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Validation of the ENSCO Surrogate Bogie Vehicle, FOIL Test Numbers 92F028 through 92F031

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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16. Abstract

This document contains the results from four crash tests conducted at the Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center in McLean, Virginia. The crash tests involved two reusable bogie vehicles impacting an instrumented rigid pole. Two of the tests used the FOIL bogie vehicle and two tests used the ENSCO Inc. bogie vehicle. The objective of this report is to show that the FOIL and ENSCO bogie vehicles are comparable vehicles. Comparisons are made between the crush characteristics of the two bogie vehicles. The crush characteristics are presented as data plots of force vs. displacement, energy vs. displacement and peak force vs. momentum.

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FOREWORD

This report documents the results of four crash tests conducted to validate the ENSCO reusable bogie vehicle. The validation was conducted by comparability tests using the Federal Outdoor Impact Laboratory (FOIL) bogie. Four frontal crash tests were conducted at the FOIL. Two tests were conducted with the FOIL's bogie and two tests of the ENSCO bogie. All of the tests were conducted into the FOIL's Instrumented Rigid Pole and the crush characteristics of the vehicles were compared.

This report (FHWA-RD-93-074) contains test data, photographs taken from high speed film and a summary of the test results for each of the four tests conducted.

This report will be of interest to those operating crash test facilities, FHWA headquarters, and highway safety researchers interested in the crashworthiness of roadside safety systems.

Lyle Saxton, 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		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	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		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	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/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

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

(Revised August 1992)

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BACKGROUND

In the 1980's, the Federal Outdoor Impact Laboratory (FOIL) developed and validated a bogie vehicle. This bogie vehicle was developed as a surrogate vehicle to simulate actual automobiles which in turn lowered the costs of crash testing roadside safety hardware. In the early 1990's, the Federal Highway Administration (FHWA) and ENSCO, Inc., signed a Cooperative R&D Agreement (CRADA) which enabled the validation of ENSCO's bogie vehicle at the FOIL. This would enable ENSCO to crash test roadside safety hardware using a surrogate vehicle approved by the FHWA.

OBJECTIVE

This document contains the results from four crash tests conducted at the Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center in McLean, Virginia. The crash tests involved two reusable bogie vehicles impacting an instrumented rigid pole. Two of the tests used the FOIL bogie vehicle and two tests used the ENSCO Inc. bogie vehicle. The objective of this report is to show that the FOIL and ENSCO bogie vehicles are similar vehicles. Comparisons are made between the crush characteristics of the two bogie vehicles. The crush characteristics are presented as data plots of force vs. displacement, energy vs. displacement and peak force vs. momentum. Further comparisons are made between data plots of load cell traces, vehicle acceleration vs. time, nose acceleration vs. time and impact force height vs. displacement.

VEHICLE

The vehicles used were the FOIL reusable bogie vehicle and the ENSCO bogie vehicle replica. The bogie vehicles were constructed from the same set of specifications and drawings outlined in *FOIL Construction*, Volumes I, II, and III.[1] The reports and drawings are stored at the FOIL facility in McLean, Virginia. Figure 1 is a sketch of the bogie vehicles. Both bogie vehicles were configured to represent an 1850-lb (839.9-kg) 1979 Volkswagen Rabbit two-door sedan. Frontal crush of the bogie vehicles which simulates the crush of an actual vehicle was accomplished using multiple cartridges of an expendable aluminum honeycomb material in a sliding nose. After a test, the honeycomb material is replaced and the vehicle reused. The honeycomb was configured to represent the crush characteristics of a 1979 Volkswagen Rabbit's left quarter point.[2] Figure 2 is a sketch of the honeycomb configuration used in both bogie vehicles. A sweeper plate was attached to the bogie vehicles such that it would hang down to a height of 4 in (101.6 mm) above the ground. The sweeper plate was constructed of a section of steel angle welded to a 1/4-in (6.3-mm) steel plate then attached to the bogie using two 3/8-in (9.5-mm) bolts. The sweeper plate was designed as a sacrificial element to simulate the performance of an automobile's undercarriage. Each bogie vehicle was weighed prior to testing and each bogie weighed 1850 lb (839 kg).

RIGID POLE

For each of these tests the bogie vehicles impacted an instrumented rigid pole. The centerline of the each bogie vehicle was aligned with the centerline of the rigid pole. The pole was designed as a narrow fixed object

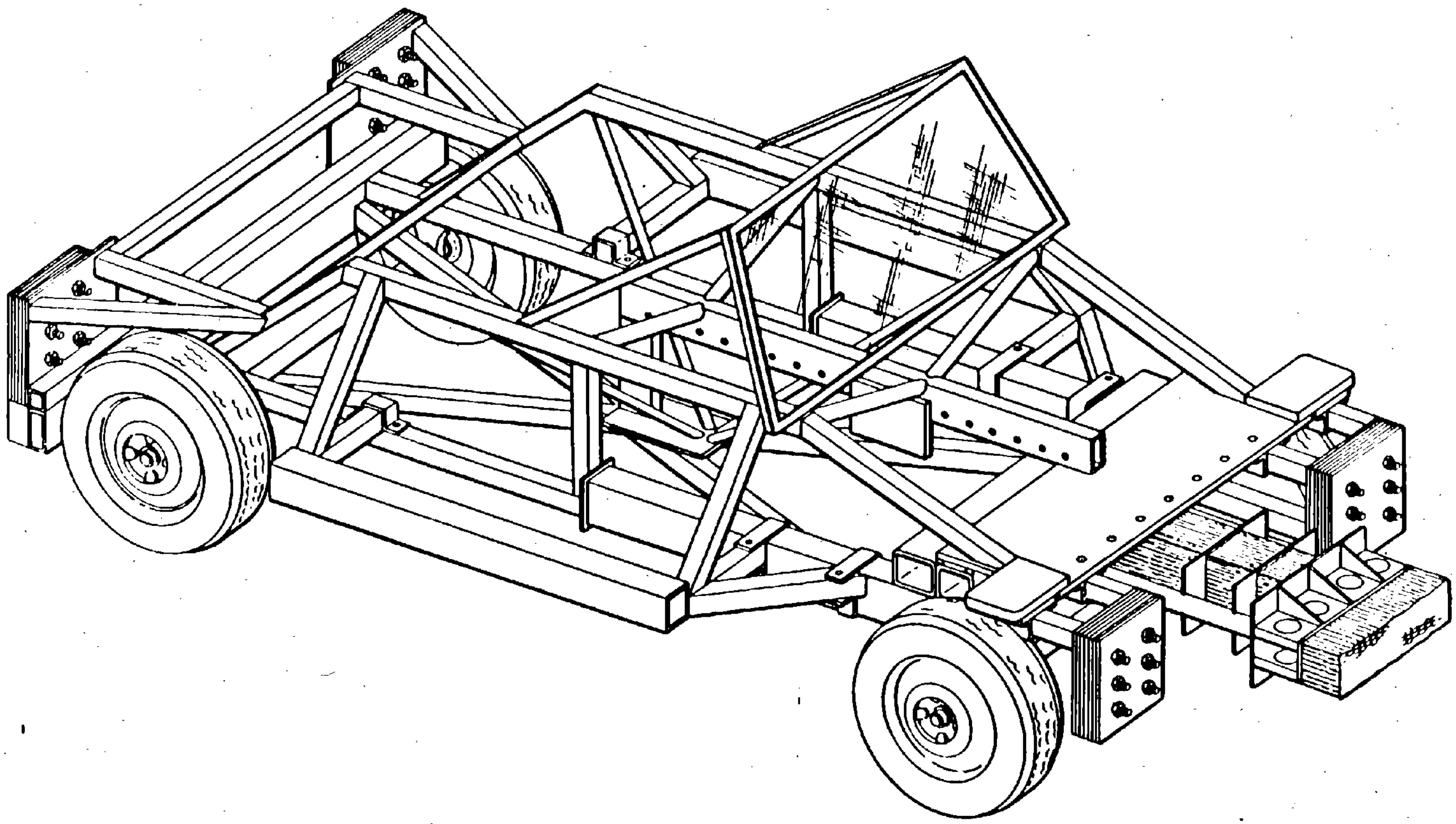
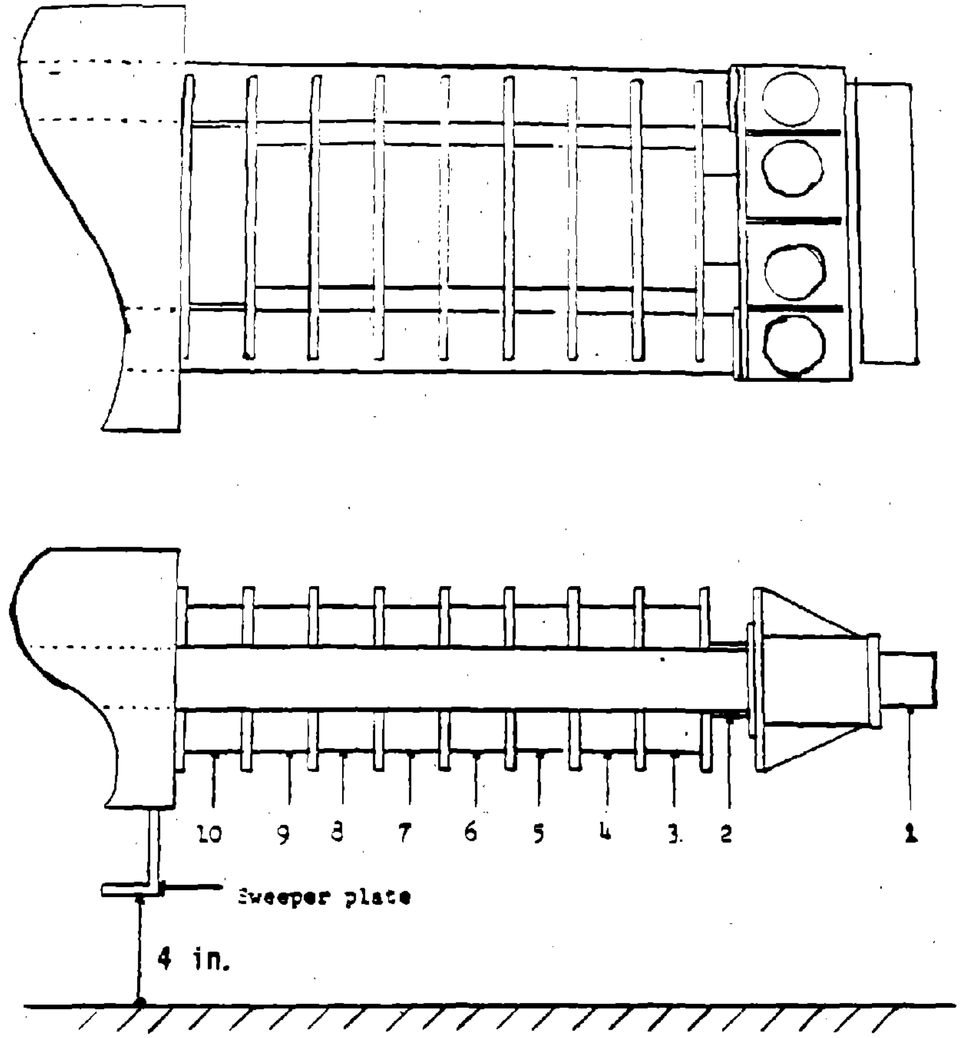


Figure 1. Sketch of bogie vehicles.



Cartridge Number	Size (in) / punch (in^2)	Static Crush Strength (psi)
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 1/2 in thick.

1 in = 25.4 mm   1 in^2 = 645.2 mm^2 1 psi = 6.89 kPa

Figure 2. Sketch of bogie honeycomb configuration.

mounted rigidly to the FOIL runway. The rigid pole was designed to measure vehicle crush characteristics.

The impact face consisted of a semicircular section of extra-heavy-walled, 8-in (203.2-mm) pipe (8 5/8-in diameter (219 mm)) supported by two connecting rods which ran through guide bearings and were attached to load cells. The force from both load cells were added together to obtain the total force. A sketch of the rigid pole is presented in figure 3.

TEST MATRIX

Four tests were conducted using the two surrogate bogie vehicles impacting an instrumented rigid pole. Two tests used the FOIL bogie vehicle and two used the ENSCO bogie vehicle which was built from the same drawings as the FOIL bogie vehicle. Each test utilized the FOIL instrumented rigid pole. The bogie vehicles impacted the rigid pole centerline on centerline. Table 1 is the test matrix followed for the bogie vehicle testing.

Table 1. Test matrix.

Test Number	Test Date	Test Vehicle	Test Speed	Test Article
92F028	9-24-92	FOIL Bogie	20 mi/h	FOIL Rigid Pole
92F029	9-24-92	FOIL Bogie	20 mi/h	FOIL Rigid Pole
92F030	10-6-92	ENSCO Bogie	20 mi/h	FOIL Rigid Pole
92F031	10-6-92	ENSCO Bogie	20 mi/h	FOIL Rigid Pole

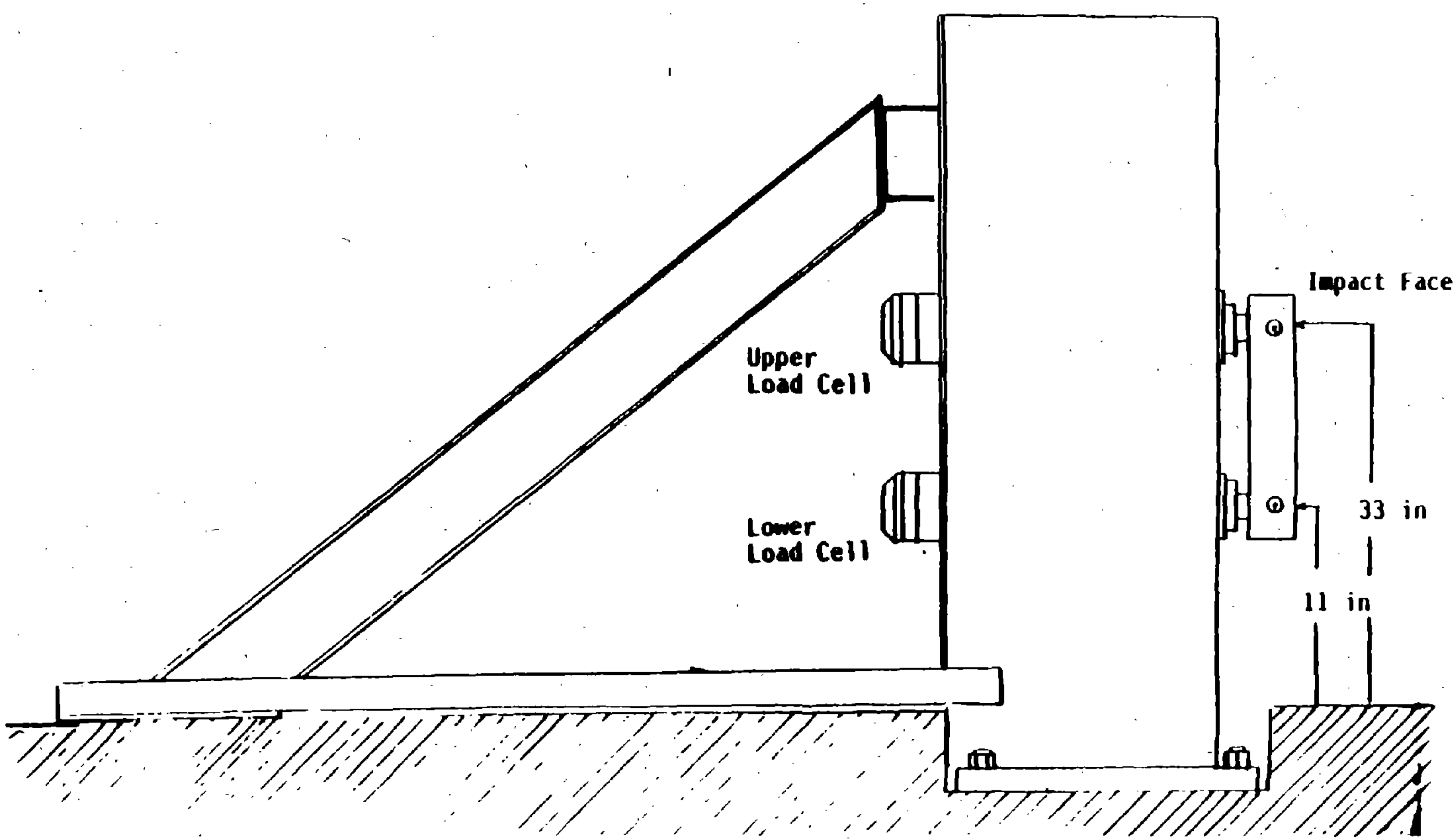
1 mi/h = 1.6 km/h

DATA ACQUISITION

For each of the four tests, speed trap, accelerometer and load cell data were collected to measure and compare the crush characteristics of the two bogie vehicles. All of the data collected was recorded by a Honeywell model 5600 analog tape recorder.

The speed trap consisted of a set of five contact switches fastened to the runway at 1-ft (0.3 m) intervals. The center of the speed trap was placed approximately 12 ft (3.7 m) before the rigid pole. As the vehicles passed over the switches, electronic pulses were recorded on analog tape. The tape was played back through a Data Translation A/D converter in conjunction with a COMPAQ SYSTEMPRO computer. The time intervals between the first pulse and each of the subsequent four pulses were then obtained using the analysis software provided with the A/D converter. The time-displacement data were entered into a computer spreadsheet and a linear regression was performed to determine the best-line fit of the data points. The impact velocity was determined from the slope of the best-line fit of the time-displacement data.

Data from four accelerometers and two load cells was recorded on the analog tape recorder during each bogie crash test. The accelerometers were mounted to a steel block located at the bogie's center-of-gravity. The two load cells were attached to the rigid pole 11 in and 33 in (279.4 mm and 838.2 mm) above ground (figure 3). The electronic transducer data was collected via two umbilical cables, one between the test vehicle's accelerometers and the recording system and one between the instrumented rigid



1 in = 25.4 mm

Figure 3. Sketch of FOIL instrumented rigid pole.

pole's load cells and the recording system. A summary of the transducers used and their limits is presented below:

Cable 1: Bogie vehicle.
- 100-g primary longitudinal (X-axis) accelerometer (A_x).
- 100-g longitudinal (X-axis) accelerometer (A_x).
- 100-g lateral (Y-axis) accelerometer (A_y).
- 100-g vertical (Z-axis) accelerometer (A_z).
- 500-g longitudinal accelerometer inside the bogie nose (N_x).

Cable 2: Rigid pole.
- 25000-lb upper load cell 33 in (838.2 mm) high.
- 25000-lb lower load cell 11 in (279.4 mm) high.

A contact switch was taped to the impact face of the rigid pole in order to synchronize all the transducer data with the time of impact. The pulse from the contact switch was recorded by the analog tape recorder. All of the transducer signals were conditioned through a Vishay model 2300 amplifier with the low-pass filter set to 10 kHz prior to being recorded. The data signals were played back from the tape recorder through an 8-pole Butterworth low-pass filter with a cut-off frequency of 500 Hz and input through a Data Translation series DT2801 A/D converter in conjunction with a COMPAQ SYSTEMPRO computer. The sampling rate of the A/D converter was 2000 Hz. The transducer data were input through a series of FORTRAN algorithms to remove zero-bias and digitally filter the data with a final cut-off frequency of 300 Hz. In addition to the speed traps, transducers and the impact contact switch, a 1 kHz timing signal was recorded to ensure the tape drive system of the tape recorder was functioning properly.

RESULTS

The bogie vehicles were accelerated to a velocity of approximately 20 mi/h (8.9 m/s) prior to impacting the rigid pole. The centerline of the bogie vehicles were aligned with the centerline of the rigid pole. During each of the tests, the bogie vehicles rebounded with a small negative velocity. Table 2 summarizes the impact speed, static honeycomb crush, load cell data and accelerometer data. The crush values under the load cell data and accelerometer data headings in table 2 were the maximum values obtained from the double integration of the acceleration traces.

Table 2. Summary of bogie testing.

Test No.	Bogie Vehicle	Impact Speed (ft/s)	Load Cell Data				Cg/Nose Accel. Data				Honey-comb Crush (in)
			Pk g's	Pk Force (1000 lbf)	ΔV ft/s	Crush (in)	Pk g's	Pk Force (1000 lbf)	ΔV ft/s	Crush (in)	
92F028	FOIL	31.7	18.8	34.7	36.6	25.5	21.1	39.0	35.5	25.9	23.2
92F029	FOIL	31.8	19.0	35.2	37.0	24.9	19.4	35.9	35.4	25.3	23.3
92F030	ENSCO	31.1	18.5	34.1	37.1	24.4	21.6	39.9	36.0	24.7	22.3
92F031	ENSCO	31.4	19.1	35.4	37.3	24.5	21.5	39.8	36.9	24.8	22.9

1 in = 25.4 mm   1 ft = 0.305 m   1 lbf = 4.45 N

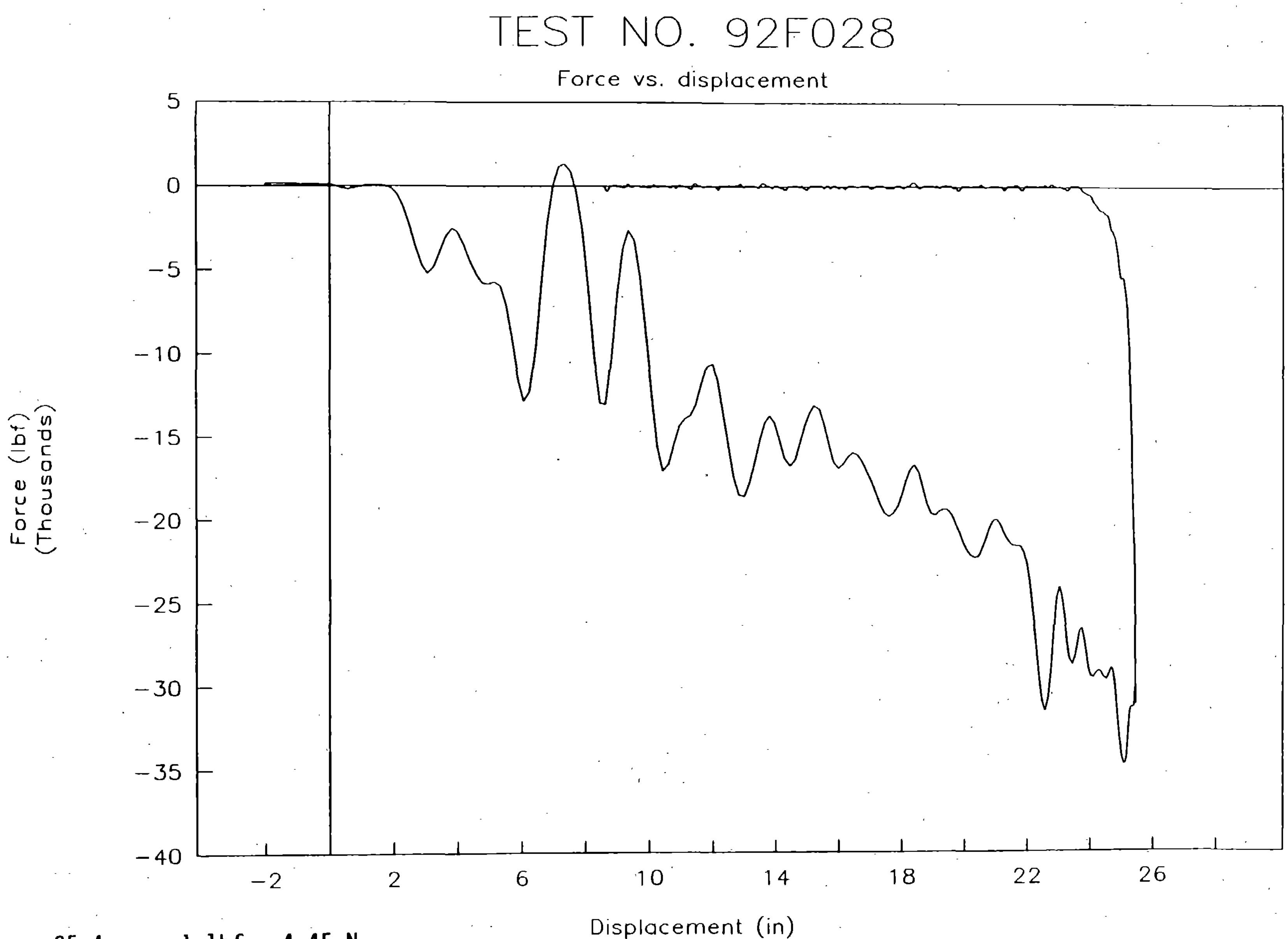
The crush characteristic data plots of the bogie vehicles are based on the load cell data because the load cell data are more representative of the actual forces exerted on the bogie vehicles. The bogie vehicles' crush characteristics are presented in figures 4 through 15. Figures 4 through 7 are force vs. displacement traces, figures 8 through 11 are energy vs. displacement traces and figures 12 through 15 are peak force vs. momentum traces from each bogie test. Data traces of force vs. time, acceleration vs. time, nose acceleration vs. time and resultant impact force height vs. displacement are presented in figures 16 through 31. Because the bogie vehicles are two mass systems the acceleration vs. time traces are produced by combining the center-of-gravity accelerometer data with the nose accelerometer data. Figures 32 through 35 are pre- and post-test photographs from each bogie test.

CONCLUSION

The results of the four crash tests presented in table 2 and figures 4 through 31 indicate that the ENSCO bogie is comparable with the FOIL bogie vehicle. The slope of the force vs. displacement traces agree well between the two bogie vehicles which is important during an impact event with break away safety hardware. This curve depicts the force level reached for a given amount of crush. The energy plots show that the energy consumption for a given crush level are essentially the same for the two bogie vehicles. Peak force vs. momentum curves compare considerably well. This is important because it shows that given a particular break away force level for a roadside appurtenance the momentum change or change in velocity imparted on a bogie vehicle will be the same for both bogies. All of the other data plots compare well and further demonstrate the comparable performance between bogie vehicles.

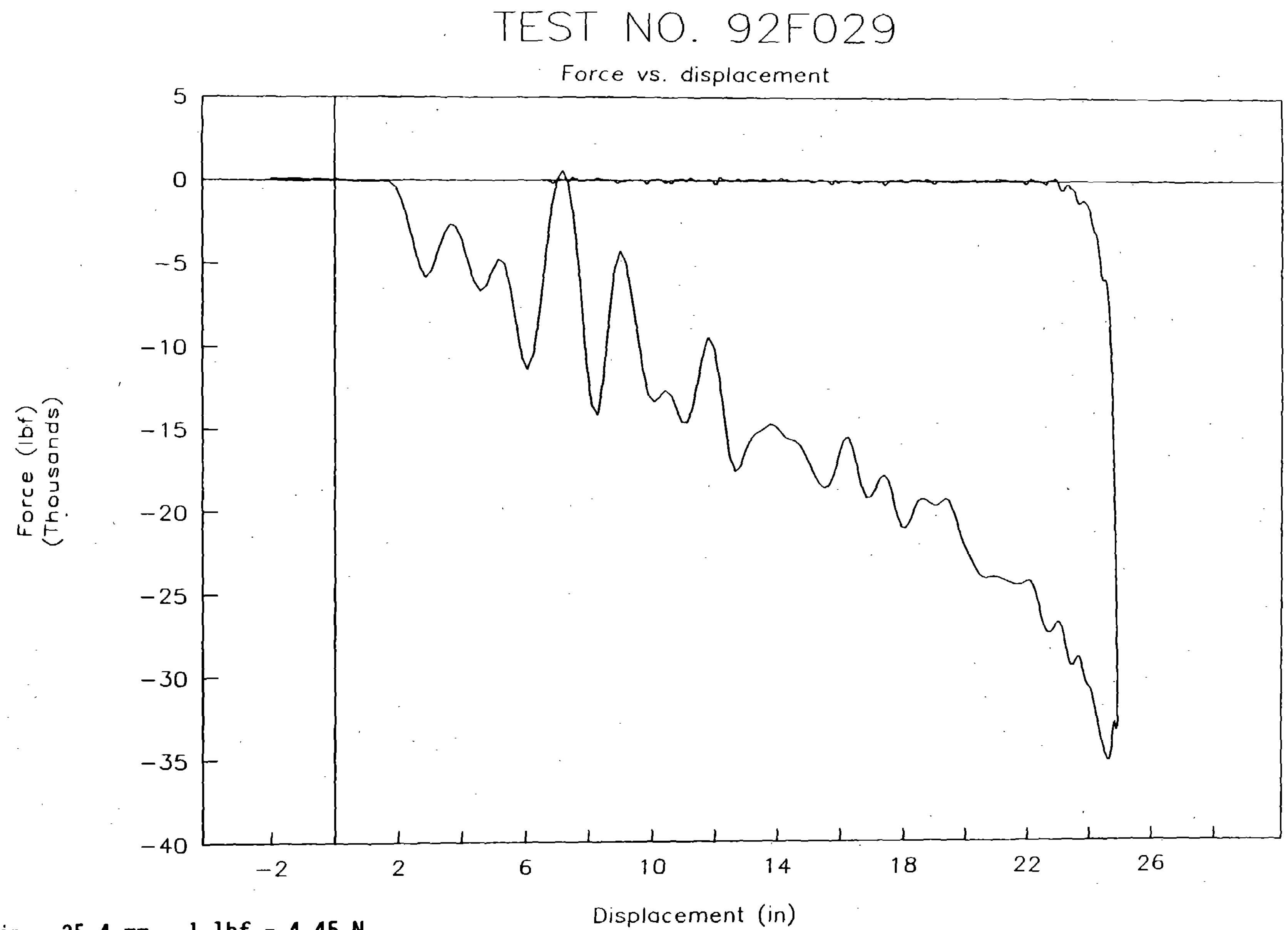
In addition to table 2 and figures 4 through 31, figures 36 through 39 further represent the comparability of the two bogie vehicles. Figures 36 through 39 are average plots for each bogie. The load cell data were averaged for each bogie and the results overlaid. The plots are of force vs. displacement, energy vs. displacement, peak force vs. momentum and force vs. time. The data plots essentially overlap each other.

The results indicate that the ENSCO bogie vehicle is an acceptable surrogate vehicle for testing roadside safety hardware.



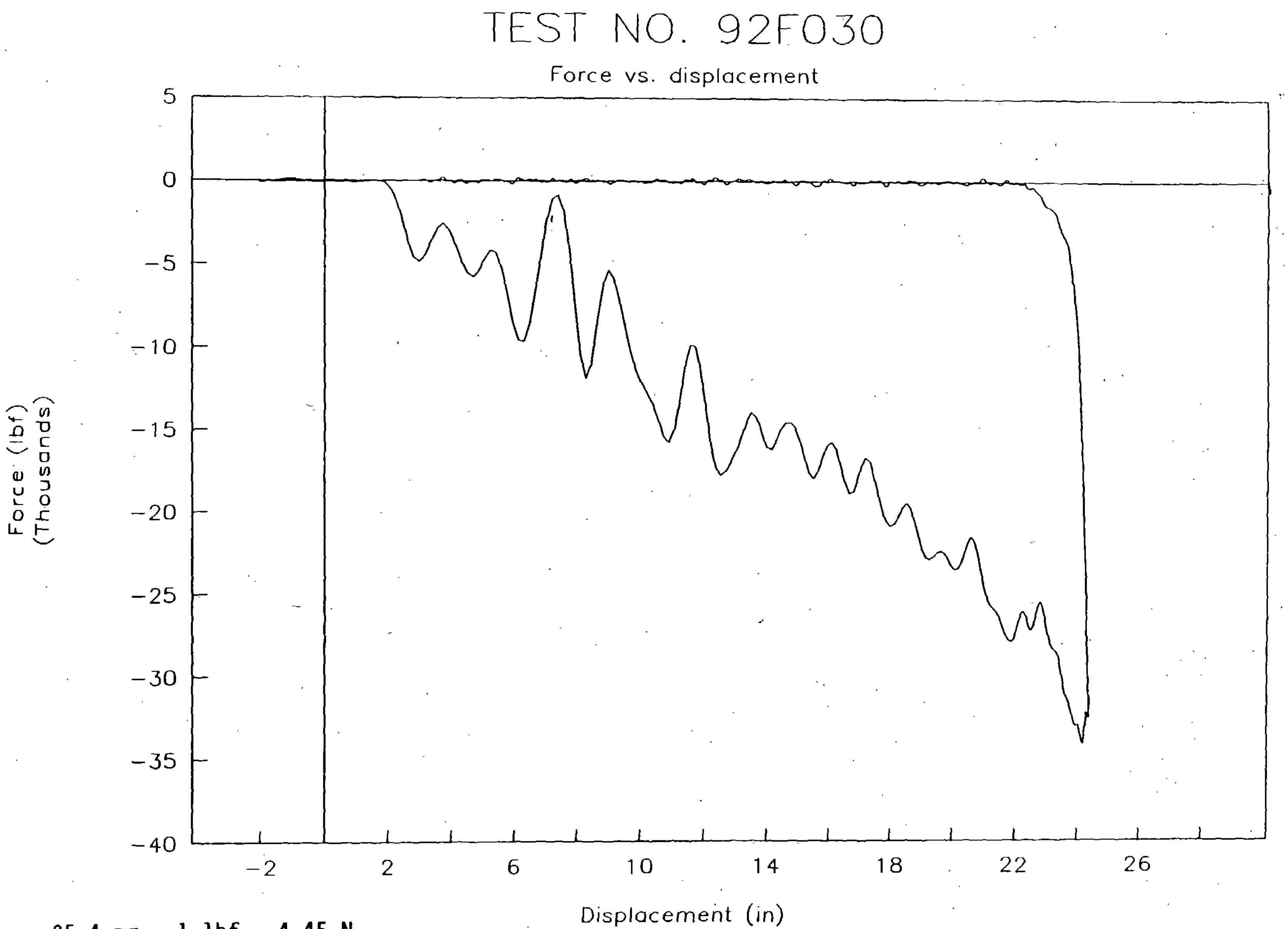
1 in = 25.4 mm   1 lbf = 4.45 N

Figure 4. Force vs. displacement, FOIL bogie, test 92F028.



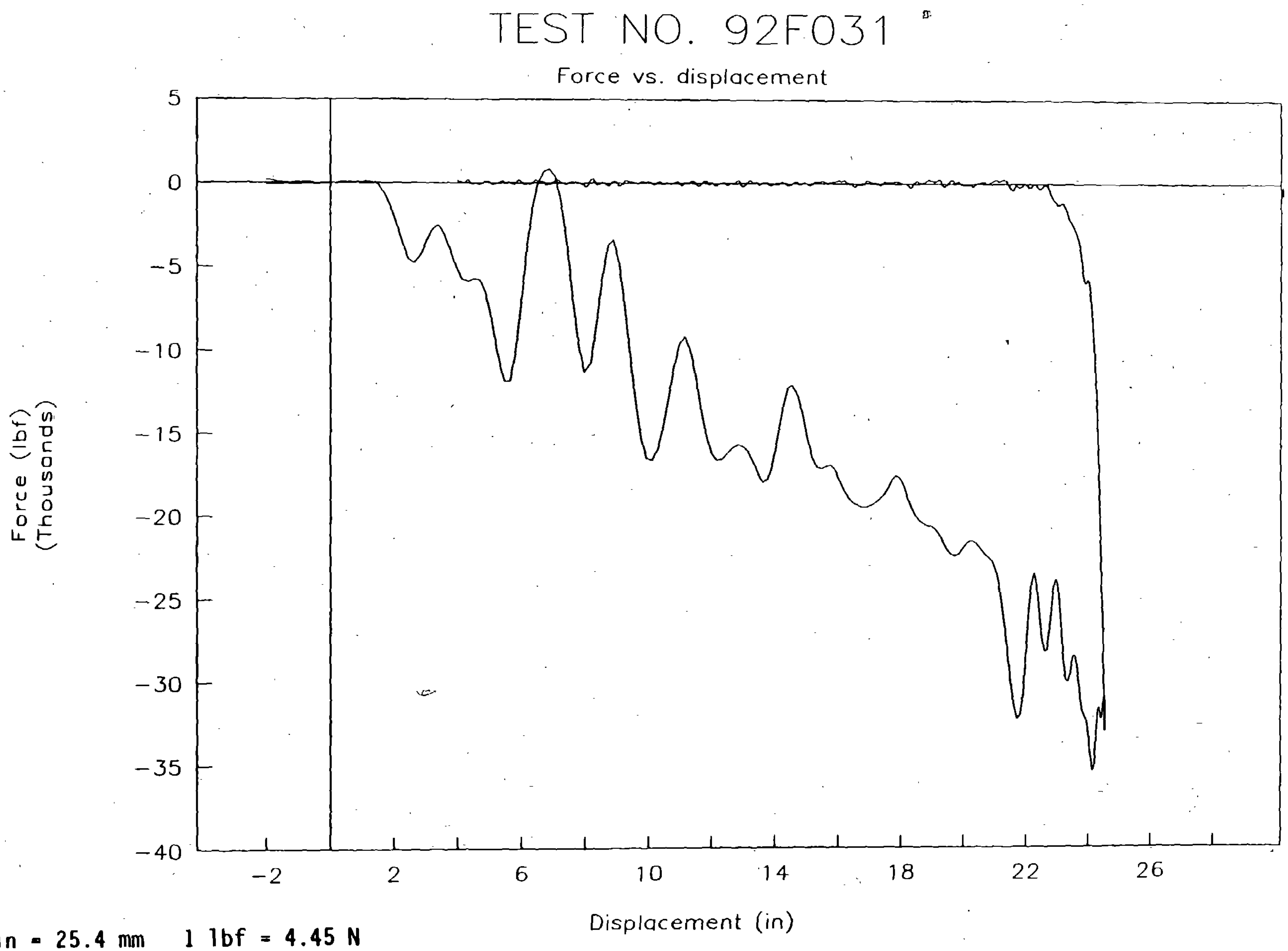
1 in = 25.4 mm   1 lbf = 4.45 N

Figure 5. Force vs. displacement, FOIL bogie, test 92F029.



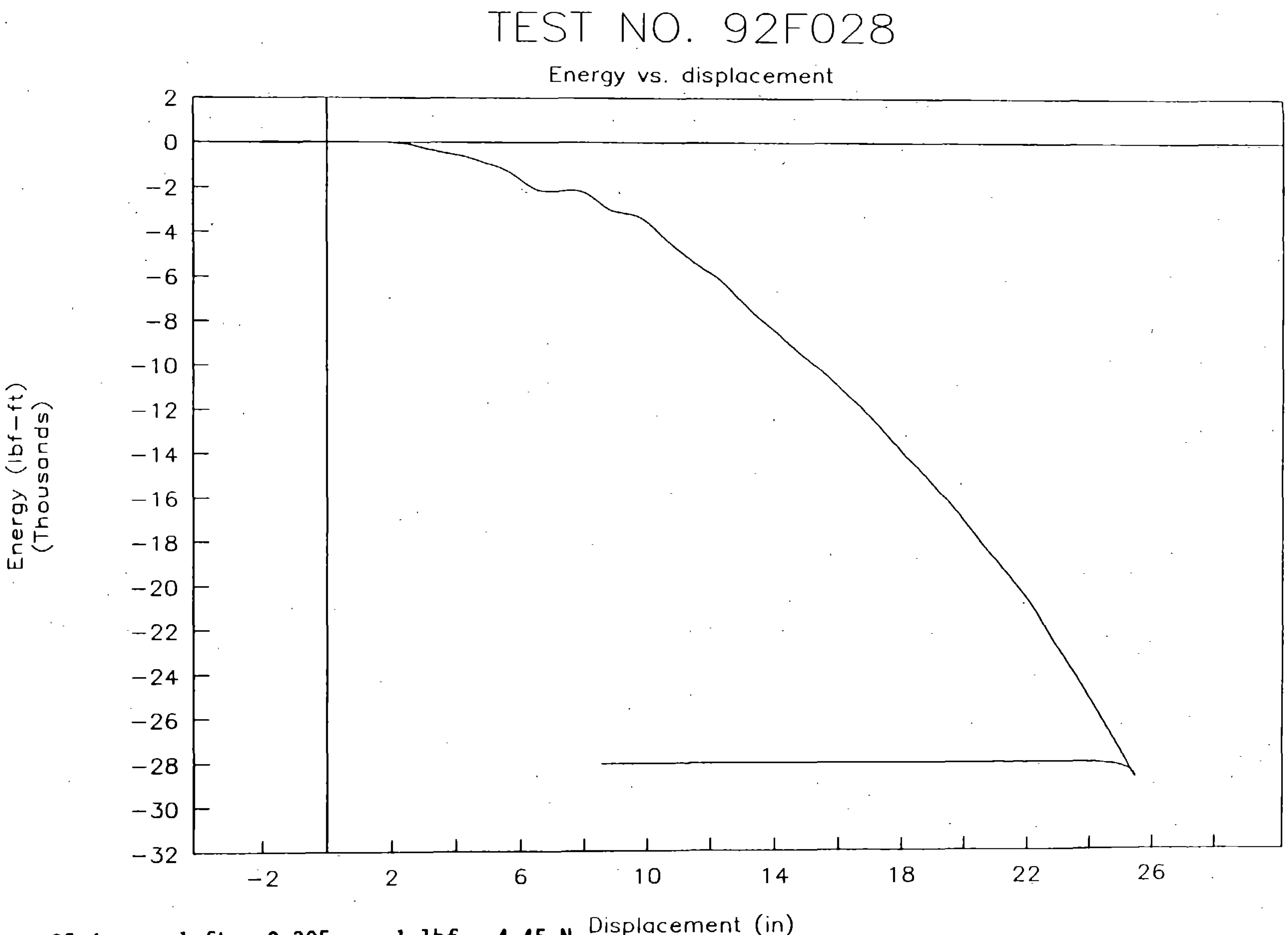
1 in = 25.4 mm   1 lbf = 4.45 N

Figure 6. Force vs. displacement, ENSCO bogie, test 92F030.



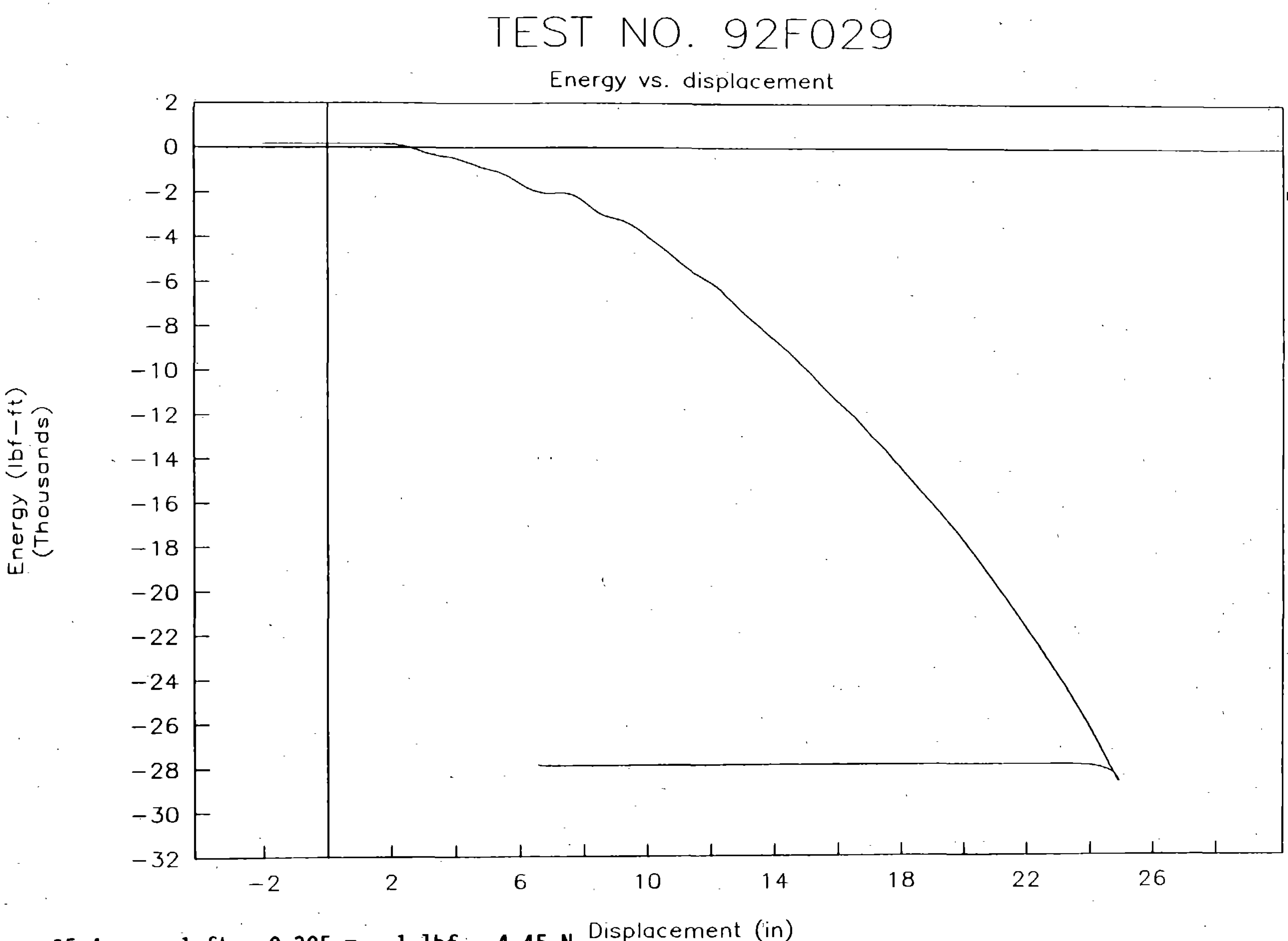
1 in = 25.4 mm   1 lbf = 4.45 N

Figure 7. Force vs. displacement, ENSCO bogie, test 92F031.



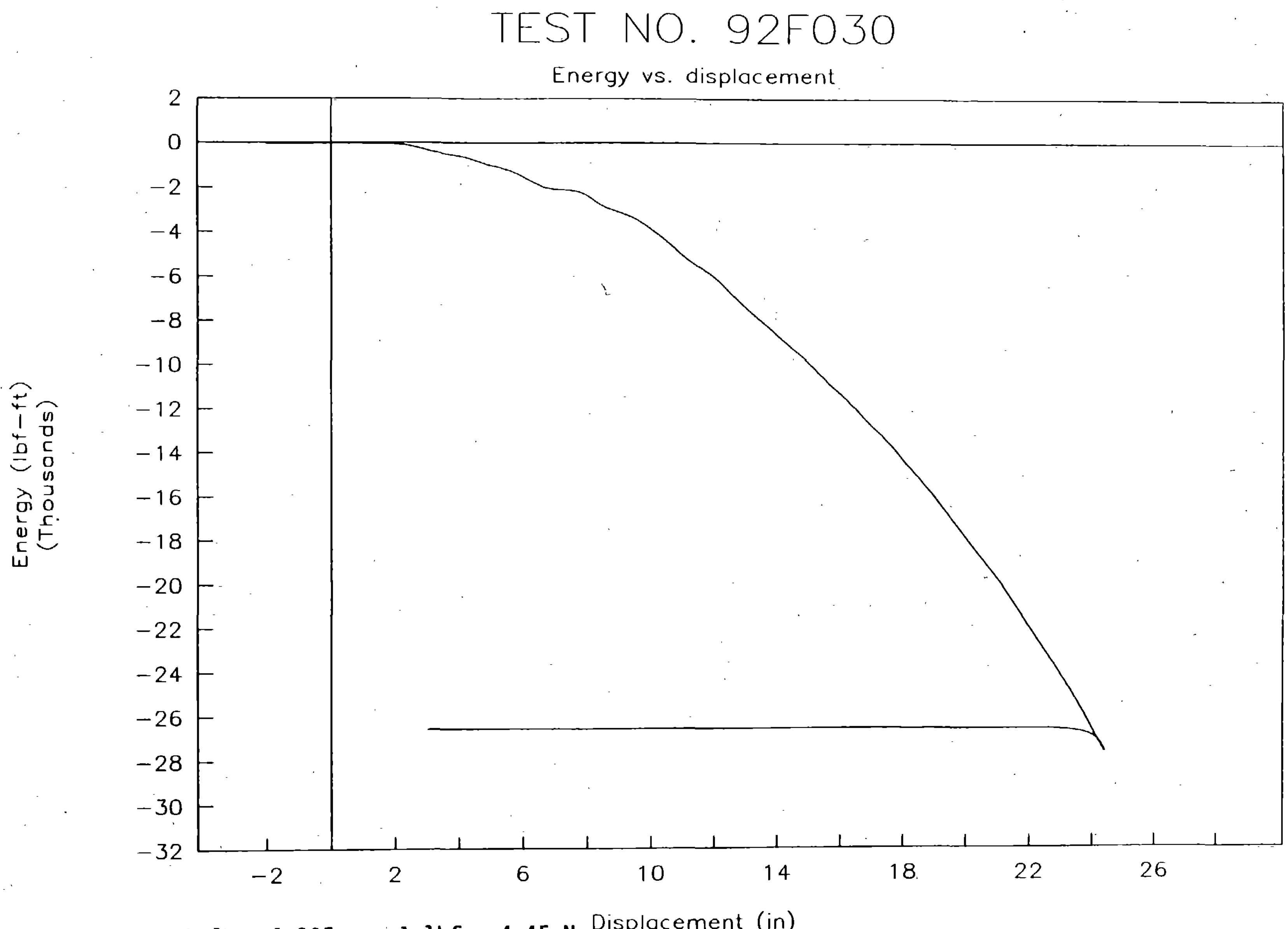
1 in = 25.4 mm   1 ft = 0.305 m   1 lbf = 4.45 N

Figure 8. Energy vs. displacement, FOIL bogie, test 92F028.



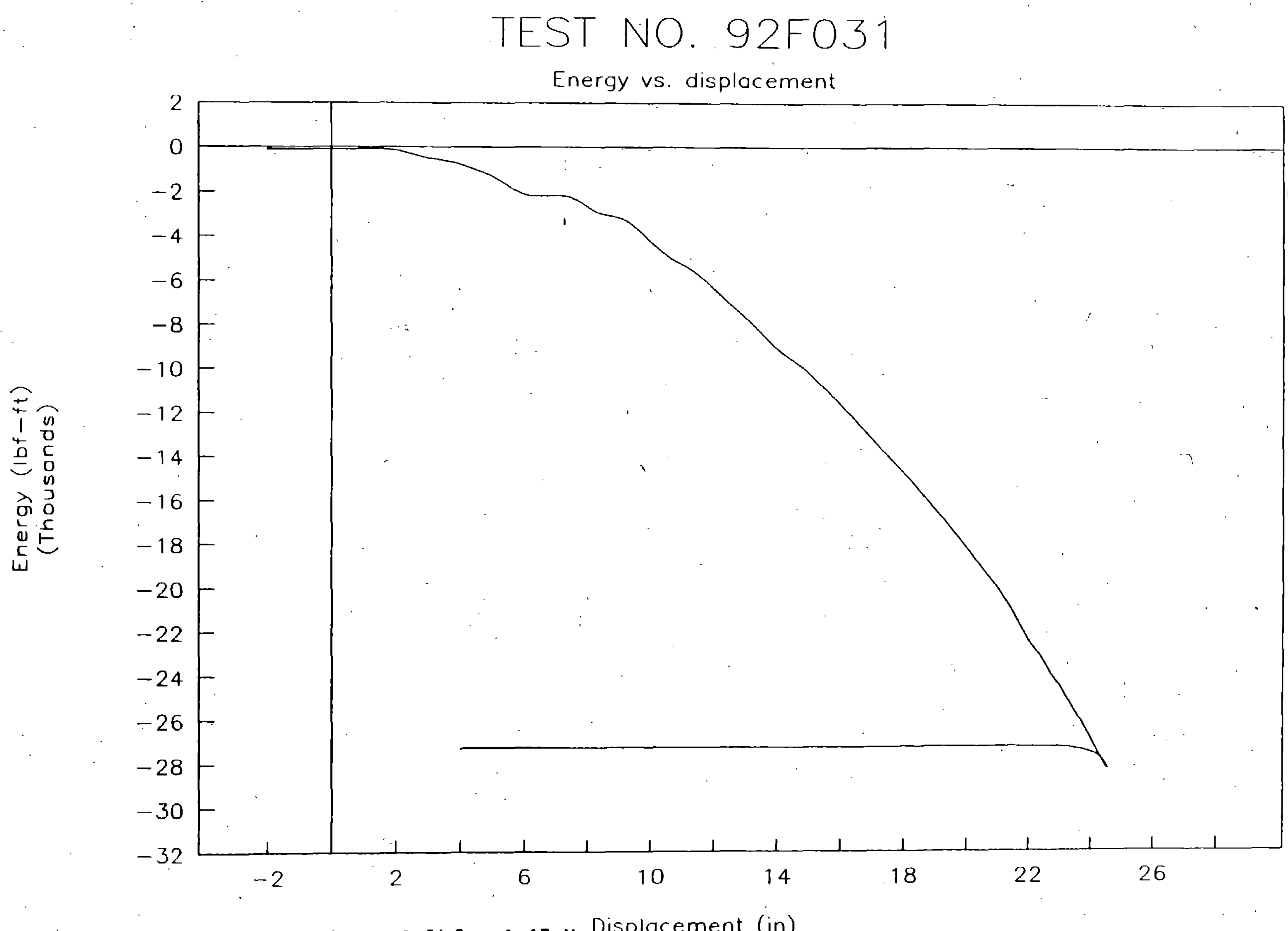
1 in = 25.4 mm   1 ft = 0.305 m   1 lbf = 4.45 N

Figure 9. Energy vs. displacement, FOIL bogie, test 92F029.



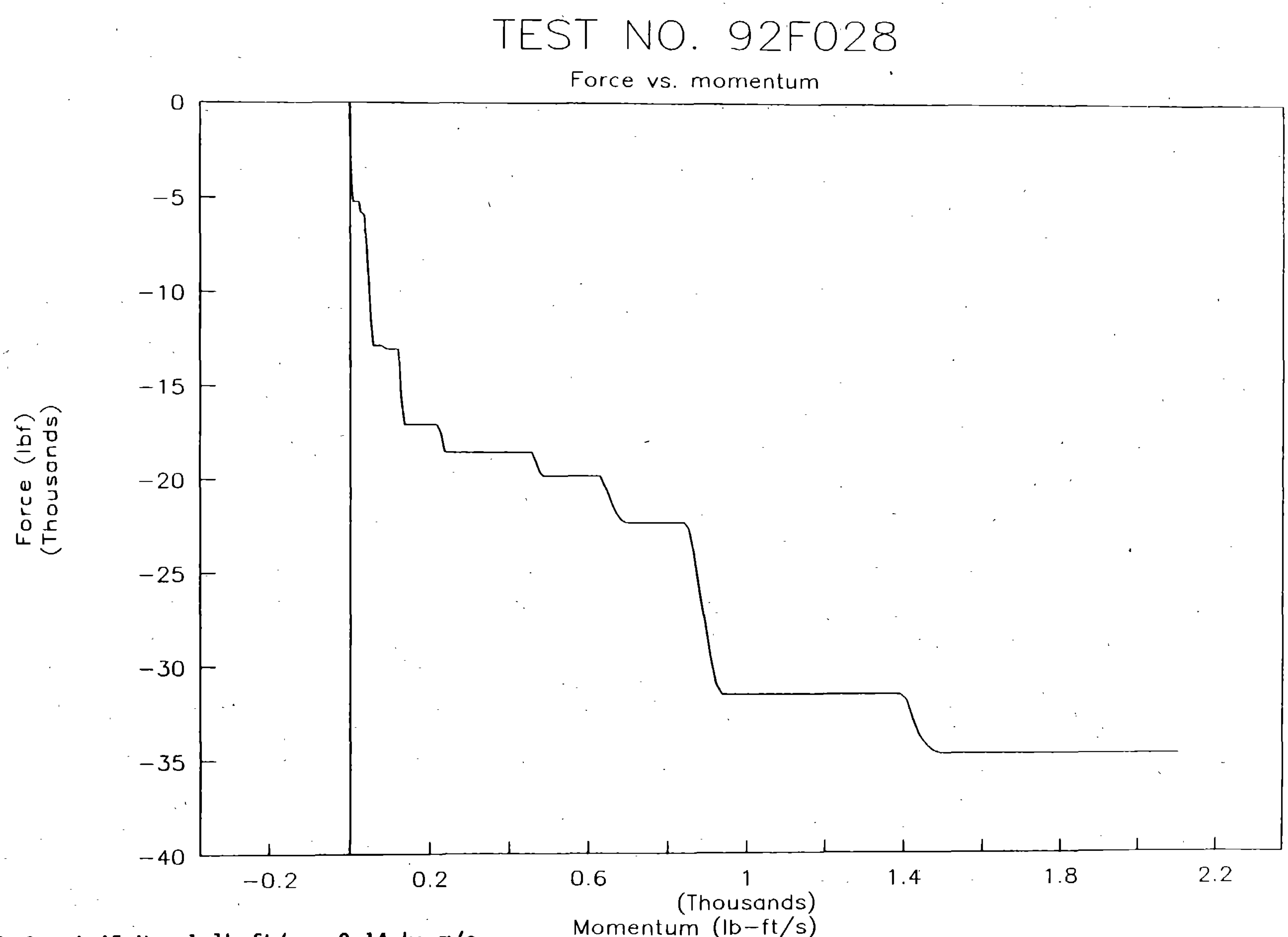
1 in = 25.4 mm   1 ft = 0.305 m   1 lbf = 4.45 N

Figure 10. Energy vs. displacement, ENSCO bogie, test 92F030.



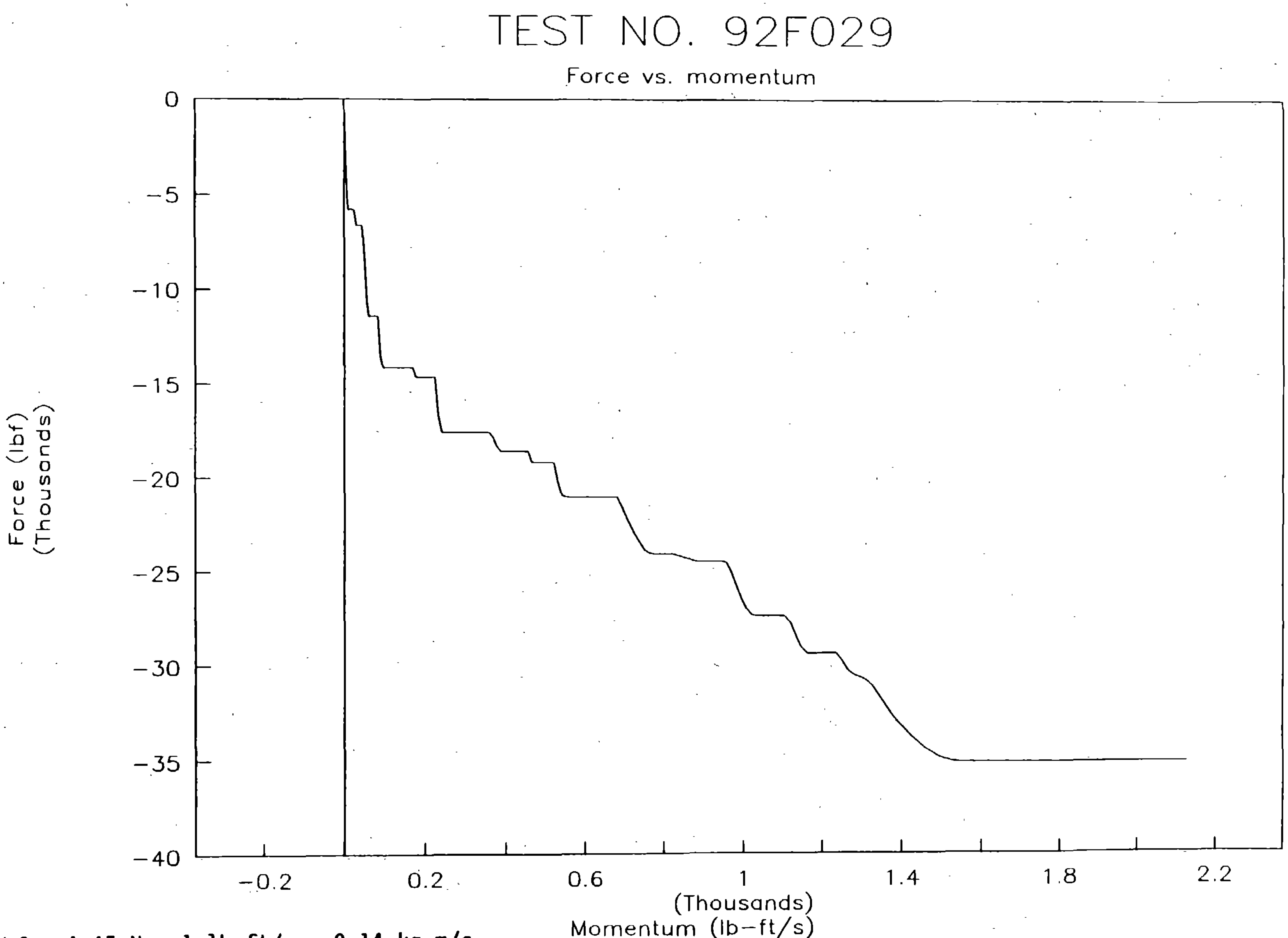
1 in = 25.4 mm   1 ft = 0.305 m   1 lbf = 4.45 N

Figure 11. Energy vs. displacement, ENSCO bogie, test 92F031.



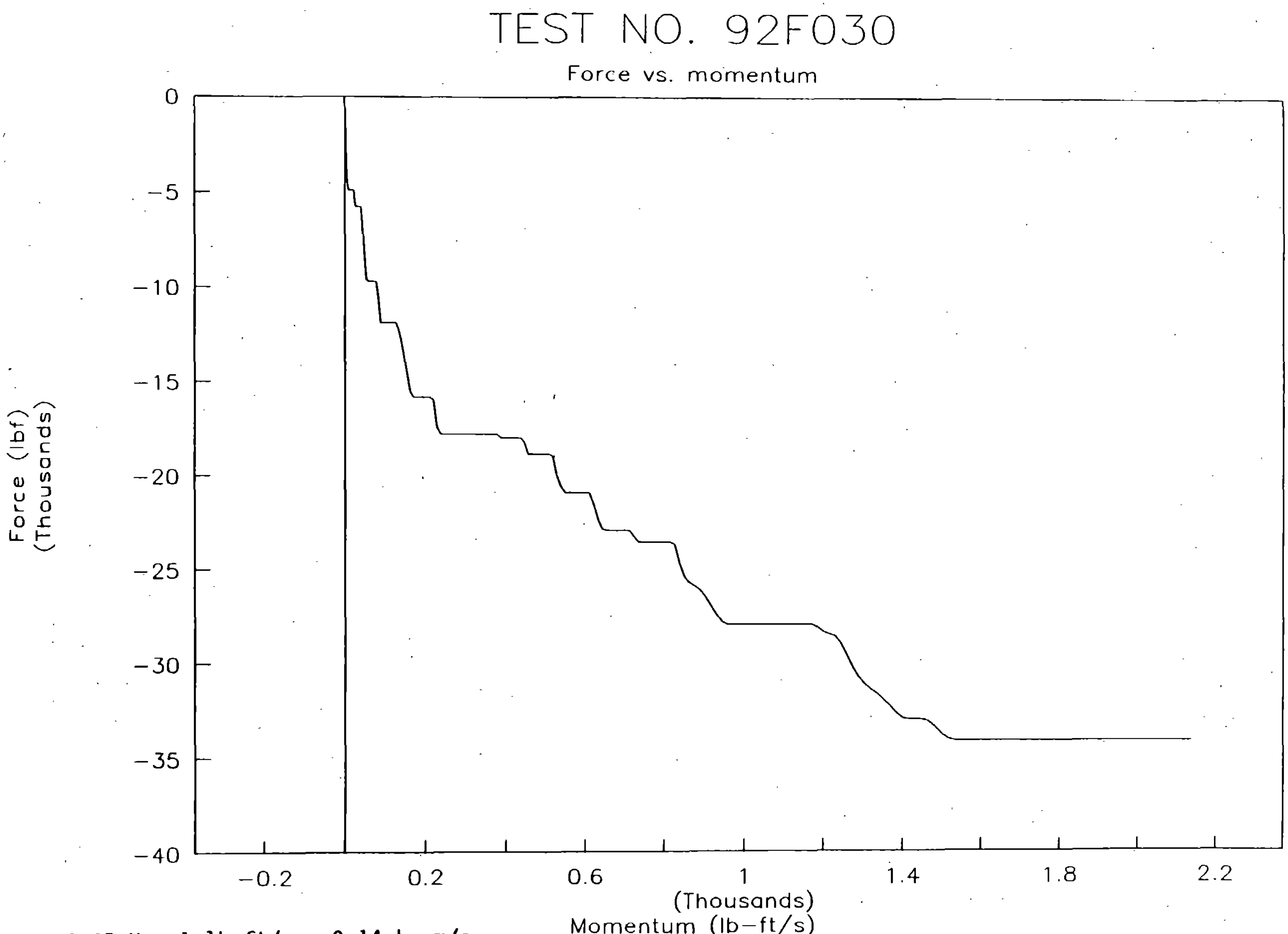
1 lbf = 4.45 N   1 lb-ft/s = 0.14 kg-m/s

Figure 12. Peak force vs. momentum, FOIL bogie, test 92F028.



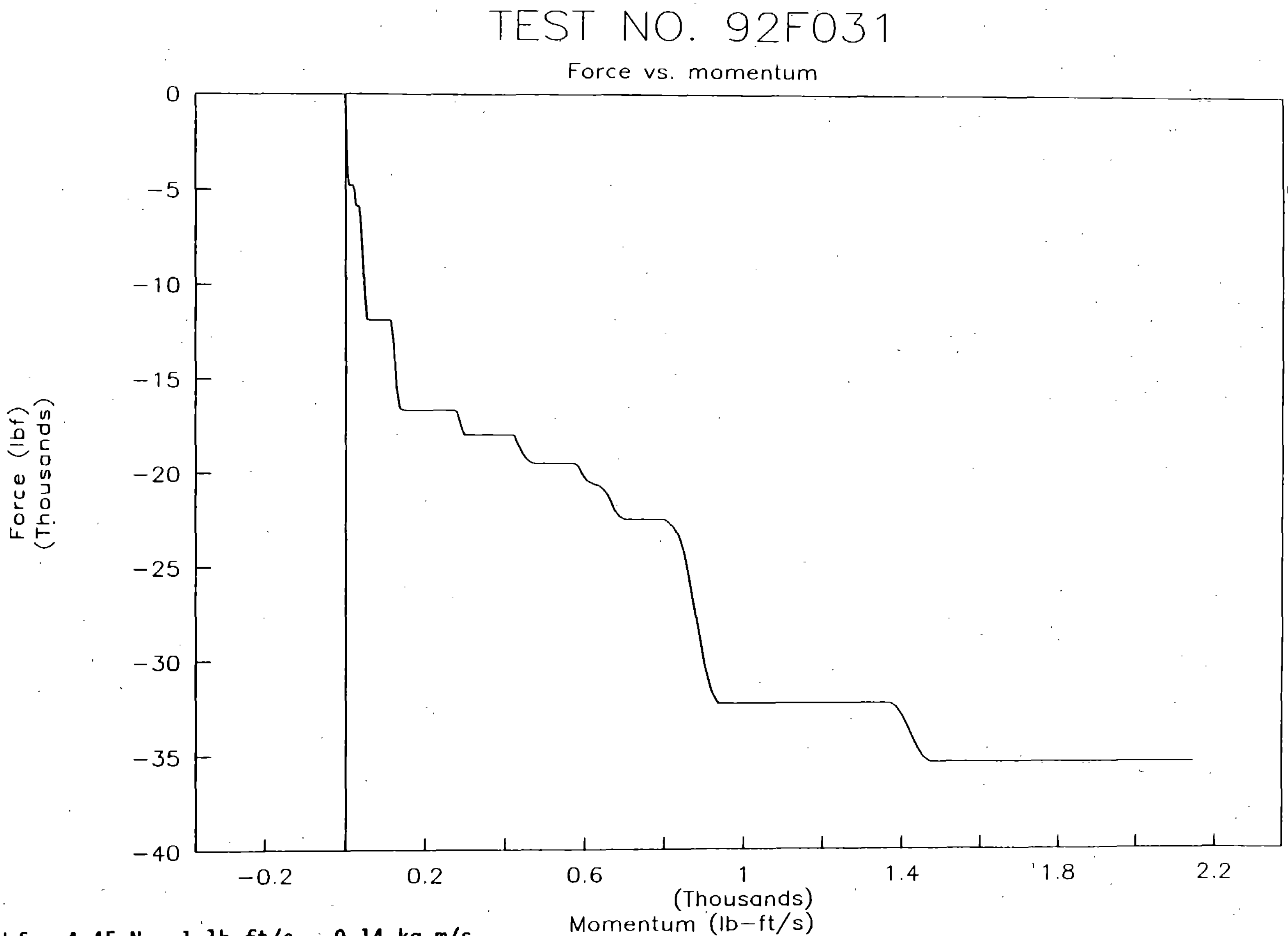
1 lbf = 4.45 N 1 lb-ft/s = 0.14 kg-m/s

Figure 13. Peak force vs. momentum, FOIL bogie, test 92F029.



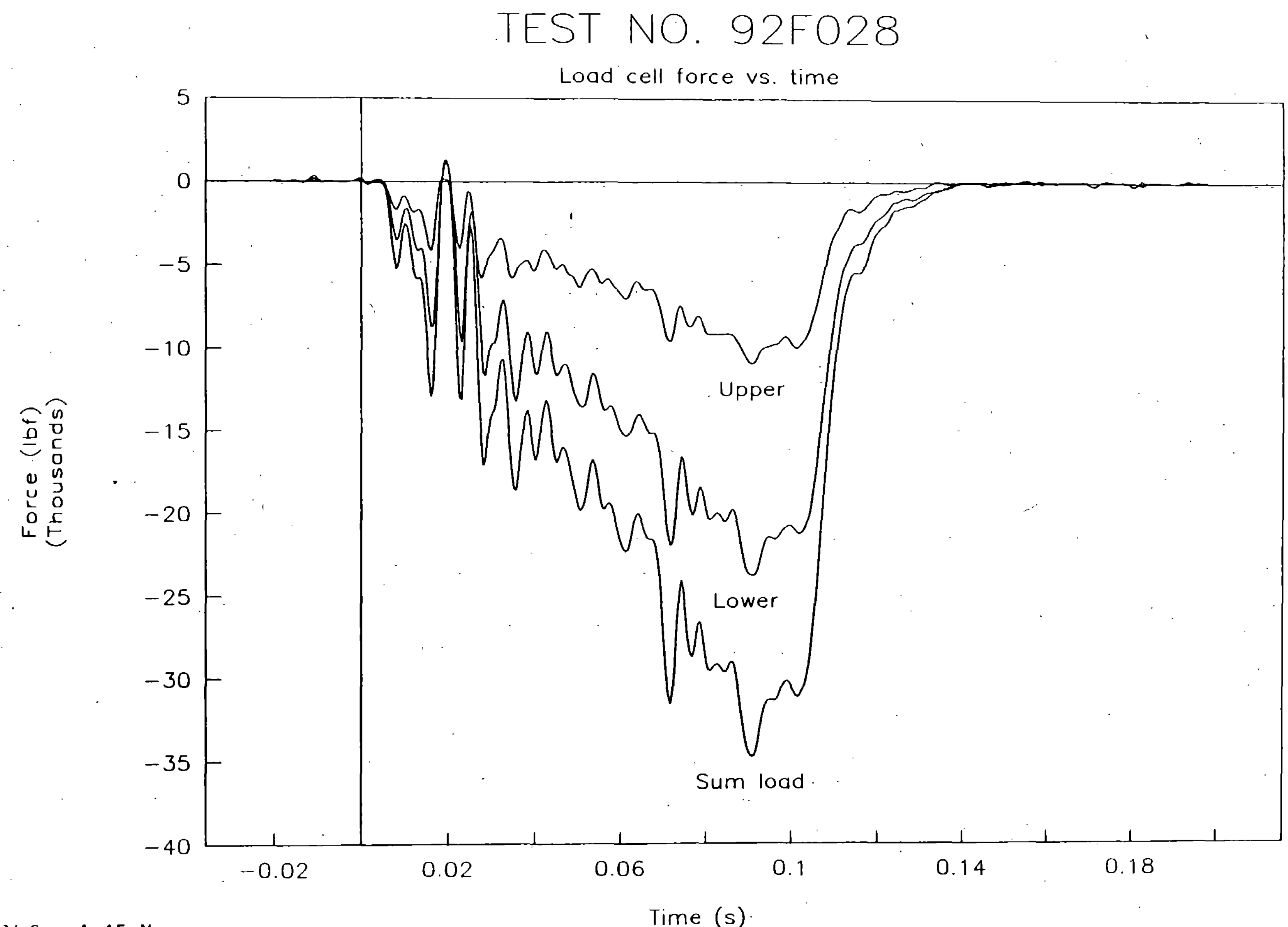
1 lbf = 4.45 N   1 lb-ft/s = 0.14 kg-m/s

Figure 14. Peak force vs. momentum, ENSCO bogie, test 92F030.



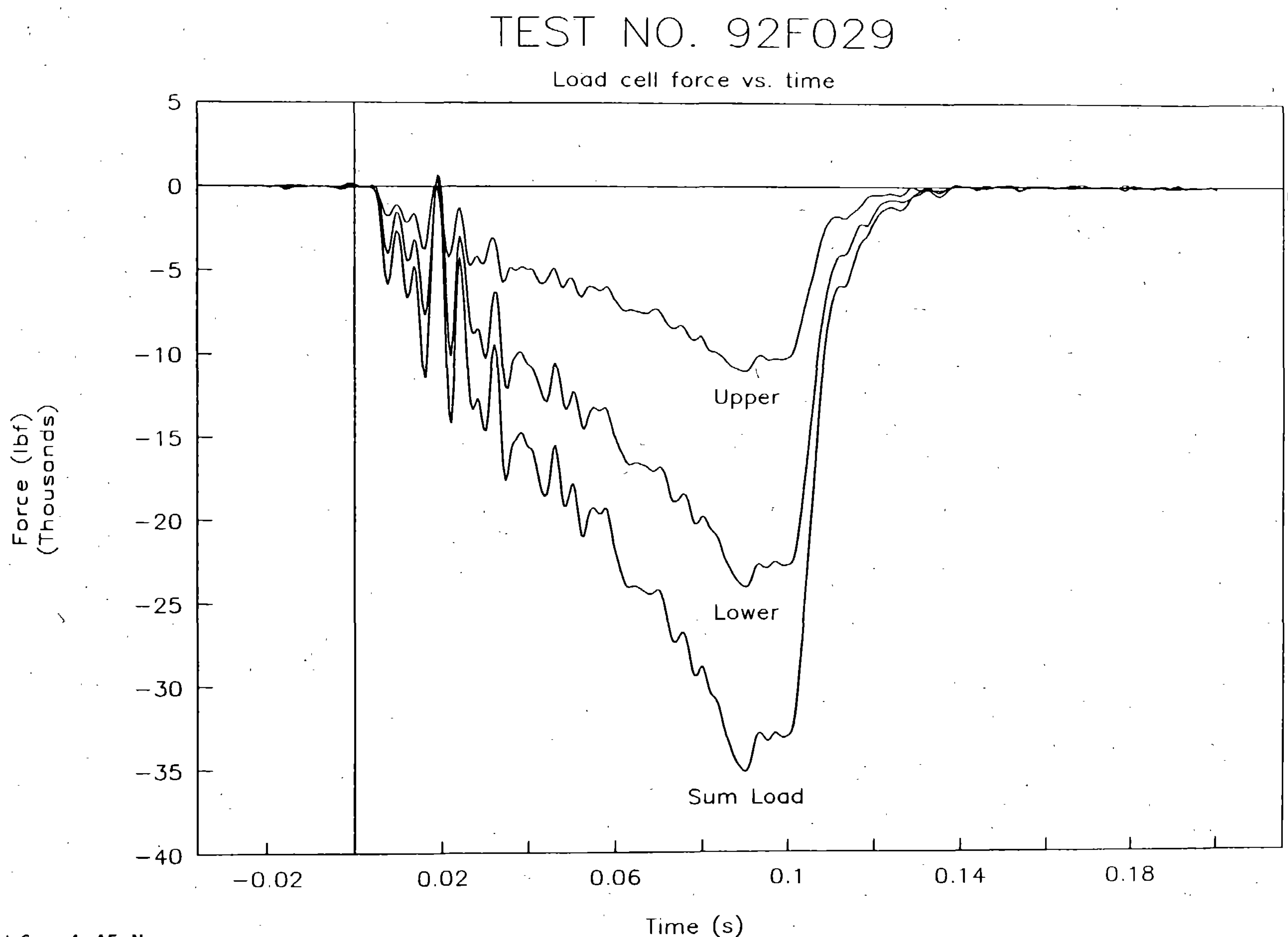
1 lbf = 4.45 N   1 lb-ft/s = 0.14 kg-m/s

Figure 15. Peak force vs. momentum, ENSCO bogie, test 92F031.



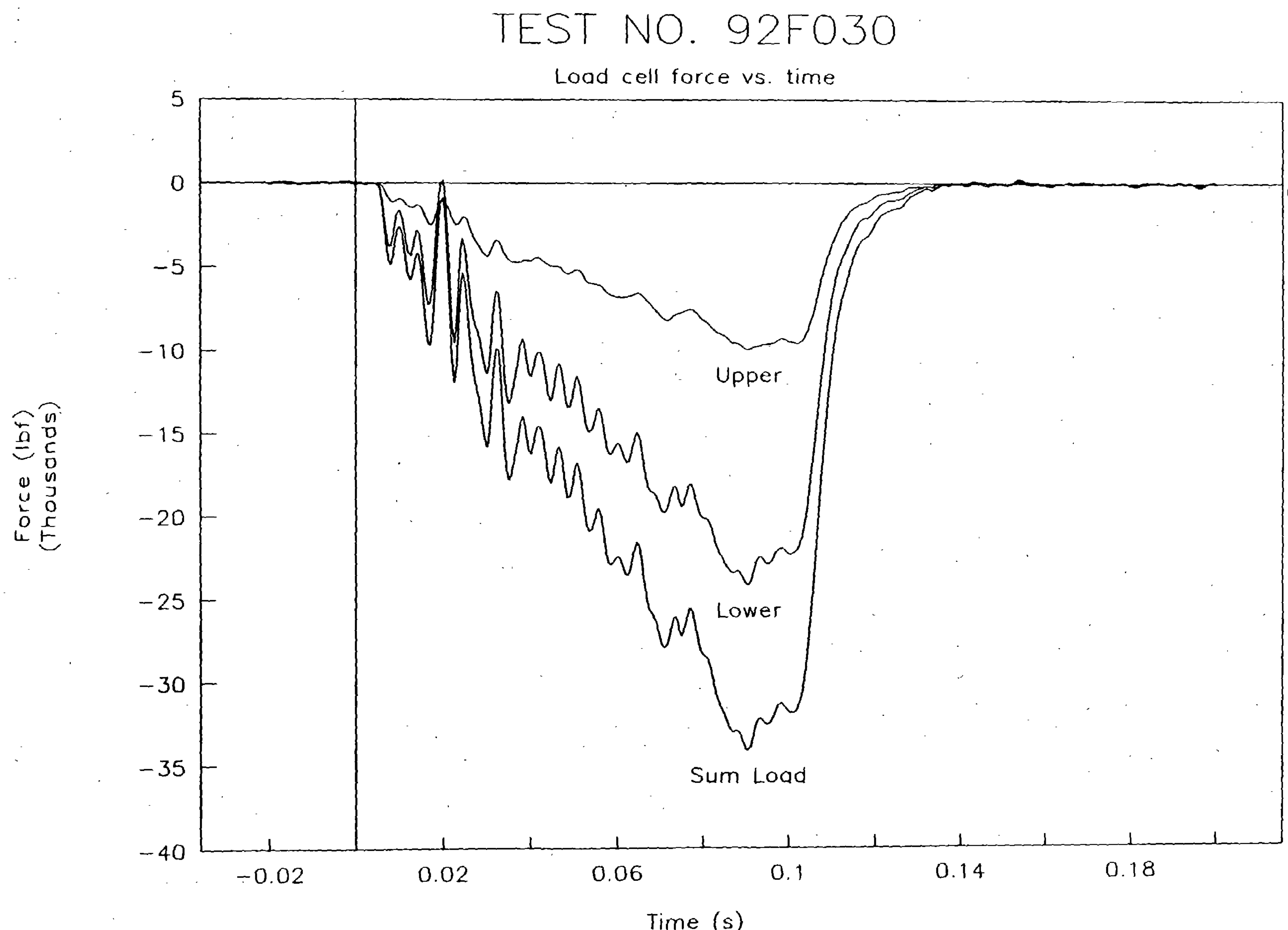
1 lbf = 4.45 N

Figure 16. Load cell force vs. time, FOIL bogie, test 92F028.



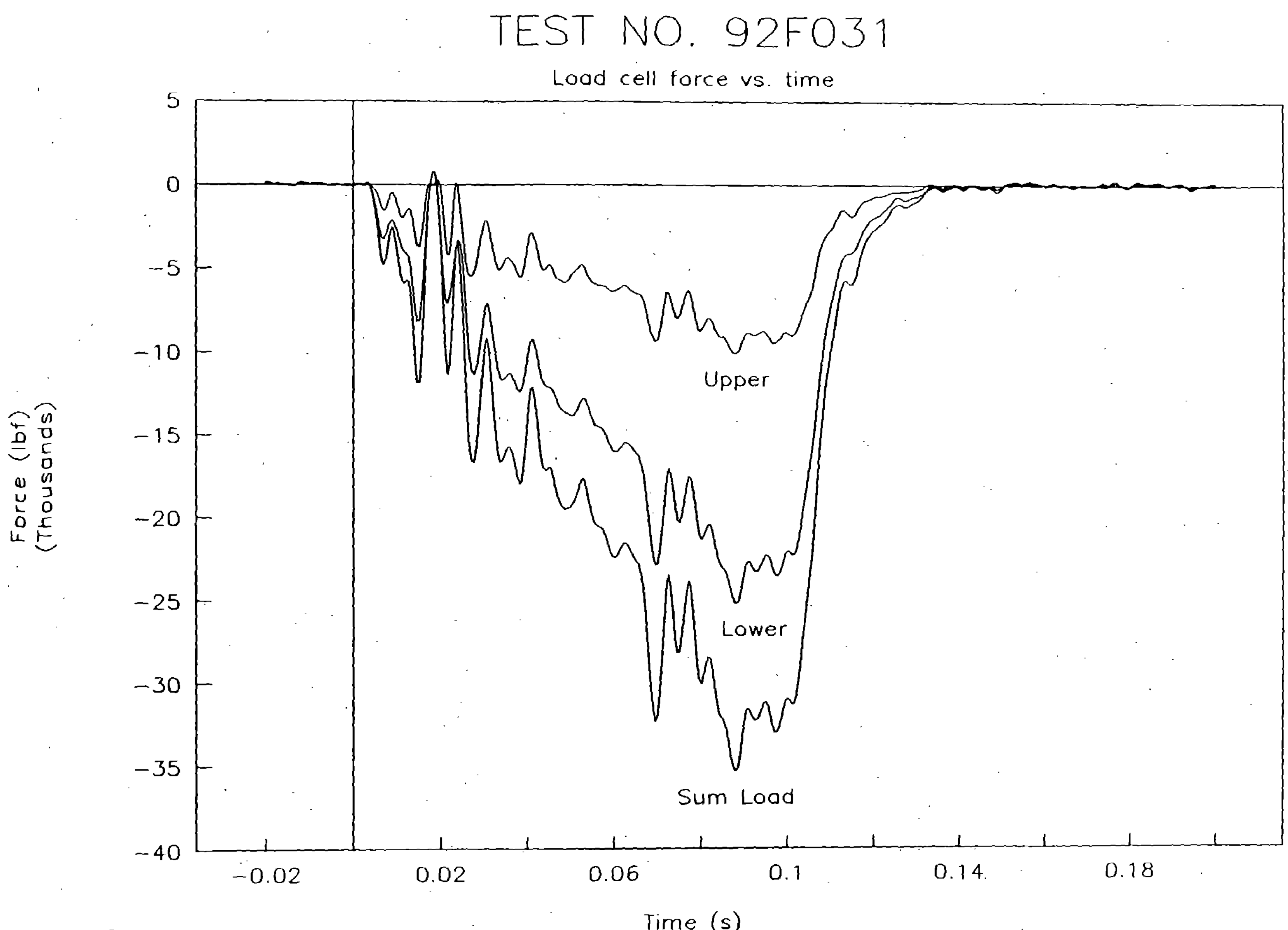
1 lbf = 4.45 N

Figure 17. Load cell force vs. time, FOIL bogie, test 92F029.



1 lbf = 4.45 N

Figure 18. Load cell force vs. time, ENSCO bogie, test 92F030.



1 lbf = 4.45 N

Figure 19. Load cell force vs. time, ENSCO bogie, test 92F031.

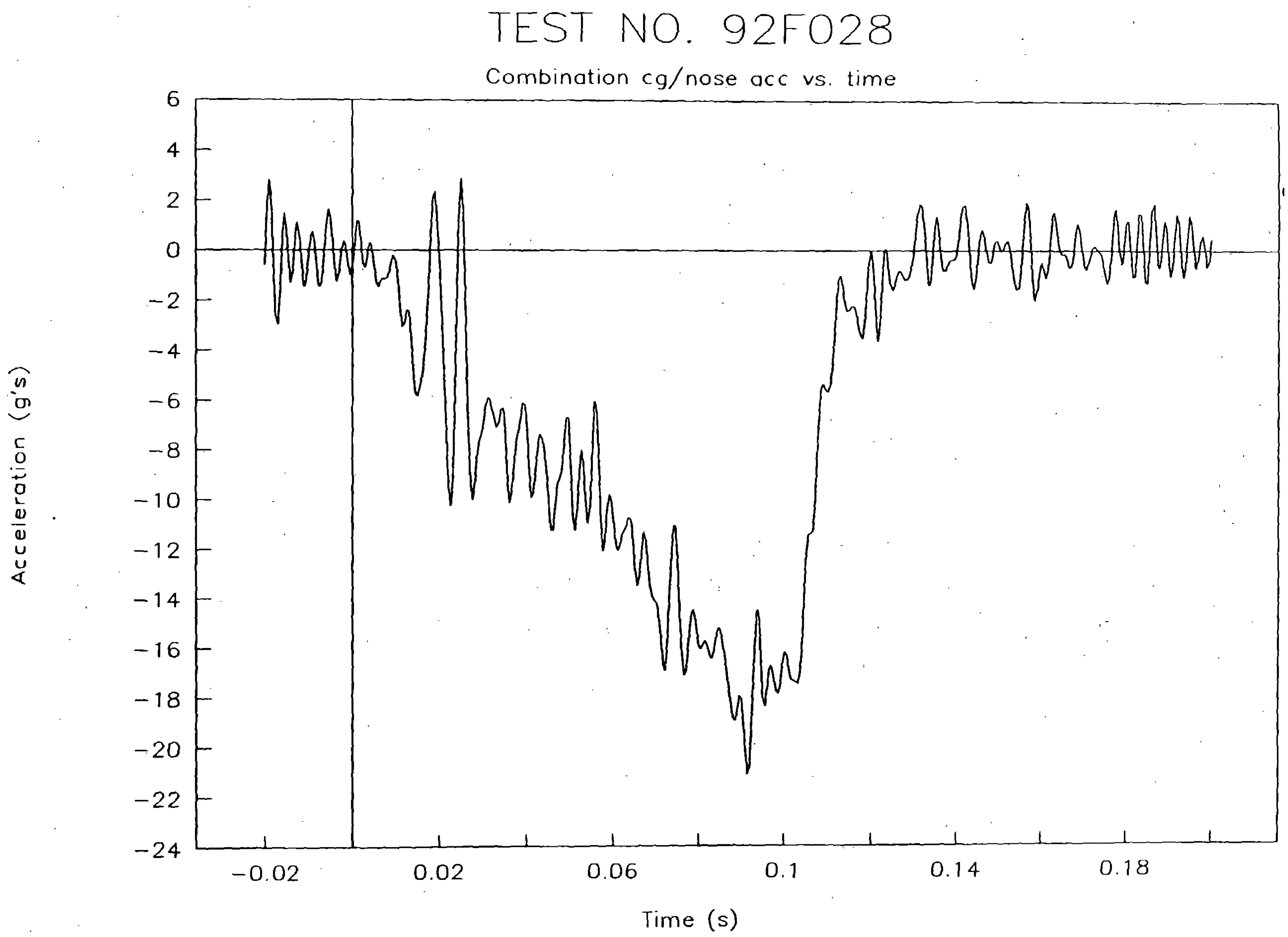


Figure 20. Longitudinal (X-axis) acceleration vs. time, FOIL bogie, test 92F028.

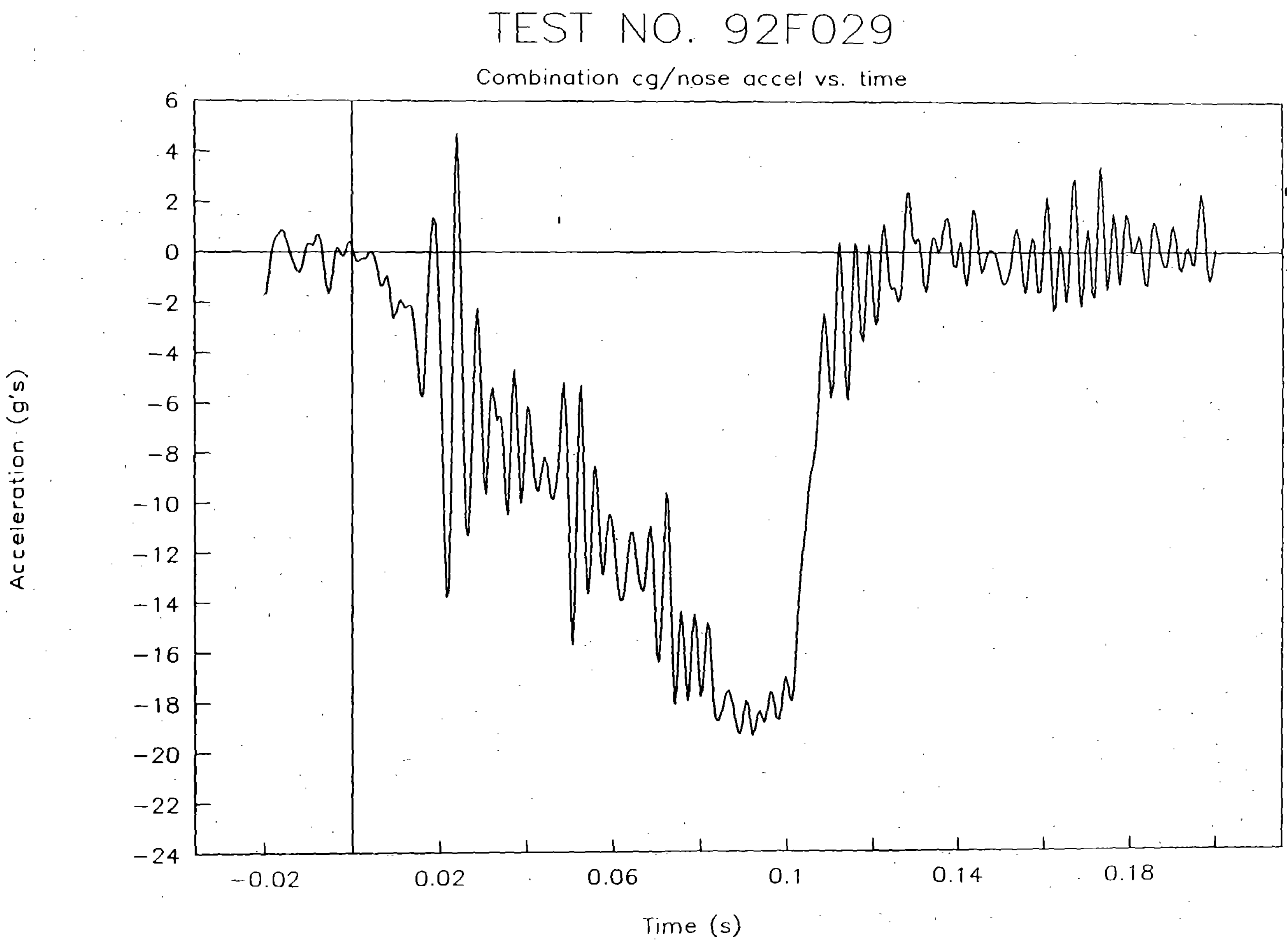


Figure 21. Longitudinal (X-axis) acceleration vs. time, FOIL bogie, test 92F029.

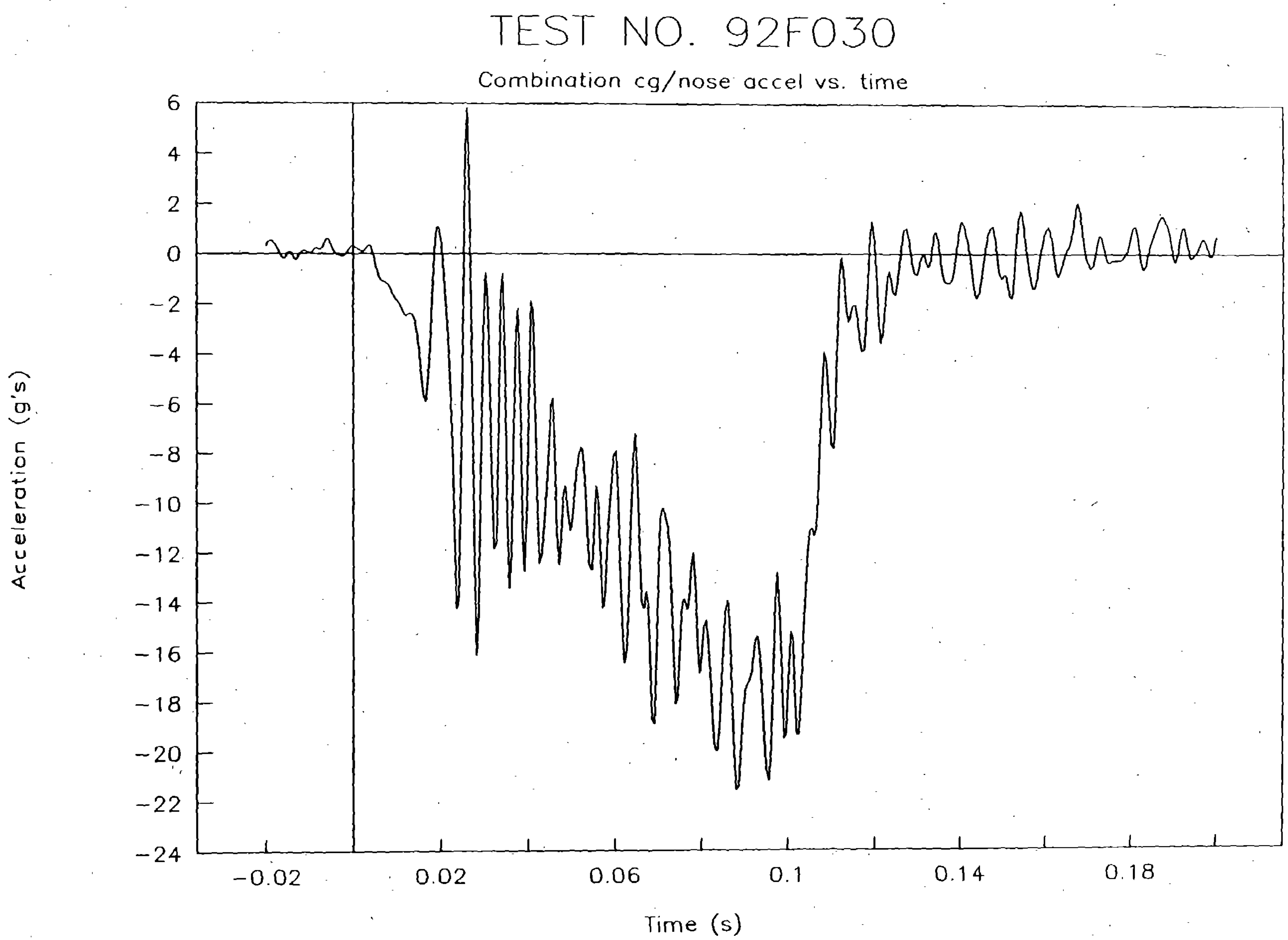


Figure 22. Longitudinal (X-axis) acceleration vs. time, ENSCO bogie, test 92F030.

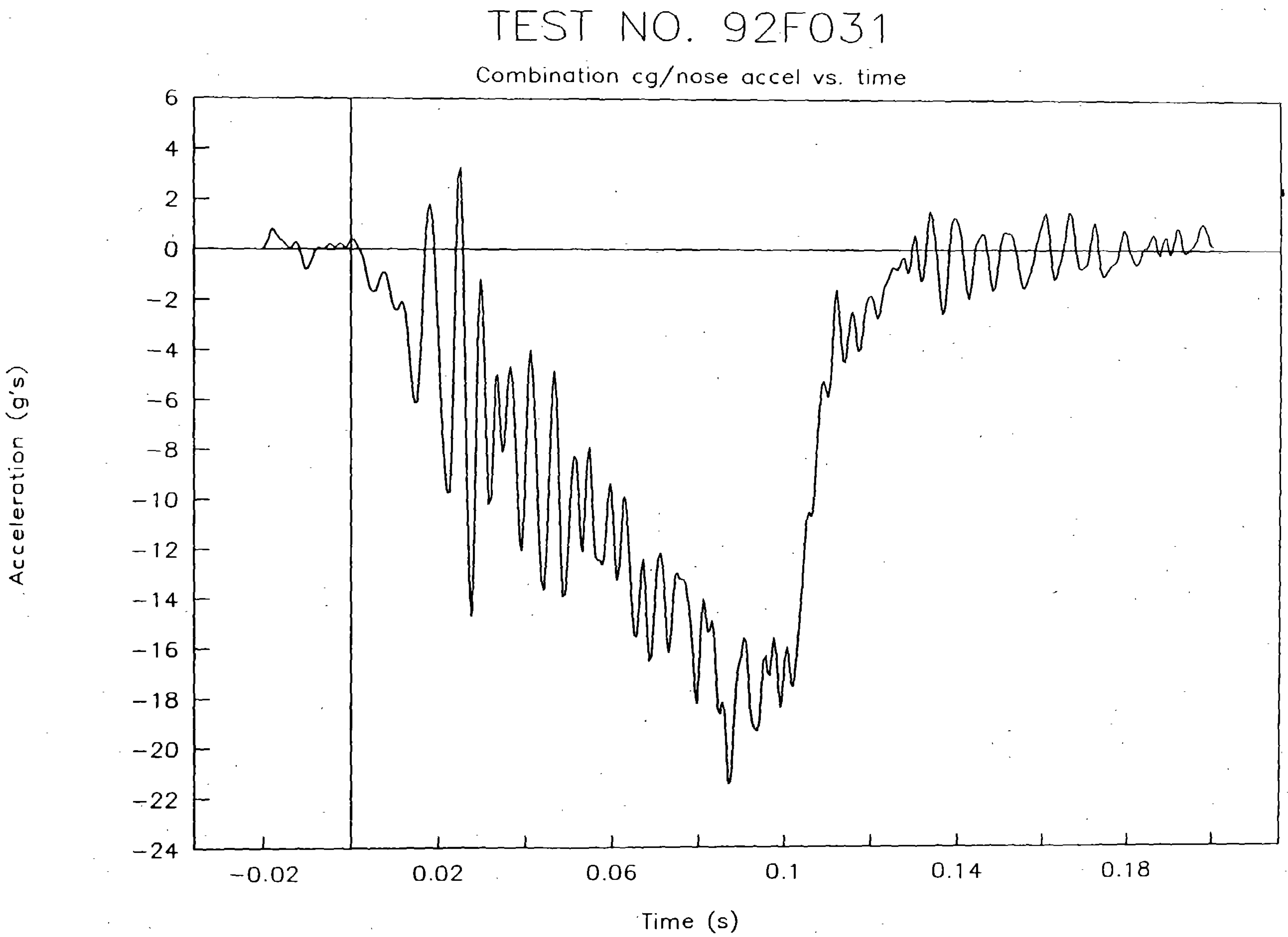


Figure 23. Longitudinal (X-axis) acceleration vs. time, ENSCO bogie, test 92F031.

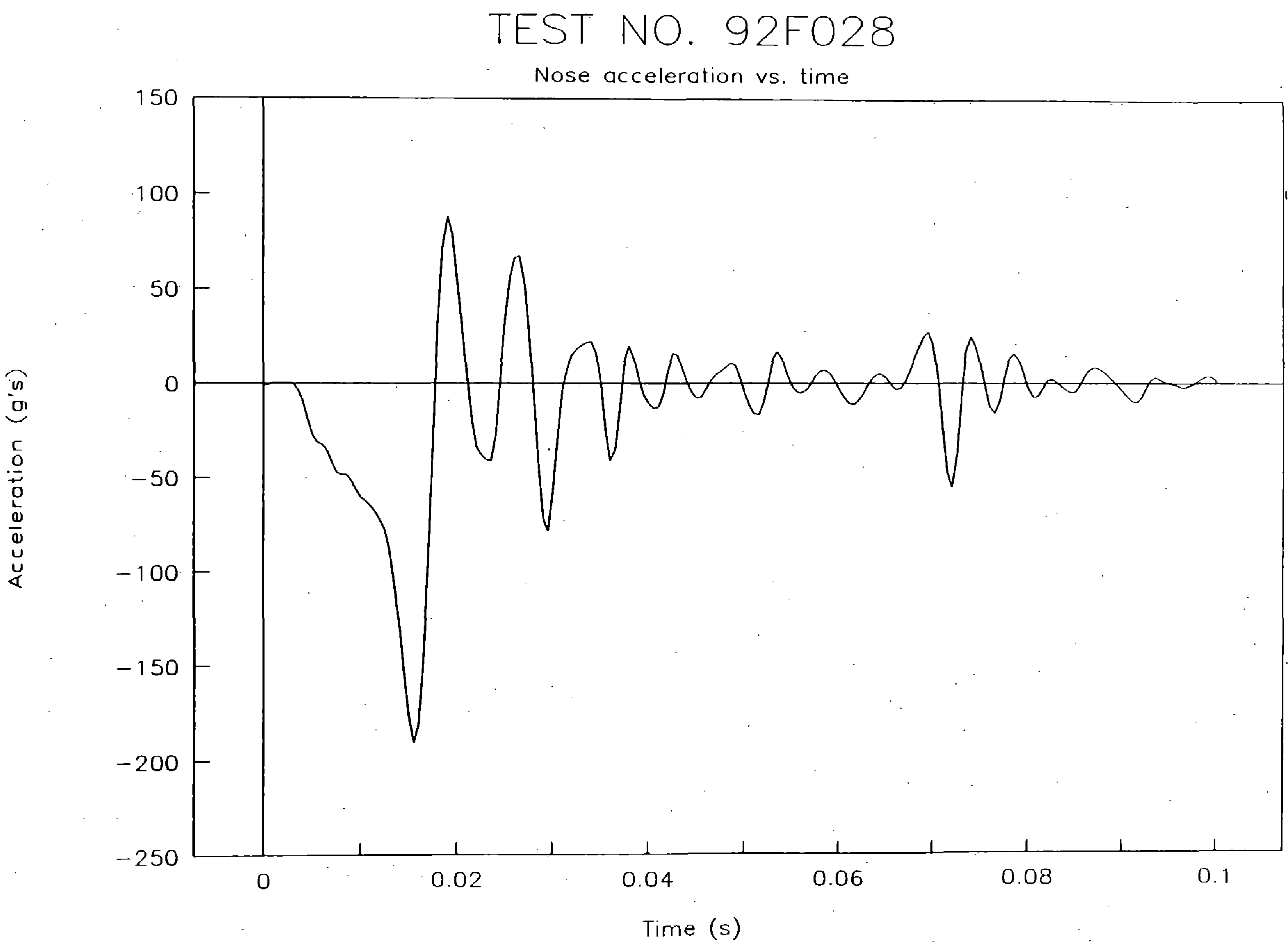


Figure 24. Nose acceleration vs. time, FOIL bogie, test 92F028.

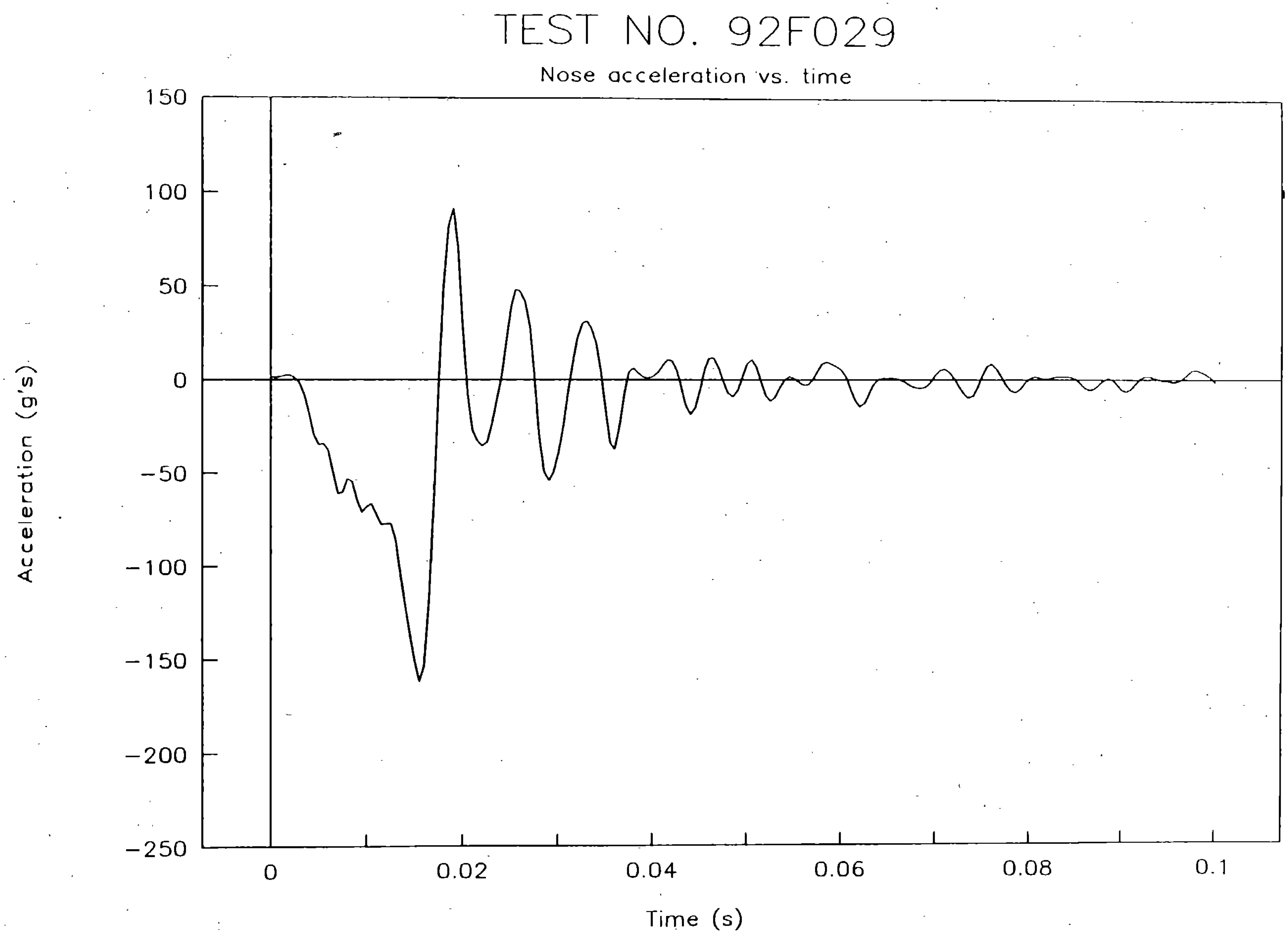


Figure 25. Nose acceleration vs. time, FOIL bogie, test 92F029.

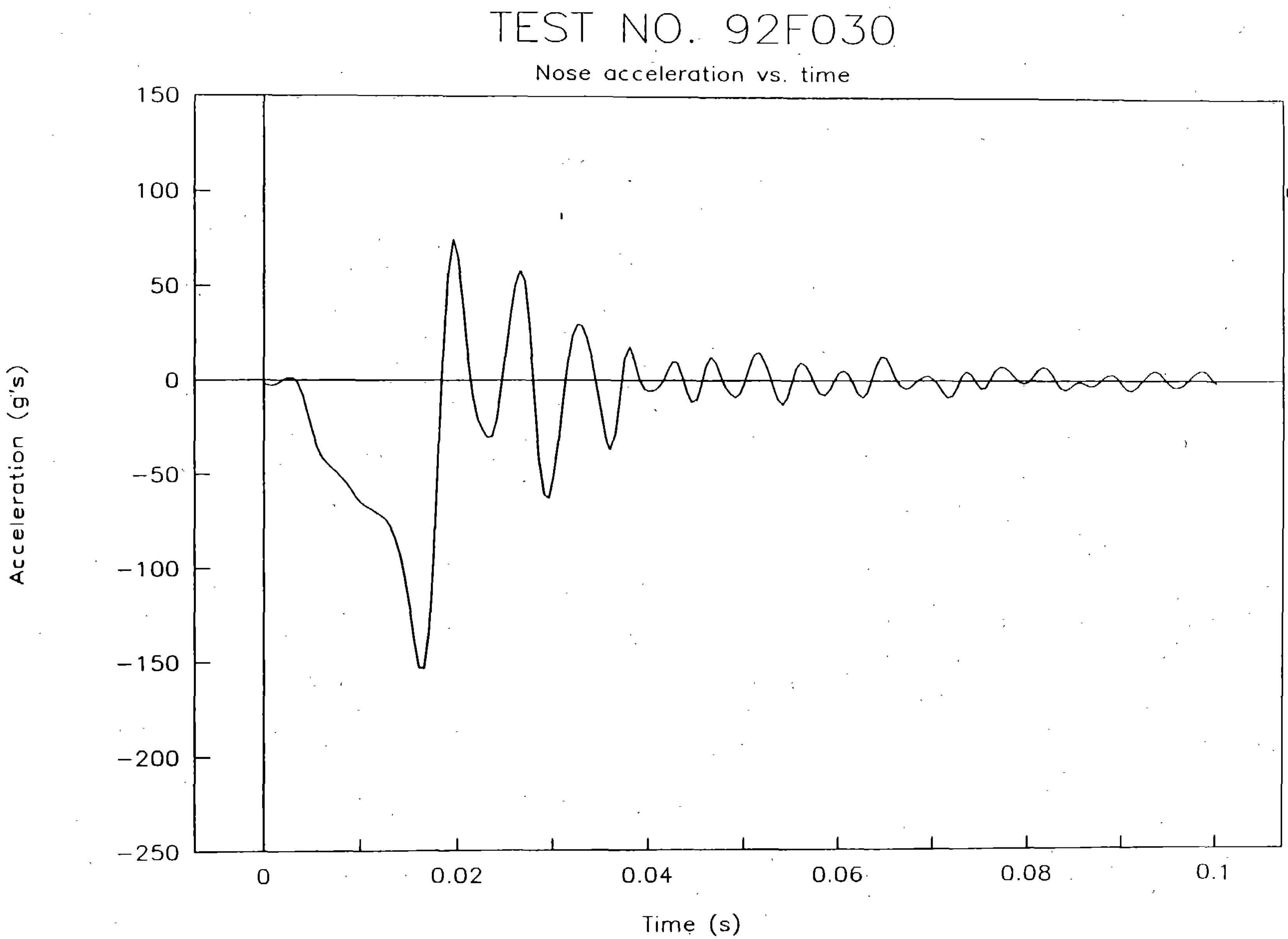


Figure 26. Nose acceleration vs. time, ENSCO bogie, test 92F030.

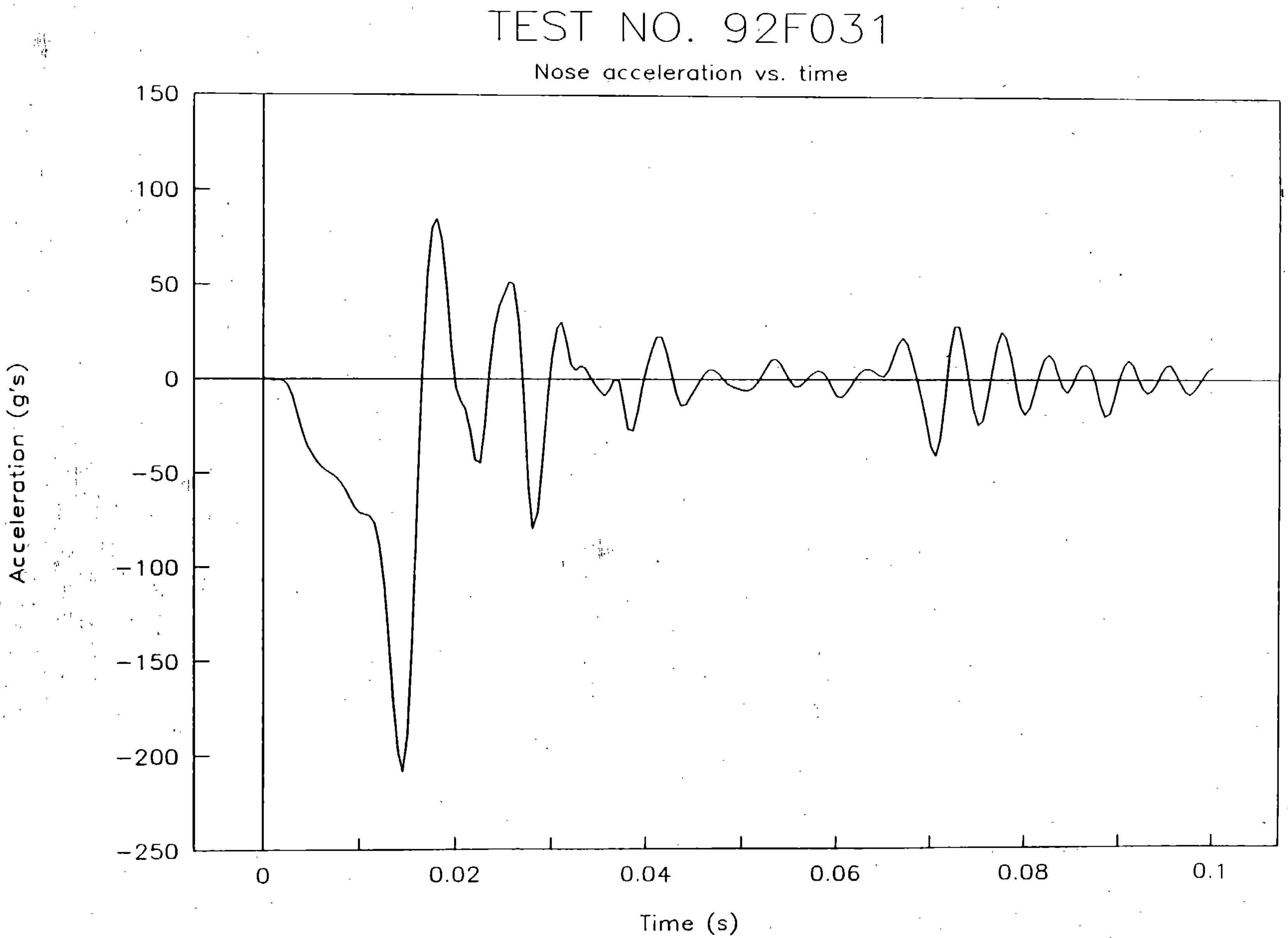
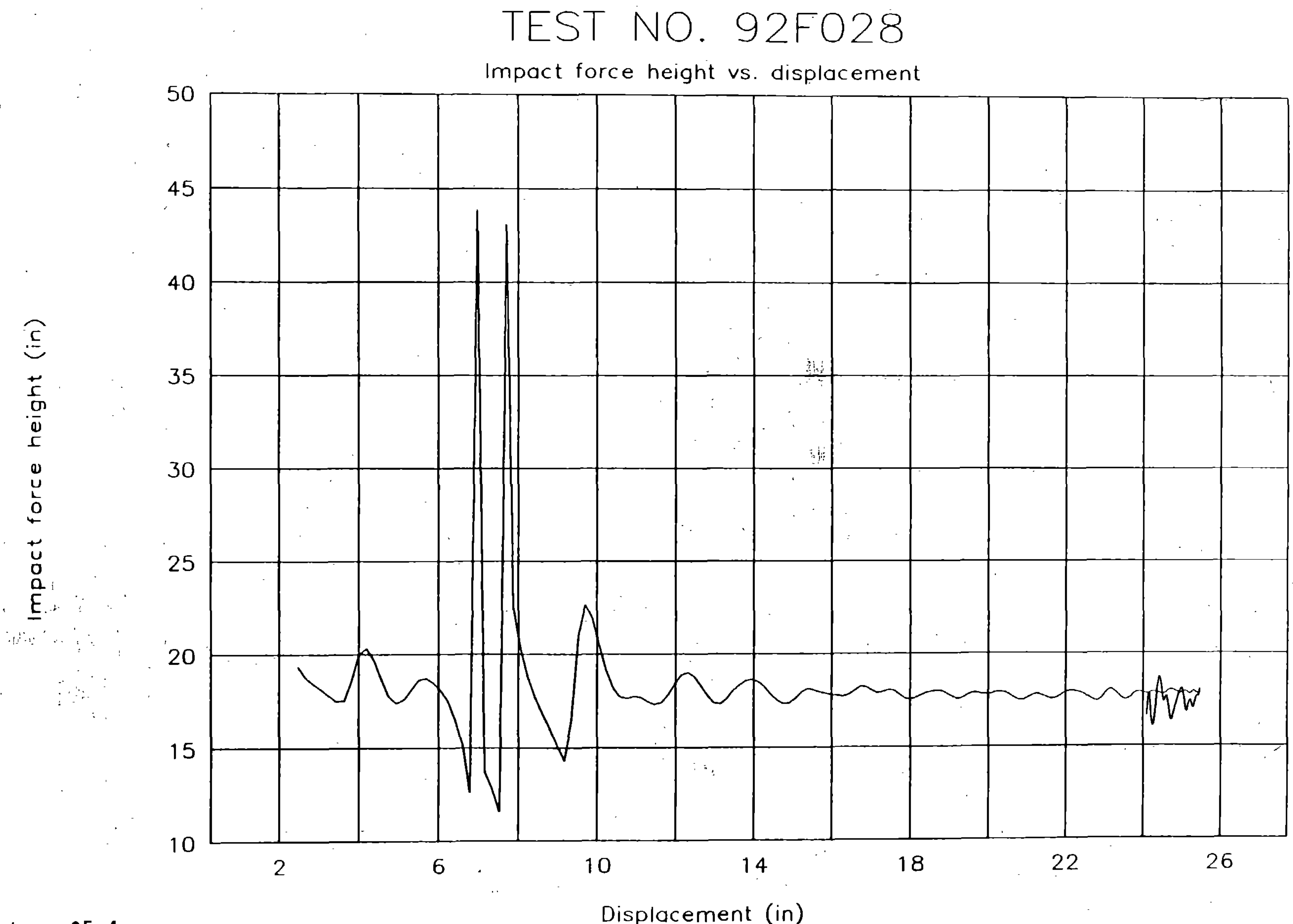
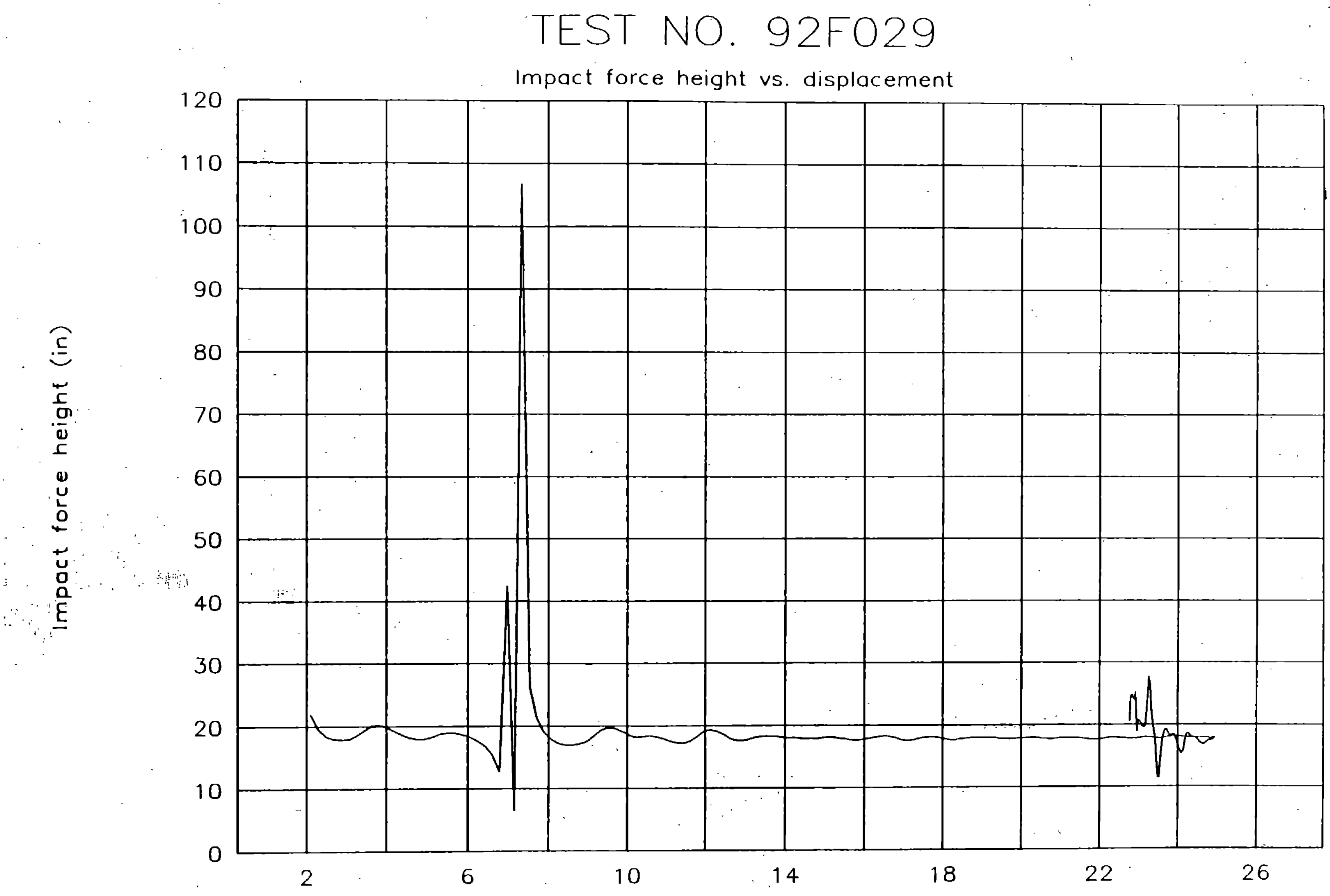


Figure 27. Nose acceleration vs. time, ENSCO bogie, test 92F031.



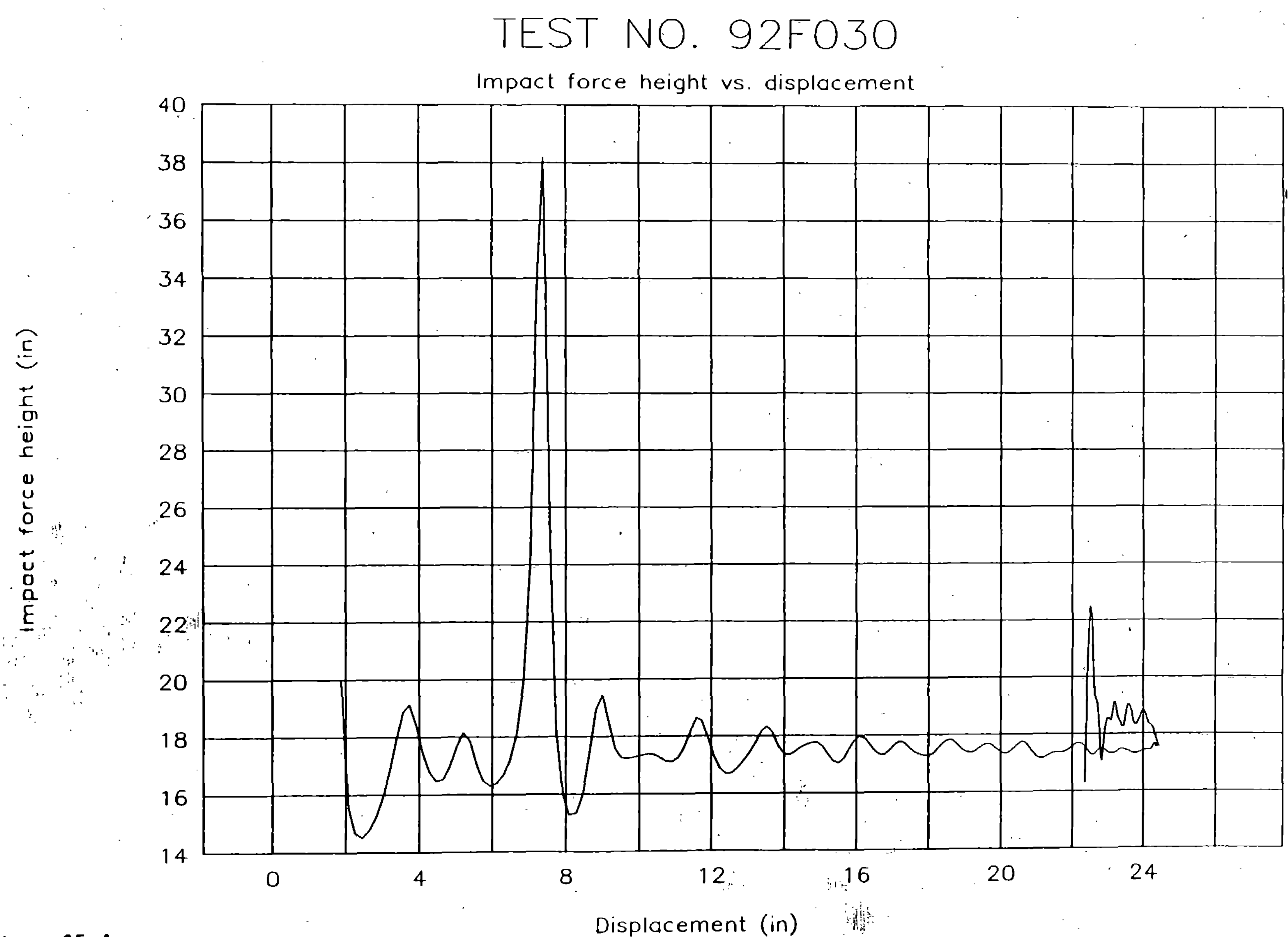
1 in = 25.4 mm

Figure 28. Impact force height vs. displacement, FOIL bogie, test 92F028.



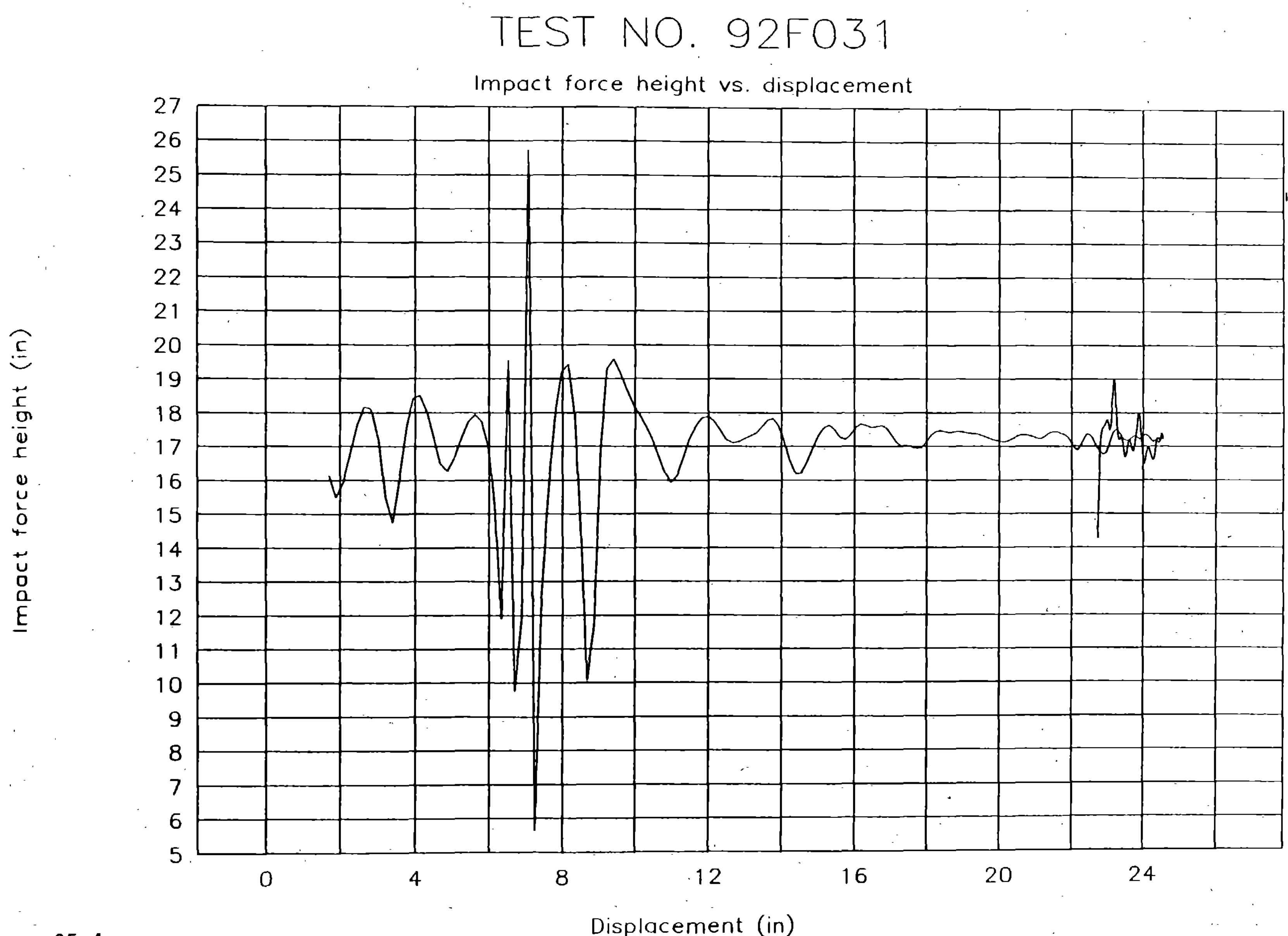
1 in = 25.4 mm

Figure 29. Impact force height vs. displacement, FOIL bogie, test 92F029.



1 in = 25.4 mm

Figure 30. Impact force height vs. displacement, ENSCO bogie, test 92F030.



1 in = 25.4 mm

Figure 31. Impact force height vs. displacement, ENSCO bogie, test 92F031.

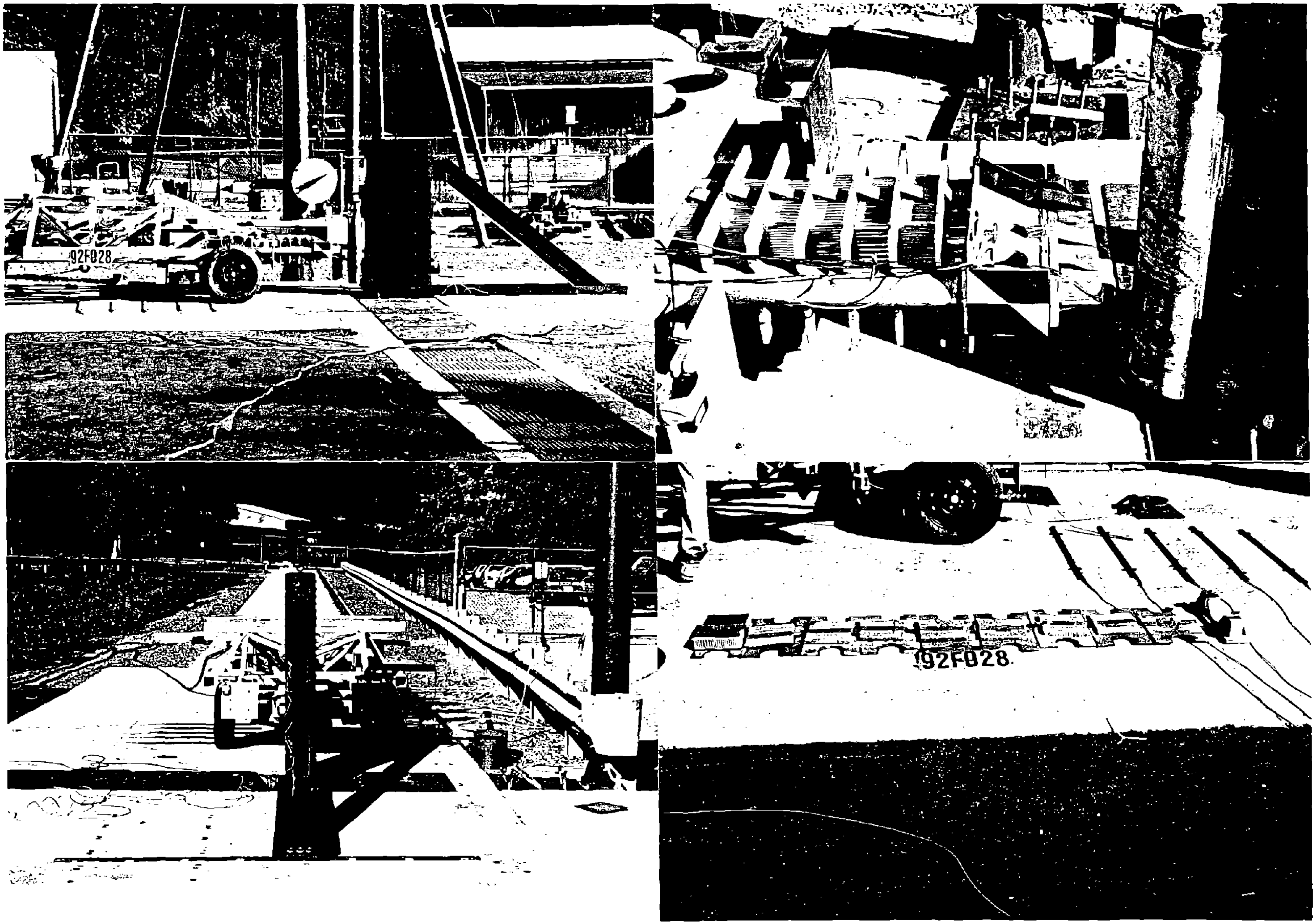


Figure 32. Pre and Post-test photographs, FOIL bogie, test 92F028.

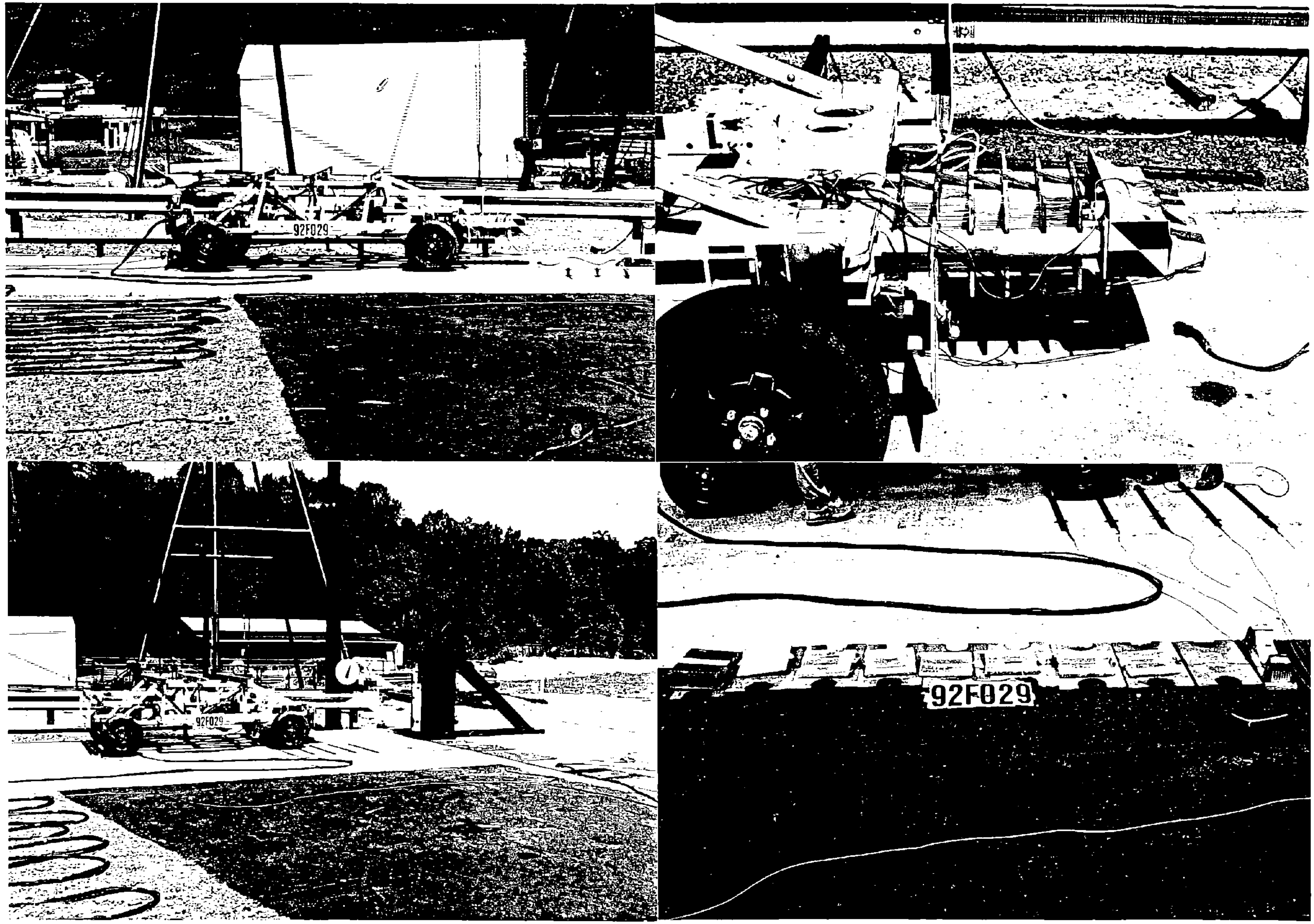


Figure 33. Pre and Post-test photographs, FOIL bogie, test 92F029.

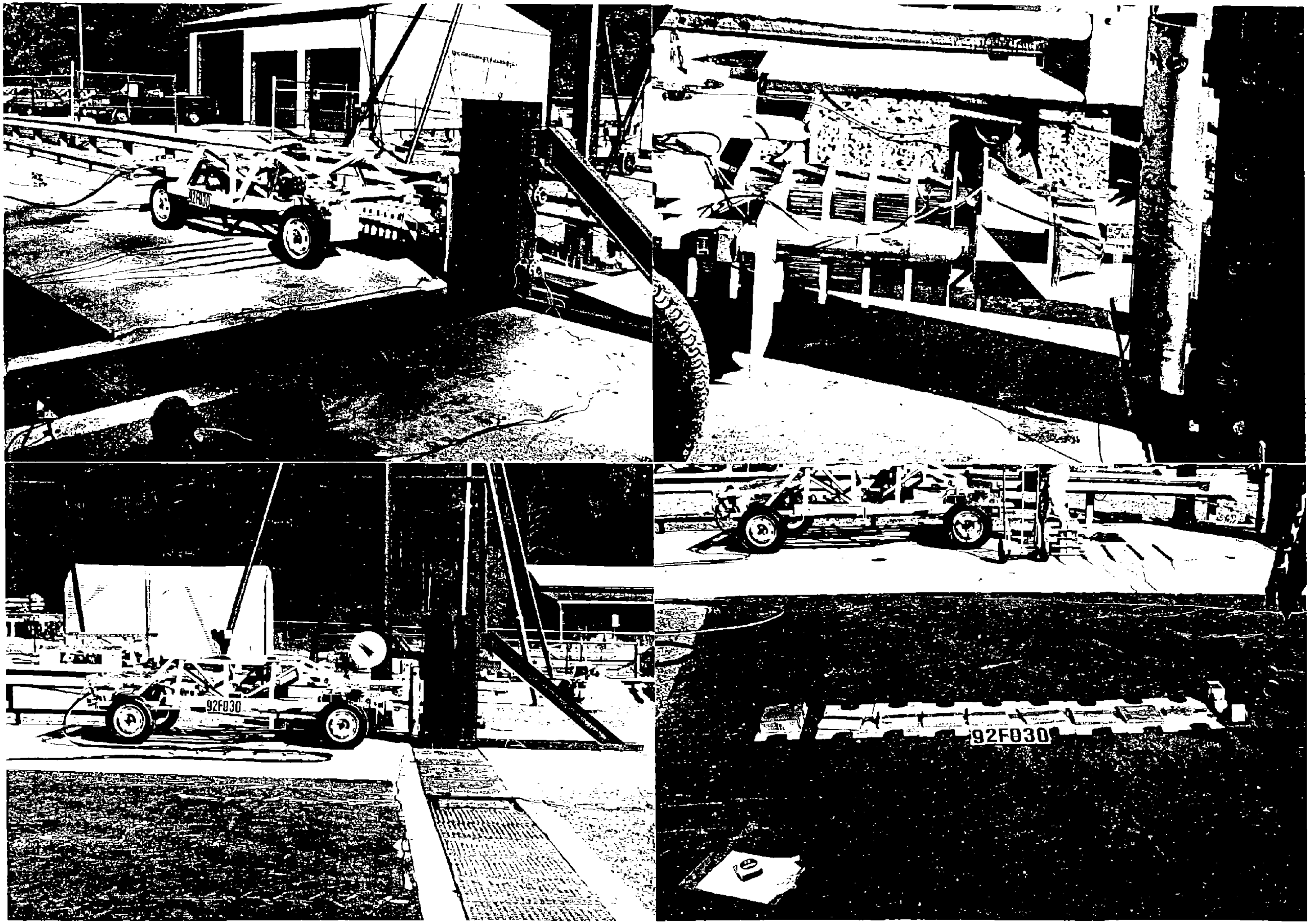


Figure 34. Pre and Post-test photographs, ENSCO bogie, test 92F030.

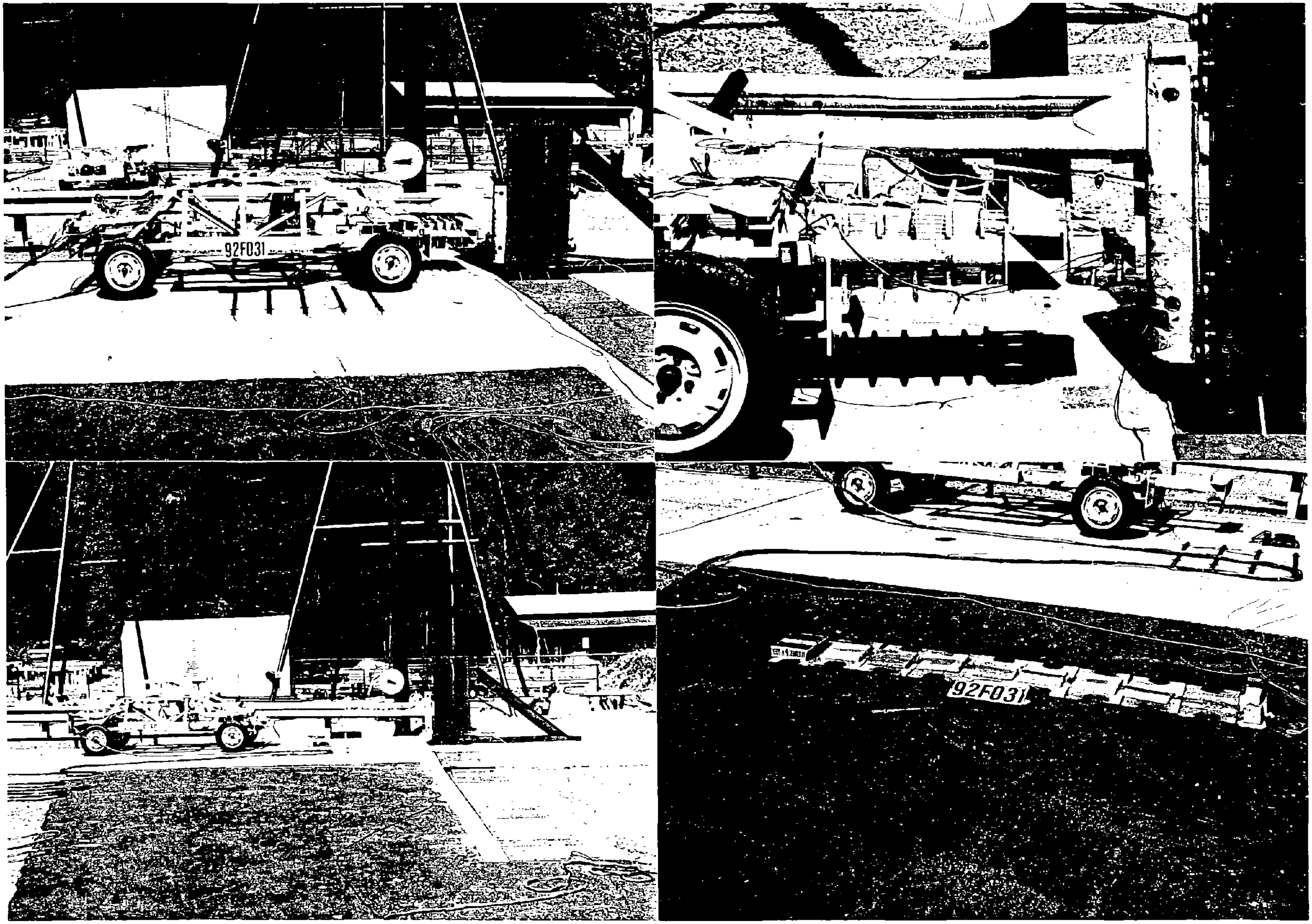
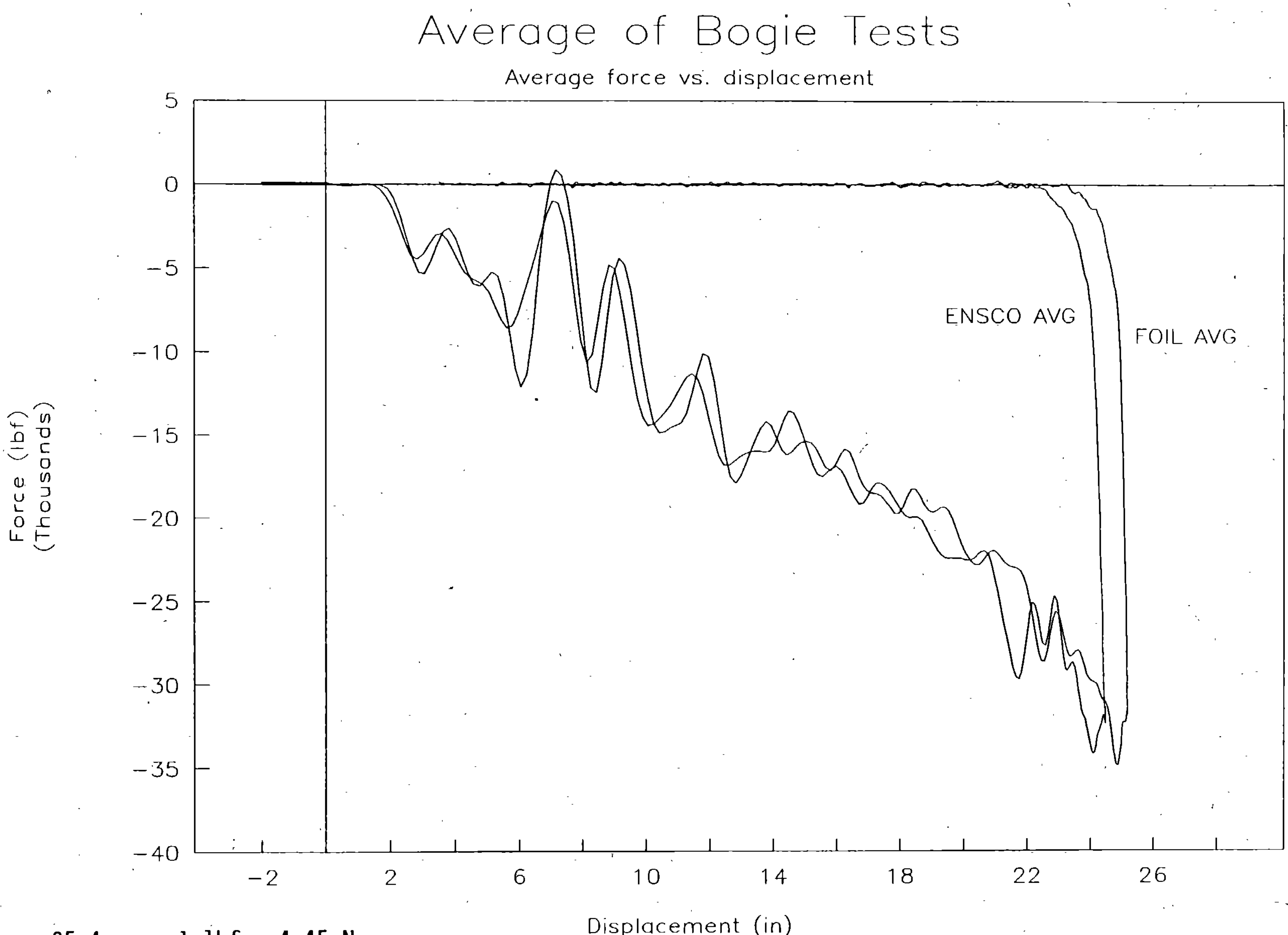
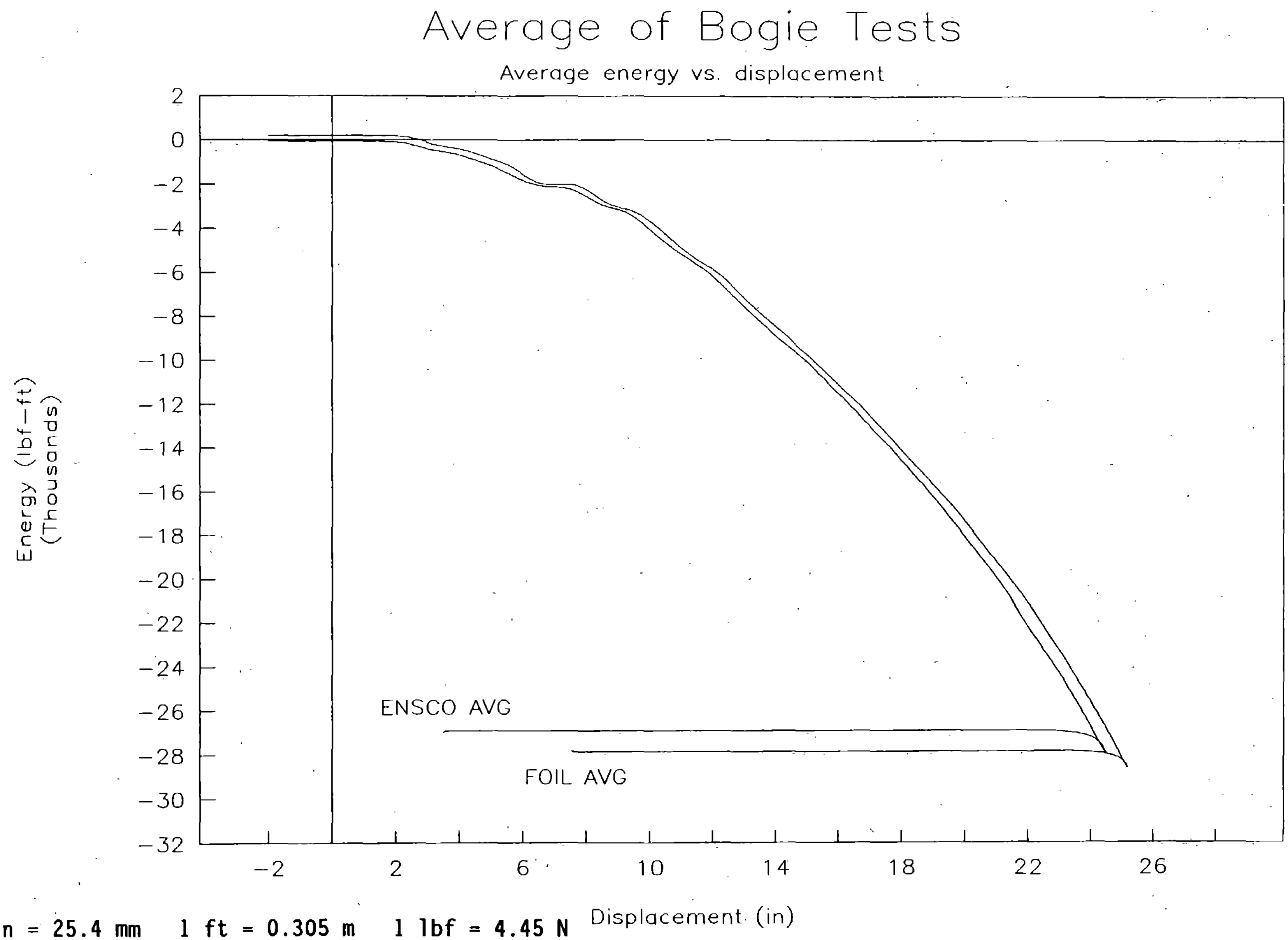


Figure 35. Pre and Post-test photographs, ENSCO bogie, test 92F031.



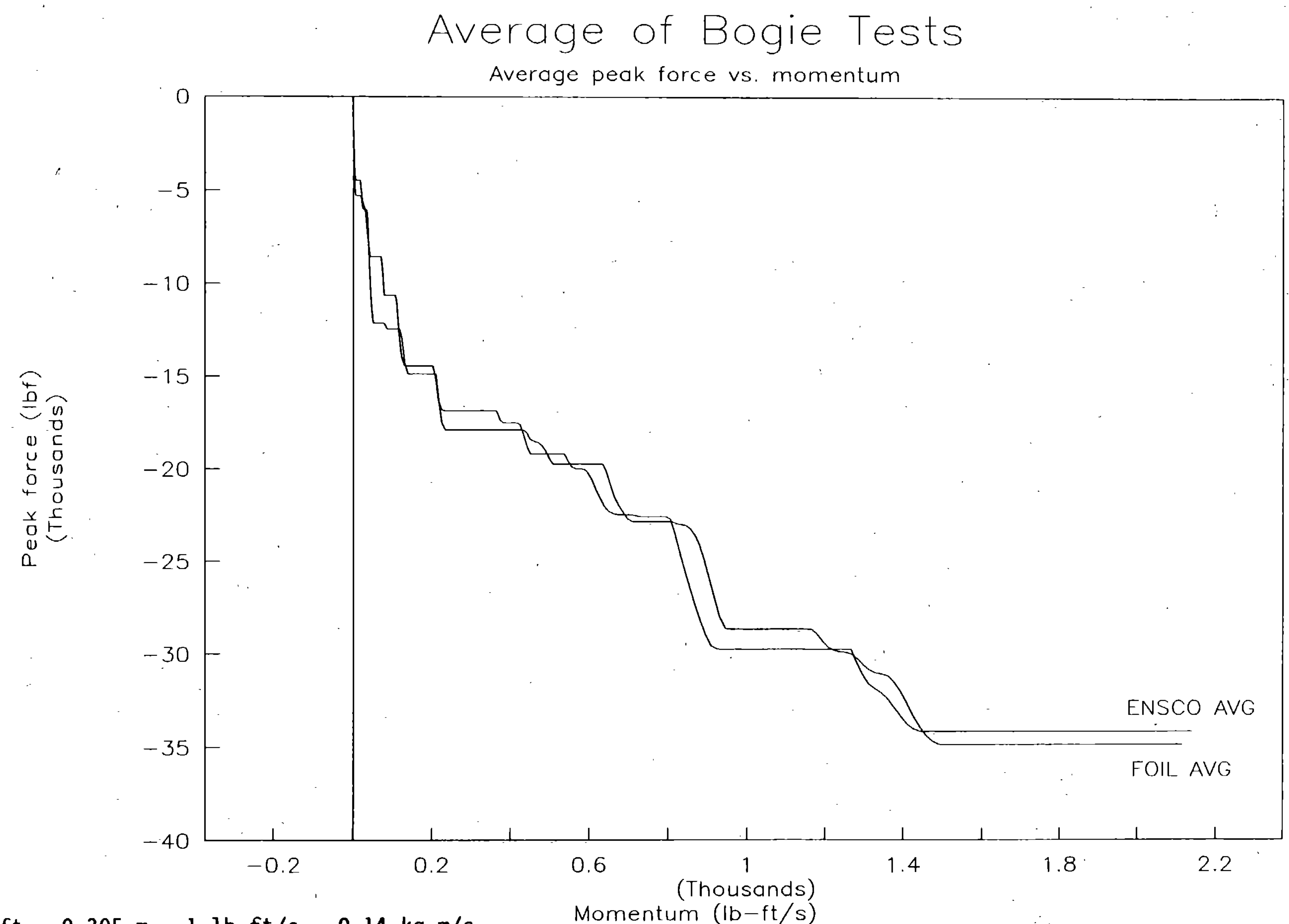
1 in = 25.4 mm   1 lbf = 4.45 N

Figure 36. Average force vs. displacement.



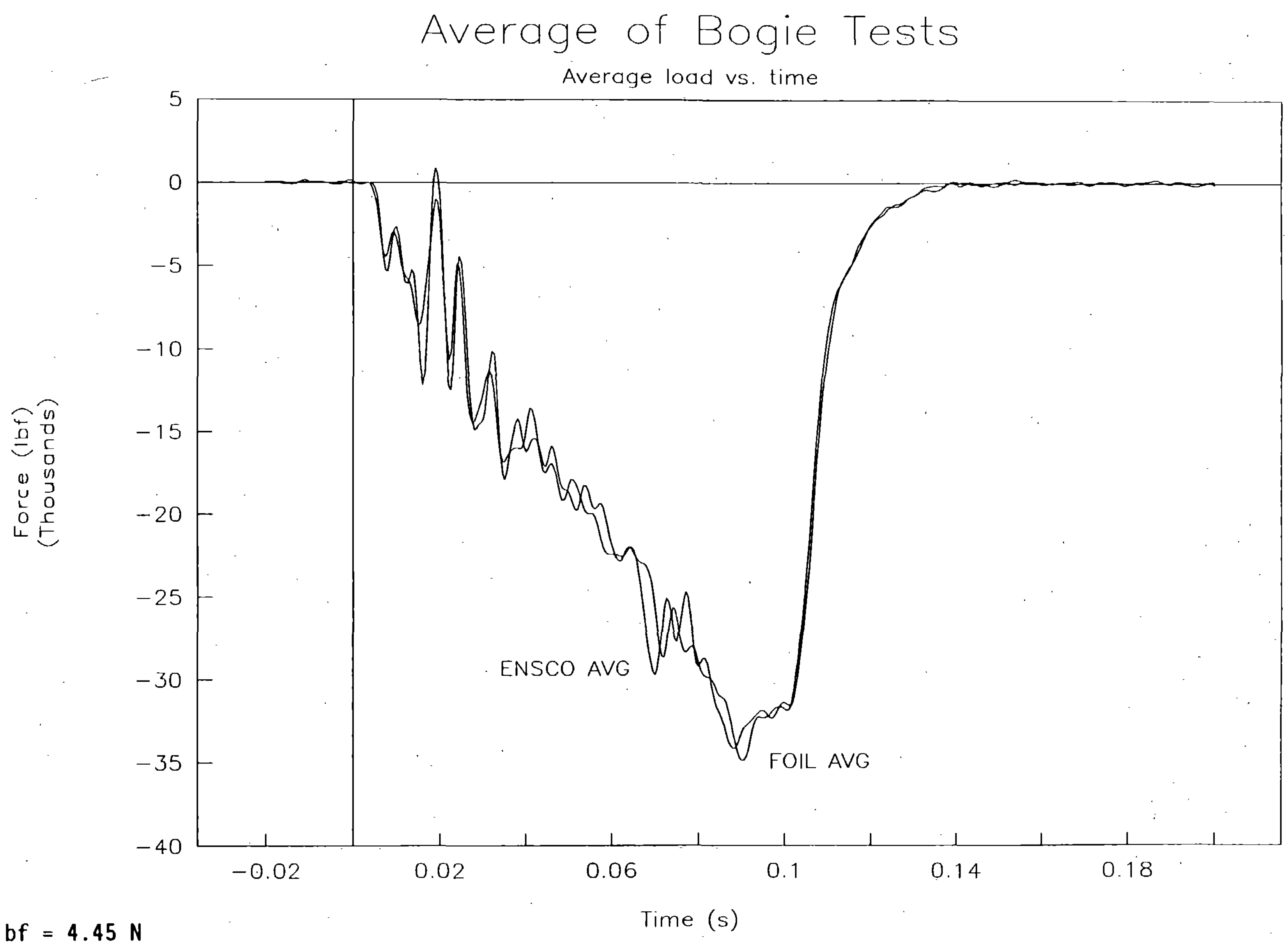
1 in = 25.4 mm   1 ft = 0.305 m   1 lbf = 4.45 N

Figure 37. Average energy vs. displacement.



1 ft = 0.305 m   1 lb-ft/s = 0.14 kg-m/s

Figure 38. Average peak force vs. momentum.



1 lbf = 4.45 N

Figure 39. Average load cell force vs. time.

REFERENCES

Number

(1) J. Hinch, G. Manhard, D. Stout, and R. Owings, *FOIL Construction, Laboratory Procedures to Determine the Breakaway Behavior of Luminaire Supports in Mini-sized Vehicle Collisions*, Volume I, II, and III. Report Nos. FHWA/RD-86/105, 106, and 107, Federal Highway Administration, Washington, D.C., August 1987.

(2) Charles R. Hott, Christopher M. Brown, Nick Totani and Allen G. Hansen, *Crush Characteristics of the 'Breakaway' Bogie*, Report No. FHWA-RD-89-107, Federal Highway Administration, Washington, D.C., July 1990.