Beam to Shell Temperature Differences for the CC Cryostat

Engineering Note # 3740.214-EN-280

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Originator: Rick Luther

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BEAM TO SHELL TEMPERATURE DIFFERENCES FOR THE CC CRYOSTAT

Introduction

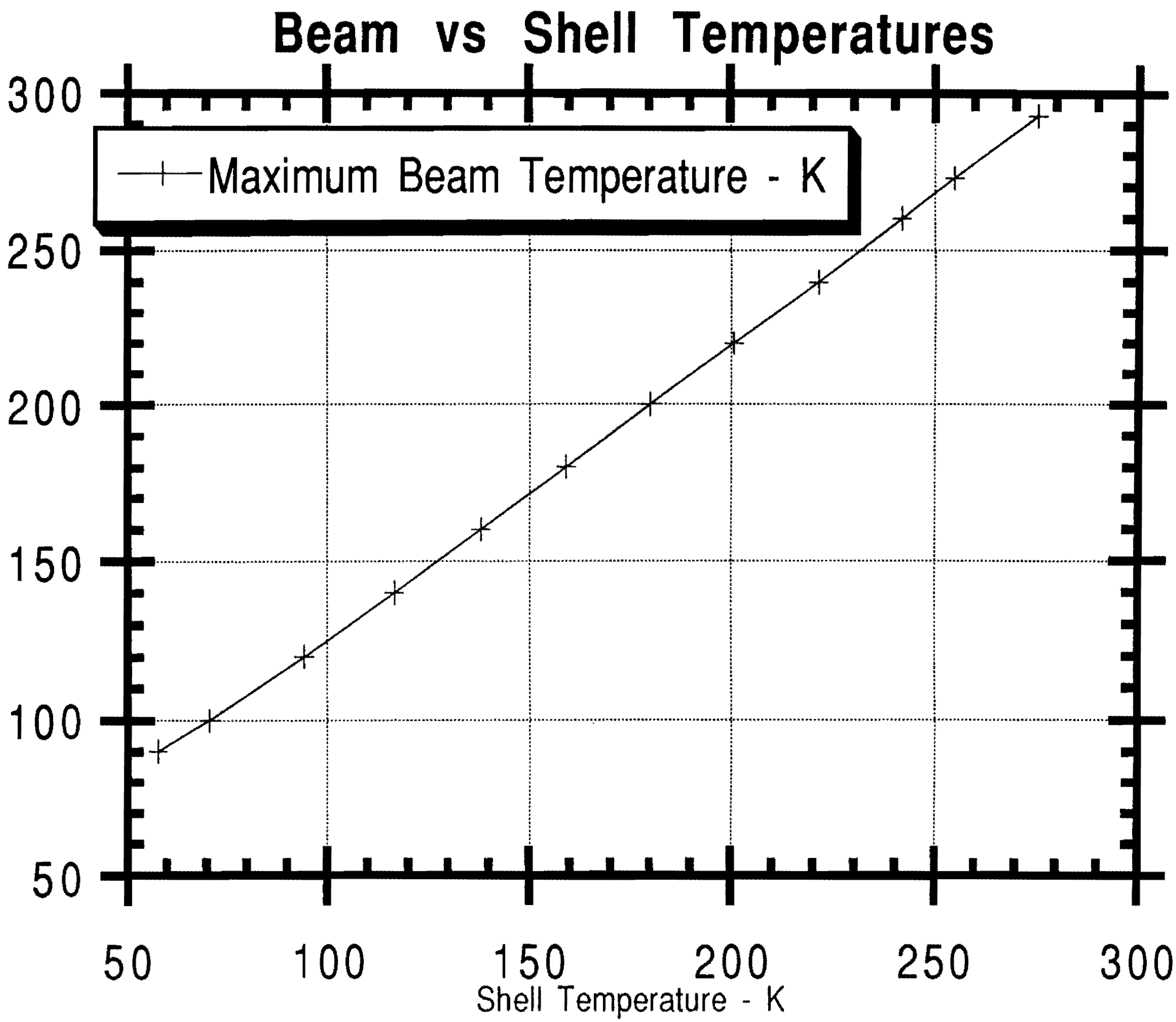
This note documents the calculation of stresses resulting from temperature differences between the CC cryostat shell and the module array support beams, and the calculation of corresponding maximum allowable temperature differences to be monitored during the cooldown of the cryostat. A finite element model of a portion of the inner vessel shell was analyzed for a uniform temperature change. The shell was assumed to be completely restrained by the support beams. A maximum allowable temperature difference was determined based on limits on secondary stress ranges prescribed by the ASME Code (Section VIII, Division 2).

Results

The maximum allowable difference between the cryostat shell and the support beams was found to vary from about 18K near room temperature to about 30K as the shell temperature approaches liquid argon temperature. The allowable values are tabulated below and plotted in Figure 1. The variation results from the decrease in the coefficient of thermal expansion of stainless steels at lower temperatures. As shown in the plot, the variation is roughly linear. Note that although the shell is assumed to be at the lower temperature in Fig. 1, the limitation on temperature difference will also apply during warmup, when the shell will likely be warmer than the beams.

Table 1.

Shell Temperature K	Max. Allowed Temp. Diff. K	Maximum Beam Temp. K
275.4	17.6	293
254.9	18.1	273
241.7	18.3	260
221.2	18.8	240
200.7	19.3	220
180	20	200
159.1	20.9	180
138.1	21.9	160
116.7	23.3	140
94.3	25.7	120
70.8	29.2	100
57.8	32.2	90



Beam vs Shell Temperatures
Maximum Beam Temperature - K
300
250
200
150
100
50
50
100
150
200
250
300
Shell Temperature - K

<u>Analysis</u>

The following is a brief description of the analysis of the shell stresses and the calculation of allowable stresses and temperature differences.

The finite element model represents an approximate "quarter model" of one side of the cryostat shell between the two "feet" where the array is supported. The shell was flattened and properties of stainless steel were assigned. A portion of the model in the area of the foot was made very stiff to represent the rigidity of the support boss which is welded into the shell. The line connecting the centers of the feet was given a symmetry boundary condition, as was the perpendicular line midway between the feet. Node number 13, located in the center of the foot, was fixed in the X-direction, and a uniform temperature of 100°F was applied. The resulting reaction force at node 13 was 270,200 lb. Since the finite element model represented only half of the shell, the calculated reaction force must be doubled to give the total reaction at each foot (540,400 lb). Sketches of the geometry and the model are included herein.

The first step in the evaluation is to calculate an allowable force at the foot based on the ASME Code. For the given geometry the force is transferred into the shell primarily by shear stresses distributed around the boss. The maximum value of this stress is approximately equal to twice the average shear stress (force/area). Because the boss is not normal to the shell, an equivalent diameter of 12" was used to calculate the area. The corresponding stress intensity is equal to twice the maximum shear stress. Section VIII, Division 2 of the ASME Code classifies stresses of this type as secondary membrane stresses and limits the total range of fluctuation of these stresses to 3S (equal to twice the yield stress). Since the stresses may reverse during warmup, the maximum stress intensity occurring during cooldown is limited to one half of the allowable range (1.5S=28.2 ksi). The reaction force which produces a stress intensity of 28.2 ksi is 166,000 lb.

Since each foot supports 180,000 lb, a coefficient of friction of at least 166/180=0.92 is required to develop the maximum allowable stress intensity. In addition, shear stresses in the 3.5" diameter block supporting the array at each foot will exceed yield if the coefficient of friction is larger than 0.75 (corresponding to a force of 135,000 lb). Therefore, it seems likely that slipping or minor plastic deformation of the support components will occur before the stress in the shell reaches its limit.

An allowable temperature difference between the cryostat shell and the warmer support beams was determined as a function of the beam temperature. As the temperature falls, the coefficient of thermal expansion decreases, and a larger temperature difference can be accommodated. The thermal strain developed in the model was first corrected to reflect the allowable force of 166,000 lb verses the force in the model of 540,000 lb, and then corrected for the proper coefficient of thermal expansion at several temperatures.

Table 1 presents the shell and beam temperatures along with the maximum allowable temperature differences. The temperatures are also plotted in Figure 1. These temperature differences will be monitored during the cooldown of the cryostat. Details of the calculations are given in the following pages.

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IN ORDER TO DEVELOP $V_M = 166^K$ THE COEFFICIENT OF FRICTION MUST BE AT LEAST:

$$\mu W_T = 166^K$$

$$\mu_{MIN} = \frac{166}{180} = 0.92$$ → THIS IS HIGH, SO SLIPPING WILL PROBABLY OCCUR.

CHECK SHEAR STRESS IN THE $3\frac{1}{2}''\phi$ BLOCK SUPPORTING THE ARRAY:

$$\tau_M = \frac{F}{A} = \frac{166^K}{\frac{\pi(3\frac{1}{2})^2}{4}} = 17.25 \text{ KSI}$$

THE CORRESPONDING S.I. IS:

$$SI = 2\tau_M = 34.5 \text{ KSI}$$

SINCE THIS STRESS REVERSES, LIMIT THIS ½ OF THE RANGE TO $\frac{3S}{2}$:

$$\frac{3(18.8)}{2} = 28.2 \text{ KSI}$$

∴ THE STRESS LIMIT IS EXCEEDED. HOWEVER, THIS IS PROBABLY NOT OBJECTIONABLE DUE TO ITS FUNCTION, ETC. THE MIN. COEFF OF FRICTION RQD TO EXCEED THE STRESS LIMIT IS:

$$\mu = 0.92\left(\frac{28.2}{34.5}\right) = 0.75$$ → SLIPPING STILL LIKELY.

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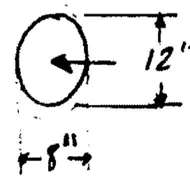
$$F_{RESULTANT} = 2 \times 270.2^K = 540.4^K$$

FOR THE BOSSES THIS FORCE IS TRANSFERRED BY SHEAR STRESSES. THE MAXIMUM STRESS IS:

$$\tau_{MAX} = \frac{2V}{A}$$



FOR THE GIVEN GEOMETRY:

$$\text{use } A = \pi(12)(5/8)$$

FOR SHEAR STRESS THE CORRESPONDING STRESS INTENSITY IS:

$$S.I. = 2\tau_{max}$$

THE MAX RANGE OF STRESS INTENSITY IS LIMITED (BY ASME SECT VIII DIV 2) TO 3S OVER THE COOLDOWN/WARMUP CYCLE. THEN, FOR THE COOLDOWN THE SI IS LIMITED TO $\frac{3S}{2}$.

$$\frac{3S}{2} = \frac{3(18.8)}{2} = 28.2 \text{ ksi}$$

$$2\tau_{MAX} \leq \frac{3S}{2}$$

$$2\left(\frac{2V}{\pi(12)(5/8)}\right) \leq 28.2 \text{ ksi}$$

$$\underline{\underline{V_{MAX} \leq 166^K}}$$

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DETERMINE ALLOWABLE ΔT AS A FUNCTION OF TEMP.

THE ANSYS MODEL USED $\alpha = 9.11 \times 10^{-6} \frac{in}{in \cdot °F}$ AND $\Delta T = 100°F$.

$$\epsilon = (9.11 \times 10^{-6})(100) = 9.11 \times 10^{-4} \frac{in}{in}$$

THE ALLOWABLE STRAIN (FOR $V_{MAX} = 166^{"}$) IS:

$$\epsilon_{ALLOW.} = 9.11 \times 10^{-4} \left(\frac{166}{540.4}\right) = 2.80 \times 10^{-4} \frac{in}{in}$$

ALLOWABLE ΔT'S ARE GIVEN IN THE TABLE BELOW, BASED ON THE WARMER COMPONENT:

°F	T_{WARM} K	α $\left(\frac{in}{in \cdot K}\right)$	ΔT_{MAX} $(\epsilon_{ALLOW}/\alpha)$	$T_{COOL\ MIN}$ K
70	293	1.59×10^{-5}	17.6	275.4
0	273	1.55	18.1	254.9
	260	1.53	18.3	241.7
	240	1.49	18.8	221.2
	220	1.45	19.3	200.7
	200	1.40	20.0	180.0
	180	1.34	20.9	159.1
	160	1.28	21.9	138.1
	140	1.20	23.3	116.7
	120	1.09	25.7	94.3
	100	.96	29.2	LIQUID 70.8
	90	.87	32.2	LIQUID 57.8

Movement

$$\delta = 2.80 \times 10^{-4} \frac{in}{in} \times 55^{"}$$

$$= .015^{"}$$

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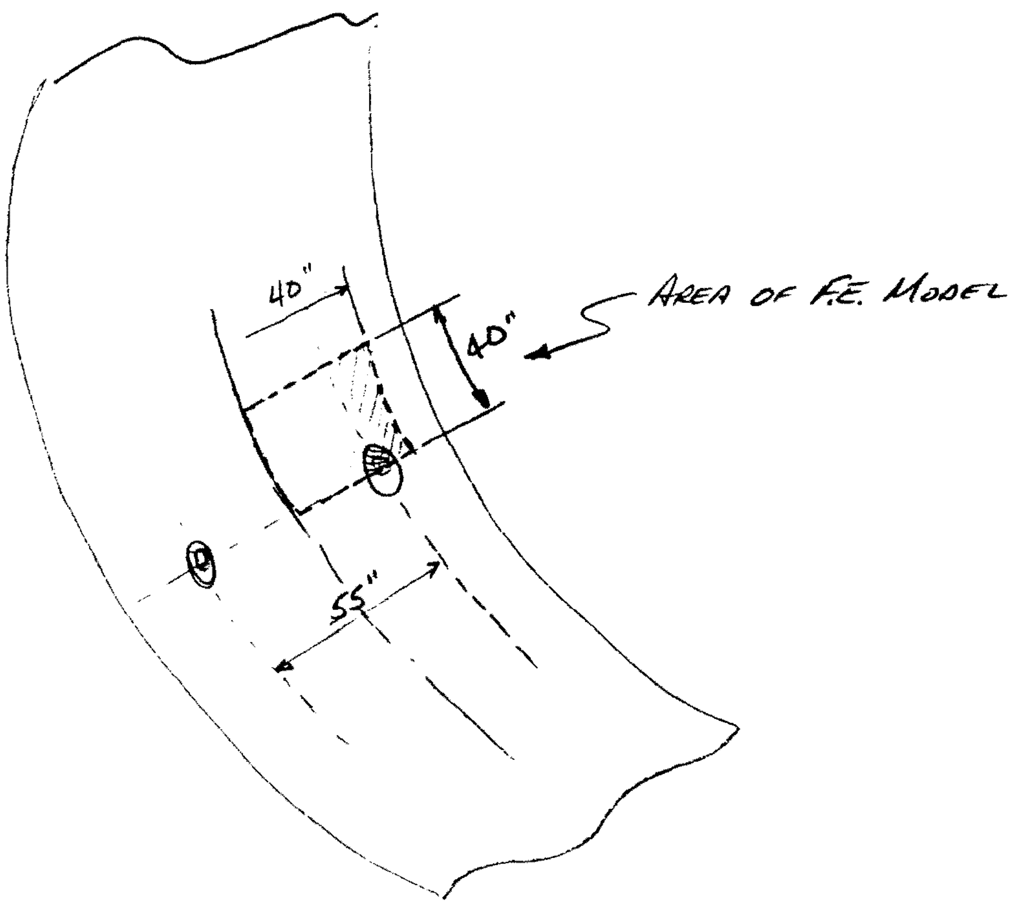
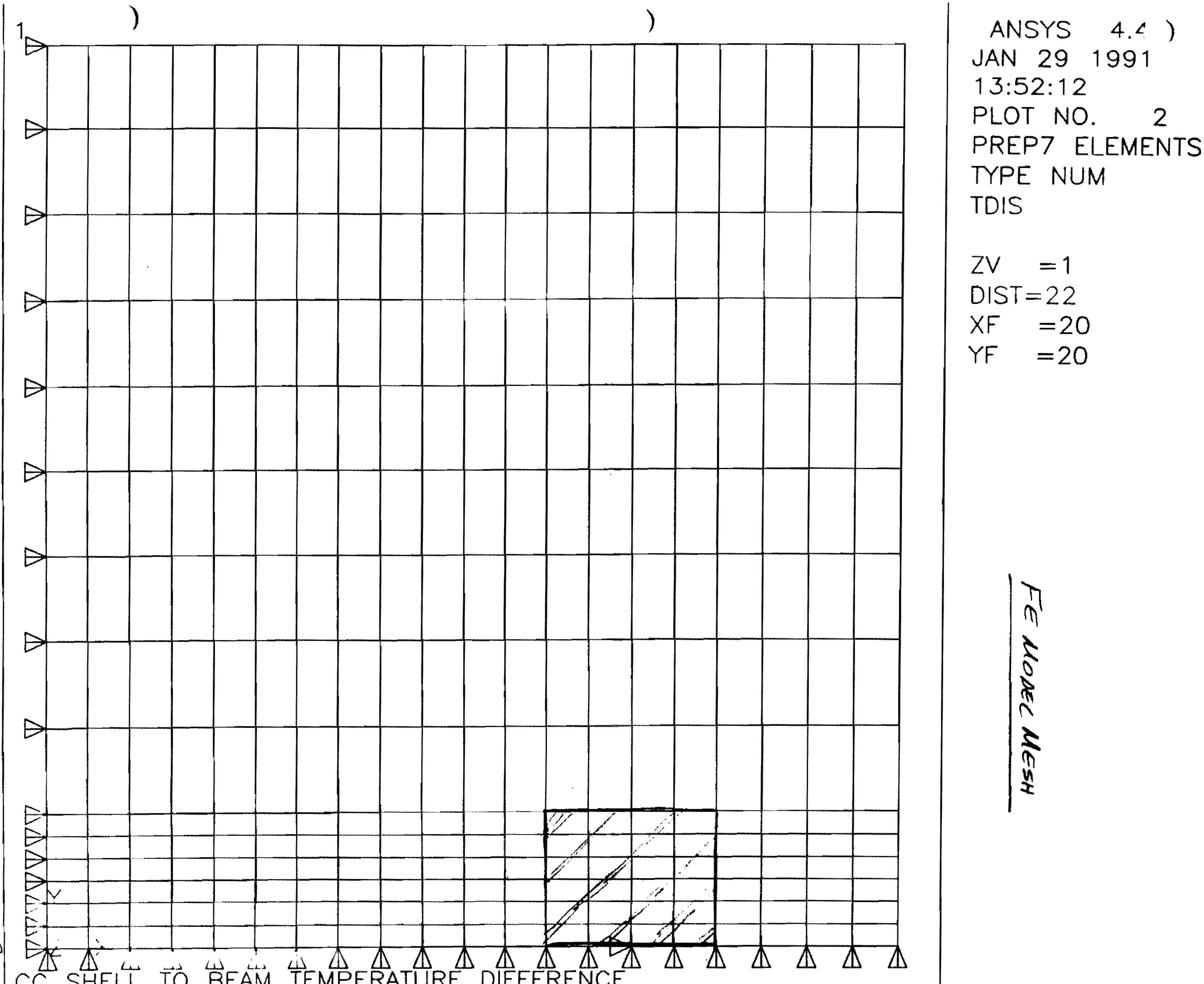
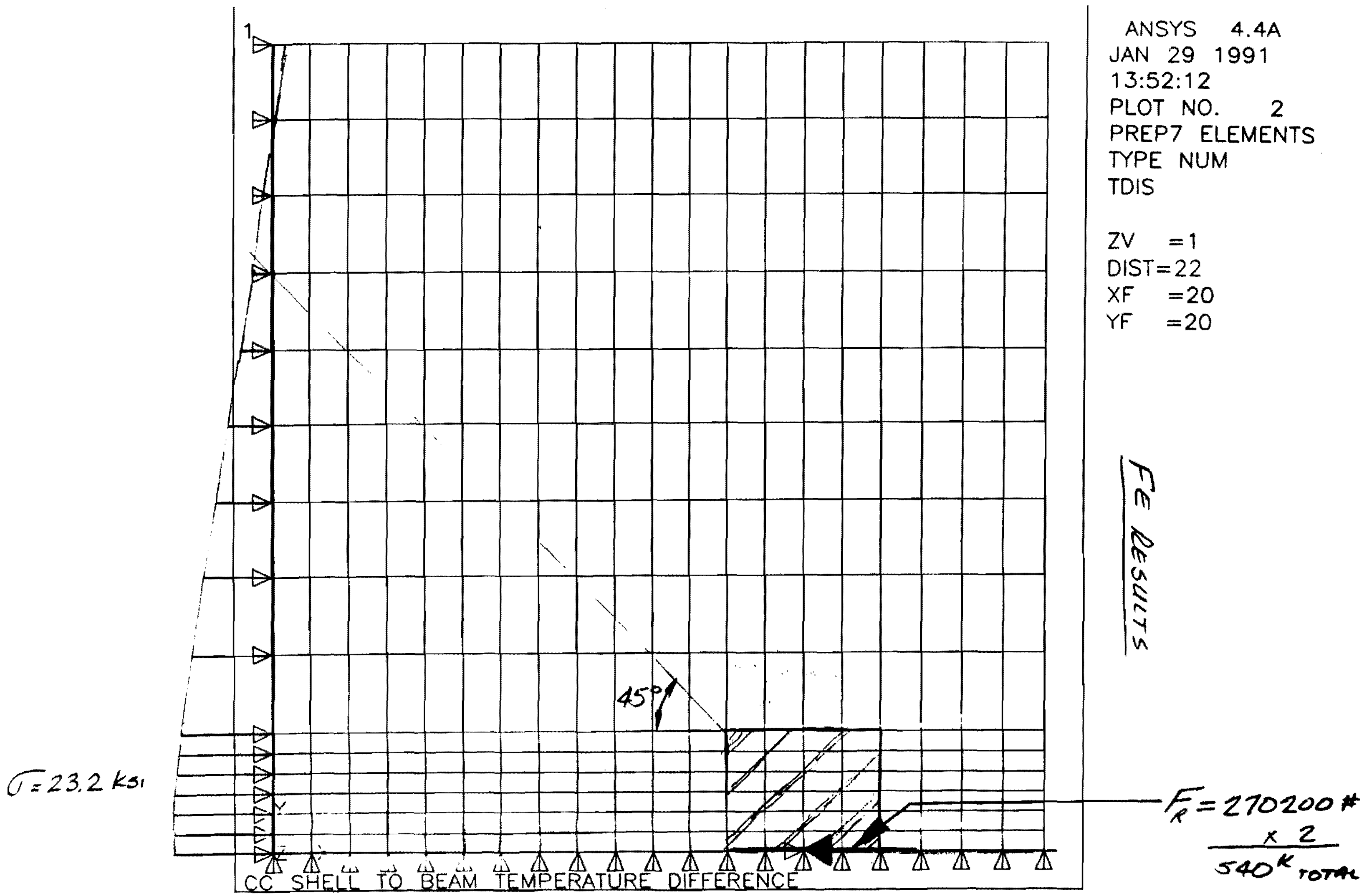
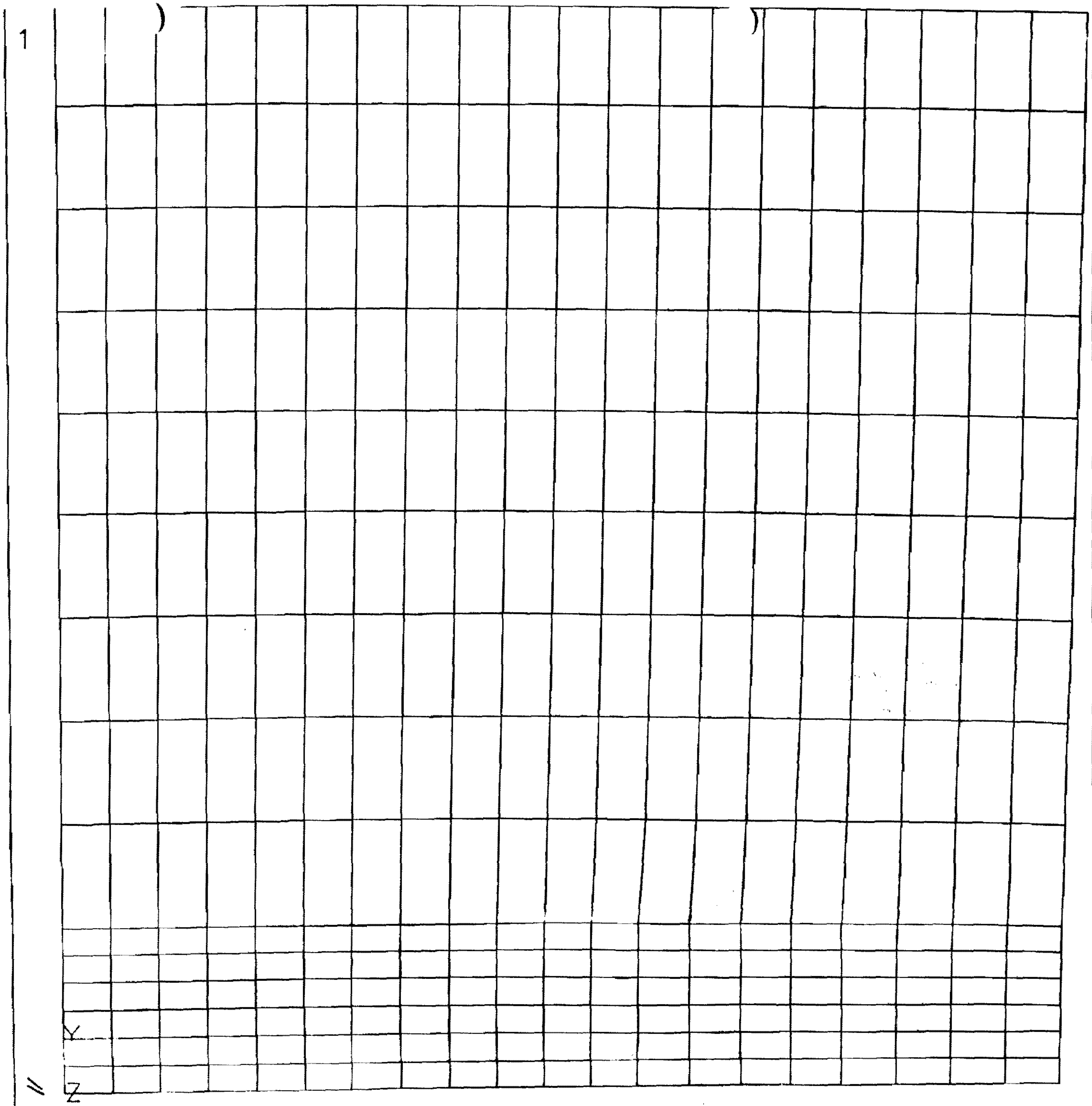




FE Model Mesh



ANSYS 4.4A
JAN 29 1991
13:52:12
PLOT NO. 2
PREP7 ELEMENTS
TYPE NUM
TDIS
ZV =1
DIST=22
XF =20
YF =20
FE RESULTS
45°
σ = 23.2 ksi
F_R = 270200 #
x 2
540^K TOTAL
CC SHELL TO BEAM TEMPERATURE DIFFERENCE

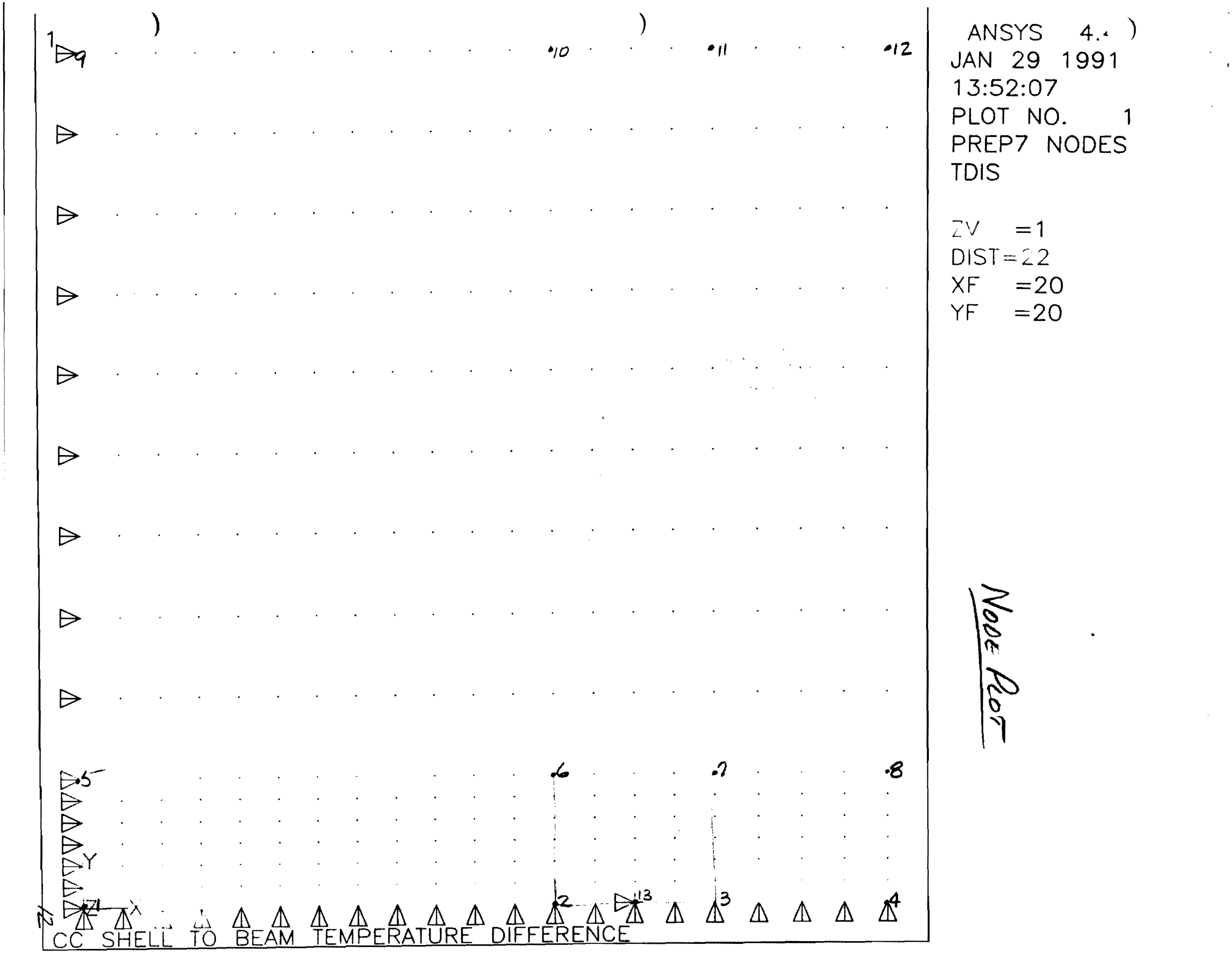


ANSYS 4.4
JAN 29 1991
14:27:28
PLOT NO. 2
POST1 DISPL.
STEP=1
ITER=1
DMX =0.049751

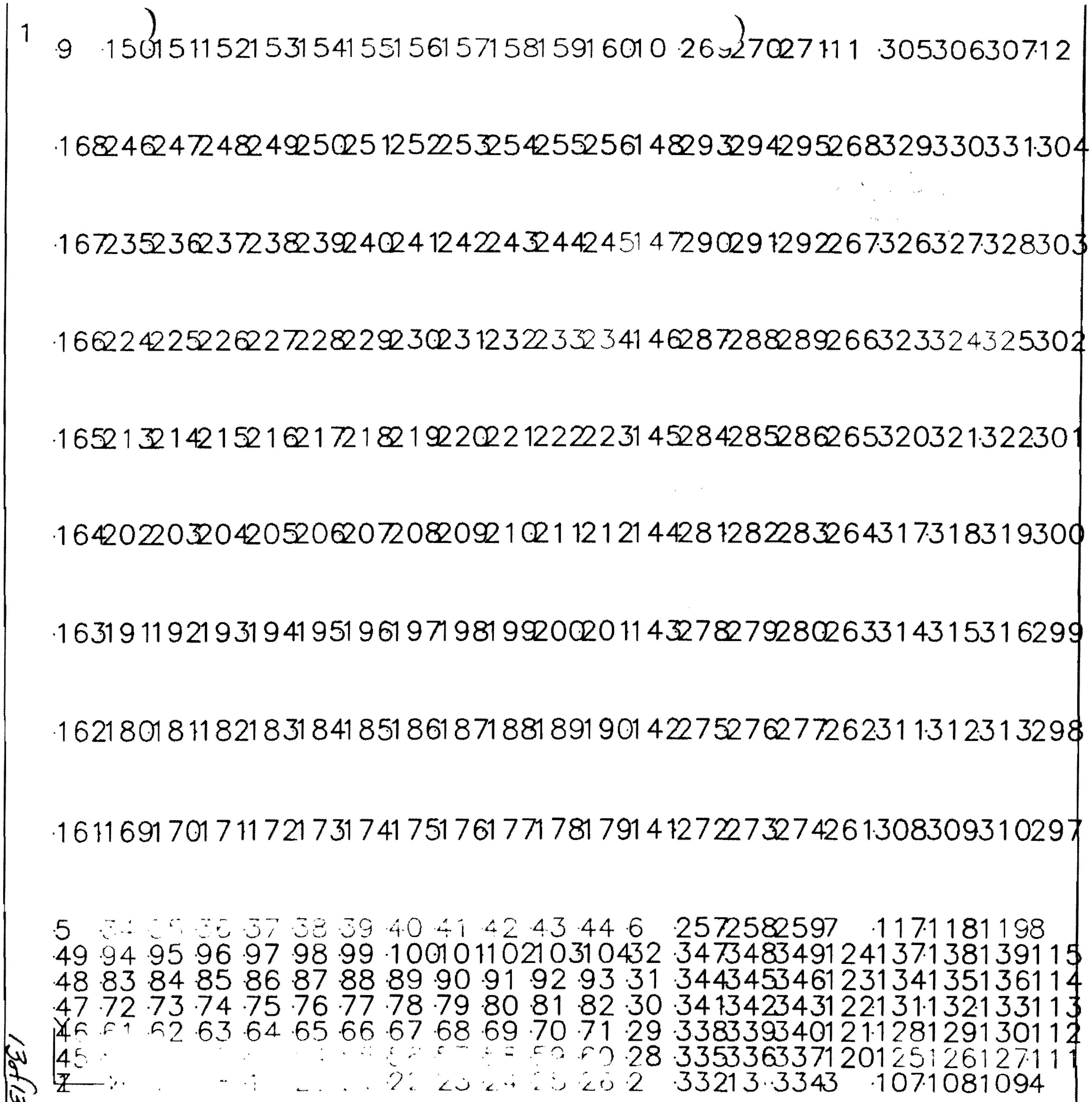
DSCA=44.22
ZV =1
DIST=22
XF =20
YF =20

DEFORMED SHAPE

CC SHELL TO BEAM TEMPERATURE DIFFERENCE



ANSYS 4.4
JAN 29 1991
13:52:07
PLOT NO. 1
PREP7 NODES
TDIS
ZV =1
DIST=22
XF =20
YF =20
CC SHELL TO BEAM TEMPERATURE DIFFERENCE
Node Plot


CC SHELL TO BEAM TEMPERATURE DIFFERENCE

ANSYS 4.4
JAN 29 1991
14:30:51
PLOT NO. 3
POST1 NODES

ZV =1
DIST=22
XF =20
YF =20

NODE NUMBERS

13 of 13