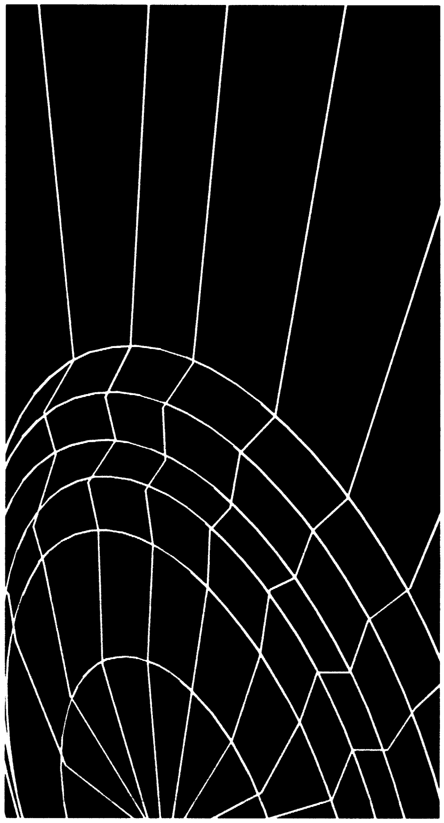
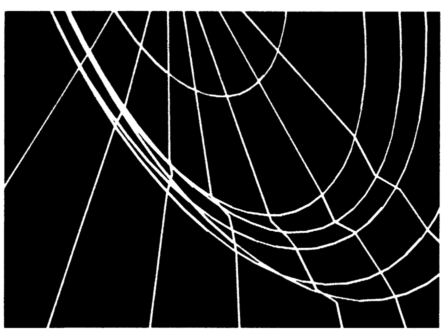


MARC



Volume E

Demonstration Problems

Version K7

MARC
Analysis
Research
Corporation

MARC
Analysis
Research
Corporation

MARC Analysis Research Corporation
260 Sheridan Avenue, Suite 309
Palo Alto, CA 94306 USA

Phone: (650) 329-6800
FAX: (650) 323-5892

Document Title: **MARC Volume E: Demonstration Problems, Part I, Version K7**
Part Number: RF-3018-07.I
Revision Date: June, 1998

Proprietary Notice

Restricted Rights Notice

Trademarks

Preface

MARC Volume E: Demonstration Problems demonstrates most of MARC's capabilities. MARC is a powerful, modern, general-purpose nonlinear finite element program for structural, thermal, and electromagnetic analyses.

In a typical finite element analysis, you need to define the:

mesh (which is an *approximate* model of the actual structure);

material properties (Young's modulus, Poisson's ration, etc.);

applied loads (static, dynamic temperature, inertial, etc.);

boundary conditions (geometric and kinematic constraints); and

type of analysis (linear static, nonlinear, buckling, thermal, etc.).

The steps leading up to the actual finite element analysis are generally termed preprocessing; currently, many users accomplish these steps by using an interactive color graphics pre- and postprocessing program such as the Mentat graphics program. After an analysis, the results evaluation phase (postprocessing) is where you check the adequacy of the design (and of the approximate finite analysis model) in terms of critical stresses, deflection, temperatures, and so forth.

MARC Volume E: Demonstration Problems is divided into five parts with each part containing two chapters. The manual has nine chapters grouped by the type of demonstration problems.

Part I

Chapter 1: *Introduction*

provides a general introduction to the problems demonstrated in all parts of *MARC Volume E: Demonstration Problems*. A set of cross-reference tables shows keywords for the following:

parameters
model definition options
mesh display options
history definition options
mesh rezoning options
element types
user subroutines

Each keyword is cross-referenced to the problem in which its use is demonstrated

Chapter 2: *Linear Analysis*

demonstrates most of the element types available to you. Many linear analysis features are illustrated. The use of adaptive meshing for linear analysis is demonstrated here.

Part II

Chapter 3: *Plasticity and Creep*

demonstrates the nonlinear material analysis capabilities. Both plasticity and creep phenomena are covered.

Chapter 4: *Large Displacement*

demonstrates MARC's ability to analyze both large displacement and small strain effects.

Part III

Chapter 5: *Heat Transfer* demonstrates both steady-state and transient heat transfer capabilities.

Chapter 6: *Dynamics* demonstrates many types of dynamic problems. These include analyses performed using both the modal and direct integration methods. The influences of fluid coupling and initial stresses on the calculated eigenvalues are shown.

Harmonic and spectrum response analysis is also demonstrated here.

Part IV

Chapter 7: *Contact* demonstrates some of the special program capabilities of MARC. This includes the ability to solve rubber (incompressible), foam, viscoelastic, contact, and composite problems as well as others.

Chapter 8: *Advanced Topics* demonstrates the capabilities most recently added to MARC. They include the ability to use substructures, in both linear and nonlinear analysis, to perform cracking analysis, analysis of contact problems, the ability to perform coupled thermal-mechanical analysis, electrostatic, magnetostatic and acoustic analysis. The use of adaptive meshing to solve nonlinear analysis is demonstrated here.

Part V

Chapter 9: *Fluid Analysis* — demonstrates the capabilities for performing fluid, fluid-thermal, and fluid-solid analyses.

Chapter 10: *Design Sensitivity and Optimization* — demonstrates the capabilities for calculating the sensitivities of the resultant based upon the design variables and optimizing the objective function for linear analysis.

MARC Volume E: Demonstration Problems summarizes the physics of each problem and describes the options required to define the problem. Figures are given of the mesh geometry and typical output results. The actual input and user subroutines are not included in the manual. They can be found on the distribution media associated with the MARC installation.

In addition to the overall Table of Contents for *MARC Volume E: Demonstration Problems*, each chapter has an individual Table of Contents, Figures, and Tables.

Each problem in *MARC Volume E, Demonstration Problems* has a **Parameters, Options, and Subroutines Summary**. Parameters, options, and user subroutines are called out in the text by the use of a different type font – such as parameter END, option CONTINUE, and user subroutine UFXORD.

Volume E Demonstration Problems

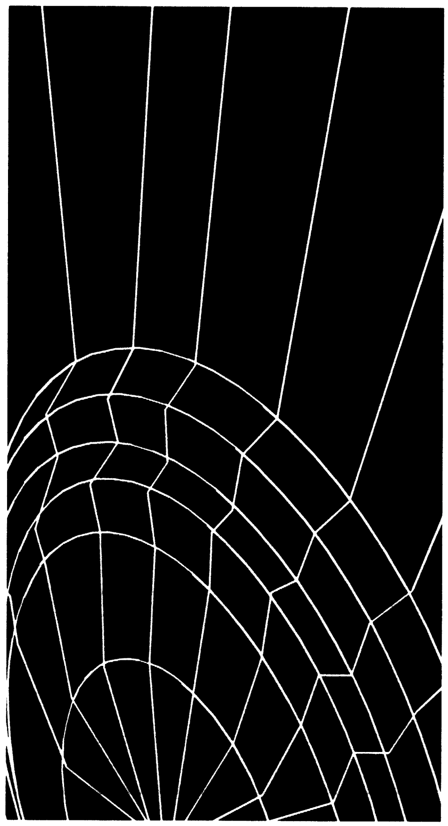
PART I

PART II

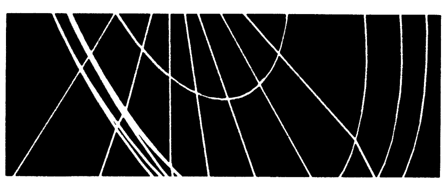
PART III

PART IV

PART V



MARC



MARC
Analysis
Research
Corporation

Volume E

Demonstration Problems

Version K7

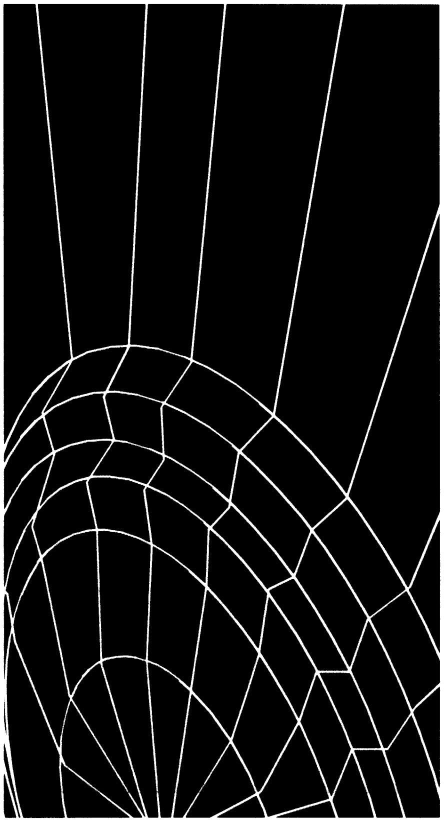
Part I

- Introduction
- Linear Analysis

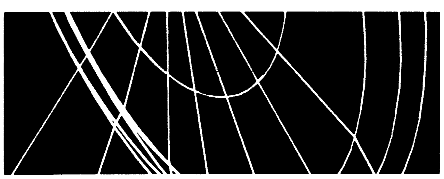
Part I

Volume E: Demonstration Problems

MARC
Analysis
Research
Corporation



MARC



Volume E

Demonstration Problems

Version K7

Chapter 1
Introduction

1 Introduction Contents

Page

Page

1 Introduction List of Figures

1 Introduction List of Tables

1 Introduction

This chapter provides a brief introduction to the MARC system. It serves as cursory background material for the demonstration problems; more detailed tables and descriptions are found in the MARC manuals. You should read this chapter and be familiar with its contents before going on to the examples. Each example is self-contained and illustrates certain MARC features and input requirements.

This manual is divided into nine main chapters. These chapters are summarized as follows:

Chapter 2	*Linear Analysis*
Chapter 3	*Plasticity and Creep*
Chapter 4	*Large Displacement*
Chapter 5	*Heat Transfer*
Chapter 6	*Dynamics*
Chapter 7	*Contact*
Chapter 8	*Advanced Topics*
Chapter 9	*Fluid Analyses*
Chapter 10	*Design Sensitivity and Optimization*

The following topics are covered in this chapter: a guide to MARC and Mentat documentation, MARC program features, element library, input description, output description, and a simple example of a hole-in-plate subjected to a distributed load.

MARC Documentation

In addition to this demonstration manual, several other MARC manuals are available. These are referential in nature and describe the features and applications of MARC in greater detail. Other manuals are as follows:

Primer	Tutorial
Volume A	*Theory and User Information* (technical basis of program and capabilities)
Volume B	*Element Library*
Volume C	*Program Input*
Volume D	*User Subroutines and Special Routines*
Volume F	*Background Papers* (Theoretical papers on MARC procedures)

For reference purposes, *MARC Volumes B: Element Library, C: Program Input*, and *D: User Subroutines* are used most often. *MARC Volume A: Theory and User Information* serves as an overview of MARC's capabilities and contains some theoretical background material. *MARC Volume F: Background Information* is a collection of journal papers which describe the algorithms and material characterizations in MARC.

Mentat Documentation

Mentat Command Reference
Mentat User's Guide (tutorial sessions on Mentat pre-/postprocessing)

Example Problems

The problems discussed in Chapters 2 through 10 are examples of the capabilities in MARC. They are designed to demonstrate the technical capability and usage using simple geometric configurations. Each description contains a statement of the problem, the element type chosen, the material properties, and the boundary conditions. The controls used are also discussed. The key features are discussed and the results are summarized. Where applicable, results are compared to analytical solutions. Figures are generated using the Mentat program to illustrate the solution.

The input data files are summarized, but not included, to reduce the volume of this manual. All input problems are included with the delivery media of the MARC system. They are found on the media in a subdirectory called "demo." Each problem is an individual file; for example, e2x1.dat for problem 2.1. A typical user subroutine is also an individual file; for example, u2x4.f for problem 2.4.

To execute an example on a UNIX system, copy the input file to your working directory and type:

```
marc -j e2x1
```

or if user subroutines are present type:

```
marc -j e2x4 -u u2x4
```

The name of the shell script can be different (such as marck72), so consult your local system administrator.

Program Features

MARC is a general purpose finite element (FE) program designed for both linear and nonlinear analyses of structural, thermal, electric, magnetic field problems. In addition, it can handle coupled thermal-mechanical, electric-thermal, and electromagnetic analyses. In nonlinear and transient problems, MARC makes your analysis easier by offering automatic load incrementation and time stepping capabilities.

Many types of analyses can be obtained by any combination of these basic MARC capabilities. The following is a cursory listing of MARC capabilities. Please refer to the appropriate MARC manual for more detailed descriptions.

Geometry

1-D: truss, beams (open or closed section)
2-D: plane stress, plane strain, generalized plane strain
2-D (axisymmetric):solid or shell (with nonaxisymmetric loading for linear problems)
3-D: solids, plates, shells, membranes

Behavior

linear/nonlinear for geometry or material
static/dynamic
steady-state/transient

Material

linear elastic
isotropic/orthotropic/anisotropic composites
elastic-plastic; work-hardening
isotropic, kinematic, and combined hardening
finite strain
cyclic loading
viscoplasticity
powder materials
rigid plastic flow
nonlinear elastic, elastomers, rubber
viscoelastic (Maxwell, Kelvin, combined)
cracking

Boundary Conditions

time/increment

temperature
displacements, velocities, accelerations
open/close contact

Libraries

- Procedure
- Element
- Material
- Function

You can combine almost any number of options from each of the four libraries and, consequently, solve virtually any structural mechanics or thermal problem.

Procedure Library

This includes all of the analysis types available in the MARC program:

Linear elastic
- standard linear finite element analysis
- superposition of multiple load cases
- Fourier (nonaxisymmetric) analysis of linear axisymmetric bodies
- design sensitivity
- design optimization

Substructuring
- multilevel, quasi-static

Nonlinear
- automatic load incrementation
- elastoplastic

  scaling to first yield
- large deformation/finite strain

  total and updated Lagrangian approaches
  buckling/collapse – linear/nonlinear
  creep buckling
  postbuckling – with adaptive load step
- rigid plastic flow – Eulerian, metal forming

- creep – with adaptive load step
- viscoelastic
  - state equations (Kelvin model)
  - hereditary integrals (generalized Maxwell or generalized Kelvin-Voigt model)
  - thermo-rheologically simple behavior
- viscoplastic – modified creep option to include plasticity effects
- contact/friction – automatic convergence

Fracture mechanics

- linear/nonlinear
- brittle/ductile
- J-integral evaluation
- dynamic J-integral
- brittle cracking concrete model

Dynamics

- modal analysis/eigenvalue extraction
  - inverse power sweep method
  - Lanczos method
- transient response
  - modal superposition
  - direct integration:
  - Newmark-Beta method
  - Houbolt method
  - Central difference method
- harmonic response
- spectrum response
- time stepping – linear/nonlinear
- adaptive time stepping algorithm

Heat transfer

- steady-state and transient analysis
  - conduction – linear/nonlinear
  - convection/radiation boundary conditions
  - internal heat generation
  - latent heat phase changes
  - adaptive time steps

Fluid analysis	– Navier Stokes (excluding turbulence
	– fluid-thermal
	– fluid-solid
Hydrodynamic bearings	– lubrication problems
	– pressure distribution and mass flow
Joule heating	– coupled electric flow with heat transfer
Electromagnetics	– electrostatics
	– magnetostatics
	– coupled electromagnetic analysis harmonics transient
Fluid/structure interaction	– incompressible and inviscid fluid
Thermo-mechanical	– quasi-coupled thermally driven stress analysis
	– fully coupled thermo-mechanical analysis solved by staggered scheme
	– large displacement effects on thermal boundary conditions
	– automated contact/friction capability
Change of state	– transient thermal analysis with change of phase and volume
	– associates stress analysis with plasticity and residual stresses

Element Library

MARC has a library of approximately 150 elements.

Material Library

This includes more than 40 different material models:

Linear elastic	– isotropic, orthotropic, and anisotropic (properties can be temperature dependent)
Composites	– laminated plates and shells
	– isotropic, orthotropic, or anisotropic layers
	– elastic or elastic-plastic behavior

Composites (continued)	– arbitrary material orientation definition with respect to any element edge with respect to global Cartesian axes with respect to a user-defined axis or through user subroutines
	– relative ply angle for each layer
	– multiple failure criteria maximum stress maximum strain Tsai-Wu Hill Hoffman, or user-defined
Hypoelastic	– nonlinear elastic (reversible)
Elastomers	– nonlinear elastic, incompressible
	– Mooney-Rivlin
	– Ogden
	– Elastomer damage model
Elastic-plastic	– Prandtl-Reuss flow rule
	– user-defined nonassociative flow law
	– von Mises yield criterion
	– Drucker-Prager yield criterion
	– isotropic, kinematic or combined hardening
	– strain hardening (or softening) as a function of strain rate and temperature
	– temperature dependence of yield stress and work hardening slopes
	– isotropic, orthotropic, and anisotropic
	– Hill's anisotropic plasticity
	– Gurson damage model
Cyclic plasticity	– isotropic, kinematic, combined hardening

Creep	– deviatoric or volumetric (swelling) strains
	– piecewise linear or exponential forms for rate of equivalent creep strain
	– temperature dependence
	– Oak Ridge National Laboratory (ORNL) model – combine creep, plasticity, and cyclic loadings
Viscoelasticity	– Maxwell and Kelvin models
	– combined Kelvin-Voigt and Maxwell models
	– hereditary integrals of strain histories with both small and large strain formulations
	– thermo-rheologically simple behavior
	– isotropic or anisotropic material
Polymers	– thermo-rheologically simple behavior
Viscoplasticity	– combining plasticity and the Maxwell model of plasticity
	– general inelastic behavior
	– unified creep plasticity
Soils	– yield surfaces as a function of hydrostatic stress
	– linear or parabolic Mohr-Coulomb law
	– modified Cam-Clay model
Concrete	– low-tension cracking
	– crushing surfaces
	– rebars

Function Library

This includes the ability to define kinematic constraints, loads, bandwidth optimization, rezoning, in-core and out-of-core solution, user subroutines, restart, output on post file, selective print, error analysis, etc. Only loads and constraints are summarized below; refer to the MARC manuals for descriptions of the others.

Loads and constraints	– mechanical loads – concentrated, distributed, centrifugal, volumetric forces
	– thermal loads – initial temperatures read from a post file produced from a thermal analysis, or from data files
	– initial stresses and initial plastic strains

- kinematic constraints
  - transformation of degrees of freedom
  - elastic foundation
  - tying (multipoint constraints or MPCs)
  - boundary conditions in user-defined axes
  - springs and gaps – with and without friction contact surfaces

The Element Library

The heart of a finite element program lies in its element library which allows you to model a structure for analysis. MARC has a very comprehensive element library which lets you model virtually any conceivable 1-D, 2-D, or 3-D structure. This section gives some basic definitions, summarizes MARC element types, and describes the most commonly used elements of interest to the user.

Definitions

Isoparametric	is a single function used to define both the element geometry and the deformation.
Numerical integration	is a method used for evaluating integrals over an element. Element quantities – such as stresses, strains, and temperatures – are calculated at each integration point of the element.
Gauss points	is the optimal integration point locations for numerical accuracy.
Full integration (quadrature)	requires, for every element, 2^d integration points for linear interpolation and 3^d points for quadratic interpolation, where scalar "d" is the number of geometric dimensions of an element (that is, d = 2 for a quad; d = 3 for a hexahedron).
Reduced integration	uses a lower number of integration than necessary to integrate exactly. For example, for an 8-node quadrilateral, the number of integration points is reduced from 9 to 4 and, for a 20-node hexahedron, from 27 to 8. For some elements, an "hourglass" control method is used to insure an accurate solution.
Interpolation (shape) function	is an assumed function relating the displacements at a point inside an element to the displacements at the nodes of an element. In MARC, four types of shape functions are used: linear, quadratic, cubic, and Hermitian.

Degrees of freedom (DOF)	is the number of unknowns at a node. In the general case, there are six degrees of freedom (DOFs) at a node in structural analysis (three translations, three rotations), and one degree of freedom (DOF) in thermal analysis (nodal temperature). In special cases, the number of DOFs is two (translations) for plane stress, plane strain, and axisymmetric elements; three (translations) for 3D truss element; six (three translations, three rotations) for a 3D beam element).
Incompressible elements	is a special class of elements in MARC which can be used to analyze incompressible (zero volume change) and nearly incompressible materials such as elastomers and rubber. They are based on a modified Herrmann variational principle, and are sometimes referred to as "Herrmann elements." Unlike the conventional finite element formulations, they can handle the case of Poisson's ratio exactly equal to one-half. They are used for elastic analysis, but are capable of analyzing large displacement effects as well as thermal and creep strains. The incompressibility constraint is imposed by using Lagrange multipliers.
Assumed strain elements	is a special class of elements which are enriched such that they can accurately calculate the shear (bending) strain.

Element Types

MARC has an extensive element library with approximately 150 element types. They are basically of two categories: structural and thermal. They cover a wide variety of geometric domains and problems.

Truss	is a 3D rod with axial stiffness only (no bending).
Membrane	is a thin sheet with in-plane stiffness only (no bending resistance).
Beam	is a 3D bar with axial, bending, and torsional stiffness.
Plate	is a flat thin structure carrying in-plane and out-of-plane loads.
Shell	is a curved, thin or thick structure with membrane/bending capabilities.
Plane stress	is a thin plate with in-plane stresses only. All normal and shear stresses associated with the out-of-plane direction are assumed to be zero. (In MARC, all plane strain elements lie in the global x-y plane.)
Generalized plane strain	is the same as plane strain except that the normal z-strain can be a prescribed constant or function of x and y.

Axisymmetric	are elements lying in the z-r (x-y) plane in MARC.
3D solid	is a solid structure with only translational degrees of freedom for each node (linear or quadratic interpolation functions).
Special	are elements in MARC including a gap/friction element, a pipe-bend element, a shear panel element, rebar elements, and several "semi-infinite" elements (which are useful for modeling a domain unbounded in one direction).

Heat Transfer Elements

Heat transfer elements in MARC consists of 3D links, planar and axisymmetric elements, 3D solid elements, and shell elements. For each heat transfer element, there exists at least one corresponding stress element. Temperature is the only DOF for each node in these elements (except in the case of Joule heating analysis which is a coupled thermal-electrical analysis).

Element Usage Hints

The following hints on element usage are useful to most MARC users and especially the first-time user.

1. Element input data generally includes element connectivity; thickness for 2-D beam, plate, and shell elements; cross section for 3-D beam elements; coordinates of nodal points; and face identifications for distributed loadings.
2. You can select different element types to represent various parts of a model. If they are incompatible (meaning conflicting degrees of freedom), you have to provide appropriate tying constrains.
3. You can use most MARC elements for both linear and nonlinear analyses; exceptions are noted in *MARC Volume A: Theory and User Information.*
4. In linear analysis, you should consider using higher-order elements, especially in problems involving bending action. In nonlinear analysis, lower-order elements are preferred to reduce computational costs.
5. When using lower-order elements (whether the analysis is linear or nonlinear), 4-node quadrilaterals are preferred over 3-node triangles in 2D problems. Similarly, 8-node bricks perform significantly better than 4-node tetrahedra in 3D problems.

6. Stresses and strains of all continuum elements are defined in the global coordinate system. For truss, beam, plate, and shell elements, stresses and strains are output in the local system for the element and the output must be interpreted accordingly. You should pay special attention to the use of these elements if the material properties have preferred orientations.
7. The coordinates and degrees of freedom of all continuum elements are defined in the global coordinate system. Truss, beam, plate, and shell elements can be defined in a local coordinate system – and you must interpret the output accordingly.
8. Distributed loads can be applied along element edges, over element surface, or over the volume of the element. MARC automatically evaluates the consistent nodal forces using numerical integration. Concentrated forces can be applied at nodes.
9. For five bilinear elements (Types 7, 10, 11, 19, and 20), an optional integration scheme can be used which imposes a constant dilatational strain constraint on the element. This option is often useful in approximately incompressible, inelastic analyses such as large strain plasticity because conventional elements give results which are too stiff for nearly incompressible behavior.
10. For four elements (Types 3, 7, 11, and 19), optional interpolation functions can be used which improve the behavior of these elements in bending. The reduced integration elements, with hourglass control, also use an assumed strain formulation.
11. Five Fourier shell and solid elements (Types 62, 63, 73, 74, and 90) exist for the analysis of linear axisymmetric structures with nonaxisymmetric loads. The circumferential load and displacement is represented by a Fourier series, but the geometry and material properties cannot change in the circumferential direction. You can, therefore, reduce a 3D problem into a series of 2D problems. These elements can only be used for linear elastic analysis because the principle of superposition applies only to this type of analysis.

Input

This section highlights MARC input concepts. Concepts such as parameter, model definition, and load incrementation are briefly described as are input formats (fixed versus free field input of numerical data, lists) and input of loads and constraints. For details, please refer to *MARC Volume C: Program Input.*

Input Units

No units are actually entered in the input file by you. MARC simply assumes that all input is being provided in a consistent manner.

Input Sections

MARC is a batch program. This means that you define the input, and this input is not changed during the program execution. This input can be created using the Mentat graphics program or a text editor. The input can be modified upon restart for nonlinear or transient analysis.

MARC input consists of three major sections:

Parameters	define the title of the analysis, the storage allocation, analysis type, element type(s), etc. This section terminates with an END statement.
Model Definition Options	define coordinates, connectivity, materials, boundary conditions, initial loads, initial stresses, nonlinear analysis controls, output options, etc. This section terminates with an END OPTION statement.

Nonlinear and/or transient analyses are performed by increments (steps). The information required to define the load history requires the additional section:

History Definition Options	defines the increments in terms of load increments and/or boundary condition changes occurring during the history definition increment. This sections ends with a CONTINUE option. (At this stage, one or more increments are analyzed.)

The first two sections (parameter and model definition) are always present. You can stack as many load incrementation options as you want. They are analyzed by MARC in sequence until the last CONTINUE option is encountered.

Input Format

A MARC input file typically consists of many blocks or lines of input, each headed by a keyword. A keyword describes some attribute of the FE model of the structure (coordinates, materials, boundary conditions, etc.). A keyword can also describe a control function for the analysis (generation of printout, writing of a post file, numerical tolerances, etc.).

A block can contain three different types of input:

Alphabetic keyword	describes the contents of the block; placed on a single line.
Numerical data	quantifies the properties of the model; floating point or integer; placed on one or more lines.
Lists	denotes the nodes, elements, and DOFs to which the properties apply. Free format.

The numerical data can be in free or fixed format. Lines in free and fixed format can both exist in the input file, although a particular option can use only one format.

Free field — is easier, safer, and recommended for hand-generated input (Mentat graphics program casts input data in fixed field format). It is flagged by at least one comma existing in the input line The last item of the line must be a comma only if there is a single entry. Data items on a line are separated by commas, which can be preceded or followed by an arbitrary number of blanks. No imbedded blanks can appear within the data item itself. Each line must contain the same number of data items that it would have using the fixed format. Floating point numbers can be given with or without an exponent. The mantissa must contain a decimal point. If an exponent is given, it must be preceded by the letter E or D and must immediately follow the mantissa (no embedded blanks). An example is shown below:

```
5.4E6,0.3,11.,0.,18.
```

Fixed field — is described in detail in MARC *Volume C: Program Input.* Standard FORTRAN conventions are observed. Integers must be right-justified in field. Floating point numbers can be given with or without exponent. The mantissa must contain a decimal point. If an exponent is given, it must be preceded by the letter E or D and must be right justified.

A list is a convenient way to identify a set of elements, nodes, DOFs, integration points, shell layers, etc. Lists come in three forms.

Sequence (`n1 n2 n3`) — list includes n numbers placed on one or more lines separated by blanks or commas. If a sequence continues onto another line, a `C` must be the last item on the line.

Range (`m TO n BY p`) — list includes all numbers from `m` to `n` with interval `p`. (Default `p = 1`)

Set name (`STEEL`) — list includes the numbers in the set named `STEEL` previously specified by the DEFINE option of the model definition options.

Furthermore, lists can be operated upon by the logical operations `AND`, `EXCEPT`, and `INTERSECT`. For example:

```
2 TO 38 BY 3 AND STEEL
```

Data can be either upper- or lowercase.

Parameter Section

Parameters control the scope and type of the analysis. Typically, the first parameter, TITLE, is the name of the problem. The SIZING parameter defines the problem size in words of the core buffer used by MARC. ELEMENTS indicates what MARC element types are used in the analysis. Other optional parameters include:

ALL POINTS	asks for stress output at all integration points of the elements.
BEAM SECT	defines the cross-sectional properties of a beam (that is, prismatic or thin-walled).
CENTROID	asks for stress output only at the centroids of the elements (not recommended for nonlinear analysis).
ELASTIC	flags linear elastic static analysis.
SHELL SECT	defines the number of integration points across the shell thickness ranging from 1 to 99.
STOP	tells MARC not to do the analysis (a check run of input only).
THERMAL	flags initial temperatures being input for stress analysis.

In this set of parameters, only the TITLE, SIZING, and END parameters are mandatory. The ELEMENTS parameter can, however, be used instead of (or in conjunction with) the SIZING parameter. All other parameters are optional.

The parameters can appear in any order. The only requirement is that they must terminate with an END parameter.

Model Definition Section

The model definition option describes the complete FE model for analysis:

- Mesh
- Materials
- Applied Loads
- Constraints
- Controls

The following paragraphs describe those options which you encounter most frequently. In a nonlinear analysis, you can alter most of this data during the later stages of the analysis. For a linear elastic analysis, the model is defined once using the model definition options. The model definition options also control the output. The selective output feature is described later in the **Output** section of this chapter.

Mesh

The shape and geometry of the FE mesh are specified using the following model definition options:

COORDINATES	of the nodes in the mesh
CONNECTIVITY	of the elements connecting the nodes
GEOMETRY	of the geometric properties of beam and shell elements (for example, beam cross section, shell thickness, etc.)
PROPERTY	of the material properties; for example: ISOTROPIC, ORTHOTROPIC, GAP DATA, MOONEY, OGDEN, WORK HARD, TEMPERATURE EFFECTS, STRAIN RATE, RATE EFFECTS, CREEP

The DOFs (loads, displacements) at a node depend on the element type connected to the node unless a triad of local axes is defined for a set of nodes using:

TRANSFORMATIONS	establishes the direction of the local nodal axes with respect to the global axes.

Mechanical Loads

Mechanical loads are of two types: concentrated and distributed.

POINT LOAD	concentrated load vector acting on a node.
DIST LOADS	volumetric (body forces such as gravity) or pressure loads (acting on surfaces or edges). The type is specified by defining the variable `IBODY`. It can be uniform or nonuniform.

Thermal Loads

The INITIAL STATE option can be used to define a nonhomogeneous initial temperature field in a stress analysis. This temperature does not produce any thermal strains. The temperatures can then be modified using the CHANGE STATE option. The change in temperature causes thermal strains, and possible changes in the material properties if TEMPERATURE EFFECTS are included.

Kinematic Constraints

You can prescribe values to individual DOFs using:

FIXED DISP	prescribed values for specified DOFs on a set of nodes.

Support Springs

Elastic springs can be defined between any two DOFs at any two nodes:

SPRINGS assigned spring constant between two DOFs for two nodes.

CONTROL Option

Another important model definition option is the CONTROL option which lets you select input parameters governing convergence and accuracy in nonlinear analysis. Items in CONTROL are mostly integers (except for tolerances which are in floating point). The first two items are the most important. Note that the number of cycles includes the first cycle, and the number of increments likewise includes the first increment.

Item	Meaning	Default
step	maximum number of increments (loads) in this analysis	4
cycle	maximum number of iterations per increment	3

There are other items on the CONTROL option, but they are usually not needed by the first-time user. These items flag such options as convergence tests, iteration schemes, nonpositive definiteness checks, etc. (See *MARC Volume C: Program Input.*)

The first increment in an analysis is considered increment 0 and should be linear elastic. Thus, four increments imply increment 0, 1, 2, and 3. Similarly, three cycles imply the first cycle and two iterations.

OPTIMIZE Option

Finally, you need to be aware of the OPTIMZE option. This option lets you choose a bandwidth optimization algorithm. The default algorithm is Cuthill-McKee which is widely used in many FE codes and suffices for most cases. Minimizing the bandwidth in your problem reduces computational costs in medium to large-sized problems. Therefore, you should make a habit to invoke the OPTIMIZE option before performing an analysis. For a description of other available bandwidth optimization algorithms, see *MARC Volume C: Program Input*. Note that it is not necessary to use the OPTIMIZE option when the element-by-element iterative solver is used.

Output

This section summarizes the MARC output and postprocessing options. The MARC output can be obtained in four forms:

- Printed Output (standard)
- Selective Output
- Post File for Mentat postprocessing
- Restart file (for continuation of analysis)

Printed Output

A standard printed output from a MARC run contains three different parts:

- input echo and interpretation
- analysis messages
- output of analysis results

Input Echo and Interpretation

This portion repeats the input to allow you to verify its correctness. It includes various items such as position of the line columns, a line count for the blocks, set up of parameters for the run, and interpretation of the input (for example, connectivity, coordinates, properties, geometry, boundary conditions, loads, etc.).

Analysis Messages

During the analysis, MARC produces several diagnostic messages. Those of interest include the following:

Algebraic sum of the distributed and point loads over the whole model.

Singularity ratio of the matrix. This is a measure of the conditioning number (hence, the accuracy) in the solution of the linear equations. The ratio and its meanings are as follows:

between 10^{-4} and 1	acceptable
between 10^{-8} and 10^{-4}	possible numerical problems (...watch out)
on order of machine accuracy (10^{-14} to 10^{-8})	singular equations (unreliable solution)

During the analysis, MARC prints out the elapsed central processing unit (CPU) time at the following points:

State of increment
Start of assembly
Start of matrix solution
End of matrix solution
End of increment

Output of Analysis Results

At the end of the analysis, MARC prints out (for each increment) element data (stresses, strains, etc.) and nodal data (displacements, equivalent nodal forces, and reaction forces at fixed boundary conditions).

Element Output

At every Gaussian integration point, stresses (or forces) and strains are printed out, depending on the element type. (If you include a CENTROID parameter, only the centroidal results are reported.)

Continuum elements	are physical components (in global axes); principal values; mean normal values (hydrostatic); equivalent Tresca and von Mises values.
Shell elements	are generalized total stress and strain resultants (stretch, curvature) at midplane; total physical stresses at integration points through the thickness.
Beam elements	are resultant forces at Gauss points: axial force, bending moment (referred to local axes of beam element), and torque.

Modal Output

For every node, the vectors of these nodal quantities are printed out, depending on the analysis:

Static	incremental and total displacements; equivalent nodal loads; reaction forces (at boundary nodes); residual loads (at nodes without boundary conditions). (If convergence has occurred during the increment, the residual loads should be small compared with the reaction forces.)	
Dynamic	for modal analysis:	eigenvectors
	for transient analysis:	total displacements, velocities, and accelerations equivalent nodal loads reaction forces residual loads
	for heat transfer:	total temperatures and optional fluxes

Selective Output

You can selectively print out data for elements or nodes using these model definition options:

PRINT ELEMENT — selects elements, integration points, and layers (for plate and shell elements) to be printed in the output.

Note: All stress components are printed out. The selected layers and integration points apply to all the selected elements in the model.

PRINT NODE — selects nodes and nodal quantities to be printed (e.g., displacements, input load vectors, output reactions/residuals).

Post File

You can use the POST command to flag the writing of a MARC post file, which can be processed later by the Mentat graphics program. The post file can be either binary or formatted. A *binary* file is machine-dependent, but is usually quite a bit smaller than a formatted file and cannot be edited. A *formatted* file is portable across different types of computers, but is usually larger than a binary file and can be edited.

The file output includes:

Complete mesh data (nodal coordinates, element connectivities)

All nodal variables (displacements, forces, etc.)

Element variables (strains, stresses, etc.) as selected in the POST option. You can select which stress component to write out for which layer. The output is produced for all integration points of all elements

A restart file can be made using the RESTART or RESTART LAST model definition option (See *MARC Volume C: Program Input*). This option is very convenient in nonlinear analysis.

Graphical Output

Almost all of the graphics in this manual have been generated using the Mentat graphics program. All input problems generate a post file which was then processed interactively. Please refer to the Mentat documentation for further details.

Discussion of MARC Input Format for New Users

The MARC input format is designed to allow the input of very complex problems. The new user is, however, faced with gaining familiarity with the system and its conventions. At the outset, therefore, the new user should adopt a systematic approach to the preparation of input data. One approach is to follow the construction of the program and adopt the procedure of preparing input for each of the parameters and options (model definition and history definition) in turn.

We shall illustrate our discussion by preparing input for the analysis of a thin plate with hole subjected to pressure loading. The problem shown in Figure 1-1 is well-known so the results can be compared to the exact solution (Timoshenko and Goodier, *Theory of Elasticity*). The hole/plate size ratio is chosen to approximate an infinite plate. A procedure for preparing the MARC input would take the following steps.

Finite Element Modeling

The plate has an outside dimension of 10" x 10" with a central hole of 1" radius. The thickness of the plate is assumed to be 0.1". The material property is assumed to be isotropic and linear elastic. The Young's modulus is 30 x 10^6 pounds per square inch (psi) with Poisson's ratio of 0.3. These quantities are sufficient to define the behavior of an isotropic, linear-elastic material.

Figure 1-1 analyzes only a quarter of the plate due to symmetry conditions. Prescribed displacement boundary conditions exist along the lines of symmetry (that is, u = 0 at line x = 0; v = 0 at line y = 0) and traction (pressure) boundary condition exits at the top of the plate.

This quarter plate is approximated by a finite element mesh consisting of 20 eight-node plane stress elements with appropriate loading and boundary conditions. The element (MARC element type 26) is a second-order, isoparametric, two-dimensional element for plane stress. There are eight nodes with two translational degrees of freedom at each node. A description of element type 26 can be found in *MARC Volume B: Element Library.*

This example uses a coarse mesh for demonstration purposes only. The sharp stress gradients must be anticipated in this problem, and the mesh designed accordingly. This is achieved in this problem by using progressively smaller elements as the hole is approached. By adding elements to the mesh, further mesh refinement can be achieved.

The input data takes the following format:

```
FIXED DISP
2,
0.,
2,
34,37,42,45,25,22,5,8,13,16,21,
0.,
1,
71,73,77,79,64,62,49,51,55,57,61,
```

This concludes the minimum amount of data required to define the problem.

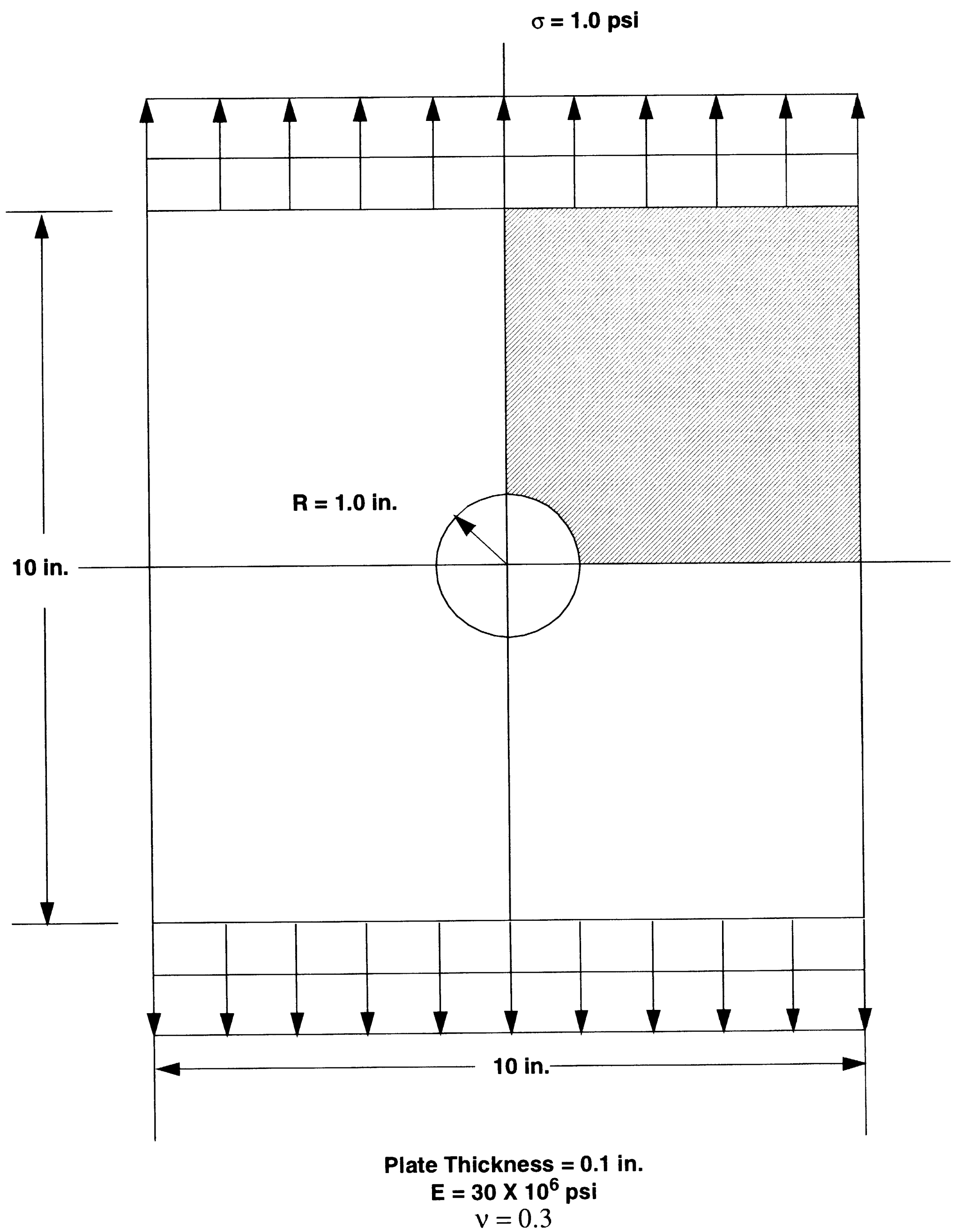


Figure 1-1 Plate with Hole

The preparation of parameter, model definition, and history definition data for this example is demonstrated below:

Parameters

The analysis to be carried out in this example is a linear elastic analysis. Consequently, only four parameters are needed for the input data:

TITLE
ELEMENTS
SIZING
END

In this example, the title *Elastic Analysis of a Thin Plate with Hole* is chosen for the problem and entered through the parameter TITLE.

The selected MARC element type 26 is entered through the parameter ELEMENTS.

The data on the parameter SIZING is selected as follows:

```
MAXALL = 100000 (core allocation)
```

Please note that the value of MAXALL should be checked with the in-house or data center system analyst for the maximum allowable core area on the system for running MARC. Refer to Table 2-1 and Table 2-2 in *MARC Volume C: Program Input* following the definition of the SIZING option in order to establish an estimate of the work space required in this problem. The estimate should only be approximate since the program adjusts the variables to use out-of-core storage if necessary. You do not need to input maximum values on SIZING.

Finally, the parameters are completed with END.

At this stage the input data is:

```
TITLE   ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE
SIZING,100000,
ELEMENTS,26,
END
```

Model Definition Options

The model definition options contain the bulk data for the analysis. The data entered here concerns:

- Topology of the Model (finite element mesh in terms of element connectivity and nodal coordinates, as well as plate thickness)
- Material Property (Young's modulus and Poisson's ratio)
- Pressure Loading and Prescribed Displacement Boundary Conditions
- Controls for convergence and output selection.

Topology of the Model

The topology of the plate model is numerically defined by the following model definition options:

CONNECTIVITY
COORDINATES
GEOMETRY

In this example, the mesh consists of 20 elements and 79 nodes. The data required for element connectivity and nodal coordinates are:

```
CONNECTIVITY
                        20,
                         1   26    1    3   11    9    2    7   10    6
                         2   26    3    5   13   11    4    8   12    7
                         3   26    9   11   19   17   10   15   18   14
                         4   26   11   13   21   19   12   16   20   15
                         5   26    5    3   27   25    4   23   26   22
                         6   26    3    1   29   27    2   24   28   23
                         7   26   30   32   40   38   31   36   39   35
                         8   26   32   34   42   40   33   37   41   36
                         9   26   38   40   27   29   39   44   28   23
                        10   26   40   42   25   27   41   45   26   44
                        11   26    1    9   53   47    6   52   50   46
                        12   26   47   53   55   49   50   54   51   48
                        13   26    9   17   59   53   14   58   56   52
                        14   26   53   59   61   55   56   60   57   54
                        15   26   49   64   66   47   62   65   63   48
                        16   26   47   66   29    1   63   67   24   46
                        17   26   30   38   75   69   35   74   72   68
                        18   26   69   75   77   71   72   76   73   70
                        19   26   38   29   66   75   43   67   78   74
                        20   26   75   66   64   77   78   65   79   76
                      COORDINATES
                         0    0
                         1    1.4000     1.4000
                         2    1.5500     1.0500
                         3    1.7000     0.7000
                         .
                         .
                         .
                        77    0.0000     1.2500
                        78    0.4931     1.1910
                        79    0.0000     1.3750
```

The data in the CONNECTIVITY block consists of element numbers (1,2,...,19,20); element type (26) and for each element, four corner node numbers and four mid-side node numbers.

The data in the coordinate block consists of the node number (1); and coordinates (x = 1.4, y = 1.4) of node 1 in the global coordinate system (x, y).

Finally, the plate thickness is entered through the GEOMETRY block as:

```
GEOMETRY
0,
0.1,
1 TO 20
```

A thickness of 0.1 inches is assumed for all twenty (1 to 20) elements.

Material Property

Material properties of the plate are entered through the ISOTROPIC block. For our problem, the only data required for a linear elastic analysis are Young's modulus and Poisson's ratio. The same material is used for the whole mesh (from Element No. 1 to Element No. 20). This is given a material id of 1. The data in the ISOTROPIC block is:

```
ISOTROPIC
1,
1
30.E6,0.3,
1 TO 20
```

Pressure Loading and Prescribed Displacement Boundary Conditions

As shown in Figure 1-2, the pressure loading is acted on two elements (elements 13 and 14), along the lines 61-60-59 and 59-58-17. From the CONNECTIVITY block, observe that these lines represent the 2-6-3 face of the elements. As a result, a distributed load type of 8 can be determined for the pressure loading from the **QUICK REFERENCE** of element 26 shown in *MARC Volume B: Element Library.*

```
"LOAD TYPE (IBODY)=8 FOR UNIFORM PRESSURE ON 2-6-3 FACE"
```

In addition, as shown in *MARC Volume B: Element Library*, the sign conversion of the pressure loading is that a negative magnitude represents a tensile distributed load. Consequently, the input for the 1 pound tensile distributed loading acting on elements 13 and 14 takes the following form:

```
DIST LOADS
0,
8,-1.,
13,14,
```

The FIXED DISP block is used for the input of prescribed displacement boundary conditions at the lines of symmetry (x = 0, y = 0). As indicated in the **QUICK REFERENCE** of element 26, the nodal degrees of freedom are:

```
dof 1 = u = global x-direction displacement
                dof 2 = v = global y-direction displacement.
```

In this example, the symmetry conditions require that:

```
dof 1 = u = 0 for nodes (71, 73, 77, 79, 64, 62, 49, 51, 55, 57, 61)
                 along the line x=0.
```

and

```
dof 2 = v = 0 for nodes (34, 37, 42, 45, 25, 22, 5, 8, 13, 16, 21)
                 along the line y=0.
```

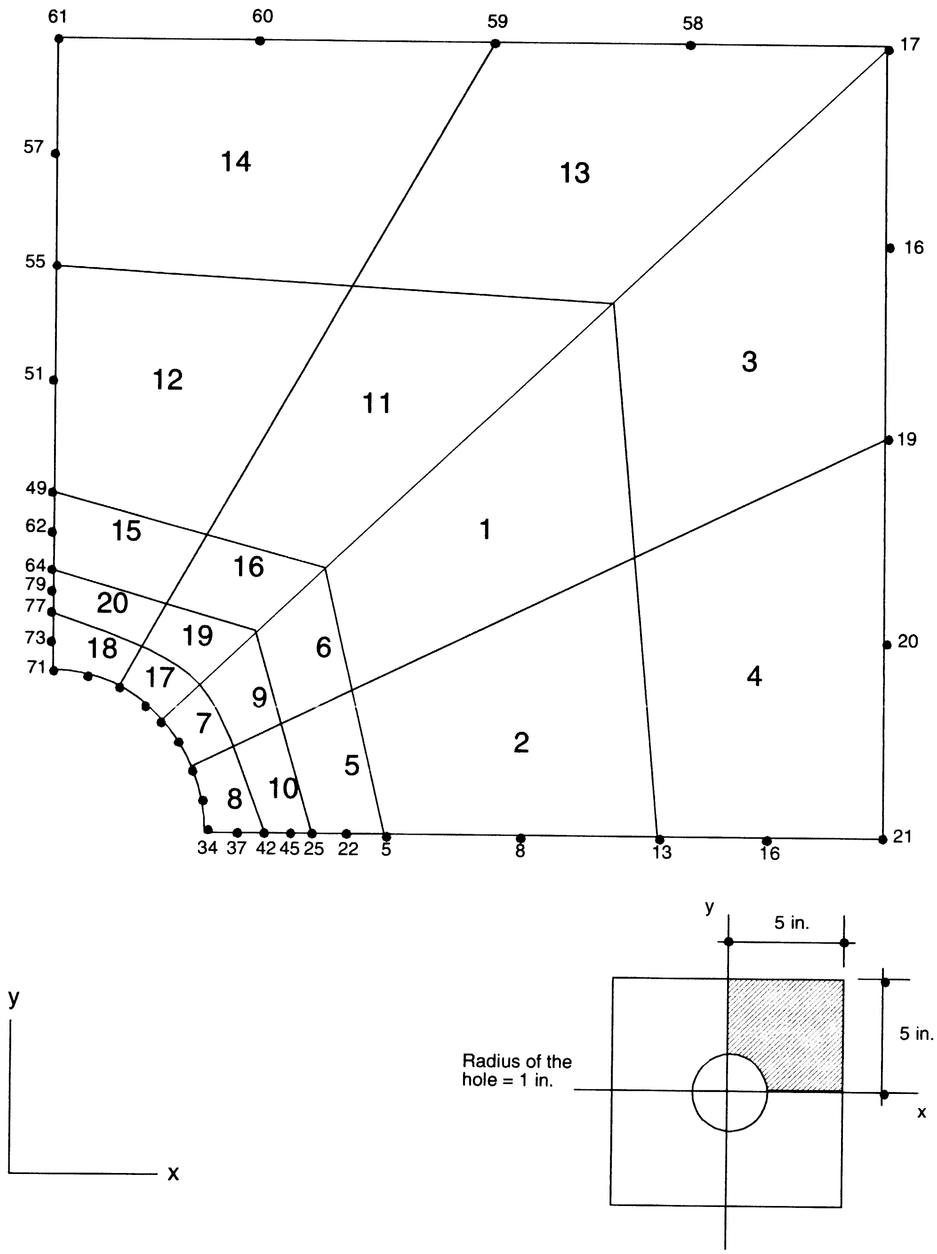


Figure 1-2 Mesh Layout for Plate with Hole

Controls

As discussed earlier, it is important to minimize the bandwidth to reduce the amount of computational time. In this problem, this is done using the Cuthill-McKee optimizer. Ten tries are used. The additional input is as follows:

```
OPTIMIZE,2,0,0,1
10,
```

As this is a linear analysis, it is unnecessary to have a CONTROL option in this problem.

The remainder of the input file is used to control the output. Only a portion of the stress and strain results are to be given in the listing file, elements 2, 4, 5, 8, and 10 at integration points 4 and 6. This is defined using the following:

```
PRINT ELEM
    1
    STRESS   STRAIN
    2    4    5    8    10
    4    6
```

MARC has the ability to report on the maximum and minimum values. This capability is invoked using the SUMMARY option.

Finally, the POST option is used to specify that an ASCII file be created on unit 19, and that it contain the components of stress and the equivalent stress. This is selected using the following:

```
POST
   0   16   17    1    0   19
  17
  11
  12
  13
```

The model definition section is concluded using the END OPTION.

A complete input data listing for the thin plate problem is given on the following page.

```
                    M A R C - C O N V E X

                      I N P U T   D A T A

PAGE 1

    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
--------------------------------------------------------------------------------
TITLE      ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE
SIZING         100000
ELEMENT       26
END
CONNECTIVITY
   20
    1   26    1    3   11    9    2    7   10    6
    2   26    3    5   13   11    4    8   12    7
    3   26    9   11   19   17   10   15   18   14
    4   26   11   13   21   19   12   16   20   15
    5   26    5    3   27   25    4   23   26   22
    6   26    3    1   29   27    2   24   28   23
    7   26   30   32   40   38   31   36   39   35
    8   26   32   34   42   40   33   37   41   36
    9   26   38   40   27   29   39   44   28   43
   10   26   40   42   25   27   41   45   26   44
   11   26    1    9   53   47    6   52   50   46
   12   26   47   53   55   49   50   54   51   48
   13   26    9   17   59   53   14   58   56   52
   14   26   53   59   61   55   56   60   57   54
   15   26   49   64   66   47   62   65   63   48
   16   26   47   66   29    1   63   67   24   46
   17   26   30   38   75   69   35   74   72   68
   18   26   69   75   77   71   72   76   73   70
   19   26   38   29   66   75   43   67   78   74
   20   26   75   66   64   77   78   65   79   76
COORDINATES
    2   79
    1    1.4000     1.4000
    2    1.5500     1.0500
    3    1.7000     0.7000
    4    1.8500     0.3500
    5    2.0000     0.0000
    6    2.3000     2.3000
    7    2.5250     1.1500
    8    2.7500     0.0000
    9    3.2000     3.2000
   10    3.2750     2.4000
   11    3.3500     1.6000
   12    3.4250     0.8000
   13    3.5000     0.0000
   14    4.1000     4.1000
   15    4.1750     2.0500
   16    4.2500     0.0000
   17    5.0000     5.0000
--------------------------------------------------------------------------------
    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

```
PAGE 2

    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
--------------------------------------------------------------------------------
    18   5.0000   3.7500
    19   5.0000   2.5000
    20   5.0000   1.2500
    21   5.0000   0.0000
    22   1.7500   0.0000
    23   1.4900   0.6150
    24   1.2300   1.2300
    25   1.5000   0.0000
    26   1.3900   0.2650
    27   1.2800   0.5300
    28   1.1700   0.7950
    29   1.0600   1.0600
    30   0.7070   0.7070
    31   0.8315   0.5557
    32   0.9238   0.3825
    33   0.9810   0.1948
    34   1.0000   0.0000
    35   0.7953   0.7953
    36   1.0129   0.4194
    37   1.1250   0.0000
    38   0.8835   0.8835
    39   1.0008   0.6753
    40   1.1019   0.4562
    41   1.1855   0.2299
    42   1.2500   0.0000
    43   0.9718   0.9718
    44   1.1910   0.4931
    45   1.3750   0.0000
    46   1.0500   1.5500
    47   0.7000   1.7000
    48   0.3500   1.8500
    49   0.0000   2.0000
    50   1.1500   2.5250
    51   0.0000   2.7500
    52   2.4000   3.2750
    53   1.6000   3.3500
    54   0.8000   3.4250
    55   0.0000   3.5000
    56   2.0500   4.1750
    57   0.0000   4.2500
    58   3.7500   5.0000
    59   2.5000   5.0000
    60   1.2500   5.0000
    61   0.0000   5.0000
    62   0.0000   1.7500
    63   0.6150   1.4900
    64   0.0000   1.5000
    65   0.2650   1.3900
    66   0.5300   1.2800
    67   0.7950   1.1700
--------------------------------------------------------------------------------
    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

```
         P A G E   3

                    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
                 --------------------------------------------------------------------------------
                   68    0.5557     0.8315
                   69    0.3825     0.9238
                   70    0.1948     0.9810
                   71    0.0000     1.0000
CARD   100         72    0.4194     1.0129
                   73    0.0000     1.1250
                   74    0.6753     1.0008
                   75    0.4562     1.1019
                   76    0.2299     1.1855
CARD   105         77    0.0000     1.2500
                   78    0.4931     1.1910
                   79    0.0000     1.3750
                 GEOMETRY
                     1
CARD   110         0.1
                   1 TO 20
                 ISOTROPIC
                     1
                     1
CARD   115        30000000.    .3
                   1 TO 20
                 DIST LOADS
                     1
                     8    -1.
CARD   120         13    14
                 FIXED DISPLACEMENT
                     2
                   0.0000E+00
                     2
CARD   125         34    37    42    45    25    22     5     8    13    16    21
                   0.0000E+00
                     1
                   71    73    77    79    64    62    49    51    55    57    61
                 OPTIMIZE,2,0,0,1,
CARD   130       10,
                 PRINT ELEMENT
                     1
                   STRESS STRAIN
                     2    4    5    8    10
CARD   135           4    6
                 SUMMARY
                 POST
                        16    17    1    0    19
                   17     EQUIVALENT VON MISES STRESS
CARD   140         11     1ST COMP OF TOTAL STRESS
                   12     2ND COMP OF TOTAL STRESS
                   13     3RD COMP OF TOTAL STRESS
                 END OPTION
                 --------------------------------------------------------------------------------
                    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
                 --------------------------------------------------------------------------------
```

Discussion of MARC Output for New Users

Selected portions of the output for this problem are shown below. The small type on the output is comments and gives a further explanation.

MARC first gives a “notes” section which identifies the version of MARC being used. This is followed by an echo of the input data and a summary of program sizing and options requested.

```
          M                 M
        MMMMM             MMMMM
      MMMMMMMMM         MMMMMMMMM
    MMMMMMMMMMMMM     MMMMMMMMMMMMM
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
MMMMMMMM MMMMMMMMMMMMMMMMM MMMMMMMM
MMMMMM       MMMMMMMMMMM       MMMMMM
MMMM           MMMMMMM           MMMM
MM               MMM               MM
M                 M                 M
MM               MMM               MM
MMMM           MMMMMMM           MMMM
MMMMMM       MMMMMMMMMMM       MMMMMM
MMMMMMMM MMMMMMMMMMMMMMMMM MMMMMMMM
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
    MMMMMMMMMMMMM     MMMMMMMMMMMMM
      MMMMMMMMM         MMMMMMMMM
        MMMMM             MMMMM
          M                 M

  MARC-             K7-2-L

MARC ANALYSIS RESEARCH CORPORATION
```

NORTH AMERICAN

CORPORATE HEADQUARTERS
MARC Analysis Research Corporation
260 Sheridan Avenue, Suite 309
Palo Alto, CA 94306-2089
Telephone: 650-329-6800
FAX : 650-323-5892

WEST COAST OFFICE
MARC Analysis Research Corporation
4330 LaJolla Village Dr.,Suite 320
San Diego, CA 92122-1244
Telephone: 619-658-9588
FAX : 619-587-8710

MIDWEST OFFICE
MARC Analysis Research Corporation
24 Frank Lloyd Wright drive
Ann Arbor, MI 48106-0523
Telephone: 734-998-0540
FAX : 734-998-0542

EAST COAST OFFICE
MARC Analysis Research Corporation
1224 Mill Street Bldg B
East Berlin, CT 06023
Telephone: 860-828-2055
FAX : 860-828-2031

EUROPE

EUROPEAN HEADQUARTERS
MARC-Europe
Dublinstraat 32
2713 HS Zoetermeer,The Netherlands
Telephone: 31-79-3510411
FAX : 31-79-3517560

GERMAN OFFICE
MARC Software Deutschland GmbH
Ismaninger Strasse 9
85609 Aschheim, Germany
Telephone: 49-89-9045033
FAX : 49-89-9030676

UNITED KINGDOM OFFICE
MARC (UK) Ltd.
11, Linford Forum
Rockingham Drive
Linford Wood
Milton Keynes MK14 6LY, UK
Telephone: 44-1908-606070
FAX : 44-1908-606633

ITALIAN OFFICE
Espri-MARC
16129 Viale Brigata Bisagno 2/10
16129 Genova, Italy
Telephone: 39-10-585949
FAX : 39-10-585949

FRENCH OFFICE
MARC France S.A.
Bercy Expo SR 6101A
40 Avenue des Terriors de France
75611 Paris Cedex 12
Telephone: 33-1-44741550
FAX : 33-1-44741554

CZECH OFFICE
MARC Overseas,Inc.
Podolska 50
14700 Prague 4
Telephone: 42-2-61214123
FAX : 42-2-61214123

PACIFIC RIM

FAR EAST HEADQUARTERS
Nippon MARC Co., Ltd.
P.O. Box 5056
Shinjuku Daiichi Seimei Bldg.
2-7-1 Nishi-Shinjuku 2-chome
Shinjuku-ku, Tokyo 163-07, Japan
Telephone: 81-3-3345-0181
FAX : 81-3-3345-1529

OSAKA OFFICE
Nippon MARC Co., Ltd.
4F, 2nd Kimi Building
2-11 Toyotucho Suita-shi
Osaka 564, Japan
Telephone: 81-6-385-1101
FAX : 81-6-385-4343

NAGOYA OFFICE
Nippon MARC Co., Ltd.
Nagoya Nishiki Daiichi Seimei Bldg
2F,6-5 Nishiki 1-chome
Naka-ku,Nagoya,Aichi 460
Telephone: 81-52-202-5661
FAX : 81-52-2-2-5665

CHINA OFFICE
MARC Overseas, Inc.
Bright Chang An Blgg, Suite 321
7#,Jian Guo Men Nei Strees
Beijing 100 005
Telephone: 86-10-6510-2056
FAX : 86-10-6510-2053

KOREAN OFFICE
MARC Overseas,Inc.
Dong Kyung Bldg 7Fl
824-19 Yuksam-Dong
Kangnam-Ku, Seoul,Korea
Telephone: 82-2-561-7543
FAX : 82-2-561-7767

```
                     M A R C

                     I N P U T   D A T A

   P A G E   1

       5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
  --------------------------------------------------------------------------------
  TITLE     ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE
  SIZING        100000
  ELEMENT      26
  END
  CONNECTIVITY
     20
     1   26    1    3   11    9    2    7   10    6
     2   26    3    5   13   11    4    8   12    7
     3   26    9   11   19   17   10   15   18   14
     4   26   11   13   21   19   12   16   20   15
     5   26    5    3   27   25    4   23   26   22
     6   26    3    1   29   27    2   24   28   23
     7   26   30   32   40   38   31   36   39   35
     8   26   32   34   42   40   33   37   41   36
     9   26   38   40   27   29   39   44   28   43
    10   26   40   42   25   27   41   45   26   44
    11   26    1    9   53   47    6   52   50   46
    12   26   47   53   55   49   50   54   51   48
    13   26    9   17   59   53   14   58   56   52
    14   26   53   59   61   55   56   60   57   54
    15   26   49   64   66   47   62   65   63   48
    16   26   47   66   29    1   63   67   24   46
    17   26   30   38   75   69   35   74   72   68
    18   26   69   75   77   71   72   76   73   70
    19   26   38   29   66   75   43   67   78   74
    20   26   75   66   64   77   78   65   79   76
  COORDINATES
     2   79
     1    1.4000    1.4000
     2    1.5500    1.0500
     3    1.7000    0.7000
     4    1.8500    0.3500
     5    2.0000    0.0000
     6    2.3000    2.3000
     7    2.5250    1.1500
     8    2.7500    0.0000
     9    3.2000    3.2000
    10    3.2750    2.4000
    11    3.3500    1.6000
    12    3.4250    0.8000
    13    3.5000    0.0000
    14    4.1000    4.1000
    15    4.1750    2.0500
    16    4.2500    0.0000
    17    5.0000    5.0000
  --------------------------------------------------------------------------------
       5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

```
                PAGE  2

                          5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
                      ---------------------------------------------------------------------------------
                         18    5.0000     3.7500
                         19    5.0000     2.5000
                         20    5.0000     1.2500
                         21    5.0000     0.0000
CARD     50              22    1.7500     0.0000
                         23    1.4900     0.6150
                         24    1.2300     1.2300
                         25    1.5000     0.0000
                         26    1.3900     0.2650
CARD     55              27    1.2800     0.5300
                         28    1.1700     0.7950
                         29    1.0600     1.0600
                         30    0.7070     0.7070
                         31    0.8315     0.5557
CARD     60              32    0.9238     0.3825
                         33    0.9810     0.1948
                         34    1.0000     0.0000
                         35    0.7953     0.7953
                         36    1.0129     0.4194
CARD     65              37    1.1250     0.0000
                         38    0.8835     0.8835
                         39    1.0008     0.6753
                         40    1.1019     0.4562
                         41    1.1855     0.2299
CARD     70              42    1.2500     0.0000
                         43    0.9718     0.9718
                         44    1.1910     0.4931
                         45    1.3750     0.0000
                         46    1.0500     1.5500
CARD     75              47    0.7000     1.7000
                         48    0.3500     1.8500
                         49    0.0000     2.0000
                         50    1.1500     2.5250
                         51    0.0000     2.7500
CARD     80              52    2.4000     3.2750
                         53    1.6000     3.3500
                         54    0.8000     3.4250
                         55    0.0000     3.5000
                         56    2.0500     4.1750
CARD     85              57    0.0000     4.2500
                         58    3.7500     5.0000
                         59    2.5000     5.0000
                         60    1.2500     5.0000
                         61    0.0000     5.0000
CARD     90              62    0.0000     1.7500
                         63    0.6150     1.4900
                         64    0.0000     1.5000
                         65    0.2650     1.3900
                         66    0.5300     1.2800
CARD     95              67    0.7950     1.1700
                      ---------------------------------------------------------------------------------
                          5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
```

```
P A G E   3

     5    10    15    20    25    30    35    40    45    50    55    60    65    70    75    80
 --------------------------------------------------------------------------------
    68    0.5557     0.8315
    69    0.3825     0.9238
    70    0.1948     0.9810
    71    0.0000     1.0000
    72    0.4194     1.0129
    73    0.0000     1.1250
    74    0.6753     1.0008
    75    0.4562     1.1019
    76    0.2299     1.1855
    77    0.0000     1.2500
    78    0.4931     1.1910
    79    0.0000     1.3750
GEOMETRY
    1
  0.1
  1 TO 20
ISOTROPIC
    1
    1
 30000000.    .3
  1 TO 20
DIST LOADS
    1
    8    -1.
   13    14
FIXED DISPLACEMENT
    2
  0.0000E+00
    2
   34    37    42    45    25    22     5     8    13    16    21
  0.0000E+00
    1
   71    73    77    79    64    62    49    51    55    57    61
OPTIMIZE,2,0,0,1,
10,
PRINT ELEMENT
    1
  STRESS STRAIN
    2    4     5     8    10
    4    6
SUMMARY
POST
        16    17     1     0    19
   17      EQUIVALENT VON MISES STRESS
   11      1ST COMP OF TOTAL STRESS
   12      2ND COMP OF TOTAL STRESS
   13      3RD COMP OF TOTAL STRESS
END OPTION
 --------------------------------------------------------------------------------
     5    10    15    20    25    30    35    40    45    50    55    60    65    70    75    80
 --------------------------------------------------------------------------------
```

```
 ************************************************
 ************************************************

  PROGRAM SIZING AND OPTIONS REQUESTED AS FOLLOWS


  ELEMENT TYPE REQUESTED*************************   26
  NUMBER OF ELEMENTS IN MESH*********************   20
  NUMBER OF NODES IN MESH************************   79
  MAX NUMBER OF ELEMENTS IN ANY DIST LOAD LIST***    2
  MAXIMUM NUMBER OF BOUNDARY CONDITIONS**********   22
  LOAD CORRECTION FLAGGED OR SET*****************
  NUMBER OF LISTS OF DISTRIBUTED LOADS***********    3
  STRESSES STORED AT ALL INTEGRATION POINTS******
  TAPE NO.FOR INPUT OF COORDINATES + CONNECTIVITY    5
  NO.OF DIFFERENT MATERIALS     1 MAX.NO OF SLOPES    5
  MAXIMUM ELEMENTS VARIABLES PER POINT ON POST TP   33
  NUMBER OF POINTS ON SHELL SECTION *************   11
  NEW STYLE INPUT FORMAT WILL BE USED************
  MAXIMUM NUMBER OF SET NAMES IS*****************   10
  NUMBER OF PROCESSORS USED *********************    1
  VECTOR LENGTH USED ****************************    1


  END OF PARAMETERS AND SIZING
 ************************************************
 ************************************************
```

At this stage, MARC attempts to allocate core for input of the model definition data and assembly of the element stiffness matrix. MARC first prints out the key to strain, stress, and displacement output for each element type chosen. Column numbers identifying output quantities are referenced to the appropriate components of stress, strain, or displacement. Then, the required number of words is printed out followed by a list of the internal core allocation parameters. They reflect the maximum requirements imposed by different elements. The internal element variables are different for each element type and are repeated for each element type used in a given analysis.

```
KEY TO STRESS, STRAIN AND DISPLACEMENT OUTPUT

         ELEMENT TYPE   26

8-NODE ISOPARAMETRIC PLANE STRESS QUADRILATERAL

STRESSES AND STRAINS IN GLOBAL DIRECTIONS
  1=XX
  2=YY
  3=XY

DISPLACEMENTS IN GLOBAL DIRECTIONS
  1=U GLOBAL X DIRECTION
  2=V GLOBAL Y DIRECTION


WORKSPACE NEEDED FOR INPUT AND STIFFNESS ASSEMBLY      48113
```

```
INTERNAL CORE ALLOCATION PARAMETERS
DEGREES OF FREEDOM PER NODE (NDEG)  2
COORDS PER NODE (NCRD)  2
STRAINS PER INTEGRATION POINT (NGENS)  3
MAX. NODES PER ELEMENT (NNODMX)  8
MAX.STRESS COMPONENTS PER INT. POINT (NSTRMX)    3
MAX. INVARIANTS PER INT. POINTS (NEQST)  1


FLAG FOR ELEMENT STORAGE (IELSTO)  0
ELEMENTS IN CORE, WORDS PER ELEMENT (NELSTO)       1840
                  TOTAL SPACE REQUIRED            36800
VECTORS IN CORE, TOTAL SPACE REQUIRED       2350


WORDS PER TRACK ON DISK SET TO 4096


INTERNAL ELEMENT VARIABLES


INTERNAL ELEMENT NUMBER   1  LIBRARY CODE TYPE 26
NUMBER OF NODES=  8
STRESSES STORED PER INTEGRATION POINT =  3
DIRECT CONTINUUM COMPONENTS STORED =  2
SHEAR CONTINUUM COMPONENTS STORED =  1
SHELL/BEAM FLAG = 0
CURVILINEAR  COORD. FLAG = 0
INT.POINTS FOR ELEM. STIFFNESS  9
NUMBER OF LOCAL INERTIA DIRECTIONS  2
INT.POINT FOR PRINT IF ALL POINTS NOT FLAGGED  5
INT. POINTS FOR DIST. SURFACE LOADS (PRESSURE)  3
LIBRARY CODE TYPE = 26
NO LOCAL ROTATION FLAG = 1
GENERALIZED DISPL. FLAG = 0
LARGE DISP. ROW COUNTS      4    4    7


RESIDUAL LOAD CORRECTION IS INVOKED
```

For nonlinear problems, it is important to note if the residual load correction was turned on. This is done automatically in the current version.

This is followed by the model definition data and how it is read and interpreted by MARC. MARC then calculates the bandwidth of the stiffness matrix and optimizes it if the OPTIMIZE model definition option is included. The original bandwidth (try 0) and the optimized bandwidth (try 10), as well as a correspondence table for nodes are then printed out.

```
MAXIMUM CONNECTIVITY IS    17  AT NODE   75


WORKSPACE NEEDED FOR OPTIMIZING =      46219
MAXIMUM SKY-LINE INCLUDING FILL-IN IS       1526 AT TRY    0 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS       1128 AT TRY    0 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS       1679 AT TRY    1 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS       1070 AT TRY    1 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS       1451 AT TRY    2 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS        966 AT TRY    2 (BACKWARD NUMBERING)
```

```
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1558 AT TRY    3 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1004 AT TRY    3 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1451 AT TRY    4 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS      966 AT TRY    4 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1451 AT TRY    5 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS      966 AT TRY    5 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1800 AT TRY    6 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1133 AT TRY    6 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1371 AT TRY    7 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS      936 AT TRY    7 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1307 AT TRY    8 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS      900 AT TRY    8 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1307 AT TRY    9 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS      900 AT TRY    9 (BACKWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS     1307 AT TRY   10 (FORWARD NUMBERING)
MAXIMUM SKY-LINE INCLUDING FILL-IN IS      900 AT TRY   10 (BACKWARD NUMBERING)
```

C O R R E S P O N D E N C E   T A B L E   F O R   N O D E S

USER, INTERNAL,   USER, INTERNAL, ETC

1...	43	2...	45	3...	46	4...	49	5...	48	6...	23	7...	27	8...	28
9...	21	10...	22	11...	24	12...	26	13...	25	14...	8	15...	11	16...	14
17...	7	18...	9	19...	10	20...	13	21...	12	22...	50	23...	47	24...	44
25...	65	26...	64	27...	62	28...	61	29...	59	30...	70	31...	71	32...	76
33...	79	34...	78	35...	69	36...	75	37...	77	38...	67	39...	68	40...	72
41...	74	42...	73	43...	60	44...	63	45...	66	46...	42	47...	40	48...	30
49...	29	50...	20	51...	17	52...	19	53...	18	54...	16	55...	15	56...	5
57...	3	58...	6	59...	4	60...	2	61...	1	62...	31	63...	41	64...	33
65...	32	66...	51	67...	53	68...	58	69...	57	70...	39	71...	38	72...	56
73...	37	74...	55	75...	54	76...	36	77...	35	78...	52	79...	34		

After the bandwidth calculation (and optimization), MARC assigns the necessary workspace for the in-core solution of this matrix. If the workspace allocated in SIZING is insufficient, it dynamically allocates more memory. If it cannot allocate more memory, MARC attempts to allocate workspace for an out-of-core solution. Information on workspace requirement is printed out.

```
MAXIMUM CONNECTIVITY IS    14  AT NODE   40


MAXIMUM HALF-BANDWIDTH IS    26  BETWEEN NODES    21  AND    46

 NUMBER OF PROFILE ENTRIES INCLUDING FILL-IN IS          900

 NUMBER OF PROFILE ENTRIES EXCLUDING FILL-IN IS          546


TOTAL WORKSPACE NEEDED WITH IN-CORE MATRIX STORAGE =       56175
```

MARC then calculates the loading and sums the load applied to each degree of freedom for distributed loads and point loads. This information provides a valuable check on the total loads in the different degrees of freedom.

```
                    LOAD INCREMENTS ASSOCIATED WITH EACH DEGREE OF FREEDOM
                    SUMMED OVER THE WHOLE MODEL

                    DISTRIBUTED LOADS
 1.233E-32 5.000E-01


                    POINT LOADS
 0.000E+00 0.000E+00
```

It prints out the time (system billing units) at the start of assembly measured from the start of the job. It prints out the bandwidth which can have changed due to optimization of the nodal numbering (if specified by you). This is followed by a printout of the time at the start of the matrix solution.

```
START OF ASSEMBLY
 TIME =       0.93


START OF MATRIX SOLUTION
 TIME =       1.18
```

If the out-of-core solver is used, a figure representing the profile of the global stiffness matrix is shown.

It prints out the following message which gives an estimate of the conditioning of the matrix. If the singularity is of the order of the accuracy of the machine, (10^{-14} for 64 bits), the equations can be considered singular and the solution unreliable. For nonlinear problems, incremental changes in the singularity ratio reflects approaching instabilities. MARC prints the time at the end of the matrix solution. This is the time at the end of matrix triangularization.

```
SINGULARITY RATIO    1.8140E-01


END OF MATRIX SOLUTION
 TIME =       1.22
```

At this stage, MARC enters a back substitution for the displacements. This is followed by calculation of element stress values. Default yield stress is set by MARC for a linear elastic analysis.

```
                                  OUTPUT FOR INCREMENT    0.    ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE


                                 ELEMENT WITH HIGHEST STRESS RELATIVE TO YIELD IS    8  WHERE EQUIVALENT STRESS IS 0.309E-
19  OF YIELD
```

A heading is printed next. The Tresca Intensity is output for application in ASME code applications. The von Mises Intensity is the equivalent yield stress. Principal stress and strain values are output. This is followed by individual stress and strain components. The number of each column is to be used with the key printed at the beginning of the analysis.

```
     TRESCA      MISES     MEAN    P R I N C I P A L   V A L U E S         P H Y S I C A L   C O M P O N E N T S
  INTENSITY INTENSITY  NORMAL   MINIMUM INTERMEDIATE MAXIMUM     1         2         3         4         5         6
                      INTENSITY


ELEMENT     2  POINT    4        INTEGRATION PT. COORDINATE=     0.255E+01    0.102E+01
SECTION THICKNESS = 0.100E+00
STRESS  1.197E+00 1.189E+00 4.043E-01 0.000E+00 1.624E-02 1.197E+00 2.112E-02 1.192E+00 7.572E-02
STRAIN  5.115E-08 3.375E-08 0.000E+00-1.142E-08 0.000E+00 3.972E-08-1.121E-08 3.951E-08 6.563E-09

ELEMENT     2  POINT    6        INTEGRATION PT. COORDINATE=     0.272E+01    0.130E+00
SECTION THICKNESS = 0.100E+00
STRESS  1.133E+00 1.068E+00 4.260E-01 0.000E+00 1.452E-01 1.133E+00 1.458E-01 1.132E+00 2.424E-02
STRAIN  4.280E-08 3.012E-08 0.000E+00-6.490E-09 0.000E+00 3.631E-08-6.464E-09 3.629E-08 2.101E-09
```

The stress and strain results follow the increment of displacements and the total displacements for all the nodes. If it is requested to print and store all stress points, a printout of the reaction forces follows the displacement output.

```
                                  N O D A L   P O I N T   D A T A



                                  I N C R E M E N T A L   D I S P L A C E M E N T S


          1 -2.17163E-08  7.15861E-08           2 -3.08177E-08  5.15029E-08            3 -4.07290E-08  3.20392E-08
          4 -4.76926E-08  1.49932E-08           5 -5.04297E-08       0.                6 -2.76616E-08  9.27126E-08
          7 -4.39062E-08  4.43055E-08           8 -5.45603E-08       0.                9 -3.22702E-08  1.16274E-07
         10 -4.01694E-08  8.65917E-08          11 -4.89835E-08  5.64992E-08           12 -5.65106E-08  2.76837E-08
         13 -6.02303E-08       0.              14 -3.35868E-08  1.37781E-07           15 -5.38023E-08  6.75310E-08
         16 -6.65910E-08       0.              17 -3.33965E-08  1.58494E-07           18 -4.60128E-08  1.17024E-07
         19 -5.78831E-08  7.56129E-08          20 -6.85415E-08  3.66168E-08           21 -7.32229E-08       0.
```

22	-4.96304E-08	0.	23	-4.01441E-08	3.13497E-08	24	-2.08547E-08	6.88011E-08
25	-4.87603E-08	0.	26	-4.63275E-08	1.48722E-08	27	-3.98008E-08	3.21380E-08
28	-3.05016E-08	5.02985E-08	29	-2.10768E-08	6.78244E-08	30	-3.00500E-08	7.88703E-08
31	-3.54531E-08	6.20915E-08	32	-3.95287E-08	4.28514E-08	33	-4.20973E-08	2.16157E-08
34	-4.27017E-08	0.	35	-2.56777E-08	7.31203E-08	6	-3.97634E-08	3.80063E-08
37	-4.58139E-08	0.	38	-2.31326E-08	6.98615E-08	39	-3.19519E-08	5.31707E-08
40	-3.97656E-08	3.50769E-08	41	-4.52082E-08	1.66544E-08	42	-4.73812E-08	0.
43	-2.17354E-08	6.82912E-08	44	-3.97941E-08	3.31902E-08	45	-4.82707E-08	0.
46	-1.27043E-08	8.80324E-08	47	-5.79619E-09	1.04377E-07	48	-1.99677E-09	1.15848E-07
49	0.	1.21338E-07	50	-9.95574E-09	1.19837E-07	51	0.	1.37765E-07
52	-2.22710E-08	1.27875E-07	53	-1.27136E-08	1.40913E-07	54	-5.45360E-09	1.52105E-07
55	0.	1.58308E-07	56	-1.33053E-08	1.63107E-07	57	0.	1.80704E-07
58	-2.09176E-08	1.71488E-07	59	-9.48572E-09	1.85090E-07	60	-2.76595E-09	1.98072E-07
61	0.	2.03816E-07	62	0.	1.17685E-07	63	-5.87403E-09	1.01890E-07
64	0.	1.15040E-07	65	-2.56043E-09	1.11113E-07	66	-6.94184E-09	1.00689E-07
67	-1.32932E-08	8.49588E-08	68	-2.37528E-08	9.27920E-08	69	-1.64856E-08	1.03335E-07
70	-8.24241E-09	1.09851E-07	71	0.	1.11859E-07	72	-1.22327E-08	1.02105E-07
73	0.	1.13032E-07	74	-1.60850E-08	8.68819E-08	5	-9.67773E-09	1.01195E-07
76	-4.07604E-09	1.10376E-07	77	0.	1.13596E-07	78	-7.96661E-09	1.00777E-07
79	0.	1.14257E-07						

T O T A L   D I S P L A C E M E N T S

1	-2.17163E-08	7.15861E-08	2	-3.08177E-08	5.15029E-08	3	-4.07290E-08	3.20392E-08
4	-4.76926E-08	1.49932E-08	5	-5.04297E-08	0.	6	-2.76616E-08	9.27126E-08
7	-4.39062E-08	4.43055E-08	8	-5.45603E-08	0.	9	-3.22702E-08	1.16274E-07
10	-4.01694E-08	8.65917E-08	11	-4.89835E-08	5.64992E-08	12	-5.65106E-08	2.76837E-08
13	-6.02303E-08	0.	14	-3.35868E-08	1.37781E-07	15	-5.38023E-08	6.75310E-08
16	-6.65910E-08	0.	17	-3.33965E-08	1.58494E-07	18	-4.60128E-08	1.17024E-07
19	-5.78831E-08	7.56129E-08	20	-6.85415E-08	3.66168E-08	21	-7.32229E-08	0.
22	-4.96304E-08	0.	23	-4.01441E-08	3.13497E-08	24	-2.08547E-08	6.88011E-08
25	-4.87603E-08	0.	26	-4.63275E-08	1.48722E-08	27	-3.98008E-08	3.21380E-08
28	-3.05016E-08	5.02985E-08	29	-2.10768E-08	6.78244E-08	30	-3.00500E-08	7.88703E-08
31	-3.54531E-08	6.20915E-08	32	-3.95287E-08	4.28514E-08	33	-4.20973E-08	2.16157E-08
34	-4.27017E-08	0.	35	-2.56777E-08	7.31203E-08	36	-3.97634E-08	3.80063E-08
37	-4.58139E-08	0.	38	-2.31326E-08	6.98615E-08	39	-3.19519E-08	5.31707E-08
40	-3.97656E-08	3.50769E-08	41	-4.52082E-08	1.66544E-08	42	-4.73812E-08	0.
43	-2.17354E-08	6.82912E-08	44	-3.97941E-08	3.31902E-08	45	-4.82707E-08	0.
46	-1.27043E-08	8.80324E-08	47	-5.79619E-09	1.04377E-07	48	-1.99677E-09	1.15848E-07
49	0.	1.21338E-07	50	-9.95574E-09	1.19837E-07	51	0.	1.37765E-07
52	-2.22710E-08	1.27875E-07	53	-1.27136E-08	1.40913E-07	54	-5.45360E-09	1.52105E-07
55	0.	1.58308E-07	56	-1.33053E-08	1.63107E-07	57	0.	1.80704E-07
58	-2.09176E-08	1.71488E-07	59	-9.48572E-09	1.85090E-07	60	-2.76595E-09	1.98072E-07
61	0.	2.03816E-07	62	0.	1.17685E-07	63	-5.87403E-09	1.01890E-07
64	0.	1.15040E-07	65	-2.56043E-09	1.11113E-07	66	-6.94184E-09	1.00689E-07
67	-1.32932E-08	8.49588E-08	68	-2.37528E-08	9.27920E-08	69	-1.64856E-08	1.03335E-07
70	-8.24241E-09	1.09851E-07	71	0.	1.11859E-07	72	-1.22327E-08	1.02105E-07
73	0.	1.13032E-07	74	-1.60850E-08	8.68819E-08	75	-9.67773E-09	1.01195E-07
76	-4.07604E-09	1.10376E-07	77	0.	1.13596E-07	78	-7.96661E-09	1.00777E-07
79	0.	1.14257E-07						

TOTAL EQUIVALENT NODAL FORCES (DISTRIBUTED PLUS POINT LOADS)

1	0.	0.	2	0.	0.	3	0.	0.
4	0.	0.	5	0.	0.	6	0.	0.
7	0.	0.	8	0.	0.	9	0.	0.
10	0.	0.	11	0.	0.	12	0.	0.
13	0.	0.	14	0.	0.	15	0.	0.
16	0.	0.	17	3.82211E-17	4.16667E-02	18	0.	0.
19	0.	0.	20	0.	0.	21	0.	0.
22	0.	0.	23	0.	0.	24	0.	0.
25	0.	0.	26	0.	0.	27	0.	0.
28	0.	0.	29	0.	0.	30	0.	0.
31	0.	0.	32	0.	0.	33	0.	0.
34	0.	0.	35	0.	0.	36	0.	0.
37	0.	0.	38	0.	0.	39	0.	0.
40	0.	0.	41	0.	0.	42	0.	0.
43	0.	0.	44	0.	0.	45	0.	0.
46	0.	0.	47	0.	0.	48	0.	0.
49	0.	0.	50	0.	0.	51	0.	0.
52	0.	0.	53	0.	0.	54	0.	0.
55	0.	0.	56	0.	0.	57	0.	0.
58	0.	0.16667	59	0.	8.33333E-02	60	3.08149E-33	0.16667
61	-3.82211E-17	4.16667E-02	62	0.	0.	63	0.	0.
64	0.	0.	65	0.	0.	66	0.	0.
67	0.	0.	68	0.	0.	69	0.	0.
70	0.	0.	71	0.	0.	72	0.	0.
73	0.	0.	74	0.	0.	75	0.	0.
76	0.	0.	77	0.	0.	78	0.	0.
79	0.	0.						

REACTION FORCES AT FIXED BOUNDARY CONDITIONS, RESIDUAL LOAD CORRECTION ELSEWHERE

1	5.63785E-18	-2.80158E-16	2	-1.73472E-17	6.93889E-18	3	-1.42030E-17	-4.53197E-17
4	4.51028E-17	3.46945E-17	5	2.25514E-17	-4.27307E-02	6	2.42861E-17	-2.77556E-17
7	1.28370E-16	1.11022E-16	8	-1.10995E-16	-0.11445	9	5.73543E-17	-6.93889E-18
10	3.03577E-17	9.19403E-17	11	-6.11490E-17	-2.08167E-17	12	-1.21431E-16	8.67362E-17
13	3.33934E-17	-5.13267E-02	14	-5.33970E-17	8.32667E-17	15	5.37764E-17	8.32667E-17
16	1.20482E-17	-9.69000E-02	17	-7.04761E-17	-8.32667E-17	18	9.38513E-17	2.77759E-17
19	-1.38073E-16	6.93889E-17	20	-1.45283E-16	9.30381E-17	21	4.62954E-17	-2.06520E-02
22	7.18397E-17	-4.78099E-02	23	7.18148E-17	-6.93889E-18	24	1.49620E-17	-5.55112E-17
25	3.03577E-17	-2.05589E-02	26	3.46945E-17	8.67362E-17	27	4.66207E-17	6.93889E-17
28	4.77049E-17	2.08167E-17	29	-6.93889E-18	-1.69136E-16	30	5.20417E-18	3.87711E-16
31	-3.68629E-17	7.63278E-17	32	1.67834E-16	1.07553E-16	33	-1.67153E-17	-2.15756E-17
34	2.35526E-17	-1.38388E-02	35	-1.37911E-16	-9.02056E-17	36	8.32667E-17	-3.46945E-17
37	4.40051E-17	-4.31462E-02	38	-2.86229E-17	-9.88792E-17	39	6.89553E-17	-2.15106E-16
40	2.18141E-16	8.23994E-17	41	7.97973E-17	5.55112E-17	42	1.01915E-16	-1.78546E-02
43	1.34441E-17	-2.08167E-16	44	-3.36970E-16	-2.77556E-17	45	-2.16840E-17	-3.07317E-02
46	-5.20417E-17	-5.13478E-16	47	-1.83881E-16	1.90820E-16	48	1.11022E-16	-2.49800E-16
49	1.06549E-04	3.81639E-17	50	1.35308E-16	-1.11022E-16	51	-3.11517E-03	1.48536E-16
52	-1.21431E-17	6.93889E-17	53	-7.97973E-17	4.23273E-16	54	3.29597E-17	1.38778E-16
55	-4.59252E-03	-6.93889E-18	56	-3.81639E-17	-4.02456E-16	57	-1.38675E-02	1.65734E-16
58	-3.15164E-17	-3.88578E-16	59	6.63532E-17	-2.77556E-16	60	-5.46031E-17	2.49800E-16
61	-7.69689E-03	1.52656E-16	62	1.72880E-03	-2.53161E-17	63	-5.55112E-17	-8.32667E-17
64	1.83992E-03	1.04734E-16	65	8.32667E-17	-2.15973E-16	66	-5.63785E-17	2.24864E-16
67	3.12250E-17	-7.97973E-17	68	-4.87891E-18	-1.18073E-16	69	5.48606E-17	-2.27249E-16
70	2.41167E-17	-3.44268E-17	71	5.30290E-03	-6.60347E-17	72	8.93383E-17	-3.58220E-16

```
    73  1.22931E-02  6.55129E-17       74 -1.38778E-16 -1.76942E-16       75  2.10769E-16  2.35922E-16
    76  9.02056E-17  5.39933E-17       77  3.65933E-03 -2.60751E-17       78 -1.01915E-16  5.06539E-16
    79  4.34147E-03  2.59368E-16

                    SUMMARY OF EXTERNALLY APPLIED LOADS

 0.12326E-31    0.50000E+00

                    SUMMARY OF REACTION/RESIDUAL FORCES

-0.36479E-17   -0.50000E+00
```

The results are concluded with an indication of the magnitude of distributed loads.

```
DISTRIBUTED LOAD    TYPE    CURRENT
LIST NUMBER                 MAGNITUDE


         1            8     -1.000         0.          0.
```

The SUMMARY model definition option asks MARC to print summary tables of stresses and strains as below:

```
************************************************************************
************************************************************************
*                                                                      *
*ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE                            *
*
*     INCREMENT      0                                   MARC K7       *
*                                                                      *
************************************************************************
*                                    *              *      *     *     *
*              QUANTITY              *    VALUE     * ELEM.* INT.*LAYER*
*                                    *              *NUMBER*POINT*     *
*                                    *              *      *     *     *
************************************************************************
*                                    *              *      *     *     *
* MAX FIRST  COMP. OF STRESS         *  0.52712E+00 *    7 *  2  *   1 *
* MIN FIRST  COMP. OF STRESS         * -0.11257E+01 *   18 *  7  *   1 *
*                                    *              *      *     *     *
*                                    *              *      *     *     *
* MAX SECOND COMP. OF STRESS         *  0.31370E+01 *    8 *  3  *   1 *
* MIN SECOND COMP. OF STRESS         * -0.75958E-01 *   18 *  4  *   1 *
*                                    *              *      *     *     *
*                                    *              *      *     *     *
* MAX THIRD  COMP. OF STRESS         *  0.15887E+00 *   18 *  1  *   1 *
* MIN THIRD  COMP. OF STRESS         * -0.84812E+00 *    7 *  3  *   1 *
*                                    *              *      *     *     *
*                                    *              *      *     *     *
* MAX   EQUIVALENT     STRESS        *  0.30910E+01 *    8 *  3  *   1 *
* MIN   EQUIVALENT     STRESS        *  0.26979E+00 *   17 *  4  *   1 *
*                                    *              *      *     *     *
*                                    *              *      *     *     *
* MAX       MEAN       STRESS        *  0.10821E+01 *    8 *  3  *   1 *
* MIN       MEAN       STRESS        * -0.38696E+00 *   18 *  7  *   1 *
*                                    *              *      *     *     *
```

```
*                                    *               *      *      *      *
* MAX     TRESCA      STRESS         *  0.31419E+01 *    8 *  3   *   1 *
* MIN     TRESCA      STRESS         *  0.29647E+00 *   17 *  4   *   1 *
*                                    *               *      *      *      *
*                                    *               *      *      *      *
* MAX FIRST  COMP. OF TOTAL STRAIN   *  0.58578E-08 *    7 *  1   *   1 *
* MIN FIRST  COMP. OF TOTAL STRAIN   * -0.37172E-07 *   18 *  7   *   1 *
*                                    *               *      *      *      *
*                                    *               *      *      *      *
* MAX SECOND COMP. OF TOTAL STRAIN   *  0.10347E-06 *    8 *  3   *   1 *
* MIN SECOND COMP. OF TOTAL STRAIN   *  0.34023E-08 *   17 *  7   *   1 *
*                                    *               *      *      *      *
*                                    *               *      *      *      *
* MAX THIRD  COMP. OF TOTAL STRAIN   *  0.13769E-07 *   18 *  1   *   1 *
* MIN THIRD  COMP. OF TOTAL STRAIN   * -0.73504E-07 *    7 *  3   *   1 *
*                                    *               *      *      *      *
*                                    *               *      *      *      *
* MAX   EQUIVALENT    TOTAL STRAIN   *  0.88382E-07 *    8 *  3   *   1 *
* MIN   EQUIVALENT    TOTAL STRAIN   *  0.88966E-08 *   17 *  4   *   1 *
*                                    *               *      *      *      *
*                                    *               *      *      *      *
* MAX      MEAN       TOTAL STRAIN   *  0.00000E+00 *    1 *  1   *   1 *
* MIN      MEAN       TOTAL STRAIN   *  0.00000E+00 *    1 *  1   *   1 *
*                                    *               *      *      *      *
*************************************************************************
```

The message "`END OF INCREMENT 0`" signifies the end of analysis for 0th increment.

```
*************************************************************************
*************************************************************************
*                                                                       *
*ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE                              *
*
*     INCREMENT      0                                    MARC K7       *
*                                                                       *
*************************************************************************
*                                    *               *      *      *      *
*              QUANTITY              *    VALUE      * ELEM.* INT.*LAYER*
*                                    *               *NUMBER*POINT*      *
*                                    *               *      *      *      *
*************************************************************************
*                                    *               *      *      *      *
* MAX     TRESCA      TOTAL STRAIN   *  0.13162E-06 *    8 *  3   *   1 *
* MIN     TRESCA      TOTAL STRAIN   *  0.12847E-07 *   17 *  4   *   1 *
*                                    *               *      *      *      *
*                                    *               *      *      *      *
* MAX TEMPERATURE                    *  0.00000E+00 *    1 *  1   *   1 *
* MIN TEMPERATURE                    *  0.00000E+00 *    1 *  1   *   1 *
*                                    *               *      *      *      *
*************************************************************************
*************************************************************************
1
```

```
******************************************************************
******************************************************************
*                                                                *
*ELASTIC ANALYSIS OF A THIN PLATE WITH HOLE                       *
*     INCREMENT      0                              MARC K7      *
*                                                                *
******************************************************************
*                                      *                 *       *
*              QUANTITY                *     VALUE       * NODE  *
*                                      *                 * NUMBER *
*                                      *                 *       *
******************************************************************
*                                      *                 *       *
* MAX FIRST  COMP. OF INCREMENTAL DISP *  -0.19968E-08   *    48 *
* MIN FIRST  COMP. OF INCREMENTAL DISP *  -0.73223E-07   *    21 *
*                                      *                 *       *
*                                      *                 *       *
* MAX SECOND COMP. OF INCREMENTAL DISP *   0.20382E-06   *    61 *
* MIN SECOND COMP. OF INCREMENTAL DISP *   0.14872E-07   *    26 *
*                                      *                 *       *
*                                      *                 *       *
* MAX FIRST  COMP. OF TOTAL DISP.      *  -0.19968E-08   *    48 *
* MIN FIRST  COMP. OF TOTAL DISP.      *  -0.73223E-07   *    21 *
*                                      *                 *       *
*                                      *                 *       *
* MAX SECOND COMP. OF TOTAL DISP.      *   0.20382E-06   *    61 *
* MIN SECOND COMP. OF TOTAL DISP.      *   0.14872E-07   *    26 *
*                                      *                 *       *
*                                      *                 *       *
* MAX FIRST  COMP. OF REACTION FORCE   *   0.12293E-01   *    73 *
* MIN FIRST  COMP. OF REACTION FORCE   *  -0.13867E-01   *    57 *
*                                      *                 *       *
*                                      *                 *       *
* MAX SECOND COMP. OF REACTION FORCE   *  -0.13839E-01   *    34 *
* MIN SECOND COMP. OF REACTION FORCE   *  -0.11445E+00   *     8 *
*                                      *                 *       *
******************************************************************
******************************************************************

                             E N D   O F   I N C R E M E N T   0
```

The MARC exit number 3004 indicates that all loading data has been successfully analyzed and the job is finished.

The above example explains the input and output for a simple elastic problem. It is our hope that these discussions give the new user a good introduction to the use of MARC.

Cross-reference Tables

The following tables give you an example(s) for parameters, model definition, history definition, or rezone options plus element types and user subroutines.

Table 1-1 Parameter Cross-reference

ACCUMULATE					
e3x15.dat					
ACOUSTIC					
e8x25.dat	e8x26.dat				
ADAPTIVE					
e2x10c.dat	e2x9d.dat	e3x21d.dat	e7x20c.dat	e8x12c.dat	e8x12e.dat
e8x40.dat	e8x41.dat	e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat
e8x57d.dat	e8x58.dat				
ALIAS					
e2x10b.dat	e2x12d.dat	e2x25b.dat	e2x30.dat	e2x32.dat	e2x45.dat
e2x51a.dat	e2x51b.dat	e2x67b.dat	e2x70.dat	e3x19b.dat	e3x19c.dat
e3x21c.dat	e3x22a.dat	e3x28.dat	e3x30a.dat	e3x32c.dat	e3x33b.dat
e3x3b.dat	e5x12.dat	e5x16b.dat	e5x3e.dat	e5x4d.dat	e5x5a.dat
e6x20a.dat	e6x20b.dat	e7x20d.dat	e7x27.dat	e7x28a.dat	e7x28b.dat
e7x28c.dat	e7x28d.dat	e7x29b.dat	e7x31a.dat	e7x31b.dat	e8x13c.dat
e8x18c.dat	e8x25.dat	e8x36.dat	e8x38c.dat	e8x43.dat	e8x43b.dat
e8x43c.dat	e8x51a.dat	e8x57c.dat	e8x57d.dat	e8x60.dat	e9x13b.dat
ALL POINTS					
e2x40a.dat	e2x40b.dat	e2x41.dat	e2x68.dat	e2x75.dat	e2x76.dat
e2x77.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x6.dat	e4x11.dat
e4x14a.dat	e4x14b.dat	e4x15.dat	e4x2.dat	e4x2c.dat	e4x2d.dat
e4x2e.dat	e5x15b.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat
e7x23.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat	e7x32.dat

Table 1-1 Parameter Cross-reference (Continued)

ALL POINTS (Continued)					
e8x41.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat
e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat
e8x56b.dat	e8x60.dat	e10x4a.dat	e10x4b.dat	e10x6a.dat	e10x6b.dat
APPBC					
e2x8.dat	e3x34.dat				
BEAM SECT					
e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59b.dat	e2x6.dat
e2x66a.dat	e2x7.dat				
BEARING					
e7x15.dat	e7x16.dat				
BUCKLE					
e3x16.dat	e3x16b.dat	e4x10.dat	e4x10b.dat	e4x12a.dat	e4x12b.dat
e4x12c.dat	e4x12d.dat	e4x15.dat	e4x1a.dat	e4x1d.dat	e4x4.dat
e4x4b.dat	e4x9.dat	e4x9b.dat			
COMMENT					
e3x24a.dat	e3x24b.dat	e3x24c.dat	e5x17b.dat	e8x33a.dat	e8x33b.dat
e8x34.dat	e8x35.dat	e8x55a.dat	e8x55b.dat		
CONSTANT DILATATION					
e3x21f.dat					
COUPLE					
e3x26.dat	e7x1b.dat	e7x1c.dat	e8x13.dat	e8x13b.dat	e8x13c.dat
—	e8x7.dat				
CREEP					
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat
e3x22c.dat	e3x22d.dat	e3x24b.dat	e3x24c.dat	e3x29.dat	

Table 1-1 Parameter Cross-reference (Continued)

DESIGN OPTIMIZATION					
e10x1b.dat	e10x2b.dat	e10x3b.dat	e10x4b.dat	e10x5b.dat	e10x6b.dat
e10x7b.dat					
DESIGN SENSITIVITY					
e10x1a.dat	e10x2a.dat	e10x3a.dat	e10x4a.dat	e10x5a.dat	e10x6a.dat
e10x7a.dat					
DIST LOADS					
e2x40a.dat	e2x40b.dat	e2x41.dat	e2x64a.dat	e2x64b.dat	e2x68.dat
e2x72.dat	e2x73.dat	e2x74.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x34.dat	e3x6.dat	e4x11.dat	e4x2.dat	e4x2c.dat	e4x2d.dat
e4x2e.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x21.dat	e6x3a.dat	e6x3b.dat	e6x3c.dat
e6x3d.dat	e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat
e8x33a.dat	e8x33b.dat	e8x36.dat	e8x42.dat	e8x43.dat	e8x43b.dat
e8x43c.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x53a.dat
e8x53b.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat
e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat
e9x1e.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat	
DYNAMIC					
e4x20.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat	e6x13b.dat
e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat
e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat	e6x1b.dat
e6x1c.dat	e6x2.dat	e6x20b.dat	e6x21.dat	e6x3a.dat	e6x3b.dat
e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat	e6x6a.dat	e6x6b.dat
e6x9.dat	e10x1a.dat	e10x1b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat
e10x4b.dat	e10x7a.dat	e10x7b.dat			

Table 1-1 Parameter Cross-reference (Continued)

ELASTIC					
e2x10c.dat	e2x35.dat	e2x35a.dat	e2x51a.dat	e2x51b.dat	e2x64a.dat
e2x64b.dat	e2x9d.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat
e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x30a.dat
e7x30b.dat	e7x31a.dat	e7x31b.dat	e8x1a.dat	e8x40.dat	e8x41.dat
e8x43.dat	e8x43b.dat	e8x43c.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat
e8x57d.dat	e8x58.dat				
EL-MA					
e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat
ELECTRO					
e8x20.dat	e8x21.dat	e8x28.dat			
ELEMENTS					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x20.dat
e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat	e2x25b.dat
e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat	e2x28.dat
e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat	e2x31a.dat
e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat	e2x35.dat
e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat	e2x39.dat
e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat	e2x43.dat
e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat	e2x46d.dat
e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat	e2x51a.dat
e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat	e2x56.dat
e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat	e2x59b.dat
e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat	e2x62.dat
e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat	e2x66a.dat
e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat	e2x7.dat

Table 1-1 Parameter Cross-reference (Continued)

ELEMENTS (Continued)					
e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat	e2x74.dat
e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat	e2x9b.dat
e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat
e3x12b.dat	e3x13.dat	e3x15.dat	e3x15b.dat	e3x16.dat	e3x16b.dat
e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat
e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat
e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x24a.dat
e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat	e3x28.dat
e3x29.dat	e3x2a.dat	e3x2b.dat	e3x30a.dat	e3x30b.dat	e3x31.dat
e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat	e3x33b.dat	e3x34.dat
e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat	e3x38a.dat	e3x38b.dat
e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat	e3x8.dat	e3x9.dat
e4x10.dat	e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat
e4x15.dat	e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat
e4x20.dat	e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat
e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7b.dat
e4x8.dat	e4x9.dat	e4x9b.dat	e5x1.dat	e5x11d.dat	e5x13a.dat
e5x13b.dat	e5x13c.dat	e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat
e5x16a.dat	e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat
e5x18b.dat	e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat
e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat
e5x4d.dat	e5x5a.dat	e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat
e5x8a.dat	e5x8b.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat
e5x9d.dat	e5x9e.dat	e6x10.dat	e6x13.dat	e6x13b.dat	e6x14.dat
e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat
e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat	e6x1b.dat	e6x1c.dat
e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat	e6x3a.dat	e6x3b.dat

Table 1-1 Parameter Cross-reference (Continued)

		ELEMENTS (Continued)			
e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat	e6x6a.dat	e6x6b.dat
e6x9.dat	e7x1.dat	e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat
e7x13c.dat	e7x13d.dat	e7x14.dat	e7x15.dat	e7x16.dat	e7x17a.dat
e7x17b.dat	e7x18.dat	e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat
e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat
e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat	e7x24a.dat	e7x24b.dat
e7x24c.dat	e7x25.dat	e7x26.dat	e7x27.dat	e7x28a.dat	e7x28b.dat
e7x28c.dat	e7x28d.dat	e7x29a.dat	e7x29b.dat	e7x3.dat	e7x30a.dat
e7x30b.dat	e7x31a.dat	e7x31b.dat	e7x32.dat	e7x3b.dat	e7x4.dat
e7x4b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat	e7x6.dat	e7x6b.dat
e7x7.dat	e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat
e7x9c.dat	e8x10.dat	e8x11.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat
e8x13.dat	e8x13b.dat	e8x13c.dat	e8x13k6.da	e8x14a.dat	e8x14b.dat
e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat
e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat
e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat
e8x1a.dat	e8x2.dat	e8x20.dat	e8x21.dat	e8x22.dat	e8x23.dat
e8x23b.dat	e8x24a.dat	e8x24b.dat	e8x25.dat	e8x26.dat	e8x27.dat
e8x28.dat	e8x29.dat	e8x3.dat	e8x30.dat	e8x30b.dat	e8x31.dat
e8x32.dat	e8x33a.dat	e8x33b.dat	e8x34.dat	e8x35.dat	e8x36.dat
e8x37.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat	e8x39.dat
e8x4.dat	e8x40.dat	e8x41.dat	e8x42.dat	e8x43.dat	e8x43b.dat
e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat	e8x46.dat
e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat
e8x56a.dat	e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat	e8x57d.dat
e8x58.dat	e8x5a.dat	e8x5b.dat	e8x6.dat	e8x60.dat	e8x7.dat
e8x8a.dat	e8x8b.dat	e8x9.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat

Table 1-1 Parameter Cross-reference (Continued)

ELEMENTS (Continued)					
e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat
e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat
e9x1e.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat	e9x3b.dat
e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat	e9x5e.dat
e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat
e9x9a.dat	e9x9b.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat
e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat
e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat		
ELSTO					
e2x22.dat	e2x27.dat	e2x30.dat	e2x45.dat	e4x2a.dat	e4x2b.dat
e4x5.dat	e7x1.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat	
END					
All MARC input files must have an END parameter line.					
EXTENDED					
e8x45.dat	e8x46.dat				
FINITE					
e3x18.dat	e3x19b.dat	e3x19c.dat	e3x20.dat	e3x21c.dat	e3x27.dat
e3x28.dat	e3x31.dat	e3x3b.dat	e7x17a.dat	e7x17b.dat	e8x12.dat
e8x12b.dat	e8x12c.dat	e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat
—	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat
e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x16.dat	e8x17.dat
e8x18.dat	e8x18b.dat	e8x18d.dat	e8x19.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x50.dat
e8x51a.dat	e8x51b.dat	e8x52.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat
e8x56b.dat	e8x7.dat				

Table 1-1 Parameter Cross-reference (Continued)

FLUID					
e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat
e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat
e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	9x2b.dat
e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat
e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat
e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat	
FOLLOW FOR					
e3x20.dat	e3x25.dat	e3x26.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x8.dat
e6x21.dat	e6x4.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat
e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x5.dat	e7x5b.dat
e7x5c.dat	e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	
FOURIER					
e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat
HARMONIC					
e6x7.dat	e6x8.dat	e8x30.dat	e8x30b.dat	e8x32.dat	e8x33a.dat
HEAT					
e3x22a.dat	e3x24a.dat	e5x1.dat	e5x10.dat	e5x11a.dat	e5x12.dat
e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat	e5x16b.dat	e5x16c.dat
e5x18a.dat	e5x18b.dat	e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat
e5x3c.dat	e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat
e5x4c.dat	e5x4d.dat	e5x5a.dat	e5x5b.dat	e5x6.dat	e5x7a.dat
e5x7b.dat	e5x8a.dat	e5x8b.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat
e5x9a.dat	e5x9d.dat	e5x9e.dat			
ISTRESS					
e2x38.dat	e3x30a.dat	e3x32b.dat	e8x34.dat	e8x35.dat	

Table 1-1 Parameter Cross-reference (Continued)

		JOULE			
e5x10.dat	e5x12.dat				
		LARGE DISP			
e2x65.dat	e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x19b.dat
e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21c.dat	e3x21e.dat	e3x23.dat
e3x23b.dat	e3x25.dat	e3x26.dat	e3x27.dat	e3x28.dat	e3x31.dat
e3x33.dat	e3x33b.dat	e3x34.dat	e3x37a.dat	e3x37b.dat	e3x38a.dat
e3x38b.dat	e3x3b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat
e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat
e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat
e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat
e4x7c.dat	e4x8.dat	e6x12.dat	e6x13b.dat	e6x16a.dat	e6x16b.dat
e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x21.dat	e6x4.dat	e6x6a.dat
e6x7.dat	e6x8.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x19b.dat
e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat
e7x25.dat	e7x26.dat	e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat
e7x28d.dat	e7x29a.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat
e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat	e8x12.dat
e8x12b.dat	e8x12c.dat	e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat
—	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat
e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x16.dat	e8x16b.dat
e8x17.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat
e8x38a.dat	e8x38b.dat	—	e8x38c.dat	e8x39.dat	e8x42.dat
e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat
e8x46.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat
e8x56a.dat	e8x56b.dat	e8x7.dat	e9x11b.dat	e9x13a.dat	e9x13b.dat

Table 1-1 Parameter Cross-reference (Continued)

			LINEAR		
e6x11.dat					
			LUMP		
e5x16a.dat	e5x16b.dat	e5x16c.dat	e5x18a.dat	e5x18b.dat	e6x15.dat
e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat
e6x19.dat	e6x9.dat				
			MAGNETO		
e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat	e8x29.dat
			NEWDB		
e8x1a.dat	e8x2.dat	e8x3.dat			
			PLASTICITY		
e3x19.dat	e3x19d.dat	e3x21a.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat
e3x33.dat	e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat
e3x37b.dat	e3x38a.dat	e3x38b.dat	e8x12d.dat	e8x12e.dat	e8x15d.dat
e8x16b.dat	e8x17b.dat	e8x18c.dat	e8x19b.dat	e8x60.dat	
			PRINT		
e2x14.dat	e2x14b.dat	e2x18.dat	e2x2.dat	e2x26.dat	e2x3.dat
e2x4.dat	e2x43.dat	e2x59a.dat	e2x62.dat	e2x70.dat	e2x9.dat
e3x11.dat	e3x21b.dat	e3x21f.dat	e3x23.dat	e3x23b.dat	e3x28.dat
e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e4x7.dat	e4x7b.dat
e4x7c.dat	e4x8.dat	e5x14.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat
e6x15.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat
e6x19.dat	e6x5.dat	e7x16.dat	e7x20.dat	e7x20b.dat	e7x20c.dat
e7x20d.dat	e7x23.dat	e7x26.dat	e7x31a.dat	e7x31b.dat	e8x12.dat
e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat
e8x13b.dat	e8x13c.dat	—	e8x14a.dat	e8x14b.dat	e8x14c.dat
e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat

Table 1-1 Parameter Cross-reference (Continued)

PRINT (Continued)					
e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat
e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1b.dat
e8x1c.dat	e8x25.dat	e8x26.dat	e8x28.dat	e8x30.dat	e8x30b.dat
e8x31.dat	e8x32.dat	e8x33b.dat	e8x36.dat	e8x37.dat	e8x38a.dat
e8x38b.dat	—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x40.dat
e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat
e8x46.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x54.dat	e8x55a.dat
e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat
e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat	e8x6.dat	e10x5a.dat
e10x5b.dat					
PROCESSOR					
e2x12c.dat	e2x12e.dat	e2x14.dat	e2x46d.dat	e2x9.dat	e3x21f.dat
e3x23b.dat	e3x32b.dat	e3x32c.dat	e3x38a.dat	e3x38b.dat	e7x29a.dat
e7x3.dat	e7x3b.dat	e8x19b.dat			
R-P FLOW					
e3x30a.dat	e3x30b.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e7x1.dat
e7x1b.dat	e7x1c.dat				
RADIATION					
e5x15.dat	e5x15b.dat				
RESPONSE					
e6x18.dat	e6x6a.dat	e6x6b.dat			
REZONING					
e7x17a.dat	e7x17b.dat	e7x31a.dat	e7x31b.dat	e8x12.dat	e8x12b.dat
e8x12r.dat					

Table 1-1 Parameter Cross-reference (Continued)

SCALE					
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x38.dat	e3x1.dat	e3x10.dat
e3x11.dat	e3x12.dat	e3x12b.dat	e3x2a.dat	e3x2b.dat	e3x4.dat
e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat	e7x13b.dat
e7x13c.dat	e7x13d.dat				
SETNAME					
e2x40a.dat	e2x40b.dat	e2x41.dat	e2x46d.dat	e2x68.dat	e2x70.dat
e2x75.dat	e2x76.dat	e2x77.dat	e3x31.dat	e3x34.dat	e3x36.dat
e3x6.dat	e4x11.dat	e4x15.dat	e4x2.dat	e4x2c.dat	e4x2d.dat
e4x2e.dat	e5x15b.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat
e6x21.dat	e7x20c.dat	e7x23.dat	e7x29a.dat	e7x29b.dat	e7x30a.dat
e7x30b.dat	e7x31a.dat	e7x31b.dat	e7x32.dat	e8x15b.dat	e8x36.dat
e8x42.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x49.dat	e8x50.dat
e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat
e8x55a.dat	e8x55b.dat	e8x60.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat
e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat
e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x6a.dat	e9x6b.dat	e9x8.dat
e10x4a.dat	e10x4b.dat	e10x6a.dat	e10x6b.dat		
SHELL SECT					
e2x11.dat	e2x15.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat
e2x55.dat	e2x56.dat	e2x68.dat	e2x69.dat	e2x70.dat	e2x72.dat
e2x73.dat	e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e3x1.dat
e3x14a.dat	e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x20.dat
e3x23.dat	e3x23b.dat	e3x32c.dat	e3x4.dat	e3x5.dat	e3x6.dat
e4x10.dat	e4x10b.dat	e4x11.dat	e4x1c.dat	e4x2.dat	e4x2c.dat
e4x2d.dat	e4x2e.dat	e4x7.dat	e4x7b.dat	e4x7c.dat	e4x9.dat
e4x9b.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat	e5x13d.dat	e5x18a.dat
e5x18b.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x24a.dat	e7x24b.dat

Table 1-1 Parameter Cross-reference (Continued)

SHELL SECT (Continued)					
e7x24c.dat	e7x25.dat	e7x26.dat	e7x3.dat	e7x3b.dat	e7x6.dat
e7x6b.dat	e7x7.dat	e8x18.dat	e8x18b.dat	e8x18d.dat	e8x38a.dat
e8x38b.dat	—	e8x38c.dat	e8x51a.dat	e8x51b.dat	e8x52.dat
e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat	e8x57a.dat
e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat	e10x4a.dat	e10x4b.dat
SIZING					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x20.dat	e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat
e2x25b.dat	e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat
e2x28.dat	e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat
e2x35.dat	e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat
e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat
e2x43.dat	e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat
e2x46d.dat	e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat
e2x51a.dat	e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat
e2x56.dat	e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat
e2x59b.dat	e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat
e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66a.dat	e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat
e2x7.dat	e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat
e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat
e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat

Table 1-1 Parameter Cross-reference (Continued)

SIZING (Continued)					
e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat
e3x21e.dat	e3x21f.dat	e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat
e3x23b.dat	e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat
e3x27.dat	e3x28.dat	e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat
e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x33.dat	e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat
e3x37b.dat	e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat
e3x6.dat	e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat
e4x10.dat	e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat
e4x15.dat	e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat
e4x20.dat	e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat
e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat
e4x7b.dat	e4x7c.dat	e4x8.dat	e4x9.dat	e4x9b.dat	e5x1.dat
e5x10.dat	e5x11a.dat	e5x11c.dat	e5x12.dat	e5x13a.dat	e5x13b.dat
e5x13c.dat	e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat
e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat
e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat
e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat
e5x5a.dat	e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat
e5x8b.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat
e5x9d.dat	e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat
e6x13b.dat	e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat
e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat
e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat
e6x6a.dat	e6x6b.dat	e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat
e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat

Table 1-1 Parameter Cross-reference (Continued)

SIZING (Continued)					
e7x14.dat	e7x15.dat	e7x16.dat	e7x17a.dat	e7x17b.dat	e7x18.dat
e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat	e7x20.dat
e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat
e7x22c.dat	e7x23.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat	e7x25.dat
e7x26.dat	e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat
e7x29a.dat	e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat
e7x31b.dat	e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat
e7x5b.dat	e7x5c.dat	e7x6.dat	e7x6b.dat	e7x7.dat	e7x8a.dat
e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat	e8x10.dat
e8x11.dat	e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat
e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x14a.dat
e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat
e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat
e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat
e8x19b.dat	e8x1a.dat	e8x1b.dat	e8x1c.dat	e8x2.dat	e8x20.dat
e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat
e8x25.dat	e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x3.dat
e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat
e8x34.dat	e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat
e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat
e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat
e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat
e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat
e8x6.dat	e8x60.dat	e8x7.dat	e8x8a.dat	e8x8b.dat	e8x9.dat
e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat
e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat

Table 1-1 Parameter Cross-reference (Continued)

SIZING (Continued)					
e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat
e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat
e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat
e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat	e10x1a.dat
e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat
e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat
e10x7b.dat					
STATE VARS					
e3x13.dat	e7x32.dat				
SUBSTRUC					
e8x1a.dat	e8x2.dat	e8x3.dat			
SUPER					
e8x1b.dat	e8x1c.dat				
THERMAL					
e2x46a.dat	e2x46b.dat	e2x46d.dat	e2x49.dat	e2x51a.dat	e2x51b.dat
e3x11.dat	e3x13.dat	e3x22c.dat	e3x22d.dat	e3x5.dat	e5x11a.dat
e5x11c.dat					
TIE					
e2x47b.dat					
TITLE					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x20.dat	e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat
e2x25b.dat	e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat
e2x28.dat	e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat
e2x35.dat	e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat

Table 1-1 Parameter Cross-reference (Continued)

TITLE (Continued)					
e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat
e2x43.dat	e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat
e2x46d.dat	e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat
e2x51a.dat	e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat
e2x56.dat	e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat
e2x59b.dat	e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat
e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66a.dat	e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat
e2x7.dat	e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat
e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x14b.dat	e3x15.dat
e3x15b.dat	e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat
e3x19b.dat	e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21b.dat
e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat	e3x22a.dat	e3x22b.dat
e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x24a.dat	e3x24b.dat
e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat	e3x28.dat	e3x29.dat
e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat	e3x30b.dat	e3x31.dat
e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat	e3x33b.dat	e3x34.dat
e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat	e3x38a.dat	e3x38b.dat
e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat	e3x7a.dat	e3x7b.dat
e3x7c.dat	e3x8.dat	e3x9.dat	e4x10.dat	e4x10b.dat	e4x11.dat
e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat	e4x13a.dat	e4x13b.dat
e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat	e4x1a.dat	e4x1b.dat
e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat	e4x2a.dat	e4x2b.dat
e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat	e4x4.dat	e4x4b.dat
e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat	e4x7c.dat	e4x8.dat
e4x9.dat	e4x9b.dat	e5x1.dat	e5x10.dat	e5x11a.dat	e5x11b.dat

Table 1-1 Parameter Cross-reference (Continued)

TITLE (Continued)					
e5x11c.dat	e5x11d.dat	e5x12.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat
e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat	e5x16b.dat
e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat	e5x2a.dat
e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat
e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat
e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8b.dat
e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat	e5x9c.dat
e5x9d.dat	e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat
e6x13b.dat	e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat
e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat
e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat
e6x6a.dat	e6x6b.dat	e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat
e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat
e7x14.dat	e7x15.dat	e7x16.dat	e7x17a.dat	e7x17b.dat	e7x18.dat
e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat	e7x20.dat
e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat
e7x22c.dat	e7x23.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat	e7x25.dat
e7x26.dat	e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat
e7x29a.dat	e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat
e7x31b.dat	e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat
e7x5b.dat	e7x5c.dat	e7x6.dat	e7x6b.dat	e7x7.dat	e7x8a.dat
e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat	e8x10.dat
e8x11.dat	e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat
e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x14a.dat
e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat
e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat
e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat

Table 1-1 Parameter Cross-reference (Continued)

TITLE (Continued)					
e8x19b.dat	e8x1a.dat	e8x1b.dat	e8x1c.dat	e8x2.dat	e8x20.dat
e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat
e8x25.dat	e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x3.dat
e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat
e8x34.dat	e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat
e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat
e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat
e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat
e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat
e8x6.dat	e8x60.dat	e8x7.dat	e8x8a.dat	e8x8b.dat	e8x9.dat
e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat
e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat
e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat
e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat
e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat
e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat	e10x1a.dat
e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat
e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat
e10x7b.dat					
T-T-T					
e5x11c.dat					

Table 1-1 Parameter Cross-reference (Continued)

		UPDATE			
e3x18.dat	e3x19b.dat	e3x19c.dat	e3x20.dat	e3x21c.dat	e3x25.dat
e3x26.dat	e3x27.dat	e3x28.dat	e3x31.dat	e3x3b.dat	e4x3.dat
e4x7.dat	e4x7b.dat	e4x7c.dat	e6x12.dat	e7x17a.dat	e7x17b.dat
e7x25.dat	e7x29a.dat	e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12r.dat
e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x14a.dat	e8x14b.dat
e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat
e8x15c.dat	e8x16.dat	e8x17.dat	e8x18.dat	e8x18b.dat	e8x18d.dat
e8x19.dat	e8x34.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x50.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat
e8x7.dat	e9x11b.dat	e9x13a.dat	e9x13b.dat		
		USER			
e3x14b.dat	e3x21b.dat				

Table 1-2 Model Definition Option Cross-reference

ADAPTIVE					
e2x10c.dat	e2x9d.dat	e7x20c.dat	e8x12c.dat	e8x12e.dat	e8x40.dat
e8x41.dat	e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat
e8x44b.dat	e8x44c.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat	e8x57d.dat
e8x58.dat					
ANISOTROPIC					
e5x7a.dat	e7x6b.dat				
ATTACH NODE					
e2x9d.dat	e7x20c.dat	e8x40.dat	e8x42.dat		
B-H RELATION					
e8x24b.dat					
BUCKLE INCREMENT					
e4x12c.dat	e4x12d.dat				
CASE COMBINATION					
e2x35a.dat	e2x51b.dat	e7x9c.dat			
CHANGE STATE					
e2x41.dat	e5x11c.dat	e7x32.dat	e7x7.dat	e8x45.dat	
CHANNEL					
e5x14.dat					
CHECK RESULTS					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x20.dat	e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat
e2x25b.dat	e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat
e2x28.dat	e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

CHECK RESULTS (Continued)					
e2x35.dat	e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat
e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat
e2x43.dat	e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat
e2x46d.dat	e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat
e2x51a.dat	e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat
e2x56.dat	e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat
e2x59b.dat	e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat
e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66a.dat	e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat
e2x7.dat	e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat
e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat
e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat
e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat
e3x21e.dat	e3x21f.dat	e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat
e3x23b.dat	e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat
e3x27.dat	e3x28.dat	e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat
e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x33.dat	e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat
e3x37b.dat	e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat
e3x6.dat	e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat
e4x10.dat	e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat
e4x15.dat	e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat
e4x20.dat	e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat
e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat
e4x7b.dat	e4x7c.dat	e4x8.dat	e4x9.dat	e4x9b.dat	e5x1.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

CHECK RESULTS (Continued)					
e5x10.dat	e5x11a.dat	e5x11c.dat	e5x12.dat	e5x13a.dat	e5x13b.dat
e5x13c.dat	e5x13d.dat	e5x14.dat	e5x15.dat	e5x16a.dat	e5x16b.dat
e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat	e5x2a.dat
e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat
e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat
e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8b.dat
e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat	e5x9d.dat
e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat	e6x13b.dat
e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat
e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat	e6x1b.dat
e6x1c.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat	e6x3a.dat
e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat	e6x6a.dat
e6x6b.dat	e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat	e7x10.dat
e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat	e7x14.dat
e7x15.dat	e7x16.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x19.dat
e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat	e7x20.dat	e7x20b.dat
e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat
e7x23.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat	e7x25.dat	e7x26.dat
e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x29a.dat
e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat
e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat
e7x5c.dat	e7x6.dat	e7x6b.dat	e7x7.dat	e7x8a.dat	e7x8b.dat
e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat	e8x10.dat	e8x11.dat
e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat
e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x14a.dat	e8x14b.dat
e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat
e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat
e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

CHECK RESULTS (Continued)					
e8x1a.dat	e8x1b.dat	e8x1c.dat	e8x2.dat	e8x20.dat	e8x21.dat
e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat	e8x25.dat
e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x3.dat	e8x30.dat
e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat	e8x34.dat
e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat	—
e8x38c.dat	e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat	e8x42.dat
e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat
e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat
e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat
e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat	e8x57b.dat
e8x57c.dat	e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e8x60.dat	e8x7.dat	e8x8a.dat	e8x8b.dat	e8x9.dat	e9x10a.dat
e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat
e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat
e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat
e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat
e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat
e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat	e10x1a.dat	e10x1b.dat
e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat
e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat
COMPOSITE					
e7x24a.dat	e7x24b.dat	e7x24c.dat	e7x25.dat	e7x6.dat	e7x6b.dat
e7x7.dat	e8x5a.dat	e8x5b.dat	e10x5a.dat	e10x5b.dat	
CONN FILL					
e2x34.dat					

Table 1-2 Model Definition Option Cross-reference (Continued)

CONN GENER					
e2x25.dat	e2x25b.dat	e2x33.dat	e2x33b.dat	e2x34.dat	e2x36.dat
e2x43.dat	e2x48.dat	e2x49.dat	e2x66a.dat	e3x20.dat	e4x4.dat
e4x4b.dat	e4x7.dat	e4x7c.dat	e6x18.dat	e7x16.dat	e8x5a.dat
e8x5b.dat	e8x6.dat	e10x5a.dat	e10x5b.dat		
CONNECTIVITY					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat	e2x25b.dat
e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat	e2x28.dat
e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat	e2x31a.dat
e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat	e2x35.dat
e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat	e2x39.dat
e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat	e2x43.dat
e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat	e2x46d.dat
e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat	e2x51a.dat
e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat	e2x56.dat
e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat	e2x59b.dat
e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat	e2x62.dat
e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat	e2x66a.dat
e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat	e2x7.dat
e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat	e2x74.dat
e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat	e2x9b.dat
e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat
e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat	e3x16.dat
e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat
e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

CONNECTIVITY (Continued)					
e3x21f.dat	e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat
e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat
e3x28.dat	e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat
e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat
e3x7a.dat	e3x8.dat	e3x9.dat	e4x10.dat	e4x10b.dat	e4x11.dat
e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat	e4x13a.dat	e4x13b.dat
e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat	e4x1a.dat	e4x1b.dat
e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat	e4x2a.dat	e4x2b.dat
e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat	e4x4.dat	e4x4b.dat
e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat	e4x7c.dat	e4x8.dat
e4x9.dat	e4x9b.dat	e5x1.dat	e5x10.dat	e5x11a.dat	e5x11c.dat
e5x12.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat	e5x13d.dat	e5x14.dat
e5x15.dat	e5x15b.dat	e5x16a.dat	e5x16b.dat	e5x16c.dat	e5x17a.dat
e5x17b.dat	e5x18a.dat	e5x18b.dat	e5x2a.dat	e5x2b.dat	e5x3a.dat
e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x4a.dat
e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat	e5x5b.dat	e5x6.dat
e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat
e5x9a.dat	e5x9b.dat	e5x9d.dat	e5x9e.dat	e6x10.dat	e6x11.dat
e6x12.dat	e6x13.dat	e6x13b.dat	e6x14.dat	e6x15.dat	e6x15b.dat
e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat
e6x19.dat	e6x1a.dat	e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat
e6x20b.dat	e6x21.dat	e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat
e6x4.dat	e6x5.dat	e6x6a.dat	e6x6b.dat	e6x7.dat	e6x8.dat
e6x9.dat	e7x1.dat	e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat
e7x13c.dat	e7x14.dat	e7x15.dat	e7x16.dat	e7x17a.dat	e7x17b.dat
e7x18.dat	e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

		CONNECTIVITY (Continued)			
e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat
e7x22b.dat	e7x22c.dat	e7x23.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat
e7x25.dat	e7x26.dat	e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat
e7x28d.dat	e7x29a.dat	e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat
e7x31a.dat	e7x31b.dat	e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat
e7x5.dat	e7x5b.dat	e7x5c.dat	e7x6.dat	e7x6b.dat	e7x7.dat
e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat	e8x10.dat
e8x11.dat	e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat
e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x14a.dat
e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat
e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat
e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat
e8x19b.dat	e8x1a.dat	e8x2.dat	e8x20.dat	e8x21.dat	e8x22.dat
e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat	e8x25.dat	e8x26.dat
e8x27.dat	e8x28.dat	e8x29.dat	e8x3.dat	e8x30.dat	e8x30b.dat
e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat	e8x34.dat	e8x35.dat
e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat
e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat	e8x42.dat	e8x43.dat
e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat
e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat
e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat
e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat
e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat	e8x6.dat	e8x60.dat
e8x7.dat	e8x8a.dat	e8x8b.dat	e8x9.dat	e9x10a.dat	e9x10b.dat
e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat
e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat
e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat
e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

CONNECTIVITY (Continued)					
e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat
e9x8.dat	e9x9a.dat	e9x9b.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat
e10x2b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat
e10x5b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat	
CONRAD GAP					
e5x14.dat					
CONTACT					
e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e4x7b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat
e6x19.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x23.dat
e7x31a.dat	e7x31b.dat	e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12d.dat
e8x12e.dat	e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—
e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat
e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat
e8x17.dat	e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat
e8x19.dat	e8x19b.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x42.dat	e8x43.dat	e8x43b.dat
e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat	e8x46.dat
e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat
e8x56a.dat	e8x56b.dat	e8x60.dat			
CONTACT NODE					
e8x15b.dat					

Table 1-2 Model Definition Option Cross-reference (Continued)

CONTACT TABLE					
e3x31.dat	e3x32b.dat	e3x32c.dat	e6x19.dat	e7x31a.dat	e7x31b.dat
e8x13c.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16b.dat
e8x38a.dat	e8x38b.dat	—	e8x38c.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x46.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x55b.dat
e8x56b.dat					
CONTROL					
e2x12b.dat	e2x65.dat	e2x67a.dat	e2x67b.dat	e2x70.dat	e2x9d.dat
e3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat	e3x12b.dat	e3x13.dat
e3x14a.dat	e3x15.dat	e3x15b.dat	e3x16.dat	e3x16b.dat	e3x17.dat
e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat	e3x20.dat
e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat	e3x22a.dat
e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x24a.dat	e3x24b.dat
e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat	e3x28.dat	e3x29.dat
e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat	e3x30b.dat	e3x31.dat
e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat	e3x33b.dat	e3x35.dat
e3x36.dat	e3x37a.dat	e3x37b.dat	e3x38a.dat	e3x38b.dat	e3x3b.dat
e3x4.dat	e3x5.dat	e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat
e3x9.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat	e4x13a.dat
e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat	e4x1a.dat
e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x20.dat	e4x2a.dat	e4x2b.dat
e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat
e4x7b.dat	e4x7c.dat	e4x8.dat	e5x11a.dat	e5x11c.dat	e5x13a.dat
e5x13b.dat	e5x13c.dat	e5x13d.dat	e5x14.dat	e5x15.dat	e5x16a.dat
e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x2a.dat	e5x2b.dat
e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat	e5x3f.dat
e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat	e5x5b.dat
e5x6.dat	e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

CONTROL (Continued)					
e5x9b.dat	e5x9d.dat	e5x9e.dat	e6x13.dat	e6x13b.dat	e6x14.dat
e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x21.dat	e6x3a.dat	e6x3b.dat	e6x3c.dat
e6x3d.dat	e6x4.dat	e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat
e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat	e7x14.dat
e7x16.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x1b.dat	e7x1c.dat
e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat
e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat	e7x25.dat	e7x26.dat
e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x29a.dat	e7x29b.dat
e7x3.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat
e7x5c.dat	e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat
e7x9c.dat	e8x10.dat	e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12d.dat
e8x12e.dat	e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—
e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat
e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat
e8x17.dat	e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat
e8x19.dat	e8x19b.dat	e8x24b.dat	e8x26.dat	e8x27.dat	e8x31.dat
e8x33b.dat	e8x34.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x41.dat	e8x42.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x51a.dat	e8x51b.dat	e8x55a.dat
e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e8x7.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat
e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat
e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat
e9x2b.dat	e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat
e9x5b.dat	e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat
e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

			CONVERT		
e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x7.dat	
			COORDINATES		
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat	e2x25b.dat
e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat	e2x28.dat
e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat	e2x31a.dat
e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat	e2x35.dat
e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat	e2x39.dat
e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat	e2x43.dat
e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat	e2x46d.dat
e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat	e2x51a.dat
e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat	e2x56.dat
e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat	e2x59b
e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat	e2x62.dat
e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat	e2x66a.dat
e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat	e2x7.dat
e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat	e2x74.dat
e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat	e2x9b.dat
e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat
e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat	e3x17.dat
e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat	e3x20.dat
e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat	e3x22a.dat
e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x24a.dat	e3x24b.dat
e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat	e3x28.dat	e3x29.dat
e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat	e3x30b.dat	e3x31.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

COORDINATES (Continued)					
e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat	e3x33b.dat	e3x34.dat
e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat	e3x38a.dat	e3x38b.dat
e3x3b.dat	e3x4.dat	e3x6.dat	e3x7a.dat	e3x8.dat	e3x9.dat
e4x10.dat	e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat
e4x15.dat	e4x1c.dat	e4x2.dat	e4x20.dat	e4x2a.dat	e4x2b.dat
e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat	e4x4.dat	e4x4b.dat
e4x5.dat	e4x6.dat	e4x7b.dat	e4x8.dat	e4x9.dat	e4x9b.dat
e5x1.dat	e5x10.dat	e5x11a.dat	e5x11c.dat	e5x12.dat	e5x13a.dat
e5x13b.dat	e5x13c.dat	e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat
e5x16a.dat	e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat
e5x18b.dat	e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat
e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat
e5x4d.dat	e5x5a.dat	e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat
e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat
e5x9d.dat	e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat
e6x13b.dat	e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat
e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat
e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat
e6x6a.dat	e6x6b.dat	e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat
e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat	e7x14.dat
e7x15.dat	e7x16.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x19.dat
e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat	e7x20.dat	e7x20b.dat
e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat
e7x23.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat	e7x25.dat	e7x26.dat
e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x29a.dat
e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

COORDINATES (Continued)					
e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat
e7x5c.dat	e7x6.dat	e7x6b.dat	e7x7.dat	e7x8a.dat	e7x8b.dat
e7x8c.dat	e7x9a.dat	e7x9b.dat	e8x10.dat	e8x11.dat	e8x12.dat
e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat
e8x13b.dat	e8x13c.dat	—	e8x14a.dat	e8x14b.dat	e8x14c.dat
e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat
e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat
e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1a.dat
e8x2.dat	e8x20.dat	e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat
e8x24a.dat	e8x24b.dat	e8x25.dat	e8x26.dat	e8x27.dat	e8x28.dat
e8x29.dat	e8x3.dat	e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat
e8x33a.dat	e8x33b.dat	e8x34.dat	e8x35.dat	e8x36.dat	e8x37.dat
e8x38a.dat	e8x38b.dat	—	e8x38c.dat	e8x39.dat	e8x4.dat
e8x40.dat	e8x41.dat	e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat
e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat
e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat
e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat
e8x5a.dat	e8x5b.dat	e8x6.dat	e8x60.dat	e8x7.dat	e8x8a.dat
e8x8b.dat	e8x9.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat
e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat
e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat
e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat
e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat
e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat
e9x9b.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat
e10x3b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat
e10x6b.dat	e10x7a.dat	e10x7b.dat			

Table 1-2 Model Definition Option Cross-reference (Continued)

CRACK DATA					
e7x11.dat	e7x3.dat	e7x3b.dat	e8x4.dat	e8x5a.dat	e8x5b.dat
e8x6.dat					
CREEP					
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat
e3x22c.dat	e3x22d.dat	e3x24b.dat	e3x24c.dat	e3x29.dat	
DAMAGE					
e3x27.dat	e3x28.dat	e7x22b.dat	e7x22c.dat	e7x30a.dat	e7x30b.dat
DAMPING					
e6x9.dat					
DEFINE					
e2x14b.dat	e2x37b.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x46d.dat
e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat	e2x68.dat	e2x70.dat
e3x12b.dat	e3x26.dat	e3x27.dat	e3x3.dat	e3x31.dat	e3x3b.dat
e3x4.dat	e3x5.dat	e3x6.dat	e4x11.dat	e4x12a.dat	e4x12b.dat
e4x12c.dat	e4x12d.dat	e4x2.dat	e5x14.dat	e5x17a.dat	e5x17b.dat
e5x18a.dat	e5x18b.dat	e5x9e.dat	e6x19.dat	e6x21.dat	e7x19.dat
e7x19b.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x23.dat
e7x6.dat	e7x6b.dat	e7x7.dat	e8x15.dat	e8x15b.dat	e8x15c.dat
e8x15d.dat	e8x23b.dat	e8x26.dat	e8x28.dat	e8x29.dat	e8x30.dat
e8x30b.dat	e8x31.dat	e8x32.dat	e8x35.dat	e8x36.dat	e8x37.dat
e8x42.dat	e8x45.dat	e8x47.dat	e8x49.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x56a.dat	e8x56b.dat	e8x9.dat	e9x11a.dat	e9x11b.dat
e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x5c.dat
e9x5d.dat	e9x6a.dat	e9x6b.dat	e9x7b.dat	e9x8.dat	
DENSITY EFFECTS					
e3x25.dat	e3x26.dat				

Table 1-2 Model Definition Option Cross-reference (Continued)

DESIGN DISPLACEMENT CONSTRAINTS					
e10x1a.dat	e10x1b.dat	e10x3a.dat	e10x3b.dat	e10x5a.dat	e10x5b.dat
e10x7a.dat	e10x7b.dat				
DESIGN FREQUENCY CONSTRAINTS					
e10x1a.dat	e10x1b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat
e10x7a.dat	e10x7b.dat				
DESIGN OBJECTIVE					
e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat
e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat
e10x7a.dat	e10x7b.dat				
DESIGN STRAIN CONSTRAINTS					
e10x2a.dat	e10x2b.dat	e10x5a.dat	e10x5b.dat		
DESIGN STRESS CONSTRAINTS					
e10x1a.dat	e10x1b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat
e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat
DESIGN VARIABLES					
e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat
e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat
e10x7a.dat	e10x7b.dat				
DIST CURRENT					
e5x10.dat					
DIST FLUXES					
e5x18a.dat	e5x18b.dat	e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat
e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x7.dat	e9x12b.dat
e9x12c.dat					

Table 1-2 Model Definition Option Cross-reference (Continued)

DIST LOADS					
e2x1.dat	e2x11.dat	e2x12b.dat	e2x12c.dat	e2x12d.dat	e2x12e.dat
e2x13.dat	e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat
e2x2.dat	e2x22.dat	e2x23.dat	e2x2b.dat	e2x2c.dat	e2x3.dat
e2x30.dat	e2x31a.dat	e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat
e2x35.dat	e2x35a.dat	e2x37.dat	e2x37b.dat	e2x39.dat	e2x4.dat
e2x40a.dat	e2x40b.dat	e2x43.dat	e2x44.dat	e2x45.dat	e2x46c.dat
e2x47b.dat	e2x49.dat	e2x5.dat	e2x51a.dat	e2x51b.dat	e2x53.dat
e2x55.dat	e2x56.dat	e2x58a.dat	e2x58b.dat	e2x6.dat	e2x60a.dat
e2x60b.dat	e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat
e2x66b.dat	e2x69.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x9.dat	e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x10.dat
e3x12.dat	e3x12b.dat	e3x15.dat	e3x15b.dat	e3x16.dat	e3x16b.dat
e3x17.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x25.dat
e3x26.dat	e3x29.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x34.dat	e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat
e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x2a.dat
e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x8.dat	e4x9.dat
e4x9b.dat	e6x14.dat	e6x20a.dat	e6x20b.dat	e6x21.dat	e6x4.dat
e7x12.dat	e7x14.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat
e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat
e7x28d.dat	e7x3.dat	e7x3b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat
e7x6.dat	e7x6b.dat	e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat
e7x9b.dat	e7x9c.dat	e8x11.dat	e8x1a.dat	e8x2.dat	e8x27.dat
e8x34.dat	e8x35.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat
e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x46.dat	e8x47.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

DIST LOADS					
e8x53a.dat	e8x53b.dat	e8x58.dat	e8x8a.dat	e8x8b.dat	e9x1a.dat
e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat
e9x2c.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x9a.dat	e9x9b.dat
e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat		
ELEM SORT					
e2x9b.dat					
END OPTION					
All MARC input files must have an END OPTION line.					
ERROR ESTIMATE					
e2x34.dat	e7x10.dat	e8x11.dat	e8x41.dat		
EXCLUDE					
e8x15d.dat	e8x46.dat				
EXIT					
e5x3c.dat	e5x3d.dat	e9x5c.dat	e9x5d.dat	e9x6a.dat	e9x6b.dat
e9x8.dat					
FAIL DATA					
e7x25.dat	e8x27.dat	e8x9.dat			
FILMS					
e3x22a.dat	e3x24a.dat	e5x10.dat	e5x11a.dat	e5x13a.dat	e5x13b.dat
e5x13c.dat	e5x13d.dat	e5x14.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat
e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x5a.dat	e5x5b.dat	e5x6.dat
e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat
e5x9d.dat	e5x9e.dat	e9x12b.dat	e9x12c.dat		

Table 1-2 Model Definition Option Cross-reference (Continued)

FIXED DISP					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x20.dat	e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat
e2x25b.dat	e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat
e2x28.dat	e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat
e2x35.dat	e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat
e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat
e2x43.dat	e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat
e2x46d.dat	e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat
e2x51a.dat	e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat
e2x56.dat	e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat
e2x59b.dat	e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat
e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66a.dat	e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat
e2x7.dat	e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat
e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat
e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat
e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat
e3x21e.dat	e3x21f.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat
e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat	e3x28.dat
e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat	e3x30b.dat
e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat	e3x33b.dat
e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat	e3x38a.dat
e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat	e3x7a.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

		FIXED DISP (Continued)			
e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat	e4x10.dat	e4x10b.dat
e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat	e4x13a.dat
e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat	e4x1a.dat
e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat	e4x2a.dat
e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat	e4x4.dat
e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat	e4x7c.dat
e4x8.dat	e4x9.dat	e4x9b.dat	e5x11c.dat	e6x10.dat	e6x11.dat
e6x12.dat	e6x13.dat	e6x13b.dat	e6x14.dat	e6x15.dat	e6x15b.dat
e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat
e6x19.dat	e6x1a.dat	e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat
e6x20b.dat	e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat
e6x5.dat	e6x6a.dat	e6x6b.dat	e6x7.dat	e6x8.dat	e6x9.dat
e7x1.dat	e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat
e7x13d.dat	e7x14.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x19.dat
e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat	e7x21.dat	e7x22a.dat
e7x22b.dat	e7x22c.dat	e7x23.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat
e7x25.dat	e7x26.dat	e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat
e7x28d.dat	e7x29a.dat	e7x29b.dat	e7x3.dat	e7x32.dat	e7x3b.dat
e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat	e7x6.dat
e7x6b.dat	e7x7.dat	e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat
e7x9b.dat	e7x9c.dat	e8x10.dat	e8x11.dat	e8x12.dat	e8x12b.dat
e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat	e8x13b.dat
e8x13c.dat	—	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat
e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat
e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat	e8x18b.dat
e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1a.dat	e8x2.dat
e8x27.dat	e8x3.dat	e8x34.dat	e8x35.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

FIXED DISP (Continued)					
e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x51a.dat
e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x56a.dat
e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat
e8x5a.dat	e8x5b.dat	e8x6.dat	e8x60.dat	e8x7.dat	e8x8a.dat
e8x8b.dat	e8x9.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat
e9x11a.dat	e9x11b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x9b.dat
e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat
e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat
e10x7a.dat	e10x7b.dat				
FIXED POTENTIAL					
e8x20.dat	e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat
e8x24b.dat	e8x28.dat	e8x29.dat	e8x30.dat	e8x30b.dat	e8x31.dat
e8x32.dat	e8x33a.dat	e8x33b.dat			
FIXED PRESSURE					
e7x15.dat	e7x16.dat	e8x26.dat			
FIXED TEMPERATURE					
e3x24a.dat	e3x26.dat	e5x1.dat	e5x12.dat	e5x15.dat	e5x15b.dat
e5x16a.dat	e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat
e5x18b.dat	e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat
e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat
e5x4d.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8c.dat	e5x8d.dat
e5x8e.dat	e7x1b.dat	e7x1c.dat	e8x13.dat	e8x13b.dat	e8x13c.dat
—	e8x7.dat				

Table 1-2 Model Definition Option Cross-reference (Continued)

FIXED VELOCITY					
e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat
e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat
e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat
e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat
e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat
e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat		
FLUID DRAG					
e6x20a.dat	e6x20b.dat				
FLUID SOLID					
e6x5.dat					
FOAM					
e7x19b.dat	e7x23.dat				
FORCDT					
e3x26.dat	e5x2b.dat	e7x17a.dat	e7x17b.dat	e8x26.dat	
FOUNDATION					
e2x29.dat	e2x36.dat	e2x42.dat			
FOURIER					
e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat
FXORD					
e2x11.dat	e2x15.dat	e3x1.dat	e6x3a.dat	e6x3c.dat	
GAP DATA					
e2x70.dat	e3x18.dat	e6x9.dat	e7x18.dat	e7x2.dat	e7x26.dat
e7x4.dat	e7x4b.dat	e8x7.dat			

Table 1-2 Model Definition Option Cross-reference (Continued)

GEOMETRY					
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x14.dat
e2x14b.dat	e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat
e2x20.dat	e2x21.dat	e2x24.dat	e2x25.dat	e2x25b.dat	e2x26.dat
e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat	e2x29.dat	e2x3.dat
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x34.dat	e2x36.dat	e2x37.dat
e2x37b.dat	e2x38.dat	e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat
e2x41.dat	e2x42.dat	e2x43.dat	e2x44.dat	e2x46a.dat	e2x46b.dat
e2x46c.dat	e2x46d.dat	e2x5.dat	e2x54.dat	e2x55.dat	e2x56.dat
e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat	e2x59b.dat
e2x6.dat	e2x62.dat	e2x64a.dat	e2x64b.dat	e2x65.dat	e2x66a.dat
e2x66b.dat	e2x68.dat	e2x7.dat	e2x71a.dat	e2x71b.dat	e2x72.dat
e2x73.dat	e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat
e2x9.dat	e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat
e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat	e3x16.dat	e3x16b.dat
e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat
e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21f.dat	e3x23.dat
e3x23b.dat	e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x27.dat	e3x29.dat
e3x3.dat	e3x30a.dat	e3x30b.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x33.dat	e3x33b.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat
e4x10.dat	e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x14a.dat	e4x14b.dat	e4x15.dat	e4x1a.dat	e4x1b.dat
e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat	e4x2a.dat	e4x2b.dat
e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat	e4x4.dat	e4x4b.dat
e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat	e4x7c.dat	e4x8.dat
e4x9.dat	e4x9b.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat	e5x13d.dat
e5x14.dat	e5x18a.dat	e5x18b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat
e5x3d.dat	e5x3e.dat	e5x3f.dat	e6x10.dat	e6x11.dat	e6x12.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

GEOMETRY (Continued)					
e6x13.dat	e6x13b.dat	e6x15.dat	e6x15b.dat	e6x18.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat
e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x5.dat	e6x6a.dat
e6x6b.dat	e6x9.dat	e7x10.dat	e7x11.dat	e7x12.dat	e7x13b.dat
e7x13c.dat	e7x13d.dat	e7x17a.dat	e7x17b.dat	e7x19.dat	e7x19b.dat
e7x21.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x29a.dat	e7x29b.dat
e7x3.dat	e7x3b.dat	e8x10.dat	e8x11.dat	e8x12.dat	e8x12b.dat
e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat	e8x13b.dat
e8x13c.dat	—	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat
e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x16.dat
e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat
e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1a.dat	e8x25.dat	e8x26.dat
e8x27.dat	e8x36.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat
e8x39.dat	e8x4.dat	e8x41.dat	e8x44.dat	e8x44b.dat	e8x44c.dat
e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat
e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat
e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat
e8x6.dat	e8x7.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat
e10x4a.dat	e10x4b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat
HYPOELASTIC					
e7x29a.dat	e8x10.dat				
INIT STRESS					
e3x34.dat	e8x34.dat	e8x35.dat			
INITIAL PC					
e8x34.dat	e8x35.dat				

Table 1-2 Model Definition Option Cross-reference (Continued)

		INITIAL STATE			
e2x41.dat	e2x51a.dat	e2x51b.dat	e3x22c.dat	e3x22d.dat	e3x24b.dat
e3x24c.dat	e3x5.dat	e7x7.dat	e8x45.dat		
		INITIAL TEMP			
e2x46d.dat	e3x22a.dat	e3x24a.dat	e5x11a.dat	e5x13a.dat	e5x13b.dat
e5x13c.dat	e5x13d.dat	e5x14.dat	e5x16a.dat	e5x16b.dat	e5x16c.dat
e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat	e5x2a.dat	e5x2b.dat
e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat	e5x3f.dat
e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat	e5x5b.dat
e5x6.dat	e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat
e5x9b.dat	e5x9d.dat	e5x9e.dat	e7x1b.dat	e7x1c.dat	e8x13.dat
e8x13b.dat	e8x13c.dat	—	e8x7.dat		
		INITIAL VEL			
e2x71b.dat	e6x13.dat	e6x13b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat
e6x17a.dat	e6x17b.dat	e6x19.dat	e6x9.dat	e9x10a.dat	e9x10b.dat
e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat
e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat
e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat
e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat		
		INITIAL VOID RATIO			
e8x34.dat	e8x35.dat				
		ISOTROPIC			
e2x1.dat	e2x10.dat	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x20.dat	e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat
e2x25b.dat	e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat
e2x28.dat	e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

ISOTROPIC (Continued)					
e2x31a.dat	e2x31b.dat	e2x32.dat	e2x33.dat	e2x33b.dat	e2x34.dat
e2x35.dat	e2x35a.dat	e2x36.dat	e2x37.dat	e2x37b.dat	e2x38.dat
e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x42.dat
e2x43.dat	e2x44.dat	e2x45.dat	e2x46a.dat	e2x46b.dat	e2x46c.dat
e2x46d.dat	e2x47b.dat	e2x48.dat	e2x49.dat	e2x5.dat	e2x50.dat
e2x51a.dat	e2x51b.dat	e2x52.dat	e2x53.dat	e2x54.dat	e2x55.dat
e2x56.dat	e2x57a.dat	e2x57b.dat	e2x58a.dat	e2x58b.dat	e2x59a.dat
e2x59b.dat	e2x6.dat	e2x60a.dat	e2x60b.dat	e2x61a.dat	e2x61b.dat
e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66a.dat	e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x69.dat
e2x7.dat	e2x70.dat	e2x71a.dat	e2x71b.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e2x9.dat
e2x9b.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat	e3x11.dat
e3x12.dat	e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat
e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat
e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat
e3x21e.dat	e3x21f.dat	e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat
e3x23b.dat	e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x26.dat	e3x27.dat
e3x28.dat	e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat
e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat
e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat	e4x10.dat
e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat
e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat
e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat
e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat
e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

ISOTROPIC (Continued)					
e4x7c.dat	e4x8.dat	e4x9.dat	e4x9b.dat	e5x1.dat	e5x10.dat
e5x11a.dat	e5x12.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat	e5x13d.dat
e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat	e5x16b.dat	e5x16c.dat
e5x17a.dat	e5x17b.dat	e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat
e5x3c.dat	e5x3d.dat	e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat
e5x4c.dat	e5x4d.dat	e5x5a.dat	e5x5b.dat	e5x6.dat	e5x7b.dat
e5x8a.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat
e5x9d.dat	e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat
e6x13b.dat	e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat
e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat
e6x1b.dat	e6x1c.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x3a.dat
e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat	e6x6a.dat
e6x6b.dat	e6x7.dat	e6x9.dat	e7x1.dat	e7x10.dat	e7x11.dat
e7x12.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat	e7x14.dat	e7x15.dat
e7x16.dat	e7x17a.dat	e7x17b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat
e7x26.dat	e7x3.dat	e7x32.dat	e7x3b.dat	e7x8a.dat	e7x8b.dat
e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat	e8x11.dat	e8x12.dat
e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat
e8x13b.dat	e8x13c.dat	—	e8x14a.dat	e8x14b.dat	e8x14c.dat
e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat
e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat
e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1a.dat
e8x2.dat	e8x20.dat	e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat
e8x24a.dat	e8x25.dat	e8x26.dat	e8x28.dat	e8x29.dat	e8x3.dat
e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat
e8x36.dat	e8x37.dat	e8x38a.da	e8x38b.dat	—	e8x38c.dat
e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat	e8x42.dat	e8x44.dat
e8x44b.dat	e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

ISOTROPIC (Continued)					
e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat
e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat
e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat
e8x6.dat	e8x60.dat	e8x7.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat
e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat
e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat
e9x1e.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat	e9x3b.dat
e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat	e9x5e.dat
e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat
e9x9a.dat	e9x9b.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat
e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat
e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat		
J-INTEGRAL					
e2x22.dat	e2x30.dat	e2x45.dat	e3x8.dat		
JOULE					
e5x10.dat	e5x12.dat				
LORENZI					
e2x63a.dat	e2x63b.dat	e6x14.dat			
MASSES					
e6x10.dat	e6x9.dat	e10x1a.dat	e10x1b.dat	e10x7a.dat	e10x7b.dat
MOONEY					
e4x14a.dat	e4x14b.dat	e6x7.dat	e6x8.dat	e7x18.dat	e7x19.dat
e7x28b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat
e8x43.dat	e8x43b.dat	e8x43c.dat	e8x49.dat		

Table 1-2 Model Definition Option Cross-reference (Continued)

			NO PRINT		
e2x40a.dat	e2x40b.dat	e2x41.dat	e2x68.dat	e2x72.dat	e2x73.dat
e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x9c.dat	e3x27.dat
e3x28.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x35.dat
e3x6.dat	e4x11.dat	e4x2.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat
e5x15b.dat	e5x16a.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat
e6x14.dat	e7x1b.dat	e7x1c.dat	e7x20.dat	e7x20b.dat	e7x20c.dat
e7x20d.dat	e7x21.dat	e7x23.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat
e7x31b.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x14a.dat
e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat
e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x18b.dat	e8x18d.dat	e8x19b.dat
e8x37.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat	e8x40.dat
e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat
e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat
e8x54.dat	e8x58.dat	e8x60.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat
e9x1d.dat	e9x1e.dat	e10x6a.dat	e10x6b.dat		
			NODAL THICKNESS		
e8x9.dat					
			NODE CIRCLE		
e2x48.dat	e2x49.dat	e2x50.dat			
			NODE FILL		
e2x25.dat	e2x25b.dat	e2x33.dat	e2x33b.dat	e2x34.dat	e2x43.dat
e2x66a.dat	e3x20.dat	e4x4.dat	e4x4b.dat	e6x18.dat	e7x16.dat
e7x28c.dat	e7x28d.dat	e7x5.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e10x5a.dat	e10x5b.dat				
			NODE SORT		
e2x9b.dat					

Table 1-2 Model Definition Option Cross-reference (Continued)

OGDEN					
e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat
e7x22b.dat	e7x22c.dat	e7x27.dat	e7x28a.dat	e7x28c.dat	e7x28d.dat
e7x29b.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat	
OPTIMIZE					
e2x10b.dat	e2x10c.dat	e2x26c.dat	e2x26d.dat	e2x2b.dat	e2x31a.dat
e2x31b.dat	e2x34.dat	e2x35.dat	e2x35a.dat	e2x37.dat	e2x38.dat
e2x40a.dat	e2x40b.dat	e2x41.dat	e2x45.dat	e2x46d.dat	e2x51a.dat
e2x51b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x70.dat	e2x72.dat
e2x73.dat	e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x9c.dat
e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x34.dat	e3x35.dat	e3x6.dat
e3x9.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat
e4x15.dat	e4x2.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x5.dat
e5x15b.dat	e5x16c.dat	e5x18a.dat	e5x18b.dat	e5x8a.dat	e5x8c.dat
e5x8d.dat	e5x8e.dat	e6x21.dat	e7x2.dat	e7x20.dat	e7x20b.dat
e7x20d.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat	e7x26.dat
e7x30a.dat	e7x30b.dat	e7x32.dat	e8x15b.dat	e8x30.dat	e8x30b.dat
e8x31.dat	e8x32.dat	e8x36.dat	e8x37.dat	e8x45.dat	e8x46.dat
e8x47.dat	e8x49.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e10x4a.dat
e10x4b.dat	e10x6a.dat	e10x6b.dat			
ORIENTATION					
e2x41.dat	e5x18a.dat	e5x18b.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat
e7x25.dat	e7x6.dat	e7x6b.dat	e7x7.dat	e8x27.dat	e8x5a.dat
e8x5b.dat	e8x9.dat	e10x5a.dat	e10x5b.dat		
ORTHOTROPIC					
e2x70.dat	e5x18a.dat	e5x18b.dat	e7x24a.dat	e7x24b.dat	e7x24c.dat
e7x25.dat	e7x6.dat	e7x7.dat	e8x24b.dat	e8x27.dat	e8x5a.dat
e8x5b.dat	e8x8a.dat	e8x8b.dat	e8x9.dat	e10x5a.dat	e10x5b.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

PARAMETERS					
e2x18.dat	e3x14a.dat	e3x23.dat	e3x23b.dat	e4x5.dat	e7x3.dat
e7x32.dat	e8x18.dat	e8x18d.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat
PHI-COEFFICIENTS					
e6x7.dat	e6x8.dat				
POINT CHARGE					
e8x20.dat	e8x21.dat	e8x28.dat			
POINT CURRENT					
e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat	e8x29.dat
POINT LOAD					
e2x10.dat	e2x10b.dat	e2x10c.dat	e2x14.dat	e2x14b.dat	e2x20.dat
e2x21.dat	e2x24.dat	e2x27.dat	e2x28.dat	e2x29.dat	e2x36.dat
e2x42.dat	e2x48.dat	e2x50.dat	e2x52.dat	e2x54.dat	e2x57a.dat
e2x57b.dat	e2x59a.dat	e2x59b.dat	e2x61a.dat	e2x61b.dat	e2x65.dat
e2x66a.dat	e2x66b.dat	e2x67a.dat	e2x67b.dat	e2x68.dat	e2x7.dat
e2x70.dat	e2x75.dat	e2x76.dat	e2x77.dat	e2x8.dat	e3x1.dat
e3x11.dat	e3x22c.dat	e3x22d.dat	e3x2a.dat	e3x2b.dat	e3x35.dat
e3x4.dat	e4x10.dat	e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat
e4x12c.dat	e4x12d.dat	e4x15.dat	e4x1a.dat	e4x1c.dat	e4x1d.dat
e4x20.dat	e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat
e4x7.dat	e4x7b.dat	e4x7c.dat	e6x11.dat	e6x12.dat	e6x3c.dat
e6x6a.dat	e6x6b.dat	e7x10.dat	e7x11.dat	e7x13b.dat	e7x13c.dat
e7x13d.dat	e7x2.dat	e7x27.dat	e8x39.dat	e8x40.dat	e8x55a.dat
e8x55b.dat	e8x56b.dat	e8x57a.dat	e8x57b.dat	e8x57c.dat	e8x57d.dat
e8x5a.dat	e8x5b.dat	e8x6.dat	e8x9.dat	e10x1a.dat	e10x1b.dat
e10x2a.dat	e10x2b.dat	e10x4a.dat	e10x4b.dat	e10x7a.dat	e10x7b.dat
POINT SOURCE					
e8x25.dat					

Table 1-2 Model Definition Option Cross-reference (Continued)

POINT TEMP

e2x46d.dat

POST

e2x1.dat	e2x10.da	e2x10b.dat	e2x10c.dat	e2x11.dat	e2x12b.dat
e2x12c.dat	e2x12d.dat	e2x12e.dat	e2x13.dat	e2x14.dat	e2x14b.dat
e2x15.dat	e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x2.dat
e2x21.dat	e2x22.dat	e2x23.dat	e2x24.dat	e2x25.dat	e2x25b.dat
e2x26.dat	e2x26b.dat	e2x26c.dat	e2x26d.dat	e2x27.dat	e2x28.dat
e2x29.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x30.dat	e2x31a.dat
e2x31b.dat	e2x32.dat	e2x33.dat	e2x34.dat	e2x35.dat	e2x36.dat
e2x37.dat	e2x38.dat	e2x39.dat	e2x4.dat	e2x40a.dat	e2x40b.dat
e2x41.dat	e2x42.dat	e2x43.dat	e2x44.dat	e2x45.dat	e2x46a.dat
e2x46b.dat	e2x46c.dat	e2x46d.dat	e2x47b.dat	e2x48.dat	e2x49.dat
e2x5.dat	e2x50.dat	e2x51a.dat	e2x51b.dat	e2x52.dat	e2x53.dat
e2x54.dat	e2x55.dat	e2x56.dat	e2x57a.dat	e2x57b.dat	e2x58a.dat
e2x58b.dat	e2x59a.dat	e2x59b.dat	e2x6.dat	e2x60a.dat	e2x60b.dat
e2x61a.dat	e2x61b.dat	e2x62.dat	e2x63a.dat	e2x63b.dat	e2x64a.dat
e2x64b.dat	e2x65.dat	e2x66a.dat	e2x66b.da	e2x67a.dat	e2x67b.dat
e2x68.dat	e2x69.dat	e2x7.dat	e2x70.dat	e2x71a.dat	e2x71b.dat
e2x72.dat	e2x73.dat	e2x74.dat	e2x75.dat	e2x76.dat	e2x77.dat
e2x8.dat	e2x9.dat	e2x9c.dat	e2x9d.dat	e3x1.dat	e3x10.dat
e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat	e3x16.dat
e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat
e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat
e3x21f.dat	e3x22a.dat	e3x23.dat	e3x23b.dat	e3x24a.dat	e3x25.dat
e3x26.dat	e3x27.dat	e3x28.dat	e3x29.dat	e3x2a.dat	e3x3.dat
e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x33.dat	e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

POST (Continued)					
e3x37b.dat	e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat
e3x6.dat	e3x8.dat	e3x9.dat	e4x10.dat	e4x10b.dat	e4x11.dat
e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat	e4x13a.dat	e4x13b.dat
e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat	e4x1a.dat	e4x1b.dat
e4x1c.dat	e4x1d.dat	e4x2.dat	e4x2a.dat	e4x2b.dat	e4x2c.dat
e4x2d.dat	e4x2e.dat	e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat
e4x6.dat	e4x7.dat	e4x7b.dat	e4x7c.dat	e4x8.dat	e4x9.dat
e4x9b.dat	e5x11a.dat	e5x11c.dat	e5x12.dat	e5x13a.dat	e5x13b.dat
e5x13c.dat	e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat
e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat
e5x2a.dat	e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat
e5x3e.dat	e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat
e5x5a.dat	e5x5b.dat	e5x6.dat	e5x8a.dat	e5x8c.dat	e5x8d.dat
e5x8e.dat	e5x9a.dat	e5x9b.dat	e5x9d.dat	e5x9e.dat	e6x10.dat
e6x11.dat	e6x12.dat	e6x13.dat	e6x13b.dat	e6x15.dat	e6x16a.dat
e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat
e6x1a.dat	e6x2.dat	e6x20a.dat	e6x20b.dat	e6x21.dat	e6x3a.dat
e6x5.dat	e6x6a.dat	e6x7.dat	e6x9.dat	e7x1.dat	e7x10.dat
e7x11.dat	e7x12.dat	e7x13b.dat	e7x13c.dat	e7x14.dat	e7x15.dat
e7x16.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x19.dat	e7x19b.dat
e7x1b.dat	e7x1c.dat	e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat
e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat
e7x24a.dat	e7x24b.dat	e7x24c.dat	e7x25.dat	e7x26.dat	e7x27.dat
e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x29a.dat	e7x29b.dat
e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat	e7x32.dat
e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat
e7x6.dat	e7x6b.dat	e7x7.dat	e7x8a.dat	e8x11.dat	e8x12.dat
e8x12b.dat	e8x12c.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

POST (Continued)					
e8x13b.dat	e8x13c.dat	—	e8x14a.dat	e8x14b.dat	e8x14c.dat
e8x14d.dat	e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat
e8x15d.dat	e8x16.dat	e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat
e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x19.dat	e8x19b.dat	e8x20.dat
e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat
e8x25.dat	e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x30.dat
e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat	e8x34.dat
e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat	—
e8x38c.dat	e8x39.dat	e8x4.dat	e8x40.dat	e8x41.dat	e8x42.dat
e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat
e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat
e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat
e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat	e8x57b.dat
e8x57c.dat	e8x57d.dat	e8x58.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e8x60.dat	e8x7.dat	e8x8a.dat	e8x8b.dat	e8x9.dat	e9x10a.dat
e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat
e9x12b.dat	e9x12c.dat	e9x13a.dat	e9x13b.dat	e9x1a.dat	e9x1b.dat
e9x1c.dat	e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat
e9x3a.dat	e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat
e9x5d.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.da	e9x7b.dat
e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat	e10x1a.dat	e10x1b.dat
e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat
e10x5a.dat	e10x5b.dat	e10x6a.dat	e10x6b.dat	e10x7a.dat	e10x7b.dat
POWDER					
e3x25.dat	e3x26.dat				

Table 1-2 Model Definition Option Cross-reference (Continued)

PRINT CHOICE					
e2x22.dat	e2x38.dat	e2x42.dat	e2x43.dat	e2x60a.dat	e2x60b.dat
e2x61a.dat	e2x61b.dat	e2x62.dat	e2x63a.dat	e2x63b.dat	e2x9b.dat
e3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat	e3x12b.dat	e3x13.dat
e3x15.dat	e3x15b.dat	e3x16.dat	e3x16b.dat	e3x17.dat	e3x18.dat
e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat
e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x24a.dat	e3x24b.dat
e3x24c.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat	e3x30b.dat
e3x33.dat	e3x33b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x7a.dat
e3x7b.dat	e3x7c.dat	e3x8.dat	e4x15.dat	e4x1b.dat	e4x1c.dat
e4x2a.dat	e4x2b.dat	e4x4.dat	e4x4b.dat	e4x7.dat	e4x7b.dat
e4x7c.dat	e5x11a.dat	e5x11c.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat
e5x13d.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x9b.dat
e6x13.dat	e6x13b.dat	e6x1a.dat	e6x1b.dat	e6x1c.dat	e6x7.dat
e6x8.dat	e6x9.dat	e7x11.dat	e7x12.dat	e7x14.dat	e7x17a.dat
e7x17b.dat	e7x18.dat	e7x19.dat	e7x19b.dat	e7x3.dat	e7x3b.dat
e8x12.dat	e8x12b.dat	e8x12c.dat	e8x12e.dat	e8x12r.dat	e8x16.dat
e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat	e8x18c.dat	e8x19.dat
e8x31.dat	e8x4.dat	e8x57a.dat	e8x57c.dat	e8x57d.dat	e8x5a.dat
e8x5b.dat	e8x7.dat				
PRINT ELEMENT					
e2x46d.dat	e2x69.dat	e2x70.dat	e3x26.dat	e6x16a.dat	e6x16b.dat
e6x16c.dat	e6x17a.dat	e6x17b.dat	e6x19.dat	e7x24a.dat	e7x24b.dat
e7x24c.dat	e7x6.dat	e7x6b.dat	e7x7.dat	e8x24a.dat	e8x25.dat
e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x33a.dat	e8x33b.dat
e8x35.dat	e8x39.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat
e8x9.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat
e9x13a.dat	e9x13b.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

PRINT ELEMENT (Continued)					
e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat
e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat
e9x9a.dat	e9x9b.dat				
PRINT NODE					
e2x2b.dat	e2x2c.dat	e2x46d.dat	e2x70.dat	e6x19.dat	e8x11.dat
e8x25.dat	e8x26.dat	e8x35.dat	e8x39.dat	e8x55a.dat	e8x55b.dat
RADIATING CAVITY					
e5x15.dat					
REAUTO					
e7x17b.dat	e7x31b.dat	e8x12r.dat			
REBAR					
e2x14b.dat	e2x37b.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat
e4x14b.dat					
REGION					
e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat
e9x12c.dat	e9x13a.dat	e9x13b.dat			
RELATIVE DENSITY					
e3x25.dat	e3x26.dat				
RESPONSE SPECTRUM					
e6x6a.dat	e6x6b.dat				
RESTART					
e2x35.dat	e2x35a.dat	e2x51a.dat	e2x51b.dat	e3x11.dat	e3x13.dat
e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat	e3x20.dat
e3x21c.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat	e3x26.dat
e3x27.dat	e3x28.dat	e3x2a.dat	e3x2b.dat	e3x7a.dat	e3x7b.dat
e3x7c.dat	e3x8.dat	e4x3.dat	e4x5.dat	e4x7.dat	e5x11c.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

RESTART (Continued)					
e5x8a.dat	e5x8b.dat	e5x8c.dat	e5x8d.dat	e5x8e.dat	e6x13.dat
e6x13b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat	e6x17b.dat
e6x6a.dat	e6x6b.dat	e6x8.dat	e7x11.dat	e7x13b.dat	e7x13c.dat
e7x13d.dat	e7x17a.dat	e7x17b.dat	e7x18.dat	e7x3.dat	e7x31a.dat
e7x31b.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x8a.dat	e7x8b.dat
e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat	e8x12.dat	e8x12b.dat
e8x12r.dat	e8x1b.dat	e8x1c.dat	e8x35.dat	e8x36.dat	e8x42.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e8x60.dat	e8x7.dat				
RESTART LAST					
e3x31.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x17.dat
e8x17b.dat					
ROTATION A					
e2x33.dat	e2x33b.dat	e2x49.dat	e2x71a.dat	e2x71b.dat	e6x4.dat
SHELL TRANSFORMATION					
e3x1.dat	e3x20.dat				
SHIFT FUNCTION					
e7x32.dat					
SOIL					
e8x34.dat	e8x35.dat				
SOLVER					
e2x12c.dat	e2x12e.dat	e2x40a.dat	e2x40b.dat	e2x41.dat	e2x46d.dat
e2x68.dat	e2x72.dat	e2x73.dat	e2x74.dat	e2x75.dat	e2x76.dat
e2x77.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x34.dat	e3x35.dat
e3x6.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat
e4x15.dat	e4x2.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e5x15b.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

SOLVER (Continued)					
e5x18a.dat	e5x18b.dat	e6x21.dat	e7x23.dat	e7x30a.dat	e7x30b.dat
e7x31a.dat	e7x31b.dat	e7x32.dat	e8x35.dat	e8x38b.dat	—
e8x38c.dat	e8x40.dat	e8x42.dat	e8x45.dat	e8x46.dat	e8x47.dat
e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat
e8x53a.dat	e8x53b.dat	e8x54.dat	e8x56a.dat	e8x56b.dat	e8x57a.dat
e8x57b.dat	e8x57c.dat	e8x57d.dat	e8x60.dat	e10x4a.dat	e10x4b.dat
e10x6a.dat	e10x6b.dat				
SPLINE					
e8x45.dat					
SPRINGS					
e2x54.dat	e3x13.dat	e4x6.dat	e8x16.dat	e8x16b.dat	e8x36.dat
e8x37.dat	e8x47.dat	e8x48.dat			
STIFSCALE					
e2x33b.dat					
STRAIN RATE					
e9x9a.dat	e9x9b.dat				
SUBSTRUCTURE					
e8x1a.dat	e8x2.dat	e8x3.dat			
SUMMARY					
e2x9b.dat					
SUPERINPUT					
e8x1b.dat	e8x1c.dat				
SURFACE					
e2x9d.dat	e7x20c.dat	e8x40.dat	e8x42.dat		

Table 1-2 Model Definition Option Cross-reference (Continued)

TEMPERATURE EFFECTS					
e3x26.dat	e3x5.dat	e5x11a.dat	e5x14.dat	e5x15.dat	e5x8a.dat
e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat	e5x9d.dat
e5x9e.dat	e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x7.dat
THERMAL LOADS					
e2x46a.dat	e2x46b.dat	e2x49.dat	e3x13.dat	e3x5.dat	
THICKNESS					
e7x15.dat	e7x16.dat				
TIME-TEMP					
e5x11c.dat					
TRANSFORMATION					
e2x2.dat	e2x23.dat	e2x2b.dat	e2x2c.dat	e2x3.dat	e2x4.dat
e2x47b.dat	e3x16.dat	e3x16b.dat	e3x5.dat	e4x1a.dat	e4x1b.dat
e4x1c.dat	e4x1d.dat	e4x7.dat	e4x7c.dat		
TYING					
e2x15.dat	e2x28.dat	e2x3.dat	e2x4.dat	e2x43.dat	e2x44.dat
e2x47b.dat	e2x52.dat	e2x53.dat	e2x65.dat	e2x70.dat	e3x1.dat
e3x18.dat	e3x22c.dat	e3x22d.dat	e4x15.dat	e6x10.dat	e6x7.dat
e7x12.dat	e7x13b.dat	e7x13c.dat	e7x15.dat	e7x16.dat	e7x18.dat
e7x19.dat	e7x19b.dat	e7x25.dat	e7x27.dat	e7x4.dat	e7x4b.dat
e8x4.dat	e10x1a.dat	e10x1b.dat	e10x7a.dat	e10x7b.dat	
UDUMP					
e3x19.dat	e3x19b.dat	e3x19c.dat	e3x21a.dat	e3x21d.dat	e3x21e.dat
e3x21f.dat	e3x3.dat	e3x3b.dat	e4x7.dat	e5x3a.dat	e5x4a.dat
e5x9a.dat	e6x5.dat	e8x19.dat	e8x19b.dat		
UFCONN					
e2x20.dat	e2x27.dat	e2x34.dat	e2x46a.dat	e2x46b.dat	e7x15.dat

Table 1-2 Model Definition Option Cross-reference (Continued)

UFXORD					
e2x16.dat	e2x17.dat	e2x18.dat	e2x19.dat	e2x20.dat	e2x55.dat
e2x56.dat	e3x16.dat	e3x16b.dat	e3x17.dat	e3x23.dat	e3x23b.dat
e3x27.dat	e3x5.dat	e4x1a.dat	e4x1b.dat	e4x1d.dat	e4x5.dat
e4x7.dat	e4x7c.dat	e6x3b.dat	e6x3d.dat	e7x15.dat	e7x3.dat
e7x3b.dat					
UMOTION					
e8x19.dat	e8x19b.dat				
UTRANFORM					
e2x62.dat	e4x14a.dat	e4x14b.dat			
VELOCITY					
e5x17a.dat	e5x17b.dat	e7x15.dat	e7x16.dat		
VIEW FACTOR					
e5x15b.dat					
VISCEL EXP					
e7x32.dat					
VISCELMOON					
e7x18.dat					
VISCELOGDEN					
e7x22c.dat					
VISCELPROP					
e7x12.dat	e7x14.dat	e7x32.dat			
VOLTAGE					
e5x10.dat	e5x12.dat				

Table 1-2 Model Definition Option Cross-reference (Continued)

		WORK HARD			
e3x1.dat	e3x10.dat	e3x11.dat	e3x16.dat	e3x16b.dat	e3x18.dat
e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat	e3x20.dat	e3x21a.dat
e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x21f.dat	e3x26.dat	e3x27.dat
e3x28.dat	e3x2a.dat	e3x2b.dat	e3x30a.dat	e3x30b.dat	e3x33.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x38a.dat	e3x38b.dat
e3x4.dat	e3x5.dat	e3x8.dat	e7x17a.dat	e7x17b.dat	e8x12d.dat
e8x13.dat	e8x13b.dat	e8x13c.dat	—	e8x15.dat	e8x15b.dat
e8x15c.dat	e8x15d.dat	e8x16.dat	e8x16b.dat	e8x18.dat	e8x18b.dat
e8x18c.dat	e8x18d.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x50.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x60.dat
e8x7.dat	e9x13a.dat				

Table 1-3 History Definition Option Cross-reference

ACCUMULATE					
e3x15.dat					
ACTIVATE					
e8x11.dat					
AUTO CREEP					
e3x12.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x22c.dat	e3x22d.dat
e3x29.dat					
AUTO INCREMENT					
e3x23.dat	e3x23b.dat	e3x6.dat	e4x1c.dat	e4x7.dat	e4x7b.dat
e7x3.dat	e7x30a.dat	e7x30b.dat	e8x39.dat	e8x5a.dat	e8x5b.dat
e8x6.dat					
AUTO LOAD					
e2x65.dat	e2x70.dat	e3x1.dat	e3x10.dat	e3x15b.dat	e3x16.dat
e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat
e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat
e3x25.dat	e3x27.dat	e3x28.dat	e3x2a.dat	e3x2b.dat	e3x3.dat
e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x7a.dat	e3x7b.dat
e3x8.dat	e3x9.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat
e4x12d.dat	e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat
e4x1b.dat	e4x2.dat	e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat
e4x2e.dat	e4x3.dat	e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat
e4x8.dat	e6x21.dat	e6x3c.dat	e7x1.dat	e7x11.dat	e7x12.dat
e7x13b.dat	e7x13c.dat	e7x14.dat	e7x17a.dat	e7x17b.dat	e7x18.dat
e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat	e7x2.dat	e7x20.dat
e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat	e7x22a.dat	e7x22b.dat

Table 1-3 History Definition Option Cross-reference

AUTO LOAD (Continued)					
e7x22c.dat	e7x23.dat	e7x25.dat	e7x27.dat	e7x29a.dat	e7x29b.dat
e7x31a.dat	e7x31b.dat	e7x32.dat	e7x4.dat	e8x12.dat	e8x12c.dat
e8x12r.dat	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat
e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x16.dat	e8x16b.dat
e8x17.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x19.dat	e8x19b.dat
e8x2.dat	e8x27.dat	e8x3.dat	e8x34.dat	e8x35.dat	e8x36.dat
e8x37.dat	e8x38a.dat	e8x38b.dat	—	e8x38c.dat	e8x4.dat
e8x42.dat	e8x43.dat	e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat
e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat
e8x54.dat	e8x55a.dat	e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x60.dat
e9x13a.dat	e9x13b.dat				
AUTO STEP					
e3x12b.dat	e3x21f.dat	e3x33.dat	e4x7c.dat	e5x8e.dat	e7x3b.dat
e7x4b.dat	e8x12d.dat	e8x12e.dat	e8x13b.dat	e8x15d.dat	e8x16b.dat
e8x17b.dat	e8x18d.dat				
AUTO THERM					
e3x11.dat	e3x22c.dat	e3x24b.dat	e3x24c.dat	e3x5.dat	e5x11c.dat
AUTO TIME					
e6x13.dat	e6x13b.dat	e6x1c.dat	e8x12b.dat		
BACKTOSUBS					
e8x1c.dat	e8x3.dat				
BUCKLE					
e3x16.dat	e3x16b.dat	e4x10.dat	e4x10b.dat	e4x12a.dat	e4x12b.dat
e4x15.dat	e4x1a.dat	e4x1d.dat	e4x4.dat	e4x4b.dat	e4x9.dat
e4x9b.dat					

Table 1-3 History Definition Option Cross-reference

CHANGE STATE					
e2x70.dat	e3x11.dat	e3x22c.dat	e3x22d.dat	e3x24b.dat	e3x24c.dat
e3x5.dat	e5x11c.dat	e7x32.dat	e8x45.dat		
COMMENT					
e8x12.dat	e8x12r.dat	e8x52.dat			
CONTACT TABLE					
e7x31b.dat	e8x16b.dat	e8x36.dat	e8x37.dat	e8x44.dat	e8x44b.dat
e8x44c.dat	e8x46.dat				
CONTINUE					
e2x35.dat	e2x38.dat	e2x51a.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66b.dat	e2x70.dat	3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat
e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat	e3x16.dat
e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat
e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat
e3x21f.dat	e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat
e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat
e3x28.dat	e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat
e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat
e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat	e4x10.dat
e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat
e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat
e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat
e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat
e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat
e4x7c.dat	e4x8.dat	e4x9.dat	e4x9b.dat	e5x1.dat	e5x10.dat
e5x11a.dat	e5x11c.dat	e5x12.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat

Table 1-3 History Definition Option Cross-reference

CONTINUE (Continued)					
e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat	e5x16b.dat
e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat	e5x2a.dat
e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat
e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat
e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8b.dat
e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat	e5x9d.dat
e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat	e6x13b.dat
e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat
e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat	e6x1b.dat
e6x1c.dat	e6x2.dat	e6x20b.dat	e6x21.dat	e6x3a.dat	e6x3b.dat
e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat	e6x6a.dat	e6x6b.dat
e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat	e7x11.dat	e7x12.dat
e7x13b.dat	e7x13c.dat	e7x13d.dat	e7x14.dat	e7x16.dat	e7x17a.dat
e7x17b.dat	e7x18.dat	e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat
e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat
e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat	e7x25.dat	e7x26.dat
e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x29a.dat
e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat
e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat
e7x5c.dat	e8x10.dat	e8x11.dat	e8x12.dat	e8x12b.dat	e8x12c.dat
e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat
—	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat
e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat
e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat
e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1c.dat	e8x2.dat	e8x20.dat
e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat
e8x25.dat	e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x3.dat
e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat

Table 1-3 History Definition Option Cross-reference

CONTINUE (Continued)					
e8x34.dat	e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x42.dat	e8x43.dat
e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat
e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat
e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat
e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e8x60.dat	e8x7.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat
e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat
e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat
e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat
e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat
e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat
e9x9b.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat
e10x3b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat
e10x6b.dat	e10x7a.dat	e10x7b.dat			
CONTROL					
e3x26.dat	e3x29.dat	e3x34.dat	e3x6.dat	e4x11.dat	e4x14b.dat
e4x2.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e5x15b.dat	e5x18a.dat
e5x18b.dat	e6x21.dat	e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x27.dat
e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x30a.dat	e7x30b.dat
e7x31a.dat	e7x31b.dat	e7x32.dat	e7x5.dat	e7x5b.dat	e7x5c.dat
e8x16b.dat	e8x3.dat	e8x35.dat	e8x43.dat	e8x43b.dat	e8x43c.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat	e8x46.dat	e8x47.dat
e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat	e8x52.dat
e8x53a.dat	e8x53b.dat	e8x54.dat	e8x60.dat		
CREEP INCREMENT					
e3x15.dat	e3x15b.dat				

Table 1-3 History Definition Option Cross-reference

DAMPING COMPONENTS					
e7x16.dat					
DEACTIVATE					
e8x11.dat					
DISP CHANGE					
e3x14a.dat	e3x18.dat	e3x20.dat	e3x21f.dat	e3x27.dat	e3x28.dat
e3x31.dat	e3x33.dat	e3x33b.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e4x10.dat	e4x10b.dat	e4x14a.dat	e4x14b.dat
e4x9.dat	e4x9b.dat	e6x21.dat	e6x7.dat	e6x8.dat	e7x18.dat
e7x19.dat	e7x19b.dat	e7x21.dat	e7x29a.dat	e7x29b.dat	e7x30a.dat
e7x30b.dat	e7x4b.dat	e8x10.dat	e8x12.dat	e8x12r.dat	e8x13.dat
e8x13b.dat	e8x13c.dat	—	e8x15d.dat	e8x16b.dat	e8x34.dat
e8x43.dat	e8x43b.dat	e8x43c.dat	e8x46.dat	e8x48.dat	e8x49.dat
e8x52.dat	e8x53b.dat	e8x54.dat	e8x56a.dat		
DIST CURRENT					
e8x30.dat	e8x32.dat				
DIST FLUXES					
e5x18a.dat	e5x18b.dat				
DIST LOADS					
e2x35.dat	e2x66b.dat	e3x12.dat	e3x12b.dat	e3x15.dat	e3x15b.dat
e3x23.dat	e3x23b.dat	e3x25.dat	e3x26.dat	e3x29.dat	e3x31.dat
e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x34.dat	e3x6.dat	e4x13a.dat
e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x2.dat	e4x2a.dat
e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x8.dat	e6x14.dat
e6x1a.dat	e6x1b.dat	e6x1c.dat	e6x20b.dat	e6x21.dat	e6x3a.dat
e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x4.dat	e7x12.dat	e7x14.dat
e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x22a.dat
e7x22b.dat	e7x22c.dat	e7x26.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat

Table 1-3 History Definition Option Cross-reference

DIST LOADS (Continued)					
e7x28d.dat	e7x3.dat	e7x3b.dat	e7x5.dat	e7x5b.dat	e7x5c.dat
e8x1a.dat	e8x34.dat	e8x35.dat	e8x42.dat	e8x43.dat	e8x43b.dat
e8x43c.dat	e8x46.dat	e8x47.dat	e8x48.dat	e8x53a.dat	e8x53b.dat
e10x2a.dat	e10x2b.dat	e10x3a.dat	e10x3b.dat		
DYNAMIC CHANGE					
e4x20.dat	e6x14.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat	e6x17a.dat
e6x17b.dat	e6x19.dat	e6x1a.dat	e6x1b.dat	e6x1c.dat	e6x20b.dat
e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat	e6x9.dat	e8x25.dat
e8x26.dat	e8x31.dat	e8x33b.dat			
EXTRAPOLATE					
e3x15.dat					
HARMONIC					
e6x7.dat	e6x8.dat	e8x30.dat	e8x30b.dat	e8x32.dat	e8x33a.dat
MODAL SHAPE					
e6x10.dat	e6x11.dat	e6x12.dat	e6x15.dat	e6x15b.dat	e6x18.dat
e6x2.dat	e6x21.dat	e6x3a.dat	e6x3b.dat	e6x3c.dat	e6x3d.dat
e6x4.dat	e6x5.dat	e6x6a.dat	e6x6b.dat	e8x25.dat	e8x26.dat
e10x1a.dat	e10x1b.dat	e10x3a.dat	e10x3b.dat	e10x4a.dat	e10x4b.dat
e10x7a.dat	e10x7b.dat				
MOTION CHANGE					
e3x30a.dat	e3x30b.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e7x20.dat
e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x31a.dat	e7x31b.dat	e8x16.dat
e8x16b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x18d.dat	e8x42.dat
e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat	e8x49.dat	e8x50.dat
e8x51a.dat	e8x51b.dat	e8x60.dat			

Table 1-3 History Definition Option Cross-reference

NO PRINT					
e3x31.dat	e7x25.dat				
POINT CURRENT					
e8x30b.dat	e8x33a.dat	e8x33b.dat			
POINT LOAD					
e2x64a.dat	e2x64b.dat	e2x65.dat	e2x66b.dat	e2x70.dat	e3x1.dat
e3x2b.dat	e3x35.dat	e3x38b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat
e4x12c.dat	e4x12d.dat	e4x1c.dat	e4x20.dat	e4x3.dat	e4x6.dat
e4x7.dat	e4x7b.dat	e4x7c.dat	e7x11.dat	e7x2.dat	e7x25.dat
e7x27.dat	e8x3.dat	e8x39.dat	e8x55a.dat	e8x55b.dat	e8x56b.dat
e8x5a.dat	e8x5b.dat	e8x6.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat
e10x2b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat
e10x6b.dat	e10x7a.dat	e10x7b.dat			
POINT SOURCE					
e8x25.dat					
POST INCREMENT					
e3x31.dat	e7x25.dat	e8x16.dat			
POTENTIAL CHANGE					
e8x31.dat					
PRINT CHOICE					
e3x14a.dat	e3x20.dat				
PRINT ELEMENT					
e7x25.dat					
PROPORTIONAL INCREMENT					
e2x38.dat	e2x70.dat	e3x1.dat	e3x10.dat	e3x11.dat	e3x16.dat
e3x16b.dat	e3x17.dat	e3x19.dat	e3x19b.dat	e3x19c.dat	e3x19d.dat
e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat	e3x22c.dat

Table 1-3 History Definition Option Cross-reference

PROPORTIONAL INCREMENT (Continued)					
e3x22d.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x34.dat	e3x35.dat
e3x3b.dat	e3x4.dat	e3x7a.dat	e3x7b.dat	e3x8.dat	e3x9.dat
e4x1a.dat	e4x1d.dat	e4x8.dat	e6x12.dat	e6x1c.dat	e6x3c.dat
e6x6a.dat	e6x7.dat	e6x8.dat	e7x11.dat	e7x13b.dat	e7x13c.dat
e7x25.dat	e7x4.dat	e8x2.dat	e8x27.dat	e8x4.dat	
RECOVER					
e3x16.dat	e3x16b.dat	e4x15.dat	e4x4.dat	e4x4b.dat	e6x10.dat
e6x15.dat	e6x18.dat	e6x2.dat	e6x21.dat	e6x5.dat	e6x6a.dat
e8x25.dat					
RELEASE					
e8x16.dat	e8x44.dat	e8x44b.dat	e8x44c.dat		
SPECTRUM					
e6x18.dat	e6x6a.dat	e6x6b.dat			
STEADY STATE					
e5x15.dat	e5x15b.dat	e5x18a.dat	e5x3a.dat	e8x20.dat	e8x21.dat
e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat	e8x28.dat
e8x29.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat
e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat
e9x1d.dat	e9x1e.dat	e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat
e9x3b.dat	e9x4.dat	e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat
e9x6a.dat	e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat
e9x9a.dat	e9x9b.dat				
STIFFNS COMPONENTS					
e7x16.dat					
TEMP CHANGE					
e5x15b.dat	e5x18a.dat	e5x18b.dat			

Table 1-3 History Definition Option Cross-reference

THERMAL LOADS					
e2x51a.dat	e3x13.dat				
THICKNS CHANGE					
e7x16.dat					
TIME STEP					
e3x25.dat	e3x30a.dat	e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat
e3x32c.dat	e3x34.dat	e3x36.dat	e4x11.dat	e4x2.dat	e4x2c.dat
e4x2d.dat	e4x2e.dat	e6x21.dat	e7x12.dat	e7x14.dat	e7x18.dat
e7x1b.dat	e7x1c.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat
e7x22c.dat	e7x23.dat	e7x31a.dat	e7x31b.dat	e7x32.dat	e8x12.dat
e8x12c.dat	e8x12r.dat	e8x14a.dat	e8x14b.dat	e8x14c.dat	e8x14d.dat
e8x14e.dat	e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x16.dat
e8x16b.dat	e8x17.dat	e8x18.dat	e8x18b.dat	e8x18c.dat	e8x19.dat
e8x19b.dat	e8x34.dat	e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat
e8x38b.dat	—	e8x38c.dat	e8x42.dat	e8x43.dat	e8x43b.dat
e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat	e8x46.dat
e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat	e8x51b.dat
e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat	e8x55b.dat
e8x56a.dat	e8x56b.dat	e8x60.dat	e9x13a.dat	e9x13b.dat	
TRANSIENT					
e3x22a.dat	e3x24a.dat	e5x1.dat	e5x10.dat	e5x11a.dat	e5x12.dat
e5x13a.dat	e5x13b.dat	e5x13c.dat	e5x13d.dat	e5x14.dat	e5x16a.dat
e5x16b.dat	e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18b.dat	e5x2a.dat
e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat
e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat
e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8c.dat
e5x8d.dat	e5x9a.dat	e5x9b.dat	e5x9d.dat	e5x9e.dat	e8x13.dat
e8x13c.dat	—	e8x7.dat	e9x11b.dat	e9x5e.dat	

Table 1-4 Rezone Option Cross-reference

COMMENT					
e8x12.dat	e8x12r.dat	e8x52.dat			
CONNECTIVITY CHANGE					
e7x31b.dat	e8x12.dat	e8x12r.dat	e8x2.dat	e8x3.dat	
CONTACT CHANGE					
e7x31b.dat	e8x12.dat	e8x12r.dat			
CONTINUE					
e2x35.dat	e2x38.dat	e2x51a.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e2x66b.dat	e2x70.dat	e3x1.dat	e3x10.dat	e3x11.dat	e3x12.dat
e3x12b.dat	e3x13.dat	e3x14a.dat	e3x15.dat	e3x15b.dat	e3x16.dat
e3x16b.dat	e3x17.dat	e3x18.dat	e3x19.dat	e3x19b.dat	e3x19c.dat
e3x19d.dat	e3x20.dat	e3x21a.dat	e3x21c.dat	e3x21d.dat	e3x21e.dat
e3x21f.dat	e3x22a.dat	e3x22c.dat	e3x22d.dat	e3x23.dat	e3x23b.dat
e3x24a.dat	e3x24b.dat	e3x24c.dat	e3x25.dat	e3x26.dat	e3x27.dat
e3x28.dat	e3x29.dat	e3x2a.dat	e3x2b.dat	e3x3.dat	e3x30a.dat
e3x30b.dat	e3x31.dat	e3x32a.dat	e3x32b.dat	e3x32c.dat	e3x33.dat
e3x33b.dat	e3x34.dat	e3x35.dat	e3x36.dat	e3x37a.dat	e3x37b.dat
e3x38a.dat	e3x38b.dat	e3x3b.dat	e3x4.dat	e3x5.dat	e3x6.dat
e3x7a.dat	e3x7b.dat	e3x7c.dat	e3x8.dat	e3x9.dat	e4x10.dat
e4x10b.dat	e4x11.dat	e4x12a.dat	e4x12b.dat	e4x12c.dat	e4x12d.dat
e4x13a.dat	e4x13b.dat	e4x13c.dat	e4x14a.dat	e4x14b.dat	e4x15.dat
e4x1a.dat	e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x2.dat	e4x20.dat
e4x2a.dat	e4x2b.dat	e4x2c.dat	e4x2d.dat	e4x2e.dat	e4x3.dat
e4x4.dat	e4x4b.dat	e4x5.dat	e4x6.dat	e4x7.dat	e4x7b.dat
e4x7c.dat	e4x8.dat	e4x9.dat	e4x9b.dat	e5x1.dat	e5x10.dat
e5x11a.dat	e5x11c.dat	e5x12.dat	e5x13a.dat	e5x13b.dat	e5x13c.dat
e5x13d.dat	e5x14.dat	e5x15.dat	e5x15b.dat	e5x16a.dat	e5x16b.dat
e5x16c.dat	e5x17a.dat	e5x17b.dat	e5x18a.dat	e5x18b.dat	e5x2a.dat

Table 1-4 Rezone Option Cross-reference (Continued)

CONTINUE (Continued)					
e5x2b.dat	e5x3a.dat	e5x3b.dat	e5x3c.dat	e5x3d.dat	e5x3e.dat
e5x3f.dat	e5x4a.dat	e5x4b.dat	e5x4c.dat	e5x4d.dat	e5x5a.dat
e5x5b.dat	e5x6.dat	e5x7a.dat	e5x7b.dat	e5x8a.dat	e5x8b.dat
e5x8c.dat	e5x8d.dat	e5x8e.dat	e5x9a.dat	e5x9b.dat	e5x9d.dat
e5x9e.dat	e6x10.dat	e6x11.dat	e6x12.dat	e6x13.dat	e6x13b.dat
e6x14.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x16c.dat
e6x17a.dat	e6x17b.dat	e6x18.dat	e6x19.dat	e6x1a.dat	e6x1b.dat
e6x1c.dat	e6x2.dat	e6x20b.dat	e6x21.dat	e6x3a.dat	e6x3b.dat
e6x3c.dat	e6x3d.dat	e6x4.dat	e6x5.dat	e6x6a.dat	e6x6b.dat
e6x7.dat	e6x8.dat	e6x9.dat	e7x1.dat	e7x11.dat	e7x12.dat
e7x13b.dat	e7x13c.dat	e7x13d.dat	e7x14.dat	e7x16.dat	e7x17a.dat
e7x17b.dat	e7x18.dat	e7x19.dat	e7x19b.dat	e7x1b.dat	e7x1c.dat
e7x2.dat	e7x20.dat	e7x20b.dat	e7x20c.dat	e7x20d.dat	e7x21.dat
e7x22a.dat	e7x22b.dat	e7x22c.dat	e7x23.dat	e7x25.dat	e7x26.dat
e7x27.dat	e7x28a.dat	e7x28b.dat	e7x28c.dat	e7x28d.dat	e7x29a.dat
e7x29b.dat	e7x3.dat	e7x30a.dat	e7x30b.dat	e7x31a.dat	e7x31b.dat
e7x32.dat	e7x3b.dat	e7x4.dat	e7x4b.dat	e7x5.dat	e7x5b.dat
e7x5c.dat	e8x10.dat	e8x11.dat	e8x12.dat	e8x12b.dat	e8x12c.dat
e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat	e8x13b.dat	e8x13c.dat
—	e8x14a.da	e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat
e8x14f.dat	e8x15.dat	e8x15b.dat	e8x15c.dat	e8x15d.dat	e8x16.dat
e8x16b.dat	e8x17.dat	e8x17b.dat	e8x18.dat	e8x18b.dat	e8x18c.dat
e8x18d.dat	e8x19.dat	e8x19b.dat	e8x1c.dat	e8x2.dat	e8x20.dat
e8x21.dat	e8x22.dat	e8x23.dat	e8x23b.dat	e8x24a.dat	e8x24b.dat
e8x25.dat	e8x26.dat	e8x27.dat	e8x28.dat	e8x29.dat	e8x3.dat
e8x30.dat	e8x30b.dat	e8x31.dat	e8x32.dat	e8x33a.dat	e8x33b.dat
e8x34.dat	e8x35.dat	e8x36.dat	e8x37.dat	e8x38a.dat	e8x38b.dat
—	e8x38c.dat	e8x39.dat	e8x4.dat	e8x42.dat	e8x43.dat

Table 1-4 Rezone Option Cross-reference (Continued)

CONTINUE (Continued)					
e8x43b.dat	e8x43c.dat	e8x44.dat	e8x44b.dat	e8x44c.dat	e8x45.dat
e8x46.dat	e8x47.dat	e8x48.dat	e8x49.dat	e8x50.dat	e8x51a.dat
e8x51b.dat	e8x52.dat	e8x53a.dat	e8x53b.dat	e8x54.dat	e8x55a.dat
e8x55b.dat	e8x56a.dat	e8x56b.dat	e8x5a.dat	e8x5b.dat	e8x6.dat
e8x60.dat	e8x7.dat	e9x10a.dat	e9x10b.dat	e9x10c.dat	e9x10d.dat
e9x11a.dat	e9x11b.dat	e9x12a.dat	e9x12b.dat	e9x12c.dat	e9x13a.dat
e9x13b.dat	e9x1a.dat	e9x1b.dat	e9x1c.dat	e9x1d.dat	e9x1e.dat
e9x2a.dat	e9x2b.dat	e9x2c.dat	e9x3a.dat	e9x3b.dat	e9x4.dat
e9x5a.dat	e9x5b.dat	e9x5c.dat	e9x5d.dat	e9x5e.dat	e9x6a.dat
e9x6b.dat	e9x7a.dat	e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat
e9x9b.dat	e10x1a.dat	e10x1b.dat	e10x2a.dat	e10x2b.dat	e10x3a.dat
e10x3b.dat	e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat	e10x6a.dat
e10x6b.dat	e10x7a.dat	e10x7b.dat			
COORDINATE CHANGE					
e7x17b.dat	e7x31b.dat	e8x12.dat	e8x12r.dat	e8x2.dat	e8x3.dat
END REZONE					
e7x17b.dat	e7x31b.dat	e8x12.dat	e8x12r.dat		
ISOTROPIC CHANGE					
e8x12.dat	e8x12r.dat	e8x2.dat			
PRINT CHOICE					
e3x14a.dat	e3x20.dat				
REZONE					
e7x17b.dat	e8x12.dat	e8x12r.dat			
SECTIONING					
e7x13d.dat					

Table 1-5 Element Type Cross-reference

Element 1					
e2x1.dat	e2x3.dat				
Element 2					
e2x2.dat	e2x3.dat				
Element 3					
e2x10.dat	e2x27.dat	e3x38a.dat	e7x11.dat	e8x46.dat	e8x47.dat
e8x48.dat	e8x9.dat				
Element 4					
e2x17.dat	e3x1.dat	e6x3a.dat	e6x3c.dat		
Element 5					
e2x5.dat	e4x20.dat	e6x1a.dat			
Element 6					
e2x23.dat	e9x1d.dat	e9x3b.dat			
Element 7					
e2x12b.dat	e2x12c.dat	e2x14b.dat	e2x64a.dat	e2x64b.dat	e2x65.dat
e3x36.dat	e6x15.dat	e6x15b.dat	e6x16a.dat	e6x16b.dat	e6x17a.dat
e6x17b.dat	e7x29a.dat	e7x30a.dat	e7x30b.dat	e7x32.dat	e8x14a.dat
e8x14b.dat	e8x14c.dat	e8x14d.dat	e8x14e.dat	e8x17.dat	e8x17b.dat
e8x19.dat	e8x19b.dat				
Element 8					
e2x11.dat	e2x15.dat	e2x16.dat	e6x3b.dat	e6x3d.dat	
Element 9					
e2x24.dat	e2x54.dat	e4x6.dat	e6x12.dat	e6x6a.dat	e6x6b.dat
e6x9.dat	e7x11.dat	e10x6a.dat	e10x6b.dat		

Table 1-5 Element Type Cross-reference (Continued)

Element 10					
e2x4.dat	e2x61a.dat	e3x12.dat	e3x12b.dat	e3x19.dat	e3x19d.dat
e3x21a.dat	e3x21e.dat	e3x21f.dat	e3x29.dat	e3x35.dat	e3x37a.dat
e3x37b.dat	e3x38b.dat	e3x7a.dat	e3x7b.dat	e3x7c.dat	e4x13b.dat
e6x4.dat	e7x17a.dat	e7x17b.dat	e7x2.dat	e7x20d.dat	e7x28a.dat
e8x12.dat	e8x12b.dat	e8x12d.dat	e8x12e.dat	e8x12r.dat	e8x13.dat
e8x13b.dat	e8x3.dat	e8x43b.dat	e8x50.dat	e8x56a.dat	e8x56b.dat
e9x13a.dat	e9x2a.dat	e9x2b.dat			
Element 11					
e2x25.dat	e2x26.dat	e2x34.dat	e2x37b.dat	e2x60a.dat	e3x25.dat
e3x3.dat	e3x9.dat	e7x31a.dat	e7x31b.dat	e8x15.dat	e8x15c.dat
e8x15d.dat	e8x16.dat	e8x16b.dat	e8x37.dat	e8x44b.dat	e8x44c.dat
e8x45.dat	e8x60.dat	e8x7.dat	e9x1a.dat	e9x3a.dat	e9x4.dat
e9x5a.dat	e9x5b.dat	e9x5e.dat	e9x6a.dat	e9x6b.dat	e9x7a.dat
e9x7b.dat	e9x7c.dat	e9x8.dat	e9x9a.dat	e9x9b.dat	e9x10a.dat
e9x10b.dat	e9x10c.dat	e9x10d.dat	e9x11a.dat	e9x11b.dat	e9x12a.dat
e9x12b.dat	e9x12c.dat	e9x13b.dat			
Element 12					
e3x18.dat	e6x9.dat	e7x18.dat	e7x2.dat	e7x4.dat	e7x4b.dat
e8x3.dat	e8x7.dat				
Element 13					
e2x6.dat					
Element 14					
e2x7.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat	e10x7a.dat	e10x7b.dat
Element 15					
e2x4.dat	e3x16.dat	e3x16b.dat	e3x18.dat	e3x5.dat	e4x1a.dat
e4x1b.dat	e4x1c.dat	e4x1d.dat	e4x4.dat	e4x4b.dat	

Table 1-5 Element Type Cross-reference (Continued)

Element 16					
e2x8.dat	e3x14a.dat	e3x20.dat	e3x4.dat	e4x7.dat	e4x7c.dat
e6x13.dat	e6x13b.dat				
Element 17					
e2x20.dat	e7x13b.dat	e7x13c.dat	e7x13d.dat		
Element 18					
e2x62.dat	e3x34.dat	e4x14a.dat	e8x18c.dat		
Element 19					
e2x27.dat					
Element 20					
e2x28.dat	e4x13c.dat				
Element 21					
e2x13.dat	e2x14.dat	e8x8a.dat	e8x8b.dat	e10x3a.dat	e10x3b.dat
Element 22					
e2x18.dat	e2x42.dat	e4x5.dat			
Element 23					
e2x14.dat					
Element 24					
e2x19.dat					
Element 25					
e2x29.dat	e3x13.dat	e4x3.dat			
Element 26					
e2x9.dat	e2x9b.dat	e3x10.dat	e3x15.dat	e3x15b.dat	e3x24b.dat
e3x24c.dat	e3x33.dat	e7x19.dat	e7x21.dat	e8x11.dat	e8x1a.dat
e8x27.dat	e8x4.dat	e10x2a.dat	e10x2b.dat		

Table 1-5 Element Type Cross-reference (Continued)

Element 27					
e2x22.dat	e2x37.dat	e2x60b.dat	e2x63a.dat	e2x63b.dat	e3x33b.dat
e3x8.dat	e6x14.dat	e6x5.dat	e7x10.dat	e7x12.dat	e8x15b.dat
e8x2.dat	e8x6.dat	e9x1b.dat	e9x1c.dat	e9x5c.dat	e9x5d.dat
Element 28					
e2x30.dat	e2x39.dat	e2x61b.dat	e3x11.dat	e3x22c.dat	e3x22d.dat
e3x26.dat	e7x14.dat	e7x28c.dat	e9x2c.dat		
Element 29					
e2x31a.dat	e2x38.dat	e2x46b.dat	e2x46c.dat		
Element 30					
e4x14b.dat	e6x11.dat				
Element 31					
e2x66a.dat	e2x66b.dat				
Element 32					
e2x32.dat	e7x1.dat	e7x18.dat	e7x4.dat	e7x4b.dat	e8x35.dat
Element 33					
e2x33.dat	e2x33b.dat	e6x7.dat	e7x5.dat		
Element 34					
e2x34.dat					
Element 35					
e2x35.dat	e2x35a.dat	e6x8.dat			
Element 36					
e5x1.dat					
Element 37					
e5x3d.dat	e7x15.dat				

Table 1-5 Element Type Cross-reference (Continued)

Element 39					
e5x12.dat	e5x14.dat	e5x3c.dat	e5x7a.dat	e5x7b.dat	e7x16.dat
e8x20.dat	e8x22.dat	e8x24a.dat	e8x24b.dat	e8x25.dat	e8x26.dat
e8x7.dat					
Element 40					
e5x10.dat	e5x9a.dat	e5x9b.dat			
Element 41					
e3x24a.dat	e5x3a.dat	e5x6.dat	e5x8a.dat	e5x8b.dat	e5x8c.dat
e5x8d.dat	e5x8e.dat	e6x5.dat	e8x28.dat	e8x29.dat	
Element 42					
e3x22a.dat	e5x11a.dat	e5x15.dat	e5x15b.dat	e5x5a.dat	
Element 43					
e5x4a.dat	e8x21.dat				
Element 44					
e5x4b.dat					
Element 45					
e2x36.dat	e6x1b.dat	e6x1c.dat	e6x2.dat		
Element 46					
e2x37.dat	e8x6.dat				
Element 47					
e2x38.dat					
Element 48					
e2x39.dat					
Element 49					
e2x40a.dat	e2x40b.dat	e4x2a.dat	e8x53b.dat		

Table 1-5 Element Type Cross-reference (Continued)

Element 50					
e2x41.dat	e3x6.dat	e4x2b.dat			
Element 51					
e4x8.dat					
Element 52					
e2x21.dat	e6x10.dat	e8x10.dat	e10x1a.dat	e10x1b.dat	
Element 53					
e2x43.dat					
Element 54					
e2x44.dat	e3x27.dat				
Element 55					
e2x45.dat	e3x28.dat	e7x28d.dat			
Element 56					
e2x31b.dat	e2x46a.dat				
Element 57					
e2x47b.dat					
Element 58					
e2x48.dat					
Element 59					
e2x49.dat					
Element 60					
e2x50.dat					
Element 61					
e2x51a.dat	e2x51b.dat				
Element 62					
e7x8a.dat	e7x8b.dat	e7x8c.dat	e7x9a.dat	e7x9b.dat	e7x9c.dat

Table 1-5 Element Type Cross-reference (Continued)

Element 64					
e2x43.dat					
Element 65					
e5x2a.dat	e5x2b.dat				
Element 66					
e2x52.dat					
Element 67					
e2x53.dat	e3x2a.dat	e3x2b.dat	e4x13a.dat	e7x27.dat	
Element 68					
e2x54.dat					
Element 69					
e5x3b.dat					
Element 70					
e5x5b.dat					
Element 71					
e5x4c.dat					
Element 72					
e2x55.dat	e2x56.dat	e3x17.dat			
Element 75					
e2x65.dat	e3x23.dat	e3x23b.dat	e4x15.dat	e7x22a.dat	e7x22b.dat
e7x22c.dat	e7x3.dat	e7x3b.dat	e7x6.dat	e7x7.dat	e8x18.dat
e8x18d.dat	e8x5a.dat	e8x5b.dat	e8x51b.dat	e8x52.dat	e8x53a.dat
e8x54.dat	e8x55a.dat	e8x55b.dat	e8x57a.dat	e8x58.dat	e8x6.dat
e10x4a.dat	e10x4b.dat	e10x5a.dat	e10x5b.dat		
Element 76					
e2x57a.dat					

Table 1-5 Element Type Cross-reference (Continued)

Element 77			
e2x58a.dat			
Element 78			
e2x57b.dat			
Element 79			
e2x58b.dat			
Element 80			
e8x49.dat			
Element 82			
e7x20.dat	e7x5b.dat		
Element 85			
e5x13a.dat			
Element 86			
e5x13b.dat			
Element 87			
e5x13c.dat			
Element 88			
e5x13d.dat			
Element 90			
e4x9.dat	e4x9b.dat	e4x10.dat	e4x10b.dat
Element 91			
e2x60a.dat			
Element 92			
e2x61a.dat			
Element 93			
e2x60b.dat			

Table 1-5 Element Type Cross-reference (Continued)

Element 94					
e2x61b.dat					
Element 98					
e2x59a.dat	e2x59b.dat				
Element 103					
e8x28.dat	e8x29.dat				
Element 109					
e8x23.dat	e8x23b.dat				
Element 111					
e8x30.dat	e8x30b.dat	e8x33a.dat	e8x33b.dat		
Element 112					
e8x31.dat					
Element 113					
e8x32.dat					
Element 114					
e2x10b.dat					
Element 115					
e2x25b.dat	e3x3b.dat				
Element 116					
e3x19b.dat	e3x19c.dat	e3x21c.dat	e7x28b.dat	e8x13c.dat	e8x36.dat
e8x43c.dat					
Element 117					
e2x12d.dat	e7x29b.dat				
Element 118					
e2x26b.dat					

Table 1-5 Element Type Cross-reference (Continued)

Element 119	
e7x5c.dat	
Element 120	
e6x16c.dat	
Element 121	
e5x3e.dat	
Element 122	
e5x9d.dat	
Element 123	
e5x16a.dat	e5x4d.dat
Element 124	
e2x9c.dat	
Element 125	
e2x26c.dat	e9x1e.dat
Element 126	
e2x2b.dat	
Element 127	
e2x67a.dat	
Element 128	
e2x26d.dat	
Element 129	
e2x2c.dat	
Element 130	
e2x67b.dat	
Element 131	
e5x3f.dat	

Table 1-5 Element Type Cross-reference (Continued)

Element 132				
e5x9e.dat				
Element 133				
e5x16b.dat				
Element 134				
e2x67c.dat				
Element 135				
e5x16c.dat				
Element 138				
e2x72.dat	e2x75.dat	e4x2c.dat	e8x57b.dat	
Element 139				
e2x73.dat	e2x76.dat	e4x2d.dat	e8x51a.dat	e8x57c.dat
Element 140				
e2x74.dat	e2x77.dat	e4x2e.dat	e8x57d.dat	
Element 142				
e4x13a.dat				
Element 143				
e2x37b.dat				
Element 144				
e4x13b.dat				
Element 145				
e4x13c.dat				

Table 1-5 Element Type Cross-reference (Continued)

Element 146
e2x14b.dat
Element 147
e4x14a.dat
Element 148
e4x14b.dat

Table 1-6 User Subroutine Cross-reference

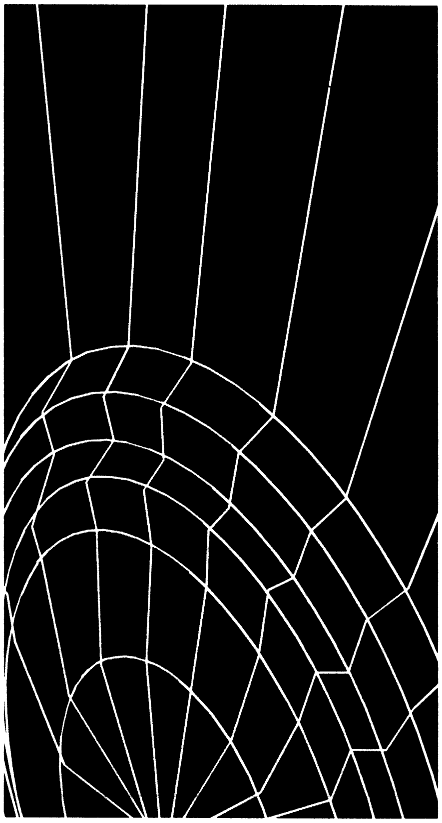
ANELAS					
u2x45.f	u2x50.f	u2x53.f	u3x8.f	u8x8.f	
ANKOND					
u5x7a.f					
ANPLAS					
u3x6.f					
CREDE					
u2x46a.f	u2x46b.f	u2x46c.f	u2x51a.f	u3x13f	
CRPLAW					
u3x12.f	u3x22c.f	u3x24.f			
FILM					
u3x22a.f	u5x5.f	u5x6.f	u5x8.f	u5x13.f	u5x14.f
FLOW					
u5x14.f					
FLUX					
u5x8.f					
FORCDT					
u3x26.f	u5x2.f	u7x17.f	u8x26.f		
FORCEM					
u2x35.f	u2x43.f	u2x46.f			
GAPU					
u2x70					
HOOKLW					
u8x8.f					
HYPELA2					
u7x29a.f					

Table 1-6 User Subroutine Cross-reference (Continued)

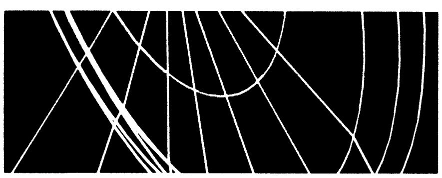
IMPD					
u3x3.f	u3x3b.f	u3x19.f	u3x19b.f	u3x19c.f	u3x21a.f
u3x21c.f	u2x21d.f	u4x7.f	u8x15b.f		
MOTION					
u8x16.f	u8x19.f	u8x19b.f			
ORIENT					
u2x50.f	u2x50b.f	u2.53.f			
PLOTV					
u2x26.f	u2x26b.f	u2x26c.f	u2x26d.f		
REBAR					
u2x14.f	u2x37.f	u2x38.f	u2x39.f	u8x6.f	
SSTRAN					
u8x1.f					
UBEAM					
u8x10.f					
UBEAR					
u7x16.f					
UFCONN					
u2x20.f	u2x27.f	u2x34.f	u2x46a.f	u2x46b.f	u7x15.f
UFORMS					
u2x4.f	u2x43.f				
UFOUR					
u7x8c.f	u7x9b.f				

Table 1-6 User Subroutine Cross-reference (Continued)

UFXORD					
u2x16.f	u2x17.f	u2x18.f	u2x19.f	u2x20.f	u2x55.f
u2x56.f	u3x5.f	u3x16.f	u3x17.f	u3x23.f	u3x27.f
u4x1.f	u4x5.f	u4x7.f	u6x3.f	u7x3.f	u7x15.f
UGROOV					
u7x15.f					
UINSTR					
u2x38.f	u3x30a.f				
USHELL					
u2x40b.f					
USSD					
u6x18.f					
UTHICK					
u7x15.f	u7x16.f				
UTRANS					
u2x62.f	u4x14.f				
UVELOC					
u7.15.f					
VSWELL					
u3x13.f					
WKSLP					
u3x5.f	u3x8.f	u3x30a.f	u3x30b.f	u3x38a.f	u8x2.f
u8x18.f					



MARC



Volume E

Demonstration Problems

Version K7

MARC Analysis Research Corporation

Chapter 2
Linear Analysis

2 Linear Analysis Contents

Description **Problem**

Description	Problem

2 Linear Analysis List of Figures

Figure **Page**

Figure		Page

Figure **Page**

Figure **Page**

Figure		Page

Figure		Page

Figure **Page**

Figure **Page**

2 Linear Analysis List of Tables

2 Linear Analysis

MARC allows you to perform an elastic analysis using any element in the program. Problems in this chapter deal only with linear elastic stress analysis and are designed to guide you through various input options. The problems demonstrate the use of different elements such as plane stress, plane strain, generalized plane strain, axisymmetric, truss, beam, membrane, plate, shell and three-dimensional solids. They also illustrate the selection of isotropic or anisotropic elastic behavior. The options demonstrated are outlined below. For further details, see *MARC Volume C: Program Input*.

Mesh generation

- MESH2D
- Incremental
- FXORD
- User subroutine UFXORD
- User subroutine UFCONN

Kinematic constraints

- Fixed Displacement
- Tying
- Servolinks
- Springs
- Elastic foundations
- Transformations

Loads

- Point loads
- Distributed loads
- Centrifugal loads
- Thermal loads
- Initial stress

Controls

- J-Integral
- Sorting
- Print choices
- Restart
- Case combination

Table 2-1 shows MARC elements and options used in these demonstration problems. It should be pointed out that any example shown here can be considered as the first step in the solution of a nonlinear problem. Extensions to more complex solutions are accomplished by addition of further options using the keyword selection for those options as illustrated in the examples in later chapters.

Table 2-1 Linear Analysis Demonstration Problems

Problem Number	Element Type(s)	Parameters	Model Definition	History Definition	User Subroutines	Problem Description
2.1	1	—	—	—	—	Hemisphere under internal pressure.
2.2	2 126 129	—	TRANSFORMATION	—	—	Thick sphere under internal pressure.
2.3	1 2	TRANSFORM	TRANSFORMATION TYING	—	—	Axisymmetric solid/ axisymmetric shell intersection.
2.4	10 15	—	TRANSFORMATION TYING	—	UFORMS	Axisymmetric solid/ axisymmetric shell intersection.
2.5	5	—	—	—	—	Doubly cantilevered beam.
2.6	13	BEAM SECT	—	—	—	Doubly cantilevered beam, open section.
2.7	14	BEAM SECT	—	—	—	Doubly cantilevered beam, closed section.
2.8	16	—	—	—	—	Curved beam, point load.
2.9	26 124	—	OPTIMIZE	—	—	Plate with circular hole.
2.10	3 114	—	—	—	—	Plane stress disk, diametrically opposing point loads.
2.11	8	SHELL SECT	FXORD	—	—	Square plate by shell elements.
2.12	7 117	PROCESSOR	SOLVER	—	—	3-dimensional plate by 8-node brick elements.
2.13	21	—	—	—	—	3-dimensional plate by 20-node brick elements.
2.14	21 23	PROCESSOR	—	—	REBAR	3-dimensional cantilever beam, reinforced with rebar, brick elements.

Table 2-1 Linear Analysis Demonstration Problems (Continued)

Problem Number	Element Type(s)	Parameters	Model Definition	History Definition	User Subroutines	Problem Description
2.15	8	SHELL SECT	TYING FXORD	—	—	Cylinder-sphere intersection, tying type 18.
2.16	8	—	OPTIMIZE	—	UFXORD	Shell roof, element type 8.
2.17	4	—	—	—	UFXORD	Shell roof, element type 4.
2.18	22	—	—	—	UFXORD	Shell roof, element type 22.
2.19	24	—	—	—	UFXORD	Shell roof, element type 24.
2.20	17	—	—	—	—	Pipe band, in-plane, half section.
2.21	52	—	—	—	—	Doubly cantilevered beam, elastic.
2.22	27	J-INT	J-INT	—	—	Double edge notched specimen linear elastic fracture mechanics.
2.23	6	—	TRANSFORMATION	—	—	Thick cylinder under internal pressure.
2.24	9	—	—	—	—	20-bar, 3-dimensional truss.
2.25	11 115	—	CONN GENER NODE FILL	—	—	Strip, bonded edges, $\upsilon = .3$.
2.26	11 118 125 128	—	—	—	PLOTV	Strip, bonded edges, $\upsilon = .4999$, constant dilatation.
2.27	19	ELSTO	—	—	UFCONN	Generalized plane strain disk, diametrically opposing point loads.
2.28	20	—	TYING	—	—	Twist and tension circular bar with varying thickness.

Table 2-1 Linear Analysis Demonstration Problems (Continued)

Problem Number	Element Type(s)	Parameters	Model Definition	History Definition	User Subroutines	Problem Description
2.29	25	—	FOUNDATION	—	—	Beam in linear elastic foundation with point load.
2.30	28	ELSTO ALIAS	J-INTEGRAL	—	—	Cylindrical notched bar in tension.
2.31	29	SCALE	OPTIMIZE	—	UFCONN	Square plate with round hole, internal pressure, generalized plane strain.
2.32	32	SCALE ALIAS	OPTIMIZE	—	—	Square plate with round hole, internal pressure, generalized plane strain, υ = .5. Mesh as in E 2.31.
2.33	33	CENT LOAD	CONN GENER NODE FILL ROTATION A STIFF SCALE	—	—	Flat spinning disk, υ = .4999.
2.34	34	—	CONN FILL NODE FILL CONN GENER QUALIFY OPTIMIZE	—	—	Bar compressed sideways generalized plane strain.
2.35	35	ELASTIC RESTART	CASE COMBIN	—	FORCEM	Square block, 1/8 model 8 elements, υ = .4999 load case 1: compression; load case 2: bending, combined.
2.36	45	—	FOUNDATION	—	—	Timoshenko beam on elastic foundation.
2.37	27 46	—	—	—	REBAR	Reinforced cantilever beam.
2.38	29 47	SCALE ISTRESS	OPTIMIZE UFCONN	PROPORTIONAL	REBAR UFCONN UINSTR	Reinforced square plate with round hole, generalized plane strain. Prestressed reinforcement.
2.39	28 48	—	—	—	REBAR	Circular cylinder with reinforcement.

Table 2-1 Linear Analysis Demonstration Problems (Continued)

Problem Number	Element Type(s)	Parameters	Model Definition	History Definition	User Subroutines	Problem Description
2.40	49	SHELL SECT	—	—	—	Flat square plate, varying thickness, simply supported pressure load.
2.41	50	SHELL SECT	CONN GENER TYING NODE FILL	—	—	Tubular beam with square cross-section cantilevered self weight.
2.42	22	SHELL SECT	FOUNDATION	—	—	Square plate on elastic foundation point load, free edges 1/4 model.
2.43	53 64	—	TYING CONN GENER NODE FILL	—	FORCEM UFORMS	I-beam modeled with plane stress and line elements cantilever, moment load.
2.44	54	—	TYING	—	—	Local load on half-space. Mesh refinement tying.
2.45	55	ANISOTROPI C J-INT	OPTIMIZE J-INTEGRAL	—	ANELAS	Axisymmetric notched bar, anisotropic in longitudinal direction.
2.46	29 56	THERMAL	THERMAL LOADS UFCONN	—	CREDE UFCONN	Square plate with hole, thermal gradient towards outer edge.
2.47	57	TRANSFORM TIE	TRANSFORMATION TYING MESH 3D	—	—	Section of cylinder with uniform internal pressure. TYING to enforce axisymmetric solution.
2.48	58	—	NODE CIRCLE CONN GENER ROTATION A	—	—	Plane straining with diametrically opposing load (1/2 model).
2.49	59	THERMAL	NODE CIRCLE CONN GENER	—	CREDE	Hollow sphere, spinning gradient across wall thickness.

Table 2-1 Linear Analysis Demonstration Problems (Continued)

Problem Number	Element Type(s)	Parameters	Model Definition	History Definition	User Subroutines	Problem Description
2.50	60	ANISOTROPI C	NODE CIRCLE	—	ANELAS ORIENT	Generalized plane strain ring with diametrically opposing point loads, circular anisotropy.
2.51	61	THERMAL ELASTIC RESTART	CASE COMBIN	—	CREDE	Square block 1/8 model 8 elements υ = .4999 load case 1: thermal gradient; load case 2: compression, combined.
2.52	66	—	TYING OPTIMIZE	—	—	Twist and tension of a circular bar with varying cross-section, υ = .4999
2.53	67	—	TYING	—	ANELAS ORIENT	Cylinder with helical anisotropy under internal pressure.
2.54	9 68	—	SPRINGS	—	—	Truss cube with shear panels, supported by springs.
2.55	72	SHELL SECT	UFXORD	—	UFXORD	Shell roof, element type 72.
2.56	72	SHELL SECT	UFXORD	—	UFXORD	Cylinder-sphere intersection, element type 72, no tying.
2.57	76 78	BEAM SECT	POINT LOAD	—	—	Cantilever beam, under point load.
2.58	77 79	BEAM SECT	POINT LOAD	—	—	Double cantilever beam under point load.
2.59	98	BEAM SECT	POINT LOAD	—	—	Cantilever beam under point load.
2.60	11 91 27 93	—	MESH2D MANY TYPES	DIST LOADS	—	Uniform load in a cavity using semi-infinite elements.
2.61	10 92 28 94	—	MESH2D	POINT LOAD POST	—	Point load on a semi-infinite body.

Table 2-1 Linear Analysis Demonstration Problems (Continued)

Problem Number	Element Type(s)	Parameters	Model Definition	History Definition	User Subroutines	Problem Description
2.62	18	—	UTRANFORM DIST LOADS POST	—	UTRANS	Truncated spherical shell.
2.63	27	—	LORENZI DIST LOADS	CONTINUE POINT LOADS	—	Double edge notch specimen, DeLorenzi method used.
2.64	7	ELASTIC	FIXED DISP DIST LOADS	POINT LOADS	—	Bending on a plate, assumed strain elements used.
2.65	7 75	LARGE DISP	FIXED DISP	AUTO LOAD POINT LOAD	—	Rigid tying test.
2.66	31	BEAM SECT	CONN GENER POINT LOAD NODE FILL	—	—	Bending of a beam.
	31	—	ISOTROPIC	POINT LOAD DIST LOAD	—	Bending of an elbow.
2.67	127 130 21	—	POINT LOAD	—	—	Cantilever beam.
2.68	49	—	POINT LOAD	—	—	Spherical shell under Point Loads.
2.69	95	SHELL SECT	DIST LOADS	—	—	Pipe subjected to bending.
2.70	95 97	—	—	—	—	Flange joint between pressurized pipes.
2.71	98	—	DIST LOADS ROTATION AXIS	—	—	Spinning beam with and without Corrolis effect.
2.72	138	—	—	—	—	Shell roof element type 138
2.73	139	—	—	—	—	Shell roof element type 139
2.74	140	—	—	—	—	Shell roof element type 140
2.75	138	—	—	—	—	Pinched cylinder
2.76	139	—	—	—	—	Pinched cylinder
2.77	140	—	—	—	—	Pinched cylinder

2.1 Hemispherical Shell Under Internal Pressure

A thin hemispherical shell is analyzed subjected to uniform internal pressure. The material behavior is considered elastic. The accuracy of element type 1 is verified.

Element

Library element type 1 is used. Element 1 is a 2-node axisymmetric thin shell with three degrees of freedom per node.

For this element, as for any 2-node element, it is necessary to adopt some unambiguous direction convention in order to provide the correct sign to the pressure loads. The convention adopted for this element is to define a right-handed set of local coordinates (x,y) for each element, with the positive x-direction from node 1 to node 2 of the element (see CONNECTIVITY). This gives a unique positive y-direction (90° counterclockwise to local x), and with this definition the following conventions hold:

> Positive pressure always gives negative nodal load components in the positive local y-direction.

The sign convention that is adopted for the global axes should be noted. A positive rotation of 90° is assumed to transform the axis of symmetry Z to the radial axis R. Nodal points have three global displacement degrees of freedom:

1. Axial (parallel to the symmetry axis)
2. Radial (normal to symmetry axis)
3. Cross-sectional rotation (right-handed)

Model

The geometry of the middle surface of the hemisphere and the mesh are shown in Figure 2.1-1. A 90-degree section is referenced to the Z-R global coordinate system. The shell is divided into nine elements with 10 nodes, each element subtending an angle of 10 degrees.

Geometry

The wall thickness of the shell is 0.01 in. and the radius of curvature is 1.0 in. The thickness is entered as EGEOM1 in the GEOMETRY option. EGEOM2 and EGEOM3 are not used for this element type.

Material Properties

All elements are assumed to have the same properties. Values used for Young's modulus and Poisson's ratio are 5 x 10^6 psi and 0.3, respectively, and are entered in the ISOTROPIC option. The material is given a high yield stress so that it will not go plastic.

Loading

A uniform internal pressure of 1.0 psi is applied to all elements.

Boundary Conditions

Node 1 is constrained to move axially, with no rotation and no translation in the R-direction. Node 10 is constrained to move radially, with no rotation and no translation in the Z-direction.

Note

Element 15 or Element 89 could also be used to model this type of problem. This higher-order element would allow a coarser mesh to be used; two element type 15 would give equivalent results in this case. Element 15 or Element 89, in addition, allows the application of nonuniform loads through the use of user subroutine FORCEM.

Results

For a thin spherical shell, the solution is that the circumferential stress is equal to pr/2t, which, for this particular problem, is 50 psi. The MARC solution is given at layer 1 on the inner surface and layer 11 at the outer surface. One observes that the MARC solution is within .02% of the exact solution. A discussion of the analytic solution can be found in many elementary books on elasticity, such as *Theory of Elasticity* by Timoshenko and Goodier.

Parameters, Options, and Subroutines Summary

Example e2x1.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC

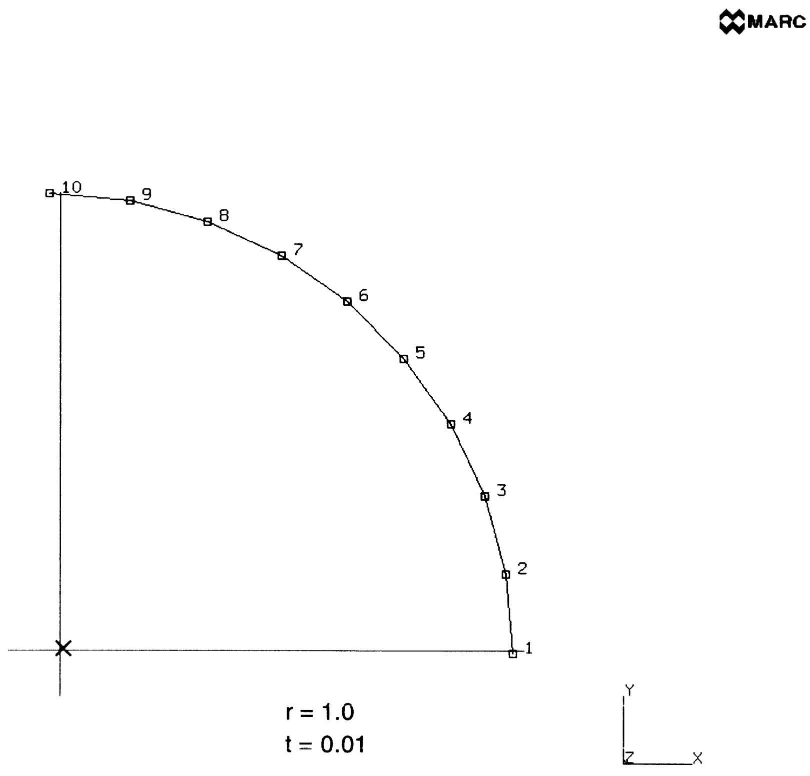


Figure 2.1-1 Geometry and Mesh Layout for Axisymmetric Shell

2.2 Thick Sphere Under Internal Pressure

A thick-walled sphere is subjected to a uniform internal pressure. The material behavior is considered elastic. The numerical solution is compared to the analytical solution. This problem demonstrates the use of element types 2, 126, and 129, and the TRANSFORMATION option.

This problem is modeled using the three techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x2	2	16	18
e2x2b	126	26	51
e2x2c	129	16	51

Elements

Element type 2 and 126 are first and second-order isoparametric elements, respectively, with triangular cross-sections revolved around an axis of symmetry. Element type 129 is the same as type 126 with a Herrmann formulation.

Model

Only a small segment of the sphere is analyzed, with symmetry being enforced through the TRANSFORMATION option of the program. The inner radius of the sphere is 1.0 inch and the sphere thickness is 2.0 inches. A small wedge of ring elements span a 0.085 radian slice as shown in Figure 2.2-1 with 16 axisymmetric ring elements.

Material Properties

The material for all elements is treated as an elastic material, with Young's modulus of 30.0E+06 psi, Poisson's ratio of 0.0, and a yield stress of 35,000 psi entered in the ISOTROPIC option.

Geometry

The GEOMETRY option is not necessary for these elements because all integrations are performed about the axis of revolution.

Loads and Boundary Conditions

A uniform distributed load of 1.0 psi is applied to the inner surface of the sphere. The boundary conditions are determined by the symmetry conditions and require the nodes along x = 0 axis, and the theta = .085 radians axis to have no displacements normal to these surfaces.

Results

The innermost element, for each of the element types used, has the largest value of equivalent stress as expected. Scaling the load to first yield would lead to an internal pressure of 29,093 psi, 24,509 psi, and 24,578 psi for element types 2, 126, and 129, respectively. The coarse mesh, with fewer degrees of freedom, gives less conservative results. Figure 2.2-2 shows the vector plot of the reaction forces which are normal to the planes of symmetry.

The exact solution may be expressed as:

$$\text{Radial Stress} = pr_i^3(1 - r_o^3/r^3)/(r_o^3 - r_i^3)$$

$$\text{Hoop Stress} = pr_i^3(1 + r_o^3/2r^3)/(r_o^3 - r_i^3)$$

For this particular problem this yields:

$$\text{Radial Stress} = (1 - 27/r^3)/26$$

$$\text{Hoop Stress} = (1 + 27/2r^3)/26$$

Figure 2.2-3 plots the radial stress for element type 2, 126, 129 and the exact value versus the radius. Note how the stress boundary conditions at the inner and outer radii are approximately satisfied by the two element types. Figure 2.2-4 plots the hoop stress for element type 2, 126, 129, and the exact value versus the radius. Here again, the 6-noded element is more accurate at the price of more nodes.

Parameters, Options, and Subroutines Summary

Example e2x2.dat:

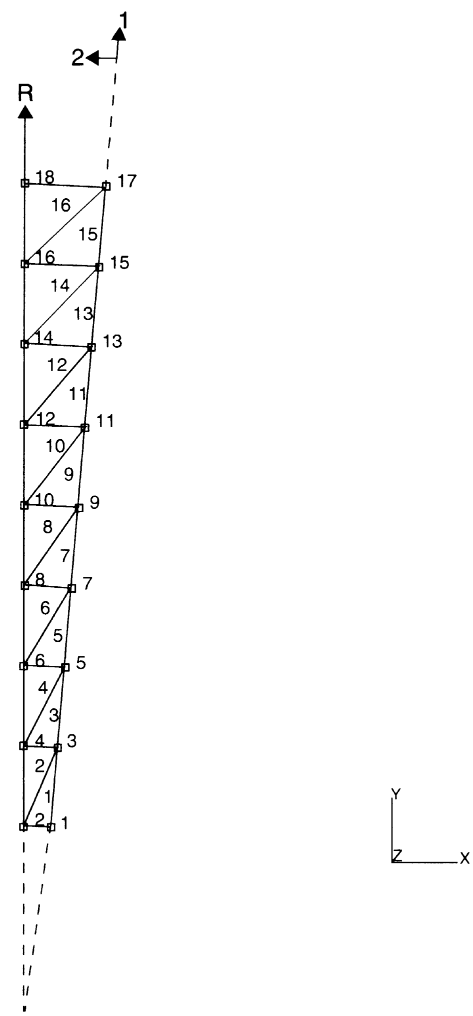
Parameters	Model Definition Options
END	CONNECTIVITY
SIZING	COORDINATES
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	ISOTROPIC
	POST
	TRANSFORMATIONS

Example e2x2b.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	OPTIMIZE
	POST
	PRINT NODE
	TRANSFORMATIONS

Example e2x2c.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	POST
	PRINT NODE
	TRANSFORMATIONS



$r_i = 1$
$r_o = 3$
$\theta = 0.085$ radians

Figure 2.2-1 Thick Sphere Mesh for Element 2

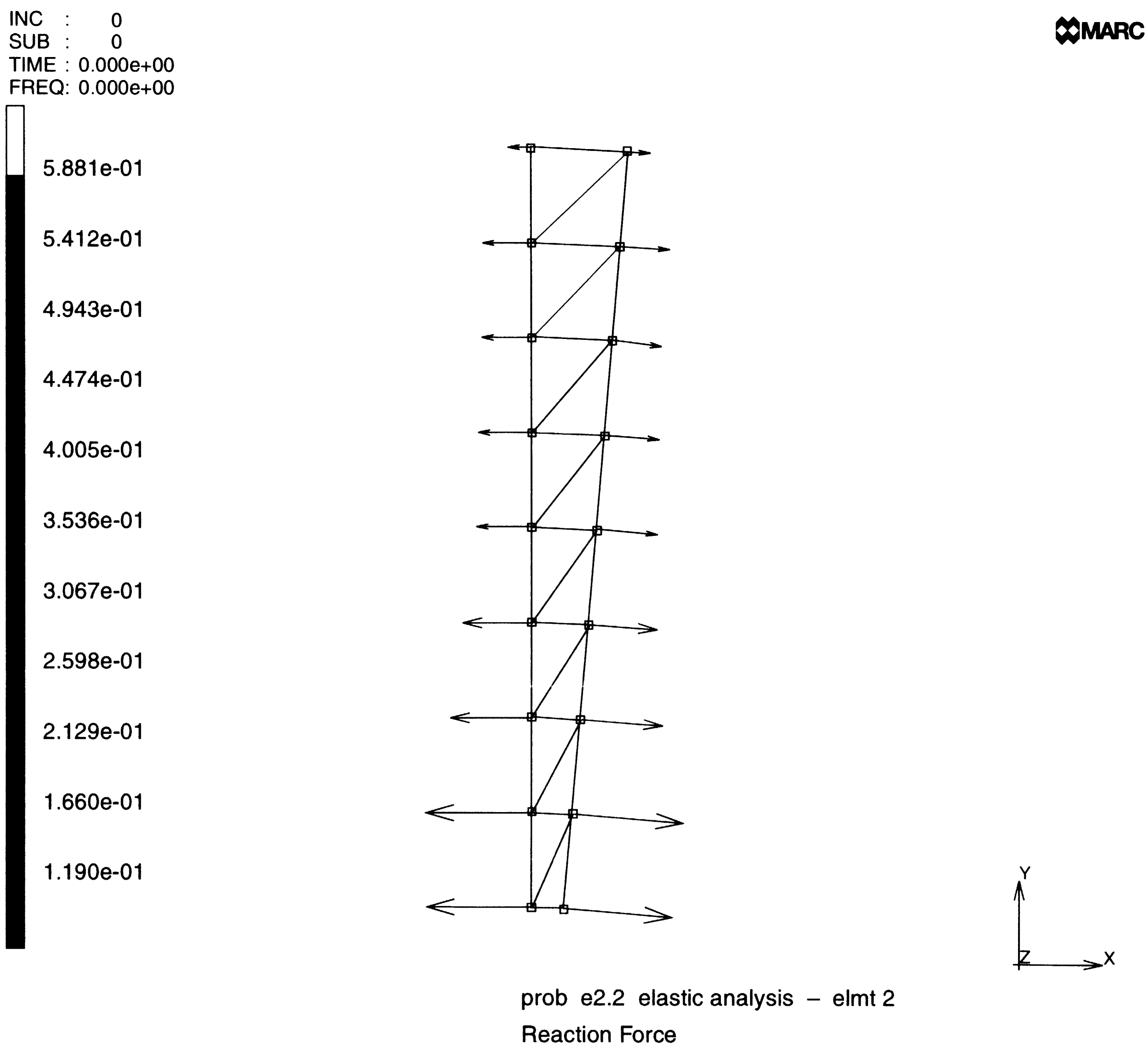


Figure 2.2-2 Vector Plot of Reactions Element 2

Radius	Type 2	Type 126	Type 129	Exact
1.	-0.65939E+00	-0.95125E+00	-0.8715844E+00	-1.0000
1.25	-0.47083E+00	-0.47338E+00	-0.4665929E+00	-0.4932
1.5	-0.26017E+00	-0.26165E+00	-0.2567940E+00	-0.2692
1.75	-0.14958E+00	-0.15189E+00	-0.1487170E+00	-0.1553
2.	-0.87530E-01	-0.89656E-01	-0.8752283E-01	-0.09135
2.25	-0.50137E-01	-0.51800E-01	-0.5034145E-01	-0.05271
2.5	-0.26241E-01	-0.27487E-01	-0.2645840E-01	-0.02800
2.75	-0.10161E-01	-0.11172E-01	-0.1042592E-01	-0.01147
3.	-0.52244E-02	0.18073E-03	-0.1021735E-02	0.0

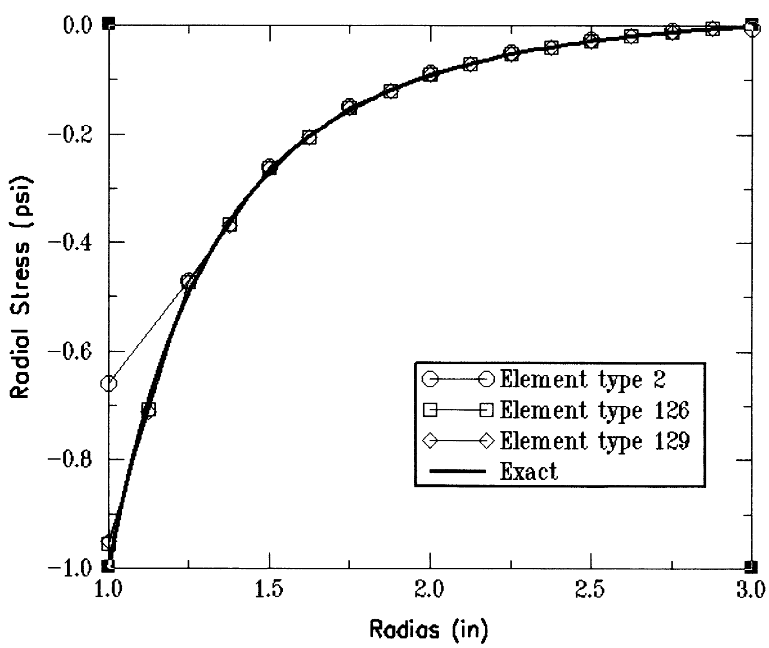


Figure 2.2-3 Radial Stress Versus Radius Elements 2, 126, 129, and Exact

Radius	Type 2	Type 126	Type 129	Exact
1.	0.42237E+00	0.53225E+00	0.4913680E+00	0.55769
1.25	0.25709E+00	0.29693E+00	0.2921591E+00	0.30431
1.5	0.16556E+00	0.18906E+00	0.1862493E+00	0.19231
1.75	0.11959E+00	0.13376E+00	0.1321118E+00	0.13534
2.	0.93388E-01	0.10251E+01	0.1014724E+01	0.10337
2.25	0.77296E-01	0.83555E-01	0.8286265E-01	0.08405
2.5	0.66863E-01	0.71393E-01	0.7091602E-01	0.07169
2.75	0.59815E-01	0.63233E-01	0.6289676E-01	0.06343
3.	0.56498E-01	0.57593E-01	0.5820292E-01	0.05769

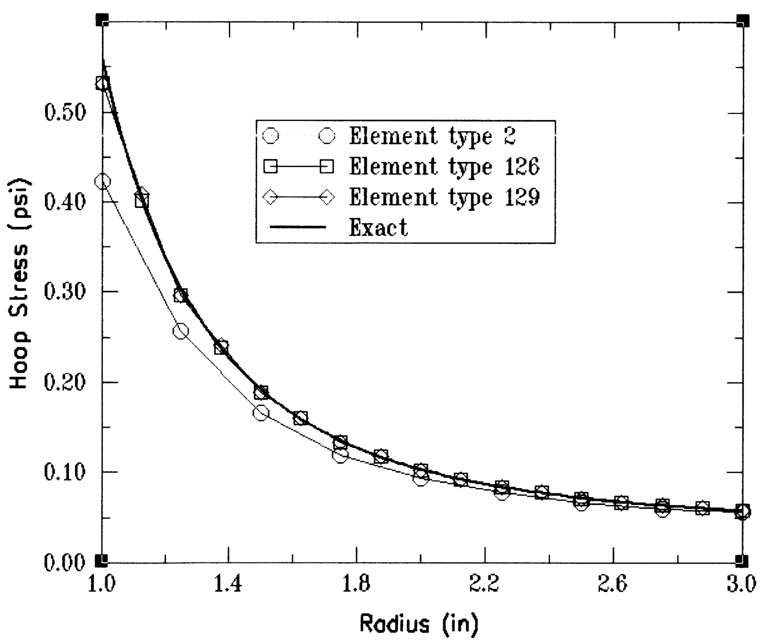


Figure 2.2-4 Hoop Stress Versus Radius Elements 2, 126, 129, and Exact

2.3 Axisymmetric Solid-Shell Intersection

This problem demonstrates the use of tying to impose the kinematic constraint at a solid-to-shell intersection. A thin axisymmetric cylinder is intersected with a thick cylinder. The combined structure is subjected to internal pressure. The cylinder is constrained such that there is no axial displacement.

Elements

Library element types 1 and 2 are used. Element type 1 is a two-node axisymmetric thin shell with three degrees of freedom per node. Element type 2 is an axisymmetric triangular ring with two degrees of freedom per node.

Model

Four shell elements are used to model the thin shell part of the structure. The solid end is modeled with 32 ring elements using 29 nodes. The finite element model is illustrated in Figure 2.3-1.

Geometry

For the shell element, EGEOM1 is used for thickness. No geometry input is required for the ring element.

Material Properties

All elements are assumed to have uniform properties. Values for Young's modulus, Poisson's ratio and yield stress used are 30 x 10^6 psi, 0.3 and 35000 psi, respectively, and are entered in the ISOTROPIC option.

Loading

Internal pressure of 1.0 psi is applied to elements 1, 2, 3, 4, 12, 20, 28, 36 (the connectivity for ring elements 12, 20, 28, 36 indicates the pressure is applied on the 1-3 element face.)

Tying

The single type of tying required between the two elements is imposed through nodal constraints on the plane of transition (z = 4.75") between the element types. Figure 2.3-2 shows the transition plane through node s (shell node) and t (ring node) normal to the RZ plane. Local coordinates are also shown. In this coordinate system the constraints are:

$v_t = v_s + z\phi_s$ (t = node numbers 5, 6, 7, 8, 9)

where z is the distance from the ring node to the shell node along local z-axis, and

$u_t = u_s$ for t = node 7

These compatibility constraints are implemented in the program as tying type 23. They are programmed in local coordinates as defined above.

Transformation

In this example, degrees of freedom at nodes 5 to 9 must be rotated clockwise 90 degrees (using the TRANSFORMATION option) to match this type of coordinate system. Then tying type 23 is used to tie the two degrees of freedom of each ring node to the three degrees of freedom of the shell node (u_s, v_s, δ_s). The constrained node is the particular off center node of the transition plane; the retained node is the middle surface node of the shell. A general discussion of tying degrees of freedom is in *Volume A: Theory and User Information.*

Boundary Conditions

Other constraints applied to the structure are fixed-end conditions for both degrees of freedom on nodal point 25 to 29 and a rotational constraint for shell node 1. The boundary conditions shown for the third degree of freedom of the ring elements are not necessary and can be deleted if desired.

Results

The structure was elastically analyzed and element 2 was found to have the largest equivalent stress and the largest membrane stress.

If one can consider the shell to be long, then in element 1 away from the thick cylinder, the hoop stress would be:

$$\frac{pr}{t} = 150 \text{ psi}$$

The calculated MARC solution is 149.4 psi. for element 1, integration pt. 1.

Parameters, Options, and Subroutines Summary

Example e2x3.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
PRINT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	TRANSFORMATION
	TYING

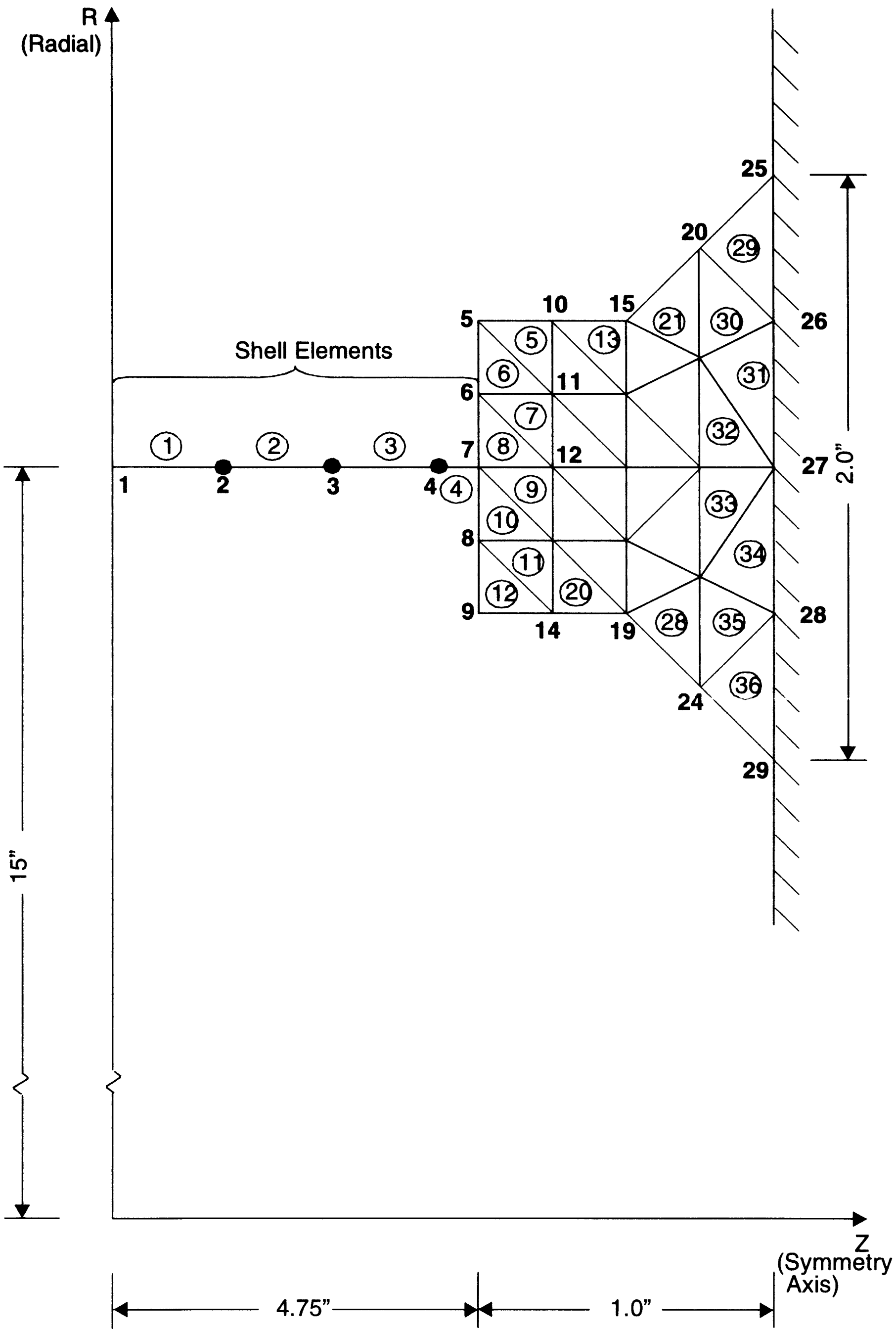


Figure 2.3-1 Mesh and Geometry for Axisymmetric Solid-Shell Intersection

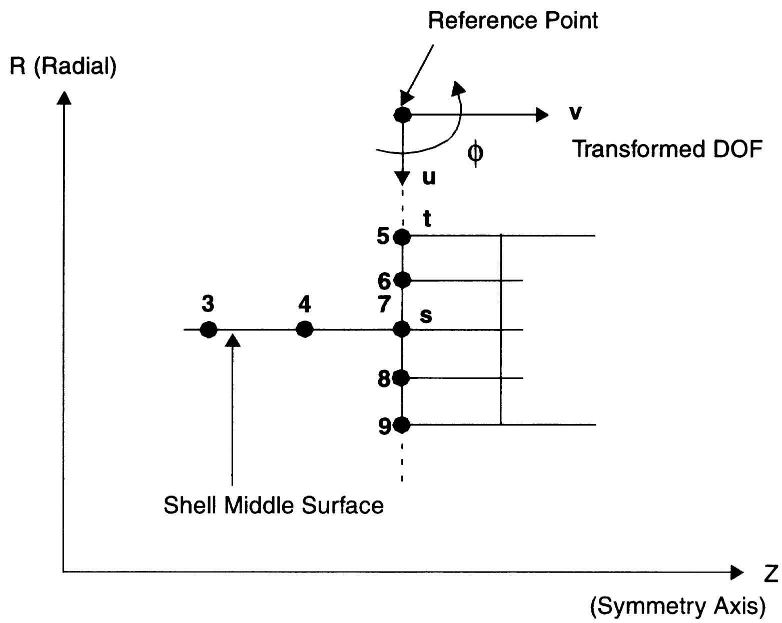


Figure 2.3-2 Tying Description

2.4 Axisymmetric Solid-Shell Intersection

This problem demonstrates the use of user subroutine UFORMS to model a solid-to-shell intersection. A thin axisymmetric cylinder is intersected with a thick cylinder. The combined structure is subjected to uniform internal pressure. This problem is identical to the one analyzed in problem 2.3, and the solution of the two can be compared.

Elements

Element types 15 and 10 are used. Element type 15 is a 2-node axisymmetric thin-shell element. Element type 10 is an axisymmetric ring element with arbitrary quadrilateral cross-section.

Model

Four shell elements, 16 ring elements, 29 nodes, and 68 degrees of freedom total are used (see Figure 2.4-1).

Geometry

Thickness (0.1 in.) for elements 1 to 4 (shell elements) is stored in EGEOM1. No geometry specification is required for the ring element.

Loading

Internal pressure of 1.0 psi is applied to elements 1, 2, 3, 4, 8, 12, 16, and 20. Please note the connectivity specifications for these elements; pressures on the 1-2 face of element type 10 (IBODY = 0), and uniform pressure (IBODY = 0) on element type 15.

Transformation

Nodes 5, 6, 8, and 9 have their degrees of freedom transformed to facilitate the use of tying.

Tying (UFORMS)

The compatibility constraint at the junction of the solid and shell elements is imposed by tying degrees of freedom between node 7 (shell degrees of freedom) and nodes 5, 6, 8, 9 (solid degrees of freedom). The tying is accomplished with a UFORMS user subroutine. First, the two degrees of freedom at nodes 5, 6, 8, 9 are rotated clockwise 90 degrees (see Figure 2.4-2). The constraint matrix equation for a node is as follows:

$$\begin{bmatrix} u_t \\ v_t \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & z_1 \end{bmatrix} \begin{bmatrix} u_s \\ v_s \\ du/ds \\ dv/ds \end{bmatrix}$$

(constrained quadrilateral node)(middle shell surface node 7)

$v_t = u_s + z_1\, dv/ds$

z_1 is the directed distance parallel to the global R-axis and positive toward the symmetry axis between the retained node and the tied node. Thus,

$v_t = u_s$ at node 7.

The tying could alternatively have been done using tying type 25.

Boundary Conditions

Nodes 25 to 29 are fixed in both degrees of freedom, and shell node 1 is fixed against rotation, $dv/ds = 0$.

Results

The structure was elastically analyzed. Element 1 was found to have the largest equivalent stress and the largest membrane stress.

The results compare closely to problem 2.3. The following results are for integration point 2.

Element	Example 2.3		Example 2.4	
	σ_1 (psi)	σ_2 (psi)	σ_1 (psi)	σ_2 (psi)
1	-.1549	151.1	-.0508	151.1
2	.9264	160.5	.0067	160.6
3	1.8610	110.9	.0598	110.6
4	.03161	19.79	.01398	19.80

The differences in the membrane stress σ_1 are attributable to the fact that element type 1 as used in problem 2.3 has a constant membrane strain variation whereas element type 15 as used in this problem allows a linear variation in membrane strain.

Parameters, Options, and Subroutines Summary

Example e2x4.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
PRINT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	TRANSFORMATION
	TYING

User subroutine in u2x4.f:
UFORMS

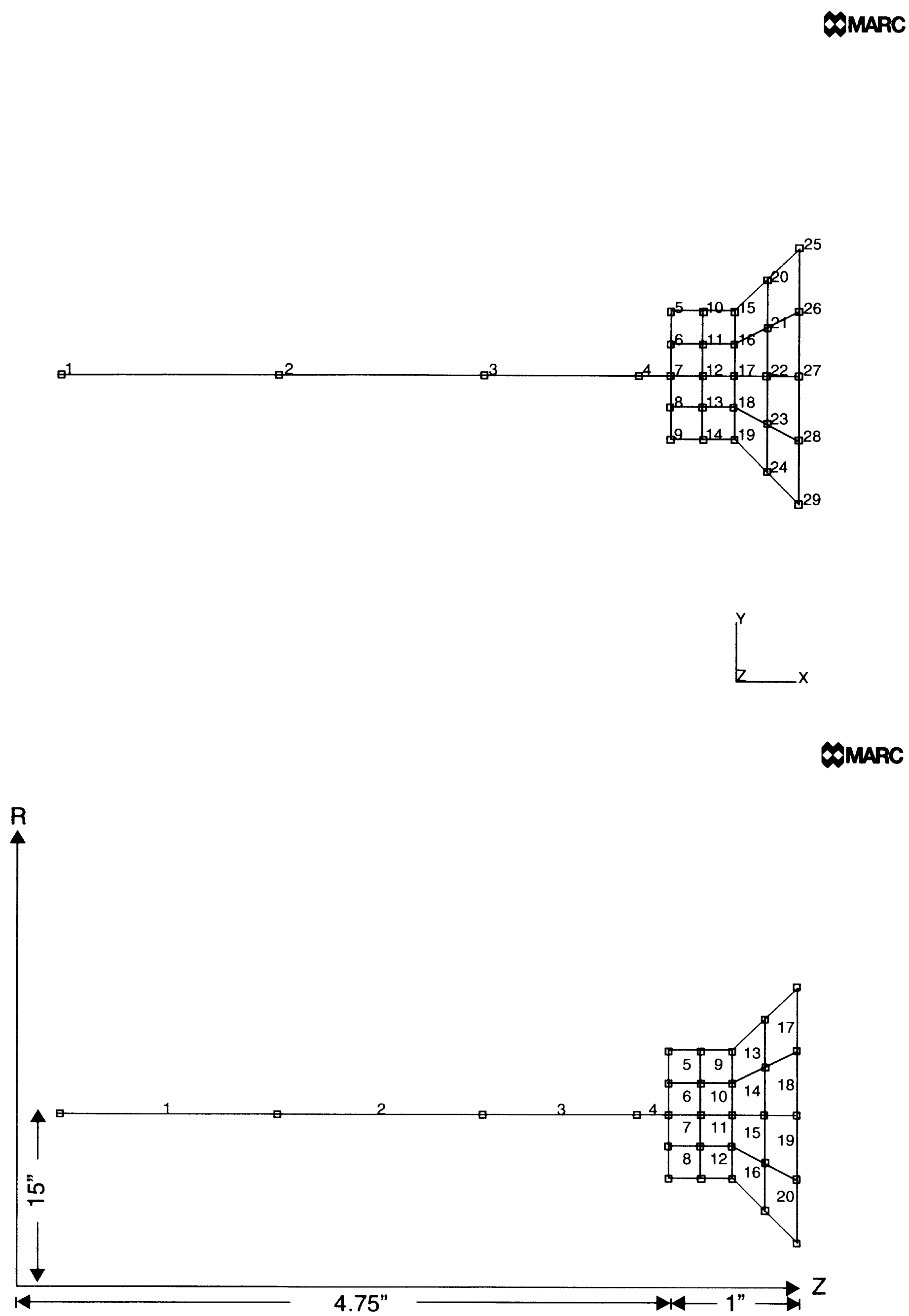


Figure 2.4-1 Solid-Shell Intersection Model

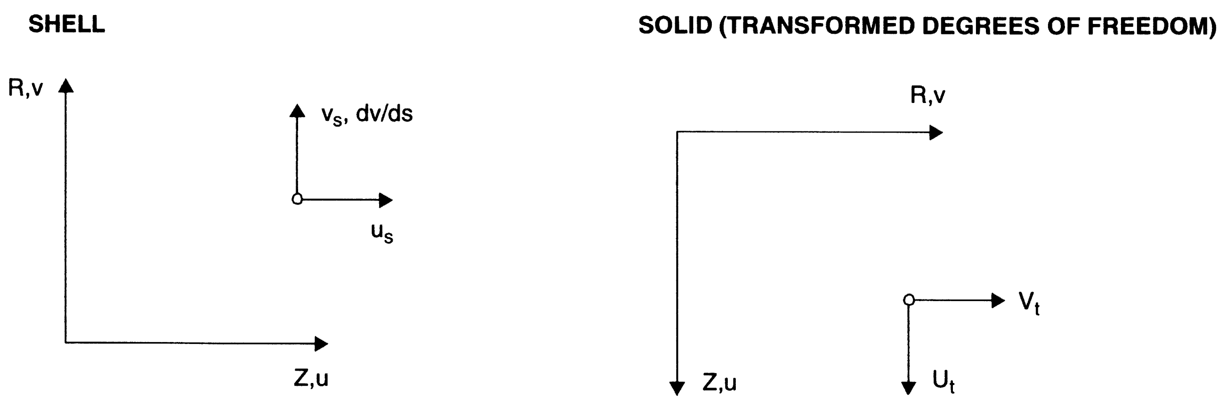


Figure 2.4-2 Tying and Transformations

2.5 Doubly Cantilevered Beam Loaded Uniformly

The solution of a cantilevered beam with a rectangular cross section subjected to a uniform load is obtained. This problem demonstrates the accuracy of the simple two-dimensional beam element.

Element

As this is a two-dimensional problem, it is possible to use element type 5, a straight, 2-node, rectangular-section, beam column. The displacement assumption is linear along the length (L) of the beam and a cubic displacement assumption in the direction normal to the beam. The numerical integration is 3-point Gaussian quadrature along the length of the element and 11-point Simpson's rule through the thickness. The two nodes of each element have three degrees of freedom each: u, v, and right-hand rotation.

Model

Symmetry allows a model of one-half the beam to be used. Five elements and six nodes are used for a total of 18 degrees of freedom (see Figure 2.5-1).

Geometry

The height of 1.0 (in-plane) is specified in the first data field, EGEOM1. The cross-sectional area of 1.0 is specified in the second data field, EGEOM2.

Loading

All five elements are loaded with a uniform distributed load of magnitude 10. This load is specified in the DIST LOADS option as type 0 (IBODY = 0).

Boundary Conditions

One end of the beam is rigidly fixed; $u = v = \theta = 0$ for node 1. The midbeam node (6) is fixed against axial expansion ($u = 0$) and against right-hand rotation ($\theta = 0$); this ensures the correct symmetry conditions.

Results

Deflections at nodal points shown in Figure 2.5-2 are tabulated in Table 2.5-1 and compared with exact answers. Correlation is very good. However, for a problem where the beam bending aspect of the model is critical, element type 16 should be used. With its higher-order integration and additional degrees of freedom per node, it will yield better answers.

Table 2.5-1 Results

Node	MARC Computed Deflection	Analytically Calculated Deflection
1	0	0
2	2.03×10^{-5}	2.03×10^{-5}
3	6.40×10^{-5}	6.40×10^{-5}
4	1.103×10^{-4}	1.103×10^{-4}
5	1.440×10^{-4}	1.440×10^{-4}
6	1.563×10^{-4}	1.563×10^{-4}

The solution can be expressed as:

$$\sigma = \frac{My}{I}$$

$$\text{Shear force } V = p\left(\frac{L}{2} - x\right)$$

$$\text{Moment } M = \frac{pL^2}{12}\left(1 - \frac{6x}{L} + \frac{6x^2}{L^2}\right)$$

$$\text{Rotation} = \frac{PL^3}{12EI}\left(\frac{2x}{L} - \frac{3x^2}{L^2} + \frac{2x^3}{L^3}\right)$$

$$\text{Displacement} = \frac{pL^4}{24EI}\left(\frac{x^2}{L^2} - \frac{2x^3}{L^3} + \frac{x^4}{L^4}\right)$$

Parameters, Options, and Subroutines Summary

Example e2x5.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC

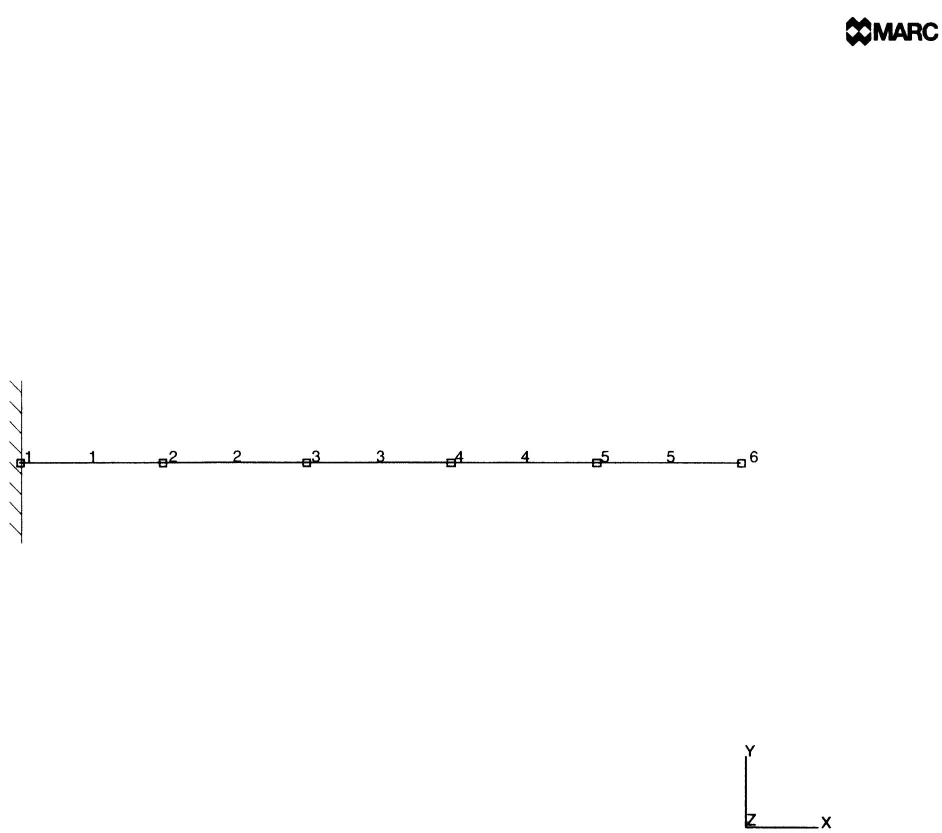


Figure 2.5-1 Beam Model

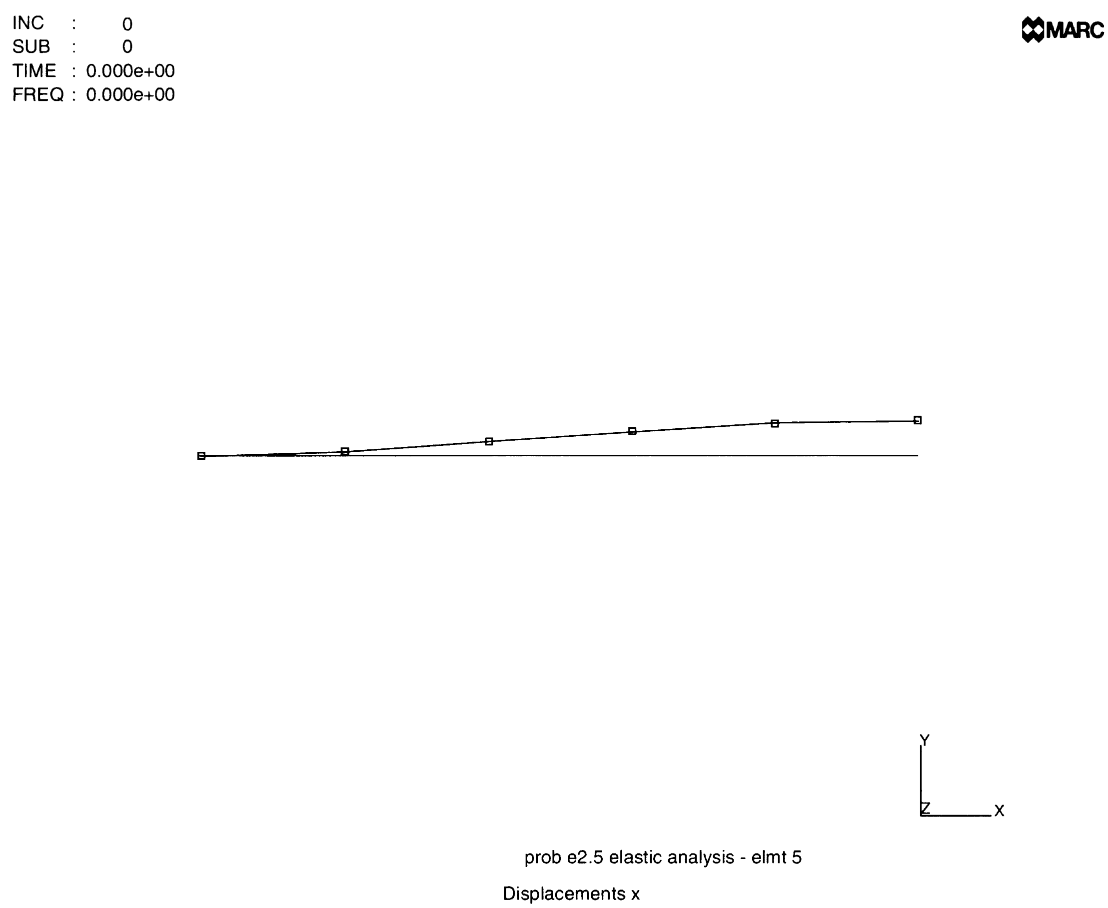


Figure 2.5-2 Deformations

2.6 Open Section, Double Cantilever Beam Loaded Uniformly

An I-section beam is loaded uniformly, parallel to the plane of the web. The beam is fixed against rotation and displacement at each end. This problem demonstrates the use of the BEAM SECT parameter to define the cross section of a beam. The results are compared to the analytic solution.

Element

Library element type 13 is used. This element is an open-section, curved, thin-walled beam of arbitrary section. It is based on classical theory of thin-walled beams with primary warping effects. The beam axis and cross-section orientation are interpolated cubically from 13 coordinates per node. This element has eight degrees of freedom per node.

Model

The beam of length 10 is modeled with 10 elements and 11 nodes for a total of 88 degrees of freedom (see Figure 2.6-1).

Geometry

EGEOM2 is used as a floating point value to cross reference the section number. EGEOM2 = 1 as only one section type is given here.

Material Properties

The Young's modulus is specified as 20 x 10^6 psi. Consistency with the analytical solution requires Poisson's ratio to be 0.

Loading

Uniform pressure of 10 pounds per length in the negative global Y direction.

Boundary Conditions

The beam is fixed against rotation and displacement at each end; that is:

$u = 0$	$dv/ds = 0$	$d\theta/ds = 0$
$v = 0$	$dw/ds = 0$	
$w = 0$	$\phi = 0$	

Special Considerations (Beam Section)

Element 13 has a cross-section specification that is entered in the parameter card section, after the header BEAM SECT. Details are given in *MARC Volume A: Theory and User Information.* In the present case, five branches are used to define the beam section (see Figure 2.6-2).

The first branch is one flange of beam, read in at constant thickness (0.18 inch) and with no curvature. The second branch is a zero thickness branch that doubles back to the flange center. The third branch is the web, straight and with constant thickness (0.31 inch). The fourth branch is half the remaining flange, with zero thickness. The fifth branch is straight and with constant thickness (0.18 inch) which doubles back over the fourth branch.

This element also requires 13 coordinates. In a more complex configuration, it would be advantageous to use subroutine UFXORD as a coordinate generator. Here, generation by hand is simpler. dx/ds and dy/ds in the section specification are not the same as dx/ds and dy/ds in the coordinate specification. The latter s is distance along the beam; the former is distance along a branch of the section. Also note the director specification, coordinates seven through nine, which orients the first axis of the local xy section plane in global xyz coordinates.

Results

An elastic analysis was performed. Five generalized strains and axial stress at integration points are printed out. The results are compared with calculated results from *Formulas for Stress and Strain*, R. J. Roark. These are summarized in Table 2.6-1. Figure 2.6-3 shows the moment diagram which was obtained by using the LINEAR parameter. Figure 2.6-4 shows the deformations.

Table 2.6-1 Results

Node	MARC Computer Deflection	Analytically Calculated Deflection
1	0	0
2	1.82×10^{-5}	1.82×10^{-5}
3	5.79×10^{-5}	5.75×10^{-5}
4	9.99×10^{-5}	9.91×10^{-5}
5	1.307×10^{-4}	1.295×10^{-4}
6	1.419×10^{-4}	1.404×10^{-4}

Parameters, Options, and Subroutines Summary

Example e2x6.dat:

Parameters

BEAM SECT
ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC

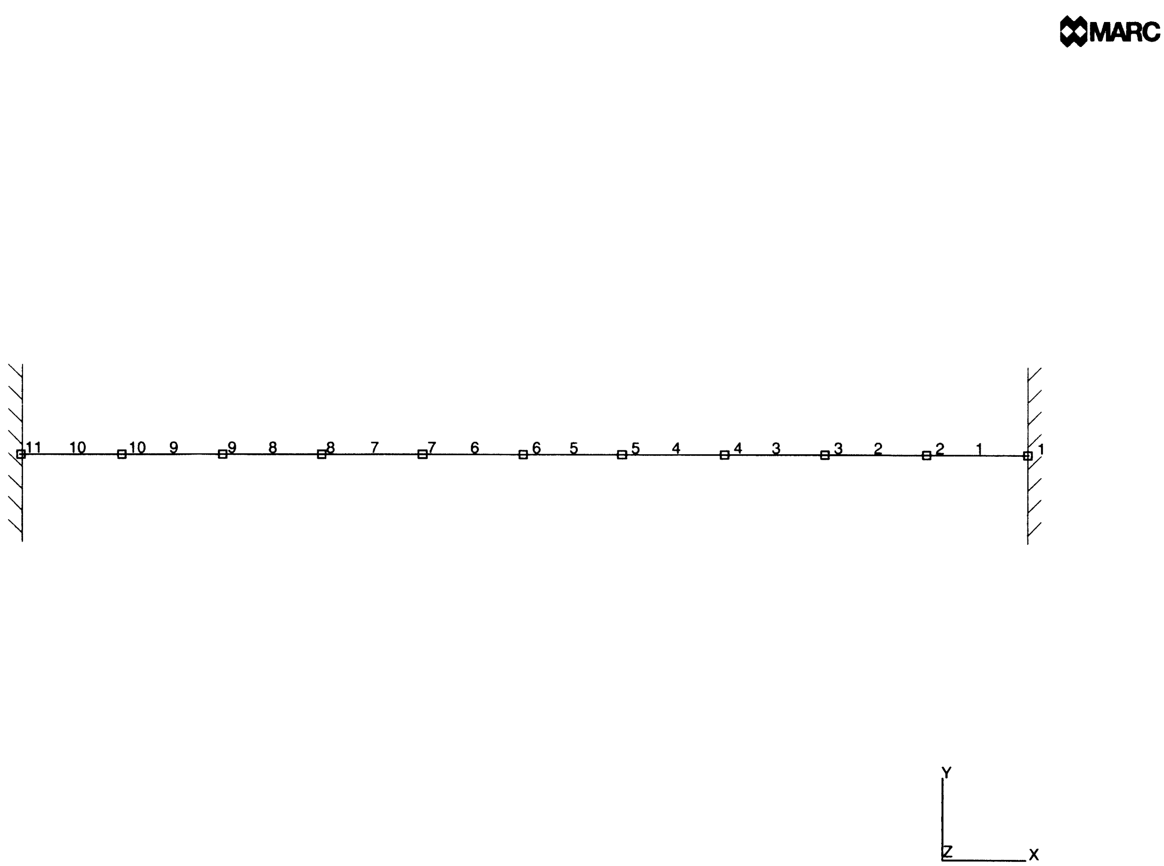


Figure 2.6-1 Open Section Beam Model

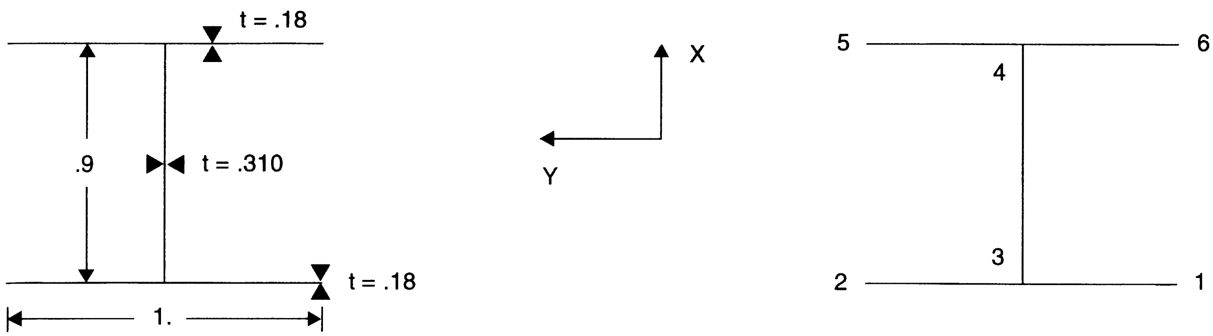


Figure 2.6-2 Beam Section and Sequence of Branch Traversal

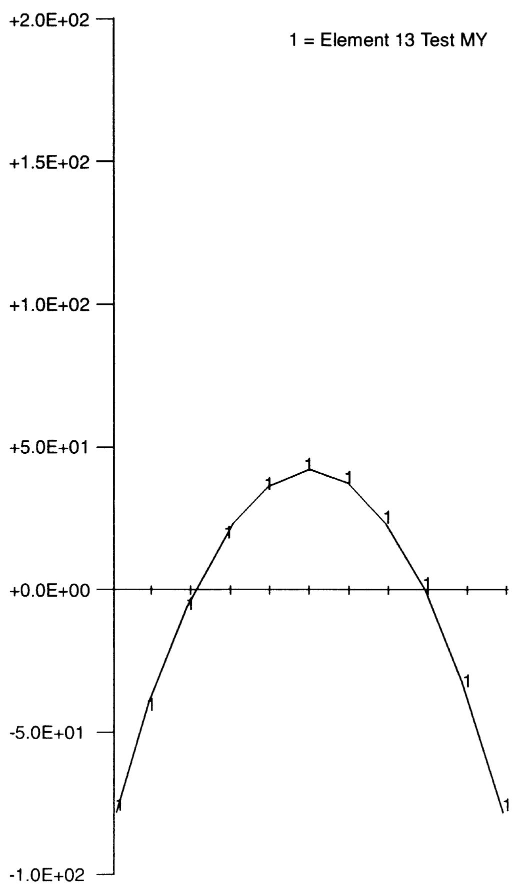


Figure 2.6-3 Moment Diagram

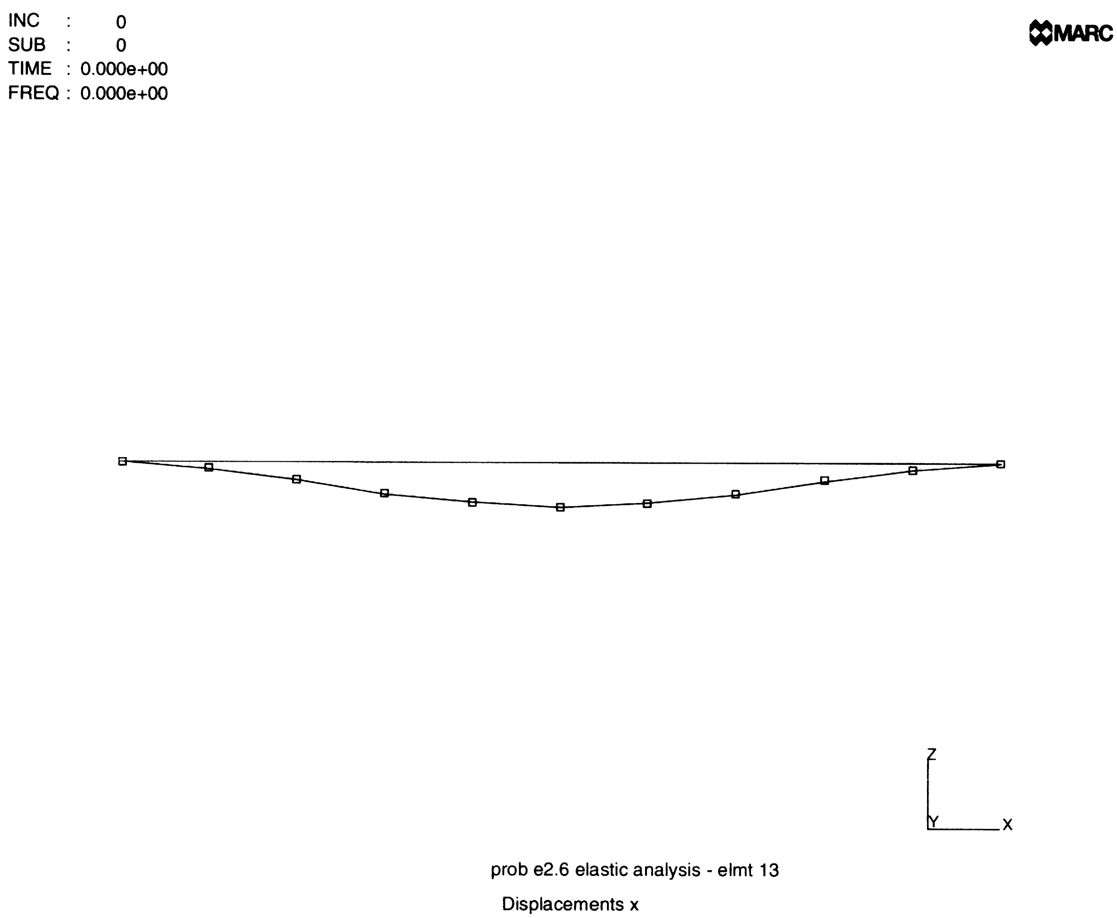


Figure 2.6-4 Deformations

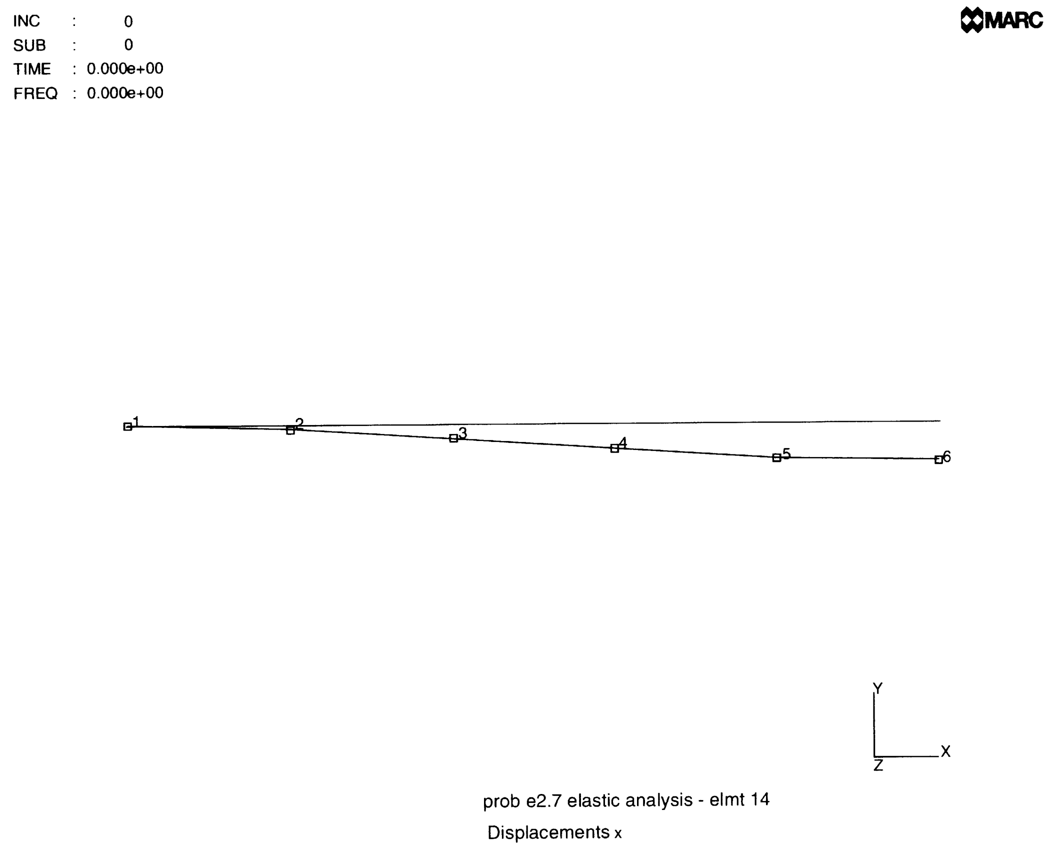


Figure 2.7-3 Deformed Beam

2.8 Curved Beam Under a Point Load

This problem demonstrates the use of the curved-beam element to model a 90-degree section of a circular beam. The beam is loaded in its plane in a radial direction on its free end. The solution is compared to the analytic solution.

Element

Since this is a two-dimensional problem, library element type 16 can be used. It is a curved, two-dimensional beam. The displacements are interpolated cubically and the element formulation is isoparametric. The four degrees of freedom are two in-plane displacements and two derivatives with respect to s, the length of the beam. See *MARC Volume B: Element Library* for a complete description.

Model

One end of the beam is fixed; the other end is loaded. There are four elements and five nodes for a total of 20 degrees of freedom (see Figure 2.8-1).

Geometry

The first data field, EGEOM1 specifies thickness at the first node of an element as 1.6 inches. Linear thickness variation is allowed along the length of the element. The third data field default, EGEOM3 = 0., assumes constant thickness. If linear thickness variation is needed, the ALL POINTS parameter should be included. The second data field EGEOM2, is used to specify the beam width; the default width is unity; here it has been set to .1 inch. Thickness is in-plane and width is normal to the plane of the beam.

Material Properties

The Young's modulus is 26×10^6 psi, and Poisson's ratio is 0.3.

Loading

A single point load of 100 lbs. in the x-direction is applied to free-end node 5.

Boundary Conditions (APPBC)

One end of the beam is fixed against displacement and rotation (dv/ds = 0). The APPBC parameter is included, which allows for a more accurate calculation of the boundary condition constraints. The APPBC parameter uses row and column elimination of the stiffness matrix for the constrained degree of freedom, resulting in a slight increased accuracy of solution.

Results

The deflection of the end node and the stresses at the end of the beam are compared with calculated values in Table 2.8-1. The analytic solution may be found in Timoshenko and Goodier, *Theory of Elasticity.*

Table 2.8-1 Displacement and Stress Results

	Analytically Calculated	MARC Computed
u displacement (in.) node 5	.04536	.04543
v displacement (in.) node 5	-.02888	-.02874
σ_o max (psi)	17625.	18620.
σ_i max (psi)	-20060.	-17270.
σ_o is stress in extreme fiber on the convex side. σ_i is stress in extreme fiber on the concave side.		

Parameters, Options, and Subroutines Summary

Example e2x8.dat:

Parameters

APPBC
ELEMENTS
END
PRINT
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
POINT LOAD

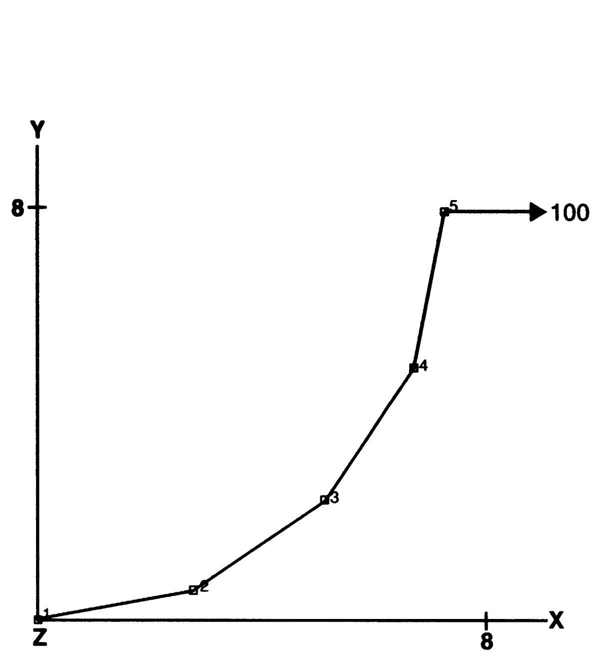


Figure 2.8-1 Curved Beam Model

2.9 Plate with Hole

This problem demonstrates several ways to solve the problem of a circular hole in plate which has a known solution (Timoshenko and Goodier, *Theory of Elasticity*). The hole radius to plate size ratio is chosen to be 5, approximating an infinite plate. The second order isoparametric elements (types 26 and 124) are used first, followed by the use of the linear order type 3 using adaptive meshing.

This problem is modeled using the four techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x9	26	20	79	
e2x9b	26	20	79	ELEM SORT, NODE SORT
e2x9c	124	40	99	
e2x9d	3	2	6	ADAPTIVE

Elements

Element type 26 and 124 are second-order isoparametric elements for plane stress. Type 26 is an 8-node quadrilateral, and type 126 is a 6-node triangle. Element type 3 is a 4-node first-order isoparametric element.

Model

The dimensions of the plate are 5 inches square with a 1 inch radius. Only one quarter of the plate is modeled due to symmetry conditions. The finite element mesh for element type 26 is shown in Figure 2.9-1, and the elements near the hole are made smaller. There are 20 elements in the quadrilateral meshes and 40 elements in the triangular meshes. The triangular mesh is made from the quadrilateral mesh by adding a node in the center of each element; then, the quadrilaterals are broken up into triangles. In problem e2x9d, the mesh initially consists of two elements as shown in Figure 2.9-2. As the mesh adapts, the number of elements increase until there are 65 elements in the mesh.

Material Properties

The material for all elements is treated as an elastic material with Young's modulus of 30.0E+06 psi and Poisson's ratio (ν) of .3.

Geometry

The plate has a thickness of 1 inch given in the first field.

Loads and Boundary Conditions

A distributed load of -1.0 psi is applied to the top edge of the mesh. The boundary conditions are determined by the symmetry conditions and require that the nodes along y = 0 axis have no vertical displacement, and the nodes along the x = 0 axis have no horizontal displacement. The origin of the model is at the center of the hole.

Adaptive Meshing

Problem e2x9d demonstrates the use of adaptive meshing. The ADAPTIVE parameter defines an upper bound to the number of elements and nodes. The ADAPTIVE model definition option is used to indicate that the adaptive criteria is based upon the stress in an element which is not to exceed 75% of the maximum stress. As this would clearly refine forever, a limit of five levels is requested. This procedure is a way to add elements where a stress concentration exists. The SURFACE option defines a circle with a radius of one. When used with the ATTACH NODE option, this insures that the newly created nodes are places on the circle. The ATTACH NODE option indicates that nodes 1, 2, and 3 are on the circle, and any newly created nodes also lie on the circle. Boundary conditions are generated automatically for the nodes created along y = 0.

Results

Figure 2.9-3 and Figure 2.9-4 contour the second component of stress (σ_{22}) over the mesh. Figure 2.9-5 tabulates and plots values of σ_{22} for Element types 26, 124 and the exact solution along the y = 0 axis. The finite element solution is approximated by a plate of finite dimensions; there is some difference in predicting the exact solution. The results would improve if more elements were used. Figure 2.9-7 through Figure 2.9-10 show the progression of the mesh during the adaptive meshing process. After adaptive meshing, the stress concentration predicted is 2.86.

Parameters, Options, and Subroutines Summary

Example e2x9.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POST

Example e2x9b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	ELEM SORT
	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NODE SORT
	PRINT CHOICE
	SUMMARY

Example e2x9c.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NO PRINT
	OPTIMIZE
	POST

Example e2x9d.dat:

Parameters	Model Definition Options
ADAPT	ADAPTIVE
ELASTIC	ATTACH NODE
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	POST
	SURFACE

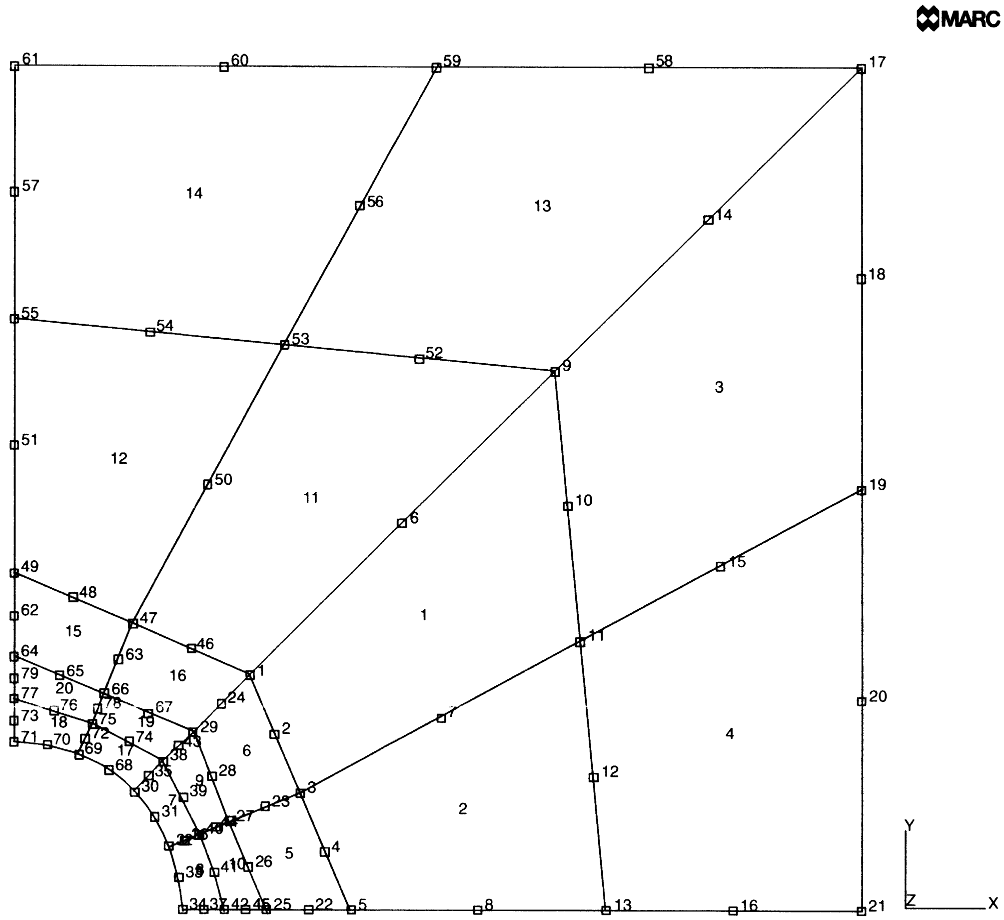


Figure 2.9-1 Mesh Layout for Plate with Hole (Element 26)

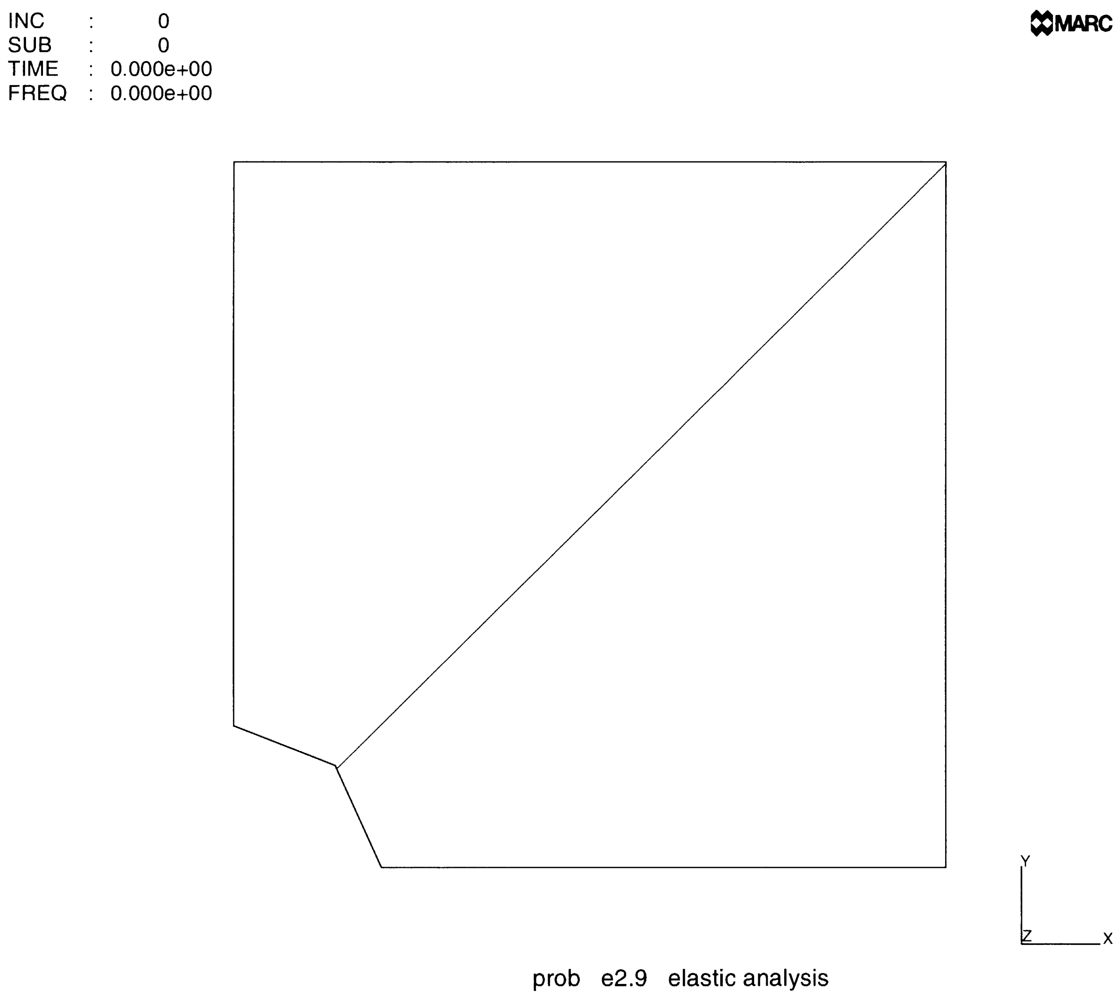


Figure 2.9-2 Original Mesh for Plate with Hole When Using Adaptive Meshing

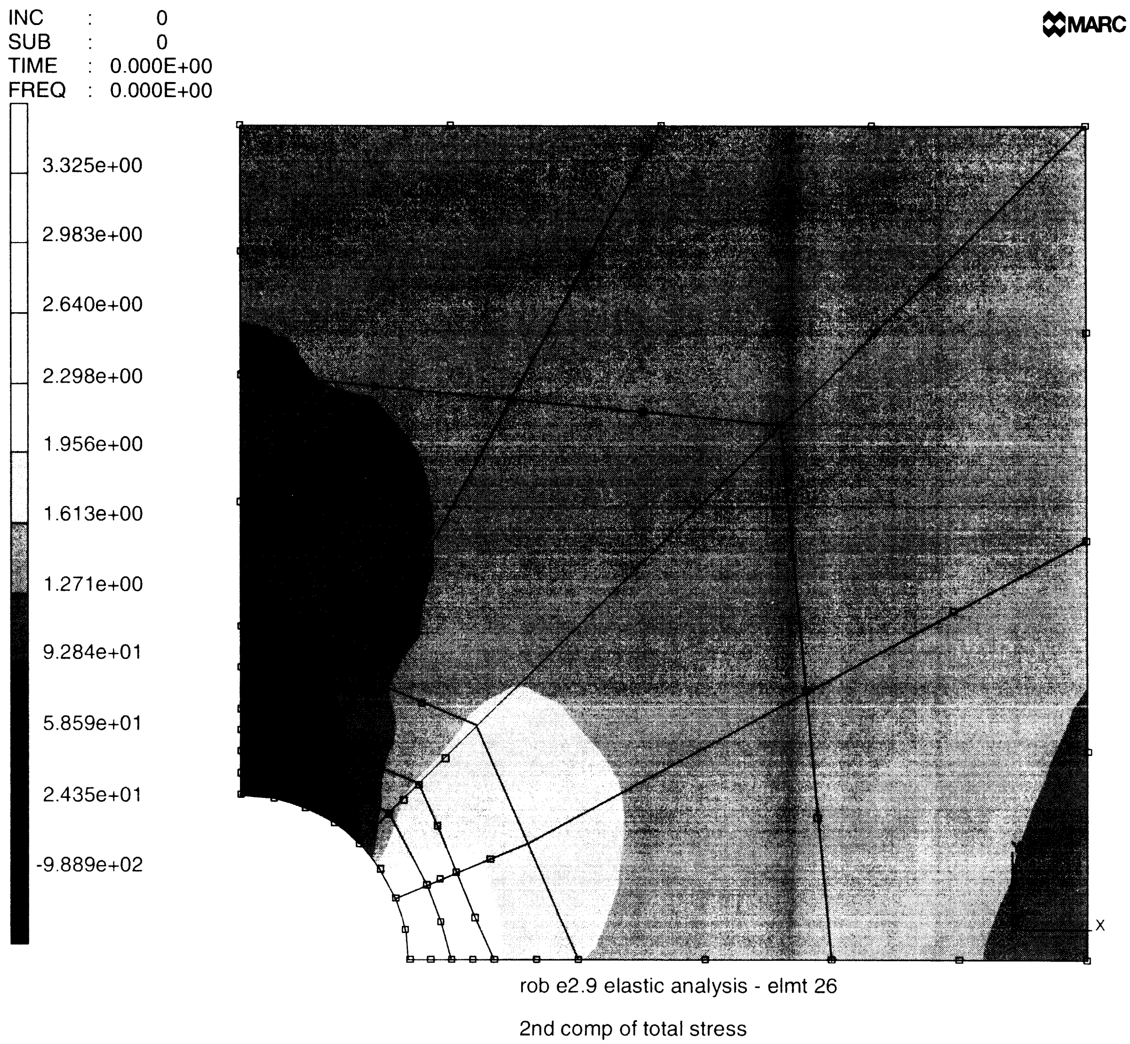


Figure 2.9-3 Contours of σ_{22} Element 26

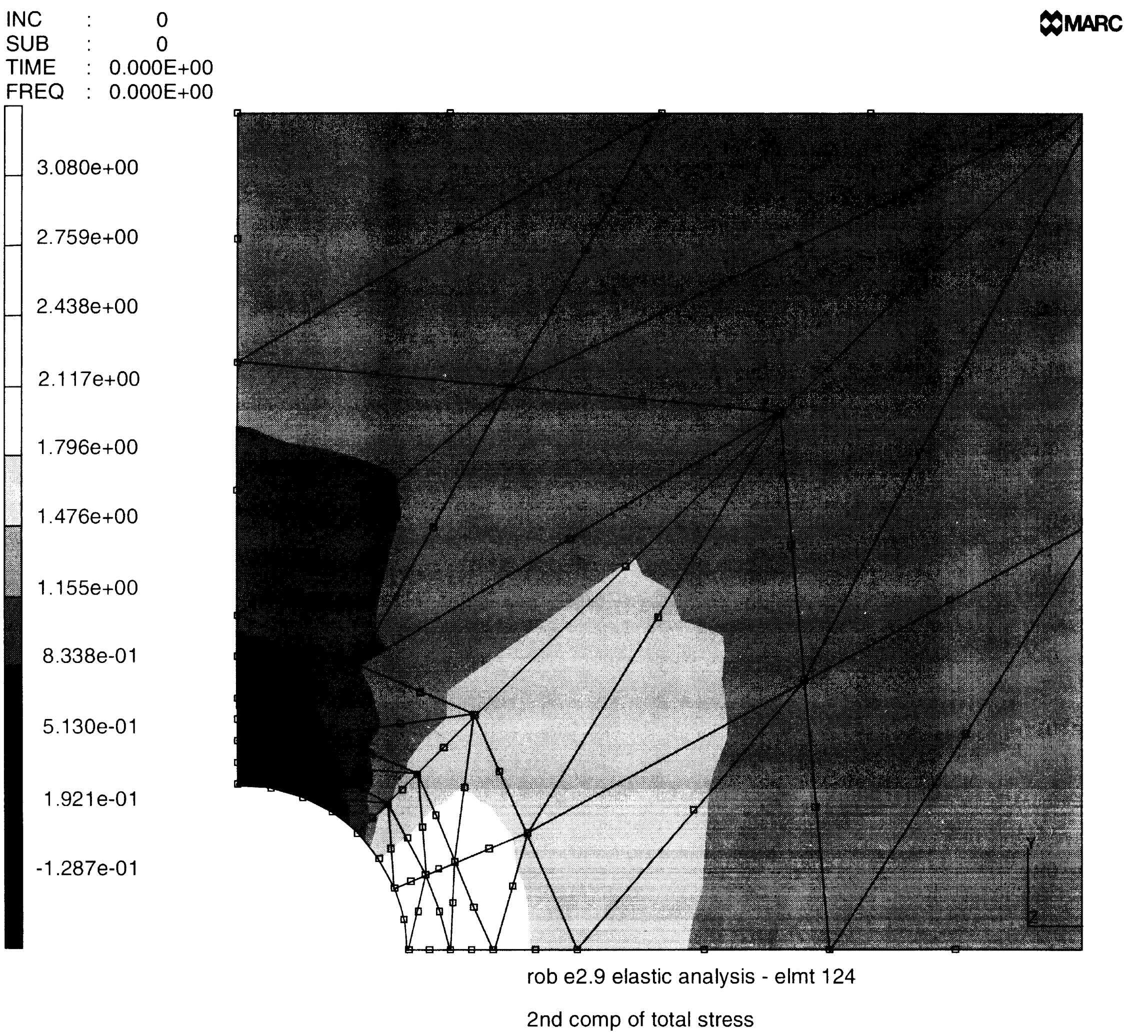


Figure 2.9-4 Contours of σ_{22} Element 124

Radius	Type 26	Type 124	Exact
1.00000	3.325290E+00	3.079772E+00	3.0000
1.12500	2.656915E+00	2.643165E+00	2.3315
1.25000	2.181081E+00	2.152462E+00	1.9344
1.37500	1.885873E+00	1.895210E+00	1.6841
1.50000	1.670818E+00	1.650798E+00	1.5185
1.75000	1.416509E+00	1.446365E+00	1.3232
2.00000	1.276260E+00	1.264376E+00	1.2188
2.75000	1.117434E+00	1.127211E+00	1.0923
3.50000	1.028915E+00	1.032025E+00	1.0508
4.25000	9.466122E-01	9.452355E-01	1.0323
5.00000	8.523712E-01	8.844259E-01	1.0224

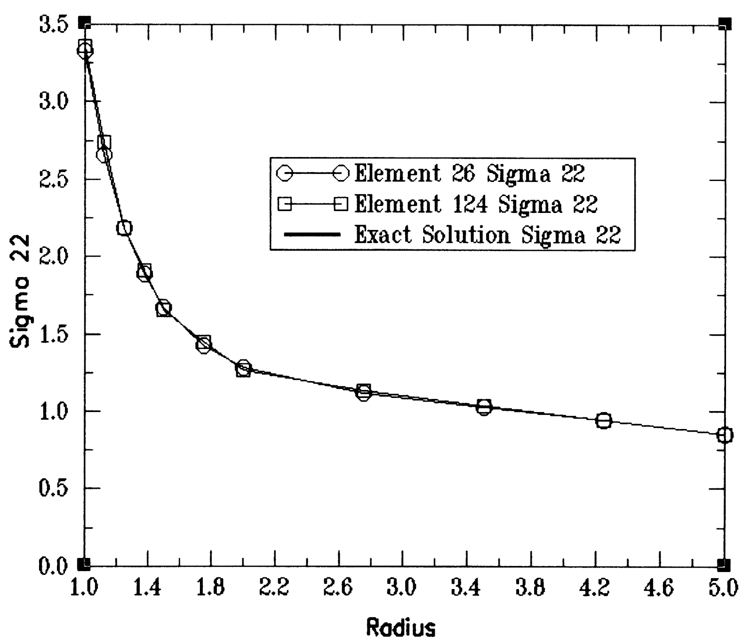


Figure 2.9-5 σ_{22} Along y = 0, Elements 26,124, and Exact

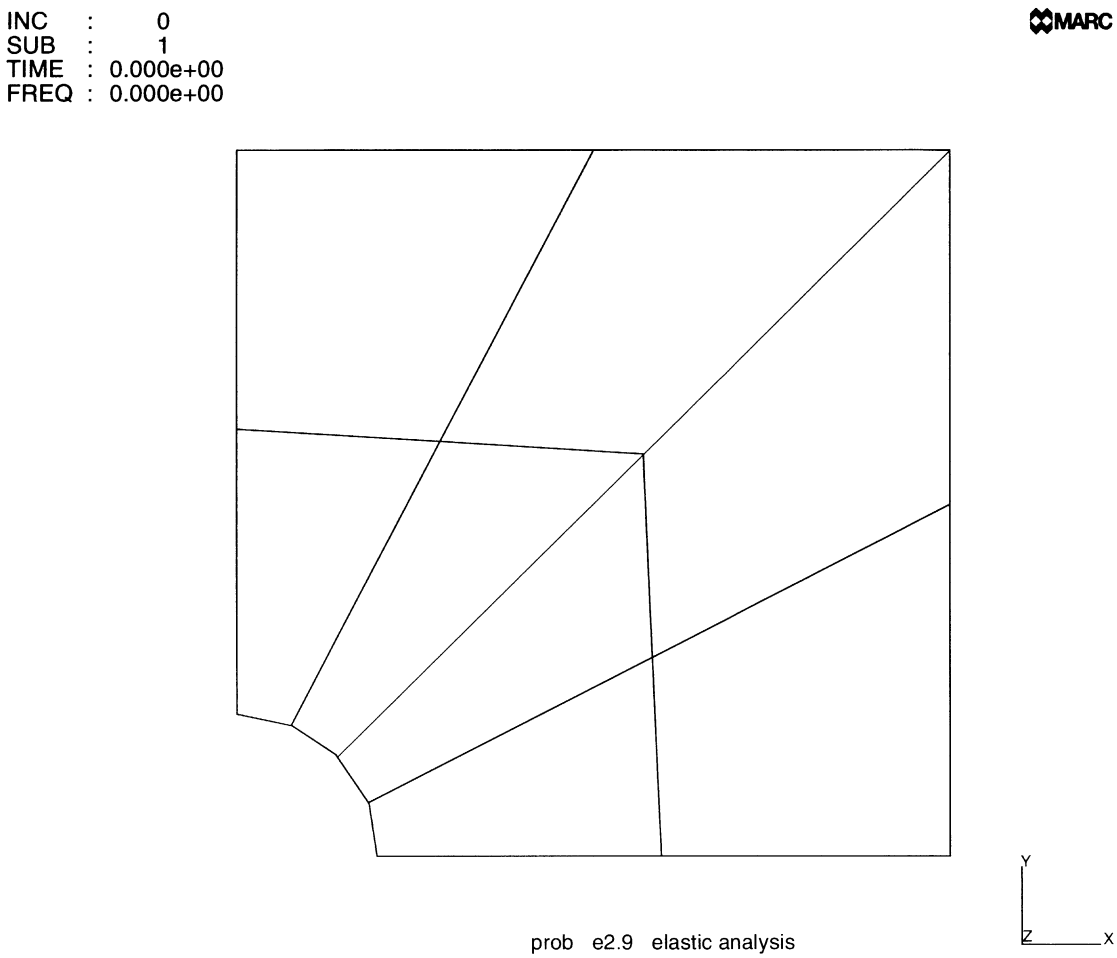


Figure 2.9-6 Mesh After First Refinement

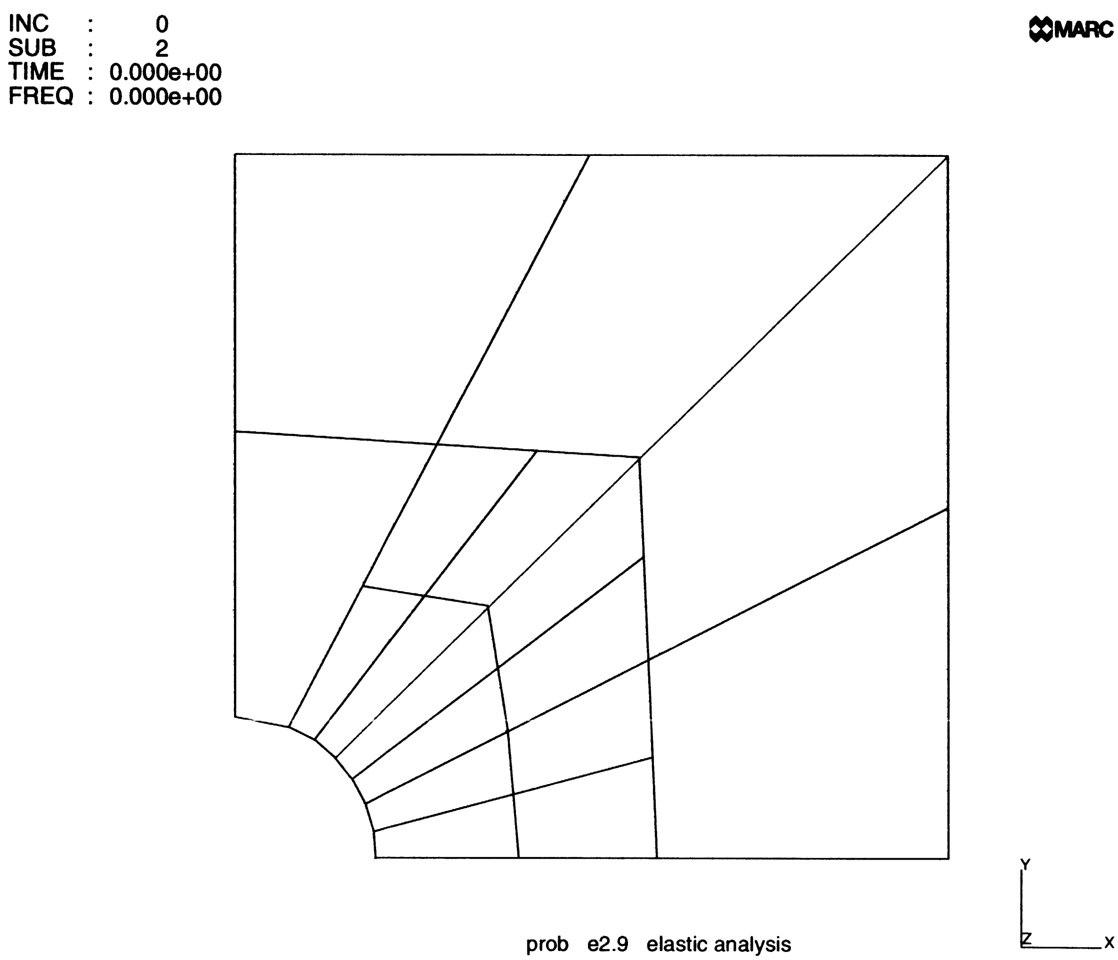


Figure 2.9-7 Mesh After Second Refinement

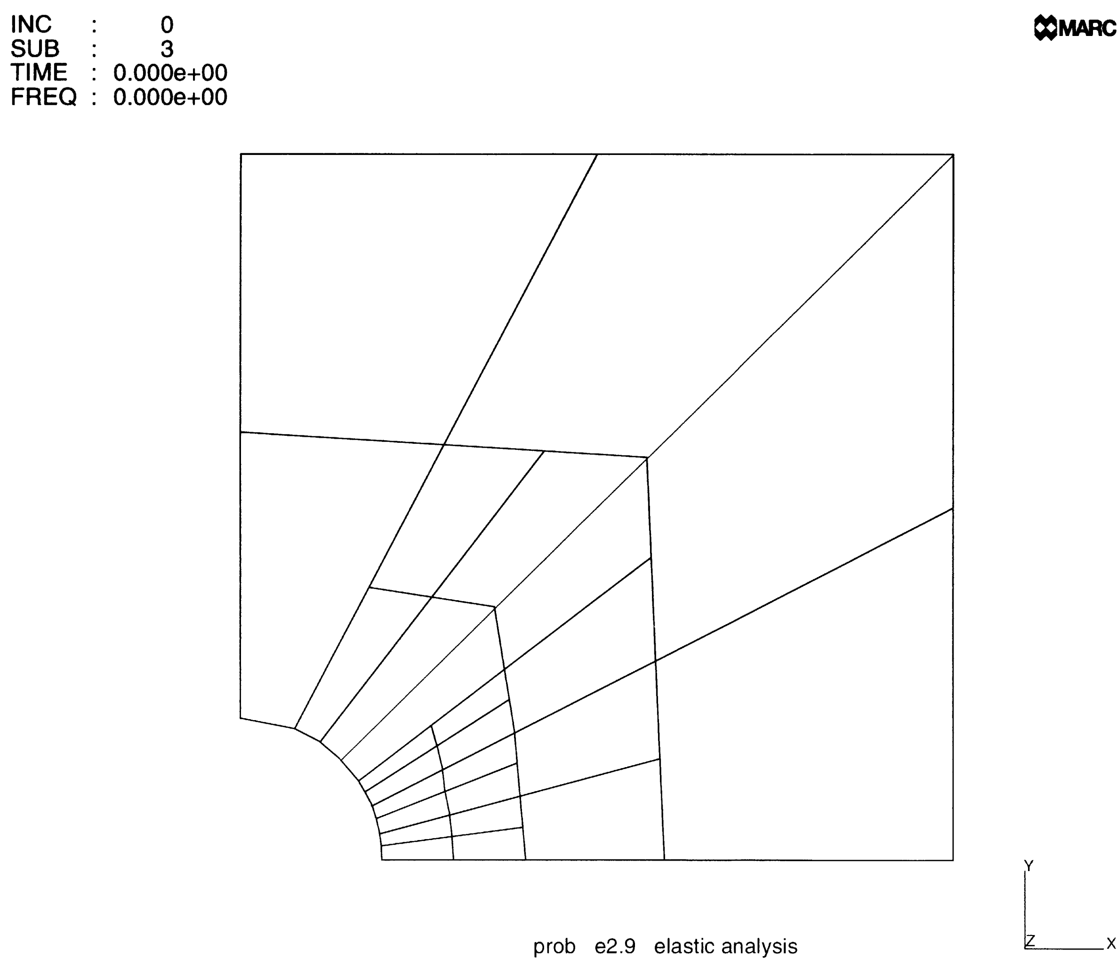


Figure 2.9-8 Mesh After Third Refinement

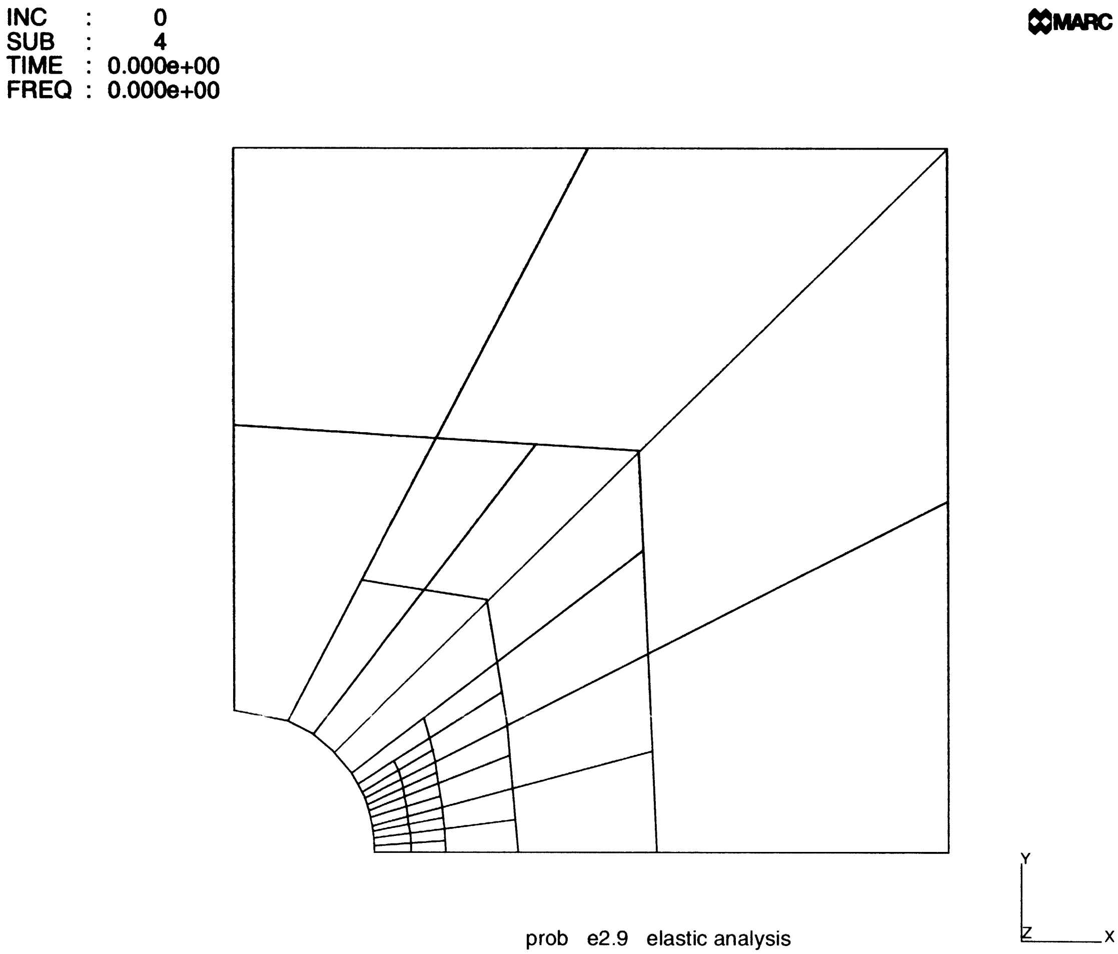


Figure 2.9-9 Mesh After Fourth Refinement

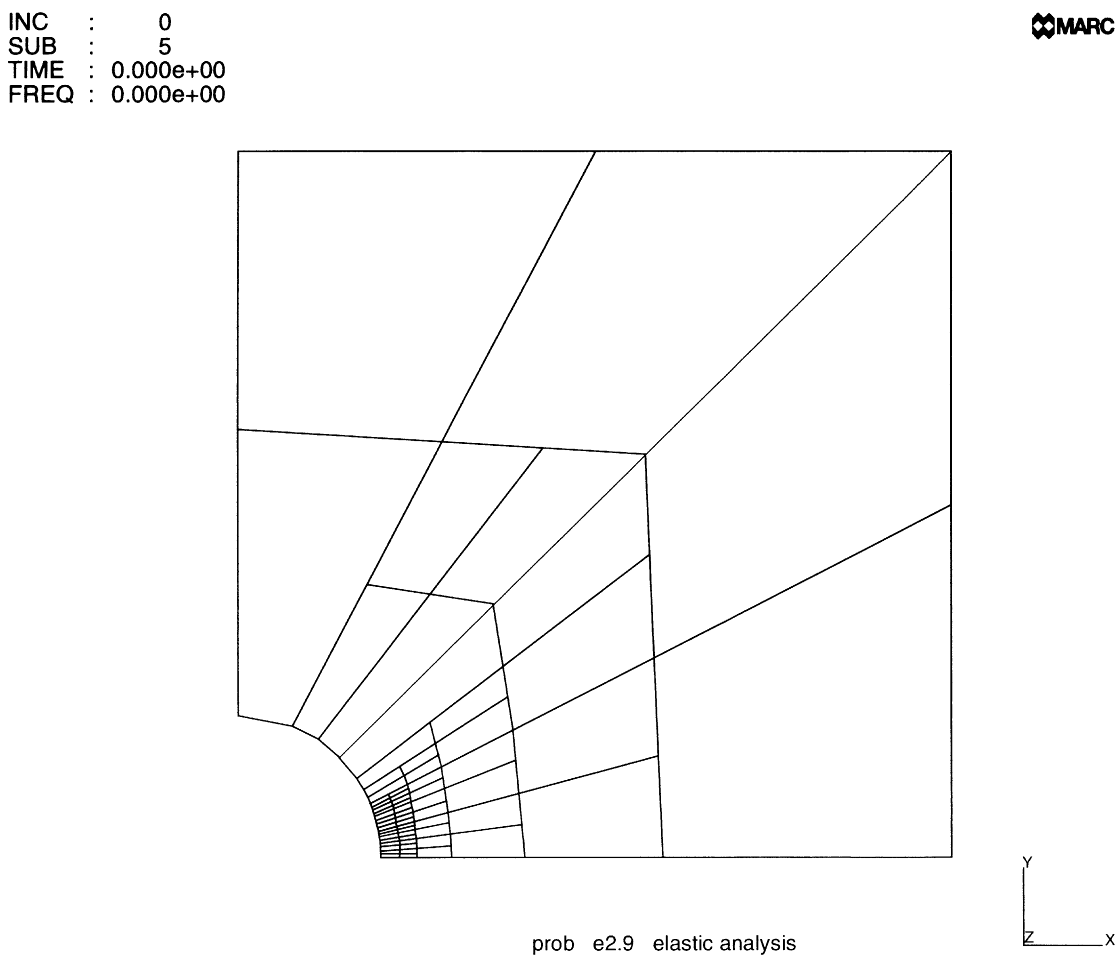


Figure 2.9-10 Mesh After Fifth Refinement

2.10 Plane Stress Disk

A thin circular disk with a diameter of 12 inches is subjected to diametrically-opposed concentrated loads of 100 lbf. The disk is modeled as an elastic material using two different types of plane stress elements. The results are compared to the analytic solution demonstrating the accuracy of the finite element model.

This problem is also modeled using the adaptive meshing procedure.

This problem is modeled using the three techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x10	3	64	82	
e2x10b	114	64	82	
e2x10c	3	64	82	adaptive meshing

Elements

The solution is obtained using first order isoparametric quadrilateral elements for plane stress, element types 3 and 114, respectively. Type 114 is similar to type 3; however, it uses reduced integration with hourglass control. The ALIAS parameter is used to switch elements between the two models.

Model

The diameter of the disk is 12 inches and only one half of the disk is modeled due to symmetry conditions. The finite element mesh used for both element types is shown in Figure 2.10-1. Initially, there are 64 elements and 82 nodes. The model origin is at the center of the disk.

Material Properties

The material for all elements is treated as an elastic material, with Young's modulus of 30.0E+04 psi, Poisson's ratio (ν) of .3, and a yield strength of 40,000 psi.

Geometry

The disk has a thickness of 1 inch given in the first field.

Loads and Boundary Conditions

A point load of -50 lbf (half of the total load) is placed on node 1 in the vertical direction. This point load is reacted by constraining the vertical displacement of the diametrically-opposed node (number 79) to zero. All nodes along the y-axis at x = 0 have their horizontal displacements constrained to zero.

Optimization

The Cuthill-McKee optimizer is used to reduce the bandwidth and hence the computational costs. Also notice that the computational costs of using element type 114 with reduced integration with hourglass control is lower than that of element type 3.

Adaptive Meshing

In problem e2x10c, the Zienkiewicz-Zhu stress error criteria is used with a tolerance of 0.05 in the third example. A maximum of three levels is allowed. The ELASTIC parameter is added to insure reanalysis until the error criteria is satisfied.

Results

The accuracy of the solution to this problem is shown in Figure 2.10-2, where the direct stress component in the vertical direction along the y = 0 axis is plotted against its exact value given in *Theory of Elasticity*, Timoshenko and Goodier, McGraw Hill, 1970, pp 122-123 as:

$$\sigma_{yy}(x,0) = 2P\,[1 - 4d^4/\left(d^2 + 4\,x^2\right)^2]\,/\,\pi\,d$$

Both σ_{xx} and σ_{yy} are shown in Figure 2.10-3.

The value of stress predicted by element type 114 is closer to the theoretical solution than element type 3. Also, the finite element solution cannot capture the singular behavior under the concentrated loads, and special elements and/or meshes are usually needed in order to obtain accurate solutions near such singularities. The adaptive meshing procedure is useful for these problems.

After the first solution in the third analysis, elements 1, 2, 4, 5, 58, 59, 62, and 63 are refined to satisfy the error criteria. After the second trial, original elements 8 and 53 are subdivided along with eight of the new elements. After the third trial, eight elements are subdivided. This procedure is continued until all of the elements either satisfy the error criteria or have been refined three times. A close-up of the final mesh is shown in Figure 2.10-4.

Parameters, Options, and Subroutines Summary

Example e2x10.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	POINT LOAD
	POST

Example e2x10b.dat:

Parameters	Model Definition Options
ALIAS	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SIZING	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	POINT LOAD
	POST

Example e2x10c.dat:

Parameters	Model Definition Options
ADAPTIVE	ADAPTIVE
ELASTIC	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SIZING	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	POINT LOAD
	POST

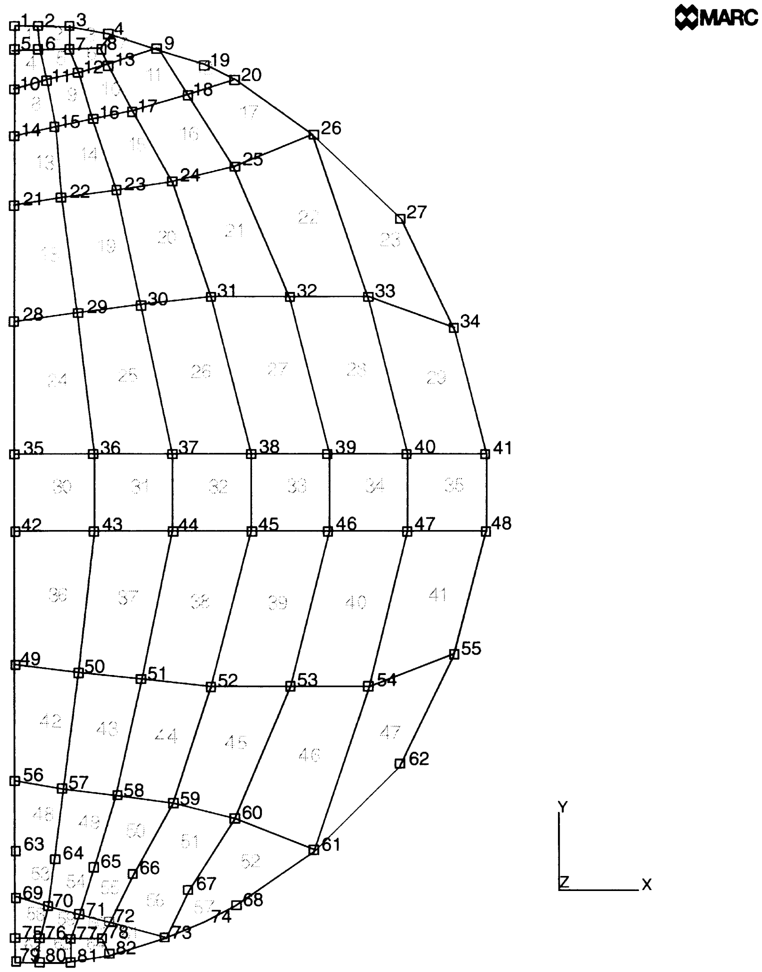


Figure 2.10-1 Model

Radius	Type 3	Type 114	Exact
0	-1.681E+01	-1.616E+01	-1.592E+01
1	-1.571E+01	-1.508E+01	-1.478E+01
2	-1.288E+01	-1.222E+01	-1.188E+01
3	-9.108E+00	-8.615E+00	-8.276E+00
4	-5.441E+00	-5.185E+00	-4.866E+00
5	-2.489E+00	-2.174E+00	-2.086E+00
6	4.879E-01	-7.582E-01	0.000E+00

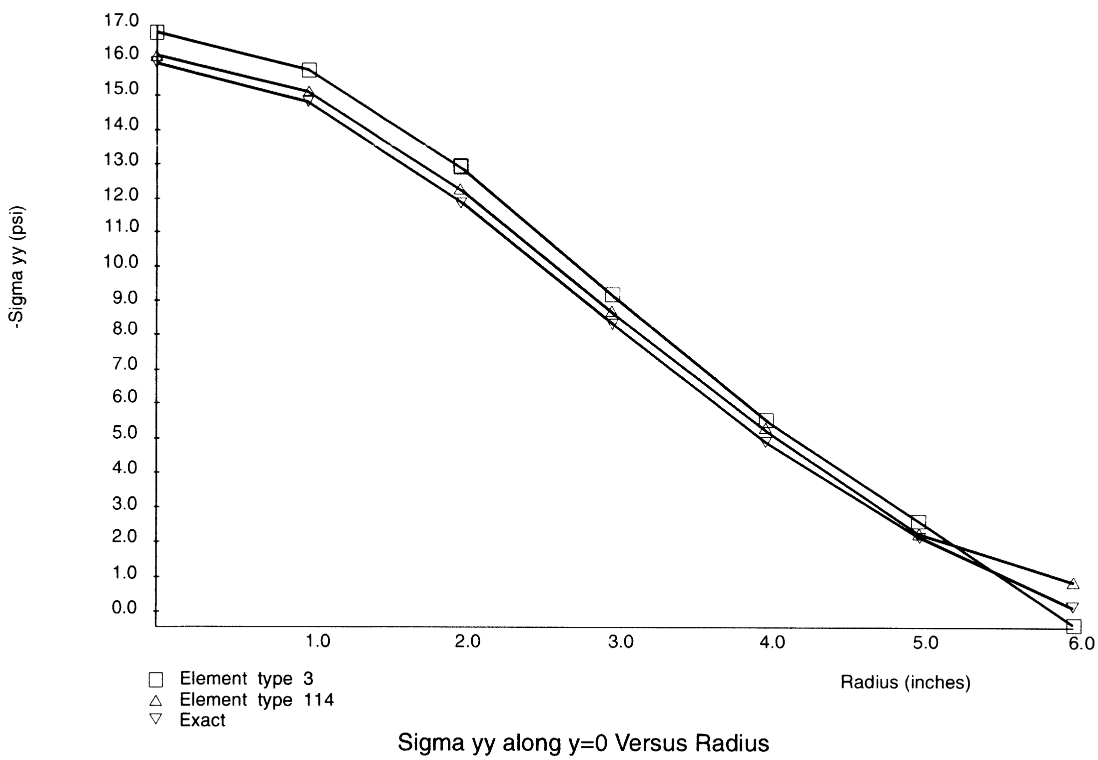


Figure 2.10-2 Sigma$_{22}$ Along y = 0 Versus Radius

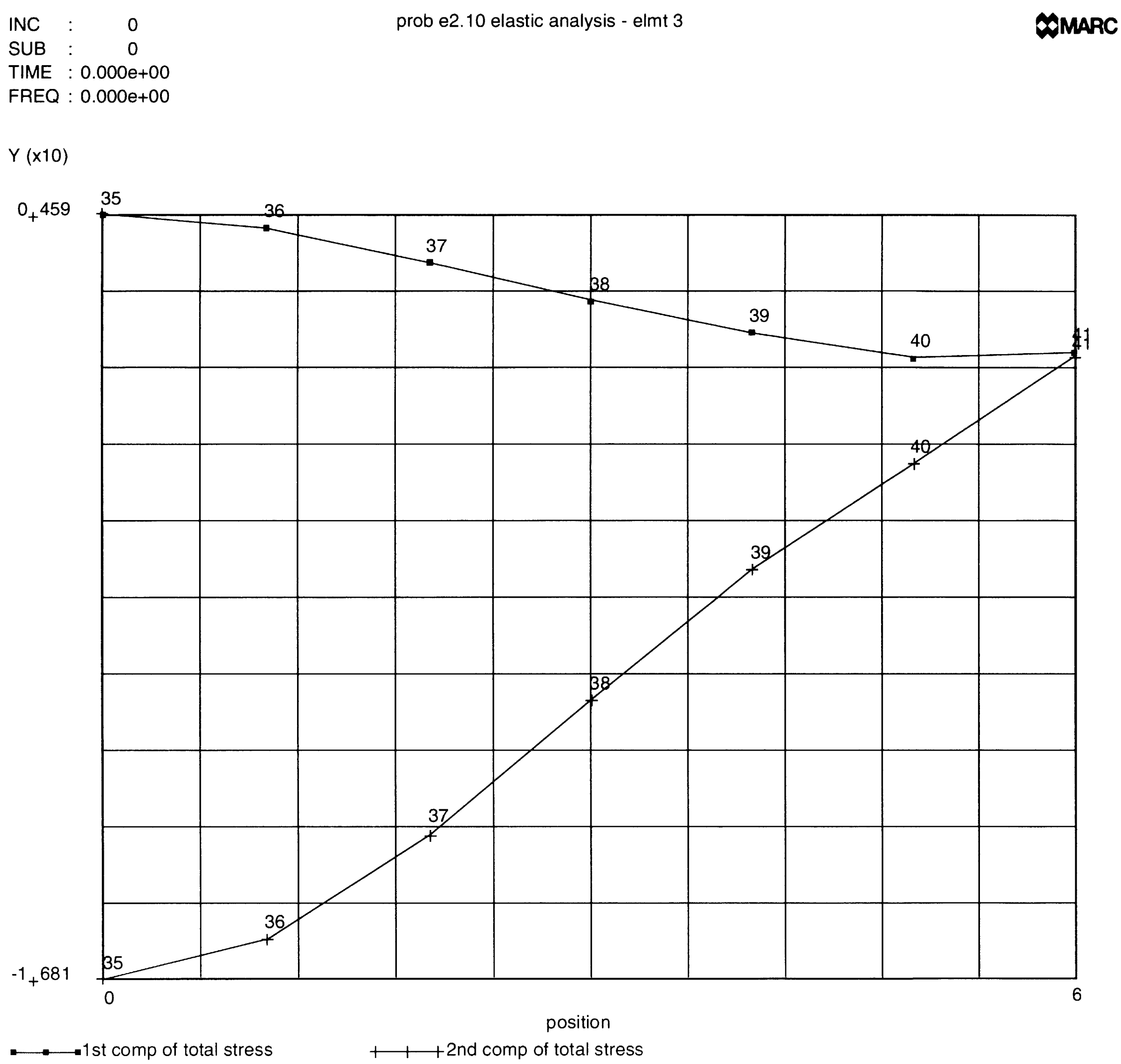


Figure 2.10-3 Stress Component Along Nodal Path

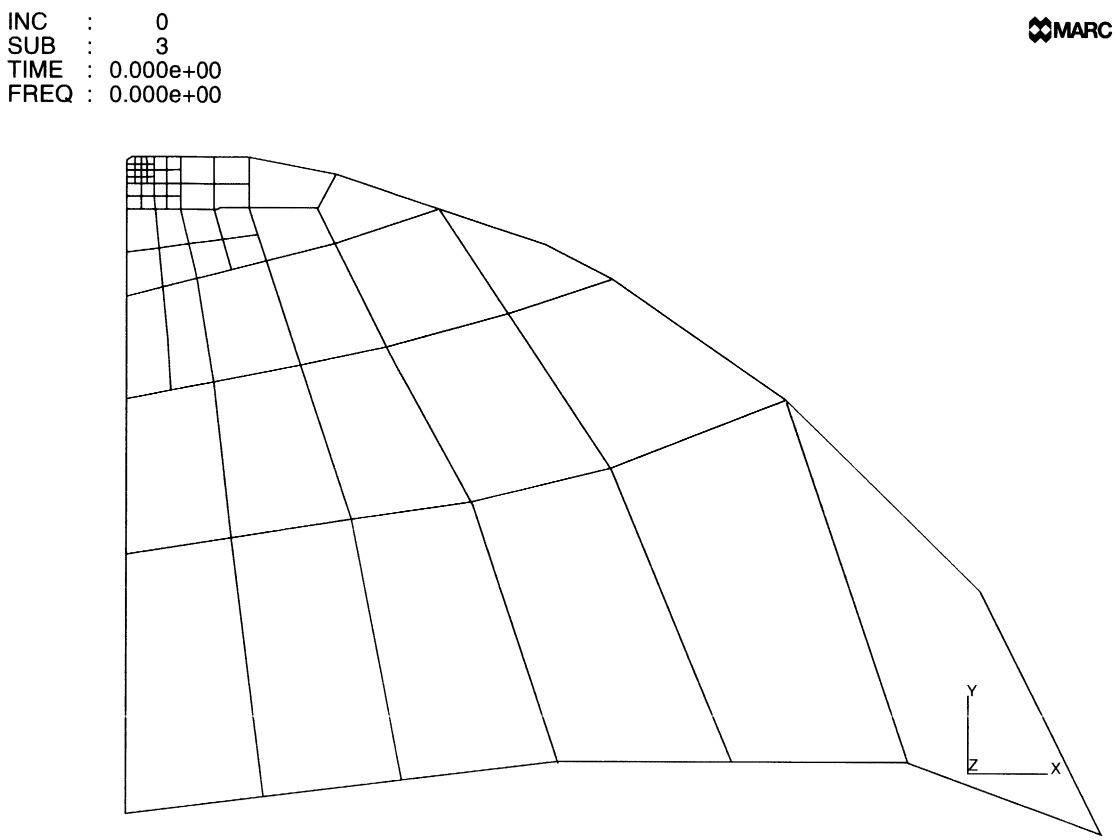


Figure 2.10-4 Close-up of Adapted Mesh

2.11 Simply-Supported Square Plate Modeled by Shell Elements

A simply-supported flat plate under uniform transverse pressure is elastically analyzed. The same problem is solved in later sections using the 8-node and 20-node bricks. This problem demonstrates the use of shell elements to solve a plate problem, and imposing the correct boundary conditions on these higher-order elements.

Element

It is often convenient to analyze plate and shell structures with a single element type; that is, by treatment of the plate problem as a degenerate shell problem. To illustrate this approach, library element type 8 is used. (Details regarding this element can be found in *MARC Volume B: Element Library*.) It is a fully conforming, triangular element that includes both bending and stretching deformation, and has nine degrees of freedom at each vertex.

The coordinates of the nodes are referred to a global Cartesian system. These coordinates can be supplied in several different ways depending on your choice. The FXORD option allows the coordinates to be generated for a choice of several simple shapes. A user subroutine, UFXORD, is also available to allow you to write your own special coordinate generation routine.

Model

One-quarter of the plate is modeled since there are two planes of symmetry in this problem. The geometry and mesh are shown in Figure 2.11-1. It contains 35 nodes and 50 triangular elements. The coordinate data which must be supplied depends on the option selection. In this case, use was made of the FXORD option and type 5 was selected. This allows specification of the x-y coordinates of each node point in the COORDINATE option, which are then converted to the required 11 coordinates through the FXORD option using the specified identity transformation between the global coordinates and the plate coordinates of that option. It should be noted that FXORD assumes that the middle plane of the plate is the x-y plane.

It should also be pointed out that the MESH2D option could be used to generate the original COORDINATE data in this case, followed by the same FXORD selection or a user-written UFXORD subroutine.

Geometry

The three-inch plate thickness is specified as EGEOM1.

Material Properties

All elements are assumed to be made of the same isotropic material. Values for Young's modulus, Poisson's ratio, and yield stress are 20 x 10^6 psi, 0.3, and 20,000 psi, respectively.

Loading

All 50 elements are loaded by a pressure of 1.0 psi. The resulting total load transverse to the plane of the plate is thus 900 lb.

Boundary Conditions

The specification of kinematic boundary conditions is somewhat more involved for an element with nine degrees of freedom per node. For transverse bending, such boundary conditions can be written only for the transverse displacement and its normal derivative, while the extensional boundary conditions can be prescribed only for the in-plane displacements. However, higher order derivatives must be made to conform to these constraints; for example, along the edges $x = 0$ and $y = 0$, the simple support condition requires that $w = 0$, which implies that $\frac{\partial w}{\partial Y} = 0$ along $x = 0$ and $\frac{\partial w}{\partial X} = 0$ along $y = 0$. Also, symmetry along the line $x = 30$ requires that $\frac{\partial w}{\partial X} = 0$, $u = 0$, and that v reach a stationary value, as a function of x. The implication are that $\frac{\partial u}{\partial Y} = 0$ and that $\frac{\partial v}{\partial X} = 0$, as well. Similar arguments indicate that

$v = \frac{\partial v}{\partial X} = \frac{\partial u}{\partial Y} = \frac{\partial w}{\partial Y} = 0$ along $y = 30$.

Results

The output for this example includes the local-global transformation matrix for FXORD. The transformation matrix is an identity matrix (apart from some roundoff error). The coordinates, by columns, are:

$$X, Y, x, \frac{\partial x}{\partial X}, \frac{\partial x}{\partial Y}, y, \frac{\partial y}{\partial X}, \frac{\partial y}{\partial Y}, z, \frac{\partial z}{\partial X}, \frac{\partial z}{\partial Y}.$$

Element data that is printed out includes the six generalized stretching and bending strains:

$\varepsilon_{xx}, \varepsilon_{yy}, \varepsilon_{xy}, \rho_{xx}, \rho_{yy}, \rho_{xy}$

given at the element centroid, and the stresses:

σ_{xx}, σ_{yy}, and τ_{xy}

given at 11 equally-spaced points through the plate cross section at the centroid. Nodal data that is printed consists of incremental and total values of the nodal variables, referred to the local coordinate system.

Figure 2.11-2 compares the transverse displacements across a plane of the plate, as obtained by the three-dimensional example of a later example, and by this degenerate shell example. The significantly greater flexibility (and, therefore, accuracy) of the latter formulation is evident. As a thin-shell element was used, there is no transverse shear (τ_{xy}, τ_{yz}) effects. As the model involves a reasonably thick shell, this results in a larger midsurface deflection than observed using the brick elements. Element type 22 or 75 would have been more appropriate.

Parameters, Options, and Subroutines Summary

Example e2x11.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	FXORD
	GEOMETRY
	ISOTROPIC

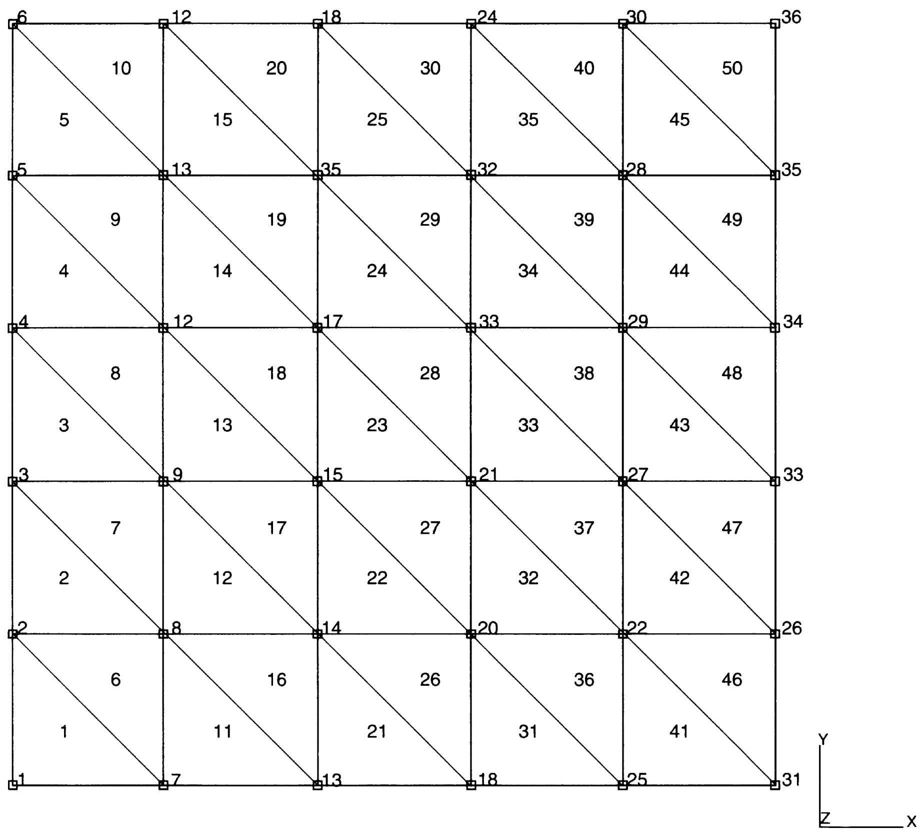


Figure 2.11-1 Geometry and Mesh for Square Plate Using Shell Elements

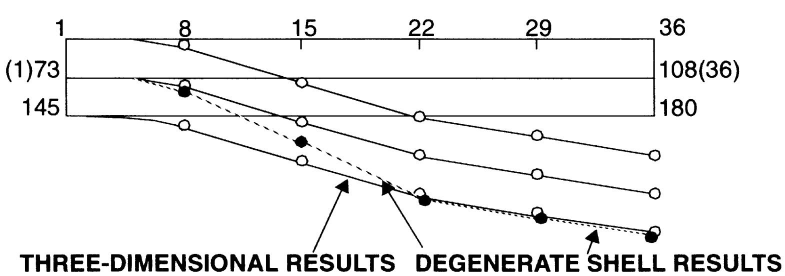


Figure 2.11-2 Comparison of Results for Shell and Three-Dimensional Models

2.12 Simply-Supported Thick Plate, using Three-Dimensional Elements

A simply-supported thick plate under uniform transverse pressure is elastically analyzed. This problem is the same as problems 2.11 and 2.13; hence, the solutions can be compared showing the discrepancies due to the choice of element types. This problem is also used to demonstrate the different choices of solution procedures.

This problem is modeled using the four techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x12b	7	100	180	
e2x12c	7	100	180	Processor, EBE solver
e2x12d	117	100	180	
e2x12e	7	100	180	Processor, sparse solver

Elements

This example illustrates the use of element types 7 and 117, the three-dimensional isoparametric elements, details of which are given in *MARC Volume B: Element Library.* There are three degrees of freedom per node point for these elements:

u displacement (parallel to the x-axis)
v displacement (parallel to the y-axis)
w displacement (parallel to the z-axis)

Model

One-quarter of the plate (60 x 60 x 3 inches) is modeled since there are two planes of symmetry in this problem. The generated mesh is shown in Figure 2.12-1. The thickness of the plate was divided into four tiers of elements. Each tier was subdivided into a five-by-five element pattern, resulting in a mesh containing 180 nodes and 100 elements.

Geometry

A nonzero number is entered in the third Geometry field to indicate that the assumed strain formulation will be activated.

Material Properties

All elements are assumed to be uniform here. Values for Young's modulus, Poisson's ratio, and yield stress used are 20 x 10^6 psi, 0.3 and 20,000 psi, respectively.

Loading

The 25 elements with faces in the upper plane (z = 3 in.) are loaded by a pressure of 1.0 psi; the total load is 900 lb. in the negative z direction. Loading of this face of the elements is obtained by setting IBODY = 0 in the DIST LOAD input.

Boundary Conditions

Homogeneous boundary conditions are imposed on u for all nodes in the plane x = 30 and on v for all nodes in the plane y = 30 to account for the symmetry conditions. Simple support conditions are imposed on w for those points in the plane z = 1.5 inches that lie along the edges x = 0 and y = 0. A total of 71 degrees of freedom, out of the total of 540, are restrained.

Solvers

Problem e2x12b uses the default MARC profile solver. The SOLVER option is not included. Problem e2x12c uses the element-by-element iterative solver. A convergence criteria of $1x10^{-16}$ is specified. Problem e2x12e uses the sparse direct solver.

Results

The six components of strain and stress for each element are referred to the global coordinate system and are computed at the element's integration points. Element type 7 has 8 integration points. Element type 117 has 1 integration point. A comparison of the maximum transverse deflection at the center of the plate shows good agreement between elements type 7, 117 and, from problem 2.11, element type 8. These are summarized below:

Type 7	1.09293E-03 inch	node	180
Type 117	1.09193E-03 inch	node	180
Type 8	1.06190E-03 inch	node	36

In addition, contour plots of von Mises stresses are shown for element types 7 and 117 on the deformed shape in Figure 2.12-2 and Figure 2.12-3. Maximum von Mises stresses are:

Type 7	1.035E+02 psi	Element 100	point 8
Type 117	8.553E+01 psi	Element 100	point 1
Type 8	1.300E+01 psi	Element 1	point 1

In problem e2x12b, you can observe that the half bandwidth is 44 and the:

number of profile entries including fill-in is	6414
number of profile entries excluding fill-in is	1754
total Workspace needed with in-core matrix storage is	320745 words

As this is a small problem, the ebe iterative solver actually requires more memory requiring 356875 words. To achieve the convergence requested, 175 iterations were required. Normally, a larger tolerance, such as 0.001, would have been chosen. In e2x12e, when using the sparse direct solver, the Workspace requirement is only 30,3619 words. For this problem, the computational speed is 2 to 3 times faster.

Parameters, Options, and Subroutines Summary

The input for MESH3D is e2x12a.dat.

Example e2x12b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	CONTROL
SIZING	COORDINATES
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	ISOTROPIC
	POST

Example e2x12c.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	CONTROL
PROCESS	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	POST
	SOLVER

Example e2x12d.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	CONTROL
SIZING	COORDINATES
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	ISOTROPI C
	POST

Example e2x12e.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	CONTROL
SIZING	COORDINATES
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	ISOTROPIC
	POST
	SOLVER

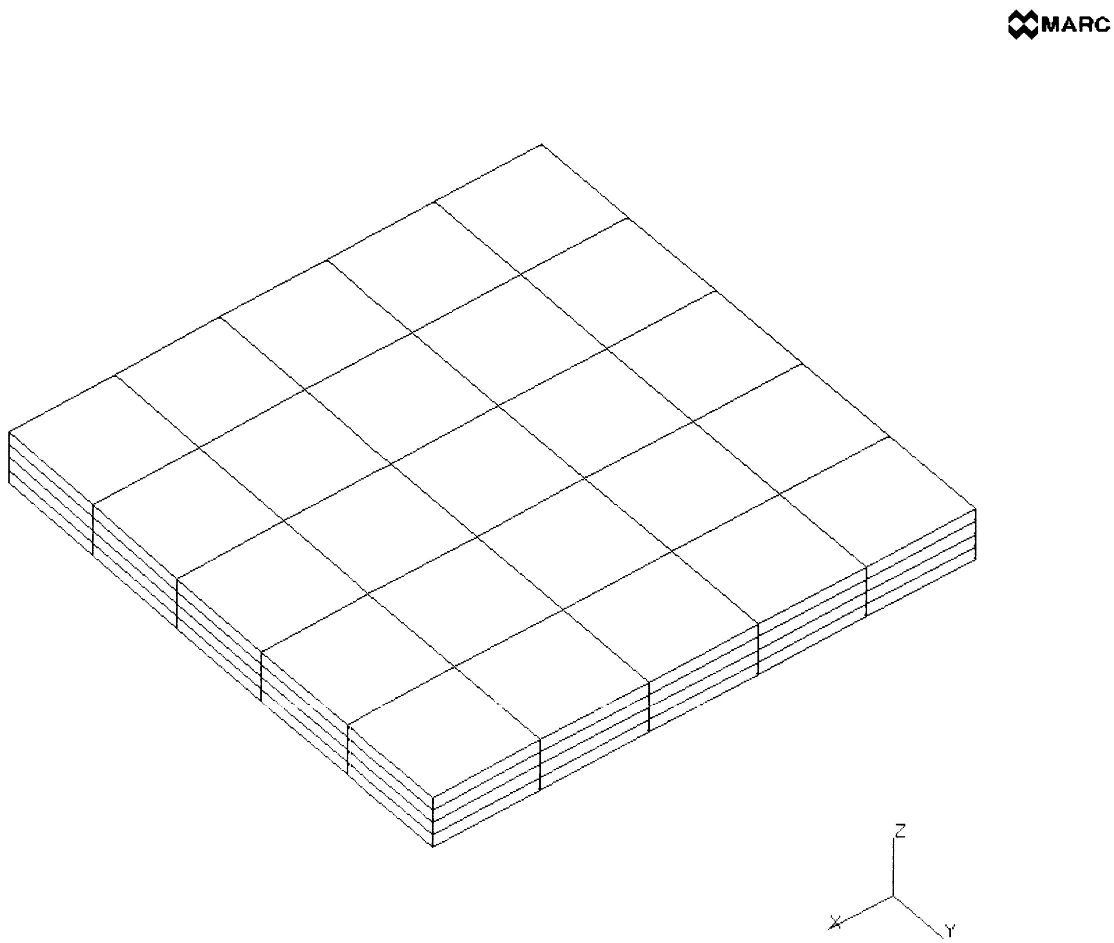


Figure 2.12-1 Model

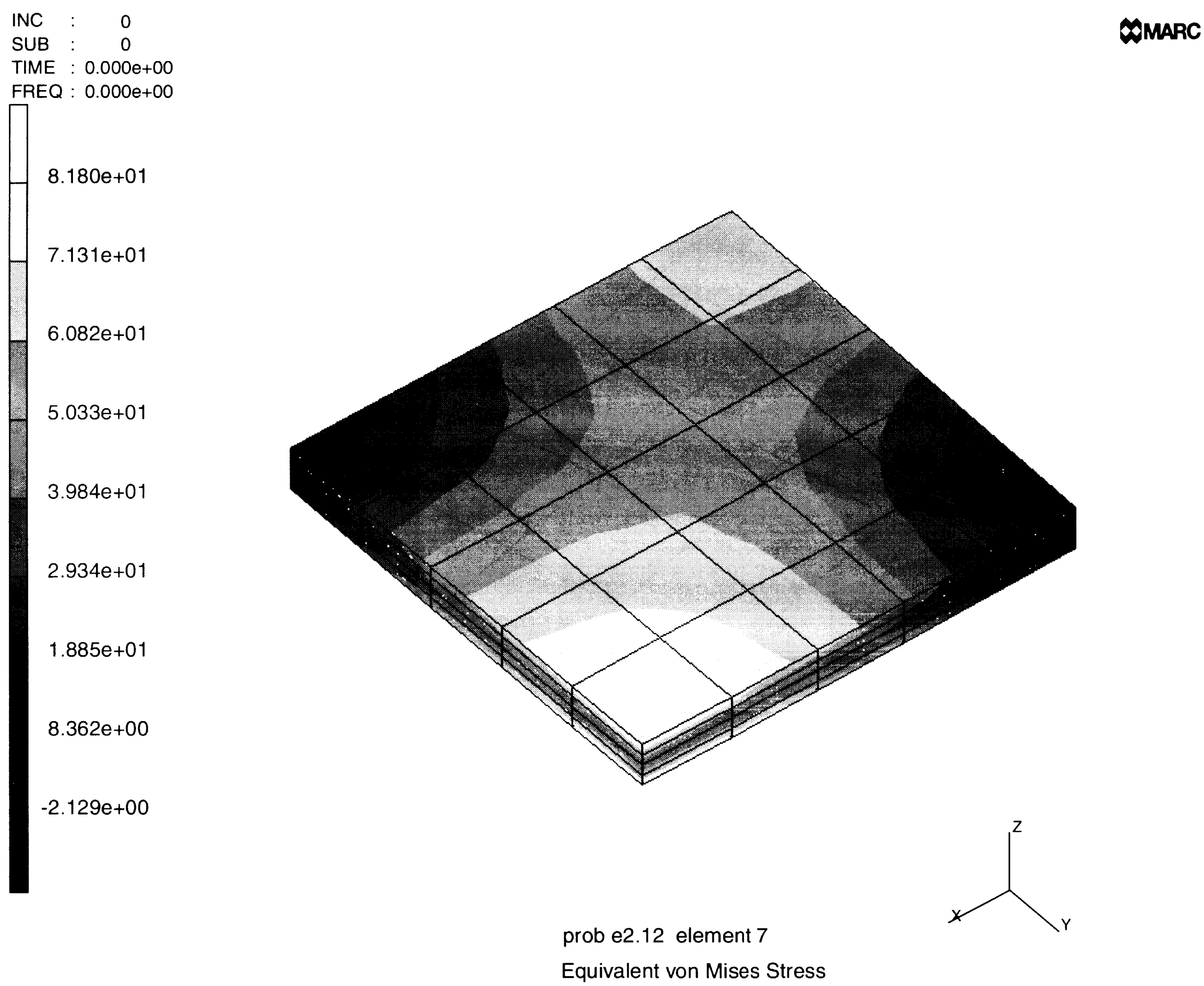


Figure 2.12-2 Plot of von Mises Stress Element 7

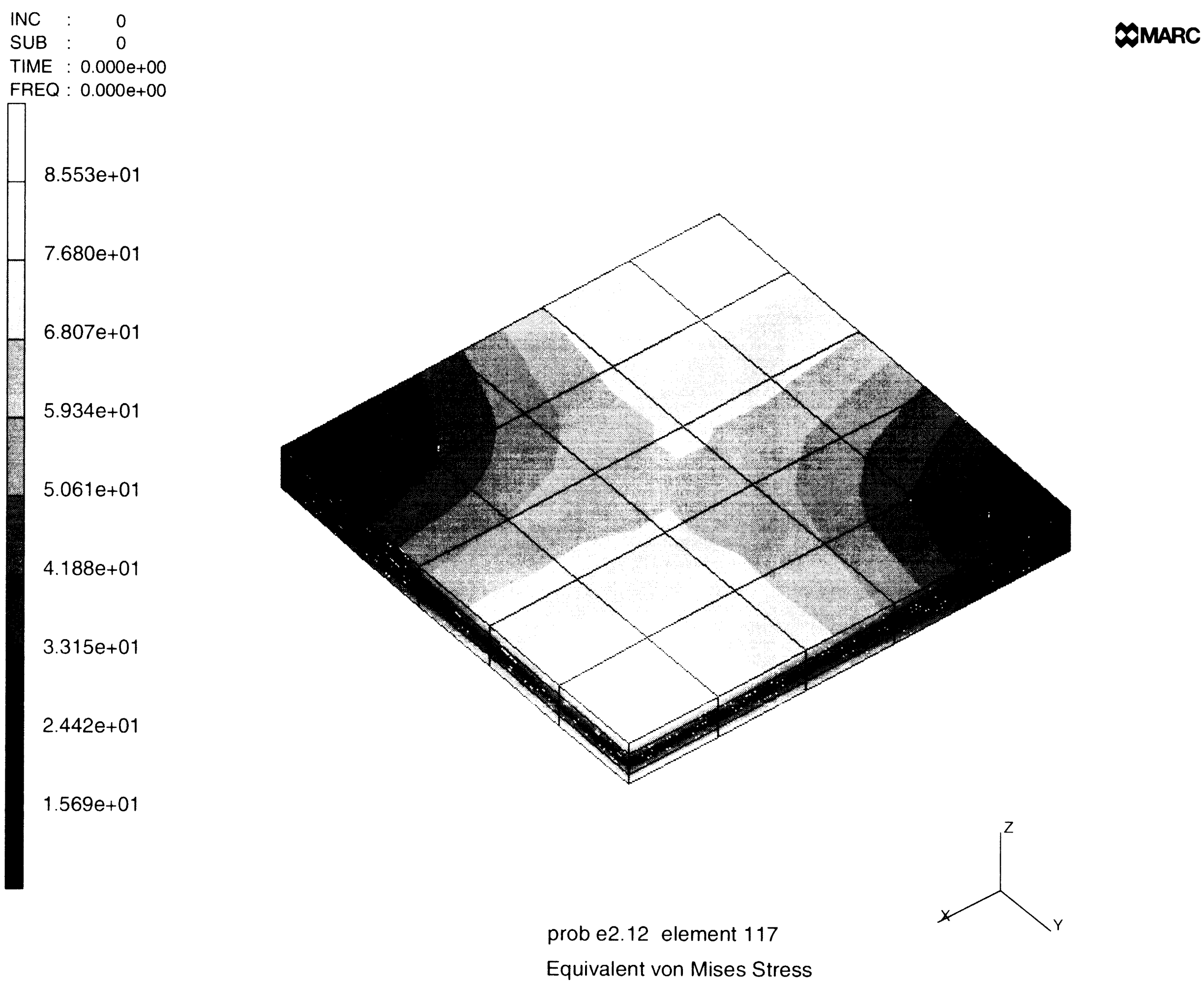


Figure 2.12-3 Plot of von Mises Stress Element 117

2.13 Simply-Supported Thick Plate, using Higher-order Three-Dimensional Elements

A thick plate, simply supported around its perimeter, is analyzed with a pressure load normal to the plate surface. This problem is the same as problems 2.11 and 2.12; hence, the solutions can be compared. This problem demonstrates the higher-order three-dimensional element.

Element

Element type 21 is a 20-node isoparametric brick. There are three displacement degrees of freedom at each node; eight are corner nodes, 12 midside. Each edge of the brick can be parabolic; a curve is fitted through the midside node. Numerical integration is accomplished with 27 points using Gaussian quadrature. See *MARC Volume B: Element Library* for further details.

Model

Because of symmetry, only one-quarter of the plate is modeled. One element is used through the thickness, two in each direction in the plane of the plate. There are 51 nodes for a total of 153 degrees of freedom. See Figure 2.13-1.

Geometry

No geometry specification is used.

Loading

A uniform pressure of 1.00 psi is applied in the DIST LOADS block. Load type 4 is specified for uniform pressure on the 6-5-8-7 face of all four elements.

Boundary Conditions

On the symmetry planes, x = 30 and y = 30, in-plane movement is constrained. On the x = 30 plane, u = 0, and on the y = 30 plane, v = 0. On the plate edges, x = 0 and y = 0; the plate is simply supported, w = 0.

Results

The solution of an elastic analysis is compared in Figure 2.13-2 with the solution of problem 2.12. A contour plot of the equivalent stress is shown in Figure 2.13-3. The exact solution is from Roark's *Formulas For Stress and Strain.*

Parameters, Options, and Subroutines Summary

Example e2x13.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC

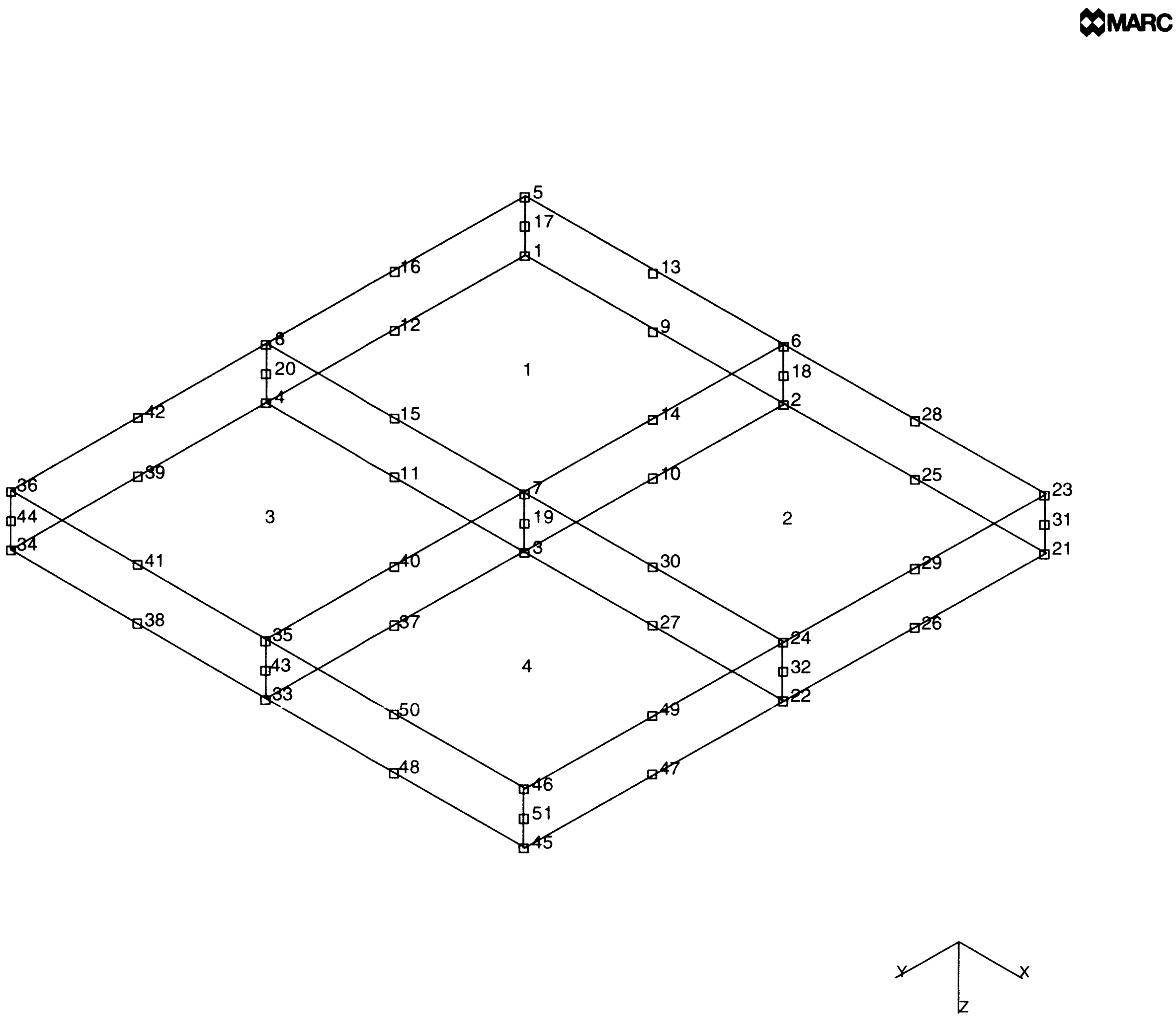


Figure 2.13-1 Thick Plate Mesh

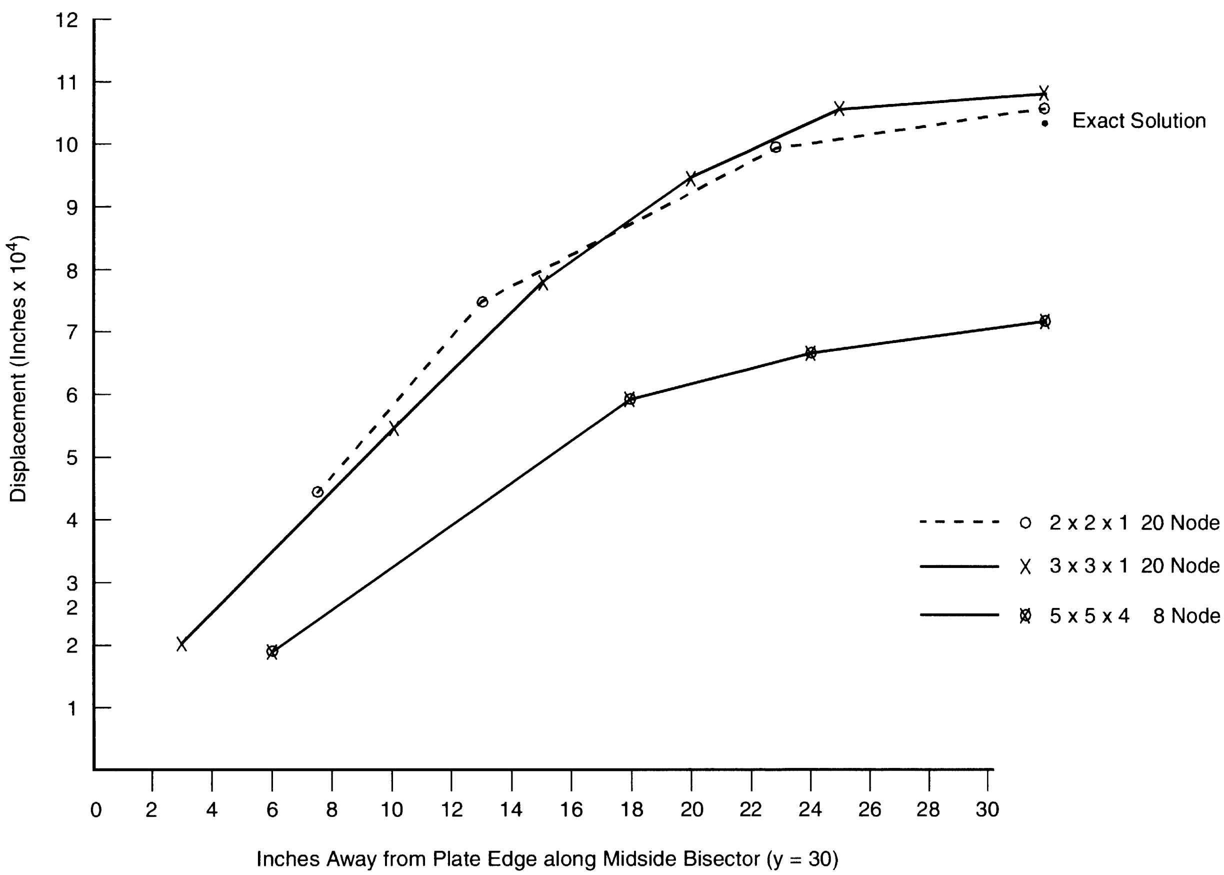


Figure 2.13-2 Pressure Loaded Simply-Supported Flat Plate Displacement Comparison

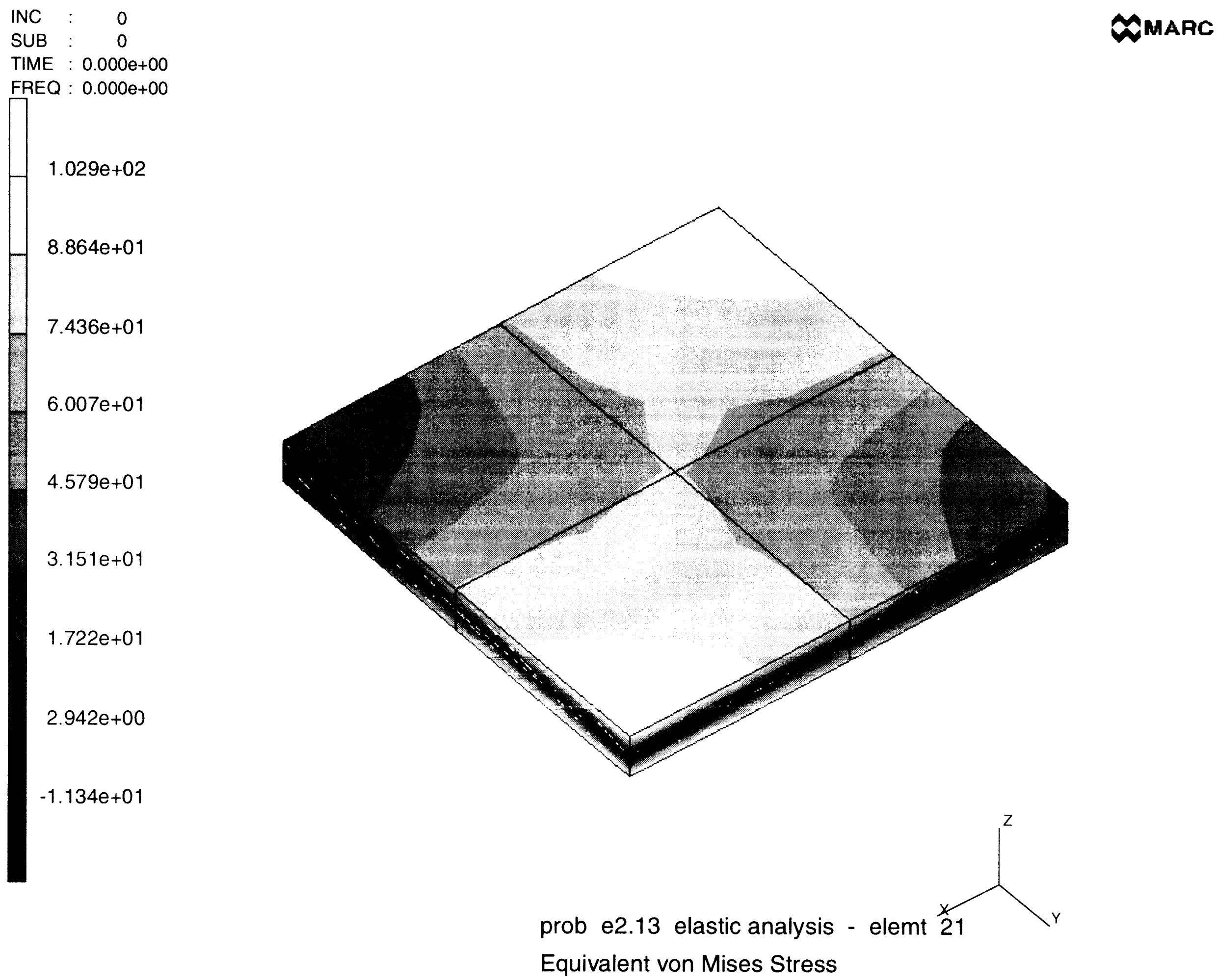


Figure 2.13-3 J2 Stress Contour

2.14 Reinforced Concrete Beam Analysis

A reinforced concrete cantilever beam is elastically analyzed. A point load at the free end of the beam is applied. This problem demonstrates the use of the rebar elements in three-dimensional analysis.

This problem is modeled using the two techniques summarized below.

Data Set	Fill Element	Rebar Element	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x14	21	23	26	20	79	rebar subroutine
e2x14b	7	146	320	405	79	REBAR option

Elements

Either element types 21 and 23 (20-node bricks) or 7 and 146 (8-node bricks) are used in the analysis. Element 21 and 7 represent the concrete. Element 23 and 146, which are specifically designed to simulate reinforcing layers in three-dimensional problems, represent the steel reinforcements in the concrete.

Model

The beam is idealized either by using 4 20-node concrete brick elements and 4 20-node rebar elements as shown in Figure 2.14-1 or by using 256 8-node concrete brick elements and 65 8-node rebar elements. One layer of steel rebars is embedded in the concrete.

Geometry

The third field defines the orientation of rebar layers with respect to the element faces (see *MARC Volume B: Element Library*). If user subroutine REBAR is used for input of rebar properties, the number of rebar layers is entered in the second field. In this example, only one layer of rebars exists.

Material Properties

The concrete has a Young's modulus of 3.0×10^6 psi and a Poisson's ratio of 0.2. The steel reinforcing bars have a Young's modulus of 2.9×10^7 psi, a cross-sectional area of 2.65 square inch, and an equivalent thickness of 0.0883 inch.

Loading

A total load of 6000 pounds is applied at the free end of the beam. This load is represented by 2000 pound loads at three of the top free-end nodes.

Boundary Conditions

The nodes at the wall are fixed in the three global degrees of freedom to simulate a built-in or clamped condition.

Rebar Data

By virtue of the simplicity of the problem, either the user subroutine REBAR or the REBAR option can be used to specify the orientation and the equivalent thickness of the reinforcing layers. The repetition is admissible by virtue of the problem simplicity. In this example, the rebars are parallel to the y-axis.

Results

A comparison of concrete and steel stress with beam theory (uncracked section) is shown in Figure 2.14-2. The concrete stress is compared at the upper and lower integration point layers. (All comparisons are at the inner layers of integration points across the width.)

Parameters, Options, and Subroutines Summary

Example e2x14.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
PRINT	END OPTION
SIZING	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	POINT LOAD

Example e2x14b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POINT LOAD
	REBAR

User subroutine in u2x14.f:

REBAR

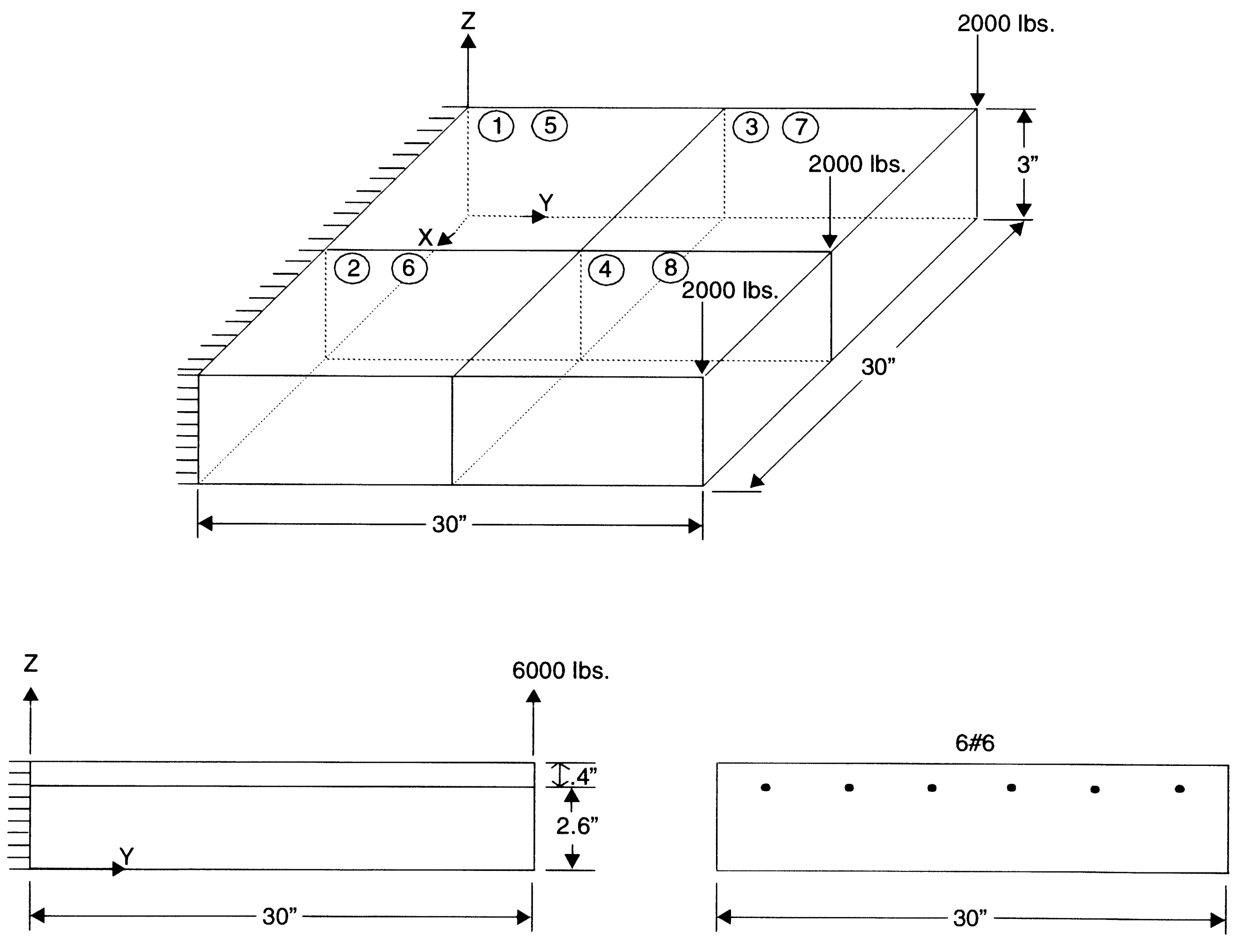


Figure 2.14-1 Reinforced Concrete Beam

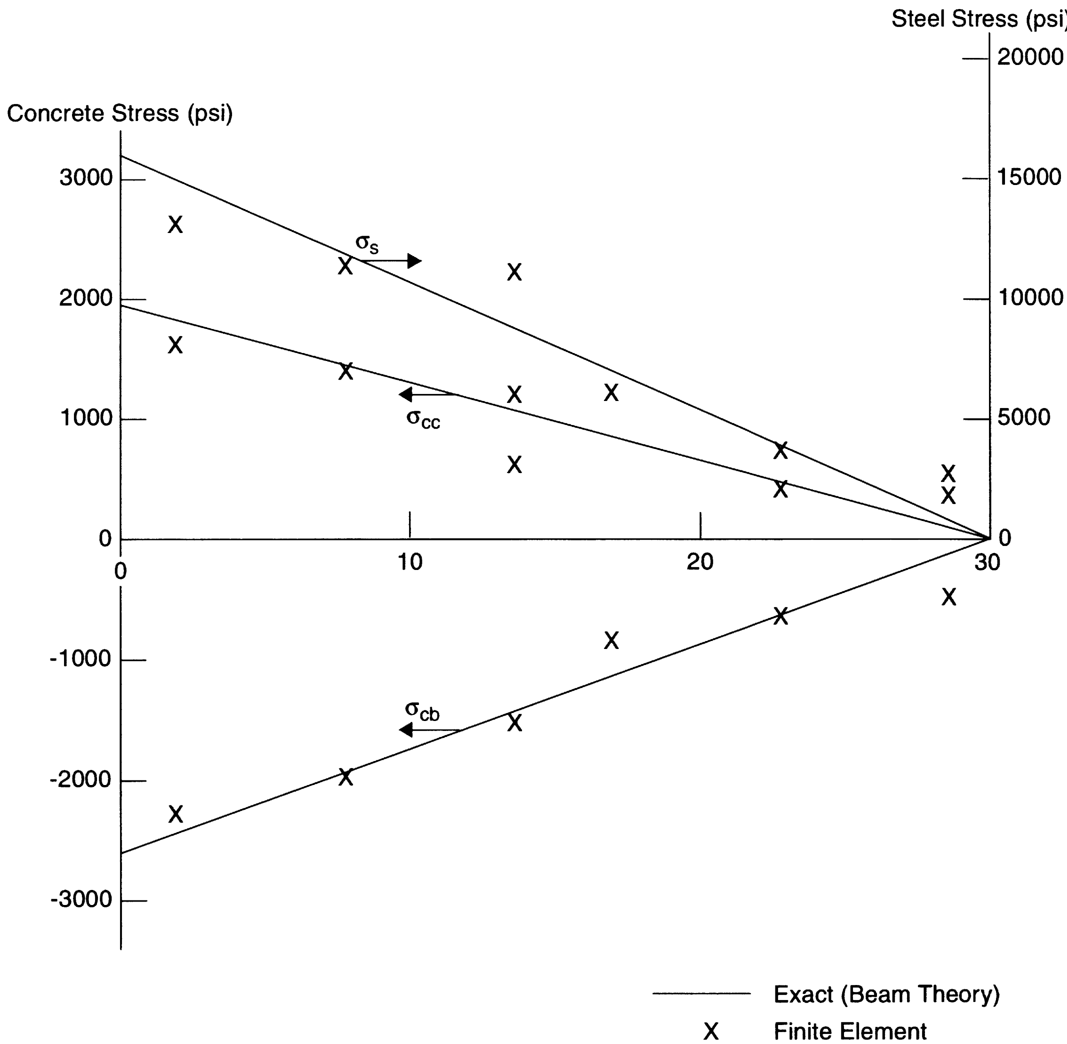


Figure 2.14-2 Concrete and Steel Stress With Beam Theory

2.15 Cylinder-sphere Intersection

A cylinder-sphere intersection under the action of uniform internal pressure is analyzed. The material is linear-elastic throughout the analysis. This problem demonstrates the program's ability to model a typical shell intersection. The FXORD and TYING capabilities are utilized in this analysis.

Element

The cylinder and sphere in this problem are both thin shells and can be modeled using element type 8. Element 8 is a doubly-curved, triangular-shell element. The details on this element are given in *MARC Volume B: Element Library.*

Model

The geometry and mesh are shown in Figure 2.15-1. The symmetry of this problem requires that only one-quarter of the shell (the x-z plane and the y-z plane are both planes of symmetry) need be modeled.

For motions other than axial shift, both shells use the same global coordinate system. The local Gaussian coordinate systems are shown on the shell surfaces for reference. The FXORD option is utilized. There are two different types of surfaces which must be developed. The TYING options in MARC are used to join the two surfaces.

The structure is modeled with four cylindrical elements (FXORD: type 4) and four spherical elements (FXORD: type 2). The SHELL SECT parameter is used to set the number of integration points through the thickness to 3. Reducing the number of integration points through the thickness does not diminish the solution accuracy for linear-elastic problems, yet it enhances the program efficiency.

Geometry

The shell thickness is taken to be 1.0 inch and is specified as EGEOM1 of this option.

Material Properties

All elements have the same elastic properties. Values for Young's modulus and yield stress are 1000 psi and 100 psi, respectively.

Loading

The uniform external pressure is applied to both shells by specifying a positive pressure of 1.0 psi of type 2 (IBODY = 2) to the θ^1, θ^2 surface. This implies a pressure in the negative outward normal direction.

Boundary Conditions

Symmetry conditions are imposed at nodes 1, 4, 7 and 10 in the x-z plane, and nodes 3, 6, 9 and 12 in the y-z plane. Support conditions are imposed on nodes 10, 11 and 12.

Tying

At the intersection of the two shells, nodes 4, 5 and 6 are joined to nodes 7, 8 and 9 through the use of the TYING option, type 18. The tying is such that each tied node is also a retained node; for example, certain degrees of freedom of the tied node are linear functions of other degrees of freedom of the tied node. In addition, they depend on degrees of freedom of the retained node. Due to the manner in which the tying is effected, the tied node that is also retained must be placed last in the tying data field.

Results

Following the tying option output (the tied nodes are also retained nodes), the sum of the consistently lumped nodal forces in each coordinate direction is printed. A check of the values shows symmetry with respect to x and y loads (first and fourth columns). The load in the z-direction is somewhat less as a result of the opening in the spherical shell. Scaling was not requested for this example, although the scale factor to cause first yielding is printed (in this case, first yielding would have occurred in element 8).

Generalized bending and stretching strains at the shell middle surface are printed (for each element) referred to the θ^1, θ^2 system. Following the strains, the physical stress components at three points through the thickness are output. In this case, θ^1 and θ^2 are orthogonal; thus, these stresses are the direct and shear stresses in the meridional and hoop directions, respectively. In a more general case involving skewed coordinates (θ^1,θ^2), the physical stress components should be interpreted with care. The equivalent stress (printed in the first column) then becomes a more convenient measure of the stress state.

The element output is followed by the incremental and total nodal point displacements, referred to the global coordinate system.

The POST option is used to write the stresses onto the auxiliary post file. This information can be processed by either the plot program or the Mentat graphics program.

Parameters, Options, and Subroutines Summary

Example e2x15.dat:

Parameters

ELEMENTS
END
SHELL SECT
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FXORD
GEOMETRY
ISOTROPIC
POST
TYING

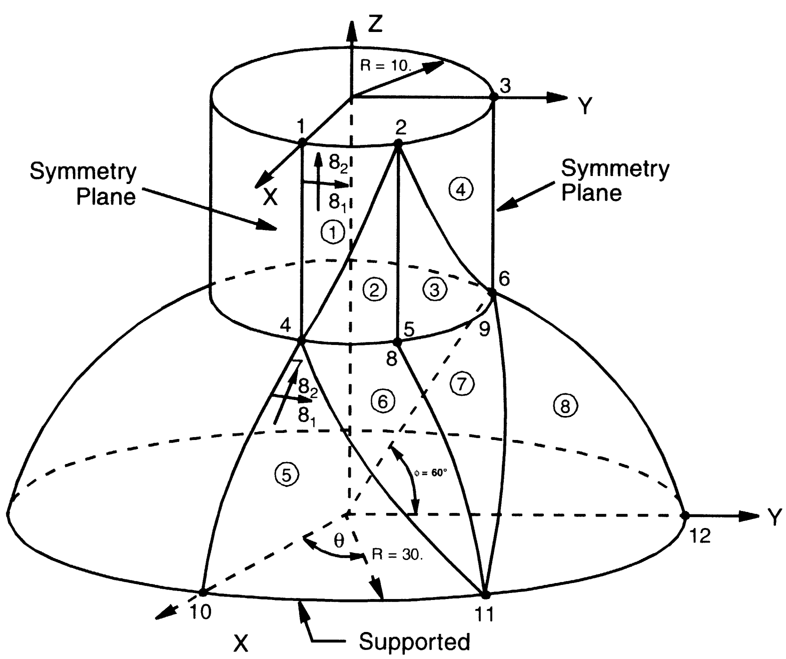


Figure 2.15-1 Mesh and Geometry for Cylinder-Sphere Intersection Problem

2.16 Shell Roof using Element 8

This problem is one of several in which a barrel-vault shell roof is loaded under its own weight. The results of these analyses are compared in problem 2.19. This example demonstrates the use of user subroutine UFXORD to generate the coordinates for element type 8.

Element

Library element type 8, an isoparametric curved triangular shell, is used. The element is based on Koiter-Sanders shell theory. The displacement interpolation functions are defined such that displacements and their first derivatives are compatible between elements. The nine degrees of freedom are three displacements in the global axes directions and six first derivatives of these displacements with respect to the surface coordinates. See *MARC Volume B: Element Library.*

Model

Forty elements are used to model one-quarter of the shell taking advantage of symmetry. The ends of the structure are supported by diaphragms and there are two free edges. The model has 30 nodes and 270 degrees of freedom (see Figure 2.16-1).

Mesh Generation

The coordinates are first entered in the x-y plane. These two coordinates are used by subroutine UFXORD to generate the full set.

Geometry

Linear thickness variation is allowed; the three nodal values are input in the first three data fields of the third block of the GEOMETRY option. Here the default of constant thickness is used with EGEOM2 = EGEOM3 = 0 and EGEOM1, the first data field, is set to the thickness of 3.

Material Properties

Young's modulus is 3.0 x 10^6 psi; Poisson's ratio is taken as 0.

Loading

All 40 elements are loaded with self weight of 90 lb/square foot or .625 lb/square inch in the negative z-direction. This is the load type (IBODY = 1) specified in the DIST LOADS option.

Boundary Conditions

Three sets of boundary conditions are required. Displacement in the plane normal to the shell is continuously zero at the supported end $\left(u = w = \frac{\partial u}{\partial \theta^1} = \frac{\partial w}{\partial \theta^1} = 0\right)$. On the y = 300 symmetry boundary, axial displacement is fixed and is continuously zero $\left(v = \frac{\partial v}{\partial \theta^1} = 0\right)$. From symmetry considerations, $\frac{\partial u}{\partial \theta^2}$ and $\frac{\partial w}{\partial \theta^2}$ must be fixed, or inadmissible warping is allowed. On the x = 0 symmetry boundary, movement tangential to the shell surface is continuously zero $\left(u = \frac{\partial u}{\partial \theta^2} = 0\right)$. From symmetry considerations, to fix the model against inadmissible rotations, $\frac{\partial w}{\partial \theta^1}$ and $\frac{\partial v}{\partial \theta^1}$ must be zero (see Figure 2.16-2).

User Subroutine

Subroutine UFXORD is used to generate the requisite 11 coordinates. The first coordinate read from the COORDINATE block is an angle that is used to generate θ^1, x, $\frac{\partial x}{\partial \theta^1}$, z, and $\frac{\partial z}{\partial \theta^1}$, the second coordinate is, in this case, y and θ^2. Remember to set NCRD = 2 in the first data field of the second line of the COORDINATE block.

Results

A comparison of the results of this problem and problems 2.17, 2.18, and 2.19 is found at the end of problem 2.19.

Parameters, Options, and Subroutines Summary

Example e2x16.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	UFXORD

User subroutine in u2x16.f:

UFXORD

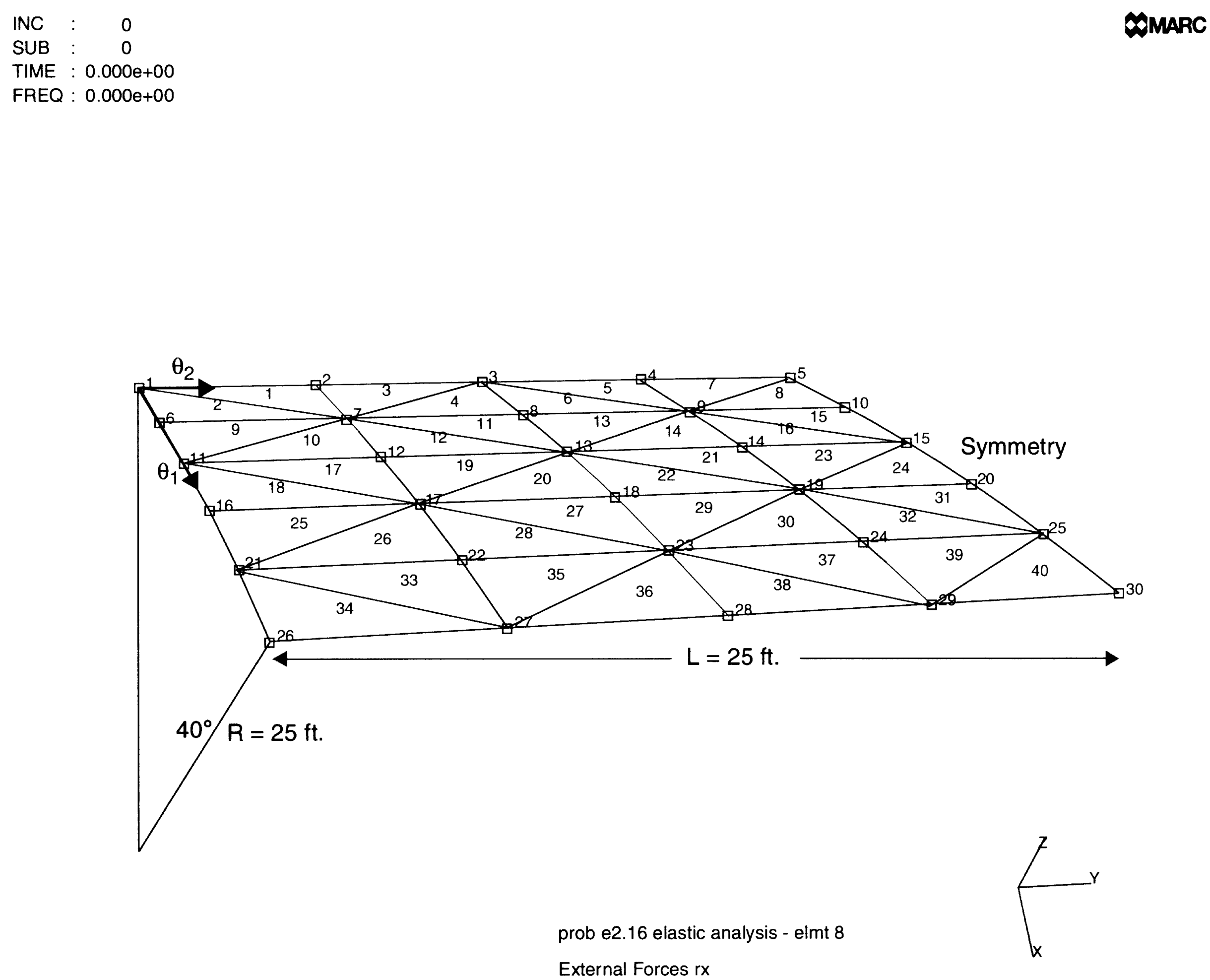


Figure 2.16-1 Cylinder Shell Roof Configuration, Element 8

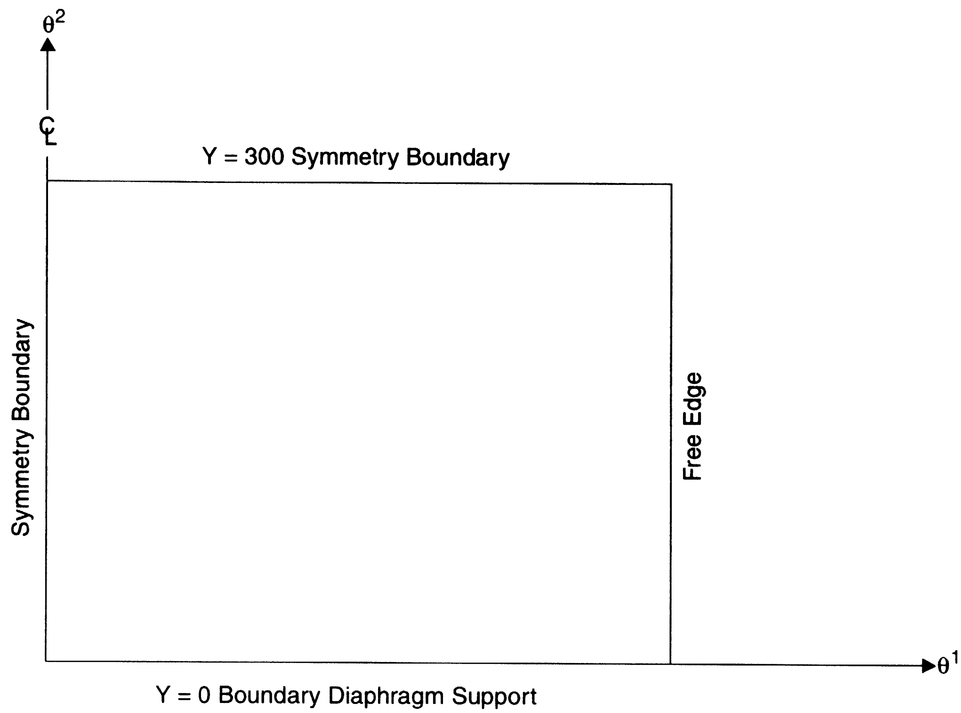


Figure 2.16-2 Shell Surface Coordinate System

2.17 Shell Roof using Element 4

This problem is one of several in which a barrel-vault shell roof is loaded under its own weight. The results of these analyses are compared in problem 2.19. This example demonstrates the use of user subroutine UFXORD to generate the coordinates for element type 4.

Element

Library element type 4 is used. It is an isoparametric, doubly-curved thin shell that is based on Koiter-Sanders shell theory. Bicubic interpolation functions are used and the numerical integration is 9-point Gaussian quadrature. Rigid body modes are represented exactly. The mesh must be rectangular in the θ^1,θ^2 plane, but any mapping can be used onto the surface.

Model

The four-element model is of a one-quarter section of the structure taking advantage of symmetry. Support conditions are as in the other shell roof examples; diaphragm supports on axial ends. There are nine nodes for a total of 108 degrees of freedom. See Figure 2.17-1.

Geometry

The thickness of the shell is 3 inches, which is specified in the first data field of the third block of the GEOMETRY option, EGEOM1 = 3.

Material Properties

Young's modulus is 3.0×10^6 psi; Poisson's ratio is taken as 0.

Loading

The four elements are loaded with self-weight, positive in the negative z direction. The magnitude is 90 lb./sq.ft. or .625 lb./square inch, and is specified as a distributed load (IBODY = 1) in the DIST LOAD option.

Boundary Conditions

Three sets of boundary conditions are necessary. (See Figure 2.16-2 and Figure 2.17-1). On the diaphragm supported end, movement in the plane normal to the shell is continuously zero $\left(u = w = \frac{\partial u}{\partial \theta^1} = \frac{\partial w}{\partial \theta^1} = 0\right)$. None of the cross-derivative terms, which represent rates of change of shear and direct strains, are zero. Care must be taken in specifying these terms. On the y = 300 symmetry boundary, axial displacement is continuously zero $\left(v = \frac{\partial v}{\partial \theta^1} = 0\right)$.

Rotation and shear are fixed $\left(\frac{\partial u}{\partial \theta^2} = \frac{\partial w}{\partial \theta^2} = 0\right)$. Also, two of the cross-derivatives are fixed by symmetry considerations $\left(\frac{\partial^2 u}{\partial \theta^1 \partial \theta^2} = \frac{\partial^2 w}{\partial \theta^1 \partial \theta^2} = 0\right)$. A nonzero rate of change of normal strain, $\frac{\partial^2 v}{\partial \theta^1 \partial \theta^2}$, is allowable. On the x = 0 symmetry boundary, movement tangential to the shell surface is continuously zero $\left(u = \frac{\partial u}{\partial \theta^2} = 0\right)$. Rotation and shear are fixed $\left(\frac{\partial v}{\partial \theta^1} = \frac{\partial w}{\partial \theta^1} = 0\right)$. Two of the three cross-derivatives, $\frac{\partial^2 v}{\partial \theta^1 \partial \theta^2}$ and $\frac{\partial^2 w}{\partial \theta^1 \partial \theta^2}$ are zero. Unfixed, these could allow warping across the symmetry boundary.

User Subroutines

Subroutine UFXORD is used to generate a full set of coordinates from two inputs from the COORDINATE block. The first coordinate is equal to both θ^2 and y; the second is used to generate x and y.

Results

The results of the model are compared with other results using shell elements type 8, 22, 24. The comparison is found following problem 2.19.

Parameters, Options, and Subroutines Summary

Example e2x17.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	UFXORD

User subroutine in u2x17.f:

UFXORD

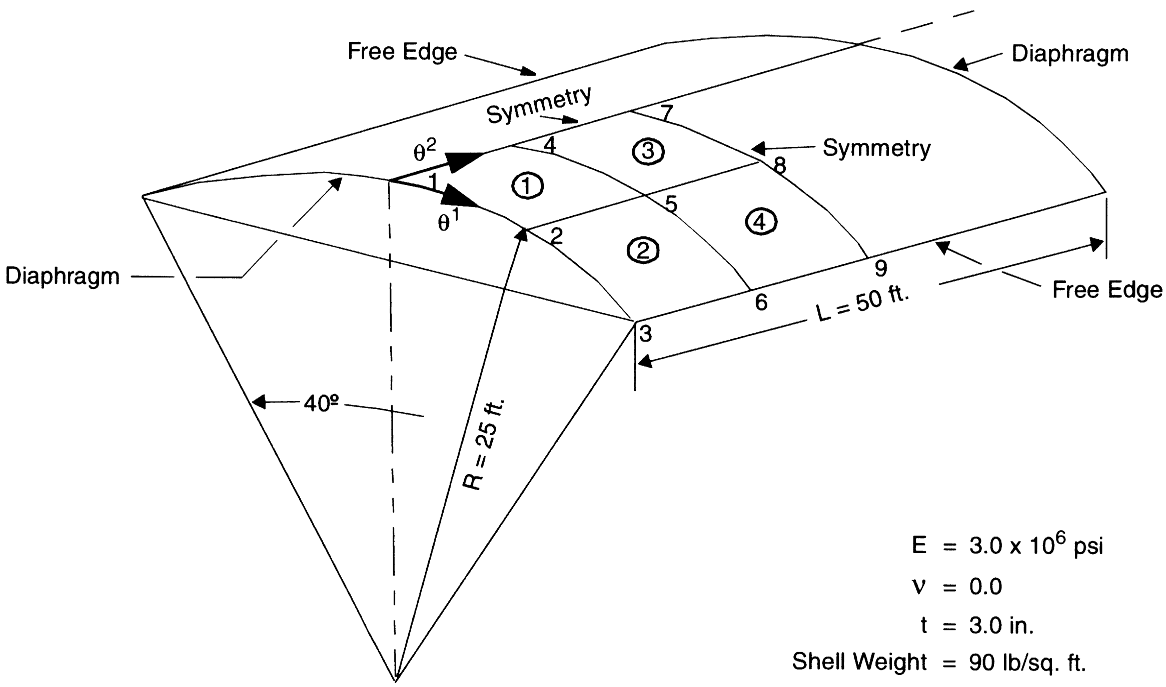


Figure 2.17-1 Cylinder Shell Configuration, Element 4

2.18 Shell Roof using Element 22

This problem is one of several in which a barrel-vault shell roof is loaded under its own weight. The results of these analyses are compared in problem 2.19. This example demonstrates the use of user subroutine UFXORD to generate the coordinates for element type 22.

Element

Element type 22, a curved quadrilateral thick-shell element, is used. The displacements are interpolated from the values of the eight nodes on the middle shell surface. The four corner nodes and four midside nodes each have six degrees of freedom, three displacements, and three rotations.

Model

The four element model takes advantage of symmetry conditions for a one-quarter section of the shell. The ends of the structure are supported by diaphragms with two free edges. The model has a support end, two symmetry boundaries, and one free edge. There are 21 nodes for a total of 126 degrees of freedom. See Figure 2.18-1.

Geometry

The thickness is 3.0 inches.

Material Properties

Young's modulus is 3.0 x 10^6 psi; Poisson's ratio is taken as 0.

Loading

All four elements are loaded under self-weight, positive in the negative z-direction. This corresponds to IBODY = 1 in the DIST LOADS option.

Boundary Conditions

Three sets of boundary conditions are necessary; one on each of the symmetry edges and one on the supported edge. At the supported end, we have u = w = 0. On the y = 300 symmetry boundary, axial displacement is fixed ($v = \theta_x = 0$). On the x = 0 symmetry boundary, movement tangential to the shell surface is fixed ($u = \theta_y = 0$). The constraint on rotation normal to the shell is imposed only at node 15. See Figure 2.16-2 and Figure 2.18-1.

User Subroutines

Subroutine UFXORD is used to generate the three coordinates. The first coordinate read from the COORDINATE block is used to generate two of the three global coordinates. Notice that NCRD = 2 on the second block of the COORDINATE block, rather than the default of 3 for this element.

Results

The results from problems 2.16, 2.17, 2.18, and 2.19 are compared in problem 2.19.

Parameters, Options, and Subroutines Summary

Example e2x18.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	UFXORD

User subroutine in u2x18.f:

UFXORD

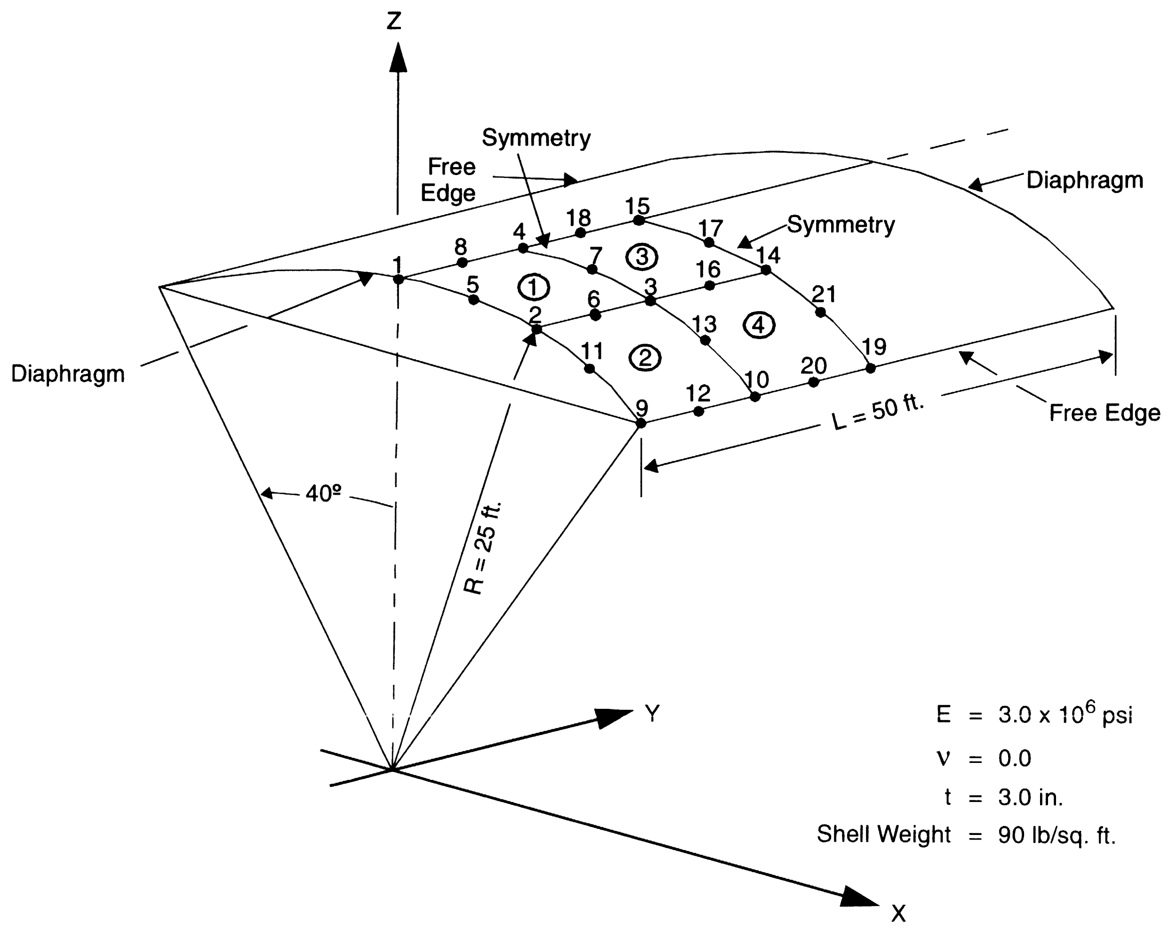


Figure 2.18-1 Cylindrical Shell Roof Configuration, Element 22

2.19 Shell Roof using Element 24

This problem is one of several in which a barrel-vault shell roof is loaded under its own weight. The results of these analyses are compared in this example. This example demonstrates the use of user subroutine UXFORD to generate the coordinates for element type 24.

Elements

Element type 24, a doubly-curved isoparametric quadrilateral shell element, is used. It is based on Koiter-Sanders shell theory and uses a De Veubeke interpolation function. It represents rigid body modes exactly and is suited to large displacement analysis. In the mapped plane, the quadrilateral shape can be arbitrary. The four corner nodes of each element have nine degrees of freedom; three are displacements in the global axes' directions, and the remaining six are first derivatives of these displacements with respect to the surface coordinates. The four midside nodes of each element have three degrees of freedom each. These are derivatives of the three displacements at the node with respect to the vector normal to the element edge in the (θ^1, θ^2) plane.

Model

Four elements are used to model one-quarter of the shell, taking advantage of symmetry. The ends of the structure are supported by diaphragm walls and there are two free edges. The model has 21 nodes and 117 degrees of freedom (see Figure 2.19-1).

Geometry

The shell thickness is specified in the first data field of the third block of the GEOMETRY option (EGEOM1 = 3).

Material Properties

A Young's modulus of 3.0×10^6 psi is specified.

Loading

All four elements are loaded under self-weight, positive in the negative z-direction. This is load type 1 (IBODY = 1), specified in the DIST LOAD option.

Boundary Conditions

Three sets of boundary conditions are necessary, for element vertex nodes (Figure 2.19-2). Displacement in the plane normal to the shell is continuously zero at y = 0 $\left(u = w = \frac{\partial u}{\partial \theta^1} = \frac{\partial w}{\partial \theta^1} = 0\right)$. On the y = 300 symmetry boundary, axial displacement is fixed and is continuously zero $\left(v = \frac{\partial v}{\partial \theta^1} = 0\right)$. From symmetry considerations, $\frac{\partial u}{\partial \theta^2}$ and $\frac{\partial w}{\partial \theta^2}$ must be fixed. On the x = 10 symmetry boundary, movement tangential to the shell surface is continuously zero $\left(u = \frac{\partial u}{\partial \theta^2} = 0\right)$. From symmetry considerations, to fix the model against rotations, $\frac{\partial w}{\partial \theta^1}$ and $\frac{\partial v}{\partial \theta^1}$ must be zero.

Two sets of boundary conditions are necessary for the midside nodes. From symmetry considerations, $\frac{\partial v}{\partial n} = \frac{\partial w}{\partial n} = 0$ on x = 0 and $\frac{\partial u}{\partial n}$ and $\frac{\partial w}{\partial n} = 0$ on y = 300.

User Subroutine

Subroutine UFXORD is used to generate the necessary 11 coordinates. The first coordinate read from the COORDINATE block is the θ^2 and y coordinate. The second coordinate is the angle, in degrees, of the normal to the shell surface, with 0 degrees being a normal parallel to the z-axis. It is used to generate θ^1, x, $\frac{\partial x}{\partial \theta^1}$, w, and $\frac{\partial w}{\partial \theta^1}$. NCRD must be set to 2 in the first data field of the second line of the COORDINATE block, and UFXORD must come after, not before, the COORDINATE block.

Results

The results of this problem are compared with the results of problems 2.16, 2.17, and 2.18.

Figure 2.19-2 and Figure 2.19-3 indicate that excellent results can be obtained by using doubly-curved isoparametric shell elements. Element type 8, the only triangular element used, is the lowest-order complete shell element that can be used.

The results from the quadrilateral shell elements are clearly superior. Element type 22, a thick shell element, shows reasonable results even in a thin shell problem. However, it tends to give a solution which is too stiff and it is known to be sensitive to the shape of the mapped mesh. (The angle between the surface coordinate axes should be orthogonal, if possible.) All of the other elements are well suited to large displacement analysis. Element type 4 yields extremely good results at a reasonable cost, but since the element has no patching functions, the mesh in the (θ^1 -θ^2) plane must be rectangular. Use of element type 24 yields the most accurate results, but it is somewhat more expensive to use than element 4. However, the specification of boundary conditions is easier for this element and it is less sensitive to the boundary conditions. Since it uses complete basis functions, it is well-known to be insensitive to distortion of the mesh.

A comparison of results against the closed-form Scordelis-Lo solution is found in Figure 2.19-4. All of the MARC doubly-curved shell elements converge very rapidly compared to flat plate elements and curved elements such as Strickland's. These elements do not fulfill either compatibility conditions or rigid body requirements.

Parameters, Options, and Subroutines Summary

Example e2x19.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	UFXORD

User subroutine in u2x19.f:

UFXORD

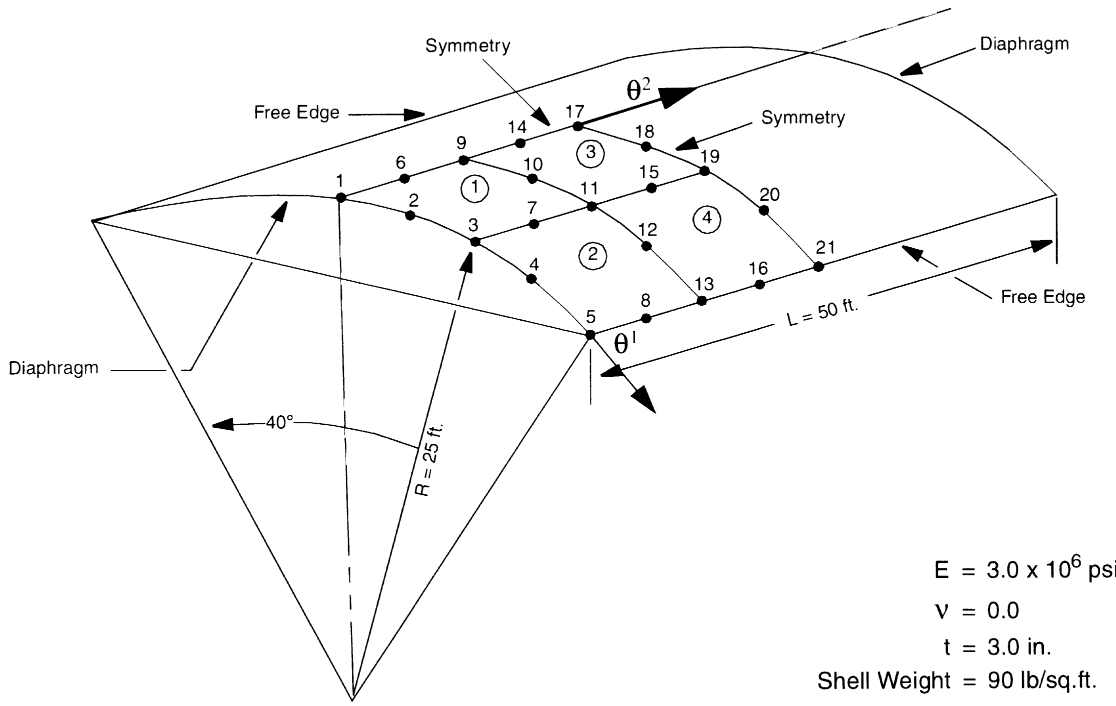


Figure 2.19-1 Cylindrical Shell Roof Configuration, Element 24

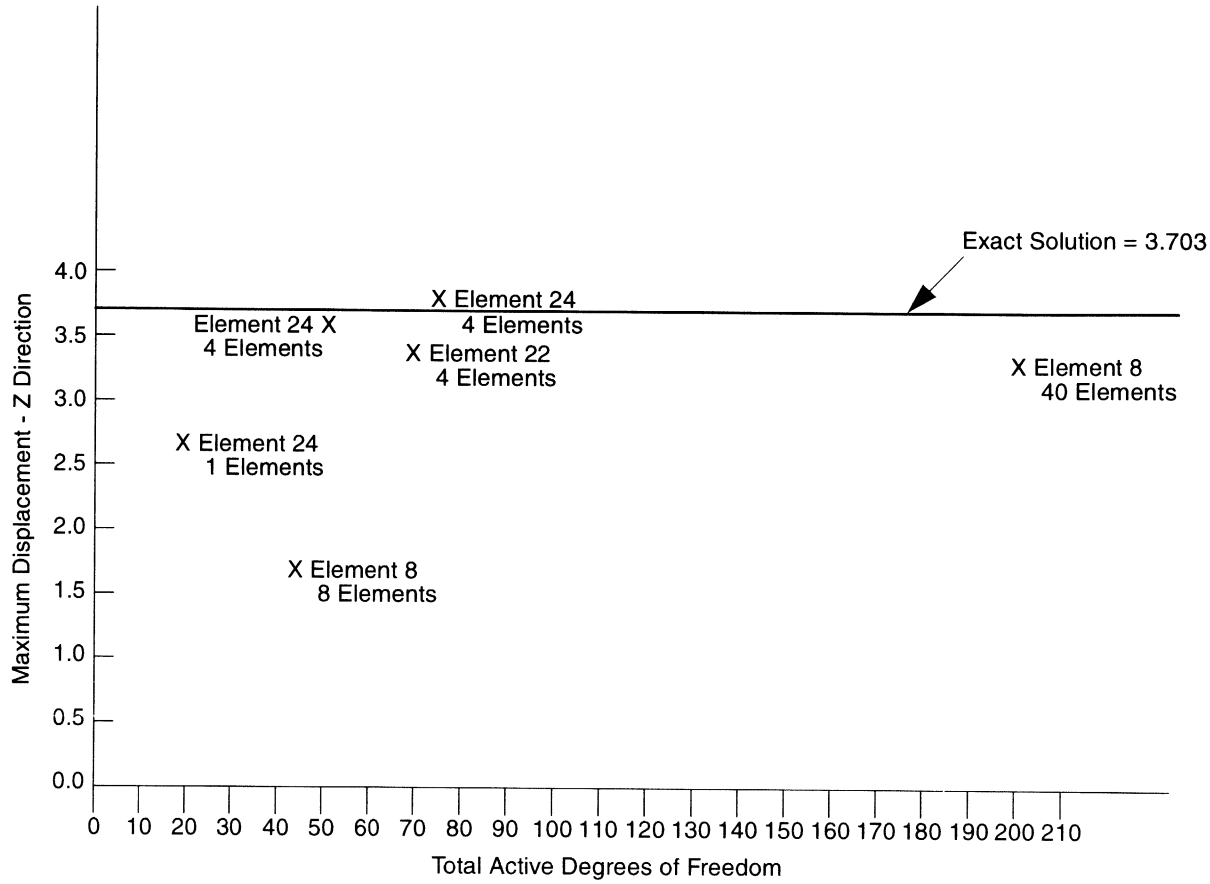


Figure 2.19-2 Maximum Z Deflection Versus Total Active Degrees of Freedom

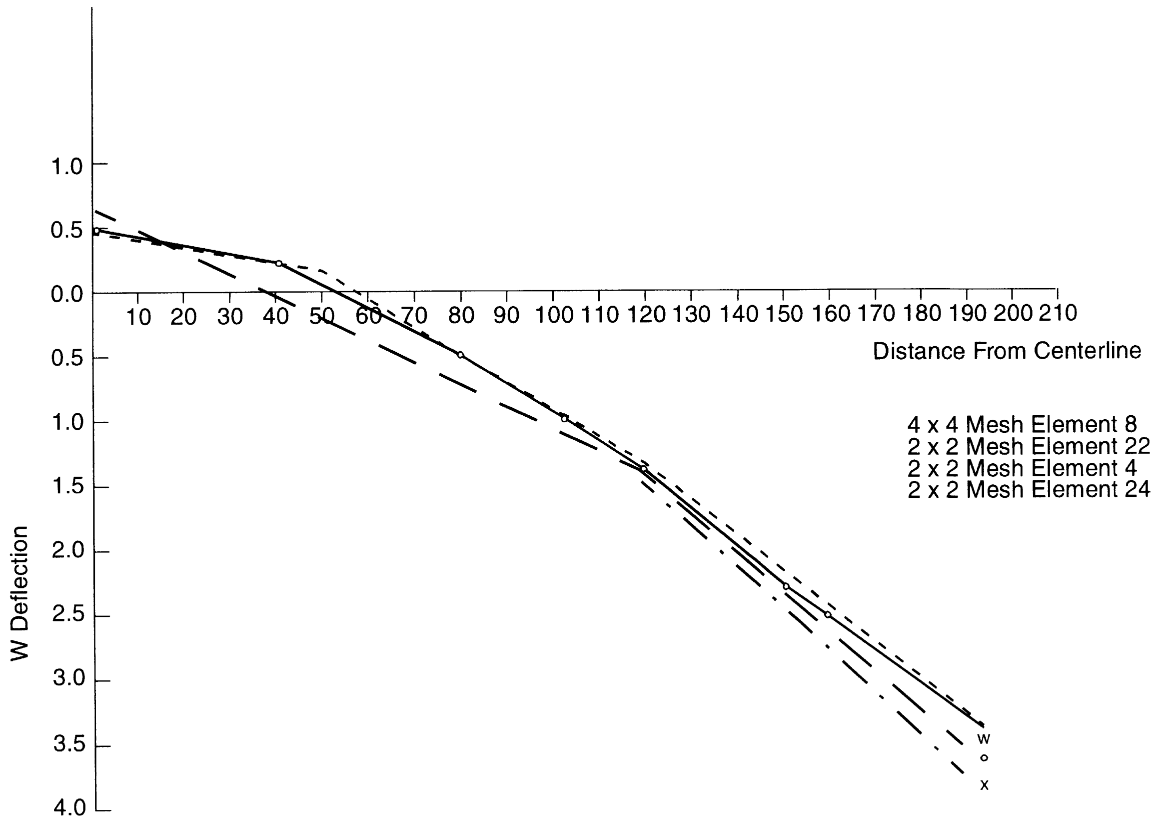


Figure 2.19-3 Vertical Deflection of the Y = 300 Symmetry Boundary vs. Distance From X = 0 Symmetry Boundary

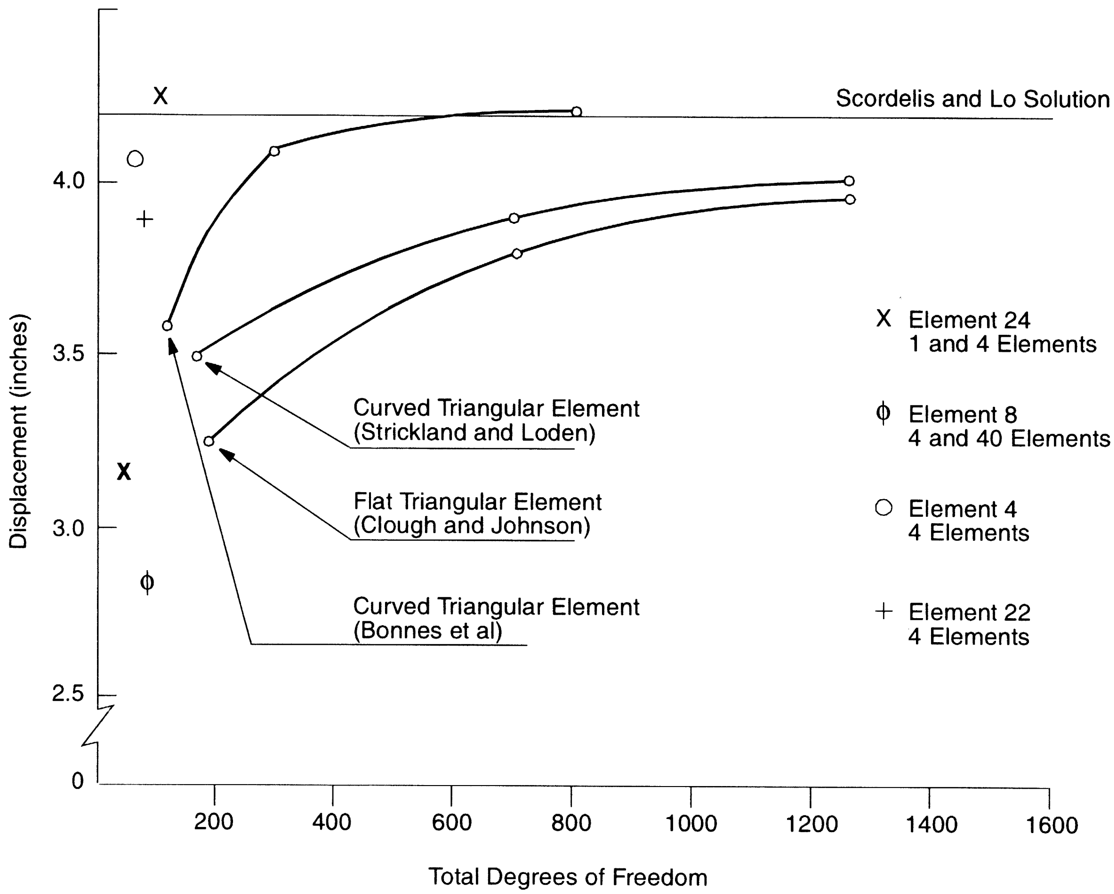


Figure 2.19-4 Vertical Displacement at the Center of the Free Edge

2.20 Pipe Bend Analysis

A 90-degree pipe bend under a concentrated 1-lb. load is elastically analyzed. This problem demonstrates the use of the special pipe bend element. For a more elaborate example, the reader is referred to problem 7.13.

Element

Element type 17 is used, which is a modification of element type 15, the two-node axisymmetric shell with four global degrees of freedom. The modification into a pipe bend approximation consists of introducing additional degrees of freedom at the centroid of the pipe in the r-z plane. The three degrees of freedom at this additional node are:

$1 = \Delta u$ – normal motion of one end plane with the other plane fixed
$2 = \Delta \phi$ – in-plane rotation of one end plane with the other end plane fixed
$3 = \Delta \psi$ – out-of-plane rotation of one end plane with the other end plane fixed

Details concerning this element are found in *MARC Volume B: Element Library.*

Model

One-half of the r-z plane cross section has been modeled with 10 elements and 12 nodes. The mesh and geometry are shown in Figure 2.20-1. The centroid node has been chosen as number 12. For convenience, user subroutines UFCONN and UFXORD are used to compute the CONNECTIVITY and COORDINATE input data and is shown in the input file.

Geometry

For this element, EGEOM1, EGEOM2 and EGEOM3 are pipe wall thickness, angular extent of the pipe bend, and radius of curvature, respectively.

Material Properties

All elements are assumed to be uniform here. Values for Young's modulus, Poisson's ratio, and yield stress used here are 30×10^6 psi, 0.3, and 30,000 psi, respectively.

Loading

A concentrated load of 1.0 lb. is applied in the r-direction at the common node, 12.

Boundary Conditions

Nodes 1 and 11 have been restrained in the one and four displacement degrees of freedom in order to prescribe symmetry about the r-axis. The common node, 12, is restrained against out-of-plane bending.

Results

Figure 2.20-2 and Figure 2.20-3 give a comparison of the stresses predicted by this analysis with experimental results of Gross, N., and Ford, H., "Flexibility of Short-Radius Pipe Bends", *Proc. Inst. Mech. Engr.*, Vol. 1B, p. 480, 1952. The stress predictions are in reasonable agreement with this experiment. It should be noted, that use of just five elements around the half pipe would yield satisfactory results in this case. For further discussion of this type of pipe bending theory for elastic-plastic analysis, see Marcal, P. V., "Elastic-Plastic Behavior of Pipe Bends With In-Plane Bending", *J. Strain Analysis*, Vol. 2, p. 84, 1967.

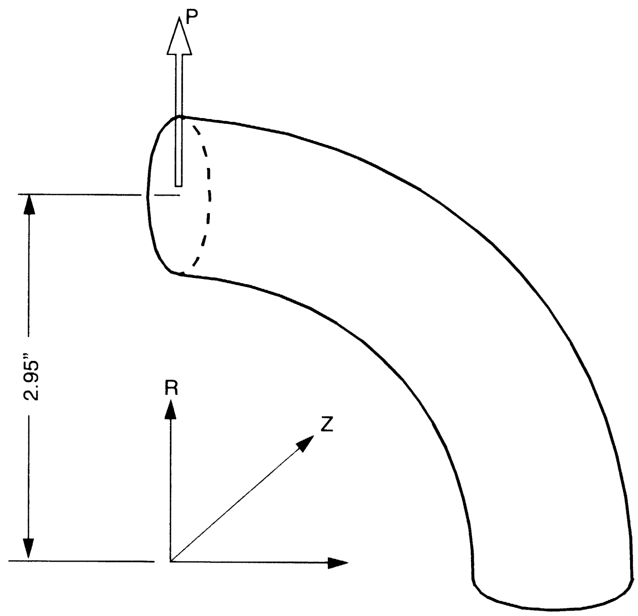
Parameters, Options, and Subroutines Summary

Example e2x20.dat:

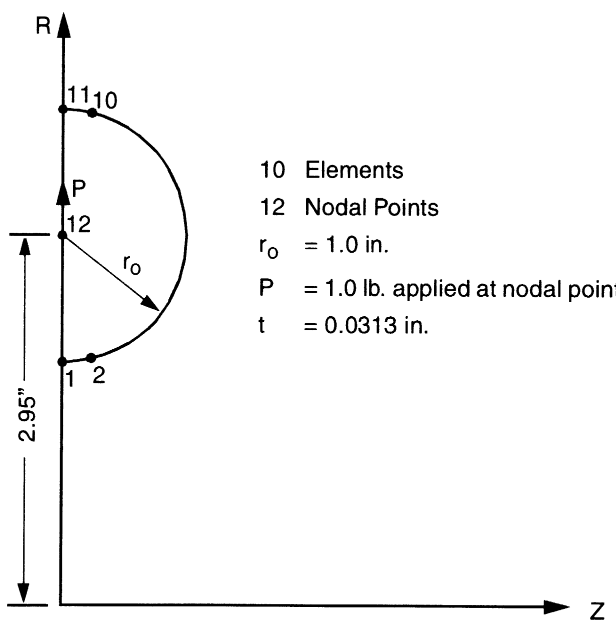
Parameters	Model Definition Options
ELEMENTS	END OPTION
END	FIXED DISP
SIZING	GEOMETRY
TITLE	ISOTROPIC
	POINT LOAD
	UFCONN
	UFXORD

User subroutines in u2x20.f:

UFXORD
UFCONN



(a) Geometry



10 Elements
12 Nodal Points
r_o = 1.0 in.
P = 1.0 lb. applied at nodal point 12
t = 0.0313 in.

(b) Mesh

Figure 2.20-1 Geometry and Mesh-Pipe Bending Problem

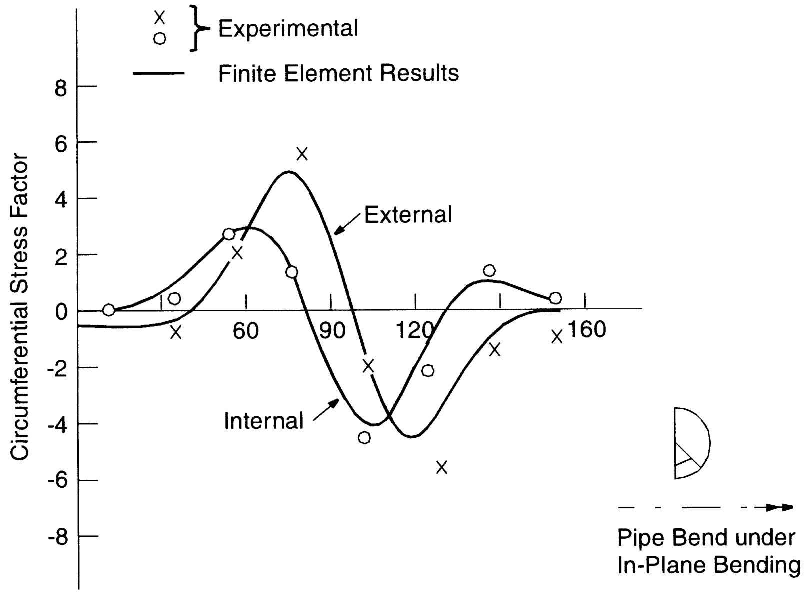


Figure 2.20-2 Distribution of Circumferential Stress $\lambda = 0.0924$

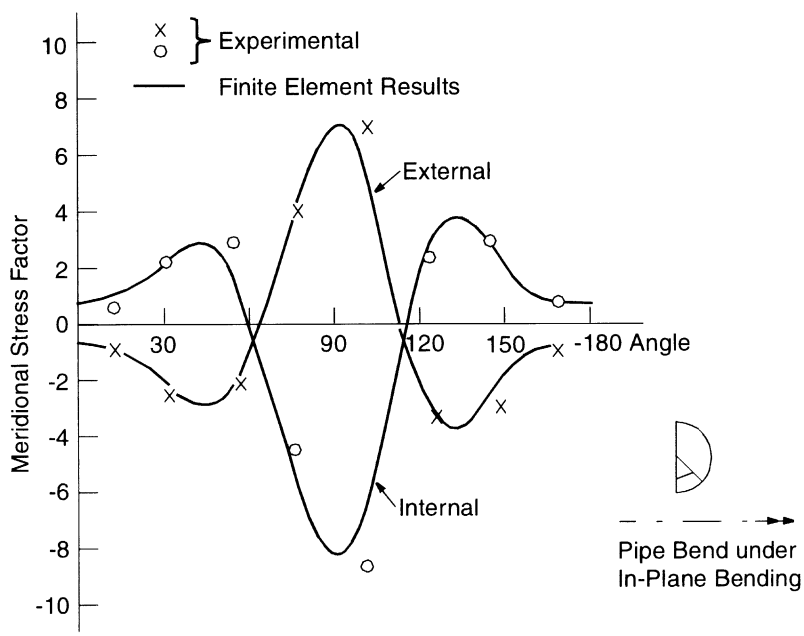


Figure 2.20-3 Distribution of Meridional Stress $\lambda = 0.0924$

2.21 Doubly Cantilevered Beam using Element 52

A hollow, square-section beam clamped at both ends is subjected to a single-point load applied at its center. This is the same problem as problem 2.7, but using element type 52. The results are compared to the analytic solution.

Element

Element type 52 is used, a straight Euler-Bernoulli beam in space. It has six degrees of freedom per node – three global Cartesian displacement coordinates and three global components of rotation. This element only allows linear elastic behavior, or nonlinear elastic behavior if user subroutine UBEAM is used in conjunction with HYPOELAS.

Model

Due to symmetry conditions, only half the beam is modeled. Five elements and six nodes are used for a total of 36 degrees of freedom. (See Figure 2.21-1). A cross-section of the beam is shown in Figure 2.21-2.

Geometry

To use element 52, the moments of inertia of the section about the local x- and y-axes and area are needed. The area is 0.0396 in^2. I_{xx} and I_{yy} are 0.0064693 in^4. Because this is an elastic element, no integration around the beam section is necessary.

Material Properties

Young's modulus is 30×10^6 psi; Poisson's ratio is taken as 0.

Loading

A single point load of 50 pounds is applied in the negative y-direction at the center node of the beam.

Boundary Conditions

In the model, the beam end node (node 1) is fixed against displacement and rotation. Thus, $u = v = w = \theta_x = \theta_y = \theta_z = 0$. The midpoint node, node 6, is fixed against axial displacement and rotation; $u = \theta_x = \theta_y = \theta_z = 0$ to ensure that symmetry is satisfied.

Results

A simple elastic analysis was run with one load increment of 50 pounds applied to node 6 in the zeroth increment. The computed results are compared with an exact solution in Table 2.21-1 and Table 2.21-2. Correlation is good for element type 52. The analytic solution may be found in R. J. Roark, *Formulas for Stress and Strain*. The deflected shape is shown in Figure 2.21-3.

Table 2.21-1 Y Deflection (in.)

Node	MARC Element 52	Analytically Calculated
1	0.	0.
2	.000419	.000422
3	.001417	.001428
4	.002609	.002628
5	.003607	.003634
6	.004026	.004056

Table 2.21-2 Moments (in.-lb.) and Reaction Forces (lb.)

MARC Element 52	Analytically Calculated
M = 125.	M = 125.
R = 50.	R = 50.

Parameters, Options, and Subroutines Summary

Example e2x21.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
POINT LOAD

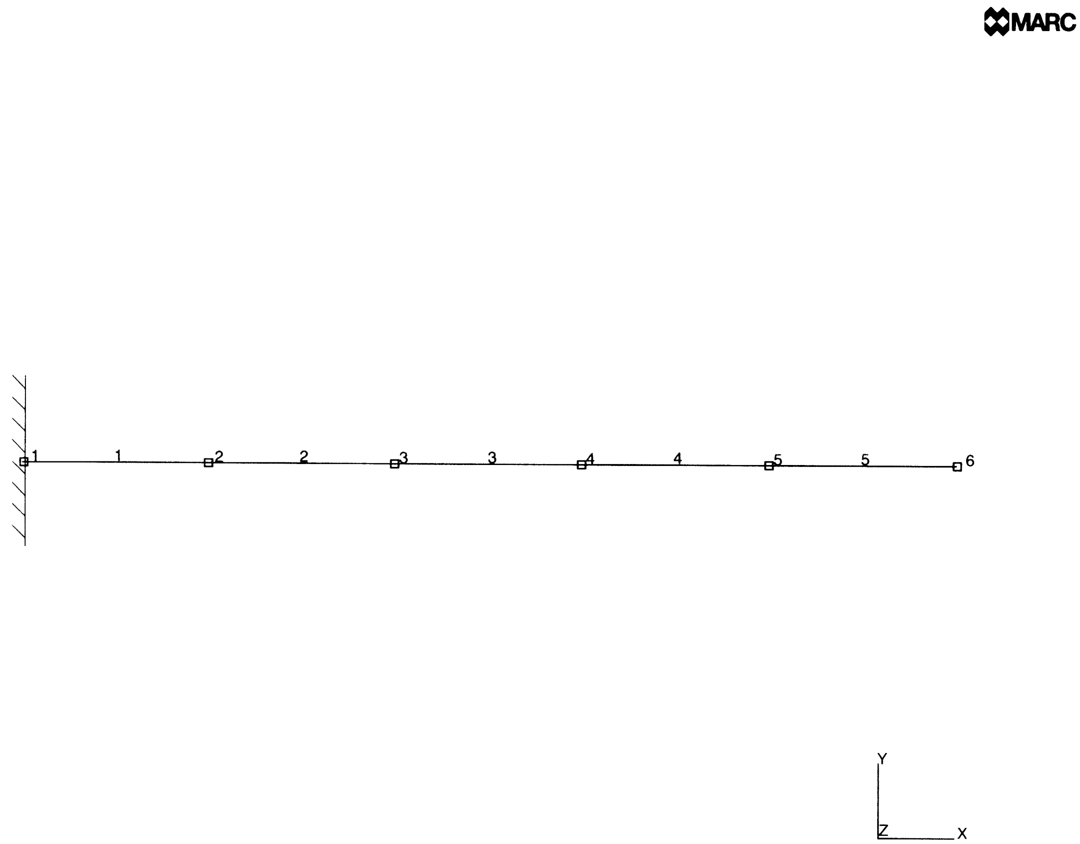


Figure 2.21-1 Closed Section Beam Model

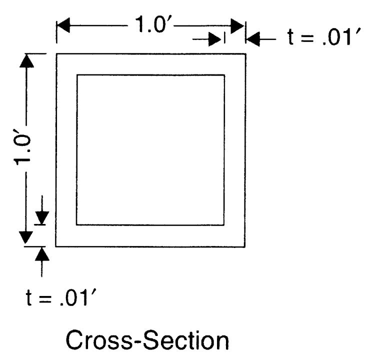


Figure 2.21-2 Hollow, Square-Section Beam

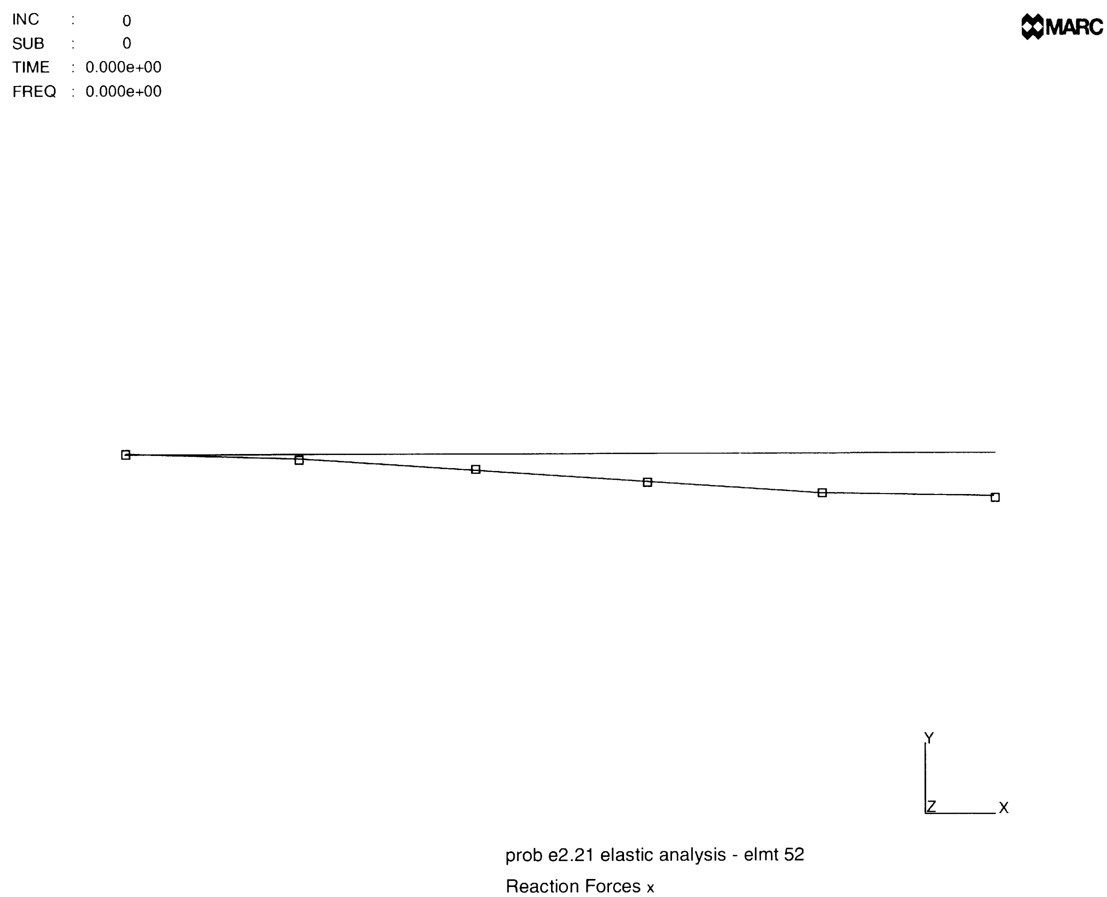


Figure 2.21-3 Defections

2.22 J-Integral Evaluation Example

This example illustrates the use of the J-Integral evaluation procedure in MARC, as well as the 1/4-point element geometry at the crack tip. The example is that of a double-edge notch (DEN) specimen under axial tension (Mode I) (Figure 2.22-1). This example is chosen because of the availability of an accepted value for K_I for comparison. The fundamental problem in a crack problem is the singularity in the strain field at the crack tip. For elastic response the singularity is of order $1/\sqrt{r}$, where r measures distance away from the crack tip. It can be shown that the second order isoparametric elements reproduce this singularity when the side nodes are placed at the 1/4-points instead of at the midsides. This condition is achieved by merging two nodes in each element at the crack tip. Based on this consideration, a rather coarse mesh for the problem is shown in Figure 2.22-2 and Figure 2.22-3. The coarseness of the mesh is acceptable because the only output required is the J-integral value, and it has been shown [1] that the differential stiffness technique, as is used in MARC, provides good estimates of J with relatively coarse models.

Element

Element type 27 is a plane-strain quadrilateral element. There are eight nodes and two degrees of freedom at each node.

Model

Only a quadrant of the model is used because of obvious symmetries. A second COORDINATES block was used to move the side nodes of the crack tip elements to the 1/4 points (1/4 of the way along the sides from the crack tip to the opposite face of the element).

Geometry

No geometry is specified.

Material Properties

The Young's modulus is 30 x 10^6 psi and Poisson's ratio is 0.3.

Loading

The loading is shown in Figure 2.22-1. The load is applied as a uniform negative pressure of 100 psi on the appropriate faces of the end elements.

Boundary Conditions

The boundary conditions for the model quadrant are determined by symmetry conditions. The edge along the y-direction is constrained in both degrees of freedom. The edge along the x-direction is constrained to displacement along the x-axis. Boundary conditions are illustrated in Figure 2.22-1.

J-Integral

The J-integral is evaluated numerically by moving nodes within a certain ring of elements around the crack tip to represent a differential crack advance and measuring the change in strain energy. The J is the negative differential of strain energy with respect to crack advance. This mesh has three obvious "rings" of elements around the crack tip, so that three evaluations of J are available. Since the J-integral should be path independent for elastic problems, the variation in J between the three values gives some idea of the accuracy of the solution. A differential movement has to be supplied to evaluate J. Numerical experiments have indicated that setting this movement to less than 1/50 times the size of the smallest crack tip element gives a convergent solution (convergence in the sense of the numerical difference providing the differential). The use of too small a movement causes roundoff difficulties.

In this case, a value of 10^{-2} was used. The smallest element dimension is 1, so that this represents 1/100, a satisfactory value. The midside nodes are moved proportionally for each evaluation.

Results

MARC provides an output of the strain energy difference. This must be normalized by the crack opening area to obtain the value of J. Since this specimen is of unit thickness, the crack opening area is $\Omega 1$, where $\Omega 1$ is the differential crack motion. The mesh used symmetry about the crack line, so that that strain energy change in the actual specimen would be twice that printed out. Finally, since this is a plane strain, Mode I problem, the J-integral can immediately be converted to K_I, the stress intensity factor, by the relation:

$$K_I = \sqrt{\frac{E}{1-\nu^2} J}$$

These results are summarized in Table 2.22-1.

It is clear from these results that the path independence is well reproduced, and that the error in the solution for K_I is quite small. The user should note that such a coarse mesh does not give an accurate model of the stress field close to the cracktip. However, because the 1/4-point technique used here includes the $1/\sqrt{r}$ singularity, a reasonable refinement of the same mesh would give excellent predictions of the near-tip elastic stress field. As a general guideline, it appears that second-order elements with the 1/4-point technique give good results for J-integral evaluation when the crack tip elements are sized about 20% of the crack depth or ligament width, whichever is smaller. For near-tip stress field prediction, the size should be reduced to about 5% of crack depth or ligament width.

Table 2.22-1 J-Integral Evaluation Results

	Move Tip Only	**Move First Ring of Elements**	**Move Second Ring of Elements**
Strain energy change given in program (Δu)	6.7313×10^{-5}	6.693×10^{-5}	6.689×10^{-5}
J-Integral	1.324×10^{-2}	1.3386×10^{-2}	1.3378×10^{-2}
$K_I = \sqrt{\frac{E}{1-\nu^2} J}$	666.	664.	664.
$K_I / \sigma_{net} \sqrt{1}$	1.052	1.050	1.050
cf 1.028 [2]	+2.4%	+2.2%	+2.2%

References

1. Parks, D. M., "A Stiffness Derivative Finite Element Technique for Determination of Elastic Crack Tip Stress Intensity Factors," *Int. J. Fracture*, Vol. 10, No. 4, December 1974, pp. 487-502.
2. Bowie, I. L., "Rectangular Tensile Sheet With Symmetric Edge Cracks," *J. Applied Mechanics*, Vol. 31, 1964, pp. 208-212.

Parameters, Options, and Subroutines Summary

Example e2x22.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
ELSTO	COORDINATES
END	DIST LOADS
J-INT	END OPTION
SIZING	FIXED DISP
TITLE	ISOTROPIC
	J-INTEGRAL
	PRINT CHOICE

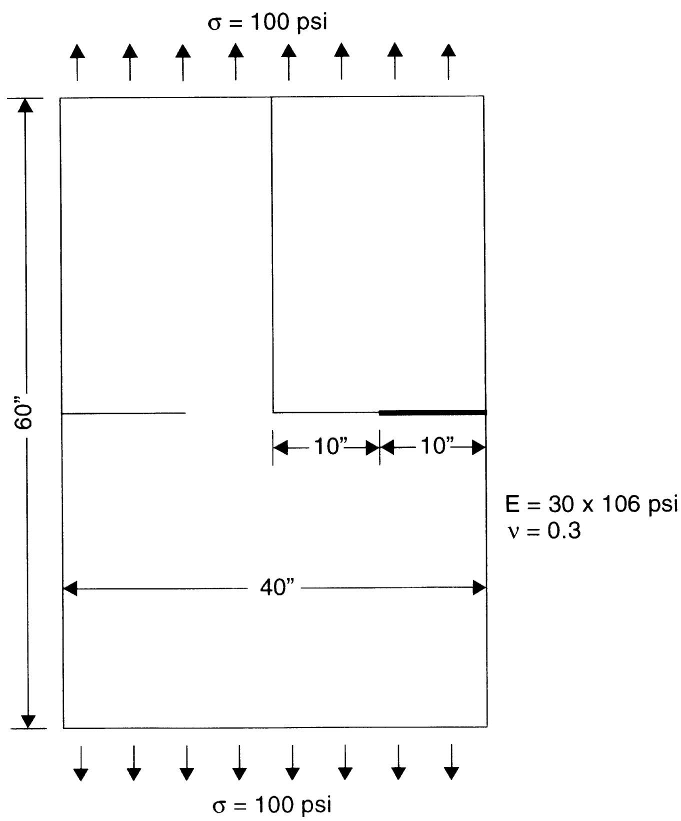


Figure 2.22-1 Double-Edge Notch Specimen, Showing Blocks for Mesh Generation

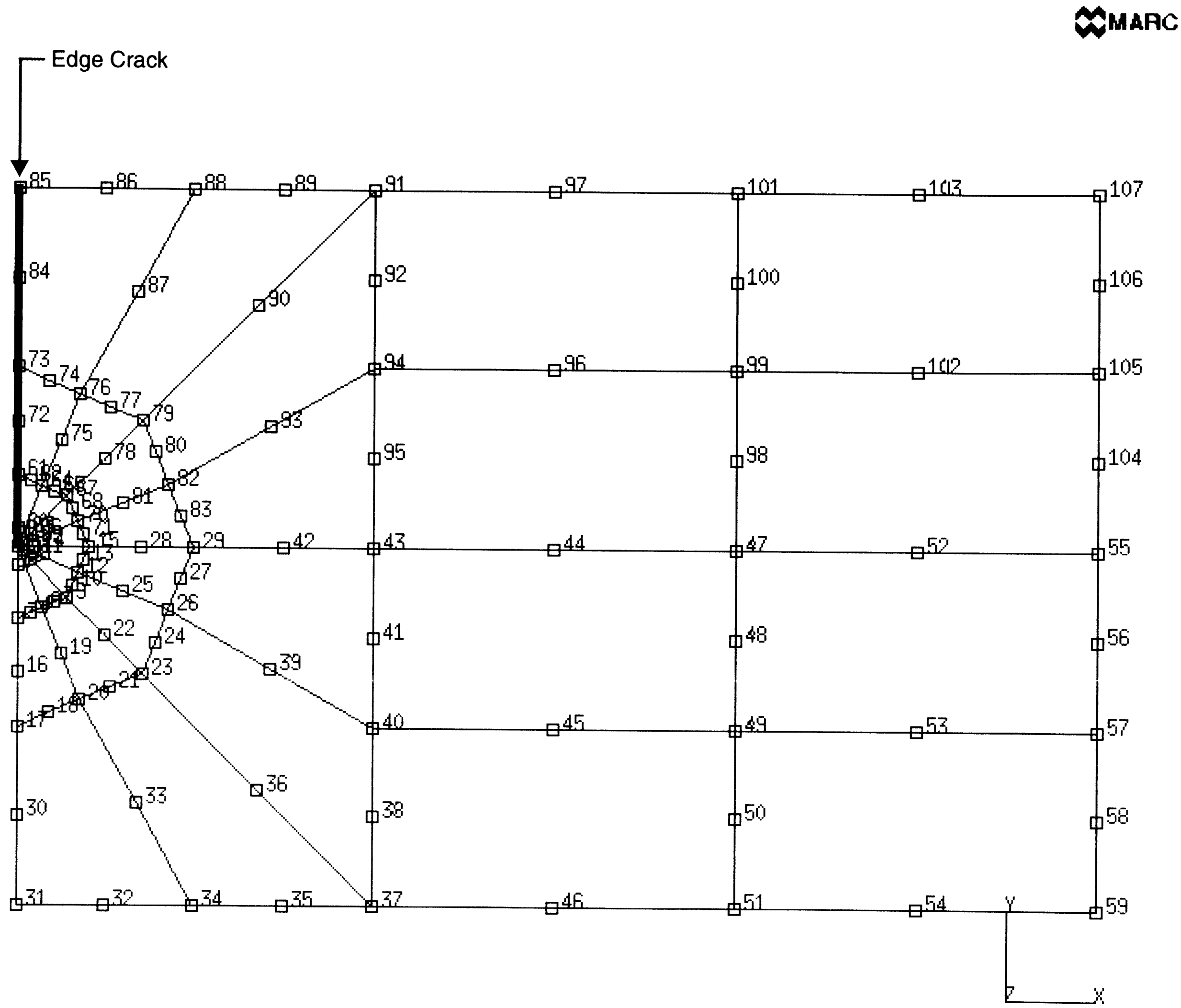


Figure 2.22-2 Mesh for Double-Edge Notch Specimen

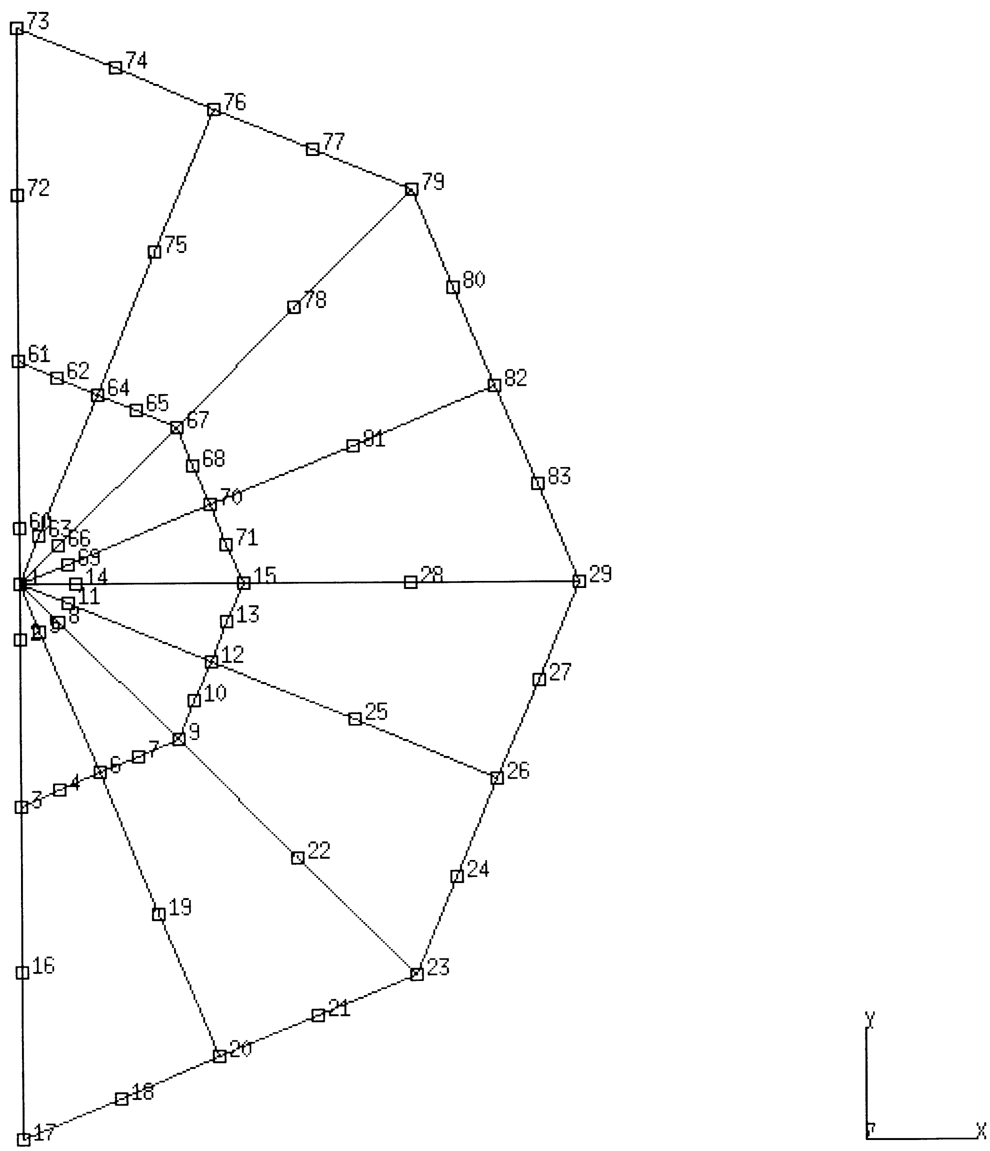


Figure 2.22-3 Mesh Detail of Double-Edge Notch Specimen

2.23 Thick Cylinder Under Internal Pressure

This problem illustrates the use of MARC element type 6 and the TRANSFORMATION option for an elastic analysis of a thick cylinder using planar elements. The cylinder is subjected to internal pressure. The results can be compared with the analytical prediction.

Element

Element type 6, the triangular plane-strain element, is used to model a section of the thick cylinder.

Model

Because of the symmetrical behavior, only a portion of the cylinder needs to be analyzed. The dimensions of the cylinder and the finite element mesh are shown in Figure 2.23-1. Sixteen elements with 18 nodes are used in the mesh.

Material Properties

The material is a typical steel with Young's modulus of 30 x 10^6 psi and Poisson's ratio of 0.3. The data is entered using the ISOTROPIC option.

Geometry

The thickness is equal to unity, the default value; hence, the GEOMETRY option is not used.

Loading

The cylinder is under an internal pressure of 1 psi. This is applied to the 2-1 face of element 1 using traction type 8 using the DIST LOADS option.

Boundary Conditions

Symmetry conditions are assumed at radial lines OY and OX. Degrees of freedom at nodal points 1, 3, 5, 7, 9, 11, 13, 15 and 17 are transformed into local coordinate system (x,y).

Results

Stresses in the thick cylinder are (as given in Timoshenko and Goodier, *Theory of Elasticity*):

$$\sigma_r = \frac{pR_1^2}{R_2^2 - R_1^2}\left(1 - \frac{R_2^2}{r^2}\right), \qquad \sigma_\theta = \frac{pR_1^2}{R_2^2 - R_1^2}\left(1 + \frac{R_2^2}{r^2}\right)$$

The stresses are plotted as a function of radial distance in Figure 2.23-2.

Parameters, Options, and Subroutines Summary

Example e2x23.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	TRANSFORMATION

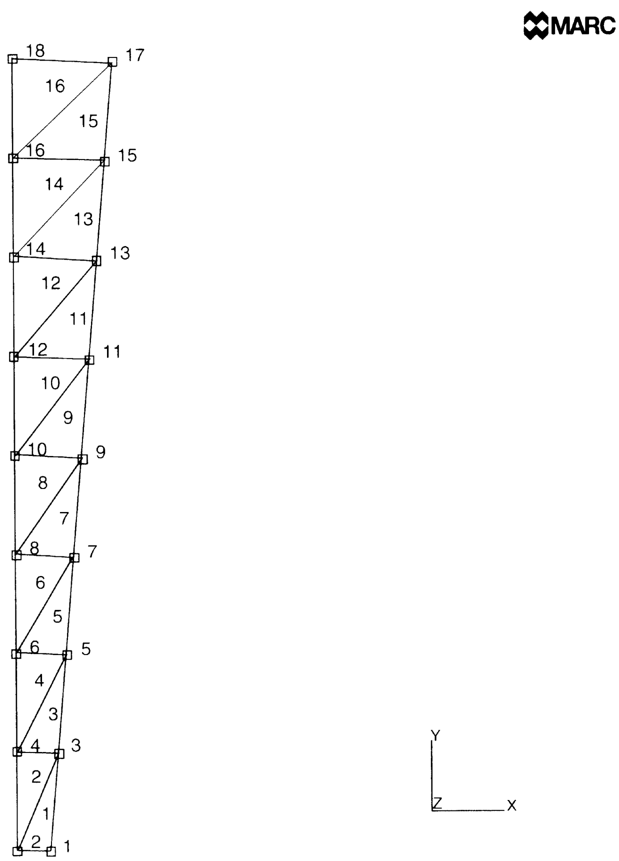


Figure 2.23-1 Thick Cylinder and Mesh

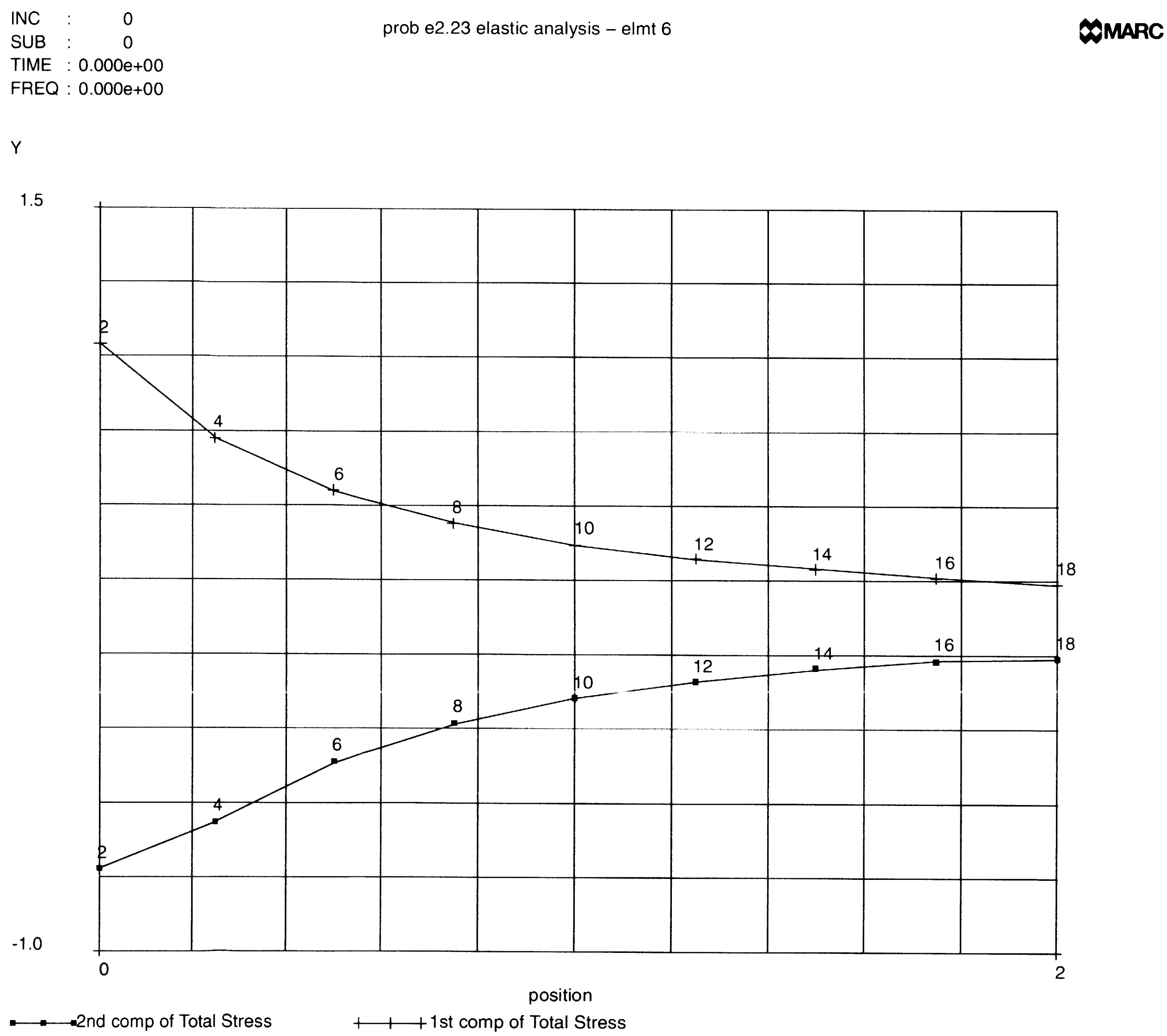


Figure 2.23-2 Stresses vs. Radial Distance

2.24 Three-Dimensional Frame Analysis

This problem illustrates the use of MARC element type 9 for an elastic analysis of a three-dimensional frame structure (a guyed wire tower). The frame is subjected to a concentrated load at the top.

Element

This frame analysis is performed with three-dimensional truss elements type 9. This element has two nodes with three degrees of freedom at each node.

Model

The dimensions of the frame structure and the finite element mesh are shown in Figure 2.24-1. There are 20 elements and 9 nodes in the mesh.

Material Properties

Elastic behavior is investigated with Young's modulus of 30 x 10^6 psi; the value is entered through the ISOTROPIC option.

Geometry

Two element cross sections are stored in two block pairs in variable EGEOM1. The cross-sectional area is 1.0 square inch for the primary members, elements 1 to 12.

The cross-section area is 0.25 square inch for the secondary members, elements 13 to 20.

Loading

A 10,000 pound concentrated load at the top (node 1) is applied in the horizontal direction (x-direction) using the POINT LOAD option.

Boundary Conditions

The FIXED DISP option is used to constrain the nodal points at the base (3, 5, 7 and 9).

Results

A deformed mesh plot is shown in Figure 2.24-2. To verify that the structure is in equilibrium, we add the reaction forces at nodes 3, 5, 7, 9 and observe that the total reactions are:

R_x = -10,000 pounds
R_y = 0 pounds
R_z = 0 pounds

balancing the applied load of 10,000 pounds.

Parameters, Options, and Subroutines Summary

Example e2x24.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POINT LOAD

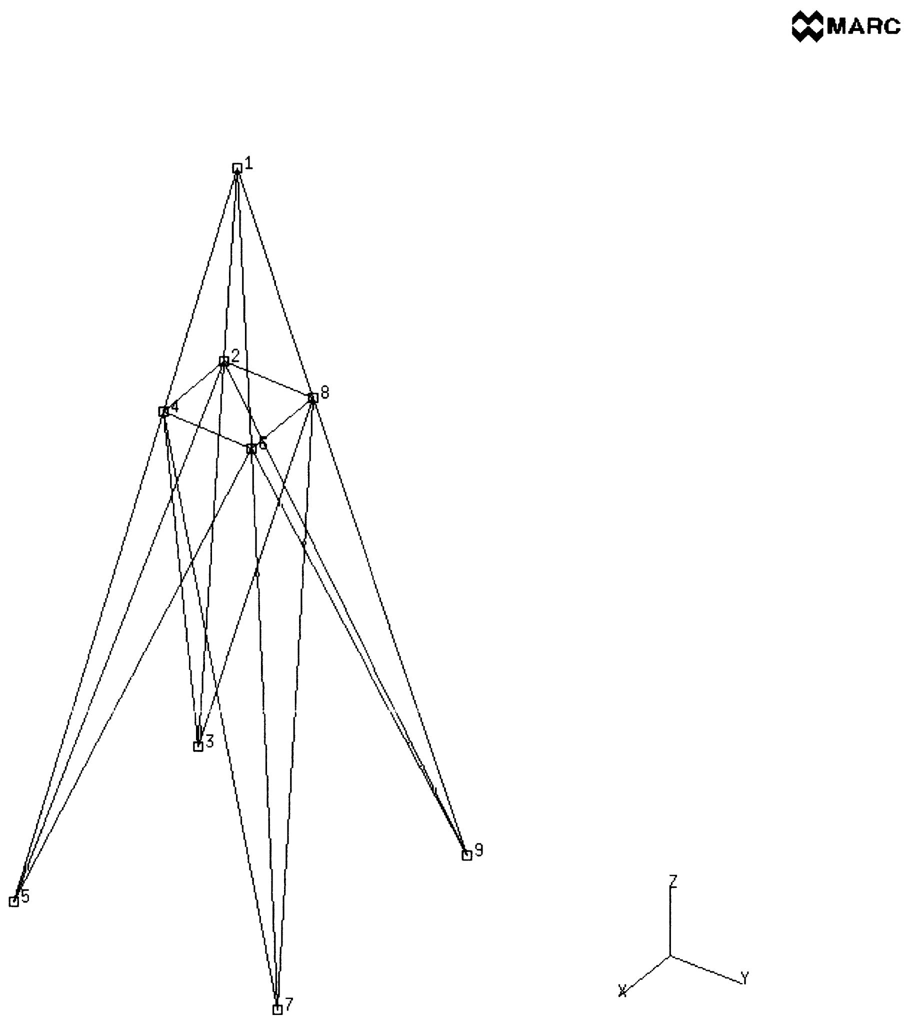


Figure 2.24-1 Three-Dimensional Frame and Mesh

Figure 2.24-2 Deformed Mesh Plot of Three-Dimensional Frame

2.25 Two-Dimensional Strip Compressed by Rigid Plates

This problem demonstrates the use of MARC element types 11 and 115 for an elastic analysis of a two-dimensional strip subjected to known displacements at a boundary line.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x25	11	24	35
e2x25b	115	24	35

Elements

Element types 11 and 115 are 4 node plane-strain quadrilaterals. Element 115 uses reduced integration with hourglass control.

Model

One quarter of a 2 by 3 inch plate is modeled with 24 elements and 35 nodes, as shown in Figure 2.25-1 on the deformed mesh. The displacements are magnified by 1200.

Material Properties

The material for all elements is treated as an elastic material with Young's modulus of 30.0E+06 psi and Poisson's ratio of 0.3.

Geometry

The strip has a thickness of 1 inch given in the first field.

Loads and Boundary Conditions

Symmetry conditions require that the vertical displacements along the bottom surface (y = 0), and the horizontal displacements along the left surface (x = 0), are constrained to zero. The applied displacement on the top surface (y = 1 inch) is -0.0001 inch in the vertical direction and zero in the horizontal direction.

Results

Figure 2.25-2 and Figure 2.25-3 show the variation of the second component of stress (σ_{22}) over the mesh for element types 11 and 115, respectively. Examining these figures, we see that the second component of stress is nearly uniform, except near the free surface. The stresses are typically within 10% of a homogeneous compression problem. This is an expected variation, due to edge effects. The far-field analytical solution becomes:

ε_{22} = 1.0E-04 in/in, and σ_{22} = 3510 psi.

The values of σ_{22} (0,0) for element types 11 and 115 from element 1 are 3791 psi and 3665 psi, respectively. The bonded top surface does not allow the material to deform in a homogeneous manner.

Parameters, Options, and Subroutines Summary

Example e2x25.dat:

Parameters	Model Definition Options
ELEMENTS	CONN GENER
END	CONNECTIVITY
SIZING	COORDINATES
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NODE FILL
	POST

Example e2x25b.dat:

Parameters	Model Definition Options
ALIAS	CONN GENER
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NODE FILL
	POST

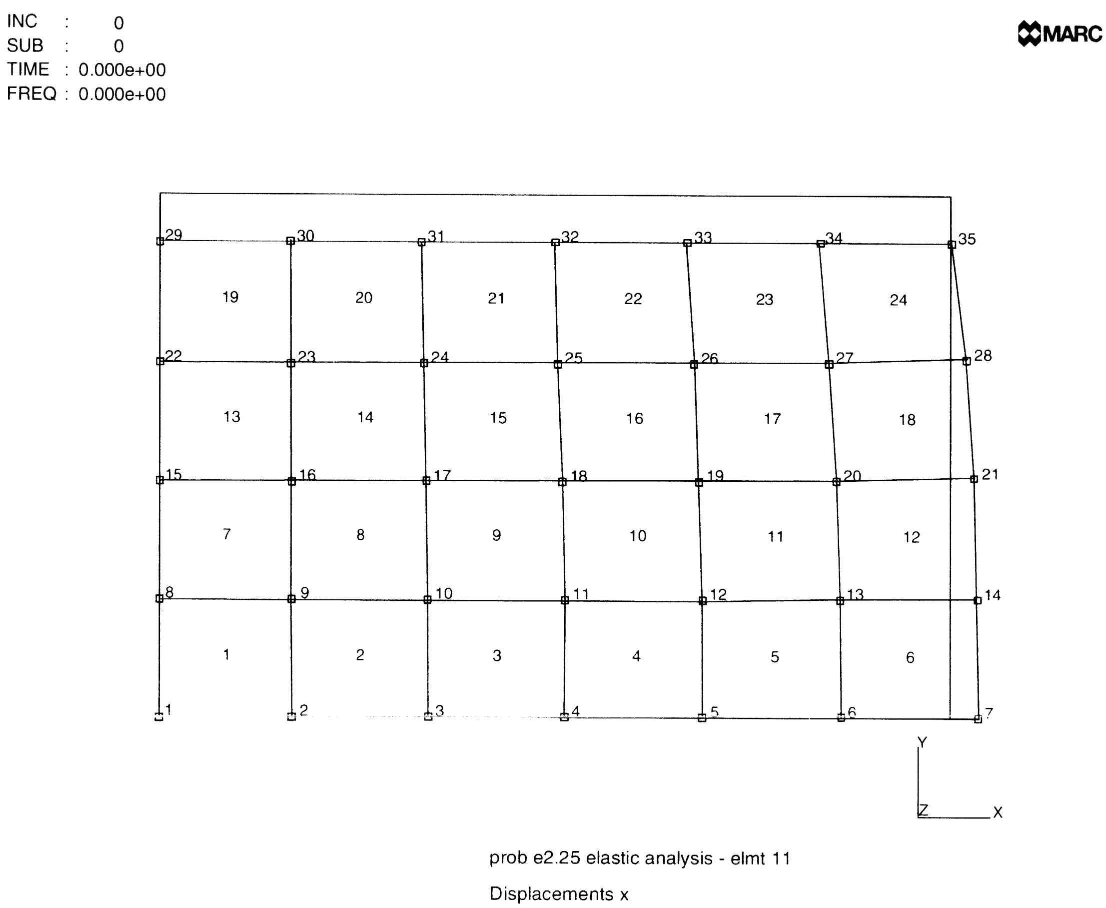


Figure 2.25-1 Deformed Mesh

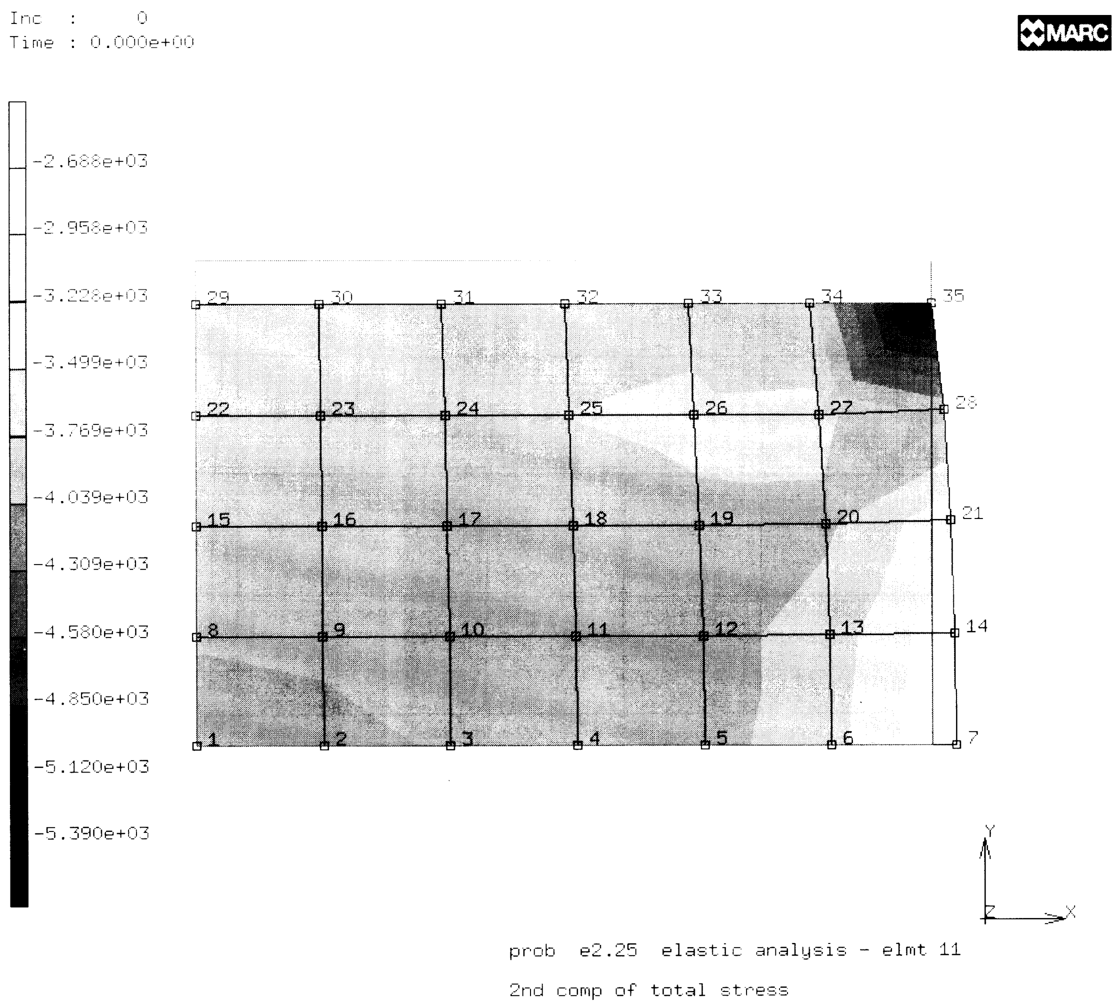


Figure 2.25-2 Contours of σ_{22} Element 11

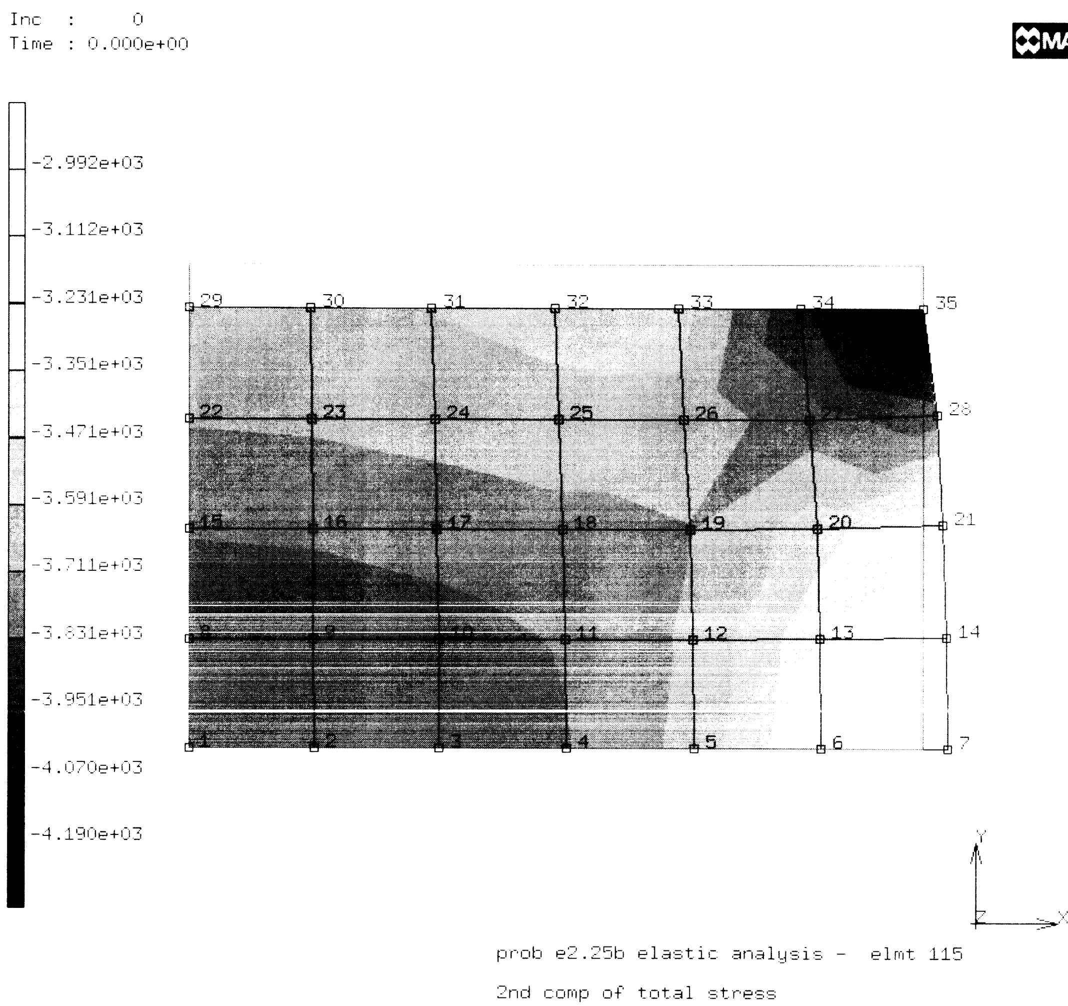


Figure 2.25-3 Contours of σ_{22} Element 115

2.26 Two-Dimensional Strip Compressed by Rigid Plates

This problem demonstrates the use of MARC element types 11, 118, 125, and 128. The nearly incompressible material (Poisson's ratio = .4999) of a strip is subjected to compression by prescribed displacements. The constant dilatation option is also used.

This problem is modeled using the four techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x26	11	24	35
e2x26b	118	24	35
e2x26c	125	48	117
e2x26d	128	48	117

Elements

Element type 11 is an 4-node, incompressible, plane-strain element. Element type 118 is a 5-node plane strain element with reduced integration and has a Herrmann formulation. Element types 125 and 128 are 6 node plane strain triangles with type 128 having a Herrmann formulation.

Model

The dimensions of the strip and the finite element meshes are shown in Figure 2.26-1. There are 24 elements in the quadrilateral meshes and 48 elements in the triangular meshes.

Material Properties

The material for all elements is treated as an elastic material with Young's modulus of 3.0E+06 psi and Poisson's ratio (ν) of .4999.

Geometry

The strip has a thickness of 1 inch given in the first field. A nonzero value is input in the second field of this option to impose a constant dilatation constraint. Improved accuracy is obtained with this technique for nearly incompressible and incompressible behavior when using element type 11.

Results

The condition of plane strain requires the third direct component of stress to become:

$$F = \sigma_{33} - \nu(\sigma_{11} + \sigma_{22}) = 0$$

Element type 11 and 125 satisfies this condition, namely F = 0, exactly. User subroutine PLOTV is used to calculate the above value of F at all integration points. Figure 2.26-2 and Figure 2.26-3 show the contours of F on the deformed shape where the displacements are magnified by 2000. Because of the Lagrange multipliers used in the Herrmann formulation for element types 118 and 128, the plane strain condition is only satisfied on the average and not at each integration point. Figure 2.26-5 and Figure 2.26-5 show the contours of F on the deformed mesh for element types 118 and 128, respectively. The maximum absolute value of F is about 63 psi compared to a maximum von Mises intensity of about 700 psi.

Parameters, Options, and Subroutines Summary

Example e2x26.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POST

User subroutine in u2x26.f:

PLOTV

Example e2x26b.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POST

User subroutine in u2x26b.f:

PLOTV

Example e2x26c.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	POST

User subroutine in u2x26c.f:

PLOTV

Example e2x26d.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	POST

User subroutine in u2x26d.f:

PLOTV

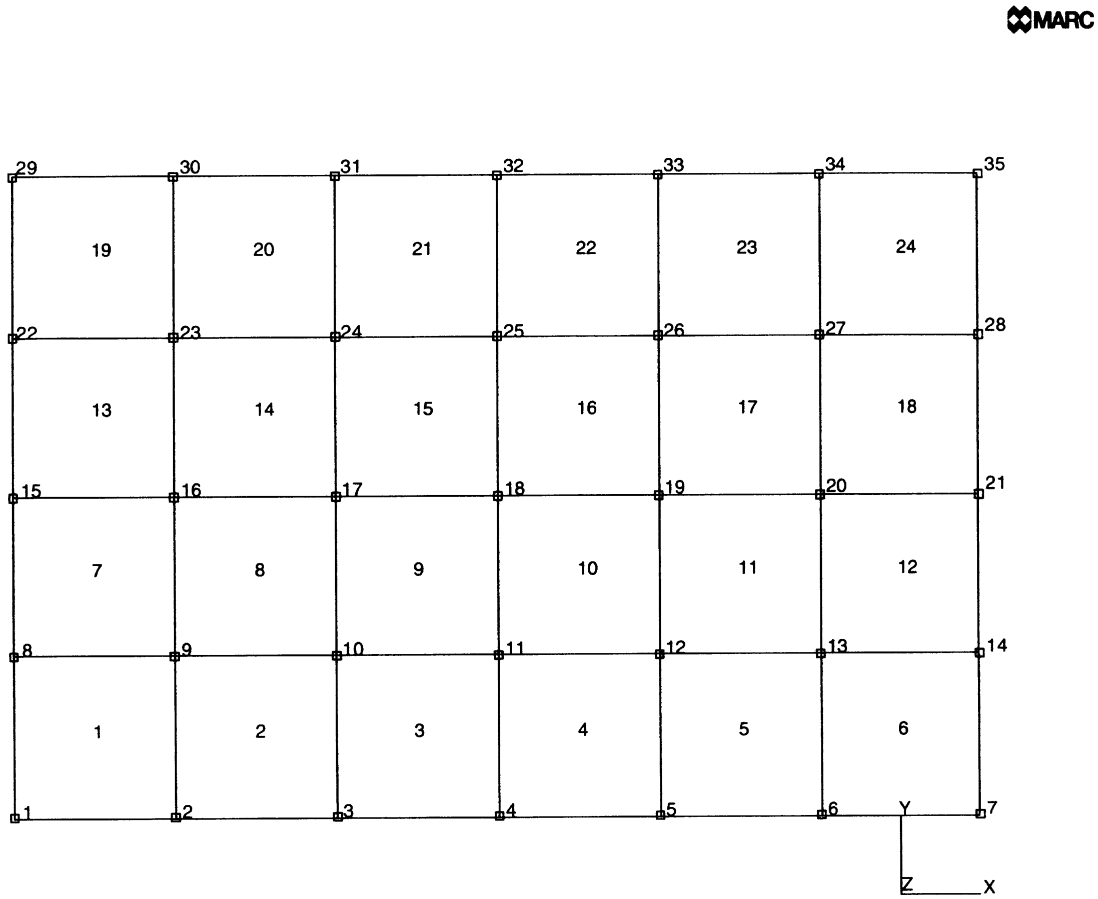


Figure 2.26-1 Finite Element Mesh

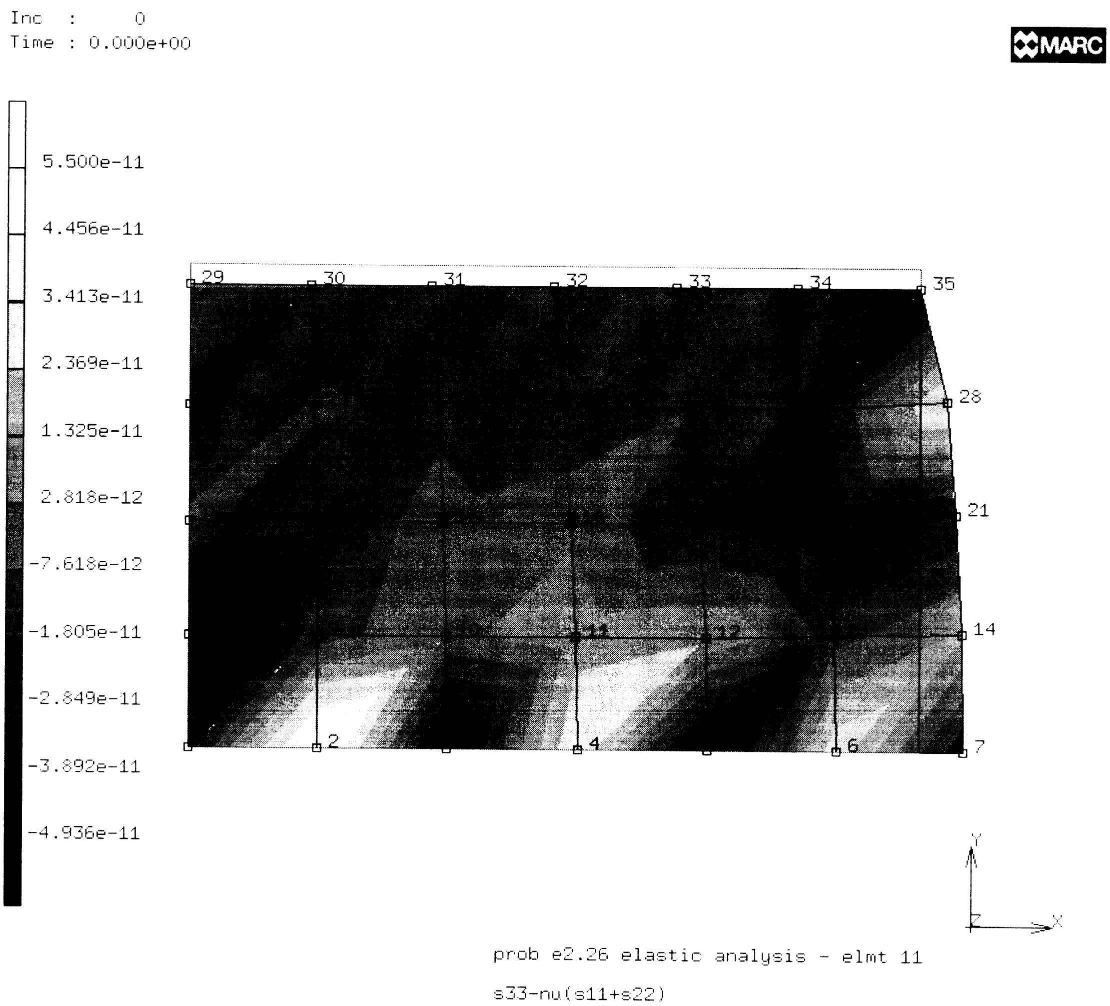


Figure 2.26-2 Contours of F = $\sigma_{33} - \nu(\sigma_{11} + \sigma_{22})$ Element 11

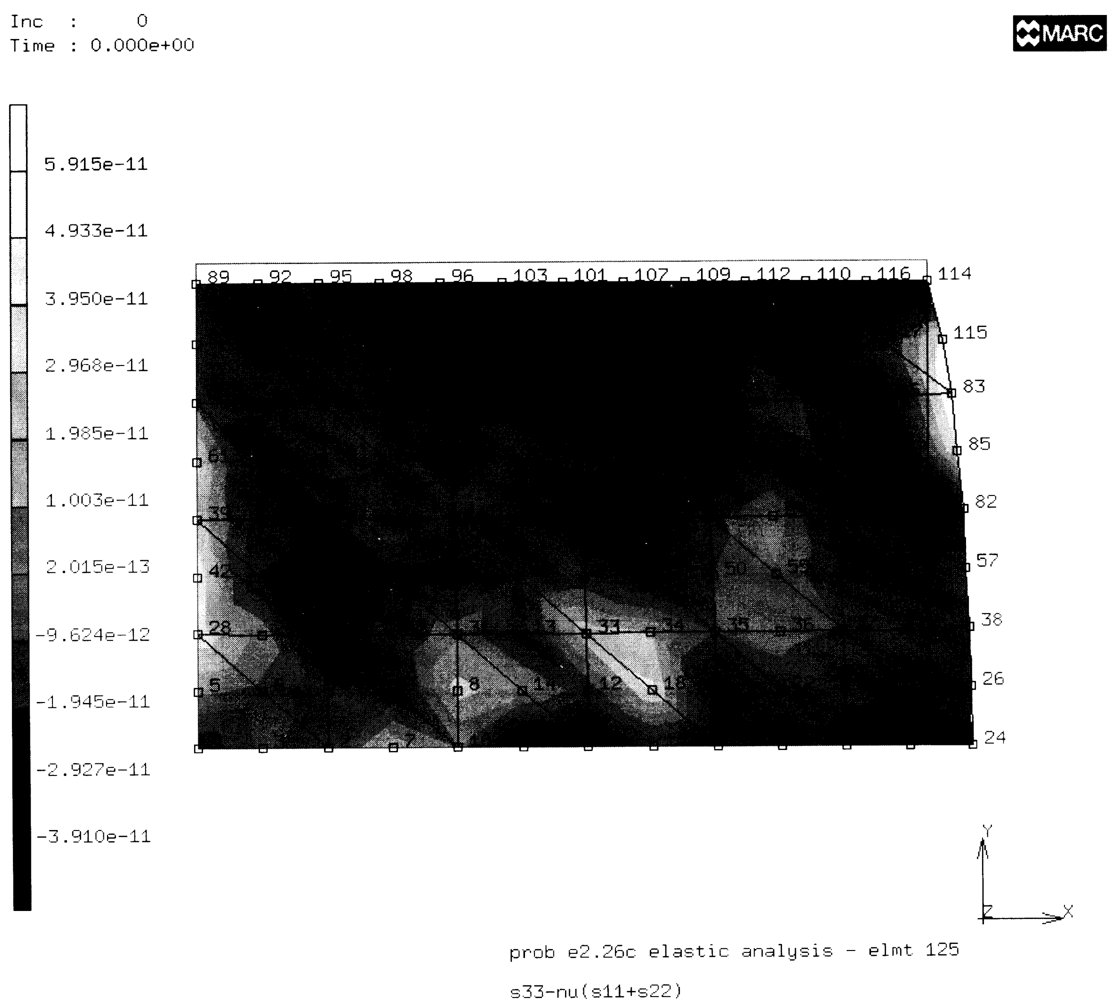


Figure 2.26-3 Contours of $F = \sigma_{33} - \nu(\sigma_{11} + \sigma_{22})$ Element 125

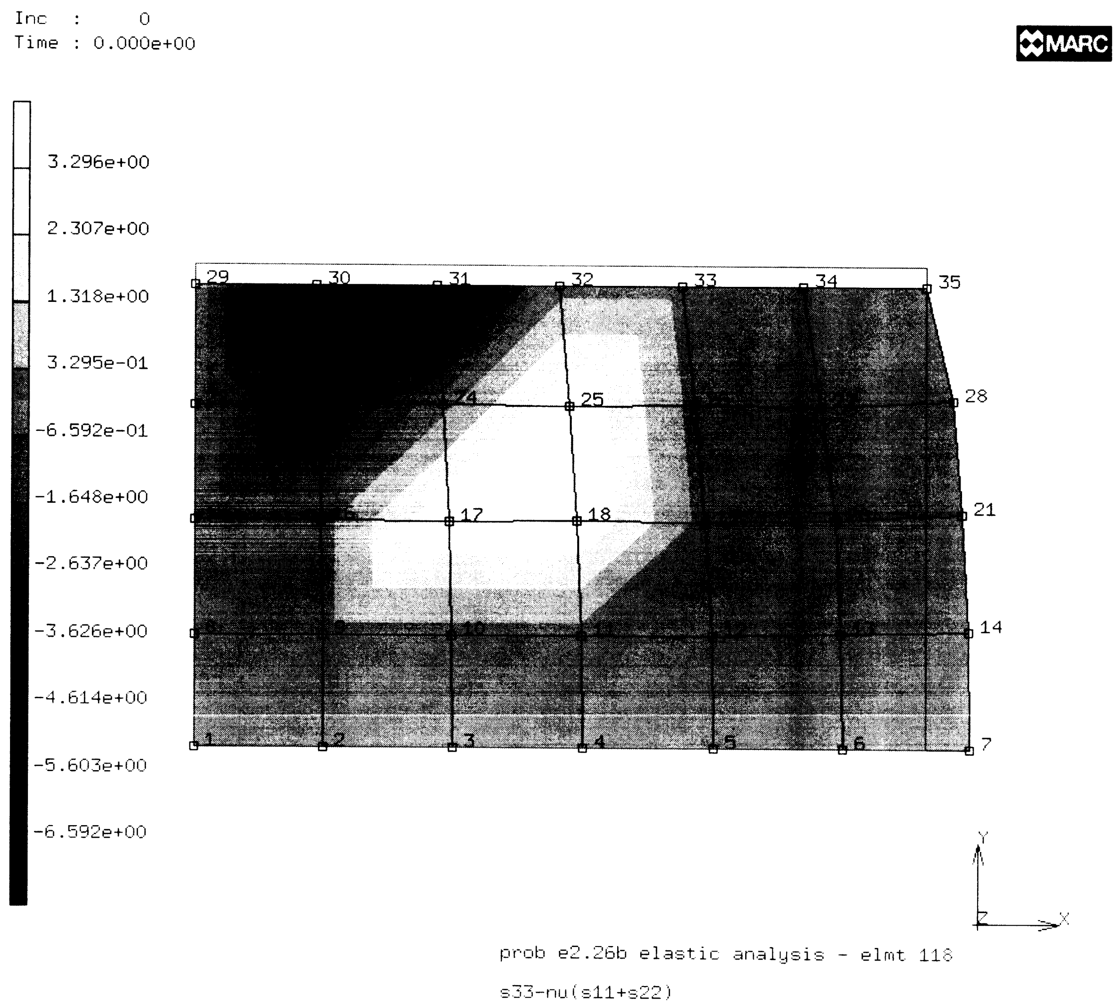


Figure 2.26-4 Contours of $F = \sigma_{33} - \nu(\sigma_{11} + \sigma_{22})$ Element 118

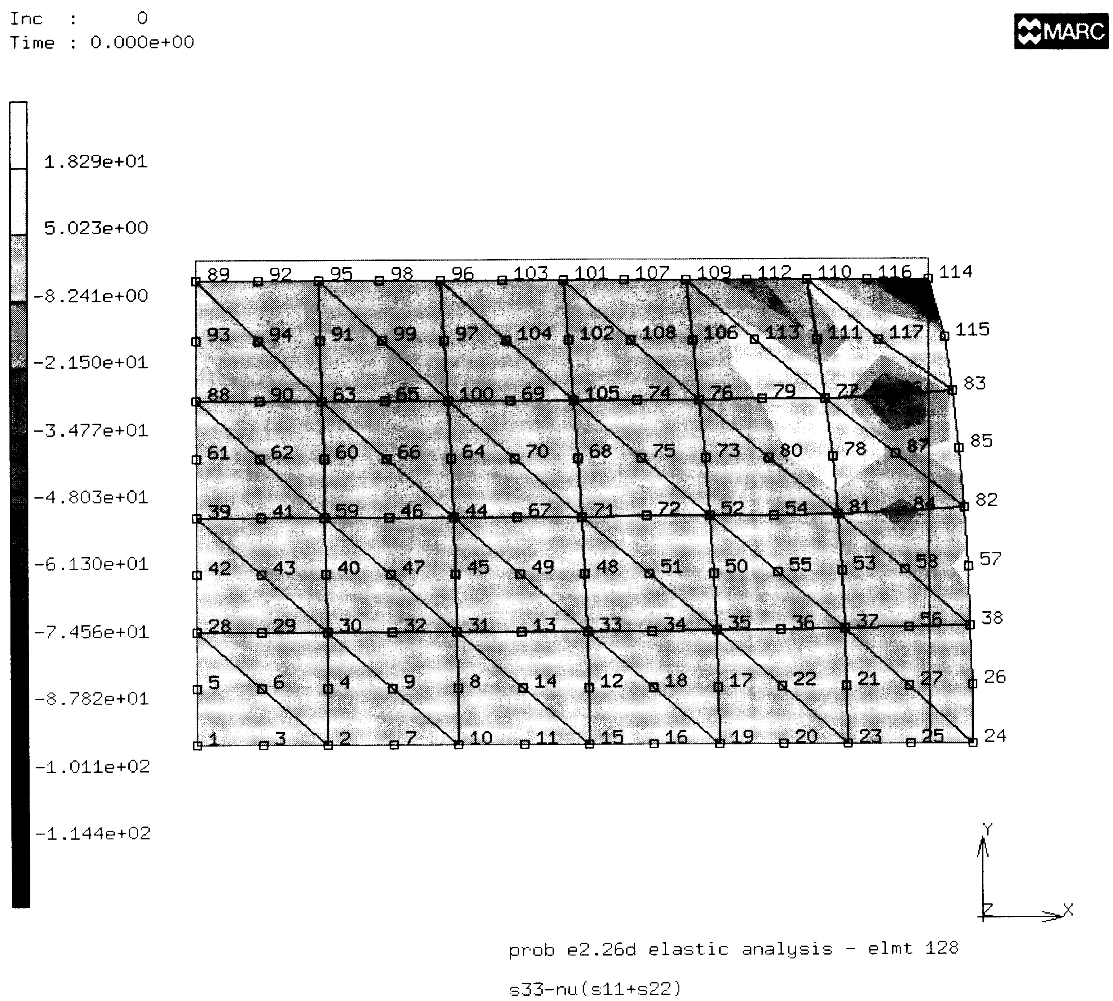


Figure 2.26-5 Contours of $F = \sigma_{33} - \nu(\sigma_{11} + \sigma_{22})$ Element 128

2.27 Generalized Plane-strain Disk, Point Loading

This problem illustrates the use of MARC element type 19 and user subroutine UFCONN for an elastic analysis of a two-dimensional circular disk. The disk is subjected to diametrically-opposite point loads. The user subroutine UFCONN is used for the modification fo element types 3 to 19, and the addition of the two shared nodes (nodal numbers 83 and 84) for each element in the CONNECTIVITY data block. This is the same problem as 2.10 except the generalized plane strain condition is imposed.

Element

Element type 19 is an extension of element type 11 (plane-strain isoparametric quadrilateral). Two extra nodes are included in each element to create the generalized plane-strain condition.

Model

The dimensions of the disk and a finite element mesh are shown in Figure 2.27-1. The extra two nodes for generalized plane-strain elements are located at the center of the disk. The degrees of freedom associated with these extra nodes represent the relative displacement and rotation of the front and back surfaces. These nodes are shared by all elements in the disk. There are 64 elements and 84 nodes in the mesh.

Material Properties

All elements are elastic with a Young's modulus of 30 x 10^6 psi and Poisson's ratio equal to 0.3.

Boundary Conditions

Both degrees of freedom are constrained for the second extra node (node 84). First degree of freedom of all nodal points are constrained (u = 0) along symmetry line (x = 0). The bottom of the disk is constrained to eliminate the rigid body mode.

Geometry

The thickness of the disk is specified as unity in EGEOM1 of this option.

Loading

A concentrated load at the top (node 1) of 100.0 lb. in the negative y-direction is applied.

ELSTO

Out-of-core storage of element data (ELSTO) is used for this problem.

Results

A displaced mesh plot is shown in Figure 2.27-2. The answers agree with those using the plane stress element (problem 2.10) for the stresses.

	Element 1 Problem 2.10 (psi)	Element 1 Problem 2.27 (psi)	Element 30 Problem 2.10 (psi)	Element 30 Problem 2.27 (psi)
σ_{xx}	1.632E2	1.655E2	1.003E1	1.001E1
σ_{yy}	-3.343E2	-3.356E2	-3.092E1	-3.089E1

Parameters, Options, and Subroutines Summary

Example e2x27.dat:

Parameters

ELEMENTS
ELSTO
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
POINT LOAD
UFCONN

User subroutine found in u2x27.f:

UFCONN

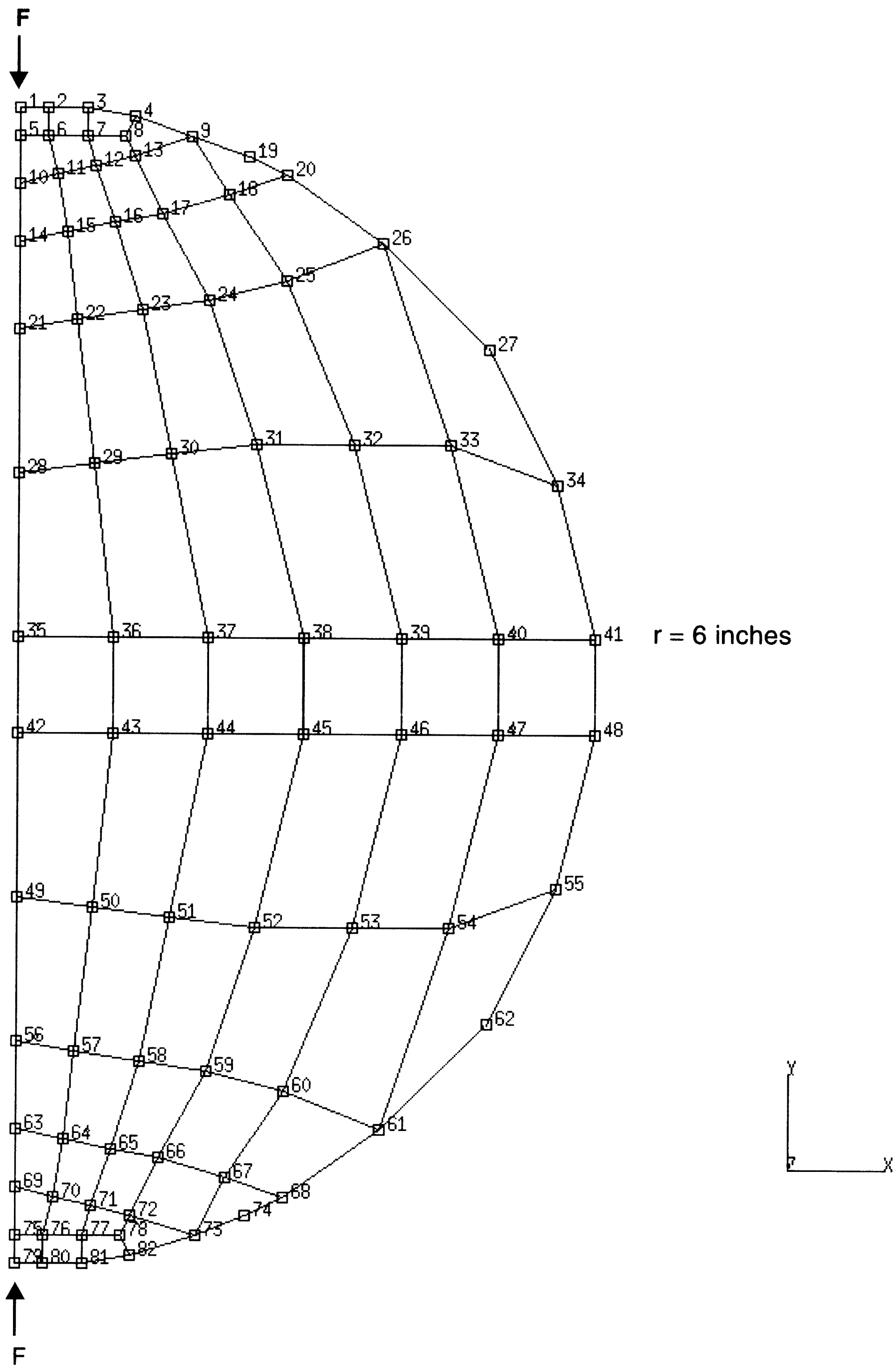


Figure 2.27-1 Disk and Mesh

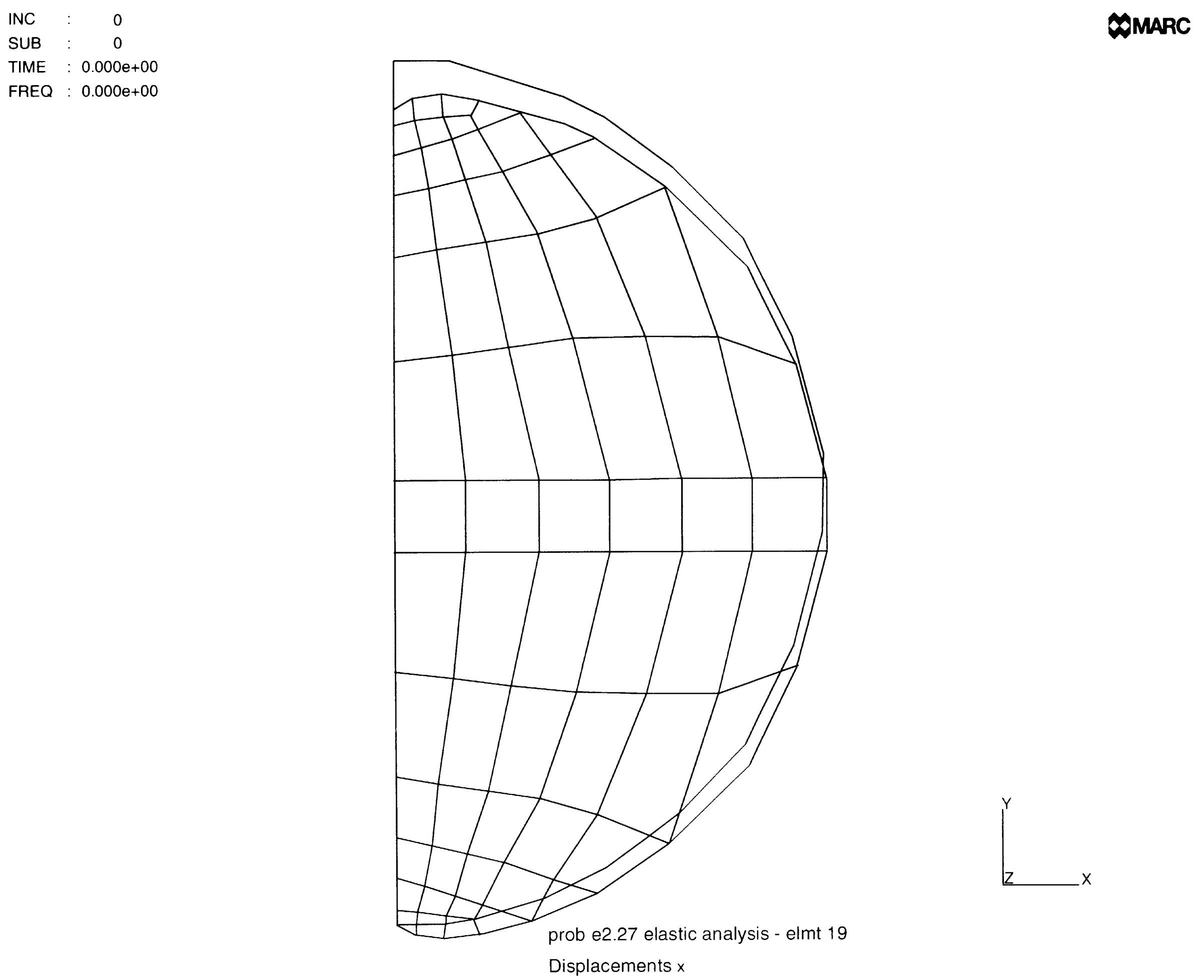


Figure 2.27-2 Deformed Mesh Plot

2.28 Circular Shaft of Variable Radius Under Tension and Twist

This problem illustrates the use of MARC element type 20 and tying constraint options for an elastic analysis of a circular rod of variable radius. The rod is subjected to a combined loading of tension and twist.

Element

Element type 20 is an isoparametric axisymmetric ring with a quadrilateral cross section. This element is identical to element type 10, modified to allow twist about the axis of symmetry. There are four nodes per element.

Model

The dimensions of the circular rod and the finite element mesh are shown in Figure 2.28-1. The ratio of radii is 2.5:1 or a ratio in area of 6.25:1. The mesh consists of 33 elements of type 20. There are a total of 8 nodes.

Material Properties

The material is considered elastic with a Young's modulus of 2.08×10^6 psi and a Poisson's ratio of 0.3.

Geometry

Not required for axisymmetric elements.

Loading

A point load ($P = 10^5$ lb.) and a torque ($T = 2 \times 10^5$ in-lb.) are applied at node 48.

Boundary Conditions

All degrees of freedom of nodes at $y = 0$ are constrained to simulate a built-in end. Radial displacements (second degree of freedom) along the symmetric axis ($r = 0$) are fixed ($v = 0$).

Tying Constraints

There are two tying types in this problem.

Tying Type	Retained Node	Tied Nodes
1	48	36, 40, 44
3	48	36, 40, 44

The total number of tying equations is six and the maximum number of retained nodes in all tying types is one. These ties are used to simulate a generalized plane-strain condition. Thus, the loaded face nodes are forced to move together.

Results

A deformed mesh plot is shown in Figure 2.28-2 and stress contours are depicted in Figure 2.28-3 through Figure 2.28-5. σ_{zz} is at x=21, approximately 6.25 times σ_{zz} at x=0.

An analytical solution for a similar problem is found in I. S. Solkolnikoff, *Mathematical Theory of Elasticity*. The displacement and stresses are compared for the MARC solution and the analytical solution:

Displacement*		**Stress σ_{zq}**	
MARC Computed	**Analytically Computed**	**MARC Computed****	**Analytically Computed*****
4.5057×10^{-2}	4.5223×10^{-2}	8.770×10^{3}	$\sigma_{z\theta}^{max} = 9.120 \times 10^{3}$

* Angular displacement about symmetric axis at point 48.
** σ_{zq} at point 3 in element 30.
*** σ_{zq} at R=2.4.

Parameters, Options, and Subroutines Summary

Example e2x28.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
ISOTROPIC
POINT LOAD
TYING

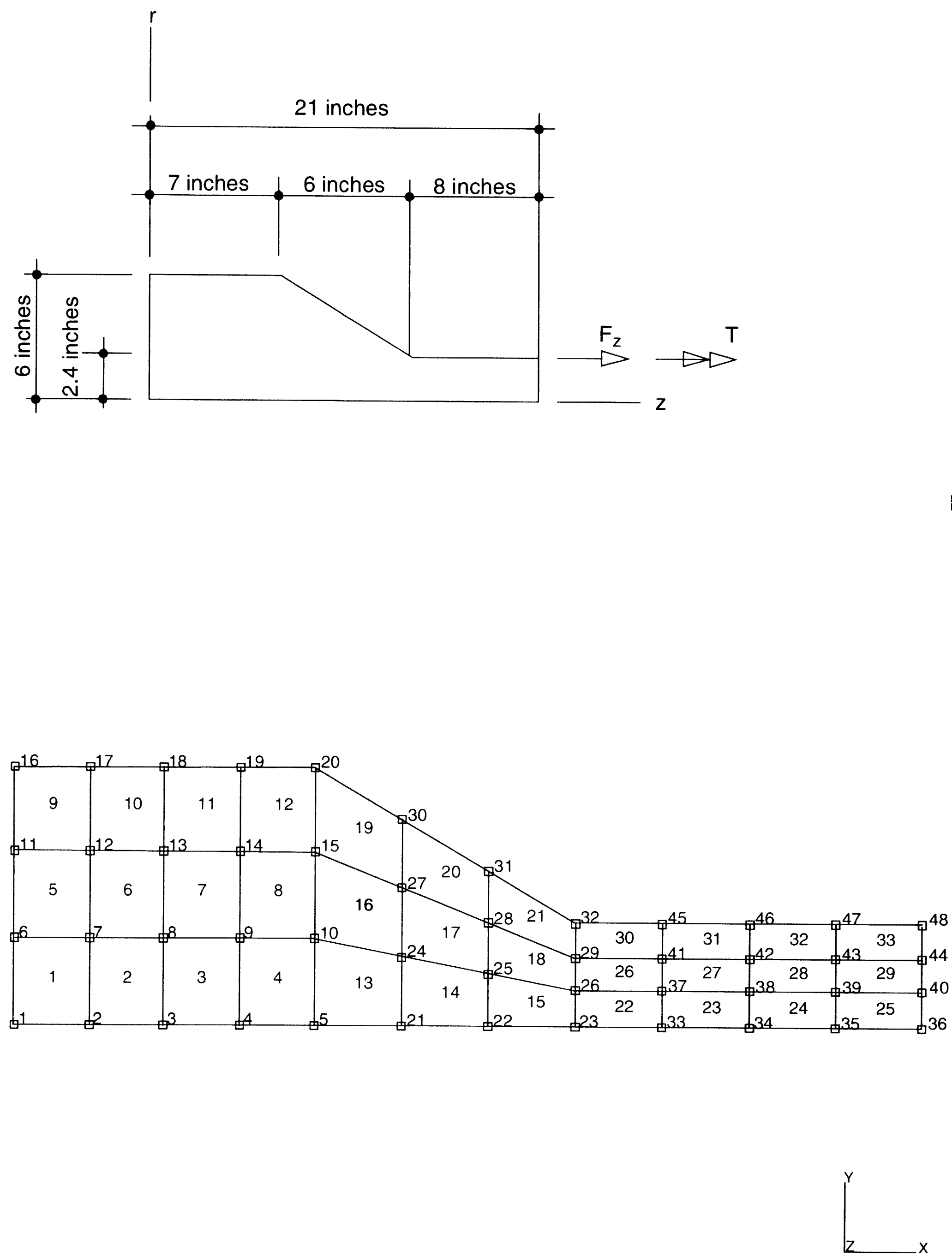


Figure 2.28-1 Circular Rod and Mesh

Figure 2.28-2 Deformed Mesh Plot

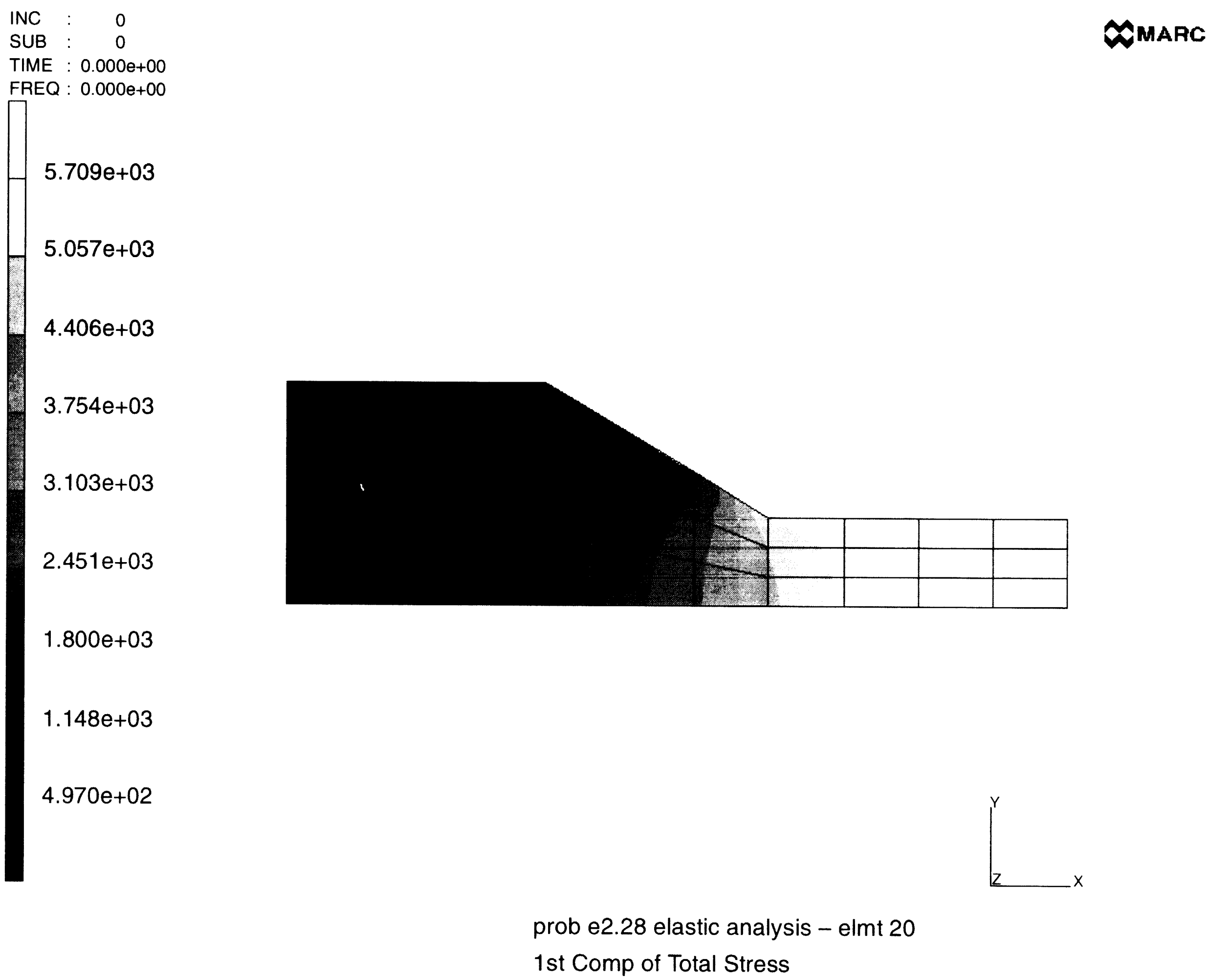


Figure 2.28-3 Stress Contours for σ_{zz}

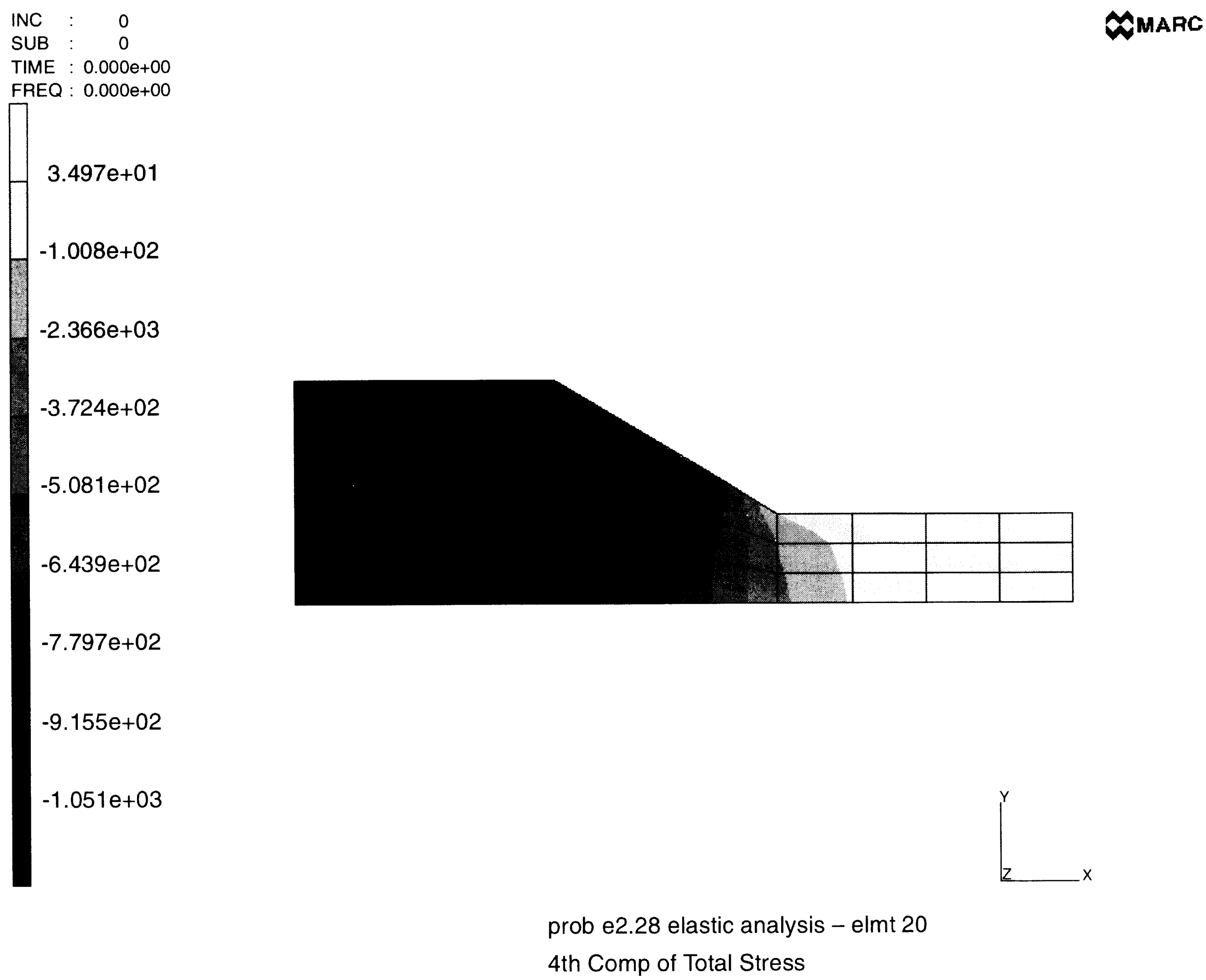


Figure 2.28-4 Stress Contours for σ_{zq}

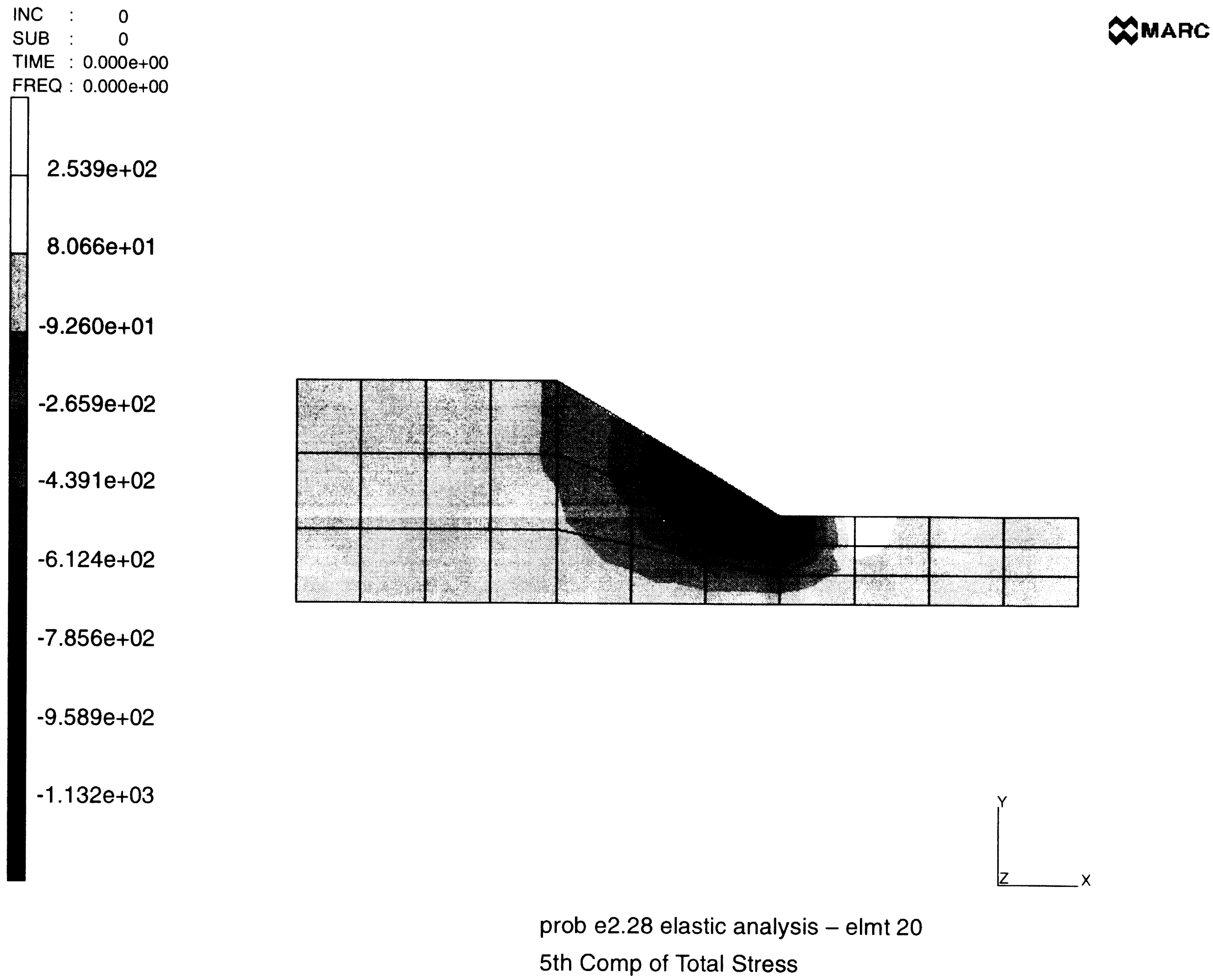


Figure 2.28-5 Stress Contours for σ_{rq}

2.29 Thin-walled Beam on an Elastic Foundation

This problem illustrates the use of MARC element type 25 and the FOUNDATION options for elastic analysis of a thin-walled beam subjected to a concentrated load at the center of the beam. The beam rests on an elastic foundation.

Element

Element type 25 is a thin-walled beam with no section warp, but with twist. The beam is a closed section hollow cylinder when EGEOM1 = 0. This is similar to element type 14, but the accuracy is greater for behavior parallel to the beam axis. The element is particularly useful for problems involving thermal gradients or large displacements.

The beam is considered to be elastic with a Young's modulus of 2×10^5 psi and a modulus of foundation of 10 lb/inch.

Model

The dimensions of the beam and a finite element mesh are shown in Figure 2.29-1. The finite element mesh consists of 20 elements of type 25; there are 21 nodes in the mesh. Only half of the beam is modeled due to symmetry.

Geometry

The beam consists of a pipe with wall thickness of 0.2 inch (EGEOM1) and mean radius (EGEOM2) of 3 inches.

Loading

A concentrated load of P/2 = 1000 pounds is applied at the center of the beam.

Boundary Conditions

Symmetry conditions are imposed at X = 0; Y = 0, Z = 0 (i.e. $u = 0$, $\theta_x = 0$, $\theta_y = 0$, $\theta_z = 0$, $du/ds = 0$). All degrees of freedom in the Y-direction are assumed to be fixed in space; hence, the analysis may be considered two-dimensional.

Elastic Foundation

The whole beam is assumed to rest on an elastic foundation. The description of the elastic foundation is given in model definition option FOUNDATION:

- Element numbers = 1 through 20
- Spring stiffness per unit length of the beam = 10. pounds/inch
- Element face I.D. = 3
- The element face identification indicates which face the beam is resting on the foundation.

Results

A deformed mesh plot is shown in Figure 2.29-2 and a comparison of deflection and moment at node 1 is given below:

Displacement:

MARC-Computed Solution δ_1 = -2.93 inches
Analytic Solution δ_1 = -2.926 inches

Moment:

MARC Solution M_1 = 17066. in-lb.
Analytic Solution M_1 = 17065. in-lb.

The analytic solution is obtained from R.J. Roark, *Formulas for Stress and Strain*, assuming that the beam is of infinite length. For beams of a finite length, the analytic solutions for an elastic beam may be found in *Handbook of Engineering Mechanics*, ed. W. Flugge.

Parameters, Options, and Subroutines Summary

Example e2x29.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	FOUNDATION
	GEOMETRY
	ISOTROPIC
	POINT LOAD

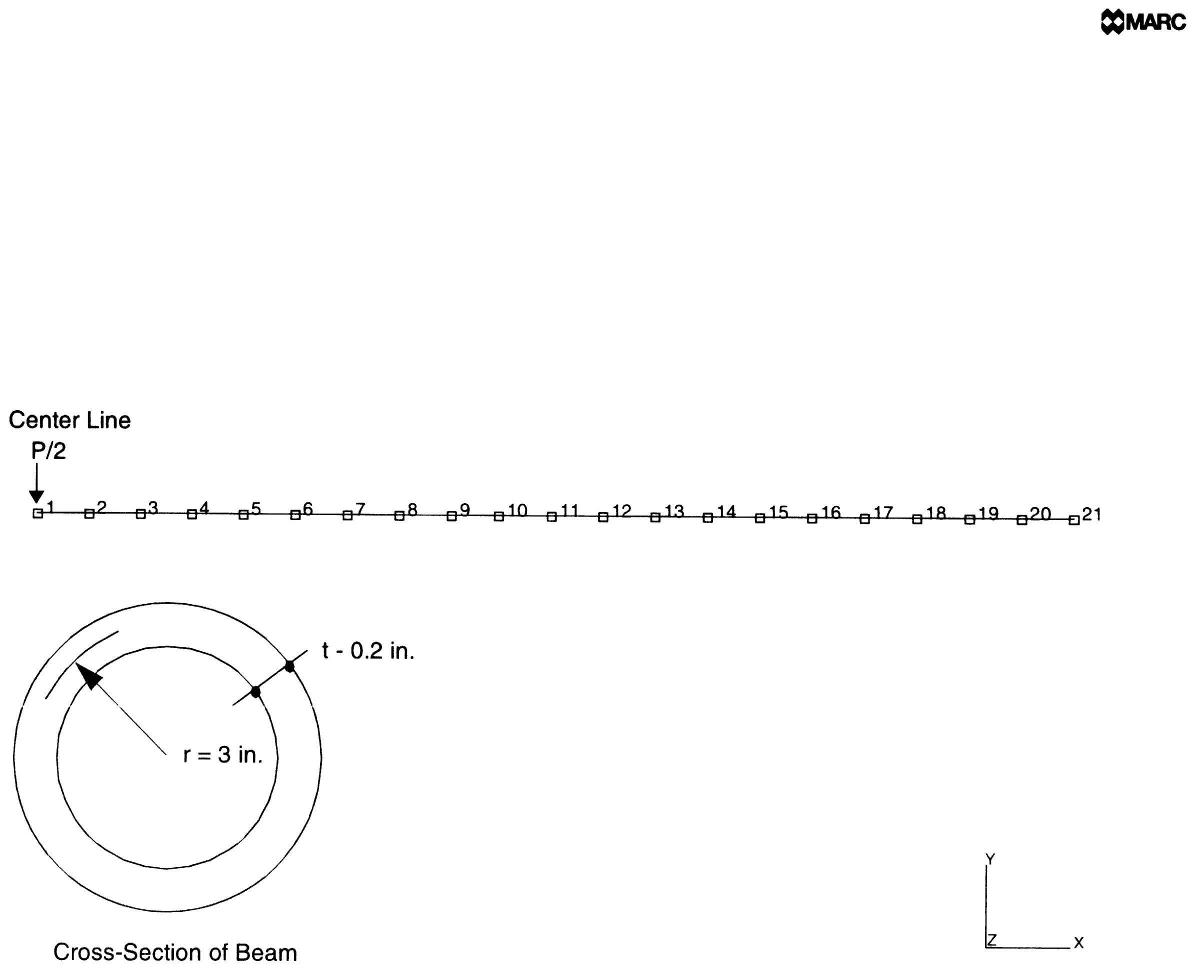


Figure 2.29-1 Thin Walled Beam and Mesh

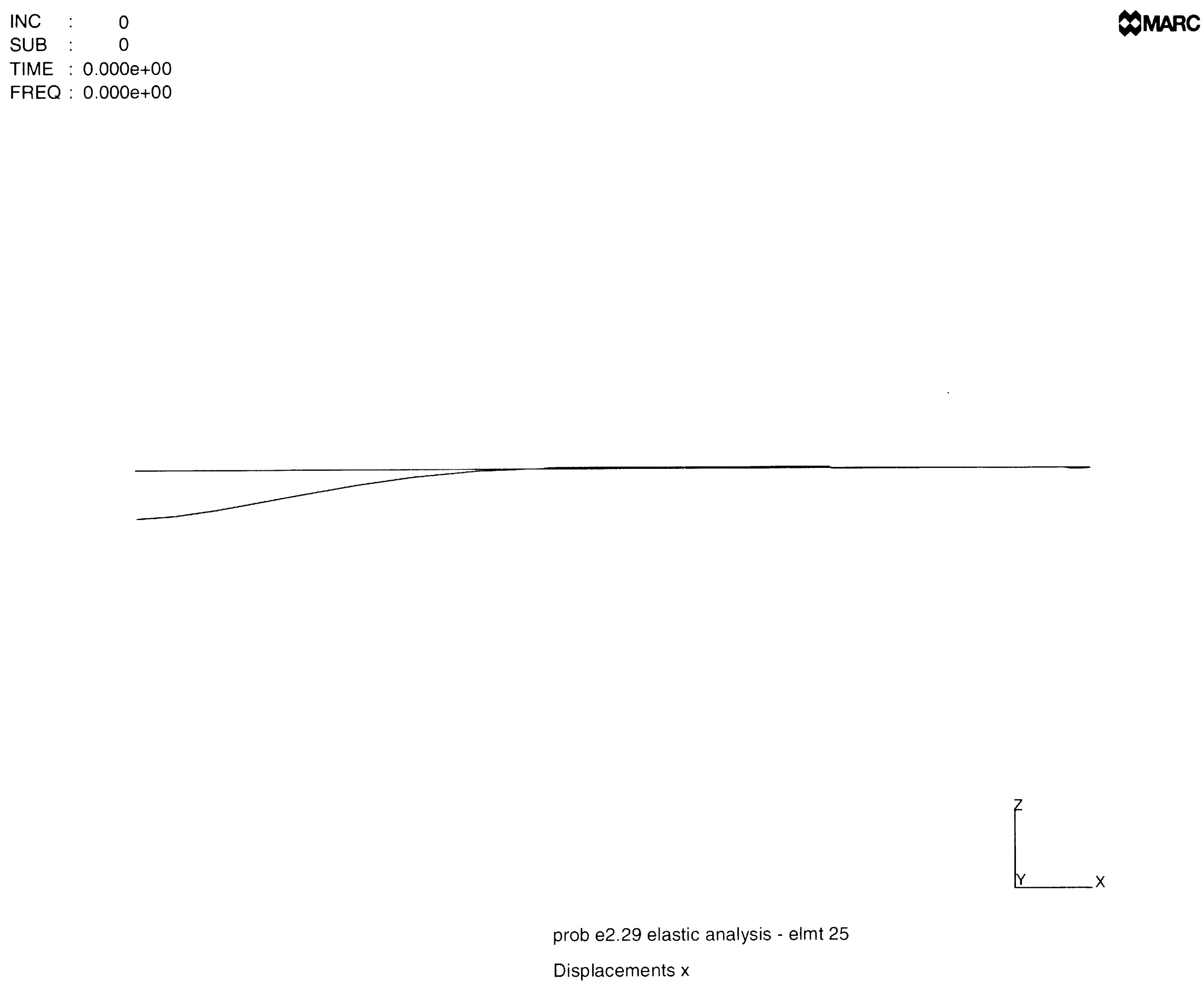


Figure 2.29-2 Deformed Mesh Plot

2.30 Notched Circular Bar, J-Integral Evaluation

This problem illustrates the use of MARC element type 28 and the J-INT option for an elastic analysis of a notched circular bar, subjected to uniformly distributed axial forces. The J-integral evaluation is intended for the study of the stress concentration at the notch of the bar. The use of parameters ELSTO and ALIAS is also illustrated.

Element

Element type 28 is a second order distorted quadrilateral with eight nodes. Each node has two degrees of freedom. For J-integral calculations, a high-order element is required; hence, the selection of element type 28.

Model

The dimensions of the bar and the finite element mesh are shown in Figure 2.30-1. This is the same mesh used in problem 2.22. The mesh consists of 32 elements and 107 nodes. The ALIAS parameter is used to convert element type 27 to 28.

Material Properties

The material is elastic with a Young's modulus of 30.E6 psi and Poisson's ratio of 0.3.

Geometry

Not required for axisymmetric elements.

Boundary Conditions

The following boundary conditions are imposed: $v = 0$ at $r = 0$ (axis of symmetry) and $u = 0$ at uncracked portion of line $z = 0$.

Loading

A distributed load of 100 psi is applied on the outer edge of elements 15, 16, 31 and 32.

The midside nodes 2, 5, 8, 11, 14, 69, 66, 63 and 60 have been moved to quarter-point position for the J-integral evaluations. The quarter-point nodes more accurately reflect the singularity at the crack tip. Their coordinates are modified by inputting a new COORDINATES model definition block. The mesh is generated as if it was made of element type 27, and the ALIAS parameter was used so that MARC would consider them to be type 28.

J-INTEGRAL

In the current analysis three rings of elements are chosen for the J-integral evaluations.

J-Integral Evaluations	Number of Nodes Moved in List Number		Nodal Movements of List Number in r Direction	
	1	2	1	2
1	1	9	-0.01	-0.0075
2	27	9	-0.01	-0.0050
3	53	9	-0.01	-0.0050

Node numbers are shown in the J-INTEGRAL model definition block.

Results

A comparison of the J-integral evaluation is tabulated in Table 2.30-1. A deformed mesh plot and stress contours are shown in Figure 2.30-3 and Figure 2.30-4, respectively.

Table 2.30-1 Comparison of J-Integral Evaluations

MARC	SED Output	J	K	Difference (K/K_I)
1	0.01131	0.0360189	1089.7	2.28%
2	0.01127	0.0358915	1087.8	2.01%
3	0.01125	0.0358278	1086.8	2.01%

Note: Stress intensity factor estimation for mode I cracking

The stress intensity factor K_I for an axisymmetric bar is:

$$K_I = \sigma_n \sqrt{\pi b} \quad F_2\left(\frac{b}{R}\right)$$

$$\sigma_n = \frac{P}{\pi b} \quad ,$$

$$F_2(\xi) = \frac{1}{2}\left(1 + \frac{1}{2}\ \xi + \frac{3}{8}\ \xi^2 - 0.363\ \xi^3 + 0.731\ \xi^4\right)\sqrt{1 - \xi}$$

(error < 1%)

therefore, $K_I = 1065.39$

For an axisymmetric model, plane strain assumption is assumed to exist locally, and the relation between J and K_I is:

$$K_I = \sqrt{\frac{E}{1-\nu^2}J} = \sqrt{32967033*J}$$

MARC output is the strain energy density (SED) of the area of crack tip movement. The expression of J-integral is:

$$J = \frac{SED*2}{\pi b^2 - \pi(b - \delta b)z^2} = \frac{SED*2}{\pi(10^2 - 9.99^2)} = \frac{SED}{0.3140022}$$

Parameters, Options, and Subroutines Summary

Example e2x30.dat:

Parameters	**Model Definition Options**
ALIAS	CONNECTIVITY
ELEMENTS	COORDINATES
ELSTO	DIST LOADS
END	END OPTION
J-INT	FIXED DISP
SIZING	ISOTROPIC
TITLE	J-INTEGRAL

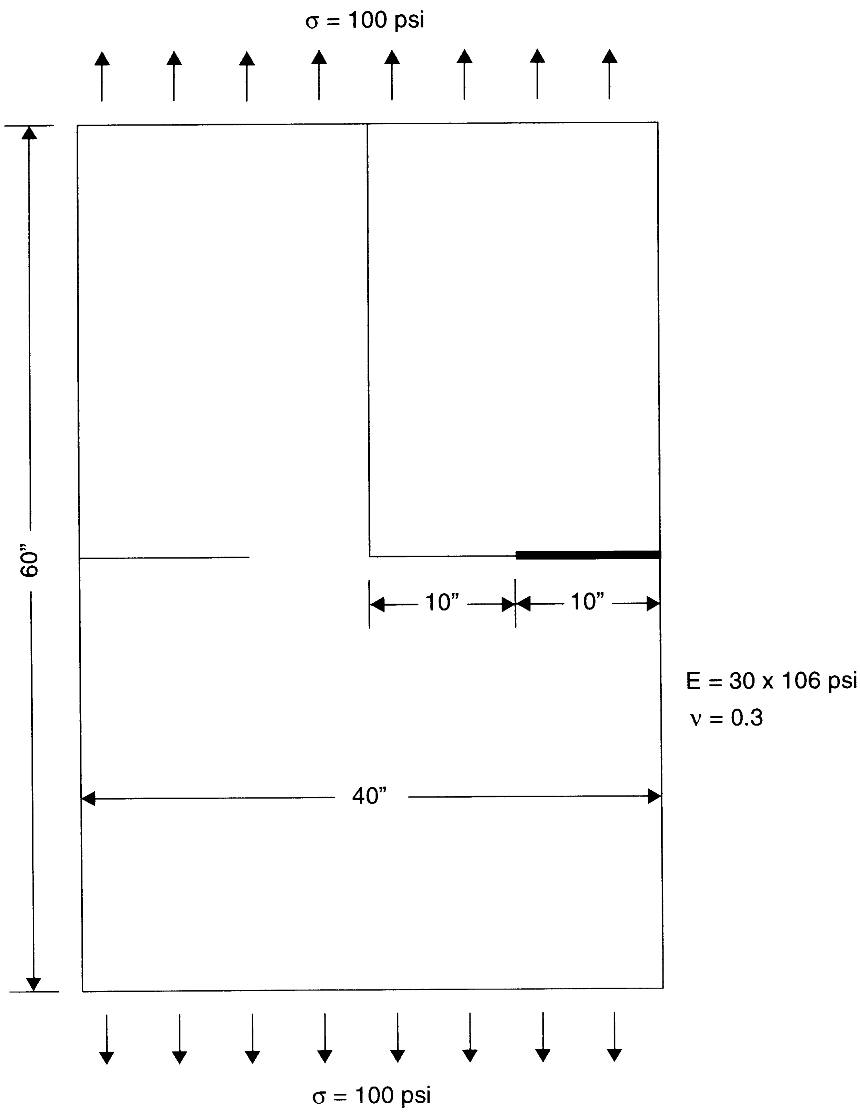


Figure 2.30-1 Notched Circular Bar and Mesh

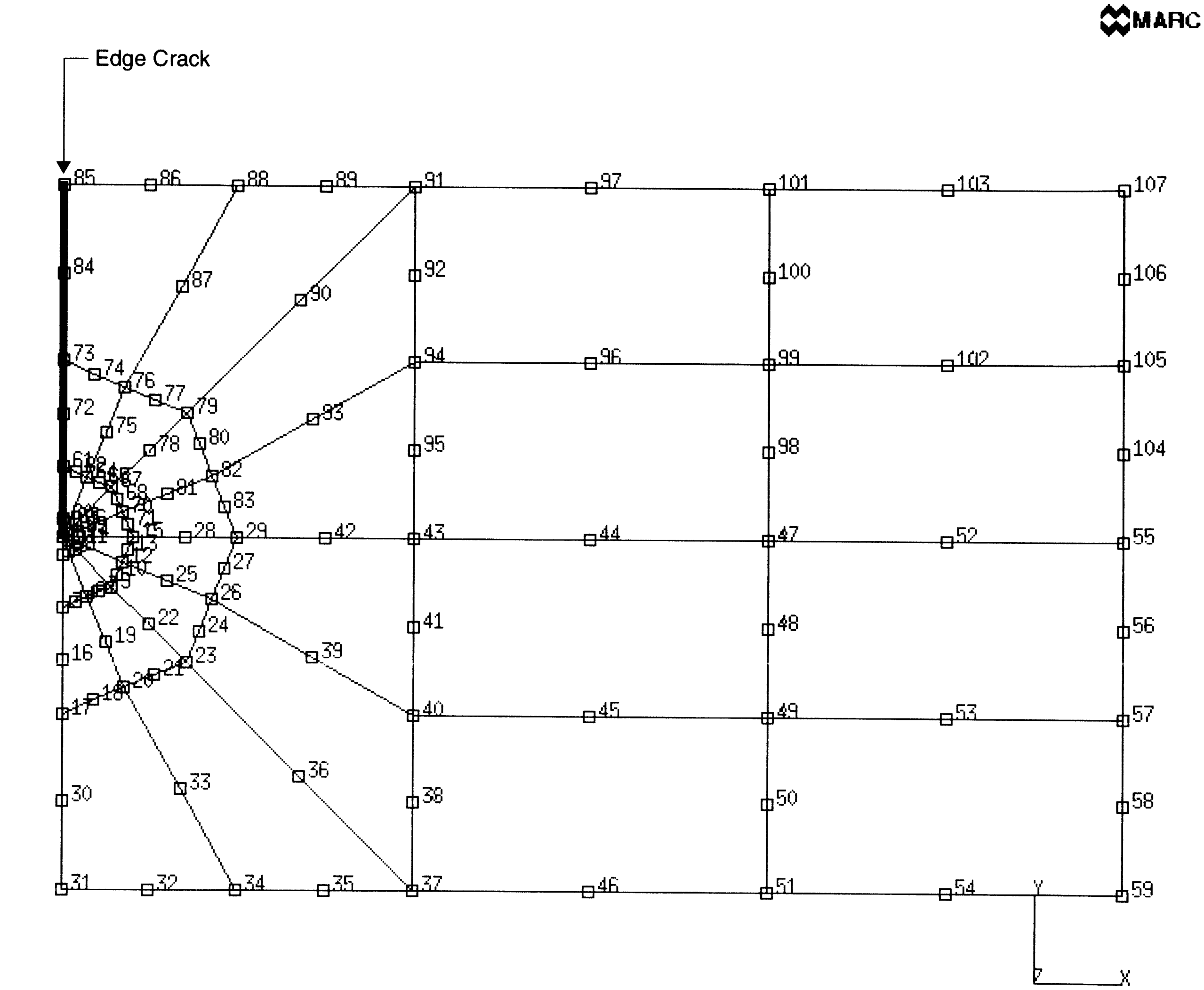


Figure 2.30-2 Mesh for Double Edge Notch Specimen

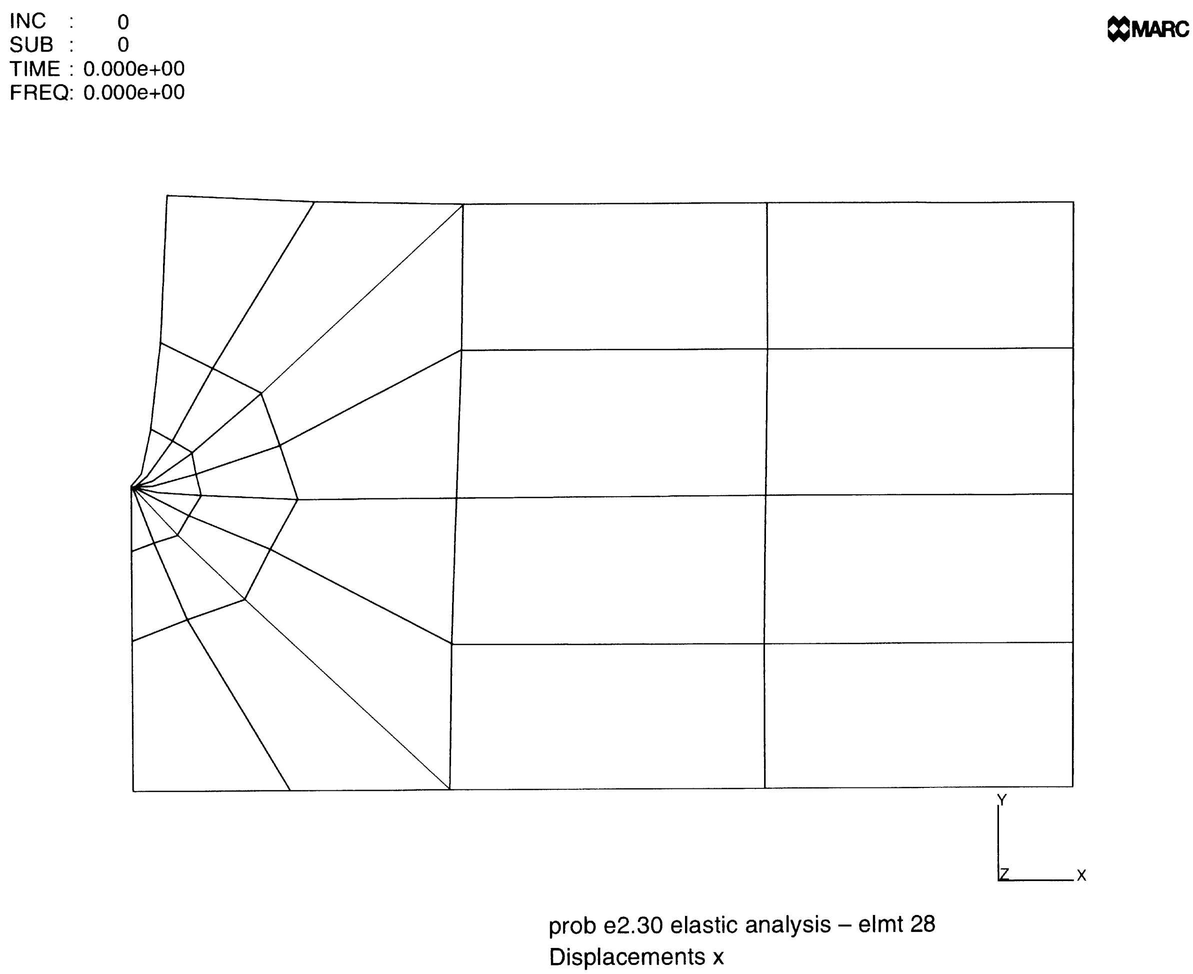


Figure 2.30-3 Deformed Mesh

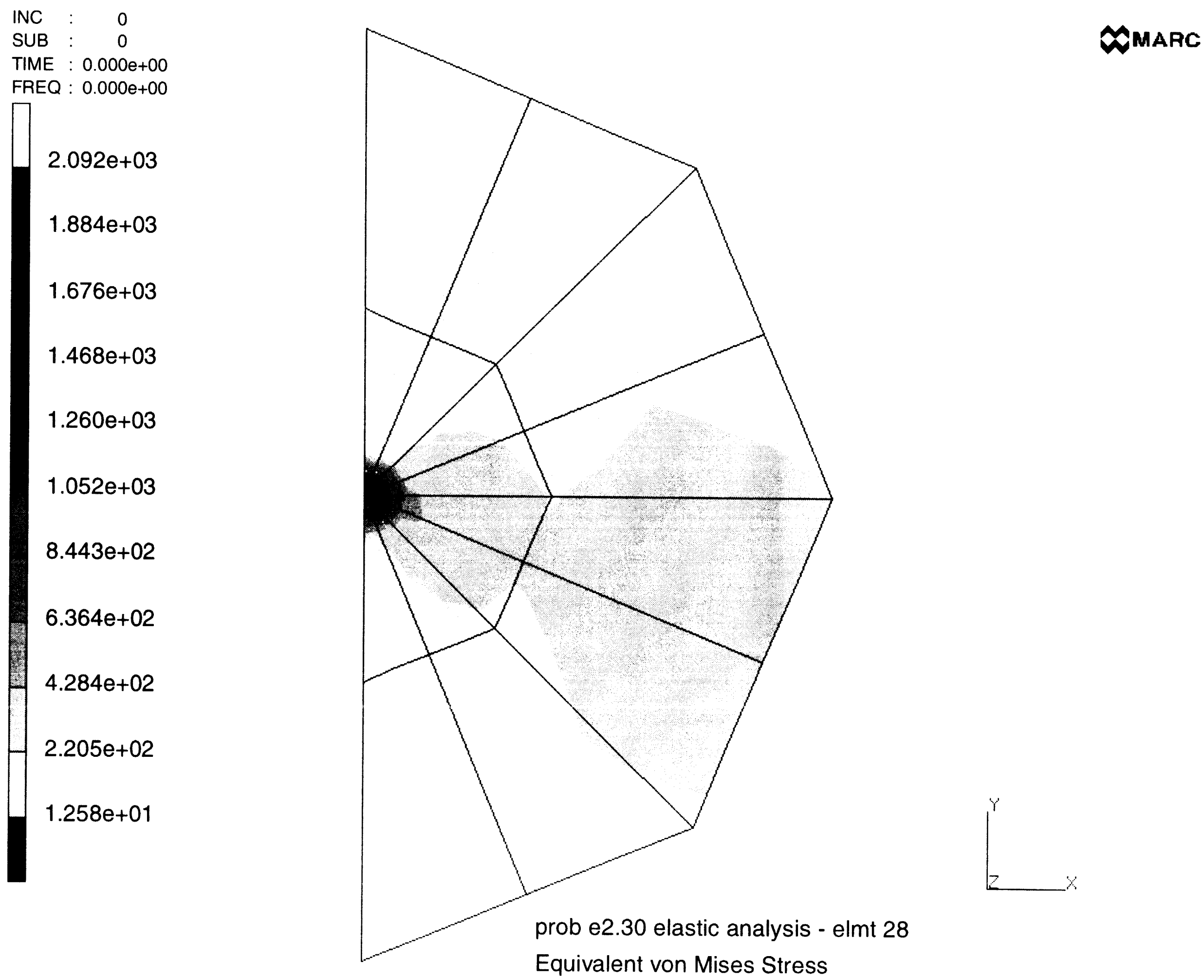


Figure 2.30-4 Stress Contours

2.31 Square Section with Central Hole using Generalized Plane Strain Element

This problem illustrates the use of MARC element types 29 and 56 (generalized plane strain, distorted quadrilateral), OPTIMIZE option, and SCALE parameter for an elastic analysis of a square plate subjected to a uniform pressure. The pressure is applied to the surface of a circular hole located at the center of the section.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x31a	29	20	79
e2x31b	56	20	79

Elements

The analysis is performed twice: first with element type 29, which uses 9-point integration, and then with element type 56, which uses 4-point integration.

Model

The dimensions of the plate and a finite element mesh are shown in Figure 2.31-1. The model consists of 20 elements and 81 nodes. Only one-quarter of the section is modeled due to symmetry.

Material Properties

The material behaves elastically with a Young's modulus of 50 x 10^4 psi and the Poisson's ratio of 0.2. The solution is scaled such that one integration point has reached the yield stress of 200 psi.

Geometry

The thickness of the section is 1.0 inch, which is given in EGEOM1.

Loading

A uniform pressure of 1000 psi is applied to the inner surface of the hole. The pressure load is scaled to the condition of first yield.

Boundary Conditions

Zero displacements are assumed to exist on the lines of symmetry: u = 0 at x = 0, and v = 0 at y = 0.

Optimization

The Sloan optimizer is used. As this is a generalized plane strain model, the bandwidth does not decrease, but the number of profile entries, including fill-in, is reduced from 1687 to 1198.

Results

A deformed mesh plot is shown in Figure 2.31-2 and the stress contours are depicted in Figure 2.31-3. First, one observes that the results are symmetrical about the 45-degree line. The scale factor using element type 29 (full integration) is 0.116, and the scale factor using element type 56 is 0.120 more than the factor computed for element 29. Element type 29 has integration points closer to the hole where the stress is larger, resulting in a lower scaling factor.

The results are compared with the analytically calculated (Timoshenko and Goodier, *Theory of Elasticity*) results of a hollow cylinder submitted to uniform pressure on the inner surface and are summarized below.

Displacement* (in.)		Stress Components (psi)	
Computed	**Calculated**	**Computed****	**Calculated*****
2.97×10^{-4}	2.80×10^{-4}	$\sigma_x = -1.08 \times 10^{-2}$	$\sigma_x = -1.16 \times 10^{-2}$ (σ_r)
		$\sigma_y = 1.18 \times 10^{-2}$	$\sigma_y = -1.16 \times 10^{-2}$ ($\sigma\theta$)
*At node point 34.		**At node point 3 in element 8	***On the inner surface

Parameters, Options, and Subroutines Summary

Example e2x31a.dat:

Parameters

ELEMENTS

END

SCALE

SIZING

TITLE

Model Definition Options

CONNECTIVITY

COORDINATES

DIST LOADS

END OPTION

FIXED DISP

GEOMETRY

ISOTROPIC

OPTIMIZE

Example e2x31b.dat:

Parameters

ELEMENTS
END
SCALE
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
OPTIMIZE

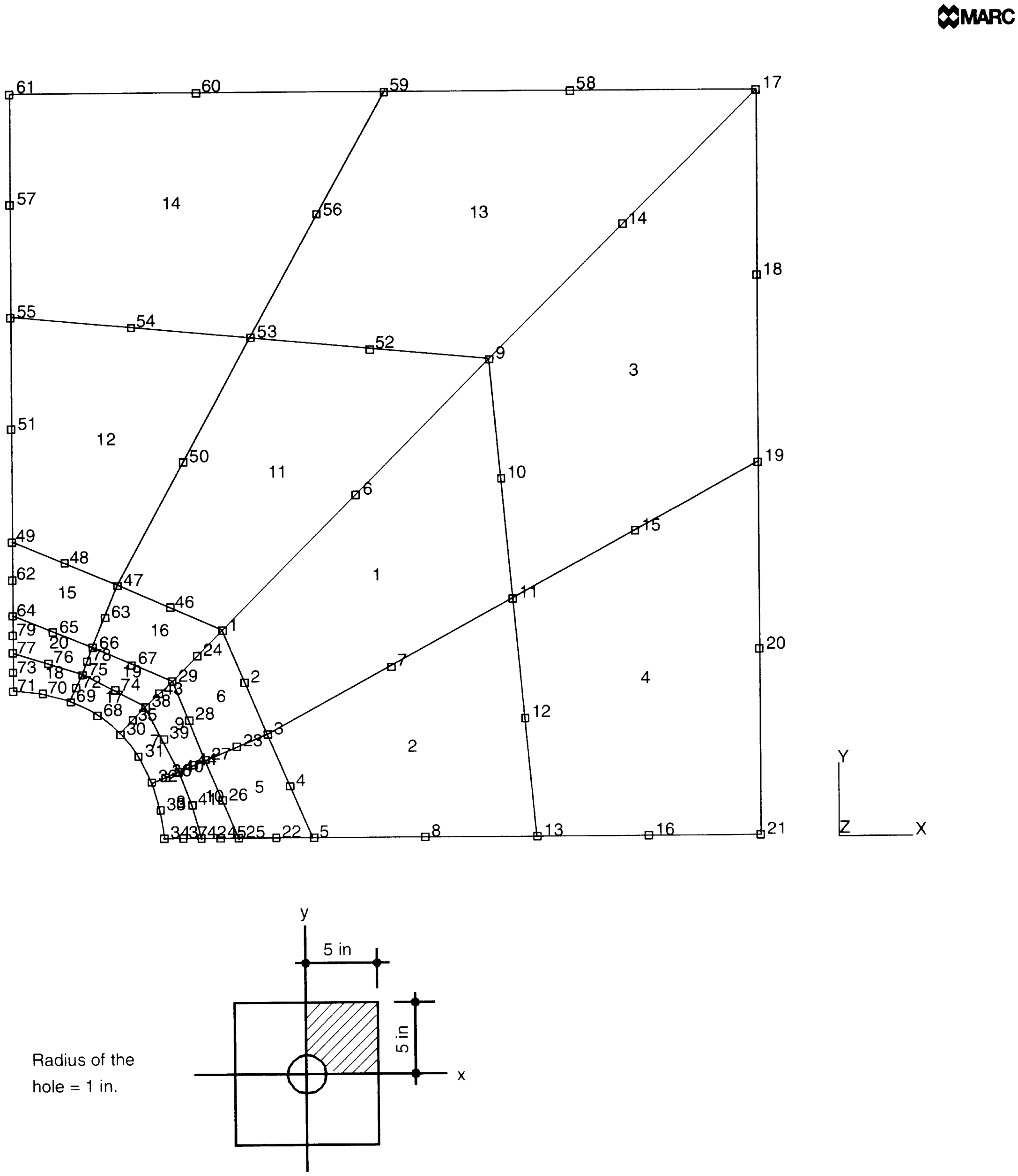


Figure 2.31-1 Square Plate and Mesh

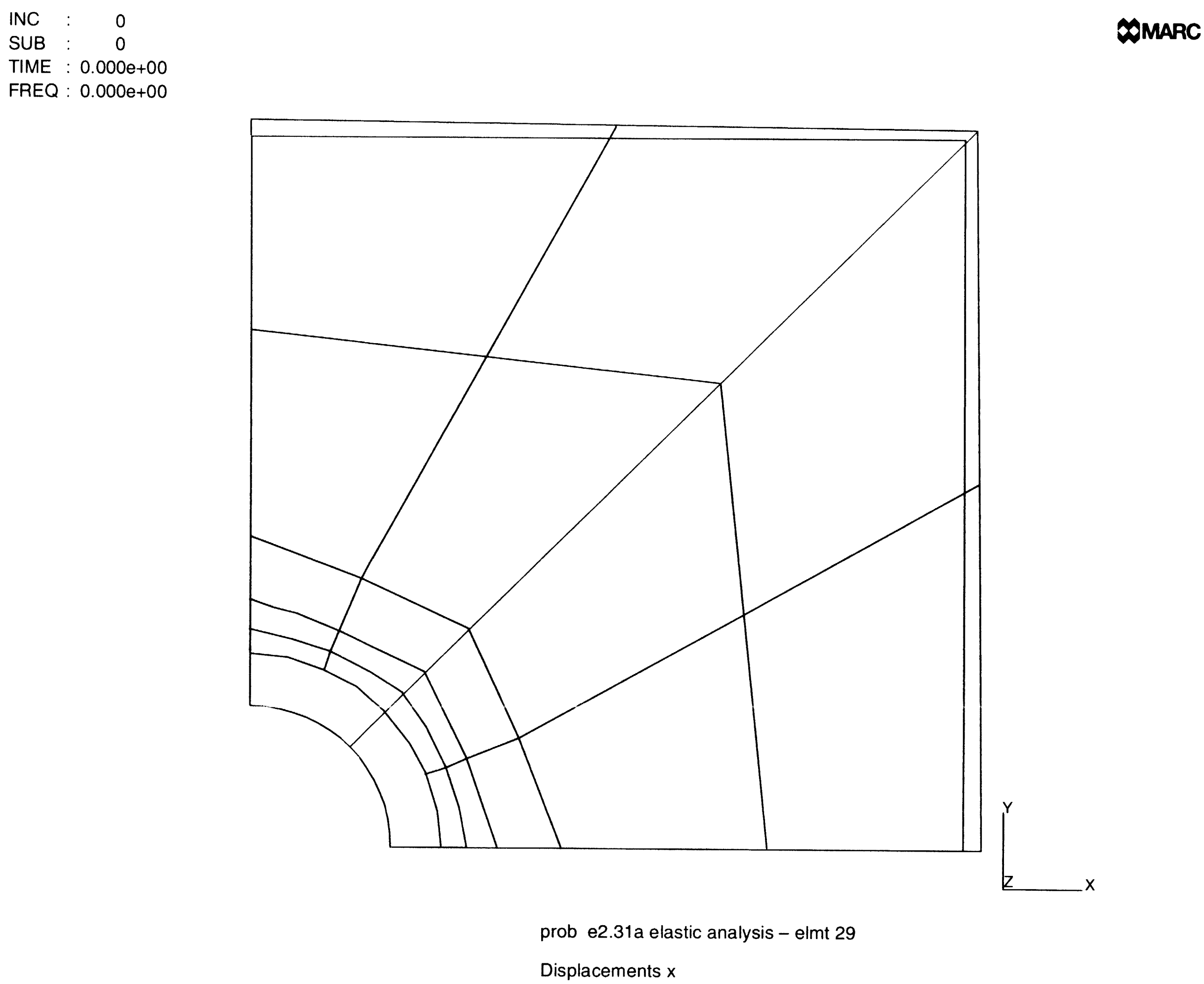


Figure 2.31-2 Deformed Mesh Plot

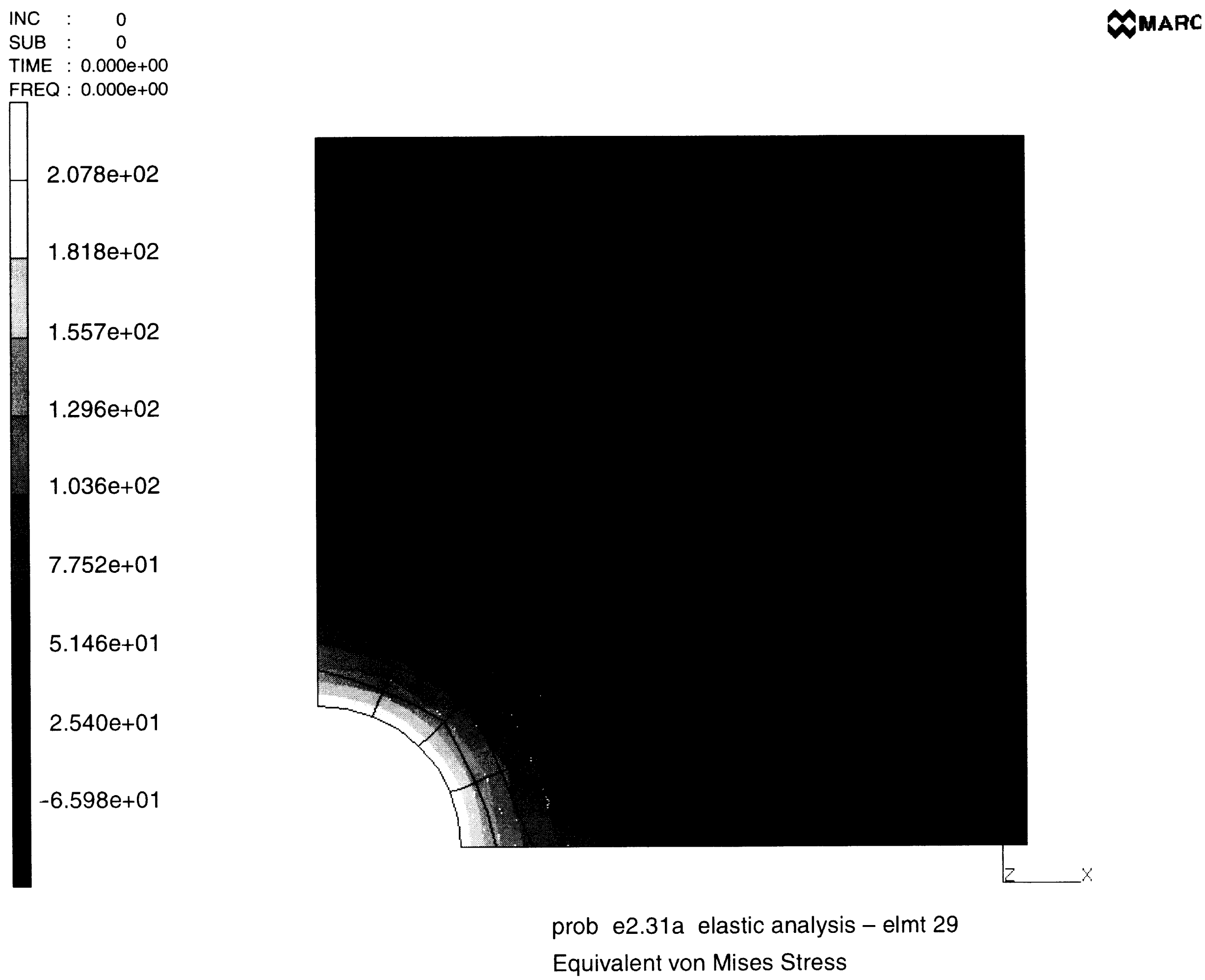


Figure 2.31-3 Stress Contours

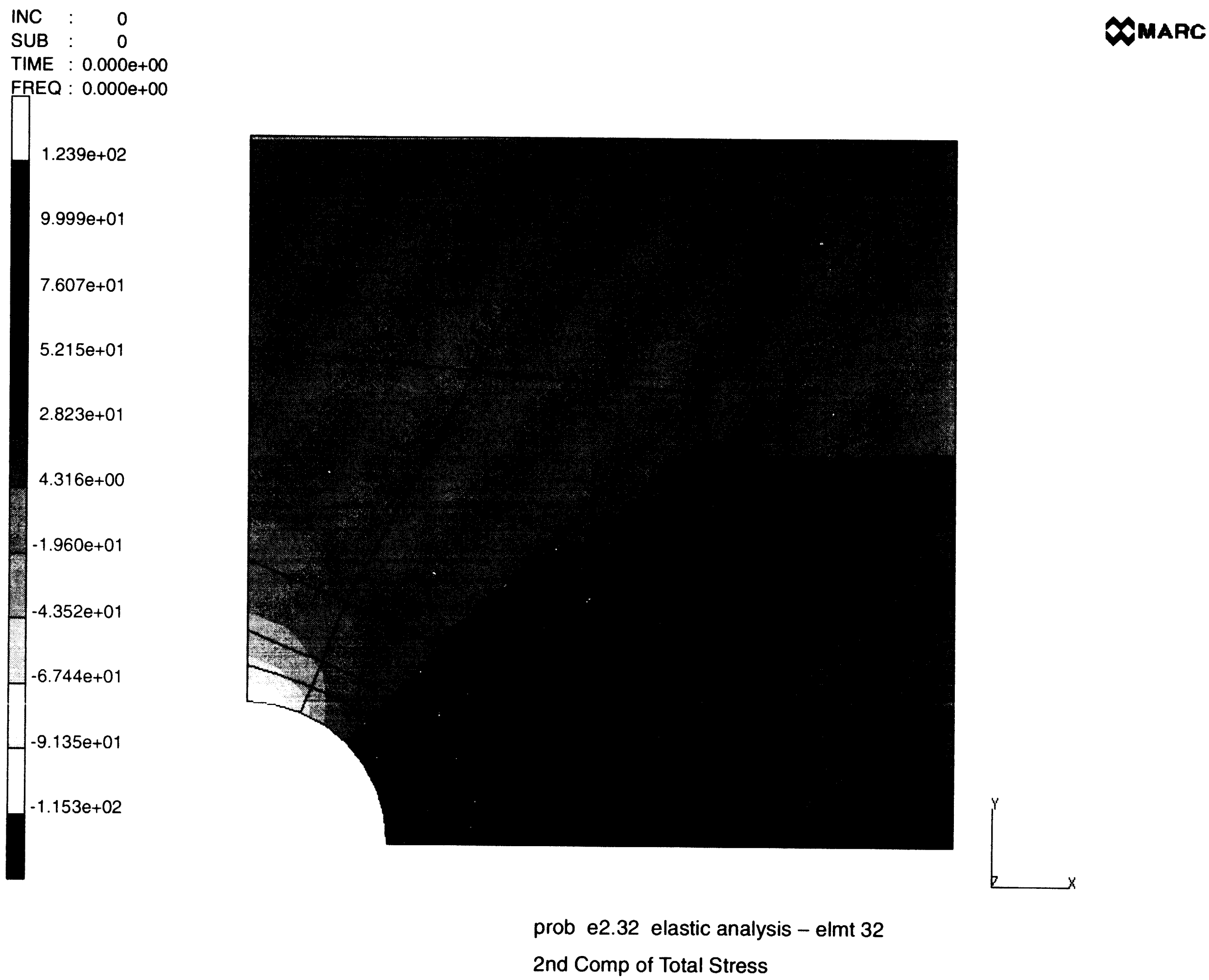


Figure 2.32-3 Stress Contours for σ_{yy}

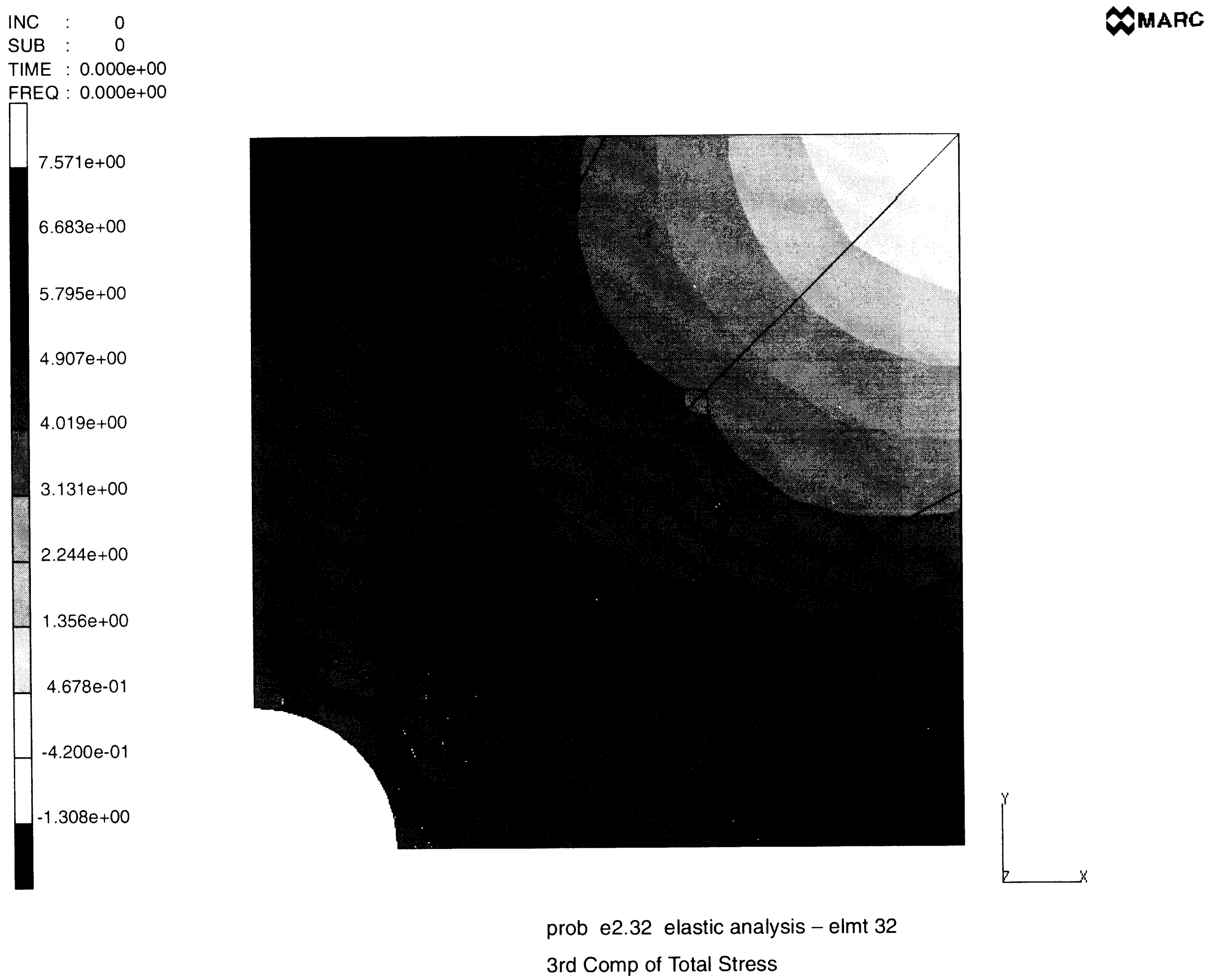


Figure 2.32-4 Stress Contours for σ_{zz}

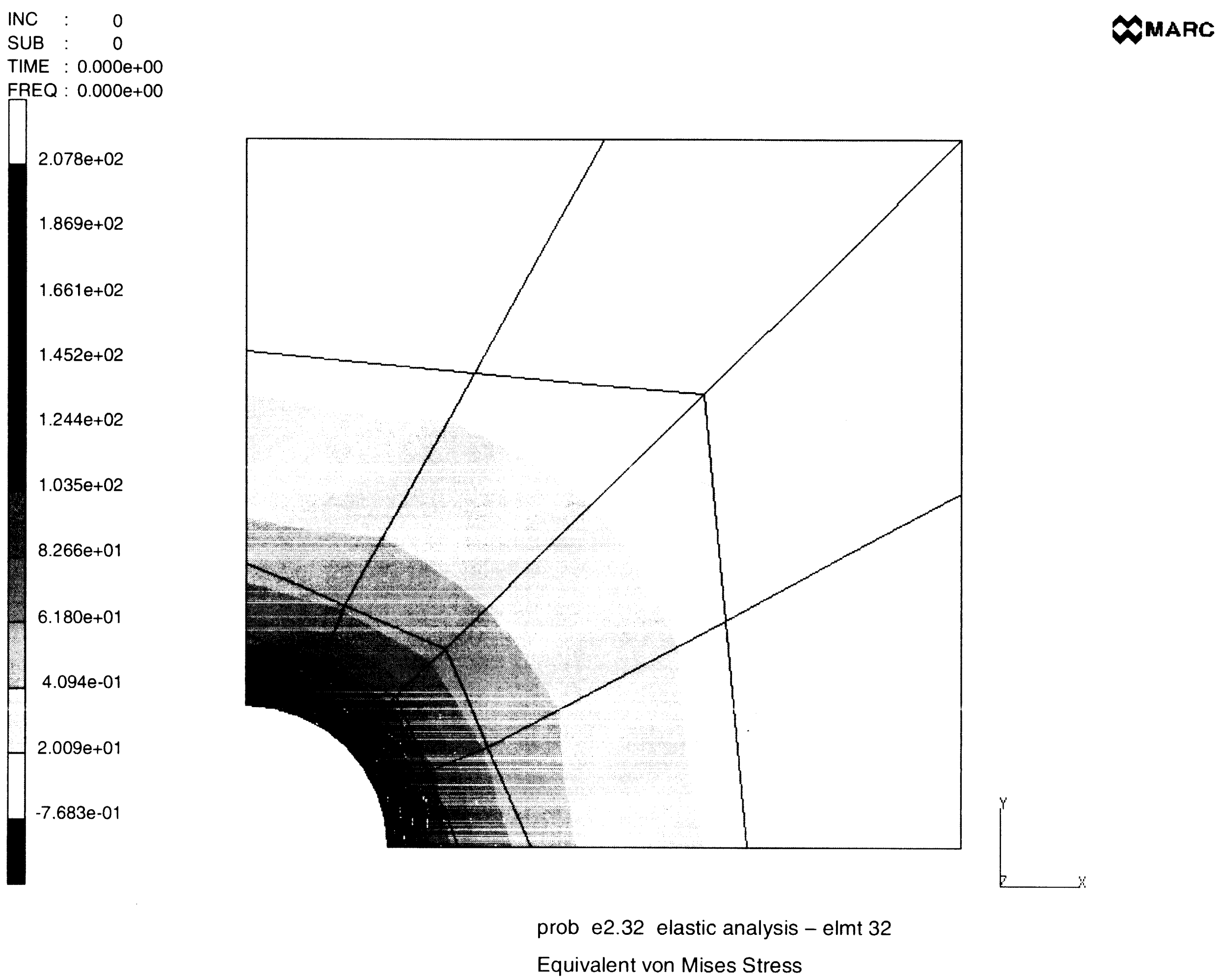


Figure 2.32-5 Stress Contours for Equivalent Stress

2.33 Flat Spinning Disk

This problem illustrates the use of MARC element type 33 for the solution of a circular disk. The disk rotates about the axis of symmetry at a constant angular velocity. The options ROTATION A and DIST LOADS are used for the input of centrifugal load. Options NODE FILL and CONN GENER are used to generate the mesh.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x33	33	15	78	
e2x33b	33	15	78	STIFFSCALE

Element

Element type 33 is used in this analysis. This is an 8-node isoparametric element similar to element 28 but modified for the Herrmann variational principle. This element has been developed for incompressible and nearly incompressible analysis.

Model

The dimensions of the disk and a finite element mesh are shown in Figure 2.33-1. The mesh consists of 15 elements and 78 nodes. The mesh is formed by one element given as an example through the CONNECTIVITY option and then CONN GENER is used to generate the rest of the elements. The coordinates of the nodes at the inner and outer radius are given, and then NODE FILL is used to generate the rest of the coordinates.

Material Properties

The properties are: Young's modulus is 30 x 10^6 psi, Poisson's ratio is 0.4999, and mass density is 0.2808 lb-sec /in^4.

Loading

Face identification for centrifugal force (IBODY = 100). The angular velocity (ω) is 20 radian/sec ($\omega^2 = 400$), and the axis of rotation is the symmetry axis (z-axis).

Boundary Conditions

The boundary conditions are u = 0 at z = 0 and v = 0 at r = 0 (line of symmetry).

Results

A comparison of the results and the analytic solution are given in Table 2.33-1. The analytical solution may be found in Timoshenko and Goodier, *Theory of Elasticity.*

Table 2.33-1 Comparison of Results

Item	Calculated	MARC
Equivalent Nodal Force (lbs)	7.93433×10^5	7.939×10^5
Nodal Displacement at r = 15 (in.)	1.5792×10^{-3}	1.586×10^{-3}
Radial Stress at r = 0 (psi)	11056	11050
Hoop Stress at r = 15 (psi)	3159	3260

Parameters, Options, and Subroutines Summary

Example e2x33.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONN GENER
CONNECTIVITY
COORDINATES
DIST LOADS
END OPTIO
FIXED DISP
ISOTROPIC
NODE FILL
ROTATION AXIS

Example e2x33b.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONN GENER
CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
ISOTROPIC
NODE FILL
ROTATION AXIS
STIFSCALE

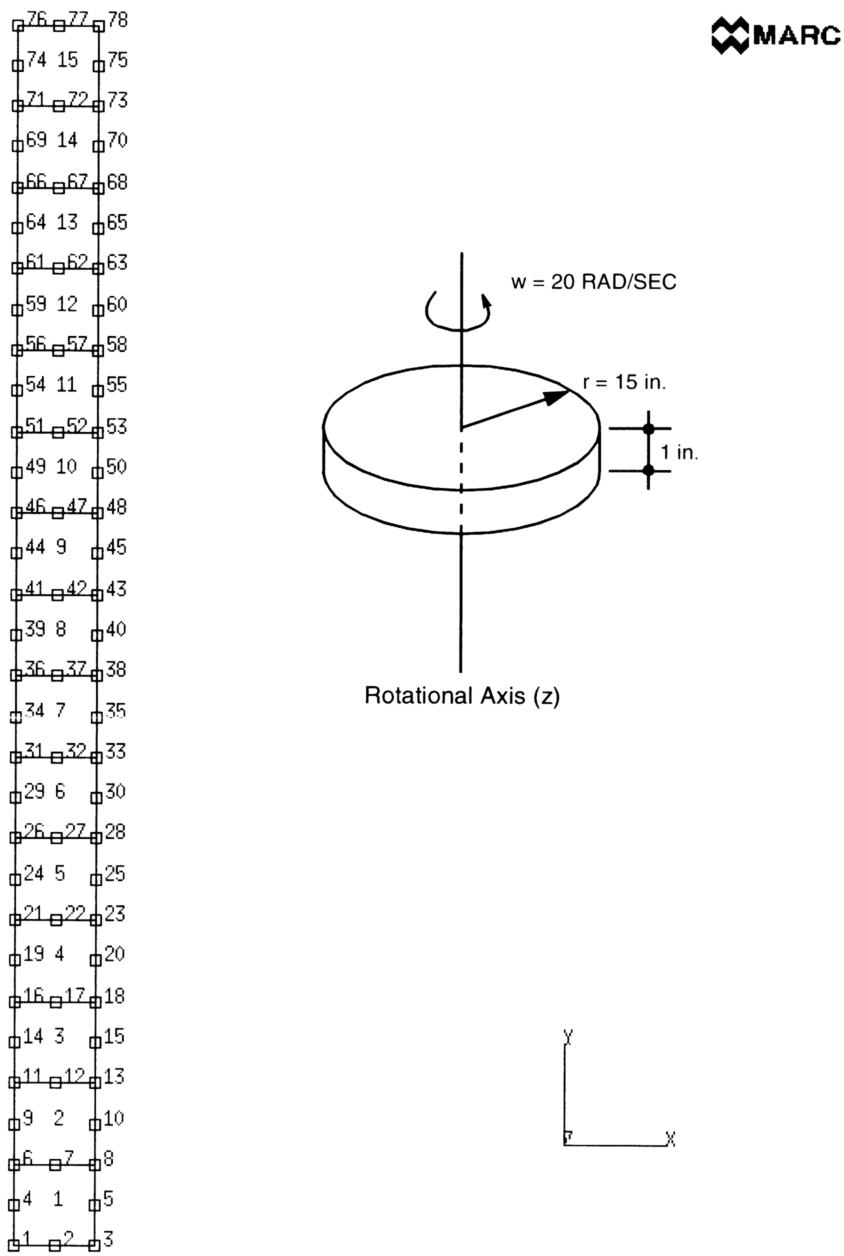


Figure 2.33-1 Flat Disk and Mesh

2.34 Strip with Bonded Edges, Error Estimates

This problem illustrates the use of MARC element type 34, option CONN FILL, OPTIMIZE, and the user subroutine UFCONN for an elastic analysis of a strip. The strip is subjected to compression. This is the same problem as 2.26, but modeled with a different element. The ERROR ESTIMATE option is used to determine mesh quality.

Element

Element type 34 is an 8-node, incompressible, generalized plane-strain element, Herrmann formulation. There are 10 nodes per element.

Model

The dimensions of the strip and a finite element mesh are shown in Figure 2.34-1. There are 24 elements and 95 nodes in the mesh.

Material Properties

The elastic properties are: Young's modulus is 3 x 10^6 psi and Poisson's ratio is 0.4999.

Geometry

The strip has a thickness of 1 inch.

Boundary Conditions

Symmetry conditions are imposed such that u = 0 at x = 0 and v = 0 at y = 0. At the top, nonzero displacement boundary condition v = -0.001 inch in the y-direction. For the second extra node of elements (node 95), both degrees of freedom are constrained (no relative rotation between planes).

Optimize

The Sloan optimizer is used here. Because generalized plane strain elements are used, the bandwidth does not change, but the number of profile entries including fill-in is reduced.

Results

A deformed mesh plot is shown in Figure 2.34-2 and a contour plot of the second component of stress is shown in Figure 2.34-3. To increase the accuracy of the analysis, additional mesh refinement should be applied to the elements associated with the node where the largest normalized stress discontinuity occurs. In this analysis, this would be elements 23 and 24. The stress singularity exists because on one edge of element 24 shear stresses are allowed to occur, but the perpendicular side is a free edge.

Parameters, Options, and Subroutines Summary

Example e2x34.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONN FILL
END	CONN GENER
QUALIFY	CONNECTIVITY
SIZING	COORDINATES
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NODE FILL
	OPTIMIZE
	UFCONN

User subroutine in u2x24.f:

UFCONN

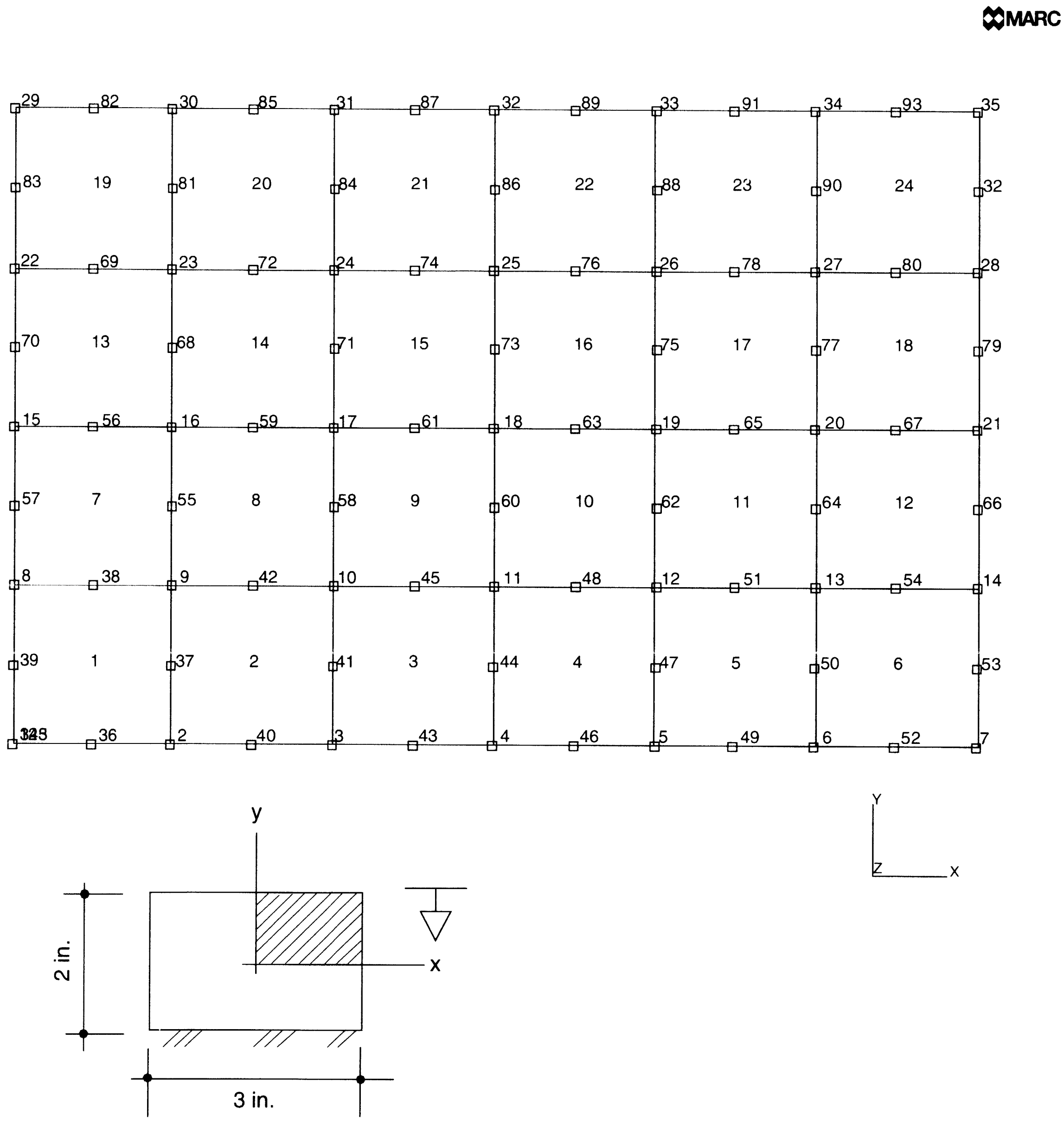


Figure 2.34-1 Two-Dimensional Strip and Mesh

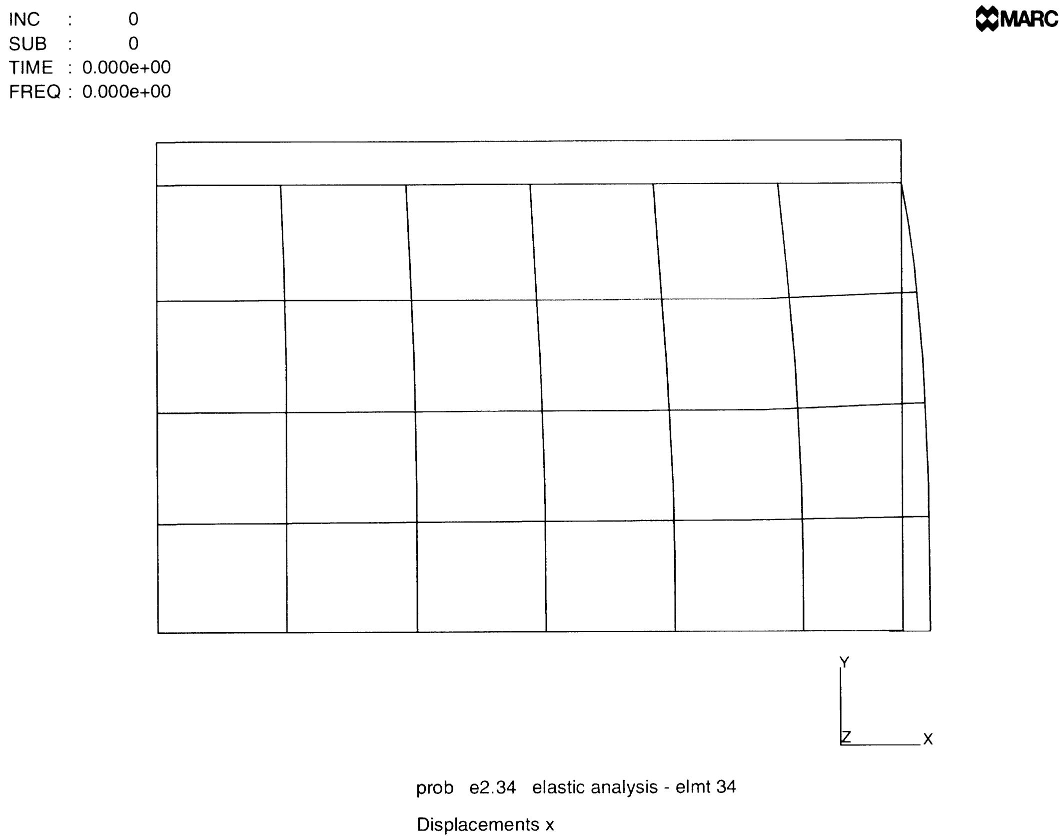


Figure 2.34-2 Deformed Mesh Plot

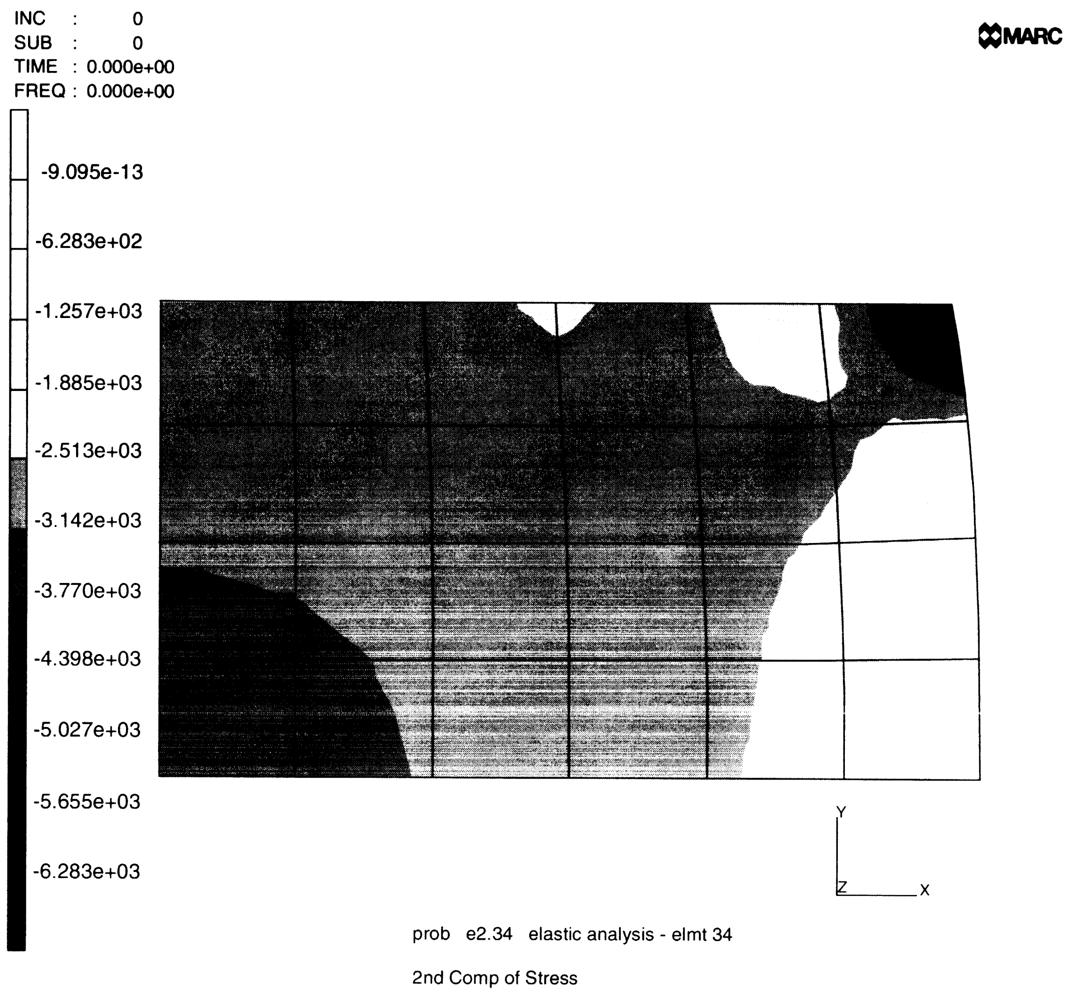


Figure 2.34-3 σ_{yy} Contours

2.35 Cube Under Pressure Loads

This problem illustrates the use of MARC element type 35, the ELASTIC parameter, the CASE COMBIN and RESTART options, and the FORCEM user subroutine for an elastic analysis of a cube. The cube is subjected to uniform and nonuniform distributed pressure.

Element

Element type 35 is written for incompressible and nearly incompressible behavior. The element is a three-dimensional brick with 20 nodes.

Model

The dimensions of the cube and a finite element mesh are shown in Figure 2.35-1. The cube is divided into eight cubes with a total of 81 nodes.

Material Properties

The elastic properties are Young's modulus is 30.E5 psi and Poisson's ratio is 0.4999.

Loading

The pressure is applied to the top surface of the block (elements 5, 6, 7 and 8). Both the uniform (IBODY = 4) and nonuniform (IBODY = 5) distributed pressure are shown in Figure 2.35-2. The uniform pressure is applied in increment 0, the nonuniform load in increment 1. Subroutine FORCEM is used to input the nonuniform distributed load. Because the ELASTIC parameter is used, the loads applied in increment 1 are total loads and not incremental loads.

Boundary Conditions

Symmetry conditions are imposed such that: u = 0 on plane x = 0, v = 0 on plane y = 0, and w = 0 on plane z = 0. The second input demonstrates the CASE COMBIN feature to superimpose the two solutions obtained in the first analysis. This is acceptable in an elastic analysis.

Results

In the first analysis the results were saved by using the RESTART option, writing to unit 8. In the second analysis, the CASE COMBINATION option was used to retrieve these results off unit 9 and combine them. This option can only be used if an ELASTIC parameter is included. In the second analysis, the two cases performed before were combined, each with a default weighting factor of 1.0. The deformed mesh for the first load case is shown in Figure 2.35-3. The third stress contours for the second load case are shown in Figure 2.35-4.

Parameters, Options, and Subroutines Summary

Example e2x35.dat:

Parameters	Model Definition Options	History Definition Options
ELASTIC	CONNECTIVITY	CONTINUE
ELEMENTS	COORDINATES	DIST LOADS
END	DIST LOADS	
SIZING	END OPTION	
TITLE	FIXED DISP	
	ISOTROPIC	
	OPTIMIZE	
	RESTART	

User subroutine in u2x35.f:

FORCEM

Example e2x35a.dat:

Parameters	Model Definition Options
ELASTIC	CASE COMBINATION
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	OPTIMIZE
	RESTART

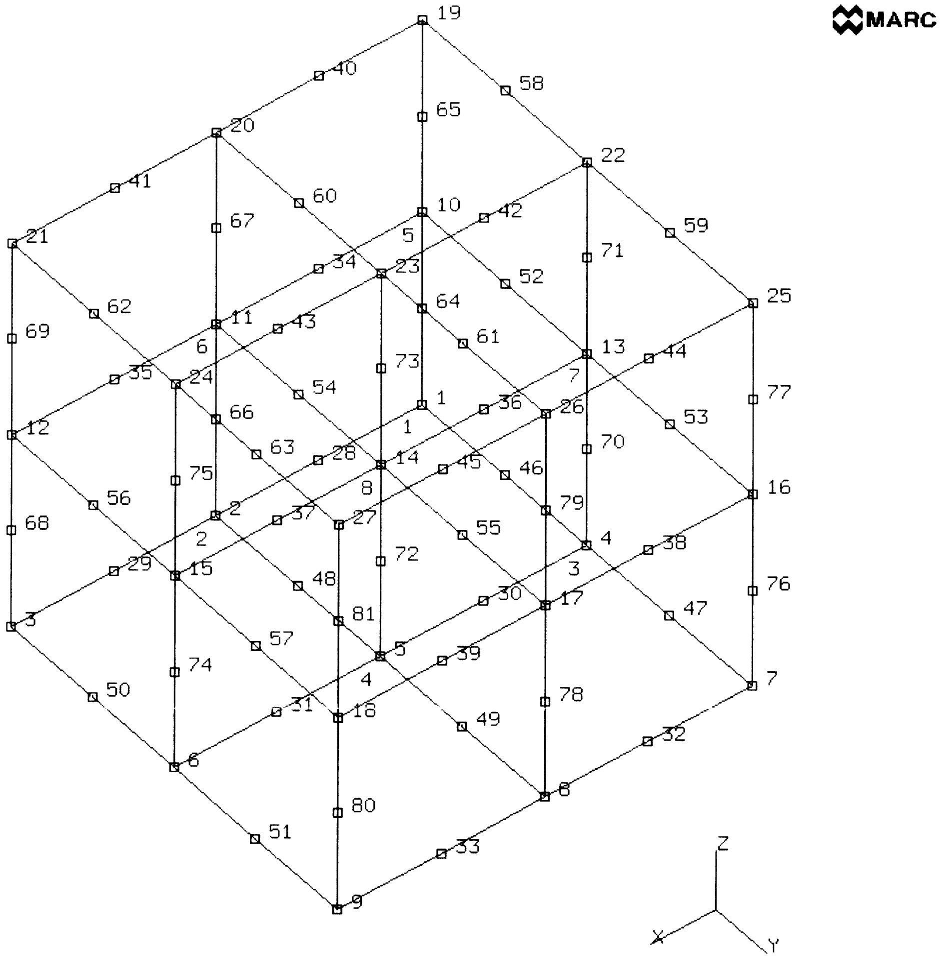
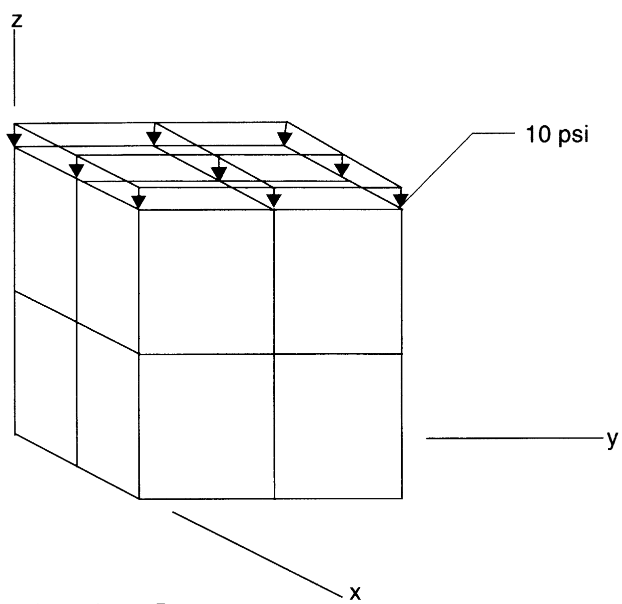
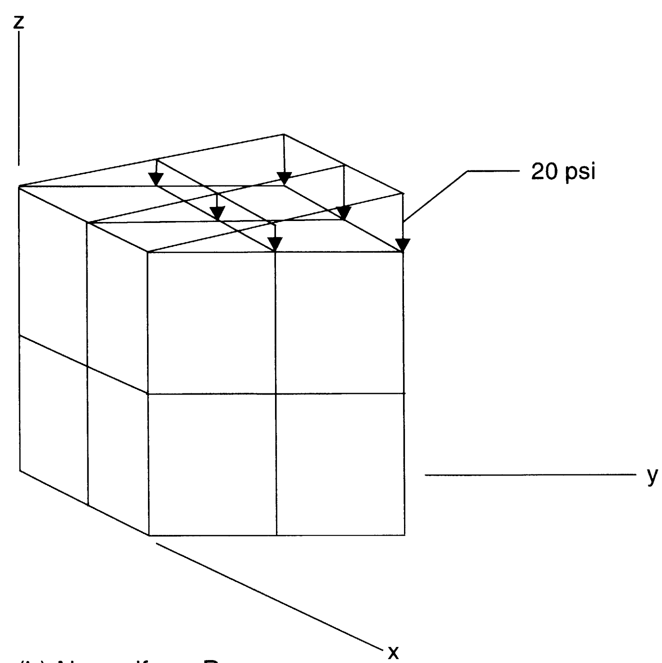


Figure 2.35-1 Square Block and Mesh



(a) Uniform Pressure



(b) Nonuniform Pressure

Figure 2.35-2 Pressure Distribution

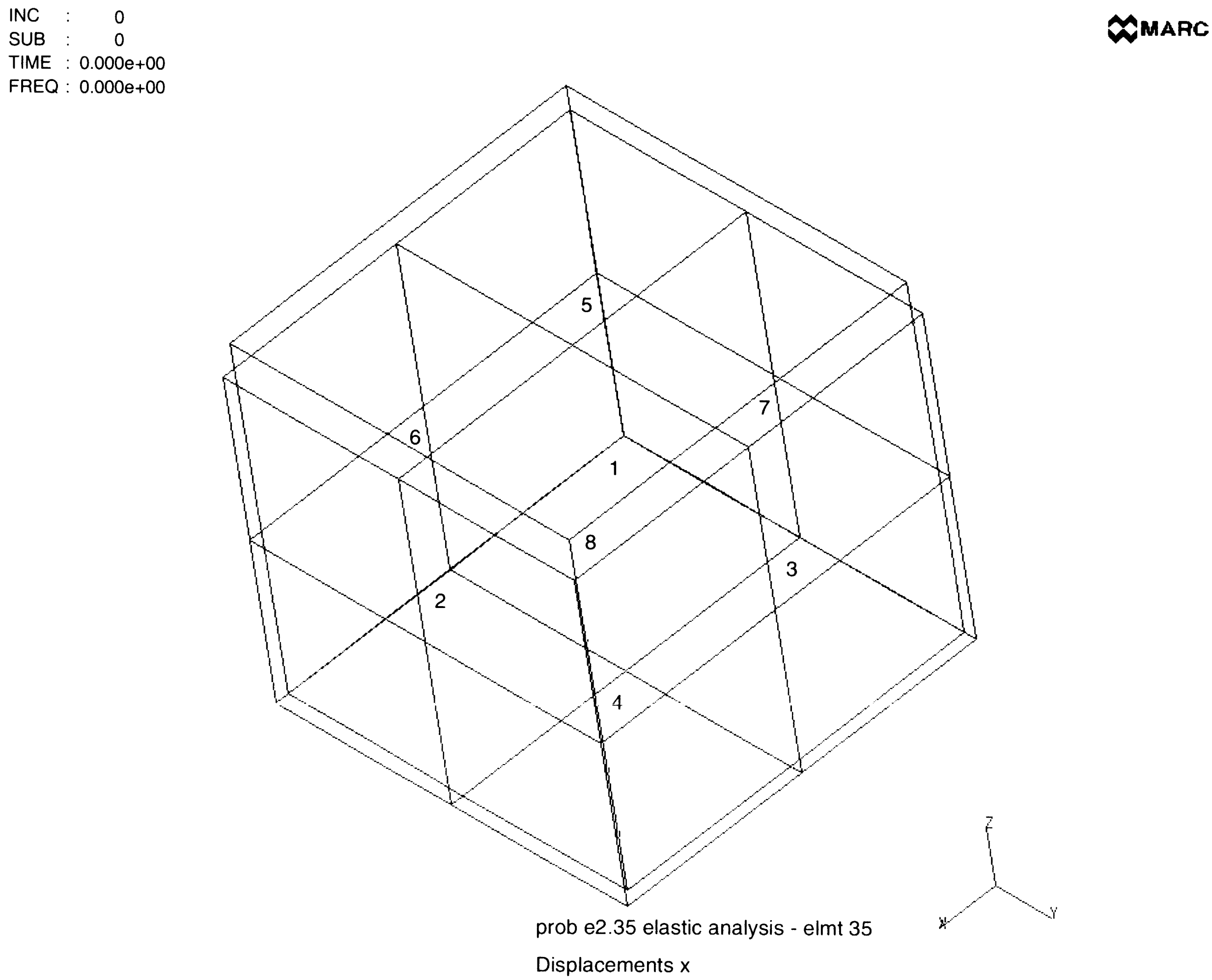


Figure 2.35-3 Deformed Mesh Plot

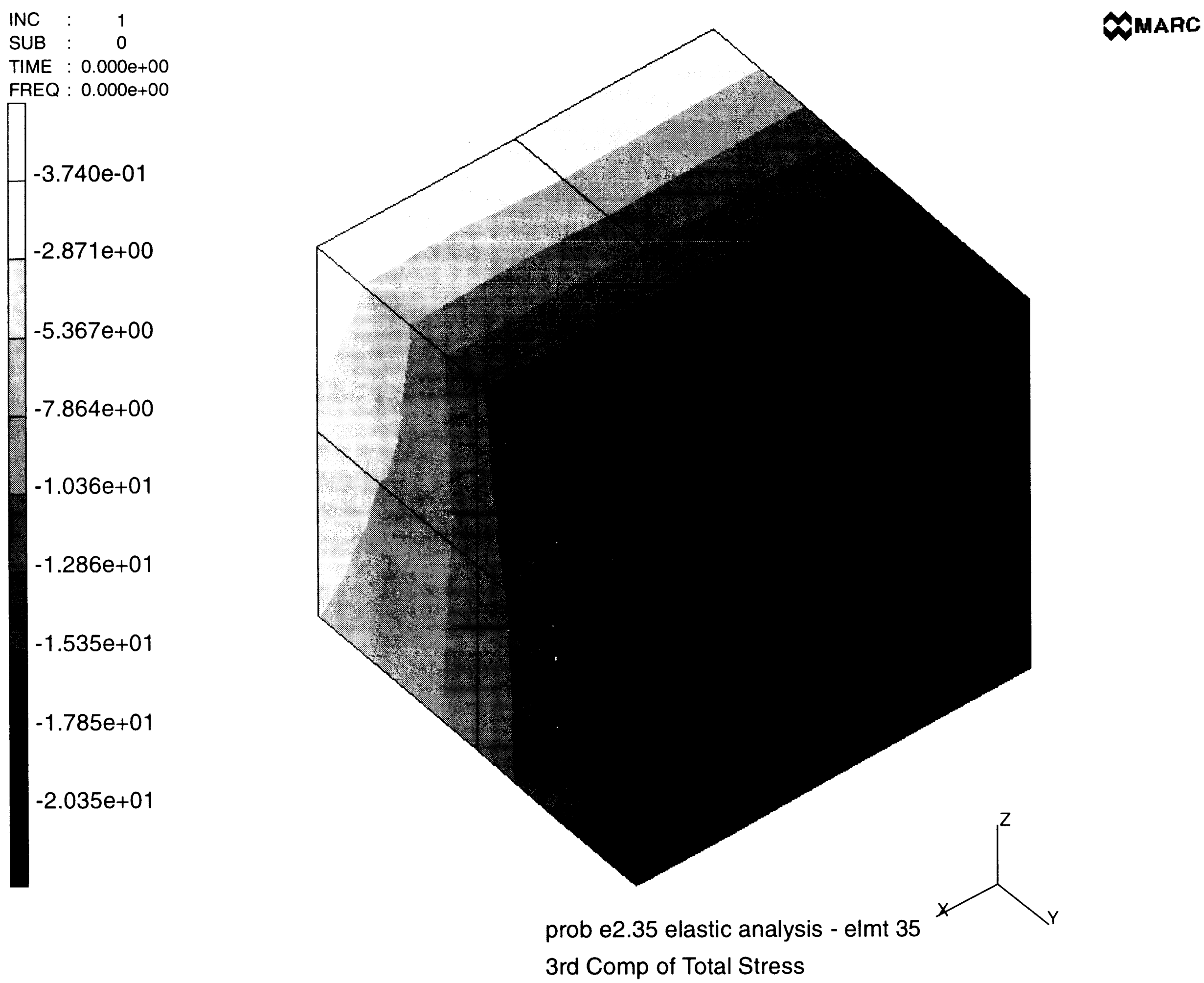


Figure 2.35-4 Stress Contours for σ_{zz}

2.36 Timoshenko Beam on an Elastic Foundation

This problem illustrates the use of MARC element type 45 and the FOUNDATION option for an elastic analysis of a Timoshenko beam resting on an elastic foundation. The beam is subjected to a concentrated load at the center of the beam. This problem is the same as 2.29, except that a different cross section is used.

Element

Element 45, a planar three-noded Timoshenko curved beam, is used for the analysis. This beam allows transverse shear strains, which improves the accuracy, especially for deep-beam analysis. The beam only has in-plane behavior.

Model

The dimensions of the beam and a finite element mesh are shown in Figure 2.36-1. The finite element mesh consists of 20 elements of type 45, with 41 nodes. Only half of the beam is modeled due to symmetry.

Material Properties

The Young's modulus is 2.0×10^5 psi. The Poisson's ratio υ is 0.3.

Geometry

The beam thickness is 5.885 inches with width of 1.0 inch. A cross section of the beam is shown in Figure 2.36-1.

Loading

A concentrated load (P/2) of 1000 pounds is applied at the center of the beam.

Boundary Conditions

Symmetry conditions are imposed at x = 0, y = 0; i.e., u = 0, and $\phi_a = 0$.

Elastic Foundation

The whole beam is assumed to rest on an elastic foundation. The description of the elastic foundation is given in model definition option FOUNDATION:

Element numbers = 1 through 20
Spring stiffness per unit length of the beam = 10. lb./inch
Element face I.D. = 0

Results

A deformed mesh plot is shown in Figure 2.36-2. The solution for maximum displacement agrees well with the analytic solution of classical beam theory. The calculated moment is less when using this element which allows transverse shear strain.

	Analytically Computed	MARC Computed
Y_{max} (x = 0)	2.929	2.963
σ_{max} (x = 2.11)	2603	2592

$$\beta = \sqrt[4]{k/4EI}$$

$$Y(x) = (P/8\beta^3 EI)e^{-\beta x}(\sin(\beta x) + \cos(\beta x))$$

$$M(x) = (P/4\beta)e^{-\beta x}(\sin(\beta x) - \cos(\beta x))$$

$$\sigma = Mc/I$$

Reference

Roark, R. J., *Formulas for Stress and Strain*

Parameters, Options, and Subroutines Summary

Example e2x36.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONN GENER
CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
FOUNDATION
GEOMETRY
ISOTROPIC
POINT LOAD

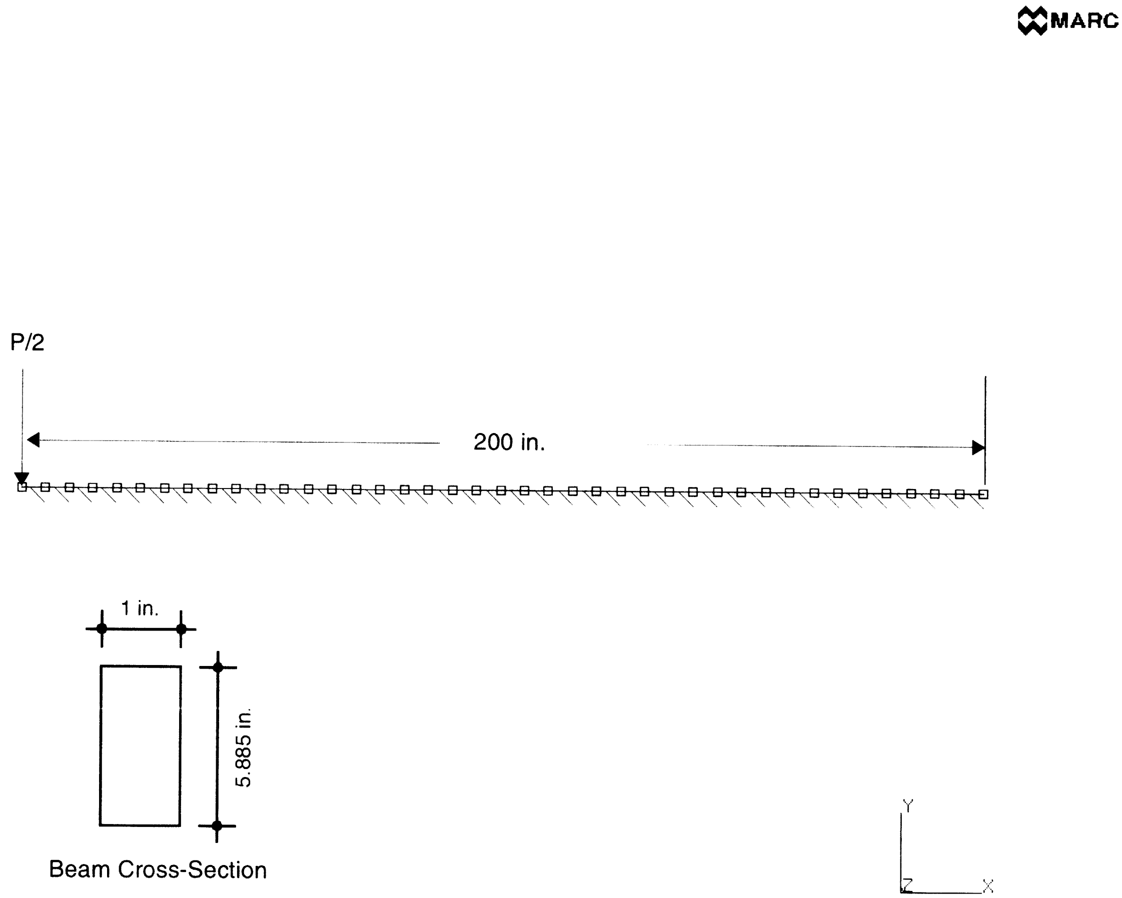


Figure 2.36-1 Timoshenko Beam and Mesh

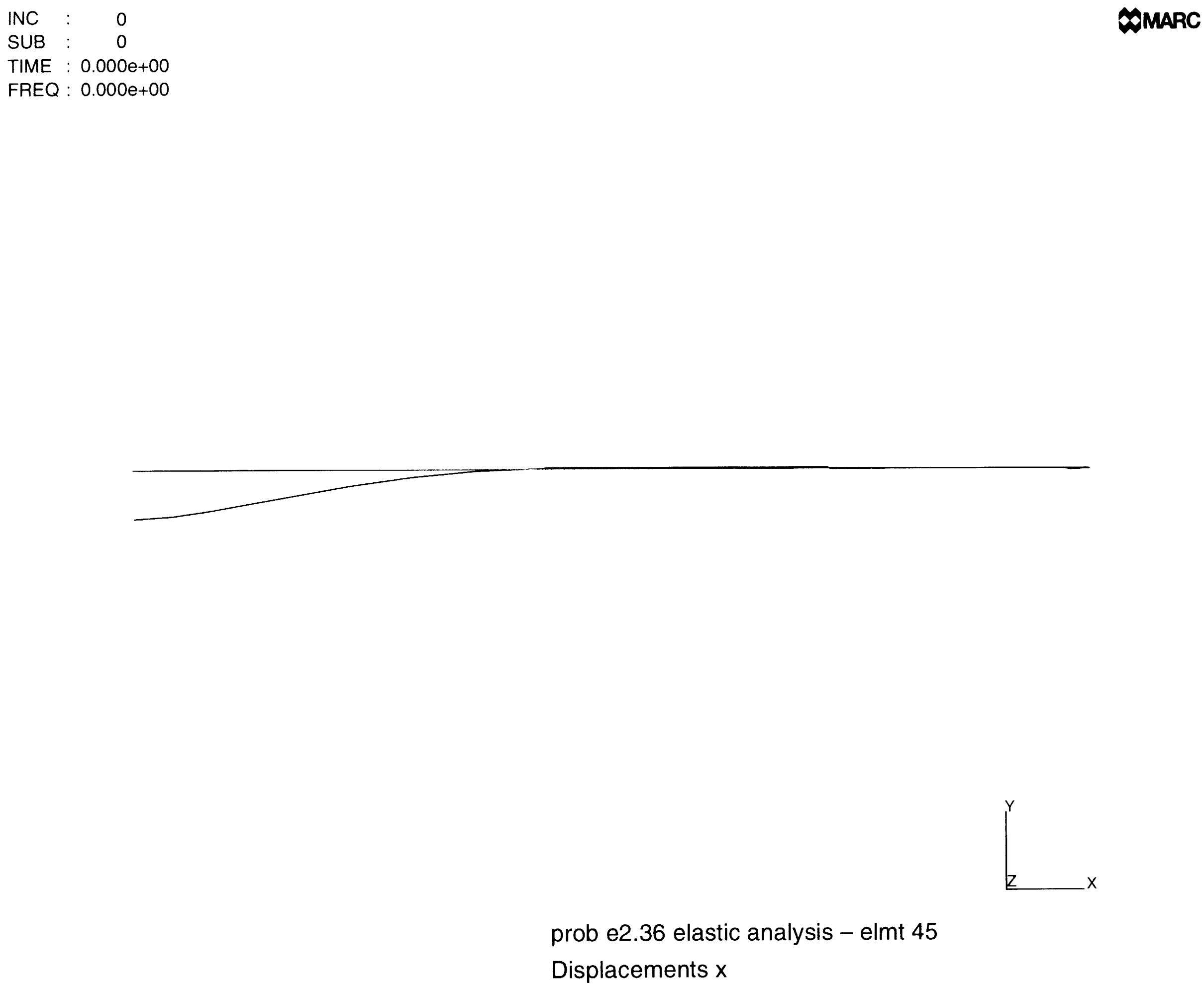


Figure 2.36-2 Deformed Mesh Plot

2.37 Reinforced Concrete Beam

This problem illustrates the use of MARC element types 27 and 46 (or 11 and 143) for an elastic analysis of a cantilevered concrete beam. The beam is subjected to a uniformly distributed load. The REBAR user subroutine or REBAR option for the input of rebar data is also demonstrated.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x37	27 & 46	24	69	rebar subroutine
e2x37b	11 & 143	192	195	REBAR option

Elements

Either element types 27 or 46 (8-node plane strain) or 11 and 143 (4-node plane strain) are used in the analysis. Element 27 and 11 represent the concrete. Element 46 and 143, which are specifically designed to simulate reinforcing layers in plane strain problems, represent the stell reinforcements in the concrete.

Model

The beam is modeled either by using 16 8-node plane strain concrete elements and 8 8-node plane strain rebar elements (data set e2x37) or by using 128 4-node plane strain concrete elements and 64 4-node plane strain rebar elements (data set e2x37b).

Material Properties

The Young's modulus is 140,000 psi for the concrete elements (elements 1-16), and 2,100,000 psi for the rebar elements (elements 17-24). The Poisson's ratio is 0.2 for the concrete elements and 0.30 for the steel elements.

Geometry

The beam thickness is 1.0 inch (see Figure 2.37-1). For the rebar elements, one layer of rebars is used.

Loading

A uniform distributed load (q) of 0.025 psi in the y-direction is applied to the beam.

Boundary Conditions

All degrees of freedom of nodes at x = 0 are constrained to model the built-in condition. The other end of the beam is free.

Optimization

The Cuthill-McKee optimizer is used.

Rebar Data

The steel cross-sectional area $A_s = 0.23$ in. The rebars lie along the length of the beam; that is, the x-direction. Equivalent thickness $TR = A_s/B = \frac{0.23}{1} = 0.23$ in. See Figure 2.37-1. The data is either read in via user subroutine REBAR or by using the REBAR option.

Results

A deformed mesh plot for example e2x37.dat is shown in Figure 2.37-2 and stresses are depicted in Figure 2.37-3. The rebar elements are coincident with the 7,8,9 integration points of elements 1-8. When examining the stresses of the rebar element 17 with respect to element 1, it is found that the rebar element supports 15 times the stress of the concrete element, which can be anticipated by examination of the ratios of the respective Young's moduli.

Parameters, Options, and Subroutines Summary

Example e2x37.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE

User subroutine in u2x37.f:

REBAR

Example e2x37b.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	OPTIMIZE
	REBAR

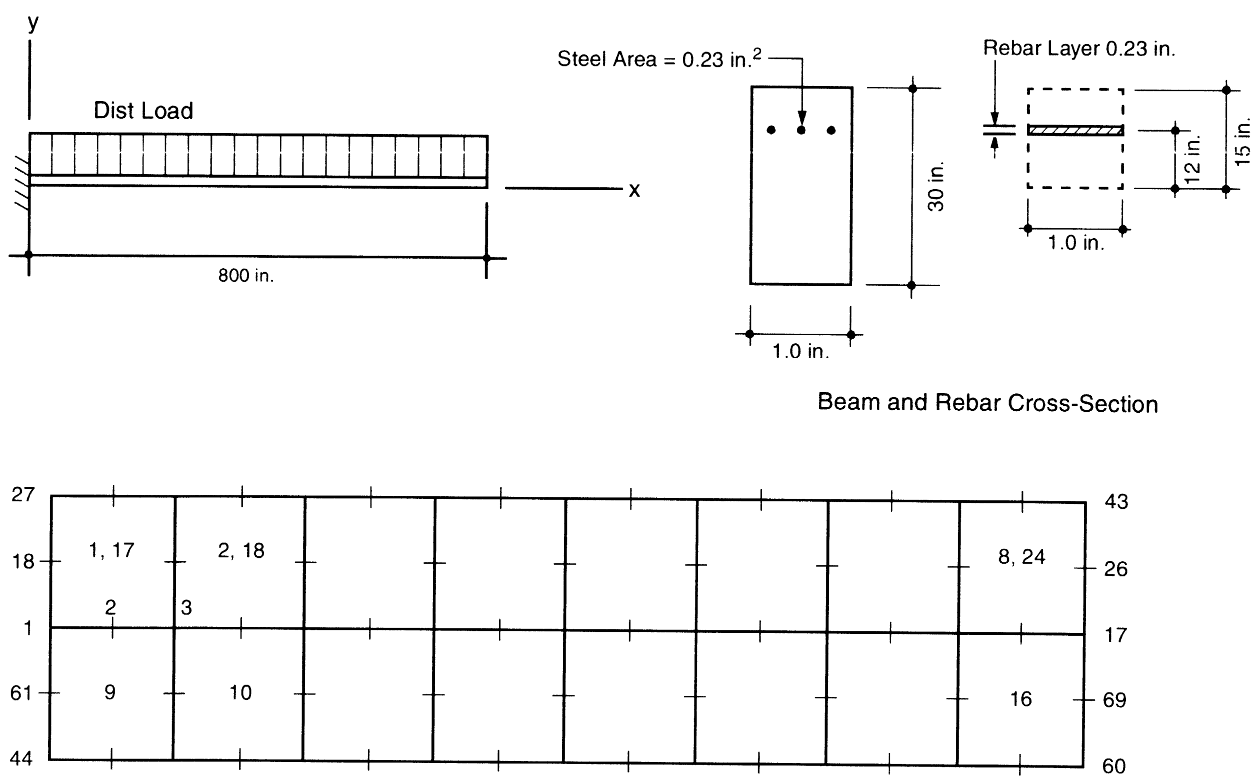


Figure 2.37-1 Reinforced Concrete Beam and Mesh

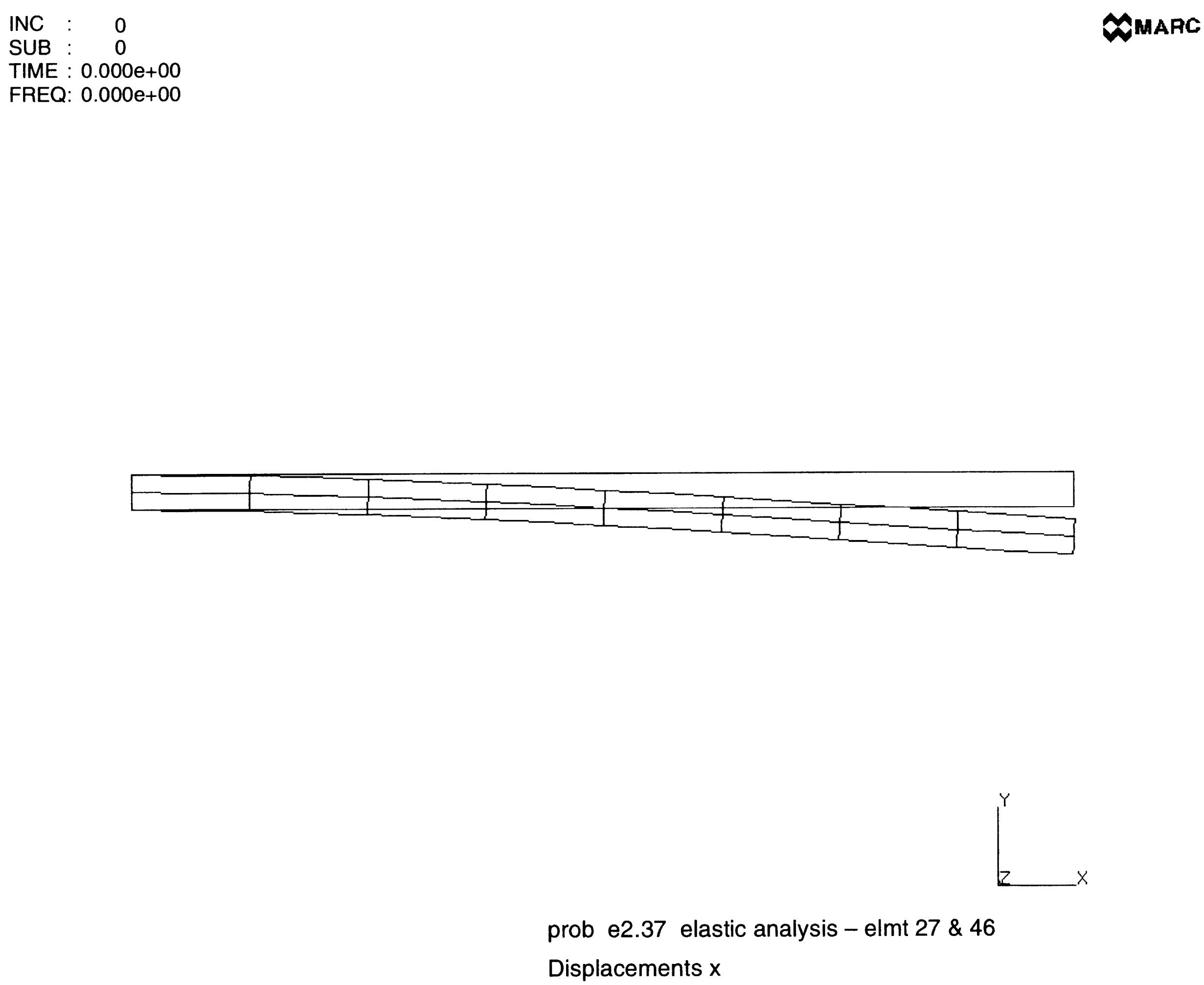


Figure 2.37-2 Deformed Mesh Plot

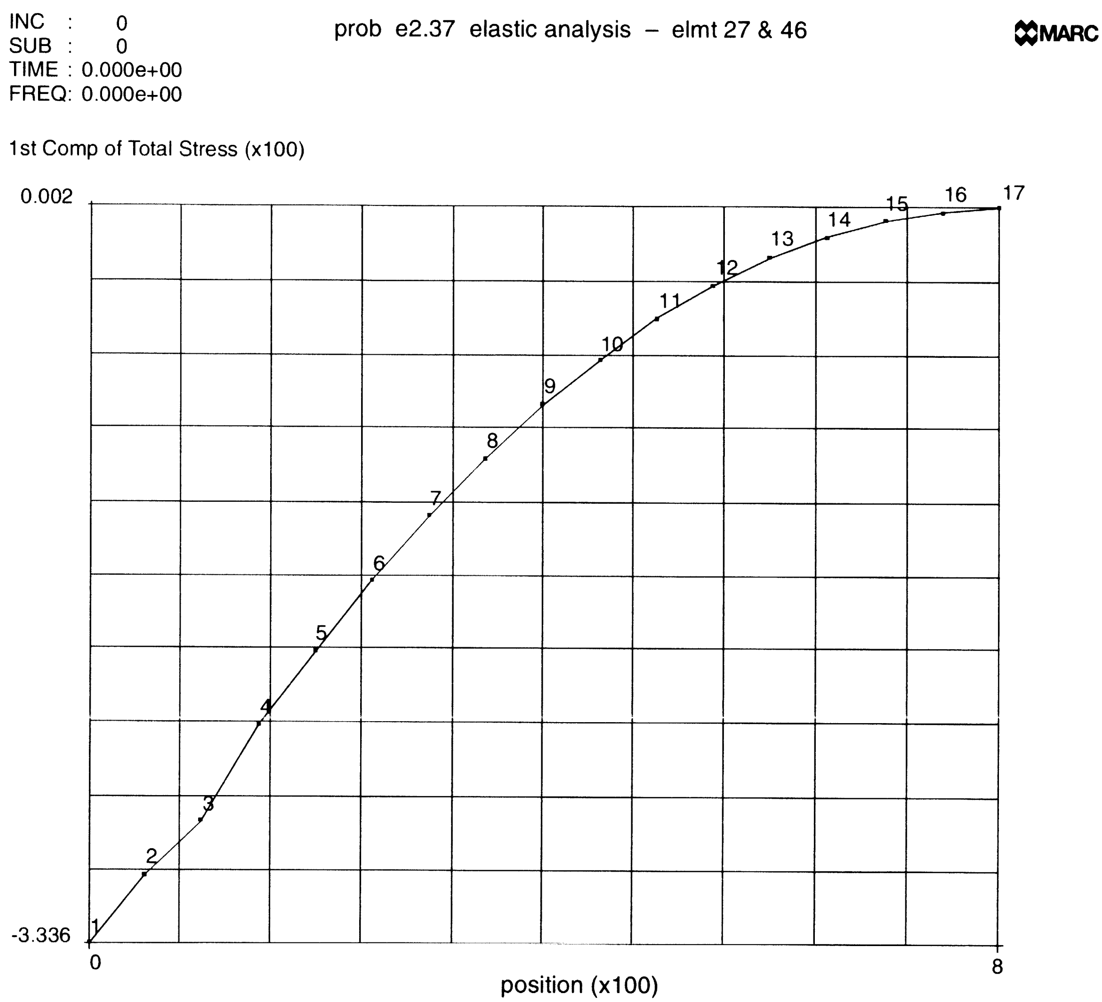


Figure 2.37-3 σ_{xx} Along Bottom Surface Along Nodes 1 to 17

2.38 Reinforced Concrete Plate with Central Hole

This problem illustrates the use of MARC elements type 29 and type 47 and user subroutines UINSTR and REBAR for an elastic analysis of a reinforced concrete plate. The plate is subject to an initial stress in the rebars. The use of the parameters ELSTO and SCALE is also demonstrated.

Model

The dimensions of the plate and a finite element mesh are shown in Figure 2.38-1. The plate is modeled under conditions of generalized plane strain. The geometry is similar to problem 2.31 with the addition that reinforcements have been placed concentrically with respect to the hole. There are 28 elements and 81 nodes in the mesh. Eight of the elements are rebar elements type 47.

Material Properties

The properties of the concrete are Young's modulus is 30 x 10^5 psi and Poisson's ratio is 0.2.

The properties of the steel are Young's modulus is 30 x 10^6 psi, and Poisson's ratio is 0.3 with a yield stress of 30 x 10^3 psi.

Boundary Conditions

Symmetry conditions exist on the lines x = 0 and y = 0 (u = 0 at x = 0; v = 0 at y = 0). Both degrees of freedom of the second extra node of generalized plane-strain elements (element 29) are constrained, restraining the relative rotation of the top and bottom surfaces.

Rebar

Three layers of rebars are assumed to be in the plate, the cross-sectional area of which is 0.25. The direction and position of the rebar layers are shown in Figure 2.38-2. The rebar data is defined in the user subroutine REBAR.

ELSTO allows the use of out-of-core element storage option; this reduces the amount of workspace necessary for the analysis.

ISTRESS allows you to input initial stresses in the rebars through the user subroutines UINSTR. The rebars are given a prestress of 100 psi, which is then scaled to the yield stress of 30000 psi.

SCALE allows the stresses in the plate to be scaled to the condition of first yield.

Optimization

The bandwidth optimization is performed by using the Sloan method.

Results

In increment zero, the initial stresses are applied and scaled to the yield stress. In increment one, the structure is allowed to return to equilibrium. The resulting deformed mesh plot is shown in Figure 2.38-3. As anticipated, the reinforcements force the plate into compression.

Parameters, Options, and Subroutines Summary

Example e2x38.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
ISTRESS	END OPTION
SCALE	FIXED DISP
SIZING	GEOMETRY
TITLE	ISOTROPIC
	OPTIMIZE
	PRINT CHOICE

User subroutines found in u2x28.f:

REBAR
UINSTR

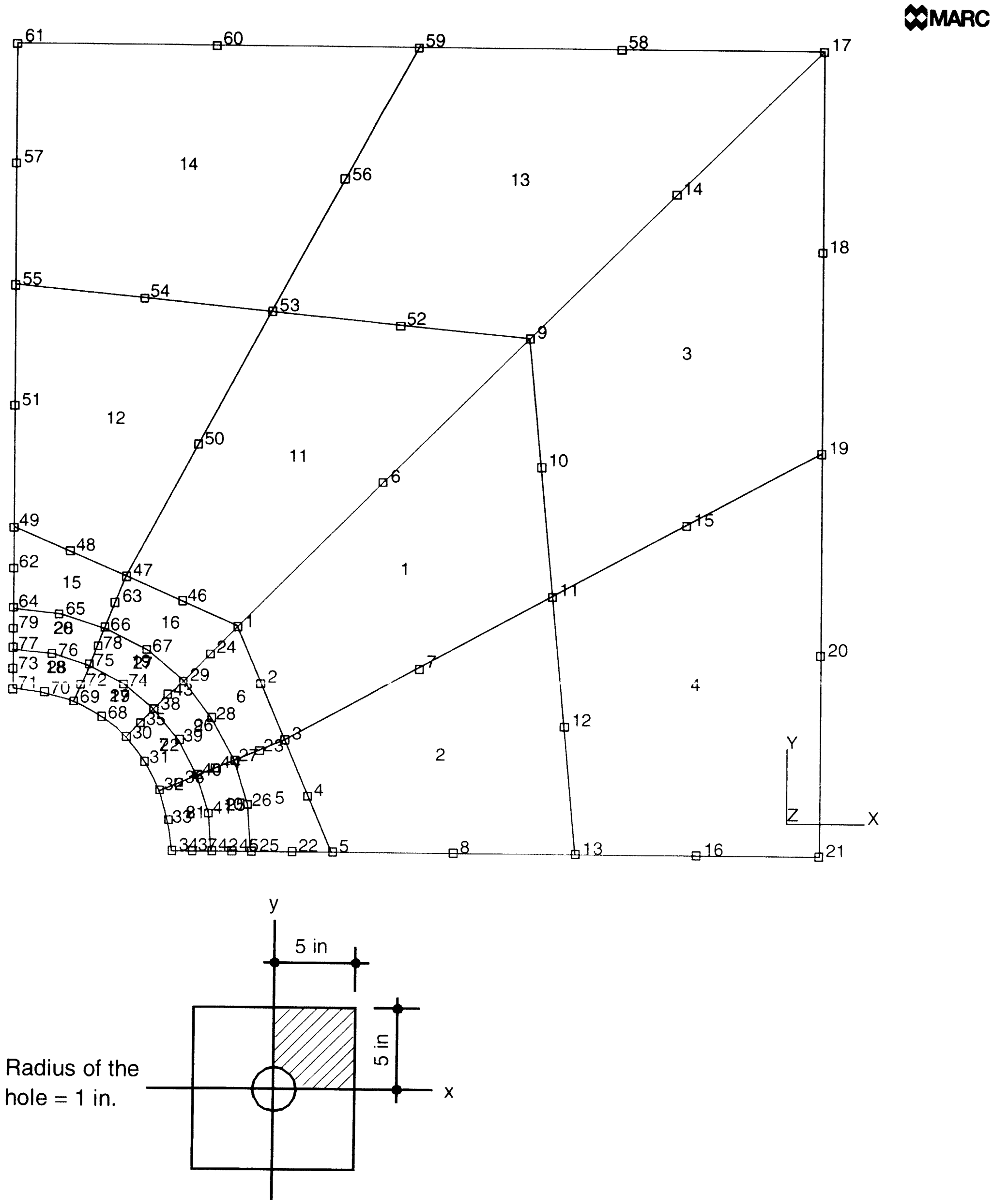


Figure 2.38-1 Reinforced Concrete Plate and Mesh

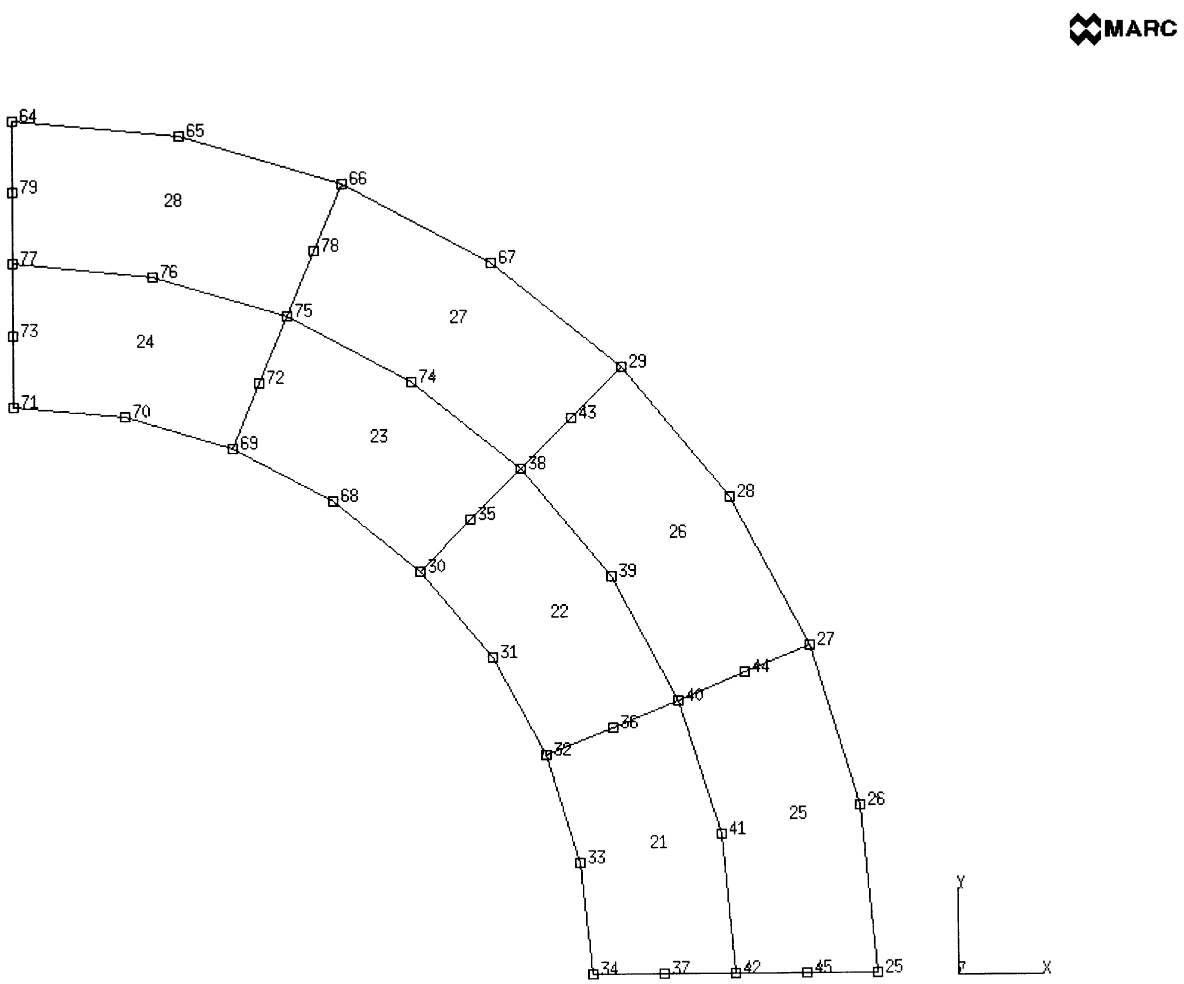


Figure 2.38-2 Rebar Layers and Elements

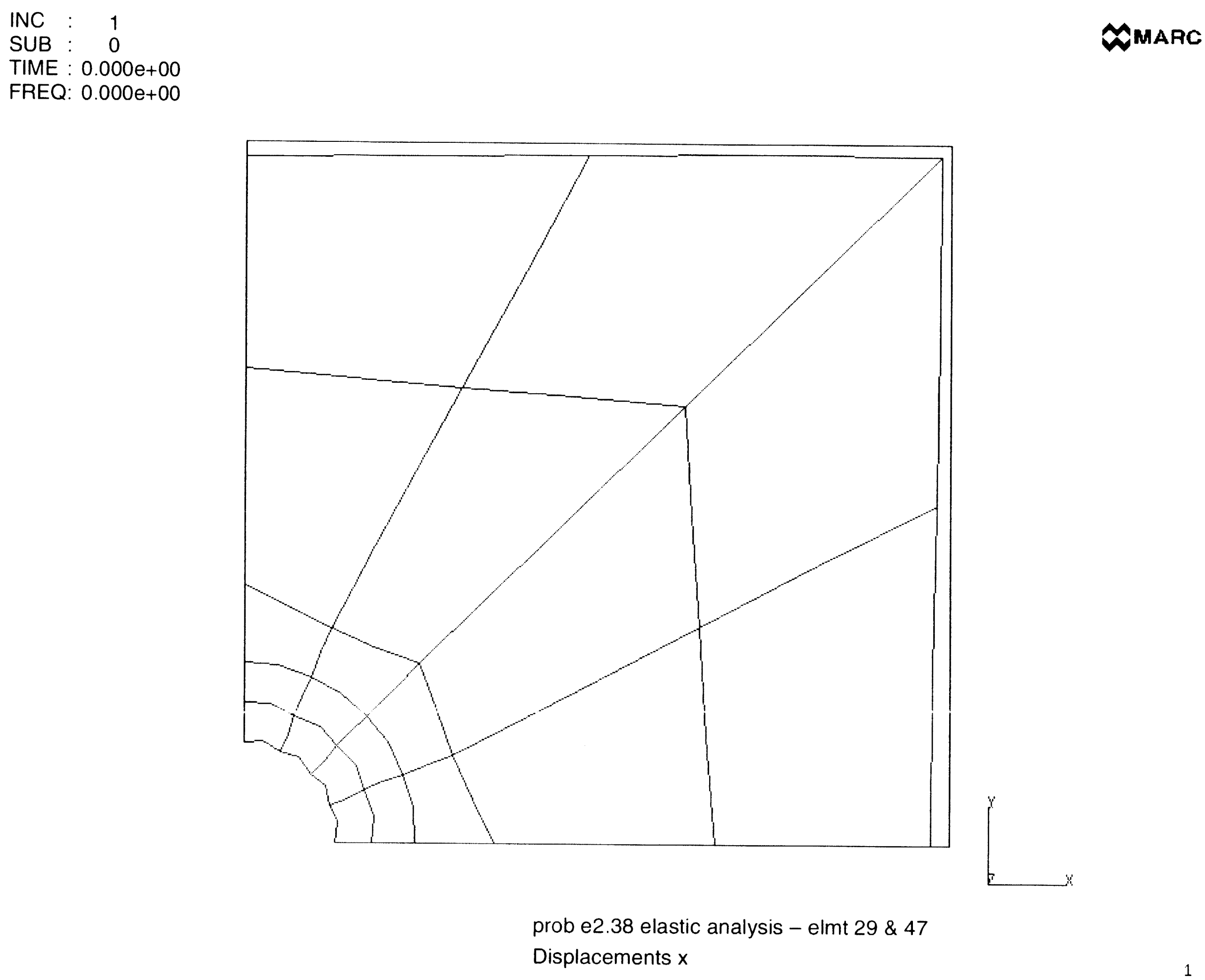


Figure 2.38-3 Deformed Mesh Plot

2.39 Cylinder with Rebars Under Internal Pressure

This problem illustrates the use of MARC elements types 28 and 48 for an elastic analysis of a hollow cylinder with rebars. The cylinder is subjected to internal pressure.

Elements

Element type 28 as a second-order distorted quadrilateral, with eight nodes. There are two degrees of freedom at each node.

Element type 48 is a hollow, 8-node quadrilateral in which you can place single strain members – in this case, reinforcing bars.

Model

The dimensions of the cylinder and the finite element mesh are shown in Figure 2.39-1. The cylinder is allowed to expand radially with no constraints; thus, there is no variation in the axial direction. The mesh is composed of 10 elements through the radius of type 28. Superimposed on this are two elements of type 48 that model the reinforcements. There are 53 nodes in the structure.

Material Properties

For Element Type 28: The Young's modulus is 30×10^5 psi and the Poisson's ratio is 0.2.

For Element Type 48: The Young's modulus is 30×10^6 and the Poisson's ratio is 0.3.

Boundary Conditions

The degrees of freedom in the z-direction ($v = 0$) are constrained at both ends ($z = 0$ and $z = 1.0$), which represents a plane-strain condition.

Loading

An internal pressure of magnitude = 500 psi acts on element 1. It is implemented by giving a DIST LOAD type = 0 (1-5-2 face)

Rebar

The number of rebar layers = 2 (1 for each element, see Figure 2.39-2). The rebar direction is in the hoop direction and the user subroutine REBAR is used for the input of rebar data.

Results

A deformed mesh plot is shown in Figure 2.39-3 and hoop stress distribution are depicted in Figure 2.39-4.

Parameters, Options, and Subroutines Summary

Example e2x39.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POST

User subroutine in u2x39.f:

REBAR

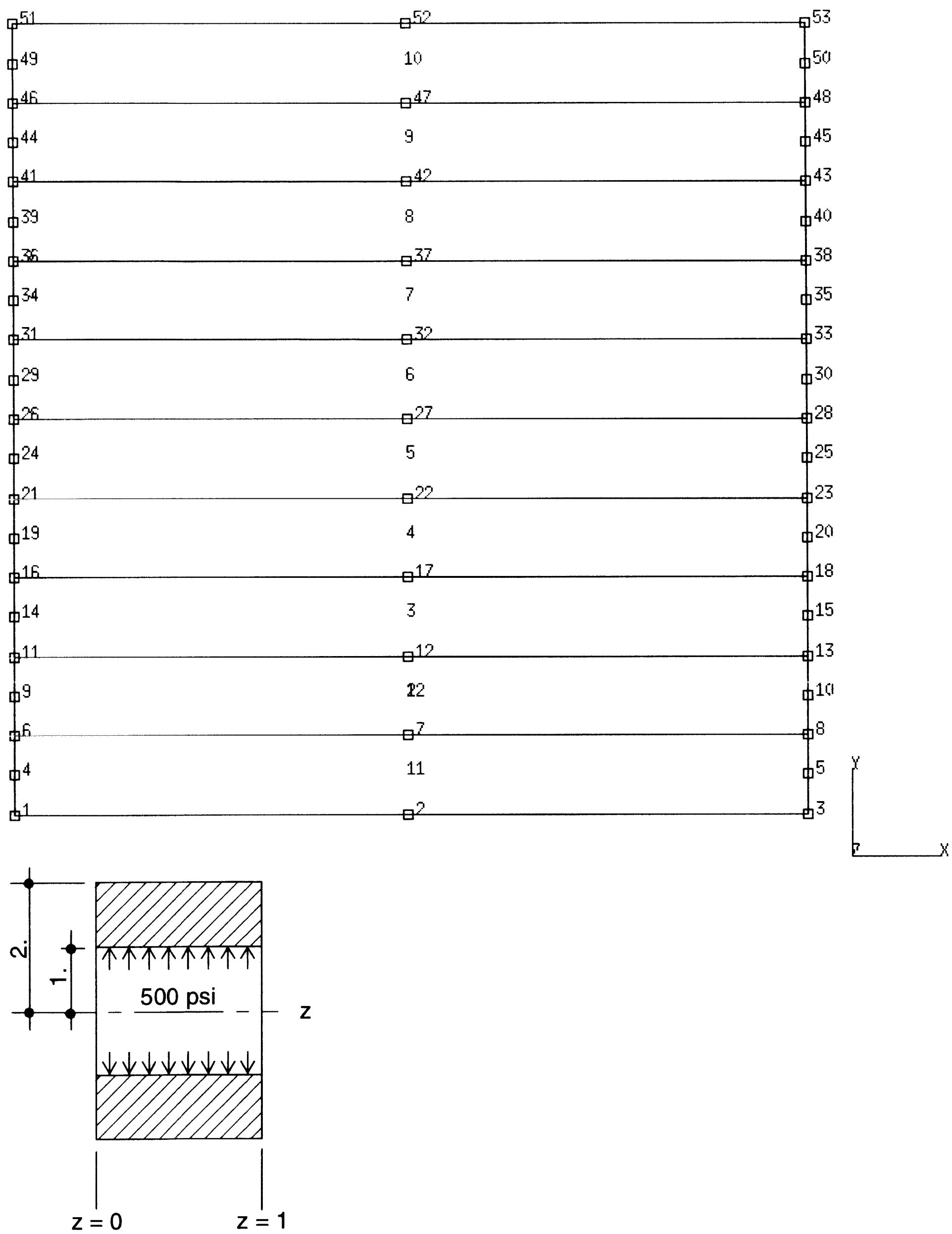


Figure 2.39-1 Cylinder and Mesh

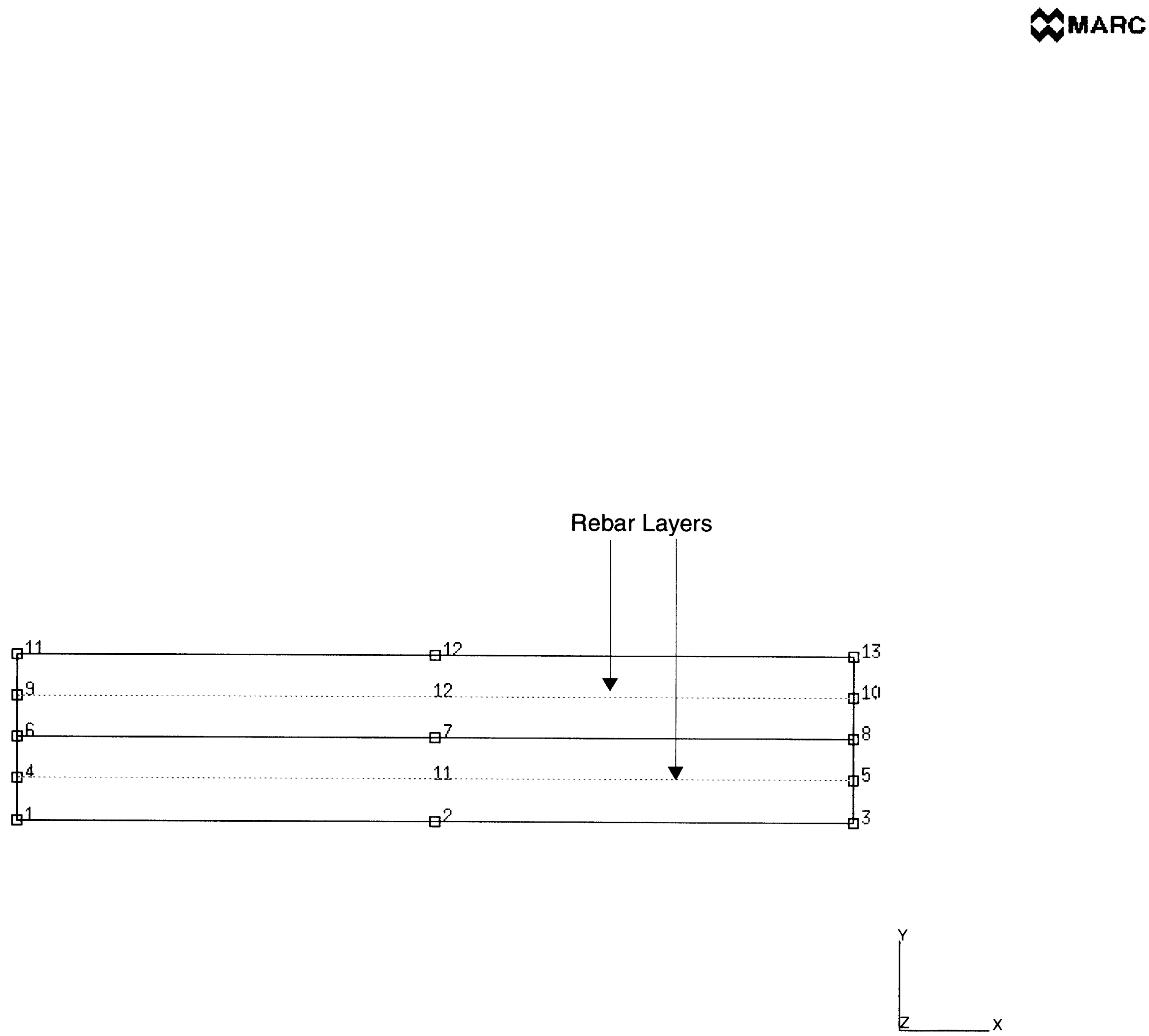


Figure 2.39-2 Rebar Layers and Elements

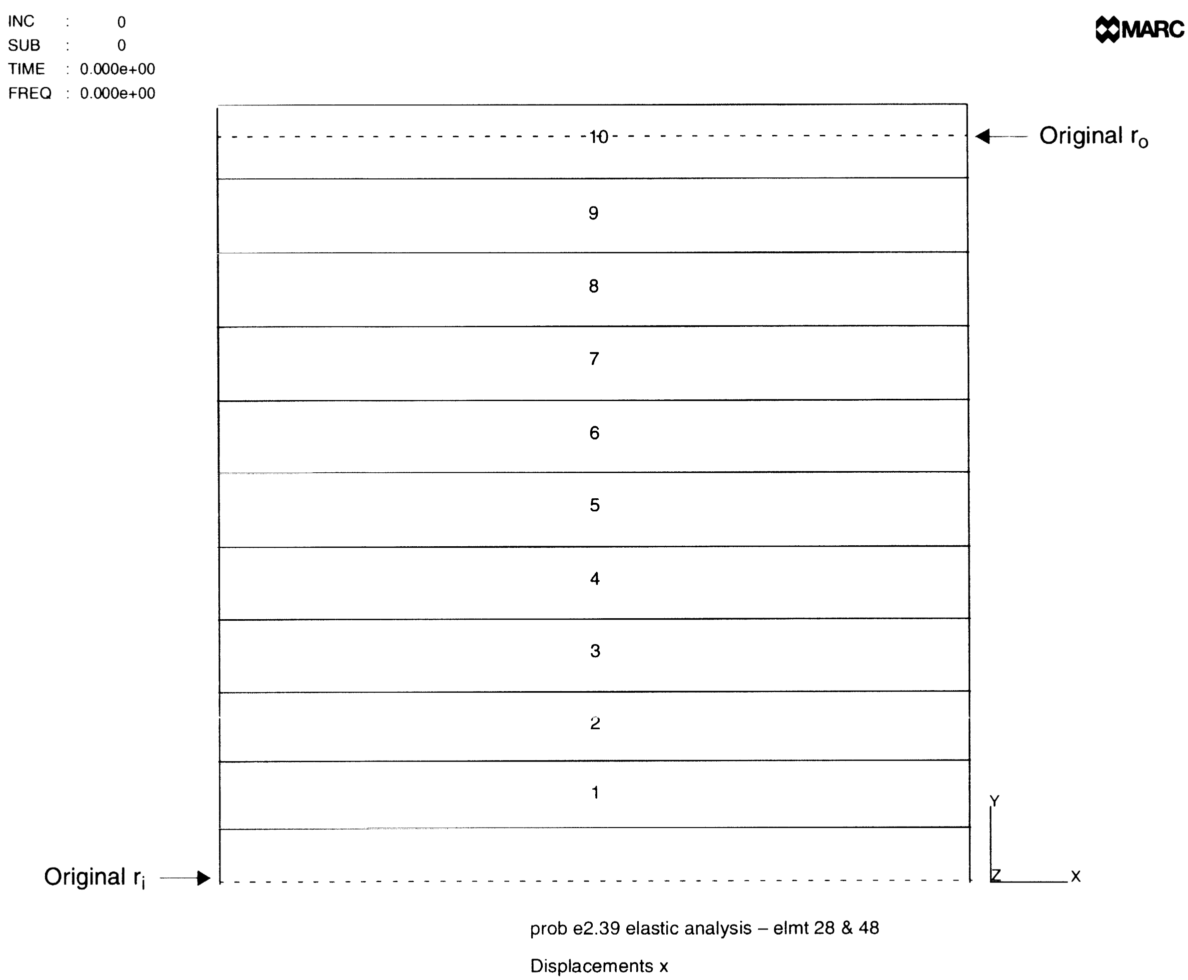


Figure 2.39-3 Deformed Mesh Plot

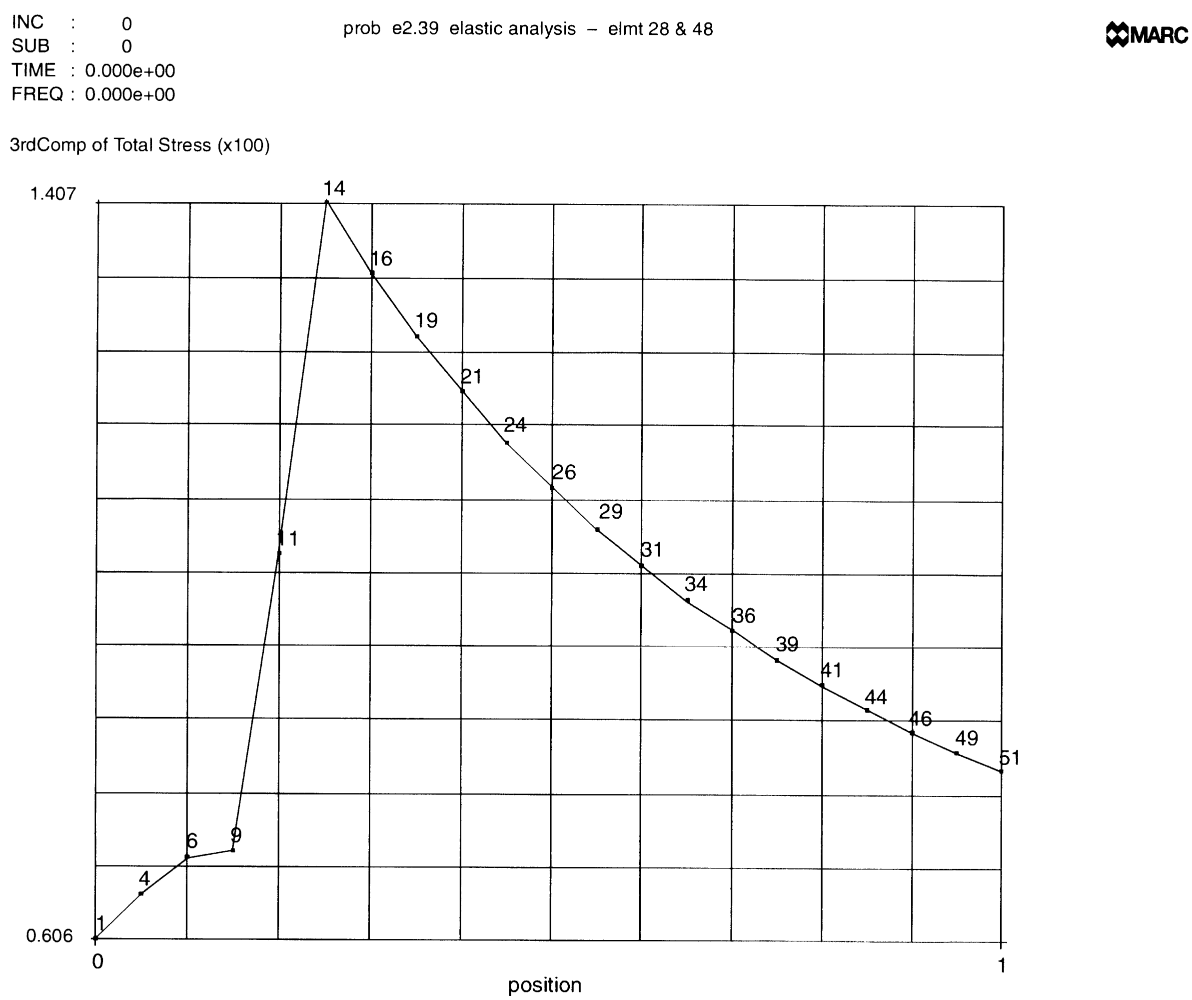


Figure 2.39-4 Hoop Stress Distribution Through Radius

2.40 Simply Supported Square Plate of Variable Thickness

This problem illustrates the use of MARC element type 49 for an elastic analysis of a simply supported square plate. The plate is subjected to uniformly distributed pressure. The analysis is performed first with a constant plate thickness and then with a linearly varying thickness. This varying thickness is entered by means of user subroutine USHELL. The SHELL SECT parameter is used for the reduction of the number of integration points through the thickness.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x40a	49	50	121	
e2x40b	49	50	121	Variable thickness

Element

Element type 49 is a nonconforming triangular shell element with arbitrary spatial orientation. There are six nodes per element, with assignable thickness at each corner node. Actually, the average thickness is used which can also be entered by means of user subroutine USHELL.

Model

The dimensions of the plate and the finite element mesh are shown in Figure 2.40-1. The plate is analyzed using 50 elements and 121 nodes. One-quarter of the plate is modelled due to symmetry considerations.

Material Properties

The elastic analysis is performed with a Young's modulus of 2×10^5 N/mm^2 and a Poisson's ratio of 0.3.

Geometry

In the first analysis (A), the plate has a constant thickness of 3.0 mm. In the second analysis (B), the plate thickness varies in both the x- and y-directions (see Figure 2.40-1). The length of the plate edges is 60 mm. Since a linear plate problem is solved, the elements can be considered as flat which is indicated by a 1 on the fifth geometry field. In this way, computational time is reduced.

Loading

A uniform pressure of 0.01 N/mm^2 in the negative z-direction is applied.

Boundary Conditions

Symmetry conditions are imposed on edges x = 30 ($u_x = 0$, $\phi = 0$ and y = 30 ($u_y = 0$, $\phi = 0$). Notice that the rotation constraints only apply for the midside nodes.

Simply supported conditions are imposed on edges x = 0 and y = 0 ($u_z = 0$).

Results

Stress contours are depicted in Figure 2.40-2 and Figure 2.40-3 for constant and varying plate thicknesses, respectively. As anticipated, the stress increases in the second analysis. The maximum stresses and deflections are:

	Constant Thickness		Varied Thickness
	MARC Solution	Analytical Solution	MARC Solution
Deflection (mm)	1.093×10^{-3}	1.065×10^{-3}	2.677×10^{-3}
Stress (N/mm^2)	1.229	1.248	2.302

The exact solution may be found in S. P. Timoshenko and S. Woinowsky-Kreiger, *Theory of Plates and Shells.*

Parameters, Options, and Subroutines Summary

Example e2x40a.dat:

Parameters

ELEMENTS
END
SHELL SECT
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DEFINE
DIST LOADS
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
POST
PRINT CHOICE

Example e2x40b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DEFINE
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POST
	PRINT CHOICE

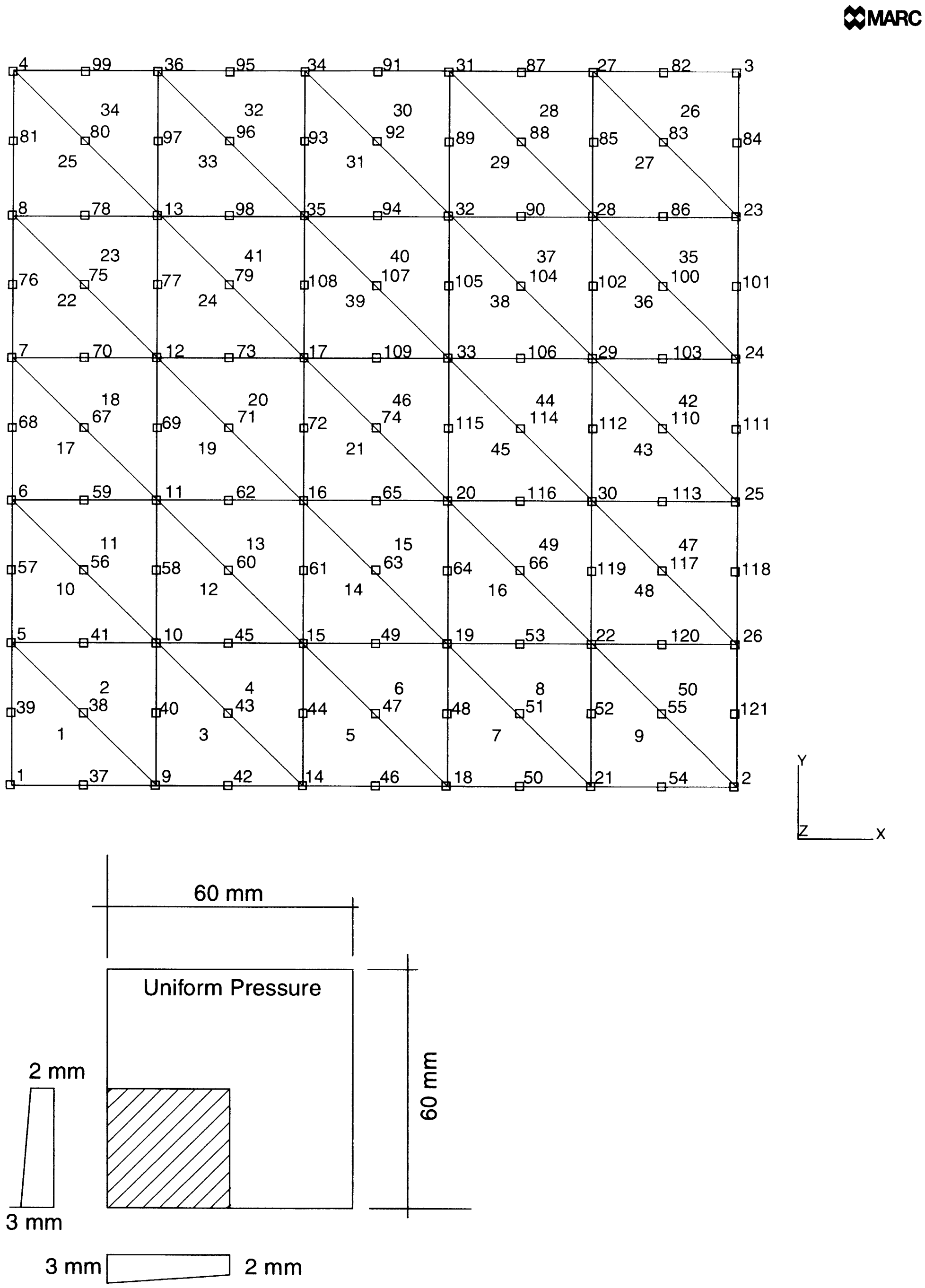


Figure 2.40-1 Square Plate and Mesh

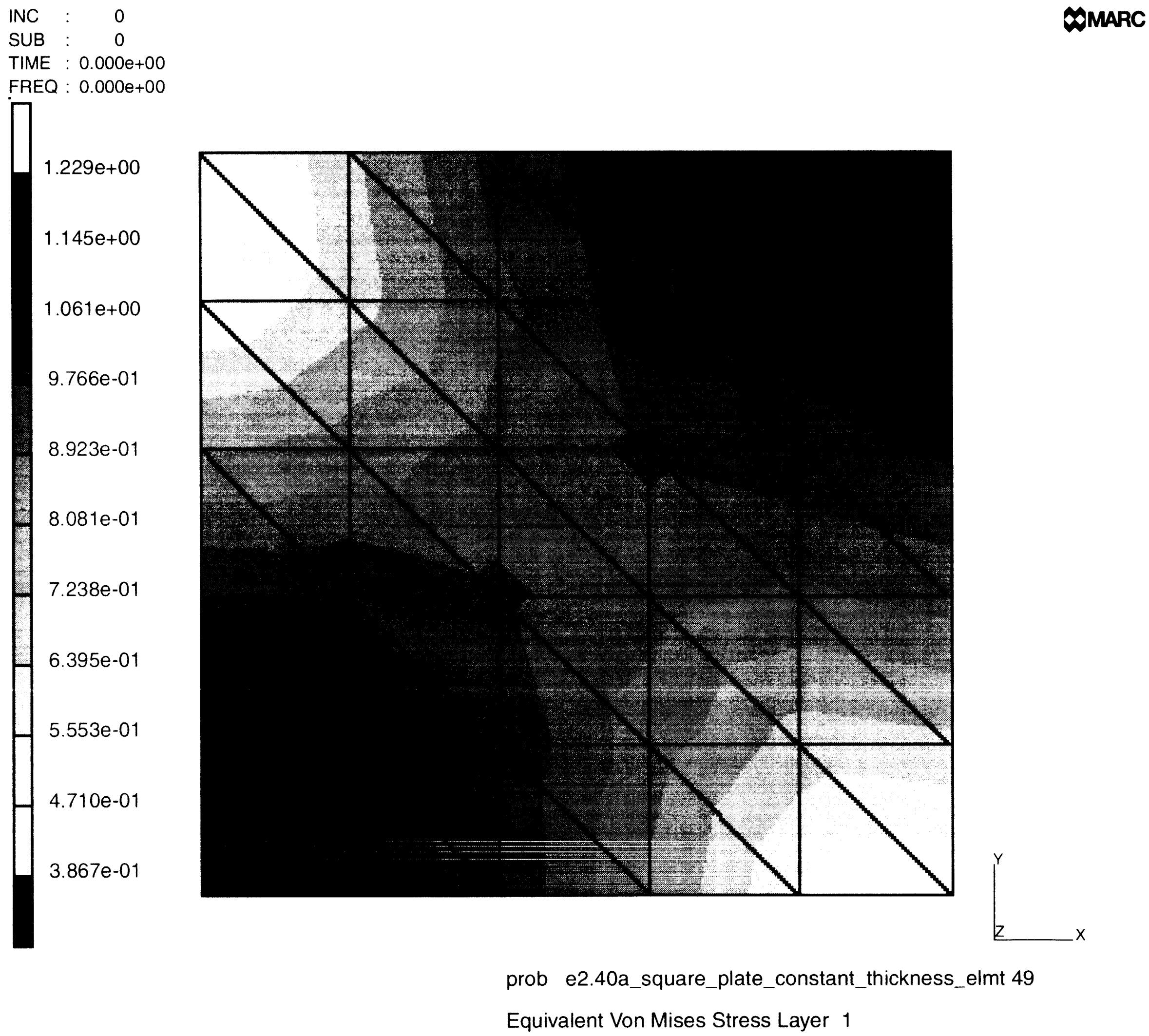


Figure 2.40-2 Stress Contours (Constant Thickness)

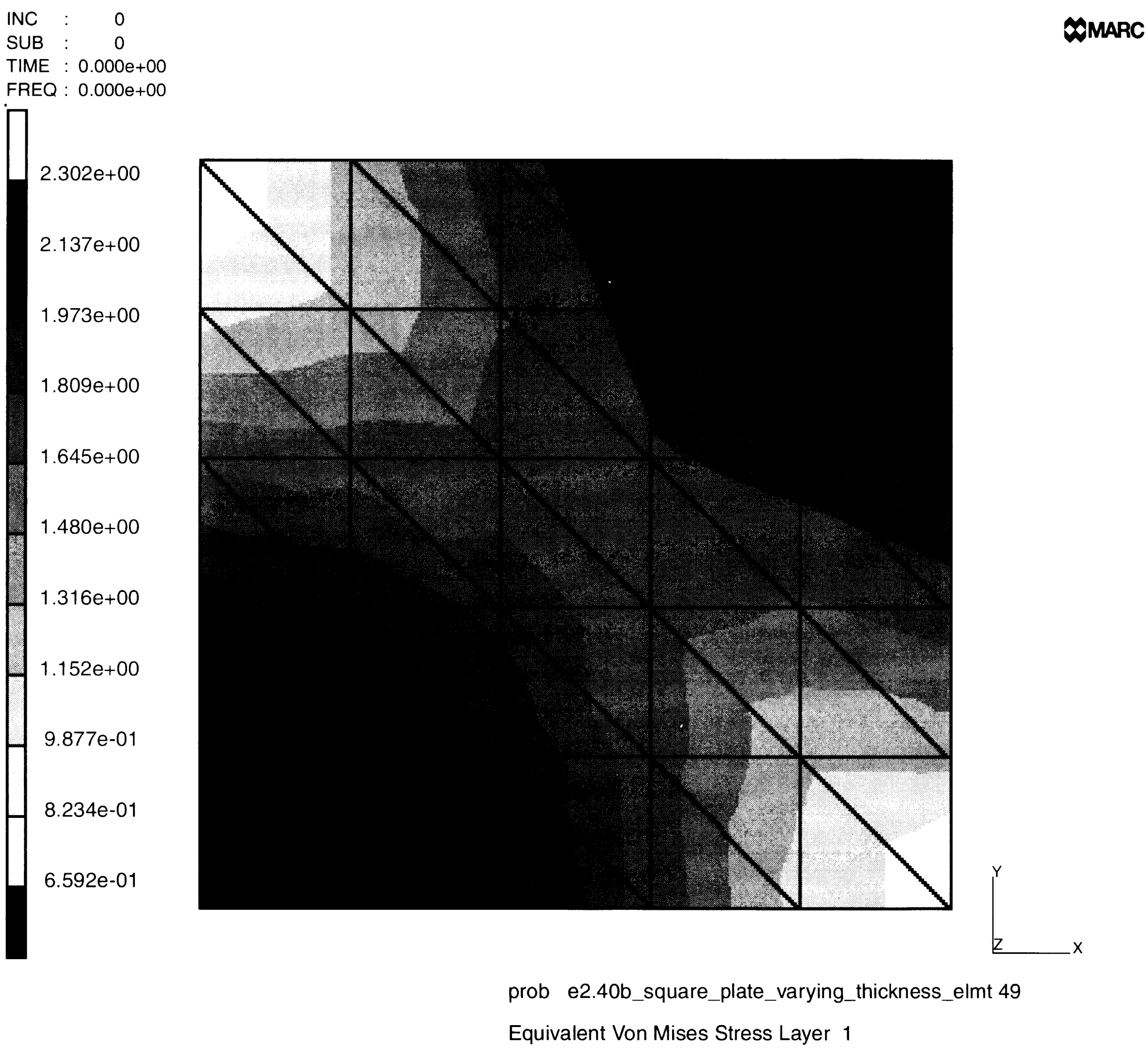


Figure 2.40-3 Stress Contours (Variable Thickness)

2.41 Thermal Stresses in a Simply Supported Triangular Plate

This problem illustrates the use of MARC element type 49 for an elastic analysis of a simply supported triangular plate subjected to nonuniform heating. The temperature variation through the thickness is entered using the INITIAL STATE and CHANGE STATE model definition options. The SHELL SECT parameter is used to reduce of the number of integration points through the thickness.

Element

Element 49 is a nonconforming triangular shell element with six nodes per element.

Model

The dimensions of the plate and the finite element mesh are shown in Figure 2.41-1. Based on symmetry considerations, only one half of the plate is modeled. The mesh is composed of 36 elements and 91 nodes.

Material Properties

The material is elastic with a Young's modulus of 2.1×10^5 N/mm^2, a Poisson's ratio of 0.3, and a coefficient of thermal expansion of 1×10^{-5}. In order to obtain layer stress components in the same direction for all elements, the ORIENTATION option is used to specify an offset of 0° with respect to the z,x-plane.

Geometry

The thickness of the equilateral triangular plate is 0.02 mm. Since a linear plate problem is solved, the elements can be considered as flat, which is indicated by a 1 on the fifth geometry field. In this way, computational time is reduced.

Loading

Initially, the temperature through the thickness is set to 10° The thermal load is applied by changing the temperature of layer 1 to 0° and of layer 3 to 20°.

Boundary Conditions

Symmetry conditions are imposed in the edge $y = 0$ ($u_y = 0$, $\phi = 0$). Notice that the rotation constraint is only applied on the midside nodes.

Simply supported conditions are imposed on the outer edges ($u_z = 0$). The remaining rigid body mode is suppressed by setting $u_x = 0$ for the node at $x = 0$, $y = 0$

Results

Stress contours of the first and second component in the preferred system for layer 1 are depicted in Figure 2.41-2 and Figure 2.41-3, respectively. The maximum stresses are:

	MARC Solution	Analytical Solution
Stress_x (N/mm^2)	24.98	26.67
Stress_y (N/mm^2)	17.85	20.00

The analytical solution can be found in *Theory of Plates and Shells* by S. P. Timoshenko and S. Woinowsky-Krieger. Since the generalized stresses per element are constant, the present finite element mesh is fairly coarse to accurately describe the stress variations.

Parameters, Options, and Subroutines Summary

Example e2x41.dat:

Parameters

ELEMENTS
END
SHELL SECT
SIZING
TITLE

Model Definition Options

CONN GENER
CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
NODE FILL
POST
TYING

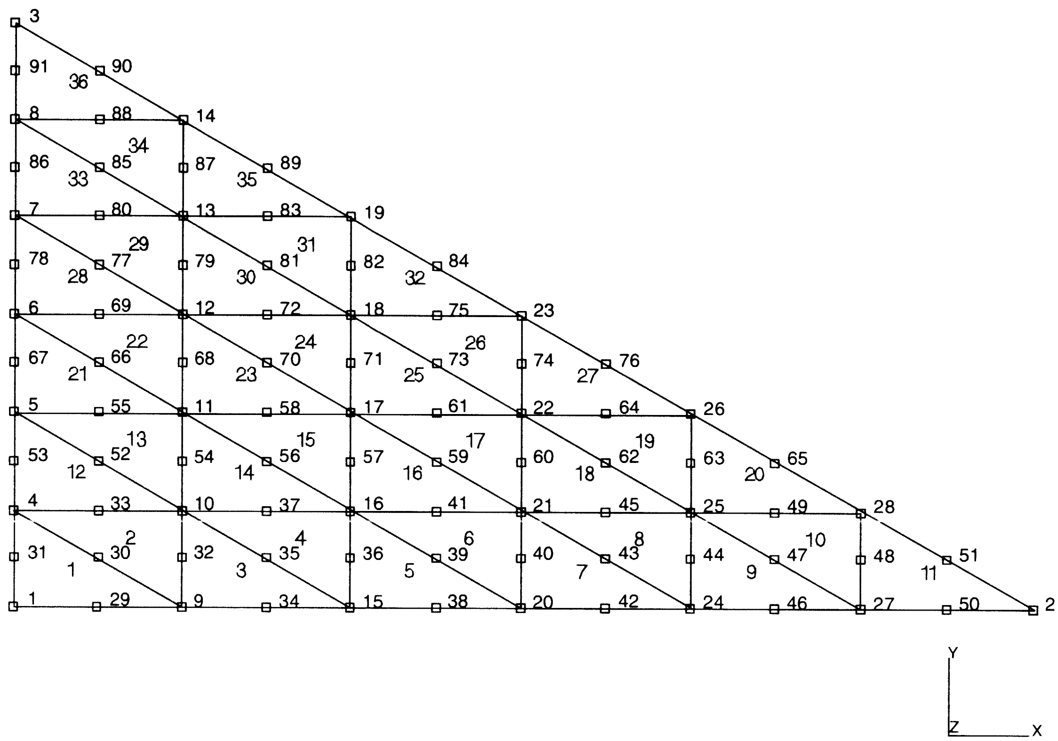


Figure 2.41-1 Triangular Plate and Finite Element Mesh

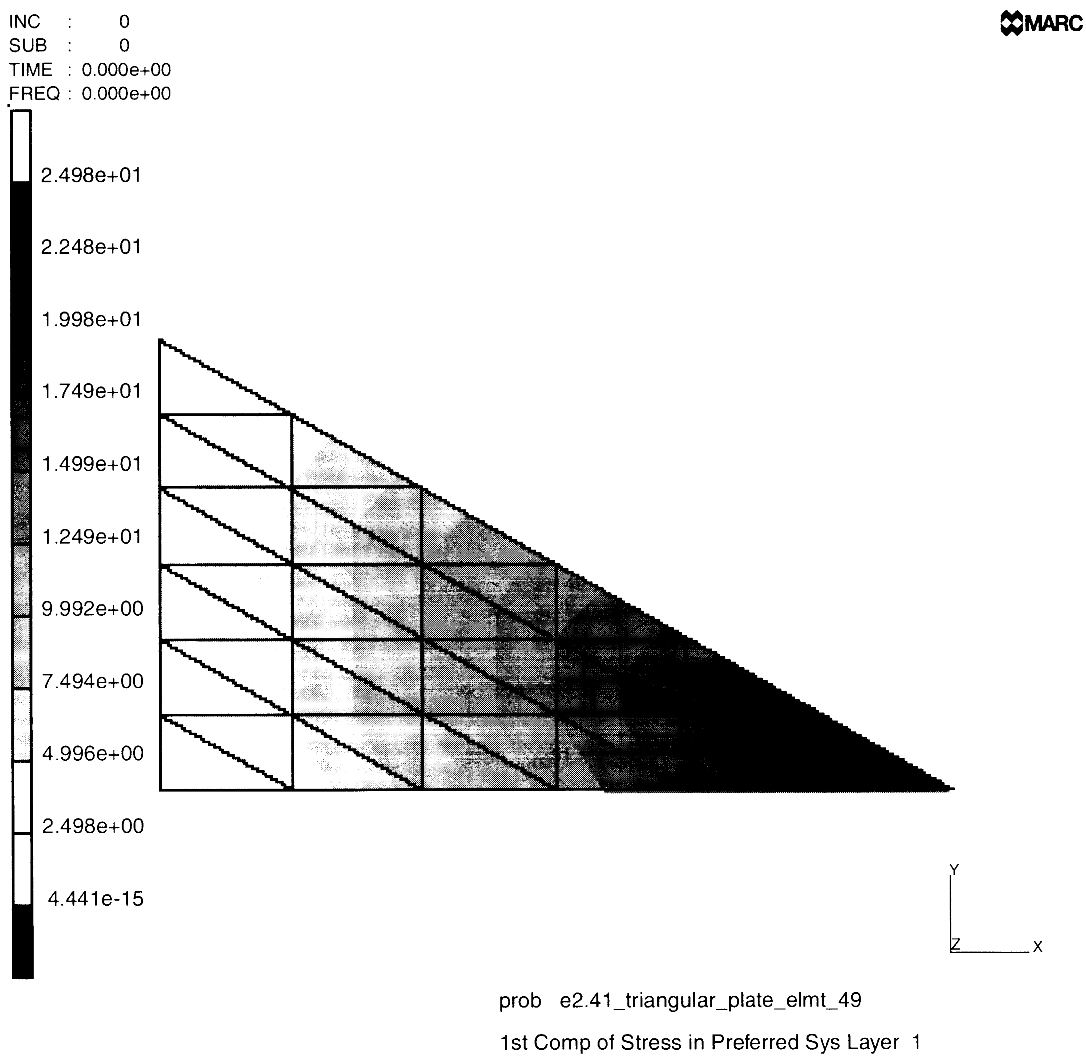


Figure 2.41-2 Stress Contours (x-component)

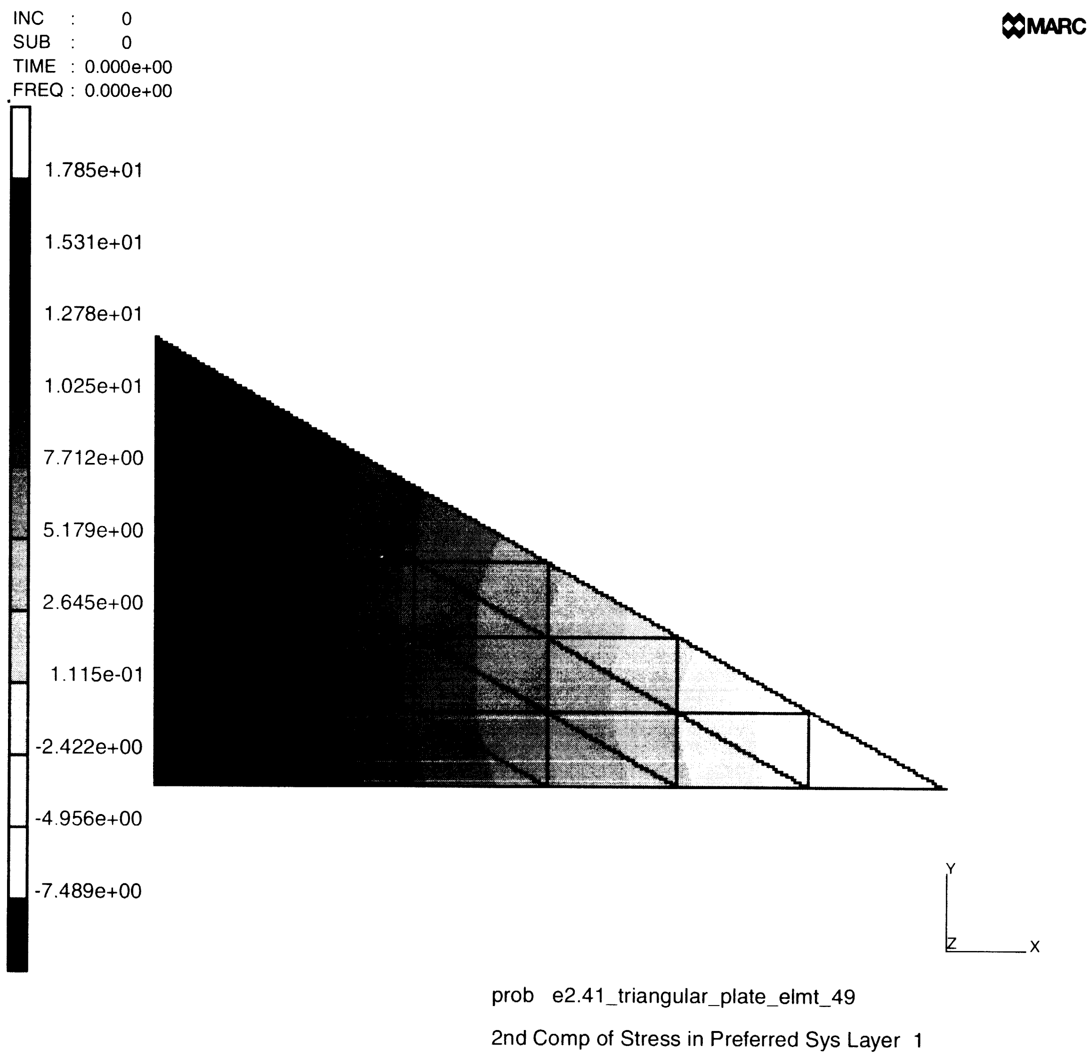


Figure 2.41-3 Stress Contours (y-component)

2.42 Square Plate on an Elastic Foundation

This problem illustrates the use of MARC element type 22 for an elastic analysis of a square plate. The plate is on an elastic foundation and subjected to a concentrated load at the center of the plate.

Element

Library element type 22, a curved quadrilateral thick-shell element, is used. The displacements are interpolated from the values at the eight nodes to the middle shell surface. The four corner nodes and four midside nodes each have six degrees of freedom, three displacements and three rotations.

Model

The dimensions of the plate and the finite element mesh are shown in Figure 2.42-1. Sixteen type 22 elements are used for this mesh. There are 65 nodes. Only one-quarter of the plate is modeled due to symmetry.

Material Properties

The material is elastic with a Young's modulus of 2.E5 psi and Poisson's ratio of 0.0.

Loading

A point load of 10.0 lb. (1/4 P) in the negative z-direction is applied at the center (node 1) of the plate.

Boundary Conditions

Displacements at the lines of symmetry are constrained, along x = 0, u = 0, $\theta_y = \theta_z = 0$, and along y = 0, v = 0, $\theta_x = \theta_z = 0$.

SHELL SECT

This option allows you to reduce the number of integration points from default value to a minimum value of three, in the plate thickness direction, for an elastic analysis.

Elastic Foundation

The whole plate is assumed to rest on an elastic foundation. The description of the elastic foundation is given in the model definition option FOUNDATION:

Element numbers = 1 through 16
Spring stiffness per unit area of the plate = 10.0 lb/in^2
Element face I.D. = 2

Results

Stress contours are shown in Figure 2.42-2. The PRINT CHOICE option is used to limit the output to element 1. The exact solution is found in Timoshenko and Woinowsky-Krieger, *Theory of Plates and Shells*.

Parameters, Options, and Subroutines Summary

Example e2x42.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	END OPTION
SIZING	FIXED DISP
TITLE	FOUNDATION
	GEOMETRY
	ISOTROPIC
	POINT LOAD
	PRINT CHOICE

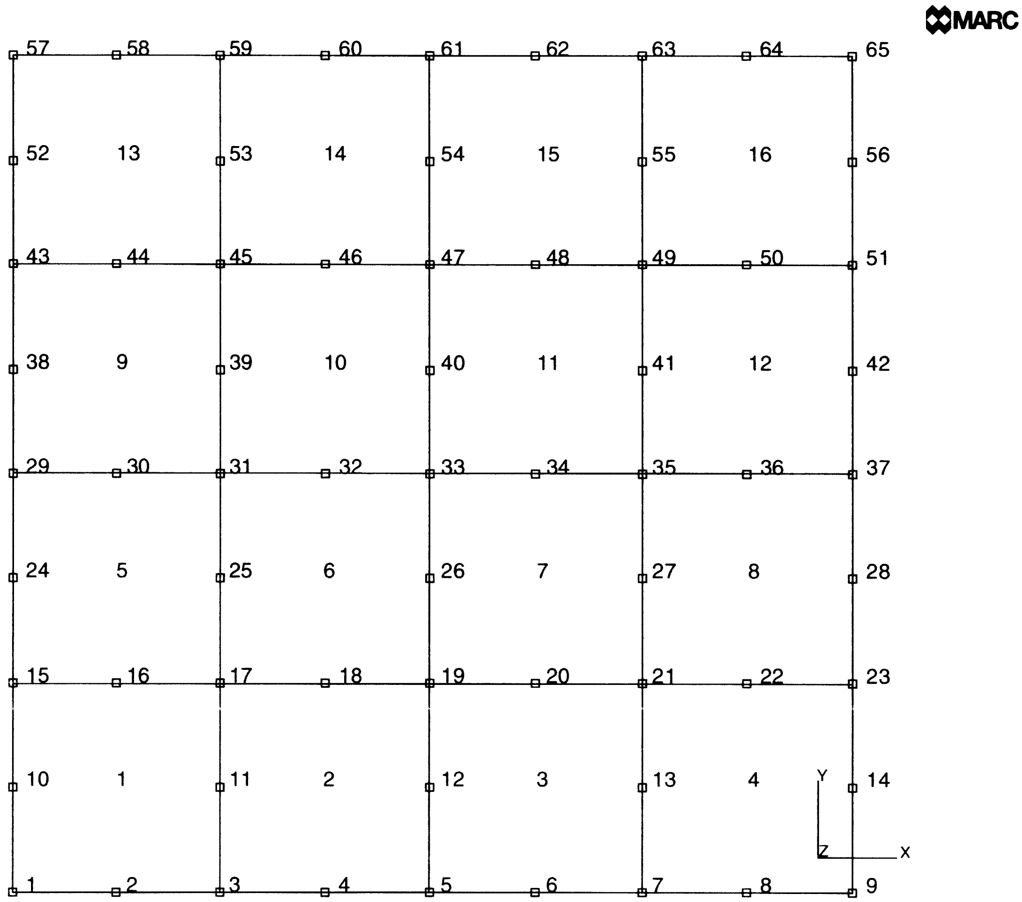


Figure 2.42-1 Square Plate and Mesh

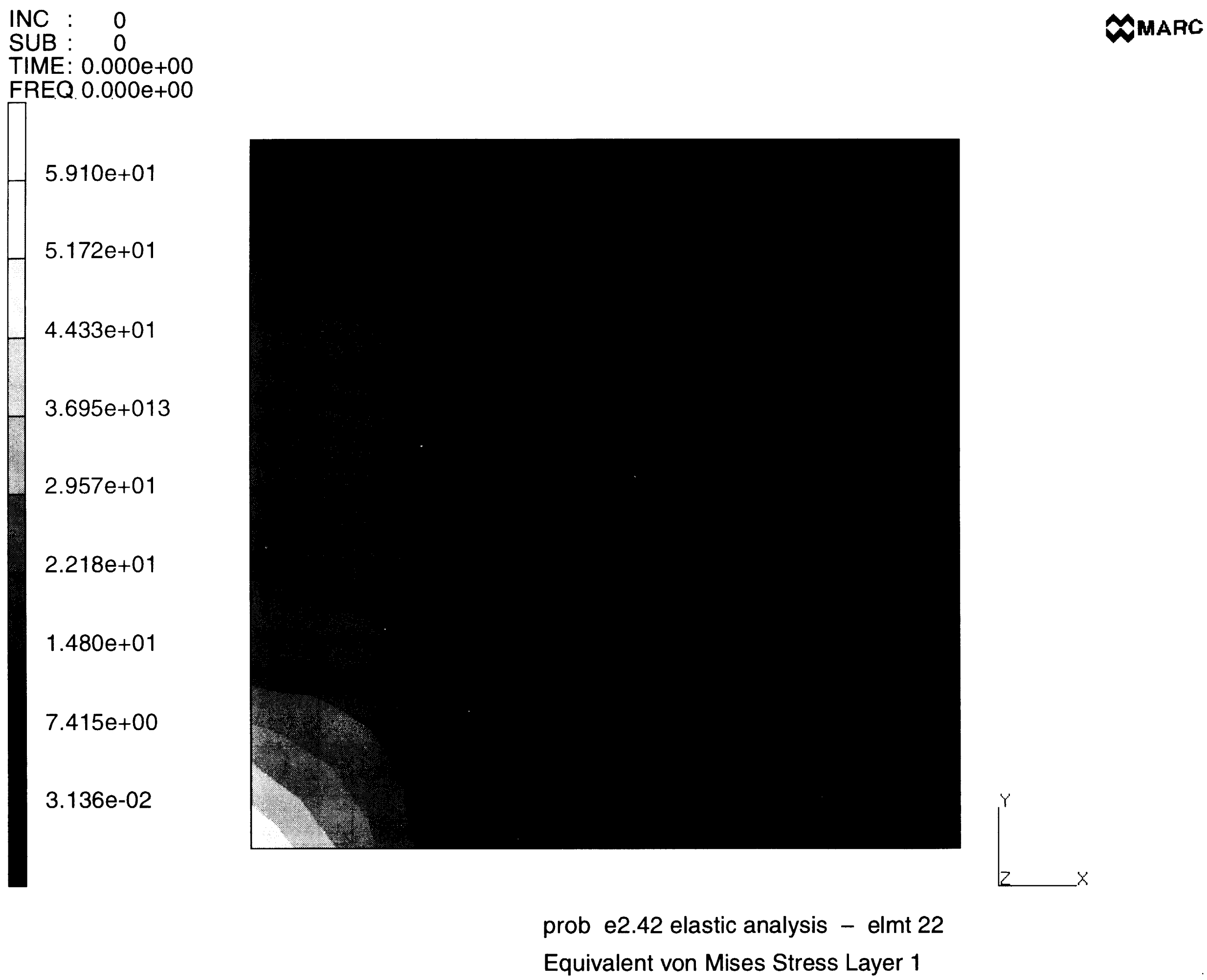


Figure 2.42-2 Equivalent Stress Contours (Layer 1)

2.43 Cantilever Beam Subjected to Concentrated Tip Moment

This problem illustrates the use of MARC element types 53 and 64 for an elastic analysis of a cantilever beam. The beam is subjected to a concentrated moment applied at the tip of the beam. The use of user subroutines UFORMS and FORCEM is also demonstrated. Subroutine UFORMS is used for the input of nodal degrees of freedom constraint relations, between truss and plane stress elements. Subroutine FORCEM allows the input of the end moment through a set of nonuniform distributed forces applied at the free end face of the beam.

Model

The dimensions of the beam and a finite element mesh are shown in Figure 2.43-1. The total number of elements is 30, with 95 nodes.

Elements

Element type 53 is a second-order, two-dimensional element with eight nodes. Each node has two degrees of freedom.

Element type 64 is an isoparametric 3-node truss. Each node has three degrees of freedom.

Material Properties

For Element 53:	The Young's modulus is 2×10^5 psi and Poisson's ratio is 0.0.
For Element 64:	The Young's modulus is 0.04 psi and Poisson's ratio is 0.0.

Loading

A linearly varying distributed load on nodes 21 to 53 simulates a moment applied to the beam. Nonuniform distributed forces are applied at the free end face of the beam (element 10). Subroutine FORCEM is used for the input of force magnitude.

The magnitude of the moment is equal to 0.0833333 in-lb, represented by a linearly varying distributed load with a maximum load intensity of 1.25 lb/square inch at nodes 21 and 53, respectively.

Boundary Conditions

A fixed-end condition is assumed to exist at x = 0. All degrees of freedom at nodes 1, 22 and 33 are constrained.

Geometry

Thickness of the plane stress element is 0.1 in. Area of the truss element is 1.0 inch.

Constraints

The nodal points of all the truss elements are constrained to have the same movements of that of the plane stress elements. Consequently, the total number of constraints is 42. The retained nodes are 1 through 21 and 33 through 53. The tied nodes are 54 through 74 and 75 through 95. This was entered using the list feature for defining the nodes. In order to illustrate the use of user subroutine UFORMS, the tying type is defined as -1.

In addition, options CONN GENER and NODE FILL are also used for the generation of a finite element mesh.

Results

The deflection at the tip of the beam is 1.251 x 10^{-3} in. ($\delta = Ml^2/2EI$, $I = 0.1 \times 2^3/12$) and the MARC result is 1.25136 x 10^{-3} in. The addition of the limp truss elements allows computation of the strains at the outer and innermost fibers.

Parameters, Options, and Subroutines Summary

Example e2x43.dat:

Parameters	Model Definition Options
ELEMENTS	CONN GENER
END	CONNECTIVITY
SIZING	COORDINATES
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NODE FILL
	PRINT CHOICE
	TYING

User subroutines in u2x43.f:

FORCEM
UFORMS

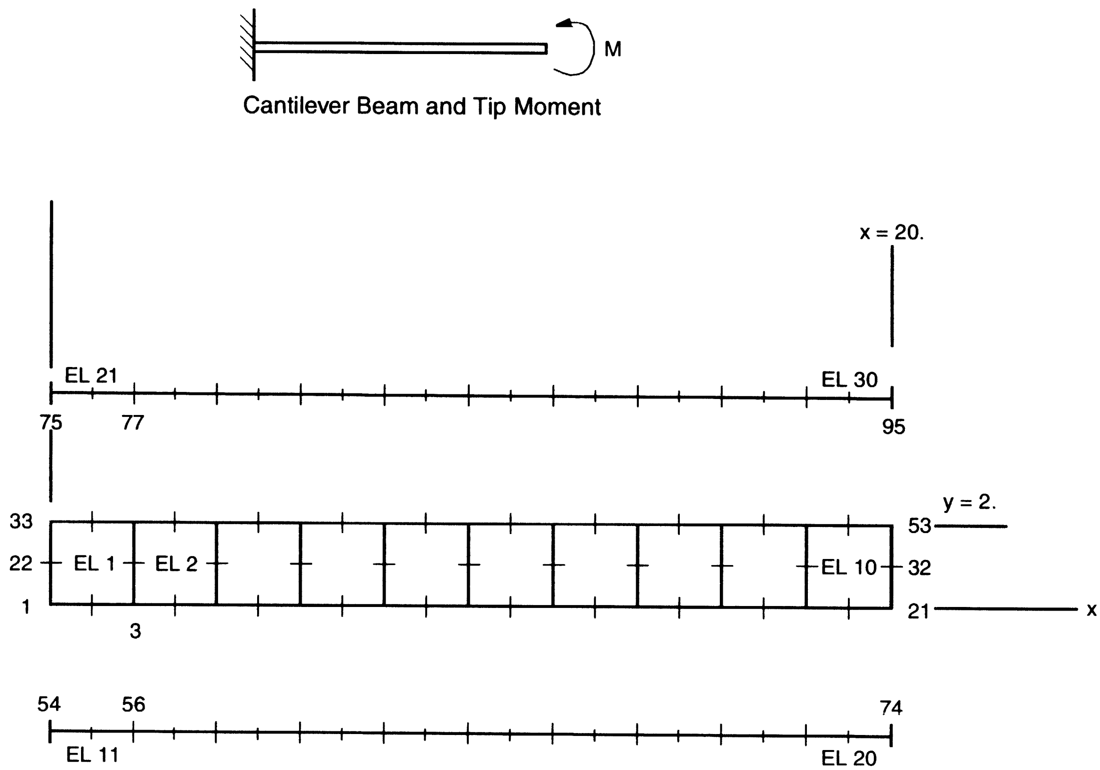


Figure 2.43-1 Cantilever Beam and Mesh

2.44 Local Load on Half-Space

This problem illustrates the use of MARC elements type 54 for an elastic analysis of a half-space subjected to a locally distributed load. The standard tying constraint option is selected for a compatible refinement of the mesh.

Element

Element type 54 is a distorted quadrilateral for plane strain. There are eight nodes and two degrees of freedom per node.

Model

The finite element mesh is shown in Figure 2.44-1. This mesh has been generated such that a more refined mesh would be near the distributed load. A total of 33 elements and 128 nodes are used in the analysis.

Material Properties

The material is elastic with a Young's modulus of 5×10^5 psi and Poisson's ratio of 0.2.

Geometry

The thickness of the model is assumed to be 1.0 inch.

Loading

A uniform pressure (w) of 150 psi is applied for a horizontal distance of 10 inches along the top surface.

Boundary Conditions

Symmetry conditions are imposed at x = 30.0, u = 0. Lines x = 0, y = 0, are assumed to be far away from the load; therefore, u = 0, v = 0.

Tying Constraint

Standard tying type 32 is used for locations where the mesh has been refined. This is necessary to ensure compatibility. A mesh plot was obtained before the tying relations could be formulated.

Results

A deformed mesh plot is shown in Figure 2.44-2. The von Mises stress intensity contours are shown in Figure 2.44-3. Mesh refinement is appropriate for a region with localized loading.

Displacement (inches)		Stress (psi)	
MARC Computed	Analytically Computed	MARC Computed	Analytically Computed
6.080×10^{-3}	5.724×10^{-3}	102.1	98.38

Reference

Timoshenko, S. P., and Goodier, J. N., *Theory of Elasticity*, McGraw-Hill, 1956, New York.

Parameters, Options, and Subroutines Summary

Example e2x44.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
TYING

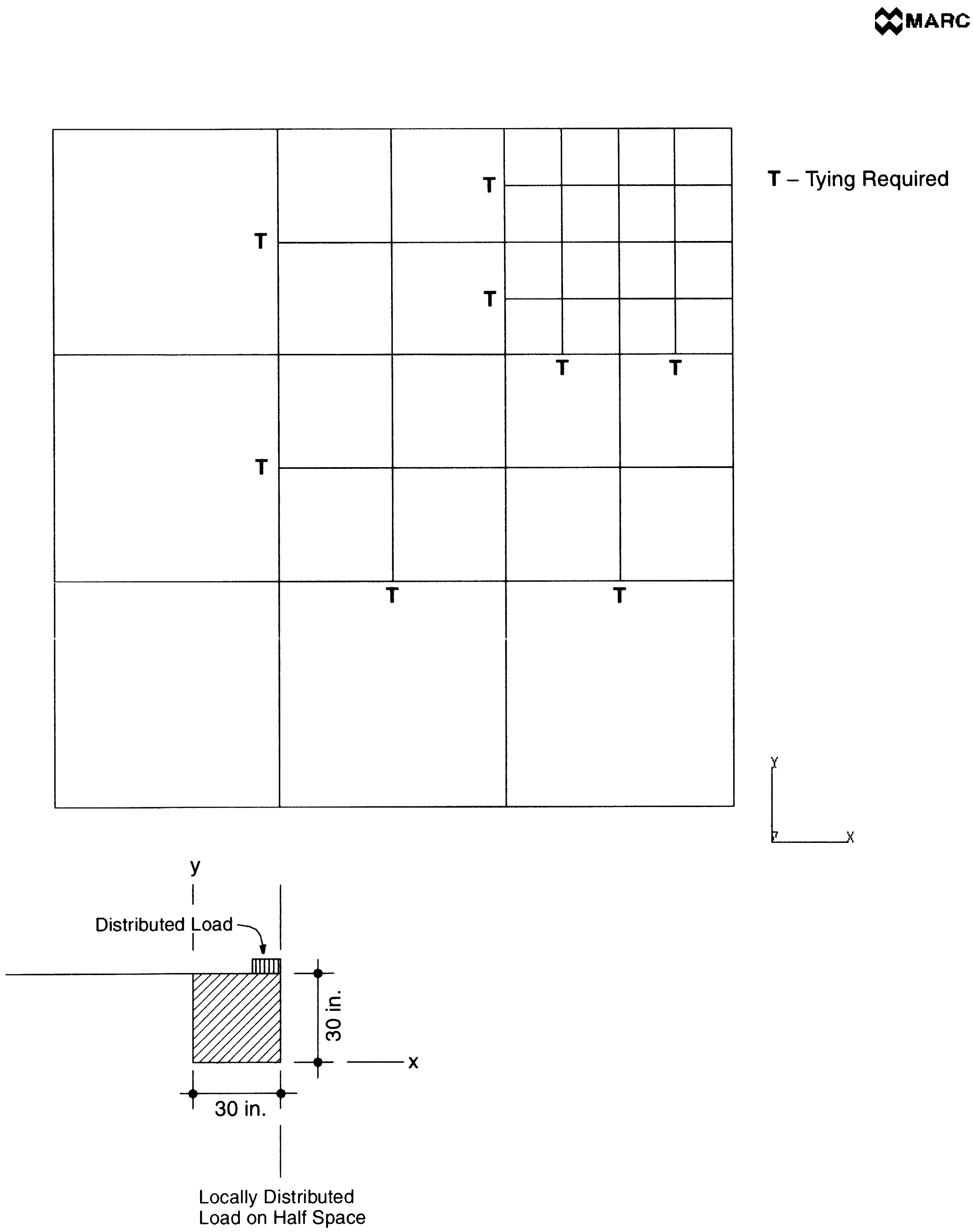


Figure 2.44-1 Half Space and Mesh

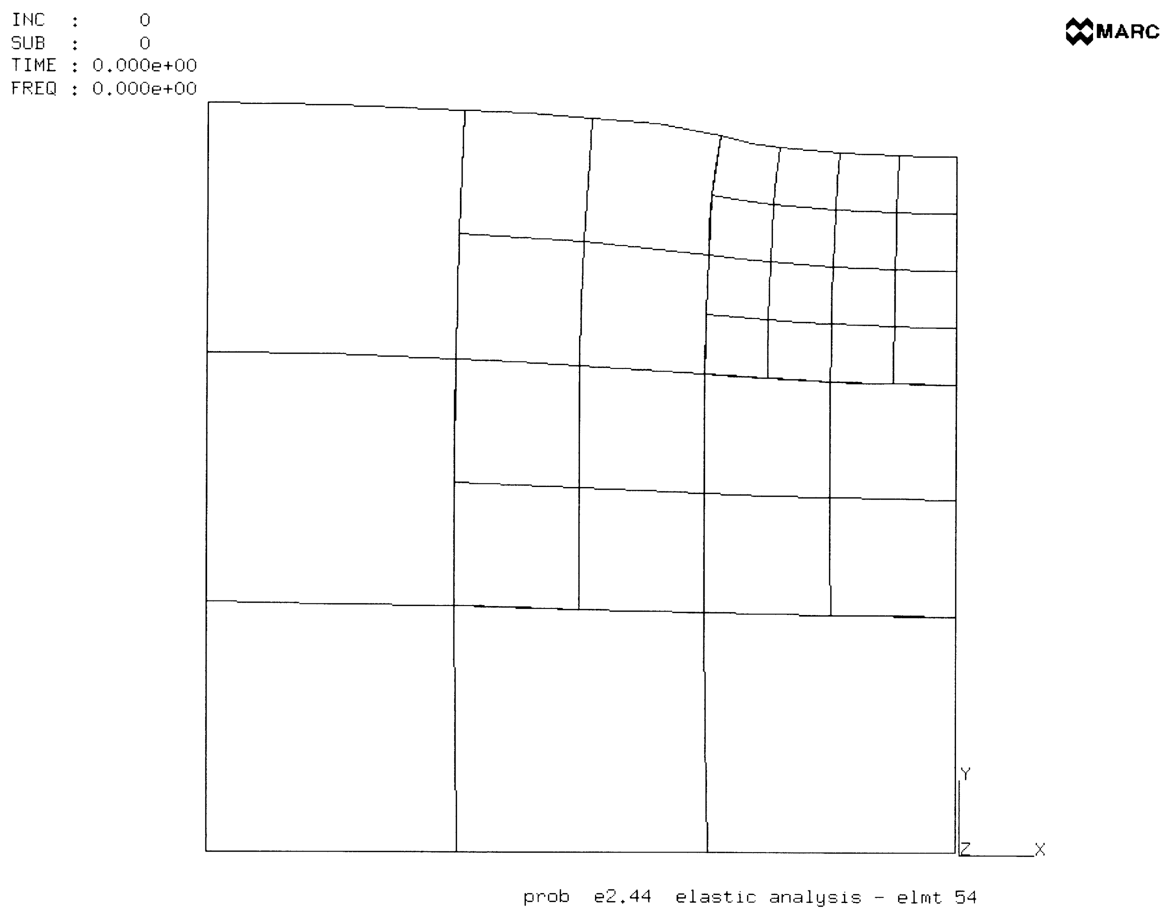


Figure 2.44-2 Deformed Mesh Plot

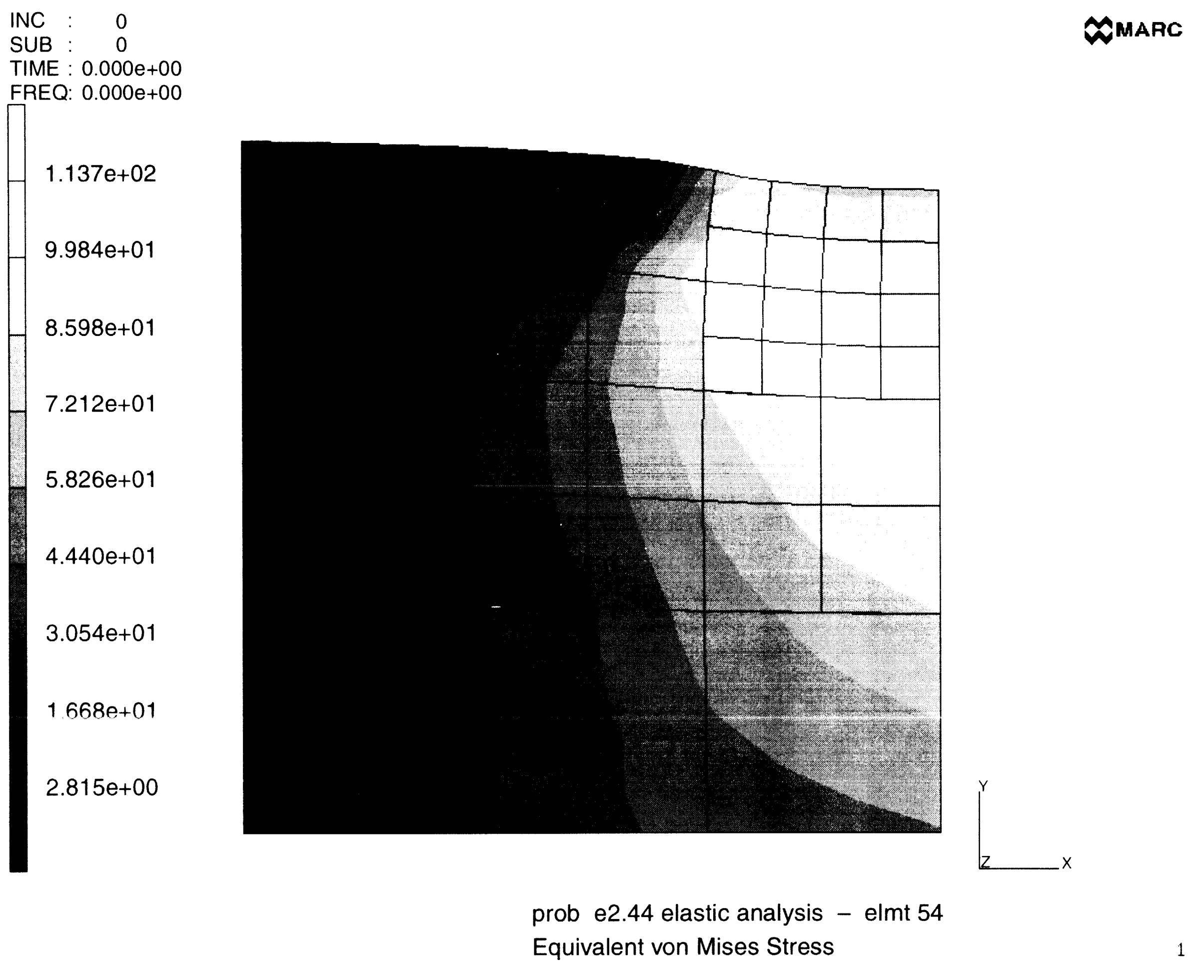


Figure 2.44-3 von Mises Stress Contours

2.45 Notched Circular Bar with Anisotropy, J-Integral Evaluation

This problem illustrates the use of MARC element type 55 and the J-INT option for an elastic analysis of an anisotropic notched bar. The bar is subjected to a distributed axial load. The MARC J-integral calculation is a measure of the strength of the subplasticity of the elastic stress field near the crack tip. The material is orthotropic with a 10 times higher modulus in the axial direction than in the other directions. The use of the ELSTO and ALIAS parameters is also illustrated.

Element

Element type 55 is an 8-node axisymmetric reduced integration element, with two degrees of freedom at each node.

Model

The element type is 55. There are 32 elements and a total of 107 nodes. The so-called "quarter-point node" technique is used for the elements adjacent to the crack tip. This involves redefinition of the coordinates of the midside nodes on the edges adjacent to the crack tip with use of a second COORDINATES block.

The dimensions of the bar and the finite element mesh are shown in Figure 2.45-1 (a and b).

Material Properties

The following properties are specified in this option: Young's modulus of 30×10^6, and Poisson's ratio of 0.3 These properties are subsequently modified with the user subroutine ANELAS.

Geometry

Not required for axisymmetric elements.

Boundary Conditions

The following symmetry conditions are applied:

v = 0 at r = 0 (axis of symmetry)
u = 0 at uncracked portion ligament on the line z = 0

Loading

A distributed tensile pressure of 100 psi is applied to the boundary line of elements 15, 16, 31 and 32.

J-INTEGRAL

In this analysis, the J-integral is evaluated for three different element rings.

J-Integral Evaluations	Number of Nodes Moved in List Number		Nodal Movements of List Number in r-Direction	
	1	2	1	2
1	1	9	-0.01	-0.0075
2	27	9	-0.01	-0.0050
3	53	9	-0.01	-0.0050

Node numbers are shown in the J-INTEGRAL Model Definition block. The midside nodes surrounding the moved part of the mesh move one-half of the distance, whereas the quarter-point nodes move three-fourths of the distance.

User Subroutine ANELAS

It is assumed that the material has "stratified" anisotropy. With the first direction the "stiff" direction, the constitutive equation has the form:

$$D = \alpha \begin{bmatrix} 1-\nu_2^2 & n\nu_1(1+\nu_2) & n\nu_1(1+\nu_2) \\ n\nu_1(1+\nu_2) & n(1-n\nu_1^2) & n(\nu_2+n\nu_1^2) \\ n\nu_1(1+\nu_2) & n(\nu_2+n\nu_1^2) & n(1-n\nu_1^2) \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ E_1/2\alpha(1+\nu_1) \end{bmatrix}$$

with $n = E_2/E_1$ and $\alpha = E_1/(1+\nu_2)(1-\nu_2-2n\nu_1^2)$, where $n \le 1$.

For material stress in the x-direction (1), this equation yields:

$$\sigma_x = E_1\varepsilon_x,\ \varepsilon_y = \varepsilon_z = -\nu_1\varepsilon_x$$

For uniaxial stress in the y-direction (2), one finds:

$$\sigma_y = E_2\varepsilon_y,\ \varepsilon_x = -n\nu_1\varepsilon_y,\ \varepsilon_z = -\nu_2\varepsilon_y,$$

and similar relations are found for uniaxial stress in the z-direction (3).

In the current problem the following values are selected:

$$E_1 = 30 \bullet 10^6, E_2 = 30 \bullet 10^5, \nu_1 = \nu_2 = 0.3$$

For isotropic materials, $E_1 = E_2 = E$ and $\nu_1 = \nu_2 = \nu$ and the above constitutive equation degenerates to the usual isotropic equation. In the subroutine ANELAS, the ratio between anisotropic and isotropic components needs to be specified.

Since the preferred directions of the anisotropic material are the same as that of the global coordinate system, the default subroutine ORIENT is used for this problem.

Results

The strain energy differences ΔW calculated by the MARC program are 0.01987, 0.01979 and 0.01975. In order to obtain the J-integral from ΔW, you have to divide ΔW by the crack length and the nodal movement distance, and multiply the results by 2 to take into account that only half of the bar is modeled:

$$J = 2\Delta W / 2\pi r \Delta l$$

In the current problem, $r = 10$ and $\Delta l = .01$, which yields the following values of J:

J(1) = 0.06325 (lbs/in)
J(2) = 0.06299
J(3) = 0.06287

A deformed mesh plot is shown in Figure 2.45-2, and stress contours are depicted in Figure 2.45-3.

Parameters, Options, and Subroutines Summary

Example e2x45.dat:

Parameters	Model Definition Options
ALIAS	CONNECTIVITY
ELEMENTS	COORDINATES
ELSTO	DIST LOADS
END	END OPTION
J-INT	FIXED DISP
SIZING	ISOTROPIC
TITLE	J-INTEGRAL
	OPTIMIZE

User subroutine in u2x45.f:

ANELAS

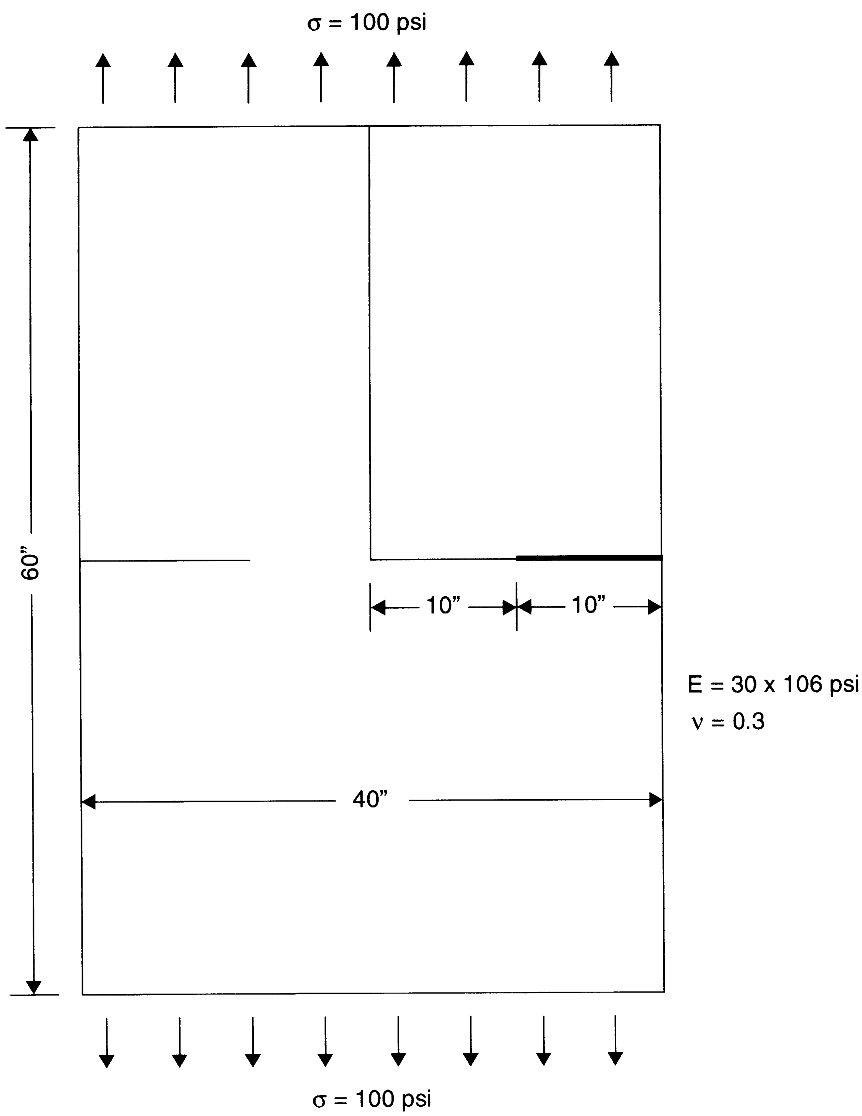


Figure 2.45-1 (a) Notched Circular Bar and Mesh

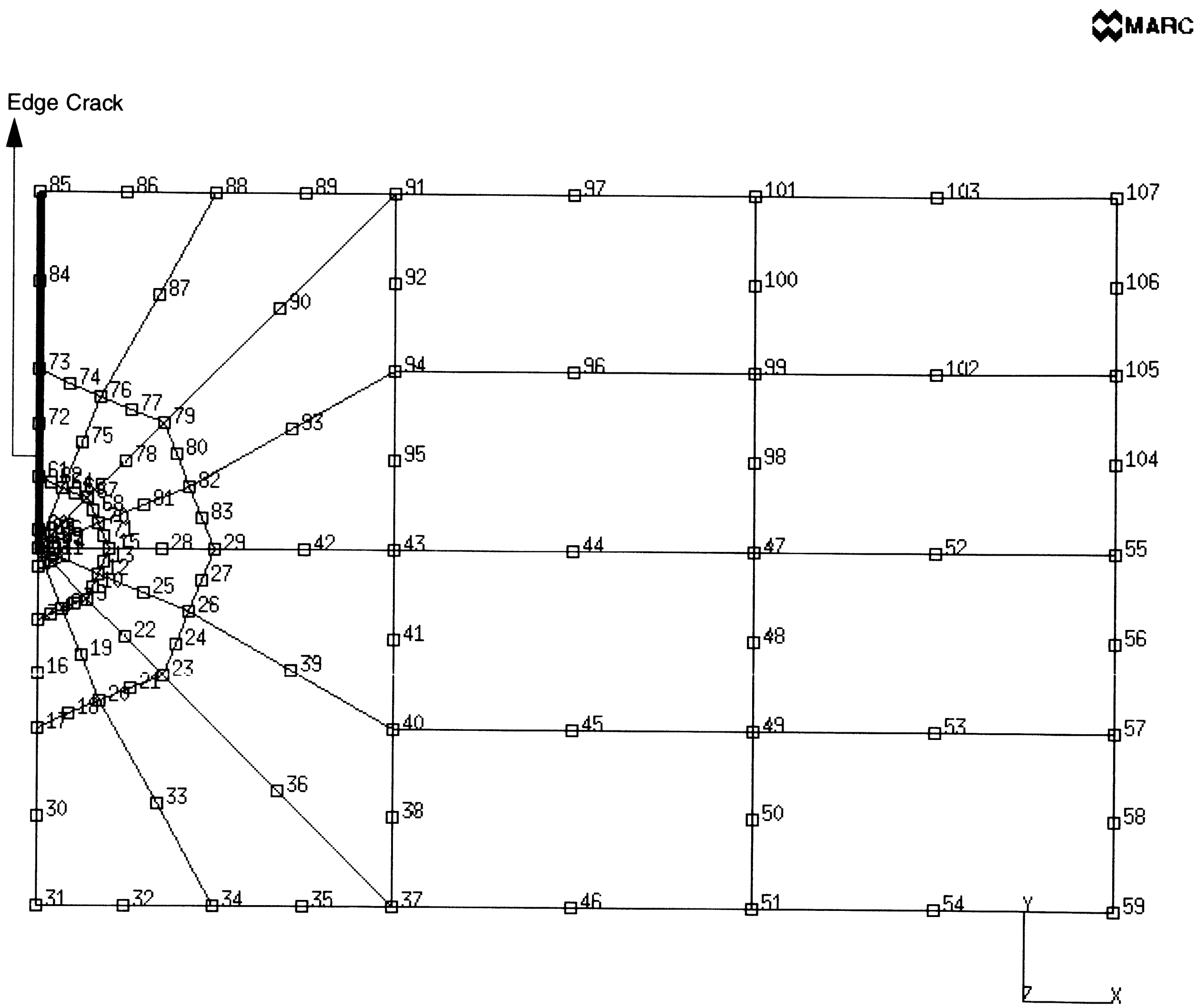


Figure 2.45-1 (b) Detail of Notched Circular Bar and Mesh

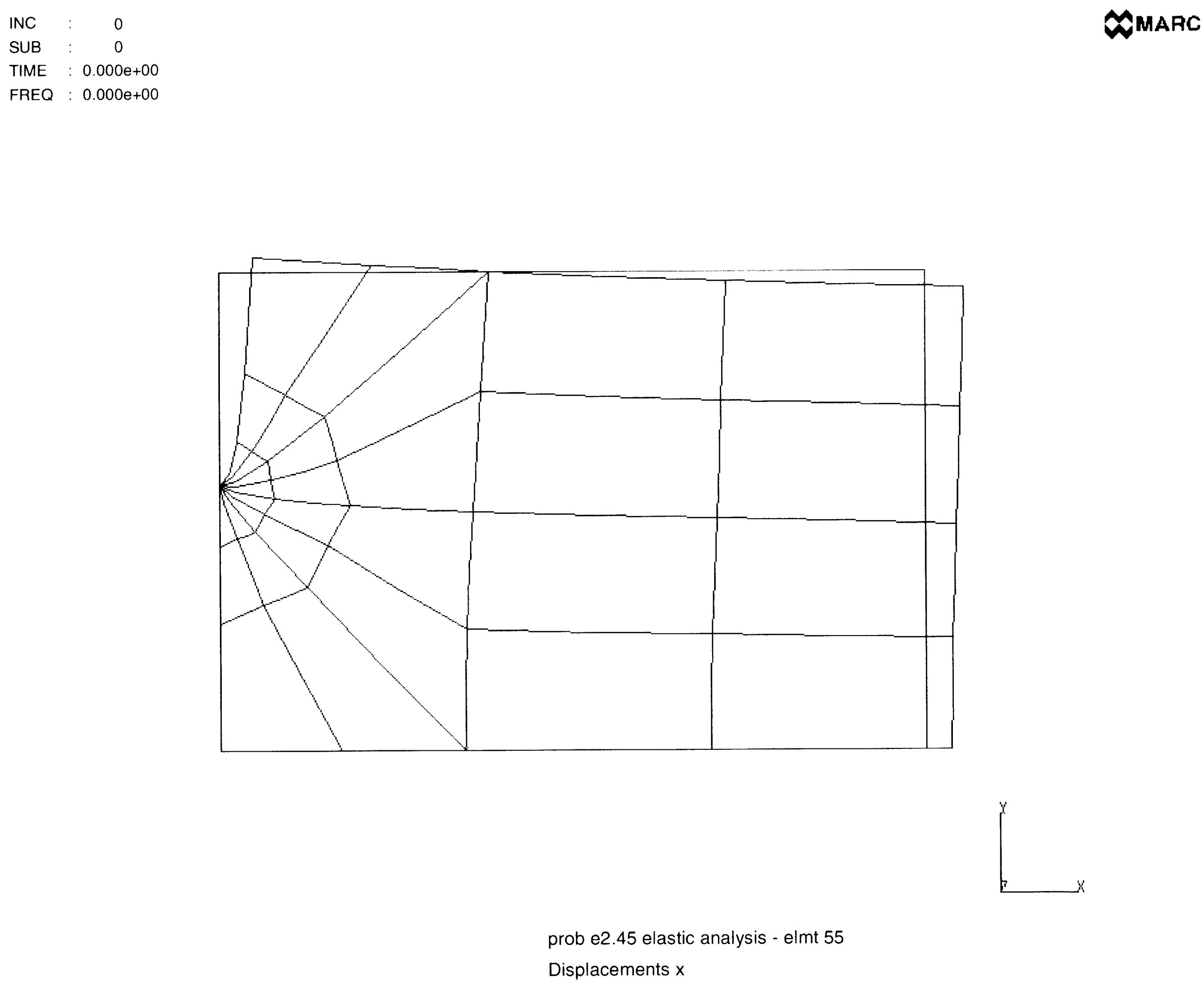


Figure 2.45-2 Deformed Mesh Plot

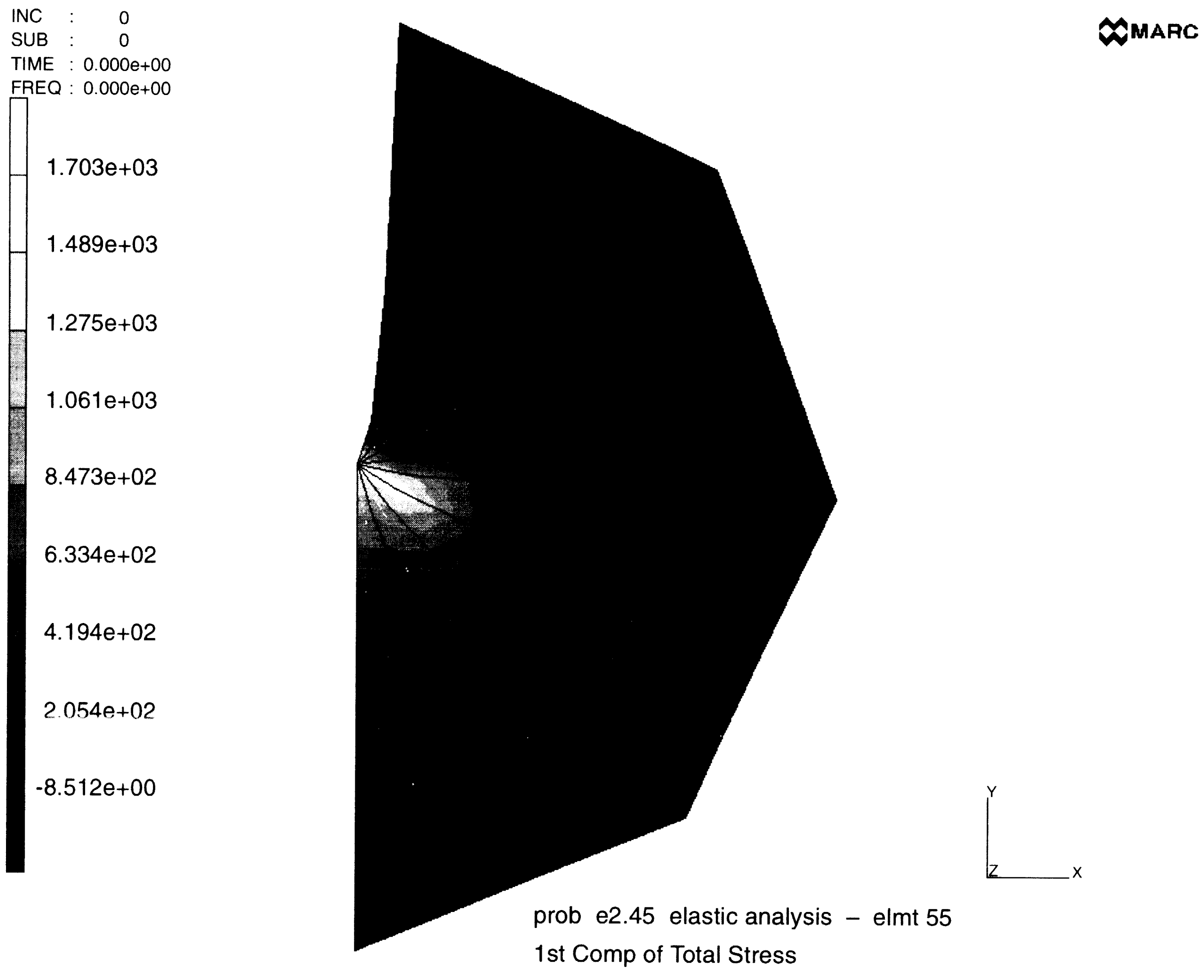


Figure 2.45-3 Stress Contours for σ_{11}

2.46 Square Plate with Central Hole, Thermal Stresses

This problem illustrates the use of MARC element types 19, 29, and 56 for an elastic analysis of a square plate with a central hole. The hole is subjected to a linearly varying thermal load in the radial direction. User subroutine CREDE is also demonstrated.

This problem is modeled using the four techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x46a	56	20	79	Uses CREDE
e2x46b	29	20	79	Uses FORCEM
e2x46c	29	20	79	Uses FORCEM
e2x46d	19	80	99	

Elements

Element 19 is a 4-node, generalized plane-strain element. Element 29 is an 8-node, generalized plane-strain element, with two degrees of freedom at each node. Element type 56 has the same functionality as element 29 but uses reduced integration.

Model

The analysis is first performed using element types 29 and 56. There are 20 elements with a total of 81 nodes. The dimensions of the plate and the finite element mesh are shown in Figure 2.46-1. In the last model, element type 19 is used with a mesh consisting of 80 elements and 101 nodes. This mesh is shown in Figure 2.46-2.

Material Properties

The Young's modulus is 30×10^5 psi, with Poisson's ratio of 0.3. The coefficient of thermal expansion is 12.4×10^{-7} in/in/°F. The plate is stress-free at a temperature of 0°F.

Geometry

The thickness of the plate is 1.0 inch.

Boundary Conditions

The following boundary conditions are applied along the symmetry lines:

$u = 0$ at $x = 0$
$v = 0$ at $y = 0$

At the shared node 81, rotations about both x- and y-axes are constrained:

$\theta_x = \theta_y = 0$

Thermal Load

The thermal load is caused by a linearly varying temperature in the radial direction. The temperatures are interpolated/extrapolated with:

T = 20°F at r = 1.0 inches
T = 100°F at r = 5.0 inches

User subroutine CREDE is used for the input of thermal load at each integration point of each element. In problems e2x46c and e2x46d, the temperatures are input via user subroutine FORCEM. This procedure has some advantages when using adaptive time stepping procedures because forcem.f is called within the iteration loop and CREDE is not. Temperatures at integration points as interpolated from the given linear distribution are specified with a data statement.

In problem e2x46d, the thermal loads are prescribed by specifying the temperature at the nodal points using the INITIAL TEMPERATURE and POINT TEMPERATURE options.

Optimization

The Cuthill-McKee technique is used to minimize the bandwidth.

Results

A deformed mesh plot is shown in Figure 2.46-3 and stress contours are depicted in Figure 2.46-4. The thermal strains created are shown in Figure 2.46-5.

Parameters, Options, and Subroutines Summary

Example e2x46a.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
THERMAL	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	THERMAL LOADS
	UFCONN

User subroutine in u2x46a.f:

CREDE

Example e2x46b.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
THERMAL	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	THERMAL LOADS
	UFCONN

User subroutines in u2x46b.f:

CREDE
UFCONN

Example e2x46c.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC

User subroutine in u2x46c.f:

FORCEM

Example e2x46d.dat:

Parameters

ELEMENTS
END
PROCESS
SETNAME
SIZING

Model Definition Options

CONNECTIVITY
COORDINATES
DEFINE
END OPTION
FIXED DISP
GEOMETRY
INITIAL TEMP
ISOTROPIC
OPTIMIZE
POINT TEMP
POST
PRINT ELEM
PRINT NODE
SOLVER

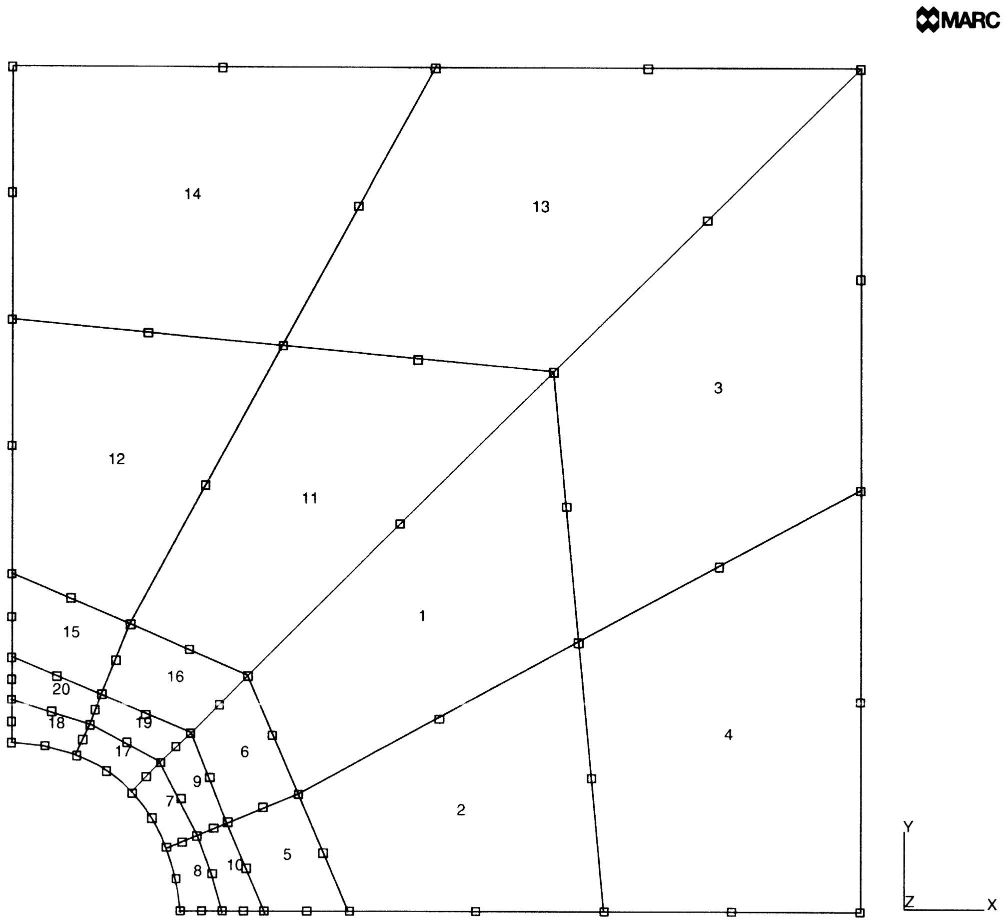


Figure 2.46-1 Square Plate with Central Hole and Mesh

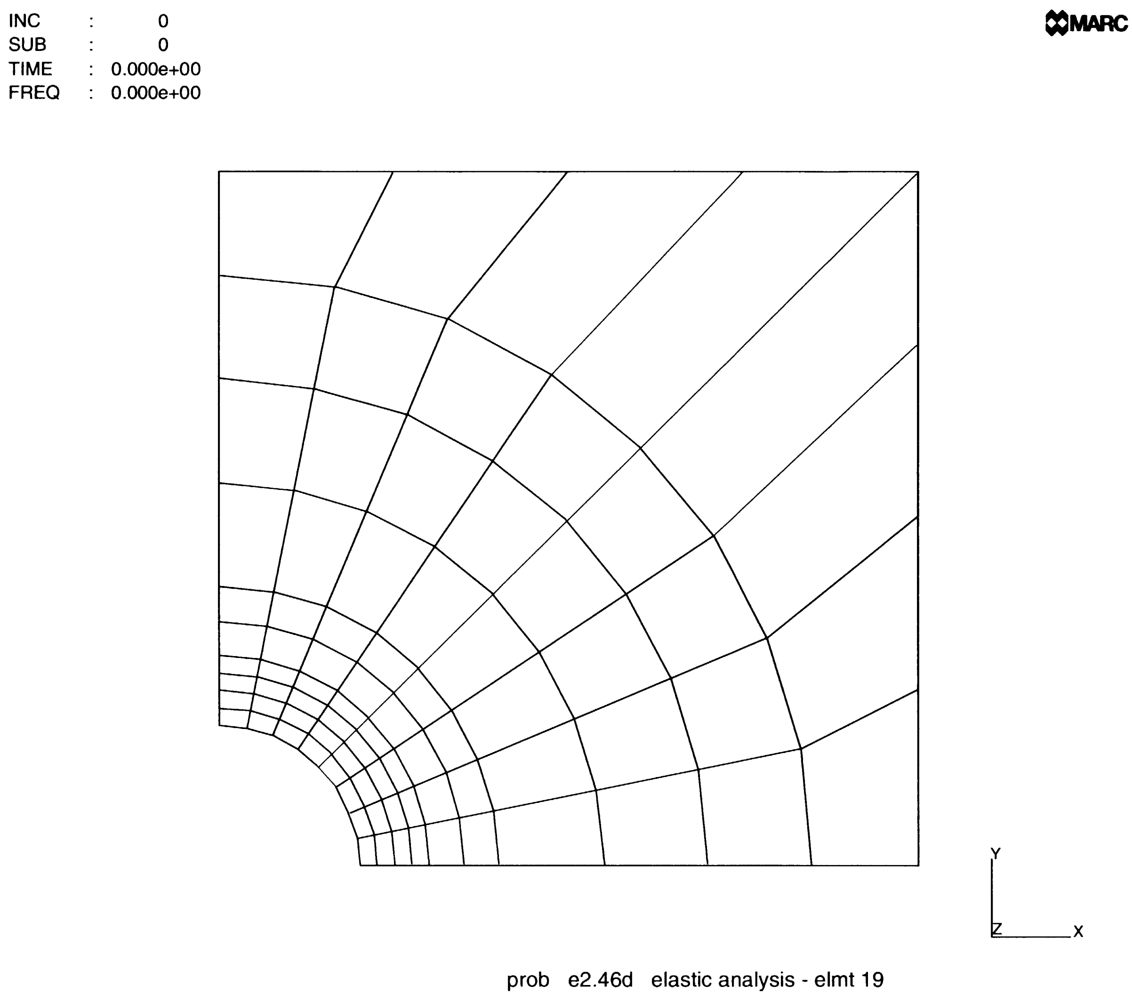


Figure 2.46-2 Fine Element Mesh Using Element Type 19

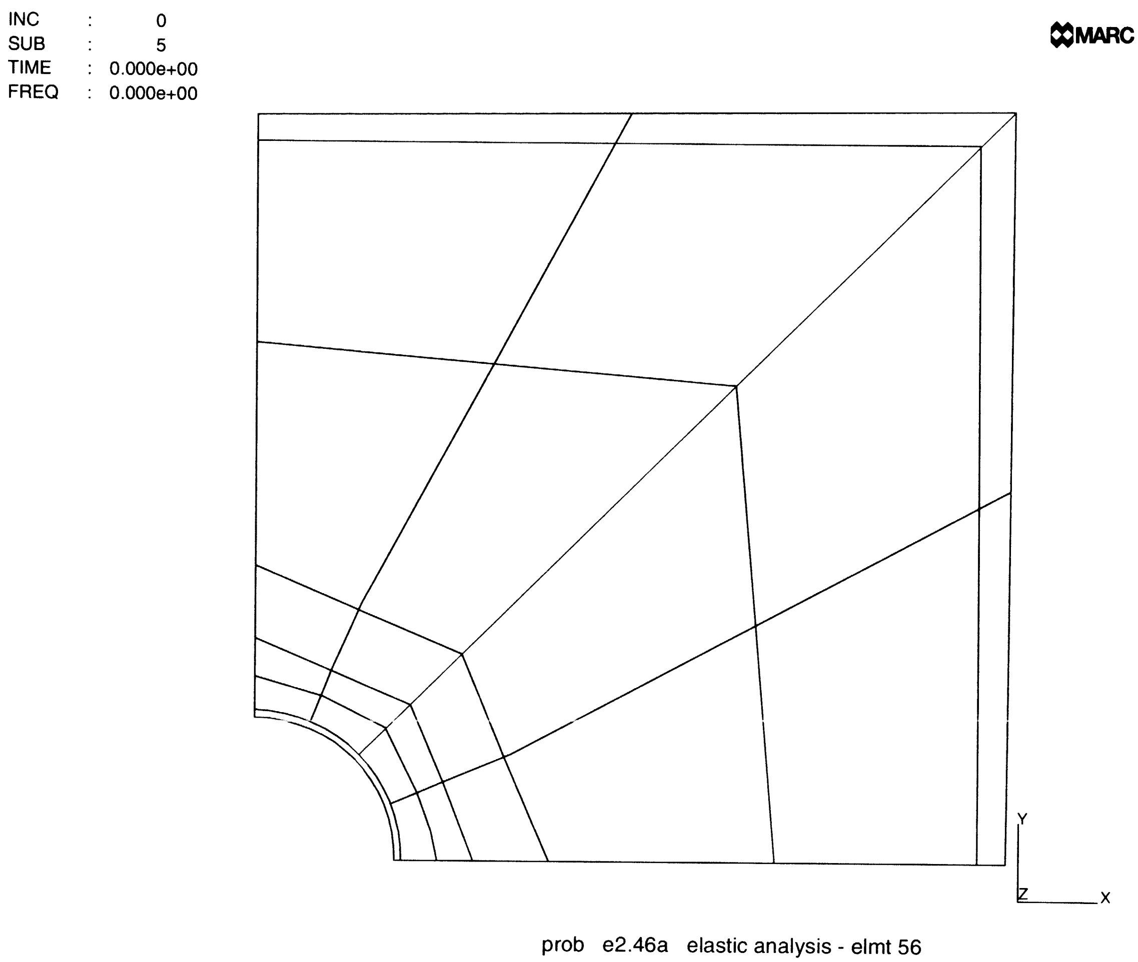


Figure 2.46-3 Deformed Mesh Plot

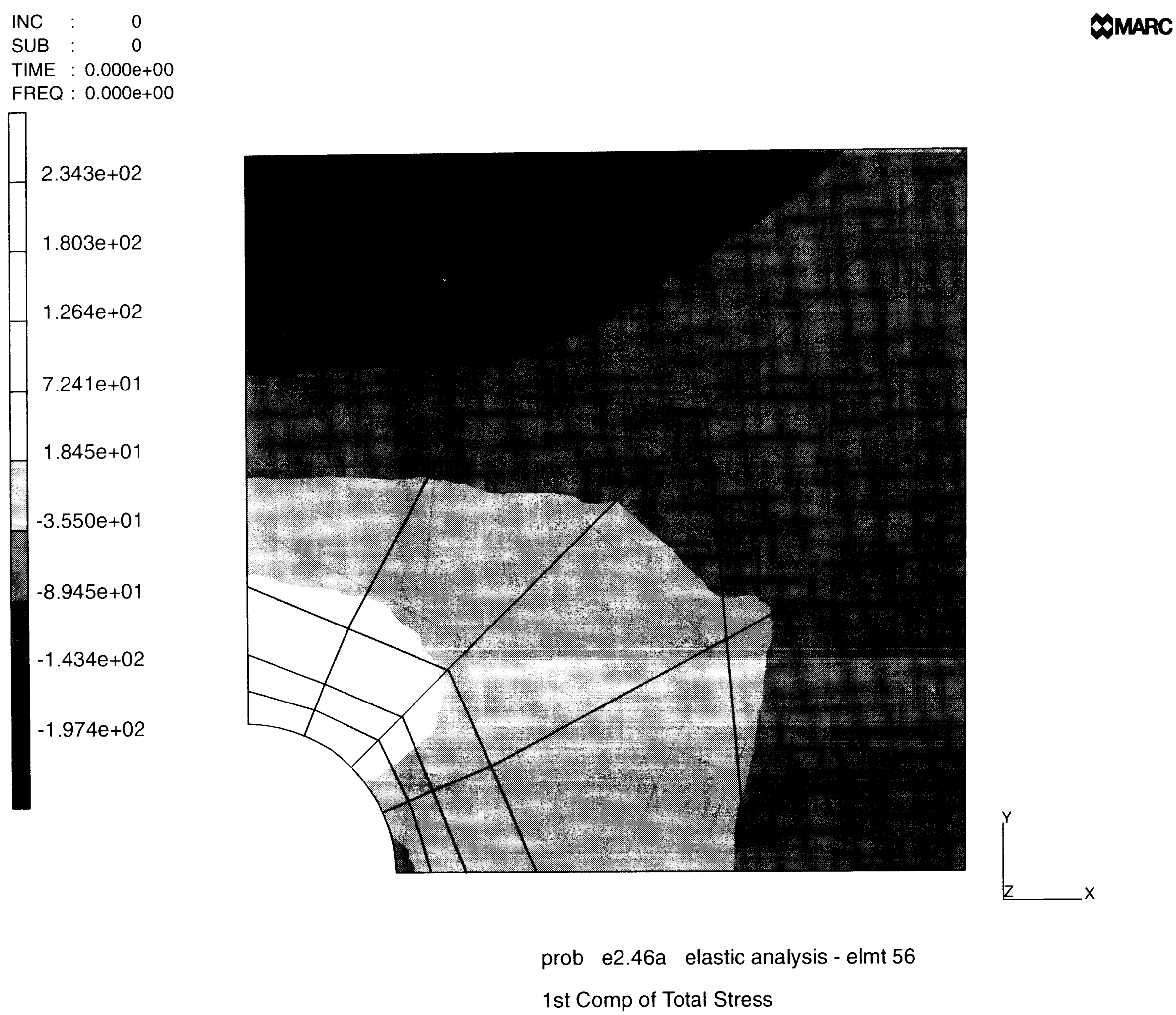


Figure 2.46-4 Stress Contours for σ_{11}

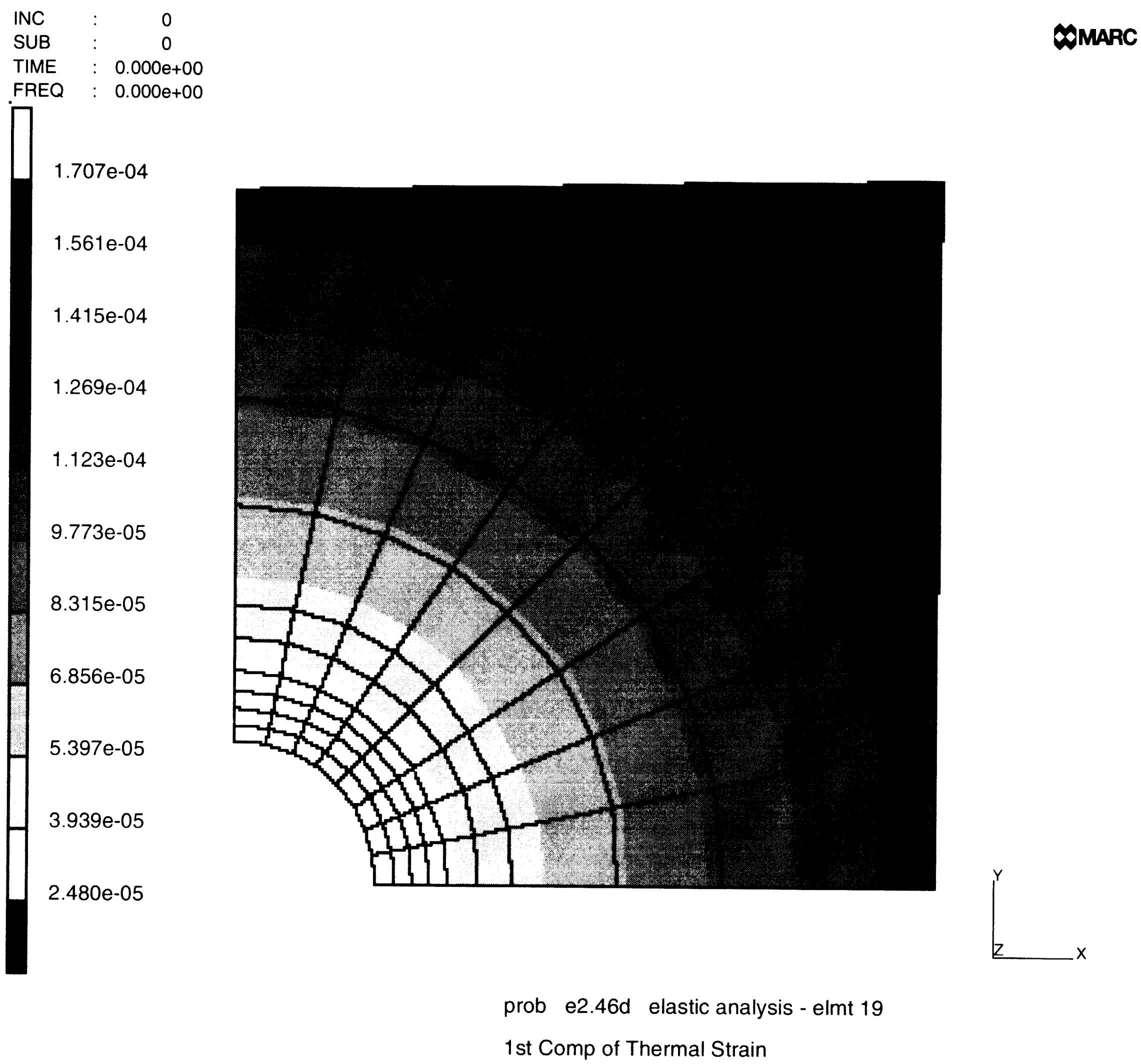


Figure 2.46-5 Contours of Thermal Strain

2.47 Thick Cylinder with Internal Pressure; Three-Dimensional Model

This problem illustrates the use of MARC element type 57 and the options TRANSFORMATION and TYING for an elastic analysis of a thick cylinder. The cylinder is subjected to a uniform internal pressure. The use of MESH3D for the generation of connectivity and coordinates blocks is also demonstrated.

Element

Element type 57 is a three-dimensional 20-node brick with reduced integration, with three global degrees of freedom.

Model

The element is type 57. There are 12 elements, with a total of 111 nodes. Dimensions of the cylinder and the finite element mesh are shown in Figure 2.47-1.

Material Properties

The Young's modulus is 2,100,000 kgf/cm^2 and Poisson's ratio is 0.3.

Loading

A uniform pressure (p) of 1000 kgf/cm^2, is applied in the radial direction at elements 2, 4, 6, 8, and 10.

Boundary Conditions

The third degree of freedom for nodes on the z = 0 plane is constrained (w = 0). Planes of symmetry: v = 0. (nodes 1 through 29, and 83 through 111)

Transformation

Degrees of freedom at nodal points 83 through 111 are transformed into local coordinate system for the convenience of defining boundary conditions (v = 0 for symmetry condition).

Tying Constraint

One type 3 tying constraint is imposed in this problem. Tying type 3 ties the degrees of freedom of all nodes on the top surface (z = 6) to node 25, which is constrained. This ensures plane strain conditions.

MESH3D

Connectivity and coordinate blocks are generated by using MESH3D.

Results

A deformed mesh plot is shown in Figure 2.47-2 and von Mises stress contours are depicted in Figure 2.47-3. This problem could have been solved using axisymmetric elements with less complications. A three-dimensional analysis would be necessary if there were any material or loading variations in the r-direction.

Parameters, Options, and Subroutines Summary

MESH3D is used in example e2x47a.dat:

Example e2x47b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TIE	END OPTION
TITLE	FIXED DISP
	ISOTROPIC
	TRANSFORMATION
	TYING

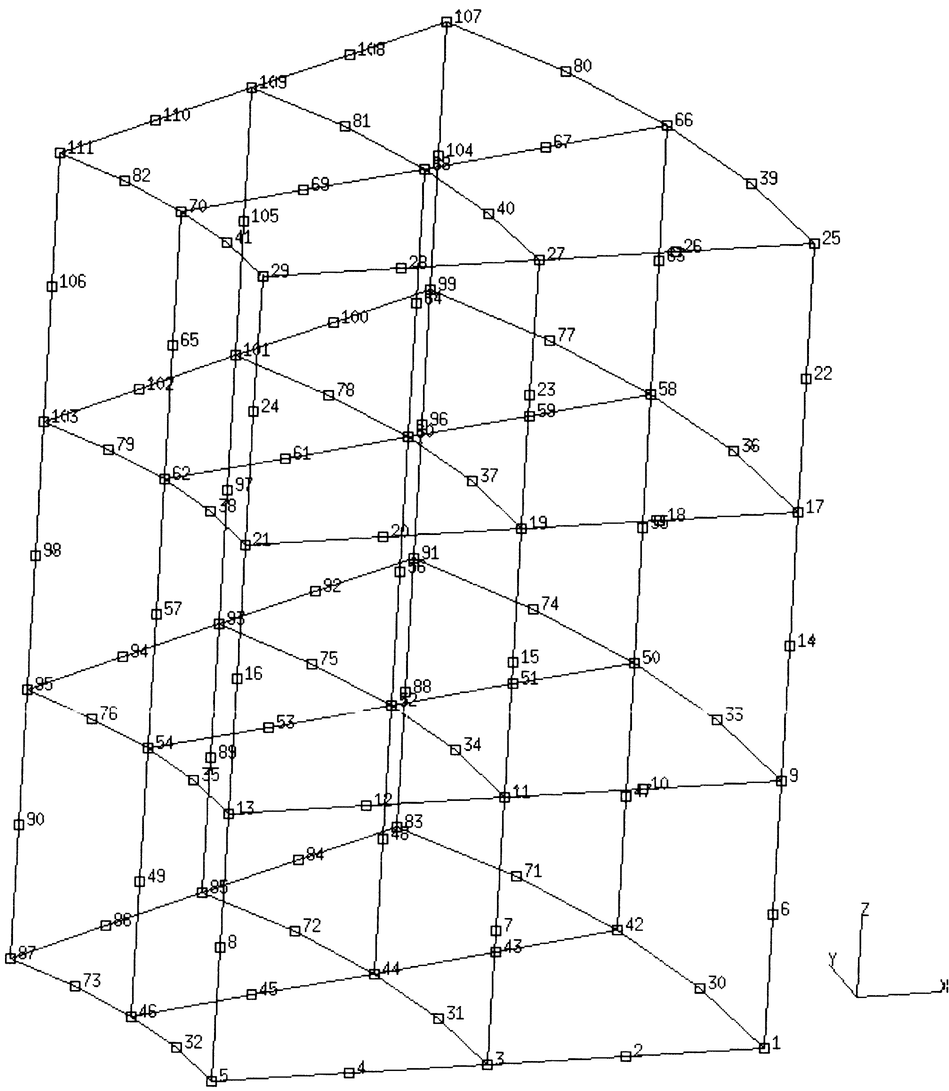


Figure 2.47-1 Cylinder and Mesh

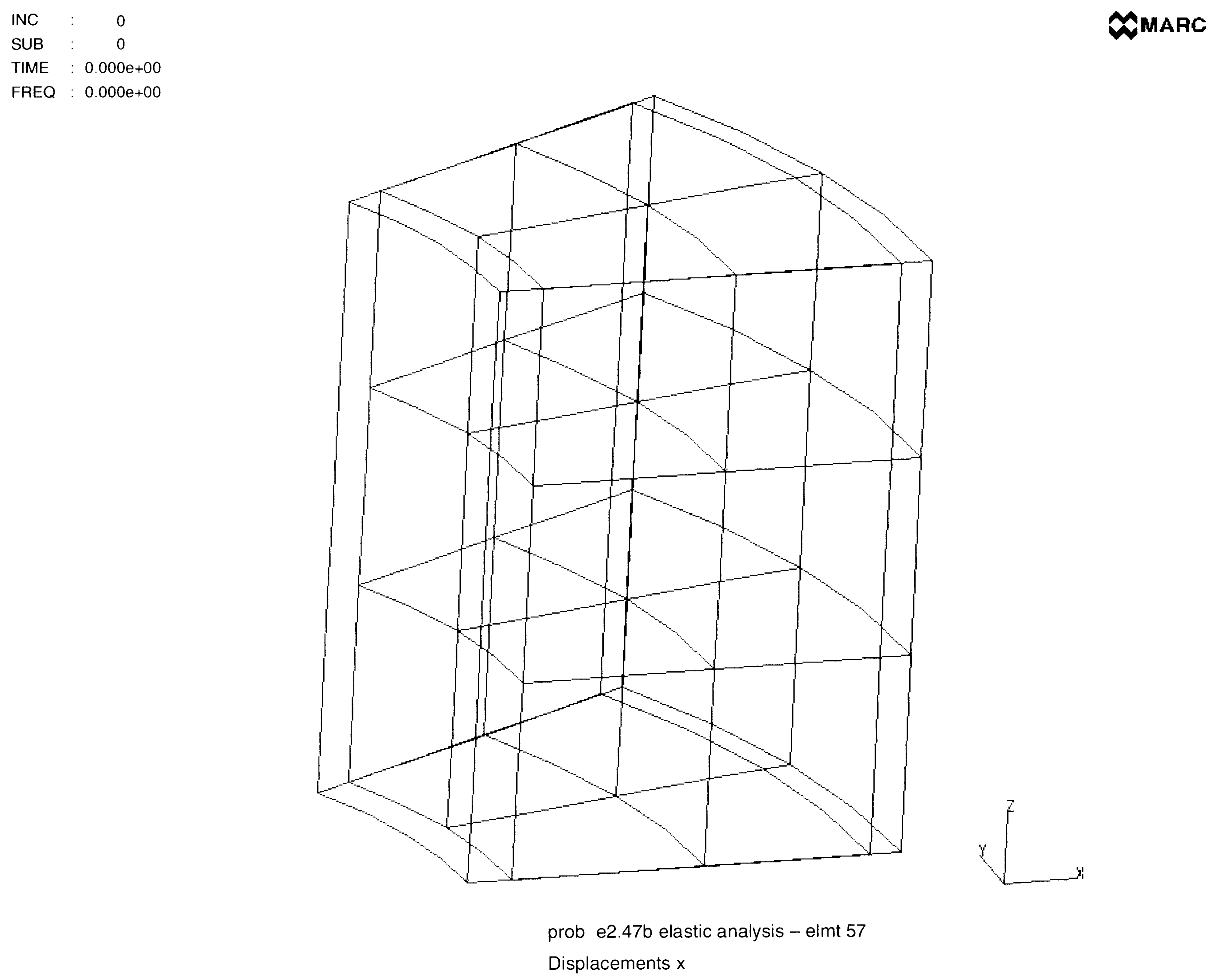


Figure 2.47-2 Deformed Mesh Plot

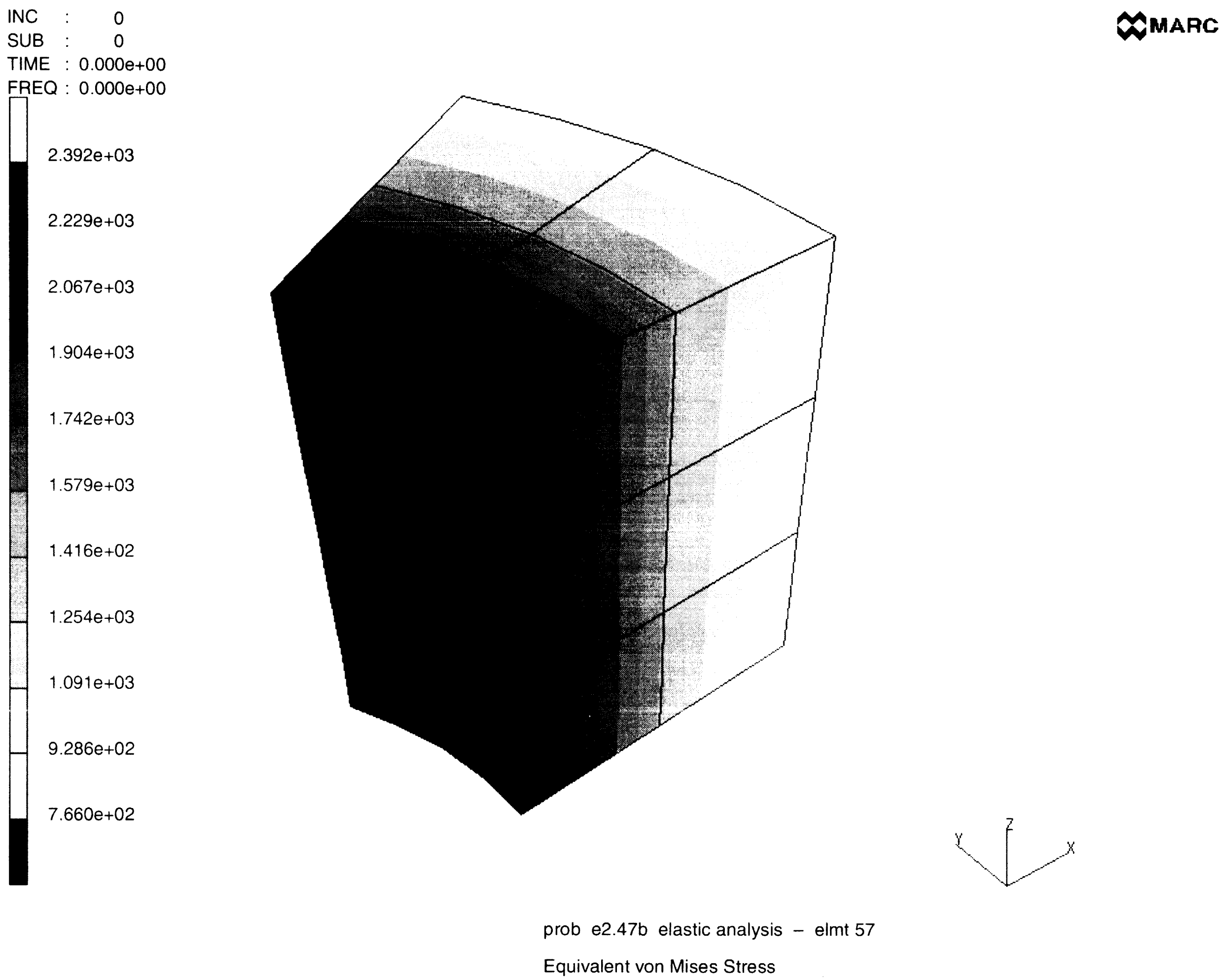


Figure 2.47-3 Equivalent von Mises Stress Contours

2.48 Circular Cylinder Subjected to Point Loads

This problem illustrates the use of MARC element type 58 and options CONN GENER and NODE CIRCLE for an elastic analysis of a hollow circular cylinder. The cylinder is subjected to diametrically opposite line loads.

Element

Element type 58 is an 8-node incompressible plane-strain element with reduced integration. There are three degrees of freedom at each corner node and two or three at each midside.

Model

The element is type 58. There are 16 elements with a total of 69 nodes. Dimensions of the cylinder and the finite element mesh are shown in Figure 2.48-1. The NODE CIRCLE option is used to generate the coordinates on the arcs.

Material Properties

Young's modulus is 30 x 10^3 psi with a Poisson's ratio of 0.4999.

Loading

A line load of 500 pounds is applied at node 69 in the positive x-direction. An equal load appears as reaction at node 5 in the negative x-direction.

Boundary Conditions

Symmetry conditions require that v = 0 at nodes 1 through 5 and 65 through 69. To eliminate rigid body motion, the displacement in the z-direction at node 33 is 0 (u = 0).

Results

A deformed mesh plot is shown in Figure 2.48-2 and stress contours are depicted in Figure 2.48-3.

Parameters, Options, and Subroutines Summary

Example e2x48.dat:

Parameters	Model Definition Options
ELEMENTS	CONN GENER
END	CONNECTIVITY
SIZING	COORDINATES
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	NODE CIRCLE
	POINT LOAD

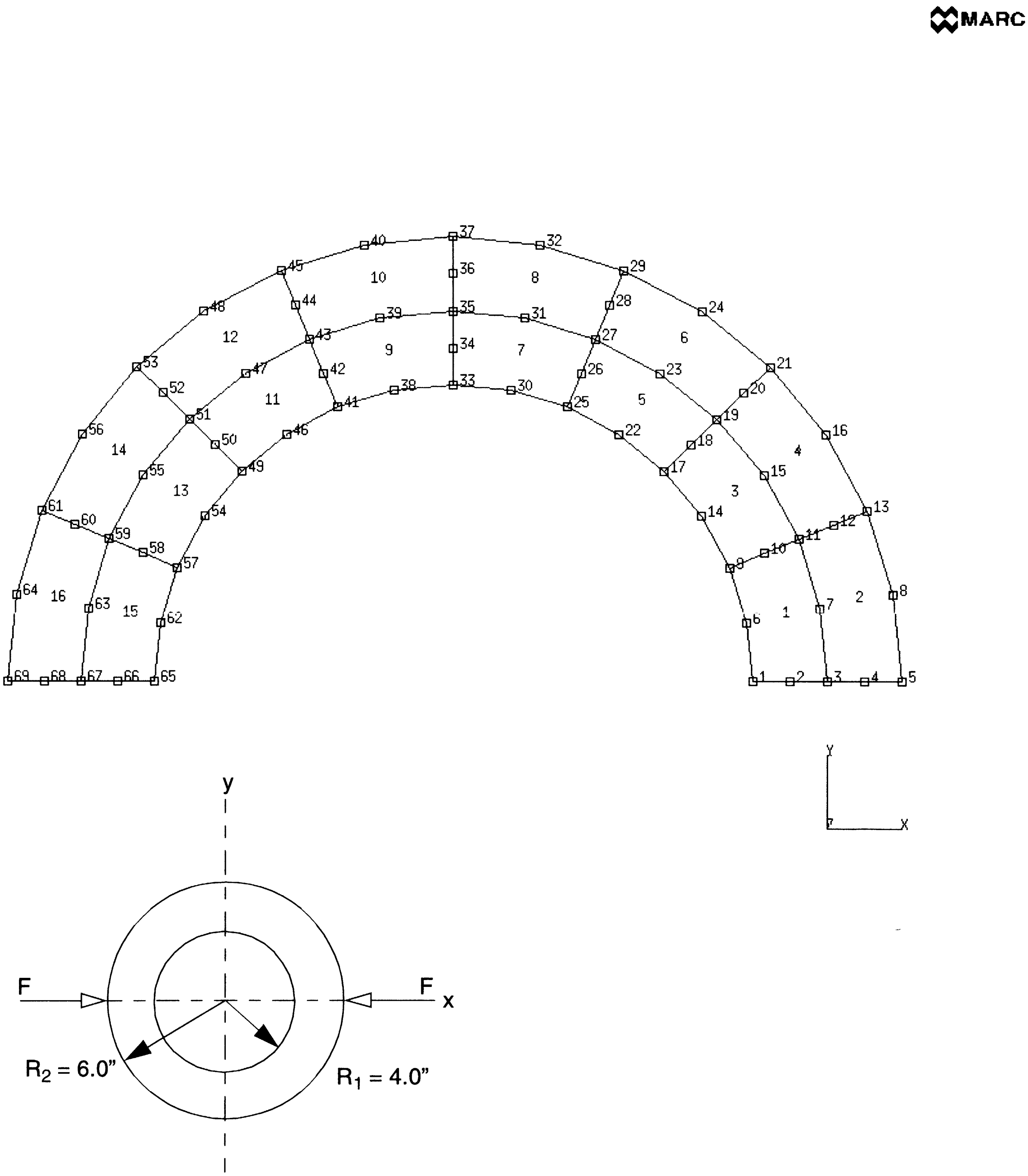


Figure 2.48-1 Circular Ring and Mesh of Half-model

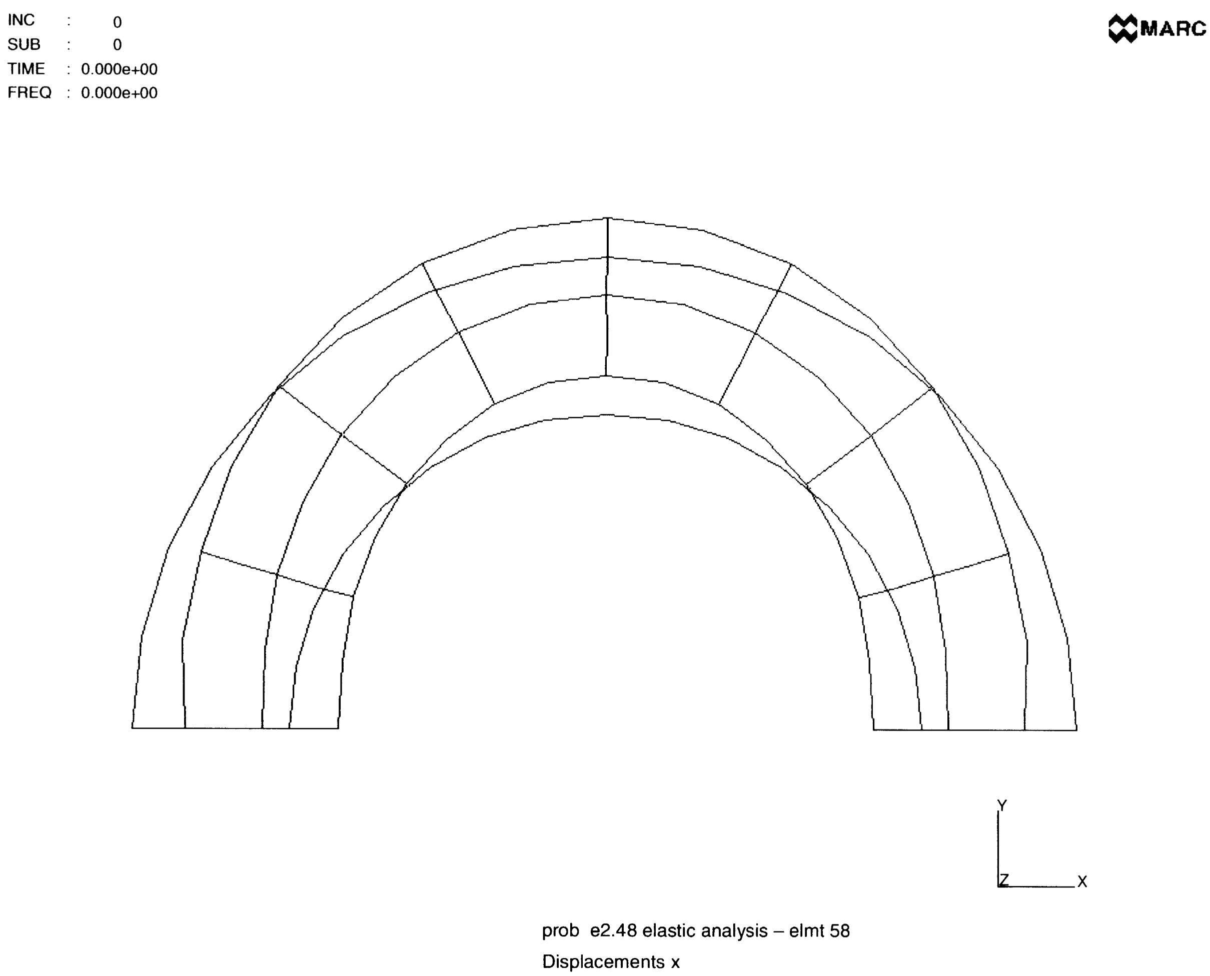


Figure 2.48-2 Deformed Mesh Plot

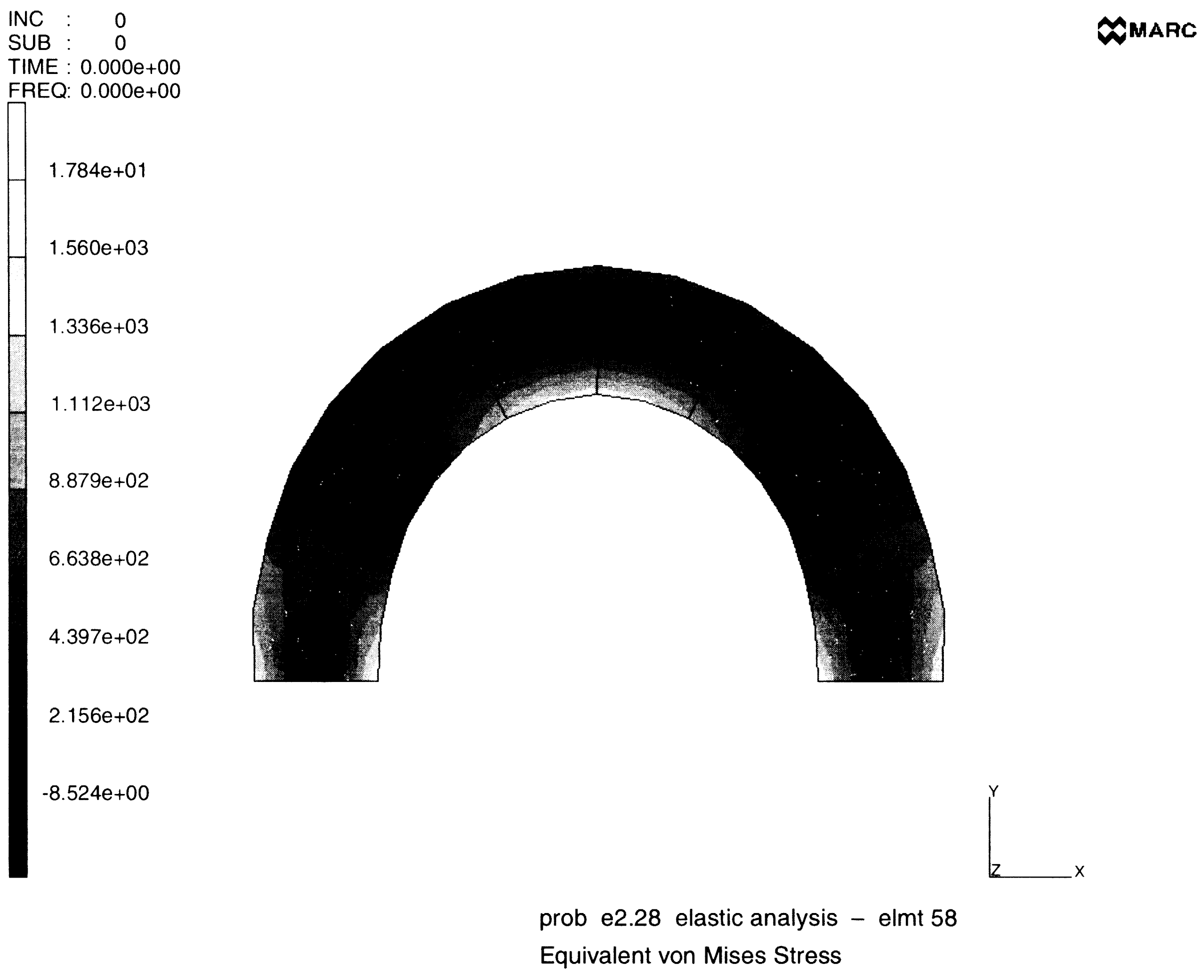


Figure 2.48-3 Equivalent von Mises Stress Contours

2.49 Hollow Spinning Sphere

This problem illustrates the use of MARC element type 59 and options CONN GENER, NODE CIRCLE, ROTATION A, and parameter CENTROID, for an elastic analysis of a hollow sphere. The sphere is subjected to both centrifugal load and nonuniform thermal load.

Element

Element type 59 is an 8-node, incompressible, axisymmetric element with reduced integration.

Model

The element is type 59. There are 16 elements, with a total of 69 nodes. The dimensions of the sphere and the finite element mesh are shown in Figure 2.49-1.

Material Properties

Young's modulus is 30 x 10^3 psi with a Poisson's ratio of 0.4999; the mass density is 0.2808 lb.sec^2/in.^{3}; the thermal expansion coefficient is 10 x 10^{-6} in/in/°F; and the initial stress-free temperature is 500°F.

Loading

A centrifugal load is applied through IBODY = 100. The angular velocity is 10 rad/sec (ω = 100) about the z-axis.

The thermal load is 500°F at the inside surface and 1000°F at the outside surface. A linear distribution of the temperatures is assumed to exist in the radial direction. The temperature is input through the user subroutine CREDE.

Boundary Conditions

Symmetry conditions are applied at r = 0 (v = 0 at nodes 1-5 and 65-69) and u = 0 at node 5 to suppress the (axial) rigid body mode.

Results

A deformed mesh plot is shown in Figure 2.49-2 and stress contours are depicted in Figure 2.49-3. The stress solution is symmetric with respect to the plane z = 0. In addition, the thermal strains and temperature are given in the output. The total centrifugal load as computed by MARC is 72,050 pounds versus the analytical solution of 72,056 pounds.

Parameters, Options, and Subroutines Summary

Example e2x49.dat:

Parameters	Model Definition Options
ELEMENTS	CONN GENER
END	CONNECTIVITY
SIZING	COORDINATES
THERMAL	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	NODE CIRCLE
	ROTATION AXIS
	THERMAL LOADS

User subroutine in u2x49.f:

CREDE

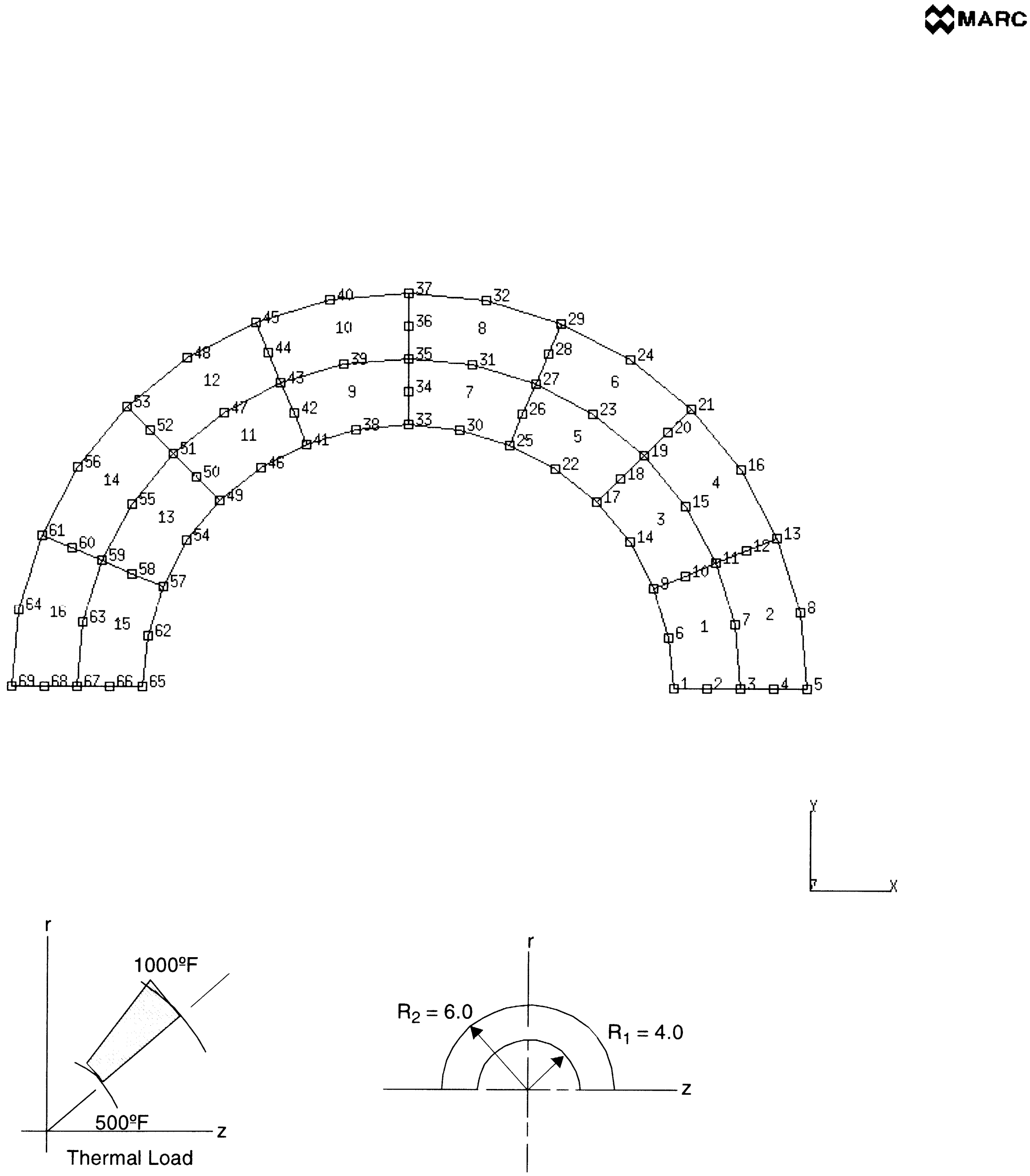


Figure 2.49-1 Hollow Sphere and Mesh

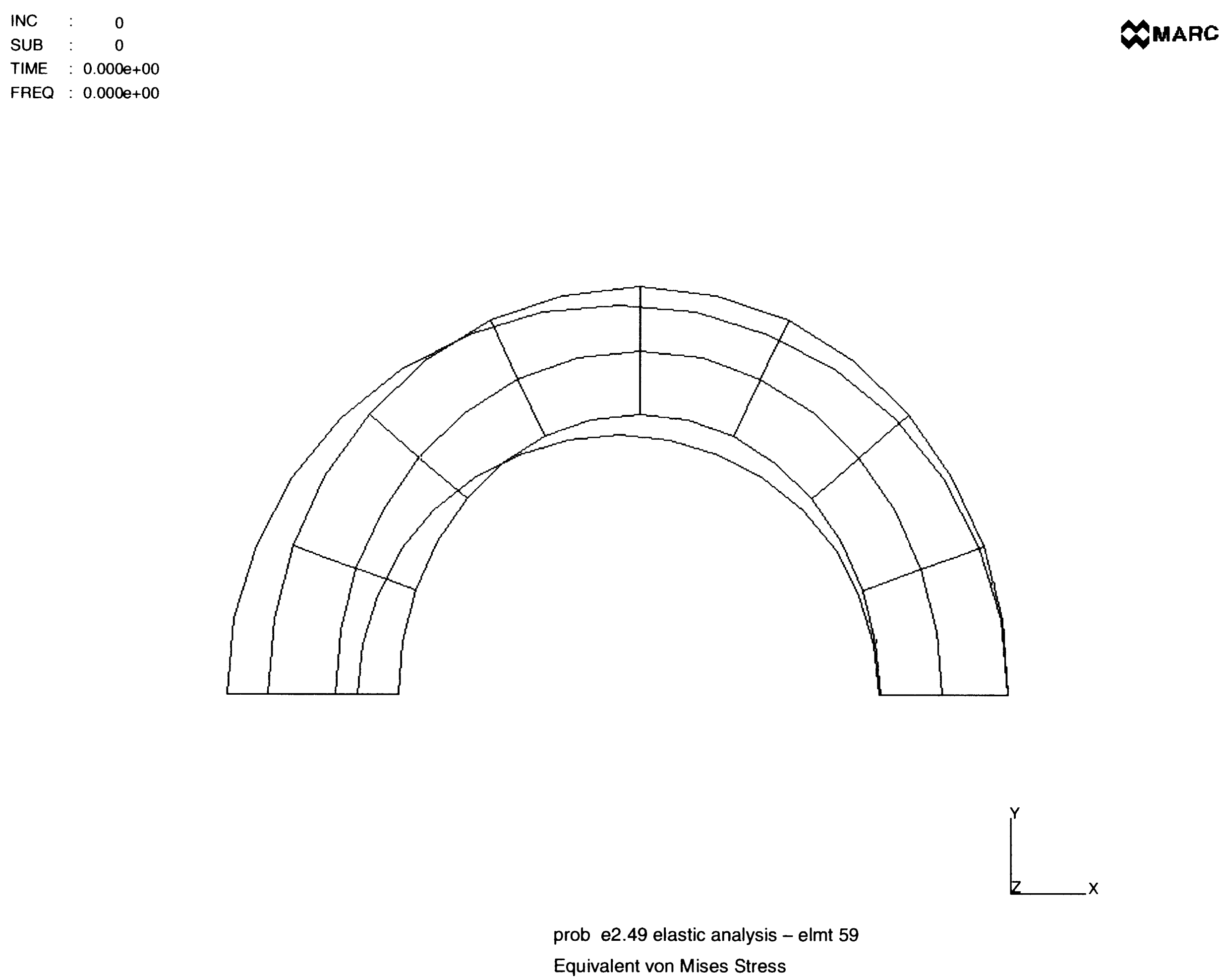


Figure 2.49-2 Deformed Mesh Plot

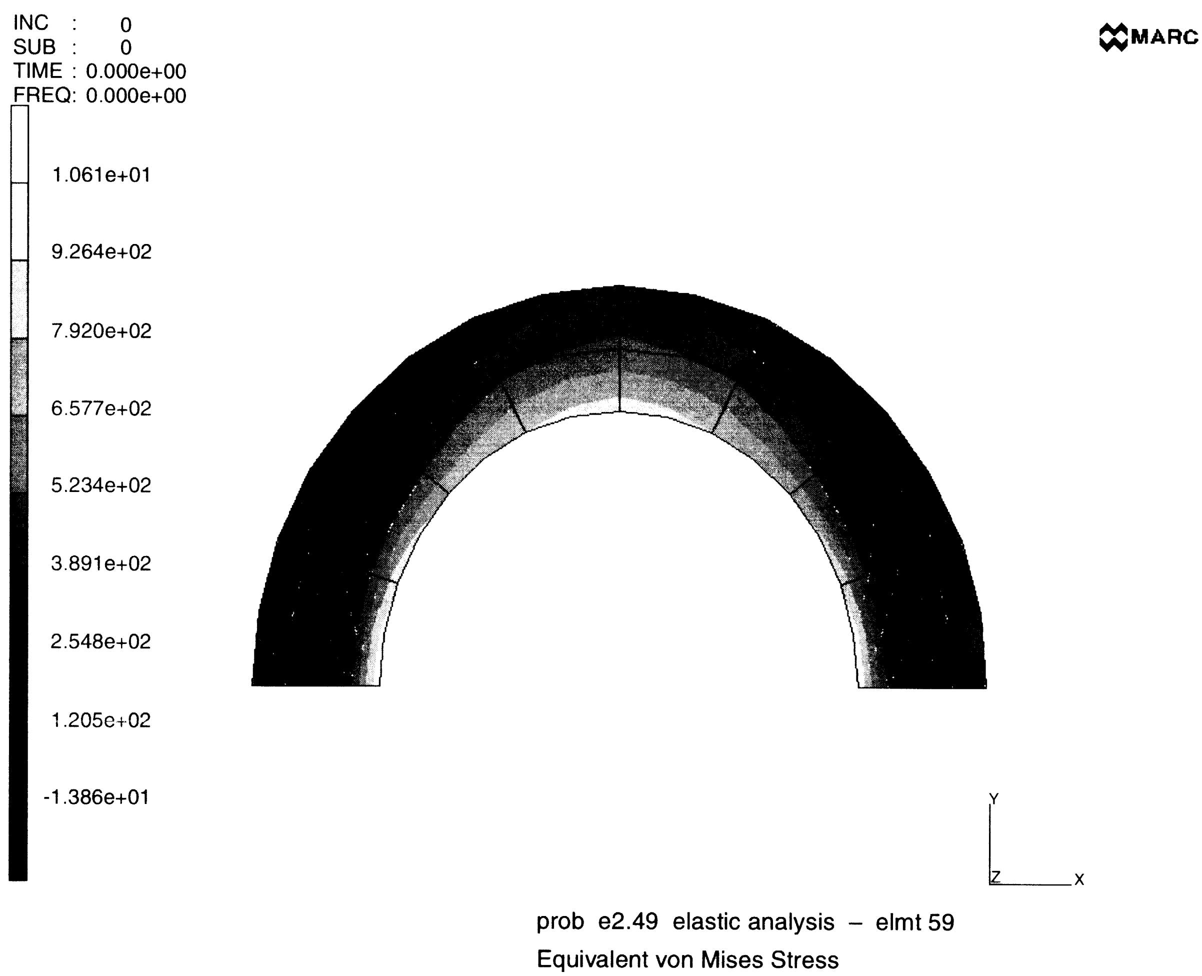


Figure 2.49-3 Equivalent von Mises Stress Contours

2.50 Anisotropic Ring Under Point Loads

This problem illustrates the use of MARC element type 60 for an elastic analysis of an anisotropic ring. The ring is subjected to equal and diametrically opposite point forces. One of the two forces is explicitly applied; the other appears as the medium force in the support. The use of option NODE CIRCLE and user subroutines ANELAS and ORIENT is also demonstrated.

Element

Element type 60 is an 8-node, incompressible, generalized plane-strain element with reduced integration.

Model

The element is type 60. There are 16 elements with a total of 71 nodes. There are 69 "regular" nodes and two nodes required for generalized plane strain. Dimensions of the ring and the finite element mesh are shown in Figure 2.50-1.

Material Properties

In the ISOTROPIC block, isotropic properties are specified. These properties are later completely overwritten with the user subroutines ANELAS and ORIENT. The fourth field is used to indicate that user subroutines are used.

Boundary Conditions

Symmetry conditions are applied at y = 0 (v = 0 at nodes 1-5 and 65-69) and u = 0 at node 5. The reaction force appears at this node. $\theta_x = \theta_y = 0$ at node 71. With these constraints, the strain in the direction normal to the ring is forced to be constant.

Loading

A 500 pound point load is applied at node 69 in the positive x-direction.

NODE CIRCLE

This option allows you to generate the coordinates of a series of nodes which lie on a circular arc.

Geometry

The default element thickness of 1.0 inch is selected for this analysis. No input data is required.

User Subroutine ORIENT

The ring is to be reinforced in the circumferential direction. The user subroutine ORIENT is used to define the local coordinate direction x^1, y^1, z^1 as follows (see Figure 2.50-1):

$$\frac{\partial x^1}{\partial x} = \cos\theta ,\frac{\partial x^1}{\partial y} = \sin\theta ,\frac{\partial x^1}{\partial z} = 0,$$

$$\frac{\partial y^1}{\partial x} = -\sin\theta,\frac{\partial y^1}{\partial y} = \cos\theta, \frac{\partial y^1}{\partial z} = 0,$$

$$\frac{\partial z^1}{\partial x} = 0 \quad ,\frac{\partial z^1}{\partial y} = 0 \quad ,\frac{\partial z^1}{\partial z} = 1.$$

y^1 is the circumferential direction in which the ring is reinforced.

User Subroutine ANELAS

For the incompressible elements in MARC, you have to specify the anisotropic compliance matrix of the material. Now we assume the ring is stiff in the tangential (y^1) direction. The (inverse) constitutive equation can then be approximated by:

$$\varepsilon_x^1 = \frac{1}{E_1}\sigma_x^1 - \frac{\nu}{E_2}\sigma_y^1 - \frac{\nu}{E_1}\sigma_z^1$$

$$\varepsilon_y^1 = \frac{\nu}{E_2}\sigma_x^1 - \frac{1}{E_2}\sigma_y^1 - \frac{\nu}{E_2}\sigma_z^1$$

$$\varepsilon_z^1 = \frac{\nu}{E_2}\sigma_x^1 - \frac{\nu}{E_2}\sigma_y^1 - \frac{1}{E_2}\sigma_z^1$$

$$\gamma_{xy}^1 = \frac{2(1+\nu)}{E_1}\sigma_{xy}^1$$

where $E_1 = 30 \times 10^3$, $E_2 = 30 \times 10^5$ and $\nu = .4999$. If the stress in the circumferential direction vanishes, the properties in the x^1-z^1 plane are isotropic. True modeling of uniaxial reinforcement in the circumferential direction would yield isotropic x^1-z^1 properties if $\varepsilon_y^1 = 0$ (plane strain). For such modeling, the constitutive equations are similar, but considerably more complicated.

Results

A deformed mesh plot is shown in Figure 2.50-2 and stress contours are depicted in Figure 2.50-3.

Parameters, Options, and Subroutines Summary

Example e2x50.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	ISOTROPIC
	NODE CIRCLE
	POINT LOAD

User subroutine in u2x50.f:

ORIENT
ANELAS

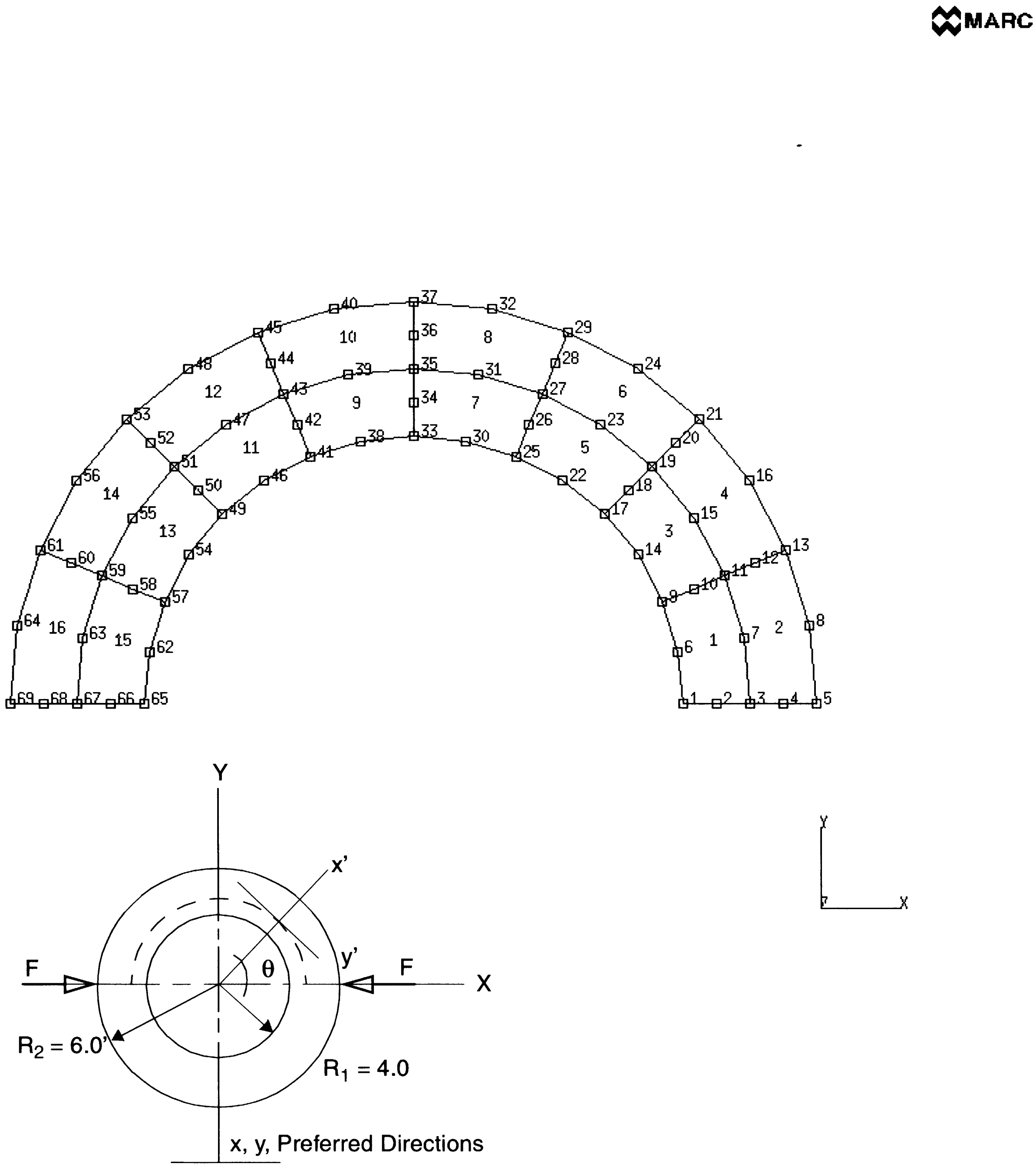


Figure 2.50-1 Anisotropic Ring and Mesh

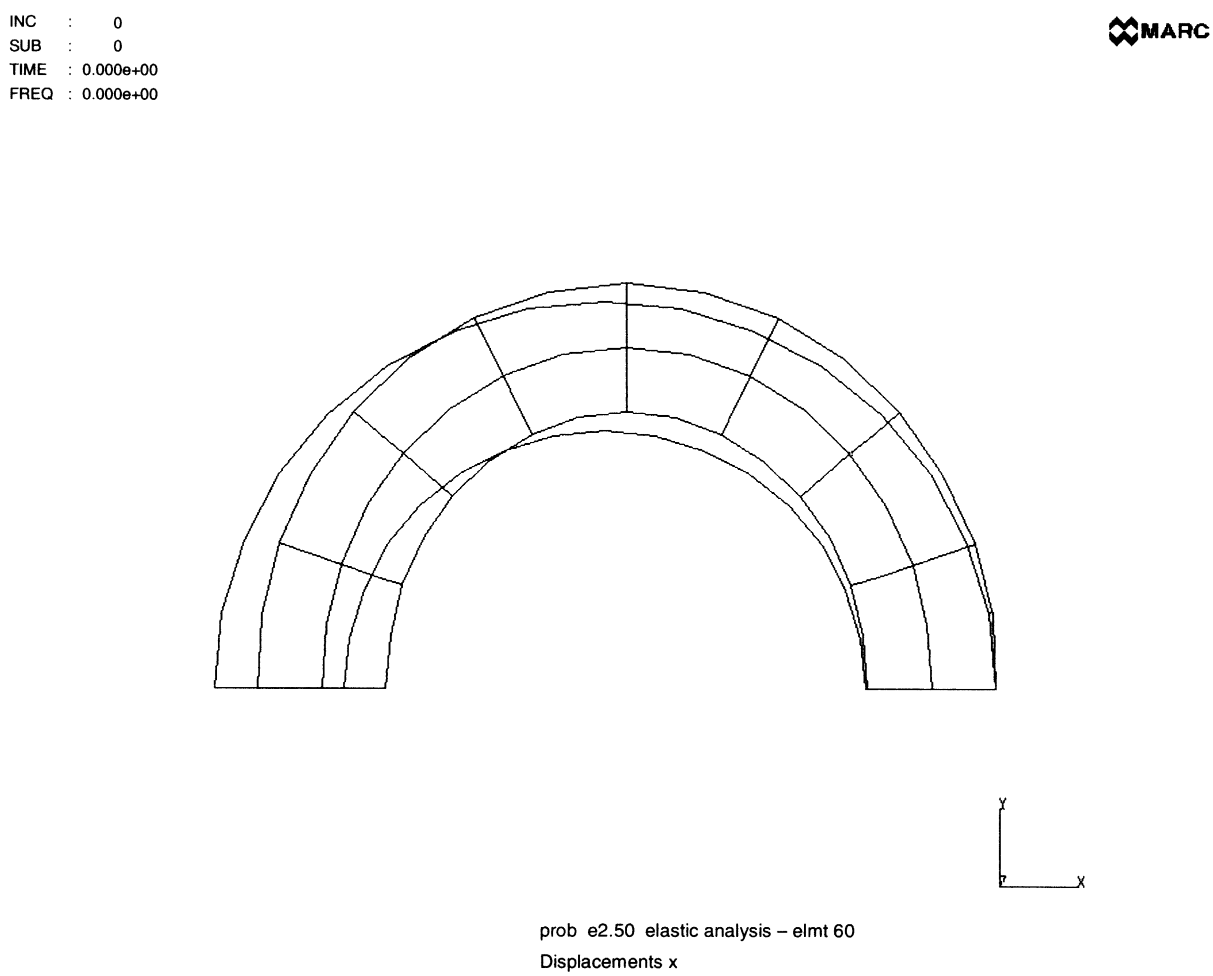


Figure 2.50-2 Deformed Mesh Plot

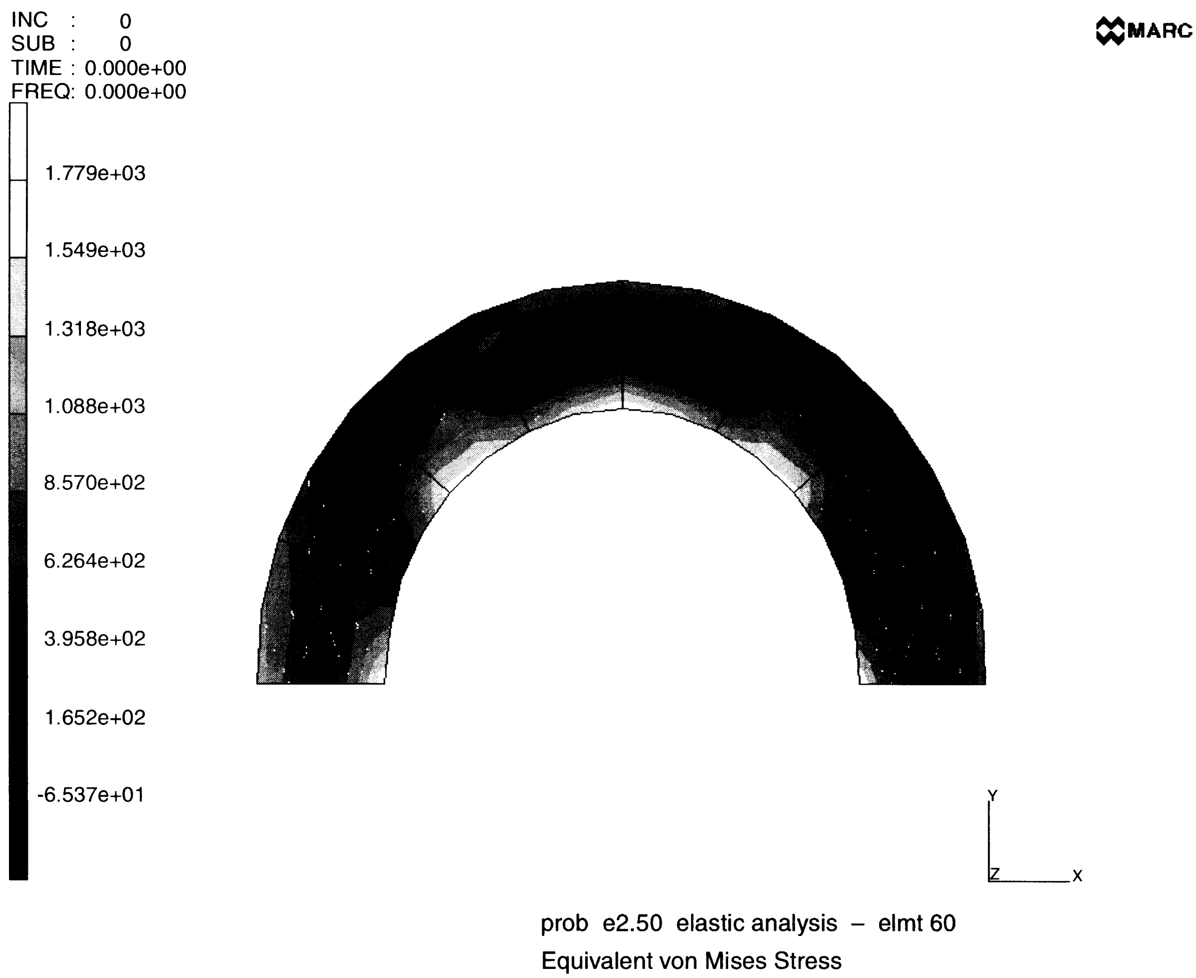


Figure 2.50-3 Equivalent von Mises Stress Contours

2.51 Square Block Subjected to Pressure and Thermal Loads

This problem illustrates the use of MARC element type 61 for an elastic analysis of a square block. The block is subjected to pressure and thermal loads. The use of the ELASTIC parameter, the CASE COMBIN and RESTART options, and the CREDE user subroutine is also demonstrated.

Element

Element 61 is a 20-node, incompressible, reduced integration solid element, with three global degrees of freedom per node.

Model

The element is type 61. There are eight elements with a total of 81 nodes. The dimensions of the square block and the finite element mesh are shown in Figure 2.51-1.

Material Properties

The Young's modulus is 30 x 10^5 psi with a Poisson's ratio of 0.4999; the thermal expansion coefficient is 10 x 10^{-7} in/in/°F; the initial stress-free temperature is 60.0°F.

Loading

Pressure load:

Uniform pressure of 100.0 psi (load type = 4) is applied at the top surface (z = 2.0) of the block.

Thermal load:

The temperature varies linearly from of 60°F at z = 0 (the plane of symmetry) to 130°F at z = 2.0 (the top surface).

User subroutine CREDE is used to input the temperature distribution. Typically, incremental temperatures are applied using the THERMAL LOAD option, but for this elastic analysis, the total temperatures are inserted.

Boundary Conditions

The following symmetry conditions are applied:

u = 0 in the plane x = 0;
v = 0 in the plane y = 0;
w = 0 in the plane z = 0.

ELASTIC

This option allows you to calculate stresses caused by the pressure and the thermal load separately. The stresses caused by the pressure load are calculated in increment 0 and the thermal stresses are calculated in increment 1.

Restart

In the first analysis, the RESTART option is used to store the solutions of the two cases obtained in increments 0 and 1.

CASE COMBIN

In a restart run, CASE COMBIN allows the results of analyses for various loading cases to be separately scaled, and then combined. In this example, the load case associated with the pressure load was scaled by a factor of 1.25. This was then added to the load case resulting from the thermal loading. The stresses and displacements under combined loading are obtained as a result.

User Subroutine CREDE

The CREDE user subroutine is used for the input of the linearly distributed temperature in the block. Usually, CREDE is used to read in the temperature distribution from a data file, such as a post file. In this problem, the temperature distribution is generated in CREDE.

Results

A deformed mesh plot for combined and thermal loads is shown in Figure 2.51-2. Stress contours are depicted in Figure 2.51-3.

Increment 0 - Uniform distributed load

	Analytically Computed	MARC Computed
σ_{zz} (psi)	−100	−100
ε_{zz}	-3.33×10^{-5}	-3.33×10^{-5}

Increment 1 - Thermal load at element 8, integration point 7

	Analytically Computed	MARC Computed
σ_{zz} (psi)	0	-3.50
ε_{zz}	6.23×10^{-5}	6.23×10^{-5}

Case combination

$1.25 * \text{inc } 0 + 1.0 * \text{inc } 1$

$\sigma_{zz} = 1.25 * (-100) - 3.5 = -128.5 \text{ psi}$

$\varepsilon_{zz} = 1.25 * (-3.33 * 10^{-5}) + 6.23 * 10^{-5}$

$= 2.06 \times 10^{-5}$

Parameters, Options, and Subroutines Summary

Example e2x51a.dat:

Parameters	Model Definition Options
ALIAS	CONNECTIVITY
ELASTIC	COORDINATES
ELEMENTS	DIST LOADS
END	END OPTION
SIZING	FIXED DISP
THERMAL	ISOTROPIC
TITLE	OPTIMIZE
	RESTART

User subroutine in u2x51a.f:

CREDE

Example e2x51b.dat:

Parameters	Model Definition Options
ALIAS	CASE COMBINATION
ELASTIC	CONNECTIVITY
ELEMENTS	COORDINATES
END	DIST LOADS
SIZING	END OPTION
THERMAL	FIXED DISP
TITLE	INITIAL STATE
	ISOTROPIC
	OPTIMIZE
	RESTART

user subroutine in u2x51.f

CREDE

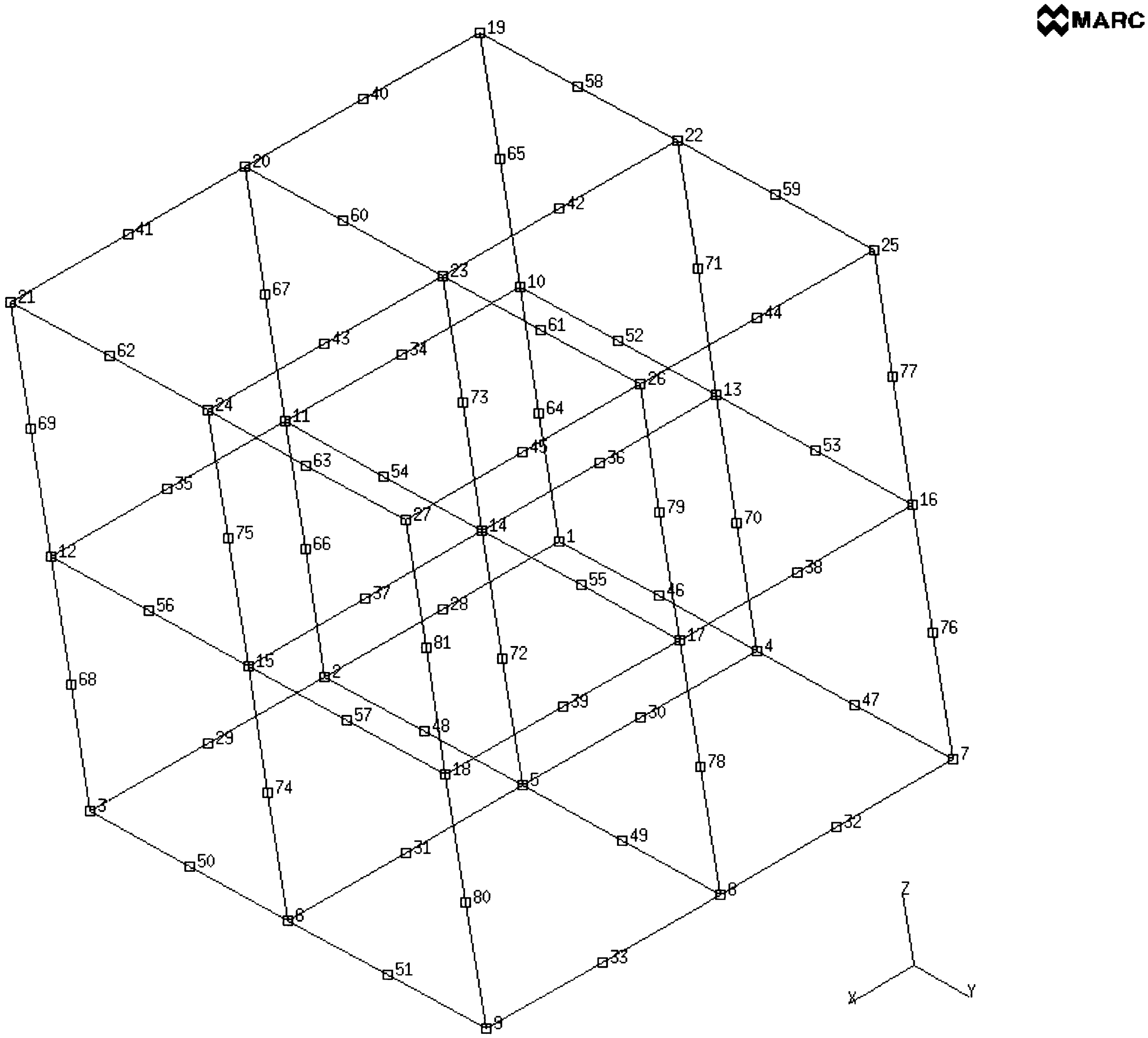


Figure 2.51-1 Square Block and Mesh

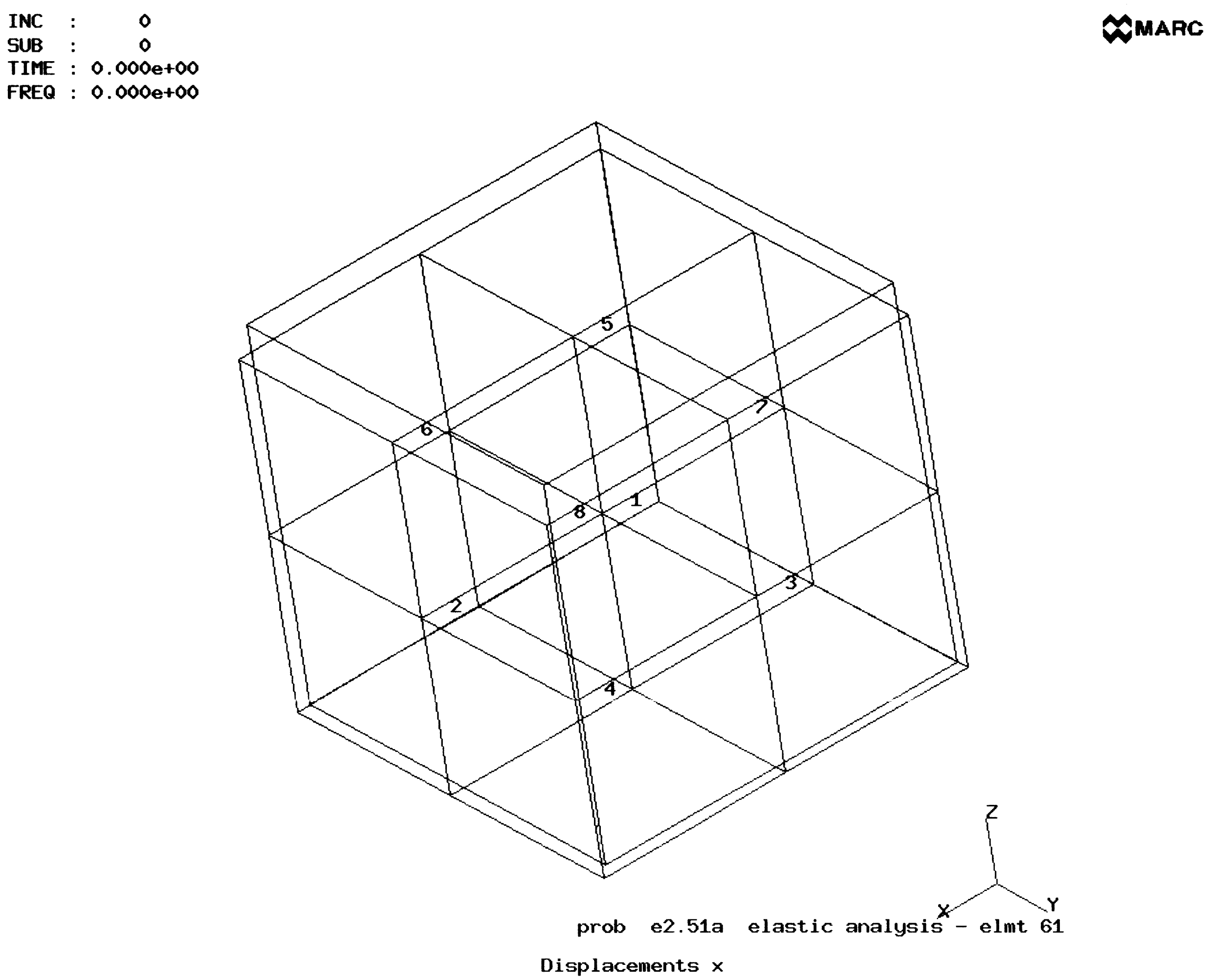


Figure 2.51-2 Deformed Mesh Plot

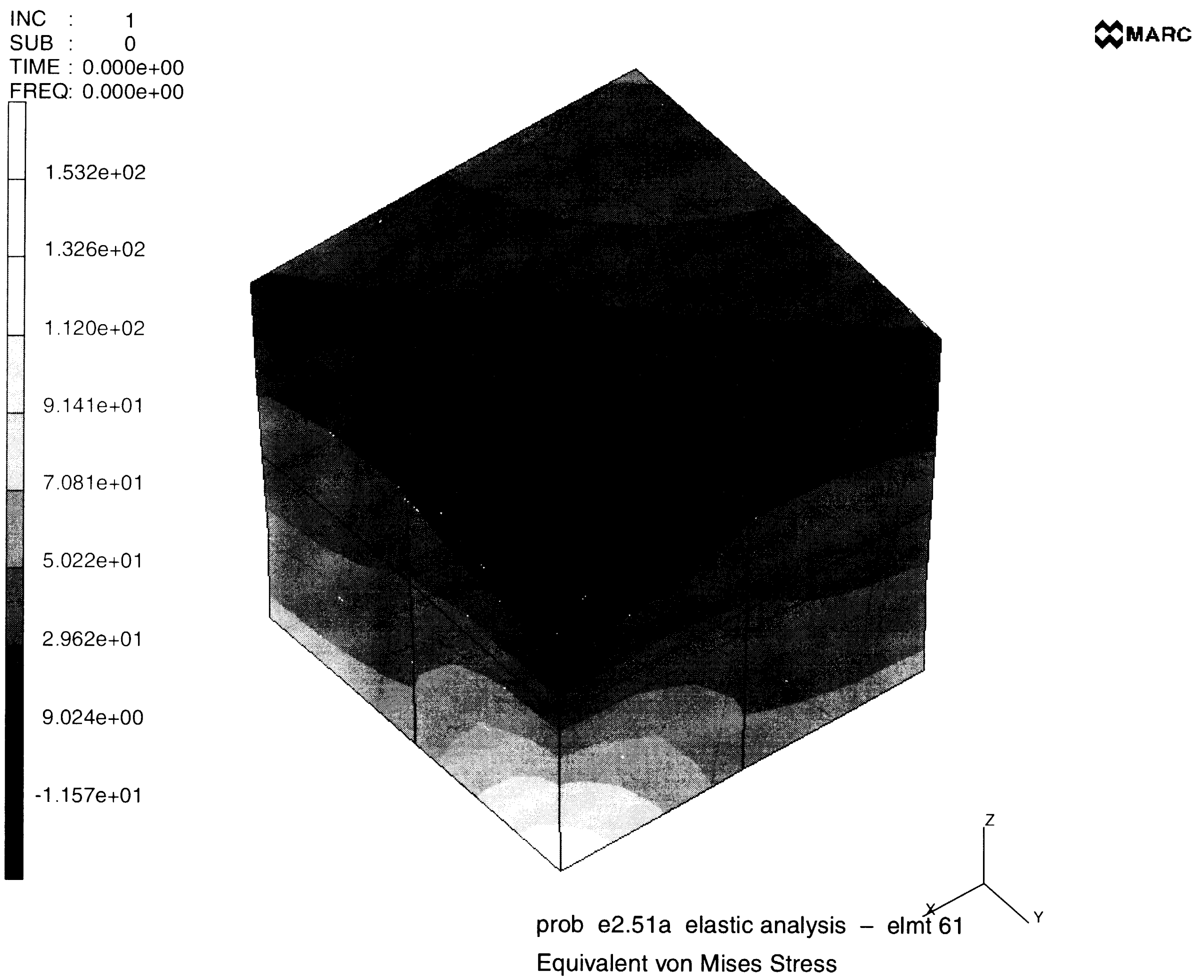


Figure 2.51-3 Equivalent Stress Contours

2.52 Twist and Extension of Circular Bar of Variable Thickness

This problem illustrates the use of MARC element 66 for an elastic analysis of a circular bar of variable thickness. The bar is subjected to both a twist moment and an axial force at the free end of the circular bar. The tying constraint option is used to insure that the cross section at the small end of the bar remains flat. This problem is identical to problem 2.28 except for the selection of element types.

Element

Element type 66 is an 8-node, incompressible, axisymmetric element with twist.

Model

The element type is 66. There are 12 elements, with a total of 53 nodes. Dimensions of the circular bar and the finite element mesh are shown in Figure 2.52-1.

Material Properties

The Young's modulus is 2,080,000 psi with a Poisson's ratio of 0.4999. A Poisson's ratio equal or close to 0.5 can be used with this element, which uses an augmented Herrmann type variational principle.

Boundary Conditions

Degrees of freedom u and w are 0 at the fixed end (nodes 1-5). Symmetry conditions are imposed at r = 0 (v = 0).

Loading

A 5000 pound point load in the positive z-direction and a 2000 inch per pound torque is applied at node 49. Due to the applied tying, the point load is distributed over the whole cross section.

Tying

Tying type 1 is used at the free end to simulate a generalized plane-strain condition in the axial (z) direction. The tied nodes are 50, 51, 52, and 53 and the retained node is 49.

Results

A deformed mesh plot is shown in Figure 2.52-2 and the stress distribution is depicted in Figure 2.52-3.

Parameters, Options, and Subroutines Summary

Example e2x52.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	ISOTROPIC
	POINT LOAD
	TYING

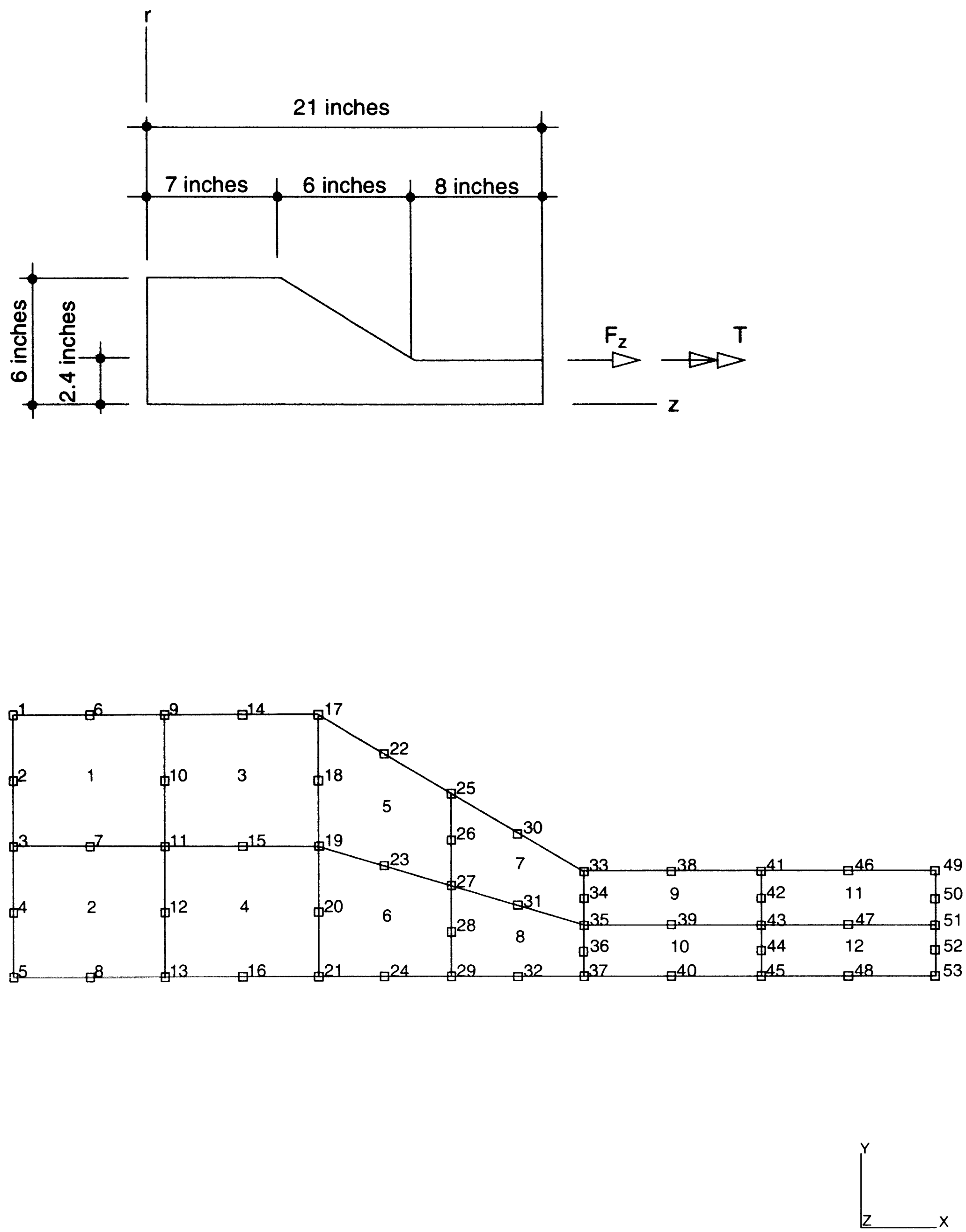


Figure 2.52-1 Circular Bar and Mesh

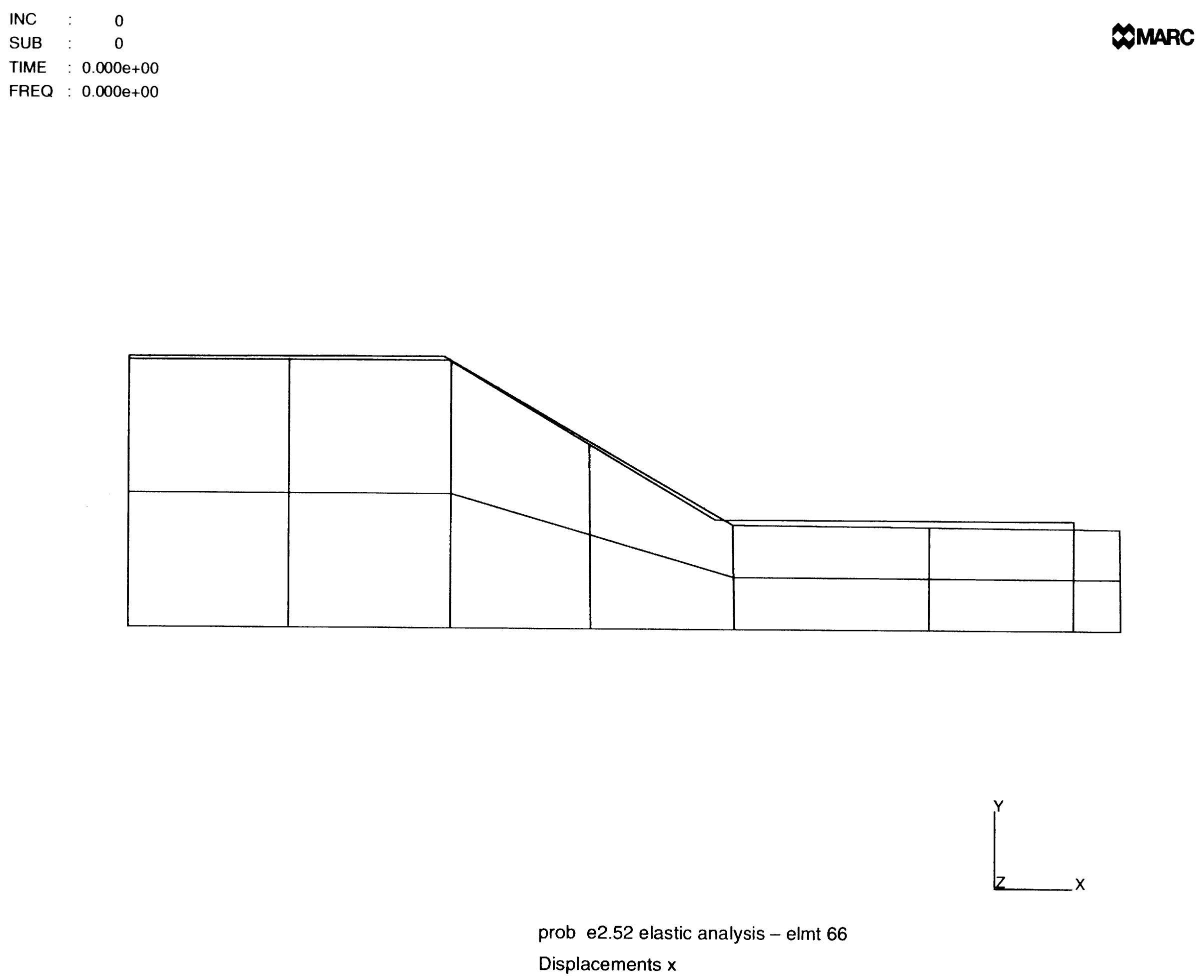


Figure 2.52-2 Deformed Mesh Plot

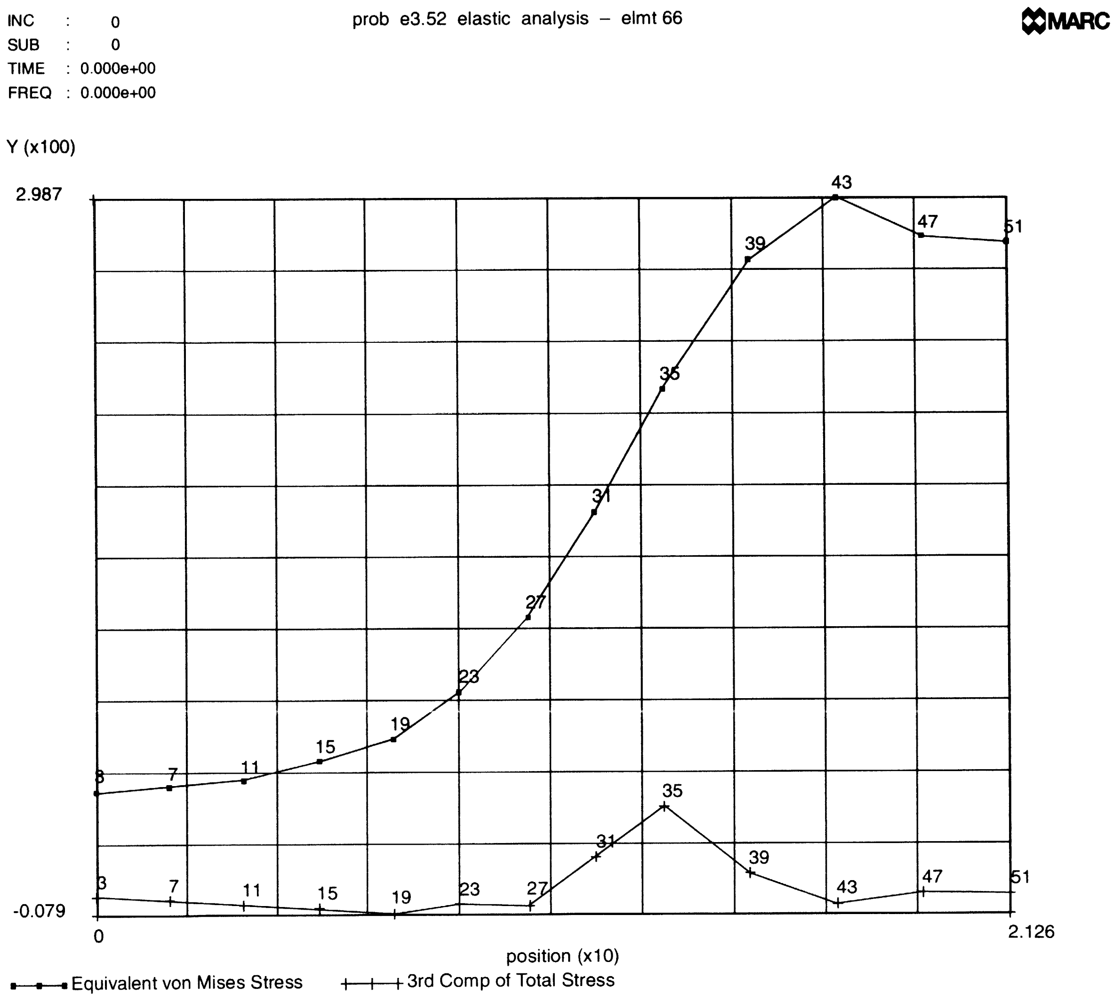


Figure 2.52-3 Stresses Along Path Between Nodes 3 and 51

2.53 Cylinder with Helical Anisotropy Under Internal Pressure

This problem illustrates the use of MARC element 67 for an elastic analysis of a thick cylinder with helical anisotropy. The cylinder is subjected to internal pressure. The use of the option TYING is also demonstrated. The tying constraint option simulates a generalized plane strain condition of the cylinder in the axial z-direction.

Element

Element type 67 is an 8-node, axisymmetric element with twist, with three degrees of freedom at each node.

Model

The element is type 67. There are 10 elements and a total of 53 nodes. The dimensions of the cylinder and the finite element mesh are shown in Figure 2.53-1.

Material Properties

In the ISOTROPIC option, isotropic properties are specified. These properties are later modified in the user subroutines ANELAS and ORIENT. The Young's modulus is 30 x 10^5 psi, with a Poisson's ratio of 0.3. The fourth field is set to one to indicate that the user subroutines are to be used.

Loading

Internal pressure of 500 psi is applied on the inside element 1.

Boundary Conditions

$u_z = u\theta = 0$ at nodes 1,4,6,...,51 (z = 0). u_z = constant at the plane 3,5,8,...,53 (z = 1.0).

User Subroutines ANELAS and ORIENT

As shown in Figure 2.53-2, the orientation of anisotropy is assumed to be helical. This helical anisotropy represents a filament-wound type structure covering an axial distance of one for every full revolution. Let x, y, z be the local coordinate system representing the preferred direction. The expression of the transformation matrix, from global (Z, R, S) to local, is as follows:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \sin\alpha & 0 & \cos\alpha \\ 0 & 1 & 0 \\ -\cos\alpha & 0 & \sin\alpha \end{bmatrix} \begin{bmatrix} Z \\ R \\ \theta \end{bmatrix}$$

The angle $\alpha(r)$ is a function of r and can be computed from:

$\alpha = \text{ARCTAN}\,(1.0/2\pi r)$

Results

A deformed mesh plot is shown in Figure 2.53-3 and hoop stress through the radius is depicted in Figure 2.53-4. Due to the anisotropy, the ends of the cylinder rotate with respect to each other by -1.187×10^{-5} radians at the inside and -2.252×10^{-5} radians at the outside radii.

Parameters, Options, and Subroutines Summary

Example e2x53.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	TYING

User subroutines in u2x53.f:

ANELAS
ORIENT

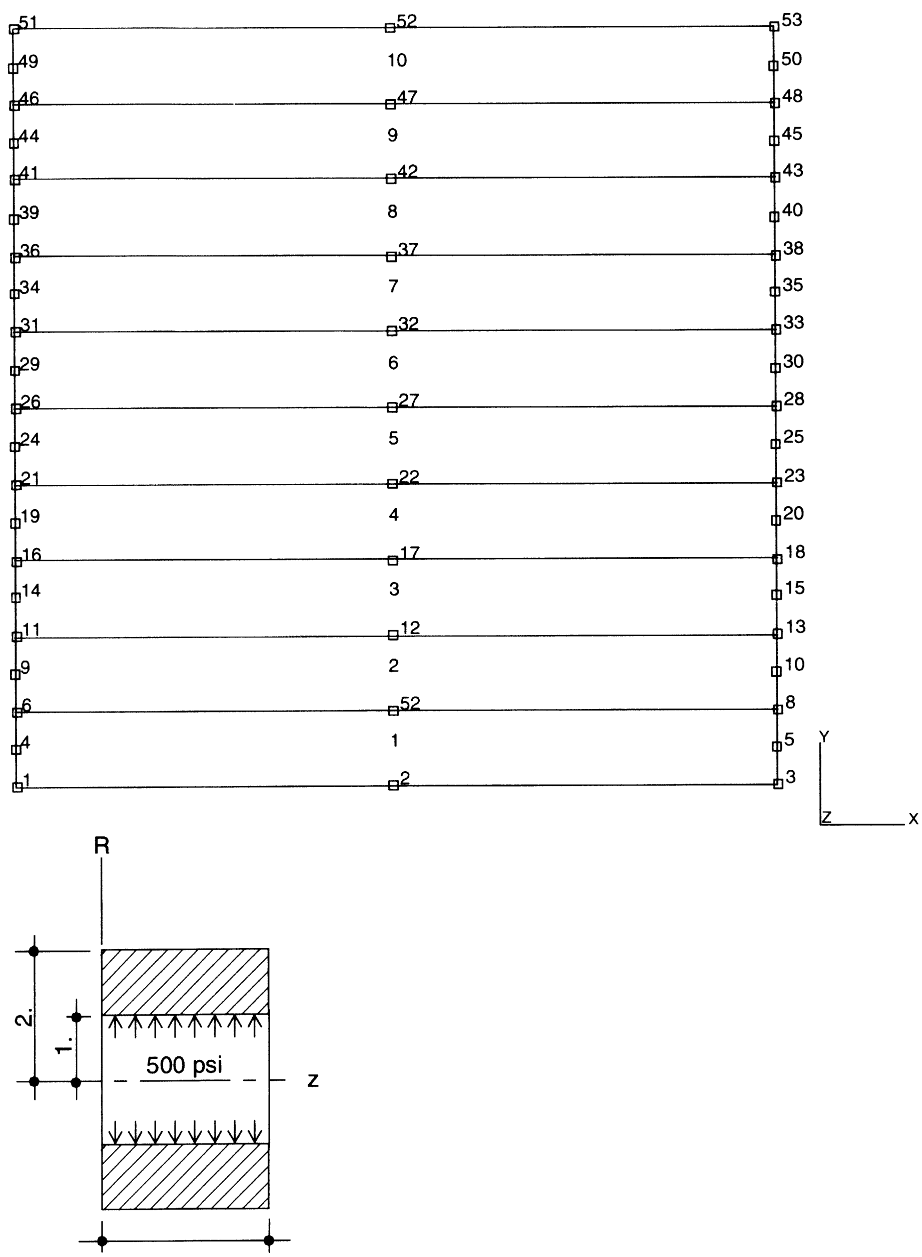


Figure 2.53-1 Cylinder and Mesh

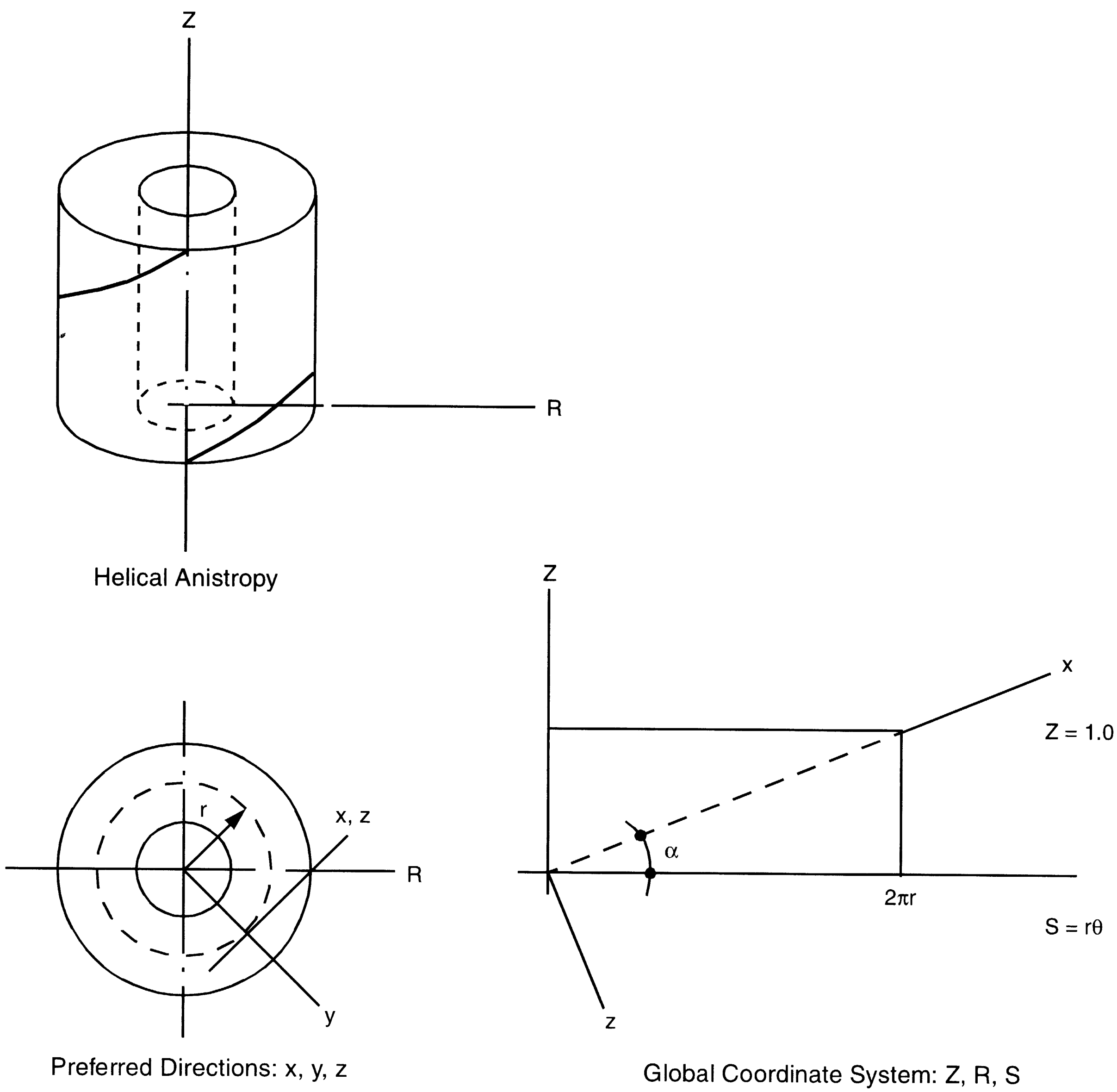


Figure 2.53-2 Helical Anisotropy

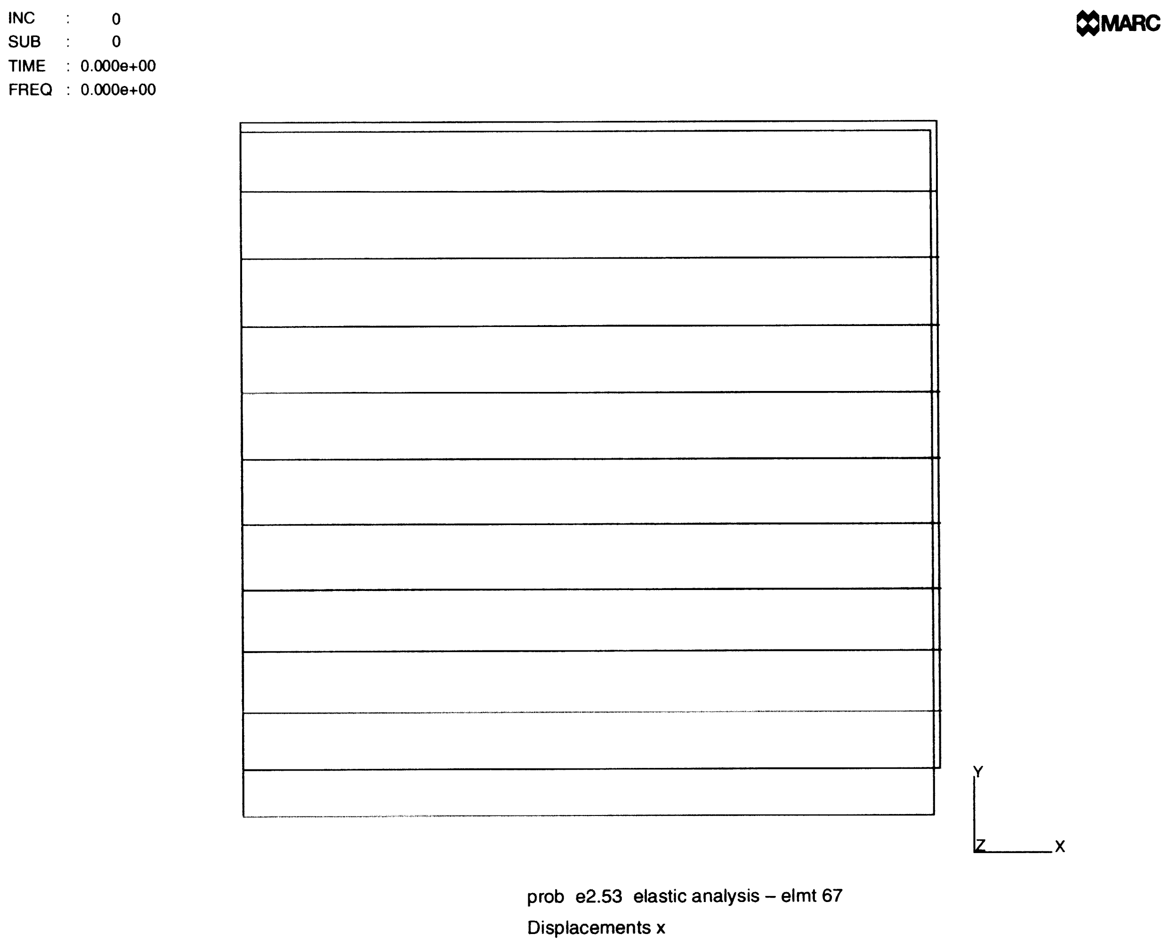


Figure 2.53-3 Deformed Mesh Plot

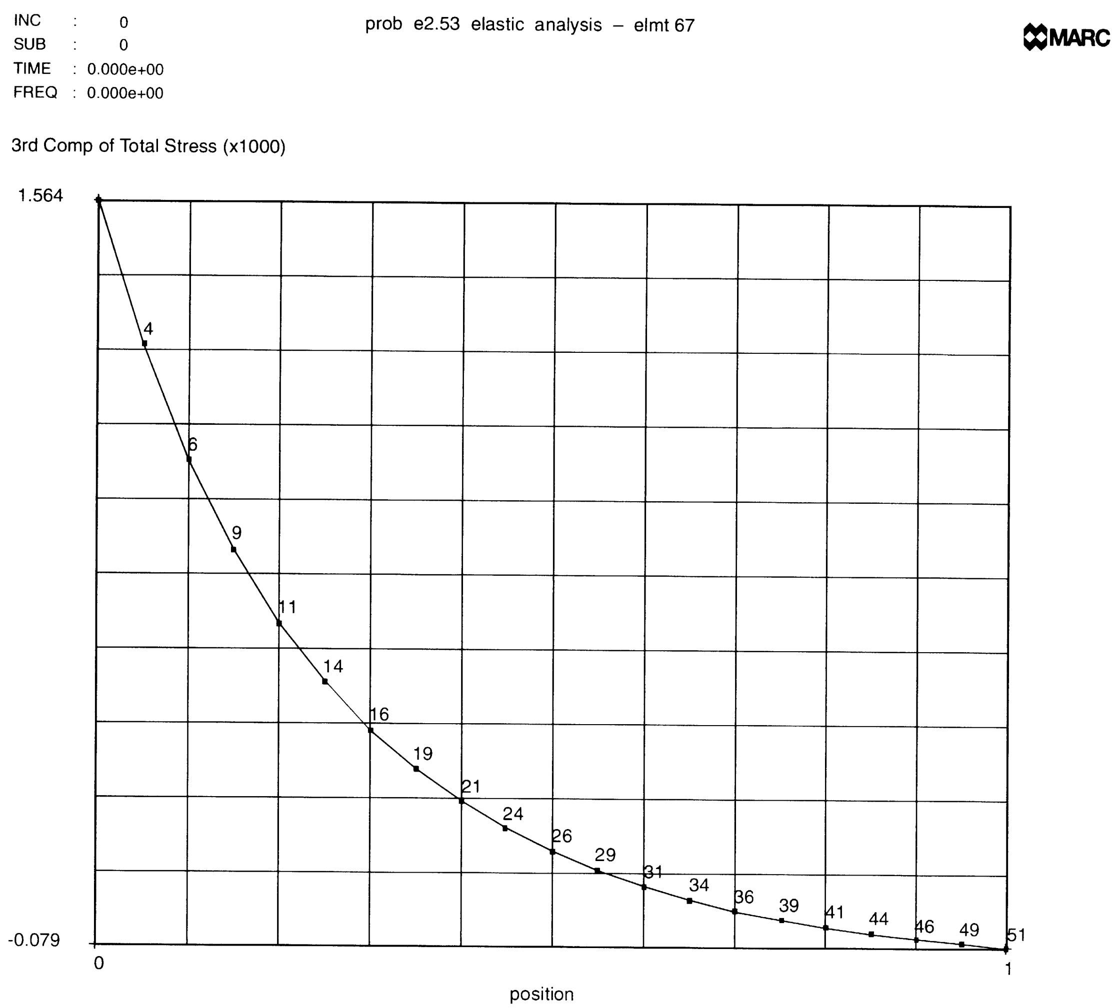


Figure 2.53-4 Hoop Stress Through Radius

2.54 Stiffened Shear Panels Supported by Springs

This problem illustrates the use of MARC element types 68 and 9, and the SPRINGS option for an elastic analysis of a stiffened cubical, supported by linear springs. The box is subjected to point forces (in-plane twisting loads). As the name indicates, the shear panel can only support shear loads. Hence, the element when used without stiffness is singular. The element can be used to stiffen frames, as in this demonstration problem.

Element

Element type 68 is a linear elastic shear panel of arbitrary shape. This element only resists shear forces. There are four nodes per element, with three degrees of freedom for each node.

Element type 9 is a three-dimensional truss element with constant cross section. There are three degrees of freedom for each node.

Model

The elements are types 68 and 9. There is a total of 18 elements – 6 elements type 68 and 12 elements type 9. There is a total of 12 nodes. Twelve springs act on the box as shown in Figure 2.54-1.

Material Properties

For element type 9, Young's modulus is 30×10^6 psi.

For element type 68, Young's modulus is 30×10^5 psi and Poisson's ratio is 0.2.

Geometry

The cross-sectional area of element type 9 is 0.6 square inch; the thickness of element type 68 is 0.05 inches.

Spring Constant

Nodes 5, 6, 7 and 8 are supported by springs in all three (x, y, z) directions. The spring constant is 18×10^4 pounds per inch. These springs simulate an elastic foundation in this example.

Loading

At the upper four corners, twisting loads are applied in the x-y plane. Magnitudes of the point loads are 100 pounds.

Boundary Conditions

Nodes 9, 10, 11 and 12 (the other end of the springs) are constrained in all directions (that is, $u = v = w = 0$).

Results

A deformed mesh plot is shown in Figure 2.54-2.

Parameters, Options, and Subroutines Summary

Example e2x54.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
POINT LOAD
SPRINGS

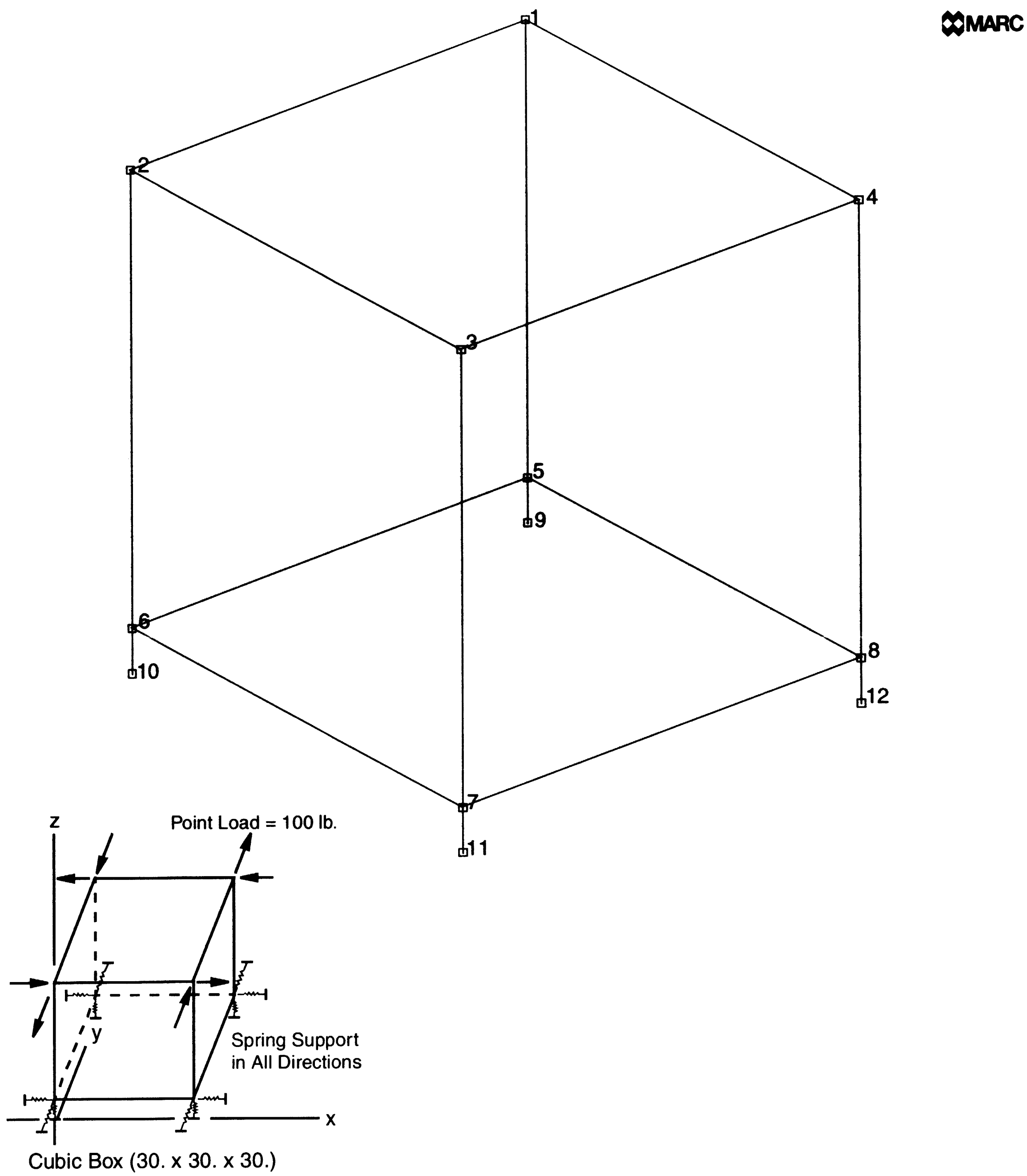


Figure 2.54-1 Stiffened Cubic Box and Mesh

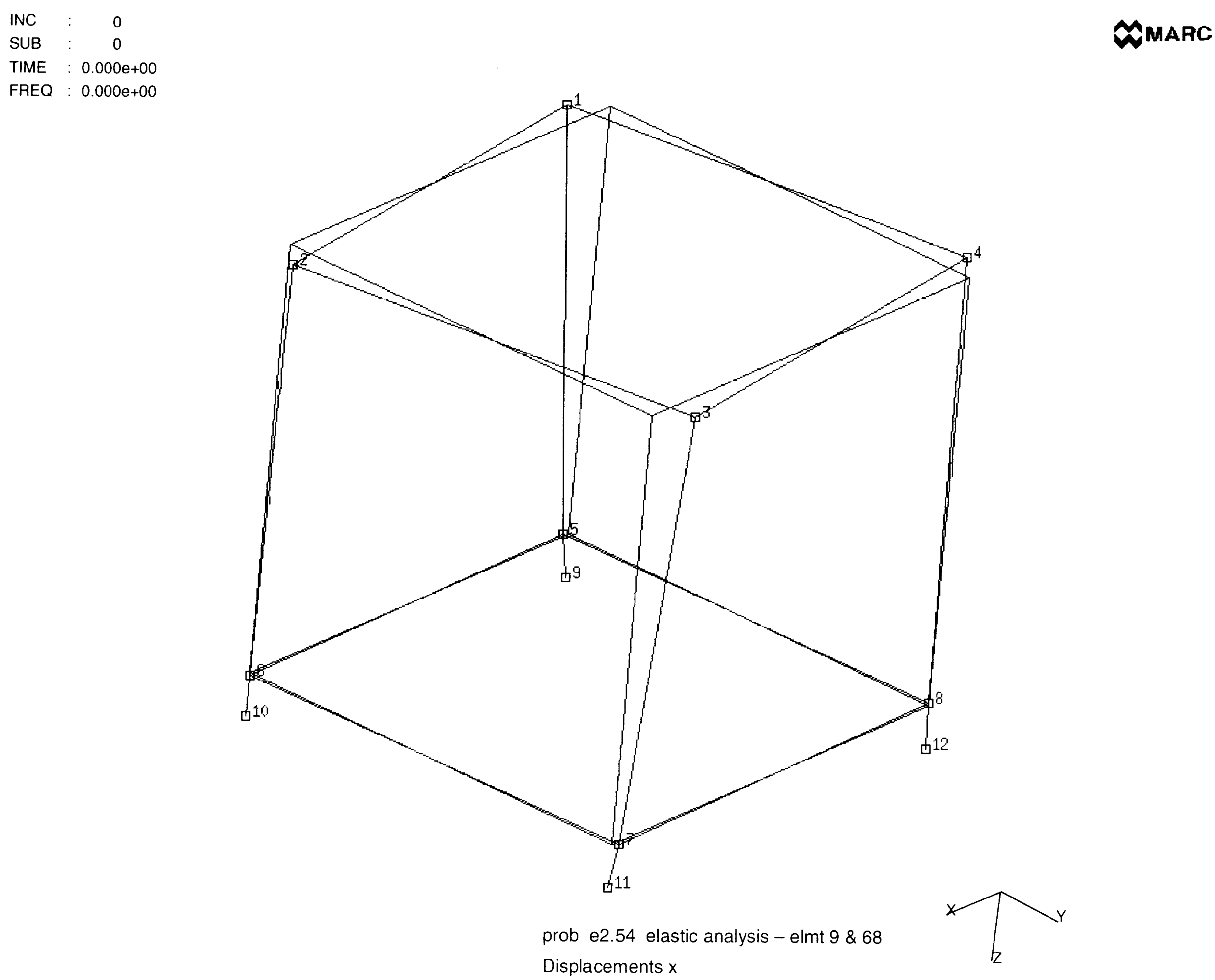


Figure 2.54-2 Deformed Mesh Plot

2.55 Shell Roof by Element 72

This problem illustrates the use of MARC element type 72 for an elastic analysis of a barrel vault shell roof. The roof is subjected to its own weight. This problem is similar to problems 2.16, 2.17, 2.18, and 2.19.

Element

Element type 72 is an 8-node thin-shell element with three degrees of freedom at each corner node, and an additional degree of freedom at the midside nodes (edge self-rotation).

Model

The element is type 72. There are 16 elements with a total of 65 nodes. The dimensions of the shell roof and the finite element mesh are shown in Figure 2.55-1.

Material Properties

Young's modulus is 30×10^5 psi. Poisson's ratio is taken to be 0.

Geometry

The shell thickness is 3.0 inches.

Loading

Uniform load in negative z-direction, specified with load type 1. The magnitude of the weight is 0.625 psi.

Boundary Conditions

Supported end:

A. $u = 0$, $w = 0$, at $y = 0$

The following degrees of freedom are constrained at the lines of symmetry:

B. $u = 0$ and $\phi = 0$ at $x = 0$

C. $v = 0$ and $\phi = 0$ at $y = 300$

SHELL SECT

The SHELL SECT option allows you to reduce the number of integration points from the default value of 11 to a minimum value of three in the shell thickness direction. This three-point integration scheme is exact as for a linear elastic problem.

Subroutine UFXORD

The coordinates are first defined in the x-y plane and are then modified by the use of the user subroutine UFXORD in order to obtain the three-dimensional model.

Results

A deformed mesh plot is shown in Figure 2.55-2. The results are in good agreement with problem 2.19. The element is much easier to use than elements type 4, 8, or 24 (used in previous problems).

Parameters, Options, and Subroutines Summary

Example e2x55.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	UFXORD

User subroutine in u2x55.f:

UFXORD

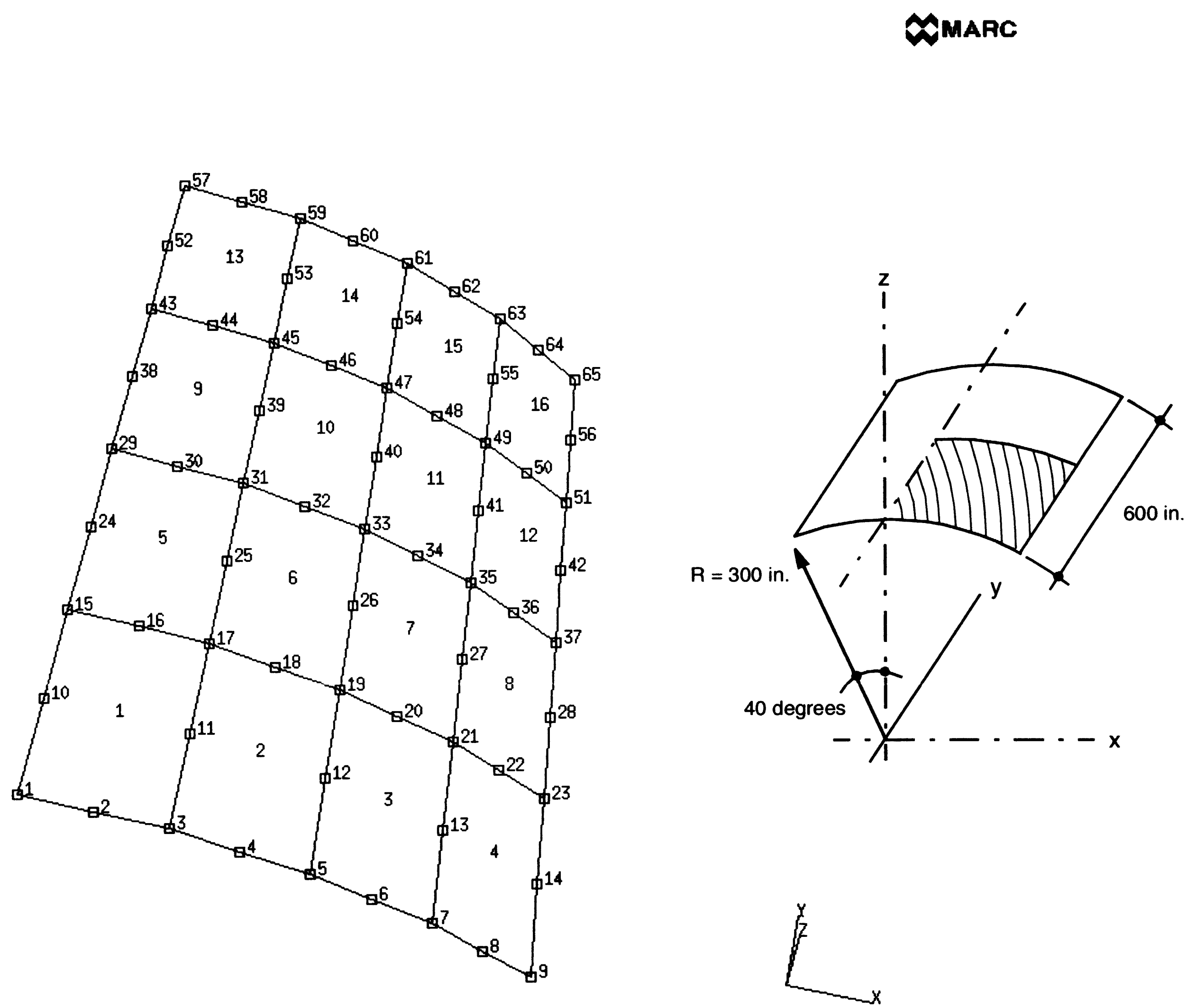


Figure 2.55-1 Shell Roof and Mesh

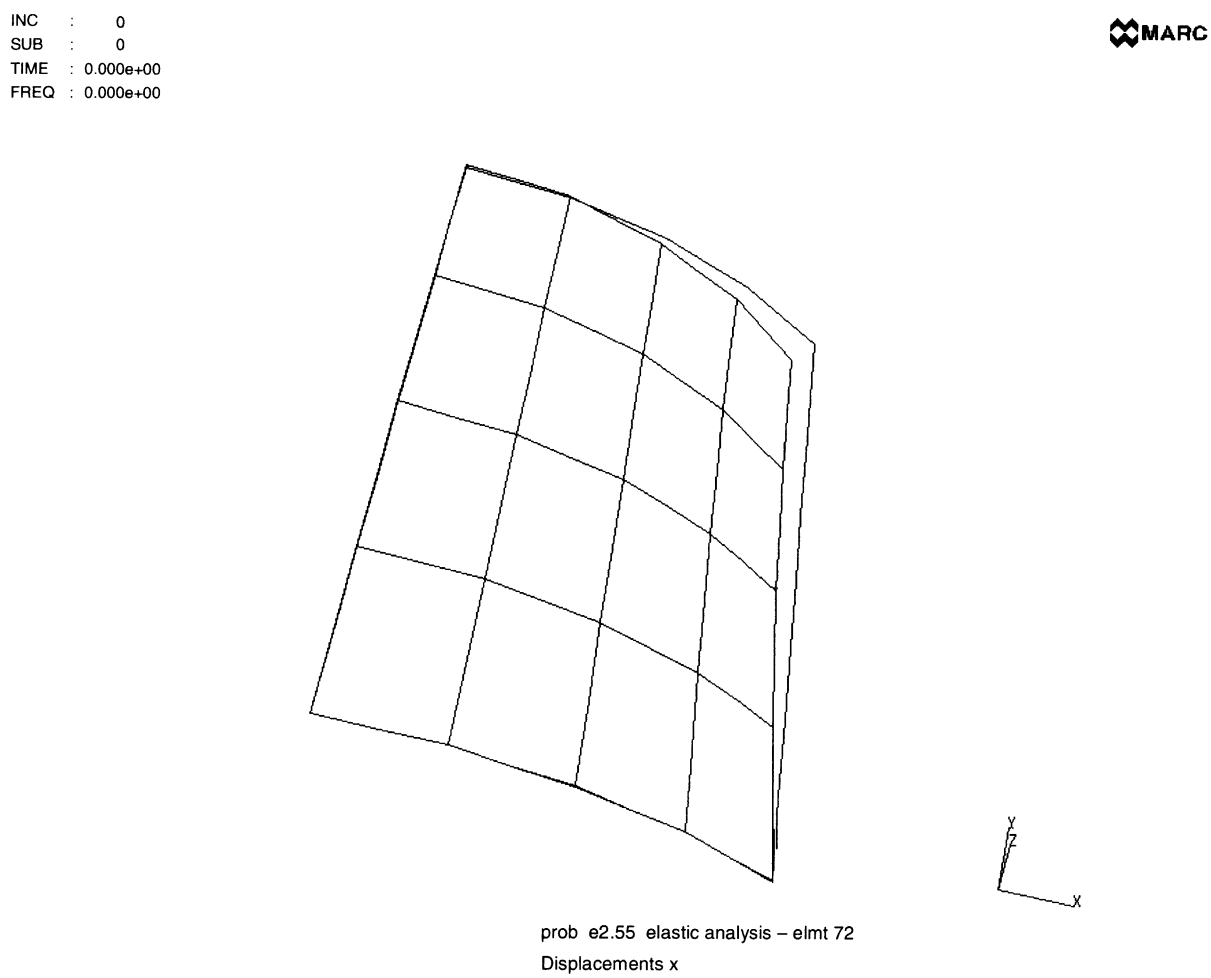


Figure 2.55-2 Deformed Mesh Plot

2.56 Cylinder-sphere Intersection by Element 72

This problem illustrates the use of MARC element type 72 for an elastic analysis of a cylinder-sphere intersection. The cylinder is subjected to internal pressure. The use of the SHELL SECT parameter and the user subroutine UFXORD is also illustrated. This problem is similar to 2.15.

Element

Element type 72 is a bilinear, constrained, 8-node shell element. With element type 72, no tying is necessary at the intersection.

Model

The element is type 72. There are 24 elements, with a total of 93 nodes. The dimensions of the shell structure and the finite element mesh used are shown in Figure 2.56-1.

Material Properties

Young's modulus is 1000.0 psi with a Poisson's ratio of 0.

Geometry

The shell thickness is 1.0 inch.

Loading

Internal pressure: this is specified with load type 2, with magnitude of 1.0 psi.

Boundary Conditions

The following degrees of freedom are constrained at the lines of symmetry:

A. $v = 0$ and $\phi = 0$ at $y = 0$,

B. $w = 0$ and $\phi = 0$ at $z = 0$,

C. $u = 0$ and $\phi = 0$ at $x = 0$,

where ϕ is the rotation around the edge.

SHELL SECT

The SHELL SECT allows you to reduce the number of integration points in the shell thickness direction from the default value of 11 to a minimum value of three. For elastic analysis, this three-point integration scheme is exact.

Subroutine UFXORD

The coordinates are first entered in the x-y plane. The coordinates are then modified by the use of user subroutine UFXORD in order to obtain the three-dimensional model.

Results

A deformed mesh plot is shown in Figure 2.56-2 and stress contours are depicted in Figure 2.56-3. The solution is axisymmetric as anticipated. The maximum stress of 1.27 occurs in the spherical shell close to the intersection. While this problem uses three times the number of elements as problem 2.15, the ratio of degrees of freedom is only 11:9.

Parameters, Options, and Subroutines Summary

Example e2x56.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	UFXORD

User subroutine in u2x56.f:

UFXORD

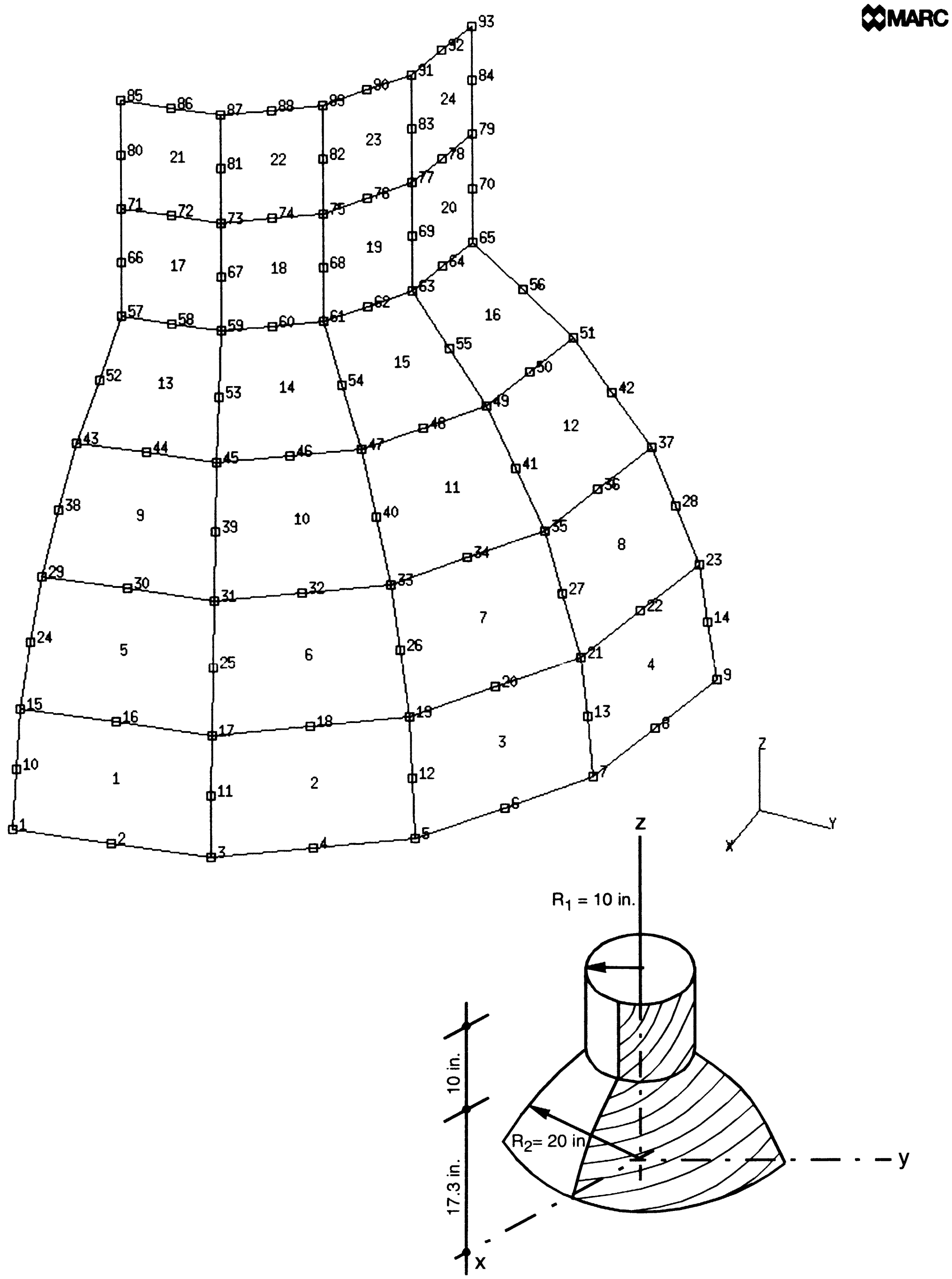


Figure 2.56-1 Shell Structure and Mesh

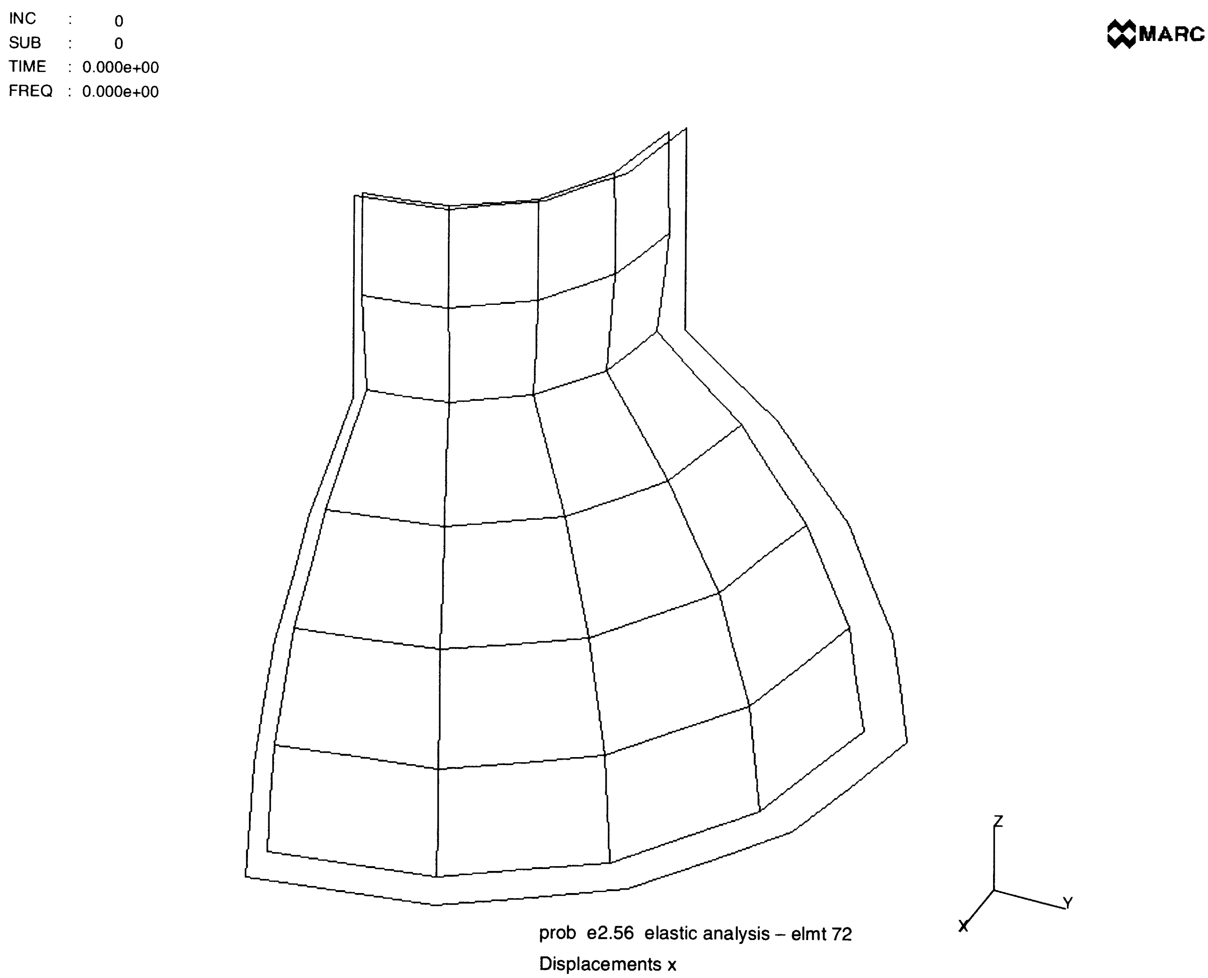


Figure 2.56-2 Deformed Mesh Plot

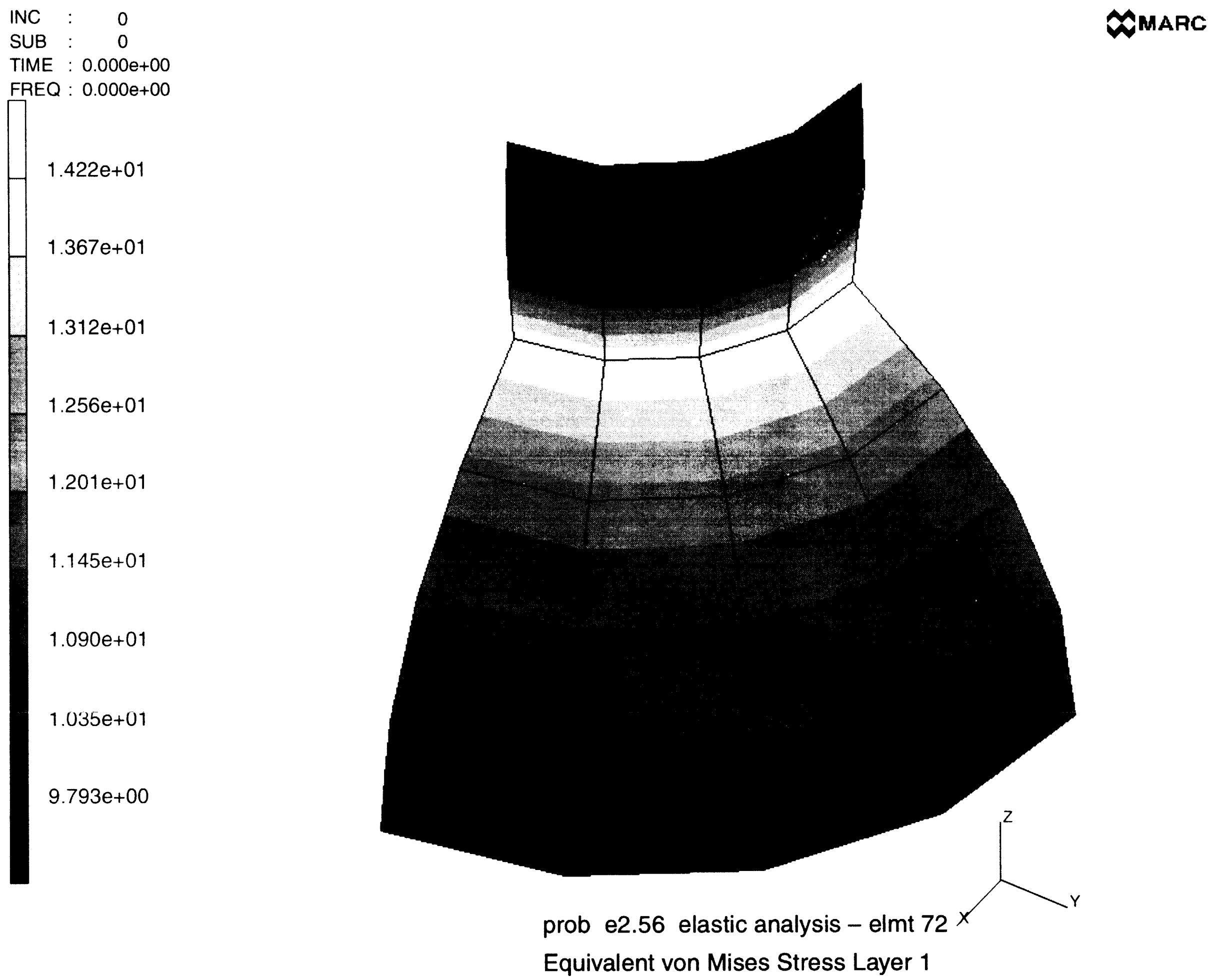


Figure 2.56-3 Equivalent von Mises Stress Contours

2.57 Closed Section Beam Subjected to a Point Load

This problem, same as problem 2.7, demonstrates the use of two closed-section beam elements (type 76, 3-node and type 78, 2-node). A hollow, square-section beam, clamped at both ends, has a single-point load applied at the center. The results are compared to the analytical solution.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x57a	76	5	11
e2x57b	78	5	6

Elements

Library element types 76 and 78 are used. Both elements are closed-section, straight-beam elements with no warping of the section, but including twist. These elements have six degrees of freedom per node – three displacements and three rotations in the global coordinate system. For the 3-node beam element (type 76), the degrees of freedom at midside node is the rotation about the beam axis.

Model

Only half of the beam with a total length of 10 inches, is modeled, taking advantage of the beam's symmetry. Five elements are used for the beam. The total number of nodes is 11 for 3-node and 6 for 2-node beam elements, respectively. (see Figure 2.57-1).

Geometry

The model uses the BEAM SECT parameter to define its cross-sectional geometry. EGEOM1 = 0 indicates a noncircular cross section. EGEOM2 gives the section number as a floating point value, here equal to 1.

Material Properties

The beam is considered elastic with a Young's modulus of 20.0 x 10^6 psi.

Loading

A single-point load of 50 pounds is applied in the negative y-direction at the center node of the beam.

Boundary Conditions

In the model, the beam-end node (node 1) is fixed against displacement and rotation, simulating a fully built-in condition. Thus, $u = v = w = \theta_x = \theta_y = \theta_z = 0$. The midpoint node, node 6, is fixed against axial displacement and rotation; $u = \theta_x = \theta_y = \theta_z = 0$, thus ensuring symmetry boundary conditions. For the 3-node beam element (type 76), the rotation about the beam axis is also constrained, $\phi_t = 0$, for all mid-side nodes (nodes 7 to 11).

Special Considerations

Elements 76 and 78 have their cross sections specified by the BEAM SECT parameter, which is given in the parameters section. Details are given in *MARC Volume A: Theory and User Information*. In this case, four branches are used to define the hollow, square section (see Figure 2.57-2).

Each branch is of constant thickness (0.01 inch) with no curvature and is 0.99 inch in length. The branches are defined at the midpoint of the thickness of the cross section. The first branch begins at local coordinates, x = -0.495, y = -0.495 and each following branch begins its length at the end coordinates of the previous branch. Except for the first branch, only the coordinates at the end of the branch need to be defined. Each branch has four divisions which provide the four stress points for the branch.

Results

A simple elastic analysis was run with one load increment of negative 50 pounds applied to node 6 in the zeroth increment. The computed results are compared with an exact solution in Table 2.57-1 and Table 2.57-2.

Table 2.57-1 Y Deflection (inches)

Node	Element 14	Element 52	Elements 76 & 78	Calculated
1	0.	0.	0.	0.
2	.000419	.000419	.000419	.000422
3	.001417	.001417	.001417	.001428
4	.002609	.002609	.002609	.002628
5	.003607	.003607	.003607	.003634
6	.004026	.004025	.004026	.004056

Table 2.57-2 Moments (inches-pounds) and Reaction Forces (pounds

Element 14	Element 52	Elements 76 & 78	Calculated
M = 125.	M = 125.	M = 125.	M = 125.
R = 50.	R = 50.	R = 50.	R = 50.

Parameters, Options, and Subroutines Summary

Example e2x57a.dat:

Parameters	Model Definition Options
BEAM SECT	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SIZING	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	POINT LOAD

Example e2x57b.dat:

Parameters	Model Definition Options
BEAM SECT	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SIZING	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	POINT LOAD

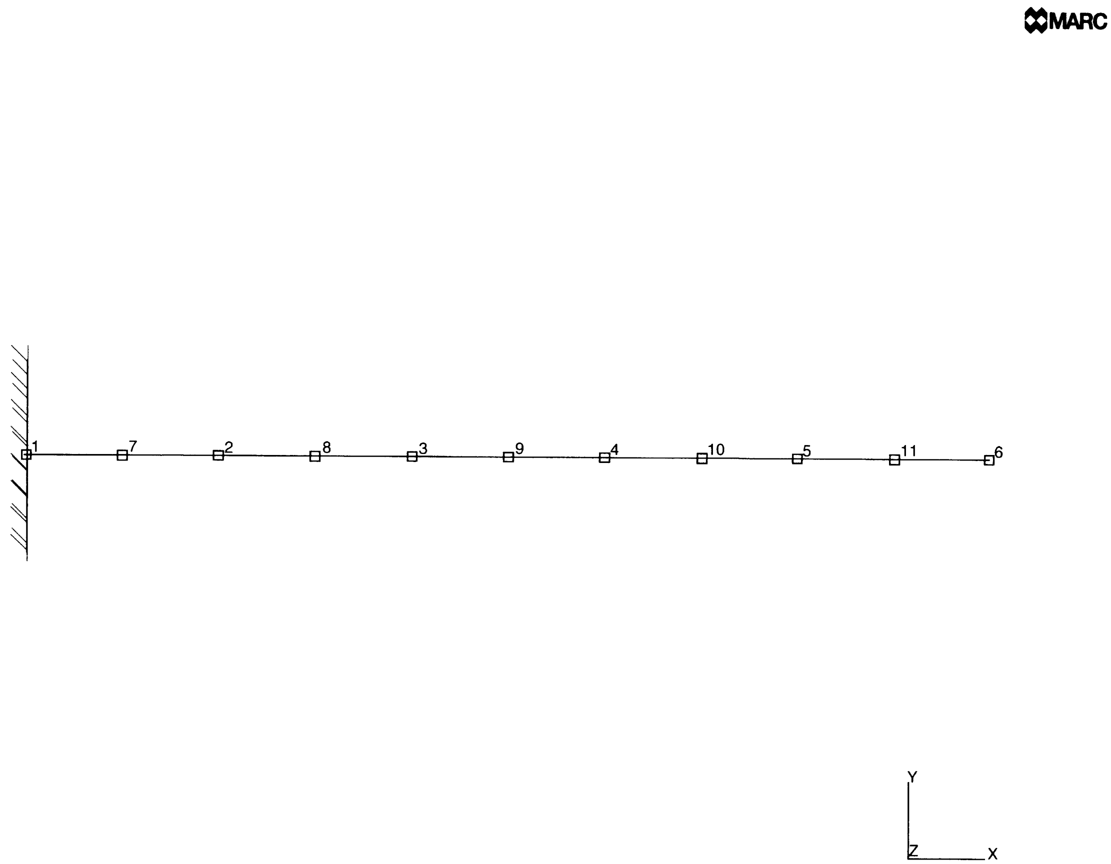


Figure 2.57-1 Closed Section Beam Model

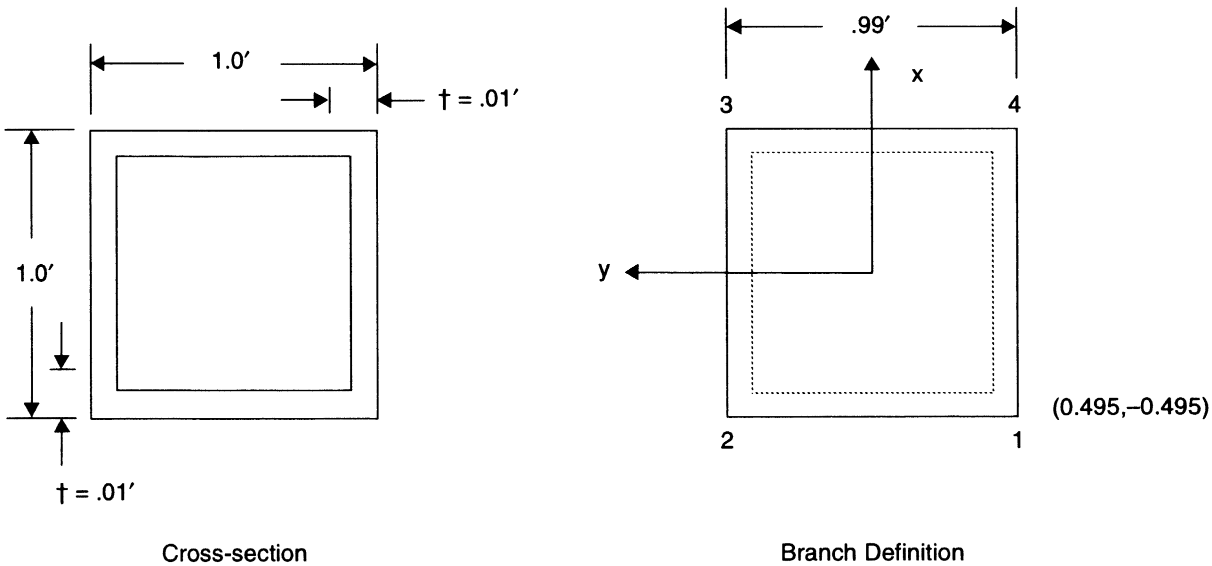


Figure 2.57-2 Hollow, Square-Section Beam

2.58 Open Section, Double Cantilever Beam Loaded Uniformly

Same as problem 2.6, an I-section beam is loaded uniformly, parallel to the plane of the web. The beam is fixed against rotation and displacement at each end. This problem demonstrates the use of the BEAM SECT parameter to define the cross section of a beam and the use of two open section beam elements (type 77, 3-node and type 79, 2-node). The results are compared to the analytic solution.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x58a	77	10	21
e2x58b	79	10	11

Elements

Library element types 77 and 79 are used. Both elements are open-section, straight, thin-walled beams including warping and twist of the section. These elements have six degrees of freedom per node – three displacements and three rotations in the global coordinate system. For the 3-node beam element (type 77), the degrees of freedom at the midside node is the rotation about the beam axis.

Model

The beam of length 10 inches is modeled with 10 elements (see Figure 2.58-1). The number of nodes is 21 for 3-node and 11 for 2-node beam elements, respectively.

Geometry

EGEOM2 is used as a floating point value to cross reference the section number; here EGEOM2 = 1. as only one section type is given.

Material Properties

Young's modulus is specified as 20 x 10^6 psi. Consistency with the analytical solution requires Poisson's ratio to be 0.

Loading

Uniform pressure of 10 pounds per length in the negative global Y direction.

Boundary Conditions

The beam is fixed against rotation and displacement at each end; that is:

$u = 0$ $\phi_x = 0$
$v = 0$ $\phi_y = 0$
$w = 0$ $\phi_z = 0$

Special Considerations

Element types 77 and 79 have a cross-section specification that is entered in the parameter block section, after the header BEAM SECT. Details are given in *MARC Volume A: Theory and User Information*. In the present case, five branches are used to define the beam section (see Figure 2.58-2).

The first branch is one flange of beam, read in at constant thickness (0.18 inch) and with no curvature. The second branch is a zero thickness branch that doubles back to the flange center. The third branch is the web, straight and with constant thickness (0.31 inch). The fourth branch is half the remaining flange, with zero thickness. The fifth branch is straight and with constant thickness (0.18 in.) which doubles back over the fourth branch.

Results

An elastic analysis was performed. Five generalized strains and axial stress at integration points are printed out. The results are compared with calculated results from *Formulas for Stress and Strain*, R. J. Roark. These are summarized in Table 2.58-1.

Table 2.58-1 Y Deflection (inches)

Node	Element 13	Elements 77 & 79	Calculated
1	0.	0.	0.
2	1.82×10^{-5}	1.83×10^{-5}	1.82×10^{-5}
3	5.79×10^{-5}	5.81×10^{-5}	5.75×10^{-5}
4	9.99×10^{-5}	10.0×10^{-5}	9.91×10^{-5}
5	1.307×10^{-4}	1.308×10^{-4}	1.295×10^{-4}
6	1.419×10^{-4}	1.419×10^{-4}	1.404×10^{-4}

Parameters, Options, and Subroutines Summary

Example e2x58a.dat:

Parameters	Model Definition Options
BEAM SECT	CONNECTIVITY
ELEMENTS	COORDINATES
END	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC

Example e2x58b.dat:

Parameters	Model Definition Options
BEAM SECT	CONNECTIVITY
ELEMENTS	COORDINATES
END	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC

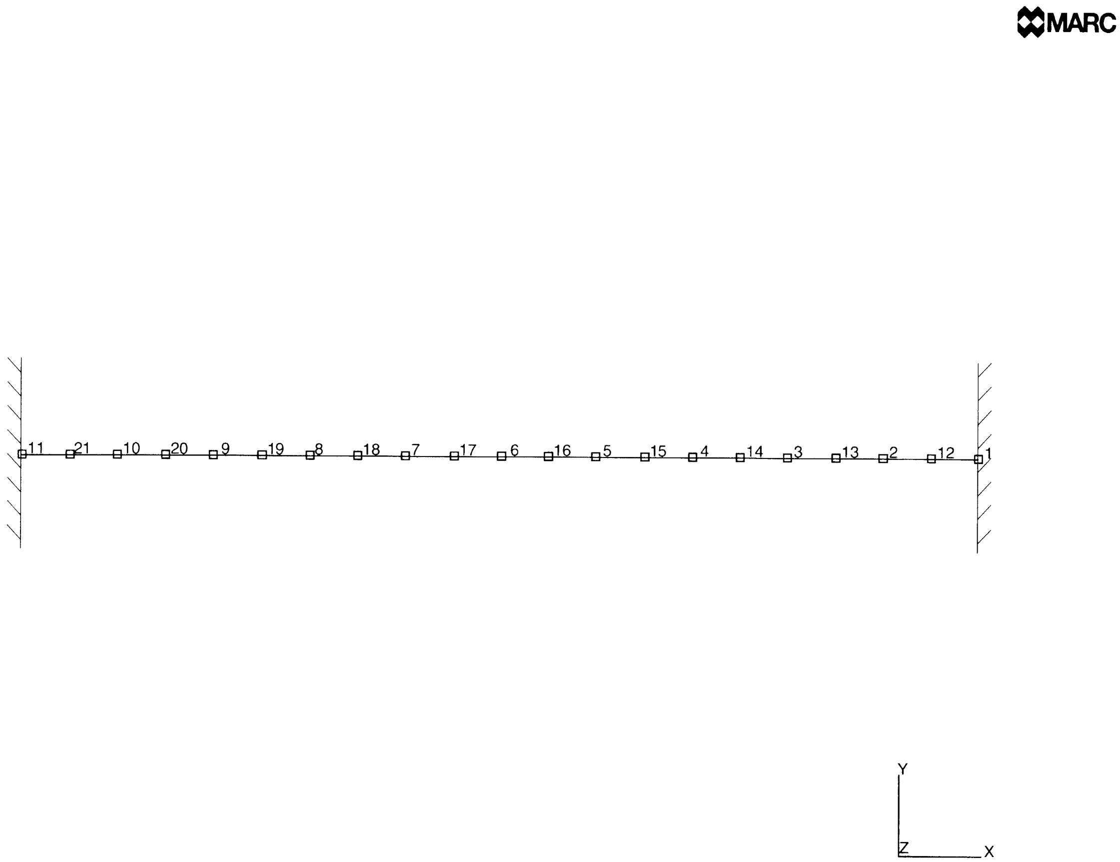


Figure 2.58-1 Open Section Beam Model

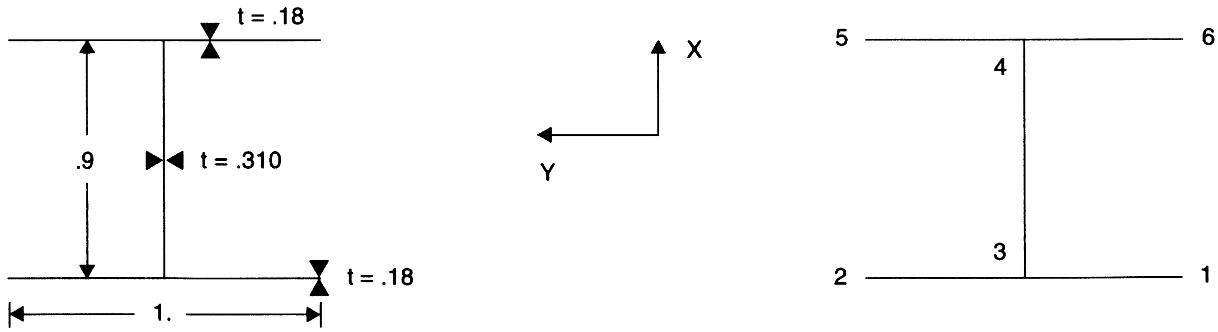


Figure 2.58-2 Beam Section and Sequence of Branch Traversal

2.59 Simply Supported Elastic Beam Under Point Load

This problem demonstrates the use of a two-node straight elastic beam for a simply supported beam structure subjected to a point load at midspan of the beam. The effects of transverse shear are included in the formulation of the beam element.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x59a	98	5	6	
e2x59b	98	5	6	BEAM SECT

Element

Element type 98 is a two-node straight elastic beam in space and includes the transverse shear effects in its formulation. It uses a linear interpolation in displacement along the axis of the beam and a cubic interpolation in the direction normal to the beam axis. In addition to elastic behavior, the element can also be used for hypoelastic materials. The hypoelastic behavior must be defined in the UBEAM user subroutine.

Model

As shown in Figure 2.59-1, due to symmetry, only one-half of the simply supported beam is modeled. The finite element mesh consists of five elements and six nodes. The span of the beam is 10 inches and the cross-section of the beam is assumed to be a closed, thin, square section.

Geometry

The GEOMETRY block is used for entering the beam section properties. There are two options available to you for the use of the GEOMETRY block. The section properties area = 0.0396 inches^2, $I_x = I_y = 6.4693 \times 10^{-3}$ inches^4, can be directly entered through the GEOMETRY block or through the BEAM SECT parameter by defining area = 0.0, I_x = section number, in the GEOMETRY block. In the latter case, you must enter the beam section properties through the BEAM SECT parameter.

BEAM SECT

The BEAM SECT parameter is required only if you choose to enter area = 0.0 and I_x = section number, in the GEOMETRY block. The beam section properties to be entered through this option area: area, I_x, I_y, torsional stiffness factor, and effective transverse shear areas.

Material Properties

The material of the beam is assumed to have a Young's modulus of 20,000 psi and Poisson's ratio of 0.3.

Loading

The beam is assumed to be subjected to a point load of 20 pounds. Due to symmetry, a 10 pound point load is applied at node 6 in the positive x-direction.

Boundary Conditions

At node 1, all translational degrees of freedom are constrained ($u_x = u_y = u_z = 0$) for the simulation of simply-supported conditions. At midspan (node 6), all degrees of freedom except u_x are constrained for the simulation of symmetry condition.

Results

A comparison of beam deflections is shown in Table 2.59-1. The beam deflection at node 6 predicted by element 98 is 4% larger than that of element 52 (3.3523/3.2203 = 1.041). The additional beam deflection is clearly due to the effect of transverse shear allowed in element 98.

Table 2.59-1 Comparison of Beam Deflections (in.)

Node	Element 52	Element 98
1	0.0	0.0
2	0.9532	0.9796
3	1.8291	1.8819
4	2.5505	2.6297
5	3.0399	3.1455
6	3.2203	3.3523

Parameters, Options, and Subroutines Summary

Example e2x59a.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POINT LOAD

Example e2x59b.dat:

Parameters	Model Definition Options
BEAM SECT	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SIZING	FIXED DISP
TITLE	GEOMETRY
	ISOTROPIC
	POINT LOAD

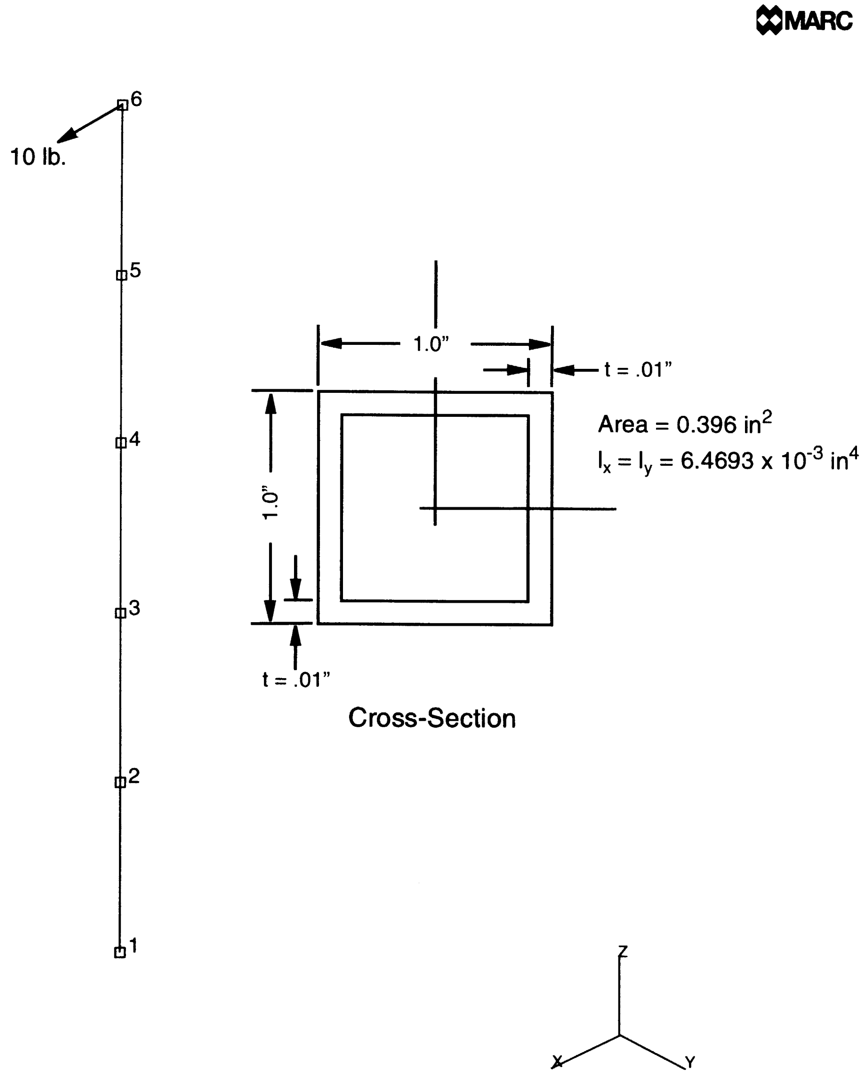


Figure 2.59-1 Simply Supported Beam Under Point Load

2.60 Uniform Pressure on Cylindrical Cavity of an Infinite Body (The Lamé Solution)

This problem demonstrates the use of plane strain and plane strain semi-infinite elements for the solution of a classical elasticity (Lamé) problem. As shown in Figure 2.60-1, the cylindrical cavity of radius a is located in the x-y plane and is extended to infinity in both the positive and negative z-directions. A uniformly distributed pressure p is assumed to be acted on the interior surface of the cavity. The finite element solution to this problem is evaluated in this example.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x60a	11 & 91	16	30
e2x60b	27 & 93	16	69

Elements

Since the Lamé problem deals with two-dimensional infinite body, it is convenient to use two types of plane strain elements for the modeling of the near and far fields of the body. In this example, the regular plane strain element types 11 (4-node) and 27 (8-node) are used for the near field and the plane strain semi-infinite element types 91 (6-node) and 93 (9-node) are used for the far field of the two-dimensional infinite body. Element type 11 is compatible with element type 91, and element type 27 is compatible with element type 93. The interpolation functions of element types 91 and 93 are such that the elements expand to infinity and the displacements at infinity are implied to be zero.

Model

A plane strain model consisting of twelve regular plane strain elements and four plane strain semi-infinite elements are used for the Lamé problem. The total number of nodes in the model is 30 for Model A (element types 11 and 91), and 69 for Model B (element types 27 and 93). Finite element meshes are shown in Figure 2.60-2 and Figure 2.60-3, respectively.

Geometry

The GEOMETRY block is not selected for this problem. As a result, a default thickness of 1.0 is used for this example.

Material Properties

The material is assumed to have a Young's modulus of 1.0 and a Poisson's ratio of 0.1.

Loading

A uniformly distributed pressure (DIST LOADS) of 1.0 is applied along the interior surface of the cavity (Elements 1, 4, 7 and 10).

Boundary Conditions

The first degrees of freedom are constrained for nodes located along the line of x = 0; the second degrees of freedom are constrained for nodes located along the line of y = 0, for the simulation of symmetry conditions. No boundary conditions at infinity are required.

Results

Deformed meshes and von Mises stress distributions are shown in Figure 2.60-4 through Figure 2.60-7 for Models A and B. Radial displacements are tabulated in Table 2.60-1. The comparison of finite element results with calculated values is reasonably good.

Table 2.60-1 Radial Displacements

Analytical Solution*		Element 91		Element 93	
R =	Displacement	Node	Displacement	Node	Displacement
1.0	1.1000	2	1.0156	3	1.0685
1.5	0.7333			5	0.7128
2.0	0.5500	4	0.5189	8	0.5357
2.5	0.4400			10	0.4280
3.0	0.3667	6	0.3480	13	0.3565
3.5	0.3143			15	0.3055
4.0	0.2750	8	0.2618	18	0.2674
8.0	0.1375	21	0.1309	53	0.1337
12.0	0.0917	26	0.0873	56	0.0891

*The R-displacements are calculated from:

$$u = \frac{(1+\nu)}{Er} p a^2$$

Parameters, Options, and Subroutines Summary

Example e2x60a.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DEFINE
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	ISOTROPIC
	POST
	PRINT CHOICE

Example e2x60b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DEFINE
TITLE	DIST LOADS
	END OPTION
	FIXED DISP
	ISOTROPIC
	POST
	PRINT CHOICE

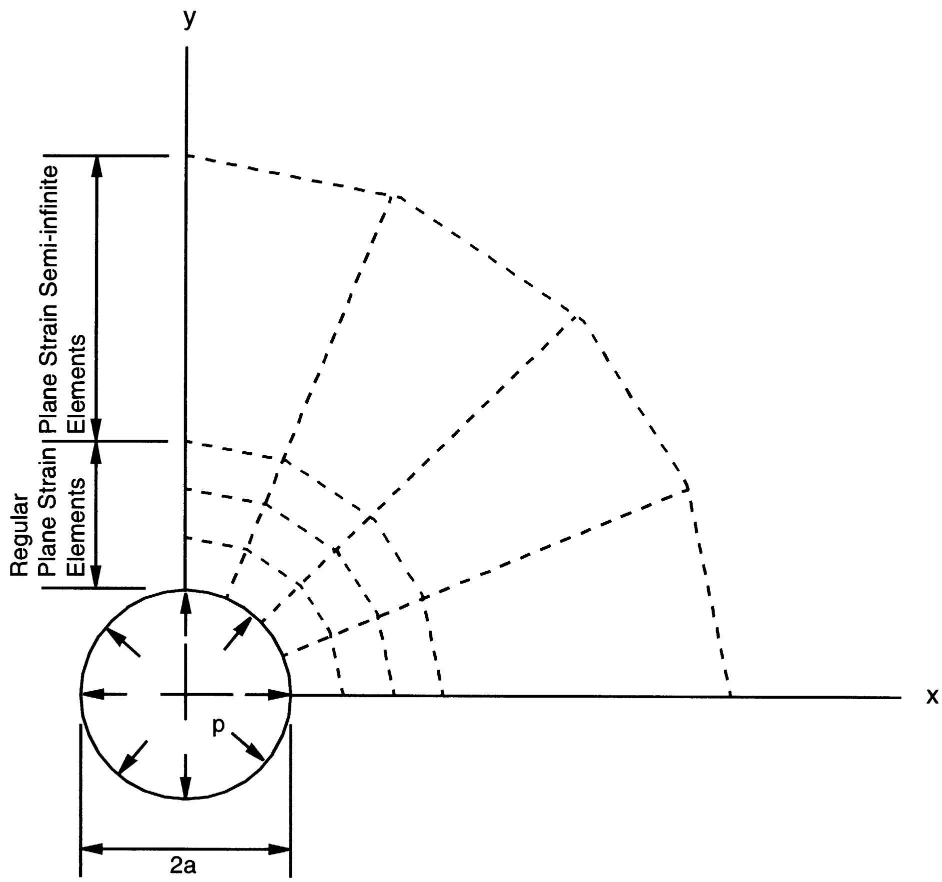


Figure 2.60-1 Uniform Pressure on Cylindrical Cavity of an Infinite Body (The Lamé Solution)

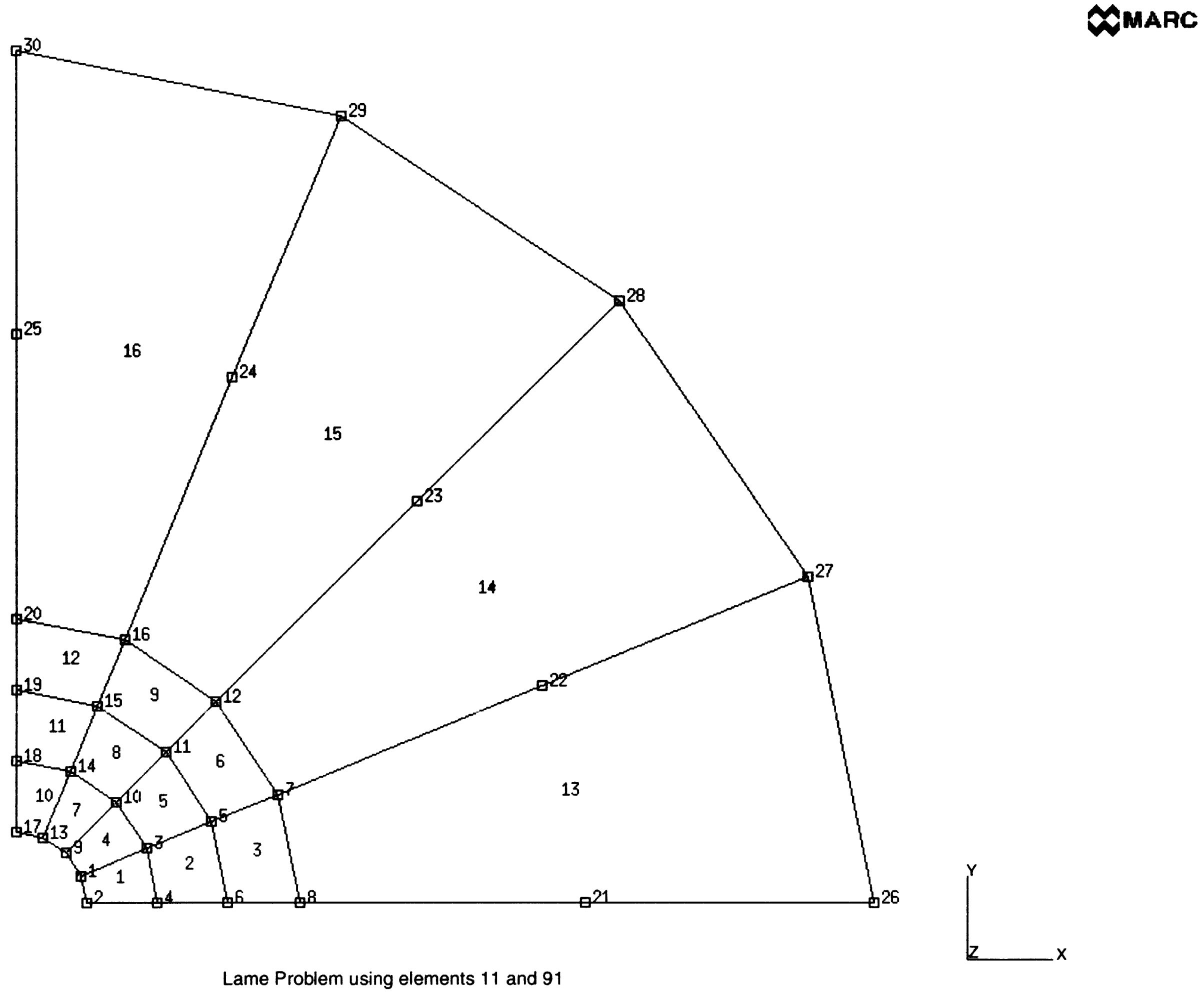


Figure 2.60-2 Finite Element Mesh (Model A) (Elements 11 and 91)

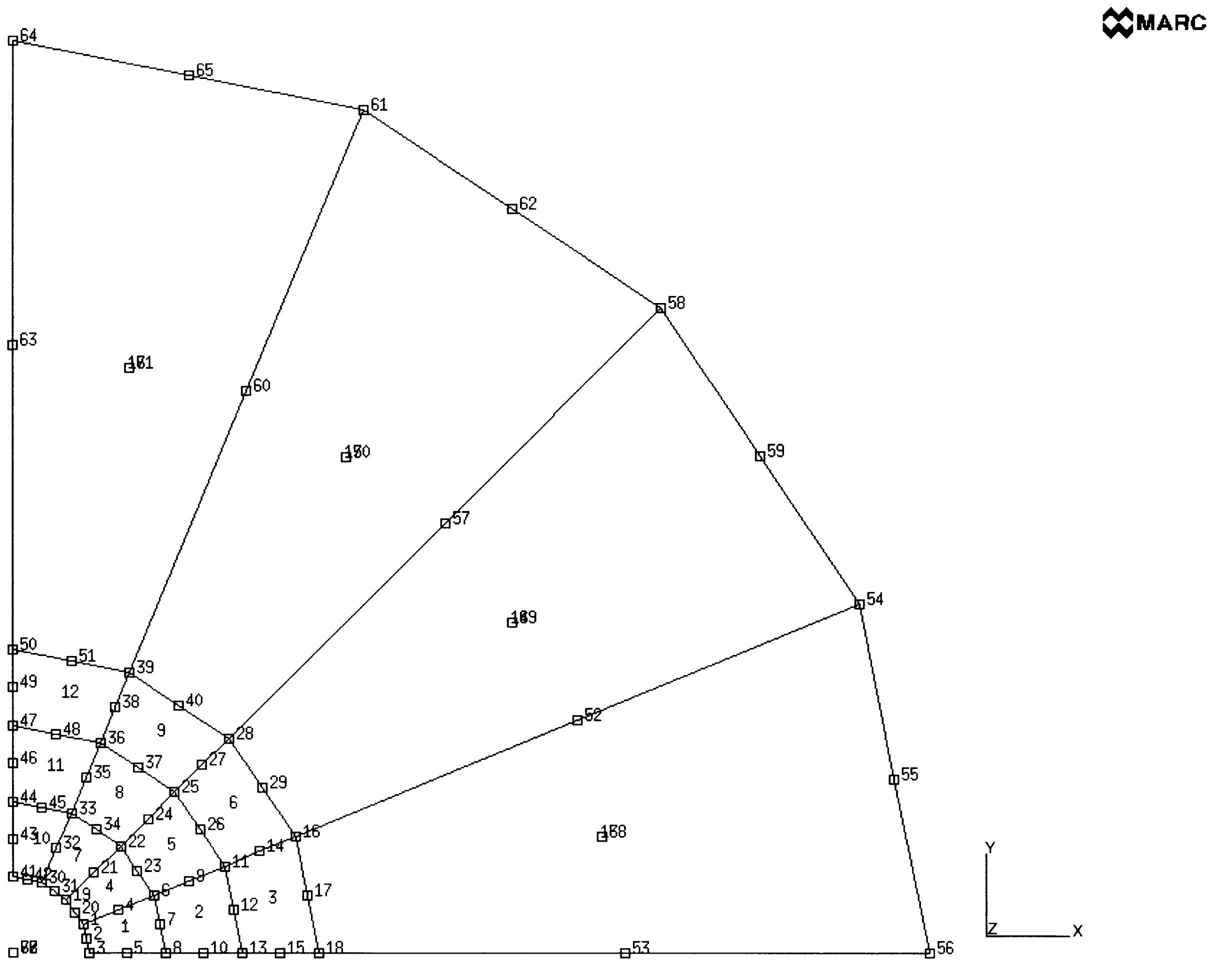


Figure 2.60-3 Finite Element Mesh (Model B) (Elements 27 and 93)

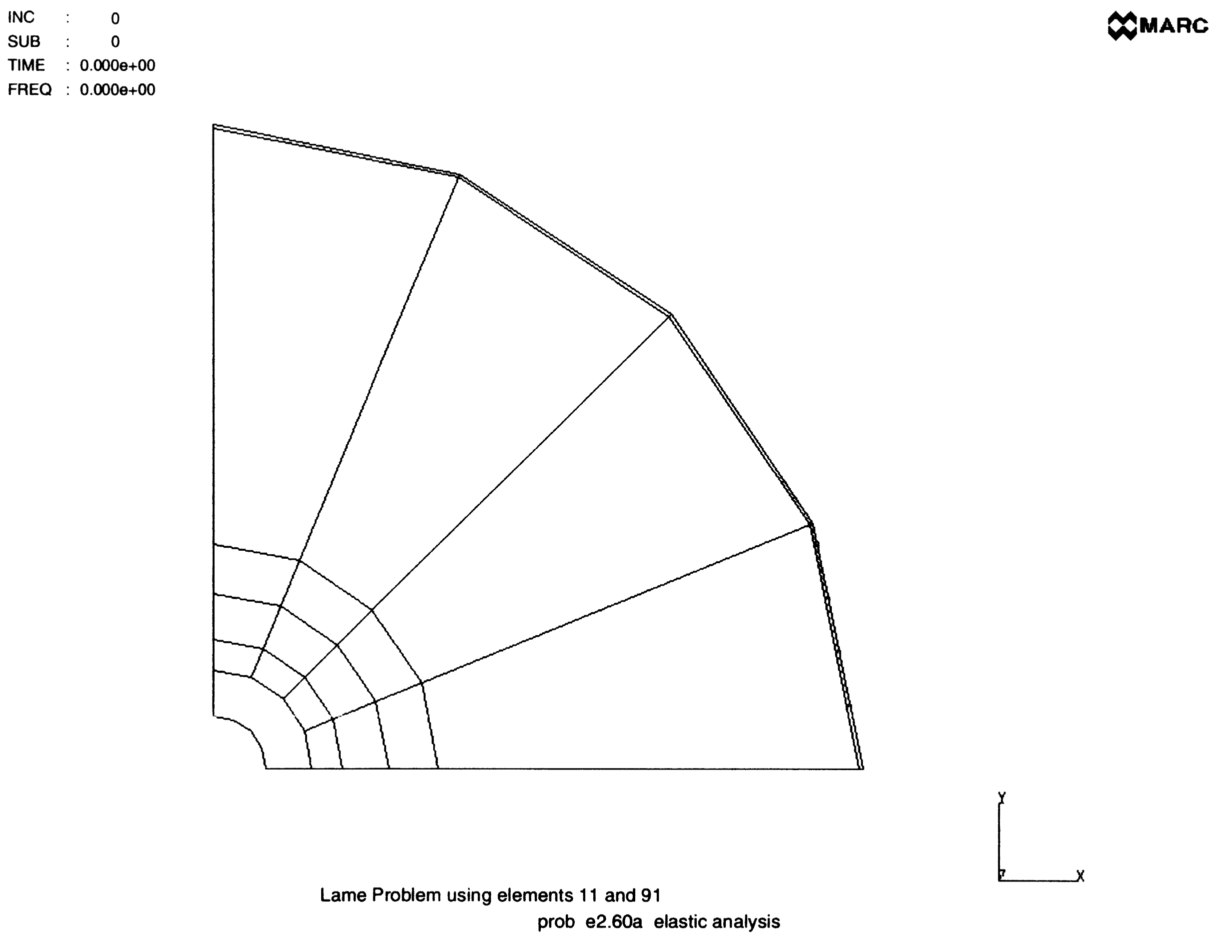


Figure 2.60-4 Deformed Mesh (Model A)

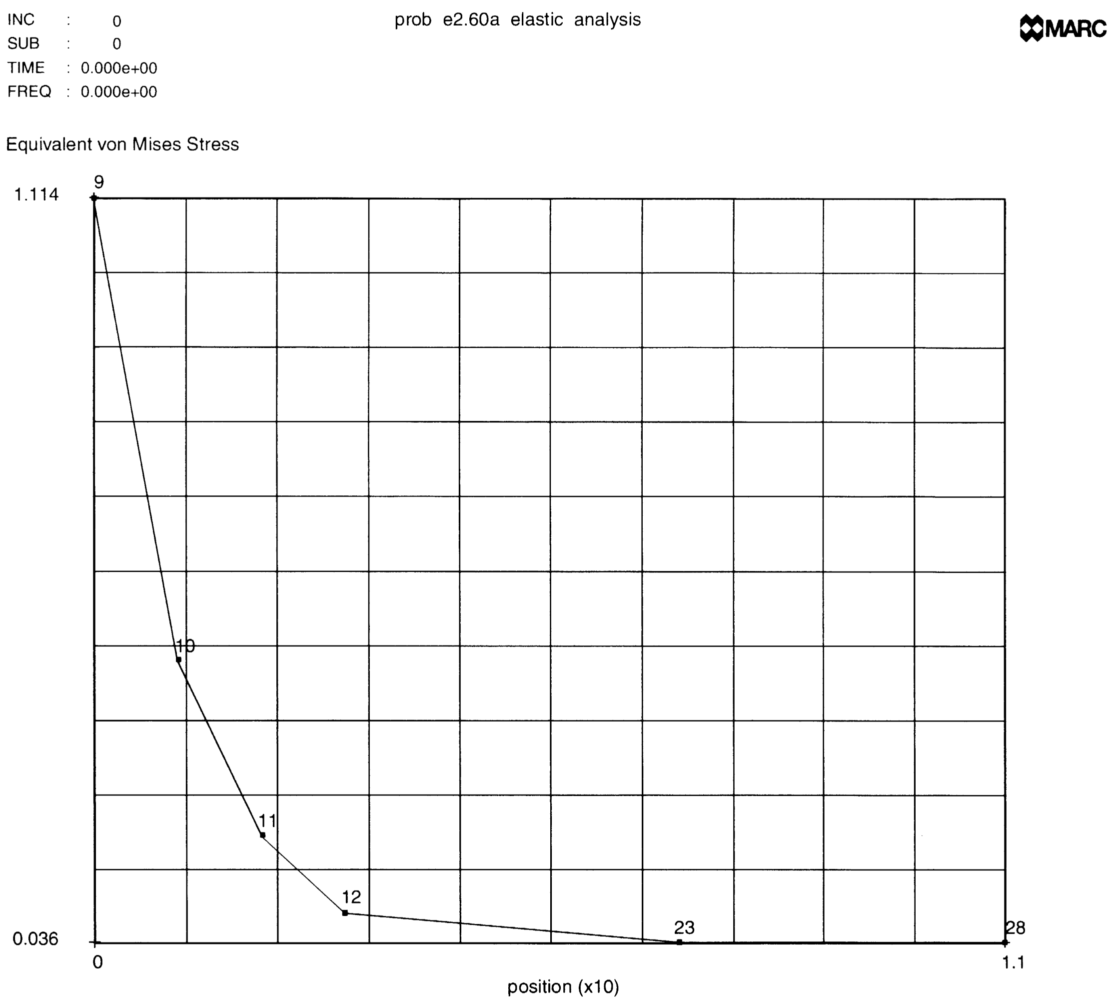


Figure 2.60-5 Stress Distribution Along Radial Path

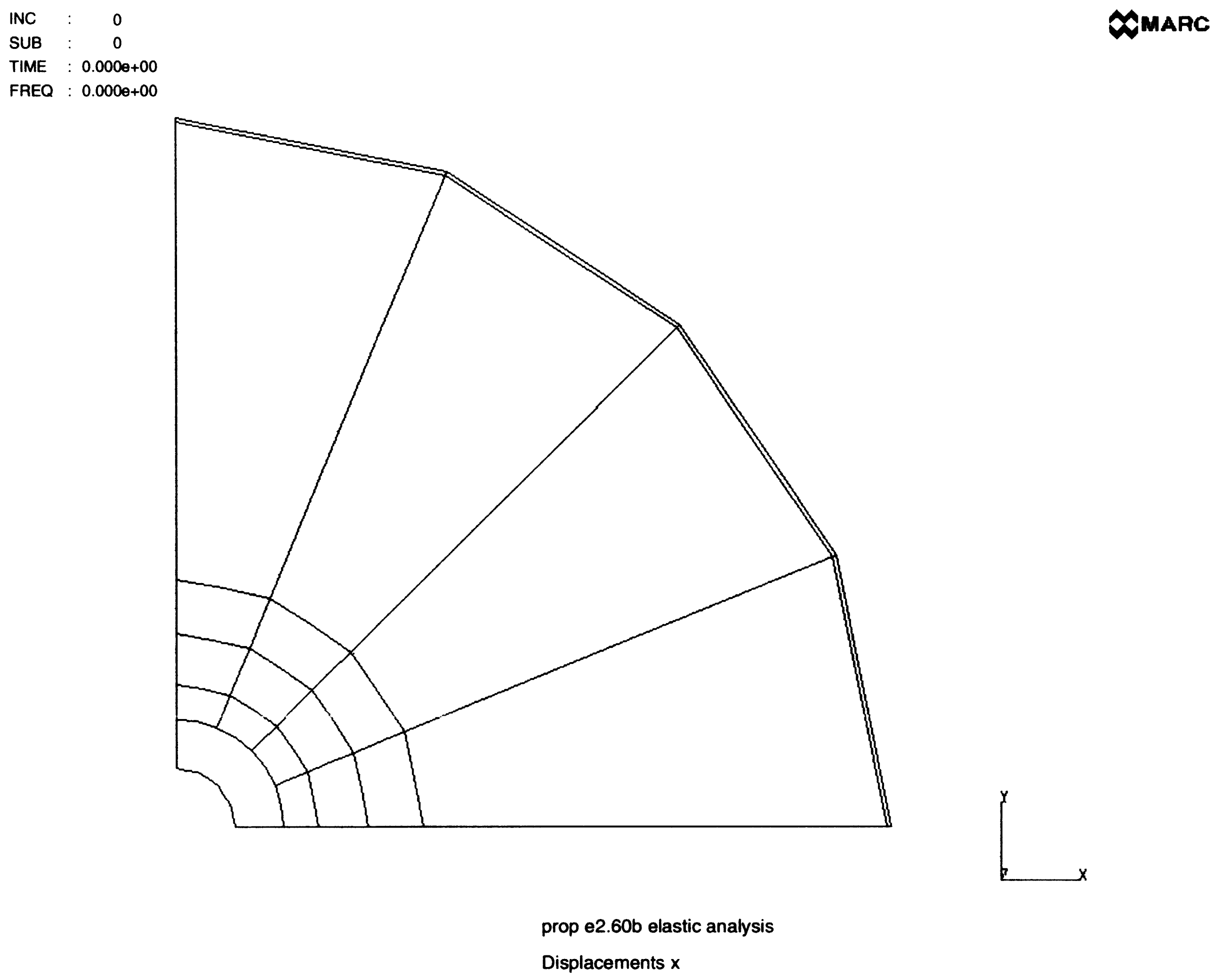


Figure 2.60-6 Deformed Mesh (Model B)

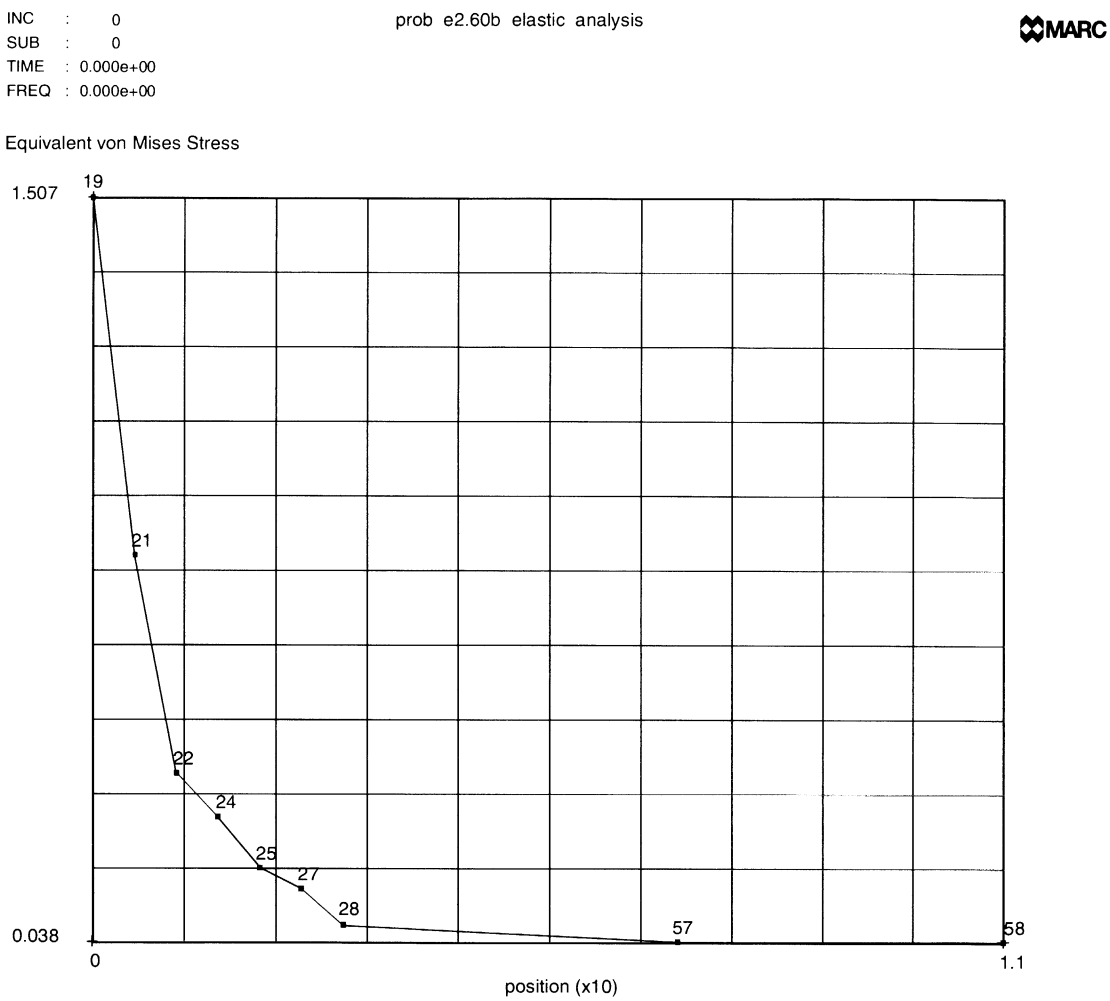


Figure 2.60-7 Stress Distribution Along Radial Path

2.61 The Boussinesq Problem (Point Load on Boundary of a Semi-infinite Body)

This problem demonstrates the use of axisymmetric ring and axisymmetric semi-infinite elements for the solution of a classical elasticity (Boussinesq) problem. As shown in Figure 2.61-1, the plane z = 0 is the boundary of a semi-infinite solid and a force P is acting on this plane along the z-axis. The solution of this problem was originally given by J. Boussinesq and a detailed discussion of the solution can be found in the reference *Theory of Elasticity*, by S. Timoshenko and J. N. Goodier, p. 362.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x61a	10 & 92	20	31
e2x61b	28 & 94	20	75

Elements

Since the Boussinesq problem deals with semi-infinite body, it is convenient to choose two types of axisymmetric elements for the modeling of the near and far fields of the body. In this example, the regular axisymmetric ring element types 10 (4-node) and 28 (8-node) are used for the near field and the axisymmetric semi-infinite element types 92 (6-node) and 94 (9-node) are used for the far field of the semi-infinite body. Element type 10 is compatible with element type 92 and element type 28 is compatible with element type 94. The interpolation functions of element types 92 and 94 are such that the elements expand to infinity, and the displacements at infinity are implied to be zero.

Model

An axisymmetric model consisting of 16 regular axisymmetric ring elements and 4 axisymmetric semi-infinite elements is used for the Boussinesq problem. The total number of nodes in the model is 31 for Model A (Elements 10 and 92), and 75 for Model B (element types 28 and 94). Finite element meshes for both models are shown in Figure 2.61-2 and Figure 2.61-3, respectively.

Geometry

For axisymmetric models, the GEOMETRY block is not required.

Material Properties

The material is assumed to have a Young's modulus of 1.0 and a Poisson's ratio of 0.1.

Loading

A unit force (POINT LOAD) is applied at node 1 in the positive z (axial) direction.

Boundary Conditions

The radial displacements (second degrees of freedom) of all the nodes located along the z-axis (line of symmetry) are constrained. No boundary conditions at infinity are required.

Results

Stress contours on the deformed mesh are shown in Figure 2.61-4 and Figure 2.61-5 for Models A and B. Z-displacements at R = 0 are tabulated in Table 2.61-1. The comparison of finite element results with calculated values is reasonably good.

Table 2.61-1 Z-Displacements at R = 0

Analytical Solution*		Element 92		Element 94	
Z =	**Displacement**	**Node**	**Displacement**	**Node**	**Displacement**
0.	∞	1	1.2579	1	3.0197
0.5	0.9549			3	1.1476
1.0	0.4775	3	0.4655	6	0.4780
1.5	0.3183			8	0.3259
2.0	0.2387	5	0.2526	11	0.2506
2.5	0.1910			13	0.1991
3.0	0.1592	7	0.1717	16	0.1639
3.5	0.1364			18	0.1404
4.0	0.1194	9	0.1295	21	0.1231
8.0	0.0597	22	0.0640	59	0.0614
12.0	0.0398	27	0.0426	62	0.0409

*The Z-displacements are calculated from:

$$w = \frac{P}{2\pi E}\left[(1+\nu)z^2(r^2+z^2)^{-\frac{3}{2}} + 2(1-\nu^2)(r^2+z^2)^{-\frac{1}{2}}\right]$$

Parameters, Options, and Subroutines Summary

Example e2x61a.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DEFINE
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	POINT LOAD
	POST
	PRINT CHOICE

Example e2x61b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DEFINE
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	POINT LOAD
	POST
	PRINT CHOICE

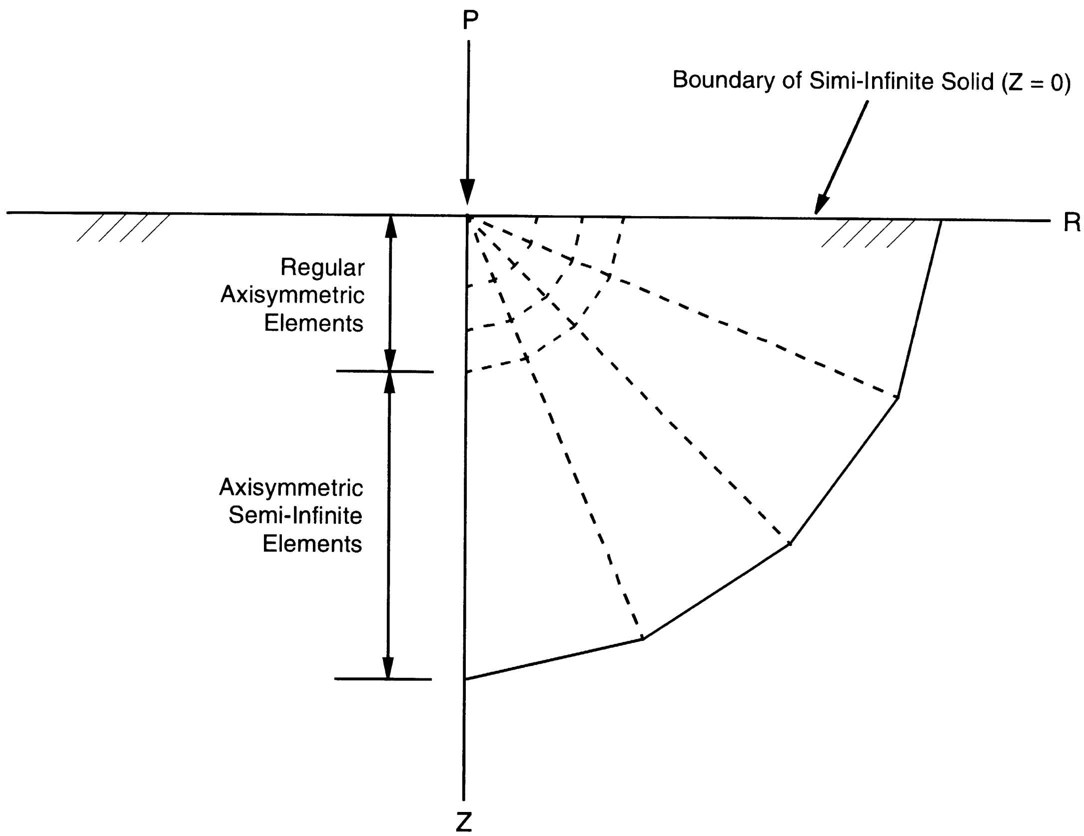


Figure 2.61-1 Boussinesq Problem (POINT LOAD on Boundary of a Semi-infinite Body)

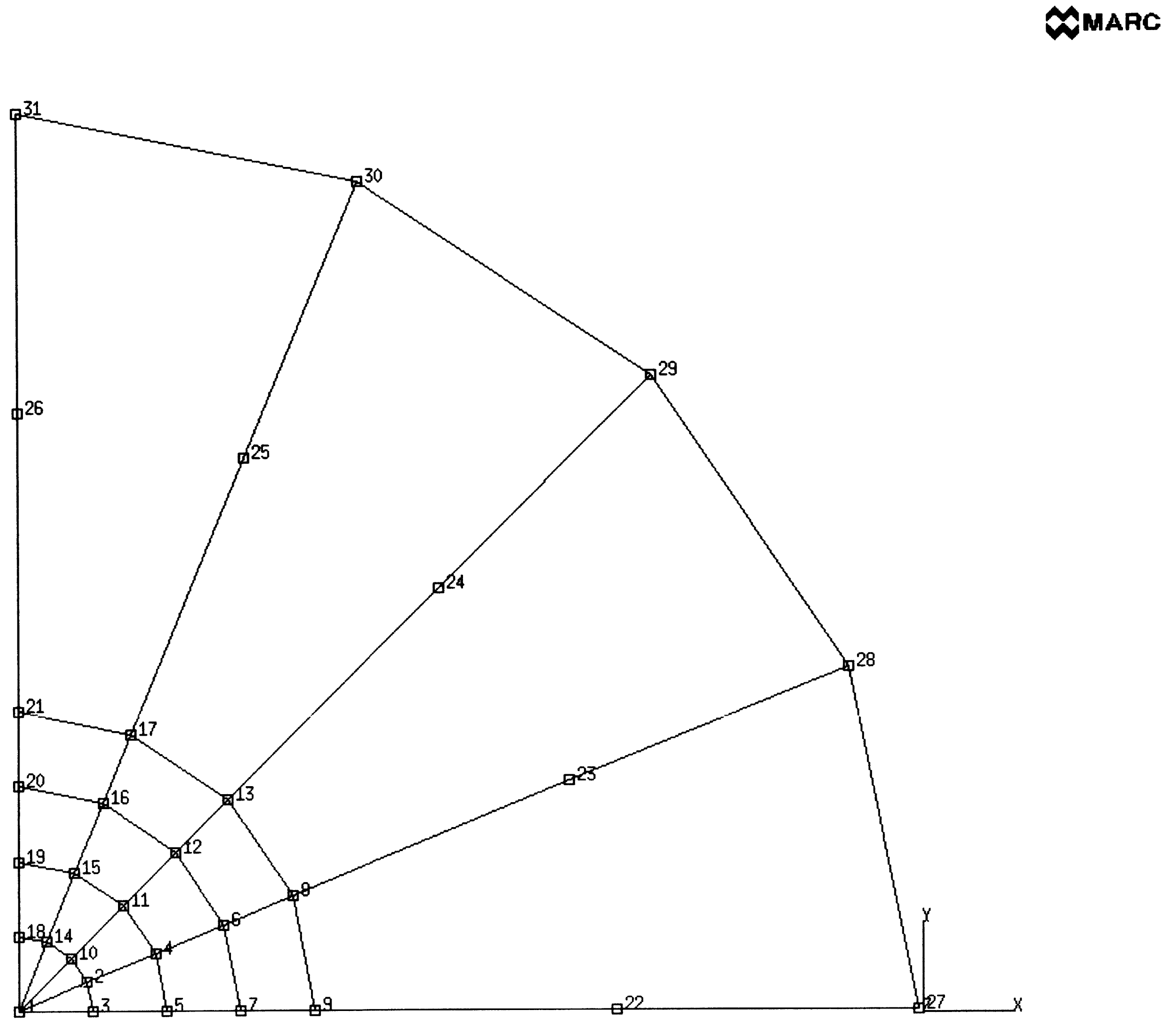


Figure 2.61-2 Finite Element Mesh (Model A) (Elements 10 and 92)

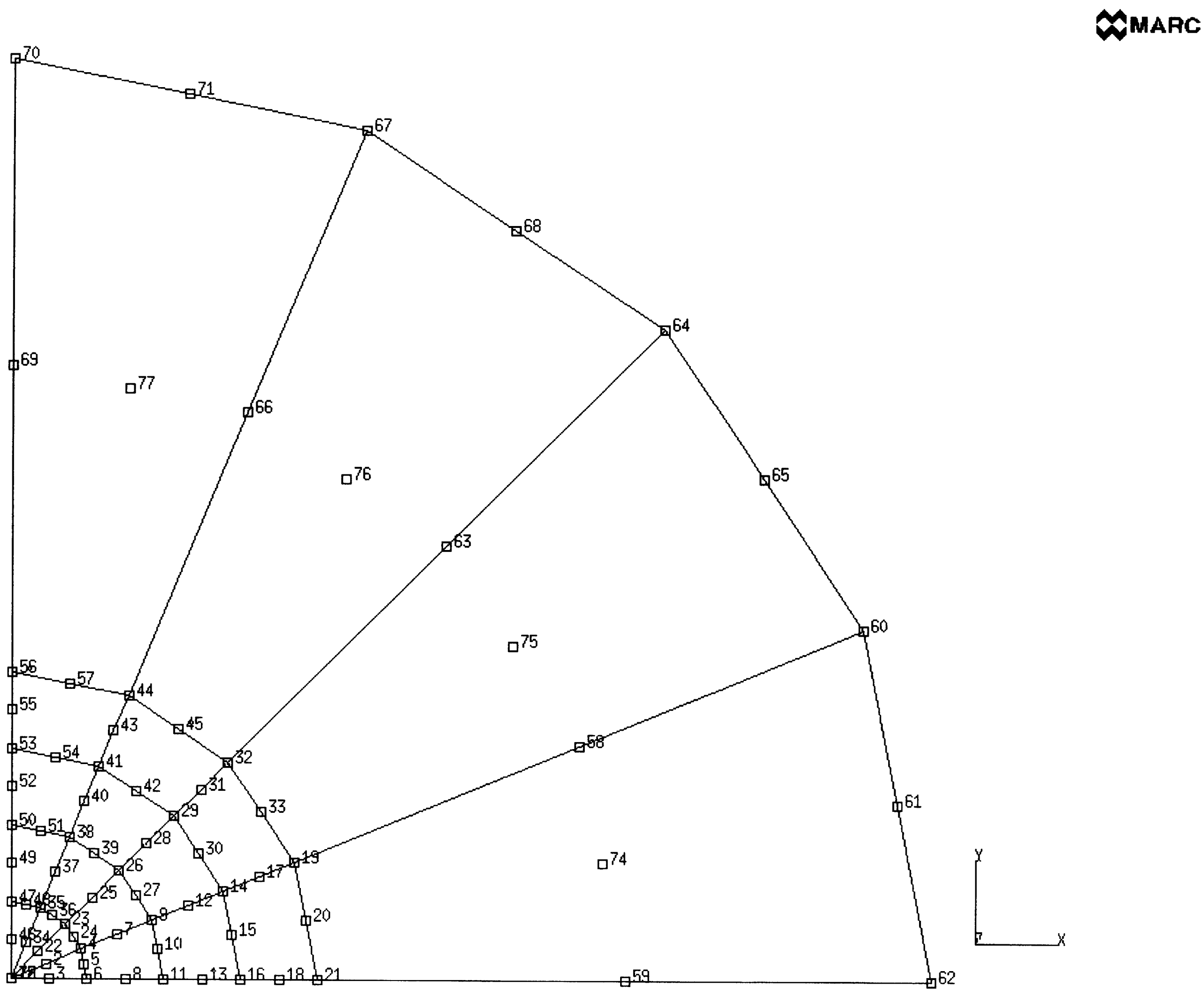


Figure 2.61-3 Finite Element Mesh (Model B) (Elements 28 and 94)

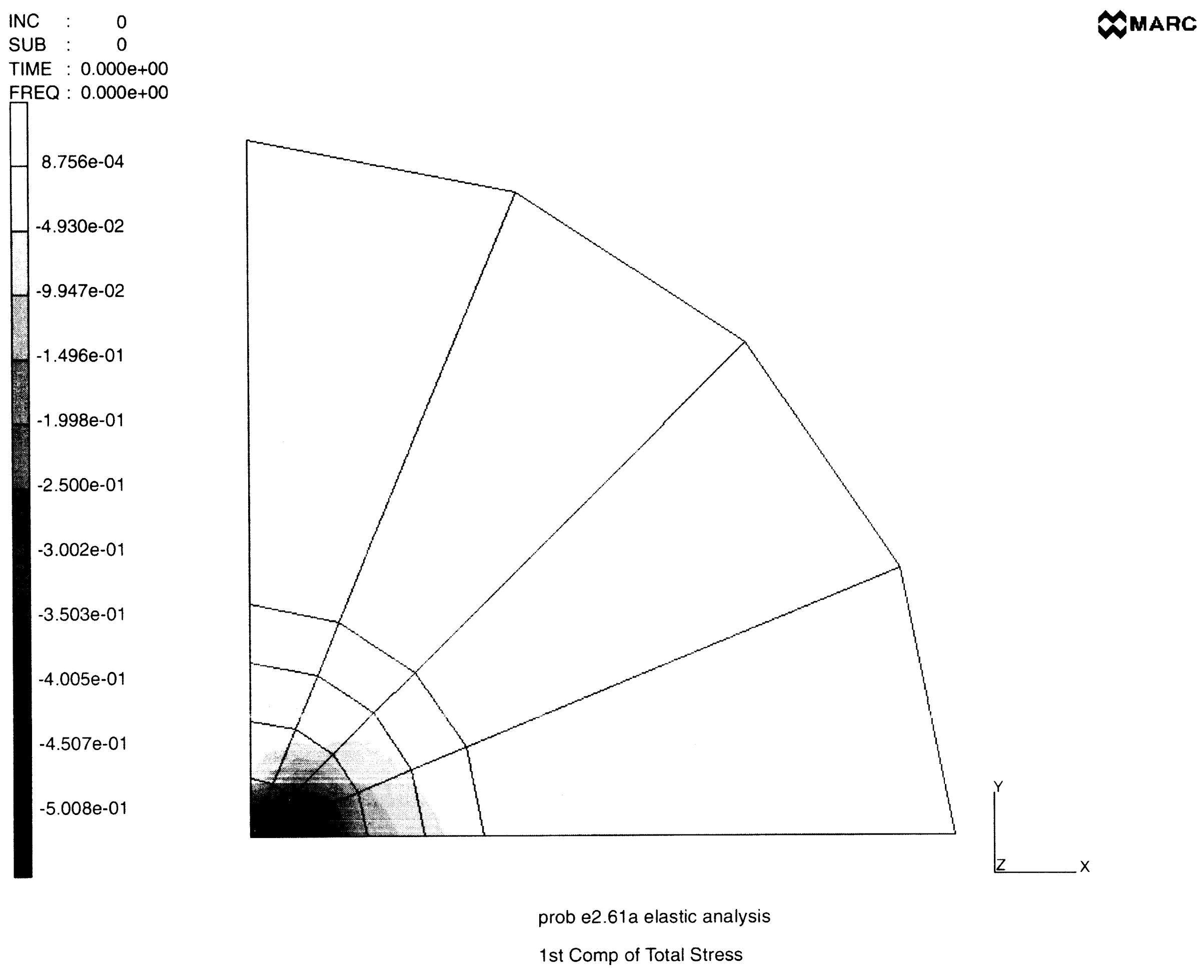


Figure 2.61-4 Stress Contours (Model A)

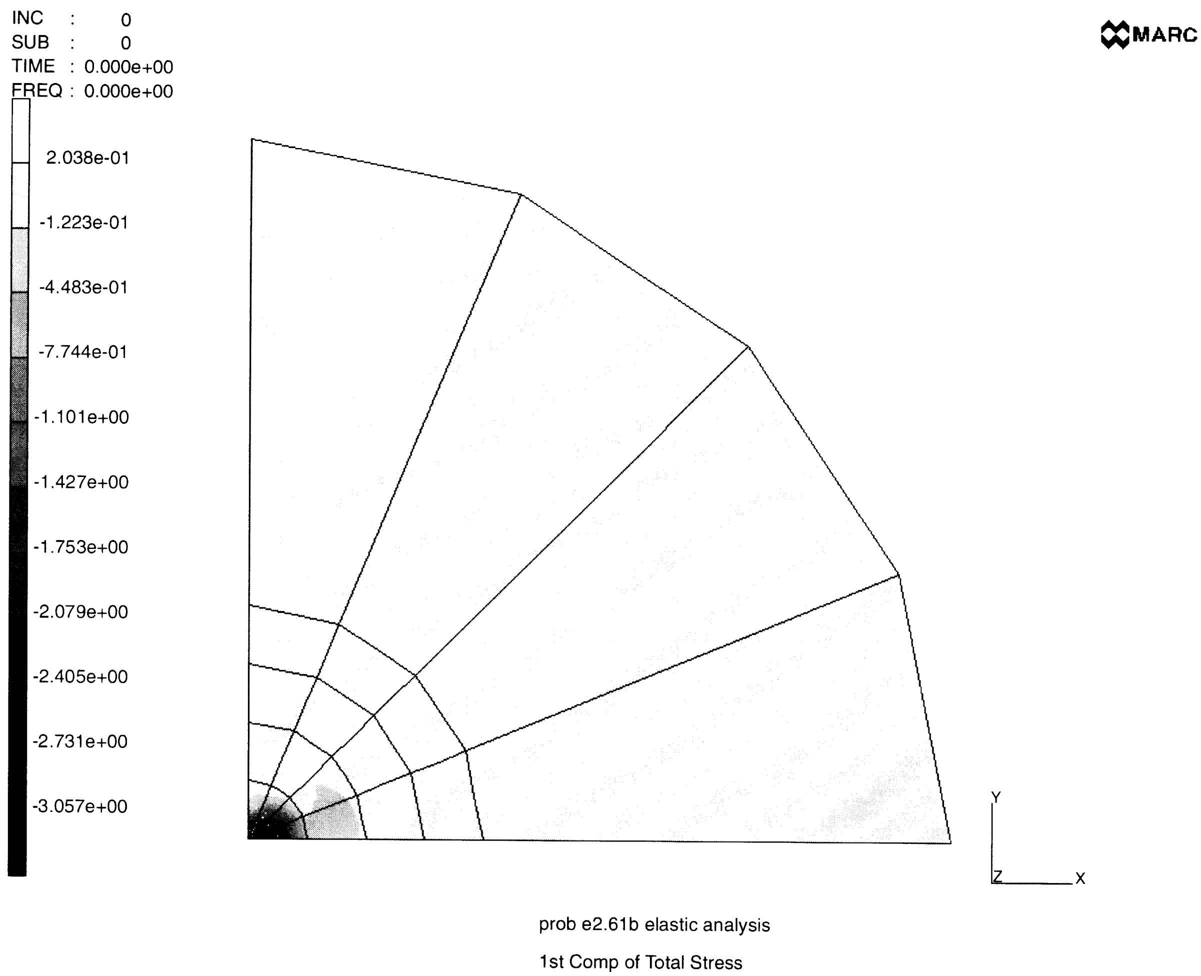


Figure 2.61-5 Stress Contours (Model B)

2.62 Truncated Spherical (Membrane) Shell Under Internal Pressure

A truncated spherical membrane shell subjected to internal pressure is analyzed using MARC membrane element type 18. The analysis is assumed to be linear elastic and demonstrates the use of MARC membrane elements.

Elements

Element type 18 is a 4-node linear, isoparametric membrane element, defined geometrically by the global Cartesian coordinates of the nodes associated with the elements. Stresses and strains are given in a local orthogonal surface coordinate system and a state of plane stress is assumed for these elements. These elements have no bending stiffness.

Model

As shown in Figure 2.62-1, due to symmetry, a 10 element mesh is used for modeling the truncated spherical membrane shell. These elements have no bending stiffness. The model is constrained along edges to ensure symmetry conditions.

Geometry

For the membrane elements, EGEOM1 is used to input the thickness of the element. A thickness of 2 inches is assumed in this analysis.

Material Properties

All elements are assumed to have constant properties. A Young's modulus of 21.8E6 psi and a Poisson's ratio of 0.32 are chosen for the model.

Loading

Internal pressure of 1.0 psi is applied to elements 1 to 10. The load type for uniform pressure is 2.

Boundary Conditions

Edges of the model are constrained (1) for the simulation of fixed support at top and bottom of the model and (2) for ensuring the symmetric conditions in the analysis.

Fixed support	:	$u = v = w = 0$	at nodes 1, 12, 11, 22
Symmetry	:	$w = 0$	at nodes 1 through 11
		$v = 0$	at nodes 12 through 22

Transformation

The UTRANS user subroutine is used to define a transformation matrix for nodes along the 30-degree line. The UTRANFORM model definition option is needed for input of the node numbers to be transformed. The node numbers are 12 to 22 for the model.

Results

The deformed mesh is shown in Figure 2.62-2.

Parameters, Options, and Subroutines Summary

Example e2x62.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	ISOTROPIC
	POST
	PRINT CHOICE
	UTRANFORM

User subroutine in u2x62.f:

UTRANS

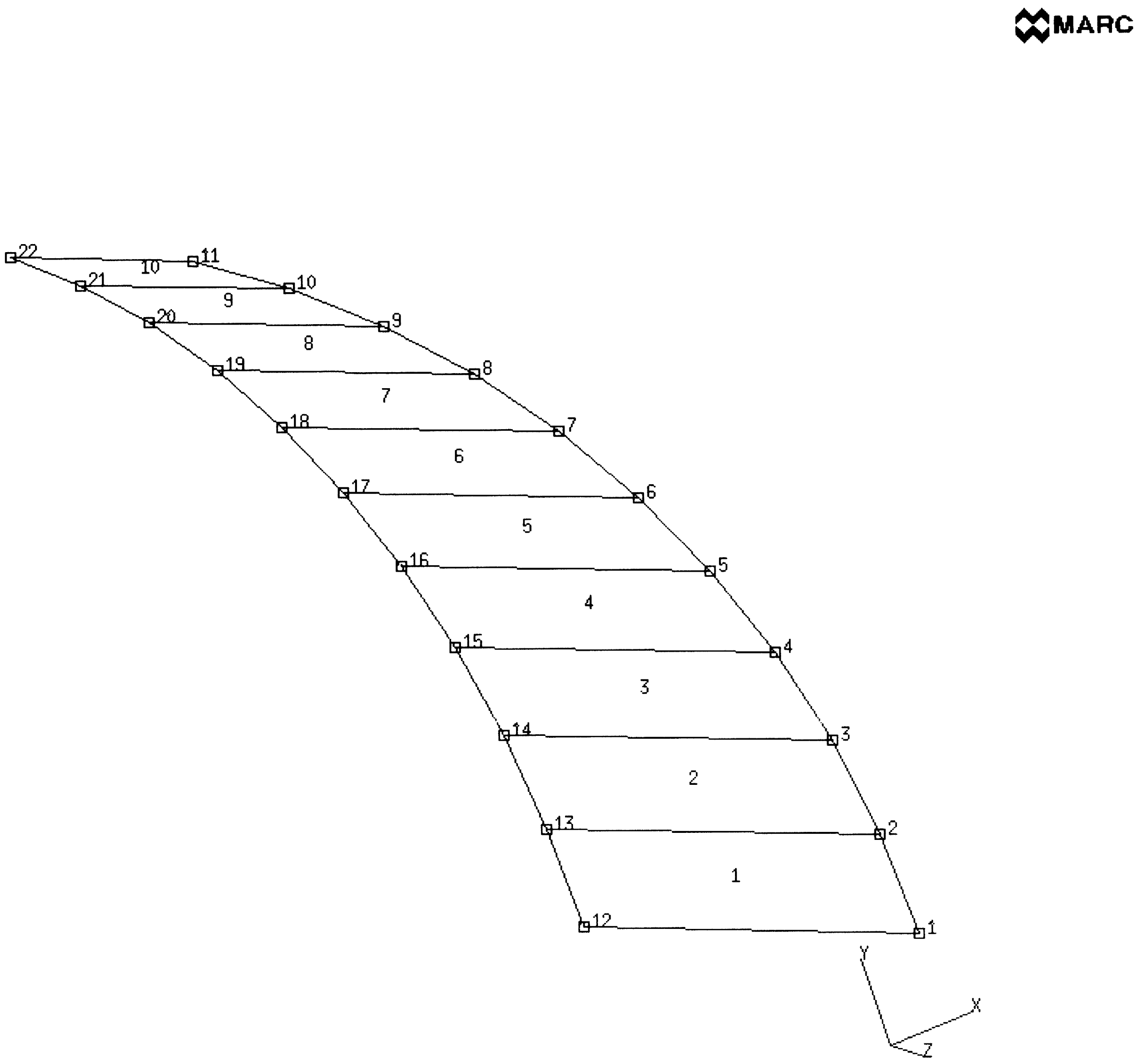


Figure 2.62-1 Membrane Structure

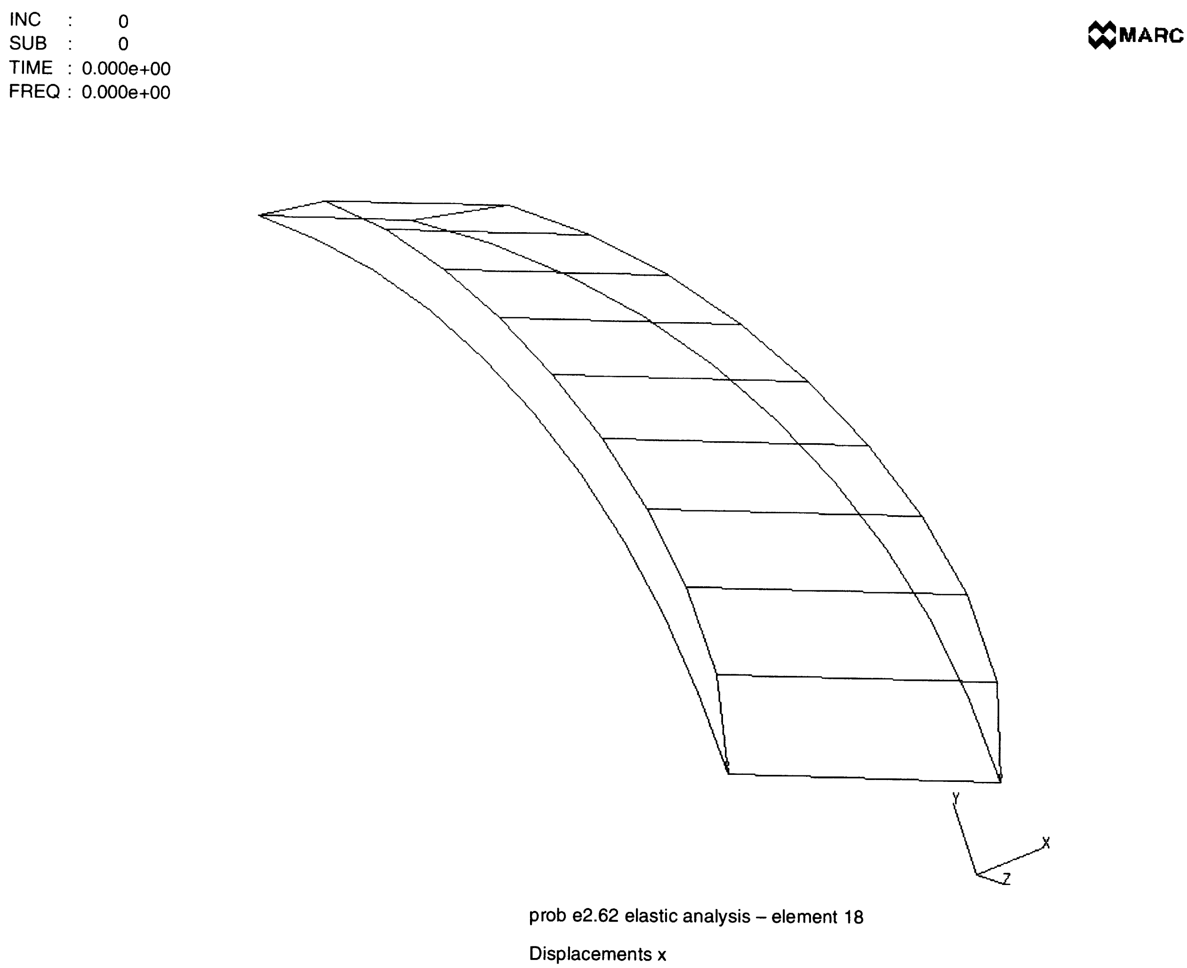


Figure 2.62-2 Deformed Mesh

2.63 J-Integral Evaluation Example using Delorenzi's Method

This example illustrates the use of the DeLorenzi method [1] to evaluate J-integral values in MARC for a double edge notched (DEN) specimen. In order to be able to compare the calculated J and K values with those obtained by means of the stiffness derivative technique [2] (J-INT option in MARC), the same problem as in 2.22 is analyzed.

This problem consists of a DEN specimen under axial tension loading. In addition, the problem of a DEN specimen with pressurized crack surfaces is analyzed to demonstrate the ability of the DeLorenzi method to obtain path-independent J-values for cracked structures subject to mechanical loads in the vicinity of the crack tip.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x63a	27	32	107	
e2x63b	27	32	107	Pressure on crack surface

Element

Element type 27 is a plane-strain quadrilateral element. There are eight nodes and two degrees of freedom at each node.

Model

Only a quadrant of the model is used because of obvious symmetries. A second COORDINATES block is used to move the side nodes of the crack tip elements to the 1/4 points (1/4 of the way along the sides from the crack tip to the opposite face of the element).

Geometry

No geometry is specified.

Material Properties

Young's modulus is 30 x 10^6 psi and Poisson's ratio is 0.3.

Loading

The loading of the DEN specimen under axial tension is specified as a uniform negative pressure of 100 psi on the appropriate faces of the end elements. For the specimen with pressurized crack surfaces, a uniform pressure of 100 psi is applied on the crack surface.

Lorenzi

One of the main differences between the differential stiffness technique and the modified DeLorenzi approach [3] as implemented in MARC is that no numerical differentiation is performed to calculate the change in strain energy. This implies that the obtained J-values (that is, energy release per crack extension) are independent of the value of the crack extension that is specified. The crack extension is specified in a similar manner as is the case with the J-INTEGRAL option. However, it is not necessary to assure that the differential movements are sufficiently small without introducing round-off difficulties. For this reason, a crack tip movement of 1. was used.

Similar to the J-INTEGRAL option of problem 2.22, three different paths have been specified in order to analyze the path independently. It should be noted that in the DeLorenzi technique, an integral over the region of deformed elements as well as an integral over the region of translated rigid elements is numerically evaluated. In case no initial strain effects (for example, thermal and creep strains) nor inertia effects nor mechanical loads are present in the rigid region, only nonzero nodal movements of the deformed elements as well as the list of deformed elements needs to be specified. In case of the pressurized crack problem, the nodal movements of the rigid elements as well as the list of rigid elements are additionally specified in order to incorporate the contribution from the distributed pressure loads.

Results

MARC provides an output of the strain energy difference. This must be normalized by the crack opening area to obtain the value of J. Since this specimen is of unit thickness, the crack opening area is Wa, where Wa is the crack extension. The mesh uses symmetry about the crack line, so that the strain energy change in the actual specimen is twice that printed out. Finally, since this is a plane strain, mode I problem, the J-integral can be immediately converted to K, the stress intensity factor, by the relation:

$$K = \sqrt{\frac{EJ}{1-\nu^2}}$$

The results are summarized in Table 2.63-1.

It is clear from these results that the path independence is well reproduced, and that the error in the solution for K is quite small. It should be noted that the accuracy is identical as obtained with the J-INTEGRAL option with an appropriate crack movement.

The results for the problem of the DEN-specimen with pressurized crack surfaces are summarized in Table 2.63-1. Because of the superposition principle, the K value for an axially loaded DEN-specimen is identical to the K value of the same specimen with pressurized crack surfaces, where the magnitude of this pressure loading equals the stress level in the noncracked structure at the position where the crack is located. From the results of Table 2.63-1, it is clear that the evaluated K values are nearly path independent and that they only differ marginally from the theoretical results.

Table 2.63-1 J-Integral Evaluation Results for DEN-Specimen Under Axial Tension

	Move Tip Only	Move First Ring of Elements	Move Second Ring of Elements
Strain energy change given in program (ΔU)	6.717×10^{-2}	6.695×10^{-2}	6.689×10^{-2}
J-Integral $\Delta u/\Delta 1$	1.343×10^{-1}	1.3390×10^{-1}	1.3378×10^{-1}
$K = \sqrt{\frac{EJ}{1 - \nu^2}}$	665.5	664.4	664.1
$K_I/\sigma_{net}\sqrt{l}$	1.062	1.050	1.050
cf 1.028 [4]	+2.4%	+2.2%	+2.2%

Table 2.63-2 J-Integral Evaluation Results for DEN-Specimen with Pressurized Cracks

	Move Tip Only	Move First Ring of Elements	Move Second Ring of Elements
Strain energy change given in program (Δu)	5.9402×10^{-2}	5.8148×10^{-2}	5.8153×10^{-2}
J-Integral $\Delta u/\Delta 1$	1.1880×10^{-1}	1.1630×10^{-1}	1.1631×10^{-1}
$K = \sqrt{\frac{EJ}{1 - \nu^2}}$	625.8	619.2	619.2
$K_I/\sigma_{net}\sqrt{l}$	1.979	1.958	1.958
cf 2.056 (=1.028)	-3.7%	-4.8%	-4.8%

References

1. DeLorenzi, H.G., "On the energy release rate and the J-integral for 3D crack configurations", *Inst. J. Fracture*, Vol. 19, 1982, pp.183-193.
2. Parks, D.M, "A Stiffness Derivative Finite Element Technique for Determination of Elastic Crack Tip Stress Intensity Factors", *Int. J. Fracture*, Vol. 10, no. 4, December 1974, pp. 487-502.
3. Peeters, F.J.H. and Koers, R.W.J., "Numerical Simulation of Dynamic Crack Propagation Phenomena by Means of the Finite Element Method", Proceedings of the 6th European Conference on Fracture, ECF6, Amsterdam, The Netherlands, June 15-20, 1986.
4. Bowie, I.L., "Rectangular Tensile Sheet With Symmetric Edge Cracks," *J. Applied Mechanics*, Vol. 31, 1964, pp. 208-212.

Parameters, Options, and Subroutines Summary

Example e2x63a.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	LORENZI
	PRINT CHOICE

Example e2x63b.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	ISOTROPIC
	LORENZI
	PRINT CHOICE

2.64 A Clamped Plate Modeled with Brick Elements

In this problem, a thin plate is modeled with brick elements to demonstrate the benefit of the assumed strain element formulation. In general, the lower-order elements do not behave well under bending because of their inability to fully represent linear variations in shear stress. The assumed strain elements reduce this error.

Model

Sixteen elements are used to model one quarter of the plate as shown in Figure 2.64-1. The square plate total dimensions are 2 inches and the thickness is 0.01 inch. Element type 7, the eight-node brick element, is used.

Geometry

In 2.64b, the third field of the GEOMETRY option is set to 1. This invokes the assumed strain option.

Material Properties

The material is elastic with a Young's modulus of 1.7472E7 lbf/in^2 and a Poisson ratio of .3.

Loading

Two independent analyses are performed by including the ELASTIC parameter. In increment zero, a uniformly distributed pressure of 1.E-4 is applied on the top surface. In increment one, a point load of magnitude 4×10^{-4} is applied at the center of the plate. Only one quarter of the load is applied due to symmetry.

Results

The analytic solution for the maximum displacement of the plate is given by:

Distributed load $y = 0.138\ da^4/Et^3$

Point Load $y = 0.0056\ Pa^2/D$

$D = Et^3/12(1-v)$

The results can be summarized as:

	Distributed Load	Point Load
Analytic	1.234×10^{-4}	4.30×10^{-6}
Conventional	7.800×10^{-9}	3.59×10^{-8}
Assumed Strain	1.258×10^{-6}	5.44×10^{-6}

The conventional element gives very poor behavior in bending, when only a single element is used through the thickness. You should also observe that while traditional isoparametric elements are always too stiff, this is not the case for the assumed strain elements.

Parameters, Options, and Subroutines Summary

Example e2x64a.dat:

Parameters	Model Definition Options	History Definition Options
ELASTIC	CONNECTIVITY	CONTINUE
ELEMENTS	COORDINATES	POINT LOAD
END	DIST LOADS	
SIZING	END OPTION	
TITLE	FIXED DISP	
	GEOMETRY	
	ISOTROPIC	
	POST	

Example e2x64b.dat:

Parameters	Model Definition Options	History Definision Options
ELASTIC	CONNECTIVITY	CONTINUE
ELEMENTS	COORDINATES	POINT LOAD
END	DIST LOADS	
SIZING	END OPTION	
TITLE	FIXED DISP	
	GEOMETRY	
	ISOTROPIC	
	POST	

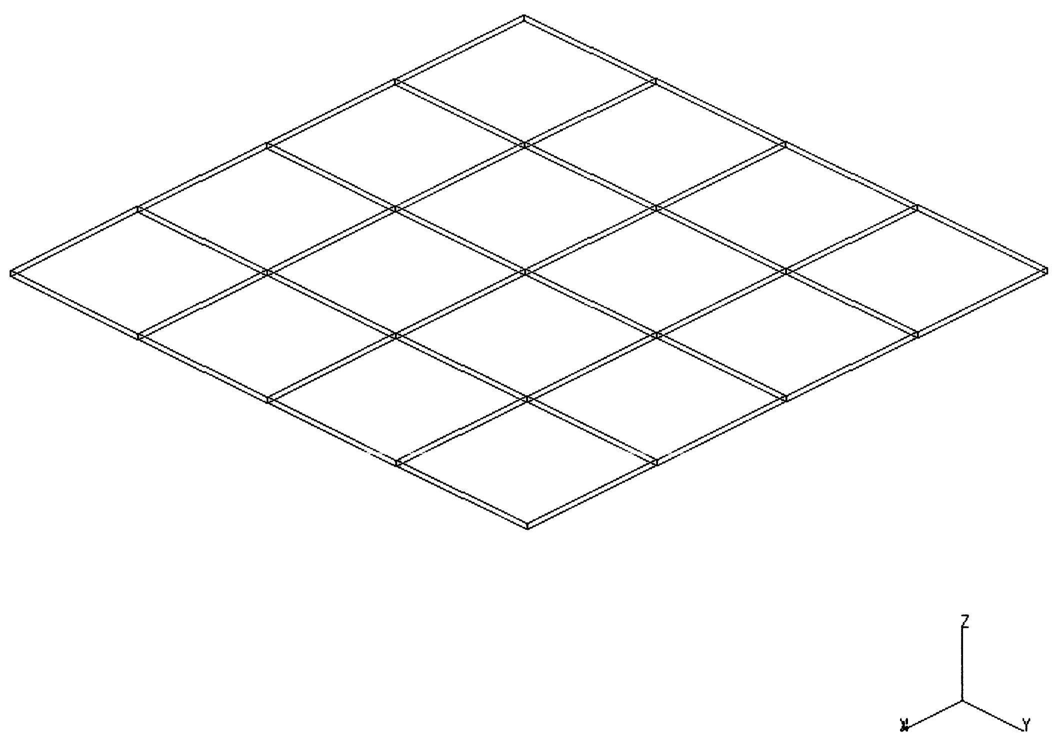


Figure 2.64-1 Clamped Plate Mesh

2.65 Use of Tying to Model a Rigid Region

This problem demonstrates the use of tying to model a rigid region. If large rotations/displacements occur, this is a nonlinear problem.

Model

The model is shown in Figure 2.65-1. Two rigid regions are included. The first represents a volume between the first and second block. The second is the surface enclosed by nodes 13, 14, 15, and 16. These are indicated by the cross-hatched regions. Element types 7 and 75 are used in this analysis.

Geometry

The shell is given a thickness of 0.01. This is element 3.

Material Properties

The material is elastic with a Young's modulus of 1000 and a Poisson's ratio of 0.3.

Loading

The bottom of the first cube is held fixed. A point load of 8 is applied to the top surface through the POINT LOAD and AUTO LOAD options.

Rigid Region

The two rigid regions are modeled using tying. An additional mode must be defined for each rigid region. The degrees of freedom associated with this node represent the rigid body rotations about this point. In the first rigid region, node 20 is used which has the same coordinate position as node 13. Tying type 80 is used to connect all of the other points associated with the rigid region to these two points.

Results

The displaced mesh is shown in Figure 2.65-2. The total displacements are on the order of 0.0. (Remember, the cubes have a length of one.)

Parameters, Options, and Subroutines Summary

Example e2x65.dat:

Parameters	Model Definition Options	History Definition Options
ELEMENTS	CONNECTIVITY	AUTO LOAD
END	CONTROL	CONTINUE
LARGE DISP	COORDINATES	POINT LOAD
SIZING	END OPTION	
TITLE	FIXED DISP	
	GEOMETRY	
	ISOTROPIC	
	POST	
	TYING	

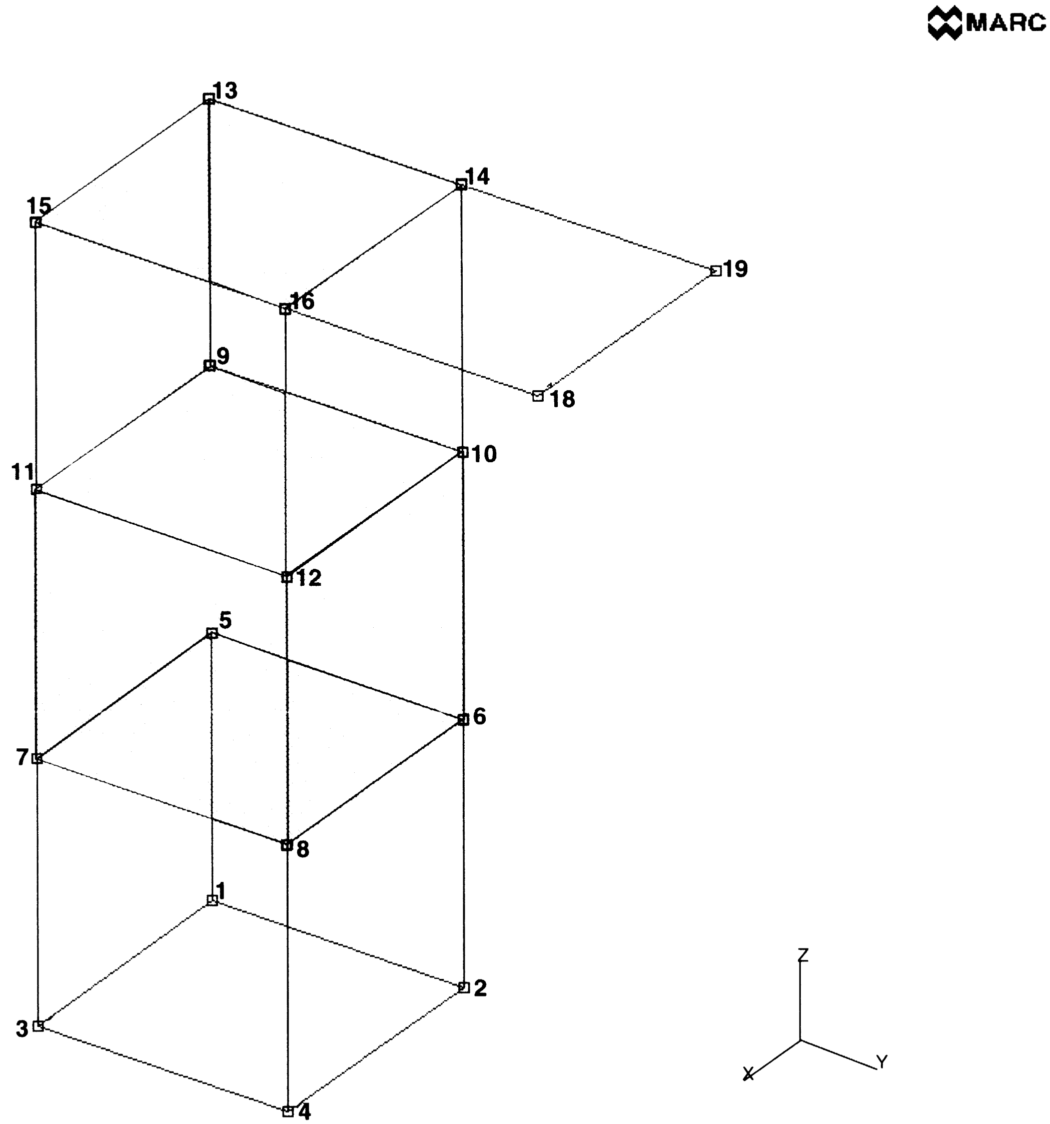


Figure 2.65-1 Mesh Showing Rigid Regions

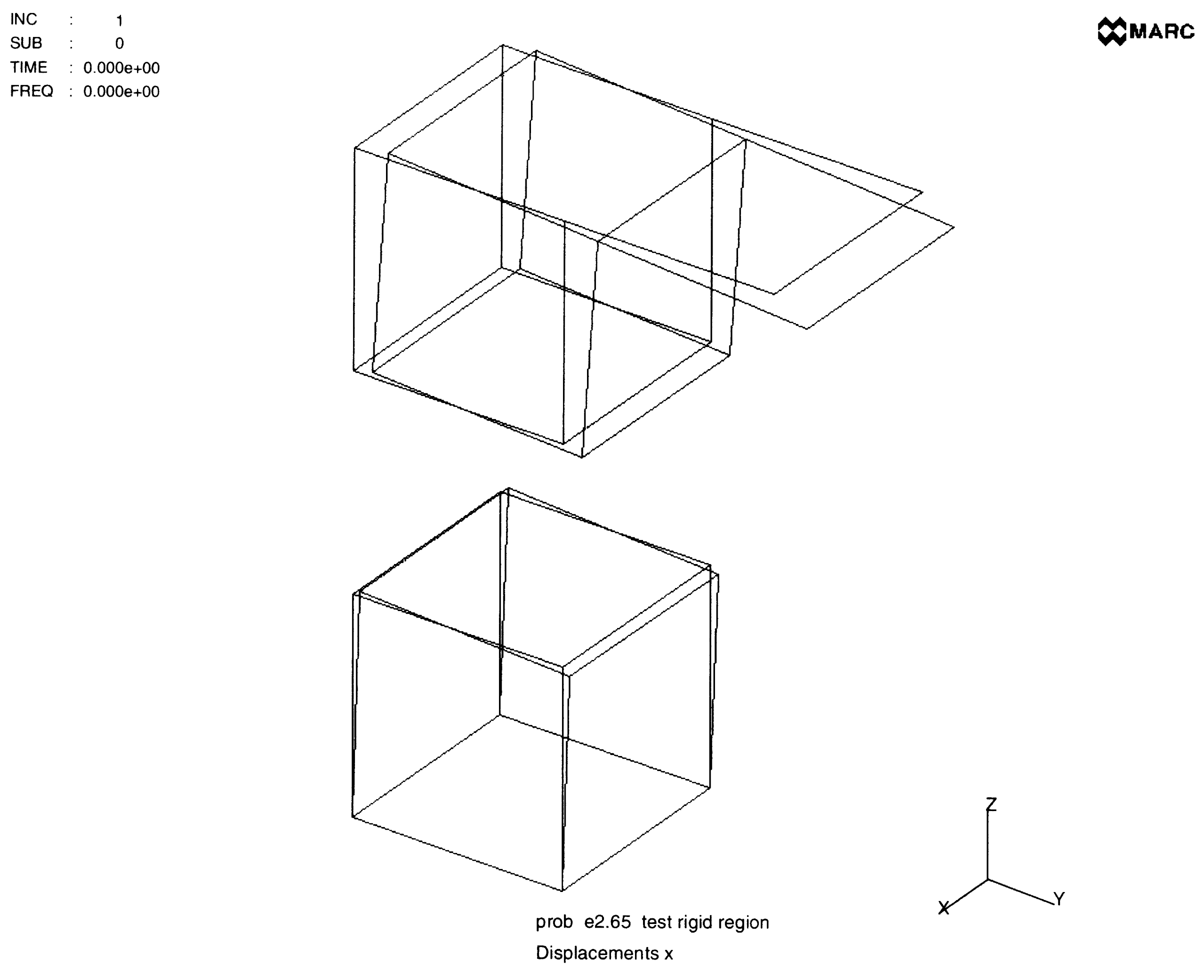


Figure 2.65-2 Deformations

2.66 Using Pipe Bend Element to Model Straight Beam or Elbow

This problem demonstrates the use of the elastic pipe bend element for modeling both a straight beam or an elbow.

Model

Two analyses are performed. Figure 2.66-1 shows a straight beam clamped at node 1 and a load placed at node 11. The beam is modeled using ten elements.

Figure 2.66-2 shows a 90° elbow section of radius 100 inches modeled using two elements. The elements are displayed as straight line segments. The elbow is clamped at node 1. Element type 31 is used in these models.

Geometry

In problem e2.66a, the BEAM SECT parameter is used to define a cross section of height 10 and width 1. The area = 10 in^2, I_{xx} = 83.33 in^4, I_{yy} = .8333 in^4, K = 84.1663 in^2. The local x direction is given through the GEOMETRY option as being in the global x direction.

In problem 2.66a, the pipe is given a radius of 10 inches and a thickness of 1 inch. The radius of curvature of the elbow is given in the third field as 100 inches.

Material Properties

The pipe is made of steel with a Young's modulus of 30.E6 psi and a Poisson ratio of .3.

Loading

In problem 2.66a, a tip load of magnitude $1000\sqrt{3}$ pounds is applied with components of 1000 pounds in each direction at node 11. In problem 2.66b, an out-of-plane load of 100 pounds is applied. In increment one, an internal pressure of 3,000,000 psi is applied.

Results

For problem 2.66a, the analytic solution for the tip deflection is:

$$y = \frac{1}{3}\frac{wl^3}{EI}$$

Hence:

	y	z
Analytic	13333.	133.33
Calculated	13330.	133.34

which is exact.

For problem 2.66b, the solution is compared to a model made up of 9 elements type 14:

	Increment zero	
element 31	2 elements	w = 1.89E-3
element 14	9 elements	w = 1.317E-3

You can observe that the element 31 is more flexible when no internal pressure exists.

In increment one, a large internal pressure is applied which stiffens the elbow. The solution then becomes:

element 31	2 elements	w = 1.363E-3

which agrees well with the element 14 results.

Parameters, Options, and Subroutines Summary

Example e2x66a.dat:

Parameters	Model Definition Options
BEAM SECT	CONN GENER
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NODE FILL
	POINT LOAD

Example e2x66b.dat:

Parameters	Model Definition Options	History Definition Options
ELEMENTS	CONNECTIVITY	CONTINUE
END	COORDINATES	DIST LOADS
SIZING	DIST LOADS	POINT LOAD
TITLE	END OPTION	
	FIXED DISP	
	GEOMETRY	
	ISOTROPIC	
	POINT LOAD	

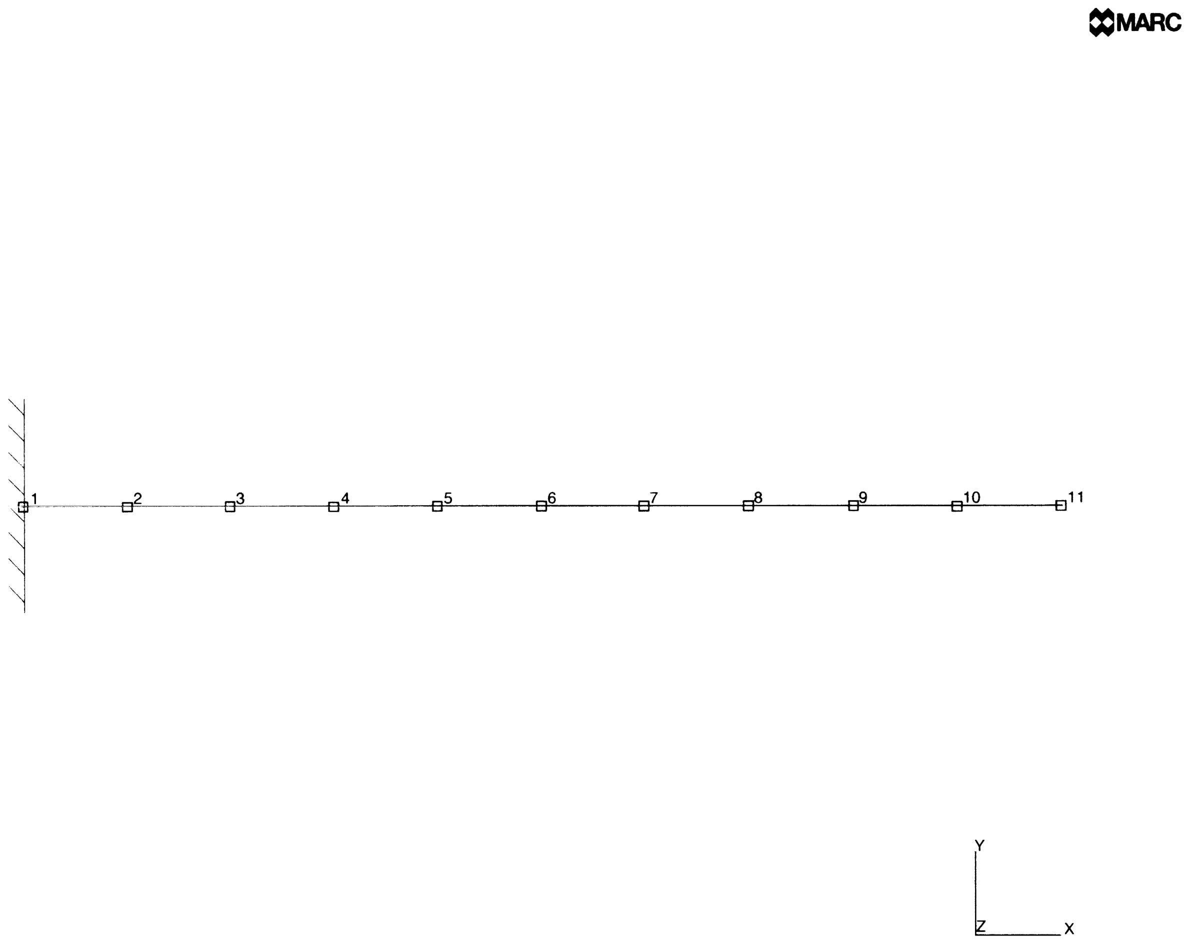


Figure 2.66-1 Straight Beam Using Element 31

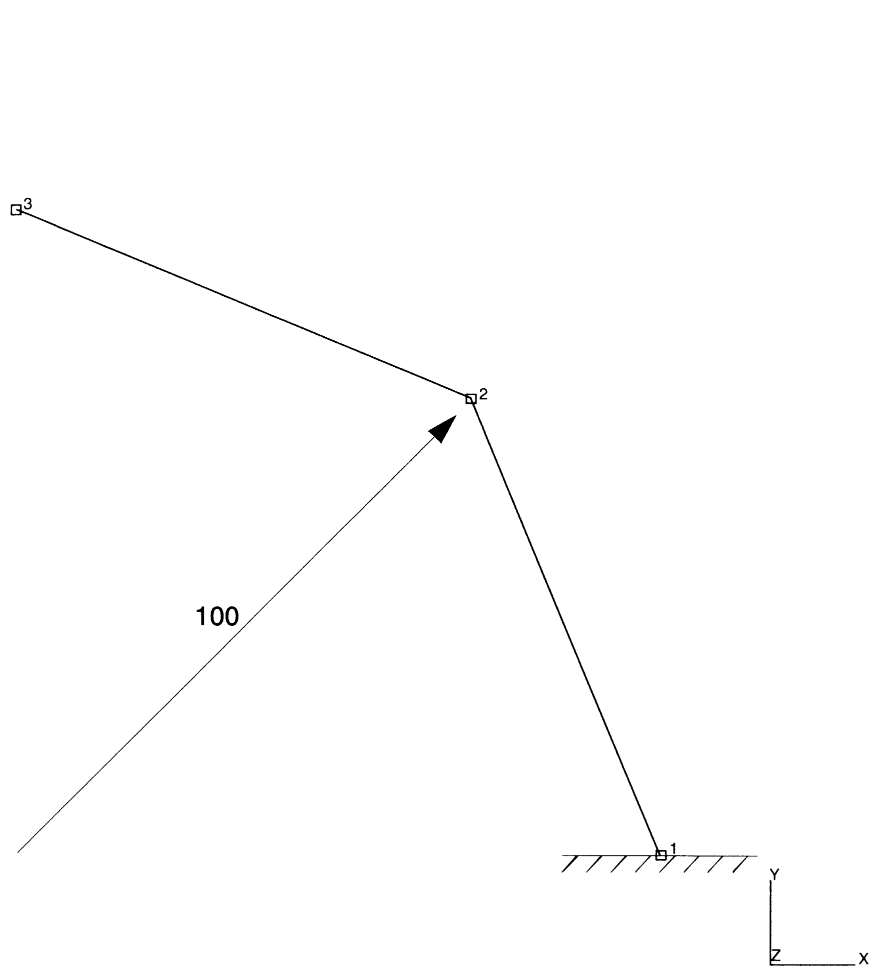


Figure 2.66-2 Pipe Bend Using Element 31

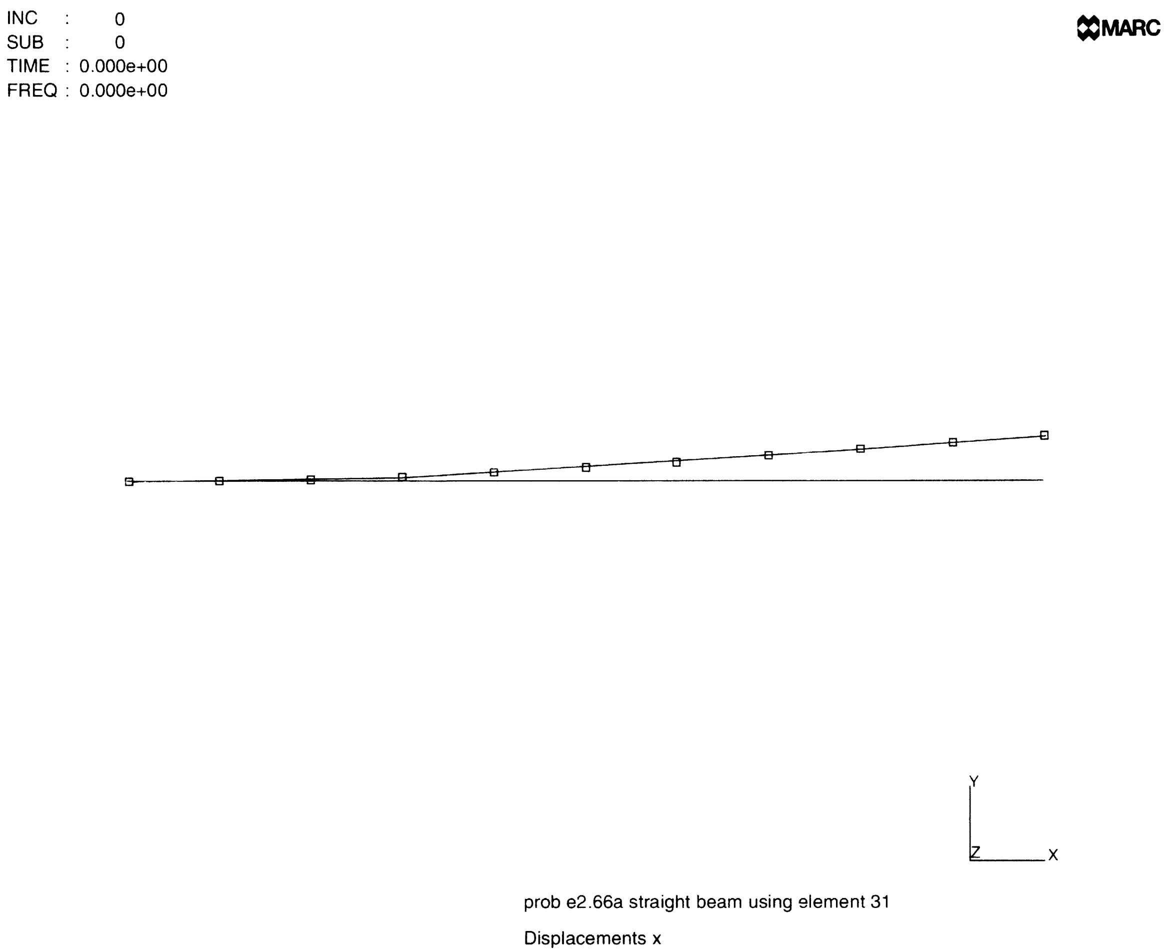


Figure 2.66-3 Deformed Beam

2.67 Cantilever Beam Analyzed using Solid Elements

A cantilever beam is analyzed subjected to a point load on the end. The material behavior is considered elastic. Three element types are used: a parabolic brick (type 21) and two tetrahedron element types 127 and 130, respectively.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes
e2x67a	127	96	225
e2x67b	130	96	225

Elements

The brick and both tetrahedral elements are second-order isoparametric elements. The brick element type 21 has 20 nodes while the tetrahedral elements have 10 nodes. Element type 130 is similar to type 127 but with a Herrmann formulation.

Model

A two inch long beam with a 1 inch square cross section is modeled with 16 brick elements and 96 tetrahedrons. The mesh using the brick elements is shown in Figure 2.67-1. The origin of the axis is on the neutral axis of the beam with the z-axis in the longitudinal direction.

Material Properties

The material for all elements is treated as elastic with Young's modulus of 30.0E+06 psi and a Poisson's ratio of 0.0.

Loads and Boundary Conditions

Two point loads are applied at the free end of the cantilever beam with magnitudes of 1000 lbf directed in the positive x and y directions. At the fixed end (the z = 2 plane), all z displacements are fixed to 0.0, and the x and y displacements along the y = 0 and x = 0 axis are fixed to 0.0.

Results

The exact solution may be expressed as:

$$\sigma_{zz} = -\{[M_y I_x - M_x I_{xy}]x + [M_x I_y - M_x I_y]y\}/(I_x I_y - I_{xy}^2)$$

Due to the symmetry of the cross section, $I_x = I_y = I$ and $I_{xy} = 0$. The symmetry in load gives $M_x = - M_y = PL$. The maximum bending stress in the z = 2 plane becomes:

$$\sigma_{zz} = \frac{-PL(x + y)}{I}$$

and the maximum component of displacement becomes:

$$u = v = \frac{-PL^3}{3(EI))}$$

Hence the neutral surface is the x + y = 0, plane that passes through the centroid of the cross section. Comparing the results we have:

	max $\lvert\sigma_{zz}\rvert$	**u(0,0,0)**
Theory	24.00 ksi	1.067-03 in
Type 21	24.15 ksi	1.207-03 in
Type 127	19.36 ksi	1.250-03 in
Type 130	19.36 ksi	1.250-03 in

Parameters, Options, and Subroutines Summary

E2x67a.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
CONTROL
COORDINATES
END OPTION
FIXED DISP
ISOTROPIC
OPTIMIZE
POINT LOAD
POST

E2x67b.dat:

Parameters	**Model Definition Options**
ALIAS	CONNECTIVITY
ELEMENTS	CONTROL
END	COORDINATES
SIZING	END OPTION
TITLE	FIXED DISP
	ISOTROPIC
	OPTIMIZE
	POINT LOAD
	POST

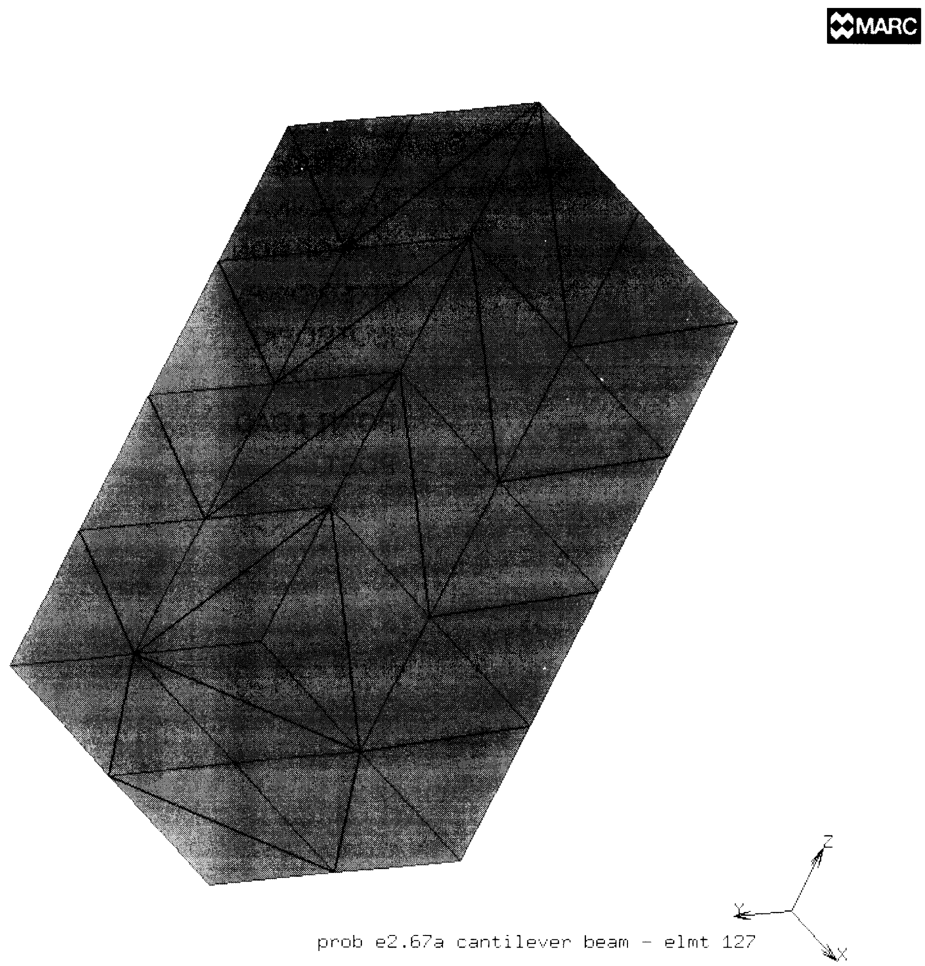


Figure 2.67-1 Model

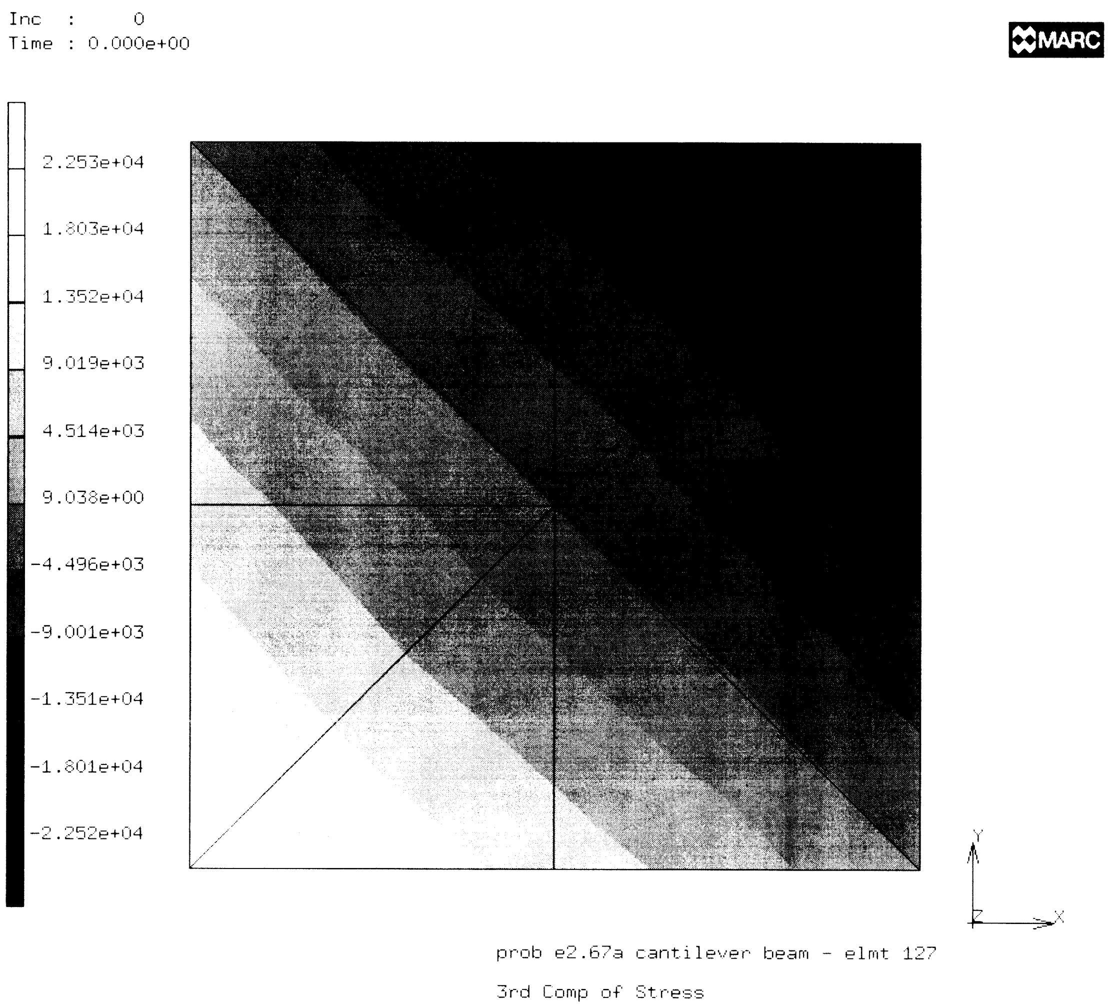


Figure 2.67-2 Bending Stress Element 127

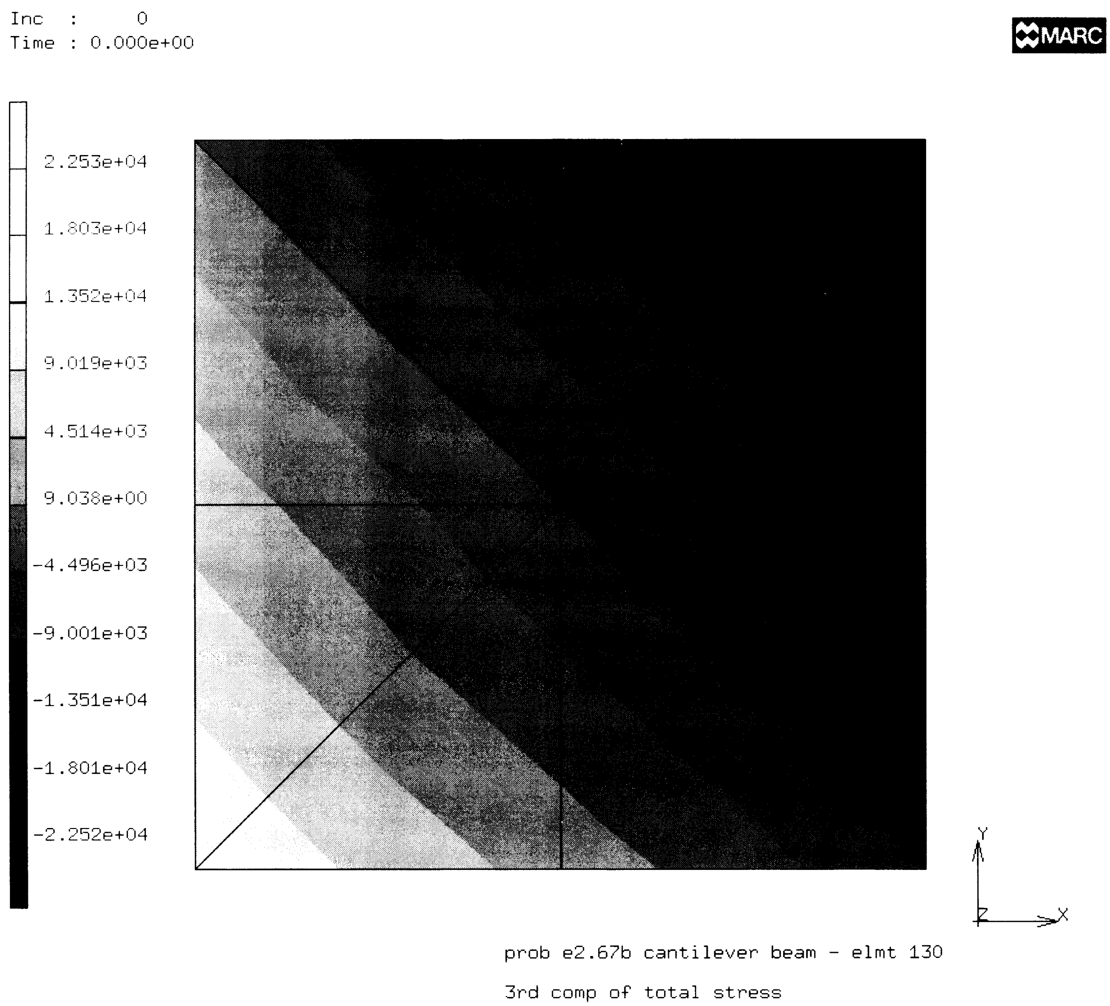


Figure 2.67-3 Bending Stress Element 130

2.68 Linear Analysis of a Hemispherical Cap Loaded by Point Loads

A hemispherical cap with an 18° hole is loaded by two inward and two outward forces (see Figure 2.68-1).

Element

Library element type 49, a 6-node triangular thin shell element, is used.

Model

The dimensions of the cap and the finite element mesh are shown in Figure 2.68-1. Based on symmetry considerations, only one quarter of the cap is modeled. The mesh is composed of 128 elements and 289 nodes.

Material Properties

The material is elastic with a Young' modulus of 6.835×10^{7} N/mm^2 and a Poisson's ratio of 0.3.

Geometry

A uniform thickness of 0.04 mm is assumed. In the thickness direction, three layers are chosen using the SHELL SECT parameter. Notice that for this problem, which is dominated by nearly inextensional bending, the initial curvature of the elements is important. This means that the default setting for the fifth geometry field must be used.

Loading

The loading consists of 2 inward and 2 outward point loads with a magnitude of 20 N.

Boundary Conditions

Symmetry conditions are imposed on the edges $x = 0$ ($u_x = 0$, $\varphi = 0$) and $y = 0$ ($u_y = 0$, $\varphi = 0$). Notice that the rotation constraints only apply for the midside nodes. To suppress the remaining rigid body motion for node 278, the z-displacement is fixed.

Results

The reference solution for the displacements of the points of application of the load is 0.93 (see, for example, J. C. Simo, D. D. Fox, and M. S. Rifai, "On a stress resultant geometrically exact shell model, Part II: The linear theory: computational aspects", *Comp. Meth. Appl. Mech. Eng.*, 79, 21-20, 1990). The results found by MARC (0.93027 for the inward displacement and 0.02708 for the outward displacement) are in close agreement with the reference solution. Finally Figure 2.68-2 shows the equivalent von Mises stress for layer 1.

Parameters, Options, and Subroutines Summary

Example e2x68.dat:

Parameters

ELEMENTS
END
SHELL SECT
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
NO PRINT
OPTIMIZE
POINT LOAD
POST
SOLVER

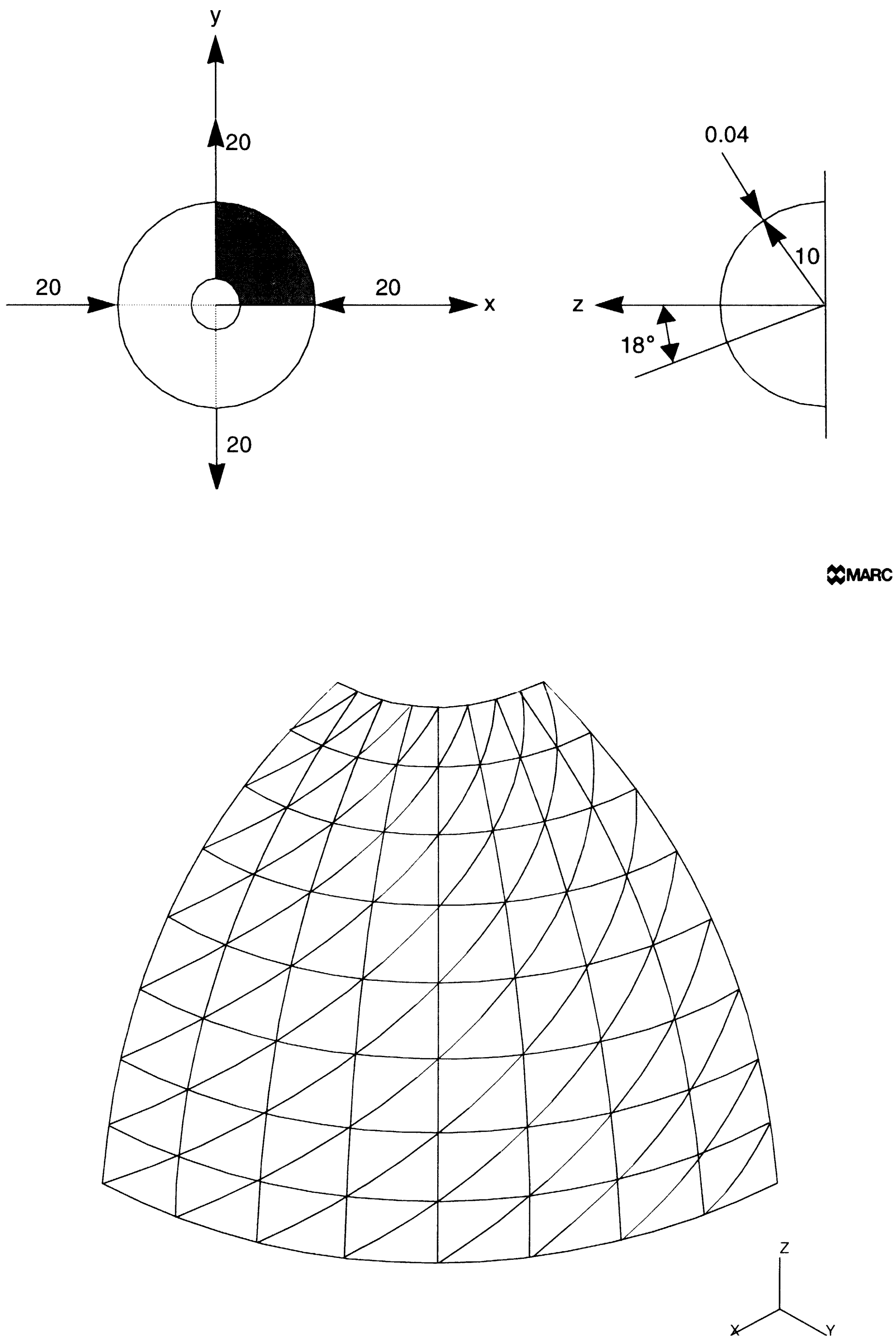


Figure 2.68-1 Hemispherical Cap, Geometry, Loading, and Finite Element Mesh

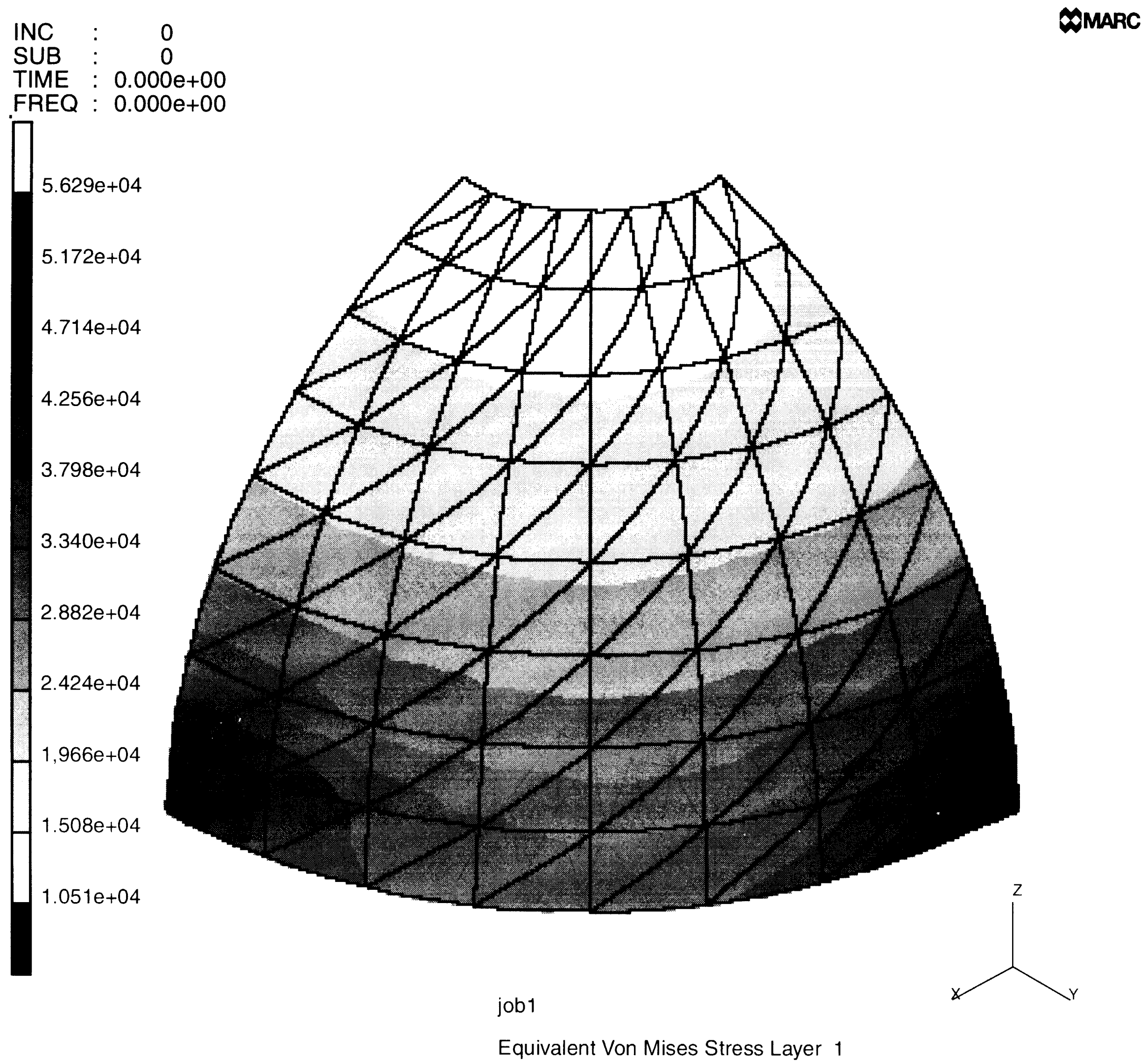


Figure 2.68-2 Stress Contours Layer 2 (Equivalent von Mises Stress)

2.69 Pipe Bend with Axisymmetric Element 95

This problem demonstrates the use of the axisymmetric element with bending (element 95) to model the flexure of a straight pipe. Units [N, mm].

The quadrilateral element 95 represents the cross-section of a ring in the r,z symmetry plane at $\theta = 0°$. A pure axisymmetric deformation induces displacements u,v in the z,r plane which remain constant for θ ranging from 0° to 360° degrees. A flexural deformation in the z,r plane induces different displacements u,v at the opposite sections; $\theta = 0°$ and $\theta = 180°$ along the ring. A twist in the ring induces a circumferential displacement w, equal at every θ, and assigned to the position $\theta = 90$.

Element

Thus, five degrees of freedom are associated to each node:

u,v displacements, at 0° and 180°, respectively
w circumferential displacement at 90° angle

Element 95 is integrated numerically in the circumferential direction. The number of integration points (odd number) is given on the SHELL SECT parameter. The points are equidistant on the half circumference. See Figure 2.69-1.

Models

The FEM model represents the longitudinal section of the pipe in the z,r plane (x,y plane for Mentat) is shown in Figure 2.69-2. The FEM mesh consists of 80 type 95 elements for a total of 123 nodes as shown in Figure 2.69-3.

Material Properties

The Young's modulus of the material is 2.0E5 N/mm^2; the Poisson's ratio is .3.

Loading

A distributed load, $P = 100\ N/mm^2$, is assigned at increment 1, at elements 79 and 80. The load acts as a pressure in the longitudinal direction and is distributed with a sinusoidal variation along θ between 0° and 180° and producing a bending moment around z;

$M = \left(2 \cdot \left(P \cdot \frac{\pi}{2} \cdot t \cdot R\right) \cdot R\right) = 2 \cdot 1.57E5 \cdot 100 = 3.1416E7$ applied at the free edge of the beam. See Figure 2.69-4.

Results

The analytic solution is compared with the MARC, element 95, solution in Table 2.69-1.

Table 2.69-1 Analytical Solution

	Analytic	MARC
$Y_{max} = \frac{Ml^2}{2EJ}$	0.624 mm	0.636 mm (Node 122)
$\sigma_{xx} = \frac{Mz}{J}$ $J = \frac{\pi}{4}(R_e^4 - R_i^4) = 3.149E7\ mm^4$	99.73 N/mm^2	100.5 N/mm^2 (Element 80, Node 122)

At increment 0, the y displacement difference is of the order of 1.9% while the stress σ_{xx} value difference is of the order of 0.7%.

Figure 2.69-5 shows the distribution of the y deflection along the axis of the pipe and the deformed shape under flexural load.

Note: Only the deformed shape at 0° can be visualized with the Mentat graphics program even if all the elements variables can be visualized. The displacements and all the nodal quantities referring to 180° can be seen on the output file.

Parameters, Options, and Subroutines Summary

Example e2x69.dat:

Parameters

ELEMENTS
END
SHELL SECT
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
ISOTROPIC
POST
PRINT ELEM

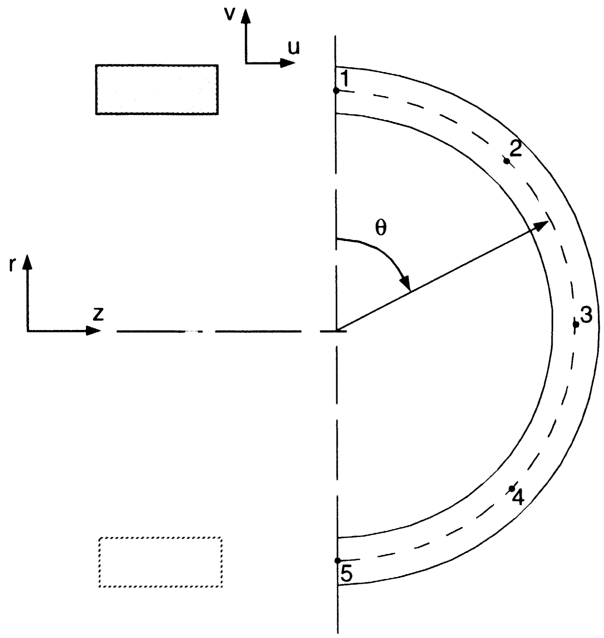


Figure 2.69-1 Element 95 Layer Points

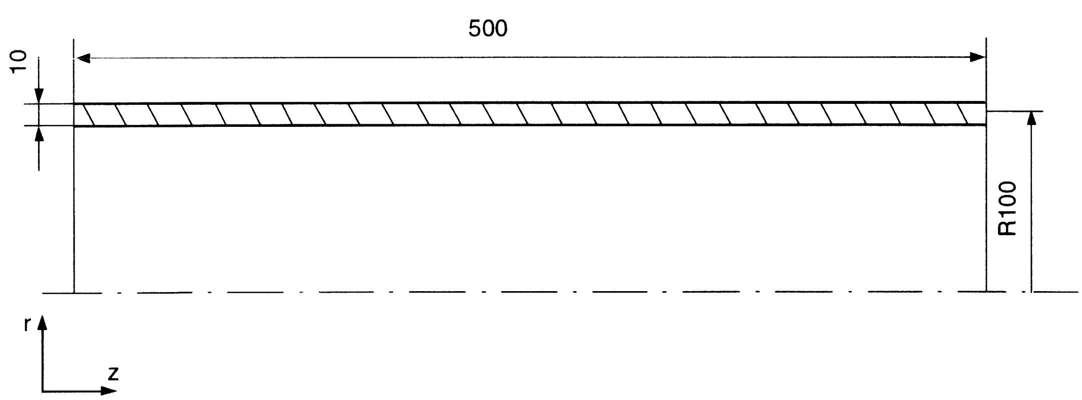


Figure 2.69-2 Longitudinal Section of the Pipe

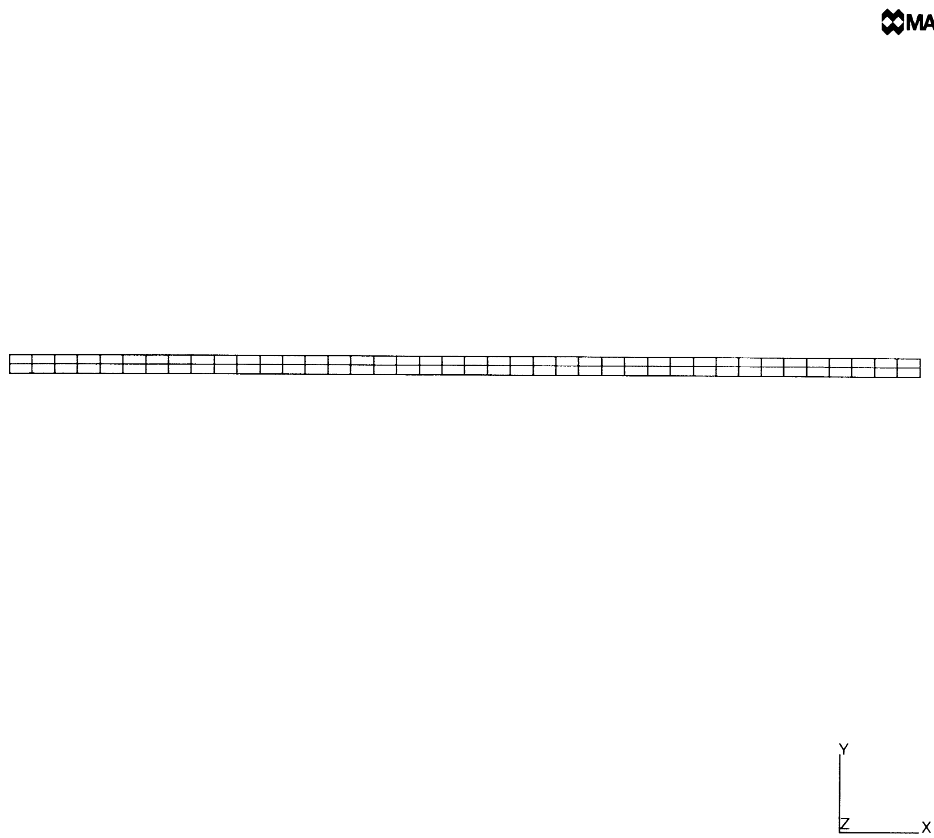


Figure 2.69-3 FEM Model of the Longitudinal Section of the Pipe

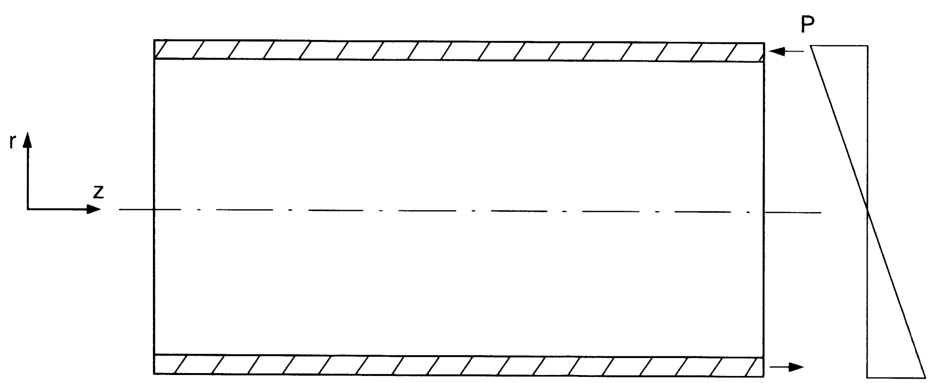


Figure 2.69-4 Distribution of the Longitudinal Pressure

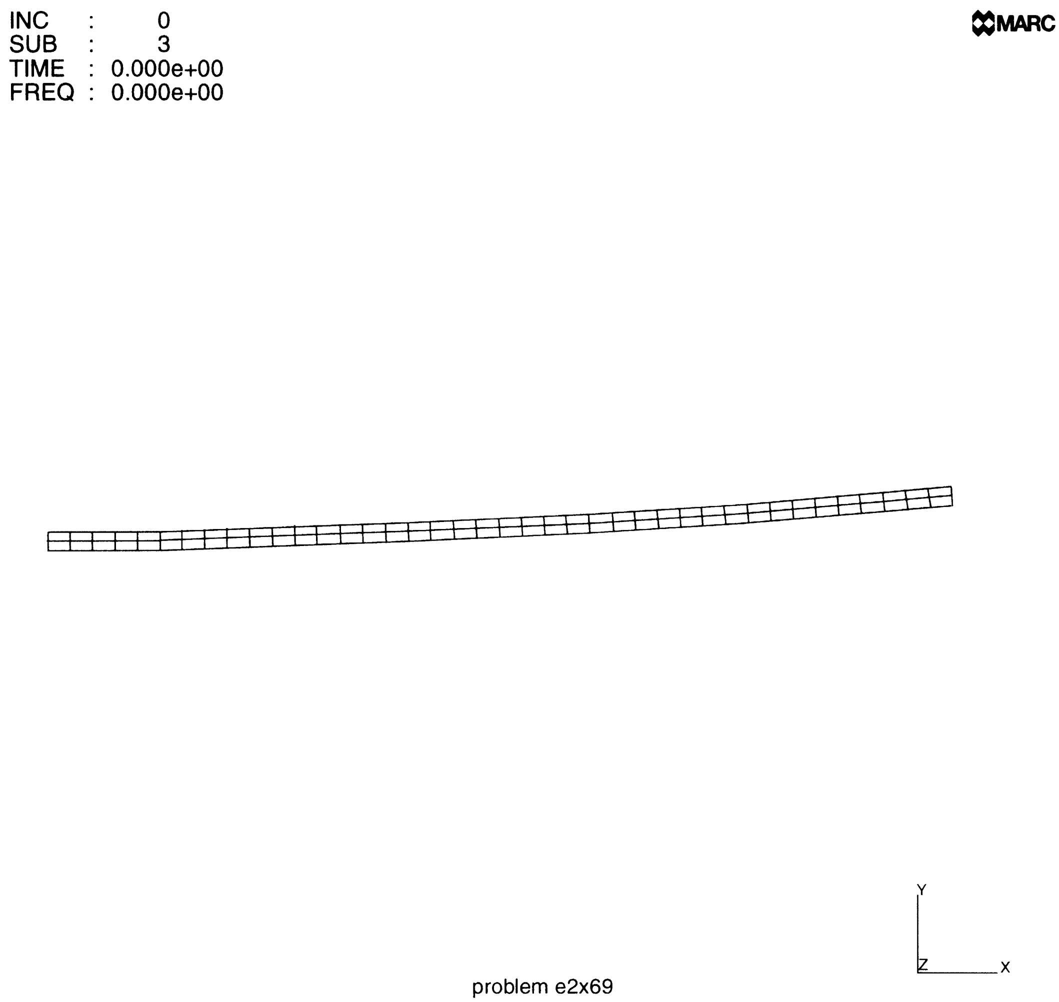


Figure 2.69-5 Deflection of the Longitudinal Section of the Pipe

2.70 Flange Joint Between Pressurized Pipes

This problem demonstrates the capability of the axisymmetric elements 95 together with the axisymmetric gap element 97 to model a flange joint between pressurized pipes including the gasket. These elements may be used even if the loads are nonaxisymmetric as in the case of bending moment and shear applied to the cross-section of one of the pipes.

The model represents an actual joint (see Figure 2.70-1). A square section cavity is filled with a thoroidal gasket. Under the gasket, a tooth of the right-hand flange penetrates into the left-hand flange. Units [N, m].

Object of the analysis is to compute:

Stresses on the flanges and pipes
Axial loads on each bolt
Value of the applied moment that opens the flanges (loss of pressure)

The quadrilateral element 95 represents the cross-section of a ring in the z,r symmetry plane at $\theta = 0°$. A pure axisymmetric deformation induces displacements u,v in the z,r plane. These remain constant for θ ranging from 0° to 360°. A flexural deformation in the z,r plane induces different displacements u,v at the opposite sections, $\theta = 0°$ and $\theta = 180°$, along the ring. A twist in the ring induces a circumferential displacement w, equal at every θ, and assigned to the position $\theta = 90°$.

The gap element 97 works in the flexural mode. Extra degrees of freedom have been added to account for independent contact and friction between the facing sides of element 95 (q = 0° - 180°).

Elements

Element 95 had five degrees of freedom associated to each node:

u,v displacements at 0° and 180°, respectively.
w circumferential displace at 90° angle

Element 95 is integrated numerically in the circumferential direction. The number of integration points (odd number) is given in the SHELL SECT parameter. The points are equidistant on the half circumference (see Figure 2.70-1). Here seven integration points along the half circumference are chosen via the SHELL SECT parameter.

Element 97 is a 4-node gap and friction link with double contact and friction (0° - 180°). It is designed to be used with element type 95.

Model

The FEM model represents the longitudinal section of the pipe joint in the z,r plane. The mesh consists of 613 elements type 95 and 18 elements type 97 for a total of 751 nodes. The mesh is shown in Figure 2.70-1.

The 12 bolts are "smeared" into a ring of equivalent stiffness that is represented by the central strip in the shadowed area in Figure 2.70-1. The remainder of the shaded area represents the "fill" in the section of the bolt.

Material Properties

The two pipes are made with the same material:

E (Young modulus) = 2.05 E11 N/m^2
ν (Poisson ratio) = 0.3

The 12 bolts are modeled with an equivalent axisymmetric ring having material properties:

E (Young modulus) = 2.702 E13 N/m^2
ν (Poisson ratio) = 0.3

The gasket material between bolts is modeled with a coarse mesh of elements type 95 having reduced properties:

E (Young modulus) = 9.04 E10 N/m^2
ν (Poisson ratio) = 0.3

For the bolts and the gasket, the moduli in the hoop direction are strongly reduced.

Loading

Bolts are pre-loaded with an axial force. This is modeled with a local reduction of temperature on the elements modeling the bolts. The bending moment applied to the pipe is assigned with a couple of point loads at the edge of the left pipe as shown in Figure 2.70-2.

Tying

The bolts are connected with the external faces of flange with a tying that links all the degrees of freedom of the joined nodes as shown in Figure 2.70-3.

Gap

The contact between the flanges is modeled with 18 gap elements placed as shown in Figure 2.70-3. Friction is not taken into account. All closure distances are nil; therefore, all gaps are closed until a force greater than 100. N acts on the gap (tensile force). A gap with assigned stiffness represents the gasket.

Boundary Condition

The edge of the right pipe is clamped. Therefore, all degrees of freedom are prescribed to be zero on this edge (see Figure 2.70-2).

Results

The results produced by MARC for the flange joint are shown in the following figures:

Figure 2.70-3 The von Mises stress at 0° at increment 1 (pre-load)
Figure 2.70-5 The von Mises stress at 0° at increment 19 (bending moment)

Note: Only the deformed shape at 0° can be visualized with the Mentat graphics program even if all the element variables can be visualized. The displacements and all the nodal quantities referring to 180 degrees can be read from the MARC output file.

In Table 2.70-1, the balance of the bending moment M_z about the symmetry axis is checked by comparing the sum of all moments due to increments of compressive force in the gaps plus the increment of force in the bolts with the moment of the applied load.

Parameters, Options, and Subroutines Summary

Example e2x70.dat:

Parameters	Model Definition Options	History Definition Options
ALIAS	CONNECTIVITY	AUTO LOAD
ELEMENTS	CONTROL	CHANGE STATE
END	COORDINATES	CONTINUE
PRINT	DEFINE	POINT LOAD
SETNAME	END OPTION	PROPORTIONAL INC
SHELL SECT	FIXED DISP	
SIZING	GAP DATA	
TITLE	ISOTROPIC	
	OPTIMIZE	
	ORTHOTROPIC	
	POINT LOAD	
	POST	
	PRINT ELEM	
	PRINT NODE	
	TYING	

Table 2.70-1 Balance of Moments

Gap	Node 1	Node 2	INC = 1 Force [N]	INC = 19 Force [N]	Δ [N]	Distance [m]	M_z [N · m]
359	359	735	3653.	3651.	-2.	0.0235	-0.0470
360	358	734	2671.	2674.	3.	0.023875	0.0716
361	357	737	2313.	2319.	6.	0.02425	0.1455
362	356	738	2158.	2167.	9.	0.024625	0.2216
363	355	740	2029.	2041.	12.	0.025	0.3000
364	354	739	1871.	1886.	15.	0.025375	0.3806
365	353	751	836.	845.	9.	0.02575	0.2318
366	368	749	1243.	1228.	-15.	0.016	-0.24
367	367	750	1768.	1743.	-25.	0.016375	-0.4094
368	366	741	1788.	1761.	-27.	0.01675	-0.4523
369	365	742	2059.	2028.	-31.	0.017125	-0.5309
370	364	748	2821.	2782.	-39.	0.0175	-0.6825
371	230	747	-74.	0.	74.	0.00825	0.6105
372	228	746	45.	-99.	-144.	0.009375	-1.3500
373	223	744	375.	275.	-100.	0.0105	-1.0500
374	222	736	840.	751.	-89.	0.011625	-1.0346
375	219	745	1047.	997.	-50.	0.01275	-0.6375
376	349	743	760.	713.	-47.	0.014766	-0.6940
Σ			2.82E4		-441.		-5.1665
Bolt Stress [N/m^2]			4.3778E8	4.495E8	1.17E7 (x-1.288E-4/2)		
Bolt Force [N]					-753.	0.0205	-15.45
							-20.62
Applied Moment [N. m]				900 x 2 = 1800.		0.013875	24.98
							Δ% = 17%

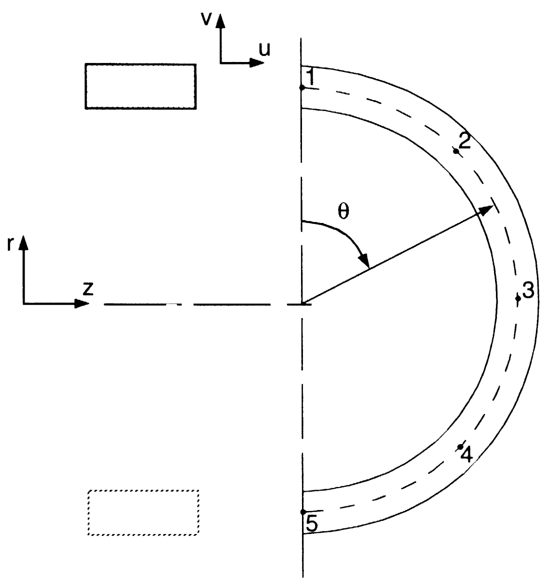


Figure 2.70-1 Element 95 Layer Points

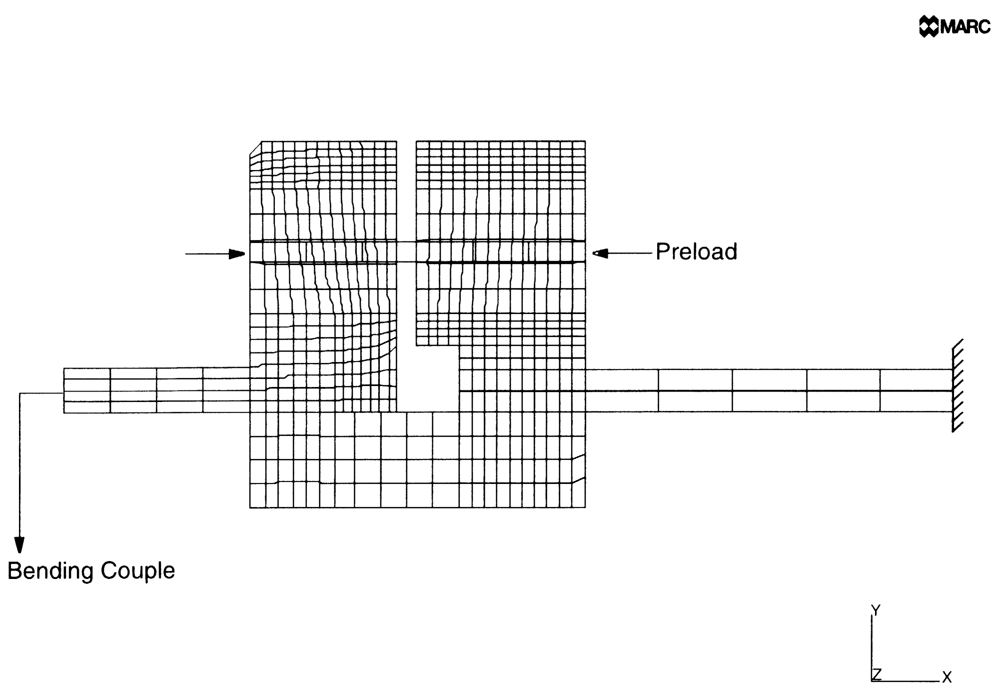


Figure 2.70-2 Loads on the Flange Joint

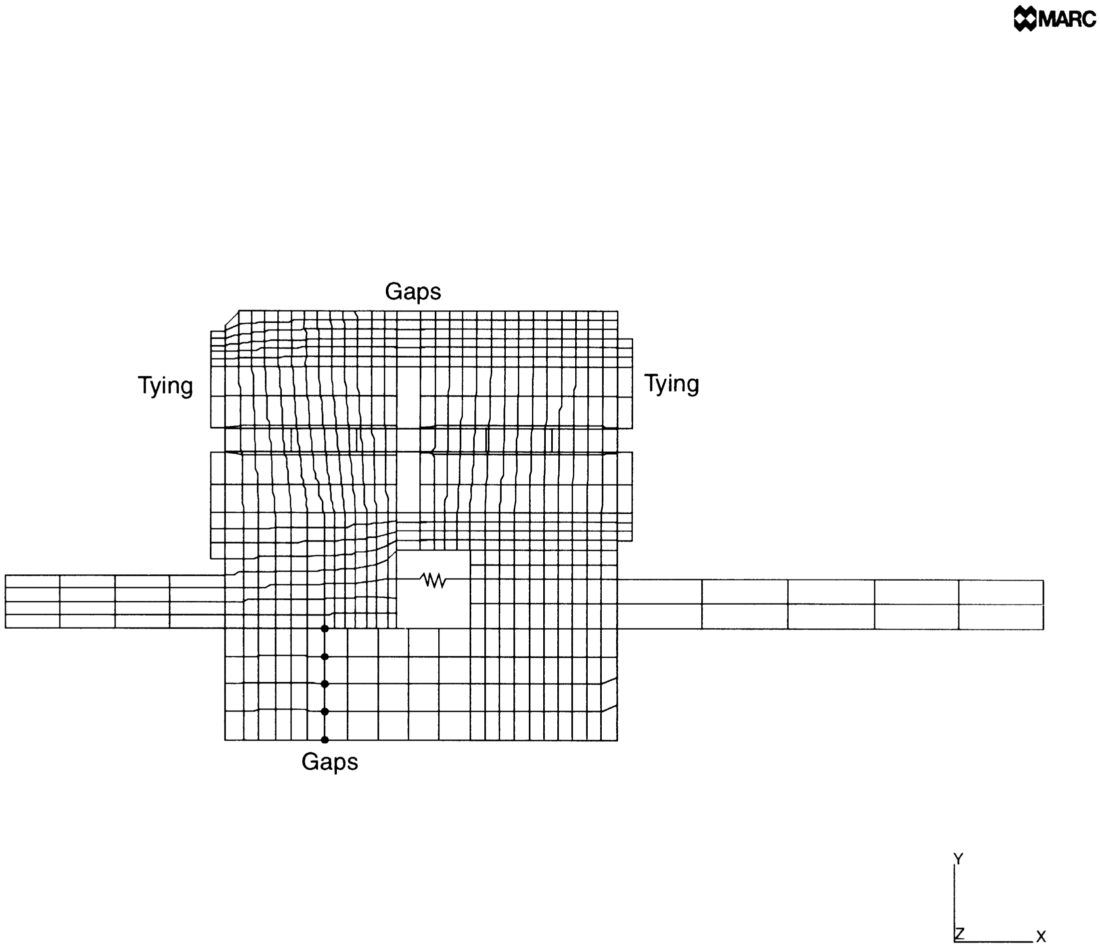


Figure 2.70-3 Tying in the Flange Joint

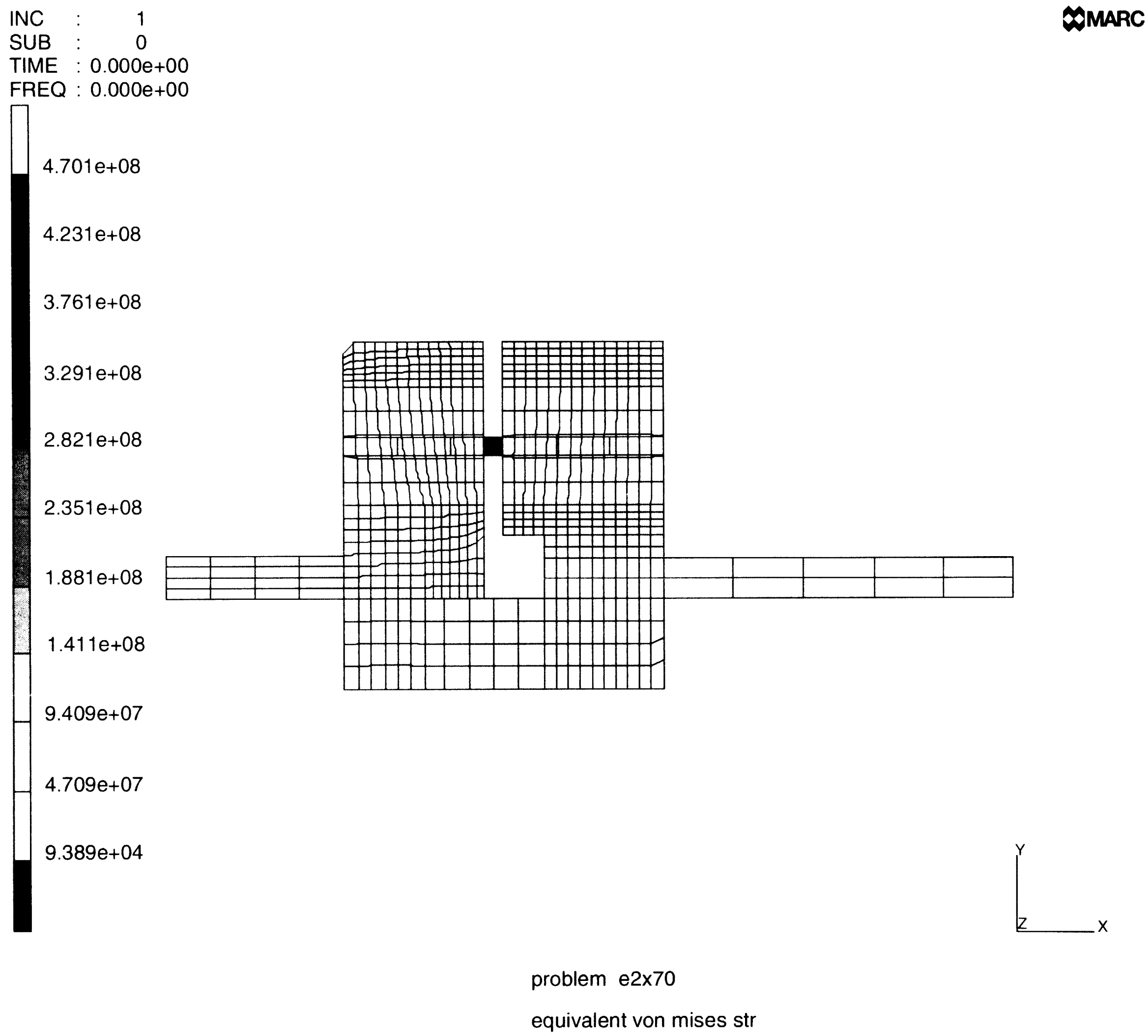


Figure 2.70-4 von Mises Stress Induced by Preload

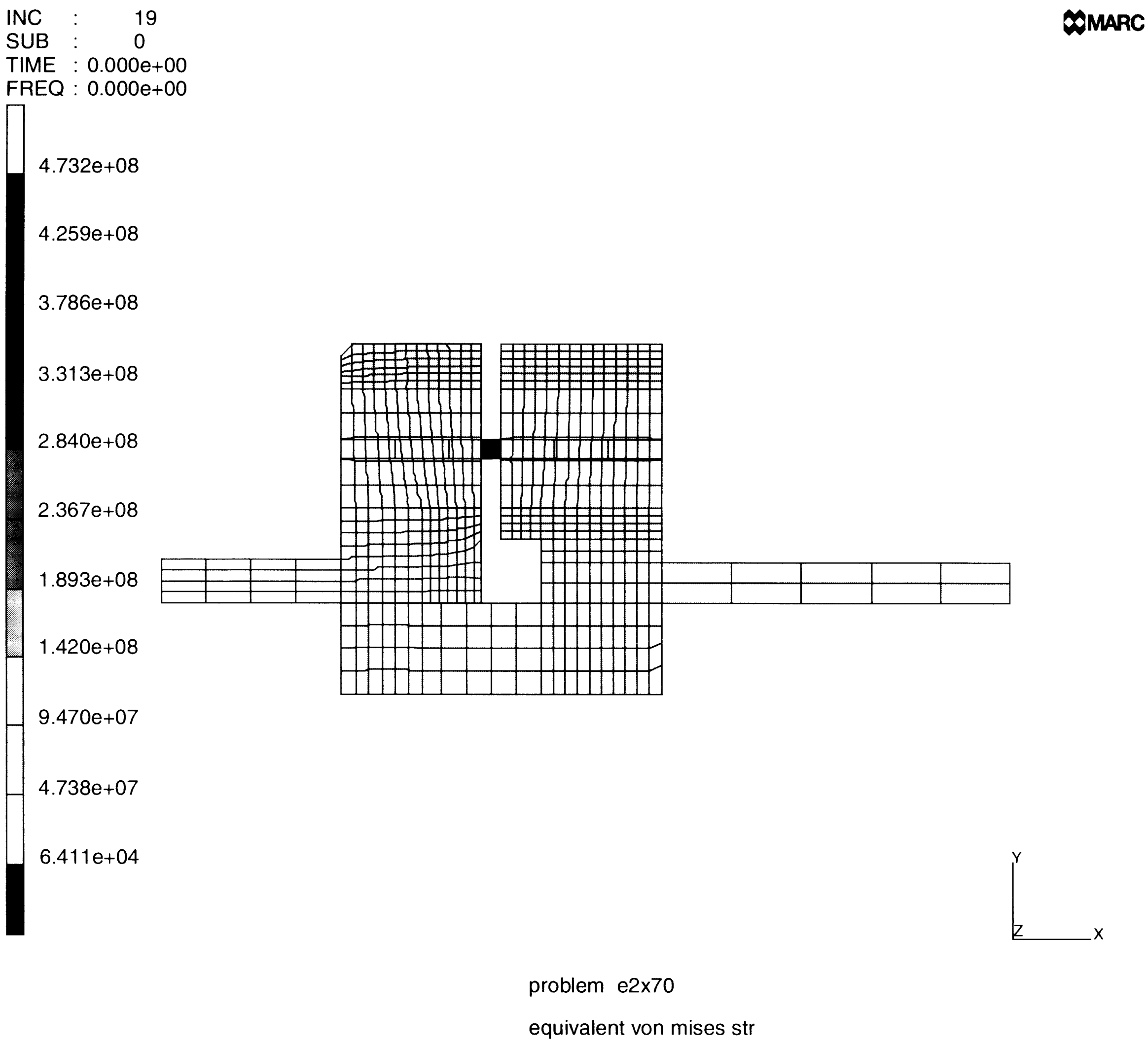


Figure 2.70-5 von Mises Stress Induced by Moment

2.71 Spinning Cantilever Beam

This problem demonstrates the use of MARC element type 98 for the solution of spinning cantilever beam. The beam rotates at a constant angular velocity. The beam also has an initial velocity which induces Coriolis effect. The ROTATION A and DIST LOADS options are used for the input of Centrifugal load. The INITIAL VEL option is used to input the initial velocity.

This problem is modeled using the two techniques summarized below.

Data Set	Element Type(s)	Number of Elements	Number of Nodes	Differentiating Features
e2x71a	98	5	6	Centrifugal loads
e2x71b	95	5	6	Centrifugal and Coriolis loads

Element

The element (Element 98) is a 2-node straight elastic beam in space and includes the transverse shear effects in its formulation.

Model

As shown in Figure 2.71-1, the finite element mesh consists of five elements and six nodes. The span on the beam is five inches and the cross-section of the beam is assumed to be a closed, thin, square section.

Geometry

The GEOMETRY block is used for entering the beam section properties. The section properties (area = 0.0369 inches^2, $I_x = I_y = 6.4693 \times 10^{-3}$ inches^4) are entered through the GEOMETRY block.

Material Properties

The material of the beam is assumed to have a Young's modulus of 3.0e+08 psi, Poisson's ratio of 0.3, and a mass density of 0.281 lb-seconds/inch^4.

Loading

The beam is subjected to Centrifugal loading (IBODY = 100) resulting from the rotation of the beam. With an angular velocity of 20 • radian/seconds ($\omega^2 = 400$) and the axis of rotation is the y axis. The beam has an initial velocity of 100 inches/second in the x-direction which induces Coriolis effect (IBODY = 103).

Boundary Condition

At node 1, all the degrees of freedom are constrained ($U_x = U_y = U_z = \theta_x = \theta_y = \theta_z = 0$).

Results

The deformation of the beam is given is Table 2.71-1.

Table 2.71-1 Beam Deflection (Inches)

Node	$\delta_x(x10^{-4})$ (Due to Centrifugal Loading)	$\delta_y(x10^{-4})$ (Due to Coriolis Effect)
1	0.	
2	1.305	1.61
3	2.385	5.022
4	3.203	9.422
5	3.722	14.241
6	3.903	19.135

Parameters, Options, and Subroutines Summary

Example e2x71a.dat:

Parameters

ELEMENTS
END
SIZING
TITLE

Model Definition Options

CONNECTIVITY
COORDINATES
DIST LOADS
END OPTION
FIXED DISP
GEOMETRY
ISOTROPIC
POST
ROTATION A

Example e2x71b.dat:

Parameters	**Model Definition Options**
ELEMENTS	CONNECTIVITY
END	COORDINATES
SIZING	DIST LOADS
TITLE	END OPTION
	FIXED DISP
	GEOMETRY
	INITIAL VEL
	ISOTROPIC
	POST
	ROTATION A

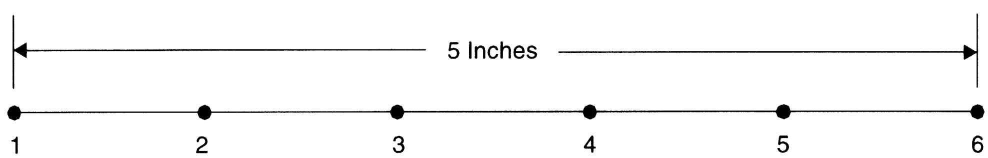


Figure 2.71-1 Finite Element Model

2.72 Shell Roof by Element 138

This problem illustrates the use of MARC element type 138 for an elastic analysis of a barrel vault shell roof. The roof is subjected to its own weight. This problem is similar to problems 2.16, 2.17, 2.18, 2.19, 2.55, 2.73, and 2.74.

Element

Element type 138 is a 3-node thin-shell element with six degrees of freedom at each corner node.

Model

The element is type 138. There are 128 elements with a total of 61 nodes. The shell roof and the finite element mesh are shown in Figure 2.72-1.

Material Properties

Young's modulus is 30 x 10^5 psi. Poisson's ratio is taken to be 0. The mass density is 1.0 lb-sec^2/in^4.

Geometry

The shell thickness is 3.0 inches.

Loading

Uniform gravity load in negative z-direction, specified with load type 102. The magnitude of the force per unit mass is 0.20833.

Boundary Conditions

Supported end:

A. u = 0, w = 0, at y = 0

The following degrees of freedom are constrained at the lines of symmetry:

B. u = 0 and θ_y = 0 at x = 0

C. v = 0 and θ_x = 0 at y = 300

SHELL SECT

The SHELL SECT option allows you to reduce the number of integration points from the default value of 11 to a minimum value of 3 in the shell thickness direction. This three-point integration scheme is exact as for a linear elastic problem.

Results

A deformed mesh plot is shown in Figure 2.72-2. The results are in good agreement with problem 2.19. The element is easy to use and inexpensive.

Parameters, Options, and Subroutines Summary

Example e2x72.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NO PRINT
	POST

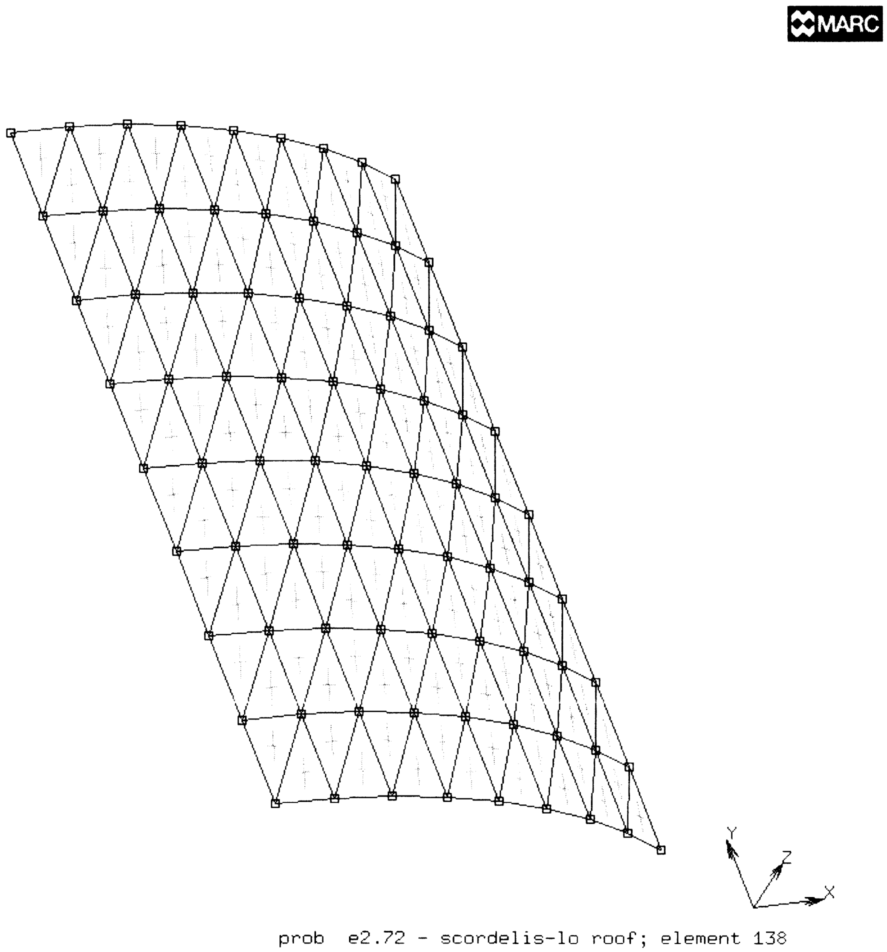


Figure 2.72-1 Shell Roof and Mesh

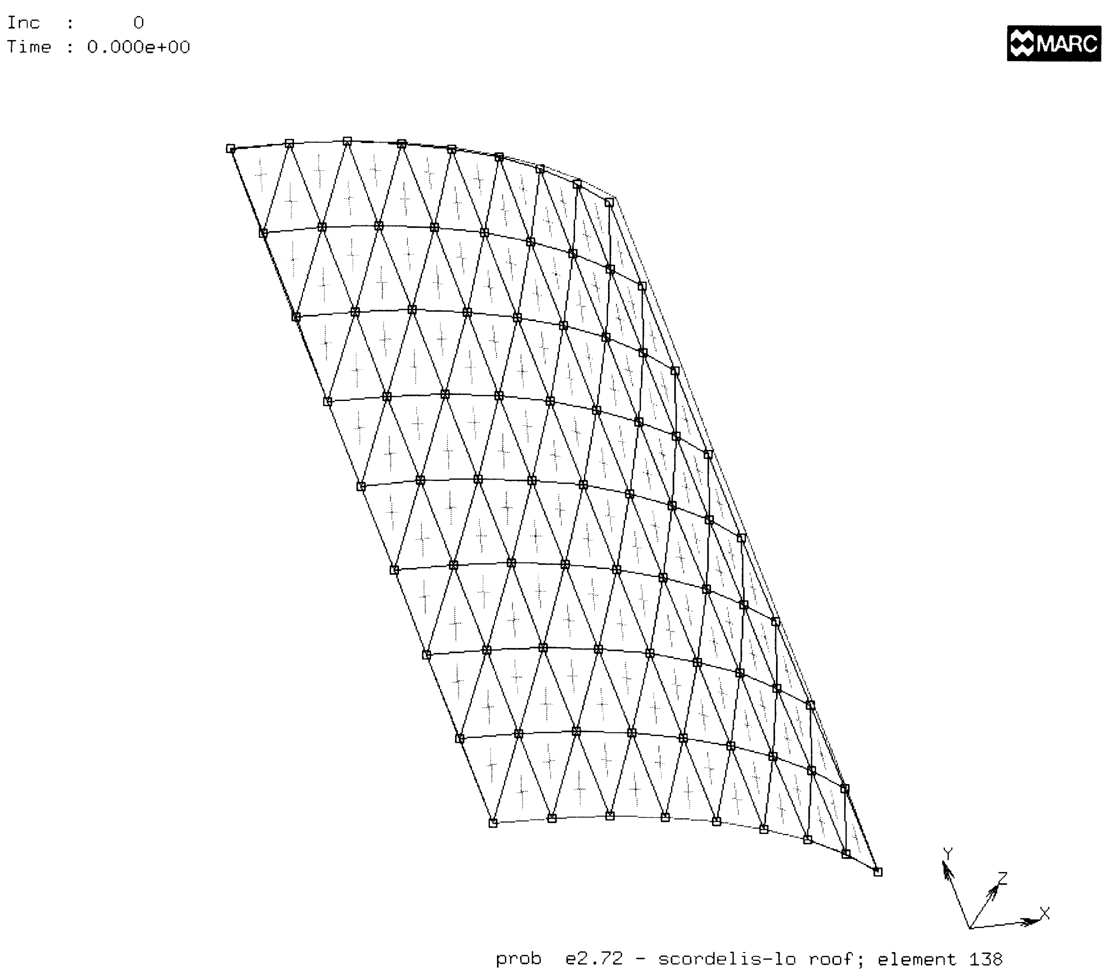


Figure 2.72-2 Deformed Mesh Plot

2.73 Shell Roof by Element 139

This problem illustrates the use of MARC element type 139 for an elastic analysis of a barrel vault shell roof. The roof is subjected to its own weight. This problem is similar to problems 2.16, 2.17, 2.18, 2.19, 2.55, 2.72, and 2.74.

Element

Element type 139 is a 4-node thin-shell element with six degrees of freedom at each corner node.

Model

The element is type 139. There are 64 elements with a total of 48 nodes. The shell roof and the finite element mesh are shown in Figure 2.73-1.

Material Properties

Young's modulus is 30 x 10^5 psi. Poisson's ratio is taken to be 0. The mass density is 1.0 lb-sec^2/in^4.

Geometry

The shell thickness is 3.0 inches.

Loading

Uniform gravity load in negative z-direction, specified with load type 102. The magnitude of the force per unit mass is 0.20833.

Boundary Conditions

Supported end:

A. u = 0, w = 0, at y = 0

The following degrees of freedom are constrained at the lines of symmetry:

B. u = 0 and $\theta_y = 0$ at x = 0

C. v = 0 and $\theta_x = 0$ at y = 300

SHELL SECT

The SHELL SECT option allows you to reduce the number of integration points from the default value of 11 to a minimum value of 3 in the shell thickness direction. This three-point integration scheme is exact as for a linear elastic problem.

Results

A deformed mesh plot is shown in Figure 2.73-2. The results are in good agreement with problem 2.19. The element is easy to use and less expensive than element type 25.

Parameters, Options, and Subroutines Summary

Example e2x73.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NO PRINT
	POST

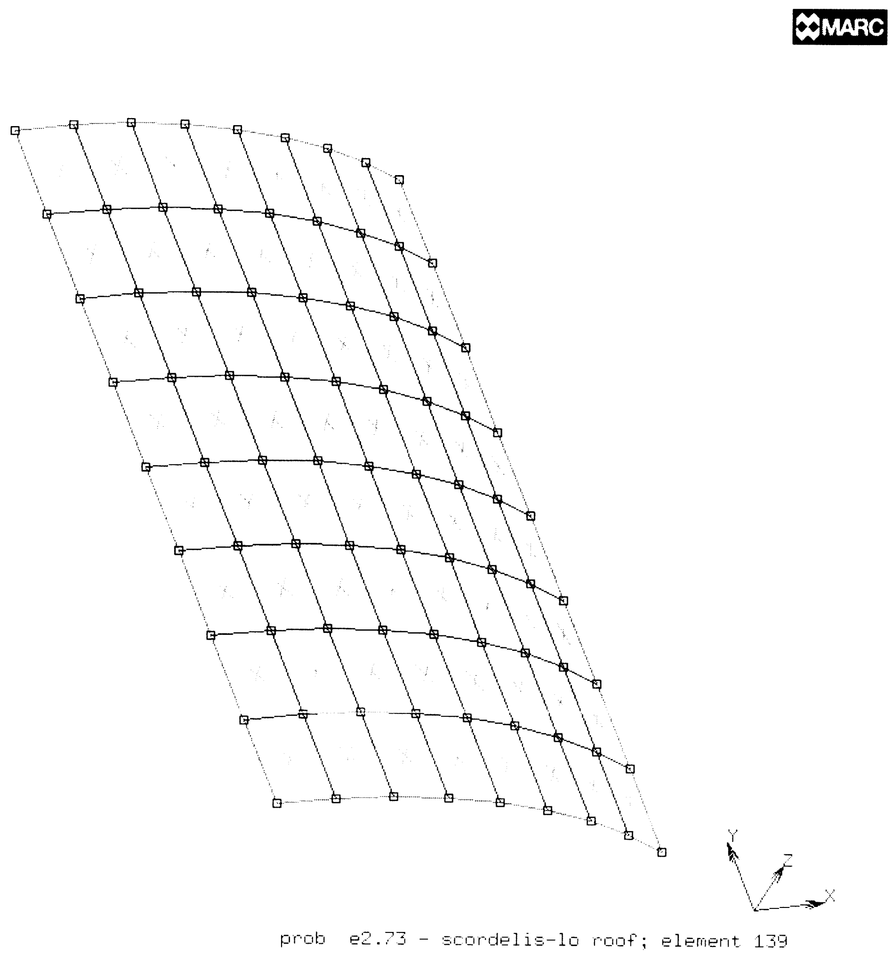


Figure 2.73-1 Shell Roof and Mesh

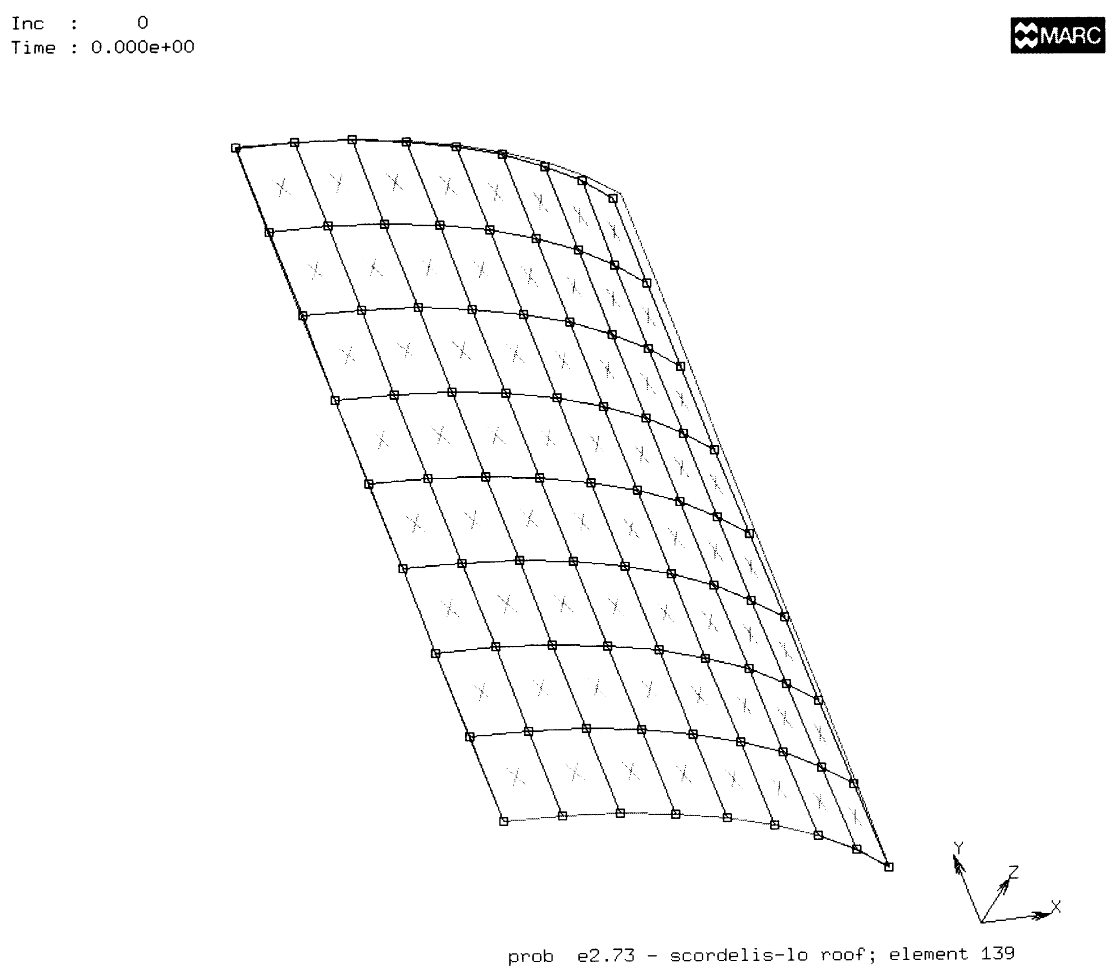


Figure 2.73-2 Deformed Mesh Plot

2.74 Shell Roof by Element 140

This problem illustrates the use of MARC element type 140 for an elastic analysis of a barrel vault shell roof. The roof is subjected to its own weight. This problem is similar to problems 2.16, 2.17, 2.18, 2.19, 2.55, 2.72, and 2.73.

Element

Element type 140 is a 4-node thin-shell element with six degrees of freedom at each corner node. This element is similar to element 75 but uses a single intergration point per element.

Model

The element is type 140. There are 64 elements, with a total of 81 nodes. The shell roof and the finite element mesh are shown in Figure 2.74-1.

Material Properties

Young's modulus is 30×10^5 psi. Poisson's ratio is taken to be 0. The mass density is 1.0 $lb\text{-}sec^2/in^4$.

Geometry

The shell thickness is 3.0 inches.

Loading

Uniform gravity load in negative z-direction, specified with load type 102. The magnitude of the force per unit mass is 0.20833.

Boundary Conditions

Supported end:

A. $u = 0$, $w = 0$, at $y = 0$

The following degrees of freedom are constrained at the lines of symmetry:

B. $u = 0$ and $\theta_y = 0$ at $x = 0$

C. $v = 0$ and $\theta_x = 0$ at $y = 300$

SHELL SECT

The SHELL SECT option allows you to reduce the number of integration points from the default value of 11 to a minimum value of 3 in the shell thickness direction. This three-point integration scheme is exact as for a linear elastic problem.

Results

A deformed mesh plot is shown in Figure 2.74-2. The results are in good agreement with problem 2.19. The element is easy to use and inexpensive.

Parameters, Options, and Subroutines Summary

Example e2x74.dat:

Parameters	Model Definition Options
ELEMENTS	CONNECTIVITY
END	COORDINATES
SHELL SECT	DIST LOADS
SIZING	END OPTION
TITLE	FIXED DISP
	GEOMETRY
	ISOTROPIC
	NO PRINT
	POST

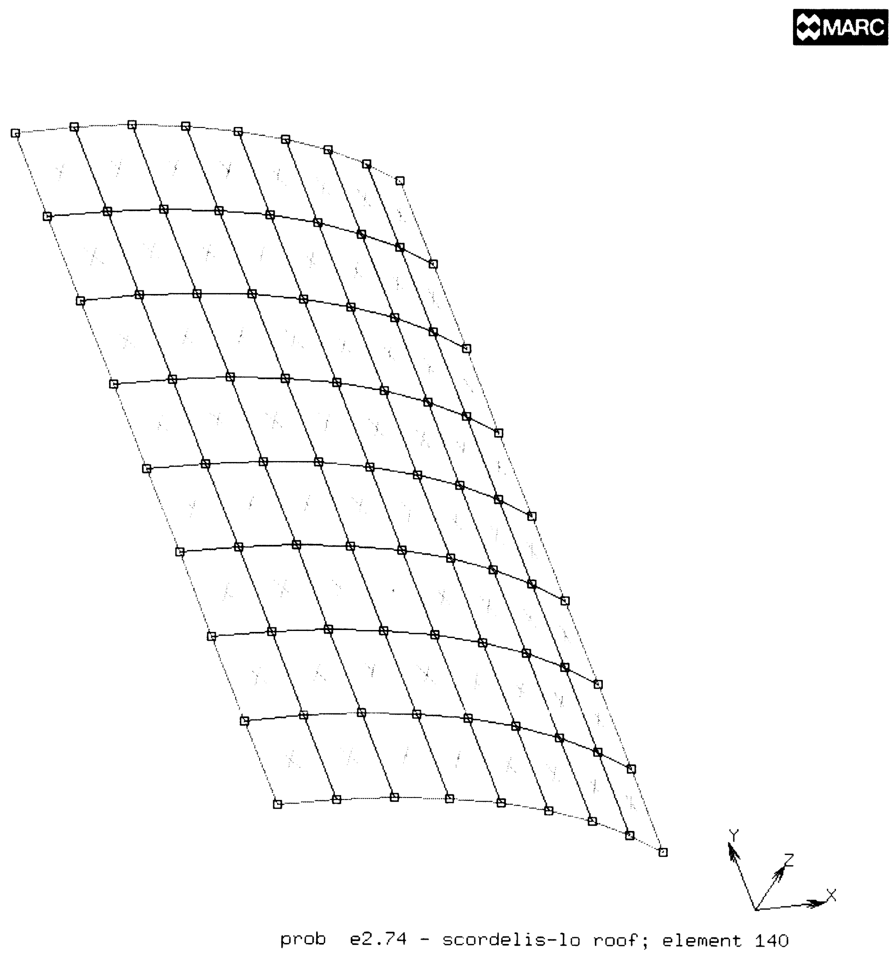


Figure 2.74-1 Shell Roof and Mesh

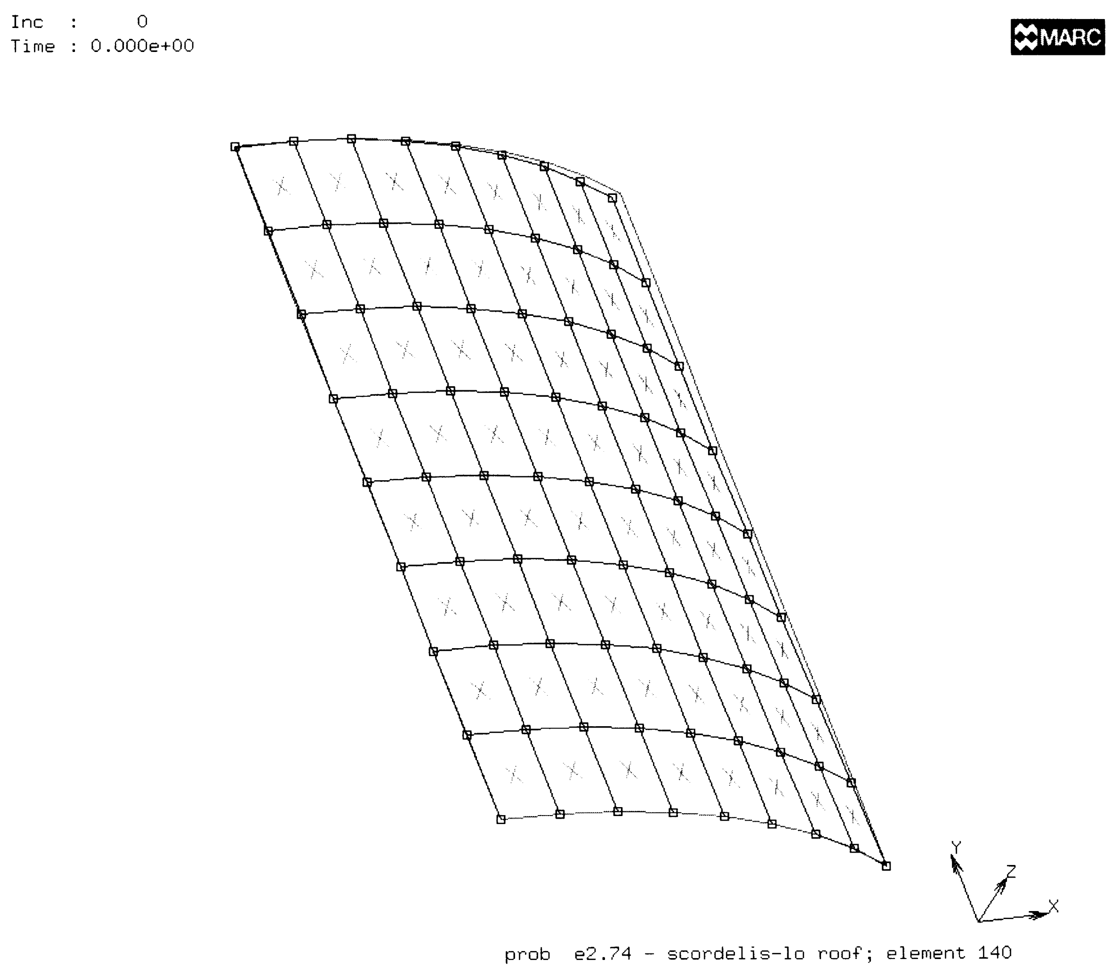


Figure 2.74-2 Deformed Mesh Plot

2.75 Cylinder Subjected to a Point Load - Element Type 138

This problem demonstrates the use of element type 138 for an elastic analysis of a cylindrical shell subjected to a point load. This example demonstrates the coupling between membrane and bending behavior.

Elements

The 3-node thin shell element is used. This element uses discrete Kirchhoff theory. There are three displacements and three rotations per node.

Model

The cylinder has a length of 60 inches, a radius of 30 inches, and a thickness of 3 inches. Because of symmetry, only 1/8 of the actual cylinder is modeled. The mesh has 288 elements and 169 nodes. The mesh is shown in Figure 2.75-1.

Material Properties

Young's modulus is 3×10^5 psi. Poisson's ratio is 0.3.

Geometry

The shell thickness is 3.0 inches and is entered through the GEOMETRY option. The radius/thickness (r/t) is 30/3 = 10 which suggests that this is a thick shell. The thick shell elements may be more appropriate (see Figure 2.75-2).

Loading

A point load of 0.50 pound is applied to the structure. Because of symmetry, 0.25 pound is applied to node 13.

Boundary Conditions

At z = 30 inches, the shell is held such that:

$U_x = 0$ $\quad U_y = 0$

At z = 0, symmetry conditions are applied:

$u_z = 0$ $\quad \theta_x = 0$ $\quad \theta_y = 0$

At x = 0, y = 30, symmetry conditions are:

$U_x = 0$ $\quad \theta_z = 0$

At x = 30, y = 0, symmetry conditions are:

$U_y = 0$ $\quad \theta_z = 0$

Solution Procedure

The default profile solver is used with the Sloan bandwidth optimization procedure.

Results

A deformed mesh is shown in Figure 2.75-2. The y deformation at x = 0 is shown as a path plot in Figure 2.75-3.

Parameters, Options, and Subroutines Summary

Example e2x75.dat:

Parameters	Model Definition Options
ALL POINTS	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SETNAME	FIXED DISP
SHELL SECT	GEOMETRY
SIZING	ISOTROPIC
TITLE	NO PRINT
	POINT LOADS
	POST

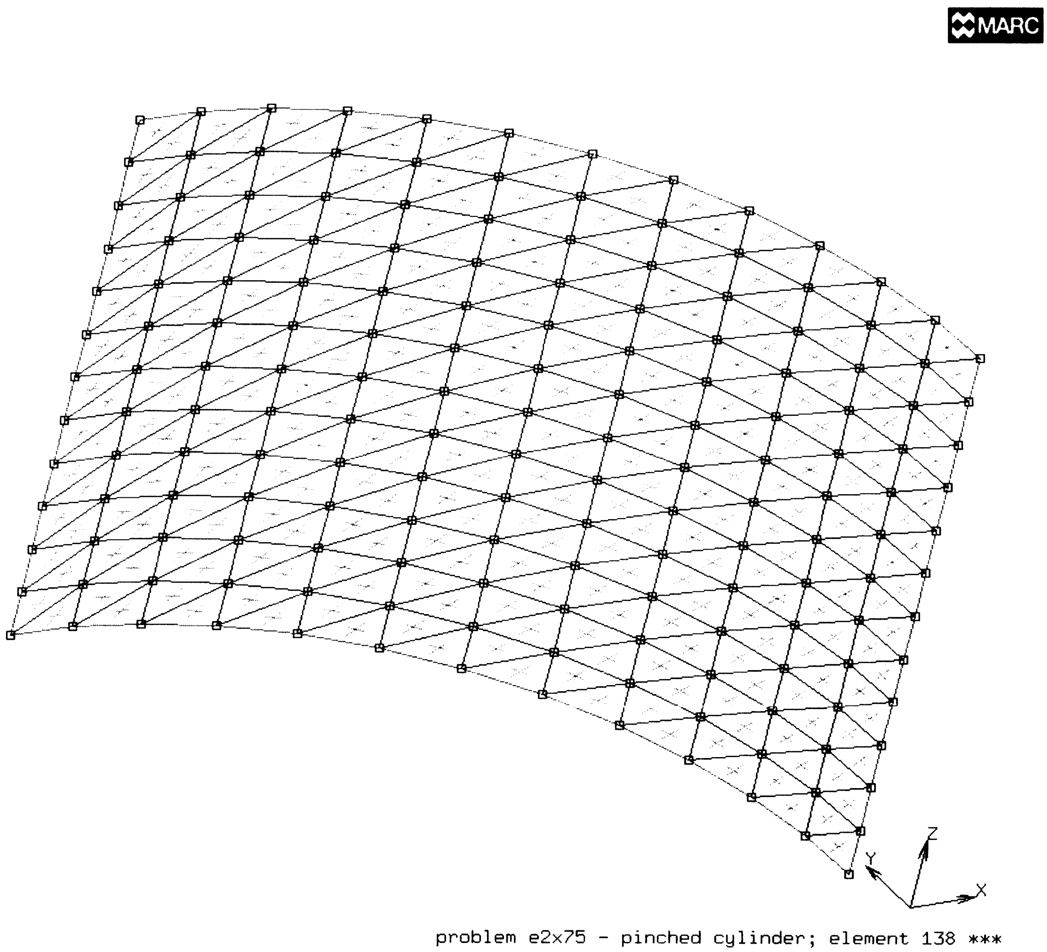


Figure 2.75-1 Shell Roof and Mesh

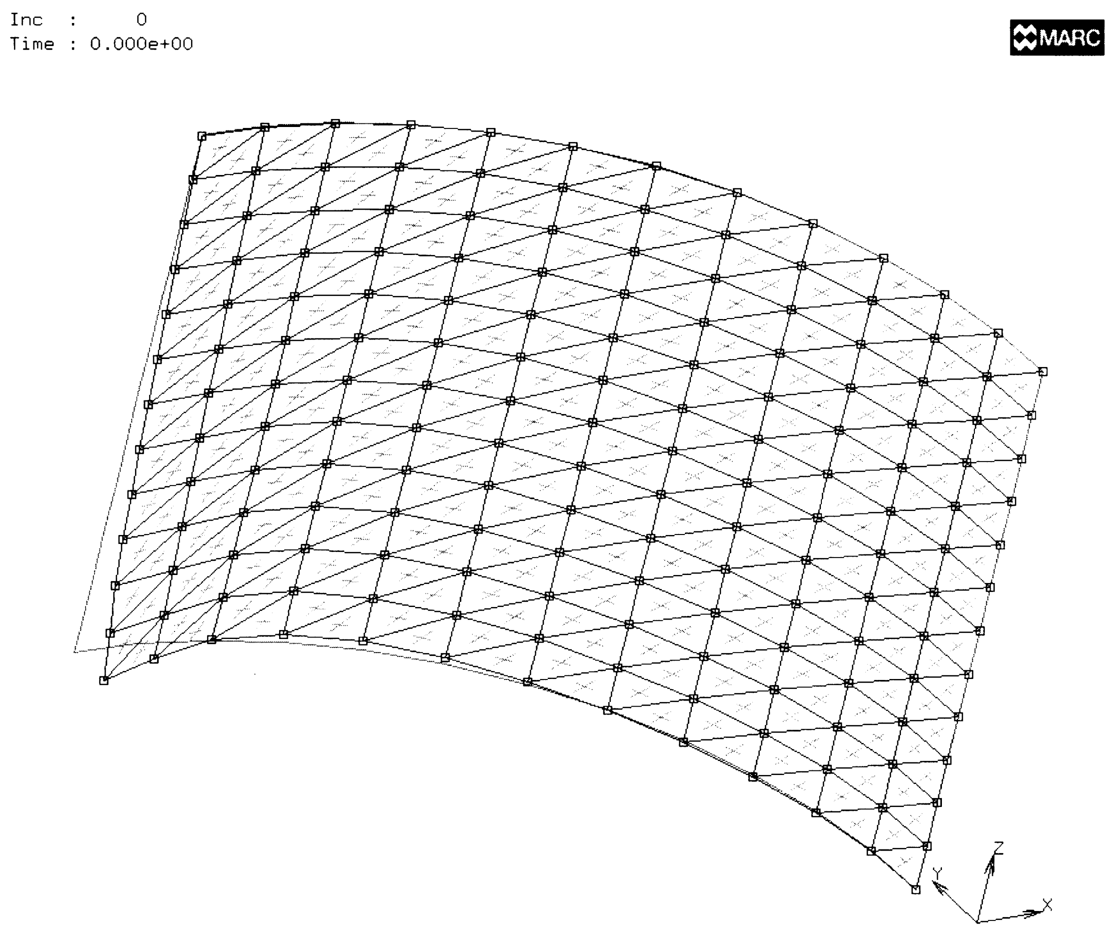


Figure 2.75-2 Deformed Mesh Plot

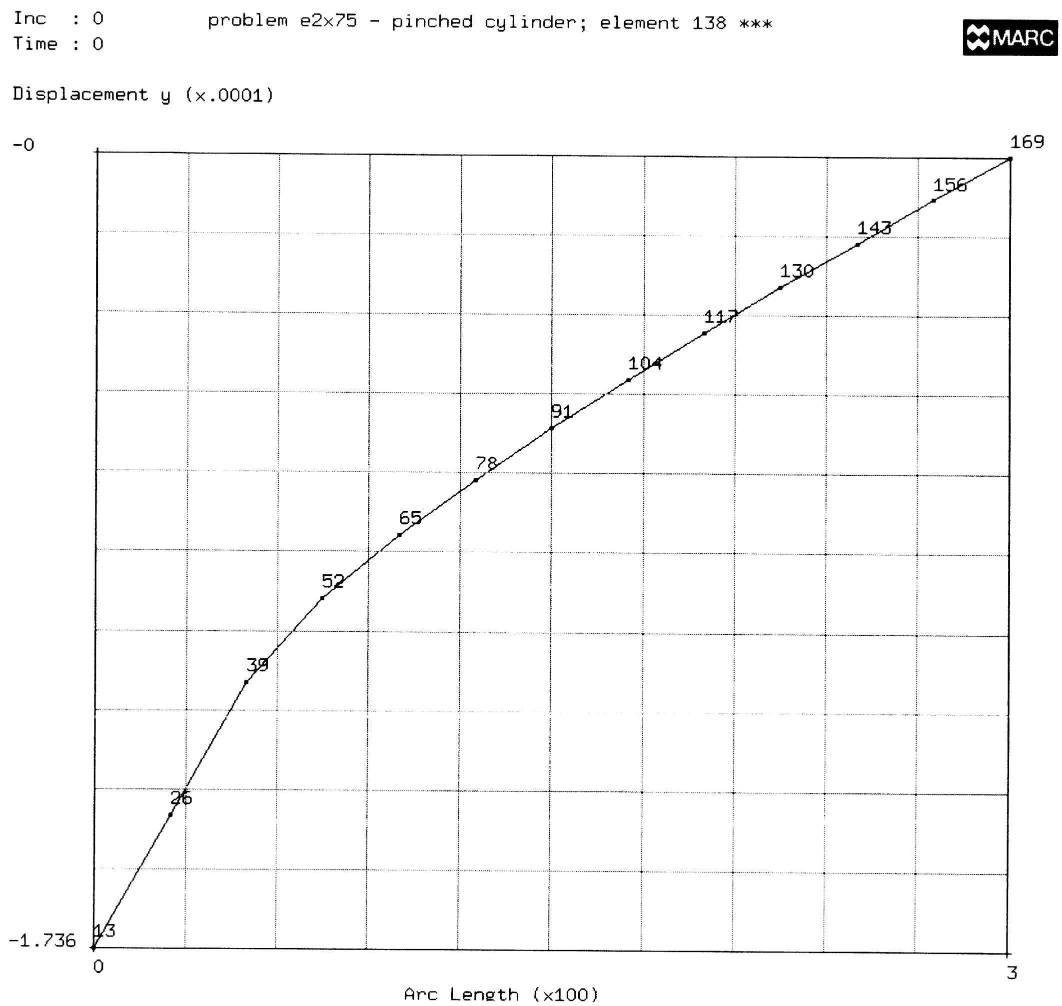


Figure 2.75-3 Y Deformation Along X = 0

2.76 Cylinder Subjected to a Point Load - Element Type 139

This problem demonstrates the use of element type 139 for an elastic analysis of a cylindrical shell subjected to a point load. This example demonstrates the coupling between membrane and bending behavior.

Elements

Element type 139 is a 4-node thin-shell element. This element uses discrete Kirchhoff theory. There are three displacements and three rotations per node.

Model

The cylinder has a length of 60 inches, a radius of 30 inches, and a thickness of 3 inches. Because of symmetry, only 1/8 of the actual cylinder is modeled. The mesh has 144 elements and 169 nodes. The mesh is shown in Figure 2.76-1.

Material Properties

Young's modulus is 3×10^5 psi. Poisson's ratio is 0.3.

Geometry

The shell thickness is 3.0 inches and is entered through the GEOMETRY option. The radius/thickness (r/t) is 30/3 = 10 which suggests that this is a thick shell. The thick shell elements may be more appropriate (see Figure 2.76-2).

Loading

A point load of 0.50 pound is applied to the structure. Because of symmetry, a load of 0.25 pound is applied to node 13.

Boundary Conditions

At z = 30 inches, the shell is held such that:

$U_x = 0$ $\qquad U_y = 0$

At z = 0, symmetry conditions are applied:

$u_z = 0$ $\qquad \theta_x = 0$ $\qquad \theta_y = 0$

At x = 0, y = 30, symmetry conditions are:

$U_x = 0$ $\qquad \theta_z = 0$

At x = 30, y = 0, symmetry conditions are:

$U_y = 0$ $\qquad \theta_z = 0$

Solution Procedure

The default profile solver is used with the Sloan bandwidth optimization procedure.

Results

A deformed mesh is shown in Figure 2.76-2. The y deformation at x = 0 is shown as a path plot in Figure 2.76-3.

Parameters, Options, and Subroutines Summary

Example e2x76.dat:

Parameters	Model Definition Options
ALL POINTS	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SETNAME	FIXED DISP
SHELL SECT	GEOMETRY
SIZING	ISOTROPIC
TITLE	NO PRINT
	POINT LOADS
	POST

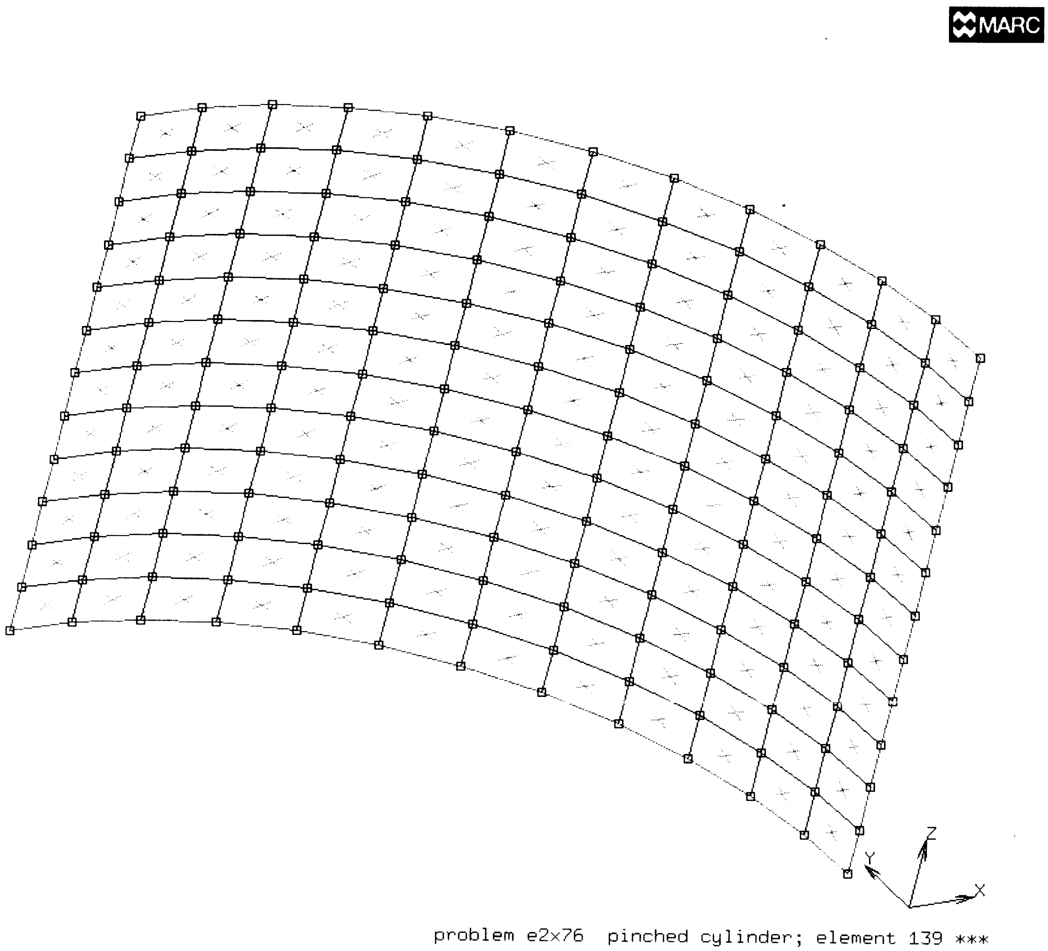


Figure 2.76-1 Shell Roof and Mesh

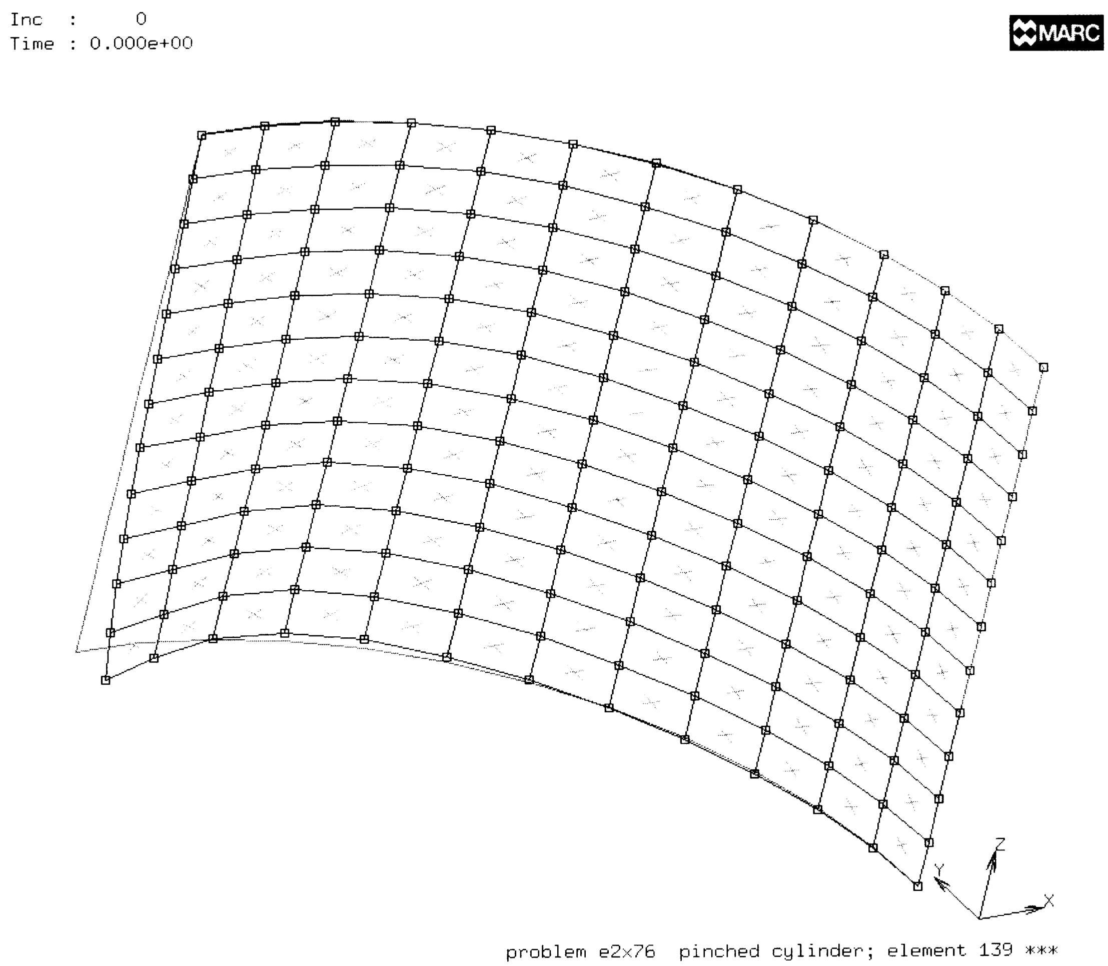


Figure 2.76-2 Deformed Mesh Plot

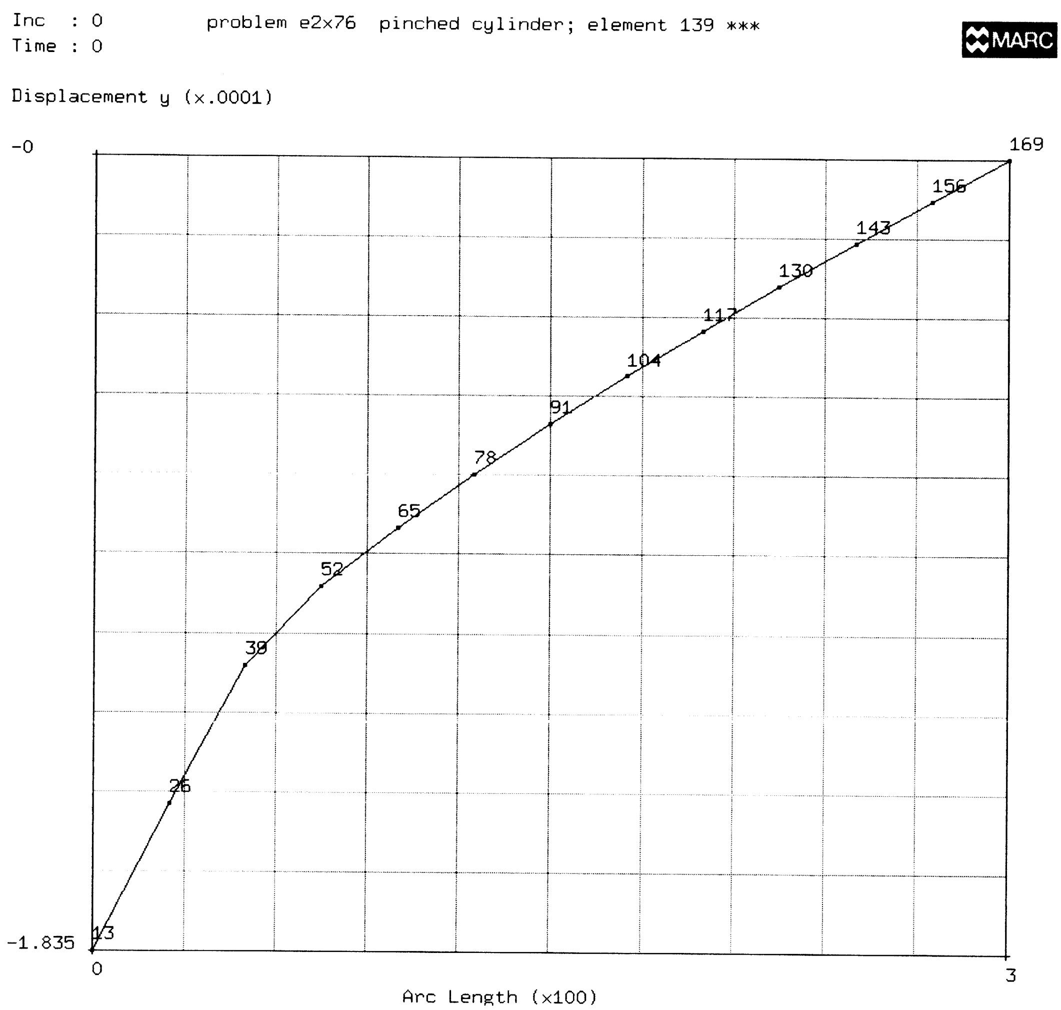


Figure 2.76-3 Y Deformation Along X = 0

2.77 Cylinder Subjected to a Point Load - Element Type 140

This problem demonstrates the use of element type 140 for an elastic analysis of a cylindrical shell subjected to a point load. It shows the coupling between membrane and bending behavior.

Elements

Element type 140 is a 4-node thick-shell element with six degrees of freedom at each corner node. This element is similar to element 75 but uses a single intergration point per element.

Model

The cylinder has a length of 60 inches, a radius of 30 inches, and a thickness of 3 inches. Because of symmetry, only 1/8 of the actual cylinder is modeled. The mesh has 144 elements and 169 nodes. The mesh is shown in Figure 2.77-1.

Material Properties

Young's modulus is 3×10^5 psi. Poisson's ratio is 0.3.

Geometry

The shell thickness is 3.0 inches and is entered through the GEOMETRY option. The radius/thickness (r/t) is 30/3 = 10 which suggests that this is a thick shell. The thick shell elements may be more appropriate (see Figure 2.77-2).

Loading

A point load of 0.50 pound is applied to the structure. Because of symmetry, a load of 0.25 pound is applied to node 13.

Boundary Conditions

At z = 30 inches, the shell is held such that:

$U_x = 0$ $\quad$ $U_y = 0$

At z = 0, symmetry conditions are applied:

$u_z = 0$ $\quad$ $\theta_x = 0$ $\quad$ $\theta_y = 0$

At x = 0, y = 30, symmetry conditions are:

$U_x = 0$ $\quad$ $\theta_z = 0$

At x = 30, y = 0, symmetry conditions are:

$U_y = 0$ $\quad$ $\theta_z = 0$

Solution Procedure

The default profile solver is used with the Sloan bandwidth optimization procedure.

Results

A deformed mesh is shown in Figure 2.77-2. The y deformation at x = 0 is shown as a path plot in Figure 2.77-3.

Parameters, Options, and Subroutines Summary

Example e2x77.dat:

Parameters	Model Definition Options
ALL POINTS	CONNECTIVITY
ELEMENTS	COORDINATES
END	END OPTION
SETNAME	FIXED DISP
SHELL SECT	GEOMETRY
SIZING	ISOTROPIC
TITLE	NO PRINT
	POINT LOADS
	POST

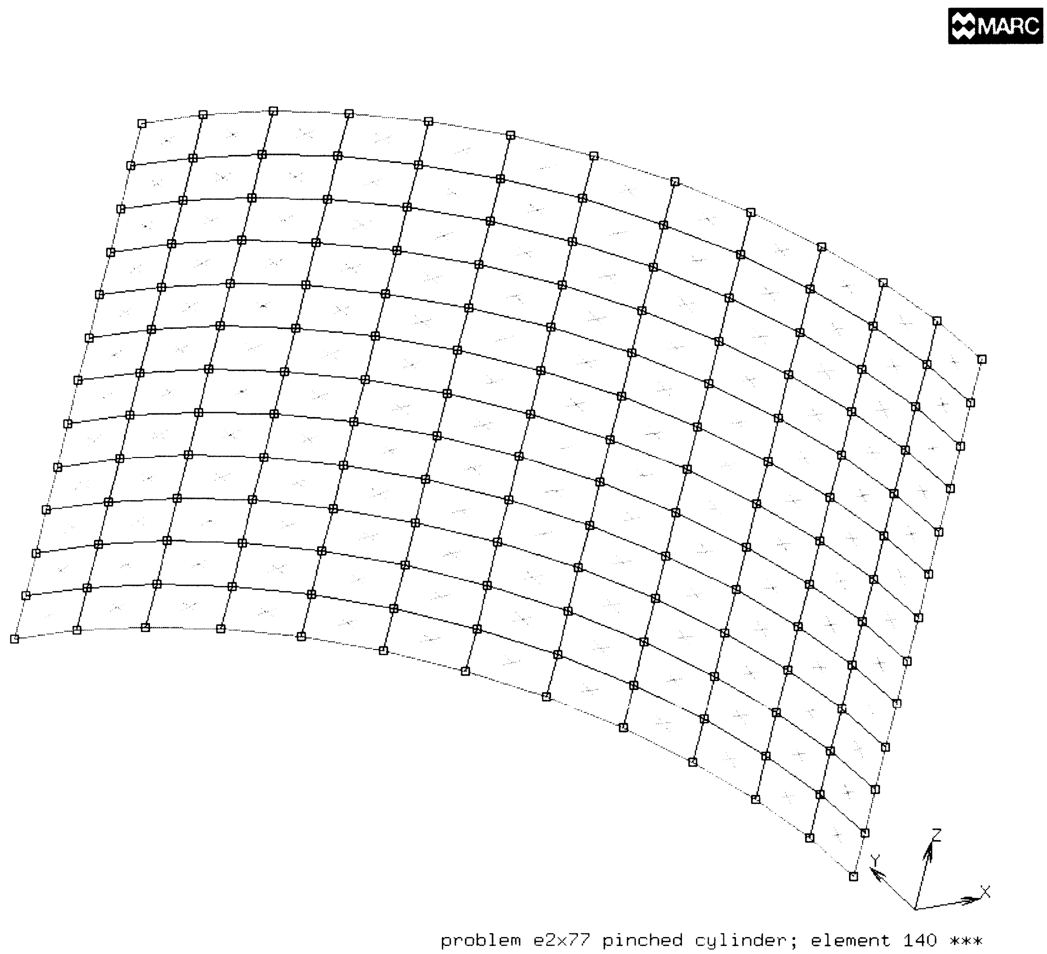


Figure 2.77-1 Shell Roof and Mesh

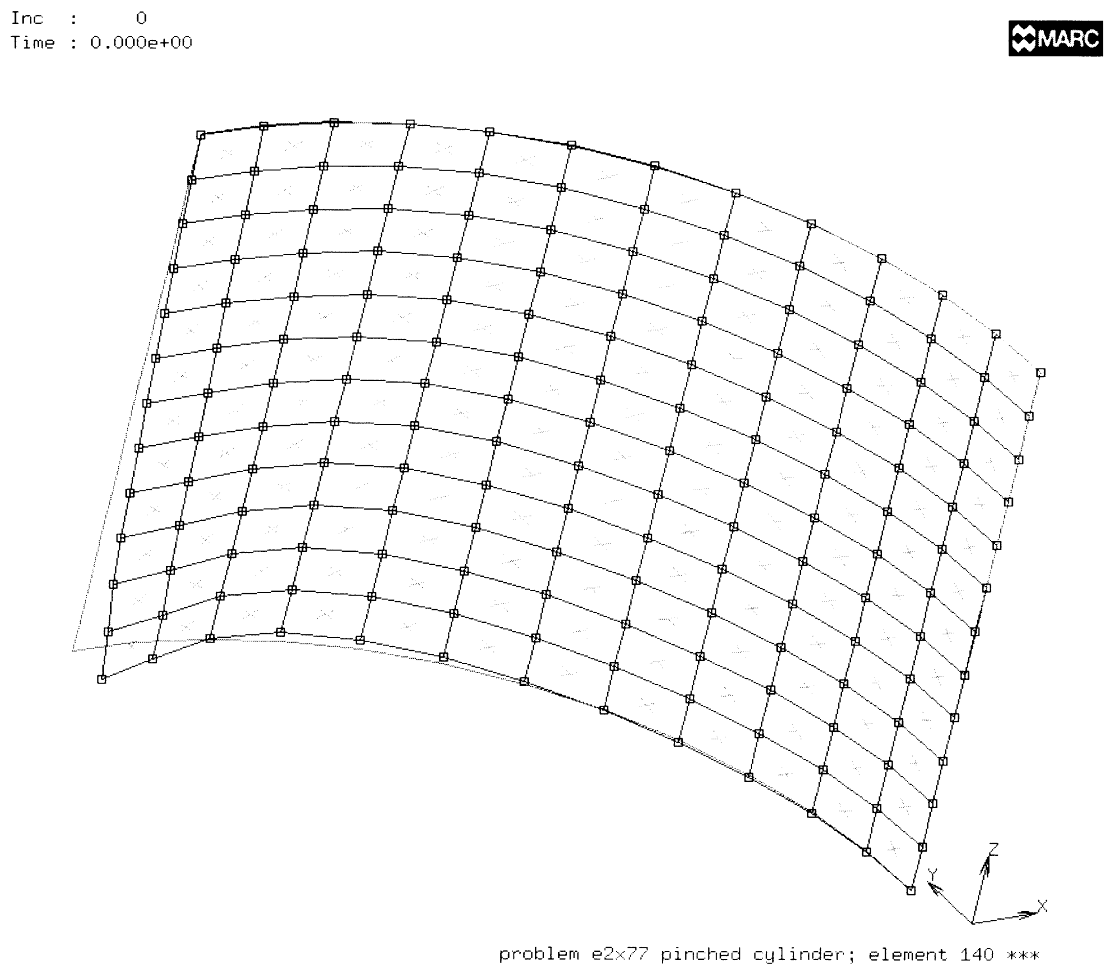


Figure 2.77-2 Deformed Mesh Plot

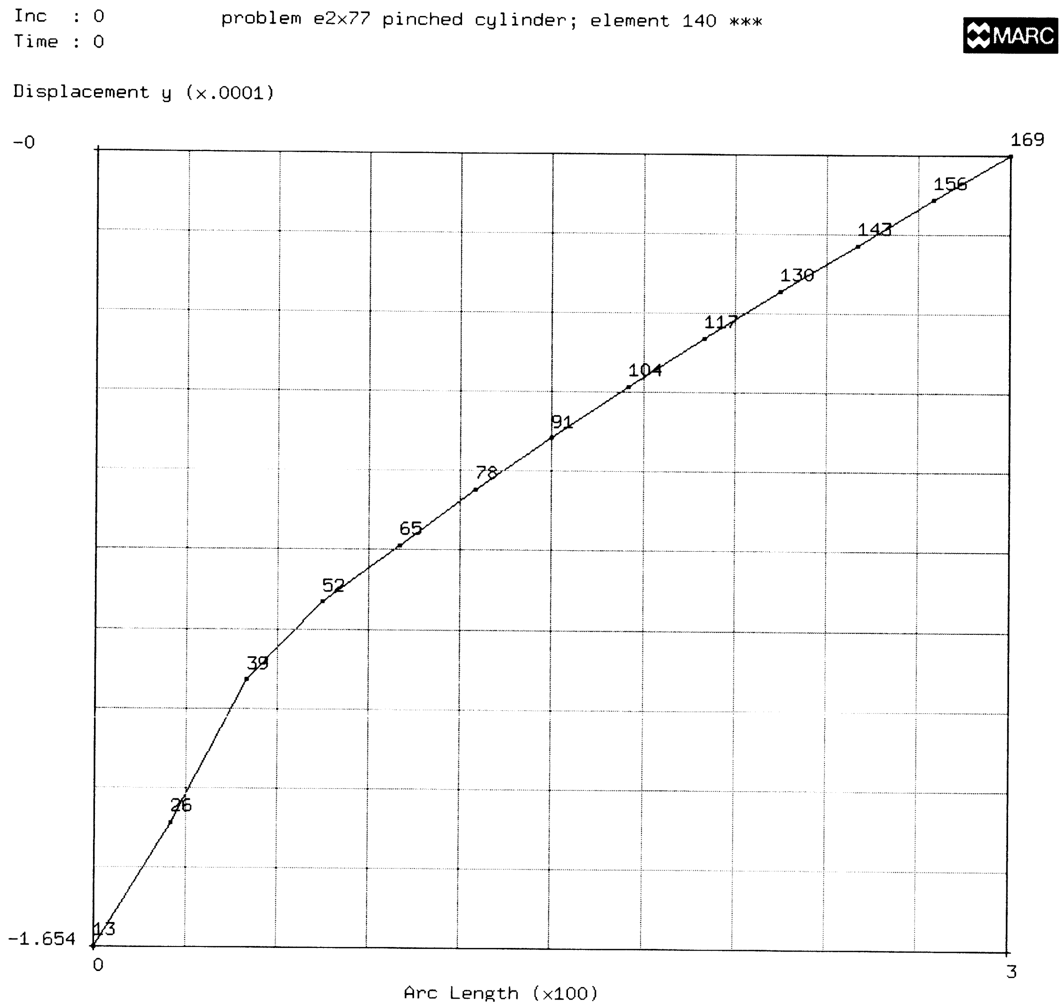


Figure 2.77-3 Y Deformation Along X = 0