RESOURCE MATERIALS

Pendulum Testing of BCT Wood Posts FOIL Tests: 91P039 through 91P045

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16. Abstract

In the summer of 1991, a research project was conducted at the Federal Outdoor Impact Laboratory (FOIL) in McLean, Virginia, to investigate vehicle side impacts with guardrail terminal ends. Four terminal end designs were tested using 1985 Honda Civics. The four designs were a standard breakaway cable terminal (BCT), an eccentric loader terminal, a modified eccentric loader terminal (MELT), and a MELT for side impact. The first three designs were tested and the terminals did not function as anticipated. The lead posts of the terminal did not break away. A study was conducted to investigate the breakaway performance of the lead wood post.

The wood post performance testing was conducted at the FOIL using the facility's 1850-lb (839-kg) pendulum. These tests were conducted on both used and new wood posts at 20 mi/h (32 km/h). This report documents the results of seven 20-mi/h (32-km/h) pendulum tests to measure the breakaway force required to break away a BCT post. Tests conducted on five standard BCT posts varied from post to post. However, even the weakest BCT post demonstrated a breakaway force higher than an automobile door could produce. Therefore, two posts were modified to reduce the required breakaway force. Explanations for the variance in performance between standard BCT posts are discussed.

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FOREWORD

This report documents research conducted at the Federal Outdoor Impact Laboratory (FOIL) to investigate the forces required to break a single BCT post. This study resulted from a previous study of vehicles side impacting guardrail end terminals in which the terminals did not all activate as anticipated and damage to the vehicles was extensive. Seven tests were conducted, on new and used wood posts, and the last two posts were modified to reduce the breaking forces.

This report contains test data and a summary of the test results for each of the 7 tests conducted. All tests were conducted at a nominal speed of 32 km/h (20 mi/h).

This report will be of interest to all States DOT's, FHWA headquarters, regional and division personnel, and highway safety researchers interested in the crashworthiness of roadside sign systems.

Jerry Reagan
Acting Director, Office of Safety and
Traffic Operations Research and
Development

NOTICE

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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1. BACKGROUND

In the summer of 1991, a research project was conducted at the Federal Outdoor Impact Laboratory (FOIL) in McLean, Virginia, to investigate vehicle side impacts with guardrail terminal ends. Four terminal end designs were tested using 1985 Honda Civics. The four designs were a standard breakaway cable terminal (BCT), an eccentric loader terminal, a modified eccentric loader terminal (MELT), and a MELT for side impact. The first three designs were tested and the terminals did not function as anticipated. The lead wood post of each terminal end should have broken away, allowing the pre-tensioned guardrail to spring away from the vehicle, which would allow the vehicle to proceed without disastrous results. Because the lead posts did not break away, the vehicle damage was severe. This problem, evident in the first three tests, led to a study to investigate the breakaway performance of the lead wood post. The wood post performance testing was conduct at the FOIL using the facility's 1850-lb (839-kg) pendulum. These tests were conducted on both used and new wood posts. The pendulum testing occurred before the MELT for side impact terminal was tested. The results from the pendulum testing indicated that the force required to break away the lead wood post was higher than the door of an automobile could withstand. Therefore, two posts were modified to reduce the required breakaway force. The two different modifications were tested with the pendulum and eventually one modification was used for the MELT for side impact crash test.

2. SCOPE

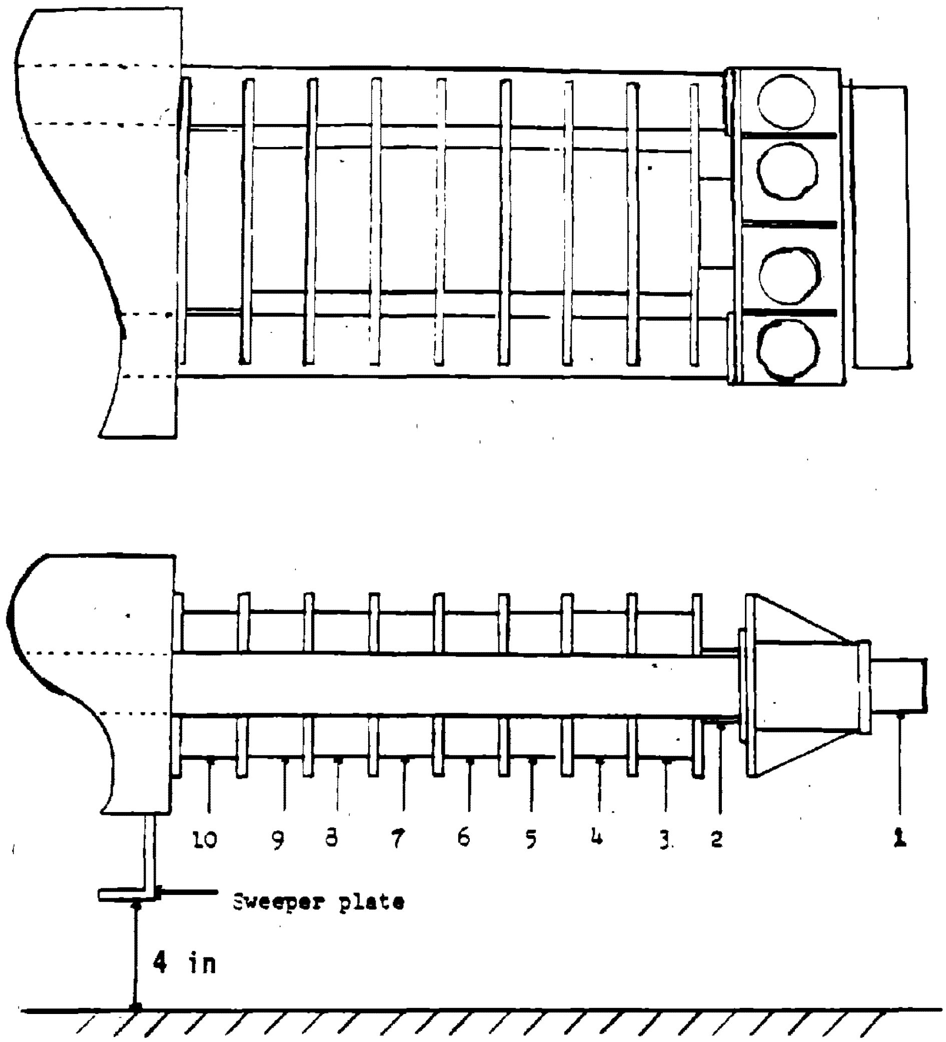
This report documents the results of seven 20-mi/h (32-km/h) pendulum tests performed on five standard BCT wood posts and two modified BCT wood posts. The standard BCT posts are typical in guardrail terminal installation. The results consist of data plots of force versus displacement and acceleration versus time for each post tested and a summary table for all seven tests. The tests were conducted on the five standard BCT posts to measure the breakaway force required to break away a BCT post. The breakaway performance varied from post to post. However, even the weakest BCT post demonstrated a breakaway force higher than an automobile door can produce. Therefore, two posts were modified to reduce the required breakaway force. This report documents the breakaway force data for the standard BCT posts tested, as well as the performance of two modified BCT posts. Explanations for the variance in performance between standard BCT posts are discussed.

3. TEST VEHICLE

The test vehicle was the FOIL's 1800-lb (816-kg) pendulum, which was ballasted to a test weight of 1850 lb (839 kg) to match the weight of the actual Honda Civics used in side impact testing of terminal ends. The pendulum consisted of a reinforced concrete mass suspended from a steel structure by four steel cables. Within the concrete mass were two aluminum guide tubes. A sliding nose was inserted into the guide tubes. Multiple cartridges of an expendable aluminum honeycomb material were placed inside the sliding nose to simulate actual vehicle crush. The honeycomb was configured to simulate a 1979 Volkswagen Rabbit's left quarter point. Because the peak force was the most important data, the honeycomb configuration was not considered critical. A sketch of the honeycomb configuration used for the pendulum testing is presented in figure 1.

4. TEST ARTICLE

The test articles for the first five pendulum tests were standard BCT wood posts, typical in breakaway guardrail terminals. Two modified BCT posts were also tested. The posts were made from pressure-treated southern yellow pine. The pendulum foundation plate had a 6- by 8-in (152- by 203-mm) steel tube tach welded to its front edge. The wood posts were then inserted into the steel tube to be held in place for testing. The posts were held such that the top of the posts were 28 in (711 mm) above ground, which is typical for guardrail installation. The pendulum was set up to impact the posts 21 in (533 mm) above ground. The standard wood posts had actual dimensions of 5.5 by 7.5 by 42.5 in (140 by 191 by 1080 mm). The first two posts tested were previously used in side impact crash tests of guardrail terminal ends. The posts showed no sign of damage after the side impact tests and, therefore, were pendulum-tested to determine their required breakaway force level. Three new posts were purchased to gather more data on the breakaway performance of standard wood posts. After the first five tests, it was determined that the force required to break away the wood posts was higher than an automobile door can withstand. Two wood posts were modified such that the breakaway



Cartridge Number	Size (in) / punch (in²)	Static Crush Strength (lbf/in²)
1	2-3/4 x 16 x 3	130
2	4 x 5 x 2	25
3	8 x 8 x 3 / 21	130
4	8 x 8 x 3 / 15	230
5	8 x 8 x 3 / 6	230
6	8 x 8 x 3	230
7	8 x 8 x 3 / 21	400
8	8 x 8 x 3 / 12	400
9	8 x 8 x 3	400
10	8 x 10 x 3	400

Spacers are made of fiberglass and are 0.5 in thick.

1 in = 25.4 mm
1 in² = 645 mm²
1 lbf/in² = 6.9 kPa

Figure 1. Pendulum honeycomb configuration.

force was decreased. The modifications effectively reduced the cross-sectional area of wood to be sheared. Figure 2 is a sketch of the standard wood posts. Figures 3 and 4 are sketches of the two different modifications. Refer to figures 3 and 4 for further dimensions and details of the modifications.

5. TEST MATRIX

Seven pendulum tests were conducted on breakaway terminal wood posts. The pendulum impacted the posts at approximately 20 mi/h (32 km/h). The centerline of the pendulum was aligned with the center of the wood posts. Table 1 presents the test matrix followed during this study.

Table 1. Test matrix for pendulum testing of wood posts.

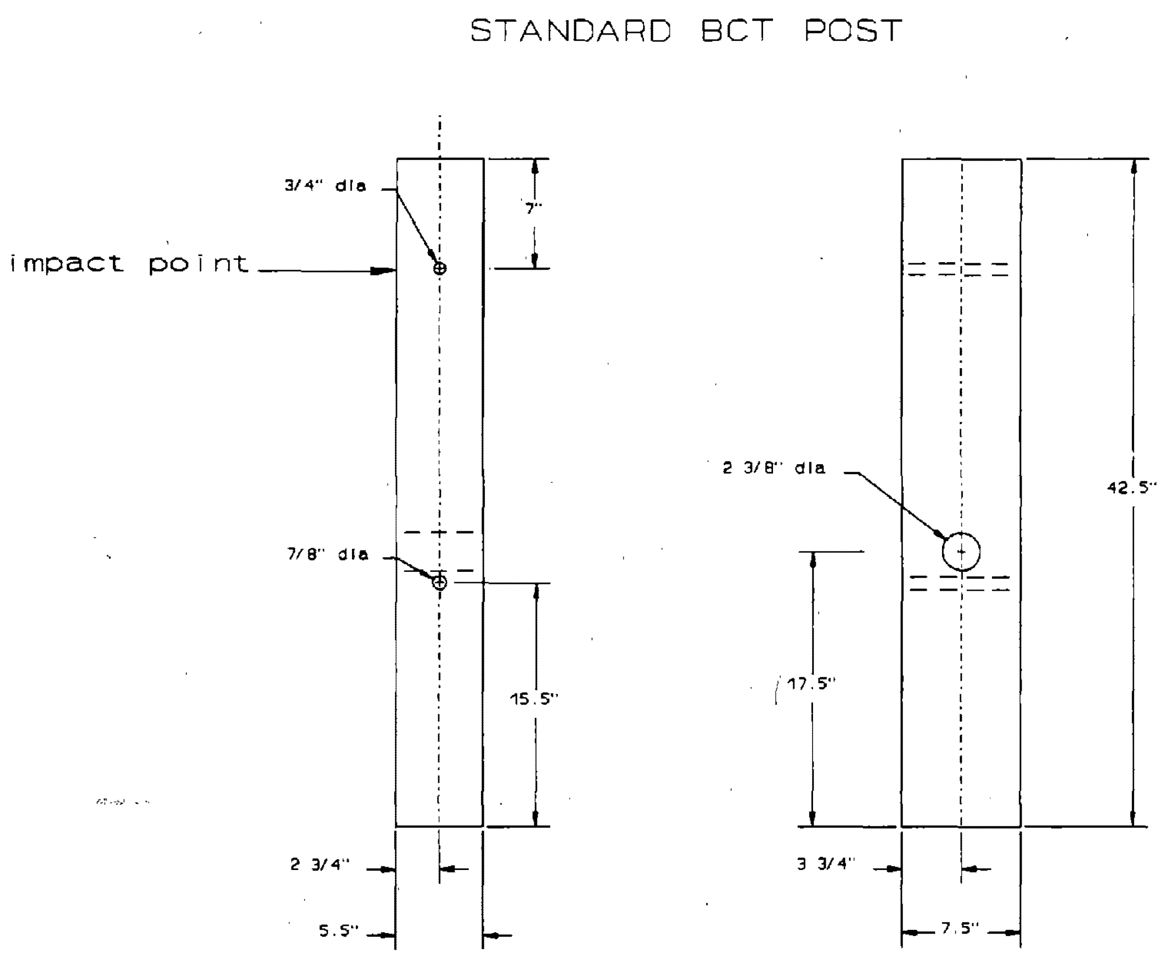
Test Number	Test Vehicle	Test Article	Test Speed	Impact Location
91P039	Pendulum	Post from BCT test	20 mi/h	Centerline
91P040	Pendulum	Post from MELT test	20 mi/h	Centerline
91P041	Pendulum	New Post	20 mi/h	Centerline
91P042	Pendulum	New Post	20 mi/h	Centerline
91P043	Pendulum	New Post	20 mi/h	Centerline
91P044	Pendulum	Modified Post I	20 mi/h	Centerline
91P045	Pendulum	Modified Post II	20 mi/h	Centerline

1 mi/h = 1.61 km/h

6. DATA SYSTEMS

a. Speed Traps. Speed traps, consisting of multiple LED infrared scanners placed a known distance apart were used to measure the pendulum speed just before and after impact. Signals from the sensors were recorded on a Honeywell model 5600 analog tape recorder. The signal are stored on analog tape for future analysis.

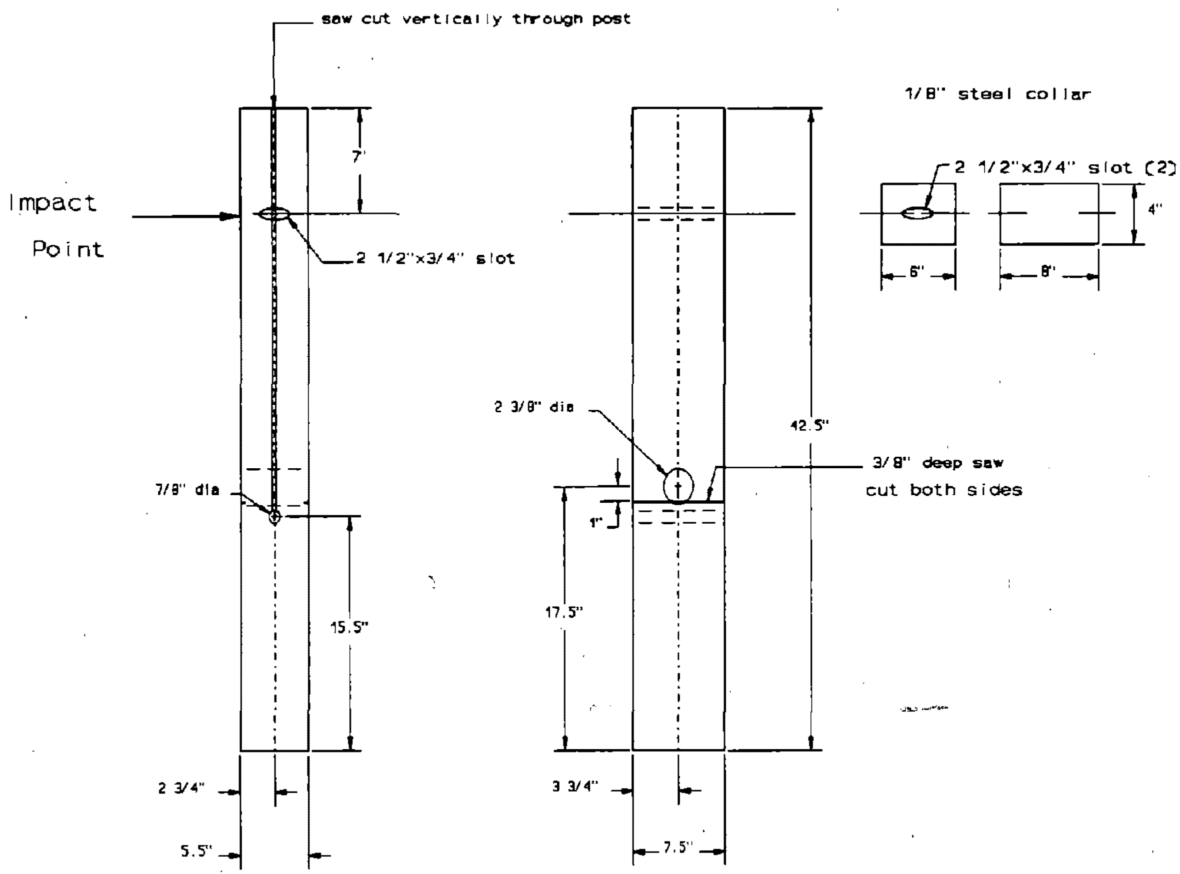
b. Accelerometers. Two longitudinal (X-axis) accelerometers were mounted at the center of the rear face of the pendulum. The nose of the



1 in = 25.4 mm   1 ft = 0.305 m

Figure 2. Standard BCT Post.

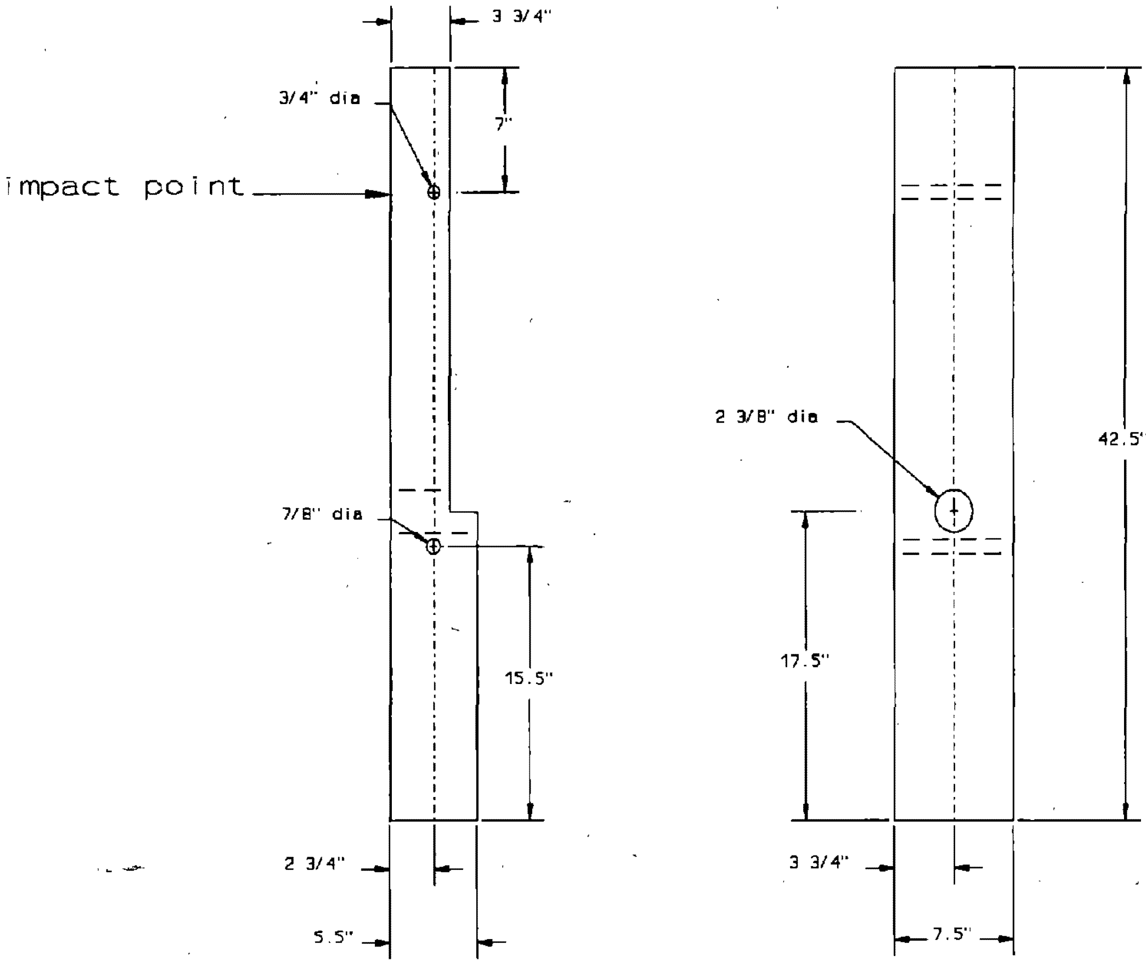
MODIFICATION #1



1 in = 25.4 mm   1 ft = 0.305 m

Figure 3. First modification to BCT post, test 91P044.

MODIFICATION #2



1 in = 25.4 mm   1 ft = 0.305 m

Figure 4. Second modification to BCT post, test 91P045.

pendulum was also equipped with an accelerometer. The following is a summary of the pendulum data acquisition package:

(a) 100 g Longitudinal (X-axis) accelerometer No. 1 (A_x).
(b) 100 g Longitudinal (X-axis) accelerometer No. 2 (A_x).
(c) 500 g Longitudinal (X-axis) accelerometer inside nose (N_x).

For each test, a contact switch was taped to the front face of the wood post to record the instant of impact on analog tape.

The signals from the accelerometers were conditioned and amplified through Vishay model 2300 amplifiers with the low-pass filter set to 10 kHz prior to recording on the Honeywell model 5600 analog tape recorder. The signals were later played back through an A/D converter in conjunction with an IBM PC-AT computer for analysis. A reference signal in the form of a 1-kHz sine wave was also recorded to ensure that the tape drive system was functioning properly.

c. High-Speed Photography. One high-speed camera set at 500 frames per second was used to record the pendulum tests. A zoom lens was attached to the camera and set to the appropriate focal length prior to the test. The camera was loaded with a roll of Kodak SO251 color film. The camera was only used for visual inspection of the impact event and not for data analysis.

7. DATA ANALYSIS

a. Speed Traps. Each speed trap consisted of a set of four LED infrared emitter/receiver pairs fastened on opposite sides of the pendulum's swing path at 6-in (152-mm) intervals. One set was positioned before and one set was positioned after the impact area to measure pre- and post-crash pendulum velocities. As the pendulum passed through the infrared scanners, electronic pulses were recorded on analog tape. The tape was played back through a Data Translation A/D converter and the time between pulses was determined. The time-distance data was entered into a computer spreadsheet and a linear regression was performed on the data to determine the pendulum speed before and after impact. The pendulum's change in velocity was computed by subtracting the exit-speed from the impact-speed.

b. Accelerometers. The accelerometer data was conditioned and amplified during the impact event. After the test, the tape recorder was played back through an 8-pole Butterworth low-pass filter with a cut-off frequency of 500 Hz. The data was then digitized at a sampling rate of 2000 Hz using a Data Translation A/D converter. Once in digital form, the data was processed using an array of FORTRAN algorithms to determine the zero bias and to filter the data. The filter was a digital Butterworth low-pass filter with a cut-off frequency of 300 Hz. After processing, the data was imported into a computer spreadsheet for analysis. Because the pendulum is a two-mass system (nose and body), the outputs from the nose accelerometer and from one pendulum accelerometer were added together by multiplying the data from each accelerometer by its respective mass, 50 lb (22.7 kg) for the nose and 1800 lb (816.3 kg) for the body, then summing the products together to obtain a total force trace. The data from the nose accelerometer and from one pendulum accelerometer were combined, then integrated twice, to generate velocity and displacement traces. The peak force (breakaway force) for the wood posts was determined from the force trace. Pendulum change in velocity was computed from the velocity trace. The force versus displacement trace was generated by plotting the force data versus the displacement data computed by double integration of the force trace.

c. High-Speed Photography. The camera was only used for visual inspection of the impact event and not for data analysis.

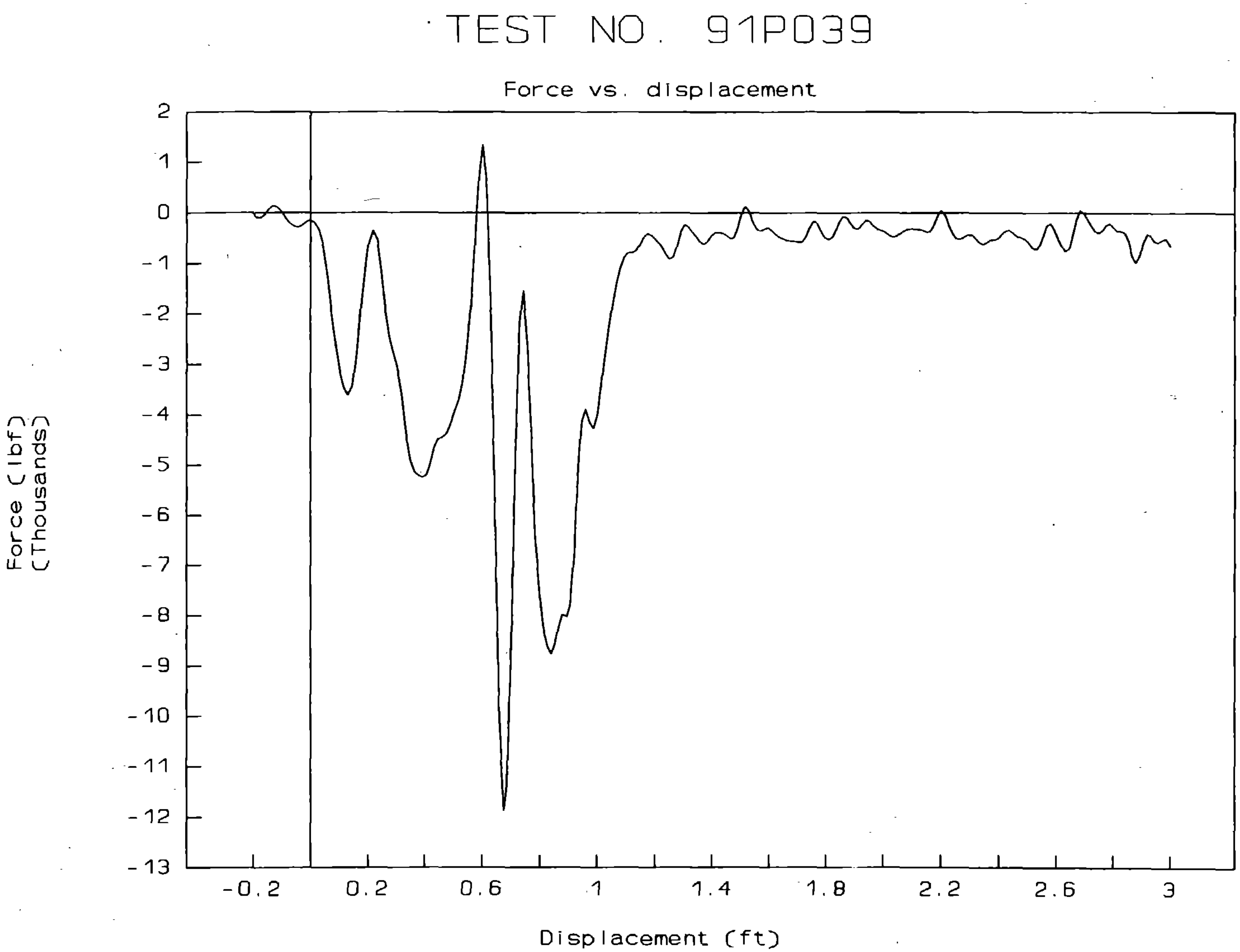
8. TEST RESULTS

The results are best presented in the form of a table. Table 1 is a summary of all seven wood post impact tests. Included in the table are physical parameters of the wood posts and other data pertinent to investigating the breakaway characteristics of the wood posts. The pendulum impacted all of the posts 21 in (533 mm) above ground. The pendulum centerline impacted the centerline of the wood posts. The impact speed for the tests are presented in the results table. Force versus displacement and acceleration versus time data plots are presented in figures 5 through 18.

Table 2. Summary of test results for tests 91P039 through 91P045.

Test Number	Impact Speed Speed Trap (ft/s)	Exit Speed Speed Trap (ft/s)	Change in Velocity Speed Trap (ft/s)	Change in Velocity Accel. (ft/s)	Peak Force (kips)	Peak Force (g's)	Honeycomb Crush (in)	Post Weight (lb)	Core Dia. (in)
91P039	29.2	26.8	2.4	3.1	11.9	6.4	6.0	36	3.0
91P040	29.5	26.3	3.2	3.2	10.4	5.6	6.3	33	4.25
91P041	29.8	20.5	9.3	9.8	15.5	8.4	12.6	42	3.25
91P042	29.3	26.5	2.8	2.6	9.7	5.2	6.4	34	1.0
91P043	29.3	25.3	4.0	4.4	11.1	6.0	8.1	38	3.25
91P044	29.3	27.5	1.8	1.8	4.8	2.6	3.1	39	NA
91P045	29.2	27.4	1.8	1.2	4.8	2.6	2.9	27	NA

1 in = 25.4 mm   1 ft/s = 0.305 m/s   1 lb = 0.454 kg   1 lbf = 4.45 N



1 ft = 0.305 ft   1 lbf = 4.45 N

Figure 5. Force versus displacement, test 91P039.

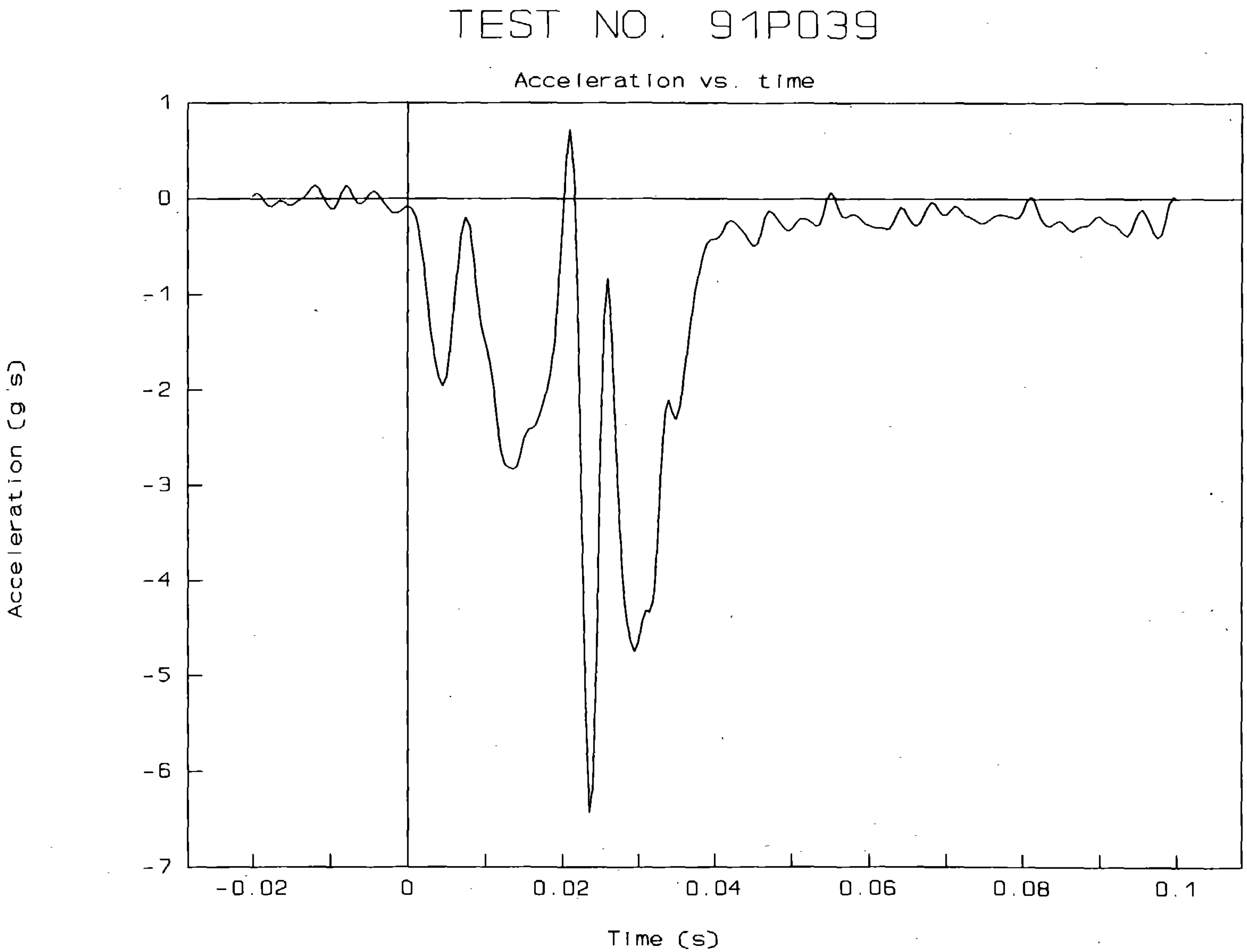
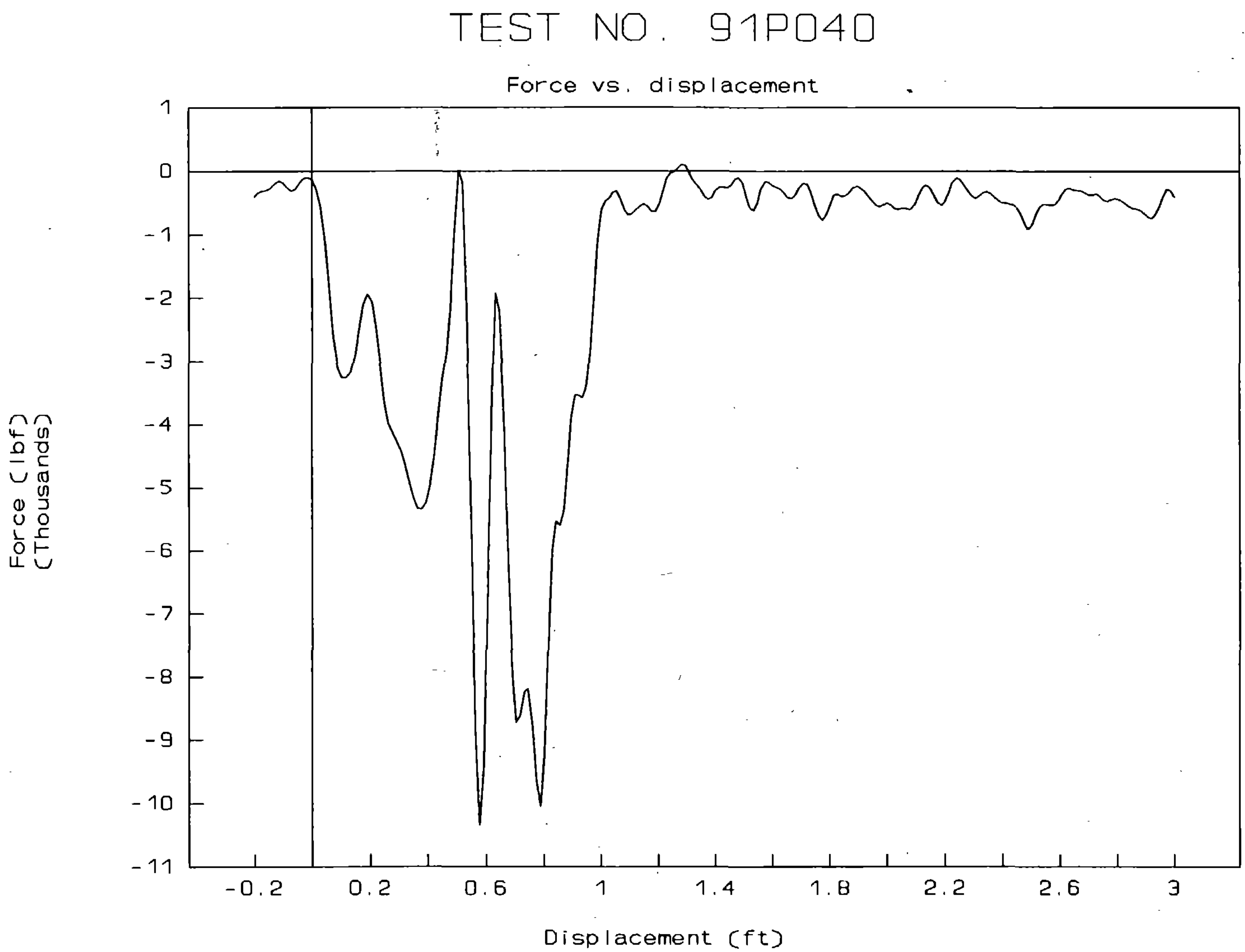


Figure 6. Acceleration versus time, test 91P039.



1 ft = 0.305 m   1 lbf = 4.45 N

Figure 7. Force versus displacement, test 91P040.

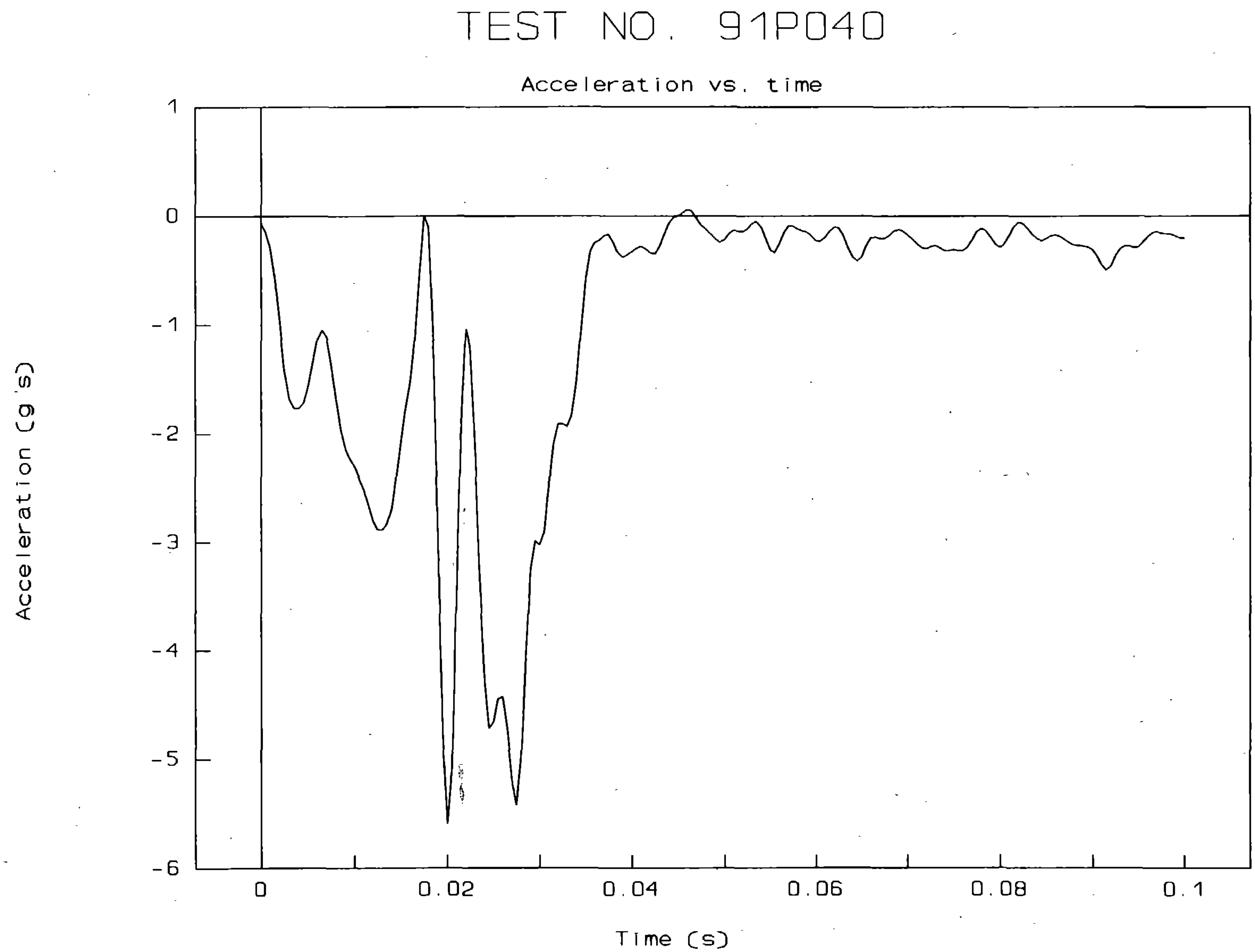
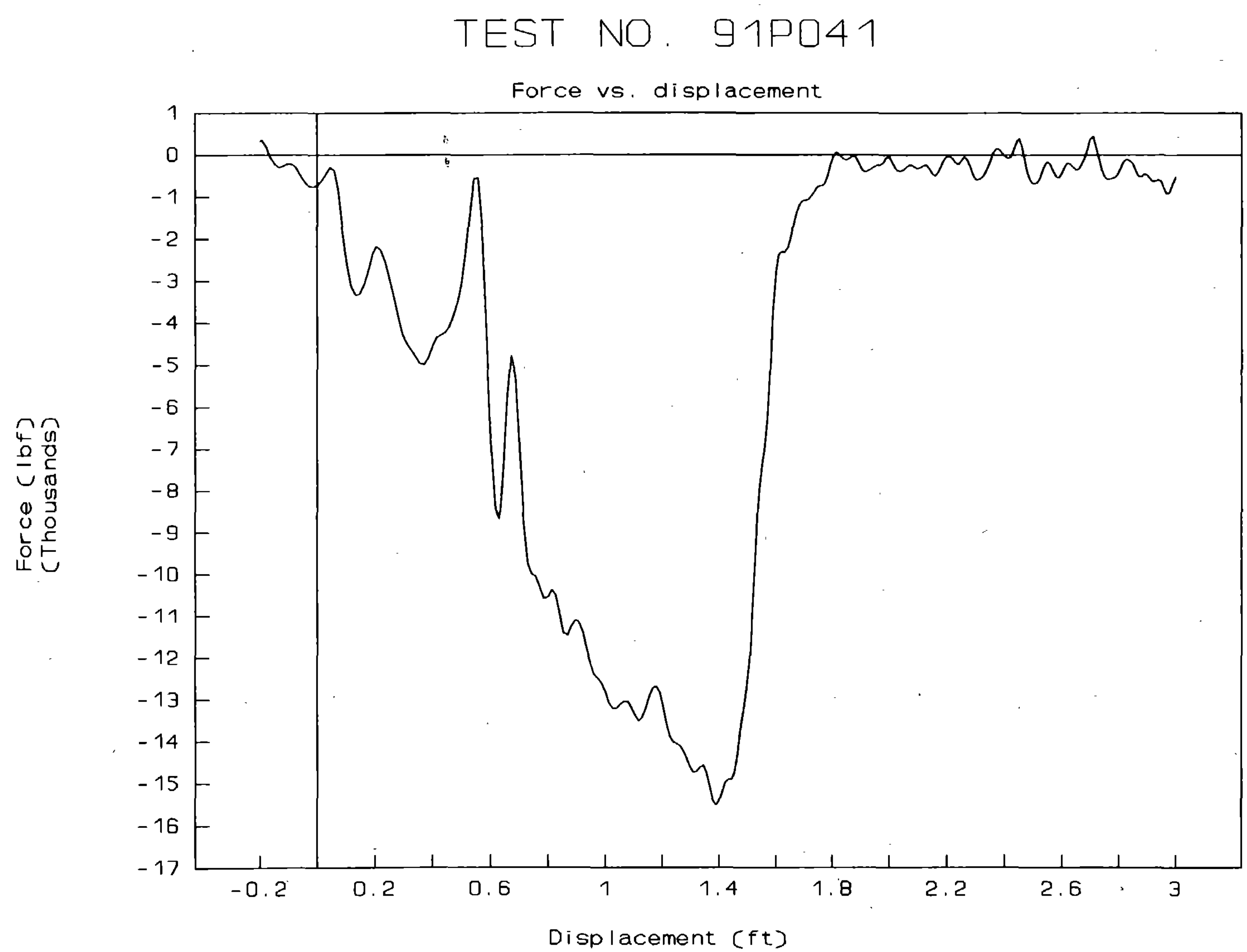


Figure 8. Acceleration versus time, test 91P040.



1 ft = 0.305 m 1 lbf = 4.45 N

Figure 9. Force versus displacement, test 91P041.

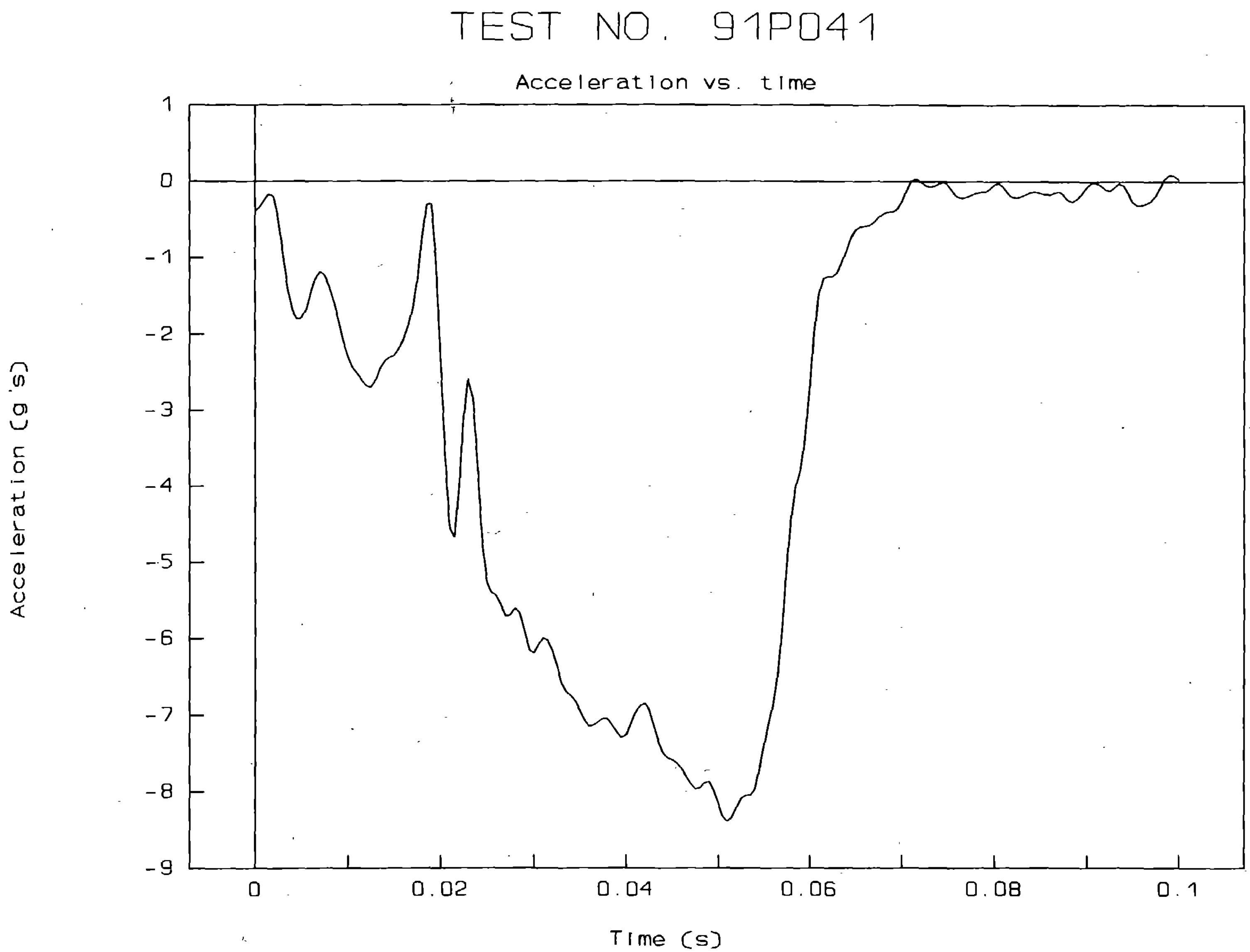
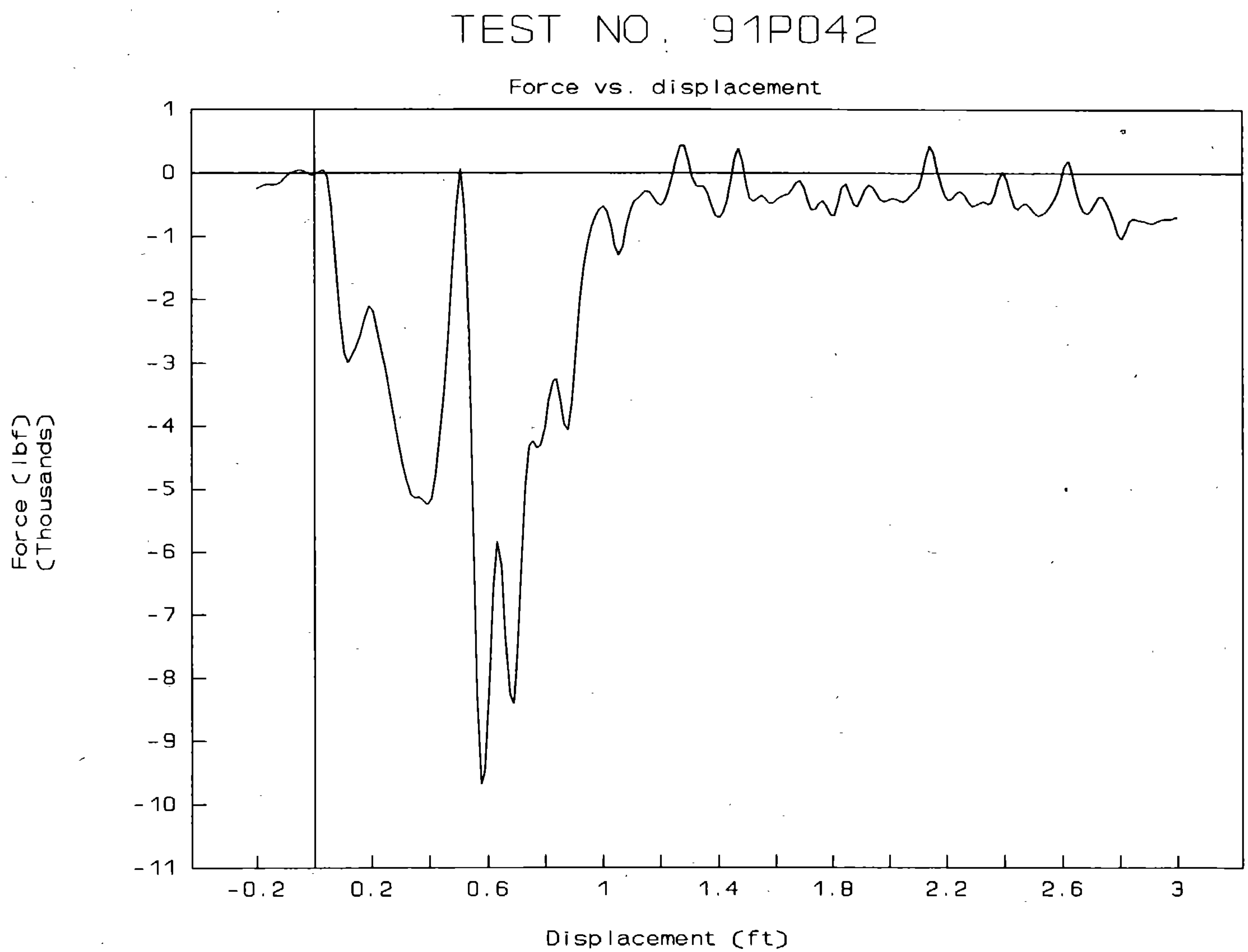


Figure 10. Acceleration versus time, test 91P041.



1 ft = 0.305 m   1 lbf = 4.45 N

Figure 11. Force versus displacement, test 91P042.

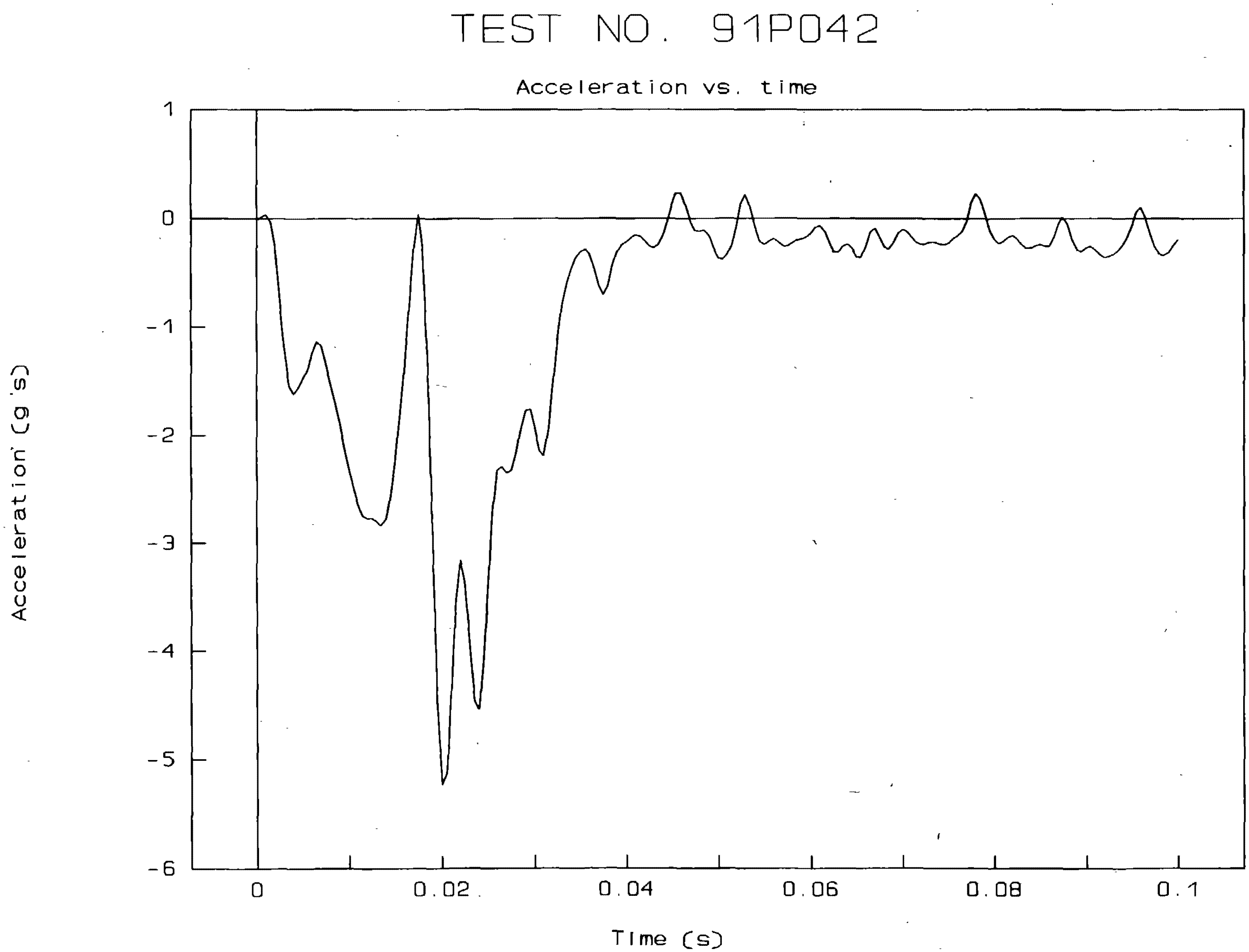
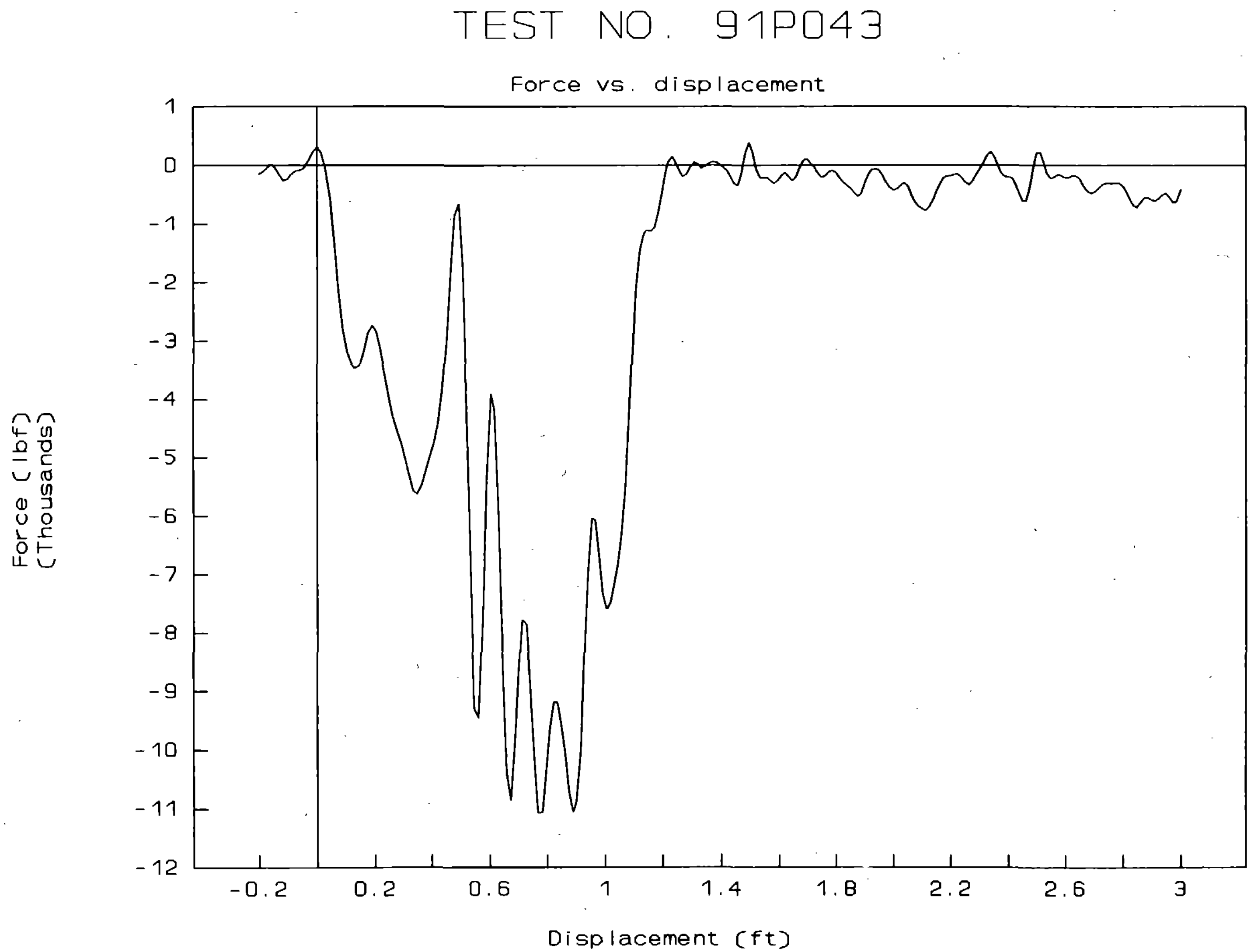


Figure 12. Acceleration versus time, test 91P042.



1 ft = 0.305 m 1 lbf = 4.45 N

Figure 13. Force versus displacement, test 91P043.

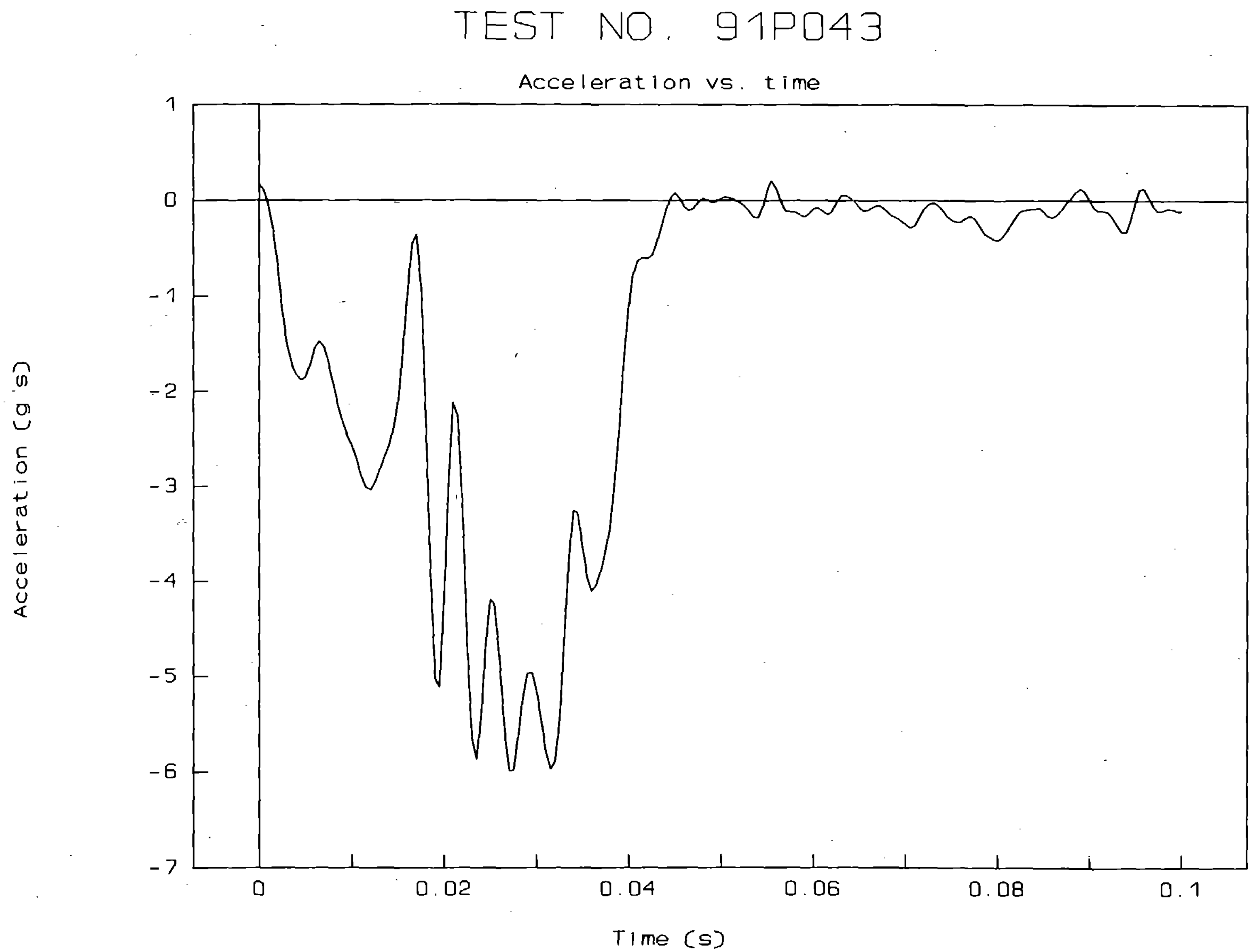
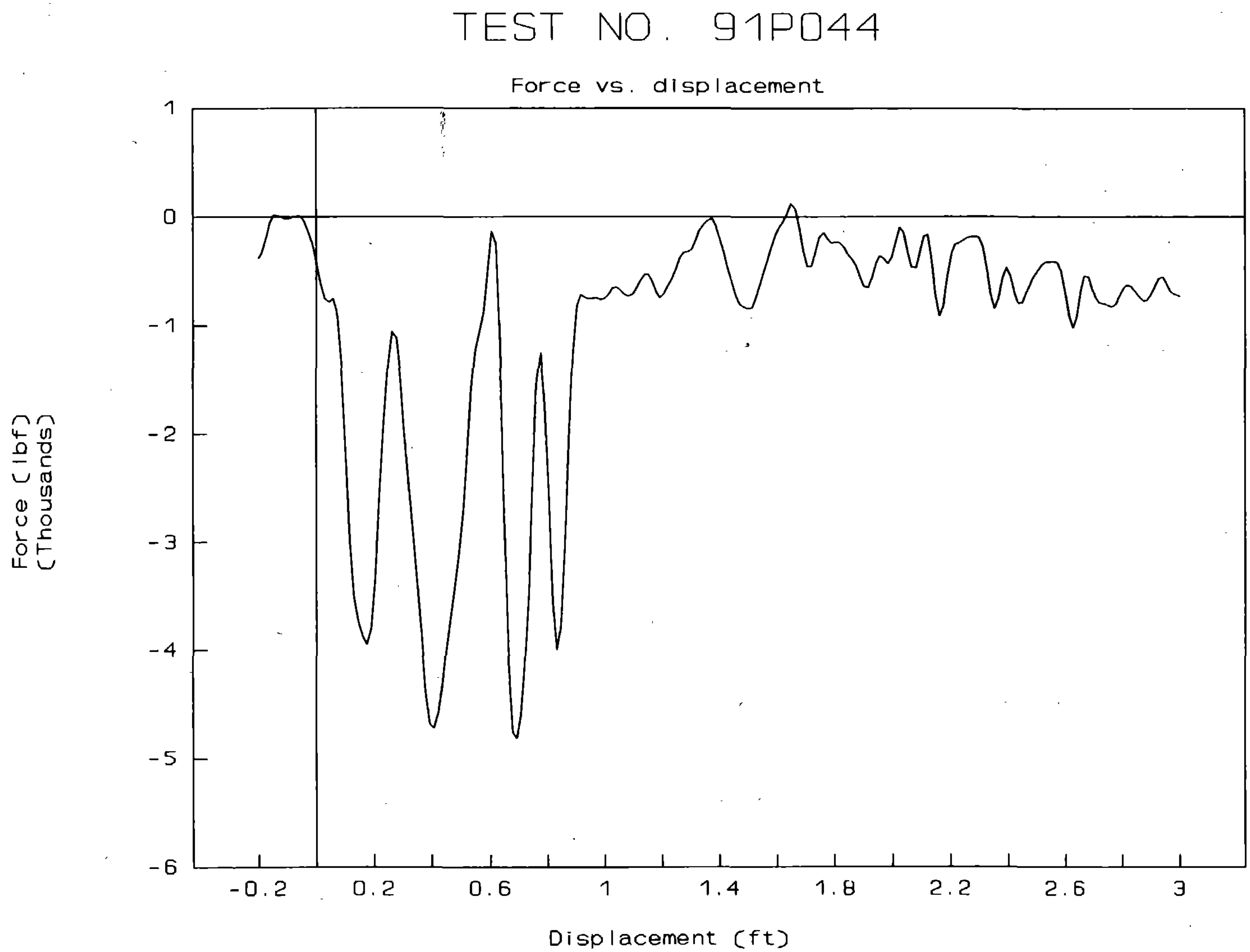


Figure 14. Acceleration versus time, test 91P043.



1 ft = 0.305 m   1 lbf = 4.45 N

Figure 15. Force versus displacement, test 91P044.

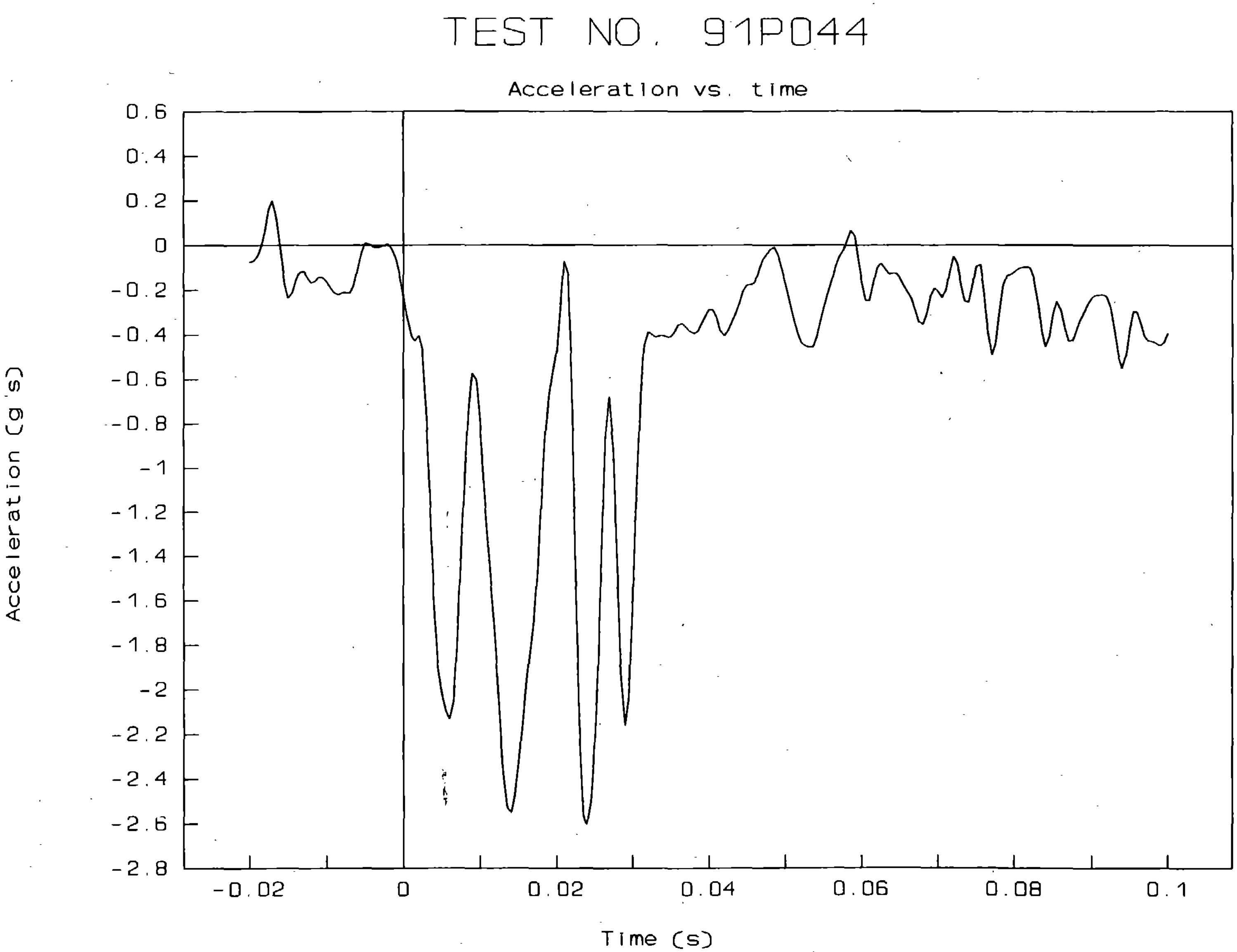
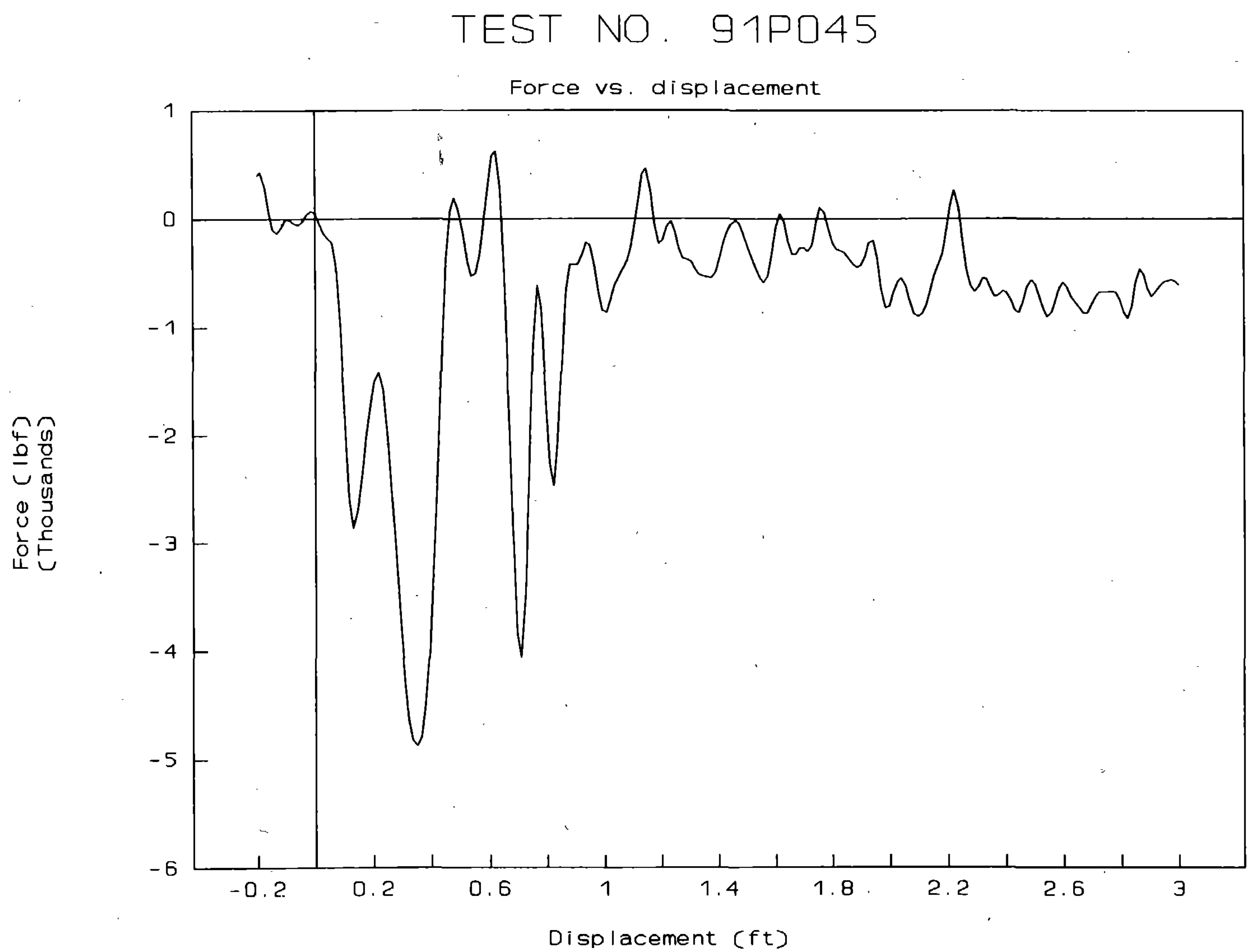


Figure 16. Acceleration versus time, test 91P044.



1 ft = 0.305 m 1 lbf = 4.45 N

Figure 17. Force versus displacement, test 91P045.

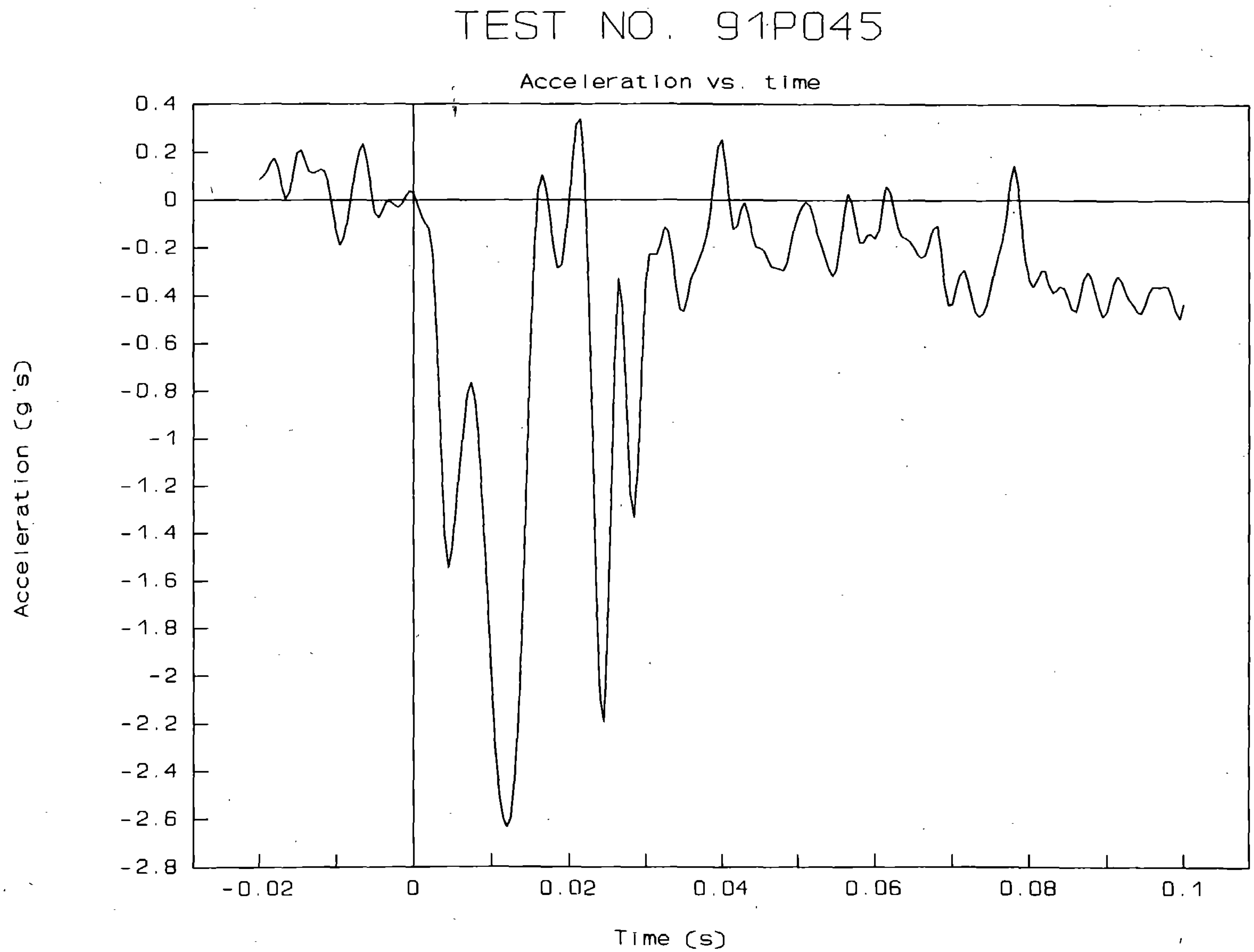
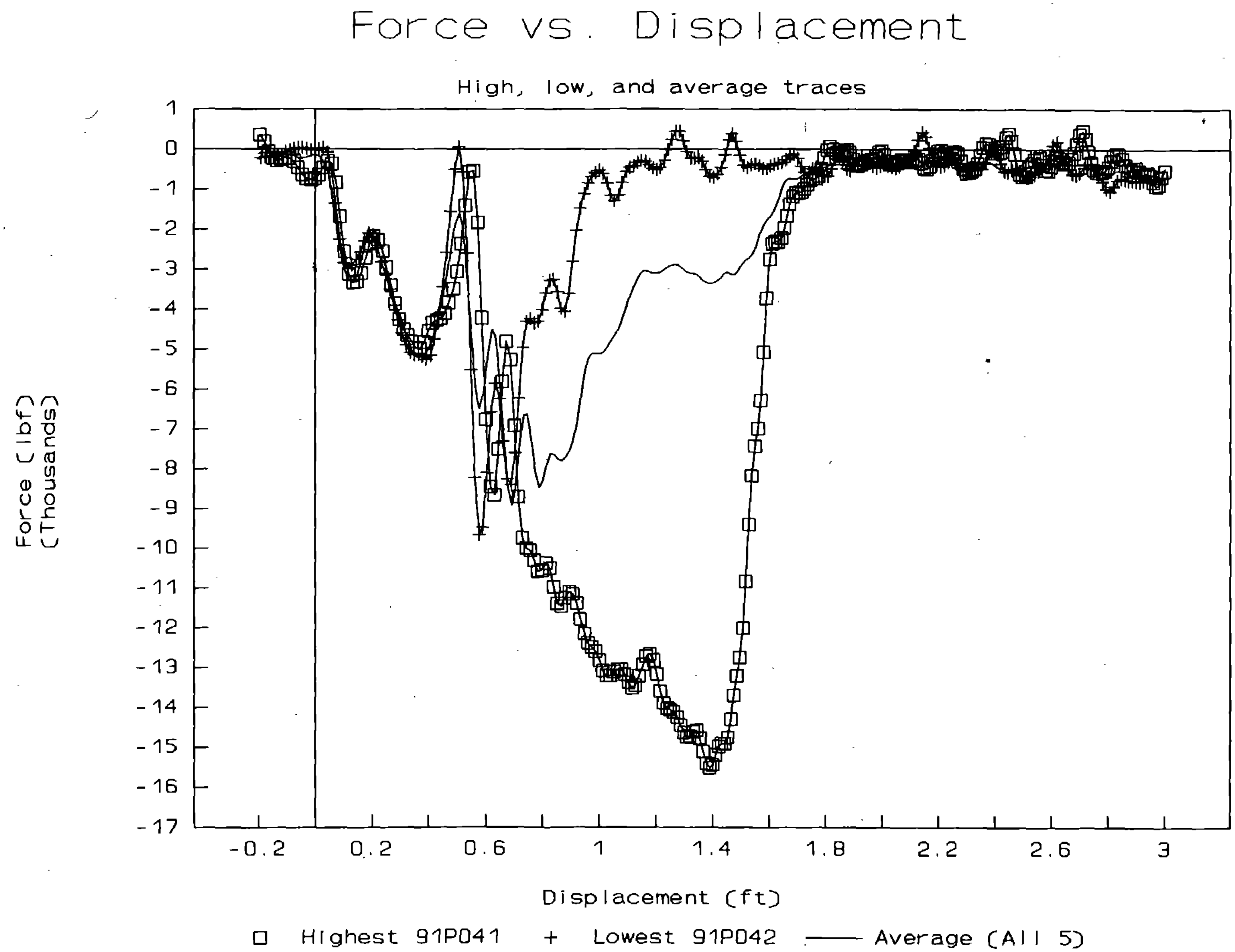


Figure 18. Acceleration versus time, test 91P045.

9. CONCLUSIONS

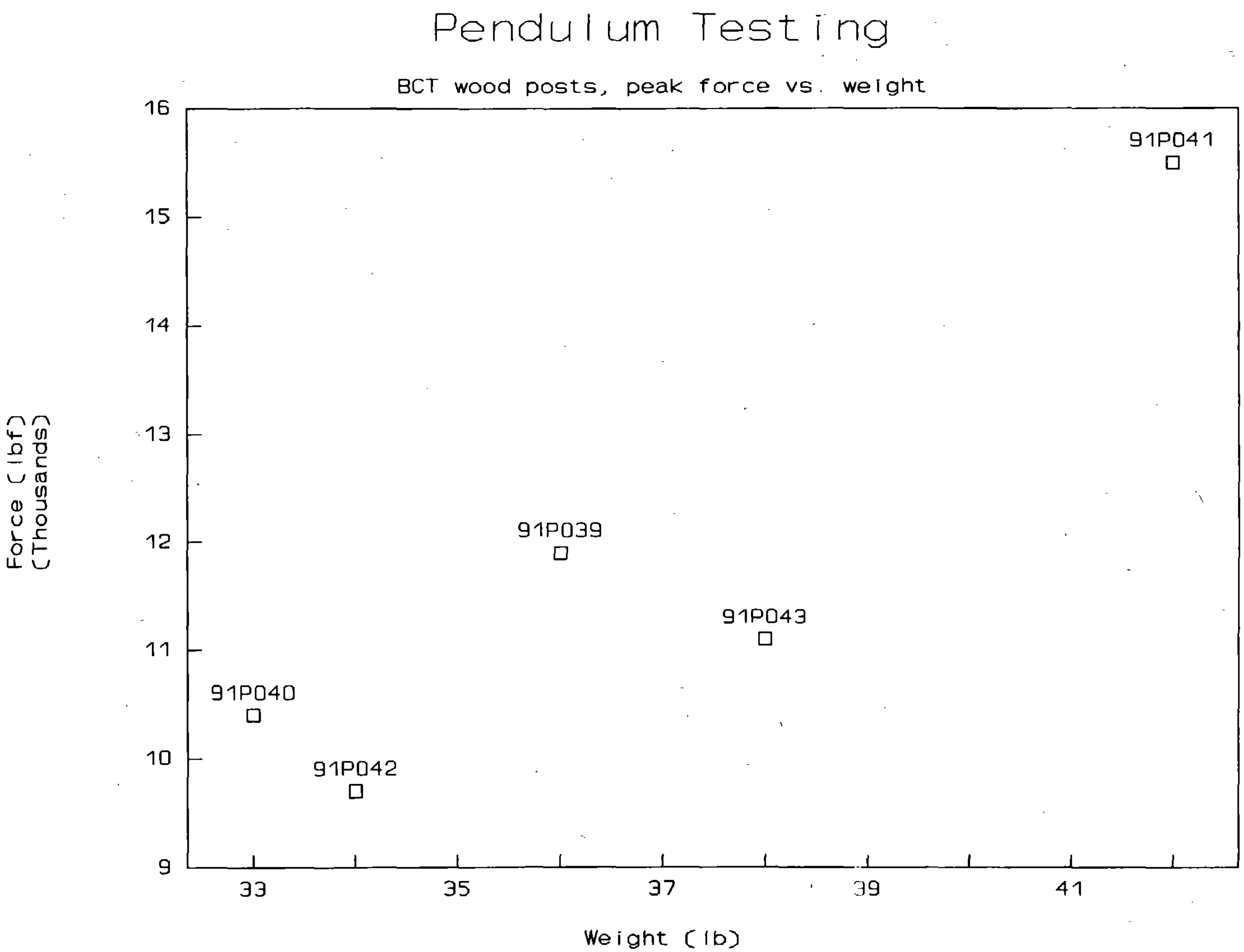
The data from the first five pendulum tests indicate that the breakaway force for the standard yellow pine BCT post varies from 9.7 kips (43.1 kN) to 15.5 kips (68.8 kN). Figure 19 is a plot of the highest, lowest, and average breakaway forces attained during the test series. The average plot is of all five standard BCT posts. The modifications were not included because they were effectively different posts. The variance may have been due to inconsistencies in manufacturing each post. The sizes of the posts varied slightly from post to post. Also, variance in the wood itself may cause discrepancies in the performance between posts. Another possible reason is the moisture content of the wood posts. The posts were pressure treated, but some posts may have been more "green" than others. Variance in weight between two posts that are close in size illustrates the difference in moisture content. The weight of the posts does correlate with the breakaway force level of the posts. The highest force level occurred while testing the post that weighed 42 lb (19.0 kg), while the lowest force occurred while testing the post that weighed 34 lb (15.4 kg). While the 34-lb (15.4-kg) post was not the lightest post, the force level required to break away the lightest post (33 lb [15.0 kg]) was only slightly higher than the 34-lb (15.4-kg) post. Figure 20 depicts this rough correlation between weight and breakaway force. More posts would need to be weighed and tested to validate any correlation that exists. A final postulate was that the wood at the center (core) of the posts was more dense than the outer layers. Therefore, the bigger the size of the core, the higher the breakaway force. However, the core size does not correlate well with the breakaway force and, therefore, does not appear to be a valid explanation.

The modifications made to the BCT posts successfully lowered the breakaway force.



1 ft = 0.305 m   1 lbf = 4.45 N

Figure 19. High, low, and average force versus displacement.



1 lbf = 4.45 N   1 lb = 0.454 kg

Figure 20. Force versus BCT post weight.