1994 Toyota Pickup Broadside Collision with a Narrow Fixed Object: FOIL Test Number 98S006

PUBLICATION NO. FHWA-RD-98-151

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U.S. Department of Transportation
Federal Highway Administration

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

FOREWORD

The National Highway Traffic Safety Administration (NHTSA) enlisted the Federal Highway Administration (FHWA) to aid in the development of laboratory test procedures to be used in an amended version of Federal Motor Vehicle Safety Standard (FMVSS) 201. This new test procedure could be used in the evaluation of dynamic side-impact protection systems (e.g., air bags). A test methodology was produced from four crash tests between 1995 Honda Accord LX four-door sedans and the FOIL 300K rigid pole (test numbers 97S003, 97S004, 97S005, and 97S006), referenced in this report. Once the test procedures were established, three additional broadside crash tests were conducted to demonstrate the practicality and feasibility of the new test procedures. The three vehicles used for these tests were a 1994 Ford Explorer XLT, a 1994 Toyota pickup truck, and a 1995 Honda Accord LX. This report documents the test procedures and test results from the second in the series between the 1994 Toyota pickup and the FOIL 300K instrumented rigid pole. The test was conducted at the FHWA Turner-Fairbank Highway Research Center in McLean, Virginia. The NHTSA supplied a calibrated SID/HIII dummy for the crash test.

This report (FHWA-RD-98-151) contains test data, photographs taken with high-speed film, and a summary of the test results.

This report will be of interest to all State departments of transportation, FHWA headquarters, region and division personnel, and highway safety researchers interested in the crashworthiness of roadside safety hardware.

A. George Ostensen, Director
Office of Safety and Traffic
Operations Research and Development

NOTICE

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16. Abstract

This report contains the test procedures, test setup, and test results from the second of three broadside crash tests conducted at the Federal Highway Administration (FHWA) Federal Outdoor Impact Laboratory (FOIL), located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The National Highway Traffic Safety Administration (NHTSA) enlisted the FHWA to aid in the development of laboratory test procedures to be used in an amended version of Federal Motor Vehicle Safety Standard (FMVSS) 201. Four crash tests with a Honda Accord LX and the(FOIL) 300K instrumented rigid pole (test numbers 97S003, 97S004, 97S005, 97S006) produced a test methodology for conducting broadside vehicle crash tests of dynamic side-impact head protection systems (e.g., air bags). Once the test procedures were established, these three additional broadside crash tests were conducted to demonstrate the practicality and feasibility of the new test procedures. The three vehicles used for these tests were a 1994 Ford Explorer XLT, a 1994 Toyota pickup truck (this report), and a 1995 Honda Accord LX.

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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.

Symbol	When You Know	Multiply By	To Find	Symbol
		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/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	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	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		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 (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/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	lbf/in^2

* 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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INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) enlisted the Federal Highway Administration (FHWA), specifically the Federal Outdoor Impact Laboratory (FOIL), to aid in the development of laboratory test procedures to be used in an amended version of Federal Motor Vehicle Safety Standard (FMVSS) 201 (Occupant Protection in Interior Impact).[1] The amendment would include a 90-degree broadside collision between a passenger vehicle and a narrow fixed object. This new test procedure could be used in the evaluation of dynamic side-impact protection systems (e.g., air bags). Four crash tests were conducted in support of this research. The four tests conducted at the FOIL were broadside collisions between 1995 Honda Accord LX four-door sedans and the FOIL's 300K rigid pole. The results from the four Honda Accord tests can be found in four separate test reports, one for each test conducted: *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S003,*[2] *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S004,*[3] *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S005,*[4] and *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S006.*[5] These four crash tests produced a test methodology for conducting broadside vehicle crash tests of dynamic side-impact head protection systems (air bags). Once the test procedures were established, three additional broadside crash tests were conducted. The tests were conducted to demonstrate the practicality and feasibility of the new test procedures. Three different types of vehicles were represented in this series of tests. The three vehicles used for these tests were a 1994 Ford Explorer XLT (sport utility), a 1994 Toyota pickup truck (small pickup truck), and a 1995 Honda Accord LX (four-door sedan).

SCOPE

This report documents the test procedures and test results from a single broadside crash test between a 1994 Toyota pickup truck and the FOIL 300K instrumented rigid pole. The test was conducted at the FHWA's FOIL located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The purpose of this test was to assess the level of practicality, repeatability, and feasibility of the new FMVSS 201 test procedures. The test procedures and test setup were similar to procedures followed for a previously conducted crash test of a 1995 Honda Accord LX (FOIL test number 97S005). The test procedures for vehicle preparation, dummy preparation and calibration, and photographic coverage follow directly from FMVSS 214.[6] However, the new FMVSS 201 test procedures included propelling a vehicle in a sideways manner into a fixed 255-mm diameter pole. The seating procedure used for this type of test utilized FMVSS 214 seating procedures as an initial dummy position, then altered the position according to recently established procedures. The dummy was positioned in the final location by altering the seat back angle and seat track adjustment until a minimum clearance of 50 mm between the rear of the dummy's head and the vehicle B-pillar was achieved.

The FOIL utilizes a drop tower system for propulsion and two steel rails bolted to a concrete runway for vehicle guidance during broadside testing. The rails were extended to within 0.3 m of the rigid pole to ensure impact location, speed, and SID/HIII stability. The concept of the vehicle remaining on the two rails raised some concern. The concern was that the rails would impede the natural collapse or crush of the vehicle and thus interfere with the accuracy of the SID/HIII data. However, the intent of these tests was to validate a test procedure for head protection system evaluation and it was determined that the event of interest (dummy contact with the pole) would be complete before significant crush of the vehicle. The FOIL broadside test procedures require that the test vehicle's tires are off the ground while the test vehicle rests on the side-impact monorail. Due to the Toyota pickup truck's ground clearance, the side-impact monorail was raised 100 mm. A 100-mm x 100-mm wood block was placed under each monorail support. Increasing the rail height (to 305 mm) allowed the tires of the truck to hang free without contact with the ground.

The NHTSA supplied a calibrated SID/HIII dummy for the crash test. Head injury criteria (HIC) and thoracic trauma index (TTI) calculations were performed on the data from the SID/HIII's head and thorax accelerometers. The HIC and TTI values were used to determine the severity of the test and to compare previous and subsequent broadside tests to evaluate the repeatability of the test procedures.

TEST MATRIX

One broadside crash test involving a 1994 Toyota pickup truck and the FOIL's instrumented 300K rigid pole was conducted. The target vehicle test weight was intended to be between the vehicle curb weight (empty, as received from the dealership) and the fully loaded weight (curb weight plus ballast to simulate the vehicle cargo capacity and one SID/HIII). The target test speed for this test was 29 km/h. The rigid pole was installed with its centerline aligned with the center-of-gravity (cg) of the SID/HIII's head. Table 1 outlines the pertinent test parameters of the broadside crash test.

Table 1. Test matrix.	
FOIL number	98S006
Date	April 7, 1998
Vehicle	1994 Toyota pickup truck
Weight (total)	1336 kg
SID/HIII Modified neck bracket	One positioned in driver seat HYBRID III neck
Fuel tank	92% capacity with stoddard solvent
Crab angle	90°
Speed (nominal)	29 km/h
Impact location	Pole aligned with SID/HIII head
Test article	FOIL 300K instrumented rigid pole

TEST VEHICLE

The test vehicle was a two-door 1994 Toyota pickup truck with a 5-speed manual transmission and a four cylinder 2.4 L motor. Table 2 describes the vehicle and optional equipment.

Table 2. Vehicle description and statistics.	
Vehicle make	Toyota
Vehicle model	1994 Toyota pickup truck
Vehicle identification number (VIN)	4TARN81A9RZ160851
Engine	2.4 L, 4 cylinder
Transmission	5-speed manual
Drive chain	Rear wheel drive
Wheel base	2620 mm
Wheel track	1350 mm
Fuel capacity	59.4 L
Tested capacity of stoddard solvent	54.9 L (92.4%)
Seat type	Bench
Position of front seats for test	82.5 mm forward of center
Seat back angle	24.6° (no adjustment)
Steering wheel adjustment for test	Center

Table 2. Vehicle description and statistics (continued).

OPTIONS					
	Air conditioning		Traction control		Clock
	Tinted glass		All wheel drive		Roof rack
x	Power steering		Cruise control		Console
	Power windows		Rear defroster		Driver air bag
	Power door locks		Sun roof/T-top		Passenger air bag
	Power seat(s)		Tachometer	x	Front disc brakes
	Power brakes		Tilt steering		Rear disc brakes
	Anti-lock brakes		AM/FM radio		Other

WEIGHTS (kg)	DELIVERED	FULLY LOADED	TEST MODE
Left front	339	369	362
Right front	334	344	355
Left rear	244	339	310
Right rear	250	330	309
TOTAL	**1167**	**1382**	**1336**
ATTITUDE (mm)	**DELIVERED**	**FULLY LOADED**	**TEST MODE**
Left front	699	700	697
Right front	703	704	700
Left rear	710	705	705
Right rear	698	694	693
ATTITUDE (degrees)	**DELIVERED**	**FULLY LOADED**	**TEST MODE**
Driver	.2 positive	.2 positive	.2 positive
Passenger	.2 negative	.1 negative	.1 negative
Front	1 negative	1 negative	.8 negative
Rear	.1 positive	.1 negative	.2 negative
cg (mm) measurements	**DELIVERED**	**FULLY LOADED**	**TEST MODE**
Behind front axle	1109	1268	1214
Lateral	675	692	680

The test vehicle was prepared for testing following procedures outlined in FMVSS 201 (similar to FMVSS 214). The NHTSA supplied an OSCAR to measure the three-dimensional coordinate of the SID/HIII's hip-point (H-point) relative to the vehicle's driver door striker. This H-point measurement was used the morning of the test to place the SID/HIII in its initial position before final positioning.

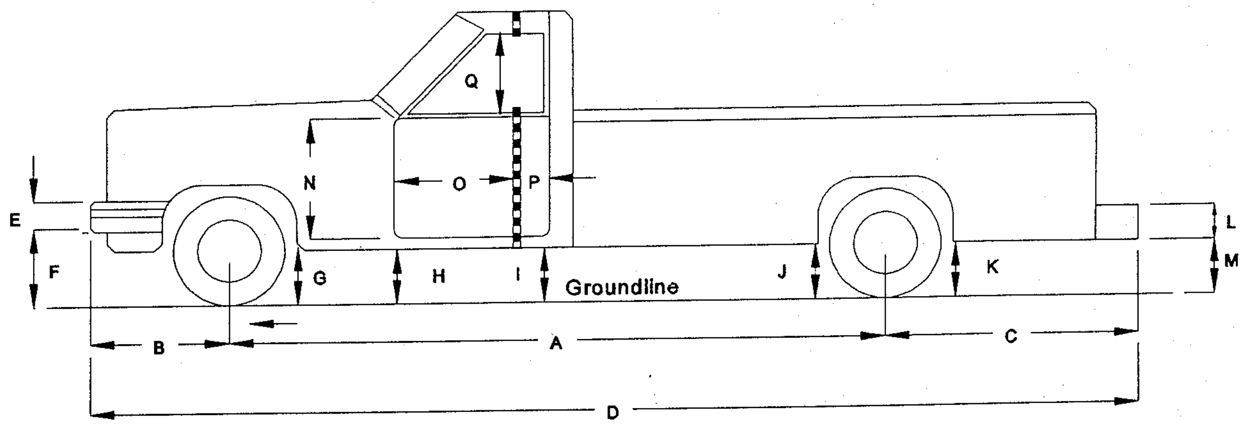
The vehicle weight and four sill attitudes were measured in each of the three modes or configurations described in FMVSS 201. The first was the "as delivered" mode. This configuration consisted of the test vehicle as delivered from a dealership with its fuel tank filled to 92 percent and 94 percent capacity with petroleum naphtha, a stoddard solvent. The second mode, cargo or "fully loaded" mode, consisted of the vehicle with one dummy placed in the driver seat and 135 kg of simulated cargo placed in the truck bed along the vehicle centerline. The final mode was the "as tested" mode. This configuration consisted of the vehicle fully instrumented for testing, excluding the 135 kg of simulated cargo but including instrumentation, guidance carriages, and one SID/HIII dummy. The four sill attitude measurements, vehicle weight distribution, and other measurements are presented in table 2. The vehicle attitudes while in position on the guidance rails were adjusted to within 0.5 degrees of the "test mode" measurements recorded while the vehicle was on the ground.

Included in the test mode configuration were the two side-impact carriages. The main monorail carriage rides down the main I-section monorail. The monorail carriage was bolted 200 mm forward of the vehicle's longitudinal cg. The main monorail carriage supports approximately 95 percent of the total vehicle weight. The monorail carriage includes a tow pin protruding out 200 mm rearward such that the tow cable pulled at the vehicle cg. The tow location allows for the least possible yaw to be induced by the tow system. The propulsion used was a gravity assist system. The FOIL utilizes a weight stack and a 6-to-1 mechanical advantage to accelerate the test vehicle. The total weight on the weight stack was reduced to 2,310 kg to prevent the SID/HIII from tipping during acceleration. The rear carriage was bolted to the bumper of the test vehicle and rides along a 50-mm steel angle. The rear carriages typically supports 5 percent of the total vehicle weight. Each carriage was constructed from aluminum and remained fastened to the test vehicle throughout the test. To prevent significant interference by the carriages, the carriages were bolted to the test vehicle using small diameter hardware quality bolts. The bolts were to shear quickly in the event the carriages made substantial contact with a structural member.

The fuel tank usable capacity (obtained from the NHTSA) was 59.4 L. The fuel tank was filled with 54.9 L (92.4 percent of capacity) of petroleum naphtha (stoddard solvent) which has the same density as gasoline but is less volatile. The tank was filled to reflect a more realistic weight of a passenger vehicle on the road. The petroleum naphtha also provided a means to observe any fuel system component leakage after the test. The original lead-acid battery in a charged state remained in the engine compartment. The vehicle test weight, including the dummy, instrumentation, cameras, ballast, and stodard solvent was 1336 kg. The SID/HIII weight was 80 kg.

Target tape and circular targets were placed on the test vehicle in accordance with FMVSS 201. The 25-mm yellow and black target tape was placed along the struck side of the vehicle at five elevations. The elevations included the lower door sill, the mid-door height, occupant H-point, top-door sill, and roof sill. The target tape was used to measure pre- and post-test side profile measurements to determine vehicle damage or crush. The FOIL used a 2.5-m-long by 1.4-m-high peg board placed along the driver (left) side of the vehicle to measure the vehicle profile. The board's position was referenced from two points directly across from the impact location on the right side of the vehicle. This was done to ensure that the reference location would not be severely damaged. The two points were chosen directly across from impact because the least amount of bowing occurs directly across from impact. It was necessary to position the board in the same position relative to the vehicle after the crash test to obtain accurate crush measurements. The pre- and post-test profile measurements are shown in figure 7 later in this report.

A list of sketches of the vehicle's physical parameters are shown in table 2 and figure 1, respectively. Figure 1 includes post-test damage measurements.



	PRE-TEST	POST-TEST	△CHANGE
A	2620	2514	-106
B	735	735	0
C	1070	1070	0
D	4425	4319	-106
E	155	155	0
F*	514 / 505	500	-5
G*	322 / 318	336	18
H*	324 / 320	342	22
I*	343 / 343	322	-21
J*	345 / 345	333	-12
K*	437 / 437	485	48
L	No bumper	0	0
M*	490 / 490	517	27
N	660	649	-11
O	1135	912	-223
P	N/A	0	0
Q	430	426	-4

* These measurements were taken in the "as delivered" and in the "as tested" configuration, respectively.

Figure 1. Vehicle physical parameters in millimeters.

INSTRUMENTED DUMMY

One SID/HIII, serial number 28, was placed in the driver seat of the Toyota pickup. The SID/HIII was supplied by the NHTSA and was calibrated by a NHTSA-approved dummy calibration facility before shipment to the FOIL. The SID/HIII is a combination of the standard SID torso with the neck and head replaced with a HYBRID III dummy's neck and head. The neck bracket was removed from the SID and replaced with a new neck bracket specifically designed for the SID/HIII. This provided the necessary bolt pattern and alignment for a HYBRID III neck and head assembly. The dummy is a surrogate occupant representing a 50^{th} percentile male. It was noted that the dummy's head had a slight twist about the neck. This may have been the result of the attachment between the neck and head, or between the neck and head assembly and the dummy's torso. Figure 2 is a sketch of the modifications made to the SID/HIII. The dummy was shipped with the necessary hardware for assembly. Tools at the FOIL were used to assemble the SID/HIII. The SID/HIII was clothed using white thermal underwear and hard sole leather shoes supplied by the NHTSA. Eighteen extension cables were supplied with the SID/HIII. The extensions allowed for installation of connectors necessary for attachment to the FOIL data acquisition system without removing the standard dummy connectors. The transducers within the dummy were of the half bridge type and therefore completion resistors were soldered into the connectors at the data acquisition system interface.

The morning of the test, the SID/HIII was positioned in the driver seat in accordance with FMVSS 214. The data acquired from the OSCAR were used to place the dummy H-point at the correct location. After the dummy was positioned in the standard FMVSS 214 position, the seat back and seat track were adjusted to place the SID/HIII forward of the B-pillar. The target minimum clearance between the rear of the dummy's head and the B-pillar was 50 mm. The following procedure was followed for dummy positioning:

1. Position the SID/HIII per FMVSS 214. This position served as a baseline starting position.

2. If the minimum head-to-B-pillar clearance of 50 mm was not present, then the seat back angle was adjusted (if adjustment was possible) as much as 5 degrees.

3. If the minimum head-to-B-pillar clearance of 50 mm was not achieved, the seat track was adjusted in one detent increments until either the minimum clearance was achieved, or the most forward adjustment was reached, or until there was knee interference between the dash or steering column.

4. If the minimum head-to-B-pillar clearance of 50 mm was not achieved, the seat back angle was adjusted in one notch increments until either the minimum clearance was achieved, or the full upright locked position was reached.

5. If the minimum head-to-B-pillar clearance of 50 mm could not be achieved after the above 4 steps, the test would be conducted without the minimum clearance.

The minimum clearance was achieved after step 3. The seat back angle could not be adjusted. The seat track was adjusted to the most forward position. No interference between the SID/HIII's knees and the dash was observed; however, the knees made contact with the steering column. The knees were spread enough to eliminate knee-steering column contact. The final seat back angle was 24.6° (measured on the front of the seat) from vertical. Using FMVSS 214 as a guide and alignment tools supplied by the NHTSA, the SID/HIII's feet, legs, thighs, pelvis, torso, and head were positioned just before the test. Pertinent SID/HIII-to-interior longitudinal and lateral clearance measurements are shown in figure 3 and figure 4. Several different color chalks were put on the side surfaces of the dummy to determine the contact points between the dummy and the vehicle's interior, as shown in table 3 below.

Table 3. SID/HIII chalk colors.

DUMMY PART	**COLOR**
Face	Light green
Top of head	Orange
Left side of head	Yellow
Back of head	Blue
Left hip	Black
Left shoulder	Dark green

P572M HEAD/NECK/TORSO ASSEMBLY

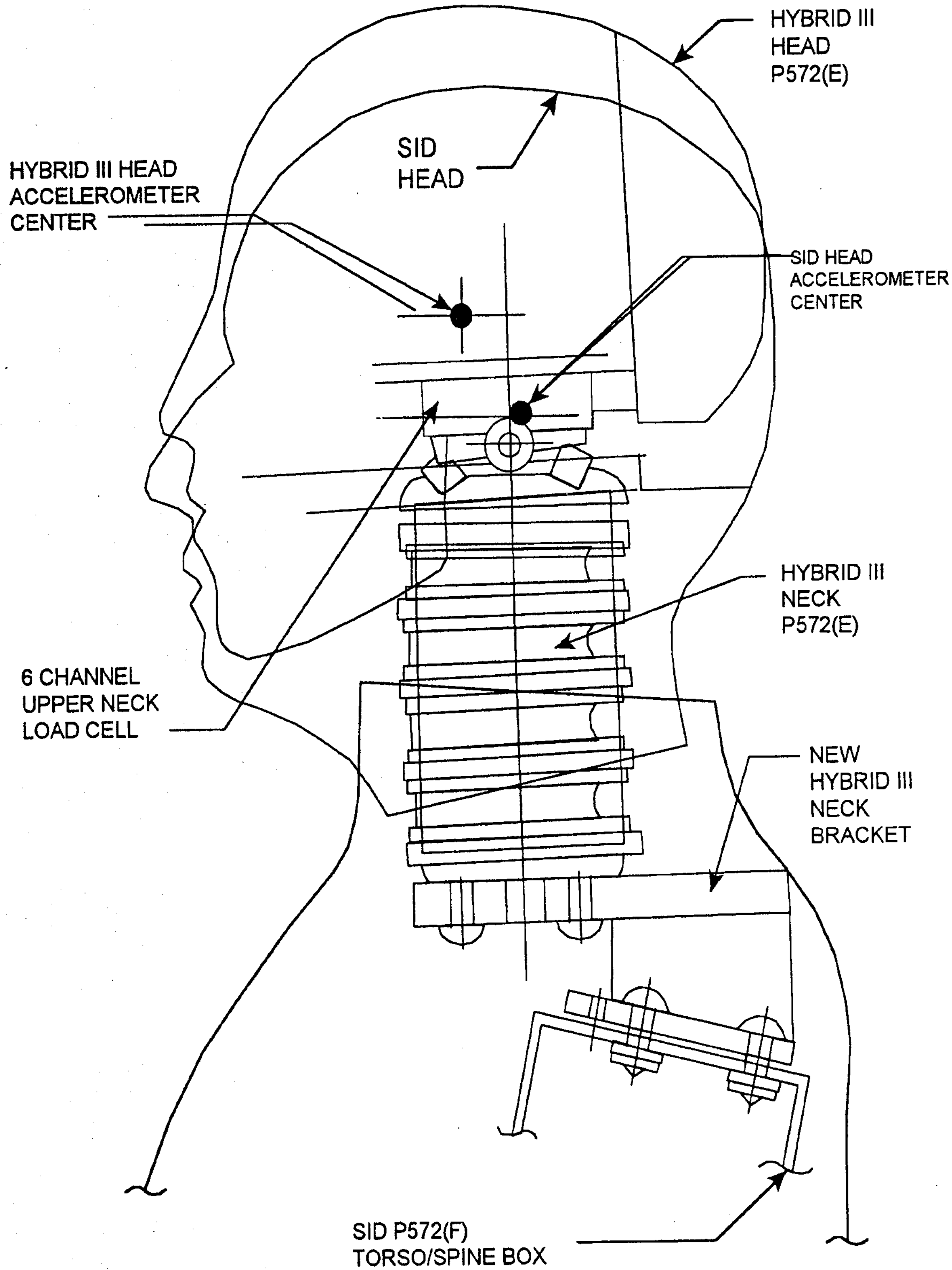
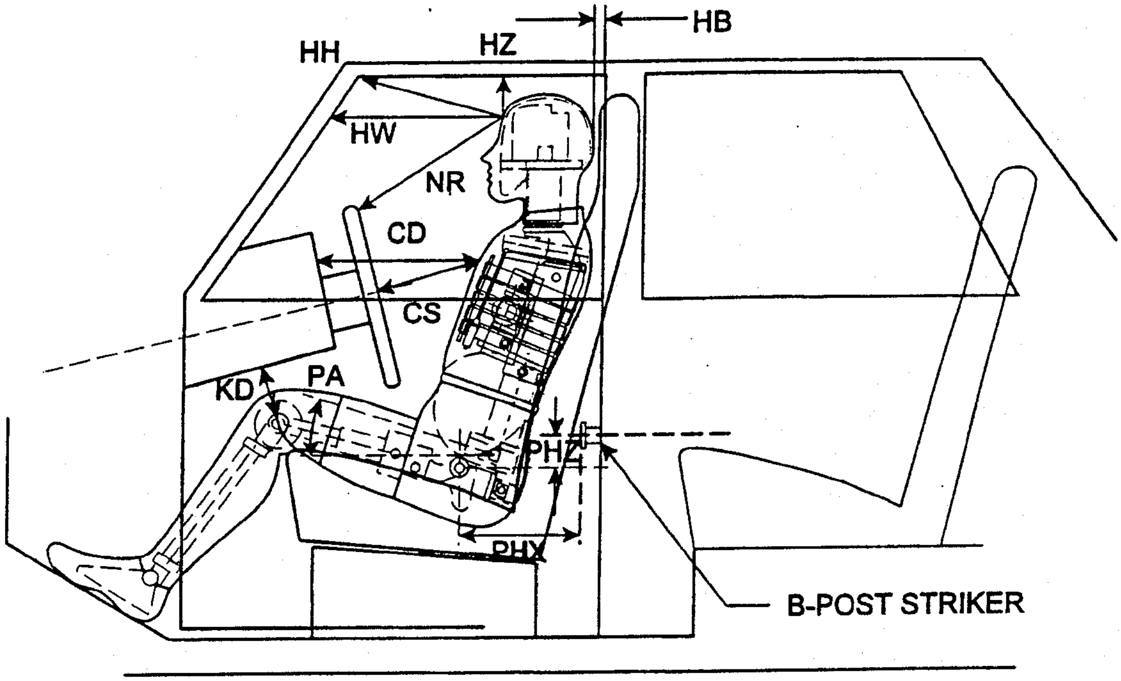


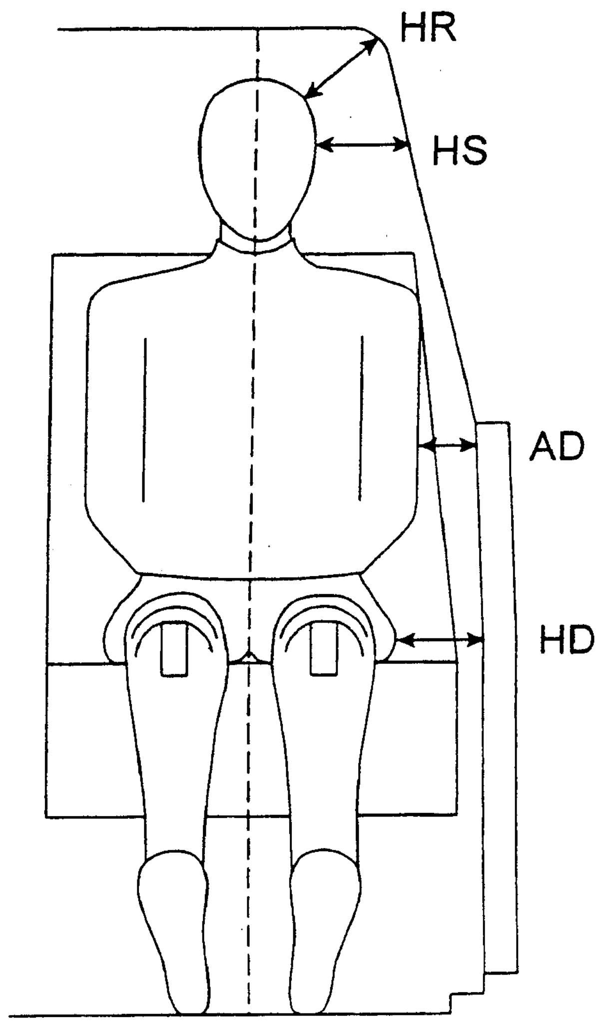
Figure 2. HYBRID III neck and head assembly on SID/HIII #28.



LEFT SIDE VIEW

MEASUREMENT (mm)	DRIVER SID/HIII ID# 28
HB	57
HH	360
HW	500
HZ	153
NR	442
CD	560
CS	235
KDL(KDA°)	120(27.3°)
KDR(KDA°)	124(26.9°)
PA°	21°
PHX	390
PHY	228
PHZ	108

Figure 3. SID/HIII longitudinal clearance and position measurements.



MEASUREMENT (mm)	DRIVER SID/HIII ID# 28
HR	160
HS	200
AD	100
HD	145

Figure 4. SID/HIII lateral clearance and position measurements.

RIGID POLE

The FOIL instrumented 300K rigid pole was designed to measure vehicle frontal and side crush characteristics. The rigid pole was set up in the side-impact configuration. The rigid pole side-impact configuration consisted of four solid half-circle steel impact faces mounted to two load cells via two high-strength connecting rods per face (eight load cells total). The diameter of the pole impact faces was 255 mm. The load cells measured the forces exerted on the pole at each location. This provided insight into what structures on the vehicle produced the significant loads. The 300K rigid pole was mounted in line with the target impact location, aligned with the cg of the dummy's head. The rigid pole can be moved laterally in either direction in 50-mm increments. The pole was placed in the FOIL foundation pit aligned with the dummy head cg. If the rigid pole mounting plate did not align properly with the holes of the foundation base plate, it was moved to the closest bolt hole position. This pole position restriction can produce a maximum ±25-mm misalignment between the dummy head cg and the rigid pole centerline.

A spike (e.g., sharpened welding rod) was affixed to one impact face to verify the impact location by physically puncturing the vehicle body. Figure 5 is a sketch of the FOIL 300K rigid pole (side-impact configuration).

INSTRUMENTATION

Electronic data from the crash test were recorded via two data acquisition systems, the FOIL umbilical cable system and the FOIL onboard data acquisition system (ODAS). A total of 40 channels of electronic data were recorded. The umbilical cable system recorded 13 data channels and the remaining 27 data channels were recorded by the ODAS system. In addition to electronic data, high-speed cameras were used to record the test on film, which was analyzed to acquire pertinent test data. The following is a summary of the electronic data collected:

Vehicle instrumentation.

• Cg triaxial accelerometer (A_x,A_y,A_z)	3 channels
• Cg redundant accelerometer for A_x,A_y	2 channel
• Biaxial accelerometer, Engine (A_x,A_y)	2 channels
• Biaxial accelerometer, Truck bed (A_x,A_y)	2 channels
• An accelerometer on driver seat (A_y)	1 channel
• Cg triaxial rate sensor (pitch,roll,yaw)	3 channels

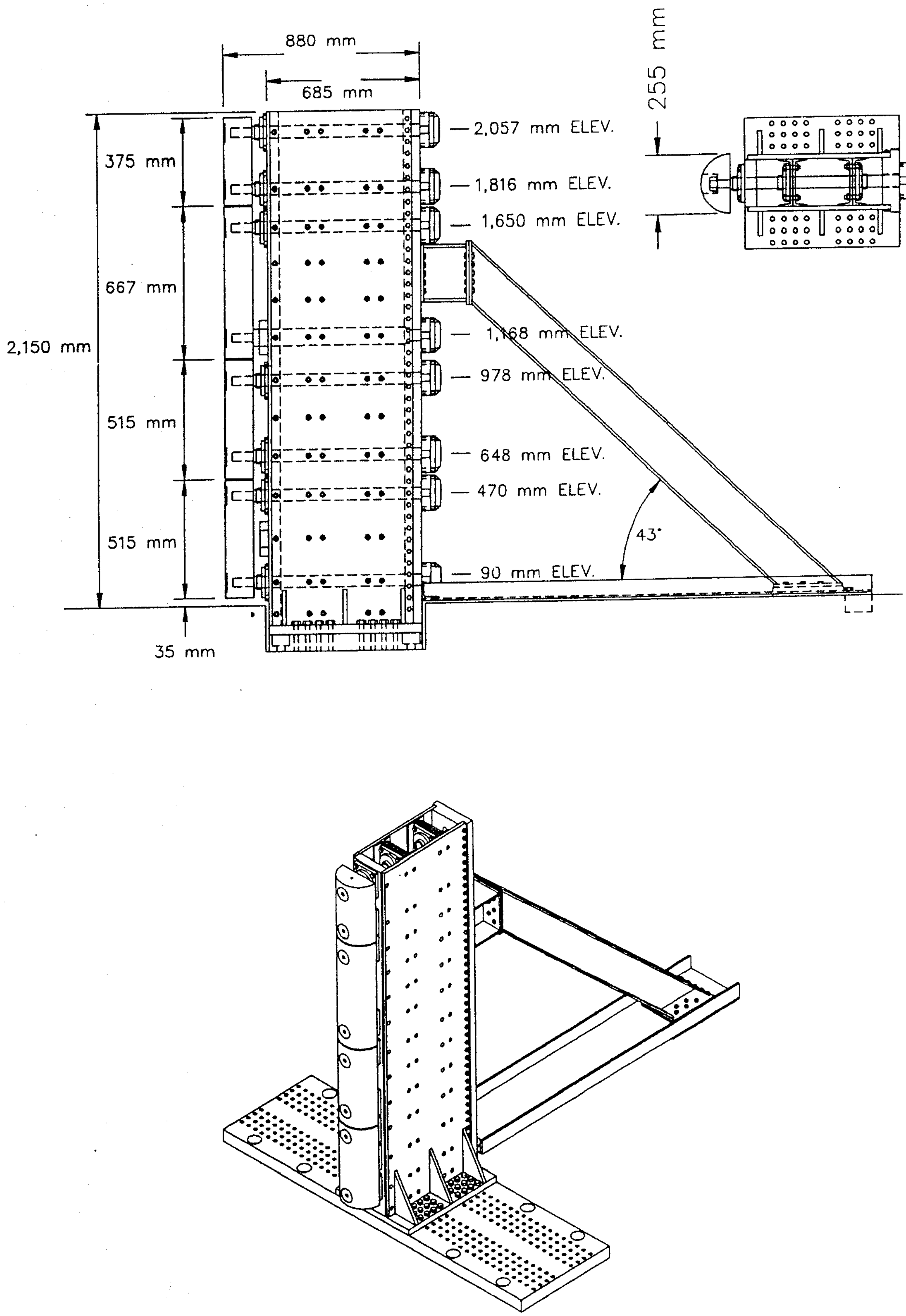


Figure 5. FOIL 300K instrumented rigid pole.

SID/HIII instrumentation.

• Triaxial accelerometer dummy head (A_x,A_y,A_z)	3 channels
• Four dummy rib accelerometers (A_y)	4 channels
• Two dummy T12 spine accelerometers (A_y)	2 channels
• One dummy pelvis accelerometer (A_y)	1 channel
• Six dummy neck sensors (F_x,F_y,F_z,M_x,M_y,M_z)	6 channels

Rigid pole instrumentation.

• Eight rigid pole load cell channels (F_y)	8 channels

Miscellaneous.

• Impact and speed trap switches	2 channels
• 1 kHz timing signal for analog tape	1 channel

Table 4 provides specific channel assignments. The first 27 channels were ODAS channels including the 16 SID/HIII channels (shaded entries). The remaining channels were recorded via the umbilical cable tape recorder system.

Two methods for mounting accelerometers were used to affix the sensors to the test vehicle. The accelerometers were supplied with two small machine screws and a small 12-mm aluminum block. The first method used the accelerometer screws to mount the accelerometer to a small 25-mm^2, 6-mm-thick steel plate, which was mounted to the vehicle using self-tapping sheet metal screws. This method was employed for the driver seat accelerometer. The second method used the aluminum block screwed to the small square-steel plate, which was welded to a larger, thicker plate. The larger plate was fastened to the vehicle using large self-tapping screws. This method was used for the accelerometers affixed to the engine block and in the trunk.

Onboard data acquisition system (ODAS)

The ODAS system collected 27 channels of data. The data were from cg, engine, driver seat, and trunk accelerometers, three rate transducers, and 16 SID/HIII channels. The output from the sensors was pre-filtered, digitally sampled, and digitally stored within the ODAS units mounted directly to the test vehicle inside the occupant compartment. The ODAS units are factory set with a 4000 Hz analog pre-filter and a digital sampling rate of 12,500 Hz.

Tape recorder-umbilical

The FOIL umbilical cable system utilizes a 90-m cable between the vehicle transducers, rigid pole load cells, or other sensors and a rack of 10 signal conditioning amplifiers. The output from the amplifiers was recorded on 25-mm magnetic tape via tape recorder. After the test, the tape was played back through anti-aliasing filters, then input to a data translation analog-to-digital converter (ADC). The sample rate was set to 5,000 Hz. The system recorded outputs from the eight rigid pole load cells, two cg accelerometers, the monorail speed trap, and an impact contact switch to electronically mark first contact between the vehicle and rigid pole. The speed trap signals and the impact contact switch were not conditioned before being recorded.

The speed trap consisted of a single micro switch mounted to the monorail 4.2 m from the rigid pole. The wheels from the main side-impact carriage trip the switch as the vehicle passes over the speed trap. The distance between the two main carriage wheels is 1015 mm.

Table 4. Summary of instrumentation.

ODAS III onboard data system			
Reference & Channel	**Transducer**	**Max. range**	**Data description**
1	Accelerometer	2000 g's	Head, X-axis
2	Accelerometer	2000 g's	Head, Y-axis
3	Accelerometer	2000 g's	Head, Z-axis
4	Accelerometer	2000 g's	Upper rib, Y-axis (P)
5	Accelerometer	2000 g's	Upper rib, Y-axis (R)
6	Accelerometer	2000 g's	Lower rib, Y-axis (P)
7	Accelerometer	2000 g's	Lower rib, Y-axis (R)
8	Accelerometer	2000 g's	Lower spine, Y-axis, T12 (P)
9	Accelerometer	2000 g's	Lower spine, Y-axis, T12 (R)
10	Accelerometer	2000 g's	Pelvis, Y-axis
11	Load cell	9000 N	Neck force, X-axis
12	Load cell	9000 N	Neck force, Y-axis
13	Load cell	9000 N	Neck force, Z-axis
14	Load cell	282 N·m	Neck moment, X moment
15	Load cell	282 N·m	Neck moment, Y moment
16	Load cell	340 N·m	Neck moment, Z moment
17	Accelerometer	100 g's	X-axis, cg data
18	Accelerometer	100 g's	Y-axis, cg data
19	Accelerometer	100 g's	Z-axis, cg data
20	Rate transducer	500 deg/s	Pitch rate, cg

Table 4. Summary of instrumentation (continued).			
21	Rate transducer	500 deg/s	Roll rate, cg
22	Rate transducer	500 deg/s	Yaw rate, cg
23	Accelerometer	2000 g's	X-axis, engine block
24	Accelerometer	2000 g's	Y-axis, engine block
25	Accelerometer	2000 g's	Driver seat track
26	Accelerometer	2000 g's	X-axis, in truck bed
27	Accelerometer	2000 g's	Y-axis, in truck bed
Umbilical cable, tape recorder system.			
1	Accelerometer	100 g's	Cg, Y-axis
2	Accelerometer	100 g's	Cg, X-axis
3	Load Cell	111 kN	Top face, upper load cell
4	Load Cell	111 kN	Top face, lower load cell
5	Load Cell	222 kN	Upper middle face, upper load cell
6	Load Cell	111 kN	Upper middle face, lower load cell
7	Load Cell	222 kN	Lower middle face, upper load cell
8	Load Cell	222 kN	Lower middle face, lower load cell
9	Load Cell	222 kN	Bottom face, upper load cell
10	Load Cell	222 kN	Bottom face, lower load cell
11	Contact switch	1.5 Volts	Time of impact, T0
12	Micro switch	1.5 Volts	Monorail speed trap
13	Generator	1.5 Volts	1 kHz reference signal

High-speed photography

A total of nine high-speed cameras were used to record the side-impact collision. All high-speed cameras were loaded with Kodak color-daylight film 2253. The cameras operated at 500 frames per second and were positioned for best viewing of the contact between the Toyota pickup truck and the 300K rigid pole. Three

35-mm still cameras and one 16-mm real-time telecine camera were used to document the pre- and post-crash environment. Table 5 lists each camera and lens used and the three-dimensional location of the camera lens. The three-dimensional coordinates were measured from the ground underneath the center of the semicircular impact faces of the rigid pole (origin) to the camera lenses. The camera numbers in table 5 are shown in figure 6. The interior of the driver door was painted flat white for better onboard camera image quality.

Table 5. Camera configuration and placement.

Camera Number	Type	Film speed (frames/s)	Lens (mm)	Orientation/ Location (m)
1	LOCAM II	500	50	90° to impact right side (21.6, 0.69, 0.91)
2	LOCAM II	500	100	90° to impact right side (22.3, 0.08, 1.4)
3	LOCAM II	500	50	45° oblique right side (9.0, 10.4, 1.2)
4	PHOTEC	500	80	45° oblique right side (21.7, 15.2, 1.1)
5	LOCAM II	500	75	45° left side (5.6, 15.2, 1.3)
6	LOCAM II	500	35	45° left side (6.2, 14.6, 0.69)
7	LOCAM II	500	25	180° to impact behind pole (0, 14.9, 0.76)
8	LOCAM II	500	12.5	overhead, over rigid pole (0, 0, 8.5)
9	LOCAM II	500	5.7	on-board passenger window
10	BOLEX	24	zoom	documentary
11	CANON A-1 (prints)	still	zoom	documentary
12	CANON A-1 (slides)	still	zoom	documentary

Black and yellow circular targets, and black and yellow target tape 25-mm wide, were placed on the Toyota pickup truck and rigid pole for film-data collection purposes. Circular targets and target tape were placed on the vehicle for certain vehicle measurements and for film analysis. The 25-mm tape was placed on the driver side of the vehicle at five levels or elevations referenced from the ground. The levels included:

- LEVEL 1 -- Axle centerline or lower door sill top height.
- LEVEL 2 -- Occupant H-point height.
- LEVEL 3 -- Mid-door height.

- LEVEL 4 -- Window sill height.
- LEVEL 5 -- Top of window height on roof rail.

In addition, target tape was placed vertically on the driver side of the vehicle coincident with the pole impact location. Target tape was also placed on top of the vehicle in the following locations:

- Along the longitudinal centerline the full length of the vehicle, excluding windows.
- Laterally across the roof perpendicular to the centerline tape and coincident with the rigid pole impact location.
- Laterally across the roof perpendicular to the centerline tape and coincident with the vehicle B-pillar.

Target tape was placed laterally on the front and rear bumpers in the YZ plane. Two vertical strips were placed on the rigid pole adjacent to and just rearward of the circular impact faces.

Black and yellow circular targets 100 mm in diameter were placed at various locations on the test vehicle for film data collection purposes. The targets were placed in the following locations:

- Driver door to denote the vehicle longitudinal cg.
- Driver door to denote the dummy H-point.
- The roof to denote the vehicle's longitudinal and lateral cg location.
- Two targets on the roof aligned with the vehicle longitudinal centerline 760 mm apart centered on the rigid pole centerline.
- Two targets aligned with the B-pillar centerline 610 mm apart centered on the vehicle's longitudinal centerline.
- Two targets on the hood aligned with the vehicle's longitudinal centerline 610 mm apart.
- Two targets on the trunk aligned with the vehicle's longitudinal centerline 255 mm apart.
- Two targets were placed on the front and back side of a vertical sheet metal stanchion fixed to the roof rearward of the B-pillar, centered on the longitudinal centerline and 610 mm apart.
- One target on top of the rigid pole's top semicircular impact face.
- Two targets on the front and rear bumper (YZ plane) 610 mm apart centered on the longitudinal centerline.

Figure 6 presents a side view of the test vehicle, showing the target tape locations. Figure 6 also contains an overhead sketch of the facility depicting the setup of the vehicle, rigid pole, test track, and the location of each high-speed camera. Positioned in each camera's view was at least one strobe light. The lights flashed when the vehicle struck the pole. This synchronized the film with the electronic data.

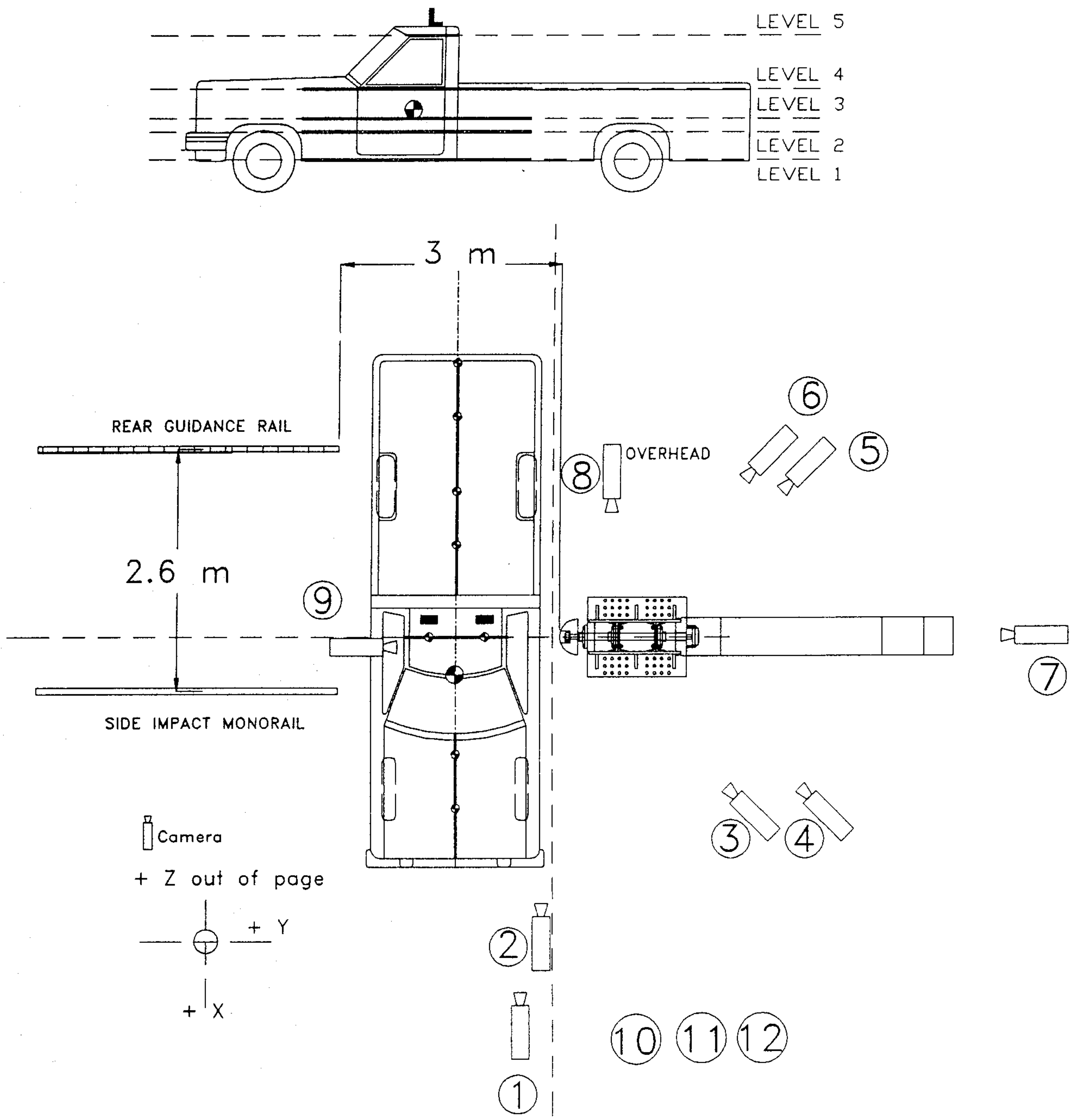


Figure 6. Camera locations and test setup.

DATA ANALYSIS

Two data acquisition systems, the ODAS system and the umbilical cable system, along with high-speed cameras were used to record the data during the side-impact crash test.

ODAS system. The data from the ODAS system included 16 channels of SID/HIII data, eight localized accelerometer channels, and three rate transducer channels. The data were filtered and digitally stored within the ODAS unit during the test. The filter was factory set at 4,000 Hz. The ADC sampling rate was factory set at 12,500 Hz. After the test, the data were down-loaded to a portable computer for analysis. The data were converted to the ASCII format, zero-bias removed, and digitally filtered at 1,650 Hz (Society of Automotive Engineers (SAE) class 1000). Rib, spine, and pelvic data were filtered a second time using an NHTSA-supplied FIR100 filter. The class-1000 data were input into a spreadsheet for plotting. The resultant head acceleration was calculated via a spreadsheet containing the data from the triaxial accelerometer inside the SID/HIII's head. The resultant acceleration data file was fed into a HIC algorithm to compute the HIC value for the crash test. The pelvic injury was equal to the peak pelvic acceleration recorded. The pelvic data were filtered using the FIR100 filter and the peak was located. The TTI was calculated from the FIR100 filtered rib and spine (T12) data. The following formula was used to compute the TTI:

$$TTI = [\text{Maximum}(4 \text{ rib channels}) + \text{Maximum}(\text{spine})] \div 2$$

Umbilical cable. Data collected via the umbilical cable tape recorder system was played back through an analog filter set at 1,000 Hz. The signal was then input to a data translation ADC. The data included eight load cell channels, two accelerometer channels (located at the cg), an impact switch, and a monorail speed trap signal. The sample rate was set to 5,000 Hz. The digital data were converted to the ASCII format, zero-bias removed, and digitally filtered to 1,650 Hz (SAE class 1000). The filtered data were input into a spreadsheet for plotting. The total force exerted on the rigid pole was computed by adding all eight load cell data signals and reading a peak from the combined force-time history.

Two square wave pulses from the lone monorail micro switch were recorded on analog tape during the crash test. The time between pulses was determined and the speed was calculated by dividing the wheel spacing (1015 mm) by the time between micro switch pulses.

High-speed film. The high-speed 16-mm film was analyzed via an NAC 160-F film motion analysis system in conjunction with an IBM PC-AT. The overhead and one 90-degree camera were used to acquire pertinent test data. The analyzer reduced the test film frame by frame to Cartesian coordinates that were input into a spreadsheet for analysis. Using the coordinate data and the known speed of the cameras, a displacement-time history was produced. Differentiation of the displacement-time history produced the initial vehicle speed. Data measurements included initial vehicle impact speed, impact roll angle, impact yaw angle, and impact pitch angle.

RESULTS

The Toyota pickup was placed on the FOIL side-impact monorail with its longitudinal centerline perpendicular to the rigid pole centerline. The morning of the test the dummy was positioned in the driver seat using the H-point data and FMVSS 214. The dummy was repositioned to the final position by adjusting the seat back angle and seat track until the proper head-to-B-pillar clearance was achieved. The final head clearance was 57 mm. Due to the rigid pole position limitations, the rigid pole centerline was 12 mm forward of the SID/HIII head cg. The dummy was restrained using the vehicle three-point shoulder-lap belt restraining system. Just prior to testing, the following was noted: the emergency brake was placed in the engaged position, the head rests were positioned in the highest adjustment, the two front seats were aligned, the windows were down, the transmission was placed in second gear, and the key was placed in the "on" position. The Toyota pickup passed over the monorail speed trap, which malfunctioned, resulting in an errant speed measurement. The initial speed was determined from high-speed film and was 29.8 km/h. The initial roll angle was found to be equal to the original roll attitude measured prior to testing (0°). The impact yaw angle was 89 degrees confirmed from high-speed film. Table 6 summarizes the test conditions and selected results.

Table 6. Summary of test conditions and results.

FOIL test number	98S006
Date of test	April 7, 1998
Test vehicle	1994 Toyota pickup truck
Vehicle weight	1336 kg
Test article	FOIL instrumented 300K rigid pole
Temperature inside vehicle	21.1°C
Impact speed: speed trap	No data
16-mm film	29.8 km/h
Impact yaw angle	89°
Head impact point	On head cg

Table 6. Summary of test conditions and results (cont'd).	
Vehicle impact point (mm)	165 mm rearward of vehicle cg
Head-to-B-pillar clearance	57 mm
Traffic accident data (TAD)	9-LP-7
Vehicle damage index (VDI)	09LPAN5
Head Injury Criteria (HIC)	
Limit	1000 g's
Observed	18,643 g's
Start time	0.050 s
Stop time	0.051 s
Interval time	0.001 s
Thoracic trauma data	
Limit (4-door)	90 g's
Peak rib acceleration (FIR100)	126.7 g's
T12 spine (FIR100)	94.1 g's
Thoracic Trauma Index (TTI)	110 g's
Pelvic injury	50.4 g's

<u>Vehicle response.</u> The sharpened rod attached to the rigid pole punctured the vehicle 18 mm rearward of the vertical target tape centerline, denoting the intended target location. The driver door cross section and floor sill began to collapse on contact with the rigid pole. The door had collapsed by 0.010 s. The intruding door struck the dummy's shoulder at approximately 0.024 s. The rigid pole continued to penetrate the occupant compartment, collapsing the B-pillar inward. The pickup truck's cab and bed were bolted to two frame rails but not to each other. As the B-pillar was forced inward, it was displaced 75 mm from its original mounted position without becoming dislodged from the frame rail. The roof rail made contact with the rigid pole at 0.030 s. Double integration of the cg acceleration-time history and the total rigid pole force-time history yielded a maximum dynamic intrusion of 535 mm and 547 mm, respectively. A static measurement was taken between the front door interior surfaces before and after the test. The net change (static intrusion) was 305 mm. Discrepancies between sensor displacement measurements and the static intrusion measurement may be attributed to the cab movement and door thickness. The bench seat was struck at approximately 0.026 s. The bench seat was displaced to the right while the dummy continued toward the pole. The bench seat struck the right door, bending slightly on the right side. The contact

from the bench seat did not cause the door to bulge or buckle. The Toyota pickup truck's undercarriage consisted of two 100-mm by 50-mm box beam frame rails spaced 990 mm apart. After the test, the distance between frame rails was reduced to 838 mm. The static frame rail deflection was 152 mm. The impact location was 165 mm behind the vehicle cg. The lever induced a yaw into the vehicle after the peak load was reached. Integration of the yaw rate transducer positioned under the dash panel on the floor tunnel at the longitudinal and lateral cg, produced a maximum yaw angle of 33 degrees, which occurred at 0.680 s. The vehicle rebounded away from the pole as it continued to yaw counterclockwise (as seen from above). Contact between the main carriage and monorail impeded the vehicle motion, limiting the yaw and rebound. The two door latches remained latched during the collision. No evidence of fuel leakage or fuel system component damage was observed. The peak cg acceleration was determined to be 21.0 g's (275 kN) and occurred 0.048 s after impact. Table 7 lists the vehicle accelerometers and their three-dimensional coordinate location referenced from the right front wheel hub. The right front wheel hub was 280 mm above ground (not on guidance rails). Included in the table are peak accelerations from each accelerometer (SAE class 60 data).

Table 7. Vehicle sensor locations and peak measurements.

Sensor	X (mm)	Y (mm)	Z (mm)	Peak g's (+)	Peak g's (-)
cg accelerometer A_x	-740	635	240	5.6	8.3
cg accelerometer A_y	-740	635	240	2.7	21.0
cg accelerometer A_z	-740	635	240	6.6	16.1
cg redundant A_x	-740	635	240	4.5	9.1
cg redundant A_y	-740	635	240	2.8	20.5
Engine block A_x	-113	785	570	6.0	8.3
Engine block A_y	-113	785	570	5.3	16.2
Trunk A_x	-2770	752	330	7.7	3.1
Trunk A_y	-2770	752	330	1.7	16.2
Driver seat A_y	-1440	1305	200	23.4	148.0

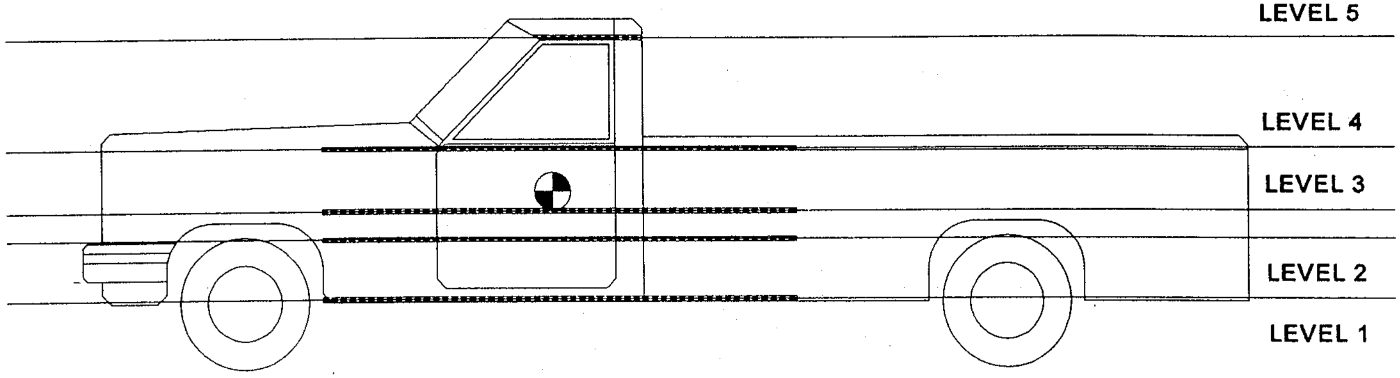
After the test, damage profile measurements were taken using two techniques. Table 8 summarizes the damage profile distance (DPD) technique. Figure 7 depicts the driver-side profile measurements before and after the test. The measurements were made using a reference line parallel to the driver side of the vehicle. The parallel line was drawn a certain distance from and perpendicular to a line formed by the passenger side sill across from the impact location. This allowed the same reference line to be drawn after the test to measure the post-test measurements. The measurements were made in 75-mm and 150-mm increments forward and aft of the impact point. After the test, measurements were taken at the same points forward and aft, rather than measuring at the same increments. From the figure, the maximum static deflection recorded was 416 mm at the mid-door height 76 mm forward of the vertical impact target tape.

Data plots of the data from transducers mounted to the test vehicle are presented in appendix A. Photographs taken from high-speed film during impact and photographs of the pre- and post-test environment are presented in appendix C.

Table 8. DPD crush measurments.

L	D	Max	LF	C1	C2	C3	C4	C5	C6	LR
1065	-72	450	-737	0	101	232	414	259	0	328

All measurements in mm.
L = total length of crush.
D = distance from vehicle cg to mid-point of L
Max = maximum crush
LF, LR = distance from impact point to points forward and rearward where no damage was observed.
C1-6 = incremental crush measurements along L, equally spaced.



Level 1 - Sill height   Level 2 - Occupant H-point   Level 3 - Mid-door   Level 4 - Window sill   Level 5 - Window top

			Distance from impact point (mm).													
LEVEL	HEIGHT		-991	-838	-686	-533	-381	-229	-152	-76	0	76	152	229	381	533
1	345	PRE		795	790	795	800	800	800	800	800	800	795	795	795	795
	339	POST		814	861	907	968	1066	1124	1153	1137	1092	1018	942	754	745
		CRUSH	0	19	71	112	168	266	324	353	337	292	223	147	-41	-50
2	650	PRE	700	700	700	700	720	725	730	730	730	730	730	730	725	710
	664	POST	712	735	798	881	974	1065	1108	1146	1128	1091	1026	947	675	661
		CRUSH	12	35	98	181	254	340	378	416	398	361	296	217	-50	-49
3	675	PRE	700	700	700	700	720	725	730	730	730	730	730	730	725	710
	689	POST	712	735	798	881	974	1065	1108	1146	1128	1091	1026	947	675	661
		CRUSH	12	35	98	181	254	340	378	416	398	361	296	217	-50	-49
4	985	PRE	760	750	750	750	750	750	750	750	750	750	750	750	750	750
	1003	POST	768	771	803	888	968	1062	1105	1128	1117	1072	992	927	708	697
		CRUSH	8	21	53	138	218	312	355	378	367	322	242	177	-42	-53
5	1450	PRE					925	900	895	890	890	890	890	890		
	1481	POST					950	1002	1045	1066	1034	996	960	937		
		CRUSH	0	0	0	0	25	102	150	176	144	106	70	47	0	0
All units of measurement are in mm.																

Figure 7. Vehicle profile measurements, test 98S006.

Occupant response. The SID/HIII remained vertical in the driver seat with only minor vibration induced by the tow and guidance system. The first contact occurred 0.024 s after impact and was between the door and the SID/HIII's shoulder region. The driver door continued to collapse as the dummy moved toward the pole. The rigid pole centerline was aligned 12 mm forward of the head cg and the pole struck the vehicle 18 mm rearward of the intended location on the vehicle. These factors coupled with the slight oscillating motion of the dummy induced an actual head contact point on the head cg. The dummy's head did not contact the B-pillar before striking the rigid pole approximately 0.050 s after impact. The neck bent over to the left as the dummy's shoulder was stopped by the door contact. The pole made contact on the side of the dummy's face. The oval mark on the side of the face was 75-mm-long by 50-mm-wide. This large oval contact suggested that the dummy was more vertical when striking the pole as opposed to leaning over toward the pole. The pole penetration pushed the bench seat and the dummy's pelvis to the right. However, the dummy's right knee was wedged between the dash and steering column, which caused a bend in the femur segment of the leg just above the right knee. No rotation was observed in the head or torso of the SID/HIII during the test. The dummy's torso was first to rebound back across the vehicle over the passenger side seat, and the neck whipped the head over, making the right side of the dummy's head hit the right shoulder. After the test, no physical damage to the SID/HIII was observed. The dummy's final position was slumped over, leaning toward the passenger seat while his lower torso remained wedged in the driver seat. The dummy's feet remained free and were not pinched or crushed. However, the dummy's knees were wedged under and between the steering column, door panel, and dash panel. Yellow chalk was found on the rigid pole, verifying contact between the dummy's head and the pole. Green chalk from the dummy's side was on the door as expected. Black chalk from the dummy's femur and leg was found on the driver door along and underneath the arm rest.

The rib and spine acceleration data produced a TTI of 110 g's. This is above the two-door vehicle limit of 90 g's specified in the FMVSS 214. The three head accelerometers produced a HIC value of 18,643 g's. This value is above the 1000 g's required in the proposed FMVSS 201 amendment. The recorded pelvic injury for this test was 50.4 g's, below the 130 g's limit specified in FMVSS 214. Table 9 summarizes the data collected from the SID/HIII.

Table 9. Summary of SID/HIII data.

Recorded Data	Maximum positive	Maximum negative
Head X-axis acceleration (g's)	146.5	-30.2
Head Y-axis acceleration (g's)	63.5	-1075.3
Head Z-axis acceleration (g's)	81.1	-95.7
X-axis neck force load cell (N)	583.0	-272.8
Y-axis neck force load cell (N)	2830.5	-543.2
Z-axis neck force load cell (N)	1216.2	-1969.7
X-axis neck moment load cell (1000 mm·N)	27.1	-116.3
Y-axis neck moment load cell (1000 mm·N)	22.0	-18.9
Z-axis neck moment load cell (1000 mm·N)	0.20	-0.09
Left upper rib acceleration (P)	7.6	-120.8
Left upper rib acceleration (R)	7.5	-126.7
Left lower rib acceleration (P)	8.3	-97.1
Left lower rib acceleration (R)	7.9	-99.2
Spine T12 Y acceleration (P)	15.0	-79.6
Spine T12 Y acceleration (R)	17.1	-94.1
Pelvis Y acceleration	9.4	-50.4

Head and neck load data are SAE class 1000.
Shaded area data are SAE class 600 (neck moment data).
Remaining data obtained from FIR100 filter output.

The values from the head accelerometers and the neck load cells were taken from class 1000 data (neck moments class 600) while the remainder are from data filtered using a FIR100 filter. Data plots from the SID/HIII transducers are presented in appendix B. All data plots are of class 1000 data.

<u>Rigid pole.</u> The load cells measured eight separate forces on the rigid pole. The total load from summing the eight load cells was 176,500 N. The significant loads were contributed by the roof-rail, floor-sill, and middle-point of the driver door. Table 10 summarizes the load cell data (SAE class 60). Data plots from the rigid pole load cells are presented in appendix D.

Table 10. Summary of rigid pole data.		
Load cell/height (mm)	**Peak force (1000 N)**	**Time (ms)**
Top face	-2.8	55.2
Upper load cell/2,057	-1.6	96.6
Lower load cell/1,816	-1.6	53.6
Middle-upper face	-33.2	51.8
Upper load cell/1,650	-14.3	52.2
Lower load cell/1,168	-19.3	51.6
Middle-lower face	-65.0	44.6
Upper load cell/978	-23.0	43.2
Lower load cell/648	-42.3	45.4
Bottom face	-86.8	48.8
Upper load cell/470	-69.3	48.6
Lower load cell/90	-17.8	58.4
Total, rigid pole	-176.5	50.8

CONCLUSIONS AND OBSERVATIONS

Visual inspection of the Toyota pickup truck after the collision produced some immediate observations and conclusions. Fuel system and door latch integrity were not breached by the broadside collision with the FOIL instrumented rigid pole. The impact speed and impact location were within reasonable tolerances, indicating accurate test procedures and setup. The dummy head cg made direct contact with the rigid pole without interference from any vehicle structures, specifically the B-pillar. The direct contact yielded an HIC value (18,643 g's) 18 times larger than values obtained during previous tests conducted where the dummy was seated with its head partially behind the B-pillar.

The HIC value of 18,643 g's is significantly higher than values obtained during two previously conducted FMVSS 201 type crash tests. The two tests conducted following the same test procedures were FOIL test numbers 97S005 (1995 Honda Accord LX) and 98S005 (1994 Ford Explorer). The results from these tests can be found in the reports *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S005,*[4] and *1994*

Ford Explorer Broadside Collision with a Narrow Fixed Object: FOIL Test Number 98S005[7]. The HIC values for 97S005 and 98S005 were 8,824 g's and 4,908 g's, respectively. The initial head contact points in tests 97S005 and 98S005 were slightly rearward of the head cg. In addition to not taking a direct hit, the offset hit may have induced enough rotation in the dummy's head so as not to allow a substantial blow. The head cg of the dummy in test 98S006 (Toyota pickup truck) made direct contact with the rigid pole; no rotation in the neck and head was observed. The oval chalk mark on the head was centered around the dummy head cg and was larger than the mark recorded on the head of the dummy after the Ford Explorer test (98S005). Another difference between the tests was that the Honda Accord and the Ford Explorer utilize independent bucket seats as opposed to the bench seat in the Toyota pickup truck. The bucket seats are free to move to the right, dip downward, and rotate upon contact. In all three tests, the seat accelerometer recorded seat contact before any dummy contact. However, the bench seat did not demonstrate any degrees of freedom. The movement in the bucket seat may have caused the dummy head to have a lower relative velocity to the pole, thus causing relatively lower contact. The bucket seat vs. bench seat variable may also have contributed to lower TTI values. The TTI values in the Honda Accord and Ford Explorer tests were 68 g's and 74 g's, respectively, both below the four-door limit (85 g's) specified in FMVSS 214. The TTI value calculated for the Toyota pickup truck was 110 g's (two-door limit 90 g's). Other physical differences, such as door thickness and relative position of the dummy in relation to the door, may have contributed to the large discrepancies between HIC values. The door width of the Toyota pickup truck is less than that of the Honda Accord and Ford Explorer (105 mm vs. 210 mm and 190 mm). The dummy was positioned closer to the door, and thus the pole, in the Toyota pickup truck test. The HS dimension from figure 4 reveals that, in the Honda Accord and Ford Explorer, the dummy head was 326 mm and 360 mm from the window opening. The HS dimension for the Toyota pickup truck test was 200 mm.

In cases where the B-pillar cannot serve as a countermeasure against injury during a broadside collision, a side dynamic head restraint system may aid in reducing occupant risk. The laboratory test procedures and setup described in this report may be used to evaluate the safety performance of side dynamic head restraint systems.

APPENDIX A. DATA PLOTS FROM VEHICLE ACCELEROMETERS

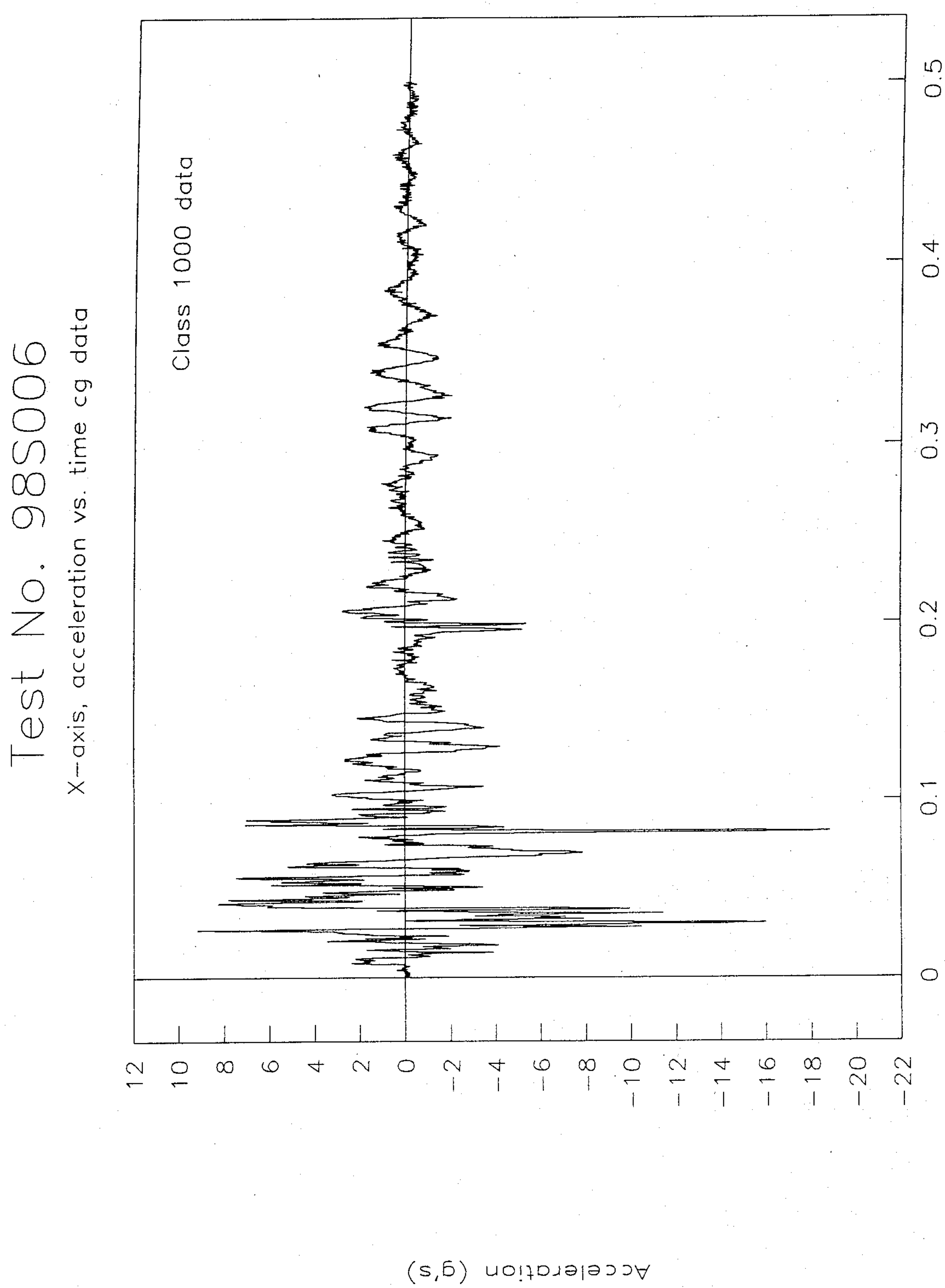


Figure 8. Acceleration vs. time, X-axis cg, test 98S006.

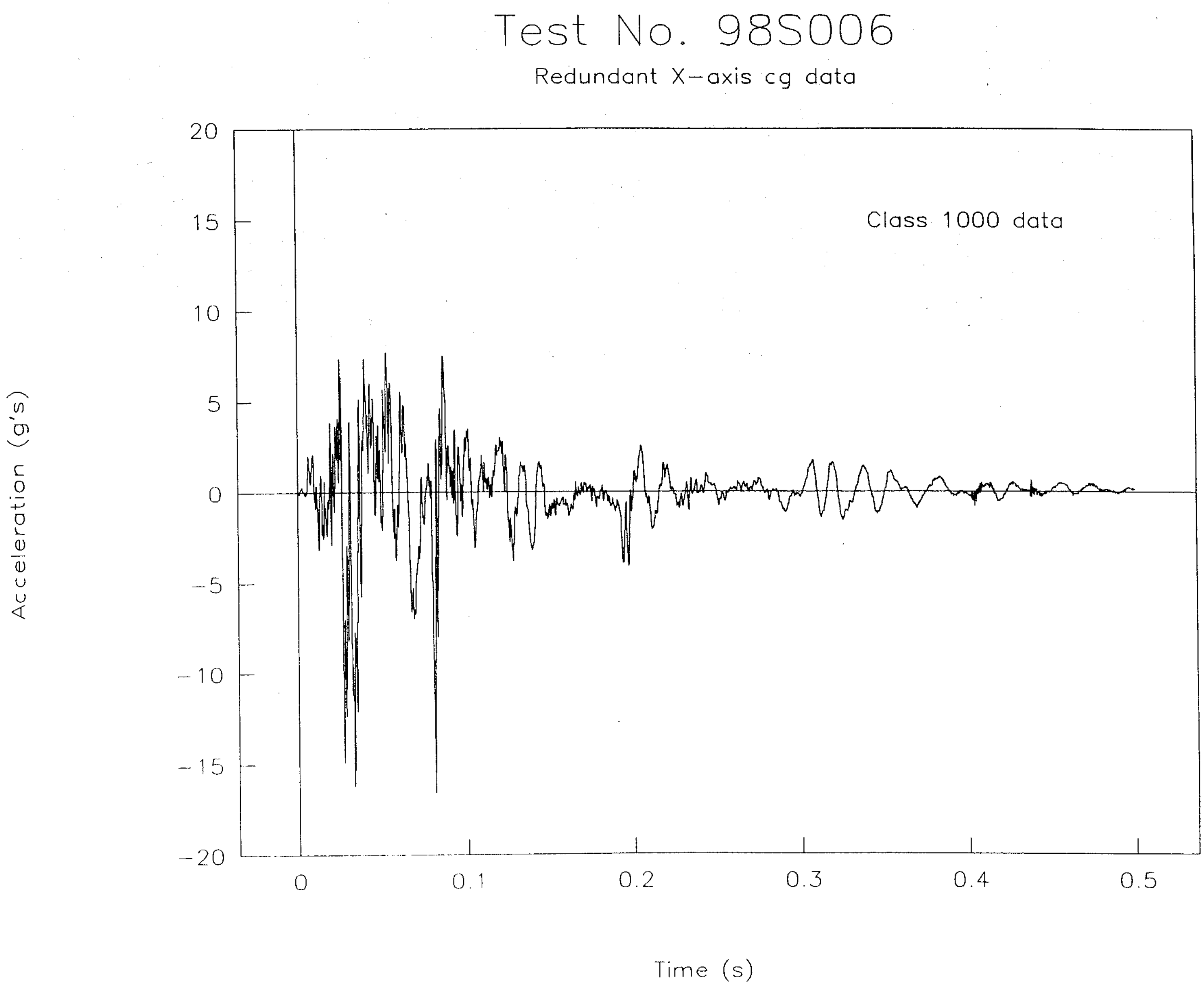


Figure 9. Acceleration vs. time, redundant X-axis cg, test 98S006.

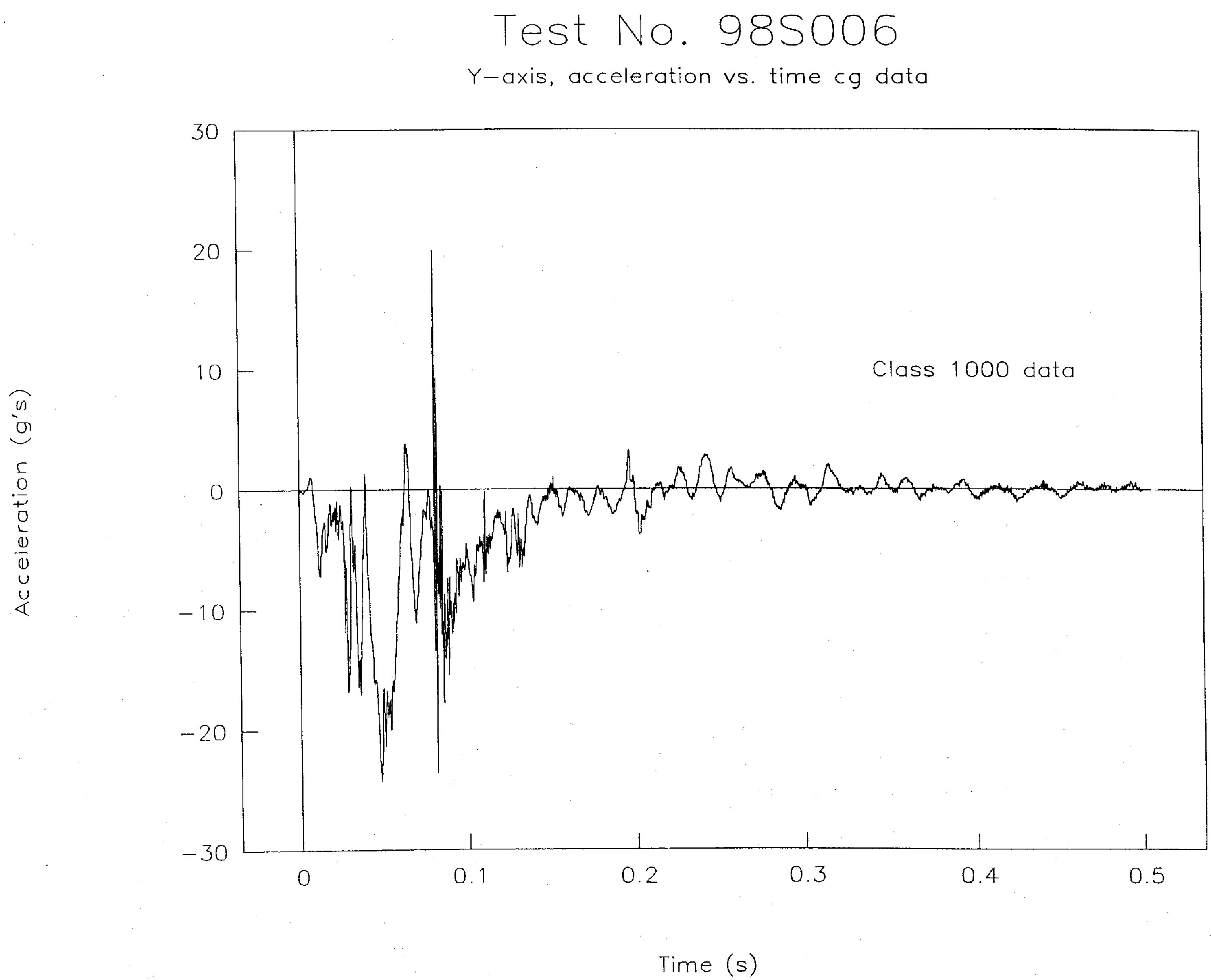


Figure 10. Acceleration vs. time, Y-axis cg, test 98S006.

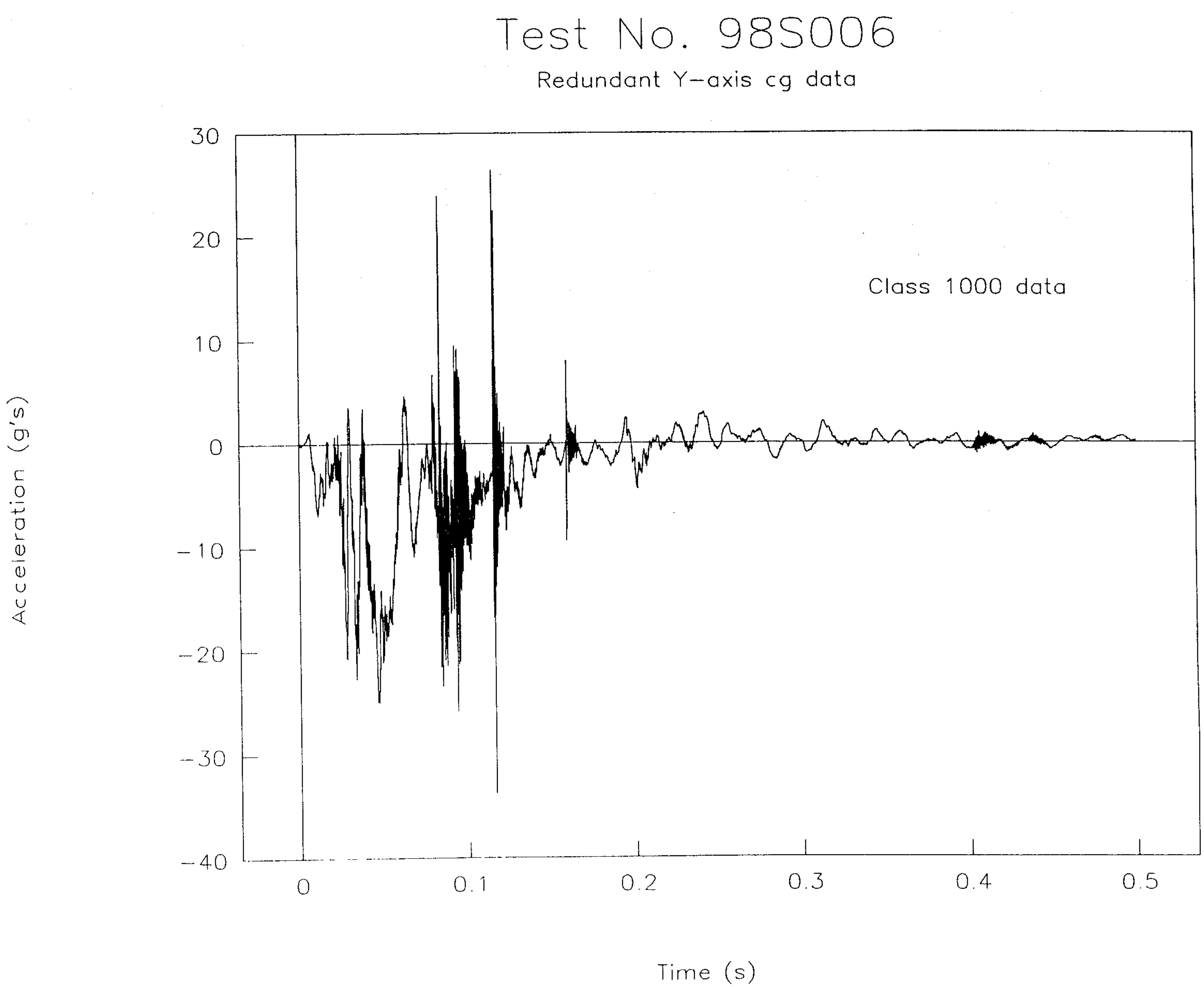


Figure 11. Acceleration vs. time, redundant Y-axis cg, test 98S006.

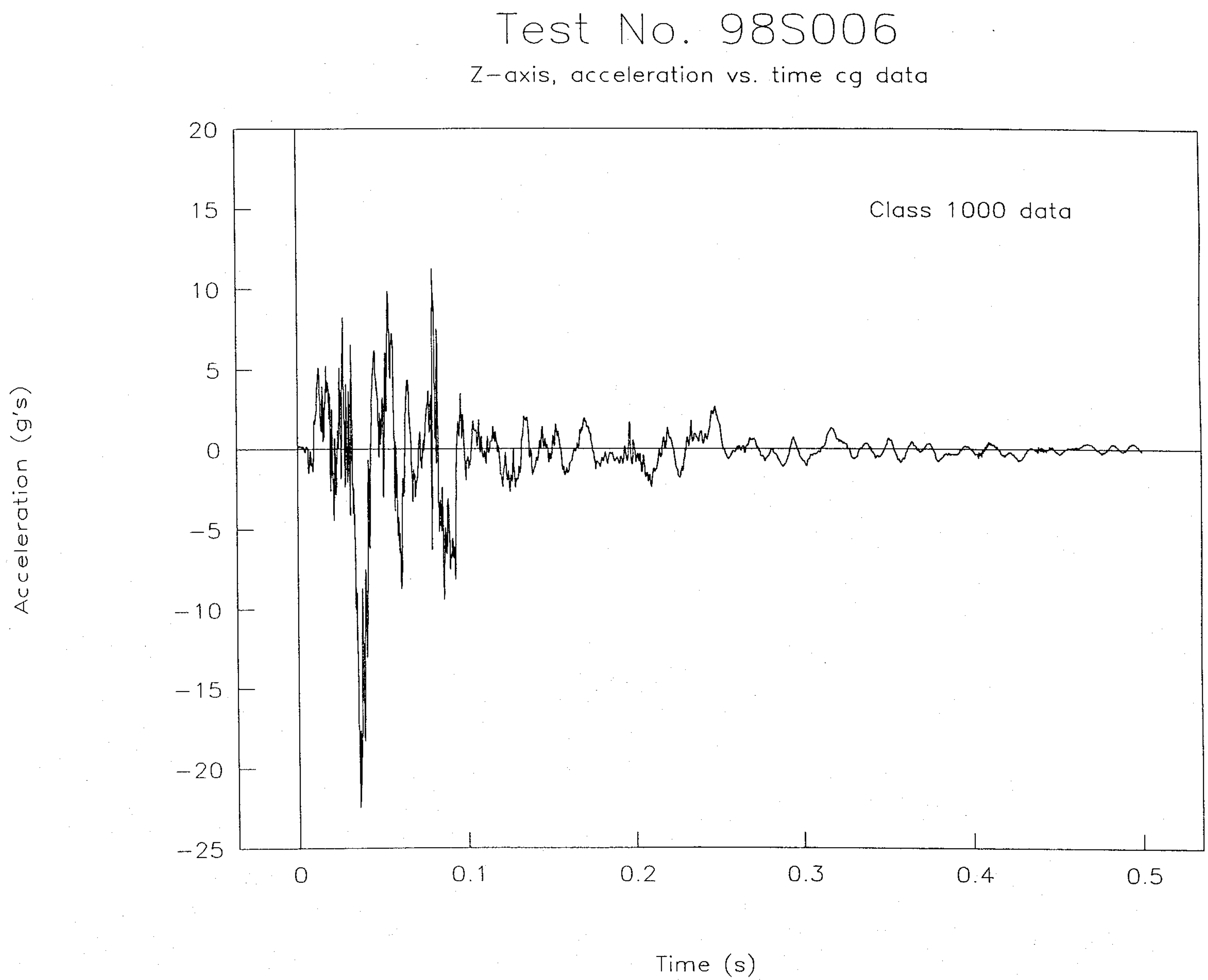


Figure 12. Acceleration vs. time, Z-axis cg, test 98S006.

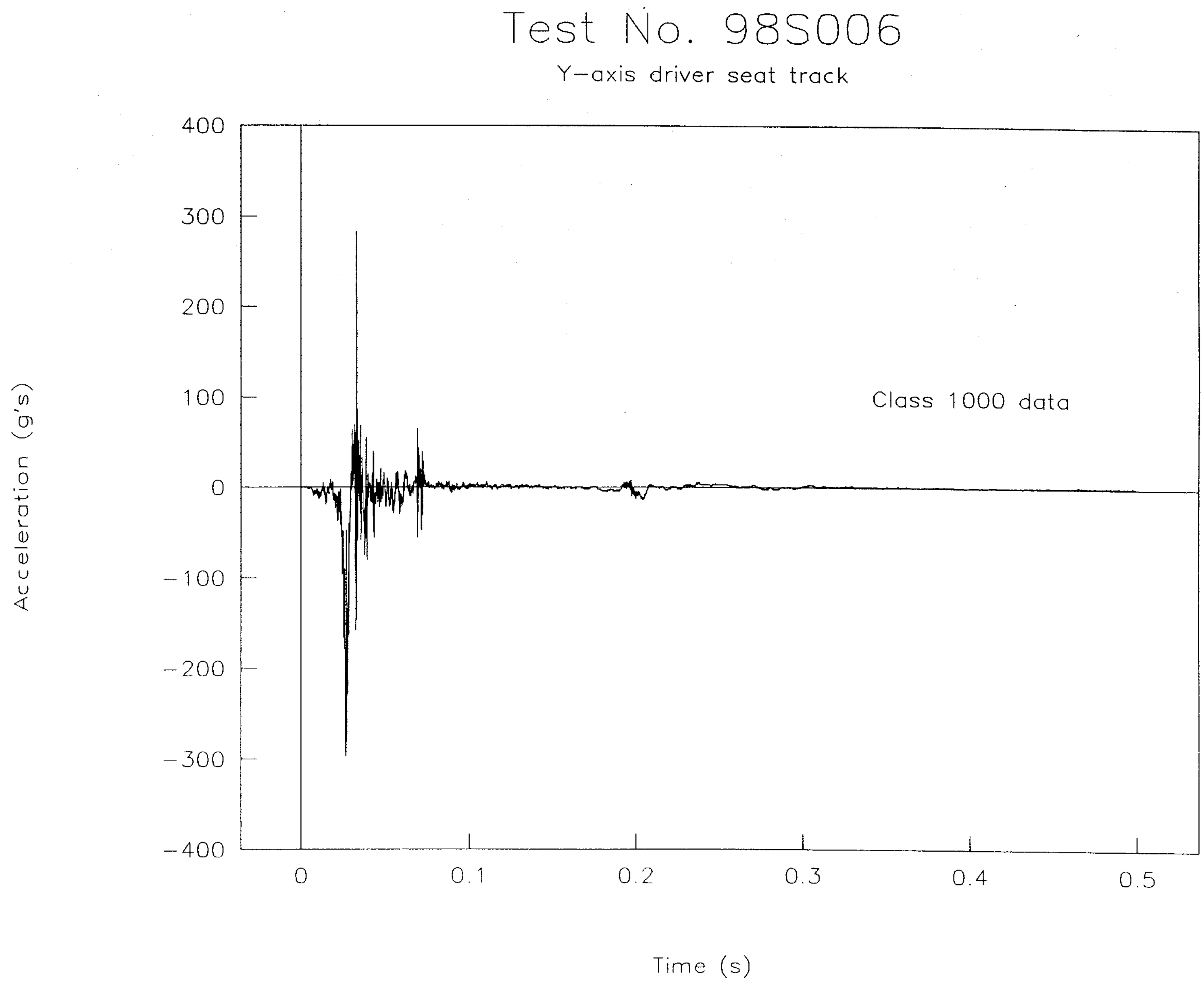


Figure 13. Acceleration vs. time, Y-axis driver seat track, test 98S006.

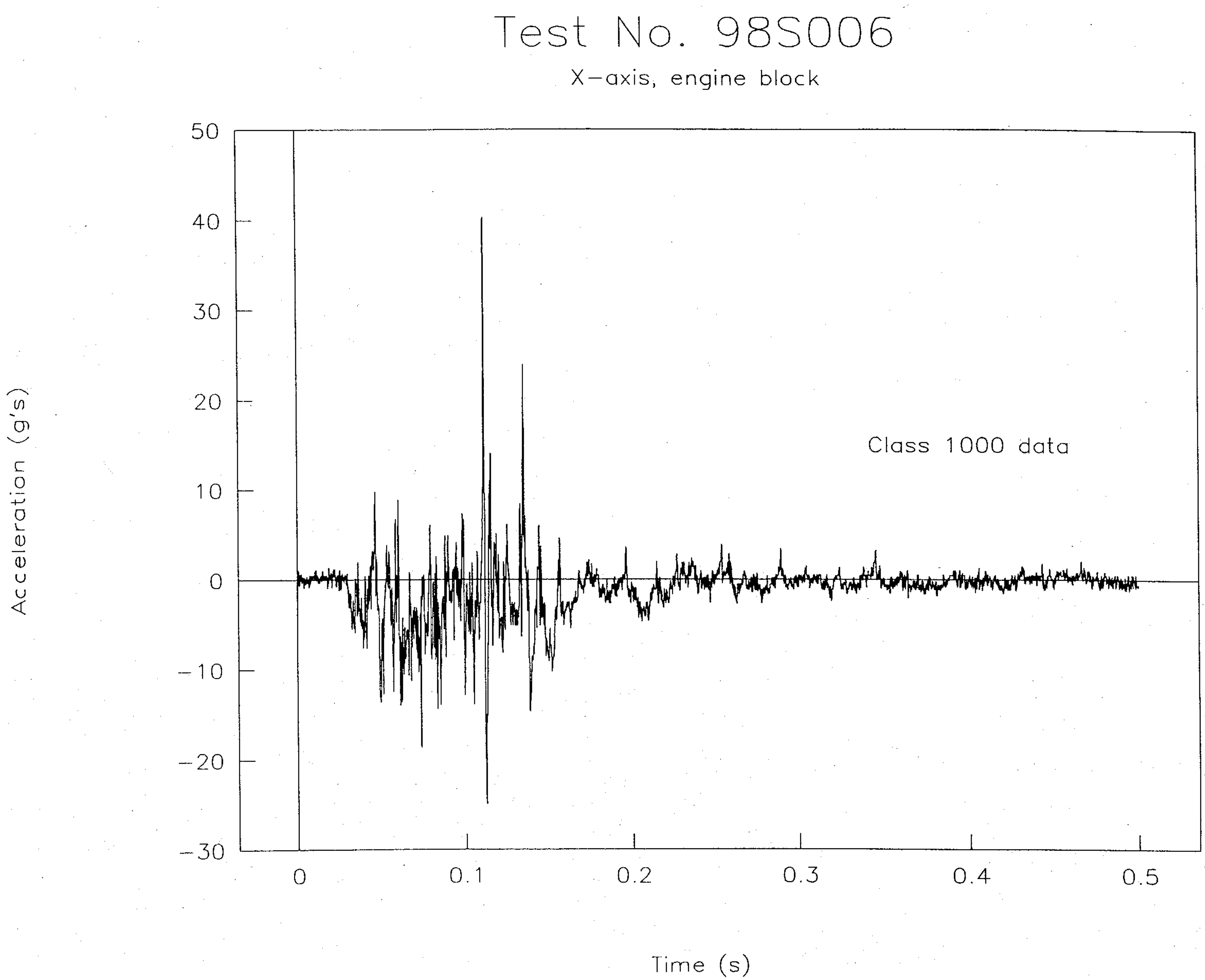


Figure 14. Acceleration vs. time, X-axis engine block, test 98S006.

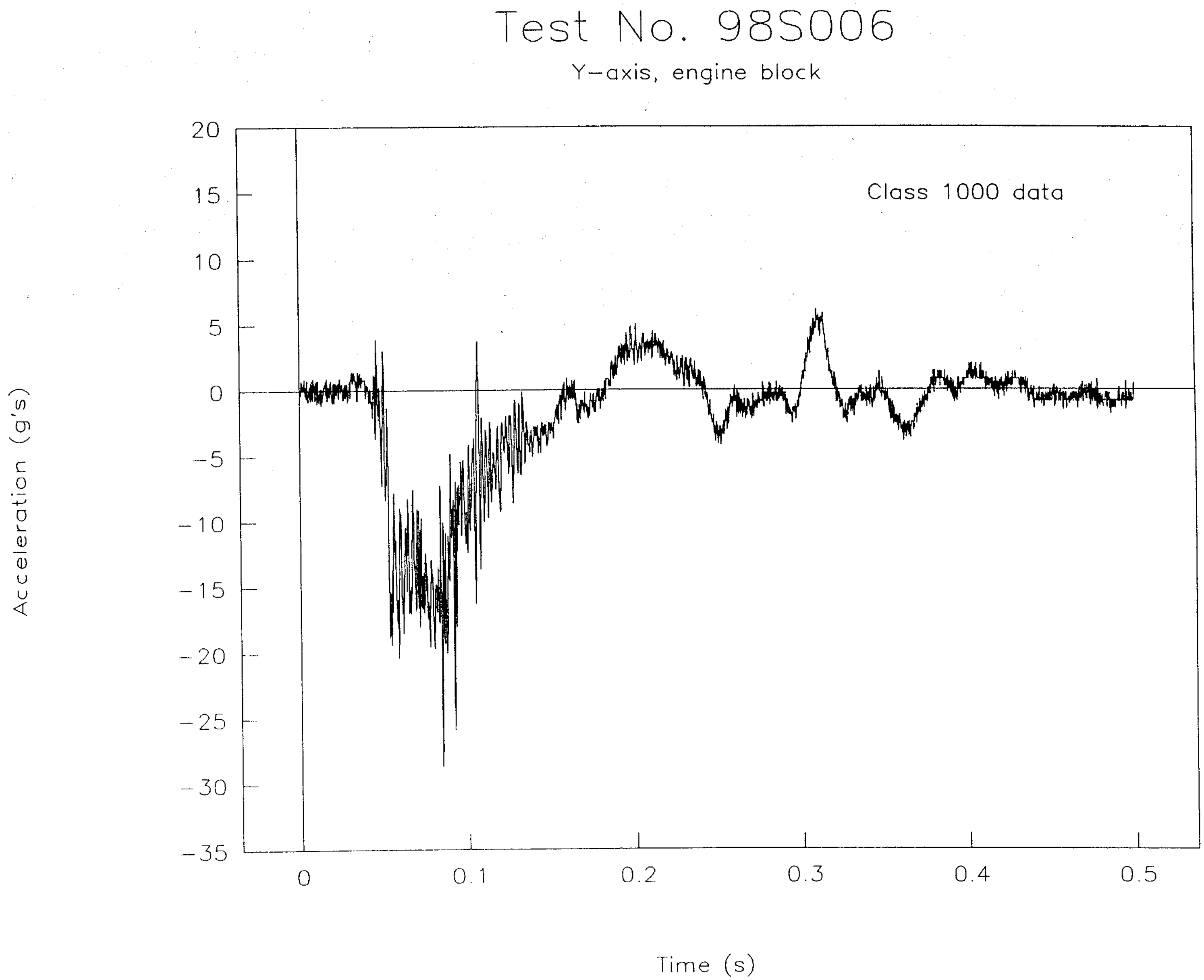


Figure 15. Acceleration vs. time, Y-axis engine block, test 98S006.

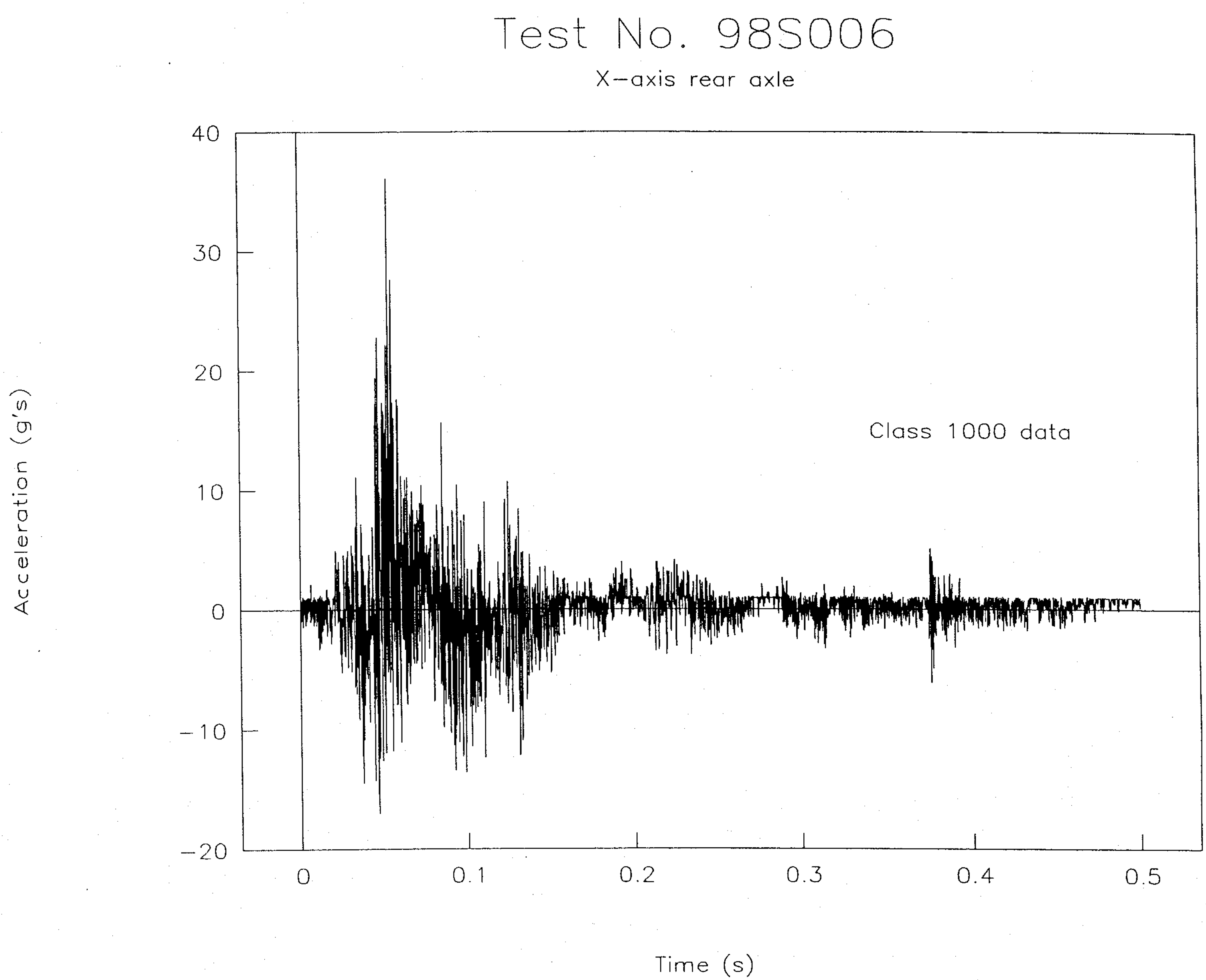


Figure 16. Acceleration vs. time, X-axis rear axle, test 98S006.

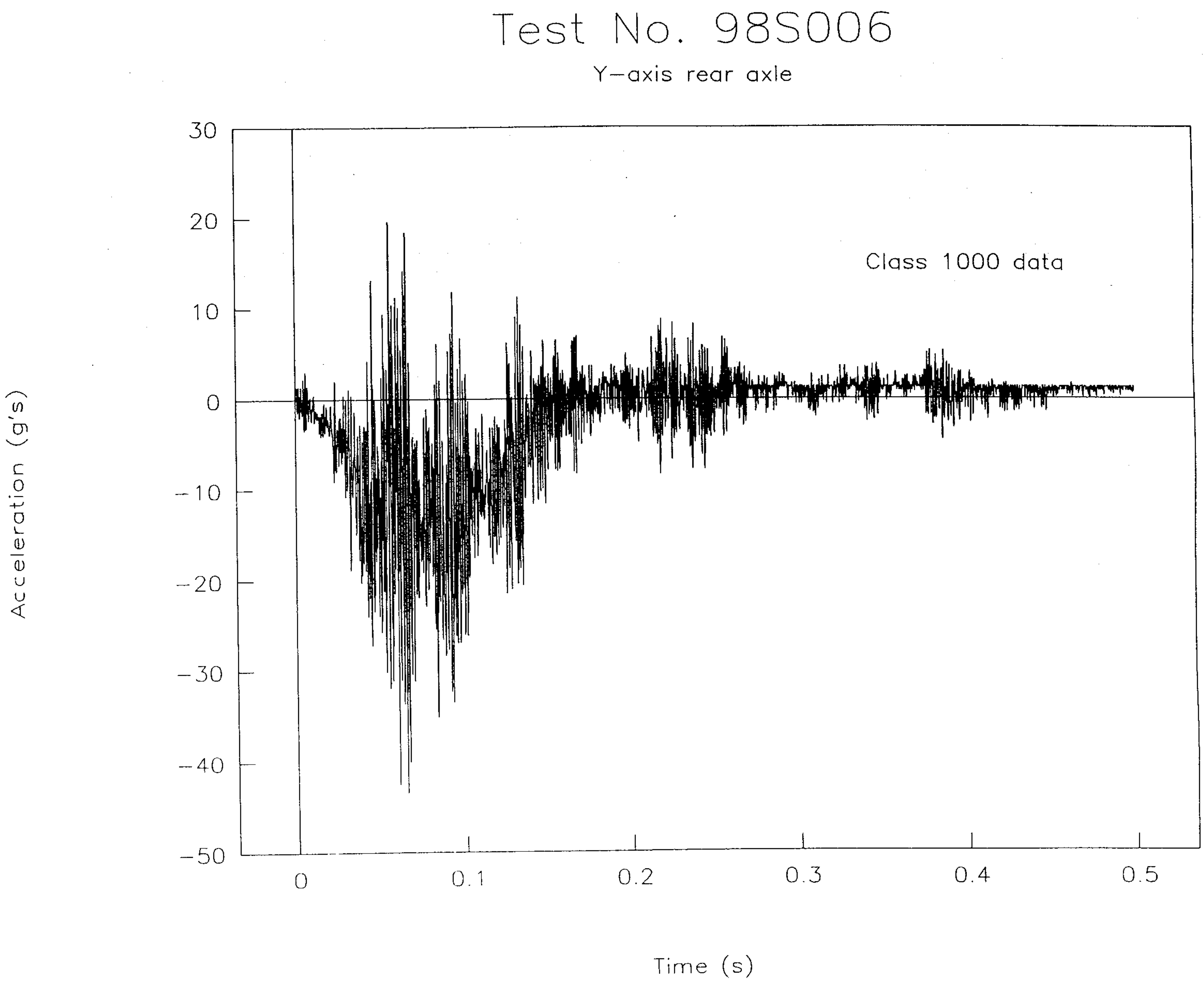


Figure 17. Acceleration vs. time, Y-axis rear axle, test 98S006.

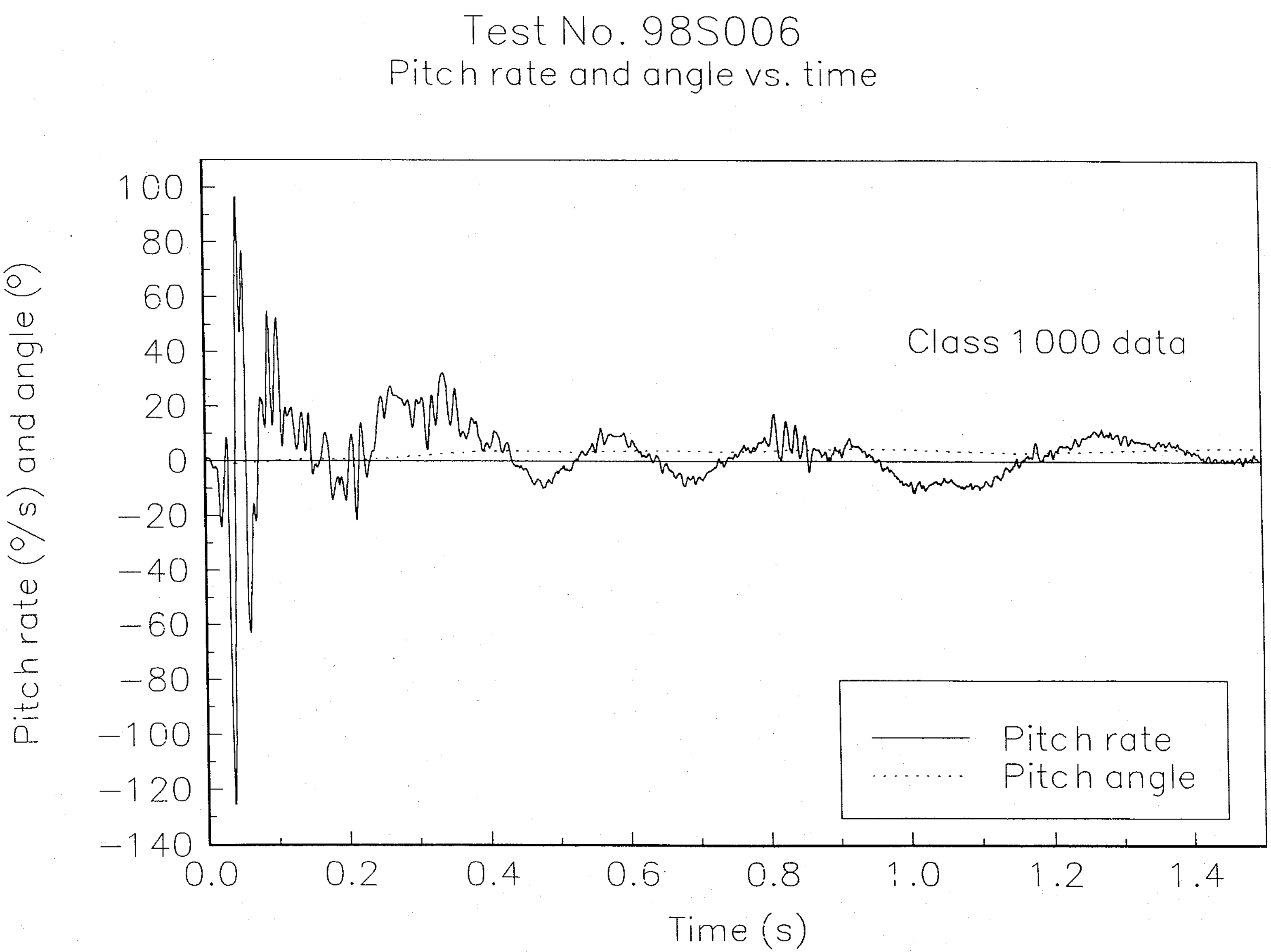


Figure 18. Pitch rate and angle vs. time, test 98S006.

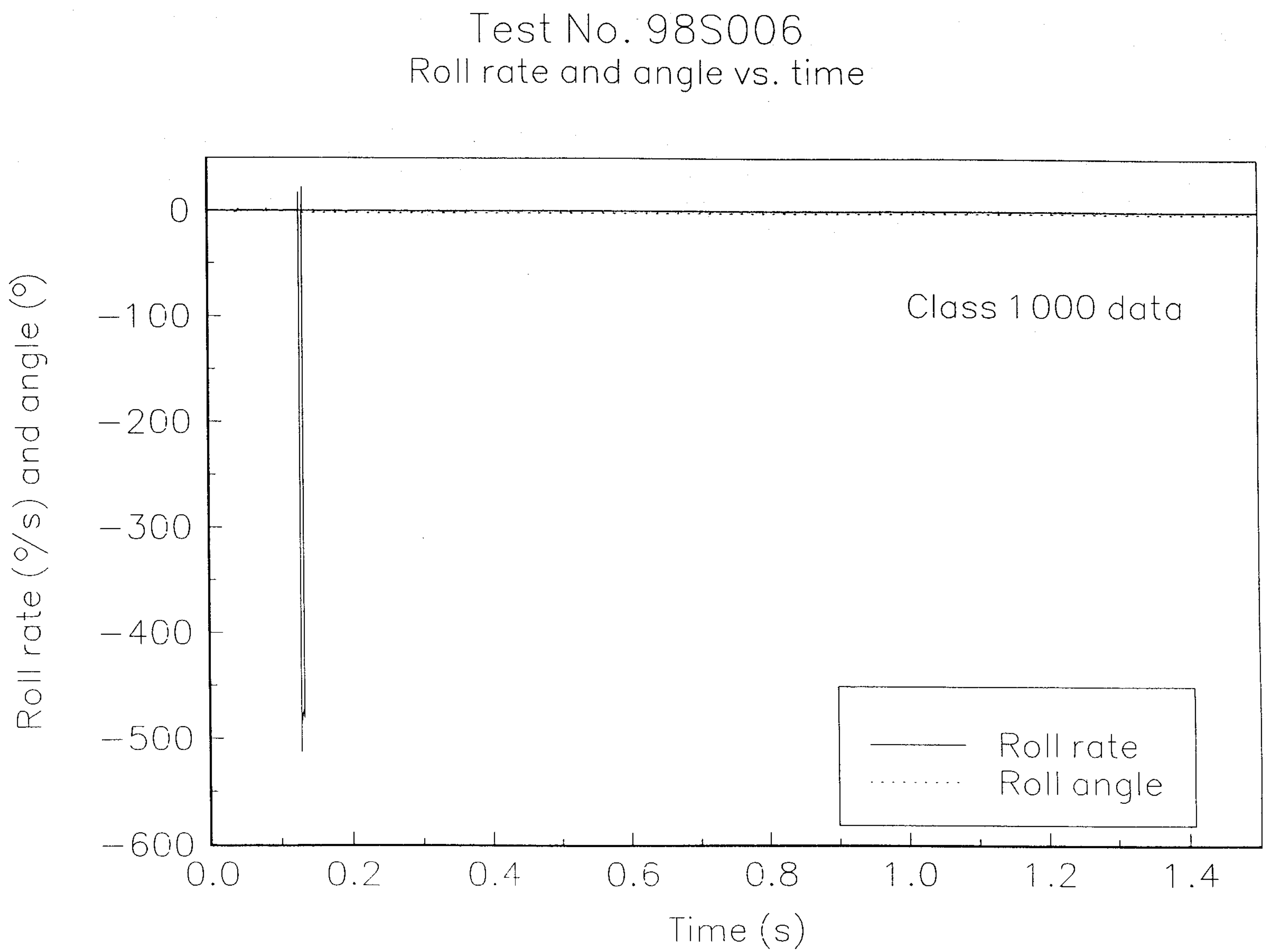


Figure 19. Roll rate and angle vs. time, test 98S006.

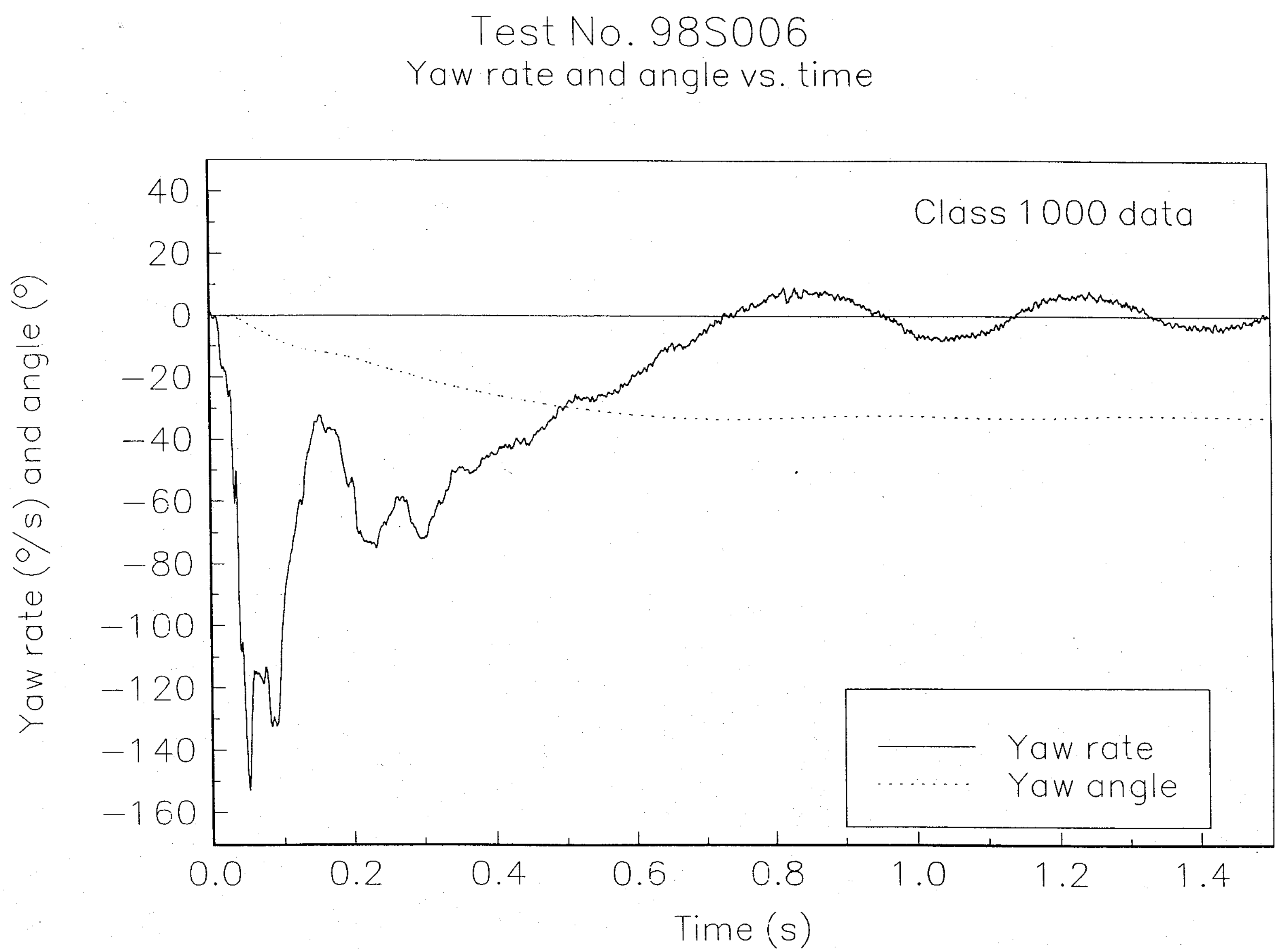


Figure 20. Yaw rate and angle vs. time, test 98S006.

APPENDIX B. DATA PLOTS FROM INSTRUMENTED SID/HIII

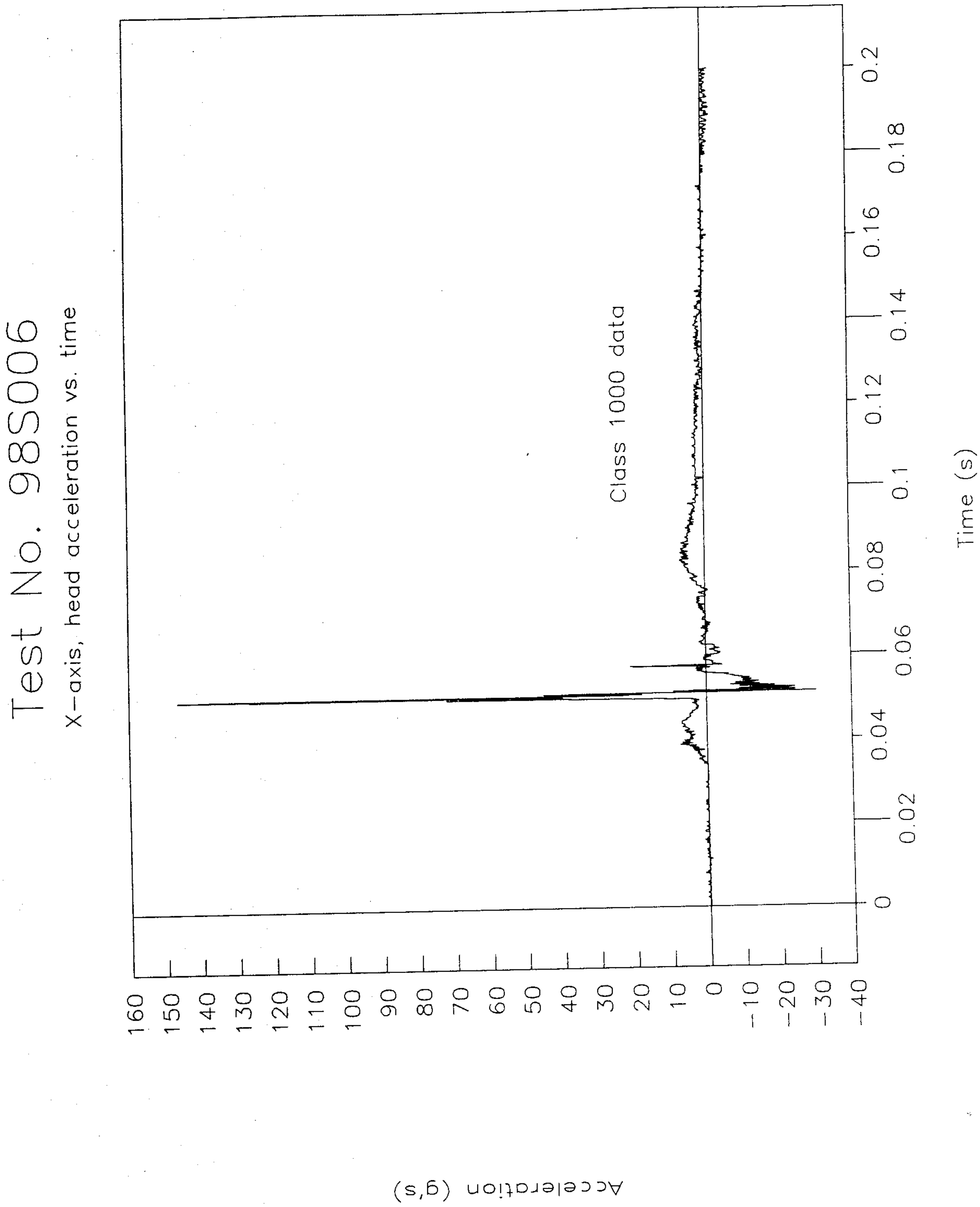


Figure 21. Acceleration vs. time, X-axis head, test 98S006.

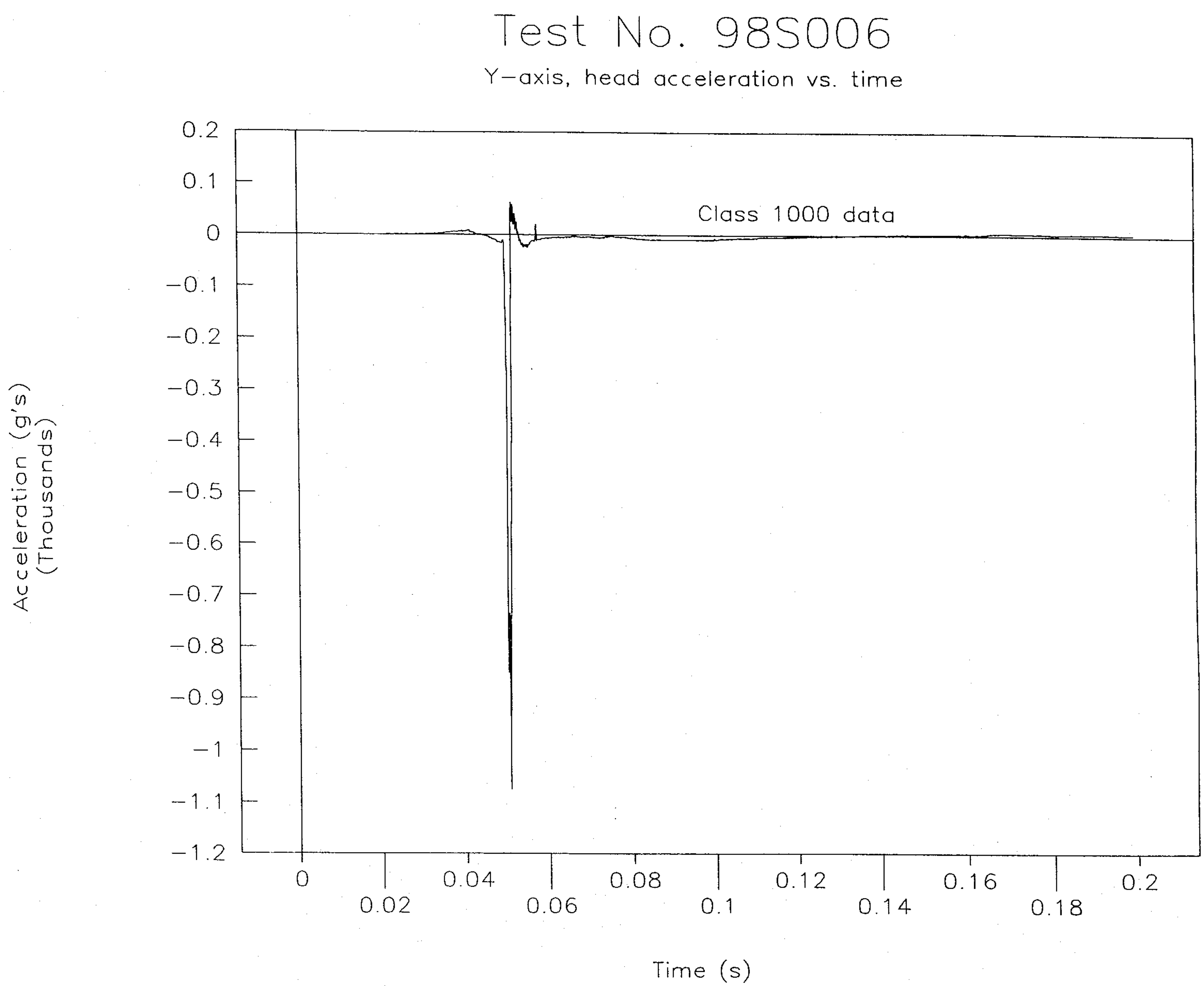


Figure 22. Acceleration vs. time, Y-axis head, test 98S006.

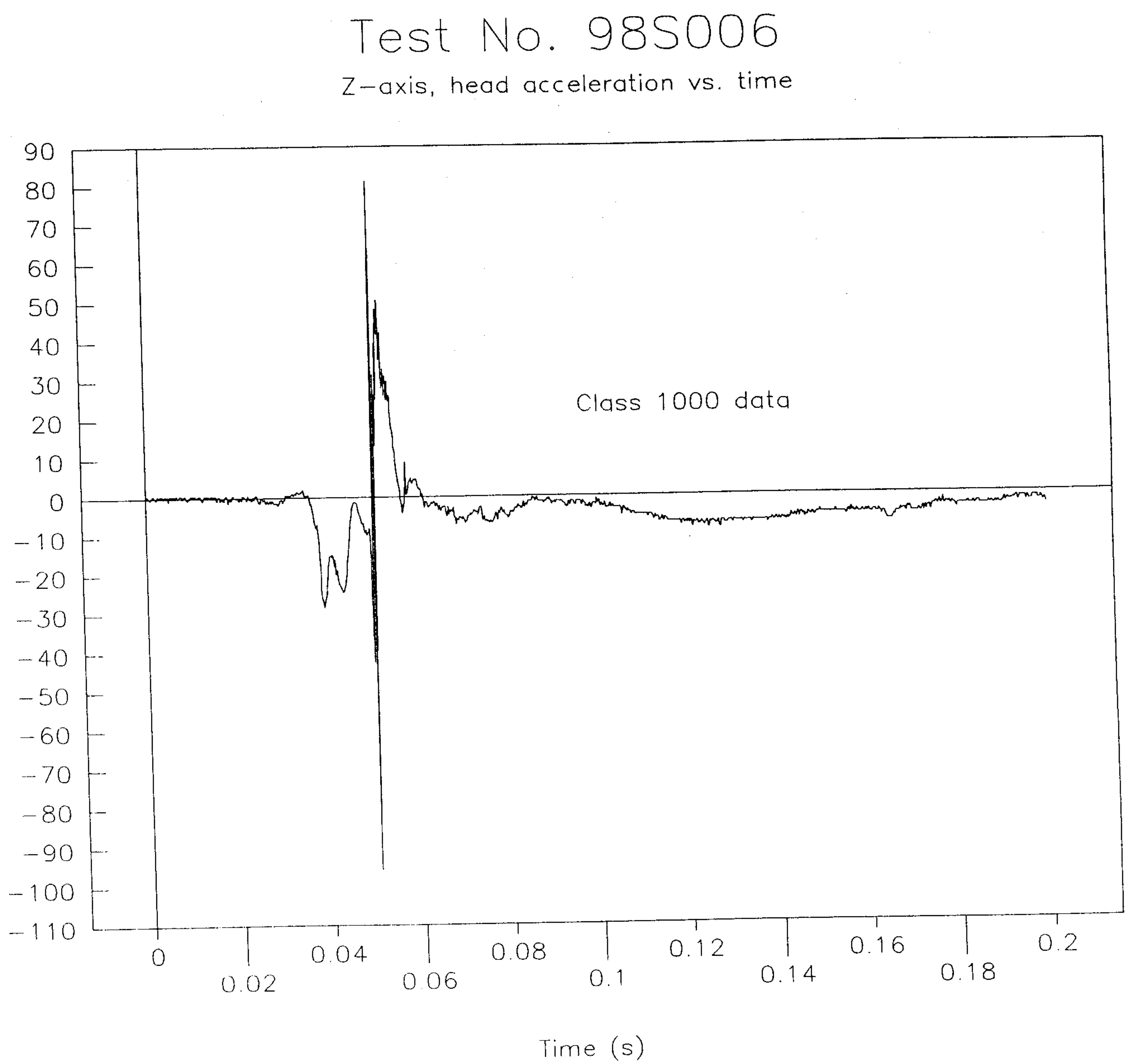


Figure 23. Acceleration vs. time, Z-axis head, test 98S006.

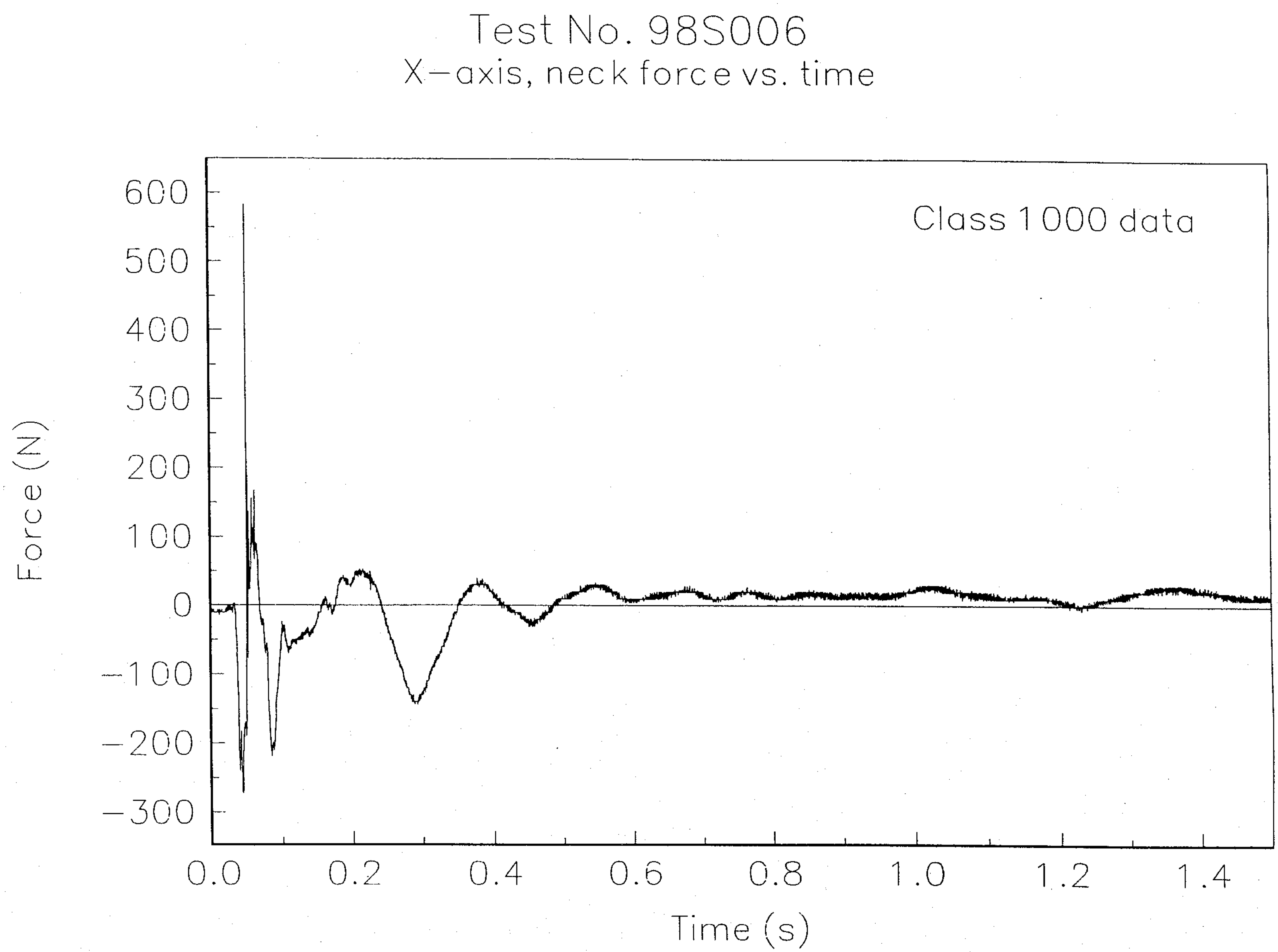


Figure 24. Force vs. time, X-axis neck, test 98S006.

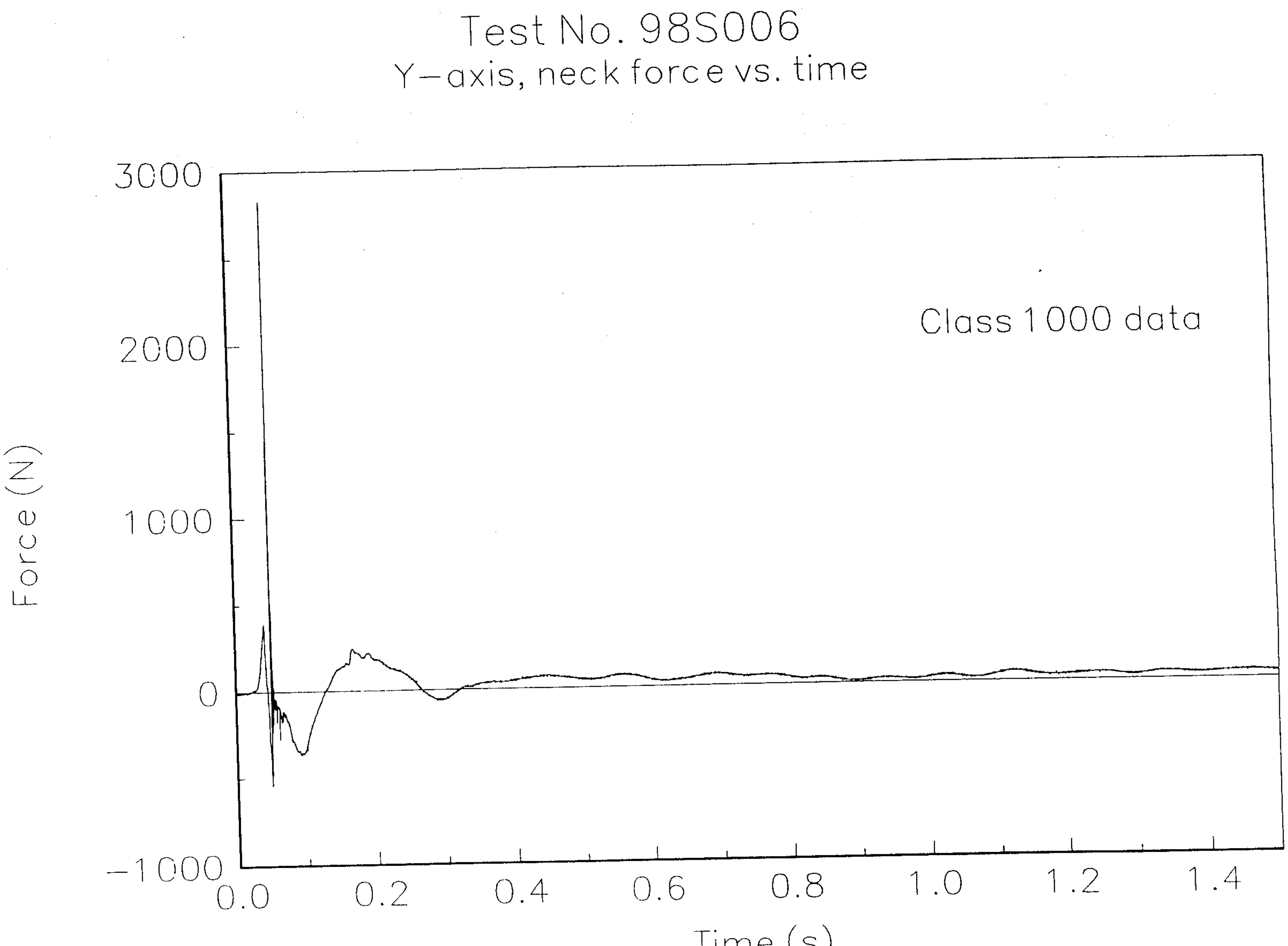


Figure 25. Force vs. time, Y-axis neck, test 98S006.

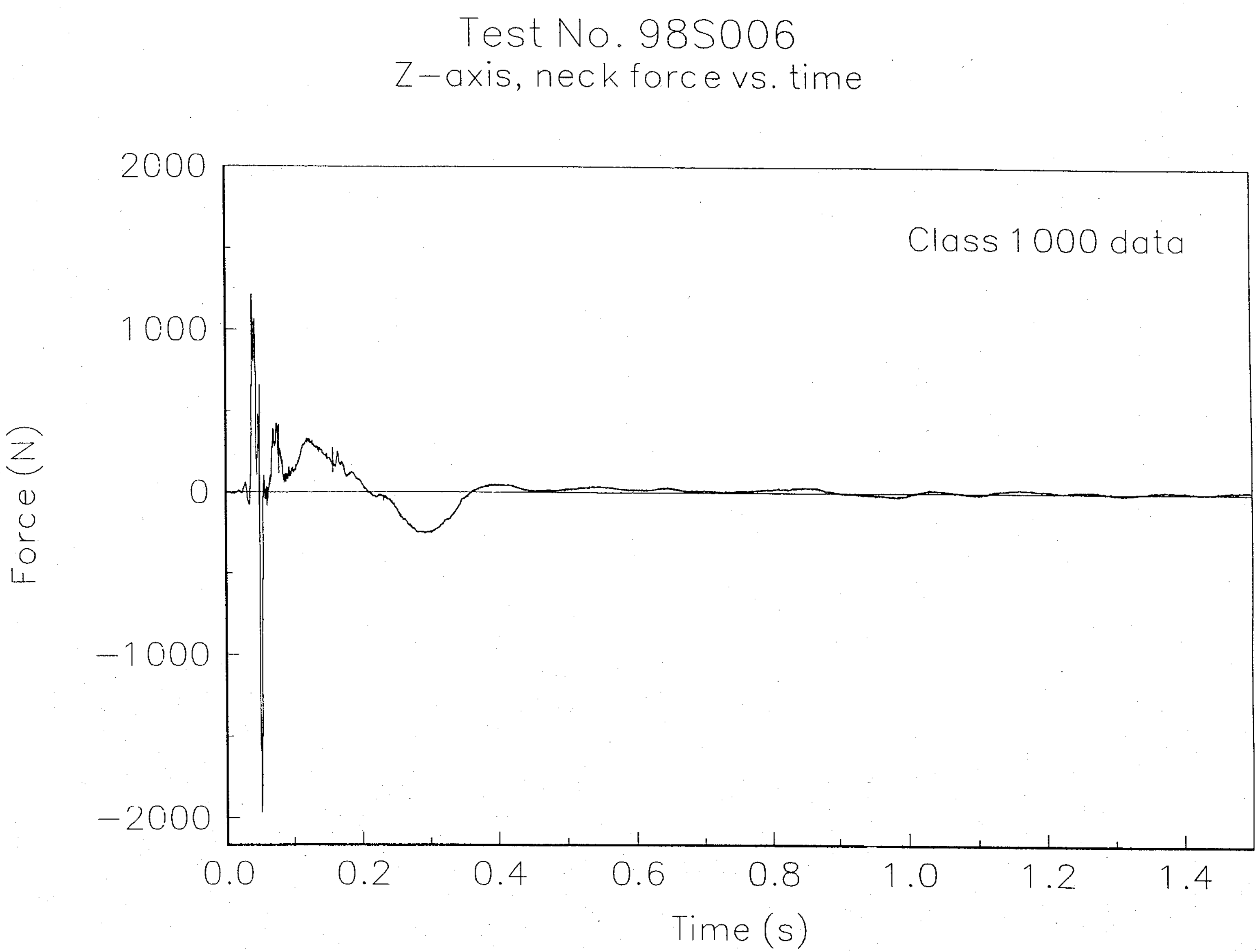


Figure 26. Force vs. time, Z-axis neck, test 98S006.

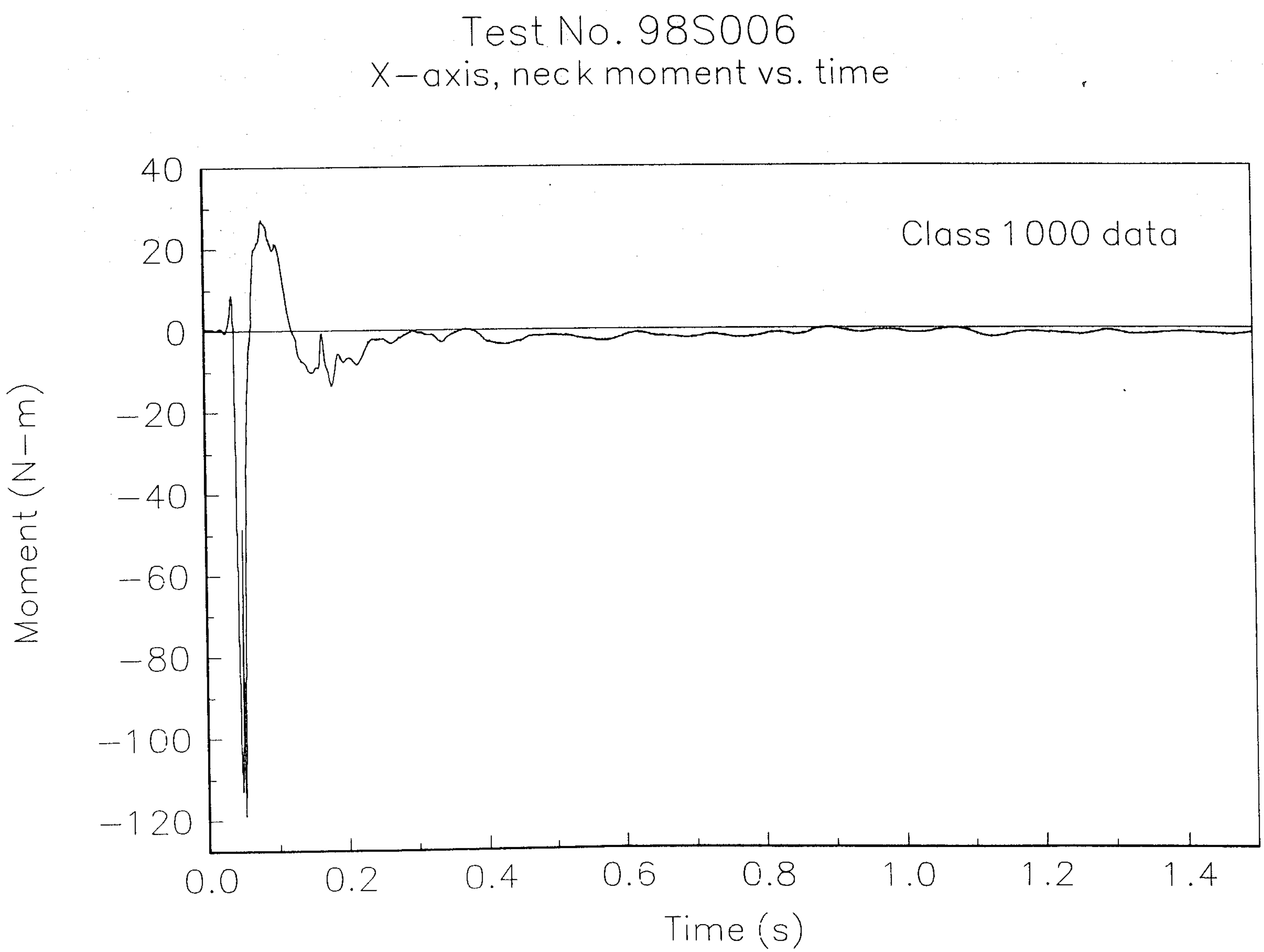


Figure 27. Moment vs. time, X-axis neck, test 98S006.

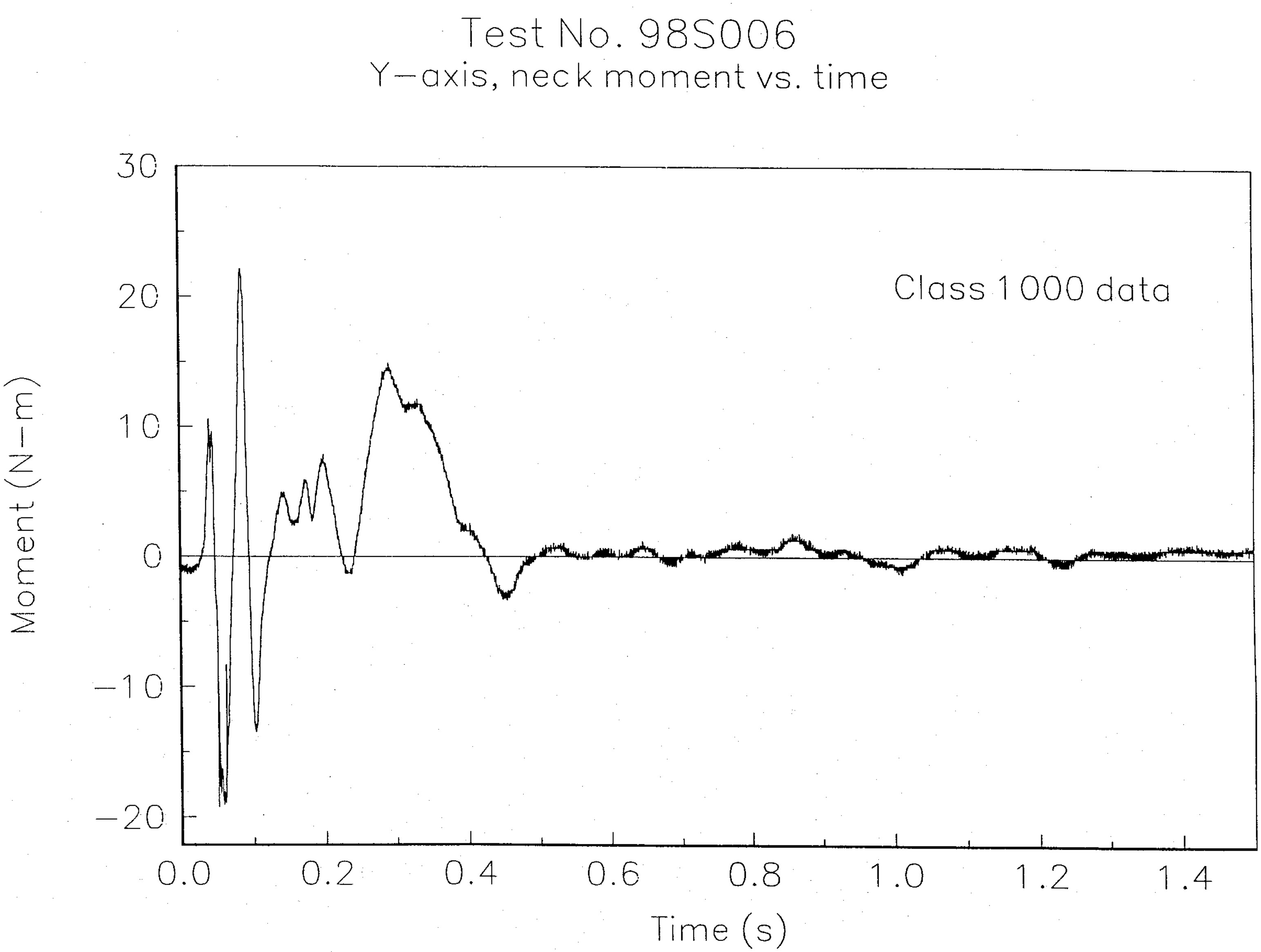


Figure 28. Moment vs. time, Y-axis neck, test 98S006.

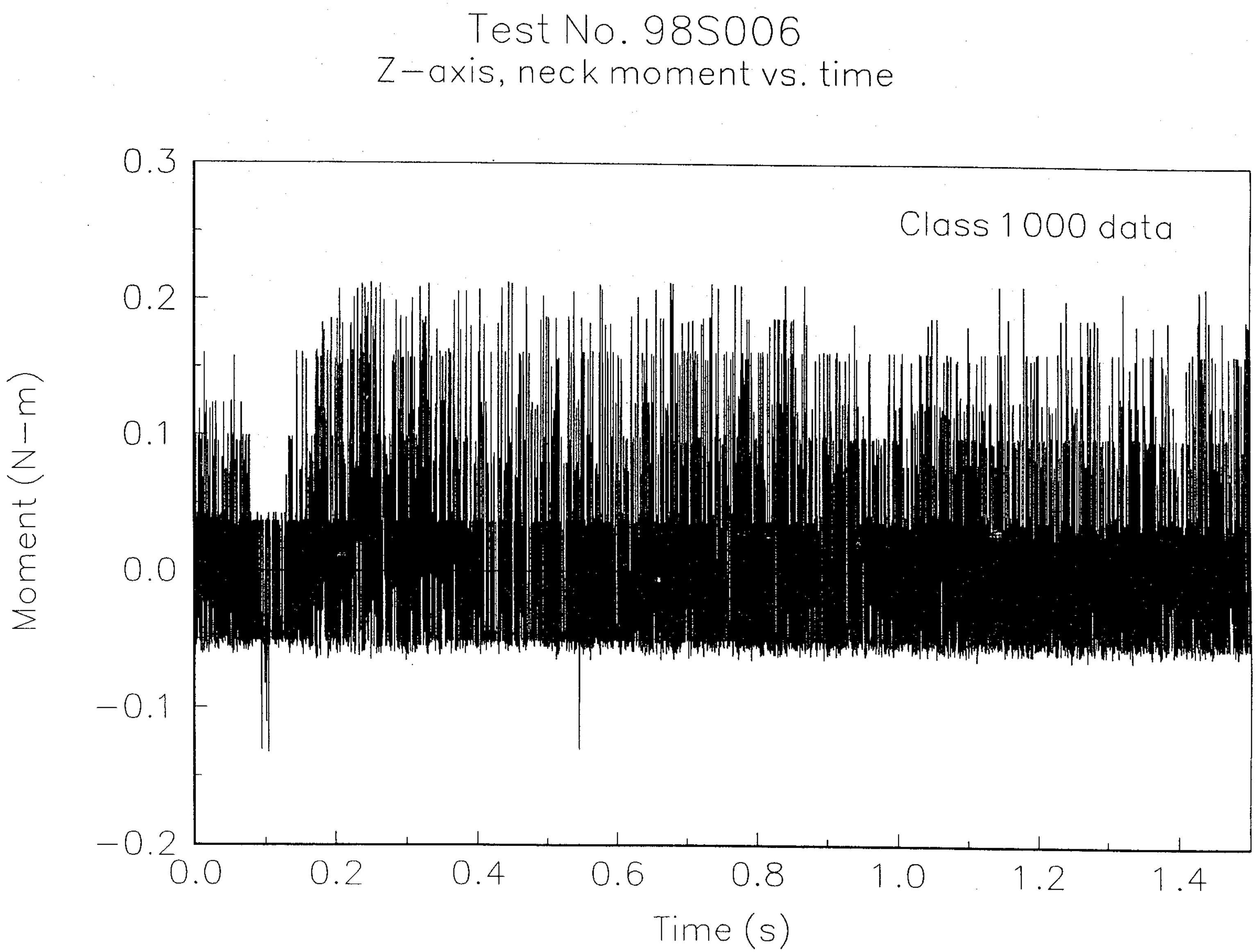


Figure 29. Moment vs. time, Z-axis neck, test 98S006.

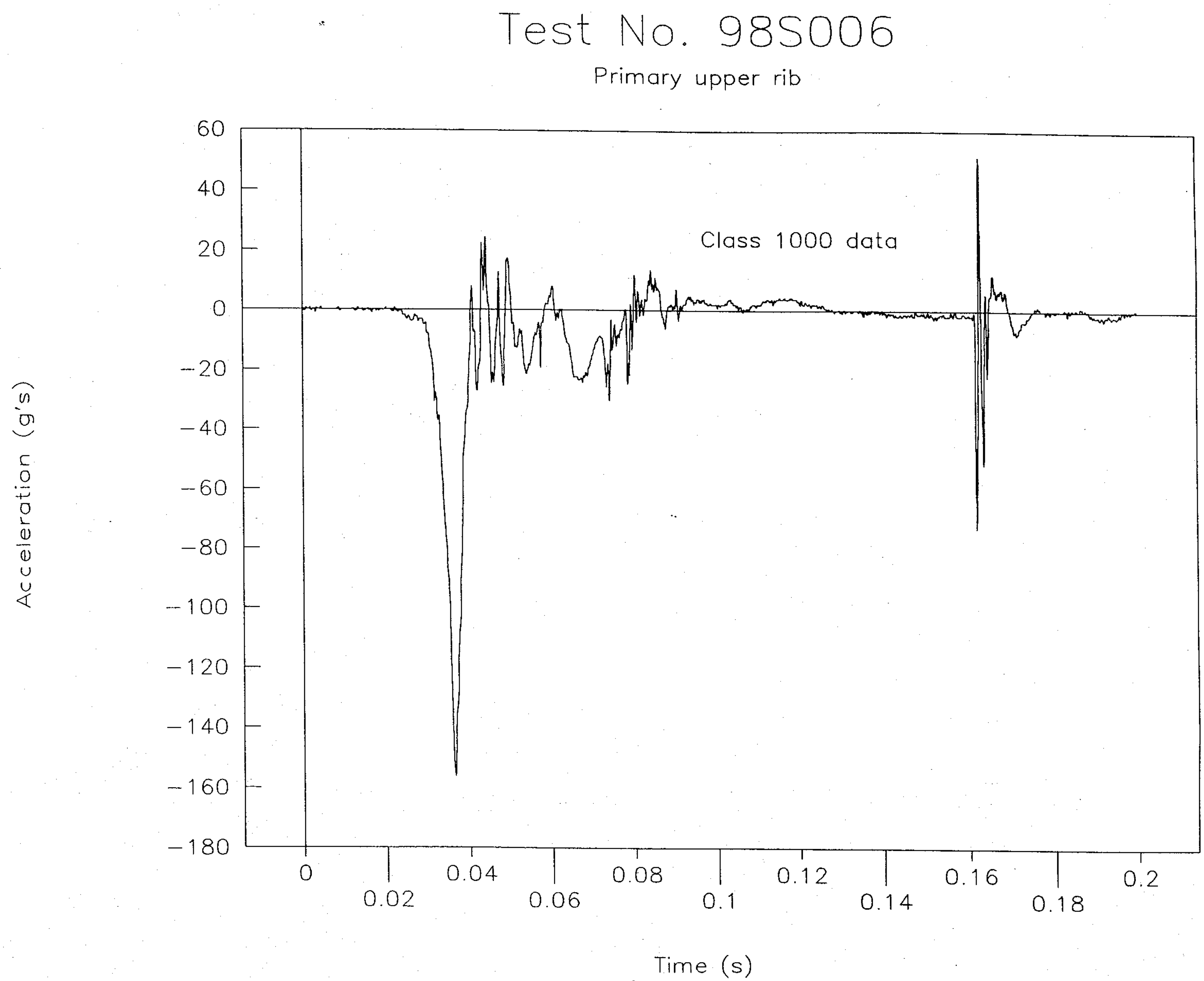


Figure 30. Acceleration vs. time, primary upper rib, test 98S006.

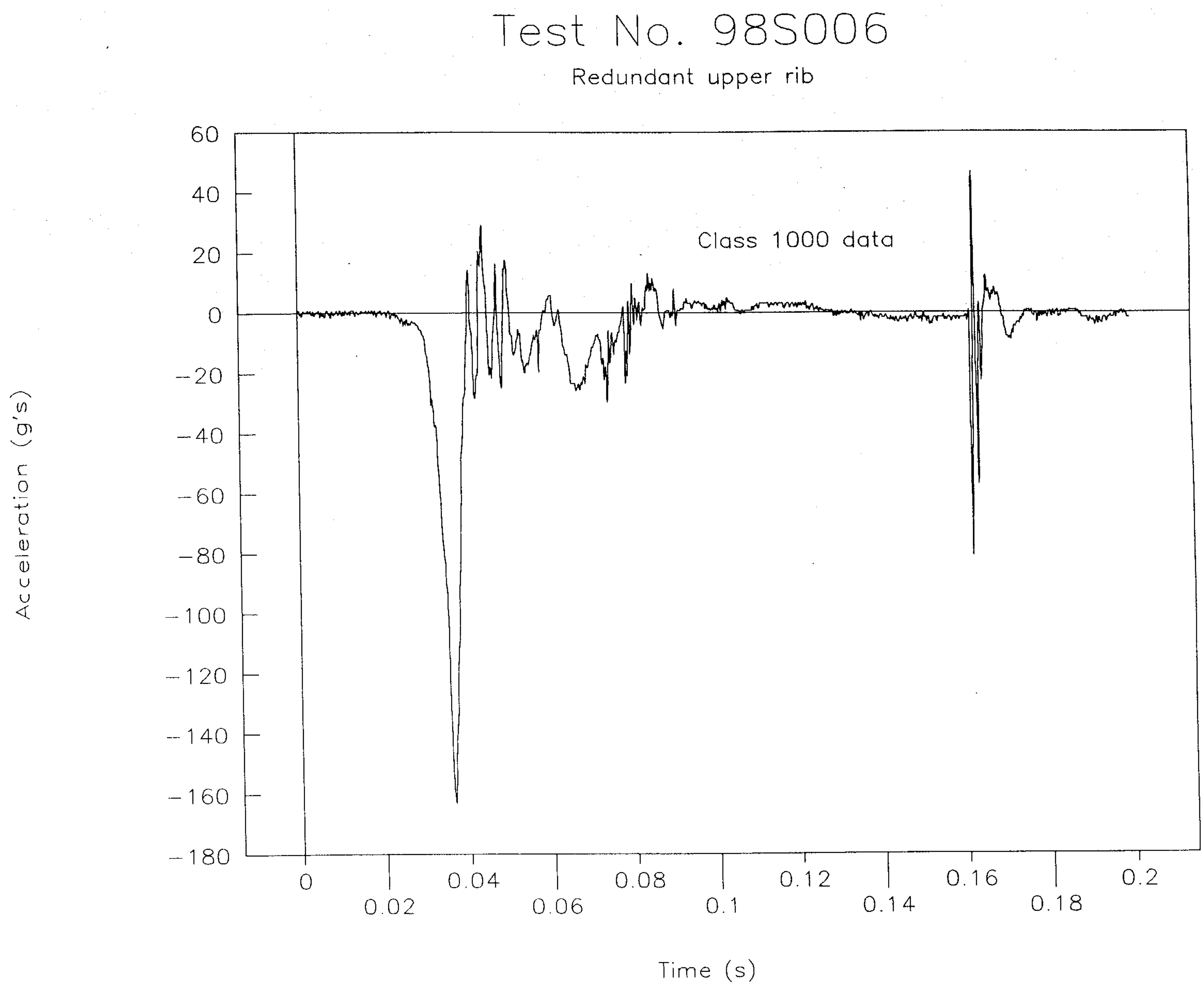


Figure 31. Acceleration vs. time, redundant upper rib, test 98S006.

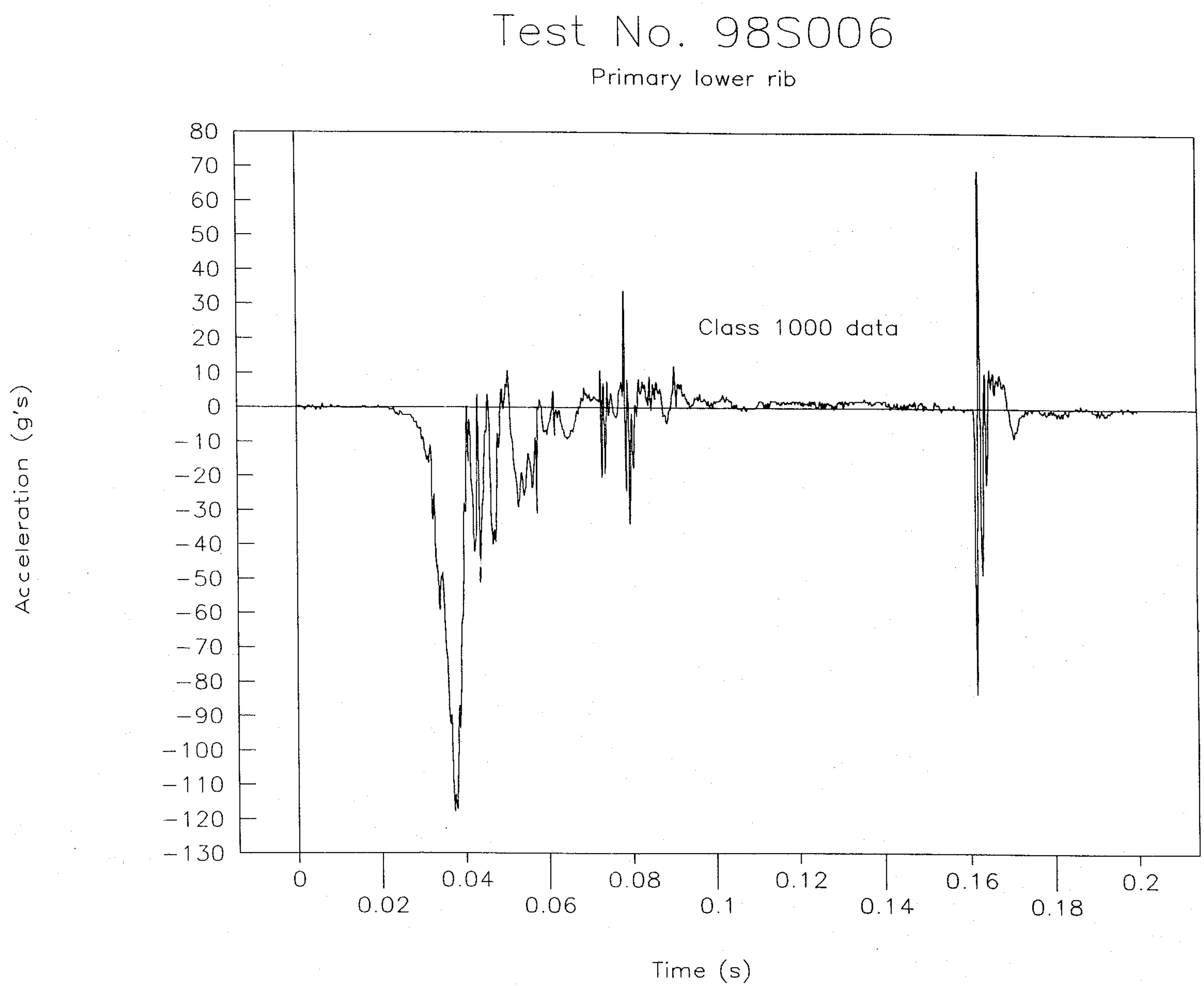


Figure 32. Acceleration vs. time, primary lower rib, test 98S006.

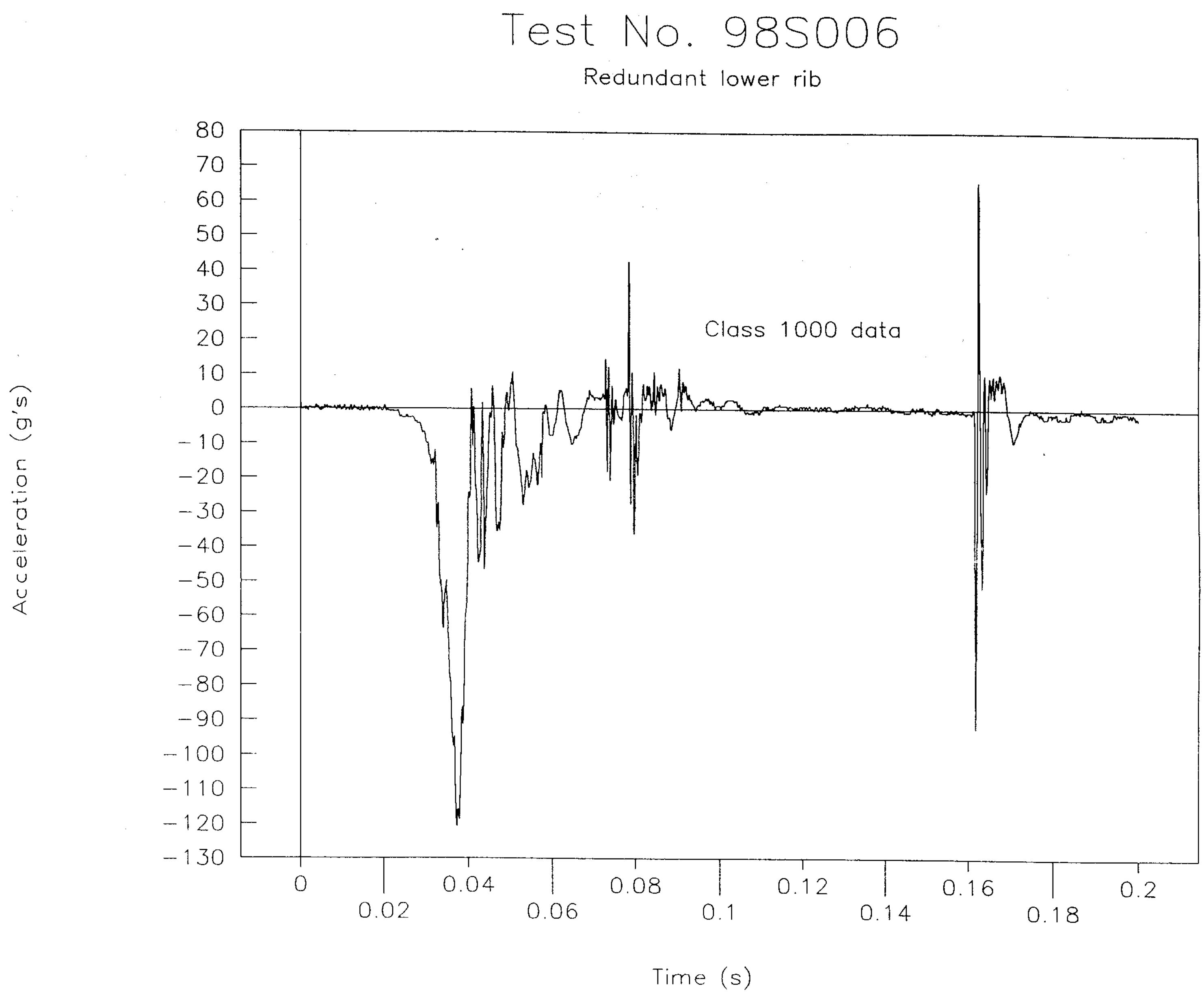


Figure 33. Acceleration vs. time, redundant lower rib, test 98S006.

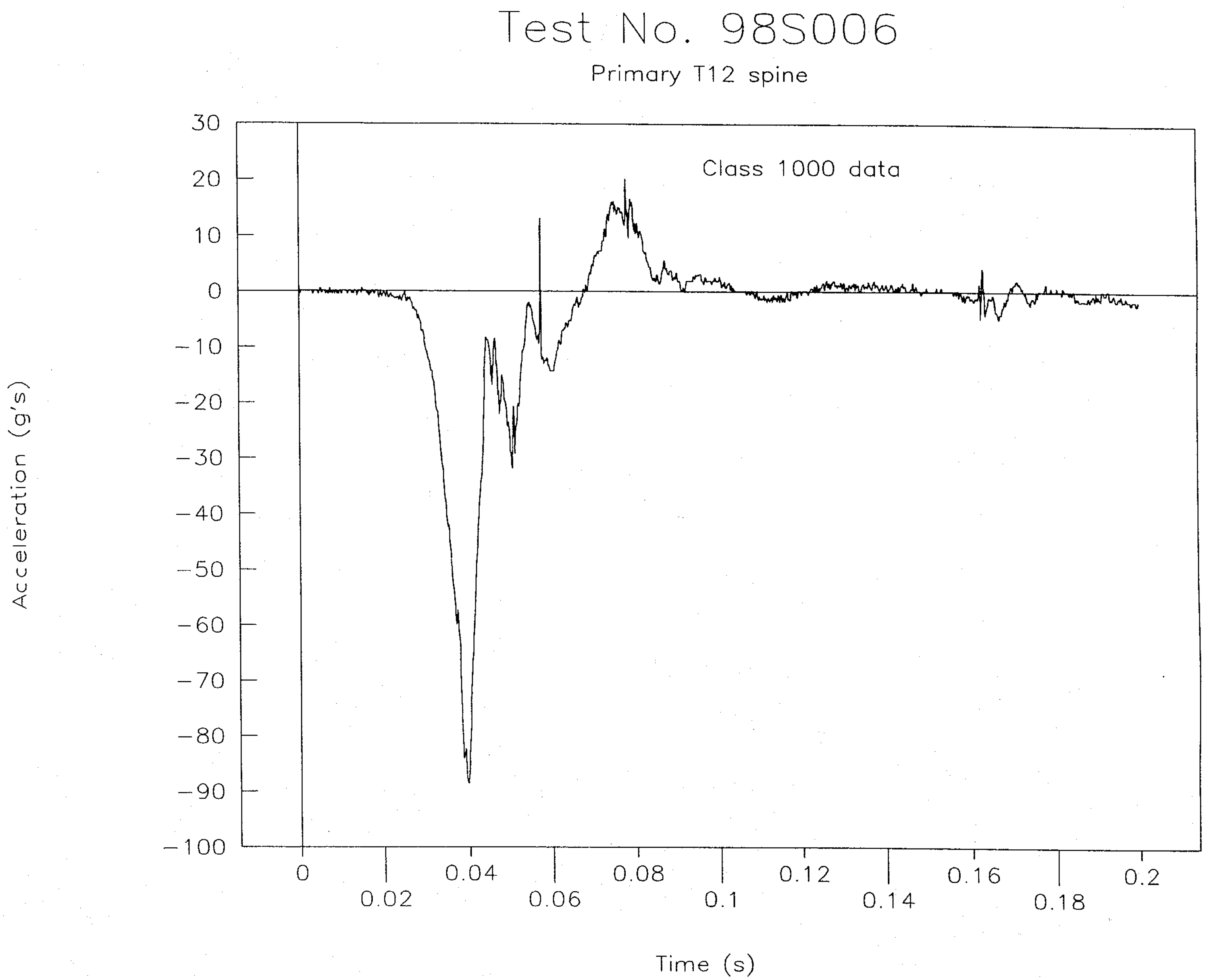


Figure 34. Acceleration vs. time, primary T12 spine, test 98S006.

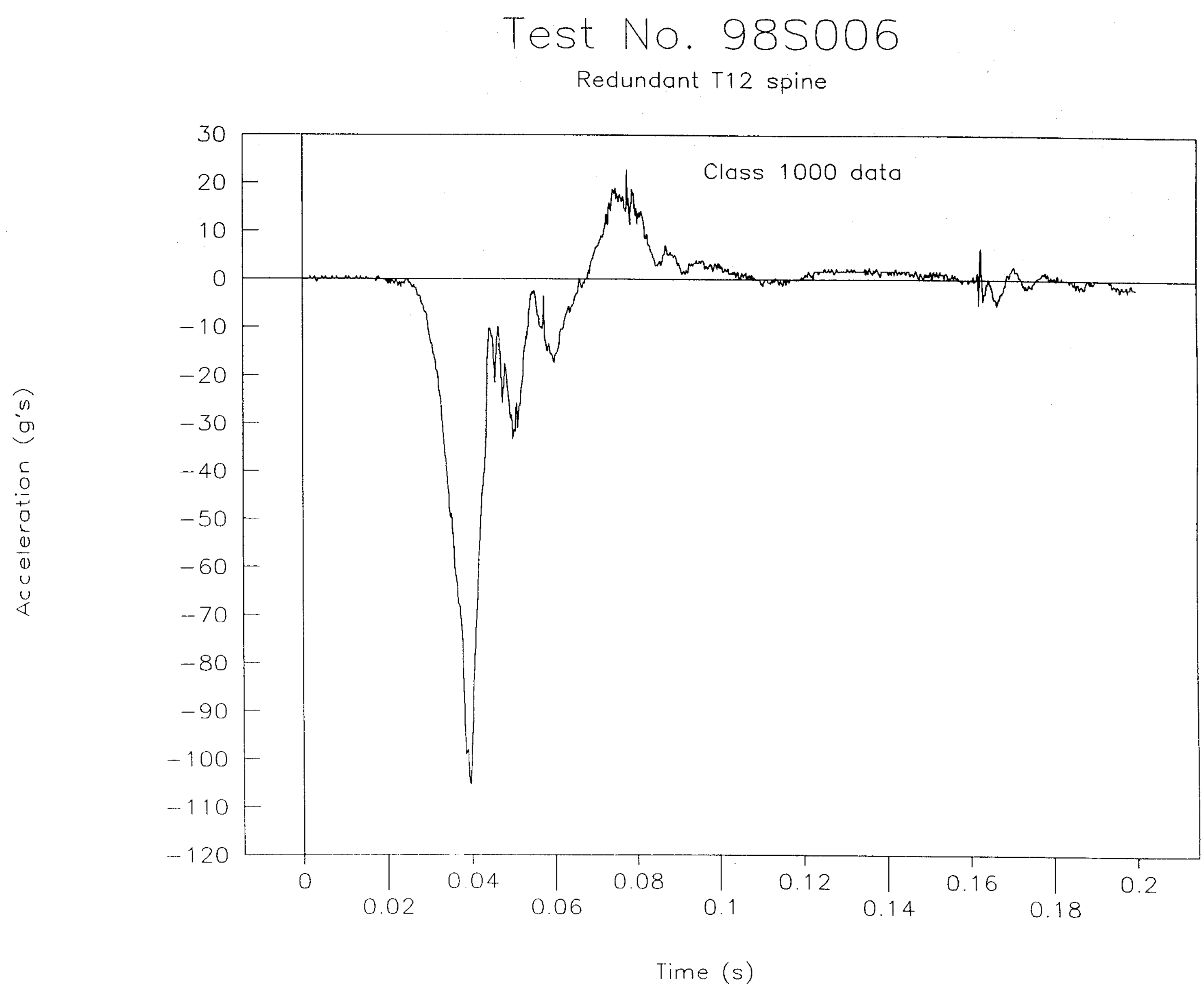


Figure 35. Acceleration vs. time, redundant T12 spine, test 98S006.

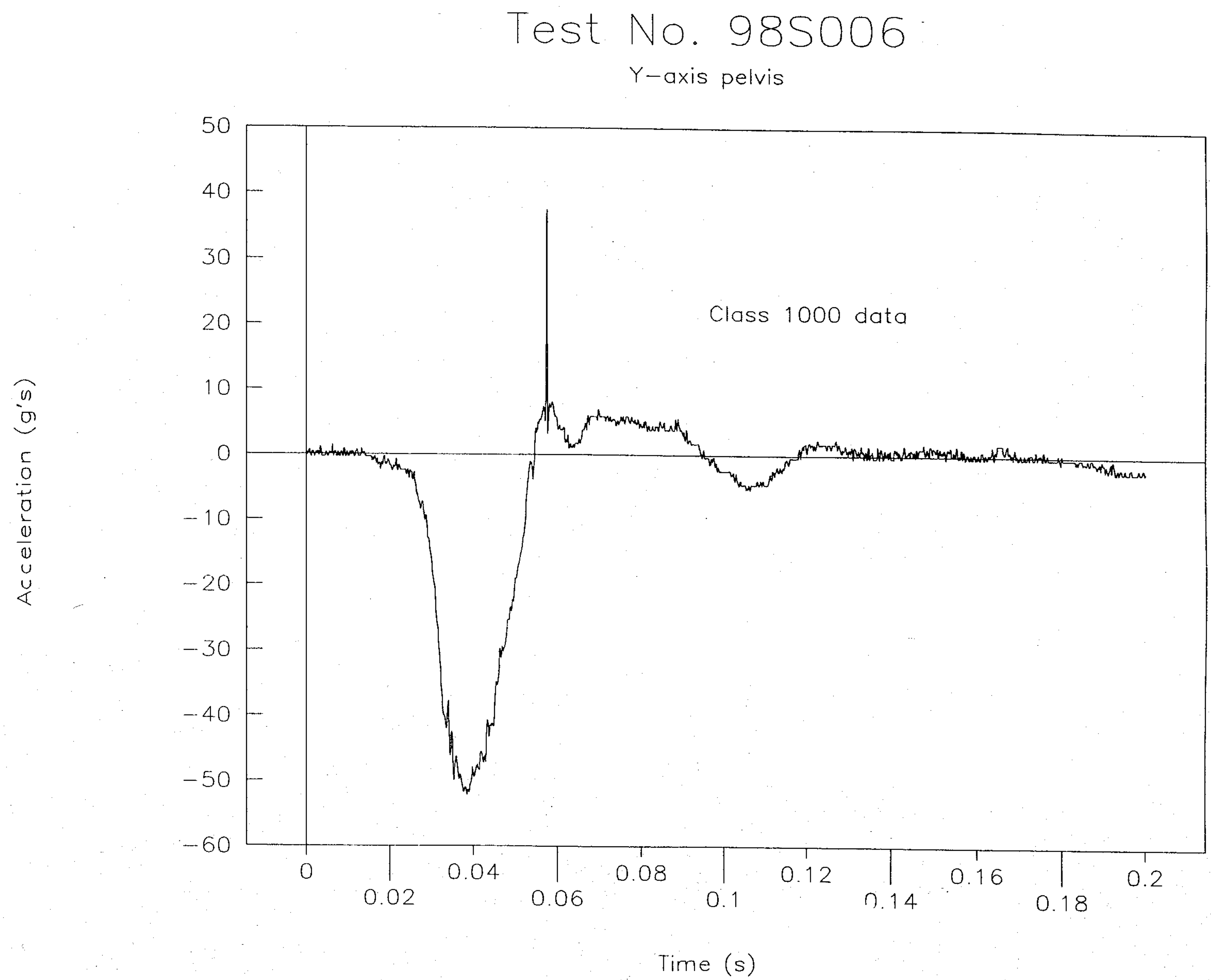


Figure 36. Acceleration vs. time, Y-axis pelvis, test 98S006.

APPENDIX C. TEST PHOTOGRAPHS

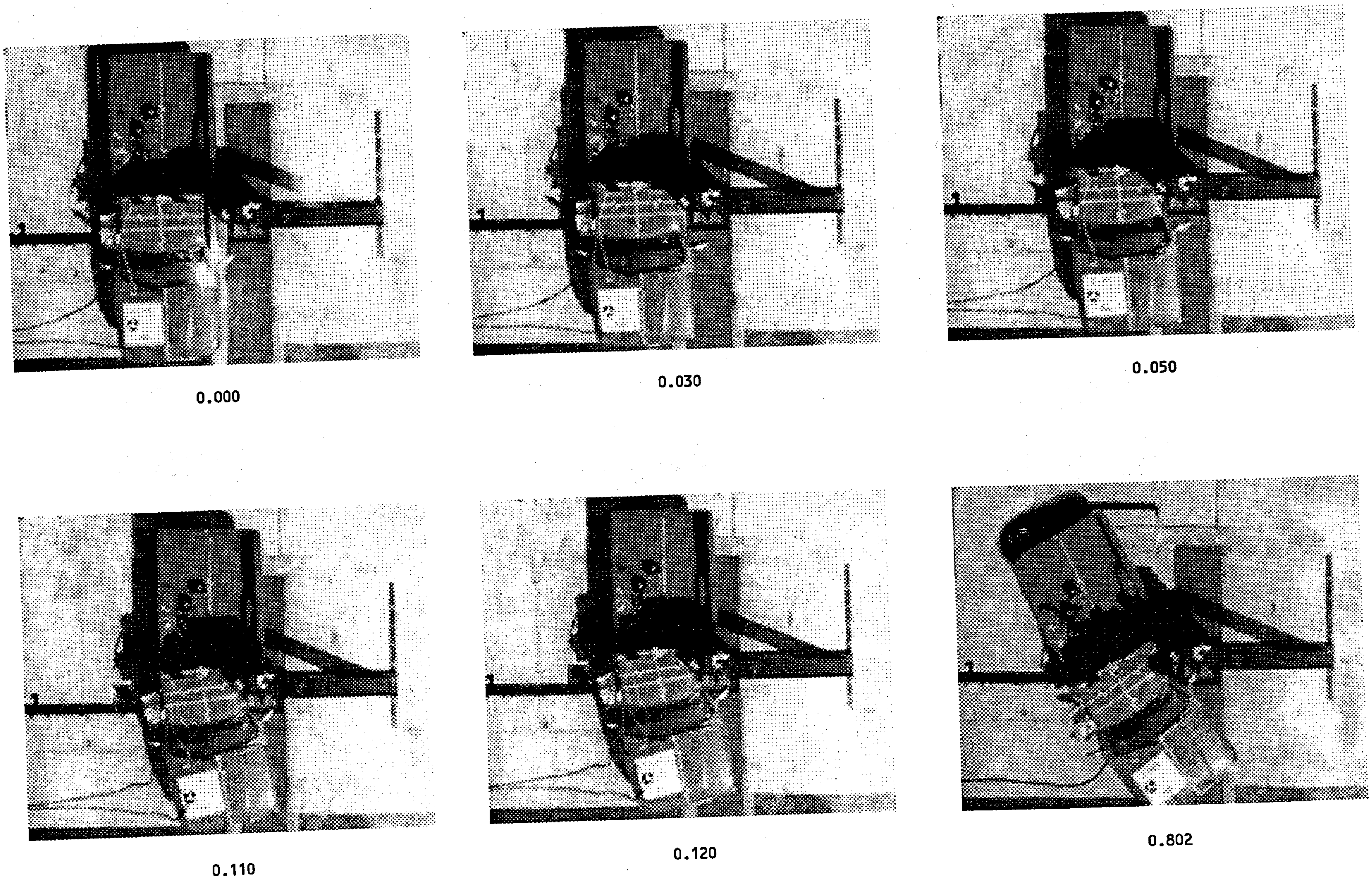


Figure 37. Test photographs during impact, test 98S006.

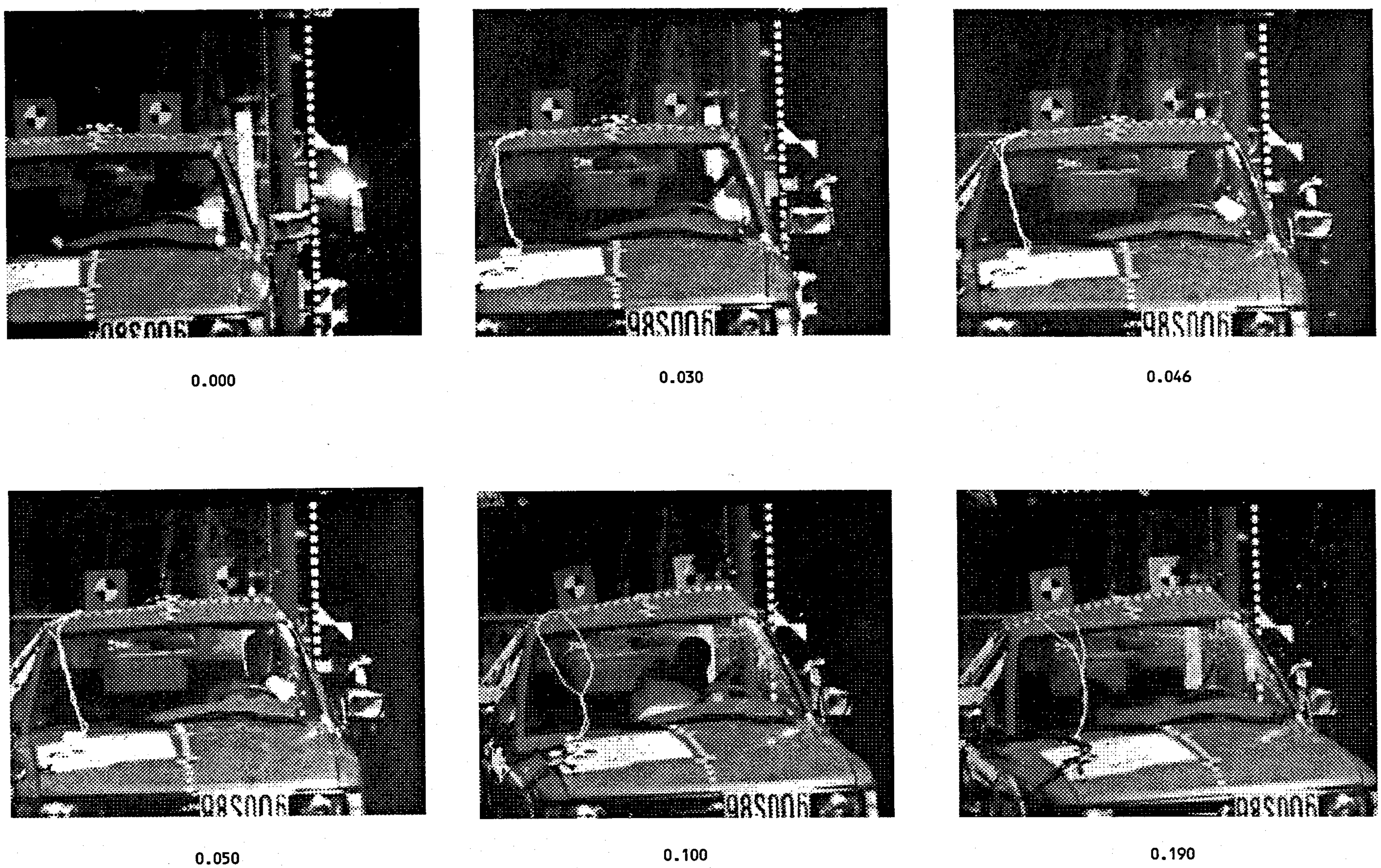
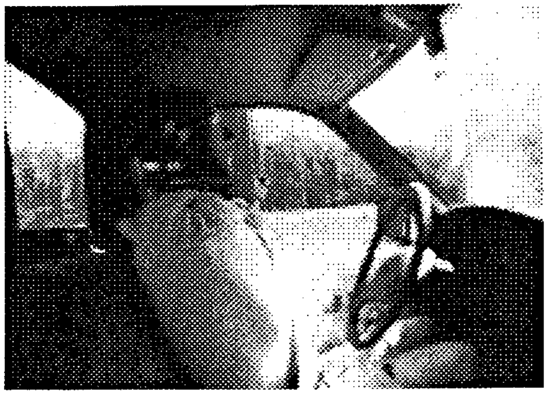
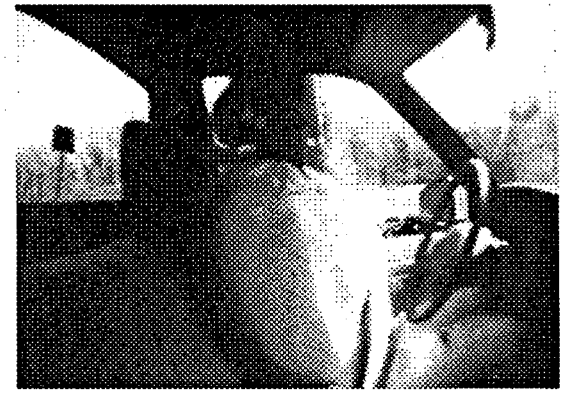


Figure 37. Test photographs during impact, test 98S006.



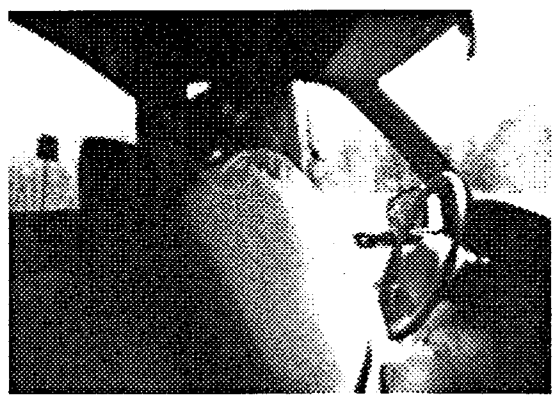
0.000

0.030



0.050

0.060



0.070

0.080

Figure 37. Test photographs during impact, test 98S006.

Figure 38. Pretest photographs, test 98S006.

Figure 38. Pretest photographs, test 98S006 (continued).

Figure 39. Post-test photographs, test 98S006.

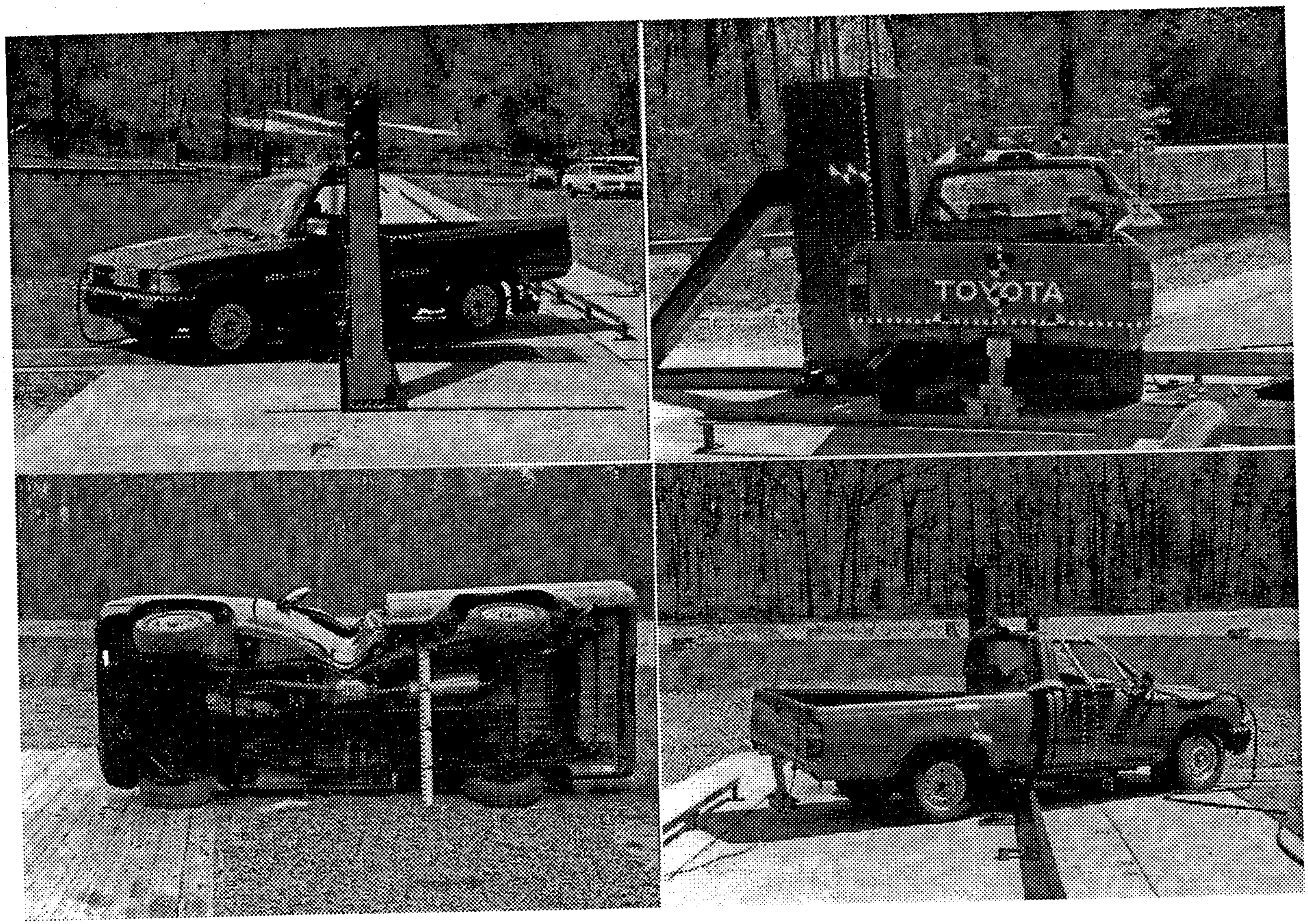


Figure 39. Post-test photographs, test 98S006 (continued).

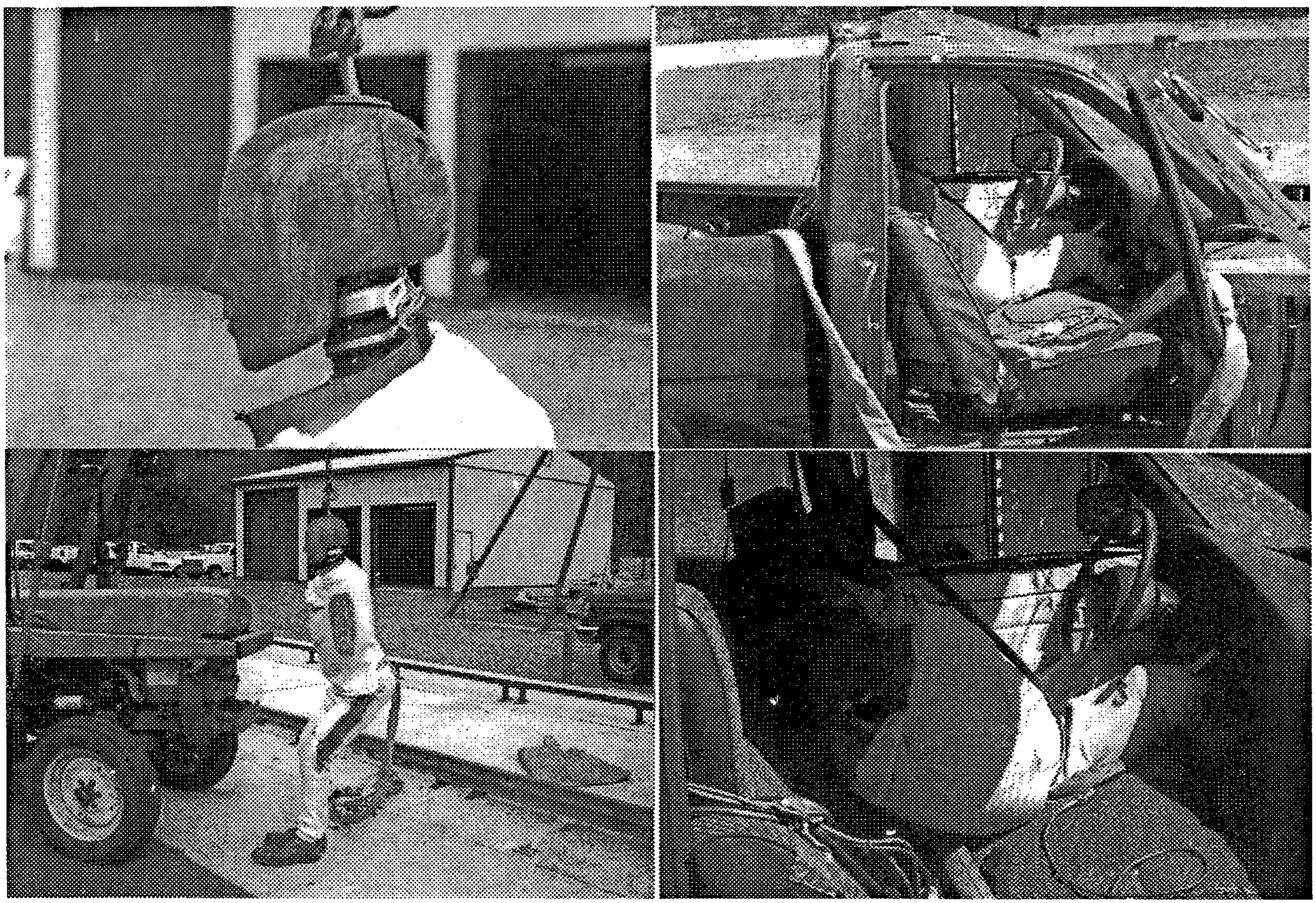


Figure 39. Post-test photographs, test 98S006 (continued).

APPENDIX D. DATA PLOTS FROM RIGID POLE LOAD CELLS

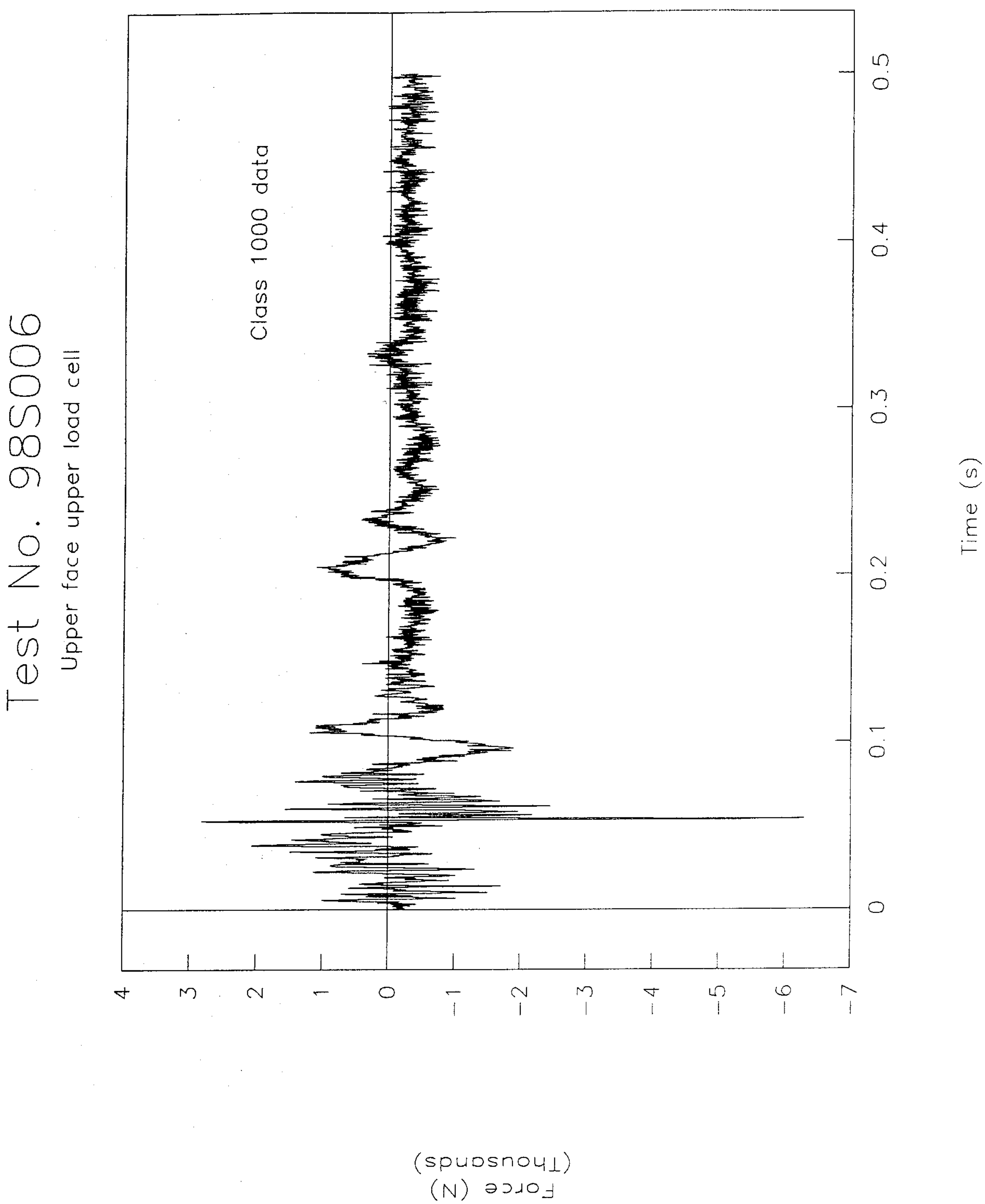


Figure 40. Rigid pole, force vs. time, upper face upper load cell, test 98S006.

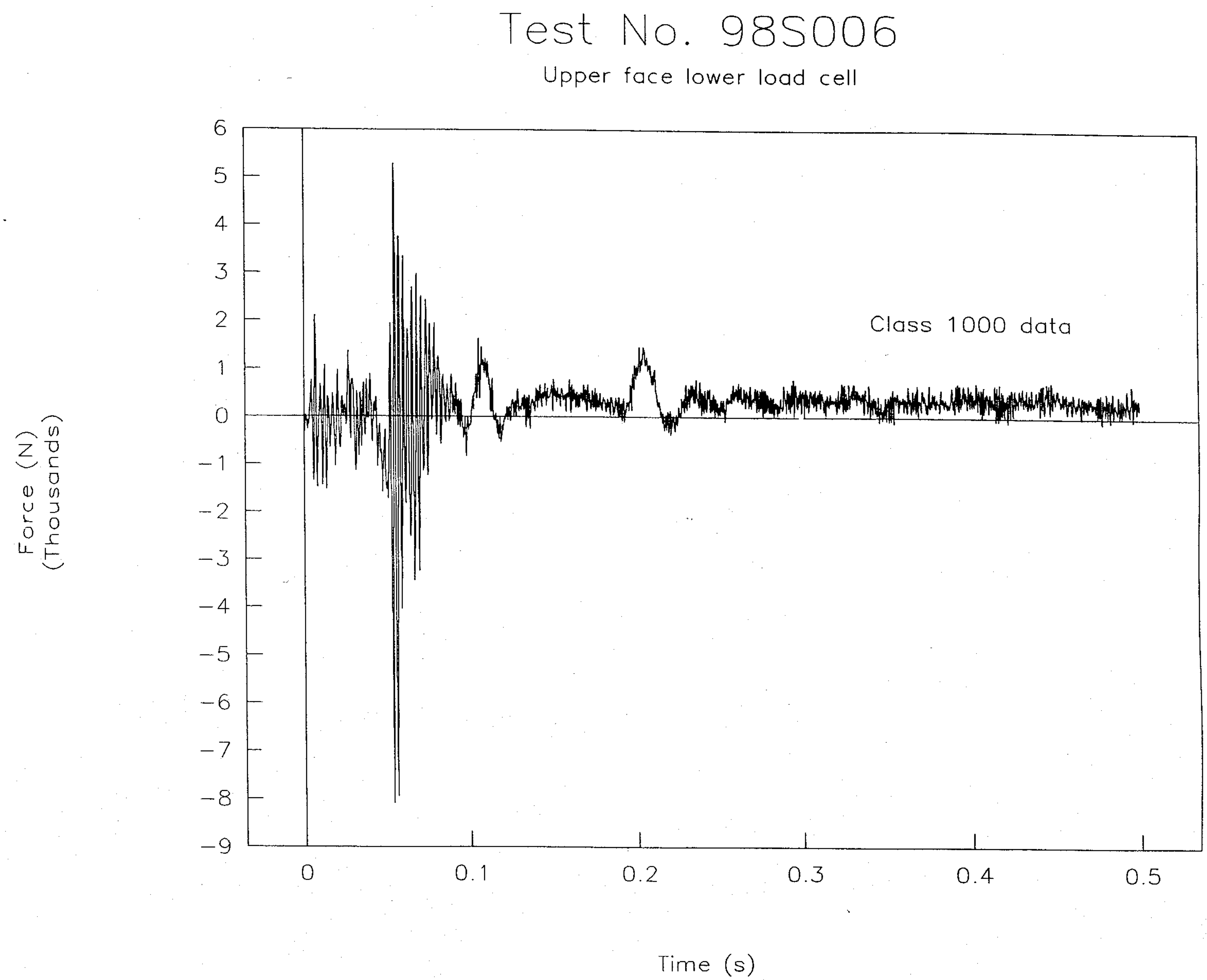


Figure 41. Rigid pole, force vs. time, upper face lower load cell, test 98S006.

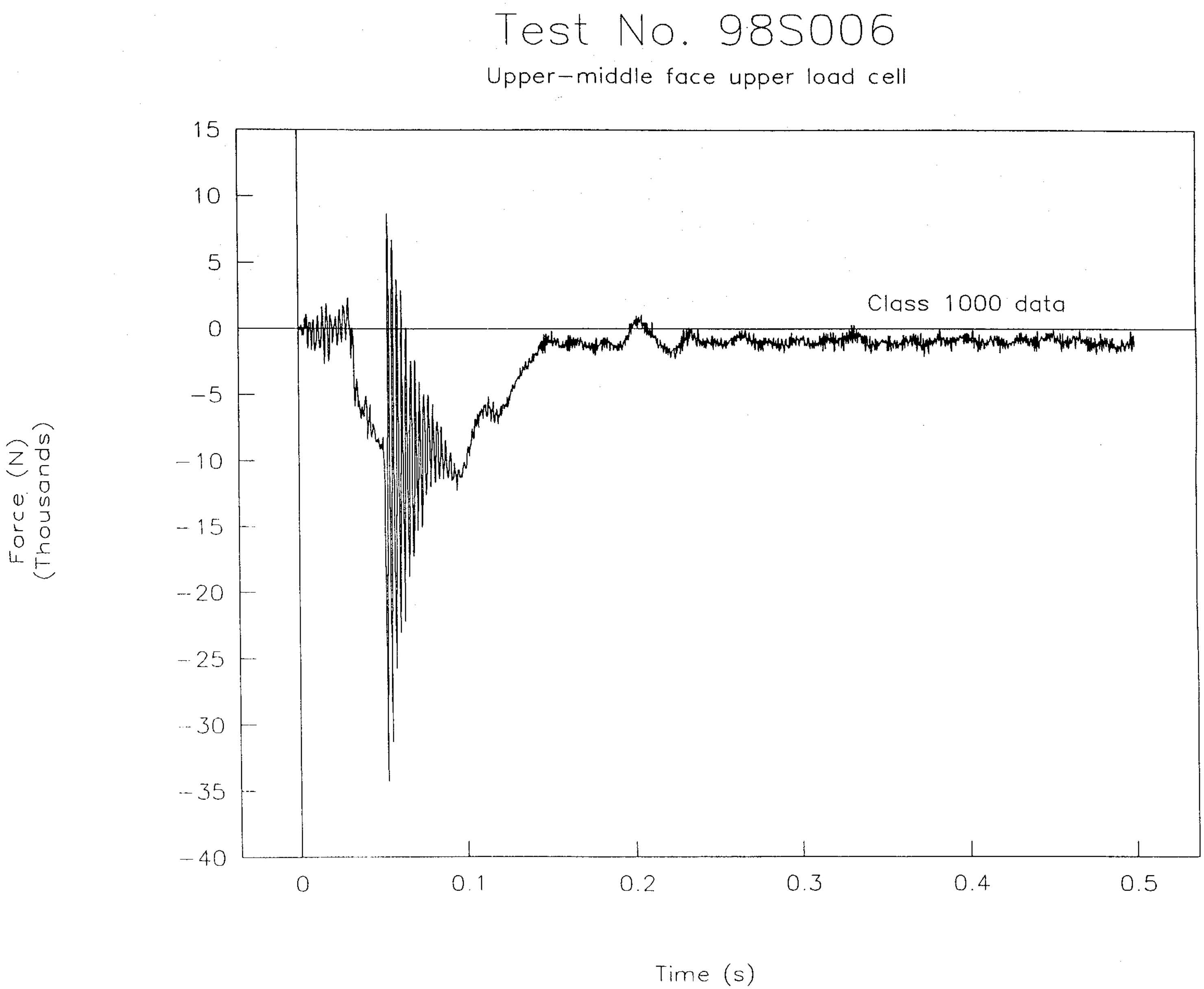


Figure 42. Rigid pole, force vs. time, upper-middle face upper load cell, test 98S006.

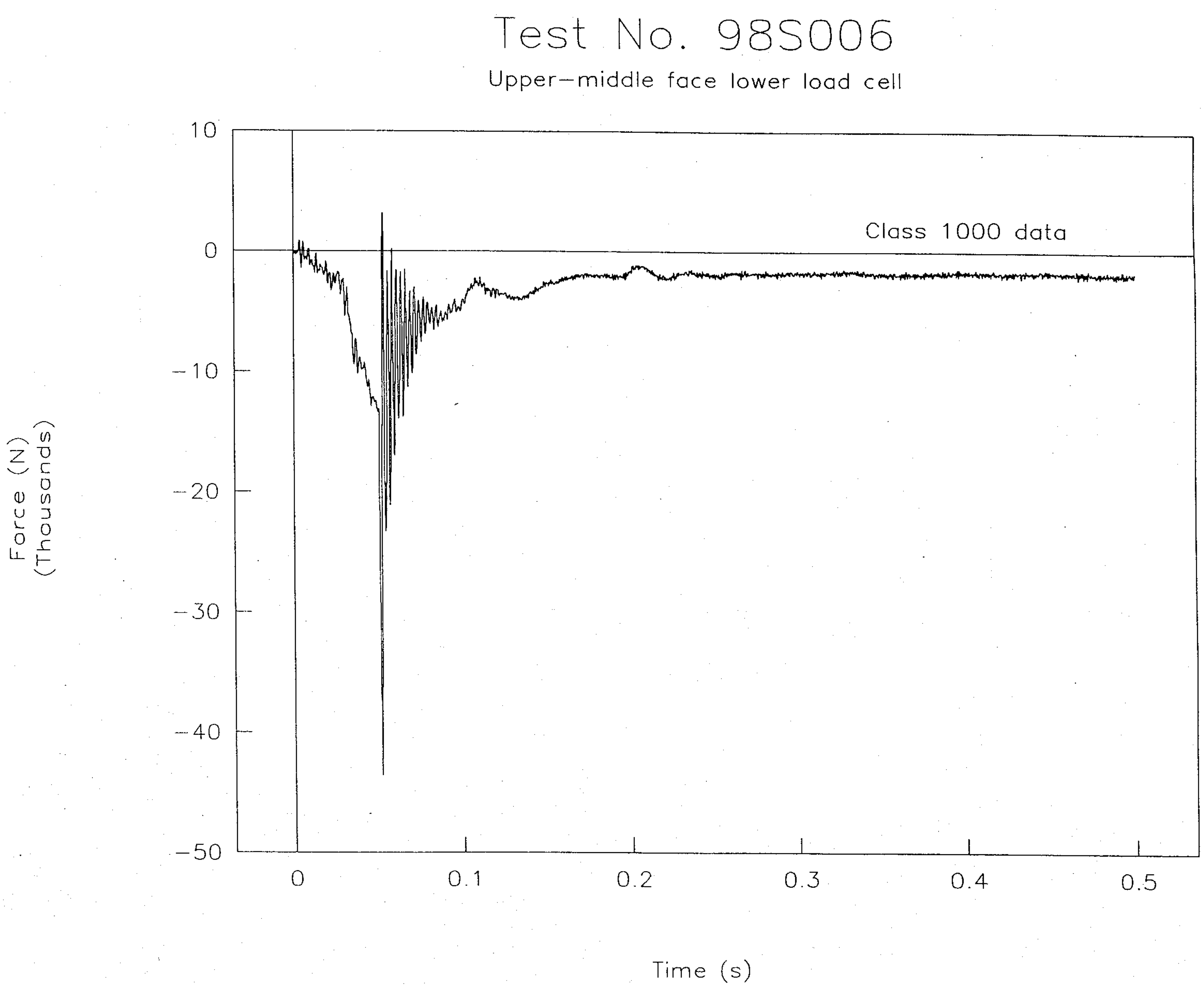


Figure 43. Rigid pole, force vs. time, upper-middle face lower load cell, test 98S006.

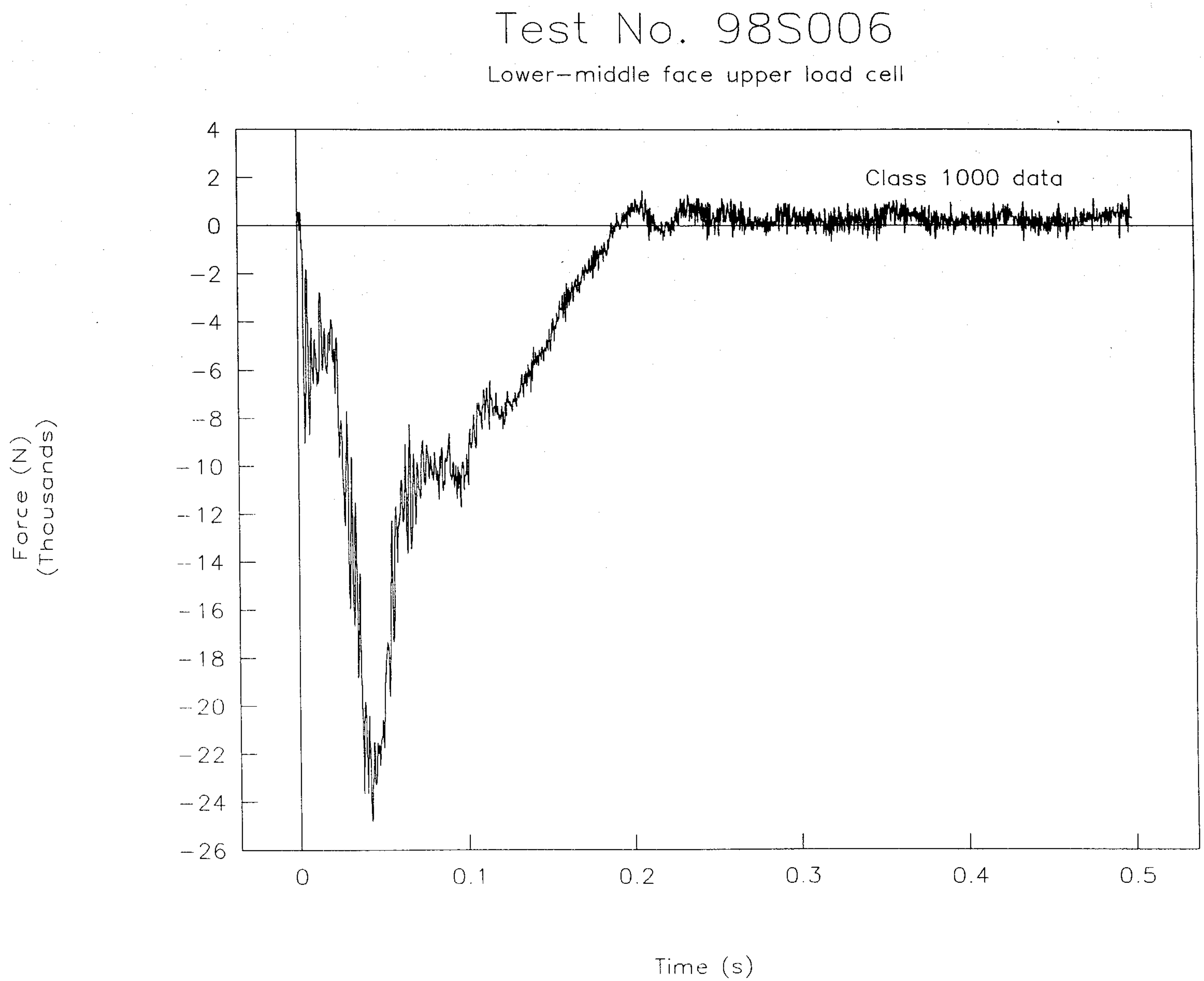


Figure 44. Rigid pole, force vs. time, lower-middle face upper load cell, test 98S006.

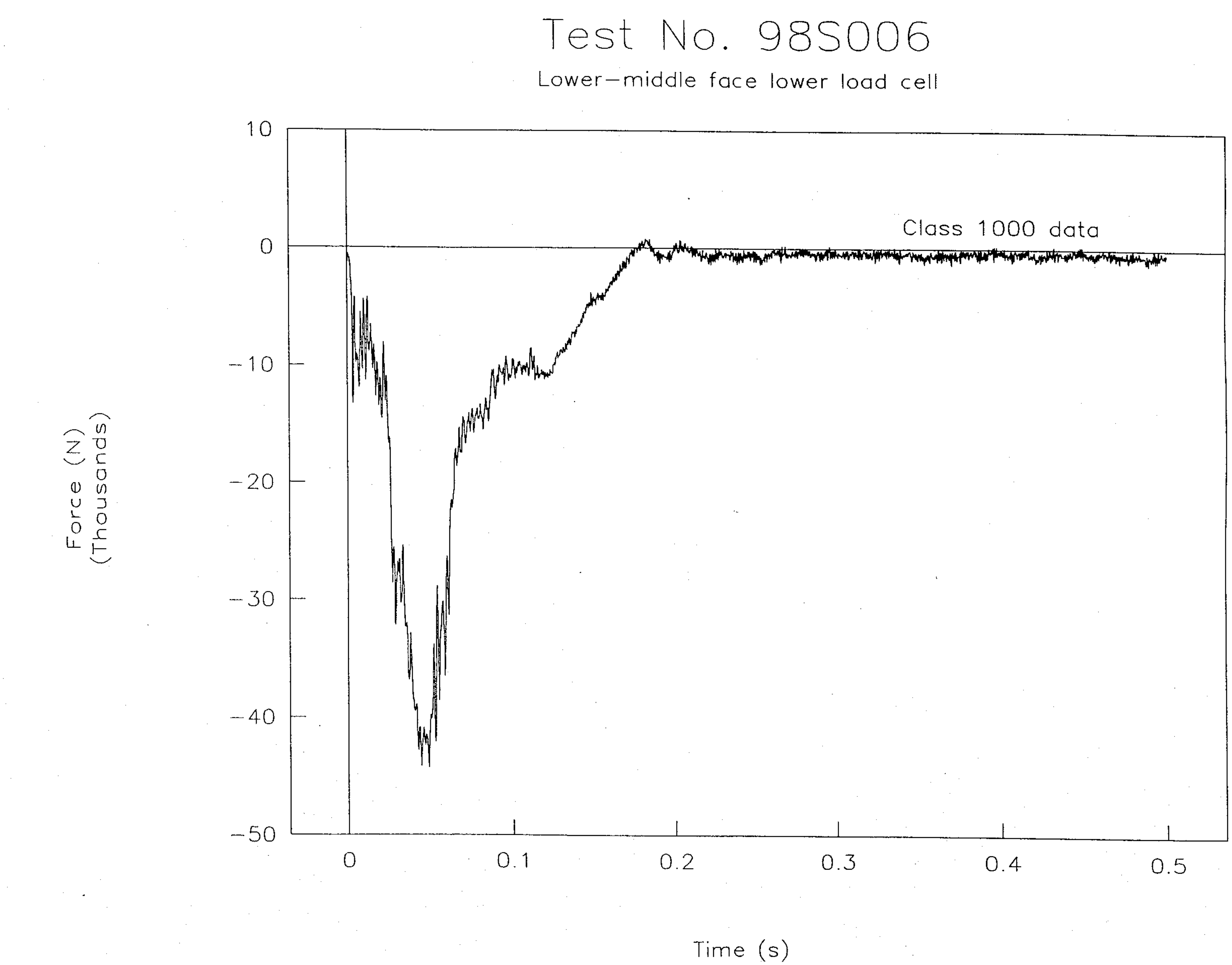


Figure 45. Rigid pole, force vs. time, lower-middle face lower load cell, test 98S006.

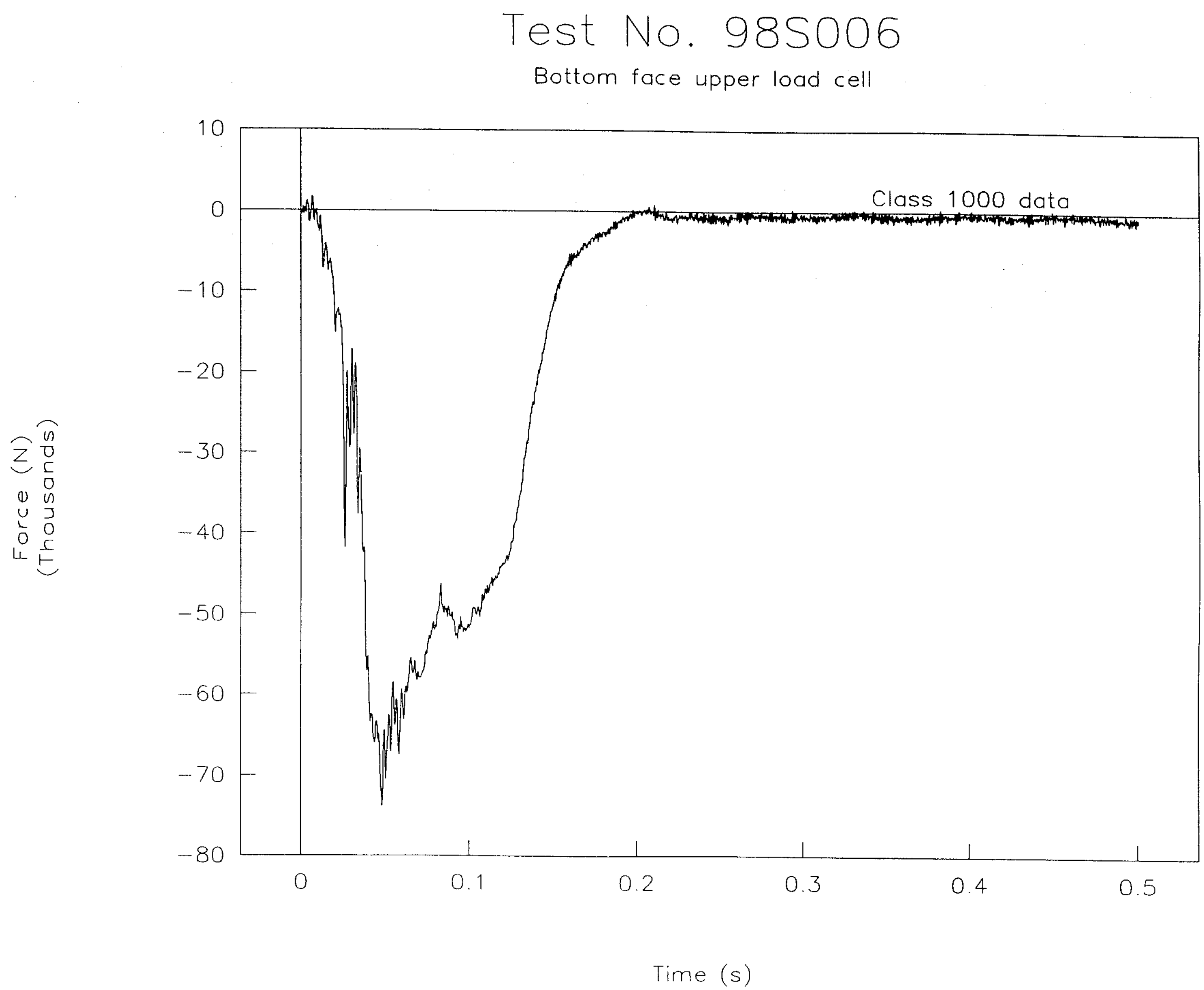


Figure 46. Rigid pole, force vs. time, bottom face upper load cell, test 98S006.

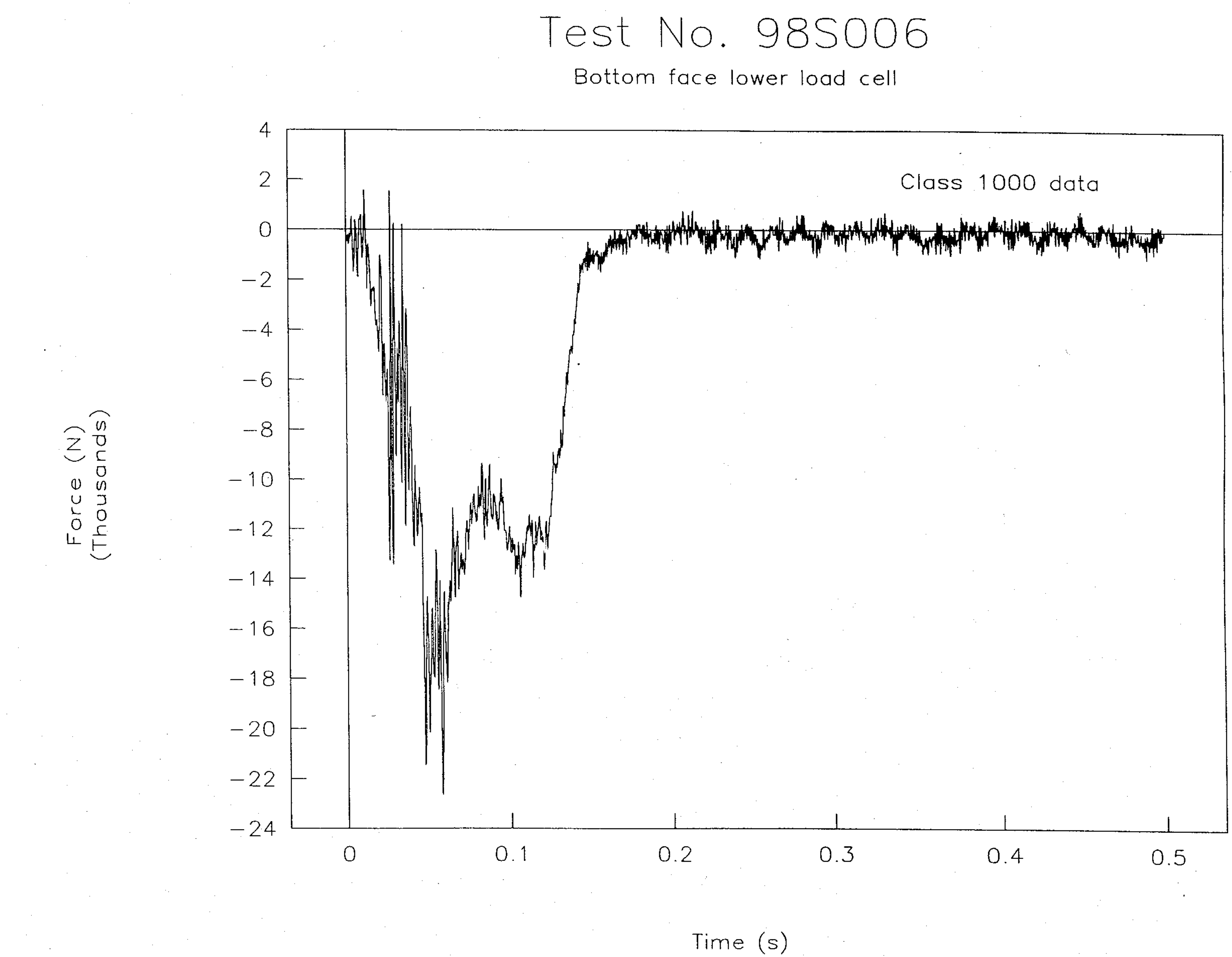


Figure 47. Rigid pole, force vs. time, bottom face lower load cell, test 98S006.

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Number

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(2) Christopher M. Brown, *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S003*, Publication No. FHWA-RD-98-008, Federal Highway Administration, Washington, DC, January 1998.

(3) Christopher M. Brown, *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S004*, Publication No. FHWA-RD-98-009, Federal Highway Administration, Washington, DC, January 1998.

(4) Christopher M. Brown, *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S005*, Publication No. FHWA-RD-98-010, Federal Highway Administration, Washington, DC, January 1998.

(5) Christopher M. Brown, *Honda Accord LX Broadside Collision with a Narrow Fixed Object: FOIL Test Number 97S006*, Publication No. FHWA-RD-98-011, Federal Highway Administration, Washington, DC. January 1998.

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(7) Christopher M. Brown, *1994 Ford Explorer Broadside Collision with a Narrow Fixed Object: FOIL Test Number 98S005*, Report pending, Federal Highway Administration, Washington, DC.