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16. Abstract

FHWA recently adopted new performance evaluation guidelines for roadside safety features set forth in NCHRP Report 350. Most of the existing roadside features were tested according to the previous guidelines contained in NCHRP Report 230 and there are concerns as to how the existing roadside safety features would perform under the new guidelines. Specifically, there is concern that existing bridge railing systems, including the 1.07-m vertical wall bridge railing, may not perform satisfactorily to contain and redirect the 36000V test vehicle, i.e. 36 000-kg tractor/van trailer, and the vehicle may roll over.

In a previous study conducted by the Texas Transportation Institute, a 22 680-kg tractor/van trailer steered around the end of a 1.07-m vertical wall bridge railing and rolled onto its side. In order to determine if a longer installation would prevent this from happening, the bridge railing was extended from 30 m to a total length of 40 m. There were also questions about the strength of the bridge railing and the strength of its connection to the deck.

This report contains the results of a crash test performed on the 1.07-m vertical wall bridge railing with a 36000V test vehicle under NCHRP Report 350 test level 5 conditions, i.e., impacting the length of need at a nominal speed and angle of 80 km/h and 15 degrees. The purpose of the test was to determine if the bridge railing would perform satisfactorily in containing and redirecting the heavy vehicle without rolling the vehicle.

The impact performance of the 1.07-m vertical wall bridge railing was considered satisfactory according to evaluation criteria set forth in NCHRP Report 350 for test designation 5-12. The 36000V vehicle did not roll after exiting the longer installation as the 22 680-kg tractor/van trailer did on the 30-m installation used during an earlier study. There was no sign of structural damage in the bridge railing or in the connection of the bridge railing and bridge deck.

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Form DOT F 1700.7 (8-69)

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
		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

NOTE: Volumes greater than 1000 l shall be shown in m^3.

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)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

Figure No. Page

LIST OF TABLES

I. INTRODUCTION

The Federal Highway Administration (FHWA) recently adopted the new performance evaluation guidelines for roadside safety features set forth in National Cooperative Highway Research Program (NCHRP) Report 350.[1] Most of the existing roadside features were tested according to the previous guidelines contained in NCHRP Report 230[2] and there are concerns as to how the existing roadside safety features would perform under the new guidelines. Specifically, there is concern that existing bridge railing systems, including the 1.07-m vertical wall bridge railing, may not perform satisfactorily to contain and redirect the 36000V test vehicle, i.e. 36 000-kg tractor/van trailer, and the vehicle may roll over.

In a previous study conducted by the Texas Transportation Institute, a 22 680-kg tractor/van trailer steered around the end of a 1.07-m vertical wall bridge railing and rolled onto its side.[3] In order to determine if a longer installation would prevent this from happening, the bridge railing was extended from 30 m to a total length of 40 m. There were also questions about the strength of the bridge railing and the strength of its connection to the deck. The 1.07-m vertical wall bridge railing was constructed on a simulated bridge deck.

This report contains the results of a crash test performed on the 1.07-m vertical wall bridge railing with a 36000V test vehicle under NCHRP Report 350 test level 5 conditions, i.e., impacting the length of need at a nominal speed and angle of 80 km/h and 15 degrees. The purpose of the test was to determine if the bridge railing would perform satisfactorily in containing and redirecting the heavy vehicle without rolling the vehicle.

II. STUDY APPROACH

TEST ARTICLE

The 1.07-m vertical wall bridge railing used for this crash test was constructed under a previous study. The total length of the original installation was 30.5 m and was extended to 39.6 m. A cross section of the test installation is shown in figure 1 and photographs of the completed installation are shown in figure 2.

The 1.07-m vertical wall bridge railing is 254 mm thick, with a thickened section of 305 mm at the top. This "beam" along the top edge serves to enhance the longitudinal distribution of forces within the wall and the deck. Two types of vertical reinforcing bars are alternated to provide #5 bars spaced at 152 mm in the traffic face. The collision force used in the design was 685 kN uniformly distributed over a longitudinal distance of 1.07-m at 864 mm above the deck surface.

CRASH TEST CONDITIONS

NCHRP Report 350 Test Designation

The crash test performed on the 1.07-m vertical wall bridge railing was NCHRP Report 350 test designation 5-12, which involves a 36000V test vehicle impacting the length of need section of the bridge railing at a nominal speed and angle of 80 km/h and 15 degrees. The impact point was 5.3 m from the end of the bridge railing. According to NCHRP Report 350, the purpose of test 5-12 is to evaluate the strength of the section in containing and redirecting the heavy test vehicle.

NCHRP Report 350 Evaluation Criteria

The crash test performed was evaluated in accordance with the criteria presented in NCHRP Report 350. As stated in NCHRP Report 350, "Safety performance of a highway appurtenance cannot be measured directly, but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of NCHRP Report 350 were used to evaluate the crash test reported herein:

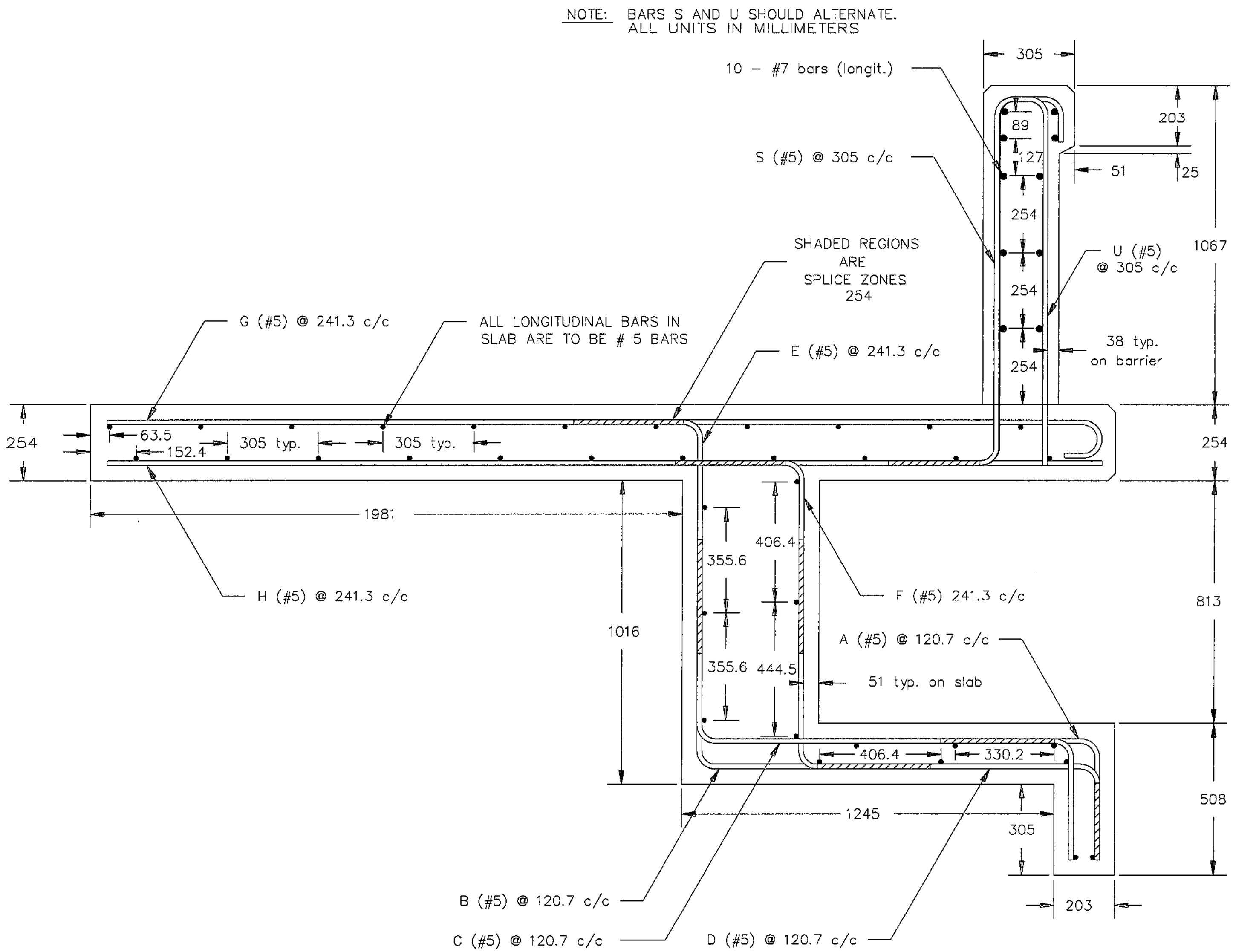


Figure 1. Details of the 1.07-m vertical wall bridge railing installation.

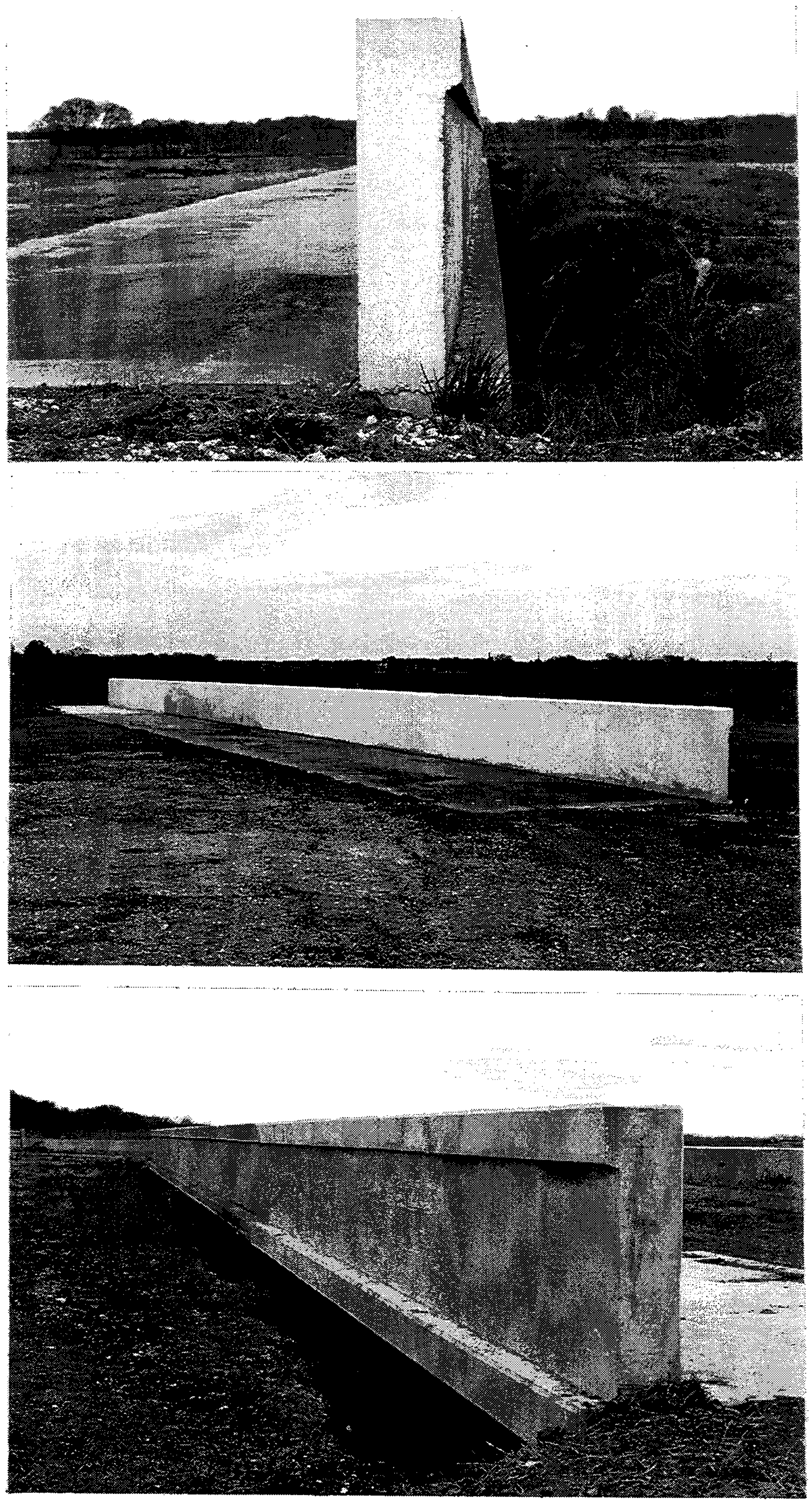


Figure 2. The 1.07-m vertical wall bridge railing installation before test 405511-2.

- **Structural Adequacy**

  A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.

- **Occupant Risk**

  D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

  G. It is preferable, although not essential, that the vehicle remain upright during and after the collision.

- **Vehicle Trajectory**

  K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

  M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.

CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 350. Brief descriptions of these procedures are presented as follows:

Electronic Instrumentation and Data Processing

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; triaxial accelerometers at the tractor center of gravity, at the fifth wheel location, and at the trailer center of gravity to measure longitudinal, lateral, and vertical acceleration levels; and two string potentiometers to measure longitudinal and vertical acceleration levels of the right front wheel. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, was received at the data acquisition station and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer for analysis and evaluation of impact performance.

The test vehicle was also instrumented with 11 uniaxial accelerometers mounted in the following locations: (1) center top surface of the instrument panel to measure longitudinal acceleration; (2) inside end of the tractor's right front wheel spindle to measure lateral acceleration; (3) top of engine block to measure longitudinal acceleration; (4) inside end of the tractor's right rear wheel spindle to measure longitudinal and lateral accelerations; (5) inside end of the tractor's left rear spindle to measure longitudinal accelerations; (6) on the frame of the rear bogie of the trailer to measure longitudinal, lateral, and vertical accelerations; and (7) on the rear axle of the trailer to measure longitudinal and lateral accelerations. The exact location of each accelerometer and potentiometer was measured and is reported in table 1. The accelerometers were ENDEVCO Model 7264A low-mass piezoresistive accelerometers with a ±2000-g range.

The data from the uniaxial accelerometers were captured using a Prosig P4000 data acquisition system. The P4000 is a modular, distributed data acquisition system based on independent data collection elements called PODs (Prosig Onboard Data System). Each POD has four high-speed analog, three digital, and time-zero inputs. The PODs sample synchronously at up to 10,000 samples per second per channel, with 12-bit resolution. Non-volatile memory holds up to 13 s at the maximum data rate. Analog inputs have integral, strain gauge accelerometer signal conditioning and anti-aliasing filters. Each channel has a fully programmable amplifier and input offset adjustment. After extracting the data from the POD units to the host computer, fourth order, Bessel, digital filtering is used to produce SAE J211 data for processing. Data capture is started by a trigger pulse from a bumper switch or a predefined g level. Twenty-five percent of the captured data is prior to the trigger signal.

Table 1. Locations of vehicle accelerometers for test 405511-2.

Location	X (mm) (distance from front axle)	Y (mm) (distance from centerline)	Z (mm) (distance from ground)	Data Axis
Instrument panel	-1200	0	-2230	+X
Right front wheel spindle	0	+900	-670	+X
Top of engine block	+155	0	-1540	+X
Right rear tractor brake	-5540	+680	-580	+X,-Y
Left rear tractor brake	-5540	-680	-580	+X
Rear trailer bogie	-15240	0	-1020	+X,+Y,+Z
Rear trailer axle	-15940	0	-590	+X,-Y
Tractor c.g.	-2670	0	-800	+X,+Y,+Z
Fifth wheel	-4920	0	-1000	+X,+Y,+Z
Right front tractor axle - string potentiometers	+140	+580	-420	+X,+Z
Trailer c.g.	+8390	0	-1230	+X,+Y,+Z

c.g. = center of gravity

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions of the functions of these two computer programs are provided as follows:

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60-Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (QUATTRO PRO).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067-s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system, with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; another placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure- sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

Test Vehicle Propulsion and Guidance

The test vehicle was directed into the test installation using a remote control guidance system. Immediately prior to impact, fuel to the engine was shut off and the test vehicle steering was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

III. CRASH TEST RESULTS

TEST 405511-2

A 1983 Freight Liner tractor with a 1984 Great Dane van trailer, shown in figures 3 and 4, was used for the crash test. The empty weight of the tractor/van trailer was 13 893 kg, and its test inertia weight was 36 000 kg. The height to the lower edge of the vehicle bumper was 410 mm and it was 800 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 5. The vehicle was directed into the installation using a remote control guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Test Description

The speed of the vehicle at impact was 80.1 km/h, and the angle of impact was 14.5 degrees. The vehicle impacted the vertical wall bridge railing 5.3 m from the upstream end. At 0.142 s, the tractor started to redirect, and at 0.154 s, the right front tire deflated. The right rear tractor tires contacted the vertical wall at 0.201 s and the left front tire left the ground. At 0.219 s, the rear of the tractor and the trailer began to redirect, and at 0.283 s, the right side of the van split. Both rear tractor tires lost contact with the ground at 0.309 s. The left front tire regained contact with the ground at 0.422 s and the tire blew out at 0.543 s. The rear of the trailer contacted the vertical wall at 0.767 s as the vehicle was traveling at 68.7 km/h. The vehicle continued riding along the vertical wall bridge railing and off the end. The vehicle subsequently came to rest 61 m down and slightly behind the vertical wall bridge railing. Sequential photographs of the test period are shown in figures 6 and 7.

Damage to Test Installation

Damage to the vertical wall bridge railing was mostly cosmetic, as shown in figures 8 and 9. There were tire marks and gouging all along the face of the bridge railing. Some spalling of concrete along the top of the bridge railing was caused as the van trailer rode along the top. The total length of contact of the vehicle with the bridge railing was 34.6 m. There was no structural damage to the connection with the bridge deck.

Vehicle Damage

Most of the damage to the vehicle was to the right side, as shown in figures 10 and 11. The following items were damaged on the tractor: the right front springs, U-bolts, mounts, shocks, and steering linkages; the right rear springs and mounts; the front axle; the right side fuel tank and mounts; the right side tires and rims; and the bumper, fan, radiator,

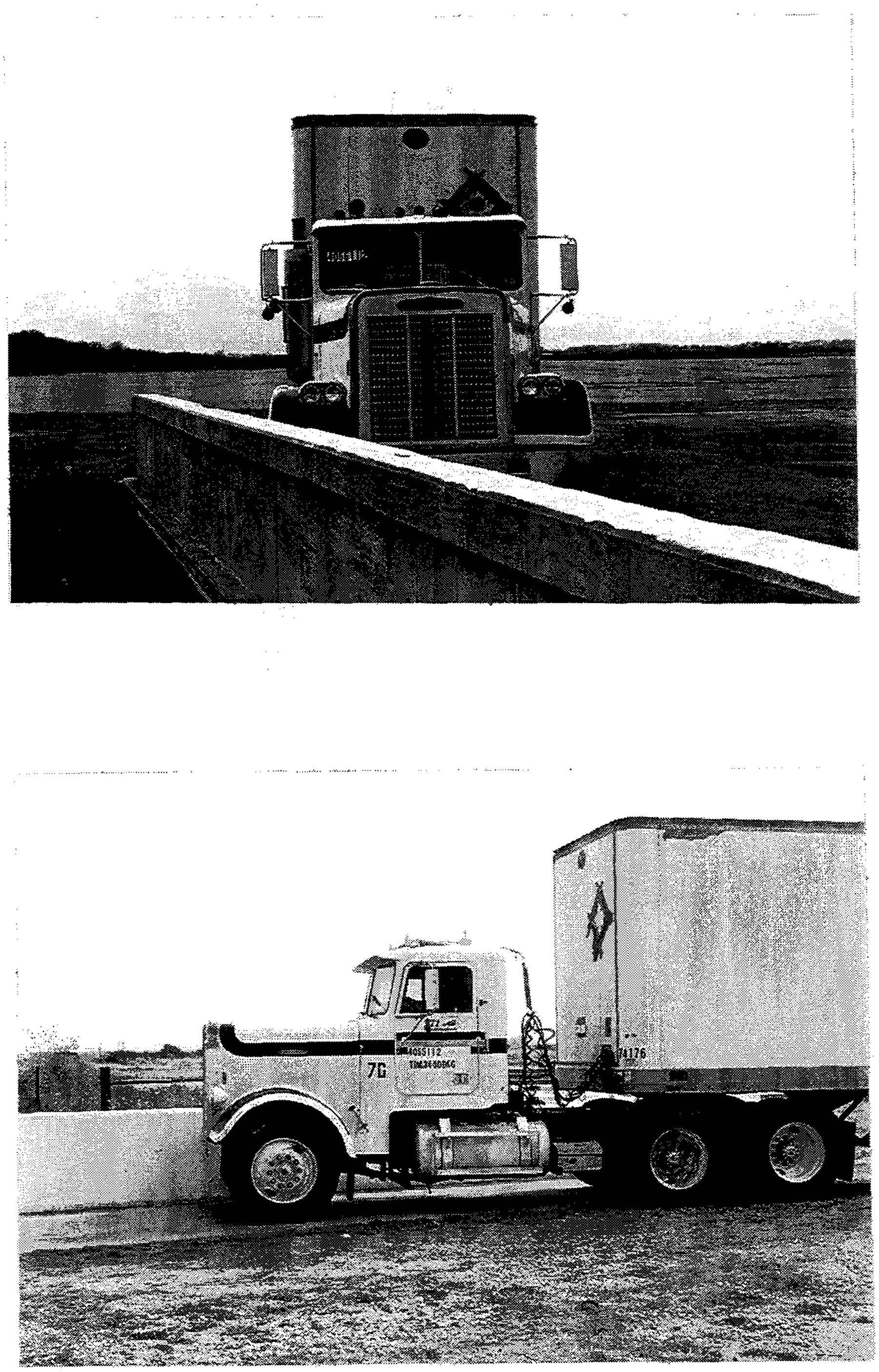


Figure 3. Vehicle/installation geometrics for test 405511-2.

Figure 4. Vehicle before test 405511-2.

DATE: 12-12-95 TEST NO.: 405511-2

TRACTOR:

YEAR: 1983 MAKE: Freight Liner MODEL:

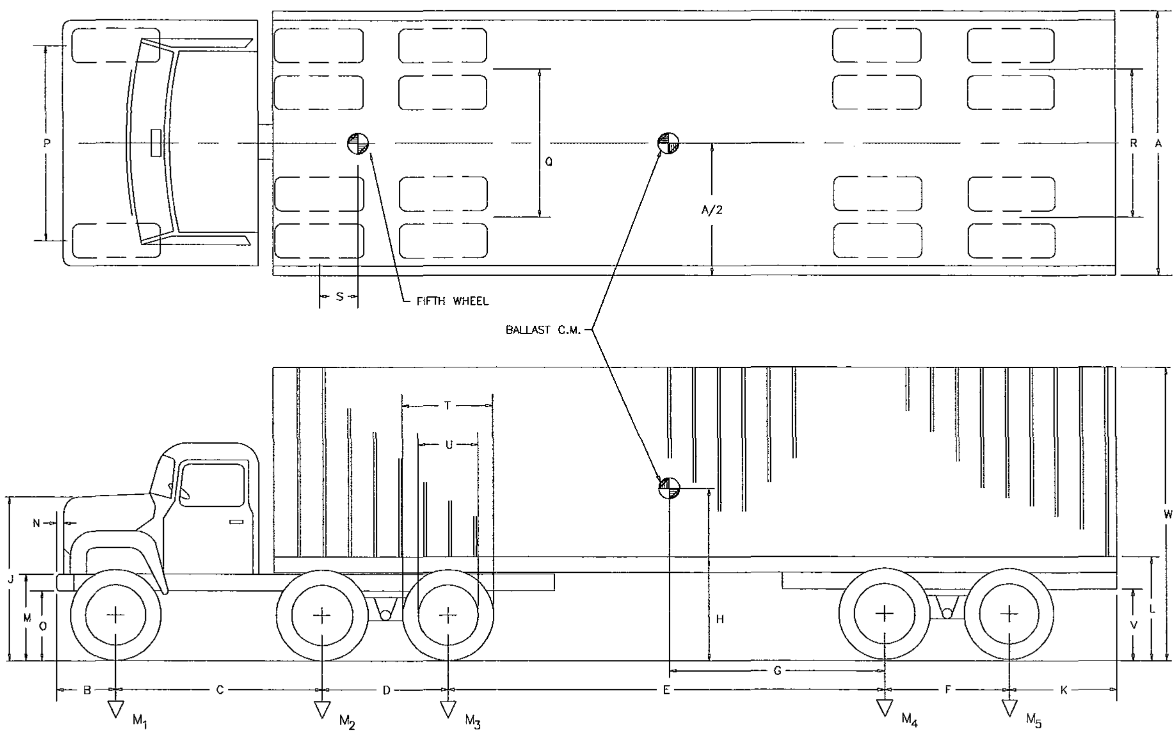
VIN NO.: 1FUPYB4DP223978 ODOMETER: 328144

TRAILER:

YEAR: 1984 MAKE: Great Dane MODEL: 7310TL45

VIN NO.: 1GRFA9024FS068401

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

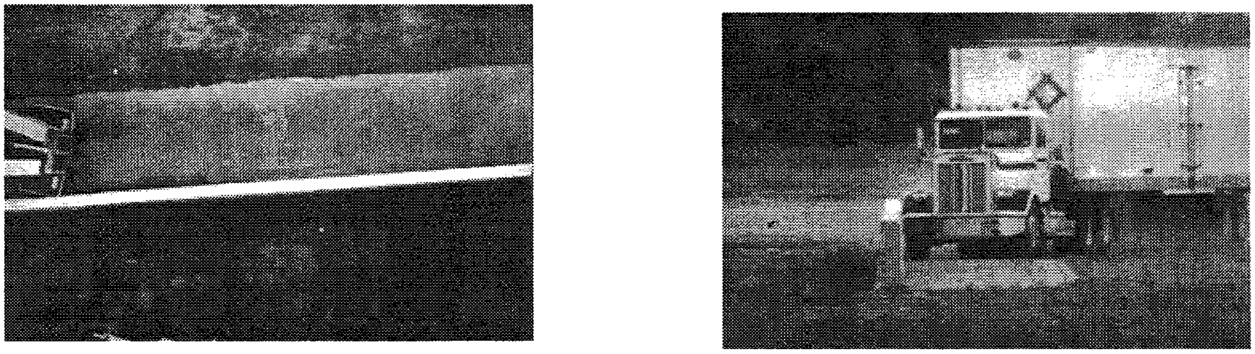


GEOMETRY – (mm)

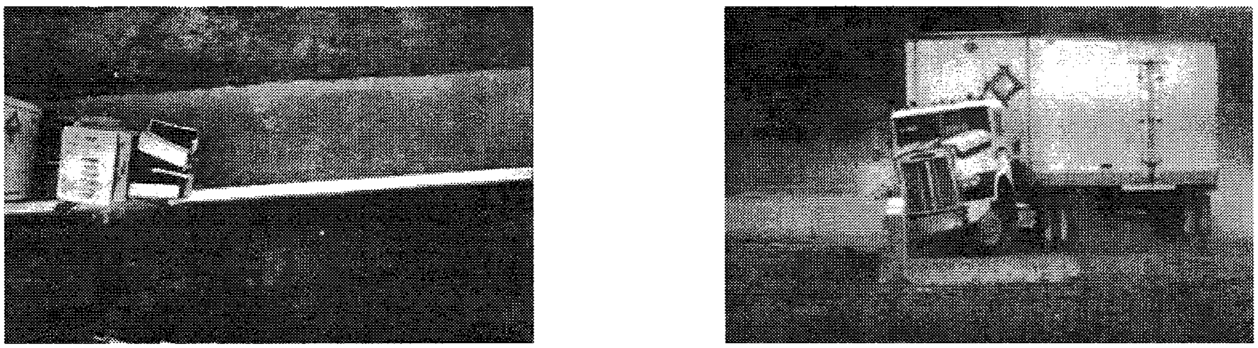
A 2590	D 1350	G 6064.5	K 1280	N 0	Q 1910	T 1120
B 660	E 9205	H 1828	L 1320	O 410	R 2010	U 640
C 4040	F 1210	J 1900	M 800	P 2010	S 270	V 950
W 4000						

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	3924	5085	
M_2	2635	8015	
M_3	2998	7520	
M_4	1710	7351	
M_5	2626	8029	
M_T	13893	36000	

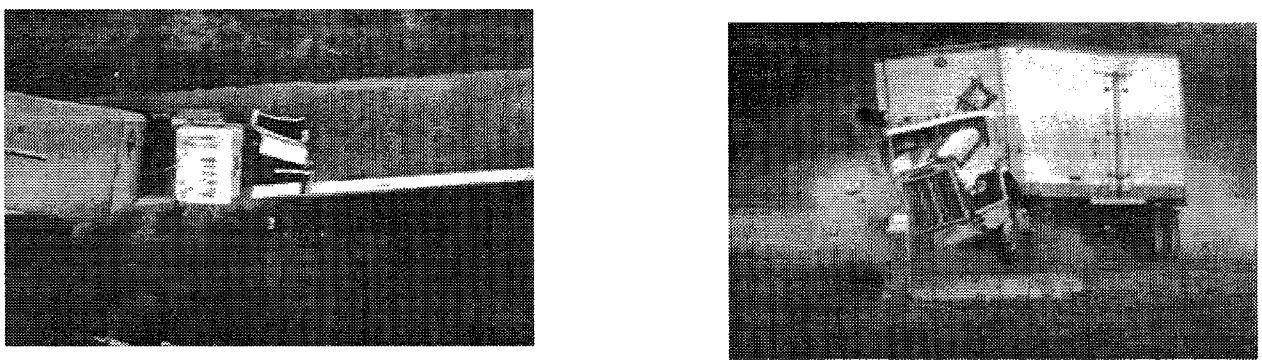
Figure 5. Vehicle properties for test 405511-2.



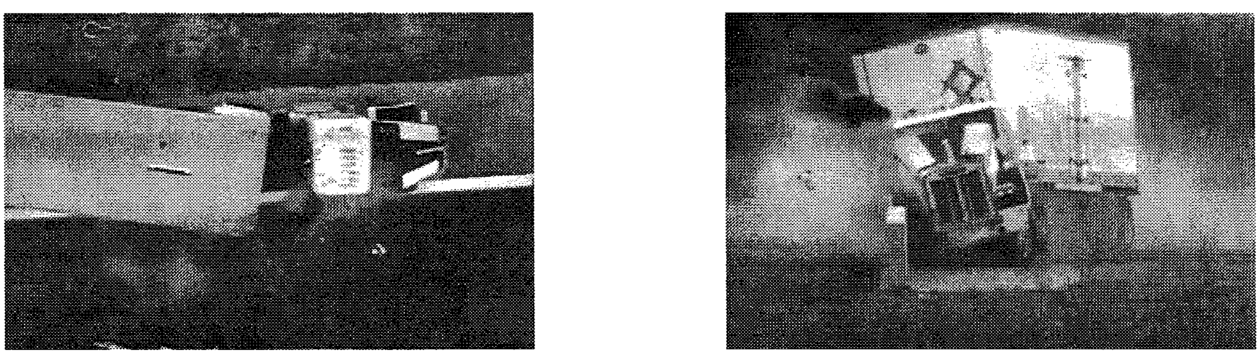
0.000 s



0.156 s

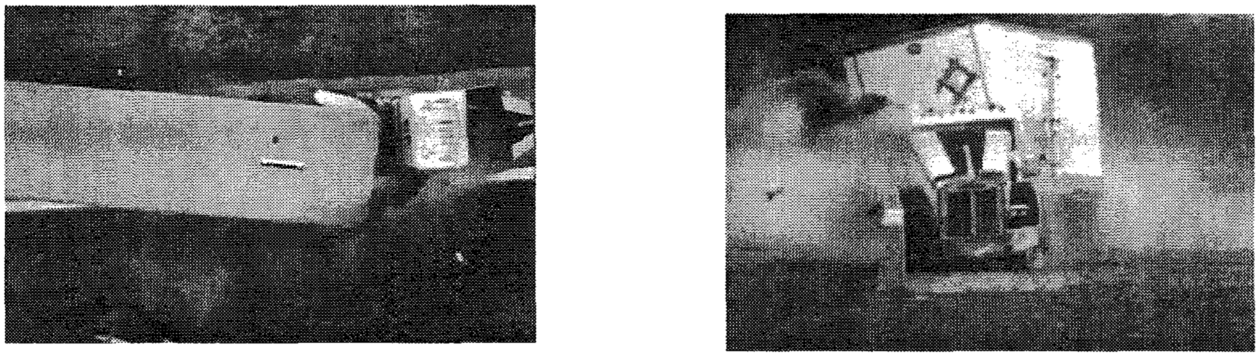


0.289 s

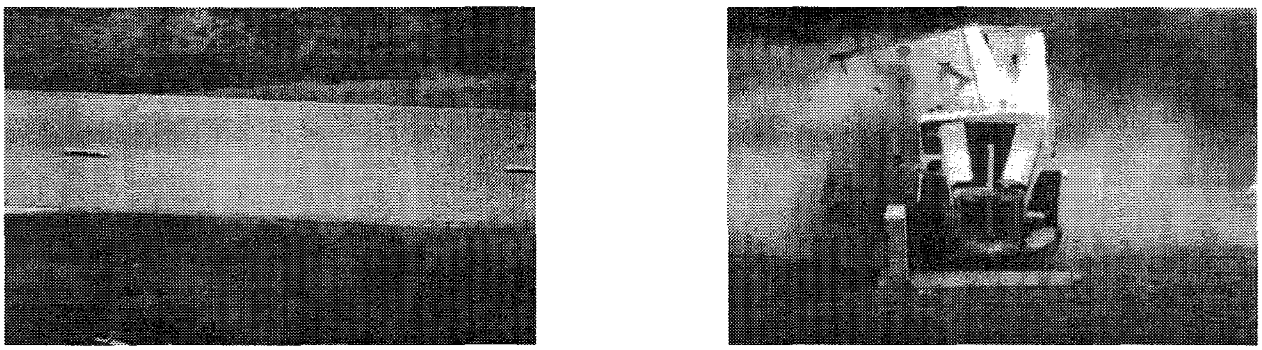


0.440 s

Figure 6. Sequential photographs for test 405511-2
(overhead and frontal views).



0.553 s



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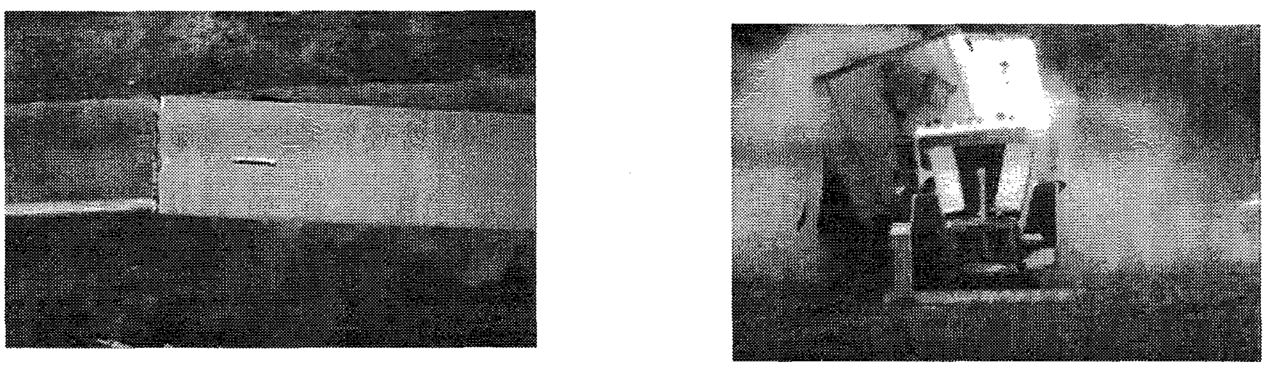

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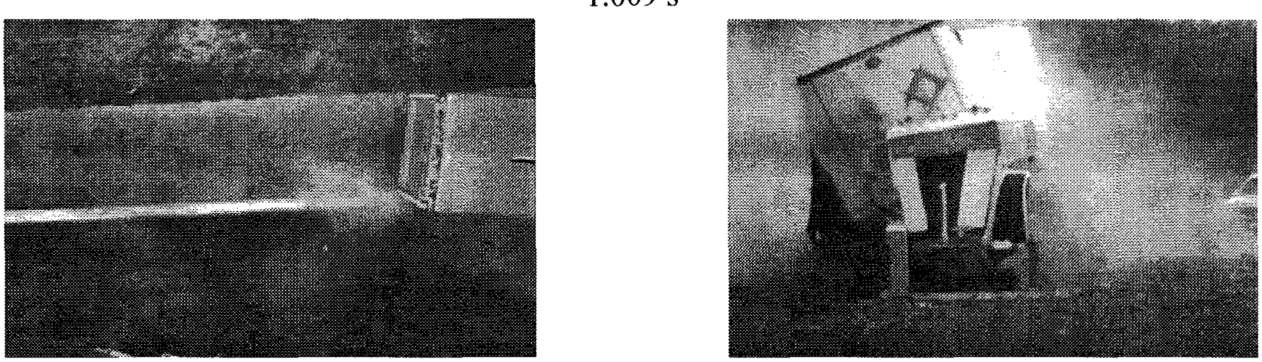
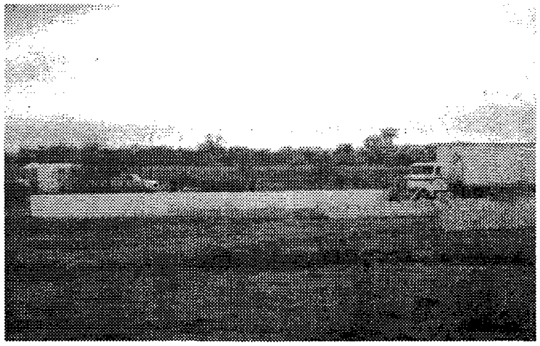
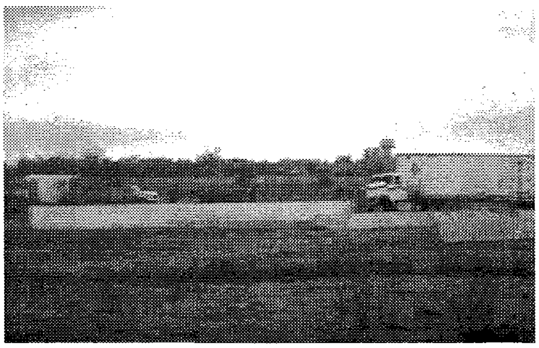


1.346 s

Figure 6. Sequential photographs for test 405511-2
(overhead and frontal views) (continued).



0.000 s



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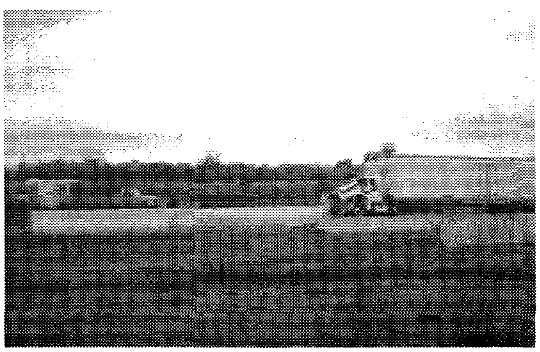

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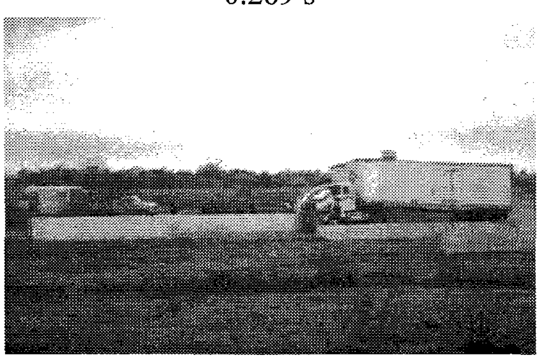

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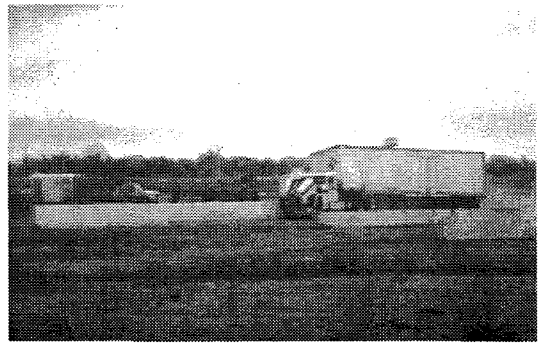

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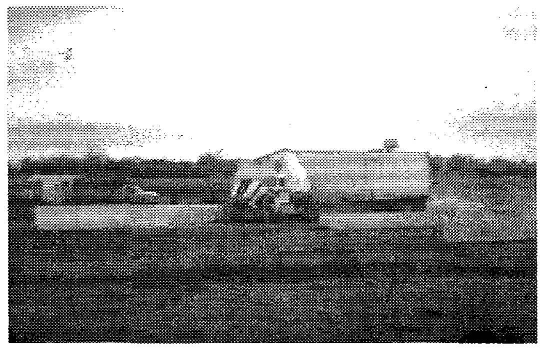

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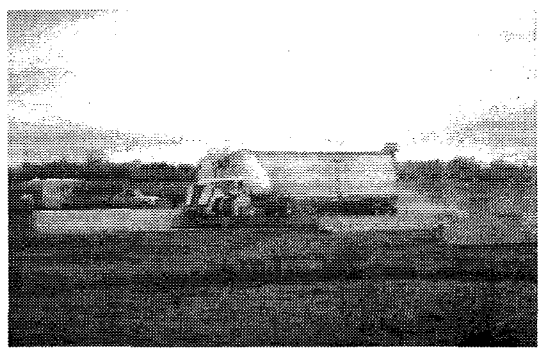

1.011 s

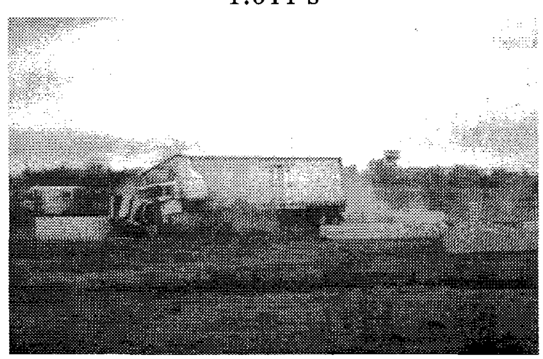

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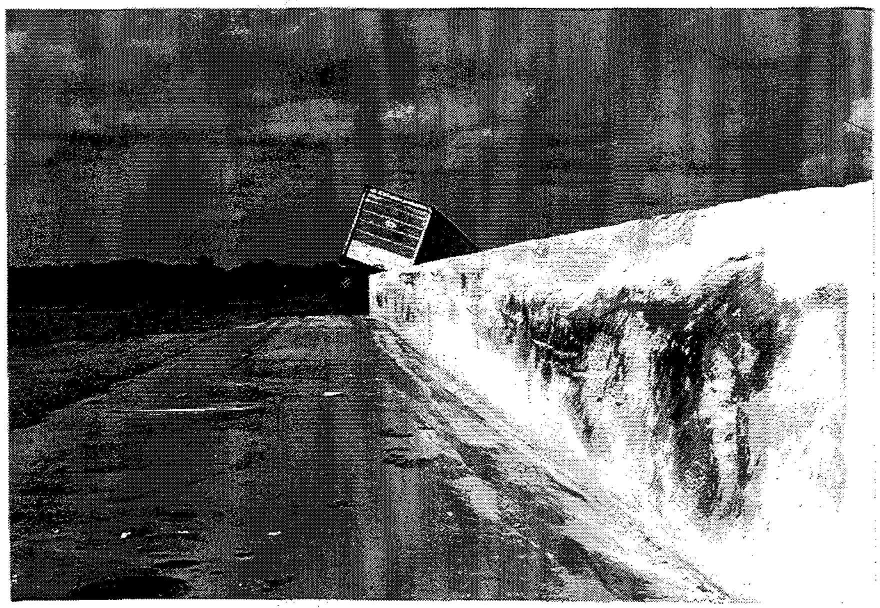
Figure 7. Sequential photographs for test 405511-2
(oblique view).



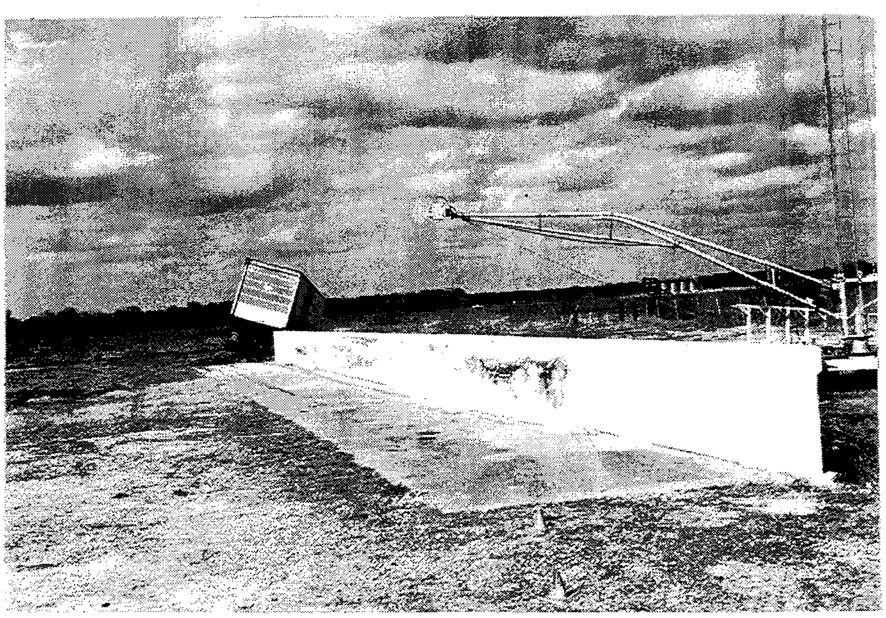


Figure 8. After-impact trajectory for test 405511-2.

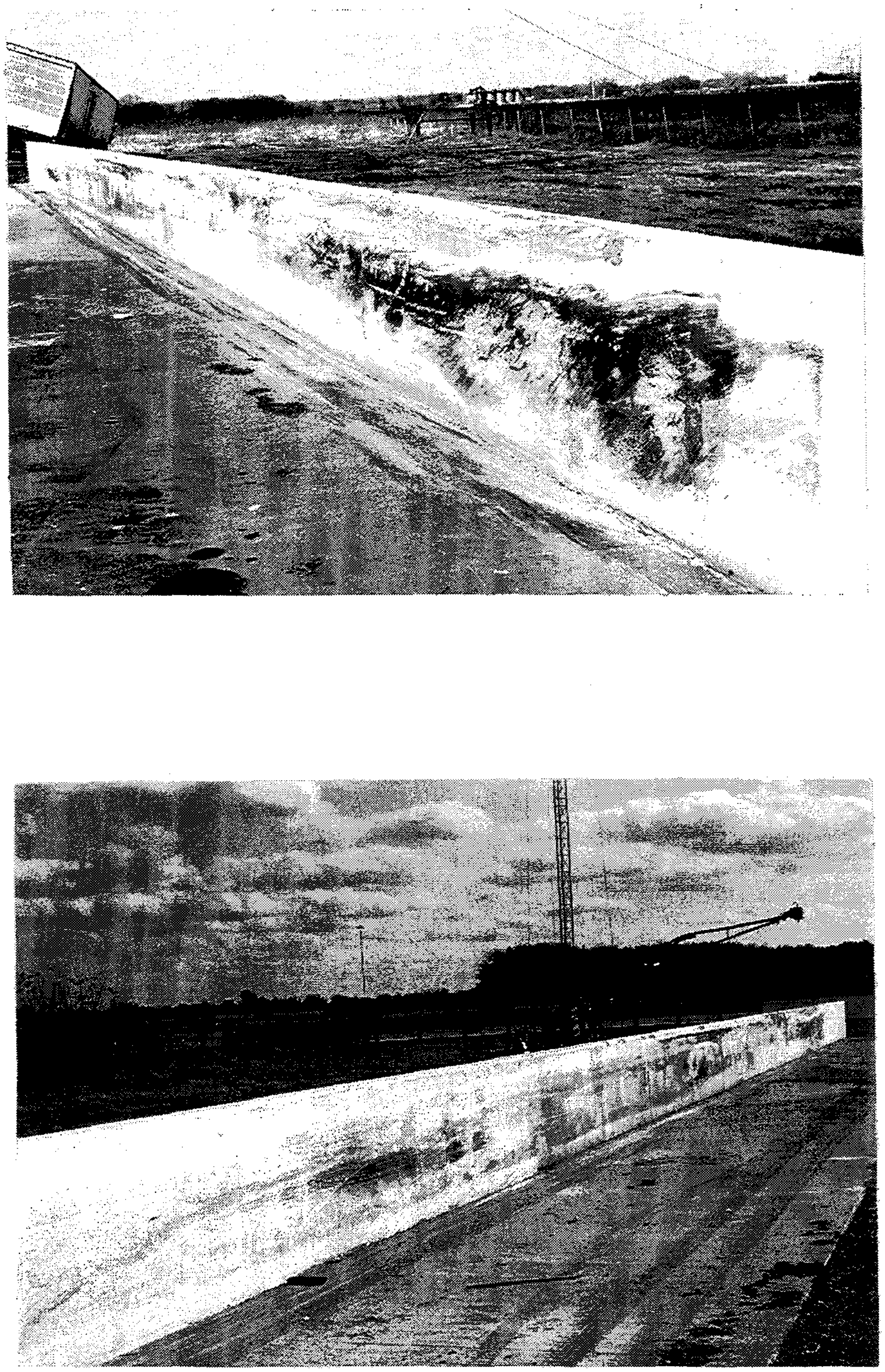


Figure 9. Installation after test 405511-2.

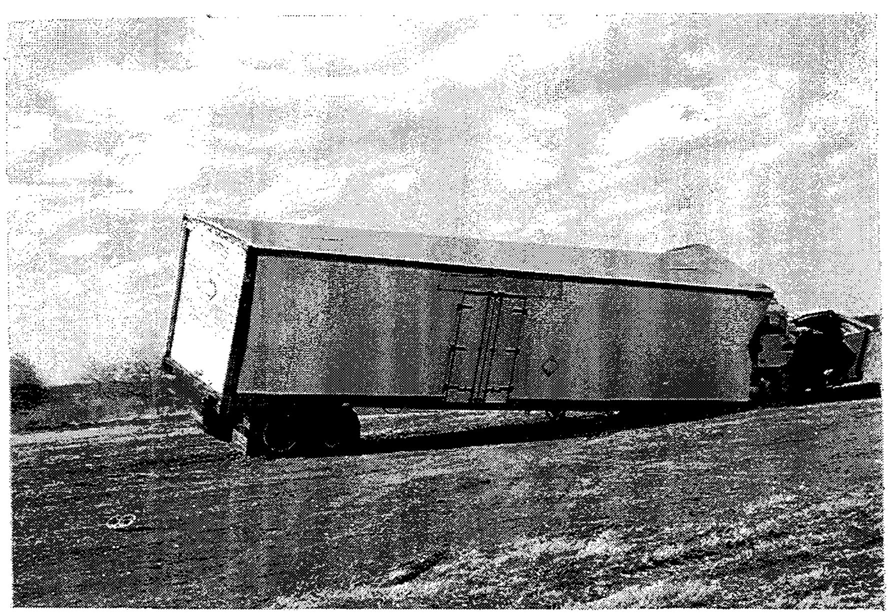


Figure 10. Right side of vehicle after test 405511-2.

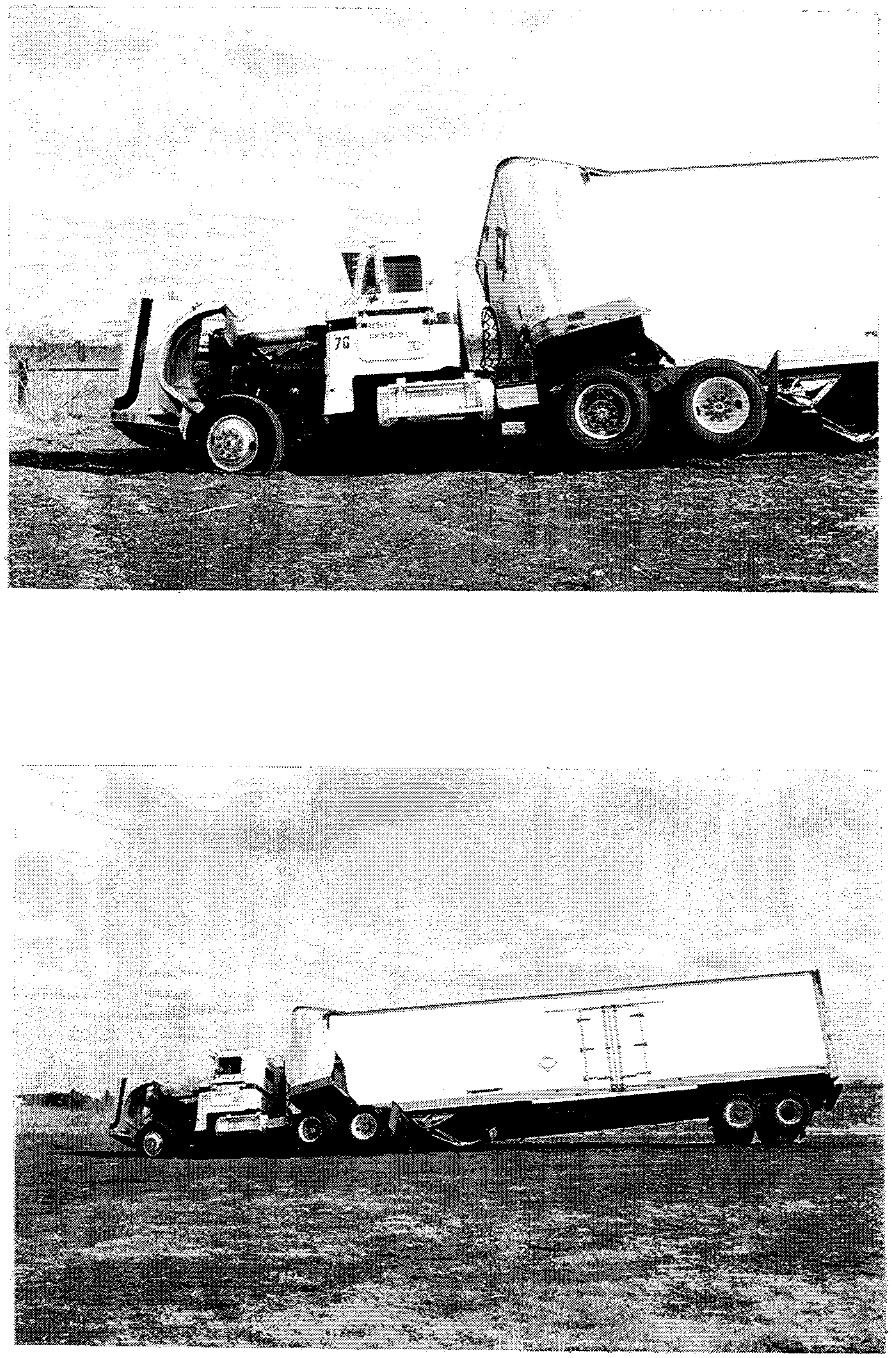
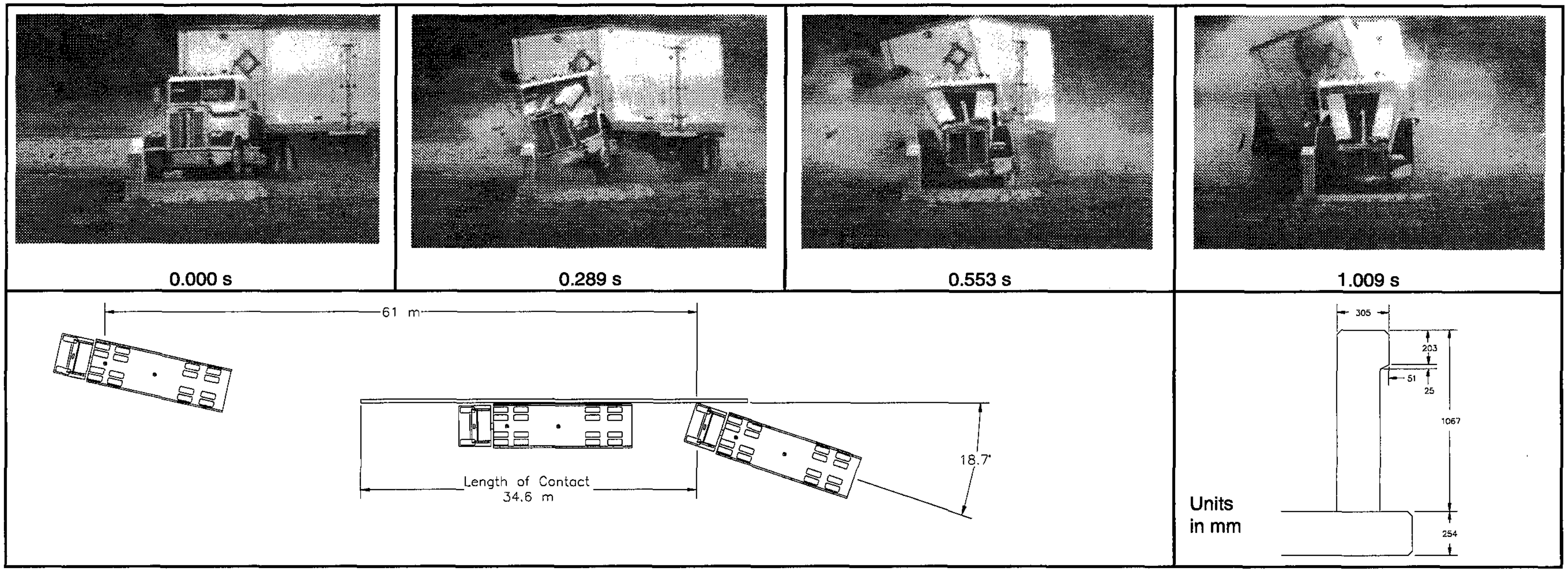


Figure 11. Left side of vehicle after test 405511-2.

hood, and cab. Damage to the trailer included the fifth wheel frame, the dolly mounts, the rear axles, and the right side tires and rims. The right front corner of the van was also torn open.

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows: In the longitudinal direction, the occupant impact velocity was 2.5 m/s at 0.519 s, the highest 0.010-s occupant ridedown acceleration was -2.9 g from 0.244 to 0.254 s, and the maximum 0.050-s average acceleration was -1.9 g between 0.165 and 0.215 s. In the lateral direction, the occupant impact velocity was 4.9 m/s at 0.225 s, the highest 0.010-s occupant ridedown acceleration was 7.2 g from 0.243 to 0.253 s, and the maximum 0.050-s average acceleration was -5.9 g between 0.171 and 0.221 s. These data and other pertinent information from the test are summarized in figure 12. Vehicle angular displacements are displayed in figure 13. Vehicular accelerations versus time traces are presented in appendix A, figures 14 through 22. Two string potentiometers and 11 uniaxial accelerometers were mounted in various places on the vehicle, as described in table 1, and traces from these measurements are shown in appendix A, figures 23 through 35.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405511-2
Date	12/12/95
Test Article	
Type	Bridge Railing
Name	1.07-m Vertical Wall
Installation Length (m)	39.6
Size and/or dimension and material of key elements	1.07-m height concrete parapet on bridge deck
Soil Type and Condition	Concrete bridge deck, dry
Test Vehicle	
Type	Production
Designation	36000V
Model	1983 Freight Liner
Mass (kg) Curb	13 893
Test Inertial	36 000
Dummy	No dummy
Gross Static	36 000

Impact Conditions	
Speed (km/h)	80.1
Angle (deg)	14.5
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.5
y-direction	4.9
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.9
y-direction	7.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-1.9
y-direction	-5.9
z-direction	4.0

Test Article Deflections (m)	
Dynamic	0
Permanent	0
Vehicle Damage	
Exterior	
VDS	
CDC	
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	350
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	14
Max. Pitch Angle (deg)	-4
Max. Yaw Angle (deg)	-14

Figure 12. Summary of results for test 405511-2.

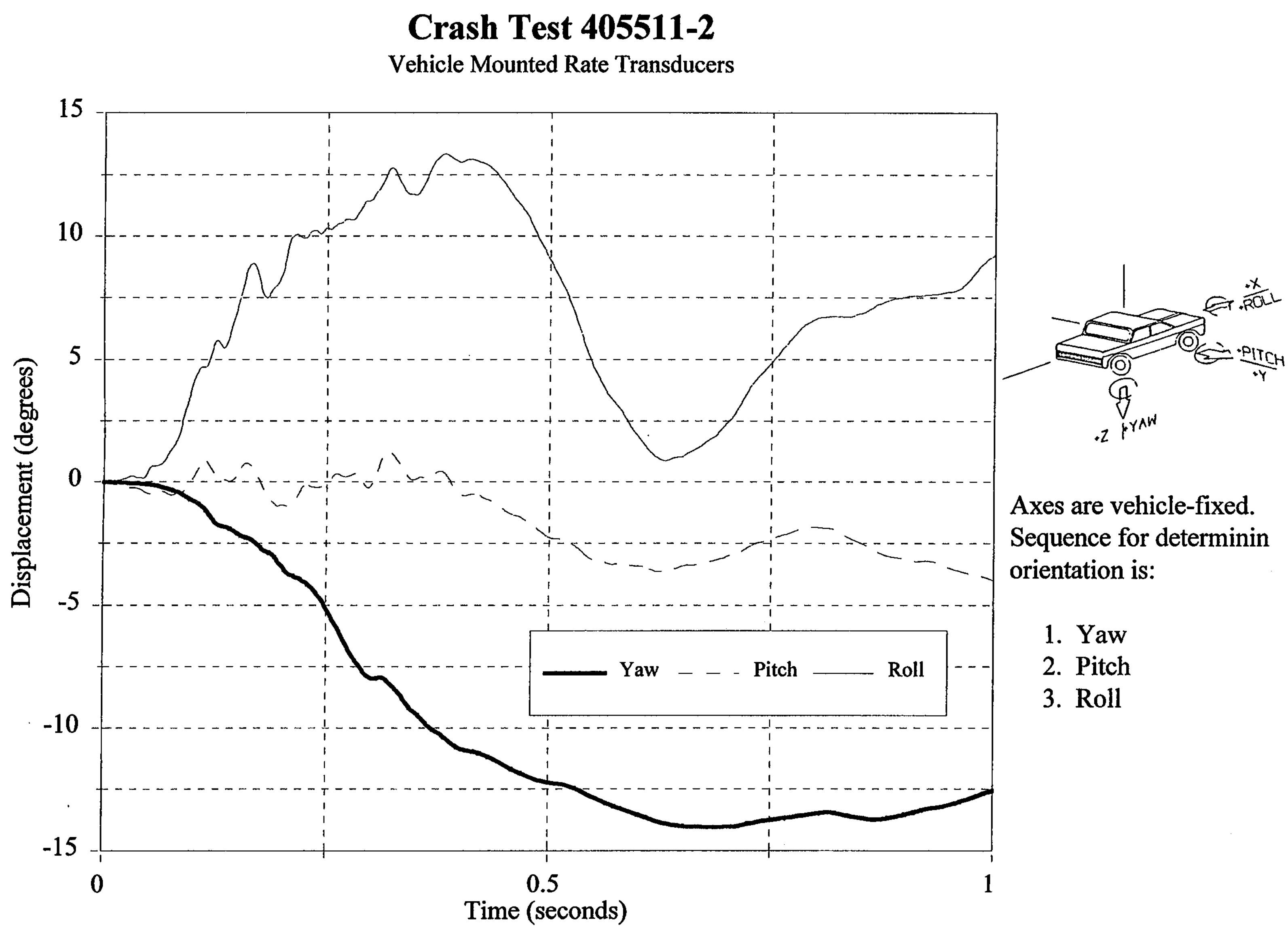


Figure 13. Vehicle angular displacements for test 405511-2.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

SUMMARY OF FINDINGS

The 1.07-m vertical wall bridge railing contained and redirected the 36000V test vehicle. The vehicle did not penetrate or override the installation. There were no detached elements or debris to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion of the occupant compartment. The vehicle remained upright during the collision and after exiting the installation. The vehicle did not intrude into adjacent traffic lanes. The exit angle, measured from tire marks, was approximately 0 degrees.

CONCLUSIONS

The impact performance of the 1.07-m vertical wall bridge railing was considered satisfactory according to evaluation criteria set forth in NCHRP Report 350 for test designation 5-12, as shown in table 2. The 36000V vehicle did not roll after exiting the longer installation as the 22 680-kg tractor/van trailer did on the 30-m installation used during an earlier study. Also, there was no sign of structural damage in the connection between the bridge railing and bridge deck.

Table 2. Performance evaluation summary for test 405511-2, NCHRP Report 350 test 5-12.

Test Agency: Texas Transportation Institute	Test No.: 405511-2	Test Date: 12/12/95
NCHRP Report 350 Evaluation Criteria	**Test Results**	**Assessment**
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.	The 1.07-m vertical wall bridge railing contained and redirected the 36000V test vehicle. The vehicle did not penetrate or override the installation.	Pass
Occupant Risk D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion of the occupant compartment.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
Vehicle Trajectory K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle, measured from tire marks, was approximately 0 degrees.	Pass

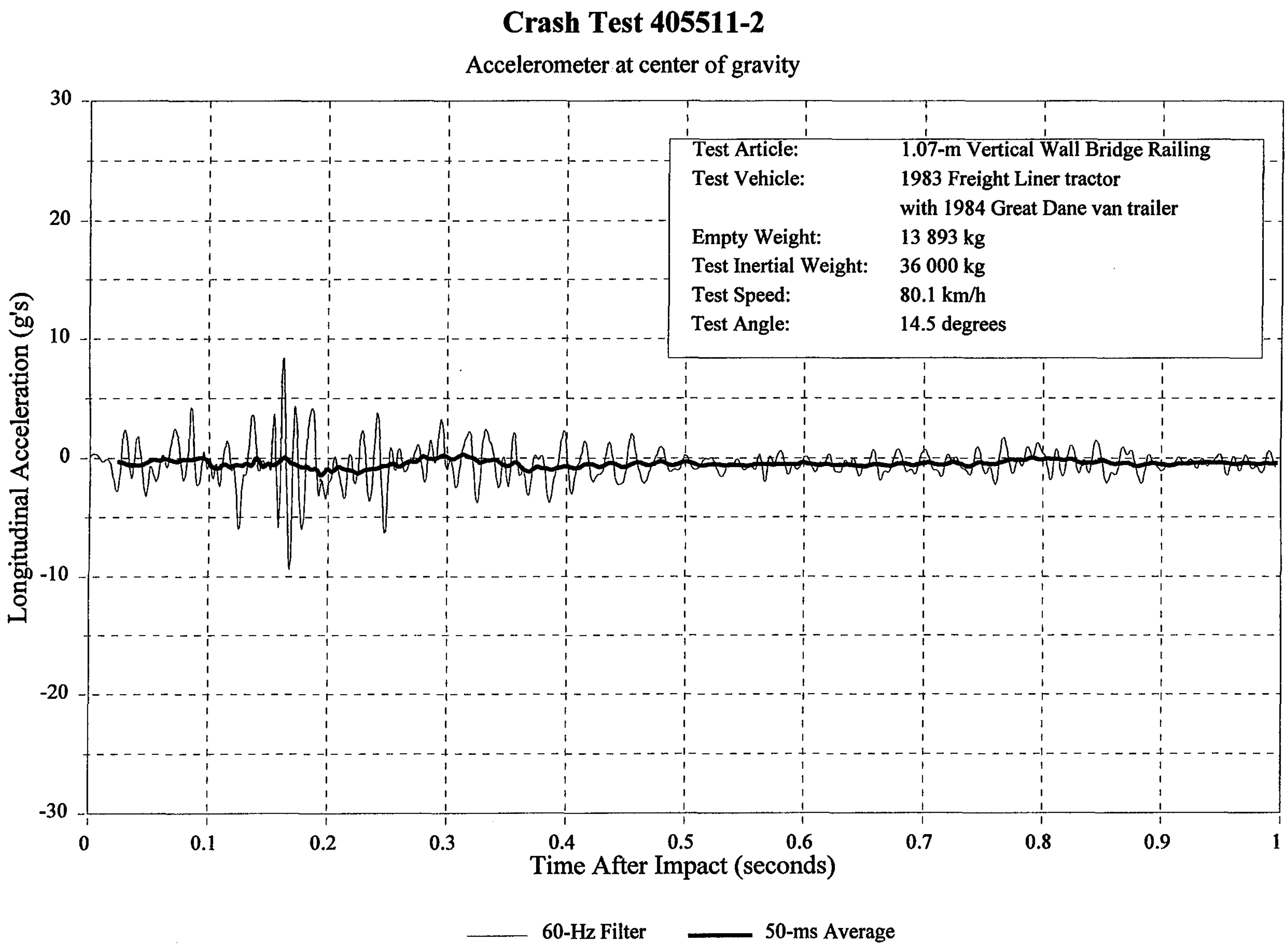


Figure 14. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located at tractor center of gravity).

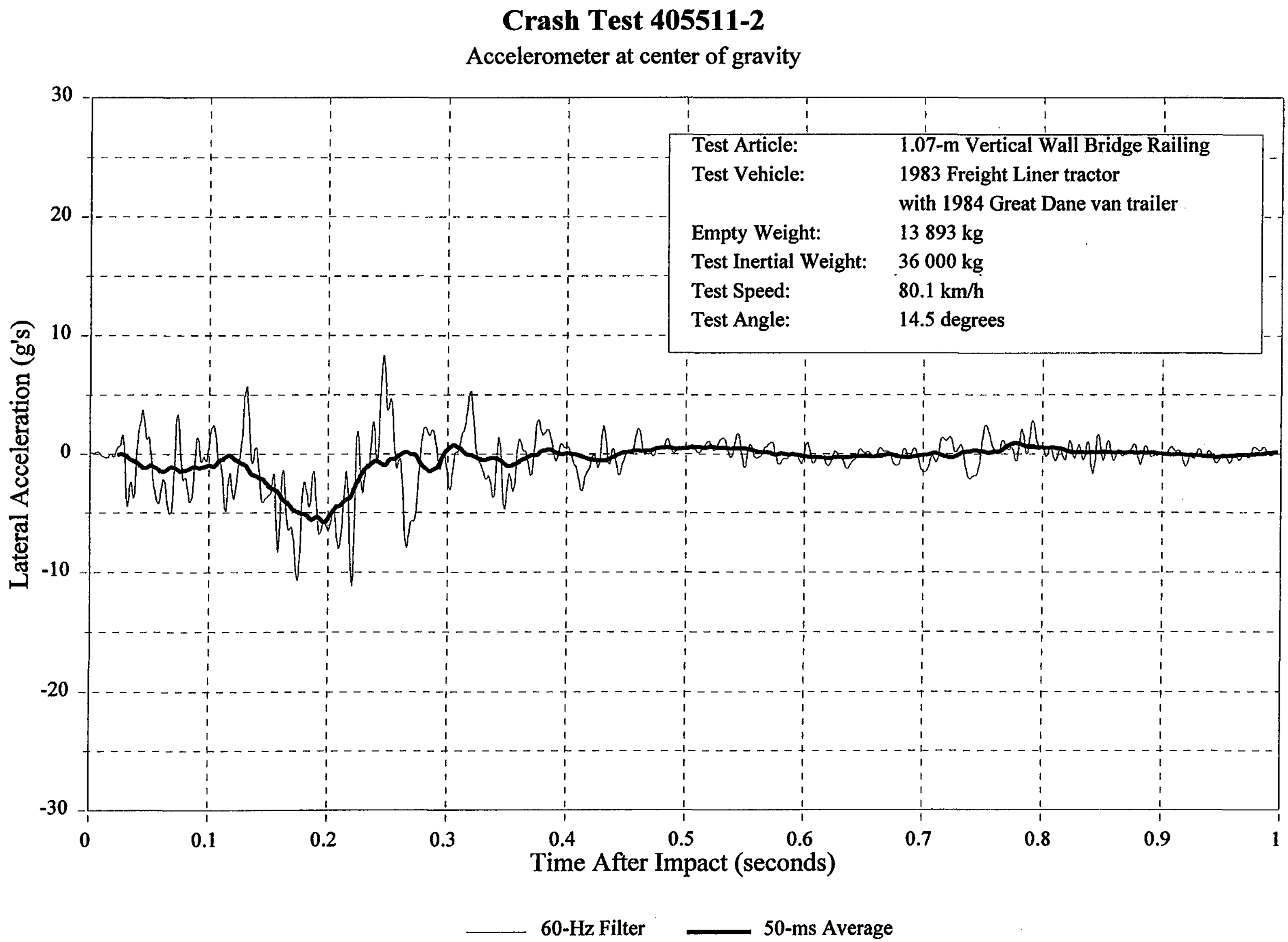


Figure 15. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located at tractor center of gravity).

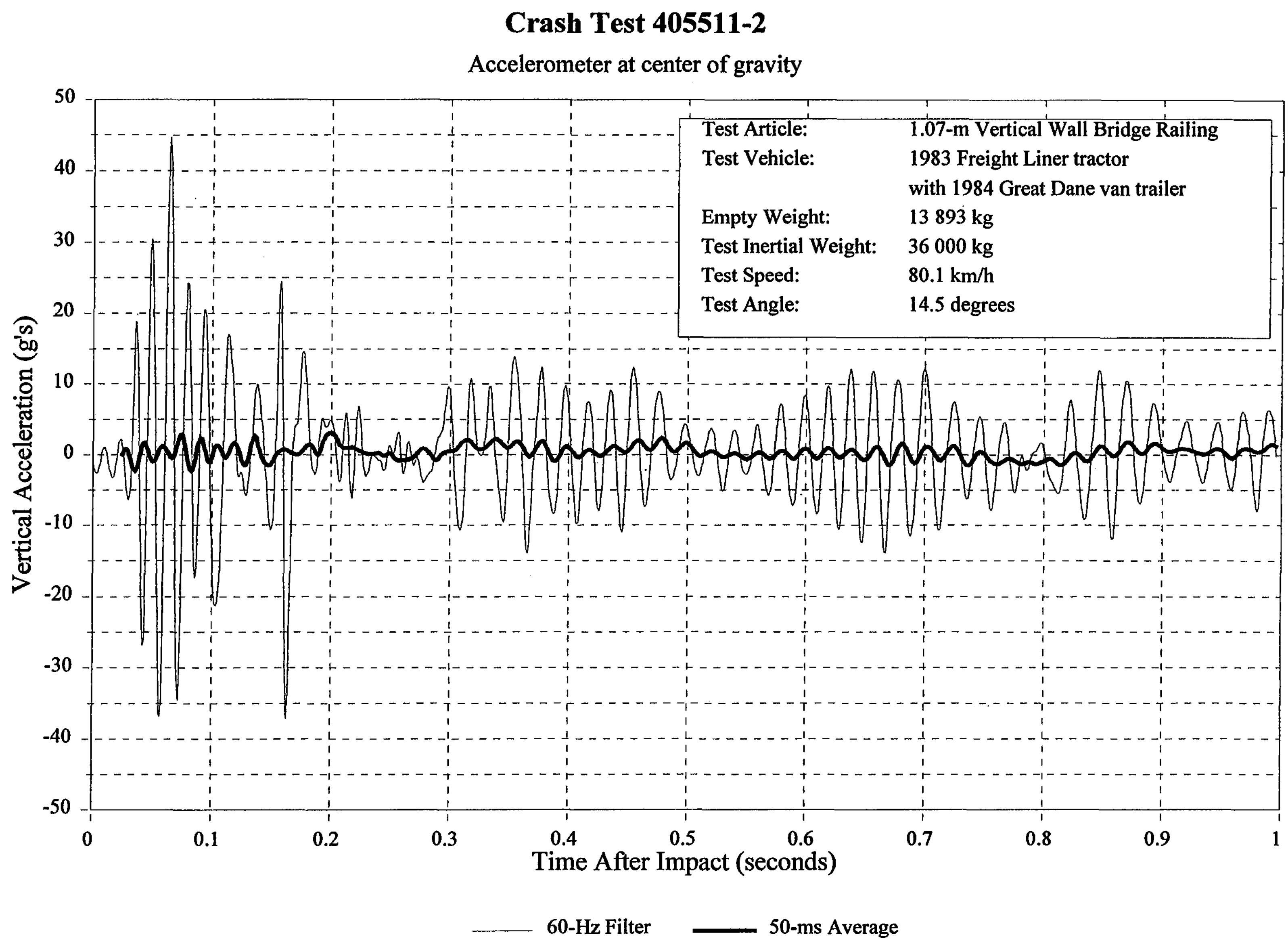


Figure 16. Vehicle vertical accelerometer trace for test 405511-2 (accelerometer located at tractor center of gravity).

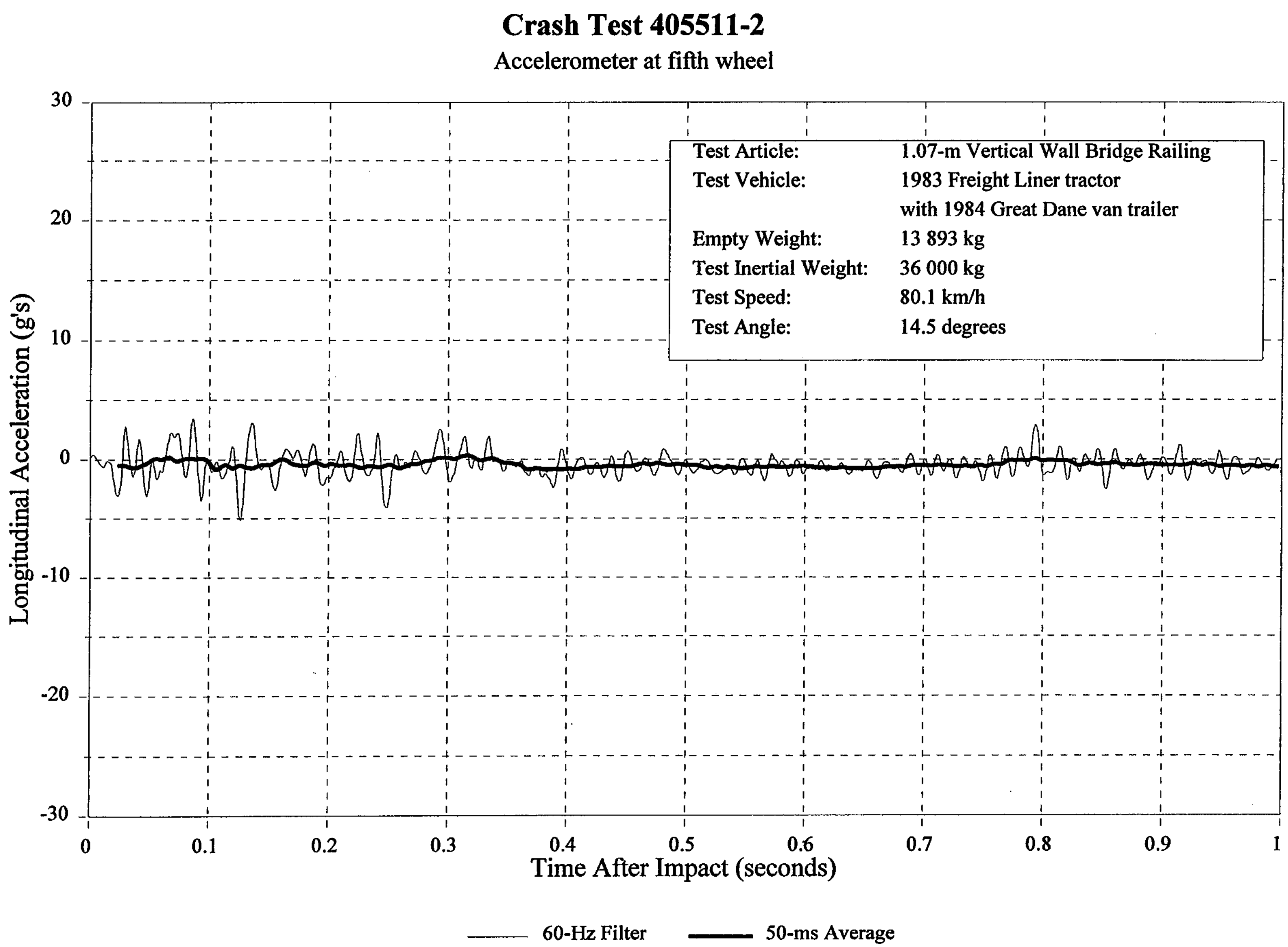


Figure 17. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located at fifth wheel).

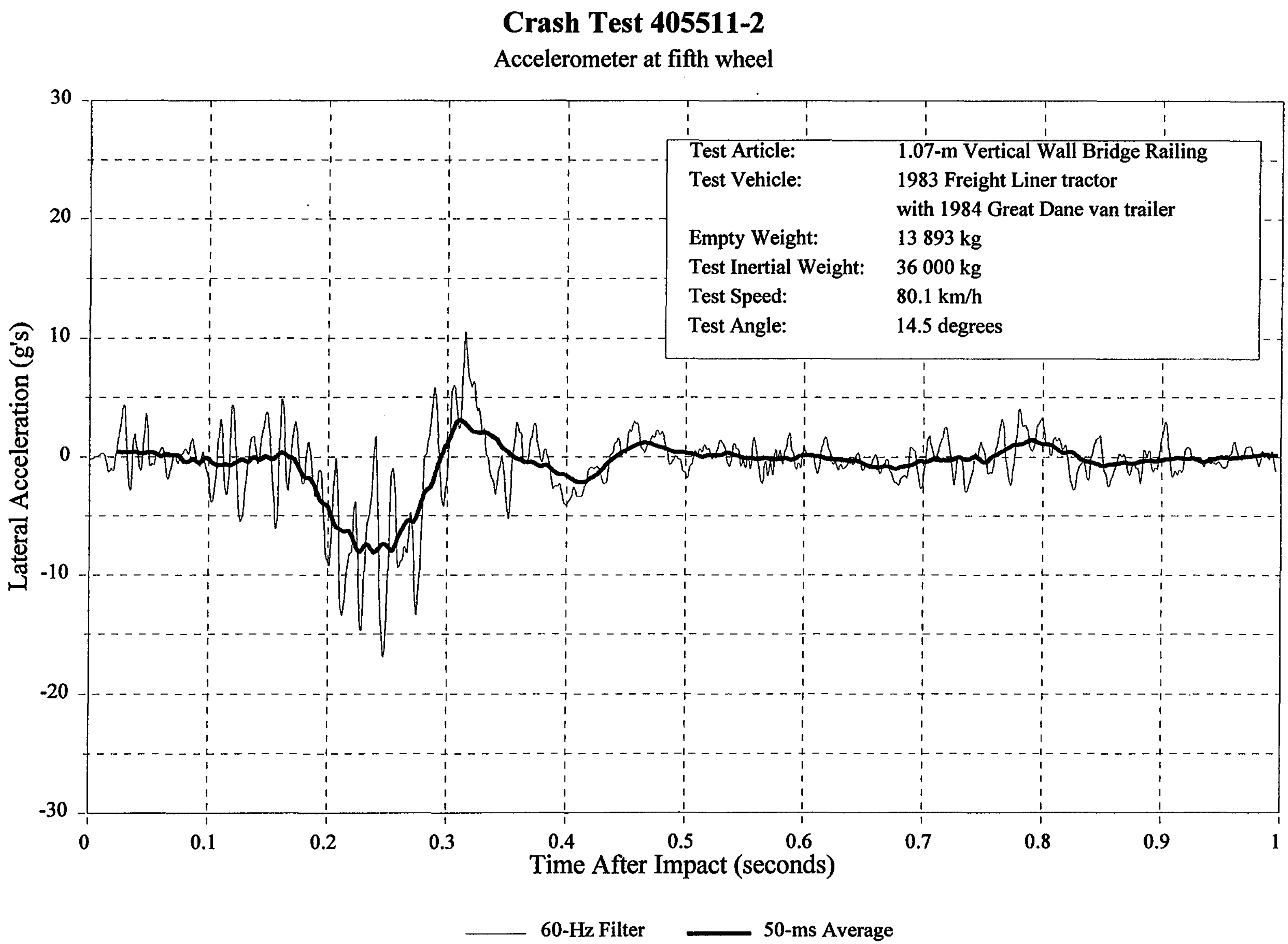


Figure 18. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located at fifth wheel).

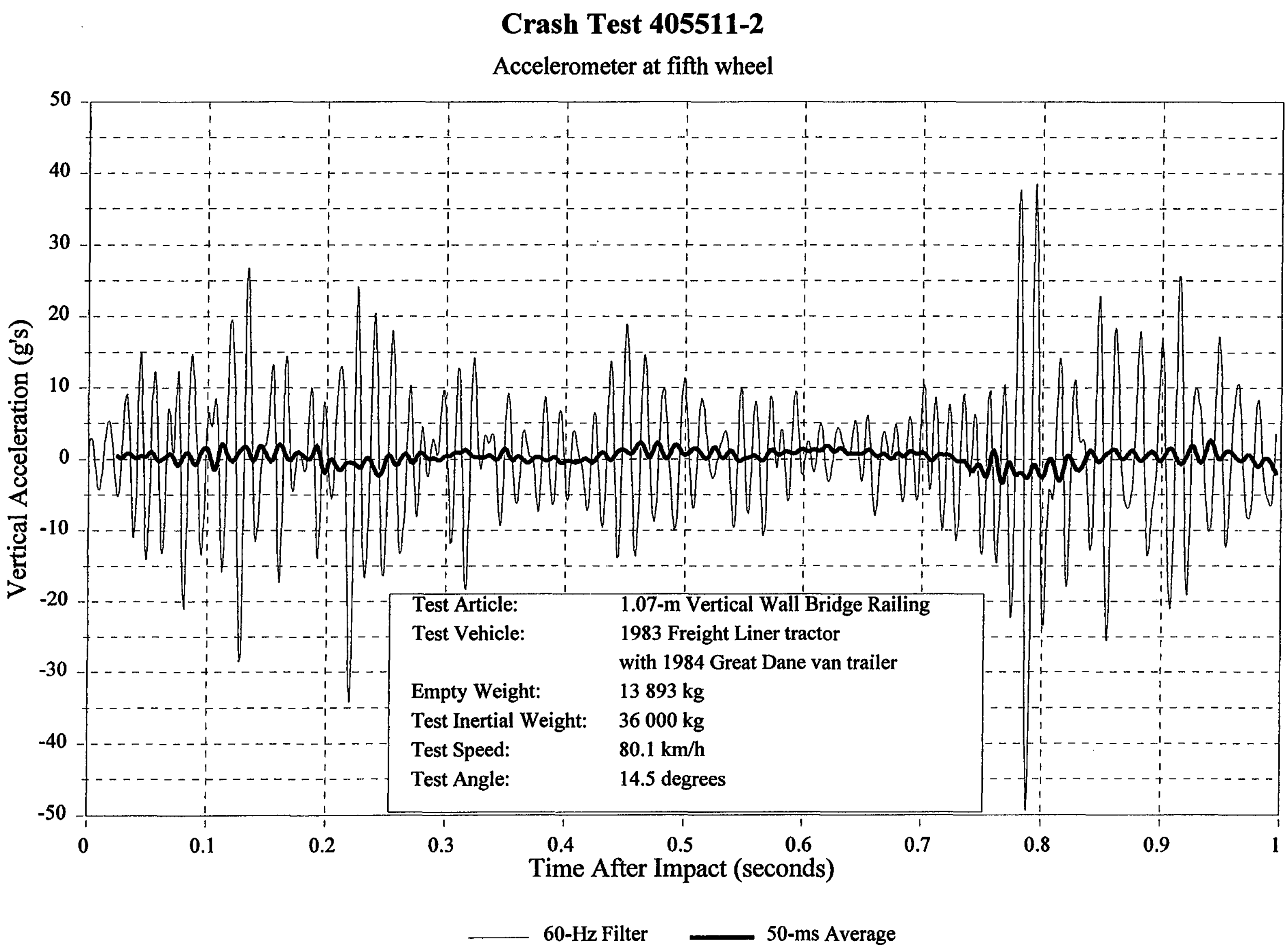


Figure 19. Vehicle vertical accelerometer trace for test 405511-2 (accelerometer located at fifth wheel).

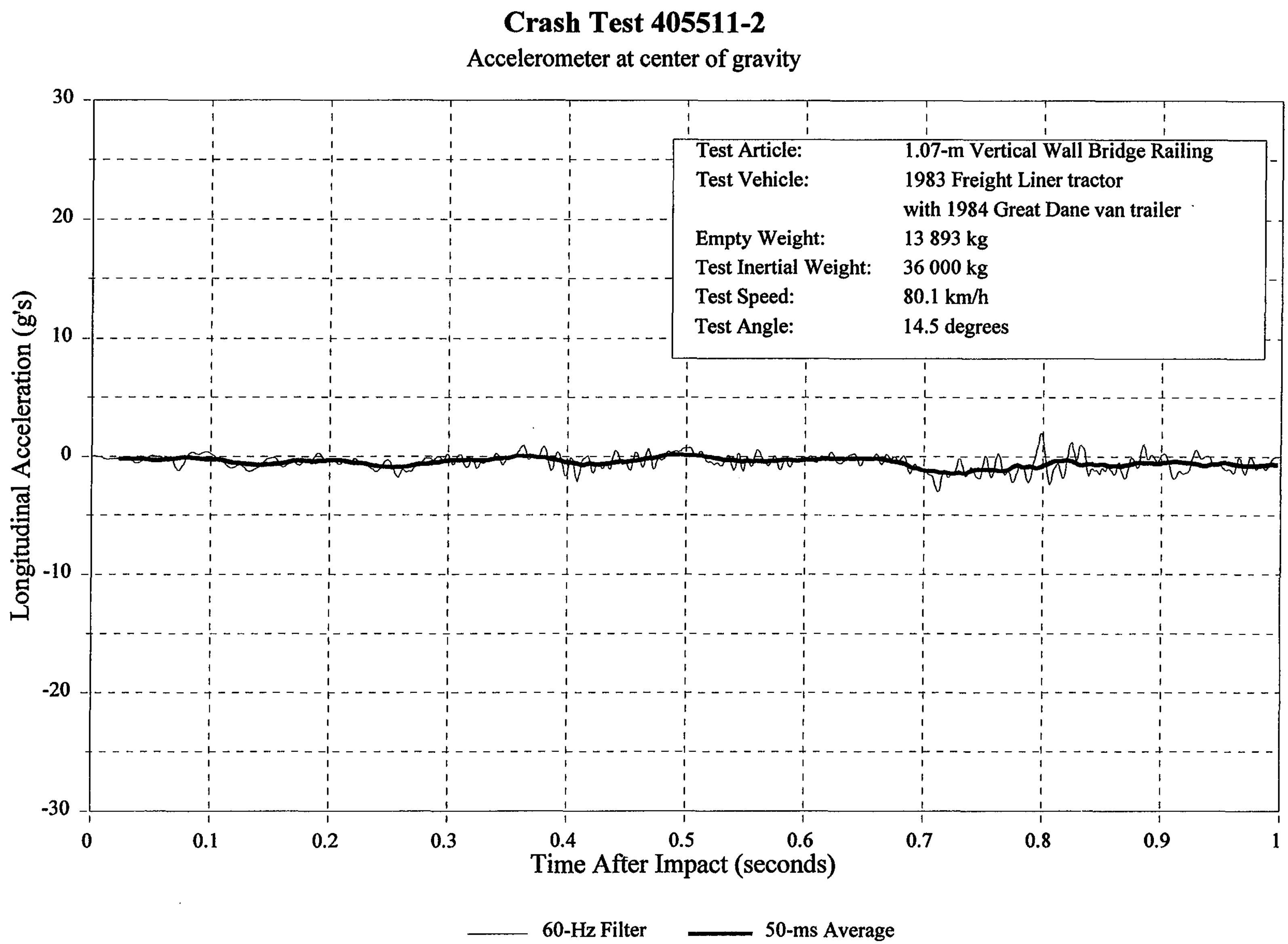


Figure 20. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located at trailer center of gravity).

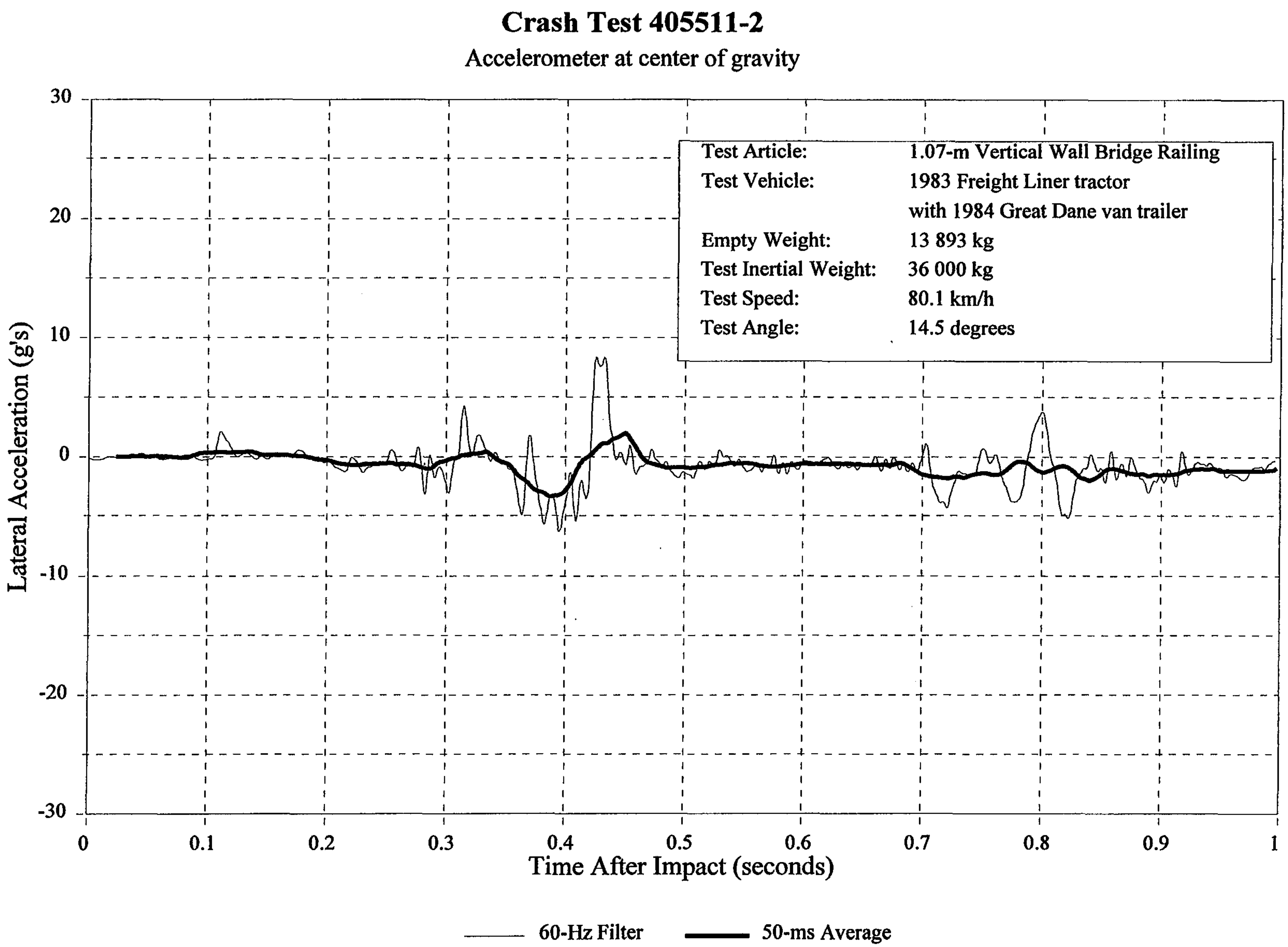


Figure 21. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located at trailer center of gravity).

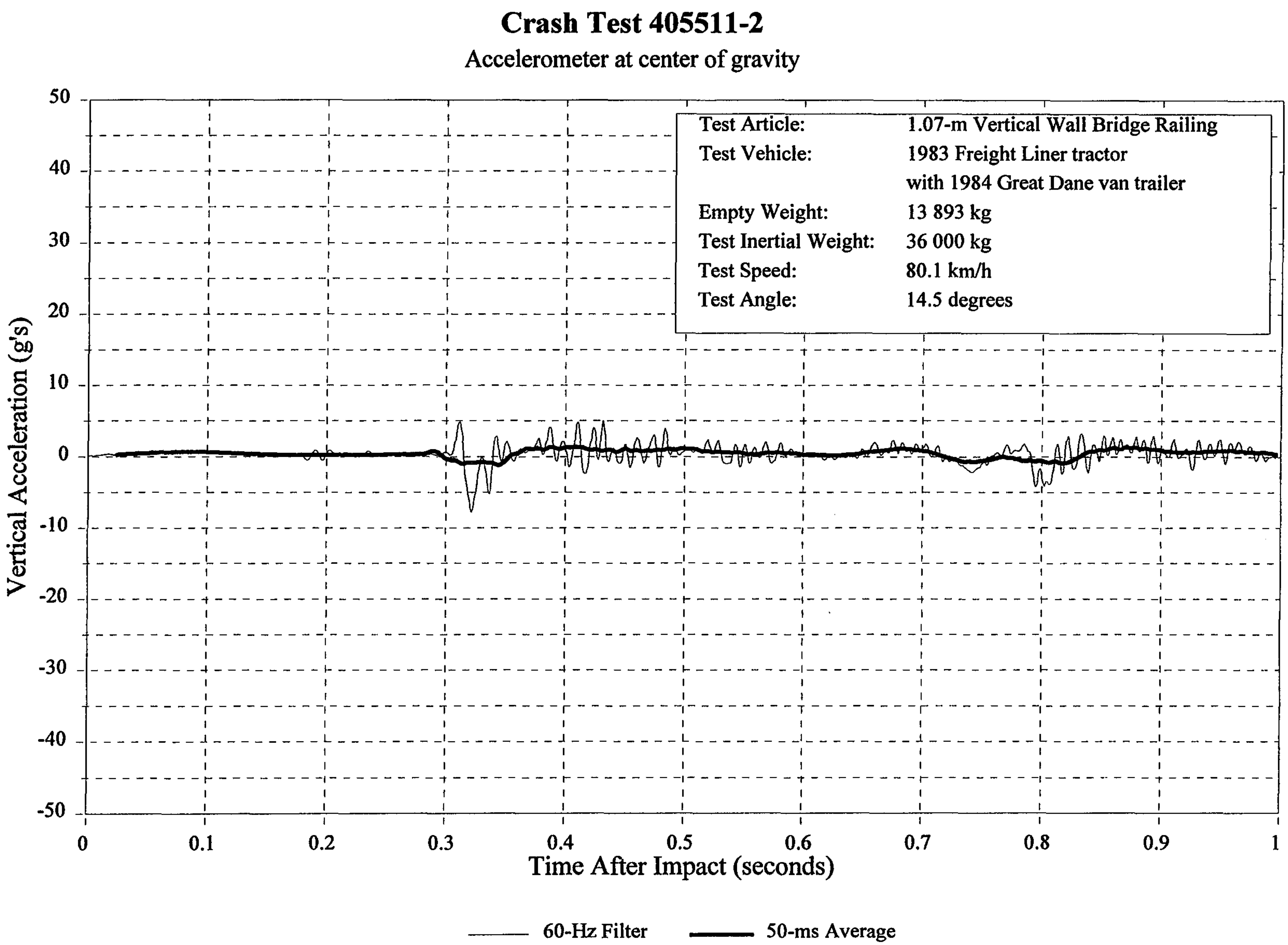


Figure 22. Vehicle vertical accelerometer trace for test 405511-2 (accelerometer located at trailer center of gravity).

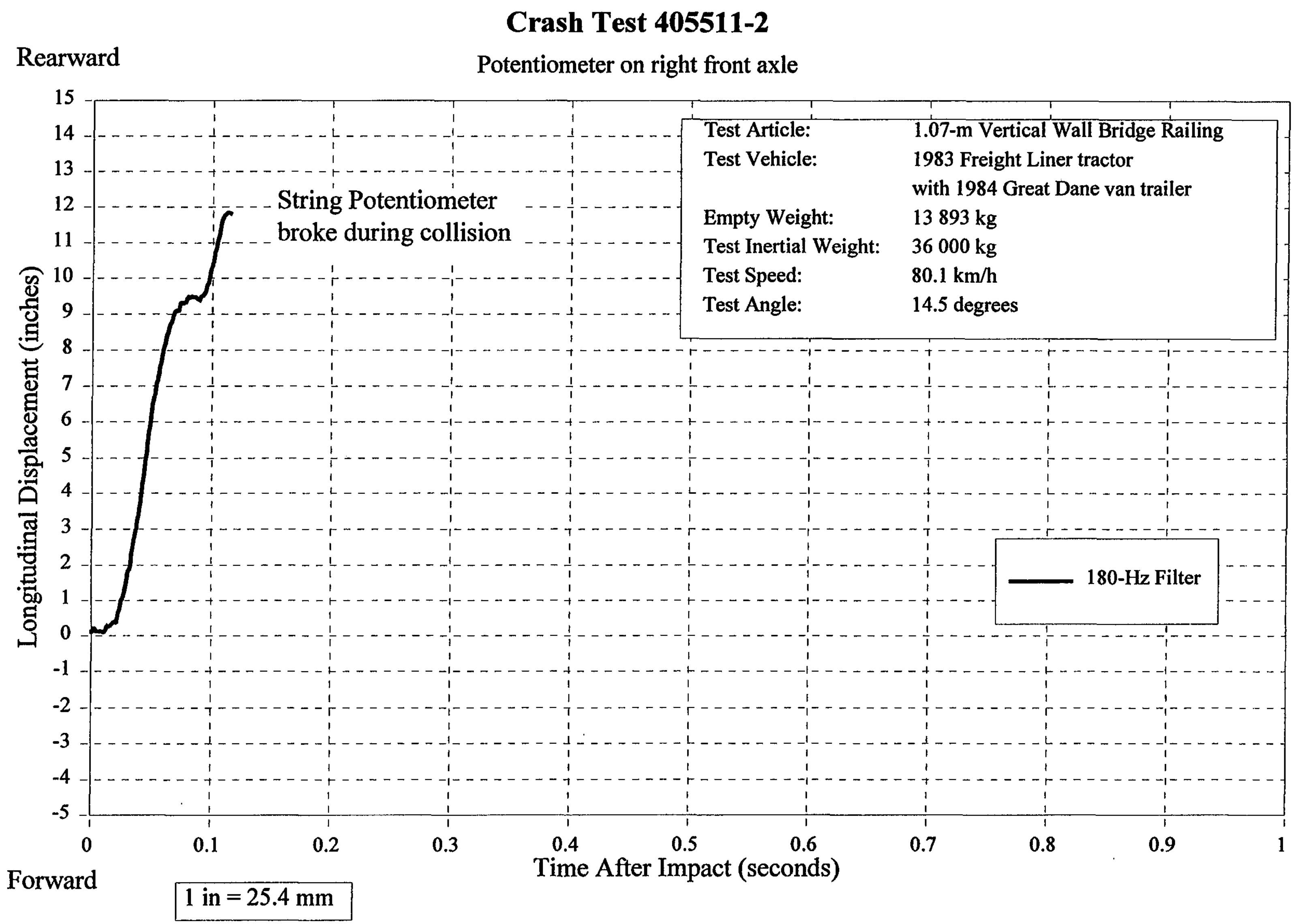


Figure 23. Longitudinal string potentiometer trace for test 405511-2 (potentiometer located on right front axle).

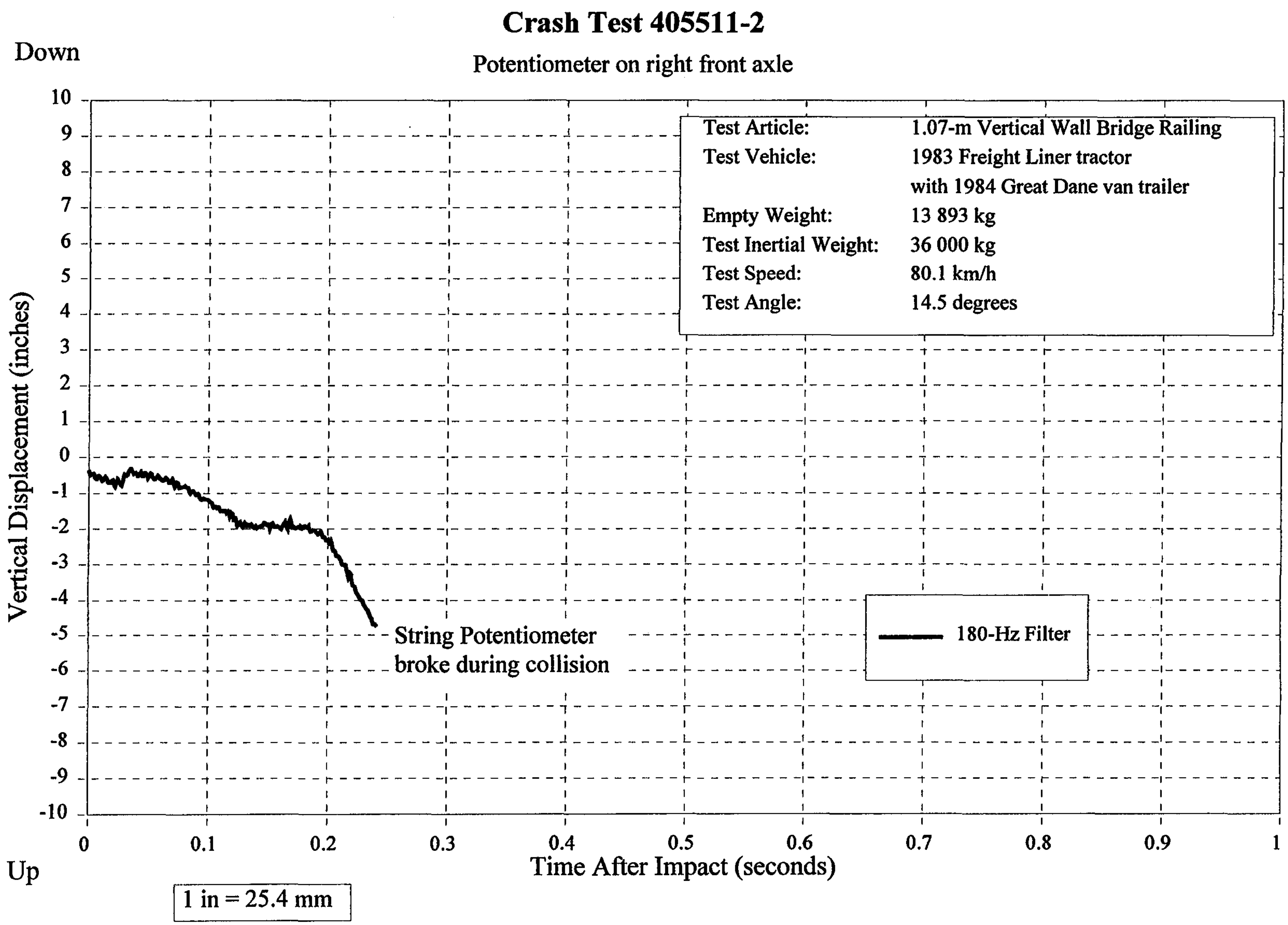


Figure 24. Vertical string potentiometer trace for test 405511-2 (potentiometer located on right front axle).

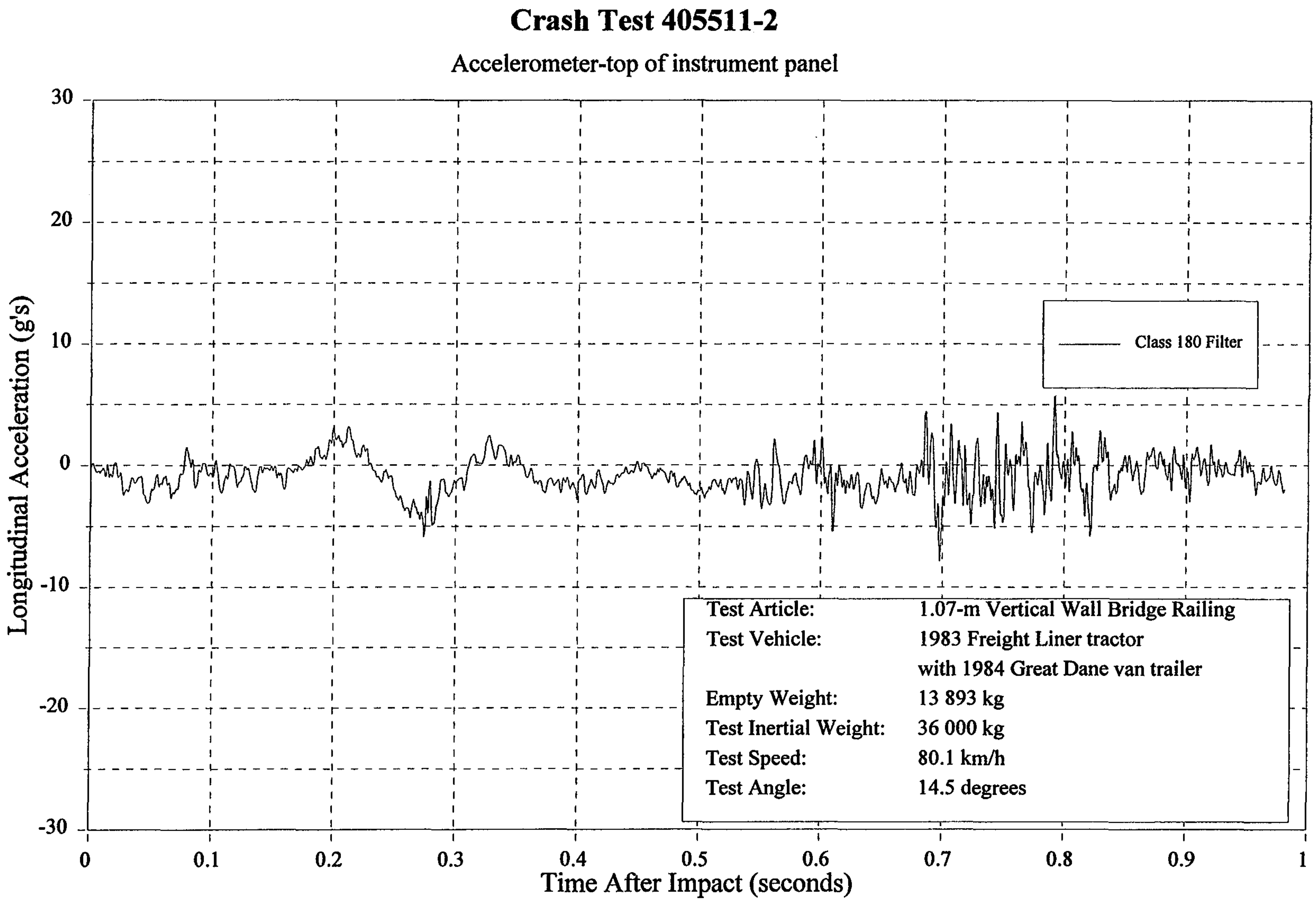


Figure 25. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located on top of instrument panel).

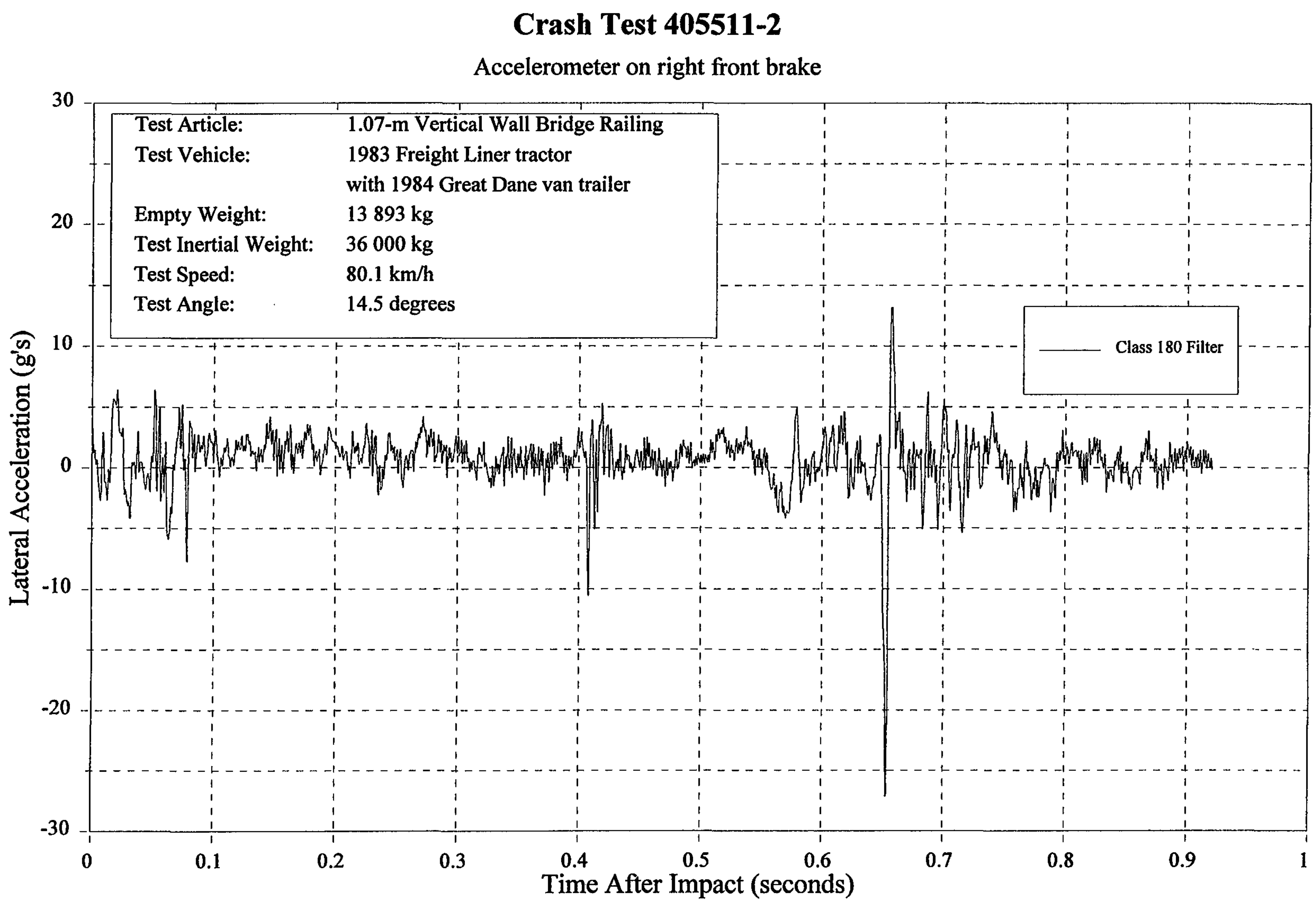


Figure 26. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located on right front tractor brake).

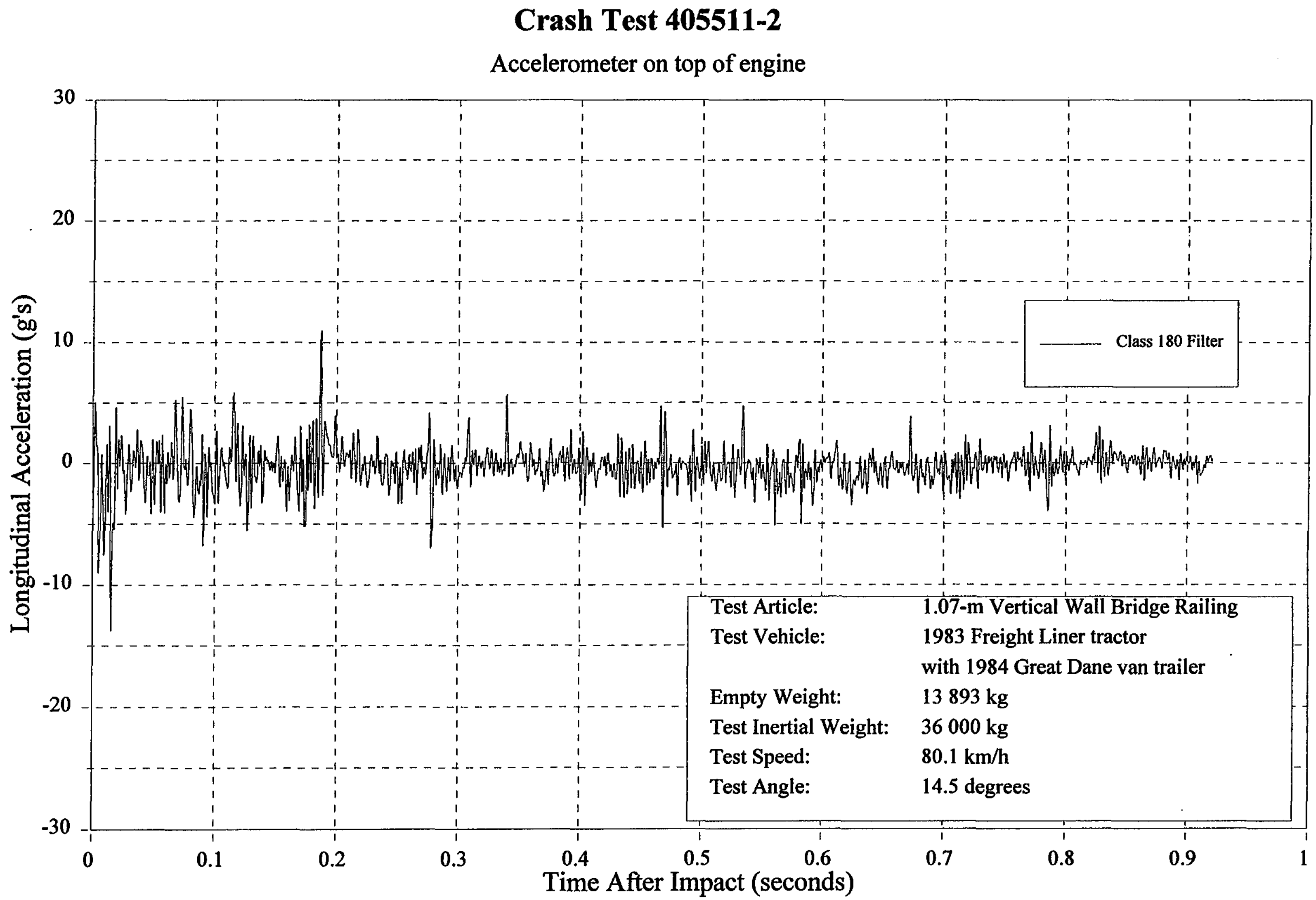


Figure 27. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located on top of engine).

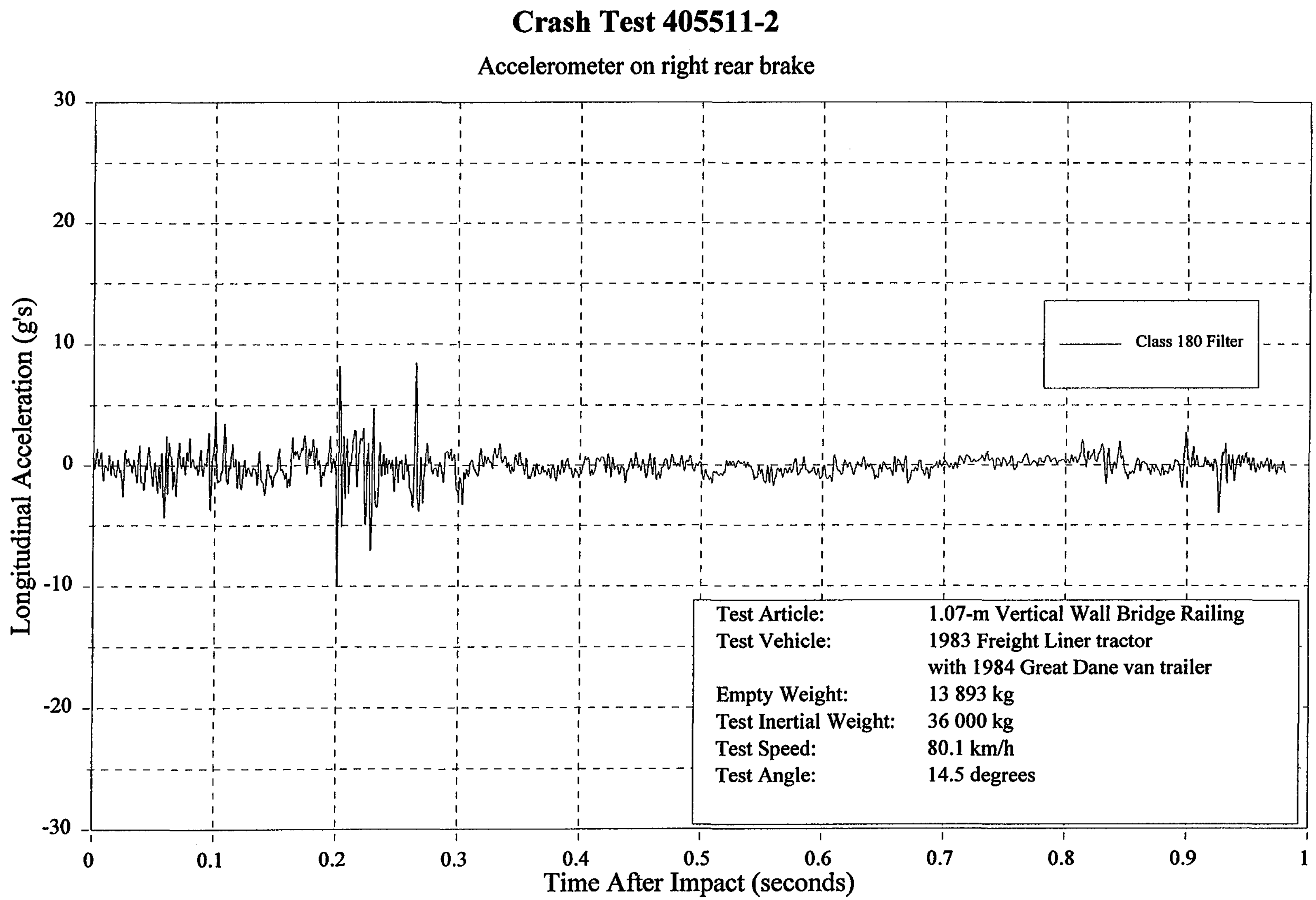


Figure 28. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located on right rear tractor brake).

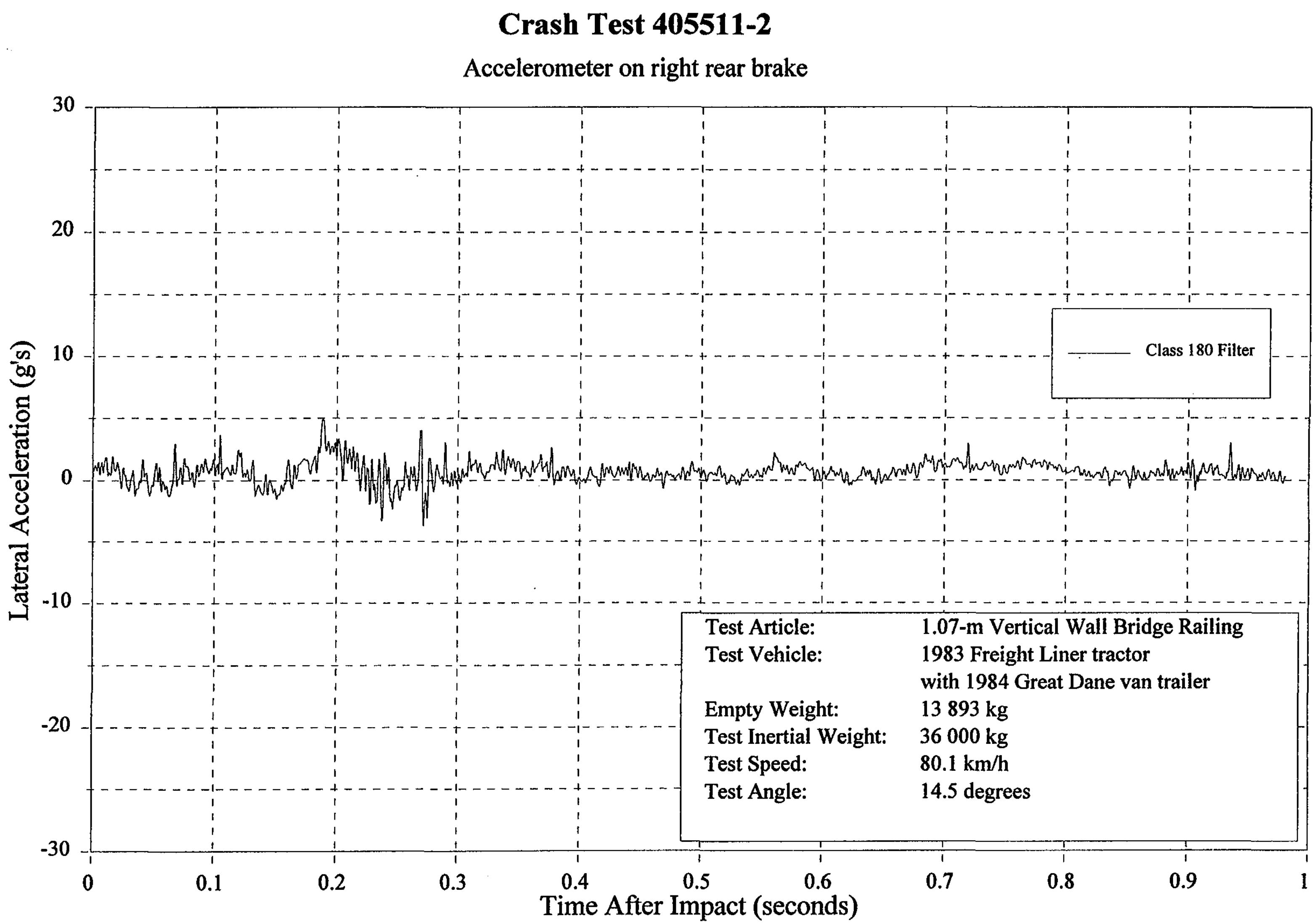


Figure 29. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located on right rear tractor brake).

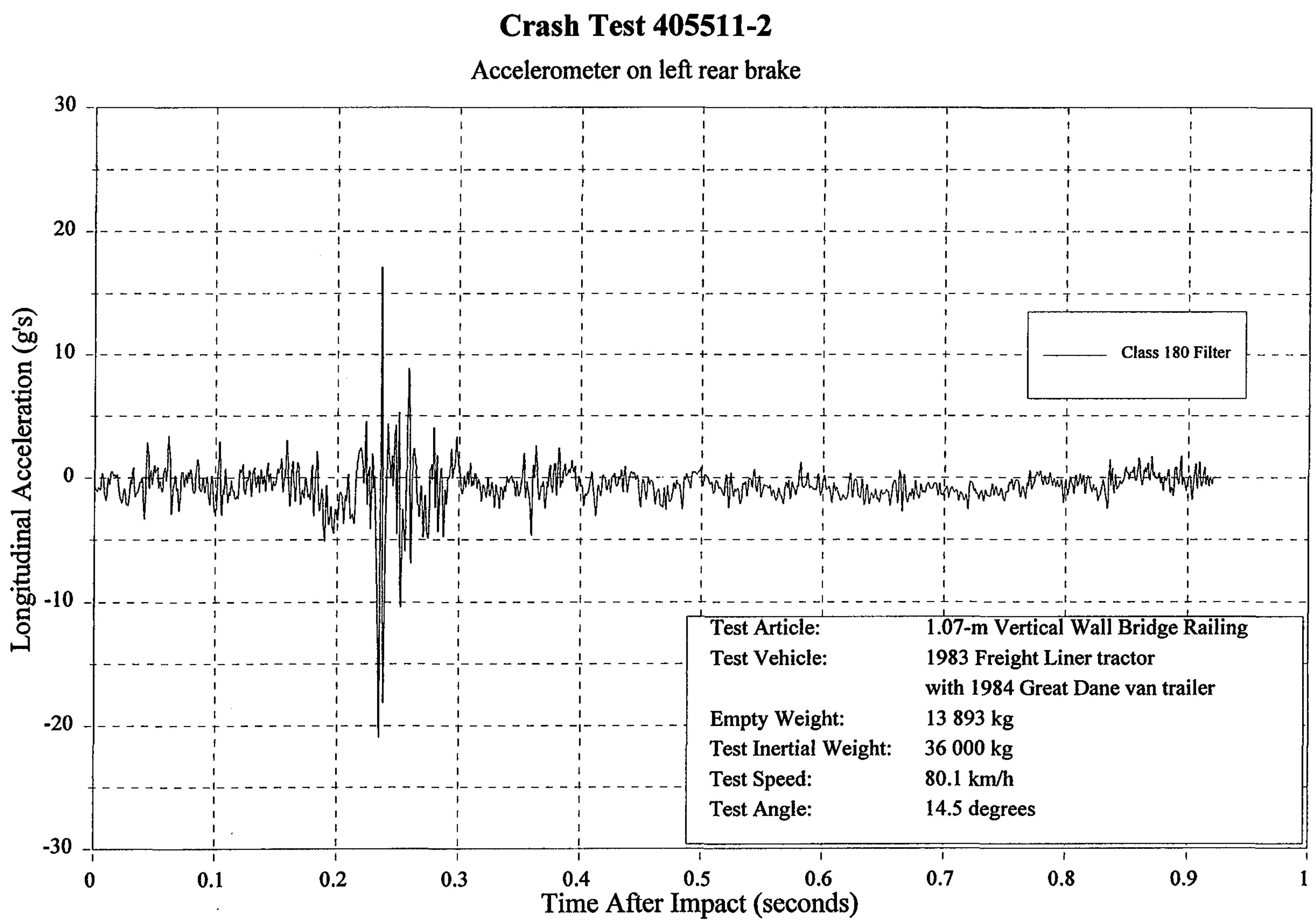


Figure 30. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located on left rear tractor brake).

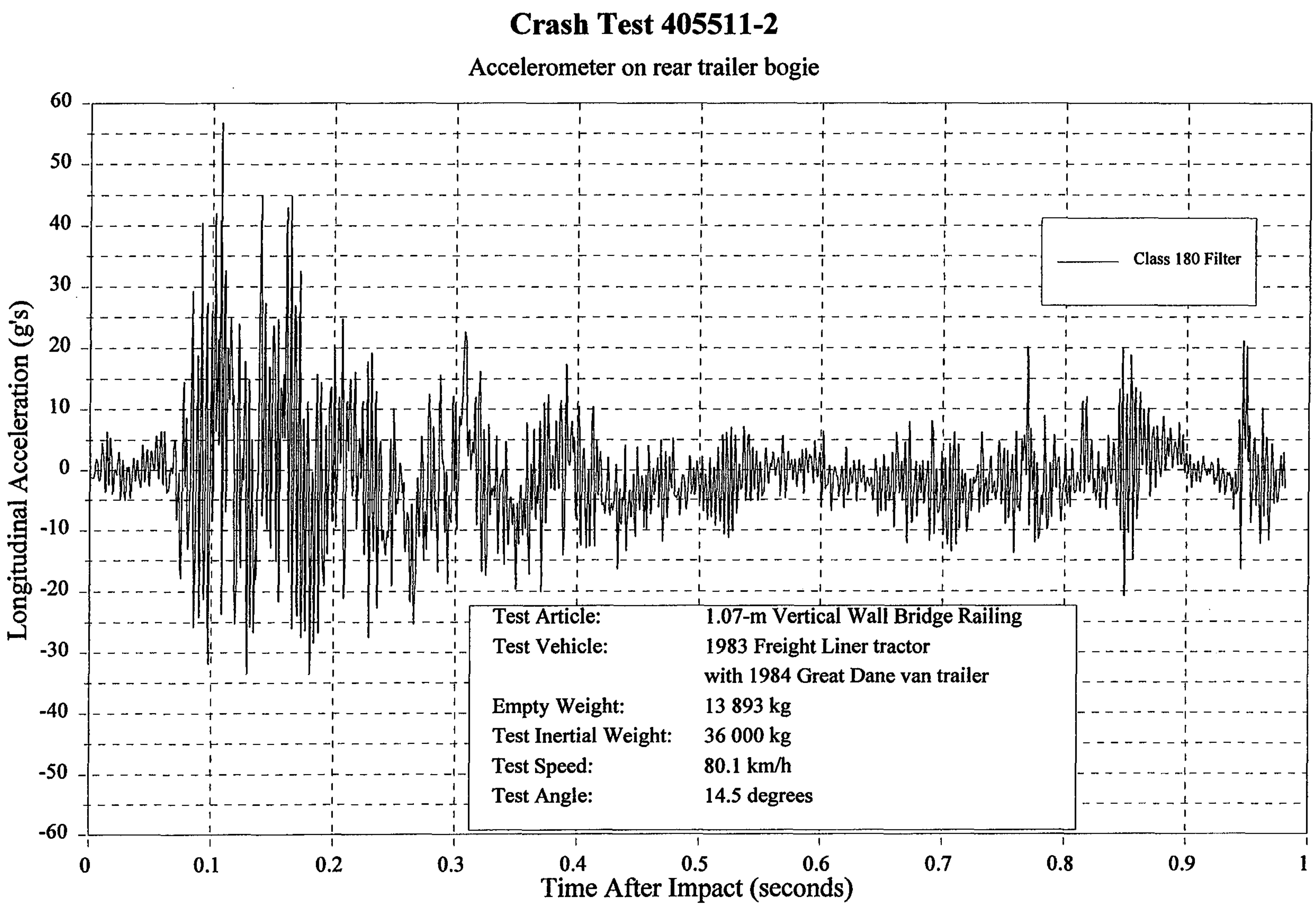


Figure 31. Vehicle longitudinal accelerometer trace for test 405511-2
(accelerometer located on rear trailer bogie).

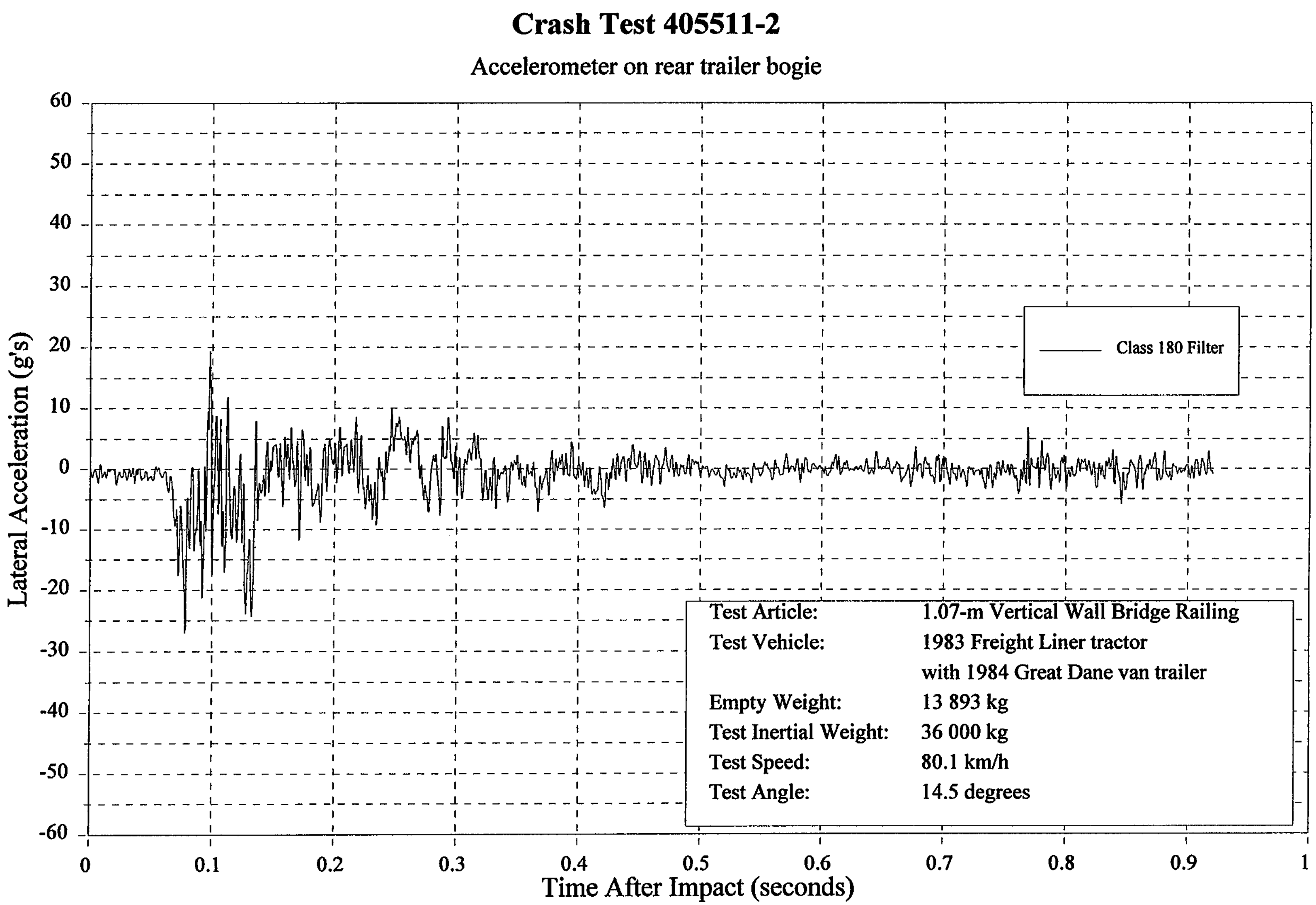


Figure 32. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located on rear trailer bogie).

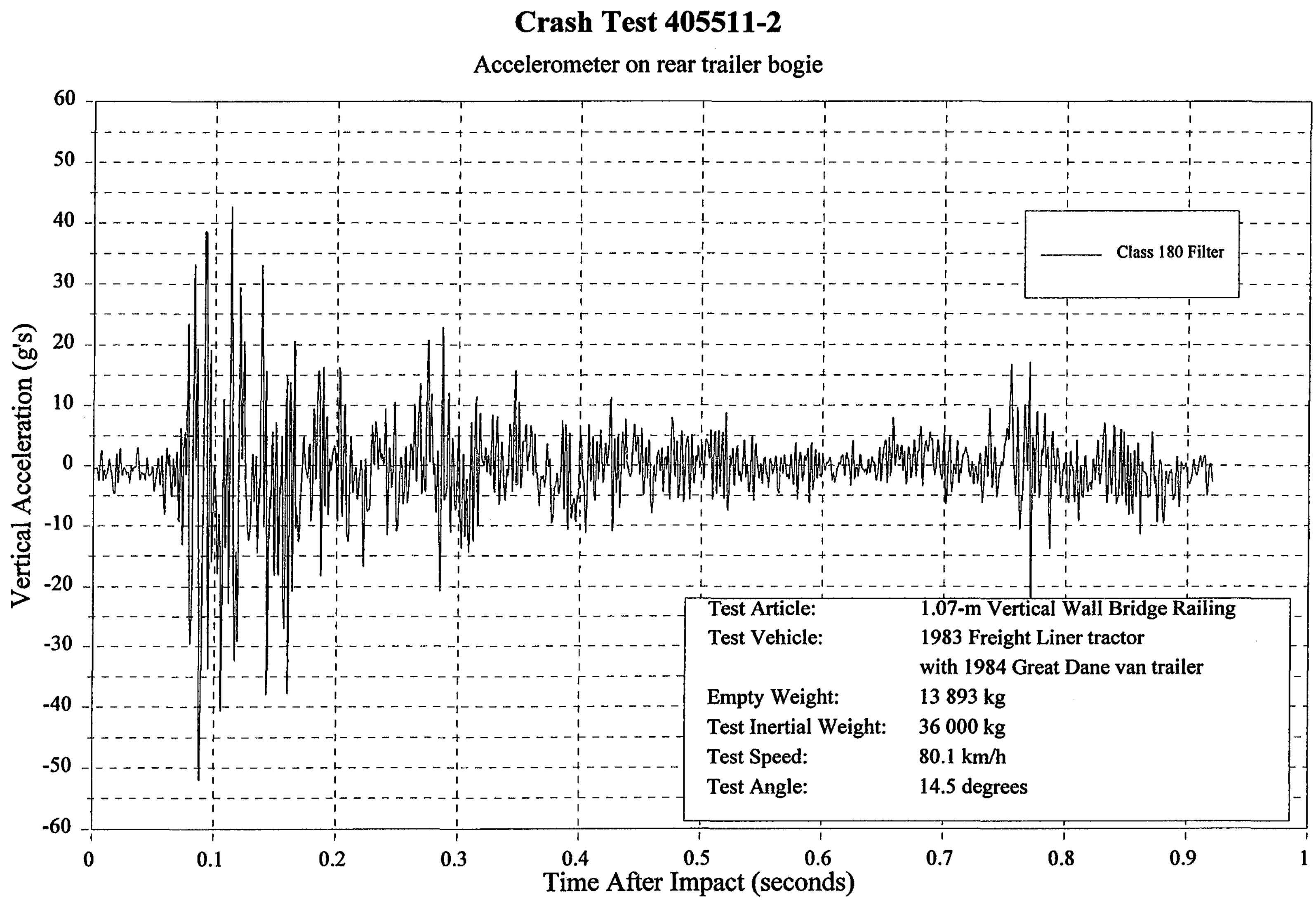


Figure 33. Vehicle vertical accelerometer trace for test 405511-2
(accelerometer located on rear trailer bogie).

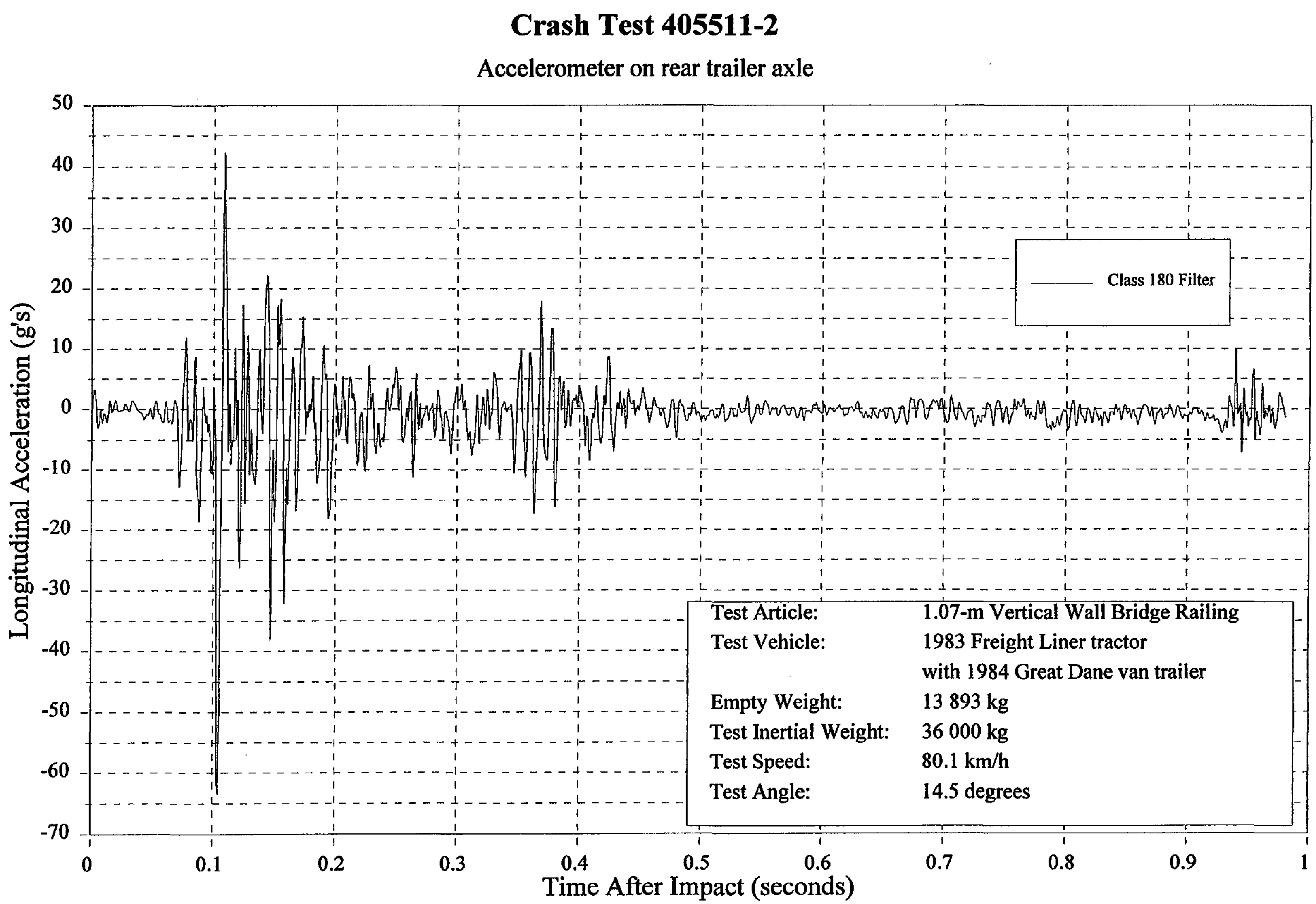


Figure 34. Vehicle longitudinal accelerometer trace for test 405511-2 (accelerometer located on rear trailer axle).

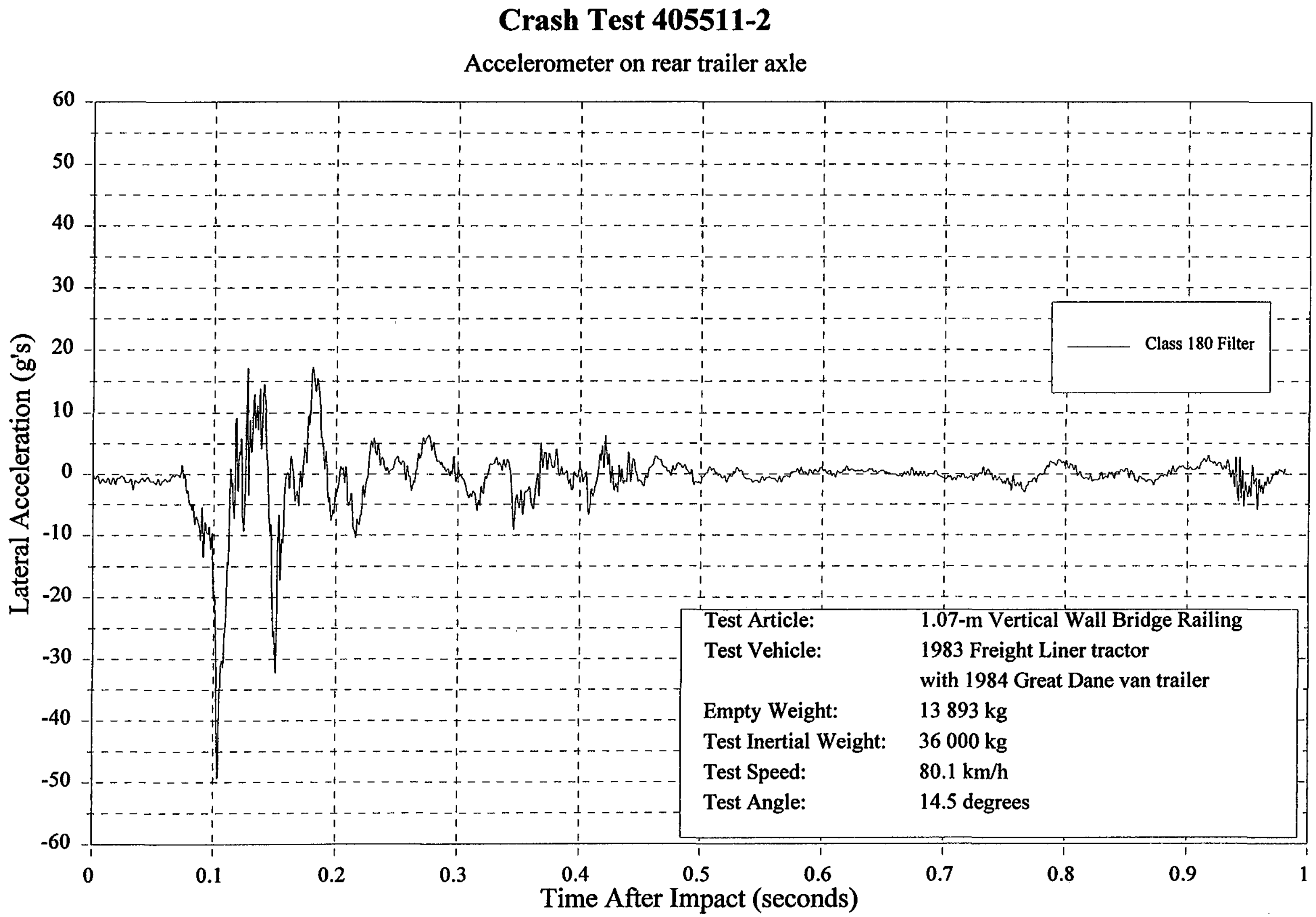


Figure 35. Vehicle lateral accelerometer trace for test 405511-2 (accelerometer located on rear trailer axle).

REFERENCES

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2. J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, NCHRP Report 230, Transportation Research Board, Washington, D.C., 1980.

3. C. Eugene Buth, T. J. Hirsch, and W. L. Menges, *Testing of New Bridge Rail and Transition Designs - Volume X: Appendix I: 42-in (1.07-m) Concrete Parapet Bridge Railing*, Report No. FHWA-RD-93-067, Pooled Funds Bridge Rail Study, Federal Highway Administration, Washington, D.C., September 1993.