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Evaluation of On-Line Pulse Control for Vibration Suppression in Flexible Spacecraft

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EVALUATION OF ON-LINE PULSE CONTROL FOR VIBRATION SUPPRESSION IN FLEXIBLE SPACECRAFT

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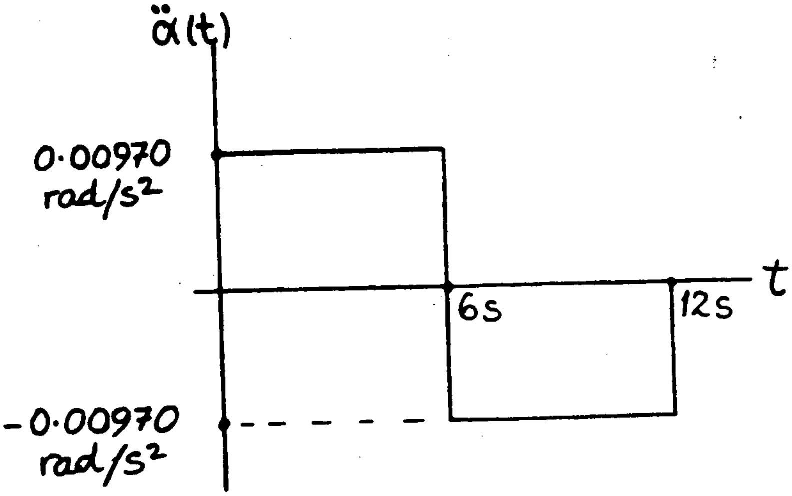
OUTLINE

I. Objective

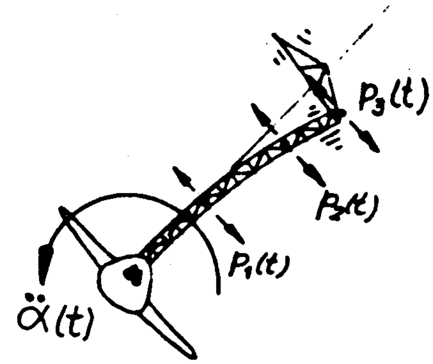
II. Modeling Issues
- Beam vs. Truss
- NL-FEM, numerical problems

III. Control Issues
- ED Pulse Actuator Development
- Pseudo Pulse Algorithm Dev.
- Large NL simulation Problems

OVERALL OBJECTIVE



(Gene Lin, 1984 SCOLE Mtg.)

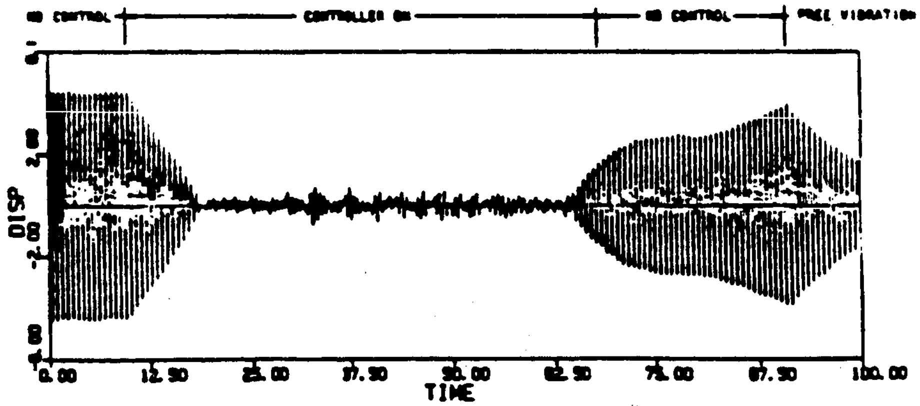


Minimum Time 20° Slew Maneuver

Mass-Ejection Pulse Control Strategy:

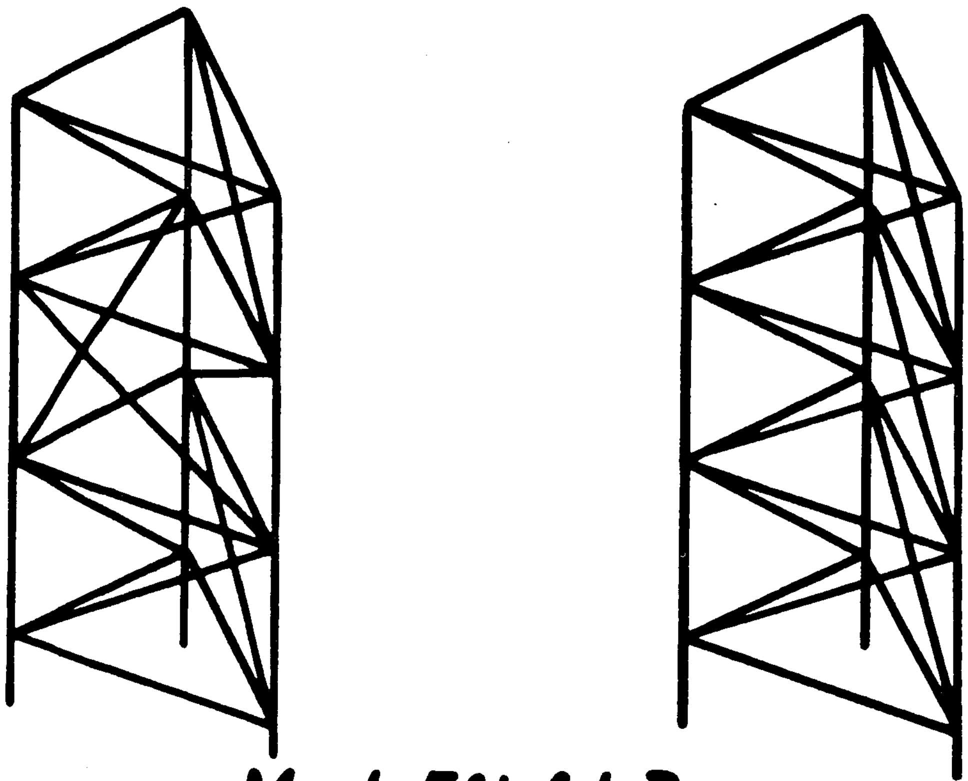
$$p_i(t) = \begin{cases} -c_i \,\mathrm{sgn}(v_i)|v_i|^{n_i}; & t_{o_i} < t < (t_{o_i} + T_{d_i}) \\ 0; & (t_{o_i} + T_{d_i}) < t < t_{o_{i+1}} \end{cases}$$

Typical Experimental Results:



MODELLING ISSUES

1. Continuous Beam vs. Truss
   - Axial / Torsional Coupling
   - Local Member Participation in Modes
   - Parametric Resonance Problems



Mast Flight Beam

Alternating Bay Diagonals

Identical Bay Diagonals

LINEAR TRUSS RESULTS

2. Linear Finite Element Model Characteristics
   - COFS-I Hardware Configuration
   - 54 Bays, 60m
   - 171 nodes, 486 elements, 522 D. of F.
   - July 1986 data for member characteristics from Astro Aerospace Corp. /Harris Corp.
   - Match modal results with Astro/Harris
   - Transient Response Simulations:
     - Rayleigh damping: $\zeta_1 = 1\%$, $\zeta_{12} = 10\%$
     - Sine-sweep, tip excitation
     - Nonstationary Random, tip excitation
     - Harmonic, base excitation

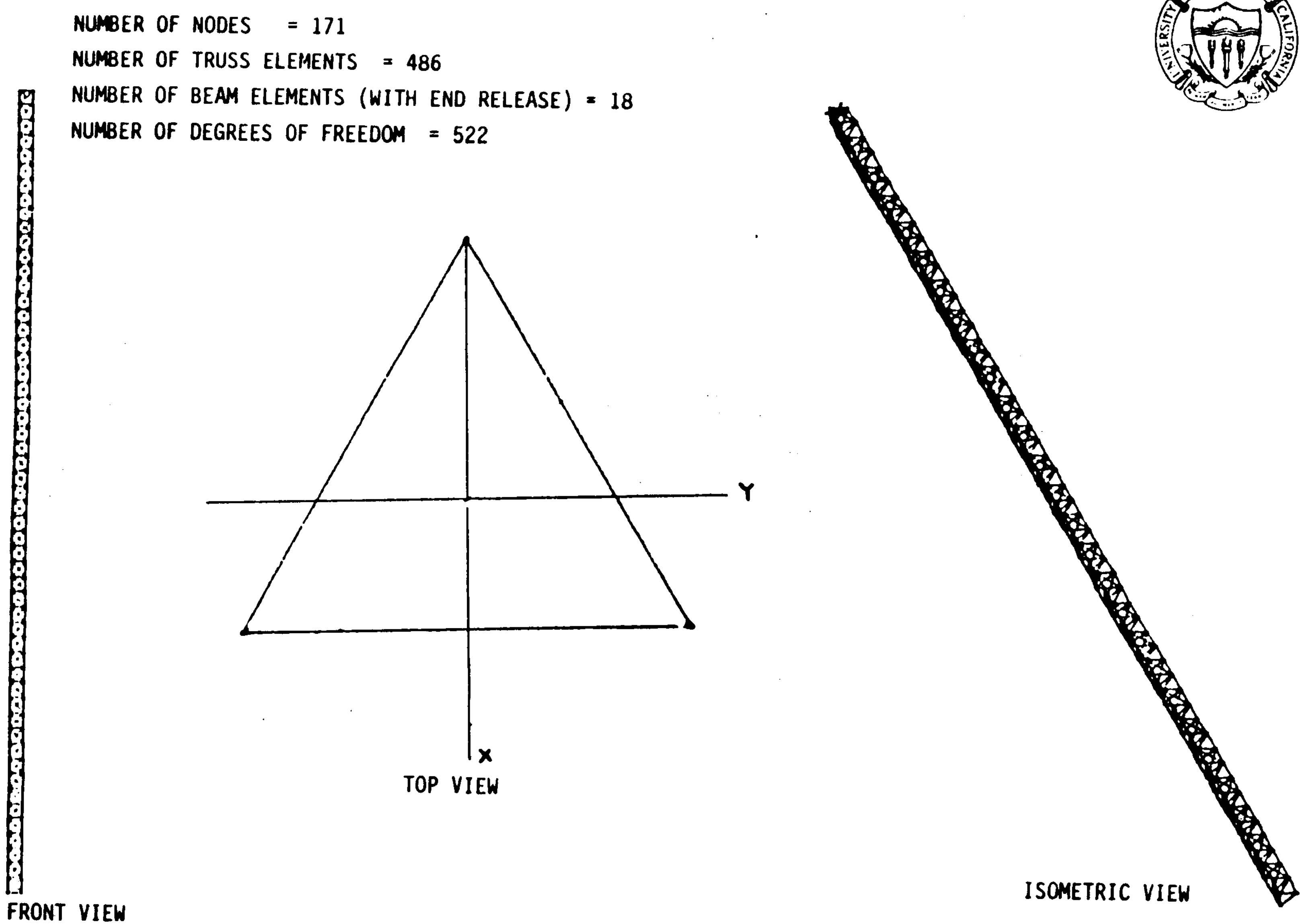


FIG. 1. NONLINEAR THREE-DIMENSIONAL FINITE ELEMENT MODEL OF COFS I MAST

	NASA RESULTS MAST ON RIGID BASE		USC RESULTS MAST ON RIGID BASE	
MODE	FREQUENCY (HZ)	TYPE	FREQUENCY (HZ)	TYPE
1	0.18	1st Bending in Y	0.18	1st Bending in Y
2	0.20	1st Bending in X	0.20	1st Bending in X
3	1.77	2nd Bending in Y	1.60	2nd Bending in Y
4	1.97	2nd Bending in X	1.72	2nd Bending in X
5	2.18	1st Torsion	2.37	1st Torsion
6	5.47	3rd Bending in Y	4.72	3rd Bending in Y
7	6.07	3rd Bending in X	5.07	3rd Bending in X
8	8.12	2nd Torsion	7.70	2nd Torsion
9	11.23	4th Bending in Y	9.29	4th Bending in Y
10	12.44	4th Bending in X	9.93	4th Bending in X
11	12.62	1st Compression	12.49	1st Compression
12	13.51	3rd Torsion	12.82	3rd Torsion

FIG. 3. FIRST 12 NATURAL FREQUENCIES AND MODE SHAPES OBTAINED BY DETERMINING THE EIGEN VALUES AND EIGENVECTORS CORRESPONDING TO THE LINEARIZED VERSION OF THE FINITE ELEMENT MODEL SHOWN IN FIG. 1.

NOTE: TORSIONAL MODE PLOTS APPEAR DISTORTED DUE TO PLOTTING ALGORITHM. ACTUAL MODE SHAPES INCLUDE NEGLIGIBLE BATTEN DEFORMATIONS.

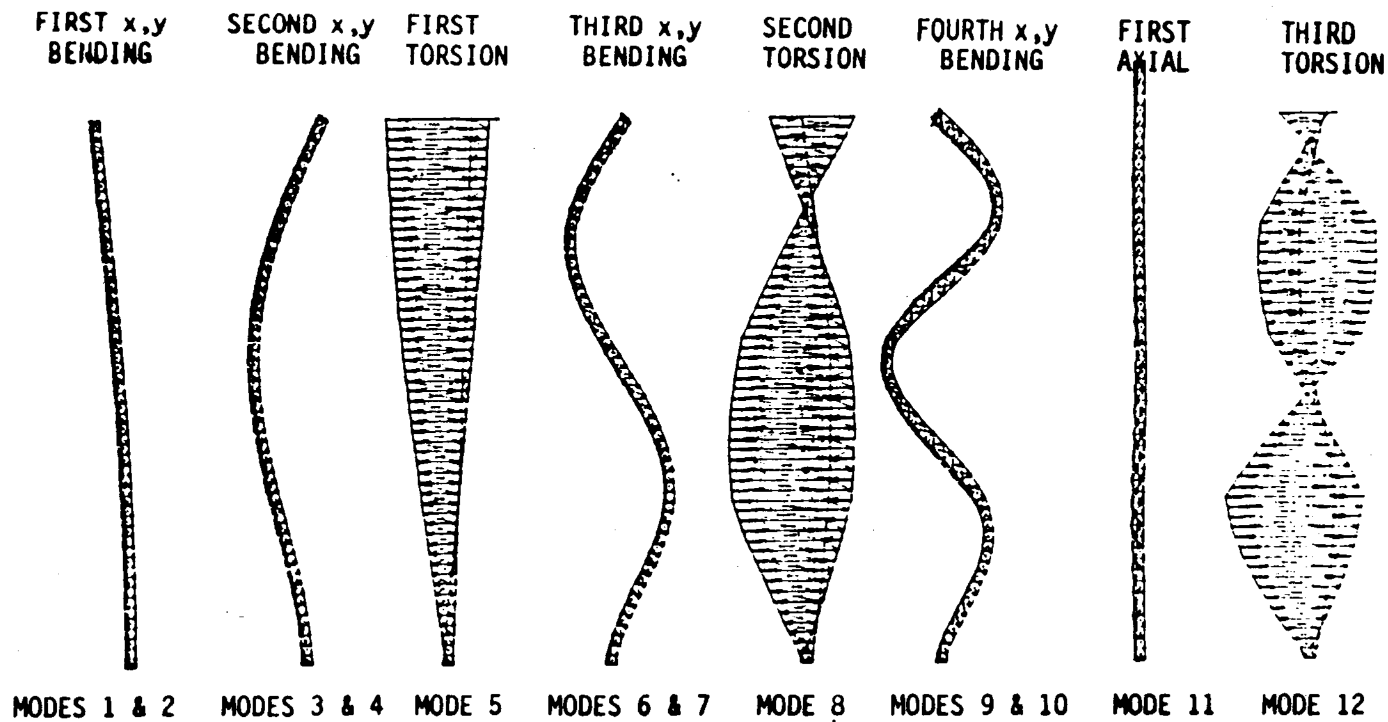
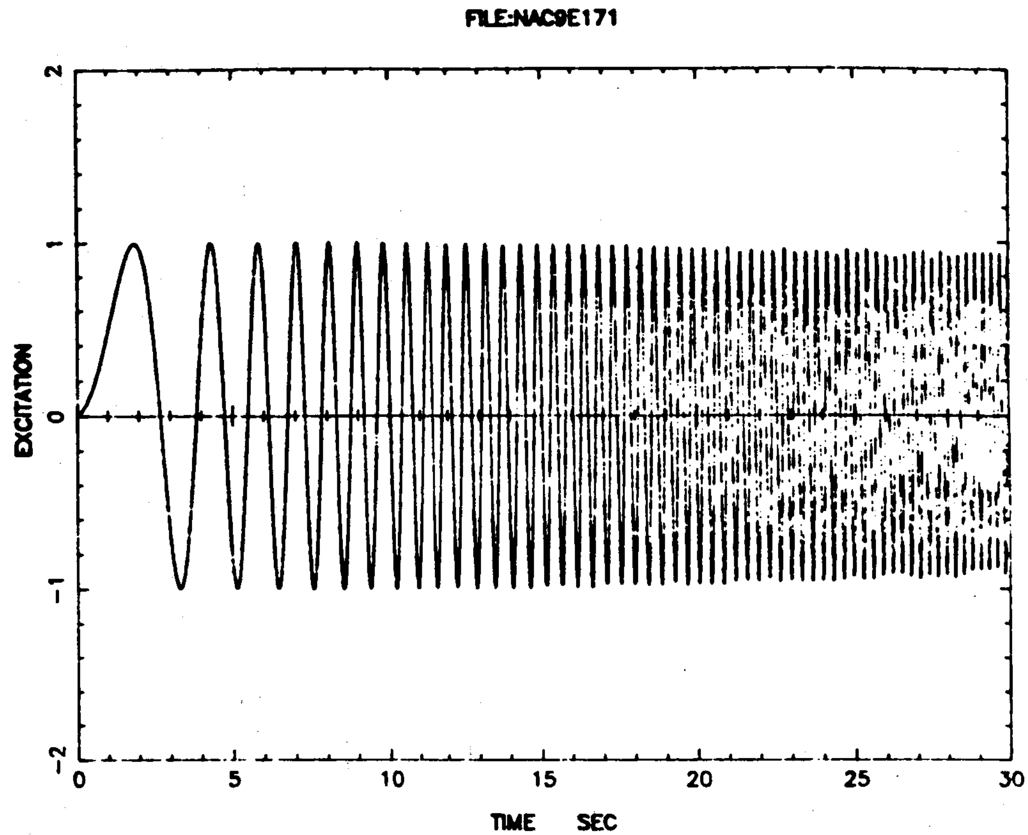
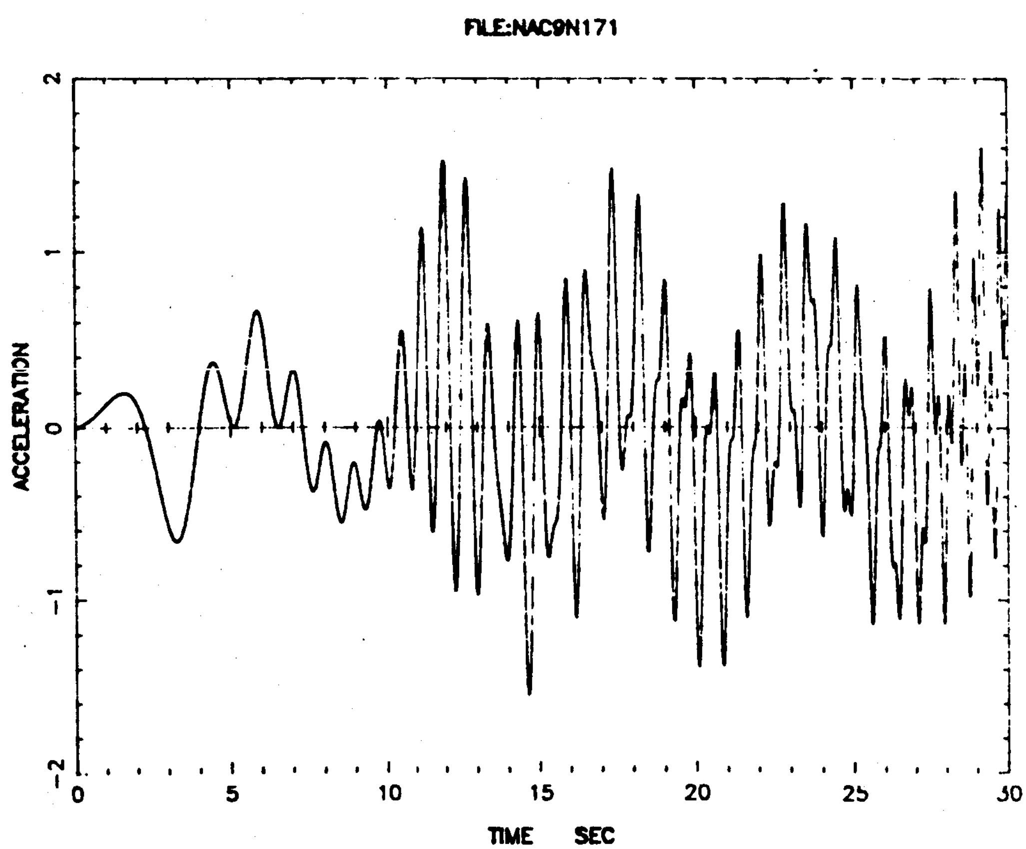
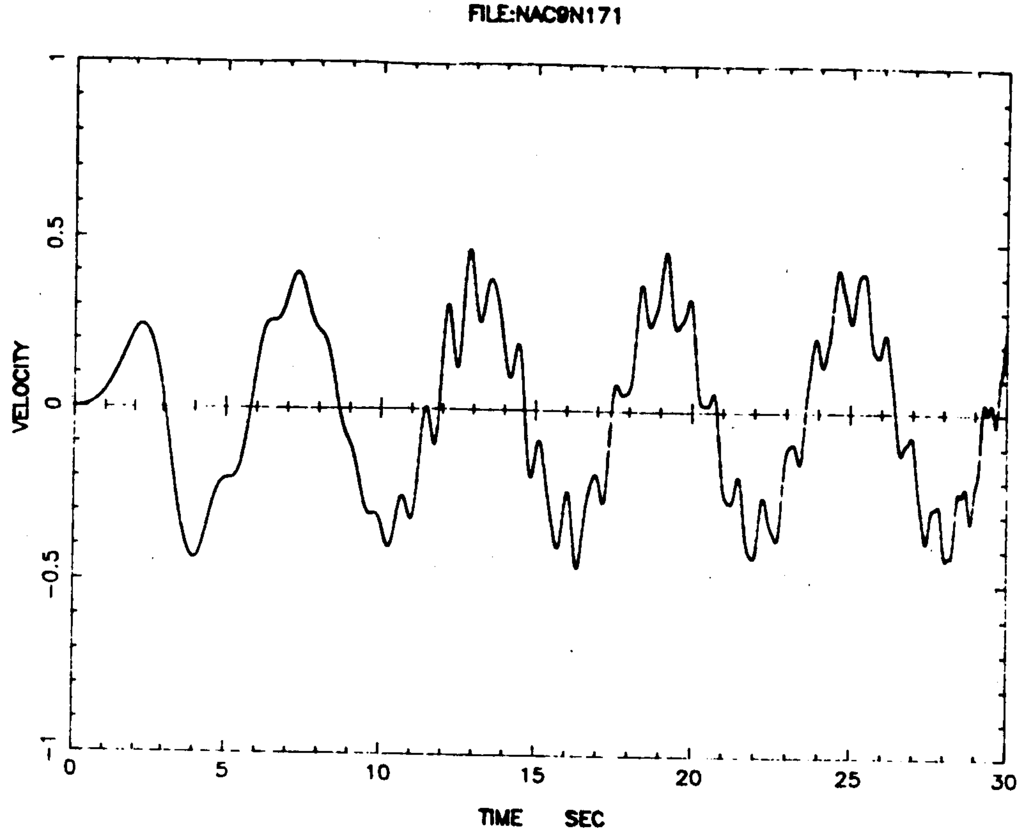


FIG. 4. REPRESENTATIVE MODE SHAPES CORRESPONDING TO THE LINEARIZED VERSION OF THE USC NONLINEAR COFS I MAST FINITE ELEMENT MODEL.

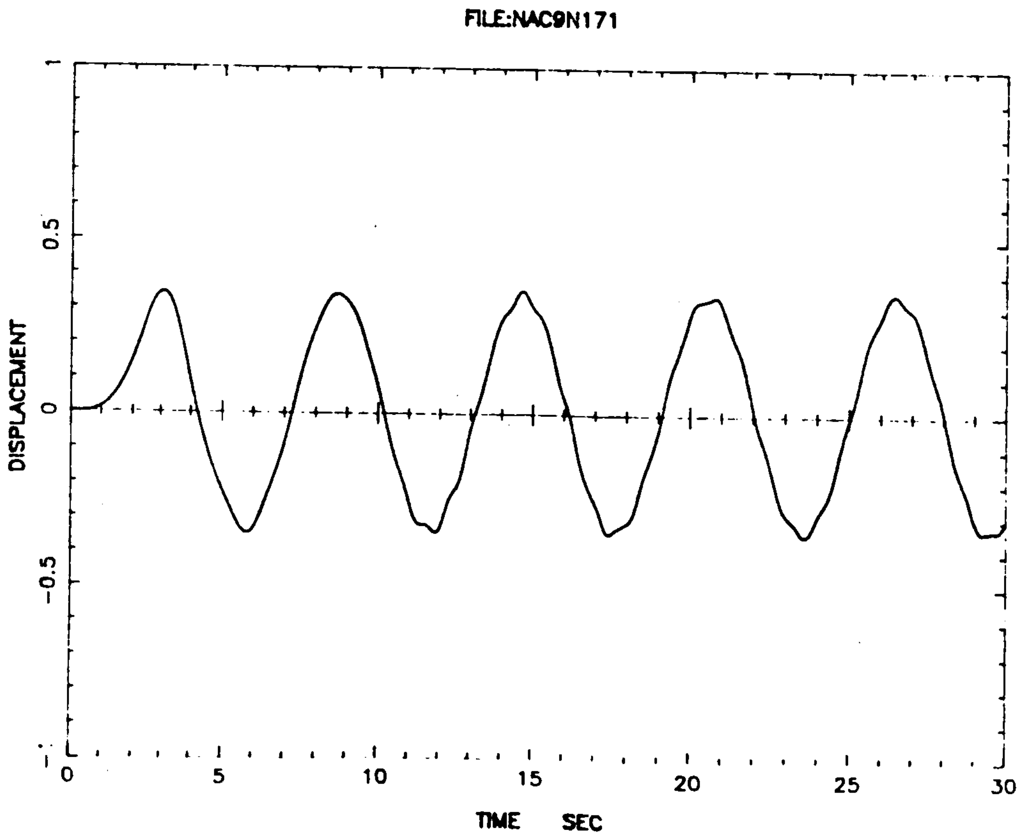


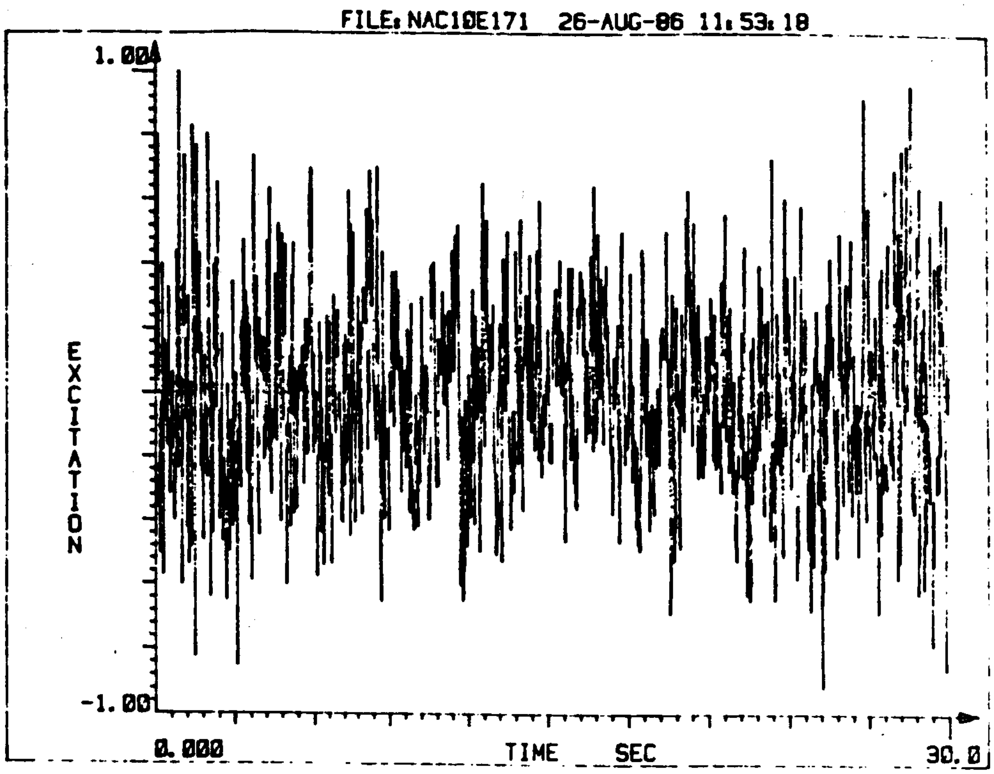
Swept Sine Response - Tip Excit.



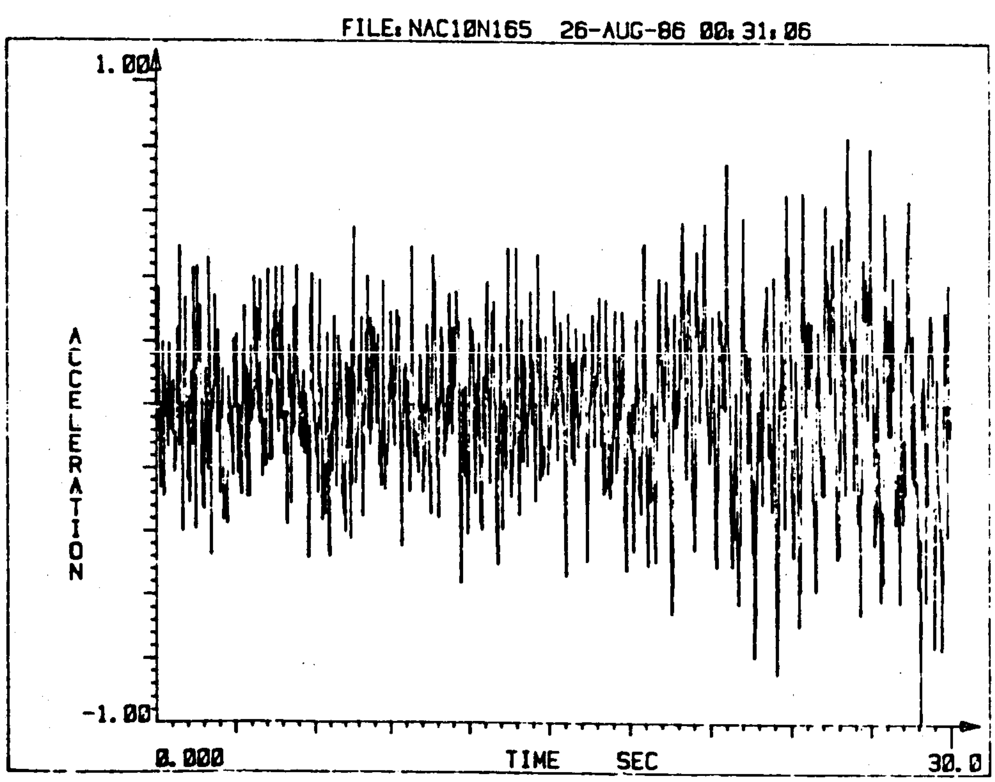


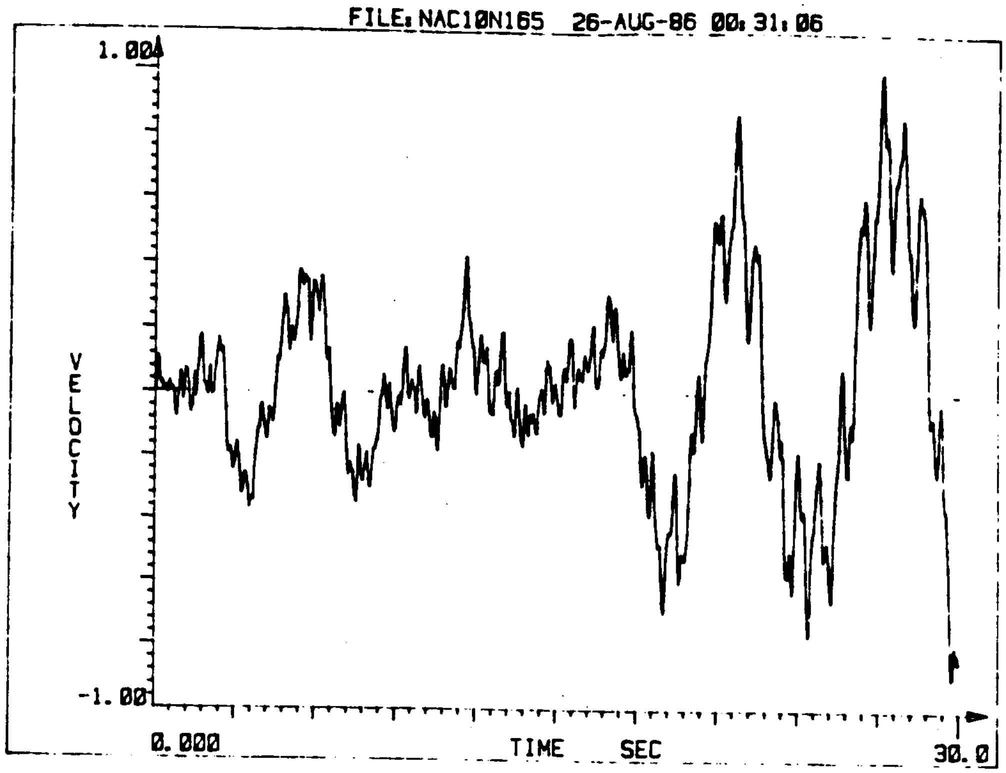
Swept Sine Response - Tip Excit.



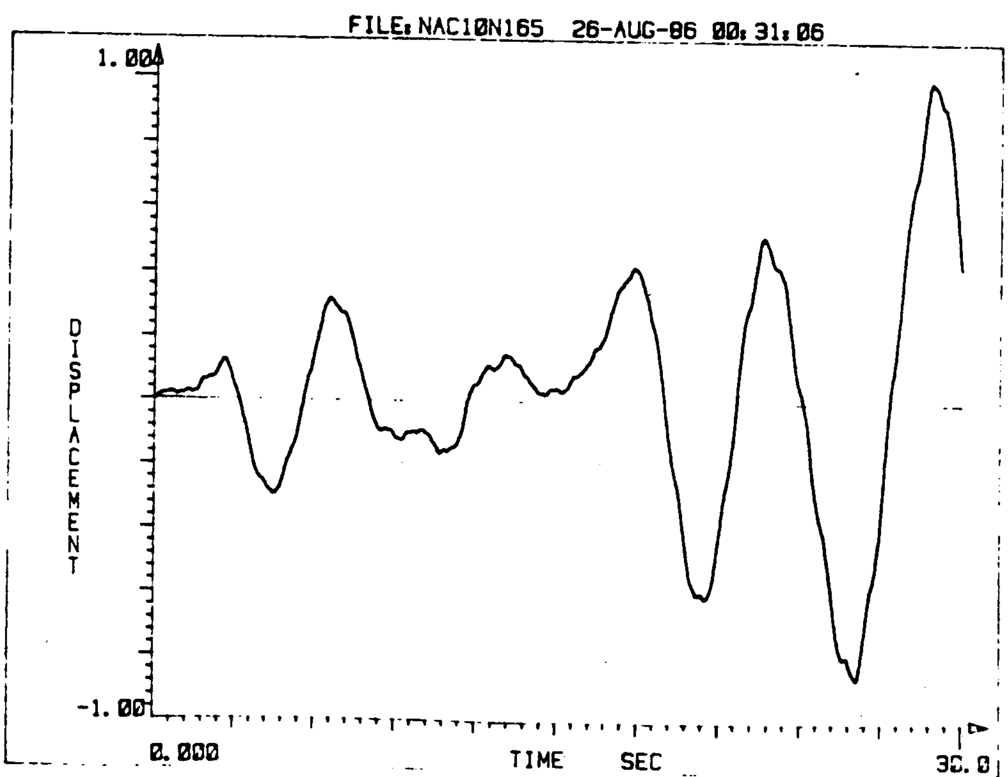


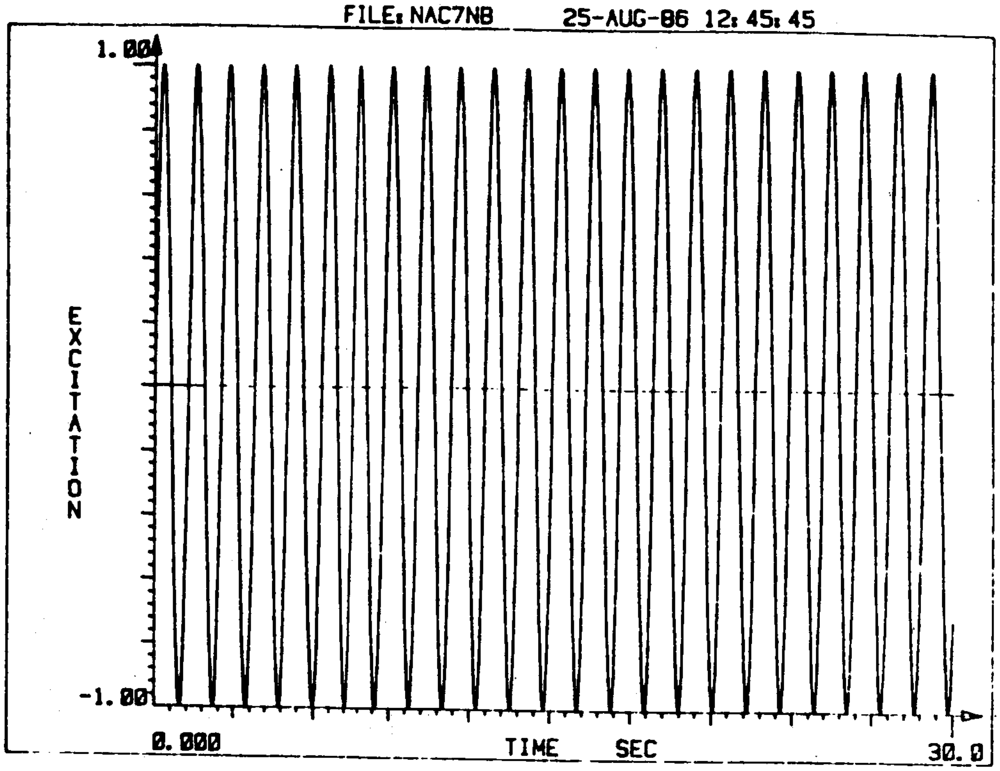
Nonstationary Random Response - Tip Excit



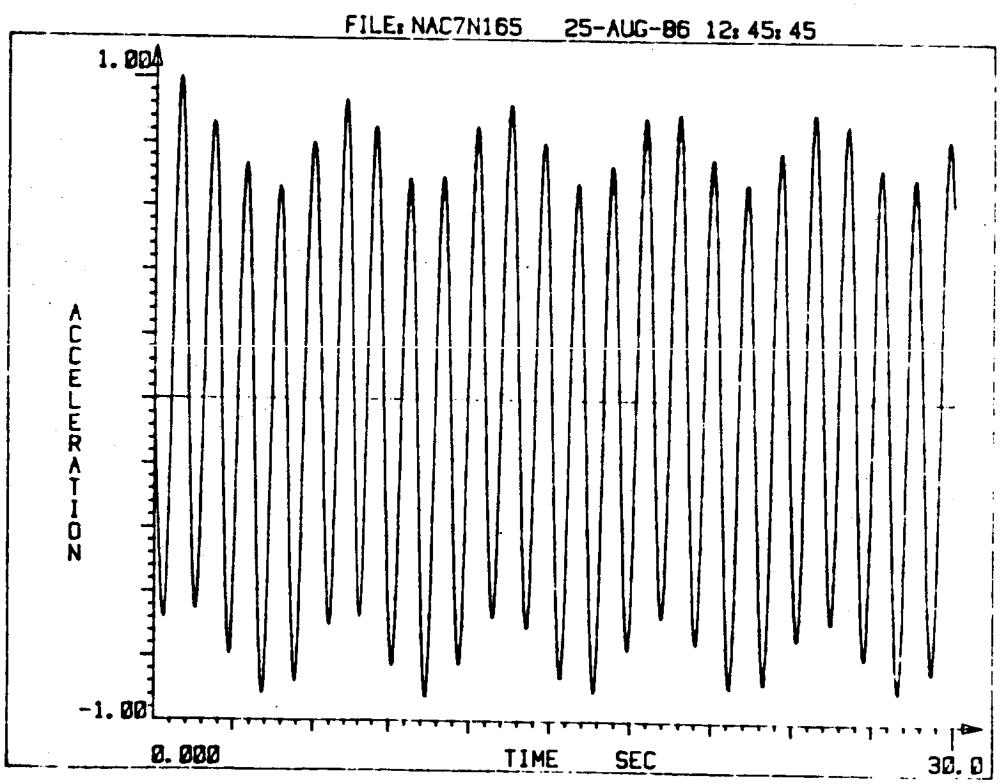


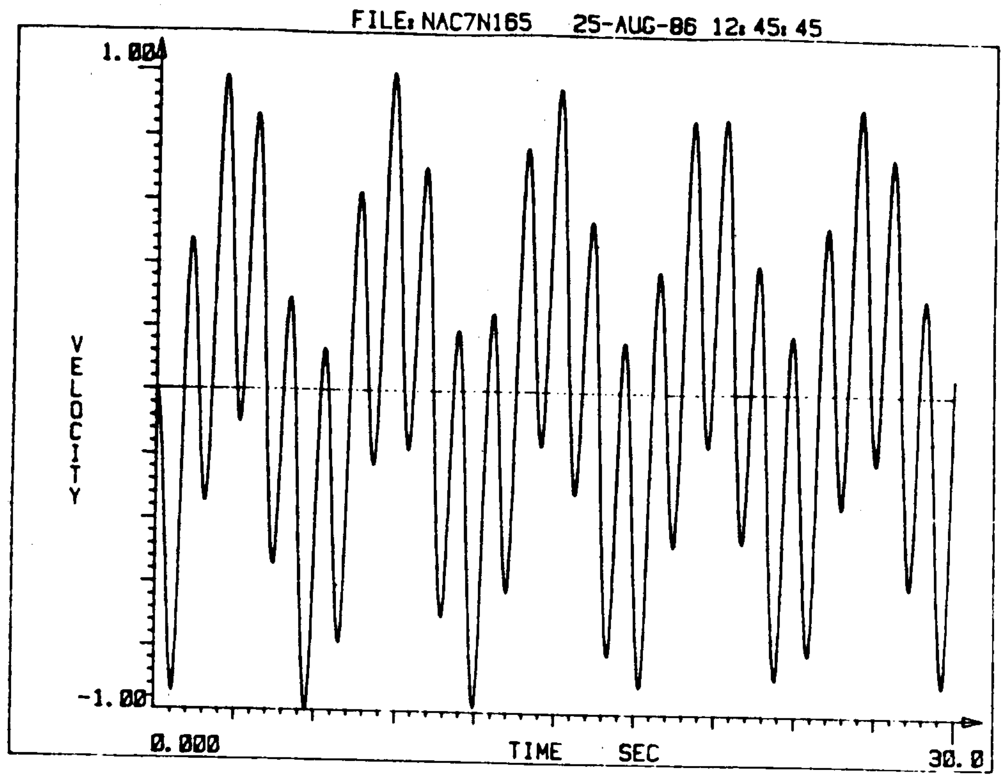
Nonstationary Random Response-Tip Excit.



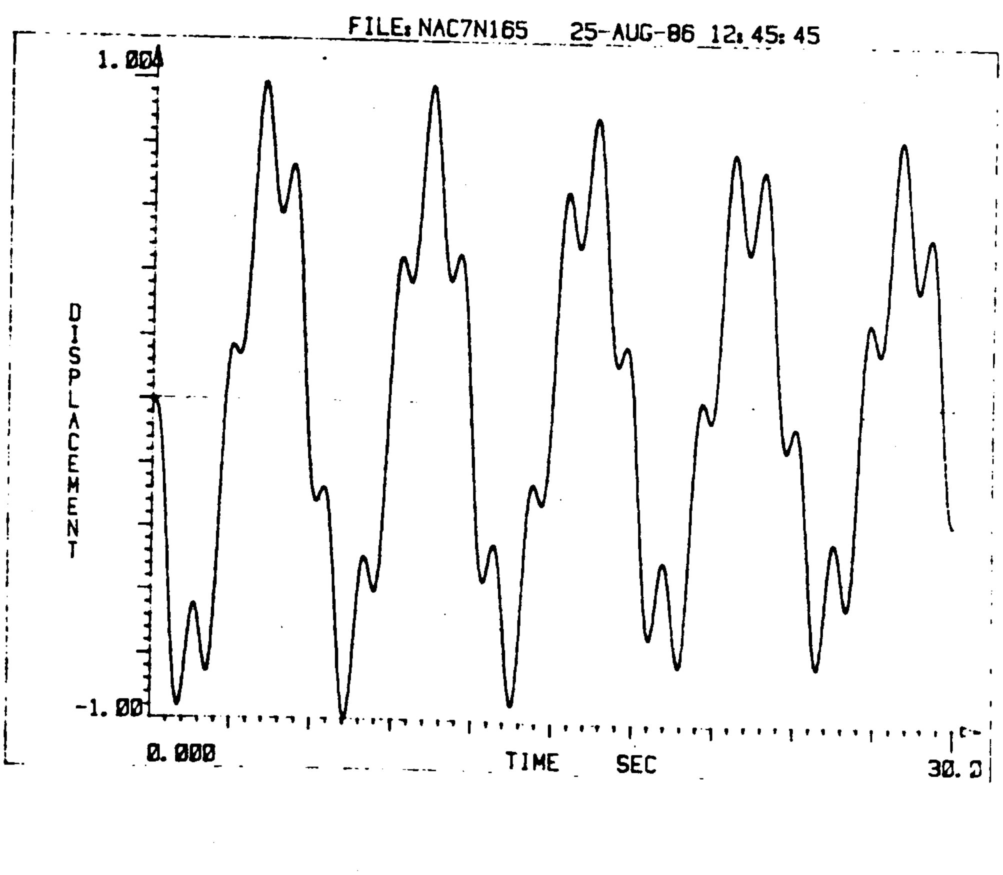


Harmonic Response - Base Excit.



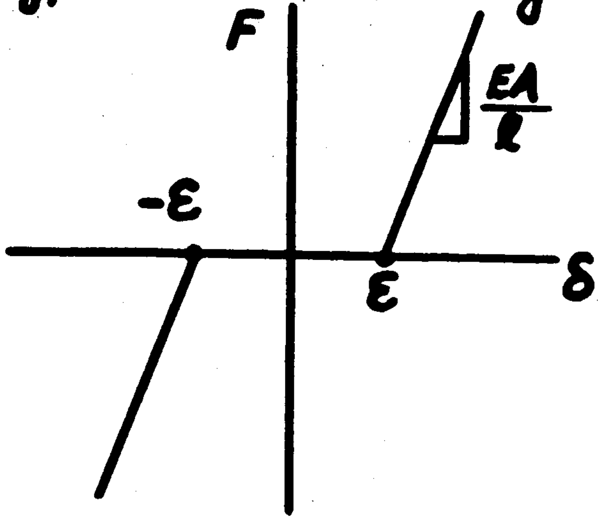


Harmonic Response - Base Excit.



NONLINEAR FINITE ELEMENT MODEL

3. Type of Nonlinearity



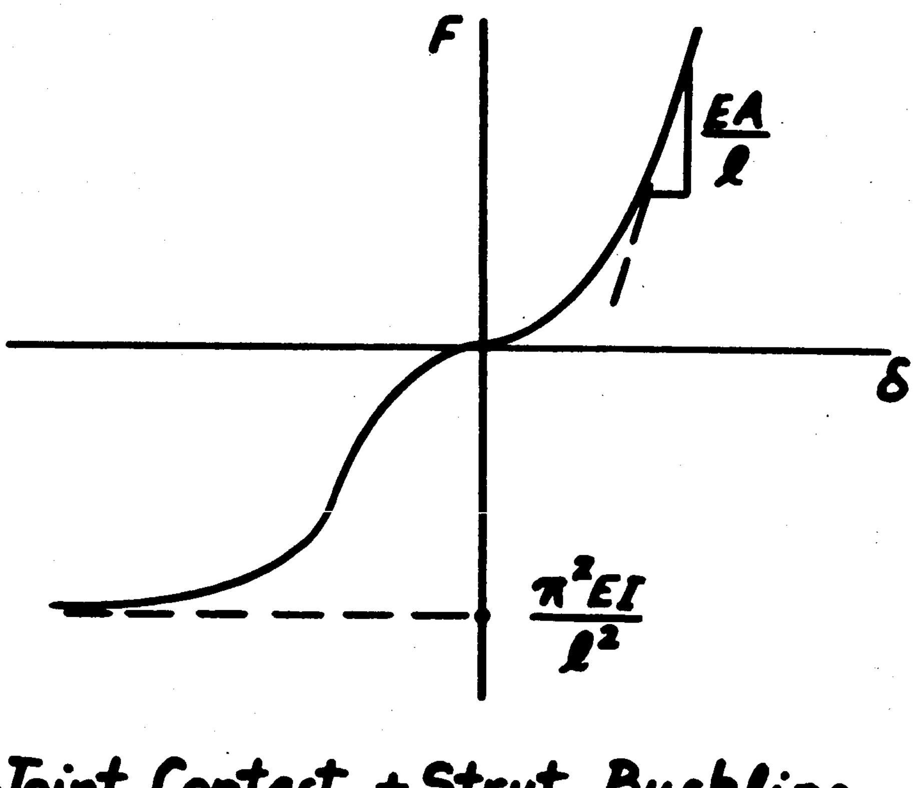
Crude Joint Clearance

$$\left(\frac{\delta}{\varepsilon}\right) = \frac{1}{2} + 0.57|f|\left[\frac{2}{3} - \ln(1.14f)\right]; \quad 0 \le |f| \le 0.63$$

$$= 0.86; \quad |f| > 0.63$$

$$\left(f \equiv \frac{F}{E\ell\varepsilon}\right)$$

Hertzian Joint Contact



Joint Contact + Strut Buckling

NONLINEAR SIMULATION PROBLEMS

1. Excessive CPU Time
   - 92+ Hours for T=3 Fundamental Periods on VAX 11/750
   - Small Δt ($\cong \tau_{12}/1000$) required for numerical stability
2. Model Order Reduction Necessary
   - Nonparametric "RONN" Model – in process
   - Parametric/Superelement Model-in process
   - Validity ???

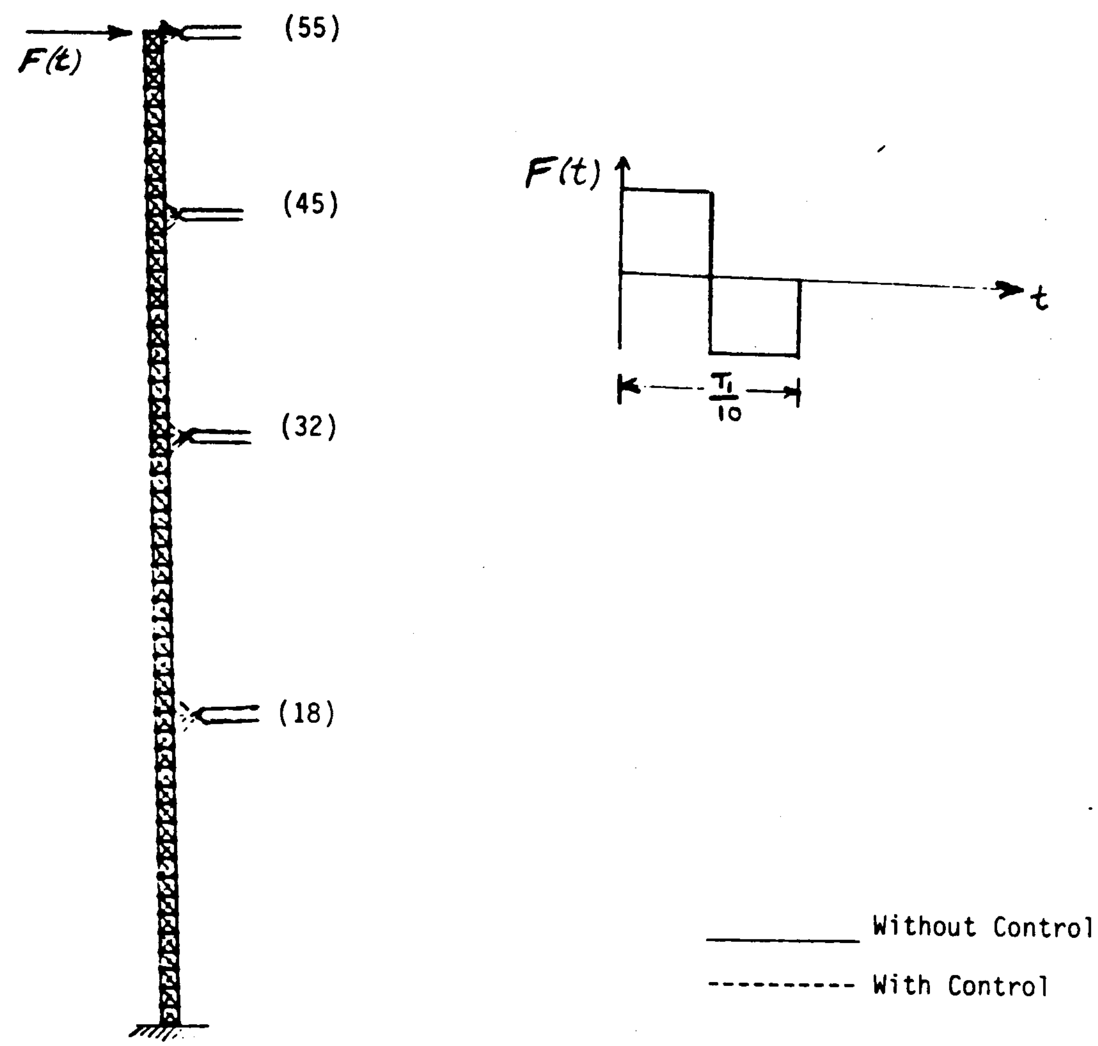
CONTROL ISSUES

1. Simulation Progress

NL-"SAP" FEM
- Lrg. Displ.
- Joint Nonlin.
- R-K, Newmark β, Wilson θ, etc.

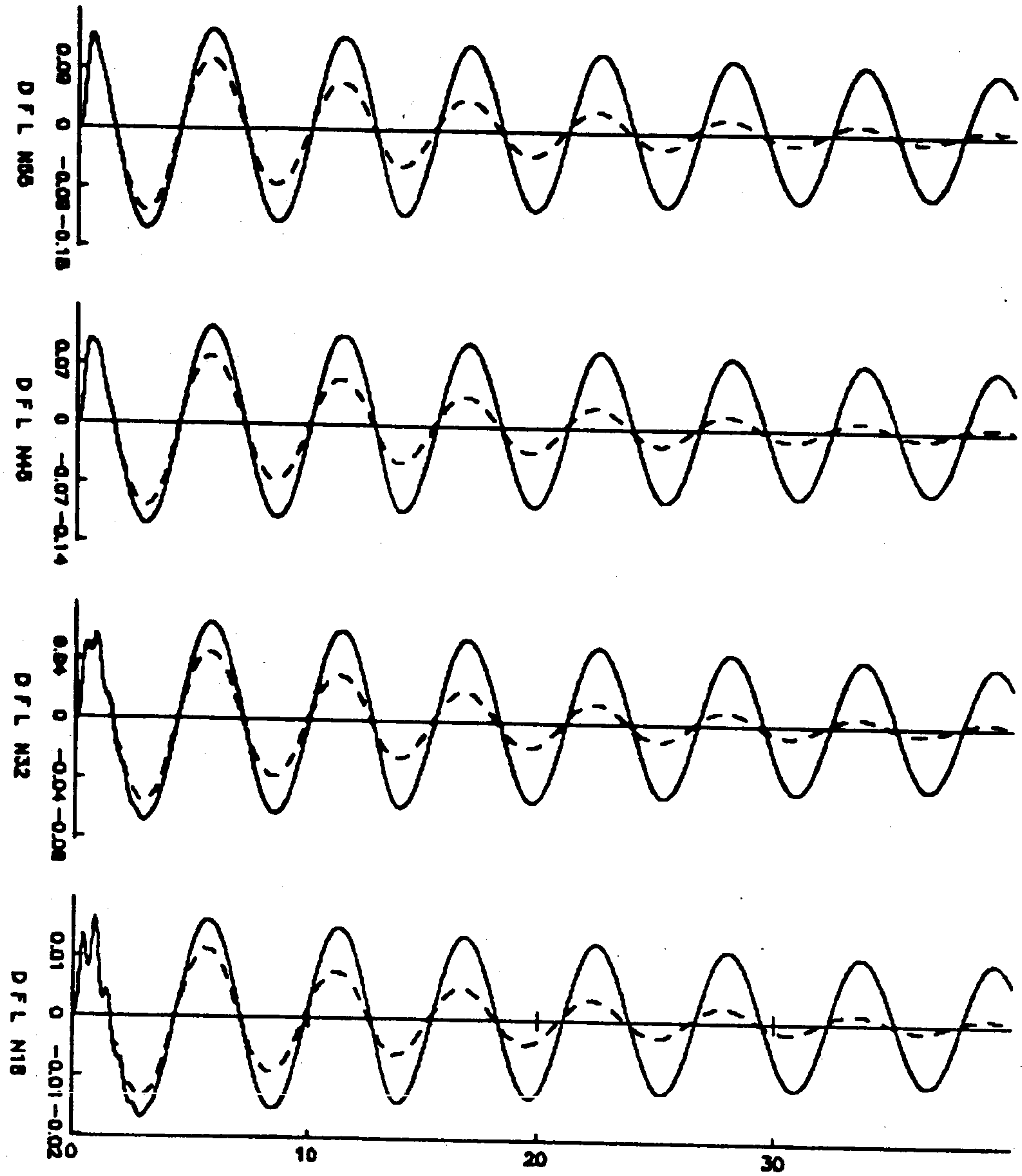
PC1-Control Code
- NL, Adaptive,
- Intermittent
- Special case: $\underset{\sim}{u} = K\underset{\sim}{x}$

1. Time step interupt req'd.
2. Excess storage for state variables
3. Stability and restart capability for time-stepping algorithms



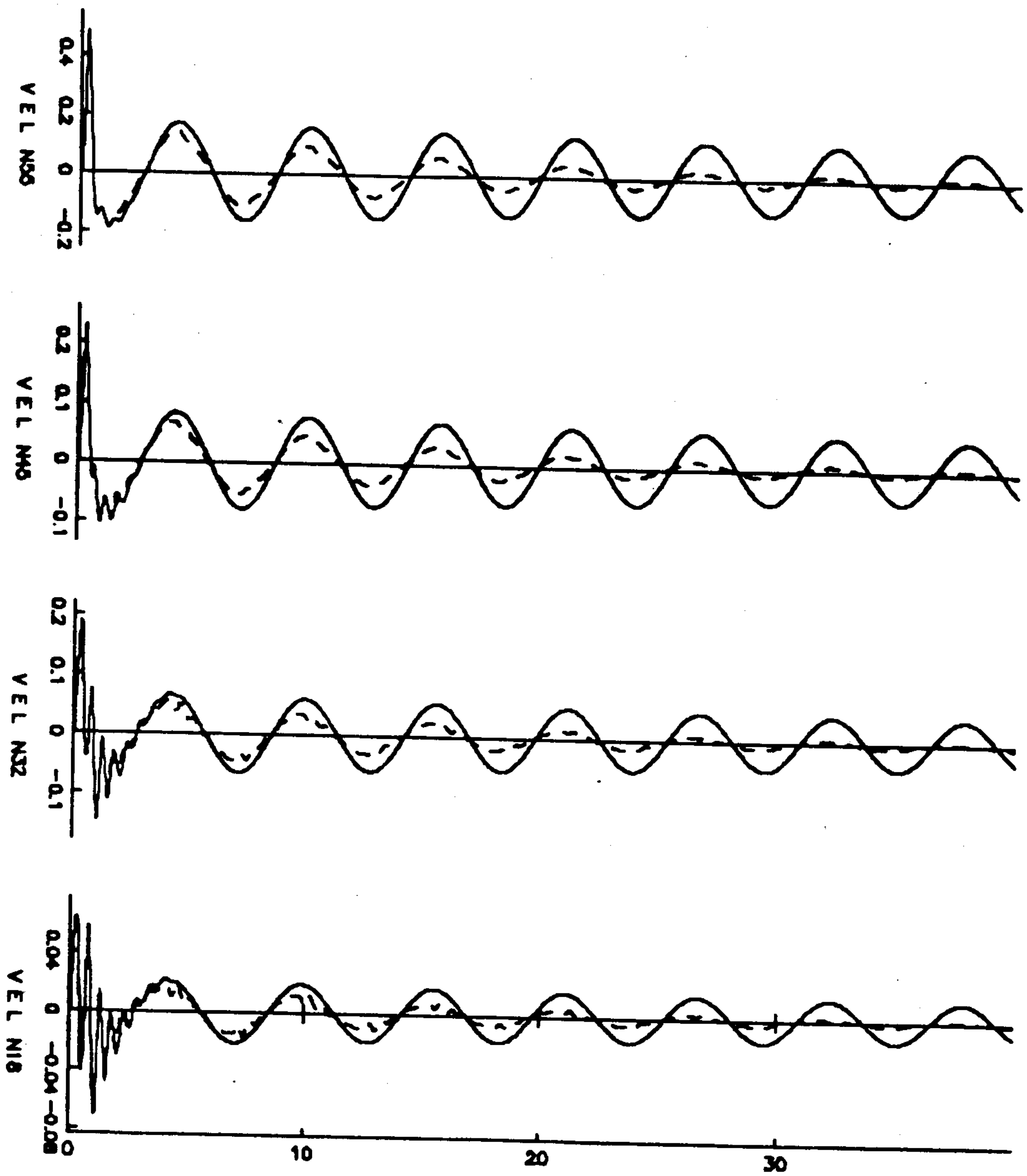
THREE-DIMENSIONAL FINITE ELEMENT MODEL OF COFS I MAST

C=100 n=1 T_d=0.2



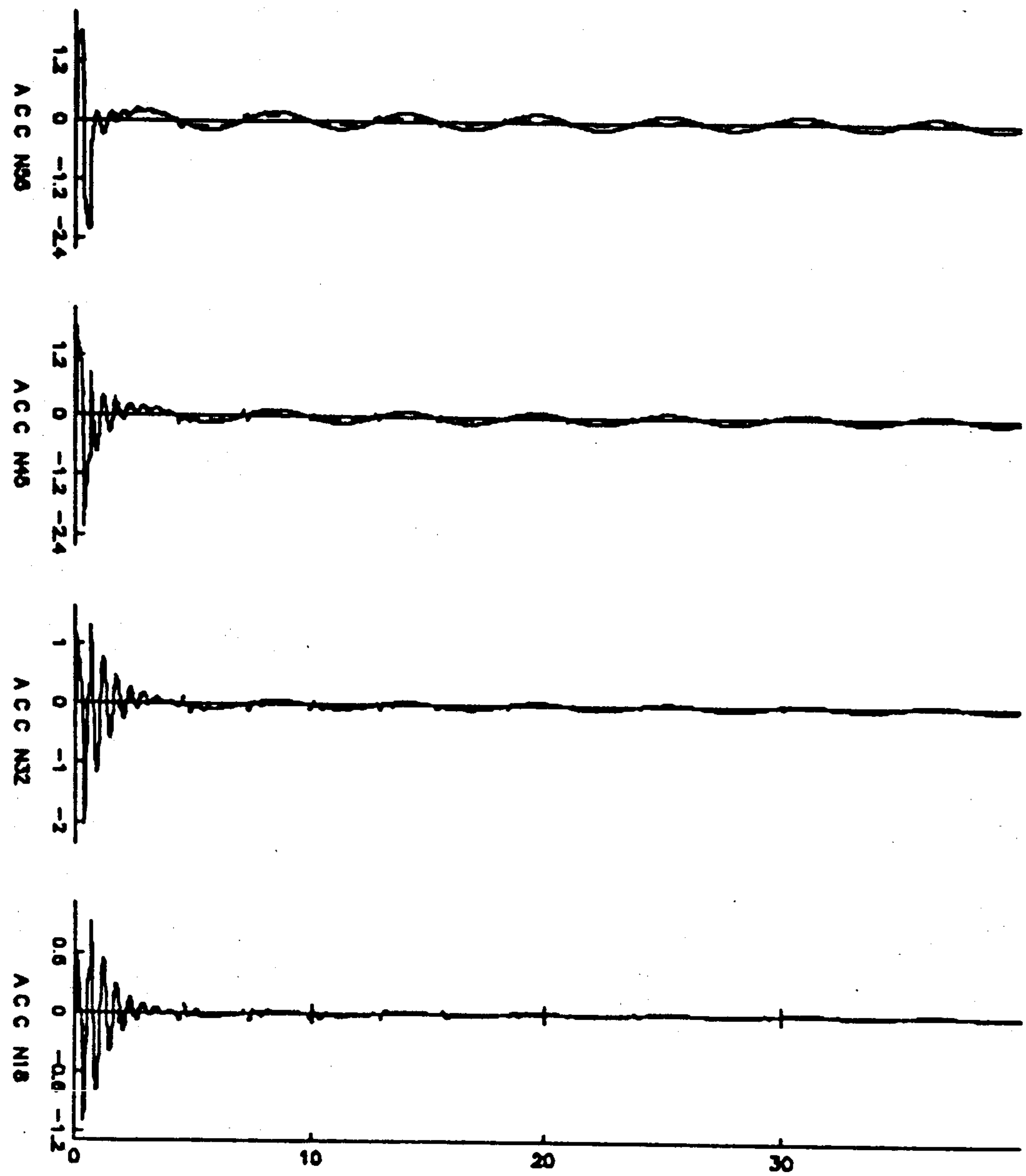
Displacement Response with and without Control

C=100 n=1 T_d=0.2



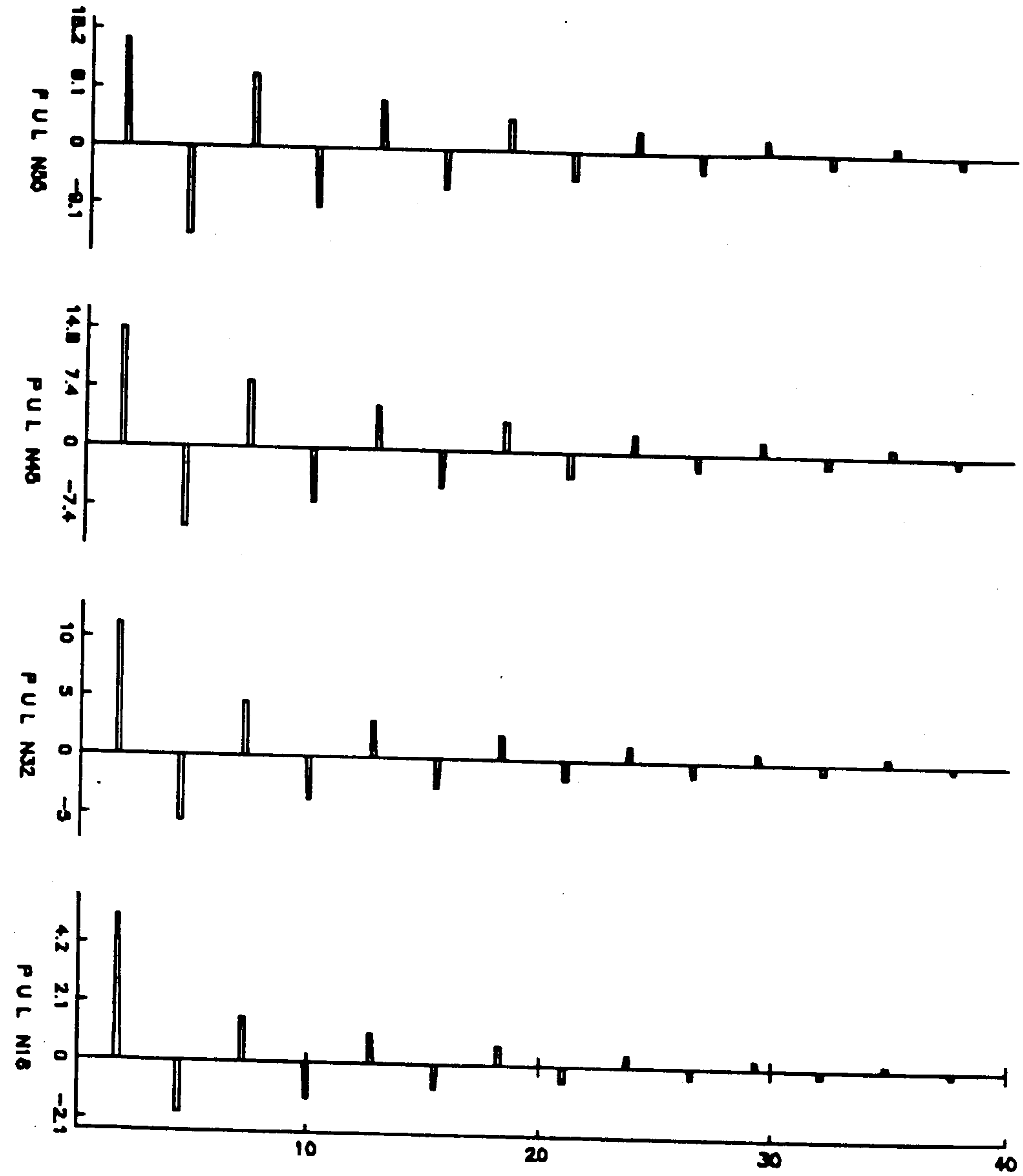
Velocity Response with and without Control

C=100 n=1 T_d=0.2



Acceleration Response with and without Control

C=100 n=1 T_d=0.2



Pulse Control Forces

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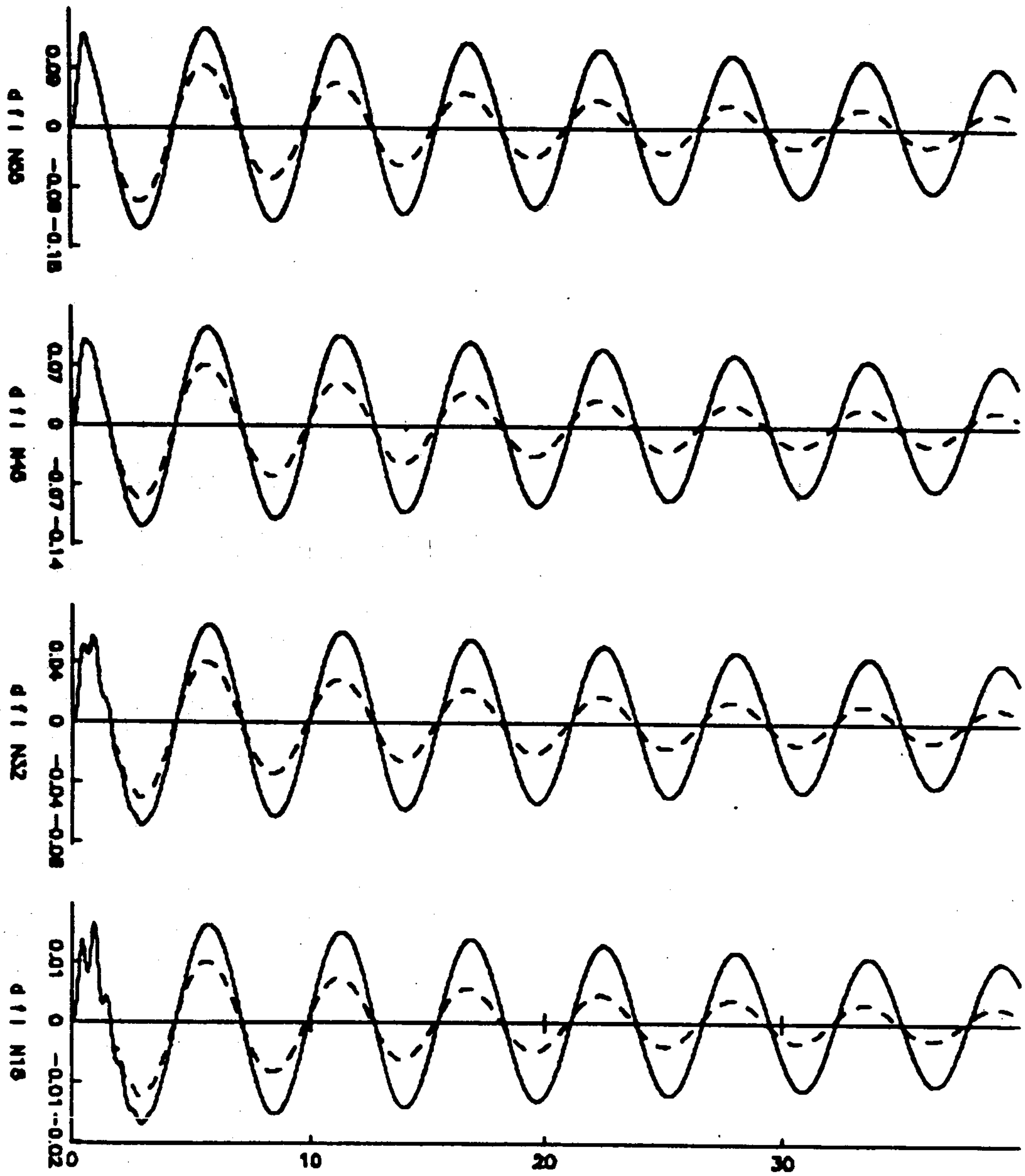
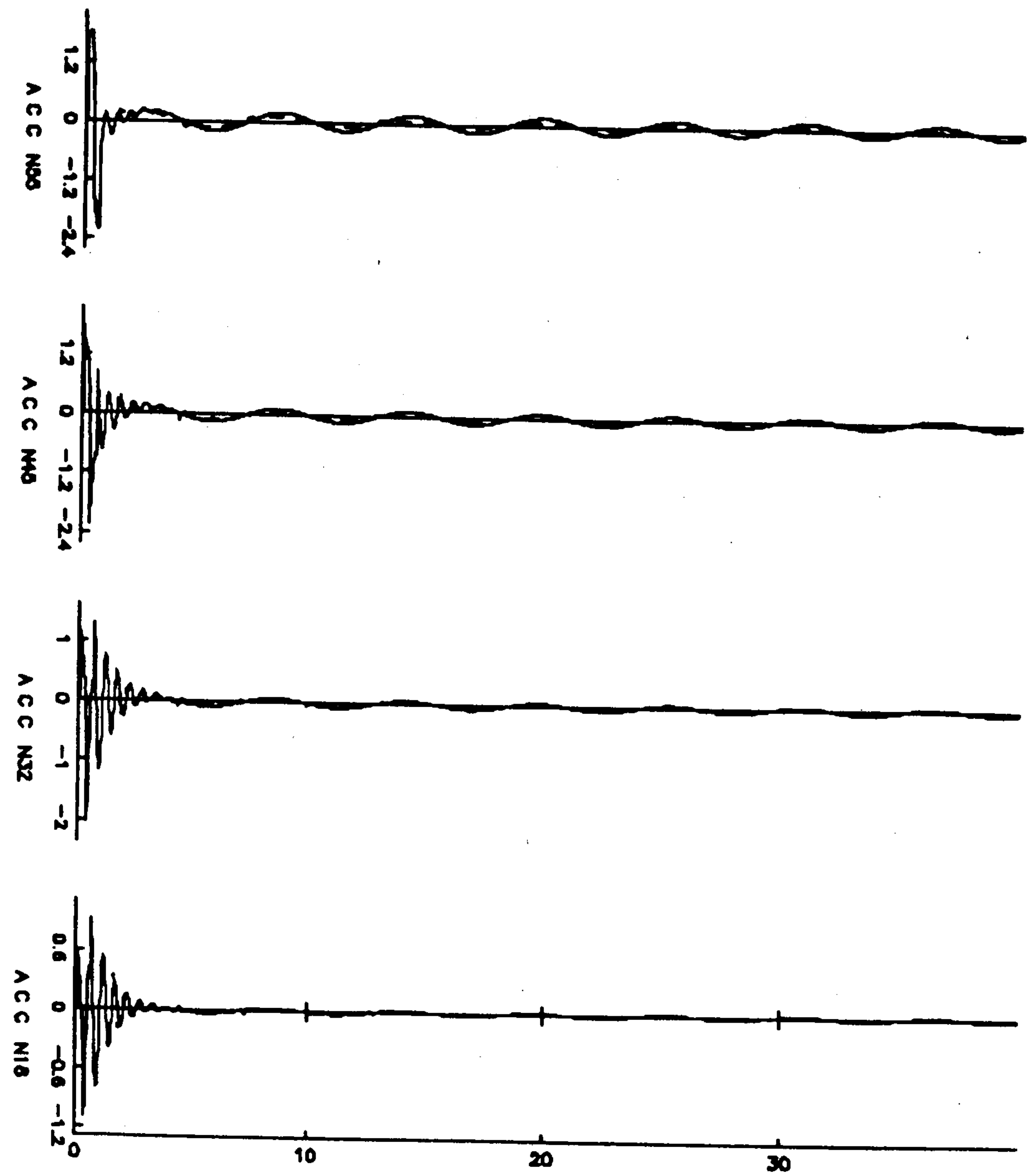
$C=100 \quad n=2 \quad T_d=0.2$



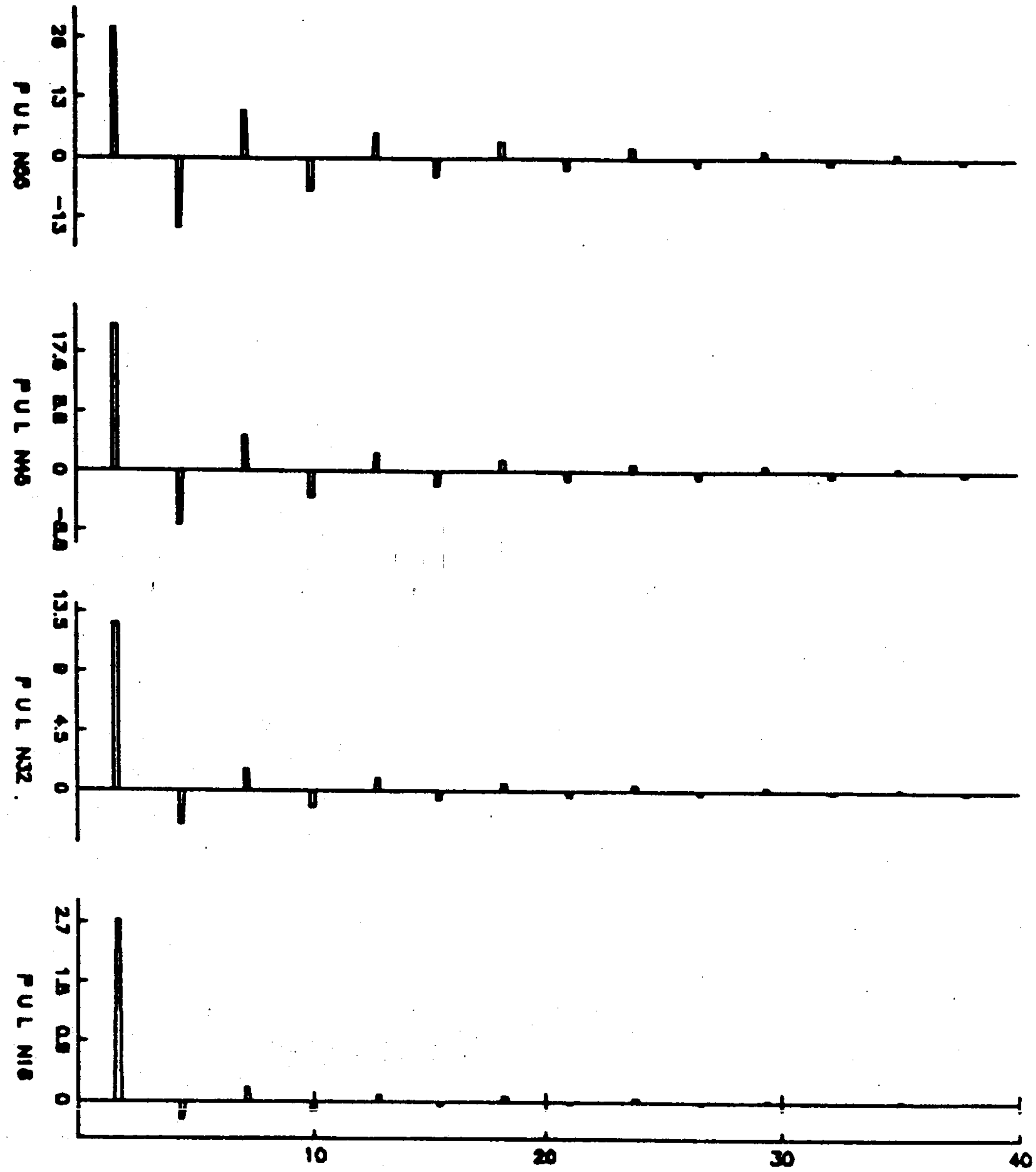
Displacement Response with and without Control

C=100 n=2 T_d=0.2

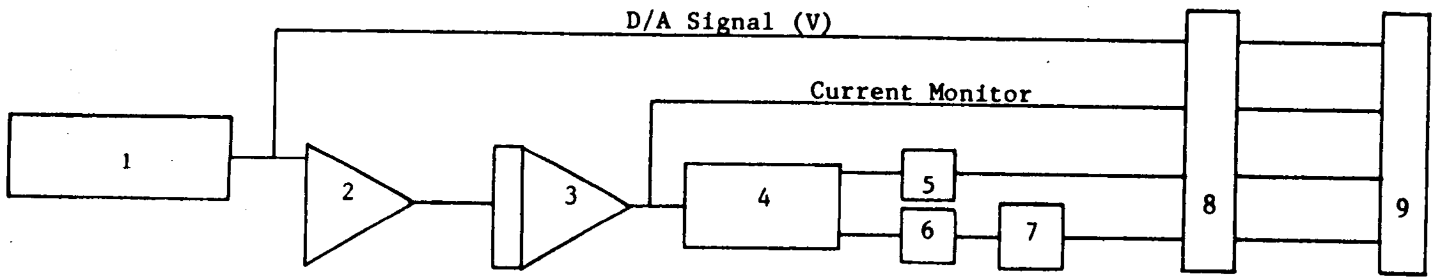


Acceleration Response with and without Control

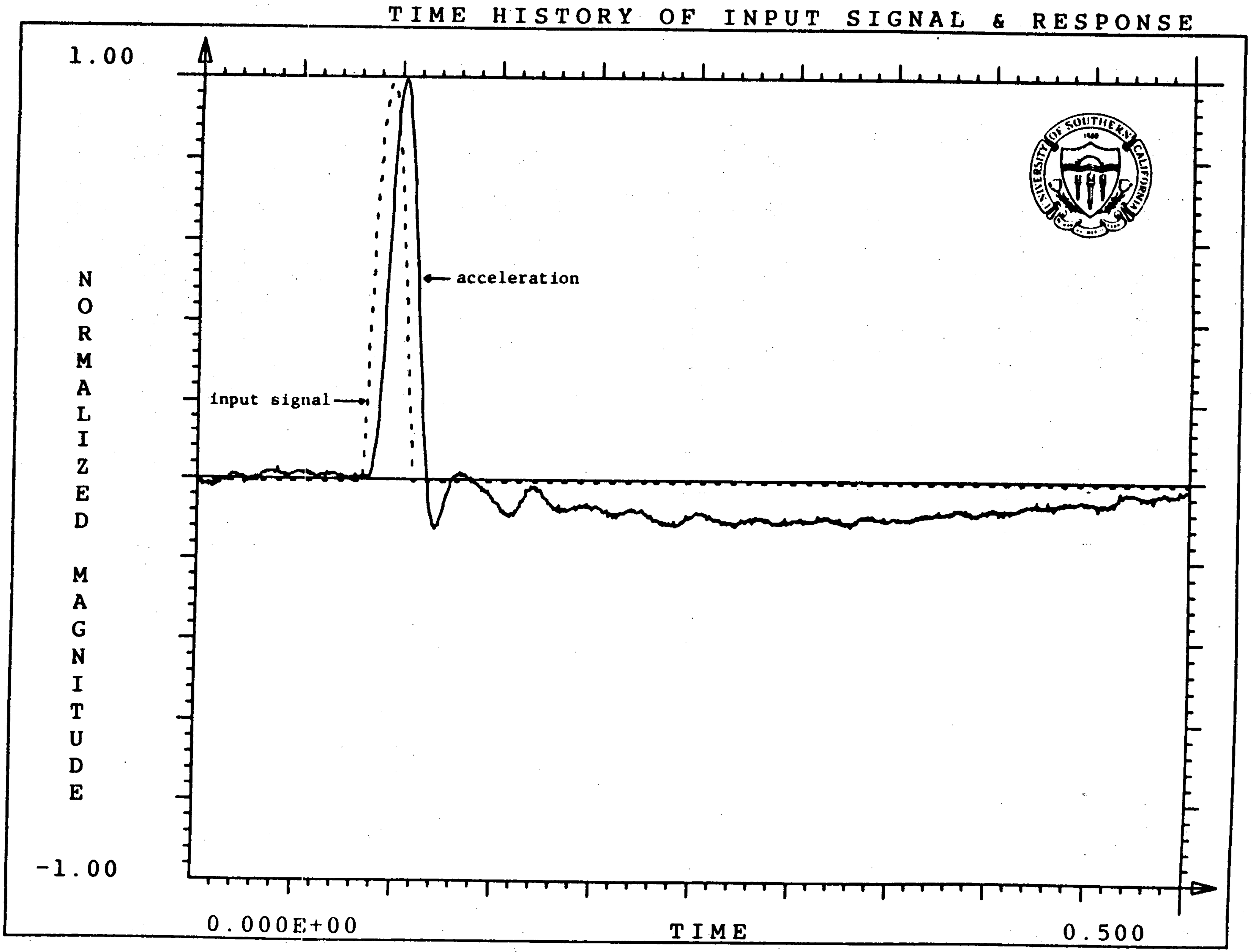
C=100   n=2 T_d=0.2

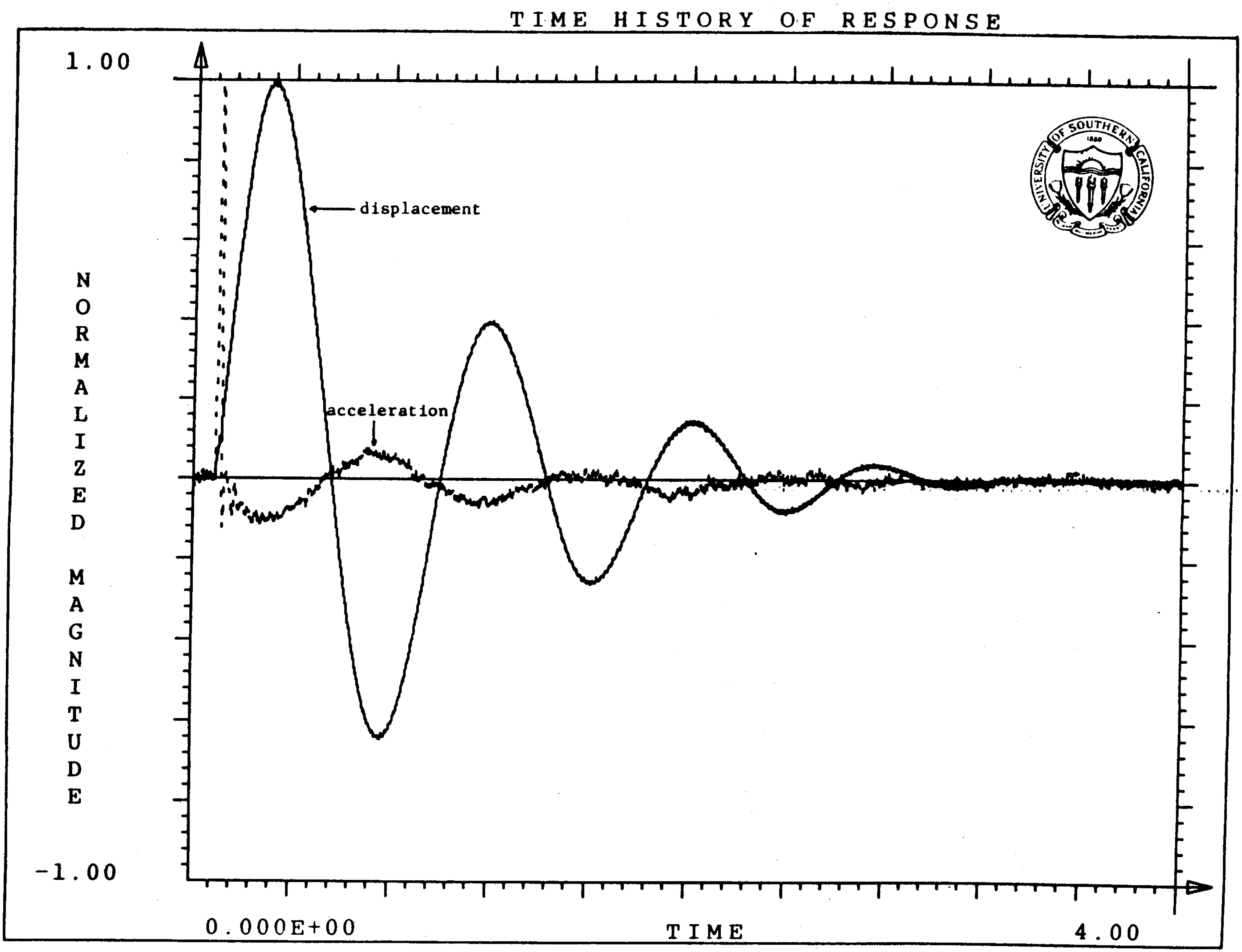


Pulse Control Forces

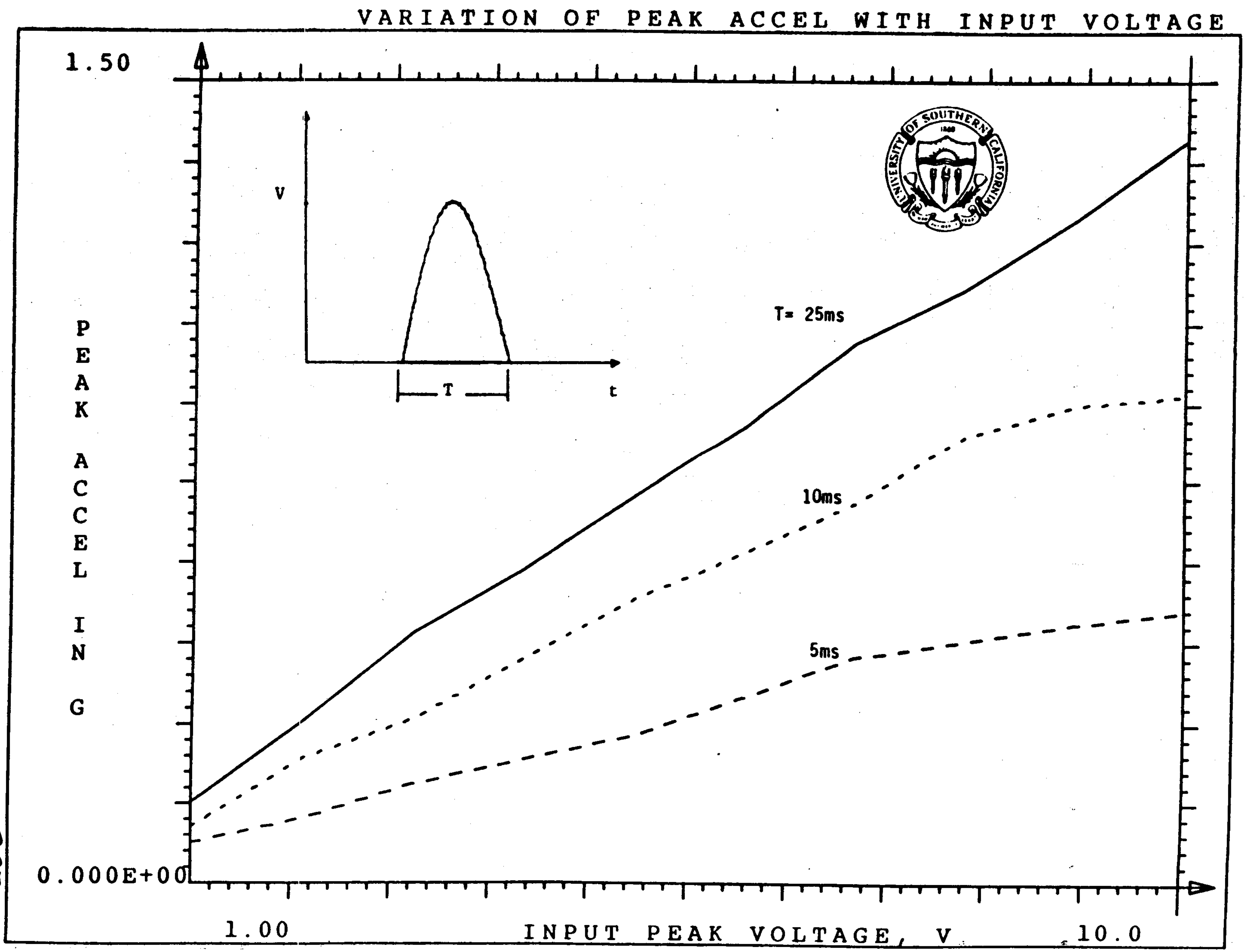


1. PC - XT
2. Operational Amplifier (X2)
3. Power Amplifier
4. Shaker
5. XCDR1 (LVDT)
6. XCDR2 (Piezoresistive accelerometer)
7. Signal Conditioning
8. Digital Filter
9. A/D Converter


TIME HISTORY OF INPUT SIGNAL & RESPONSE
1.00
-1.00
NORMALIZED MAGNITUDE
input signal
acceleration
0.000E+00
TIME
0.500



TIME HISTORY OF RESPONSE
1.00
-1.00
NORMALIZED MAGNITUDE
displacement
acceleration
0.000E+00
TIME
4.00



VARIATION OF PEAK ACCEL WITH INPUT VOLTAGE
1.50
0.000E+00
PEAK ACCEL IN G
V
T
t
T= 25ms
10ms
5ms
1.00
10.0
INPUT PEAK VOLTAGE, V