DEPARTMENT OF CIVIL ENGINEERING
COLLEGE OF ENGINEERING
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA 23508

SUBSTRUCTURE ANALYSIS USING NICE/SPAR AND APPLICATIONS OF FORCE TO LINEAR AND NONLINEAR STRUCTURES

By

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Progress Report
For the period ended June 30, 1987

Prepared for the
National Aeronautics and Space Administration
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Under
Research Grant NAG-1-438
Dr. Olaf O. Storaasli, and
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Zia Razzaq[1], Venkatesh Prasad[2], Siva Prasad Darbhamulla[2], Ravinder Bhati[2], and Cai Lin[2]

ABSTRACT

Parallel computing studies are presented for a variety of structural analysis problems. Included are the substructure planar analysis of rectangular panels with and without a hole, the static analysis of space mast, using NICE/SPAR and FORCE, and substructure analysis of plane rigid-jointed frames using FORCE. The computations are carried out on the Flex/32 MultiComputer using one to eighteen processors. The NICE/SPAR runstream samples are documented for the panel problem. For the substructure analysis of plane frames, a computer program is developed to demonstrate the effectiveness of a substructuring technique when FORCE is enforced. On-going research activities for an elasto-plastic stability analysis problem using FORCE, and stability analysis of the focus problem using NICE/SPAR are briefly summarized. Speedup curves for the panel, the mast, and the frame problems provide a basic understanding of the effectiveness of parallel computing procedures utilized or developed, within the domain of the parameters considered. Although the speedup curves obtained exhibit various levels of computational efficiency, they clearly demonstrate the excellent promise which parallel computing holds for the structural analysis problems.

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TABLE OF CONTENTS

1. SUBSTRUCTURE ANALYSIS OF RECTANGULAR PANEL WITH HOLE USING NICE/SPAR AND FORCE

1.1 Problem Description

A two-dimensional elastic stress analysis of a rectangular panel with a central hole is conducted using NICE/SPAR while invoking concurrent processing with the use of FORCE. References 1 through 5 represent the relevant documents on NICE/SPAR and FORCE. Figure 1 shows the rectangular panel dimensions and the applied uniform compressive loading. The Young's modulus and the Poisson's ratio of the panel material are, respectively 10,000 ksi, and 0.3, which represent a typical aluminum alloy. The panel thickness is taken as 0.1 in. Initially, the panel is analyzed in the absence of a central hole using substructuring. The analysis of panel including the hole is then conducted using two substructures representing the regions around and away from the hole.

1.2 Finite Element Discretization and Substructuring

Figures 2 through 4 show the various types of discretizations investigated using E41 quadrilateral elements of NICE/SPAR. Figure 2(a) shows the rectangular panel divided into four elements as well as the boundary simulations. Figure 2(b) shows substructures 1 and 2 with revised element and node numbering at the substructure level. Similarly Figure 3 shows an eight-element discretization and the corresponding substructures. Figure 4 shows the finite element discretization of the rectangular panel with hole. Figure 4(a) shows the node numbering scheme commencing from the inner region around the hole for nodes 1 through 24, and continues at the bottom left corner of the panel with nodes 25

through 78. Figure 4(b) shows the element numbering scheme commencing from the inner region around the hole for elements 1 through 16, and for the remainder of the panel for elements 1 through 44 starting at the bottom left corner. The common element numbering from 1 to 16 can be used as long as the outer and the inner regions of the panel are modelled as separate substructures as shown in Figures 5(a), and 5(b), respectively.

1.3 Solution Procedure and Parallel Computations

The solution procedure for the substructuring method using NICE/SPAR is given in this section. The relevant SPAR processors and CLAMP procedures. The steps of the procedure are as follows:

1. The AUS subprocessor TABLE is created to input the number of substructures, the number of nodes per element, and the number of elements in each substructure.
2. Interface nodes are entered using subprocessor TABLE. These are stored in the NICE/SPAR library in the form of data sets.
3. Steps 1 and 2 are stored in a procedure called SUB_TABLE.
4. An external file PRESERVE is introduced into the main runstream. This file consists of CLAMP procedures END_SUB and GLOB_DAT.
5. The individual substructure data such as the number of nodes in the substructure, material properties, joint locations, boundary conditions, and element connectivity are entered. At the end of each substructure data, procedure END_SUB is called to store the data set sequence number.
6. Procedure GLOB__DAT is called for generating the data sets required for the assembled structure, from the data obtained from each

substructure.

7. Processor K is executed to obtain the final stiffness matrix.
8. subroutine getrow is used to extract the K matrix from the NICE/SPAR data library, and stored by rows in the upper triangular part of the matrix.
9. The FORCE subroutine SGEFA is called to perform the decomposition of the square matrix using gaussian elimination with partial pivoting.
10. Subroutine SGESL is called to solve the system of equations for the static displacements by back substitution.
11. The FORCE subroutines in steps 9 to 10 are run on several processors for speedup study.

1.4 Numerical Results and Discussion

In this section as well as sections 2 and 4 of this report, the following definitions of speedup and efficiency are used. Speedup is defined as the execution time on a uniprocessor divided by execution time on n processors. Parallel efficiency is defined as the speedup divided by the number of processors times 100. Table 1 presents the speedup and efficiencies for the four element rectangular panel shown in Figure 2. The corresponding speedup versus the number of processors relationship is shown in Figure 6, involving a 27 x 27 stiffness matrix. The maximum speedup factor is 3.7 for 8 processors. The efficiency reduces continuously with an increase in the number of processors.

Table 2 presents the speedup and efficiencies for the eight-element rectangular panel shown in Figure 3. The corresponding speedup versus number of processors relationship is shown in Figure 7, involving a 45 x 45 stiffness matrix. The maximum speedup factor is 5.14 for 8 and 12

processors. The efficiency reduces continuously with an increase in the number of processors, though at a lower rate than that for the four element panel.

Table 3 presents the speedup and efficiencies for the rectangular panel with a central hole shown in Figure 4. The corresponding speedup versus the number of processors relationship is in Figure 8, involving a 234 x 234 stiffness matrix. The maximum speedup factor is 13.2 for 18 processors. Here the speedup increases continuously with an increase in the number of processors while the efficiency decreases gradually.

2. CONCURRENT STATIC ANALYSIS OF MAST USING FORCE

2.1 The Mast Problem

Figure 9 shows the mast problem. The mast is a 60-meter high truss divided into 55 platforms with three nodes at each platform level. Each node has three degrees of freedom, that is, displacements in x, y, and z directions. The mast consists of horizontal batten members, inclined diagonal members, and vertical longeron members. The bottom platform with first three nodes is constrained against displacements. A concentrated load of 100 tons is applied at the upper most node in the global x direction. The datasets were stored in the NICE/SPAR library named MASTM3.L01. The problem is to determine the static nodal deflections using NICE/SPAR and FORCE.

2.2 Results and Discussion

The stiffness matrix generated by NICE/SPAR is of the order 495 X 495, including the support nodes. The linear system of equations is solved using FORCE. Table 4 presents the speedup and efficiencies when 1, 2, 4, 8, 12, 16, and 18, processors are used to solve the system of equations. The highest speedup is obtained when 18 processors are used, and is 15.71. The computational efficiency decreases slightly with an increase in number of processors. The results are shown by the dashed curve in Figure 10, in which the theoretical ideal relationship is also shown for a direct comparison. In comparison to the results presented in Section 1 for the rectangular panel problem of the order 234 X 234, the speedups for the mast show better promise due to an increase of the stiffness matrix size to 495 X 495.

3. ELASTO-PLASTIC STABILITY ANALYSIS USING FORCE

3.1 Biaxially Restrained Imperfect Column

In a study reported in Reference 6 by Darbhamulla, Razzaq, and Storaasli, a concurrent elasto-plastic solution for the stability analysis of biaxially restrained imperfect column was presented which employed the Finite Element Machine. Appendix C presents the listing of the corresponding computer program in PASCAL. This program is being converted to CONCURRENT FORTRAN so that the efficiency of the algorithm can be studied using FORCE developed by Jordan and Norbert (Reference 5) and implemented on FLEX/32. As described in Reference 6, the problem involves solving three coupled nonlinear differential equations whose coefficients vary with the applied loads and spatial coordinates. In that sense, the concepts developed are of general use in various types of materially nonlinear structural problems. A brief outline of the algorithm utilizing FORCE is given in the following section.

3.2 Concurrent Elasto-Plastic Algorithm Using FORCE

The computer program given in Appendix C is being converted to CONCURRENT FORTRAN based on the following algorithm:

1. Read initial data and compute required cross-sectional properties.
2. Assemble a global stiffness matrix and a force vector concurrently uing FORCE.
3. Compute initial displacement vector using the FORCE simultaneous equation solver.
4. Synchronize all processors.
5. Compute elasto-plastic cross-sectional properties at various

locations along the length concurrently using the procedure presented in Reference 8.

6. Reassemble the global stiffness matrix and the new force vector concurrently, and update the displacement vector using, again, the FORCE simultaneous equation solver.
7. Check convergence and proceed to Step 8 if convergence is achieved. Otherwise, go to Step 4.
8. Increment the external load and go to Step 4 if the member collapse has not occurred.

The program is being implemented on the FLEX/32 MMOS computer.

3.3 Publication

Reference 8 is scheduled to appear in Engineering with Computers, An International Journal for Computer-aided Mechanical and Structural Engineering this year. The proof-copy of this paper is given in Appendix D.

4. SUBSTRUCTURE ANALYSIS OF PLANE FRAMES USING FORCE

4.1 Problem Definition and Goals

The problem is to develop a concurrent algorithm for the linear load-deflection analysis of rigid-jointed plane frames using substructuring. Figure 11 (a) shows an example of a three story frame ABCDEFGH with a span L and story height h. Figure 11 (b) shows one way of dividing the structure into two substructures, CDEF and ABCFGH. The main goal of this study is to evaluate the computational efficiency of the concurrent algorithm developed while employing FORCE when substructures of the type shown in Figure 11 are adopted. For the present, a special purpose matrix stiffness substructure analysis program has been developed and implemented on FLEX/32 parallel computer for a direct investigation of the effectiveness of FORCE, as the main objective. The concurrent substructuring technique being considered may be generalized for arbitrary frames for implementation on NICE/SPAR later.

4.2 Substructuring Technique

The substructuring technique adopted for the analysis of the frame considered here is given in Reference 9 and summarized in Appendix E of this report. A number of equations presented in Appendix E are used in a concurrent algorithm outlined in Section 4.3. The following is a brief summary of the applicable equations. The various terms are defined in Appendix E.

The static joint equilibrium matrix equation for the k-th substructure is given by Equation E.1 as follows:

$$[S]\{\Delta\} = \{P\} + \{R\} \qquad (1)$$

Equation E.4 for the k-th substructure can be written as:

$$[S_{uu}]_k\{\Delta_u\}_k = \{P_u\}_k, \tag{2}$$

for k = 1, 2, 3,..., n. The reactions at the restrained nodes can be found using Equation E.5:

$$\{R_r\}_k = [S_{ru}]_k\{\Delta_u\}_k, \tag{3}$$

since $\{P_r\} = \{0\}$ for the substructures shown in Figure 11 (b) owing to the fact that the nodes C, F, A and H, are completely restrained.

The substructure stiffness matrix given by Equation E.12 can be expressed as:

$$[S_s]_k = [S_{rr}]_k - [S_{ru}]_k[S_{uu}]_k^{-1}[S_{ur}]_k \tag{4}$$

If a concurrent inversion subroutine is unavailable, the matrix product $[S_{uu}]_k^{-1}[S_{ur}]_k$ can be obtained as follows:

$$[\lambda_{ur}]_k = [S_{uu}]_k^{-1}[S_{ur}]_k \tag{5}$$

which may be expressed as:

$$[S_{uu}]_k[\lambda_{ur}]_k = [S_{ur}]_k \tag{6}$$

where:

$$[\lambda_{ur}]_k = [\{\lambda_{u1}\}\ \{\lambda_{u2}\}\cdots\{\lambda_{ur}\}]_k \tag{7}$$

$$[S_{ur}]_k = [\{S_{u1}\}\ \{S_{u2}\}\cdots\{S_{ur}\}]_k \tag{8}$$

and {} are column vectors of the order u x 1. Thus, Equation 6 can be written as a series of matrix equations as follows:

$$\begin{aligned}
&[S_{uu}]_k\{\lambda_{u1}\}_k = \{S_{u1}\}_k \\
&[S_{uu}]_k\{\lambda_{u2}\}_k = \{S_{u2}\}_k \\
&\cdots\cdots\cdots\cdots\cdots\cdots \\
&[S_{uu}]_k\{\lambda_{ur}\}_k = \{S_{ur}\}_k
\end{aligned} \tag{9}$$

Solving the system of Equation 9 for $\{\lambda_{u1}\}_k$, $\{\lambda_{u2}\}_k$,.. $\{\lambda_{ur}\}_k$ by means of a simultaneous equations solver, the matrix $[\lambda_{ur}]_k$ in Equation 6 can be formed. This clearly provides the matrix product

indicated in Eq. 4 without inverting the matrix $[S_{uu}]_k$. Equation 4 can now be written as:

$$[S_s]_k = [S_{rr}]_k - [S_{ru}]_k [\lambda_{ur}]_k \tag{10}$$

The static equilibrium equation for the nodes linking the various substructures is given by Equation E.13 as follows:

$$[S_a]\{\Delta_a\} = \{P_a\} + [R_a], \tag{11}$$

in which the various terms of $[S_a]$ and $\{P_a\}$ are obtained as explained in Section E.3 of Appendix E.

The true deflection vector, $\{\Delta_{rd}\}$, for the nodes linking the various substructures is found using Equation E.16 in the following form:

$$\{P_{rd}\} = [S_{11}]\{\Delta_{rd}\} \tag{12}$$

The deflections of the unrestrained nodes for the k-th substructure is found using Equation E.19.

$$\{\Delta_{un}\}_k = (\{\Delta_u\} - [S_{ur}]\{\Delta_{rd}\})_k \tag{13}$$

The procedure described in this section can be readily applied to any type of framed structures behaving in a linear elastic manner. A concurrent algorithm utilizing this technique is given in the following section.

4.3 Concurrent Algorithm

Based on the substructuring technique outlined in Section 3.2, the following concurrent algorithm has been developed on FLEX/32 parallel computer.

1. Formulate the stiffness matrix [S] given in Equation 1 for the substructures k = 1, 2, 3,..., m, on n processors concurrently.
2. Extract $[S_{uu}]_k$ appearing in Equation 2, from the [S] matrices, concurrently, for all k values.

3. Solve Equation 2 for $\{\Delta_u\}_k$ with k = 1, to determine the deflections of Substructure 1 by invoking FORCE simultaneous equations solver SOLVE, concurrently using n processors. Similarly, solve Equation 2 for $\{\Delta_u\}_k$ with k = 2, 3,..., m, corresponding to Substructures 2, 3,..., m, using FORCE.

4. Extract $[S_{ru}]_k$ appearing in Equation 3, from the [S] matrices, concurrently for all k values.

5. Compute the vectors $\{R_r\}_k$ with k = 1 to determine the reactions in Substructure 1 by invoking FORCE matrix multiplication subroutine called MATMP, concurrently. Similarly, determine $\{R_r\}_k$ for k = 2, 3,..., m, corresponding to Substructures 2, 3,..., m, using FORCE.

6. For k = 1, determine $\{\lambda_{uv}\}_k$ with v = 1 as represented in Equations 9 using SOLVE, concurrently on n processors. Repeat the process of finding $\{\lambda_{uv}\}_k$ for v = 2, 3,..., r, respectively, to generate the matrix $[\lambda_{ur}]_k$ as indicated in Equation 7. Obtain $[S_s]_k$ using Equation 10 concurrently on n processors.

7. Repeat Step 6 for k = 2, 3,..., m.

8. Assemble the global matrix $[S_a]$ and the vector $\{P_a\}$ appearing in Equation 11, on a single processor using the $[S_s]_k$ matrices generated in Steps 6 and 7; $\{R_r\}_k$ generated in Step 5, while employing Equations E.14 and E.16 given in Appendix E.

9. From $[S_a]$ and $\{P_a\}$ obtained in Step 8, formulate Equation 12.

10. Solve Equation 12 concurrently, using SOLVE, on n processors.

11. For k = 1, determine the true deflection $\{\Delta_{un}\}_k$ of the unrestrained nodes, using Equation 13, concurrently on n processors.

12. Repeat Step 11 for k = 2, 3,..., m.

The algorithm outlined above is coded in CONCURRENT FORTRAN for the problem shown in Figure 11. A listing of the program is given in Appendix F with a sample input/output. The computational efficiency of the algorithm is explained in the following section.

4.4 Numerical Results for 3-Story Frame

With three degrees-of-freedom per joint (vertical and horizontal displacements, and a rotation), the frame stiffness matrix is of the order 18 x 18. Table 5 presents the computational time t, speedup factor s, and efficiency for 1 to 5 parallel processors for a concurrent analysis of the 3-story frame. The time t is measured in rtick units. One rtick equals 1/50th of a second. For solving the 18 simultaneous equations concurrently, Subroutine SOLVE developed by Jordan and his research associates from the University of Colorado, was utilized. A complete listing of the subroutine appears as a part of the computer program presented in Appendix F. The speedup factor versus the number of processors data given in Table 5 is used to plot the 'actual' curve in Figure 12 in which the theoritical ideal relationship is also given for a comparison. The maximum speedup is 2.60 and is obtained when a total of 4 processors are used corresponding to a computational efficiency of 65%. The use of 2 processors, however, results in an efficiency of 81%.

Table 6 presents the computational times T_1 through T_4, defined as follows:

T_1 = time taken to assemble the stiffness matrices [S] given in Equation 1, for Substructures 1 and 2 shown in Figure 11,

T_2 = time taken for solving Equations 2, 3 and 4 for Substructure 1 with each of the matrices S_{uu}, S_{ru} and S_s of order 6 x 6

T_3 = time taken for solving Equations 2, 3 and 4 for Substructure 2, with the matrices S_{uu}, S_{ru} and S_s of the order 6 x 6, 12 x 6 and 12 x 12 respectively,

T_4 = time taken for solving Equation 12 for the complete system;

the speedup factor, s, based on the total time T_t given by:

$$T_t = T_1 + T_2 + T_3 + T_4;$$

and efficiency η based on s; for 1 to 5 parallel processors for a concurrent substructure analysis of the 3-story frame. The FORCE subroutine SOLVE was used concurrently for the two substructures for obtaining solutions to a pair of six simultaneous equations. It is noted here that there are two levels of computational parallelization involved in this solution scheme:

Level 1: parallel generation of the two substructure stiffness matrices on two different processors, and

Level 2: parallel solution of two sets of six simultaneous equations using SOLVE on up to five processors.

The parallel processors work on one set of equations at a time.

The value of T_1 ranges from 3 to 5 rticks. The T_2 value is in the range from 3 t 4 rticks, whereas T_3 is in the range from 5 to 10 rticks. One may expect to obtain nearly identical values for T_2 and T_3 since they represent the computational times for handling the two substructures with equal number of free nodes. That this is not indeed the case can be understood by realizing that the orders of S_{ru} and S_s matrices for Substructures 1 and 2 are not equal, as described above in the definitions for T_2 and T_3. The value of T_4 is halved when 2 to 5 processors are used instead of just one. The total time T_t varies between 12 and 21 rticks, the latter being the time taken by one

processor. For 2, 3 and 4 processors, T_t value is nearly constant. For 5 processors it is greater than for 2, 3 or 4 processors. The maximum speedup is 1.75 and is obtained when a total of 3 or 4 processors are used. However, the efficiency with 3 processors is greater than that with 4 processors. The maximum efficiency is obtained with 2 processors and is 80.5%, of course excluding the case of one processor.

The reason for the relatively low speedups obtained is that the matrix sizes for the problem considered are relatively small. As the number of processors is increased, the overhead time (for example, while executing the Barrier, End Barrier and Join statements) becomes significant as compared to the time consumed by arithmatical operations required for the simultaneous equations.

5. BUCKLING ANALYSIS OF FOCUS PROBLEM USING NICE/SPAR

The buckling solution to the CSM Focus Problem 1 outlined in Reference 2 is being run for various discretizations. The finite element meshes are generated using CSM1 with NICE/SPAR E43 finite elements. Presently, all computations are being carried out on a single FLEX/32 processor. The implementation of concurrent buckling and postbuckling solution procedures will be carried out once rigorous study of these problems is completed on a single processor.

Table 1. Speedup and efficiencies for four-element rectangular panel

Number of Processors	Computational time (secs)	Speedup	Efficiency
1	0.96	-	-
2	0.54	1.78	89.0
4	0.28	3.43	85.7
8	0.26	3.70	46.2
12	0.30	3.20	26.7
16	0.42	2.29	14.3
18	0.48	2.00	12.0

Table 2. Speedup and efficiencies for eight-element rectangular panel

Number of Processors	Computational time (secs)	Speedup	Efficiency
1	3.60	-	-
2	1.88	1.91	95.7
4	1.06	2.25	56.2
8	0.70	5.14	64.3
12	0.70	5.14	42.8
16	0.84	4.30	27.0
18	0.92	3.91	21.7

Table 3. Speedup and efficiencies for rectangular panel with central hole

Number of Processors	Computational time (secs)	Speedup	Efficiency
1	474.62	-	-
2	248.74	1.90	95.4
4	128.82	3.69	92.1
8	66.80	7.10	88.8
12	47.50	9.99	83.3
16	38.56	12.31	77.0
18	35.96	13.20	73.3

Table 4. Speedup and efficiencies for the mast problem

Number of Processors	Computational time (secs)	Speedup	Efficiency
1	4530.02	-	-
2	2388.80	1.90	94.8
4	1228.10	3.69	92.3
8	610.00	7.43	93.0
12	417.38	10.85	90.5
16	320.60	14.13	88.3
18	288.30	15.71	87.3

Table 5. Computational time measurements, speedup factors and efficiencies for concurrent analysis of 3-story frame

Number of Processors	Execution time t (rticks)	Speedup factor	Efficiency η
1	13	1.00	100.0
2	8	1.62	80.5
3	6	2.16	58.3
4	5	2.60	43.7
5	6	2.16	28.0

Table 6. Computational time measurements, speedup factors, and effciencies for concurrent substructure analysis of 3-story frame

Number of Processors	Execution time t (rticks)				Total Time	Speedup Factor	Efficiency η
	T_1	T_2	T_3	T_4			
1	5	4	10	2	21	1.00	100.0
2	3	3	6	1	13	1.62	80.5
3	3	3	5	1	12	1.75	58.3
4	3	3	5	1	12	1.75	43.7
5	4	4	6	1	15	1.40	28.0

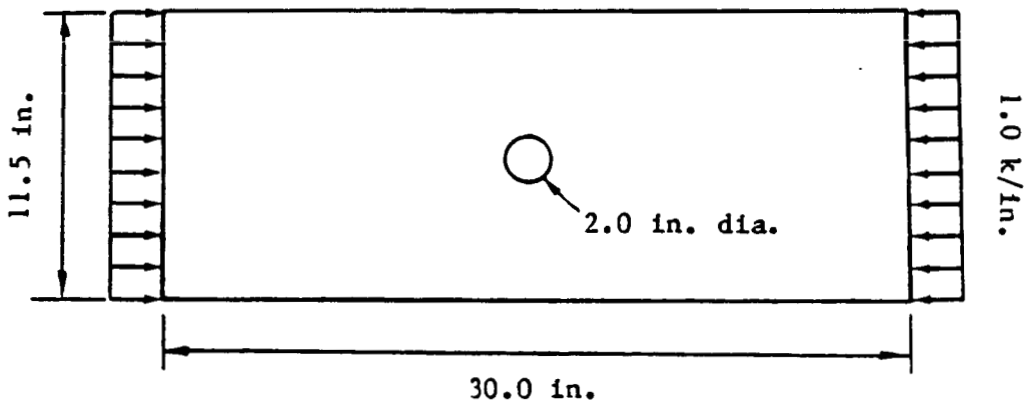
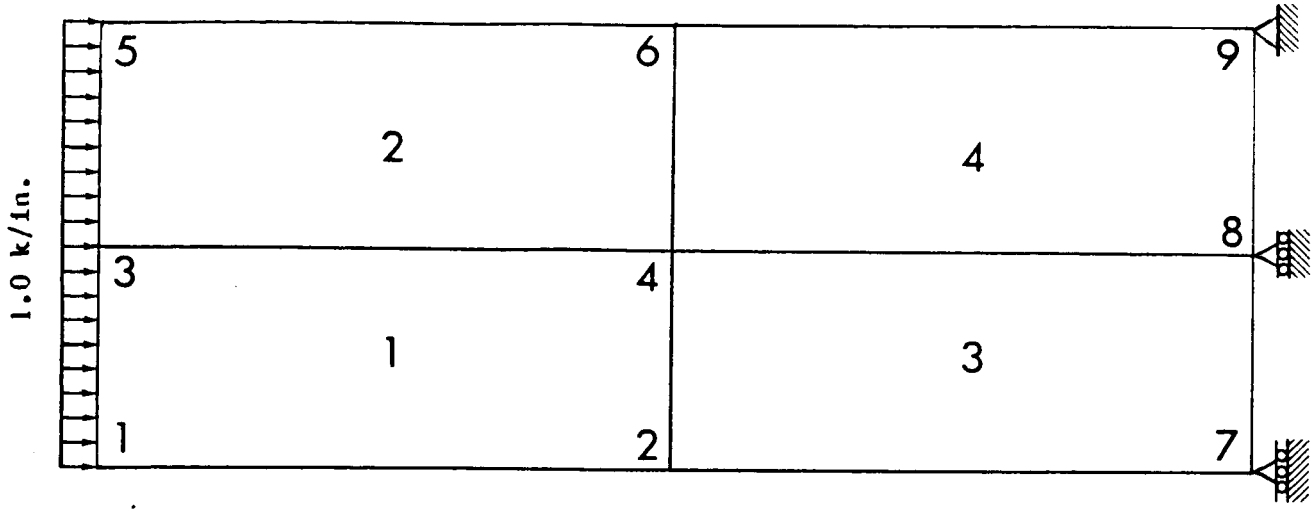


Figure 1. Rectangular panel with hole and uniform compression



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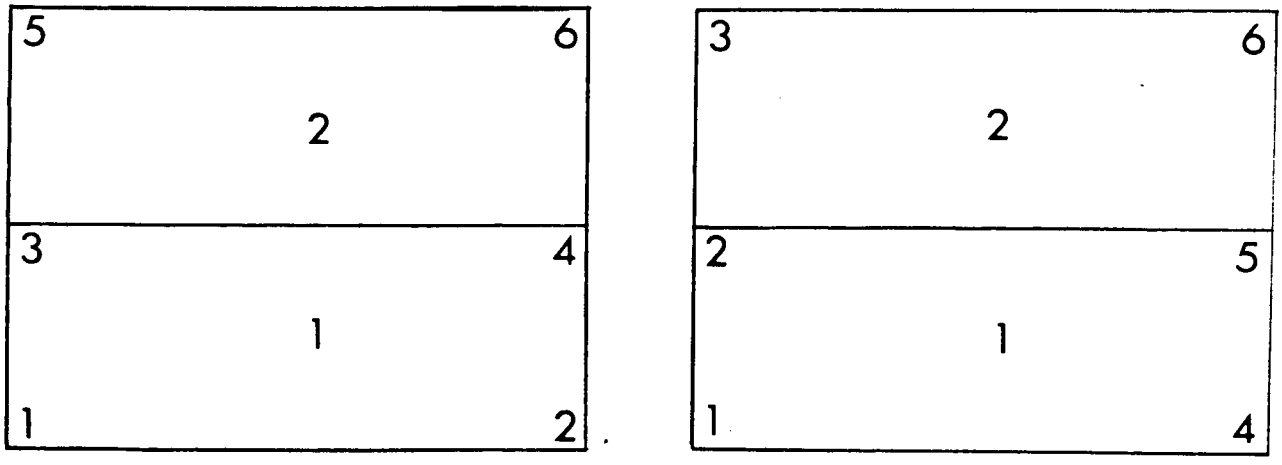
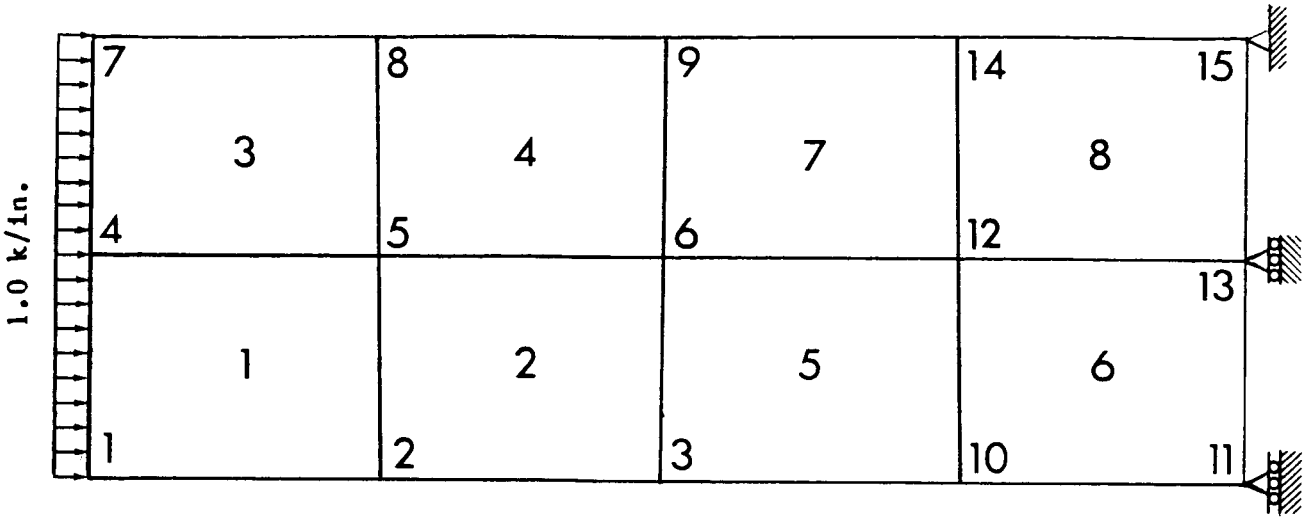


Substructure 1

Substructure 2

(b)

Figure 2. Substructuring of panel with four elements



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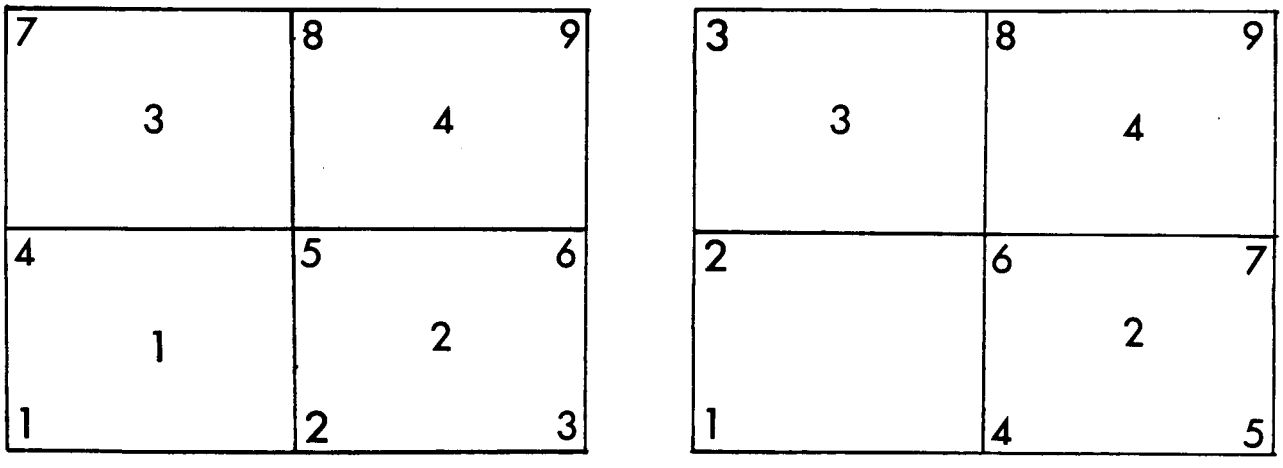
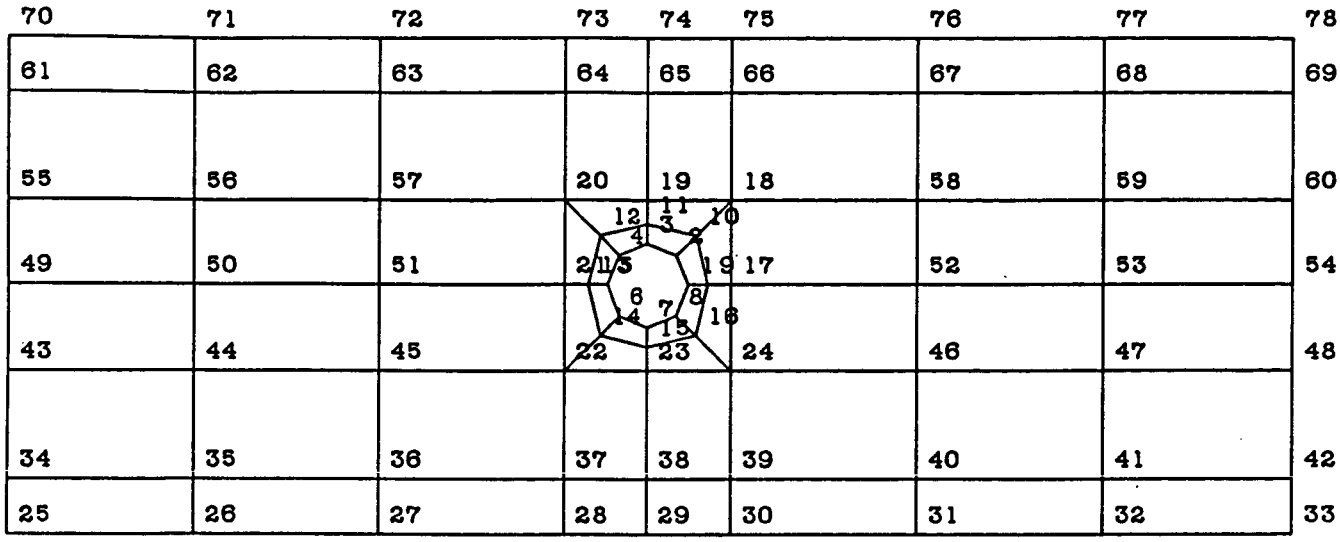


Substructure 1

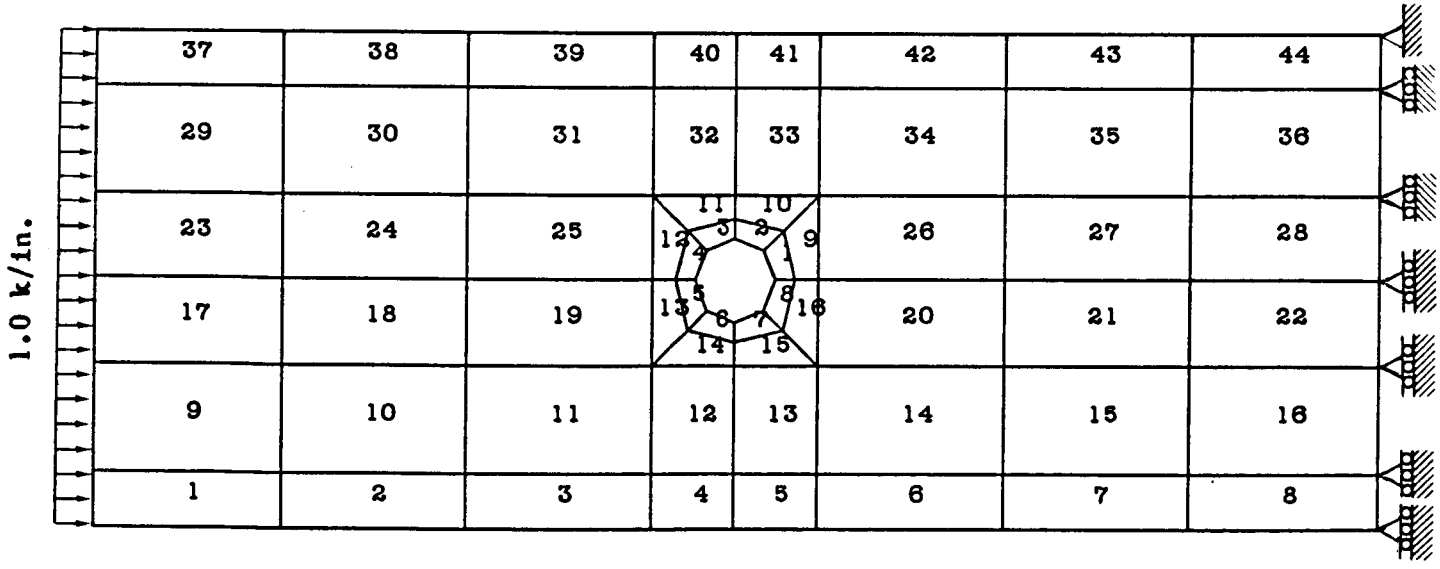
Substructure 2

(b)

Figure 3. Substructuring of panel with eight elements

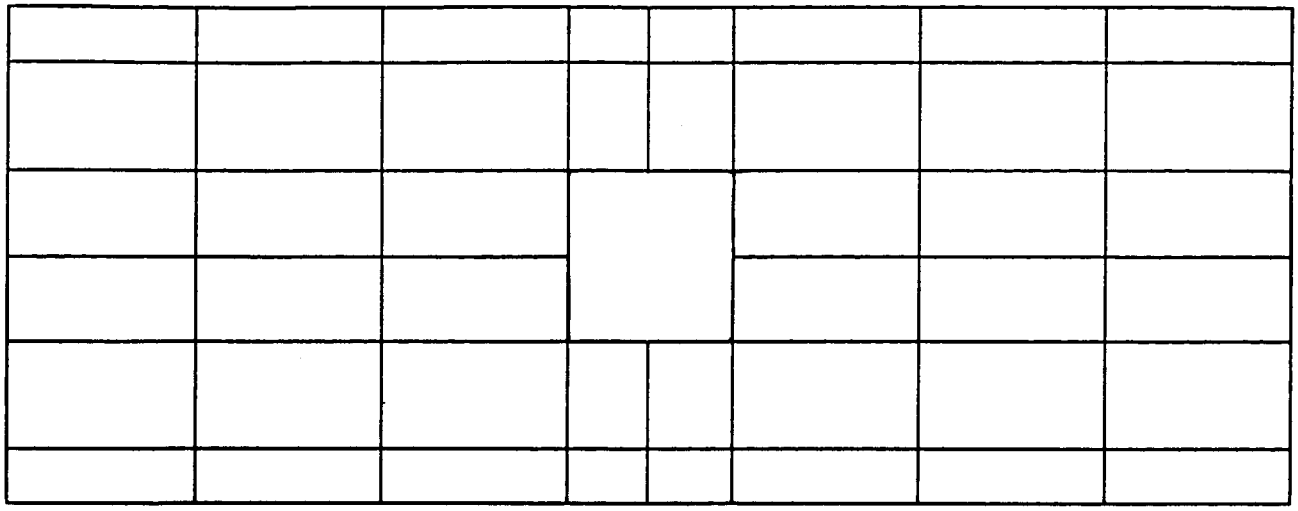


(a) Node numbering scheme

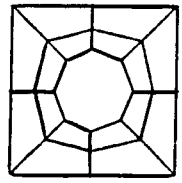


(b) Element numbering scheme

Figure 4. Finite element discretization of panel with hole



(a) Substructure 1



(b) Substructure 2

Figure 5. Substructuring of panel with hole and sixty elements

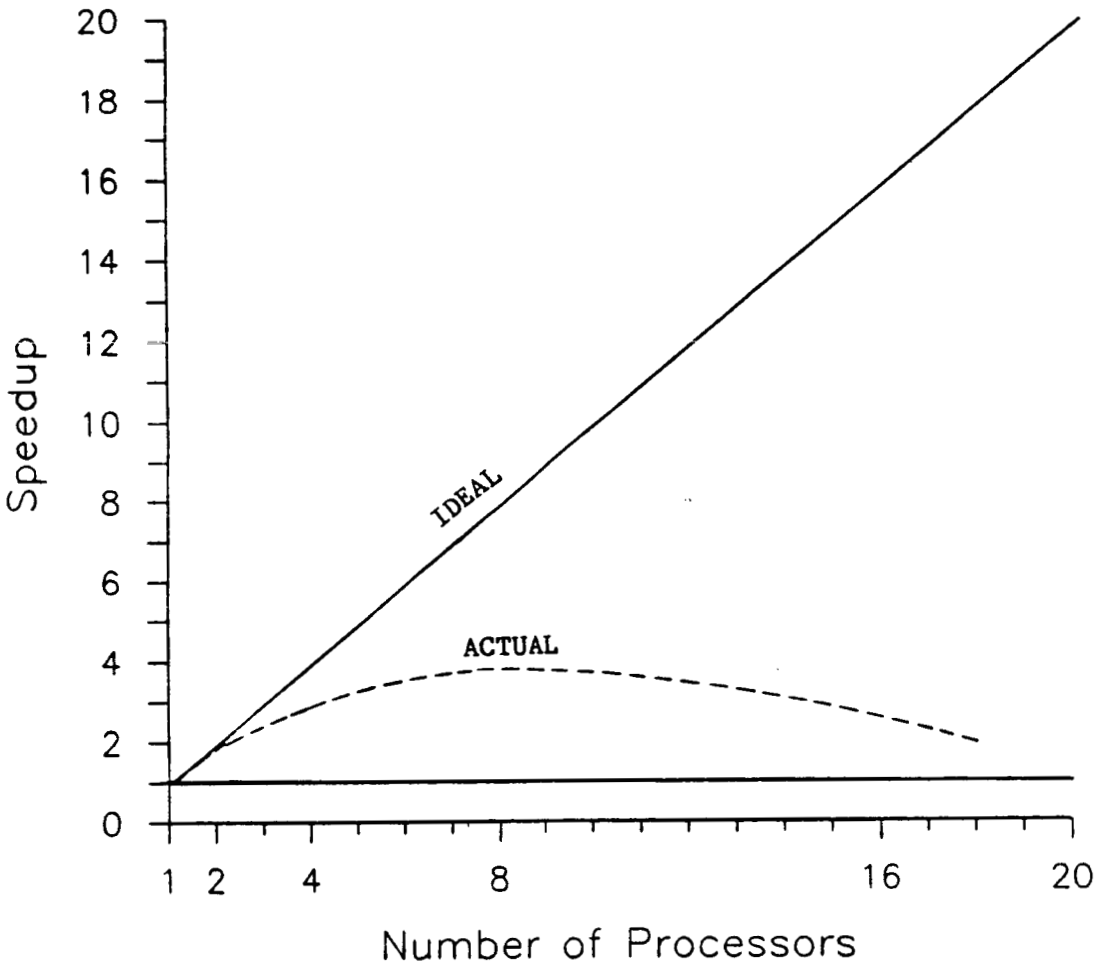


Figure 6. Speedup factor versus number of processors for four-element rectangular panel

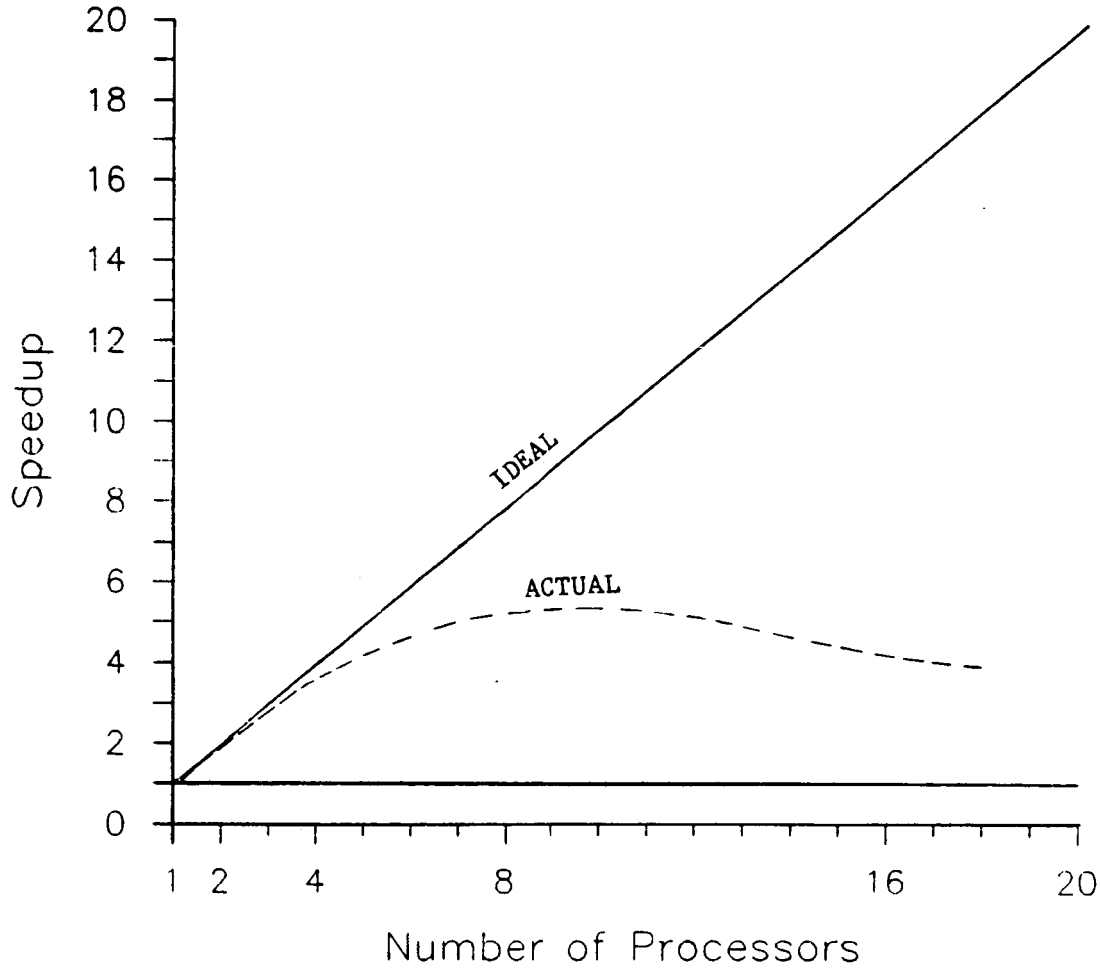


Figure 7. Speedup factor versus number of processors for eight-element rectangular panel

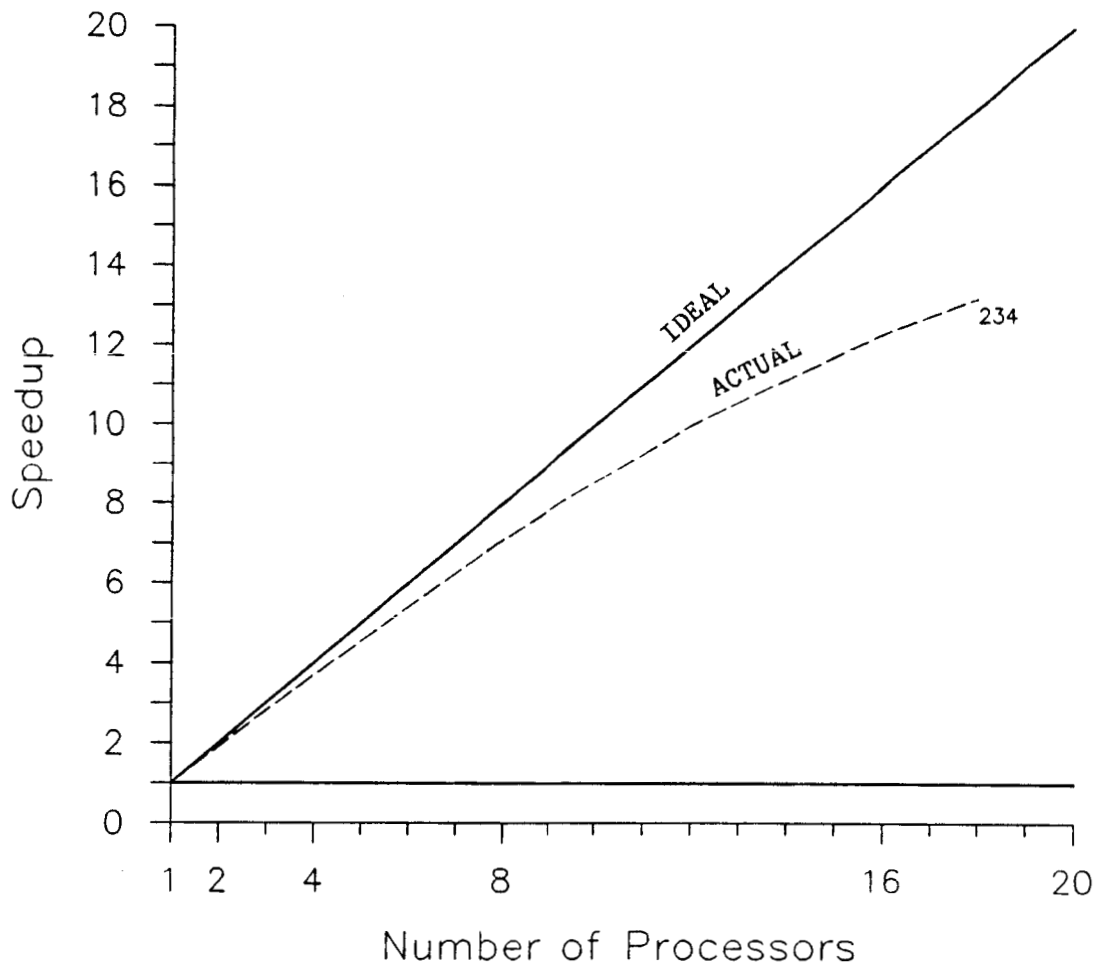
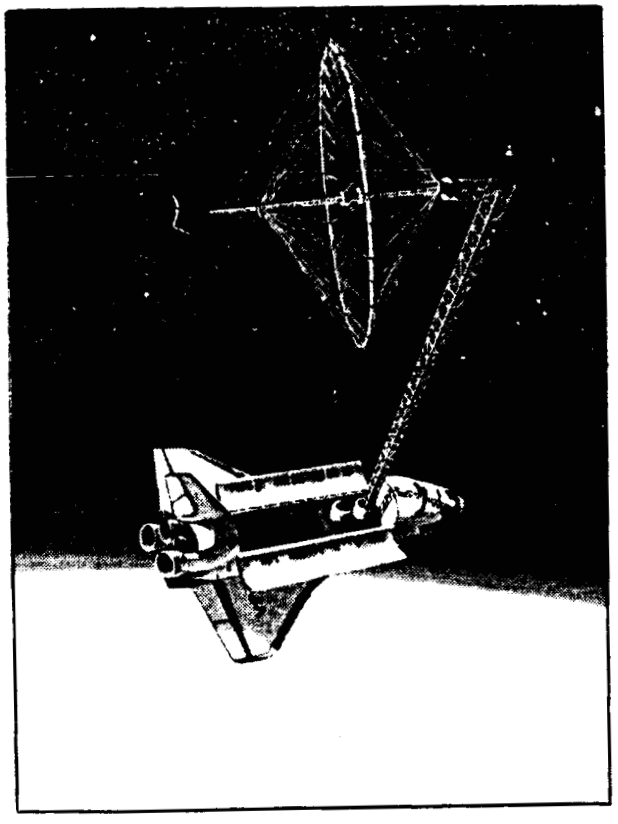


Figure 8. Speedup factor versus number of processors for rectangular panel with hole



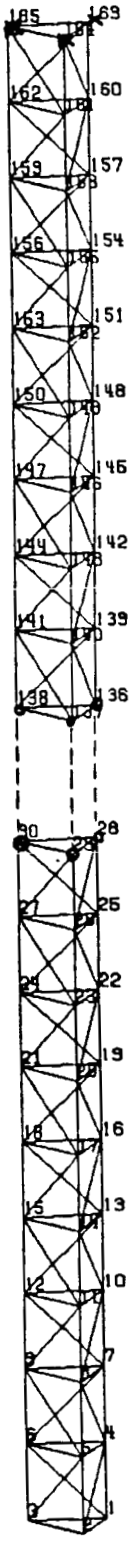


Figure 9. The mast problem

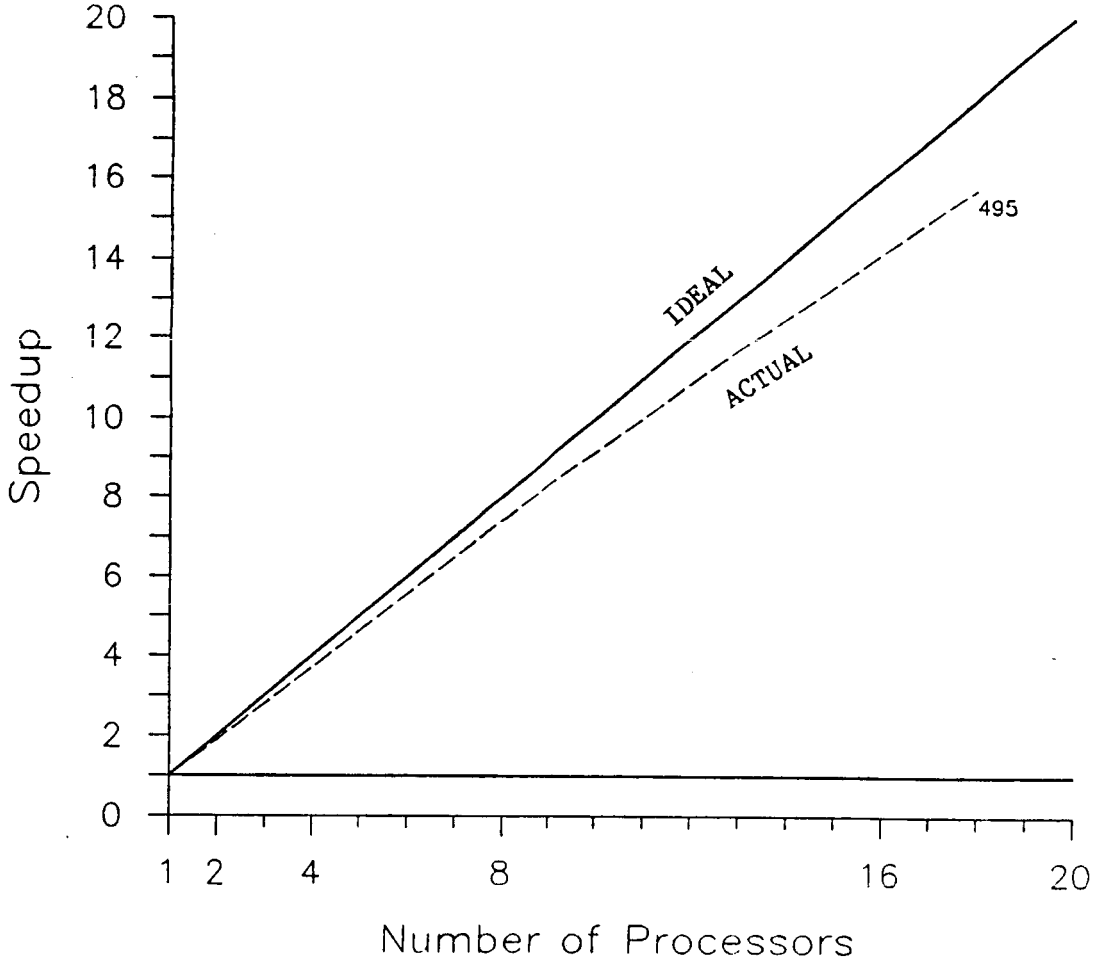


Figure 10. speedup factor versus number of processors for the mast problem

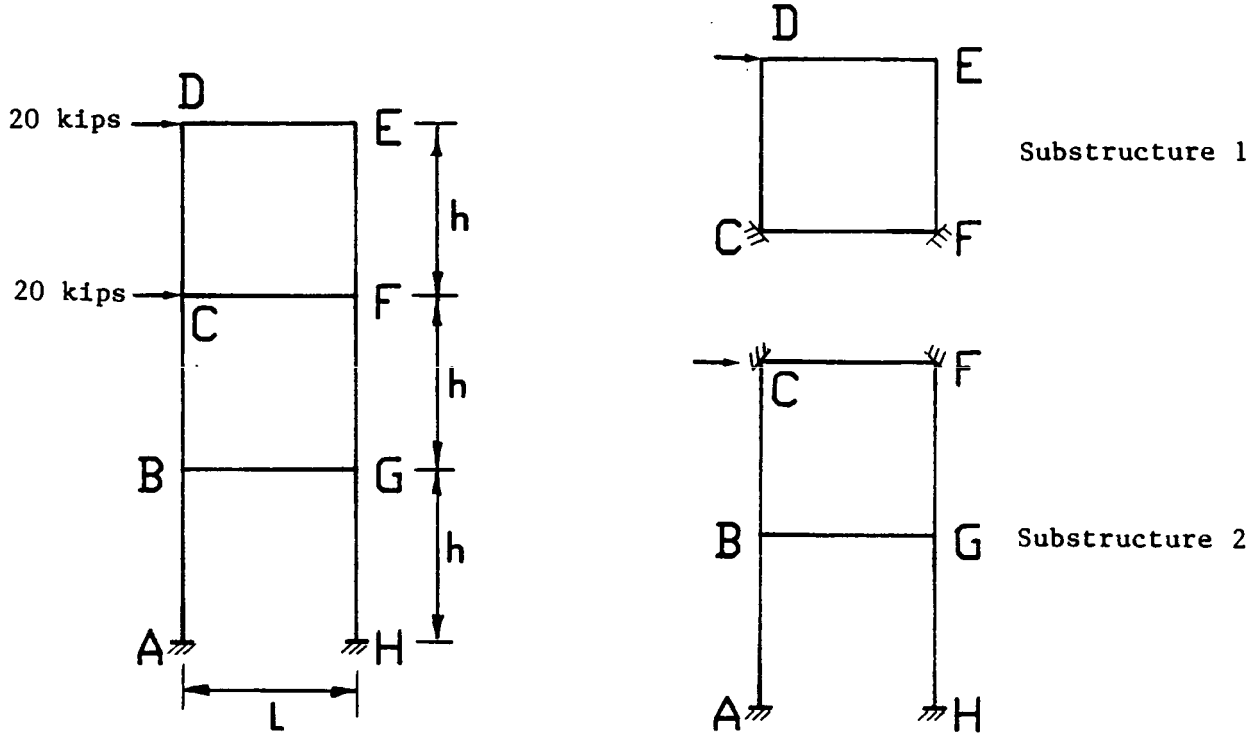


Figure 11. Framed structure with two substructures

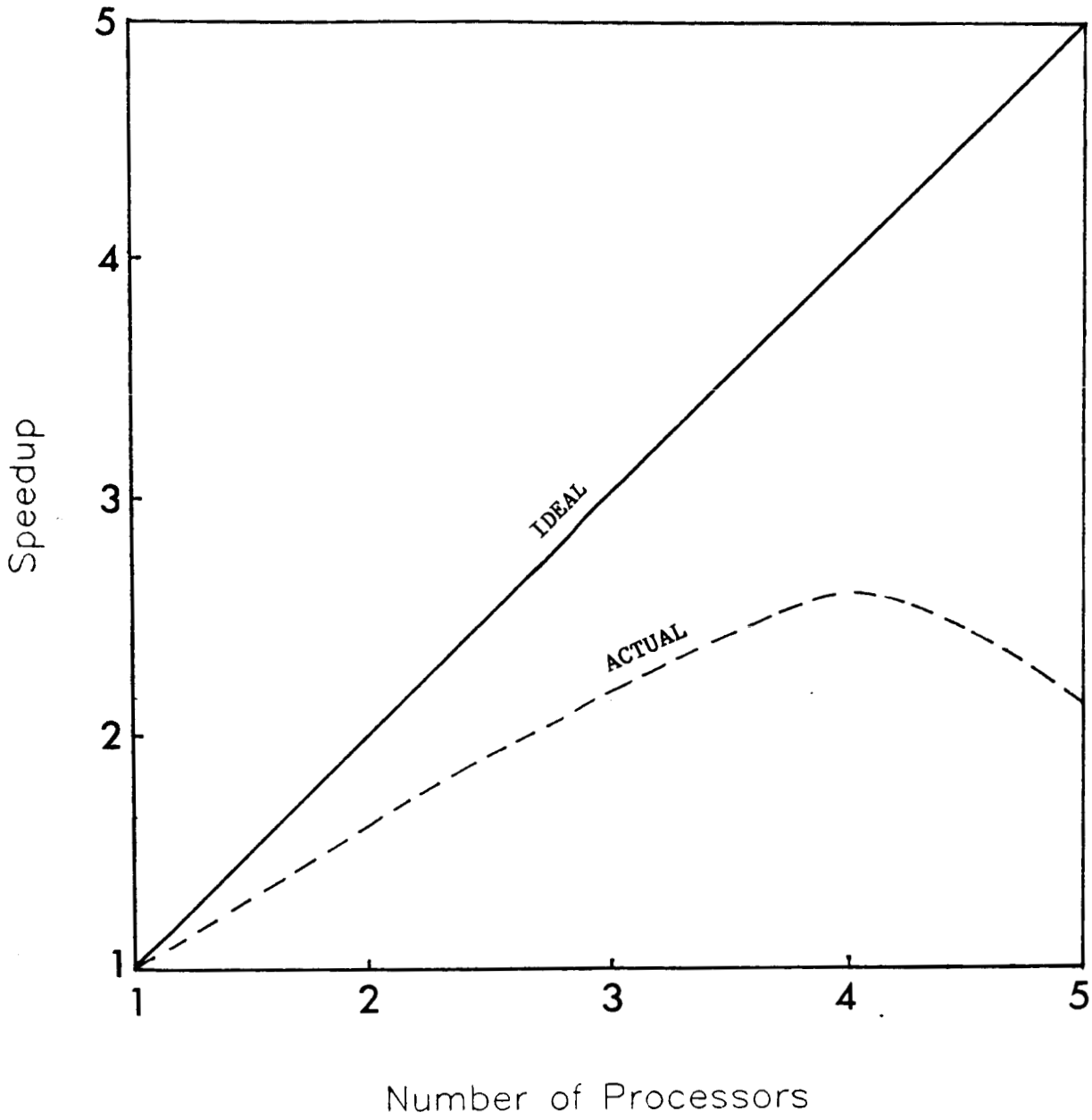


Figure 12. Speedup factor versus the number of processors for 3-story frame using FORCE Subroutine SOLVE

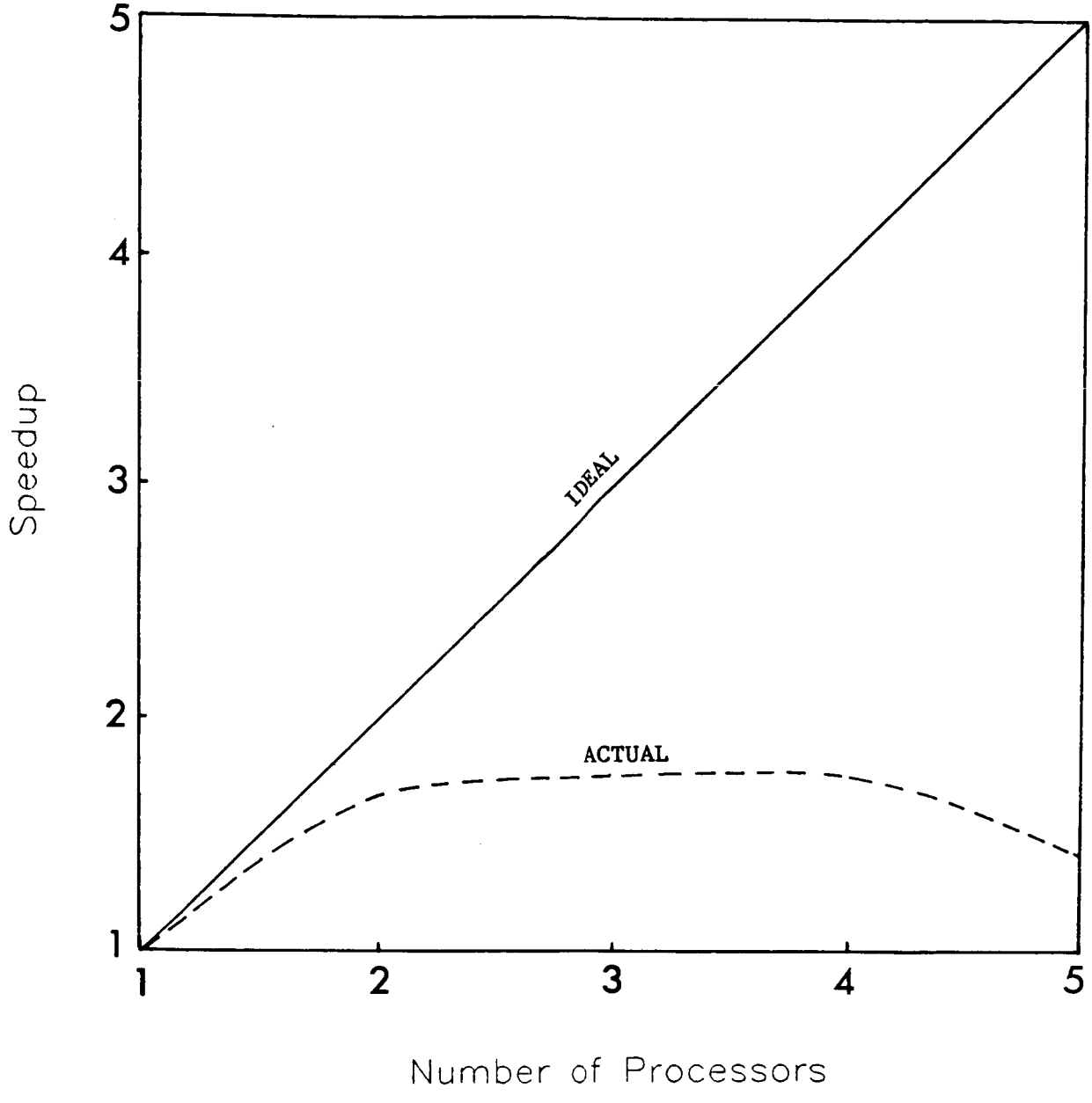


Figure 13. Speedup factor versus the number of processors for 3-story frame with two substructures using FORCE

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APPENDIX A

RELEVANT SPAR PROCESSORS AND CLAMP PROCEDURES

A.1 Relevant SPAR Processors

A number of SPAR processors are described in Reference 3 some of which are used in the solution procedure presented in section 1.3 of this report. A brief description of the relevant SPAR processors is given in this section. The corresponding page numbers from volume 1 of reference 3 are indicated in the parentheses following the SPAR processor names.

1. Processor TAB (3.1-1)

The function of this processor is to define the finite element model of the structure. The following subprocessors of TAB are utilized:

JLOC defines the joint locations in a structure;

MATC defines the material constants of the structure;

JREF defines the orientation of reference frame associated with the joints;

CON is used in defining constraints and applied loading; and

SA generates a table of shell (or panel) section properties to which reference is made during the definition of SPAR element E41.

All the subprocessors generate their respective data sets which are stored in a data library.

2. Processor ELD (3.2-1)

This processor produces datasets containing element definitions such as the connecting joints, the type of SPAR element used, and the integers pointing to applicable lines in the table of section properties.

3. Processor AUS (5.1-1)

This processor is comprised of an array of subprocessors which are data set constructors. The subprocessors are summarized in tab 5-1 (page 5.1-2,reference3) according to their functional categories. The functional categories include matrix arithmetic and modification of data tables. The following subprocessors of AUS are utilized:

TABLE (2.5.1) creates the data sets which details the number of interface nodes, the number of substructures, and the number of elements in a substructure; and

SYSVEC (5.1.3) is used primarily to represent either the joint displacements and rotations, or the applied forces and moments.

4. Processor E (3.3-1)

This processor generates in a skeletal form an element information packet for each element in the structure, and supplies general information such as the connecting joint numbers, material constants, and section properties data previously identified by processor ELD.

5. Processor EKS (3.4-1)

This processor reads data sets created by processor E and generates the element stiffness matrices.

6. Processor TOPO (4.1-1)

This processor analyzes element interconnection topology and creates data sets (KMAP and AMAP), Reference 4) for the assembly of the system stiffness matrix in SPAR standard sparse-matrix format.

7. Processor K (4.2-1)

This processor assembles unconstrained system stiffness matrix in a SPAR standard sparse-matrix format. The input for K comes from the processors EKS, TOPO and partly from TAB. The output is a data set named K SPAR containing the unconstrained system stiffness matrix

8. Processor INV (4.5-1)

This processor factors assembled system matrix in the SPAR standard sparse-matrix format. It requires the unconstrained system matrix, the constraint definitions, and the topological information in AMAP.

9. Processor SSOL (6.3-1)

This processor computes the displacements and reactions due to applied loading at the joints.

10. Processor GSF (7.1-1)

This processor generates data sets containing element stresses. The input data sets are structural deformations from SSOL. The output data sets are named STRS.

11. Processor PSF (7.2-1)

This processor prints the element stresses and stress resultants from the data sets generated by GSF.

12. Processor VPRT (5.3-1)

This processor is used to edit and display information in SYSVEC format, such as the static displacements and reactions. It is also called the Vector Printer.

A.2 CLAMP Procedures

The substructure analysis using NICE/SPAR requires the use of MACRO subprocessors and CLAMP procedures described below.

1. MACRO Subprocessor

This is a subprocessor within the processor AUS, and is used to define a macrosymbol. The macrosymbols are used to establish variable like items which can perform arithmetic manipulations, access built-in functions, and rename directives.

2. PROCEDURES

The substructure CLAMP procedures END__SUB and GLOB_DAT are used to minimize the user input data. These two procedures are stored in a data file named PRESERVE in the runstream presented in Appendix B. The procedures are described briefly as follows:

Procedure END__SUB scans through the table of contents and stores the sequence number of data sets. Later, the sequence numbers are used for global topology generation. The data sets are then renamed to make them distinct in order to avoid disability of the existing data set.

Procedure GLOB__DAT consists of a number of intermediate procedures such as Inter, Glob__Jloc, Glob__Matc. Procedure Inter searches the interface table for interface joints and separates it. procedure Glob_Jloc translates the substructure joint numbers to global joint numbers, and sets up global joint location data set. Procedure Glob_Matc creates the data set of material constants for the assembled structure.

APPENDIX B

NICE/SPAR RUNSTREAM SAMPLES

The runstreams for the eight-element rectangular panel with hole are presented in this appendix including the outputs. The attached computer listings include:

1. Runstream for eight-element rectangular panel.
2. Output for eight-element rectangular panel.
3. Runstream for rectangular panel with hole.
4. Output for rectangular panel with hole.

A listing of the FORCE program for concurrent solution of simultaneous equations developed by Jordan and his research associates, from the University of Colorado, is also contained in item 3 mentioned above.

RUNSTREAM FOR EIGHT-ELEMENT RECTANGULAR PANEL

```
rmproc1
rm SUB_TABLE
rm SS1.L01
nicespar ((\endinput
*set echo=off
*open 1 ss1.l01 /new
.
.
DUMMY START CARD
[xqt tab
start 1000
.
*procedure SUB_TABLE
.
. SET UP TABLES
.
.
[xqt aus

TABLE(NI=3,NJ=1,ITYPE=0): SUBS PARA 1 1
J=1: 2 4 1   . nsubs nnpe iopt
.
. NO. OF ELEMENTS IN SUBSTR.
.
TABLE(NI=2,NJ=1,ITYPE=0): SUBS ELEM 1 1
J=1: 4 4         . no. of elements per sub. (for n subs)

. SUBSTRUCTURE INTERFACES
.
. syntax:
. J=m: j1 s1 j2 s2      m=1,no. of interface nodes
.
.
TABLE(NI=4,NJ=3,ITYPE=0): SUBS SUBI 1 1
J=1: 3 1 1 2
J=2: 6 1 2 2
J=3: 9 1 3 2
.
 *end
 *call SUB_TABLE
*add preserve
.
.
. DEFINE SUBSTRUCTURE -1
.
[xqt tab
start 9,4,5,6
matc:1 10000 0.3
```

```
online=0
jloc: format=1
1 0.0 0.0 0.0 15.0 0.0 0.0 3 1 3
3 0.0 11.5 0.0 15.0 11.5 0.0
sa(1):1 0.1
con=1
zero 3:1,9
[xqt eld
online=0
e41
1 2 5 4 1 2 2
online=1
[xqt topo
[xqt e
[xqt eks
stop
*call end_sub
.
.
.  DEFINE SUBSTRUCTURE -2
.
.
[xqt tab
start 9,4,5,6
matc: 1 10000 0.3
jloc: format=1
online=0
1 15. 0. 0. 15. 11.5 0. 3 1
4 22.5 0.0 0.0 30.0 0.0 0.0 2 1 3
2 22.5 11.5 0.0 30.0 11.5 0.0
sa(1):1 0.1
con=1
zero 3:1,9
zero 1:5,9,2
zero 2:9
[xqt eld
online=0
e41: 1 4 6 2
2 6 8 3
4 5 7 6 1 1 2
online=1
[xqt topo
[xqt e
[xqt eks
stop
*call end_sub
*call glob_dat
.
[xqt k
[xqt inv
[xqt aus
alpha
```

```
case titles
1' external load
sysvec
applied forces
case 1
I=1
J=1:2.875
J=4:5.75
J=7:2.875
[xqt ssol
[xqt gsf
[xqt dcu
[xqt psf
[xqt vprt
 tprint stat disp
 tprint stat reac
[xqt exit
endinput
```

OUTPUT FOR EIGHT-ELEMENT RECTANGULAR PANEL

```
 (CL) PUT_message,Comment)
 (CL) $root,L0001,000001)*set echo=off
 (DM) OPEN,  Ldi:  1, File: SS1.L01 , Attr: new, Block I/O
 ** BEGIN TAB  **   DATA SPACE=   200000 WORDS

  1000 JOINTS.
0ACTIVE JOINT MOTION COMPONENTS= 1 2 3 4 5 6
0LIB READ ERROR, NU,L,KORE,IERR,IOP=      1      0  196988      -1      11
     NAME= MASK BTAB         2         5
0*** ERRORS IN INPUT PREVENT CALCULATION OF QJ(3,3,JT)
 EXIT TAB  CPUTIME=    7.0 I/O(DIR,BUF)=      0      0
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                           TABL COMPLETED.
                           TABL COMPLETED.
                           TABL COMPLETED.
 EXIT AUS  CPUTIME=    5.3 I/O(DIR,BUF)=      0      0
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                           MACR COMPLETED.
                           MACR COMPLETED.
                           MACR COMPLETED.
 EXIT AUS  CPUTIME=    1.9 I/O(DIR,BUF)=      0      0

     9 JOINTS.
0ACTIVE JOINT MOTION COMPONENTS= 1 2 3
 EXIT TAB  CPUTIME=   47.6 I/O(DIR,BUF)=      0      0
 ** BEGIN ELD  **   DATA SPACE=   200000 WORDS
 EXIT ELD  CPUTIME=    7.4 I/O(DIR,BUF)=      0      0
 ** BEGIN TOPO **   DATA SPACE=   200000 WORDS
 (DM) OPEN,  Ldi: 25, File: NS.L25 , Attr: scratch, Block I/O
 (DM) OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O
 NO. OF   4-NODE ELEMENTS=     4
0TOTAL NO. OF ELEMENTS=      4
0MAXCON, MAXSUB, ILMAX=   1872   1400     52
0KSIZE,NR5,LR5=        13         1      896
0MAXCON, MAXSUB, ILMAX=   1864   1400     52
0SIZE INDEX=     15,  IC1, IC2=    85    33, NR4=    1
 (DM) CLOSE, Ldi: 25, File: NS.L25
 (DM) CLOSE, Ldi: 26, File: NS.L26
 EXIT TOPO CPUTIME=    7.3 I/O(DIR,BUF)=      0      0
 ** BEGIN E    **   DATA SPACE=   200000 WORDS
 T=   0.10000E-19-0.10000E-02 0.10000E-04 0.10000E-04
      0.20000E+02 0.10000E-03 0.10000E-03 0.10000E-03
 ERROR LEVELS= 2 2 0 2 2 2 2 2
0
0
                L, VOL OR    STRUCTURAL   NON-STRUCTURAL
 TYPE GROUP     AREA SUM      WEIGHT        WEIGHT
 E41    1   0.172500E+03 0.000000E+00 0.000000E+00

0
 TOTAL                    0.000000E+00 0.000000E+00
```

```
TOTAL  4-NODE=   0.172500E+03
EXIT E    CPUTIME=    6.3 I/O(DIR,BUF)=      0      0
** BEGIN EKS **   DATA SPACE=   200000 WORDS
E41  COMPLETED
EXIT EKS  CPUTIME=    2.3 I/O(DIR,BUF)=      0      0
OKAY 1
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                            MACR COMPLETED.
                            MACR COMPLETED.
                            MACR COMPLETED.
                            MACR COMPLETED.
OKAY 1.2
OKAYY 1.4
njsect = 43
nsect[1] = 1
                            MACR COMPLETED.
EXIT AUS  CPUTIME=    9.3 I/O(DIR,BUF)=      0      0
(CL) lv:0 t:615.8   SECTL[1]       10.000000
OKAY 2 2 2
OKAYY  3 3 3
EXIT TAB  CPUTIME=   26.5 I/O(DIR,BUF)=      0      0
** BEGIN ELD **   DATA SPACE=   200000 WORDS
EXIT ELD  CPUTIME=   11.9 I/O(DIR,BUF)=      0      0
** BEGIN TOPO **   DATA SPACE=   200000 WORDS
 (DM) OPEN,  Ldi: 25, File: NS.L25 , Attr: scratch, Block I/O
 (DM) OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O
 NO. OF   4-NODE ELEMENTS=     4
CTOTAL NO. OF ELEMENTS=      4
0MAXCON, MAXSUB, ILMAX=   1872   1400     52
0KSIZE,NR5,LR5=         13        1      896
0MAXCON, MAXSUB, ILMAX=   1864   1400     52
0SIZE INDEX=     15,  IC1, IC2=    60    32, NR4=    1
 (DM) CLOSE, Ldi: 25, File: NS.L25
 (DM) CLOSE, Ldi: 26, File: NS.L26
 EXIT TOPO CPUTIME=   16.8 I/O(DIR,BUF)=      0      0
 ** BEGIN E    **   DATA SPACE=   200000 WORDS
 T=   0.10000E-19-0.10000E-02 0.10000E-04 0.10000E-04
      0.20000E+02 0.10000E-03 0.10000E-03 0.10000E-03
 ERROR LEVELS= 2 2 0 2 2 2 2 2
0
0
              L, VOL OR    STRUCTURAL   NON-STRUCTURAL
 TYPE GROUP   AREA SUM     WEIGHT       WEIGHT
 E41    1   0.172500E+03 0.000000E+00 0.000000E+00

0
 TOTAL                   0.000000E+00 0.000000E+00
```

```
TOTAL  4-NODE@   0.1725000E+03
EXIT E    CPUTIME=   10.7 I/O(DIR,BUF)=      0      0
** BEGIN EKS  **   DATA SPACE=   200000 WORDS
E41  COMPLETED
EXIT EKS  CPUTIME=    4.2 I/O(DIR,BUF)=      0      0
OKAY 1
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
OKAY 1.2
OKAYY 1.4
nsect = 43
rsect[2] = 1
                          MACR COMPLETED.
EXIT AUS  CPUTIME=   12.1 I/O(DIR,BUF)=      0      0
(CL) lv:0 t:G15.8   SECTL[1]       10.000000
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
(CL) lv:0 t:I       GJNT[1]        1
(CL) lv:0 t:I       GJNT[2]        2
(CL) lv:0 t:I       GJNT[3]        3
(CL) lv:0 t:I       GJNT[4]        4
(CL) lv:0 t:I       GJNT[5]        5
(CL) lv:0 t:I       GJNT[6]        6
(CL) lv:0 t:I       GJNT[7]        7
(CL) lv:0 t:I       GJNT[8]        8
(CL) lv:0 t:I       GJNT[9]        9
(CL) lv:0 t:I       GJNT[10]       3
(CL) lv:0 t:I       GJNT[11]       6
(CL) lv:0 t:I       GJNT[12]       9
(CL) lv:0 t:I       GJNT[13]       10
(CL) lv:0 t:I       GJNT[14]       11
(CL) lv:0 t:I       GJNT[15]       12
(CL) lv:0 t:I       GJNT[16]       13
(CL) lv:0 t:I       GJNT[17]       14
(CL) lv:0 t:I       GJNT[18]       15
EXIT AUS  CPUTIME=  130.1 I/O(DIR,BUF)=      0      0
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                          DEFI COMPLETED.
                          DEFI COMPLETED.
                          TABL COMPLETED.
                          MACR COMPLETED.
                          TABL COMPLETED.
                          TABL COMPLETED.
                          TABL COMPLETED.
                          TABL COMPLETED.
                          TABL COMPLETED.
                          TABL COMPLETED.
```

```
EXIT AUS  CPUTIME=   59.3 I/O(DIR,BUF)=      0      0
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            DEFI COMPLETED.
                            DEFI COMPLETED.
                            TABL COMPLETED.
EXIT AUS  CPUTIME=   19.6 I/O(DIR,BUF)=      0      0
START 15 4,5,6
EXIT TAB  CPUTIME=   11.6 I/O(DIR,BUF)=      0      0
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            MACR COMPLETED.
# of elements in substructure 1 - 4
NJ of DEF dataset is 56
                            MACR COMPLETED.
# of elements of substructure 2 - 4
                            MACR COMPLETED.
                            TABL COMPLETED.
                            MACR COMPLETED.
                            TABL COMPLETED.
                            MACR COMPLETED.
                            TABL COMPLETED.
                            MACR COMPLETED.
                            TABL COMPLETED.
EXIT AUS  CPUTIME=   69.3 I/O(DIR,BUF)=      0      0
** BEGIN ELD  **   DATA SPACE=   200000 WORDS
EXIT ELD  CPUTIME=   16.8 I/O(DIR,BUF)=      0      0
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            TABL COMPLETED.
EXIT AUS  CPUTIME=    4.0 I/O(DIR,BUF)=      0      0
** BEGIN TOPO **   DATA SPACE=   200000 WORDS
<DM> OPEN,  Ldi: 25, File: NS.L25 , Attr: scratch, Block I/O
<DM> OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O
NO. OF   4-NODE ELEMENTS=     8
0TOTAL NO. OF ELEMENTS=      8
0MAXCON, MAXSUB, ILMAX=   1872   1400     52
0KSIZE,NR5,LR5=        18         1       896
0MAXCON, MAXSUB, ILMAX=   1864   1400     52
0SIZE INDEX=     23,  IC1, IC2=   221    70, NR4=    1
<DM> CLOSE, Ldi: 25, File: NS.L25
<DM> CLOSE, Ldi: 26, File: NS.L26
EXIT TOPO CPUTIME=   18.0 I/O(DIR,BUF)=      0      0
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            DEFI COMPLETED.
                            DEFI COMPLETED.
                            UNIO COMPLETED.
EXIT AUS  CPUTIME=    7.9 I/O(DIR,BUF)=      0      0
** BEGIN K    **   DATA SPACE=   200000 WORDS
EXIT K    CPUTIME=   10.9 I/O(DIR,BUF)=      0      0
** BEGIN INV  **   DATA SPACE=   200000 WORDS
0NSING,NNEG=      0      0
EXIT INV  CPUTIME=    6.8 I/O(DIR,BUF)=      0      0
** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            ALPH COMPLETED.
                            SYSV COMPLETED.
```

```
 EXIT AUS  CPUTIME=    4.8 I/O(DIR,BUF)=      0      0
 ** BEGIN SSOL **   DATA SPACE=   200000 WORDS
 (DM) OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O

0 CASE      F*U             U*KU            ERR

     1   0.3450000E+00   0.3450001E+00  -0.8636353E-07
 (DM) CLOSE, Ldi: 26, File: NS.L26
 EXIT SSOL CPUTIME=   16.8 I/O(DIR,BUF)=      0      0
 ** BEGIN DCU  **   DATA SPACE=   200000 WORDS
0
 EXIT DCU  CPUTIME=    0.2 I/O(DIR,BUF)=      0      0
 ** BEGIN VPRT **   DATA SPACE=   200000 WORDS
1STATIC DISPLACEMENTS.                                    ID=   1/ 1/  1
  external load
0JOINT      1           2           3
     1  0.300E-01  -0.345E-02   0.000E+00*
     2  0.225E-01  -0.345E-02   0.000E+00*
     3  0.150E-01  -0.345E-02   0.000E+00*
     4  0.300E-01  -0.173E-02   0.000E+00*
     5  0.225E-01  -0.173E-02   0.000E+00*
     6  0.150E-01  -0.173E-02   0.000E+00*
     7  0.300E-01  -0.759E-07   0.000E+00*
     8  0.225E-01  -0.521E-07   0.000E+00*
     9  0.150E-01  -0.296E-07   0.000E+00*
    10  0.750E-02  -0.345E-02   0.000E+00*
    11  0.000E+00* -0.345E-02   0.000E+00*
    12  0.750E-02  -0.173E-02   0.000E+00*
    13  0.000E+00* -0.173E-02   0.000E+00*
    14  0.750E-02  -0.120E-07   0.000E+00*
    15  0.000E+00*  0.000E+00*  0.000E+00*
1STATIC REACTIONS,  FORCE ERRORS.                         ID=   1/ 1/  1
  external load
0JOINT      1           2           3
     1 -0.119E-05  -0.283E-06   0.000E+00*
     2  0.626E-06   0.119E-06   0.000E+00*
     3 -0.121E-05   0.249E-06   0.000E+00*
     4  0.143E-05   0.586E-07   0.000E+00*
     5  0.400E-06  -0.149E-06   0.000E+00*
     6 -0.341E-07  -0.108E-07   0.000E+00*
     7 -0.477E-06   0.539E-06   0.000E+00*
     8 -0.212E-06  -0.394E-06   0.000E+00*
     9 -0.999E-07  -0.680E-07   0.000E+00*
    10  0.597E-06  -0.395E-06   0.000E+00*
    11 -0.288E+01* -0.684E-07   0.000E+00*
    12  0.569E-08   0.290E-06   0.000E+00*
    13 -0.575E+01*  0.167E-06   0.000E+00*
    14 -0.293E-07   0.671E-07   0.000E+00*
    15 -0.287E+01*  0.178E-05*  0.000E+00*
 EXIT VPRT CPUTIME=    4.2 I/O(DIR,BUF)=      0      0
 (DM) CLOSE, Ldi:  1, File: SSL.L01
 (CL) CSS exhausted
      ENDRUN called by CLIP
```

ORIGINAL PAGE IS OF POOR QUALITY

```
rm PAN1.L01
rmprocl
nicespar <<\endinput
*set echo=off
*open 1 pan1.101
.
.
DUMMY START CARD
[xqt tab
start 1000
.
 *procedure SUB_TABLE
.
. SET UP TABLES
.
[xqt sub
.
TABLE(NI=3,NJ=1,ITYPE=0): SUBS PARA 1 1
J=1: 2 4 1    . nsubs nnpe iopt
.
. NO. OF ELEMENTS IN SUBSTR.
.
TABLE(NI=2,NJ=1,ITYPE=0): SUBS ELEM 1 1
J=1: 16 44        . no. of elements per sub. (for n subs)

. SUBSTRUCTURE INTERFACES
.
. syntax:
. J=m: j1 s1 j2 s2      m=1,no. of interface noces
.
.
TABLE(NI=4,NJ=8,ITYPE=0): SUBS SUBI 1 1
J=1: 17 1 1 2
J=2: 18 1 2 2
J=3: 19 1 3 2
J=4: 20 1 4 2
J=5: 21 1 5 2
J=6: 22 1 6 2
J=7: 23 1 7 2
J=8: 24 1 8 2
.
 *end
 *call SUB_TABLE
  *add preserve
.
.
. DEFINE SUBSTRUCTURE -1
[xqt tab
start 24,4,5,6
matc:1 10000 0.3
online=0
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
$loc; format=1
     1      0.160000E+02   0.575000E+01   0.000000E+00
     2      0.157071E+02   0.645711E+01   0.000000E+00
     3      0.150000E+02   0.675000E+01   0.000000E+00
     4      0.142929E+02   0.645711E+01   0.000000E+00
     5      0.140000E+02   0.575000E+01   0.000000E+00
     6      0.142929E+02   0.504289E+01   0.000000E+00
     7      0.150000E+02   0.475000E+01   0.000000E+00
     8      0.157071E+02   0.504289E+01   0.000000E+00
     9      0.164444E+02   0.575000E+01   0.000000E+00
    10      0.161516E+02   0.690155E+01   0.000000E+00
    11      0.150000E+02   0.719444E+01   0.000000E+00
    12      0.138484E+02   0.690155E+01   0.000000E+00
    13      0.135556E+02   0.575000E+01   0.000000E+00
    14      0.138484E+02   0.459845E+01   0.000000E+00
    15      0.150000E+02   0.430556E+01   0.000000E+00
    16      0.161516E+02   0.459845E+01   0.000000E+00
    17      0.170000E+02   0.575000E+01   0.000000E+00
    18      0.170000E+02   0.775000E+01   0.000000E+00
    19      0.150000E+02   0.775000E+01   0.000000E+00
    20      0.130000E+02   0.775000E+01   0.000000E+00
    21      0.130000E+02   0.575000E+01   0.000000E+00
    22      0.130000E+02   0.375000E+01   0.000000E+00
    23      0.150000E+02   0.375000E+01   0.000000E+00
    24      0.170000E+02   0.375000E+01   0.000000E+00
sa(1):1 0.1
online=0
con=1
zero 3:1,24
!xqt eld
reset LREC=1250
 541
   1    9   10    2 #
   2   10   11    3 #
   3   11   12    4 #
   4   12   13    5 #
   6   14   13    5 #
   7   15   14    6 #
   8   16   15    7 #
   1    9   16    8 #
   9   17   18   10 #
  10   18   19   11 #
  11   19   20   12 #
  12   20   21   13 #
  14   22   21   13 #
  15   23   22   14 #
  16   24   23   15 #
   9   17   24   16 #
!xqt topo
!xqt e
!xqt exs
stop
rcall end_sub
```

```
. DEFINE SUBSTRUCTURE -2
.
[xot tab
start 62,4,5,6
mate: 1 10000 0.3
]loc: format=1
```

1	0.170000E+02	0.575000E+01	0.000000E+00
2	0.170000E+02	0.775000E+01	0.000000E+00
3	0.150000E+02	0.775000E+01	0.000000E+00
4	0.130000E+02	0.775000E+01	0.000000E+00
5	0.130000E+02	0.575000E+01	0.000000E+00
6	0.130000E+02	0.375000E+01	0.000000E+00
7	0.150000E+02	0.375000E+01	0.000000E+00
8	0.170000E+02	0.375000E+01	0.000000E+00
9	0.000000E+00	0.000000E+00	0.000000E+00
10	0.433333E+01	0.000000E+00	0.000000E+00
11	0.866667E+01	0.000000E+00	0.000000E+00
12	0.130000E+02	0.000000E+00	0.000000E+00
13	0.150000E+02	0.000000E+00	0.000000E+00
14	0.170000E+02	0.000000E+00	0.000000E+00
15	0.213333E+02	0.000000E+00	0.000000E+00
16	0.256667E+02	0.000000E+00	0.000000E+00
17	0.300000E+02	0.000000E+00	0.000000E+00
18	0.000000E+00	0.125000E+01	0.000000E+00
19	0.433333E+01	0.125000E+01	0.000000E+00
20	0.866667E+01	0.125000E+01	0.000000E+00
21	0.130000E+02	0.125000E+01	0.000000E+00
22	0.150000E+02	0.125000E+01	0.000000E+00
23	0.170000E+02	0.125000E+01	0.000000E+00
24	0.213333E+02	0.125000E+01	0.000000E+00
25	0.256667E+02	0.125000E+01	0.000000E+00
26	0.300000E+02	0.125000E+01	0.000000E+00
27	0.000000E+00	0.375000E+01	0.000000E+00
28	0.433333E+01	0.375000E+01	0.000000E+00
29	0.866667E+01	0.375000E+01	0.000000E+00
30	0.213333E+02	0.375000E+01	0.000000E+00
31	0.256667E+02	0.375000E+01	0.000000E+00
32	0.300000E+02	0.375000E+01	0.000000E+00
33	0.000000E+00	0.575000E+01	0.000000E+00
34	0.433333E+01	0.575000E+01	0.000000E+00
35	0.866667E+01	0.575000E+01	0.000000E+00
36	0.213333E+02	0.575000E+01	0.000000E+00
37	0.256667E+02	0.575000E+01	0.000000E+00
38	0.300000E+02	0.575000E+01	0.000000E+00
39	0.000000E+00	0.775000E+01	0.000000E+00
40	0.433333E+01	0.775000E+01	0.000000E+00
41	0.866667E+01	0.775000E+01	0.000000E+00
42	0.213333E+02	0.775000E+01	0.000000E+00
43	0.256667E+02	0.775000E+01	0.000000E+00
44	0.300000E+02	0.775000E+01	0.000000E+00
45	0.000000E+00	0.102500E+02	0.000000E+00

```
    46      0.433333E+01   0.102500E+02   0.000000E+00
    47      0.866667E+01   0.102500E+02   0.000000E+00
    48      0.130000E+02   0.102500E+02   0.000000E+00
    49      0.150000E+02   0.102500E+02   0.000000E+00
    50      0.170000E+02   0.102500E+02   0.000000E+00
    51      0.213333E+02   0.102500E+02   0.000000E+00
    52      0.256667E+02   0.102500E+02   0.000000E+00
    53      0.300000E+02   0.102500E+02   0.000000E+00
    54      0.000000E+00   0.115000E+02   0.000000E+00
    55      0.433333E+01   0.115000E+02   0.000000E+00
    56      0.866667E+01   0.115000E+02   0.000000E+00
    57      0.130000E+02   0.115000E+02   0.000000E+00
    58      0.150000E+02   0.115000E+02   0.000000E+00
    59      0.170000E+02   0.115000E+02   0.000000E+00
    60      0.213333E+02   0.115000E+02   0.000000E+00
    61      0.256667E+02   0.115000E+02   0.000000E+00
    62      0.300000E+02   0.115000E+02   0.000000E+00
sa(1):1 0.1
con=1
ZERO 3:1,62
ZERO 1:17,26,9
ZERO 1:32,44,6
ZERO 1:53,62,9
ZERO 2:62
[xqt elc
e41
9 10 19 18 1 8 1
18 19 28 27 1 2 1
20 21 6 29
21 22 7 6 1 2 1
23 24 30 8
24 25 31 30 1 2 1
27 28 34 33 1 2 1
29 6 5 35
8 30 36 1
30 31 37 36 1 2 1
33 34 40 39 1 2 1
35 5 4 41
1 36 42 2
36 37 43 42 1 2 1
39 40 46 45 1 2 1
41 4 48 47
4 3 49 48
3 2 50 49
2 42 51 50
42 43 52 51 1 2 1
45 46 55 54 1 8 1
online=1
[xqt topo
[xqt e
[xqt eks
stop
```

```
*call end_sub
*call glob_dat
,
[xqt k
[xqt inv
[xqt sus
sysvec
applied forces
case 1
 I=1
 J=   25:   0.625
 J=   34 :  1.875
 J=   43 :  2.250
 J=   49 :  2.0
 J=   55 :  2.250
 J=   61 :  1.875
 J=   70 :  0.625
[xqt ssol
[xqt ccu
[xqt vprt
 tprint stat disp
 tprint stat reac
[xqt exit
endinput
```

```
C       !!!      link with /usr/u1/elp/lib/nslib.a   !!!!!
       Force LUD of NP ident ME
C.....Test program for parallel PLU decomposition using Force versions
C......of "Linpack" routines.
C.....This program calls a (single stream) routine to read in a matrix
C......and vector, then SGEFA is called to factor the matrix into a PLU form,
C......then SGESL is called to solve the system.  The computation is timed,
C......and then a (single stream) routine is called to output the results.

       Shared INTEGER N, IPVT(500), INFO
       Shared DOUBLE PRECISION A(500,500) ,B(500)
       shared INTEGER ITM1, ITM2, ITM3
       shared REAL DELTA1, DELTA2, RATE1, RATE2
       Private integer amax,numjnt,dof,ierr,rmax,bw
       Private integer rowptr(1000), rowlen(1000)
       Private double precision amat(50000),x(1000)
       Private integer i, j
       End declarations

       Barrier
         amax = 10000
         rmax = 1000
         call getrow(amat,amax,rowptr,rowlen,rmax,
     :     '/usr/u1/venkatesh/panel/MAS.L01',
     :      x,b,numjnt,dof,bw,ierr)
         if (ierr.ne.0) write(*,5) ierr
5        format('error return code = ',i2)
         N = numjnt*dof
         print*,'starts to print matrix'
         do 1 i = 1,N
           write(*,2) i,rowptr(i),rowlen(i),amat(rowptr(i))
1        continue
2        format('row ',i3,' start ',i6,'lth= ',i3,'diag= ',g15.5)
C.........Code to transfer from vector to symetric array, a
         print*,'starts symmetric array'
         do 20 irow = 1,N
          ip = rowptr(irow)
C         ilen = rowlen(irow)
          ilen = (irow-1) + rowlen(irow)
          do 10 icol = irow,ilen
            a(irow,icol) = amat(ip)
            ip = ip + 1
 10       continue
C.........zero out the remainder of the array
          do 15 icol = ilen+1, N
            a(irow,icol) = 0.
 15       continue
 20      continue
          print*,'o k a y 3'
         do 40 icol = 1, N
           do 30 irow = icol, N
             a(irow,icol) = a(icol,irow)
30         continue
40       continue
```

```
C        CALL PRNTB2(A, B, N)
         CALL CFrtic(ITM1)
         End barrier

         Forcecall SGEFA(A, 500, N, IPVT, INFO)
         IF (INFO .NE. 0) THEN
C          matrix is singular...
           if (me .eq. 1) print *, 'matrix is singular'
           Join
         END IF
         print*,'o k a y 4'

         IF (ME .EQ. 1)  CALL CFrtic(ITM2)

         Forcecall SGESL(A, 500, N, IPVT, B, 0)

         Barrier
         print*,'o k a y 5'
           CALL CFrtic(ITM3)
           CALL PRINTB(A, B, N)

           DELTA1 = (ITM2 - ITM1)/50.0
           DELTA2 = (ITM3 - ITM2)/50.0
           OPEN(8,FILE='/usr/u1/venkatesh/time.dat',CPU=1)
           IF (DELTA1 .NE. 0) THEN
             RATE1 = (2.0*N*N*N/3.0)*1.0E-6/DELTA1
             WRITE (8, 400)  NP, N, ME, DELTA1, RATE1
           ELSE
             WRITE (8, 400)  NP, N, ME, DELTA1, 0.0
             WRITE (8, 402)
           ENDIF
           IF (DELTA2 .NE. 0) THEN
             RATE2 = (N*N)*1.0E-6/DELTA2
             WRITE (8, 401)  ME, DELTA2, RATE2
           ELSE
             WRITE (8, 401)  ME, DELTA2, 0.0
             WRITE (8, 402)
           ENDIF
           print*,'o k a y 6'
400        FORMAT('   Number of processes =',I3,' Matrix order =',I4,/
     +     ' matrix decomposition: ',F12.4,' seconds (',F5.3,' MFLOPS)')
401        FORMAT(
     +     ' Fwd/back subst:       ',F12.4,' seconds (',F5.3,' MFLOPS)')
402        FORMAT(' No elapsed time measured.')
           End barrier
         Join
         END
```

```
      Forcesub SGESL(A, LDA, N, IPVT, B, JOB) of NP ident me
C     SGESL:  Force parallel version of LINPACK's SGESL which solves
C               Ax=b, using (column orientated) foward/backward subst.
C               A call to SGEFA must precede the call to SGESL.
C               SGEFA provides the PLU factorization of A.
C     A:      the working matrix
C     LDA:    the declared dimension of A
C     N:      the working dimension of A
C     IPVT:   the pivot array
C     B:      the input/output vector (solved in place)
C               B is the only argument altered by SGESL.
C     JOB:    job selector:   job=0: solves Ax=b
C                             job=1: solves Transpose(A)x=b, not implemented
C             All argument MUST be declared "Shared" in the calling module!
      integer LDA, N, IPVT(LDA), JOB
      double precision A(LDA,LDA), B(LDA)
      Private integer I, K, L
      Shared real     TEM
      End declarations

C     first solve:  L*Y = B
      do 20 K = 1, N-1
        Barrier
          L    = IPVT(K)
          TEM  = B(L)
          B(L) = B(K)
          B(K) = TEM
        End barrier
        Presched do 22  I = K+1, N
          B(I) = B(I) + TEM * A(I,K)
22      End presched do
20    continue

C     then solve:  U*X = Y
      do 40 K = N, 1, -1
        Barrier
          B(K) = B(K)/A(K,K)
          TEM  = -B(K)
        End barrier
        Presched do 42  I = 1, K-1
          B(I) = B(I) + TEM * A(I,K)
42      End presched do
40    continue
      Barrier
      End barrier
      RETURN
      END
```

```
      Forcesub SGEFA(A, LDA, N, IPVT, INFO) of NP ident ME
      INTEGER LDA, N, IPVT(LDA), INFO
      DOUBLE PRECISION A(LDA, LDA)
C
      Private REAL ABSMAX
      Private REAL T
      Private INTEGER KK, I, MAXI, J, KP1
      Shared INTEGER IALL
      Shared REAL PIV, ALLMAX
      Shared logical ILOCK
      End declarations

      Barrier
         INFO = 0
         ALLMAX = 0.0
      End barrier

C.....For each row of the matrix

      DO 1000  KK = 1, N-1

      IF(INFO.NE.0) GOTO 2000

C.....Reset local maxima

         ABSMAX = 0.0

C.....Find the pivot row

         Presched DO  100  I = KK, N
            T = ABS( A(I, KK) )
            IF (ABSMAX .LT. T)  THEN
               MAXI = I
               ABSMAX = T
            ENDIF
100      End Presched DO

C.....Update the Shared Information if necessary

         Critical ILOCK
         IF (ALLMAX .LT. ABSMAX)  THEN
            IALL = MAXI
            ALLMAX = ABSMAX
         ENDIF
         End critical

         Barrier
            IF (ALLMAX .EQ. 0.0)  THEN
               INFO = KK
               IPVT(KK)=KK
            ELSE
               IPVT(KK)=IALL
            ENDIF
         End Barrier
```

```
C........If the matrix is singular then pass the information

          IF (INFO .EQ. KK)  GOTO 1000
          MAXI = IALL
          IF (MAXI .NE. KK)  THEN

C........Swap rows if necessary

             Presched DO  110  J = KK, N
                TEMP = A(MAXI, J)
                A(MAXI, J) = A(KK, J)
                A(KK, J) = TEMP
110          End Presched DO
          ENDIF

C.......Self schedule row reductions

          KP1 = KK + 1
          Barrier
              PIV = -1.0/A(KK, KK)
          End Barrier

          Selfsched Do  130  I = KP1, N
             TEMP = PIV*A(I, KK)
             A(I,KK) = TEMP
             DO  120  J = KP1, N
                A(I, J) = A(I, J) + TEMP*A(KK, J)
120          CONTINUE
130       End Selfsched DO

          Barrier
             ALLMAX=0
          End barrier

1000    CONTINUE

2000    RETURN
        END
*******************************************************************************
************************** i/o routines (replacable)**************************
*******************************************************************************
        subroutine printb(a, b, n)
C......this routine prints B(N) & A(N,N)
C......where B(N) is the solution vector, and A(N,N) is the working matrix.
C......the user may replace this single stream subroutine.
        double precision b(1), a(500,500)
         open(8,FILE="/usr/u1/venkatesh/panel/venk.dat",CPU=1)
         rewind (8)
        do 10 i=1,n
10      write(8,90) 'b(',i,')=',b(i)
         close (8)
90      format(a,i3,a,e14.7)
        return
        end
```

```
      subroutine prntb2(a, b, n)
C.....this routine prints B(N) & A(N,N)
C.....where B(N) is the solution vector, and A(N,N) is the working matrix.
C.....the user may replace this single stream subroutine.
      double precision b(1), a(500,500)
       open(8,FILE='/usr/ui/venkatesh/panel/venk.predat',CPU=1)
       rewind (8)
      do 10 i=1,n
10    write(8,90) 'b(',i,')=',b(i),(a(i,j), j=1,n)
       close (8)
90    format(a,i3,a,300e14.7)
      return
      end
```

OUTPUT FOR RECTANGULAR PANEL WITH HOLE

```
 <CL> PUT_message,Commnt>
 <CL> $root,L0001,C00001>*set echo=off
 <DM> OPEN,  Ldi:  1, File: PAN1.L01 , Attr: new, Block I/O
 ** BEGIN TAB  **   DATA SPACE=   200000 WORDS

  1000 JOINTS.
0ACTIVE JOINT MOTION COMPONENTS= 1 2 3 4 5 6
0LIB READ ERROR, NU,L,KORE,IERR,IOP=       1       0  198988      -1      11
     NAME= MASK BTAB         2         5
0*** ERRORS IN INPUT PREVENT CALCULATION OF QJ(3,3,JT)
 EXIT TAB  CPUTIME=    7.5 I/O(DIR,BUF)=      0       0
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            TABL COMPLETED.
                            TABL COMPLETED.
                            TABL COMPLETED.
 EXIT AUS  CPUTIME=    5.7 I/O(DIR,BUF)=      0       0
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                            MACR COMPLETED.
                            MACR COMPLETED.
                            MACR COMPLETED.
 EXIT AUS  CPUTIME=    1.8 I/O(DIR,BUF)=      0       0

    24 JOINTS.
0ACTIVE JOINT MOTION COMPONENTS= 1 2 3
 EXIT TAB  CPUTIME=   50.0 I/O(DIR,BUF)=      0       0
 LREC=    1280
 ** BEGIN ELD  **   DATA SPACE=   200000 WORDS
 EXIT ELD  CPUTIME=    8.8 I/O(DIR,BUF)=      0       0
 ** BEGIN TOPO **   DATA SPACE=   200000 WORDS
 <DM> OPEN,  Ldi: 25, File: NS.L25 , Attr: scratch, Block I/O
 <DM> OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O
 NO. OF   4-NODE ELEMENTS=    16
0TOTAL NO. OF ELEMENTS=     16
0MAXCON, MAXSUB, ILMAX=   1872   1400     52
0KSIZE,NR5,LR5=         28        1      896
0MAXCON, MAXSUB, ILMAX=   1864   1400     52
0SIZE INDEX=     66,  IC1, IC2=   967   191, NR4=    1
 <DM> CLOSE, Ldi: 25, File: NS.L25
 <DM> CLOSE, Ldi: 26, File: NS.L26
 EXIT TOPO CPUTIME=    7.2 I/O(DIR,BUF)=      0       0
 ** BEGIN E    **   DATA SPACE=   200000 WORDS
 T=   0.10000E-19-0.10000E-02 0.10000E-04 0.10000E-04
      0.20000E+02 0.10000E-03 0.10000E-03 0.10000E-03
 ERROR LEVELS= 2 2 0 2 2 2 2 2
0
0
              L, VOL OR    STRUCTURAL   NON-STRUCTURAL
 TYPE GROUP    AREA SUM     WEIGHT       WEIGHT
 E41    1   0.131716E+02 0.000000E+00 0.000000E+00
```

```
0
 TOTAL                  0.000000E+00 0.000000E+00


 TOTAL  4-NODE@   0.1317158E+02
 EXIT E    CPUTIME=    6.7 I/O(DIR,BUF)=     0      0
 ** BEGIN EKS  **   DATA SPACE=   200000 WORDS
 E41  COMPLETED
 EXIT EKS  CPUTIME=    6.7 I/O(DIR,BUF)=     0      0
 OKAY 1
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
 OKAY 1.2
 OKAYY 1.4
 njsect = 43
 nsect[1] = 1
                          MACR COMPLETED.
 EXIT AUS  CPUTIME=    9.0 I/O(DIR,BUF)=     0      0
 <CL> lv:0 t:G15.8   SECTL[1]       10.000000
 OKAY 2 2 2
 OKAYY  3 3 3
 EXIT TAB  CPUTIME=   42.4 I/O(DIR,BUF)=     0      0
 ** BEGIN ELD  **   DATA SPACE=   200000 WORDS
 EXIT ELD  CPUTIME=   13.8 I/O(DIR,BUF)=     0      0
 ** BEGIN TOPO **   DATA SPACE=   200000 WORDS
 <DM> OPEN,  Ldi: 25, File: NS.L25 , Attr: scratch, Block I/O
 <DM> OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O
 NO. OF   4-NODE ELEMENTS=    44
0TOTAL NO. OF ELEMENTS=     44
0MAXCON, MAXSUB, ILMAX=   1872   1400     52
0KSIZE,NR5,LR5=         52         2       896
0MAXCON, MAXSUB, ILMAX=   1863   1400     52
0SIZE INDEX=    210,  IC1, IC2=  4905   702, NR4=    4
 <DM> CLOSE, Ldi: 25, File: NS.L25
 <DM> CLOSE, Ldi: 26, File: NS.L26
 EXIT TOPO CPUTIME=   14.9 I/O(DIR,BUF)=     0      0
 ** BEGIN E    **   DATA SPACE=   200000 WORDS
 T=   0.10000E-19-0.10000E-02 0.10000E-04 0.10000E-04
      0.20000E+02 0.10000E-03 0.10000E-03 0.10000E-03
 ERROR LEVELS= 2 2 0 2 2 2 2 2
0
0
              L, VOL OR    STRUCTURAL   NON-STRUCTURAL
 TYPE GROUP   AREA SUM     WEIGHT       WEIGHT
 E41    1   0.329000E+03 0.000000E+00 0.000000E+00

0
 TOTAL                  0.000000E+00 0.000000E+00
```

```
TOTAL  4-NODE@   0.3290000E+03
EXIT E    CPUTIME=   11.7 I/O(DIR,BUF)=      0       0
** BEGIN EKS **   DATA SPACE=   200000 WORDS
E41  COMPLETED
EXIT EKS  CPUTIME=   15.9 I/O(DIR,BUF)=      0       0
OKAY 1
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
OKAY 1.2
OKAYY 1.4
njsect = 43
nsect[2] = 1
                          MACR COMPLETED.
EXIT AUS  CPUTIME=   12.1 I/O(DIR,BUF)=      0       0
<CL> lv:0 t:G15.8   SECTL[1]       10.000000
OKAY 2 2 2
OKAYY  3 3 3
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
                          MACR COMPLETED.
EXIT AUS  CPUTIME=  954.2 I/O(DIR,BUF)=      0       0
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                          TABL COMPLETED.
                          TABL COMPLETED.
                          TABL COMPLETED.
EXIT AUS  CPUTIME=  214.2 I/O(DIR,BUF)=      0       0
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                          DEFI COMPLETED.
                          DEFI COMPLETED.
                          TABL COMPLETED.
EXIT AUS  CPUTIME=   25.3 I/O(DIR,BUF)=      0       0
START 78 4,5,6

   78 JOINTS.
0ACTIVE JOINT MOTION COMPONENTS= 1 2 3
EXIT TAB  CPUTIME=   10.7 I/O(DIR,BUF)=      0       0
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                          MACR COMPLETED.
# of elements in substructure 1 - 16
NJ of DEF dataset is 80
                          MACR COMPLETED.
# of elements of substructure 2 - 44
** BEGIN ELD **   DATA SPACE=   200000 WORDS
EXIT ELD  CPUTIME=   20.7 I/O(DIR,BUF)=      0       0
** BEGIN AUS **   DATA SPACE=   200000 WORDS
                          TABL COMPLETED.
```

```
 EXIT AUS  CPUTIME=    4.2 I/O(DIR,BUF)=      0      0
 ** BEGIN TOPO **   DATA SPACE=   200000 WORDS
 <DM> OPEN,  Ldi: 25, File: NS.L25 , Attr: scratch, Block I/O
 <DM> OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O
 NO. OF   4-NODE ELEMENTS=    60
0TOTAL NO. OF ELEMENTS=     60
0MAXCON, MAXSUB, ILMAX=   1872   1400     52
0KSIZE,NR5,LR5=        52         3       896
0MAXCON, MAXSUB, ILMAX=   1863   1400     52
0SIZE INDEX=    210,  IC1, IC2=  5923   872, NR4=    4
 <DM> CLOSE, Ldi: 25, File: NS.L25
 <DM> CLOSE, Ldi: 26, File: NS.L26
 EXIT TOPO CPUTIME=   21.2 I/O(DIR,BUF)=      0      0
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                             DEFI COMPLETED.
                             DEFI COMPLETED.
                             UNIO COMPLETED.
 EXIT AUS  CPUTIME=   15.1 I/O(DIR,BUF)=      0      0
 ** BEGIN K    **   DATA SPACE=   200000 WORDS
 EXIT K    CPUTIME=   28.0 I/O(DIR,BUF)=      0      0
 ** BEGIN INV  **   DATA SPACE=   200000 WORDS
0NSING,NNEG=      0      0
 EXIT INV  CPUTIME=   20.7 I/O(DIR,BUF)=      0      0
 ** BEGIN AUS  **   DATA SPACE=   200000 WORDS
                             SYSV COMPLETED.
 EXIT AUS  CPUTIME=    3.5 I/O(DIR,BUF)=      0      0
 ** BEGIN SSOL **   DATA SPACE=   200000 WORDS
 <DM> OPEN,  Ldi: 26, File: NS.L26 , Attr: scratch, Block I/O

0 CASE      F*U             U*KU            ERR

     1   0.3532554E+00   0.3532554E+00  -0.1687296E-06
 <DM> CLOSE, Ldi: 26, File: NS.L26
 EXIT SSOL CPUTIME=   18.1 I/O(DIR,BUF)=      0      0
 ** BEGIN DCU  **   DATA SPACE=   200000 WORDS
0
 EXIT DCU  CPUTIME=    0.2 I/O(DIR,BUF)=      0      0
 ** BEGIN VPRT **   DATA SPACE=   200000 WORDS
0LIB READ ERROR, NU,L,KORE,IERR,IOP=       1       0       0      -1      10
     NAME= CASE TITL         11263747405
1STATIC DISPLACEMENTS.                                    ID=   1/ 1/  1
0JOINT      1          2          3
     1  0.123E-01  -0.173E-02   0.000E+00*
     2  0.134E-01  -0.107E-02   0.000E+00*
     3  0.152E-01  -0.716E-03   0.000E+00*
     4  0.174E-01  -0.115E-02   0.000E+00*
     5  0.184E-01  -0.173E-02   0.000E+00*
     6  0.174E-01  -0.232E-02   0.000E+00*
     7  0.152E-01  -0.275E-02   0.000E+00*
     8  0.134E-01  -0.240E-02   0.000E+00*
     9  0.123E-01  -0.173E-02   0.000E+00*
    10  0.136E-01  -0.134E-02   0.000E+00*
    11  0.154E-01  -0.478E-03   0.000E+00*
```

12	0.170E-01	-0.133E-02	0.000E+00*
13	0.186E-01	-0.173E-02	0.000E+00*
14	0.170E-01	-0.214E-02	0.000E+00*
15	0.154E-01	-0.299E-02	0.000E+00*
16	0.136E-01	-0.213E-02	0.000E+00*
17	0.122E-01	-0.173E-02	0.000E+00*
18	0.130E-01	-0.110E-02	0.000E+00*
19	0.154E-01	-0.584E-03	0.000E+00*
20	0.177E-01	-0.109E-02	0.000E+00*
21	0.185E-01	-0.173E-02	0.000E+00*
22	0.177E-01	-0.238E-02	0.000E+00*
23	0.154E-01	-0.288E-02	0.000E+00*
24	0.130E-01	-0.237E-02	0.000E+00*
25	0.307E-01	-0.348E-02	0.000E+00*
26	0.264E-01	-0.340E-02	0.000E+00*
27	0.219E-01	-0.340E-02	0.000E+00*
28	0.174E-01	-0.371E-02	0.000E+00*
29	0.154E-01	-0.379E-02	0.000E+00*
30	0.134E-01	-0.371E-02	0.000E+00*
31	0.882E-02	-0.340E-02	0.000E+00*
32	0.430E-02	-0.341E-02	0.000E+00*
33	0.000E+00*	-0.347E-02	0.000E+00*
34	0.307E-01	-0.311E-02	0.000E+00*
35	0.264E-01	-0.303E-02	0.000E+00*
36	0.220E-01	-0.300E-02	0.000E+00*
37	0.174E-01	-0.332E-02	0.000E+00*
38	0.154E-01	-0.343E-02	0.000E+00*
39	0.133E-01	-0.332E-02	0.000E+00*
40	0.873E-02	-0.300E-02	0.000E+00*
41	0.433E-02	-0.303E-02	0.000E+00*
42	0.000E+00*	-0.310E-02	0.000E+00*
43	0.307E-01	-0.233E-02	0.000E+00*

1

44	0.264E-01	-0.232E-02	0.000E+00*
45	0.222E-01	-0.226E-02	0.000E+00*
46	0.853E-02	-0.226E-02	0.000E+00*
47	0.435E-02	-0.232E-02	0.000E+00*
48	0.000E+00*	-0.233E-02	0.000E+00*
49	0.307E-01	-0.173E-02	0.000E+00*
50	0.264E-01	-0.173E-02	0.000E+00*
51	0.221E-01	-0.173E-02	0.000E+00*
52	0.867E-02	-0.173E-02	0.000E+00*
53	0.430E-02	-0.173E-02	0.000E+00*
54	0.000E+00*	-0.173E-02	0.000E+00*
55	0.307E-01	-0.113E-02	0.000E+00*
56	0.264E-01	-0.115E-02	0.000E+00*
57	0.222E-01	-0.121E-02	0.000E+00*
58	0.853E-02	-0.121E-02	0.000E+00*
59	0.435E-02	-0.115E-02	0.000E+00*
60	0.000E+00*	-0.114E-02	0.000E+00*
61	0.307E-01	-0.362E-03	0.000E+00*
62	0.264E-01	-0.438E-03	0.000E+00*
63	0.220E-01	-0.469E-03	0.000E+00*
64	0.174E-01	-0.151E-03	0.000E+00*

```
    65  0.154E-01  -0.341E-04   0.000E+00*
    66  0.133E-01  -0.153E-03   0.000E+00*
    67  0.873E-02  -0.469E-03   0.000E+00*
    68  0.433E-02  -0.433E-03   0.000E+00*
    69  0.000E+00* -0.372E-03   0.000E+00*
    70  0.307E-01   0.125E-04   0.000E+00*
    71  0.264E-01  -0.640E-04   0.000E+00*
    72  0.219E-01  -0.701E-04   0.000E+00*
    73  0.174E-01   0.243E-03   0.000E+00*
    74  0.154E-01   0.325E-03   0.000E+00*
    75  0.134E-01   0.242E-03   0.000E+00*
    76  0.882E-02  -0.701E-04   0.000E+00*
    77  0.430E-02  -0.596E-04   0.000E+00*
    78  0.000E+00*  0.000E+00*  0.000E+00*
0LIB READ ERROR, NU,L,KORE,IERR,IOP=      1       0       0      -1      10
     NAME= CASE TITL         11263747405
1STATIC REACTIONS,  FORCE ERRORS.                          ID=   1/ 1/  1
0JOINT      1          2          3
     1  0.100E-06   0.109E-06   0.000E+00*
     2  0.583E-06  -0.224E-06   0.000E+00*
     3  0.982E-06   0.220E-06   0.000E+00*
     4  0.659E-06  -0.384E-06   0.000E+00*
     5 -0.584E-06   0.113E-05   0.000E+00*
     6  0.177E-06   0.668E-06   0.000E+00*
     7  0.695E-06  -0.108E-06   0.000E+00*
     8  0.352E-06  -0.740E-06   0.000E+00*
     9  0.140E-05  -0.858E-07   0.000E+00*
    10 -0.967E-06  -0.569E-06   0.000E+00*
    11 -0.231E-05  -0.168E-06   0.000E+00*
    12 -0.252E-05  -0.122E-05   0.000E+00*
    13 -0.177E-05   0.186E-05   0.000E+00*
    14 -0.456E-05  -0.245E-08   0.000E+00*
    15 -0.491E-06  -0.823E-06   0.000E+00*
    16  0.240E-05   0.284E-06   0.000E+00*
    17 -0.113E-05  -0.833E-06   0.000E+00*
    18  0.318E-05  -0.154E-06   0.000E+00*
    19  0.867E-06   0.162E-06   0.000E+00*
    20  0.411E-05  -0.230E-06   0.000E+00*
    21  0.488E-05  -0.138E-05   0.000E+00*
    22  0.213E-05   0.139E-05   0.000E+00*
    23  0.370E-06  -0.750E-06   0.000E+00*
    24 -0.923E-06   0.103E-05   0.000E+00*
    25  0.954E-06   0.149E-06   0.000E+00*
    26  0.197E-06  -0.454E-06   0.000E+00*
    27  0.974E-06   0.388E-06   0.000E+00*
    28  0.414E-06   0.415E-06   0.000E+00*
    29 -0.474E-06   0.488E-06   0.000E+00*
    30  0.525E-06   0.123E-06   0.000E+00*
    31 -0.307E-06   0.436E-06   0.000E+00*
    32 -0.588E-07   0.813E-07   0.000E+00*
    33 -0.620E+00* -0.365E-07   0.000E+00*
    34 -0.238E-06   0.453E-06   0.000E+00*
    35  0.128E-05  -0.149E-06   0.000E+00*
    36  0.350E-05  -0.867E-06   0.000E+00*
```

```
   37  0.240E-05  -0.118E-05   0.000E+00*
   38 -0.346E-05  -0.531E-06   0.000E+00*
   39  0.154E-05  -0.723E-07   0.000E+00*
   40 -0.751E-06   0.330E-06   0.000E+00*
   41 -0.959E-07  -0.841E-06   0.000E+00*
   42 -0.187E+01* -0.146E-06   0.000E+00*
   43 -0.238E-05   0.464E-06   0.000E+00*
1
   44  0.275E-05   0.106E-05   0.000E+00*
   45 -0.655E-05  -0.226E-06   0.000E+00*
   46  0.746E-06  -0.305E-06   0.000E+00*
   47  0.911E-06   0.415E-06   0.000E+00*
   48 -0.225E+01*  0.299E-06   0.000E+00*
   49 -0.238E-05   0.104E-05   0.000E+00*
   50 -0.330E-05  -0.676E-06   0.000E+00*
   51 -0.697E-06  -0.187E-05   0.000E+00*
   52 -0.477E-06   0.201E-06   0.000E+00*
   53 -0.100E-05   0.341E-06   0.000E+00*
   54 -0.202E+01*  0.592E-07   0.000E+00*
   55  0.334E-05  -0.133E-06   0.000E+00*
   56 -0.287E-05   0.136E-05   0.000E+00*
   57 -0.159E-05   0.958E-06   0.000E+00*
   58 -0.104E-05  -0.367E-06   0.000E+00*
   59 -0.202E-06  -0.314E-06   0.000E+00*
   60 -0.225E+01* -0.458E-07   0.000E+00*
   61  0.715E-06  -0.646E-06   0.000E+00*
   62  0.199E-05  -0.162E-05   0.000E+00*
   63  0.291E-05   0.101E-05   0.000E+00*
   64 -0.752E-06   0.849E-06   0.000E+00*
   65 -0.190E-07   0.553E-06   0.000E+00*
   66  0.436E-06  -0.145E-06   0.000E+00*
   67  0.716E-07  -0.438E-06   0.000E+00*
   68 -0.166E-06   0.946E-07   0.000E+00*
   69 -0.187E+01* -0.121E-06   0.000E+00*
   70 -0.119E-06   0.276E-07   0.000E+00*
   71 -0.135E-05   0.967E-06   0.000E+00*
   72 -0.175E-05   0.204E-06   0.000E+00*
   73  0.854E-06  -0.544E-06   0.000E+00*
   74 -0.754E-06  -0.336E-07   0.000E+00*
   75 -0.101E-05  -0.187E-06   0.000E+00*
   76 -0.411E-06  -0.285E-06   0.000E+00*
   77 -0.190E-06  -0.155E-06   0.000E+00*
   78 -0.620E+00*  0.493E-05*  0.000E+00*
 EXIT VPRT CPUTIME=    8.3 I/O(DIR,BUF)=      0      0
 <DM> CLOSE, Ldi:  1, File: PAN1.L01
 <CL> CSS exhausted
      ENDRUN called by CLIP
```

APPENDIX C

PROGRAM FOR ELASTO-PLASTIC STABILITY PROBLEM

The program written in PASCAL is divided into two parts. Part I is called PROGRAM COLUMN. This part of the program is down-loaded onto one of the NPR number of processors and this processor is designated as "Master Processor". Part II of the program is named PROGRAM TANGENT. This program is down-loaded onto the rest of the processors of the NPR number of processors. These (NPR-1) number of processors are called "Assistant Processors". The assistant processors are utilized to compute elastic-plastic cross-sectinal properties of various cross sections along the length of the member which are communicated to the master processor. The master processor assembles the global stiffness matrix upon receipt of the cross sectional properties form assistants. The lateral displacement vector is computed on the master processor. Thus the operation is sequential between the assembly of global stiffness values and evaluation of the lateral displacements of the member. A detailed flow chart of the algorithm used and the concurrent computational procedure is outlined in Reference 6.

The input to the program consists of the member length, material constants, end rotational stiffness characteristics, initial out-of-straightness midspan amplitudes, cross-sectional dimensions, and residual stresses. The output from the program consists of axial load level, corresponding converged lateral displacements of the member, nondimensionalized determinant of the global stiffness matrix at each load level, and the computational times of each processor.

PROGRAM FOR ELASTO-PLASTIC STABILITY PROBLEM

```
(*$WIDELIST,NO ASSERTS, NO TRACEBACK*)
(* $GLOBALOPT *)

PROGRAM COLUMN;
CONST   MAXIDX=255;   (*MAX NBR I/O INDEX TAG *)
        MAXREC=255;   (*MAX REC LENGTH FOR NBR I/O *)
        MAXNODE=36;   (*MAX NODE NUMBERS *)
        MAXDA=31;     (*MAX DATA AREA NUMBER *)
        MAXINT=32767; (*MAX INTEGER *)
        SYSFLAG=1;    (*SYSTEM FLAG *)
TYPE    NODE=1..MAXNODE;
        IDX=1..MAXIDX;
        RECLEN=1..MAXREC;
        DANUM=1..MAXDA;
        FLAG=0..7;
        ADDR=INTEGER;
        POSINT=1..MAXINT;

(* PASLIB EXTERNAL PROCEDURES AND FUNCTIONS FOLLOW *)
(*-------------------------------------------------------*)
(*-------------- TIMER PROCEDURES ----------------------*)
FUNCTION XTIME:LONGINT;EXTERNAL;
PROCEDURE TSTART(T:POSINT);EXTERNAL;
FUNCTION TREAD:LONGINT;EXTERNAL;
PROCEDURE TSTOP;EXTERNAL;
(*--------  TEXT OUTPUT PROCEDURES  -----------------*)
PROCEDURE MSG(STRING:PACKED ARRAY[1..?] OF CHAR);EXTERNAL;
PROCEDURE MSGLN(STRING:PACKED ARRAY[1..?] OF CHAR);EXTERNAL;
PROCEDURE NXTLN;EXTERNAL;
PROCEDURE MSGI(I:INTEGER);EXTERNAL;
PROCEDURE MSGR(X:REAL);EXTERNAL;
PROCEDURE MSGL(I:LONGINT);EXTERNAL;
PROCEDURE ENDLN(N:POSINT);EXTERNAL;
(*                                                     *)
(*------------  INTERACTIVE INPUT --------------------*)
(*                                                     *)
PROCEDURE QUERY;EXTERNAL;
FUNCTION RDI:INTEGER;EXTERNAL;
FUNCTION RDR:REAL;EXTERNAL;
(*                                                   *)
(*--------------- DATA AREAS -------------------------*)
FUNCTION DAPTR(DA:DANUM):ADDR;EXTERNAL;
(*                                                   *)
(*------------ FLOATING OPERATIONS -----------------*)
FUNCTION ADD(X,Y:REAL):REAL;EXTERNAL;
```

```
FUNCTION SUB(X,Y:REAL):REAL;EXTERNAL;
FUNCTION MULT(X,Y:REAL):REAL;EXTERNAL;
FUNCTION DIVD(X,Y:REAL):REAL;EXTERNAL;
FUNCTION NEG(X:REAL):REAL;EXTERNAL;
FUNCTION ABS95(X:REAL):REAL;EXTERNAL;
FUNCTION CMP(X,Y:REAL):REAL;EXTERNAL;
FUNCTION SQRT95(X:REAL):REAL;EXTERNAL;
(*                                                    *)
(*---------- FLOATING POINT CONSTANTS ------------*)
FUNCTION MAX95:REAL;EXTERNAL;
FUNCTION MIN95:REAL;EXTERNAL;
(*---------- FLOATING POINT CONVERSIONS ----------*)
FUNCTION IFIX(X:REAL):INTEGER;EXTERNAL;
FUNCTION FLOATI(I:INTEGER):REAL;EXTERNAL;
FUNCTION CV9512(X:REAL):REAL;EXTERNAL;
FUNCTION VDP(N:POSINT; VAR A:ARRAY[1..?] OF REAL;
               VAR B:ARRAY[1..?] OF REAL):REAL;EXTERNAL;
(*------------ NBR COMMUNICATIONS ---------------*)
PROCEDURE SEND2(N:NODE; INDEX:IDX; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
PROCEDURE SEND2ALL(INDEX:IDX; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
PROCEDURE RECV2(N:NODE; INDEX:IDX; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
(*------------FLAG ROUTINES----------------------*)
PROCEDURE FLGEN(F:FLAG);EXTERNAL;
PROCEDURE FLGSET(F:FLAG);EXTERNAL;
PROCEDURE FLGRES(F:FLAG);EXTERNAL;
PROCEDURE BAR(F:FLAG);EXTERNAL;
FUNCTION ANY(F:FLAG):BOOLEAN;EXTERNAL;
(*---------- PROCESSOR IDENTIFICATION -----------*)

PROCEDURE PSCL$$;

CONST
   EDIM=3;
TYPE
   DA7=ARRAY[1..3] OF INTEGER;
   DA8=ARRAY[1..4] OF REAL;
VAR
   PB:REAL; NENTRY:INTEGER; DATA:ARRAY [1..4] OF REAL;
   NEW,IO,NPR,NSEC,NPROB,N,MDIM :INTEGER;
                          ELASTIC :BOOLEAN;
                    ZERO,ONE,TWO :REAL;
   DETI,DET,PINC,TOL1,TOL2,TOL3 :REAL;
            DALL7 :@DA7;  DALL8 :@DA8;
                       CLK1,CLK3 :LONGINT;
PROCEDURE  GLOBAL(N,MDIM,NPROB,NSEC:INTEGER);
```

```
LABEL  10,20;

TYPE
   VECTOR=ARRAY[1..N] OF REAL;
   MATRIX=ARRAY[1..N,1..N] OF REAL;
VAR
   K:MATRIX;  DIS,DI,D,F:VECTOR;
   UV:ARRAY[1..MDIM] OF REAL;
   COEF:ARRAY[1..14] OF REAL;  IDSEC,ITER,TANIDX:INTEGER;
                               COUNT,CNTR,NITER,ISEC:INTEGER;
   READY:ARRAY[1..NPR,1..NPROB] OF BOOLEAN;
                                          ICNT:INTEGER;
(*****************************************************************)

PROCEDURE  MATINV(VAR A:MATRIX; N:INTEGER;  VAR DET:REAL);
(* MATRIX INVERSION PROCEDURE *)
(* METHOD - JOHNSON(1) METHOD *)
(* A IS N X N SYMMETRIC MATRIX*)

    VAR
                  IPV:ARRAY[1..N,1..3] OF INTEGER;
          NSWAP,L,I,ICOL,JCOL,IROW,JROW :INTEGER;
                    TEMP,T,PIV,SWAP,AMAX :REAL;

  BEGIN
     DET:=ONE; TEMP:=A[1,1];
     FOR J:=1 TO N DO IPV[J,3]:=0;
       I:=1;
        REPEAT (* UNTIL DET=0 OR I>N *)
         AMAX:=ZERO;
    FOR J:=1 TO N DO
    BEGIN
      IF IPV[J,3]<>1 THEN
         BEGIN
         FOR KK:=1 TO N DO
          BEGIN
          IF IPV[KK,3]<>1 THEN
              IF CMP(AMAX,ABS95(A[J,KK]))<0 THEN
                 BEGIN
                 IROW:=J; (* SAVE ROW & COLUMN *)
                 ICOL:=KK;
                 AMAX:=ABS95(A[J,KK]);
               END;     (* IF AMAX *)
          END;   (* FOR KK *)
      END;    (* IF IPV[J,3] *)
```

```
   END;      (* FOR J *)

  (* IF PIVOT ELEMENT IS EQ 0 - DET = 0 *)
  IF CMP(AMAX,TOL2)<0 THEN DET:=ZERO

    ELSE
BEGIN
     IPV[ICOL,3]:=IPV[ICOL,3]+1;
     IPV[I,1]:=IROW;
     IPV[I,2]:=ICOL;
   (* INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL *)
     IF IROW<>ICOL THEN
            FOR J:=1 TO N DO
             BEGIN
             SWAP:=A[IROW,J];
             A[IROW,J]:=A[ICOL,J];
             A[ICOL,J]:=SWAP;
             END;    (*     FOR J  1 TO N   *)

(* DIVIDE PIVOT ROW BY PIVOT  ELEMENT *)
PIV:=A[ICOL,ICOL];
DET:=MULT(DET,DIVD(PIV,TEMP));
A[ICOL,ICOL]:=ONE;
  FOR KK:=1 TO N DO
       A[ICOL,KK]:=DIVD(A[ICOL,KK],PIV);
(* REDUCE THE NON-PIVOT ROW BY SUBTRACTION *)
FOR L1:=1 TO N DO
   IF L1<>ICOL THEN    (* AVOID  DIAGONAL *)
    BEGIN
    T:=A[L1,ICOL];
    A[L1,ICOL]:=ZERO;
    FOR KK:=1 TO N DO
      A[L1,KK]:=SUB(A[L1,KK],MULT(A[ICOL,KK],T))
    END;    (*  IF L1 <> ICOL *)
I:=I+1;    (* GO ON TO NEXT *)
END;    (* ELSE IF AMAX<TOL *)
UNTIL (I>N) OR CMP(DET,ZERO)=0;

(* INTERCHANGE THE COLUMNS AND MODIFY DET *)
  NSWAP:=0;     (* THIS IS SIGN FLAG *)
  IF CMP(DET,ZERO)<>0 THEN BEGIN  (* DO ONLY IF DET.NE.0.0 *)
  FOR J:=1 TO N DO
      BEGIN
      L:=N-J+1;
      IF IPV[L,1]<>IPV[L,2] THEN
```

```
          BEGIN
          JROW:=IPV[L,1];
          JCOL:=IPV[L,2];
          NSWAP:=NSWAP+1; (* COUNT SWAPS *)
          FOR KK:=1 TO N DO
            BEGIN
            SWAP:=A[KK,JROW];
            A[KK,JROW]:=A[KK,JCOL];
            A[KK,JCOL]:=SWAP;
            END;  (* FOR KK *)
          END;  (* IF IPV *)
  END;  (* FOR J *)

IF ODD(NSWAP) THEN SWAP:=NEG(ONE)
       ELSE  SWAP:=ONE;
END;  (* IF DET<>0.0 *)
DET:=MULT(DET,SWAP);
END;  (*  MATINV PROCEDURE  *)
(*****************************************************************)
PROCEDURE SOLVE( N:INTEGER; VAR X:MATRIX; VAR SOLNS:VECTOR;
                                          SUMS:VECTOR; VAR DET:REAL);

BEGIN   (* MAIN PROGRAM *)
MATINV(X,N,DET); (* CALL MATINV PROCEDURE *)
IF CMP(DET,ZERO)=0 THEN
    MSGLN('MATRIX IS SINGULAR')
 ELSE
  BEGIN
    FOR J:=1 TO N DO
     BEGIN
       SOLNS[J]:=ZERO;  (* INITIALIZE  *)
       SOLNS[J]:=VDP(N,X[J],SUMS);
     END;  (* FOR  J  *)
  END;  (* ELSE i.e. DET .NE. 0.0 *)
END;

PROCEDURE ASSEMBLE(IDSEC:INTEGER);

VAR   IK:INTEGER;

BEGIN
(*$ NO OPTIMIZE *)
IF IDSEC<=3 THEN
BEGIN
  IF IDSEC=1 THEN
```

```
BEGIN
  K[1,1]:=ADD(COEF[1],COEF[5]);
  K[1,2]:=COEF[3];
  K[1,3]:=SUB(COEF[1],COEF[5]);
  K[1,4]:=COEF[3];
  K[1,N-1]:=NEG(COEF[6]);
  K[1,N-3]:=COEF[6];
  F[1]:=COEF[7];
  K[2,1]:=COEF[8];
  K[2,2]:=ADD(COEF[10],COEF[12]);
  K[2,3]:=COEF[8];
  K[2,4]:=SUB(COEF[10],COEF[12]);
  K[2,N]:=NEG(COEF[13]);
  K[2,N-2]:=COEF[13];
  F[2]:=COEF[14];
END
ELSE
  IF IDSEC=2 THEN
  BEGIN
    K[3,1]:=COEF[5];
    K[3,3]:=SUB(COEF[2],COEF[5]);
    K[3,4]:=COEF[4];
    K[3,5]:=COEF[1];
    K[3,6]:=COEF[6];
    K[3,N-1]:=NEG(COEF[6]);
    K[3,N-3]:=COEF[6];
    F[3]:=COEF[7];
    K[4,2]:=COEF[12];
    K[4,3]:=COEF[9];
    K[4,4]:=SUB(COEF[11],COEF[12]);
    K[4,5]:=COEF[8];
    K[4,6]:=COEF[10];
    K[4,N]:=NEG(COEF[13]);
    K[4,N-2]:=COEF[13];
    F[4]:=COEF[14];
  END
  ELSE
    BEGIN
      K[5,1]:=COEF[5];
      K[5,3]:=SUB(COEF[1],COEF[5]);
      K[5,4]:=COEF[3];
      K[5,5]:=COEF[2];
      K[5,6]:=COEF[4];
      K[5,7]:=COEF[1];
      K[5,8]:=COEF[3];
```

```
          K[5,N-1]:=NEG(COEF[6]);
          K[5,N-3]:=COEF[6];
          F[5]:=COEF[7];
          K[6,2]:=COEF[12];
          K[6,3]:=COEF[8];
          K[6,4]:=SUB(COEF[10],COEF[12]);
          K[6,5]:=COEF[9];
          K[6,6]:=COEF[11];
          K[6,7]:=COEF[8];
          K[6,8]:=COEF[10];
          K[6,N]:=NEG(COEF[13]);
          K[6,N-2]:=COEF[13];
          F[6]:=COEF[14];
        END;        (*  IDSEC=3    *)
END    (* IDSEC<=3  THEN    *)
ELSE
  IF IDSEC>=NSEC-2 THEN
  BEGIN
    IK:=(EDIM-1)*IDSEC;
    IF IDSEC=NSEC-2 THEN
    BEGIN
      K[IK-1,1]:=COEF[5];
      K[IK-1,3]:=NEG(COEF[5]);
      K[IK-1,N-7]:=COEF[1];
      K[IK-1,N-6]:=COEF[3];
      K[IK-1,N-5]:=COEF[2];
      K[IK-1,N-4]:=COEF[4];
      K[IK-1,N-3]:=ADD(COEF[1],COEF[6]);
      K[IK-1,N-2]:=COEF[3];
      K[IK-1,N-1]:=NEG(COEF[6]);
      F[IK-1]:=COEF[7];
      K[IK,N-7]:=COEF[8];
      K[IK,N-6]:=COEF[10];
      K[IK,N-5]:=COEF[9];
      K[IK,N-4]:=COEF[11];
      K[IK,N-3]:=COEF[8];
      K[IK,N-2]:=ADD(COEF[10],COEF[13]);
      K[IK,N]:=NEG(COEF[13]);
      K[IK,2]:=COEF[12];
      K[IK,4]:=NEG(COEF[12]);
      F[IK]:=COEF[14];
    END
    ELSE
      IF IDSEC=NSEC-1 THEN
      BEGIN
```

```
        K[IK-1,N-5]:=COEF[1];
        K[IK-1,N-4]:=COEF[3];
        K[IK-1,N-3]:=ADD(COEF[2],COEF[6]);
        K[IK-1,N-2]:=COEF[4];
        K[IK-1,N-1]:=NEG(COEF[6]);
        K[IK-1,1]:=COEF[5];
        K[IK-1,3]:=NEG(COEF[5]);
        F[IK-1]:=COEF[7];
        K[IK,N-5]:=COEF[8];
        K[IK,N-4]:=COEF[10];
        K[IK,N-3]:=COEF[9];
        K[IK,N-2]:=ADD(COEF[11],COEF[13]);
        K[IK,N]:=NEG(COEF[13]);
        K[IK,2]:=COEF[12];
        K[IK,4]:=NEG(COEF[12]);
        F[IK]:=COEF[14];
      END
      ELSE
        BEGIN
          K[IK-1,N-3]:=ADD(COEF[1],COEF[6]);
          K[IK-1,N-2]:=COEF[3];
          K[IK-1,N-1]:=SUB(COEF[1],COEF[6]);
          K[IK-1,N]:=COEF[3];
          K[IK-1,1]:=COEF[5];
          K[IK-1,3]:=NEG(COEF[5]);
          F[IK-1]:=COEF[7];
          K[IK,N-3]:=COEF[8];
          K[IK,N-2]:=ADD(COEF[10],COEF[13]);
          K[IK,N-1]:=COEF[8];
          K[IK,N]:=SUB(COEF[10],COEF[13]);
          K[IK,2]:=COEF[12];
          K[IK,4]:=NEG(COEF[12]);
          F[IK]:=COEF[14];
        END;
  END     (*  IDSEC>=NSEC-2  THEN    *)
  ELSE
    BEGIN
      IK:=(EDIM-1)*IDSEC;
      K[IK-1,1]:=COEF[5];
      K[IK-1,3]:=NEG(COEF[5]);
      K[IK-1,N-3]:=COEF[6];
      K[IK-1,N-1]:=NEG(COEF[6]);
      K[IK-1,2*(IDSEC-1)-1]:=COEF[1];
      K[IK-1,2*(IDSEC-1)]:=COEF[3];
      K[IK-1,2*IDSEC-1]:=COEF[2];
```

```
        K[IK-1,2*IDSEC]:=COEF[4];
        K[IK-1,2*(IDSEC+1)-1]:=COEF[1];
        K[IK-1,2*(IDSEC+1)]:=COEF[3];
        F[IK-1]:=COEF[7];
        K[IK,2]:=COEF[12];
        K[IK,4]:=NEG(COEF[12]);
        K[IK,N-2]:=COEF[13];
        K[IK,N]:=NEG(COEF[13]);
        K[IK,2*(IDSEC-1)-1]:=COEF[8];
        K[IK,2*(IDSEC-1)]:=COEF[10];
        K[IK,2*IDSEC-1]:=COEF[9];
        K[IK,2*IDSEC]:=COEF[11];
        K[IK,2*(IDSEC+1)-1]:=COEF[8];
        K[IK,2*(IDSEC+1)]:=COEF[10];
        F[IK]:=COEF[14];
    END;    (*   IDSEC  other than (<=3)  (>=NSEC-2)       *)
END;(*     Assemble end       *)

BEGIN
  NENTRY:=0;  ICNT:=0;  CNTR:=0; CLK3:=0;
  ELASTIC:=TRUE;
  FOR I:= 1 TO N DO
    BEGIN
       FOR J:= 1 TO N DO K[I,J]:=ZERO;
       D[I]:=ZERO;
       DI[I]:=ZERO;
       F[I]:=ZERO;
       K[I,I]:=ONE
    END;
  FOR I:=1 TO MDIM DO UV[I]:=ZERO;
REPEAT      (*  SMALL PINC   *)
REPEAT      (*  UNTIL CAPACITY  *)
  PB:=ADD(PB,PINC);
  NITER:=0;
  REPEAT  (* UNTIL  UV  CONVERGES  *)
     DATA[1]:=SUB(D[4],D[2]);
     DATA[2]:=SUB(D[N-2],D[N]);
     DATA[3]:=SUB(D[3],D[1]);
     DATA[4]:=SUB(D[N-3],D[N-1]); (* Terms to set Mbx,Mtx,..etc. *)
     CLK1:=TREAD;SEND2ALL(1,LOCATION(PB),11);CLK3:=CLK3+TREAD-CLK1;
     NEW:=1;
     ISEC:=0;
     FOR I:= 1 TO NPR DO
       BEGIN
         FOR J:= 1 TO MDIM DO UV[J]:=D[ISEC+J];
```

```
    ISEC:=ISEC+MDIM;CLK1:=TREAD;
    SEND2(I,2,LOCATION(UV),2*MDIM);CLK3:=CLK3+TREAD-CLK1
  END;
CLK1:=TREAD;
BAR(2);
CLK3:=CLK3+TREAD-CLK1;
FOR I:=1 TO N DO  FOR J:=1 TO N DO  K[I,J]:=ZERO;
FOR I:=1 TO NPR DO  FOR J:=1 TO NPROB DO READY[I,J]:=FALSE;
COUNT:=0;
WHILE  (COUNT<NSEC)  DO  (* Asynchronous Communication  *)
  FOR I:= 1 TO NPR DO
  FOR J:= 1 TO NPROB DO
  IF NOT READY[I,J] THEN
  BEGIN
    CLK1:=TREAD;
    RECV2(I,J,LOCATION(COEF),31);CLK3:=CLK3+TREAD-CLK1;
    IF ITER>ICNT THEN
      BEGIN
        IF TANIDX=1 THEN GOTO 20;
        READY[I,J]:=TRUE;
        COUNT:=COUNT+1;
        IF IO<=5 THEN MSGI(IDSEC);
        ASSEMBLE(IDSEC)
      END;
   END;
IF IO<=3 AND ANY(5) THEN
 BEGIN
    NXTLN;
    FOR I:=1 TO N DO  BEGIN
    FOR J:=1 TO N DO  BEGIN MSGR(K[I,J]);MSG('    ')  END;
                                    ENDLN(2);            END;
 END;
IF NENTRY=0 THEN
BEGIN
  SOLVE(N,K,D,F,DET);
  DETI:=DET;  DET:=DIVD(DET,DETI);
  NENTRY:=1;
  FOR I:=1 TO N DO  DI[I]:=F[I];
END
ELSE
  BEGIN
    SOLVE(N,K,D,F,DET);
    DET:=DIVD(DET,DETI);
    IF IO<=4 THEN BEGIN NXTLN;MSGR(DET);NXTLN; END;
    IF CMP(DET,TOL2)<=0 THEN GOTO 20;
```

```
          CNTR:=0;
          FOR I:=1 TO N DO
          BEGIN
            IF CMP(ABS95(SUB(F[I],DI[I])),TOL1)<=0 THEN CNTR:=CNTR+1;
          END;
        END;
  IF (CNTR<>N) THEN FOR I:=1 TO N DO DI[I]:=F[I];
  IF NOT ANY(5) THEN NEW:=0 ELSE IF CNTR=N THEN NEW:=0 ELSE NEW:=1;
  CLK1:=TREAD;SEND2ALL(3,LOCATION(NEW),1);BAR(7);CLK3:=CLK3+TREAD-CLK1;
  ICNT:=ICNT+1;
  NITER:=NITER+1;
  UNTIL (CNTR=N) OR (NITER=8) ;
IF NITER>=8 THEN BEGIN MSG('NO GLOBAL CONVERGENCE'); GOTO 20  END;
IF IO<=5 THEN
BEGIN
   NXTLN;MSG('AXIAL LOAD=');MSGR(PB);
   NXTLN;MSGLN('DISPLACEMENT VECTOR');
   FOR I:=1 TO N DO BEGIN MSGR(D[I]);MSG('   ');END;NXTLN;
END;
FOR I:=1 TO N DO DIS[I]:=D[I];
IF IO>=7 THEN  BEGIN MSG('AXIAL LOAD=');MSGR(PB);NXTLN; END;
MSG('Determinant of Global Stiffness Matrix =');MSGR(DET);NXTLN;
UNTIL CMP(DET,TOL2)<=0;
20: ;
IF TANIDX=1 OR CMP(DET,TOL2)<=0  THEN ICNT:=ICNT+1;
IF NITER<8 THEN
   IF NEW=1 THEN BEGIN CLK1:=TREAD;
                       SEND2ALL(3,LOCATION(NEW),1);BAR(7);
                       CLK3:=CLK3+TREAD-CLK1;  END;
FOR I:=1 TO N DO D[I]:=DIS[I];
PB:=SUB(PB,PINC);    (* Retain nonincremented PB  *)
PINC:=DIVD(PINC,TWO);
UNTIL CMP(PINC,TOL3)<=0;
10: FLGSET(6);
BAR(2);
NXTLN;
END;     (* PROCEDURE  GLOBAL     *)

BEGIN      (* MAIN PROGRAM    *)
FLGEN(2);FLGEN(5);FLGEN(6);FLGEN(7);
FLGRES(2);FLGRES(5);FLGRES(6);FLGRES(7);BAR(SYSFLAG);
ZERO:=CV9512(0.0); ONE:=CV9512(1.0); TWO:=CV9512(2.0);
DALL7::ADDR:=DAPTR(7);  DALL8::ADDR:=DAPTR(8);
NSEC:=DALL7@[1];  NPR:=DALL7@[2];  IO:=DALL7@[3];
TOL1:=CV9512(DALL8@[1]); TOL2:=CV9512(DALL8@[2]);
```

```
TOL3:=CV9512(DALL8@[3]);
PINC:=CV9512(DALL8@[4]); PB:=ZERO;
TSTART(1);
MSG('CROSS SECTIONS=');MSGI(NSEC);
MSG('      PROCESSORS=');MSGI(NPR+1); NXTLN;
NPROB:=NSEC DIV NPR;
MDIM:=NPROB*(EDIM-1);
N:=NSEC*(EDIM-1);
GLOBAL(N,MDIM,NPROB,NSEC);
TSTOP;
ENDLN(2);MSG('PROCESSING TIME =');MSGL(TREAD);NXTLN;
NXTLN;MSG('EXECUTION  TIME =');MSGL(TREAD-CLK3);NXTLN;
END;

BEGIN (*$NO OBJECT*)
END.
```

```
(*$WIDELIST,NO ASSERTS,NO TRACEBACK*)
(* $GLOBALOPT *)

PROGRAM TANGENT;
CONST   MAXIDX=255;   (*MAX NBR I/O INDEX TAG *)
        MAXREC=255;   (*MAX REC LENGTH FOR NBR I/O *)
        MAXNODE=36;   (*MAX NODE NUMBERS *)
        MAXDA=31;     (*MAX DATA AREA NUMBER *)
        MAXINT=32767;(*MAX INTEGER *)
        SYSFLAG=1;    (*SYSTEM FLAG *)
TYPE    NODE=1..MAXNODE;
        IDX=1..MAXIDX;
        RECLEN=1..MAXREC;
        DANUM=1..MAXDA;
        FLAG=0..7;
        ADDR=INTEGER;
        POSINT=1..MAXINT;

(* PASLIB EXTERNAL PROCEDURES AND FUNCTIONS FOLLOW *)
(*-------------------------------------------------*)
(*-------------- TIMER PROCEDURES -----------------*)
FUNCTION XTIME:LONGINT;EXTERNAL;
PROCEDURE TSTART(T:POSINT);EXTERNAL;
FUNCTION TREAD:LONGINT;EXTERNAL;
PROCEDURE TSTOP;EXTERNAL;
(*-------  TEXT OUTPUT PROCEDURES  ---------------*)
PROCEDURE MSG(STRING:PACKED ARRAY[1..?] OF CHAR);EXTERNAL;
PROCEDURE MSGLN(STRING:PACKED ARRAY[1..?] OF CHAR);EXTERNAL;
PROCEDURE NXTLN;EXTERNAL;
PROCEDURE MSGI(I:INTEGER);EXTERNAL;
PROCEDURE MSGR(X:REAL);EXTERNAL;
PROCEDURE MSGL(I:LONGINT);EXTERNAL;
PROCEDURE ENDLN(N:POSINT);EXTERNAL;
(*                                                 *)
(*------------  INTERACTIVE INPUT -----------------*)
(*                                                 *)
PROCEDURE QUERY;EXTERNAL;
FUNCTION RDI:INTEGER;EXTERNAL;
FUNCTION RDR:REAL;EXTERNAL;
(*                                                 *)
(*--------------- DATA AREAS ----------------------*)
FUNCTION DAPTR(DA:DANUM):ADDR;EXTERNAL;
(*                                                 *)
(*----------- FLOATING OPERATIONS -----------------*)
FUNCTION ADD(X,Y:REAL):REAL;EXTERNAL;
```

```
FUNCTION SUB(X,Y:REAL):REAL;EXTERNAL;
FUNCTION MULT(X,Y:REAL):REAL;EXTERNAL;
FUNCTION DIVD(X,Y:REAL):REAL;EXTERNAL;
FUNCTION NEG(X:REAL):REAL;EXTERNAL;
FUNCTION ABS95(X:REAL):REAL;EXTERNAL;
FUNCTION CMP(X,Y:REAL):REAL;EXTERNAL;
FUNCTION SQRT95(X:REAL):REAL;EXTERNAL;
(*                                                    *)
(*---------- FLOATING POINT CONSTANTS ------------*)
FUNCTION MAX95:REAL;EXTERNAL;
FUNCTION MIN95:REAL;EXTERNAL;
(*---------- FLOATING POINT CONVERSIONS ----------*)
FUNCTION IFIX(X:REAL):INTEGER;EXTERNAL;
FUNCTION FLOATI(I:INTEGER):REAL;EXTERNAL;
FUNCTION CV9512(X:REAL):REAL;EXTERNAL;
FUNCTION VDP(N:POSINT; VAR A:ARRAY[1..?] OF REAL;
               VAR B:ARRAY[1..?] OF REAL):REAL;EXTERNAL;
FUNCTION SINE(X:REAL):REAL;EXTERNAL;
(*------------- NBR COMMUNICATIONS ---------------*)
PROCEDURE SEND2(N:NODE; INDEX:IDX; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
PROCEDURE SEND2ALL(INDEX:IDX; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
PROCEDURE RECV(N:NODE; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
PROCEDURE RECV2(N:NODE; INDEX:IDX; LOC:ADDR; NWORDS:RECLEN);EXTERNAL;
(*-------------FLAG ROUTINES-----------------------*)
PROCEDURE FLGEN(F:FLAG);EXTERNAL;
PROCEDURE FLGSET(F:FLAG);EXTERNAL;
PROCEDURE FLGRES(F:FLAG);EXTERNAL;
FUNCTION ANY(F:FLAG):BOOLEAN;EXTERNAL;
PROCEDURE BAR(F:FLAG);EXTERNAL;
(*----------- PROCESSOR IDENTIFICATION -----------*)
FUNCTION PSELF:NODE;EXTERNAL;
FUNCTION LSELF:NODE;EXTERNAL;

PROCEDURE PSCL$$;

CONST
      EDIM=3;
TYPE
     TANDIM=1..EDIM;
     TANMAT=ARRAY[TANDIM,TANDIM] OF REAL;
     VECTOR2=ARRAY[TANDIM] OF REAL;
     DA4=ARRAY[1..9] OF INTEGER;
     DA5=ARRAY[1..16] OF REAL;

VAR
```

```
      S:TANMAT;    EL:BOOLEAN;
      PB:REAL; NENTRY:INTEGER; DATA:ARRAY[1..4] OF REAL; ZBAR:REAL;
                                  NEW,IO,MDIM,NDIM,NSEC,NPR :INTEGER;
                                                  CLK8,CLK9 :LONGINT;
                                  STRES,LOAD,LINC,LOADB,DEL :VECTOR2;
                                    PP,PR,MXP,MYP,MXRE,MYRE :REAL;
                           ZERO,ONE,TWO,FOUR,TWLVE,SIXTN,PI :REAL;
      AR,ARND,IX,IXND,IY,IYND,ZX,ZXND,ZY,ZYND,RXND,RYND :REAL;
             EBW,EBT,EDW,EAB,EAD,EDT,XRTB,XRTD,YRCB,YRCD :REAL;
   IDX1,IDX2,IPR,NPROB,NCNTR,NS,NB,ND,NTB,NTD,CNTR,CNT2 :INTEGER;
                 B,D,T,E,SIGY,SIGRC,SIGRT,SIGRTM,SIGR,ER :REAL;
                                                 DET,RC,RT :REAL;
                   UINT,VINT,LENGTH,KBX,KBY,KTX,KTY,SEGL :REAL;
    (*   Spring constants       *) CBX,CBY,CTX,CTY,C1,C2 :REAL;
                                        DALL4:@DA4; DALL5 :@DA5;
                                     TOL1,TOL2,TOL3,TOL4 :REAL;
(* SIGRTM MODIFIED TO a/c FOR c/c CALCULATIONS  *)
PROCEDURE PROPERTY;

VAR
    B_2T,B_T,D_2T,D_T,BSQ,BCU,TSQ,TCU,DSQ,DCU:REAL;
    FNB,FNTB,FND,FNTD:REAL;

BEGIN
(*                                                                    *)
(*-------------- CALCULATION OF GEOMETRIC PROPERTIES ---------------*)

(*----------------- CALCULATION OF AREA & AREA ND -------------------*)
AR:=ADD(MULT(TWO,MULT(D,T)),MULT(TWO,MULT(T,SUB(B,MULT(T,TWO)))));
ARND:=MULT(FOUR,DIVD(AR,MULT(B,D)));
(*MSG('AREA OF CROSS-SECTION  AR=');
MSGR(AR);MSGLN('  IN**2');
MSG('NON-DIMENSIONAL AREA  ARND=');
MSGR(ARND);ENDLN(2);*)
B_2T:=SUB(B,MULT(TWO,T));
B_T:=SUB(B,T);
D_2T:=SUB(D,MULT(TWO,T));
D_T:=SUB(D,T);
TSQ:=MULT(T,T);
TCU:=MULT(TSQ,T);
BSQ:=MULT(B,B);
BCU:=MULT(B,BSQ);
DSQ:=MULT(D,D);
DCU:=MULT(D,DSQ);
```

```
(*------------------ CALCULATION OF IX & IXND ---------------------*)
IX:=DIVD(MULT(B_2T,MULT(T,MULT(D_T,D_T))),FOUR);
IX:=ADD(IX,MULT(B_2T,DIVD(TCU,TWLVE)));
IX:=ADD(IX,MULT(T,DIVD(DCU,TWLVE)));
IX:=MULT(IX,TWO);
(*MSG('MOMENT OF INERTIA  IX= ');
MSGR(IX);MSGLN('  IN**4'); *)
IXND:=MULT(B,DCU);
IXND:=MULT(SIXTN,DIVD(IX,IXND));
(*MSG('NON-DIMENSIONAL MOMENT OF INERTIA  IXND= ');
MSGR(IXND);ENDLN(2);*)
RXND:=SQRT95(DIVD(IXND,ARND));

(*------------------ CALCULATION OF IY & IYND ---------------------*)
IY:=MULT(D_2T,MULT(T,MULT(B_T,DIVD(B_T,FOUR))));
IY:=ADD(IY,MULT(D_2T,DIVD(TCU,TWLVE)));
IY:=ADD(IY,MULT(BCU,DIVD(T,TWLVE)));
IY:=MULT(TWO,IY);
IYND:=MULT(SIXTN,DIVD(IY,MULT(BCU,D)));
(*MSG('MOMENT OF INERTIA  IY= ');
MSGR(IY);MSGLN('  IN**4');
MSG('NON-DIMENSIONAL MOMENT OF INERTIA  IYND= ');
MSGR(IYND);ENDLN(2); *)
RYND:=SQRT95(DIVD(IYND,ARND));

(*---------------- PLASTIC MODULI ZX,ZXND,ZY,ZYND ------------------*)
ZX:=ADD(MULT(B,MULT(T,DIVD(D_T,TWO))),MULT(T,MULT(D_2T,
                                                  DIVD(D_2T,FOUR))));
ZX:=MULT(TWO,ZX);
(*MSG('PLASTIC MODULUS  ZX= ');
MSGR(ZX);MSGLN('  IN**3');*)
ZXND:=MULT(FOUR,MULT(TWO,DIVD(ZX,MULT(B,DSQ))));
(*MSG('NON-DIMENSIONAL PLASTIC MODULUS  ZXND=');
MSGR(ZXND);ENDLN(2);*)
ZY:=ADD(MULT(D,MULT(T,DIVD(B_T,TWO))),
                                    MULT(T,MULT(B_2T,DIVD(B_2T,FOUR))));
ZY:=MULT(TWO,ZY);
(*MSG('PLASTIC MODULUS  ZY= ');
MSGR(ZY);MSGLN('  IN**3');*)
ZYND:=MULT(FOUR,MULT(TWO,DIVD(ZY,MULT(D,BSQ))));
(*MSG('NON-DIMENSIONAL PLASTIC MODULUS  ZYND= ');
MSGR(ZYND);ENDLN(2);*)

(*------------------ ELEMENTAL PROPERTIES ---------------------*)
```

```
(*---------- ALL QUANTITIES ARE NON-DIMENSIONAL ----------*)
FNB:=FLOATI(NB);
FNTB:=FLOATI(NTB);
FND:=FLOATI(ND);
FNTD:=FLOATI(NTD);
EBW:=DIVD(TWO,FNB);
EBT:=MULT(TWO,DIVD(T,MULT(D,FNTB)));
EDW:=MULT(TWO,DIVD(T,MULT(B,FNTD)));
EDT:=DIVD(D_2T,FND);EDT:=DIVD(MULT(TWO,EDT),D);
(*MSGLN('MAJOR AXIS - HORIZONTAL');
MSGLN('ELEMENTAL PROPERTIES - NONDIMENSIONAL');
MSGLN('-----------------------------------');
MSG('WIDTH OF ELEMENT IN FLANGES  EBW= ');
MSGR(EBW);NXTLN;
MSG('DEPTH OF ELEMENT IN FLANGES  EBT= ');
MSGR(EBT);NXTLN;
MSG('WIDTH OF ELEMENT IN WEB      EDW= ');
MSGR(EDW);NXTLN;
MSG('DEPTH OF ELEMENT IN WEB      EDT= ');
MSGR(EDT);ENDLN(3);*)
IF CMP(RT,ZERO)=0
THEN
   BEGIN
     XRTB:=ZERO;
     XRTD:=ZERO;
     YRCB:=ZERO;
     YRCD:=ZERO;
   END
ELSE
  BEGIN
    XRTB:=ADD(B,D_2T);
    XRTB:=MULT(MULT(RC,RT),XRTB);
    XRTB:=DIVD(XRTB,MULT(MULT(TWO,ADD(RC,RT)),ADD(RC,RT)));
    XRTD:=MULT(TWO,DIVD(XRTB,D));
    XRTB:=MULT(TWO,DIVD(XRTB,B));
    YRCB:=MULT(DIVD(RC,RT),XRTB);
    YRCD:=MULT(DIVD(RC,RT),XRTD);
    SIGRTM:=DIVD(MULT(RT,T),MULT(D,XRTD));
    SIGRTM:=ADD(RT,SIGRTM);
(*  MSG('SIGRTM= ');MSGR(SIGRTM);NXTLN;
    MSG('SIGRC= ');MSGR(SIGRC);ENDLN(3);  *)
  END;
(*MSGLN('RESIDUAL STRESS DISTRIBUTION DIMENSIONS');
MSG('IN FLANGES  XRTB= ');MSGR(XRTB);MSG('  YRCB= ');MSGR(YRCB);NXTLN;
MSG('IN WEB      XRTD= ');MSGR(XRTD);MSG('  YRCD= ');MSGR(YRCD);NXTLN;*)
```

```
(* CALCULATE CONSTANTS *)
SEGL:=FLOATI(NSEC-1);
SEGL:=DIVD(LENGTH,SEGL);
C1:=MULT(DSQ,DIVD(E,SIGY));
C1:=DIVD(C1,MULT(MULT(SEGL,SEGL),FOUR)); (* Relates phi-ubar,vbar *)
C2:=MULT(BSQ,DIVD(E,SIGY));
C2:=DIVD(C2,MULT(MULT(SEGL,SEGL),FOUR));
(* CBX,CBY,CTX,CTY - Constants of Restrints *)
CBX:=MULT(MULT(TWO,FOUR),MULT(IX,SIGY));
CBX:=MULT(CBX,SEGL);     CBY:=CBX;
CBX:=DIVD(DSQ,CBX);
CBY:=DIVD(BSQ,CBY);
CTX:=MULT(CBX,KTX);
CBX:=MULT(CBX,KBX);
CTY:=MULT(CBY,KTY);
CBY:=MULT(CBY,KBY);
NXTLN;MSG('CBX,CTX,CBY,CTY,C1,C2   are ');
MSGR(CBX);MSGR(CTX);MSGR(CBY);MSGR(CTY);MSGR(C1);MSGR(C2);NXTLN;
END;    (*---     PROCEDURE PROPERTIES ---*)

(*                                                                    *)
PROCEDURE ROUTINE(N,M:INTEGER);

LABEL 10;

VAR
       COEF:ARRAY[1..14] OF REAL; IDSEC,ITER,TANIDX:INTEGER;
       STORED,STOREL:ARRAY[1..N] OF REAL;
         VCTRD,VCTRL:ARRAY[1..N] OF REAL;
                  UV:ARRAY[1..M] OF REAL;
               UO,VO:REAL;
                 ITR:ARRAY[1..NPR,1..NPROB] OF INTEGER;
(*-------------- PROCEDURE TO CALCULATE RESIDUAL STRESSES ----------------*)
PROCEDURE RESY(VAR SIGR,EPSR:REAL; Y:REAL);
VAR
  YD,FNB,FNTB,XRD:REAL;
BEGIN
 XRD:=ADD(XRTD,DIVD(T,D)); (* a/c FOR CORNER DEDUCTION *)
 YD:=ABS95(Y);
  IF CMP(YD,SUB(ONE,ADD(XRD,YRCD)))<=0 THEN
    BEGIN
      SIGR:=SIGRC;
      EPSR:=SIGR;
    END     (*  IF - THEN  *)
  ELSE
```

```
        BEGIN
          FNB:=SUB(ONE,YD);
          FNTB:=ABS95(SIGRC);
          IF CMP(RT,ZERO) <>0
          THEN
            BEGIN
              SIGR:=DIVD(ADD(FNTB,SIGRTM),ADD(XRD,YRCD));
              SIGR:=SUB(SIGRTM,MULT(SIGR,FNB));
            END
          ELSE   SIGR:=ZERO;
          EPSR:=SIGR;
        END;    (*  IF - ELSE  *)
(*      MSG('RESY');MSGR(SIGR);MSGR(EPSR);NXTLN;        *)

END;  (*    --- PROCEDURE END ---   *)

PROCEDURE RESX(VAR SIGR,EPSR:REAL; X:REAL);

VAR
 XRB,XB,TT,T1:REAL;
BEGIN
 XRB:=ADD(XRTB,DIVD(T,B));  (* a/c FOR CORNER  *)
 XB:=ABS95(X);
 IF CMP(XB,SUB(ONE,ADD(XRB,YRCB)))<=0 THEN
   BEGIN
     SIGR:=SIGRC;
     EPSR:=SIGR;
   END    (*  IF - THEN  *)
  ELSE
     BEGIN
       TT:=SUB(ONE,XB);
       T1:=ABS95(SIGRC);
       IF CMP(RT,ZERO) <>0
       THEN
         BEGIN
           SIGR:=DIVD(ADD(T1,SIGRTM),ADD(XRB,YRCB));
           SIGR:=SUB(SIGRTM,MULT(TT,SIGR));
         END
       ELSE   SIGR:=ZERO;
       EPSR:=SIGR;
     END;    (*  IF - ELSE  *)
(*   MSG('RESX');MSGR(SIGR);MSGR(EPSR);NXTLN;       *)
END;  (*  -----  PROCEDURE END  ----  *)
PROCEDURE CHECK(VAR EL:BOOLEAN);FORWARD;
PROCEDURE ESTIFF(VAR S:TANMAT; VAR EL:BOOLEAN;  DEL:VECTOR2;
```

```
      ARND,IXND,IYND:REAL; VAR PP,PR,MXP,MYP,MXRE,MYRE:REAL);FORWARD;
PROCEDURE SOLVE(X:TANMAT; SUMS:VECTOR2; VAR SOLNS:VECTOR2;
                                                VAR DET:REAL);FORWARD;
PROCEDURE TANGNT(LD,LOADB:VECTOR2;  VAR DEL:VECTOR2; VAR S:TANMAT;
                                      VAR CNT2:INTEGER;  UO,VO:REAL);
LABEL 10;
VAR
          LD1,SOLNS,DEL1:VECTOR2;
                     CNT:INTEGER;
            CLK1,CLK2:LONGINT;
BEGIN
  CNT2:=0;
  CHECK(EL);
  IF (EL) THEN
    BEGIN
      SOLVE(S,LOADB,SOLNS,DET);
      FOR I:=1 TO EDIM DO DEL[I]:=SOLNS[I];
    END  (* --  IF - THEN -- *)
   ELSE
     BEGIN
      FOR I:=1 TO EDIM DO DEL1[I]:=DEL[I];
      REPEAT  (* --  UNTIL LD[1,2,&3] < TOL  -- *)
        CNT:=0;
        CNT2:=CNT2+1;
        FOR I:=1 TO EDIM DO   LD[I]:=SUB(LOADB[I],LD[I]);
        FOR I:=1 TO EDIM DO
            IF  CMP(ABS95(LD[I]),TOL1)<=0 THEN CNT:=CNT+1;
        IF  CNT<EDIM THEN
        BEGIN
          SOLVE(S,LD,SOLNS,DET);
          IF CMP(DET,TOL2)<=0 THEN GOTO 10;
          FOR I:=1 TO EDIM DO   DEL1[I]:=ADD(DEL1[I],SOLNS[I]);
          (*---- CALCULATE STRESSES  F1 --- *)
          ESTIFF(S,EL,DEL1,ARND,IXND,IYND,PP,PR,MXP,MYP,MXRE,MYRE);
          FOR I:=1 TO EDIM  DO  LD1[I]:=VDP(EDIM,S[I],DEL1);
          LD1[1]:=ADD(LD1[1],ADD(PP,PR));
          LD1[2]:=ADD(LD1[2],ADD(MXP,MXRE));
          LD1[3]:=SUB(LD1[3],ADD(MYP,MYRE));
          FOR I:=1 TO EDIM DO LD[I]:=LD1[I];
        END;   (* ----- ELSE  CNVRG<>TRUE  ----- *)
        IF CNT=EDIM THEN
        FOR I:=1 TO EDIM DO  DEL[I]:=DEL1[I];
        IF CNT2=15 THEN MSGLN('NO CONVERGENCE IN 15 ITERATIONS')
      UNTIL  (CNT=EDIM) OR (CNT2>=15)
      END;  (* --- ELSE --- *)
```

```
 (*    MSGLN('  CONVERGED  VALUES OF LOAD AND DISPLACEMENT ');
       MSGLN('-----------------------------------------------');
       MSG('         ');MSG('LOAD VECTOR');
       MSG('          ');MSGLN('DISPLACEMENT');
       FOR I:=1 TO EDIM DO
        BEGIN
         NXTLN;MSGI(I);MSG('   ');MSGR(LOADB[I]);MSG('    ');MSGR(DEL[I]);
        END;                *)
10: END;   (* --- PROCEDURE TANGNT ---- *)

(* ---------------------- PROCEDURE ESTIFF ------------------------- *)
PROCEDURE ESTIFF;    (*  --(VAR S:TANMAT; VAR EL:BOOLEAN;
              ARND,IXND,IYND:REAL; VAR PP,PR,MXP,MYP,MXRE,MYRE:REAL)- *)
VAR
                                        CNT1,CNT2,MB,MD:INTEGER;
      SUM,ASUM,BSUM,CSUM,DSUM,ESUM,TX,TY,X,Y,TMP:REAL;
                                          DEL2,DEL3,B:REAL;
PROCEDURE STIFF;
(*$ NO OPTIMIZE *)
       BEGIN
          S[1,1]:=DIVD(SUM,ARND);
          S[1,2]:=DIVD(ASUM,ARND);
          PP:=DIVD(PP,ARND);
          PR:=DIVD(PR,ARND);
          MXP:=DIVD(MXP,IXND);
          MYP:=DIVD(MYP,IYND);
          MXRE:=DIVD(MXRE,IXND);
          MYRE:=DIVD(MYRE,IYND);
          S[1,3]:=NEG(DIVD(BSUM,ARND));
          S[3,1]:=NEG(DIVD(BSUM,IYND));
          S[3,2]:=NEG(DIVD(CSUM,IYND));
          S[3,3]:=DIVD(DSUM,IYND);
          S[2,3]:=NEG(DIVD(CSUM,IXND));
          S[2,2]:=DIVD(ESUM,IXND);
          S[2,1]:=DIVD(ASUM,IXND);
       END;
PROCEDURE STIFCAL(MB,NTB,IDX:INTEGER;
                                  EBT,EBW,EAB,DEL2,DEL3:REAL);
   LABEL  20,30;

   BEGIN
(*    IDX=0  USES RESX     IDX=1 USES  RESY       *)
        CNT1:=1;
   30:  FOR I:=1 TO  NTB DO
          BEGIN
```

```
        Y:=FLOATI(2*I-1);
        Y:=SUB(ONE,MULT(Y,DIVD(EBT,TWO)));
        IF CNT1>=2  THEN Y:=NEG(Y);
        TY:=MULT(Y,DEL2);
        CNT2:=1;
20:     FOR J:=1 TO MB DO
          BEGIN
            X:=FLOATI(2*J-1);
            X:=MULT(X,DIVD(EBW,TWO));
            IF CNT2>=2 THEN X:=NEG(X);
            IF IDX=0 THEN RESX(SIGR,ER,X)
                     ELSE RESY(SIGR,ER,X);
            TX:=MULT(DEL3,X);
            IF IDX=0 THEN  TX:=ADD(SUB(DEL[1],TX),ADD(TY,ER))
                     ELSE  TX:=ADD(SUB(DEL[1],TY),ADD(TX,ER));
            IF CMP(ABS95(TX),ONE)>=0  THEN
              BEGIN
                IF CMP(TX,ZERO)<0
                THEN
                  BEGIN
                  PP:=ADD(PP,NEG(EAB));
                  IF IDX=0 THEN
                  BEGIN
                  MXP:=ADD(MXP,MULT(Y,NEG(EAB)));
                  MYP:=ADD(MYP,MULT(X,NEG(EAB)));
                  END
                  ELSE BEGIN
                       MXP:=ADD(MXP,MULT(X,NEG(EAB)));
                       MYP:=ADD(MYP,MULT(Y,NEG(EAB)));
                       END;
                  END
                ELSE
                 BEGIN
                  PP:=ADD(PP,EAB);
                  IF IDX=0 THEN
                  BEGIN
                  MXP:=ADD(MXP,MULT(Y,EAB));
                  MYP:=ADD(MYP,MULT(X,EAB));
                  END
                  ELSE BEGIN
                       MXP:=ADD(MXP,MULT(X,EAB));
                       MYP:=ADD(MYP,MULT(Y,EAB));
                       END;
                 END;    (* -- IF ELSE  -- *)
              END   (* IF TX>1.0  *)
```

```
                    ELSE
                      BEGIN
                        SUM:=ADD(SUM,EAB);
                        PR:=ADD(PR,MULT(SIGR,EAB));
                        IF IDX=0 THEN
                        BEGIN
                        ASUM:=ADD(ASUM,MULT(Y,EAB));
                        BSUM:=ADD(BSUM,MULT(X,EAB));
                        CSUM:=ADD(CSUM,MULT(MULT(X,Y),EAB));
                        DSUM:=ADD(DSUM,MULT(MULT(X,X),EAB));
                        ESUM:=ADD(ESUM,MULT(MULT(Y,Y),EAB));
                        MXRE:=ADD(MXRE,MULT(SIGR,MULT(Y,EAB)));
                        MYRE:=ADD(MYRE,MULT(SIGR,MULT(X,EAB)));
                        END
                        ELSE BEGIN
                              ASUM:=ADD(ASUM,MULT(X,EAB));
                              BSUM:=ADD(BSUM,MULT(Y,EAB));
                              CSUM:=ADD(CSUM,MULT(MULT(X,Y),EAB));
                              DSUM:=ADD(DSUM,MULT(MULT(Y,Y),EAB));
                              ESUM:=ADD(ESUM,MULT(MULT(X,X),EAB));
                              MXRE:=ADD(MXRE,MULT(SIGR,MULT(X,EAB)));
                              MYRE:=ADD(MYRE,MULT(SIGR,MULT(Y,EAB)));
                              END;
                          END; (* -- ELSE -- *)
                      END;  (* --- FOR J --- *)
                    CNT2:=CNT2+1;
                    IF CNT2<=2 THEN GOTO 20;
                  END;  (* --- FOR I --- *)
                CNT1:=CNT1+1;
                IF CNT1<=2 THEN  GOTO 30;
        END;
    BEGIN
      FOR I:=1 TO EDIM DO
        BEGIN
          FOR J:=1 TO EDIM DO  S[I,J]:=ZERO
        END;
        CHECK(EL); (* --- CHECK YIELDING OF CROSS-SECTION --- *)
      IF NOT (EL)  THEN
          BEGIN
            MB:=NB DIV 2;
            MD:=ND DIV 2;
            PR:=ZERO;
            PP:=PR;
            MXP:=PP;
            MYP:=PP;
```

```
          MXRE:=PP;
          MYRE:=PP;

(*    note: P -VE, MX +VE, and MY -VE
            phiY BE POS. VALUE & phiX BE POS. VALUE      *)
          EAB:=MULT(EBW,EBT);
          EAD:=MULT(EDW,EDT);
          SUM:=ZERO;
          ASUM:=SUM;
          BSUM:=SUM;
          CSUM:=SUM;
          DSUM:=SUM;
          ESUM:=SUM;
          STIFCAL(MB,NTB,0,EBT,EBW,EAB,DEL[2],DEL[3]);
          STIFCAL(MD,NTD,1,EDW,EDT,EAD,DEL[3],DEL[2]);
          STIFF;
        END
        ELSE (* IF ELASTIC  *)
        BEGIN
          FOR I:=1 TO EDIM DO
          BEGIN
            FOR J:=1 TO EDIM DO
            BEGIN
              IF I<>J THEN S[I,J]:=ZERO
                      ELSE S[I,J]:=ONE;
            END;
          END;
          PR:=ZERO;
          PP:=PR;
          MXP:=PP;
          MYP:=PP;
          MXRE:=PP;
          MYRE:=PP;
        END; (* -- ELSE --  *)
END;   (* -- PROCEDURE ESTIFF -- *)

(* ------ PROCEDURE TO CHECK YIELDING OF CROSS-SECTION  -------- *)
(*                                                               *)

PROCEDURE CHECK;   (* --(VAR EL:BOOLEAN)-- *)

VAR
  X,Y,XRB,XRD:REAL;
  I:INTEGER;
```

```
BEGIN
  XRB:=ADD(XRTB,DIVD(T,B));
  XRD:=ADD(XRTD,DIVD(T,D));
  X:=ADD(XRB,YRCB);
  X:=SUB(ONE,X);
  X:=DIVD(X,EBW);
  I:=IFIX(X);
  I:=2*(I-1)+1;
  X:=FLOATI(I);
  X:=MULT(X,DIVD(EBW,TWO));
  IF CMP(DEL[3],ZERO)<0 THEN  X:=NEG(X);
  RESX(SIGR,ER,X);
  X:=MULT(X,DEL[3]);
  Y:=SUB(ONE,DIVD(EBT,TWO));
  IF CMP(DEL[2],ZERO)>0 THEN Y:=NEG(Y);
  Y:=MULT(Y,DEL[2]);
  X:=ADD(SUB(DEL[1],X),ADD(Y,ER));
  IF CMP(ABS95(X),ONE) >=0
    THEN  EL:=FALSE
    ELSE
    BEGIN
       Y:=ADD(XRD,YRCD);
       Y:=SUB(ONE,Y);
       Y:=DIVD(Y,EDT);
       I:=IFIX(Y);
       I:=2*(I-1)+1;
       Y:=FLOATI(I);
       Y:=MULT(Y,DIVD(EDT,TWO));
       IF CMP(DEL[2],ZERO)>0 THEN Y:=NEG(Y);
       RESY(SIGR,ER,Y);
       Y:=MULT(Y,DEL[2]);
       X:=SUB(ONE,DIVD(EDW,TWO));
       IF CMP(DEL[3],ZERO)<0 THEN X:=NEG(X);
       X:=MULT(X,DEL[3]);
       Y:=ADD(SUB(DEL[1],X),ADD(Y,ER));
       IF CMP(ABS95(Y),ONE) >=0
       THEN   EL:=FALSE
       ELSE
       BEGIN
          X:=SUB(ONE,DIVD(EBW,TWO));
          IF CMP(DEL[3],ZERO)>0 THEN X:=NEG(X);
          Y:=SUB(ONE,DIVD(EDT,TWO));
          IF CMP(DEL[2],ZERO)<0 THEN Y:=NEG(Y);
          X:=MULT(X,DEL[3]);
          Y:=MULT(Y,DEL[2]);
```

C-2

```
            X:=ADD(SUB(DEL[1],X),ADD(Y,SIGRT));
            IF CMP(ABS95(X),ONE) >=0
            THEN  EL:=FALSE
            ELSE  EL:=TRUE;
        END;    (* --  ELSE --*)
    END;   (* -- ELSE --*)
IF NOT EL THEN   FLGSET(5);
END;   (* --- PROCEDURE --- *)

(* MATRIX INVERSION SUITABLE FOR FEM *)
(*****************************************************************)

PROCEDURE  MATINV(VAR A:TANMAT; N:TANDIM);
(* MATRIX INVERSION PROCEDURE *)
(* METHOD - JOHNSON(1) METHOD *)
(* A IS N X N SYMMETRIC MATRIX*)

    VAR
         NSWAP:INTEGER; IPV:ARRAY[TANDIM,1..3] OF INTEGER;
         L,I,ICOL,JCOL,IROW,JROW:TANDIM;
         T,PIV,SWAP,AMAX:REAL;

 BEGIN
   DET:=ONE;
   FOR J:=1 TO N DO IPV[J,3]:=0;
   I:=1;
   REPEAT (* UNTIL DET=0 OR I>N *)
     AMAX:=ZERO;
     FOR J:=1 TO N DO
     BEGIN
     IF IPV[J,3]<>1 THEN
       BEGIN
       FOR K:=1 TO N DO
          BEGIN
          IF IPV[K,3]<>1 THEN
              IF CMP(AMAX,ABS95(A[J,K]))<0 THEN
                 BEGIN
                 IROW:=J; (* SAVE ROW & COLUMN *)
                 ICOL:=K;
                 AMAX:=ABS95(A[J,K]);
               END;     (* IF AMAX *)
           END;   (* FOR K *)
      END;    (* IF IPV[J,3] *)
   END;      (* FOR J *)
 (* IF PIVOT ELEMENT IS EQ 0 - DET = 0 *)
```

```
 IF CMP(AMAX,TOL2)<=0 THEN DET:=ZERO
 ELSE
   BEGIN
    IPV[ICOL,3]:=IPV[ICOL,3]+1;
    IPV[I,1]:=IROW;
    IPV[I,2]:=ICOL;
  (* INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL *)
    IF IROW<>ICOL THEN
            FOR J:=1 TO N DO
             BEGIN
             SWAP:=A[IROW,J];
             A[IROW,J]:=A[ICOL,J];
             A[ICOL,J]:=SWAP;
             END;    (*     FOR J  1 TO N   *)
(* DIVIDE PIVOT ROW BY PIVOT  ELEMENT *)
  PIV:=A[ICOL,ICOL];
  DET:=MULT(DET,PIV);
  A[ICOL,ICOL]:=ONE;
  FOR K:=1 TO N DO
       A[ICOL,K]:=DIVD(A[ICOL,K],PIV);
(* REDUCE THE NON-PIVOT ROW BY SUBTRACTION *)
  FOR L1:=1 TO N DO
  IF L1<>ICOL THEN    (* AVOID  DIAGONAL *)
    BEGIN
      T:=A[L1,ICOL];
      A[L1,ICOL]:=ZERO;
      FOR K:=1 TO N DO
      A[L1,K]:=SUB(A[L1,K],MULT(A[ICOL,K],T))
    END;    (*  IF L1 <> ICOL *)
  I:=I+1;    (* GO ON TO NEXT *)
  END;    (* ELSE IF AMAX<TOL *)
UNTIL (I>N) OR CMP(DET,ZERO)=0;
(* INTERCHANGE THE COLUMNS AND MODIFY DET *)
  NSWAP:=0;     (* THIS IS SIGN FLAG *)
  IF CMP(DET,ZERO)<>0 THEN BEGIN  (* DO ONLY IF DET.NE.0.0 *)
  FOR J:=1 TO N DO
       BEGIN
       L:=N-J+1;
       IF IPV[L,1]<>IPV[L,2] THEN
          BEGIN
          JROW:=IPV[L,1];
          JCOL:=IPV[L,2];
          NSWAP:=NSWAP+1; (* COUNT SWAPS *)
          FOR K:=1 TO N DO
            BEGIN
```

```
            SWAP:=A[K,JROW];
            A[K,JROW]:=A[K,JCOL];
            A[K,JCOL]:=SWAP;
            END;  (* FOR K *)
          END;  (* IF IPV *)
  END;  (* FOR J *)

IF ODD(NSWAP) THEN SWAP:=NEG(ONE)
              ELSE SWAP:=ONE;
END;  (* IF DET<>0.0 *)
DET:=MULT(DET,SWAP);
END;  (*  MATINV PROCEDURE  *)

PROCEDURE SOLVE;

VAR  SIZE:INTEGER;

BEGIN   (* MAIN PROGRAM *)
SIZE:=EDIM;
MATINV(X,SIZE); (* CALL MATINV PROCEDURE *)
IF CMP(DET,TOL2)<=0
 THEN   MSGLN('MATRIX IS SINGULAR')
 ELSE
  BEGIN
    FOR J:=1 TO SIZE DO
      BEGIN
         SOLNS[J]:=ZERO;  (* INITIALIZE  *)
         SOLNS[J]:=VDP(SIZE,X[J],SUMS);
      END;  (* FOR  J  *)
  END;  (* ELSE i.e. DET .NE. 0.0 *)
END;
(*=================================================================*)
BEGIN   (* Routine's main body starts here *).
ITER:=0;FOR I:=1 TO NPR DO FOR J:=1 TO NPROB DO ITR[I,J]:=0;
UINT:=DIVD(MULT(UINT,LENGTH),DIVD(B,TWO));
VINT:=DIVD(MULT(VINT,LENGTH),DIVD(D,TWO));
REPEAT   (*   Until failure of column    *)
    IPR:=0;   IDX1:=0; IDX2:=0;
    TANIDX:=0;
    CLK8:=TREAD;
    BAR(2);
    CLK9:=CLK9+TREAD-CLK8;
    IF ANY(6) THEN GOTO 10;
    CLK8:=TREAD;
    RECV2(NPR+1,1,LOCATION(PB),11);(*Recieve PB to DATA[4];DATA=M coef*)
```

```
    RECV2(NPR+1,2,LOCATION(UV),2*MDIM); (*Recieve UBARs & VBARs  *)
    CLK9:=CLK9+TREAD-CLK8;
    FOR I:=1 TO MDIM DO
       IF(ODD(I)) THEN UV[I]:=MULT(DIVD(PB,MULT(RYND,RYND)),UV[I])
                  ELSE UV[I]:=MULT(DIVD(PB,MULT(RXND,RXND)),UV[I]);
       DATA[1]:=MULT(CBX,DATA[1]); DATA[2]:=MULT(CTX,DATA[2]);
       DATA[3]:=MULT(CBY,DATA[3]); DATA[4]:=MULT(CTY,DATA[4]);
    REPEAT  (* Until NPROB are completed  *)
       IPR:=IPR+1;
       ITER:=ITR[LSELF,IPR];
       IF(NENTRY=0)   (* NENTRY=0 for start of GLOBAL PROBLEM  *)
         THEN FOR I:=1 TO EDIM DO
           BEGIN  DEL[I]:=ZERO; LOAD[I]:=ZERO   END
         ELSE FOR I:=1 TO EDIM DO
           BEGIN DEL[I]:=STORED[I+IDX1];LOAD[I]:=STOREL[I+IDX1] END;
       ESTIFF(S,EL,DEL,ARND,IXND,IYND,PP,PR,MXP,MYP,MXRE,MYRE);
       IDSEC:=NPROB*(LSELF-1)+IPR;
       IF IDSEC=1 THEN BEGIN  UV[1]:=ZERO; UV[2]:=ZERO;  END;
       IF IDSEC=NSEC THEN BEGIN UV[MDIM]:=ZERO; UV[MDIM-1]:=ZERO; END;
       ZBAR:=DIVD(FLOATI(IDSEC-1),FLOATI(NSEC-1));
       UO:=MULT(SINE(MULT(PI,ZBAR)),UINT);
       VO:=MULT(SINE(MULT(PI,ZBAR)),VINT);
       LOADB[1]:=NEG(PB);
       LOADB[2]:=MULT(SUB(ZBAR,ONE),DATA[1]);
       LOADB[2]:=SUB(ADD(LOADB[2],UV[IDX2+2]),MULT(ZBAR,DATA[2]));
       LOADB[2]:=ADD(MULT(DIVD(PB,MULT(RXND,RXND)),VO),LOADB[2]);
       LOADB[3]:=MULT(SUB(ONE,ZBAR),DATA[3]);
       LOADB[3]:=ADD(SUB(LOADB[3],UV[IDX2+1]),MULT(ZBAR,DATA[4]));
       LOADB[3]:=SUB(LOADB[3],MULT(DIVD(PB,MULT(RYND,RYND)),UO));
       TANGNT(LOAD,LOADB,DEL,S,CNT2,UO,VO);
       TANIDX:=0;
       ITR[LSELF,IPR]:=ITR[LSELF,IPR]+1;ITER:=ITR[LSELF,IPR];
IF IO<=3 AND ANY(5) THEN
 BEGIN NXTLN; FOR I:=1 TO EDIM  DO
              BEGIN FOR J:=1 TO EDIM DO MSGR(S[I,J]);NXTLN; END; END;
IF IO<=4 AND ANY(5) THEN
  BEGIN  MSG('LOAD=');MSGR(PB);MSG('      DET=');MSGR(DET);NXTLN;  END;
       IF  CMP(DET,TOL2)<=0  OR CNT2=15 THEN  TANIDX:=1;
       FOR I:=1 TO 14 DO COEF[I]:=ZERO;
       IF  TANIDX<>1 THEN
       BEGIN
       COEF[8]:=SUB(S[2,3],MULT(S[2,1],DIVD(S[1,3],S[1,1])));
       COEF[8]:=MULT(C2,COEF[8]);
       COEF[9]:=MULT(NEG(TWO),COEF[8]);
       COEF[10]:=SUB(MULT(S[2,1],DIVD(S[1,2],S[1,1])),S[2,2]);
```

```
        COEF[10]:=MULT(C1,COEF[10]);
        COEF[11]:=SUB(MULT(NEG(TWO),COEF[10]),DIVD(PB,MULT(RXND,RXND)));
        COEF[12]:=MULT(CBX,SUB(ZBAR,ONE));
        COEF[13]:=MULT(CTX,NEG(ZBAR));
        COEF[14]:=ADD(PR,ADD(PP,PB));
        COEF[14]:=ADD(MULT(PB,DIVD(VO,MULT(RXND,RXND))),
                                    DIVD(MULT(COEF[14],S[2,1]),S[1,1]));
        COEF[14]:=SUB(COEF[14],ADD(MXRE,MXP));
        FOR I:=8 TO 14 DO COEF[I]:=NEG(COEF[I]); (* Consistant with tan*)
        COEF[1]:=SUB(S[3,3],MULT(S[3,1],DIVD(S[1,3],S[1,1])));
        COEF[1]:=MULT(C2,COEF[1]);
        COEF[2]:=ADD(MULT(NEG(TWO),COEF[1]),DIVD(PB,MULT(RYND,RYND)));
        COEF[3]:=SUB(MULT(S[3,1],DIVD(S[1,2],S[1,1])),S[3,2]);
        COEF[3]:=MULT(C1,COEF[3]);
        COEF[4]:=MULT(NEG(TWO),COEF[3]);
        COEF[5]:=MULT(CBY,SUB(ONE,ZBAR));
        COEF[6]:=MULT(CTY,ZBAR);
        COEF[7]:=MULT(DIVD(S[3,1],S[1,1]),ADD(ADD(PR,PP),PB));
        COEF[7]:=ADD(ADD(COEF[7],MYRE),SUB(MYP,MULT(PB,
                                    DIVD(UO,MULT(RYND,RYND)))));
        FOR I:=1 TO EDIM DO
          BEGIN VCTRD[IDX1+I]:=DEL[I]; VCTRL[IDX1+I]:=LOADB[I]; END;
        END;
        CLK8:=TREAD;SEND2(NPR+1,IPR,LOCATION(COEF),31);
        CLK9:=CLK9+TREAD-CLK8;
        IDX1:=IDX1+EDIM;
        IDX2:=IDX2+(EDIM-1);
    UNTIL (IPR=NPROB)  OR TANIDX=1;
CLK8:=TREAD; BAR(7); RECV2(NPR+1,3,LOCATION(NEW),1);
CLK9:=CLK9+TREAD-CLK8;
IF  NEW=0 THEN
FOR I:=1 TO N DO
    BEGIN STORED[I]:=VCTRD[I];STOREL[I]:=VCTRL[I] END;
UNTIL  ANY(6);   (*  Failure of column  *)
10:NXTLN;
END;  (* Routine Ends Here *)
(* ------- MAIN PROGRAM BEGINS ------ *)
BEGIN
  FLGEN(2);FLGEN(5);FLGEN(7);FLGEN(6);
  FLGRES(2);FLGRES(5);FLGRES(7);FLGRES(6);BAR(SYSFLAG);
  ZERO:=CV9512(0.0);
  ONE:=CV9512(1.0);
  TWO:=CV9512(2.0);
  FOUR:=CV9512(4.0);
  TWLVE:=CV9512(12.0);
```

```
  SIXTN:=CV9512(16.0);
  PI:=CV9512(3.141592654);
  (* GET DATA AREAS *)
  DALL4::ADDR:=DAPTR(4);
  NPROB:=DALL4@[1];  NCNTR:=DALL4@[2];
  NB:=DALL4@[3];    ND:=DALL4@[4];
  NTB:=DALL4@[5];   NTD:=DALL4@[6];
  NSEC:=DALL4@[7]; NPR:=DALL4@[8]; IO:=DALL4@[9];(*NSEC-No.of Sections
                                NPR -No. of Processors used less one *)
  DALL5::ADDR:=DAPTR(5);
  B:=CV9512(DALL5@[1]); D:=CV9512(DALL5@[2]); T:=CV9512(DALL5@[3]);
  RT:=CV9512(DALL5@[4]);  RC:=CV9512(DALL5@[5]);
  TOL2:=CV9512(DALL5@[6]);
  LENGTH:=CV9512(DALL5@[7]);
  KBX:=CV9512(DALL5@[8]);  KBY:=CV9512(DALL5@[9]);
  KTX:=CV9512(DALL5@[10]);  KTY:=CV9512(DALL5@[11]);
  UINT:=CV9512(DALL5@[12]); VINT:=CV9512(DALL5@[13]);
  E:=CV9512(DALL5@[14]);    SIGY:=CV9512(DALL5@[15]);
  TOL1:=CV9512(DALL5@[16]);
  SIGRC:=NEG(RC);
  SIGRT:=RT; NXTLN;
  IF CMP(RT,ZERO)=0 THEN MSGLN('MEMBER WITHOUT RESIDUAL STRESSES')
                    ELSE MSGLN('MEMBER WITH RESIDUAL STRESSES');
(*IF CMP(KBX,ZERO)=0 AND CMP(KTX,ZERO)=0 THEN
                   MSGLN('NO PARTIAL RESTRAINT AGAINST X AXIS');
  IF CMP(CBY,ZERO)=0 AND CMP(CTY,ZERO)=0 THEN
                   MSGLN('NO PARTIAL RESTRAINT AGAINST Y AXIS');  *)
  TSTART(1); CLK9:=0;
  PROPERTY;
  DET:=ONE;
  NPROB:=NSEC DIV NPR;
  NDIM:=EDIM*NPROB;
  MDIM:=(EDIM-1)*NPROB; (* NDIM,MDIM - Variable lengths of STORE,UV *)
  ROUTINE(NDIM,MDIM);
  TSTOP;
  ENDLN(2);MSG('PROCESSING TIME =');MSGL(TREAD);NXTLN;
  NXTLN;MSG('EXECUTION  TIME =');MSGL(TREAD-CLK9);NXTLN;
END;     (* End of the main program *)

BEGIN (*$NO OBJECT*)
END.
```

APPENDIX D

PROOF-COPY OF THE CONCURRENT PROCESSING PAPER FROM ENGINNERING WITH COMPUTERS JOURNAL

A proof-copy of the paper mentioned in Section 3.3 is given in this appendix.

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APPENDIX E

FRAME SUBSTRUCTURING

E.1 Introduction

The substructuring technique applied for the study presented in Section 4 of this report is given in Reference 9. This appendix presents a summary of the technique.

If a structure such as the one shown in Figure 11 (a) is partitioned into substructures, a restrained structure can be defined by assuming just those joints at the boundaries of the specified substructure to be restrained. Defining the restrained structure in this manner, the various substructures shown in Figure 11 (b) become the basic components to be used in the analysis of the structural system. The advantage of substructuring is that the number of unknown components of joint displacements to be evaluated at any one time in the analysis of the total system is less than the number of unknowns generated by a direct procedure, thus a considerable reduction in CPU time may be realized.

A substructure can be defined as an element or a group of elements that forms a portion of a structural system. The analysis of the substructure with its boundaries fixed can be carried out using the direct procedure as if it were a complete system in itself. From such an analysis, the fixed boundary actions, which are analogous to the fixed end actions for a beam element and the displacements of the unrestrained joints of the substructure stiffness matrix can also be evaluated. Obviously, the joint displacements determined from the analysis will not be true true displacements of the unrestrained joints of the substructure due to the fact that some of the boundaries of the substructure are

artificially constrained in the basic model, i.e., the restrained structure. Therefore, these displacements must be corrected to account for the response of the substructure to the displacement of its artificially restrained boundaries, which will be determined from the analysis of the total structure. Once the actual displacements of all of the unrestrained joints of the total structure have been evaluated, the final end actions can be determined for each element of the structure.

E.2 Analysis of the Substructure

For the analysis of the k-th substructure, the static joint equilibrium equations can be expressed as follows:

$$[S]\{\Delta\} = \{P\} + \{R\} \qquad \text{E.1}$$

The various terms in Equation E.1 are defined as follows:

[S] = stiffness matrix,

{Δ} = displacement vector,

{P} = joint load vector, and

{R} = boundary reaction vector.

For substructure k, Equation E.1 can be partitioned relative to the unrestrained (u) and restrained (r) boundary displacements of the substructure,as follows:

$$\left[\begin{array}{c|c} [S_{uu}] & [S_{ur}] \\ \hline [S_{ru}] & [S_{rr}] \end{array}\right] \left\{\begin{array}{c} \{\Delta_u\} \\ \hline \{0\} \end{array}\right\} = \left\{\begin{array}{c} \{P_u\} \\ \hline \{P_r\} \end{array}\right\} + \left\{\begin{array}{c} \{0\} \\ \hline \{R_r\} \end{array}\right\} \qquad (E.2)$$

The true response of a substructure, as part of the total system, is the sum of: (i) the response of the substructure, with its boundaries restrained, to the external loads; and (ii) the response of the system to the actual boundary displacements. The equilibrium equation for the response of the substructure due to the displacement of the "restrained"

nodes alone can be written as follows:

$$\left[\begin{array}{c|c} [S_{uu}] & [S_{ur}] \\ \hline [S_{ru}] & [S_{rr}] \end{array}\right] \left\{\begin{array}{c} \{\Delta_{ud}\} \\ \hline \{\Delta_{rd}\} \end{array}\right\} = \left\{\begin{array}{c} \{\ 0\ \} \\ \hline \{R_{rd}\} \end{array}\right\} \tag{E.3}$$

in which $\{\Delta_{ud}\}$, and $\{\Delta_{rd}\}$ are, respectivly, the displacements of the unrestrained, and restrained nodes of the substructure due to the boundary action vector $\{R_{rd}\}$, required to maintain equilibrium when the boundries are subjected to the displacement $\{\Delta_{rd}\}$.

Equation E.2 can be expanded as follows:

$$[S_{uu}]\{\Delta_u\} = \{P_u\}, \tag{E.4}$$

$$[S_{ru}]\{\Delta_u\} = \{P_r\} + \{R_r\}. \tag{E.5}$$

Solving Equation E.4 gives:

$$\{\Delta_u\} = [S_{uu}]^{-1}\{P_u\} \tag{E.6}$$

substituting which into Equation E.5 leads to:

$$\{R_r\} = [S_{ru}][S_{uu}]^{-1}\{P_u\} - \{P_r\} \tag{E.7}$$

Similarly, expanding Equation E.3 gives:

$$[S_{uu}]\{\Delta_{ud}\} + [S_{ur}]\{\Delta_{rd}\} = \{0\}, \tag{E.8}$$

$$[S_{ru}]\{\Delta_{ud}\} + [S_{rr}]\{\Delta_{rd}\} = \{R_{rd}\} \tag{E.9}$$

From Equation E.8,

$$\{\Delta_{ud}\} = -[S_{uu}]^{-1}[S_{ur}]\{\Delta_{rd}\} \tag{E.10}$$

substituting which into Equation E.9 leads to:

$$\{R_{rd}\} = [S_s]\{\Delta_{rd}\} \tag{E.11}$$

in which $[S_s]$ is the substructure stiffness matrix given by:

$$[S_s] = [S_{rr}] - [S_{ru}][S_{uu}]^{-1}[S_{ur}] \tag{E.12}$$

E.3 Deflection of Nodes Linking Various Substructures

The static equilibrium of the nodes linking the various substructures k = 1, 2, 3,..., n, and the real boundries can be expressed as follows:

$$[S_a]\{\Delta_a\} = \{P_a\} + \{R_a\} \tag{E.13}$$

in which the various elements of $[S_a]$ are found as follows:

$$(S_a)_{ij} = (\Sigma(S_s)_k)_{ij}, \tag{E.14}$$

where Σ is over k, with k = 1, 2, 3,..., n. Also, $\{P_a\}$ is the external applied load vector for the nodes linking the various substuctures, and $\{\Delta_a\}$ is the true deflection vector for the same nodes. $\{R_a\}$ is the nodal reaction vector.

Equation E.13 can be written in the following form:

$$\left[\begin{array}{c|c} [S_{11}] & [S_{12}] \\ \hline [S_{21}] & [S_{22}] \end{array}\right] \left\{\begin{array}{c} \{\Delta_{rd}\} \\ \hline \{\Delta_b\} \end{array}\right\} = \left\{\begin{array}{c} \{P_{rd}\} \\ \hline \{P_b\} \end{array}\right\} + \left\{\begin{array}{c} \{\ 0\ \} \\ \hline \{R_b\ \} \end{array}\right\} \tag{E.15}$$

in which $\{\ _{rd}\}$ has been defined in Section E.2. The terms of $\{P_{rd}\}$ are generated using the following equation.

$$(P_{rd})_i = -(\Sigma(R_{rd})_k)_i + (P)_i, \tag{E.16}$$

where again, Σ is over k, with k = 1, 2, 3,..., n; and $\{P_b\}$ is the external load vector corresponding to the actual boundaries of the structure. With $\{\ _b\} = \{0\}$ Equation E.15 can be expanded to give:

$$\{\Delta_{rd}\} = [S_{11}]^{-1}\{P_{rd}\}, \tag{E.17}$$

$$\{R_b\ \} = [S_{21}][S_{11}]^{-1}\{P_{rd}\} - \{P_b\}. \tag{E.18}$$

E.4 Deflection of Unrestrained Nodes

The true deflection of the unrestrained nodes is obtained as follows:

$$\{\Delta_{un}\}_k = (\{\Delta_u\}_k + \{\Delta_{ud}\})_k, \tag{E.19}$$

for all k values. Substituting Equation E.10 into Equation E.19 provides:

$$\{\Delta_{un}\}_k = (\{\Delta_u\} - [S_{uu}]^{-1}[S_{ur}]\{\Delta_{rd}\})_k. \tag{E.20}$$

APPENDIX F

FORCE PROGRAM LISTING WITH SAMPLE INPUT/OUTPUT

FOR SUBSTRUCTURE ANALYSIS OF 3-STORY FRAME

The information regarding each substructure, the corresponding member properties, and the nodal numbering related to the various members are read from an input file named SSR.IN6. The input variables for this file are SSN, NOM, NOD, NOF, TOR, M, N, MM, NN, L, A, X, where:

SSN = substructure number,

NOM = number of members,

NOD = total number of nodes times the degree of freedom related to each node,

NOF = number of unrestrained nodes times the degree of freedom related to each node,

TOR = type of member (100 for vertical, and 200 for horizantal),

M, N = identification numbers for end 1 of the member,

MM, NN = identification numbers for end 2 of the member,

L = member length,

A = member cross-sectional area,

X = cross-sectional moment of inertia.

The identification numbers for the substructures shown in Figure 11 are as follows. For the upper substructure , the identification numbers M, N, or MM, NN, are:

1, 3 for D,

4, 6 for E,

7, 9 for C, and

10, 12 for F.

The identification numbers for the lower substructure are:

1, 3 for B,

4, 6 for G,

7, 9 for C,

10, 12 for F,

13, 15 for A, and

16, 18 for H.

All members have been assumed to be elastic I-sections, with a Young's modulus of 29,000 ksi, and the following properties:

L = 180.0 in.,

A = 10.3 $in.^2$,

X = 127.4 $in.^4$.

The external nodal loads and the connectivity information about the nodes linking the various substructures are read from an input file named SSR.IN7. The input variables for this file are:

LV = the external load vector,

NODD = the number of boundary nodes in the substructure,

NS = node connectivity integer between various substructures (0 if unconnected, and a non-zero integer if connected).

The output of the program is directed to a file named SSR.OPT which stores the degrees of freedom at the global level, and the corresponding deflections.

```
JOB NAME = ssr5.frc
```

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```
      Force SSR of NP ident ME
* Declaration of arrays and variables
      REAL K11(3,3),K12(3,3),K21(3,3),K22(3,3),_
      Shared DOUBLE PRECISION LV(18),LV1(18),DLRF(18)
      Shared INTEGER TOR,S,TOPS,NOD,NOF,SSN,NOM,F,I,NB(18),PV(18)
      Shared INTEGER  TIME1,TIME2,PVT(2,18)
      Shared DOUBLE PRECISION SM(25,25),DF(40),SUU(18,18),SRR(18,18)
      Shared DOUBLE PRECISION SRU(18,18),DUF(18),RRF(18),SSS(18,18)
      Shared DOUBLE PRECISION RRR(18,18),SS(18,18),DUFF(18)
      Shared DOUBLE PRECISION SS3(21,21),RRF3(21),SUR(18,18)
      Shared DOUBLE PRECISION SURR(18,18),SSSS(2,18,18)
      Shared DOUBLE PRECISION SSUR(2,18,18),SSUU(2,18,18),DDUF(18,2)
      Shared DOUBLE PRECISION SSRR(2,18,18),SSRU(2,18,18)
      CHARACTER*40 FILENM
      End declarations
      Barrier
* ssr.in6-input file for member properties data,ssr.in7-input file for
* external nodal loads,ssr.out-output file for deflections of the nodes
      open(6,file='/usr/u1/ravi/ssr5.in6',cpu=1)
      open(1,file='/usr/u1/ravi/ssr5.in7',CPU=1)
      open(2,file='/usr/u1/ravi/ssr5.out',CPU=1)
      CALL CPrtic (TIME1)
      DO 9  I=1,21
      LV1(I)=0.00
      RRF3(I)=0.00
      DO 10 J=1,21
      SS3(I,J)=0.00
   10 CONTINUE
   9  CONTINUE
      End barrier
      Pcase
      FILENM="/usr/u1/ravi/ssr5.in4"
      CALL  FM(1,4,12,6,SSUU,SSUR,SSRU,SSRR,FILENM)
      Usect
      FILENM="/usr/u1/ravi/ssr5.in5"
      CALL  FM(2,5,18,6,SSUU,SSUR,SSRU,SSRR,FILENM)
      End pcase
* External nodal loads are read for various substructures by
* different processors
      Barrier
      print*,'OK'
      NOD=12
       NOF=6
      SSN=1
       F=NOD-NOF
      End barrier
* Equation # 2 is solved using the parallel subroutine 'SOLVE'
  104  continue
      Barrier
      READ (1,*)  (LV(I),I=1,NOF)
      End barrier

      Presched DO 201 I=1,NOF
      DO 202 J=1,NOF
  202  SUU(I,J)=SUU(SSN,I,J)
```

```
 201   End presched do
       Presched do 203 I=1,NOF
       DO 204 J=1,F
 204   SUR(I,J)=SSUR(SSN,I,J)
  203  End presched do
       Presched Do 205 I=1,F
       DO 206 J=1,NOF
  206  SUU(I,J)=SSUU(SSN,I,J)
205    End presched do
       Presched do 208 I=1,F
       DO 207 J=1,F
       SRR(I,J)=SSRR(SSN,I,J)
 207   CONTINUE
 208   End presched DO

       Forcecall SOLVE(SUU,LV,DUF,NOF,PV)
       Presched DO 71 I=1,NOF
       DDUF(I,SSN)=DUF(I)
       PVT(I,SSN)=PV(I)
  71   End presched do
* Solving equation number 3 & 4 using parallel subroutine MATMP
       Forcecall MATMP(SRU,DUF,RRF,F,NOF,1)
       Forcecall SGES2(SUU,SUR,SSS,NOF,F,PV)
       Forcecall MATMP(SRU,SSS,RRR,F,NOF,F)

       Presched do  117 I=1,NOF
       DO 118 J=1,F
       SSSS(SSN,I,J)=SSS(I,J)
 118   CONTINUE
 117   End presched do
       Presched DO 81 I=1,F
       DO 82 J=1,F
       SS(I,J)=SRR(I,J)-RRR(I,J)
  82   CONTINUE
  81   End presched do
* Forming SRR effective for every substructure and placing the elements
* of substructura
       Barrier
       READ(6,*) NODD
       PRINT*,NODD,'NODD OK'
       READ (6,*) (NS(I),I=1,NODD)
       PRINT*,NS(NODD),'NS OK'
       NC=1
       DO 130 I=1,NODD
       IF(NS(I).EQ.0) GOTO 130
       RRF3(NC)=RRF3(NC)+RRF(NC)
       MC=1
       DO 121 J=1,NODD
       IF(NS(J).EQ.0) GOTO 121
       SS3(I,J)=SS3(I,J)+SS(NC,MC)
       MC=MC+1
 121   CONTINUE
       NC=NC+1
 130   CONTINUE
       SS=1
```

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```
      NOD=18
      NOF=6
      End barrier
      IF(SSN.EQ.1) GOTO 104
      Barrier
      SSN=3
      NOD=12
      NOF=6
      F=NOD-NOF
      DO 49 I=1,NOF
      LV1(I)=(-1.0)*RRF3(I)
      DO 50 J=1,NOF
      SUU(I,J)=SS3(I,J)
 50   CONTINUE
 49   CONTINUE
      READ (1,*) (LV(I),I=1,NOF)
      DO 139 I=1,NOF
      LV(I)=LV(I)+LV1(I)
 139  CONTINUE
      print*,'OaK'
      End barrier
      Forcecall SOLVE(SUU,LV,DUF,NOF,PV)
      Forcecall MATM2(SSSS,DUF,DUFF,NOF,F,1)
      Barrier
      print*,'OK TILL HERE'
* Solving equaton 6 for  substructure number 1
      DO 69 I=7,12
      DUF(I)=DDUF(I-6,1)-DUFF(I-6)
   69 CONTINUE
      End barrier
      Forcecall MATM2(SSSS,DUF,DUFF,NOF,F,2)
      Barrier
      print*,'OK'
* Solving equation 6 for sbstructure number 2
      DO 79 I=13,18
      DUF(I)=DDUF(I-12,2)-DUFF(I-12)
   79 CONTINUE
      CALL CPrtic (TIME2)
      print*, 'OK'
      print*, TIME2,TIME1
* Writing deflections for common nodes using single processor
      WRITE (2,78)
      WRITE (2,75)
   78 FORMAT (/,3X,'DEFLECTIONS OF NODES COMMON TO SUBSTRUCTURES 1 & 2'
     /,/)
   75 FORMAT (3X,'DEG. OF FREEDOM',16X,'DEFLECTION',//)
   77 FORMAT (10X,I2,15X,1PE12.5)
      DO 76 I=1,6
      WRITE (2,77) I,DUF(I)
      WRITE (2,*)
   76 CONTINUE
      WRITE (2,99)
      WRITE (2,75)
* Writing deflections of nodes of substructure 1 using one processor
   99 FORMAT (/,3X,'DEFLECTIONS OF NODES OF SUBSTRUCTURE 1',/)
```

```
      DO 100 I=7,12
      WRITE (2,77) I,DUF(I)
      WRITE (2,*)
  100 CONTINUE
* Writing deflections of nodes of substructure II using single processor
  111 FORMAT (/,5X,'DEFLECTIONS OF NODES OF SUBSTRUCTURE II'/) '
      WRITE (2,111)
      WRITE (2,75)
      DO 109 I=13,18
      WRITE (2,77) I,DUF(I)
      WRITE (2,*)
  109 CONTINUE
      End Barrier
      Join
      END
      SUBROUTINE FM(SSN,NOM,NOD,NOF,SSUU,SSUR,SSRU,SSRR,FILENM)
      REAL L,K11(3,3),K12(3,3),K21(3,3),K22(3,3)
      INTEGER TOR,SSN,F,Z
      DOUBLE PRECISION LV(18),LV1(18)
      DOUBLE PRECISION SSUU(2,18,18), SSUR(2,18,18),SM(18,18)
      DOUBLE PRECISION SSRU(2,18,18),SSRR(2,18,18)
      CHARACTER*40 FILENM
      OPEN (4,FILE=FILENM,CPU=1)
      E=29000.0
* Sub-structure stiffness matrix formation starts.
* NOD-Total degrees of freedom in the substructure,NOF-total number of interi
* nodes,NOM=number of members,SSN-number of the substructure
      DO 11 I=1,NOD
      DO 12 J=1,NOD
      SM(I,J)=0.0
   12 CONTINUE
   11 CONTINUE

* Reads individual member properties,L-length,A-area of cross-section
* X-inertia of the section
* Reads M,N-leftside DOF numbering,MM,NN-right side DOF numbering,
* TOR is 100 for vertical members,200 for horz. members
      DO 108 Z=1,NOM
       READ(4,*) L,A,X
       READ(4,*) M,N,MM,NN,TOR
      print*,'M,N,OK'
      DO 17 I=1,3
      DO 18 J=1,3
      K11(I,J)=0
      K12(I,J)=0
      K21(I,J)=0
      K22(I,J)=0
   18 CONTINUE
   17 CONTINUE
      IF(TOR.EQ.200) GO TO 110
      K11(1,1)=12*E*X/L**3
      K11(1,3)=(6*E*X/L**2)*(-1)
      K11(2,1)=K11(1,2)
      K11(2,2)=E*A/L
      K11(3,1)=K11(1,3)
```

```
      K11(3,2)=K11(2,3)
      K11(3,3)=4*E*X/L
      K12(1,1)=K11(1,1)*(-1)
      K12(1,2)=K11(1,2)
      K12(1,3)=K11(1,3)
      K12(2,1)=K11(1,2)
      K12(2,2)=K11(2,2)*(-1)
      K12(2,3)=K11(2,3)
      K12(3,1)=K12(1,3)*(-1)
      K12(3,3)=2*E*X/L
      DO 19 I=1,3
      DO 20 J=1,3
      K21(I,J)=K12(J,I)
20    CONTINUE
19    CONTINUE
      K22(1,1)=12*E*X/L**3
      K22(1,3)=6*E*X/L**2
      K22(2,2)=E*A/L
      K22(3,1)=6*E*X/L**2
      K22(3,3)=4*E*X/L
245   KK=0
      LL=0
      DO 21 I=MM,NN
      KK=KK+1
      DO 22 J=M,N
      LL=LL+1
      SM(I,J)=SM(I,J)+K21(KK,LL)
22    CONTINUE
      LL=0
21    CONTINUE
      CONTINUE
      KK=0
      LL=0
      DO 23 I=MM,NN
      KK=KK+1
      DO 24 J=MM,NN
      LL=LL+1
      SM(I,J)=SM(I,J)+K22(KK,LL)
24    CONTINUE
      LL=0
23    CONTINUE
      KK=0
      LL=0
      DO 25 I=M,N
      KK=KK+1
      DO 26 J=MM,NN
      LL=LL+1
      SM(I,J)=SM(I,J)+K12(KK,LL)
26    CONTINUE
      LL=0
25    CONTINUE
      KK=0
      LL=0
      DO 27 I=M,N
      KK=KK+1
```

```
      DO 28 J=M,N
      LL=LL+1
      SM(I,J)=SM(I,J)+K11(KK,LL)
28    CONTINUE
      LL=0
27    CONTINUE
      GOTO 108
110   K11(1,1)=E*A/L
      K11(2,2)=12*E*X/L**3
      K11(2,3)=6*E*X/L**2
      K11(3,2)=K11(2,3)
      K11(3,3)=4*E*X/L
      K12(1,1)=K11(1,1)*(-1)
      K12(2,2)=K11(2,2)*(-1)
      K12(2,3)=K11(2,3)
      K12(3,2)=K11(2,3)*(-1)
      K12(3,3)=2*E*X/L
      DO 29 I=1,3
      DO 30 J=1,3
      K21(I,J)=K12(J,I)
30    CONTINUE
29    CONTINUE
      K22(1,1)=K11(1,1)
      K22(2,2)=K11(2,2)
      K22(2,3)=K12(3,2)
      K22(3,2)=K12(3,2)
      K22(3,3)=K11(3,3)
240   KK=0
      LL=0
      DO 31 I=M,N
      KK=KK+1
      DO 32 J=MM,NN
      LL=LL+1
      SM(I,J)=SM(I,J)+K12(KK,LL)
32    CONTINUE
      LL=0
31    CONTINUE
      KK=0
      LL=0
      DO 33 I=M,N
      KK=KK+1
      DO 34 J=M,N
      LL=LL+1
      SM(I,J)=SM(I,J)-K11(KK,LL)
34    CONTINUE
      LL=0
33    CONTINUE
      KK=0
      LL=0
      DO 35 I=MM,NN
      KK=KK+1
      DO 36 J=MM,NN
      LL=LL+1
      SM(I,J)=SM(I,J)+K22(KK,LL)
36    CONTINUE
```

```
      LL=0
35    CONTINUE
      KK=0
      LL=0
      DO 37 I=MM,NN
      KK=KK+1
      DO 38 J=M,N
      LL=LL+1
      SM(I,J)=SM(I,J)+K21(KK,LL)
38    CONTINUE
      LL=0
37    CONTINUE
100   CONTINUE
* Sub structure stiffness matrix formation ends for various
* sub structures.
* Matrix for various sub sructures is divided according
* to number of interior and exterior nodes
      F=NOD-NOF
      DO 1 I=1,NOF
      DO 2 J=1,NOF
      SSUU(SSN,I,J)=SM(I,J)
    2 CONTINUE
    1 CONTINUE
      DO 3 I=1,F
      DO 4 J=1,F
      SSRR(SSN,I,J)=SM(I+NOF,J+NOF)
    4 CONTINUE
    3 CONTINUE
      DO 5 I=1,NOF
      DO 6 J=1,F
      SSUR(SSN,I,J)=SM(I,J+NOF)
    6 CONTINUE
    5 CONTINUE
      DO 7 I=1,F
      DO 8 J=1,NOF
      SSRU(SSN,I,J)=SM(I+NOF,J)
    8 CONTINUE
    7 CONTINUE
      RETURN
      END
* Suoroutine for inversion of matrix (sequetial)
      SUBROUTINE INV(A,N)
      DOUBLE PRECISION A
      DIMENSION A(18,18)
      NP=N+1
      A(1,NP)=1
      DO 10 K=2,N
10    A(K,NP)=0
      DO 40 J=1,N
      DO 20 L=1,N
20    A(NP,L)=A(1,L+1)/A(1,1)
      DO 30 K=2,N
      DO 30 L=1,N
30    A(K-1,L)=A(K,L+1)-A(K,1)*A(NP,L)
      DO 40 L=1,N
```

```
40      B(N,L)=A(NP,L)
        RETURN
        END
*  Subroutine for matrix multiplication
        SUBROUTINE MULT(A,B,C,M,N)
        DOUBLE PRECISION A(18,18),B(18),C(18)
        DO 30 I=1,M
        C(I)=0.0
        DO 30 L=1,N
30      C(I)=C(I)+A(I,L)*B(L)
        RETURN
        END
*  Subroutine for matrix multiplication (sequential)
        SUBROUTINE MULT2(A,B,C,M,K,N)
        DOUBLE PRECISION  A(18,18),B(18,18),C(18,18)
        DO 20 J=1,N
        DO 30 I=1,M
        SUM=0.0
        DO 40 L=1,K
        SUM=SUM+A(I,L)*B(L,J)
     40 CONTINUE
        C(I,J)=SUM
     30 CONTINUE
     20 CONTINUE
        RETURN
        END
        SUBROUTINE MULT3(A,B,C,M,K,N,II)
        DOUBLE PRECISION A(2,18,18),B(2,18,18),C(18,18)
        DO 20 J=1,N
        DO 30 I=1,M
        SUM=0.0
        DO 40 L=1,K
        SUM=SUM+A(II,I,L)*B(II,L,J)
   40   CONTINUE
        C(I,J)=SUM
   30   CONTINUE
   20   CONTINUE
        RETURN
        END

*  Force subroutine for matrix multiplication in parallel

        Forcesub MATMP(A,B,C,M,N,D) of NP ident ME
        DOUBLE PRECISION A(18,18),B(18,18),C(18,18)
        INTEGER M,N,D
        Shared INTEGER LDIM
        Private INTEGER I,J,K
        Private DOUBLE PRECISION SUM
        End declarations
        Barrier
        End Barrier
        Presched DO 200 I=1,M
          DO 200 J=1,D
           SUM=0.0
            DO 100 K=1,N
```

```
            SUM=SUM+A(I,K)*B(K,J)
  100   CONTINUE
        C(I,J)=SUM
  200   CONTINUE
  300   End presched do
        Barrier
         End barrier
        RETURN
        END
* Force subroutine for solving equation # 7
        Forcesub MATM2(A,B,C,M,N,II) of NP ident MP
        DOUBLE PRECISION A(2,18,18),B(18),C(18)
        INTEGER M,N,II
        Private INTEGER I,K
        Private DOUBLE PRECISION SUM
        End Declarations
        Barrier
        End Barrier
        Presched DO 300 I=1,M
              SUM=0.0
               DO 100 K=1,N
                SUM=SUM+A(II,I,K)*B(K)
  100   CONTINUE
        C(I)=SUM
  300   End presched do
         Barrier
          End Barrier
           RETURN
           END
* Force subroutine for solving [A][x]=[b] in parallel

        Forcesub SOLVE(A,B,X,N,IPVT) of NP ident ME
C.....Test program for parallel PLU decomposition using Force versions
C.....of "Linpack" routines.
C.....This program calls a (single stream) routine to read in a matrix
C.....and vector, then SGEFA is called to factor the matrix into a PLU form,
C.....then SGESL is called to solve the system.  The computation is timed,
C.....and then a (single stream) routine is called to output the results.

          INTEGER N,IPVT(18)
          Shared INTEGER INFO
          DOUBLE PRECISION A(18,18), B(18),X(18)
          Shared INTEGER ITM1, ITM2, ITM3
          REAL DELTA1, DELTA2 , RATE1, RATE2
          End declarations

          Barrier
            CALL CFrtic(ITM1)
          End barrier

          Forcecall SGEFA(A, 18, N, IPVT, INFO)
          IF (INFO .NE. 0) THEN
            matrix is singular...
            if (me .eq. 1) print *, 'matrix is singular'
            Join
```

```
      END IF

      IF (ME .EQ. 1)  CALL CFrtic(ITM2)

      Forcecall SGESL(A, 18, N, IPVT, B, 0)
      Barrier
       DO 44 I=1,N
   44  X(I)=B(I)
        CALC CFrtic(ITM3)
C       CALL PRINTB(A, B, N)
C       do 25 i=1,n
C25     print*,(a(i,J),J=1,n),b(i),x(i)

        DELTA1 = (ITM2 - ITM1)/50.0
        DELTA2 = (ITM3 - ITM2)/50.0
        IF (DELTA1 .NE. 0) THEN
          RATE1 = (2.0*N*N*N/3.0)*1.0E-6/DELTA1
C         WRITE (*, 400)  NP, N, DELTA1, RATE1
        ELSE
C         WRITE (*, 400)  NP, N, DELTA1, 0.0
C         WRITE (*, 402)
        ENDIF
        IF (DELTA2 .NE. 0) THEN
          RATE2 = (N*N)*1.0E-6/DELTA2
C         WRITE (*, 401)  DELTA2, RATE2
        ELSE
C         WRITE (*, 401)  DELTA2, 0.0
C         WRITE (*, 402)
        ENDIF
  400   FORMAT('    Number of processes =',I3,' Matrix order =',I4,/
     +  ' matrix decomposition: ',F12.4,' seconds (',F5.3,' MFLOPS)')
  401   FORMAT(
     +  ' Fwd/back subst:       ',F12.4,' seconds (',F5.3,' MFLOPS)')
  402   FORMAT(' No elapsed time measured.')
      End barrier
      RETURN
      END
*****************************************************************************
      Forcesub SGESL(A, LDA, N, IPVT, B, JOB) of NP ident me
C     SGESL:  Force parallel version of LINPACK's SGESL which solves
C               Ax=b, using (column orientated) foward/backward subst.
C               A call to SGEFA must precede the call to SGESL.
C               SGEFA provides the PLU factorization of A.
C     A:        the working matrix
C     LDA:      the declared dimension of A
C     N:        the working dimension of A
C     IPVT:     the pivot array
C     B:        the input/output vector (solved in place)
C               B is the only argument altered by SGESL.
C     JOB:      Job selector:   JOB=0: solves Ax=b
C                               JOB=1: solves Transpose(A)x=b, not implemented
C     All argument MUST be declared "Shared" in the calling module.
      Integer LDA, N, IPVT(18), JOB
      DOUBLE PRECISION A(LDA,1), B(1)
      Private Integer I, K, L
```

```
      Shared DOUBLE PRECISION TEM
      End declarations

C     first solve:  L*Y = B
      do 20 K = 1, N-1
        Barrier
          L    = IPVT(K)
          TEM  = B(L)
          B(L) = B(K)
          B(K) = TEM
        End barrier
        Prescned do 22  I = K+1, N
          B(I) = B(I) + TEM * A(I,K)
22      End prescned do
20    continue

C     then solve:  U*X = Y
      do 40 K = N, 1, -1
        Barrier
          B(K) = B(K)/A(K,K)
          TEM  = -B(K)
        End barrier
        Prescned do 42  I = 1, K-1
          B(I) = B(I) + TEM * A(I,K)
42      End prescned do
40    continue
      Barrier
      End barrier
      RETURN
      END
*************************************************************************
      Forcesub SGEFA(A, LDA, N, IPVT, INFO) of NP ident ME
      INTEGER LDA, N, IPVT(LDA), INFO
      DOUBLE PRECISION A(LDA, LDA)
C
      Private DOUBLE PRECISION ABSMAX
      Private DOUBLE PRECISION T
      Private INTEGER KK, I, MAXI, J, KP1
      Shared INTEGER IALL
      Shared DOUBLE PRECISION PIV, ALLMAX
      Shared logical ILOCK
      End declarations

      Barrier
         INFO = 0
         ALLMAX = 0.0
      End barrier

C.....For each row of the matrix

      DO 1000  KK = 1, N-1

      IF(INFO.NE.0) GOTO 2000

C.....Reset local maxima
```

```
            ABSMAX = 0.0

C.......Find the pivot row

            Prescned DO  100  I = KK, N
               T = ABS( A(I, KK) )
               IF (ABSMAX .LT. T)  THEN
                  MAXI = I
                  ABSMAX = T
               ENDIF
100         End Prescned DO

C.......Update the Shared Information if necessary

            Critical ILOCK
            IF (ALLMAX .LT. ABSMAX)  THEN
               IALL = MAXI
               ALLMAX = ABSMAX
            ENDIF
            End critical

            Barrier
               IF (ALLMAX .EQ. 0.0)  THEN
                  INFO = KK
                  IPVT(KK)=KK
               ELSE
                  IPVT(KK)=IALL
               ENDIF
            End Barrier

C........If the matrix is singular then pass the information

            IF (INFO .EQ. KK)  GOTO 1000
            MAXI = IALL
            IF (MAXI .NE. KK)  THEN

C........Swap rows if necessary

               Prescned DO  110  J = KK, N
                  TEMP = A(MAXI, J)
                  A(MAXI, J) = A(KK, J)
                  A(KK, J) = TEMP
110            End Prescned DO
            ENDIF

C.......Self schedule row reductions

            KP1 = KK + 1
            Barrier
               DIV = -1.0/A(KK, KK)
            End Barrier

            Selfsched Do  130  I = KP1, N
               TEMP = DIV*A(I, KK)
```

```
                A(I,KK) = TEMP
                DO  120  J = KP1, N
                   A(I, J) = A(I, J) + TEMP*A(KK, J)
120             CONTINUE
130          End Selfsched DO

             Barrier
                ALLMAX=0
             End barrier

1000      CONTINUE

2000      RETURN
          END
      Forcesub SGES2(A,B,X,N,M,IPVT) of NP ident ME
      INTEGER N,IPVT(18),JOB,M
      DOUBLE PRECISION A(18,18),B(18,18),X(18,18)
      Private integer I,K,L,J
      Shared DOUBLE PRECISION TM
      End declarations
      DO 30 J=1,M
*first solve L*Y=B
       DO 20 K=1,N-1
      Barrier
        L=IPVT(K)
        TM=B(L,J)
        B(L,J)=B(K,J)
        B(K,J)=TM
      End barrier
      Presched do 22 I=K+1,N
      B(I,J)=B(I,J)+TM*A(I,K)
22    End presched do
20    continue
* then solve U*X=y
      DO 40 K=N,1,-1
      Barrier
      B(K,J)=B(K,J)/A(K,K)
      TM=-B(K,J)
        End barrier
      Presched do 42 I=1,K-1
      B(I,J)=B(I,J)+TM*A(I,K)
42    End presched do
40    continue
      do 25 I=1,N
25    X(I,J)=B(I,J)
30    continue
      Barrier
      End barrier
      RETURN
      END

      Forcesub SGES3(A,B,C,N,M,IPVT,II) of NP ident ME
      INTEGER N,M,IPVT(18,2),JOB
      Private INTEGER I,J,K,L
      DOUBLE PRECISION A(2,18,18),B(2,18,18),C(18,18)
```

```
      Shared DOUBLE PRECISION TN
      End declarations
      DO 30 J=1,M
* FIRST SOLVE L*Y=B
      DO 20 K=1,N-1
      Barrier
      L=IPVT(K,II)
      TN=B(II,L,J)
      B(II,L,J)=B(II,K,J)
      B(II,K,J)=TN
      End barrier
      Presched DO 22 I=K+1,N
      B(II,I,J)=B(II,I,J)+TN*A(II,I,K)
 22   End Presched do
 20   CONTINUE
*NOW SOLVE U*X=Y
      DO 40 K=N,1,-1
      Barrier
      B(II,K,J)=B(II,K,J)/A(II,K,K)
      TN=-B(II,K,J)
      End barrier
      Presched do 42 I=1,K-1
      B(II,I,J)=B(II,I,J)+TN*A(II,I,K)
42    End Presched do
40    CONTINUE
      DO 50 I=1,N
      C(I,J)=B(II,I,J)
50    CONTINUE
30    CONTINUE
      RETURN
      END
```

JOB NAME = ssr.in6


```
 ssr.in6

12,6,4,1
180.0,10.3,127.0
1,3,4,6,200
180.0,10.3,127.0
7,9,10,12,200
180.0,10.3,127.0
7,9,1,3,100
180.0,10.3,127.0
10,12,4,6,100
12
1,2,3,4,5,6,0,0,0,0,0,0
18,6,5,2
180.0,10.3,127.0
1,3,4,6,200
180.0,10.3,127.0
1,3,7,9,100
180.0,10.3,127.0
4,6,10,12,100
180.0,10.3,127.0
13,15,1,3,100
180.0,10.3,127.0
16,18,4,6,100
12
1,2,3,4,5,6,7,8,9,10,11,12

7 [$]
```

```
JOB NAME = ssr.in7


 ssr.in7

20.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0
0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0
20.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0
6 [$]
```

ORIGINAL PAGE IS
OF POOR QUALITY

JOB NAME = ssr.out

ssr5.out

DEFLECTIONS OF NODES COMMON TO SUBSTRUCTURES I & II

DEG. OF FREEDOM	DEFLECTION
1	11.72159
2	0.06937
3	-0.02147
4	11.71558
5	-0.06937
6	-0.02145

DEFLECTIONS OF NODES OF SUBSTRUCTURE I

DEG. OF FREEDOM	DEFLECTION
7	15.88023
8	0.07696
9	-0.01008
10	15.87420
11	-0.07696
12	-0.01009

DEFLECTIONS OF NODES OF SUBSTRUCTURE II

DEG. OF FREEDOM	DEFLECTION
13	4.89344
14	0.04478
15	-0.02506
16	4.89343
17	-0.04478
18	-0.02504

APPENDIX G

TITLES OF ABSTRACTS FOR 29TH AIAA/SDM CONFERENCE

The following abstracts are submitted for the 29th AIAA/SDM Conference to be held in Williamsburg, Virginia, April 18-20, 1988:

1. Prasad, V., Razzaq, Z., and Storaasli, O.O., " Two-Dimensional Concurrent Finite Element Analysis of Rectangular Panel with Hole."

2. Bhati, R., Razzaq, Z., and Storaasli, O.O., "Concurrent Substructure Analysis of Plane Frames."