Crash Test Between a 6-KG/M U-Channel Sign Support and a 1997 Geo Metro: FOIL Test Number 99F010

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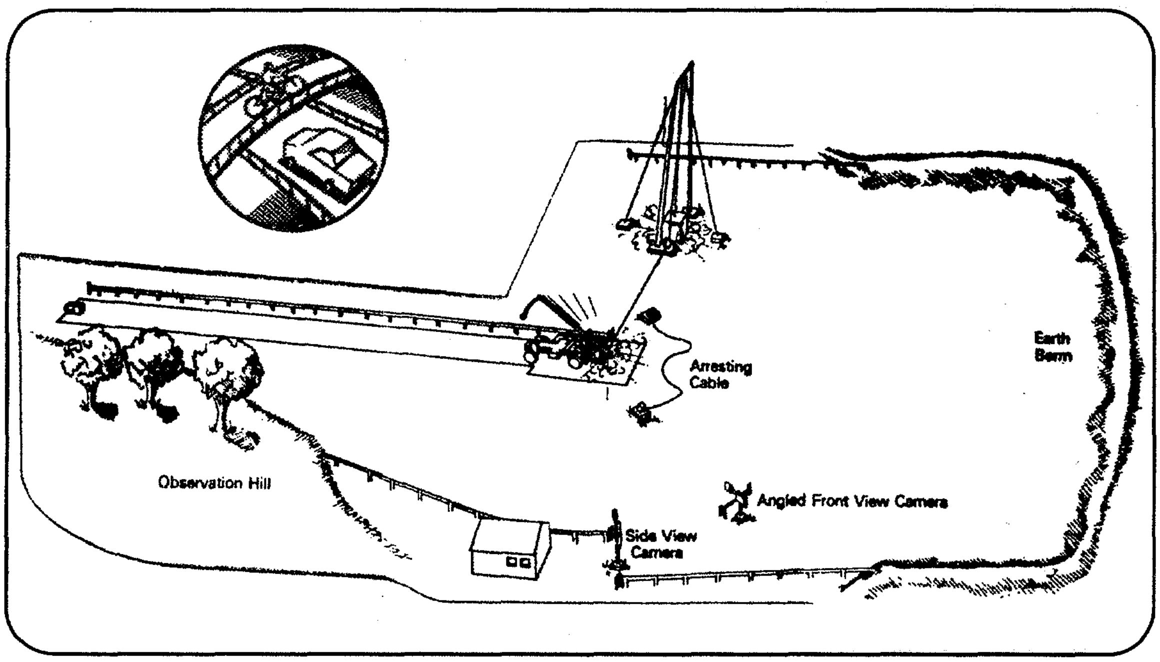

FOIL

U.S. Department of Transportation
Federal Highway Administration

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

FOREWORD

This report documents the results from one crash test between a 1997 Geo Metro two-door hatchback and a single-leg 6-kg/m u-channel sign support. The Federal Highway Administration (FHWA) has invested many resources in the development of finite element models (FEM) of passenger vehicles, pickup trucks, and roadside safety hardware. Computer simulations using these FEMs of collisions between the vehicles and roadside safety hardware are used to investigate the behavior of and improve the safety performance of roadside safety hardware. An essential step for developing the FEM is to validate the model by comparing data from simulation output with data collected from full-scale vehicle crash tests with roadside safety hardware. The FHWA's Federal Outdoor Impact Laboratory (FOIL) was used to conduct this test to develop and validate an FEM of the Geo Metro. The nominal test speed for the test was 100 km/h and the nominal test weight of the test vehicle was 820 kg.

This report (FHWA-RD-01-046) 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 crash worthiness of roadside safety hardware.

Michael F. Trentacoste

Michael Trentacoste, Director
Office of Safety and Traffic
Operations Research and Development

NOTICE

Technical Report Documentation Page

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CRASH TEST BETWEEN A 6-KG/M U-CHANNEL SIGN SUPPORT AND A 1997 GEO METRO: FOIL TEST NUMBER 99F010	5. Report Date 6. Performing Organization Code
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16. Abstract

This report contains the test procedures followed and test results from one crash test between a 1997 Geo Metro and a single-leg small sign support. The test was conducted at the Federal Highway Administration's (FHWA) Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The target test speed for the test was 100 km/h and the target test inertial weight was 820 kg. A dummy was not used in this crash test. The test was conducted to provide data for validating a finite element model (FEM) of a Geo Metro and to investigate the potential for windshield penetration by the sign support after fracture. Computer simulations using the latest FEMs of a Geo Metro indicated that windshield penetration was possible while striking a small sign support with a sign panel mounting height of 1,525 mm. The results from the test verified the simulation's prediction that if a Geo Metro struck this particular sign support design with these material properties there was a high probability of windshield penetration or severe windshield/roof damage. Because the post fractured, other important safety performance measures including predictability of device activation and longitudinal occupant impact velocity met the safety performance criteria specified in the National Cooperative Highway Research Program (NCHRP) *Report 350*, test designation 3-61. The data and high-speed film coverage will aid in the continuing evolution of the Geo Metro FEM.

17. Key Words	18. Distribution Statement
Geo Metro, acceleration, FOIL, sign support, occupant impact velocity, ridedown acceleration, *NCHRP Report 350*	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif (of this report)	20. Security Classif. (of this page	21. No. of Pages	22. Price
Unclassified	Unclassified	39	

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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.				
		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 CONVERSIO

Symbol	When You Know	Multiply
		LENGTH
mm	millimeters	0.039
m	meters	3.28
m	meters	1.09
km	kilometers	0.621
		AREA
mm^2	square millimeters	0.0016
m^2	square meters	10.764
m^2	square meters	1.195
ha	hectares	2.47
km^2	square kilometers	0.386
		VOLUME
mL	milliliters	0.034
L	liters	0.264
m^3	cubic meters	35.71
m^3	cubic meters	1.307
		MASS
g	grams	0.035
kg	kilograms	2.202
Mg (or "t")	megagrams (or "metric ton")	1.103
		TEMPERATURE
°C	Celcius temperature	1.8C + 3
		ILLUMINAT
lx	lux	0.0929
cd/m^2	candela/m^2	0.2919
		FORCE and PRESSUF
N	newtons	0.225
kPa	kilopascals	0.145

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

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SCOPE

This report documents the procedures followed and the results from one crash test conducted at the Federal Outdoor Impact Laboratory (FOIL) located at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia. The test involved a 1997 Geo Metro two-door hatchback traveling at 100 km/h and a single-leg 6-kg/m sign support mounted in a strong soil. The test was conducted to provide actual crash test data for verifying the results from finite element computer simulations investigating variation in sign support safety performance as a function of sign mounting height. The simulation efforts were conducted by the National Crash Analysis Center (NCAC).

The results indicate that, for this particular sign post and vehicle combination, a mounting height of 1.5 m led to windshield contact by the sign panel during a collision. However, other calculated safety performance values were below the allowable safety performance criteria for sign supports outlined in the National Cooperative Highway Research Program Report 350 (*NCHRP Report 350*).[1]

TEST MATRIX

One crash test was performed on a 6-kg/m sign support. The test was conducted in accordance with *NCHRP Report 350* test designation 3-61. Test designation 3-61 outlines parameters for a safety performance test of support structures involving an 820C (820-kg) vehicle striking a support at 100 km/h with an impact angle of 0° to 20°. Table 1 summarizes the nominal test conditions for test 99F010. The target impact location was center-of-post aligned with the vehicle's longitudinal centerline.

Table 1. Summary of nominal test conditions.

Test number	99F010
Test date	12-17-99
Vehicle	1997 Geo Metro
Nominal vehicle weight	820 kg
Nominal speed	100 km/h
Impact angle	0°
Support	6 kg/m u-channel (hat-section)
Soil	FOIL strong soil pit, Virginia 21A
Embedment depth	1,220 mm
Impact location	Vehicle centerline

VEHICLE

The test vehicle used was a 1997 Geo Metro LSi two-door hatchback with an automatic transmission. Prior to the test, the vehicle was drained of all fluids and its curb weight recorded. The vehicle's inertial properties were then measured using the FOIL inertial measurement device (IMD). The vehicle was stripped of certain components (spare tire, rear seat, shifter linkage, etc.) and instrumented with data acquisition equipment, sensors, an automated brake system, a high-speed film camera, and vehicle guidance equipment. The final vehicle test weight was determined and the vehicle's inertial properties were measured a second time as instrumented. The target vehicle inertial weight was 820 kg. A dummy was not used for this test. No components were removed from the vehicle's engine compartment. The battery remained in a charged state and connected to the power harness. The key was placed in the "start" position to activate air-bag power. Table 2 summarizes the test vehicle's inertial properties and figure 1 lists the vehicle's physical parameters.

Table 2. Inertial properties of 1997 Geo Metro.

Test Number	Weight (kg)	Height (mm) *	Long.cg ** (mm)	Pitch kg•m^2	Roll kg•m^2	Yaw kg•m^2	Bumper Height (mm)	Wheel Base (mm)
Curb Weight Configuration								
99F010	812	538	862	1,019	246	1,108	455	2360
Test Configuration (inertial)								
99F010	835	543	831	1,022	243	1,101	455	2360

* Height of vehicle center-of-gravity.
** Longitudinal center-of-gravity, distance behind front axle.

DATE: 12-17-99 TEST NO: 99F010 TIRE PRESSURE: 35 psi MAKE: GEO

MODEL: METRO YEAR: 1997 ODOMETER: ______ GVW: ______

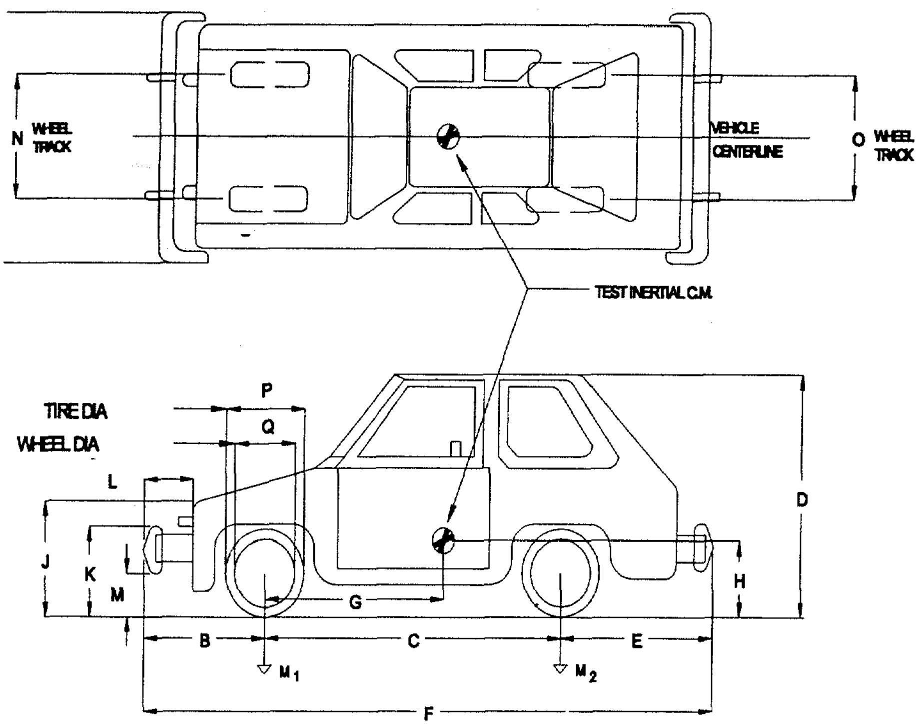
TIRE SIZE: 155/80 R13 VIN NUMBER: 2C1MR2296V6760556 TREAD TYPE: ______

MASS DISTRIBUTION: CURB: LF 265 RF 251 LR 143 RR 153

TEST INERTIAL: LF 276 RF 265 LR 149 RR 145

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

NONE



ENGINE TYPE: 1.3L 4 CYL.

ENGINE CID: ______

TRANSMISSION TYPE:

X AUTO

___ MANUAL

OPTIONAL EQUIPMENT:

AIR CONDITIONING

Radio

Driver and passenger

Air Bags

DUMMY DATA:

TYPE: None

MASS: ______

SEAT POSITION: ______

GEOMETRY

A 1525	E 591	J 718	N 1385	R
B 830	F 3785	K 502	O 1351	S
C 2363	G 831	L 106	P 577	T
D 1415	H 538	M 410	Q 361	U

MASS	CURB	TEST INERTIAL	GROSS STATIC
M_1	516	541	541
M_2	296	294	294
M_T	812	835	835

1 psi = 6.89 kPa

Figure 1. Vehicle properties for test 99F010.

TEST DEVICE

The device tested at the FOIL was a single-leg small sign support buried in *NCHRP Report 350* S1 strong soil. The sign support was constructed from one 6-kg/m u-channel hat-section and a 650-mm square aluminum sheet. The u-channel was cut to length (3,660 mm)and the sign panel was attached 1,525 mm above the ground line. The assembled sign support was placed in a 1,220-mm hole within the FOIL strong soil (crush-and-run) pit. The hole was back filled and compacted in 305-mm increments until ground level was reached. The sign panel was attached to the sign post using two 9-mm hardware quality bolts. A flat round washer was placed under the bolt head and nut.

Figure 2 illustrates the sign support installation. Refer to figures 7 and 8 in Appendix A for photographs of the test installation. Appendix C contains a stress-strain curve for the sign post material. The material testing was performed on specimens taken from the actual sign post tested. The material testing was conducted by the NCAC.

INSTRUMENTATION

Speed-trap, accelerometer, and high-speed film data were collected during the sign support test.

<u>Speed trap.</u> A speed trap was used to determine the vehicle's speed just prior to contact with the sign support. The center of the speed trap was located approximately 4 m before the sign support. The speed trap consisted of a set of five contact switches fastened to the runway in 305-mm intervals. As the vehicle passed over the switches, electronic pulses were recorded on analog tape.

<u>Transducer data.</u> The instrumentation used during the test consisted of a tri-axial accelerometer and a tri-axial angular rate transducer at the vehicle's center-of-gravity (c.g.). The data from the transducers were recorded by two data acquisition systems: the Diversified Technical Systems TDAS PRO onboard data acquisition system (TDAS PRO) and an umbilical cable tape recorder system. Table 3 describes the instrumentation used during the test. A three-dimensional sensor location is included in table 3. The location coordinates were referenced from the right-front wheel hub, which was 265 mm above ground.

The TDAS PRO is a self-contained system. The output from the sensors was filtered, digitally sampled, and digitally stored within the TDAS 8-channel modules mounted directly to the test vehicle inside the occupant compartment. The TDAS PRO system was set with a 3000-Hz analog pre filter and a digital sampling rate of 12,500 Hz. C.g. acceleration data, windshield data, and rate transducer data were collected via the TDAS PRO system.

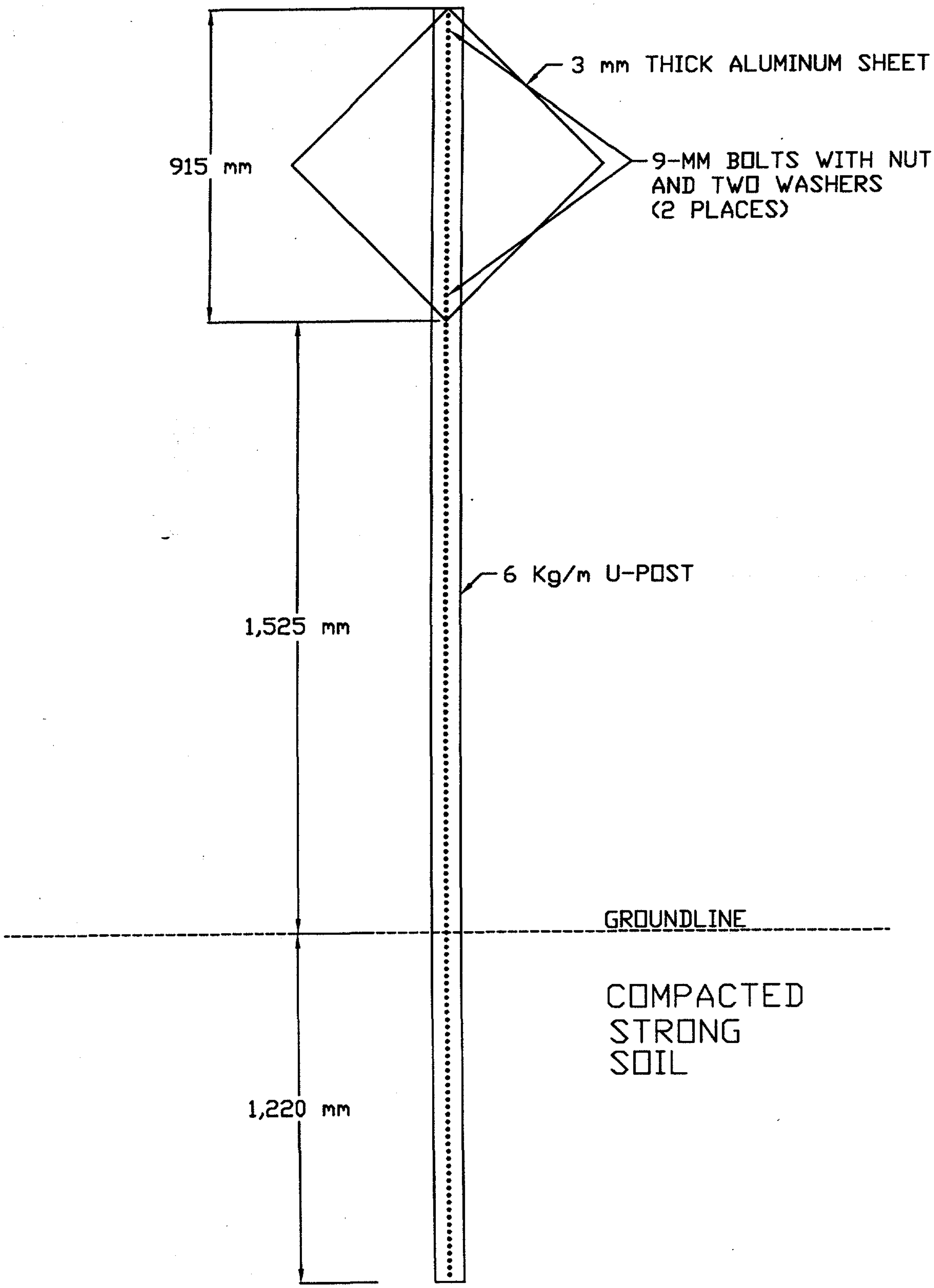


Figure 2. Sketch of small sign support.

The FOIL umbilical cable system utilizes a 90-m cable between the vehicle transducers and a rack of signal conditioning amplifiers. The output from the amplifiers was recorded on 25-mm magnetic tape via a Honeywell 5600E tape recorder. After the test, the tape is played back through anti-aliasing filters (set to 3000 Hz), then input to a Data Translation analog-to-digital converter (ADC). The sample rate was set to 12,500 Hz. The umbilical cable system recorded c.g. acceleration data.

Table 3. Summary of instrumentation and channel assignments for test 99F010.

TDAS PRO onboard data system				
Ch	**Transducer**	**Maximum range**	**Data description**	**Location* (X,Y,Z) mm**
1	Accelerometer	100 g	Vehicle c.g., X-axis	-800,750,140
2	Accelerometer	100 g	Vehicle c.g., Y-axis	-800,750,140
3	Accelerometer	100 g	Vehicle c.g., Z-axis	-800,750,140
4	Accelerometer	200 g	Roof-windshield	-930,725,1,025
5	Rate transducer	500 °/s	Pitch rate, c.g.	-800,750,140
6	Rate transducer	500 °/s	Roll rate, c.g.	-800,750,140
7	Rate transducer	500 °/s	Yaw rate, c.g.	-800,750,140
Umbilical cable, tape recorder system.				
1	Accelerometer	100 g	Vehicle c.g., X-axis	-800,750,140
2	Accelerometer	100 g	Vehicle c.g., Y-axis	-800,750,140
3	Accelerometer	100 g	Vehicle c.g., Z-axis	-800,750,140
11	Contact switch	1.5 V	Time of impact, T0	Not available
12	Contact switches	1.5 V	Runway speed trap	Not available
14	Generator	1.5 V	1 kHz reference signal	Not available

* Origin located at right front wheel hub (265 mm above ground)

High-speed photography. The crash test was photographed using seven high-speed cameras with an operating speed of 500 frames/s. All high-speed cameras used Kodak 2253 daylight film. In addition to the high-speed cameras, one real-time camera loaded with Kodak 7239 daylight film and two 35-mm still cameras were used to document the test. Table 4 summarizes the cameras used and their respective placements. The camera numbers listed in table 4 are shown in figure 3.

Table 4. Summary of camera placement.

Camera number	Type	Film speed frames/s	Lens (mm)	Location
1	LOCAM II	500	10	Overhead
2	LOCAM II	500	5.7	On-board, in vehicle
3	LOCAM II	500	50	Right side 90° to impact
4	LOCAM II	500	100	Right side 90° to impact
5	LOCAM II	500	25	Right side 45°
6	LOCAM II	500	150	Behind sign support in line with vehicle
7	LOCAM II	500	100	Left side 45°
8	BOLEX	24	ZOOM	Documentary
9	CANNON A-1	still	ZOOM	Documentary
10	CANNON A-1	still	ZOOM	Documentary

DATA ANALYSIS

Data were collected via the FOIL analog tape recorder system, including speed-trap data, the FOIL TDAS PRO onboard data system, and high-speed film.

Speed trap. As the vehicle passed over the speed-trap tape switches, electronic pulses were recorded to analog tape. The tape was played back through a Data Translation ADC inside a desktop computer. The time between pulses was then determined using the software provided with the ADC. The time intervals between the first pulse and each of the subsequent four pulses together with the distances between corresponding tape switches were entered into a computer spreadsheet and a linear regression was performed to determine the best-line fit of the data points. The impact velocity was then determined from the slope of the best-line fit of the displacement vs. time curve.

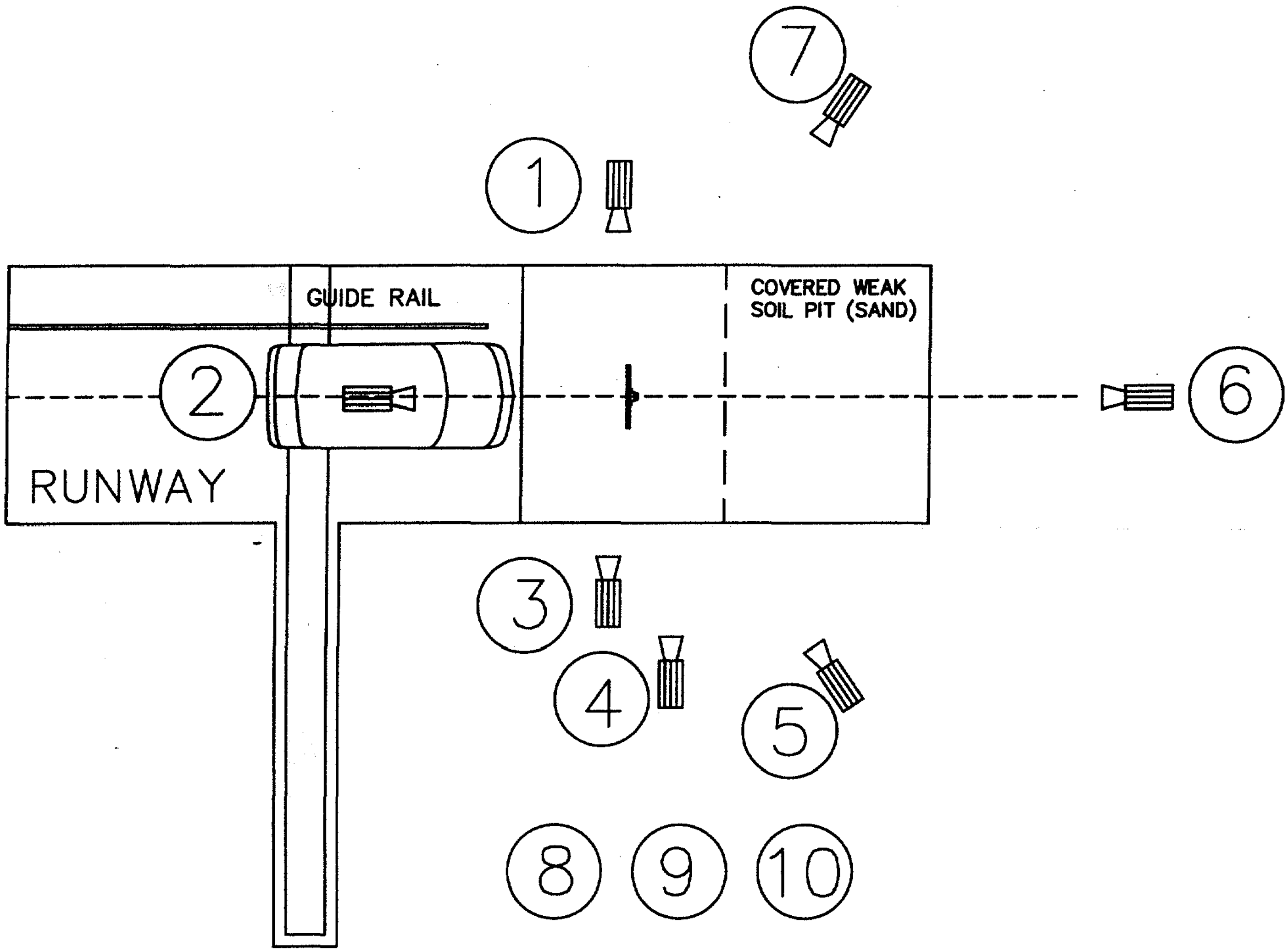


Figure 3. Camera placement, test 99F010.

Transducer data package. After the test, data from both data systems were converted to digital format and stored. The digital data from the tape recorder system and the TDAS PRO system were converted to the ASCII format, the zero bias was removed, and the data were digitally filtered using a digital Butterworth low-pass filter. The data from the crash test were digitally filtered with a cutoff frequency of 300 Hz (SAE J211 Class 180). The data were transferred to a spreadsheet for analysis.

The longitudinal c.g. acceleration data were integrated twice to produce velocity and displacement traces. Using techniques outlined in *NCHRP Report 350* the occupant risk values were determined.

High-speed photography. The crash event was recorded on 16-mm film by seven high-speed cameras. The film from the camera perpendicular to the vehicle trajectory, with a 50-mm lens, was analyzed for initial vehicle velocity. The overhead camera was used to verify the impact location, impact angle, exit angle, and exit speed. Analysis was performed using an NAC Film Motion Analyzer model 160-F in conjunction with a desktop personal computer. The motion analyzer digitized the 16-mm film, reducing the image to Cartesian coordinates. The Cartesian coordinate data were then imported into a computer spreadsheet for analysis. Using the Cartesian coordinate data, a displacement vs. time history was obtained. A linear regression was performed on the first 20 data points of the displacement vs. time traces to verify the vehicle's impact velocity. The film was used to verify data obtained from the speed trap and rate transducer and could be used in the event of transducer malfunction. The film was used to observe roll, pitch, and yaw angular displacements. The speed trap and accelerometer data were the primary data systems.

RESULTS

The Geo Metro was positioned on the runway and attached to the FOIL propulsion system. The windows were up, the emergency brake was released, and the ignition was in the "on" position to activate the air-bags. The vehicle was accelerated to 97.5 km/h prior to striking the small sign support. The vehicle made first contact with the sign post along the centerline as intended. The vehicle bumper began to collapse on contact with the sign support. At 0.010 s after contact the bumper had been pushed back to the radiator while the sign post was slightly bowed and had begun to plow through the soil. The sign post and the plowing action imparted enough force on the vehicle to deploy the air-bags (0.028 s). The vehicle continued forward and the sign post fractured at approximately 0.40 s. The upper portion of the sign post rotated downward striking the vehicle at the windshield

roof boundry. The vehicle passed over the sign stub and continued out into the FOIL runout area where the brakes were applied. The vehicle's bumper was torn from the vehicle prior to sign post fracture. The vehicle remained stable and upright. The vehicle came to rest after contact with the FOIL catch fence 101 m downstream from the impact location. Figure 4 summarizes the results from the small sign support test. Appendix A contains photographs of the test during the collision and the pre and post test environments. Table 5 lists the maximum and minimum peak values obtained from the vehicle accelerometers. The values listed are Class 180 data (digital filter cut-off frequency of 300 Hz). Appendix B contains data plots of the data collected from each vehicle sensor and velocity and displacement data plots created from the longitudinal cg acceleration trace. All acceleration data plots are from Class 180 data.

Table 5. Maximum and minimum peak values recorded.

Location	**Peak Acceleration (g's)**	
	Max (+)	**Max (-)**
Cg X-axis	27.8	28.7
Cg X-axis, redundant	19.9	18.9
Cg Y-axis	10.6	15.9
Cg Y-axis, redundant	18.7	13.1
Cg Z-axis	29.1	27.7
Cg Z-axis, redundant	33.6	27.6
Windshield acceleration (peaks from data before sensor broke)	55.3	57.0

Occupant responses. The longitudinal occupant impact velocity (OIV) was determined to be 1.7 m/s and occurred approximately 0.4 s after initial contact between the vehicle and the sign support. The OIV value is below the limits specified in NCHRP Report 350. The longitudinal ridedown acceleration was below the allowable limits specified and was determined to be 0.4 g's.

Vehicle damage. Damage to the vehicle was extensive. The hood, roof, grill, head lights, and core supports were either crushed and/or dislodged from the vehicle. The bumper and lower front cross-member were torn from the vehicle. The windshield was shattered. Both air-bags were deployed.

Sign damage. The sign support fractured approximately 305 mm above ground. The remaining stub was bent backward and the sign

panel and post were launched downrange approximately 43 m. The trajectory of the sign post was in line with the vehicle trajectory. There was no evidence of post pull-out before fracture. The sign post could not be reused.

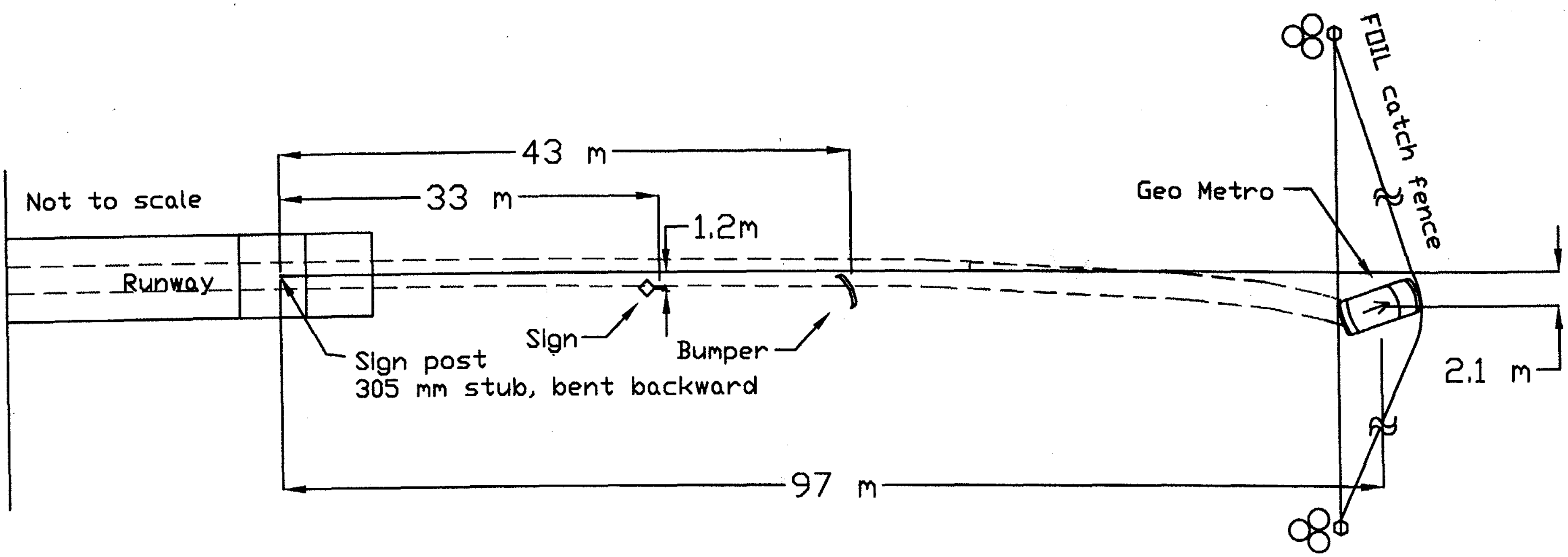
CONCLUSION

The data were successfully collected and the high-speed film successfully taken during the sign support test. The data and film will aid in the development and validation of a Geo Metro FEM and will help make sign mounting height recommendations. Computer simulations predicted that, for a sign support with these material properties, the sign support would strike a Geo Metro's windshield. The sign post fractured as anticipated and severely dented the vehicle's roof and shattered the windshield.

The results summarized in figure 4 indicate that the 6-kg/m small sign support embedded in strong soil did not meet the safety performance criteria outlined in *NCHRP Report 350* (test designation 3-61). The sign support did fracture as anticipated and the longitudinal OIV (1.7 m/s) was below the allowable limit (5 m/s). However, the sign post contact with the vehicle caused a significant amount of denting to the roof and shattered the windshield, diminishing a driver's visibility. Table 6 summarizes the safety performance of the small sign support.

Table 6. Sign support safety performance summary.

Evaluation Factor	**Evaluation Criteria**	**Pass (P) or Fail (F)**
Structural Adequacy	Test article should activate in a predictable manner.	P
Occupant Risk	**Occupant compartment intrusion, debris hazard.**	**F, windshield and roof damgage**
	Vehicle should remain upright and stable.	P
	Longitudinal OIV (<5 m/s).	P, 1.7 m/s
	Longitudinal ridedown (<20 g's).	P, 0.4 g's
Vehicle Trajectory	Vehicle trajectory should not intrude into adjacent lanes.	P
	Vehicle trajectory behind article is acceptable.	P



Test location............................FHWA FOIL
Test number..................................99F010
Date............................December 17, 1999
Test designation..............NCHRP 350 test 3-61
Test device........................Sign support
  Posts...........Single leg 6-kg/m u-channel post
  Sign panel..........650-mm square aluminum sheet
  Soil..............Compacted 21A or crush-and-run
  Panel height..........................1,525 mm
  Total height above ground..............2,440 mm

Foundation........Embedded 1,220 mm in strong soil

Vehicle............................1997 Geo Metro
    Weight: Inertial.......................835 kg
        Gross..............................835 kg
        Dummy...........................No dummy
Impact speed...........................97.5 km/h
Actual impact location.....................center
Impact angle.................................0.0°

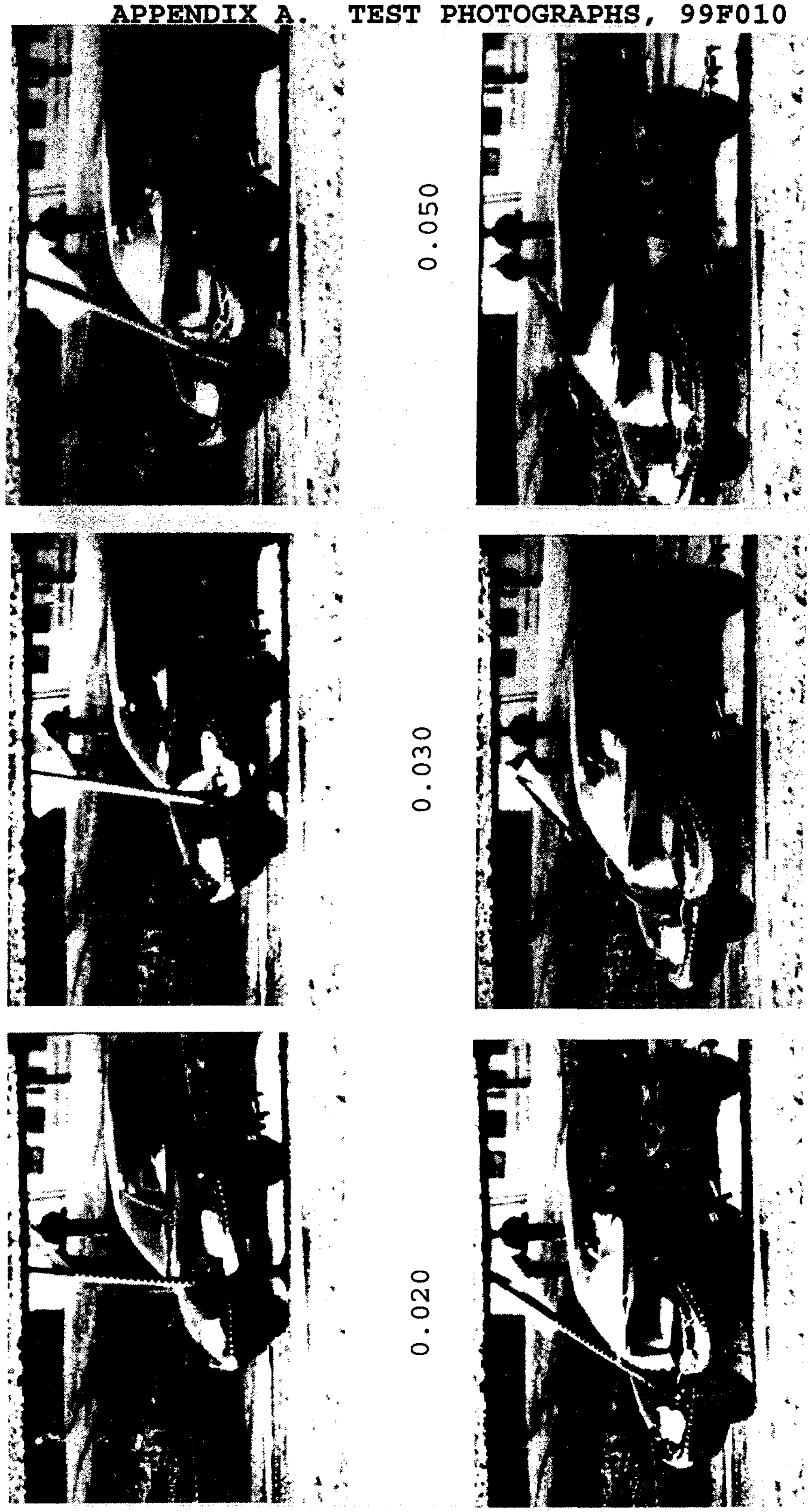
Occupant Risk:	Observed	Design/Limit
Longitudinal:		
Occupant delta V at 0.6 m	1.7 m/s	3/5 m/s
Ridedown acceleration	0.4 g's	15/20 g's
Lateral:		
Occupant Delta V at 0.3 m	no contact	NA
Ridedown acceleration	no contact	NA

Peak 50 ms acceleration:
    Longitudinal................................ 3.3 g's
    Lateral.......................................NA
Vehicle Damage:
    Traffic Accident Data (TAD)..................12-FC-4
    Vehicle Damage Index (VDI)...................12FCEN3
    Static crush..................................305 mm
Post fracture........................305 mm above ground

Exit speed....................................90.5 km/h
Exit angle.......................................0.0°

Figure 4. Summary of results, test 99F010.

APPENDIX A. TEST PHOTOGRAPHS, 99F010

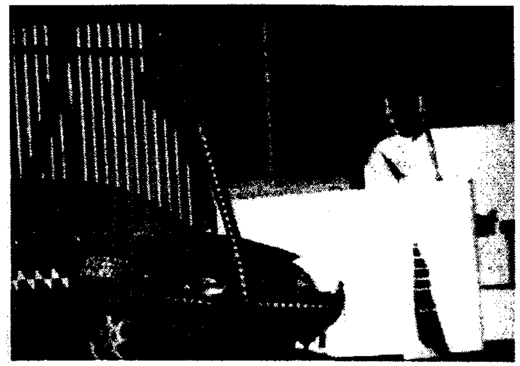


0.020 0.030 0.050

0.060 0.070 0.086

Figure 5. Photographs during the test, test 99F010.

0.010



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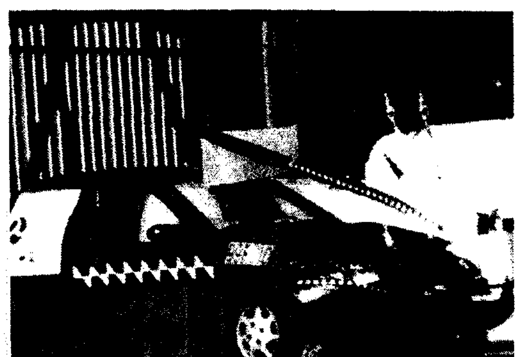

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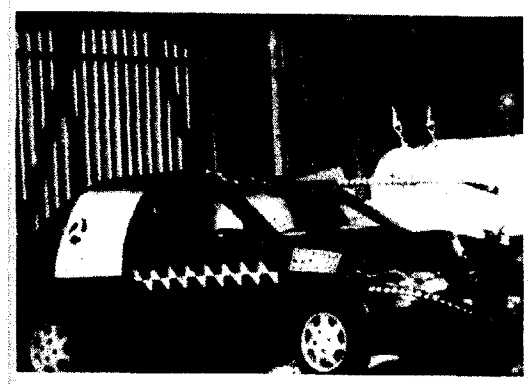

0.100

Figure 6. Additional photographs during the test, test 99F010.

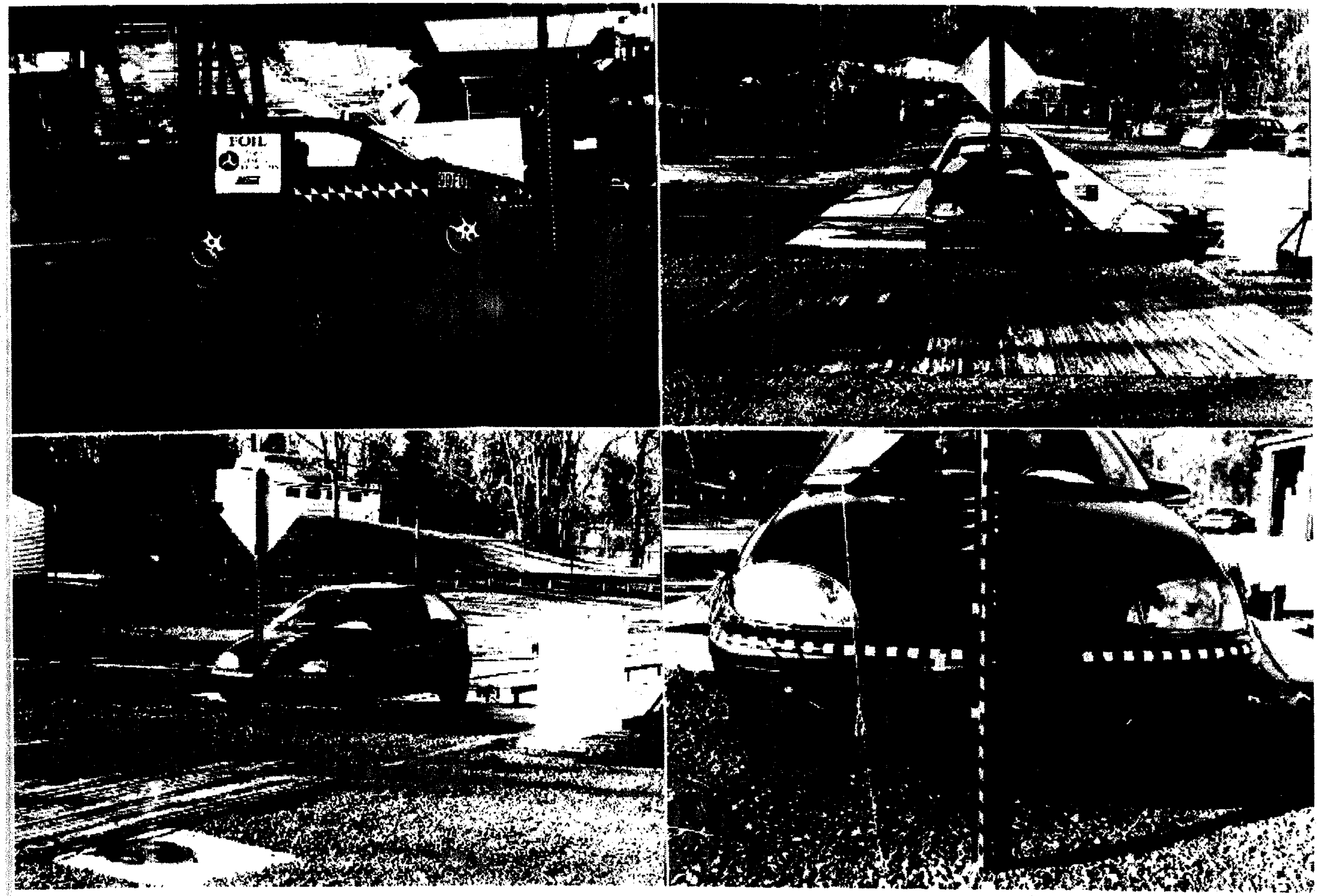

Figure 7. Pre-test photographs, test 99F010.

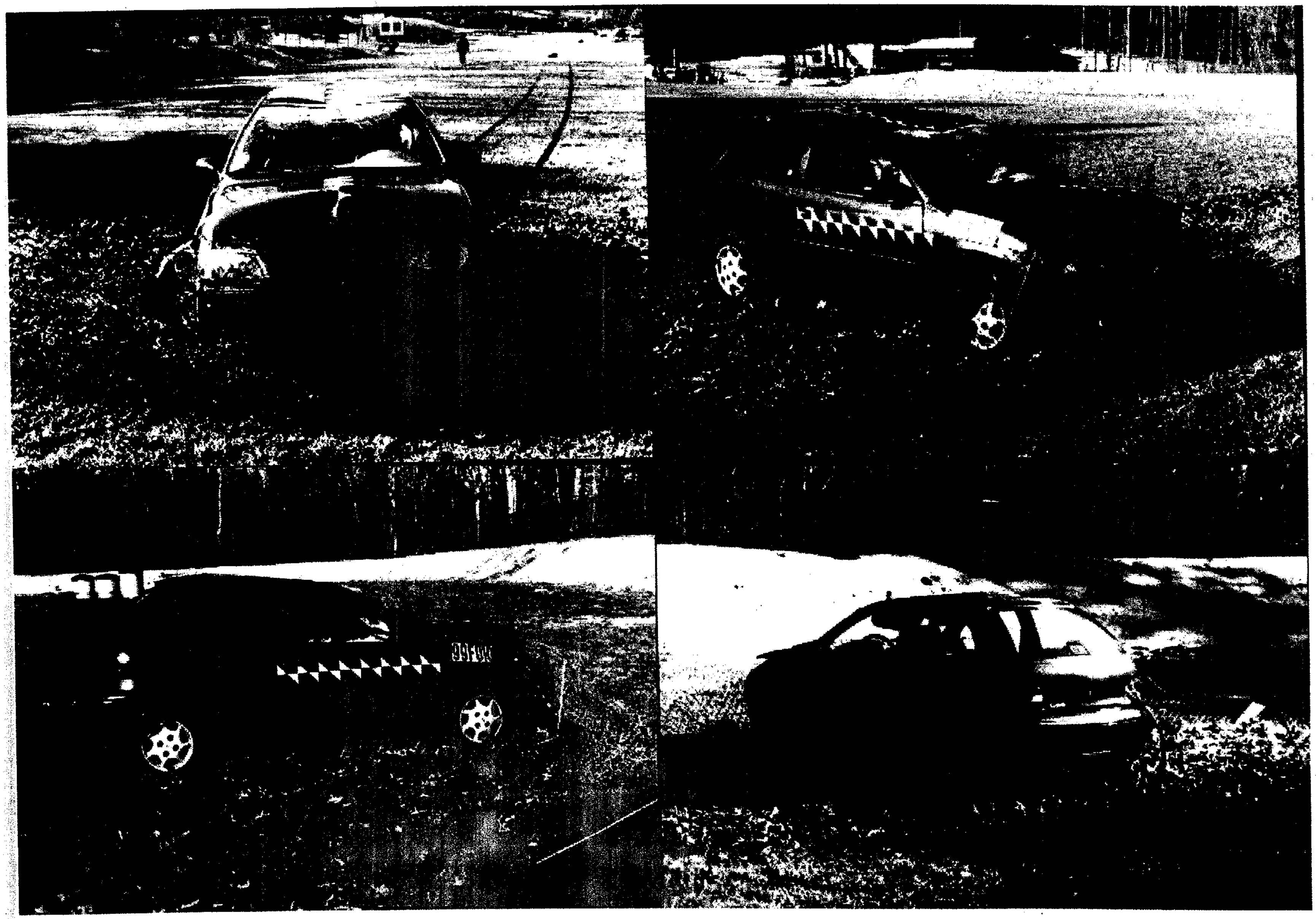

Figure 8. Post-test photographs, test 99F010.

Figure 9. Post-test photographs continued, test 99F010.

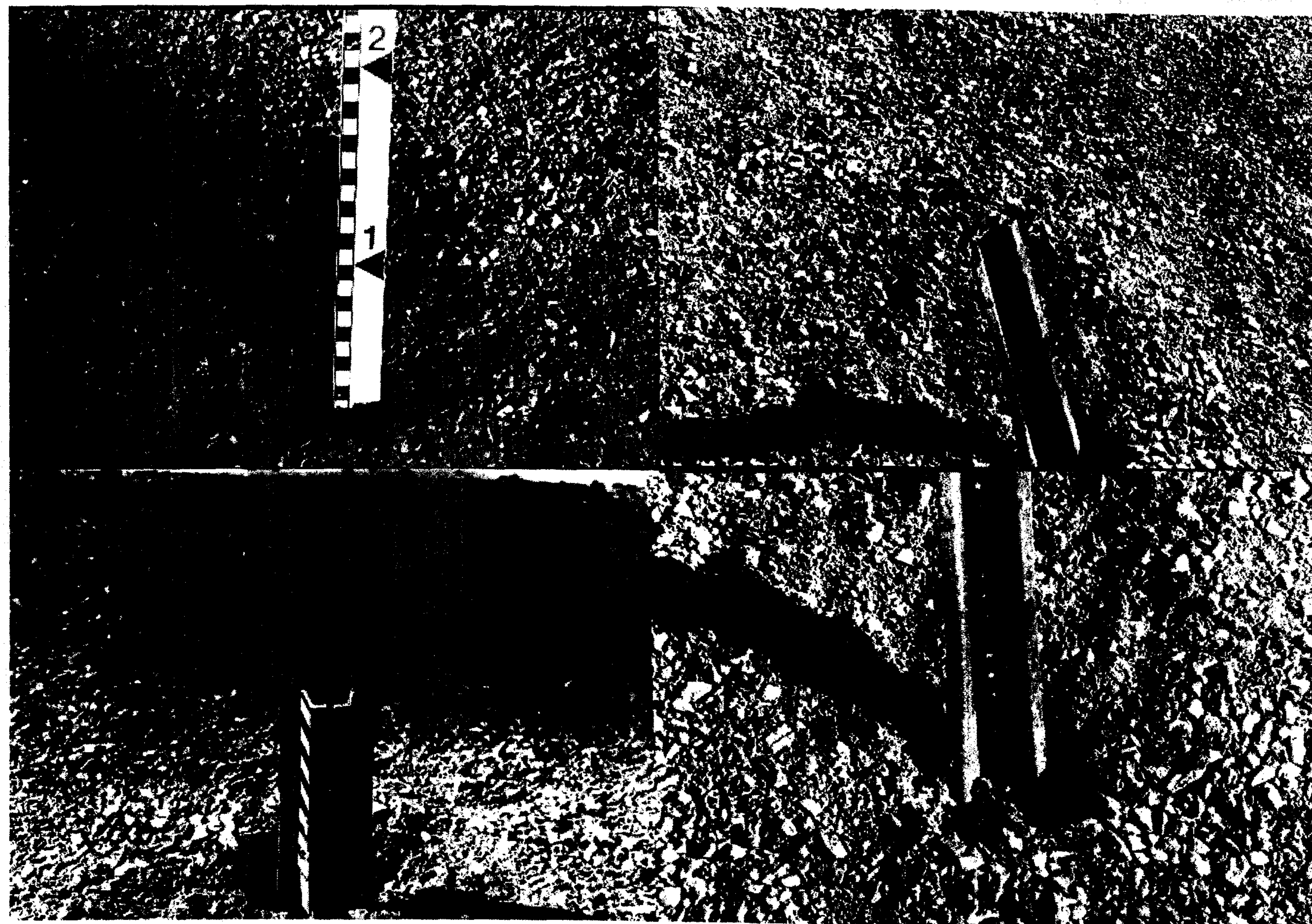

Figure 10. Additional post-test photographs, test 99F010.

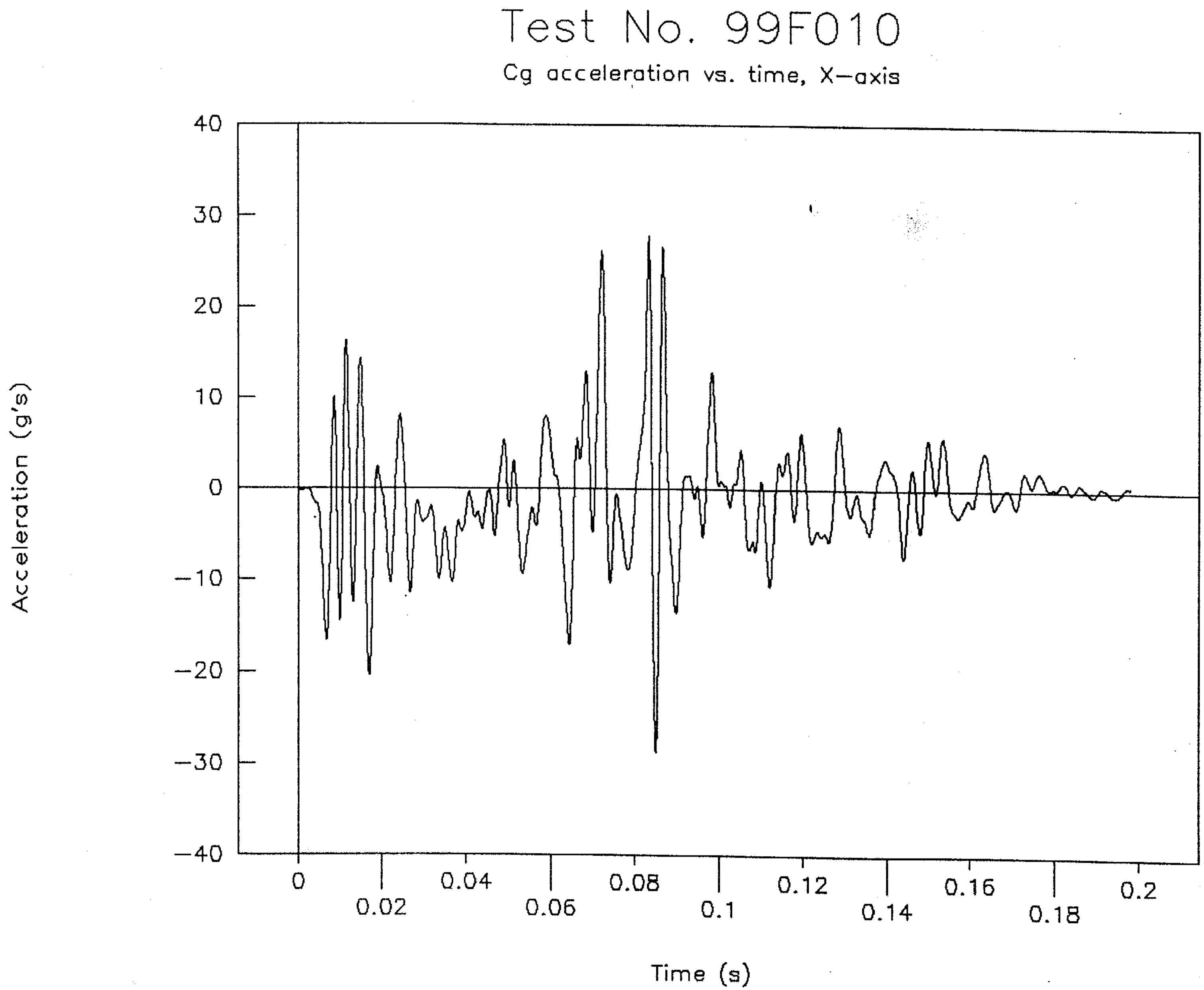

Figure 11. C.g. acceleration vs. time, X-axis, test 99F010.

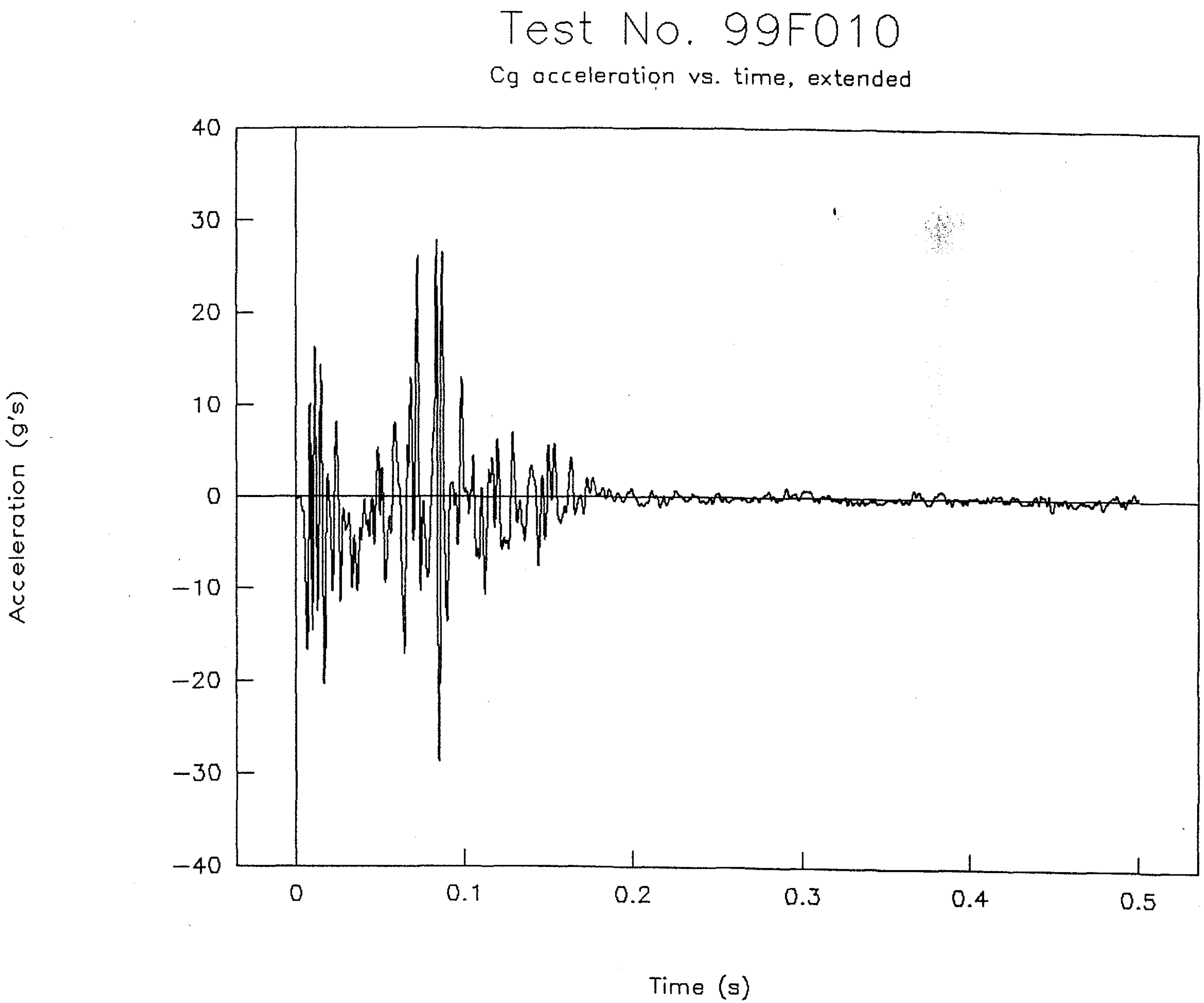

Figure 12. C.g. acceleration vs. time, X-axis extended, test 99F010.

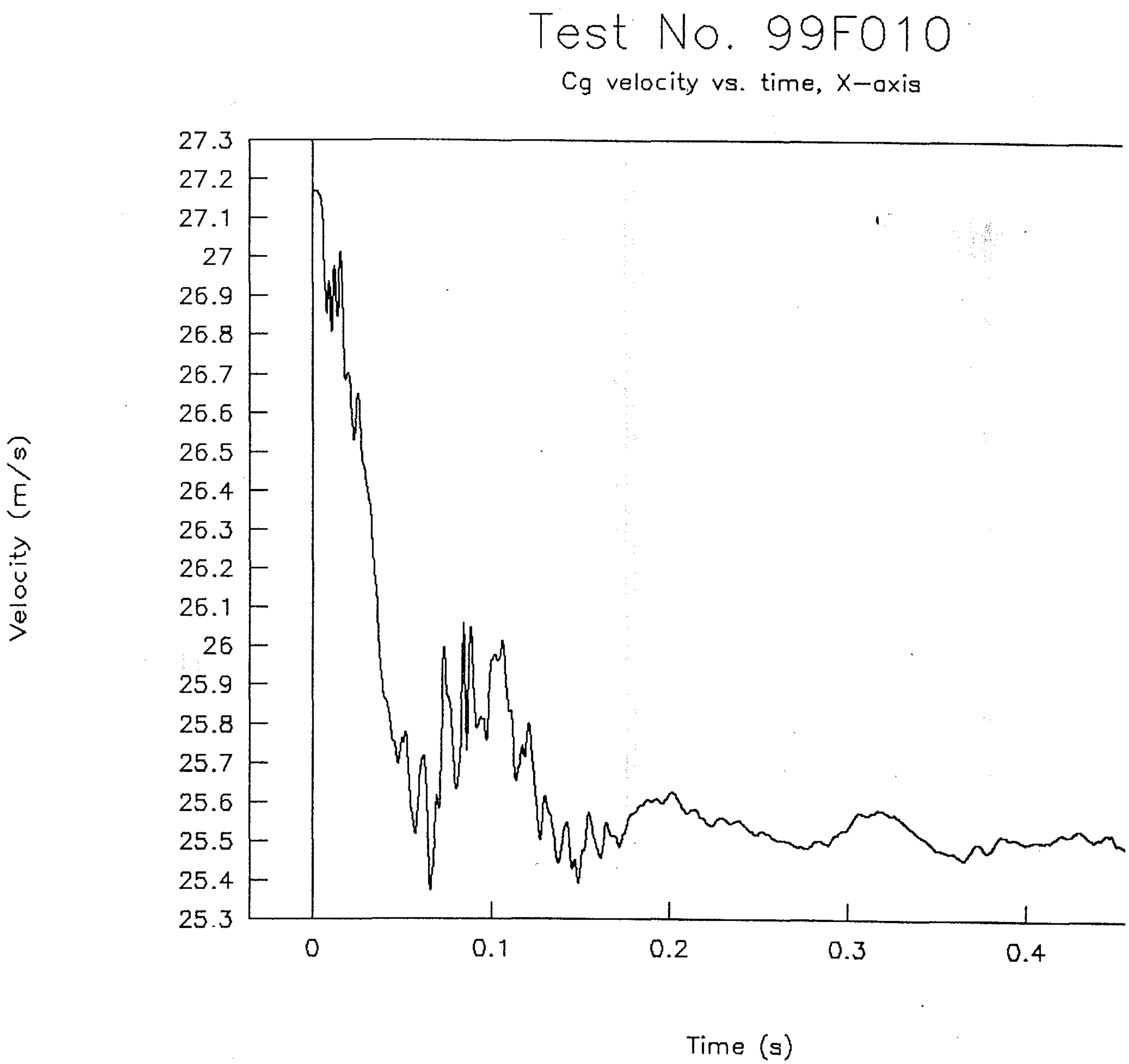

Figure 13. C.g. velocity vs. time, X-axis, test 99F010

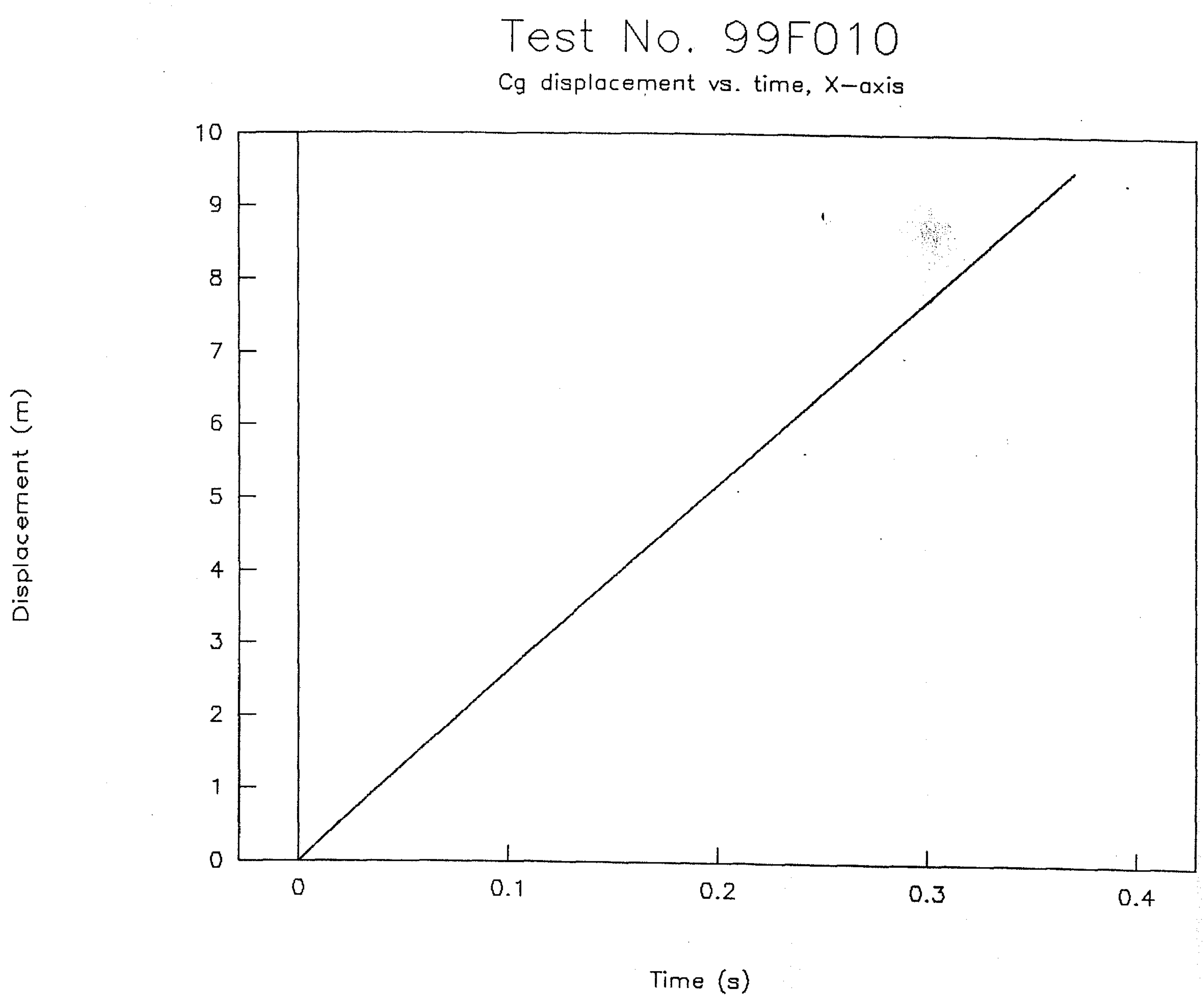

Figure 14. C.g. displacement vs. time, X-axis, test 99F010.

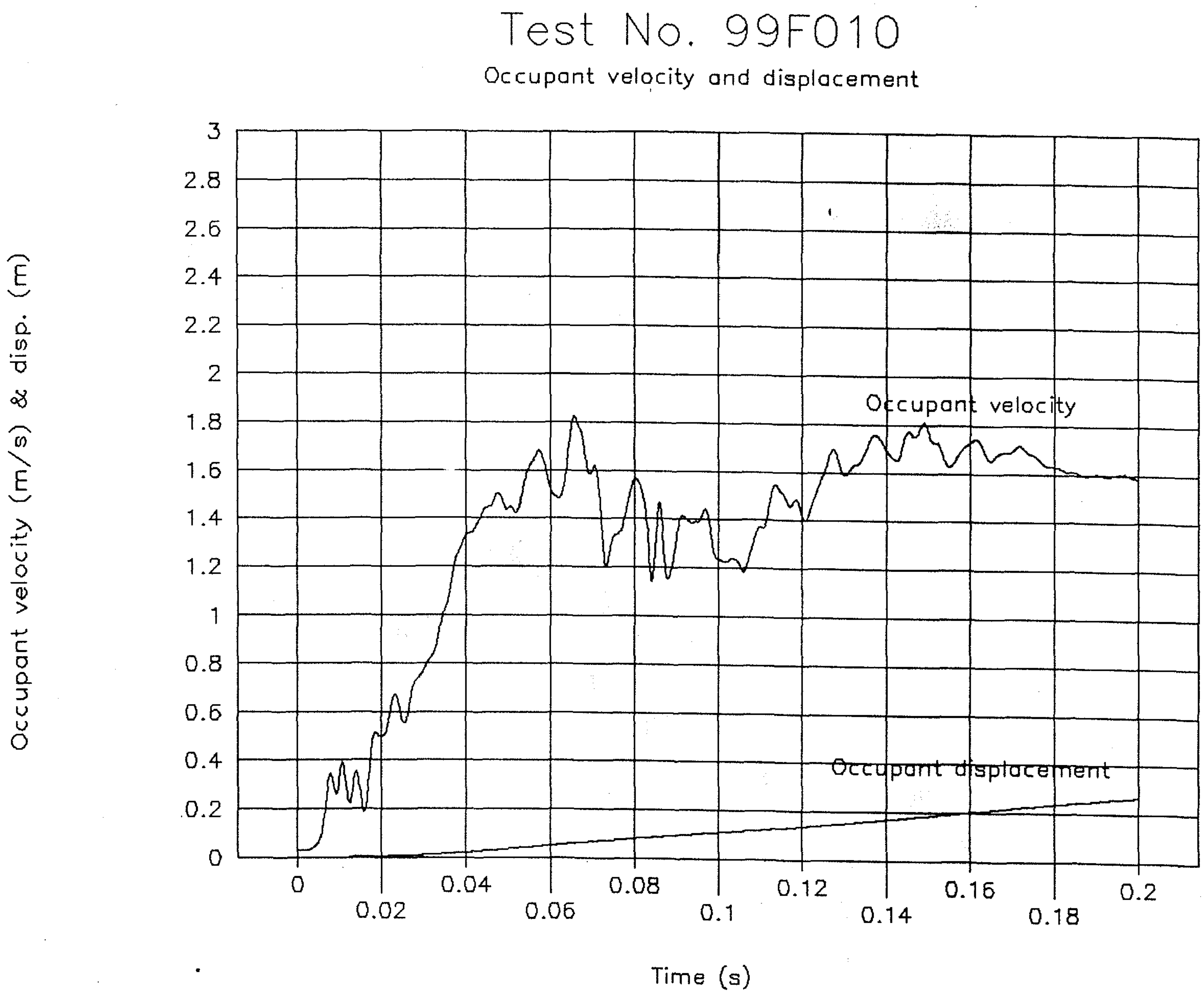

Figure 15. Longitudinal occupant velocity and displacement vs. time, test 99F010.

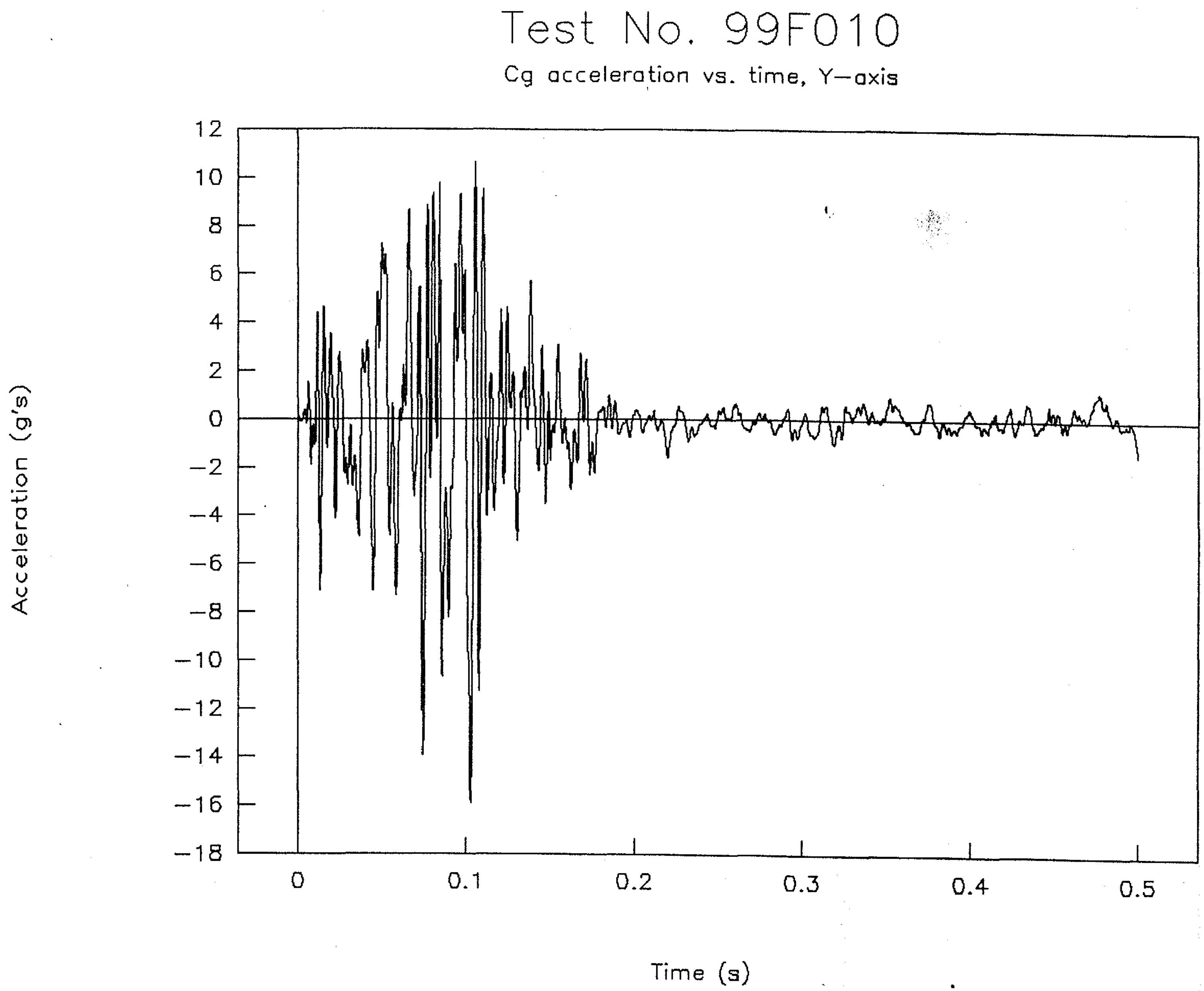

Figure 16. C.g. acceleration vs. time, Y-axis, test 99F010.

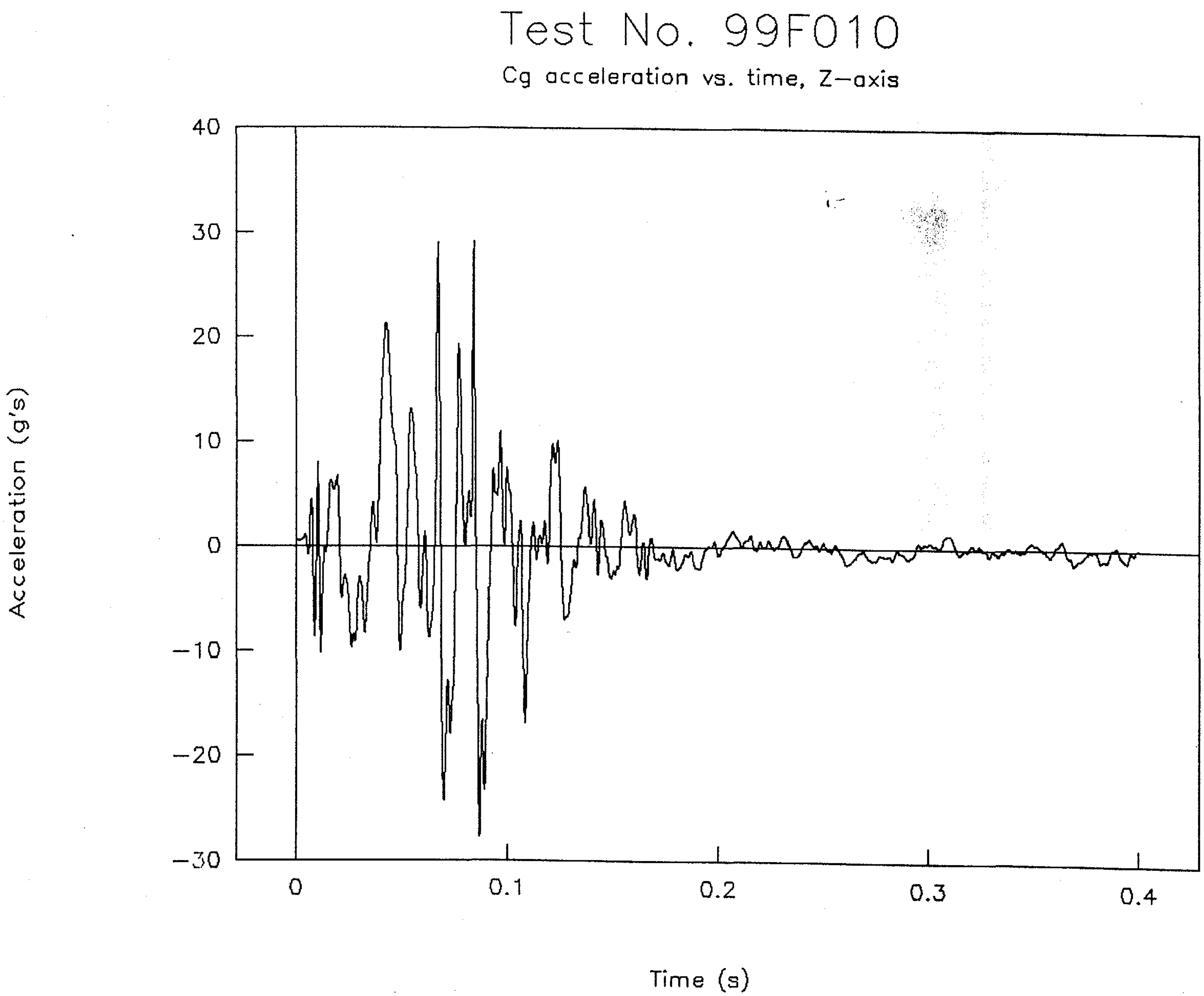

Figure 17. C.g. acceleration vs. time, Z-axis, test 99F010.

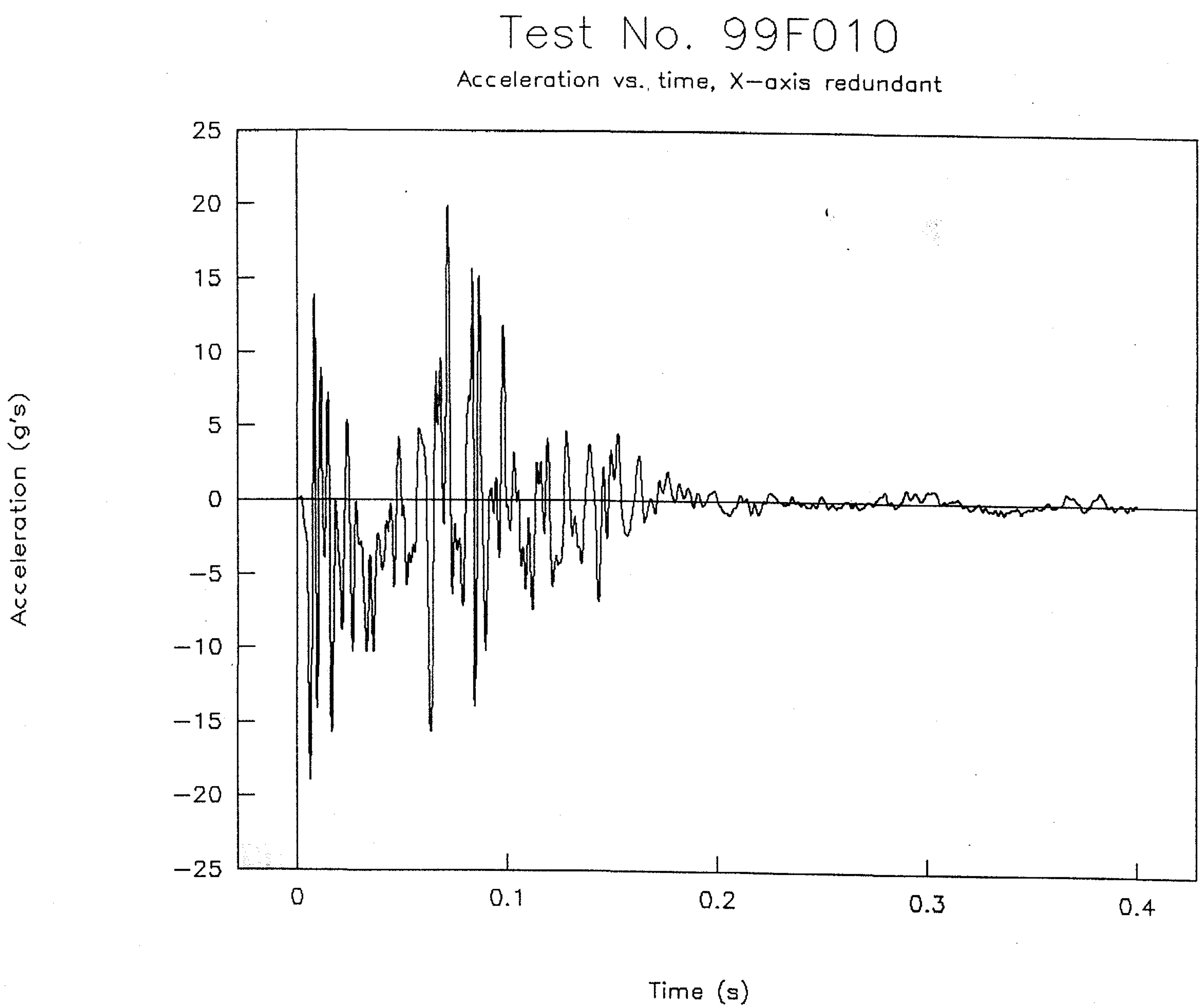

Figure 18. C.g. acceleration vs. time, X-axis redundant, test 99F010.

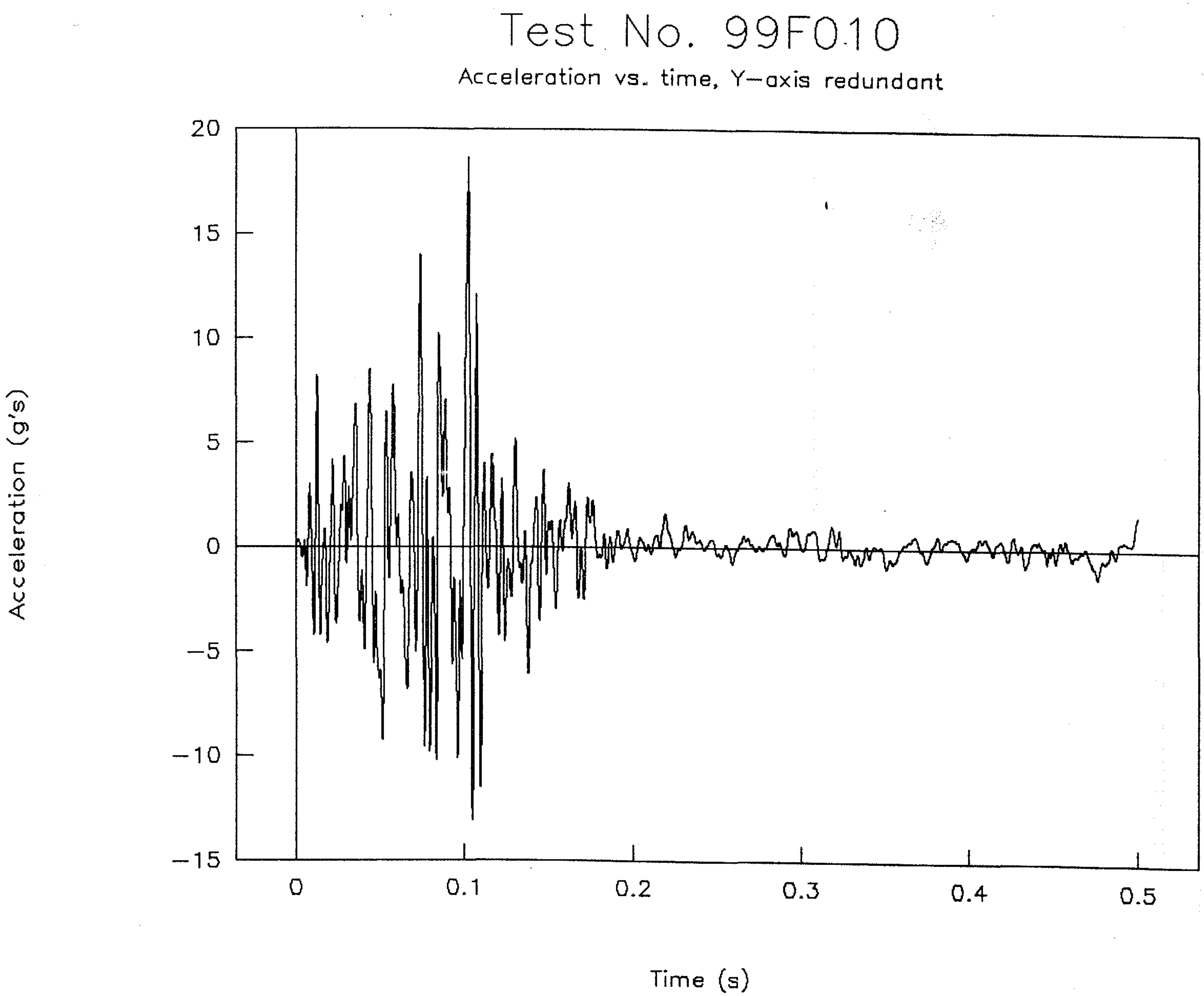

Figure 19. C.g. acceleration vs. time, Y-axis redundant, test 99F010.

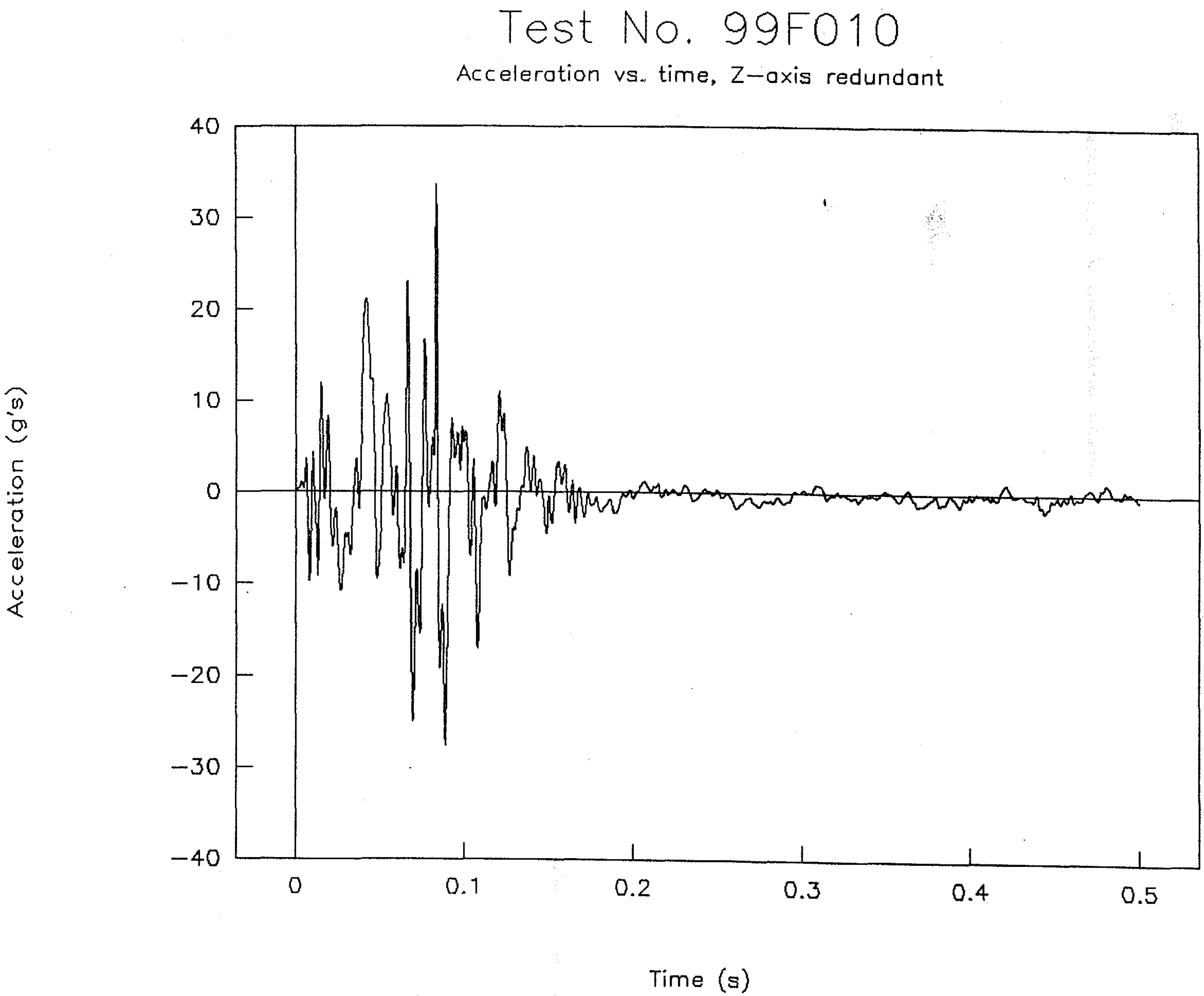

Figure 20. C.g. acceleration vs. time, Z-axis redundant, test 99F010.

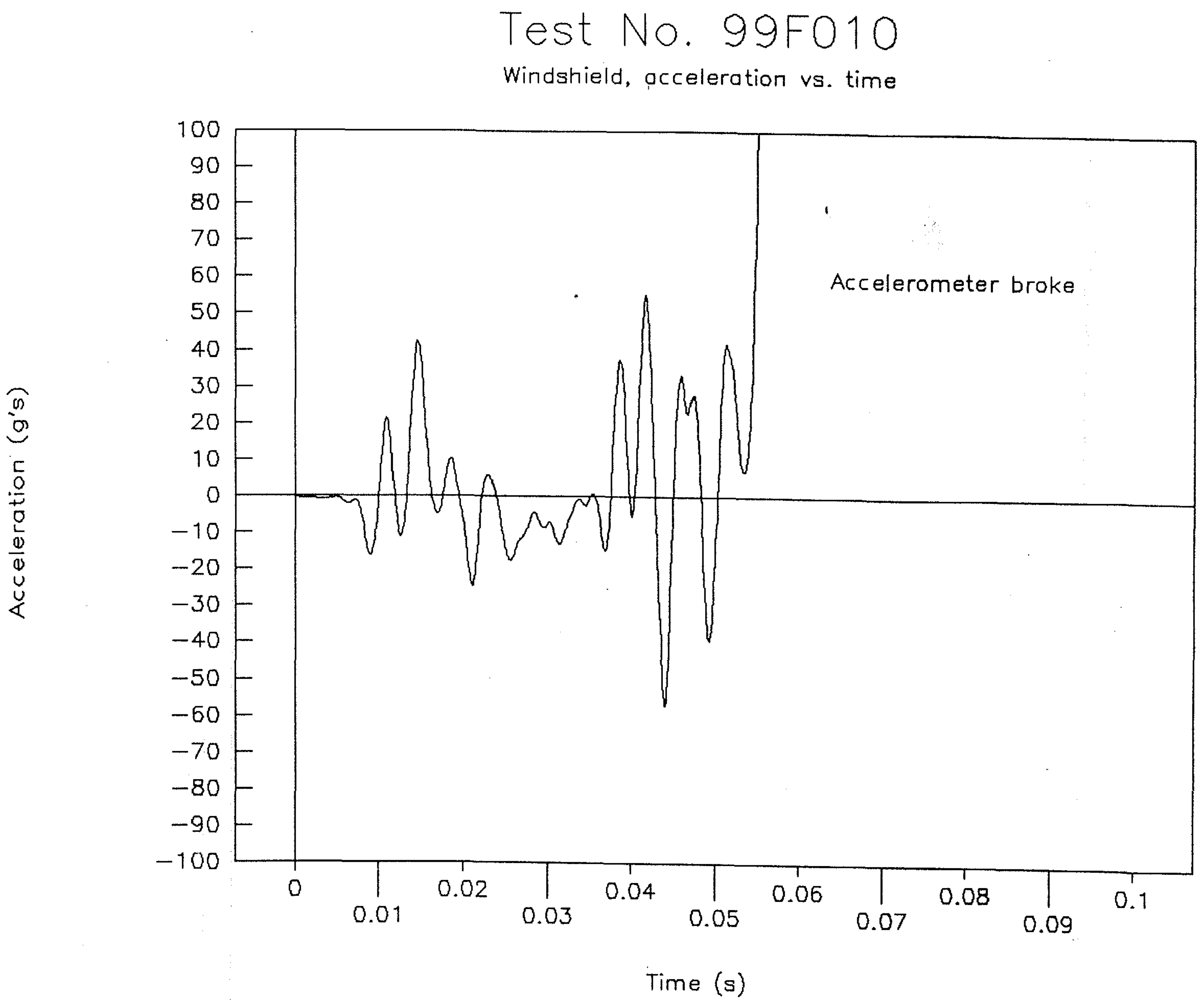

Figure 21. Windshield accelerometer, acceleration vs. time, test 99F010.

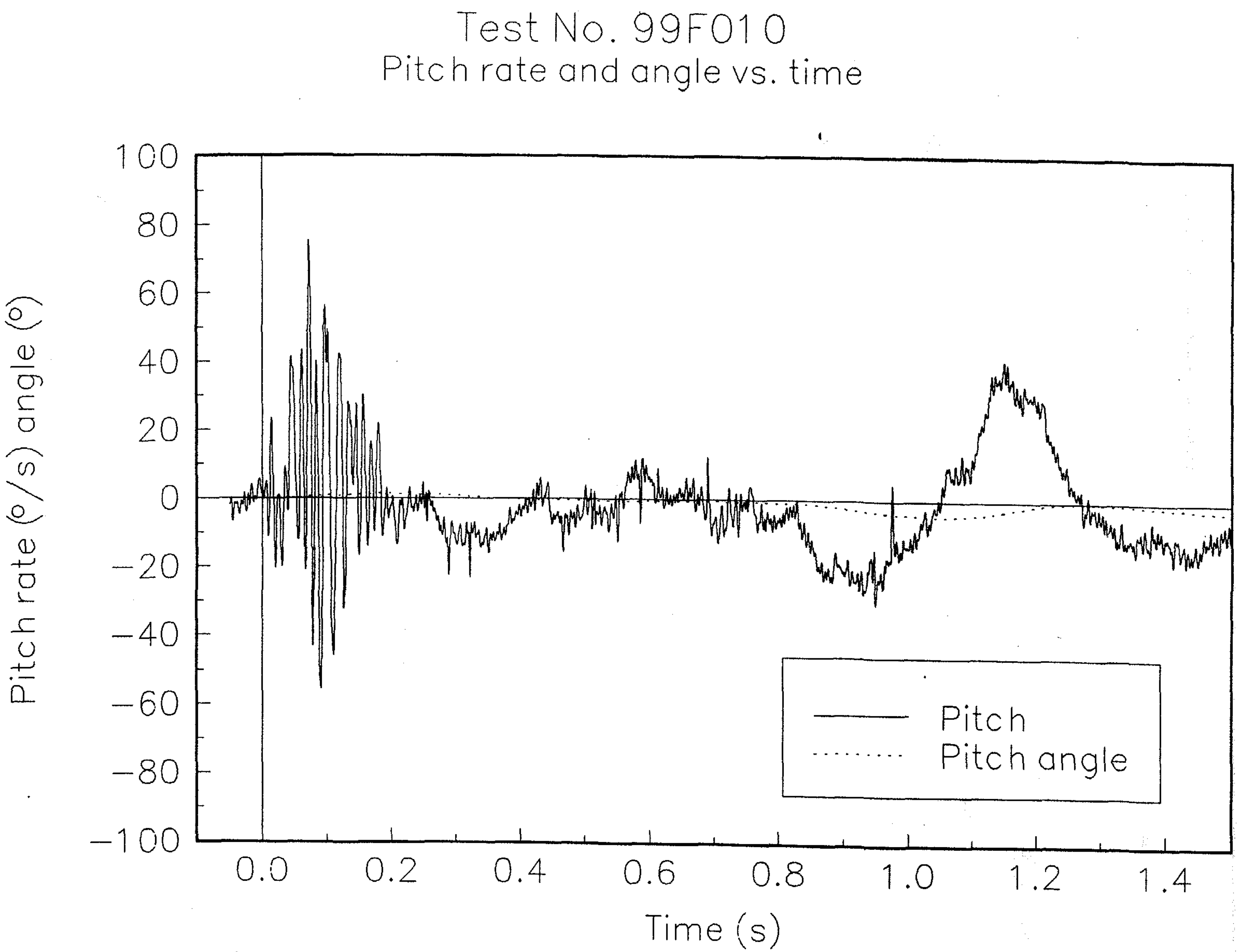

Figure 22. Pitch rate and angle vs. time, test 99F010.

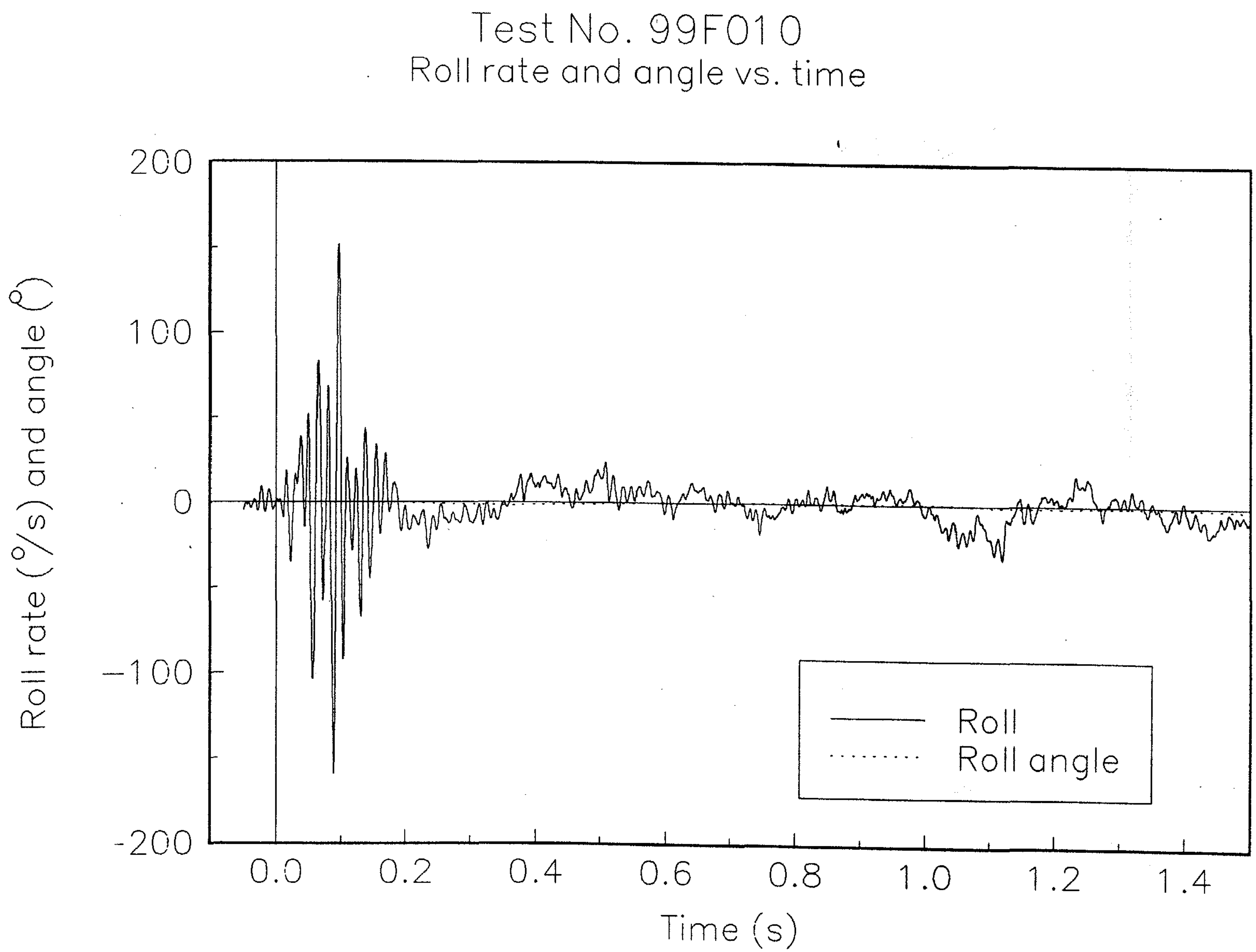

Figure 23. Roll rate and angle vs. time, test 99F010.

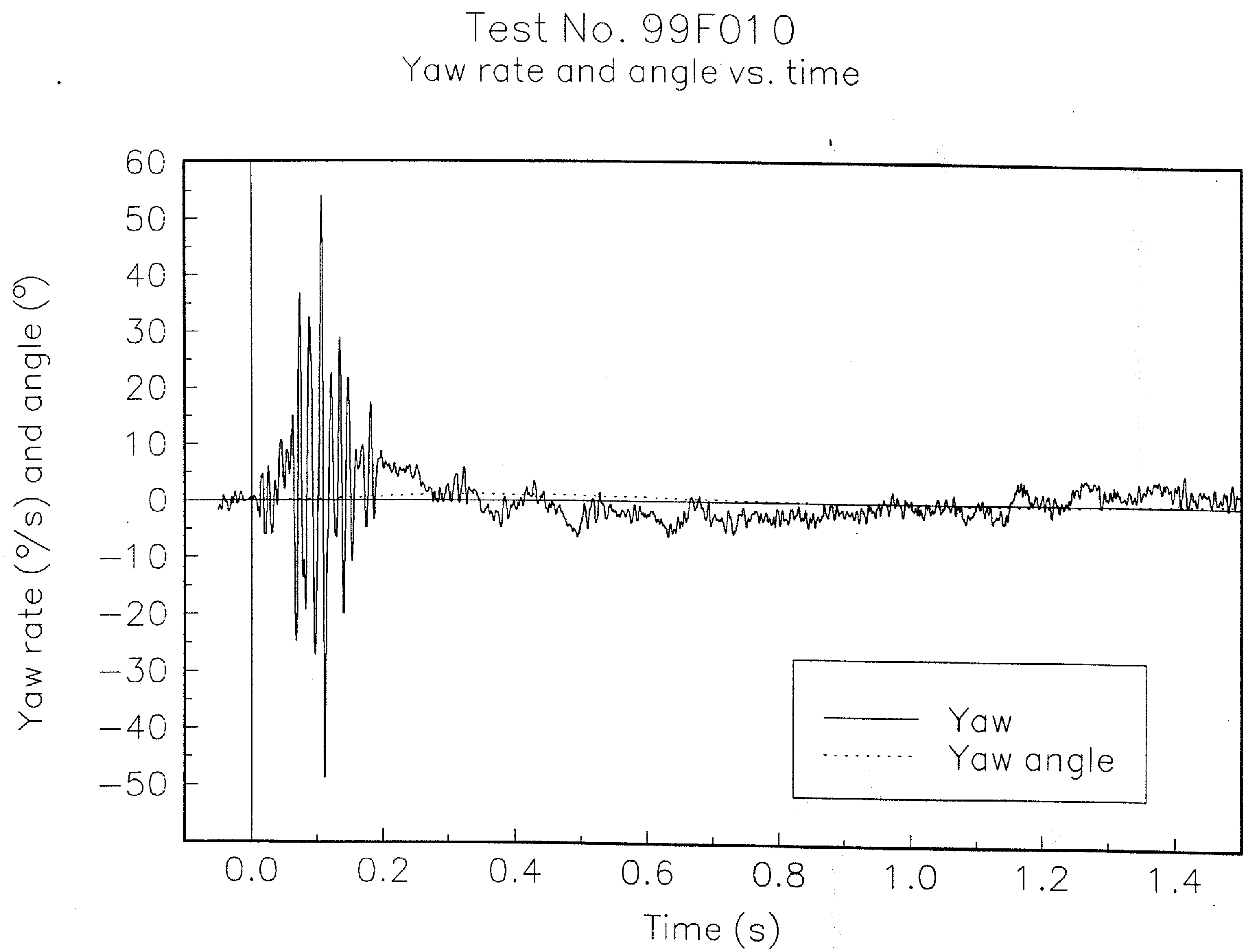

Figure 24. Yaw rate and angle vs. time, test 99F010.

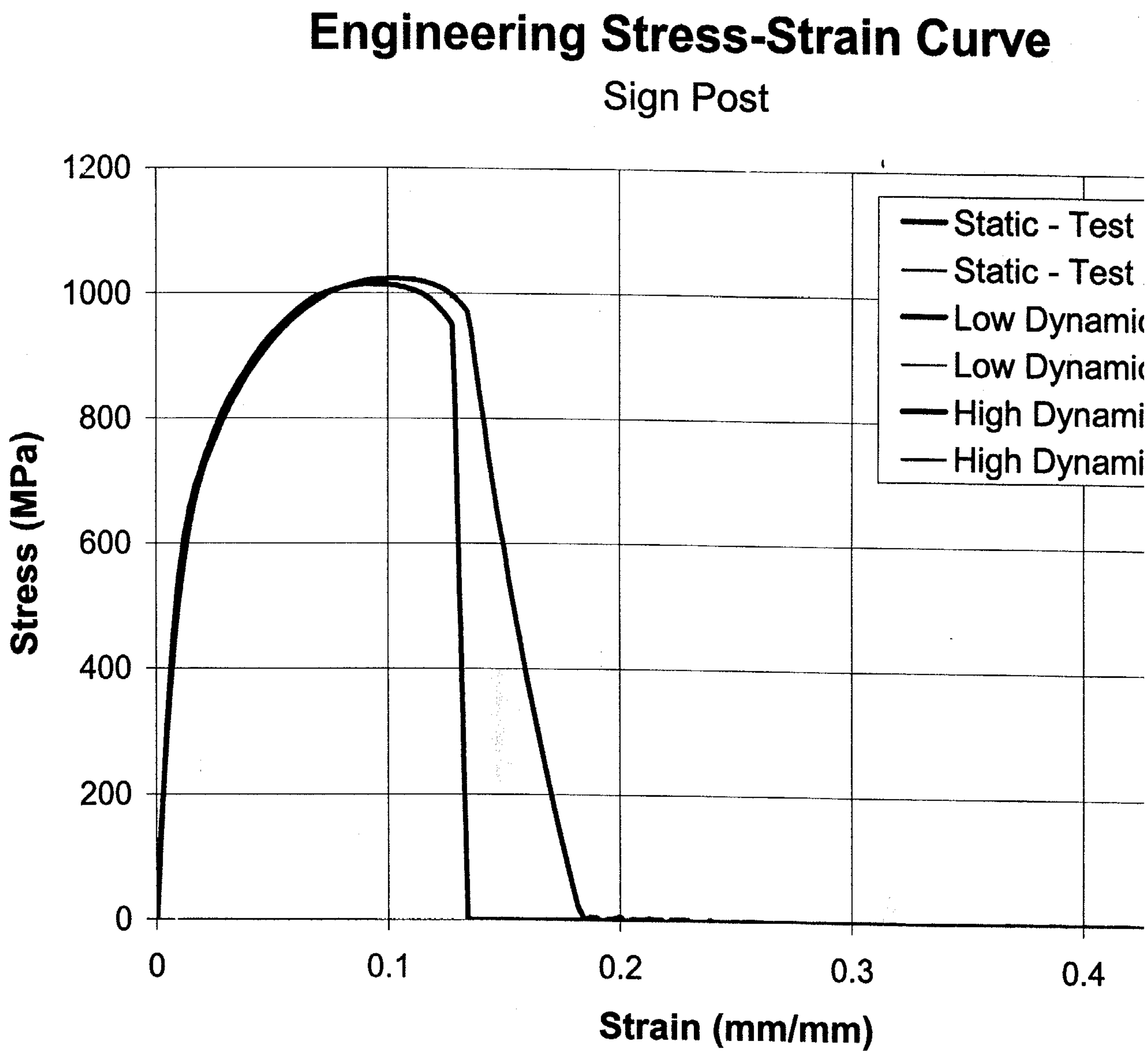

Figure 25. Engineering stress-strain curve for tested sign post,

REFERENCE

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