September 26, 2014

I/O data format for Axisymmetric Stress Analysis
(f90_FEM_ASNT.f90)

1. Outline of a program 'f90_FEM_ASNT.f90'

- This is a program for Axisymmetric Stress Analysis with the function of no-tension stress analysis.
- As a method to simulate no-tension state, stress transfer method by Zienkiewicz is used. In this method, equilibrium state can be obtained by iterative calculation method using linear stiffness matrix and coordinate transformation method of internal forces. It is assumed that Poisson ratio in no-tension state element is zero.
- 4 noded isoparametric element with 4 Gauss points is used. 1 node has 2 degrees of freedom in axial direction and radius direction.
- Thickness of circumference direction of 1 element is 1 radian.
- Nodal forces, nodal displacements and nodal temperature changes can be given as loads. Inertia force can not be treated. If you give zero displacements to the nodes, it means completely restricted boundary.
- Only an isotropic material can be treated. However, since the tensile strength of a element is inputted as the element characteristic, when the tensile principal stress of an element exceeds the tensile strength of it, the behavior of the element turns into a behavior as a No-tension element which does not share tensile stress. If all elements have sufficiently large tensile strength, the behavior of a structure becomes a behavior as an elastic body.
- In coordinate system, z-direction is defined as axial direction and r-direction is defined as radius direction.
- Simultaneous linear equations are solved using Cholesky method for banded matrix. Although this solving process has iterative process for no-tension analysis, stiffness matrix is not changed using stress transfer method. Therefore, to create the triangular matrix is carried out only one time, and forward elimination and backward substitution process are repeated depending on the values of unbalanced forces.
- Convergence criterion is that the case ratio of displacement increment to total displacement for all degrees of freedom becomes less than 1×10^{-6}. Upper limit of iteration is set to 2000 times.
- Input/Output file name can be defined arbitrarily with the format of 'csv' and those are inputted from command line of MS-Windows.
- Used language for program is 'Fortran 90' and used compiler is 'MinGW gfortran.'

2. Format for input data file ('csv' format)

Items for input	Remarks
comment	Comment
NODT,NELT,MATEL,KOZ,KOR,NF,IPR	Basic values for analysis
Em,po,gamma,gkz,alpha,ts ....(1∼MATEL)....	Material properties
node-1,node-2,node-3,node-4,matno ....(1∼NELT)....	Element connectivity, Material set number (counterclockwise order of node numbers)
z,r,deltaT ....(1∼MNODT)....	Node coordinates, Temperature change of node (z: axial direction, r: radius direction)
nokz,rdis ....(1∼KOZ)....	Restricted node number and displacement in z-direction (Omit data input if KOZ=0)
nokr,rdis ....(1∼KOR)....	Restricted node number and displacement in r-direction (Omit data input if KOY=0)
node,fz,fr ....(1∼NF)....	Loaded node number, Load in z-direction, Load in r-direction (Omit data input if NF=0)

NODT : Number of nodes
NELT : Number of elements
MATEL : Number of material sets
KOZ : Number of restricted nodes in z-direction
KOR : Number of restricted nodes in r-direction
NF : Number of loaded nodes
IPR : Output format of stresses (0 or 1)
(0: Stresses for all Gauss points)
(1: Average stresses of element)

matno : Material set number
Em : Elastic modulus of element
po : Poisson's ratio of element
gamma : Unit weight of element
gkz : Acceleration in axial (z) -direction (ratio to 'g')
alpha : Coefficient of thermal expansion of element
ts : Tensile strength of element

■Notice

- ◯ Acceleration in only axial (z) -direction can be considered. Acceleration in radius (r) -direction cannot be considered in this program.
- ◯ Temperature changes are inputted as them of nodes ans they must be written in the same row written the node coordinates. For this item, temperature rising is positive.
- ◯ When tensile strength of element is not large and temperature decrease is large, equilibrium state may not be obtained because of indeterminate of structure.
- ◯ Restricted node means the node which has known (given) displacement. As a known (given) value of nodal displacement, any value can be given including zero for a restricted node.

■Load input method

We consider the cylinder under the internal pressure. The cylinder has the radius of r=3000mm, the length in axial direction of z=200mm and internal pressure of p=1 N/mm^2 is acted. Total load acted to 1 element with thickness of 1 radian is shown below.

$$p \times r \times 1(rad) \times z = 1(N/mm^2) \times 3,000(mm) \times 1(rad) \times 200(mm) = 600,000(N)$$

So, below loads must be acted for each node according to the thinking of equivalent nodal force,

Coordinate of node	Nodal force	Direction of load
(z,r)=(0,3,000)	300,000(N)	Positive radius direction
(z,r)=(200,3,000)	300,000(N)	Positive radius direction

3. Format for output data file ('csv' format)

Items for output
Comment
NODT,NELT,MATEL,KOZ,KOR,NF,IPR (Each value for above items)
*node characteristics node,z,r,fz,fr,fix-z,fix-r,rdis-z,rdis-r,deltaT node : Node number z,r : z & r-coordinates fz,fr : z & r-direction nodal forces fix-z : z-direction restricted condition (1: restricted, 0: not restricted) fix-r : r-direction restricted condition (1: restricted, 0: not restricted) rdis-z : z-direction specified displacement rdis-r : r-direction specified displacement deltaT : Temperature change of node .....(1∼NODT).....
*element characteristics element,node-1,node-2,node-3,node-4,E,po,alpha,ts,matno element : Element number node-1,node-2,node-3,node-4 : Element-nodes relationship E : Elastic modulus of element po : Poisson's ratio of element gamma : Unit weight of element gkz : Acceleration in z-direction (ratio to 'g') alpha : Coefficient of thermal expansion of element ts : Tensile strength of element matno : material set number .....(1∼NELT).....
*displacement and force node,coord-z,coord-r,dist-z,dist-r,reac-z,reac-r,ftvec-z,ftvec-r node : Node number coord-z,coord-r : Coordinates of z & r-direction dist-z,dist-r : Displacement in z & r-direction reac-z,reac-r : Internal force in z & r direction ftvec-z,ftvec-r : Unbalanced force in z & r-direction .....(1∼NODT).....
*stresses element,kk,sig-z,sig-r,sig-t.tau-zr,ps1,ps2,ang,noten,matno element : Element number kk : Gauss point number (IPR=0: 1∼4, IPR=1: Average stress of element) sig-z,sig-r,sig-t,tau-zr : Normal stresses in z & r & θ-direction, shearing stress ps1,ps2,ang : 1st & 2nd principal stresses, principal direction (degree) noten : flag for No-tension (0: Elastic, 1: ps1=no-tension, 2: ps1 and ps2=no-tension) matno : Material set number .....(1∼NELT, depending on the value of IPR).....
NODT=(Number of nodes), nt=(nt), mm=(mm), ib=(ib) nnn=(Number of itaration), icount=(Number of converged degrees of freedom) Calculation time=(calculation time) Date_time=(date of execution)

nt : Total degrees of freedom of FE equation
mm : Dimension of reduced FE equation
ib : band width of reduced FE equation

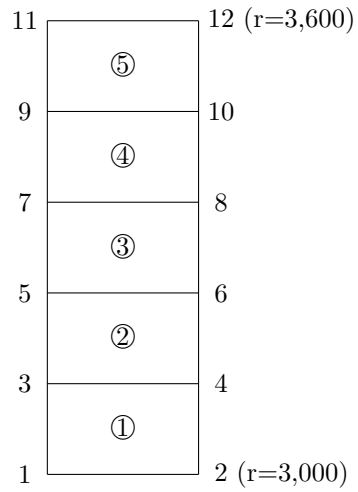
4. Simple model analysis

4.1 Outline of model

- ◯ Consider the pipe with internal diameter of 3000mm, thickness of 600mm internal water pressure of 1MPa.
- ◯ Characteristics of material are like cement concrete.
- ◯ Axial displacements are restricted. (All nodal displacements in z-direction are zero, pipe can be deformed freely.)
- ◯ Length of element in axial direction is 200mm.
- ◯ Pipe thickness is divided to 5 elements, so model has 12 nodes.
- ◯ Consider the elastic behavior of pipe, and elements have enough tensile strength.
- ◯ Nodal load of 300,000N is loaded for each node in order to realize the internal water pressure of 1MPa.

Material properties of element

Elastic modulus	Em	25,000 N/mm^2
Poisson's ratio	po	0.2
Unit weight	gamma	2.4×10^3 N
Acceleration in z-direction	gkz	0
Coefficient of thermal expansion	alpha	1.0×10^{-5} 1/∘C
Tensile strength	ts	1000 N/mm^2



4.2 Input data sample

```
Axsym_3000+600_in Comment
12,5,1,12,0,2,1 NODT,NELT,MATEL,KOZ,KOR,NF,IPR
2.5E+04,0.2,2.4e3,0,1.00E-05,1000 Material properties (Em,po,gamma,gkz,alpha,ts) for material set No.1
1, 2, 4, 3,1   Element-nodes relationship for element No.1, Material set number (No.1)
3, 4, 6, 5,1   Element-nodes relationship for element No.2, Material set number (No.1)
5, 6, 8, 7,1   Element-nodes relationship for element No.3, Material set number (No.1)
7, 8,10, 9,1   Element-nodes relationship for element No.4, Material set number (No.1)
9,10,12,11,1   Element-nodes relationship for element No.5, Material set number (No.1)
  0,3000,0     Coordinates (z,r) and temperature change for node No.1
200,3000,0     Coordinates (z,r) and temperature change for node No.2
  0,3120,0     Coordinates (z,r) and temperature change for node No.3
200,3120,0     Coordinates (z,r) and temperature change for node No.4
  0,3240,0     Coordinates (z,r) and temperature change for node No.5
200,3240,0     Coordinates (z,r) and temperature change for node No.6
  0,3360,0     Coordinates (z,r) and temperature change for node No.7
200,3360,0     Coordinates (z,r) and temperature change for node No.8
  0,3480,0     Coordinates (z,r) and temperature change for node No.9
200,3480,0     Coordinates (z,r) and temperature change for node No.10
  0,3600,0     Coordinates (z,r) and temperature change for node No.11
200,3600,0     Coordinates (z,r) and temperature change for node No.12
 1,0           Restricted node number and displacement in z-direction
 3,0           Restricted node number and displacement in z-direction
 5,0           Restricted node number and displacement in z-direction
 7,0           Restricted node number and displacement in z-direction
 9,0           Restricted node number and displacement in z-direction
11,0           Restricted node number and displacement in z-direction
 2,0           Restricted node number and displacement in z-direction
 4,0           Restricted node number and displacement in z-direction
 6,0           Restricted node number and displacement in z-direction
 8,0           Restricted node number and displacement in z-direction
10,0           Restricted node number and displacement in z-direction
12,0           Restricted node number and displacement in z-direction
1,0,300000     Loaded node number and load value in z & r directions
2,0,300000     Loaded node number and load value in z & r directions
```

4.3 Output data sample

Output data sample is shown below.

```
Axsym_3000+600_in Comment
NODT,NELT,MATEL,KOZ,KOR,NF,IPR
12,5,1,12,0,2,1
*node characteristics
node,z,r,fz,fr,fix-z,fix-r,rdis-z,rdis-r,deltaT
1,0.0000000E+00,0.3000000E+04,0.0000000E+00,0.3000000E+06,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
2,0.2000000E+03,0.3000000E+04,0.0000000E+00,0.3000000E+06,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
3,0.0000000E+00,0.3120000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
4,0.2000000E+03,0.3120000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
5,0.0000000E+00,0.3240000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
6,0.2000000E+03,0.3240000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
7,0.0000000E+00,0.3360000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
8,0.2000000E+03,0.3360000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
9,0.0000000E+00,0.3480000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
10,0.2000000E+03,0.3480000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
11,0.0000000E+00,0.3600000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
12,0.2000000E+03,0.3600000E+04,0.0000000E+00,0.0000000E+00,1,0,0.0000000E+00,0.0000000E+00,0.0000000E+00
*element characteristics
element,node-1,node-2,node-3,node-4,E,po,gamma,gkz,alpha,ts,matno
1,1,2,4,3,0.2500000E+05,0.2000000E+00,0.2400000E+04,0.0000000E+00,0.1000000E-04,0.1000000E+04,1
2,3,4,6,5,0.2500000E+05,0.2000000E+00,0.2400000E+04,0.0000000E+00,0.1000000E-04,0.1000000E+04,1
3,5,6,8,7,0.2500000E+05,0.2000000E+00,0.2400000E+04,0.0000000E+00,0.1000000E-04,0.1000000E+04,1
4,7,8,10,9,0.2500000E+05,0.2000000E+00,0.2400000E+04,0.0000000E+00,0.1000000E-04,0.1000000E+04,1
5,9,10,12,11,0.2500000E+05,0.2000000E+00,0.2400000E+04,0.0000000E+00,0.1000000E-04,0.1000000E+04,1
*displacements and forces
node,coord-z,coord-r,dist-z,dist-r,reac-z,reac-r,ftvec-z,ftvec-r
1,0.0000000E+00,0.3000000E+04,0.0000000E+00,0.6674946E+00,-0.1683410E+06,0.3000000E+06,0.1683410E+06,0.2444722E-08
2,0.2000000E+03,0.3000000E+04,0.0000000E+00,0.6674946E+00,0.1683410E+06,0.3000000E+06,-0.1683410E+06,-0.3259629E-08
3,0.0000000E+00,0.3120000E+04,0.0000000E+00,0.6572293E+00,-0.3401861E+06,-0.3230525E-08,0.3401861E+06,0.3230525E-08
4,0.2000000E+03,0.3120000E+04,0.0000000E+00,0.6572293E+00,0.3401861E+06,-0.8032657E-08,-0.3401861E+06,0.8032657E-08
5,0.0000000E+00,0.3240000E+04,0.0000000E+00,0.6483059E+00,-0.3532905E+06,0.5966285E-08,0.3532905E+06,-0.5966285E-08
6,0.2000000E+03,0.3240000E+04,0.0000000E+00,0.6483059E+00,0.3532905E+06,0.7421477E-08,-0.3532905E+06,-0.7421477E-08
7,0.0000000E+00,0.3360000E+04,0.0000000E+00,0.6405806E+00,-0.3663929E+06,-0.1367880E-08,0.3663929E+06,0.1367880E-08
8,0.2000000E+03,0.3360000E+04,0.0000000E+00,0.6405806E+00,0.3663929E+06,0.8440111E-09,-0.3663929E+06,-0.8440111E-09
9,0.0000000E+00,0.3480000E+04,0.0000000E+00,0.6339296E+00,-0.3794935E+06,0.7006747E-08,0.3794935E+06,-0.7006747E-08
10,0.2000000E+03,0.3480000E+04,0.0000000E+00,0.6339296E+00,0.3794935E+06,-0.2248271E-08,-0.3794935E+06,0.2248271E-08
11,0.0000000E+00,0.3600000E+04,0.0000000E+00,0.6282455E+00,-0.1922959E+06,-0.9432474E-08,0.1922959E+06,0.9432474E-08
12,0.2000000E+03,0.3600000E+04,0.0000000E+00,0.6282455E+00,0.1922959E+06,0.2153777E-08,-0.1922959E+06,-0.2153777E-08
*stresses
element,kk,sig-z,sig-r,sig-t,tau-zr,ps1,ps2,ang,noten,matno
1,0,0.9093931E+00,-0.8727786E+00,0.5419744E+01,0.2153978E-14,0.9093931E+00,-0.8727786E+00,0.6924914E-13,0,1
2,0,0.9093356E+00,-0.6398659E+00,0.5186544E+01,0.6325174E-15,0.9093356E+00,-0.6398659E+00,0.2339307E-13,0,1
3,0,0.9092880E+00,-0.4318988E+00,0.4978339E+01,0.1166049E-14,0.9092880E+00,-0.4318988E+00,0.4981385E-13,0,1
4,0,0.9092484E+00,-0.2454381E+00,0.4791680E+01,0.1515119E-14,0.9092484E+00,-0.2454381E+00,0.7518052E-13,0,1
5,0,0.9092151E+00,-0.7761736E-01,0.4623693E+01,0.3015901E-14,0.9092151E+00,-0.7761736E-01,0.1751041E-12,0,1
NODT=12 nt=24 mm=12 ib=4
nnn=2 dtest=0.6877D-12 ftest=0.5341D-07
Calculation time=   0.000(sec)
Date_time=26 September 2014 at 04:50 (gfortran)
```