Graphite Rod Test / Simulation
Response from LANSCE- WNR Proton Beam

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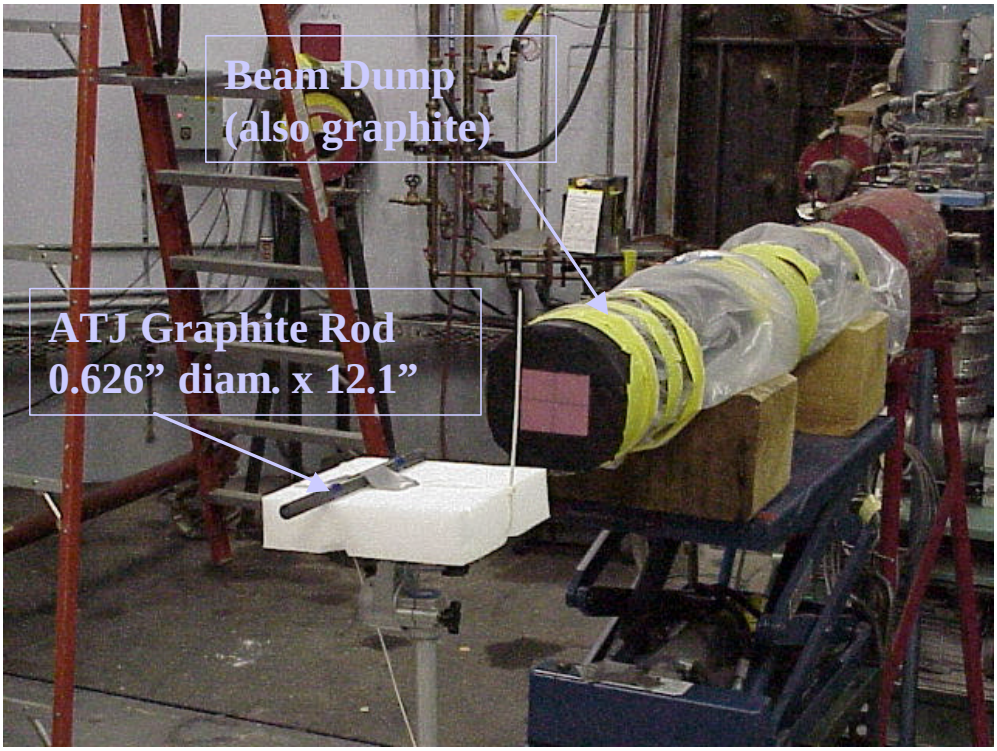
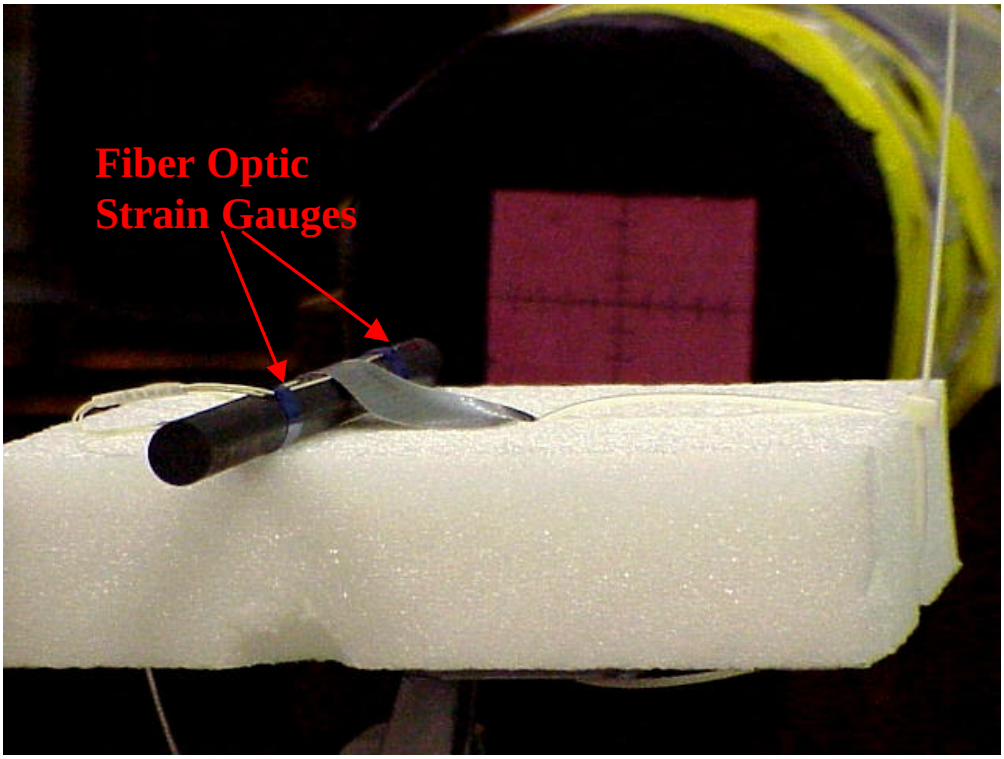
Graphite rods were instrumented with fiber optic strain gages to measure dynamic response from LANSCE 800 MeV proton beam pulses (of about 2.3e13 protons, with FWHM ~ 300 ns). Structural analysis simulations of the response were performed with the finite element code ABAQUS/Explicit. Predicted and measured strains at the mid length location compare favorably.

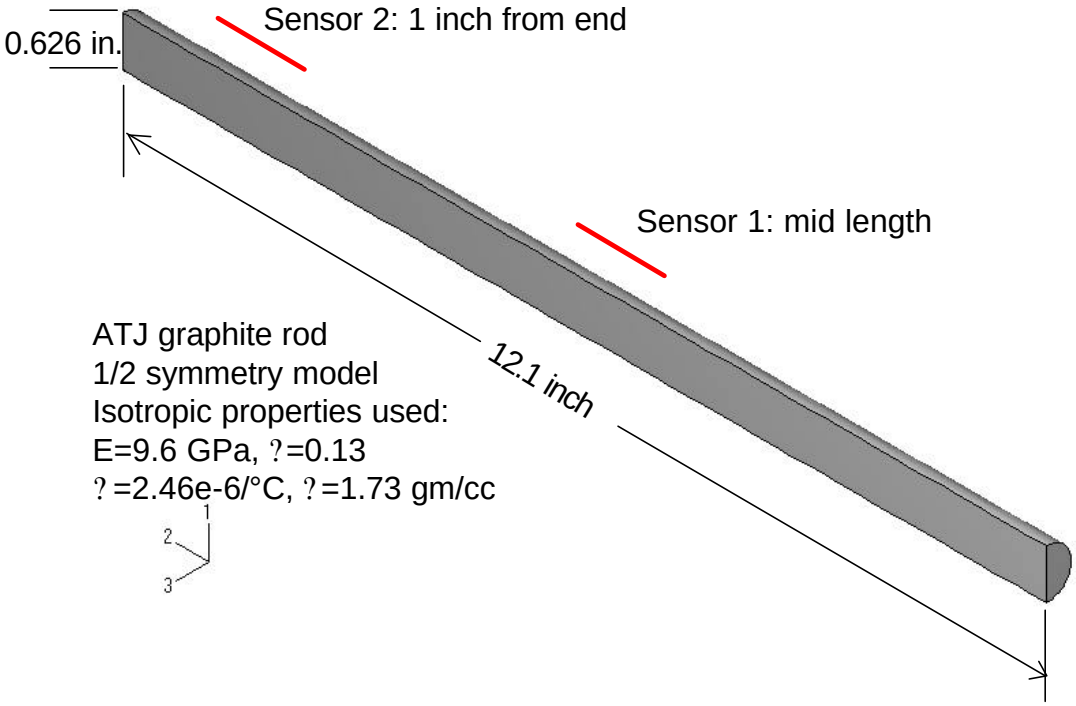
The measured strains indicated the first bending mode of the rod was strongly excited. This indicated it was necessary to use three dimensional analysis to simulate this response character. Energy deposition in the rod (data provided by P. Ferguson) was shifted parallel to the rod axis approximately 5 mm, or 60% of the radius. How this compares to the actual beam offset / axis is not known.

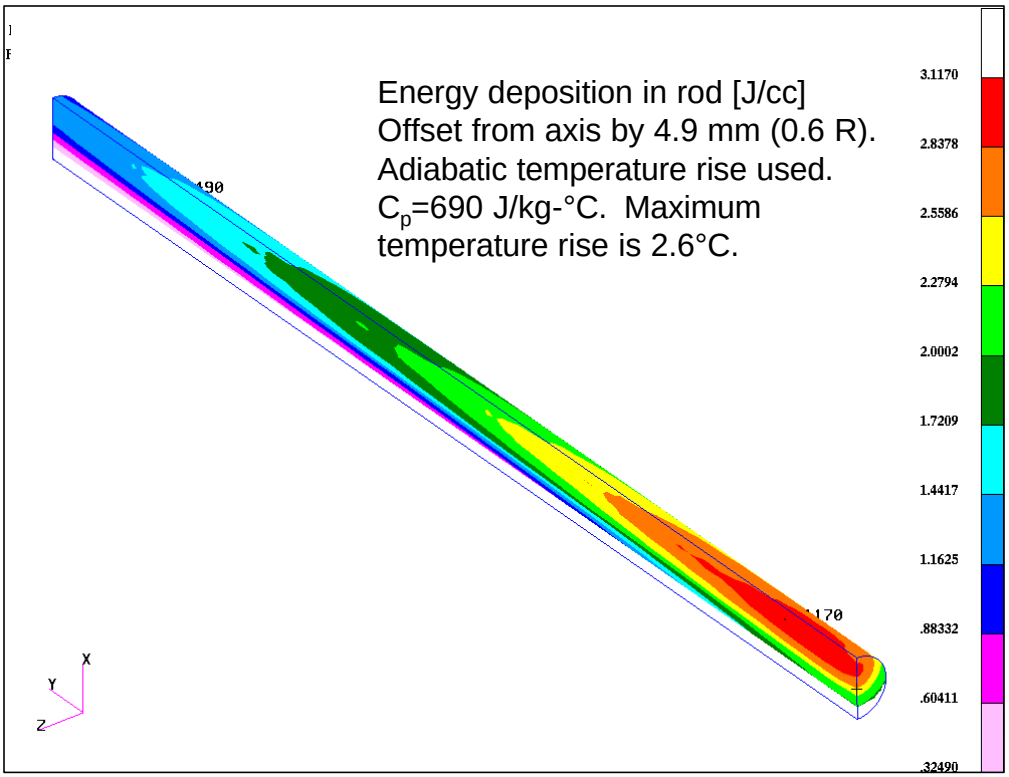
Higher order response observed in the strain correspond to axial wave propagation and radial wave propagation. Displacement results from the simulation also indicate a higher bending mode is also excited.

The tested graphite rod was the ATJ variety. Although it has some amount of anisotropy, isotropic thermal - mechanical properties were used for this work. Maximum stress predicted by simulation is 0.130 MPa. At room temperature ATJ tensile strength is above 15 MPa.


Beam Dump
(also graphite)
ATJ Graphite Rod
0.626” diam. x 12.1”


Fiber Optic
Strain Gauges

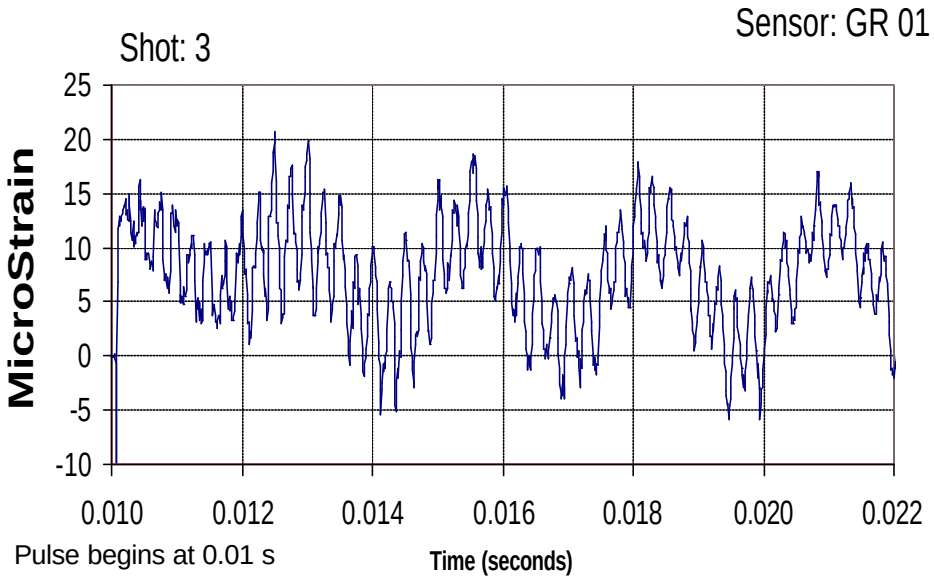

0.626 in.
Sensor 2: 1 inch from end
Sensor 1: mid length
12.1 inch
ATJ graphite rod
1/2 symmetry model
Isotropic properties used:
E=9.6 GPa, ?=0.13
?=2.46e-6/°C, ?=1.73 gm/cc
1
2
3


Energy deposition in rod [J/cc]
Offset from axis by 4.9 mm (0.6 R).
Adiabatic temperature rise used.
C_p=690 J/kg-°C. Maximum
temperature rise is 2.6°C.
3.1170
2.8378
2.5586
2.2794
2.0002
1.7209
1.4417
1.1625
.88332
.60411
.32490
X
Y
Z

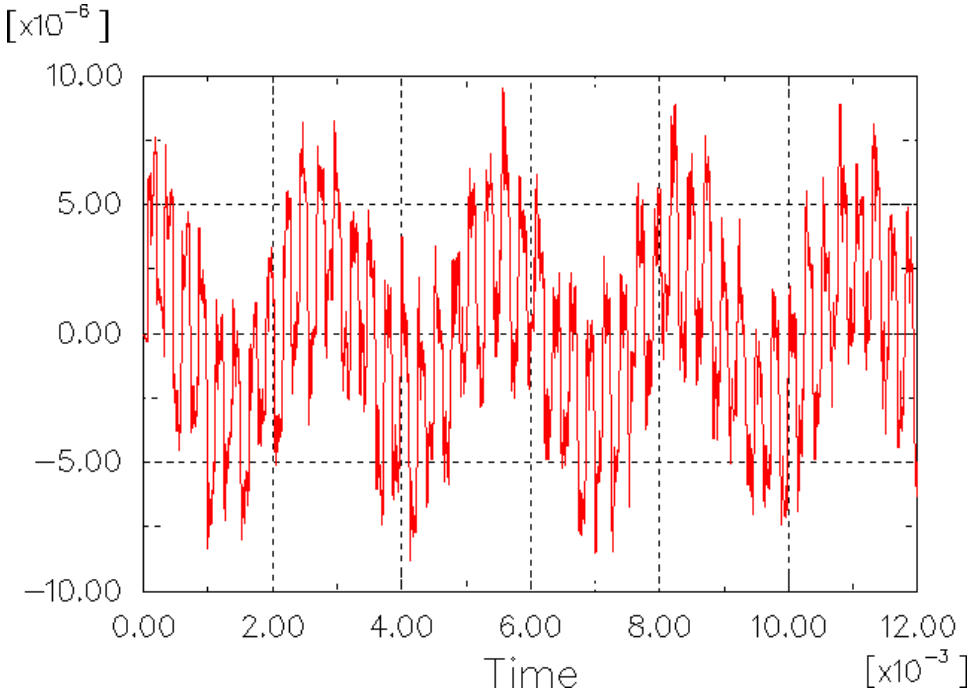
The figures on the following page show measured and simulated strain at a mid length location. At this time it is not possible to know in which direction the actual beam offset was, so the locations do not necessarily correspond. Also, test data has yet to be post processed to correct for minor anomalies in the data acquisition process.

Nevertheless, the simulated strains compare well with measured strains in magnitude and dynamic character. The lowest frequency is 350 Hz. Modal analysis using an unconstrained 1D model indicates this to be the first bending mode.

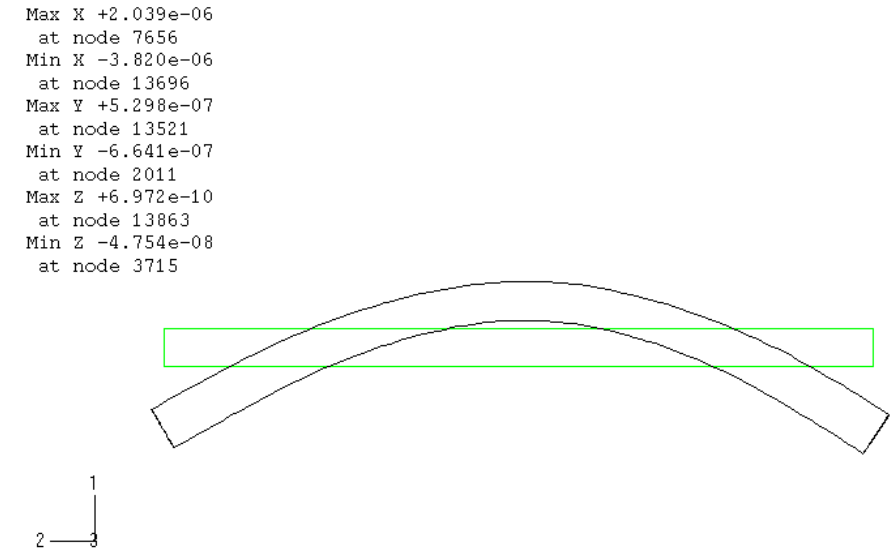
The next lowest observed frequency is 3833 hz. The longitudinal wave speed (uniform bar) is $c=(E/?)^{1/2}$ = 2356 m/s. The time for a wave to traverse the rod length is (12.1 in)(0.0254 m/in)/(2356 m/s) = 130 ?s, or 7666 hz. For the wave to reflect and return the length again, the frequency is halved giving 3833 hz.



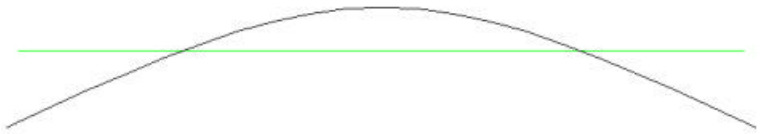
Measured strain at center gage, shot G1-03



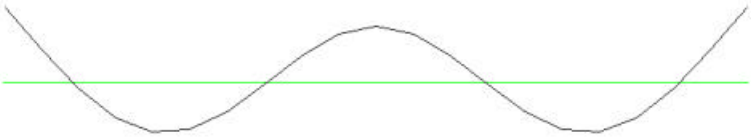
Predicted strain. Some small degree of smoothing applied.



Deformed shape at 12 ms (10000x) show bending mode character.
(animation available at \\Snsnta\users\Riemer\SNS\graphite\Def2_d.mov)

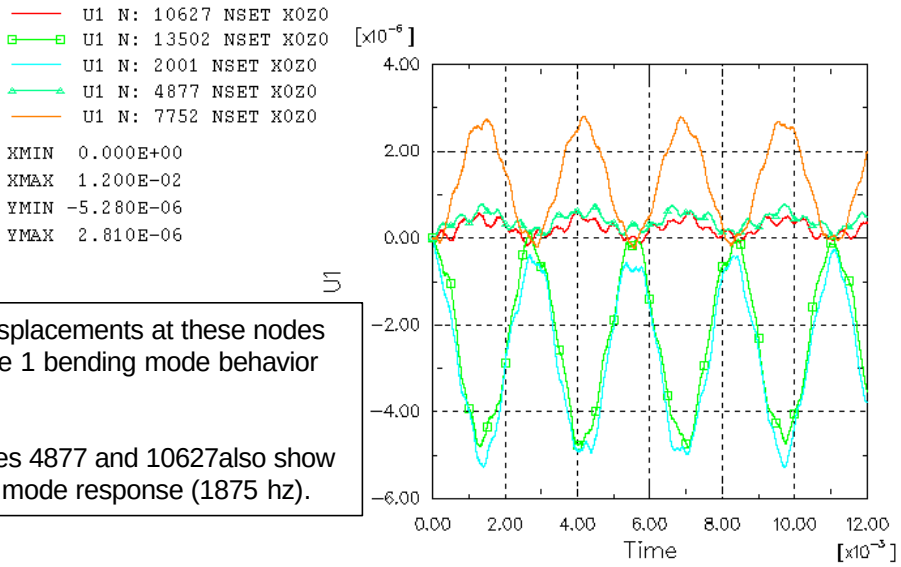


1st bending mode from 1D modal analysis. 348 Hz



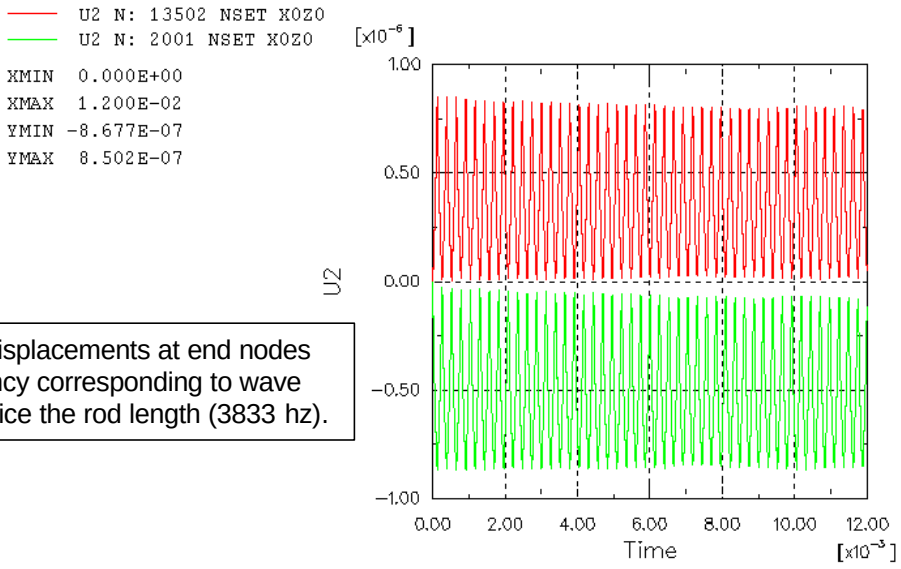
3rd bending mode from 1D modal analysis (1817 Hz). Displacement in 1 direction at 1/4 point nodes show evidence of this mode.

Displacements at selected nodes from simulation



Direction 1 displacements at these nodes all show mode 1 bending mode behavior (350 hz).

1/4 point nodes 4877 and 10627also show third bending mode response (1875 hz).



Direction 2 displacements at end nodes have frequency corresponding to wave traversing twice the rod length (3833 hz).