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U.S. Department
of Transportation

Federal Highway
Administration

FORD TAURUS BROADSIDE COLLISION WITH A NARROW FIXED OBJECT
FOIL TEST NUMBER: 95S014

Office of Safety and Traffic Operations R&D
Turner-Fairbank Highway Research Center
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McLean, Virginia 22101-2296

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16. Abstract

This report contains the test procedures, test setup and test results from the second of two broadside crash tests performed at the Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The results and test description from the first test are contained in the report *Ford Taurus Broadside Collision with a Narrow Fixed Object, FOIL Test Number: 95S008.* The test was conducted by the Federal Highway Administration (FHWA) for the National Highway Traffic Safety Administration (NHTSA). This was a repeat test of a previously conducted test between a 1990 Ford Taurus four door sedan and the FOIL instrumented rigid pole at a nominal test speed of 35 km/h. The objective of the test was to provide the NHTSA with data to support validation efforts of passenger vehicle Finite Element Models (FEM). In addition to the validation support, the test was conducted to provide insight into the relative strength of a mid-sized sedan when it strikes a narrow fixed object. In this test a modified anthropomorphic side impact dummy(SID) was used to measure occupant risk. The dummy consisted of a regular SID with a Hybrid III neck and head. Results from the test are presented as graphs of data from the transducers affixed to the test vehicle and the SID and photographs before and after the test. The data and high-speed test film provided support for the validation effort.

17. Key Words	18. Distribution Statement
Acceleration, displacement, rigid pole, side-impact, peak force, FOIL, load cell, Ford Taurus.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

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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 Federal Highway Administration (FHWA) and the National Highway Traffic Safety Administrations (NHTSA) have developed finite element models (FEM) of passenger vehicles to be used as tools for improving the safety of passenger vehicles and the safety performance of roadside safety hardware. These vehicle FEM's have been developed for frontal and side impact collisions. The Ford Taurus is a vehicle which has been modeled for side impact collisions. Validation of the model has been performed by comparing computer generated data with data from an actual side impact collision. The model has been validated for vehicle-to-vehicle or wide object broadside collisions. Vehicle models of broadside collisions with narrow fixed objects have yet to be validated by actual test data. Two validation tests for narrow fixed-object collisions were conducted at the FHWA's Federal Outdoor Impact Laboratory (FOIL) using 1990 Ford Taurus four-door sedans and the FOIL instrumented rigid pole.

SCOPE

This report documents the results from the second of two broadside crash tests between a 1990 Ford Taurus and the FOIL instrumented rigid pole. This crash test was contrived as a repeat test of a previously conducted broadside test. The results and test description from the first test are contained in the report *Ford Taurus Broadside Collision with a Narrow Fixed Object, FOIL Test Number: 95S008.*[1] Validation of a FEM of the Ford Taurus in a broadside collision with a narrow-fixed object was one objective of the crash test. In addition to the validation effort, the side impact integrity of a vehicle when striking a narrow-fixed object was investigated. The side impact integrity was determined from multiple variables. The FOIL rigid pole provided insight into the relative strength of the vehicle side structure and a modified anthropomorphic side impact dummy (SID) was used to measure occupant risk. A displacement transducer was used to measure maximum dynamic intrusion as well as rate of intrusion into the occupant compartment. The side impact integrity was also determined by how well door latches and fuel system components respond when involved in a narrow-fixed object collision. Steering column air-bag deployment sensors remained active to investigate whether or not frontal air-bag deployment occurs during a side impact collision.

TEST MATRIX

One crash test involving a 1990 Ford Taurus and the FOIL instrumented pole was conducted. The test parameters including speed, crab angle, and impact location were determined by the NHTSA from analysis of accident data. The Ford Taurus was oriented on the FOIL runway such that the vehicle centerline was perpendicular to the runway centerline. The nominal test speed was 35 km/h. The impact location was 1,150 mm rearward of the front axle centerline. This corresponds to a point on the door midway between the steering wheel and the SID's chest after the SID was positioned in the driver seat in accordance with Federal Motor Vehicle Safety Standard 214 (FMVSS 214)[2]. Table 1 outlines the test matrix for the side impact test.

Table 1. Test matrix.

FOIL number	95S014
Date	December 18, 1995
Vehicle	1990 Ford Taurus
Weight (total)	1,639 kg
SID (serial number 904) Modified neck.	One positioned in driver seat HYBRID III neck
Fuel tank	94% capacity with stodard solvent
Crab angle	90°
Speed (nominal)	35 km/h
Impact location	1,150 mm rearward of front axle
Test article	FOIL instrumented rigid pole

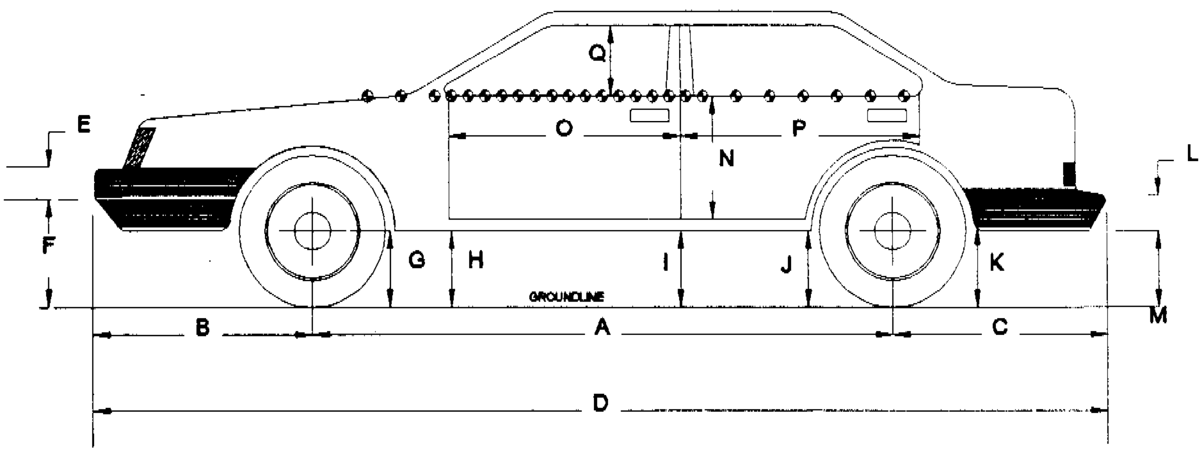
VEHICLE

The test vehicle was a 1990 Ford Taurus four-door sedan with front-wheel drive, automatic transmission, and a 3.8 L motor. Prior to the test, the vehicle's fluids were drained and it's inertial properties measured. The vehicle was stripped of certain components to allow for the installation of transducers, high-speed cameras, data acquisition equipment, and side impact carriages. The side impact carridges were constructed from aluminum and remained fastened to the vehicle throughout the test. Once the vehicle had been instrumented its final inertial properties were determined. A SID was positioned in the driver seat and was restrained by the vehicle's seat belt restraint system. The fuel tank was filled (94% of capacity) with petroleum naphtha (stodard solvent) which has the same density as gasoline but is less volatile. The SID and stodard solvent were added to the vehicle after the final, ballasted inertial properties were determined. The original lead-acid battery in a charged state remained in the engine compartment. This was done to investigate frontal air-bag deployment during a side impact collision. The vehicle test weight, including the dummy, ballast, and stodard solvent was 1,639 kg. The SID weighed 80 kg. No brake system was installed in the test vehicle. Ballast was added to the trunk of the test vehicle to artificially move the longitudinal center-of-gravity (cg) to 1,046 mm rearward of the front axle. This enabled the vehicle to be fit on the FOIL inertial measurement device (IMD) and to enable the vehicle to fit between the two runway side impact rails. A list and sketches of the vehicle's physical parameters are shown in table 2 and figure 1 respectively. Figure 1 includes post test damage measurements.

Table 2. Vehicle description and statistics.

Vehicle make		Ford
Vehicle model		1990 Taurus
Vehicle identification number (VIN)		1FACP5249LG104560
Engine		3.8 L V6,6 cylinder
Transmission		4 speed automatic
Drive chain		Front wheel drive
Wheel base		2,692 mm
Wheel track		1,525 mm
Fuel capacity		68 l
Tested capacity of stodard solvent		64 l (94%)
Seat type		Splitbench,electric
Position of front seats for test		Center position
Steering wheel adjustment for test		Center position
Front seat arm rests		Up position
	DELIVERED	**TESTED**
Weight (kg)	**1,409**	**1639**
Left front (kg)	469	508
Right front (kg)	454	494
Total front (kg)	**923.00**	**1,002.00**
Left rear (kg)	254	347
Right rear (kg)	232	290
Total rear (kg)	**486.00**	**637.00**

Table 2. Vehicle description and statistics.		
Cg measurements (mm):		
Behind front axle	930	1,072
Lateral	742	730
Height	521	511
Pitch inertia ($kg \cdot m^2$)*	2,403	2,689
Roll inertia ($kg \cdot m^2$)*	295	330
Yaw inertia ($kg \cdot m^2$)*	2,984	3,025
* Values do not include SID or stodard solvent.		



	PRE-TEST	POST-TEST	ΔCHANGE
A	2,692	2,388	-304
B	1,010	1,010	0
C	1,099	1,099	0
D	4,807	4,674	-133
E	140	140	0
F	375	451	76
G	181	279	98
H	181	152	-29
	337	267	-70
I	165	102	-63
	318	292	-26
J	152	229	77
K	254	305	51
L	203	203	0
M	295	359	64
N	610	610	0
O	1,067	699	-368
P	997	997	0
Q	419	349	-70

Figure 1. Vehicle physical parameters.

INSTRUMENTED DUMMY

One SID, serial number 904, was placed in the driver seat of the Ford Taurus. The SID was supplied by the NHTSA and was calibrated by a NHTSA approved SID calibration facility before shipment to the FOIL. The standard SID neck and head were replaced with a HYBRID III dummy's neck and head. The neck bracket was removed from the SID and replaced with the neck bracket from a HYBRID III. This provided the necessary bolt pattern and alignment for a HYBRID III neck and head assembly. Figure 2 is a sketch of the modifications made to the SID. The dummy was shipped with the necessary hardware for assembly. Tools at the FOIL were used to assemble the SID and clothing (not including shoes) consisting of white thermal underwear was purchased and put on the dummy. Eighteen extension cables were supplied with the SID. 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 SID was positioned in the driver seat in accordance with FMVSS 214. The driver seat was set in the center position with the back rest leaning back 25° from the vertical. Using FMVSS 214 as a guide and alignment tools supplied by the NHTSA, the SID's feet, legs, thighs, pelvis, torso, and head were positioned just before test. Pertinent SID-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.

RIGID POLE

The FOIL instrumented rigid pole was designed to measure vehicle frontal and side crush characteristics. The rigid pole was setup in the side impact configuration. The side impact configuration consisted of three 220-mm-diameter semi-circular impact faces, installed vertically end-to-end at various heights above ground. Attached to each face via two high-strength connecting rods were two load cells for a total of six load cells. 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. Figure 5 is a sketch of the FOIL rigid pole (side impact configuration).

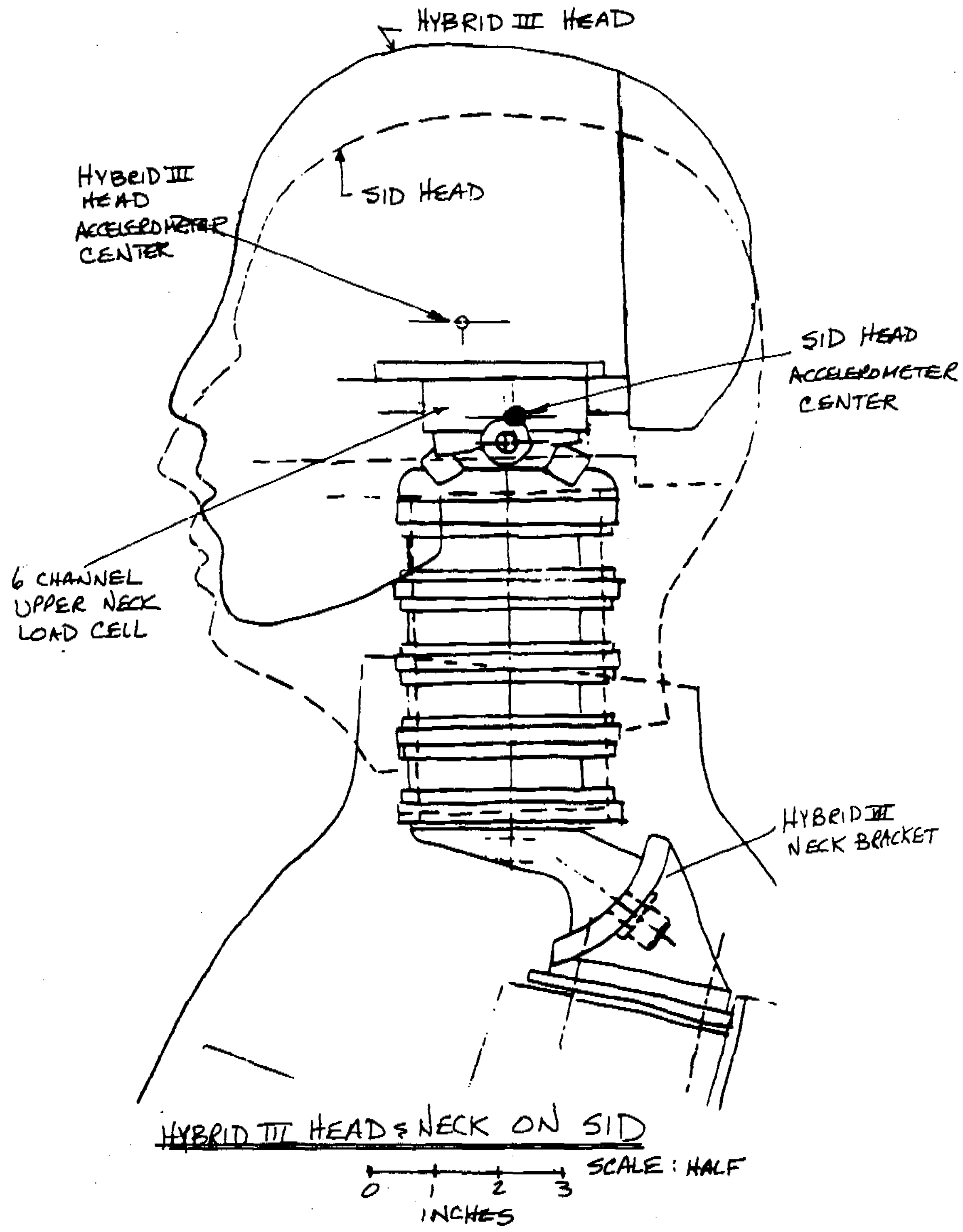
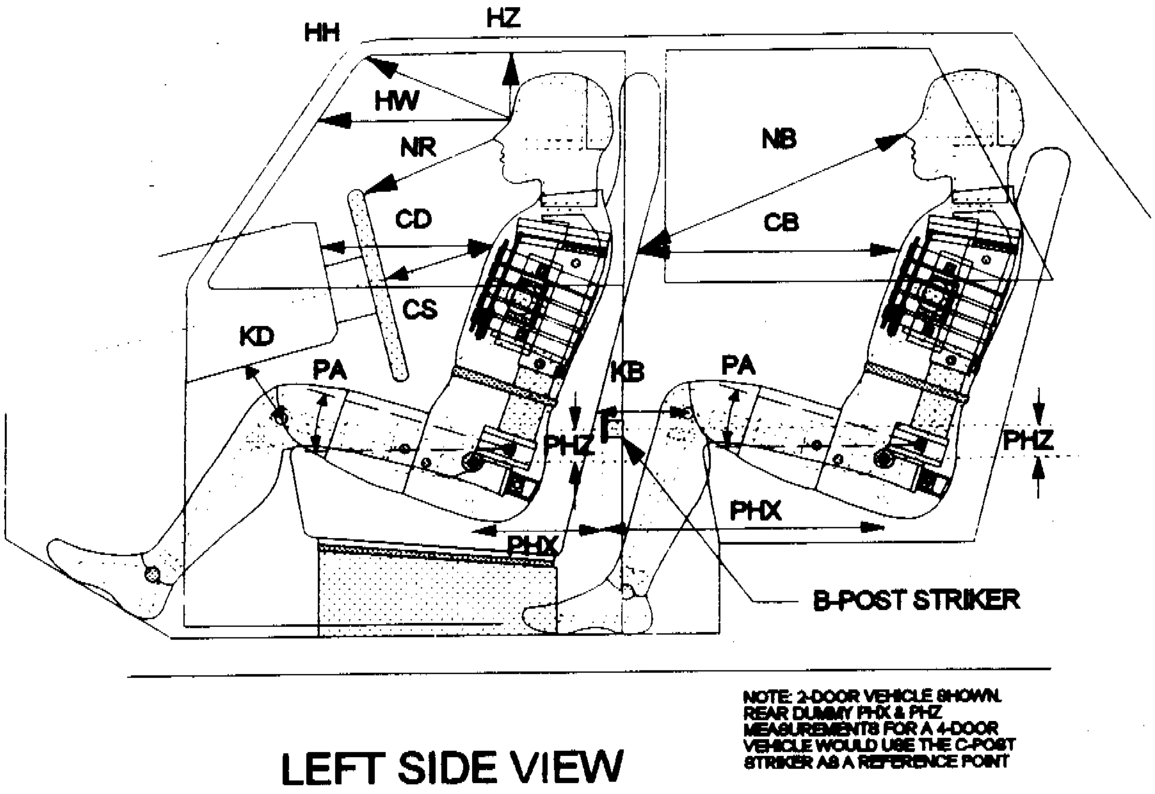
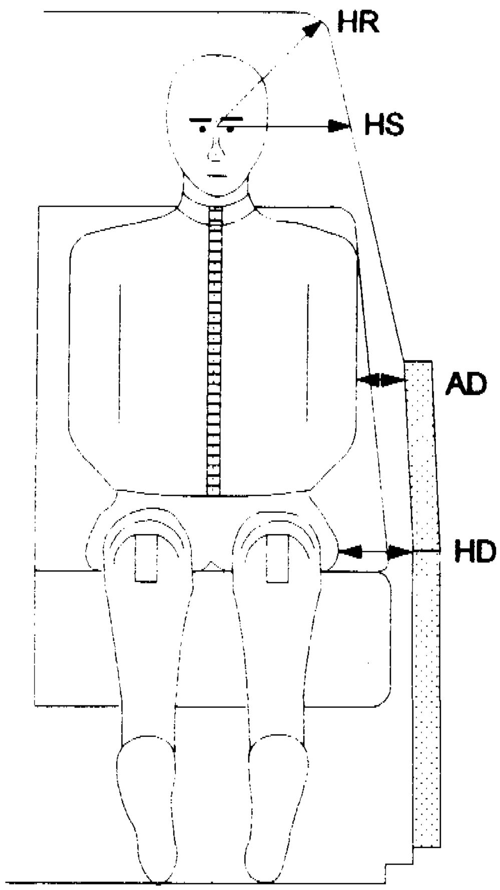


Figure 2. HYBRID III neck and head assembly on SID 904.



MEASUREMENT (mm)	DRIVER SID #904
HH	314
HW	533
HZ	159
NR	451
CD	568
CS	260
KDL(KDA°)	165(28°)
KDR	162
PA°	25°
PHX	244
PHZ	451

Figure 3. SID longitudinal clearance and position measurements.



MEASUREMENT (mm)	DRIVER SID #904
HR	181
HS	302
AD	56
HD	197

Figure 4. SID lateral clearance and position measurements.

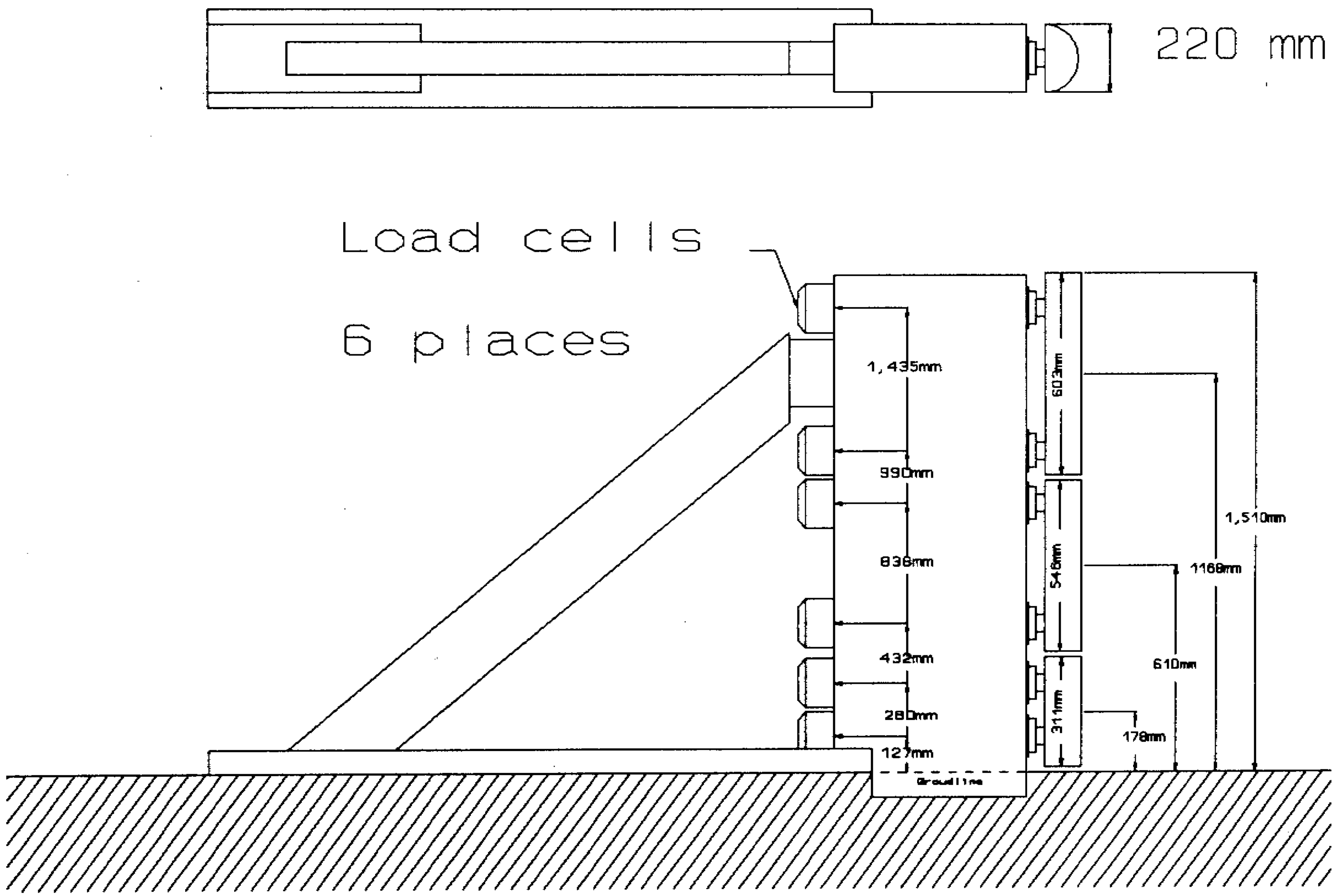


Figure 5. FOIL instrumented rigid pole, side impact configuration.

INSTRUMENTATION

Electronic data from the crash test was recorded via two data acquisition systems, the FOIL umbilical cable system and the FOIL on-board data acquisition system (ODAS). A total of 52 channels of electronic data were recorded. The umbilical cable system recorded 13 data channels and the remaining 39 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 brief summary of the data collected:

- 20 Localized vehicle accelerometers
- 16 SID accelerometer channels
- 6 Rigid pole load cell channels
- 3 center-of-gravity (cg) accelerometer channels
- 3 Rate sensor channels (located at the cg)
- 1 Displacement transducer channel
- 2 Channels for impact and speed trap switches
- 1 Channel for a tape recorder timing signal, 1kHz

Table 3 provides specific channel assignments. The first 39 channels were ODAS channels including the 16 SID channels (shaded entries). The remaining channels were recorded via umbilical cable. Figure 6 shows details on specific accelerometer placements.

Three 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. One technique was to mount the accelerometer to the aluminum block which was mounted directly to the vehicle with self-tapping sheet-metal screws. The second method used the accelerometer screws to mount the accelerometer to a small 25-mm square, 6-mm thick steel plate which was mounted to the vehicle using self-tapping sheet-metal screws. The third 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. The third technique was used only for mounting the engine-block accelerometers where the thick engine block caused problems for the smaller machine screws utilized in the first two techniques. Selected examples of accelerometer mounting techniques are shown in figure 51 of appendix C.

On-board data acquisition system (ODAS)

The ODAS system collected 39 channels of data. The data was from 20 localized vehicle accelerometers, 3 rate transducers, and 16 SID channels. The localized accelerometers were positioned at various locations around the vehicle. The output from the sensors were 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 to a digital sampling rate of 12,500 Hz.

Tape recorder-umbilical

The FOIL umbilical cable system utilizes a 90-mm cable between vehicle transducers, rigid pole load cells, or other sensors and a rack of 10 conditioning amplifiers. The output from the amplifiers is typically recorded on 25-mm magnetic tape via a Honeywell 5600E tape recorder. However, due to tape recorder malfunctions the output from the amplifiers and other sensors were pre-filtered and connected directly to a Data Translation analog-to-digital converter (ADC). The sample rate was set to 4000 Hz. The system recorded outputs from the 6 rigid pole load cells, the 3 cg accelerometers, the mono-rail speed trap, and the impact contact switch.

Table 3. Summary of ODAS channel assignments.

Reference & Channel	**Transducer**	**Max. range**	**Data description**
1	Accelerometer	2000 g's	Driver door, pelvis height
2	Accelerometer	2000 g's	Driver door, shoulder height
3	Accelerometer	2000 g's	Driver door, impact point
4	Accelerometer	2000 g's	Rear seat, above rear axle
5	Rate transducer	500 deg/s	CG, Pitch rate
6	Rate transducer	500 deg/s	CG, Roll rate
7	Rate transducer	500 deg/s	CG, Yaw rate
8	Load cell	9000 N	Neck force, Y-axis
9	Load cell	282 N·m	Neck moment, Y moment
10	Accelerometer	2000 g's	Head, X-axis
11	Accelerometer	2000 g's	Head, Y-axis
12	Accelerometer	2000 g's	Head, Z-axis
13	Accelerometer	2000 g's	Lower rib, Y-axis (P)

Table 3. Summary of ODAS channel assignments.			
Reference & Channel	**Transducer**	**Max. range**	**Data description**
14	Accelerometer	2000 g's	Upper rib, Y-axis (P)
15	Accelerometer	2000 g's	Lower spine, Y-axis, T12 (P)
16	Accelerometer	2000 g's	Upper spine, Y-axis, T0
17	Accelerometer	2000 g's	Lower rib, Y-axis (R)
18	Accelerometer	2000 g's	Lower spine, X-axis, T12
19	Accelerometer	2000 g's	Upper rib, Y-axis (R)
20	Accelerometer	2000 g's	Lower spine, Y-axis, T12 (R)
21	Accelerometer	2000 g's	Lower spine, Z-axis, T12
22	Accelerometer	2000 g's	Pelvis, X-axis
23	Accelerometer	2000 g's	Pelvis, Y-axis
24	Accelerometer	2000 g's	B-pillar at door latch
25	Accelerometer	2000 g's	B-pillar at floor sill
26	Accelerometer	2000 g's	Middle of B-pillar
27	Accelerometer	2000 g's	Roof rail near dummy's head
28	Accelerometer	2000 g's	Right side floor-sill
29	Accelerometer	2000 g's	Right side roof-rail
30	Accelerometer	2000 g's	Engine, Y-axis
31	Accelerometer	2000 g's	Engine, X-axis
32	Accelerometer	2000 g's	B-pillar at roof-rail
33	Accelerometer	2000 g's	Driver floor-sill
34	Accelerometer	2000 g's	Driver seat track
35	Accelerometer	2000 g's	A-pillar at floor-sill
36	Accelerometer	2000 g's	Middle of A-pillar
37	Accelerometer	2000 g's	A-pillar at upper door-hinge

Table 3. Summary of ODAS channel assignments.			
Reference & Channel	**Transducer**	**Max. range**	**Data description**
38	Accelerometer	2000 g's	A-pillar at roof-rail
39	Accelerometer	2000 g's	Driver door, knee height
40	Accelerometer	100 g's	CG, X-axis
41	Accelerometer	100 g's	CG, Y-axis
42	Accelerometer	100 g's	CG, Z-axis
43	Load Cell	111 kN	Top segment, upper cell
44	Load Cell	111 kN	Top segment, lower cell
45	Load Cell	222 kN	Mid segment, upper cell
46	Load Cell	222 kN	Mid segment, lower cell
47	Load Cell	222 kN	Bottom segment, upper cell
48	Load Cell	111 kN	Bottom segment, lower cell
49	Displacement transducer	1,525 mm	Between front doors, impact location, intrusion
50	Contact switch	1.5 Volts	Time of impact, T0
51	Micro switch	1.5 Volts	Rail speed
52	Generator	1.5 Volts	1 kHz reference signal

High-speed photography

A total of eight 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 Ford Taurus and the rigid pole. Three 35-mm still-motion cameras and one 16-mm real-time telecine camera were used to document the pre and post crash environment. Timing stickers 305 mm in length, black and yellow circular targets, and black and yellow target tape 25 mm wide, were placed on the Ford Taurus and rigid pole for film-data collection purposes. Target sticker locations included:

- Several end-to-end along the front grill and bumper for speed and initial roll angle measurements.

- Several end-to-end along the longitudinal and lateral roof centerlines through the cg for speed, displacement, and yaw angle measurements.

- Several end-to-end along the driver-side roof-rail longitudinally.

- Several placed strategically along the impact side of the vehicle. Reference sticker and marker for the impact location and to measure initial pitch angle. Five parallel strips of target tape were placed at each of the five levels described in figure 8.

Figure 7 is an overhead sketch of the facility depicting the setup of the vehicle, rigid pole, test track, and the location of each high-speed camera. Cartesian coordinates of the cameras are included on figure 7. The coordinates were referenced from the ground underneath the center of the semicircular impact faces of the rigid pole (origin) to the camera lenses. Positioned in each view was at least one strobe light. The lights flashed when the vehicle struck the pole. This synchronized the film with the electronic data.

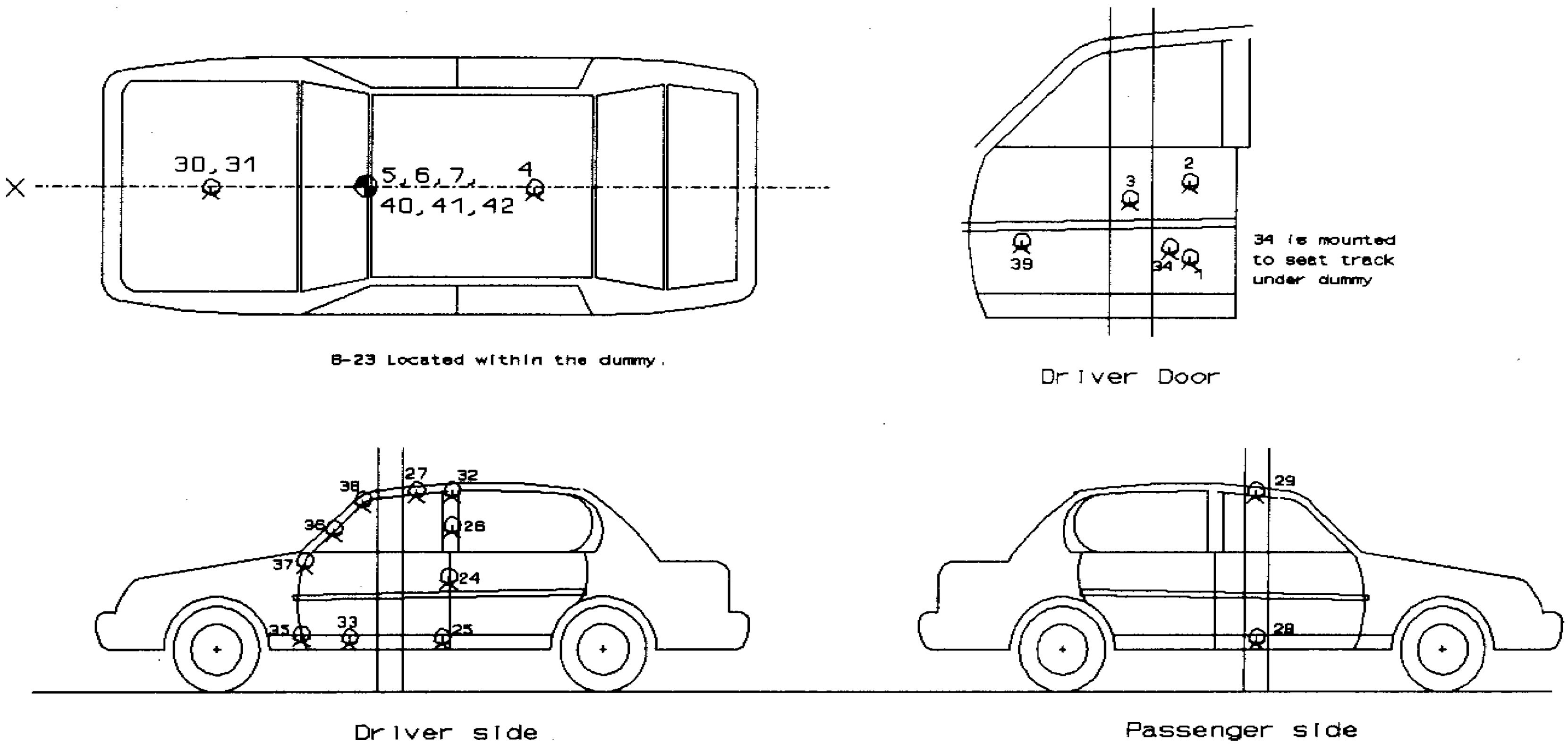
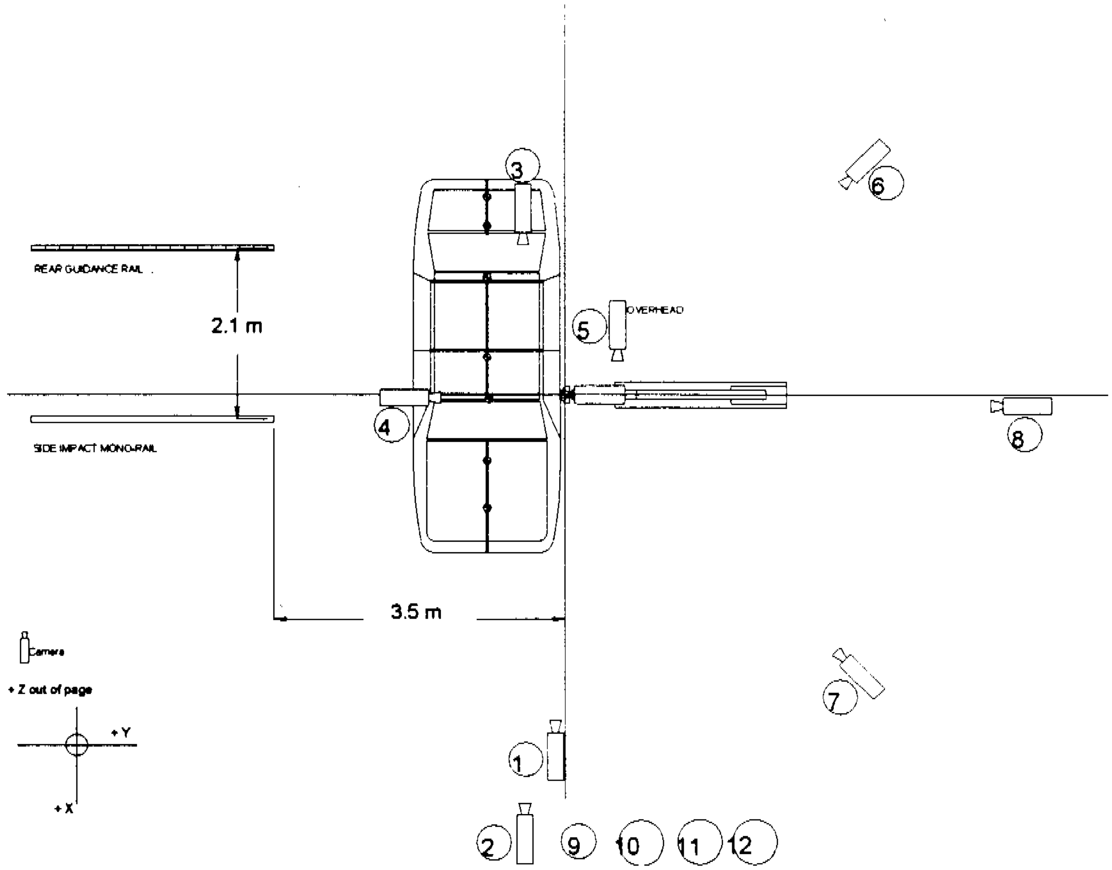


Figure 6. Vehicle accelerometer locations.



NO.	Model	Film speed	Lens focal length	Data	Orientation/ Location (m)
1	LOCAM II	500 F/S	50 mm	Speed, roll angle	90° to impact (16.1,-0.53,0.79)
2	PHOTEC	500 F/S	80 mm	redundant camera 1	90° to impact (21.4,-0.67,1.3)
3	LOCAM II	500 F/S	5.7 mm	behind driver	On-board malfunctioned
4	LOCAM II	500 F/S	5.7 mm	90° to driver	On-board (1.8,0.0,0.86)
5	LOCAM II	500 F/S	10 mm	Displacement , yaw angle	Overhead (-0.05,-0.37,8.2)
6	LOCAM II	500 F/S	75 mm	visual	45° to impact (-7.5,5.9,0.70)
7	LOCAM II	500 F/S	50 mm	visual	45° to impact (12.0,10.9,0.61)
8	LOCAM II	500 F/S	75 mm	visual, pitch angle	180° to impact (0.13,16.8,0.86)
9	BOLEX	24 F/S	Zoom	documentary	90° to impact
10	CANNON	Still	Zoom	documentary	varied
11	CANNON	Still	Zoom	documentary	varied
12	NIKON	Still	Zoom	documentary	90° to impact

Figure 7. 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 broadside test.

ODAS system. The data from the ODAS system included 16 channels of SID data, 20 localized accelerometer channels, and 3 rate transducer channels. The data was filtered and digitally stored within the ODAS unit during the test. The filter was factory set at 4000 Hz. The ADC sampling rate was factory set at 12,500 Hz. After the test, the data was down loaded to a portable computer for analysis. The data was converted to the ASCII format, zero-bias removed, and digitally filtered at 1650 Hz (SAE class 1000). Rib, spine, and pelvic data were filtered a second time using a NHTSA supplied FIR100 filter. The class-1000 data was input into a spreadsheet for plotting.

Vehicle accelerometers measuring y-axis accelerations were not adjusted for the initial roll angle induced by the vehicle falling from the side impact monorail and by the frictional forces between the tires and the FOIL runway. Many accelerometers were mounted with the axis of sensitivity at an angle relative to the y-z plane. No adjustments were made to the data to account for this original mounted roll angle. The initial angle measurements are presented in the results section of this report.

Umbilical cable. Data collected via the umbilical cable was digitally sampled at the time of the test. The data included 6 load cell channels, 3 accelerometer channels (located at the cg), one displacement transducer, and the impact switch and mono-rail speed trap. The data was directly input to a Data Translation ADC. The sample rate was set to 4,000 Hz. The digital data was converted to the ASCII format, zero-bias removed and digitally filtered to 1650 Hz (SAE class 1000). The filtered data was input into a spreadsheet for plotting.

High-speed film. The high-speed 16-mm film was analyzed via a NAC 160-F film motion analysis system in conjunction with and IBM PC-AT. The overhead, one 90°, and the 180° camera were used to acquire pertinent test data. The analyzer reduced the test-film frame by frame to cartesian coordinates which 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, roll angle, yaw angle, and pitch angle.

RESULTS

The Ford Taurus was placed on the FOIL side impact monorail with its longitudinal centerline perpendicular to the rigid pole centerline. The Taurus exited the monorail at 36.6 km/h. Due to the vehicle falling from the monorail and the frictional forces between the tires and the concrete runway, the vehicle struck the rigid pole at 32.8 km/h (initial energy of 68,030 N·m), at an initial roll angle of 3°, and an initial yaw angle of 89° (1° off perpendicular). Table 4 summarizes the test conditions and selected results.

Table 4. Summary of test conditions and results.

FOIL test number	95S014
Date of test	December 18, 1995
Test vehicle	1990 Ford Taurus, 4-door sedan
Vehicle weight	1639 kg
Test article	FOIL instrumented rigid pole
Ground conditions	Wet concrete runway
Temperature inside vehicle	14° C
Mono-rail exit speed	36.6 km/h
Impact speed	32.8 km/h
Impact point	1,150 mm rearward of front axle
Traffic accident data, TAD	9-LP-7
Vehicle damage index, VDI	09LPAN5
Occupant impact velocities	
Design limit (Report 350)	9 m/s
Allowable limit (Report 350)	12 m/s
Calculated 0.3 m flail space	6.3 m/s
Impact time 0.30 m flail (actual flail space was 0.3 m)	0.092 s
Occupant ridedown accelerations	
Design limit (Report 350)	15 g's

Table 4. Summary of test conditions and results.	
Allowable limit (Report 350)	20 g's
Calculated value at 0.30 m flail space	21.2 g's
Head Injury Criteria (HIC)	
Limit	1000 g's
Observed	184 g's
Start time	0.02632 s
Stop time	0.09816 s
Interval time	0.07184 s
Thoracic trauma	
Limit (4-door)	85 g's
Peak rib acceleration (FIR100)	45.6 g's
T12 spine (FIR100)	53.0 g's
Thoracic Trauma Index (TTI)	49.3 g's

Vehicle response. The film showed that the vehicle made contact with the rigid pole 1,150 mm rearward of the front axle. After the test, the observed point of maximum intrusion was 50 mm behind the target impact location. The front and rear of the vehicle yawed independently and as the vehicle wrapped around the pole the penetration shifted toward the door latch. Film analysis yielded a front end yaw angle of 10° and a rear end yaw angle of 8.5°. Integration of the yaw rate transducer positioned under the dash panel on the floor tunnel 640 mm forward of the vehicle cg produced a maximum yaw angle of 7.5°. The four door latches remained latched during the collision. No evidence of fuel leakage or fuel system component damage was observed. The driver air-bag did not deploy during the test. The rigid pole shattered the driver-side window 0.010 s after initial contact and penetrated the occupant compartment collapsing the roof-rail, door, and floor-sill. The pole began to rotate the driver seat clockwise (from overhead) and tip the seat rearward 0.044 s after initial contact. The pole penetrated the occupant compartment pushing the door into the steering wheel bending it toward the right side of the vehicle. Steering wheel contact began at 0.048 s. Double integration of the cg accelerometer yielded a maximum dynamic intrusion of 660 mm. The attachment of the displacement transducer's string line to the driver door was made 50-mm forward of the impact location. Therefore the displacement transducer did not measure the intrusion at impact. The displacement transducer measured 445 mm of intrusion and an intrusion rate of 12 m/s at the attachment location. As the pole penetrated the door it pulled the trunk release cable, opening the trunk during impact. The peak cg acceleration was determined to be 97.8 g's (1.5 MN) and occurred 0.05155 s after impact.

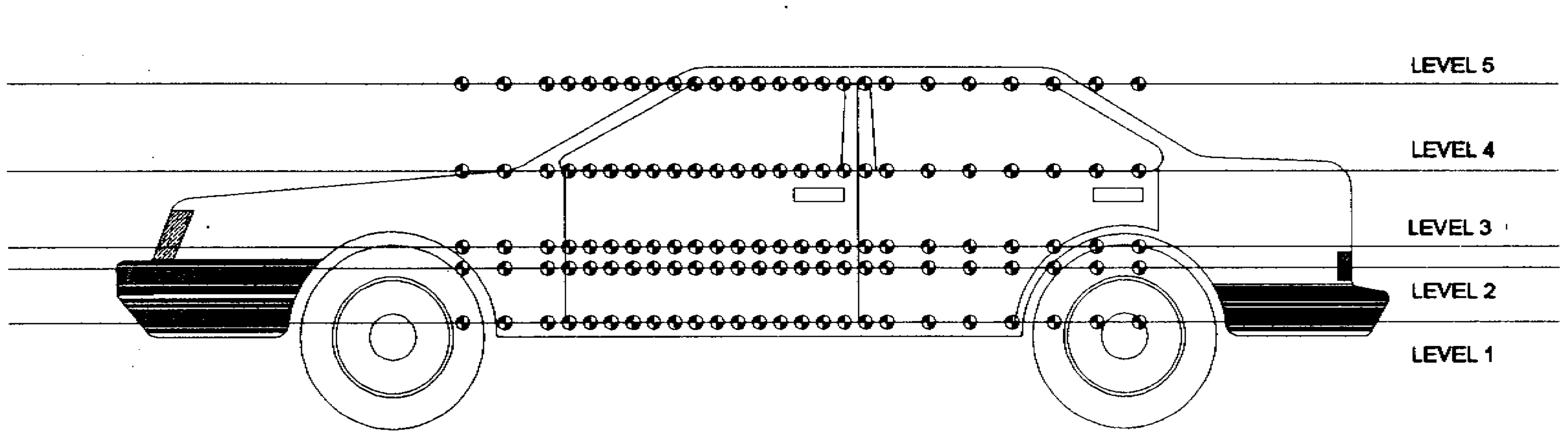
After the test a damage profile of the vehicle was produced. Figure 8 depicts the driver-side profile measurements before and after the test. The measurements were made using a reference line parallel to the driver side of the vehicle. The parallel line was drawn an arbitrary distance from and perpendicular 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 the same forward and aft increments were used rather than measuring the identical point on the vehicle as was measured before the test.

Table 5 lists each accelerometers' location and orientation before and after the test. The coordinate data is referenced from a point on the passenger side sill across from the impact point. The point on the sill was 320 mm above ground. The angular measurements were taken using an inclinometer placed on or adjacent to the accelerometer. Data plots of the data from transducers mounted to the test vehicle are presented in appendix A. Pre and post-test photographs are presented in appendix C.

Table 5. Accelerometer location and orientation.

Accelerometer position	Pre-test measurements				Post-test measurements					
	X(mm)	Y(mm)	Z(mm)	Ang.[1]	X(mm)	Y(mm)	Z(mm)	Ang.[1]	Ang.[2]	Peak (g's)
Top of engine (X)	1,468	695	531	0°	1,397	794	550	0°	10°	-4.8
Top of engine (Y)	1,468	708	531	1.5°	1,397	807	550	1.5°	10°	-15.5
Rear seat (Y)	-2,388	771	154	1°	-2,380	991	175	1°	7°	-22.1
Door knee level(Y)	435	1,571	191	1°	26	1,170	213	1°	45°	NA
Door shoulder (Y)	-146	1,559	432	5°	-114	1,075	391	23°	21°	-673.0
Door pelvis (Y)	-95	1,565	172	0°	-89	1,067	137	20°	12°	-975.5
Door in-line w/ impact	-38	1,559	432	4°	10	1,067	404	0°	35°	No data
Driver seat (Y)	-197	1,422	64	0°	-152	1,155	61	0°	10°	-251.2
Roof rail at dummy's head	-302	1,394	978	3°	-254	1,130	1,001	3°	23°	-291.8
A-pillar upper level(Y)	108	1,390	733	26°	102	1,181	899	24°	35°	No data
B-pillar upper level(Y)	-521	1,394	981	5°	-394	1,195	1,026	32°	11°	-596.3
B-pillar middle level(Y)	-473	1,556	740	25°	-305	1,240	760	13°	11°	-126.6
B-pillar lower@latch (Y)	-432	1,626	460	3°	-279	1,271	480	4°	28°	-236.7
B-pillar floor level(Y)	-425	1,601	3	0°	-280	1,265	23	0°	43°	-448.4
Driver floor fwd. impact	314	1,533	29	0°	178	1,384	35	0°	45°	-118.9
A-pillar floor level (Y)	584	1,622	22	20°	394	1,575	-2.5	13°	23°	No data
A-pillar lower level (Y)	625	1,610	479	0°	457	1,613	464	3°	25°	No data
A-pillar middle level(Y)	311	1,470	606	30°	254	1,321	747	45°	28°	-143.5
Passenger roof at impact	-29	20	645	0°	-29	178	711	15°	10°	-210.4
Passenger floor at impact	6	70	19	0°	6	70	19	0°	0°	-35.7
Vehicle cg (X)	115	791	67	0°	115	733	38	0°	10°	33.8
Vehicle cg (Y)	143	705	65	0°	143	647	36	8°	0°	-97.8
Vehicle cg (Z)	159	794	89	0°	159	736	60	8°	NA	-17.1
Triaxial rate transducer	521	794	57	0°	465	787	0	8°	11°	NA

[1] Angle between accelerometer axis of sensitivity and the y-axis (Y-Z plane).
[2] Angle between accelerometer axis of sensitivity and the x-axis (X-Y plane).



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**		**-914**	**-762**	**-686**	**-610**	**-533**	**-457**	**-381**	**-305**	**-229**	**-152**	**-76**	**0**	**76**
1	318	**PRE**			873	864	860	854	851	845	842	835	829	826	822
	298	**POST**				838	848	857	879	949	1,022	1,105	1,222	1,353	1,343
		CRUSH				-26	-12	3	28	104	180	270	393	527	521
2	476	**PRE**		845	841	821	826	819	819	810	806	797	794	787	810
	460	**POST**				800	814	816	845	924	984	1,099	1,222	1,353	1,356
		CRUSH				-21	-12	-3	26	114	178	302	428	566	546
3	568	**PRE**		854	848	838	832	826	819	816	810	803	800	794	787
	546	**POST**			794	803	810	822	845	938	1,013	1,067	1,238	1,359	1,356
		CRUSH				-35	-22	-4	26	122	203	264	438	565	569
4	857	**PRE**	927	914		895	892	889	883	876	873	868	864	859	856
	838	**POST**	810	829	838	845	851	864	902	953	997	1,121	1,302	1,370	1,353
		CRUSH	-117	-85		-50	-41	-25	19	77	124	253	438	511	497
5	1,283	**PRE**											1,111	1,105	1,099
	1,299	**POST**											1,343	1,416	1,422
		CRUSH											232	311	323

All units of measurement are in mm.

Figure 8. Vehicle profile measurements.

			Distance from impact point (mm).												
LEVEL	**HEIGHT**		**152**	**229**	**305**	**381**	**457**	**533**	**610**	**686**	**762**	**838**	**991**	**1,143**	**1,295**
1		**PRE**	816	813	803	800	794	787	775	767	759				
		POST	1,283	1,203	1,124	1,063	1,000	987	946	911	876				
		CRUSH	467	390	321	263	206	200	171	144	117				
2		**PRE**	772	772	768	762		756		749		737	730	721	
		POST	1,295	1,099	1,051	1,022		953		905		813	759	765	
		CRUSH	523	327	283	260		197		156		76	29	44	
3		**PRE**	781	778	772	768		762		749		743	737	727	718
		POST	1,302	1,111	1,057	1,029		956		908		845	784	772	756
		CRUSH	521	333	285	261		194		159		102	47	45	38
4		**PRE**	849	846	841	832		822		813		806	800	794	787
		POST	1,264	1,168	1,121	1,086		1,029		956		921	870	822	832
		CRUSH	415	322	280	254		207		143		115	70	28	45
5		**PRE**	1,105	1,105	1,105	1,105	1,095	1,086	1,080		1,067		1,060	1,041	1,038
		POST	1,403	1,343	1,311	1,248	1,260	1,238	1,248		1,197		1,146	1,118	1,095
		CRUSH	298	238	206	143	165	152	168		130		86	77	57

All units of measurement are in mm.

Figure 8. Vehicle profile measurements (continued).

<u>Occupant response.</u> The SID began leaning toward the driver door as soon as the vehicle fell from the side impact monorail and began to skid toward the rigid pole. Because the on-board camera positioned behind the driver failed, data on initial occupant speed (relative to the vehicle) and initial dummy position were not ascertained. The first contact occurred 0.026s after impact and was between the door and the SID's pelvis-femur region. The back third of the SID's head struck the b-pillar at 0.032 s. This prevented significant head protrusion from the window. However, the head protruded enough to be pinched between the b-pillar and rigid pole. The head begins to be pinched at 0.080 s and remains stuck until 0.246 s. While the head is pinched it is stationary relative to its torso and the seat. As the pole continues to rotate the seat the torso twists about the neck while the neck is in full flexion, bending forward and down in the direction of the left front tire. After the test, no physical damage to the SID was observed.

The neck (T01) accelerometer malfunctioned during the test and no data was recorded. The remaining 15 SID data channels were successfully recorded. The rib and spine produced a thoracic trauma index (TTI) of 49.3 g's. This is below the 4-door sedan limit of 85 g's specified in the Federal Motor Vehicle Safety Standard 214 (FMVSS 214). The three head accelerometers produced and Head Injury Criteria (HIC) value of 184 g's. This value is below the 1000 g's required by FMVSS 214. Table 6 summarizes the data collected from the SID. The values from the

Table 6. Summary of SID data.

Accelerometer	Maximum positive (g's)	Maximum negative (g's)
Head X	23.7	-34.9
Head Y	32.1	-40.7
Head Z	13.6	-27.0
Neck force load cell (N)	311.0	-463.7
Neck moment load cell (N·m)	37.5	-57.3
Neck T0 Y	No data	No data
Left upper rib (P)	13.2	-40.7
Left upper rib (R)	12.4	-38.9
Left lower rib (P)	8.8	-45.6
Left lower rib (R)	7.2	-44.8
Spine T12 X	10.4	-19.7
Spine T12 Y (P)	16.5	-53.0
Spine T12 Z	6.6	-15.8
Spine T12 Y (R)	17.0	-52.5
Pelvis X	19.3	-8.0
Pelvis Y	15.7	-99.0

Shaded area data is SAE class 1000.
Remaining data obtained from FIR100 filter output.

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

Rigid pole. The load cells measured six separate forces on the rigid pole. The resultant load could not be computed because one load cell channel did not record properly. The total load from summing the remaining five load cells was 137.1 kN. The significant loads were contributed by the roof-rail, floor-sill, and middle-point of the driver door. Summation of each rigid pole segments' load cell data shows that the roof-rail produced a peak force of 31.0 kN while the floor-sill produced a total load of 74.9 kN. The total middle segment load was not available due to a malfunction in one load cell data channel. Table 7 summarizes the load cell data. Data plots from the rigid pole load cells are presented in appendix D.

Table 7. Summary of rigid pole data.

Load cell / height (mm)	Peak force (1000 N)	Time (ms)
Top segment / 1,168	31.0	37.79
Upper load cell / 1,435	17.9	42.54
Lower load cell / 990	14.8	35.04
Middle segment / 610	43.5	No data
Upper load cell / 838	No data	No data
Lower load cell / 432	43.5	40.04
Bottom segment / 178	74.9	45.80
Upper load cell / 280	28.8	34.78
Lower load cell / 127	50.9	65.32
Total, rigid pole	137.1	44.29

CONCLUSIONS AND OBSERVATIONS

Visual inspection of the Ford Taurus after the collision produced immediate conclusions. Fuel system and door latch integrity were not breached by the broadside collision with the FOIL instrumented rigid pole (narrow-fixed object). The air-bag sensors were not sensitive in the lateral direction as denoted by the lack of air-bag deployment. The data recorded and the high-speed film will help validate the Ford Taurus FEM for broadside collisions with narrow-fixed objects.

The roof-rail, floor-sill, door latch, and door hinges contributed to the structural strength of the vehicle. The floor-sill provided the most stiffness as it collapsed in an accordion manner. The door thickness of 127 mm at its thickest cross-section collapses quickly, then the resistance comes from the connection between the door and the vehicle frame. The roof-rail provided the least amount of resistance. The roof buckled from a relatively low load. These three locations reached their peak force at approximately 0.04 s after impact. At this time the roof buckles and the hinges and latches move inward. The a-pillar and b-pillar get pulled in by the hinges and latch transferring load to the a- and b-pillars.

APPENDIX A. DATA PLOTS FROM VEHICLE ACCELEROMETERS.

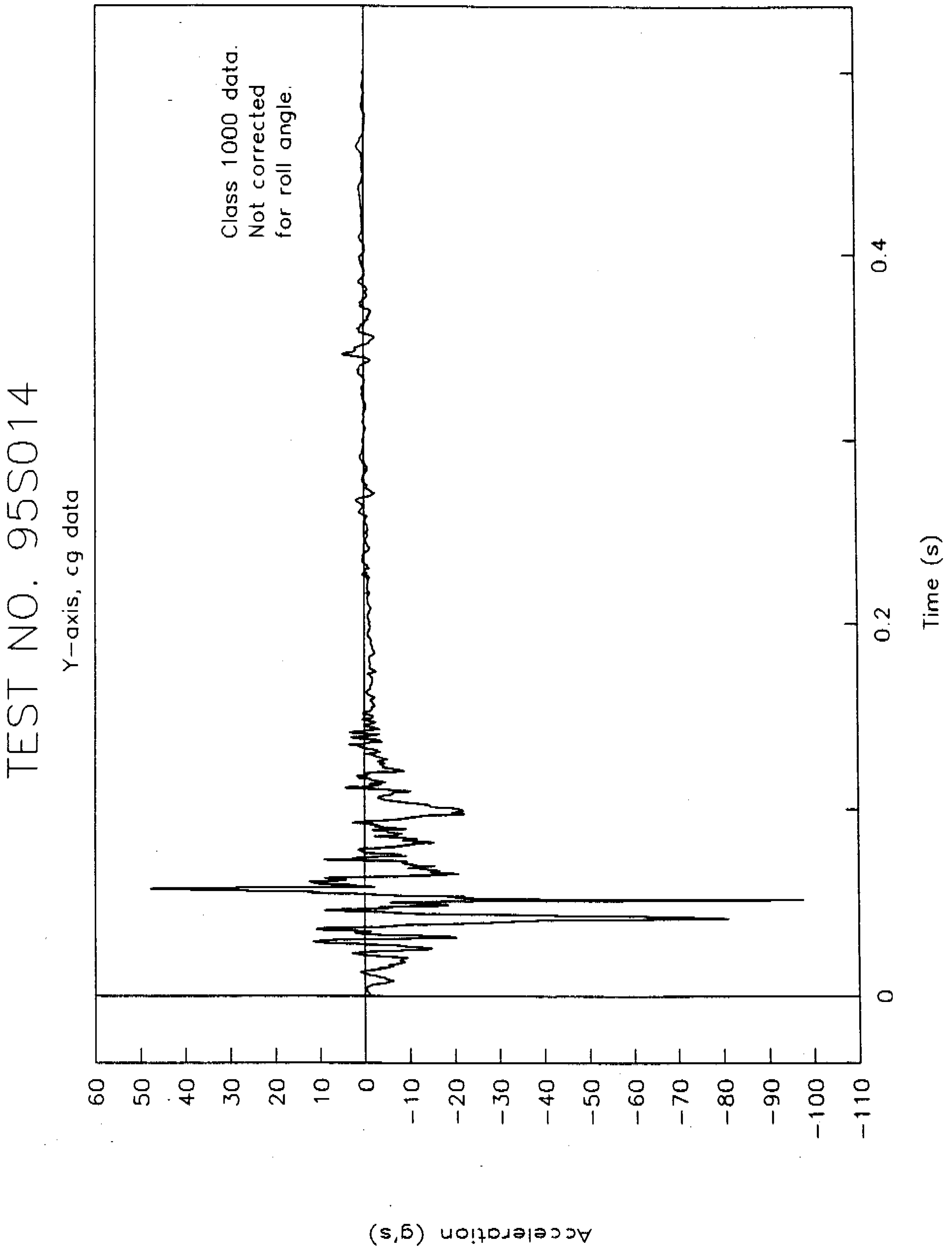


Figure 9. Acceleration vs. time, cg y-axis, test 95S014.

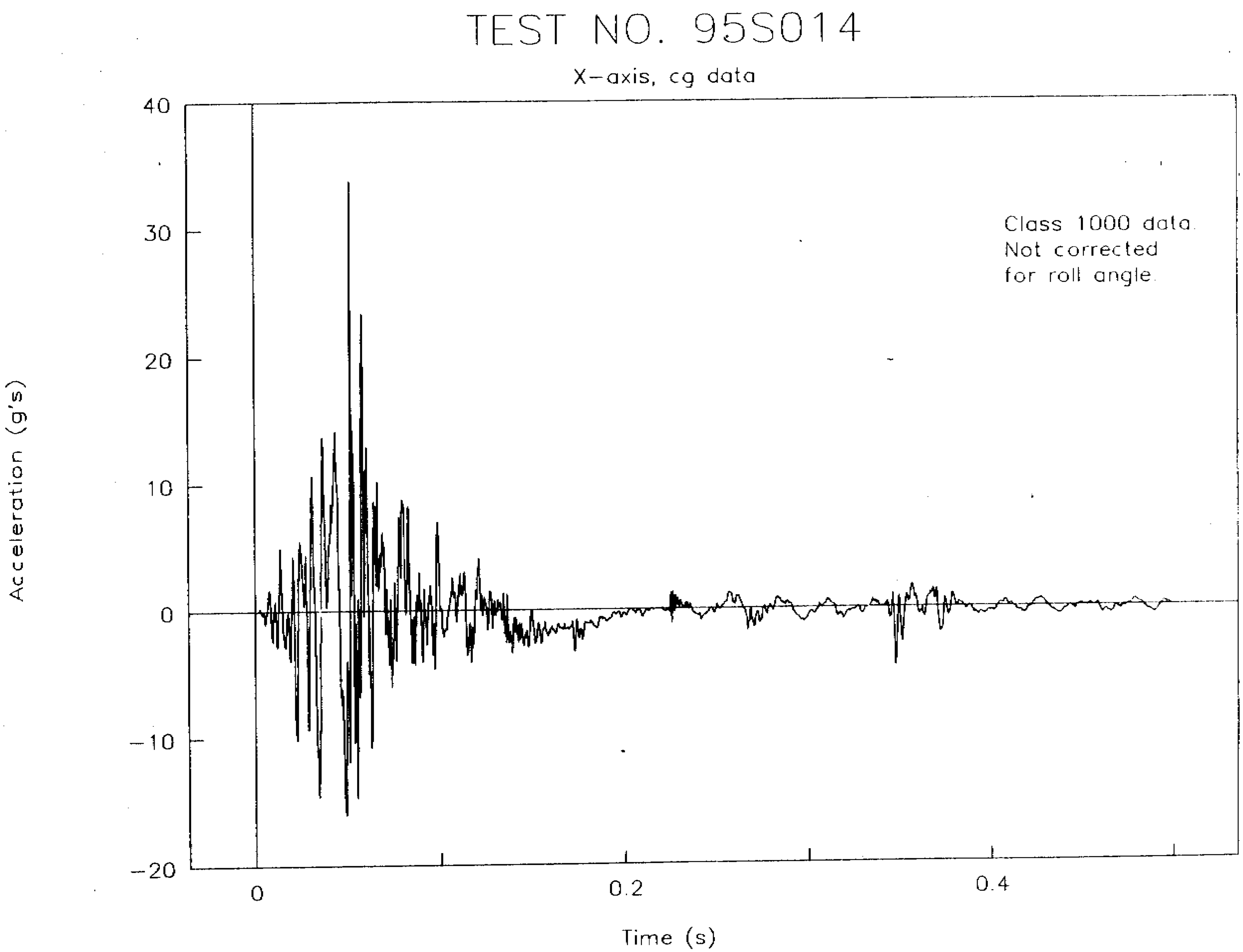


Figure 10. Acceleration vs. time, cg x-axis, test 95S014.

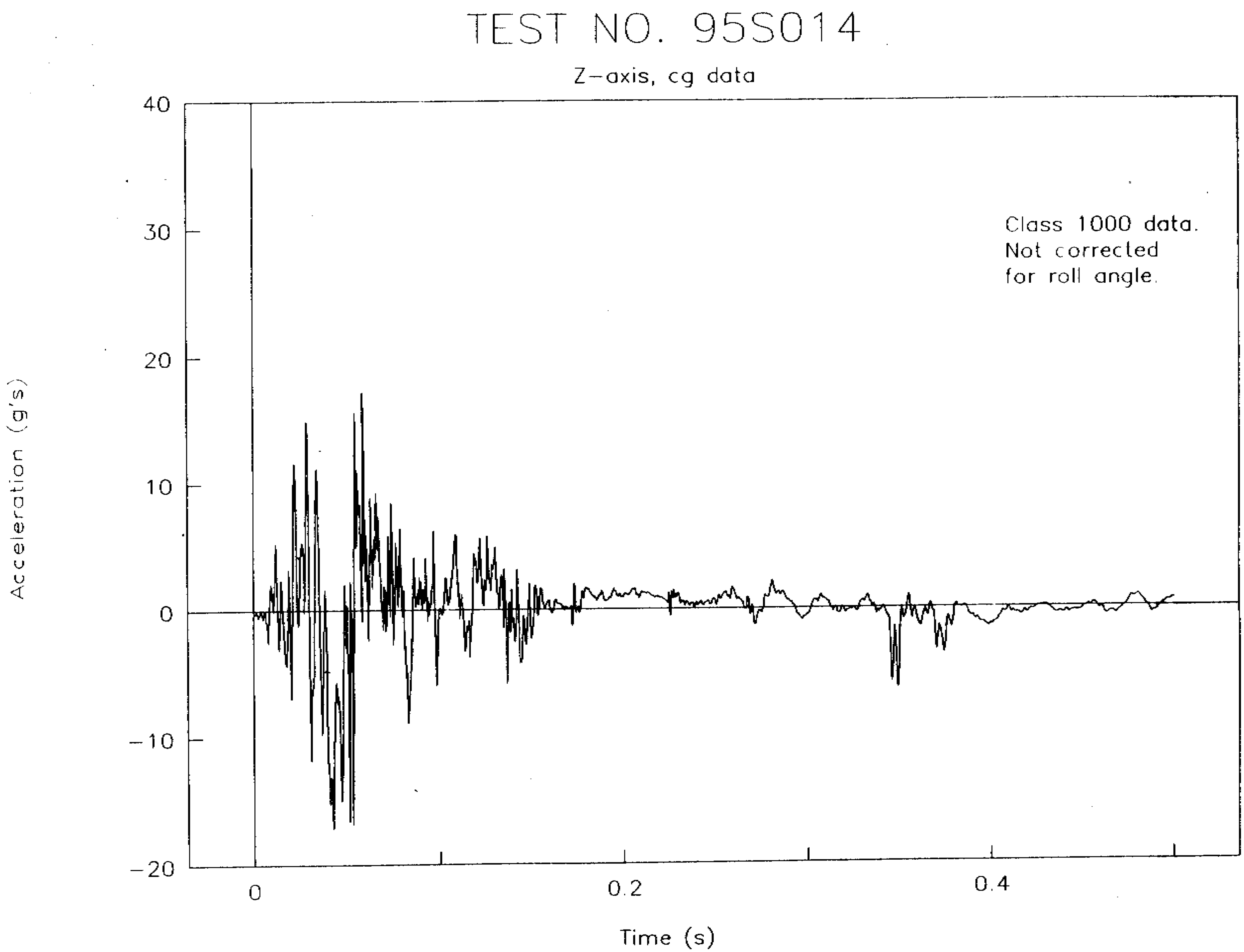


Figure 11. Acceleration vs. time, cg z-axis, test 95S014.

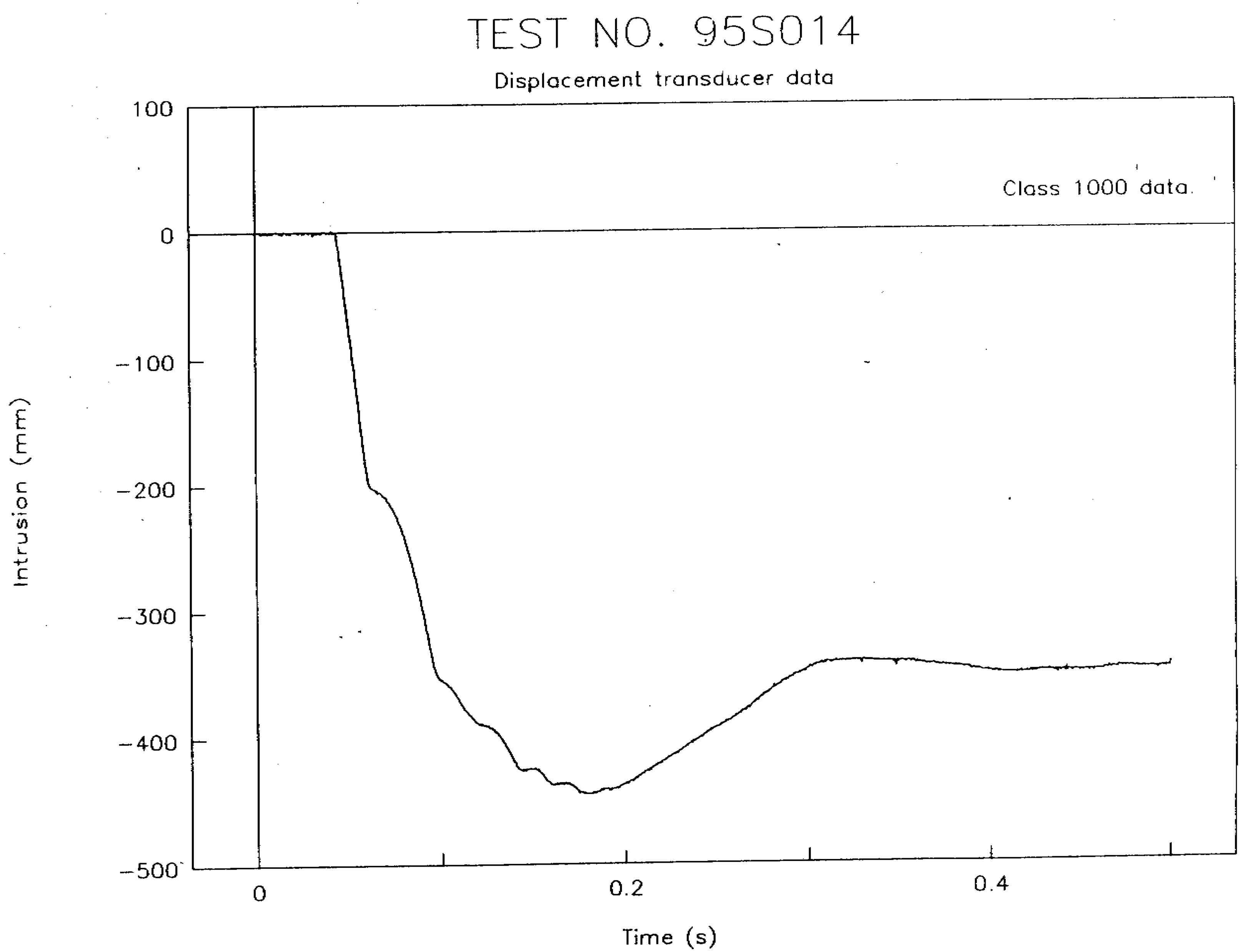


Figure 12. Intrusion vs. time, displacement transducer data, test 95S014.

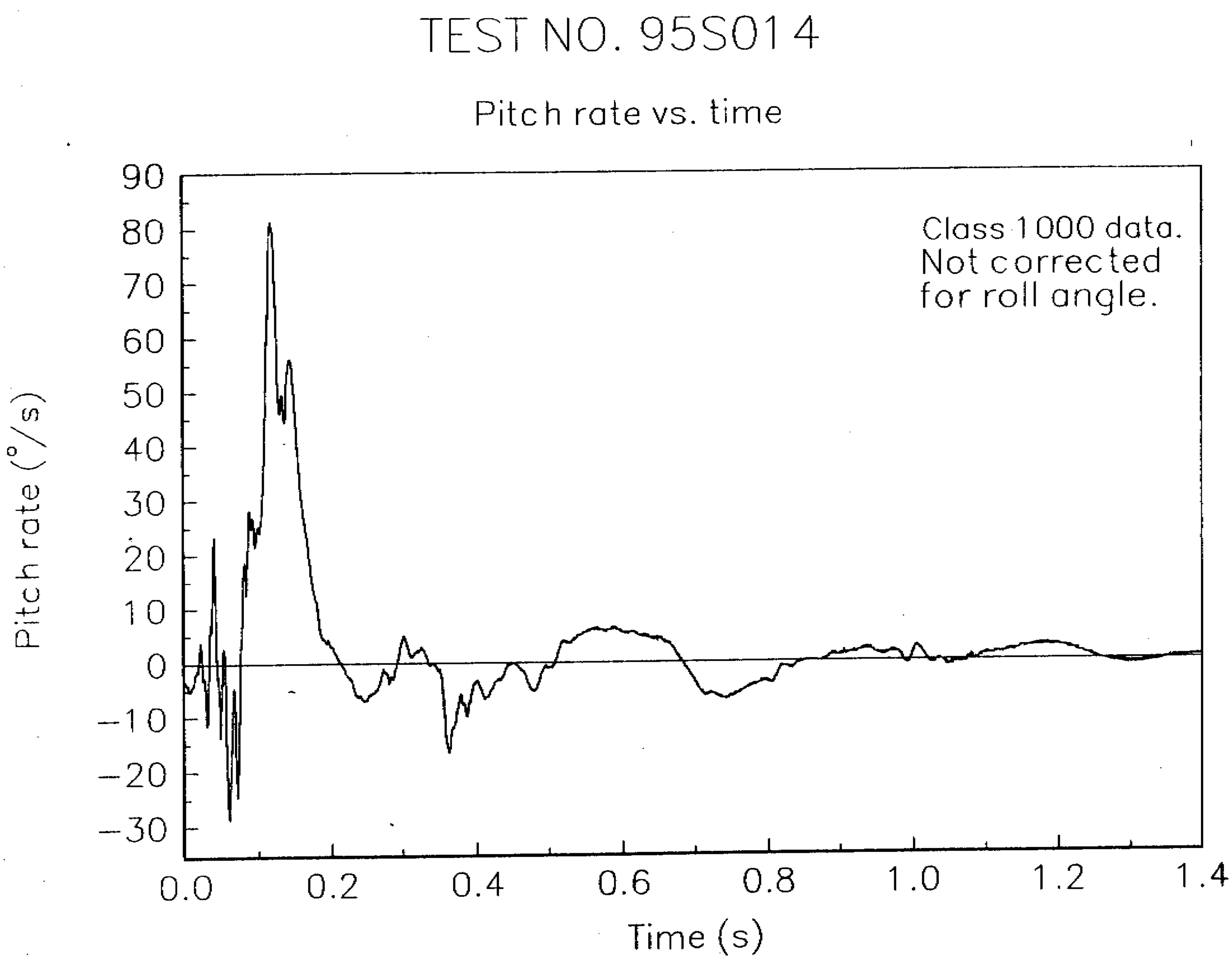


Figure 13. Pitch rate vs. time, test 95S014.

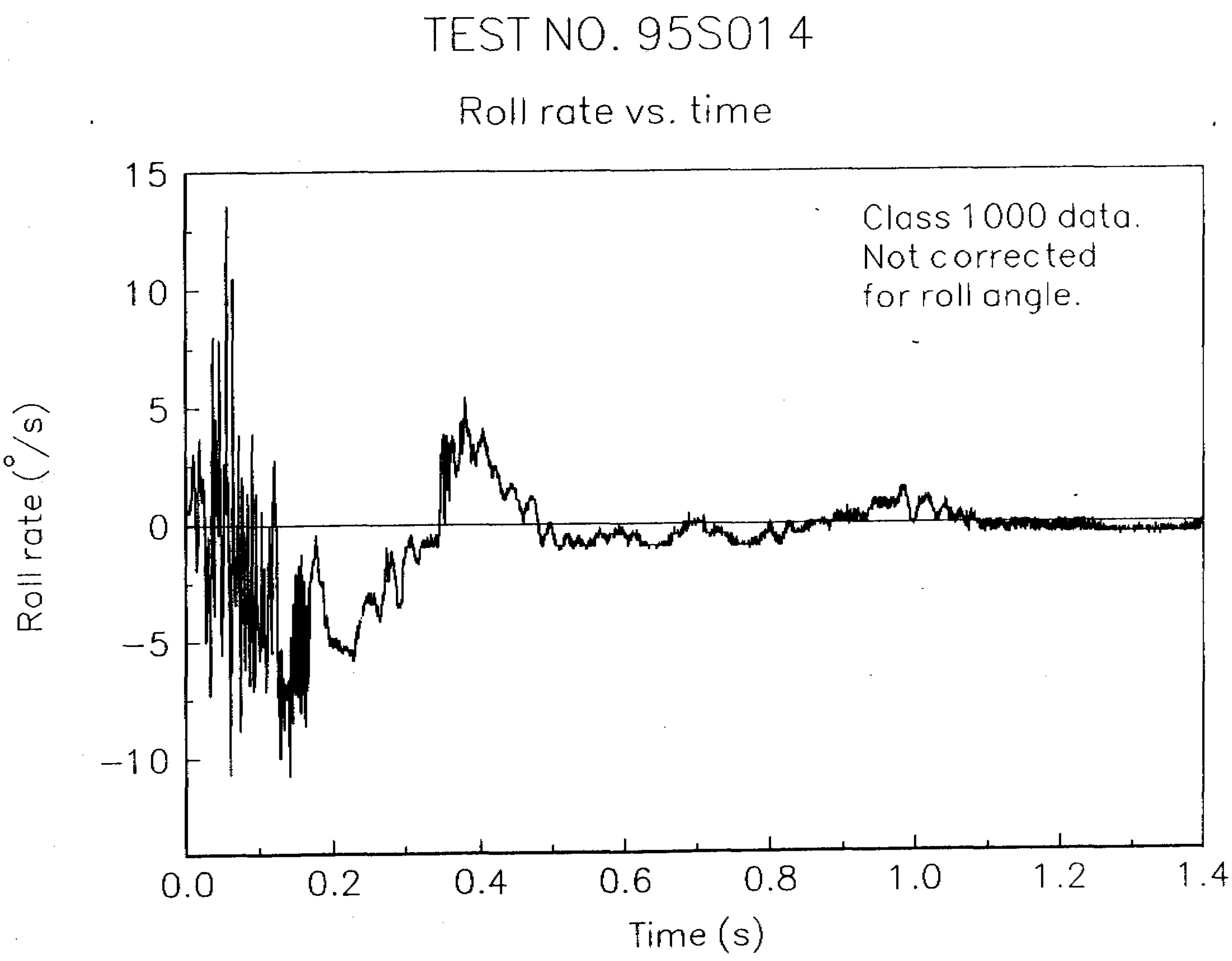


Figure 14. Roll rate vs. time, test 95S014.

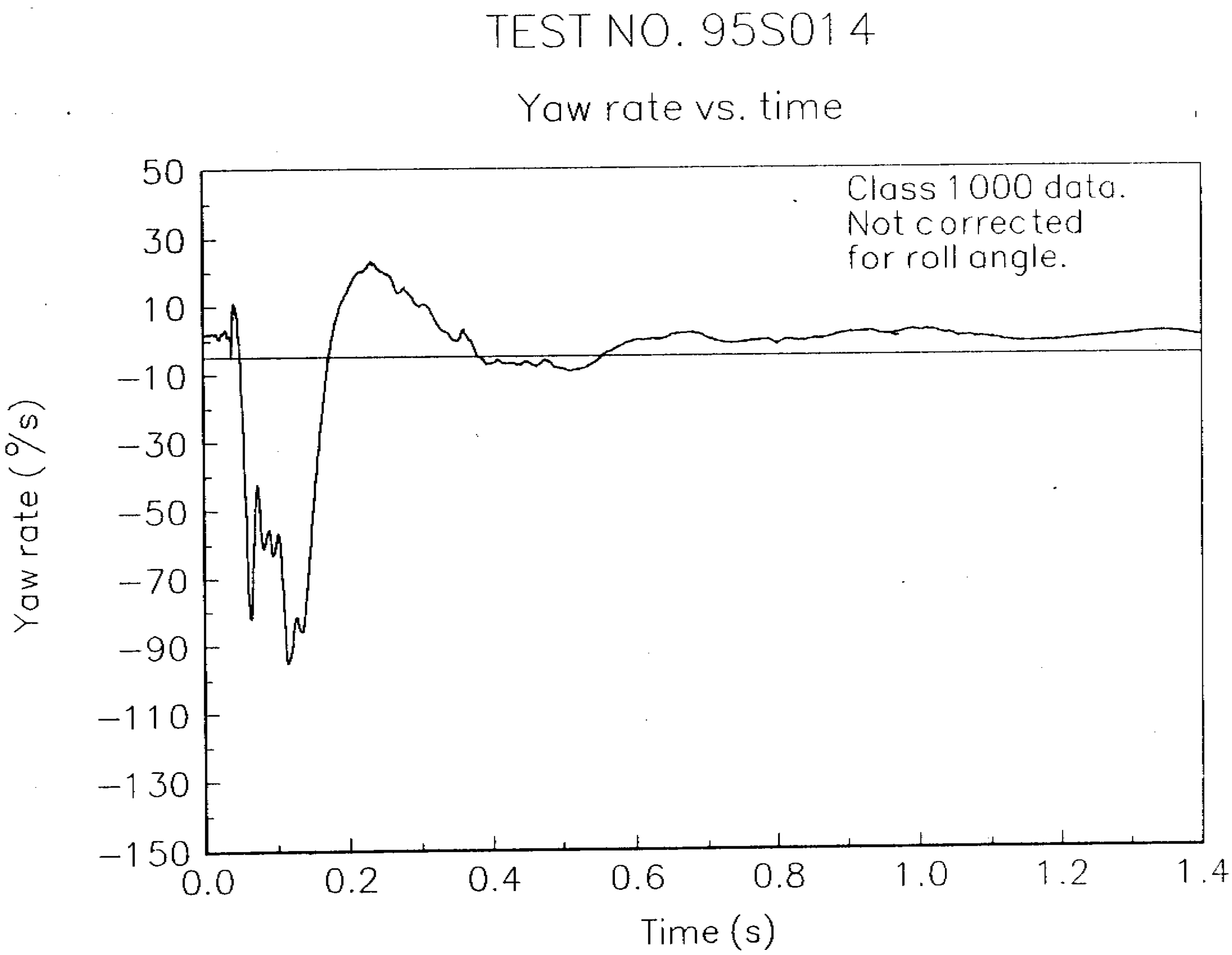


Figure 15. Yaw rate vs. time, test 95S014.

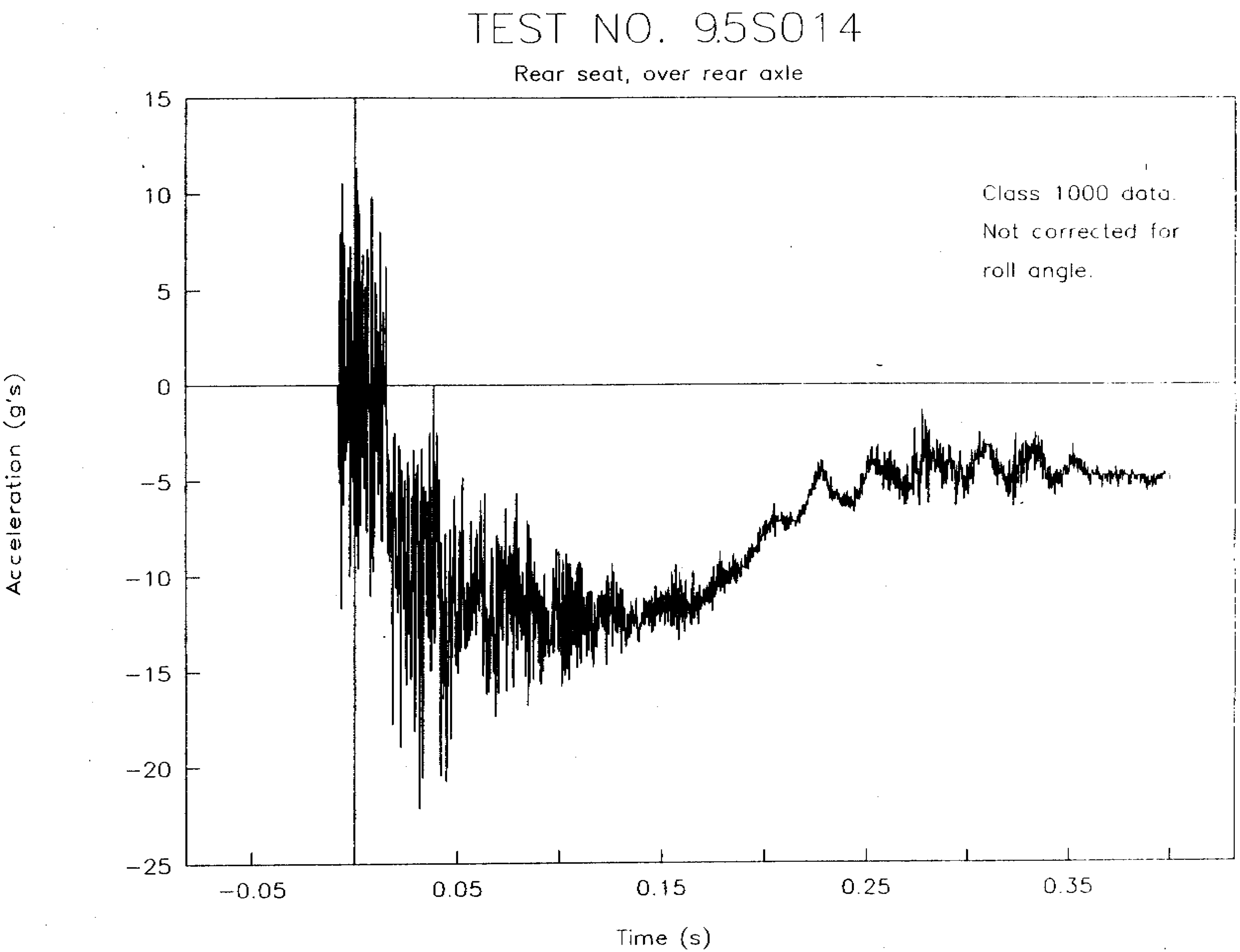


Figure 16. Acceleration vs. time, rear seat over rear axle, test 95014.

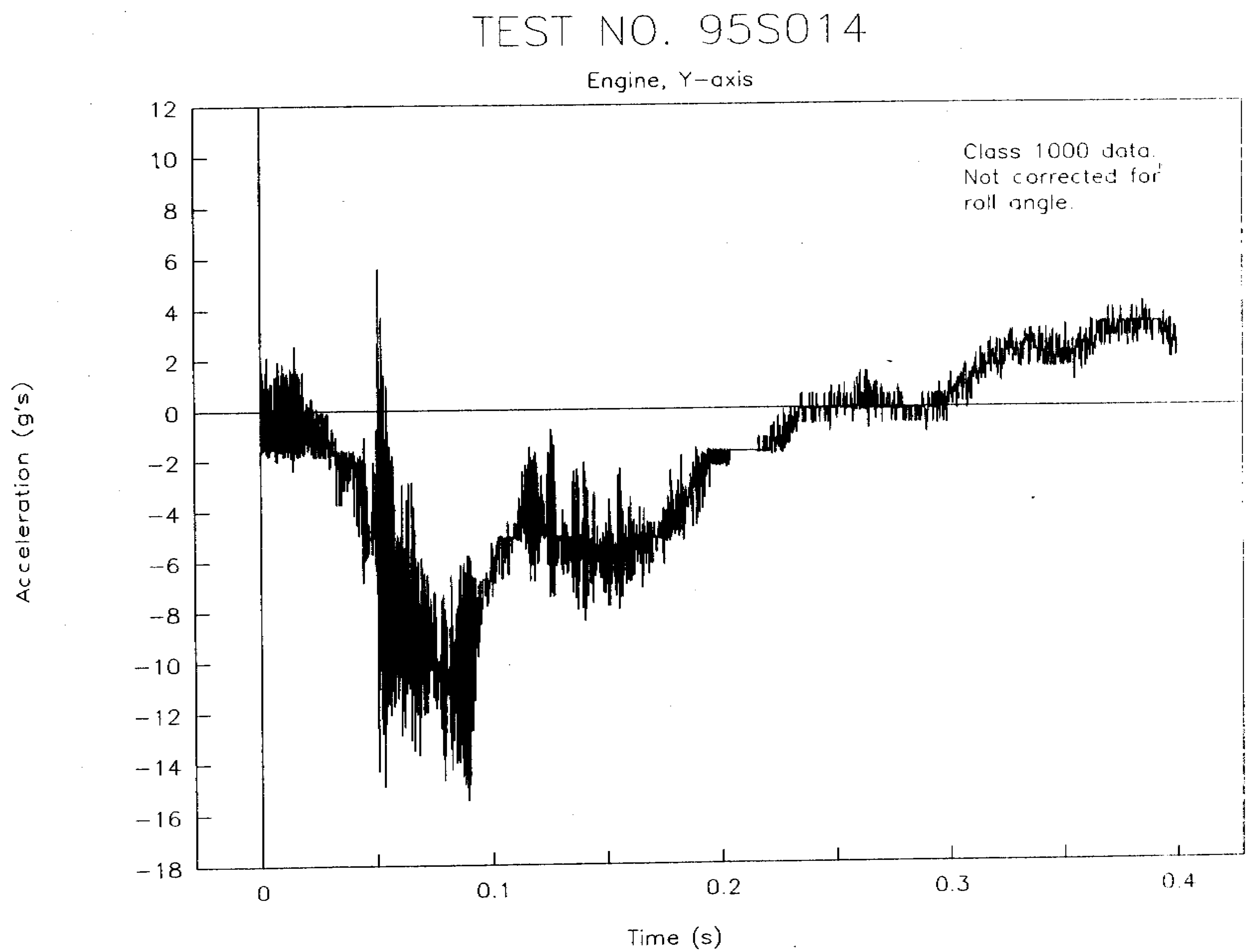


Figure 17. Acceleration vs. time, engine, y-axis, test 95S014.

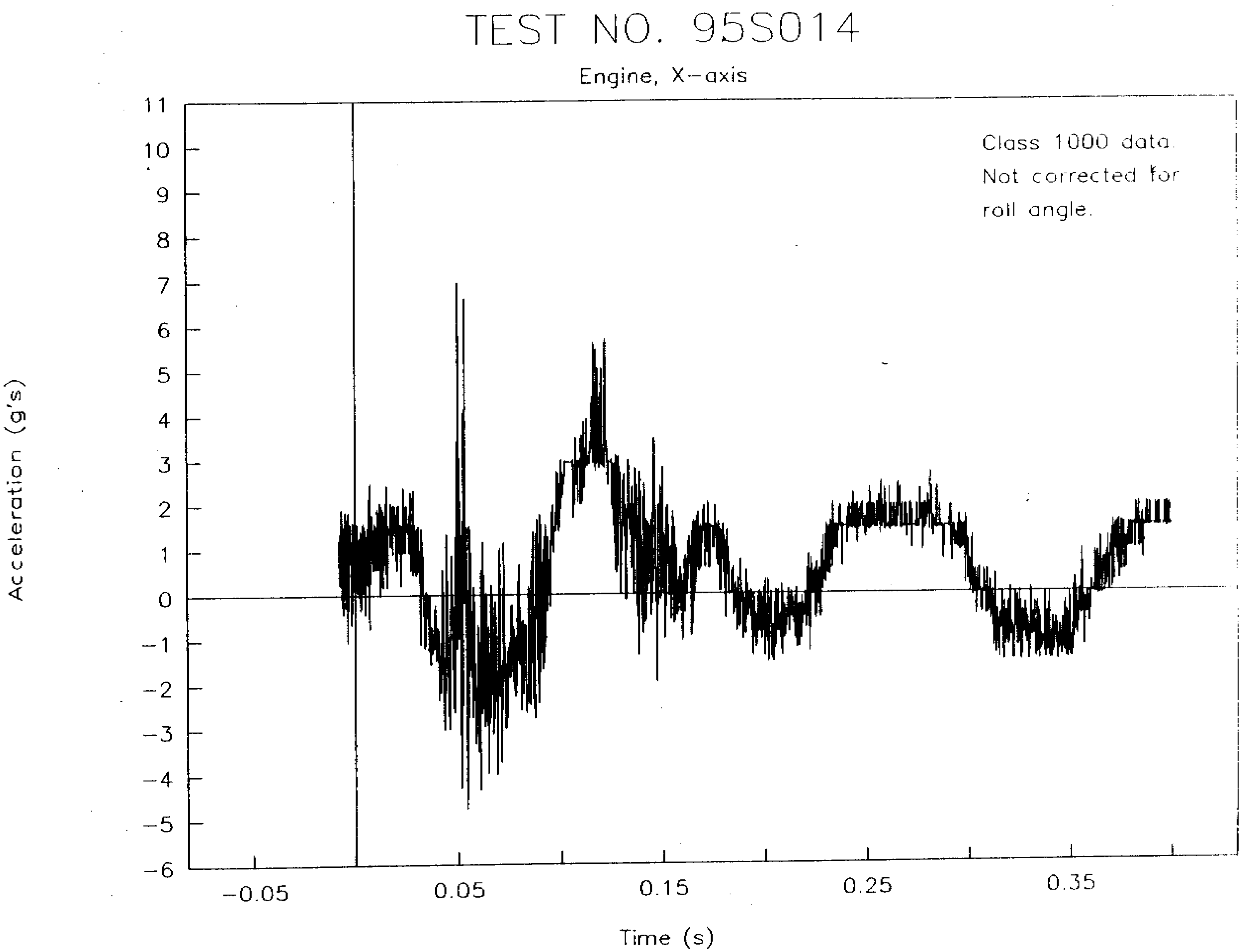


Figure 18. Acceleration vs. time, engine, X-axis, test 95S014.

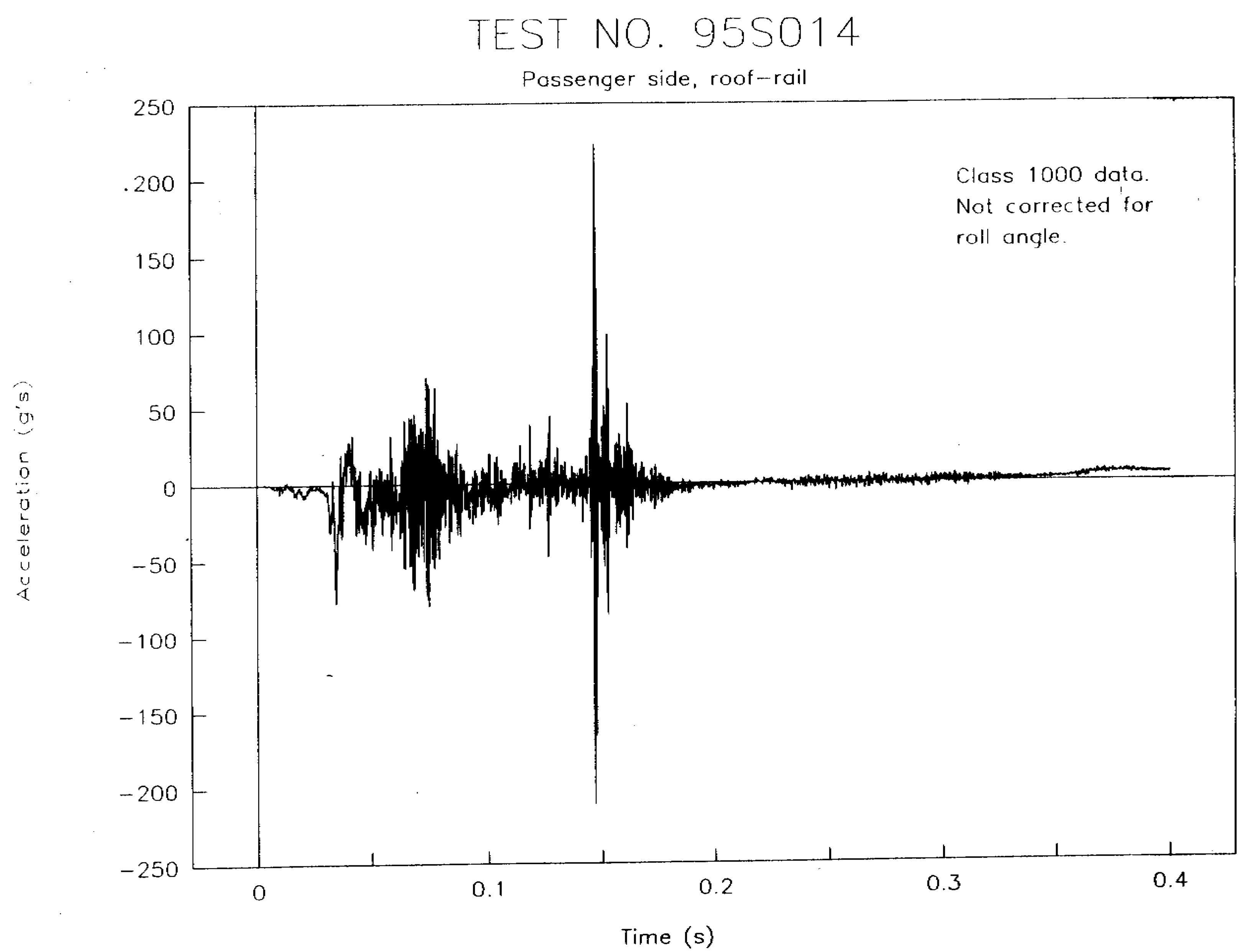


Figure 19. Acceleration vs. time, passenger side, roof-rail, test 95S014.

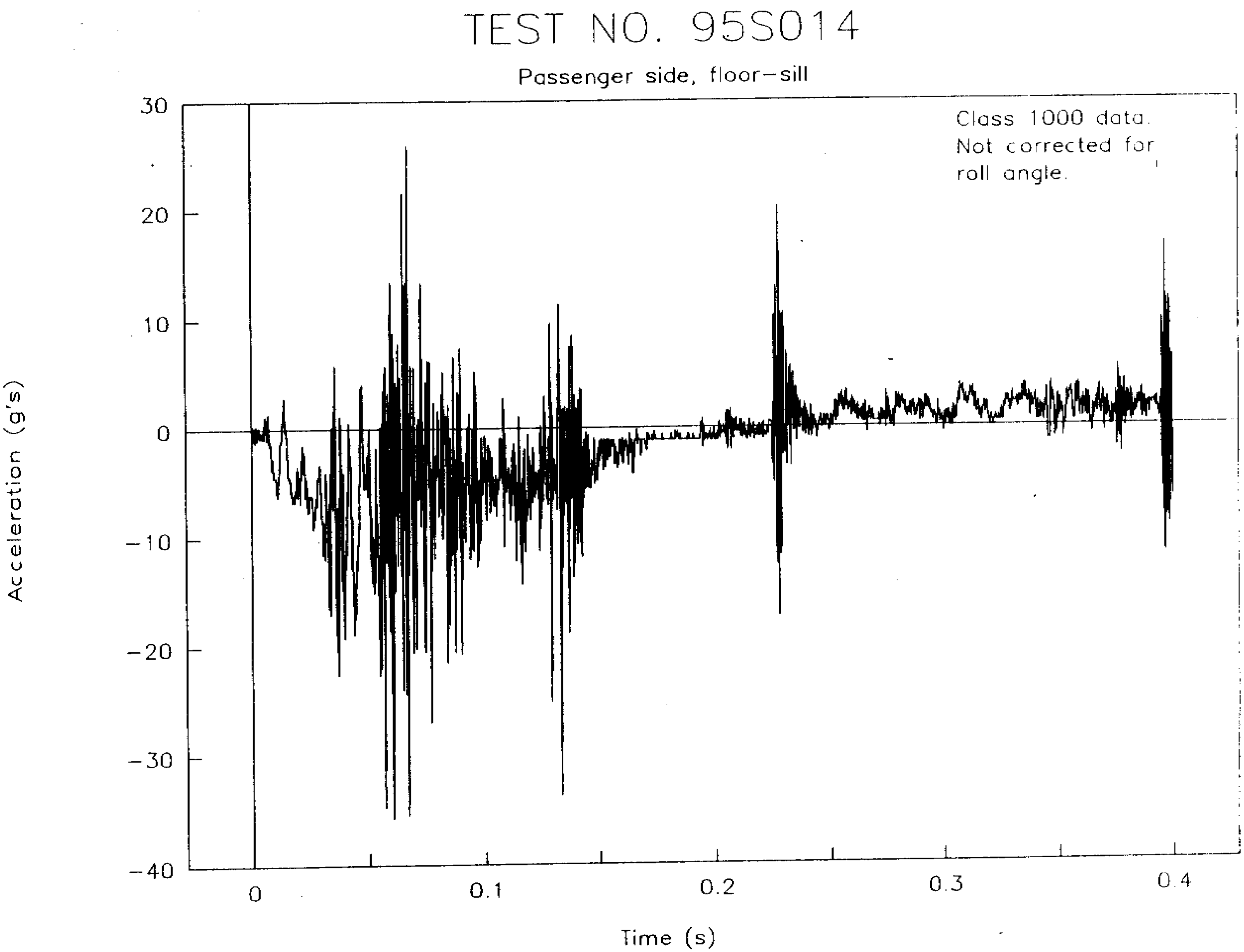


Figure 20. Acceleration vs. time, passenger floor-sill, test 95014.

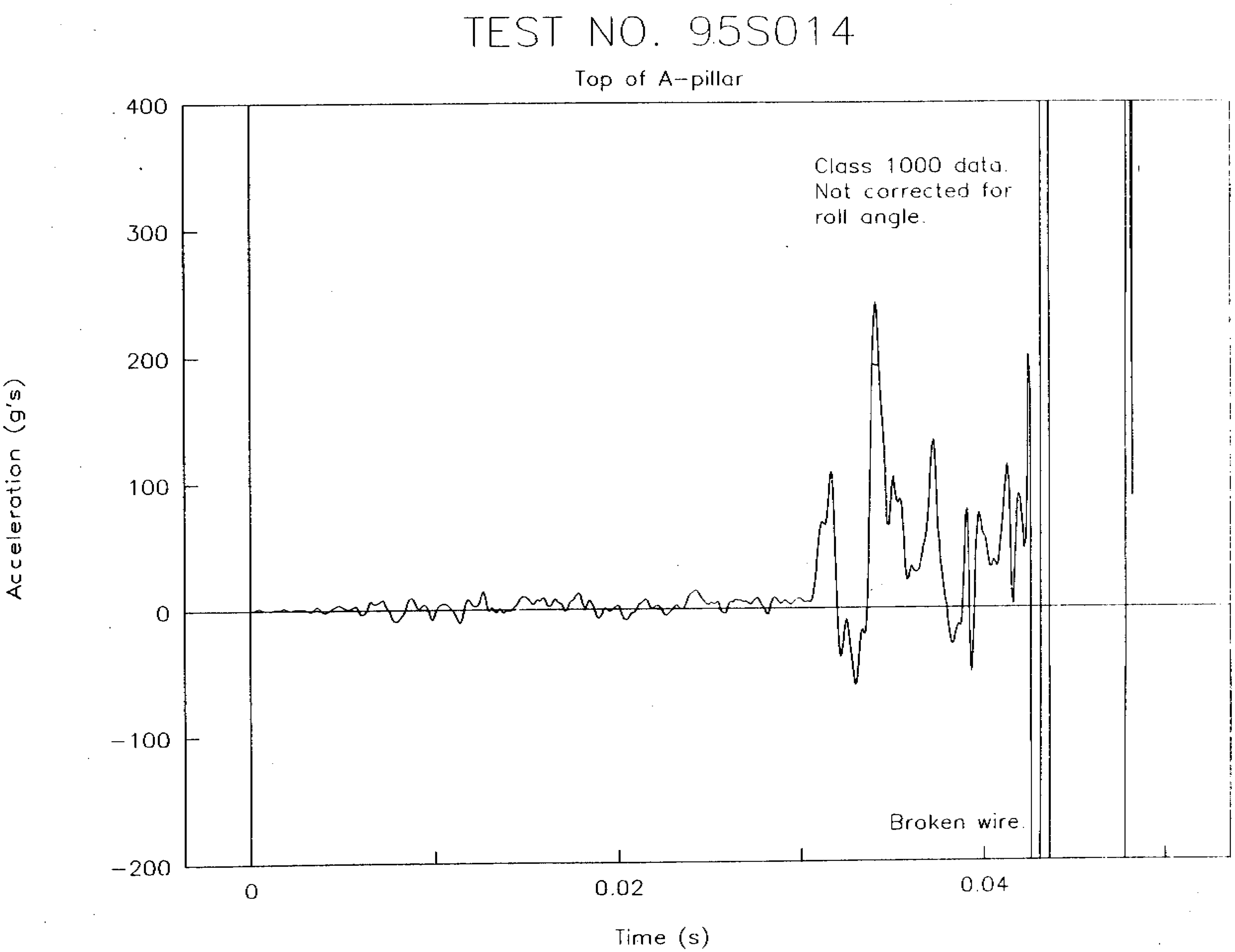


Figure 21. Acceleration vs. time, top of A-pillar, test 95S014.

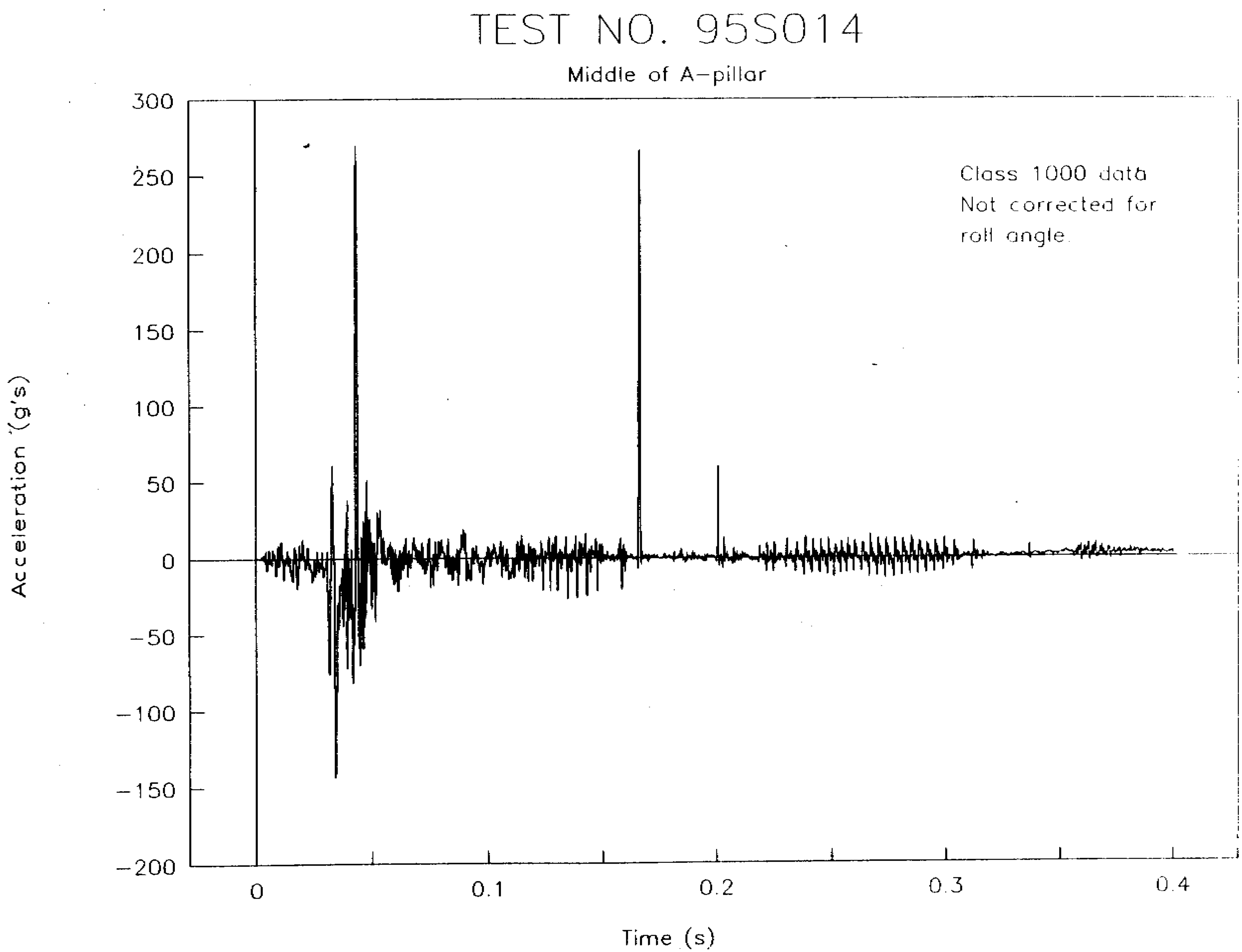


Figure 22. Acceleration vs. time, middle of A-pillar, test 95S014.

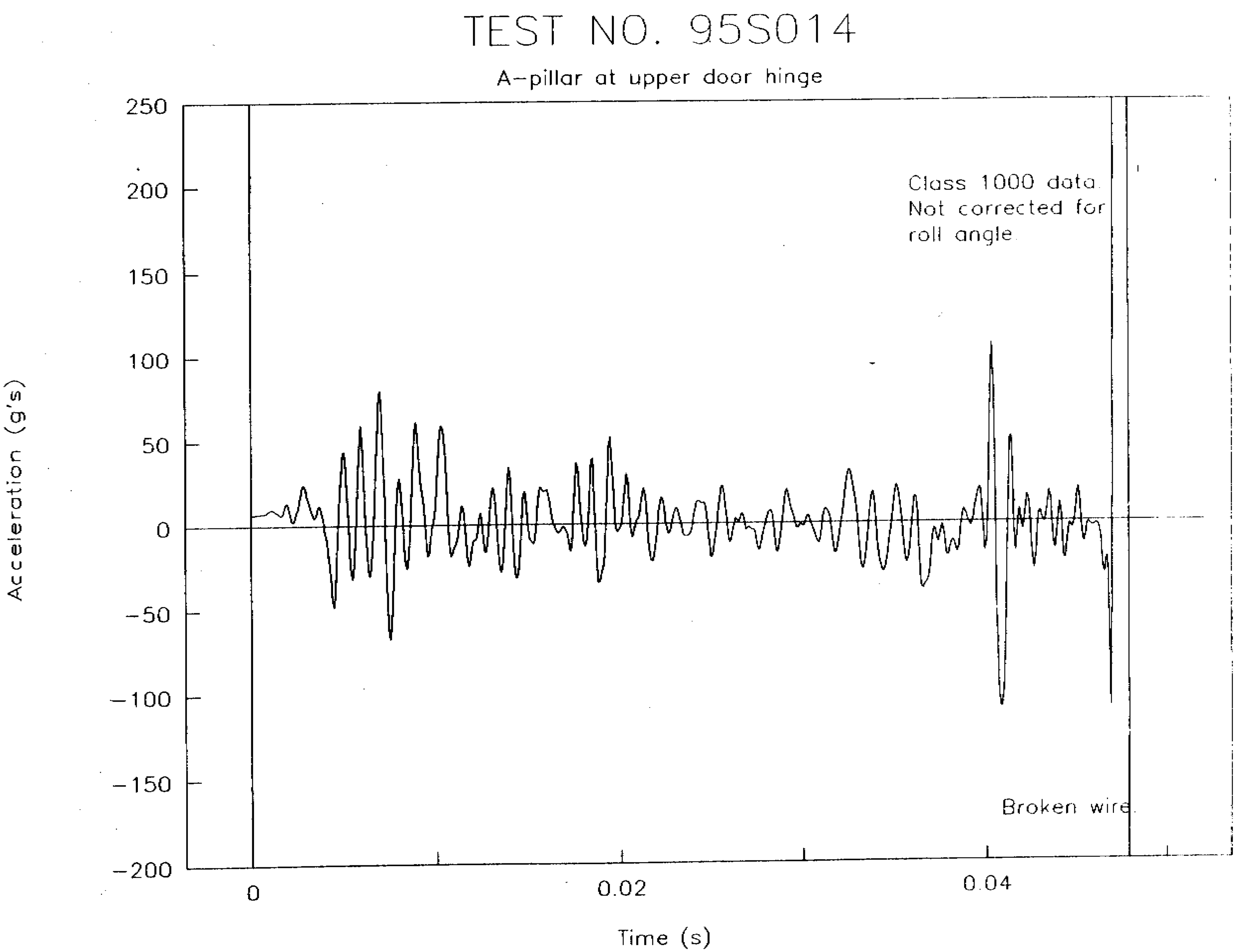


Figure 23. Acceleration vs. time, A-pillar at upper door hinge, test 95S014.

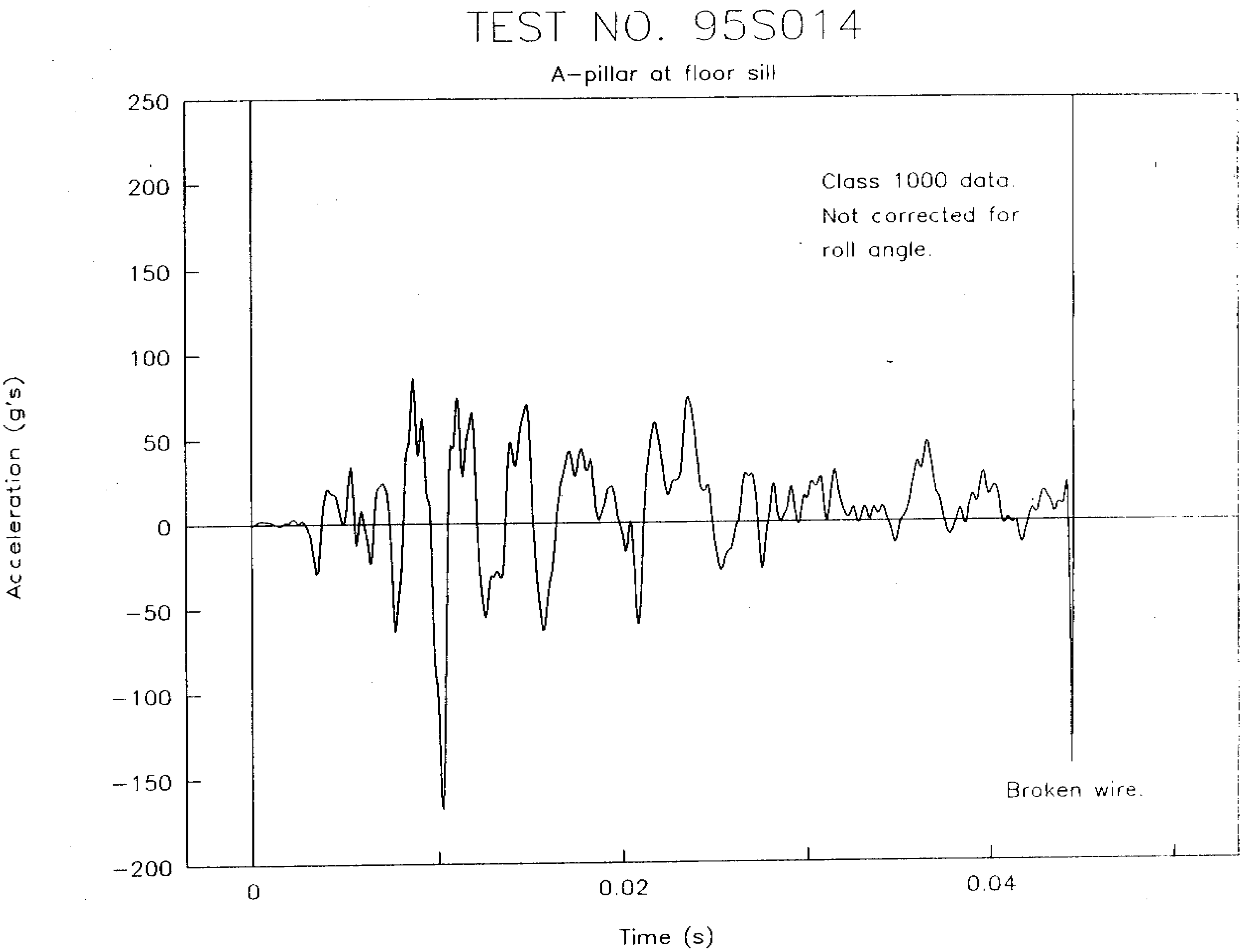


Figure 24. Acceleration vs. time, A-pillar at floor sill, test 95S014.

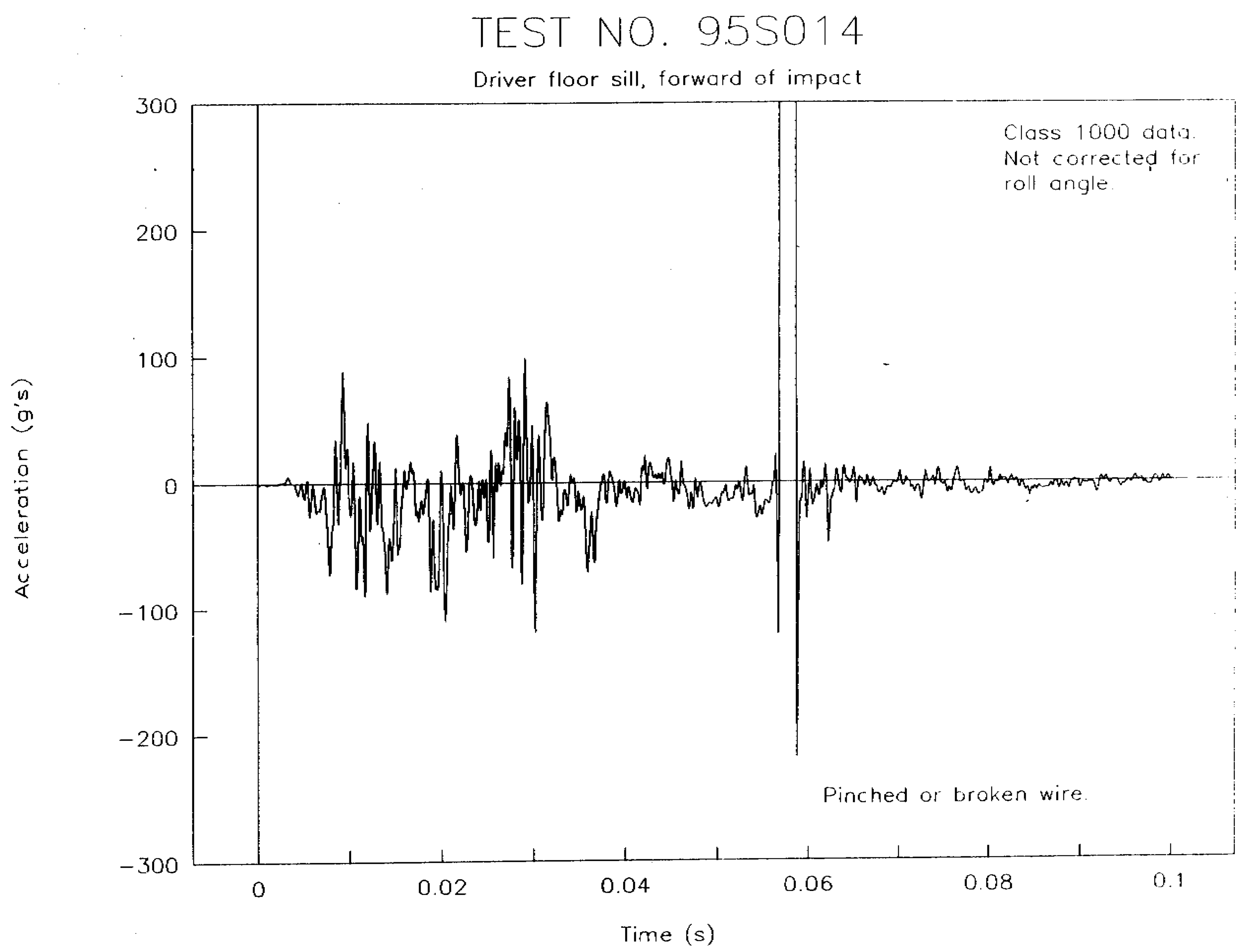


Figure 25. Acceleration vs. time, driver floor sill, forward of impact, test 95S014.

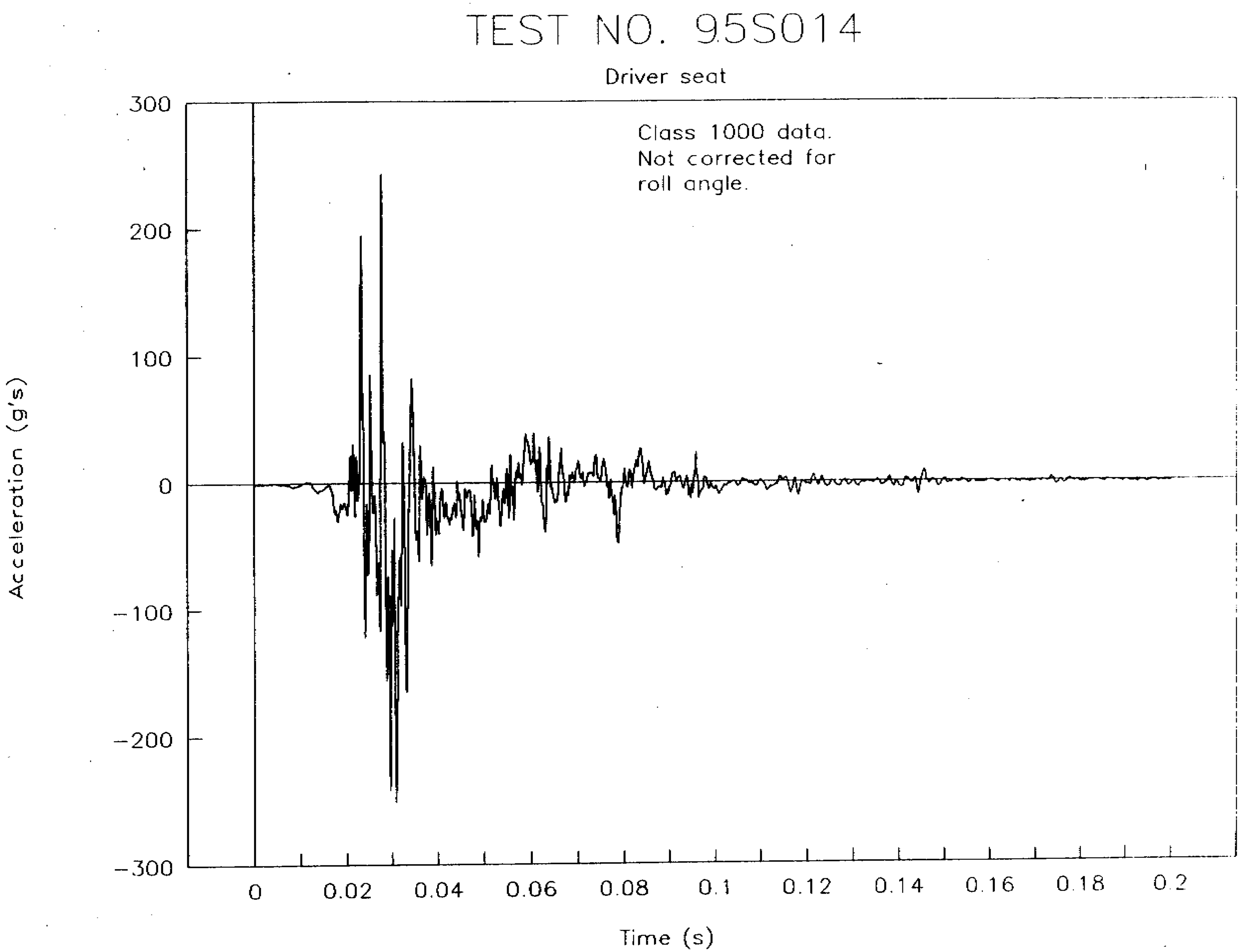


Figure 26. Acceleration vs. time, driver seat, test 95S014.

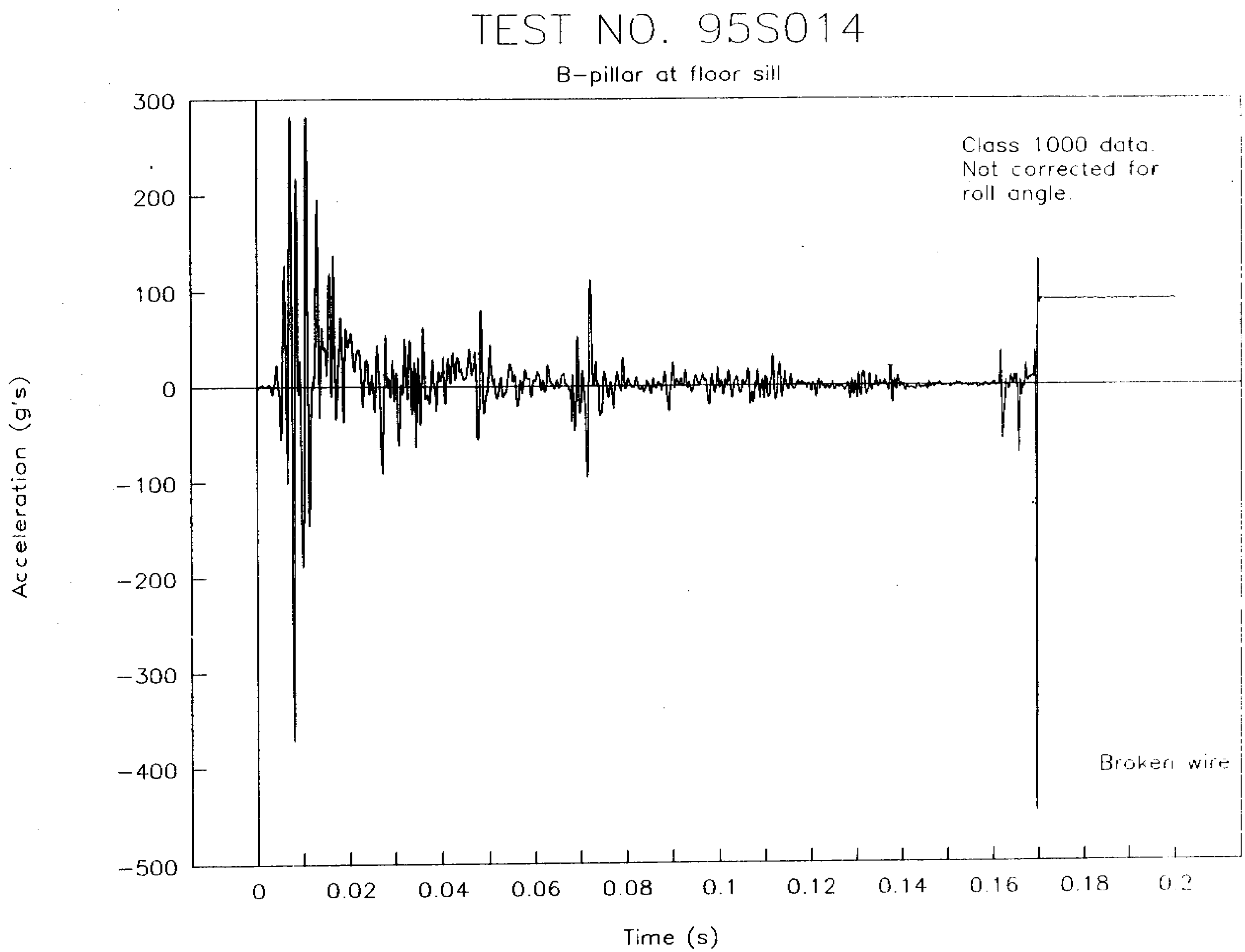


Figure 27. Acceleration vs. time, B-pillar at floor sill, test 95S014.

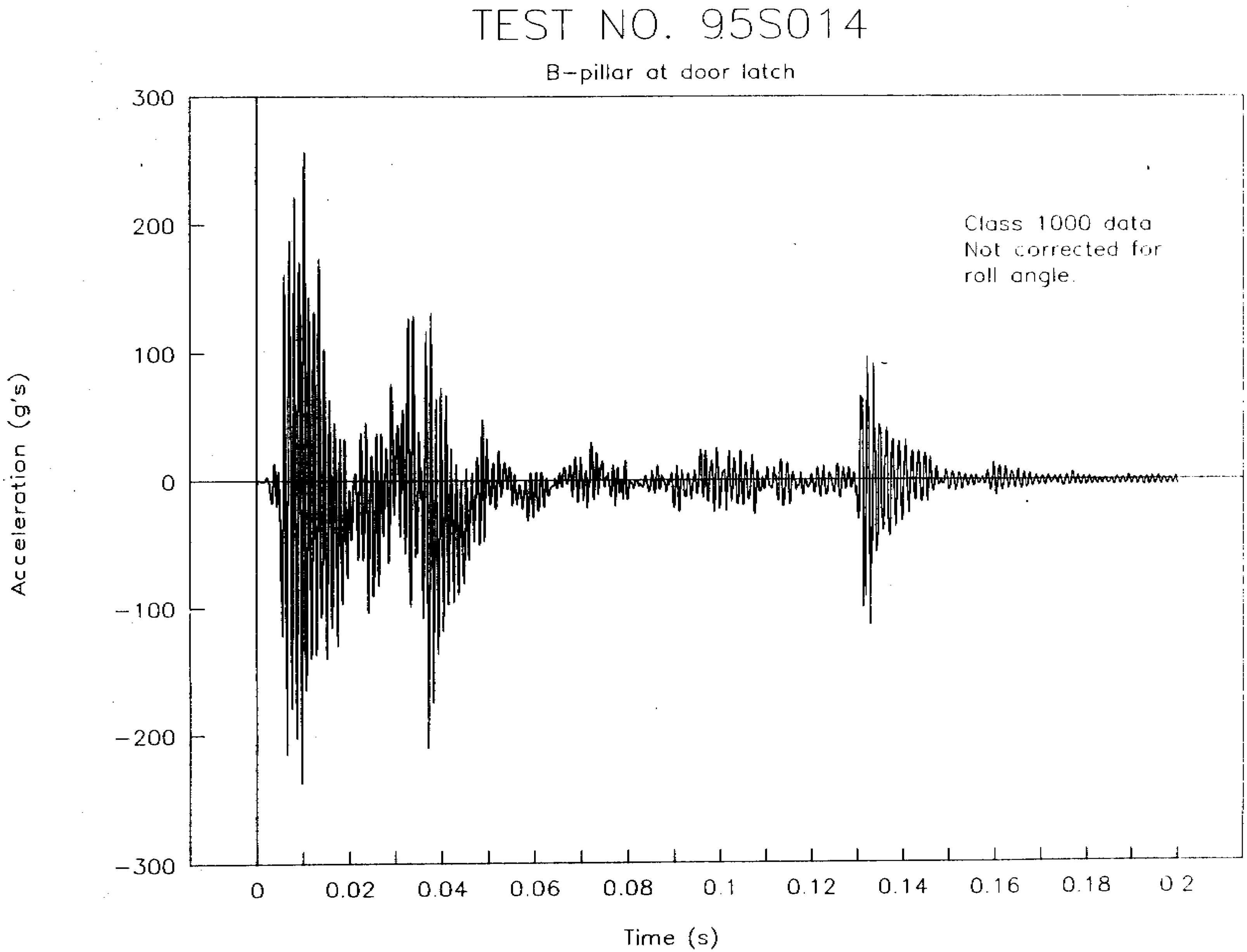


Figure 28. Acceleration vs. time, B-pillar at door latch, test 95S014.

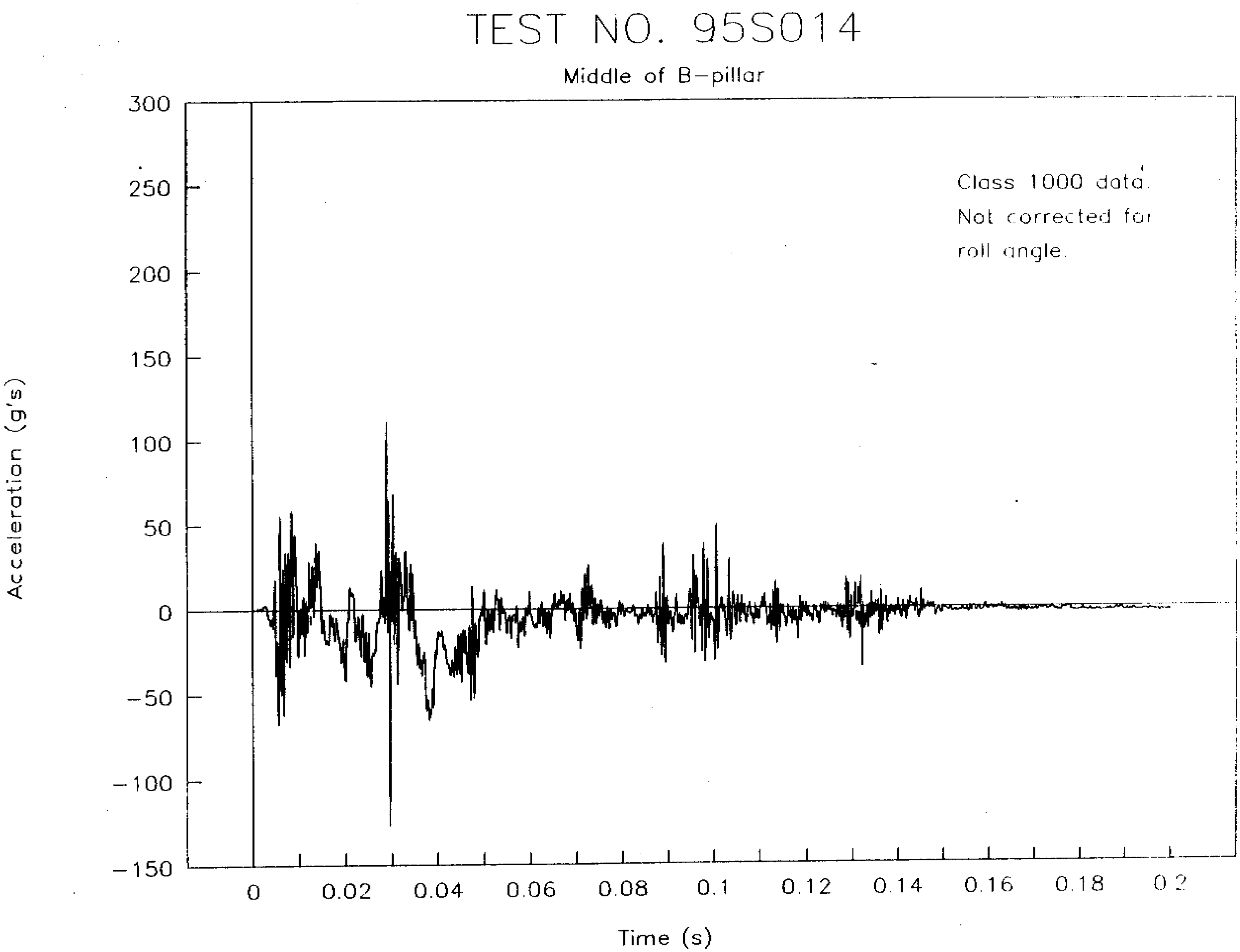


Figure 29. Acceleration vs. time, middle of B-pillar, test 95S014.

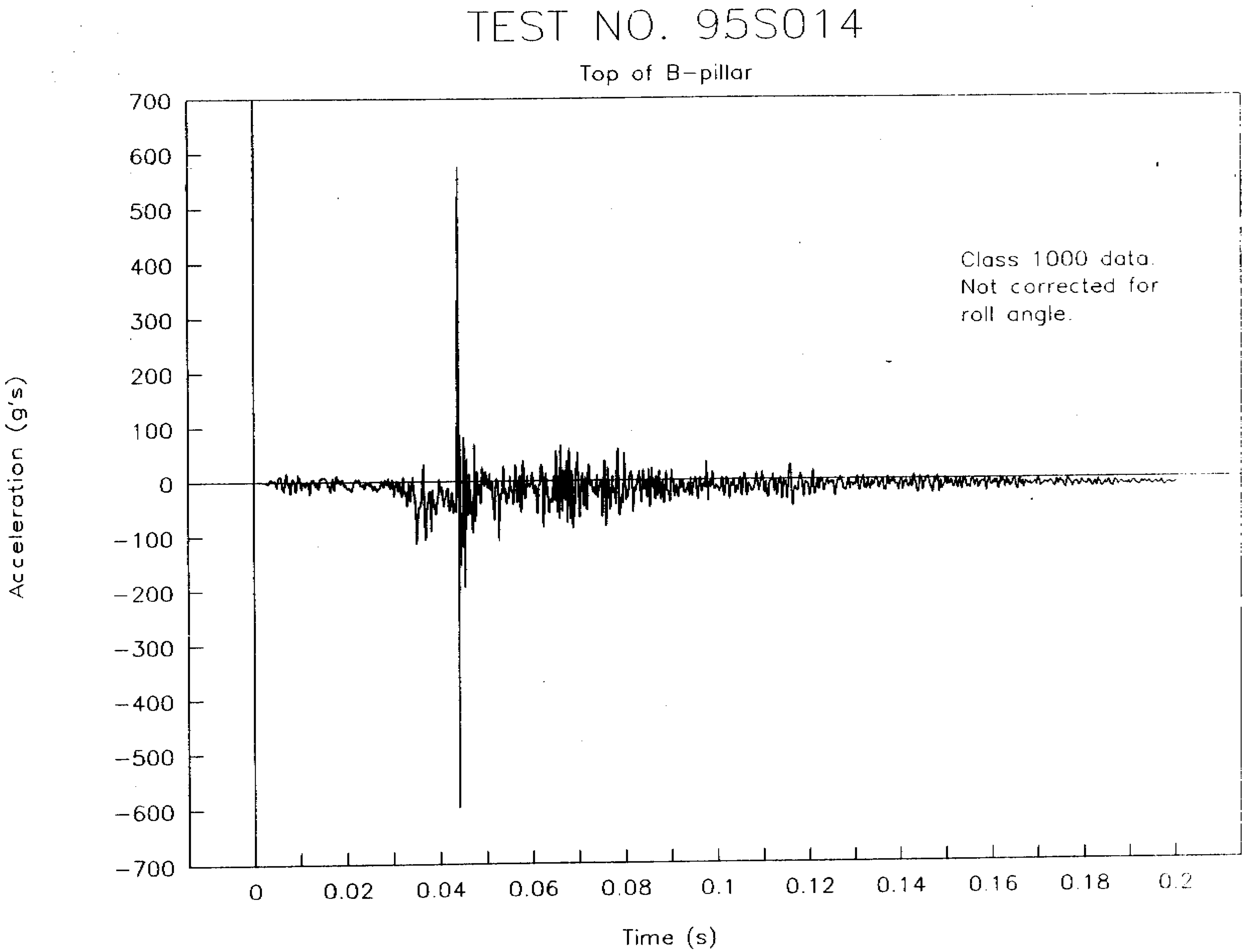


Figure 30. Acceleration vs. time, top of B-pillar, test 95S014.

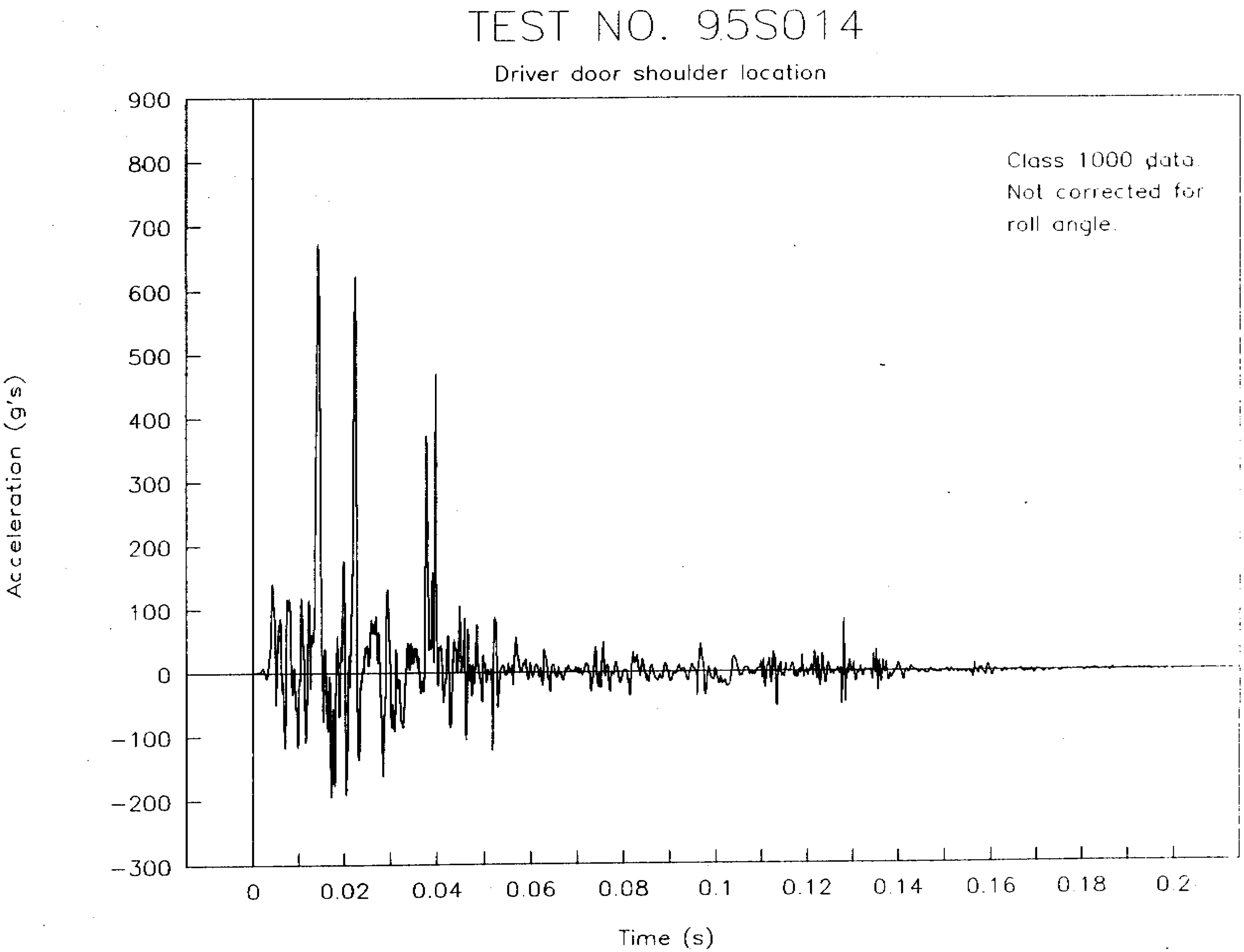


Figure 31. Acceleration vs. time, driver door shoulder location, test 95S014.

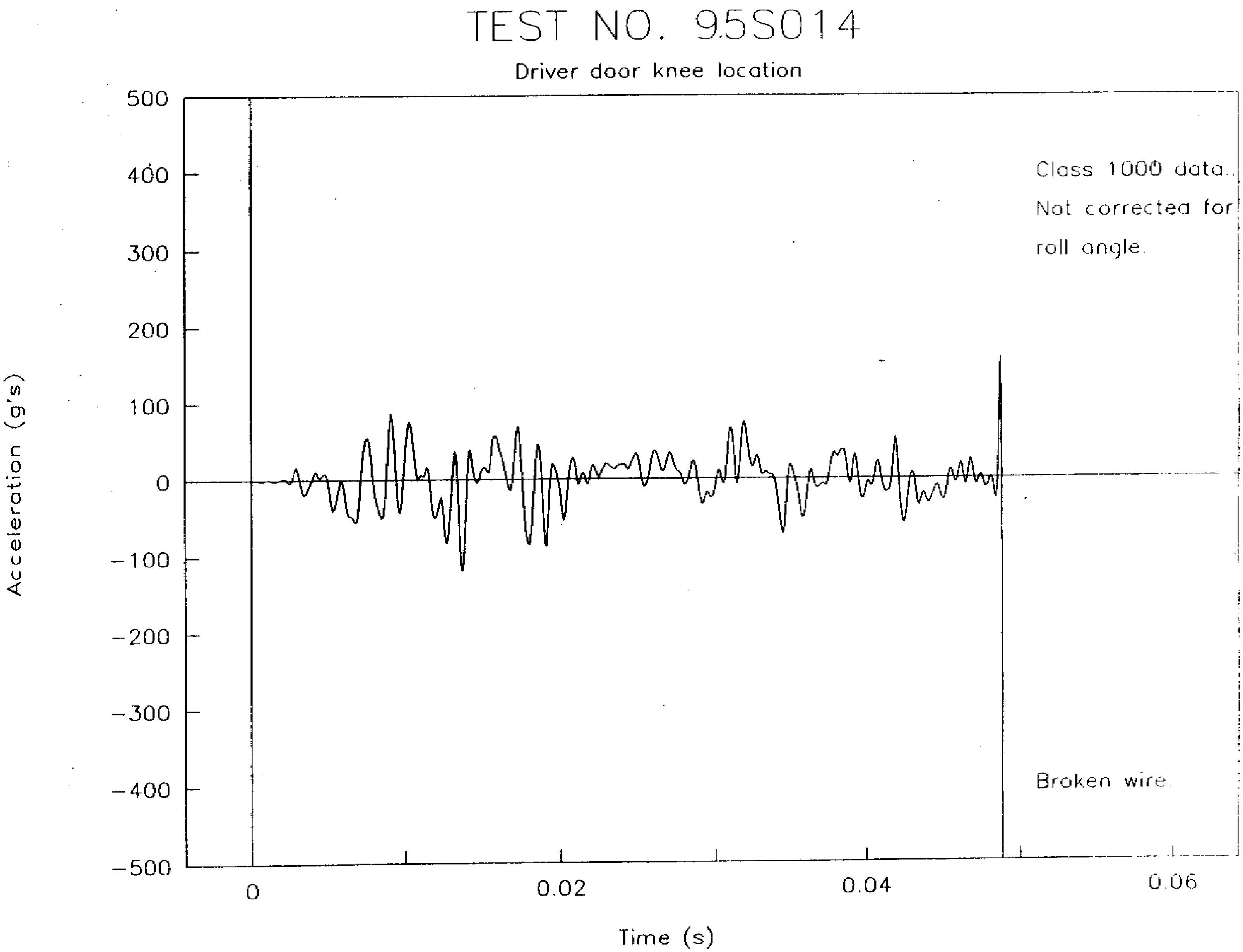


Figure 32. Acceleration vs. time, driver door knee location, test 95S014.

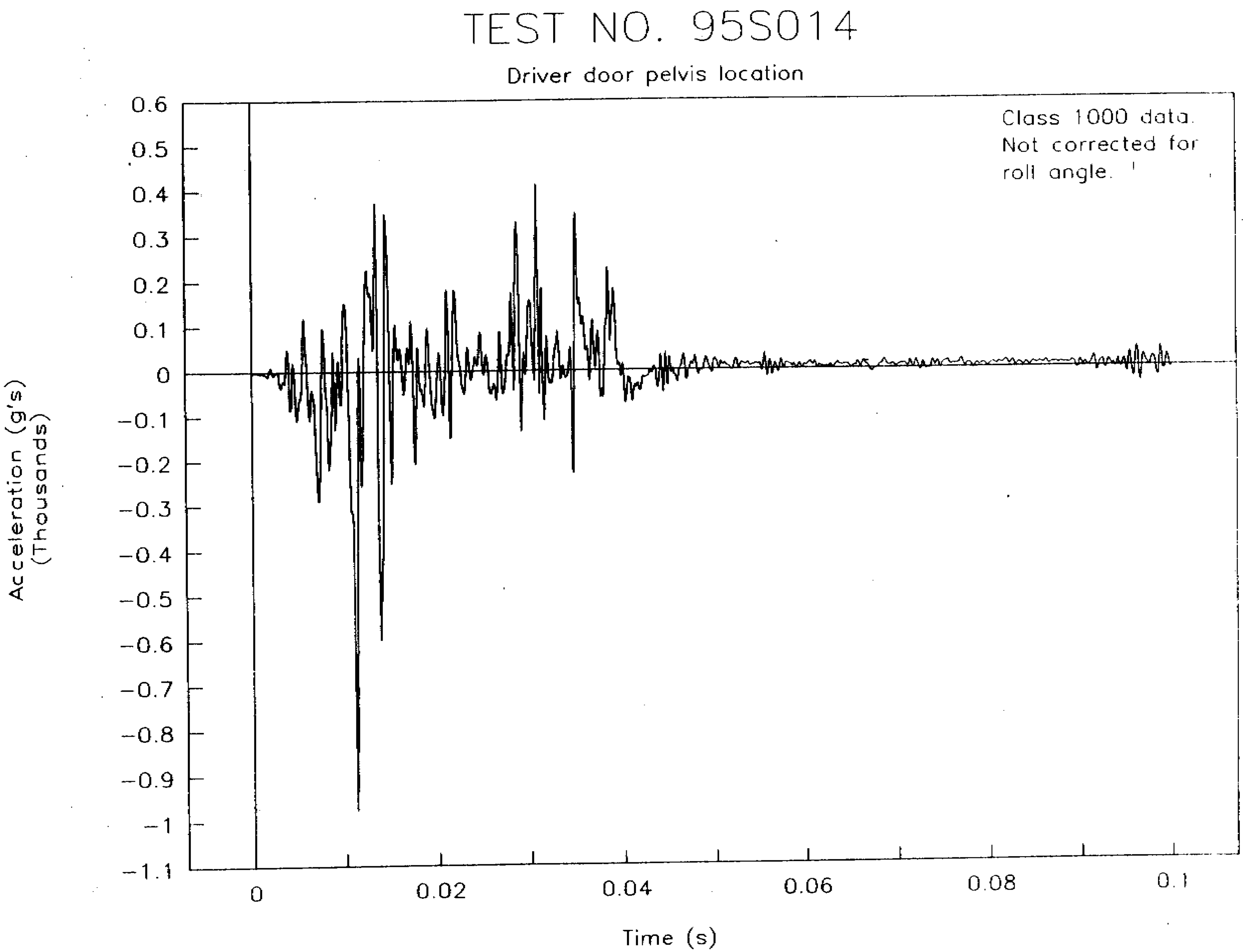


Figure 33. Acceleration vs. time, driver door pelvis location, test 95S014.

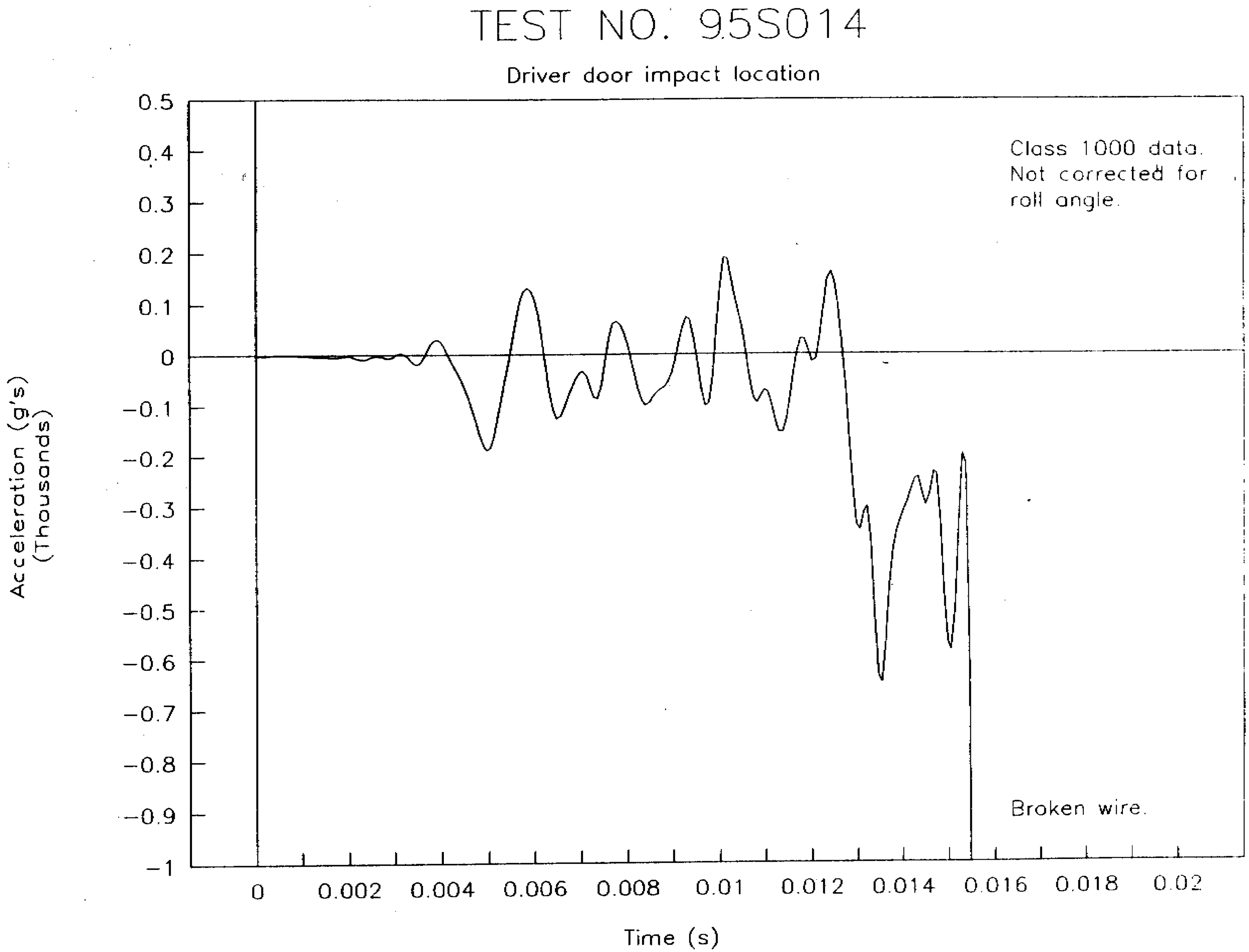


Figure 34. Acceleration vs. time, driver door impact location, test 95S014.

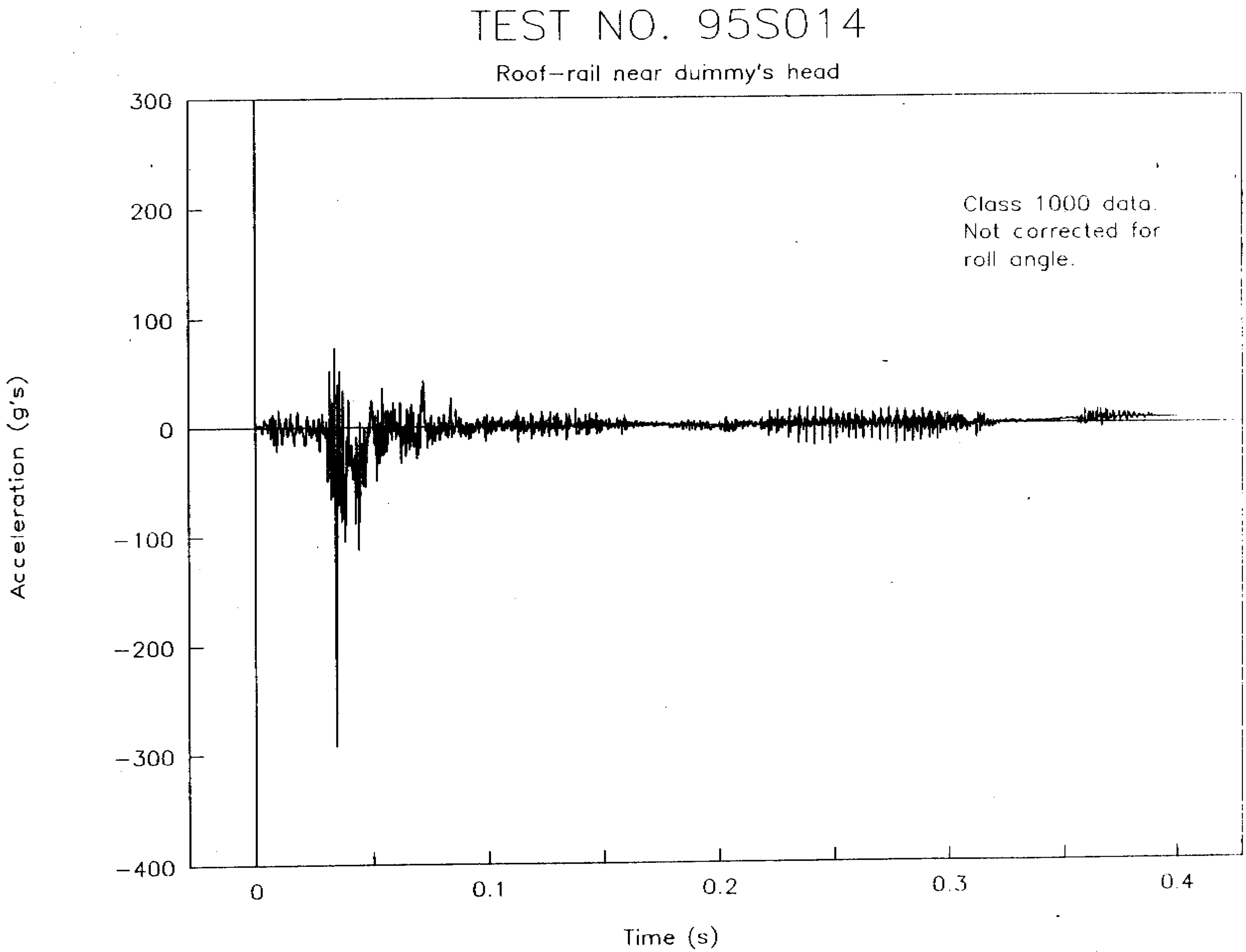


Figure 35. Acceleration vs. time, roof-rail near dummy's head, test 95S014.

APPENDIX B. DATA PLOTS FROM INSTRUMENTED SID.

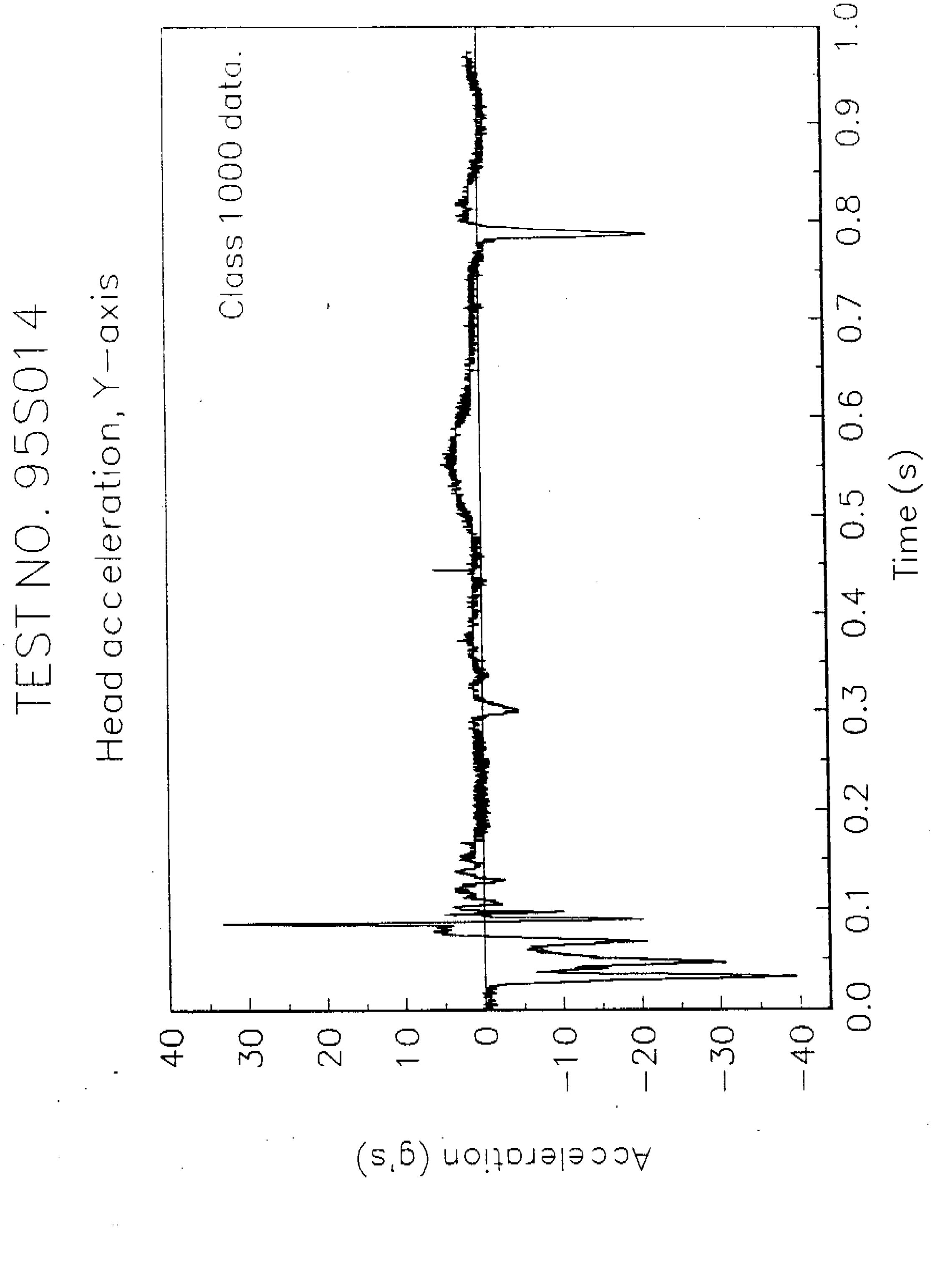


Figure 36. Acceleration vs. time, head acceleration, Y-axis, test 95S014.

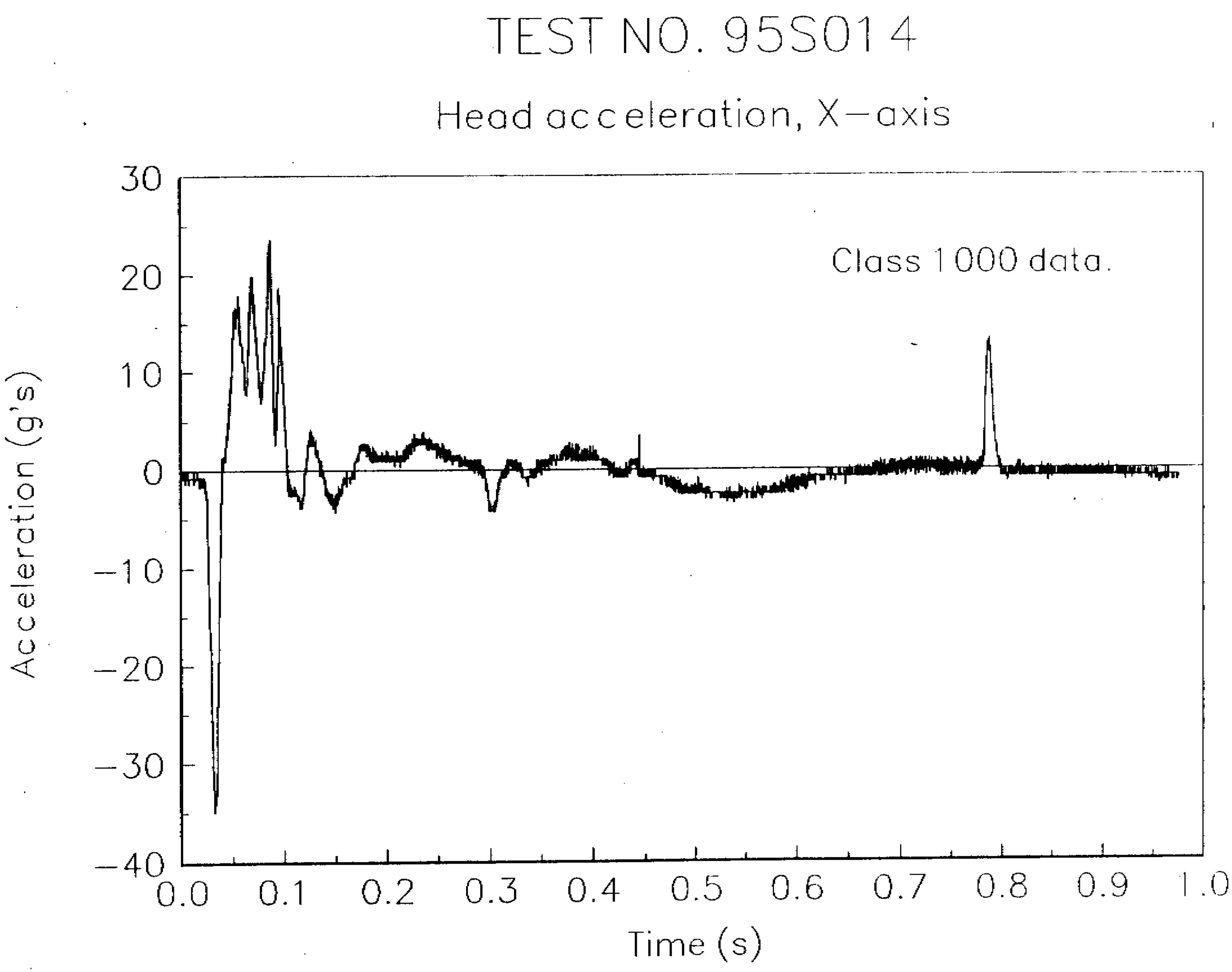


Figure 37. Acceleration vs. time, head acceleration, X-axis, test 95S014.

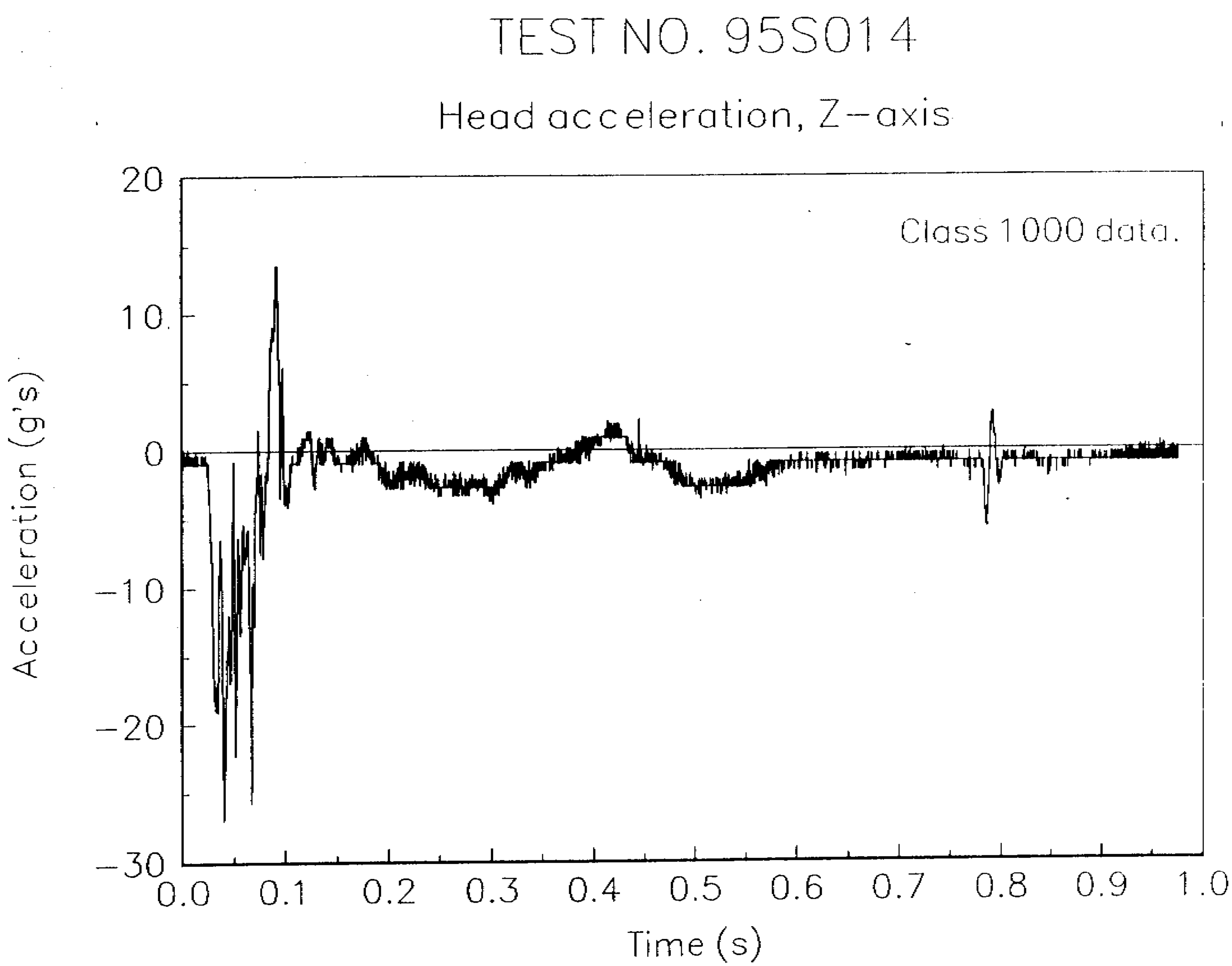


Figure 38. Acceleration vs. time, head acceleration, Z-axis, test 95S014.

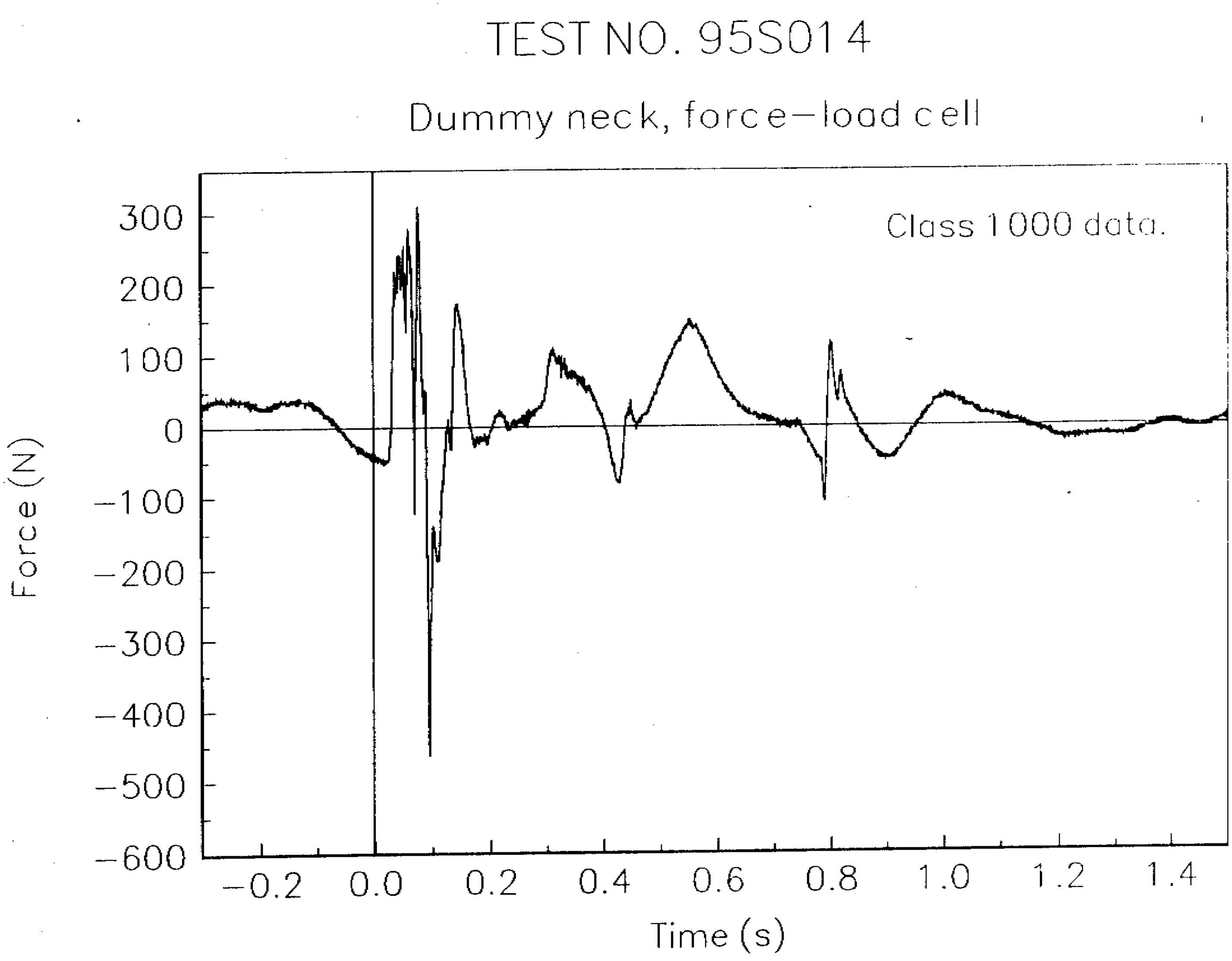


Figure 39. Force vs. time, dummy neck, force-load cell, test 95S014.

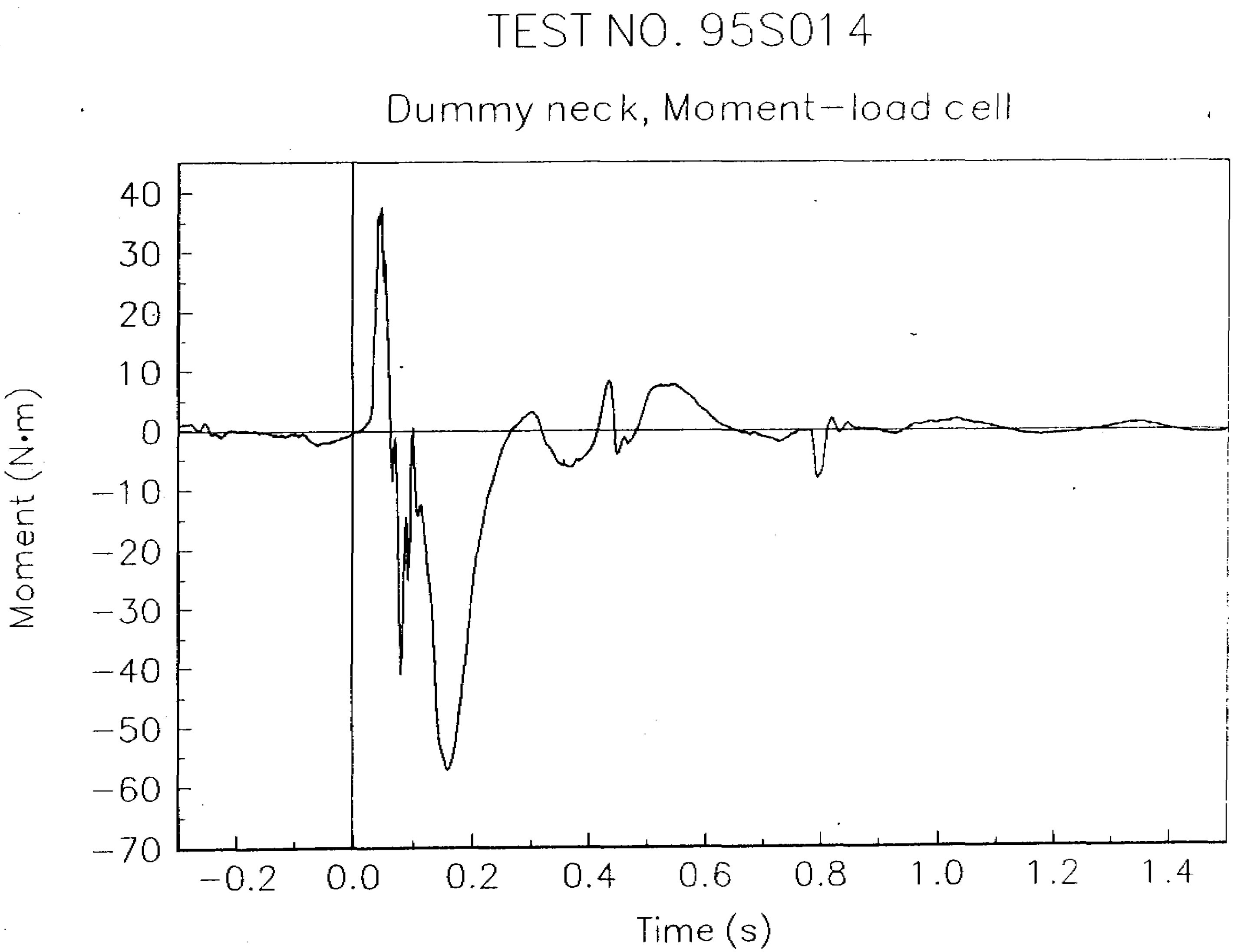


Figure 40. Moment vs. time, dummy neck, moment-load cell, test 95S014.

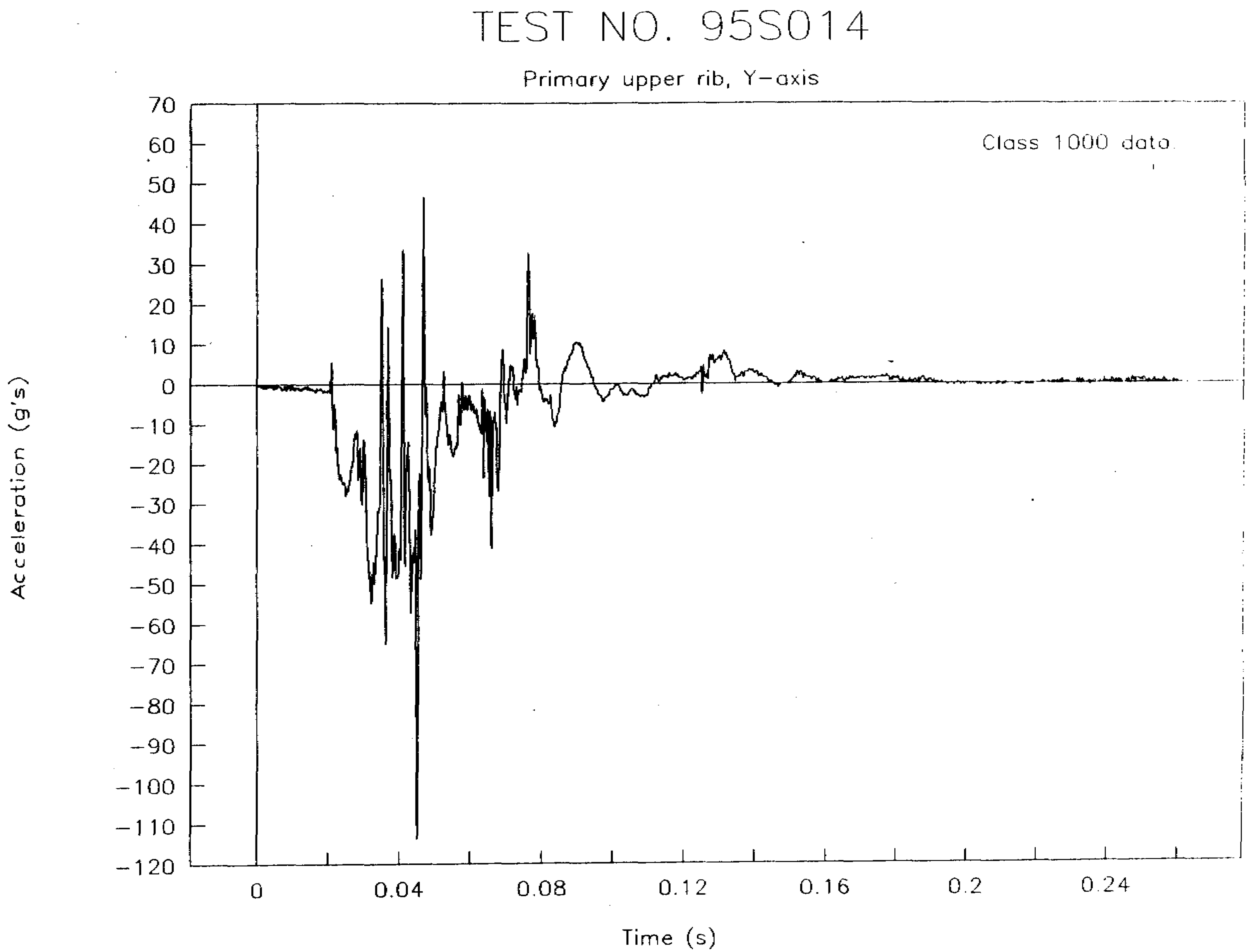


Figure 41. Acceleration vs. time, primary upper rib, Y-axis, test 95S014.

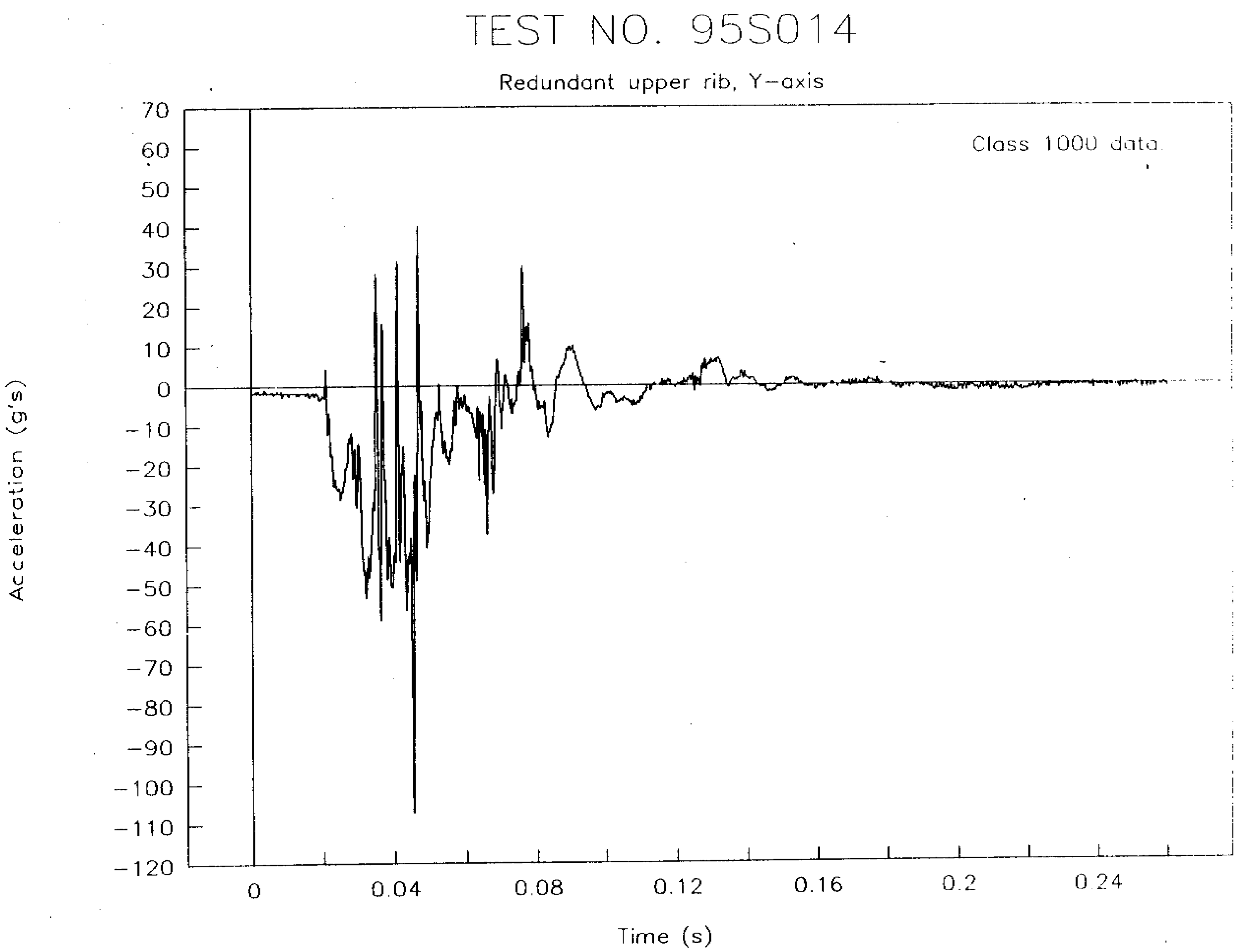


Figure 42. Acceleration vs. time, redundant upper rib, Y-axis, test 95S014.

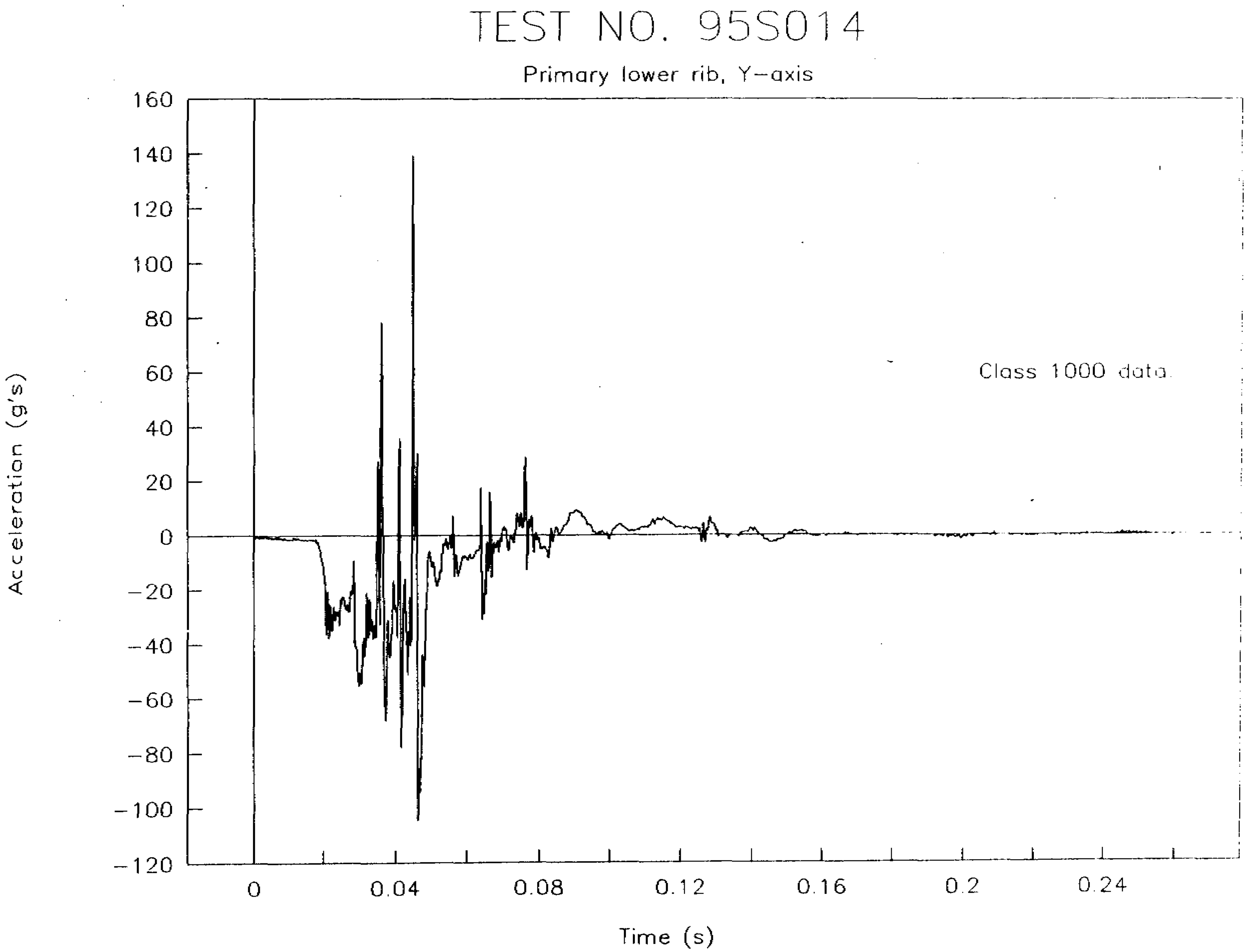


Figure 43. Acceleration vs. time, primary lower rib, Y-axis, test 95S014.

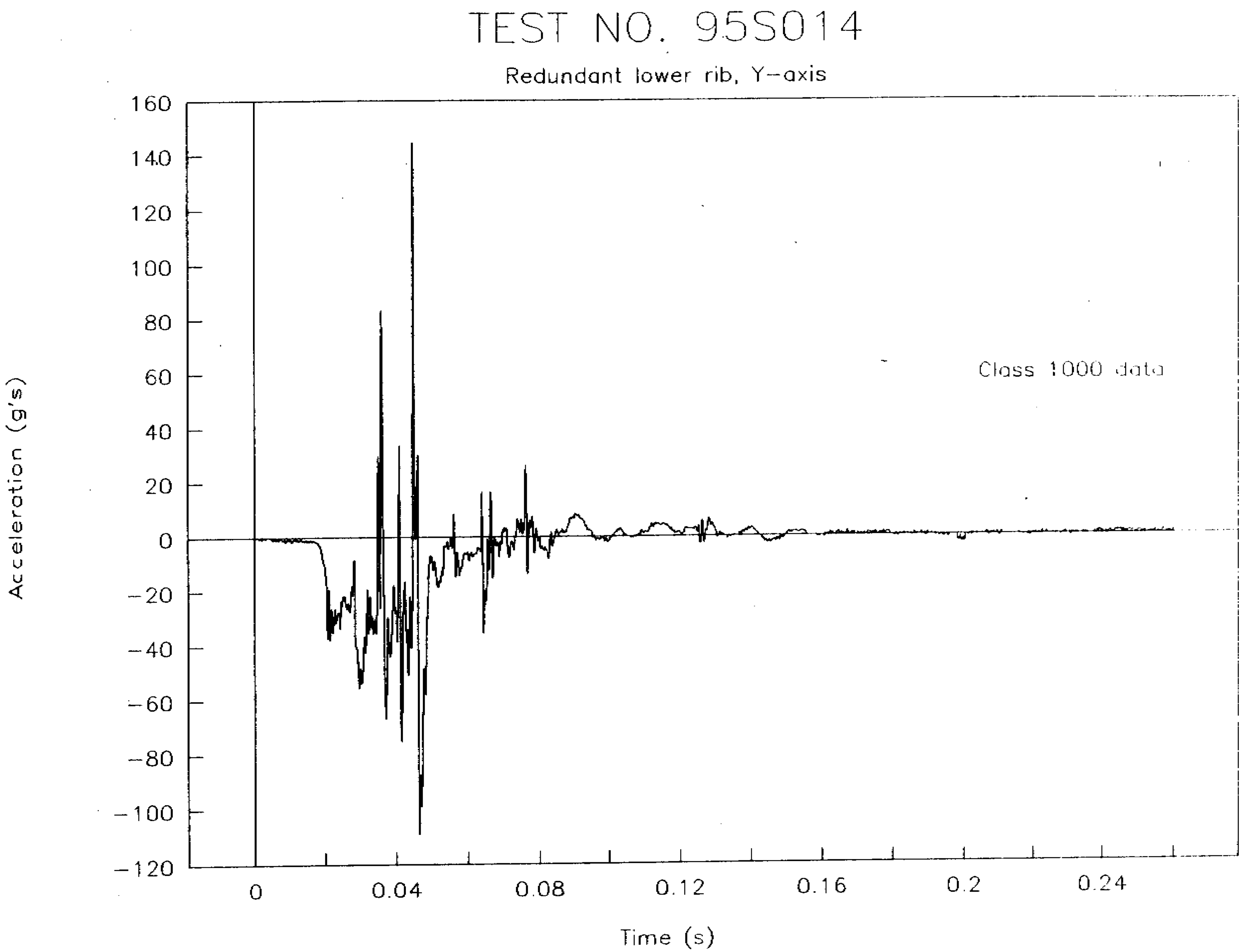


Figure 44. Acceleration vs. time, redundant lower rib, Y-axis, test 95S014.

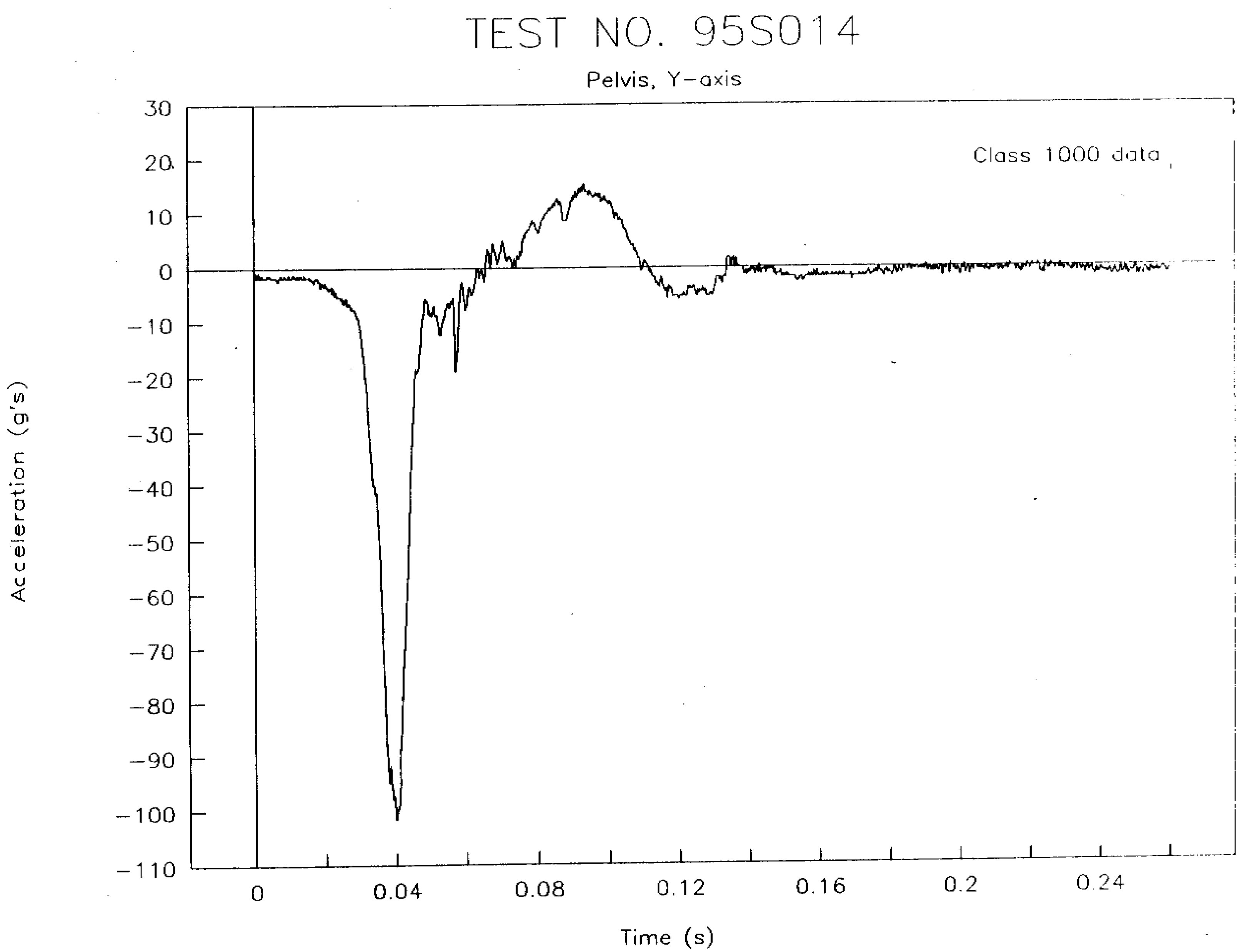


Figure 45. Acceleration vs. time, pelvis, Y-axis, test 95S014.

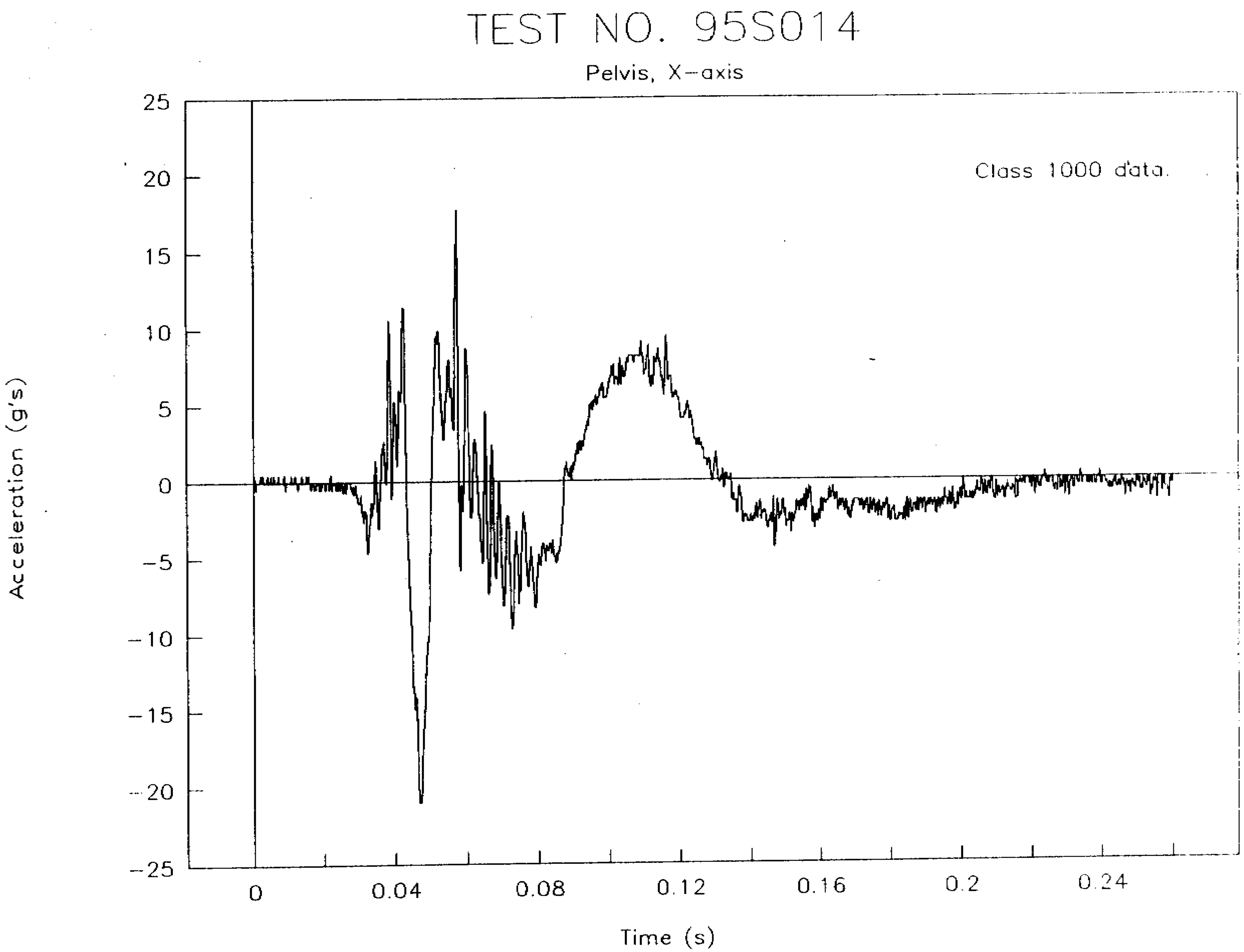


Figure 46. Acceleration vs. time, pelvis, X-axis, test 95S014.

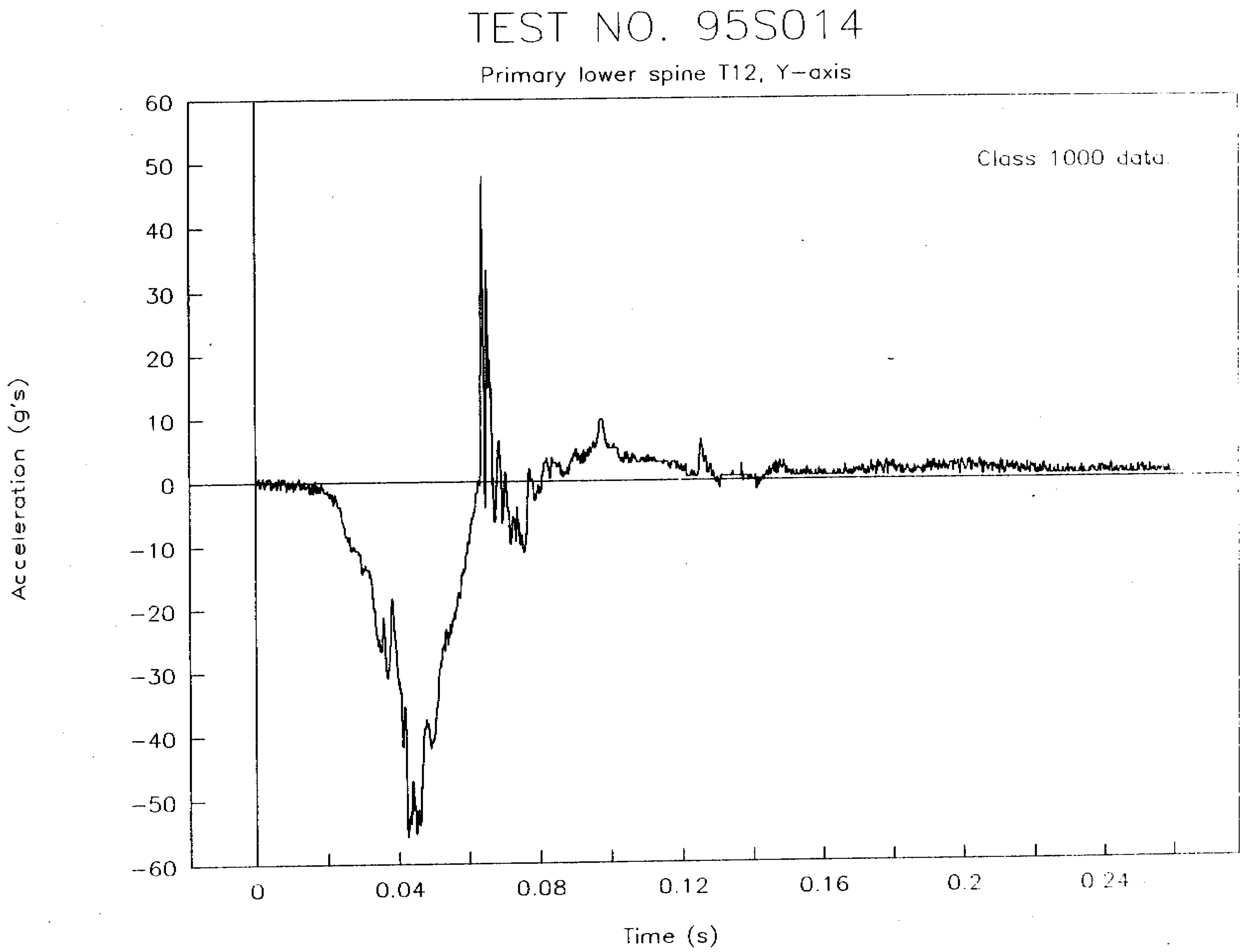


Figure 47. Acceleration vs. time, primary lower spine T12, Y-axis, test 95S014.

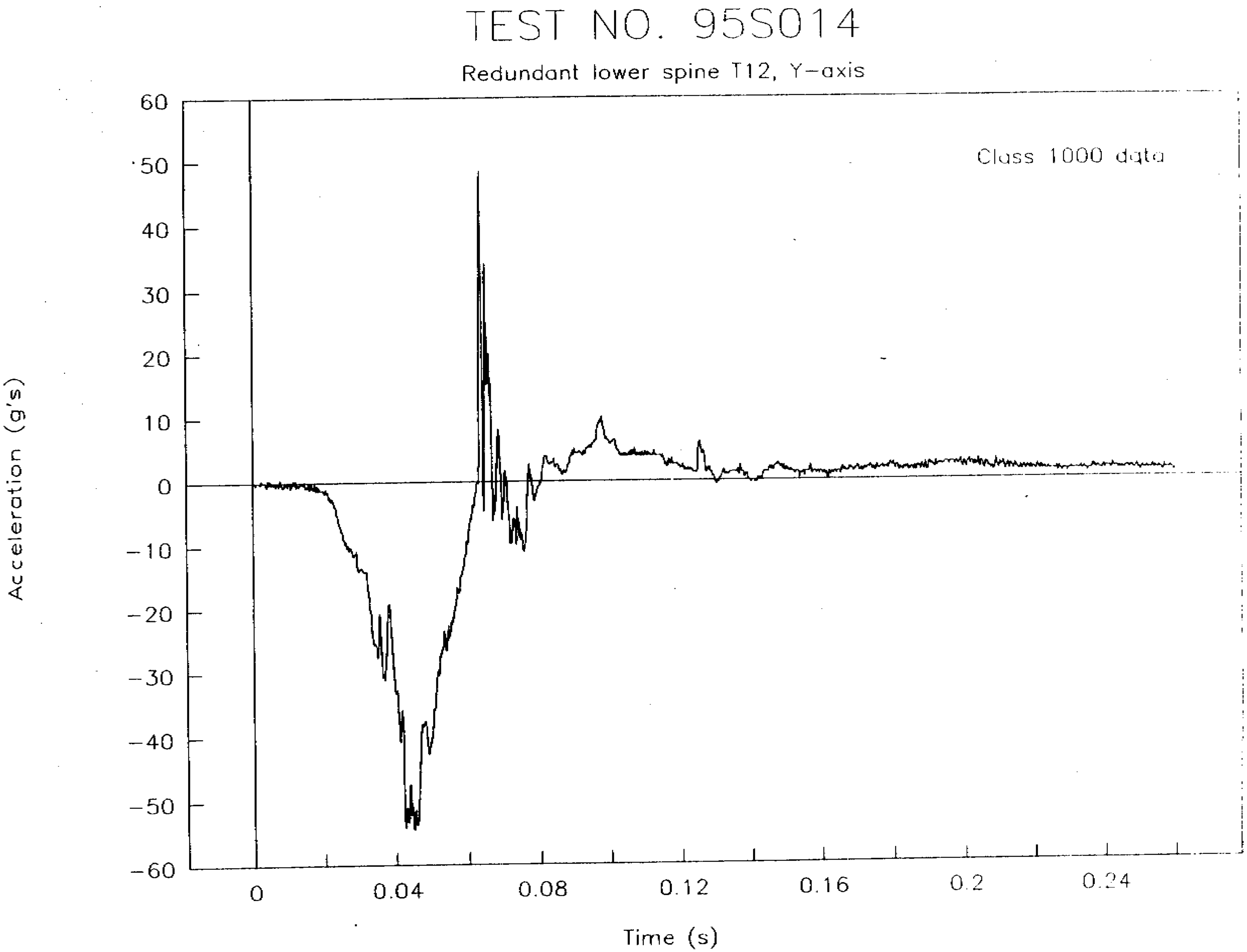


Figure 48. Acceleration vs. time, redundant lower spine T12, Y-axis, test 95S014.

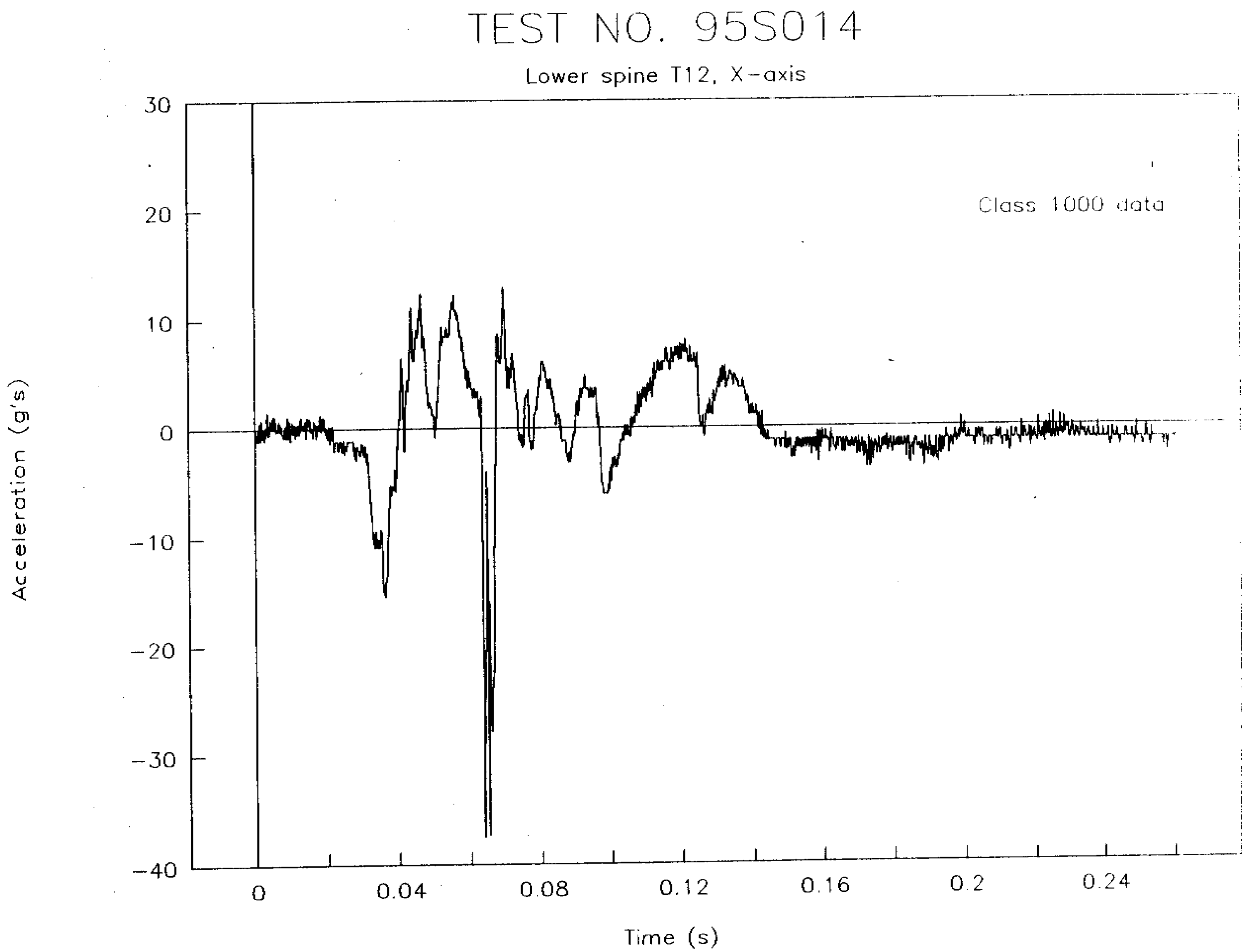


Figure 49. Acceleration vs. time, lower spine T12, X-axis, test 95S014.

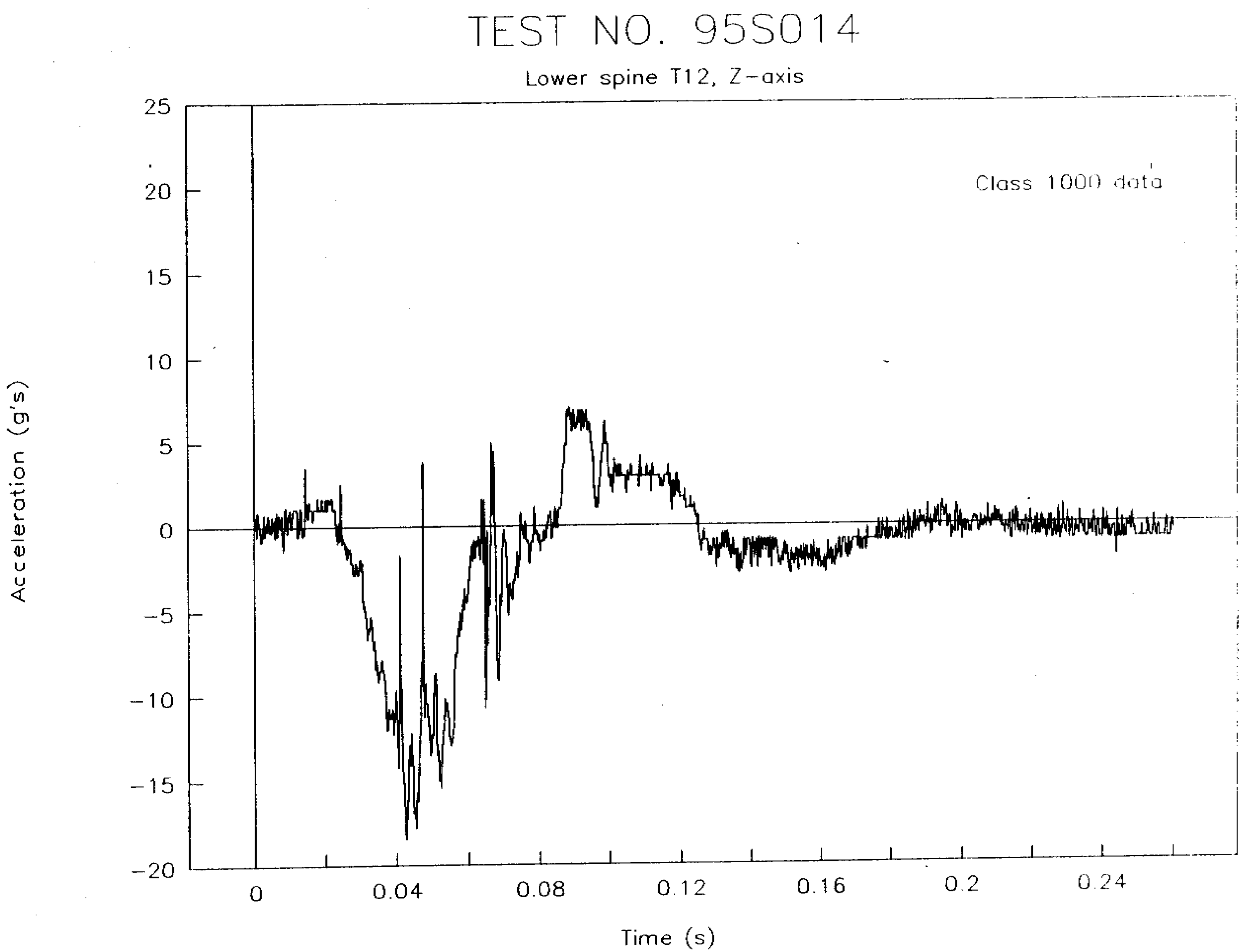


Figure 50. Acceleration vs. time, lower spine T12, Z-axis, test 95S014.

APPENDIX C. TEST PHOTOGRAPHS.

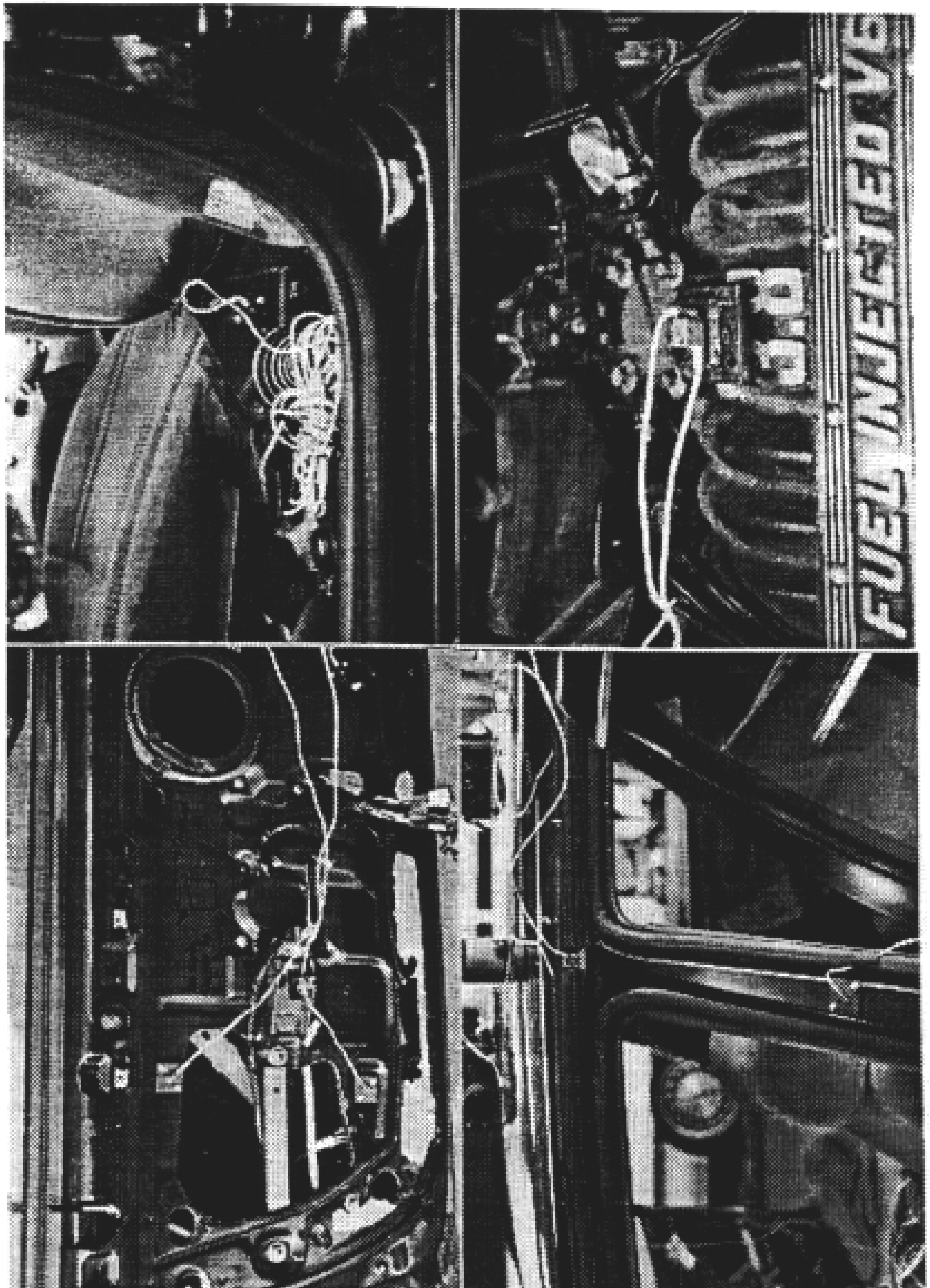


Figure 51. Examples of accelerometer mounting techniques.

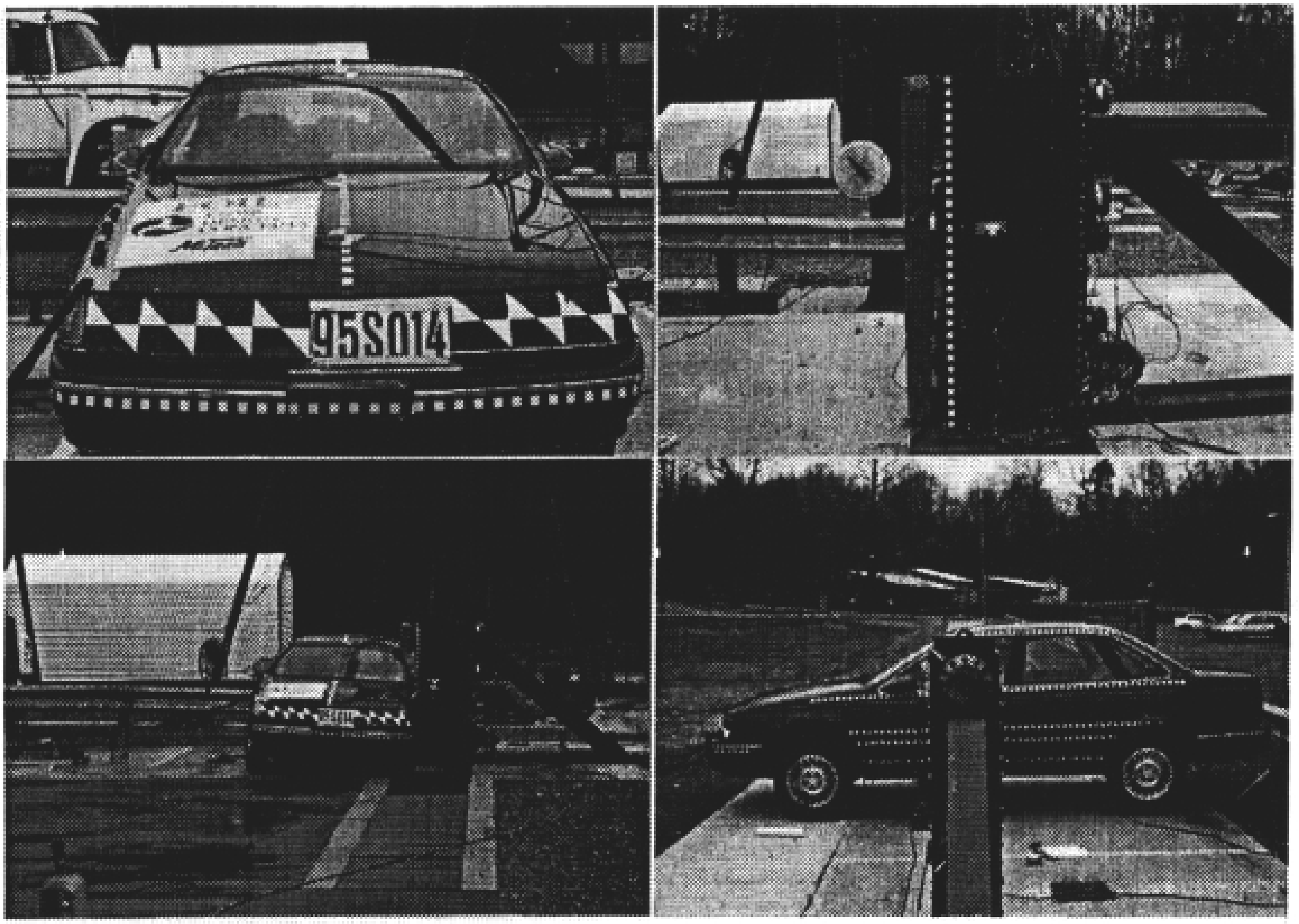


Figure 52. Pretest photographs, test 95S014.

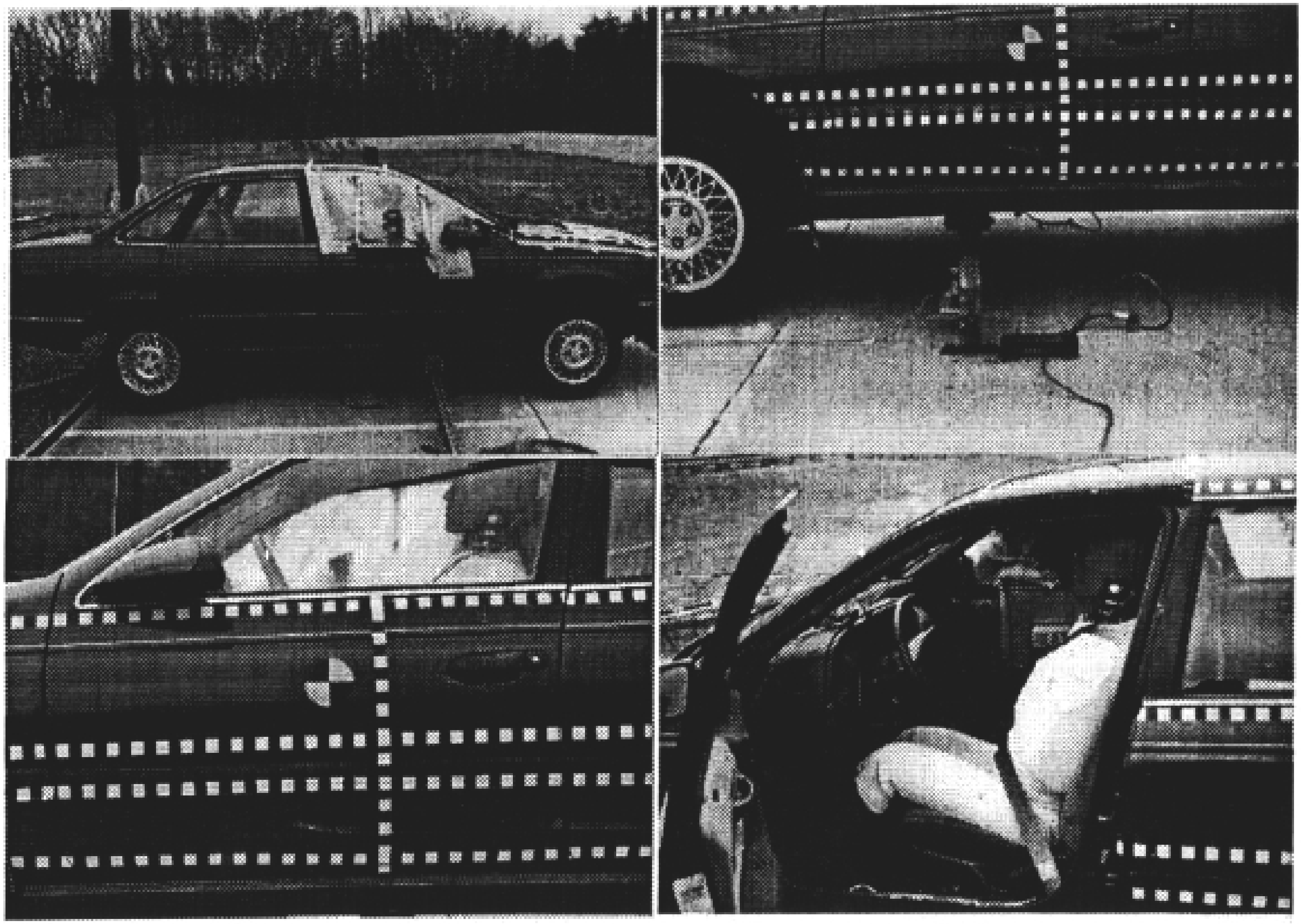


Figure 52. Pretest photographs, test 95S014 (continued).

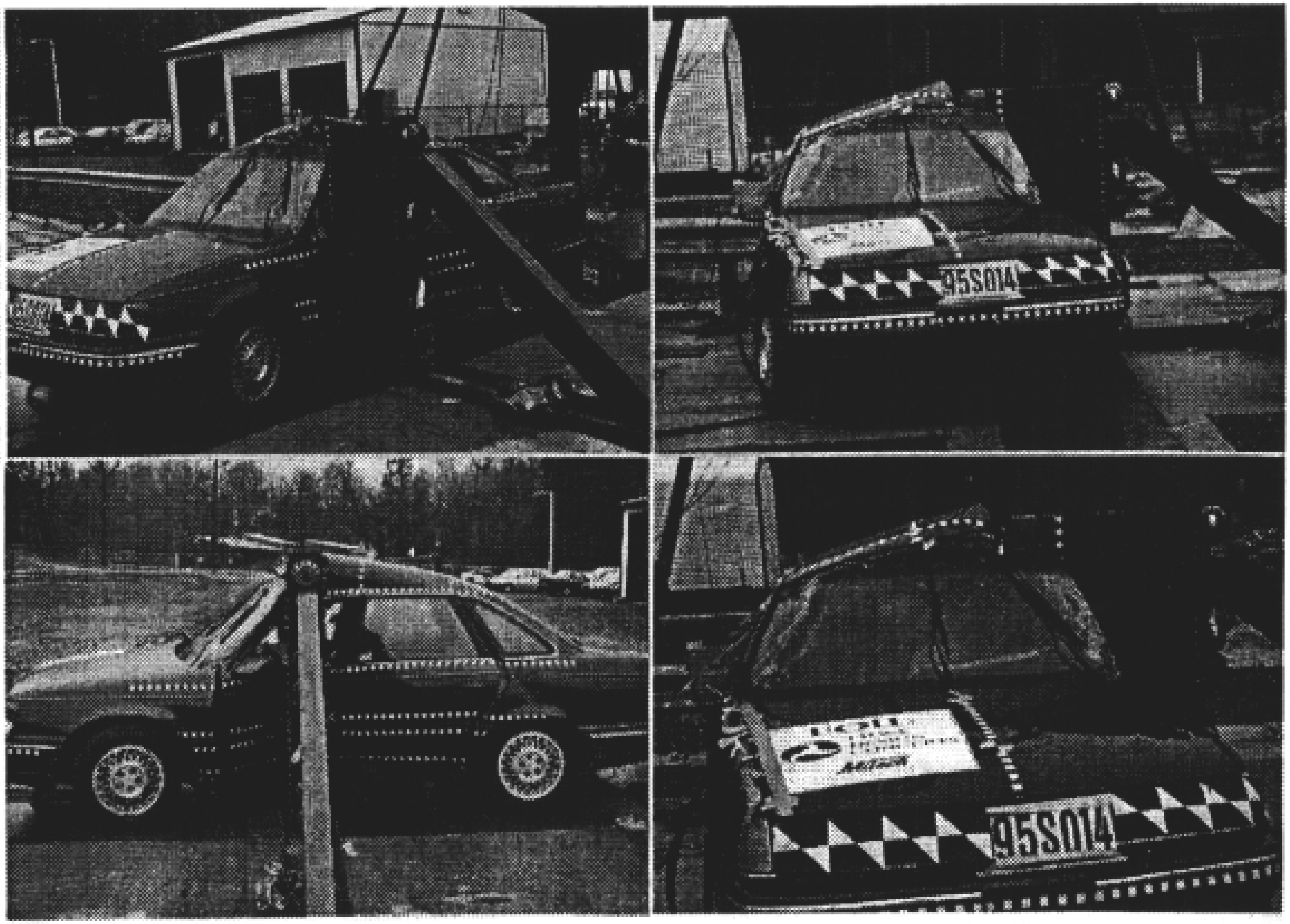


Figure 53. Post-test photographs, test 95S014.

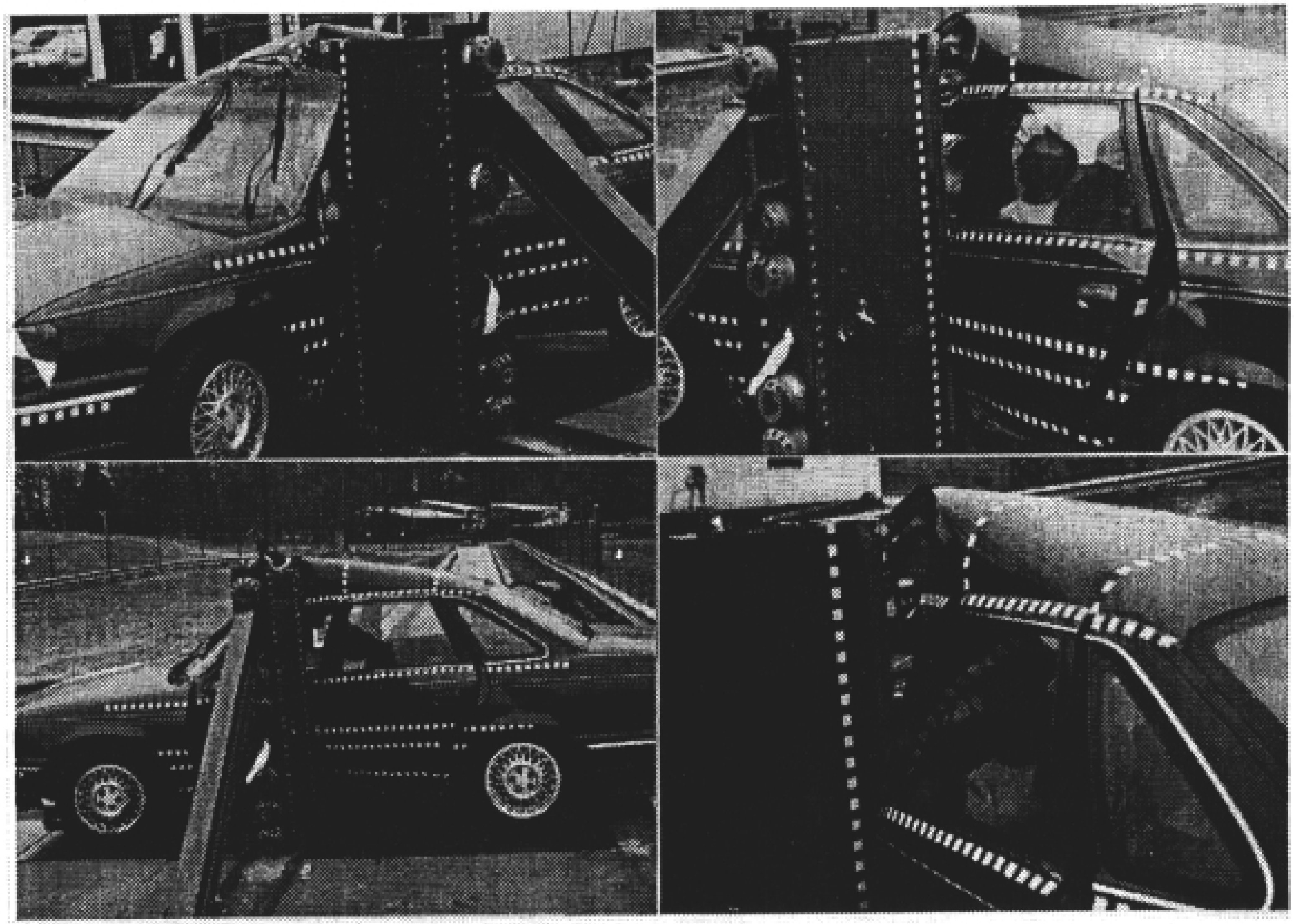


Figure 53. Post-test photographs, test 95S014 (continued).

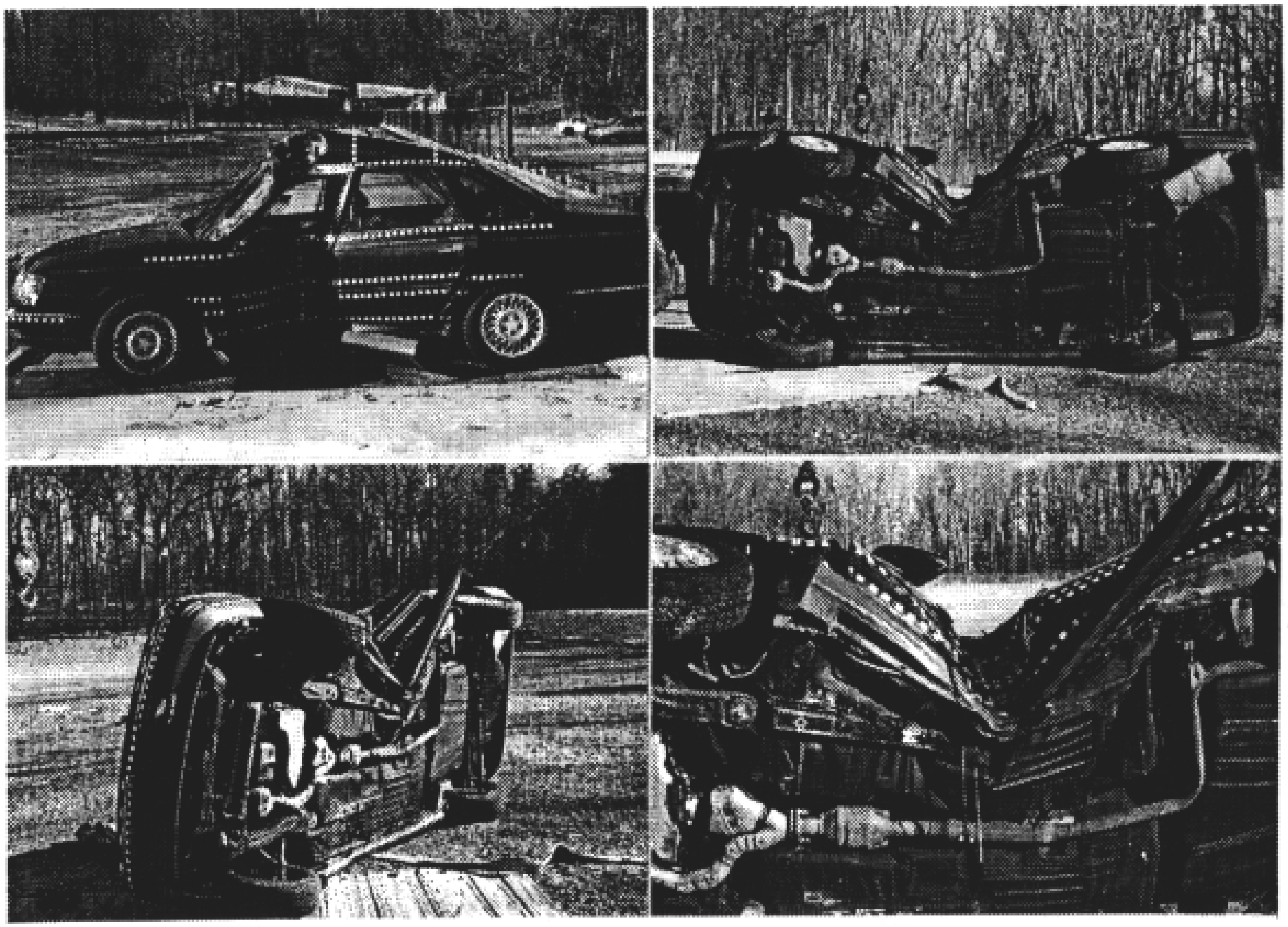


Figure 53. Post-test photographs, test 95S014 (continued).

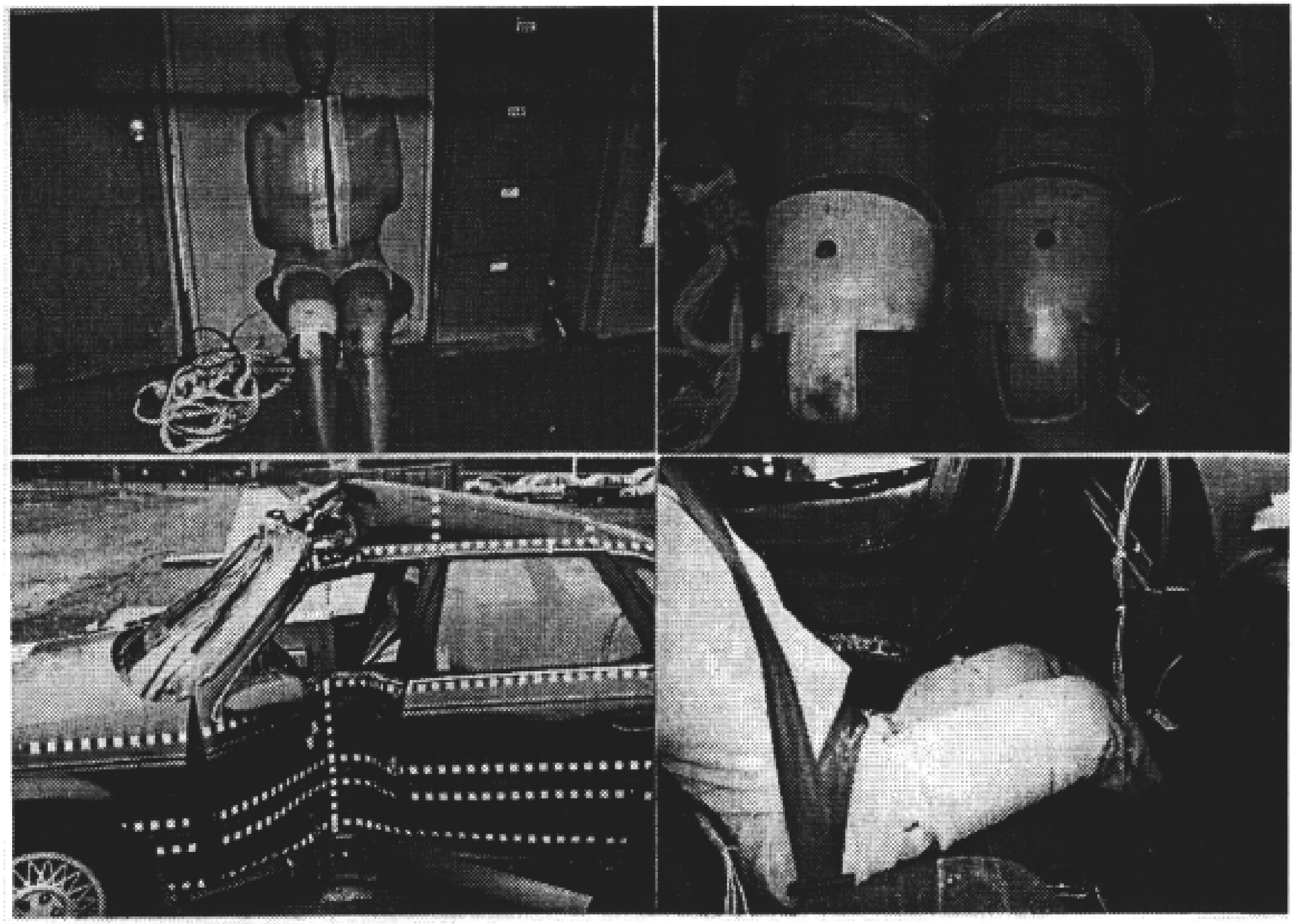


Figure 53. Post-test photographs, test 95S014 (continued).

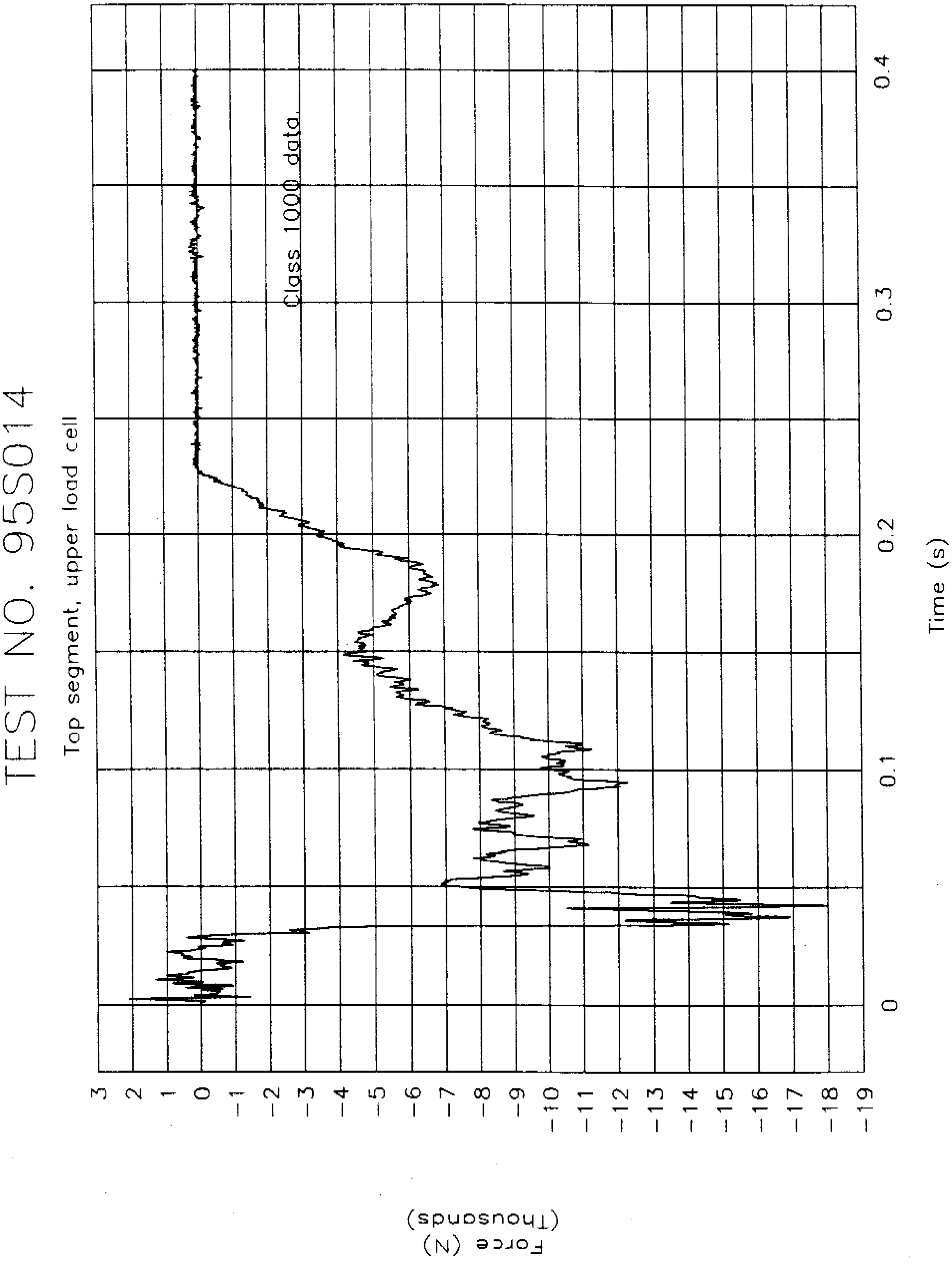


Figure 54. Rigid pole, top segment, upper load cell, force vs. time, test 95S014.

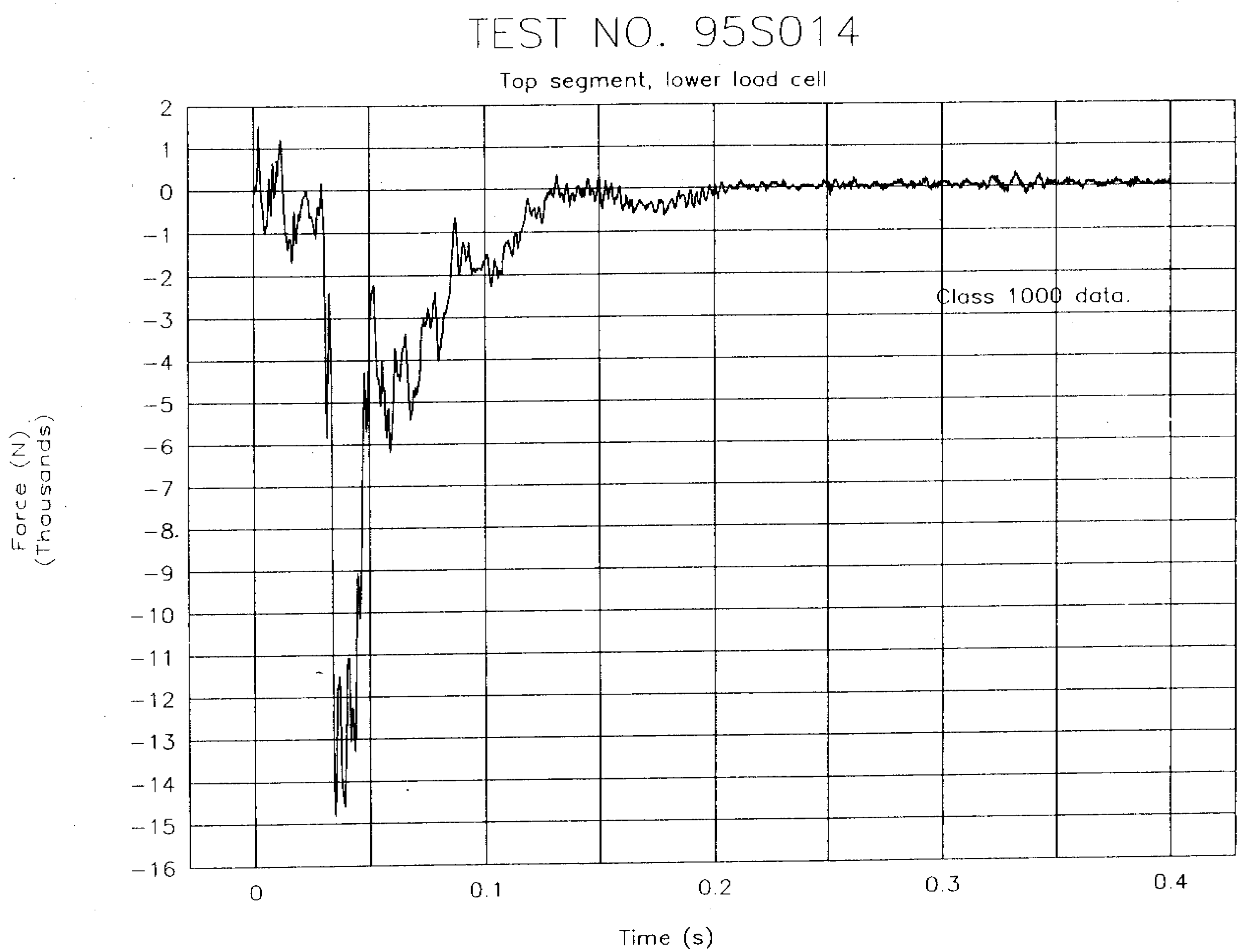


Figure 55. Rigid pole, top segment, lower load cell, force vs. time, test 95S014.

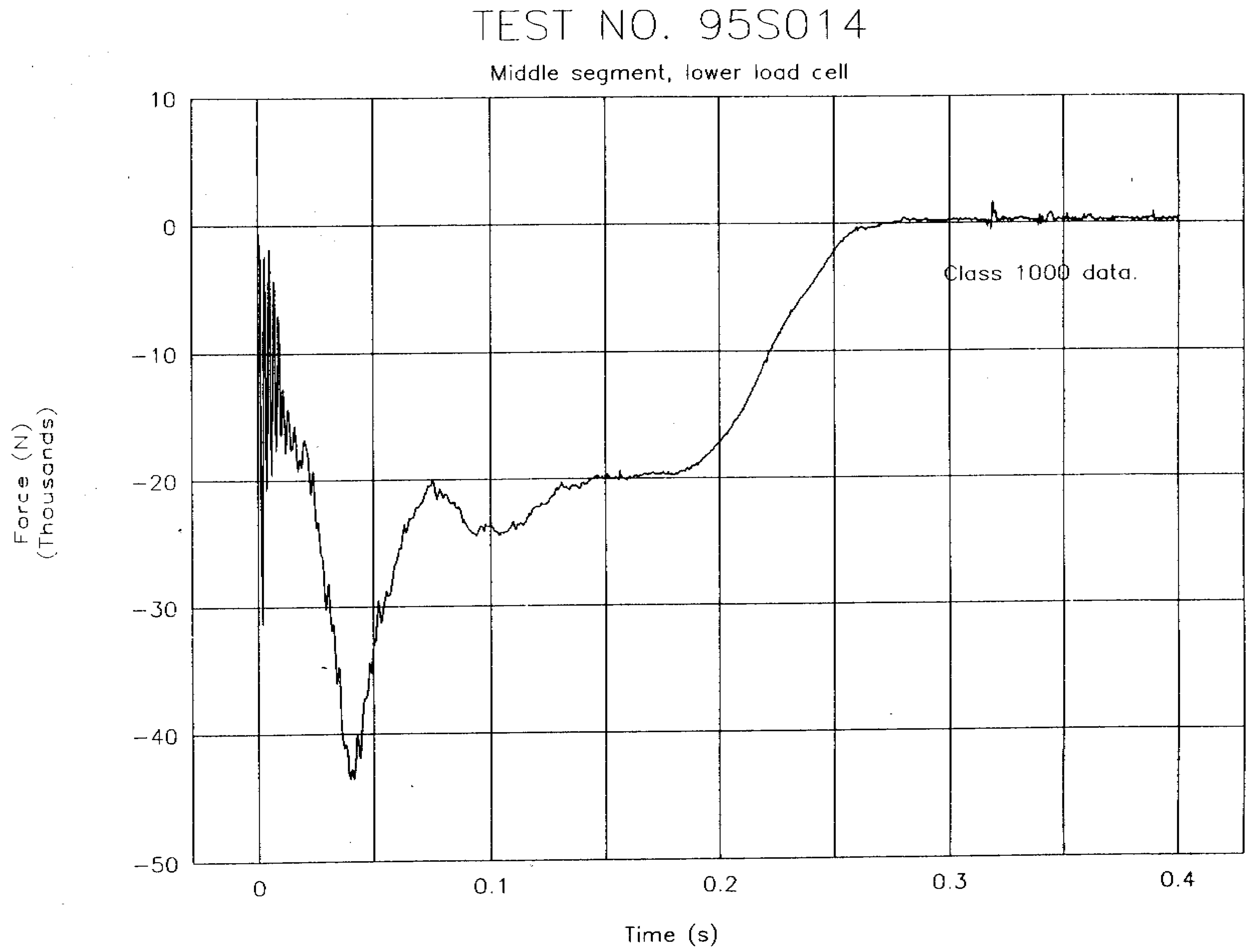


Figure 56. Rigid pole, middle segment, lower load cell, force vs. time, test 95S014.

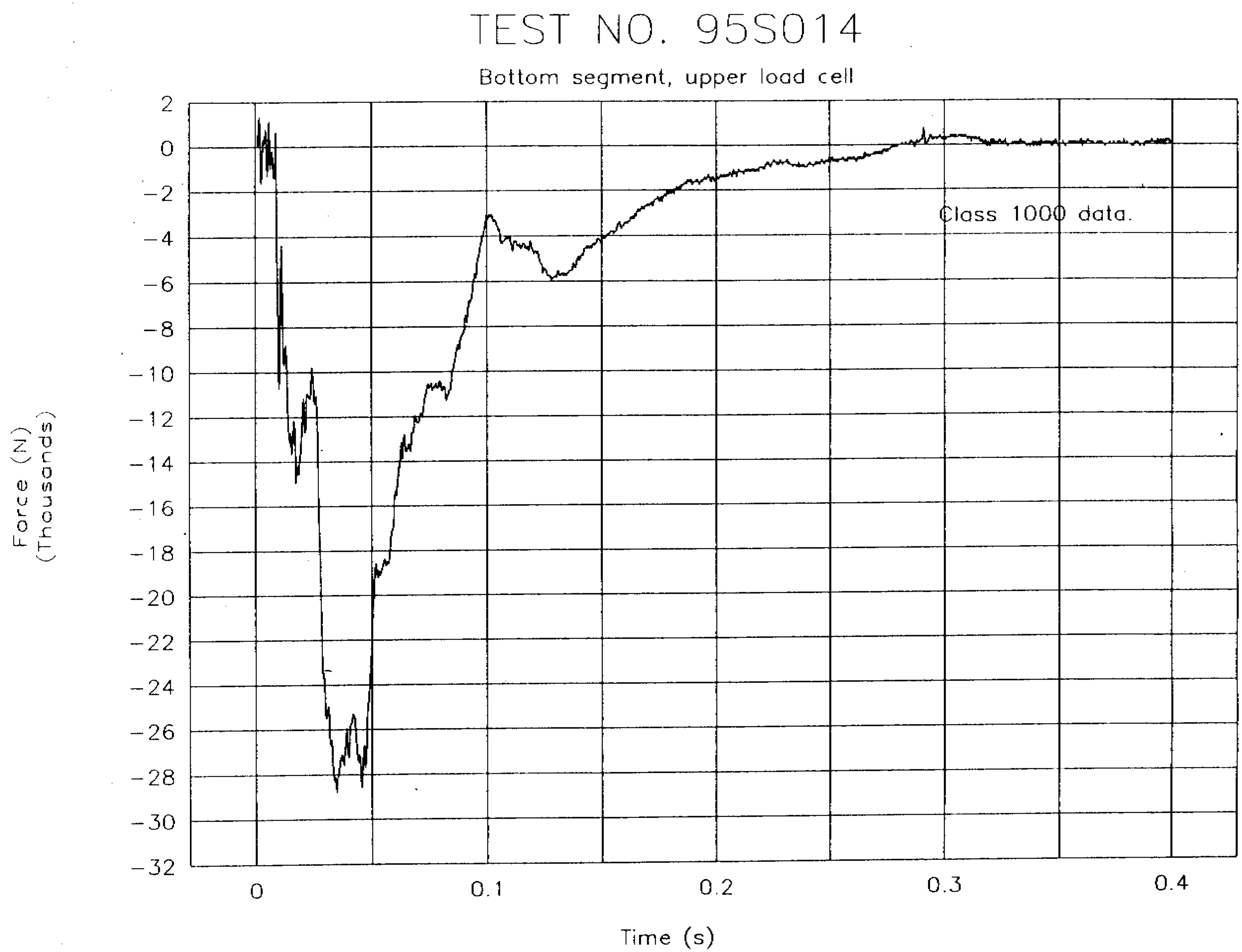


Figure 57. Rigid pole, bottom segment, upper load cell, force vs. time, test 95S014.

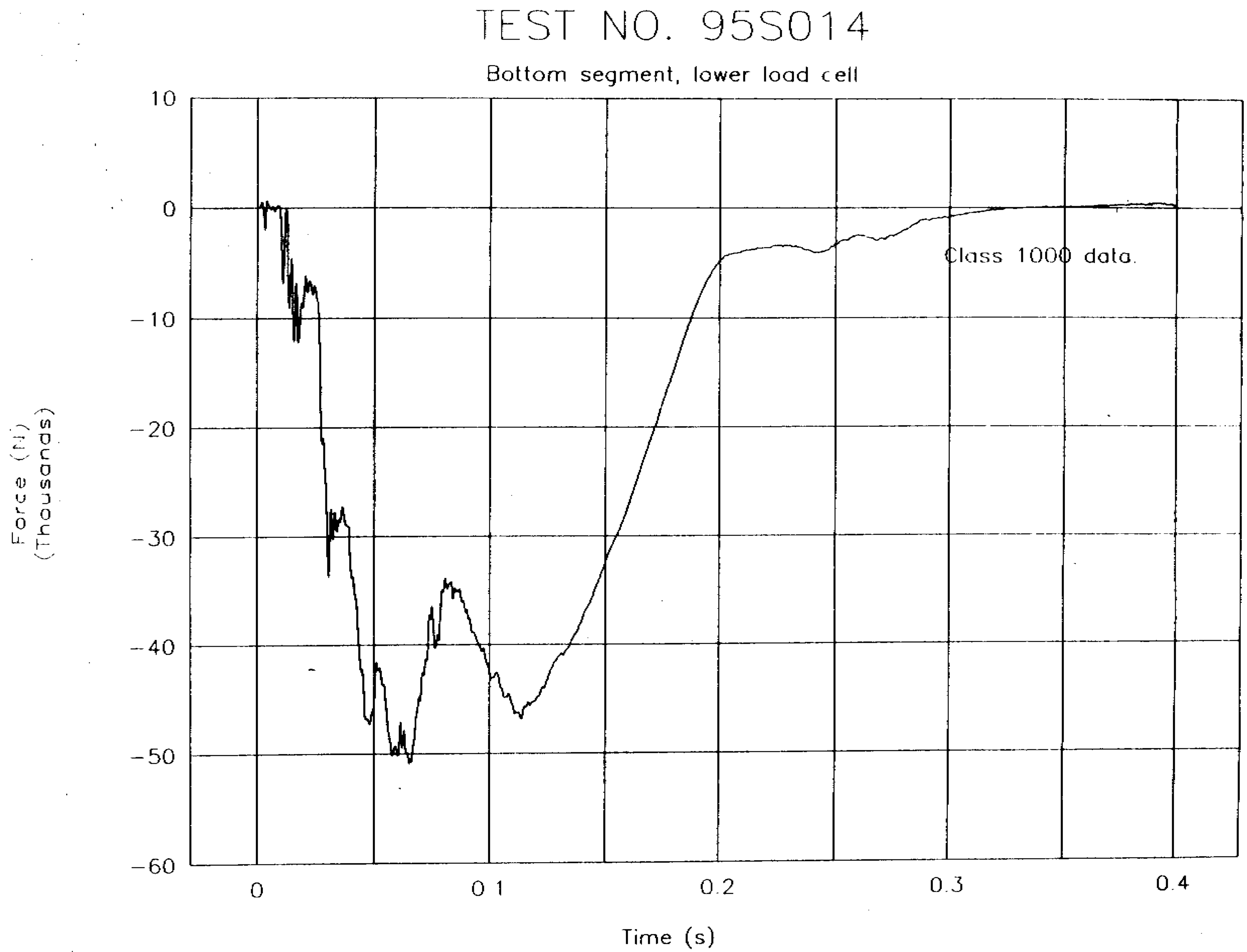


Figure 58. Rigid pole, bottom segment, lower load cell, force vs. time, test 95S014.

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Number

(1) C. Brown, *Ford Taurus Broadside Collision with a Narrow Fixed Object, FOIL Test Number: 95S008*, FHWA, Washington, D.C.

(2) NHTSA. *Laboratory Test Procedure for Federal Motor Vehicle Safety Standard 214,* National Highway Traffic Safety Administration, Washington, D.C., May 1992.

(3) H. E. Ross, Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features,* Transportation Research Board, Washington, D.C., 1993.