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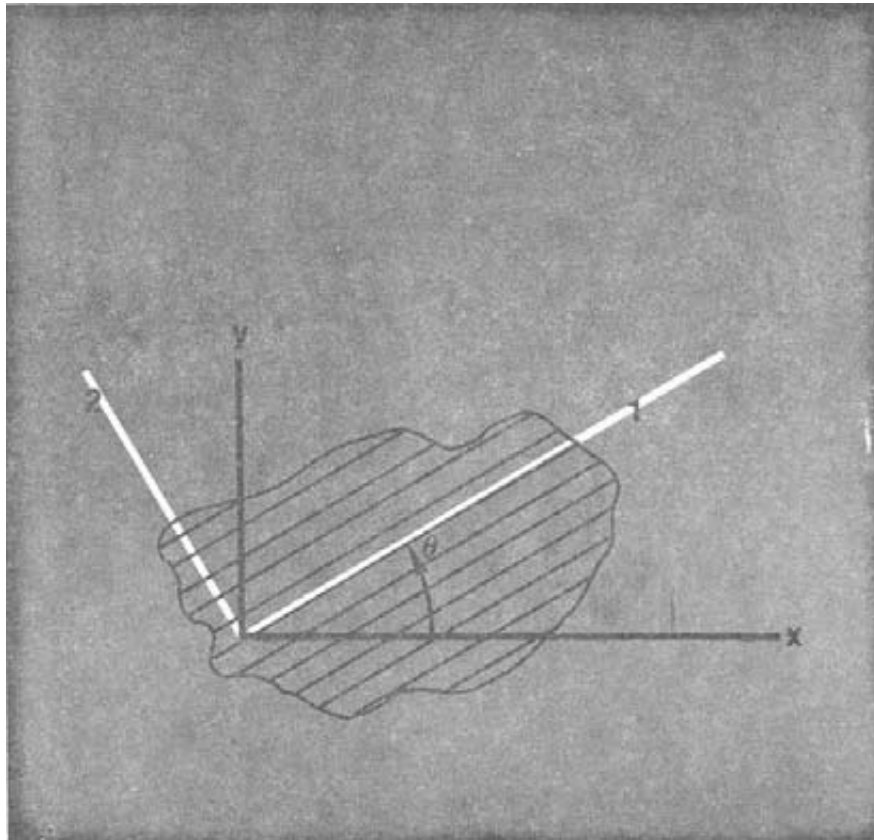
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FPL 35



Plane Stress Analysis of Wood Members Using Isoparametric Finite Elements

A Computer Program



Abstract

A finite element program is presented which computes displacements, strains, and stresses in wood members of arbitrary shape which are subjected to plane strain/stress-loading conditions. This report extends a program developed by R. L. Taylor in 1977, by adding both the cubic isoparametric finite element and the capability to analyze nonisotropic materials. The computer subroutines developed by the author are listed in this report, along with both the details for incorporating them into Taylor's program and the required user instructions.

Keywords: Finite element analysis, computer program, isoparametric elements, stress analysis, orthotropic materials, anisotropic materials, plane loading, design, cubic finite element, quadratic finite element.

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March 1983

Plane Stress Analysis of Wood Members Using Isoparametric Finite Elements A Computer Program

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Introduction

The finite element (FE) computer program written by the author and presented in this report was developed as part of a cooperative research effort involving the National Wooden Pallet and Container Association (NWPCA), Virginia Polytechnic Institute and State University (VPI&SU), and the USDA Forest Service. This research is designed to establish rational engineering design procedures for wood pallets. The author's role in this endeavor is to determine the stiffness and strength of notched stringer members of pallets as functions of notch geometry, material properties, and loading conditions. As part of this effort, the author developed the FE program described in this paper to compute displacements and stresses in wood members of any geometrical shape which are under arbitrary plane stress or strain-loading conditions. This computer program is to be applied to the notched-stringer problem. Details of the program development, user instructions, and program listing are presented in this report. The program was verified by a comparison of FE predictions of displacements and strains in center-loaded, double-tapered wood beams with data available in the literature (4).² This comparison is presented in another paper.³

The developed subroutines are listed in the appendix, however no other support is offered.

Program Development

The decision to develop an FE program rather than purchase one of the many multipurpose programs available was based on several factors:

- (1) The existence of subroutines in the literature to form the basis of a general-purpose FE program,
- (2) The belief that a developed program could be more readily expanded for future research needs, and
- (3) The desire to include the cubic isoparametric element in the program.

An FE computer program developed by Taylor (6) was used as a starting point. Taylor's program can input data for one-, two-, or three-dimensional structures. It is written in a modular form: Adding a new element requires writing a single subroutine. This flexibility is quite appealing to the researcher because the added element, whether a three-dimensional solid element or even a fluid or heat-transfer element, utilizes existing (and debugged) code for data input, matrix assembly, matrix inversion, etc. The program has a macro instruction language that allows a variable algorithm capability. Also, storage requirements are dynamically assigned for each problem and stored in a single array. In this manner, available computer memory is used efficiently for any type of problem. Finally, the following isoparametric plane elements are available: triangular, linear quadrilateral, quadratic serendipity and Lagrangian quadrilateral elements. A much more detailed description of the Taylor FE program is given in (7).

¹ Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

² Italicized numbers in parentheses refer to literature cited at end of report.

³ Gerhardt, T. D. On finite element modeling of tapered wood beams. in preparation. U.S. Dep. Agric. Forest Ser., For. Prod. Lab., Madison, Wis.

The program presented here adds to the Taylor program the capability to analyze nonisotropic materials and the cubic quadrilateral isoparametric plane element. The former addition makes analysis of wood- or composite-based structures possible by providing proper formulation for elements with orthotropic and anisotropic (wood with slope of grain) elastic properties. The cubic element can be easily collapsed to provide an accurate, fully compatible fracture mechanics element (5). Although the cubic element is not included in commercially available FE programs, some researchers have used the cubic element to model certain regions in notch problems (1,2).

User Instructions

To properly input data for an FE run, first review Taylor's (6) instructions in section 24.3, pages 690 to 695. These instructions need to be modified only minimally, with the exception of inputting the material property data. The following comments will consider both material property input and use of the cubic isoparametric element.

Inputting Material Property Data.

Four cards are now required for each material in the structure instead of the three required by Taylor (6). The first two cards are identical to Taylor's. The first card indicates that material property data follows, and the second card inputs the material set number and the element type (IEL). IEL should be input as 1 for any of the plane stress/strain elements. Card 3 is in a 4I5,F10.0 format as follows:

Columns	Variable
1-5	MATYPE
6-10	I
11-15	L
16-20	K
21-30	ANGLE

MATYPE is the material-type variable and has the following values:

- 1 for isotropic materials.
- 2 for materials orthotropic in the global x-y plane.
- 3 for materials orthotropic in a local 1-2 plane (see fig. 1).
- 4 for anisotropic materials.

I is the plane loading variable and has the following values:

- = 0 for plane strain loading.
- ≠ 0 for plane stress loading.

L is the order of Gaussian quadrature specified for stiffness matrix determination (L x L points/element).

K is the order of Gaussian quadrature specified for stress determination (K x K points/element).

ANGLE is the counterclockwise orientation of 1-2 local coordinates from global x-y coordinates (only used when MATYPE = 3); θ in figure 1.

The recommended order of Gaussian quadrature (7) is L = K = 3 for the cubic 12-node element, L = K = 2 for the quadratic 8-node element, and L = K = 1 for both the linear 4-node and triangular 3-node elements.

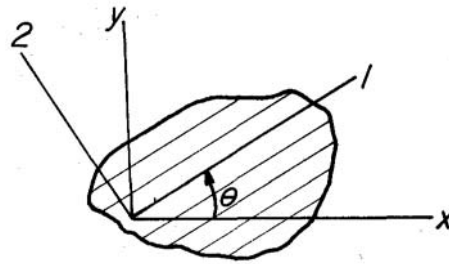


Figure 1.—Principal material axes. (M151918)

The fourth card is in an 8F10.0 format. The form of the fourth card depends on the value of MATYPE specified on the third card:

MATYPE = 1	
Columns	Variable
1-10	D(4)
11-20	E
21-30	v

MATYPE = 2	
Columns	Variable
1-10	D(4)
11-20	E _x
21-30	v _{xy}
31-40	E _y
41-50	G _{xy}
51-60*	E _z *
61-70*	v _{xz} *
71-80*	v _{yz} *

MATYPE = 3	
Columns	Variable
1-10	D(4)
11-20	E ₁
21-30	v ₁₂
31-40	E ₂
41-50	G ₁₂
51-60*	E ₃ *
61-70*	v ₁₃ *
71-80*	v ₂₃ *

MATYPE = 4	
Columns	Variable
1-10	D(4)
11-20	D ₁₁
21-30	D ₁₂
31-40	D ₁₃
41-50	D ₂₂
51-60	D ₂₃
61-70	D ₃₃

D(4) is material density—notneeded for static analysis.

E is modulus of elasticity.

G is the shear modulus.

v is Poisson's ratio.

D_{ij} are componets of the symmetric "Moduli of Elasticity" matrix for an anisotropic material. These componets are defined in (3).

* (*) indicates that these properties are only required for plane strain analysis (I = 0).

Specifying 12-Node Cubic Isoparametric Element

The following steps are needed to specify the 12-node cubic isoparametric element:

- (1) In the control card set $NEN = 12$.
- (2) When inputting element data (ELEM) use the local node numbering sequence shown in figure 2.

The cubic element can be degenerated to either quadratic or linear displacement fields on any desired side by specifying $IX = 0$ for one or two of the side nodes. This capability is useful when the structure is to be modeled by more than one type of element. For example, it may be desirable to model regions in areas of suspected stress concentrations with cubic elements and the remainder of the structure with quadratic or linear elements.

Implementation of Program and Listing

The details required for incorporating the developed program into Taylor's program (6) are described in this section.

Deletions

Delete statements 31-36 in subroutine SHAP2 in (6). This eliminates the nine-node Lagrangian element.

Additions

Add subroutines ELPROP, SHAP3, TRANSF, and BTREB in the appendix to the program in (6).

Add the following 'Common' statement to subroutine PMESH in (6):

```
COMMON / WRITE / PRT
```

Add the following 'Implicit' statement to all subroutines in (6) if double precision computations are desired:

```
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
```

Substitutions

Substitute subroutine ELMT01 in the appendix for subroutine ELMT01 in (6).

Substitute the two statements that follow for statement 18 in subroutine SHAPE in (6):

```
120 IF(NEL.GT.4.AND.NEL.LE.8) CALL SHAP2  
    (SS,TT,SHP,IX,NEL)
```

```
IF(NEL.GT.8) CALL SHAP3(SS,TT,SHP,IX)
```

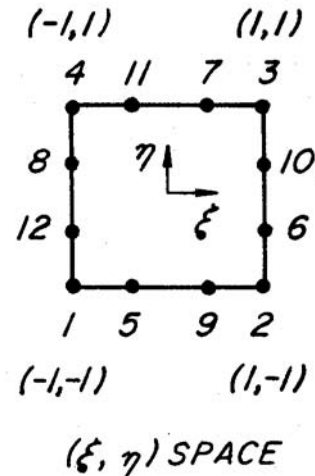


Figure 2—The cubic isoparametric element (local node numbering). (M151917)

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Appendix

The subroutines which follow were written in ASCII Fortran Level 9R1 (Sperry Univac Series 1100). This language allows IF-THEN-ELSE blocking statements. If the program is to be used with a version of Fortran which does not permit these statements, conventional IF statements must be substituted.

Subroutine ELPROP

```
1      SUBROUTINE ELPROP(D)
2 C.... THIS SUBROUTINE DETERMINES MATRIX COEFFICIENTS OF [D] FOR
3 C.... ISOTROPIC OR ORTHOTROPIC MATERIALS UNDER PLANE STRESS/STRAIN
4 C.... LOADING CONDITIONS FROM THE APPROPRIATE MATERIAL CONSTANTS.
5      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
6      LOGICAL PRT
7      COMMON /CDATA/ O,HEAD(20),NUMNP,NUMEL,NUMMAT,NEN,NEQ,IPR
8      COMMON/ELDATA/ DM,N,MA,MCT,IEL,NEL
9      COMMON /WRITE/ PRT
10     DIMENSION D(1),WD(2),T(3,3),DXY(3,3)
11     DATA WD/4HRESS,4HRAIN/
12 C....
13     READ (5,1000) MATYPE,I,L,K,ANGLE
14     READ (5,1001) D(4),E1,RNU12,E2,G,E3,RNU13,RNU23
15 C.... DETERMINE WHETHER THE PROBLEM IS PLANE STRESS OR PLANE STRAIN.
16     IF (I.NE.0) I=1
17     IF (I.EQ.0) I=2
18 C.... STORE VALUE OF MATYPE (FOR USE IN SUBROUTINE ELMT01)
19     D(1) = MATYPE
20 C.... STORE ORDERS OF GAUSSIAN QUADRATURE TO BE USED IN STIFFNESS MATRIX
21 C.... AND STRESS EVALUATION (L AND K - FOR USE IN SUBROUTINE ELMT01)
22     L = MIN0(3,MAX0(1,L))
23     D(2) = L
24     K = MIN0(3,MAX0(1,K))
25     D(3) = K
26     IF (PRT) WRITE(6,2000) WD(1),MATYPE
27 C....
28 C.... GO TO CORRECT ARRAY PROCESSOR
29     GO TO (1,2,2,4),MATYPE
30 C....
31 C.... ISOTROPIC MATERIAL
32 C....
33 1     D(5) = E1*(1. + (1-I)*RNU12)/(1. + RNU12)/(1. - I*RNU12)
34     D(6) = RNU12*D(5)/(1. + (1 - I)*RNU12)
35     D(8) = E1/2./(1. + RNU12)
36     D(7) = D(5)
37     IF (PRT) WRITE(6,2101) E1,RNU12
38     GO TO 20
39 C....
40 C.... ORTHOTROPIC MATERIAL
41 C....
42 2     IF (MATYPE.EQ.2.AND.PRT) WRITE (6,2202)
43     IF (MATYPE.EQ.3.AND.PRT) WRITE (6,2302) ANGLE
44     IF (PRT) WRITE (6,2203) E1,E2,RNU12,G
45     D(8) = G
46     RNU21 = RNU12*E2/E1
47     IF (I.EQ.2) GO TO 10
48 C.... PLANE STRESS
49     DUM = 1.0 - RNU12*RNU21
50     D(5) = E1/DUM
51     D(7) = E2/DUM
```

```

52      D(6) = RNU12*D(7)
53      GO TO 20
54 C.... PLANE STRAIN
55 10     RNU31 = RNU13*E3/E1
56       RNU32 = RNU23*E3/E2
57       DUM = 1. - RNU12*RNU21 - RNU13*RNU31 - RNU23*RNU32 -
58 1      RNU21*RNU32*RNU13 - RNU12*RNU31*RNU23
59       D(5) = E1*(1. - RNU23*RNU32)/DUM
60       D(6) = E2*(RNU12 + RNU32*RNU13)/DUM
61       D(7) = E2*(1. - RNU13*RNU31)/DUM
62       IF (PRT) WRITE (6,2204) E3,RNU13,RNU23
63 20     IF (PRT) WRITE(6,2001) D(4),L,L,K,K
64       IF (MATYPE.EQ.3) GO TO 3
65       RETURN
66 C....
67 C.... ORTHOTROPIC WITH RESPECT TO 1-2 COORDINATES
68 C....
69 C.... DETERMINE TRANSFORMATION MATRIX
70 3      CALL TRANSF (ANGLE,T)
71 C.... TRANSFORM PROPERTIES MATRIX TO GLOBAL (X,Y) COORDINATES.
72       CALL BTREB (T,3,D(5),D(6),D(7),D(8),DXY)
73       K=5
74       DO 31 I=1,3
75       DO 31 J=1,3
76       D(K) = DXY(I,J)
77       K = K + 1
78 31     CONTINUE
79       RETURN
80 C....
81 C.... ANISOTROPIC MATERIAL
82 C....
83 4      IF (PRT) WRITE (6,2402) E1,RNU12,E2,G,E3,RNU13
84       D(5) = E1
85       D(6) = RNU12
86       D(7) = E2
87       D(8) = G
88       D(9) = E3
89       D(10) = RNU13
90       GO TO 20
91 C.... FORMAT STATEMENTS
92 1000    FORMAT (4I5,F10.0)
93 1001    FORMAT (8F10.0)
94 2000    FORMAT(//,5X,8HPLANE ST,A4,23H LINEAR ELASTIC ELEMENT,10X,'MATYPE
95         1= ',12,/)
96 2001    FORMAT(/20X,7HDENSITY,10X,E18.5,/,20X,44HGAUSS PTS IN XI, ETA DIRE
97         1CTIONS RESPECTIVELY,/,30X,'(1). FOR STIFFNESS COMPUTATION',5X,I1,
98         2 ',/,I1,/,30X,'(2). FOR STRESS COMPUTATION',8X,I1,/,/,I1)
99 2101    FORMAT (10X,'ISOTROPIC MATERIAL',/,/,15X,18HYOUNG'S MODULUS = , 4X,
100        1E18.5,/,15X,18HPOISSON'S RATIO = ,10X,F8.5)
101 2202    FORMAT (10X,'ORTHOTROPIC MATERIAL, PRINCIPAL DIRECTIONS (1,2) COIN
102        1CIDE WITH GLOBAL (X,Y) AXES RESPECTIVELY')
103 2203    FORMAT (1X,/,/,15X, 7HE1 = , E18.5,/,15X,7HE2 = , E18.5,/,15X
104        1,7HNU12 = , 6X,F8.5,/,15X,7HG12 = ,E18.5)
105 2204    FORMAT (15X,7HE3 = , E18.5,/,15X,7HNU13 = , 6X,F8.5,/,15X,7HNU23
106        1 = ,6X,F8.5)
107 2302    FORMAT (10X,'ORTHOTROPIC MATERIAL, PRINCIPAL DIRECTION 1 ORIENTED
108        1AT A CCW ANGLE OF ',F9.4,' DEGREES FROM THE GLOBAL X AXIS.')
109 2402    FORMAT (10X,'ANISOTROPIC MATERIAL',/,/,15X,'E(1,1) = ',E18.5,/,15X
110        1,'E(1,2) = ',E18.5,/,15X,'E(1,3) = ',E18.5,/,15X,'E(2,2) = ',E18.5,
111        2/,15X,'E(2,3) = ',E18.5,/,15X,'E(3,3) = ',E18.5)
112       END

```

*** STATEMENT NUMBERS ***

1	29	*33		
2	29	*42		
3	64	*70		
4	29	*83		
10	47	*55		
20	38	53	*63	90
31	74	75	*78	
1000	13	*92		
1001	14	*93		
2000	26	*94		
2001	63	*96		
2101	37	*99		
2202	42	*101		
2203	44	*103		
2204	62	*105		
2302	43	*107		
2402	83	*109		

*** VARIABLES ***

ANGLE	*13	43	70										
BTREB	72												
D	1	10	*14	*19	*23	*25	*33	*34	*35	*36	*45	*50	
	*51	*52	*59	*60	*61	63	72	*76	*84	*85	*86	*87	
	*88	*89											
DM	8												
DUM	*49	50	51	*57	59	60	61						
DXV	10	72	76										
E1	*14	33	35	37	44	46	50	55	59	83	84		
E2	*14	44	46	51	56	60	61	83	86				
E3	*14	55	56	62	83	88							
ELPROP	1												
G	*14	44	45	83	87								
HEAD	7												
I	*13	*16	*17	26	33	34	47	*74	75	76			
IEL	8												
IPR	7												
J	*75	76											
K	*13	*24	25	63	*73	76	*77						
L	*13	*22	23	63									
MA	8												
MATYPE	*13	19	26	29	42	43	64						
MAX0	22	24											
MCT	8												
MIN0	22	24											
N	8												
NEL	8												
NEN	7												
NEQ	7												
NUMEL	7												
NUMMAT	7												
NUMNP	7												
O	7												
PRT	6	9	26	37	42	43	44	62	63	83			
RNU12	*14	33	34	35	37	44	46	49	52	57	60	83	85
RNU13	*14	55	57	60	61	62	83	89					
RNU21	*46	49	57										
RNU23	*14	56	57	59	62								
RNU31	*55	57	61										
RNU32	*56	57	59	60									
T	10	70	72										
TRANSF	70												
WD	10	*11	26										

Subroutine TRANSF

```

1  SUBROUTINE TRANSF(BETA,T)
2  IMPLICIT DOUBLE PRECISION (A-H,O-Z)
3  DIMENSION T(3,3)
4  DATA PI/3.141592653589793238D000/
5  C.... THIS SUBROUTINE CONSTRUCTS THE PLANE TRANSFORMATION MATRIX [T]
6  C.... FOR AN ANGLE OF BETA DEGREES, I.E. THE LOCAL 1-2 COORDINATES ARE
7  C.... ORIENTATED BETA DEGREES COUNTER-CLOCKWISE OF THE GLOBAL
8  C.... X-Y COORDINATES
9  BETA = BETA*PI/180.
10 T(1,1) = DCOS(BETA)**2
11 T(1,2) = DSIN(BETA)**2
12 T(1,3) = DSIN(BETA)*DCOS(BETA)
13 T(2,1) = T(1,2)
14 T(2,2) = T(1,1)
15 T(3,2) = 2.0*T(1,3)
16 T(2,3) = -1.0*T(1,3)
17 T(3,1) = 2.0*T(2,3)
18 T(3,3) = T(1,1) - T(1,2)
19 RETURN
20 END

```

```

*** VARIABLES ***
BETA      1    *9    10    11    12
DCOS      10   12
DSIN      11   12
PI        *4    9
T          1    3    *10   *11   *12   *13   *14   *15   *16   *17   *18
TRANSF    1

```

Subroutine BTREB

```

1      SUBROUTINE BTREB (B,IBCOLS,E11,E12,E22,E33,PROD)
2 C.... THIS SUBROUTINE COMPUTES THE MATRIX MULTIPLICATION BT*E*B = PROD
3 C.... E IS A 3 BY 3 SYMMETRIC MATRIX WITH NON ZERO COMPONENTS E(1,1),
4 C.... E(1,2),E(2,1),E(2,2),E(3,3).  B IS A 3 BY IBCOLS MATRIX.
5 C.... PROD IS A SYMMETRIC MATRIX. ONLY THE UPPER HALF IS COMPUTED.
6      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
7      DIMENSION B(3,IBCOLS),PROD(IBCOLS,IBCOLS)
8      DO 1 I=1,IBCOLS
9          B1I = B(1,I)
10         B2I = B(2,I)
11         DUM1 = E11*B1I + E12*B2I
12         DUM2 = E12*B1I + E22*B2I
13         DUM3 = E33*B(3,I)
14         DO 1 J=I,IBCOLS
15 1      PROD(I,J) = B(1,J)*DUM1 + B(2,J)*DUM2 + B(3,J)*DUM3
16      RETURN
17      END

```

*** STATEMENT NUMBERS ***

	1	8	14	*15	***	VARIABLES	***
					10	13	15
B		1	7	9			
B1I		*9	11	12			
B2I		*10	11	12			
BTREB		1					
DUM1		*11	15				
DUM2		*12	15				
DUM3		*13	15				
E11		1	11				
E12		1	11	12			
E22		1	12				
E33		1	13				
I		*8	9	10	13	14	15
IBCOLS		1	7	8	14		
J		*14	15				
PROD		1	7	*15			

Subroutine SHAP3

```

1  SUBROUTINE SHAP3(XI,ETA,SHP,IX)
2  C.... THIS SUBROUTINE ADDS SHAPE FUNCTIONS AND NECESSARY
3  C.... DERIVATIVES FOR THE ISOPARAMETRIC CUBIC ELEMENT AS REQUIRED
4  C.... IMPLICIT DOUBLE PRECISION (A-H,O-Z)
5  C.... DIMENSION IX(1),SHP(3,1)
6  C....
7  C.... SET VALUES FOR NEEDED CONSTANTS
8  S2 = (1. - XI*XI)/2.
9  T2 = (1. - ETA*ETA)/2.
10 C0 = 27./16.
11 ONETHD = 1./3.
12 CXISQ = C0*S2
13 CETASQ = C0*T2
14 C1XI = XI - ONETHD
15 C2XI = XI + ONETHD
16 C1ETA = ETA - ONETHD
17 C2ETA = ETA + ONETHD
18 D1XI = CXISQ - C0*XI*C1XI
19 D2XI = CXISQ - C0*XI*C2XI
20 D1ETA = CETASQ - C0*ETA*C1ETA
21 D2ETA = CETASQ - C0*ETA*C2ETA
22 C1MXI = 1. - XI
23 C1PXI = 1. + XI
24 C1META = 1. - ETA
25 C1PETA = 1. + ETA
26 C....
27 C.... ZERO SHP(J,II)
28 DO 100 I = 5,12
29 DO 100 J = 1,3
30 100 SHP(J,I) = 0.0
31 C.... IF MIDSIDE NODE II IS NOT SPECIFIED, I.E. IX(II) = 0,
32 C.... THEN SHP(J,II) ,J=1-3,WILL STILL EQUAL 0 AFTER THE
33 C.... FOLLOWING STATEMENTS
34 C.... THUS, THE CORNER NODES ON THIS EDGE WILL RETAIN ONLY
35 C.... QUADRATIC OR LINEAR TERMS
36 C....
37 C....
38 C.... COMPUTE SHAPE FUNCTIONS AND DERIVATIVES - SEE FIG.2 FOR NUMBERING
39 C....
40 IF (IX(5).EQ.0.AND.IX(9).EQ.0) GO TO 101
41 IF (IX(5).NE.0.AND.IX(9).NE.0) THEN
42 SHP(1,5) = -C1META*D1XI
43 SHP(2,5) = C1XI*CXISQ
44 SHP(3,5) = -C1META*SHP(2,5)
45 SHP(1,9) = C1META*D2XI
46 SHP(2,9) = -C2XI*CXISQ
47 SHP(3,9) = -C1META*SHP(2,9)
48 ELSE
49 SHP(1,5) = -XI*C1META
50 SHP(2,5) = -S2
51 SHP(3,5) = S2*C1META
52 END IF
53 101 IF (IX(6).EQ.0.AND.IX(10).EQ.0) GO TO 102
54 IF (IX(6).NE.0.AND.IX(10).NE.0) THEN
55 SHP(1,6) = -C1ETA*CETASQ
56 SHP(2,6) = -C1PXI*D1ETA
57 SHP(3,6) = C1PXI*SHP(1,6)
58 SHP(1,10) = C2ETA*CETASQ
59 SHP(2,10) = C1PXI*D2ETA
60 SHP(3,10) = C1PXI*SHP(1,10)
61 ELSE

```

```

62      SHP(1,6) = T2
63      SHP(2,6) = -ETA*C1PXI
64      SHP(3,6) = T2*C1PXI
65      END IF
66 102  IF (IX(7).EQ.0.AND.IX(11).EQ.0) GO TO 103
67      IF (IX(7).NE.0.AND.IX(11).NE.0) THEN
68          SHP(1,7) = C1PETA*D2XI
69          SHP(2,7) = C2XI*CXISQ
70          SHP(3,7) = C1PETA*SHP(2,7)
71          SHP(1,11) = -C1PETA*D1XI
72          SHP(2,11) = -C1XI*CXISQ
73          SHP(3,11) = C1PETA*SHP(2,11)
74      ELSE
75          SHP(1,7) = -XI*C1PETA
76          SHP(2,7) = S2
77          SHP(3,7) = S2*C1PETA
78      END IF
79 103  IF (IX(8).EQ.0.AND.IX(12).EQ.0) GO TO 104
80      IF (IX(8).NE.0.AND.IX(12).NE.0) THEN
81          SHP(1,8) = -C2ETA*CETASQ
82          SHP(2,8) = C1MXI*D2ETA
83          SHP(3,8) = -C1MXI*SHP(1,8)
84          SHP(1,12) = C1ETA*CETASQ
85          SHP(2,12) = -C1MXI*D1ETA
86          SHP(3,12) = -C1MXI*SHP(1,12)
87      ELSE
88          SHP(1,8) = -T2
89          SHP(2,8) = -ETA*C1MXI
90          SHP(3,8) = T2*C1MXI
91      END IF
92  C....
93  C.... CORRECT CORNER NODES FOR PRESENCE OF MIDSIDE NODES
94 104  K = 8
95      KK = 12
96      DO 109 I = 1,4
97          L = I + 4
98          LL = I + 8
99  C.... ADJUST CORNER SHAPE FUNCTION FOR NODES ON THE CW SIDE
100      IF (IX(KK).NE.0.AND.IX(K).NE.0) THEN
101          DO 111 J=1,3
102 111      SHP(J,I) = SHP(J,I) - ONETHD*(2.0*SHP(J,KK) + SHP(J,K))
103      ELSE
104          DO 121 J=1,3
105 121      SHP(J,I) = SHP(J,I) - 0.5*SHP(J,K)
106      END IF
107  C.... ADJUST CORNER SHAPE FUNCTION FOR NODES ON THE CCW SIDE
108      IF (IX(LL).NE.0.AND.IX(L).NE.0) THEN
109          DO 112 J=1,3
110 112      SHP(J,I) = SHP(J,I) - ONETHD*(2.0*SHP(J,L) + SHP(J,LL))
111      ELSE
112          DO 122 J=1,3
113 122      SHP(J,I) = SHP(J,I) - 0.5*SHP(J,L)
114      END IF
115      K = L
116 109  KK = LL
117      RETURN
118      END

```

*** STATEMENT NUMBERS ***

100	28	29	*30
101	40	*53	
102	53	*66	
103	66	*79	
104	79	*94	
109	96	*116	
111	101	*102	
112	109	*110	
121	104	*105	
122	112	*113	

*** VARIABLES ***

C0	*10	12	13	18	19	20	21						
C1ETA	*16	20	55	84									
C1MET	*24	42	44	45	47	49	51						
C1MXI	*22	82	83	85	86	89	90						
C1PETA	*25	68	70	71	73	75	77						
C1PXI	*23	56	57	59	60	63	64						
C1XI	*14	18	43	72									
C2ETA	*17	21	58	81									
C2XI	*15	19	46	69									
CETASQ	*13	20	21	55	58	81	84						
CXISQ	*12	18	19	43	46	69	72						
D1ETA	*20	56	85										
D1XI	*18	42	71										
D2ETA	*21	59	82										
D2XI	*19	45	68										
ETA	1	9	16	17	20	21	24	25	63	89			
I	*28	30	*96	97	98	102	105	110	113				
IX	1	5	40	41	53	54	66	67	79	80	100	108	
J	*29	30	*101	102	*104	105	*109	110	*112	113			
K	*94	100	102	105	*115								
KK	*95	100	102	*116									
L	*97	108	110	113	115								
LL	*98	108	110	116									
ONETHD	*11	14	15	16	17	102	110						
S2	*8	12	50	51	76	77							
SHAP3	1												
SHP	1	5	*30	*42	*43	*44	*45	*46	*47	*49	*50	*51	
	*55	*56	*57	*58	*59	*60	*62	*63	*64	*68	*69	*70	
	*71	*72	*73	*75	*76	*77	*81	*82	*83	*84	*85	*86	
	*88	*89	*90	*102	*105	*110	*113						
T2	*9	13	62	64	88	90							
XI	1	8	14	15	18	19	22	23	49	75			

Subroutine ELMT01

```

1      SUBROUTINE ELMT01(D,UL,XL,IX,TL,S,P,NDF,NDM,NST,ISW)
2 C
3 C.... PLANE STRESS/STRAIN ELASTIC LINEAR ELEMENT ROUTINE.
4 C
5      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
6      COMMON /CDATA/ O,HEAD(20),NUMNP,NUMEL,NUMMAT,NEN,NEQ,IPR
7      COMMON/ELDATA/ DM,N,MA,MCT,IEL,NEL
8      DIMENSION D(1),UL(NDF,1),XL(NDM,1),IX(1),TL(1),S(NST,1),P(1)
9      1 ,SHP(3,12),XI(9),ETA(9),WT(9),SIG(6),EPS(3)
10 C....
11 C.... GO TO CORRECT ARRAY PROCESSOR.
12      GO TO (1,2,3,4,5,4), ISW
13 C....
14 C.... INPUT MATERIAL PROPERTIES.
15 C....
16 1      CALL ELPROP(D)
17      LINT = 0
18      RETURN
19 2      RETURN
20 C....
21 C.... DETERMINE ELEMENT STIFFNESS MATRIX S(I,J)
22 C....
23 3      L = D(2)
24      IF(L*L.NE.LINT) CALL PGAUSS(L,LINT,XI,ETA,WT)
25      MATYPE = D(1)
26 C....      FOR EACH INTEGRATION POINT COMPUTE STIFFNESS CONTRIBUTION
27      DO 320 L = 1,LINT
28      CALL SHAPE(XI(L),ETA(L),XL,SHP,DETJAC,NDM,NEL,IX,.FALSE.)
29      DV = DETJAC*WT(L)
30      D11 = D(5)*DV
31      D12 = D(6)*DV
32      IF (MATYPE.LE.2) THEN
33      D22 = D(7)*DV
34      D33 = D(8)*DV
35      ELSE
36      D13 = D(7)*DV
37      D22 = D(8)*DV
38      D23 = D(9)*DV
39      D33 = D(10)*DV
40      END IF
41 C....
42 C....      FOR EACH NODE J COMPUTE DB = D*B
43 C....
44      DO 320 J = 1,NEL
45      IF (MATYPE.LE.2) THEN
46      DB11 = D11*SHP(1,J)
47      DB12 = D12*SHP(2,J)
48      DB21 = D12*SHP(1,J)
49      DB22 = D22*SHP(2,J)
50      DB31 = D33*SHP(2,J)
51      DB32 = D33*SHP(1,J)
52      ELSE
53      DB11 = D11*SHP(1,J) + D13*SHP(2,J)
54      DB12 = D12*SHP(2,J) + D13*SHP(1,J)
55      DB21 = D12*SHP(1,J) + D23*SHP(2,J)
56      DB22 = D22*SHP(2,J) + D23*SHP(1,J)
57      DB31 = D33*SHP(2,J) + D13*SHP(1,J)
58      DB32 = D33*SHP(1,J) + D23*SHP(2,J)
59      END IF
60 C....
61 C....      FOR EACH NODE I COMPUTE S = BT*DB

```

```

62 C....
63      DO 320 I = 1,J
64      S(I+I-1,J+J-1)=S(I+I-1,J+J-1)+SHP(1,I)*DB11+SHP(2,I)*DB31
65      S(I+I-1,J+J)=S(I+I-1,J+J)+SHP(1,I)*DB12+SHP(2,I)*DB32
66      S(I+I,J+J-1)=S(I+I,J+J-1)+SHP(1,I)*DB31+SHP(2,I)*DB21
67      S(I+I,J+J)=S(I+I,J+J)+SHP(1,I)*DB32+SHP(2,I)*DB22
68 320      CONTINUE
69 C....
70 C.... COMPUTE LOWER TRIANGULAR PART BY SYMMETRY
71 C....
72      NL = NEL + NEL
73      DO 330 I = 2,NL
74      DO 330 J = 1,I
75 330      S(I,J) = S(J,I)
76      RETURN
77 C....
78 C.... COMPUTE ELEMENT STRESSES, STRAINS, AND FORCES
79 C....
80 4      L = D(2)
81      IF(ISW.EQ.4) L = D(3)
82      IF(L*.NE.LINT) CALL PGAUSS(L,LINT,XI,ETA,WT)
83      MATYPE = D(1)
84      DO 600 L = 1,LINT
85 C.... COMPUTE ELEMENT SHAPE FUNCTIONS
86      CALL SHAPE(XI(L),ETA(L),XL,SHP,DETJAC,NDM,NEL,IX,.FALSE.)
87 C.... COMPUTE STRAINS AND COORDINATES
88      DO 410 I = 1,3
89 410      EPS(I) = 0.0
90      XX = 0.0
91      YY = 0.0
92      DO 420 J = 1,NEL
93      XX = XX + SHP(3,J)*XL(1,J)
94      YY = YY + SHP(3,J)*XL(2,J)
95      EPS(1) = EPS(1) + SHP(1,J)*UL(1,J)
96      EPS(3) = EPS(3) + SHP(2,J)*UL(2,J)
97 420      EPS(2) = EPS(2) + SHP(1,J)*UL(2,J) + SHP(2,J)*UL(1,J)
98 C.... COMPUTE STRESSES
99      IF (MATYPE.LE.2) THEN
100      SIG(1) = D(5)*EPS(1) + D(6)*EPS(3)
101      SIG(3) = D(6)*EPS(1) + D(7)*EPS(3)
102      SIG(2) = D(8)*EPS(2)
103      ELSE
104      SIG(1) = D(5)*EPS(1) + D(6)*EPS(3) + D(7)*EPS(2)
105      SIG(3) = D(6)*EPS(1) + D(8)*EPS(3) + D(9)*EPS(2)
106      SIG(2) = D(7)*EPS(1) + D(9)*EPS(3) + D(10)*EPS(2)
107      END IF
108 C.... GO TO STATEMENT 620 FOR COMPUTATION OF ELEMENT NODAL FORCES
109      IF(ISW.EQ.6) GO TO 620
110      CALL PSTRES(SIG,SIG(4),SIG(5),SIG(6))
111 C.... OUTPUT STRESSES AND STRAINS
112      MCT = MCT - 2
113      IF(MCT.GT.0) GO TO 430
114      WRITE(6,2001) 0,HEAD
115      MCT = 50
116 430      WRITE(6,2002) N,MA,XX,YY,SIG,EPS
117      WRITE (26,2010) N,XX,YY,EPS(1),EPS(3),EPS(2)
118 600      CONTINUE
119      RETURN
120 C....
121 C.... COMPUTE INTERNAL FORCES
122 C....
123 620      DV = DETJAC*WT(L)

```

```

124 J1 = 1
125 DO 610 J = 1,NEL
126 P(J1) = P(J1) - (SHP(1,J)*SIG(1) + SHP(2,J)*SIG(2))*DV
127 P(J1+1) = P(J1+1) - (SHP(1,J)*SIG(2) + SHP(2,J)*SIG(3))*DV
128 610 J1 = J1 + NDF
129 GO TO 600
130 C....
131 C.... COMPUTE CONSISTENT MASS MATRIX - SEE TAYLOR'S ELMT01
132 C....
133 5 WRITE (6,990)
134 990 FORMAT (10X,'**** MASS MATRIX FORMULATION FOR THIS ELEMENT
135 1 'IS NOT AVAILABLE AT THIS TIME ****')
136 STOP
137 C.... FORMATS FOR INPUT-OUTPUT
138 2001 FORMAT(A1,20A4//5X,16HELEMENT STRESSES//,5X,20H ELEMENT MATERIAL
139 1 ,7H1-COORD,6X,7H2-COORD,4X,9H11-STRESS,4X,9H12-STRESS,4X,
140 2 9H22-STRESS,5X,8H1-STRESS,5X,8H2-STRESS,3X,5HANGLE/50X,
141 3 9H11-STRAIN,4X,9H12-STRAIN,4X,9H22-STRAIN)
142 2002 FORMAT(2I10,2F13.4,5E13.4,F8.2/46X,3E13.4)
143 2010 FORMAT(I3,5D15.5)
144 END

```

*** STATEMENT NUMBERS ***

1	12	*16
2	12	*19
3	12	*23
4	12	*80
5	12	*133
320	27	44 63 *68
330	73	74 *75
410	88	*89
420	92	*97
430	113	*116
600	84	*118 129
610	125	*128
620	109	*123
990	133	*134
2001	114	*138
2002	116	*142
2010	117	*143

*** VARIABLES ***

	1	8	16	23	25	30	31	33	34	36	37	38
D	39	80	81	83	100	101	102	104	105	106		
D11	*30	46	53									
D12	*31	47	48	54	55							
D13	*36	53	54	57								
D22	*33	*37	49	56								
D23	*38	55	56	58								
D33	*34	*39	50	51	57	58						
DB11	*46	*53	64									
DB12	*47	*54	65									
DB21	*48	*55	66									
DB22	*49	*56	67									
DB31	*50	*57	64	66								
DB32	*51	*58	65	67								
DETJAC	28	29	86	123								
DM	7											
DV	*29	30	31	33	34	36	37	38	39	*123	126	127
ELMT01	1											
ELPROP	16											
EPS	8	*89	*95	*96	*97	100	101	102	104	105	106	116
	117											
ETA	8	24	28	82	86							

HEAD	6	114										
I	*63	64	65	66	67	*73	74	75	*88	89		
IEL	7											
IPR	6											
ISW	1	12	81	109								
IX	1	8	28	86								
J	*44	46	47	48	49	50	51	53	54	55	56	57
	58	63	64	65	66	67	*74	75	*92	93	94	95
	96	97	*125	126	127							
J1	*124	126	127	*128								
L	*23	24	*27	28	29	*80	*81	82	*84	86	123	
LINT	*17	24	27	82	84							
MA	7	116										
MATYPE	*25	32	45	*83	99							
MCT	7	*112	113	*115								
N	7	116	117									
NDF	1	8	128									
NDM	1	8	28	86								
NEL	7	28	44	72	86	92	125					
NEN	6											
NEG	6											
NL	*72	73										
NST	1	8										
NUMEL	6											
NUMMAT	6											
NUMNP	6											
O	6	114										
P	1	8	*126	*127								
PGAUSS	24	82										
PSTRES	10											
S	1	8	*64	*65	*66	*67	*75					
SHAPE	28	86										
SHP	8	28	46	47	48	49	50	51	53	54	55	56
	57	58	64	65	66	67	86	93	94	95	96	97
	126	127										
SIG	8	*100	*101	*102	*104	*105	*106	110	116	126	127	
TL	1	8										
UL	1	8	95	96	97							
WT	8	24	29	82	123							
XI	8	24	28	82	86							
XL	1	8	28	86	93	94						
XX	*90	*93	116	117								
YY	*91	*94	116	117								

Gerhardt, Terry D. Plane stress analysis of wood members using isoparametric finite elements: A computer program. USDA For. Serv. Gen. Tech. Rep. FPL 35. Madison, WI: For. Prod. Lab.; 1983.16 p.

A finite element program is presented for stress analysis of wood members of arbitrary shape which are subjected to plane strain/stress-loading conditions. This program extends one which is available in the literature. User instructions and a listing of the developed subroutines are presented.

Keywords: Finite element analysis, computer program, isoparametric elements, stress analysis, orthotropic materials, anisotropic materials, plane loading, design, cubic finite element, quadratic finite element.

