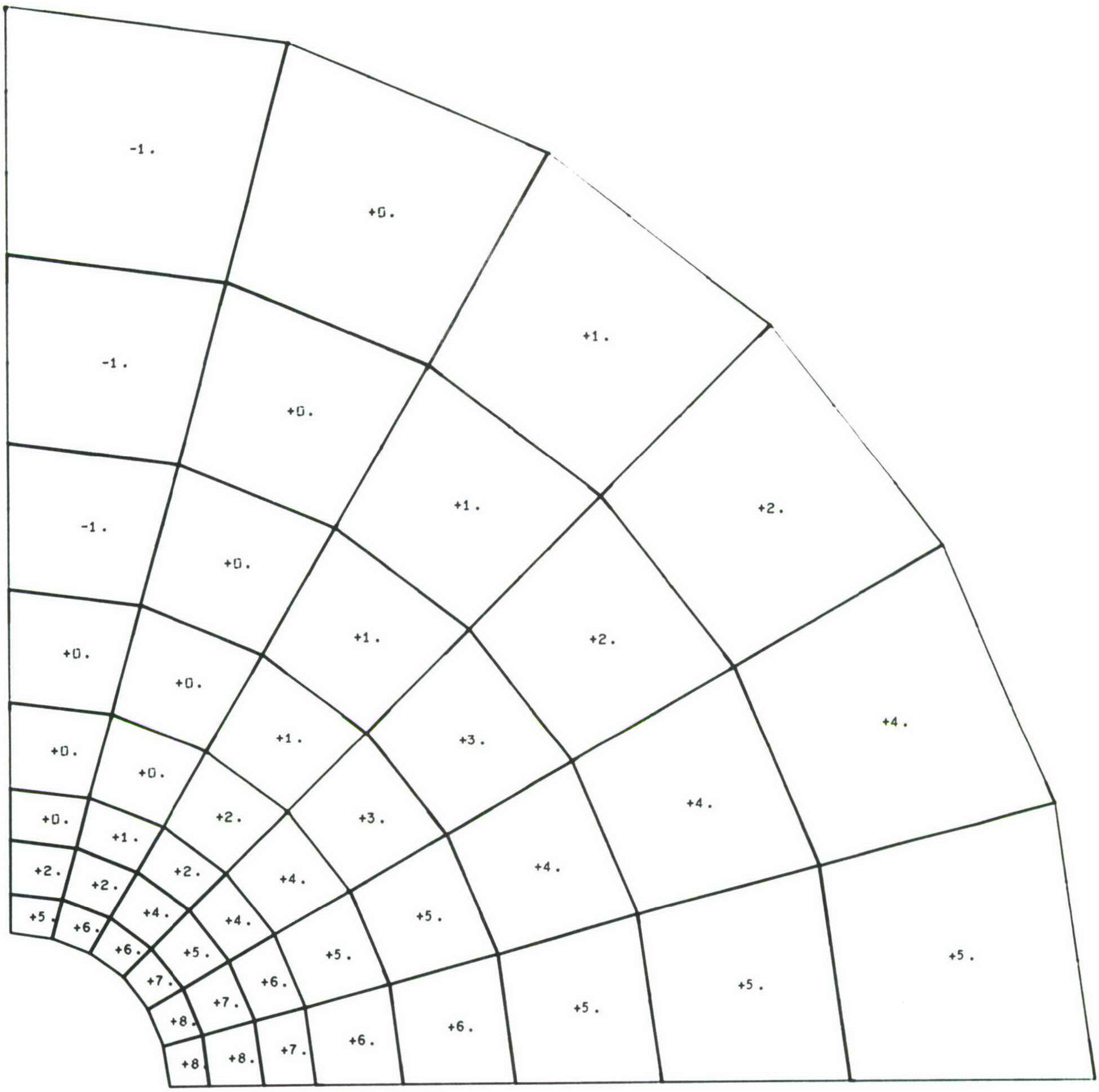


Figure AIII-117 Tangential Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

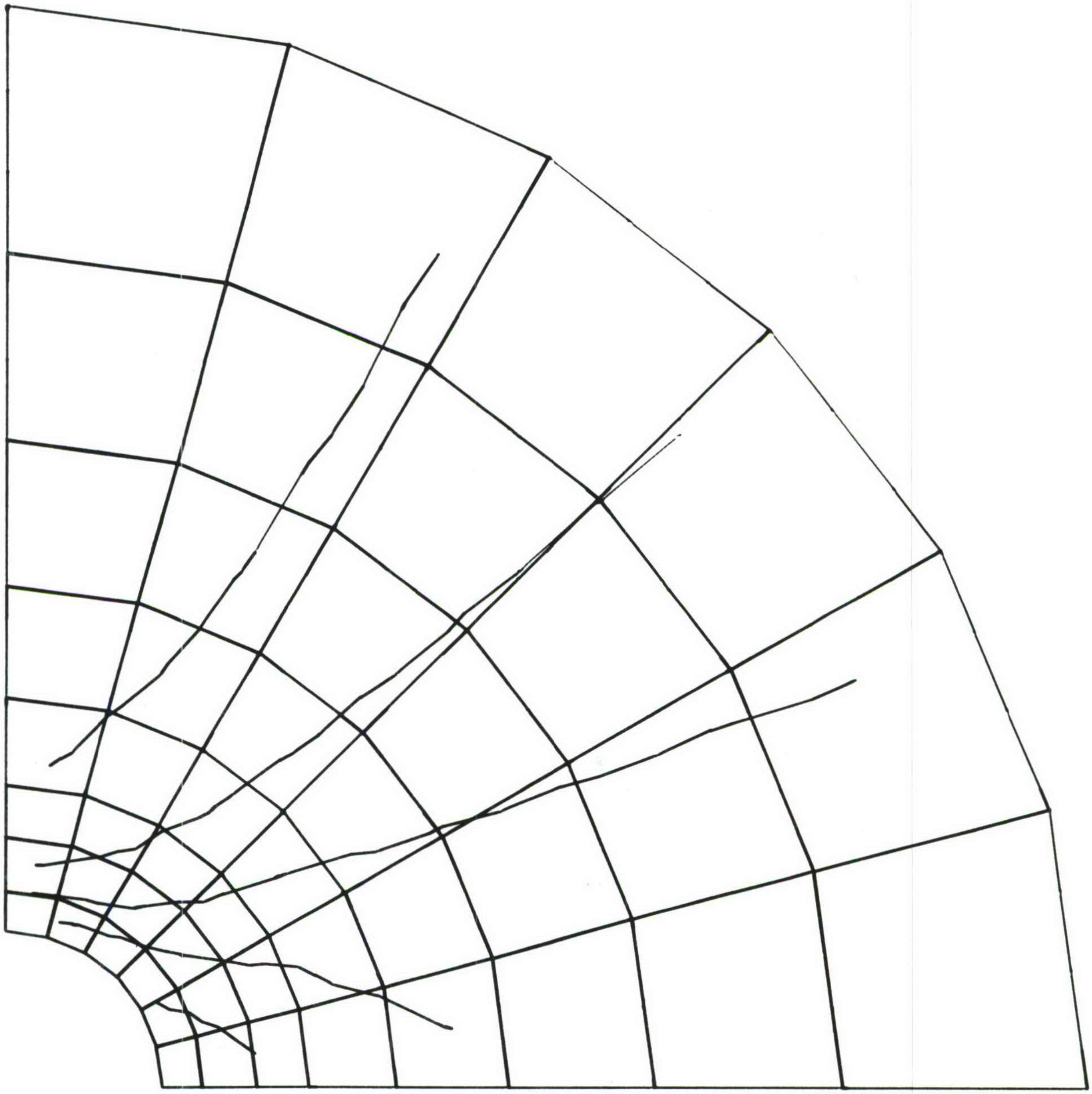


Figure AIII-118 Tangential Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

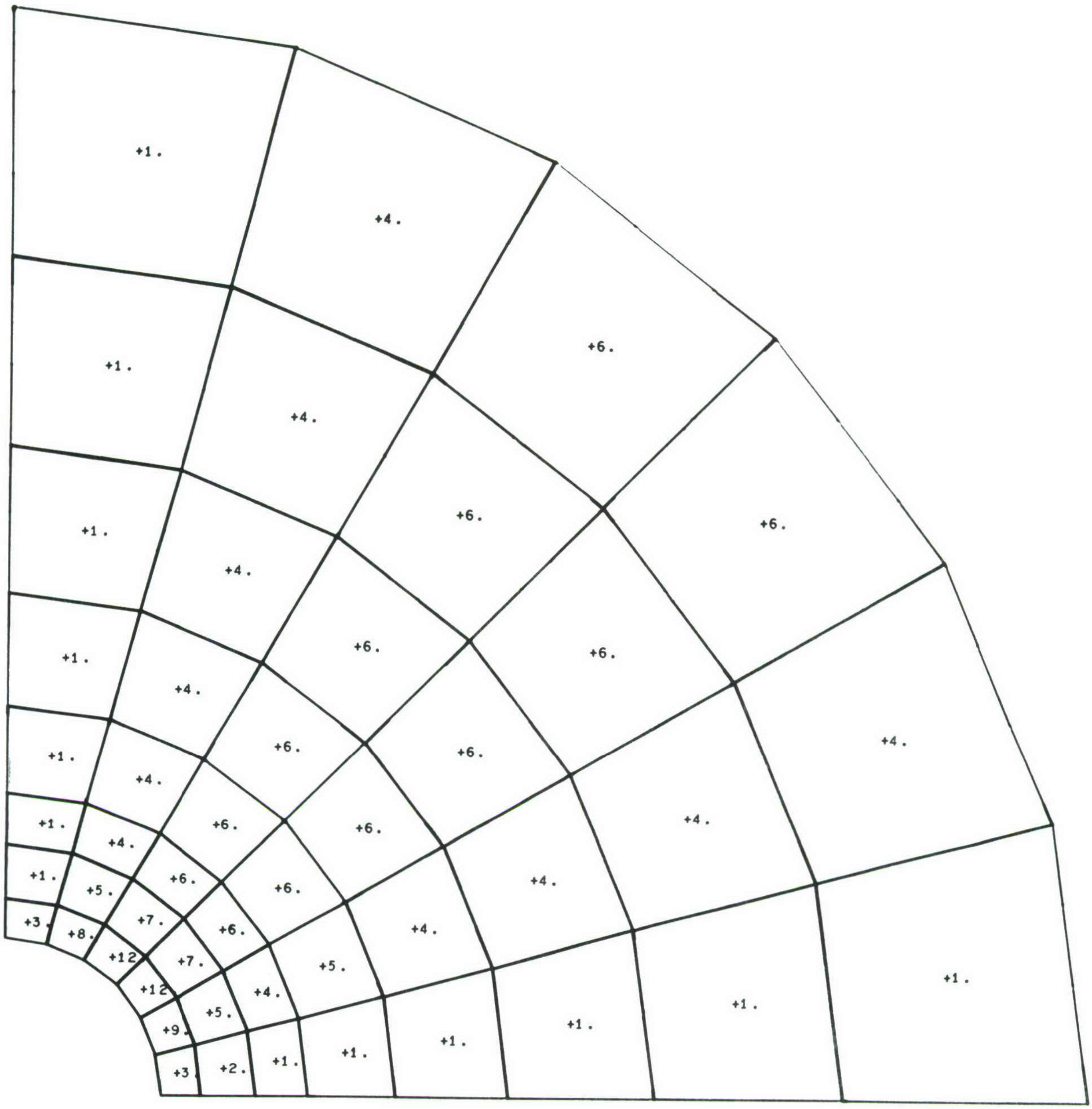


Figure AIII-119 Radial-Tangential Shear Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

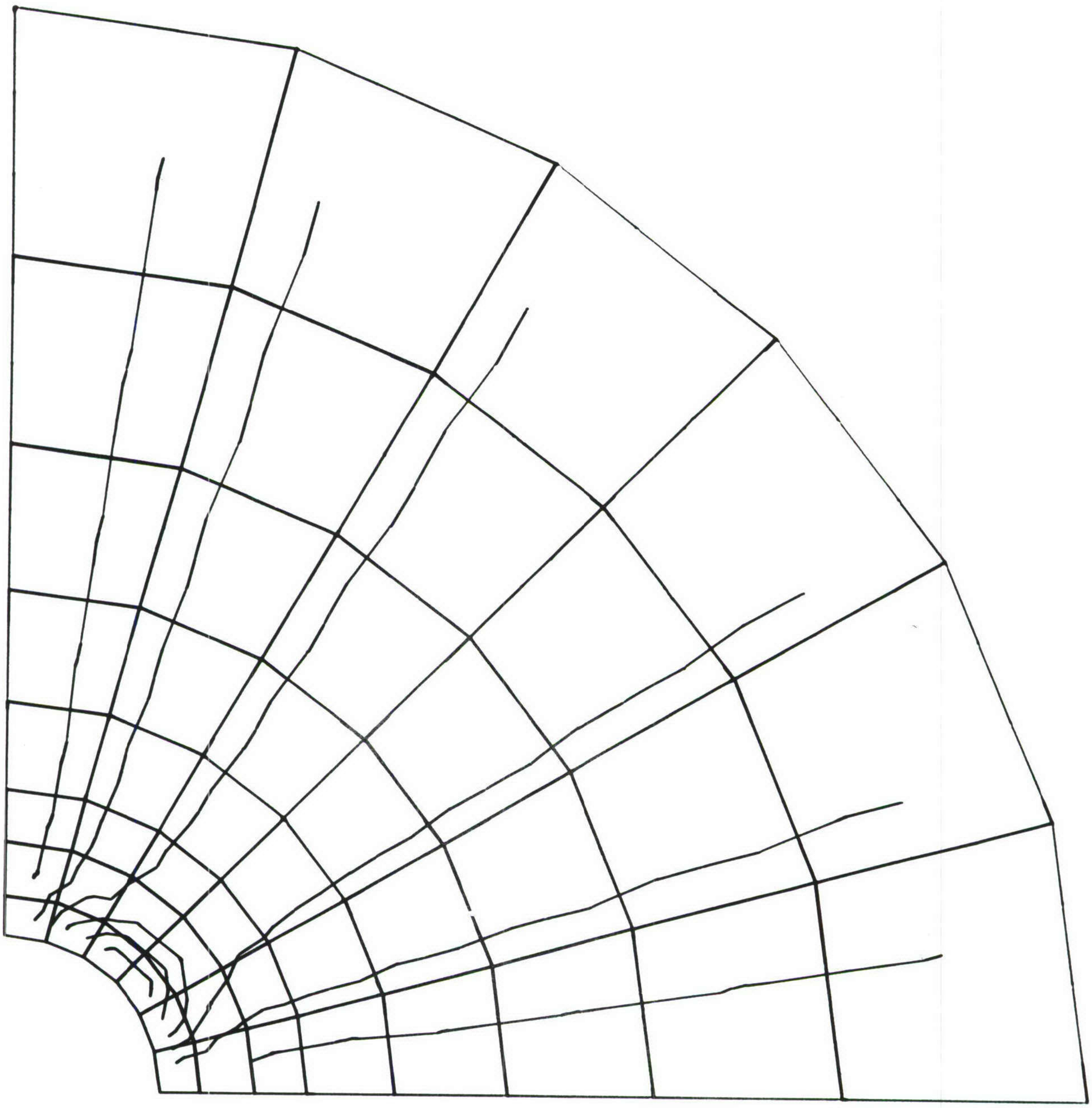


Figure AIII-120 Radial-Tangential Shear Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

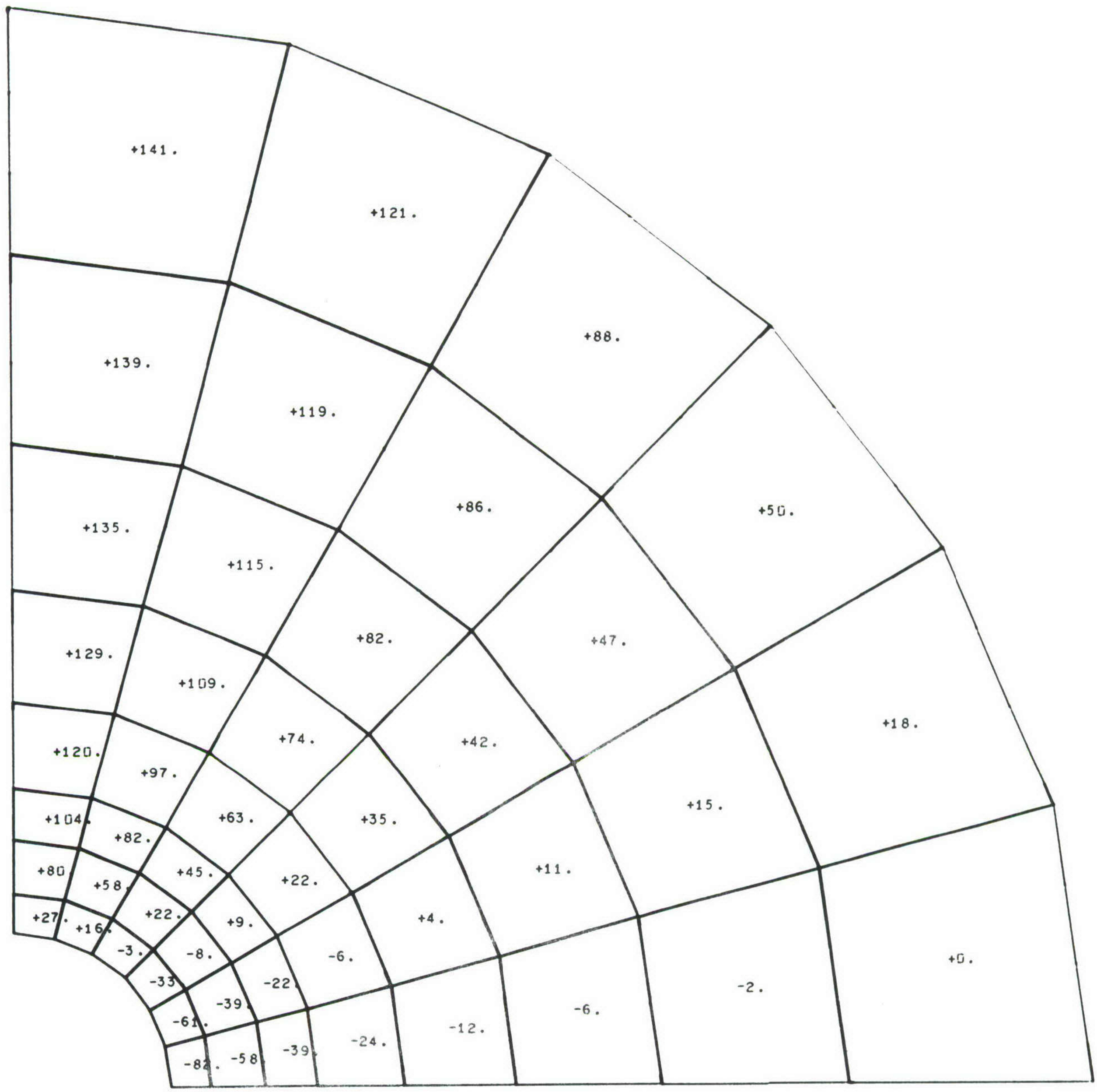


Figure AIII-121 Radial Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

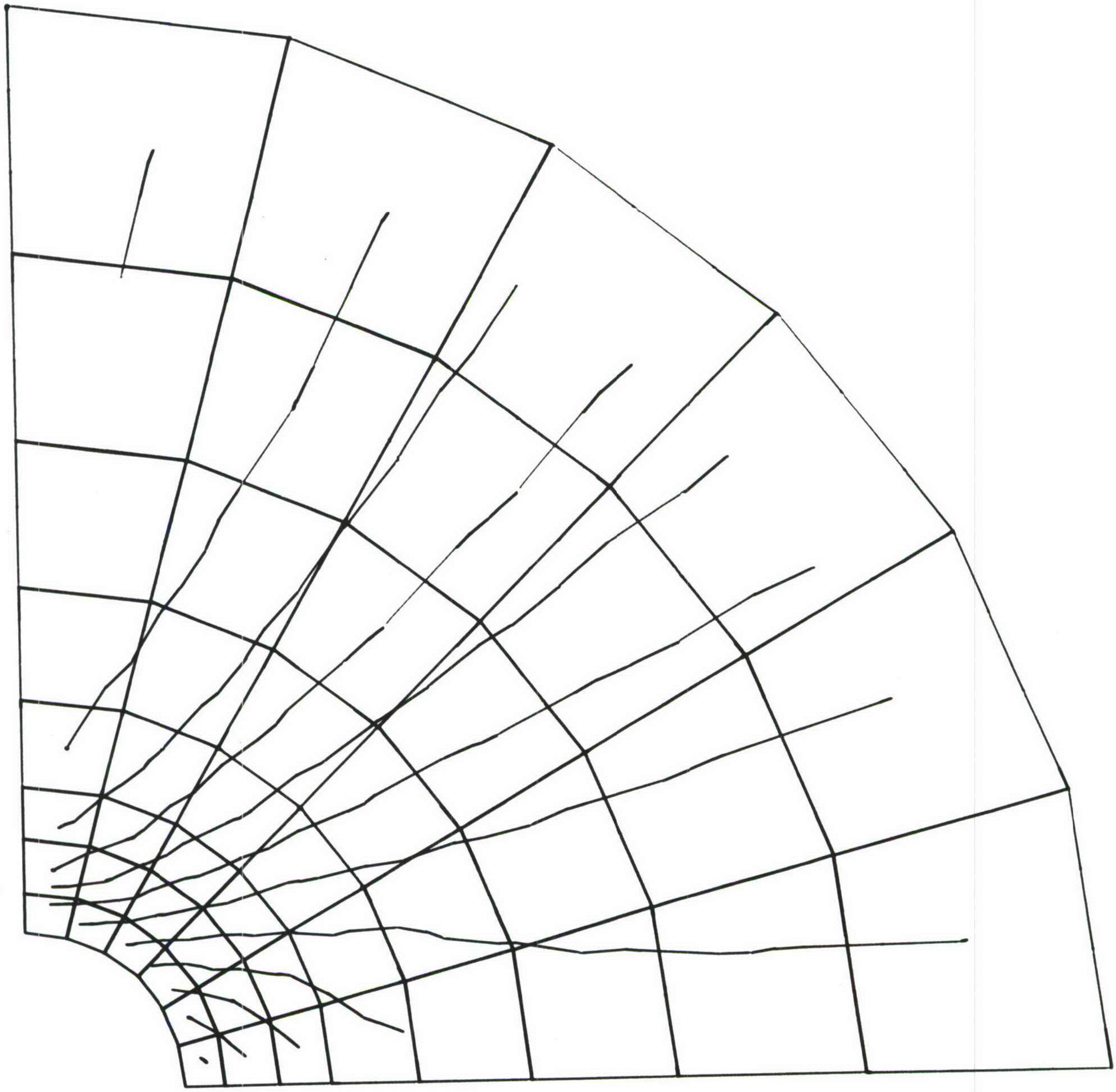


Figure AIII-122 Radial Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

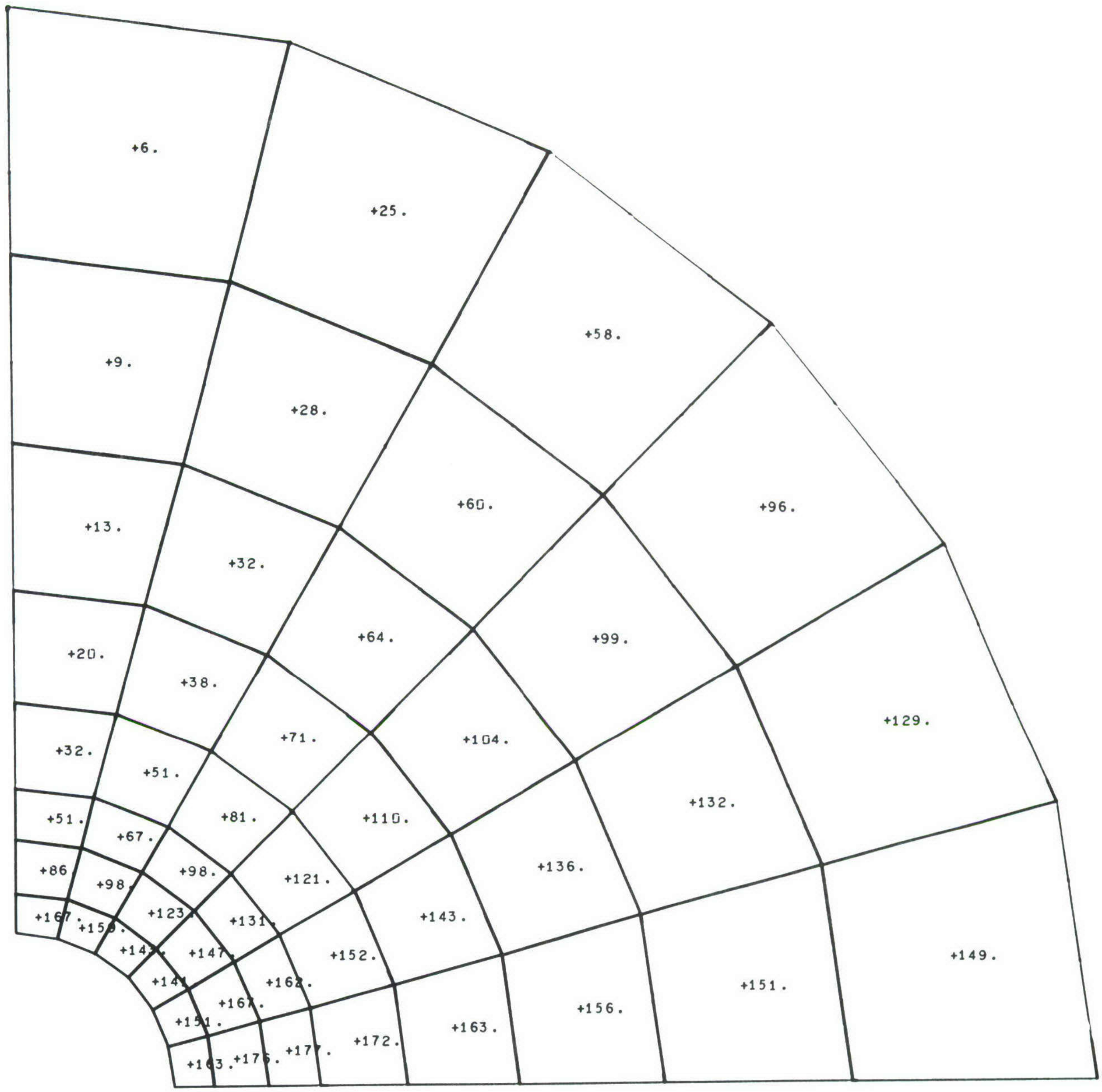


Figure AIII-123 Tangential Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

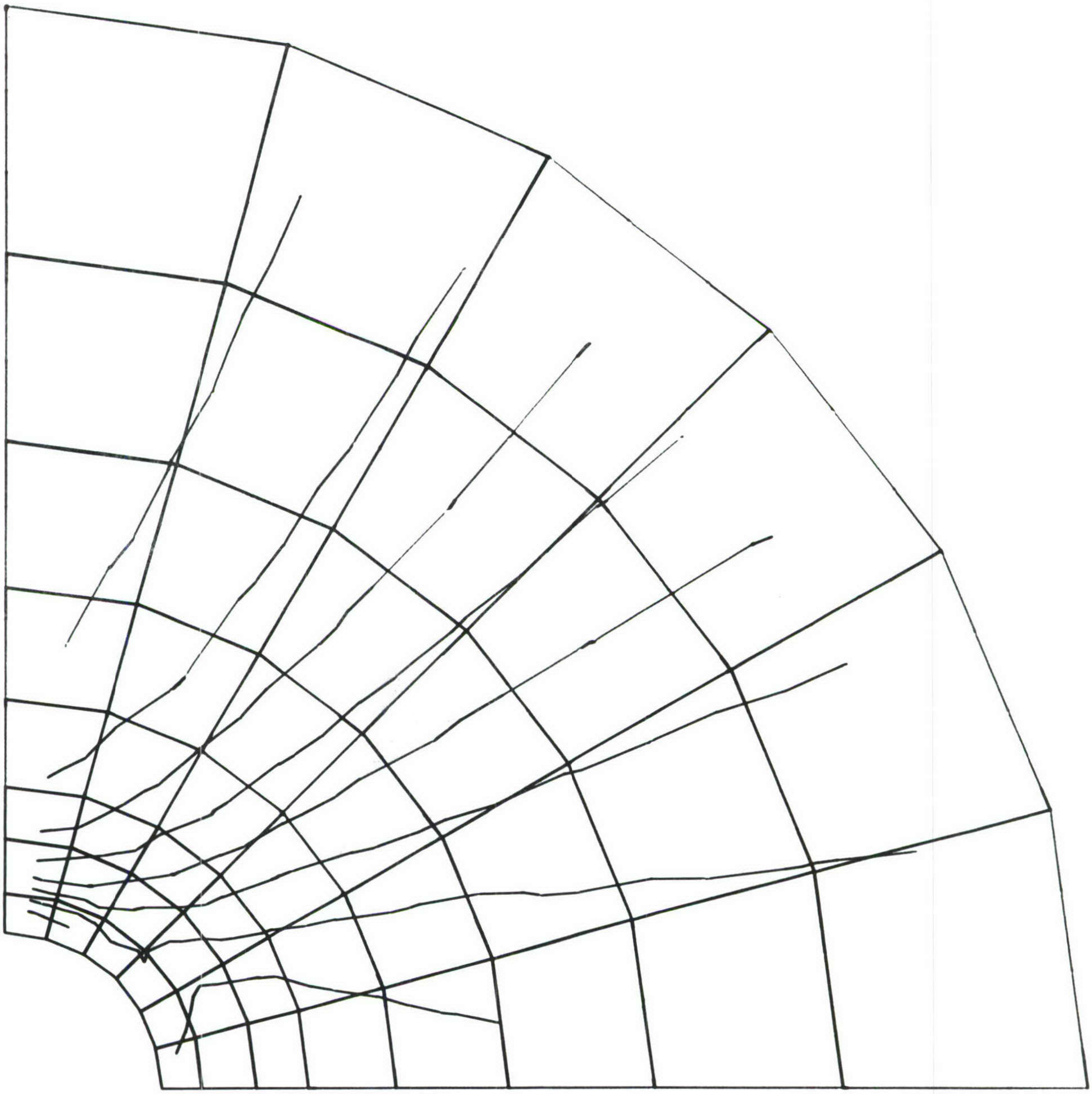


Figure AIII-124 Tangential Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

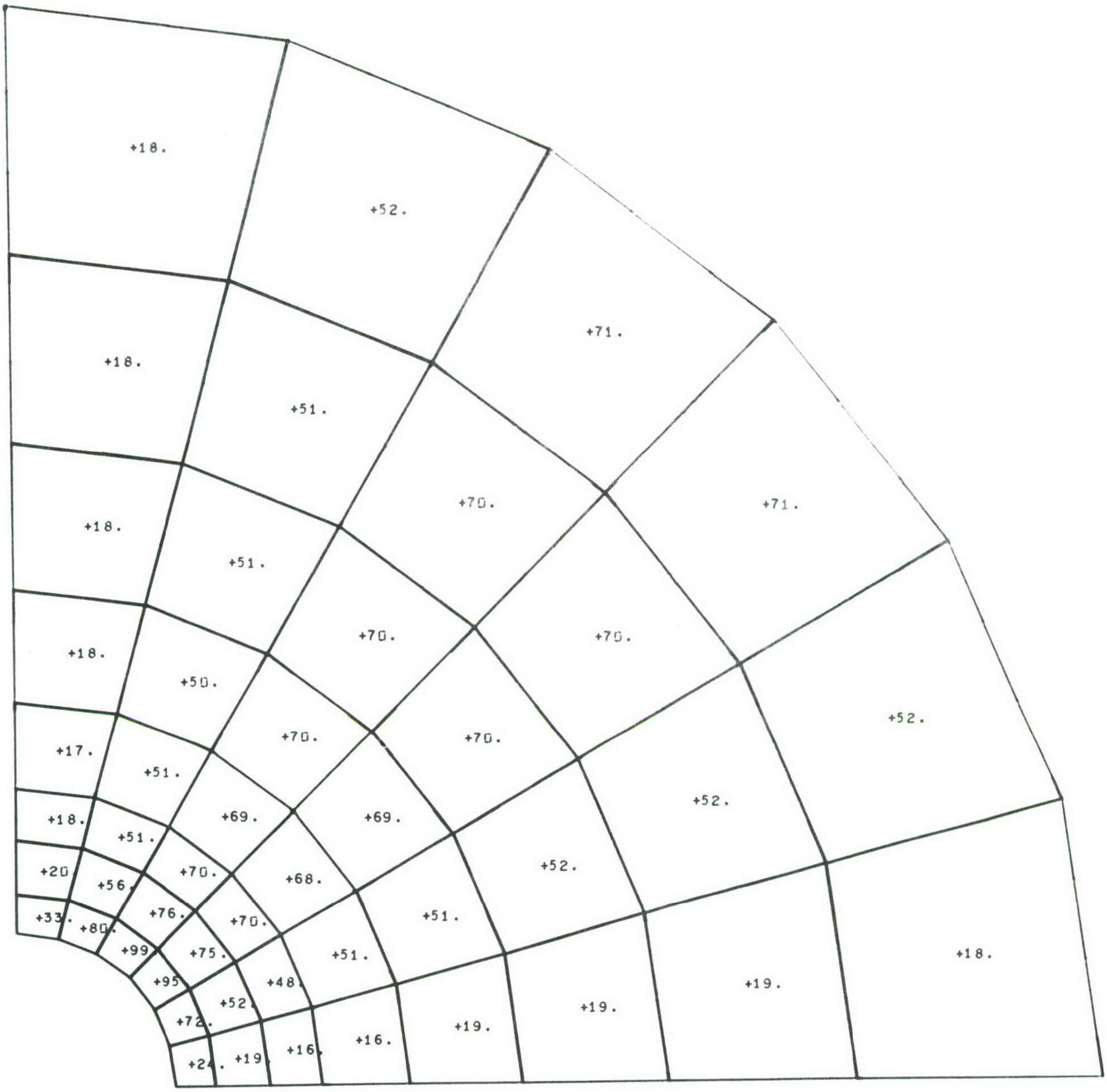


Figure AIII-125 Radial-Tangential Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

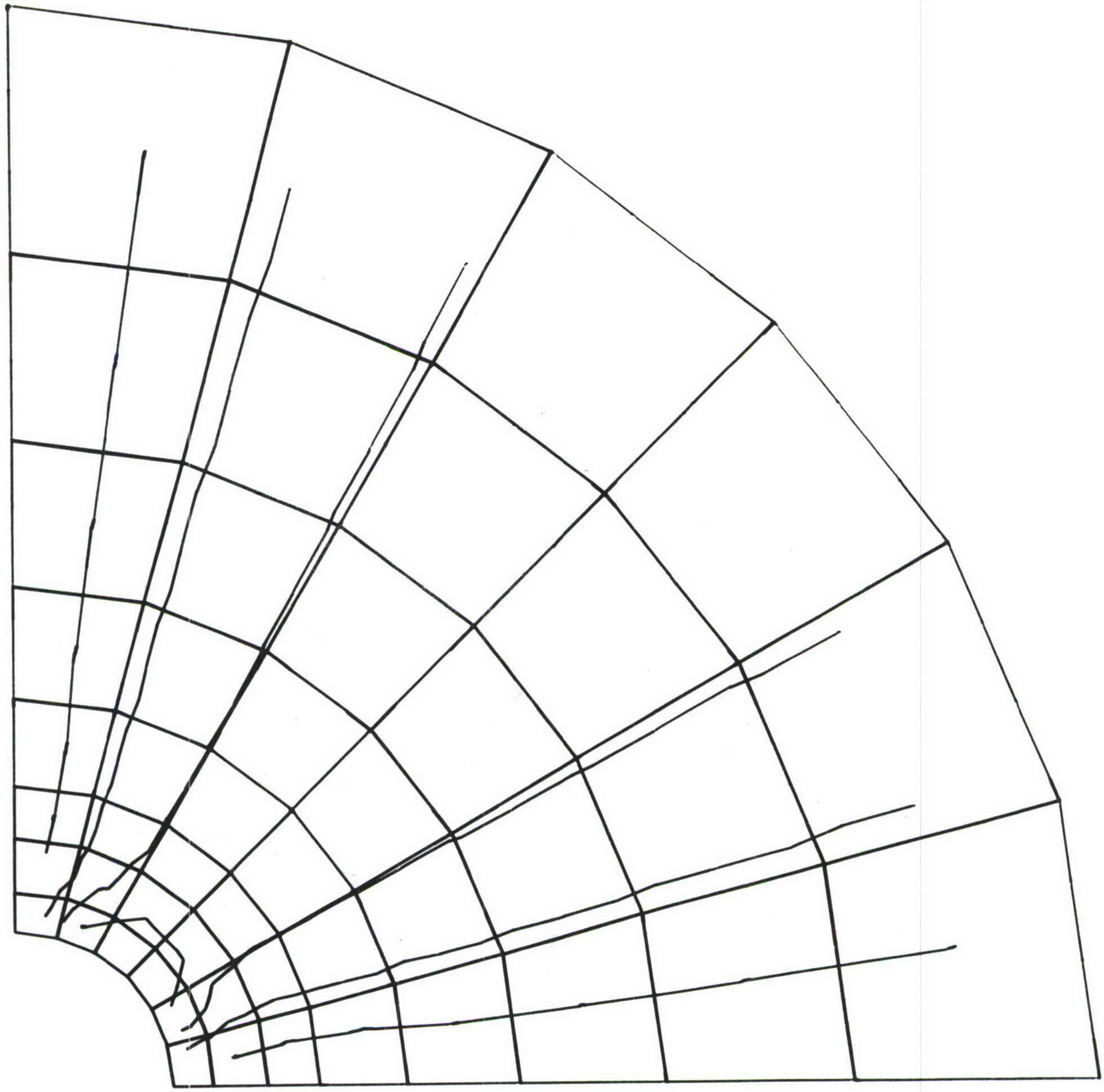


Figure AIII-126 Radial Tangential Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

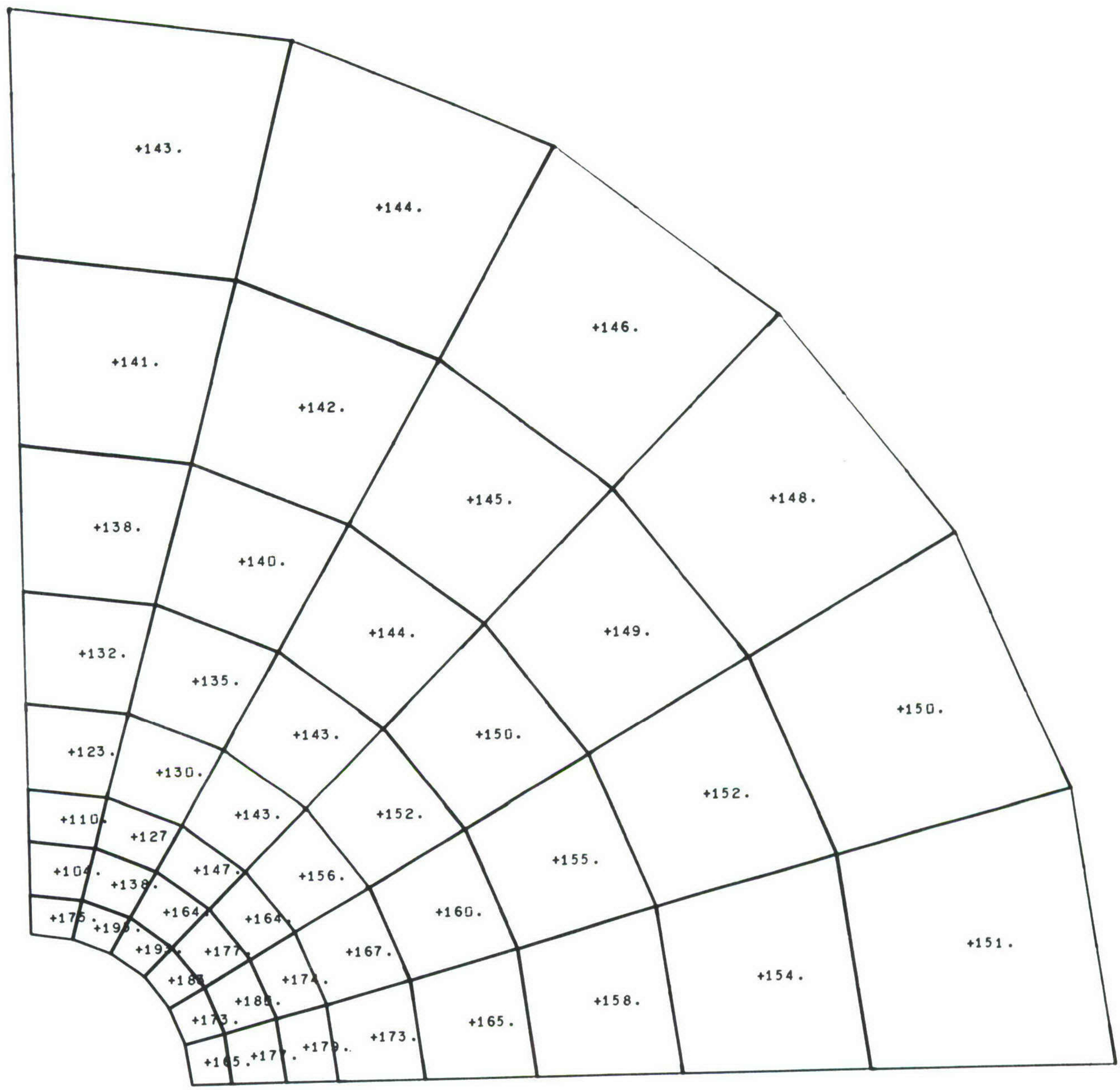


Figure AIII-127 First Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

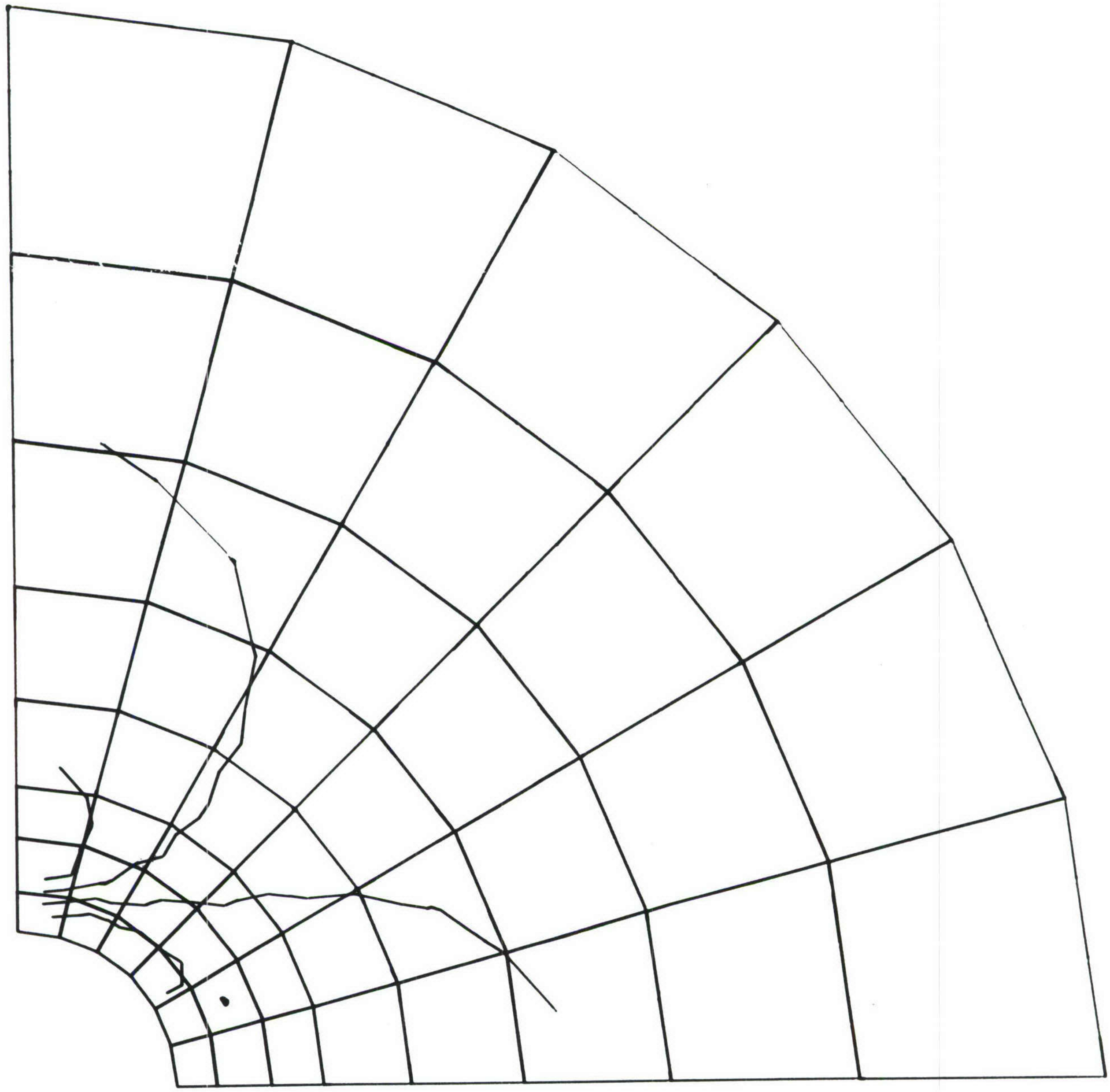


Figure AIII-128 First Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

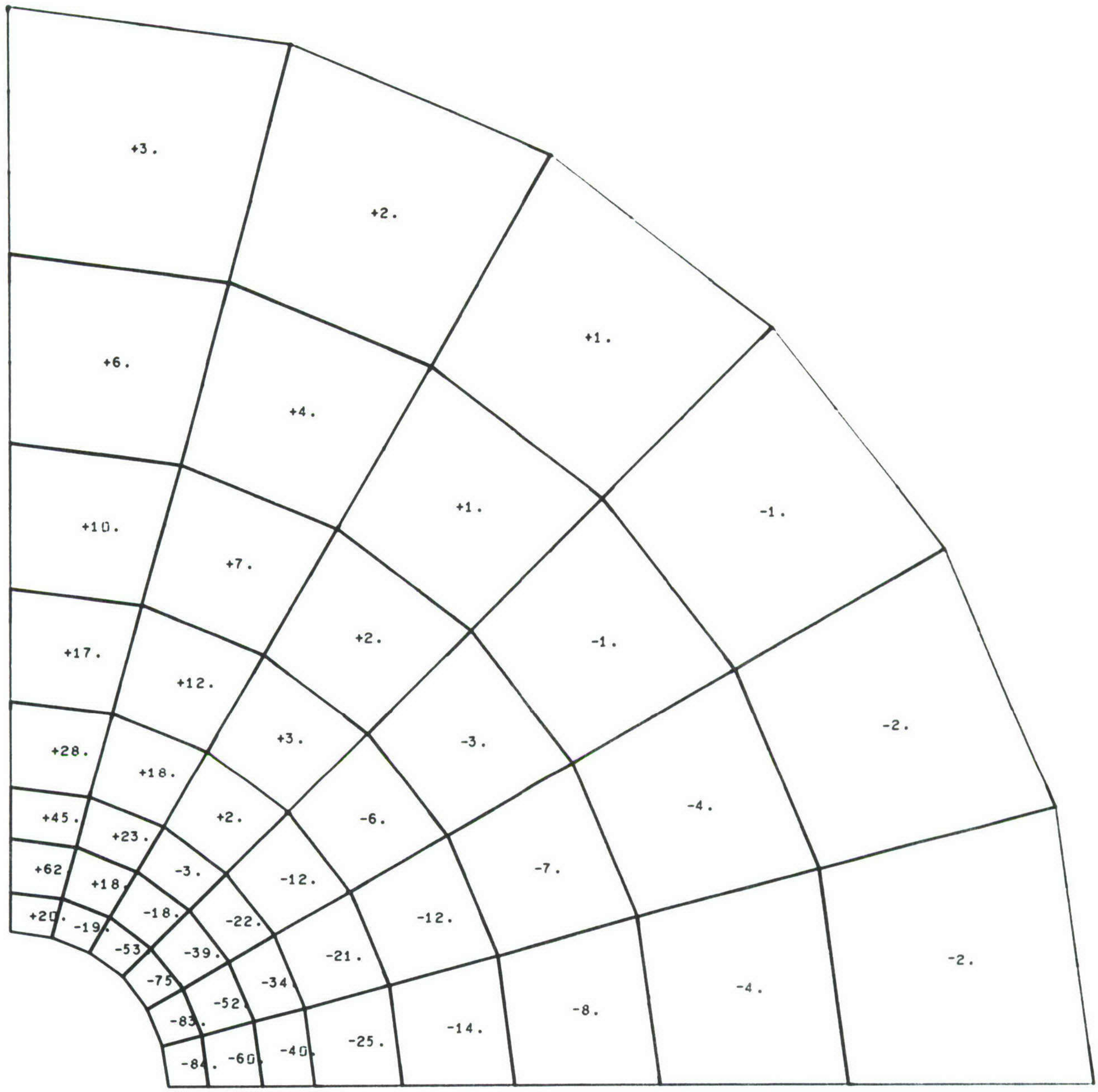


Figure AIII-129 Second Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

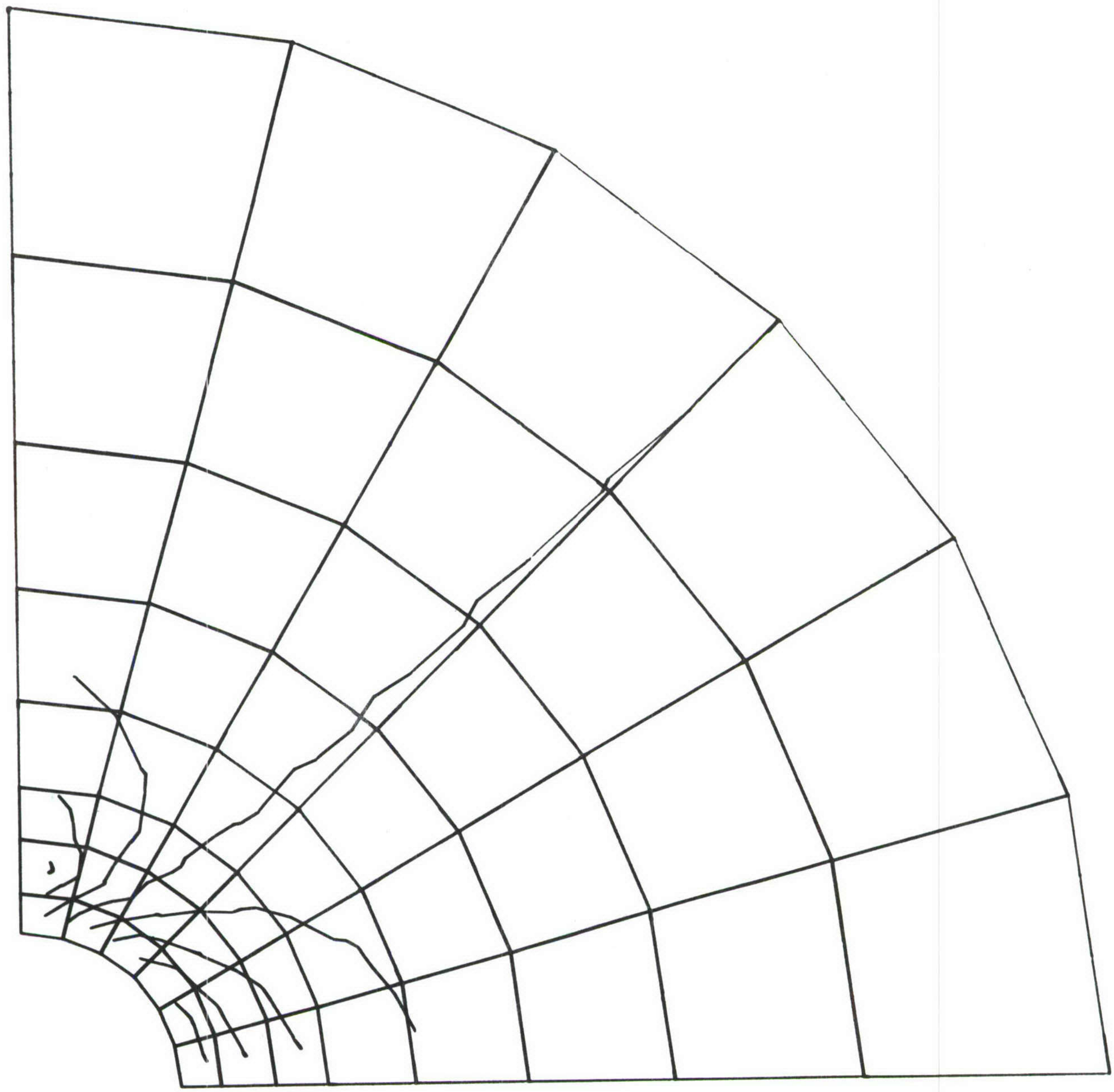


Figure AIII-130 Second Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

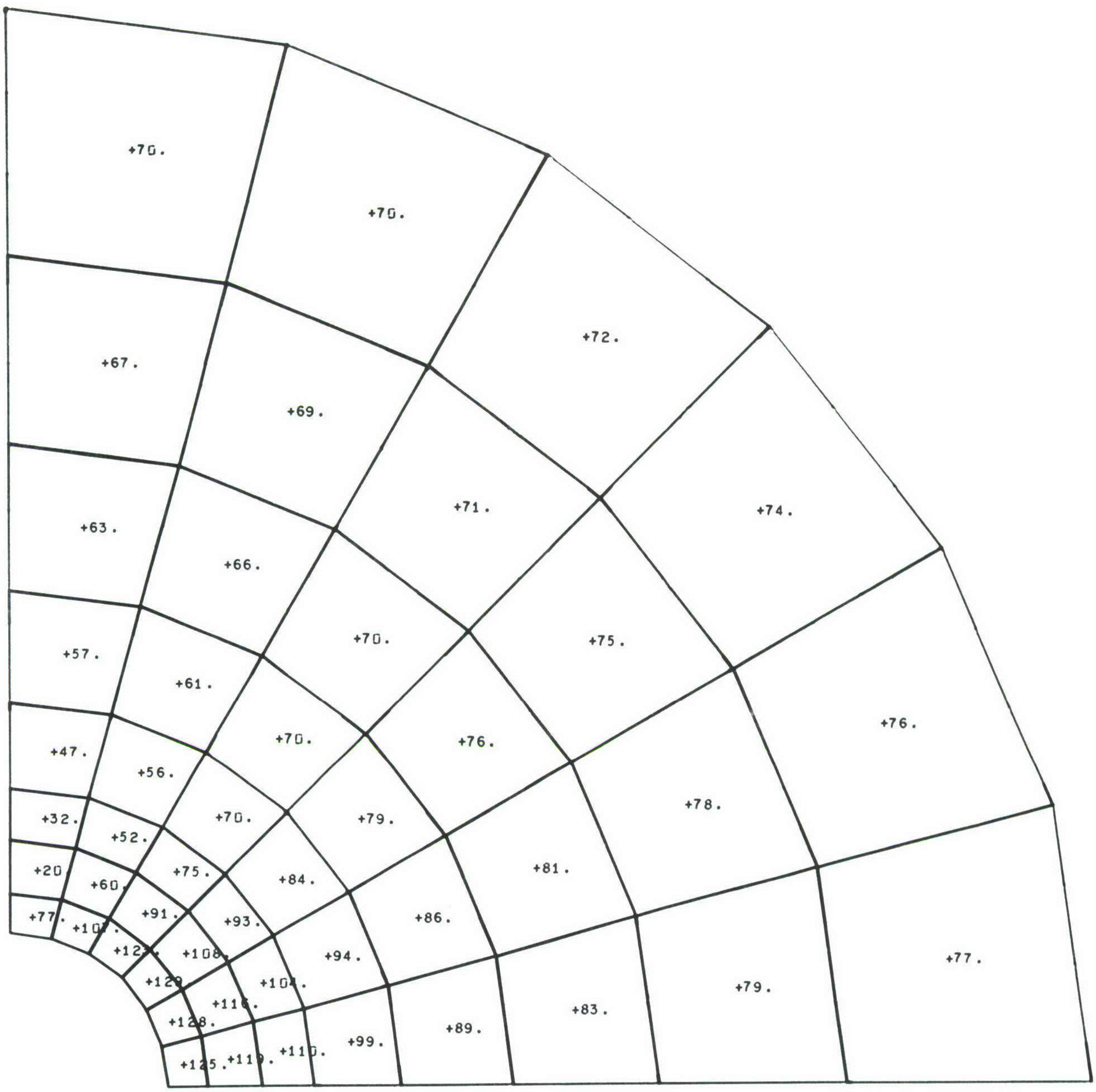


Figure AIII-131 Principal Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

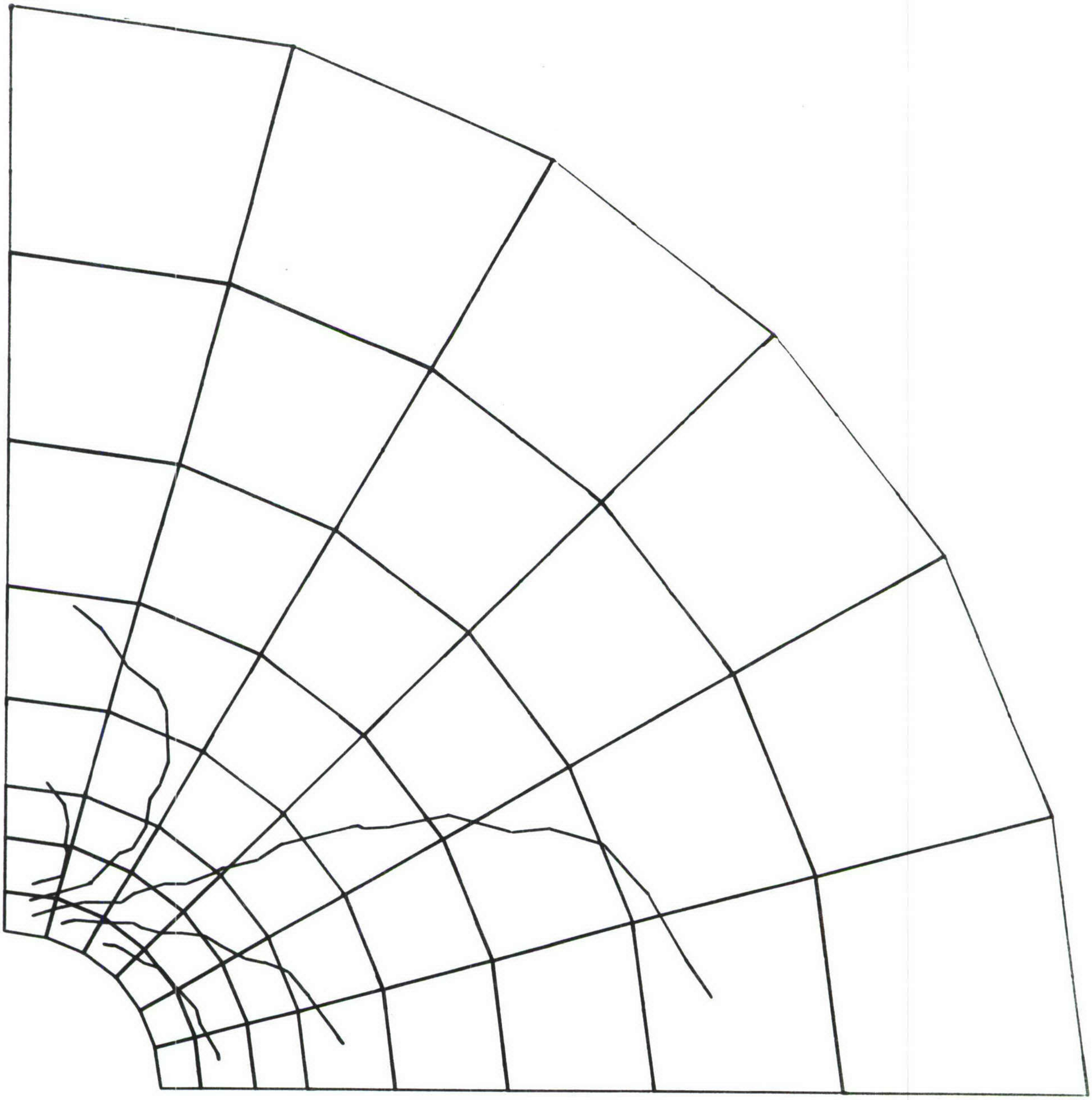


Figure AIII-132 Principal Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.00125 Inch Radial Interference; 70% Uniaxial Load

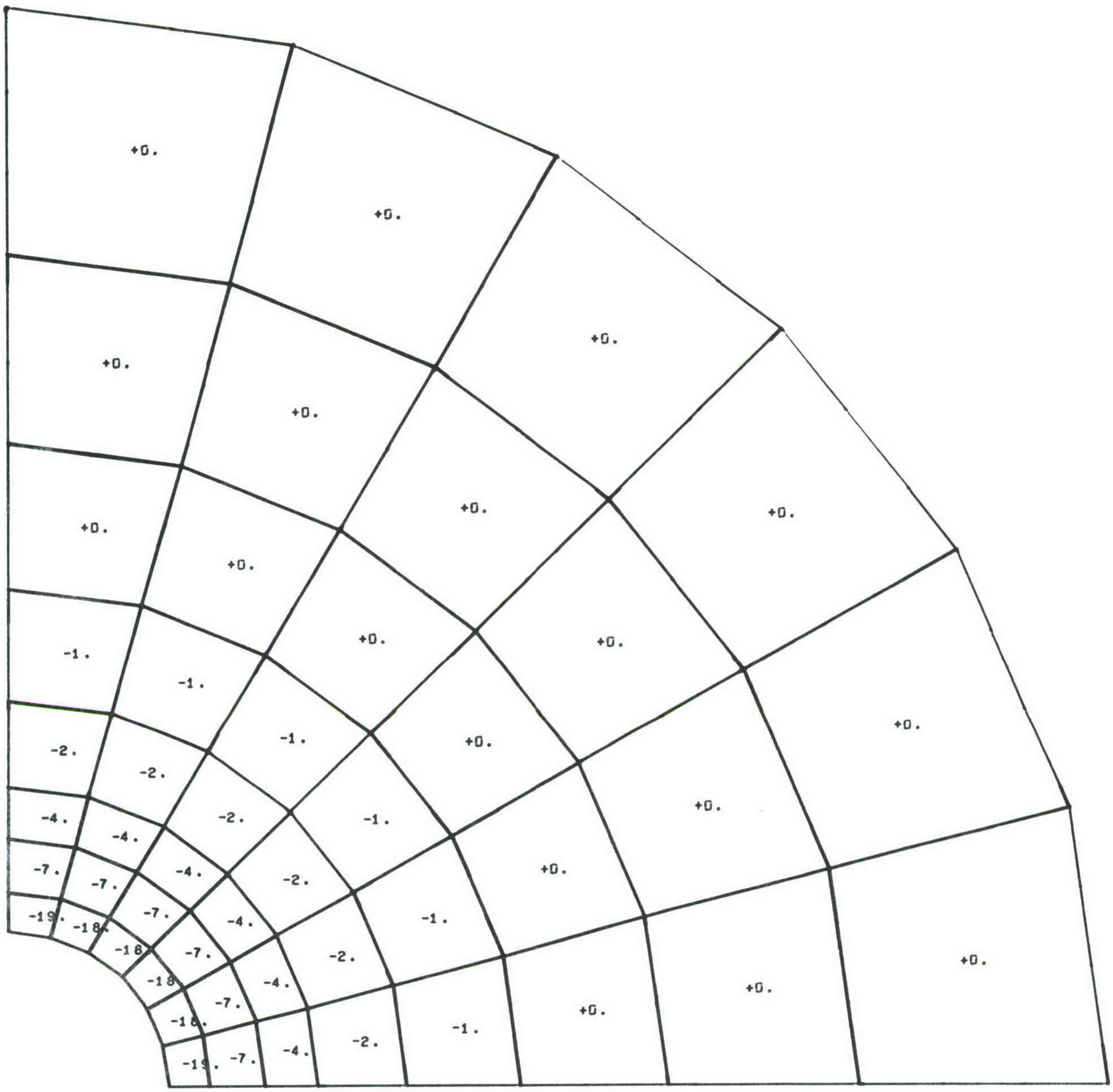


Figure AIII-133 Radial Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

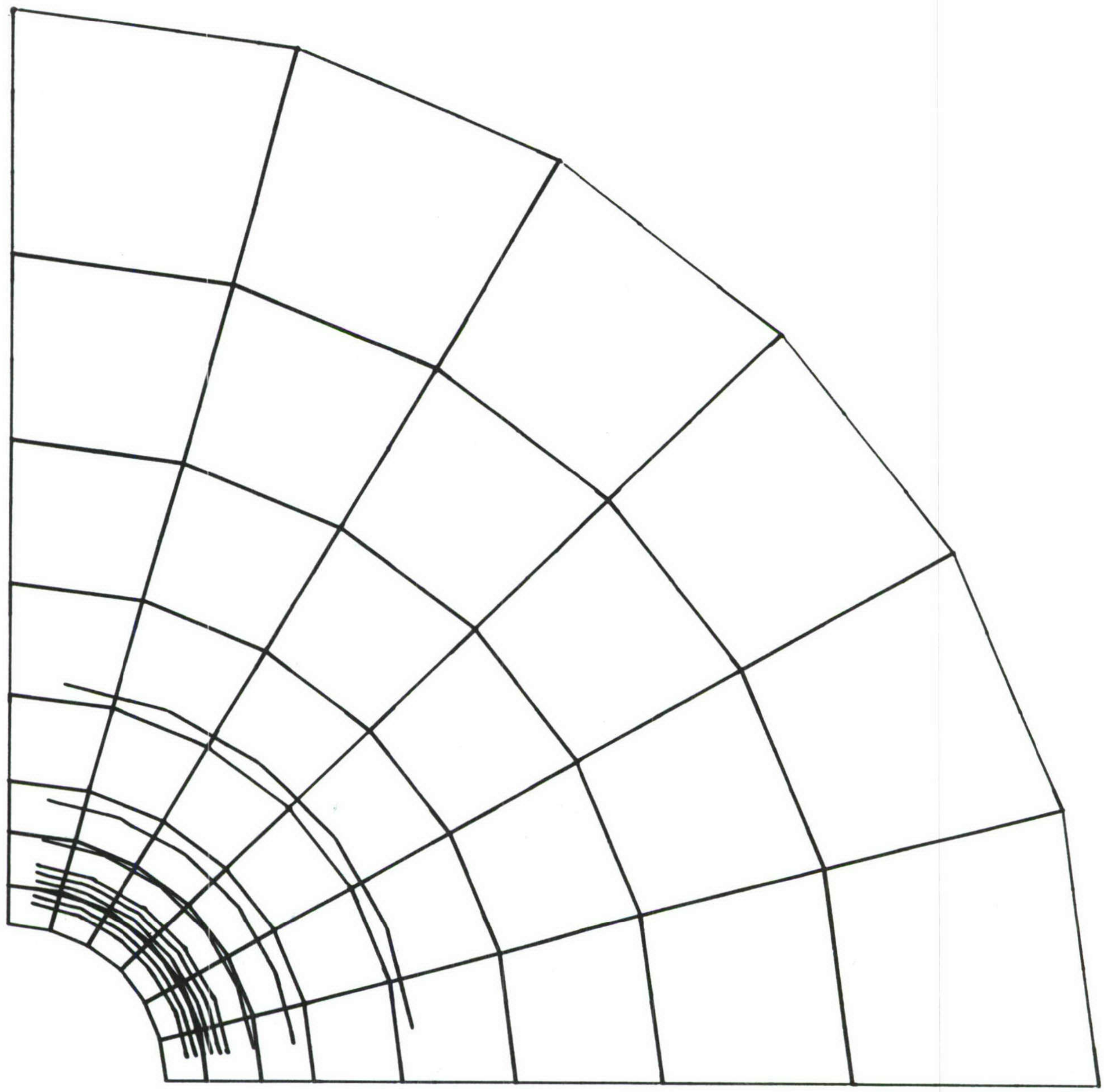


Figure AIII-134 Radial Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

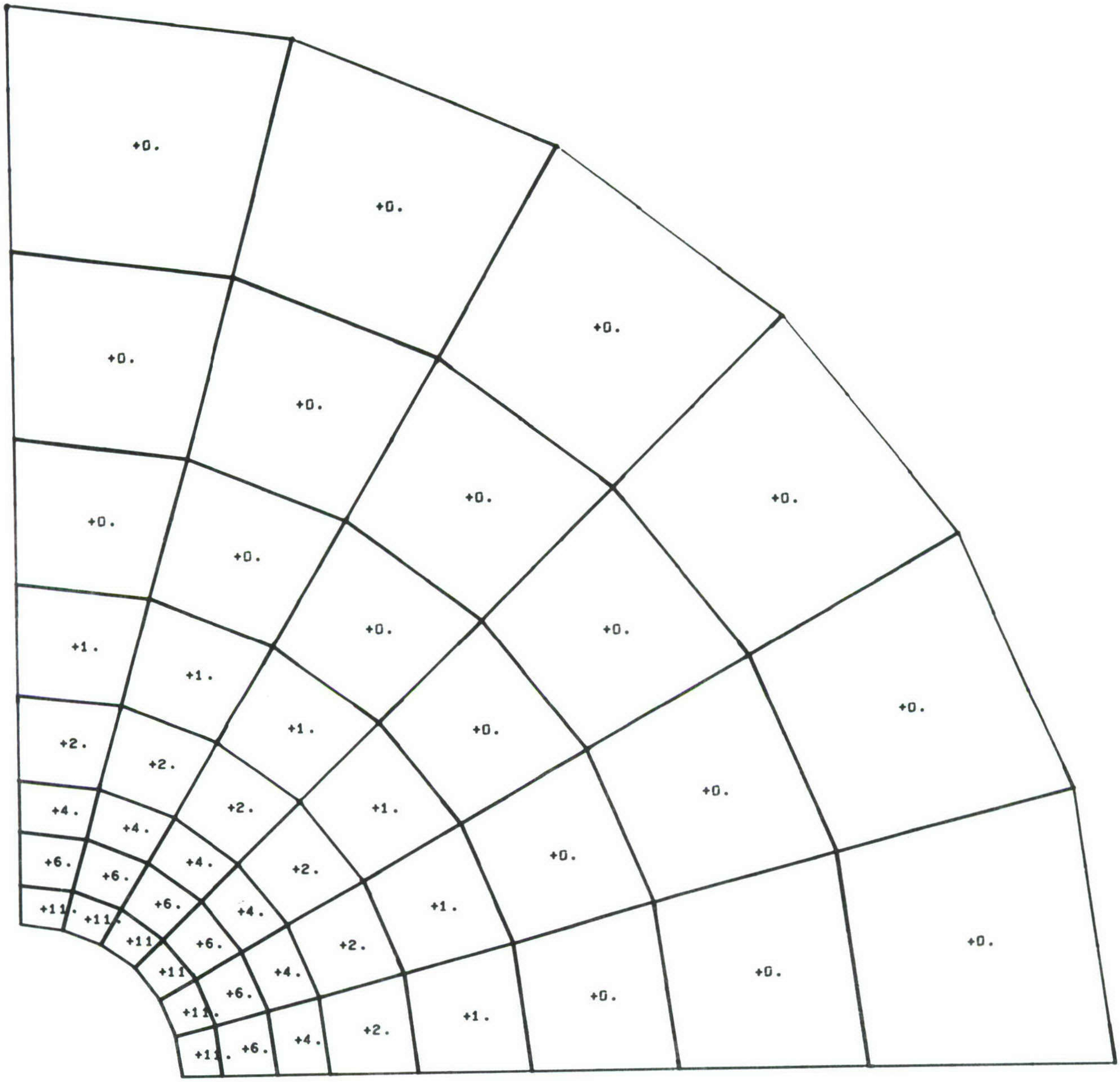


Figure AIII-135 Tangential Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

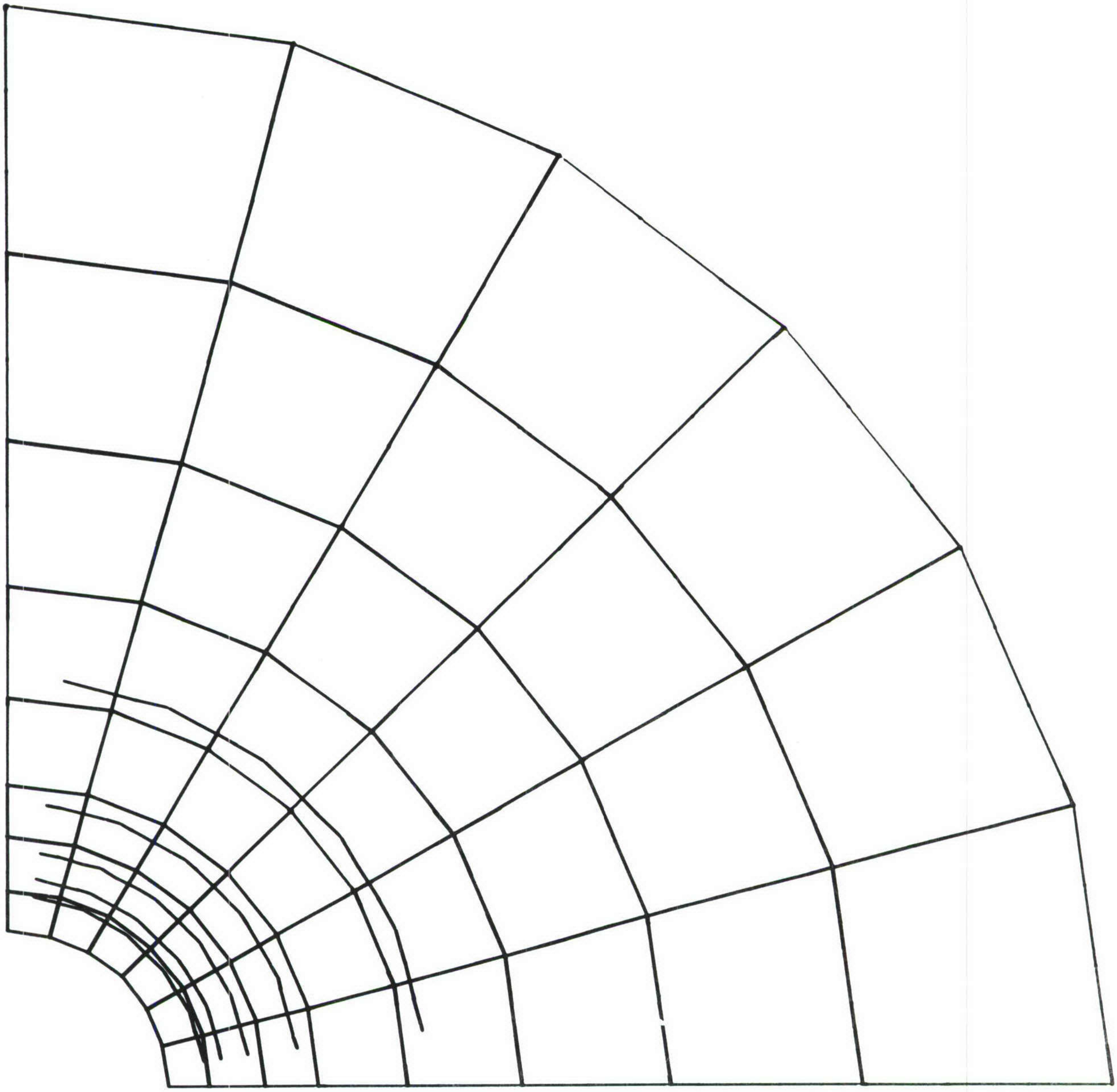


Figure AIII-136 Tangential Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

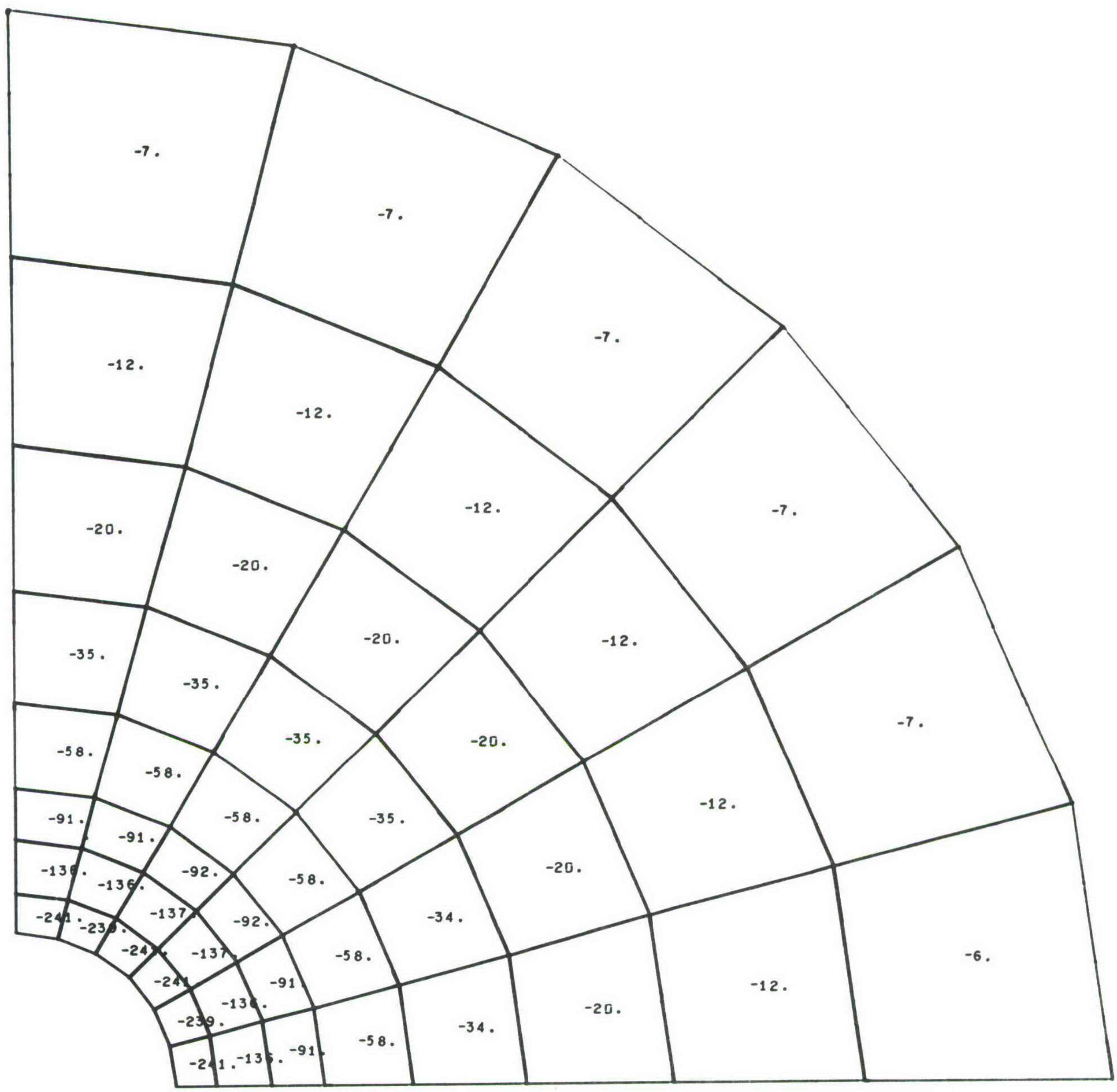


Figure AIII-137 Radial Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

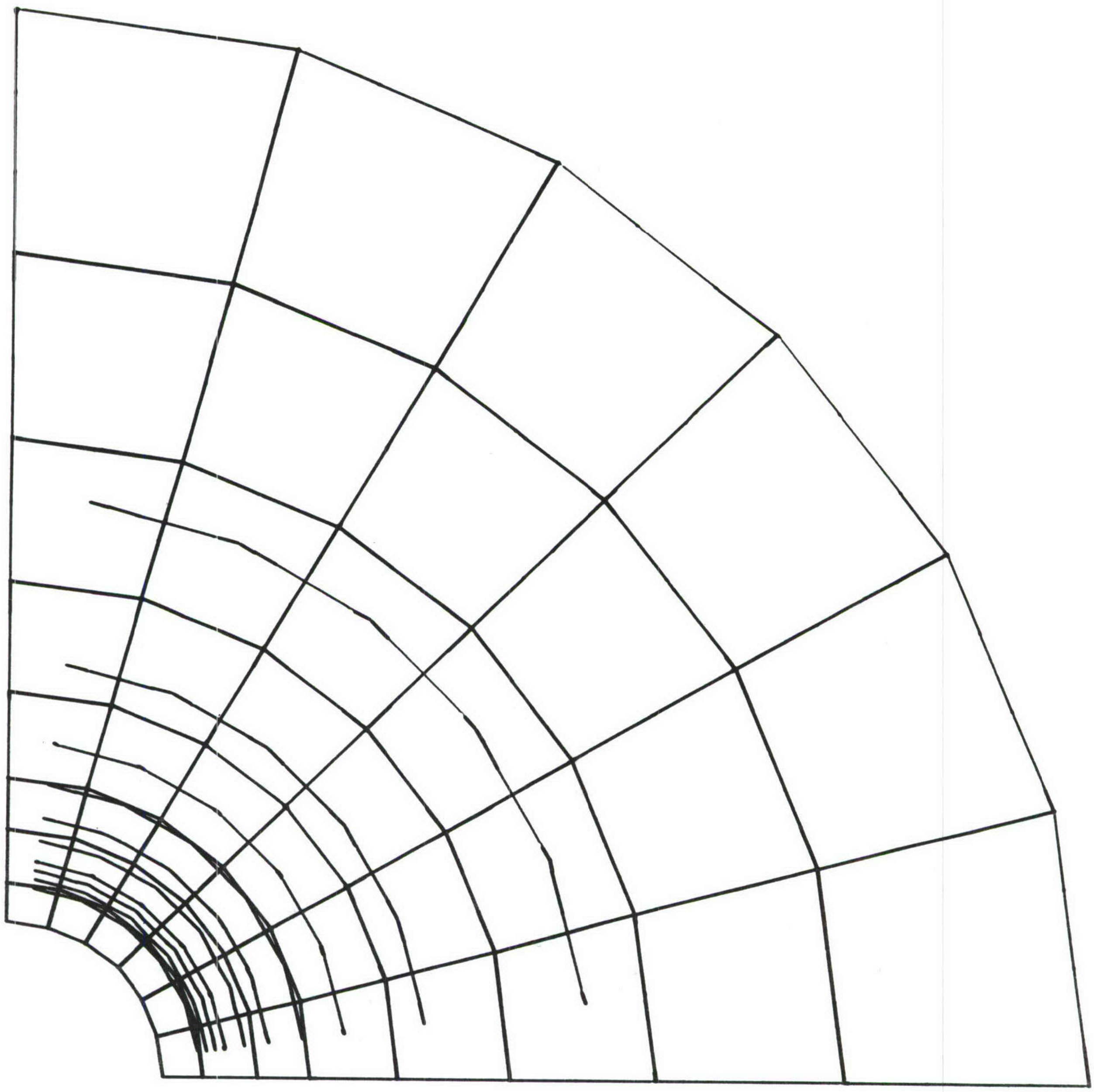


Figure AIII-138 Radial Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

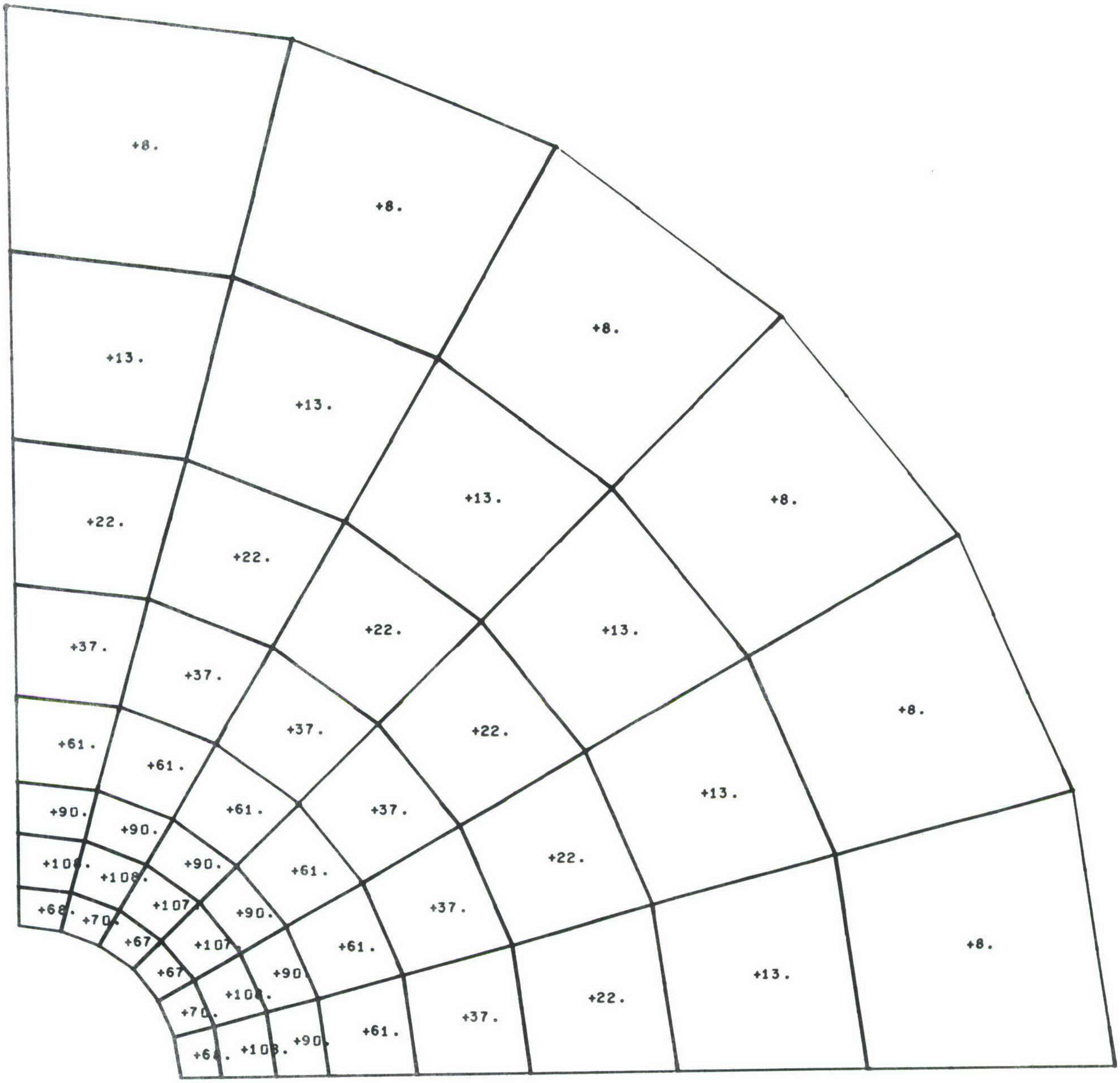


Figure AIII-139 Tangential Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

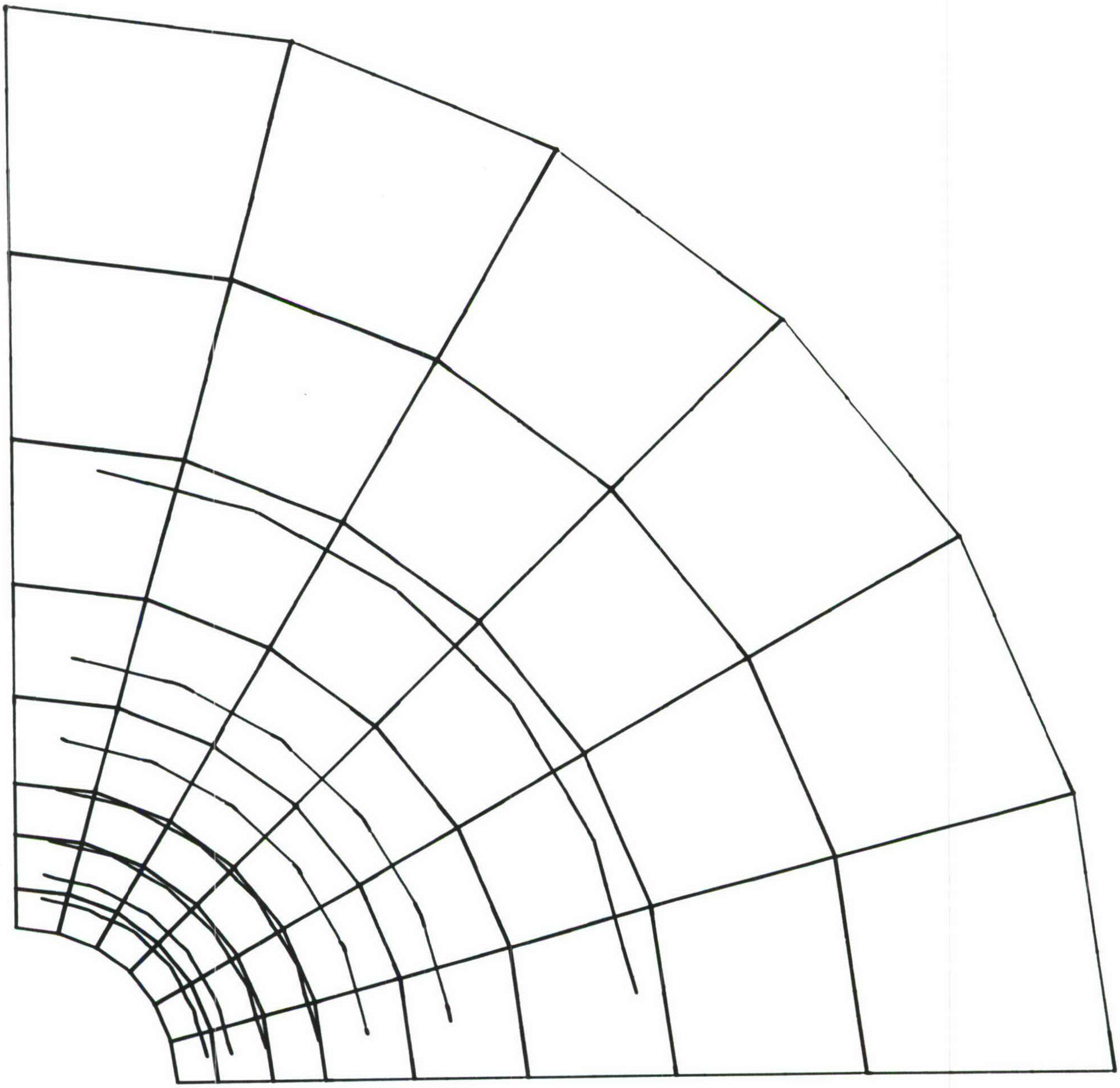


Figure AIII-140 Tangential Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; No Uniaxial Load

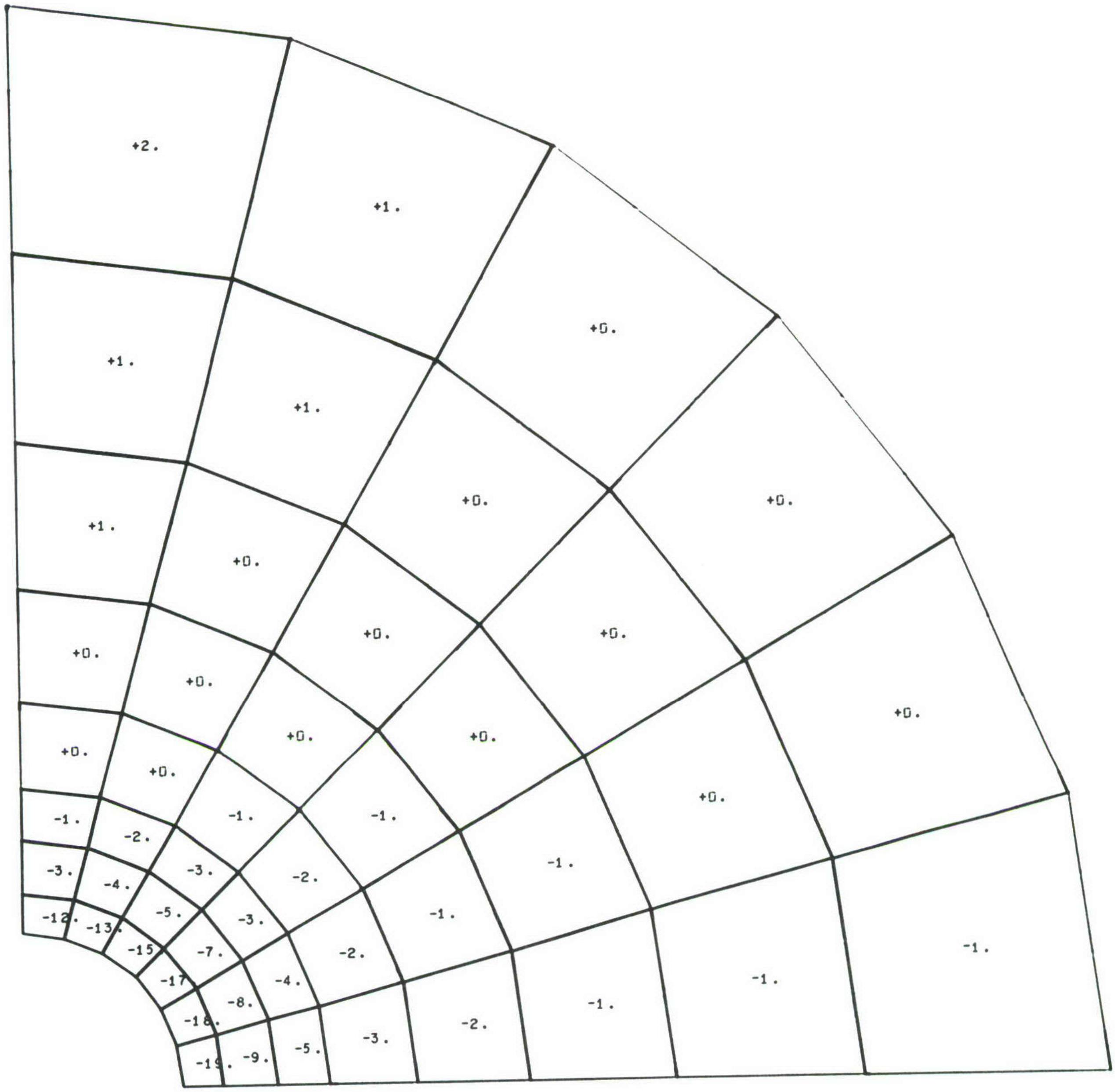


Figure AIII-141 Radial Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

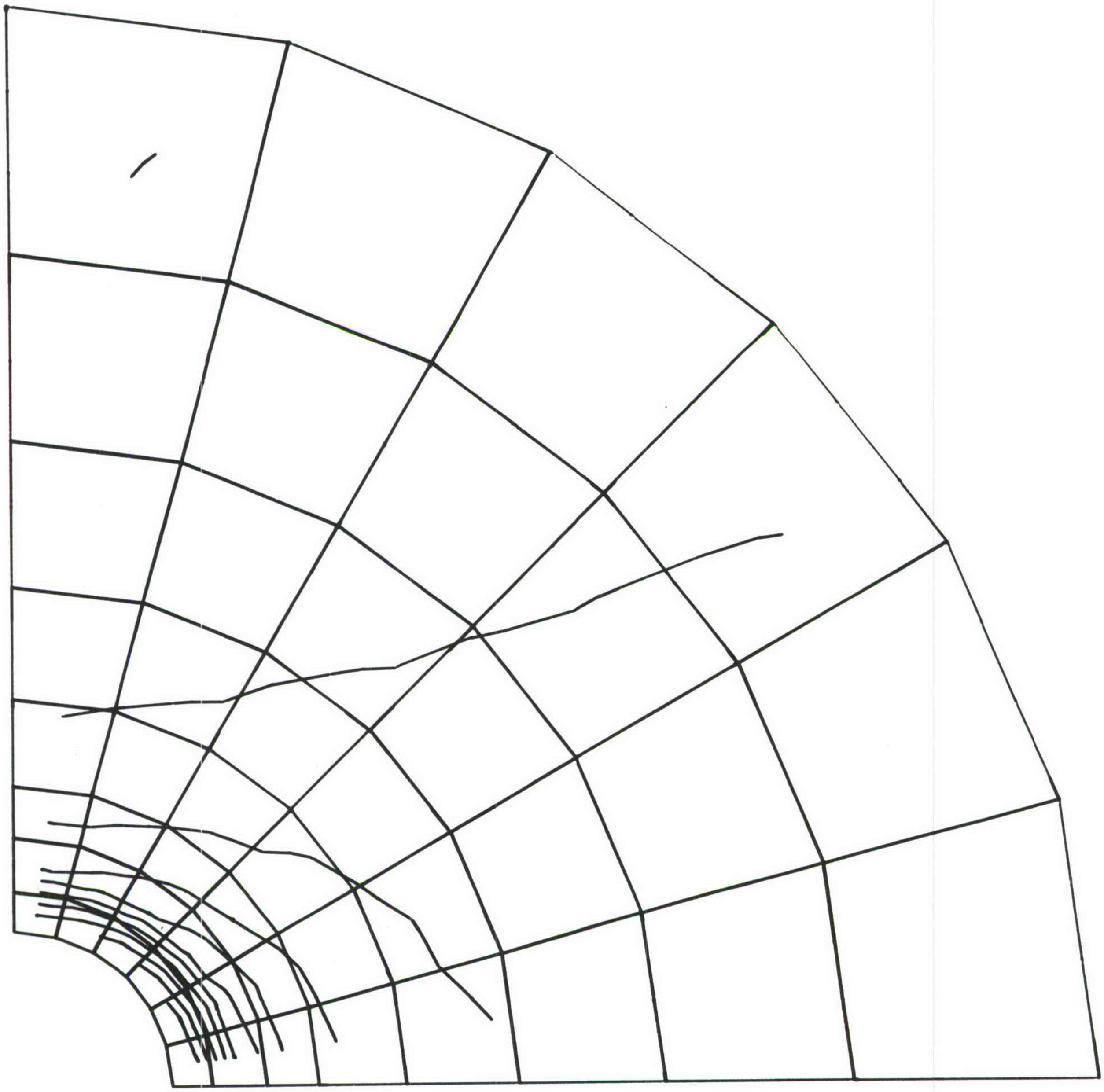


Figure AIII-142 Radial Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

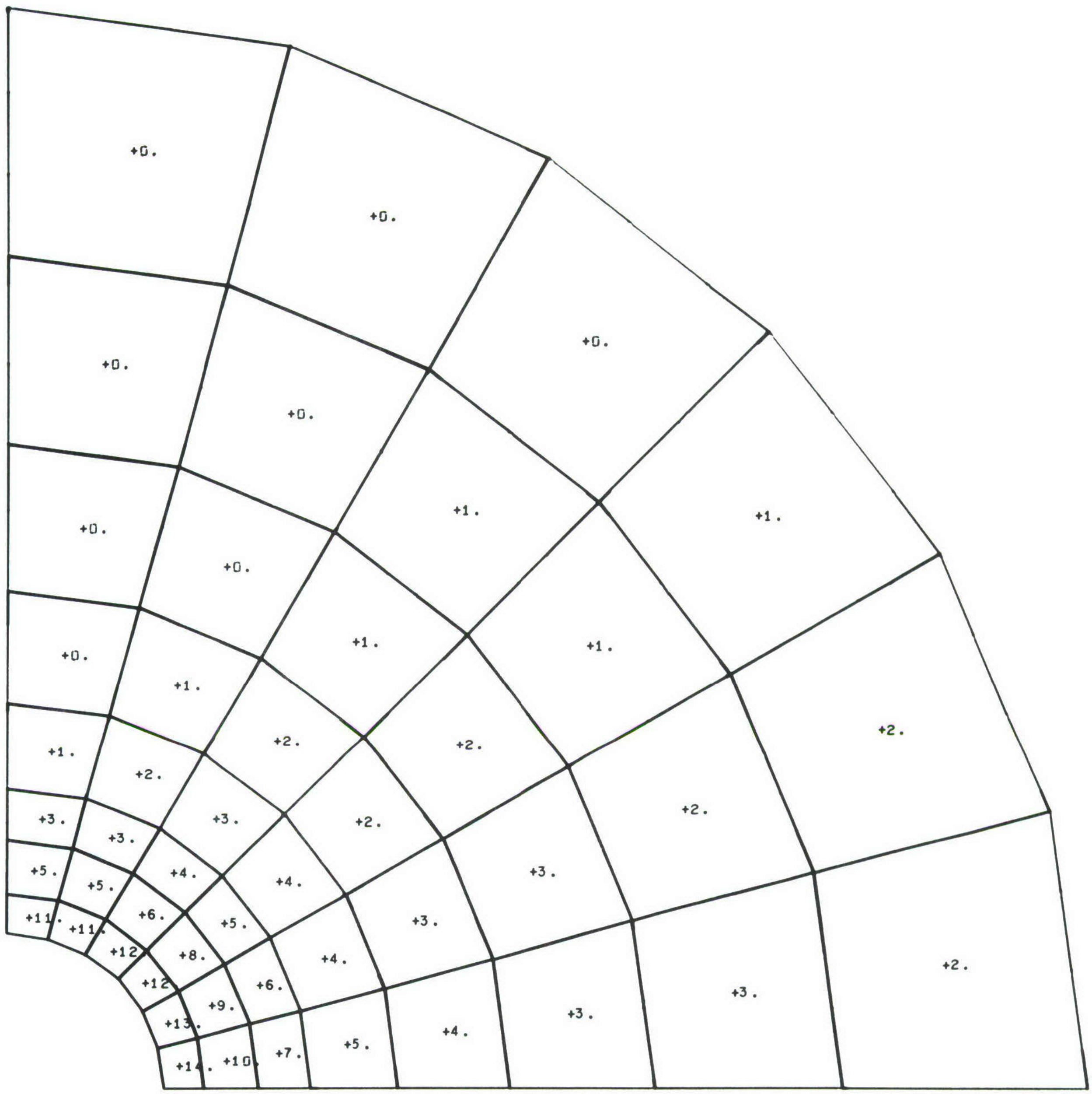


Figure AIII-143 Tangential Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

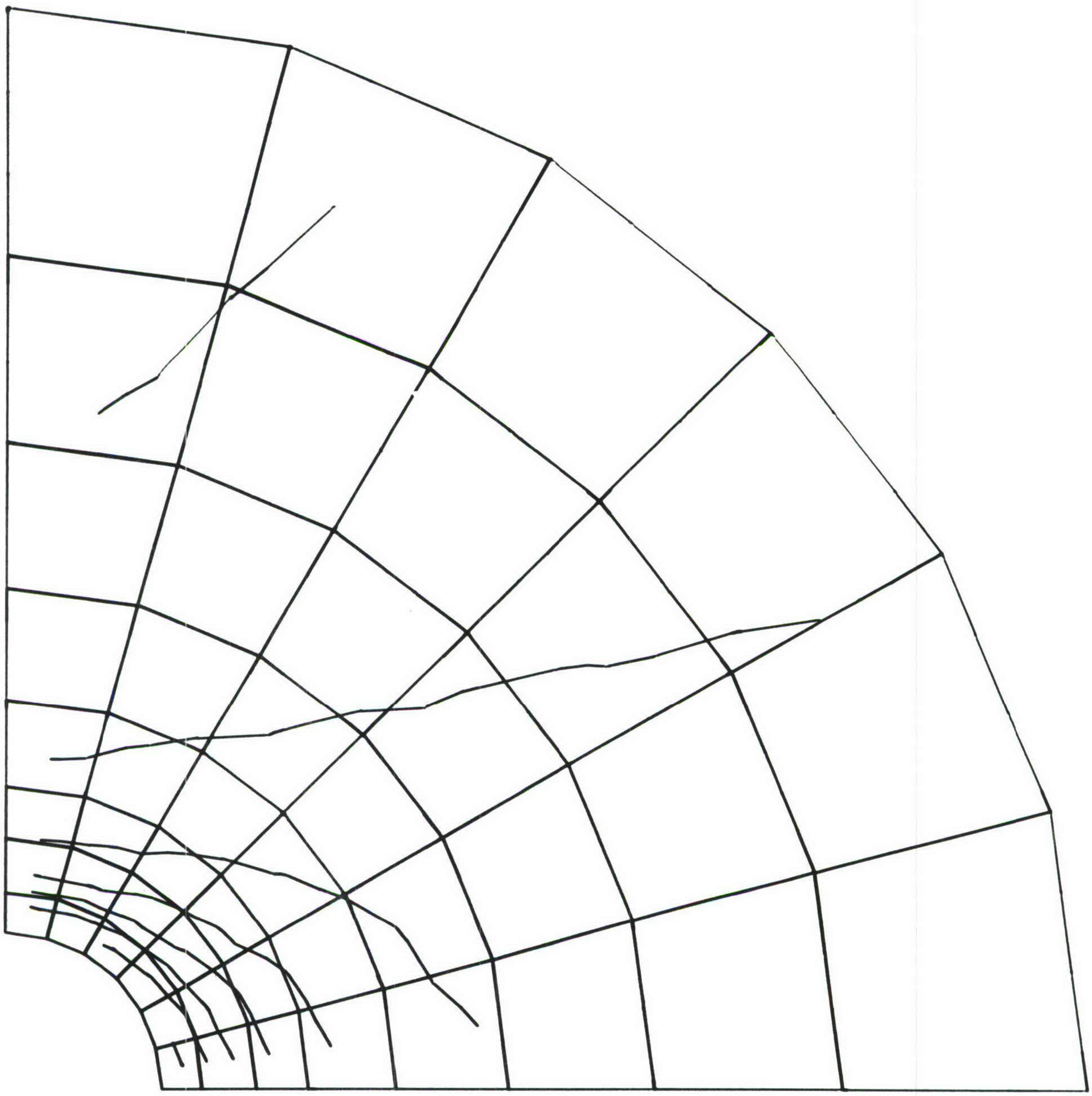


Figure AIII-144 Tangential Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

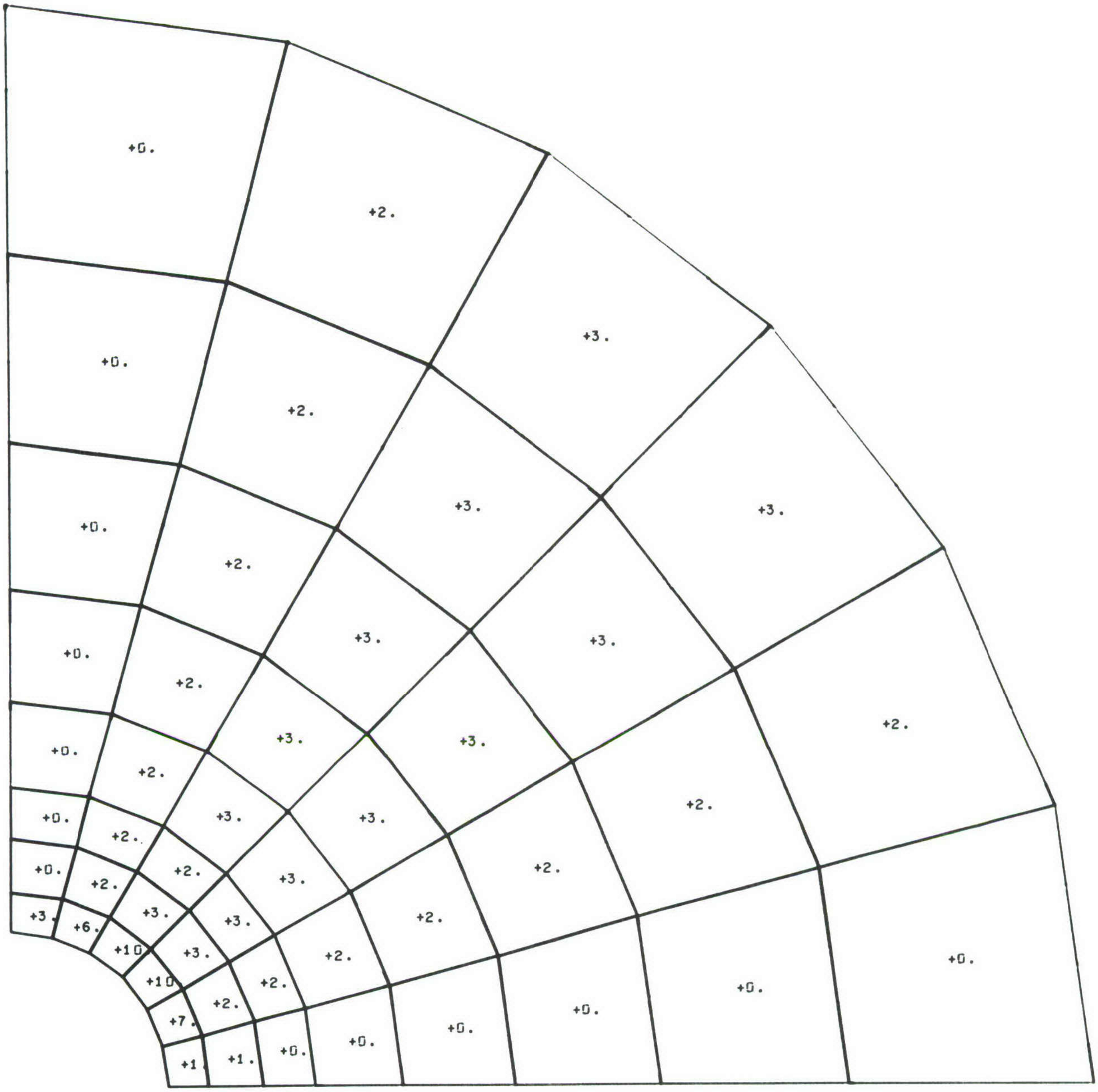


Figure AIII-145 Radial-Tangential Shear Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

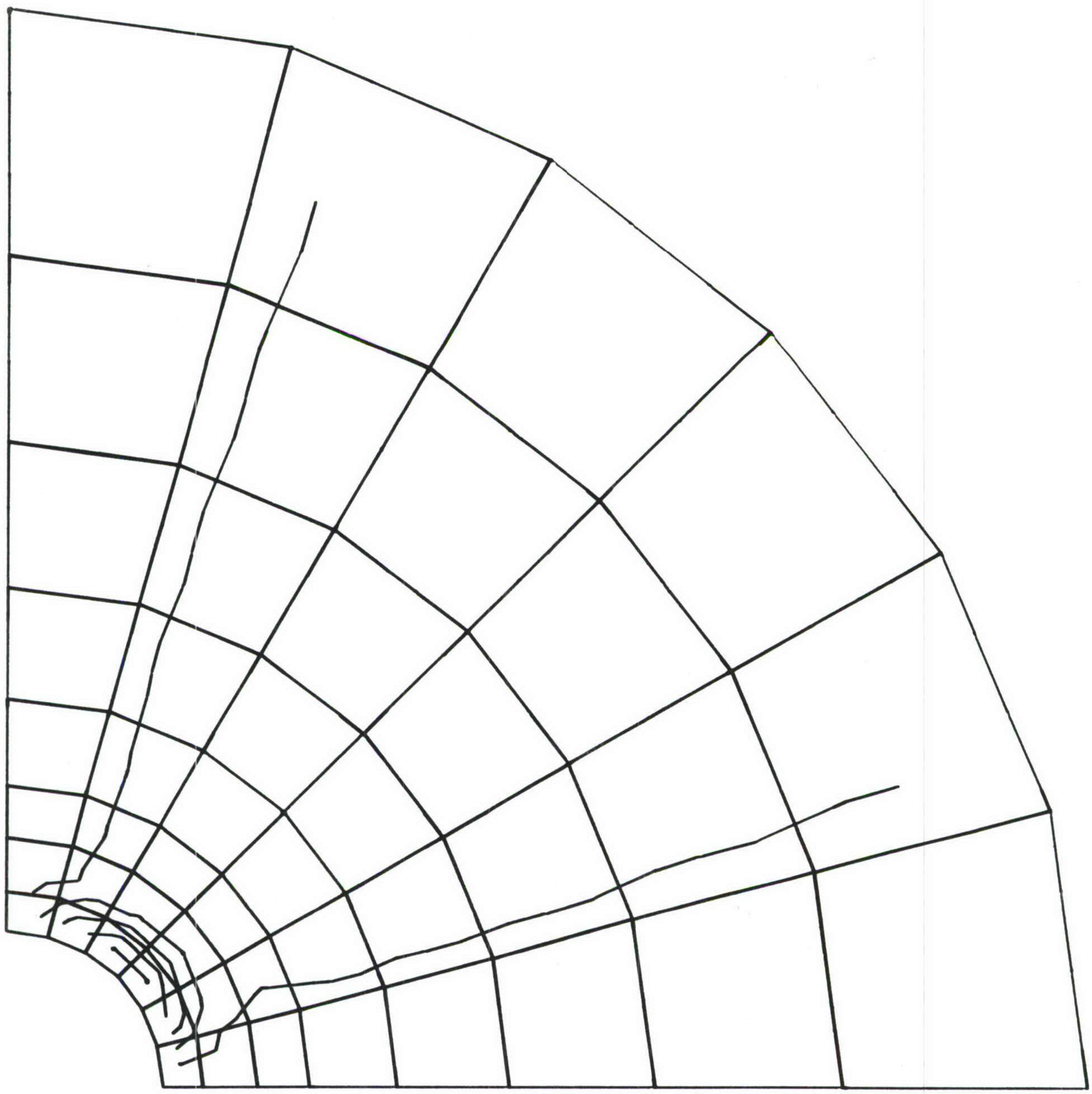


Figure AIII-146 Radial-Tangential Shear Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

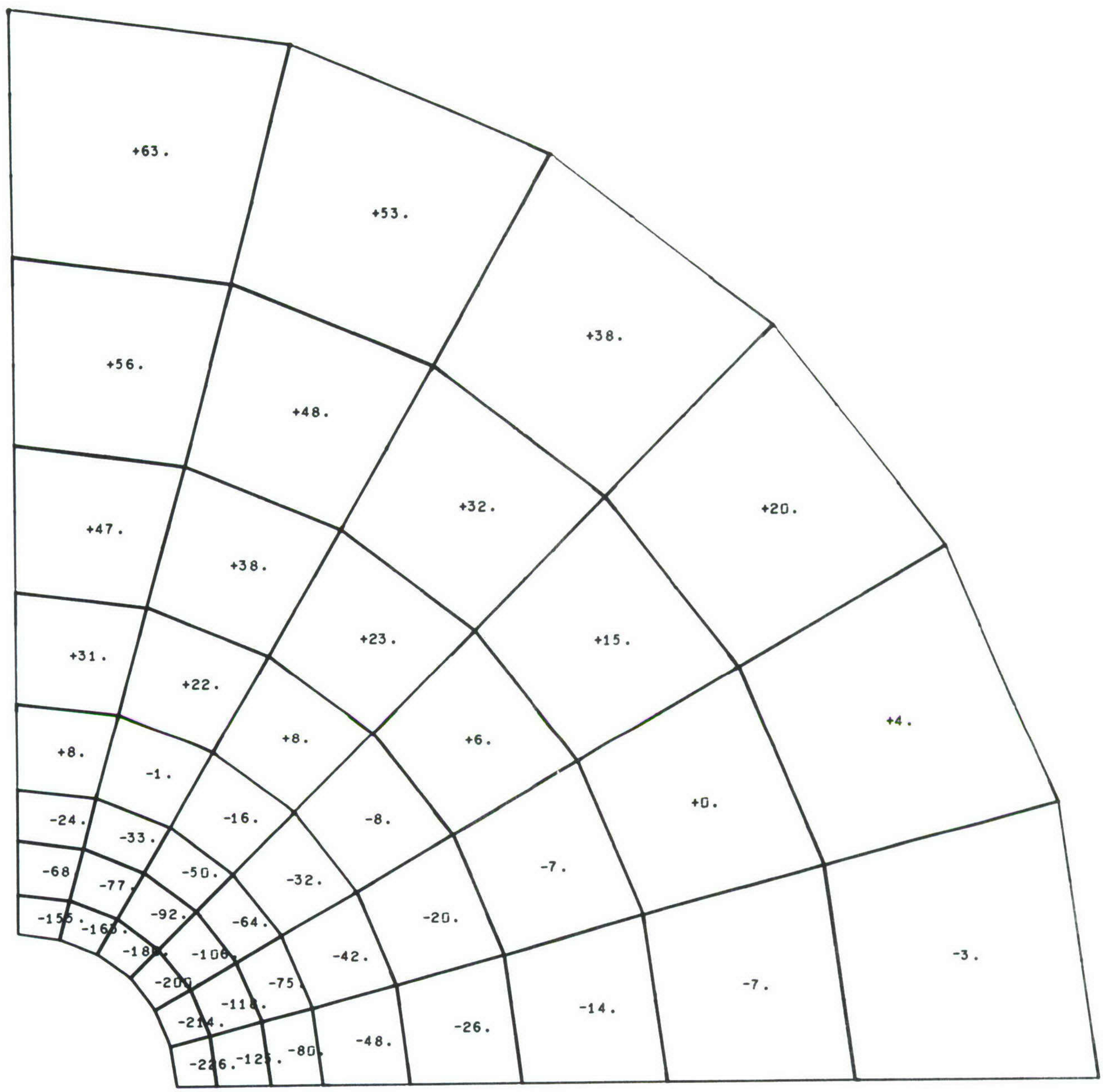


Figure AIII-147 Radial Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

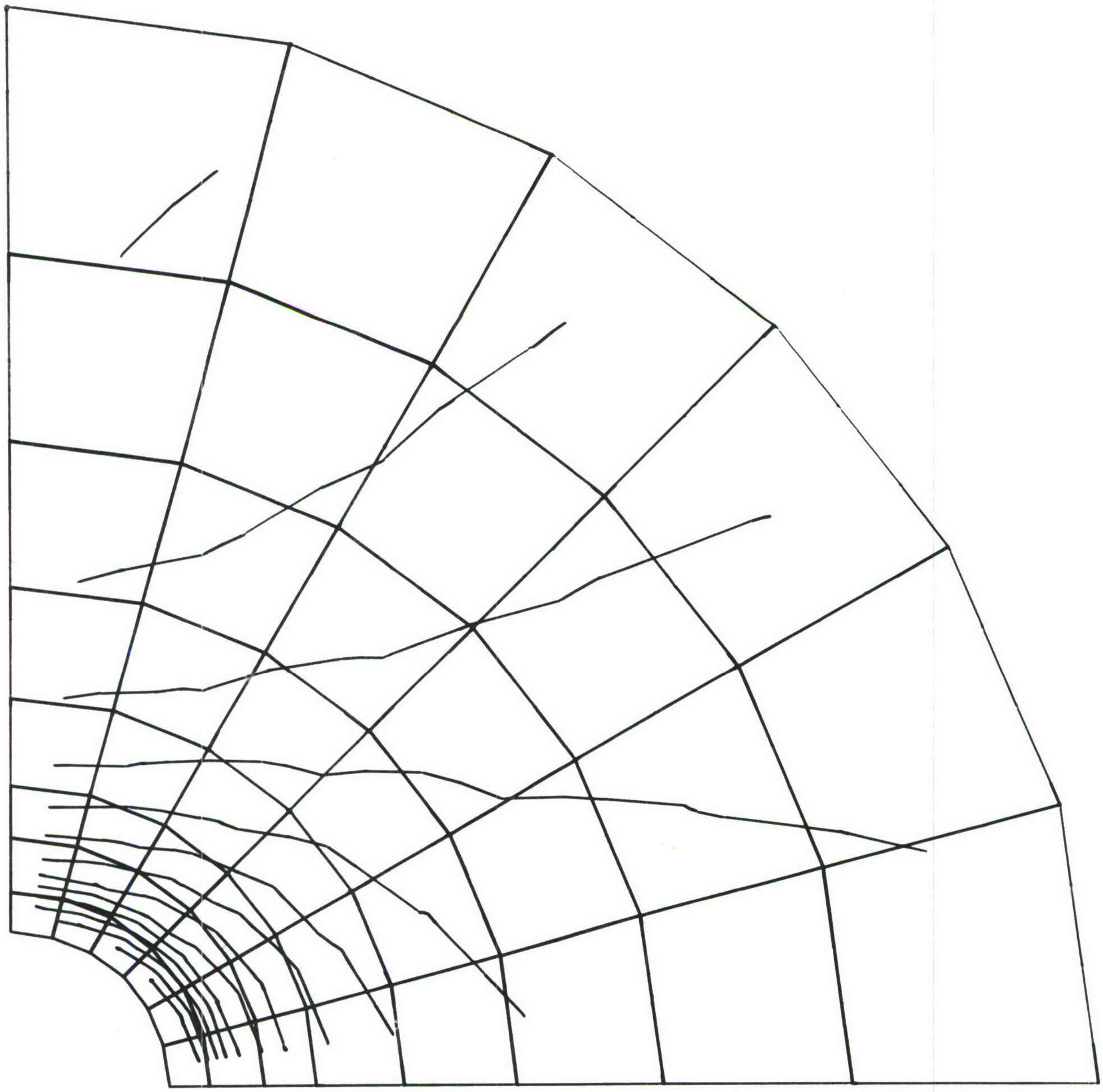


Figure AIII-148 Radial Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

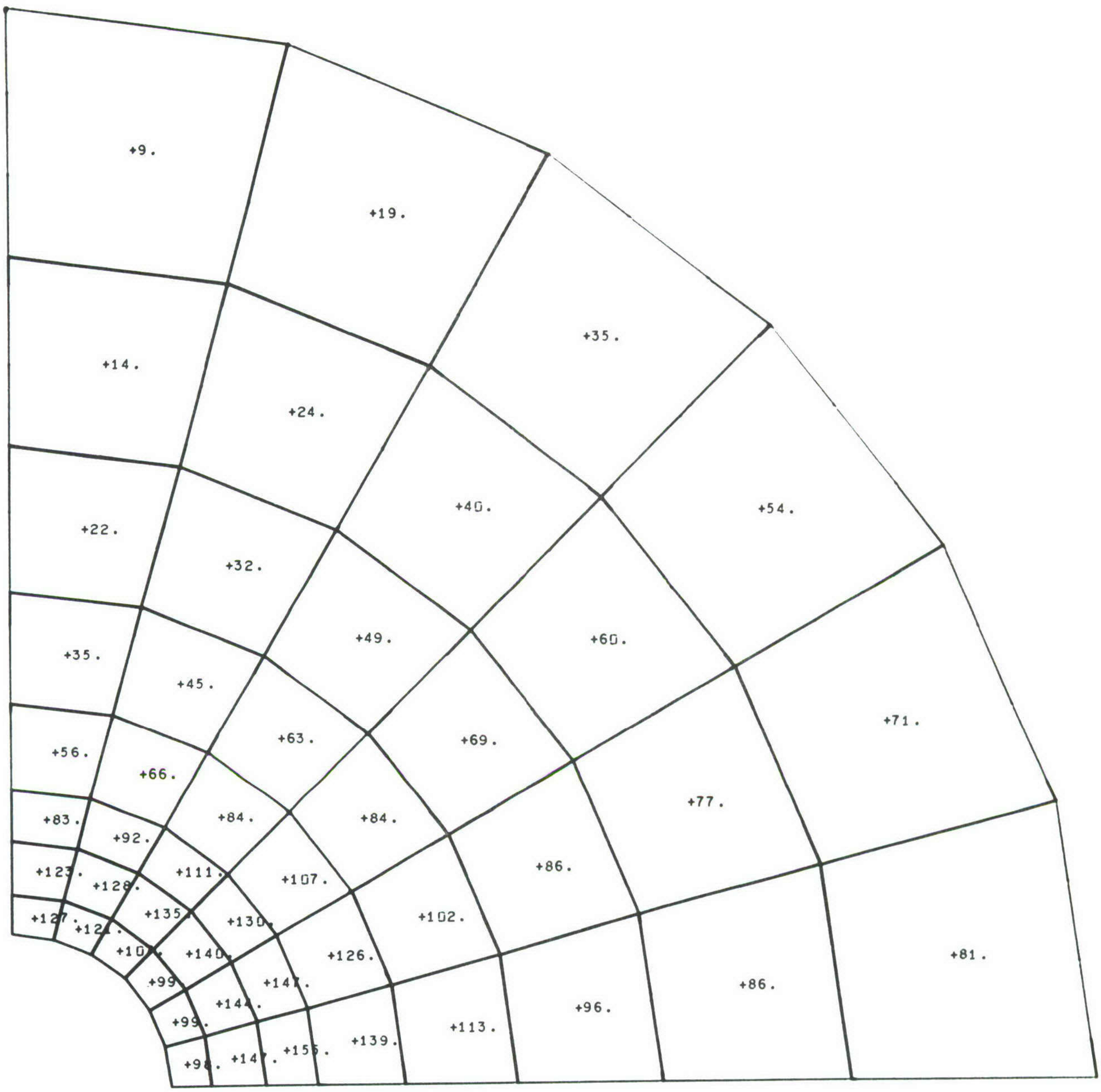


Figure AIII-149 Tangential Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

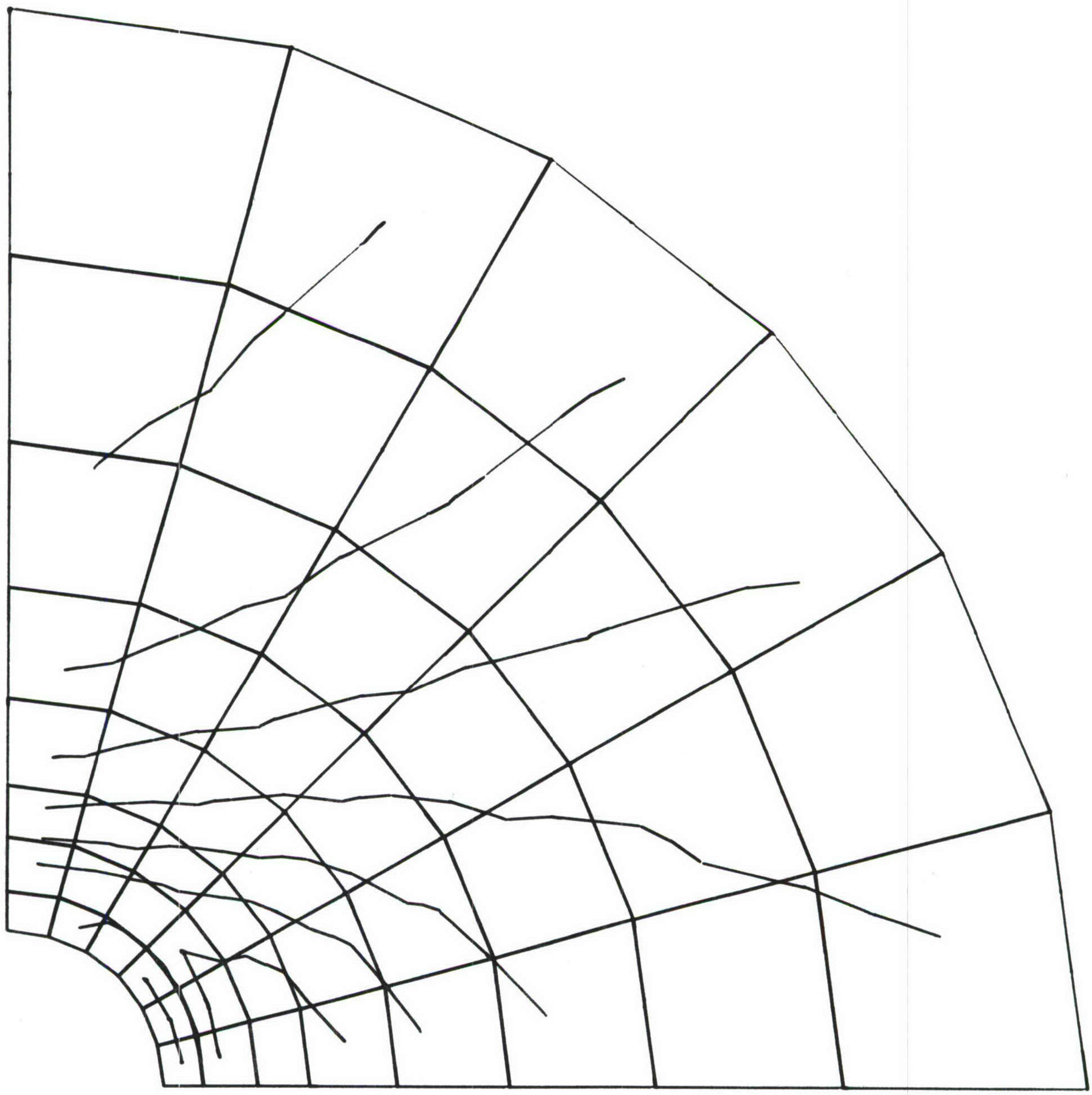


Figure AIII-150 Tangential Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

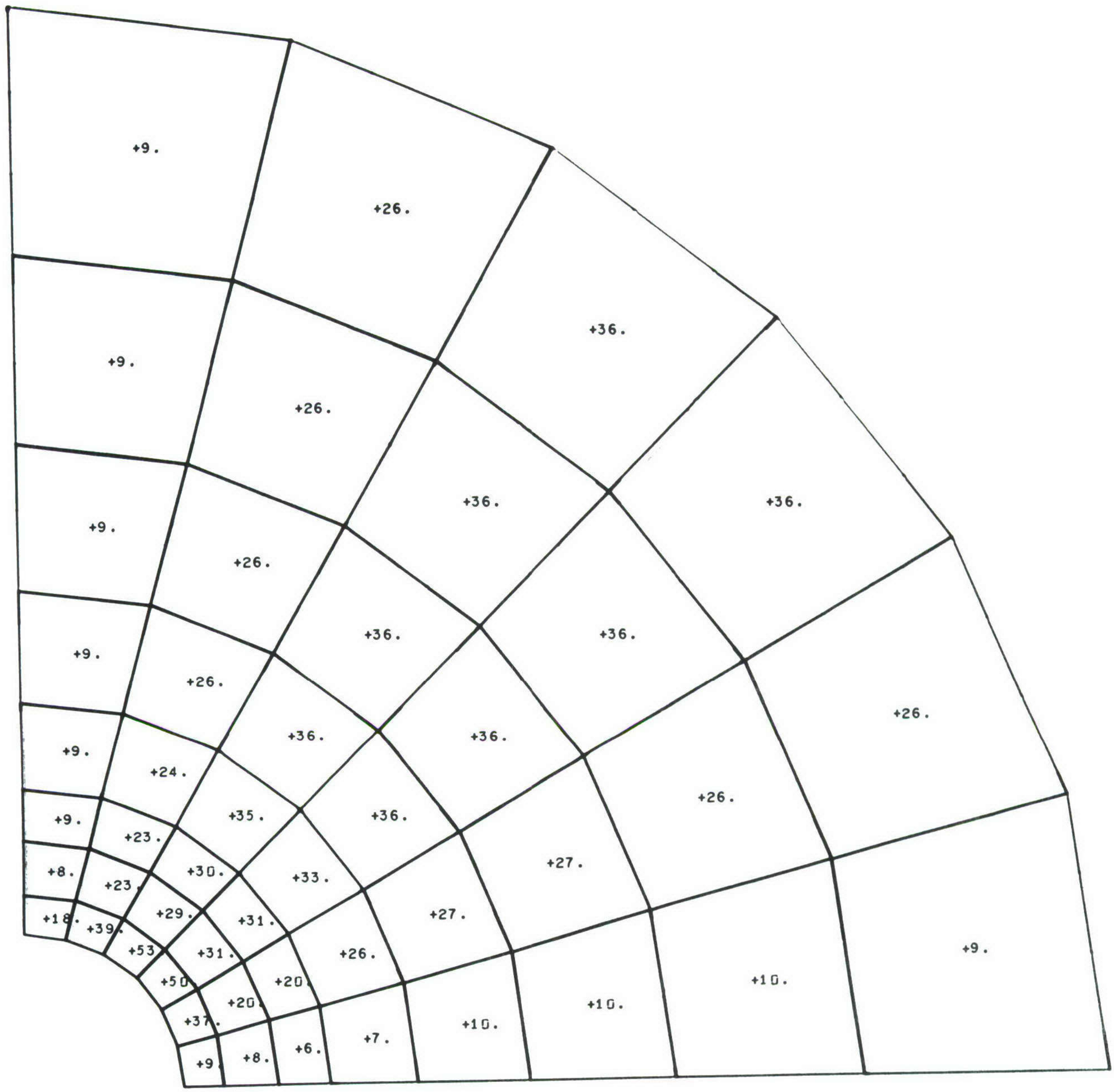


Figure AIII-151 Radial-Tangential Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

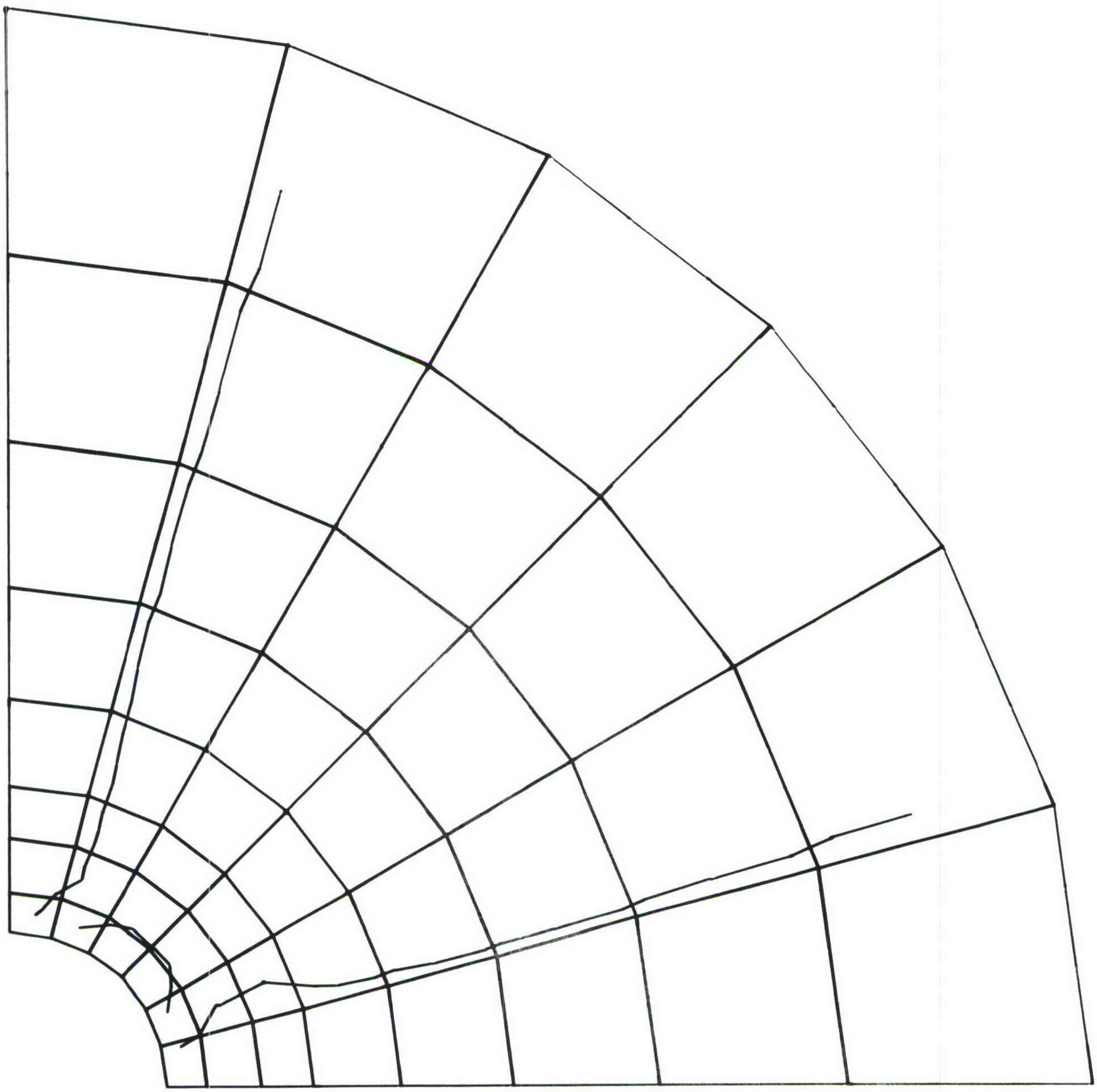


Figure AIII-152 Radial Tangential Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

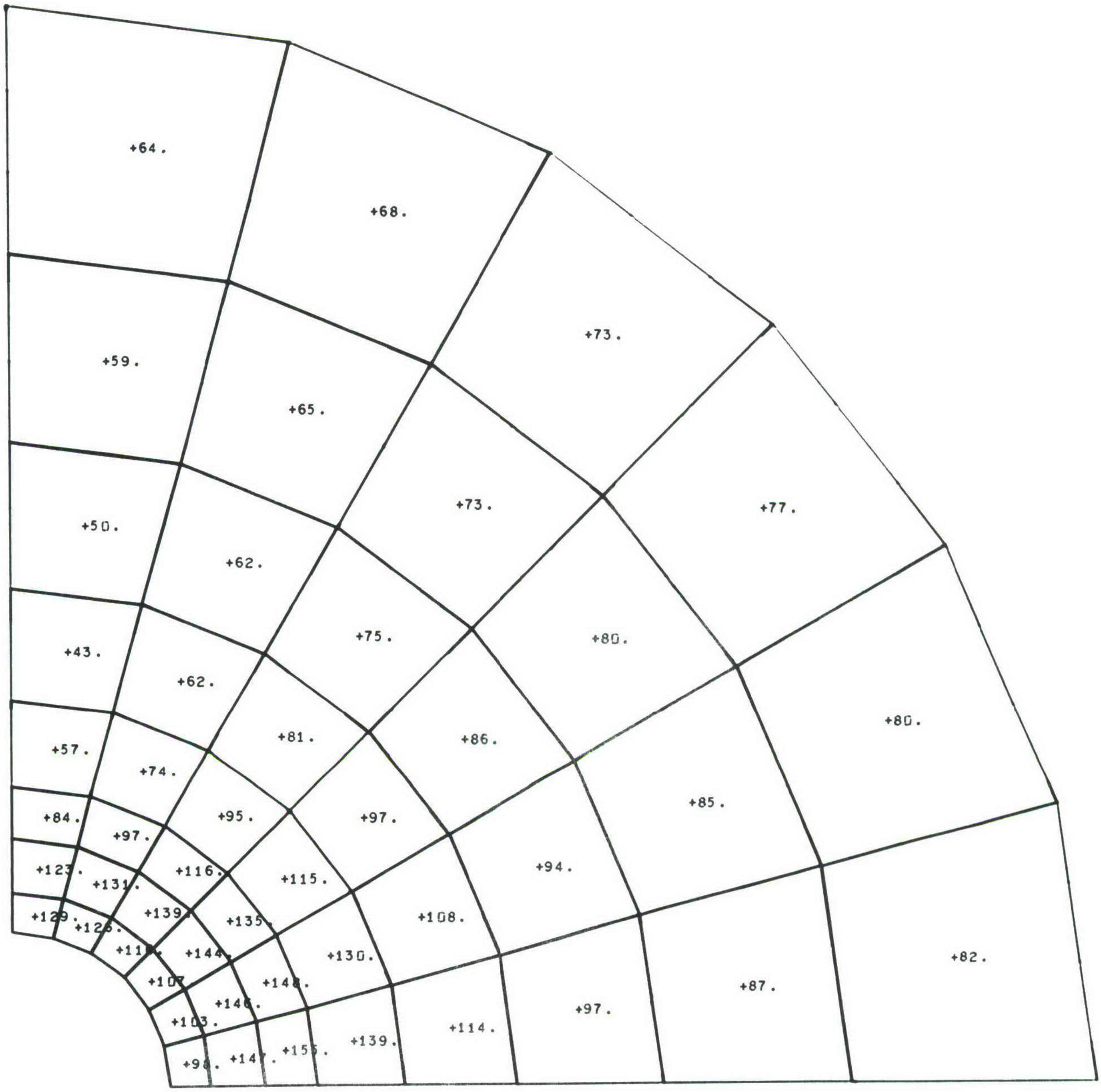


Figure AIII-153 First Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

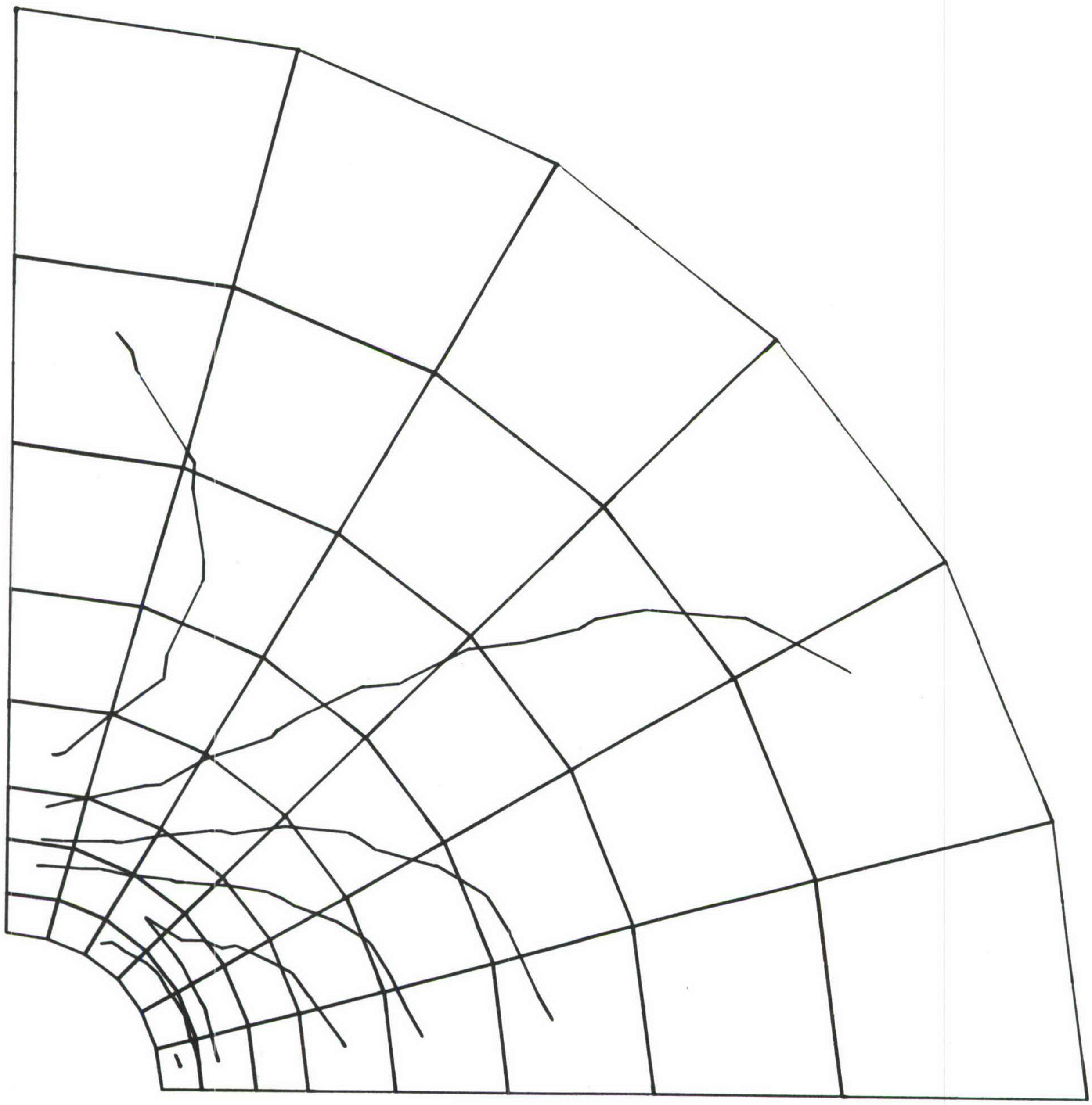


Figure AIII-154 First Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

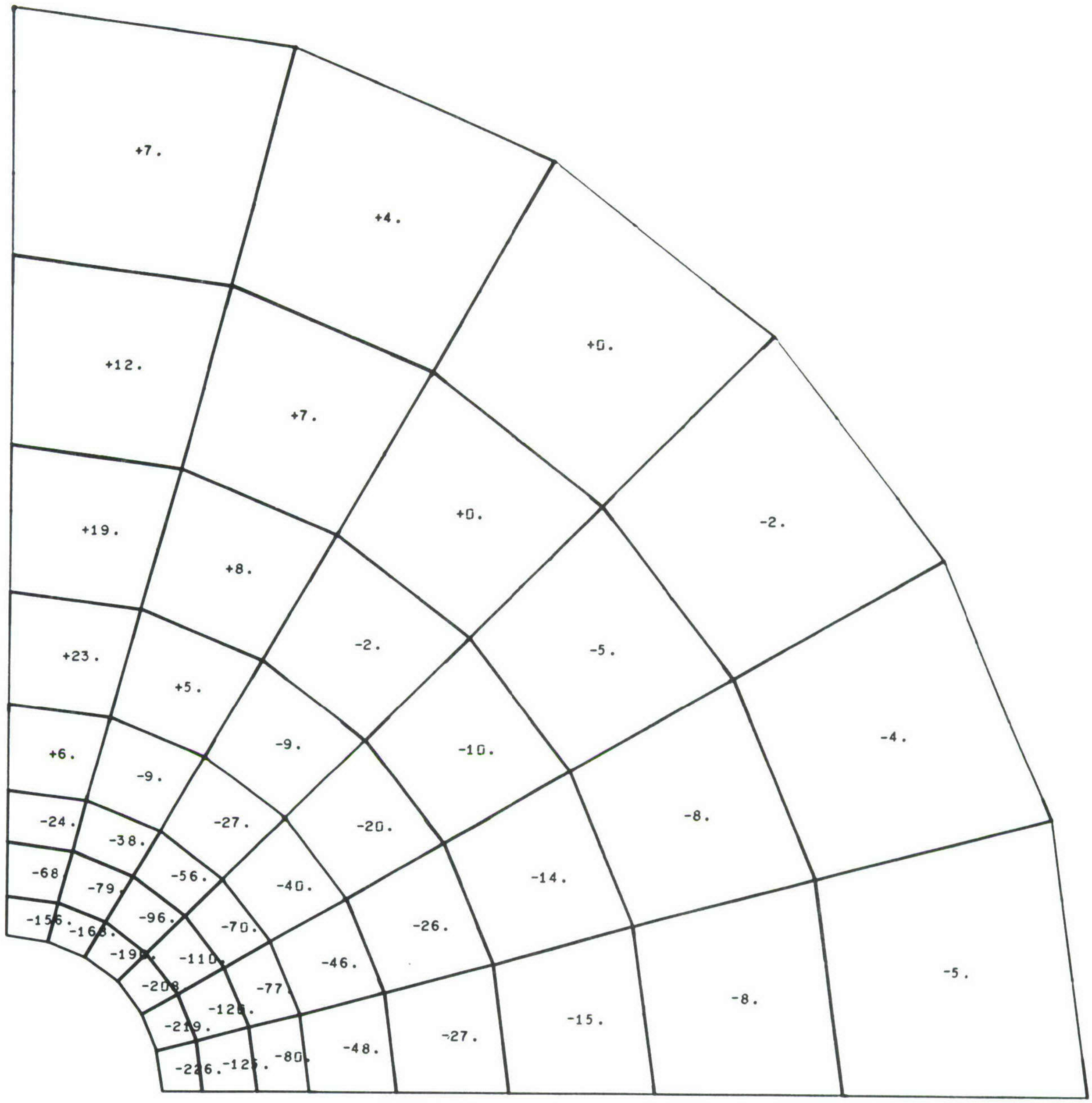


Figure AIII-155 Second Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

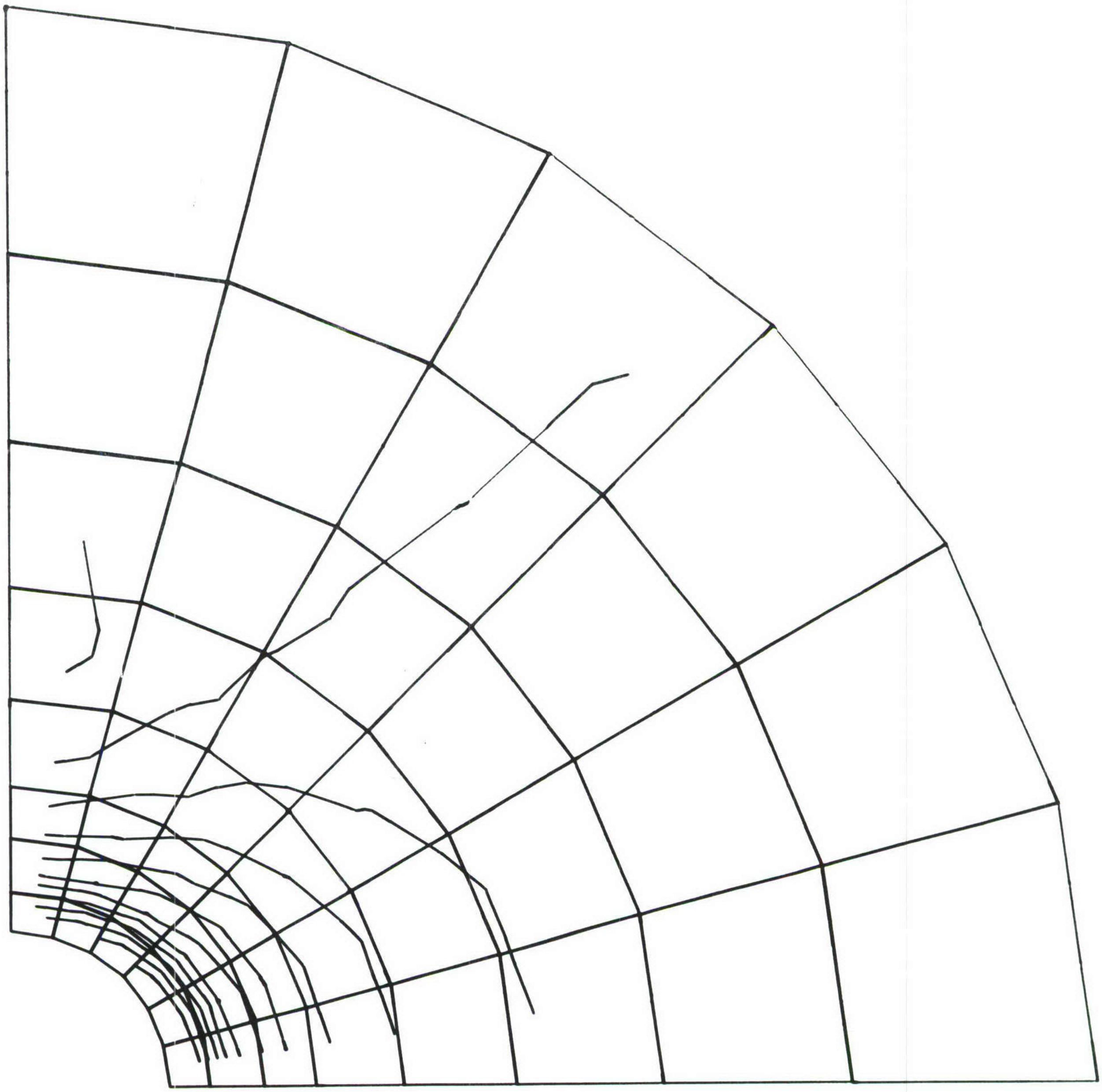


Figure AIII-156 Second Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

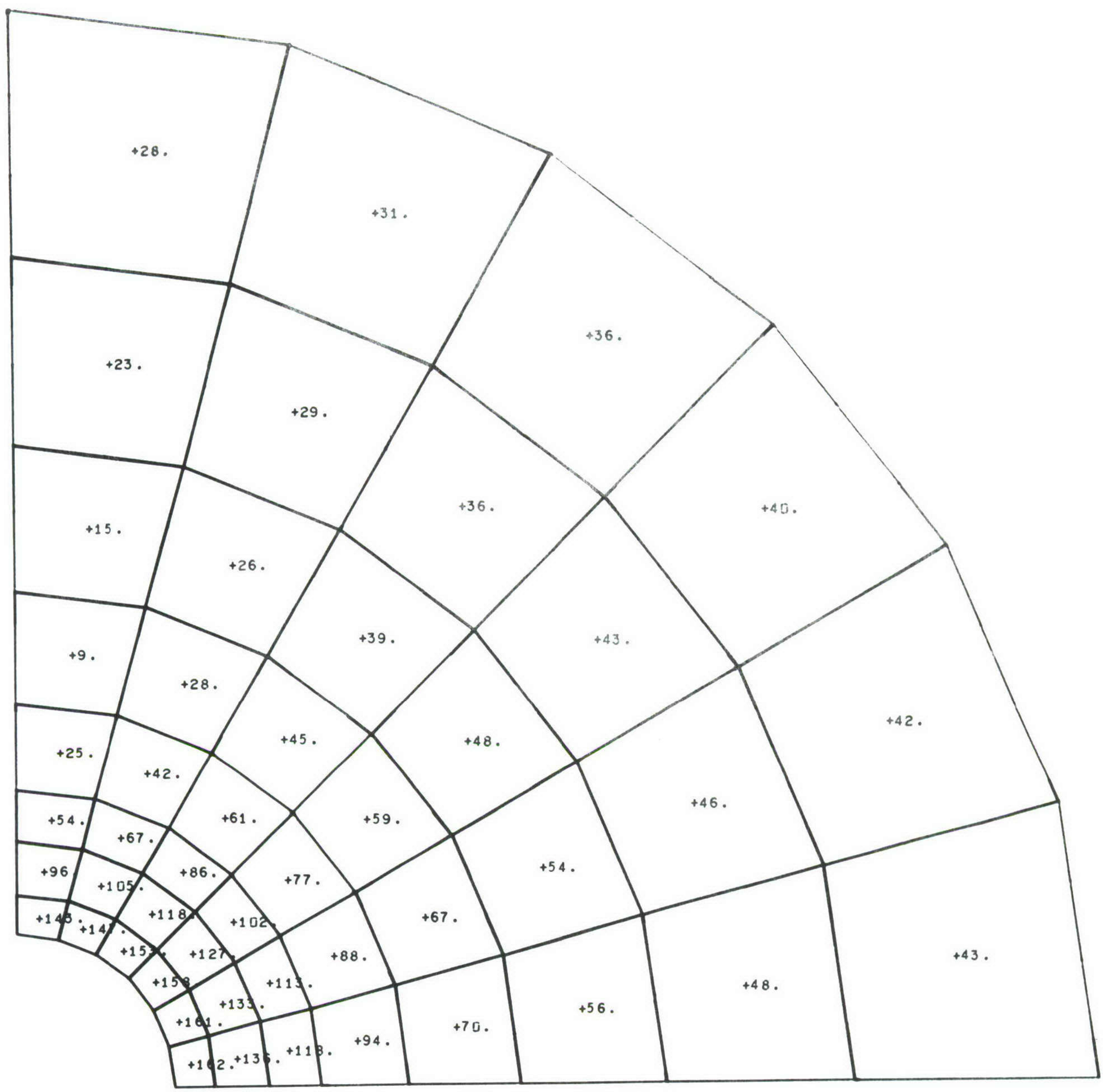


Figure AIII-157 Principal Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

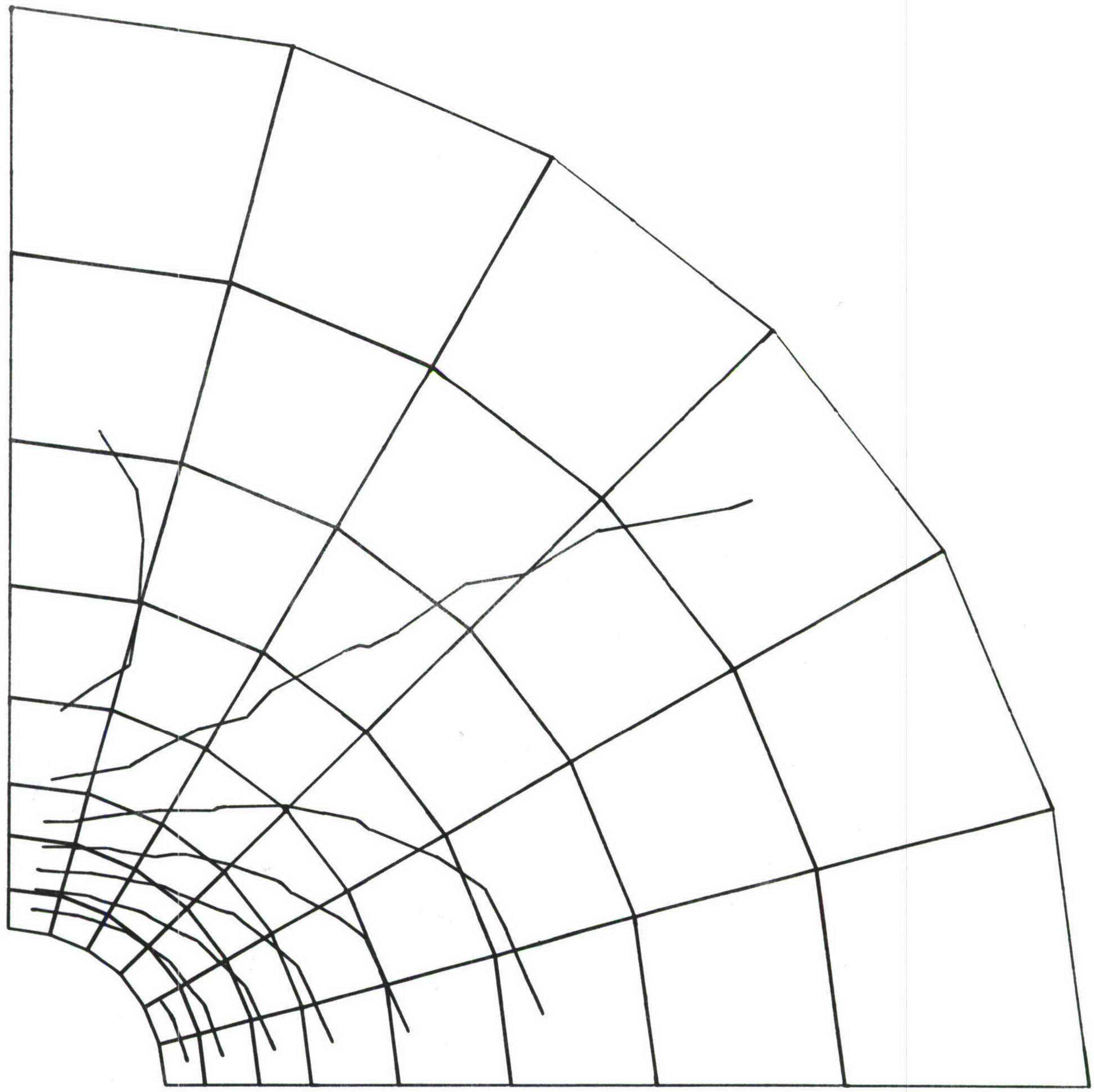


Figure AIII-158 Principal Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 35% Uniaxial Load

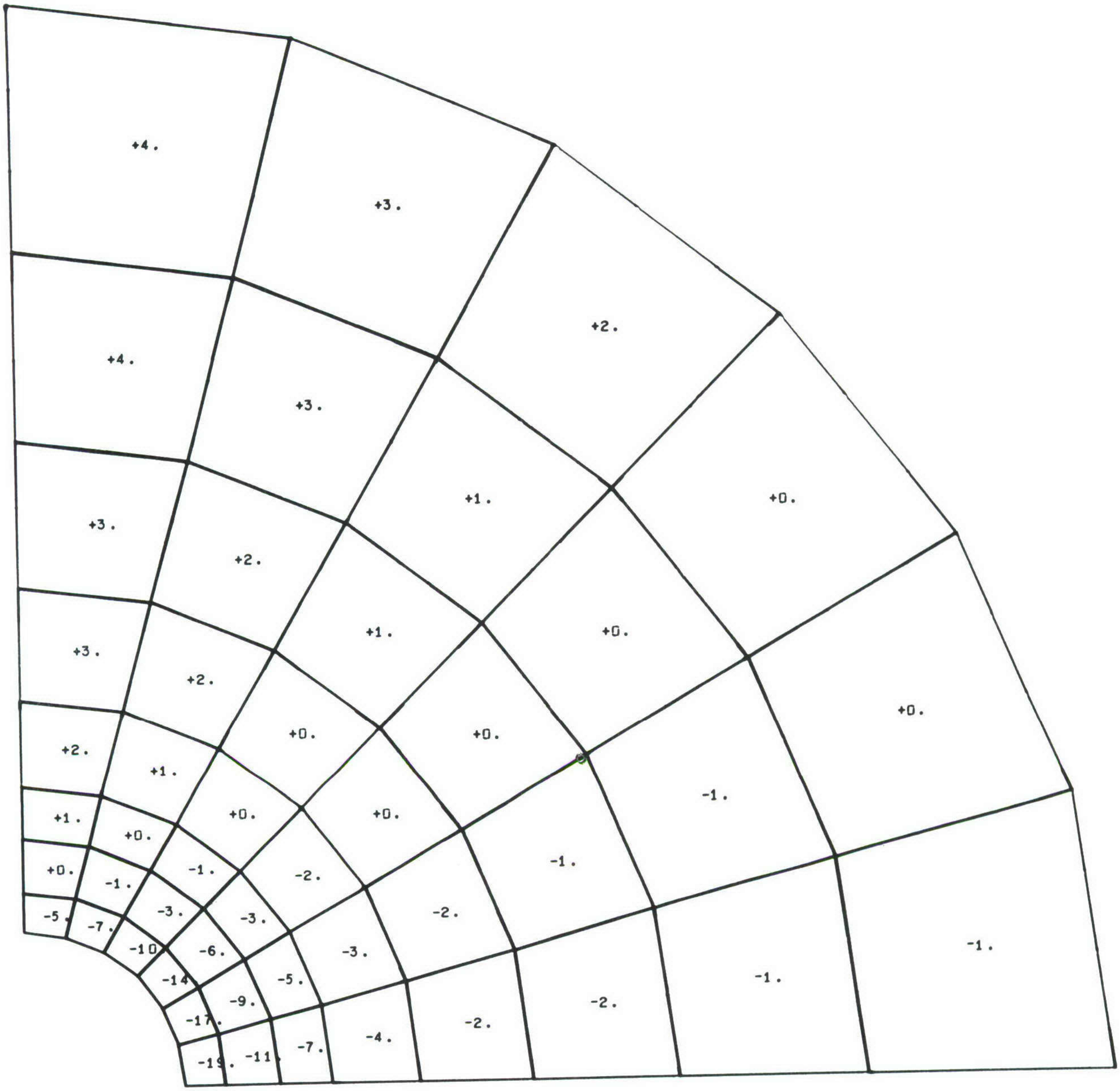


Figure AIII-159 Radial Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

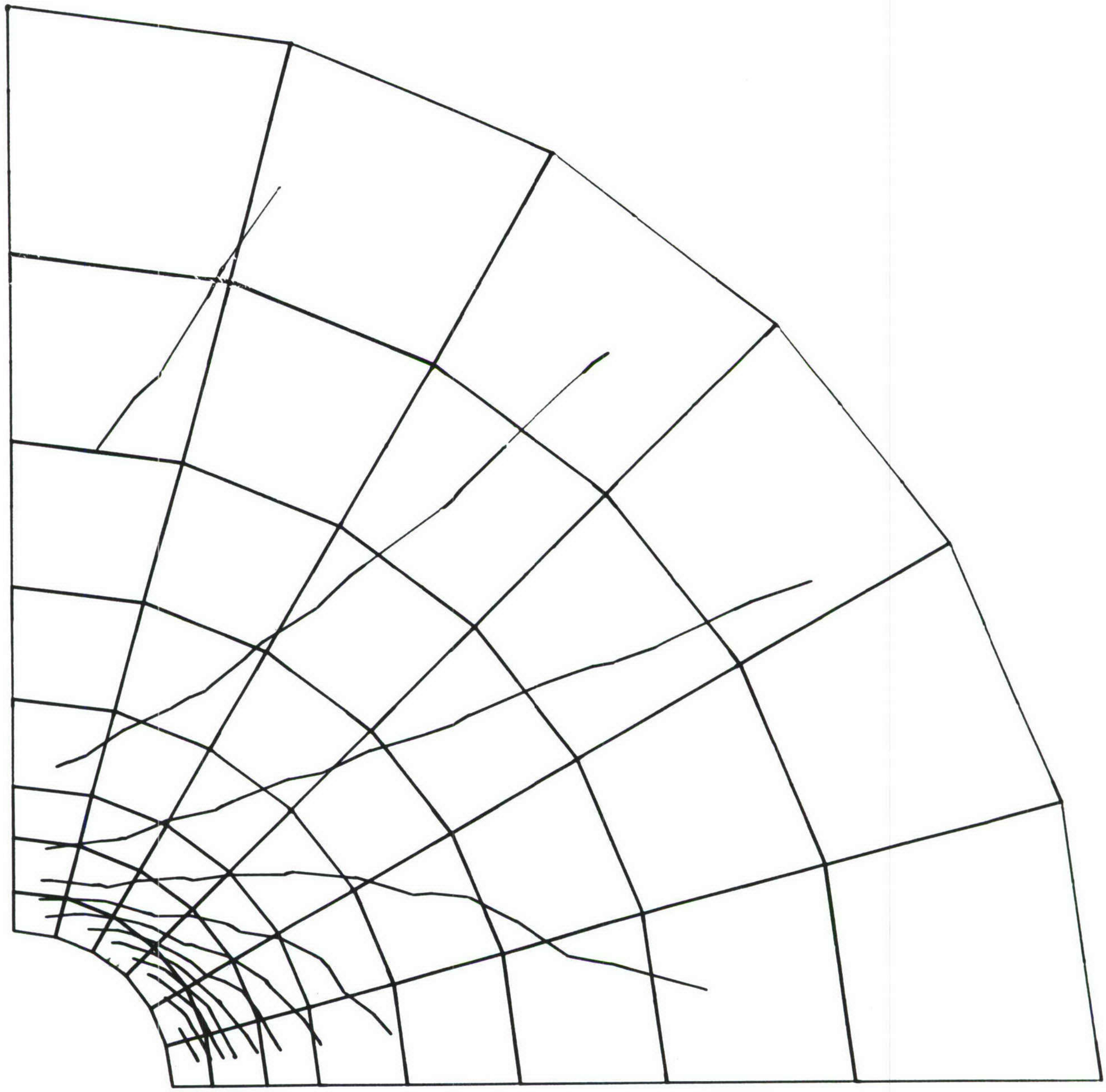


Figure AIII-160 Radial Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

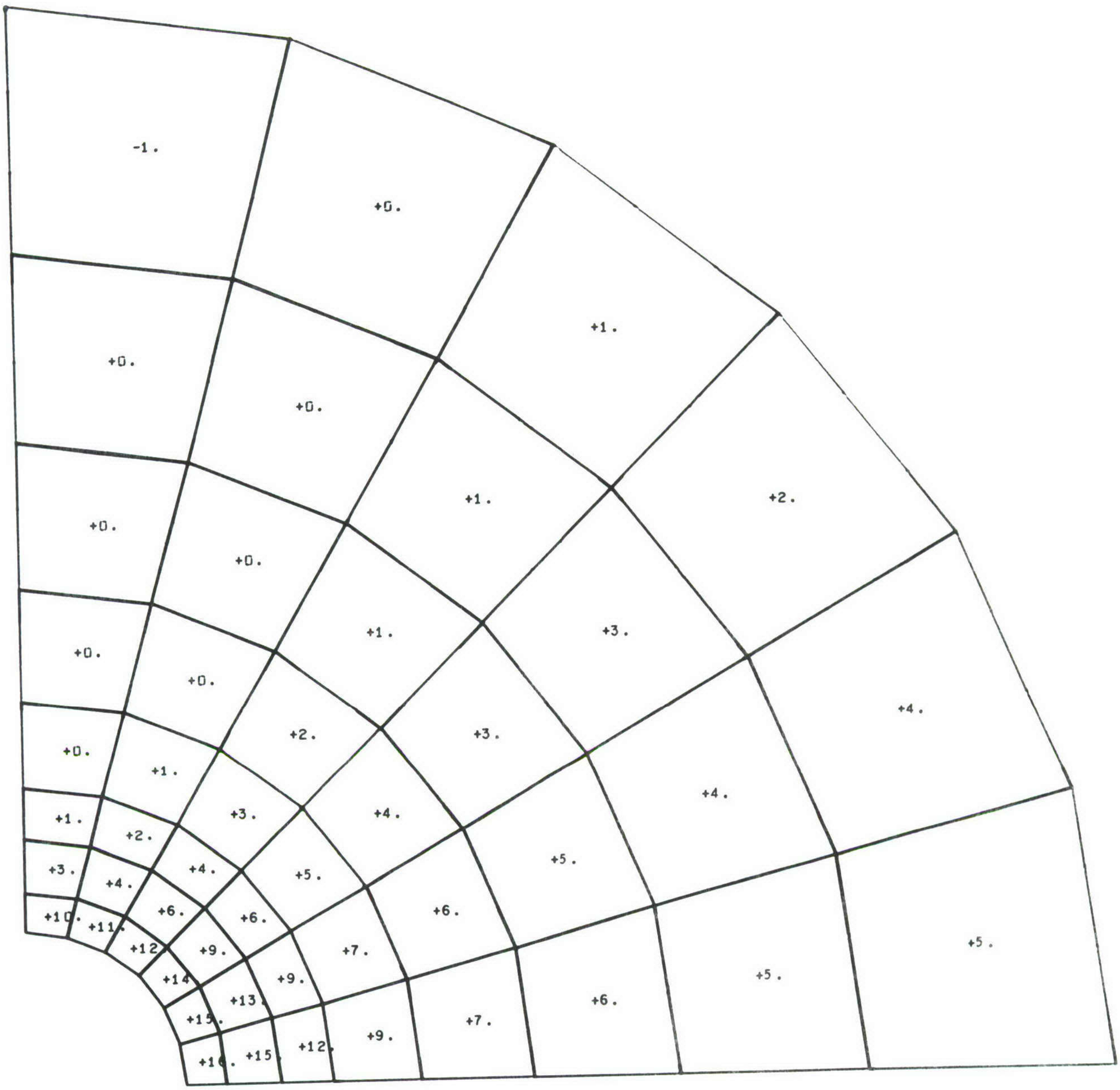


Figure AIII-161 Tangential Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

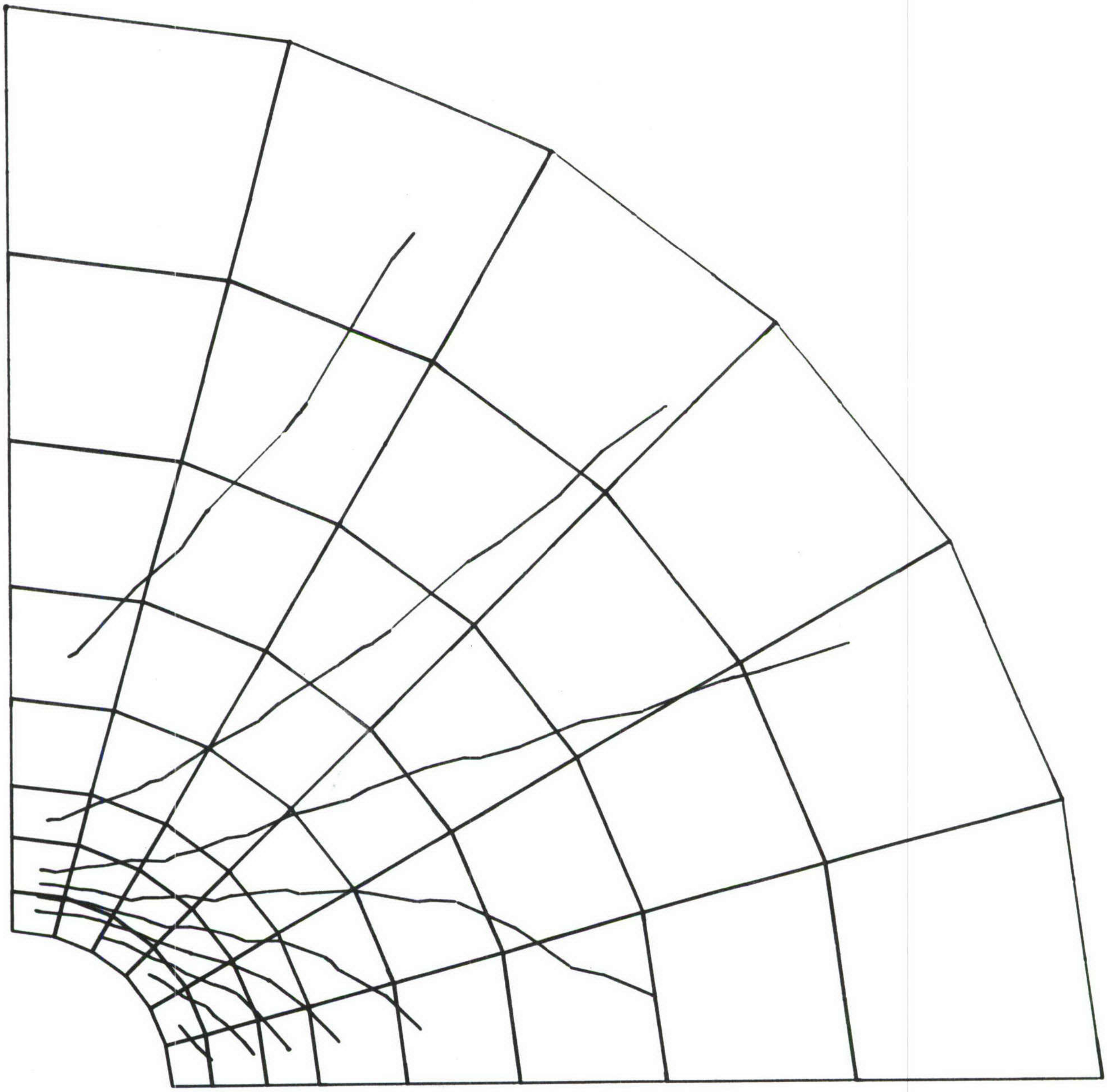


Figure AIII-162 Tangential Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

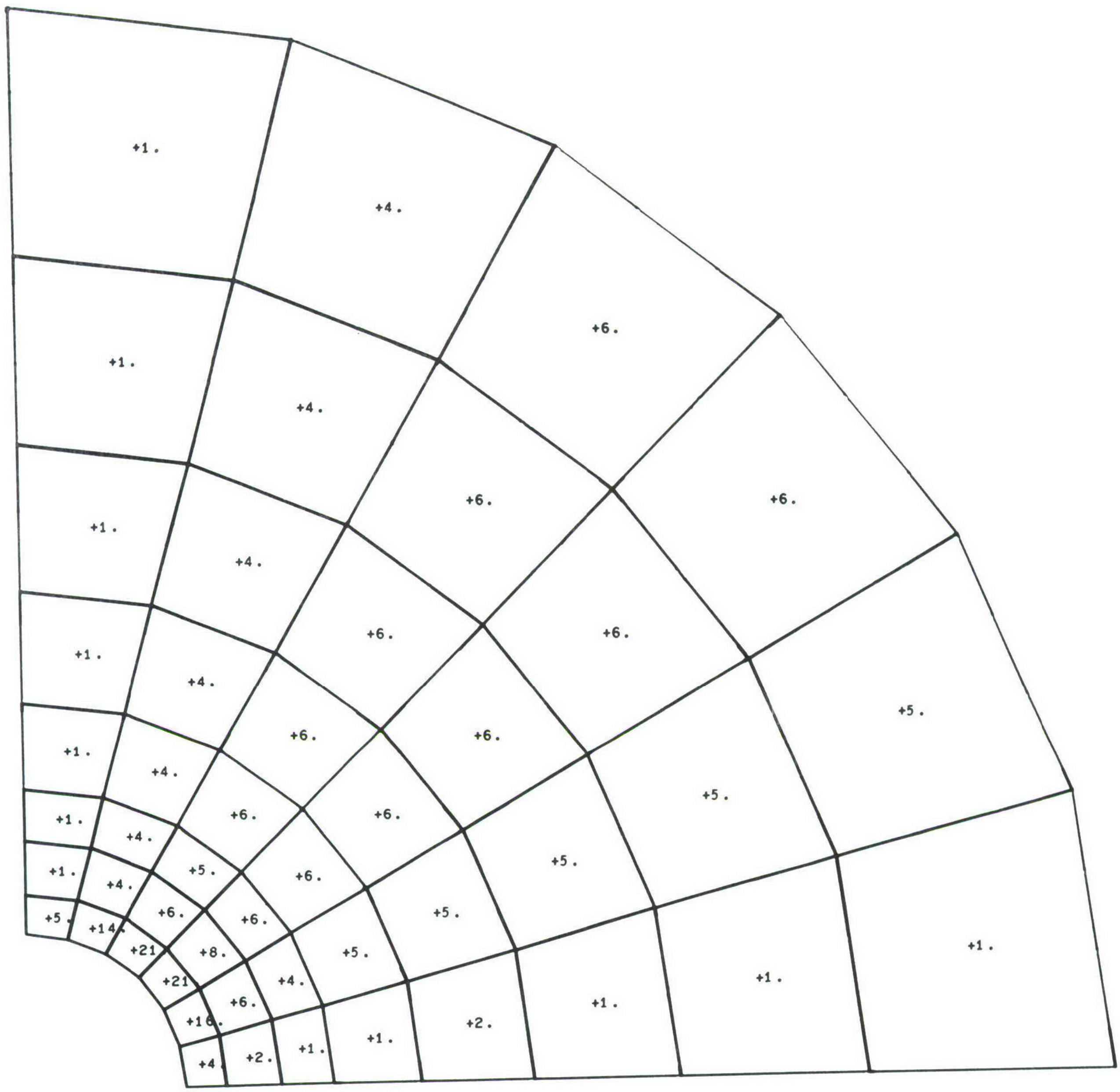


Figure AIII-163 Radial-Tangential Shear Strain Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

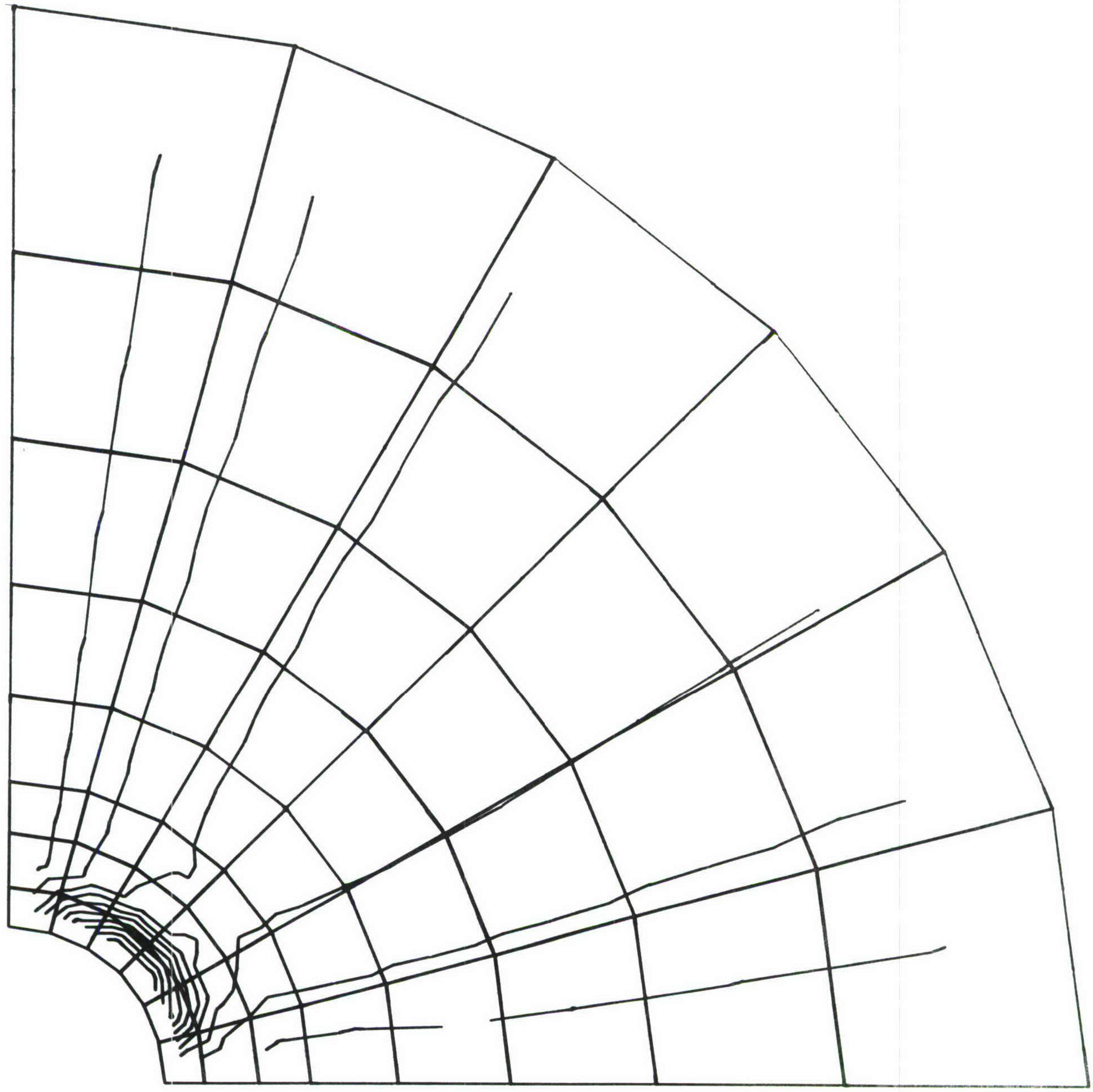


Figure AIII-164 Radial-Tangential Shear Strain Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

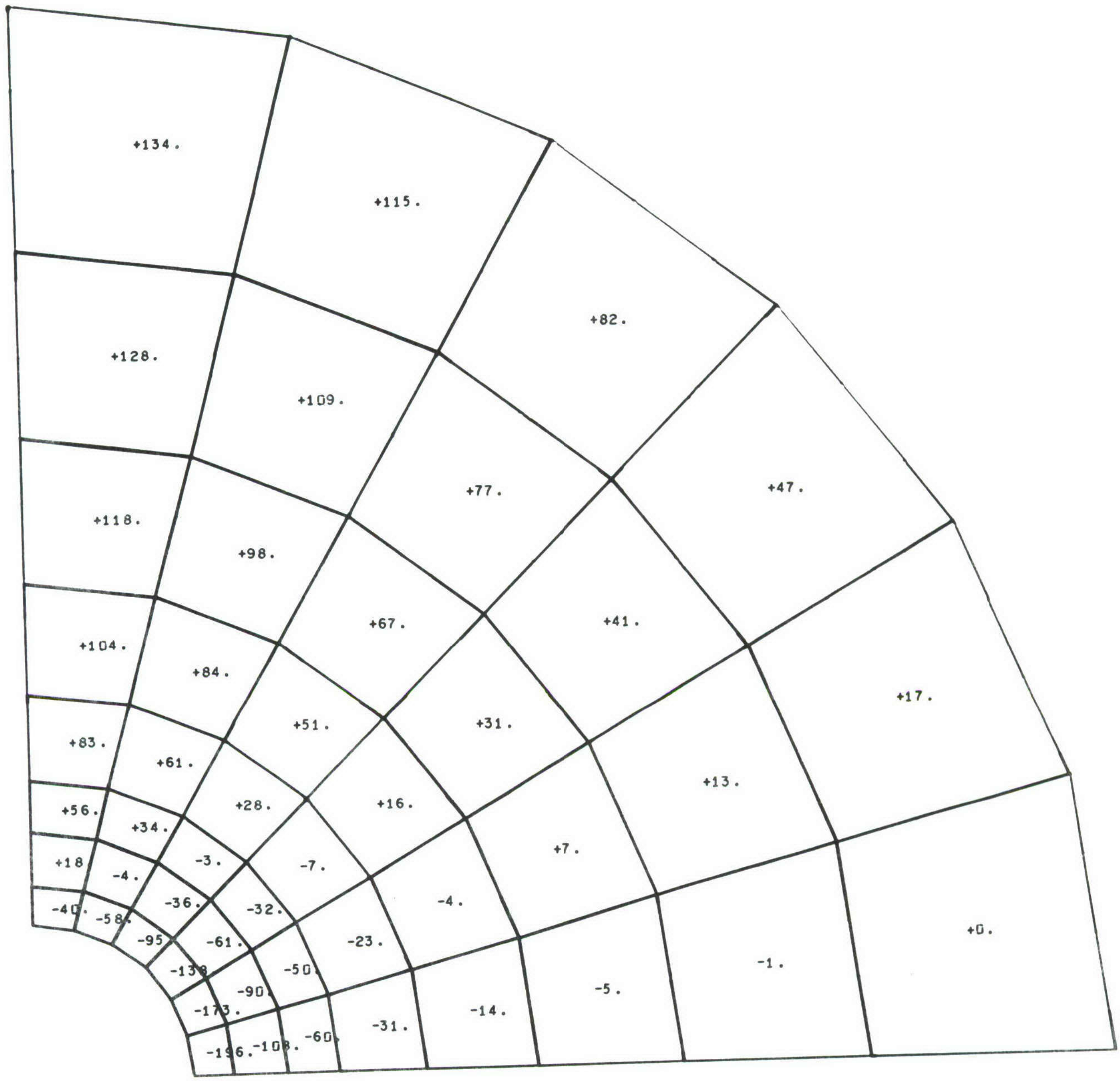


Figure AIII-165 Radial Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

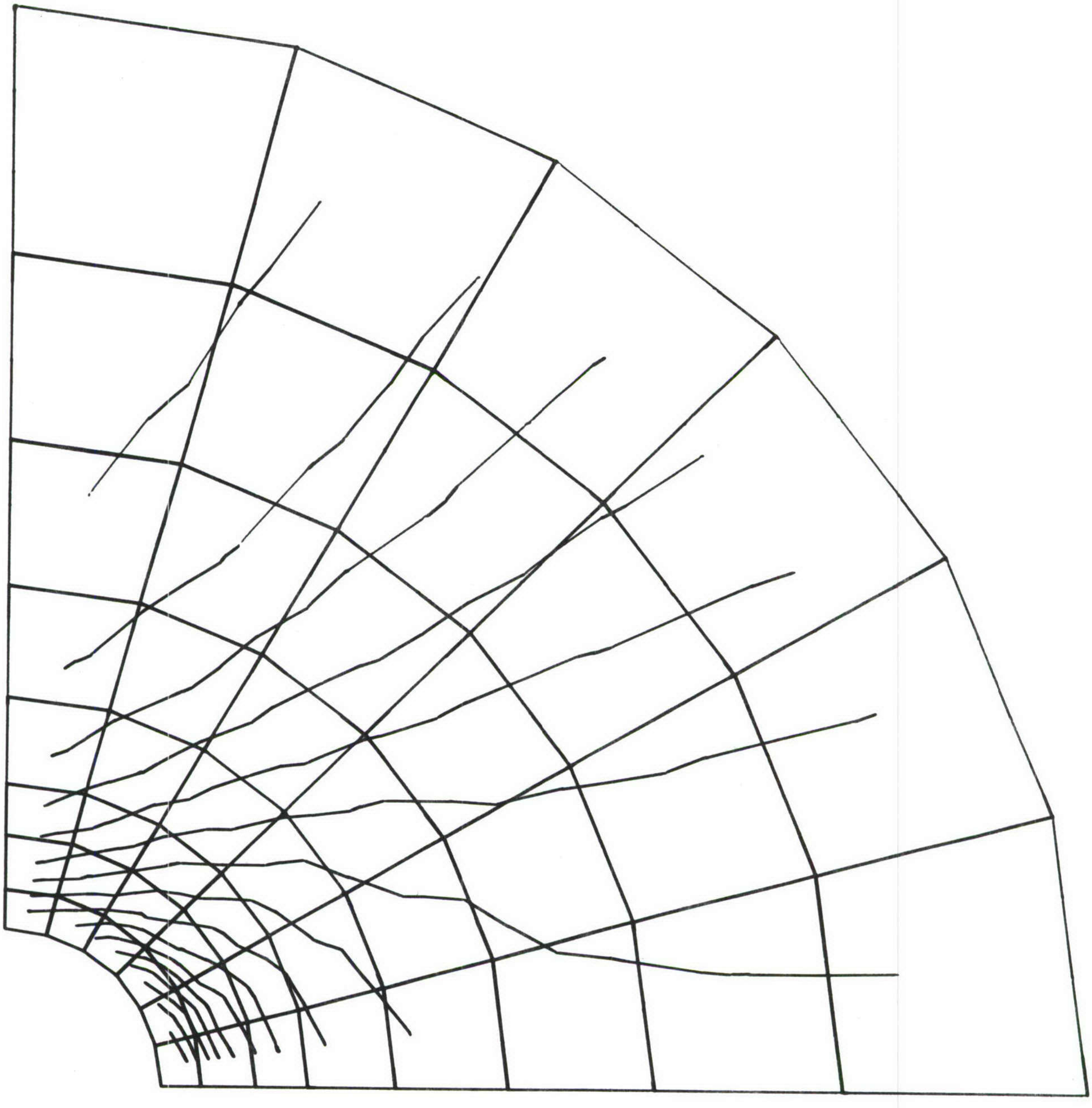


Figure AIII-166 Radial Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

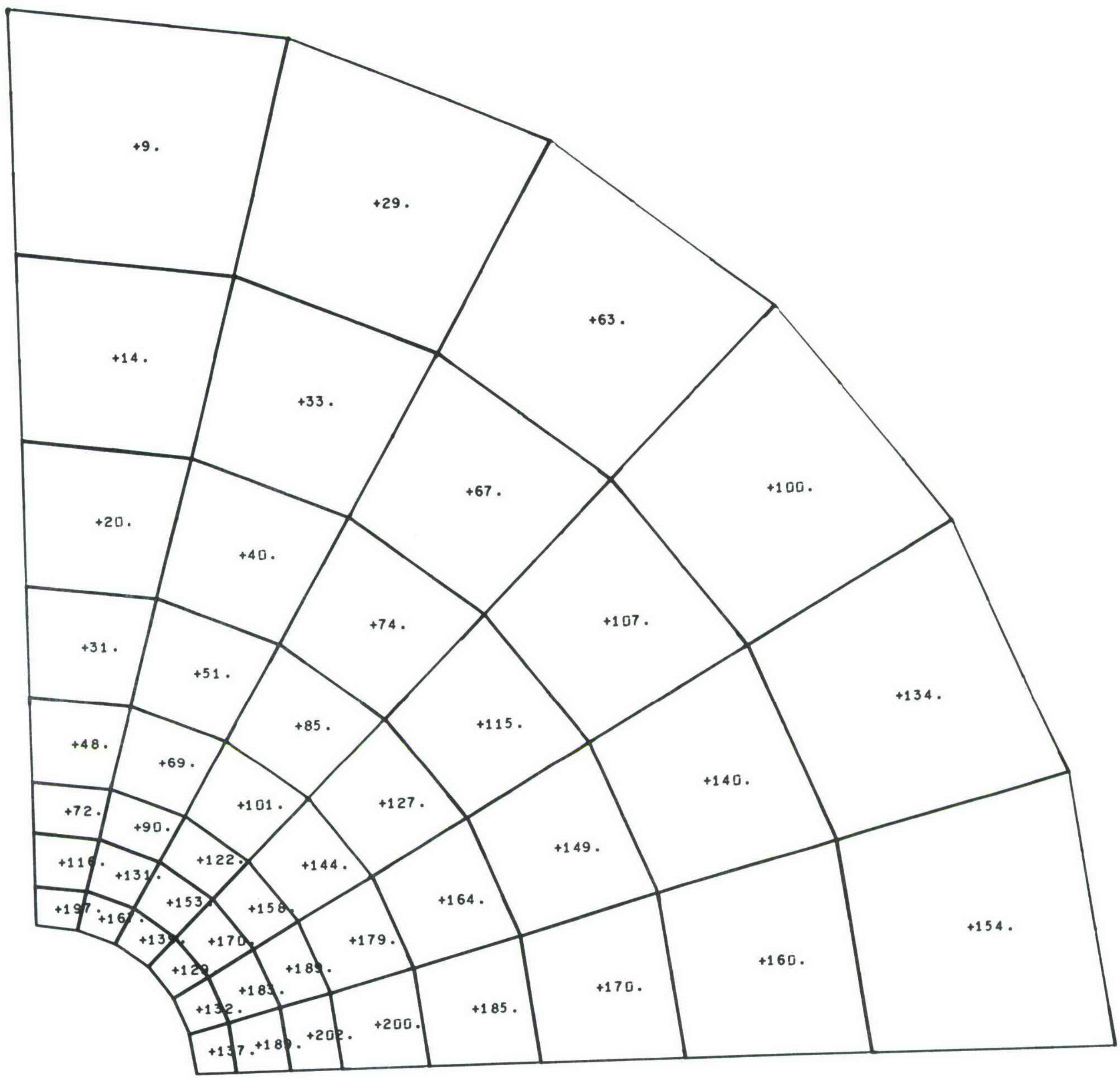


Figure AIII-167 Tangential Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

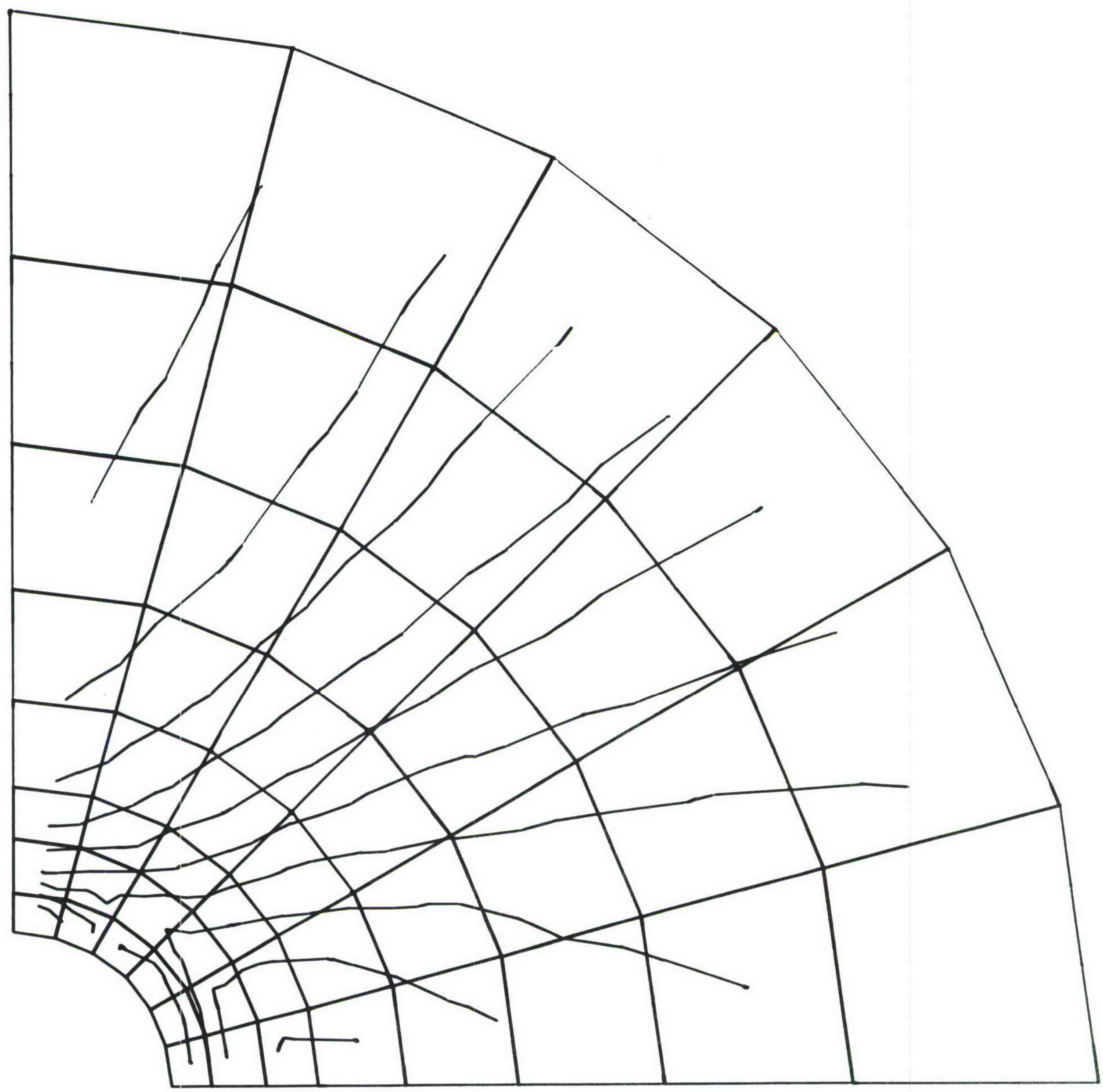


Figure AIII-168 Tangential Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

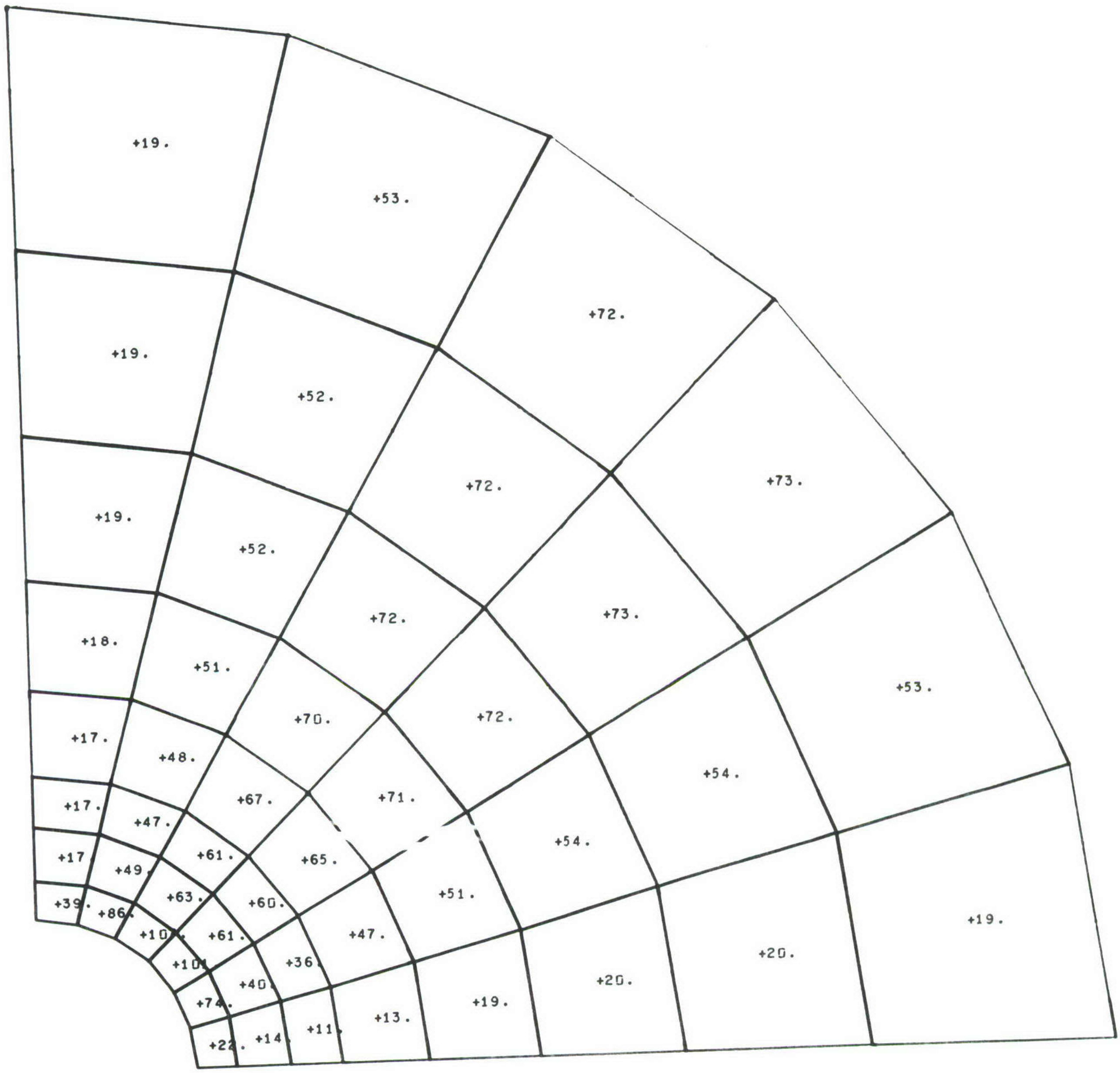


Figure AIII-169 Radial-Tangential Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

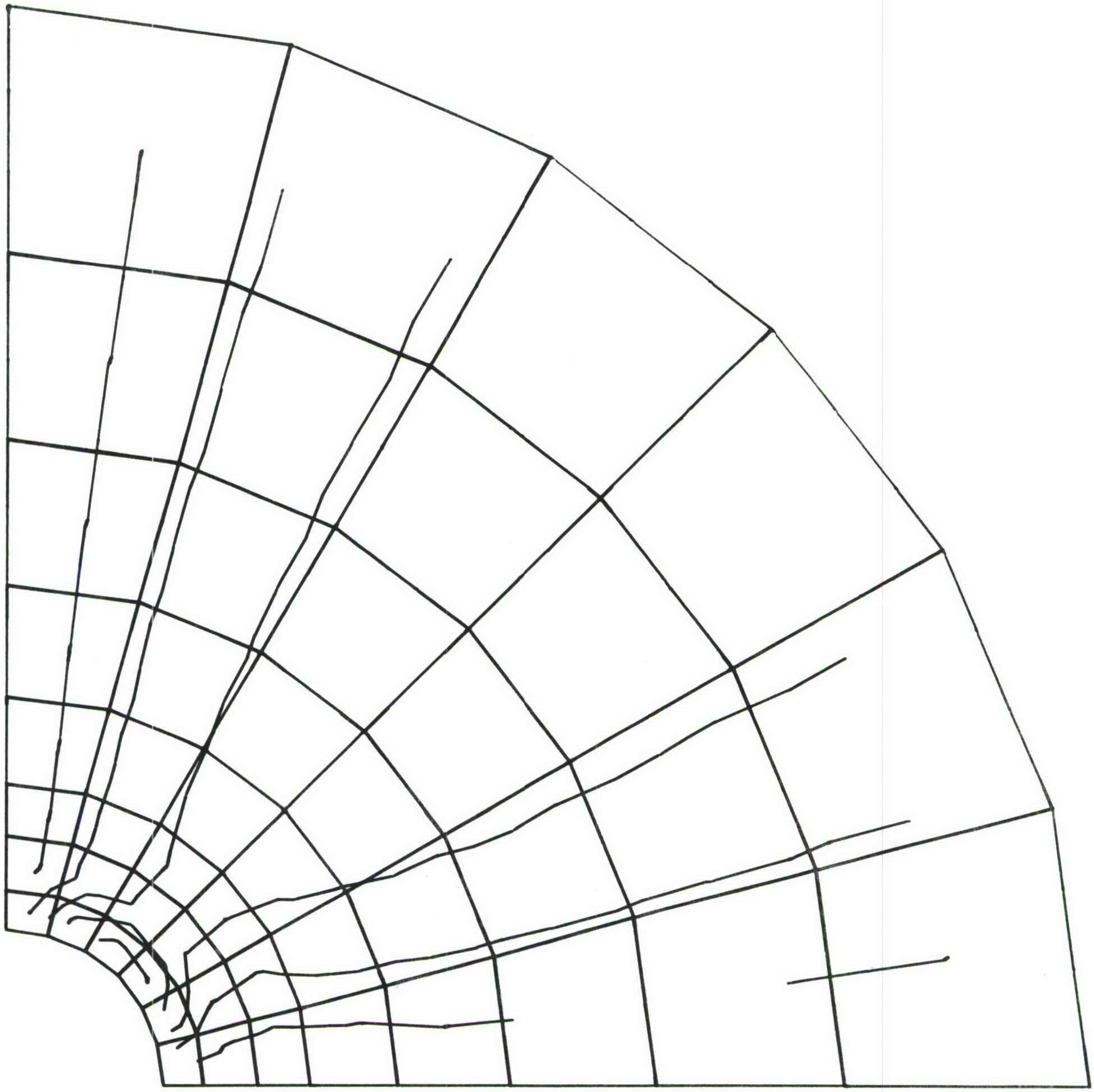


Figure AIII-170 Radial-Tangential Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

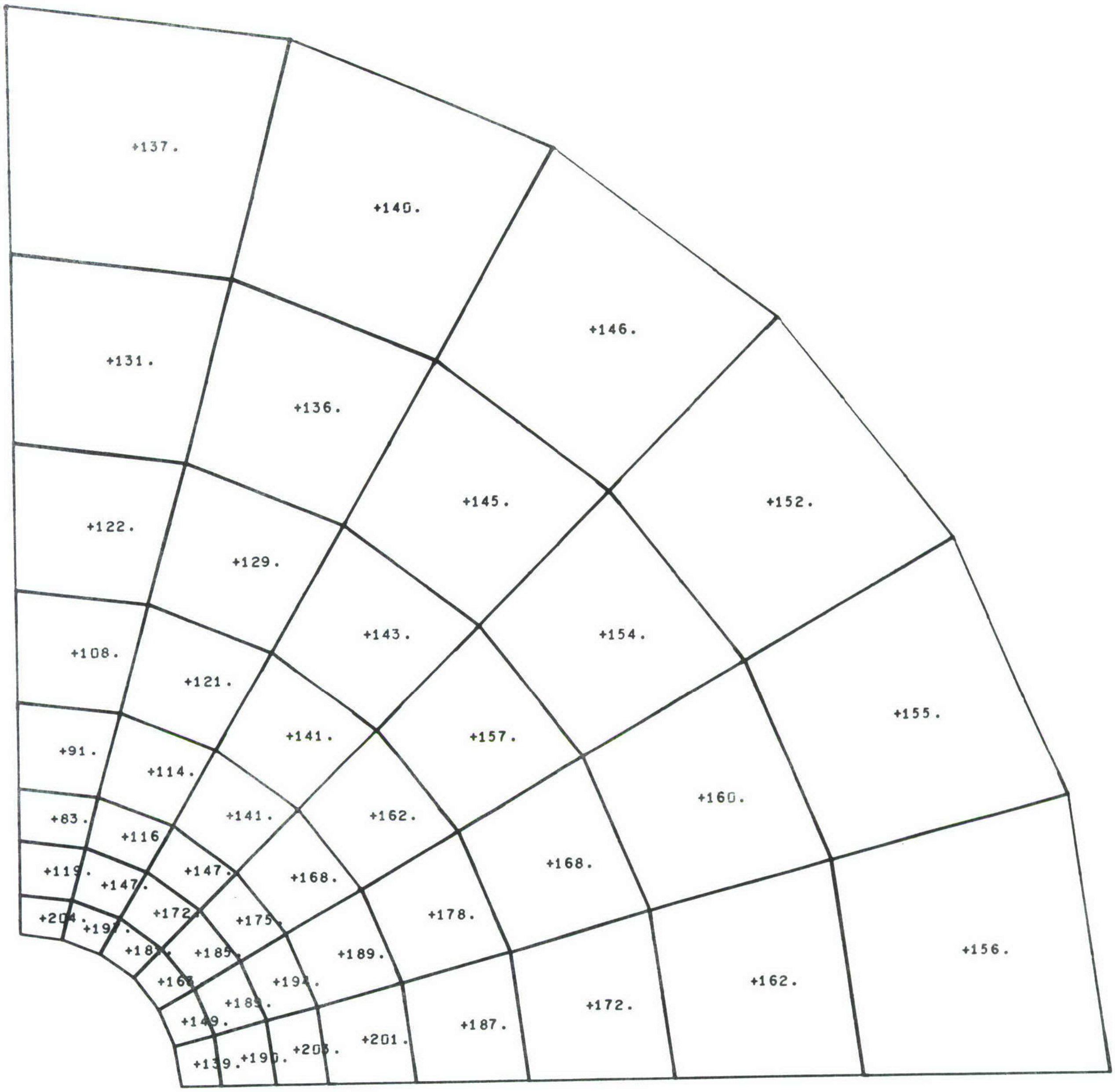


Figure AIII-171 First Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

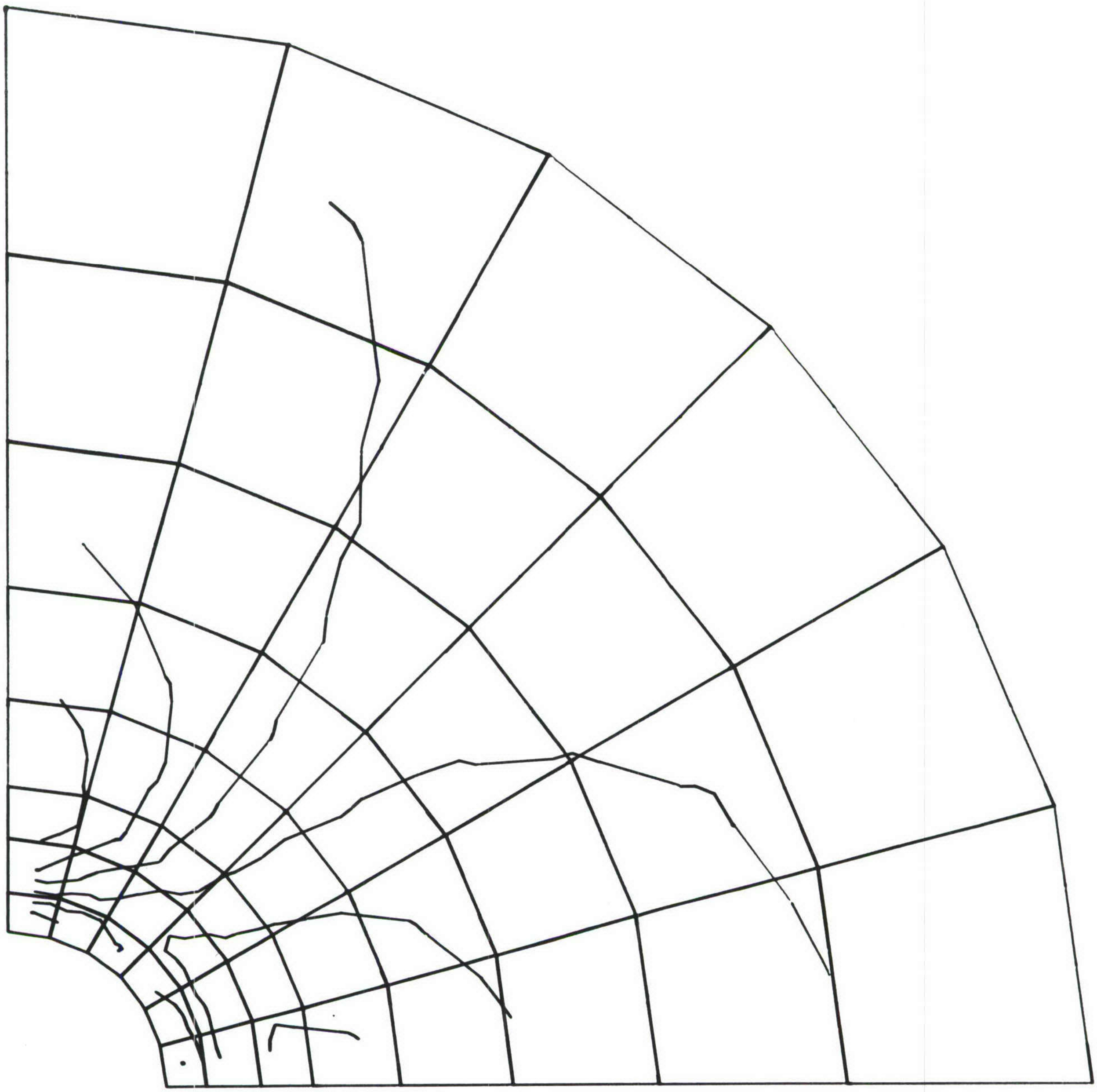


Figure AIII-172 First Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

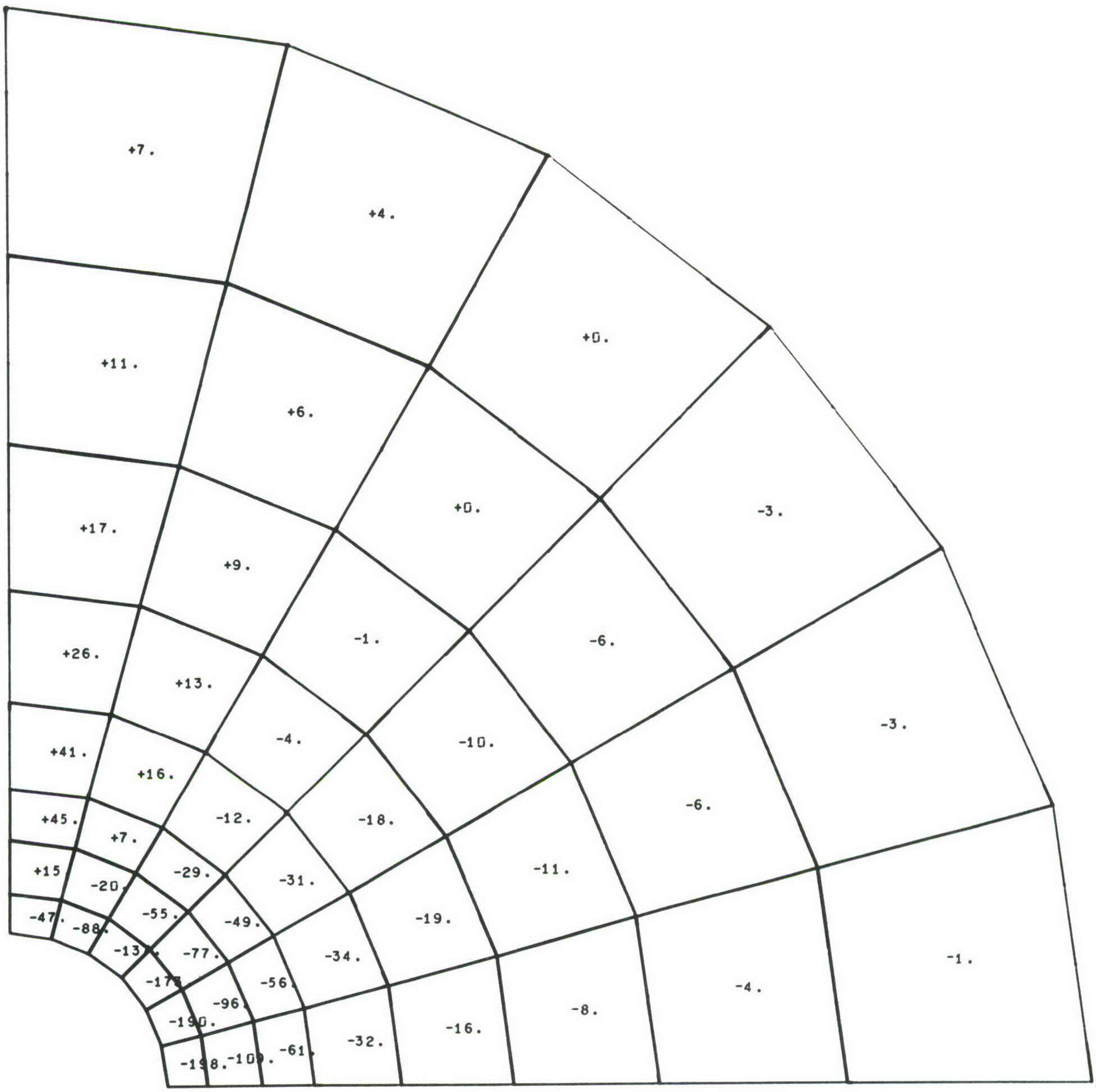


Figure AIII-173 Second Principal Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

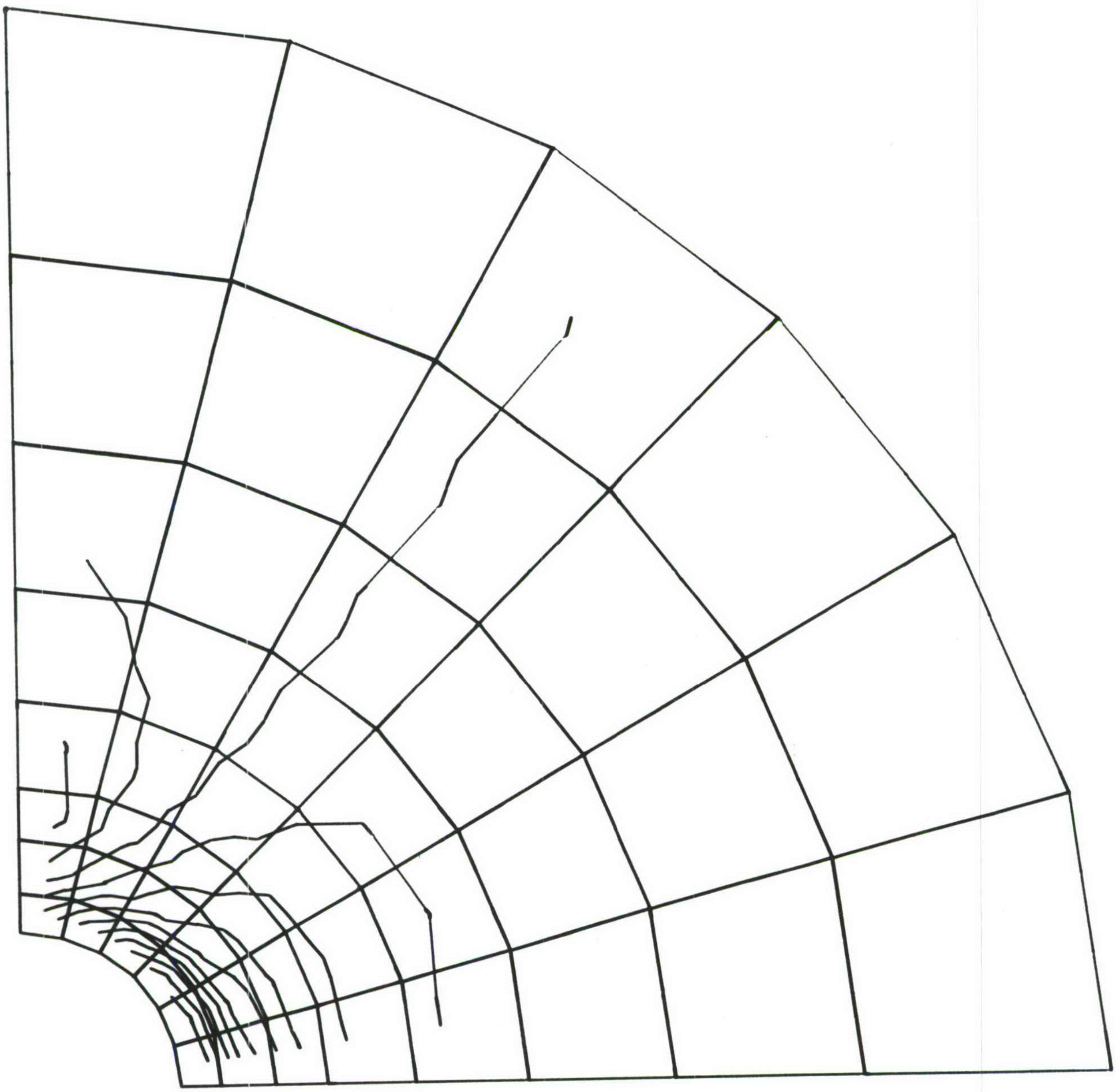


Figure AIII-174 Second Principal Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

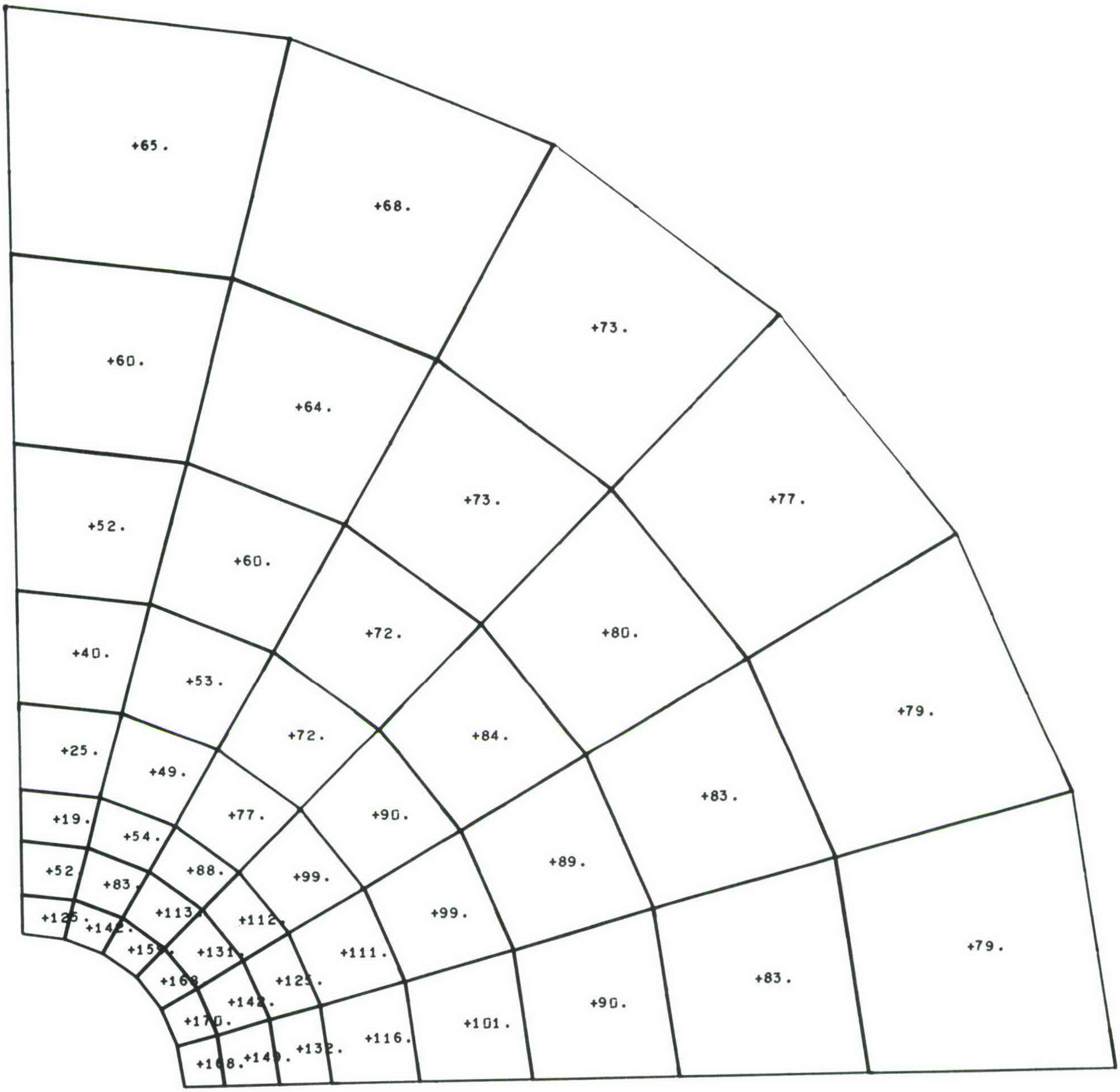


Figure AIII-175 Principal Shear Stress Values for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

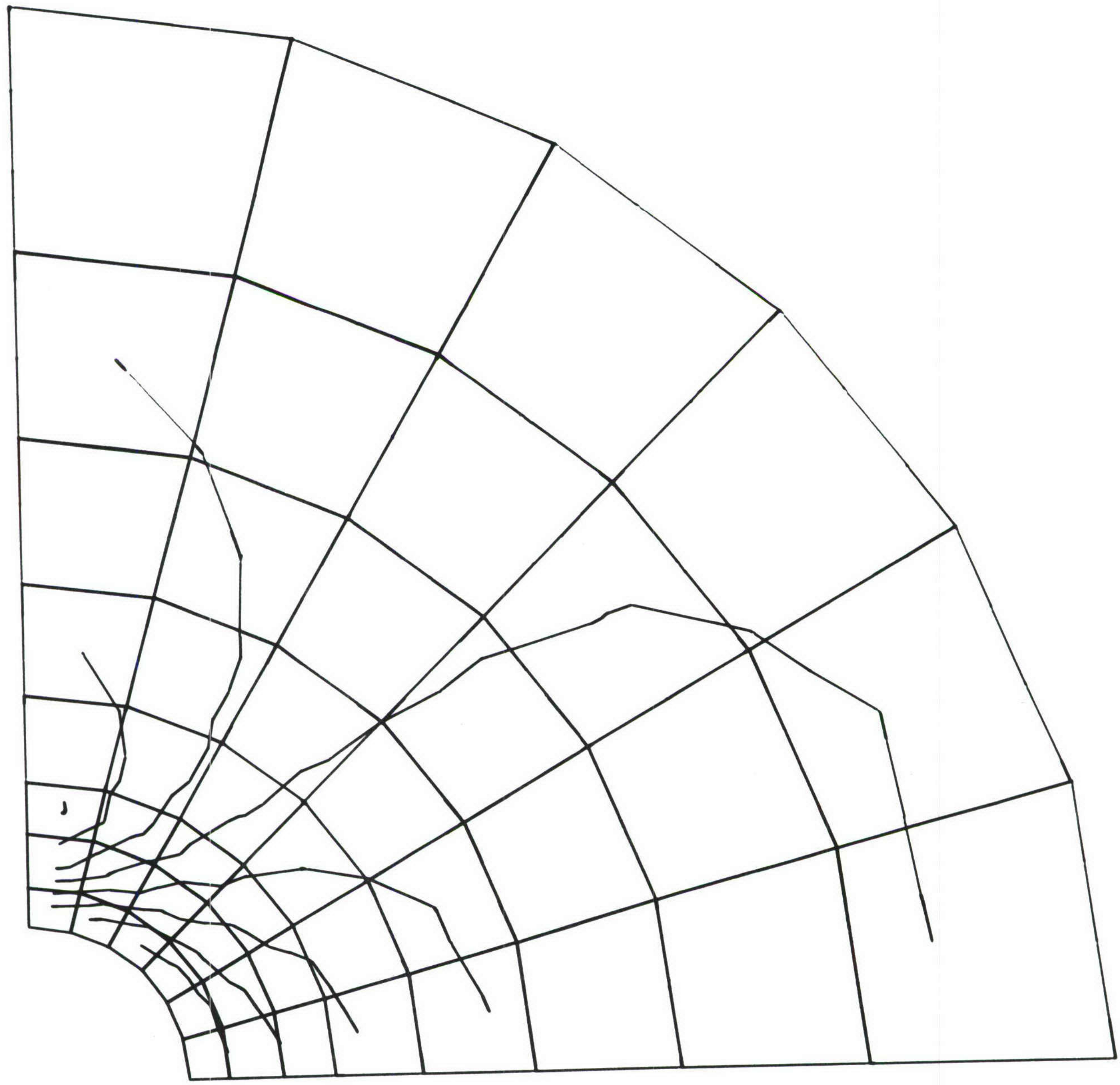


Figure AIII-176 Principal Shear Stress Contours for Steel Plate with 1/8 Inch Hole Radius; 0.0025 Inch Radial Interference; 70% Uniaxial Load

APPENDIX I INDEX OF FIGURES

ALUMINUM PLATE RESULTS

(NOTE: Because of the large number of figures (176) included to present the aluminum plate results, this index is included in lieu of a list of figures. The data presents the figure and the page numbers in 2 rows. Figure numbers are in the first row; page numbers are immediately below in the second row).

Bolt Hole Size (Inches)	Uniaxial Load (Percent)	Radial Interference (Inches)	Radial-Tangential Strains						Radial-Tangential Stress						Principal Stress					
			ε_R		ε_T		γ_{RT}		σ_R		σ_T		τ_{RT}		σ_1		σ_2		τ_{12}	
3/8	0	0.001875	1 36	2 37	3 38	4 39			5 40	6 41	7 42	8 43								
3/8	35	0.001875	9 44	10 45	11 46	12 47	13 48	14 49	15 50	16 51	17 52	18 53	19 54	20 55	21 56	22 57	23 58	24 59	25 60	26 61
3/8	70	0.001875	27 62	28 63	29 64	30 65	31 66	32 67	33 68	34 69	35 70	36 71	37 72	38 73	39 74	40 75	41 76	42 77	43 78	44 79
3/8	0	0.00375	45 80	46 81	47 82	48 83			49 84	50 85	51 86	52 87								
3/8	35	0.00375	53 88	54 89	55 90	56 91	57 92	58 93	59 94	60 95	61 96	62 97	63 98	64 99	65 100	66 101	67 102	68 103	69 104	70 105
3/8	70	0.00375	71 106	72 107	73 108	74 109	75 110	76 111	77 112	78 113	79 114	80 115	81 116	82 117	83 118	84 119	85 120	86 121	87 122	88 123
1/4	0	0.00125	89 124	90 125	91 126	92 127			93 128	94 129	95 130	96 131								
1/4	35	0.00125	97 132	98 133	99 134	100 135	101 136	102 137	103 138	104 139	105 140	106 141	107 142	108 143	109 144	110 145	111 146	112 147	113 148	114 149
1/4	70	0.00125	115 150	116 151	117 152	118 153	119 154	120 155	121 156	122 157	123 158	124 159	125 160	126 161	127 162	128 163	129 164	130 165	131 166	132 167
1/4	0	0.00250	133 168	134 169	135 170	136 171			137 172	138 173	139 174	140 175								
1/4	35	0.00250	141 176	142 177	143 178	144 179	145 180	146 181	147 182	148 183	149 184	150 185	151 186	152 187	153 188	154 189	155 190	156 191	157 192	158 193
1/4	70	0.00250	159 194	160 195	161 196	162 197	163 198	164 199	165 200	166 201	167 202	168 203	169 204	170 205	171 206	172 207	173 208	174 209	175 210	176 211

APPENDIX II INDEX OF FIGURES

TITANIUM PLATE RESULTS

(NOTE: Because of the large number of figures (176) included to present the titanium plate results, this index is included in lieu of a list of figures. The data presents the figure number and the page numbers in 2 rows. Figure numbers are in the first row; page numbers are immediately below in the second row).

APPENDIX III INDEX OF FIGURES

STEEL PLATE RESULTS

(NOTE: Because of the large number of figures (176) included to present the steel plate results, this index is included in lieu of a list of figures. The data presents the figure numbers and the page numbers in 2 rows. Figure numbers are in the first row; page numbers are immediately below in the second row).

Bolt Hole Size (Inches)	Uniaxial Load (Percent)	Radial Interference (Inches)	Radial-Tangential Strains						Radial-Tangential Stress						Principal Stress					
			ε_R		ε_T		γ_{RT}		σ_R		σ_T		τ_{RT}		σ_1		σ_2		τ_{12}	
3/8	0	0.001875	1 390	2 391	3 392	4 393			5 394	6 395	7 396	8 397								
3/8	35	0.001875	9 398	10 399	11 400	12 401	13 402	14 403	15 404	16 405	17 406	18 407	19 408	20 409	21 410	22 411	23 412	24 413	25 414	26 415
3/8	70	0.001875	27 416	28 417	29 418	30 419	31 420	32 421	33 422	34 423	35 424	36 425	37 426	38 427	39 428	40 429	41 430	42 431	43 432	44 433
3/8	0	0.00375	45 434	46 435	47 436	48 437			49 438	50 439	51 440	52 441								
3/8	35	0.00375	53 442	54 443	55 444	56 445	57 446	58 447	59 448	60 449	61 450	62 451	63 452	64 453	65 454	66 455	67 456	68 457	69 458	70 459
3/8	70	0.00375	71 460	72 461	73 462	74 463	75 464	76 465	77 466	78 467	79 468	80 469	81 470	82 471	83 472	84 473	85 474	86 475	87 476	88 477
1/4	0	0.00125	89 478	90 479	91 480	92 481			93 482	94 483	95 484	96 485								
1/4	35	0.00125	97 486	98 487	99 488	100 489	101 490	102 491	103 492	104 493	105 494	106 495	107 496	108 497	109 498	110 499	111 500	112 501	113 502	114 503
1/4	70	0.00125	115 504	116 505	117 506	118 507	119 508	120 509	121 510	122 511	123 512	124 513	125 514	126 515	127 516	128 517	129 518	130 519	131 520	132 521
1/4	0	0.00250	133 522	134 523	135 524	136 525			137 526	138 527	139 528	140 529								
1/4	35	0.00250	141 530	142 531	143 532	144 533	145 534	146 535	147 536	148 537	149 538	150 539	151 540	152 541	153 542	154 543	155 544	156 545	157 546	158 547
1/4	70	0.00250	159 548	160 549	161 550	162 551	163 552	164 553	165 554	166 555	167 556	168 557	169 558	170 559	171 560	172 561	173 562	174 563	175 564	176 565

REFERENCES

1. Richard, R. M. and Blacklock, J. R., Finite Element Analysis of Inelastic Structures, AIAA Journal, Volume 7, Number 3, March 1969.

2. Sokolnikoff, I. S., Mathematical Theory of Elasticity, Second Edition, McGraw-Hill Book Company, Inc., New York, N. Y., 1956.

3. Wang, Chi-Teh, Applied Elasticity, McGraw-Hill Book Company, Inc., New York, N. Y., 1953.

4. MIL-HDBK-5B, Military Standardization Handbook, Metallic Materials and Elements for Aerospace Vehicle Structures, Volume 1 of 2 Volumes, 1 September 1971.

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13. ABSTRACT

A body of detailed stress and strain distributions in the vicinity of interference fit fasteners has been analytically obtained and is presented. These data, obtained on simple installations, present trends which may be used by designers in determining how or whether to use interference fit fasteners.

The analysis was performed with a finite element digital procedure which has the nonlinear constitutive behavior programmed and interrelates internal loading and deformations. Preparations for the analysis of thirty six conditions included analyzing a test article for which good correlations are shown.

Stress and strain distributions are presented for conditions which include two fastener hole sizes, two levels of interference fit, three plate materials (steel, titanium and aluminum) and three levels of uniaxial loading.

The results indicate that the radial strains in that part of the plate which is strained beyond the yield point are sensitive to the value of plastic modulus of the material. Also, the fastener diameters may be any size provided that the insertion is adjusted accordingly.

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Stresses and Strains						
Plasticity						
Nonlinear Materials						

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