Title
STRUCTURAL ANALYSIS OF 10T Nb3Sn SUPERCONDUCTING DIPOLE MAGNET USING SAP4

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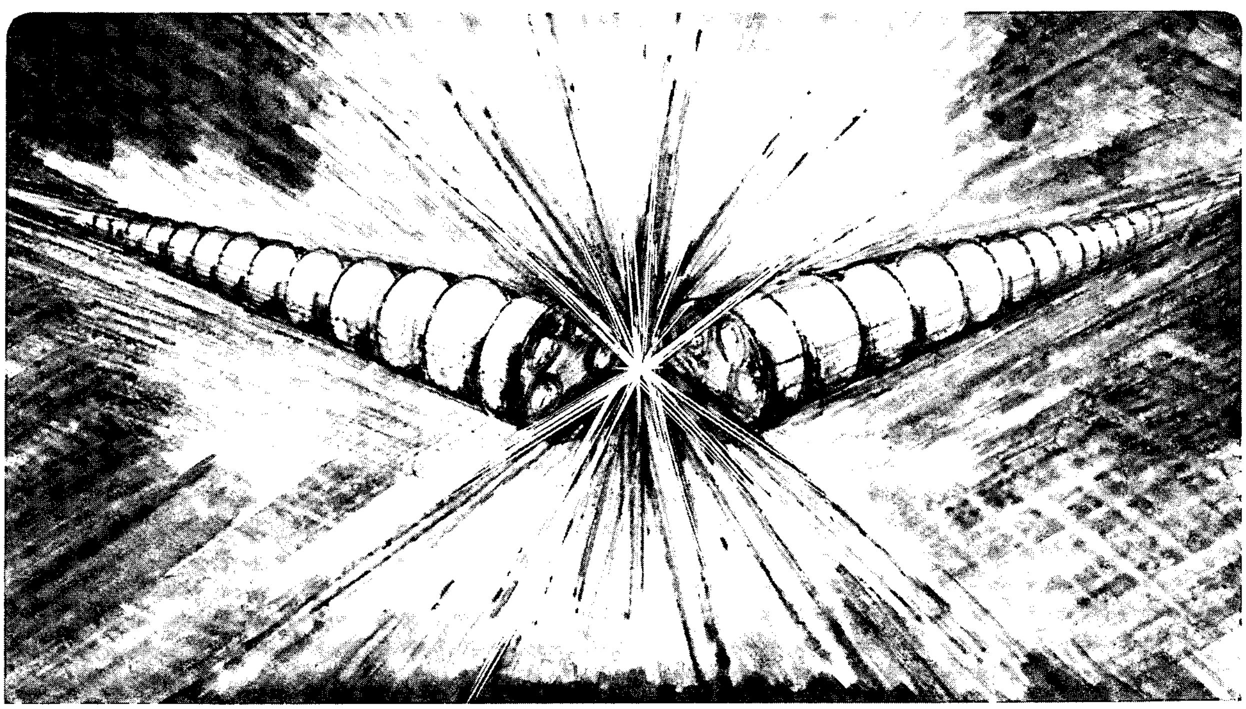
May 1982



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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Structural Analysis of 10T Nb_3Sn Superconducting Dipole Magnet Using SAP4

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Introduction

The finite element code SAP4 was used to analyze the winding blocks of a 10T Nb_3Sn superconducting dipole magnet. The overall analysis required the interaction between 3 large computer codes:

1). Poisson – Generates the local Lorentz body forces.

2). SAP4 – Stress analysis.

3). GRAPE – Plotting and presentation.

The control cards for SAP4 and GRAPE are listed in Appendix A.

Geometry

The analysis was done on a two dimensional crossection through the straight section of one quadrant, using plain strain (element 4). The 4 block dimensions were somewhat modified to include an integer number of 1 x 1 mm squares (Figure 1-3) resulting in 1944 elements and 2055 nodal points. The Lorentz forces were calculated at the center of each element and equally divided between adjacent nodes.

As indicated on the individual runs some of the boundaries were free the other fixed preventing deflection normal to the boundary but permitting nonfriction slippage in the transverse direction. The 4 blocks are assumed physically connected and whenever a slip plane was required a row of elements were given mechanical properties which simulated such a case. The conductor modulus of elasticity is:

$E_1 = E_2 = E_3 = 2.E{+}6$ psi; shear modulus $G = .77E{+}6$ psi

poisson ratio $\nu_{12} = \nu_{13} = \nu_{23} = .3$

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The slip plane properties are:

E_1 = .05E+6 psi in the slip direction

E_2 = 2. E+6 psi normal to the slip

E_3 = .05E+6 psi

G = .047 E+6 psi

$\nu_{12} = .8$

$\nu_{13} = \nu_{23} = .02$

All calculation assume a constant temperature.

RESULTS

At 10T central field the stored energy and current density were calculated from Poisson. Assuming 11 turns in the top block and 14 turns in each of the other blocks the total current and inductance are calculated.

	Stored Energy E(kJ/meter)	Current Density J(A/mm^2)	Current I(A) ±1.5	Inductance (mH/meter)
No Iron	520	413.3	15150	4.5
Including Iron	470	358	13200	5.5

(Crossection area is over all the blocks)

Fig. 4 is the mesh used in Poisson and Fig. 5 shows the flux lines. Using AIRCO data by Sanger et al, ("Critical Properties of Multifilamentary Nb_3Sn between 8 and 14 Tesla", Applied Superconductivity Conference, Sante Fe, 1980), the Jc - B curve and load line are plotted in Fig. 6. Using the boundary conditions as shown in Fig. 3 the displacements due to Lorentz forces only, are plotted in Fig. 7. The largest displacement of 4.65 mil occurs in the left upper node and introducing an extra slip plane between blocks 1 and 2 will increase the displacement by no more than .05 mil.

The mininmum principal stress under compression (maximum absolute stress) is plotted as contour lines of constant stress across the 4 blocks. A "three dimensional representation", were the minimum principal stress is elevated over the geometry according to its value, is also plotted. Some visual difficulties might arise since this 3 dimensional surface is plotted without its reference.

Assuming a slip plane between blocks 2 and 3 only and using the B.C. of Fig. 3 the minimum principal stress is plotted in Fig. 8-9 when only Lorentz forces are introduced.

To add precompression to the blocks the boundary conditions were changed and the Lorenz forces replaced by a fixed displacement as shown in Fig. 10. With a displacement of $\delta = 5$ mil as predicted by the Lorentz forces, the principal stress contours are plotted in Fig. 11-12 for precompression only (no Lorentz forces).

To combine precompression and Lorentz forces the boundary conditions remain as shown in Fig 10. Accordingly, the displacements are plotted in Fig. 13-14 and the principal stress contours in Fig. 15-16. The average reacting forces (per unit conductor length) on the sides of the blocks are shown in Fig. 17.

A finite element stess analysis which includes the surrounding structure is being investigated at present.

18 Jan 82
Wolgast

10 T Nb_3Sn – 4 Horiz. Blocks

Preliminary Coil Dim. for design and stress calc.
Schafer Schlomo

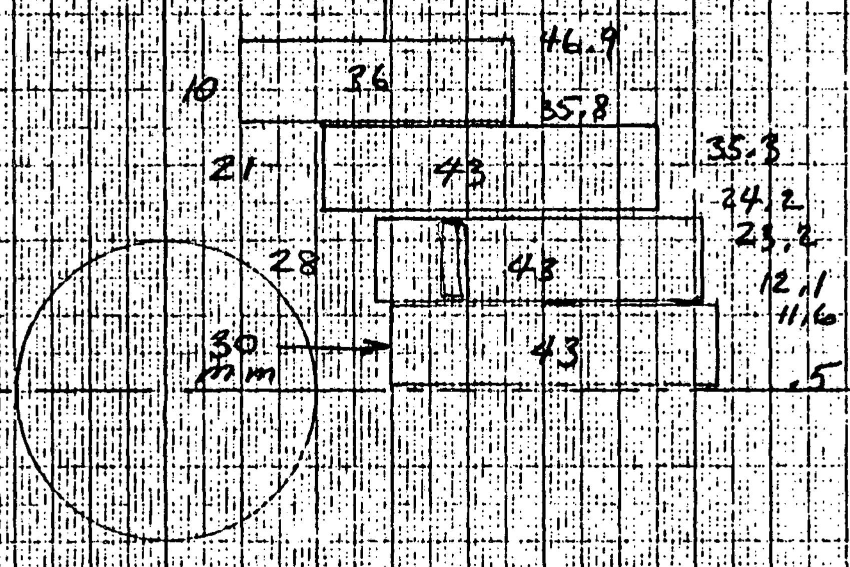
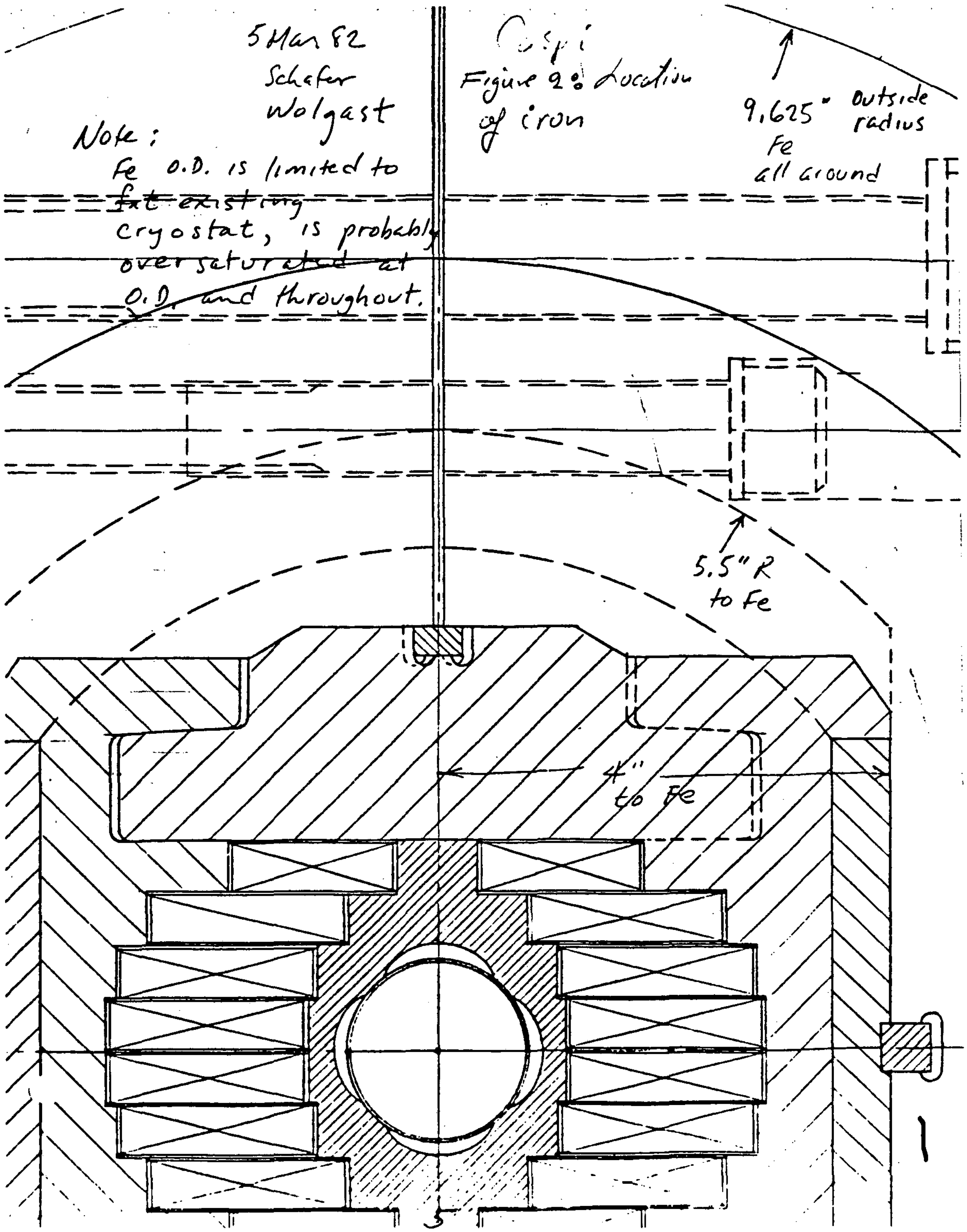


Figure 1 Preliminary Coil Dim.


5 Mar 82
Schafer
Wolgast
Cuspi
Figure 2: Location of iron
9.625" outside radius Fe all around
Note:
Fe O.D. is limited to ~~fit existing~~ cryostat, is probably ~~oversaturated at~~ O.D. and throughout.
5.5" R to Fe
4" to Fe

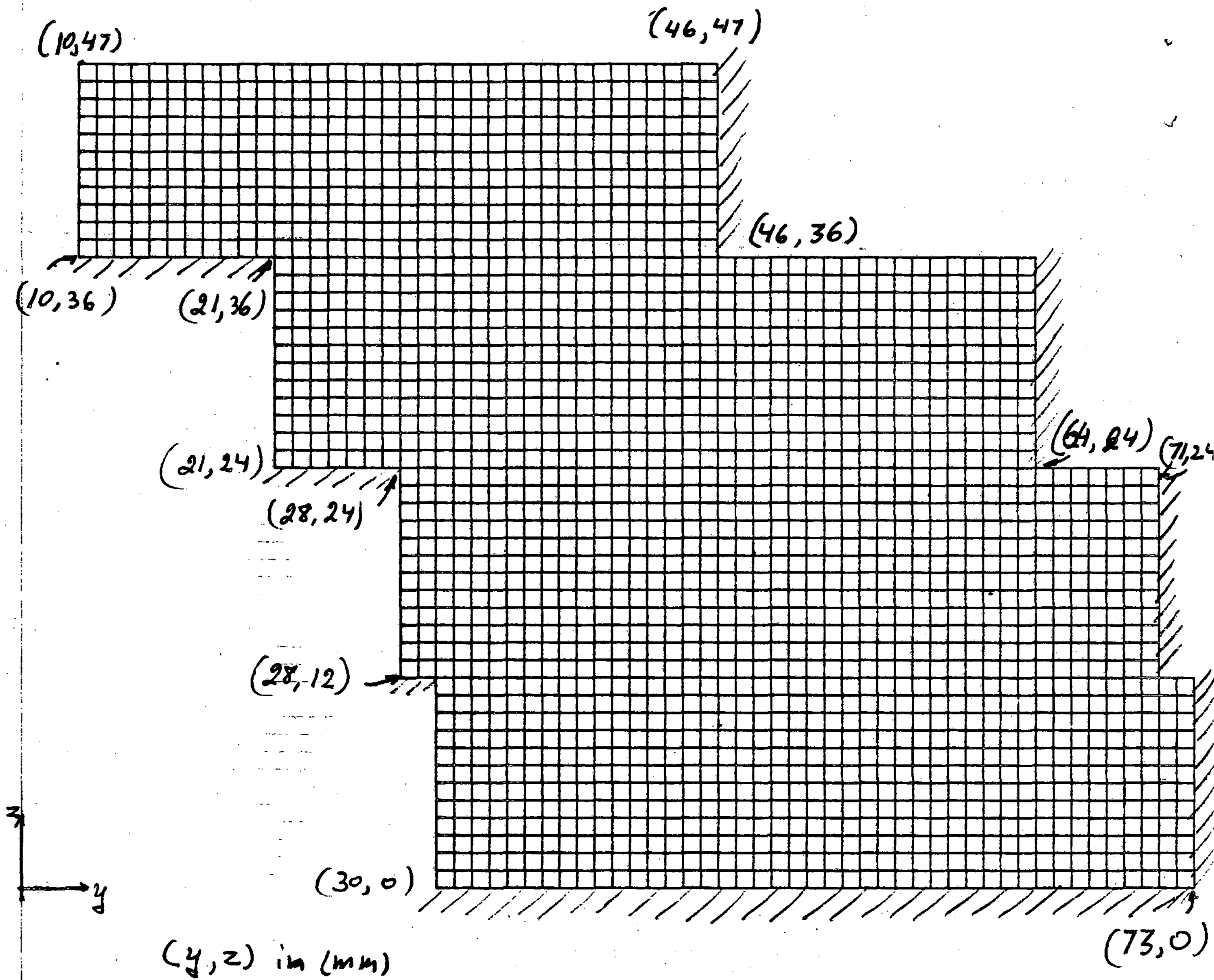


Figure 3. Boundary condition during Lorentz loading.

Fig. 4 Mesh input to Poisson

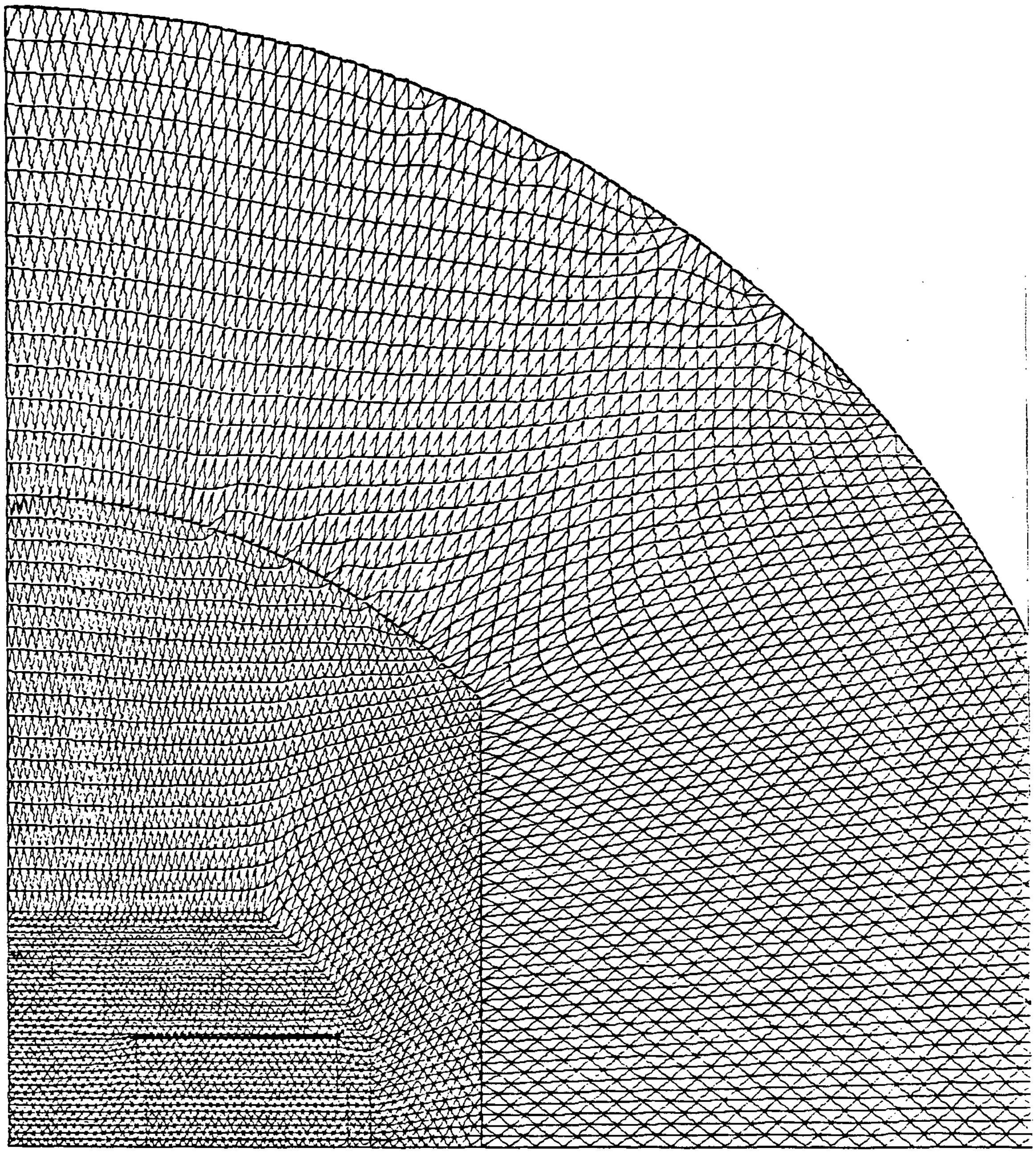
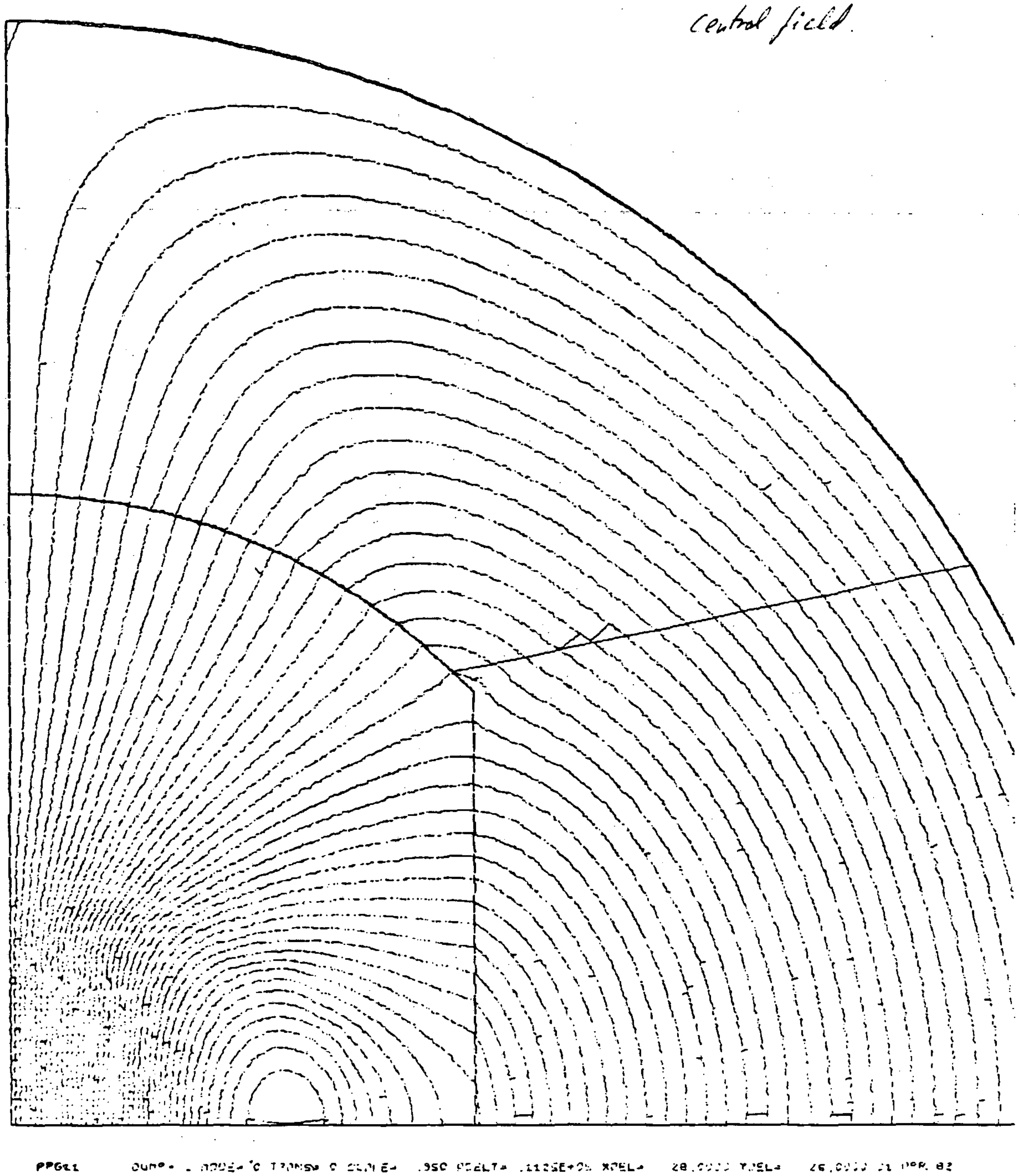
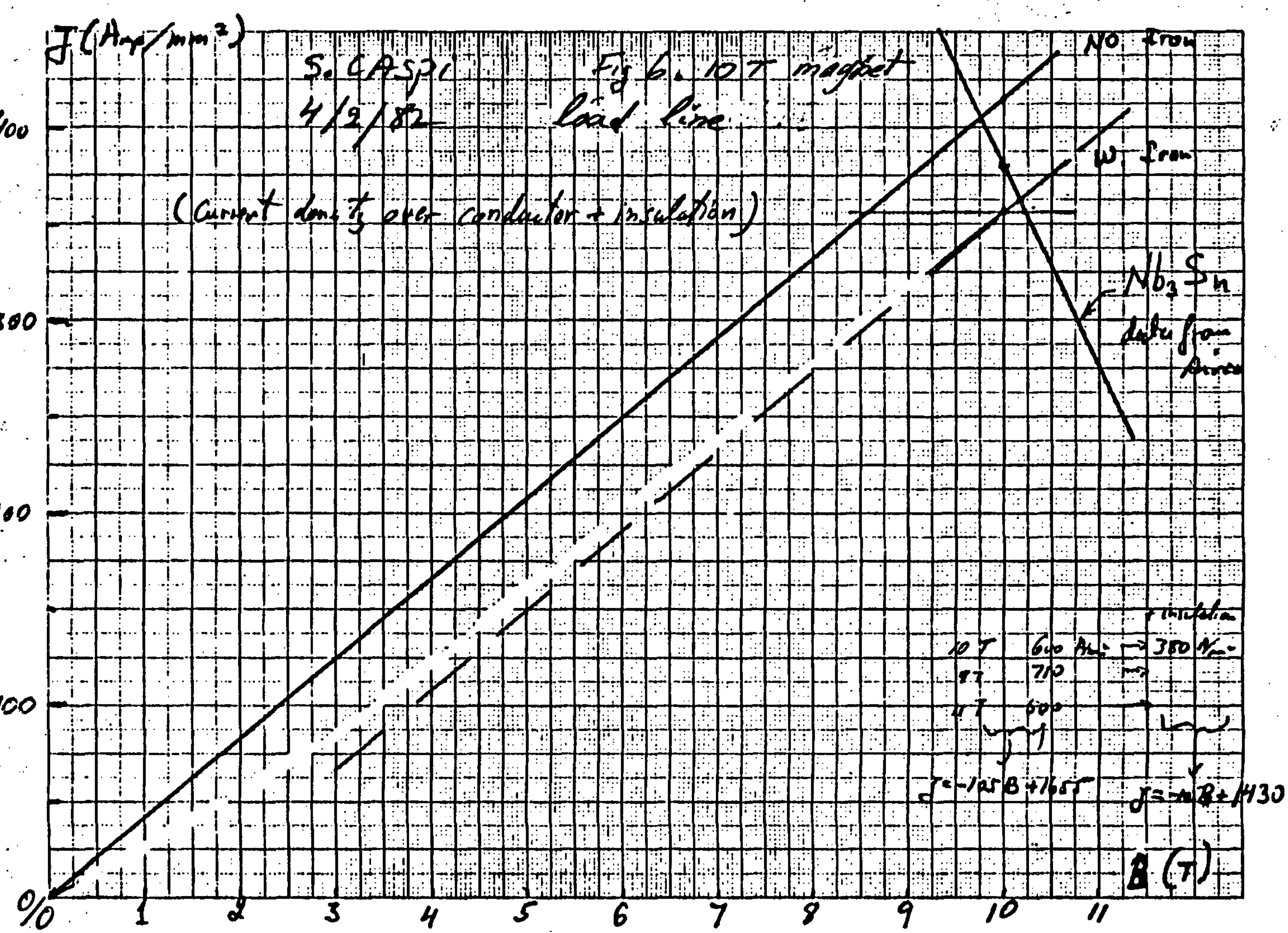


Fig. 5. Flux lines at 10 T central field.





J (Amp/mm²)
S. CASPI
4/2/82
Fig 6. 10T magnet load line
(Current density over conductor + insulation)
NO Iron
W. Iron
Nb₃Sn data from
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
B (T)
10 T
9 T
4 T
600
710
600
+ insulation
350
J = -125 B + 1655
J = B + 1430

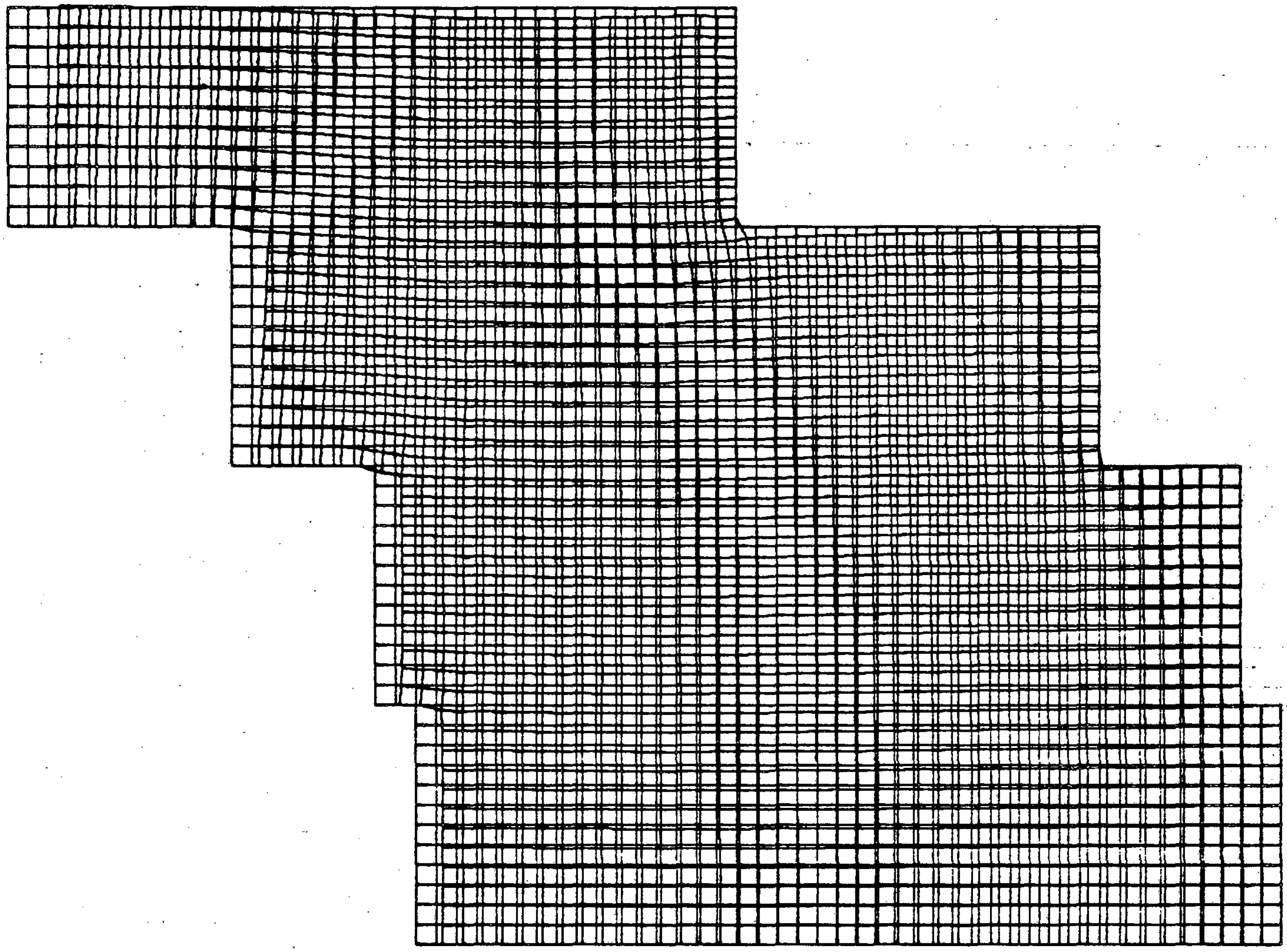


Fig. 7 – Deformation x 20 during a 10 T central field (no precompression). Boundary conditions are shown in Fig. 3.

DISP. SCALE FACTOR = .200E+02

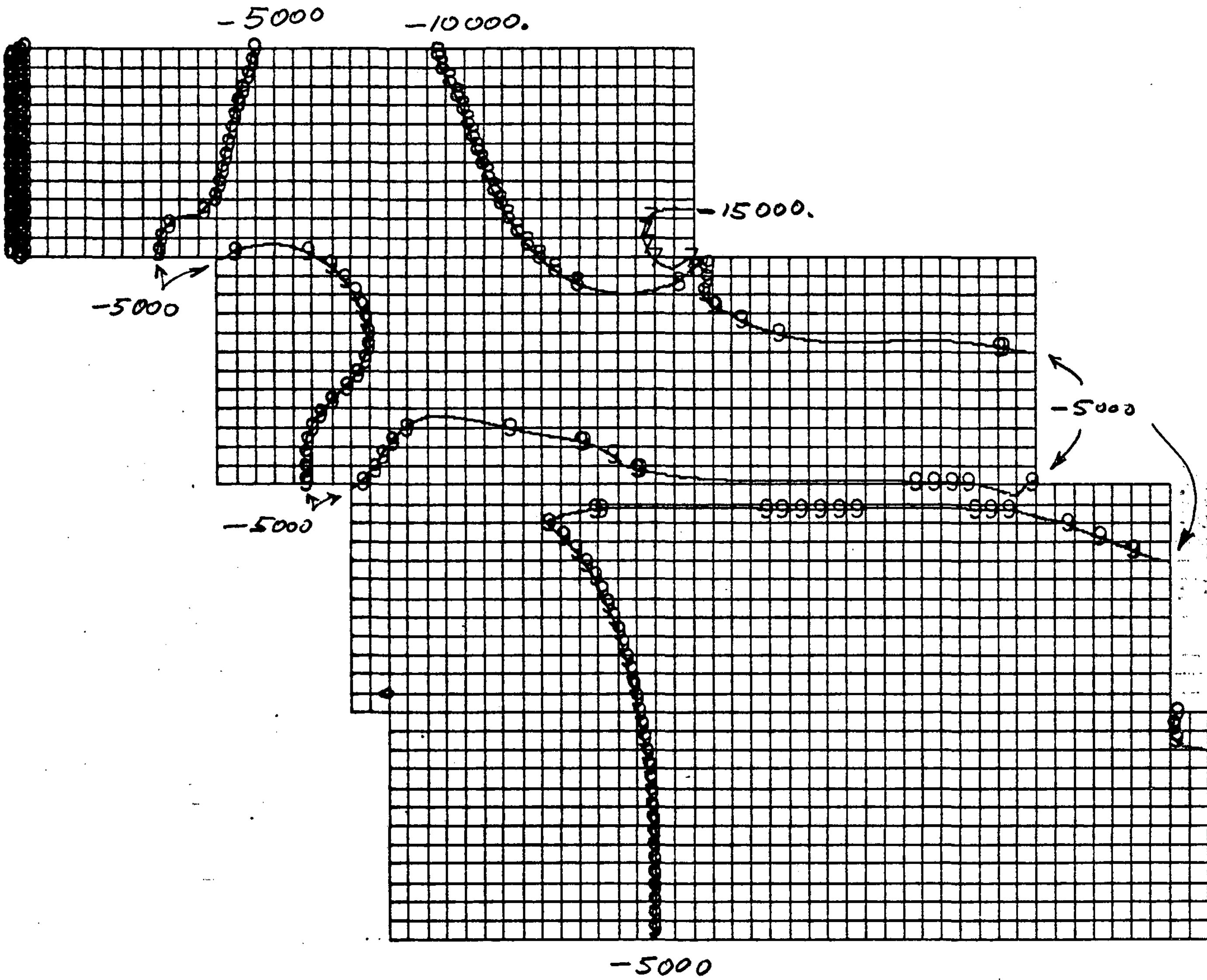


Fig. 8 - Principal stress contours at 10 T central field
1 slip plane between block two and three.
(no precompression).

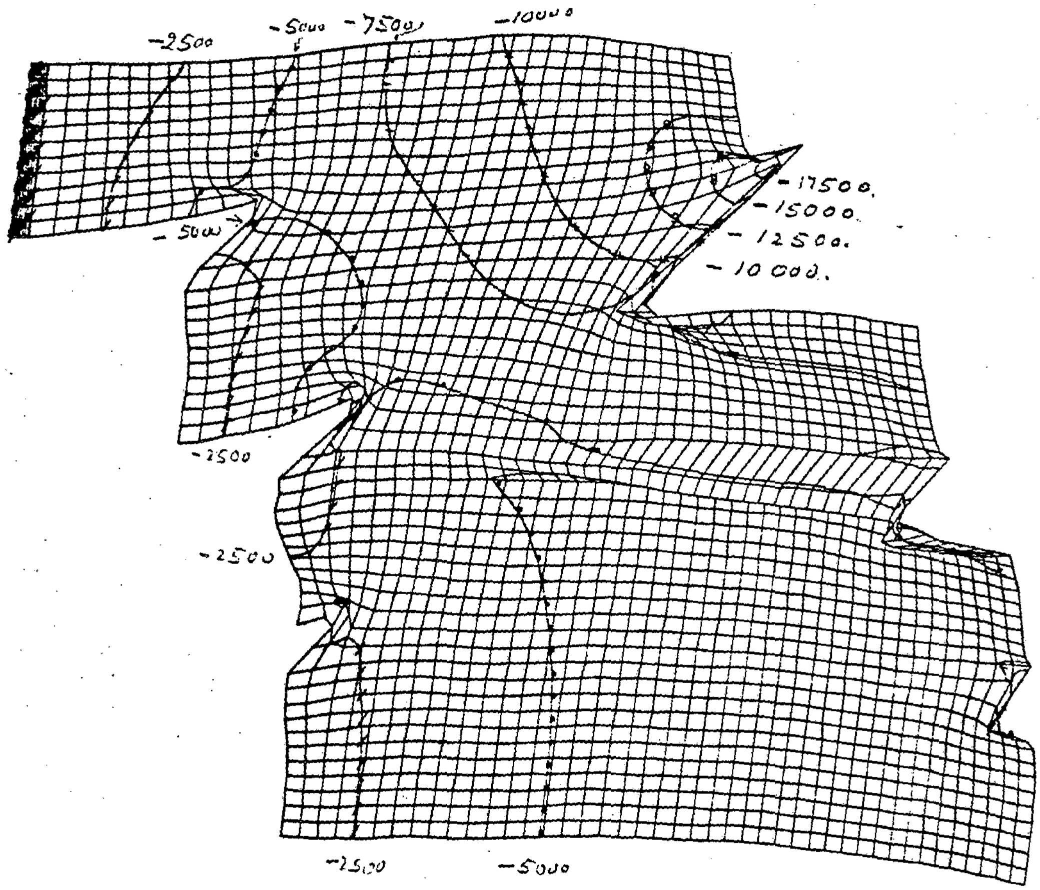
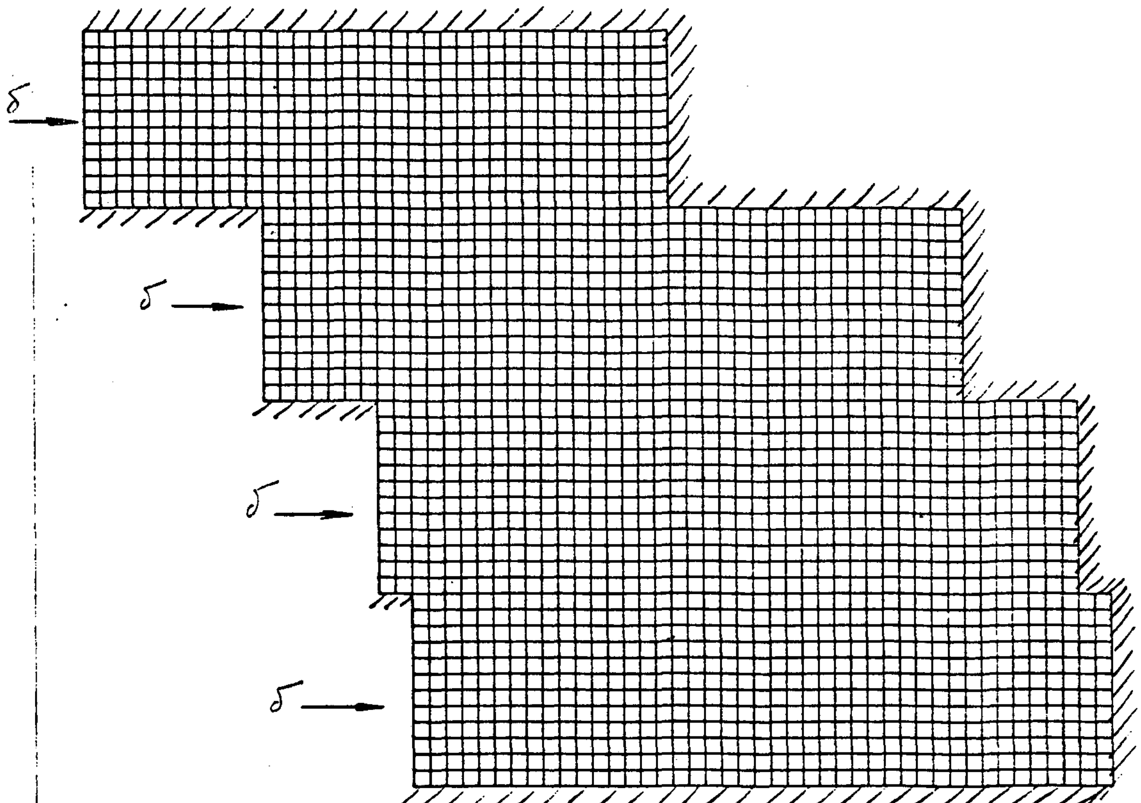


Fig. 9 - Principal stress contours (elevated) at 10 T central field, 1 slip plane between blocks 1 and 2.



$\delta = 5$ mil.

Fig. 10 - Boundary condition during precompression.

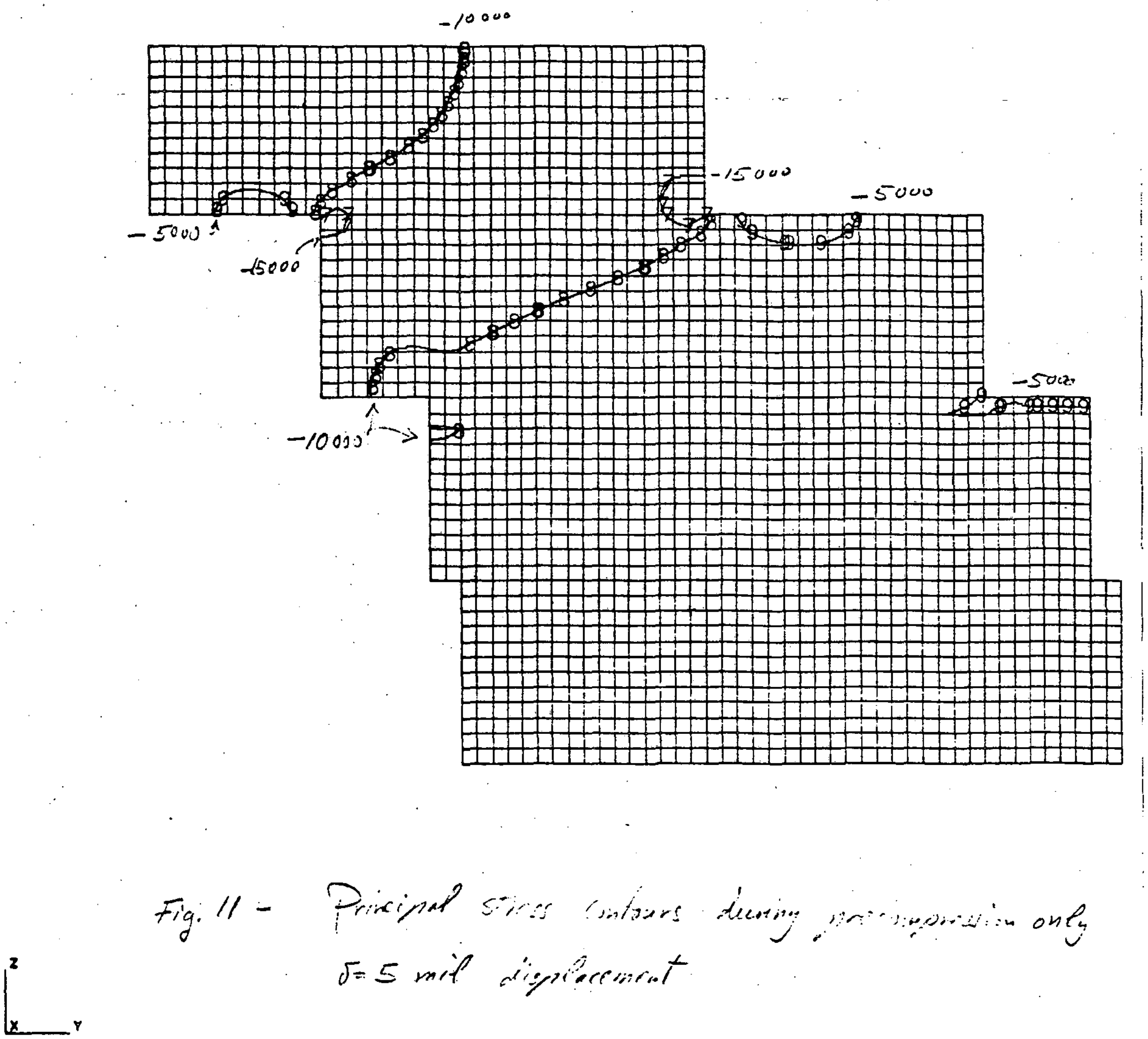


Fig. 11 - Principal stress contours during pressurization only
$\delta = 5$ mil displacement

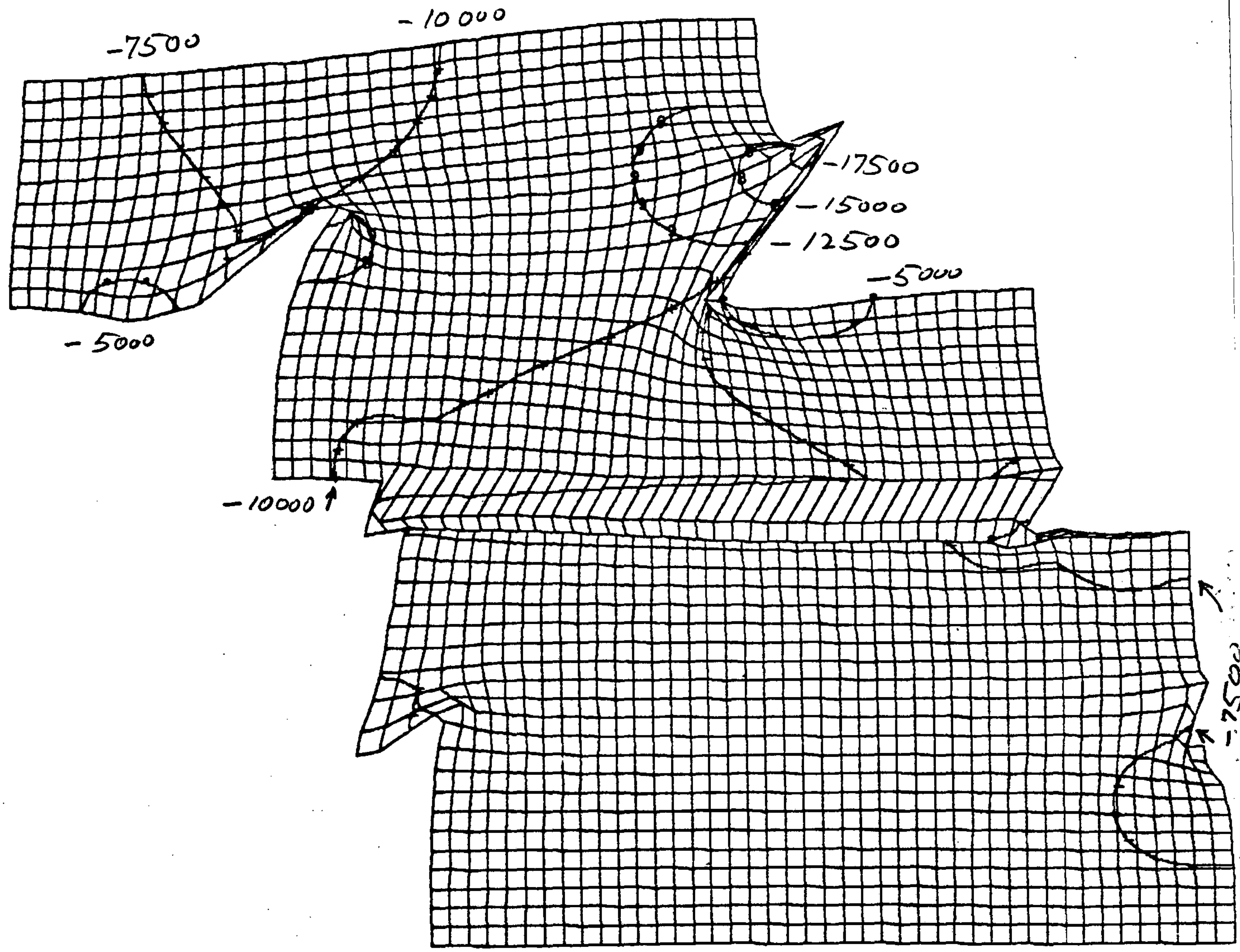


Fig 12 - Principal stress contours during a 5 mil displacement

CASE = 1

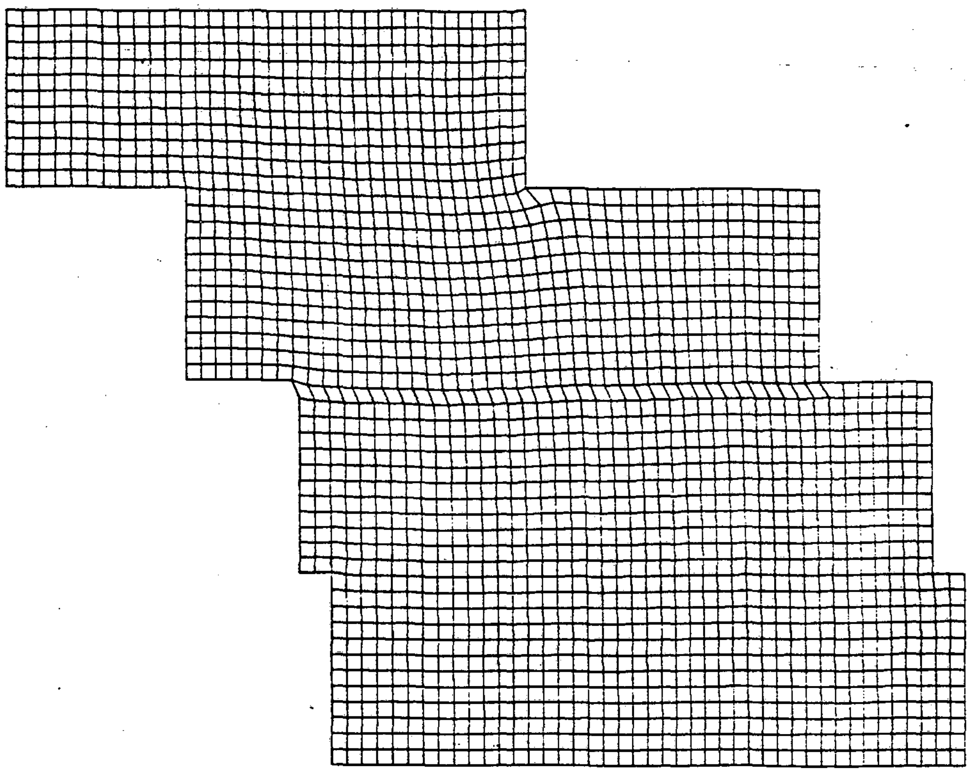


Fig.-13 Displacements x30 due to Lorentz forces and precompression of δ=5 mil.

Y

DISP. SCALE FACTOR = .300E+02

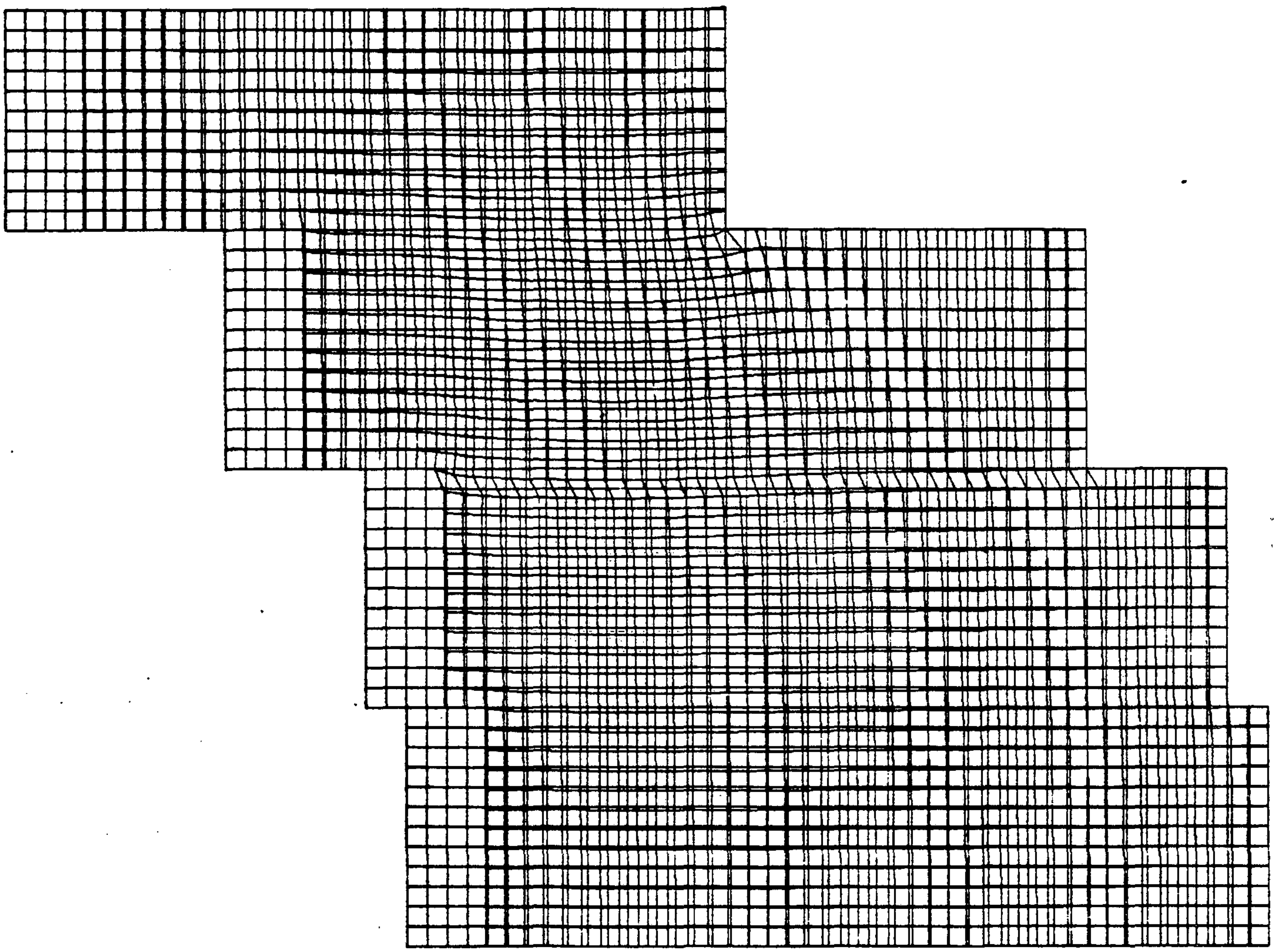
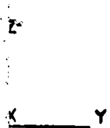


Fig 14 - Relative displacement x30 due to Lorentz forces and precompression of 5 mil.



DISP. SCALE FACTOR = .300E+02

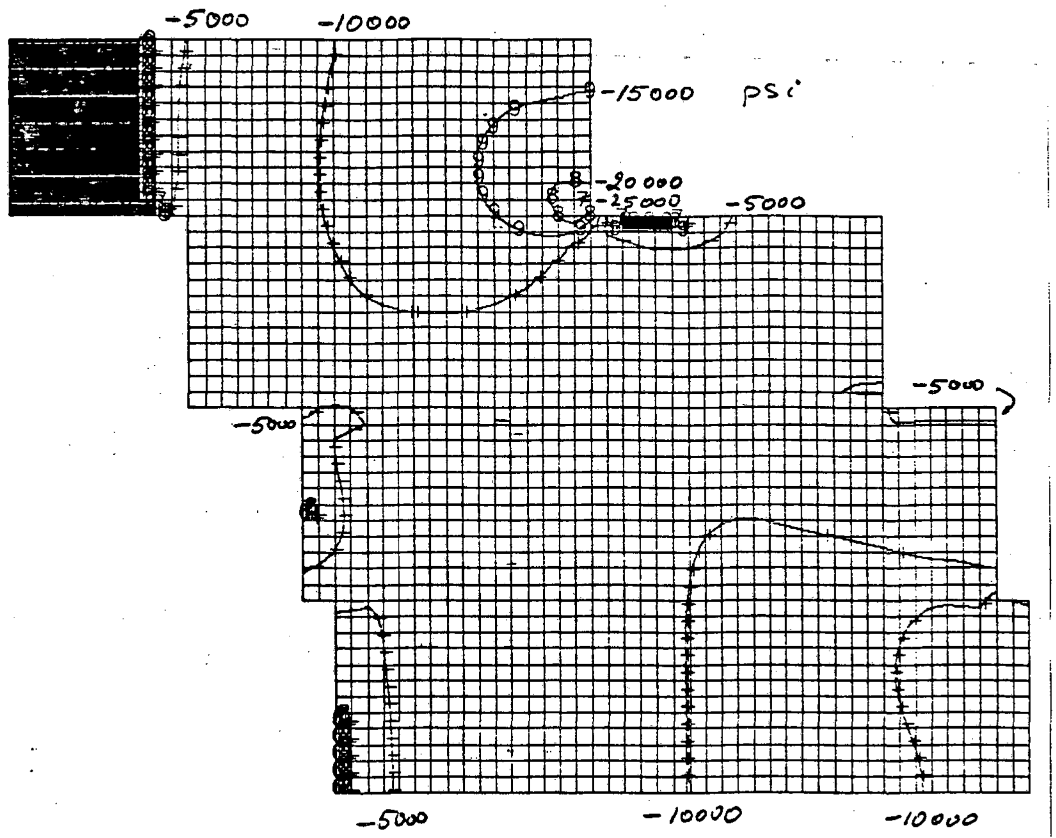


Fig 15 - Principal stress contours at 10T and precompression of 5 mil.

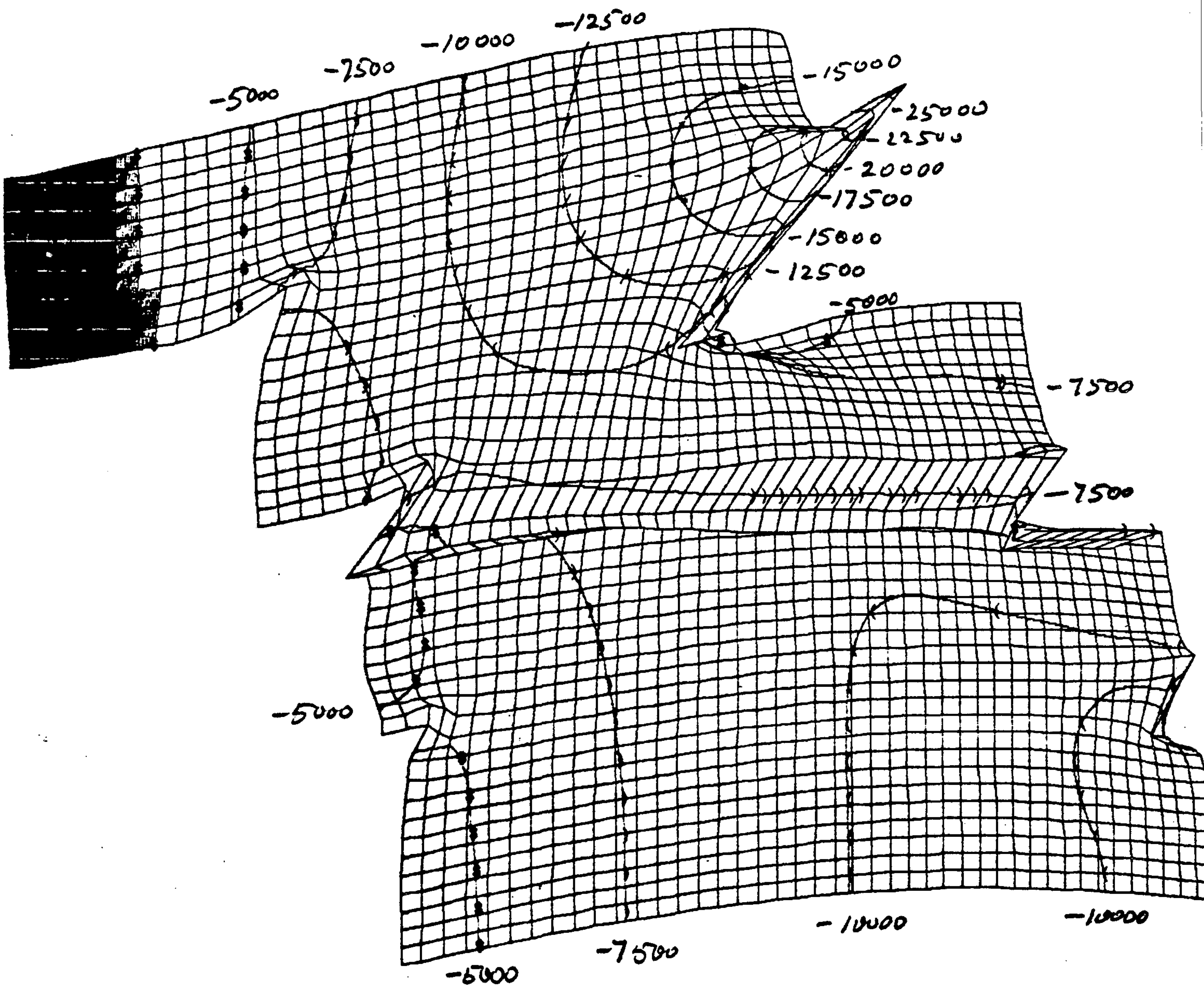


Fig 16 Principal Stress contours (elevated) at 10 T and a precompression of 5 mil

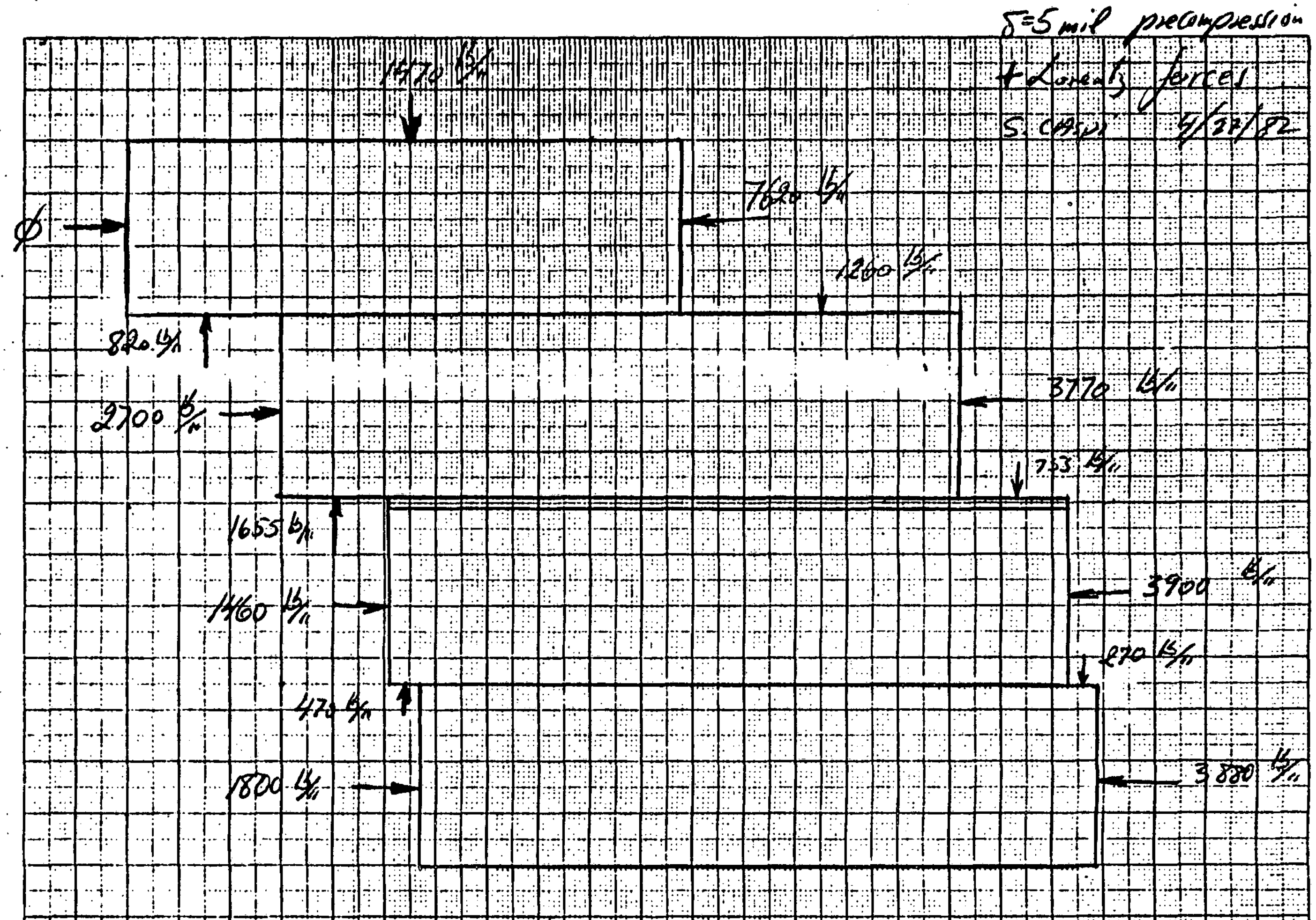


Fig 17 Average reacting forces per unit axial length

Appendix A.

SAP4 CCARD

```
1,10
SUPER ,7,900,70000.454010,CASPI
*HOLDOUT.
FETCHPS,LIVERMORE,SSAP/RR,SSAP.
COPY,INPUT,A/RR.
DISKHOG,15000.
LINK,X,F=SSAP,PP=ELC=20000,A,OUTPUT1.
LIBRITE,SUPER,TAPE1,TAPE1,159,W=CASPI.
LIBRITE,SUPER,TAPE10,TAPE10,159,W=CASPI.
EOR
                                         WITH IRON
      :
      :
```

GRAPE CCARD

```
GRAPE,7,900,70000.454010,CASPI
*HOLDOUT
FETCHPS,SUPER,SARGE/RR,SARGE.
LIBCOPY,SUPER,SAP4I/RR,SAPI02.      input from SAP4
LIBCOPY,SUPER,TAPE1/RR,TAPE1.
LIBCOPY,SUPER,TAPE10/RR,TAPE10.
SARGE.
FETCHPS,SUPER,GRAPE/RR,GRAPE.
REWIND,SAPGI.
COPY,INPUT,12,TAPE6/RR.
GRAPE.
EXIT.
DUMP(0)
FIN.
FETCHPS,PLOTTER,GRAPHIC,GRAPHIC.
GRAPHIC,FN=FILM,FT=VA.
COPY,TAPE4/RK,OUTPUT.
COPY,TAPE5/RK,OUTPUT.               end control cards
NO BOX NUMBER AT BKY
BI SAPGI 1 1 16
 DISPLAY CC 1024 Y
 ROTA X -90
 ROTA Y -90
 TRIAD
 CONT 4 2 -20000 -5000
 EXPAND 40000
 VIEW
 TRIAD
 WARP .00001 -.00006 -.00006
 CONT 8 2 -20000 -2500
 EXPAND 40000
 VIEW
 END END
```

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