Accelerator Development Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York 11973

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Results for the G-11 Outer Tube Test Piece

D. P. Brown
R. J. Gibbs
K. C. Wu
D. L. Horne

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RHIC Technical Note

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ABSTRACT

A test piece consisting of a G-11 fiberglass-epoxy tube with shrink fit joint flanges at both ends has been installed on a tensile test machine and loaded as a cantilever. The primary goal is to verify the strength of the fixed end shrink fit joint which has a greater interference than the earlier design. In addition the deflections are measured and are compared with finite element analysis and elementary beam formulas. The ultimate shear stress for the G-11 tube has also been found. It turns out that the shear effect is as important as the bending effect for this test. Good agreement between the finite element analysis and the elementary formulas are obtained if both shear and bending are considered. However, the measured deflections are higher than the calculations by a factor of 2 to 3.

TEST PIECE AND TEST PROCEDURES

The test piece consisting of a G-11 outer tube with shrink fit joint flanges on both ends is shown in Fig. 1. The diameter of the tube is 7 inches and the length excluding the flanges is 6 inches. Since the length of the test piece is about the same as its diameter, the test piece should be considered as a short beam in which both bending and shear effects must be taken into account. The test piece is mounted horizontally on a stand at the INSTRON 1125 tensile test machine. Cantilever loads are applied on the upper flange of the test piece. In order to simulate the maximum design moment for the 300 K lower flange joint, 5000 lb load is required. This is approximate twice the design shear load for the post leg.

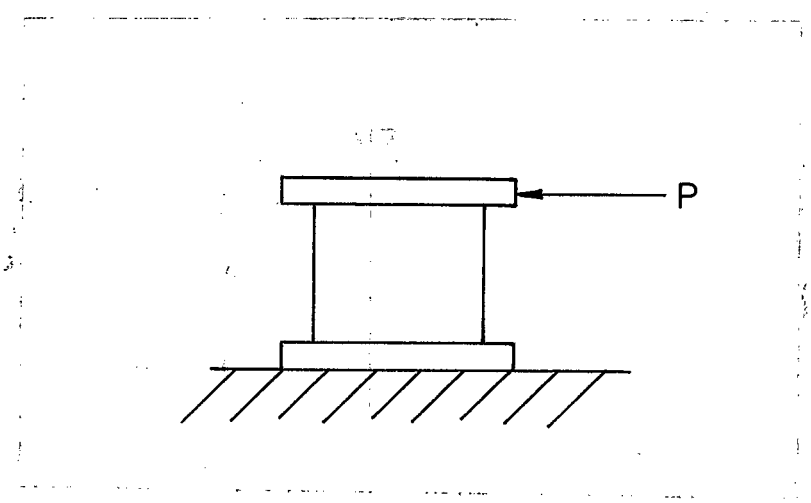


Fig. 1. Test piece under a cantilever load

Three tests with different incremental loads have been performed on May 17, 18, and 20, 1988. A Brown & Sharpe dial gauge with 0.0005 inch accuracy is used to measure the deflection of the upper flange. Load versus deflection data were recorded. The first two tests were not valid due to deformations of the upper aluminum flanges. Permanent diametric deformation of 0.05 inches were measured after the tests were completed. In the third test, a reinforcing steel disc and bolt assembly are put inside the upper aluminum disc to prevent diametric deformation of the cylindrical cross section of the G-11 tube flanges.

Three sets of data were measured for the third test. The G-11 tube broke at approximately 4600 lb load due to shear failure. But the integrity of the 300 K joint remained throughout the entire tests.

FINITE ELEMENT ANALYSIS

The ANSYS finite element package is used to simulate the test piece under a cantilever load. The analysis is performed on a three dimensional model and the resulting deformation and the stress contours are plotted. The results for the deformation, the bending stress and the shear stress under 2200 lb load are given in Figs. 2, 3 and 4. As one can see from Fig. 2, the deformation pattern of the G-11 tube is effected both by shear and by bending similar to short beams. As the elementary beam theory predicts, the maximum bending stress occurs at the top and the bottom of the test piece near the lower flanges. The maximum shear stress occurs at the neutral axis of the test piece. Generally speaking, a three dimensional model has stresses in more than one direction, the combined stress should be used as criteria for analysis. The stress intensity, defined as twice the maximum shear stress, and the equivalent stress, calculated from the three principal stresses, for the test piece under 2200 lb cantilever load are given in Fig. 5 and 6. In both Figs. 5 and 6, the maximum stress is located near the neutral axis near where the tube failed during test.

ELEMENTARY BEAM THEORY

In parallel to the finite element approach, the elementary beam formulas for stress and strain are examined to see if one could correlate the finite element results with the simple theory and gain insight about the structural behavior of the test piece.

1) Bending Effect

Maximum deflection and maximum slope for a concentrated load P at the free end of a cantilever beam are given in Eqs. 1 and 2.

$$\delta_m = \frac{P\ell^3}{3EI} \tag{1}$$

$$\theta_m = \frac{P\ell^2}{2EI} \tag{2}$$

The maximum bending stress is given in Eq. 3.

$$\sigma_m = \frac{P \ell r}{I} \tag{3}$$

where

δ_m is the maximum deflection

θ_m is the maximum slope

P is the load

ℓ is the length of the G-11 tube excluding two flanges

E is the elastic modulus (3×10^6 psi)

I is the moment of inertia and equals to $\pi t r^3$

σ_m is the maximum bending stress

r is the radius

t is the wall thickness

2) Shear Effect

The maximum shear stress for a thin wall tube is found to be located in the neutral axis of the test piece and is given by Eq. 4.

$$\tau_m = \frac{2 P}{A} \tag{4}$$

For tubes with flanges on the end, the shear strain and the deflection of the upper flange are not available. Equation 5 and 6 calculate the shear strain and deflection using the maximum shear stress.

$$\gamma = \frac{\tau_m}{G} \tag{5}$$

$$\delta_\tau = \gamma \cdot \ell \tag{6}$$

where

τ_m is the maximum shear stress

A is the cross sectional area

G is the shear modulus and equals to $\frac{E}{2(1+\mu)}$

μ is the Poisson's ratio ($\mu = 0.21$)

γ is the shear strain

δ_τ is the deflection due to shear

Total deflection equals to the sum of δ_m and δ_τ. However, the slope at the free end equals to θ_m, since only bending caused a rotation of the upper flange. A comparison between ANSYS and the elementary formulas are given below in Table 1.

Table 1

Comparison Between ANSYS and Elementary Formulas at 2200 Lb Load

	ANSYS	Elementary Formulas
Max. Deflection - in	0.0234	0.0223
Max. Slope - radian	0.0018	0.0016
Max. Bending stress - psi	6061	5582
Max. Shear stress - psi	3424	3256

As shown in Table 1, the agreement between ANSYS and the elementary formulas are quite good. Because it is much easier to calculate results from the elementary formula, the elementary results will be used to compare with the measurements.

Results

Three separate sets of measurements with 440 and 1100 lb incremental loads have been taken. The first set of measurements were terminated because the test piece can not maintain the load with loads exceed 4400 lbs. The second set of measurement is limited to a maximum load of 2200 lbs and little hysteresis is observed when loads are removed. During the third measurement, the wall of the G-11 outer tube failed at approximately 4600 lbs, corresponding to 6,800 psi maximum shear stress or 13,600 psi stress intensity. The measured deflection versus calculation for all three sets of loading conditions are given in Fig. 7. As one can see, the measurements are higher than the calculatons. For loads less than 2000 lb, the measured deflection is approximately twice that calculated. For loads greater than 2000 lb, the measured deflection is approximately three times that calculated.

Discussions

It is not clear why the measured deflections are higher than the calculations when the finite element analysis and the elementary formulas are in good agreement. Complete review on the test setup, material properties and analysis will be performed for future tests on the post leg assembly. As for the primary goal of the test, the strength of the 300 K shrink fit joint has been verified.

Fig. 2 Deformation of the G-11 outer tube test piece

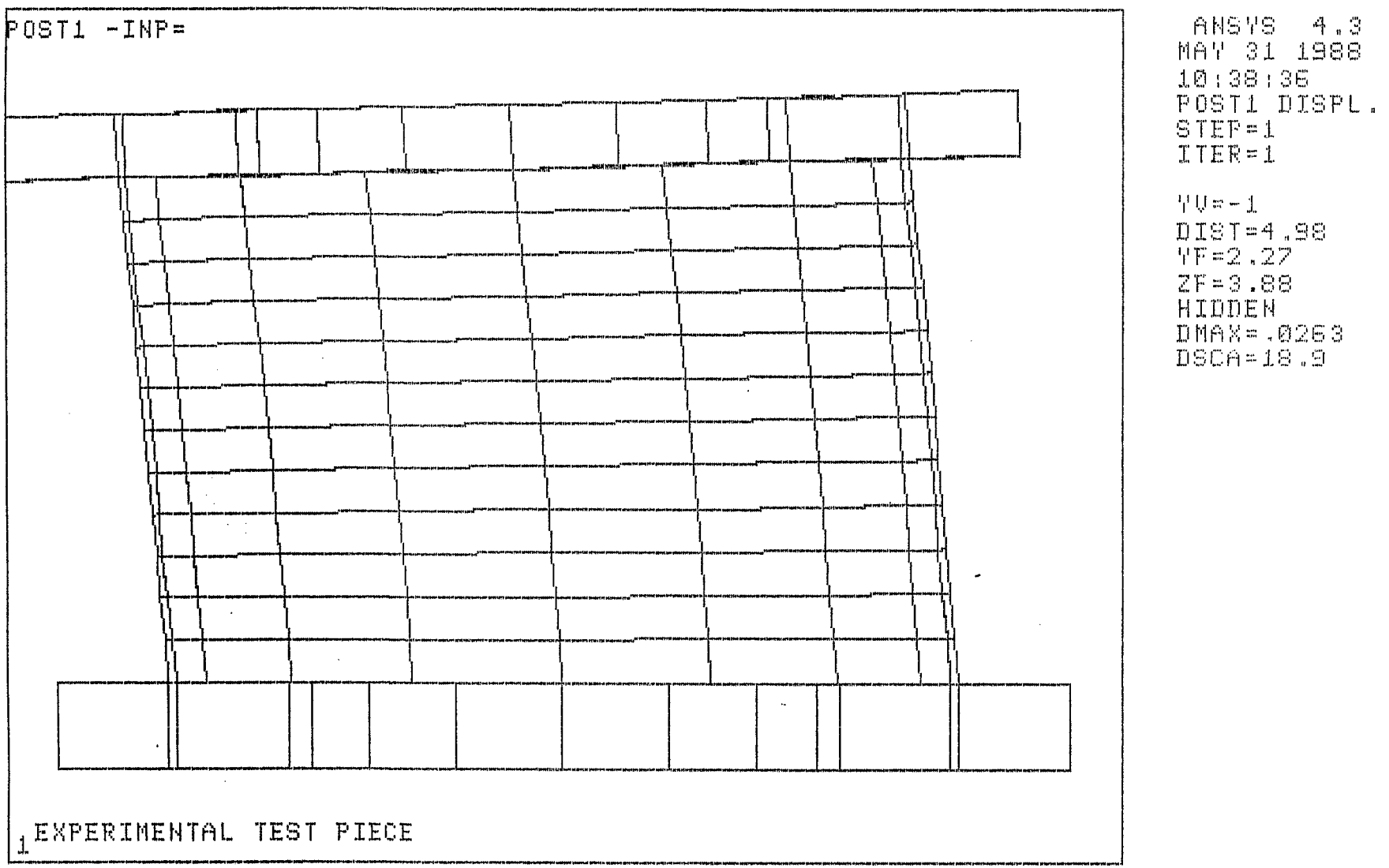


Fig. 3 Bending stress of the G-11 outer tube test piece

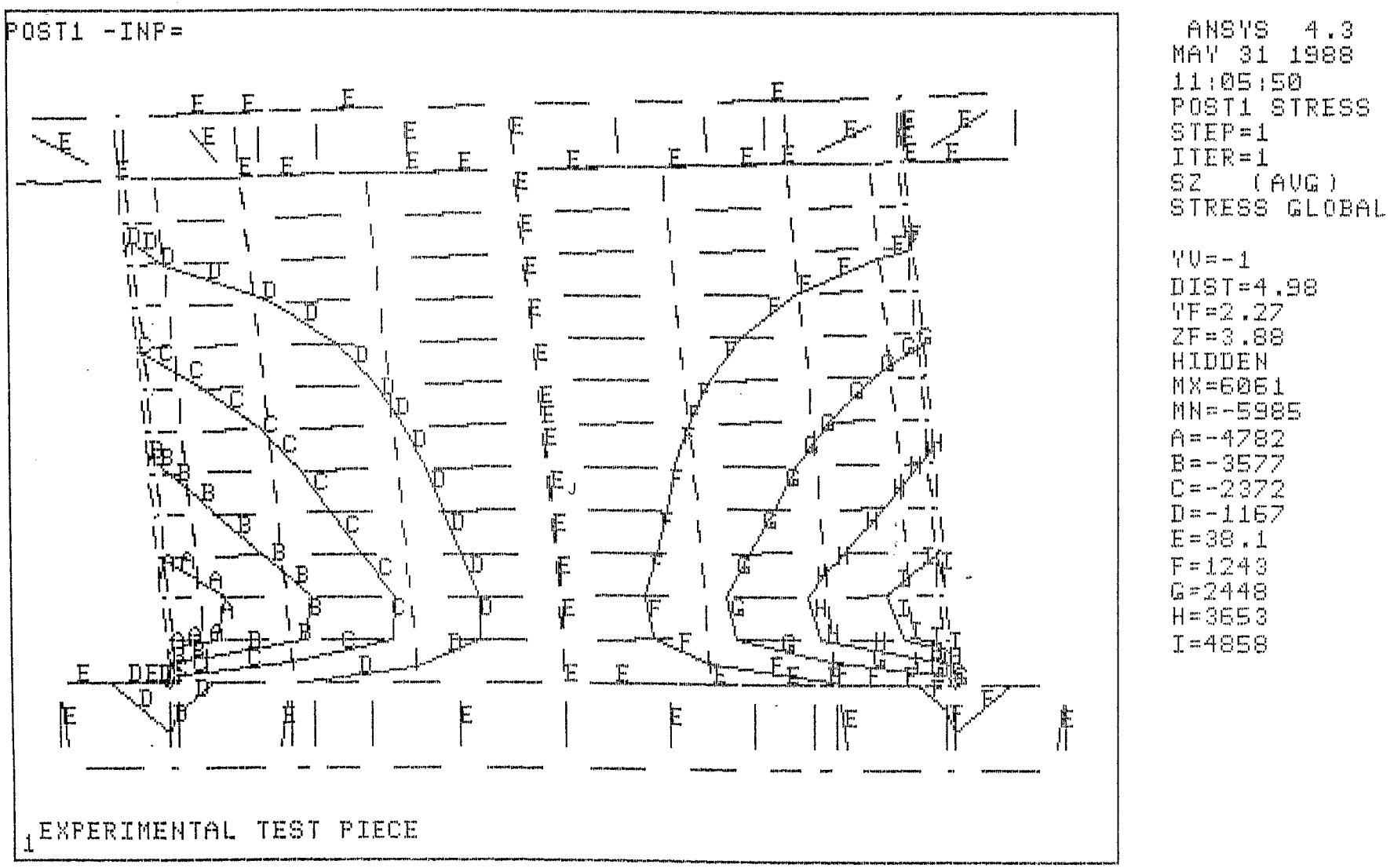
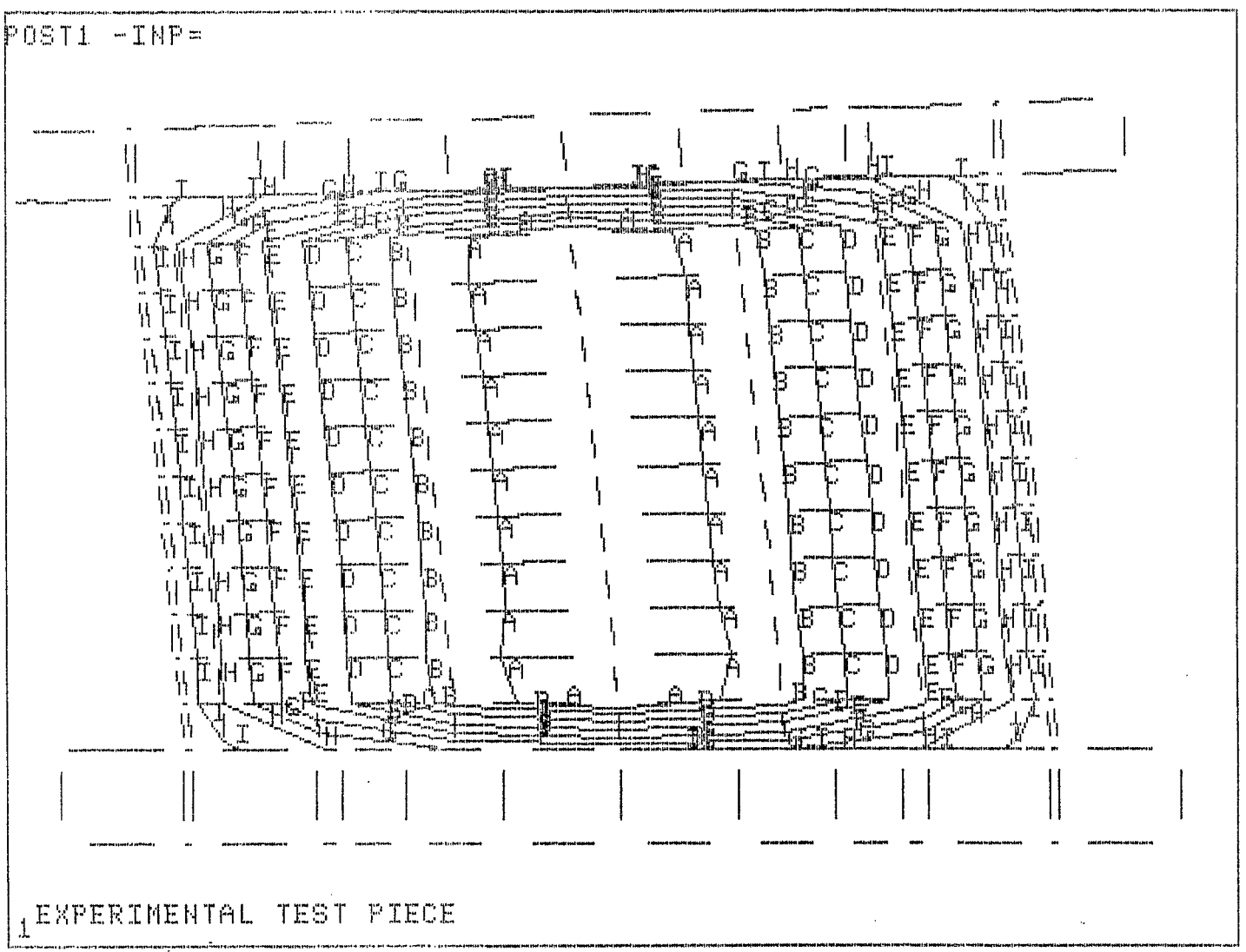


Fig. 4 Shear stress of the G-11 outer tube test piece



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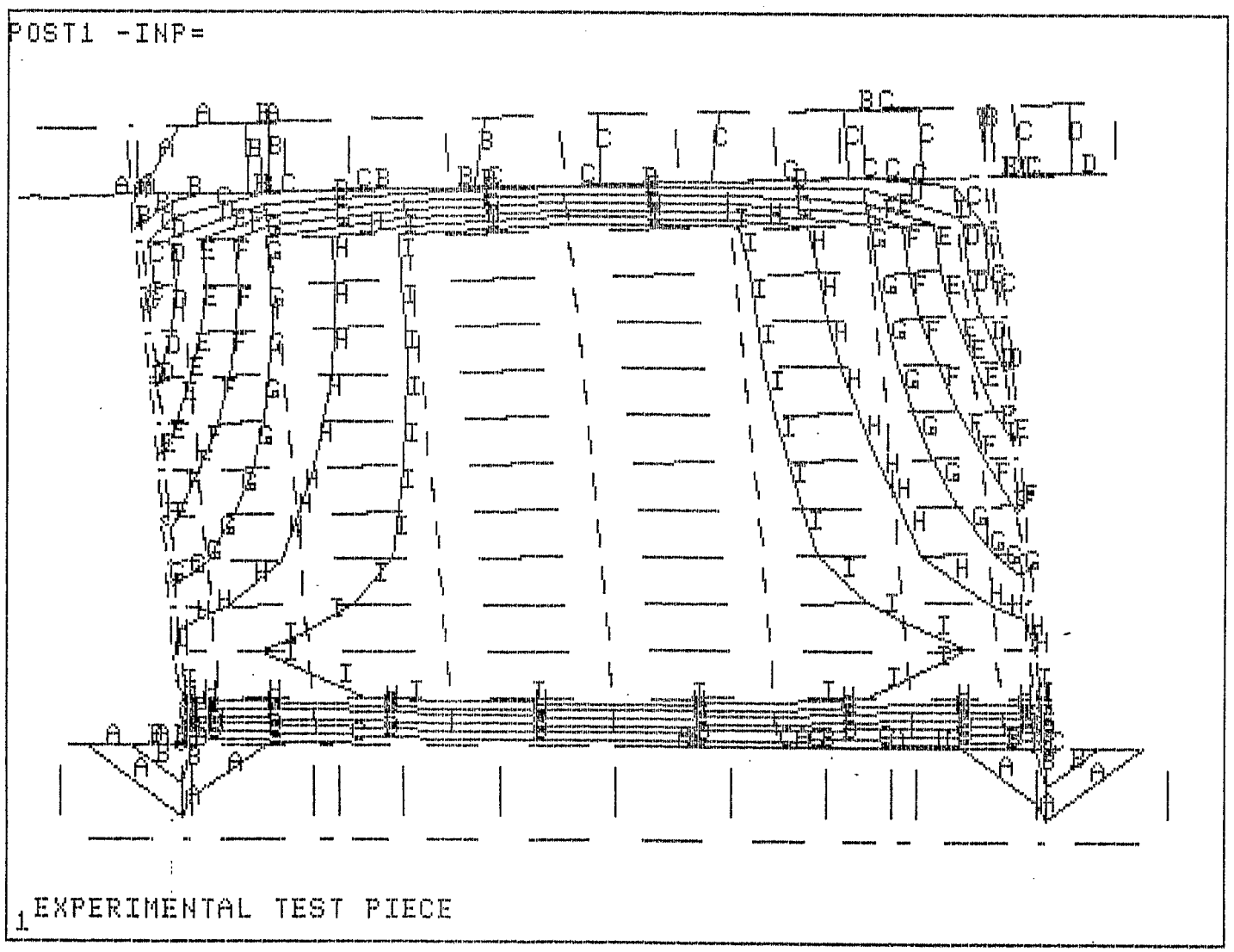
MAY 31 1988
11:09:58
POST1 STRESS
STEP=1
ITER=1
SXZ (AVG)
STRESS GLOBAL

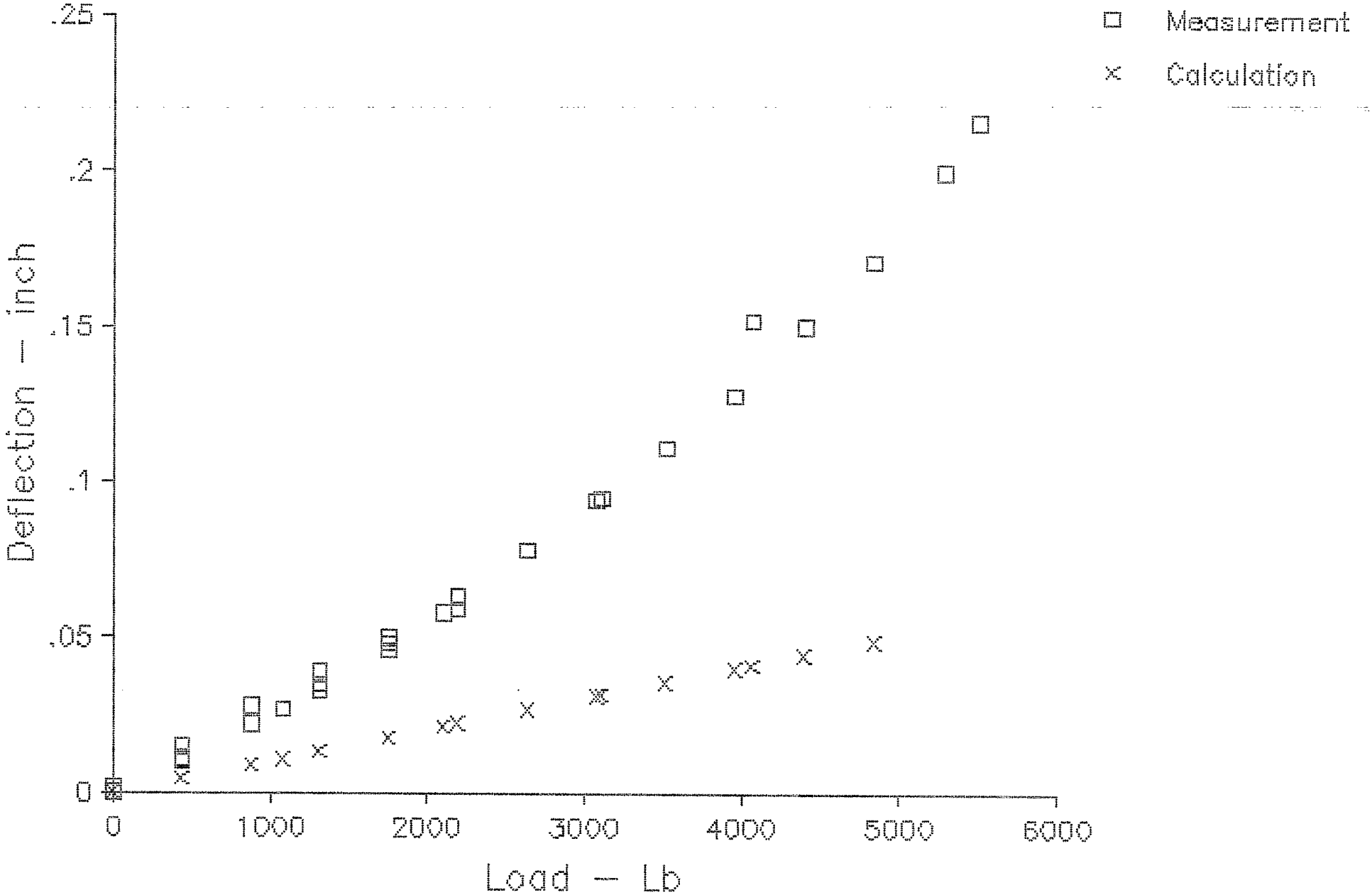
VV=-1
DIST=4.98
VF=2.27
ZF=3.88
HIDDEN
MX=98.3
MN=-3324
A=-2985
B=-2642
C=-2299
D=-1956
E=-1613
F=-1270
G=-927
H=-584
I=-241

Fig. 5 Stress intensity of the G-11 outer tube test piece



ANSYS 4.3
MAY 31 1988
10:48:17
POST1 STRESS
STEP=1
ITER=1
SI (AVG)

VV=-1
DIST=4.98
YF=2.27
ZF=3.88
HIDDEN
MX=6649
MN=61.2
A=719
B=1378
C=2037
D=2696
E=3355
F=4014
G=4673
H=5332
I=5991

Fig. 7 Deflection versus Load

For G-11 Outer Tube Test Piece