

# Low-Velocity Impact Testing of Solid Steel Billet onto Concrete Pads

A Summary of Twelve Drop Tests Conducted February 1996  
at Lawrence Livermore National Laboratory

Monika C. Witte, Jess R. Squires, Roger W. Carlson, Jack Hovingh

Lawrence Livermore National Laboratory  
University of California/Livermore, California

March 1997



This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.  
Work performed under the auspices of the U.S. Department of Transportation and the Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

9704150081 970328  
PDR MISC  
9704150047 PDR

# **Low-Velocity Impact Testing of Solid Steel Billet onto Concrete Pads**

---

**A Summary of Twelve Drop Tests Conducted February 1996  
at Lawrence Livermore National Laboratory**

**Monika C. Witte  
Jess R. Squires  
Roger W. Carlson  
Jack Hovingh**

**March 7, 1997**



**FESSP**

**Fission Energy and Systems Safety Program**

**Lawrence Livermore National Laboratory**



## Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy, and performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

# Table of Contents

Acknowledgment.....	iv
1.0 Introduction.....	1
2.0 Test Descriptions .....	2
2.1 Concrete Pads.....	2
2.2 Steel Billet .....	2
2.3 Instrumentation .....	3
2.4 Testing Environment .....	3
3.0 Test Results.....	3
3.1 Post-Test Appearance of Concrete Pads .....	3
3.2 Billet.....	3
3.3 Data .....	3
3.4 Photos.....	4

## Tables and Figures

Table 1. Drop Test Descriptions .....	5
Table 2. Concrete Strength .....	8
Table 3. Surface Depressions in Concrete .....	8
Figure 1. Labeling and Numbering of Concrete Pads .....	9
Figure 2. Accelerometer Channel Locations .....	10
Figure 3. Crack Patterns on Concrete .....	11

## Plots

### Test #1

Unfiltered Accelerations .....	1-1
Fourier Transforms .....	1-6
Velocities .....	1-11
Displacements .....	1-15

### Test #2

Unfiltered Accelerations .....	2-1
Fourier Transforms .....	2-6
Velocities .....	2-11
Displacements .....	2-15

### Test #3

Unfiltered Accelerations .....	3-1
Fourier Transforms .....	3-6
Velocities .....	3-11
Displacements .....	3-16

### Test #4

Unfiltered Accelerations .....	4-1
Fourier Transforms .....	4-6
Velocities .....	4-12
Displacements .....	4-16

### Test #5

Unfiltered Accelerations .....	5-1
Fourier Transforms .....	5-7
Velocities .....	5-13
Displacements .....	5-17

### Test #6

Unfiltered Accelerations .....	6-1
Fourier Transforms .....	6-6
Velocities .....	6-11
Displacements .....	6-15

### Test #7

Unfiltered Accelerations .....	7-1
Fourier Transforms .....	7-6
Velocities .....	7-11
Displacements .....	7-15

### Test #8

Unfiltered Accelerations .....	8-1
Fourier Transforms .....	8-6
Velocities .....	8-11
Displacements .....	8-15

## Test #9

Unfiltered Accelerations .....	9-1
Fourier Transforms .....	9-6
Velocities .....	9-11
Displacements .....	9-15

## Test #10

Unfiltered Accelerations .....	10-1
Fourier Transforms .....	10-6
Velocities .....	10-11
Displacements .....	10-15

## Test #11

Unfiltered Accelerations .....	11-1
Fourier Transforms .....	11-5
Velocities .....	11-9
Displacements .....	11-13

## Test #12

Unfiltered Accelerations .....	12-1
Fourier Transforms .....	12-5
Velocities .....	12-9
Displacements .....	12-13

## Acknowledgment

This report was prepared by the Lawrence Livermore National Laboratory and was funded by the Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission. The authors wish to thank David Tang of the NRC for his support and encouragement.



# Low-Velocity Impact Testing of Solid Steel Billet onto Concrete Pads

## A Summary of Twelve Drop Tests Conducted February 1996 at Lawrence Livermore National Laboratory

### 1.0 Introduction

Spent fuel storage casks intended for use at Independent Spent Fuel Storage Installations (ISFSIs) typically are evaluated during the package application and review process for low-energy impacts representative of possible handling accidents. Because drop testing of spent fuel storage casks is very expensive, most storage cask Safety Analysis Reports (SARs) analytically evaluate the effects of possible handling accidents. In the past, the analyses involved in these drop evaluations have assumed that the casks dropped onto an unyielding surface, because this is a conservative and simplifying assumption. Since the regulation imposed by the U.S. Nuclear Regulatory Commission (NRC), 10 CFR Part 72, does not require this assumption, applicants are currently seeking a more lenient and realistic model for the analyses and are using analytical models which predict the effect of a cask dropping onto a concrete pad, including the energy-absorbing aspects such as cracking and flexure. Because the availability of benchmarking data for drop tests onto concrete is very limited, the NRC has undertaken a drop testing program which will allow an applicant to use the data for benchmarking an analytical model of a spent fuel storage cask impacting on a concrete pad at low velocities.

The tests described in this report were primarily intended to determine the response characteristics of concrete pads during tipover and side impacts of a solid steel billet onto the pads. This series of tests is fourth in a program of tests funded by the NRC; all four series of tests in this program address issues of possible handling accidents involving spent fuel storage casks. The first series was performed in March 1993 by Sandia National Laboratories and involved five end-drops of a billet nearly identical to the one used here onto a variety of surfaces from a height of 18". The first three series of tests are described in Sandia's report.<sup>1</sup> The second series of tests was performed between July and October 1993, and involved four end-drops of a near-full-scale empty Excellox 3A cask onto a full-scale concrete pad and foundation, or onto an essentially unyielding surface, from heights ranging from 18" to 60", and was conducted by the British Nuclear Fuels Limited in Winfrith, England. (Two of the drops in this series were sponsored by Electric Power Research Institute.) The third test series was performed in September 1993 by Sandia National Laboratories, and involved eight further end-drop tests of the billet onto concrete pads cast on engineered fill resting on undisturbed soil, from heights ranging from 18" to 6'.

This fourth test series included twelve drops of a solid steel cylindrical billet onto a reinforced concrete pad resting on undisturbed soil. The size of the billet was selected to match the billet used in the Series 1 and 3 tests; it is roughly a 1/3-scale model of a spent fuel storage cask (the linear dimension is scaled). The dimensions of the concrete pad were selected to match the concrete pads used in the Series 1 and 3 tests, although the outside pad dimension is somewhat larger, because tests in this series are primarily side-drops and earlier tests were end-drops. The concrete pads are roughly 1/3-scale models of the symmetry section of a hypothetical ISFSI concrete storage pad, including the reinforcing steel and gravel within the concrete.

---

<sup>1</sup>McConnell, P. et. al., "Test Report, Drop Tests onto Concrete Pads for Benchmarking Response of Interim Spent Fuel Storage Installations," Sandia National Laboratory, September 1993.

This is the first of two reports on this test series. This report describes the tests and provides (1) the raw acceleration-time history results, (2) some velocities and displacements obtained by numerically integrating the acceleration data, and (3) Fourier transforms to characterize the frequency characteristics of the data. The second report will provide an evaluation of the results.

## 2.0 Test Descriptions

These tests consist of twelve drops of a solid steel cylindrical billet onto six concrete pads. The drops include two end-drops, eight side-drops, and two CG-over-corner tipover drops. The billet was instrumented to capture the acceleration response of the billet-pad system. In general, an attempt was made to minimize the damage to the pad (i.e., in nearly every case, a lower-velocity drop preceded a higher-velocity drop). In the case of drops #9 and #10, this sequence was reversed to gain some understanding of the effect of dropping onto a pre-cracked pad. The tests were conducted over the three-day period, February 7, 8, and 9, 1996. The orientation of each test is described in Table 1.

The tests were conducted by the LLNL Weapons Test Group. A test plan was prepared<sup>2</sup> and describes in detail the test apparatus, data acquisition, and other test parameters. The sequencing of the tests was modified to simplify operations, so that the numbering of the tests shown in the Test Plan is not consistent with the actual test sequence.

### 2.1 Concrete Pads

Six concrete pads were poured at the Building 836 Test Facility at Site 300 of the Lawrence Livermore National Laboratory. Nominal compressive strength of the concrete was requested to be 3000 psi (20.7 Mpa) at 28 days curing time per test in accordance with the specifications and codes of the American Concrete Institute (ACI 318). The actual concrete strength for each pad is listed in Table 2 and is somewhat higher than the requested 3000 psi. The coarse aggregate for the scaled concrete pads was 3/8" (9.5mm). The gradation requirements conformed to those specified in ASTM 33.

The pads were poured on an earth surface which was graded level, with no other preparation. The soil was not evaluated. The surfaces of the concrete pads were essentially flat.

The length and width of the square pads was 10', the pad thicknesses were 12", the thickness of the concrete cap (from the top and bottom surfaces of the pad to the edge of the rebar) was 1", the rebar diameter was 3/8", and the rebar pitch (top and bottom, two way) was 18". The reinforcing steel was deformed billet steel conforming to ASTM A 615, Grade 60, where the nominal yield strength of the rebar was 60 ksi. The pads were numbered 1 through 6, as shown in Figure 1.

The concrete pads were poured on Dec. 20, 1995. Standard concrete test cylinders (6" x 12") were poured at the same time.

### 2.2 Steel Billet

The steel billet consisted of a solid steel cylinder 20.25" in diameter, 72" long, weighing 6475 lb. The material of the billet was ASTM 576 Grade 1045 steel, with a tensile strength of 80 ksi and a yield strength of 60 to 67 ksi, per the supplier. No coupon testing was performed on the billet material.

The billet was prepared for the drops by machining threaded holes for the lifting hardware. Flat surfaces were machined in 4 locations on the cylindrical surface of the billet, so that the

<sup>2</sup>Squires, Jess, Engineering Test Plan #2993, "FEESP Drop Test," February 5, 1996.

accelerometers could be mounted flush with the billet, and holes were drilled as required for the accelerometers and accelerometer blocks (used for 90° mounts). The ends of the billet were machined in order for the accelerometer attachment points to be perfectly flat. The angles between the bottom and top surfaces of the billet and the cylindrical sides of the billet were verified to be 90°. In addition, a small bevel was machined onto the edge of the billet which contacted the ground during the tipover, in order to increase the friction and minimize instability during the lift in preparation for the tipover. Also, two 24-inch long 2" angles were welded to the cylindrical surface of the billet to ensure that the billet did not roll after the side- or tipover drops. These turned out to be unnecessary, as no rolling occurred.

### 2.3 Instrumentation

The instrumentation used is described in detail in the Engineering Test Plan;<sup>3</sup> Endevco brand piezoelectric accelerometers were used, together with Endevco mounting blocks as needed. A 100-Khz 6-pole Bessel analog antialias filter was used. Figure 2 shows the locations and channel numbers of the accelerometers.

### 2.4 Testing Environment

The tests were conducted during a generally dry (clear or overcast, not raining) three-day period in the middle of an exceptionally wet Livermore winter. The ground was very wet. The concrete pads were poured into a graded area which was 12" below the grade of the surrounding ground, so that the surface of the pads would be at grade following the testing. As a result, the below-grade channels surrounding the pads were partially filled with water during the three-day period, and tended to dry out during the three days. The water was judged to have minimal or no effect on the test results.

## 3.0 Test Results

### 3.1 Post-Test Appearance of Concrete Pads

The concrete pads were cracked as a result of the drop tests. The cracking patterns are described for each test in Figure 3. The steel billet had a small amount of rust on the cylindrical surface, which proved helpful in being able to see the drop footprint after the billet was removed from the pad. In general, there was no significant surface depression of the concrete for any of the tests conducted. Minor depressions are described in Table 3.

### 3.2 Billet

There was no damage to the billet. The impact footprint was visible as concrete dust on the surface of the billet. Every possible effort was made to line up the billet during the drop preparations so that the billet would fall in the desired orientations. Generally, this was successful. A review of the acceleration plots will indicate the degree of success.

### 3.3 Data

In general, the accelerometers worked as expected. Six new accelerometers were purchased for this test series, two additional on hand accelerometers were recalibrated. Four accelerometers experienced some form of problems during the test series and were replaced as required. From Test #7 to Test #10, one desired accelerometer channel was not functioning correctly. The channel location for the non-working accelerometer was either A2 or A3, depending on the drop. The plots show clearly the missing channel location. Plots of the raw data including accelerations

---

<sup>3</sup> See reference 2 above.

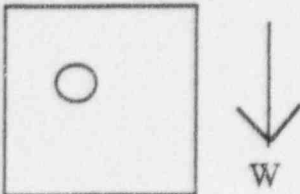
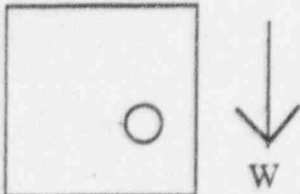
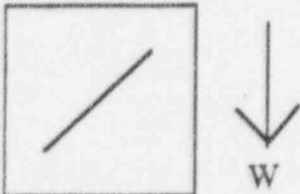
and Fourier transforms are presented in the following pages. Additionally, some integrated data to provide velocities and displacements are included.

The locations for all of the accelerometers were prepared, as previously noted, by machining flat locations and drilling mounting holes. The hole configuration for the accelerometer connected to Channel A4 during the side-drop (see Figure 2) was directly impacted during the two end-drops. In order to protect the machined holes, a small plate (1/16" thick, 1.25" diameter) was bolted to the connection location with high-strength bolts. This arrangement protruded from the bottom surface of the billet about 1/8". One bolt dug into the concrete slightly, and failed in shear just inside the hole. The other hole remained usable during the side-drops. A small amount of Eastman 910 glue was used to attach the accelerator mounting block to the hole with the damaged bolt. The results from that channel location appear to be unaffected by this mounting procedure. There were no major difficulties with the accelerometers.



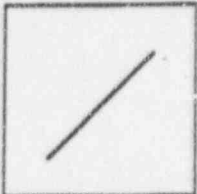
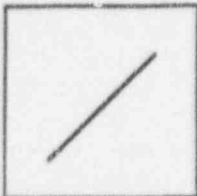
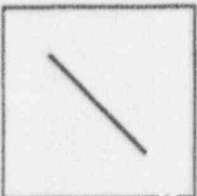
### **3.4 Photos**

A collection of photos is available as an addendum to this report to document the concrete crack patterns and other test conditions.

Table 1. Drop Test Descriptions

Test #	Pad #	Drop Orientation	Drop Height	Location and # of Accelerometers
1	5	End Drop 	18"	5 accelerometers: <ul style="list-style-type: none"> <li>• 2 on top flat surface</li> <li>• 2 on cylindrical surface near impact end</li> <li>• 1 mid-height on cylindrical surface</li> </ul>
2	5	End Drop 	18"	same as above
3	3	Side 	18"	5 accelerometers: <ul style="list-style-type: none"> <li>• 1 on top flat surface close to impact edge</li> <li>• 3 on cylindrical 180° from impact side</li> <li>• 1 on bottom flat surface close to impact edge</li> </ul>



Test #	Pad #	Drop Orientation	Drop Height	Location and # of Accelerometers
4	3	Side  ↓ W	36"	same as above
5	4	Side  ↓ W	18"	same as above
6	4	Side  ↓ W	6'	same as above
7	6	Side  ↓ W	36"	same as above
8	6	Side  ↓ W	6'	same as above

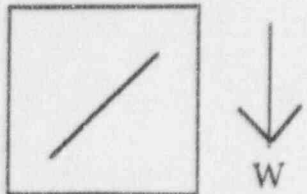
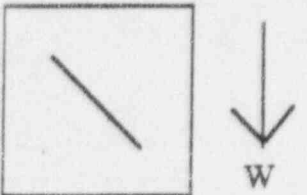
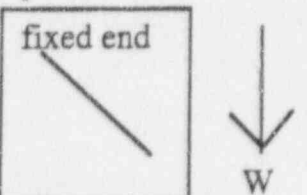
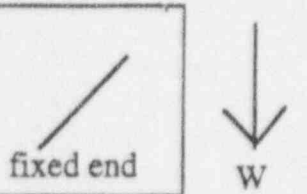
Test #	Pad #	Drop Orientation	Drop Height	Location and # of Accelerometers
9	2	Side 	36"	same as above
10	2	Side 	18"	same as above
11	1	Tipover 	CG over corner	4 accelerometers: <ul style="list-style-type: none"> <li>• 1 on top flat surface close to impact edge</li> <li>• 3 on cylindrical 180° from impact side</li> </ul>
12	1	Tipover 	CG over corner	same as above

Table 2. Concrete Strength

Pad #	Crush Strength, psi (average of specimens)		
	Climate Controlled Cure Specimens		Field Cured Specimens
	28 day test	Drop Test day (48 days, 1 sample only)	Drop Test day (48 days)
#1 (North -East)	5385 psi	5410 psi	4610 psi
#2 (South-East)	5050 psi	5240 psi	4440 psi
#3 (North-Center)	4600 psi	5270 psi	4265 psi
#4 (South Center)	5210 psi	5290 psi	4405 psi
#5 (North -West)	4625 psi	5180 psi	4400 psi
#6 (South -West)	4945 psi	5160 psi	4645 psi

Table 3. Surface Depressions in Concrete

Type of Drop	Depth Of Surface Depressions
18" End Drops	0.1 to 0.2 cm
18" Side Drops	Ranged from not measurable (on Test #5) to roughly 0.2 cm deep
36" Side Drops	0.4 to 0.5 cm on ends
6' Side Drops	0.6 to 0.8 cm on ends, nearly none in center (Test #6)
	0.8 to 1.0 cm on ends, less in center (Test #8)
Tipovers	Top end depression is about 0.1 to 0.2 cm (pivot end showed some damage due to billet digging into concrete during handling plus during drop.)

Figure 1. Labeling and Numbering of Concrete Pads

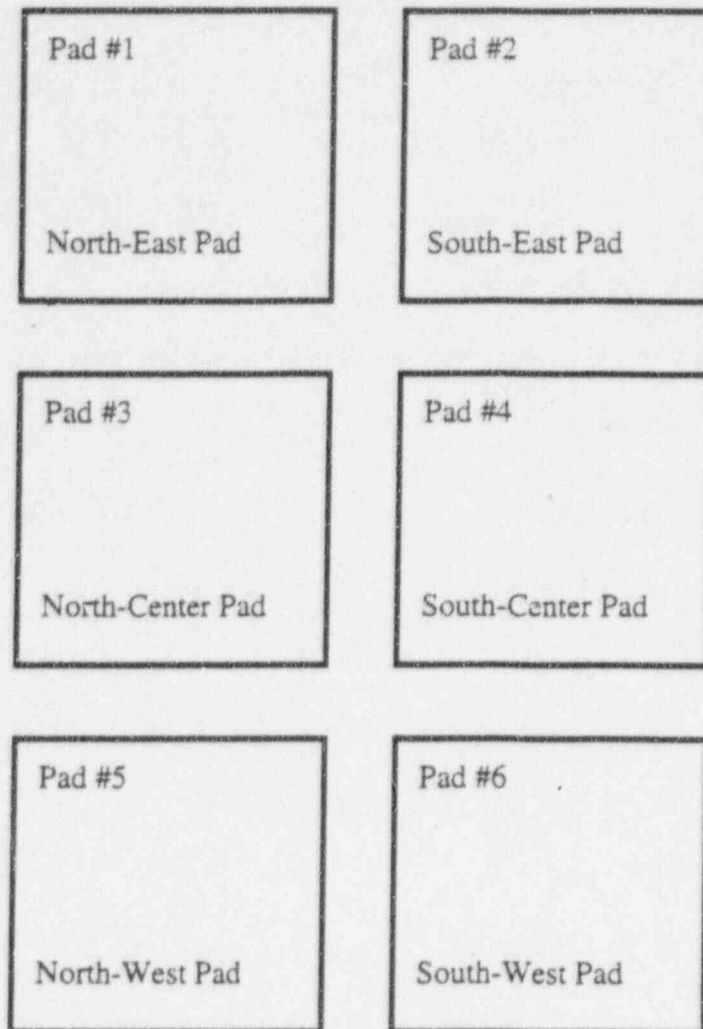
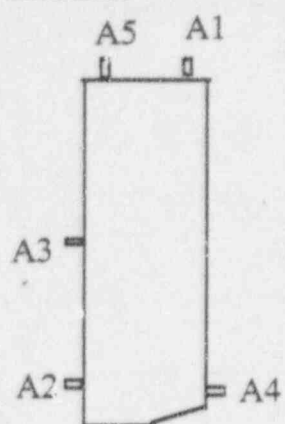
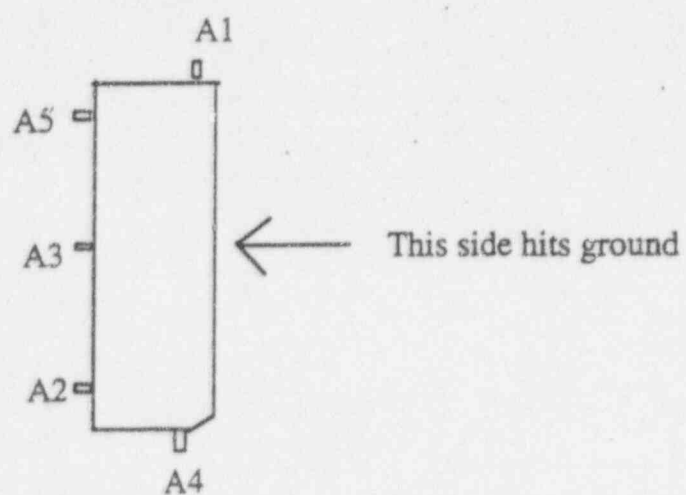


Figure 2. Accelerometer Channel Locations

## End Drop Channel Locations



## Side Drop Channel Locations



## Tipover Channel Locations

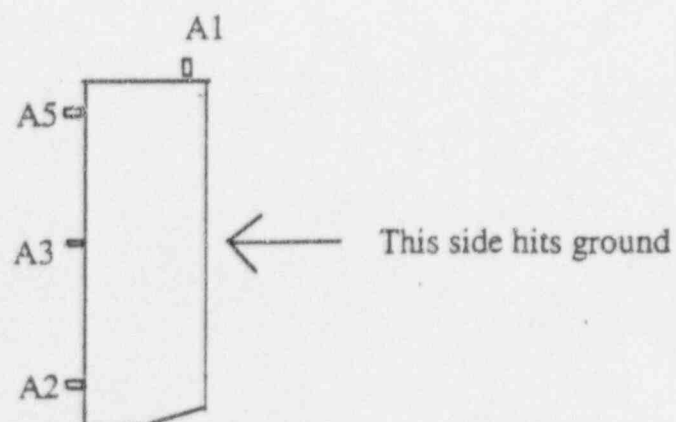
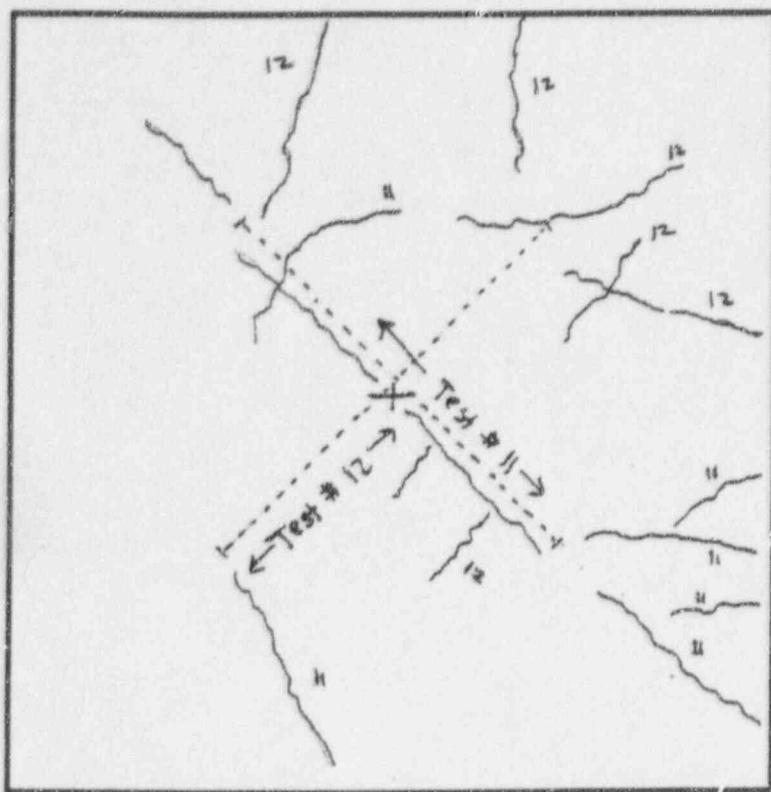
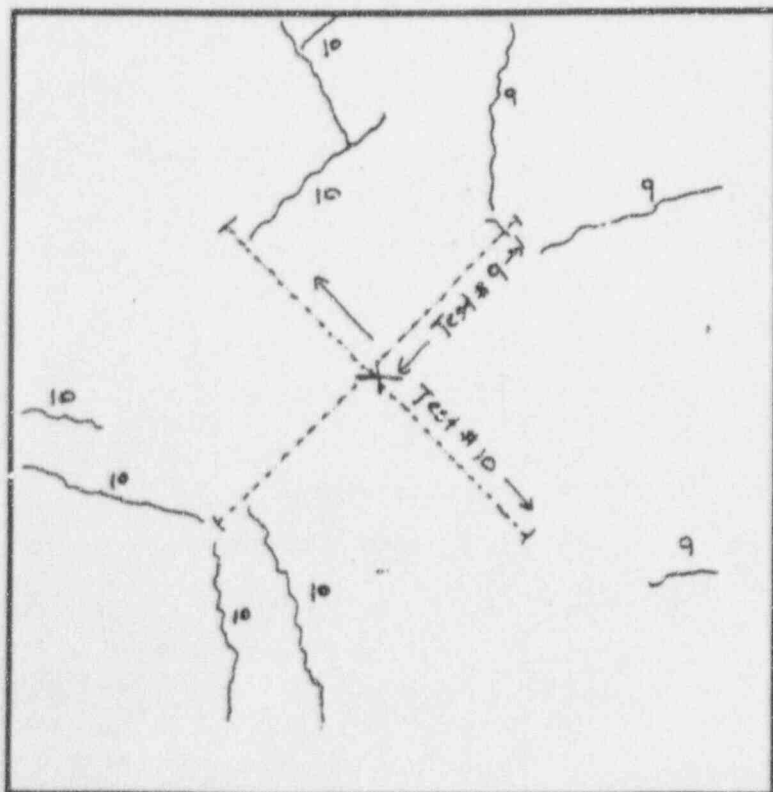




Figure 3. Crack Patterns on Concrete

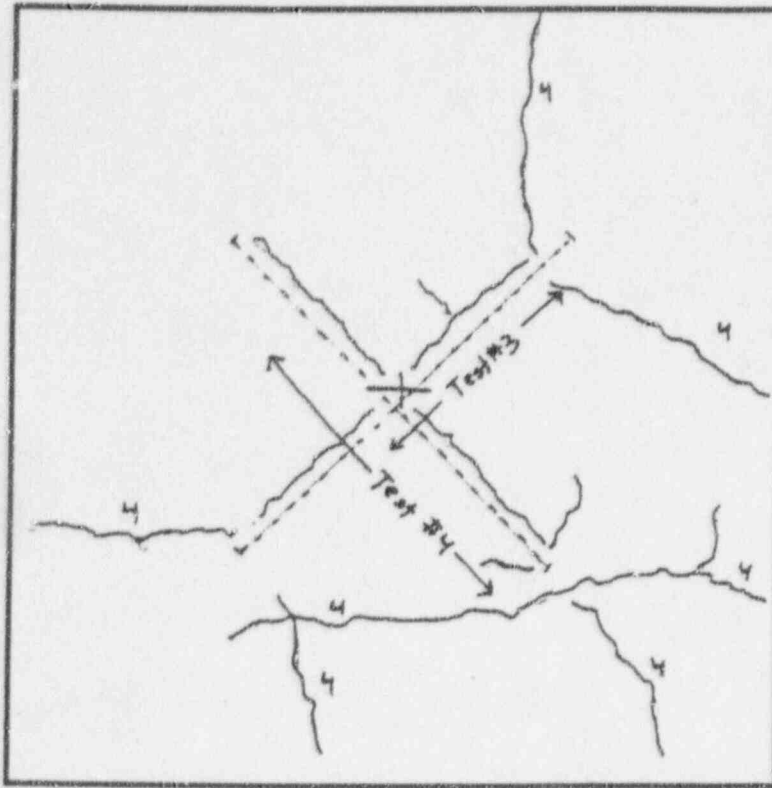
**Pad 1**

Moderately heavy damage.  
Some visible crack  
openings on top surface of  
pad, more significant  
openings on pad sides

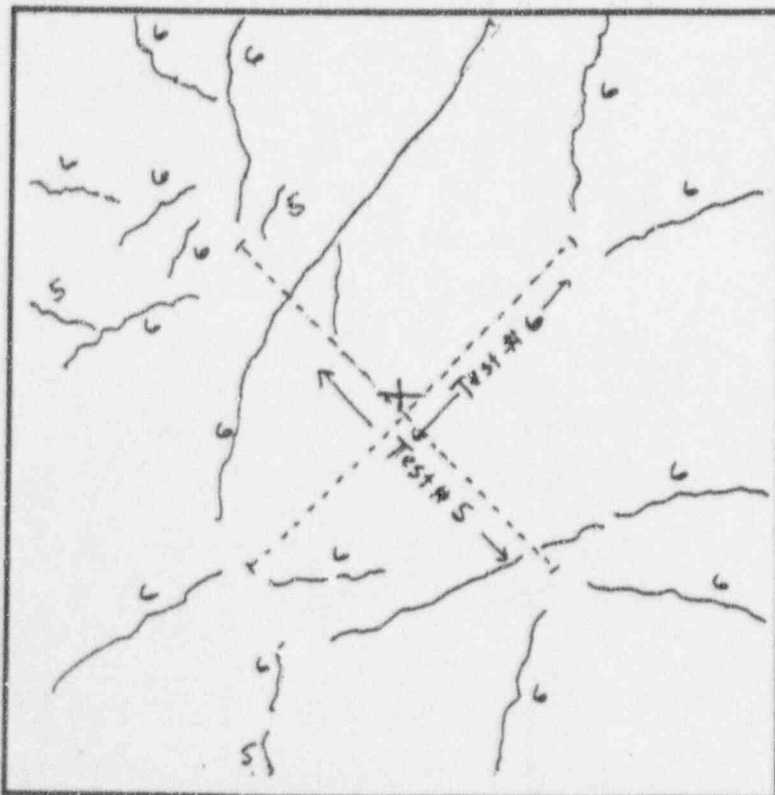
**Pad 2**

Cracking appears minor.  
Footprint from drop #10 is  
difficult to see. It can be  
seen at the ends, and in the  
region near the ends. Fairly  
uniform width of visible  
footprint from Test #9,  
about 1 to 1.5" width.

Figure 3. Crack Patterns on Concrete (continued)

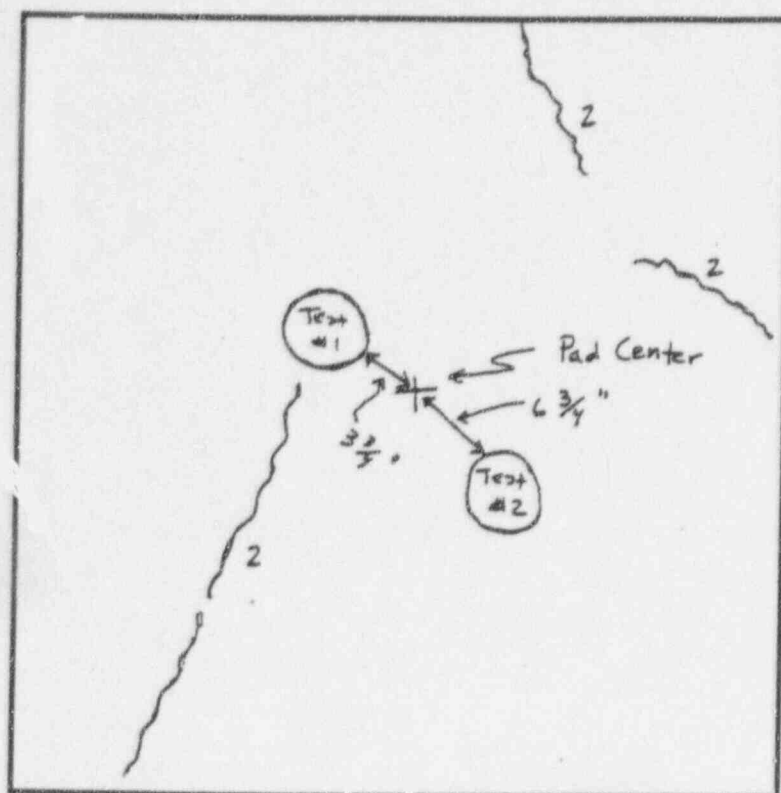
**Pad 3**

Lots of cracks, nevertheless cracking appears minor. No crack openings in top surface of concrete. Some openings on sides.

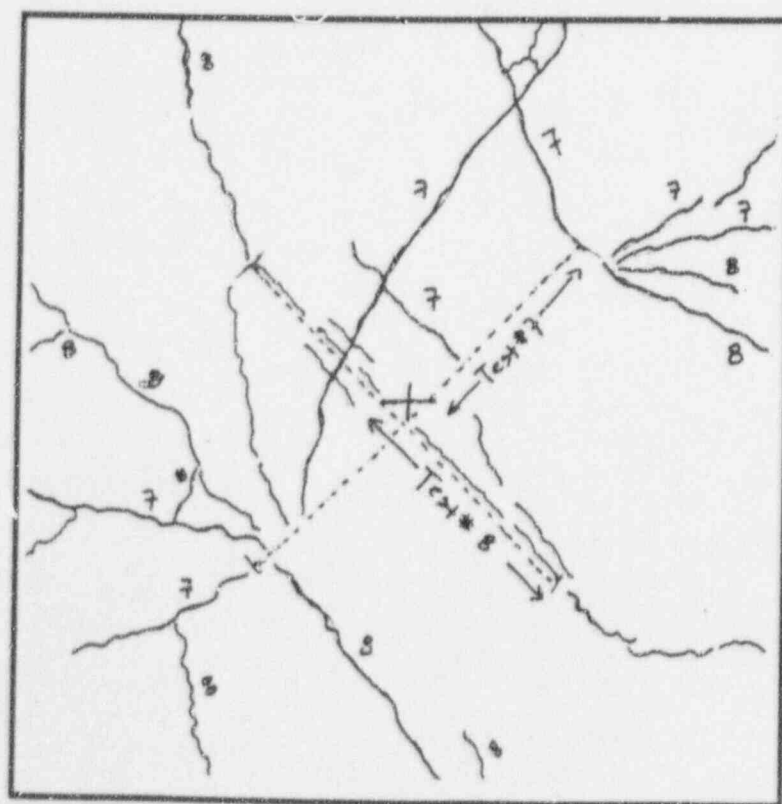
**Pad 4**

Heavily cracked pad. Some visible crack openings both top and sides. Nearly all cracking occurs after Test #6. Footprint from Test #5 difficult to see, but is clearly not uniform. Footprint from Test #6 is visible and not uniform.

Figure 3. Crack Patterns on Concrete (continued)

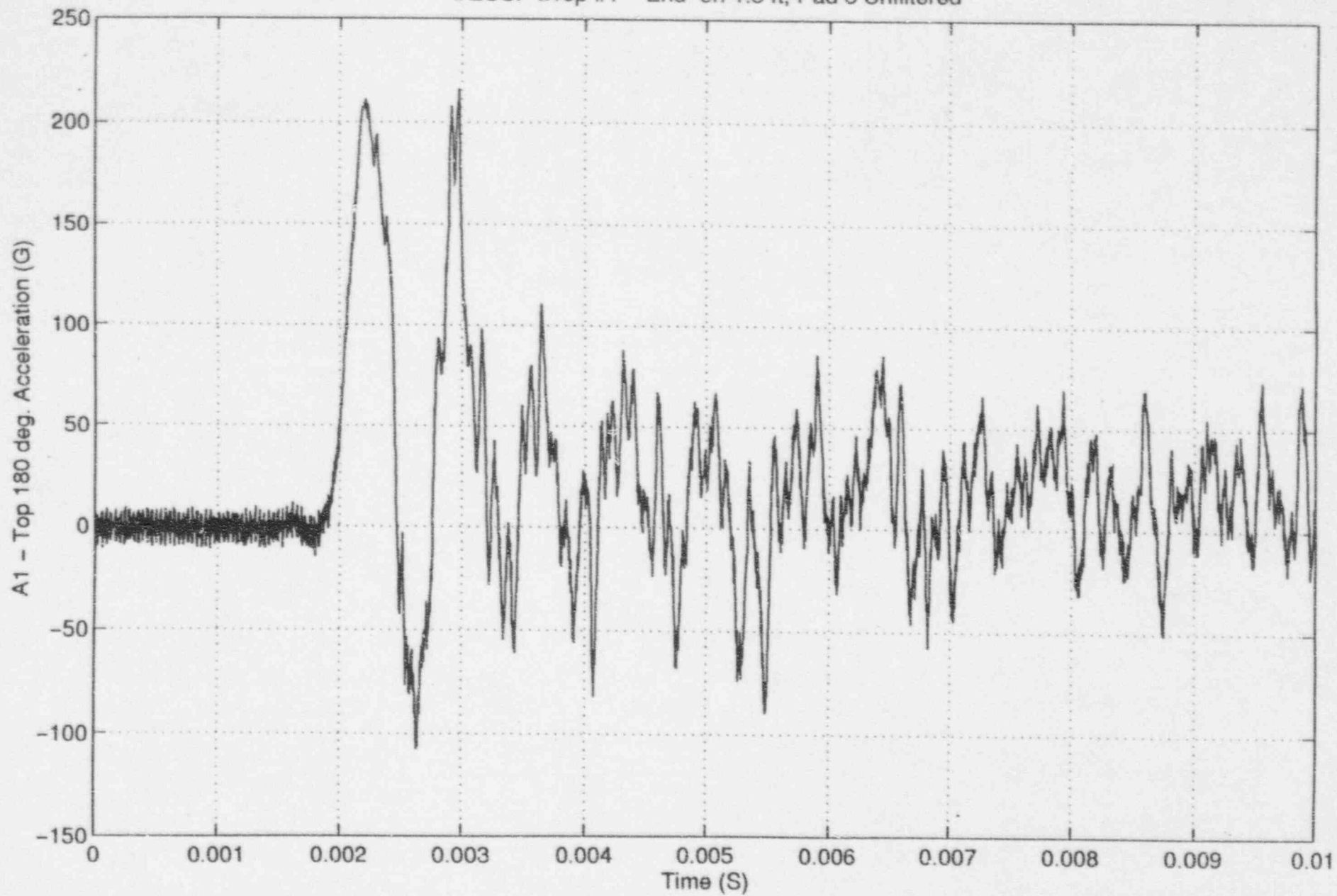
**Pad 5**

No cracking on top surface for Test #1. Some on sides. Minimal cracking on top surface for Test #2, indicating likely internal damage resulting from Test #1. Crack openings visible (roughly 1/8") on sides only, none on top surface.

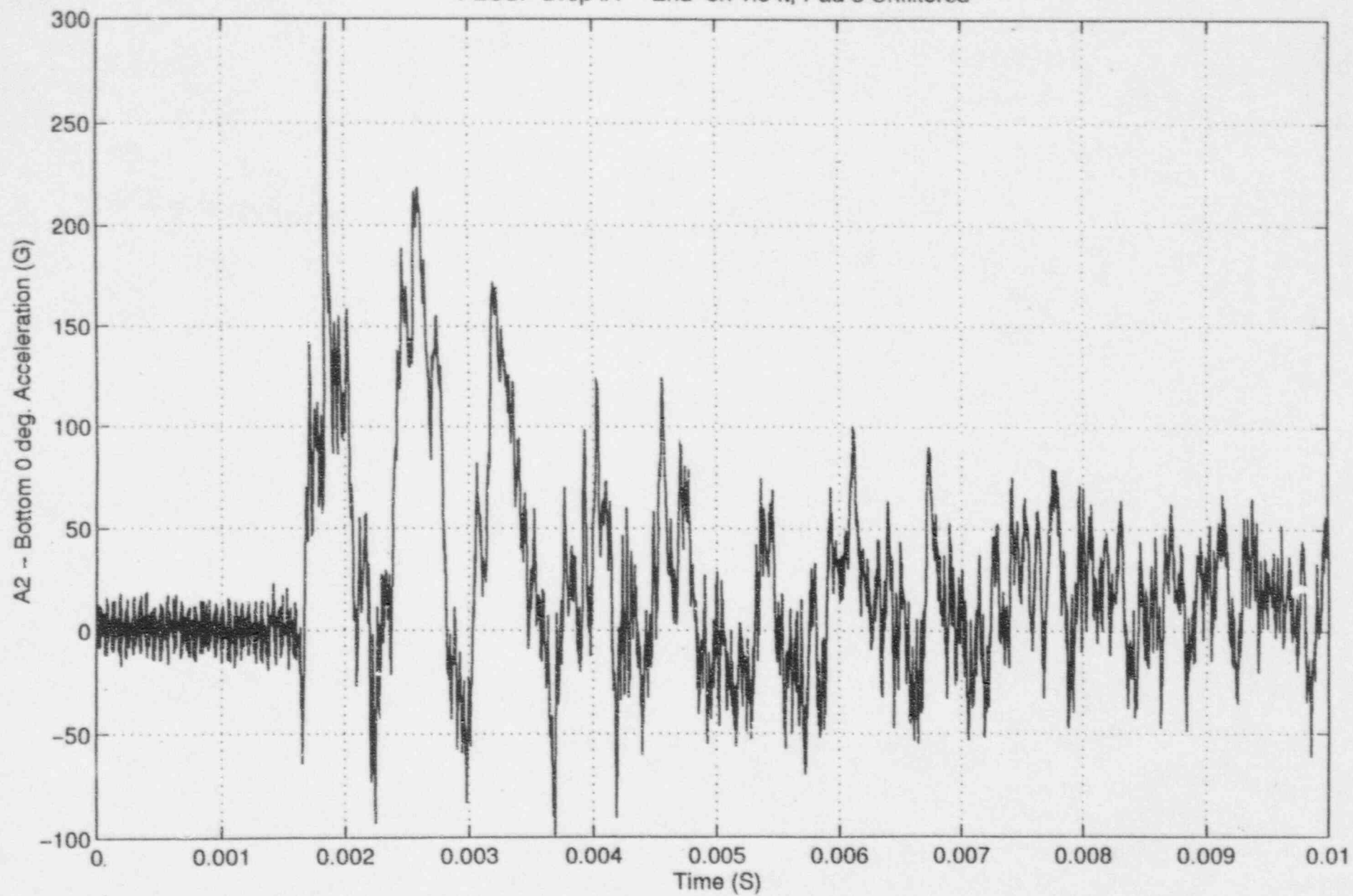
**Pad 6**

Substantial cracking, top and sides. Visible crack openings on both top and sides of pad. Footprint of billet difficult to see from Test #7, easier to see from Test #8. Neither footprint is uniform in width.

FESSP Drop #1 - End-on 1.5 ft, Pad 5 Unfiltered

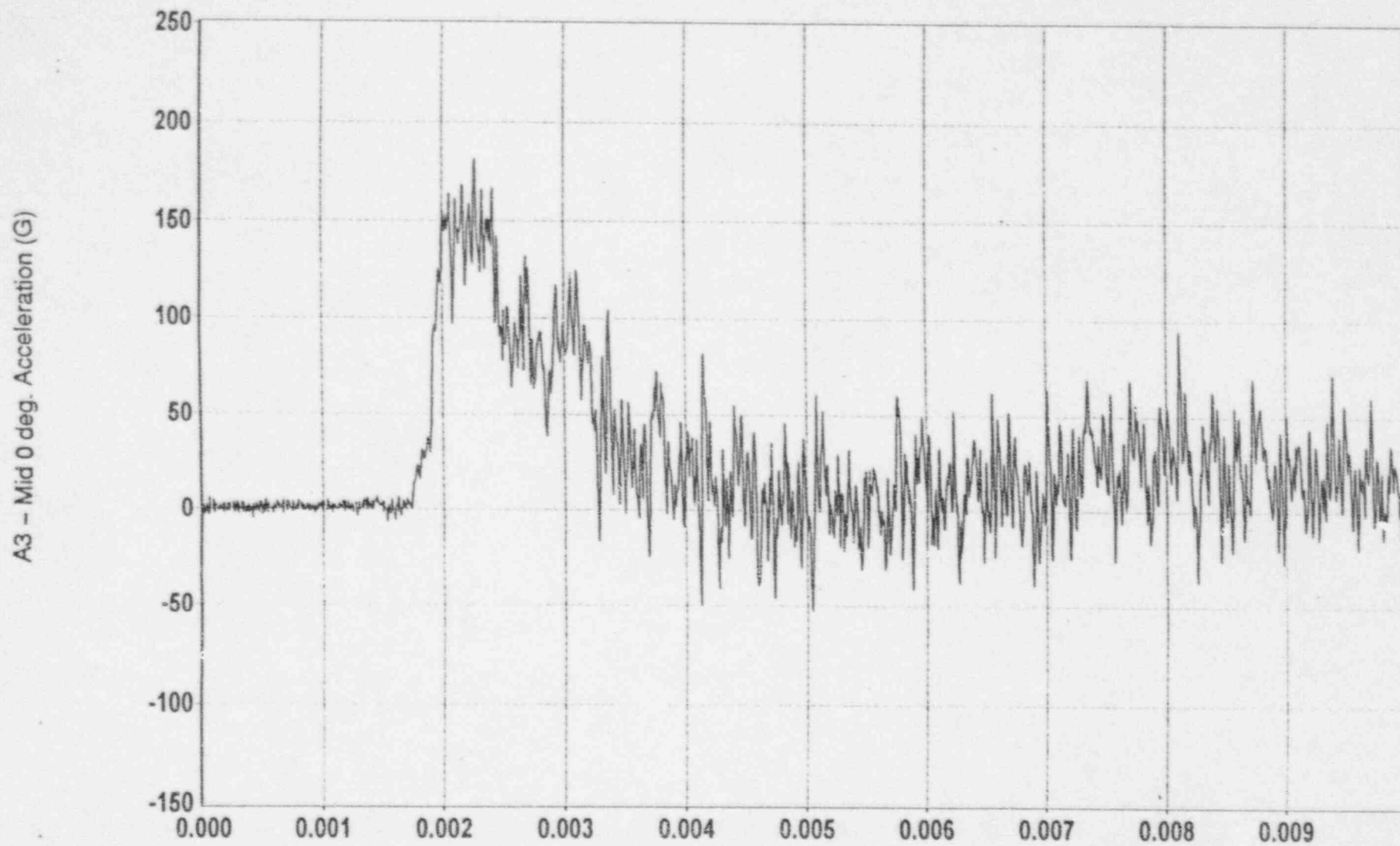


FESSP Drop #1 - End-on 1.5 ft, Pad 5 Unfiltered

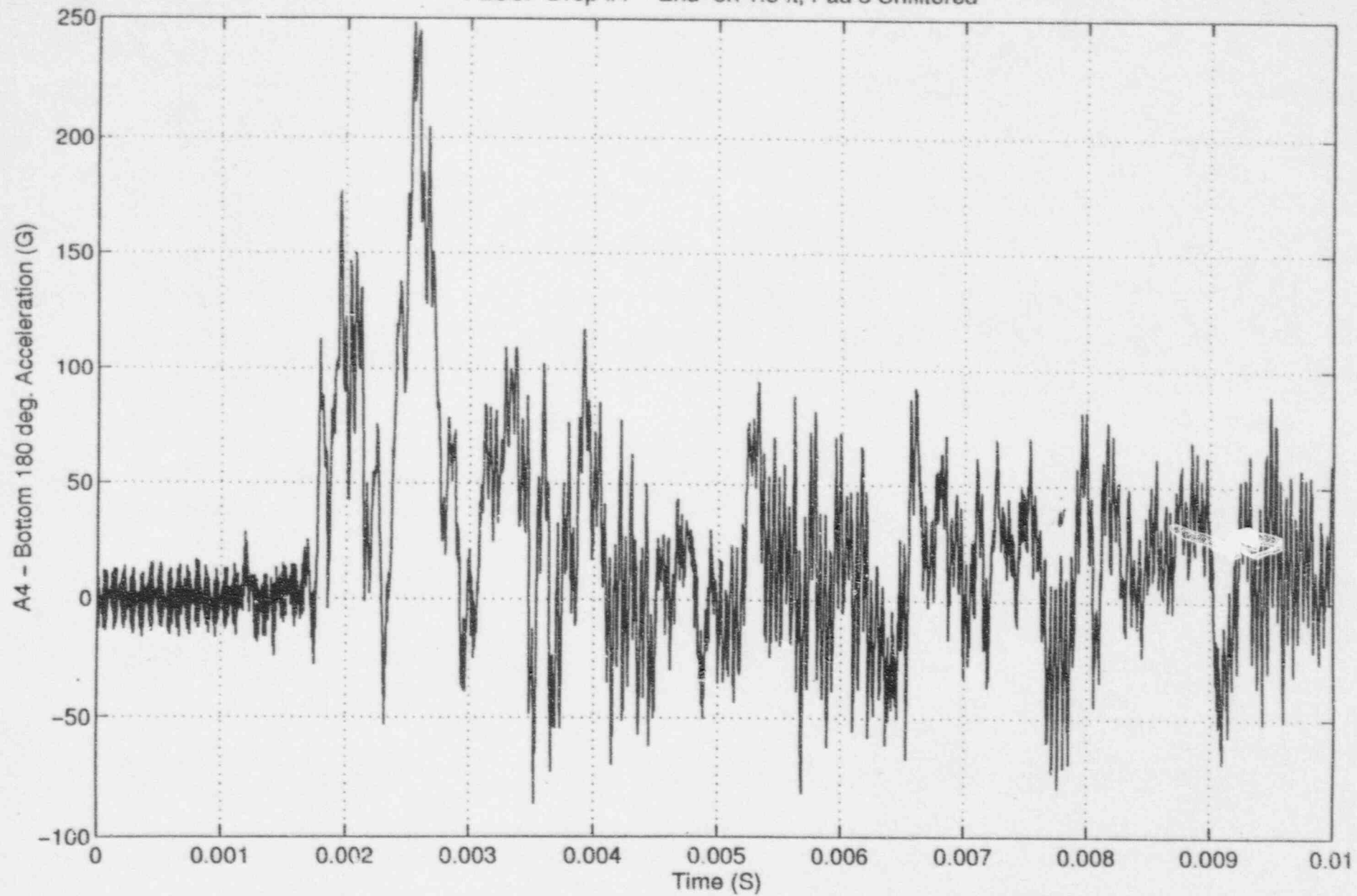




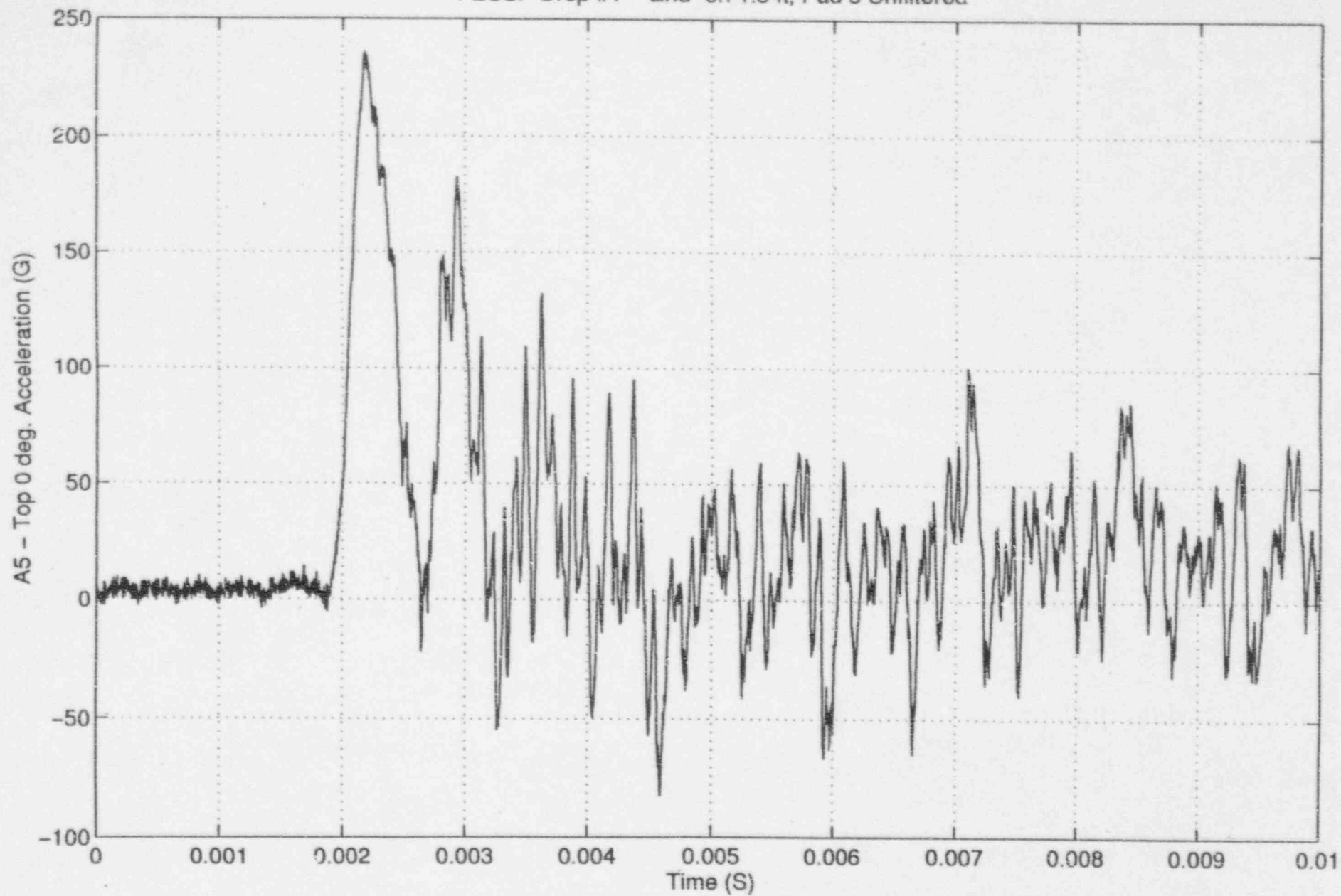
FESSP Drop #1 - End-on 1.5 ft, Pad 5 Unfiltered



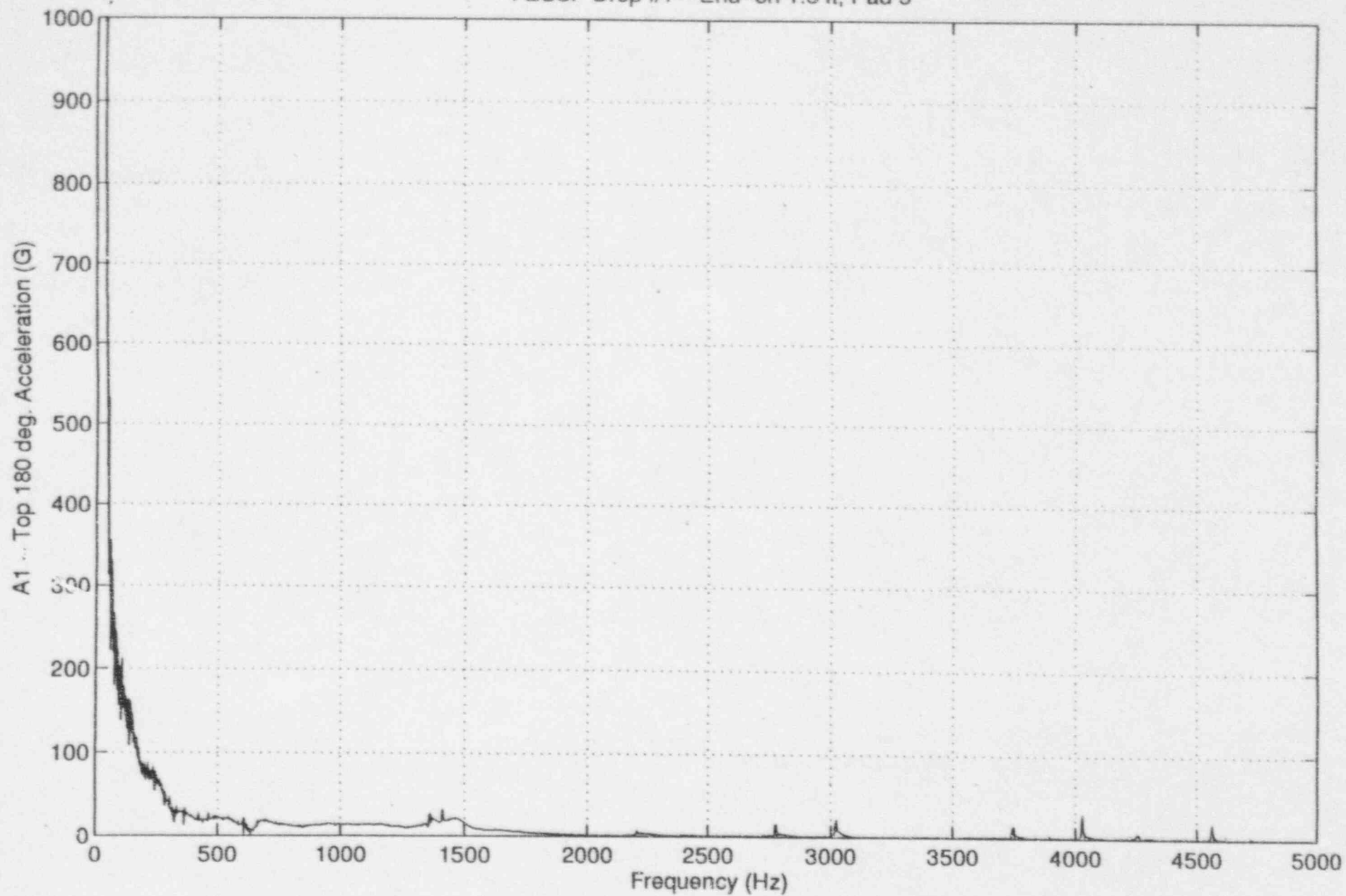
FESSP Drop #1 - End-on 1.5 ft, Pad 5 Unfiltered



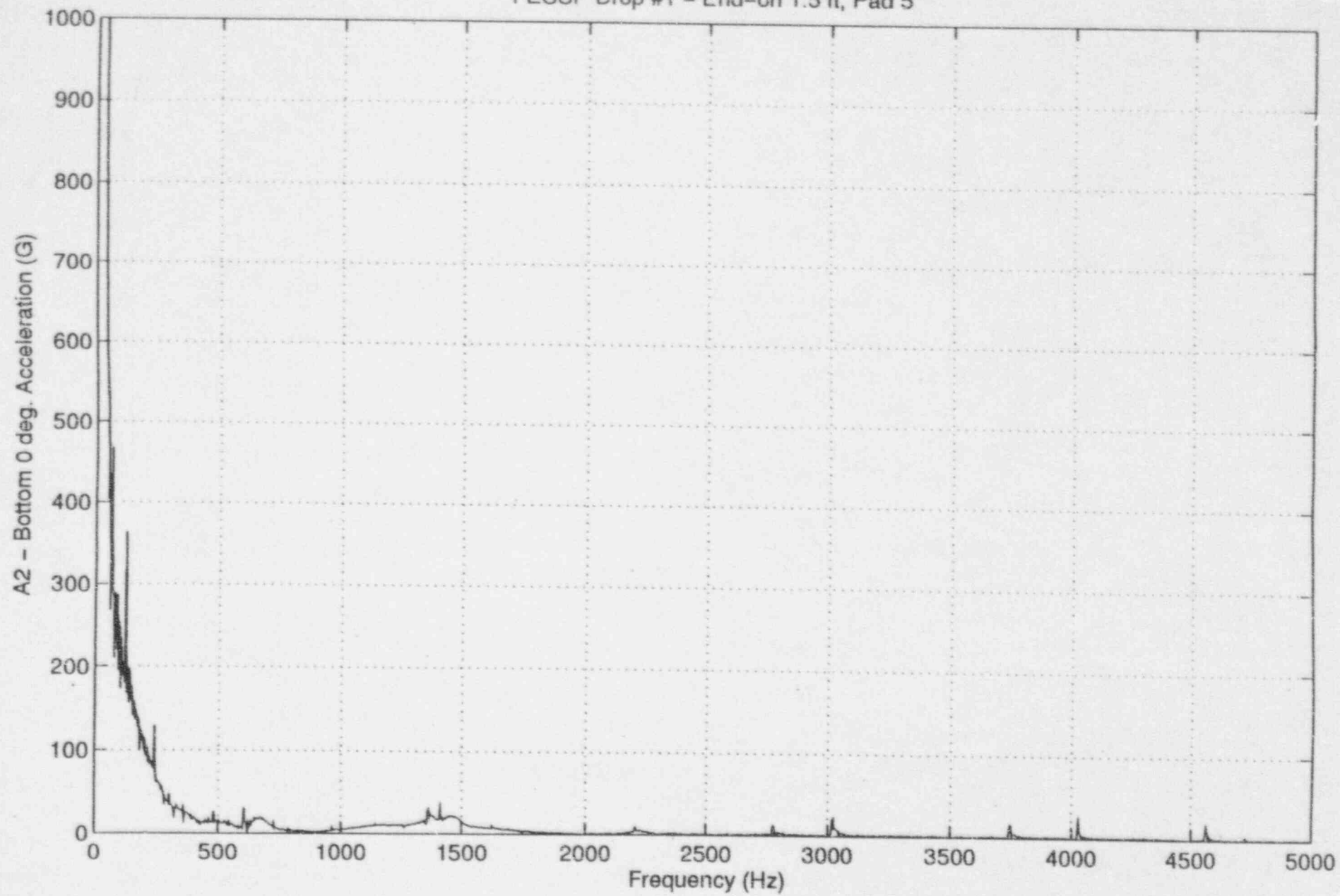
FESSP Drop #1 - End-on 1.5 ft, Pad 5 Unfiltered



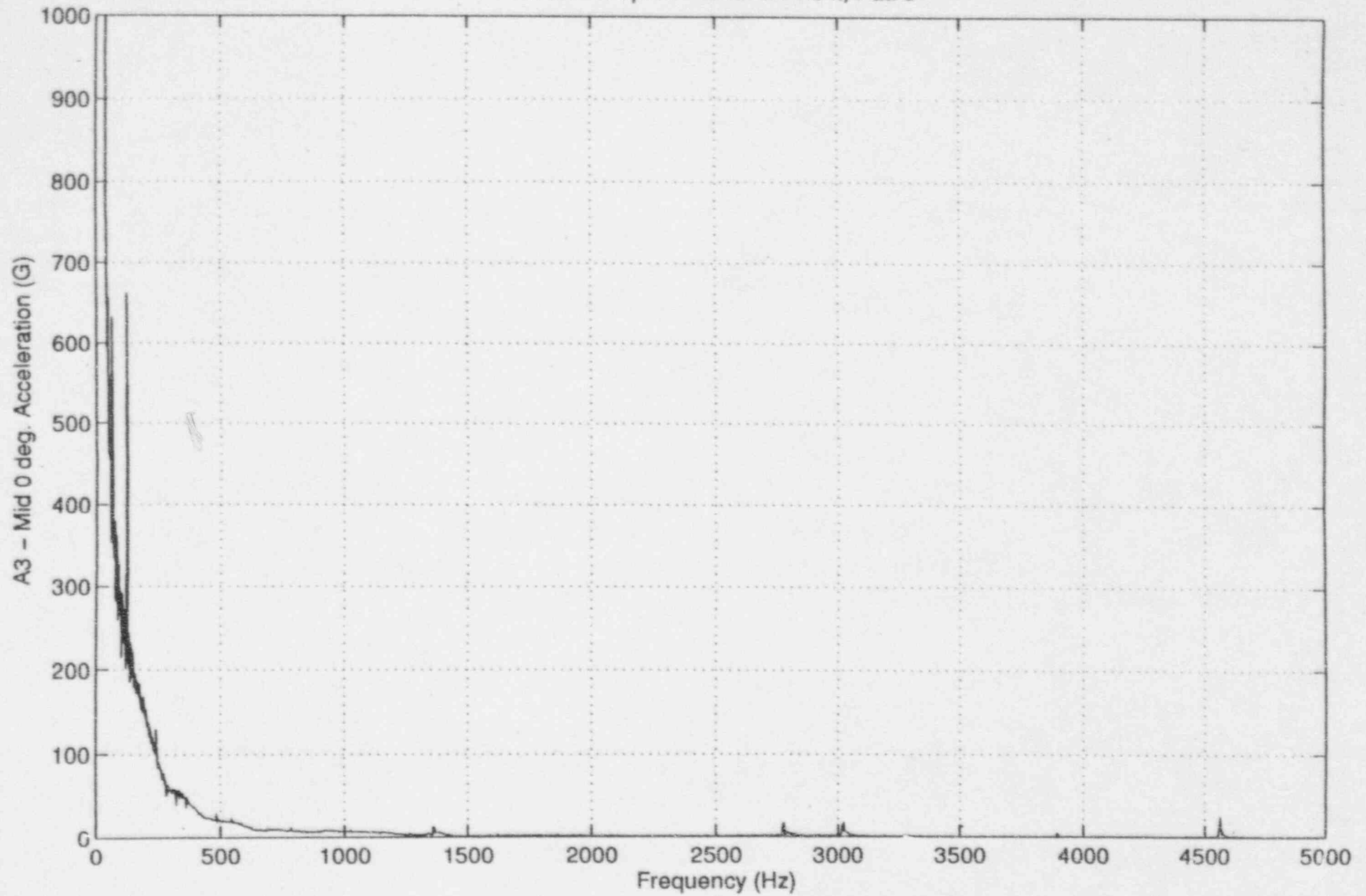
FESSP Drop #1 - End-on 1.5 ft, Pad 5



FESSP Drop #1 - End-on 1.5 ft, Pad 5

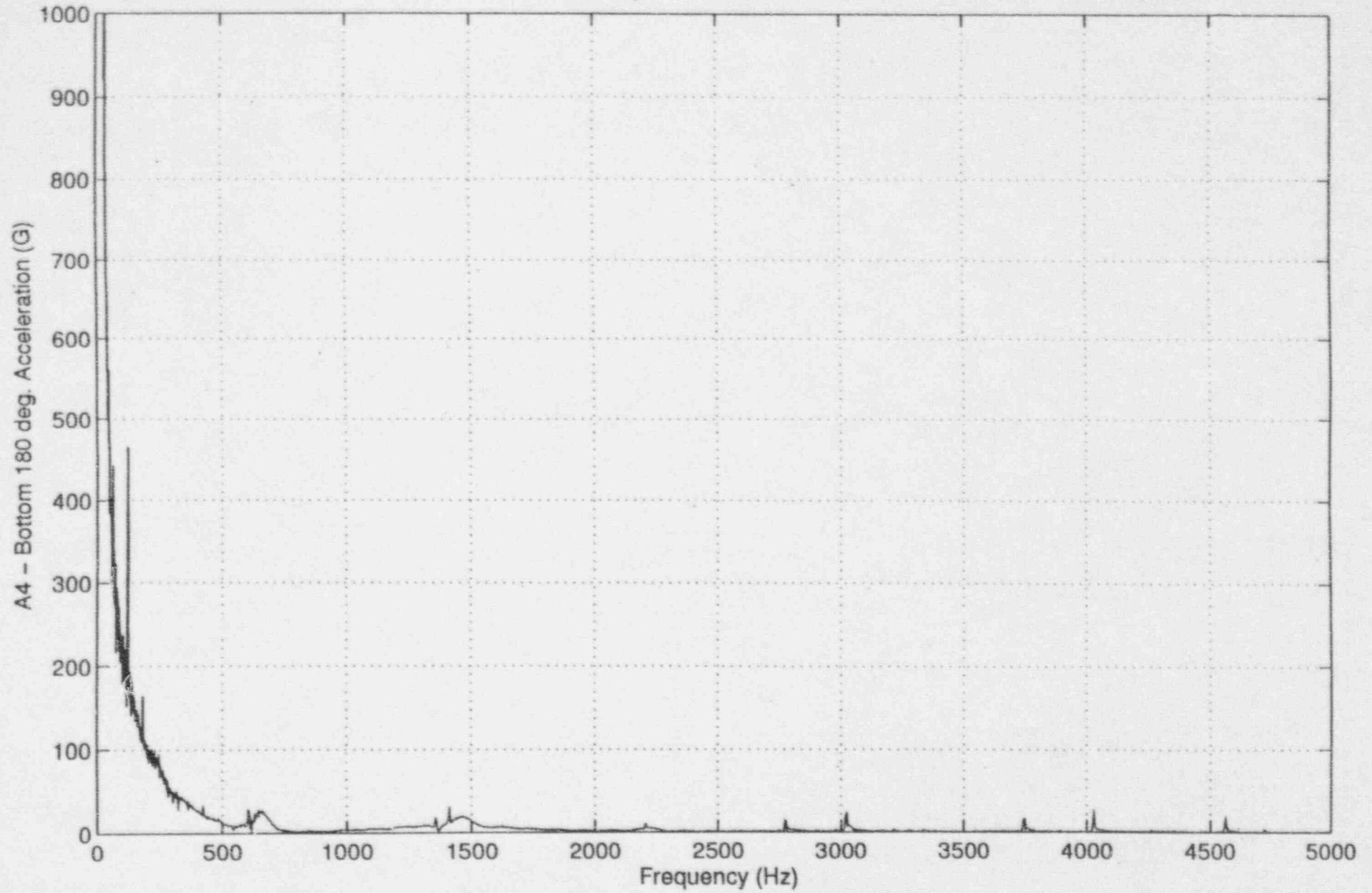


FESSP Drop #1 - End-on 1.5 ft, Pad 5

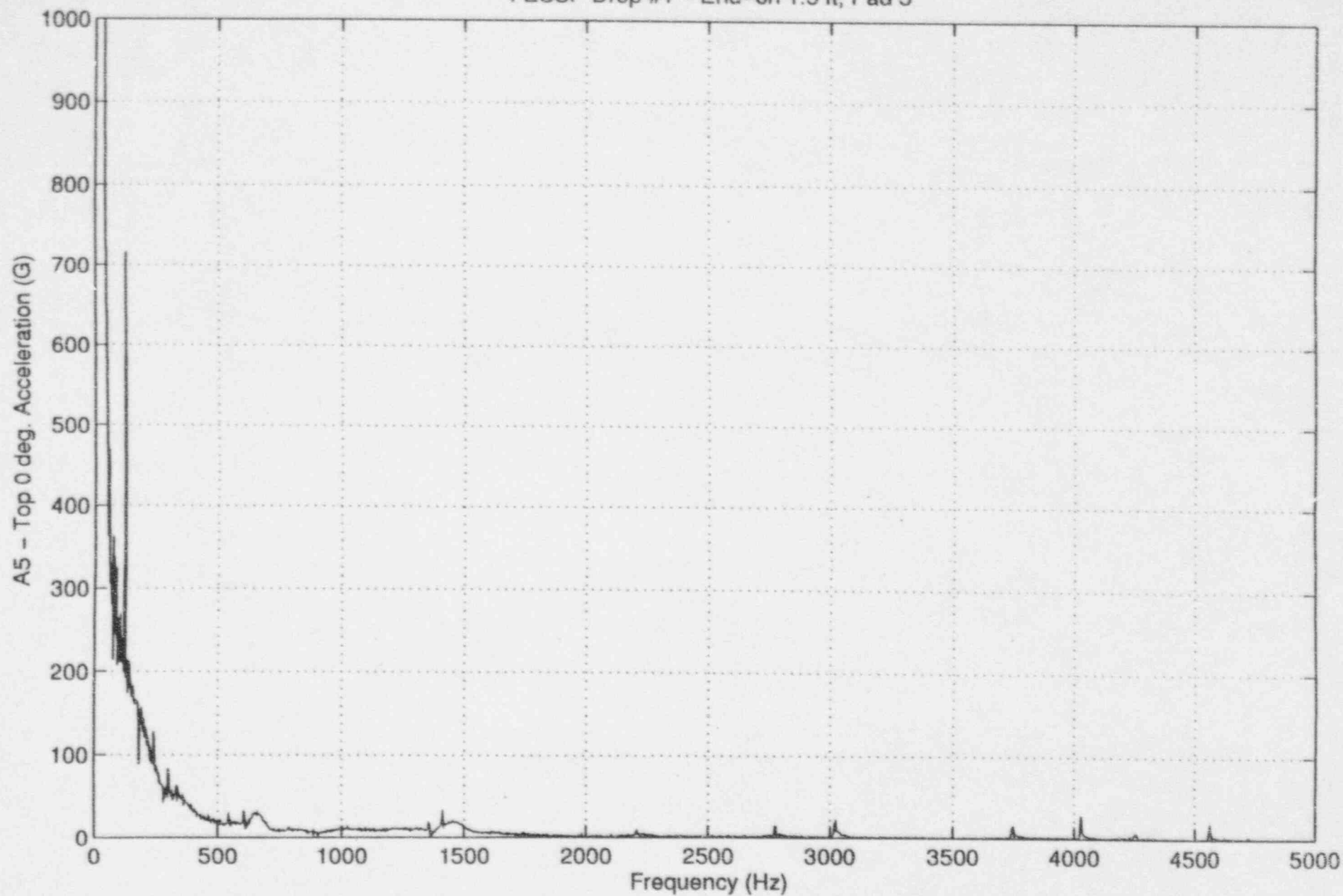




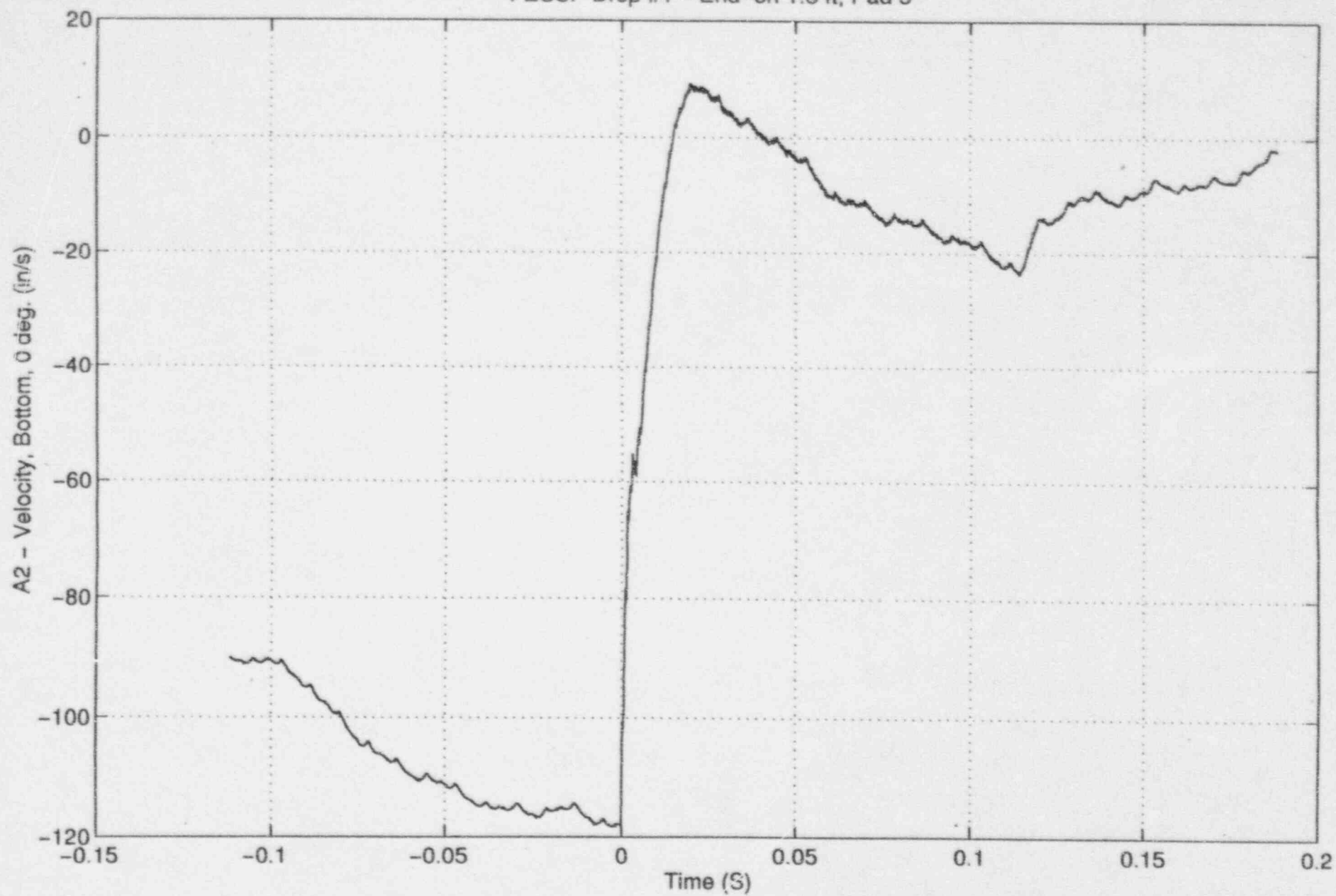
FESSP Drop #1 - End-on 1.5 ft, Pad 5



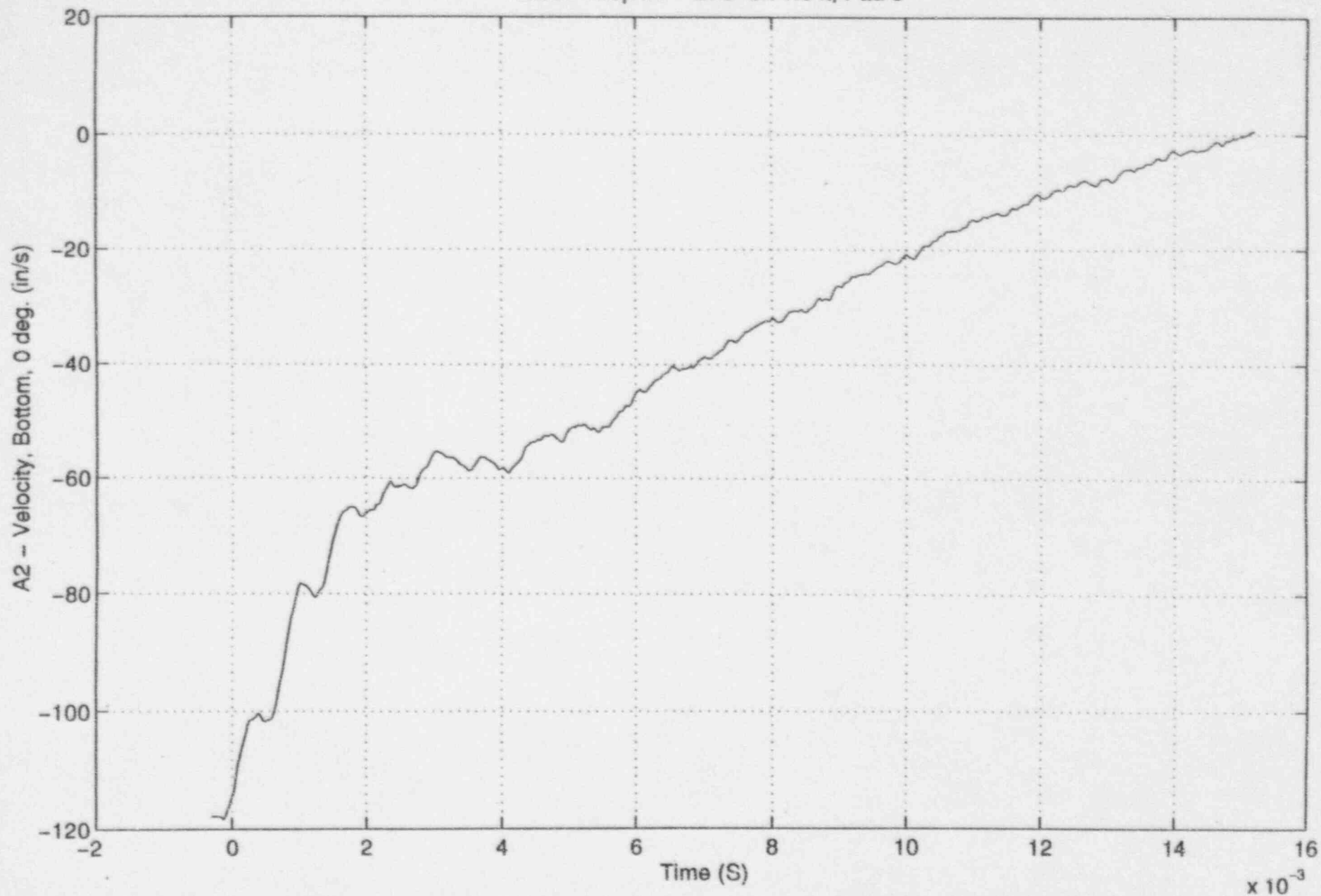
FESSP Drop #1 - End-on 1.5 ft, Pad 5



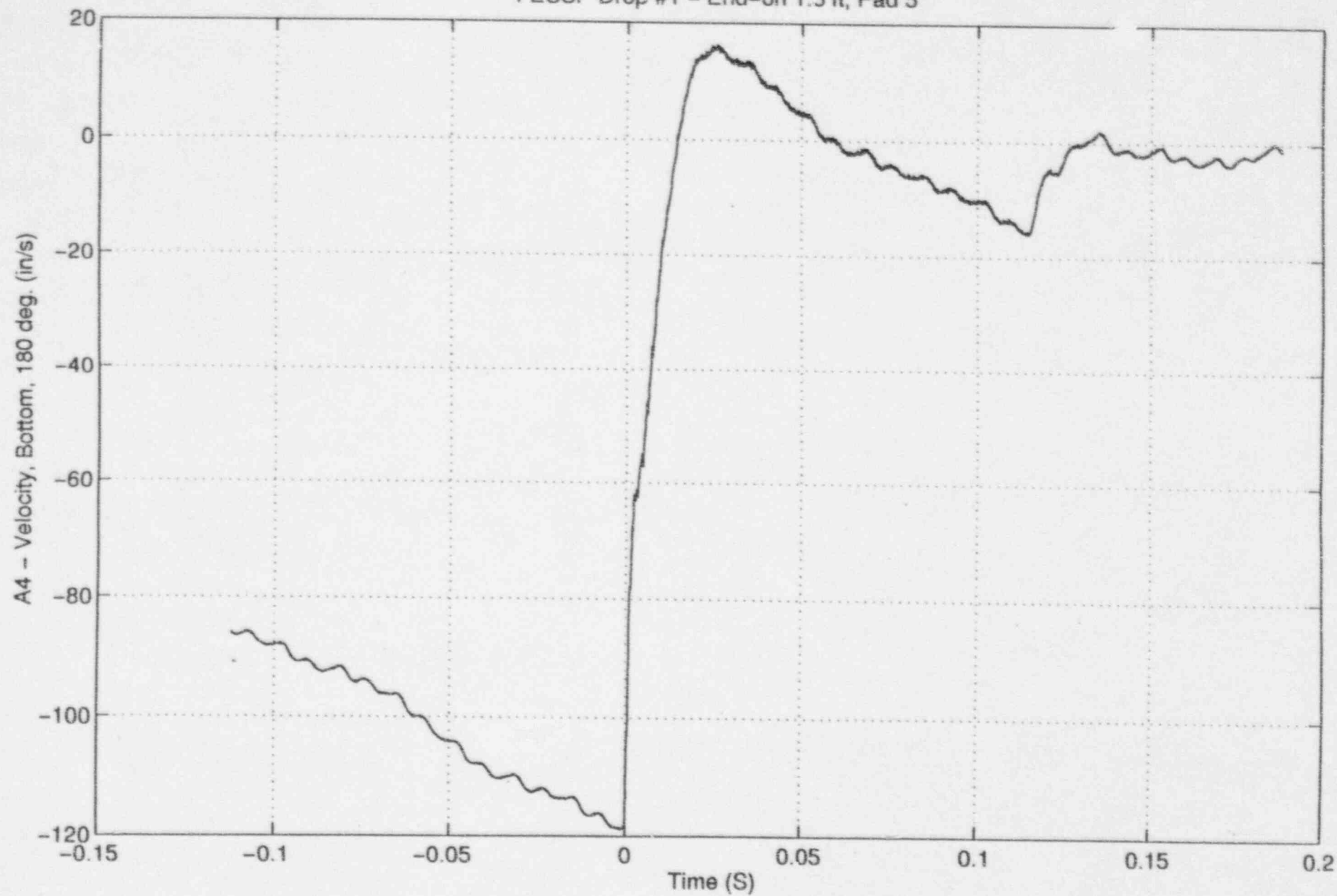
FESSP Drop #1 - End-on 1.5 ft, Pad 5



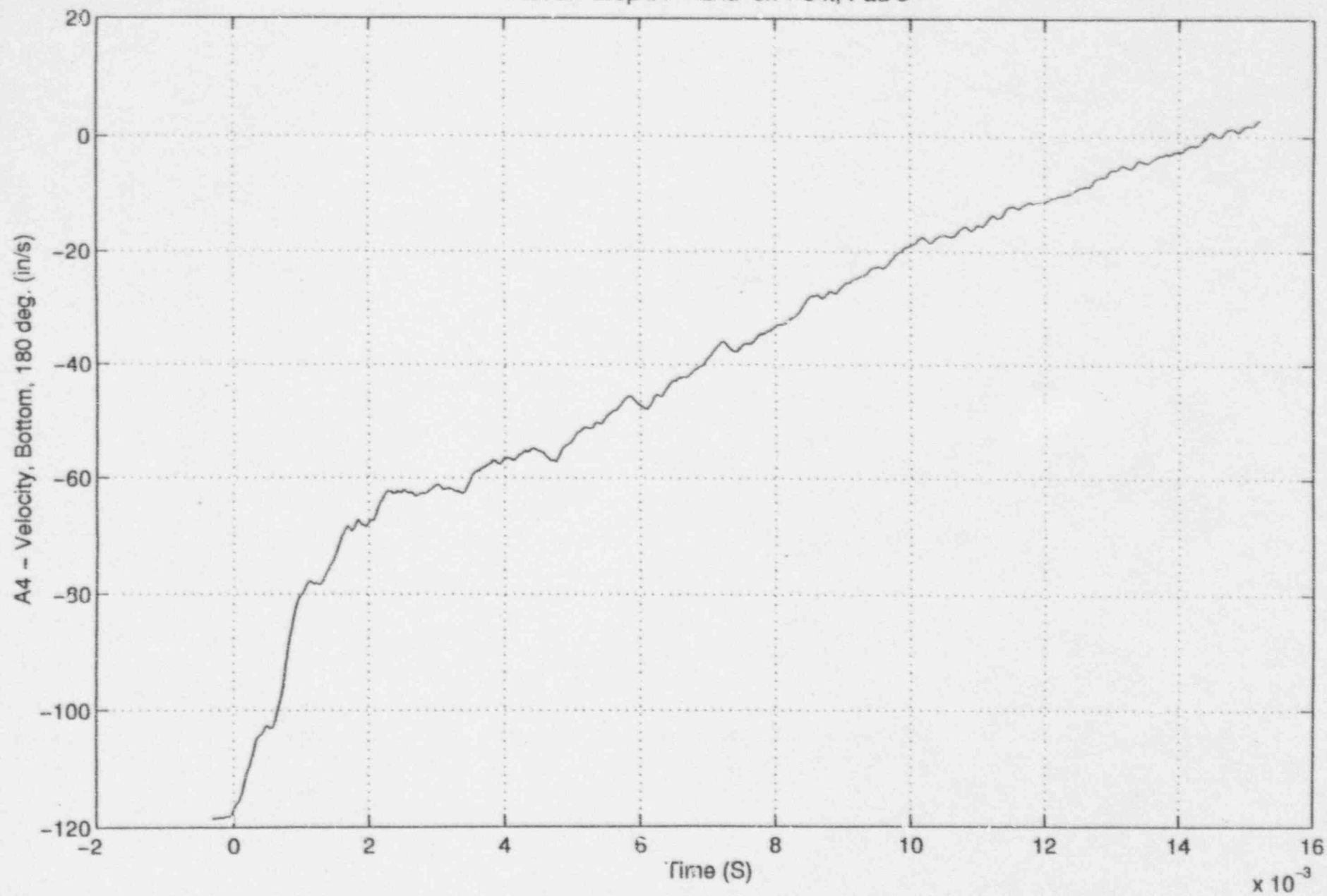
FESSP Drop #1 - End-on 1.5 ft, Pad 5



FESSP Drop #1 - End-on 1.5 ft, Pad 5

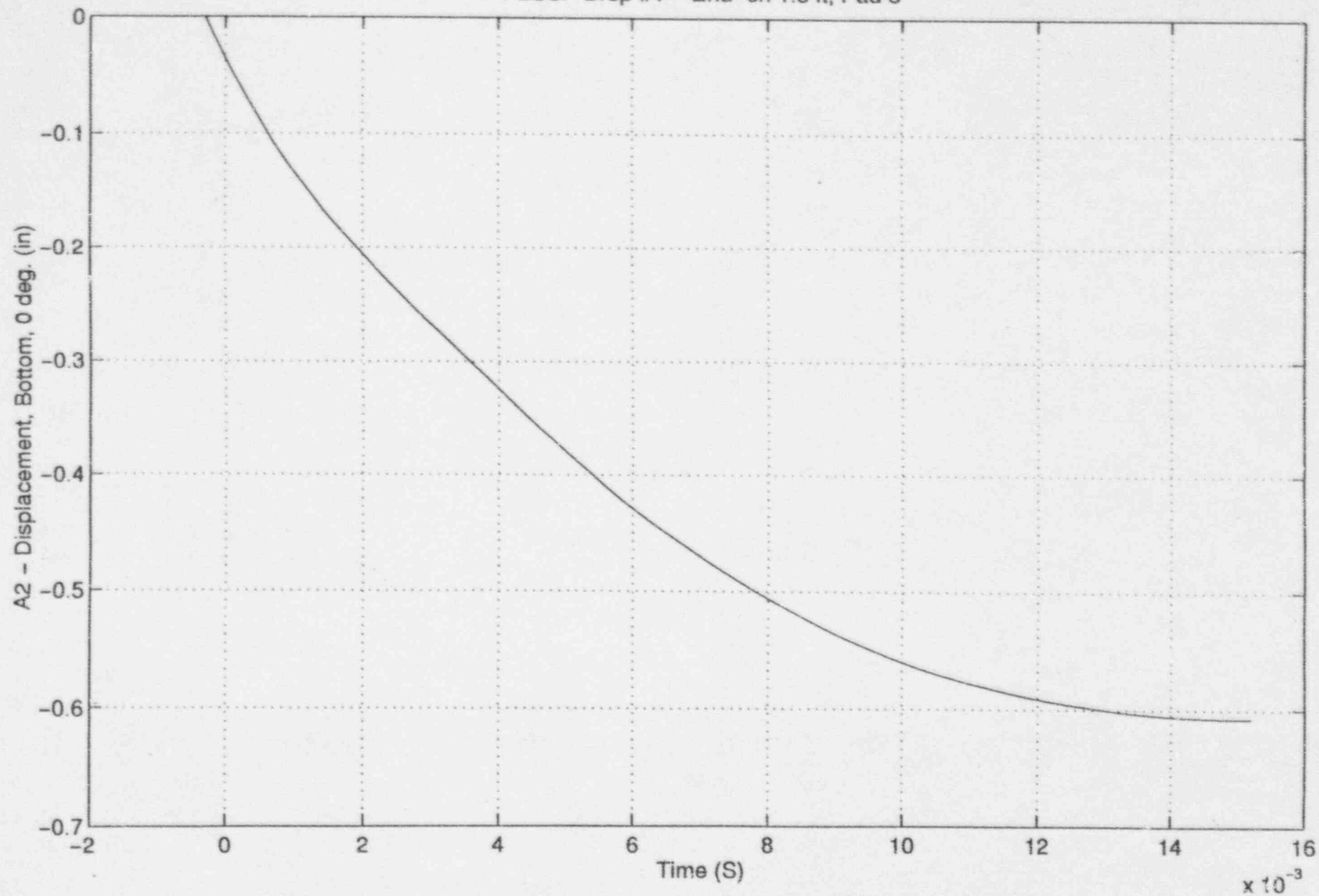


FEESP Drop #1 - End-on 1.5 ft, Pad 5

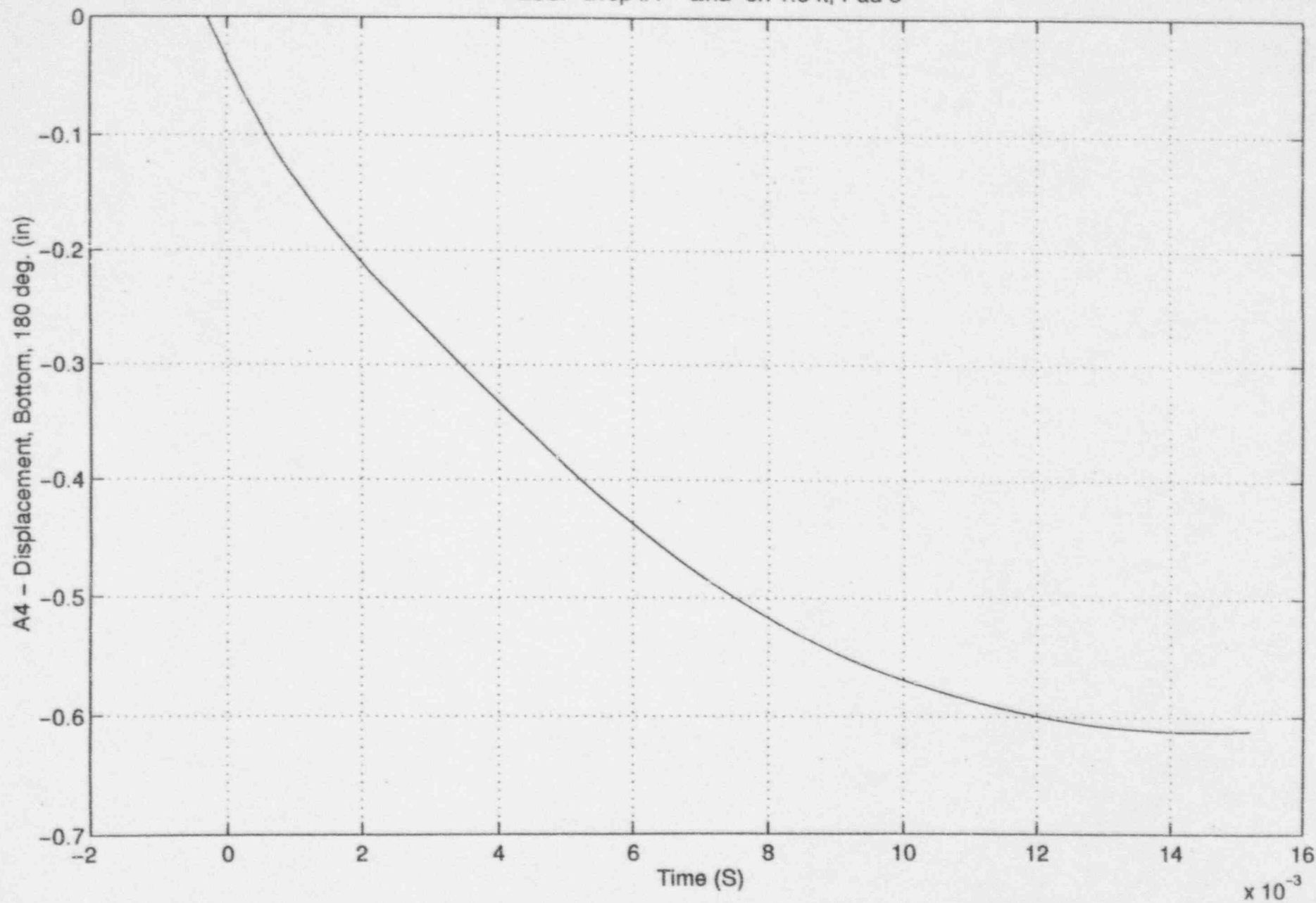




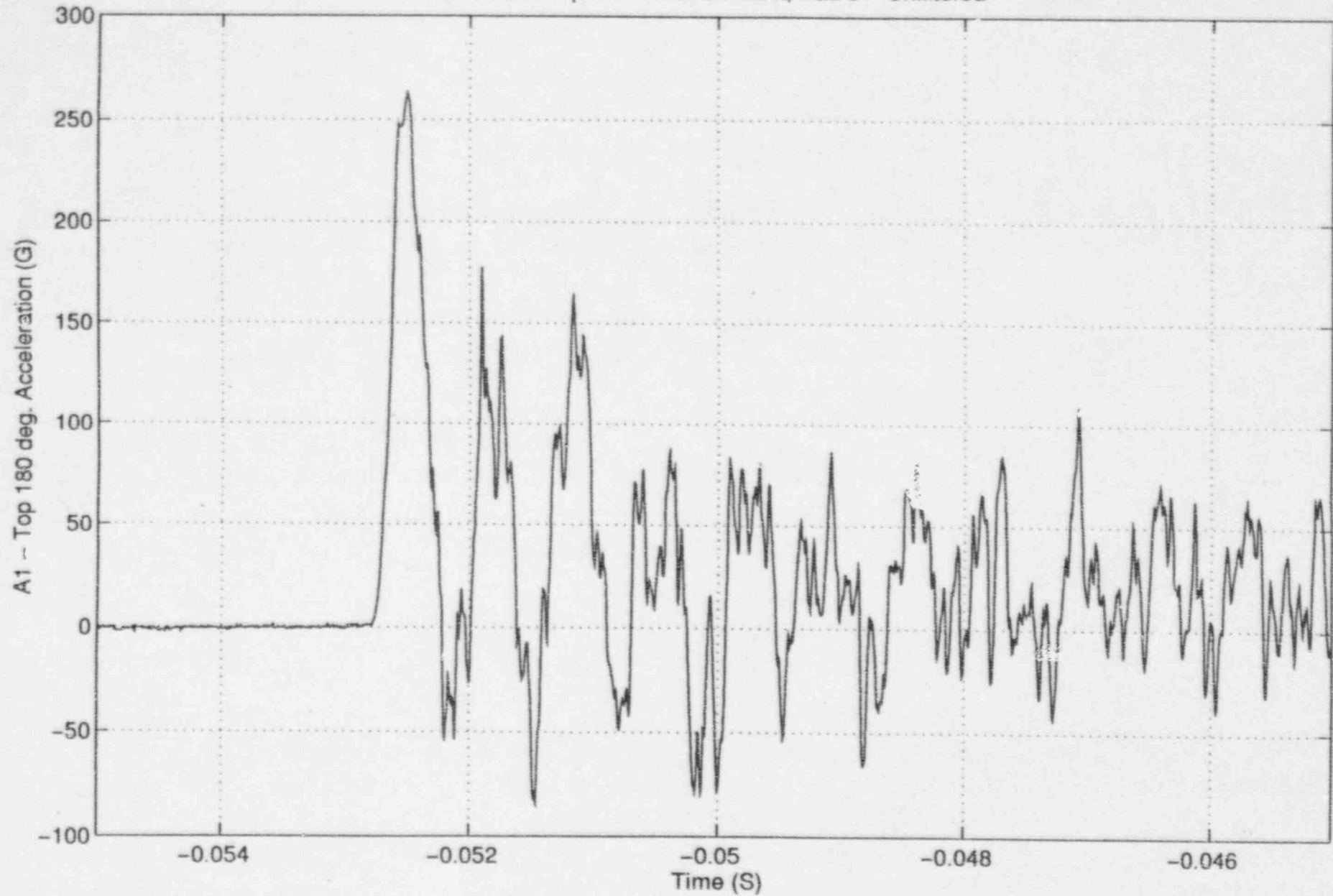
FESSP Drop #1 - End-on 1.5 ft, Pad 5



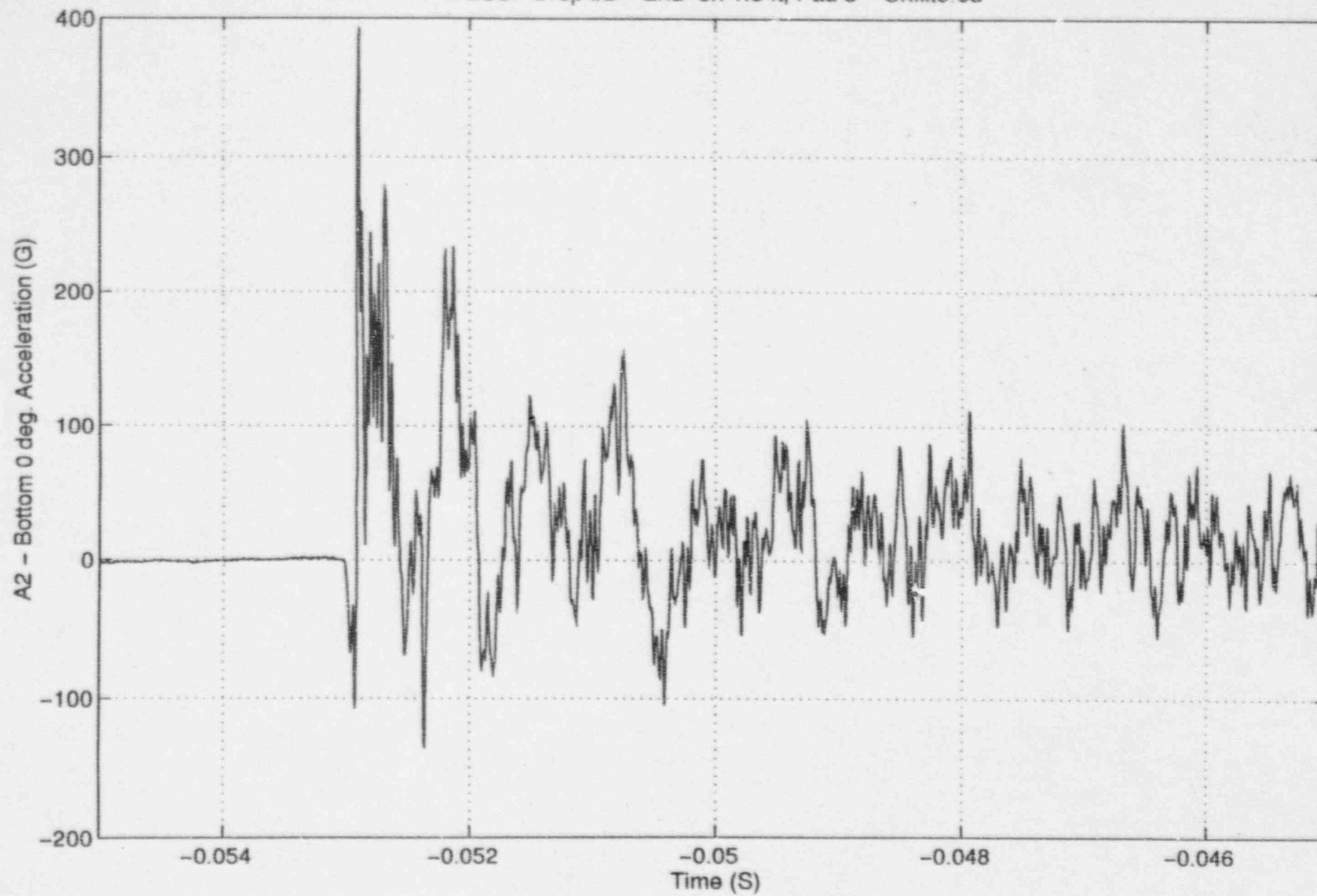
FESSP Drop #1 - End-on 1.5 ft, Pad 5



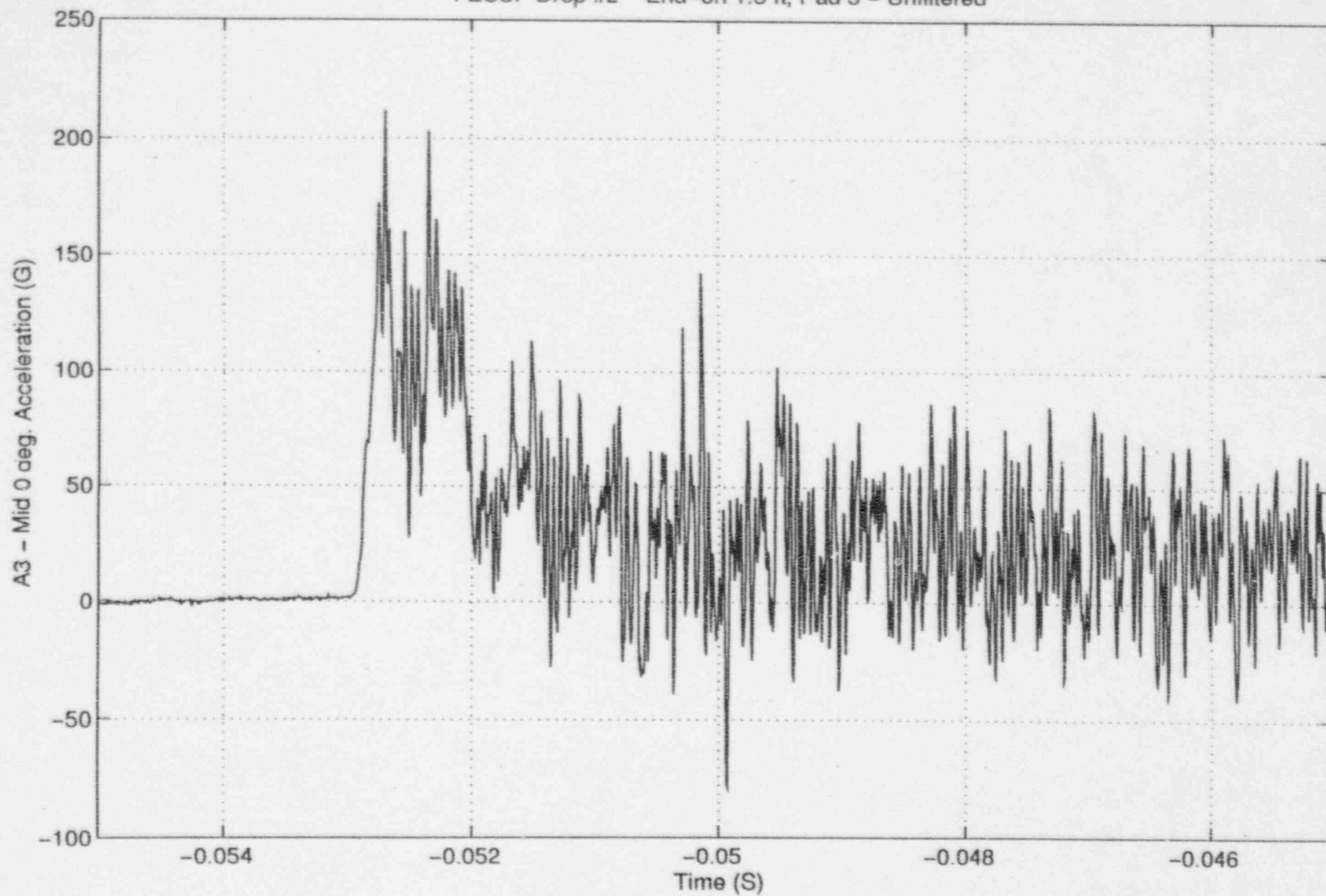
FESSP Drop #2 - End-on 1.5 ft, Pad 5 - Unfiltered

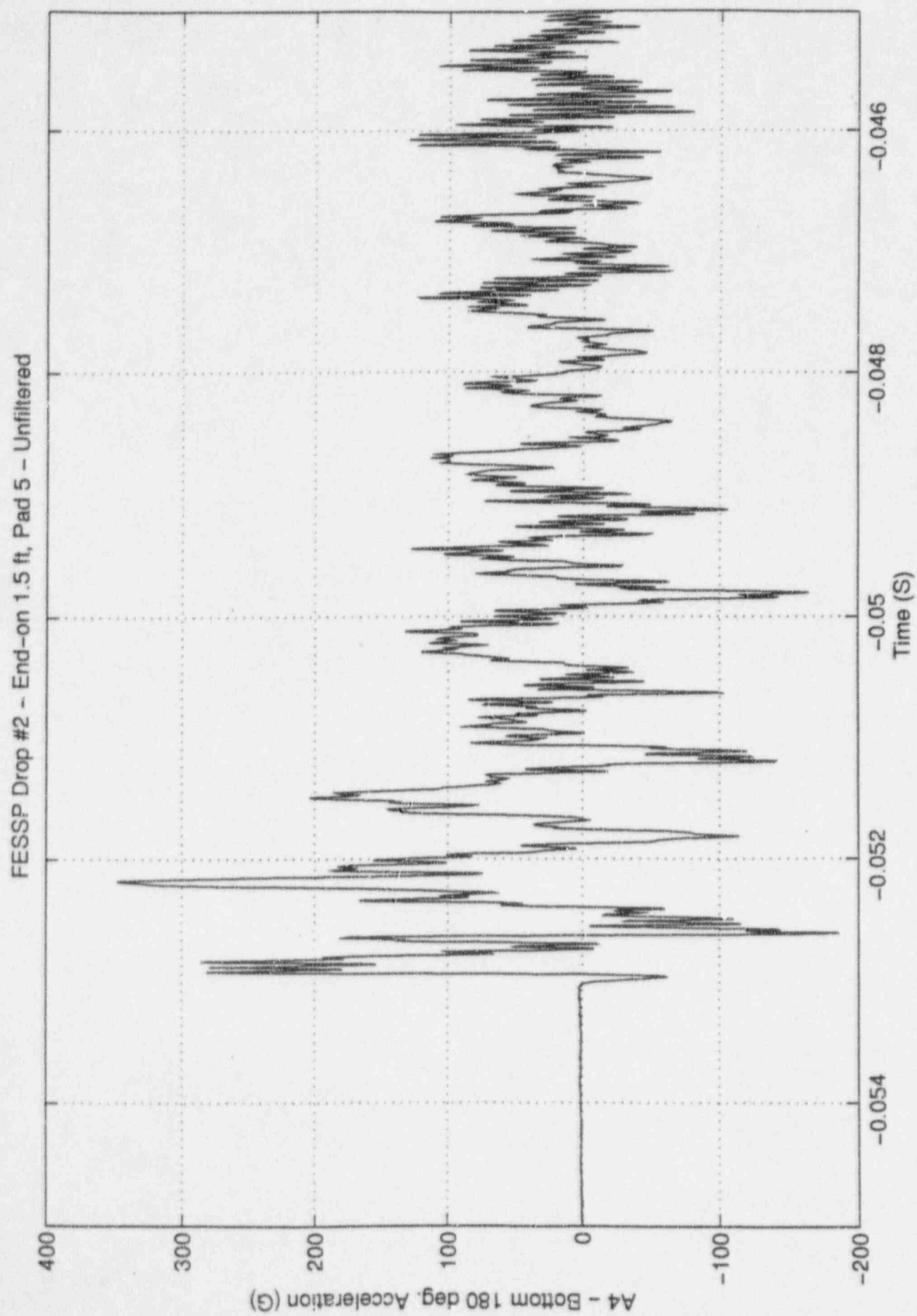


FESSP Drop #2 - End-on 1.5 ft, Pad 5 - Unfiltered



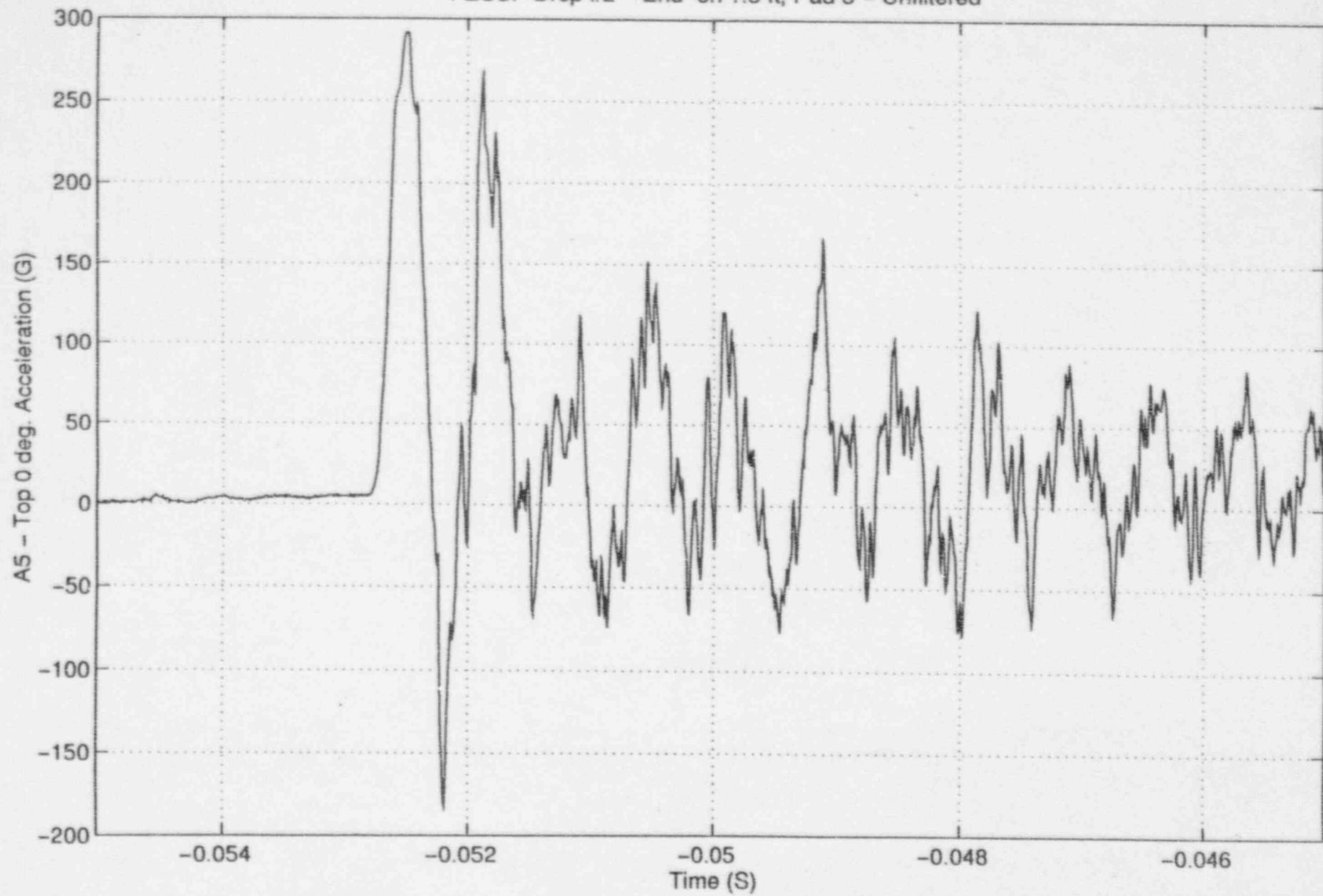
FESSP Drop #2 - End-on 1.5 ft, Pad 5 - Unfiltered

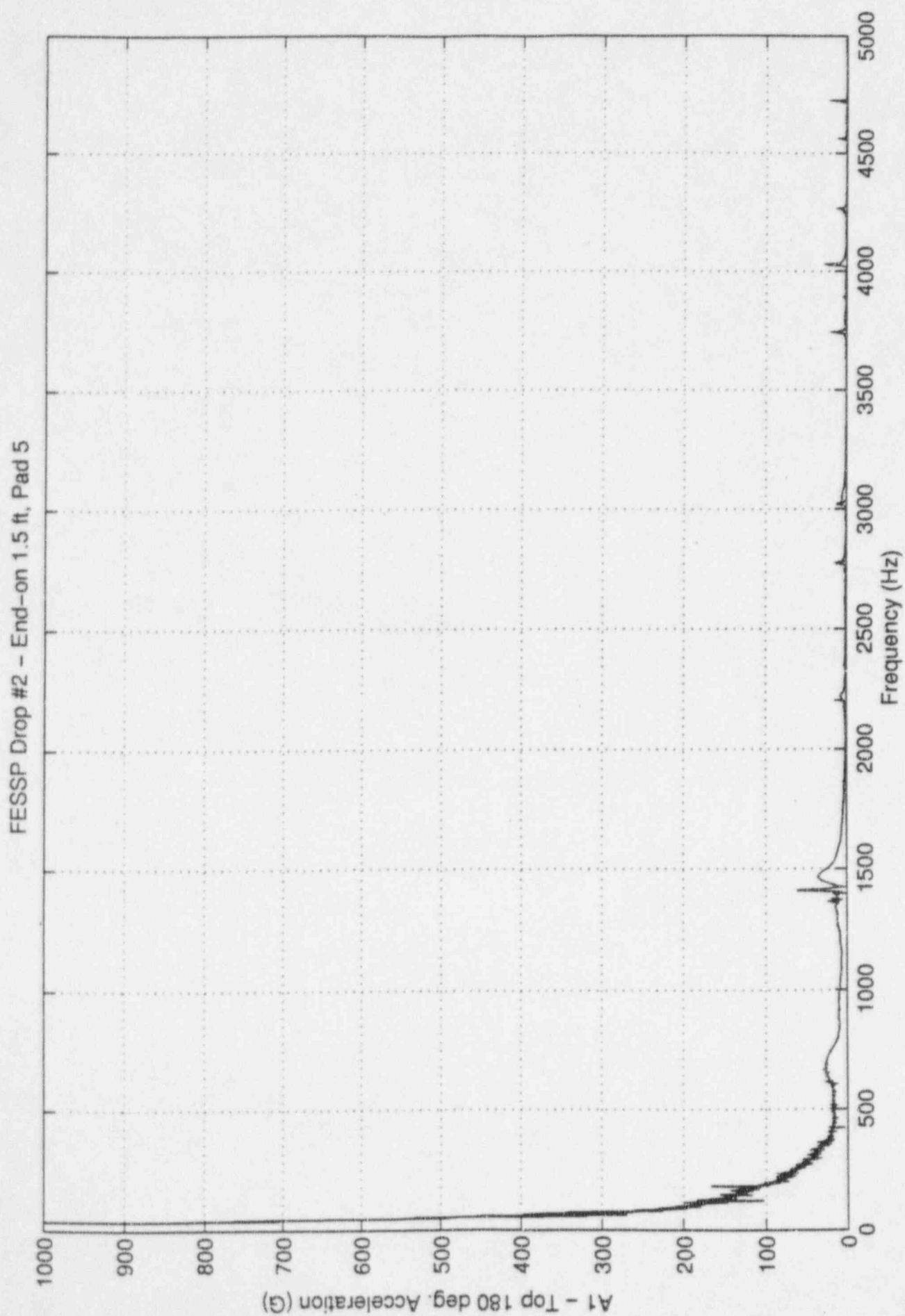




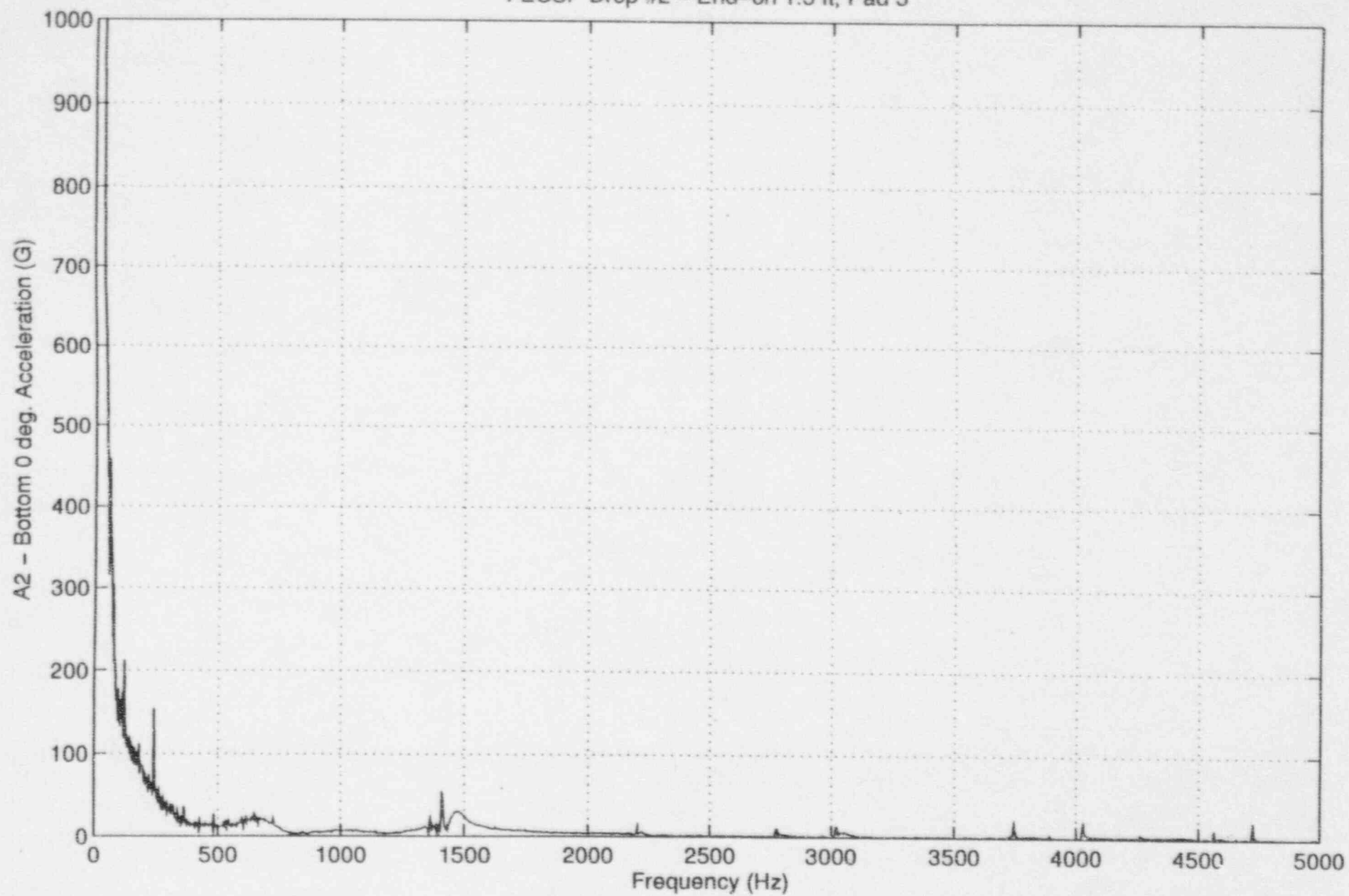


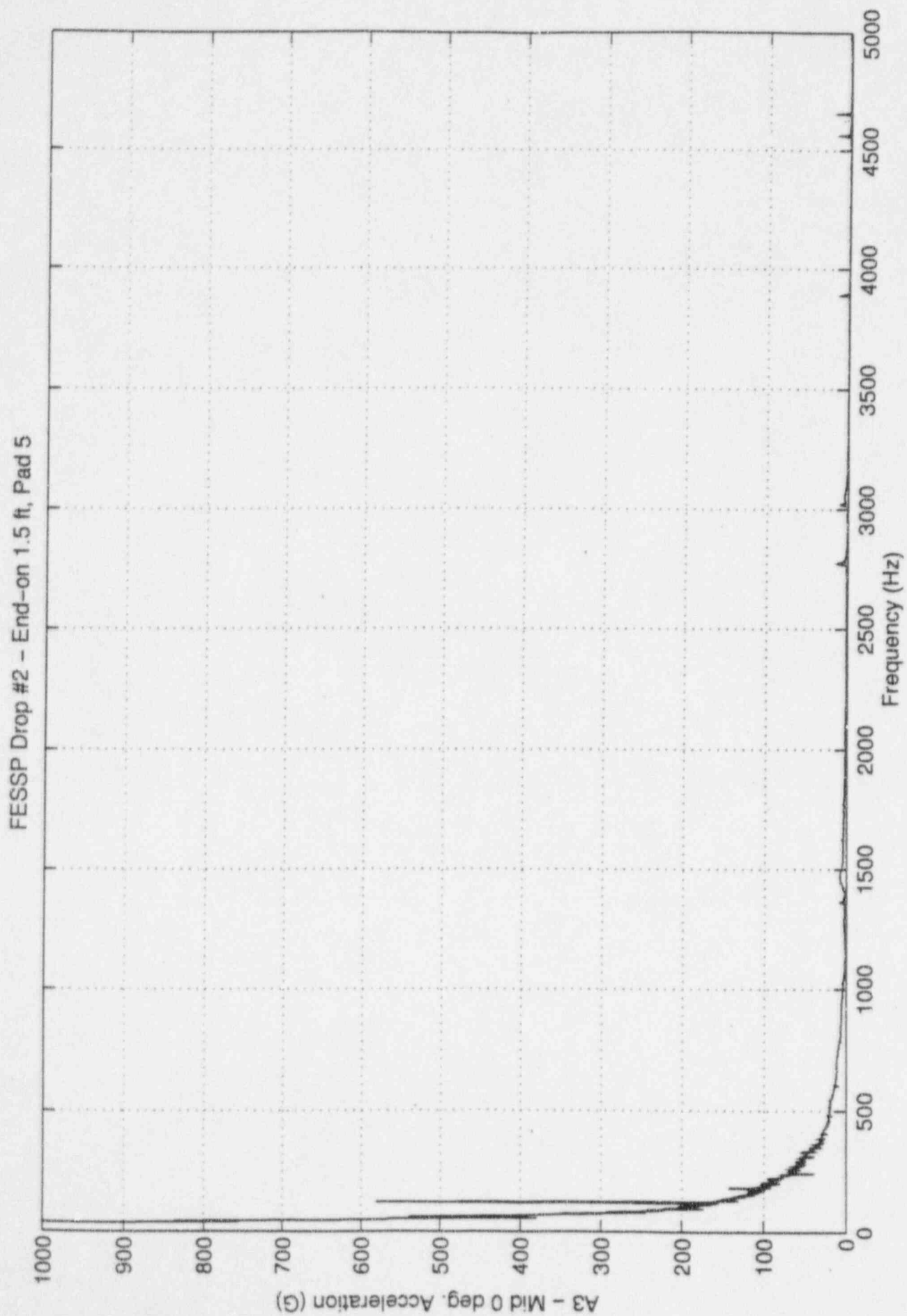
FESSP Drop #2 - End-on 1.5 ft, Pad 5 - Unfiltered

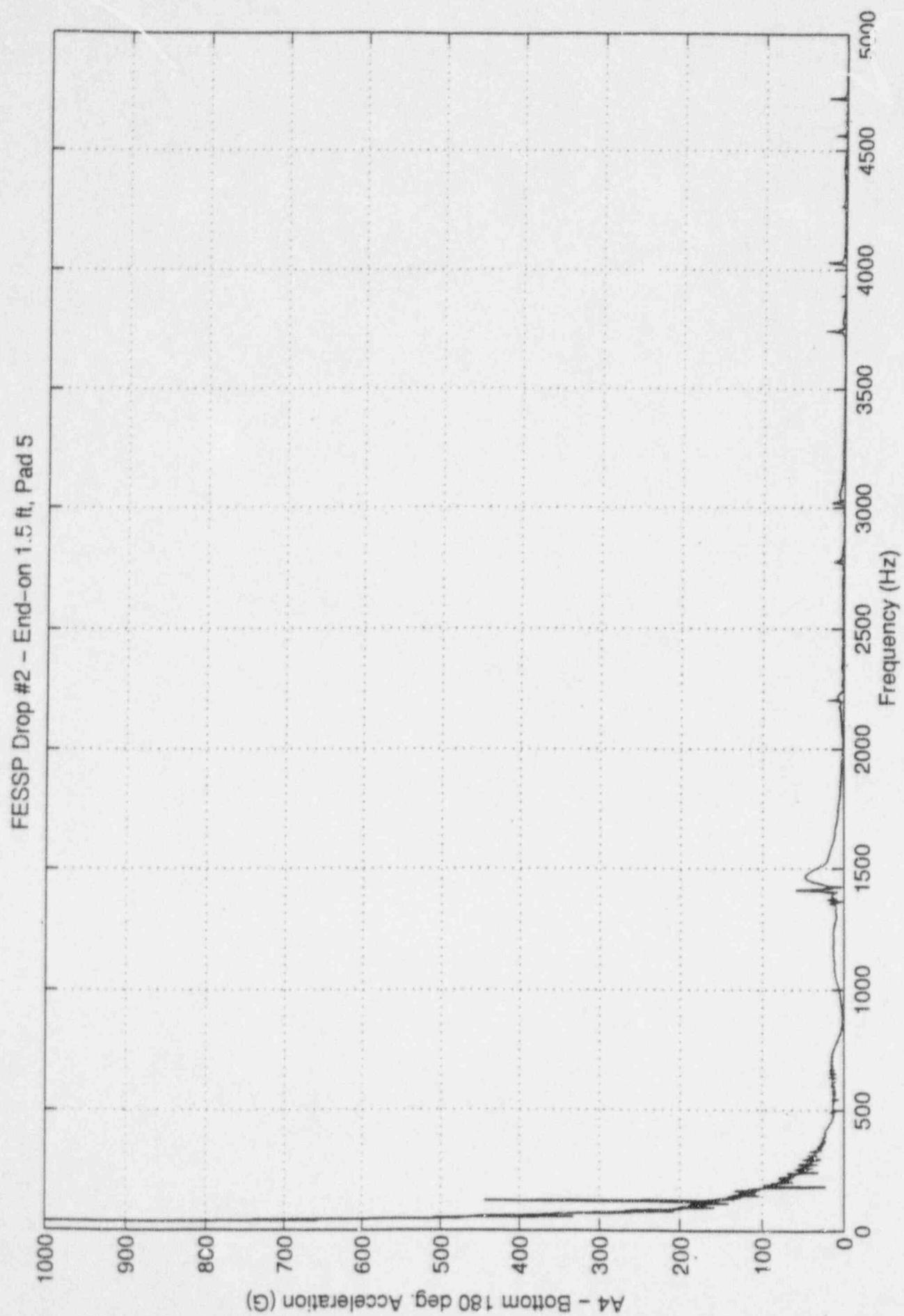


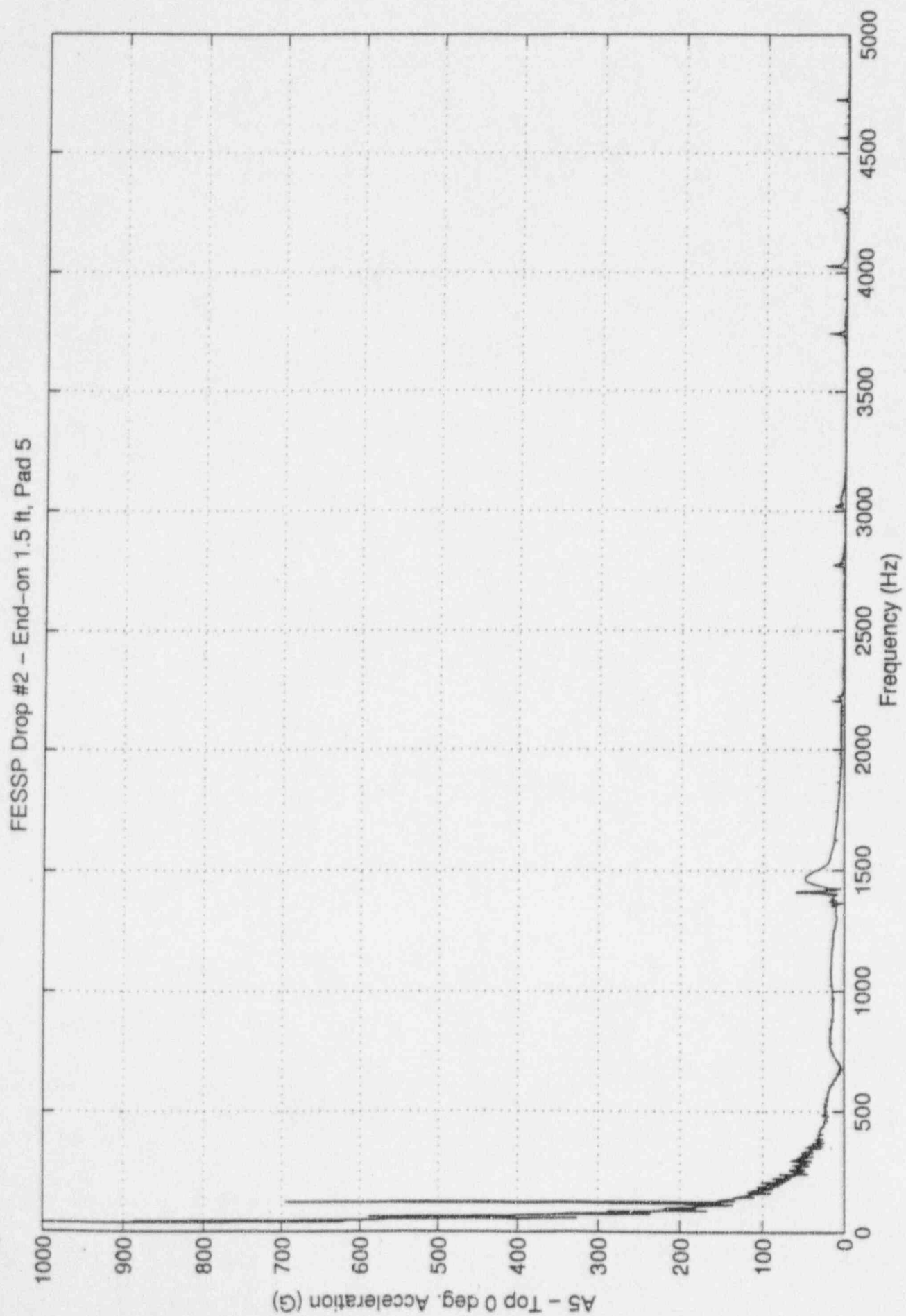


FESSP Drop #2 - End-on 1.5 ft, Pad 5

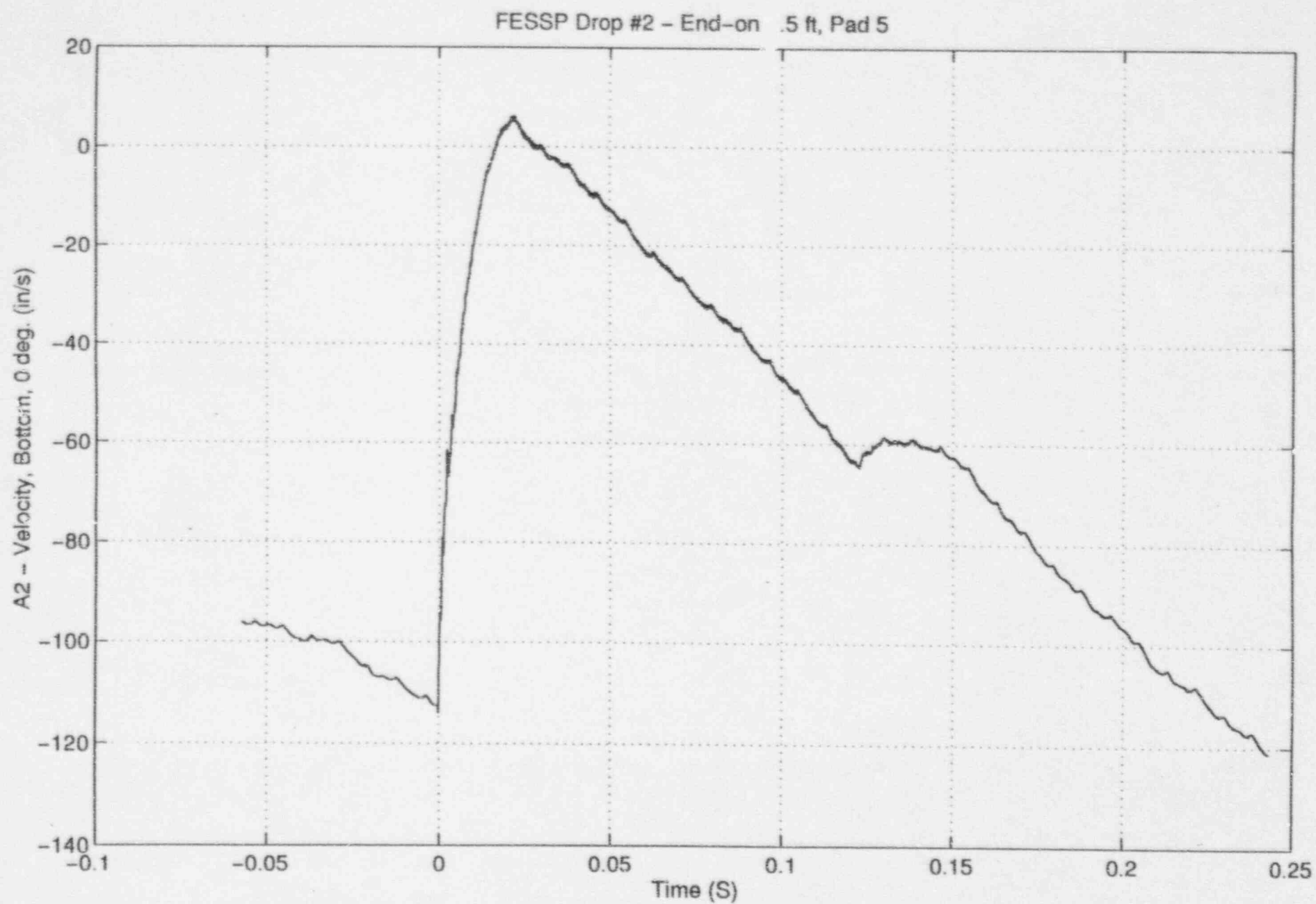




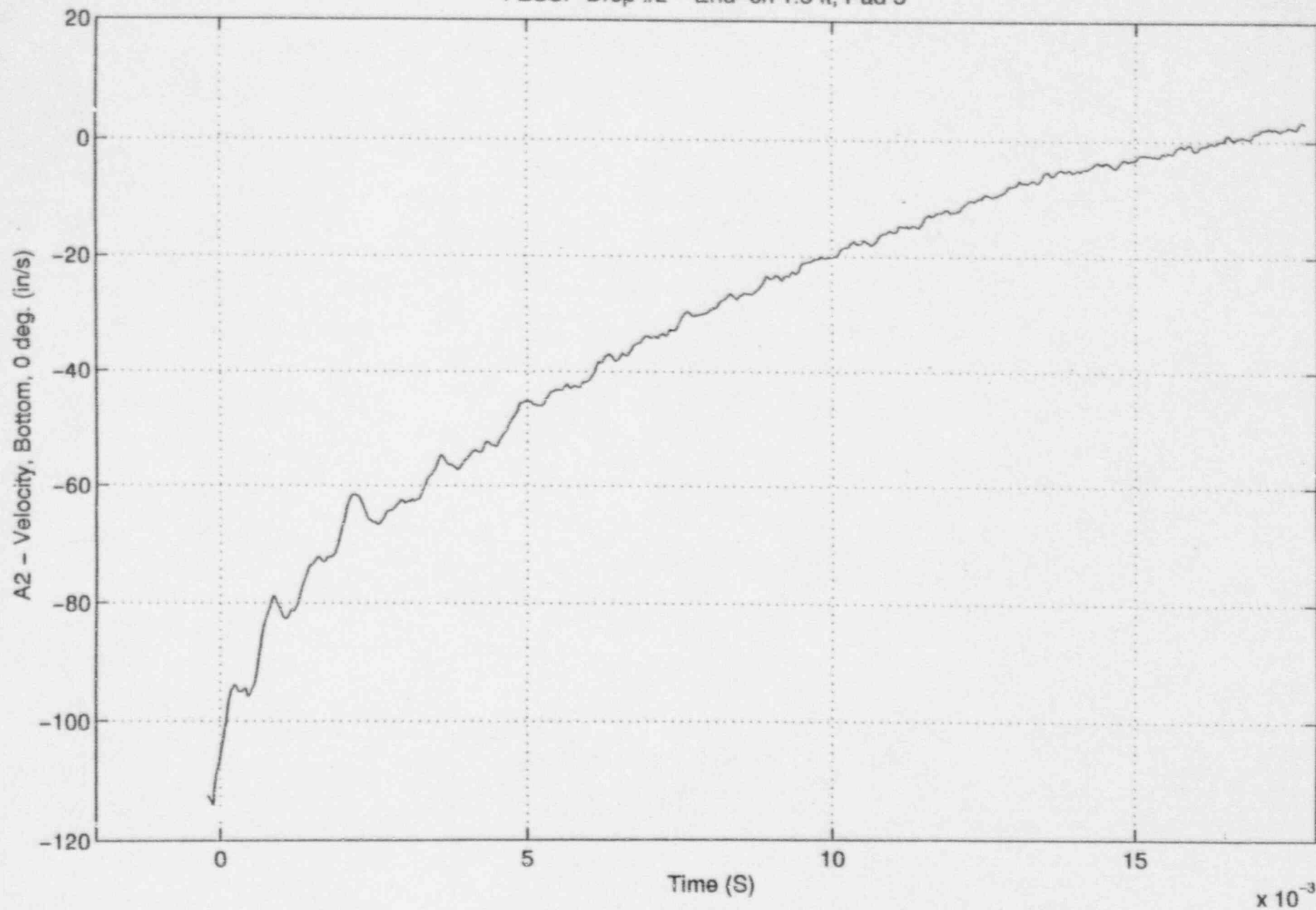


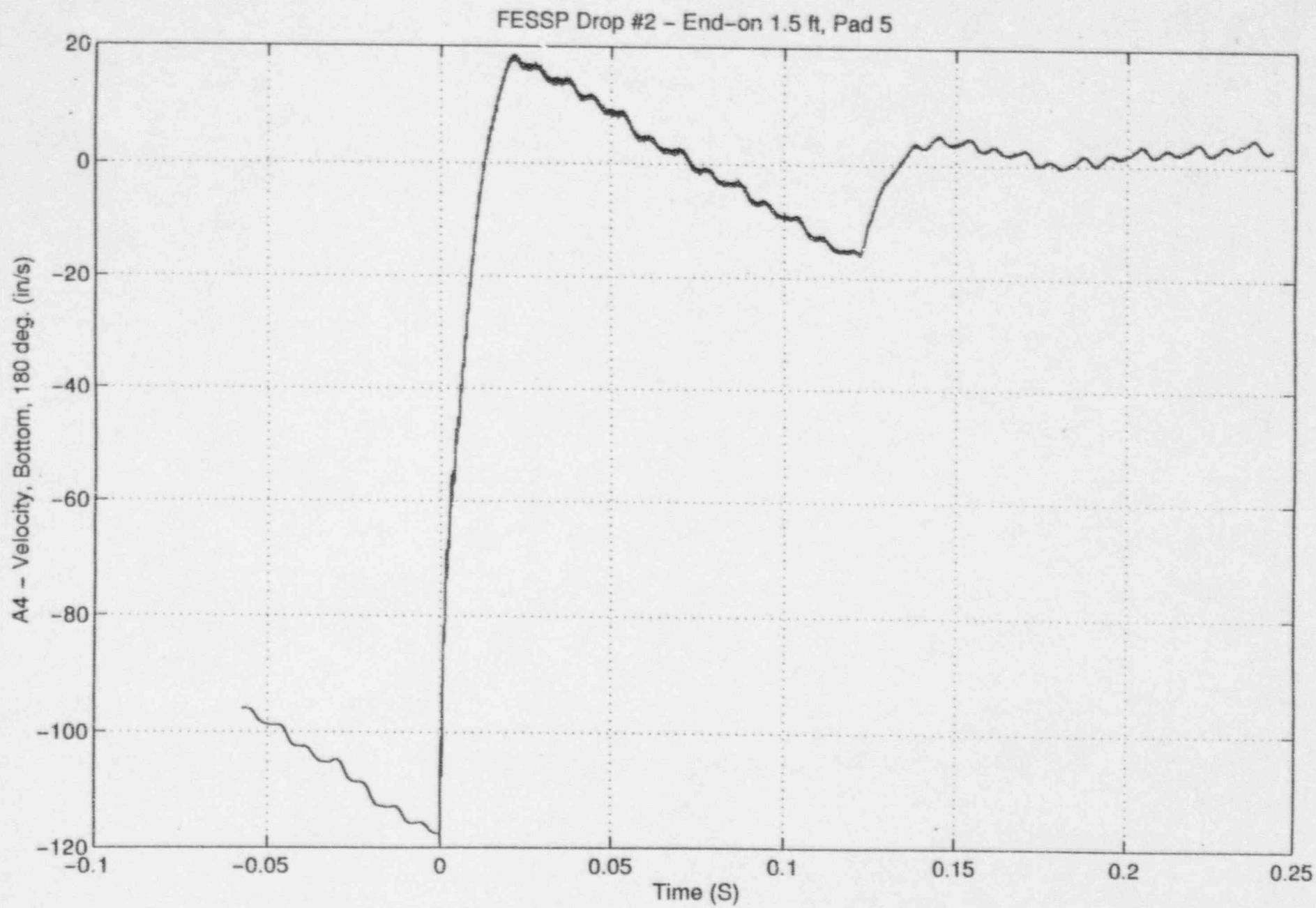




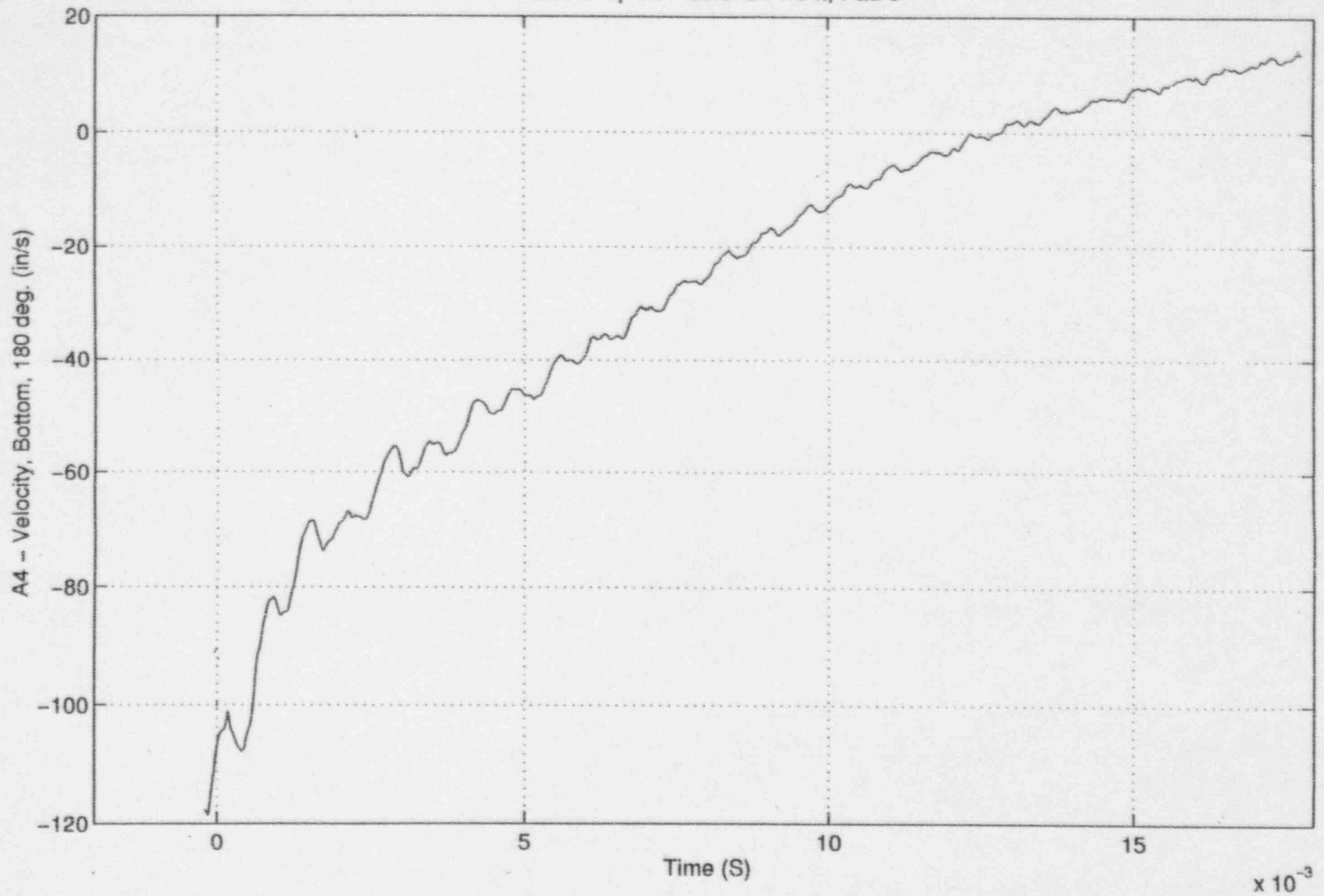


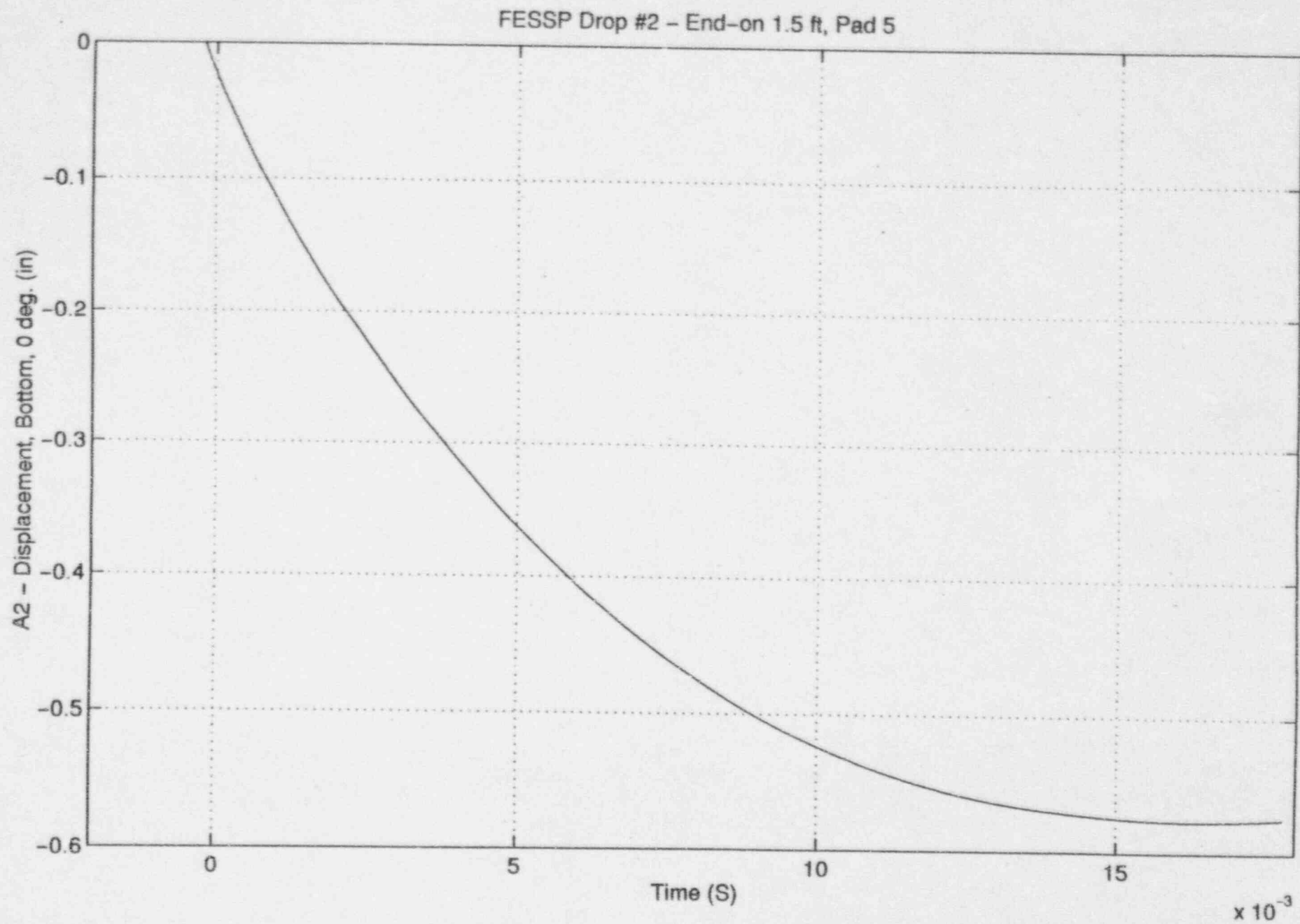
FESSP Drop #2 - End-on 1.5 ft, Pad 5



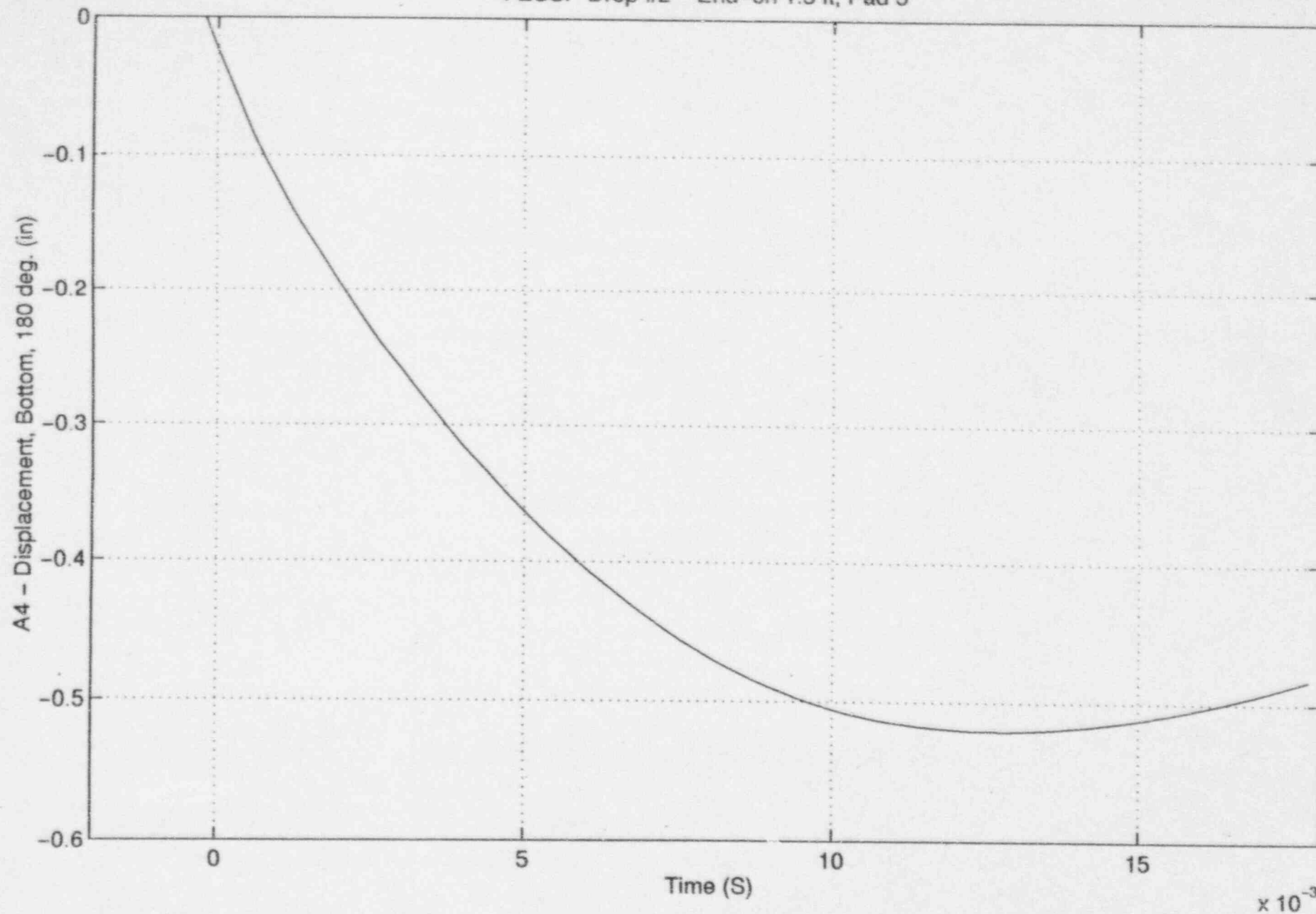


FESSP Drop #2 - End-on 1.5 ft, Pad 5

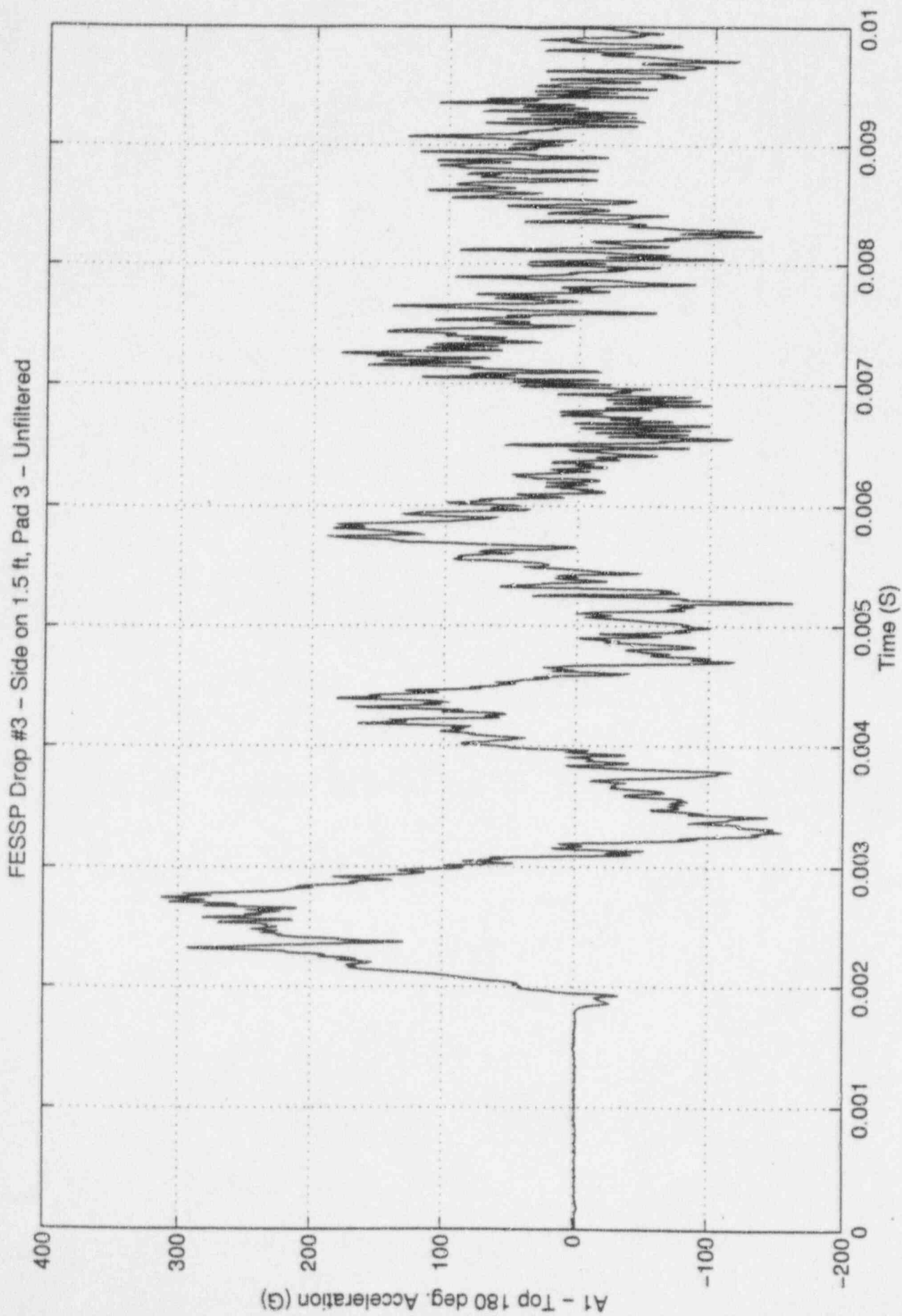




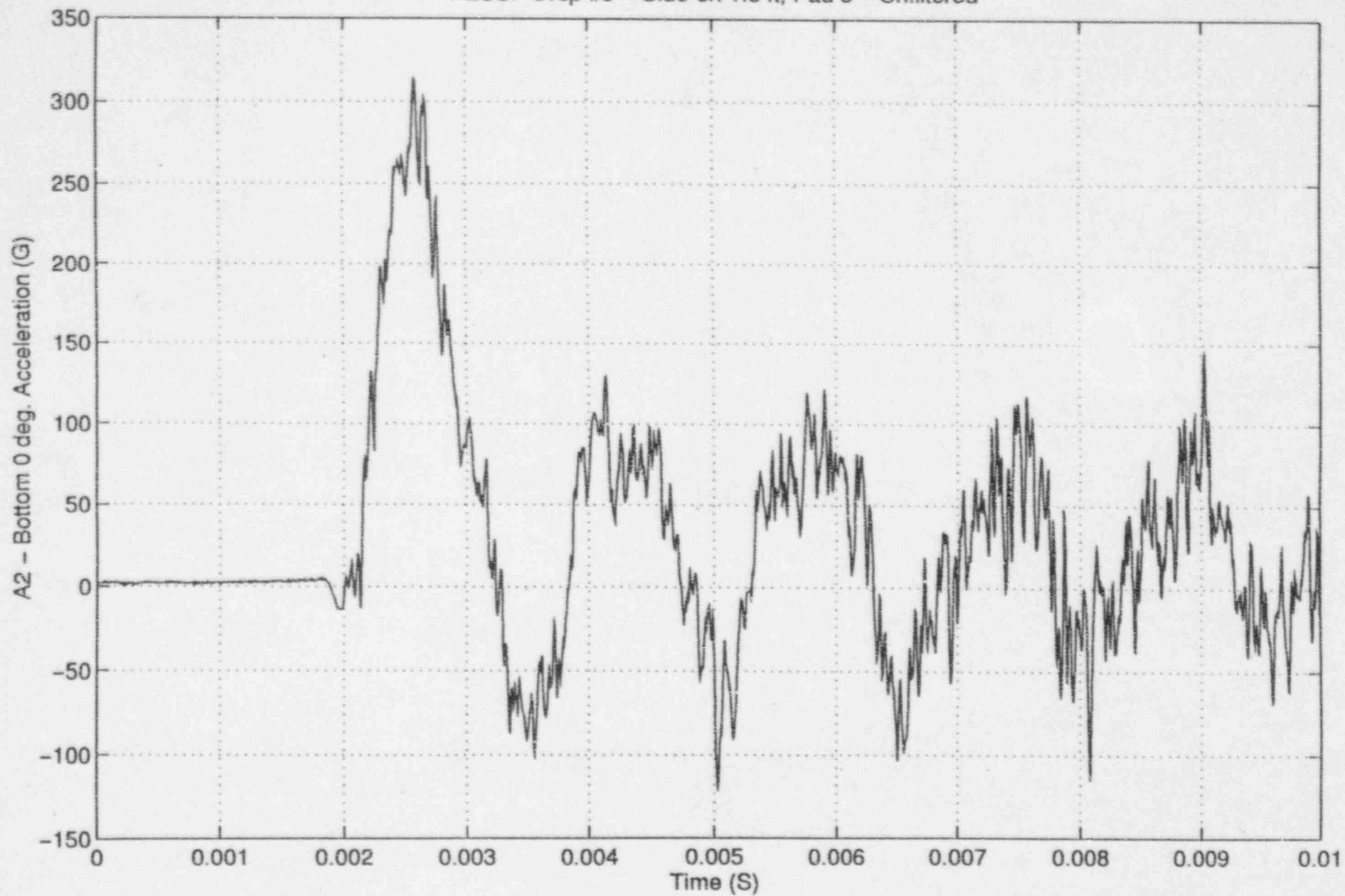
FESSP Drop #2 - End-on 1.5 ft, Pad 5

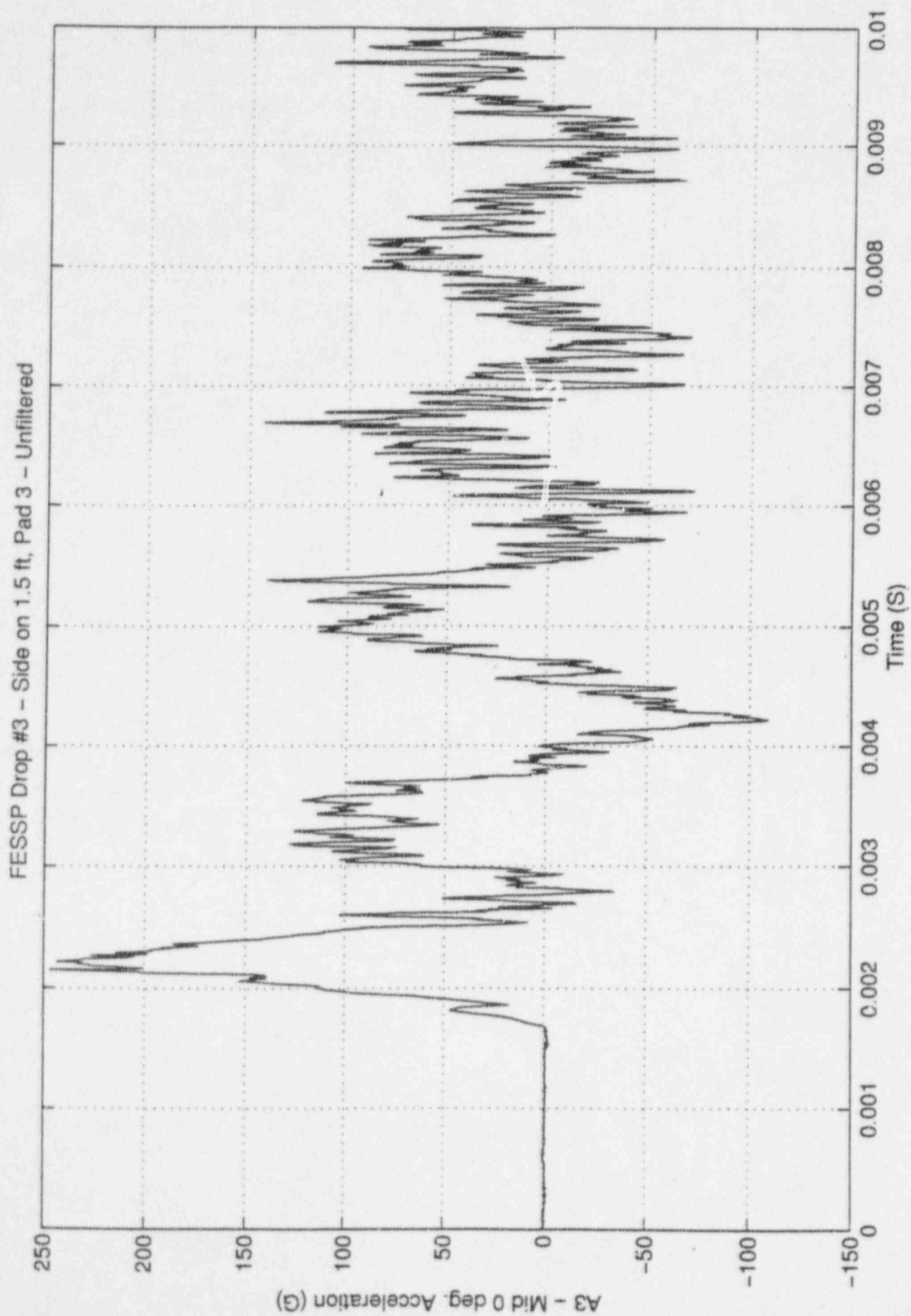




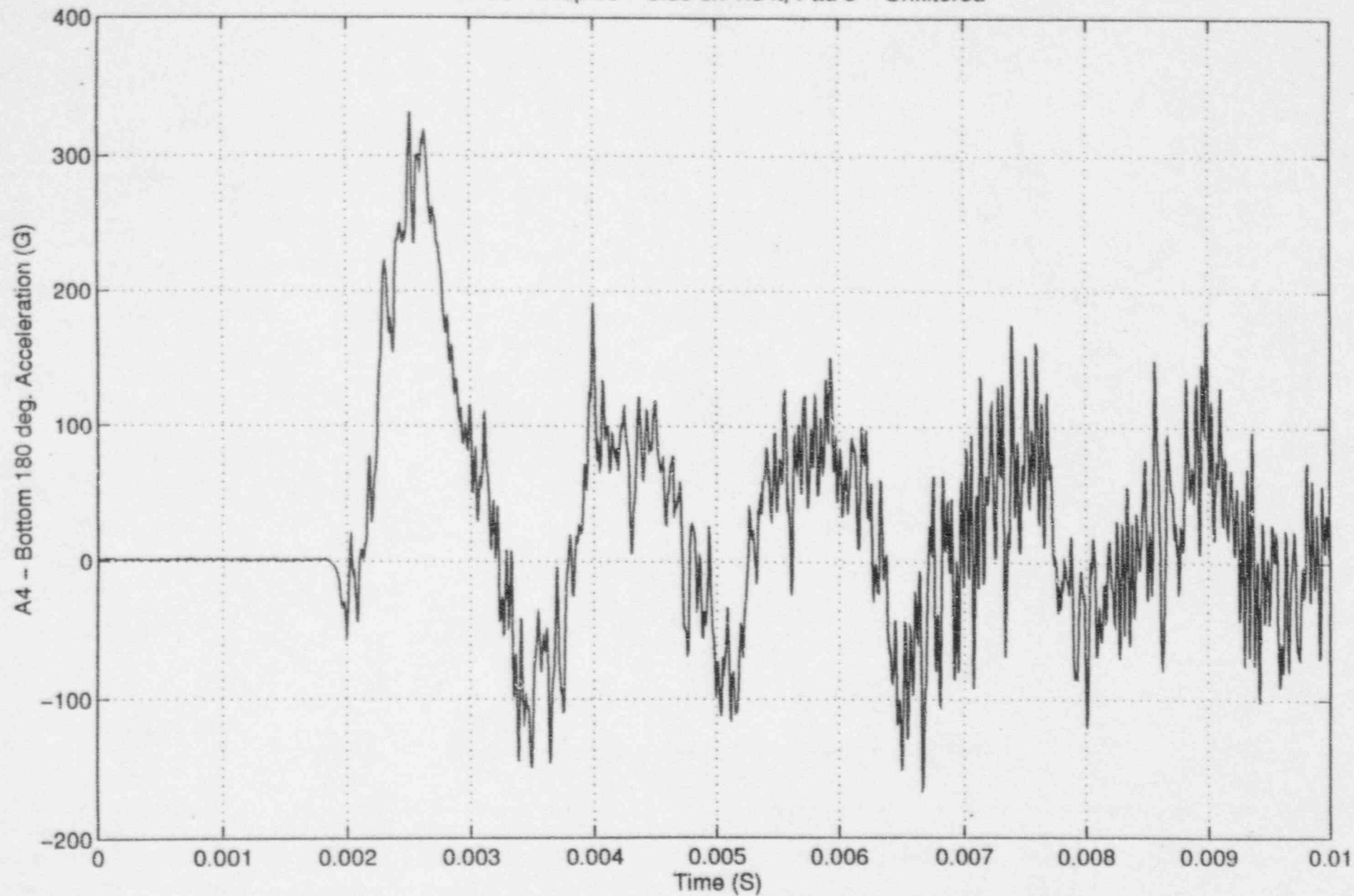


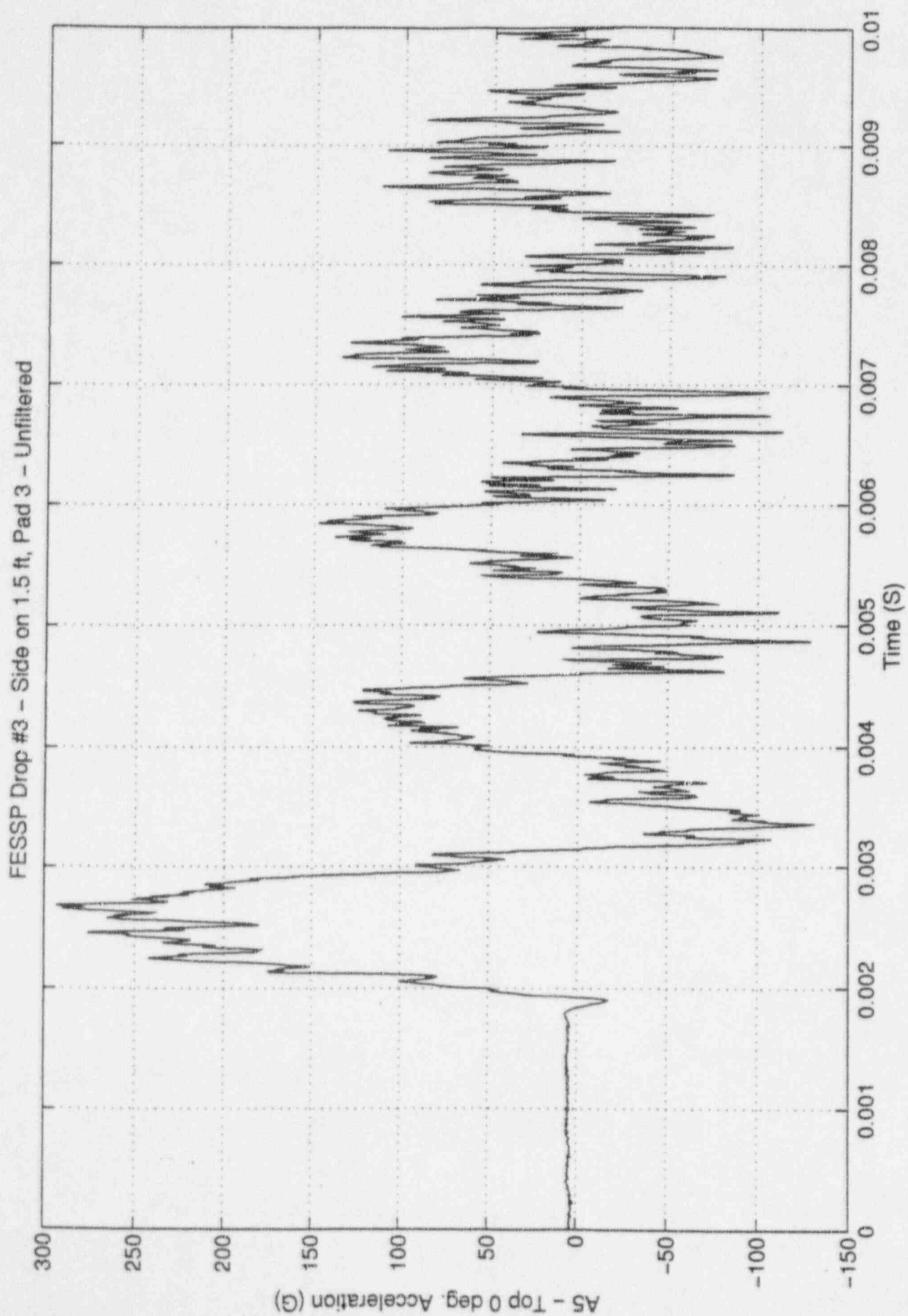
FESSP Drop #3 - Side on 1.5 ft, Pad 3 - Unfiltered



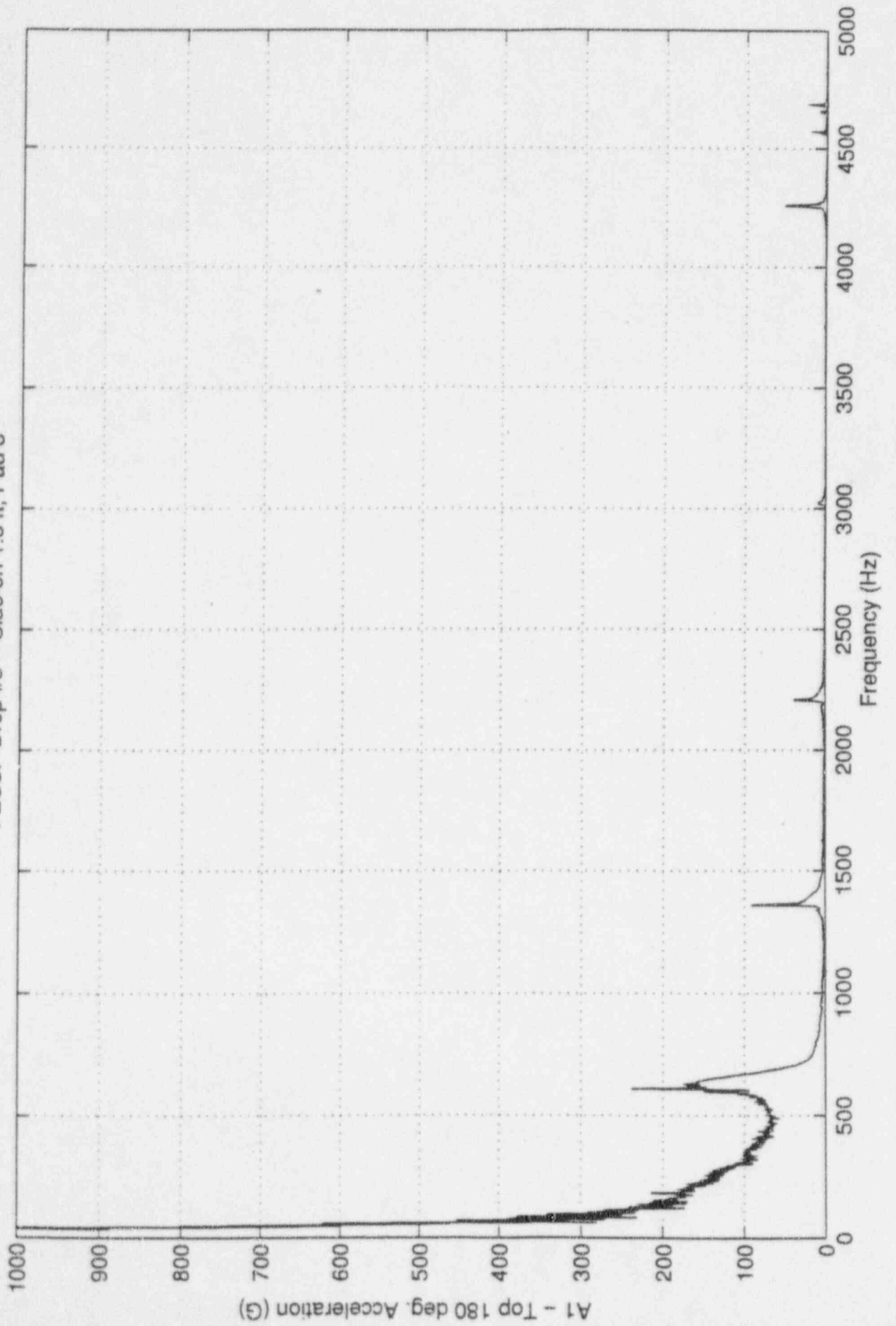


FESSP Drop #3 - Side on 1.5 ft, Pad 3 - Unfiltered

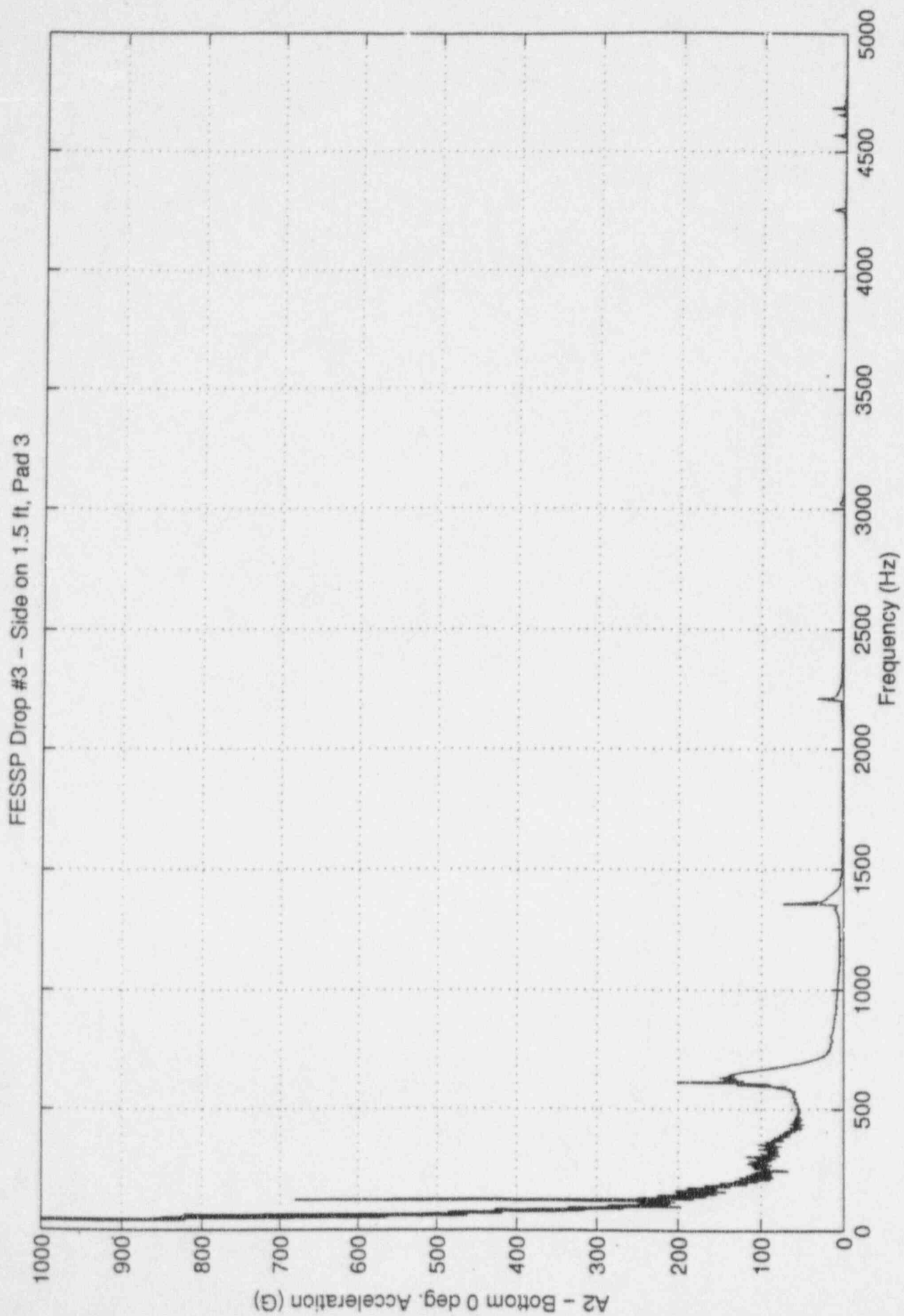




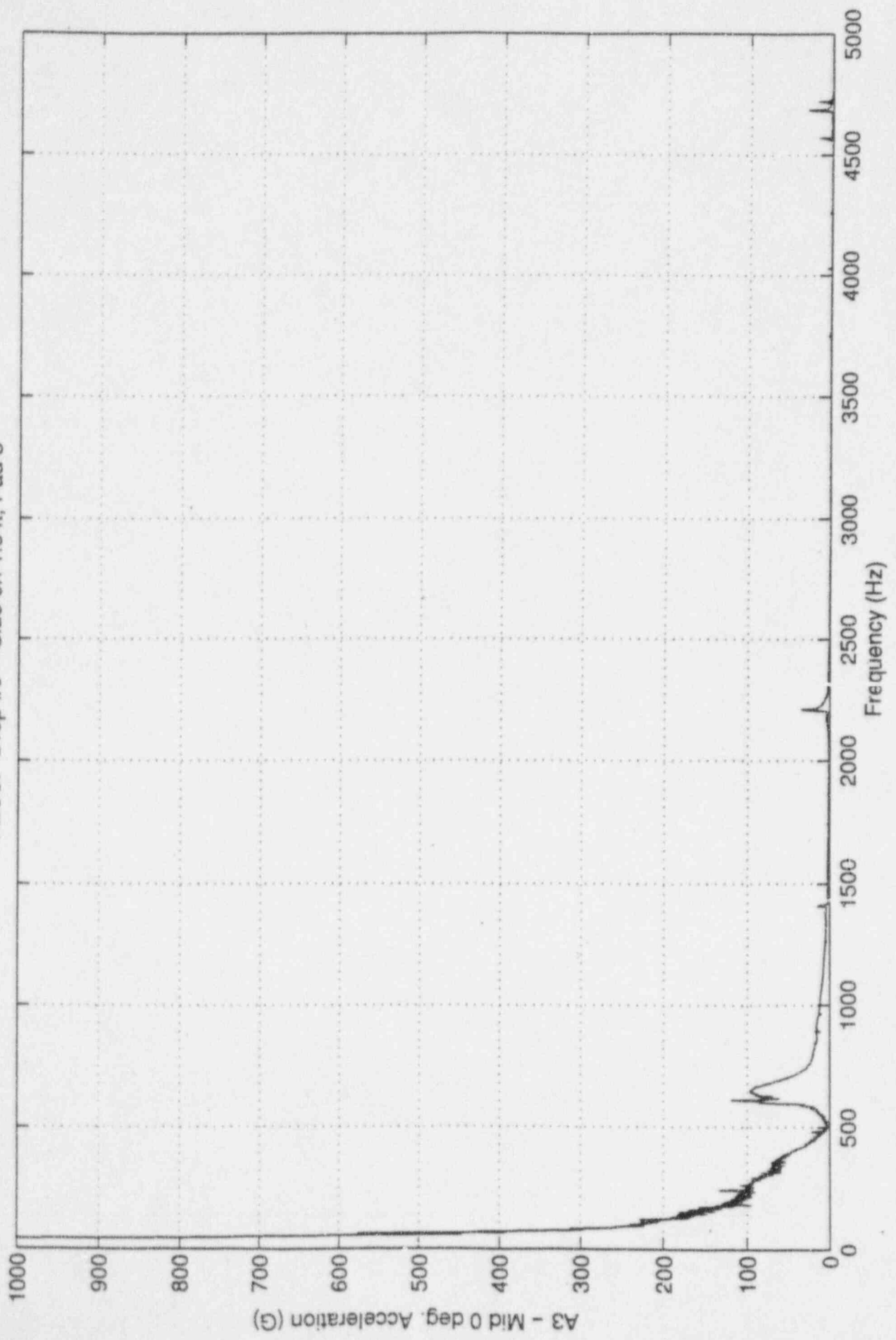
FESSP Drop #3 - Side on 1.5 ft, Pad 3

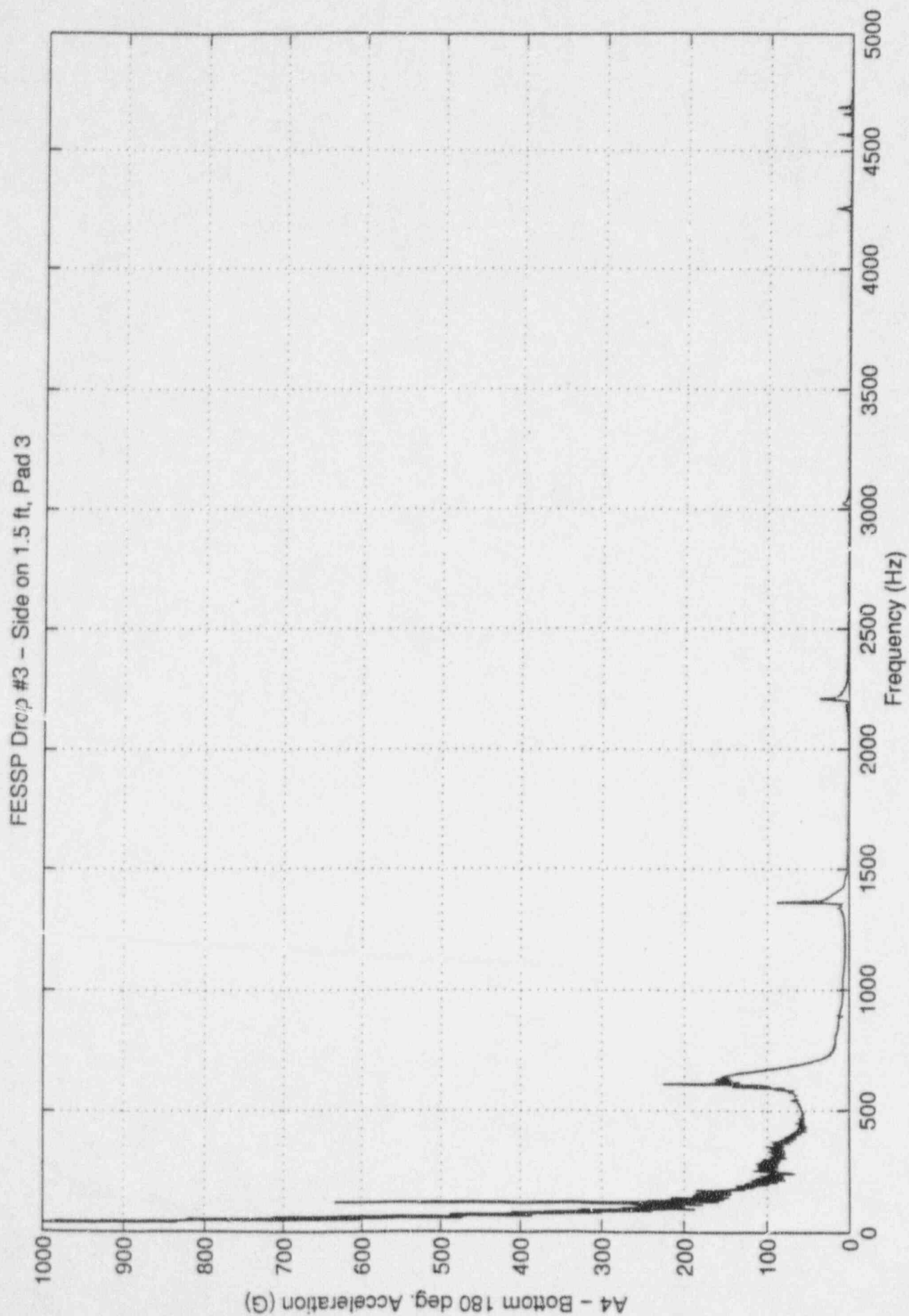




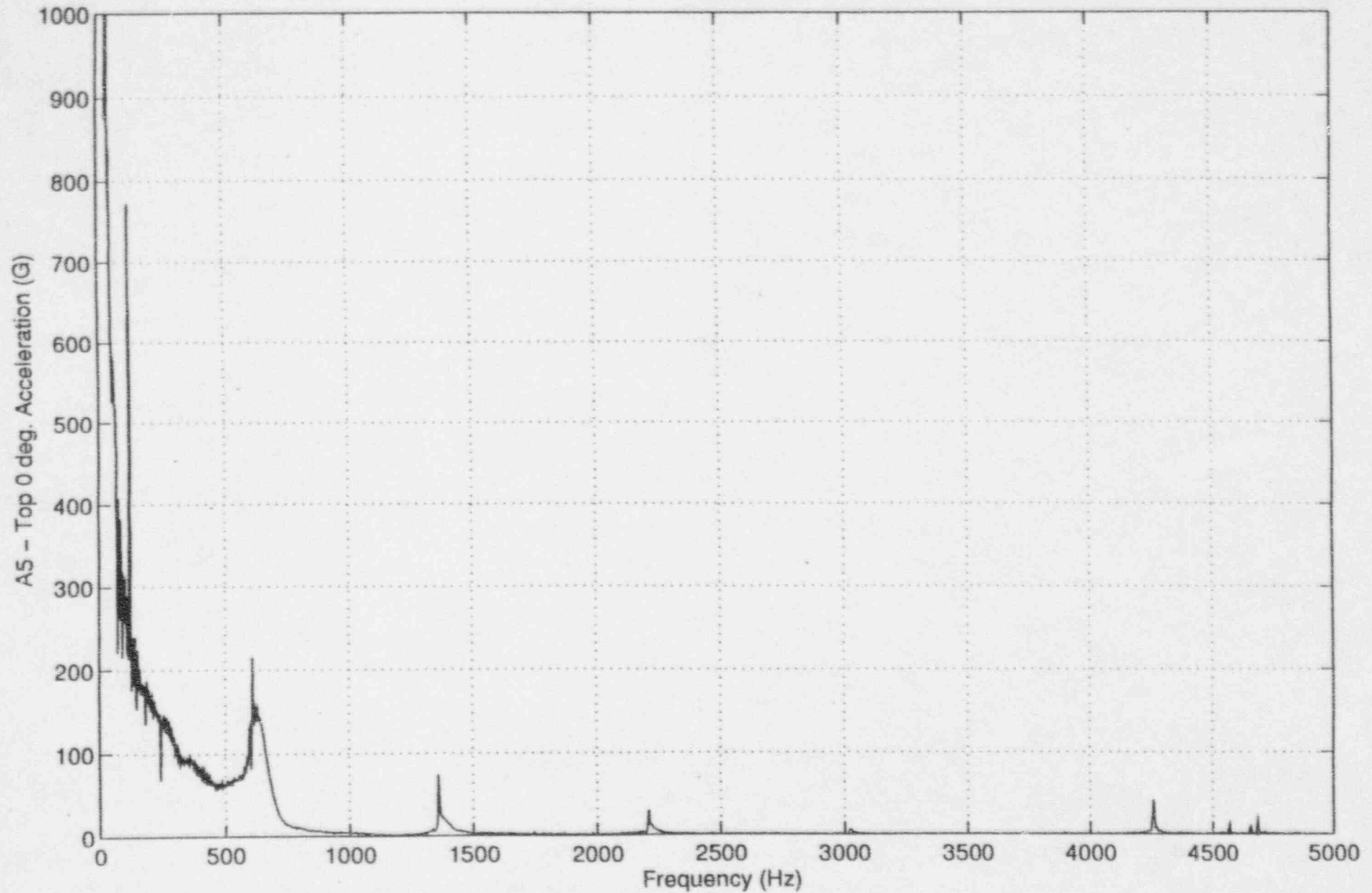


FESSP Drop #3 - Side on 1.5 ft, Pad 3

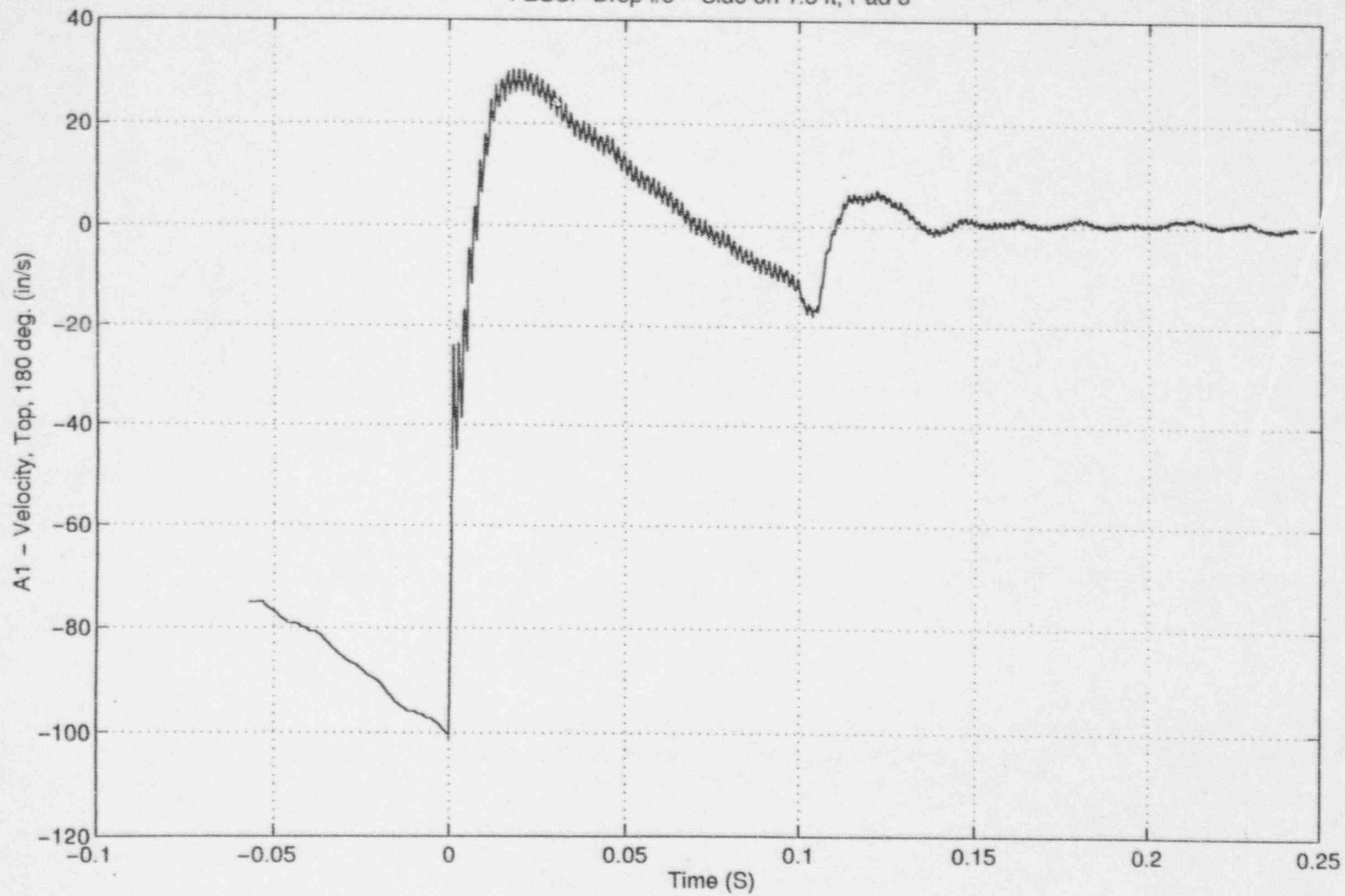




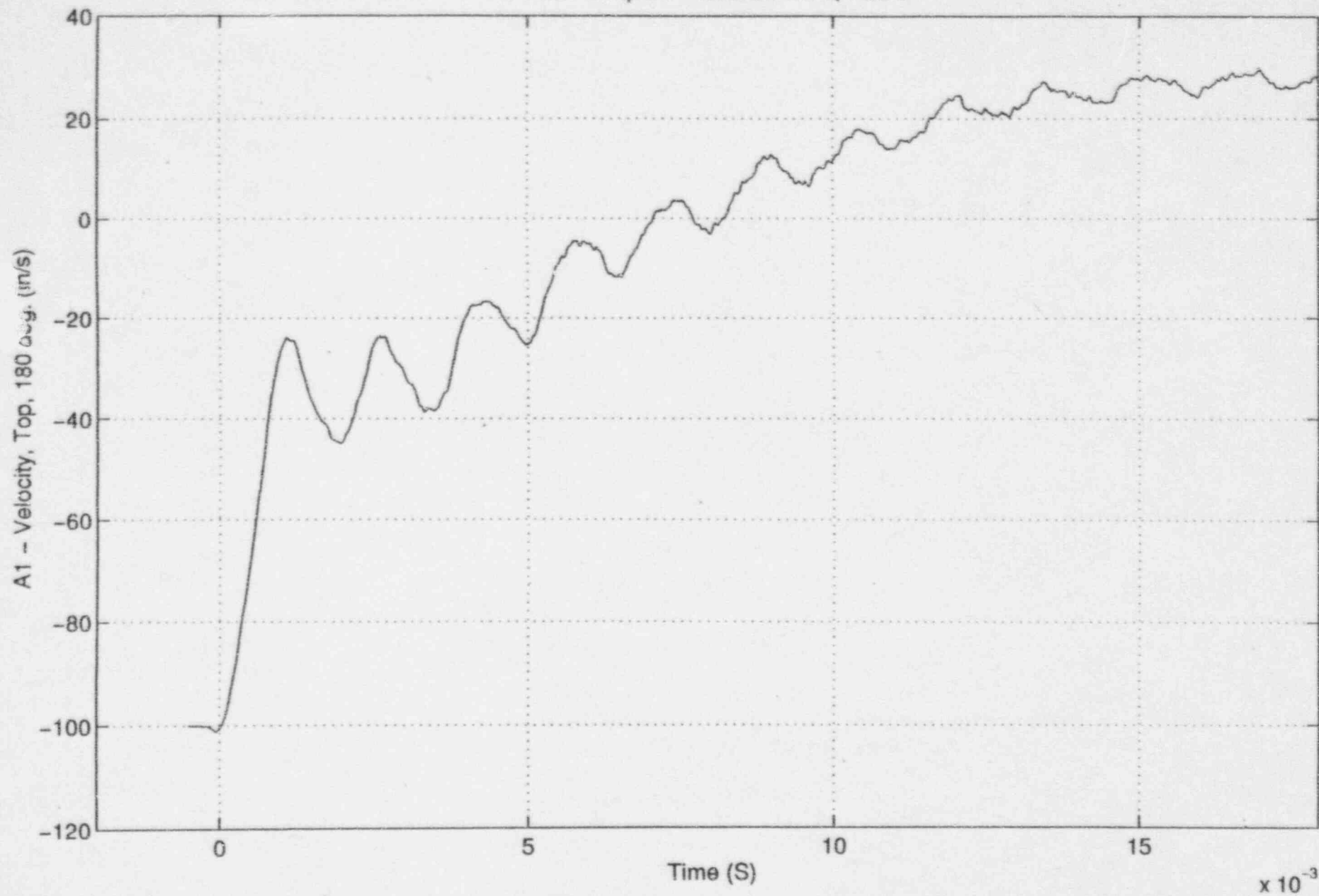
FESSP Drop #3 - Side on 1.5 ft, Pad 3



FESSP Drop #3 - Side on 1.5 ft, Pad 3

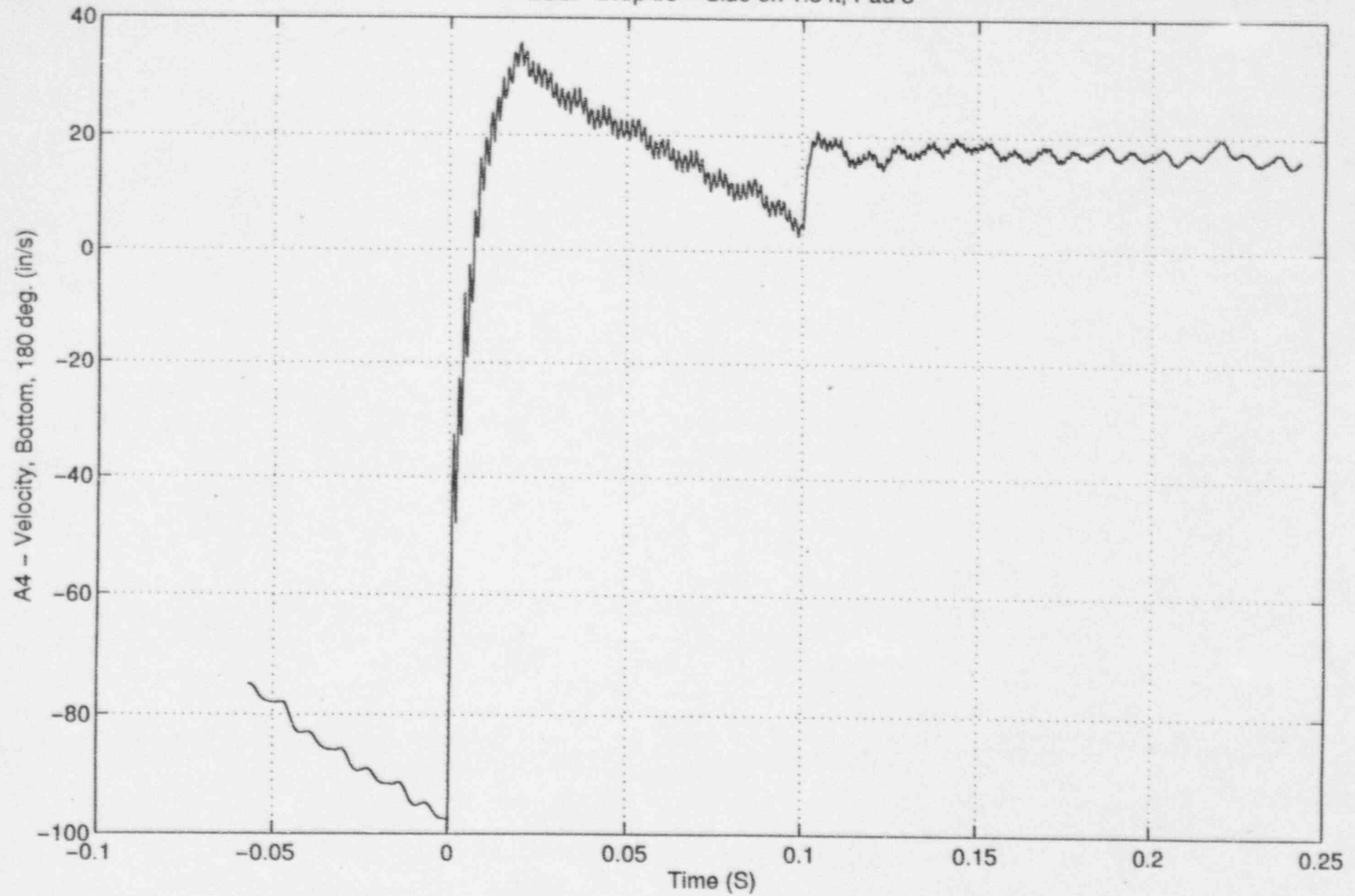


FESSP Drop #3 - Side on 1.5 ft, Pad 3

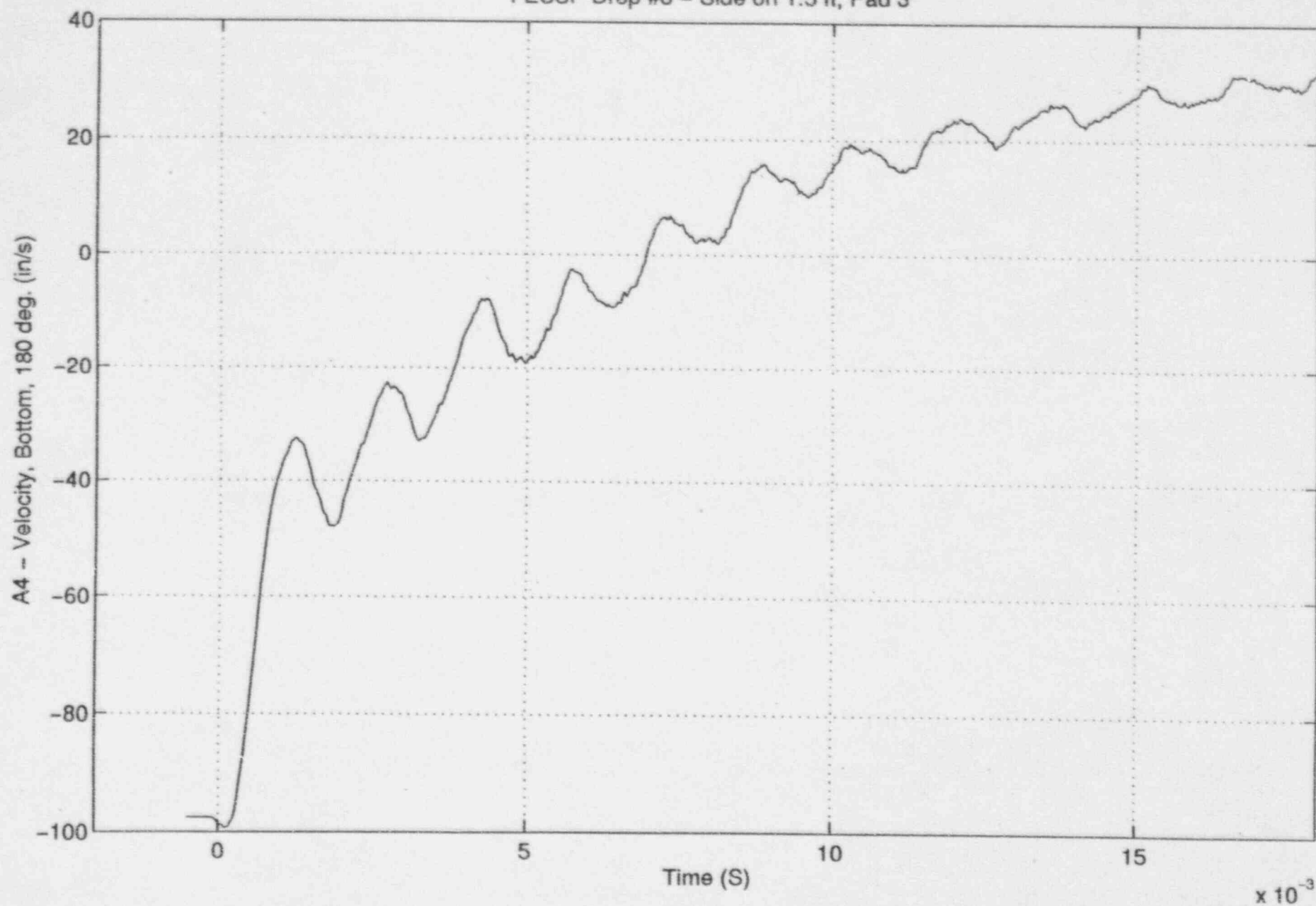




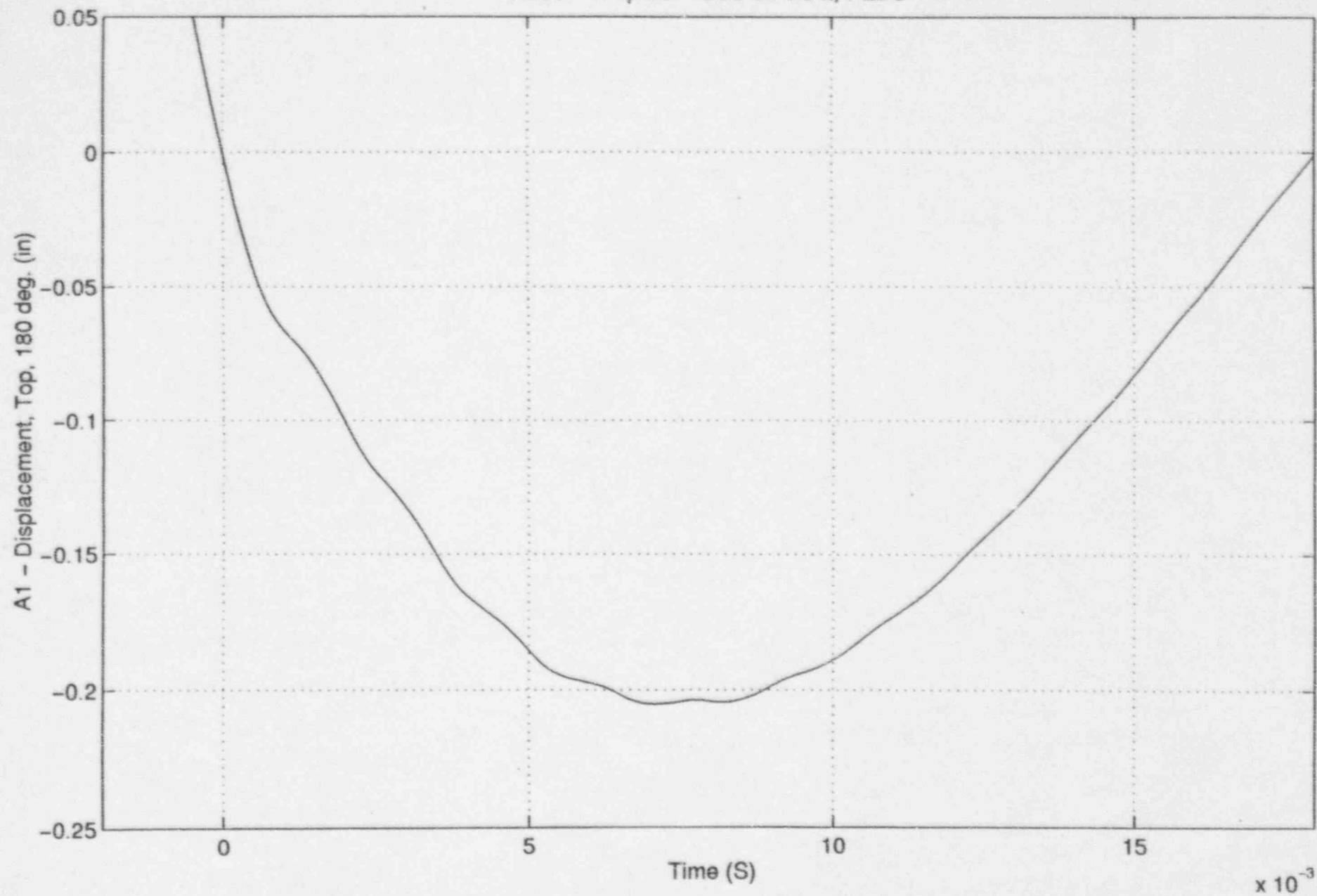
FESSP Drop #3 - Side on 1.5 ft, Pad 3



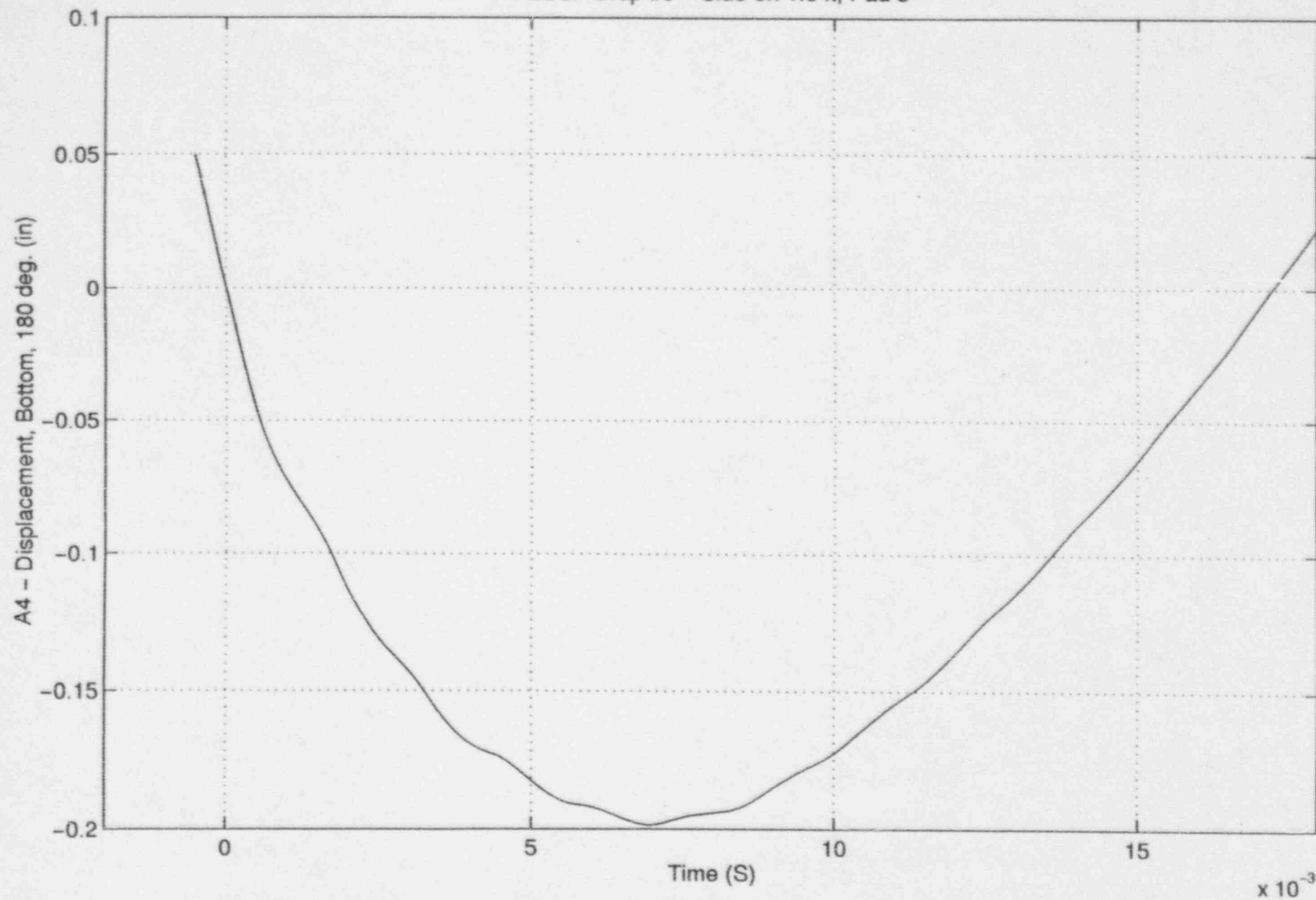
FESSP Drop #3 - Side on 1.5 ft, Pad 3



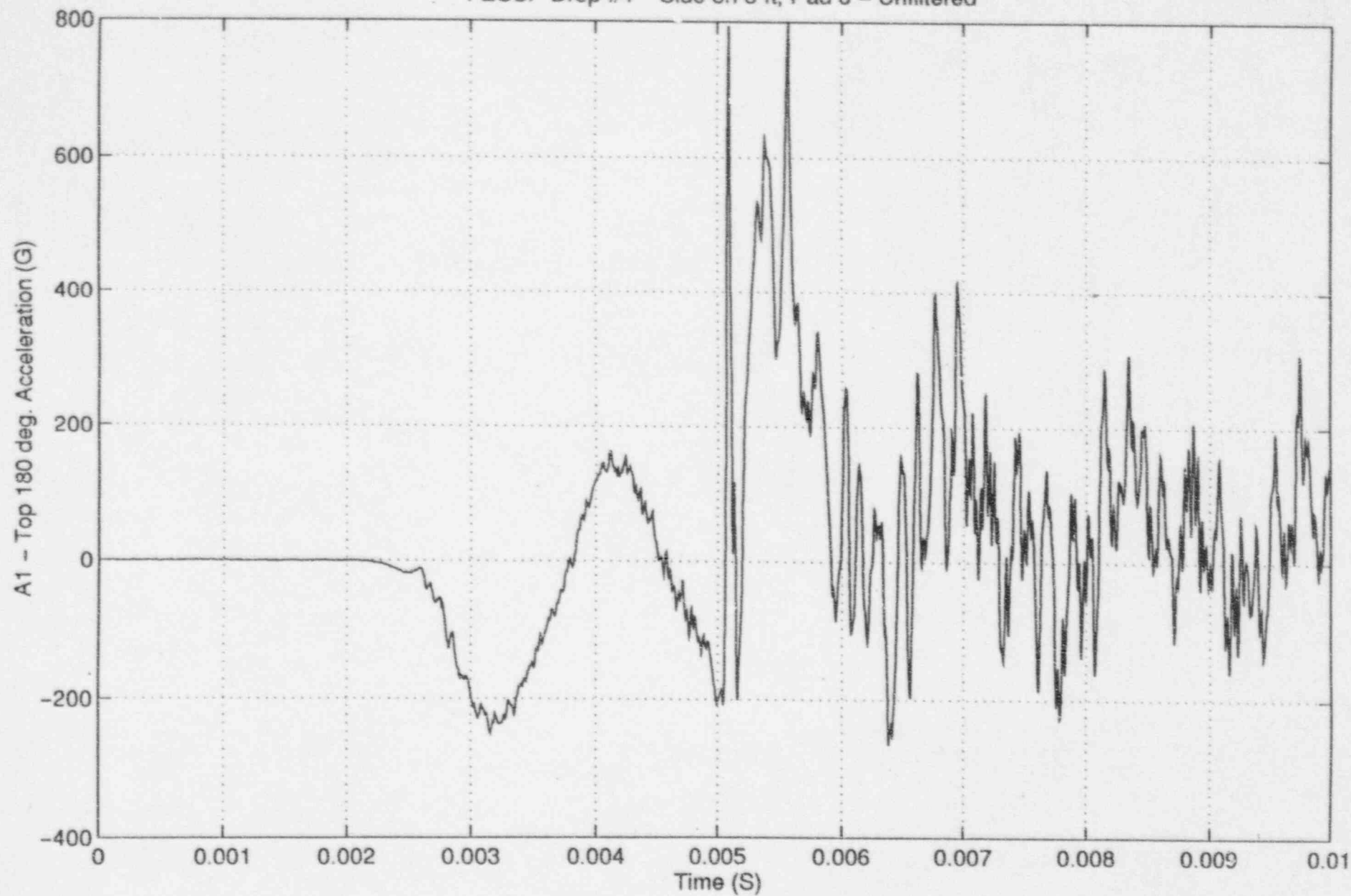
FESSP Drop #3 - Side on 1.5 ft, Pad 3



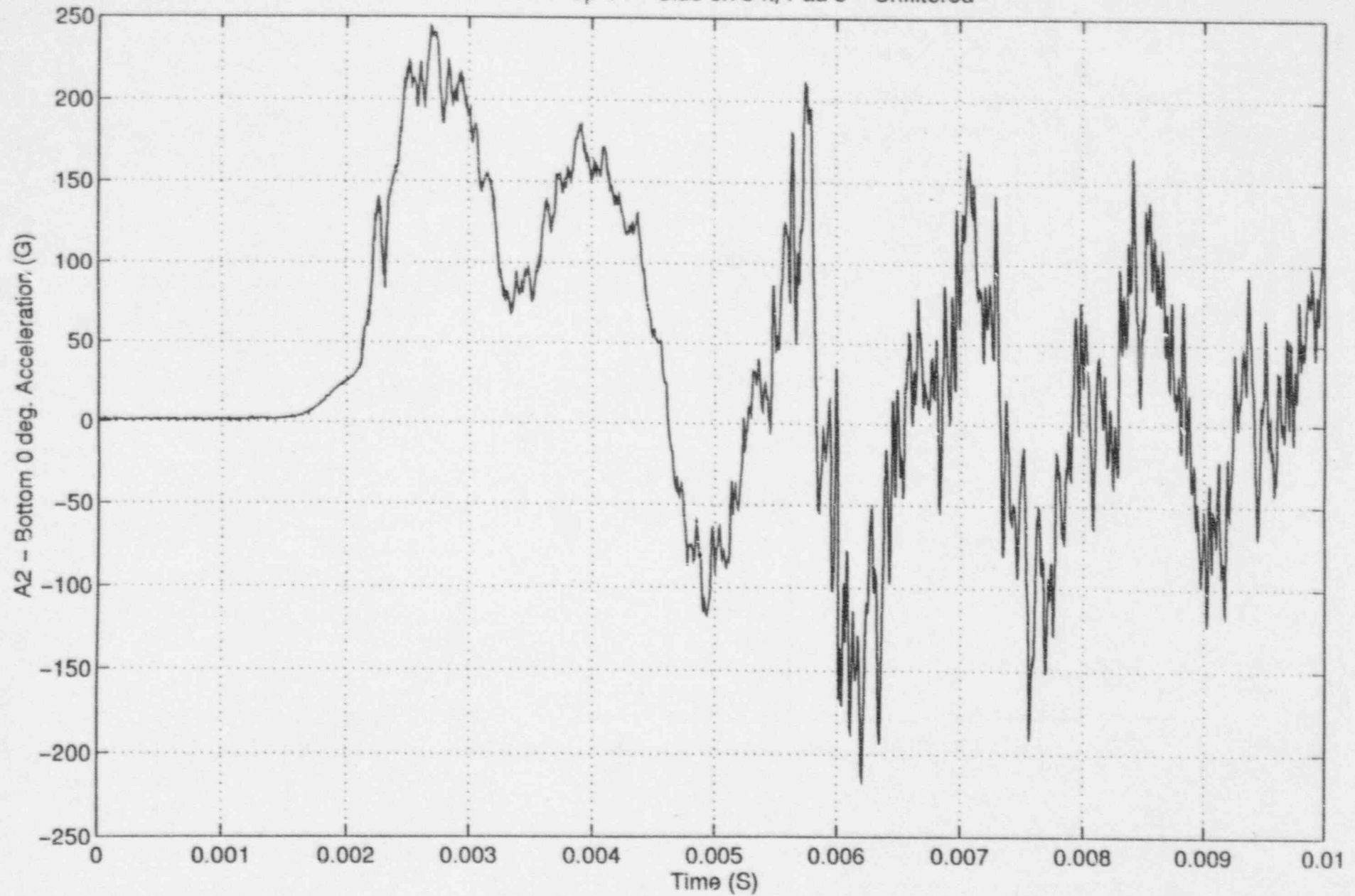
FESSP Drop #3 - Side on 1.5 ft, Pad 3



FESSP Drop #4 - Side on 3 ft, Pad 3 - Unfiltered

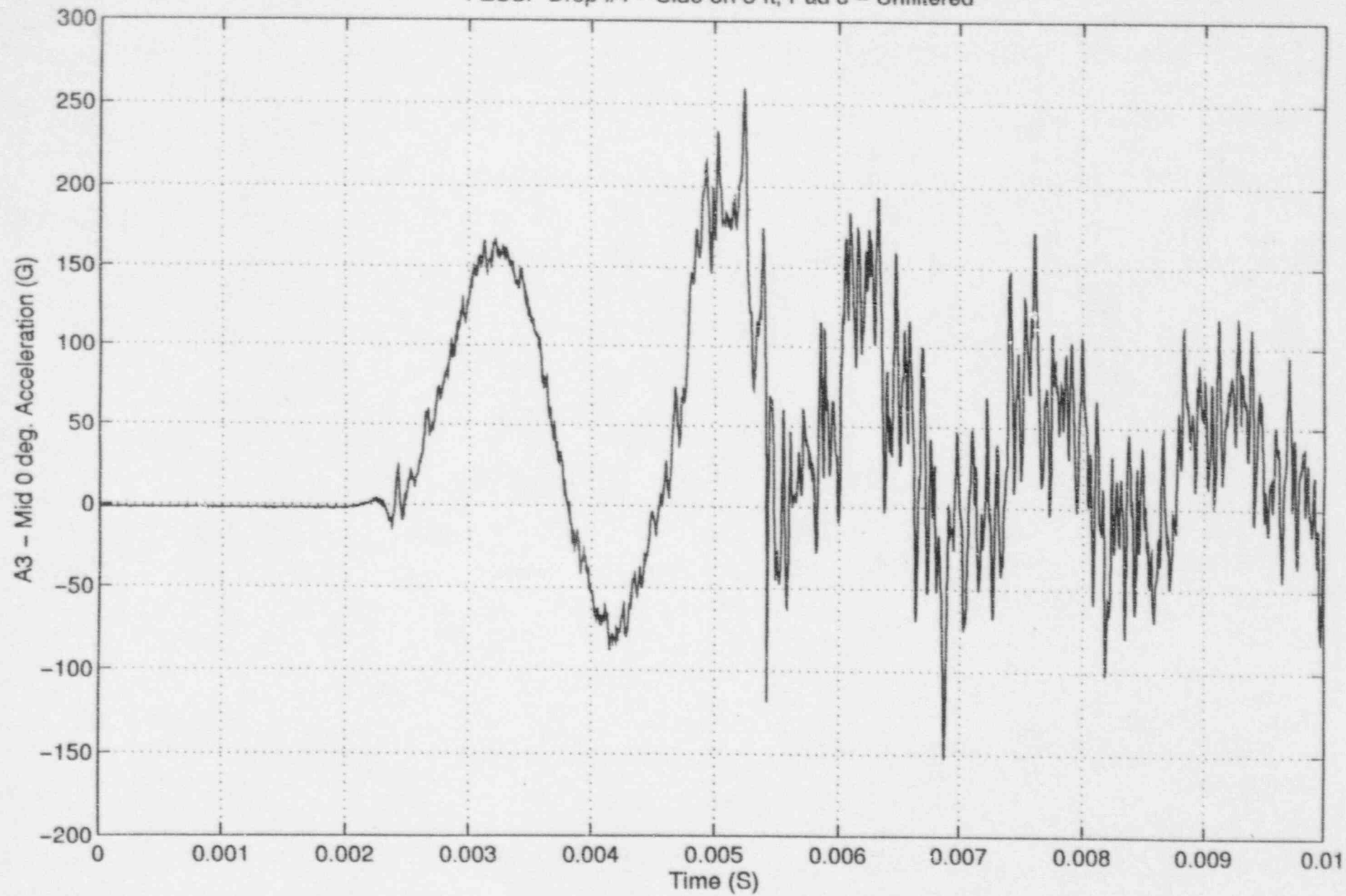


FESSP Drop #1 - Side on 3 ft, Pad 3 - Unfiltered

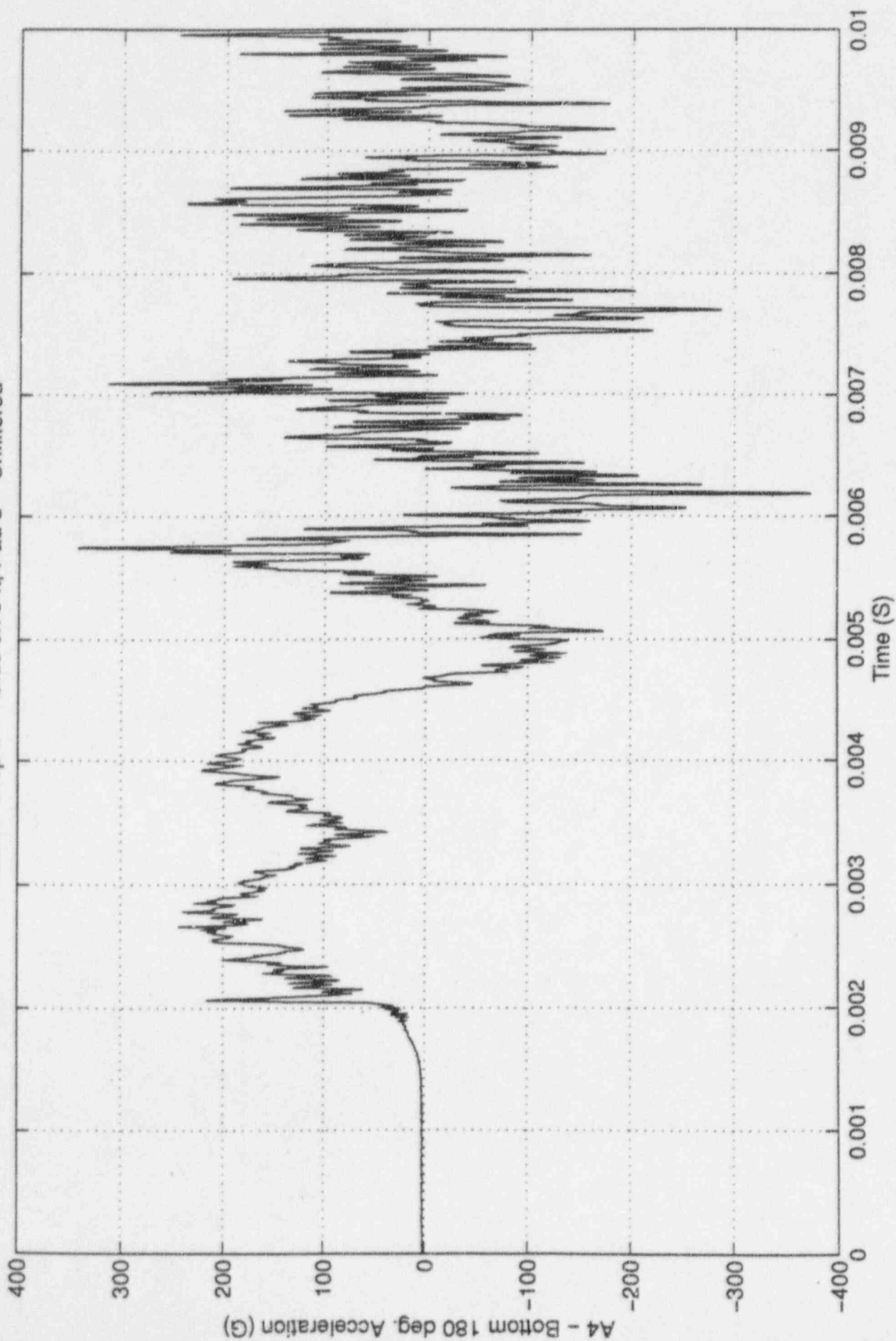


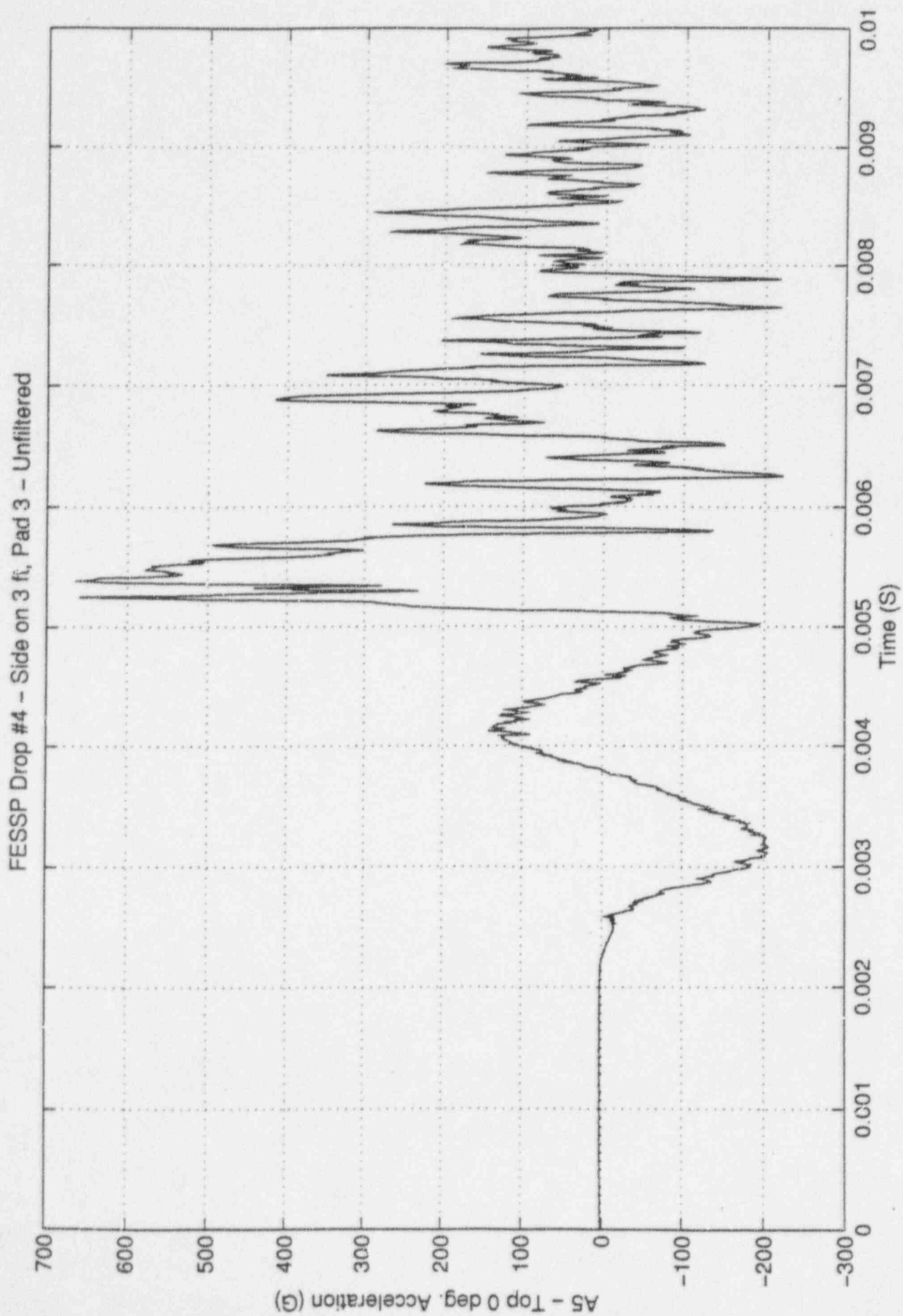


FESSP Drop #4 - Side on 3 ft, Pad 3 - Unfiltered

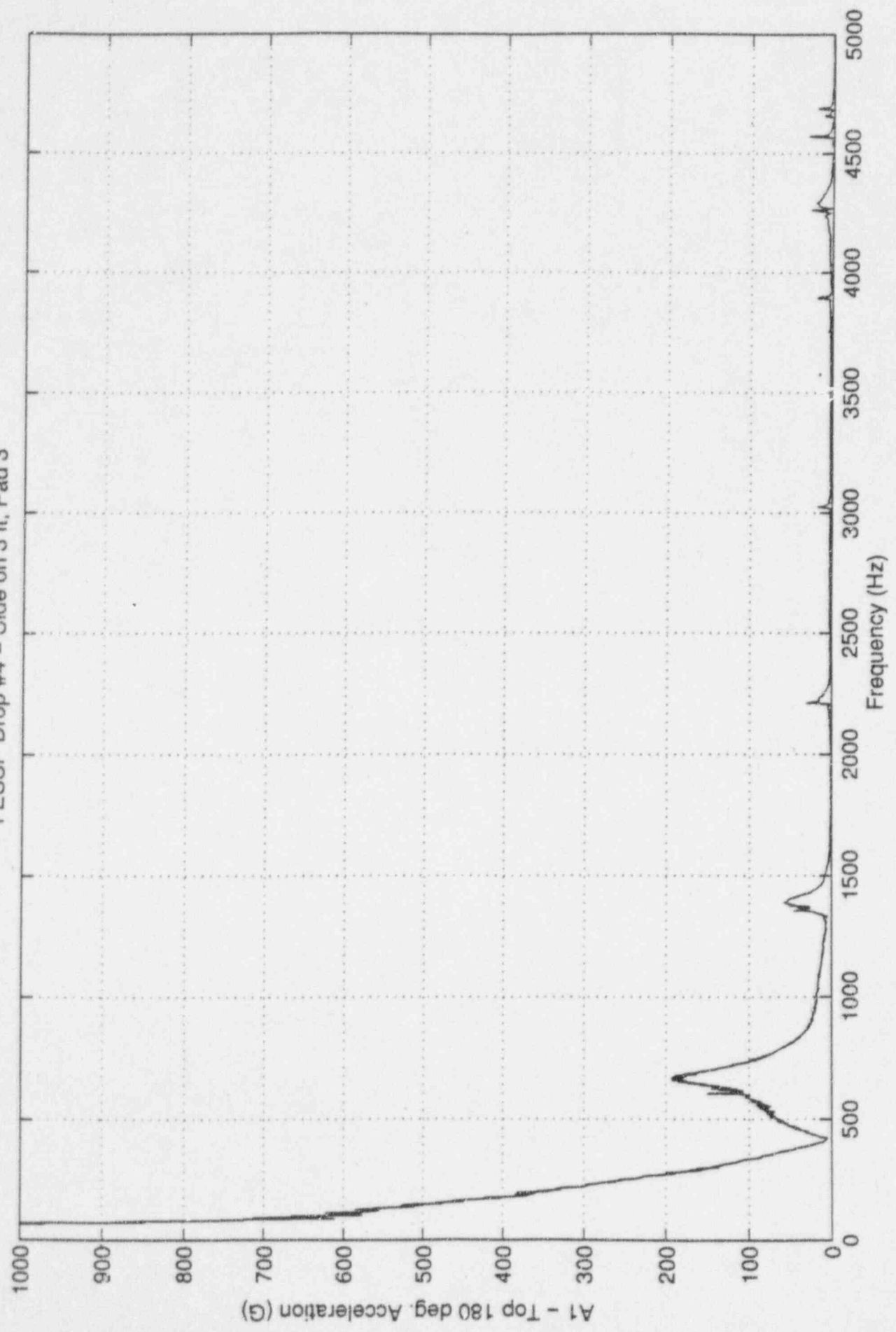


FESSP Drop #4 - Side on 3 ft, Pad 3 - Unfiltered

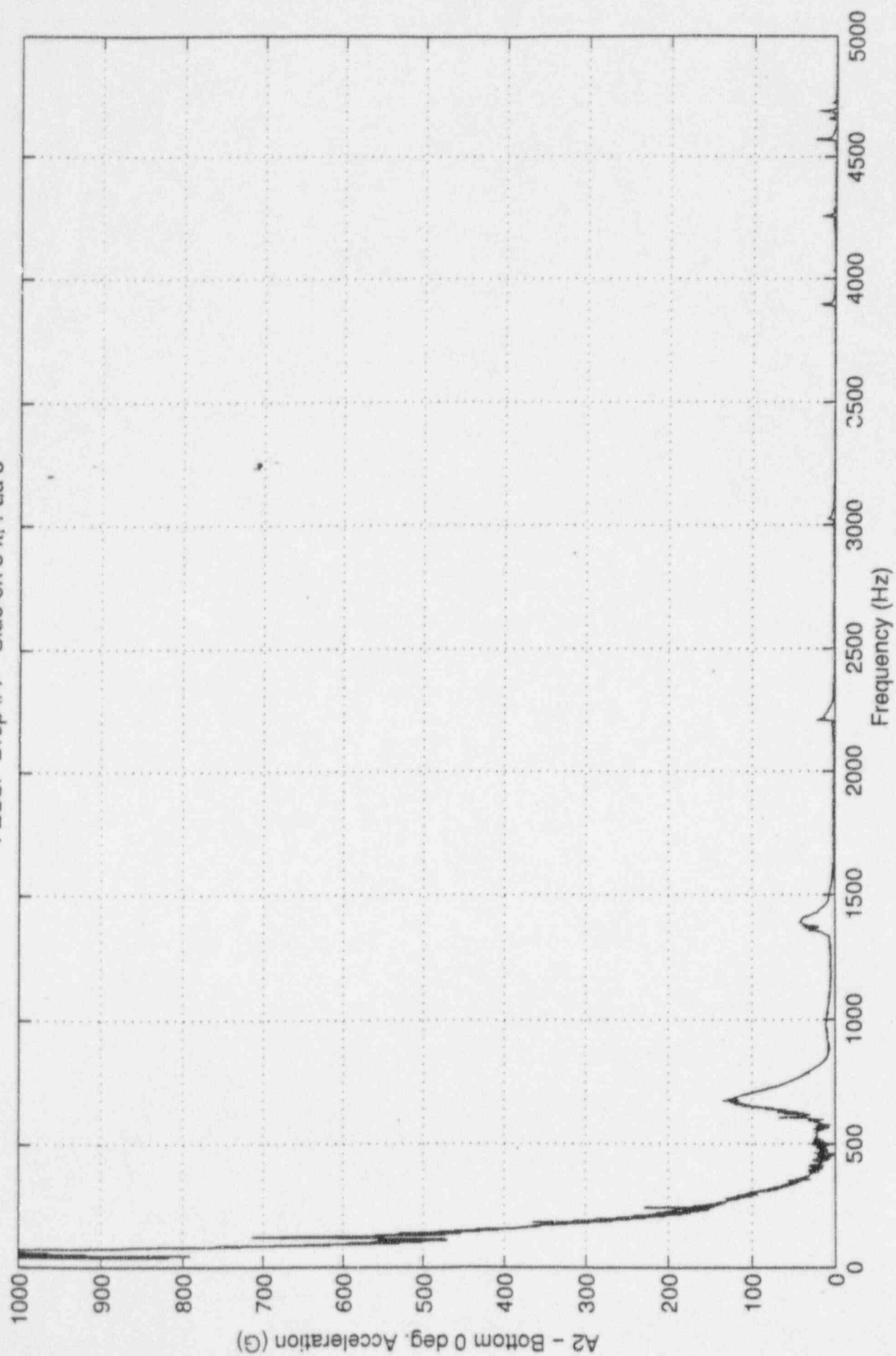


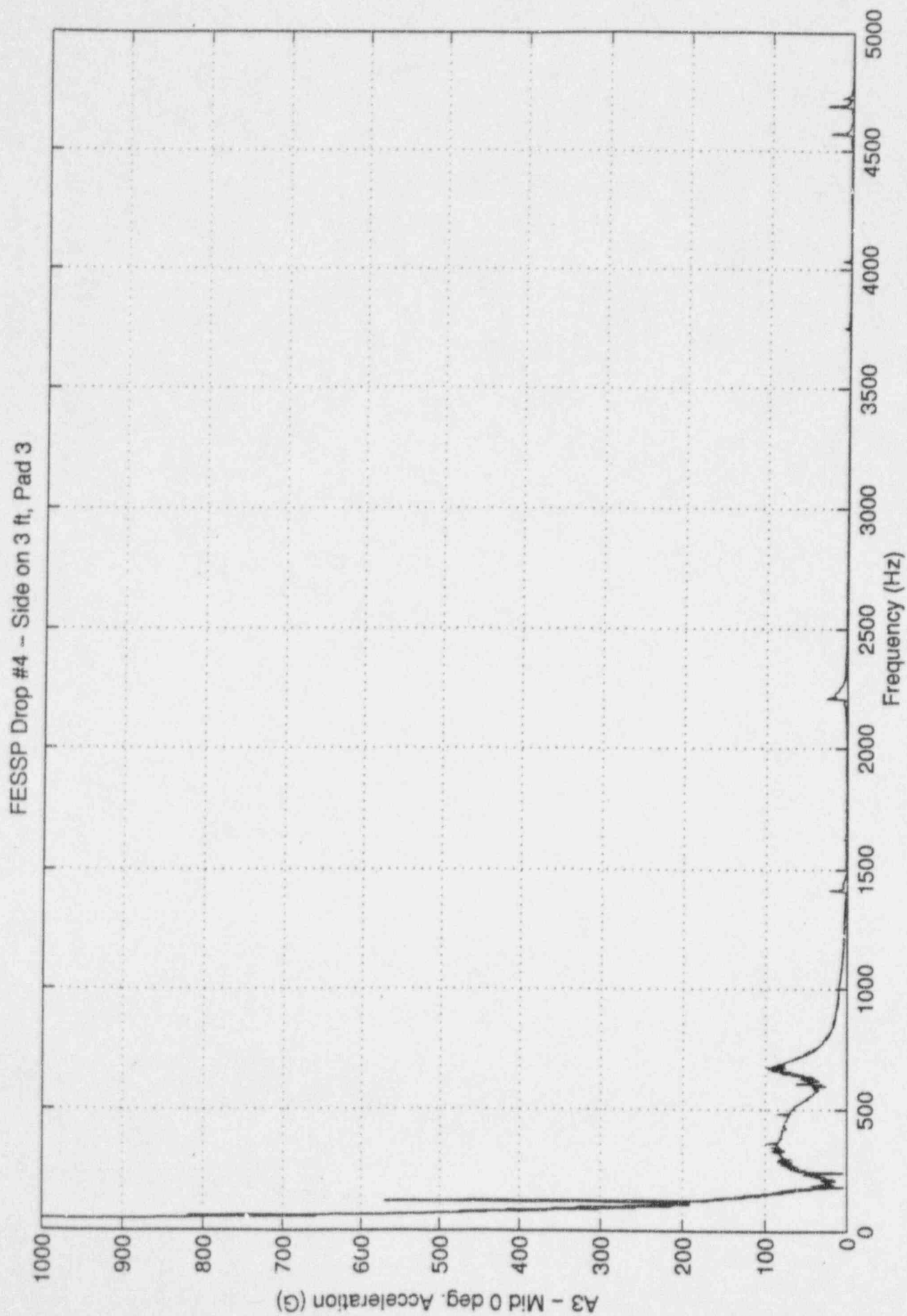


FESSP Drop #4 - Side on 3 ft. Pad 3

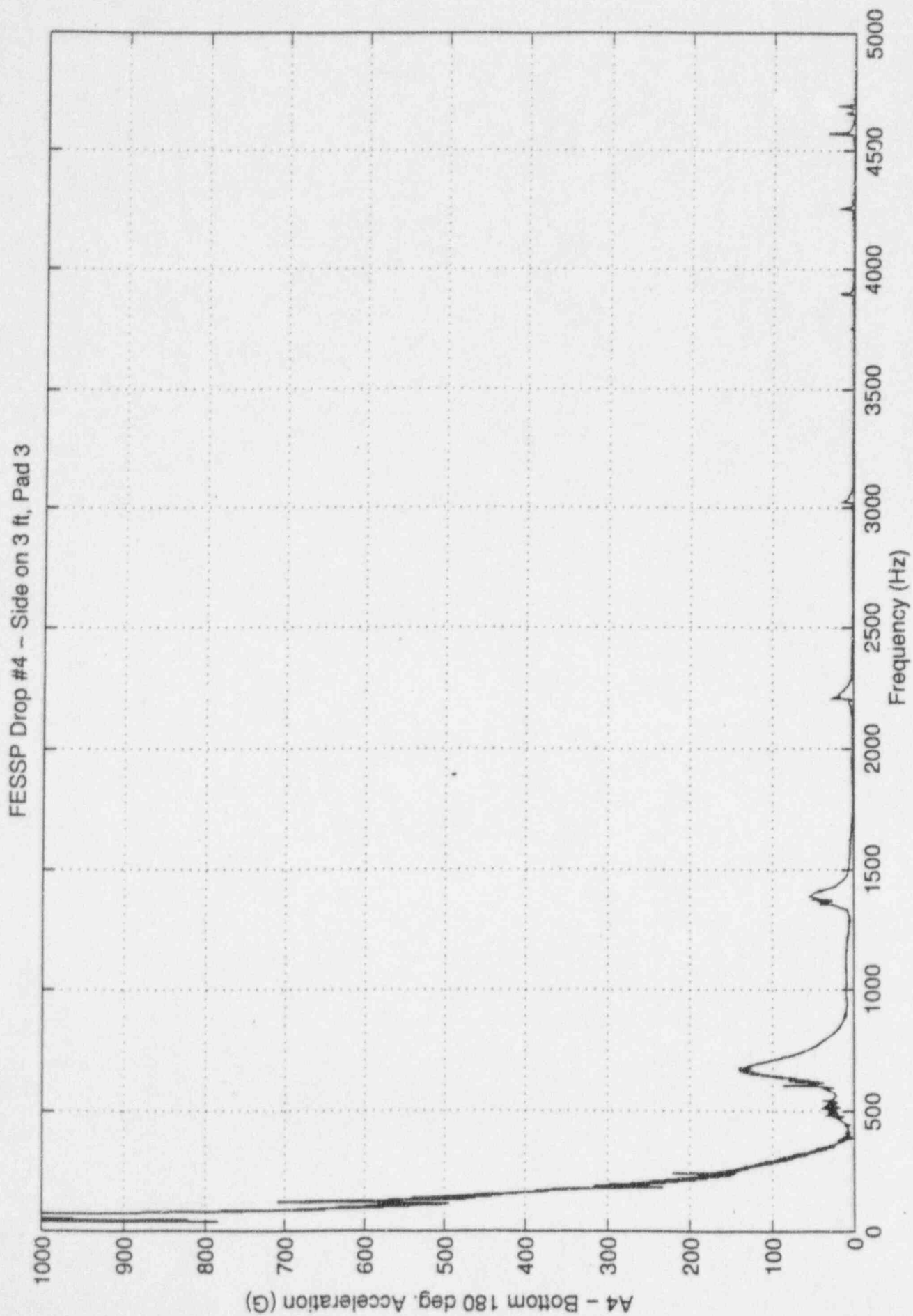


FESSP Drop #4 - Side on 3 ft, Pad 3

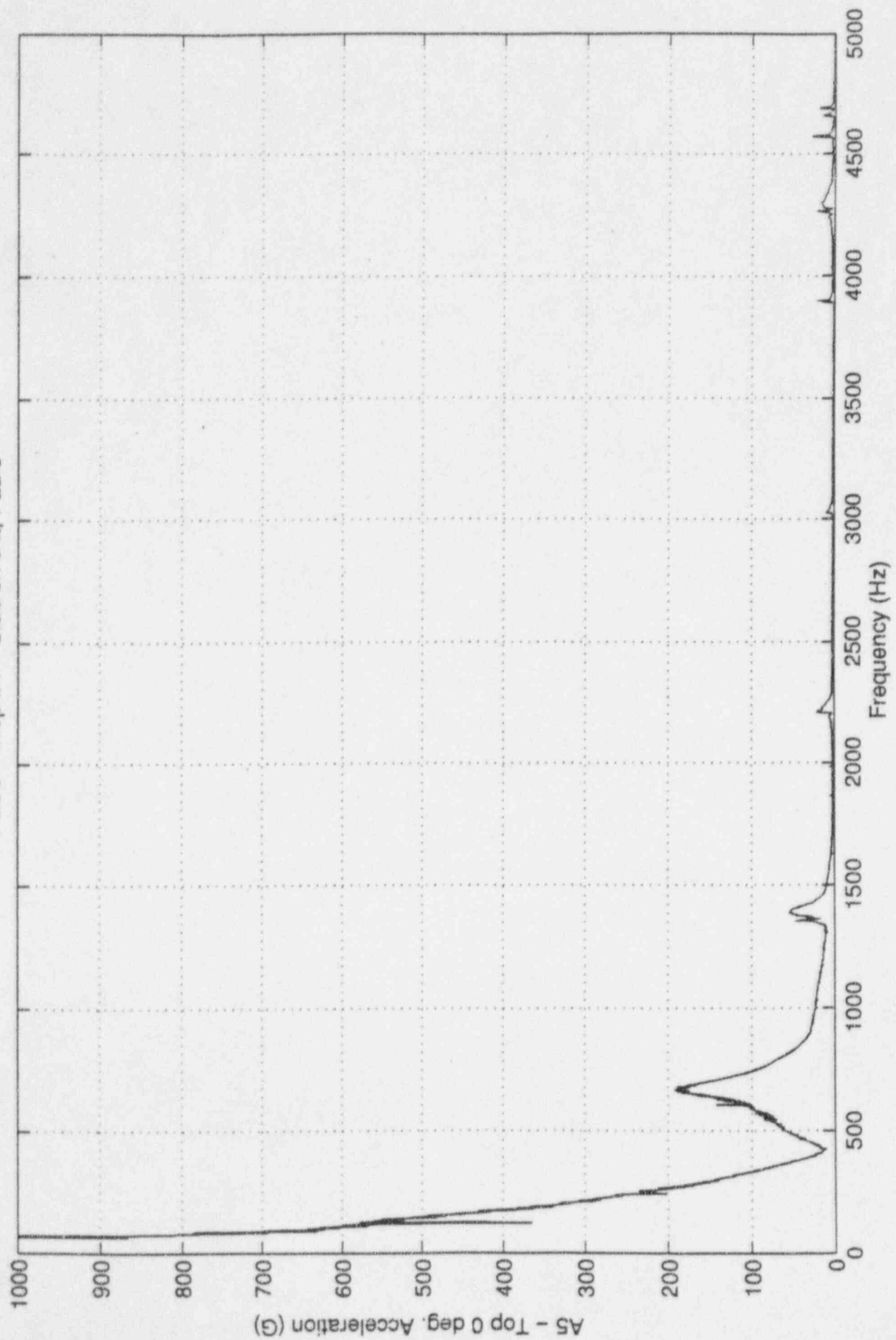


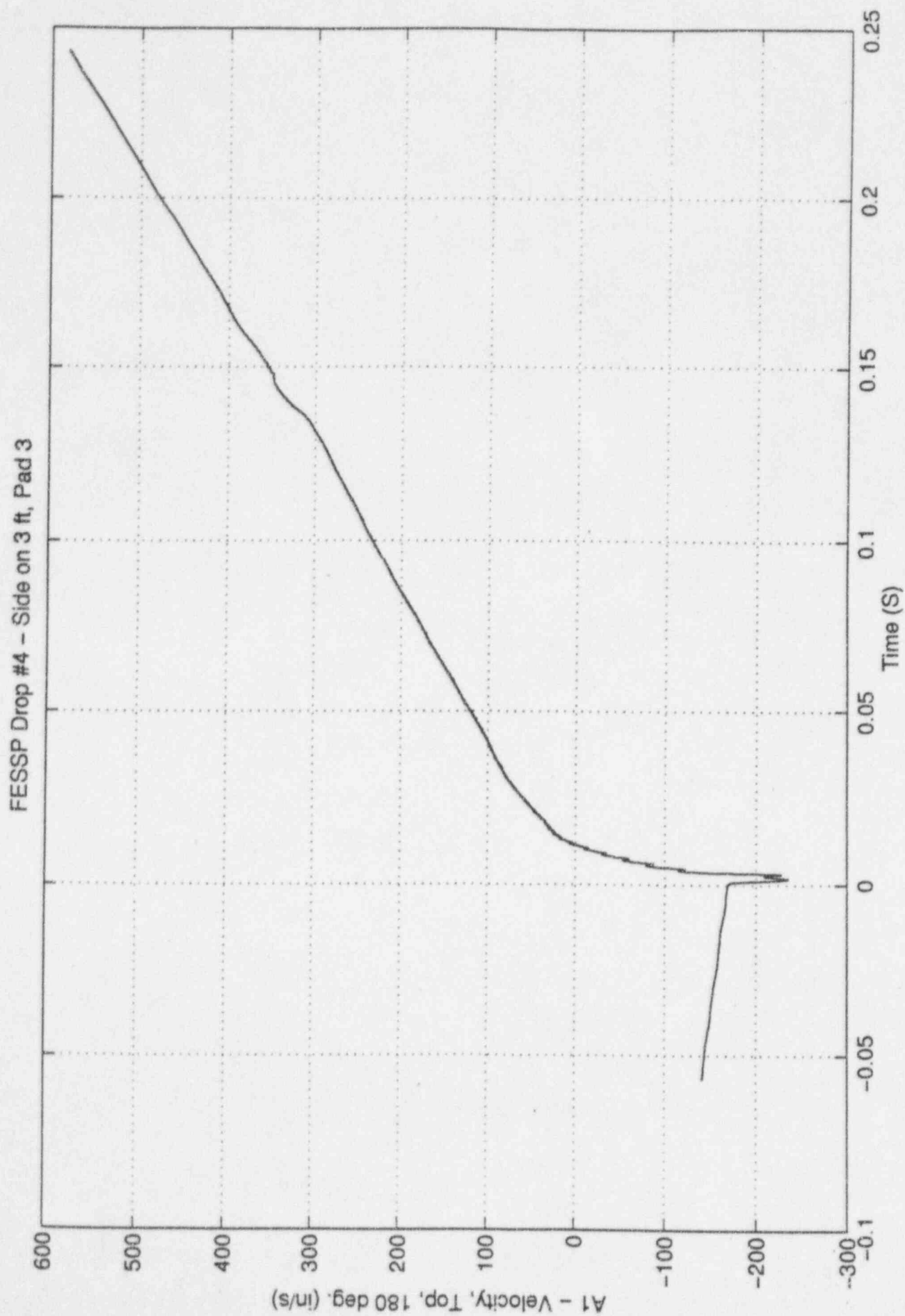




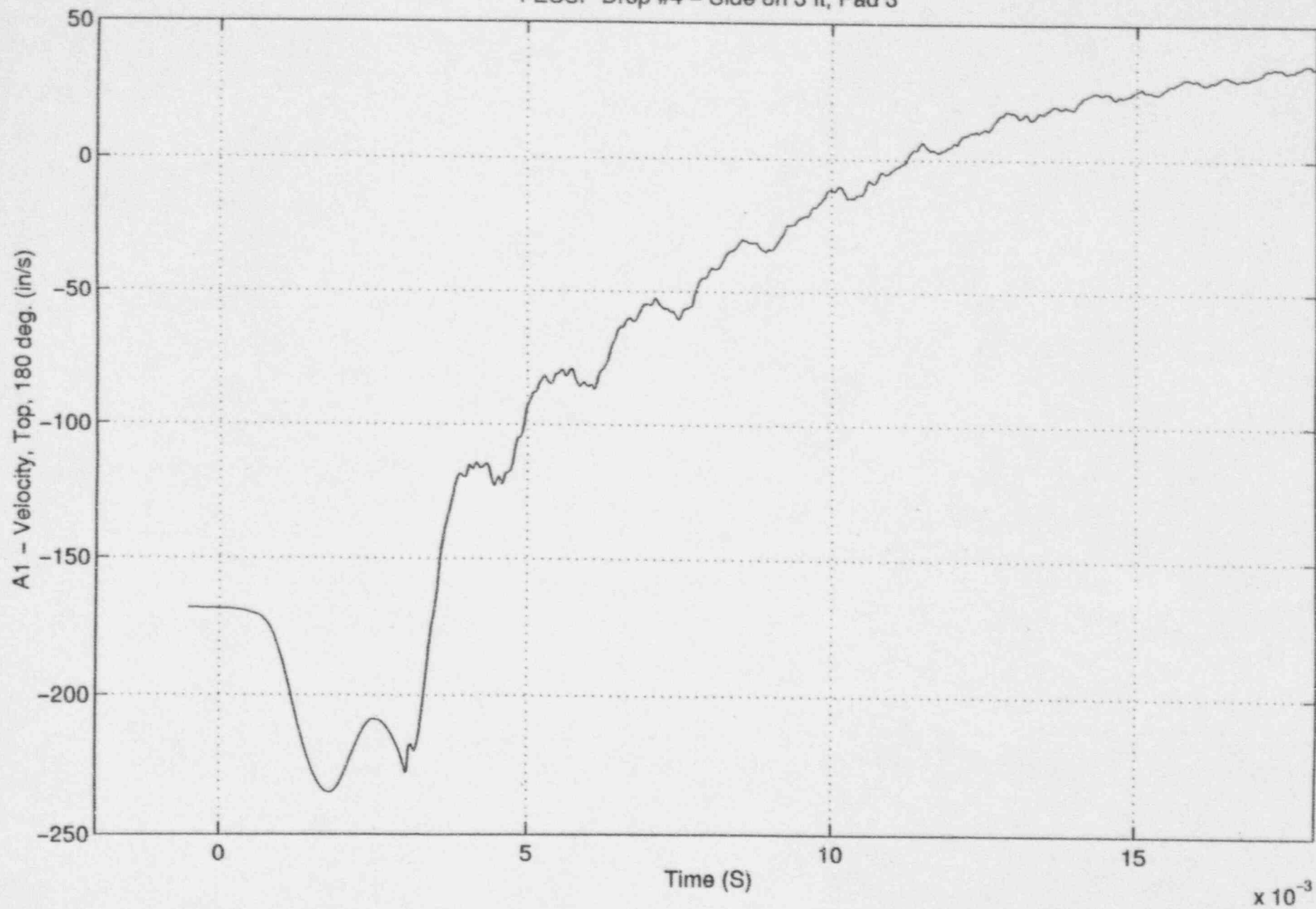


FESSP Drop #4 - Side on 3 ft, Pad 3

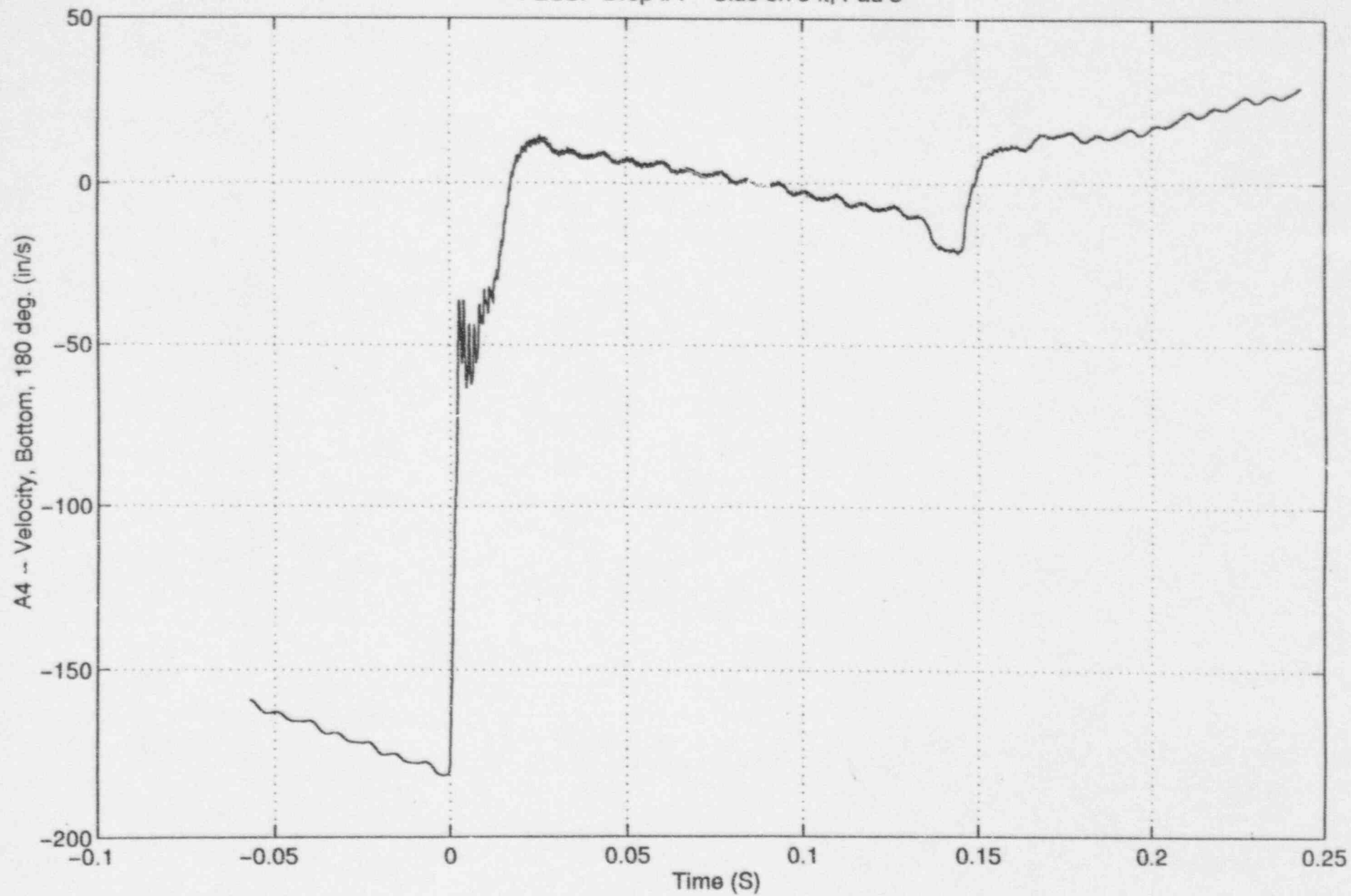




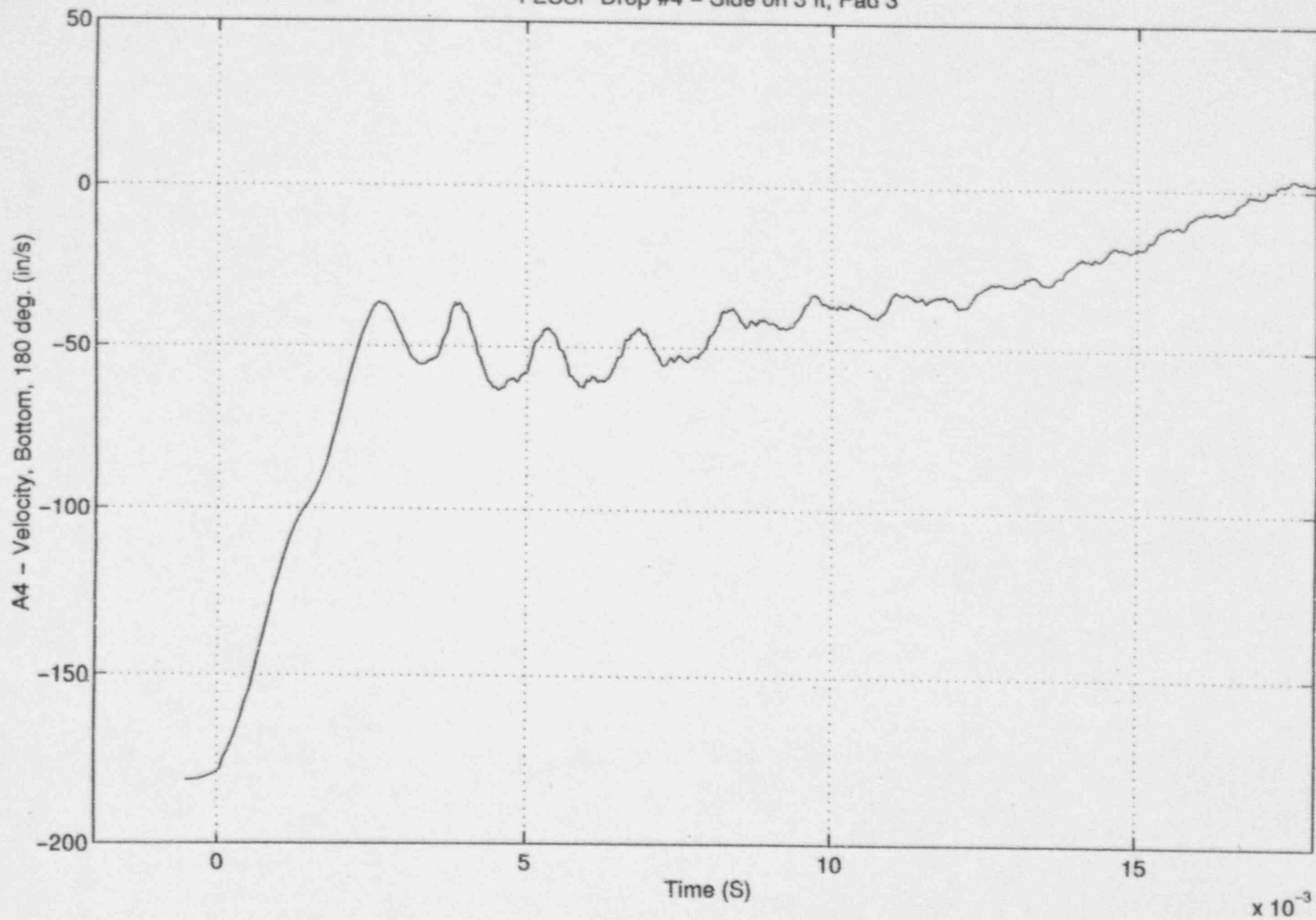
FESSP Drop #4 - Side on 3 ft, Pad 3



FESSP Drop #4 - Side on 3 ft, Pad 3

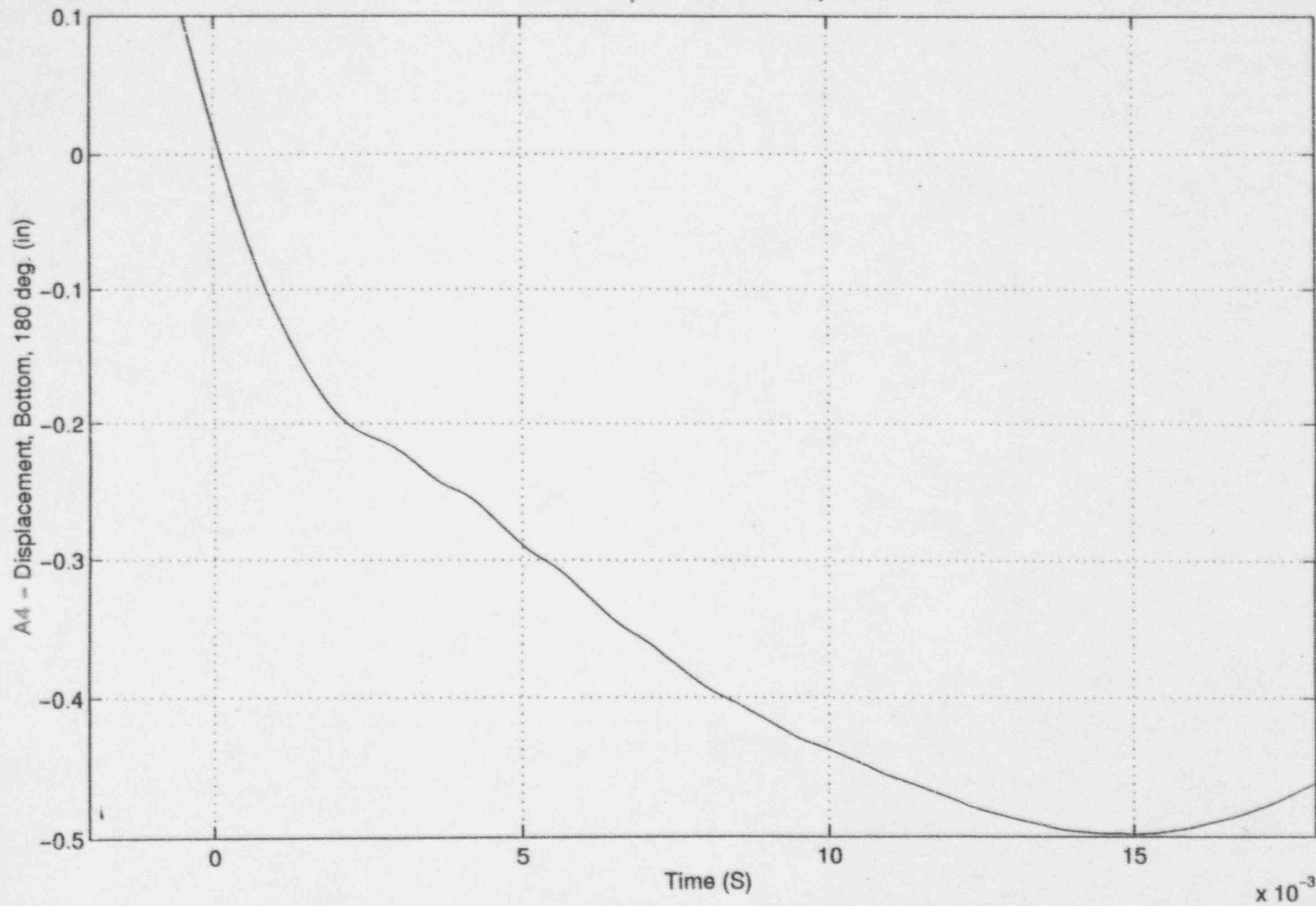


FESSP Drop #4 - Side on 3 ft, Pad 3

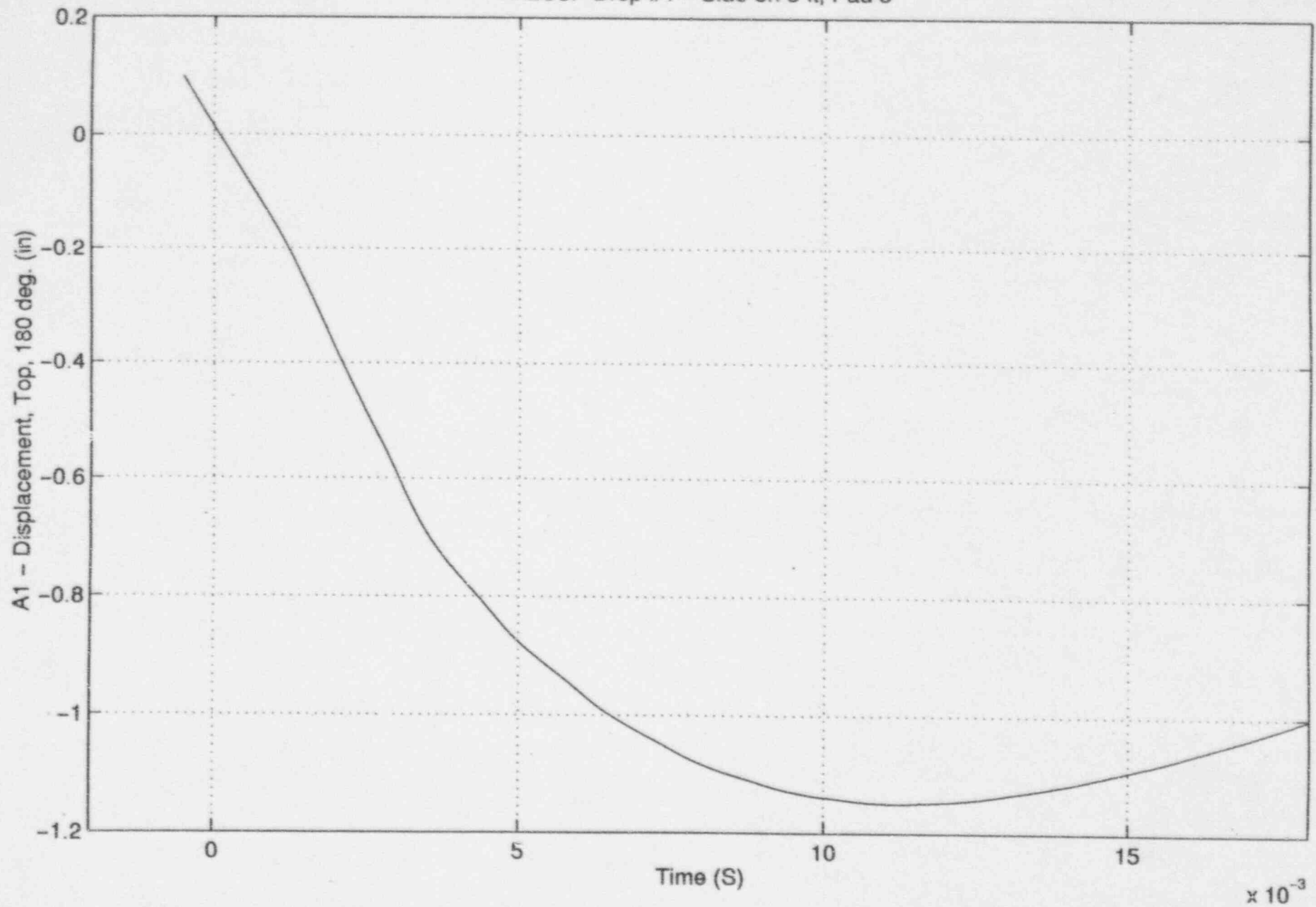




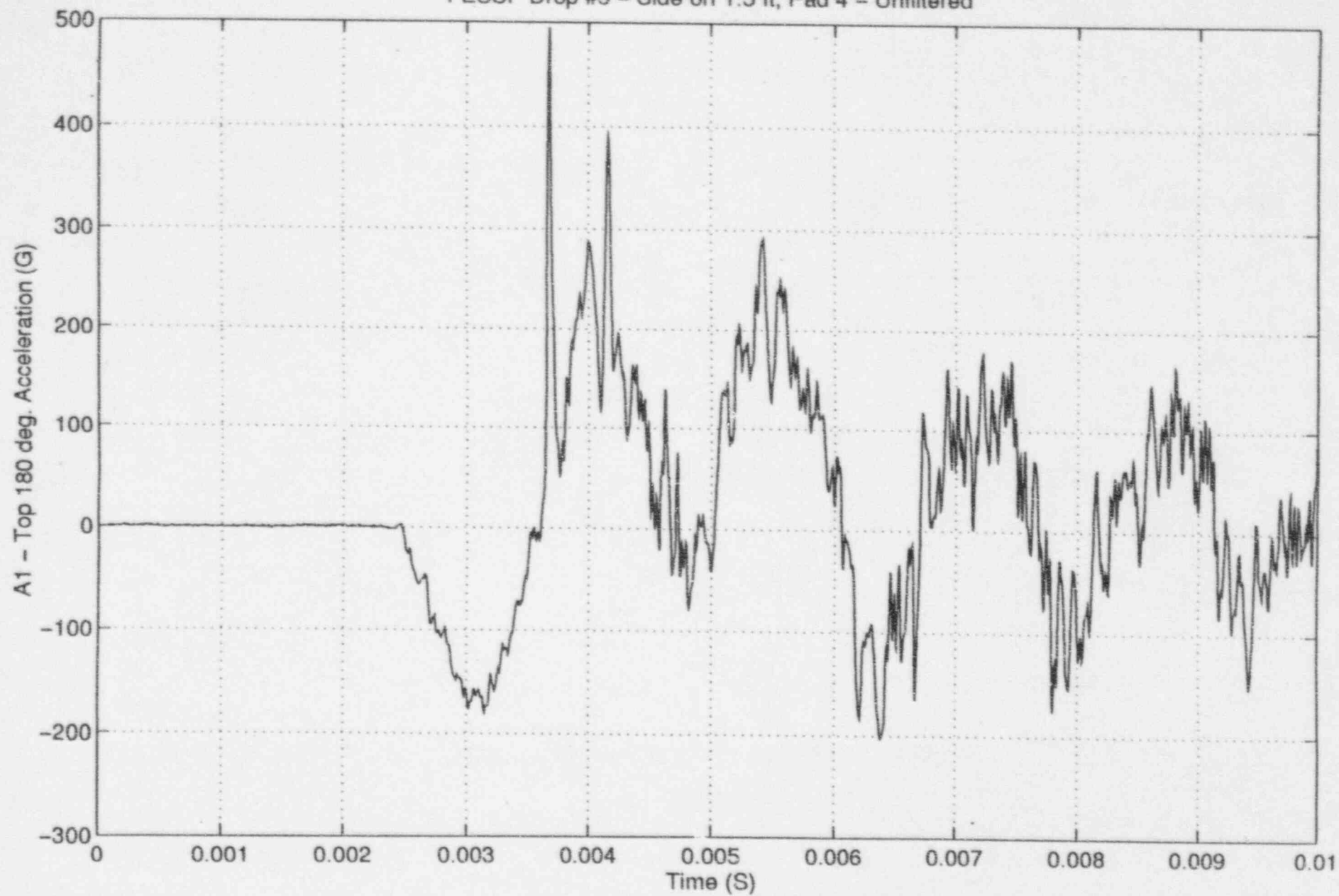
FESSP Drop #4 - Side on 3 ft, Pad 3



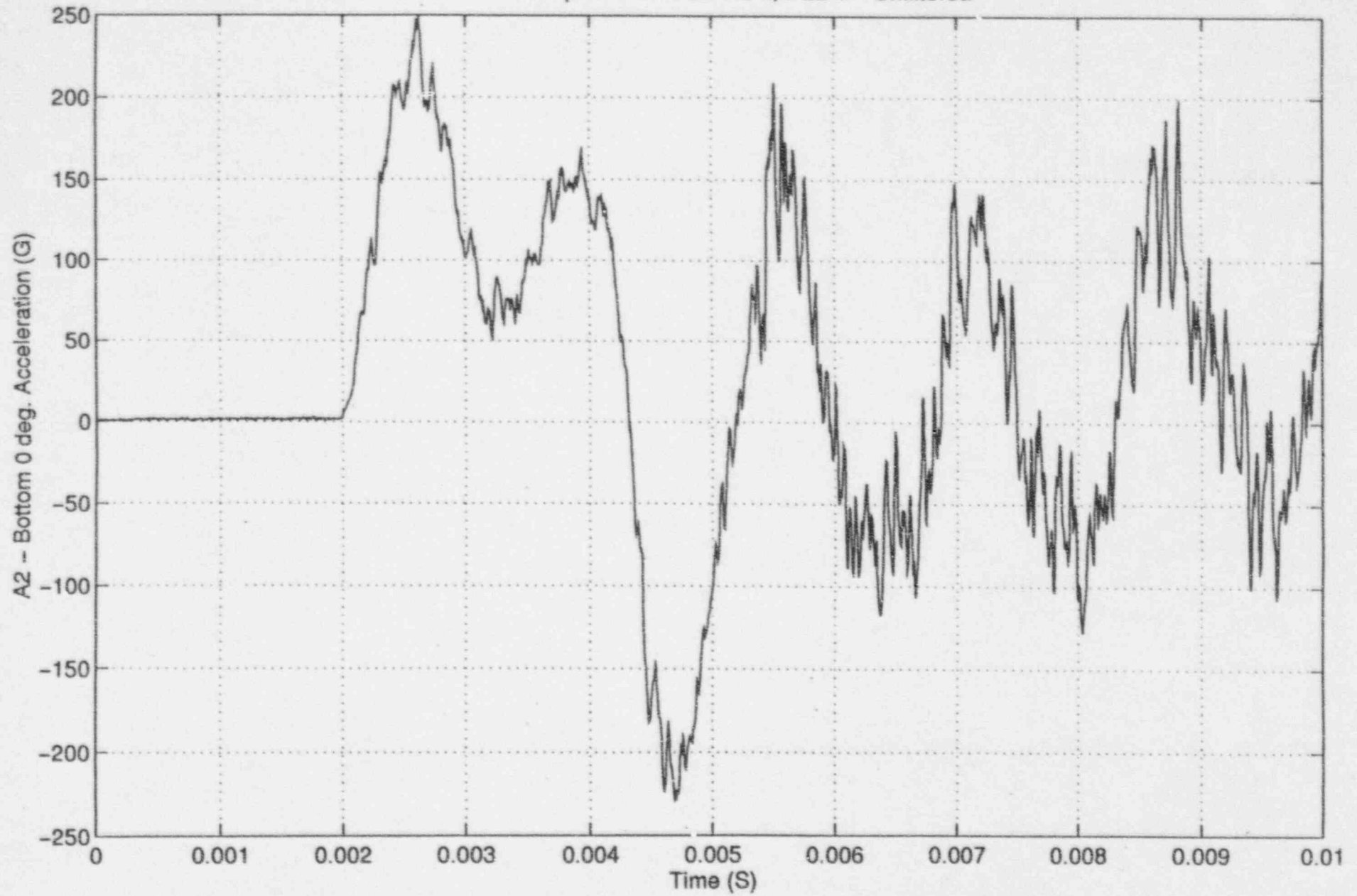
FESSP Drop #4 - Side on 3 ft, Pad 3



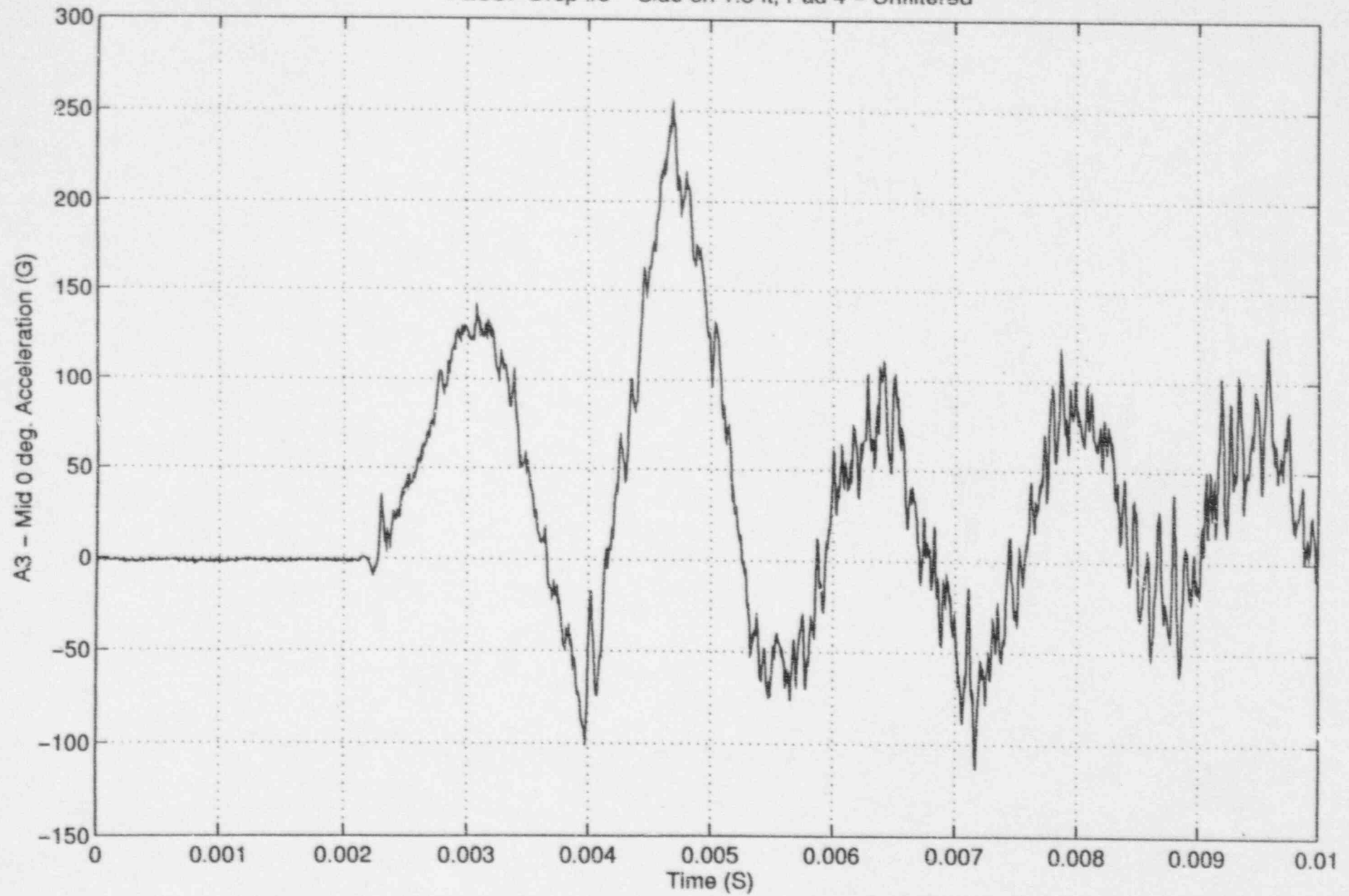
FESSP Drop #5 - Side on 1.5 ft, Pad 4 - Unfiltered



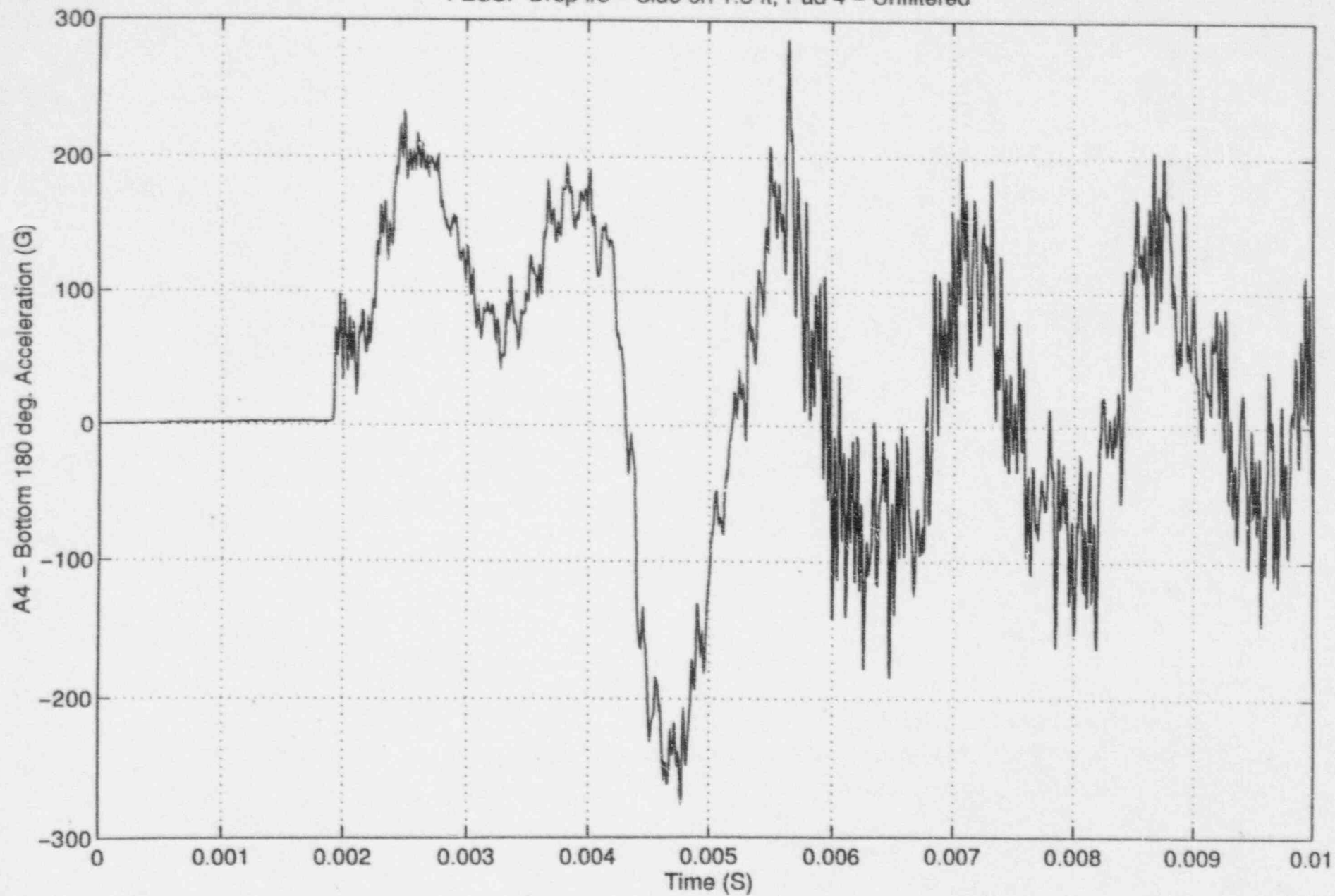
FESSP Drop #5 - Side on 1.5 ft, Pad 4 - Unfiltered



FESSP Drop #5 - Side on 1.5 ft, Pad 4 - Unfiltered

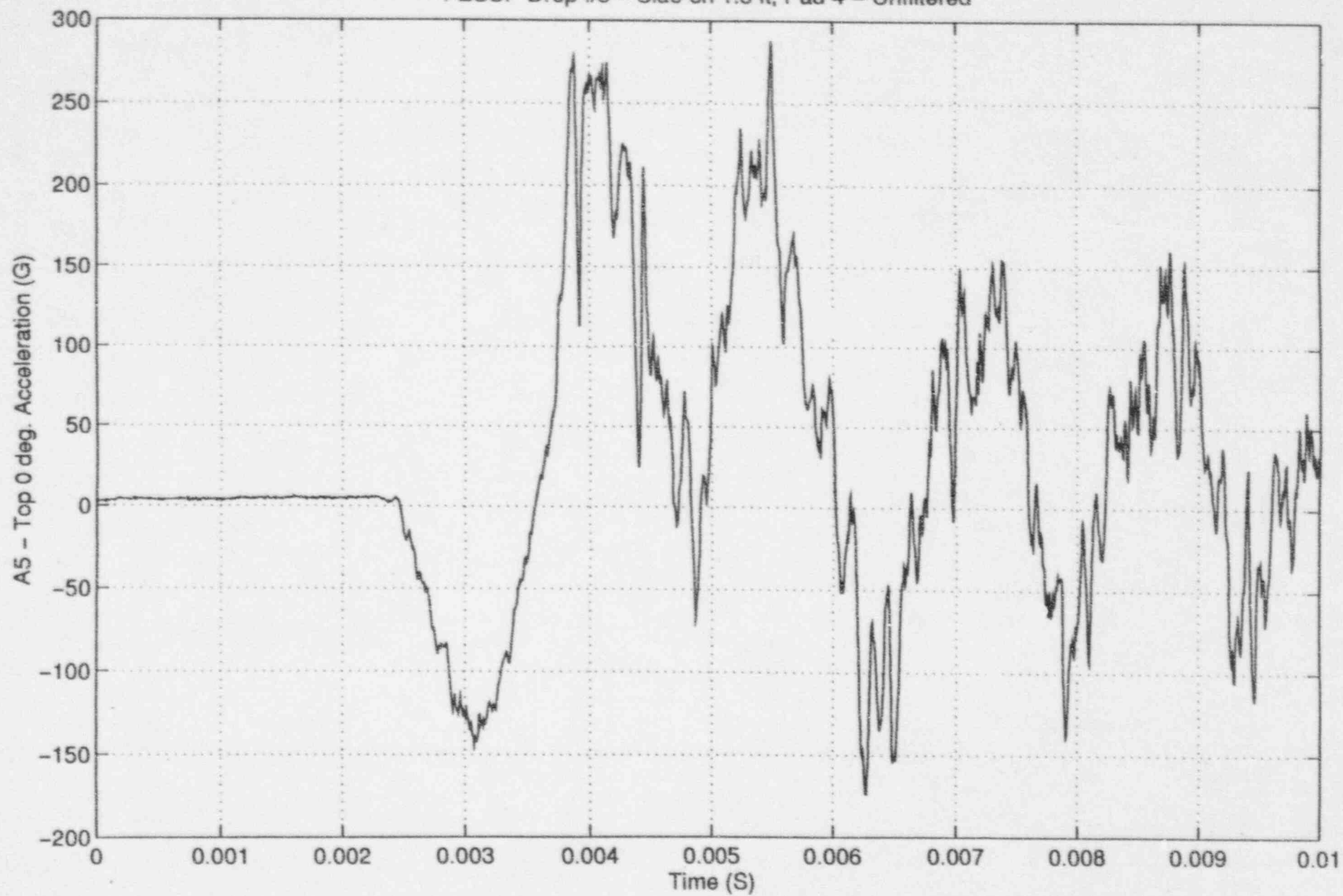


FESSP Drop #5 - Side on 1.5 ft, Pad 4 - Unfiltered

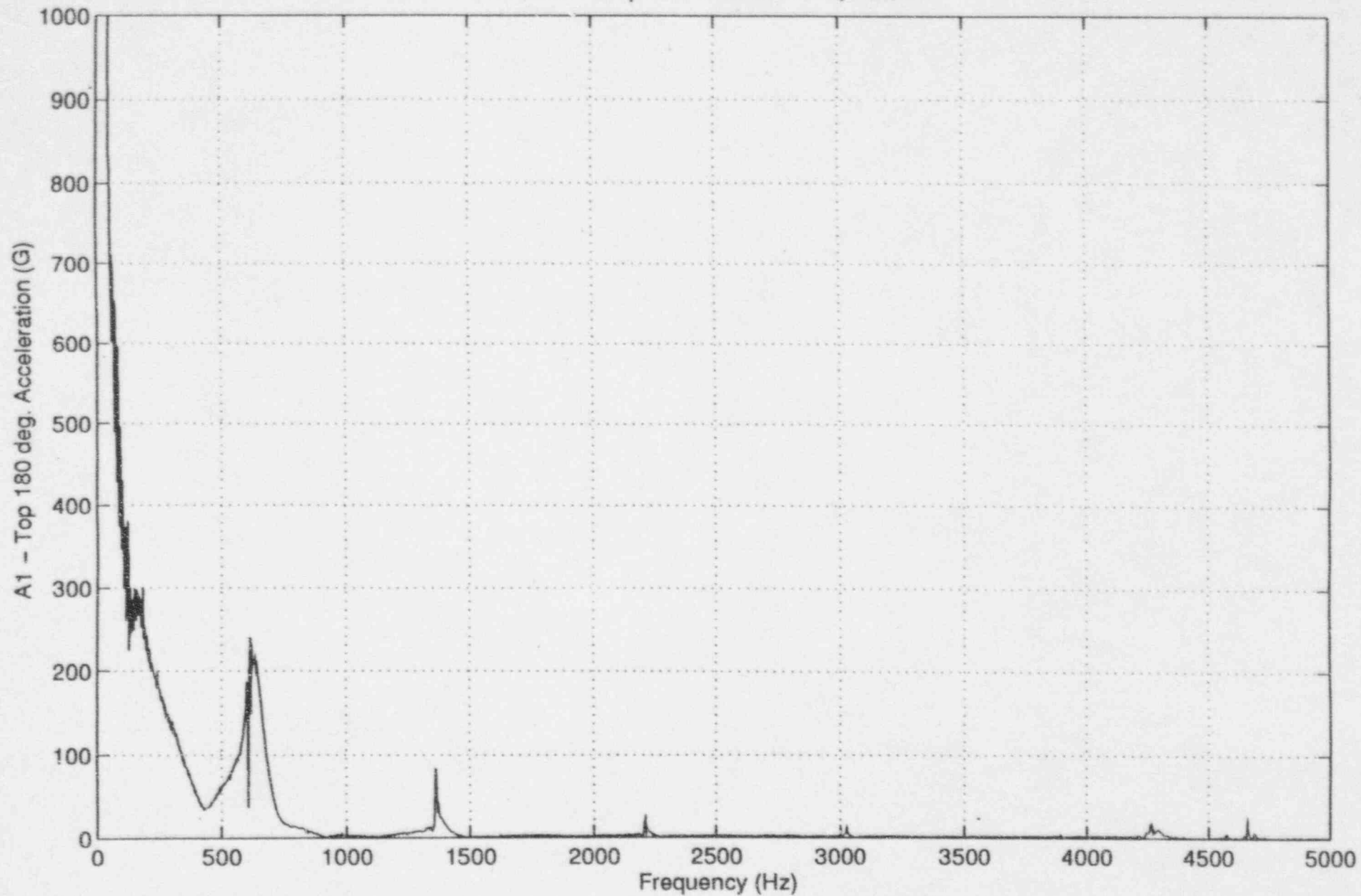




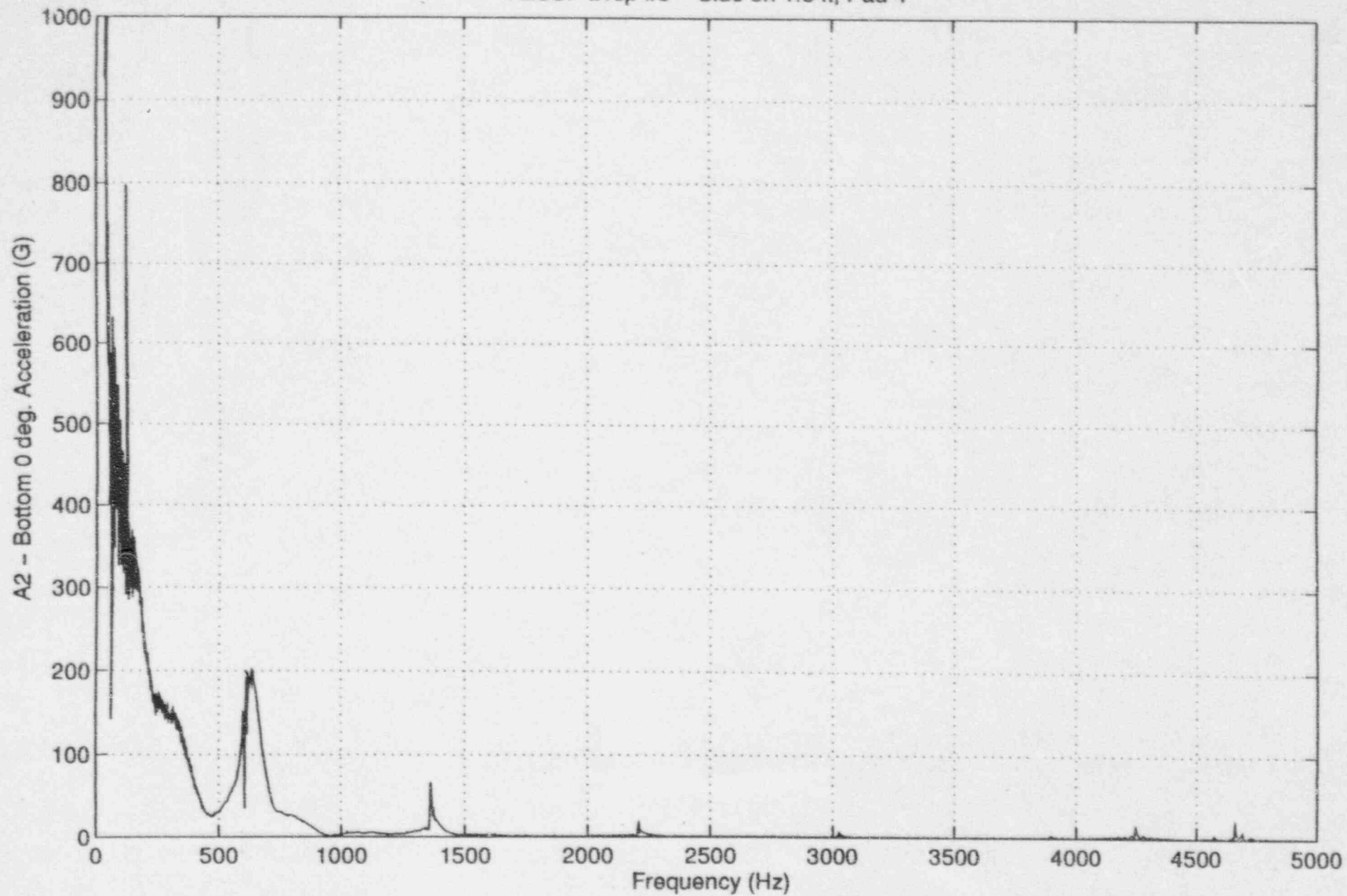
FESSP Drop #5 - Side on 1.5 ft, Pad 4 - Unfiltered



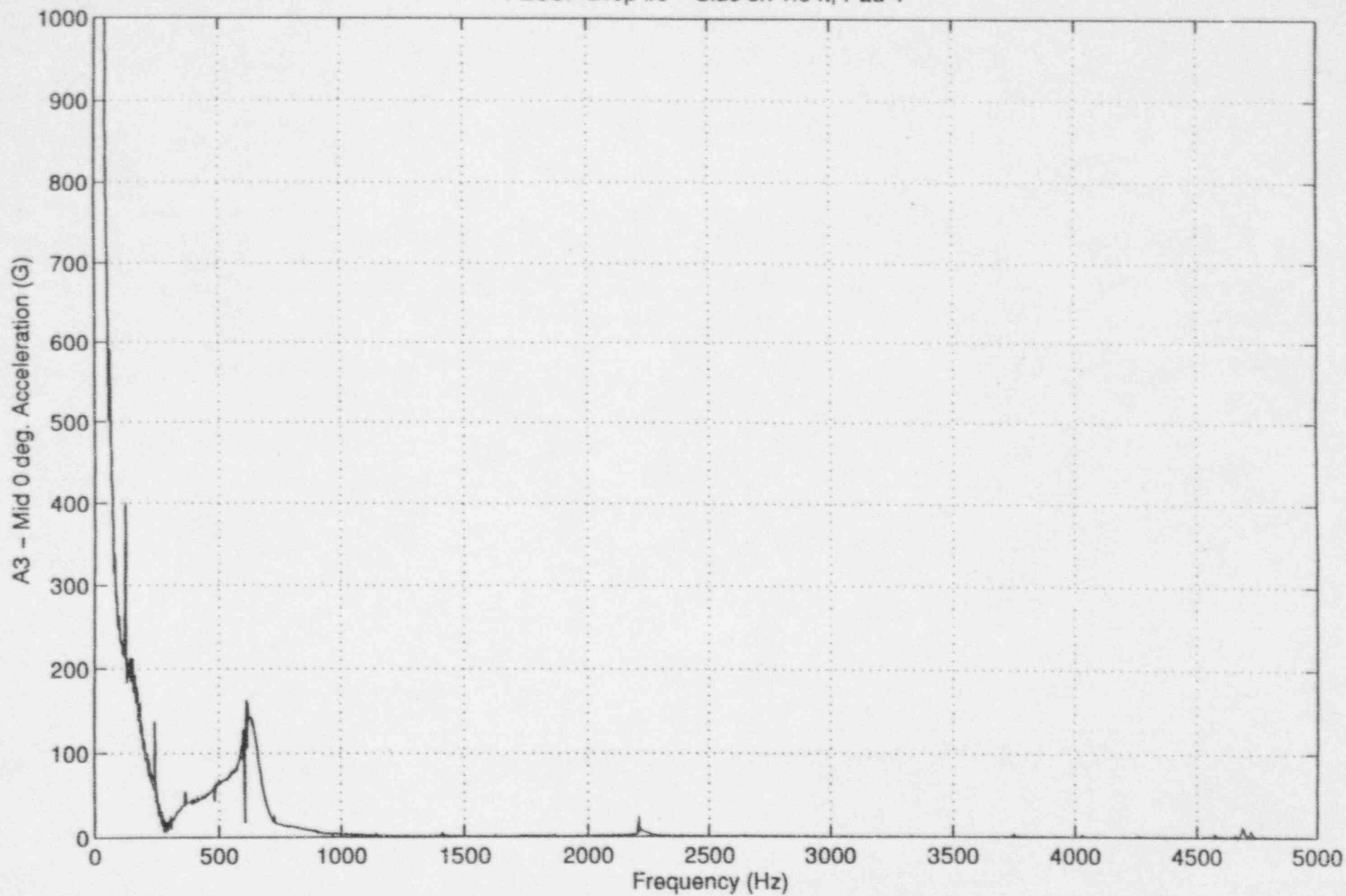
FESSP Drop #5 - Side on 1.5 ft, Pad 4



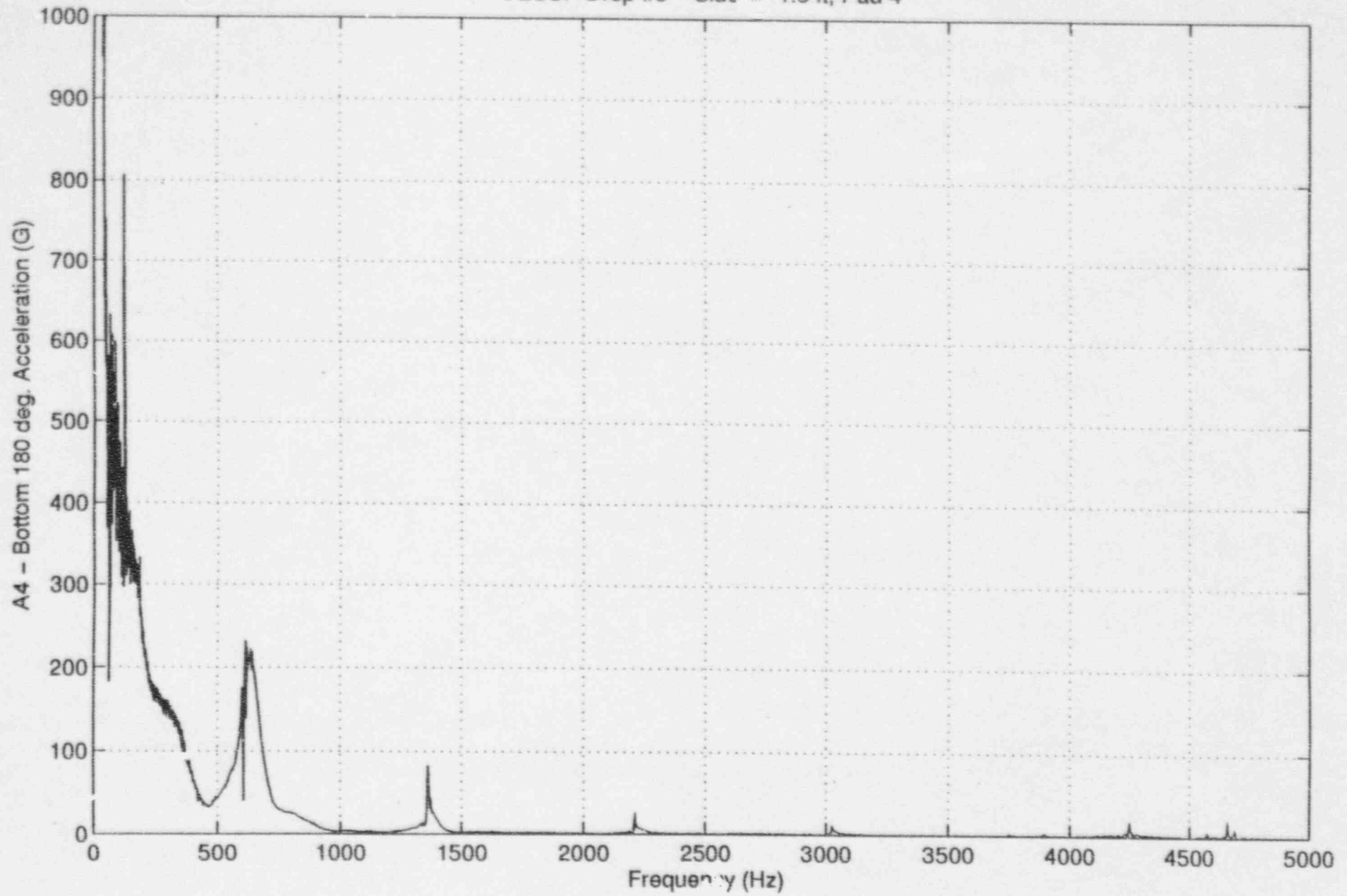
FESSP Drop #5 - Side on 1.5 ft, Pad 4



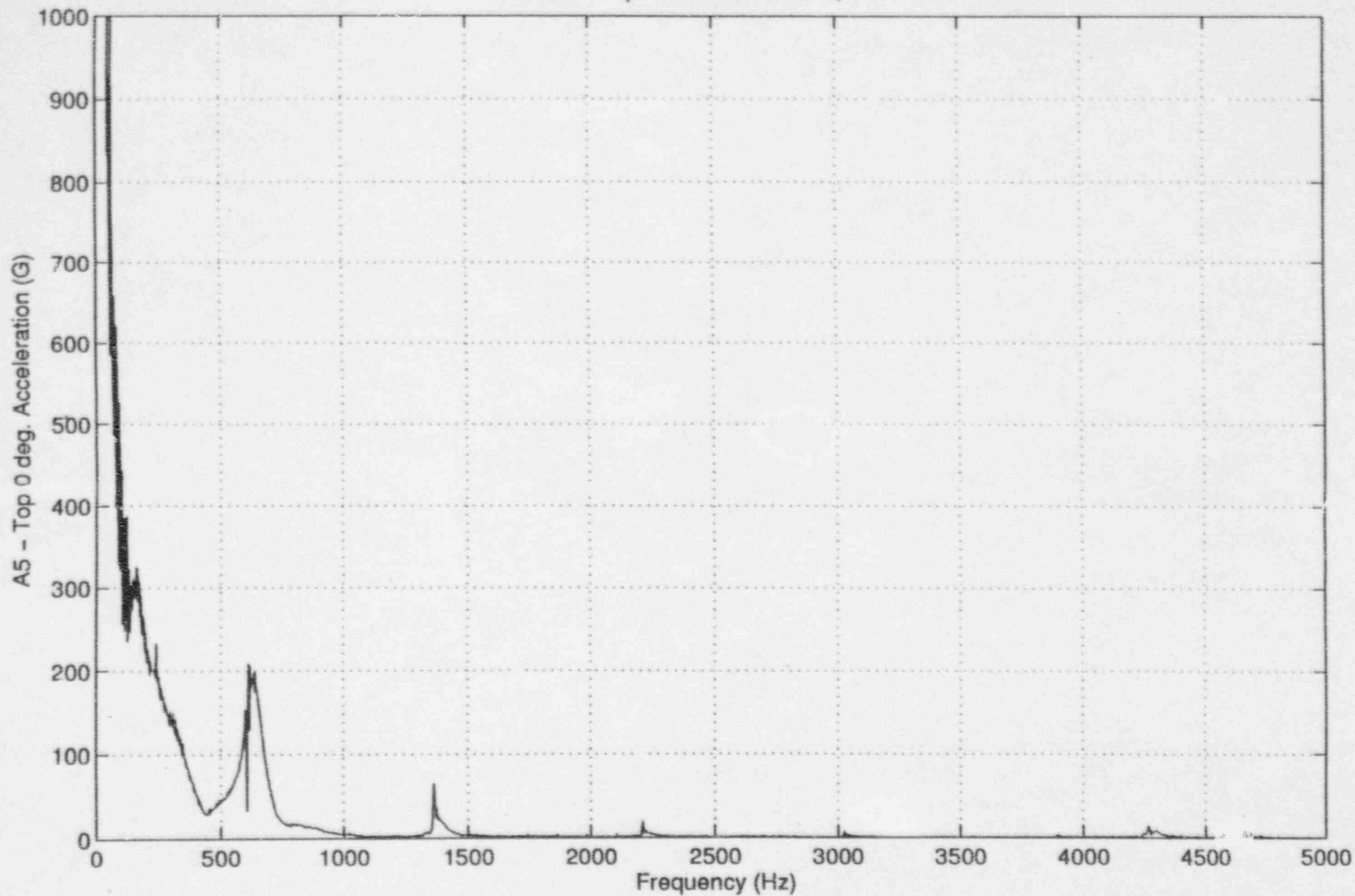
FESSP Drop #5 - Side on 1.5 ft, Pad 4



FESSP Drop #5 - Side on 1.5 ft, Pad 4

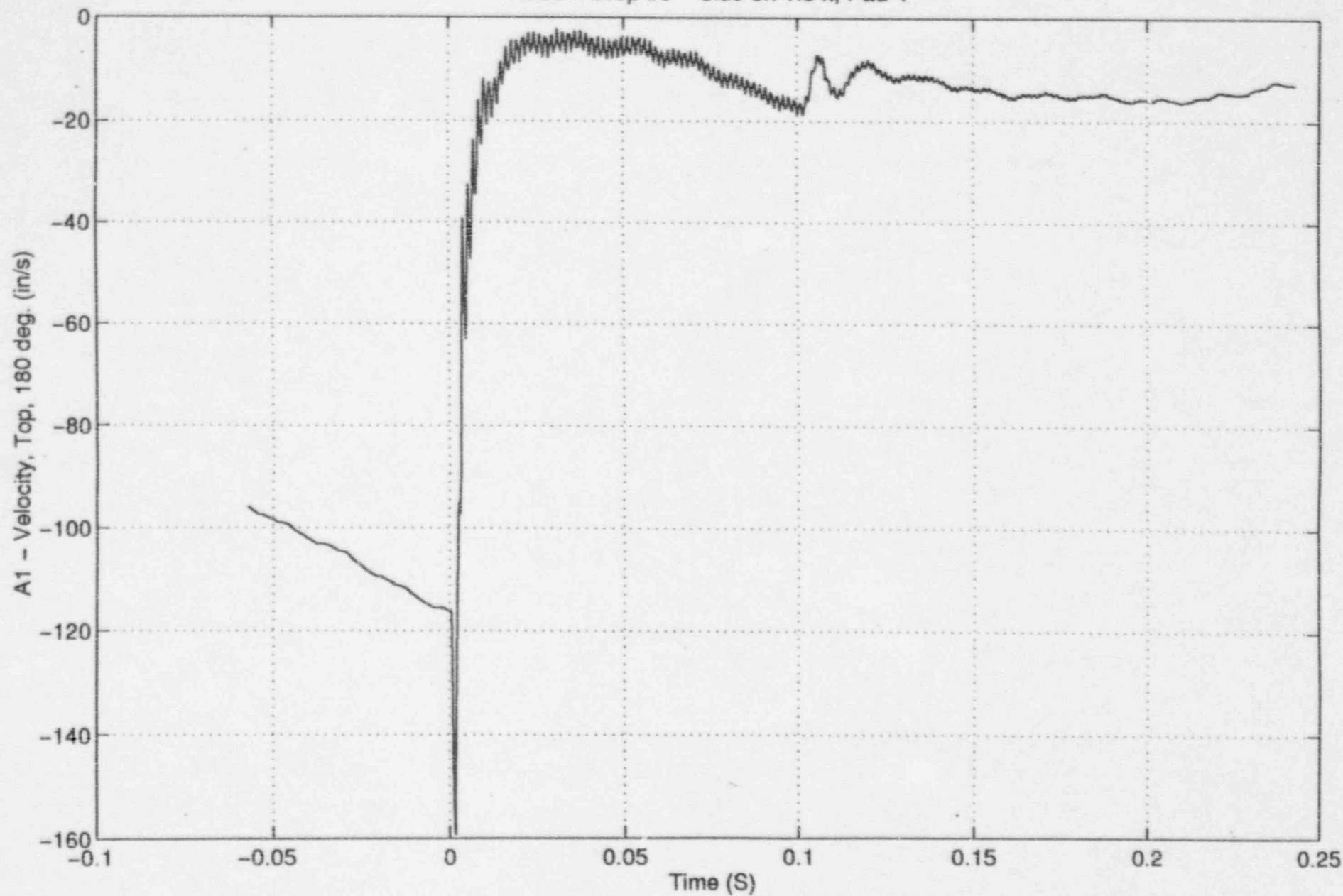


FESSP Drop #5 - Side on 1.5 ft, Pad 4

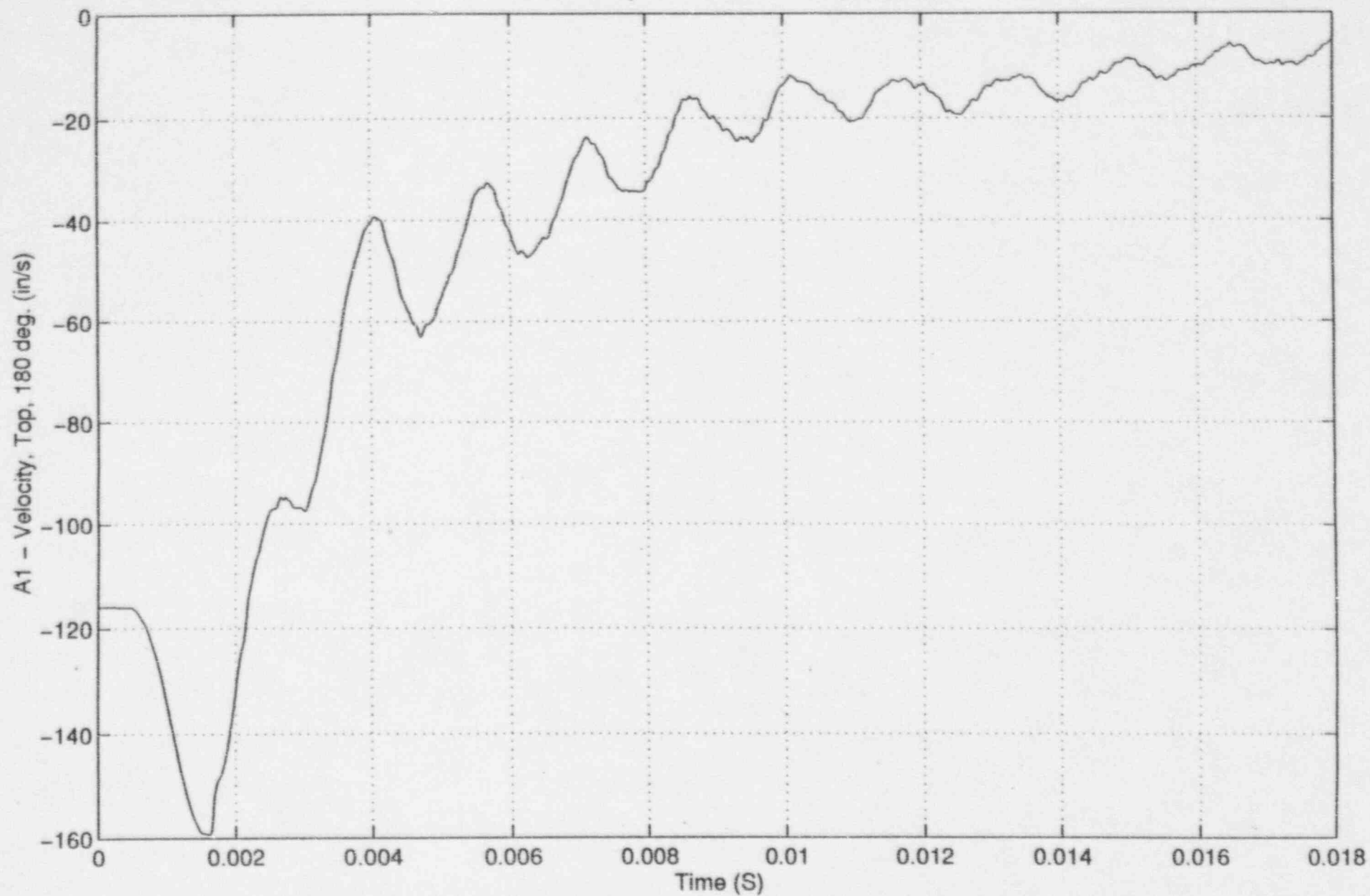


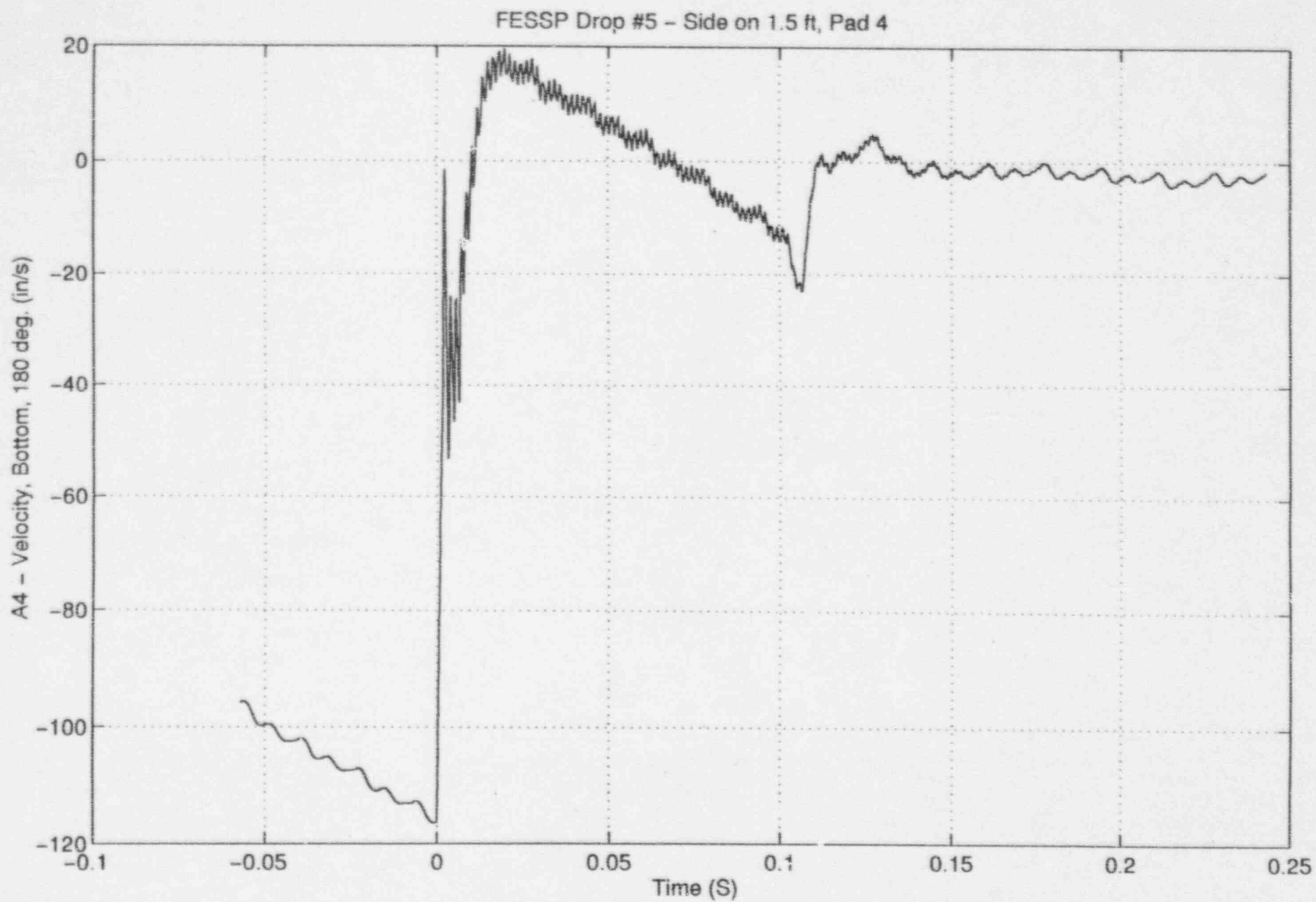


FESSP Drop #5 - Side on 1.5 ft, Pad 4

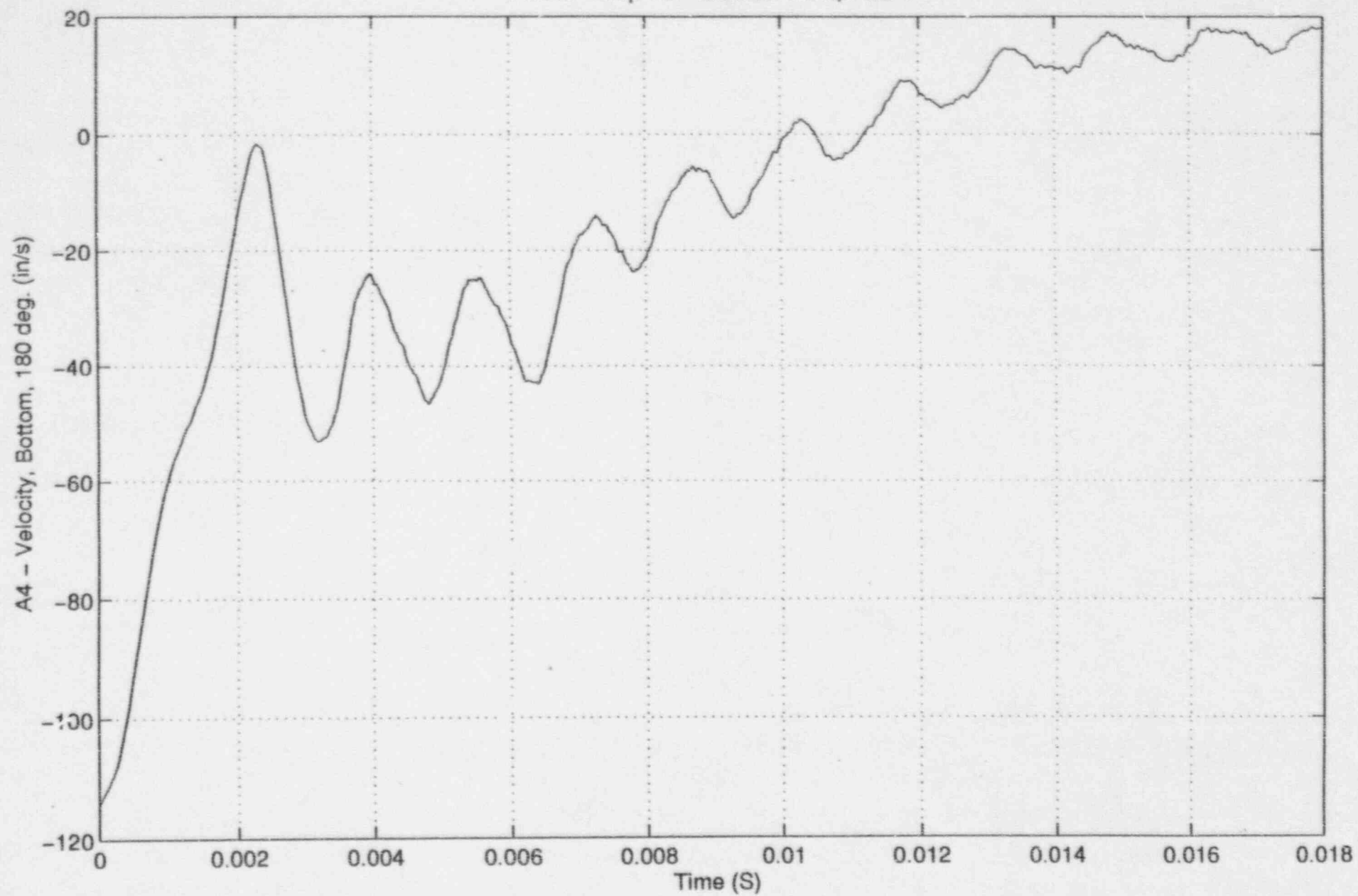


FESSP Drop #5 - Side on 1.5 ft, Pad 4

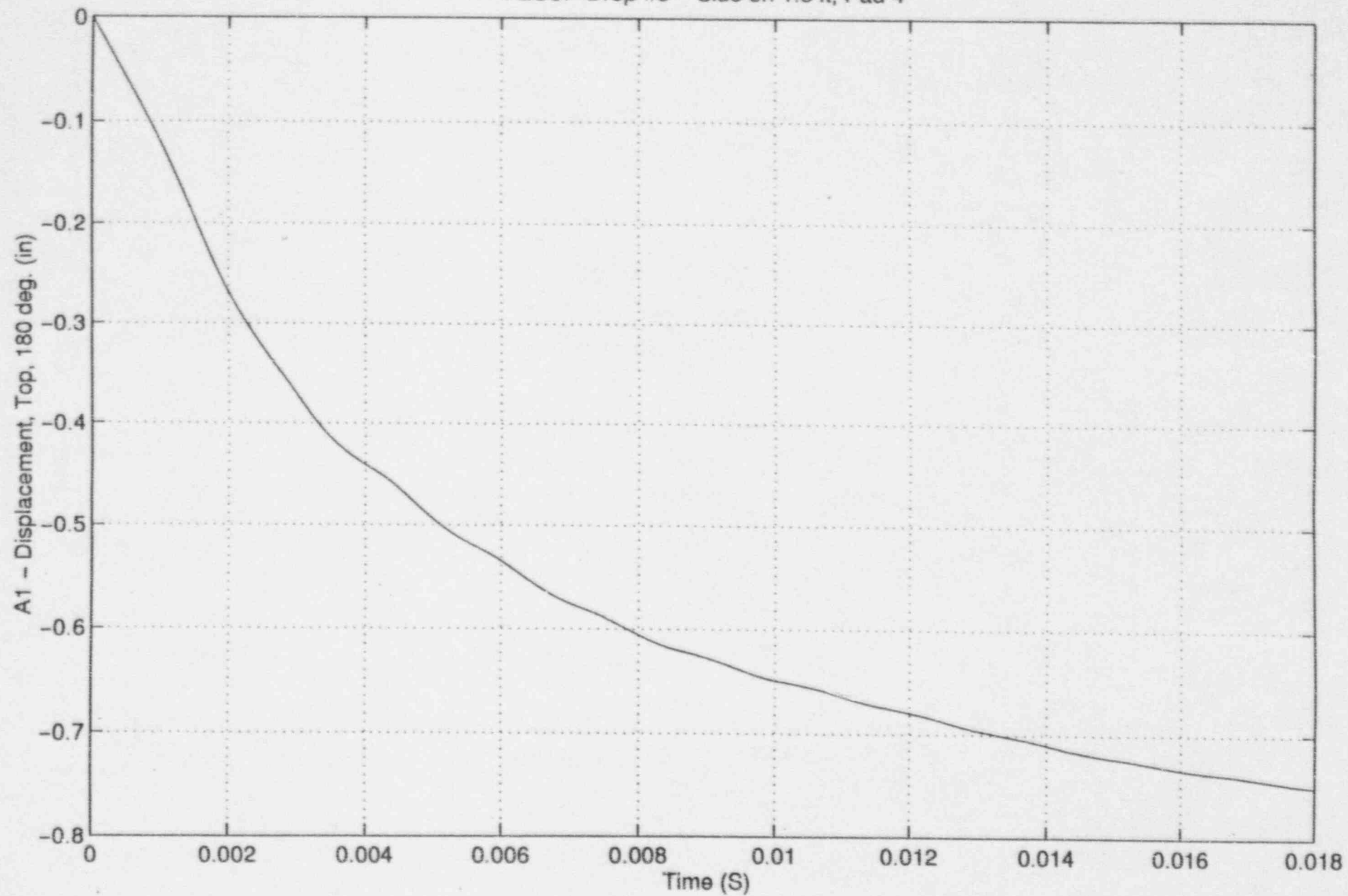




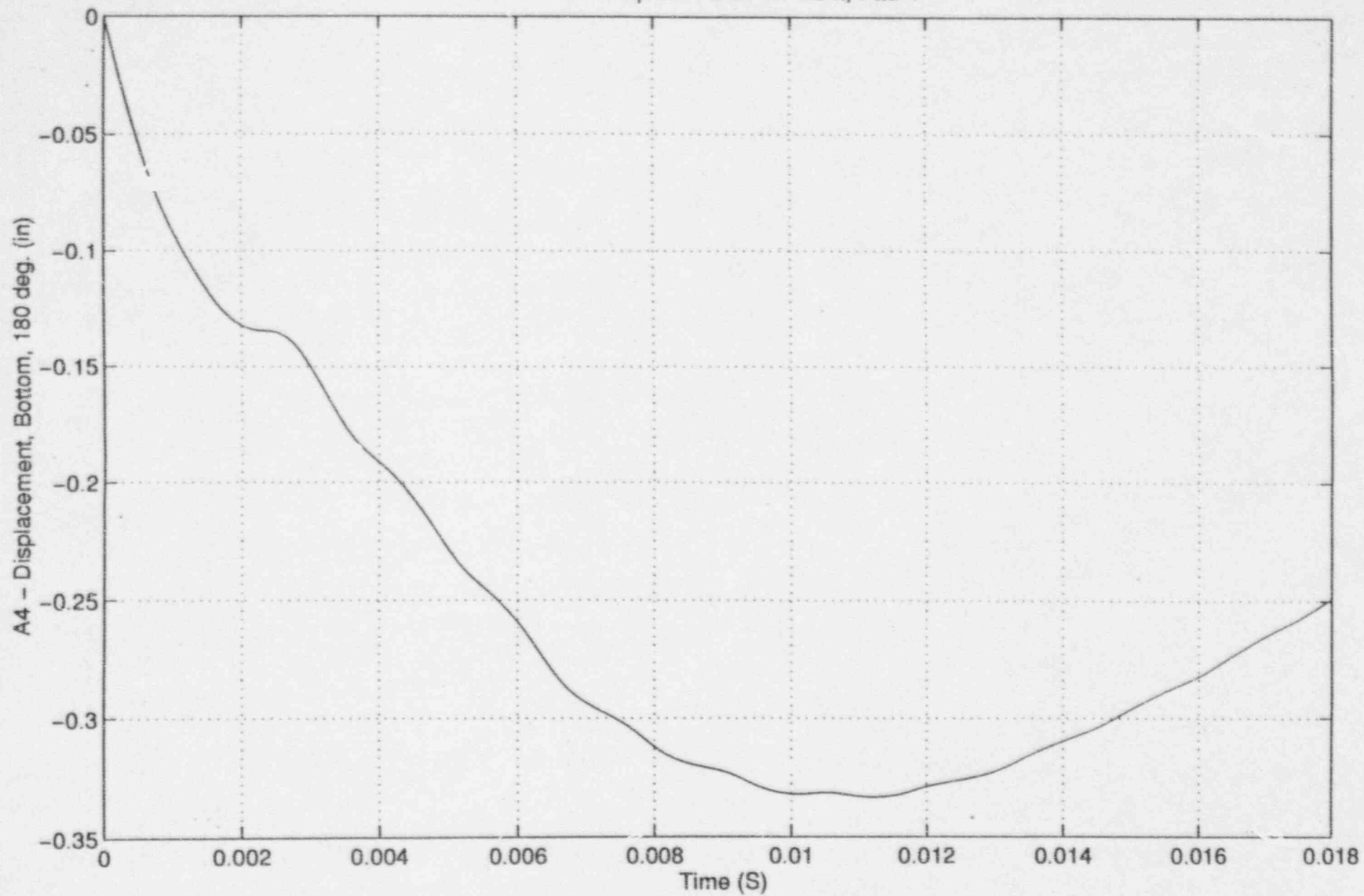
FESSP Drop #5 - Side on 1.5 ft, Pad 4



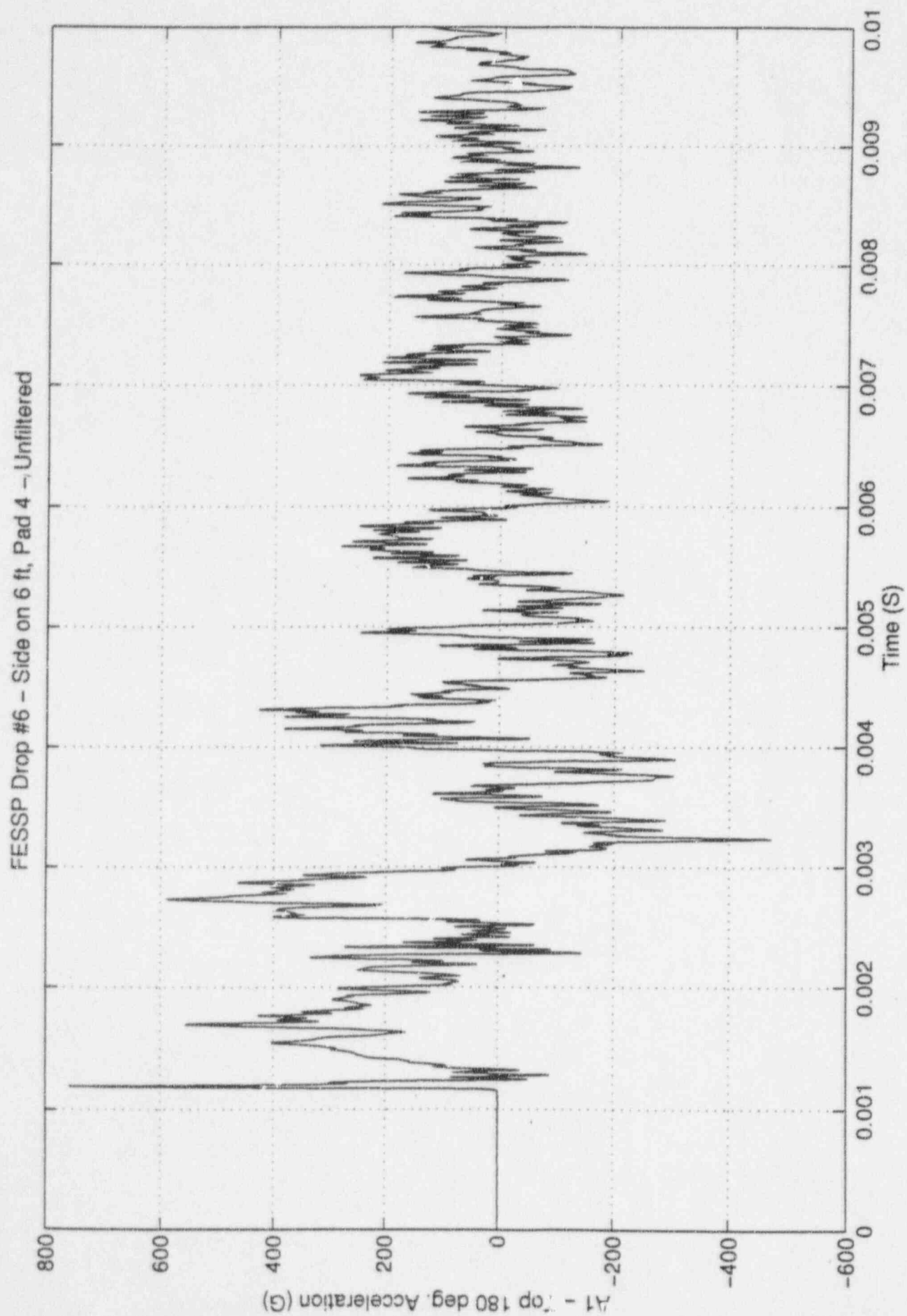
FESSP Drop #5 - Side on 1.5 ft, Pad 4

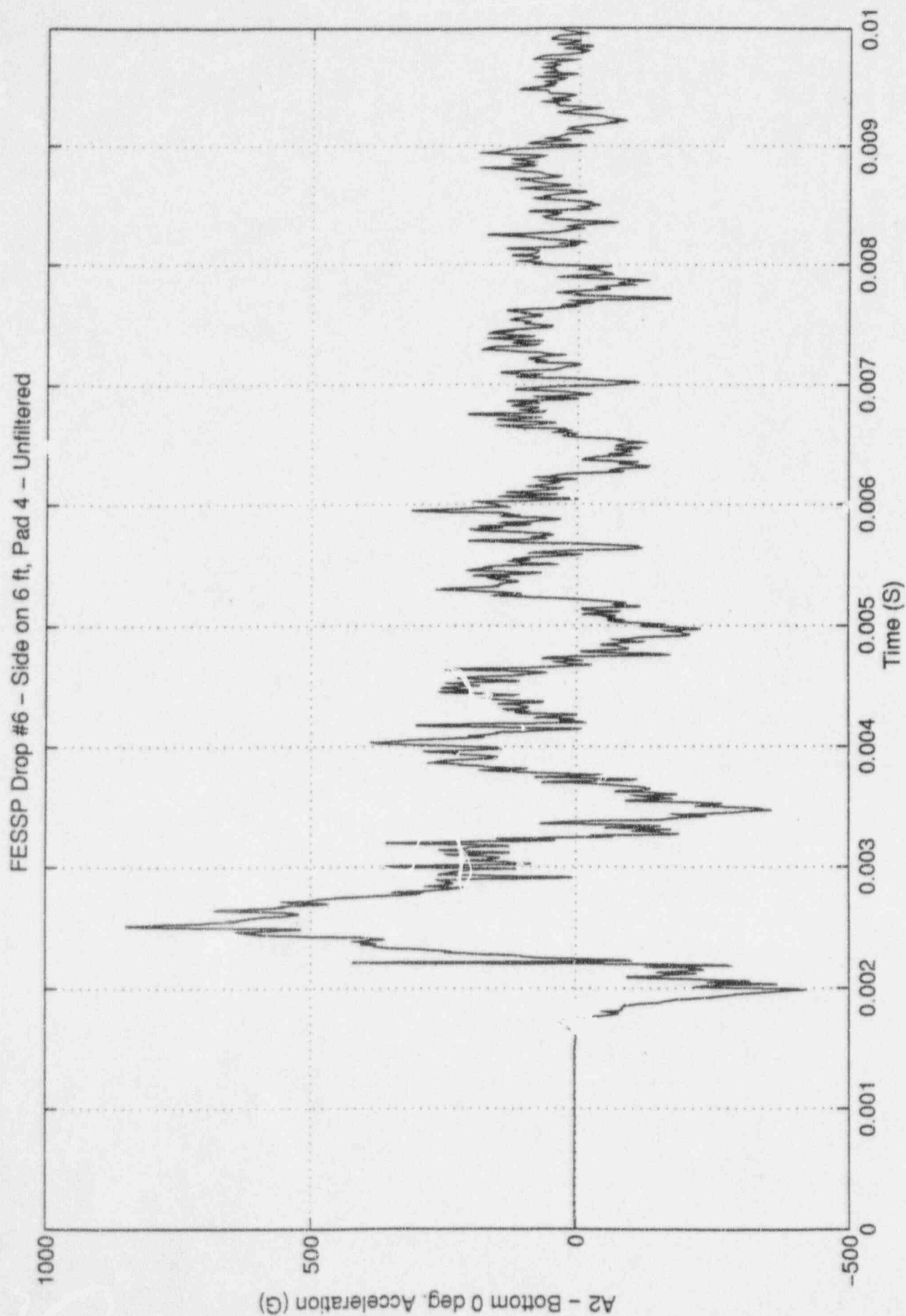


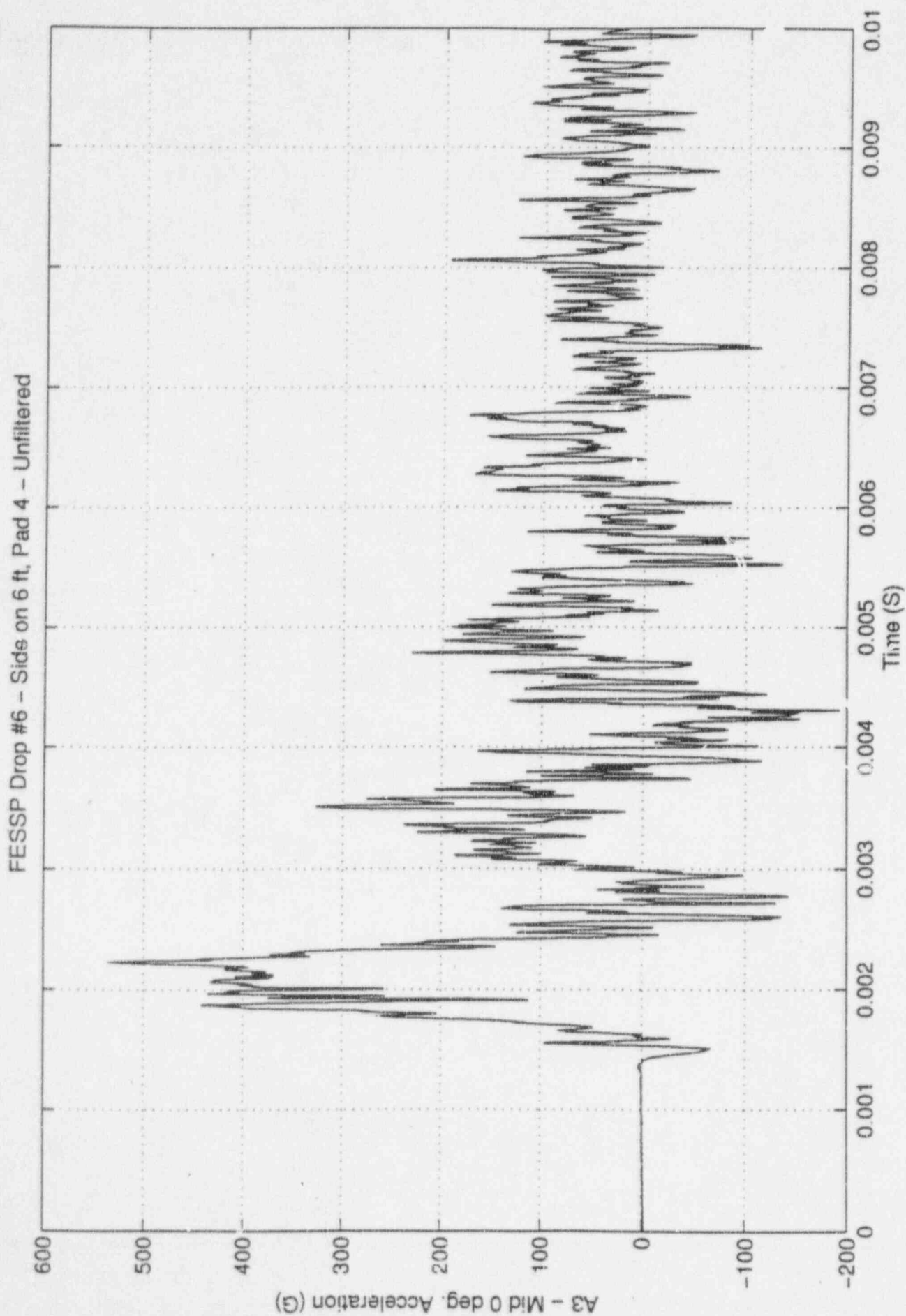
FESSP Drop #5 - Side on 1.5 ft, Pad 4



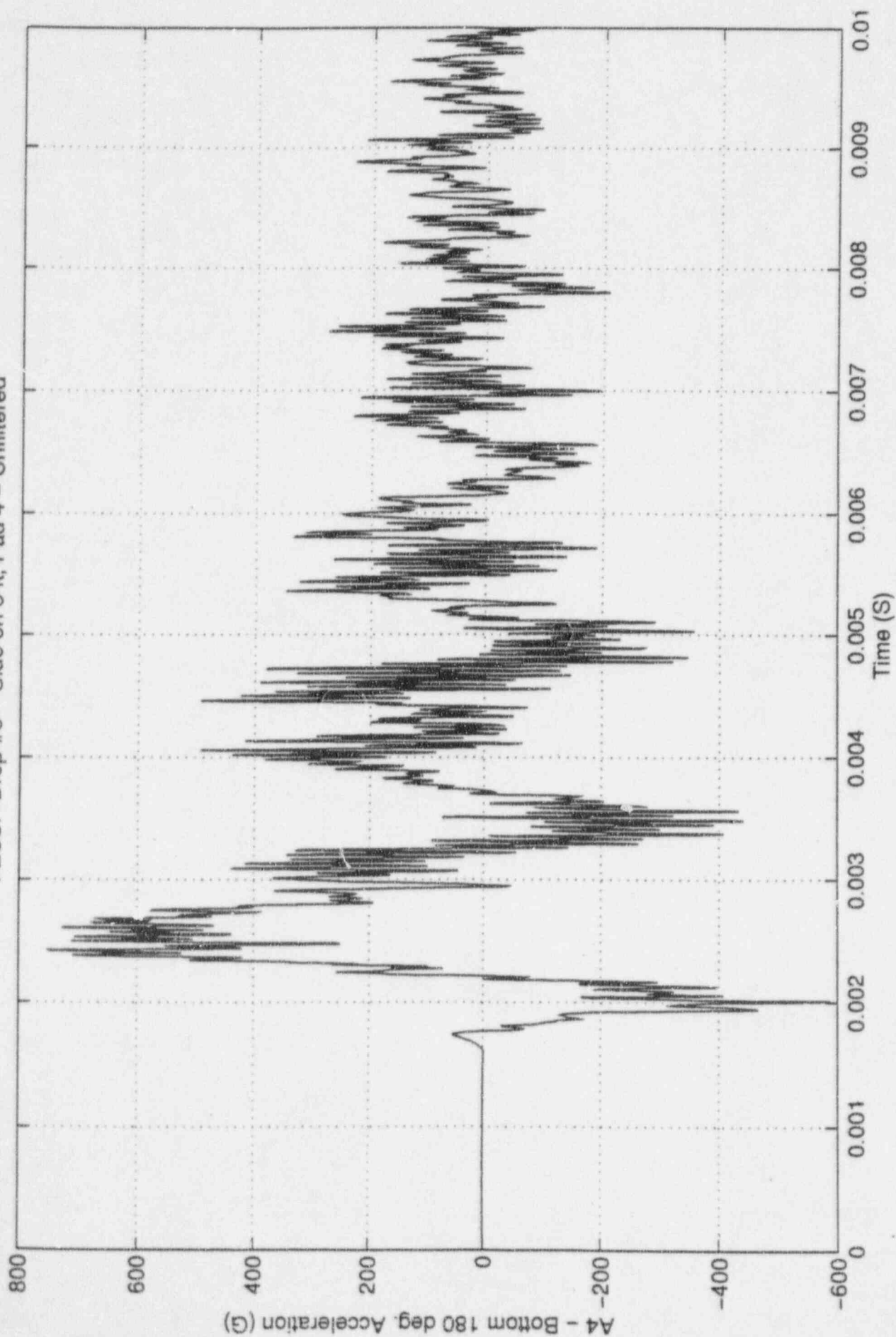




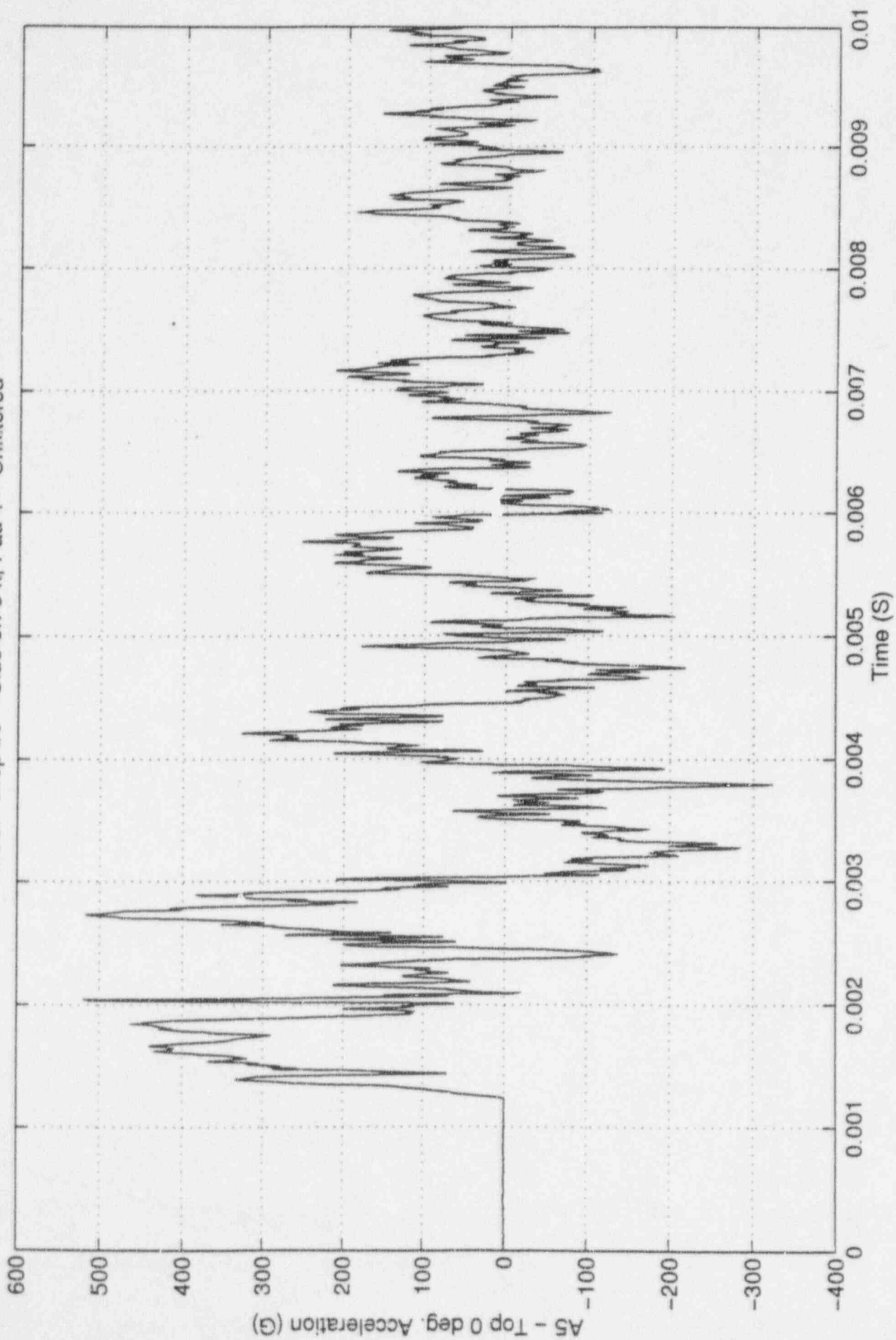




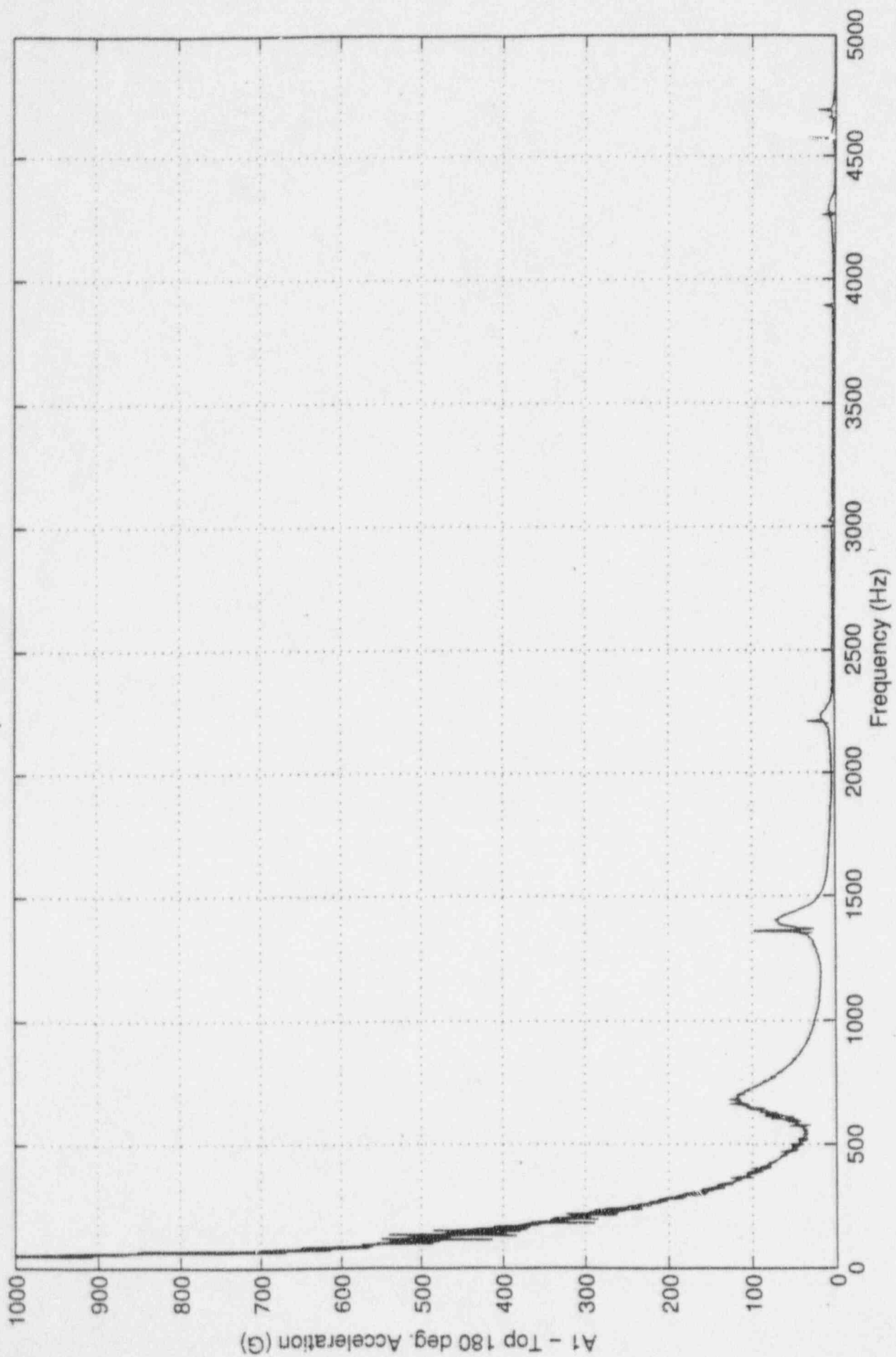
FESSP Drop #6 - Side on 6 ft, Pad 4 - Unfiltered



FESSP Drop #6 - Side on 6 ft, Pad 4 - Unfiltered

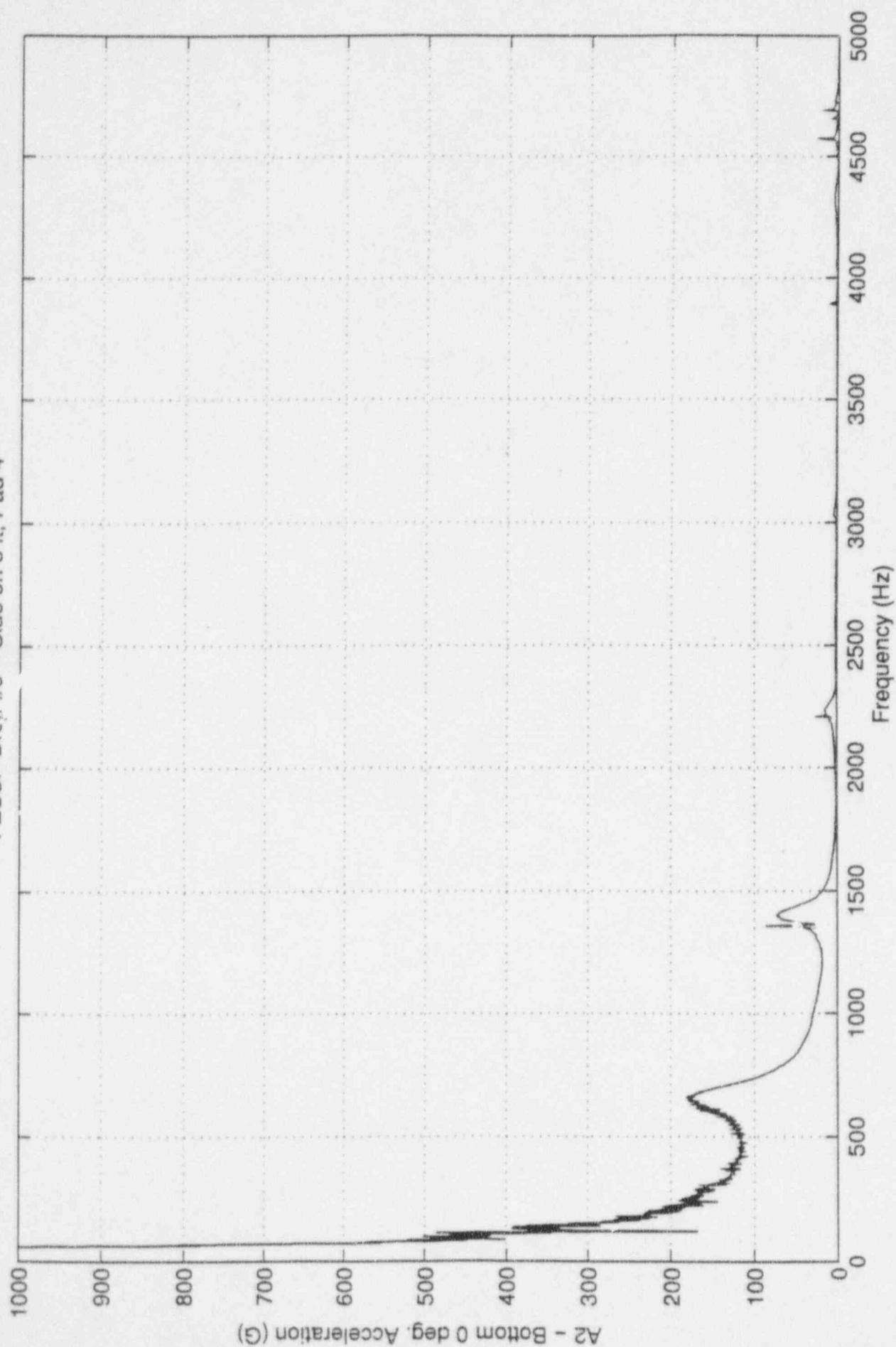


FESSP Drop #6 - Side on 6 ft, Pad 4

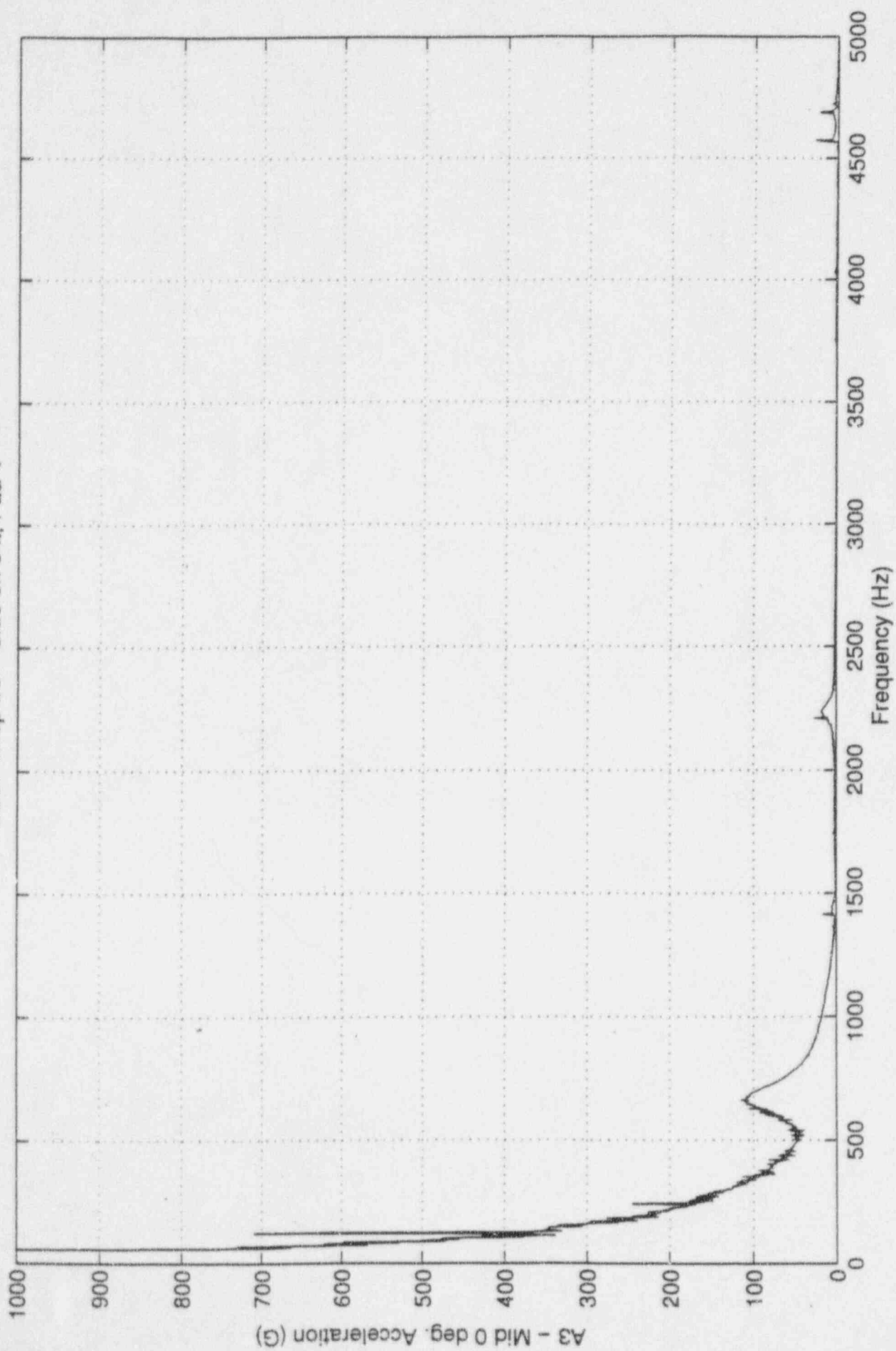




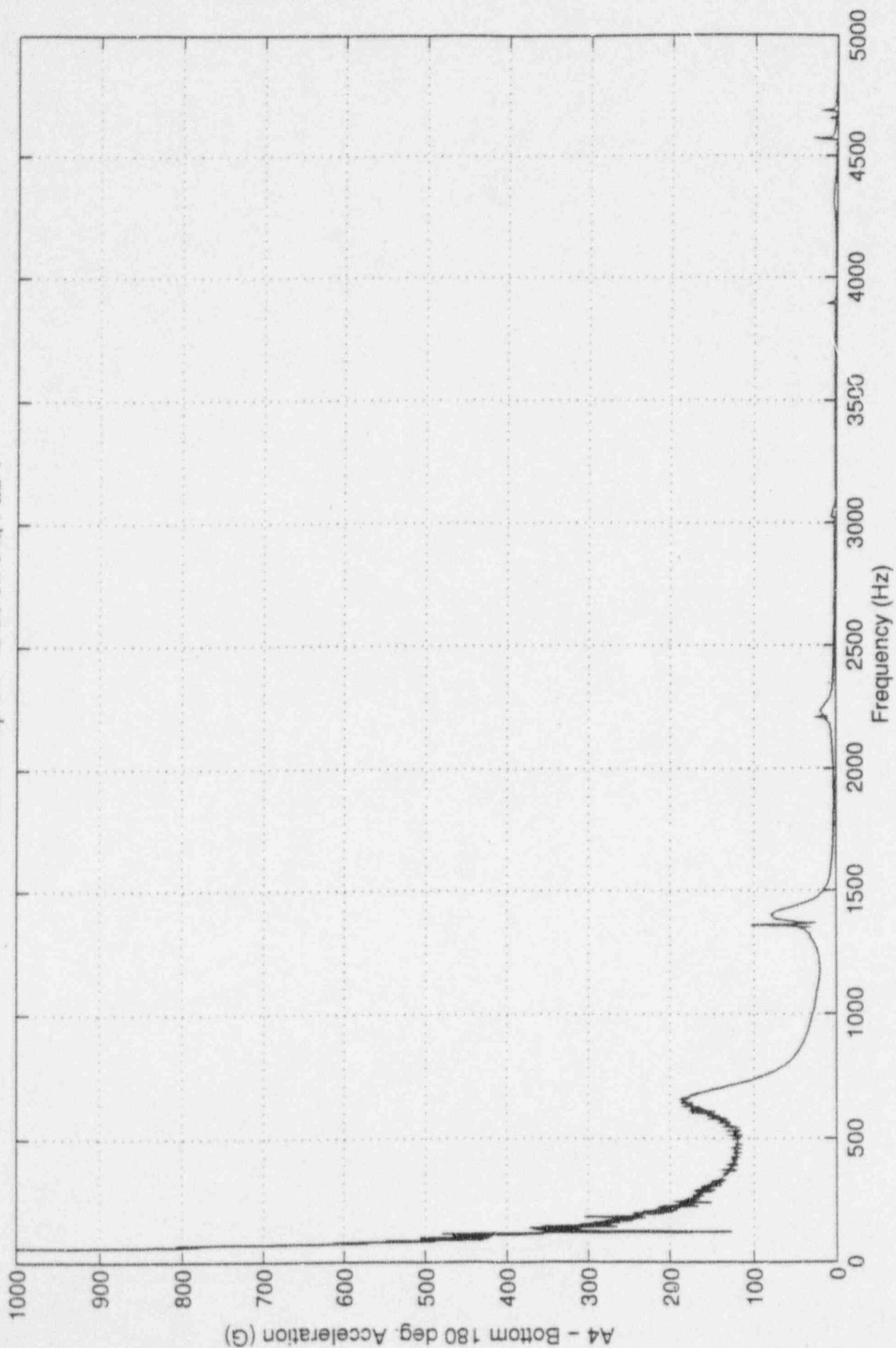
FESSP Drop #6 - Side on 6 ft. Pad 4

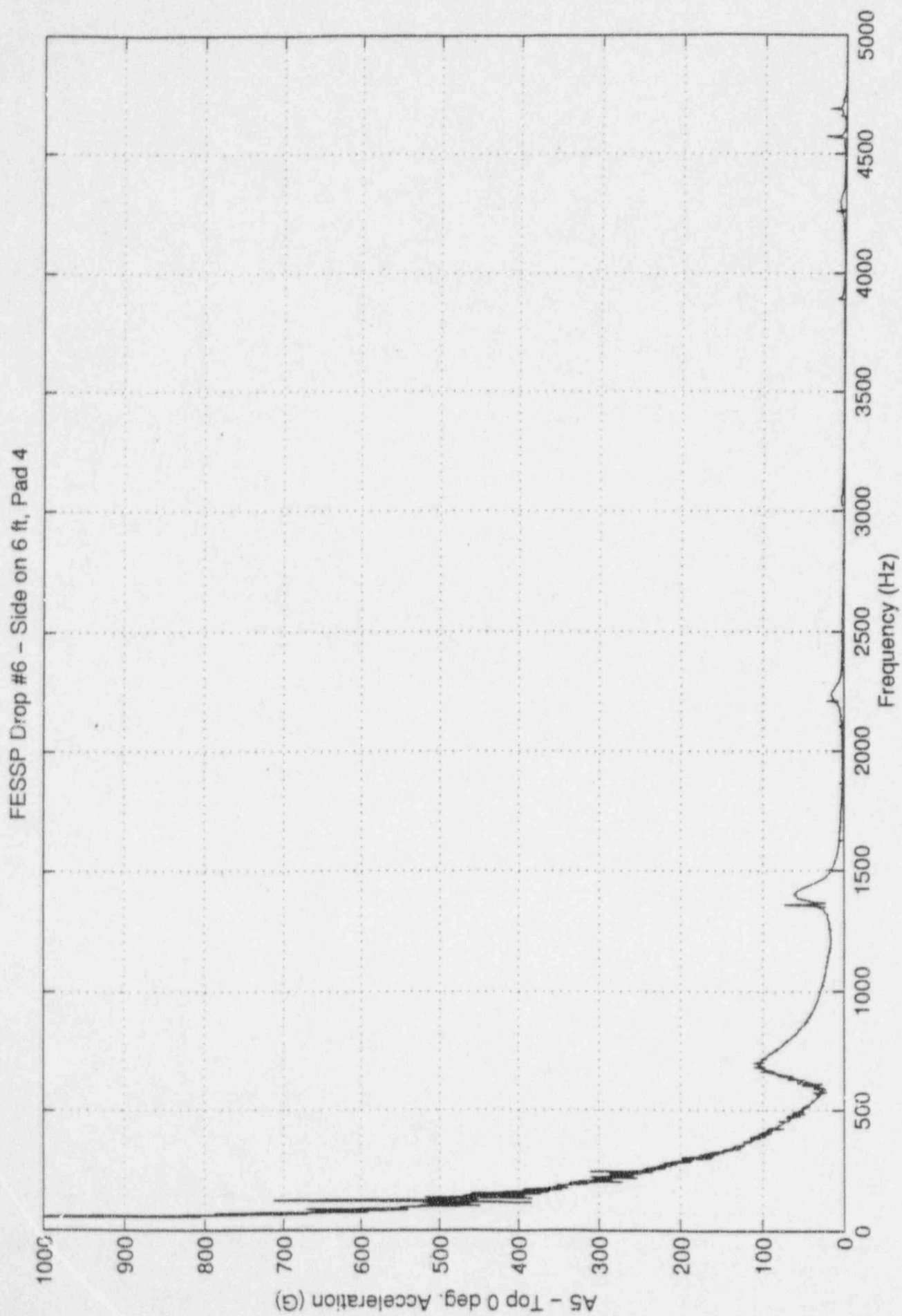


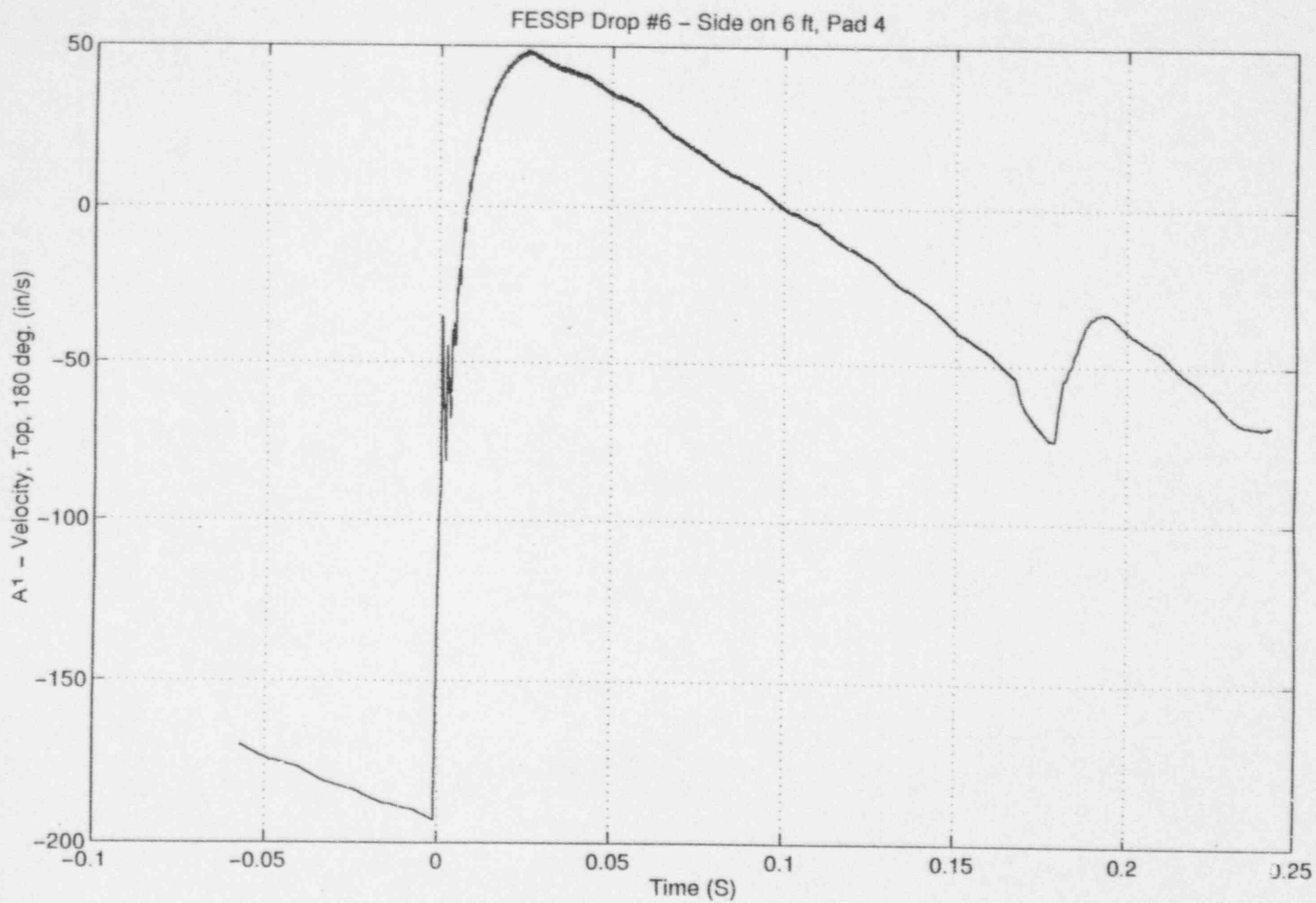
FESSP Drop #6 - Side on 6 ft, Pad 4



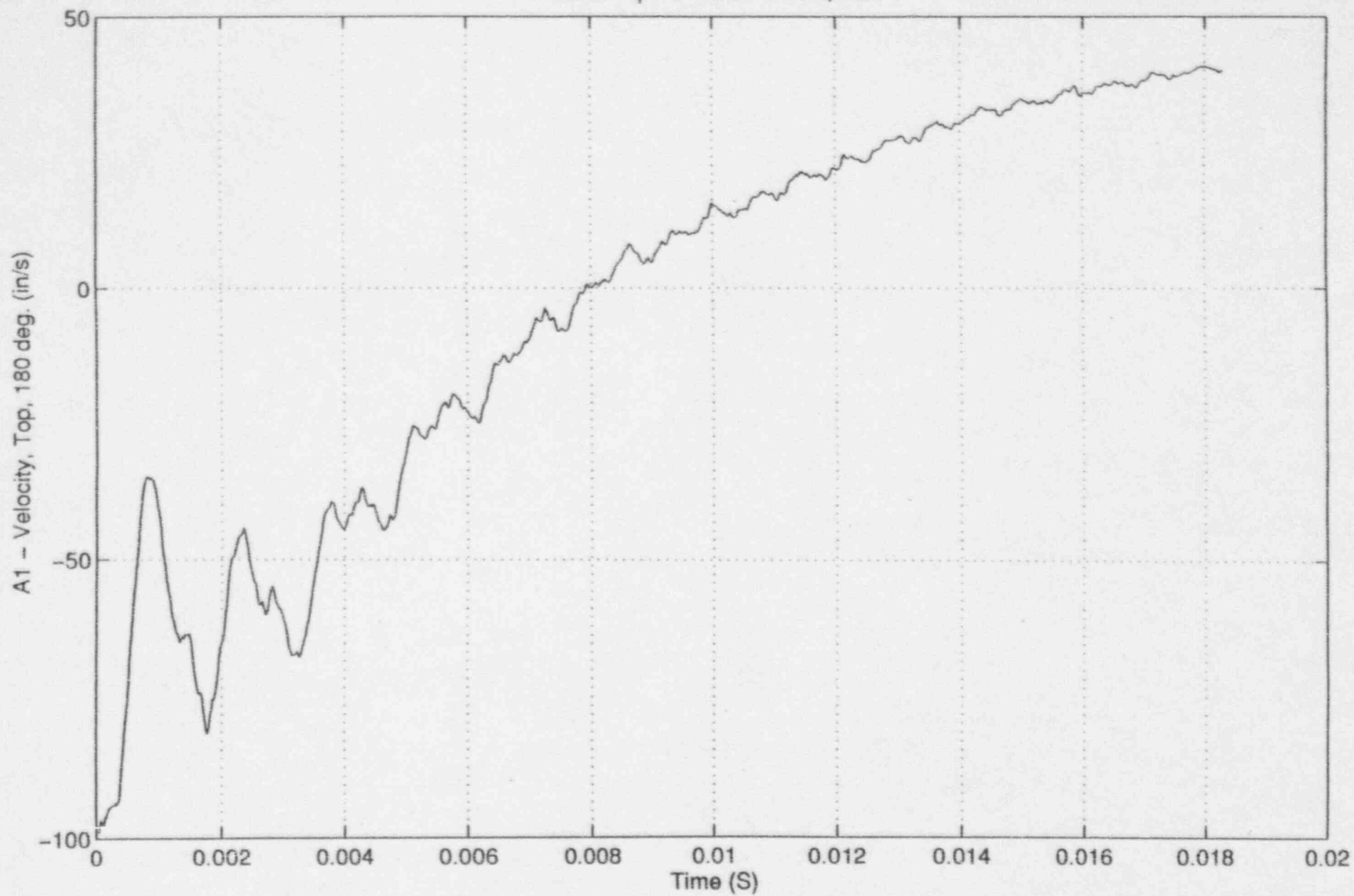
FESSP Drop #6 - Side on 6 ft, Pad 4





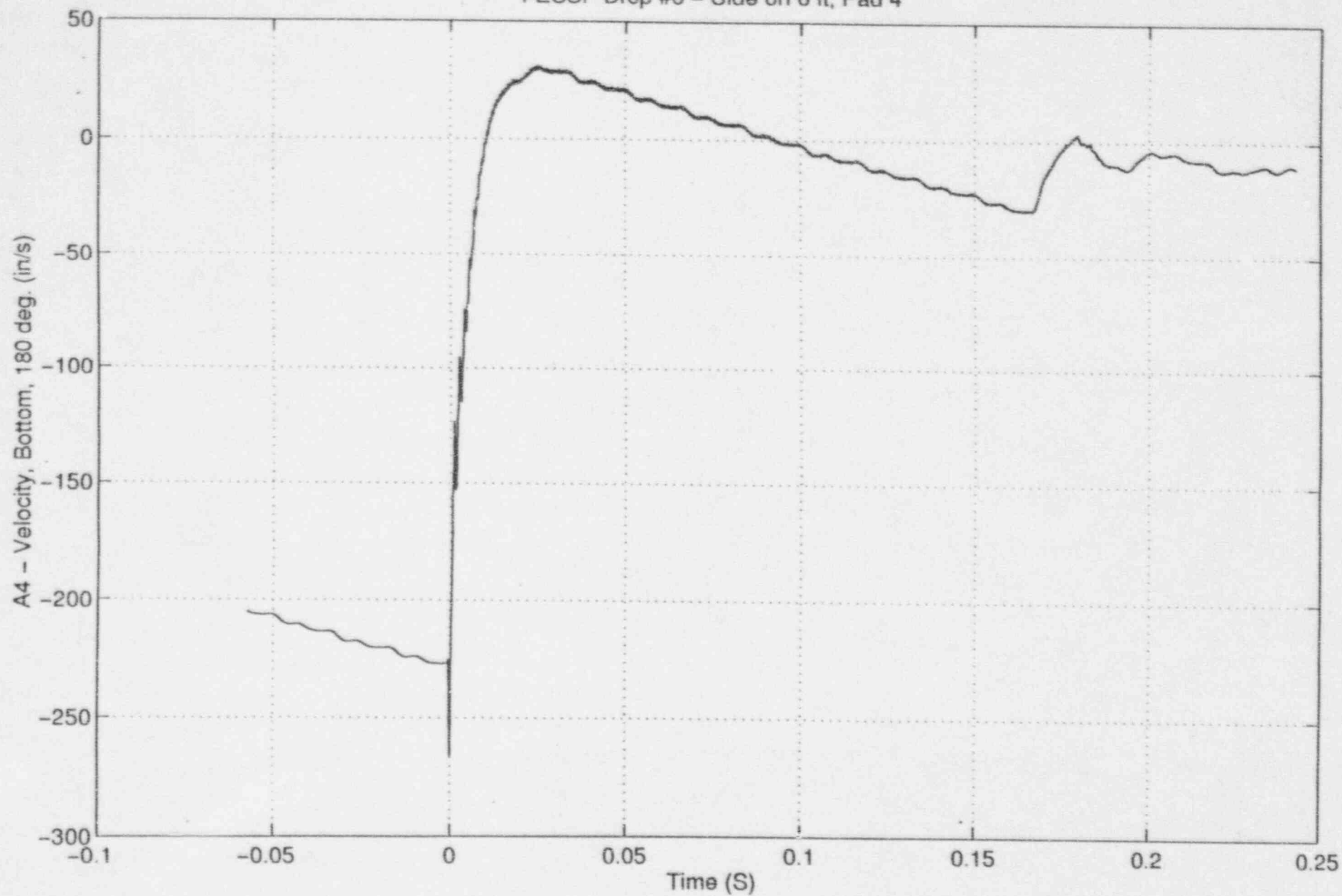


FESSP Drop #6 - Side on 6 ft, Pad 4

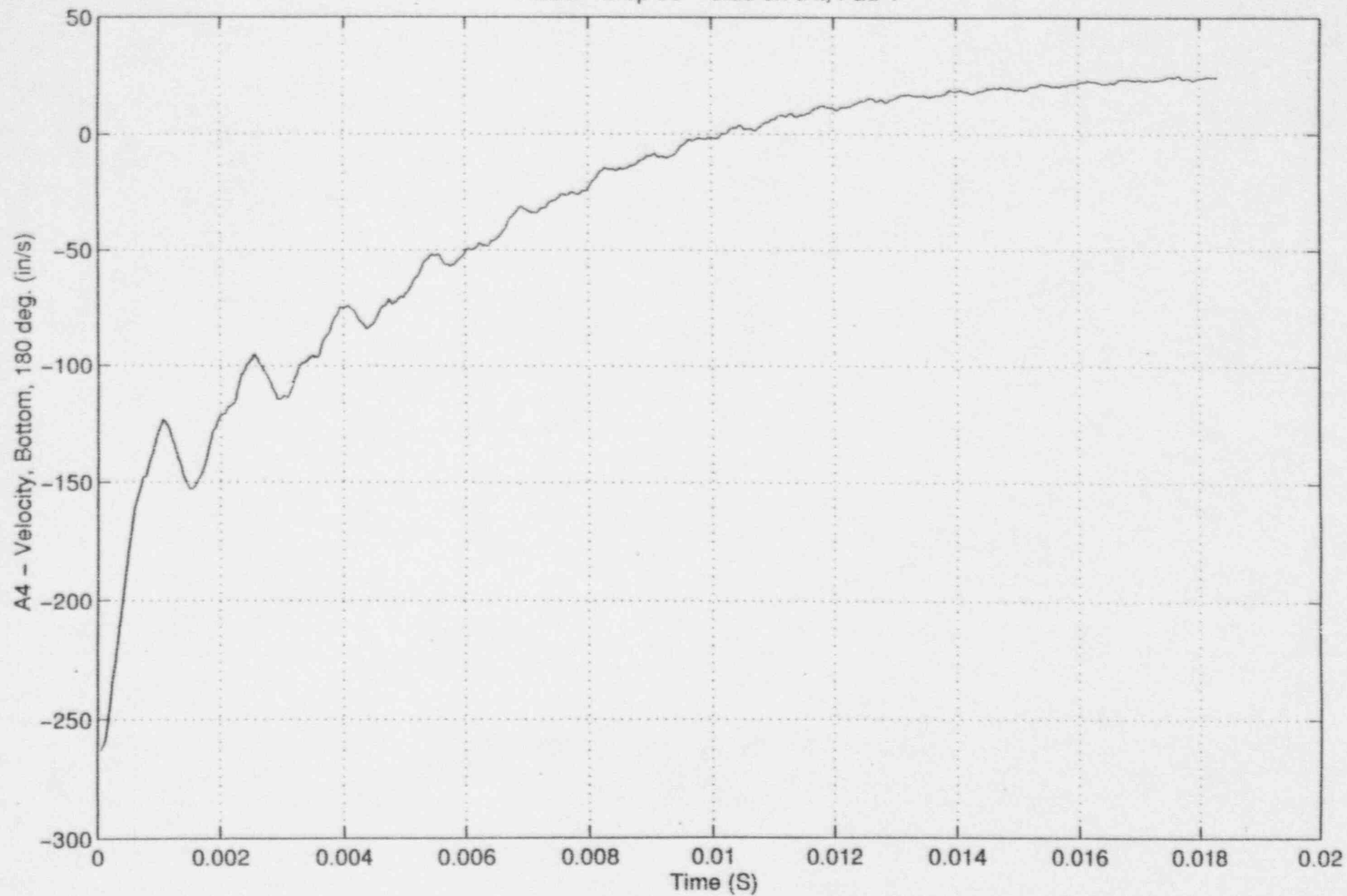




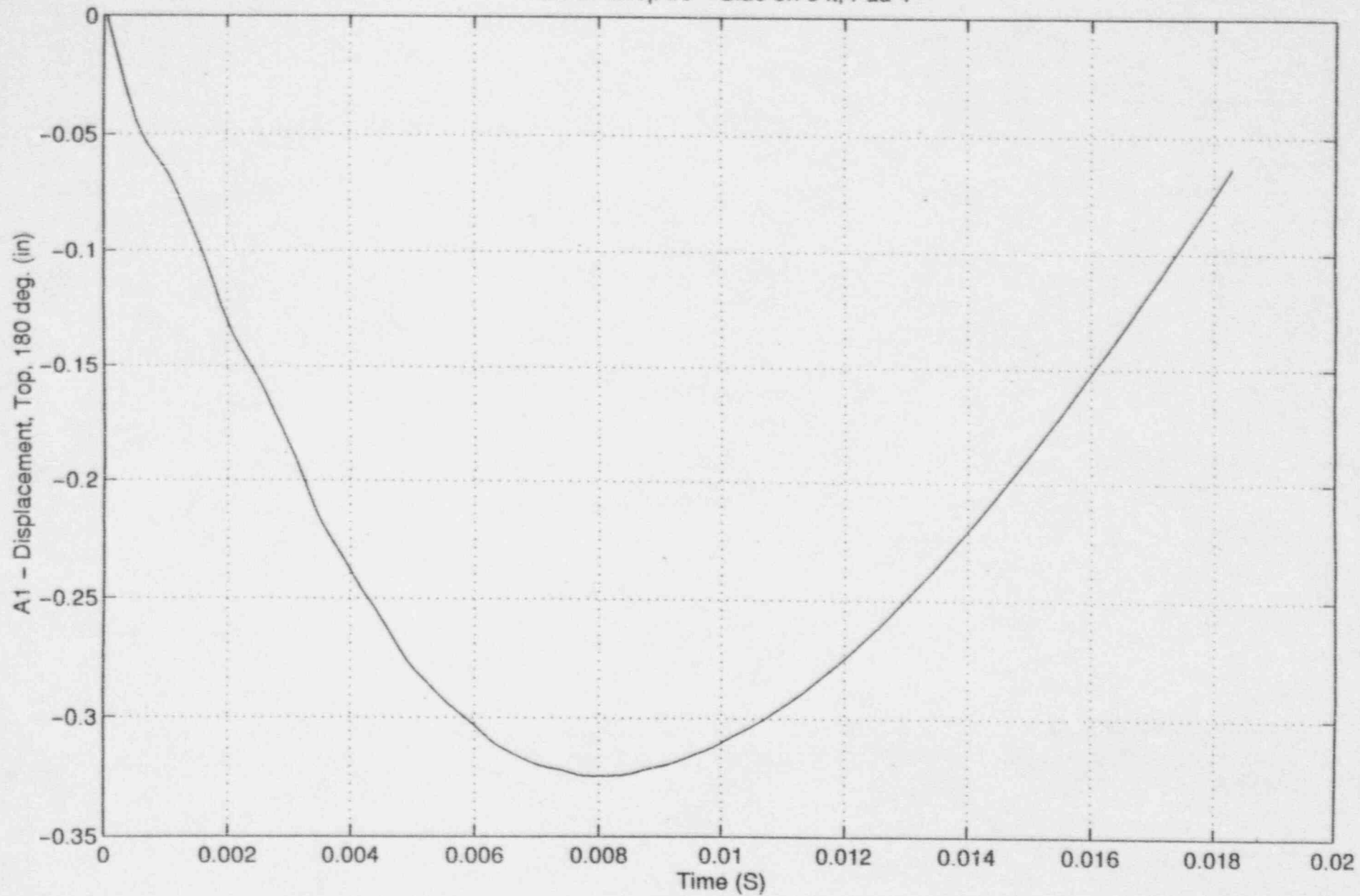
FESSP Drop #6 - Side on 6 ft, Pad 4



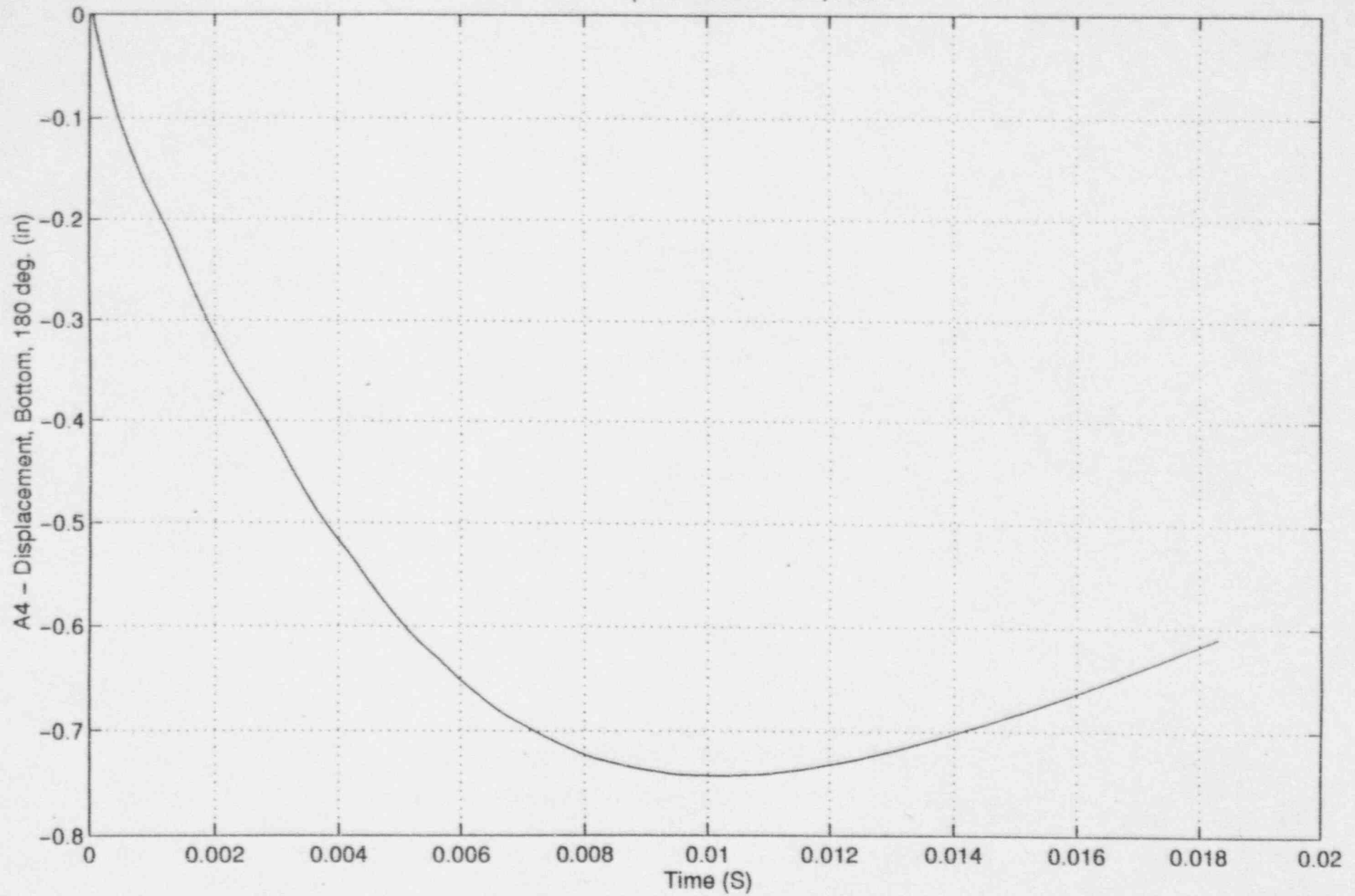
FESSP Drop #6 - Side on 6 ft, Pad 4

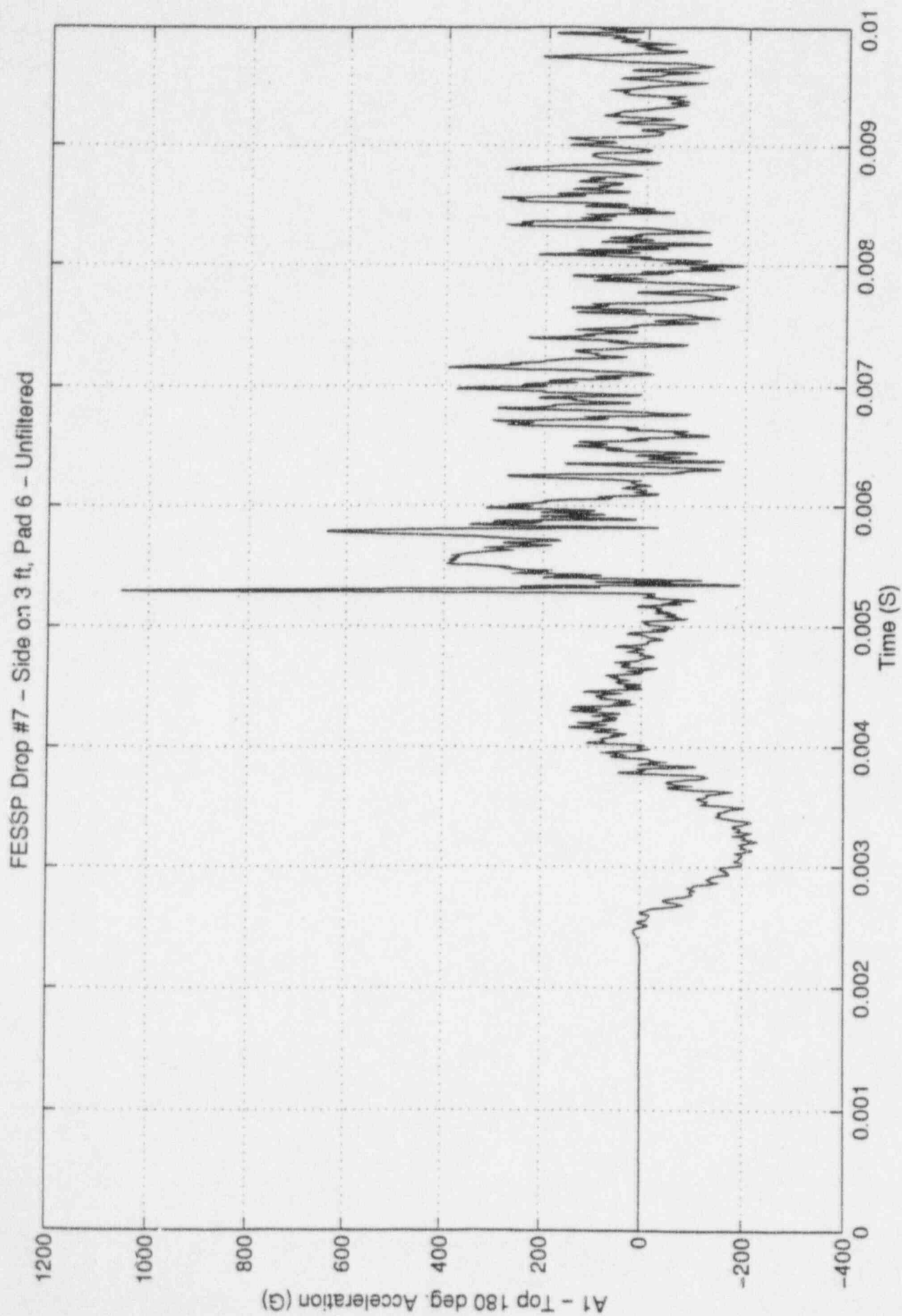


FESSP Drop #6 - Side on 6 ft, Pad 4

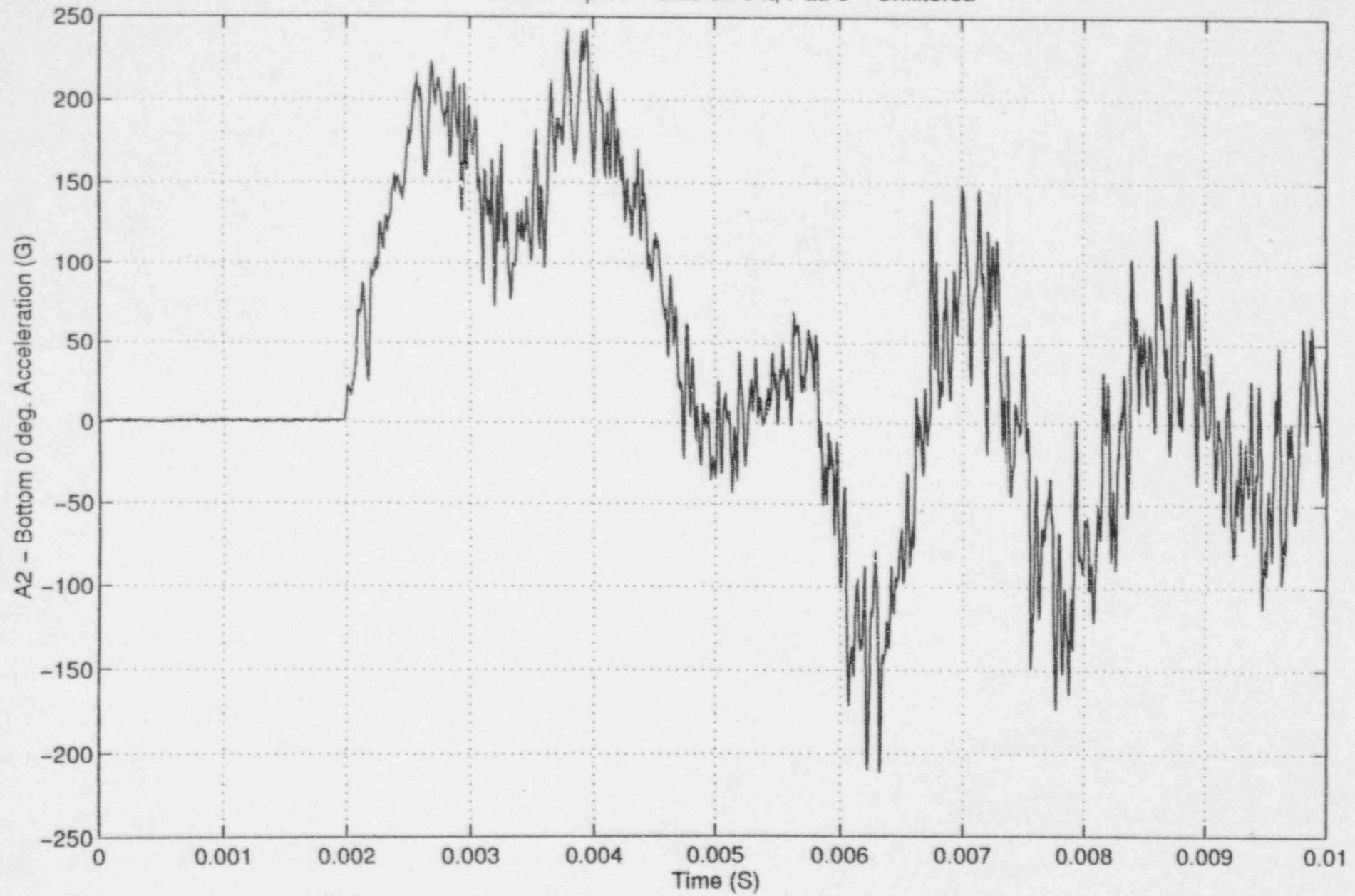


FESSP Drop #6 - Side on 6 ft, Pad 4



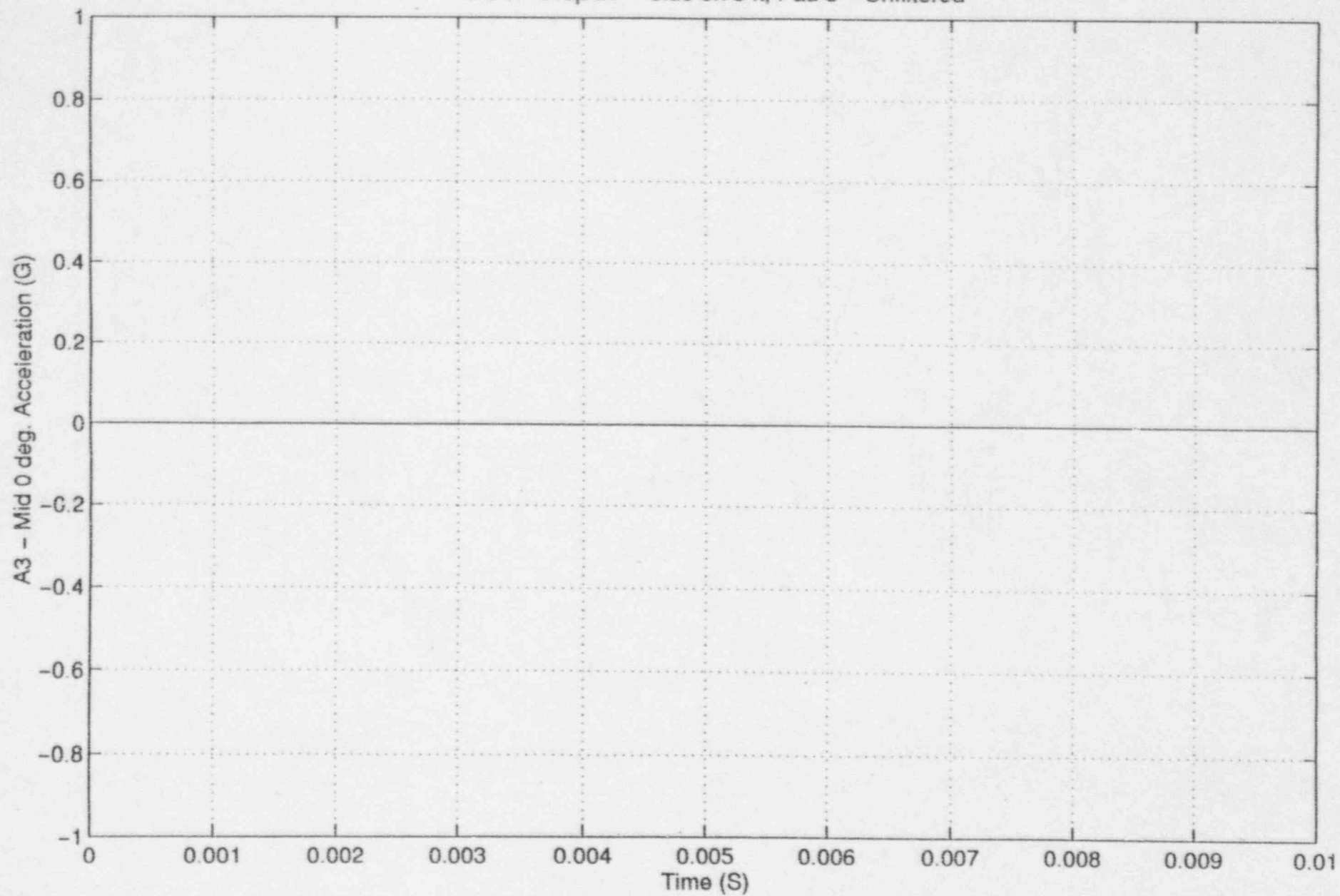


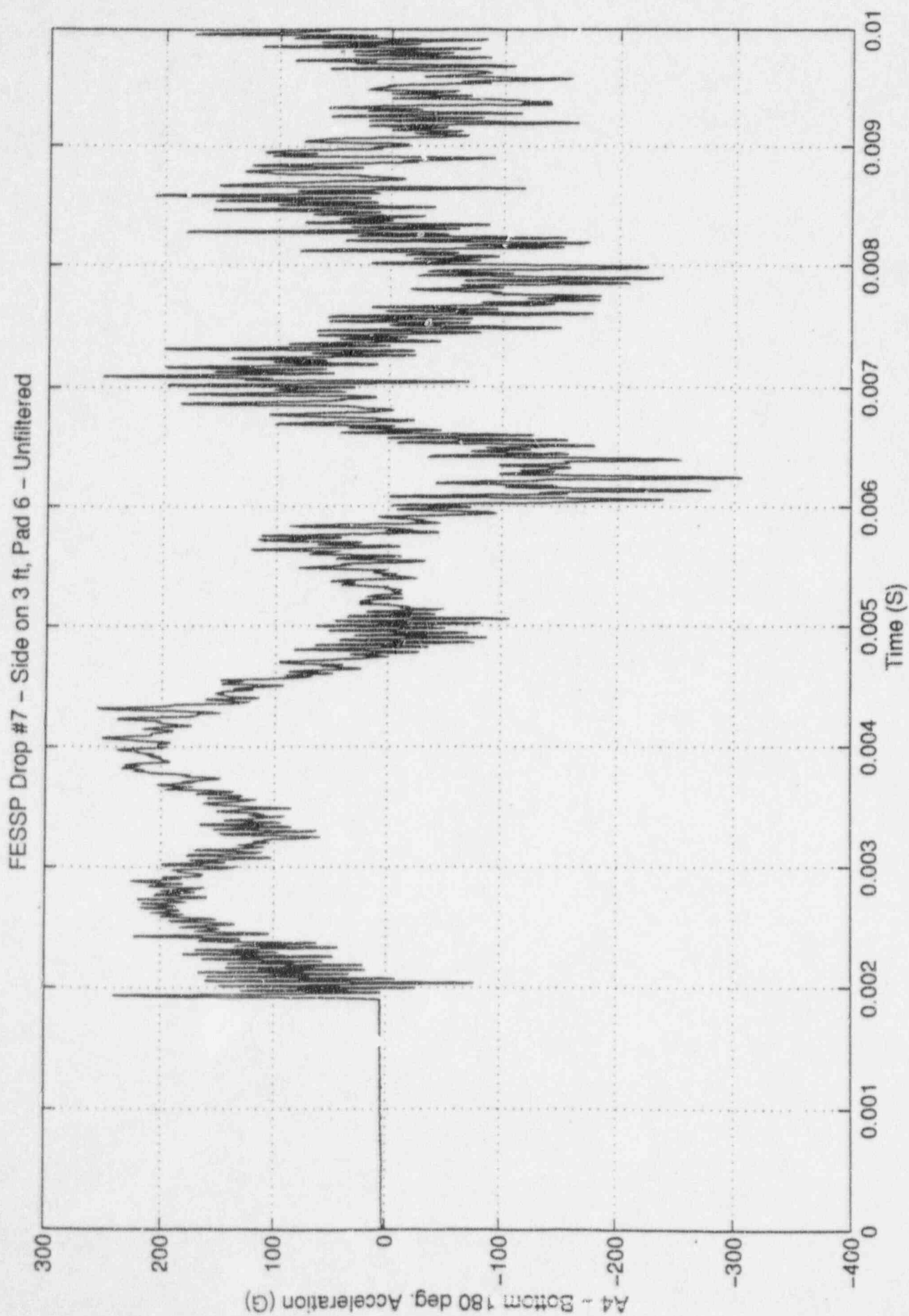
FESSP Drop #7 - Side on 3 ft, Pad 6 - Unfiltered



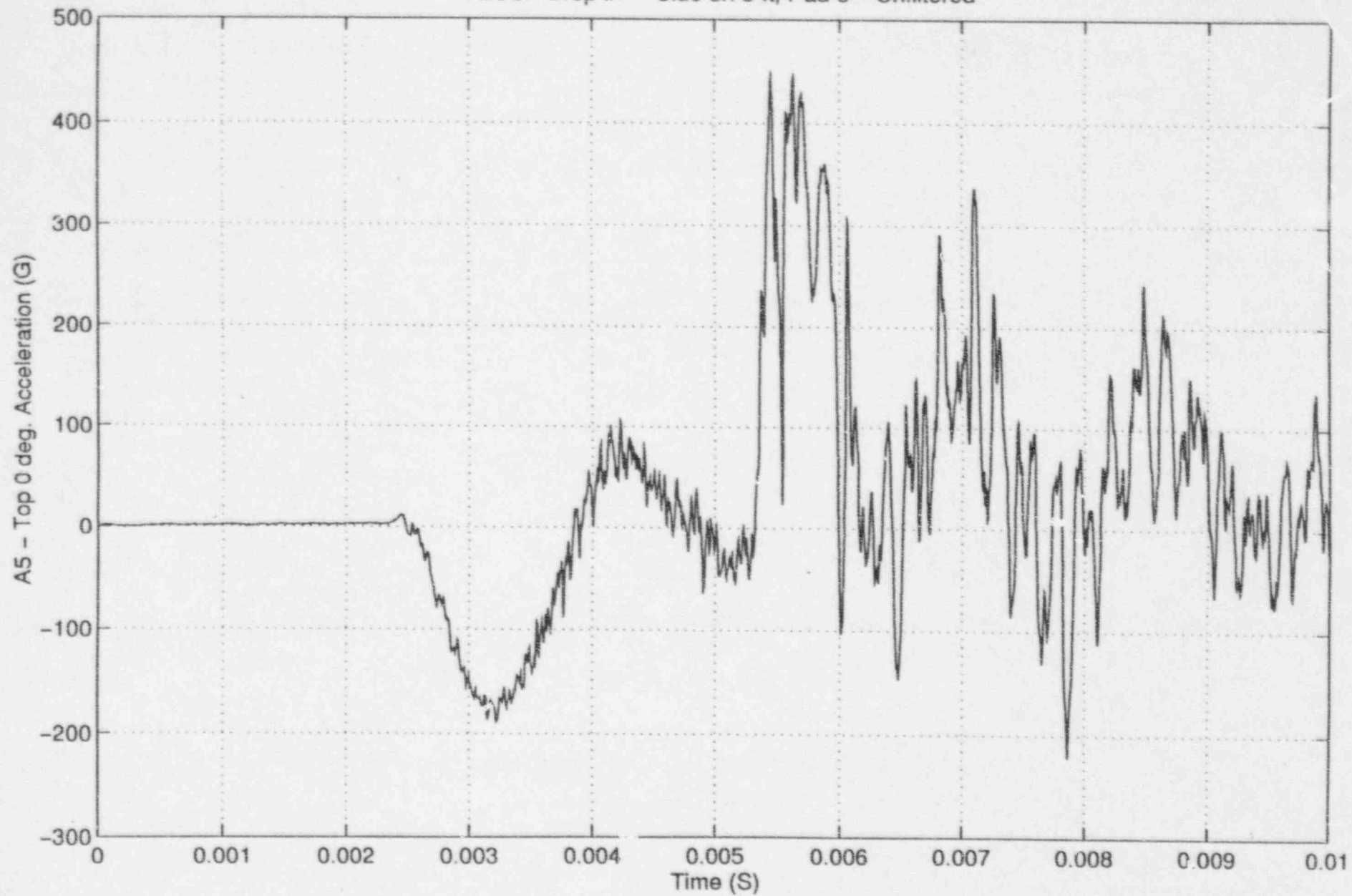


FESSP Drop #7 - Side on 3 ft, Pad 6 - Unfiltered

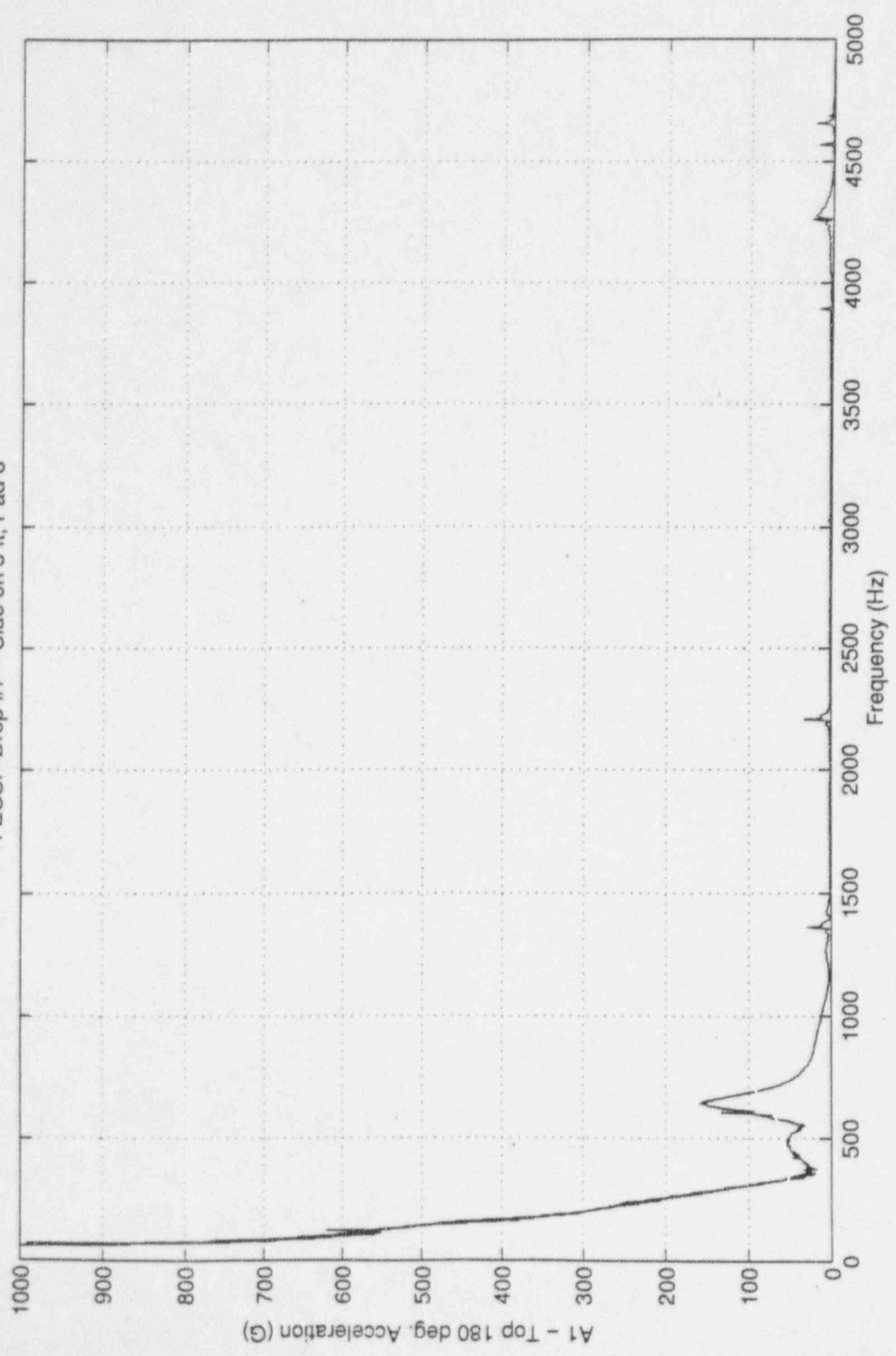


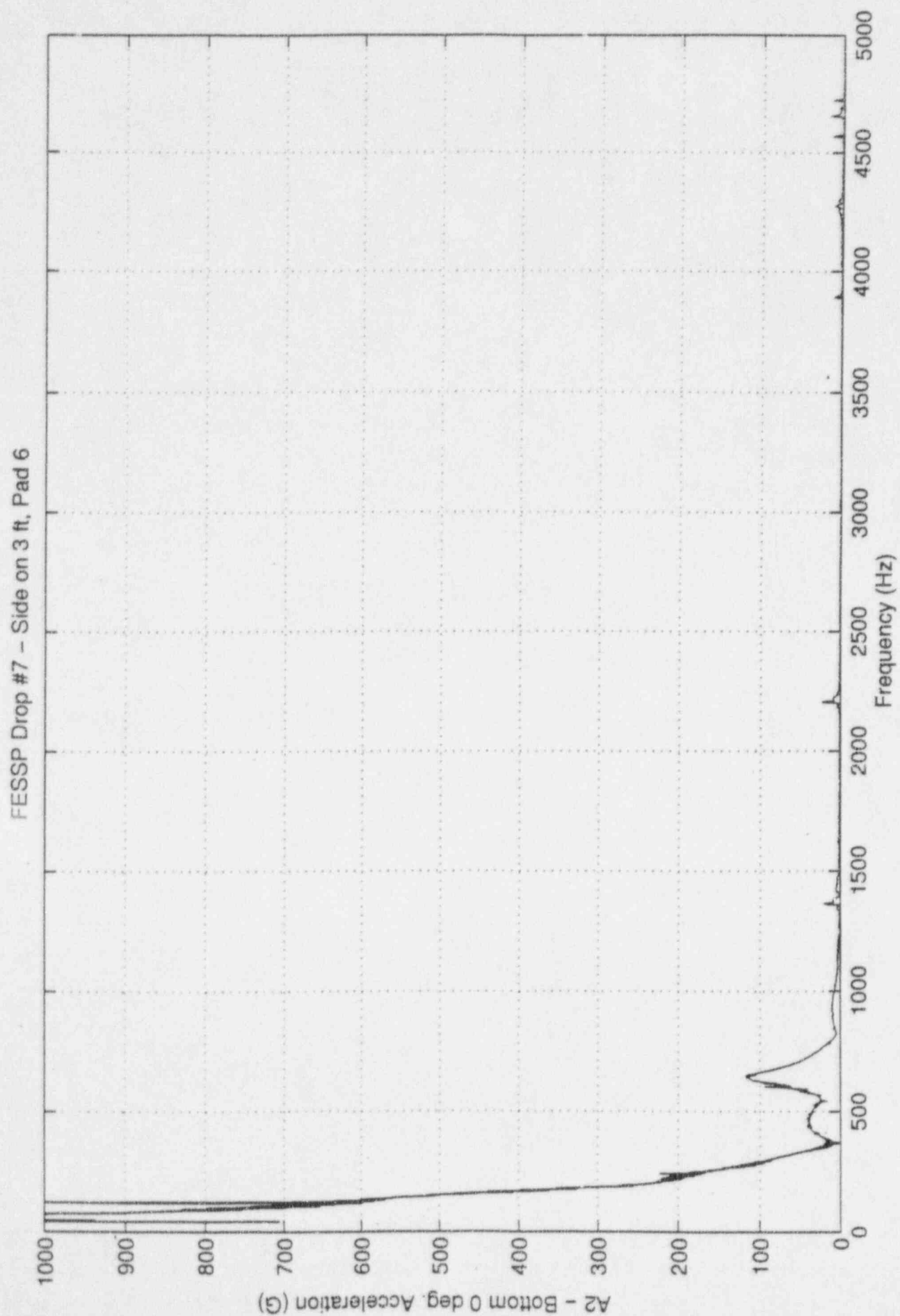


FESSP Drop #7 - Side on 3 ft, Pad 6 - Unfiltered

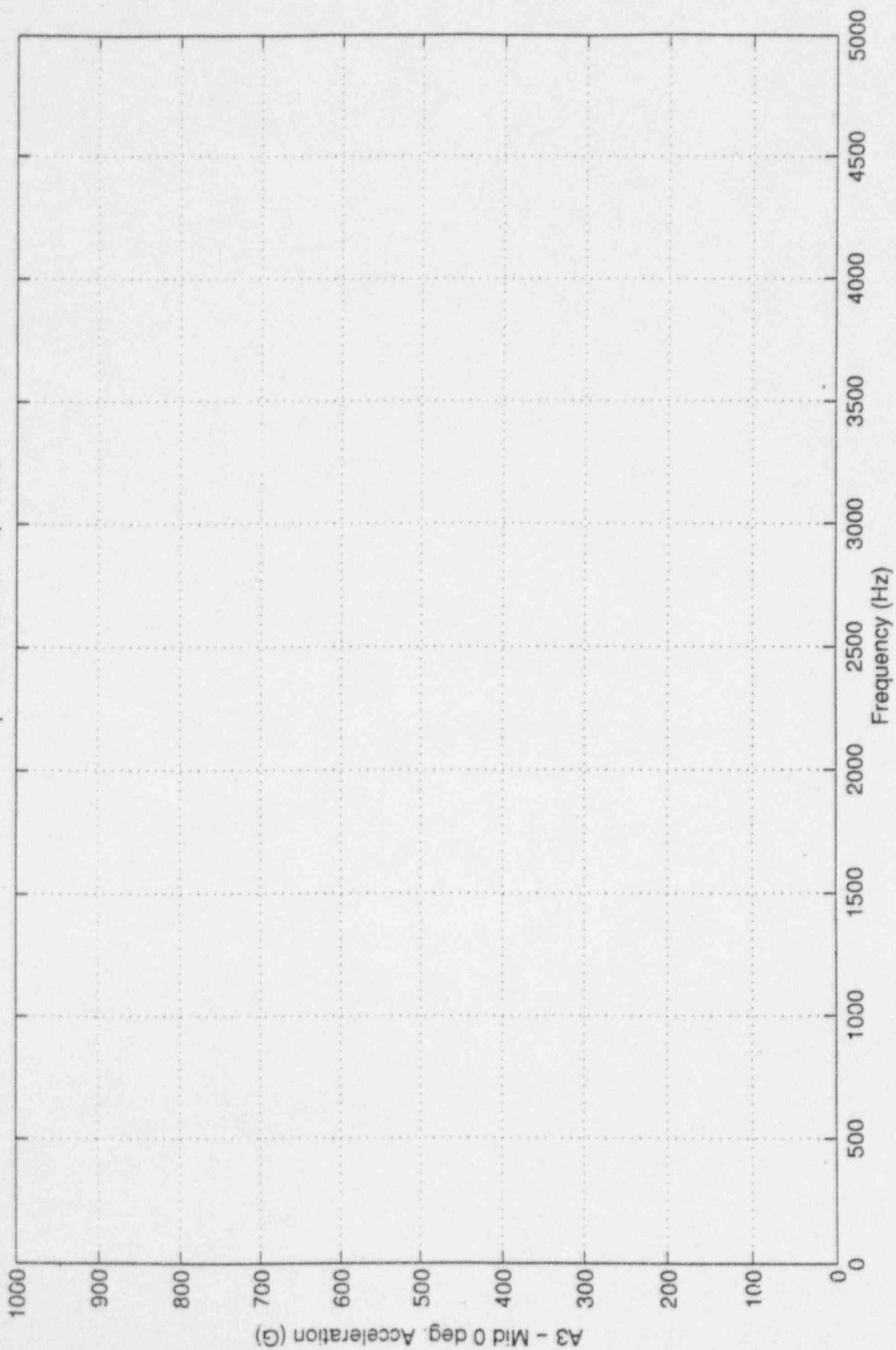


FESSP Drop #7 - Side on 3 ft, Pad 6

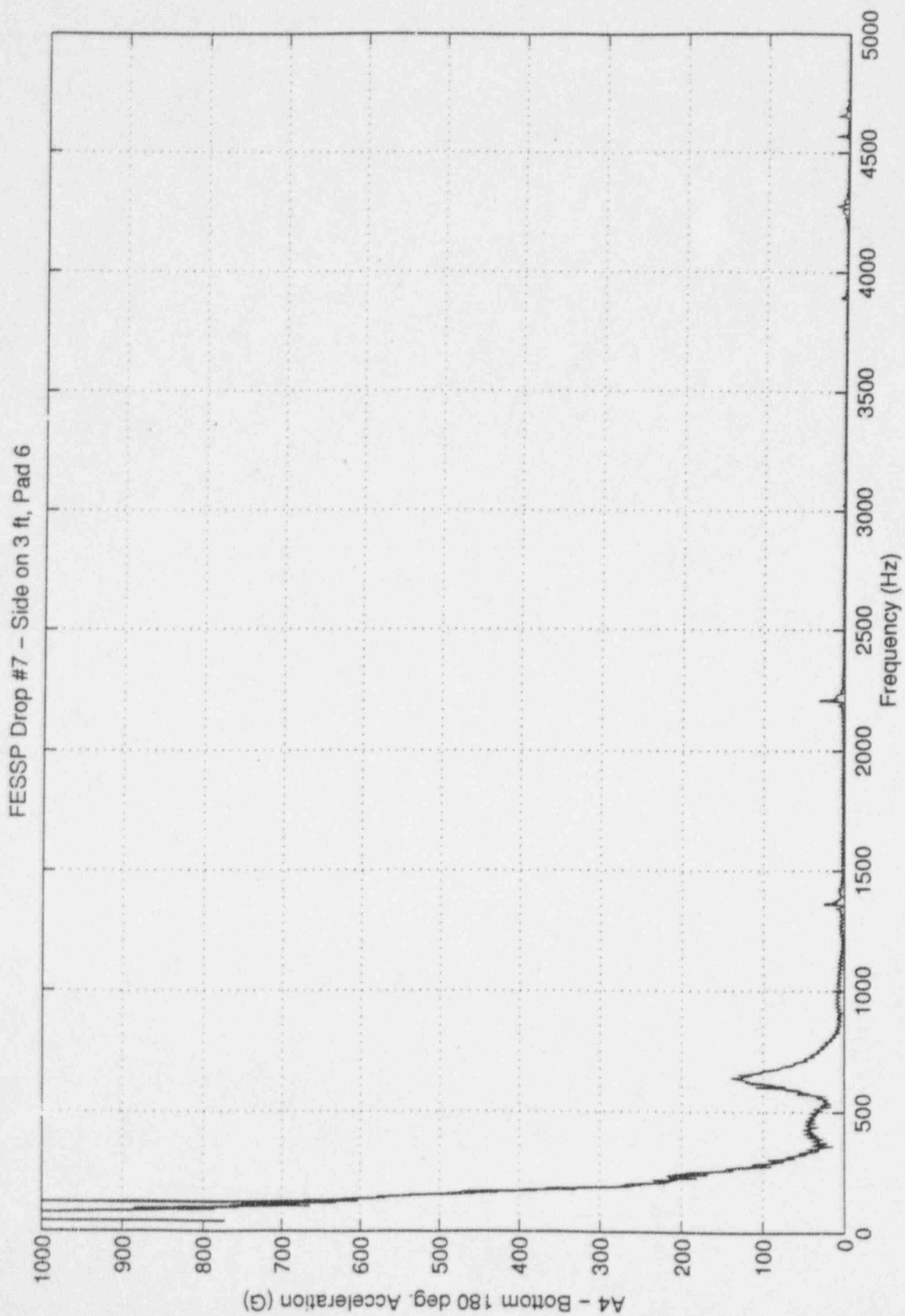




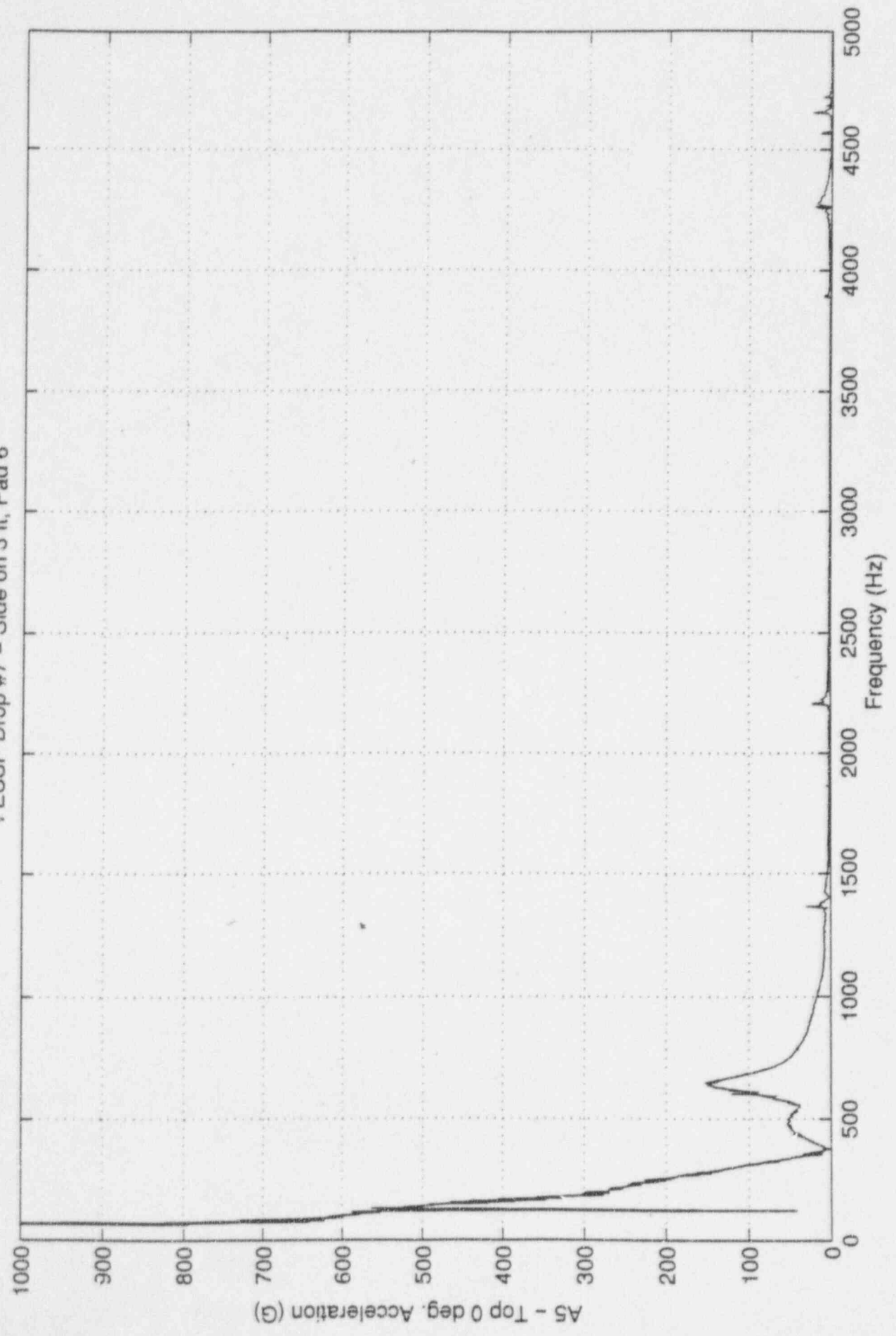
FESSP Drop #7 - Side on 3 ft, Pad 6

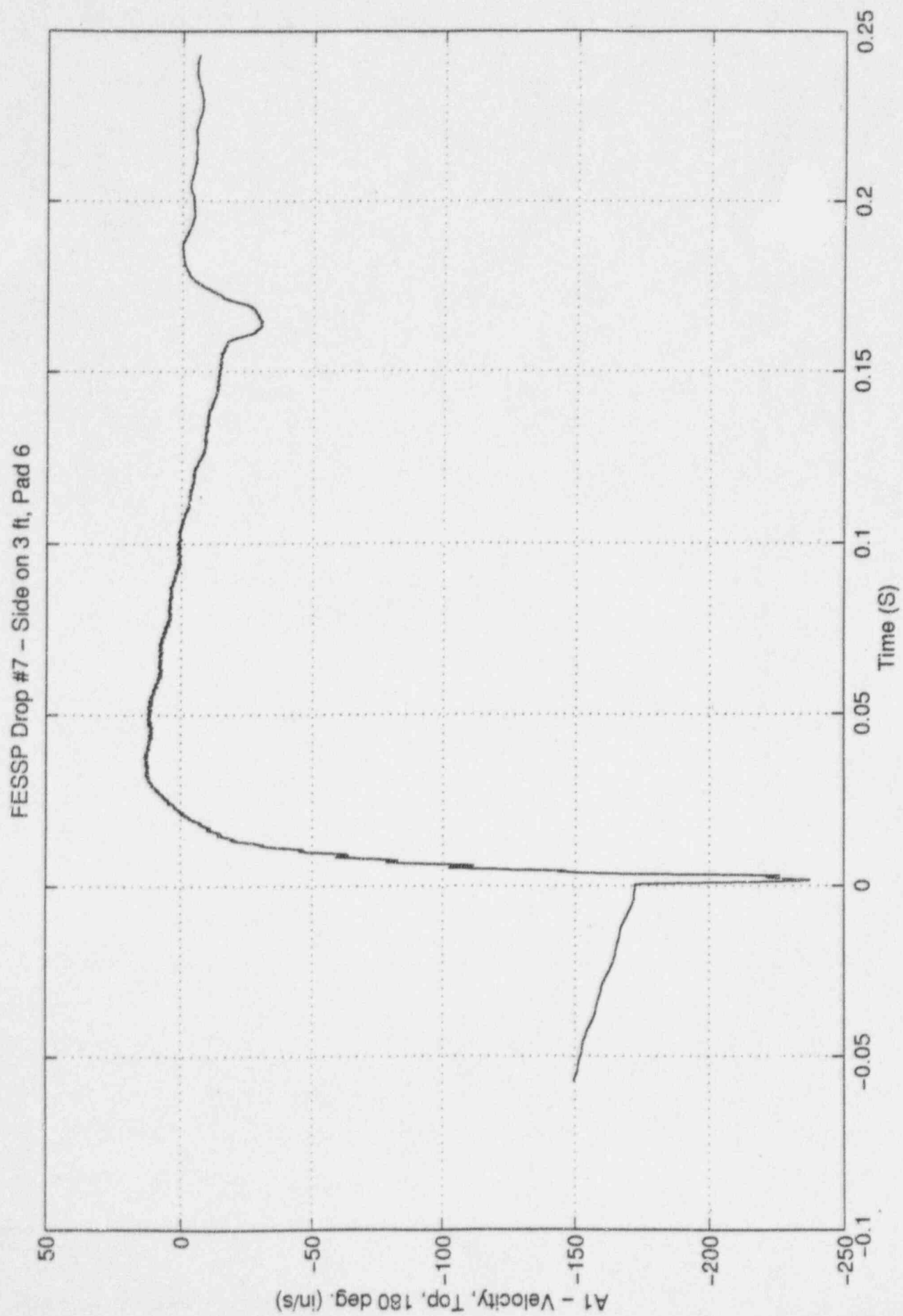




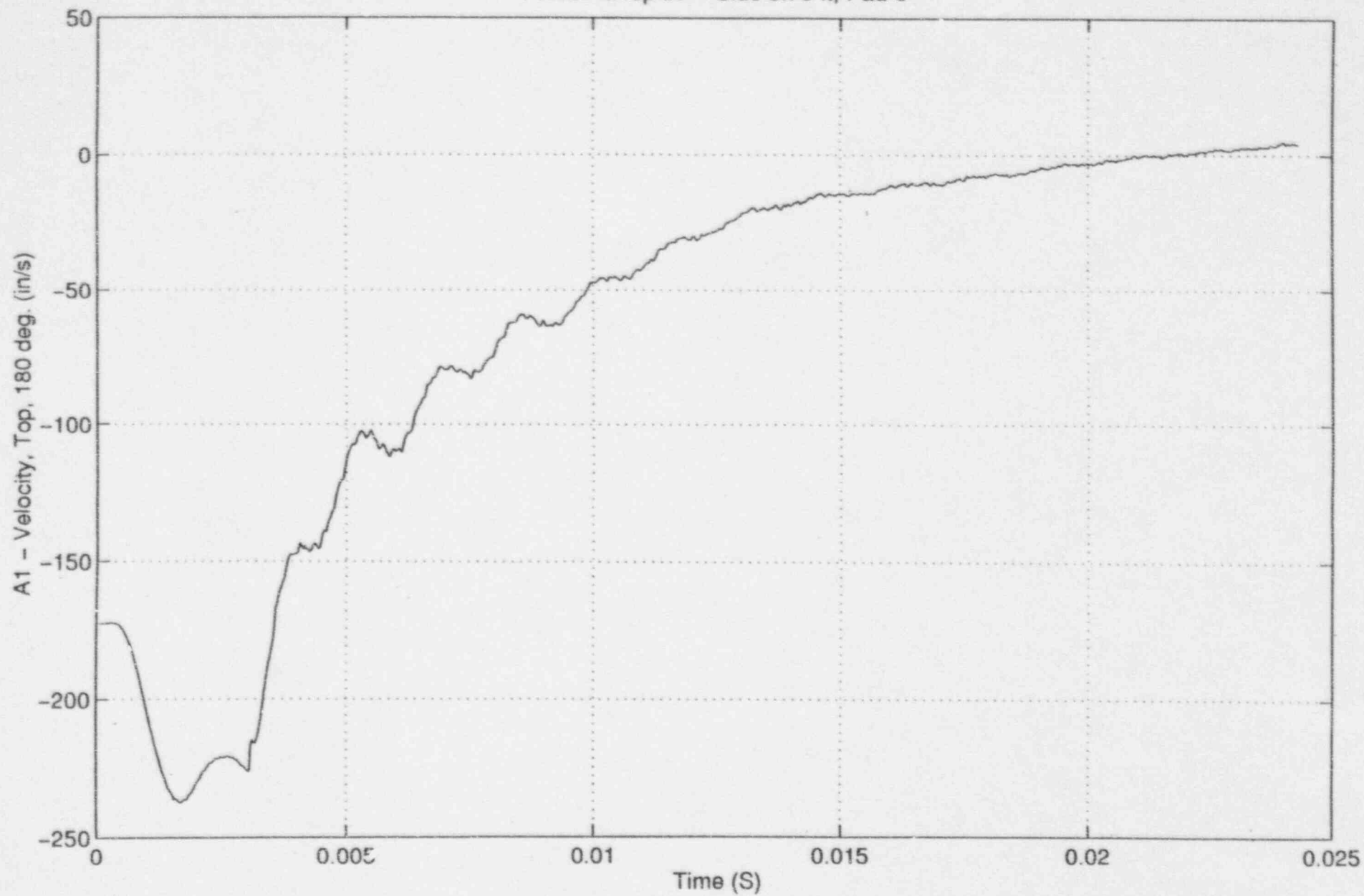


FESSP Drop #7 - Side on 3 ft, Pad 6

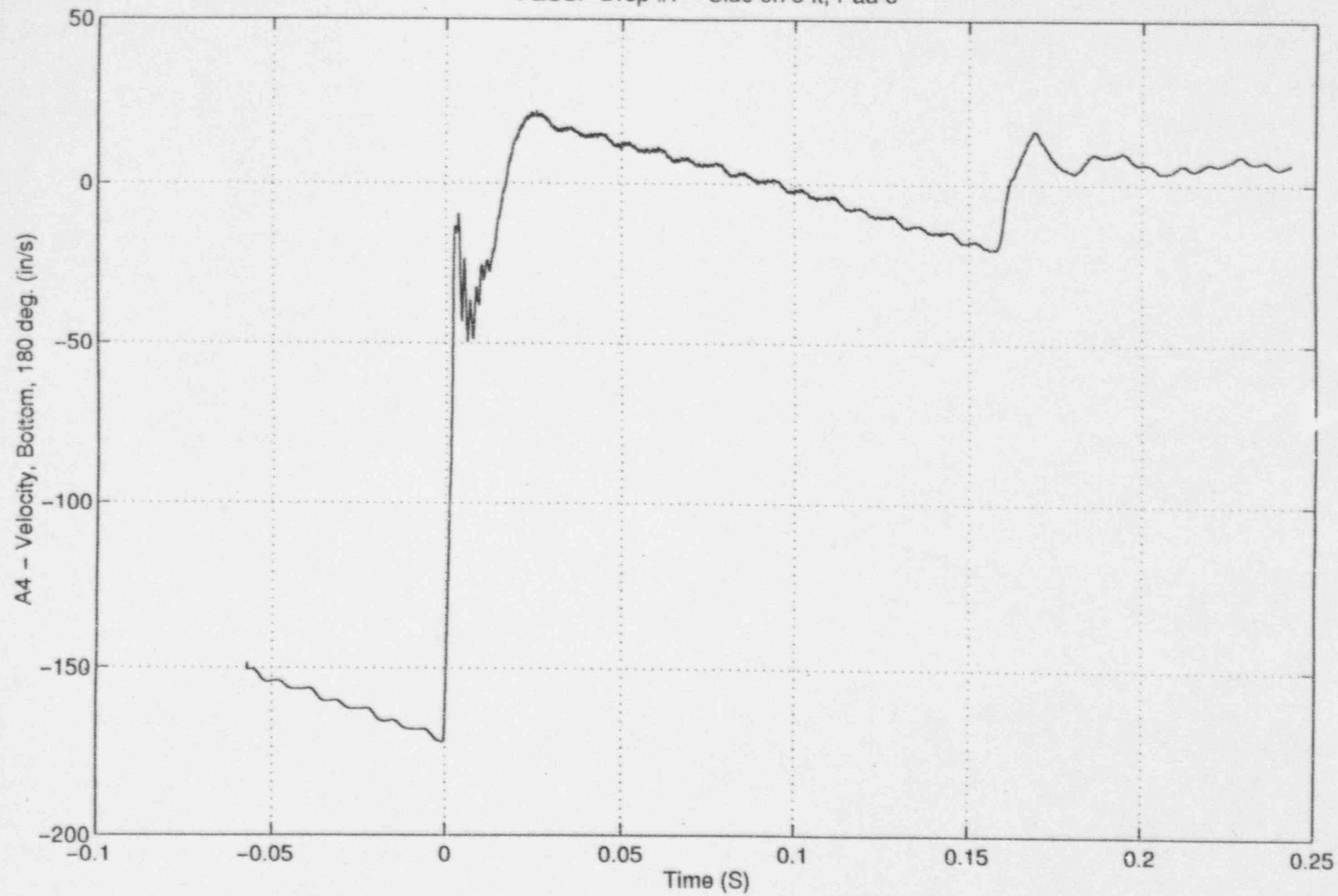




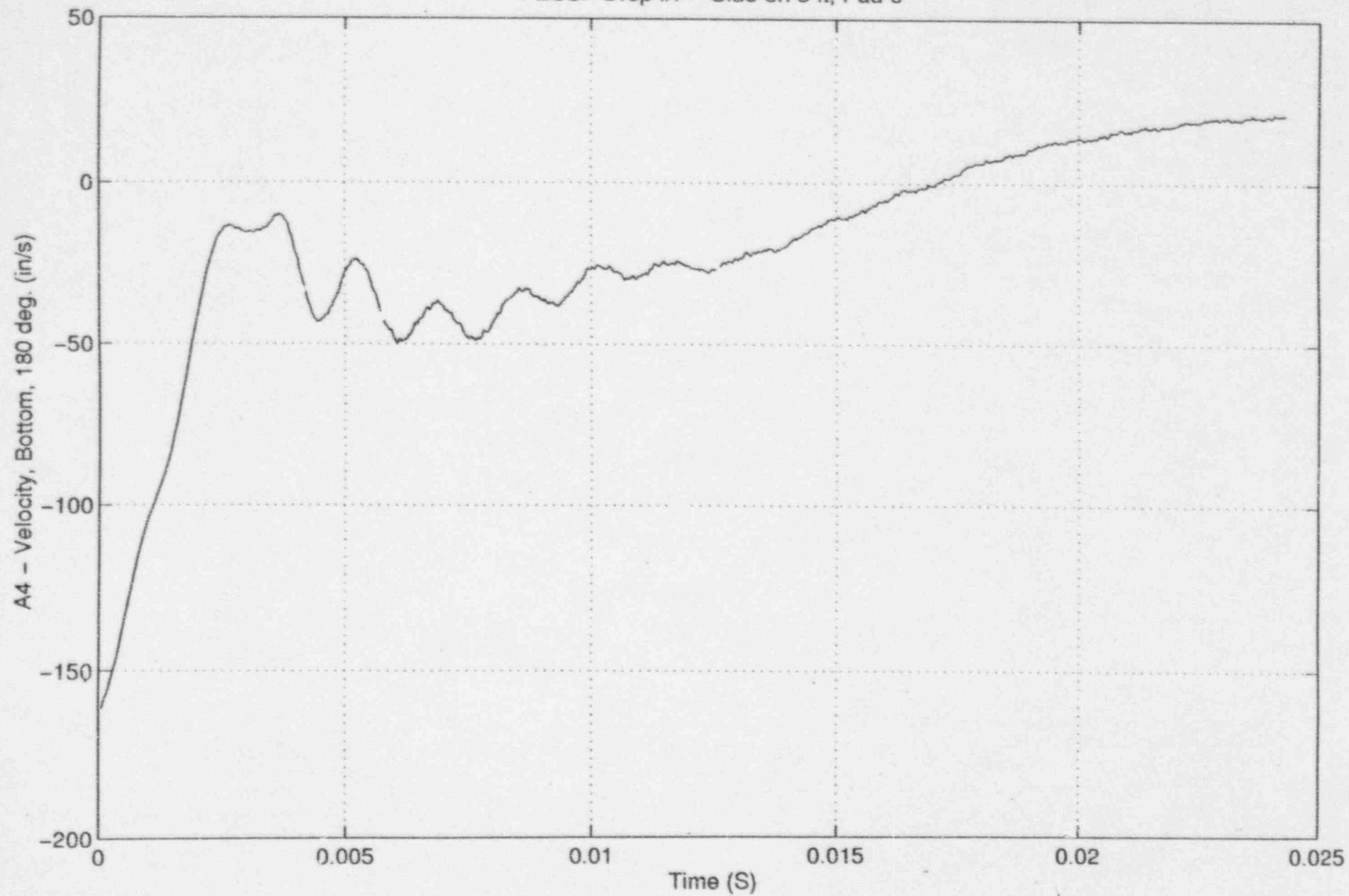
FESSP Drop #7 - Side on 3 ft, Pad 6



FESSP Drop #7 - Side on 3 ft, Pad 6

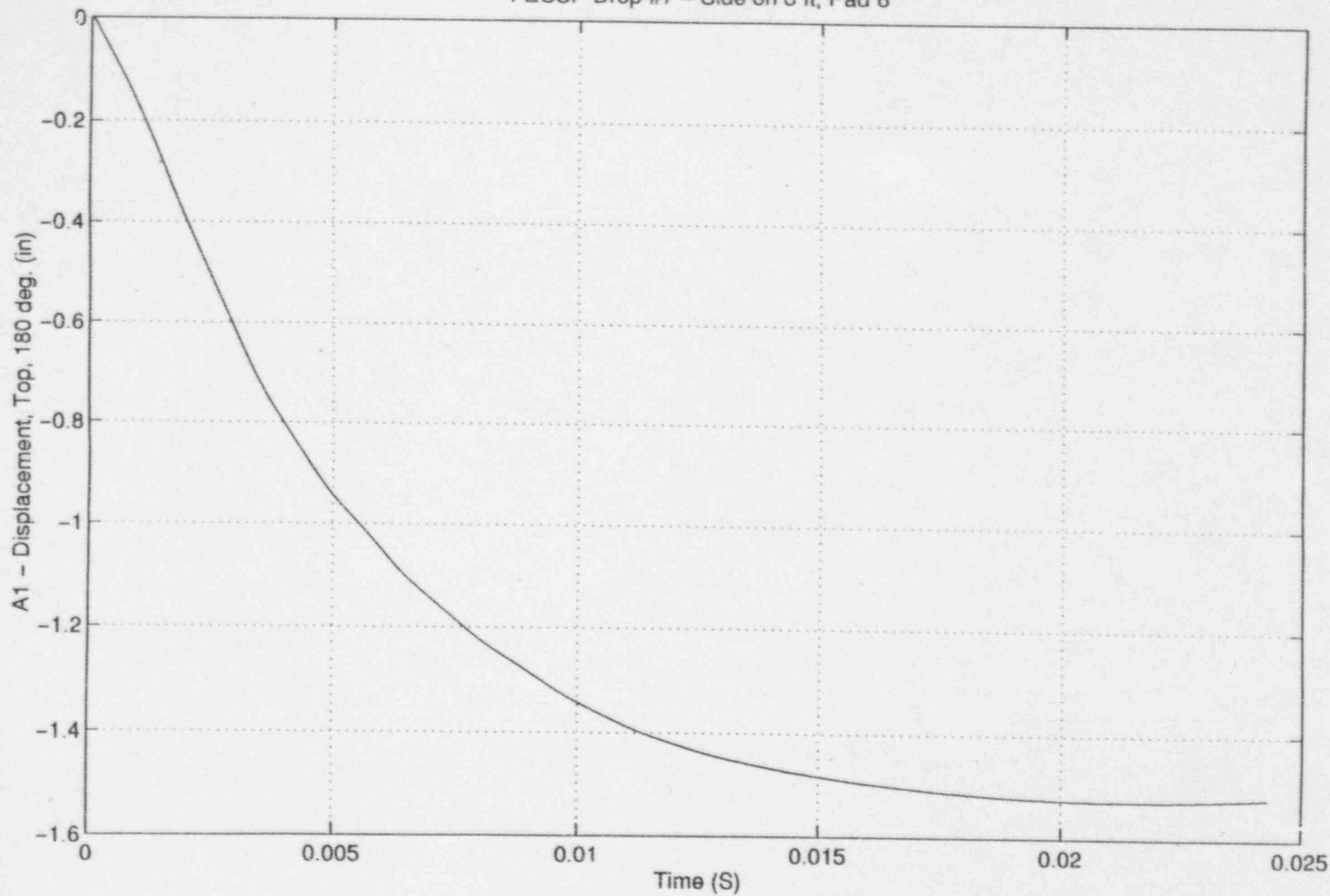


FESSP Drop #7 - Side on 3 ft, Pad 6

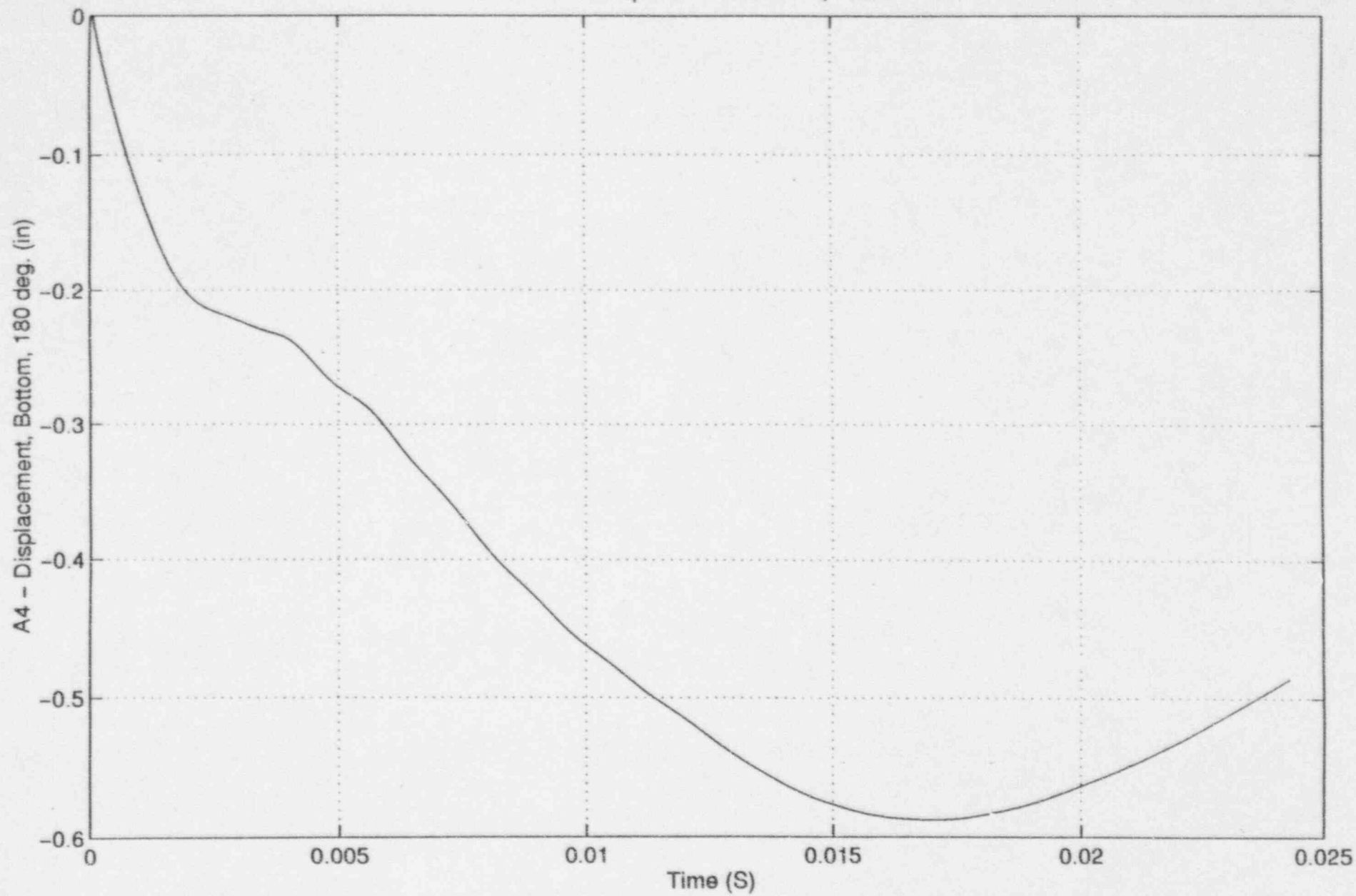




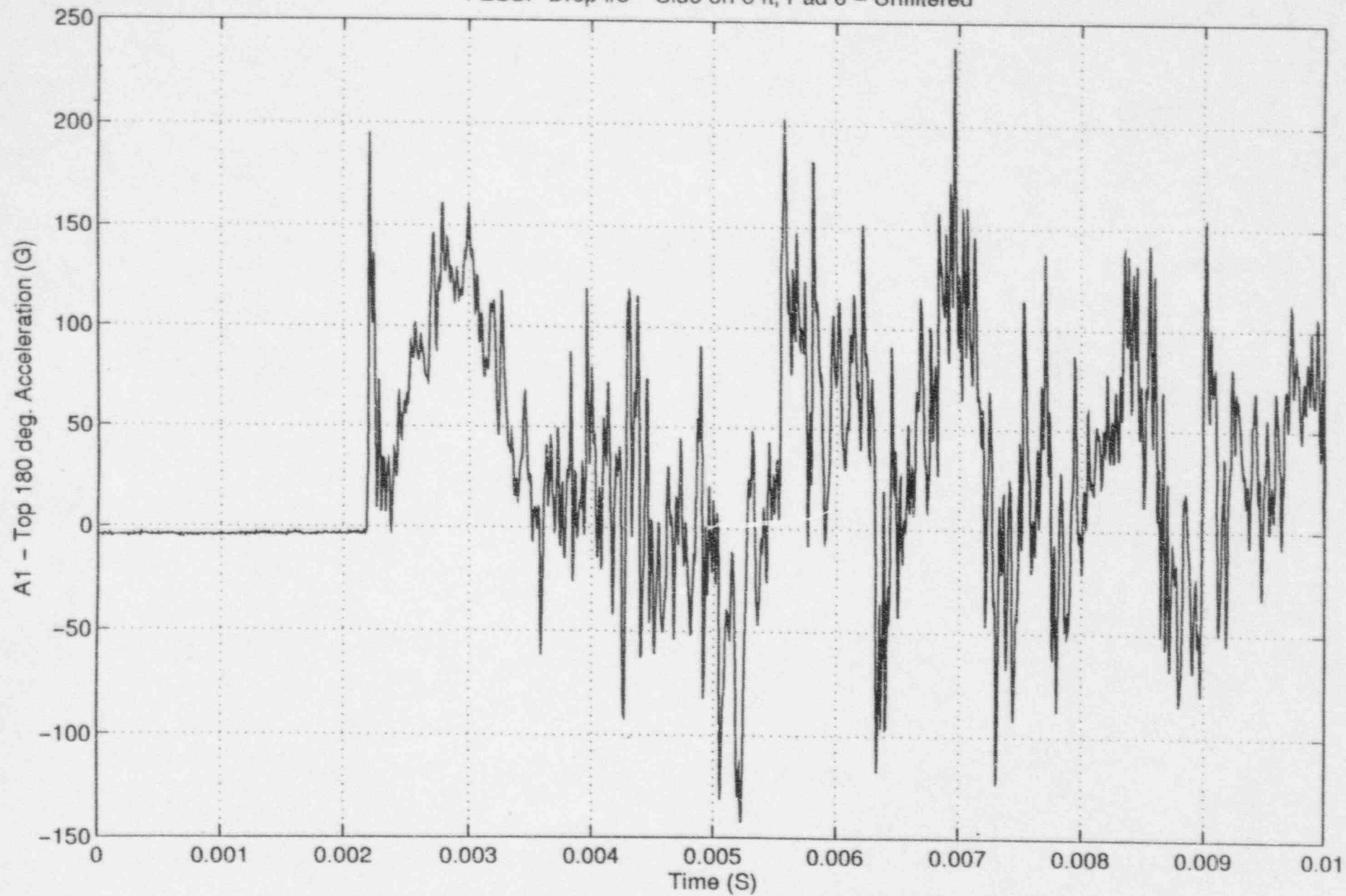
FESSP Drop #7 - Side on 3 ft, Pad 6



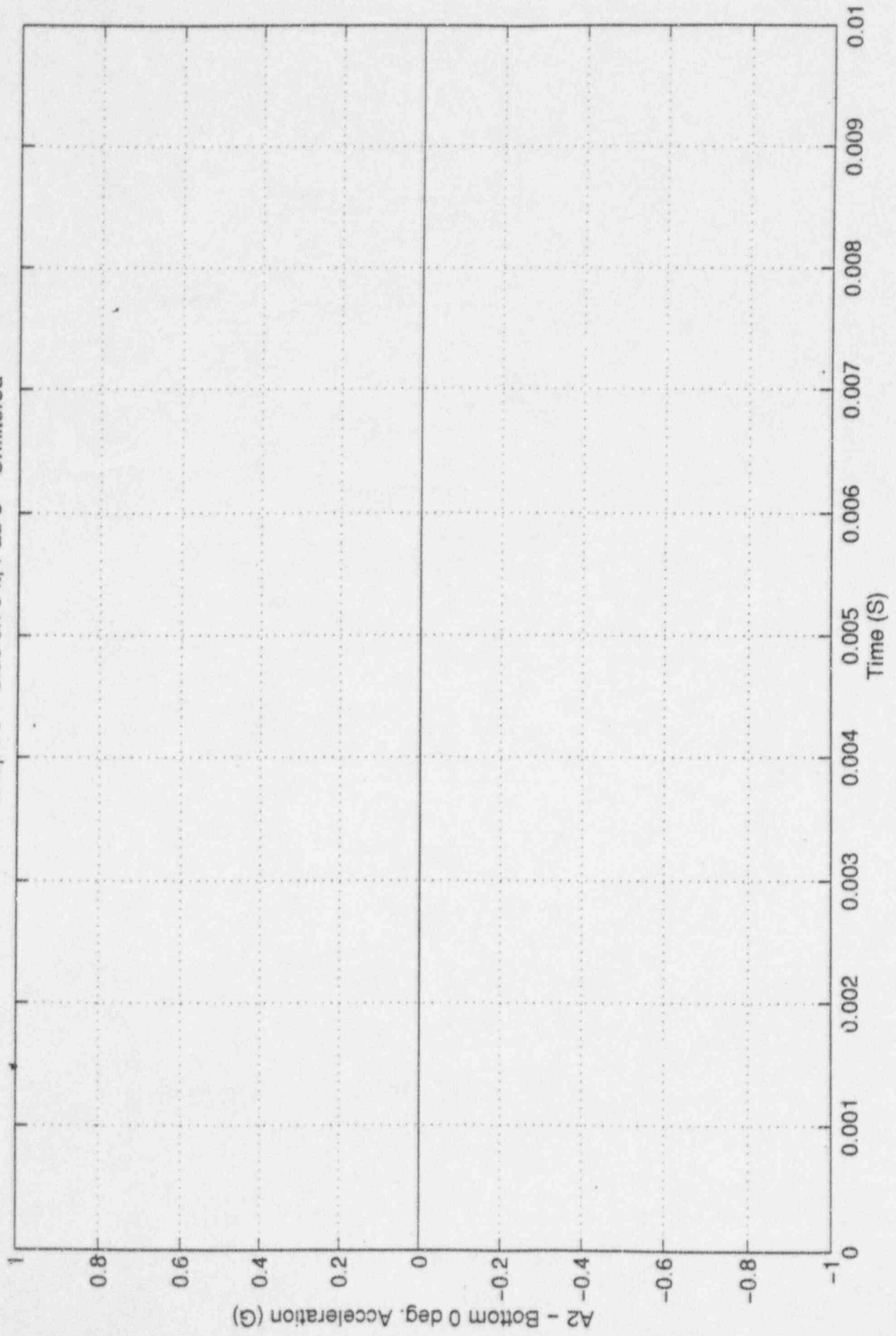
FESSP Drop #7 - Side on 3 ft, Pad 6

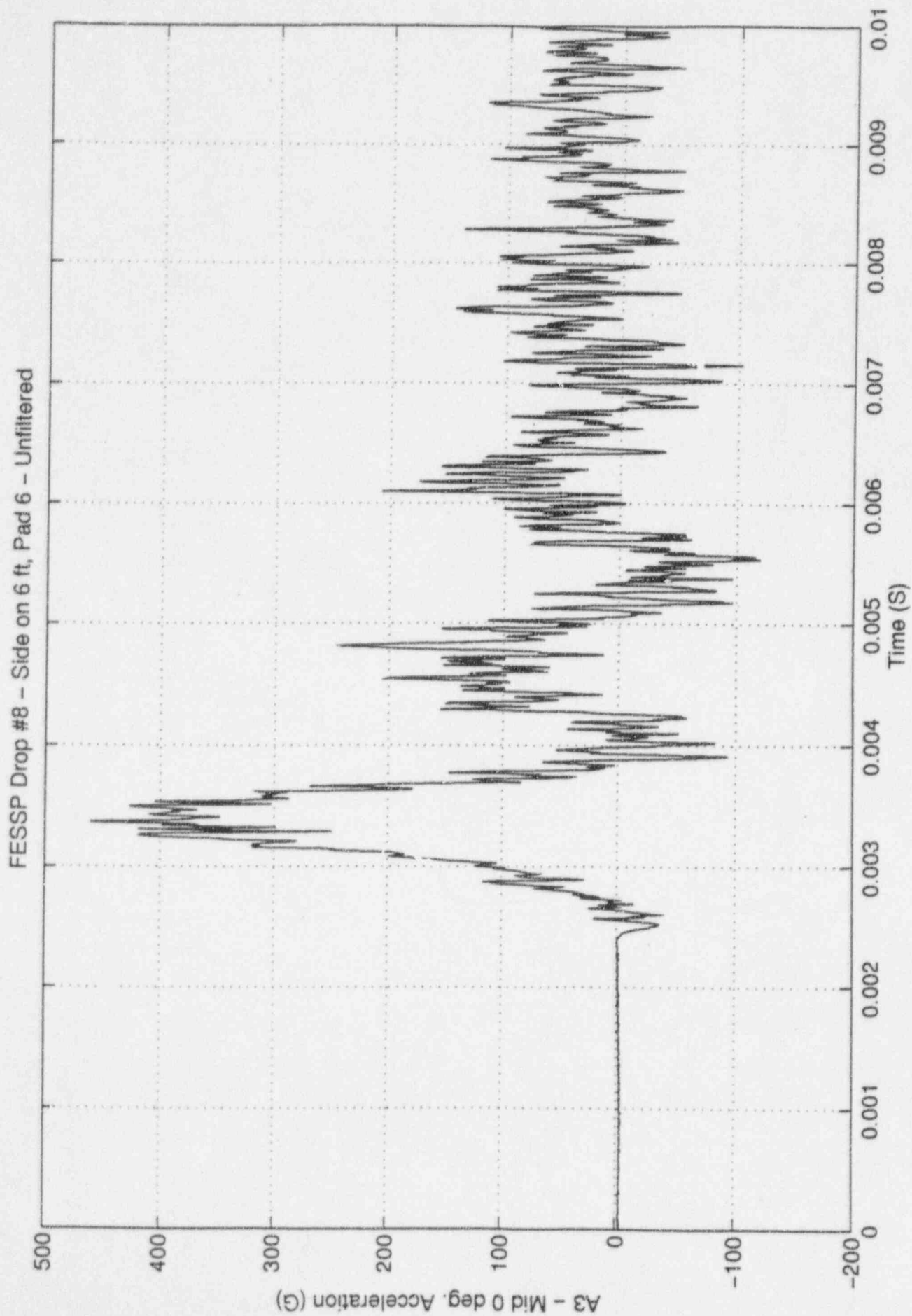


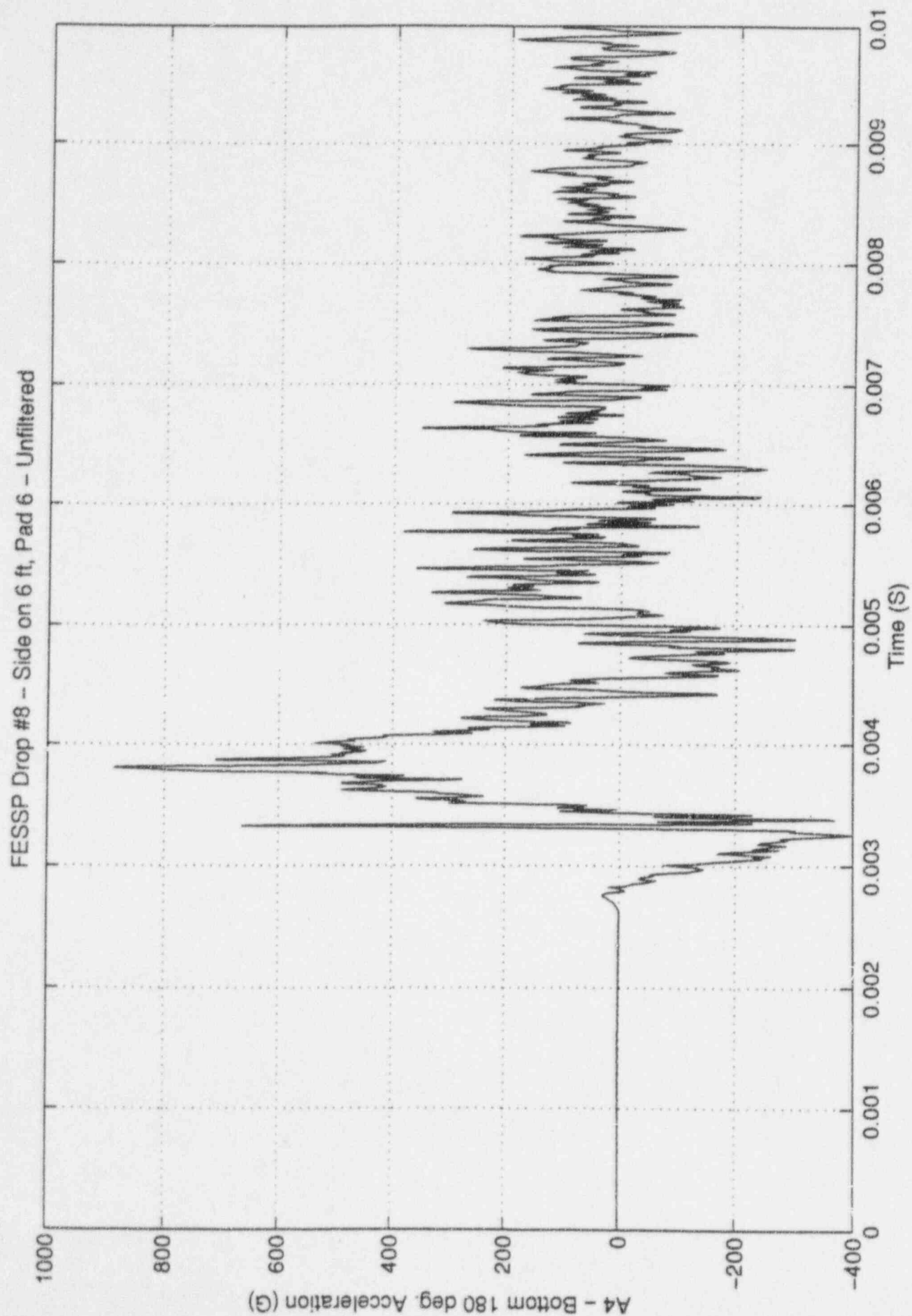
FESSP Drop #8 - Side on 6 ft, Pad 6 - Unfiltered



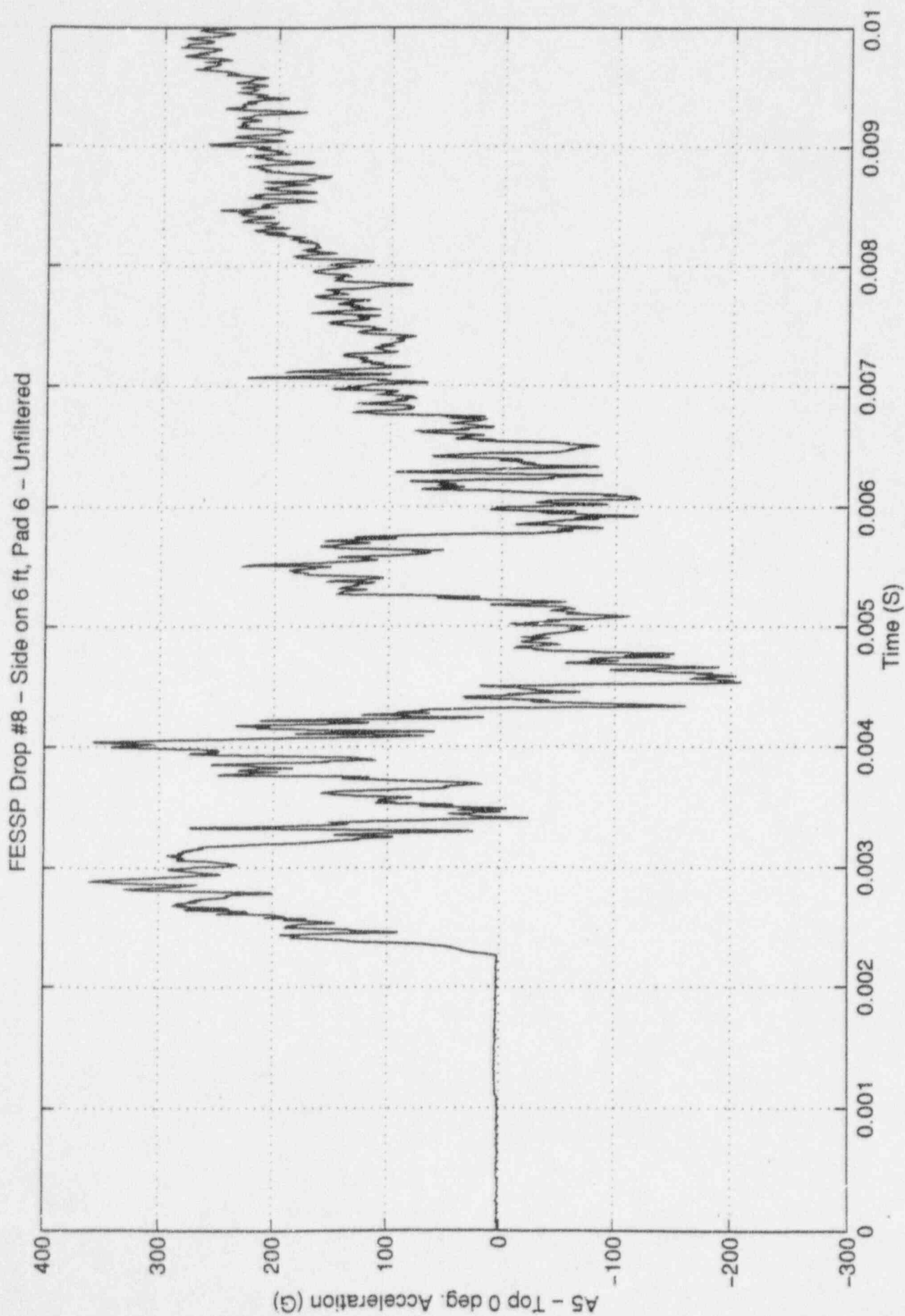
FESSP Drop #8 - Side on 6 ft, Pad 6 - Unfiltered



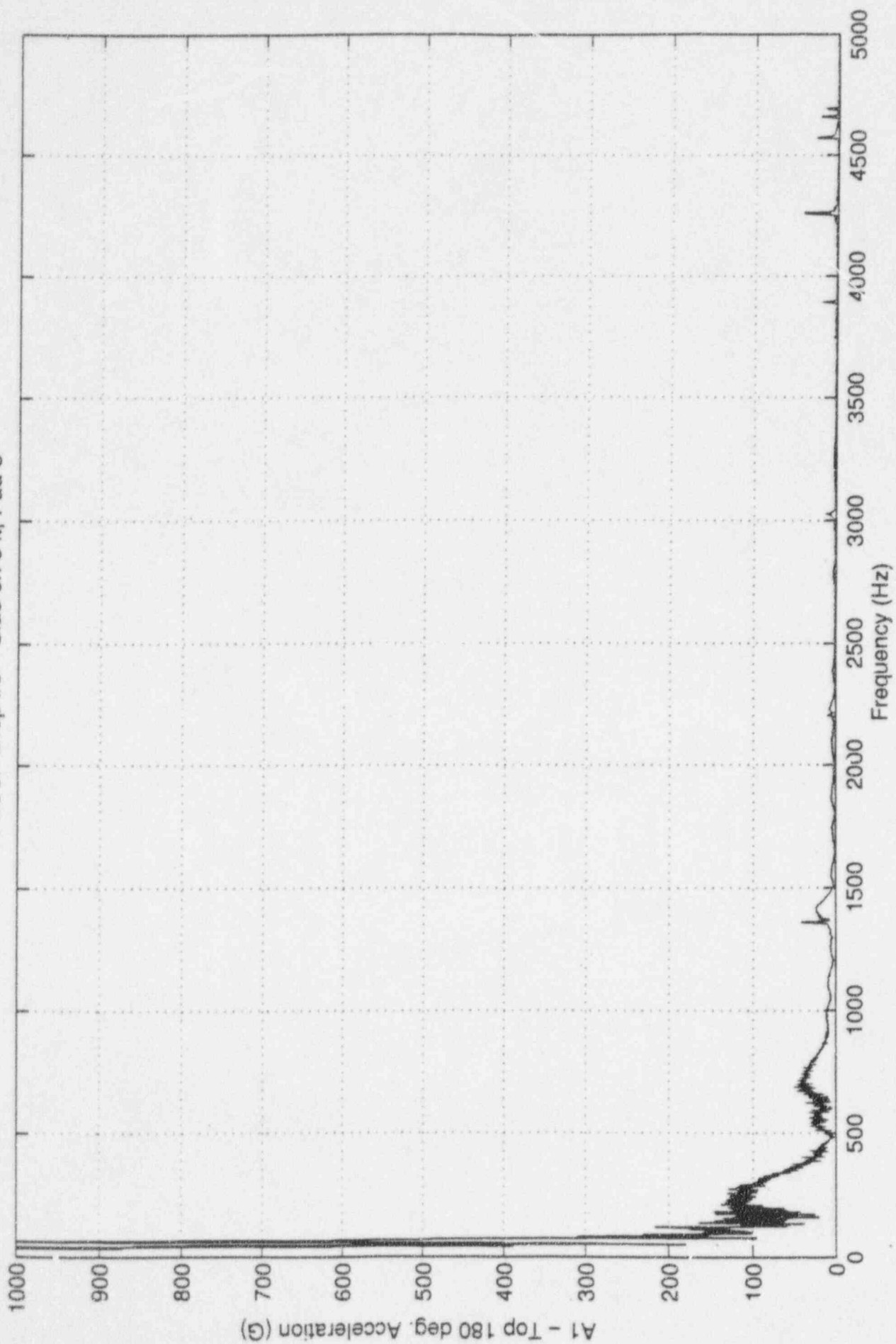


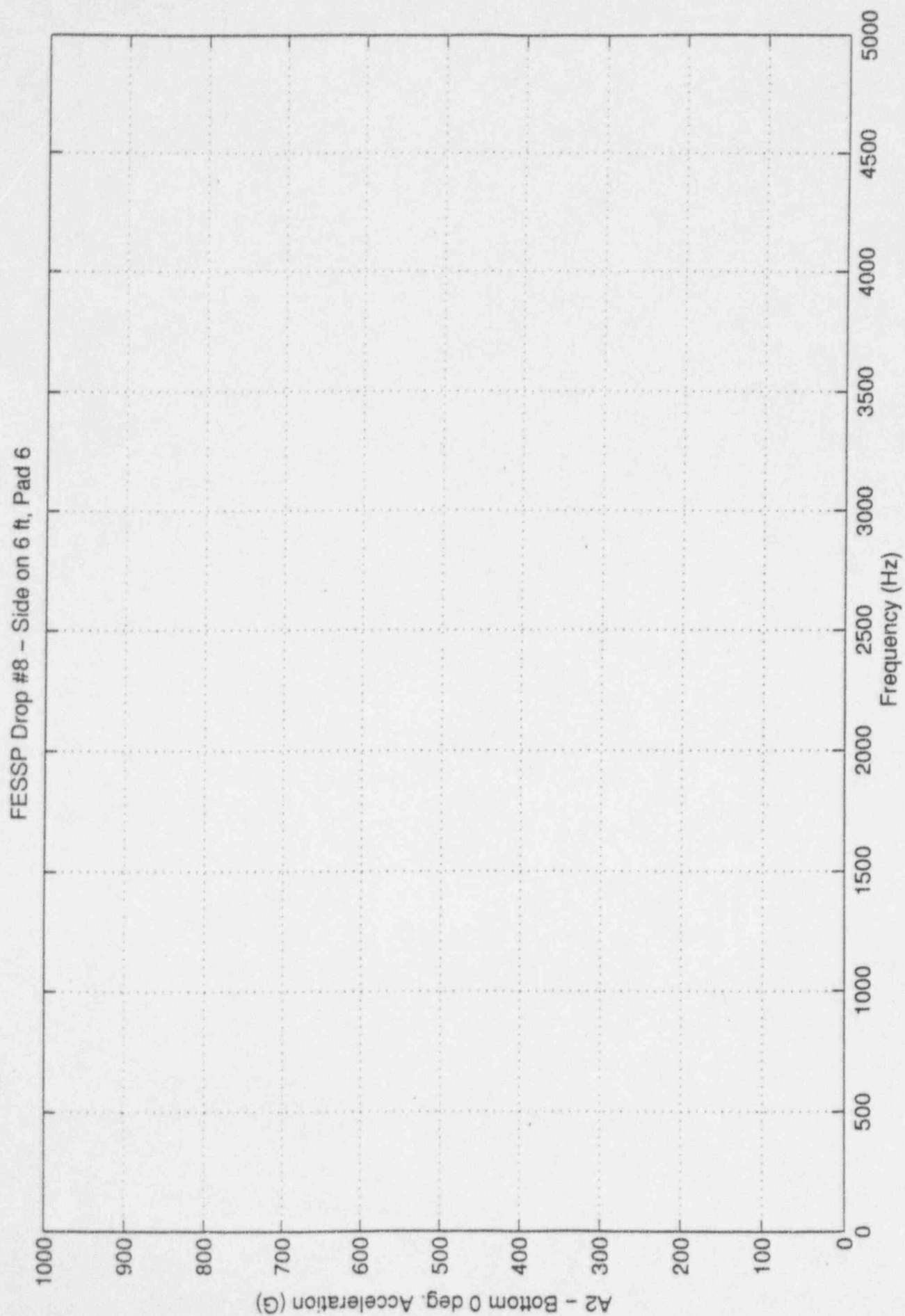




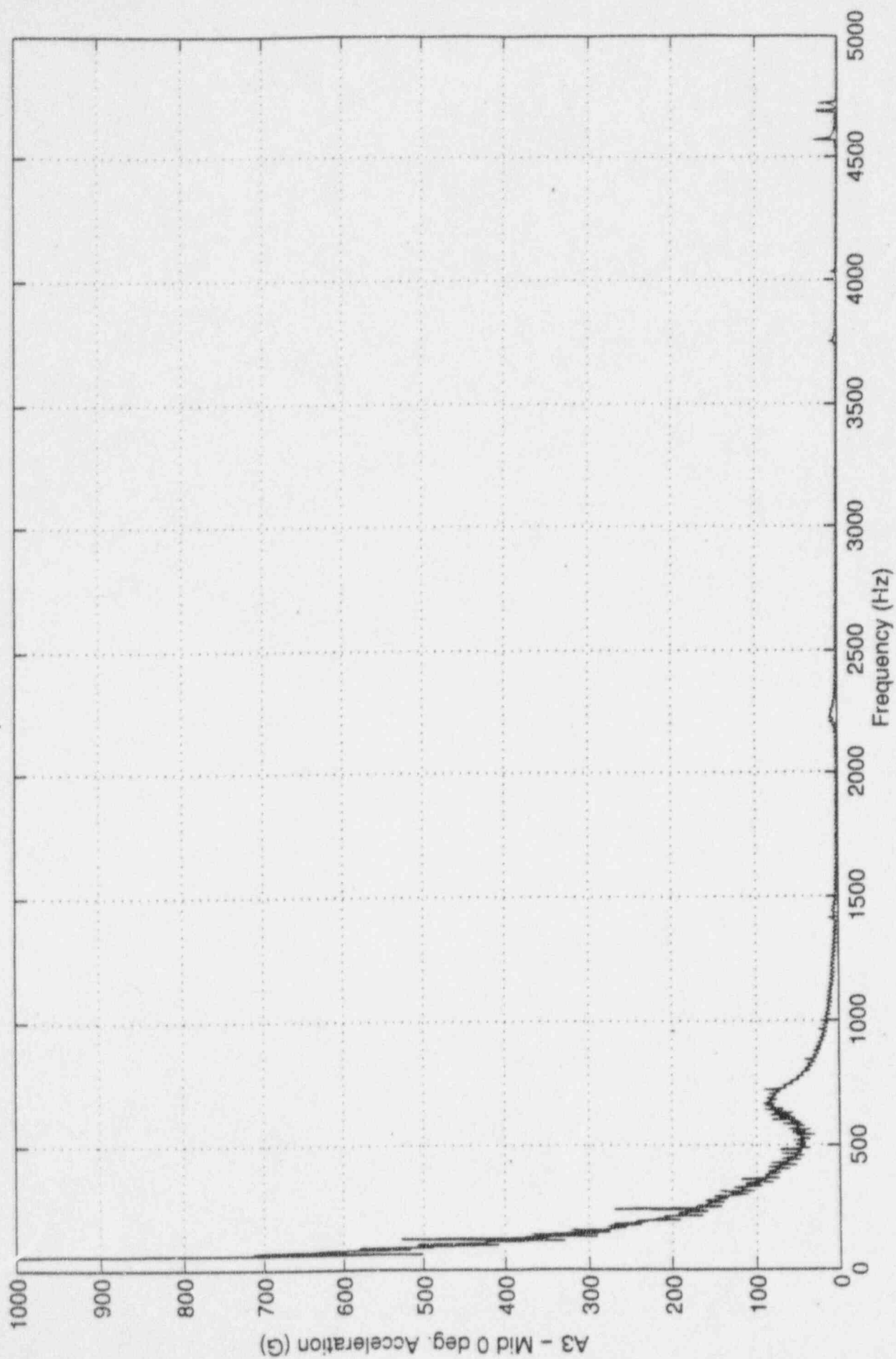


FESSP Drop #8 - Side on 6 ft, Pad 6

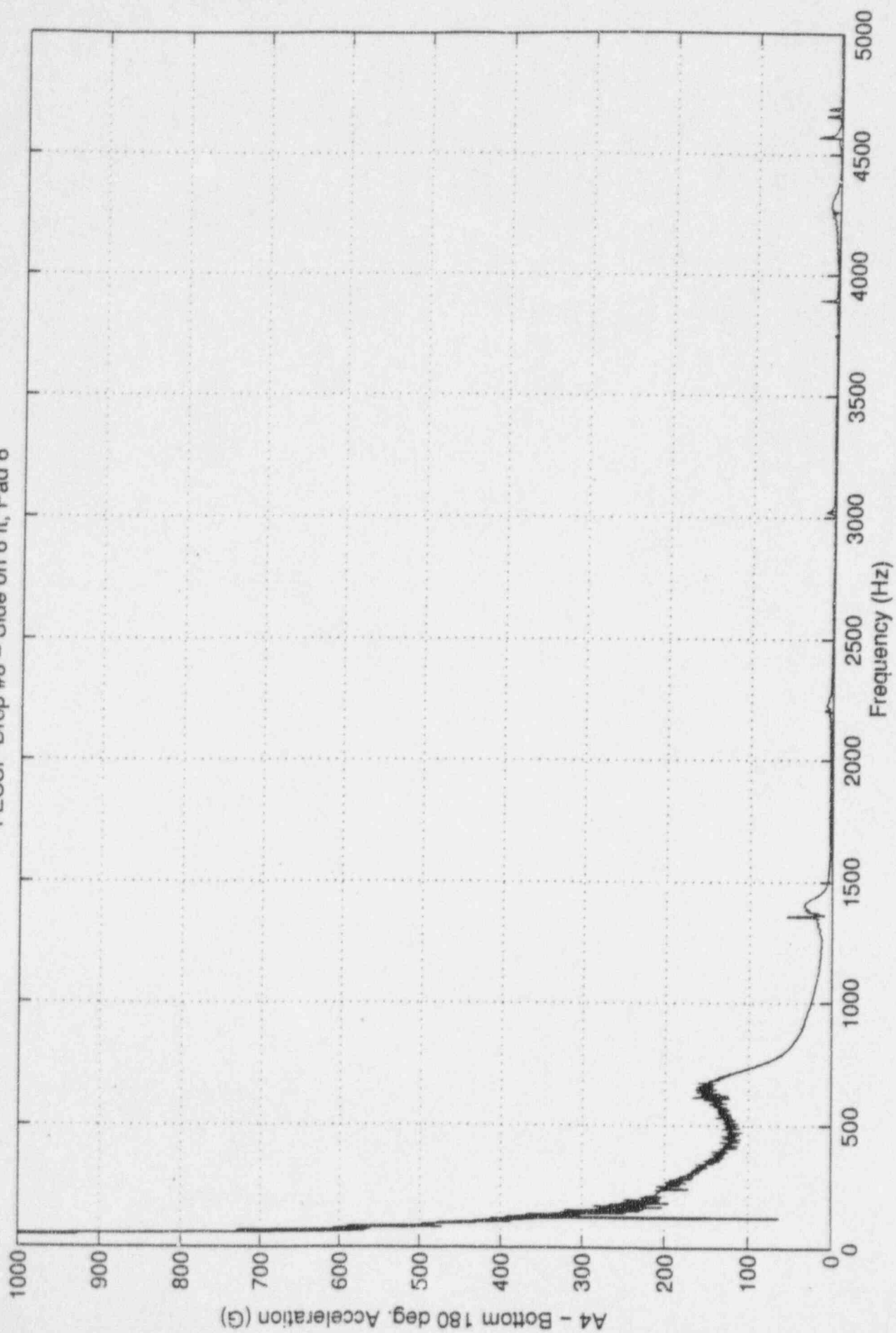




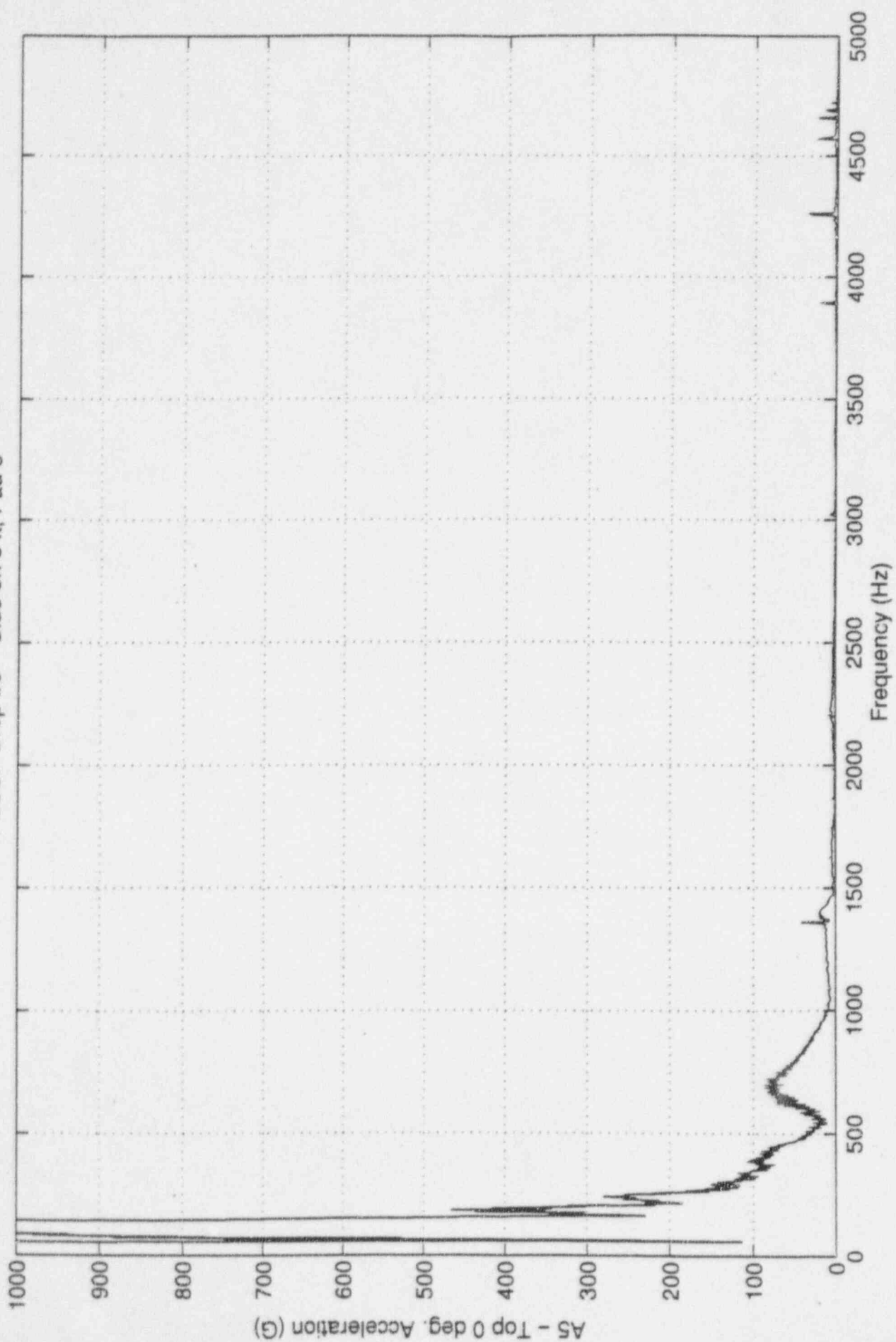
FESSP Drop #8 - Side on 6 ft, Pad 6



FESSP Drop #8 - Side on 6 ft, Pad 6

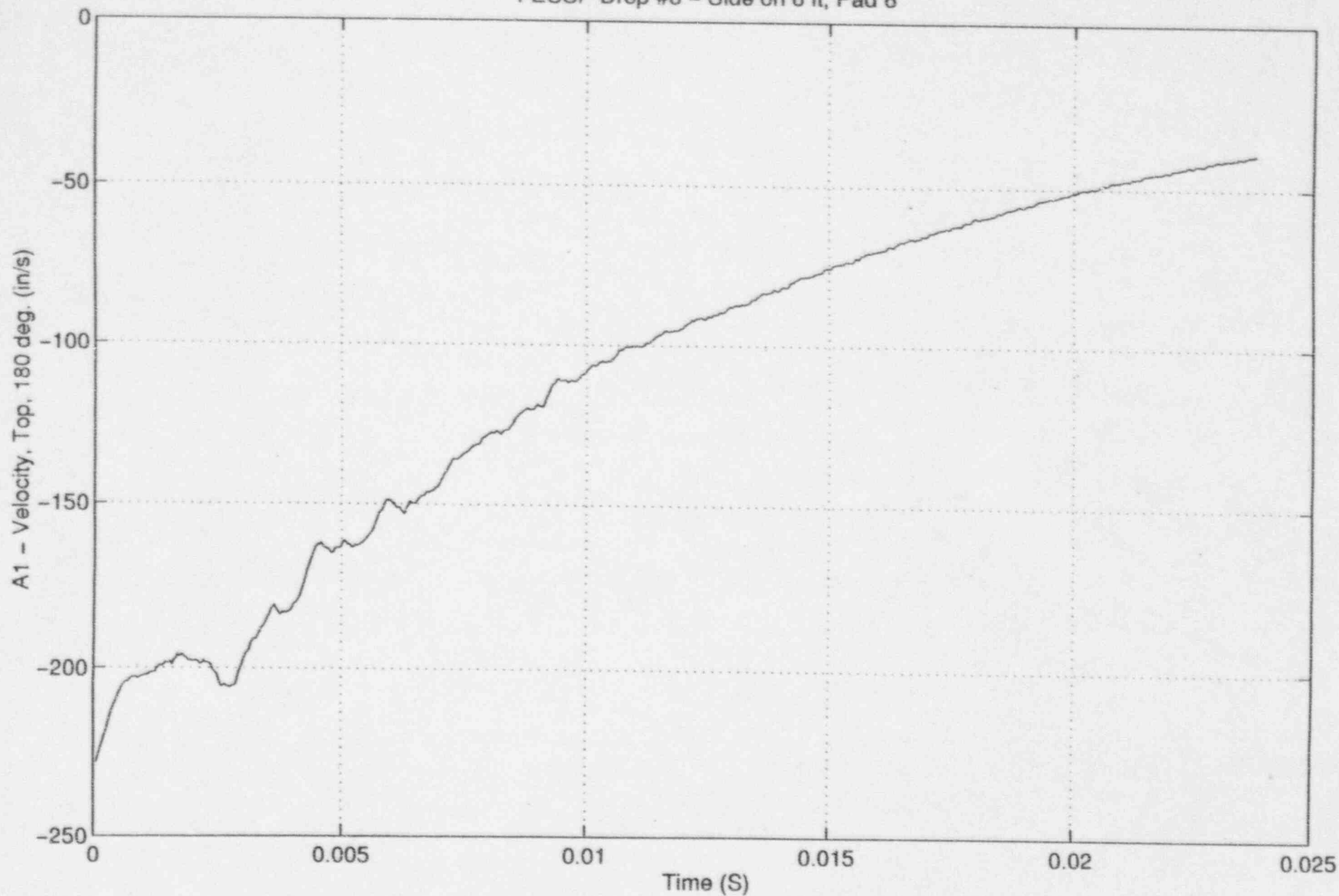


FESSP Drop #8 - Side on 6 ft, Pad 6

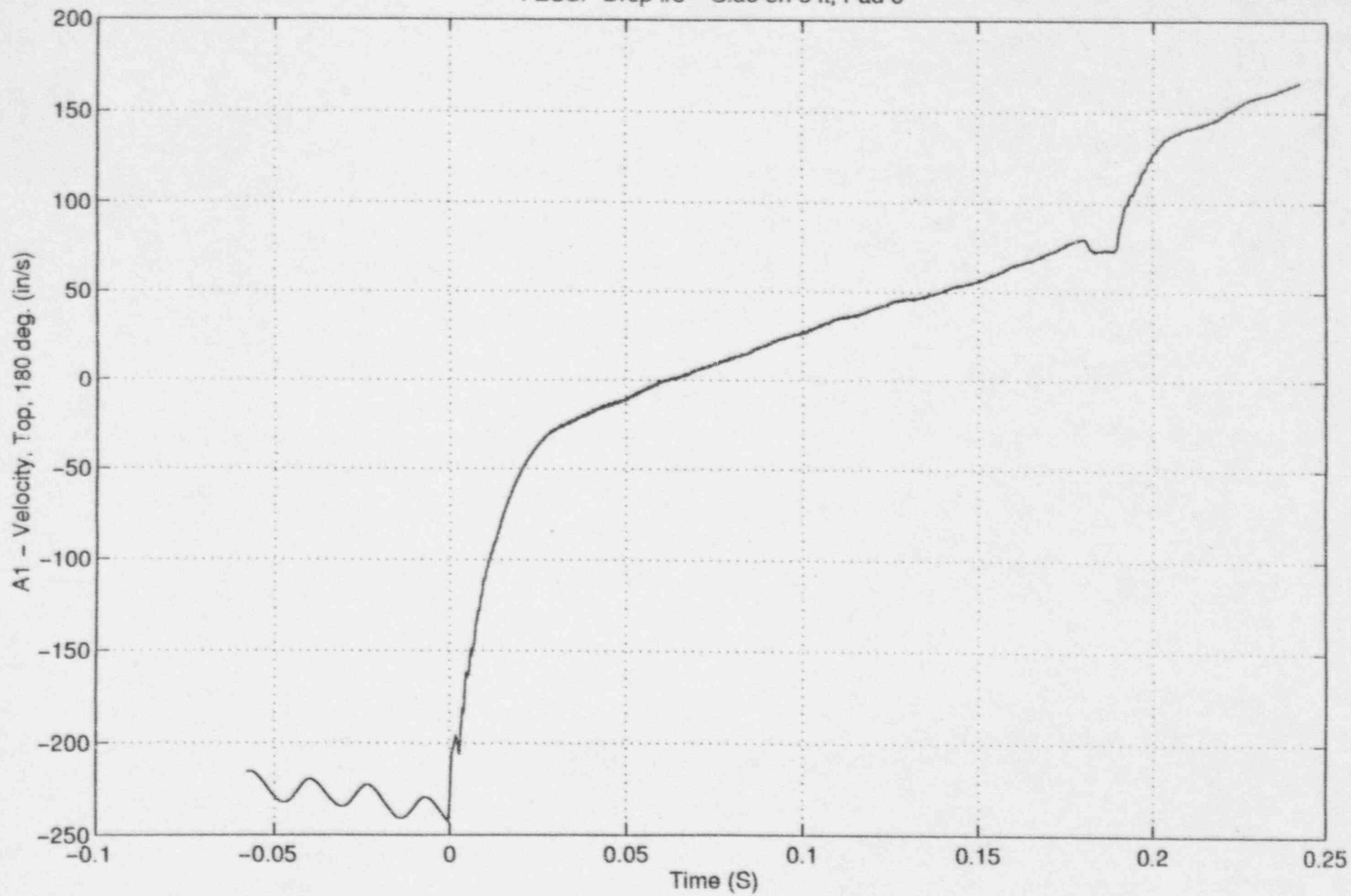




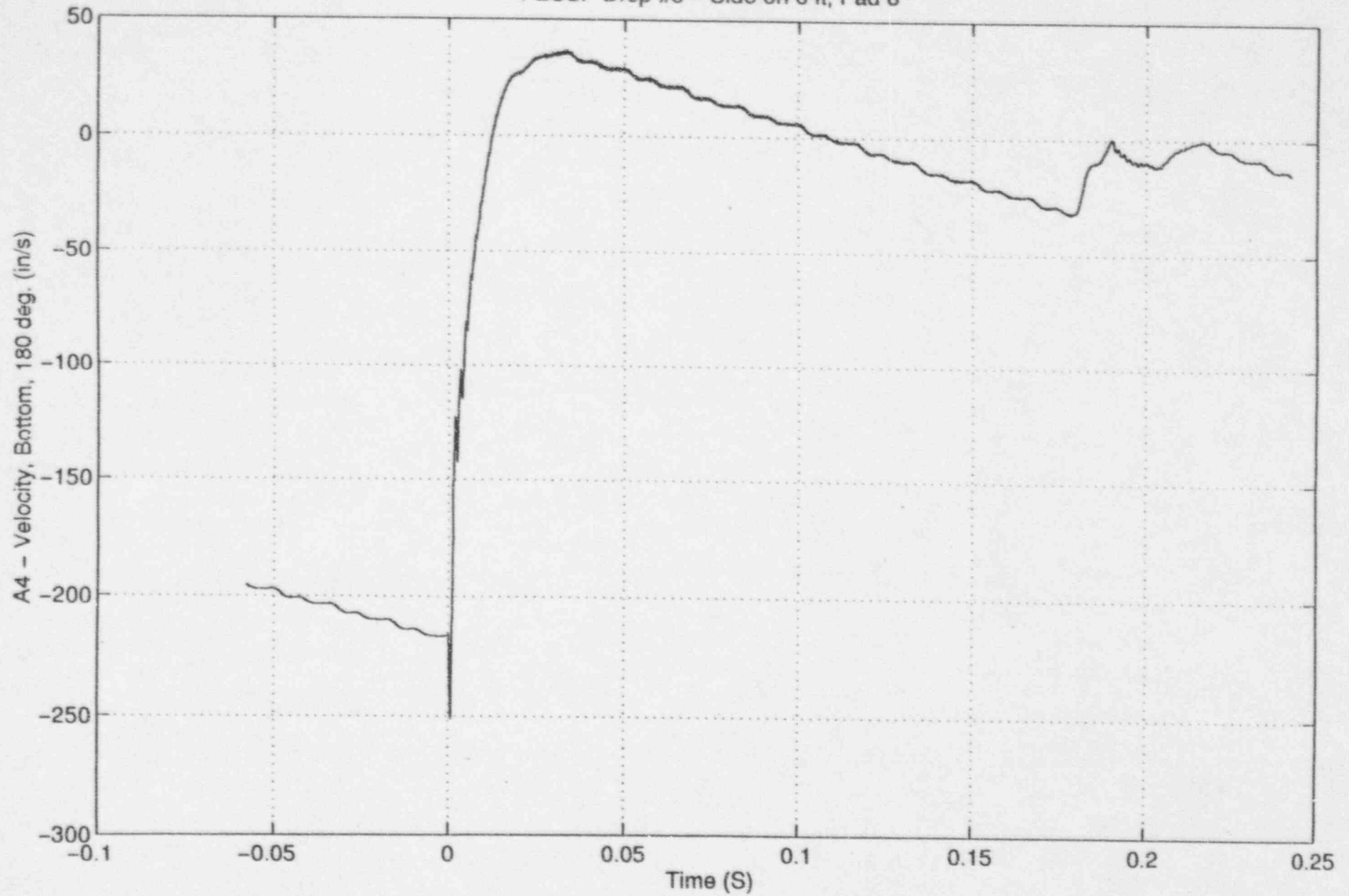
FESSP Drop #8 - Side on 6 ft, Pad 6



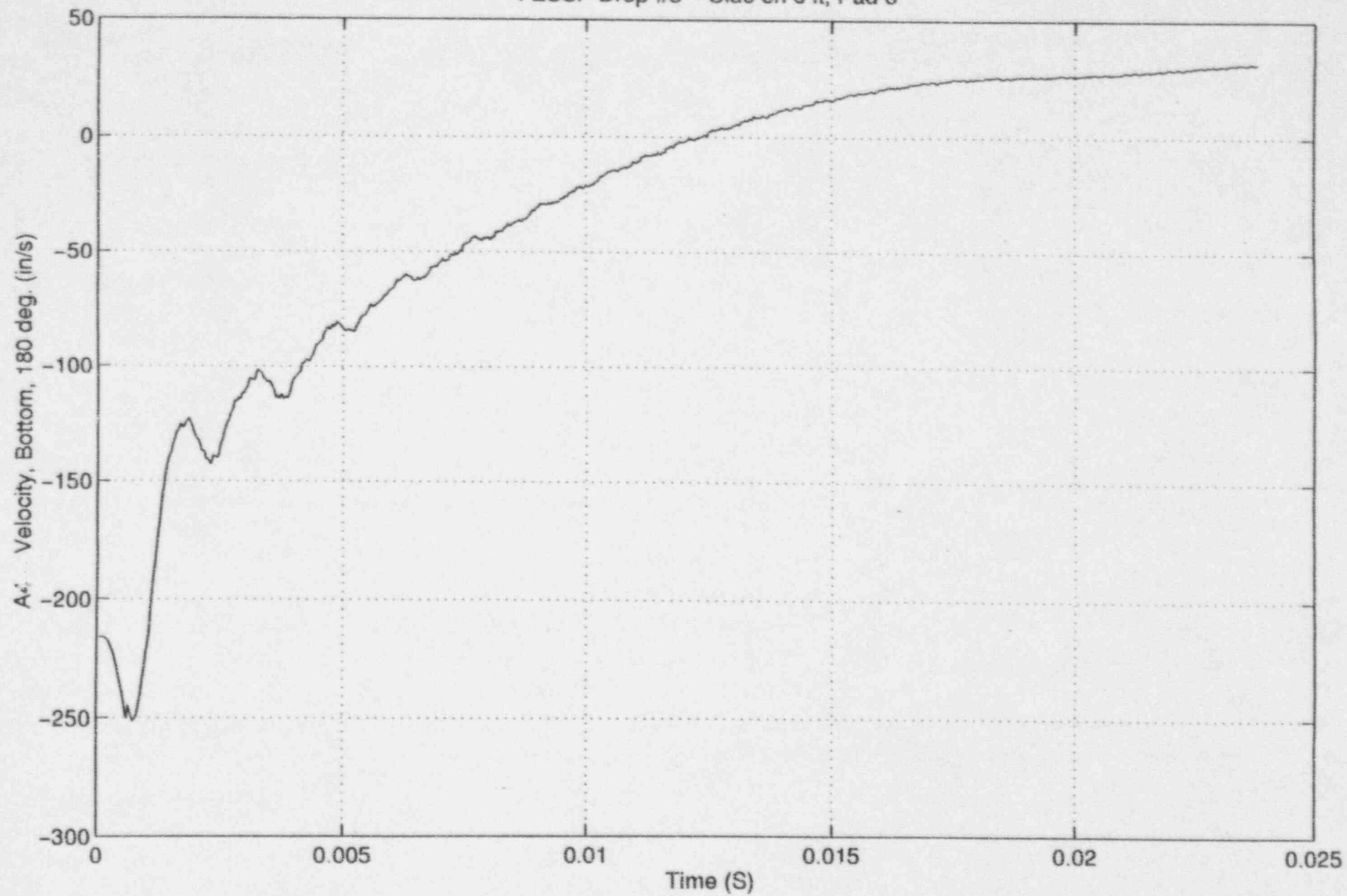
FESSP Drop #8 - Side on 6 ft, Pad 6



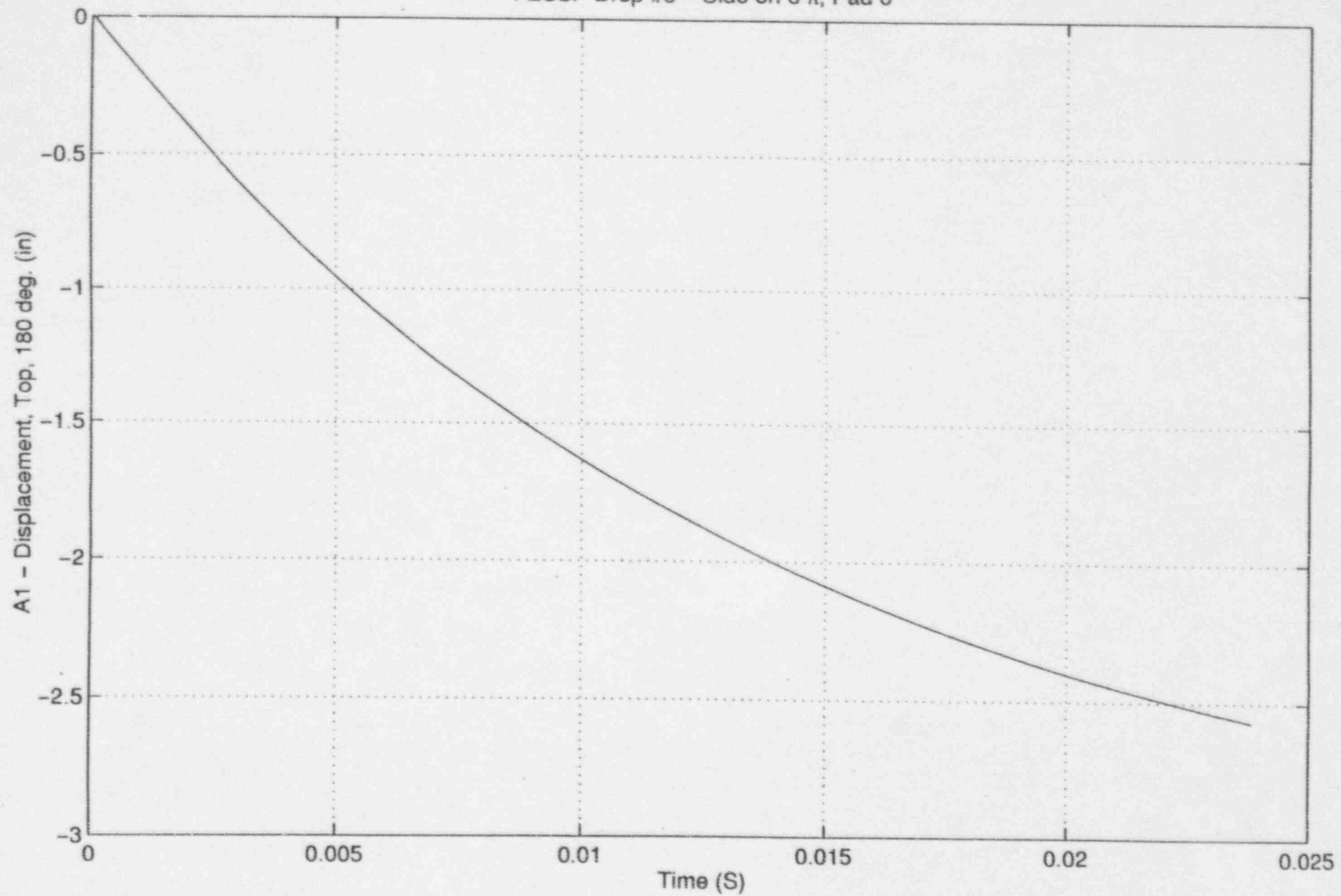
FESSP Drop #8 - Side on 6 ft, Pad 6



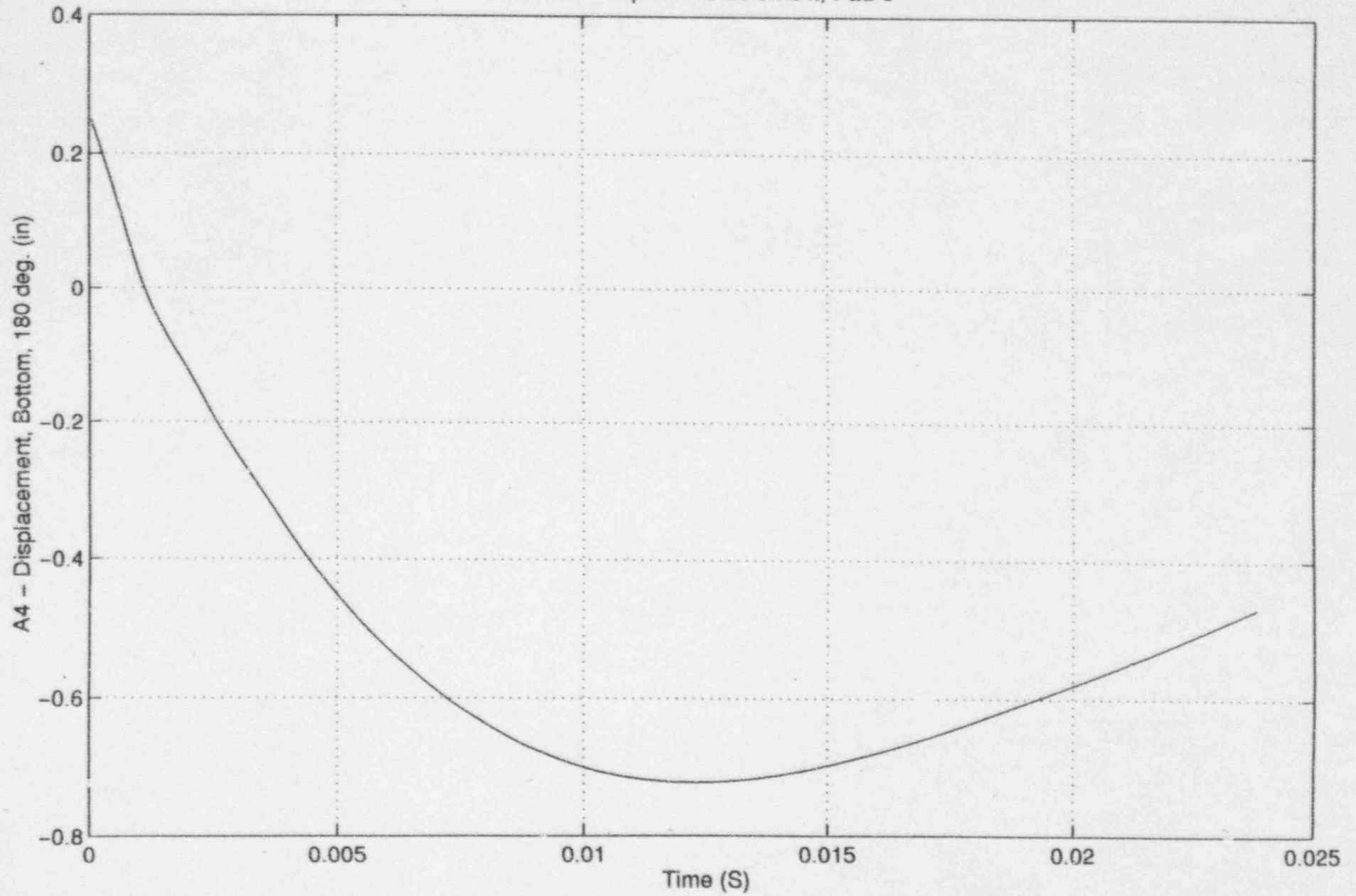
FESSP Drop #8 - Side on 6 ft, Pad 6



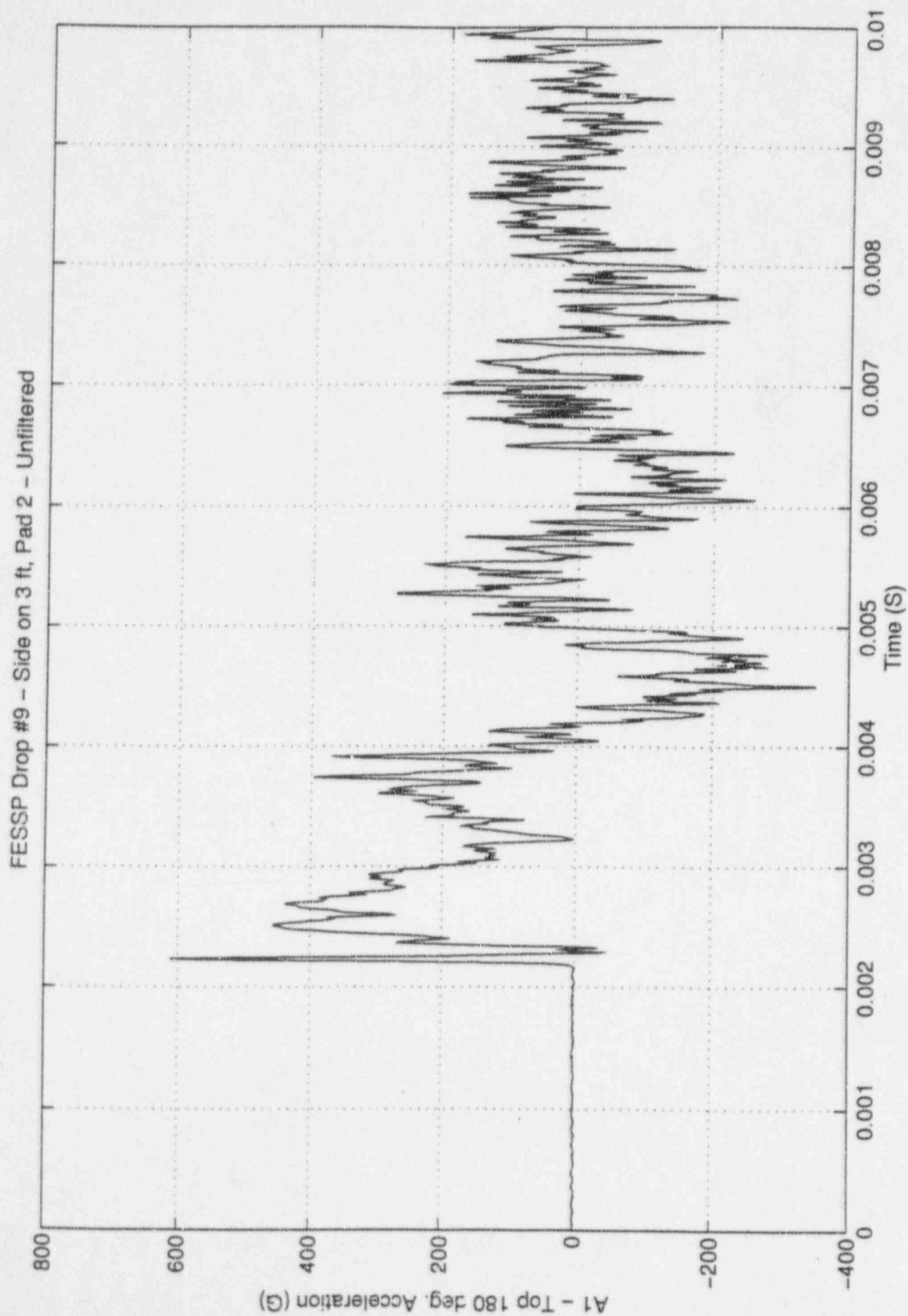
FESSP Drop #8 - Side on 6 ft, Pad 6

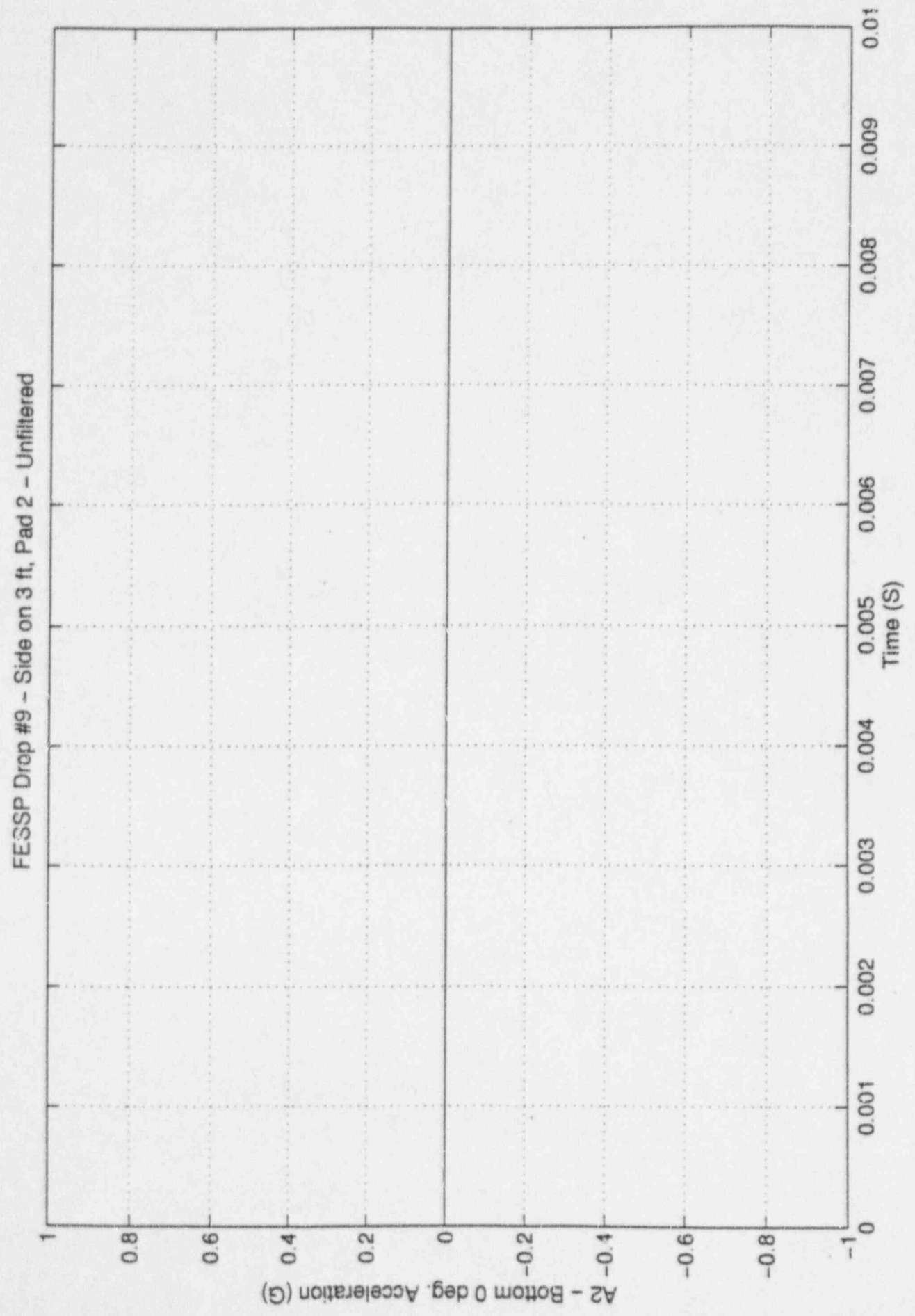


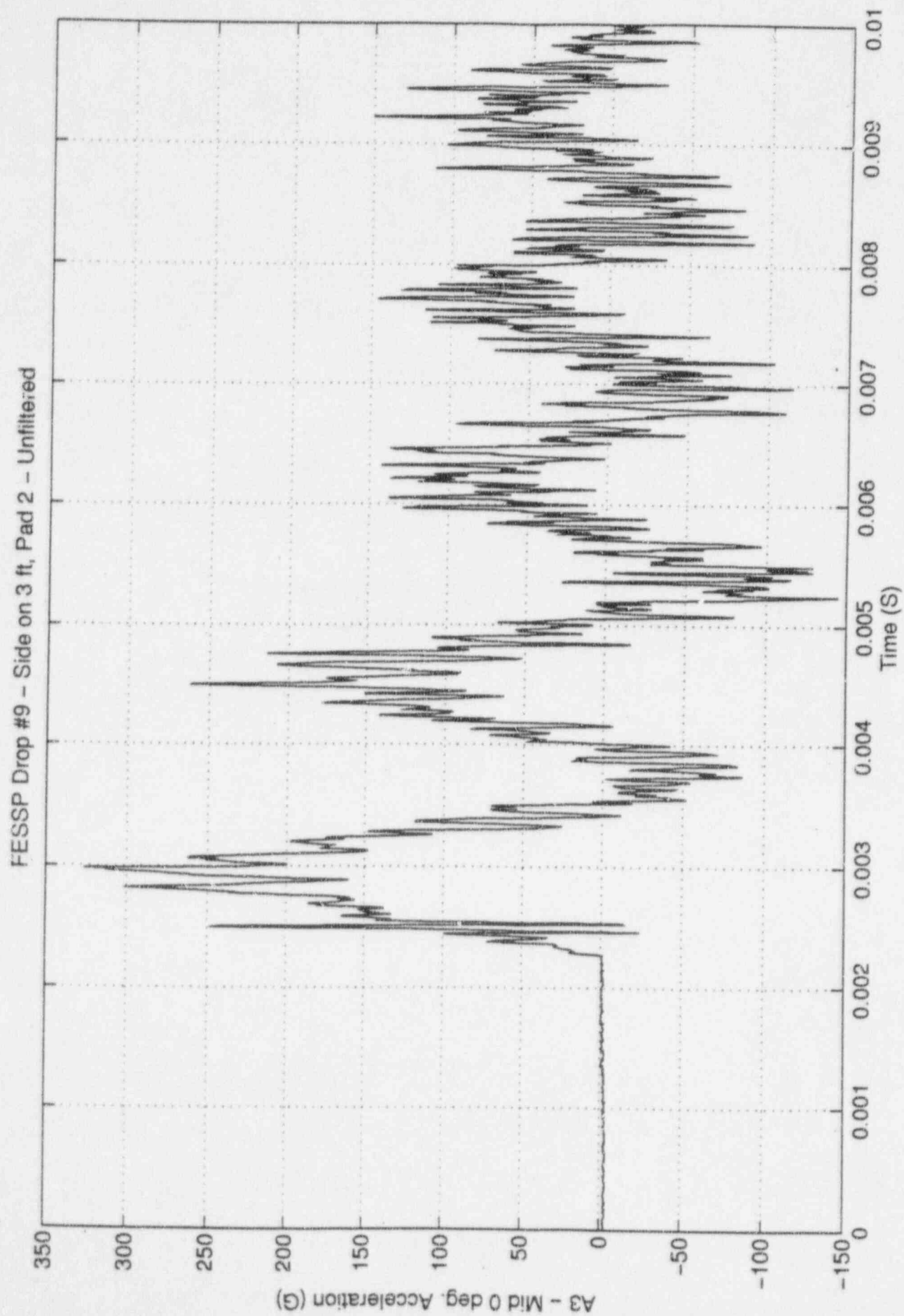
FESSP Drop #8 - Side on 6 ft, Pad 6

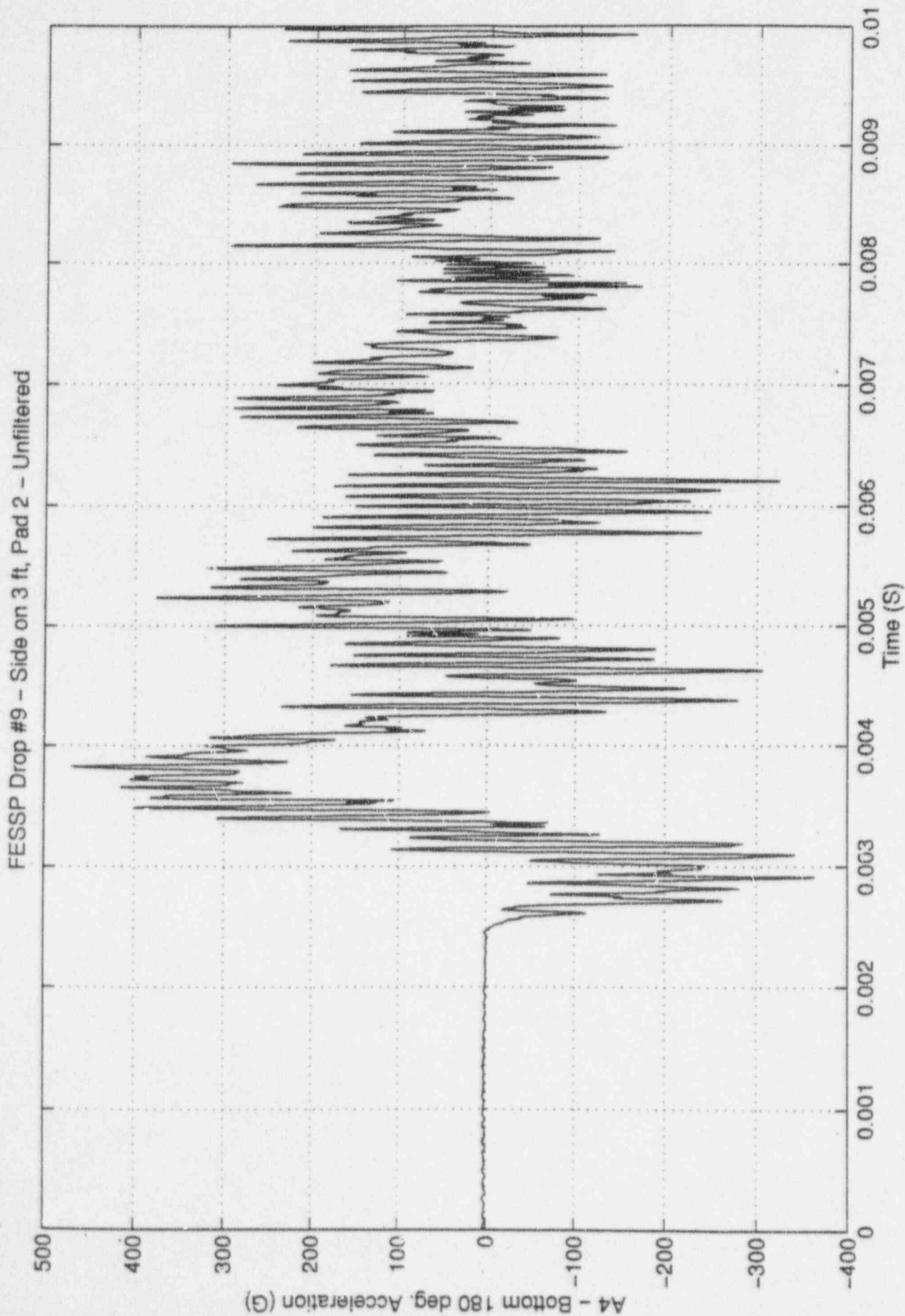


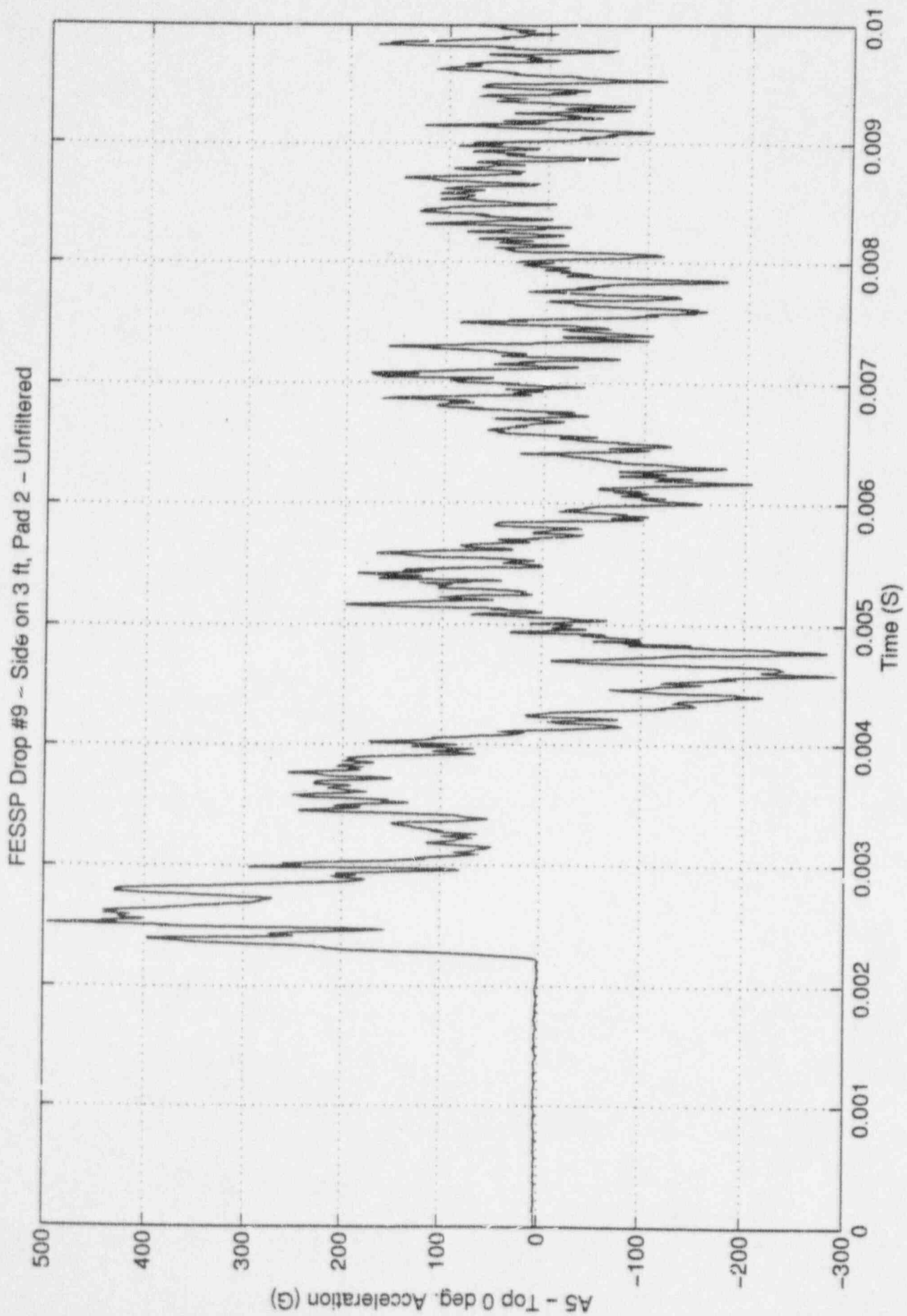




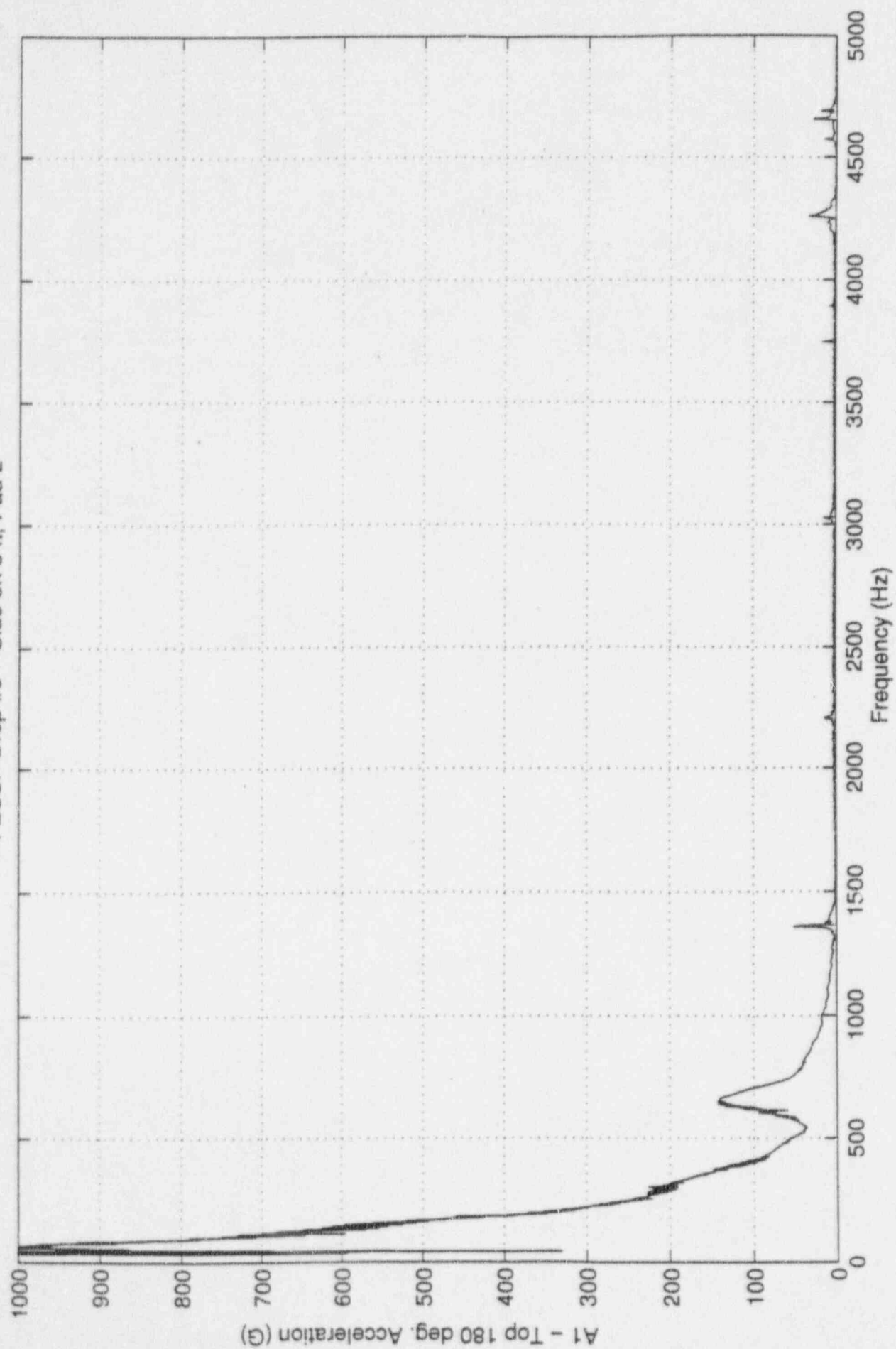




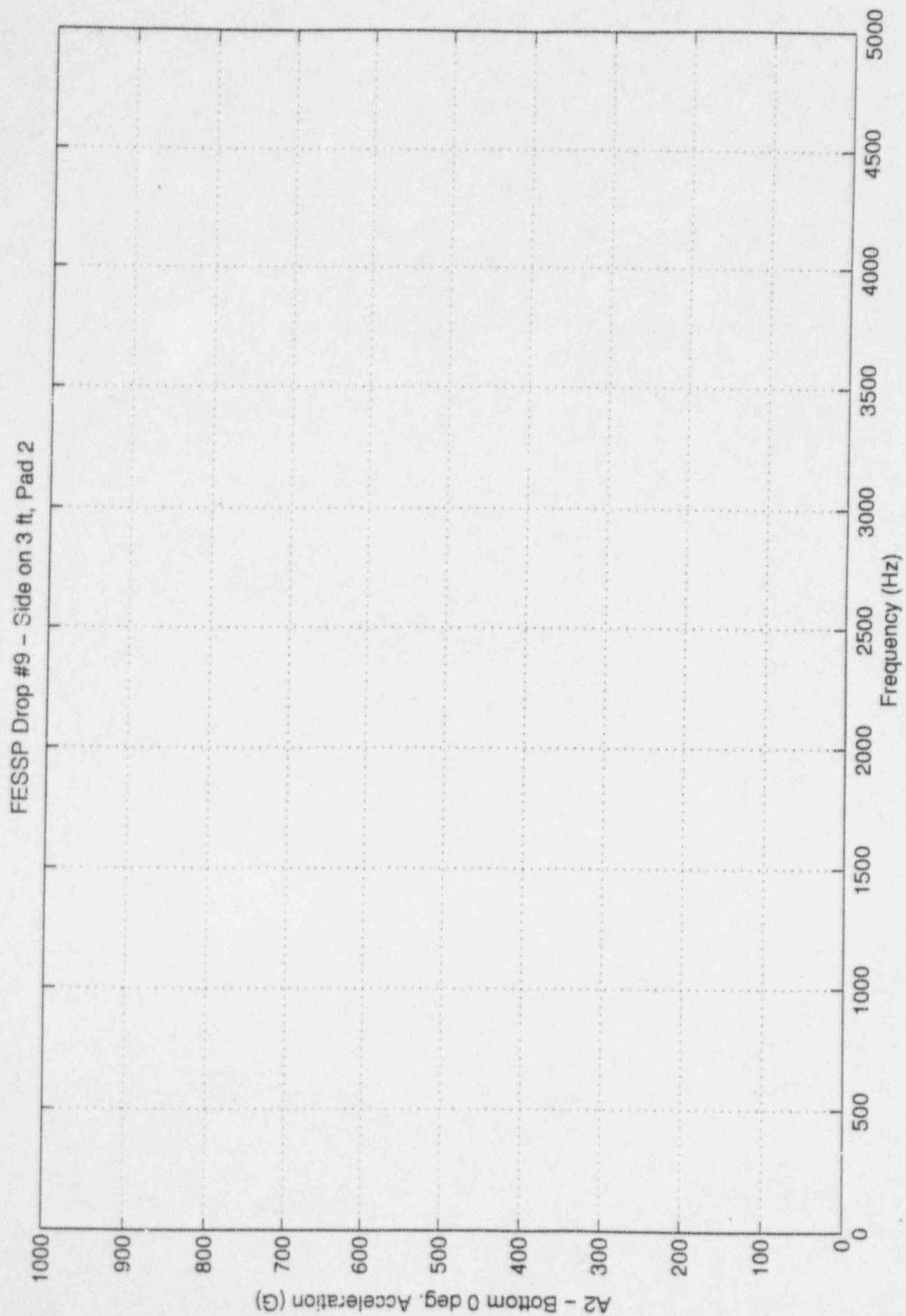




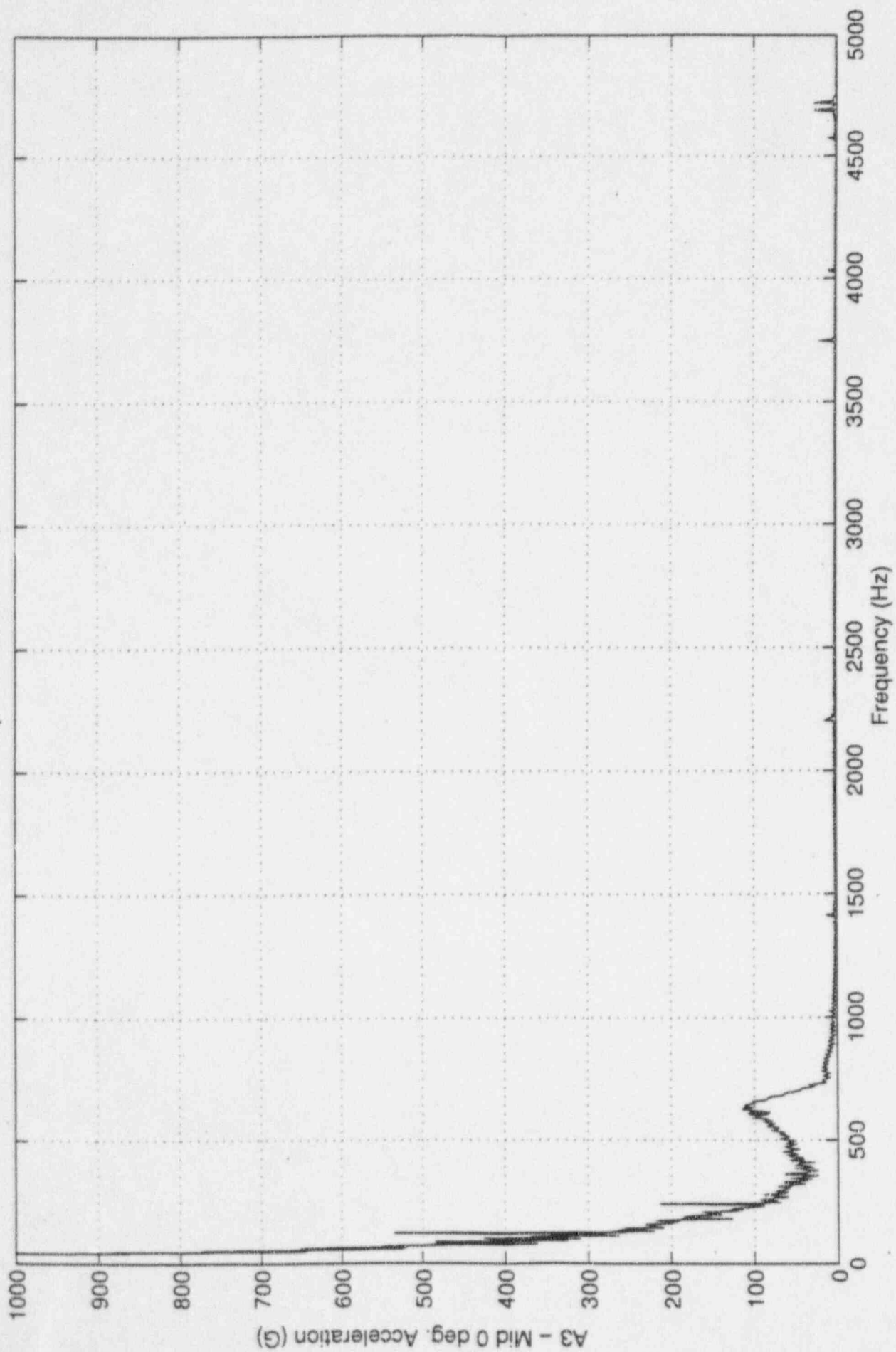
FESSP Drop #9 - Side on 3 ft, Pad 2



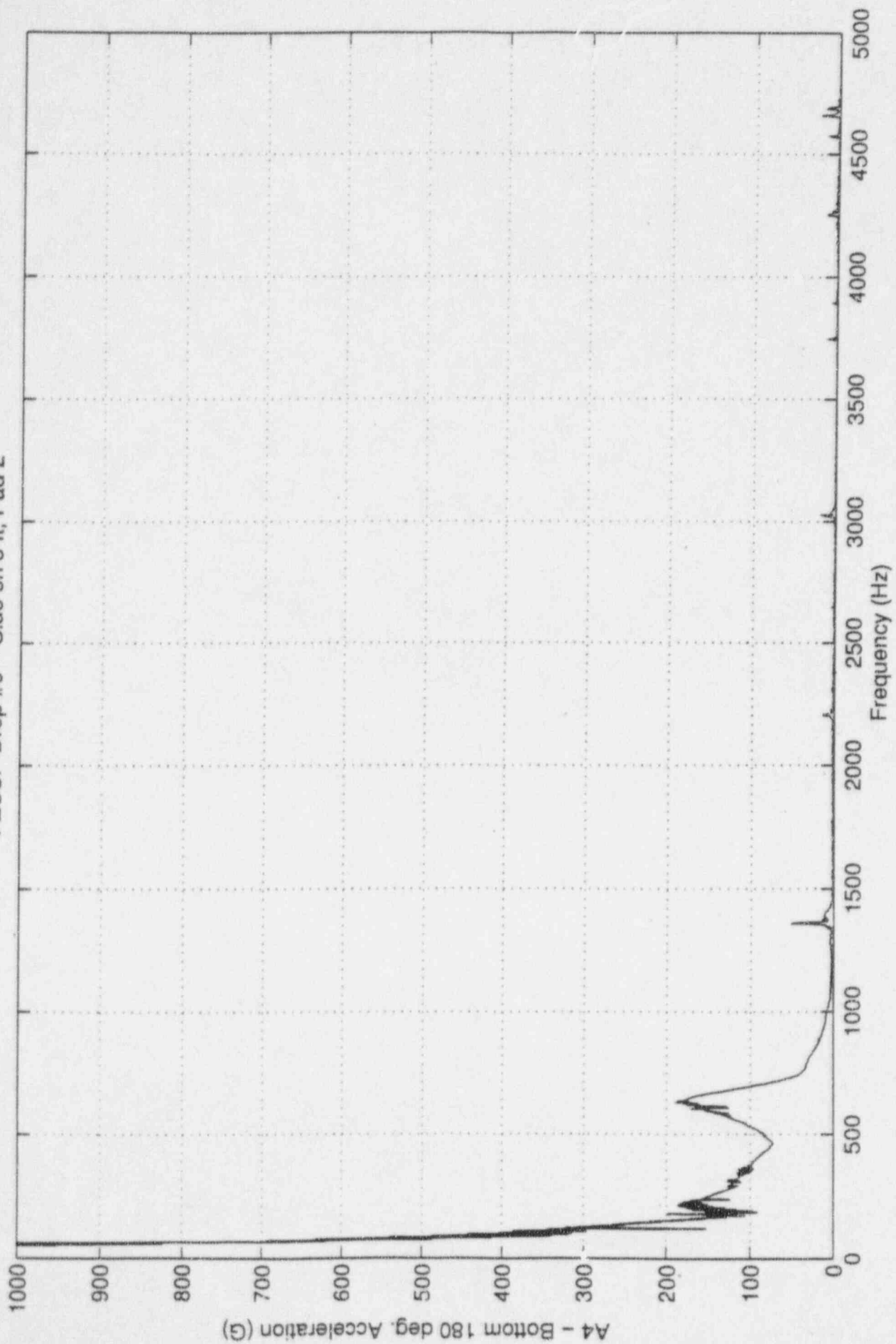




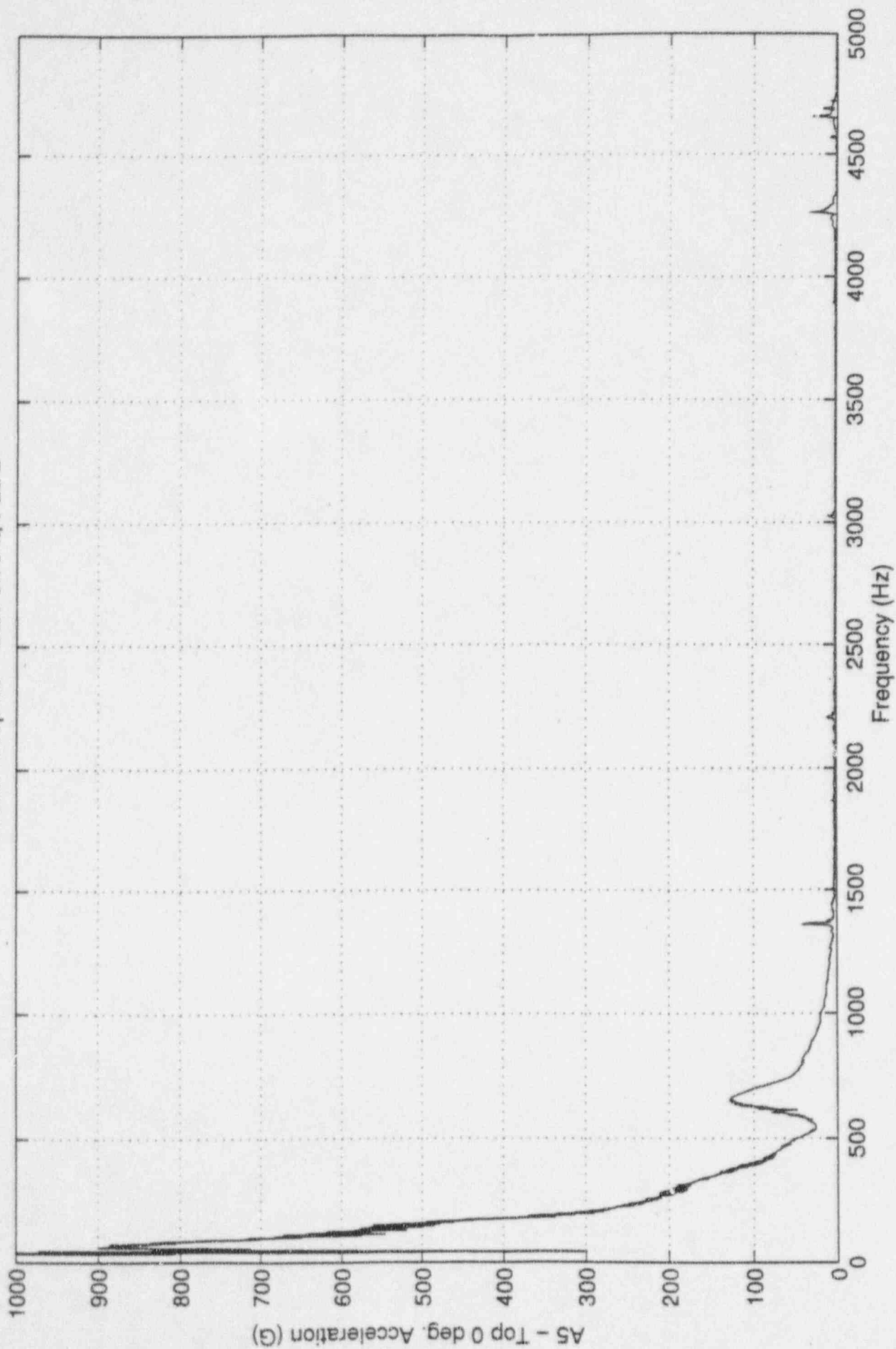
FESSP Drop #9 - Side on 3 ft, Pad 2



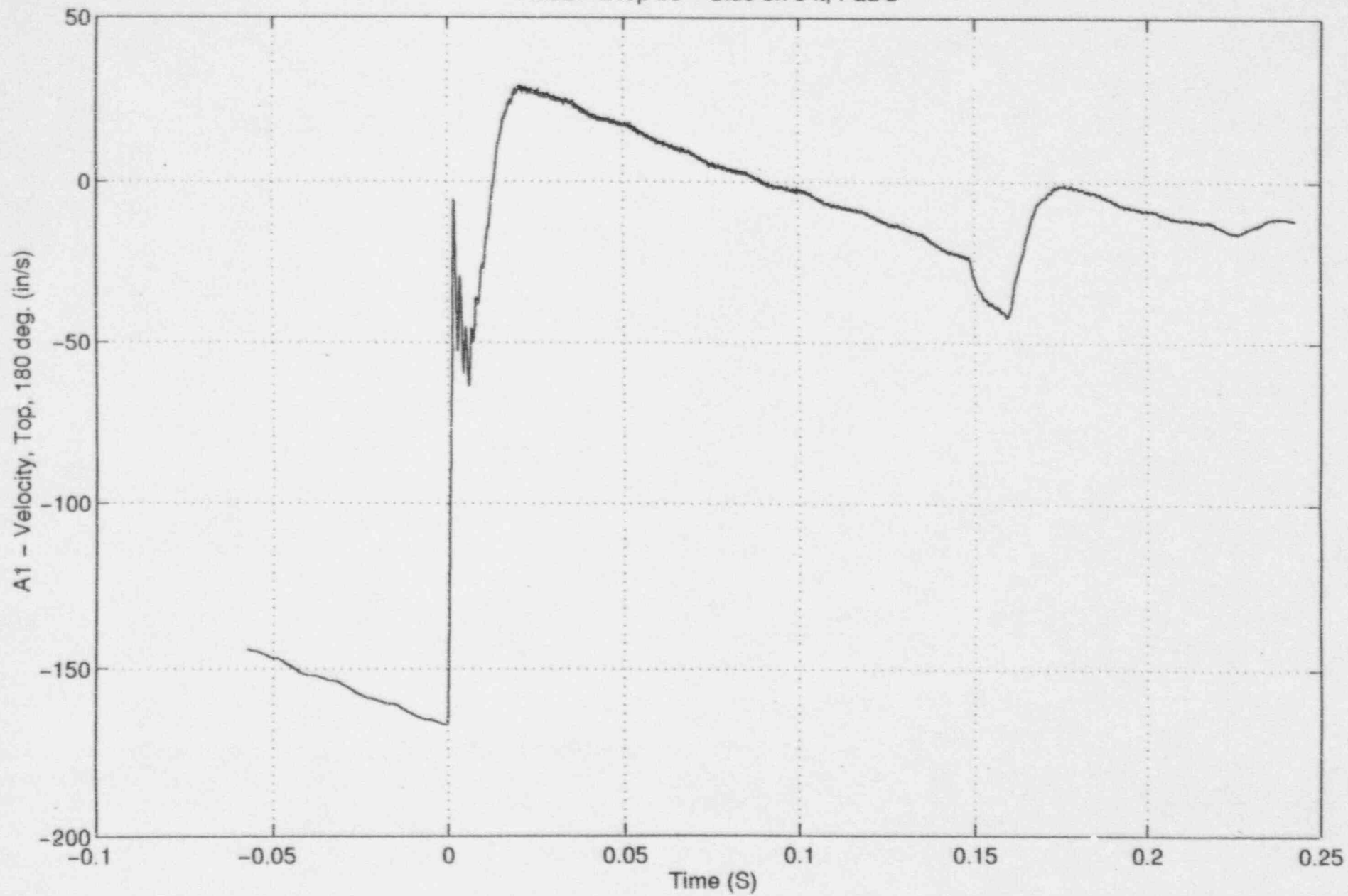
FESSP Drop #9 - Side on 3 ft, Pad 2



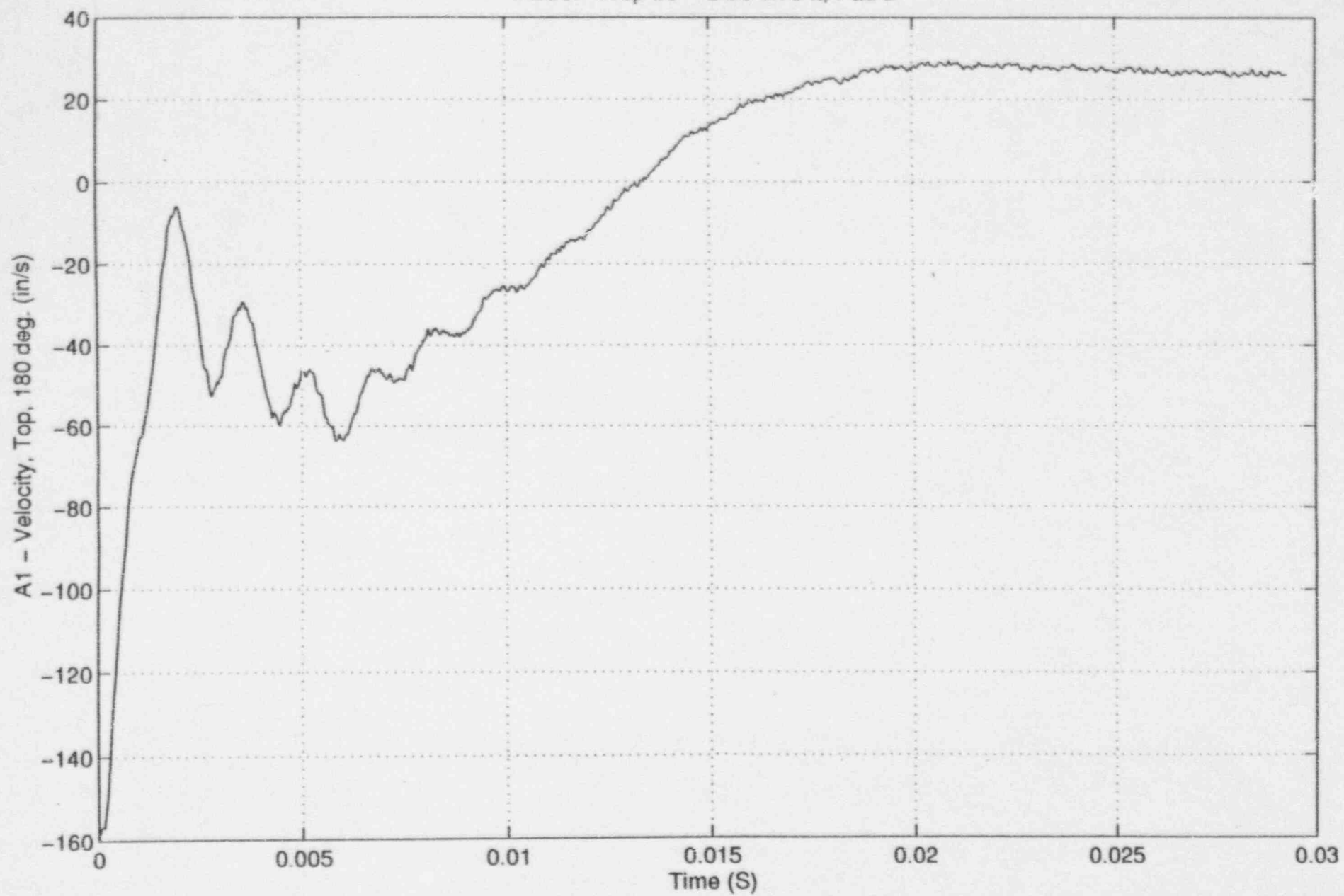
FESSP Drop #9 - Side on 3 ft, Pad 2



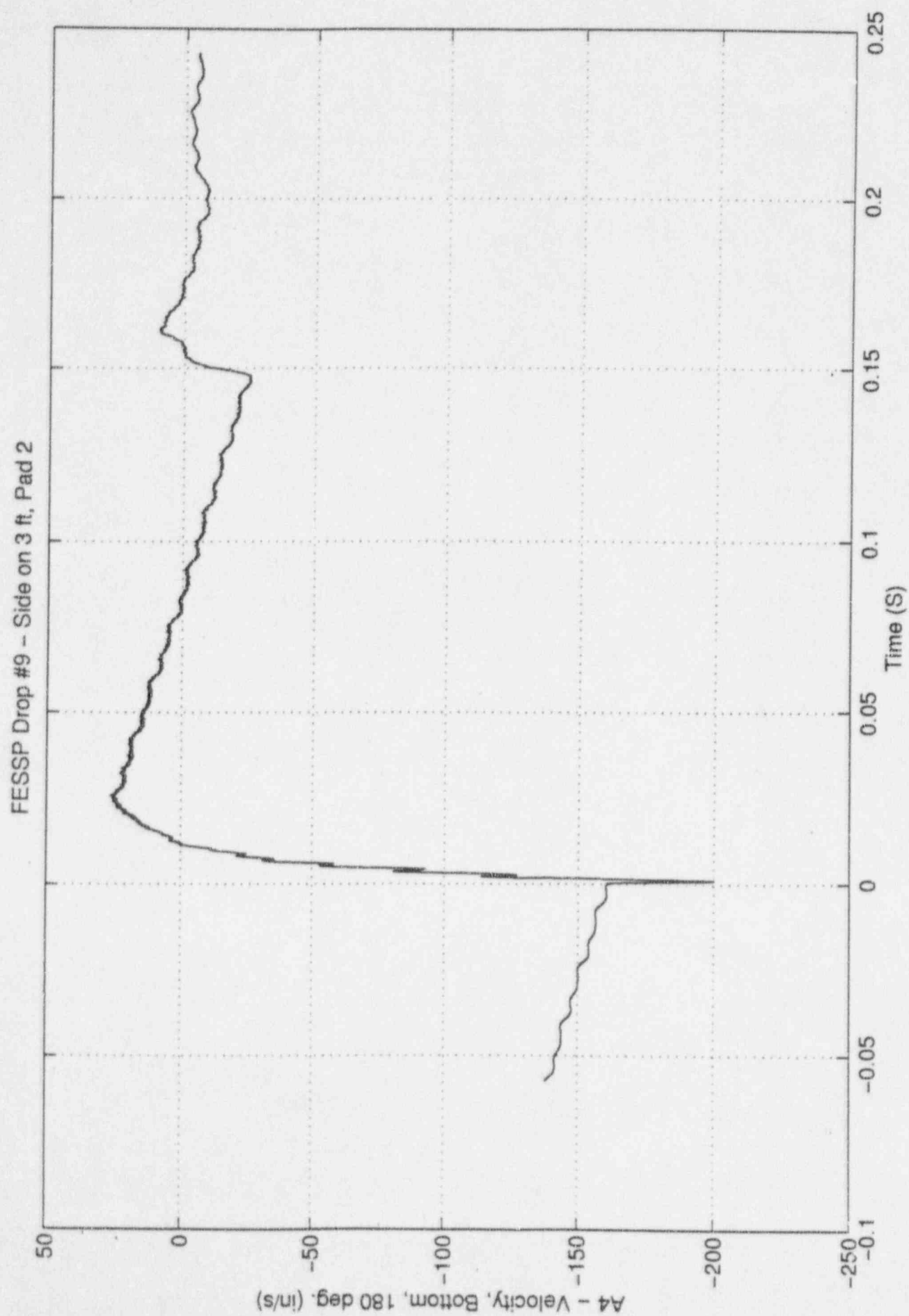
FESSP Drop #9 - Side on 3 ft, Pad 2



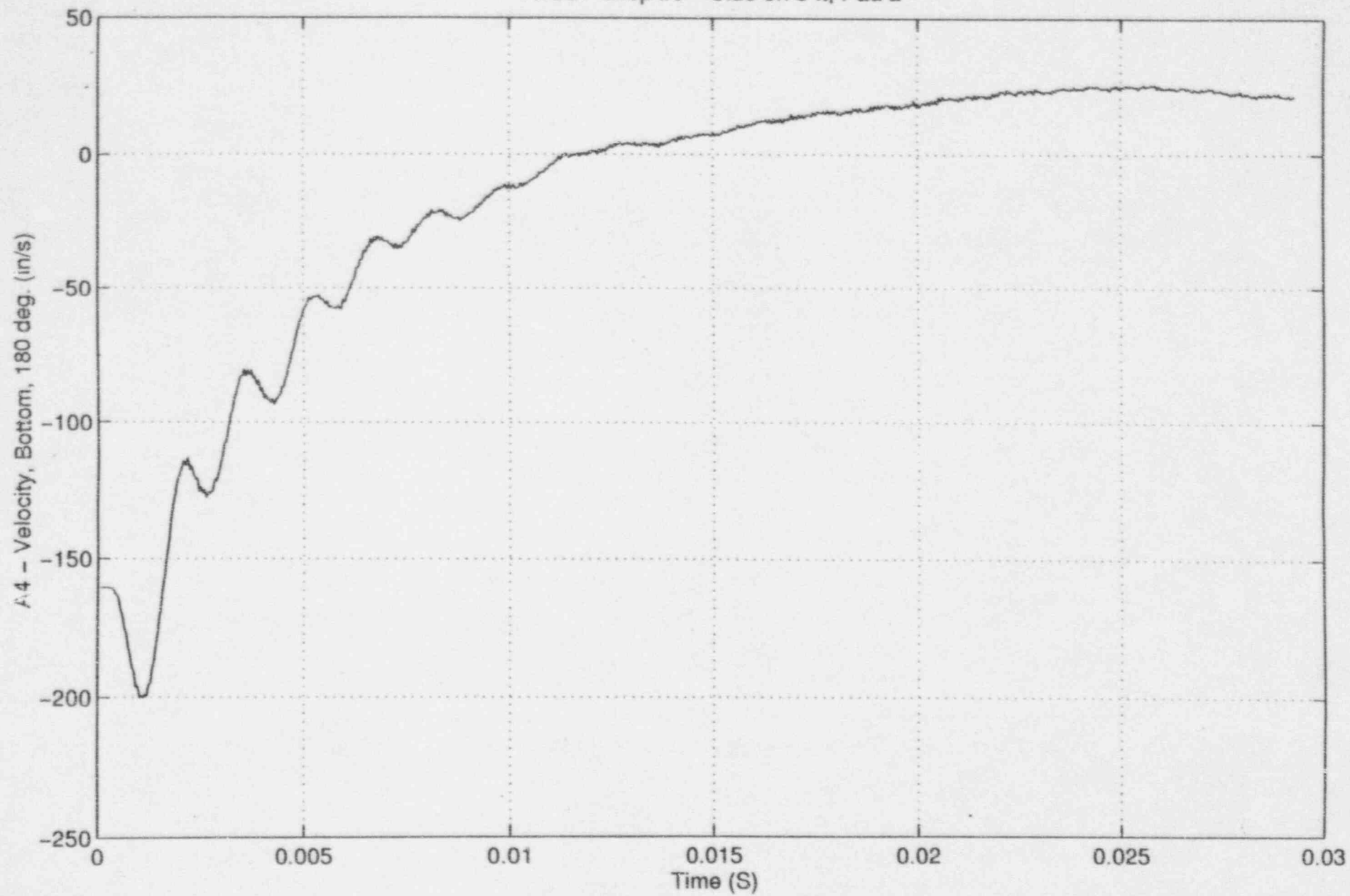
FESSP Drop #9 - Side on 3 ft, Pad 2



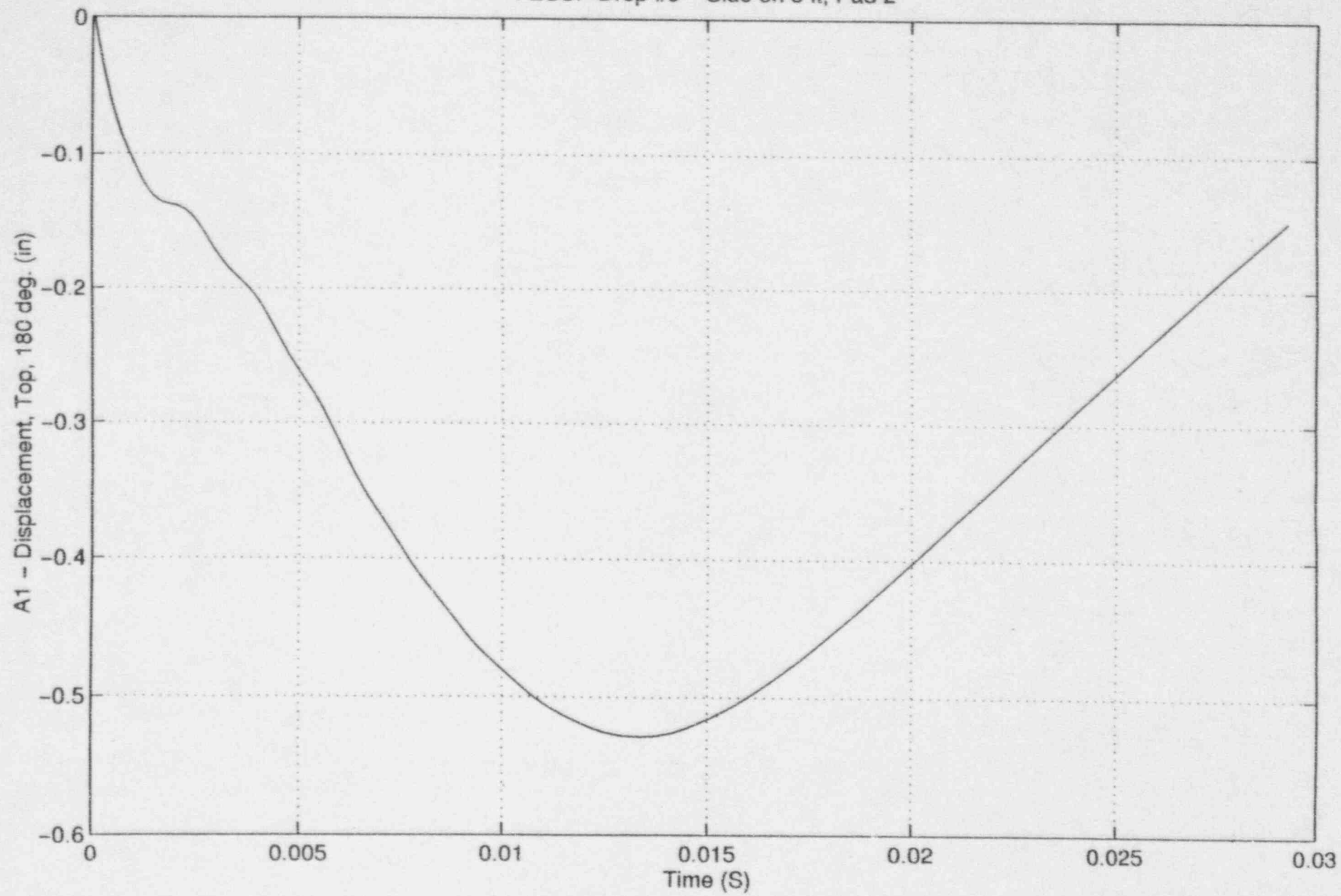




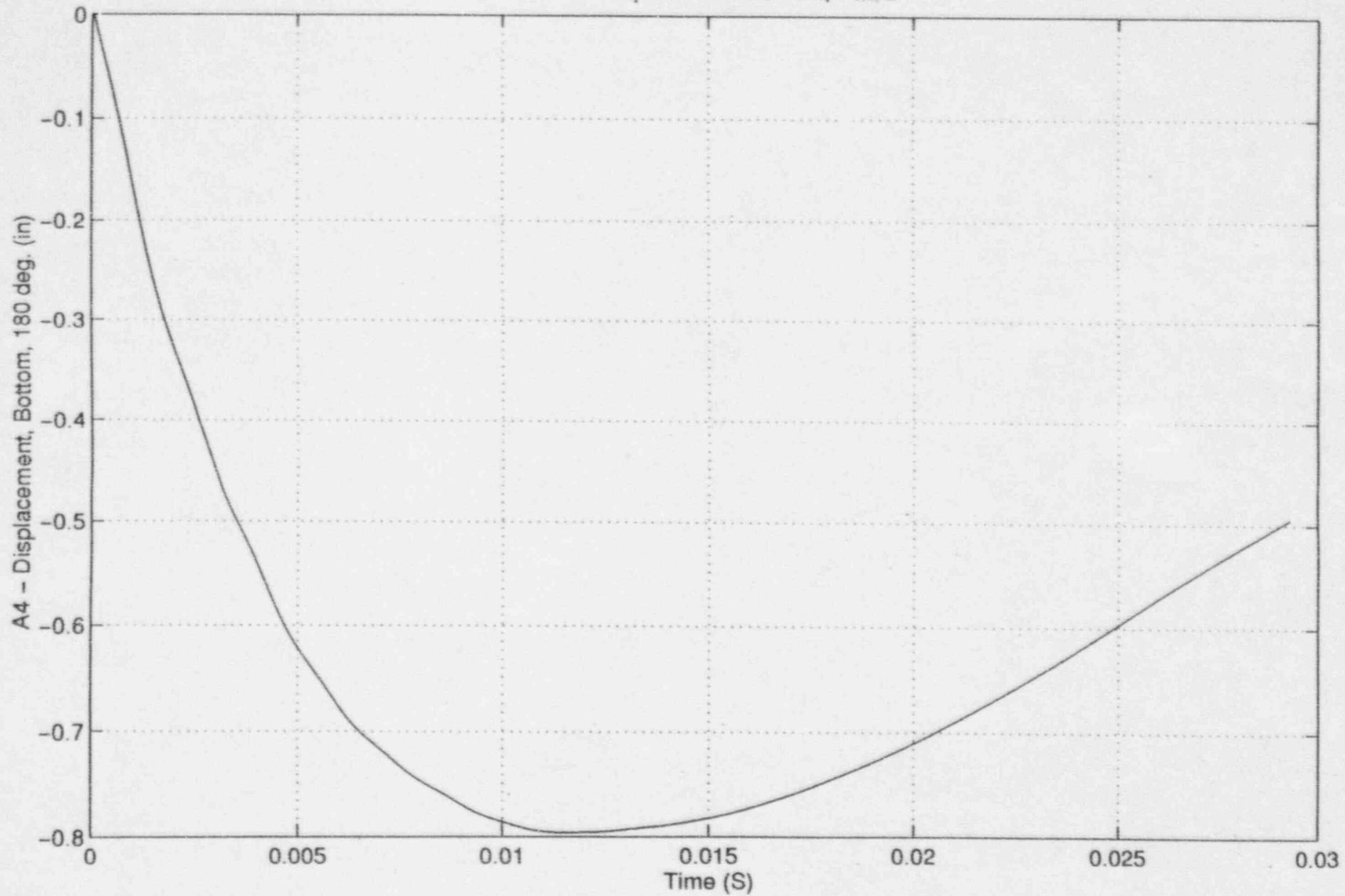
FESSP Drop #9 - Side on 3 ft, Pad 2



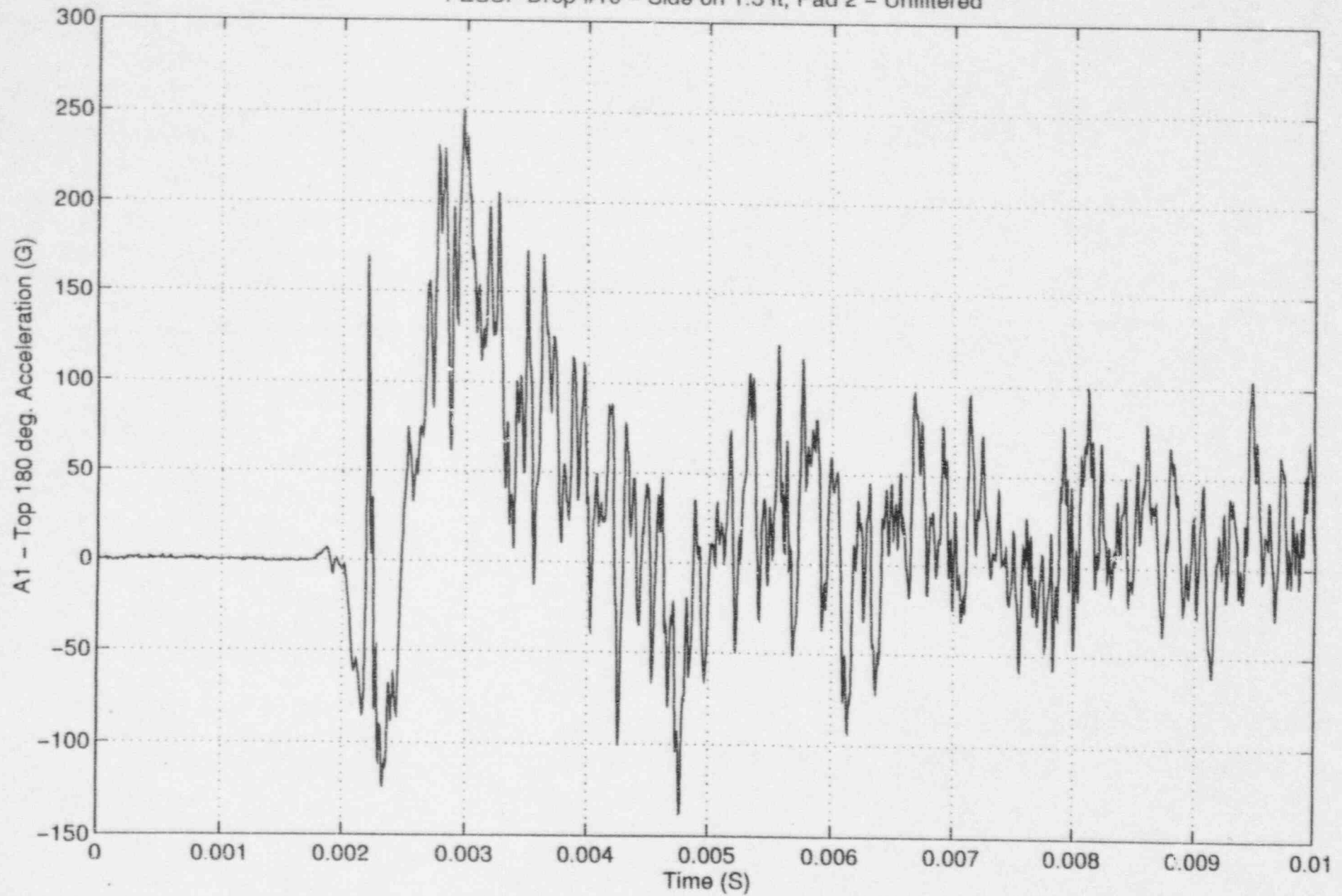
FESSP Drop #9 - Side on 3 ft, Pad 2



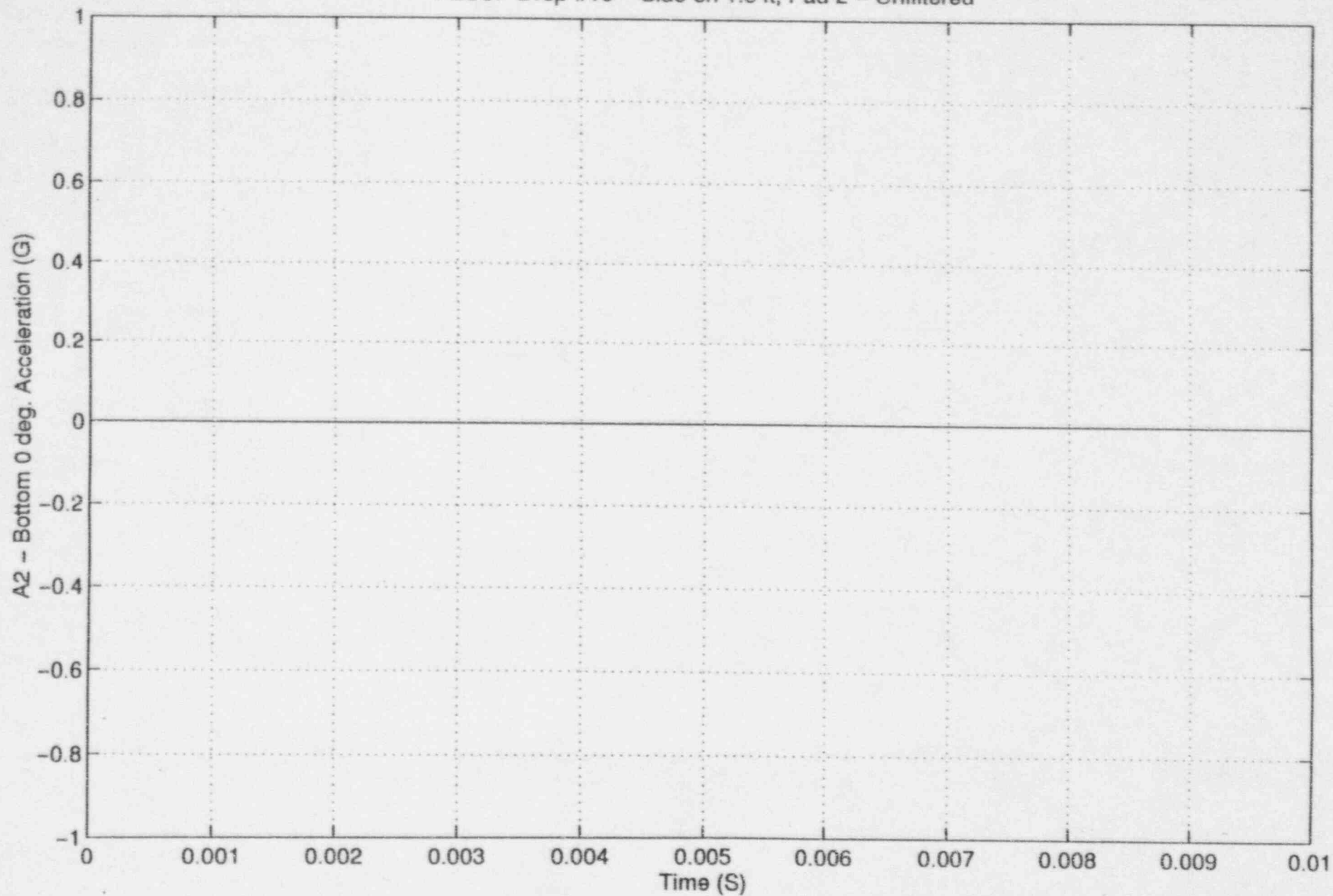
FESSP Drop #9 - Side on 3 ft, Pad 2



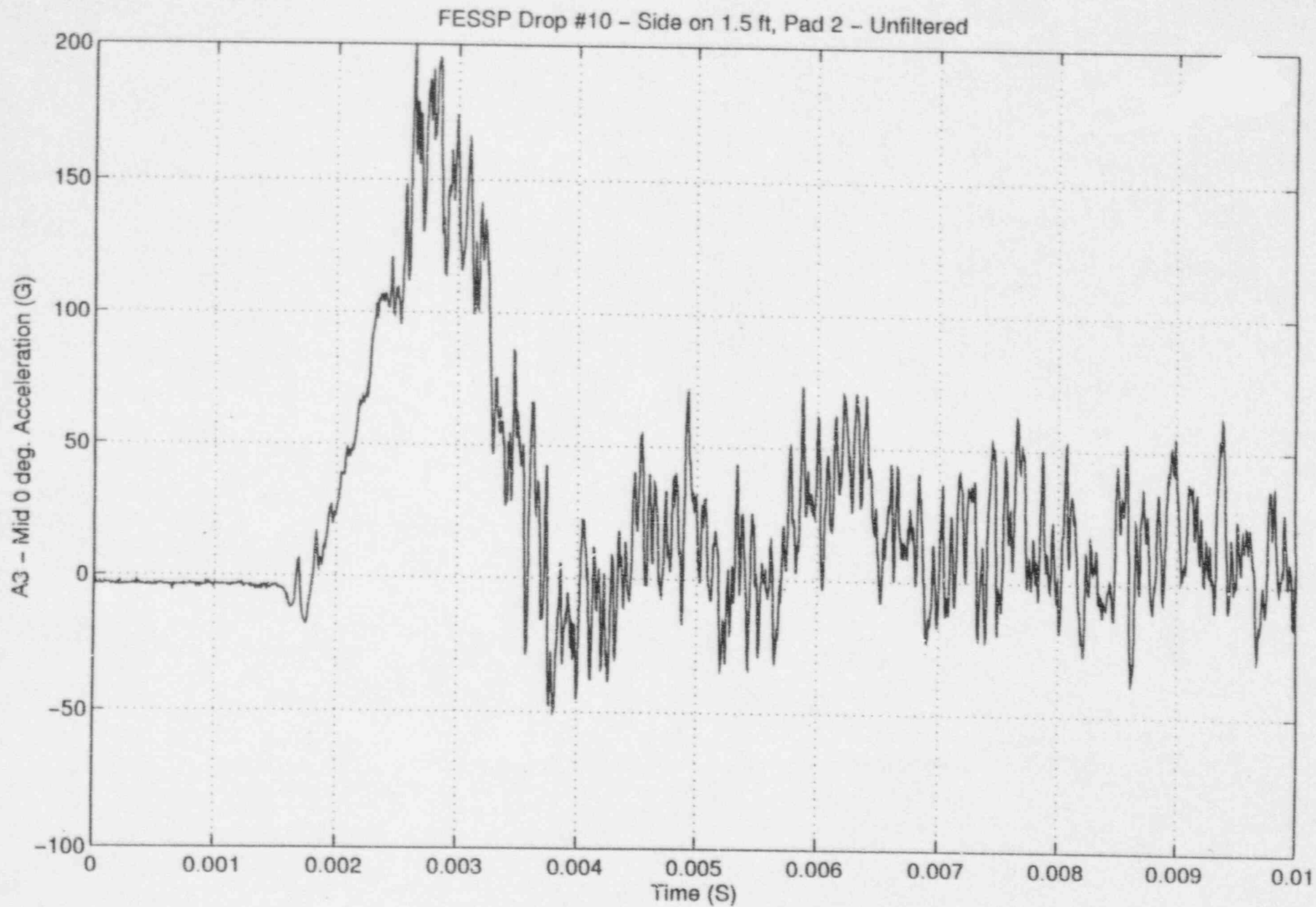
FESSP Drop #10 - Side on 1.5 ft, Pad 2 - Unfiltered



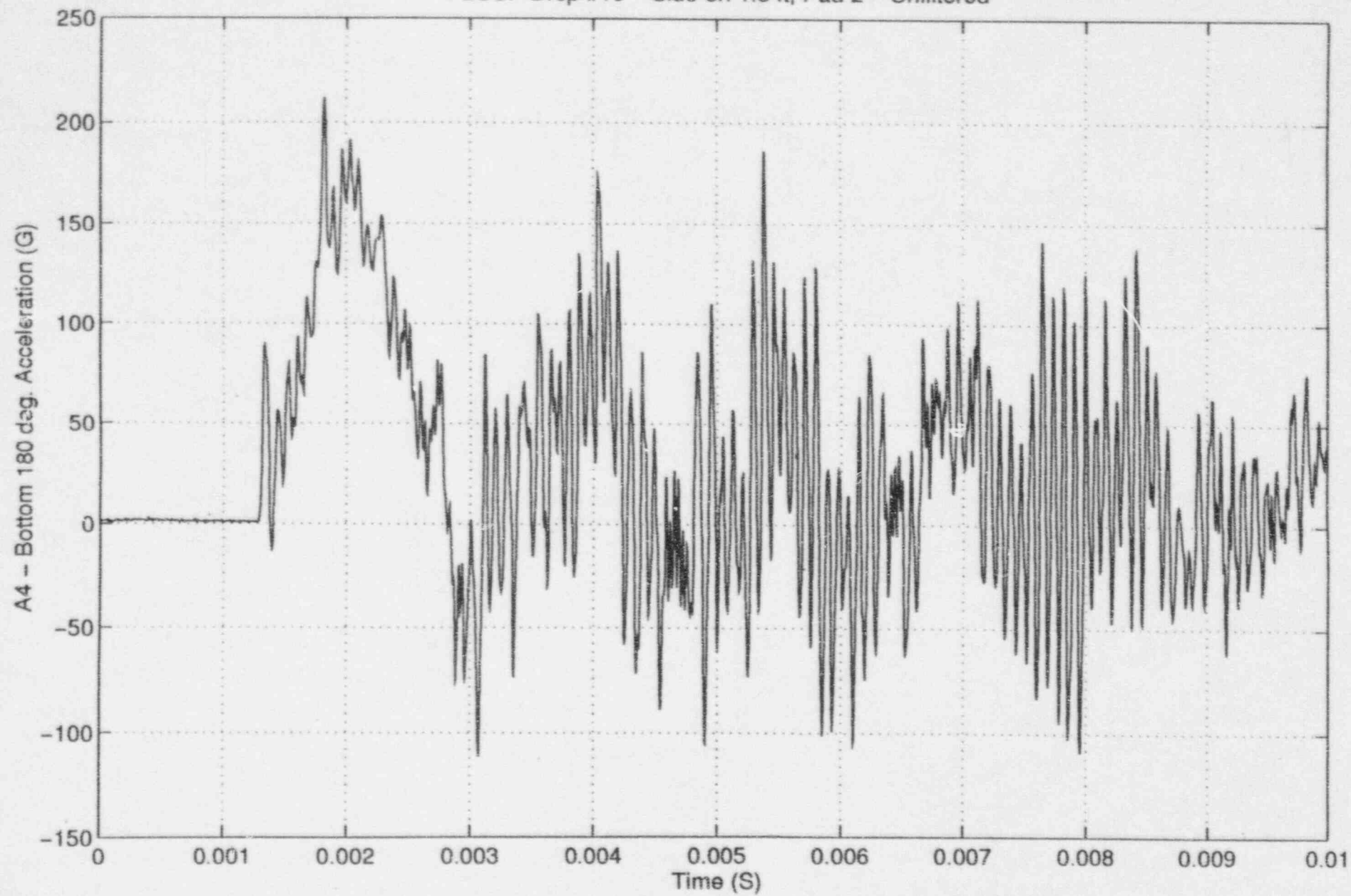
FESSP Drop #10 - Side on 1.5 ft, Pad 2 - Unfiltered



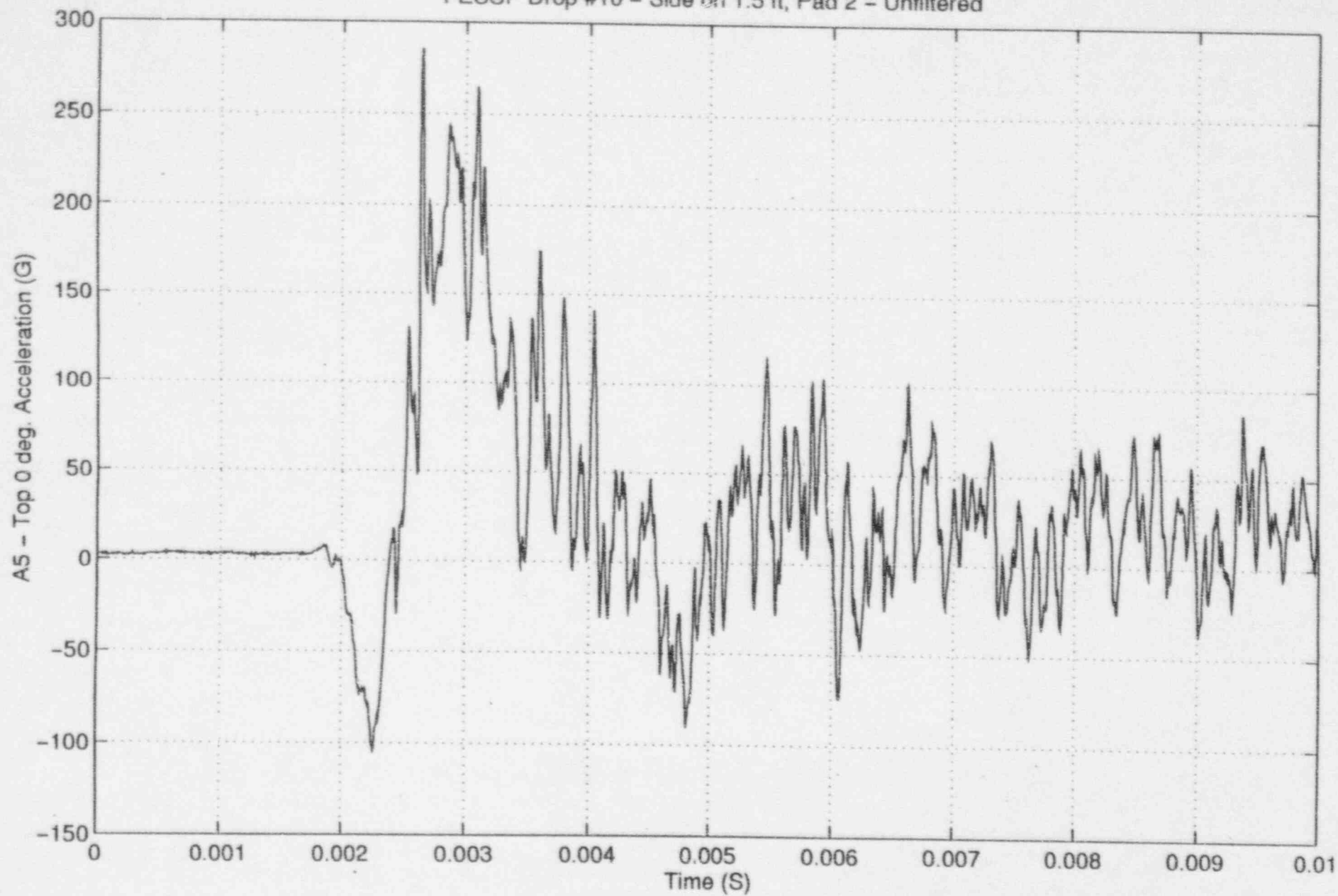




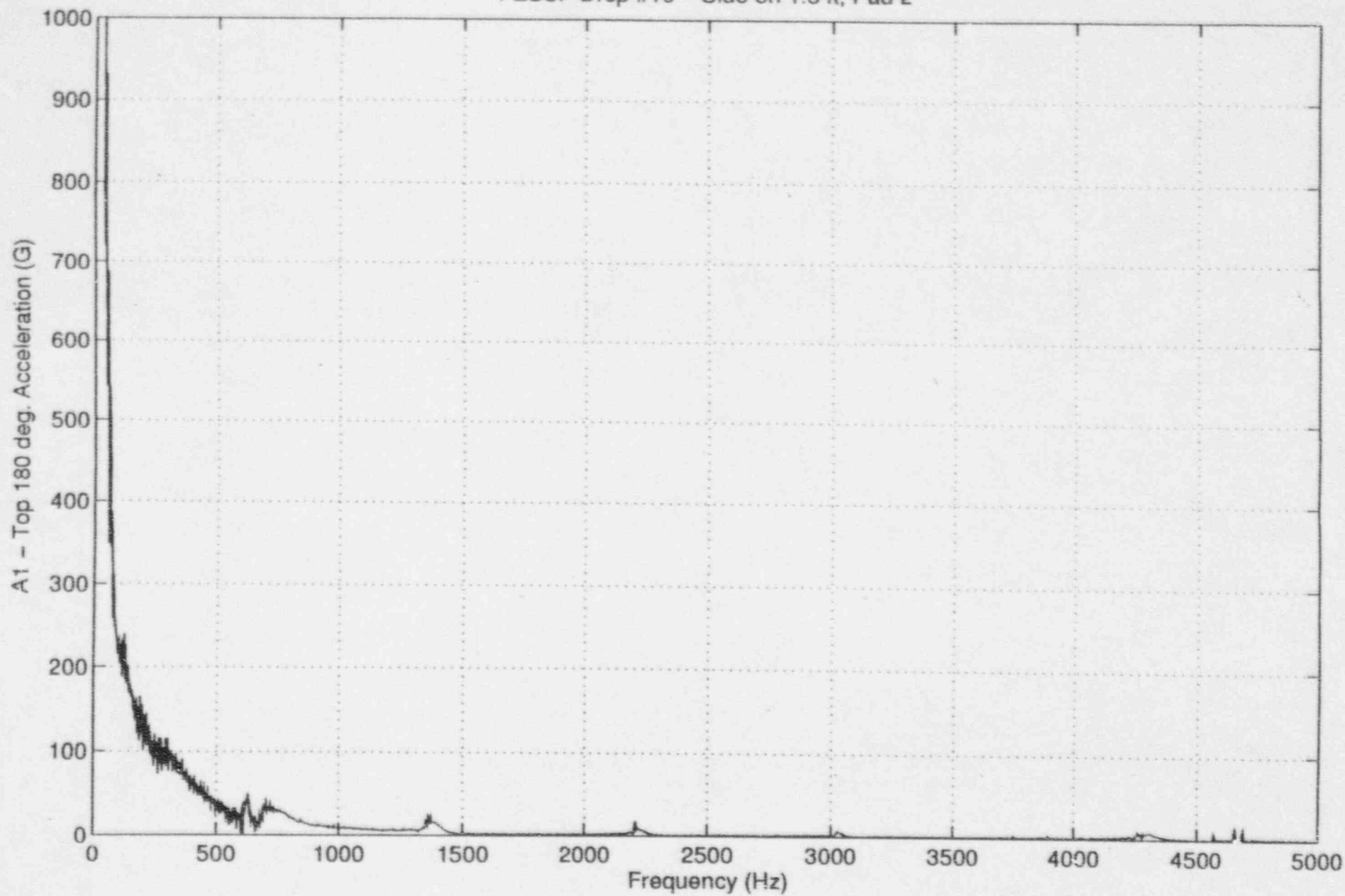
FESSP Drop #10 - Side on 1.5 ft, Pad 2 - Unfiltered

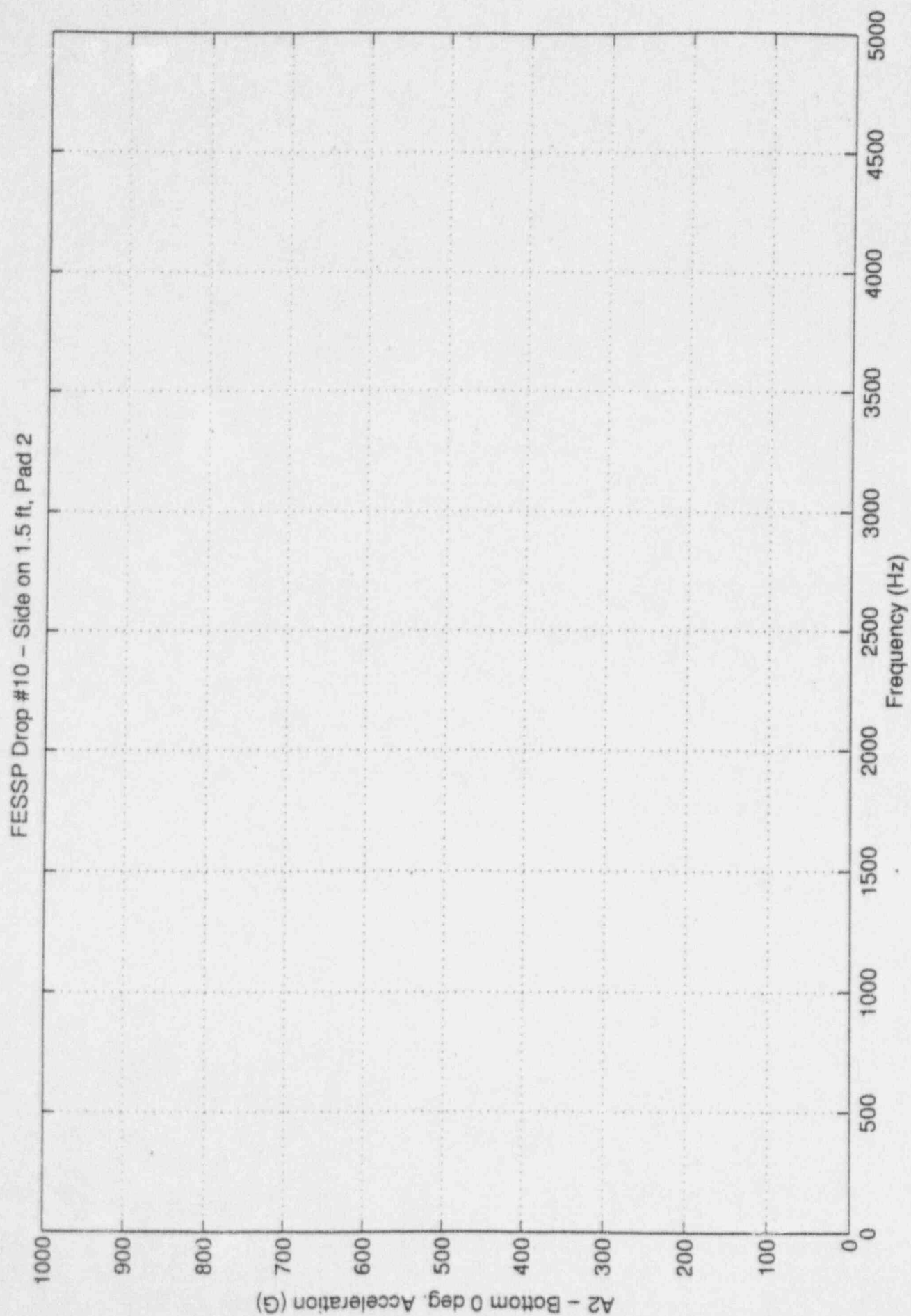


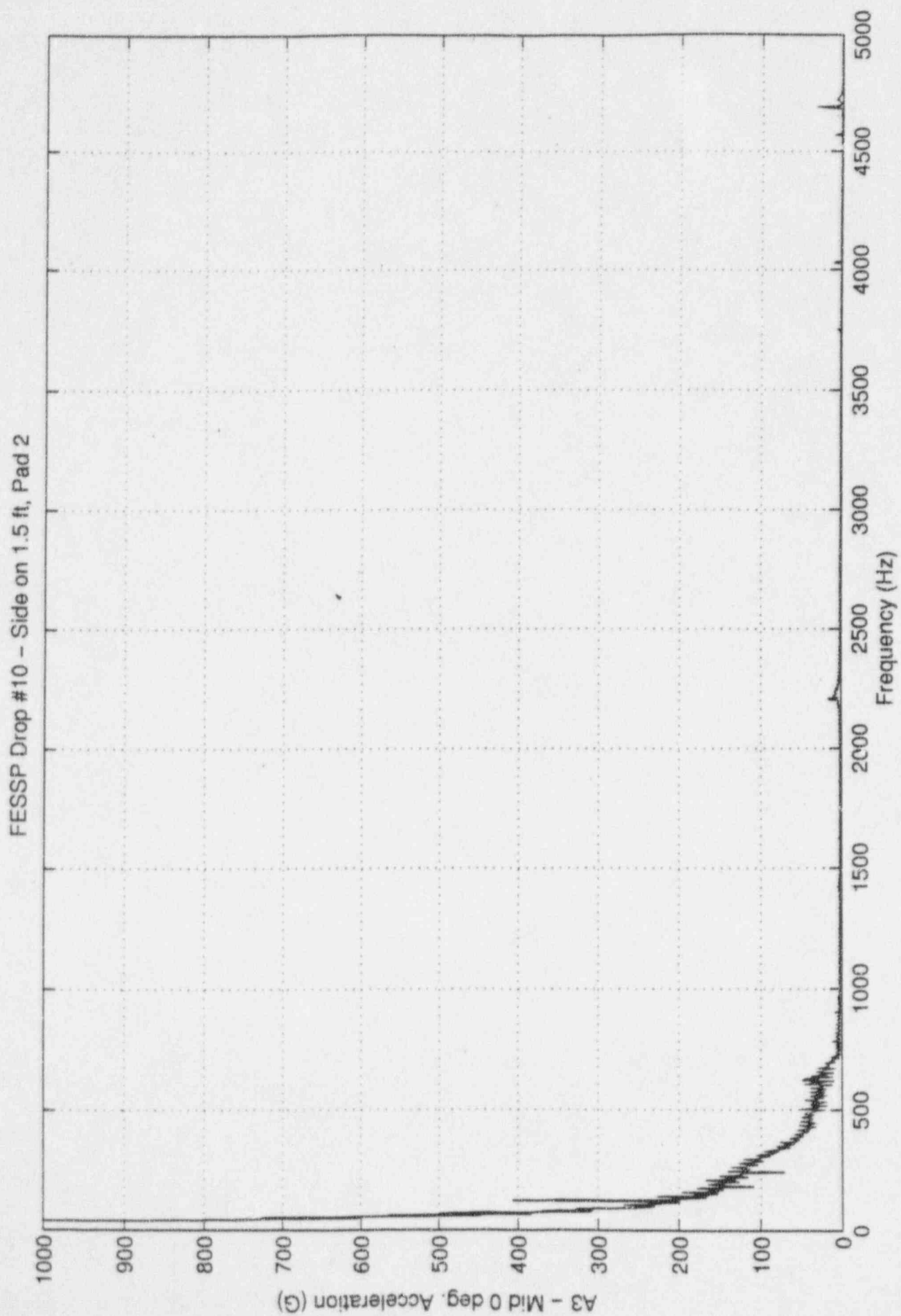
FESSP Drop #10 - Side on 1.5 ft, Pad 2 - Unfiltered



FESSP Drop #10 - Side on 1.5 ft, Pad 2

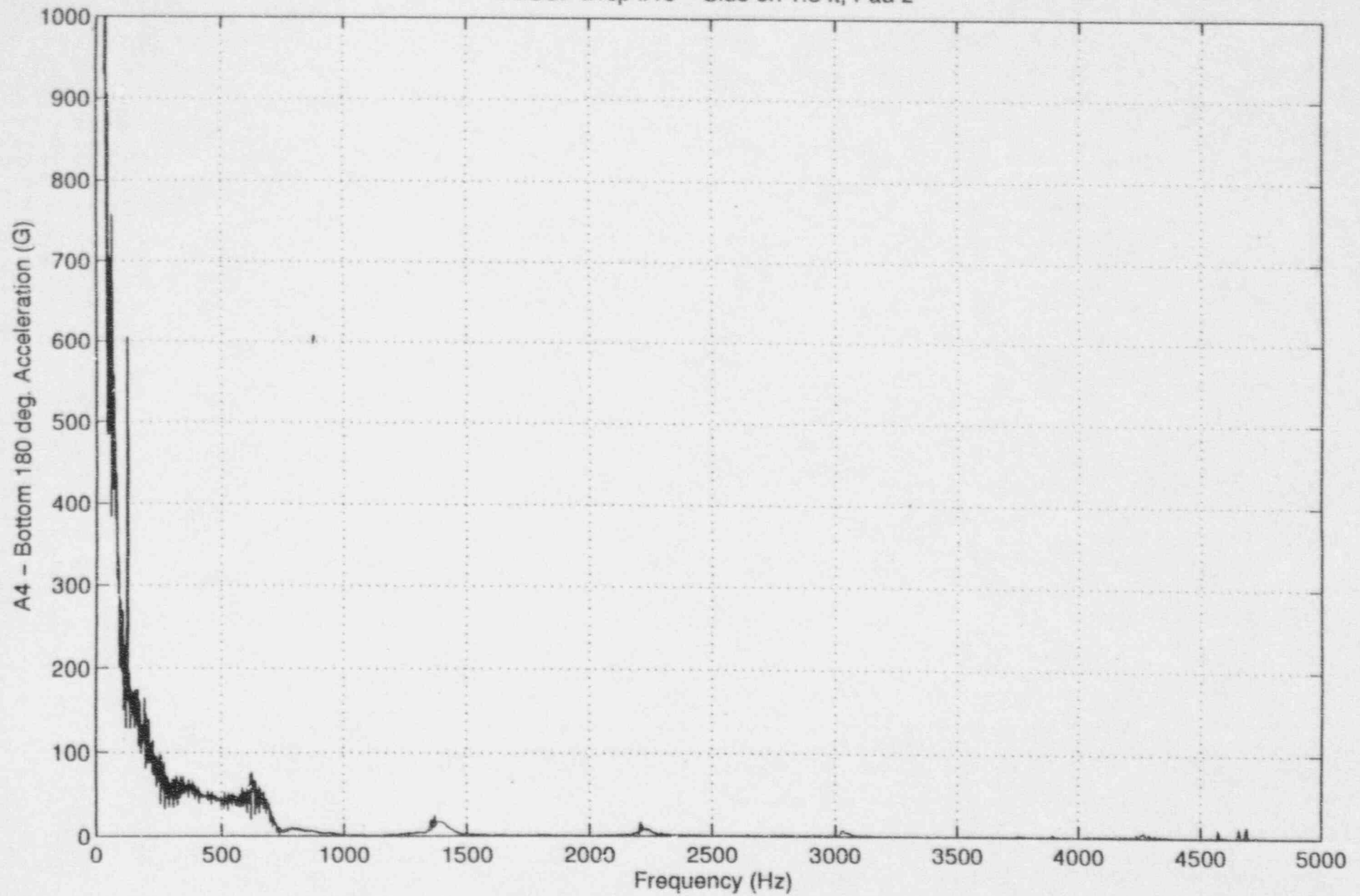




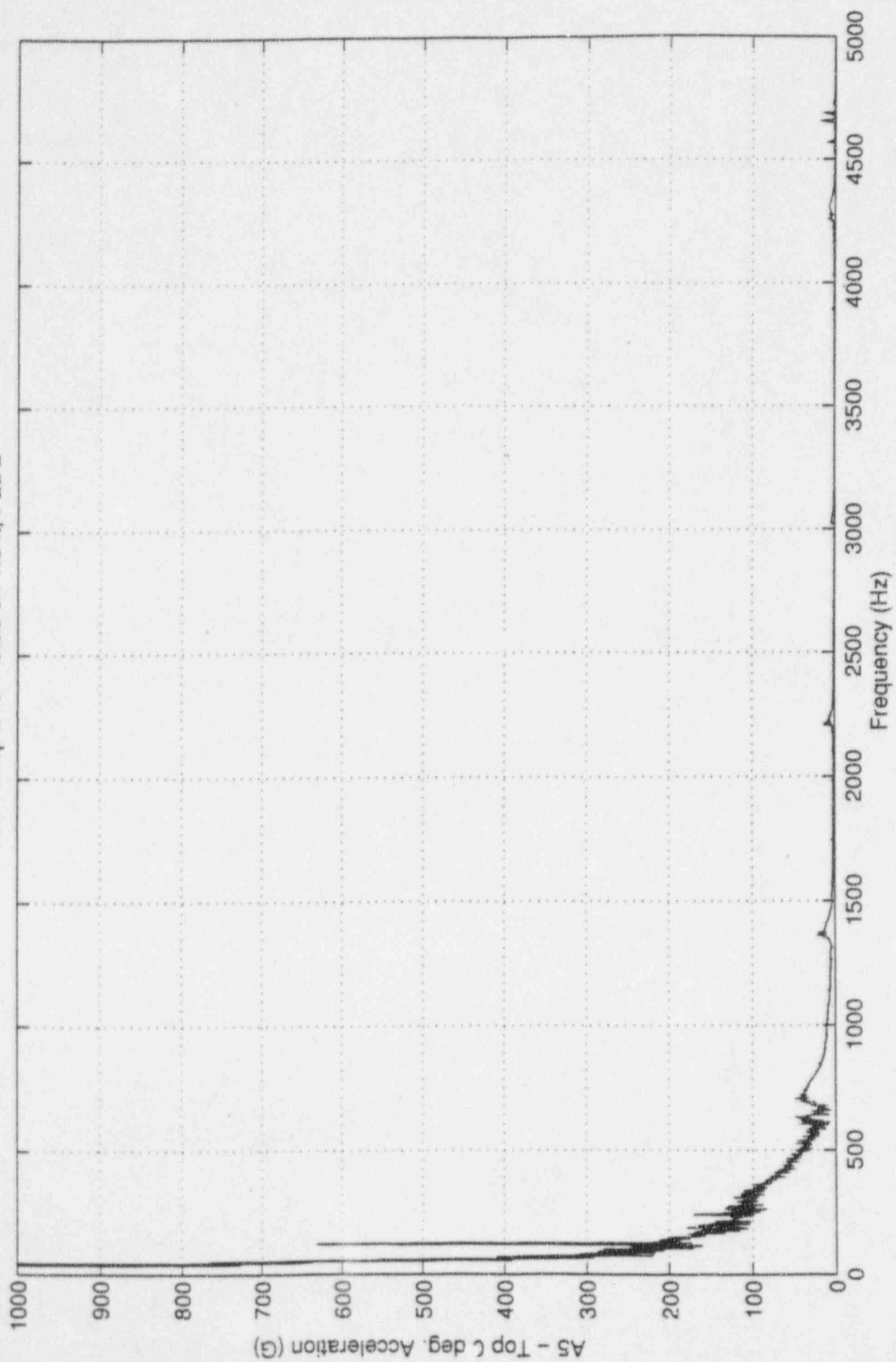




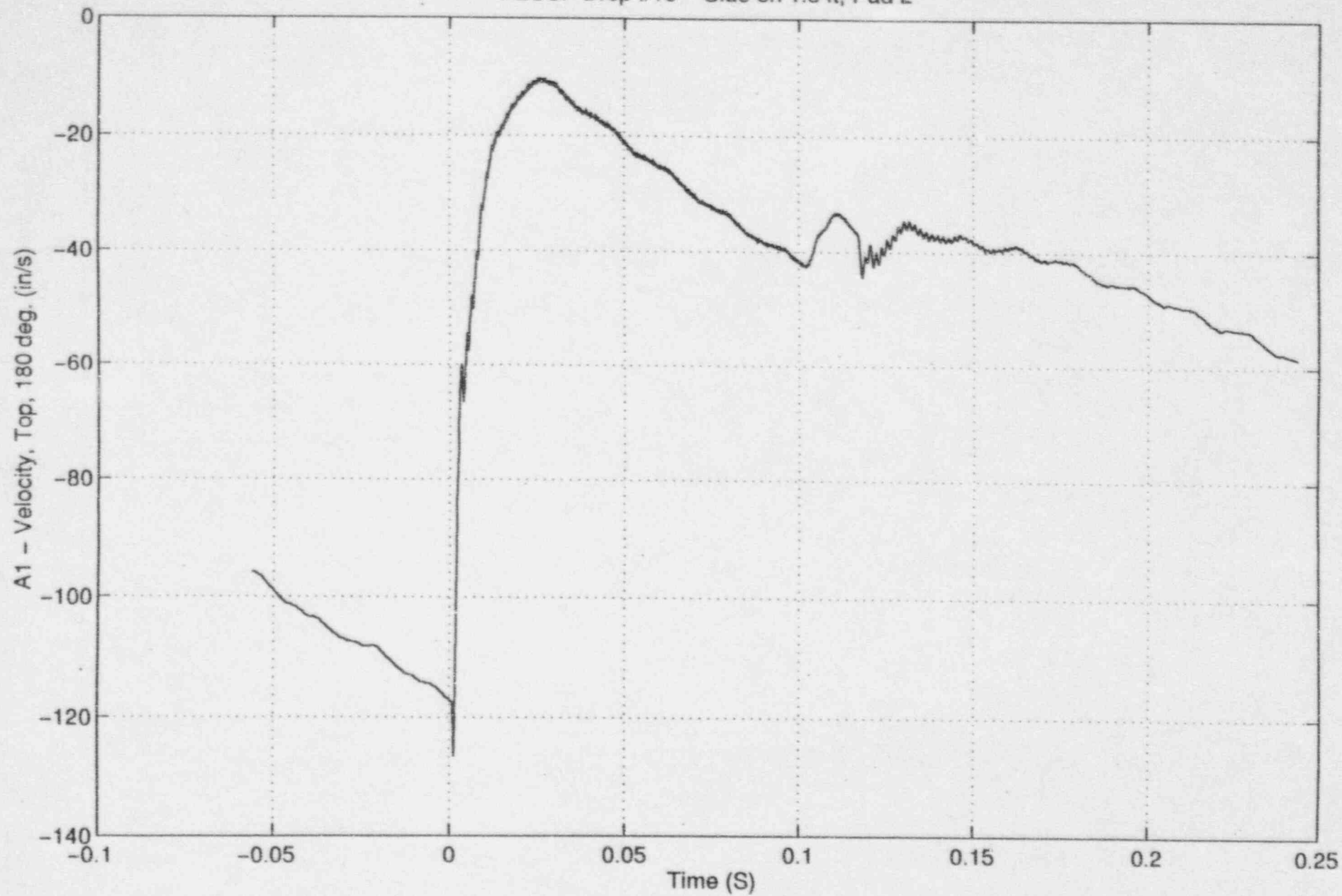
FESSP Drop #10 - Side on 1.5 ft, Pad 2



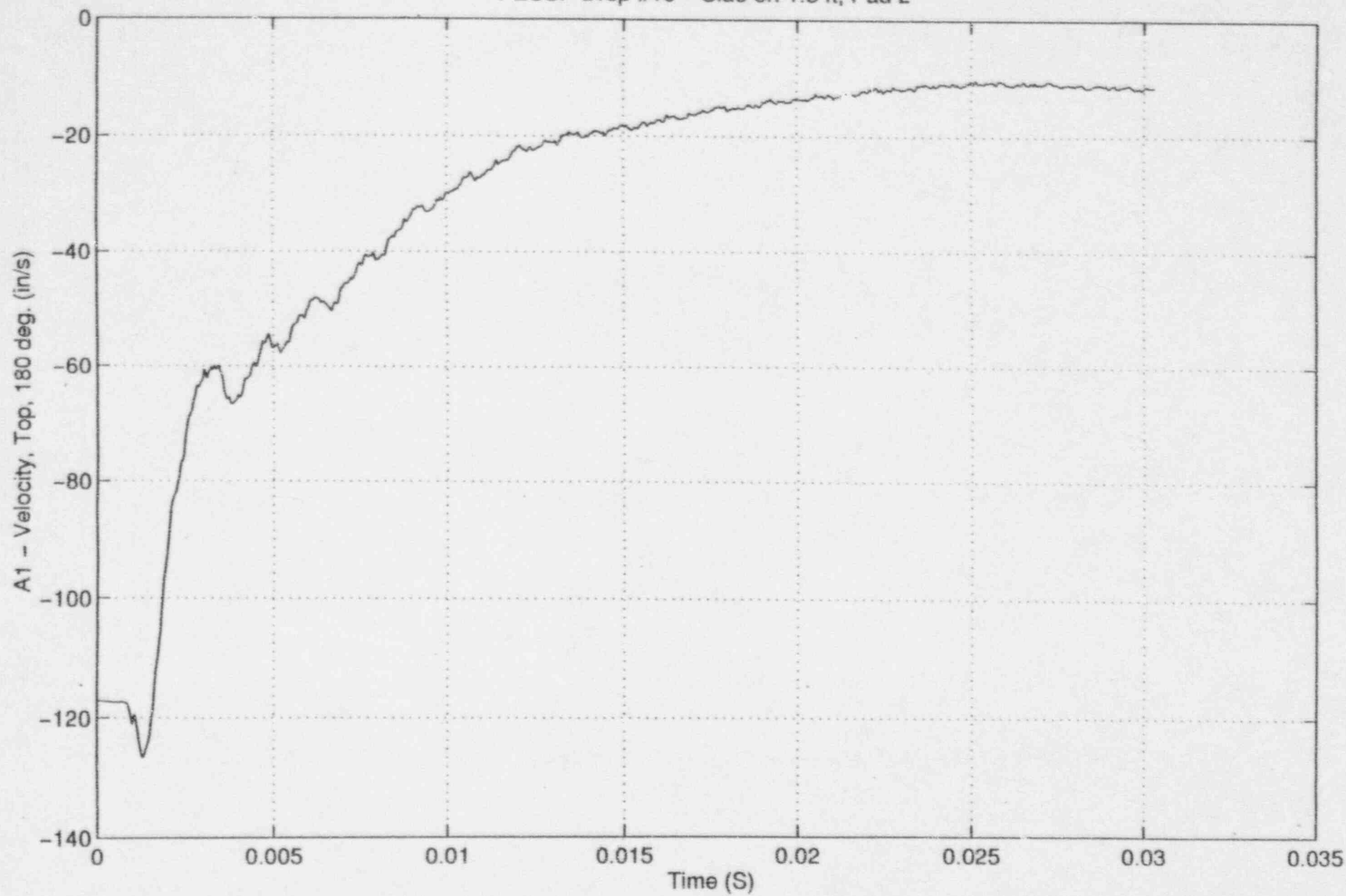
FESSP Drop #10 - Side on 1.5 ft, Pad 2

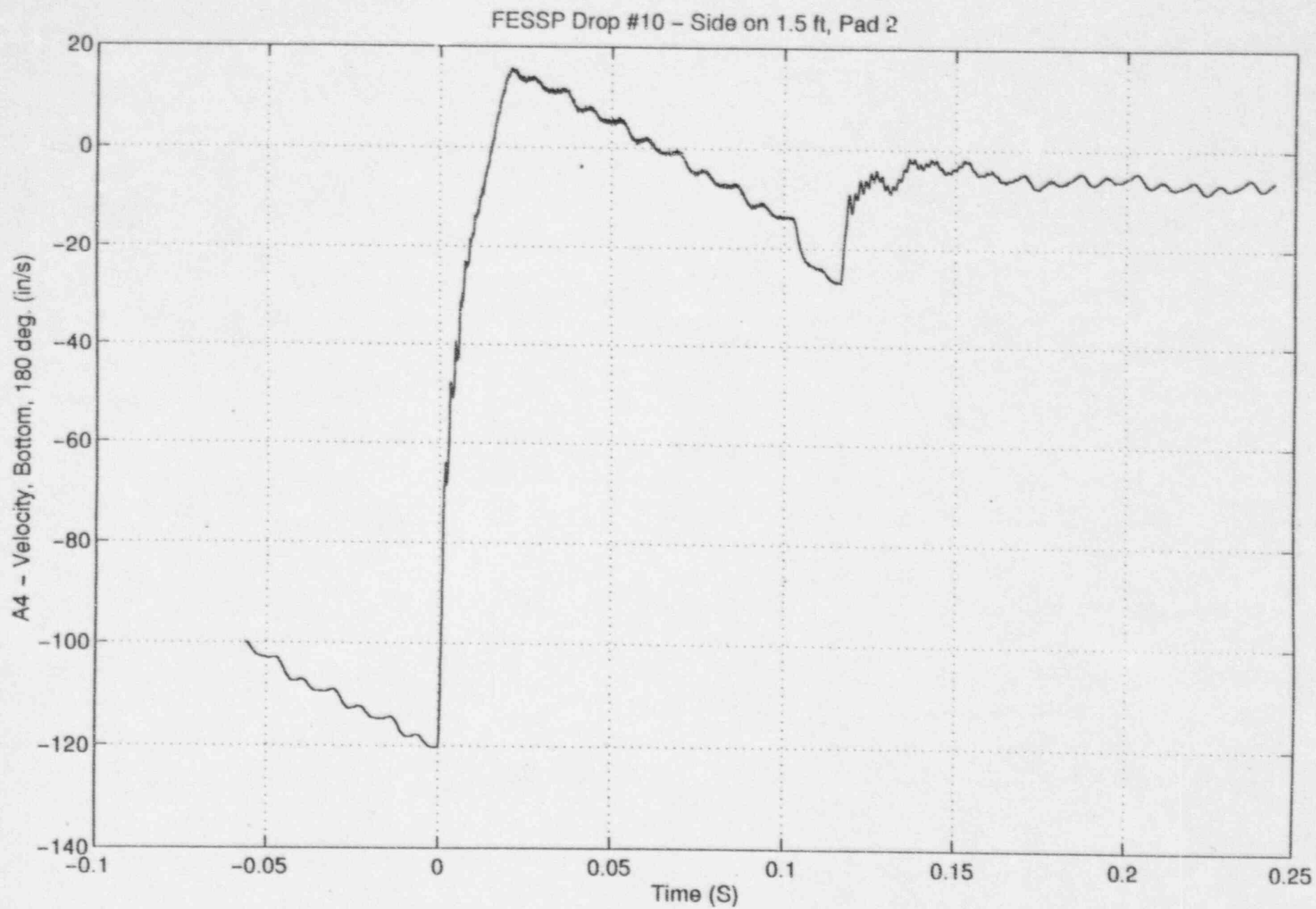


FESSP Drop #10 - Side on 1.5 ft, Pad 2

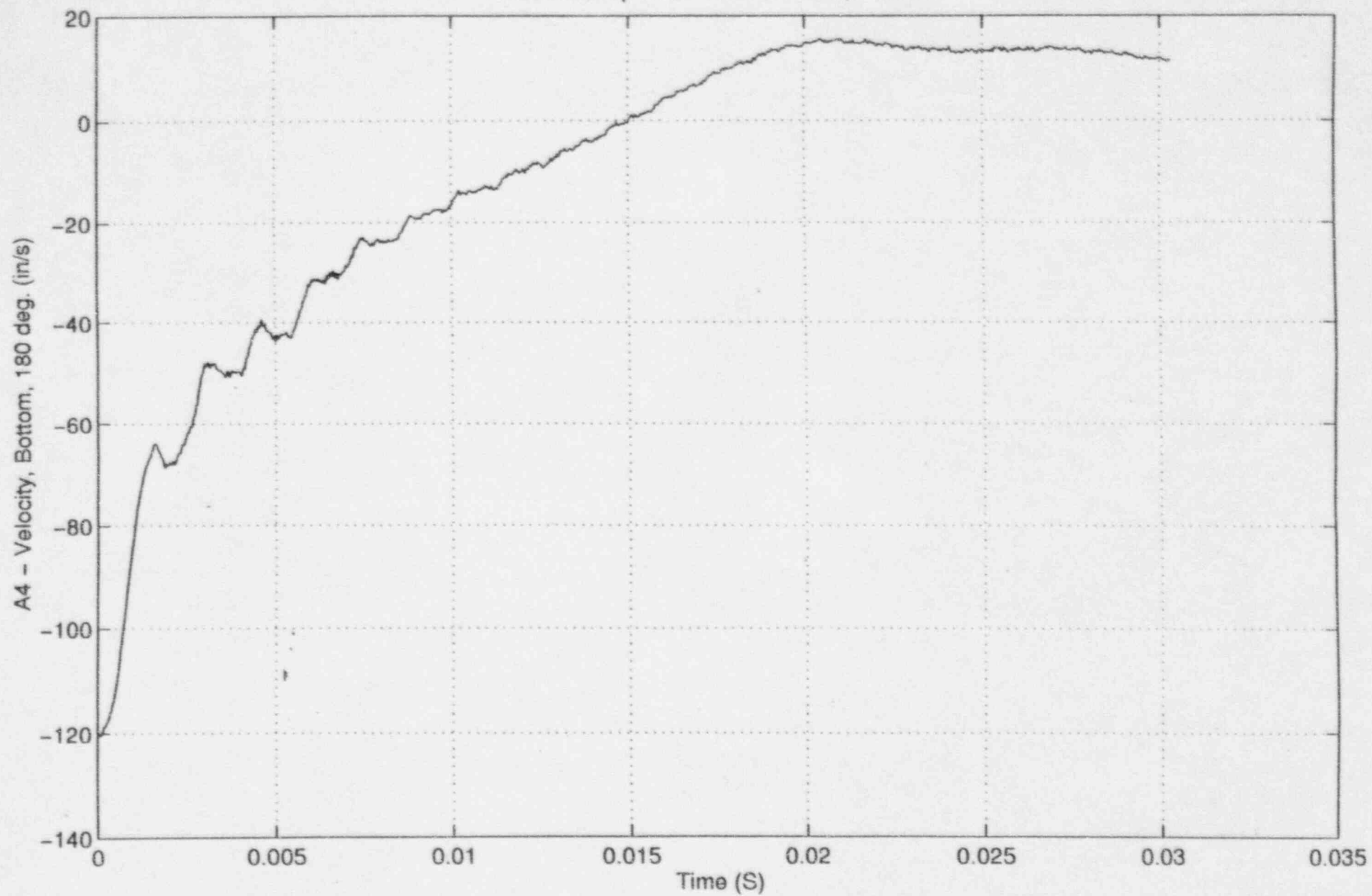


FESSP Drop #10 - Side on 1.5 ft, Pad 2



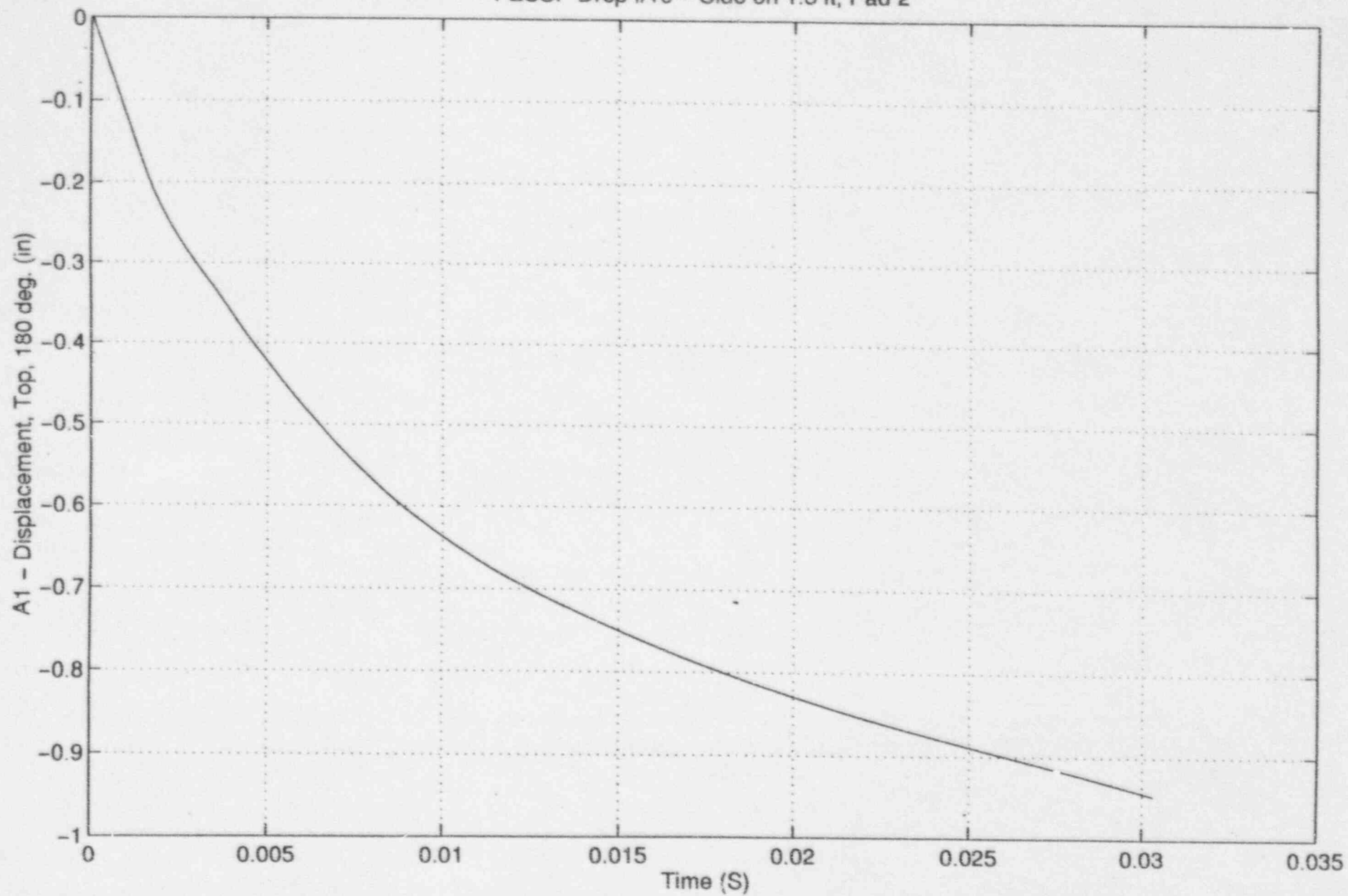


FESSP Drop #10 - Side on 1.5 ft, Pad 2

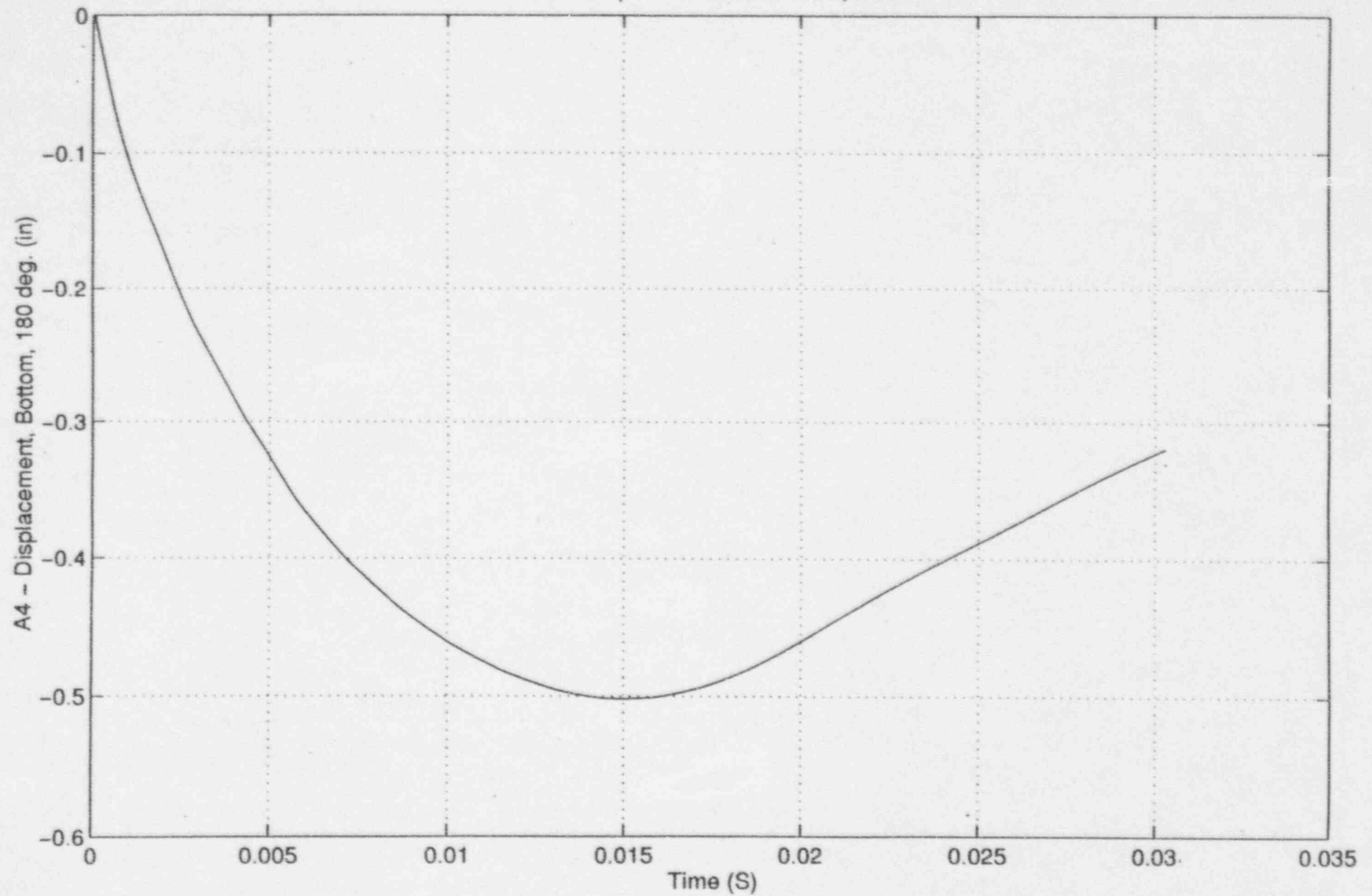


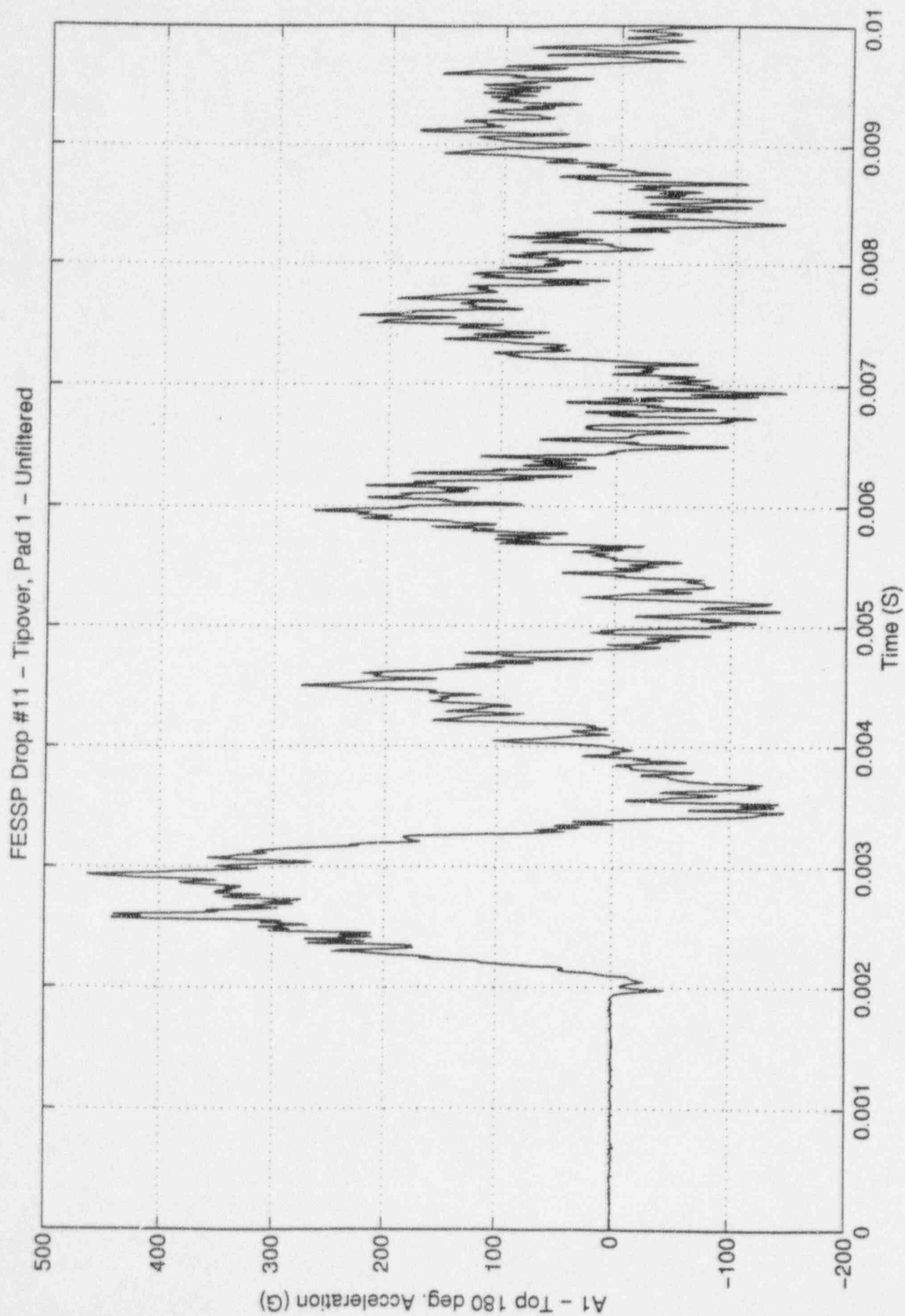


FESSP Drop #10 - Side on 1.5 ft, Pad 2

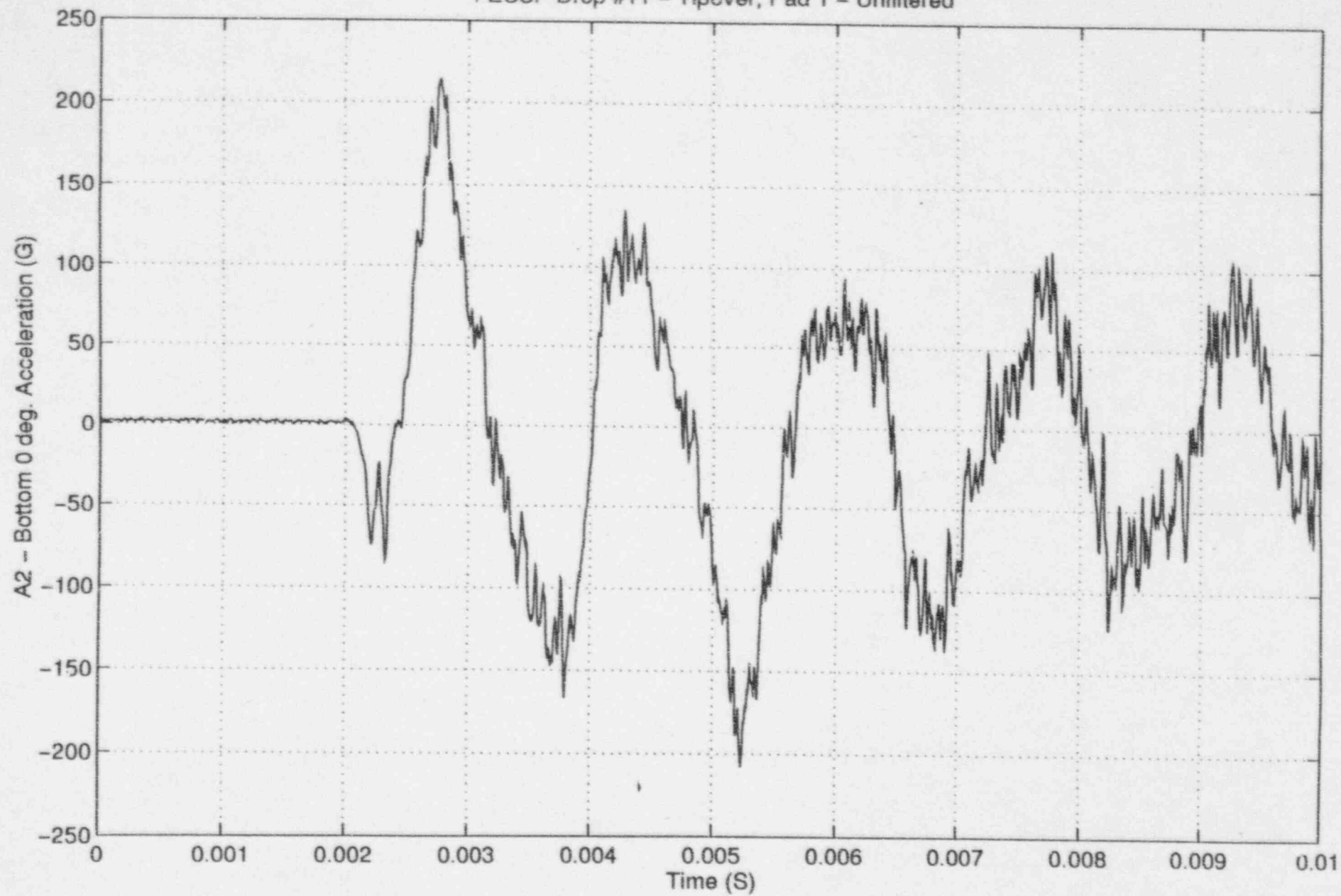


FESSP Drop #10 - Side on 1.5 ft, Pad 2

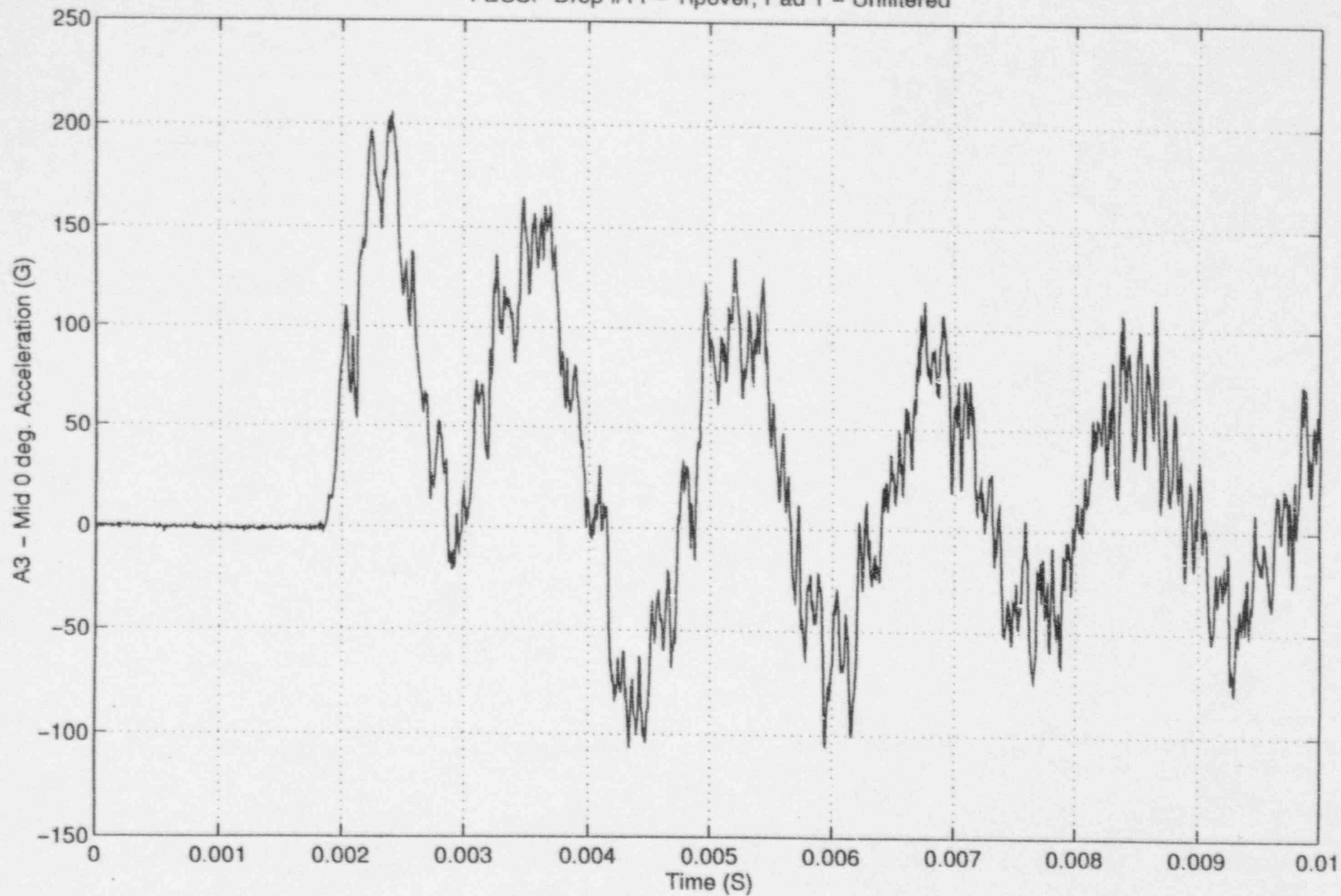




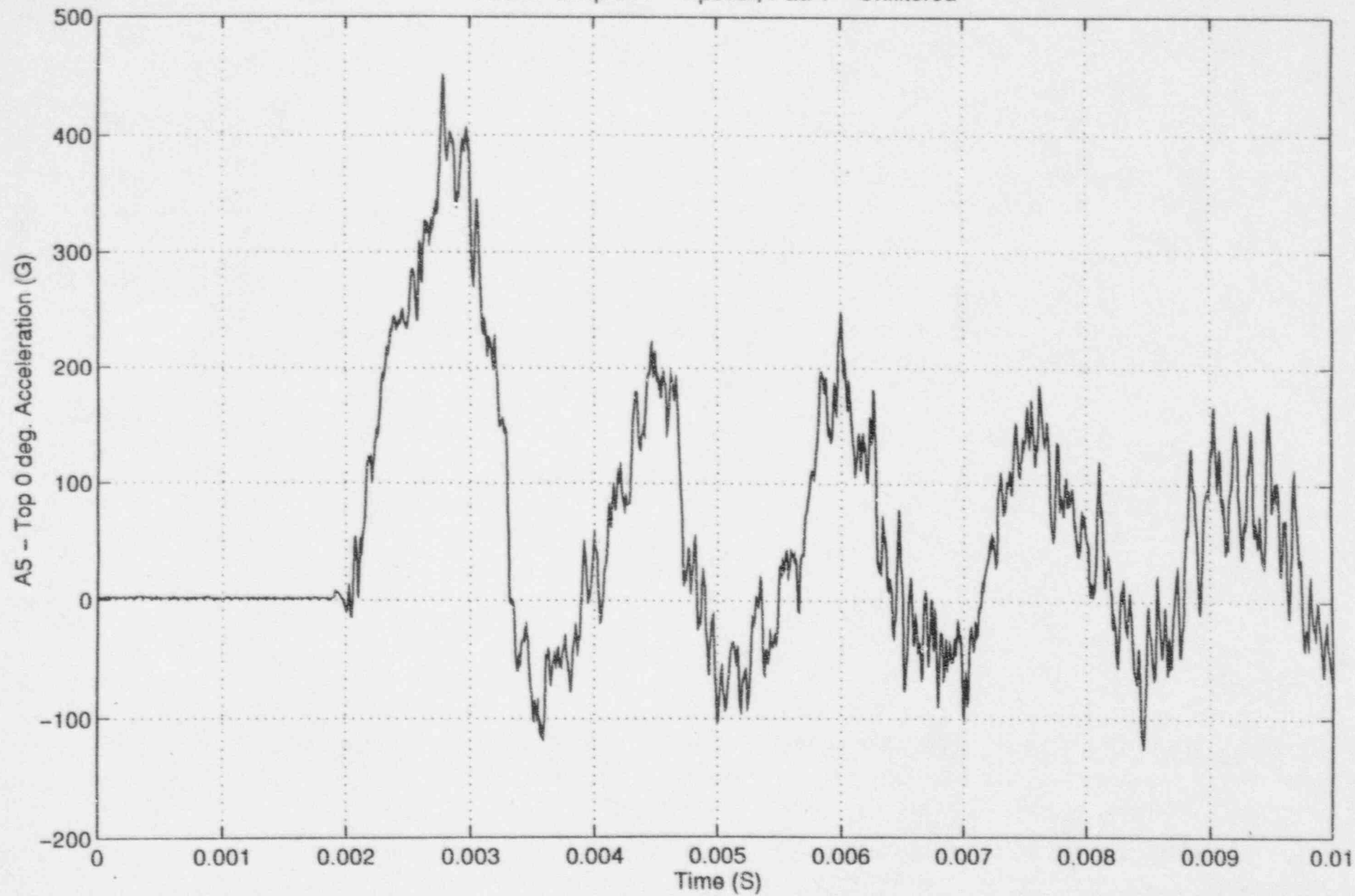
FESSP Drop #11 - Tipover, Pad 1 - Unfiltered



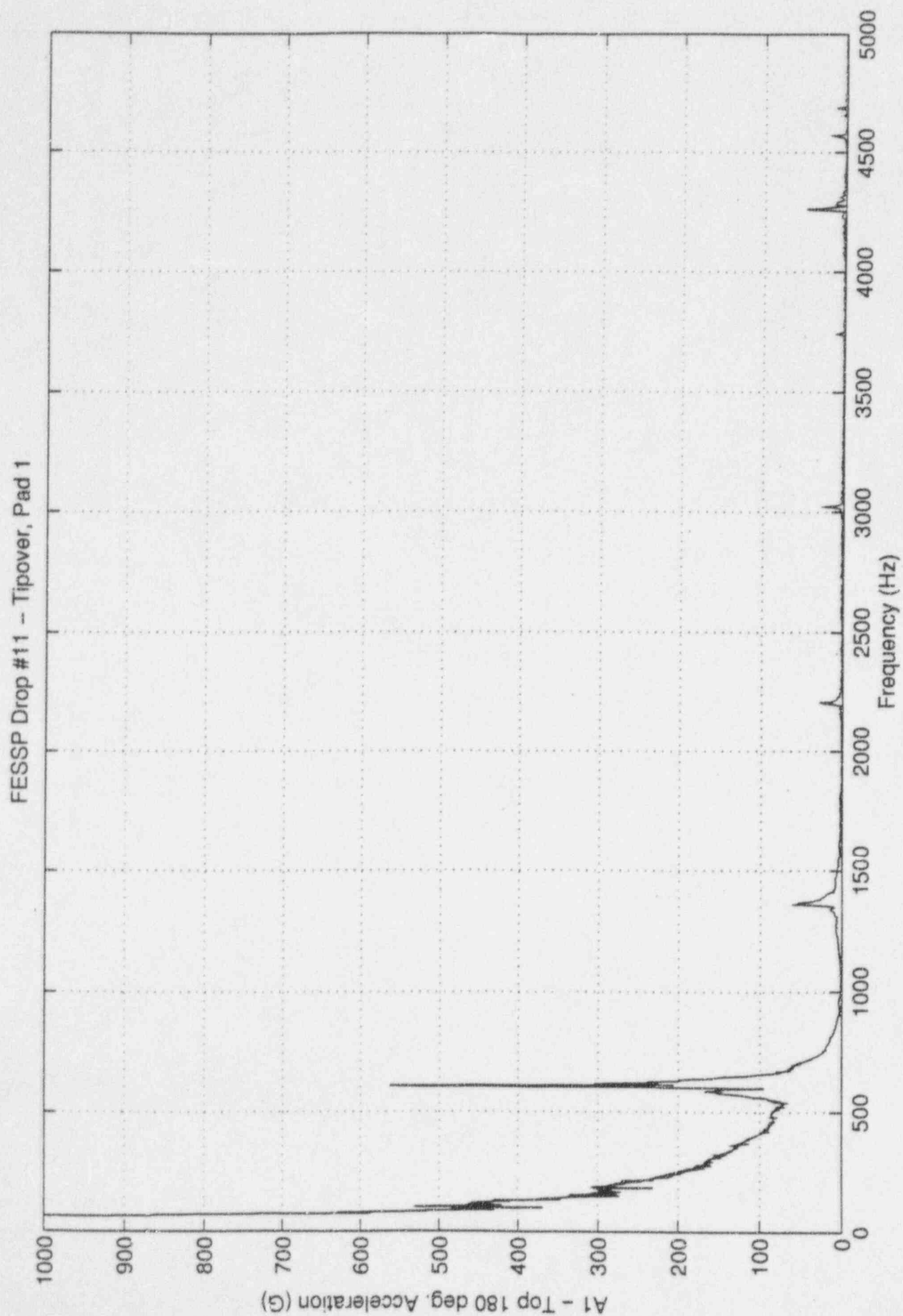
FESSP Drop #11 - Tipover, Pad 1 - Unfiltered

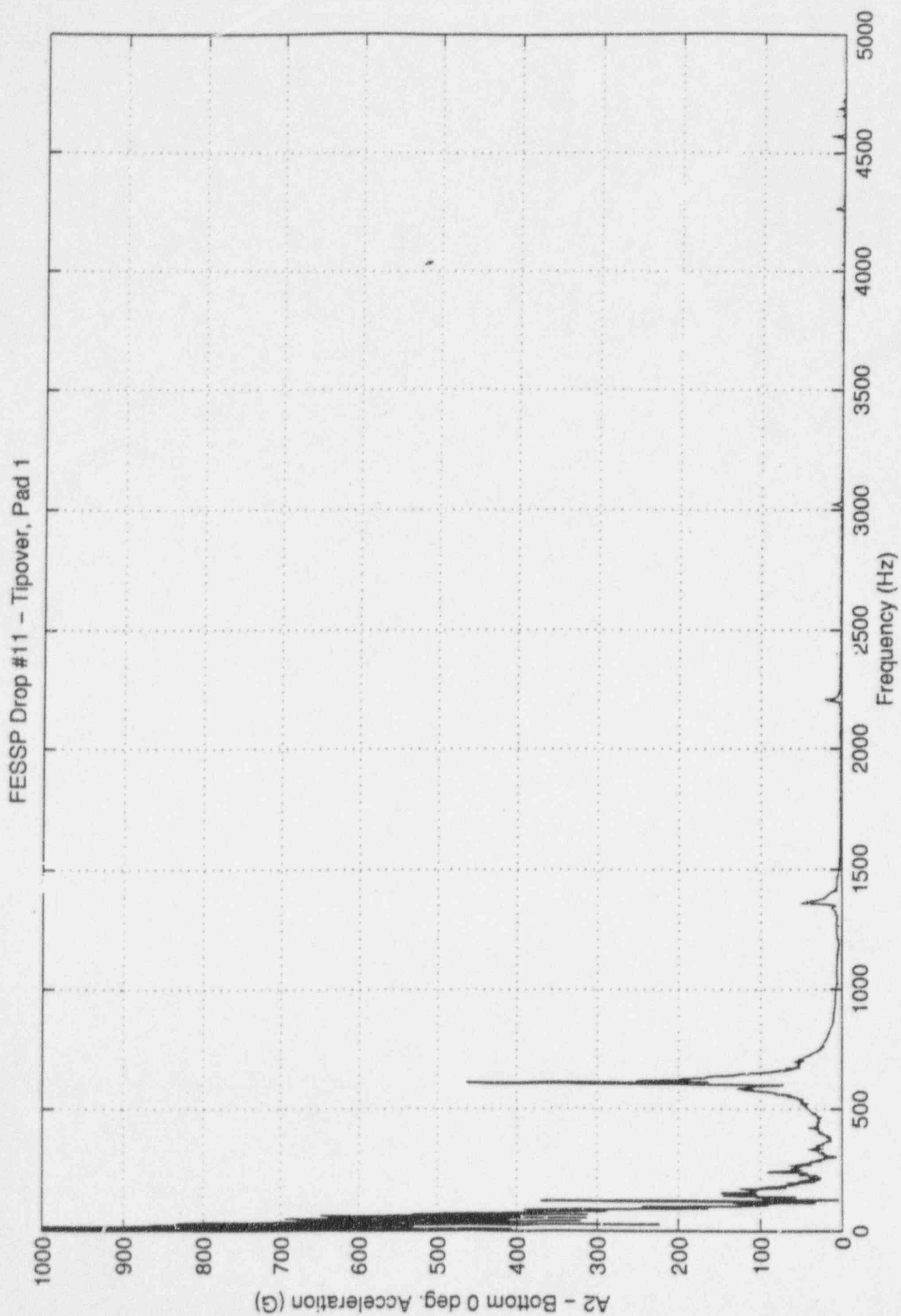


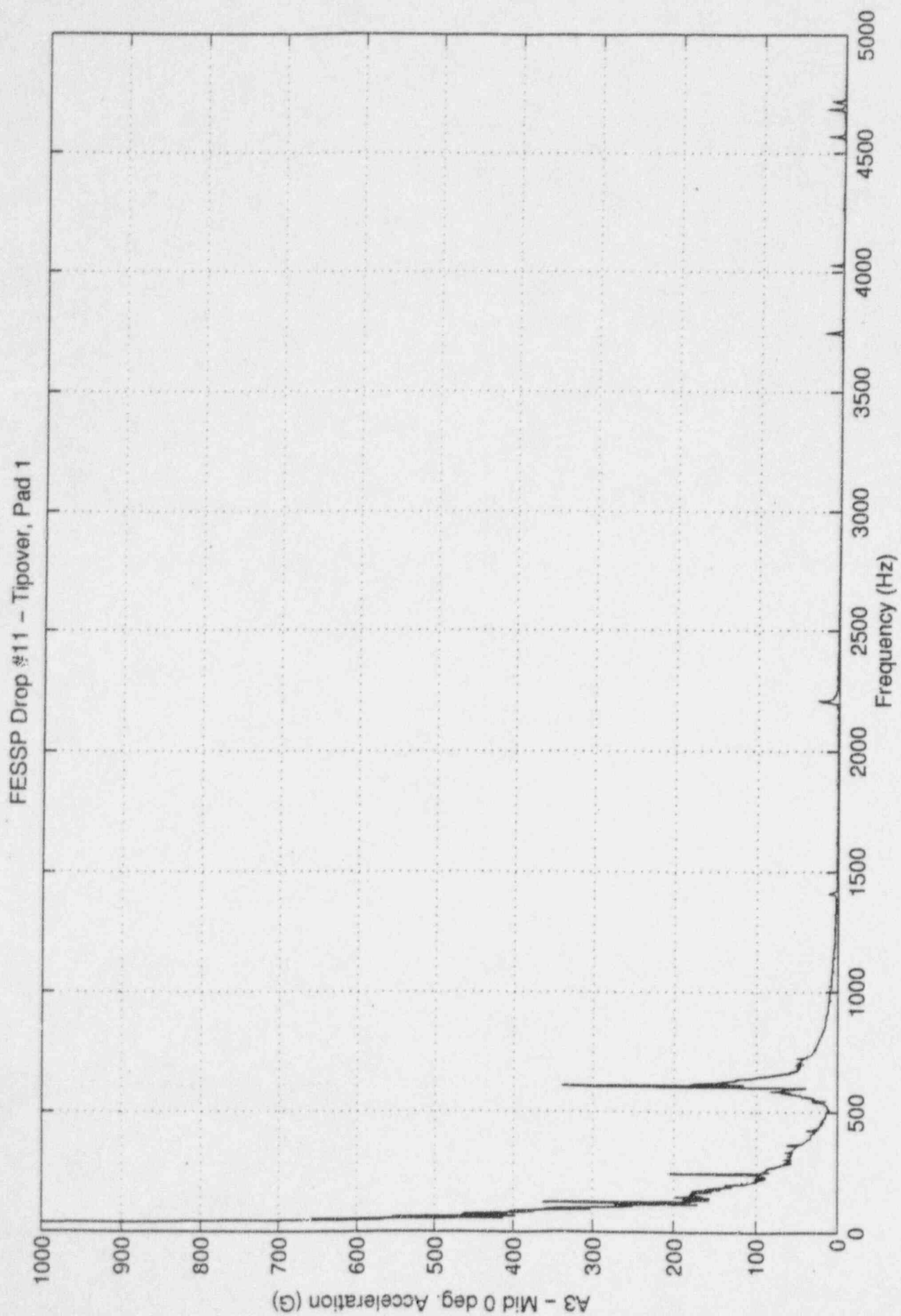
FESSP Drop #11 - Tipover, Pad 1 - Unfiltered



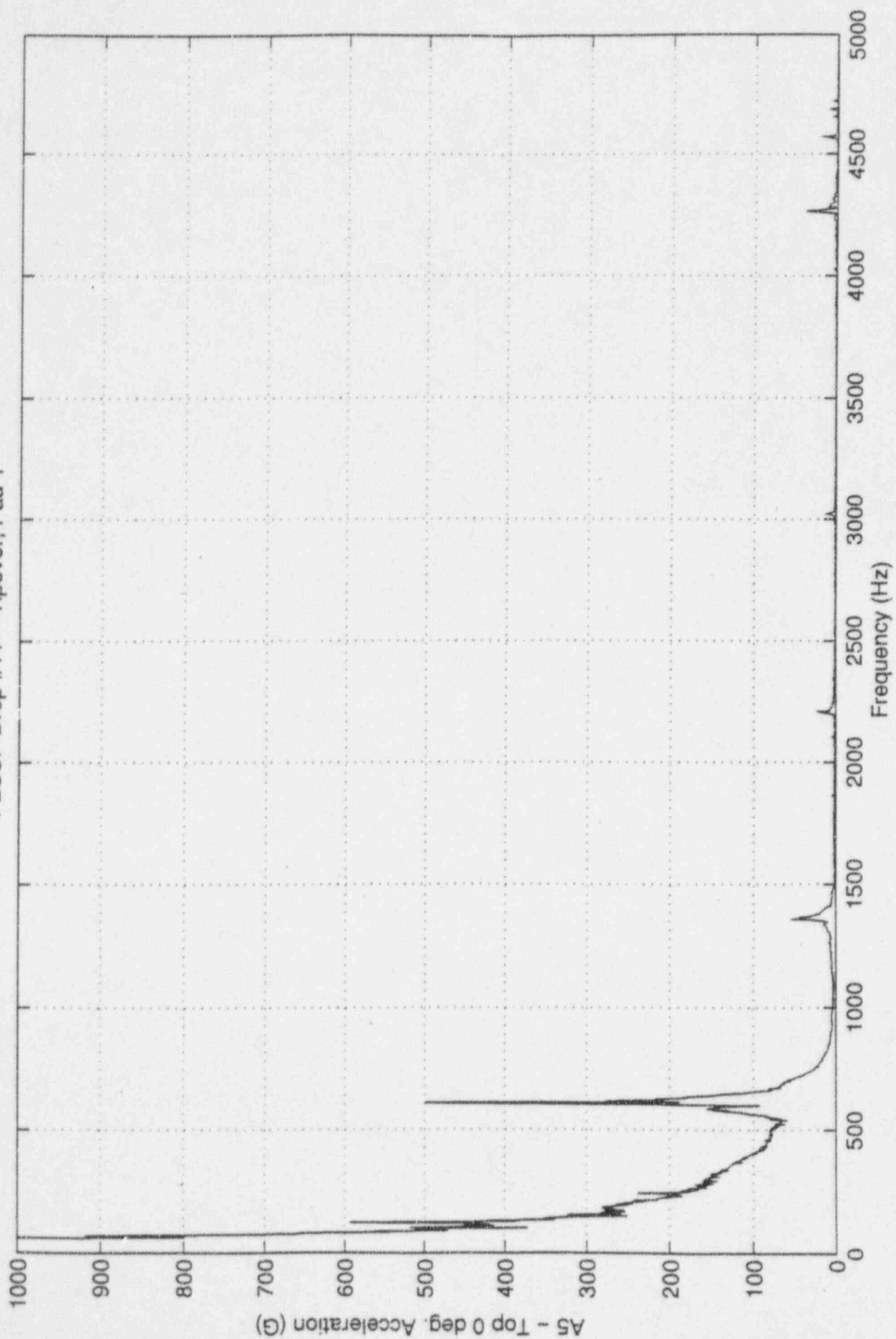




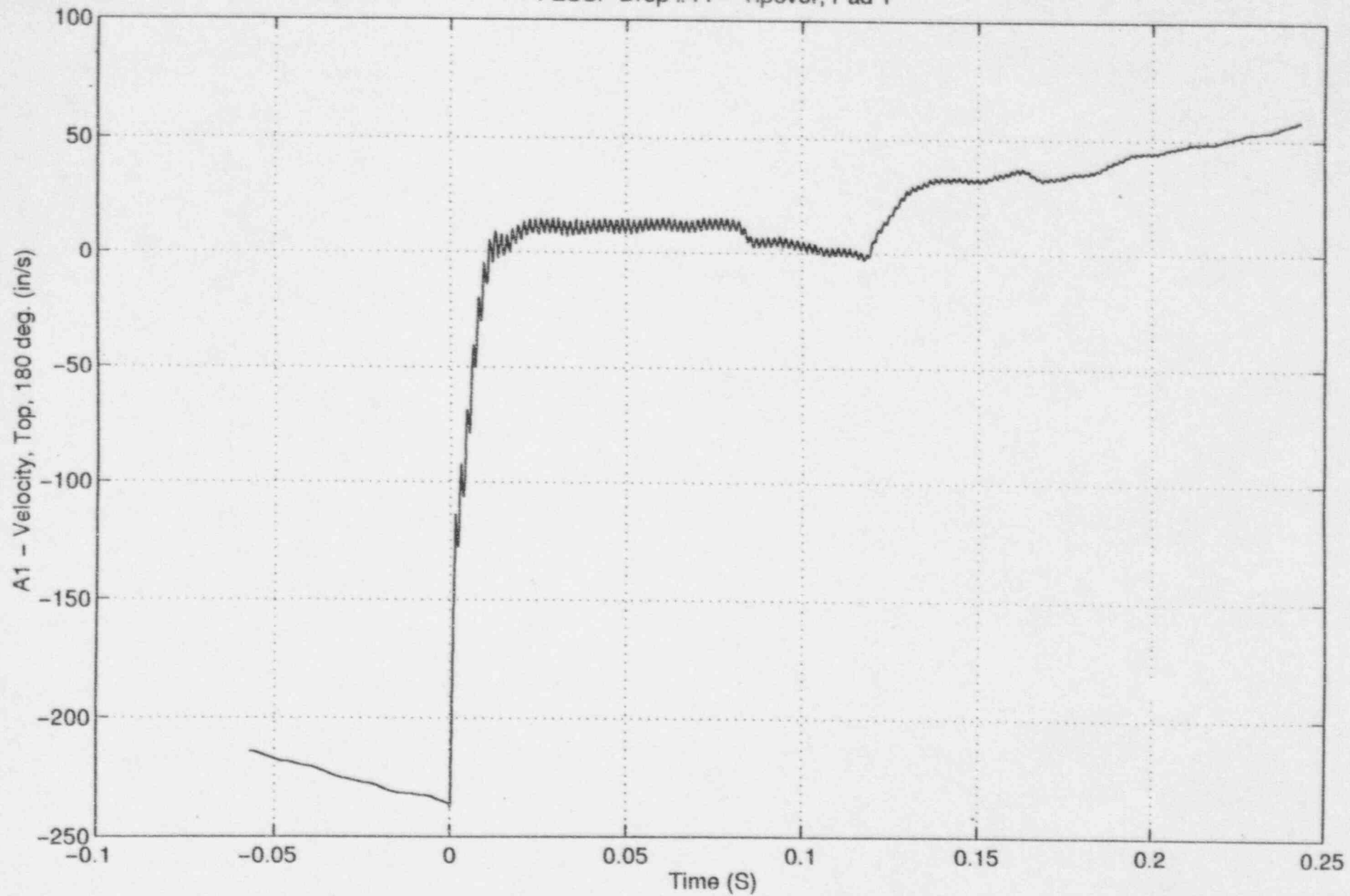




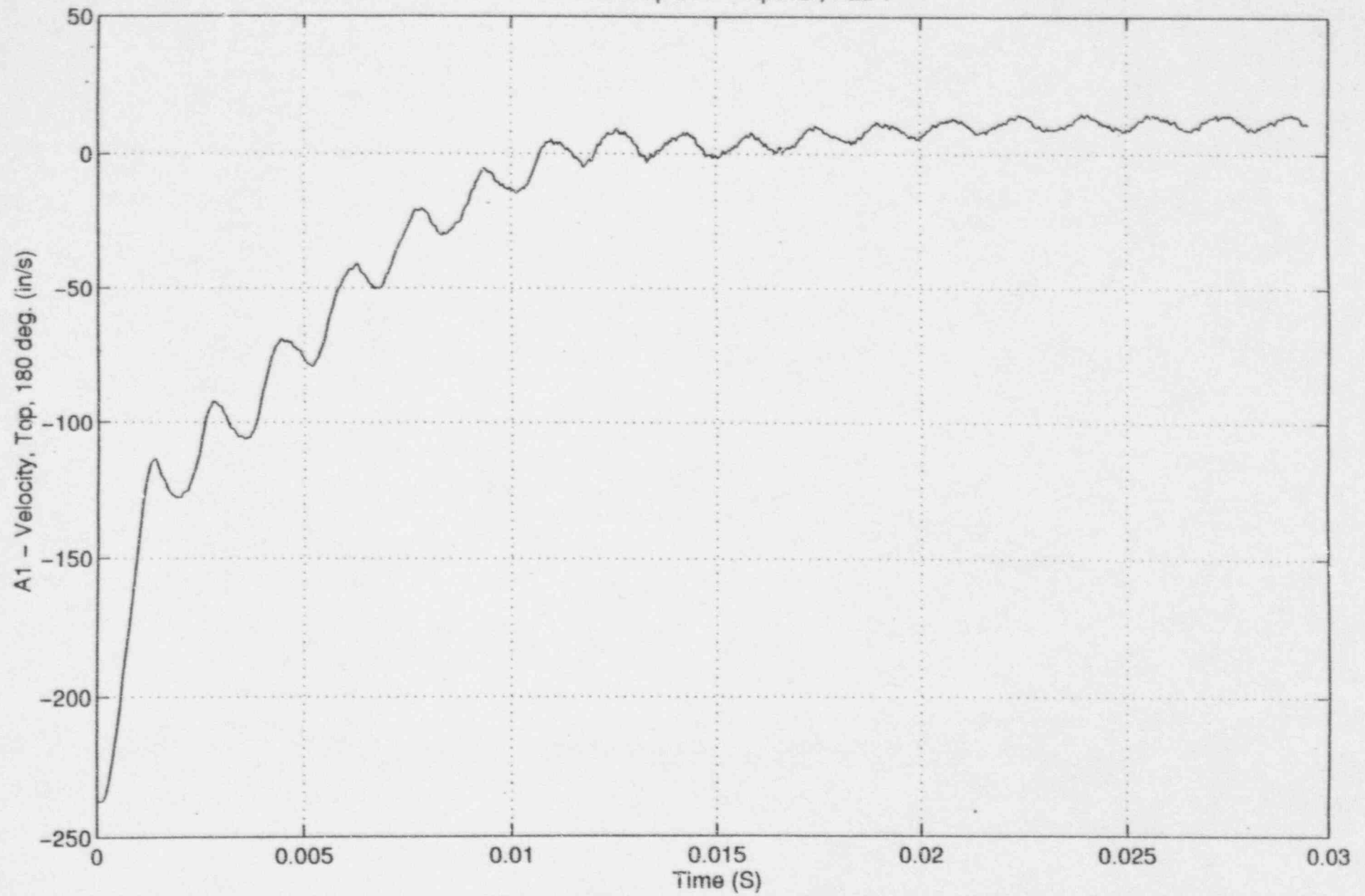
FESSP Drop #11 - Tipover, Pad 1



FESSP Drop #11 - Tipover, Pad 1

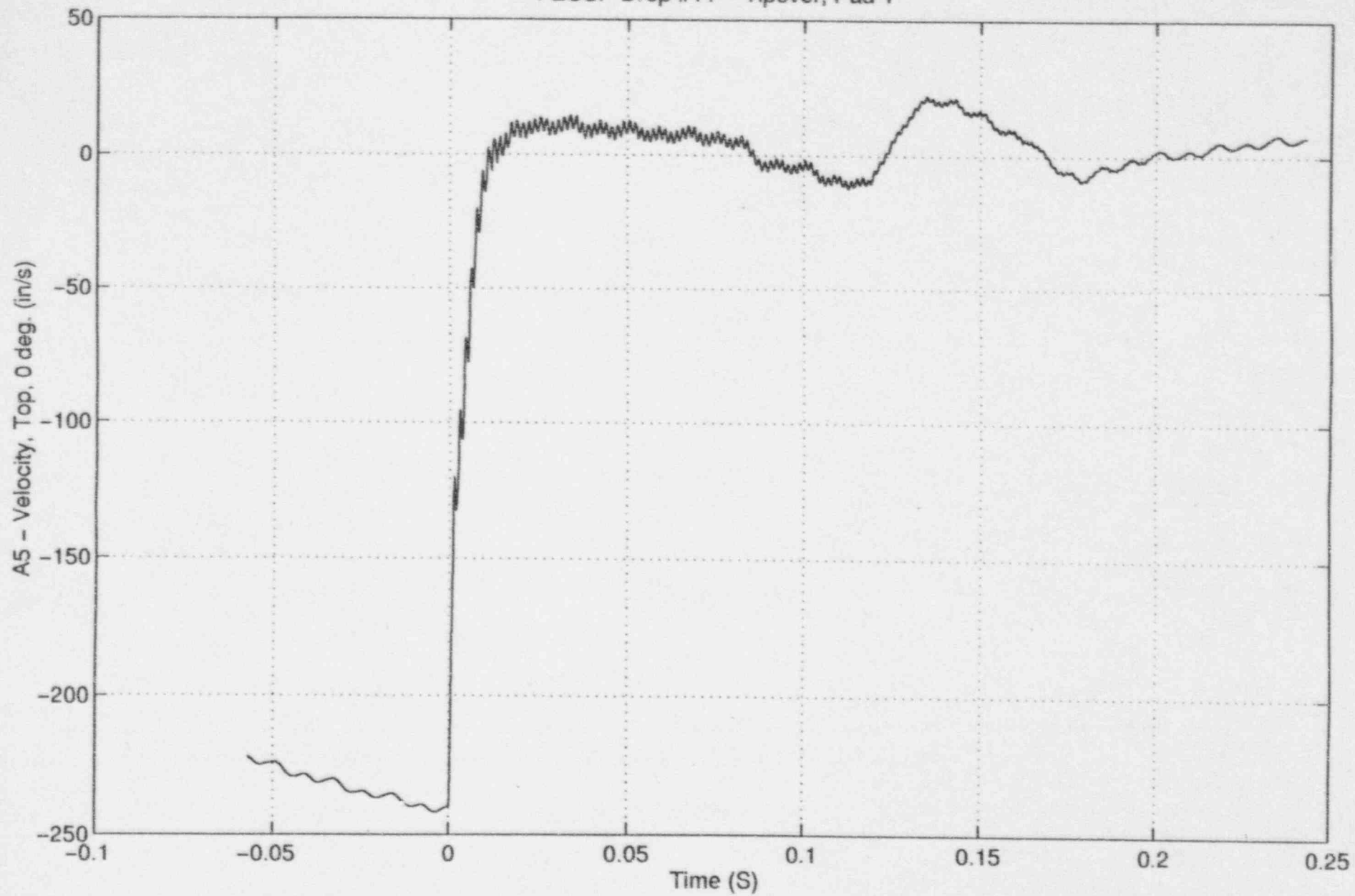


FESSP Drop #11 - Tipover, Pad 1

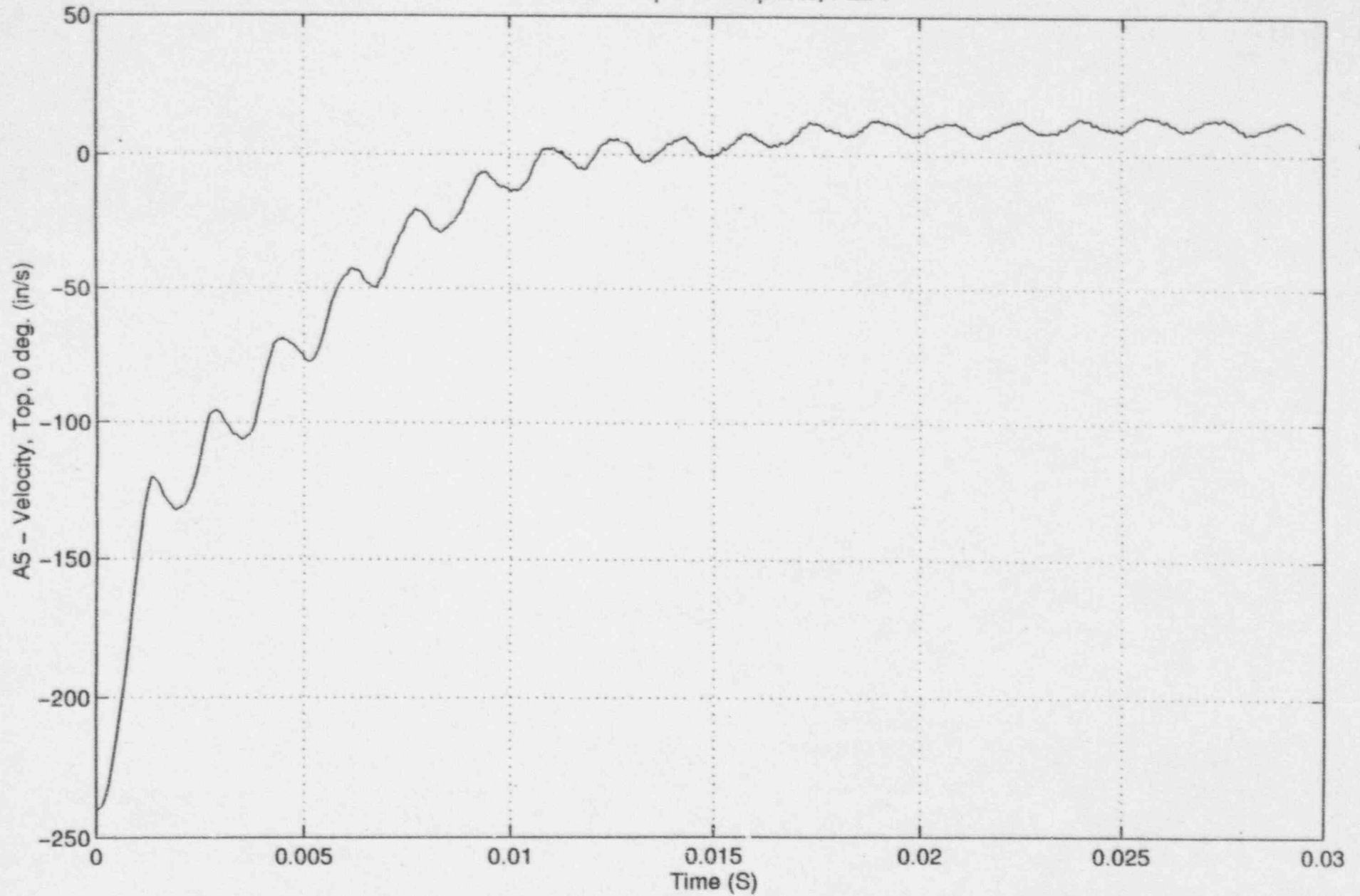




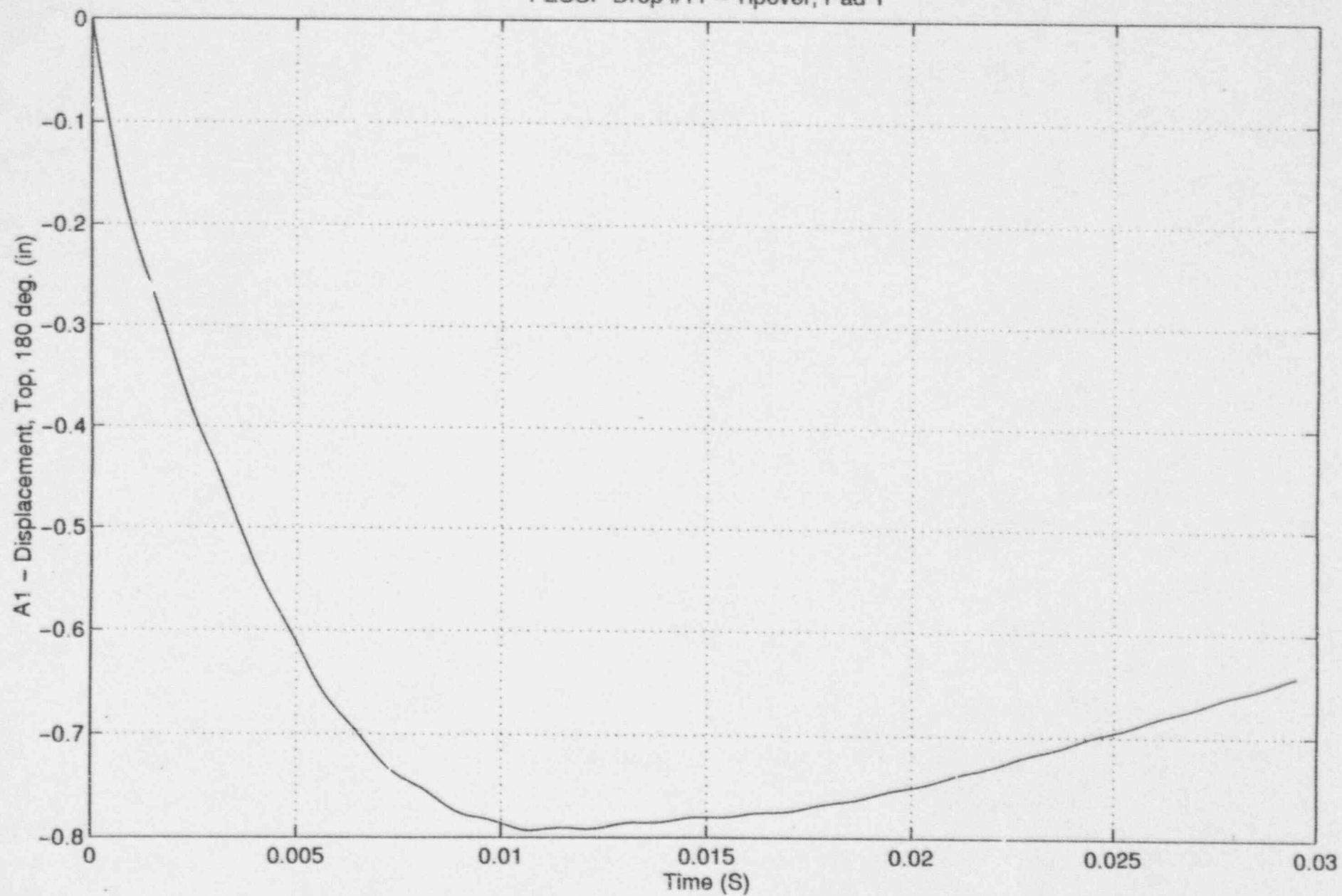
FESSP Drop #11 - Tipover, Pad 1



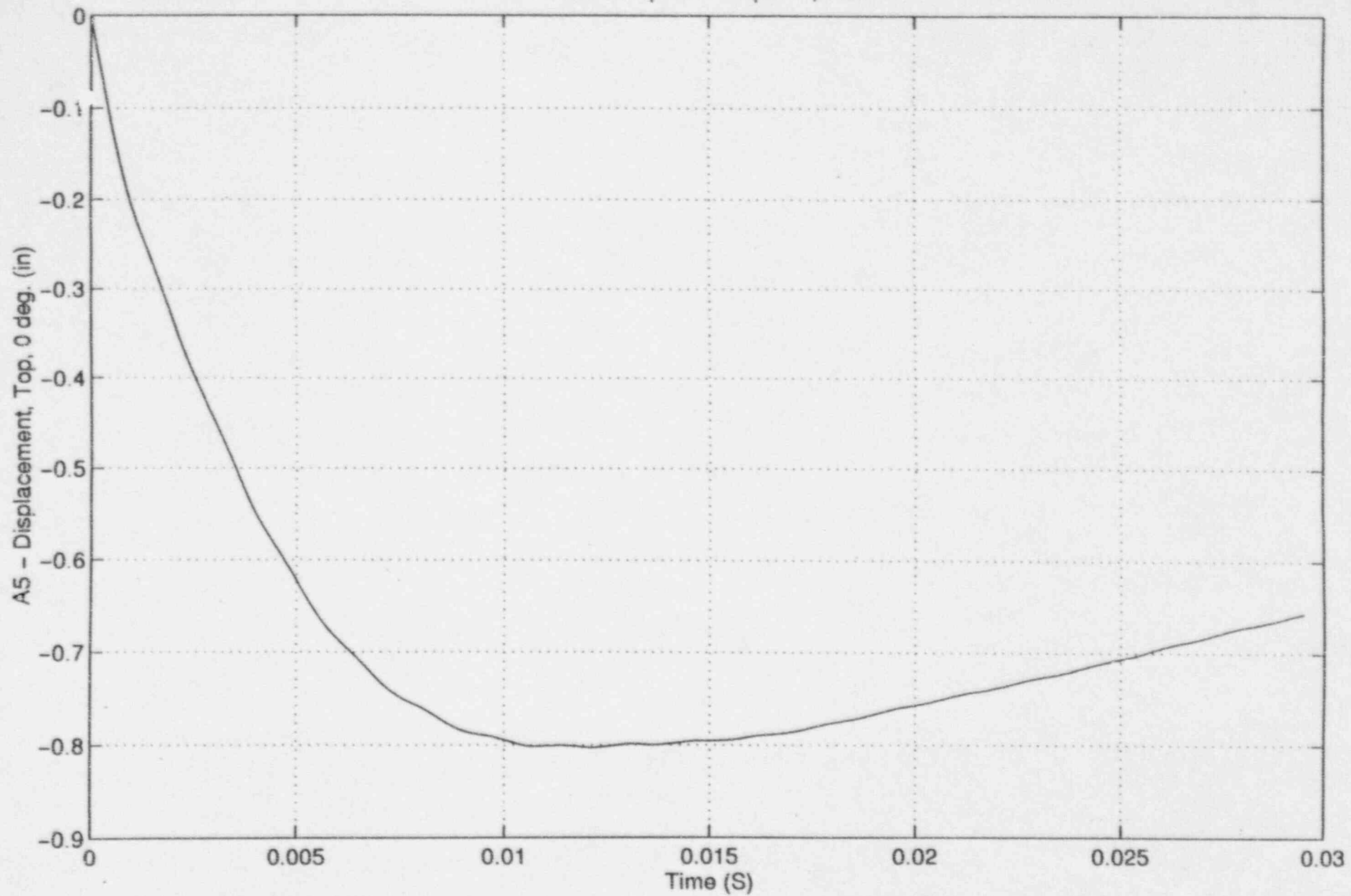
FESSP Drop #11 - Tipover, Pad 1

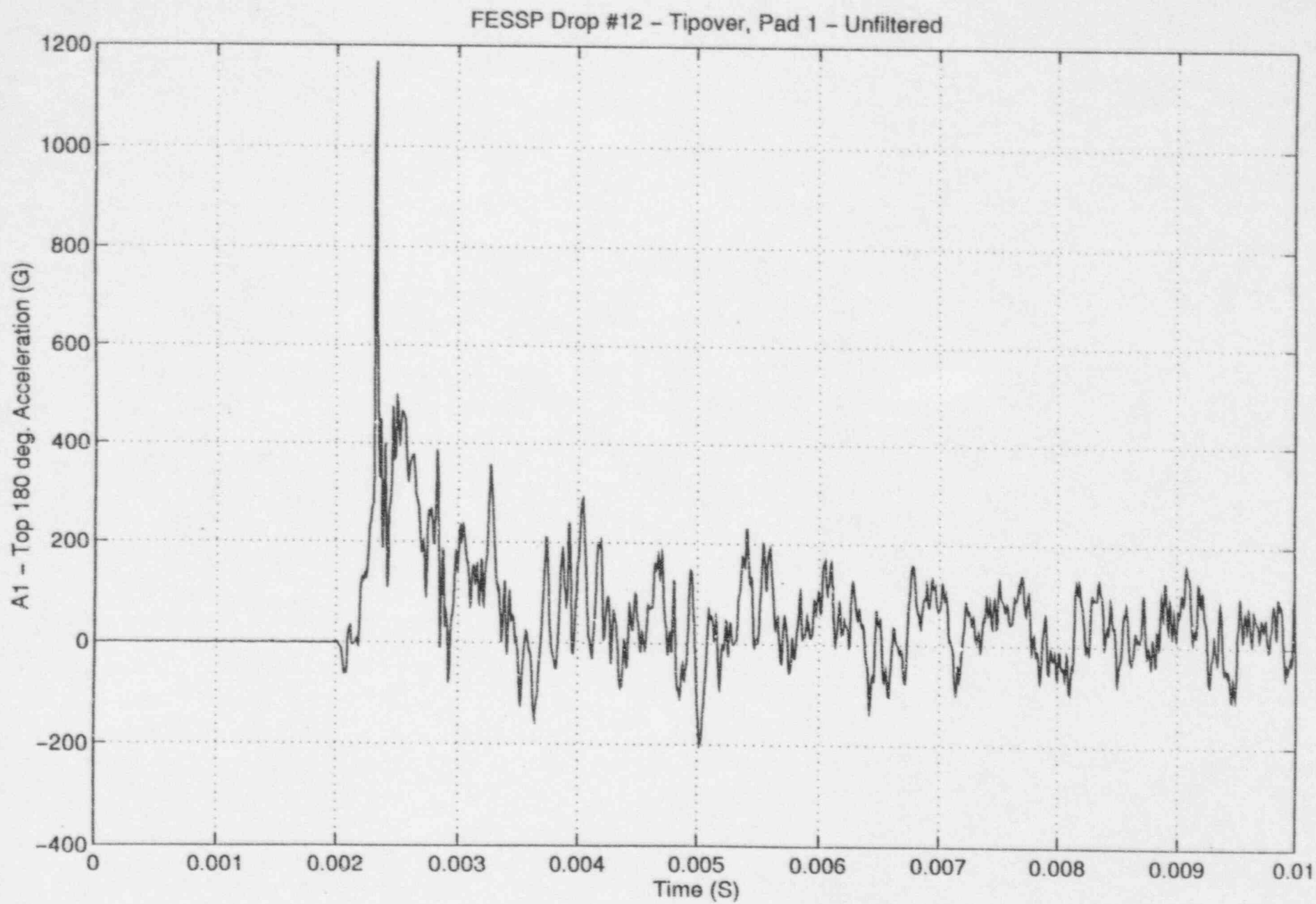


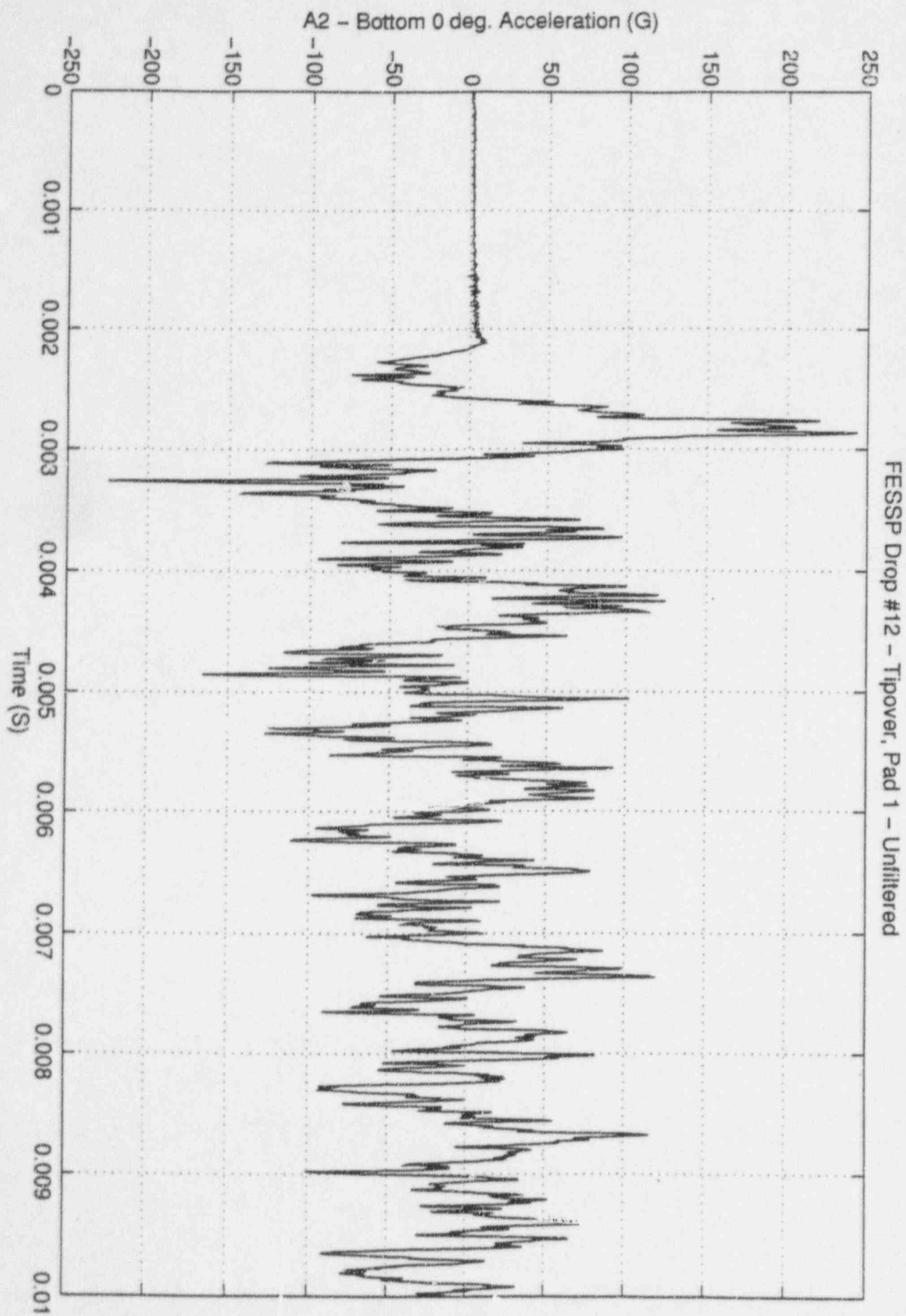
FESSP Drop #11 - Tipover, Pad 1



FESSP Drop #11 - Tipover, Pad 1

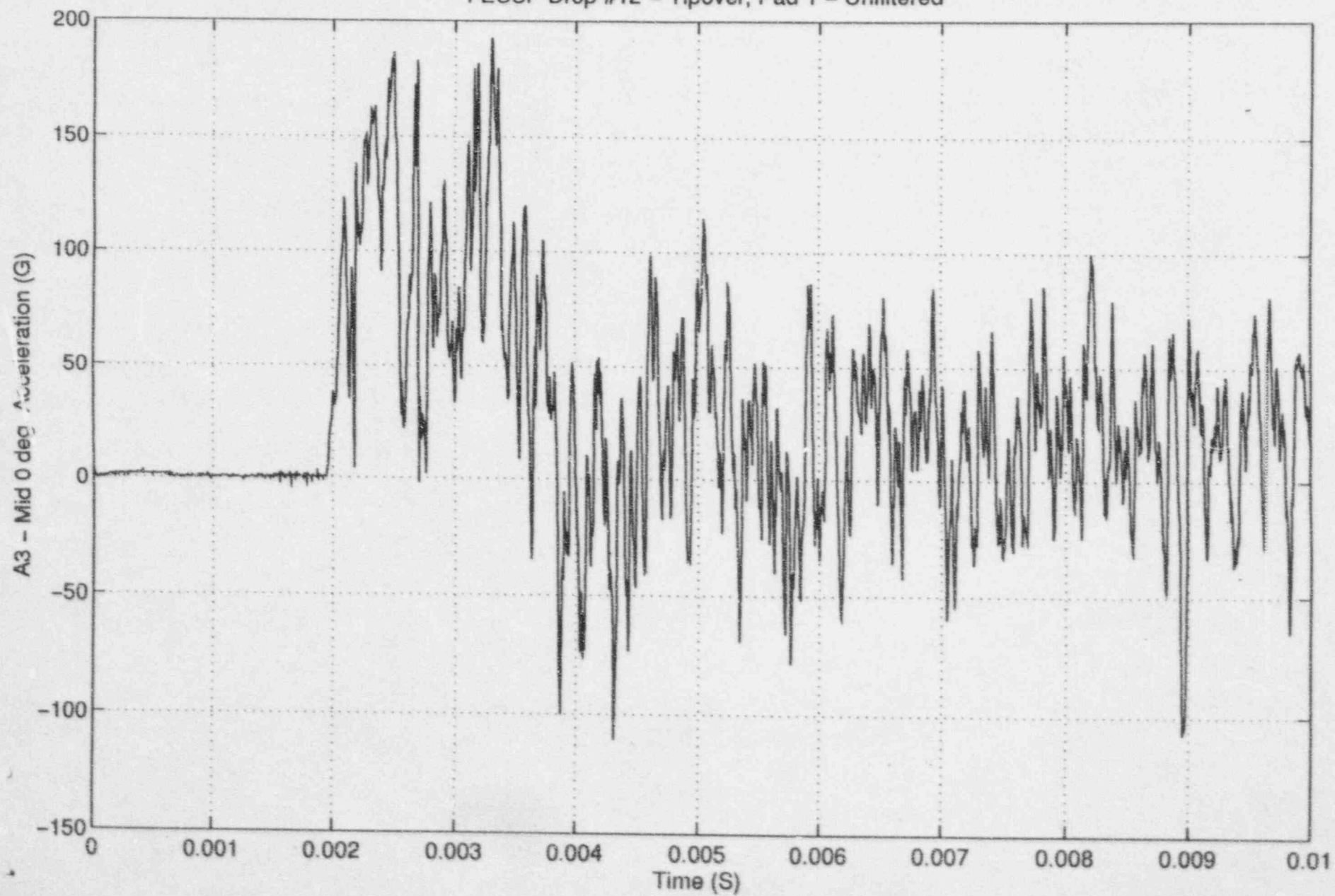




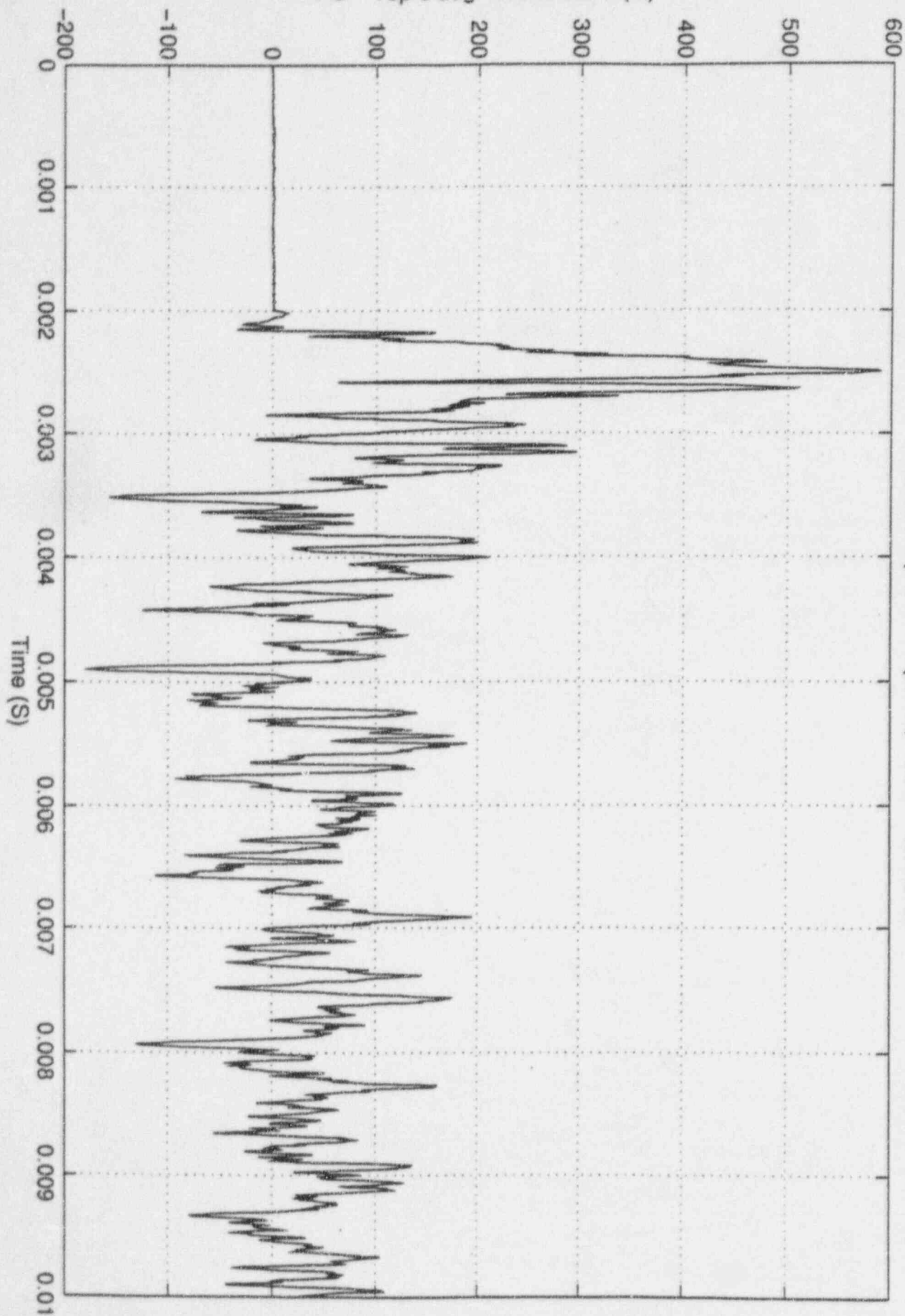




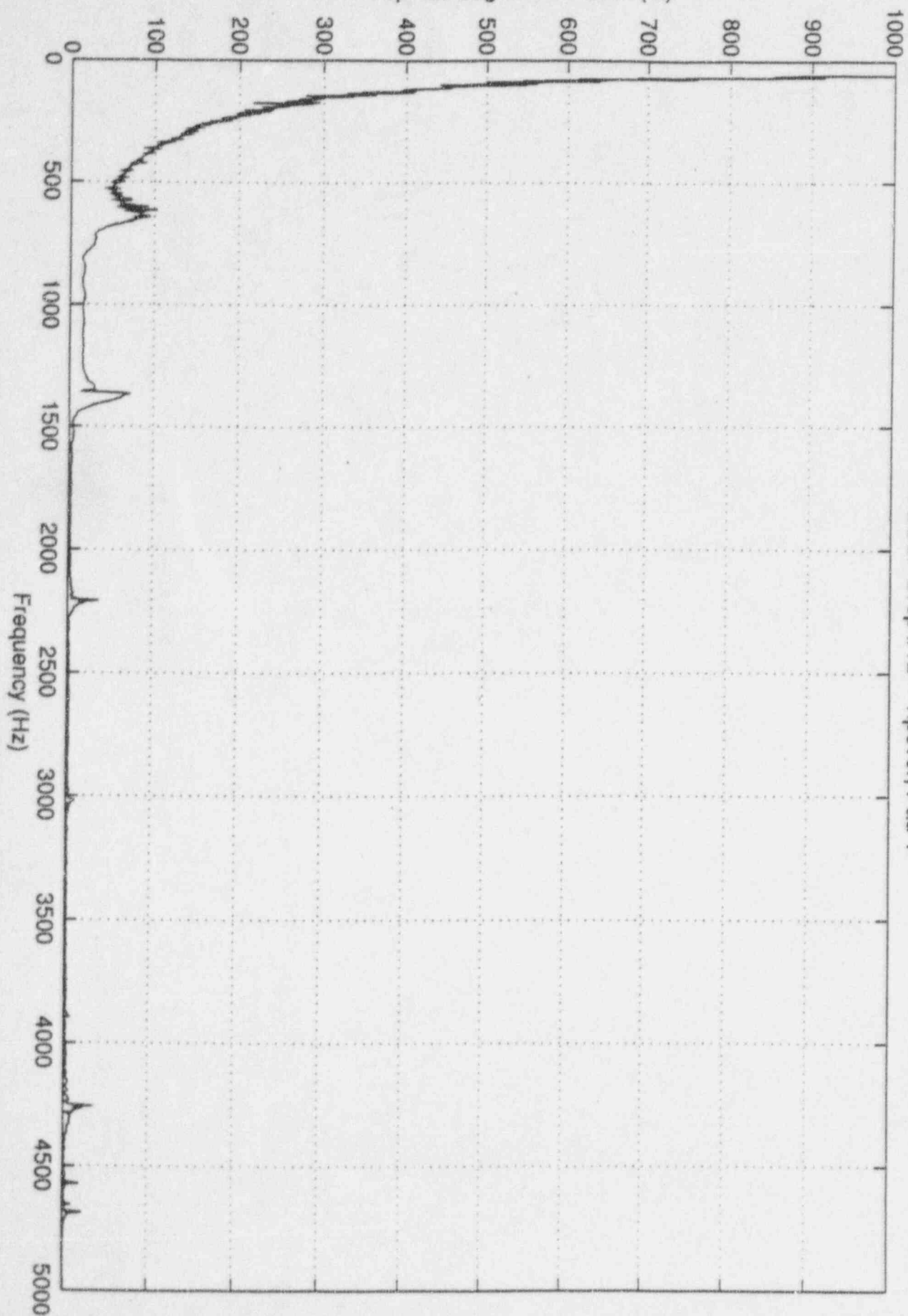
FESSP Drop #12 - Tipover, Pad 1 - Unfiltered

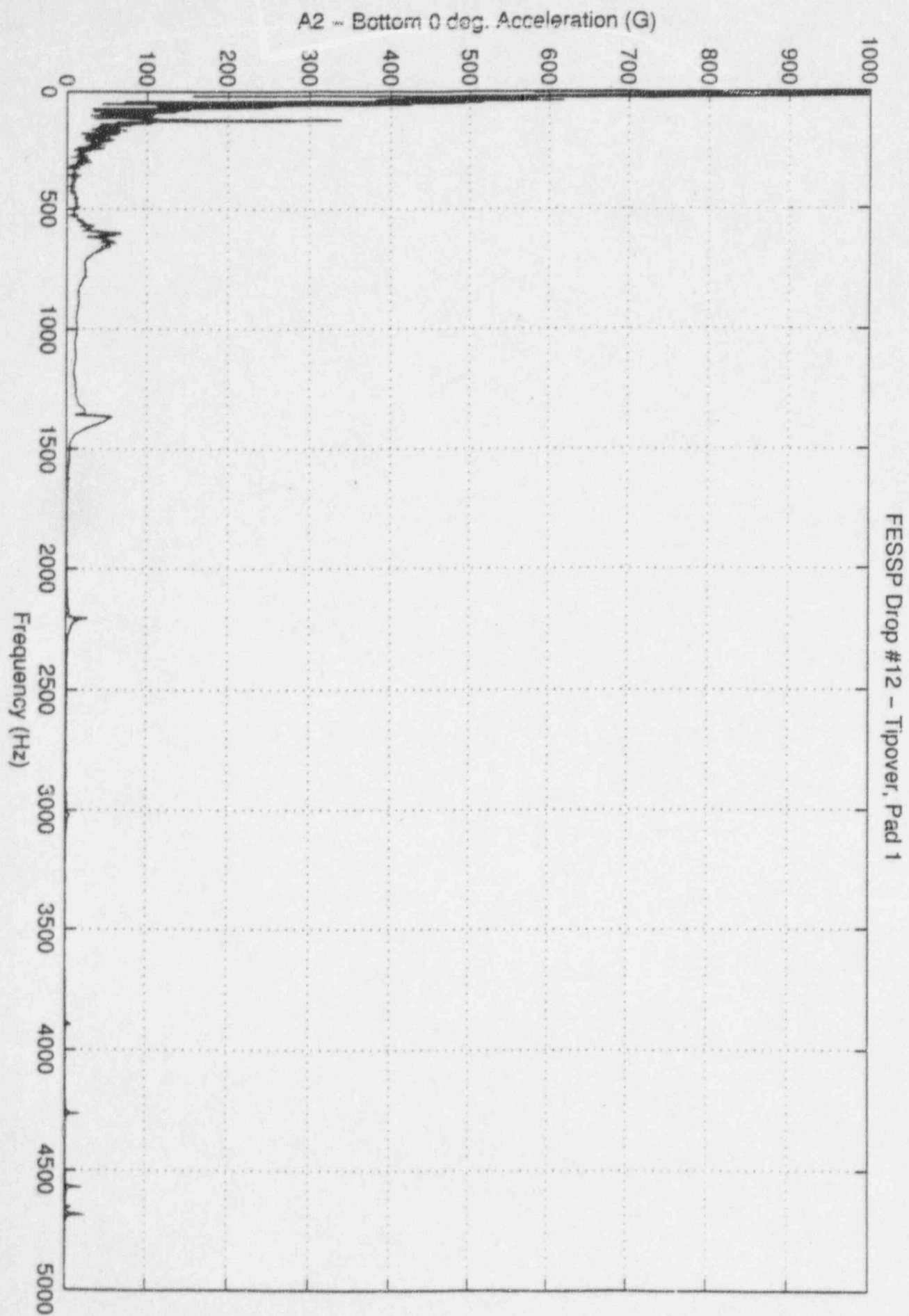


A5 - Top 0 deg. Acceleration (G)

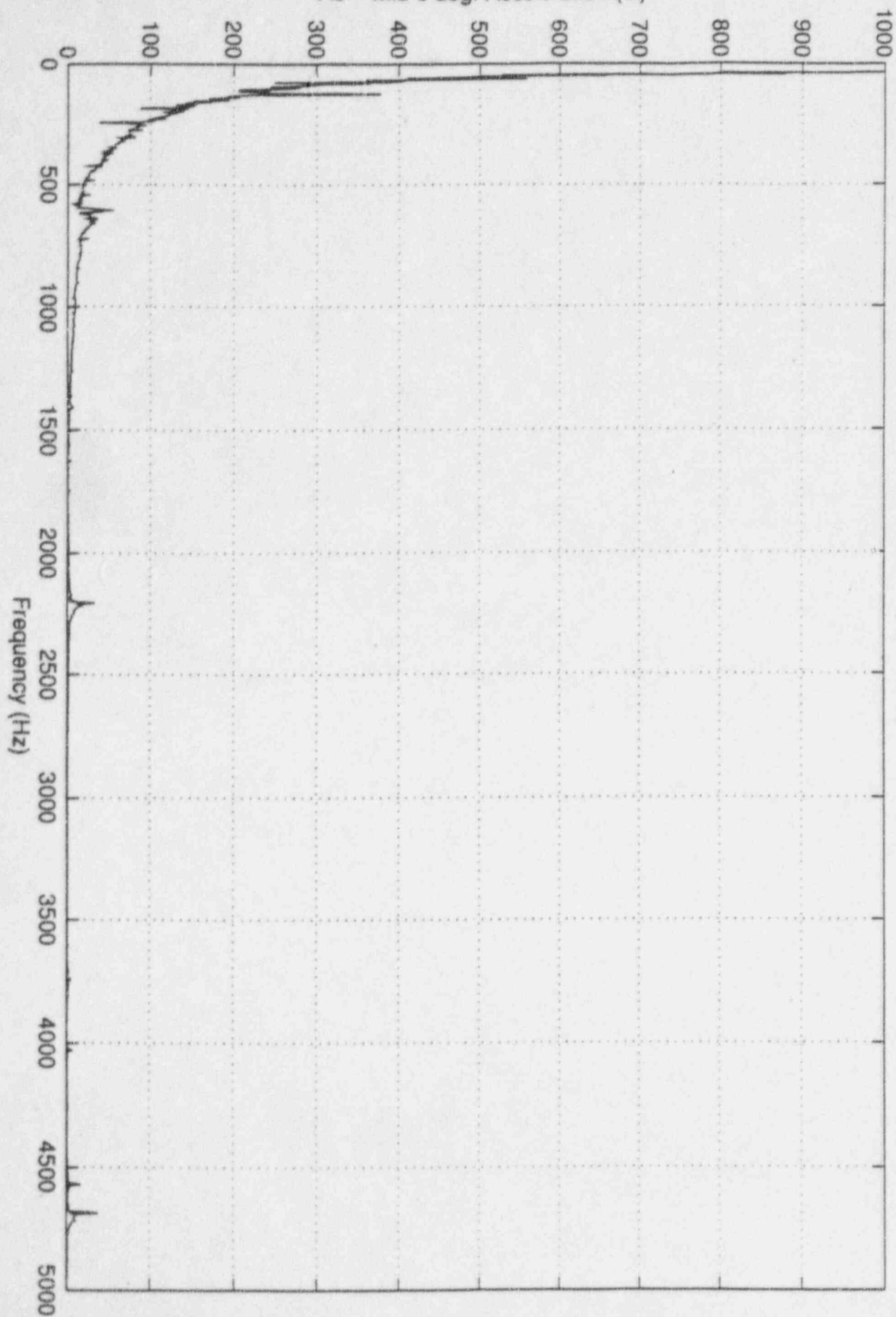


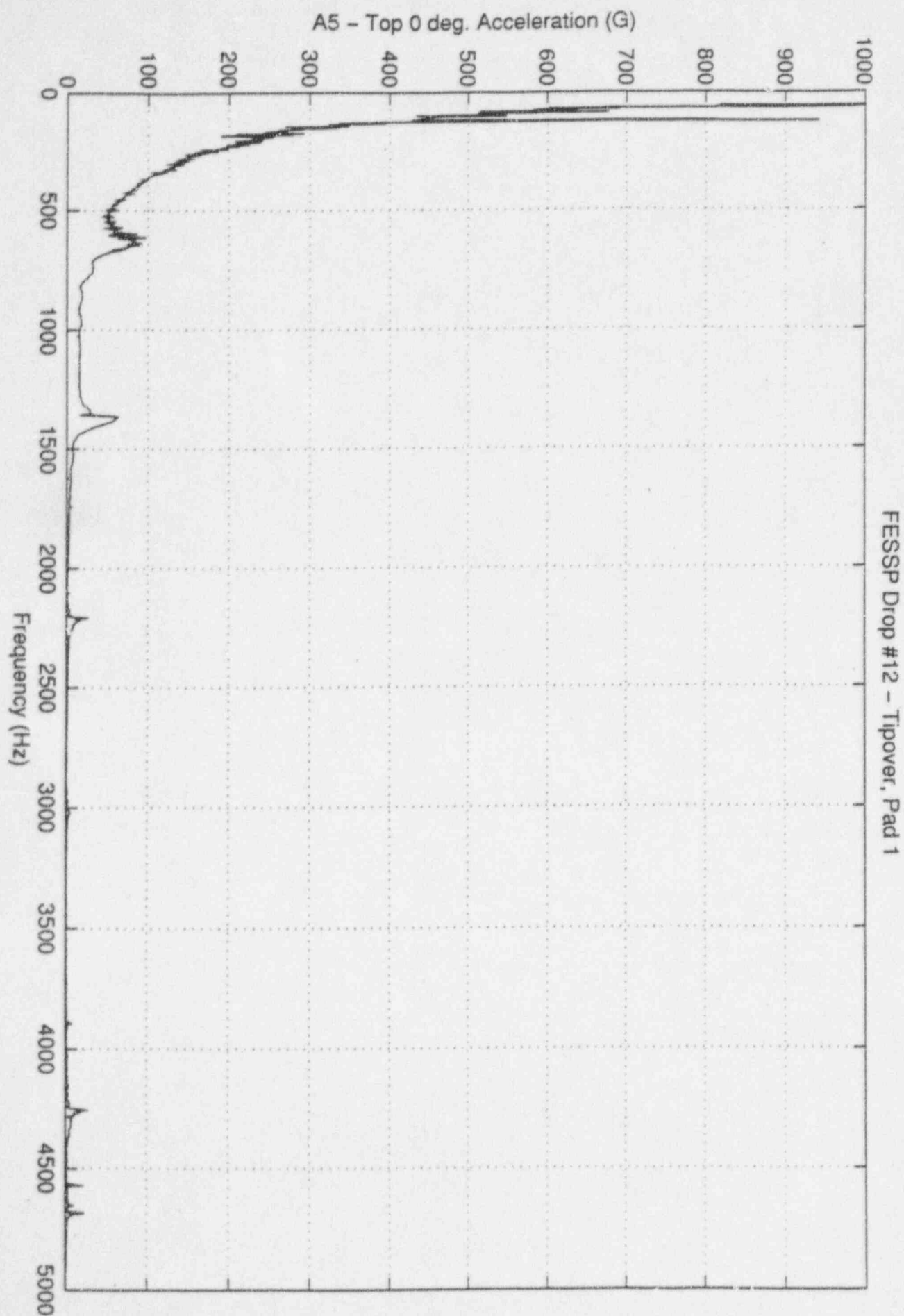
A1 - Top 180 deg. Acceleration (G)





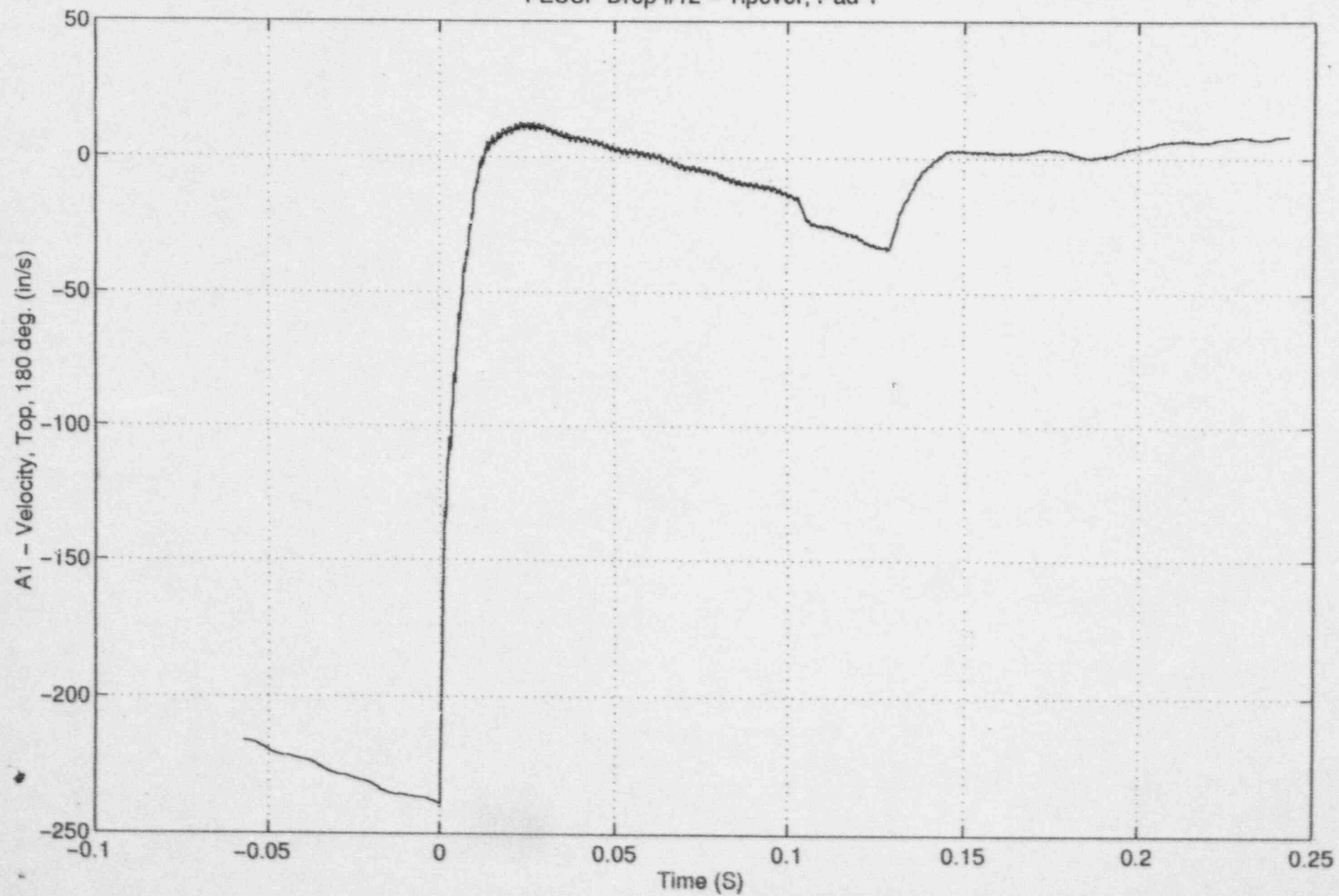
A3 - Mid 0 deg. Acceleration (G)



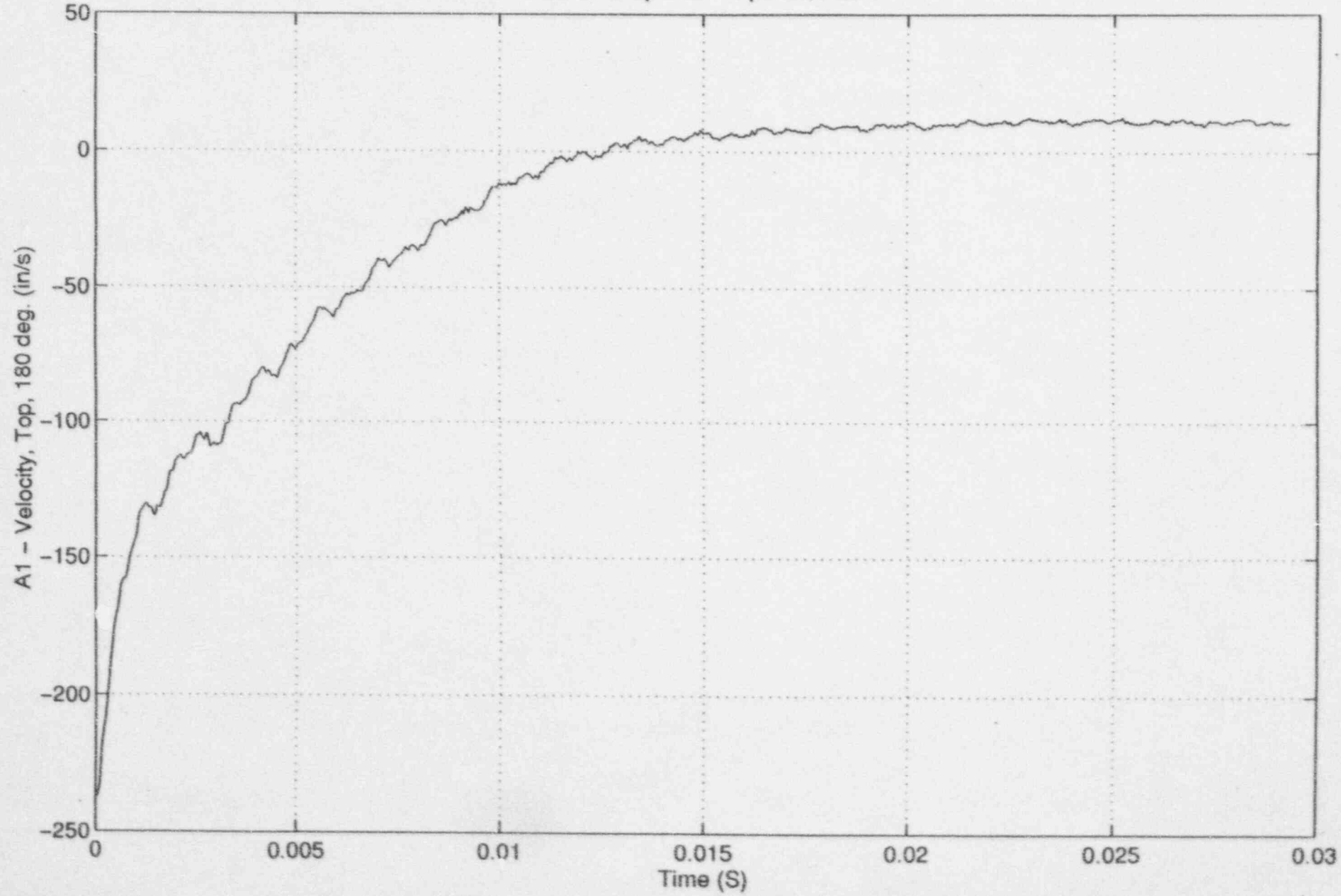




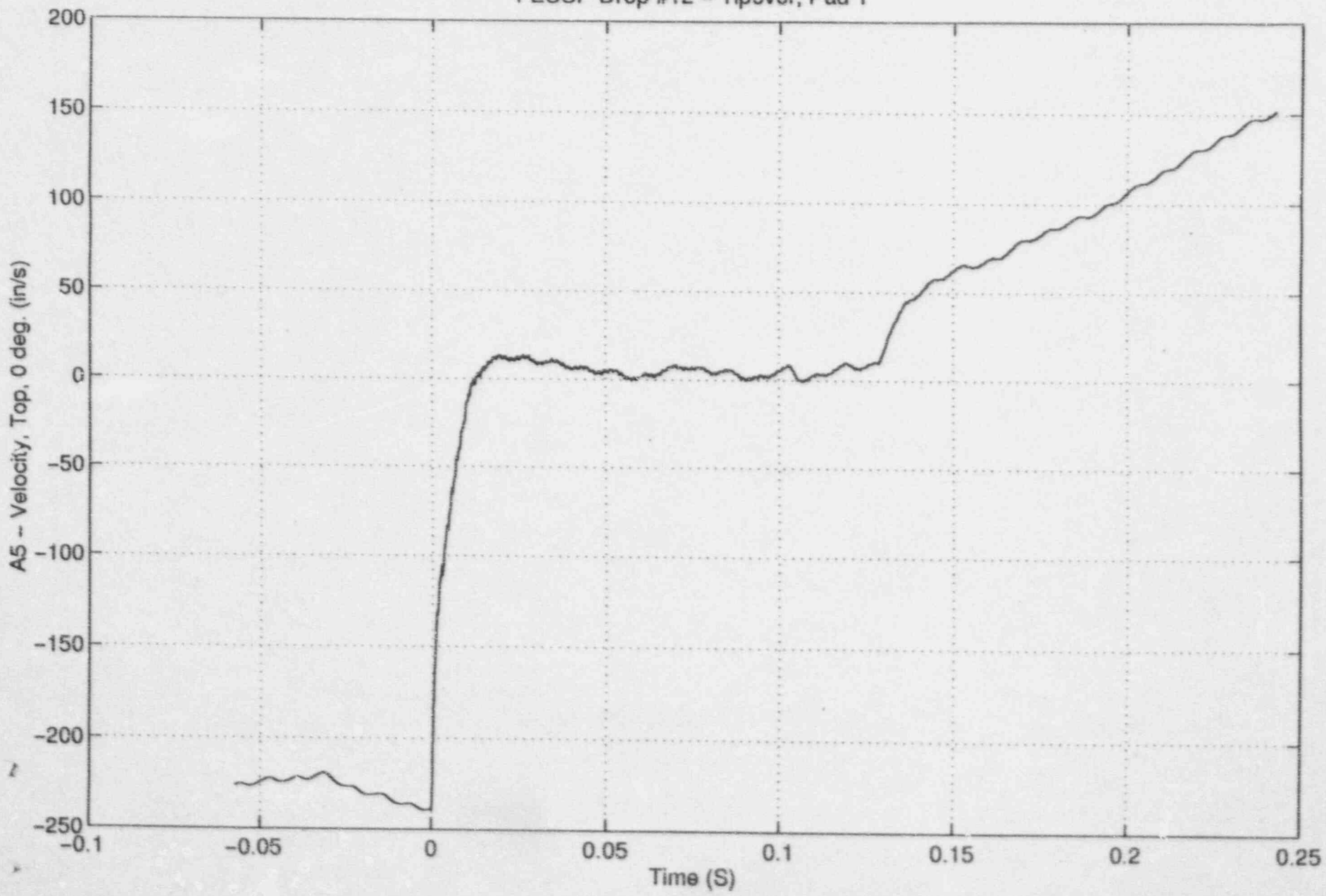
FESSP Drop #12 - Tipover, Pad 1

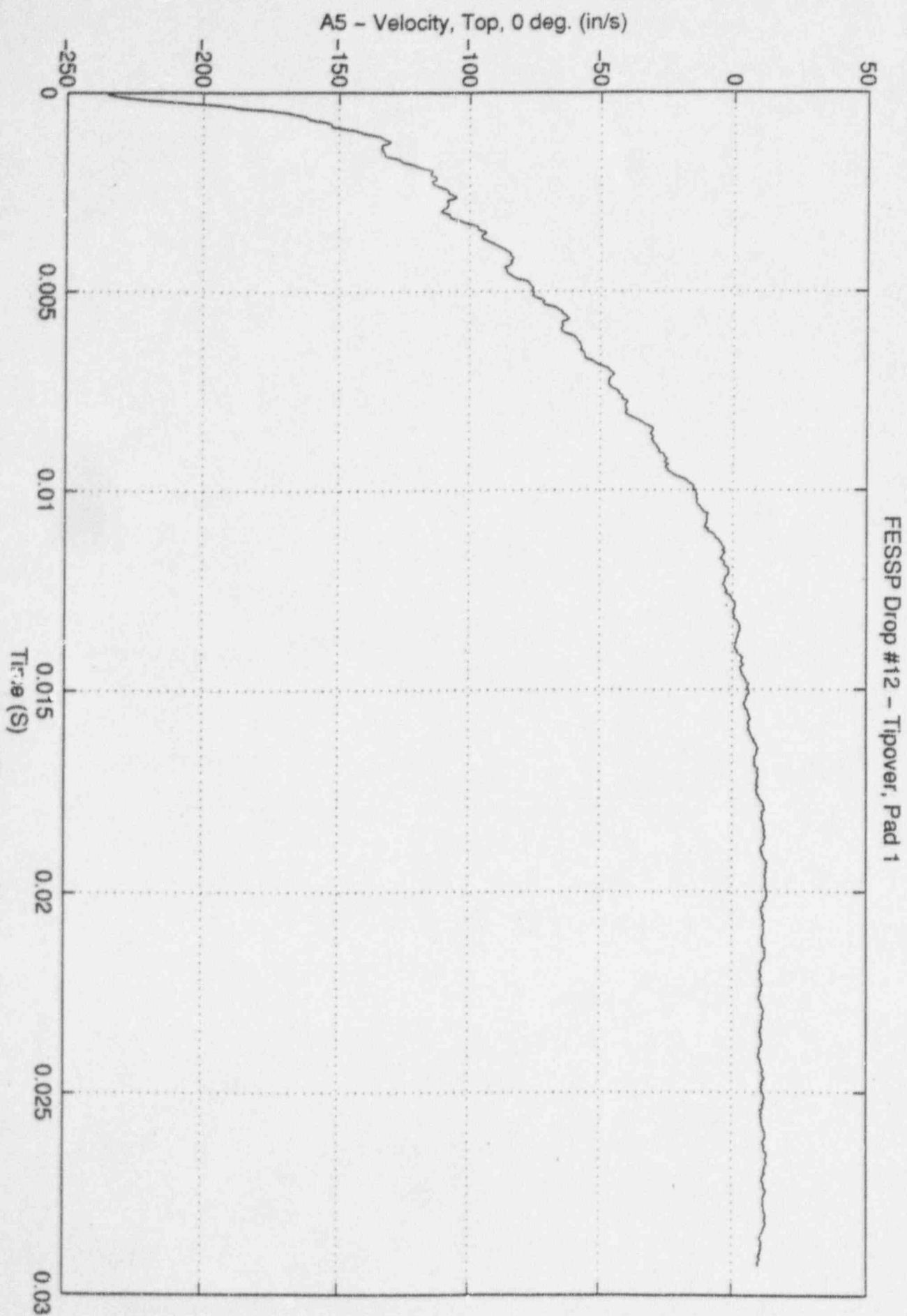


FESSP Drop #12 - Tipover, Pad 1



FESSP Drop #12 - Tipover, Pad 1





FESSP Drop #12 - Tipover, Pad 1

