Testing of New Bridge Rail and Transition Designs

Volume XI: Appendix J

42-in (1.07-m) F-Shape Bridge Railing

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

FOREWORD

This report presents the results of a State Planning and Research (SP&R) pooled-fund study to develop safer bridge rail and transition designs. This pooled-fund study was sponsored by the Federal Highway Administration, 23 States, and the District of Columbia. A panel of representatives from those agencies selected the designs to be studied. Ten bridge rails and two transitions were designed and crash tested in accordance with the recommendations for the various Performance Levels in the *1989 AASHTO Guide Specifications for Bridge Railings*. Acceptable performance was demonstrated for all of the crash tested designs.

Detailed drawings are presented for documentation and to facilitate implementation.

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

NOTICE

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract

A 42-in (1.07-m) high F-shape concrete parapet bridge railing was designed and tested to performance level three of the 1989 *Guide Specifications for Bridge Railings*. The parapet has a thickened section along the top to stiffen the top edge and enhance longitudinal distribution of the load. It was mounted on a 10-in (254-mm) simulated bridge deck overhang. Acceptable performance of the parapet was demonstrated.

This volume is the eleventh in a series. The other volumes in the series are: Volume I: Technical Report; Volume II: Appendix A, "Oregon Side Mounted Bridge Railing;" Volume III: Appendix B, "BR27D Bridge Railing;" Volume IV: Appendix C, "Illinois 2399-1 Bridge Railing;" Volume V: Appendix D, "32-in (813-mm) Concrete Parapet Bridge Railing;" Volume VI: Appendix E, "32-in (813-mm) New Jersey Safety Shape;" Volume VII: Appendix F, "32-in (813-mm) F-Shape Bridge Railing;" Volume VIII: Appendix G, "BR27C Bridge Railing;" Volume IX: Appendix H, "Illinois Side Mount Bridge Rail;" Volume X: Appendix I, "42-in (1.07-m) Concrete Parapet Bridge Railing;" Volume XII: Appendix K, "Oregon Transition;" Volume XIII: Appendix L, "32-in (813-mm) Thrie-Beam Transition;" and Volume XIV: Appendix M, "Axial Tensile Strength of Thrie and W-Beam Terminal Connectors."

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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
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 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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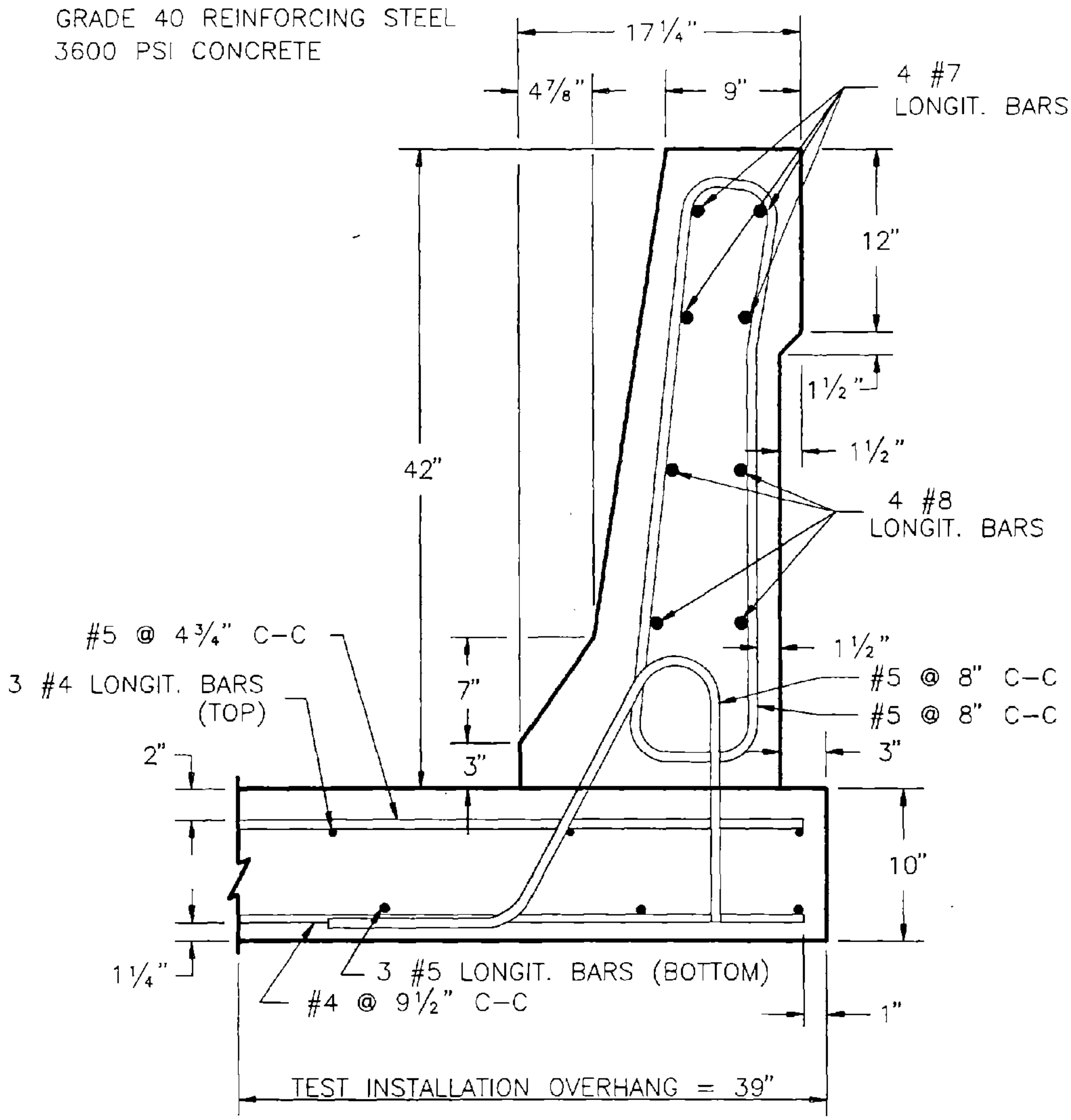
The 42-in (1.07-m) F-shape bridge railing was designed to meet performance level three of the 1989 *Guide Specifications for Bridge Railings*.[1] It was first tested with a 40,000-lb (18 160-kg) intercity bus traveling at 55 mi/h (88 km/h) with an approach angle of 15 degrees (proposed test condition in *Guide Specifications for Bridge Railings* in 1987).[2] The railing was later tested with a 50,000-lb (22 700-kg) tractor-trailer at 50 mi/h (80.5 km/h) and 15 degrees.

Design force for the tractor-trailer test is 124 kips (552 kN) of uniformly distributed line force 42 in (1.07 m) long located 38 to 40 in (960 mm to 1.02 m) above the roadway surface.

A cross section of the railing is shown in figure 1. The total height of the F-shape is 42 in (1.07 m). The thickness of the rail is 17.3 in (439 mm) at its base and tapers along the height with a thickened section at the top of 9 in (230 mm). The slope at the bottom of the rail serves to minimize vehicle damage at low angles of impact by causing the tire to ride up on the rail and redirect itself back to the pavement. The thickened section at the top acts as a continuous beam and serves to enhance longitudinal distribution of forces in the parapet and deck.

Four #7 longitudinal bars were used in the thickened section at the top of the 42-in (1.07-m) F-shape and four #8 longitudinal bars were placed throughout the tapered portion of the railing. The vertical steel used were #5 bent stirrups spaced at 8 in (203 mm) on center. Specified concrete strength was 3,600 psi (24 804 kPa) at 28 days and specified steel yield was 40,000 psi (275 600 kPa). The cantilevereed deck was supported on a foundation so that the deck overhang was 39 in (991 mm).

The strength of the railing was computed using yieldline analysis procedures.[3] The strength computations are presented in Chapter 4. The analysis predicts the length of the failure mechanism to be 17.6 ft (5.4 m) and the calculated ultimate load capacity to be 127 kips (565.8 kN). The analysis shows that the yield lines are confined to the wall rather than extending onto the bridge deck.



1 in = 25.4 mm
1 psi = 6.89 kPa

Figure 1. 42-in (1.07-m) F-shape bridge railing.

CHAPTER 2. CRASH TEST PROCEDURES

This bridge railing was tested to performance level three requirements.[1] The test conditions used in this series of testing was:

40,000-lb (18 160-kg) scenicruiser bus | 55 mi/h (88.6 km/h) | 15 degrees (test 7069-7)
50,000-lb (22 700-kg) tractor-trailer | 50 mi/h (80.5 km/h) | 15 degrees (test 7069-10)

The test with a 40,000-lb (18 160-kg) intercity bus was the strength test for performance level three in the proposed 1987 test matrix in the guide specifications.[2] The test matrix was later modified and a test with a 50,000-lb (22 700-kg) tractor-trailer was adopted for a strength test for performance level three in the 1989 guide specifications.[1]

The 42-in (1.07-m) F-shape was initially tested with a 40,000-lb (18 160-kg) bus and was later tested with a 50,000-lb (22 700-kg) tractor-trailer. The passenger car and pickup tests listed for performance level three in the 1989 guide specifications were not performed on this railing design.[1]

For test 7069-7, the bus was equipped with triaxial accelerometers mounted near the center-of-gravity and two biaxial accelerometers--one set placed forward of the center-of-gravity and one set placed in the rear of the bus. For test 7069-10, the tractor was equipped with triaxial accelerometers mounted near the center-of-gravity and a biaxial block over the rear tractor tandems. Two biaxial accelerometer blocks were also placed in the trailer: one set toward the front and one set toward the rear. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration. In addition, each vehicle was instrumented with three solid-state angular rate transducers mounted near the center-of-gravity of each vehicle to measure yaw, pitch, and roll rates. The electronic signals from the accelerometer and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and displaying on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data.

Pressure sensitive contact switches on the bumper of each 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. Each initial contact also produced an "event" mark on the data record to establish the instant of impact.

The multiplex of data channels transmitted on one radio frequency was received at a data acquisition station and demultiplexed into separate tracks of Intermediate 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 performance.

For the bus test (test 7069-7) one Alderson Research Laboratories Hybrid II, 50th percentile anthropomorphic dummy was placed in the window seat on the second row of the right (impact) side of the bus. The dummy was uninstrumented. There were no seat belts, therefore the dummy was not restrained. There was no dummy used in the tractor-trailer test (7069-10).

The digitized data obtained from the electronic transducers were then processed using two computer programs: DIGITIZE AND PLOTANGLE. Brief descriptions on the functions of these two computer programs are as follows.

The DIGITIZE program digitizes the data from vehicle-mounted linear accelerometers and uses these data to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, highest 0.010-s average of vehicle acceleration after occupant/compartment impact, and time of highest 0.010-s average. 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 0.050-s intervals in each of three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package (QUATTRO PRO). For each of these graphs, a 0.050-s average window was calculated at the center of the 0.050-s interval and then plotted with the first 0.050-s average plotted at 0.026 s.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in degrees at 0.001-s intervals and instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented herein. 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 coverage of the test included three high-speed cameras: one placed to have a field of view parallel to and aligned with the bridge railing at the downstream end, one placed perpendicular to the front of the bridge railing, and a third over head with a field of view perpendicular to the ground and directly over the point of impact. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the bridge railing 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 professional video camera, and a 3/4-in (19 mm) video recorder along with 35-mm still cameras were used for documentary purposes and to record conditions of the test vehicle and bridge railing before and after the test.

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

CHAPTER 3. FULL-SCALE CRASH TESTS

TEST 7069-7

Test Description

The 1954 GMC Scenicruiser bus (figure 2) was directed into the 42-in (1.07-m) F-shape bridge railing (figure 3) using a remote control guidance system. Test inertia mass of the vehicle was 29,840 lb (13 547 kg) and its gross static mass was 40,560 lb (18 414 kg). The height to the lower edge of the vehicle bumper was 25.0 in (635 mm) and it was 38.25 in (972 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figure 4. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 55.7 mi/h (89.6 km/h) and the angle of impact was 15.7 degrees. The vehicle impacted the bridge railing at 35 ft (10.1 m) from the upstream end. At approximately 0.035 s after impact the right front wheel contacted the bridge railing. The vehicle began to redirect at 0.098 s as the rear end began to slide toward the bridge railing. The rear of the vehicle slapped the bridge railing at 0.3872 s, and by 0.396 s the vehicle was traveling parallel with the bridge railing. The vehicle very briefly lost contact with the bridge railing and recontacted it again. The vehicle rode against the bridge railing and off the end. The brakes were applied and the vehicle subsequently came to rest approximately 250 ft (76 m) downstream and 40 ft (12 m) on the field side of the point of impact.

The bridge railing received cosmetic damage and some scraping gouging. As shown in figure 5, there were tire marks on the bridge railing from just before the impact point extending a total of 25 ft (7.6 m) along the face. The vehicle then lost contact for 26 ft (7.9 m) and then recontacted the bridge railing for another 21 ft (6.4 m) when the bridge railing ended. There was also a longitudinal hairline crack along the bridge deck starting approximately at the point of impact for about 35 ft (11 m) and running nominally 2 ft (610 mm) from the base of the railing.

The vehicle sustained extensive damage to the right side as shown in figure 6. Maximum crush at the right front corner at bumper height was 4.0 in (102 mm). The right front and right rear wheel rims were scratched. The front wheel assembly and suspension was damaged. The door was bent and the windshield was broken out. The right rear panel was dented and scraped.

Test Results

Impact speed was 55.7 mi/h (89.6 km/h) and the angle of impact was 15.7 degrees. The speed at 1.0 s after impact was 42.5 mi/h (68.4 km/h) and the vehicle trajectory path was 0 degrees. The effective coefficient of friction was calculated to be 0.31. Occupant impact velocity was 7.9 ft/s (2.4 m/s) in the longitudinal direction and 5.4 ft/s (1.6 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -2.4 g (longitudinal) and 21.7 g (lateral). These data and other pertinent information from the test are summarized in figure 7 and tables 1 and 2. Sequential photographs are shown in figures 8 and 9. Vehicular angular displacements are displayed in figure 10.

Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 11 through 17. These data were further analyzed to obtain 0.050-s average accelerations versus time. A 0.050-s interval immediately prior to impact was averaged to establish zero acceleration. The data were then processed with a moving 0.050-s average window with the first 0.050-s average plotted at 0.026 s for each trace. The maximum 0.050-s averages were -1.5 g (longitudinal) and 6.5 g (lateral).

Conclusions

The 42-in (1.07-m) F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. See figure 7 and tables 1 and 2 for a more detailed description.

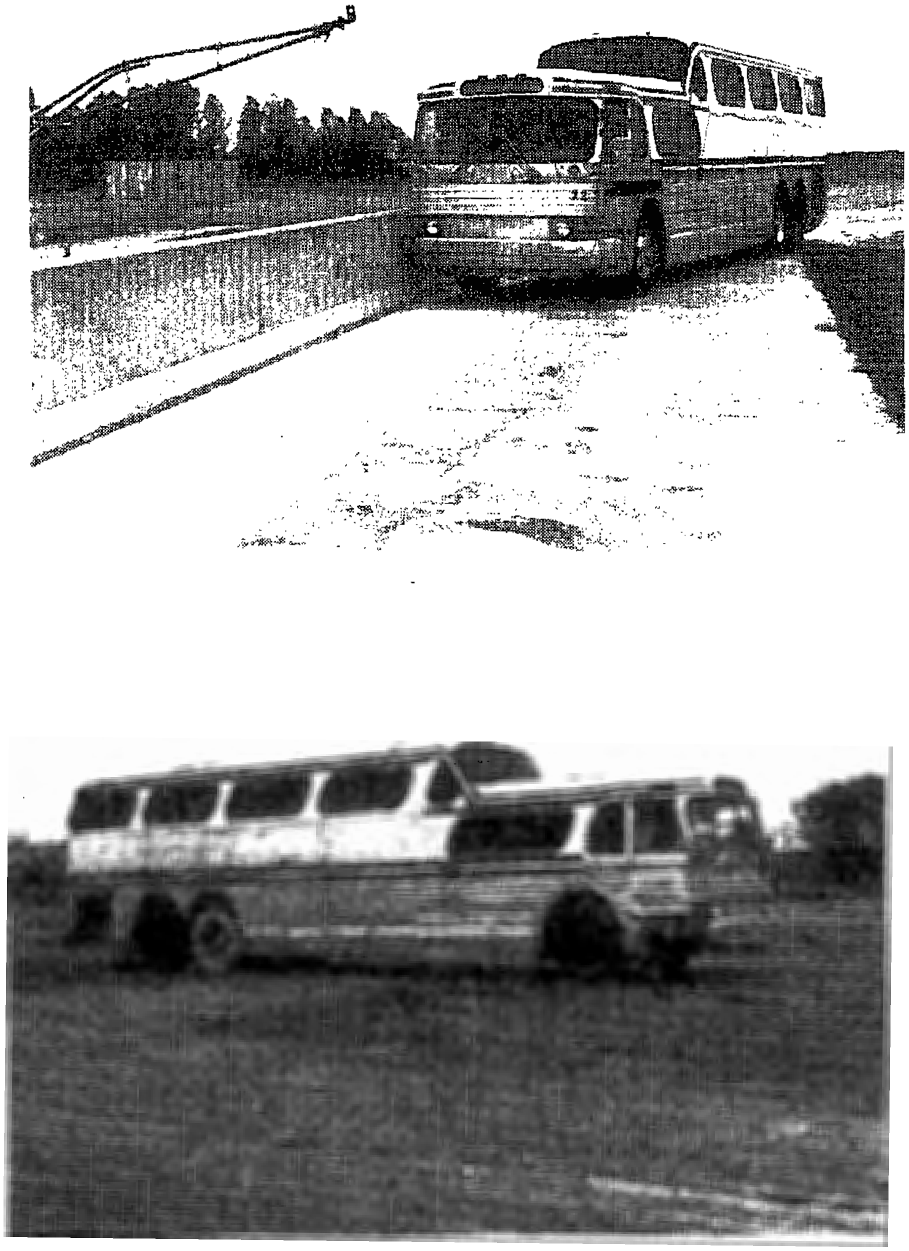
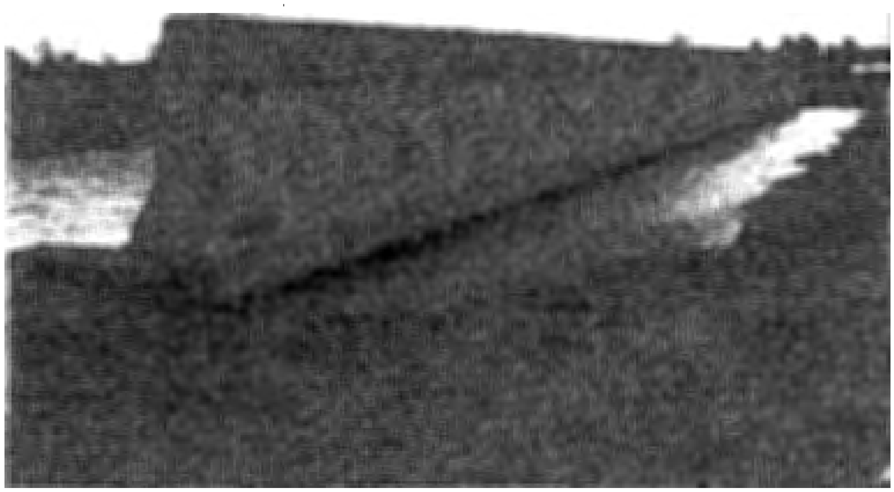


Figure 2. Vehicle before test 7069-7 .



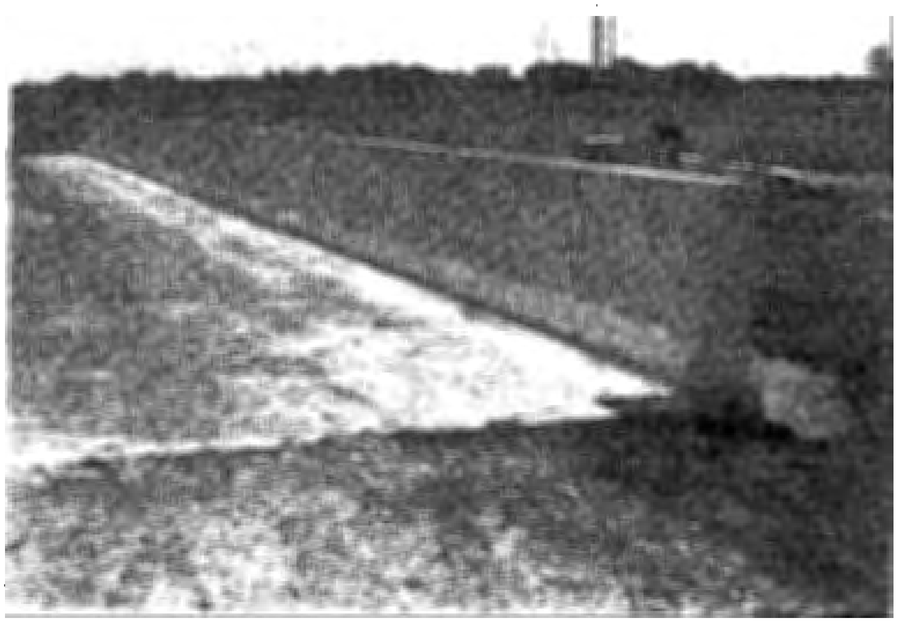
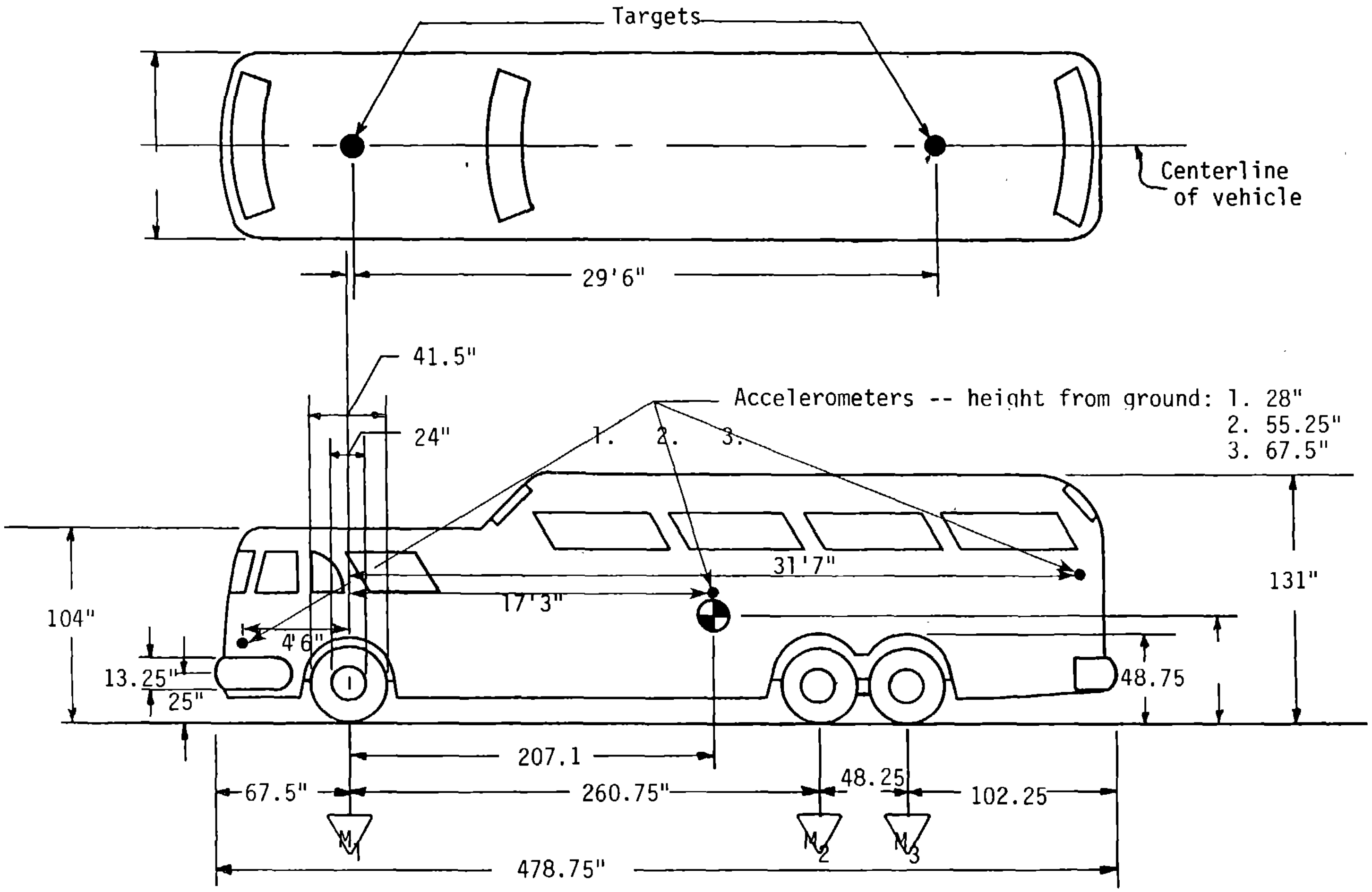


Figure 3. 42-in (1.07-m) F-shape bridge railing before test 7069-7.



1 in = 25.4 mm
1 lb - 0.454 kg

Mass - lb	Empty	Gross Static
M_1	7,370	11,010
M_2	11,360	15,180
M_3	11,110	14,370
M_T	29,840	40,560

Figure 4. Vehicle properties for test 7069-7.

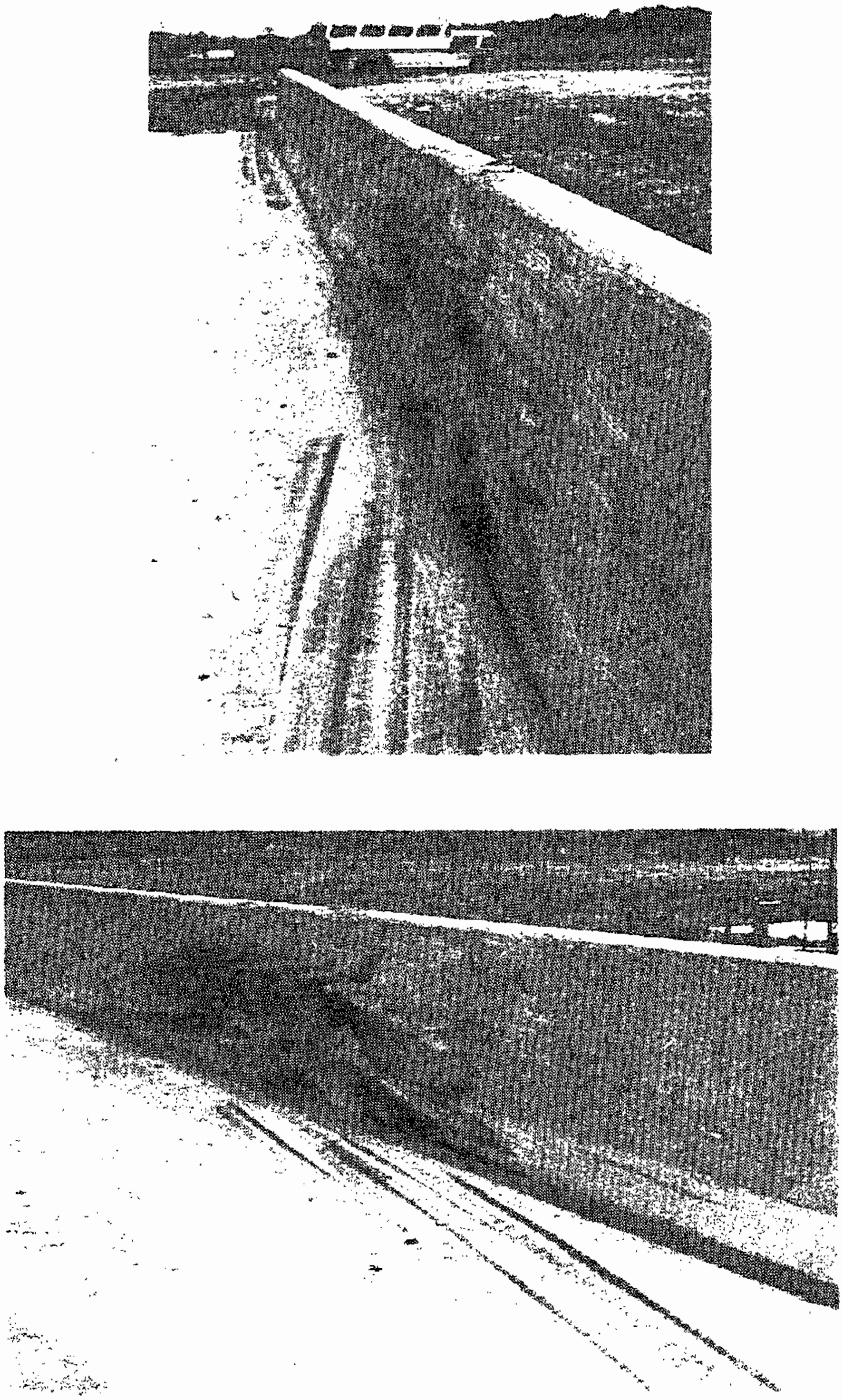
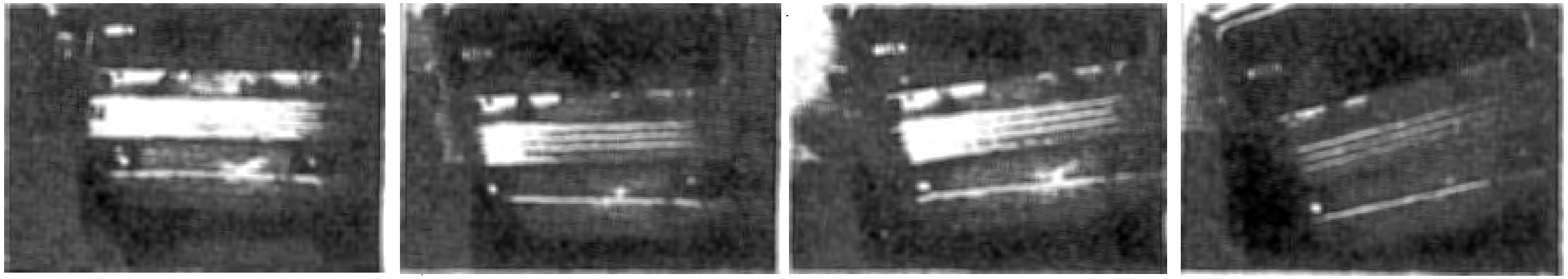
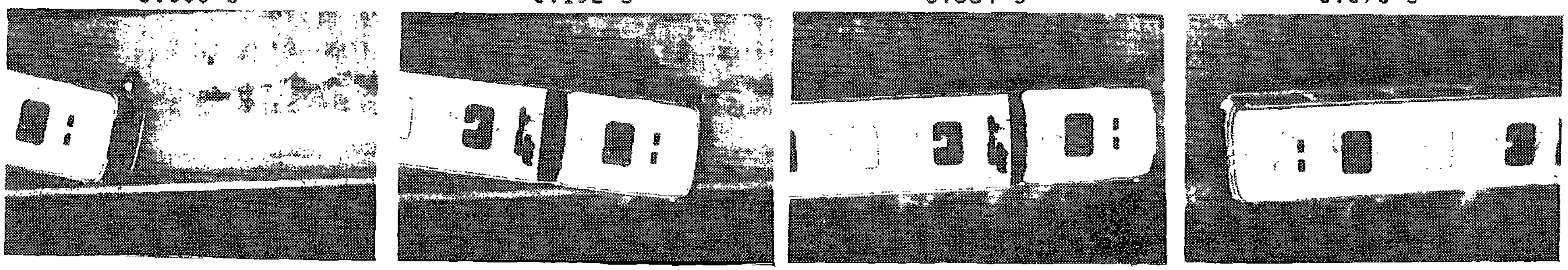


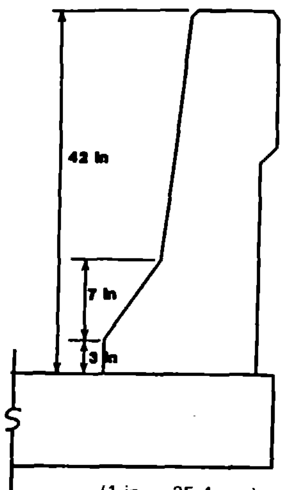
Figure 5. 42-in (1.07-m) F-shape bridge railing after test 7069-7.

Figure 6. Vehicle after test 7069-7.



0.000 s | 0.192 s | 0.384 s | 0.576 s





(1 in = 25.4 mm)

Test No.	7069-7
Date	11/19/87
Test Installation . . .	42-in (1.07-m) F-shape Bridge Railing
Installation Length . .	100 ft (30 m)
Vehicle	1954 GMC Scenicruiser Bus
Vehicle Weight	
Test Inertia	29,840 lb (13,547 kg)
Gross Static	40,560 lb (18,414 kg)
Vehicle Damage Classification	
TAD	N/A
CDC	N/A
Maximum Vehicle Crush .	4.0 in (102 mm)

Impact Speed. . . .	55.7 mi/h (89.6 km/h)
Impact Angle. . . .	15.7 deg
Exit Speed	42.5 mi/h (68.4 km/h)
Exit Trajctory . .	0 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal. . .	-1.5 g
Lateral	6.5 g
Occupant Impact Velocity	
Longitudinal. . .	7.9 ft/s (2.4 m/s)
Lateral	5.4 ft/s (1.6 m/s)
Occupant Ridedown Accelerations	
Longitudinal. . .	-2.4 g
Lateral	21.7 g

Figure 7. Summary of results for test 7069-7.

Table 1. Evaluation of crash test no. 7069-7.
{42-in (1.07-m) F-shape bridge railing [40,560 lb (18 414 kg)|55.7 mi/h (89.6 km/h)|15.7 degrees]}

	CRITERIA *	TEST RESULTS	PASS/FAIL
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction		
	μ / Assessment 0 - .25 / Good .26 - .35 / Fair > .35 / Marginal	μ / Assessment .31 / Fair	Pass
G.	Shall be less than		
	Occupant Impact Velocity - ft/s (m/s) Longitudinal / Lateral 30 (9.2) / 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal / Lateral 7.9 (2.4) / 5.4 (1.6)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal / Lateral 15 / 15	Occupant Ridedown Accelerations - g's Longitudinal / Lateral -2.4 / 21.7	N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was 0 degrees	Pass

* A, B, C, and D are required. E, F, and H are desired. G is not applicable for this test. (See table 2)

Table 2. Bridge railing performance levels and crash test criteria
(Guide Specifications for Bridge Railings, proposed).(2)

PERFORMANCE LEVELS		TEST SPEEDS -- mph [1,2]			
		TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
		Small Automobile W = 1.8 Kips A = 5.4' B = 5.5' H_{cg} = 19" θ = 20 deg.	Pickup Truck W = 5.4 Kips A = 8.9' B = 6.5' H_{cg} = 33" θ = 20 deg.	Intercity Bus (loose ballast) W = 40.0 Kips A = 23.2' B = 8.0' H_{cg} = 56" θ = 15 deg.	Van-Type Tractor-Trailer[4] No. 2 W = 80.0 Kips A = 13.1' B = 8.0' H_{cg} = 72" R = 0.58 θ = 15 deg.
PL-1		50	45		
PL-2		60	65		
PL-3		60	65	60	
PL-4		60	65		55
CRASH TEST EVALUATION CRITERIA[3]	Required	a,b,c,d,g	a,b,c,d	a,b,c,d	a,b,c
	Desirable[5]	e,f,h	e,f,g,h	e,f,h	d,e,f,h

Notes:

1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report No. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.

2. Permissible tolerances on the test speeds and angles are as follows:

Speed	-1.0 mph	+2.5 mph
Angle	-1.0 deg.	+2.5 deg.

   Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.

3. Criteria for evaluating bridge railing crash test results are as follows:

   a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.

   b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

   c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.

   d. The vehicle shall remain upright during and after collision.

Table 2. Bridge railing performance levels and crash test criteria *(Guide Specifications for Bridge Railings,* proposed continued).(2)

Notes (cont.):

e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degress away from the railing from time of impact until the vehicle separates from the railing.

f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ:

μ	Assessment
0 - 0.25	Good
0.26 - 0.35	Fair
>0.35	Marginal

where $\mu = (\cos\theta - V_p/V)/\sin\theta$

g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral displacements, shall be less than:

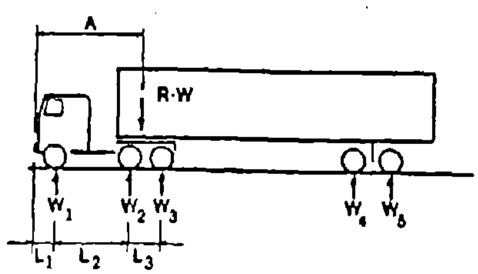
Occupant Impact Velocity - fps	
Longitudinal	Lateral
30	25

and the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant Ridedown Accelerations - g's	
Longitudinal	Lateral
15	15

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. after losing contact with the railing, the vehicle shall move no more than 20 ft. plus the vehicle width from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100 ft. from the point of initial impact.

4. Values A and R are estimated values describing the test vehicle and its loading. Values of A and R are described in the figure below and calculated as follows:



$$A = L_1 + \frac{W_2 L_2 + W_3 (L_2 + L_3)}{W_1 + W_2 + W_3}$$

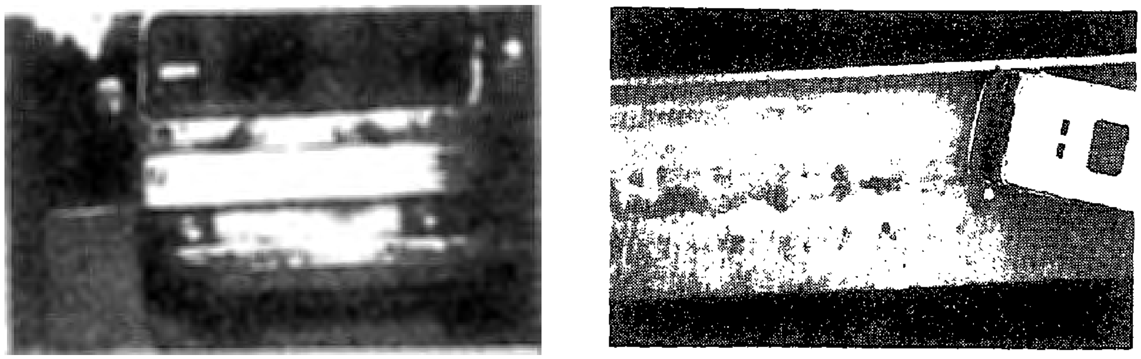
$$R = \frac{W_1 + W_2 + W_3}{W}$$

$$W = W_1 + W_2 + W_3 + W_4 + W_5$$

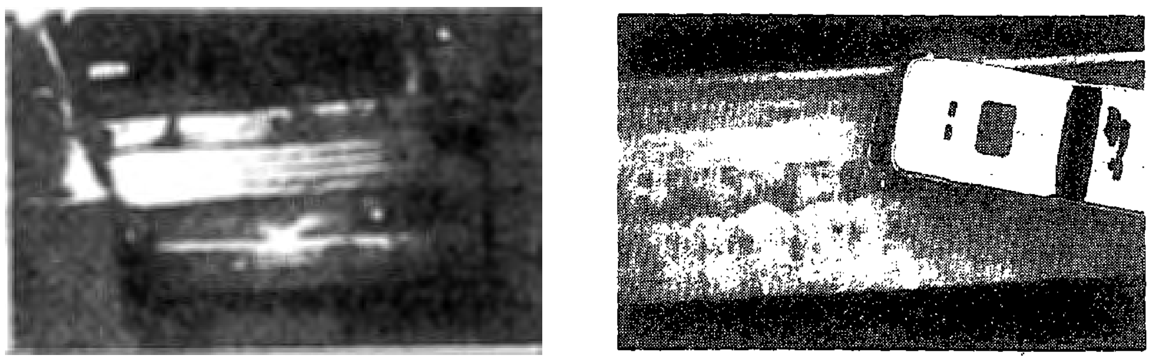
= total vehicle weight.

5. Test articles that do not meet the "desirable" evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

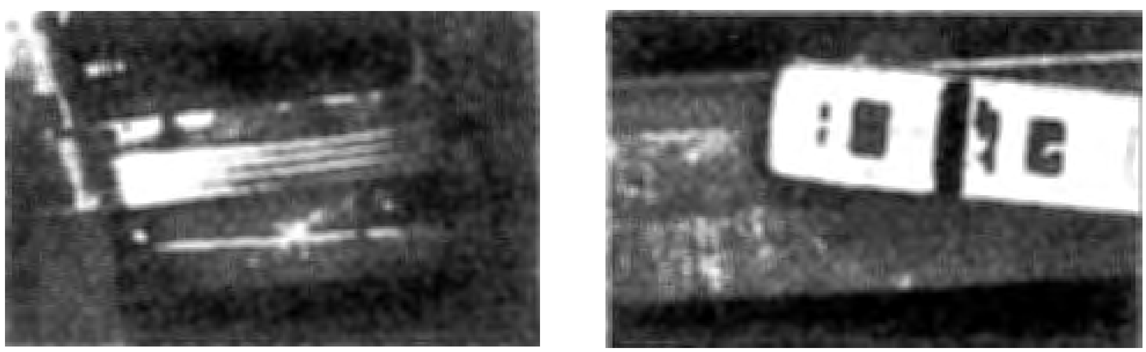
1 kip = 4.45 kN
1 mi/h = 1.609 km/h
1 ft = 0.305 m



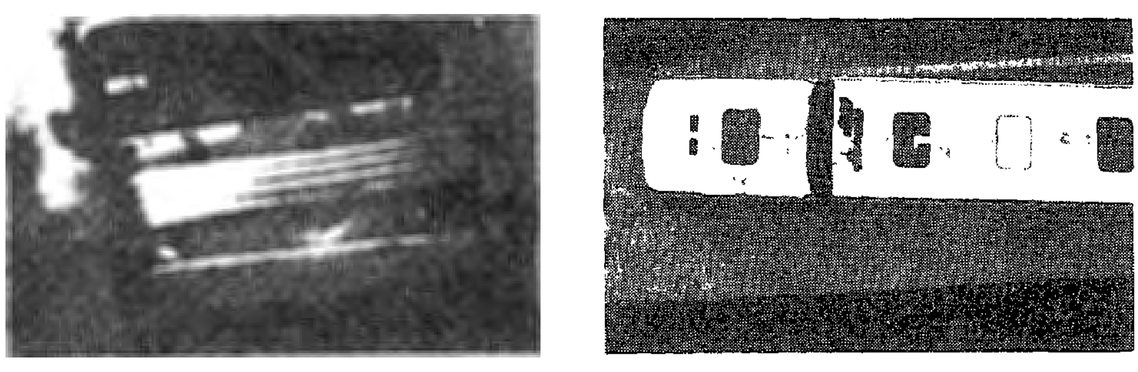
0.000 s



0.096 s

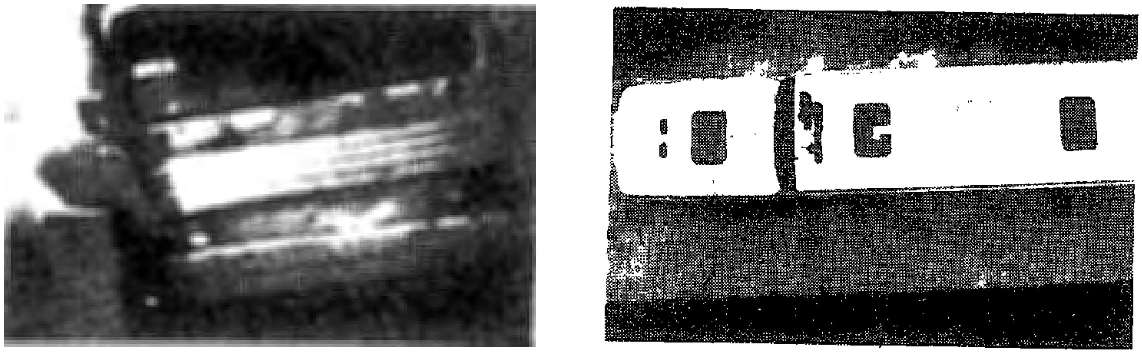


0.192 s

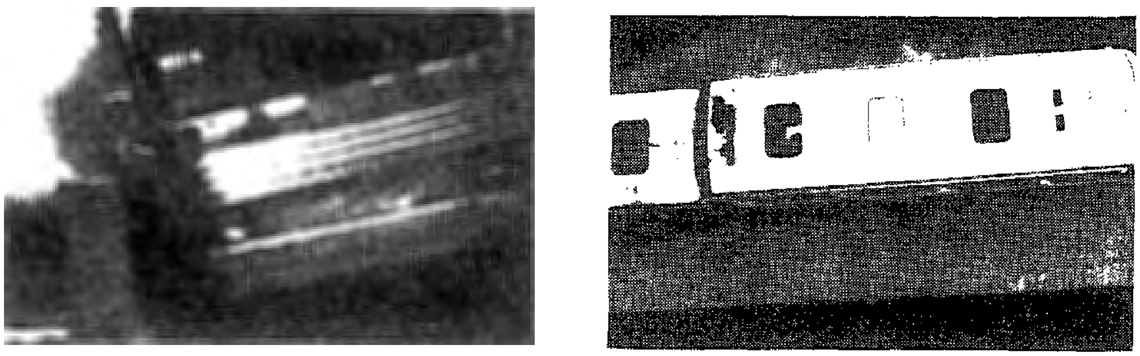


0.288 s

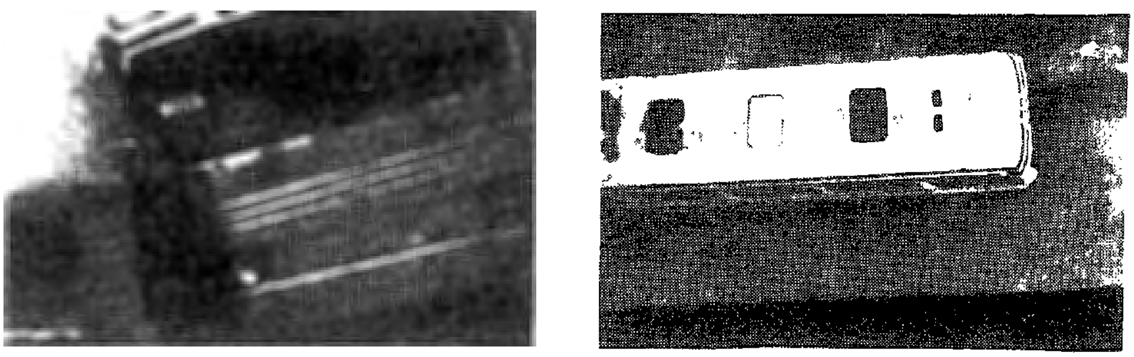
Figure 8. Sequential photographs for test 7069-7.



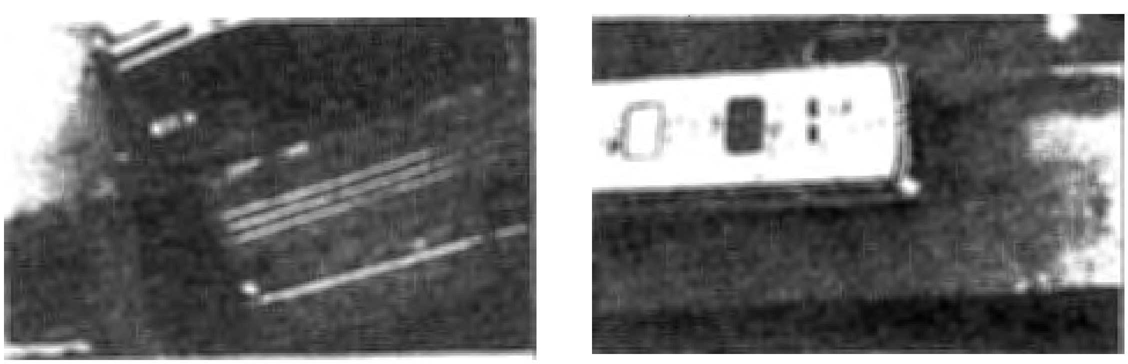
0.384 s



0.480 s

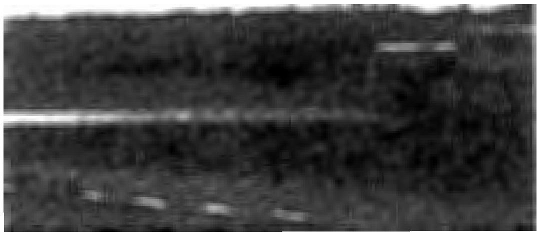


0.576 s

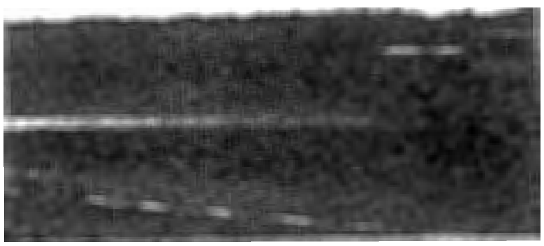


0.672 s

Figure 8. Sequential photographs for test 7069-7 (continued).

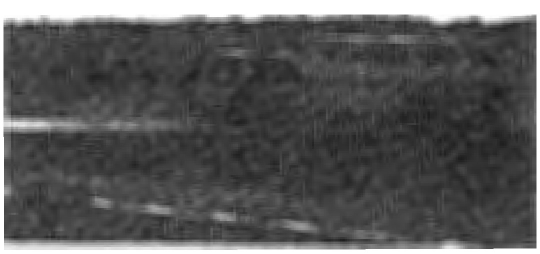


0.000 s



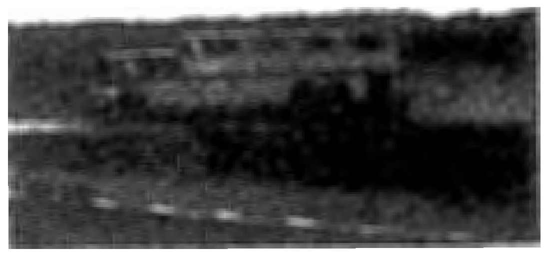
0.096 s

0.192 s

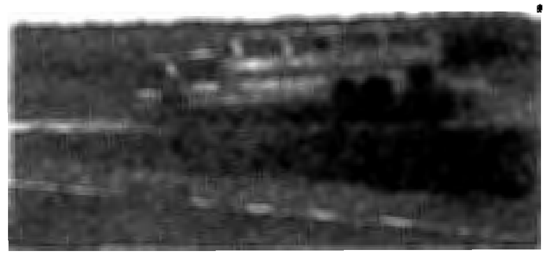


0.288 s

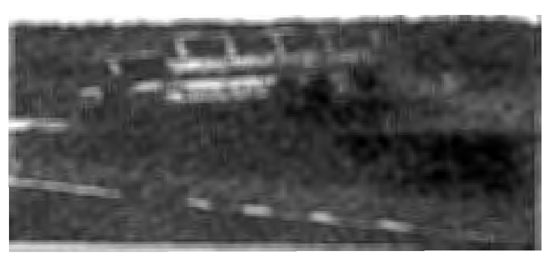
0.384 s



0.480 s

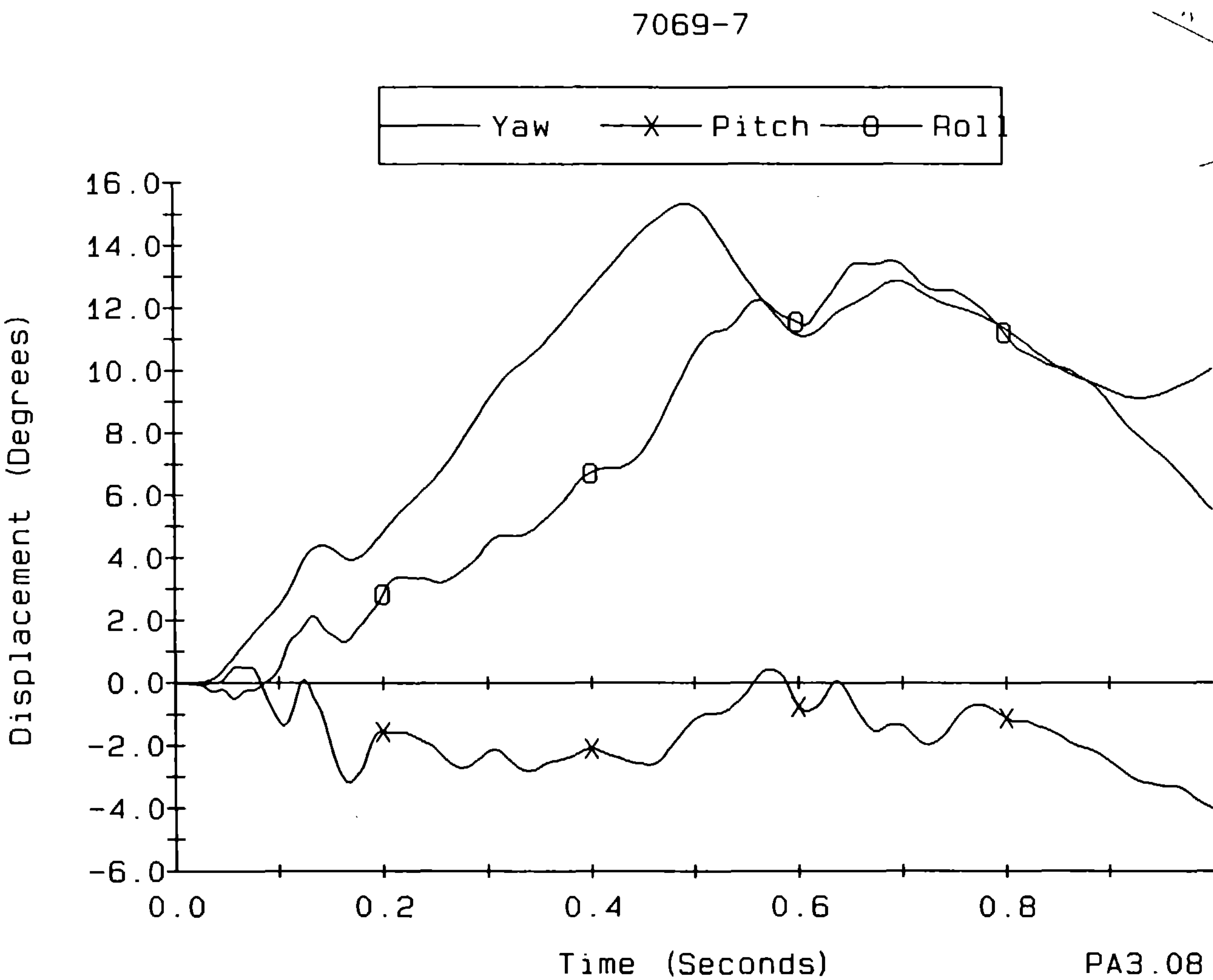


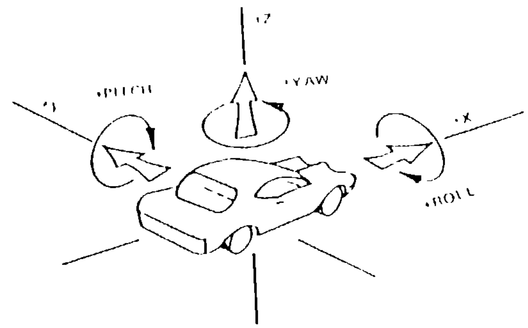
0.576 s



0.672 s

Figure 9. Perpendicular sequential photographs for test 7069-7.





Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 10. Vehicle angular displacements for test 7069-7.

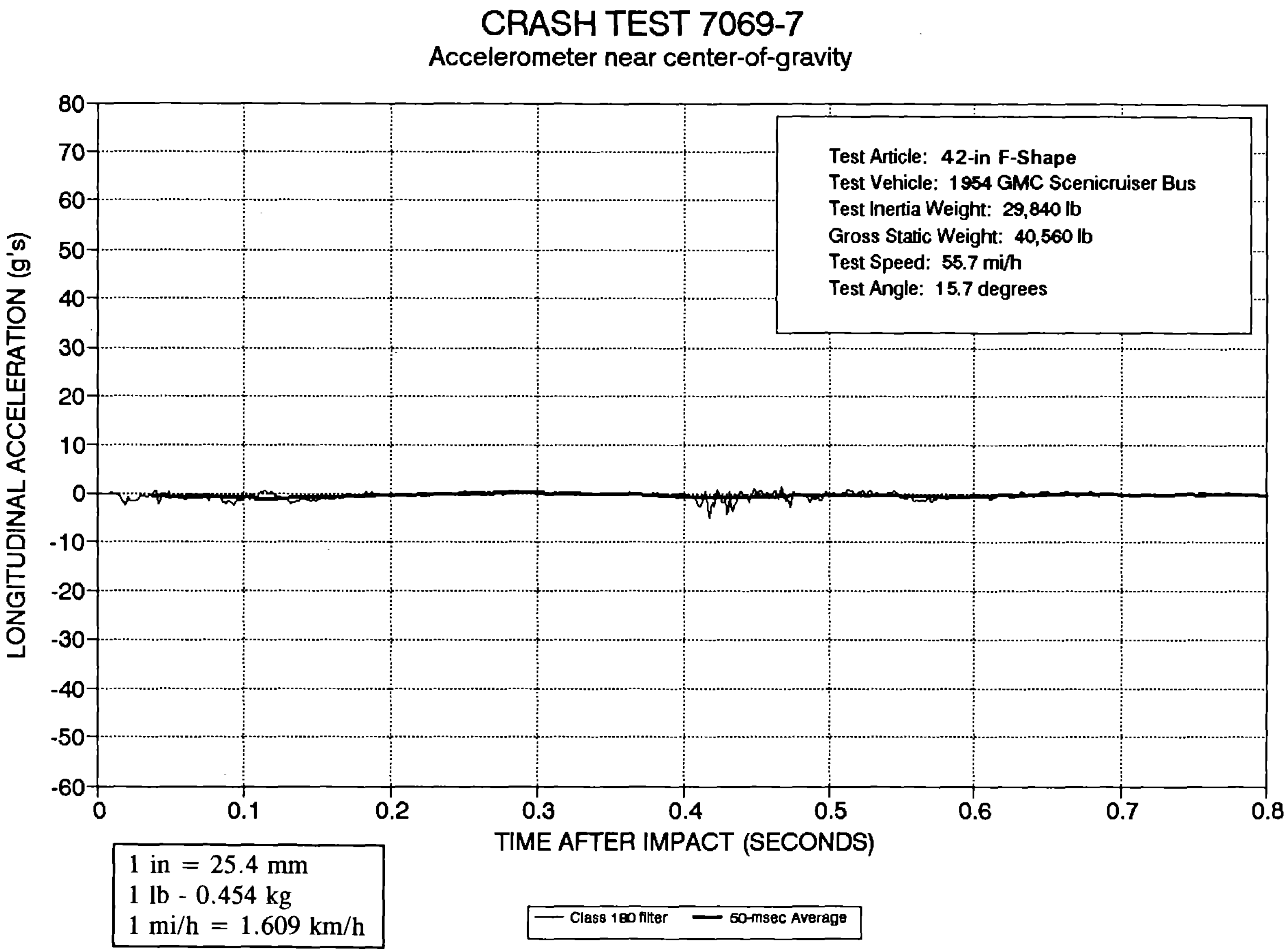


Figure 11. Vehicle longitudinal accelerometer trace for test 7069-7
(accelerometer located near center-of-gravity).

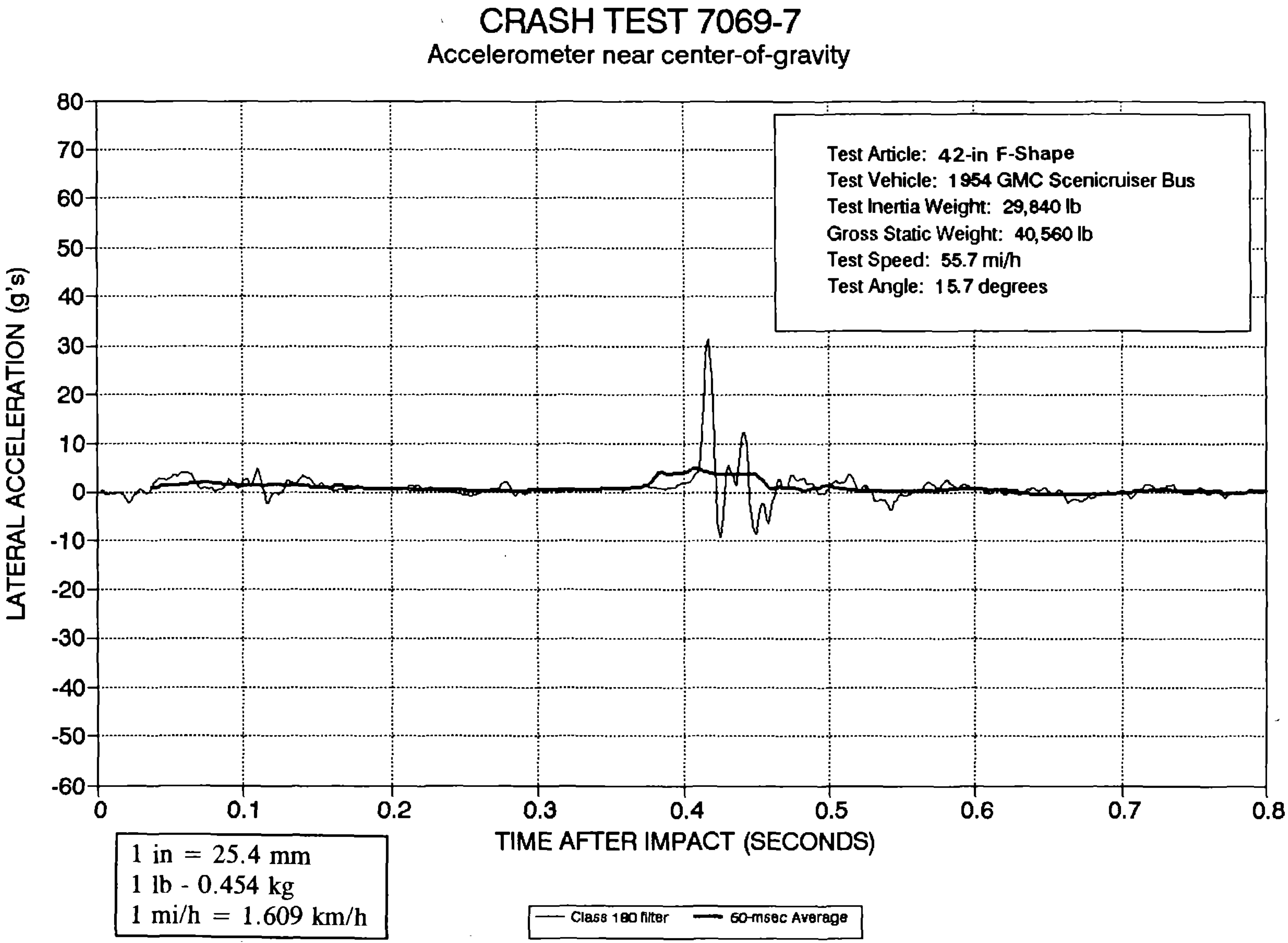


Figure 12. Vehicle lateral accelerometer trace for test 7069-7 (accelerometer located near center-of-gravity).

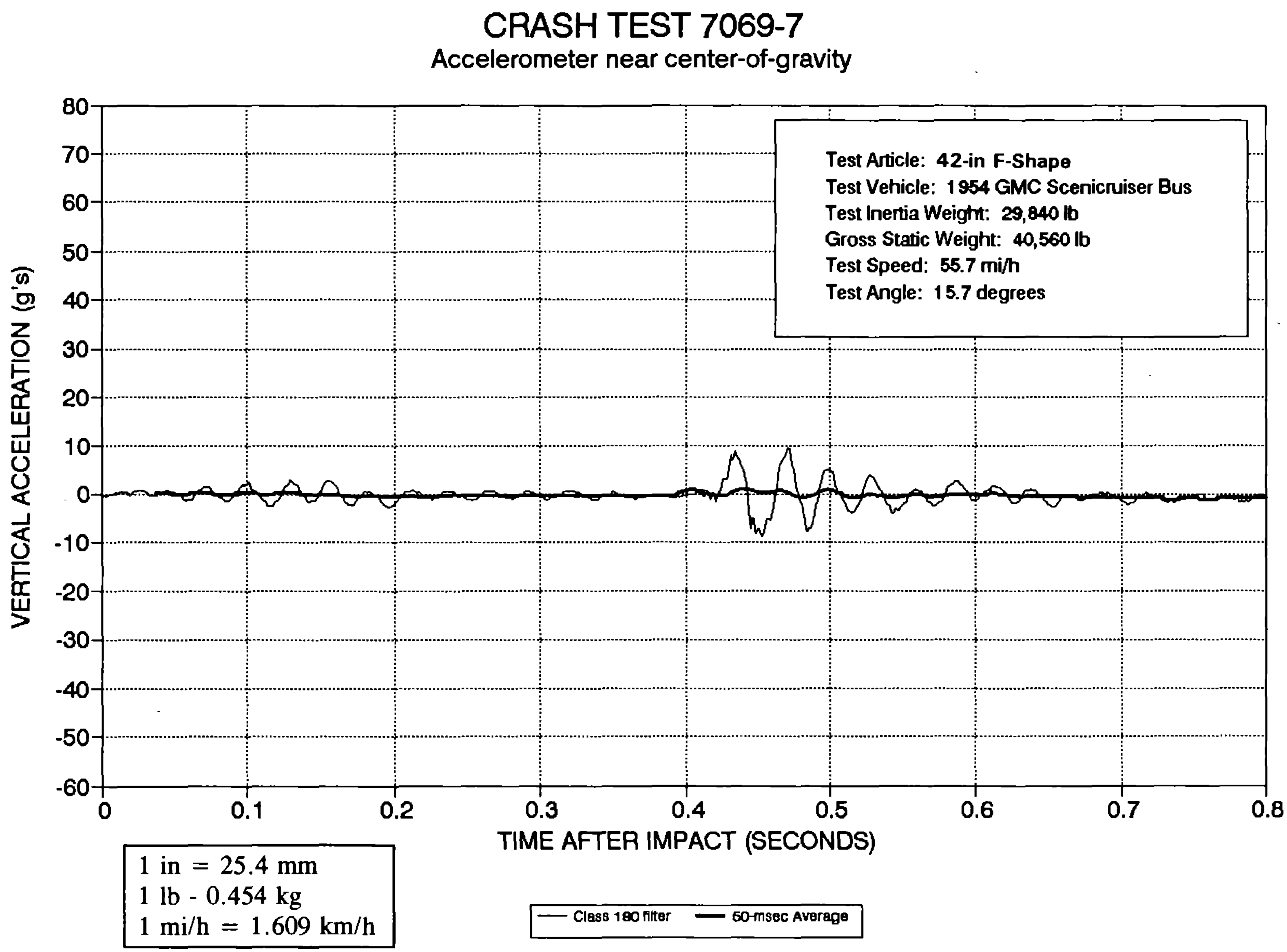


Figure 13. Vehicle vertical accelerometer trace for test 7069-7 (accelerometer located near center-of-gravity).

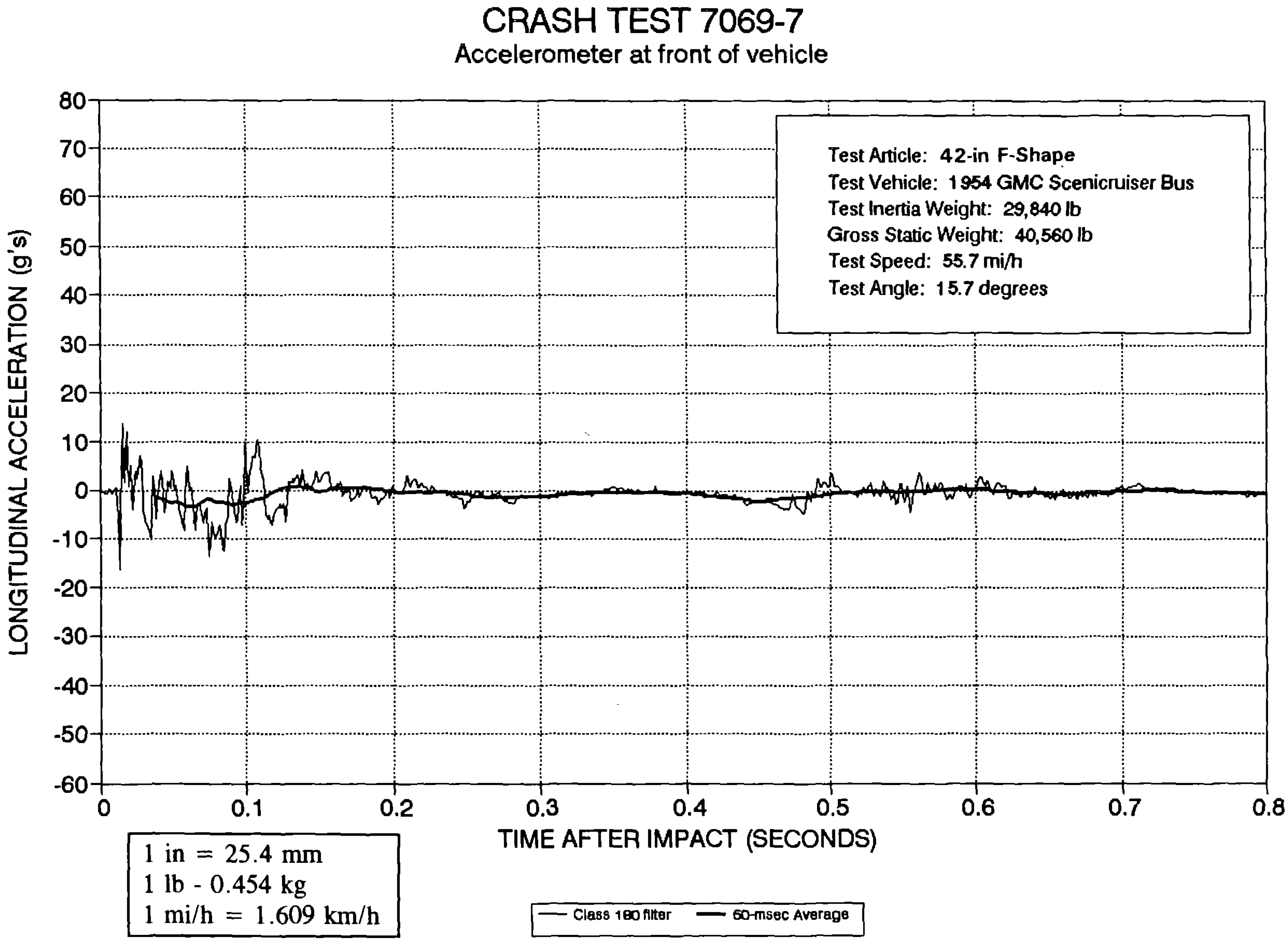


Figure 14. Vehicle longitudinal accelerometer trace for test 7069-7 (accelerometer located at front of vehicle).

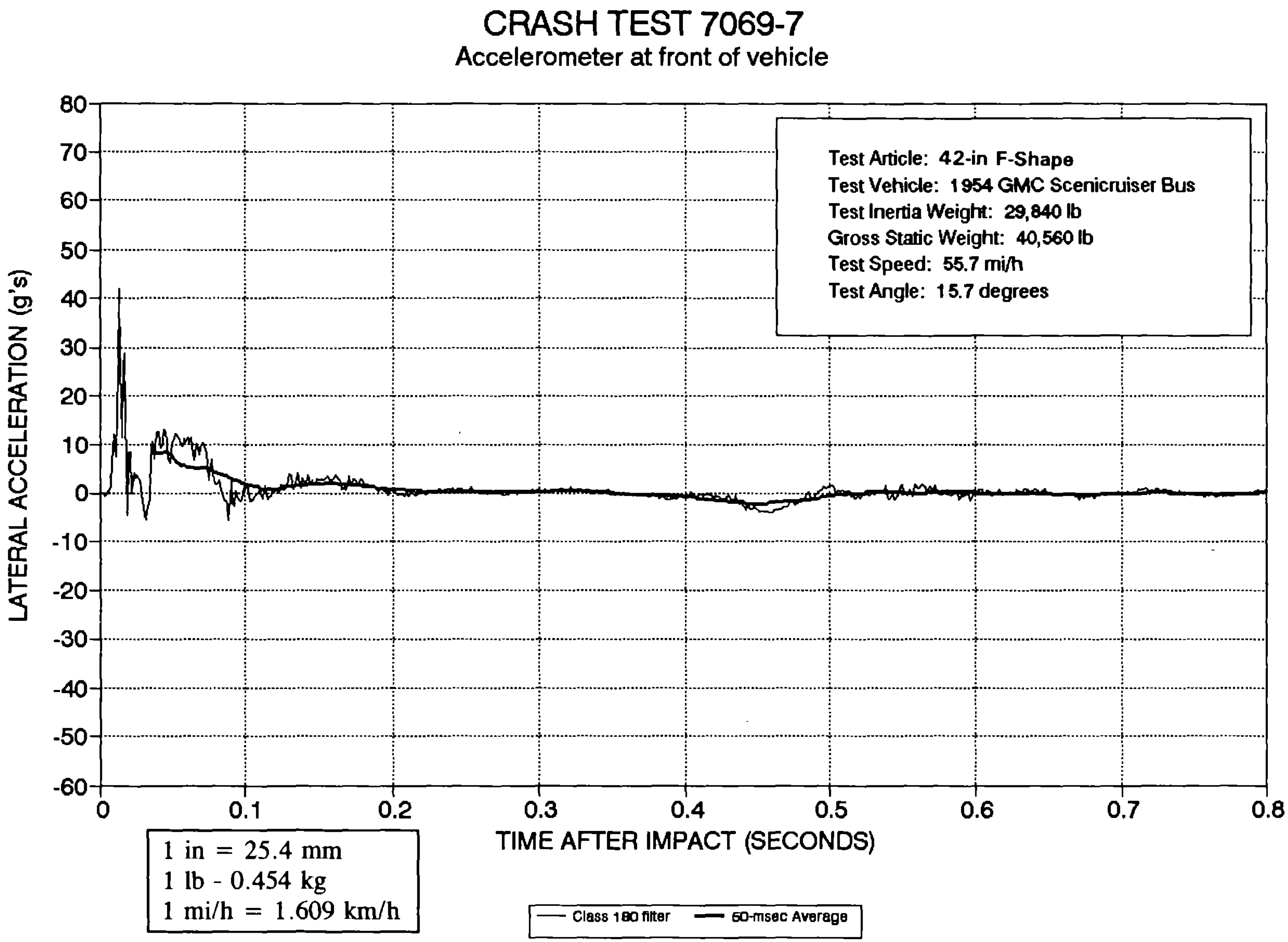


Figure 15. Vehicle lateral accelerometer trace for test 7069-7
(accelerometer located at front of vehicle).

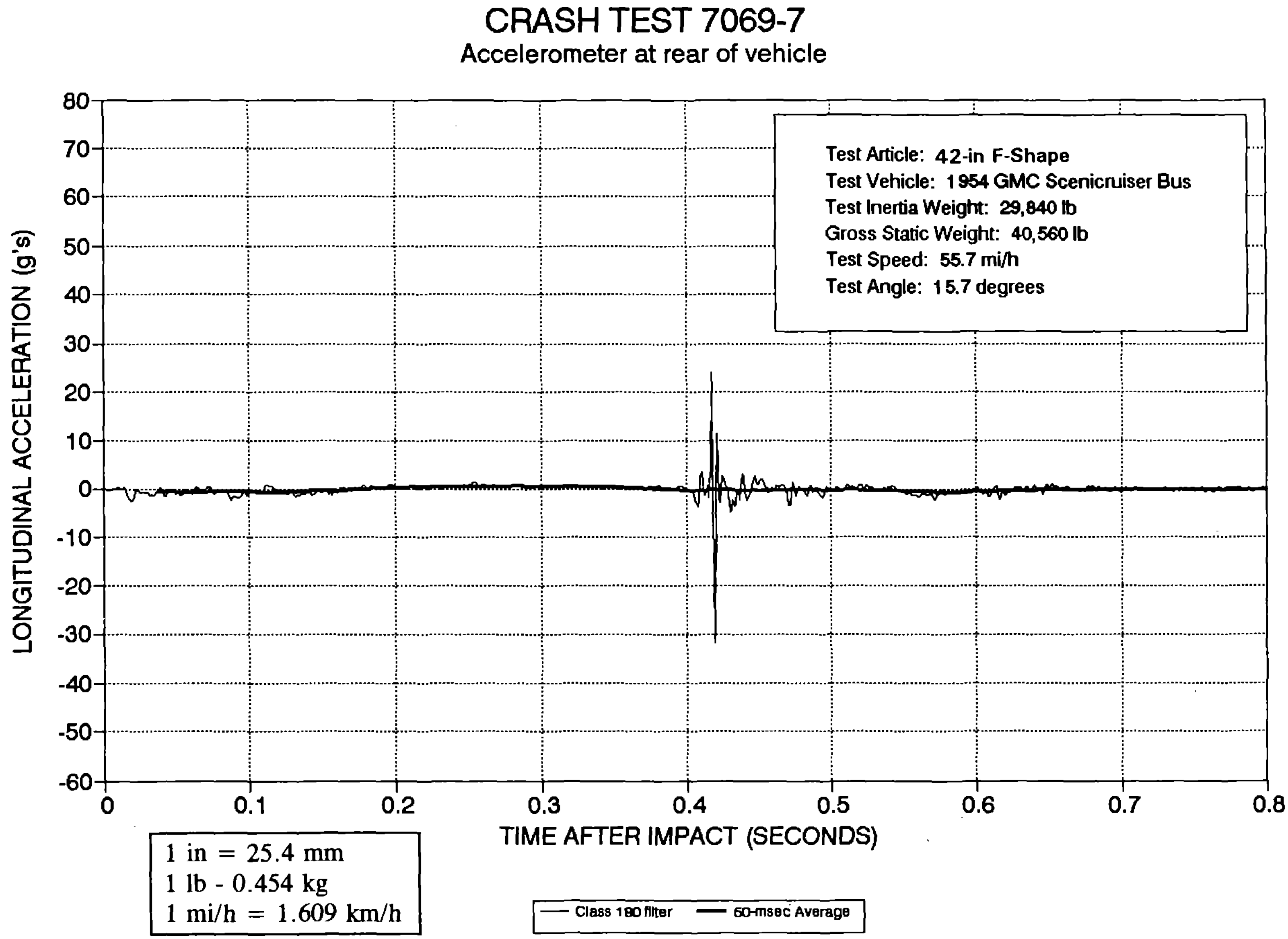


Figure 16. Vehicle longitudinal accelerometer trace for test 7069-7 (accelerometer located at rear of vehicle).

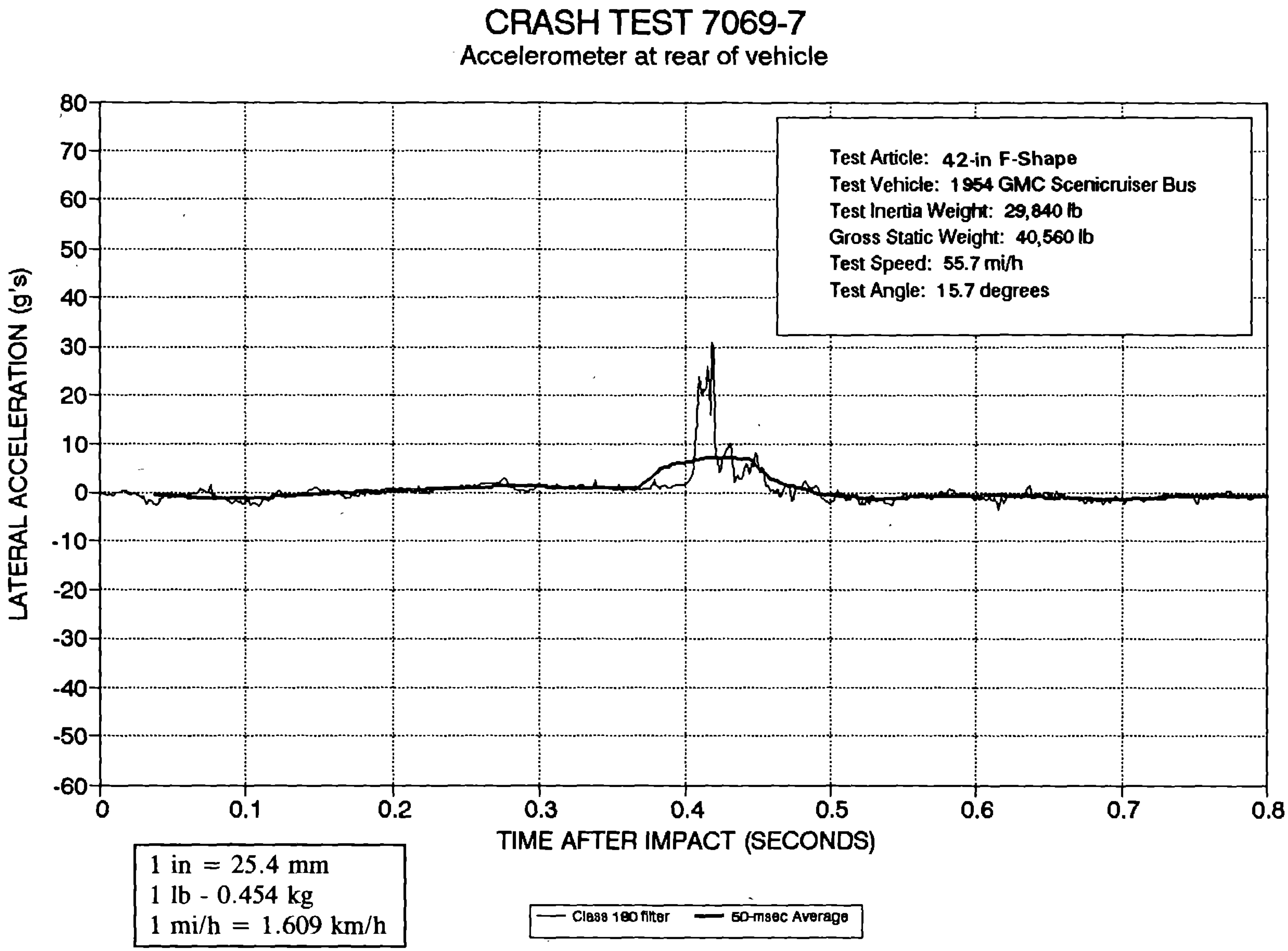


Figure 17. Vehicle lateral accelerometer trace for test 7069-7 (accelerometer located at rear of vehicle).

TEST 7069-10

Test Description

A 1979 International Transtar 4200 tractor with a 45-ft van-trailer (figures 18 and 19) was directed into the 42-in (1.07-m) F-shape bridge railing (figure 20) using a remote control guidance system. Test inertia mass of the vehicle was 29,900 lb (13 574 kg) and its gross static mass was 50,000 lb (22 700 kg). The height to the lower edge of the vehicle bumper was 20.5 in (521 mm) and it was 30.5 in (775 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figures 21 through 23. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 52.2 mi/h (84.0 km/h) and the angle of impact was 14.0 degrees. The vehicle impacted the bridge railing at 35 ft (10.1 m) from the upstream end. At approximately 0.005 s after impact the right front wheel contacted the bridge railing and began to ride up the face of the bridge railing. The right front wheel left the pavement at 0.032 s, and the left front wheel left the pavement at 0.120 s. The vehicle began to redirect at 0.124 s as the rear end began to slide toward the bridge railing. At 0.260 s the right front corner of the trailer contacted the top of the bridge railing. The rear wheels of the tractor lost contact with the pavement at 0.309 s, and the tractor remained airborne until 0.594 s when the front wheels touched down. The rear trailer wheels contacted the bridge railing at about 0.785 s. The vehicle rode against the bridge railing and off the end. The brakes were applied and the vehicle subsequently came to rest approximately 300 ft (91 m) downstream from the point of impact.

The bridge railing received cosmetic damage and some scraping and gouging. As shown in figure 24, there were tire marks on the bridge railing from just before the impact point extending a total of 72 ft (21.9 m) along the face. There was also a piece of the top of the bridge railing chipped off where the edge of the trailer impacted.

The vehicle sustained extensive damage to the right side as shown in figures 25 and 26. Maximum crush at the right front corner at bumper height was 18.0 in (457 mm). Both outside right rear wheel rims were bent and the tires aired out. The front wheel assembly and suspension was damaged. The shock mounts were broken, the tie rods bent, the steering rod was bent, and the springs were loose. The right side door was dented.

Test Results

Impact speed was 52.2 mi/h (84.0 km/h) and the angle of impact was 14.0 degrees. Exit speed was not available. The speed at 0.785 s after impact was 45.7 mi/h (73.5 km/h) and the vehicle trajectory path was 0 degrees. The effective coefficient of friction was not available. Occupant impact velocity was 9.1 ft/s (2.8 m/s) in the longitudinal direction and 9.3 ft/s (2.8 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -4.7 g (longitudinal) and 3.7 g (lateral). These data and other pertinent information from the test are summarized in figure 27 and table 3. Sequential photographs are shown in figures 28 and 29. Vehicular angular displacements are displayed in figure 30.

Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 31 through 39. These data were further analyzed to obtain 0.050-s average accelerations versus time. A 0.050-s interval immediately prior to impact was averaged to establish zero acceleration. The data were then processed with a moving 0.050-s average window. The maximum 0.050-s averages at the tractor c.g. were -2.2 g (longitudinal) and 4.7 g (lateral).

Conclusions

The 42-in (1.07-m) F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There were no debris or detached elements. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. See figure 27 and table 3 for a more detailed descriptions.

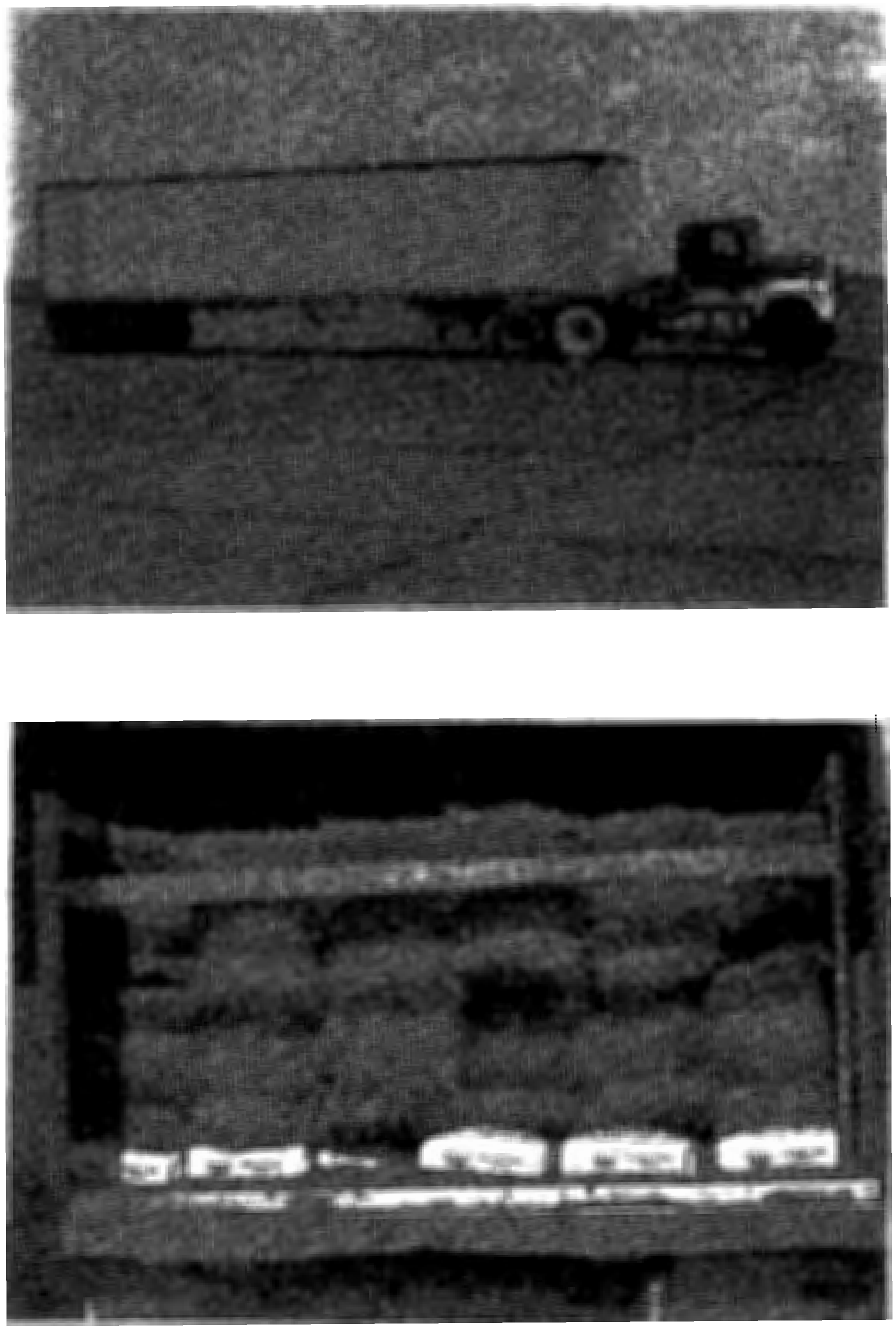
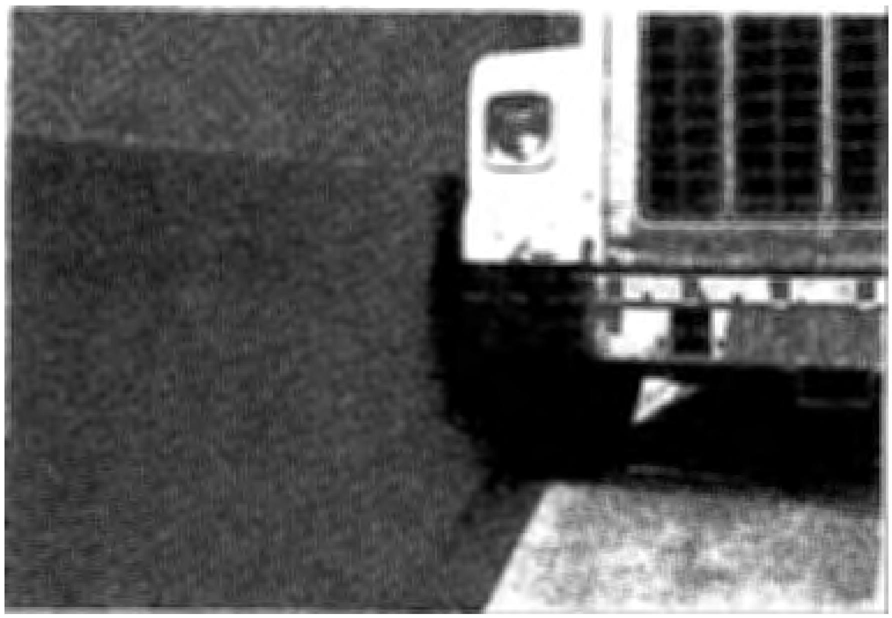


Figure 18. Vehicle before test 7069-10.



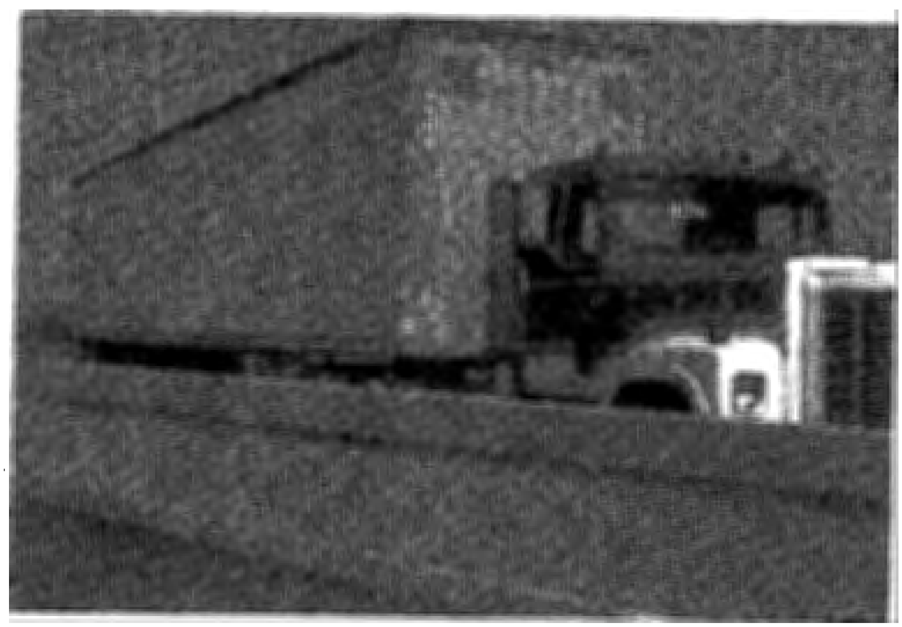


Figure 19. Vehicle/bridge rail geometrics for test 7069-10.

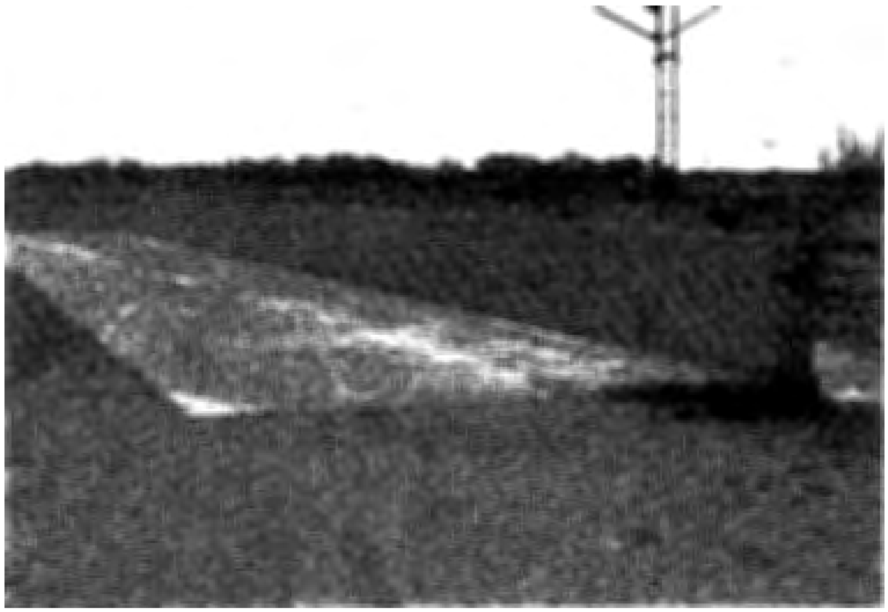
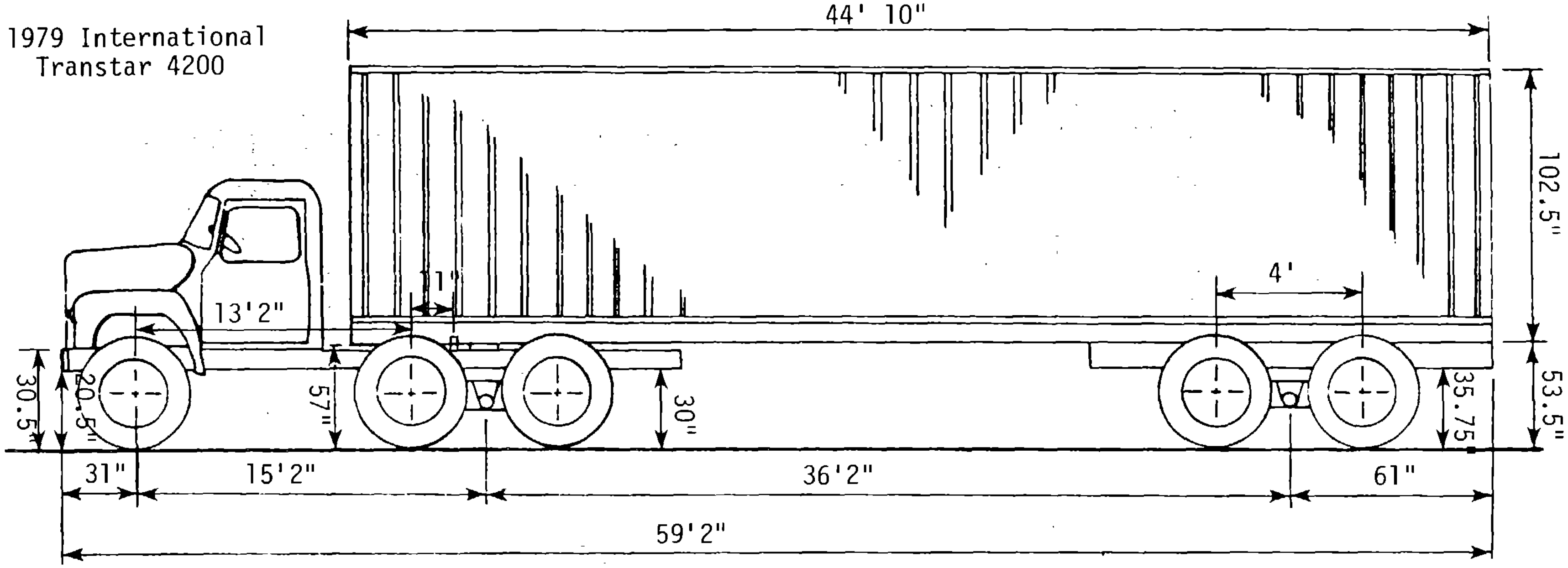


Figure 20. 42-in (1.07-m) F-shape bridge rail before test 7069-10.

TRACTOR - TRAILER

1979 International
Transtar 4200



EMPTY WEIGHT: 29,900 lb

LOADED WEIGHTS:

Weight on front axle:	9,400
Weight on center axles:	21,760
Weight on rear axles:	18,840
TOTAL LOADED WEIGHT:	50,000

LOCATION OF CENTER-OF-GRAVITY:

Tractor

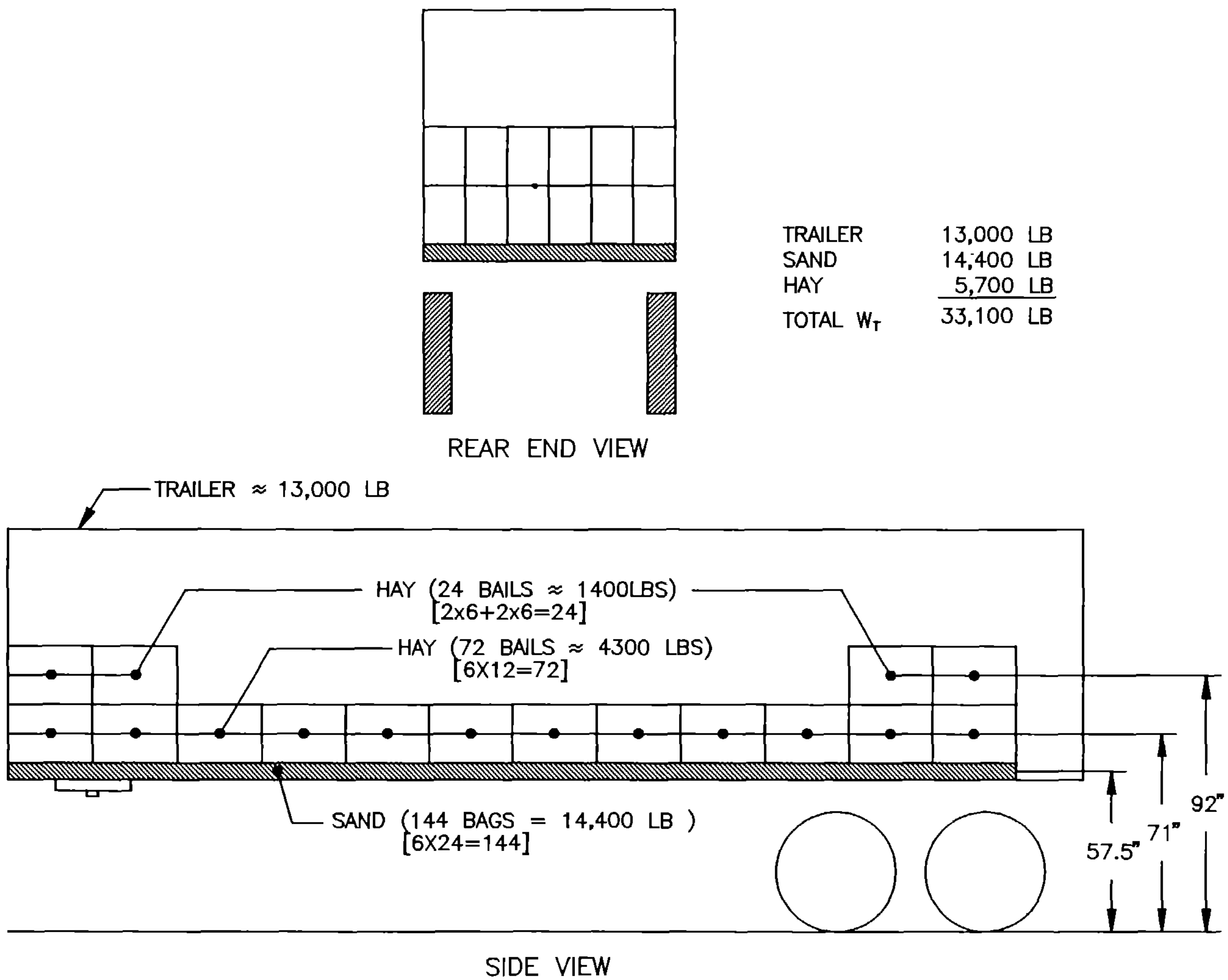
92 in behind front axle
35 in above the ground

Trailer

336.4 in from front of box
58 in from ground (trailer empty)
61 in from ground (composite)

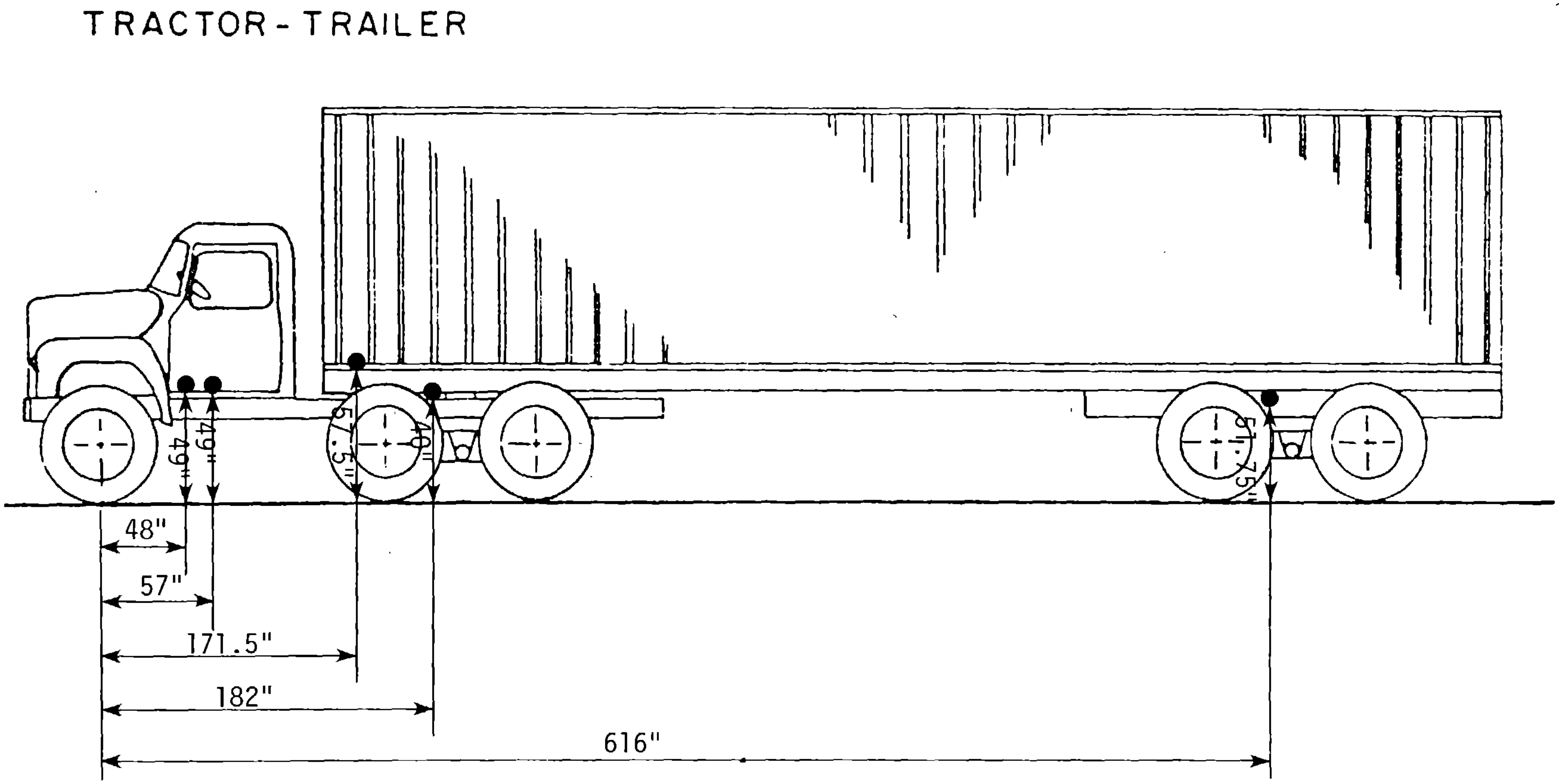
1 in = 25.4 mm
1 lb - 0.454 kg

Figure 21. Vehicle properties for test 7069-10.



1 in = 25.4 mm
1 lb - 0.454 kg

Figure 22. Position of load in trailer for test 7069-10.



1 in = 25.4 mm
1 lb - 0.454 kg

Figure 23. Accelerometer locations for test 7069-10.

Figure 24. 42-in (1.07-m) F-shape bridge rail after test 7069-10.

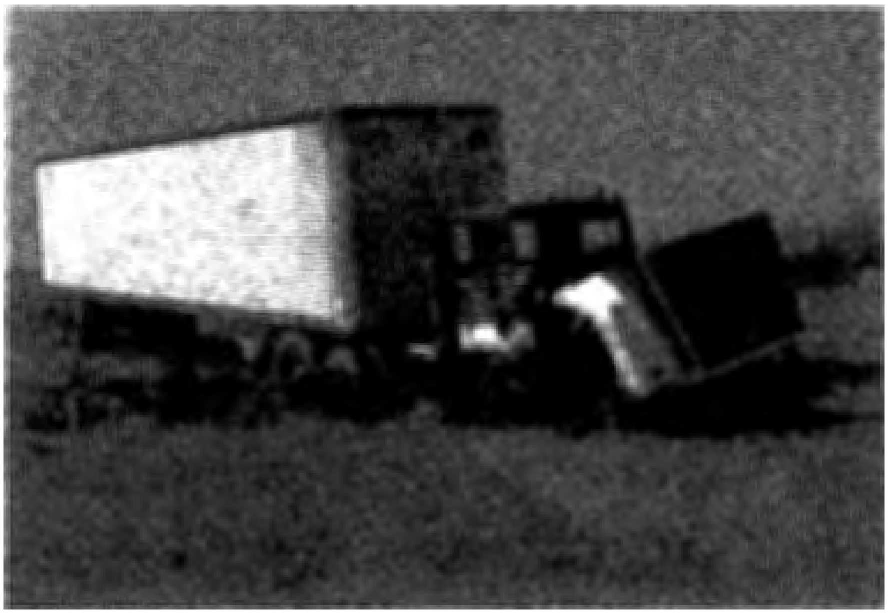
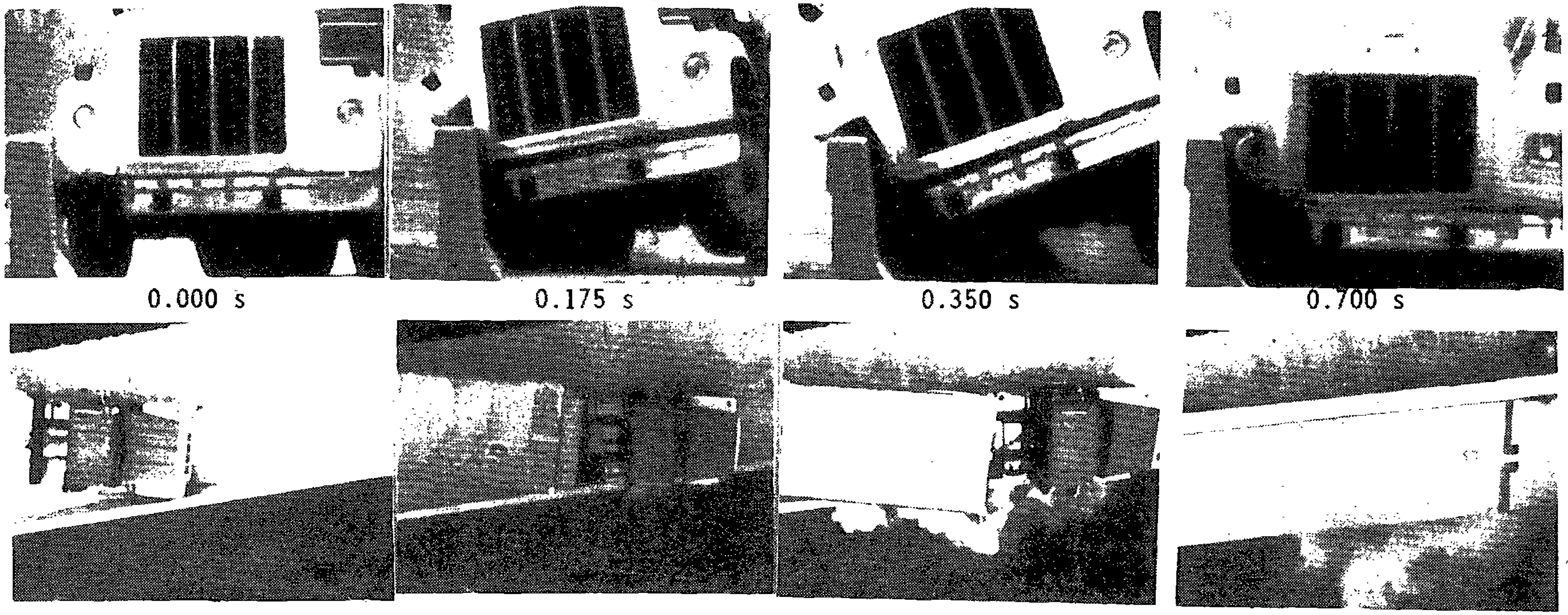


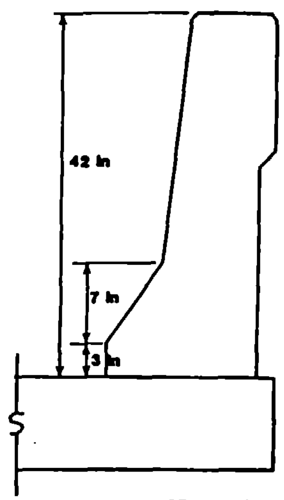
Figure 25. Vehicle after test 7069-10.

Right Front Tractor

Right Rear Tractor

Figure 26. Details of damage to vehicle after test 7069-10.





Test No.	7069-10
Date	3/3/88
Test Installation . . .	42-in (1.07-m) F-shape Bridge Railing
Installation Length . .	100 ft (30 m)
Vehicle	1979 International Transtar 4200 Tractor
Vehicle Weight	
Test Inertia	29,900 lb (13,574 kg)
Gross Static	50,000 lb (22,700 kg)
Maximum Vehicle Crush .	18.0 in (457 mm)

Impact Speed. . . .	52.2 mi/h (84.0 km/h)
Impact Angle. . . .	14.0 deg
Exit Speed.	N/A
Exit Trajectory . .	0 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal. . .	-2.2 g
Lateral	4.7 g
Occupant Impact Velocity	
Longitudinal. . .	9.1 ft/s (2.8 m/s)
Lateral	9.3 ft/s (2.8 m/s)
Occupant Ridedown Accelerations	
Longitudinal. . .	-4.7 g
Lateral	3.7 g

Figure 27. Summary of results for test 7069-10.

Table 3. Evaluation of crash test no. 7069-10.
{42-in (1.07-m) F-shape bridge railing [50,000 lb (22 700 kg)|52.2 mi/h (84 km/h)|14.0 degrees]}

	CRITERIA	TEST RESULTS	PASS/FAIL*
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright	Vehicle remained upright	Pass
E.	Must smoothly redirect the vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair > .35 — Marginal	μ — Assessment NOT AVAILABLE	N/A
G.	Shall be less than Occupant Impact Velocity - ft/s (m/s) Longitudinal 30 (9.2) — Lateral 25 (7.6)	Occupant Impact Velocity - ft/s (m/s) Longitudinal 9.1 (2.8) — Lateral 9.3 (2.8)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal 15 — Lateral 15	Occupant Ridedown Accelerations - g's Longitudinal -4.7 — Lateral 3.7	N/A
H.	Exit angle shall be less than 12 degrees	about 0 degrees	Pass

* A, B, C, are required. D, E, F, and H are desired. G is not applicable for this test. (See table 2)

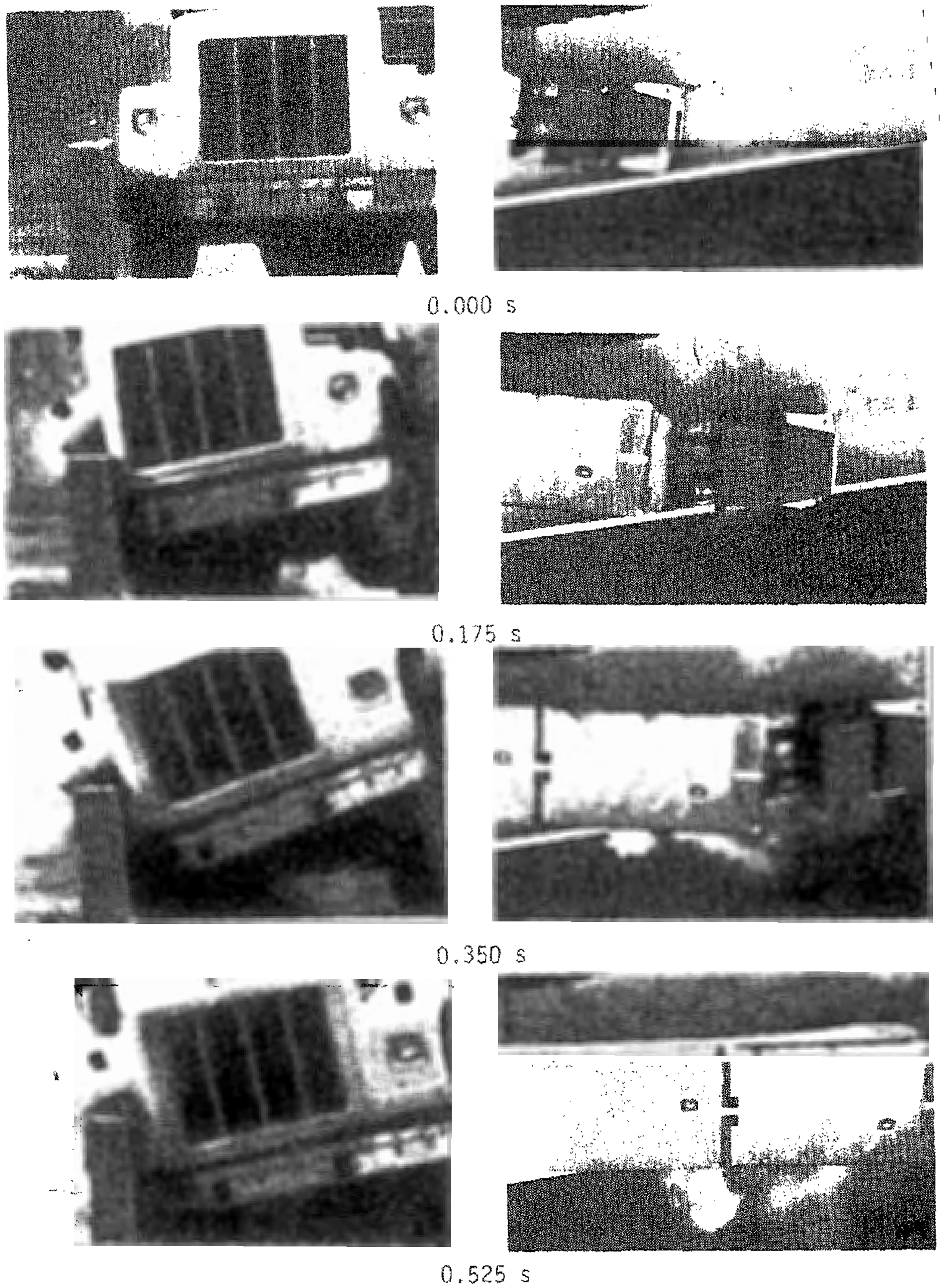
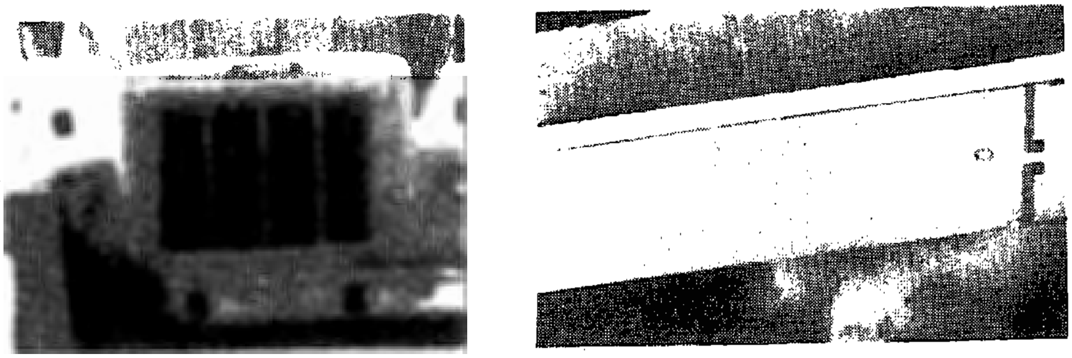
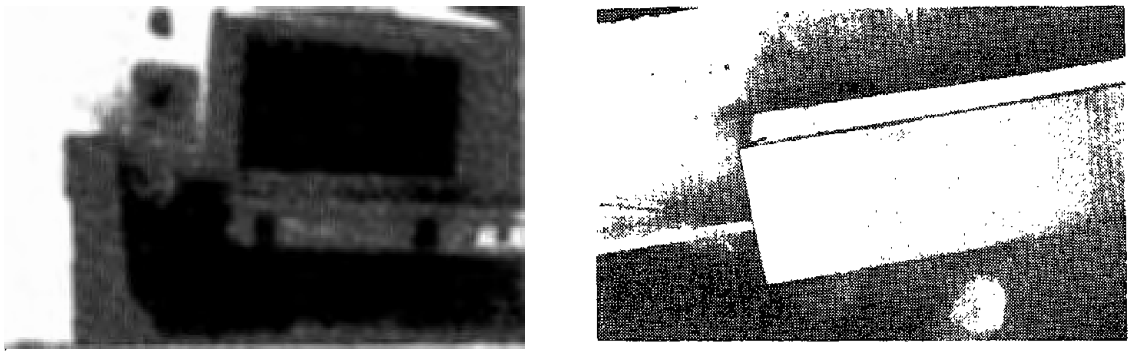


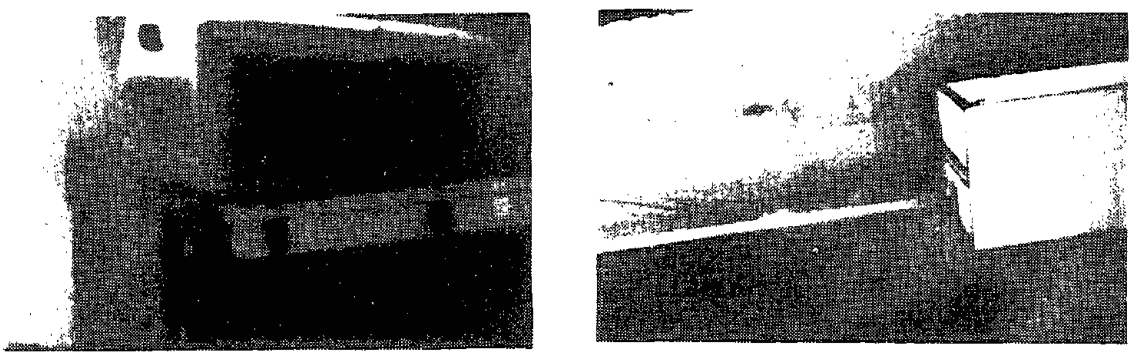
Figure 28. Sequential photographs for test 7069-10.



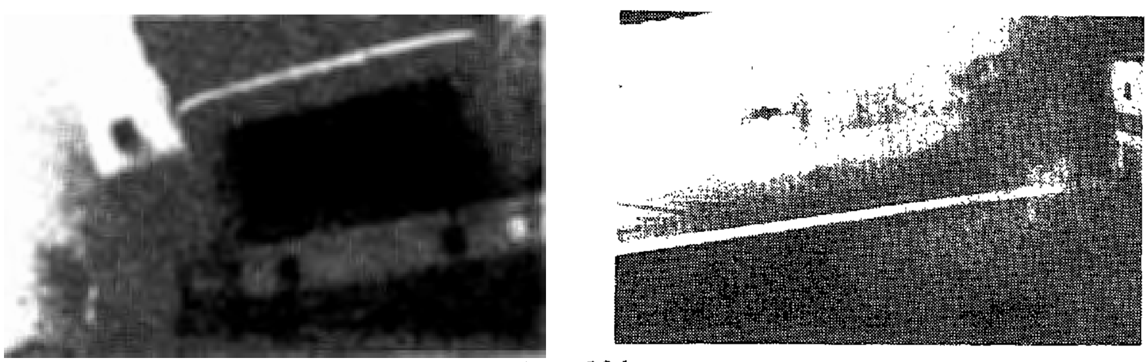
0.700 s



0.875 s



1.050 s



0.1.224

Figure 28. Sequential photographs for test 7069-10 (continued).

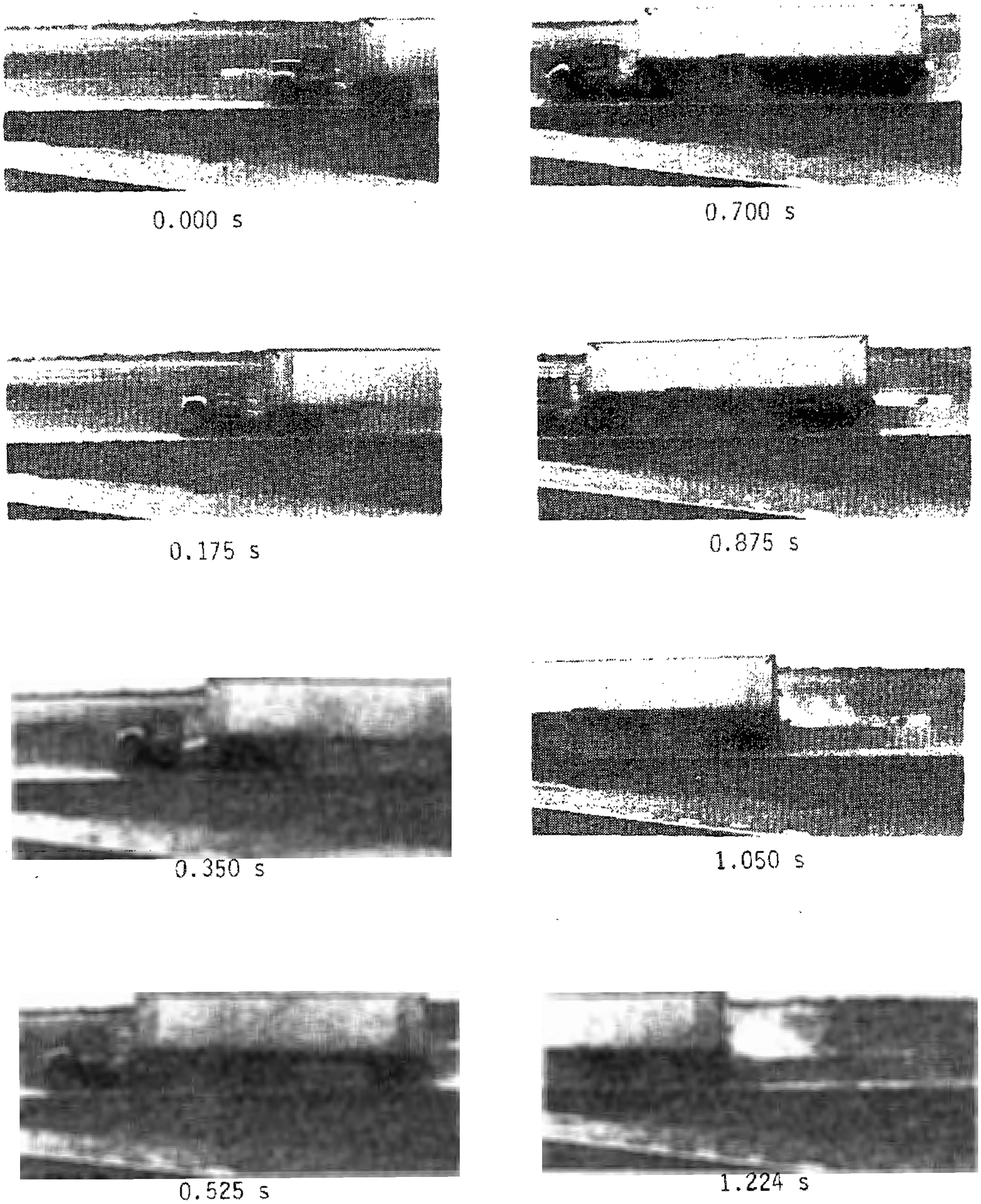
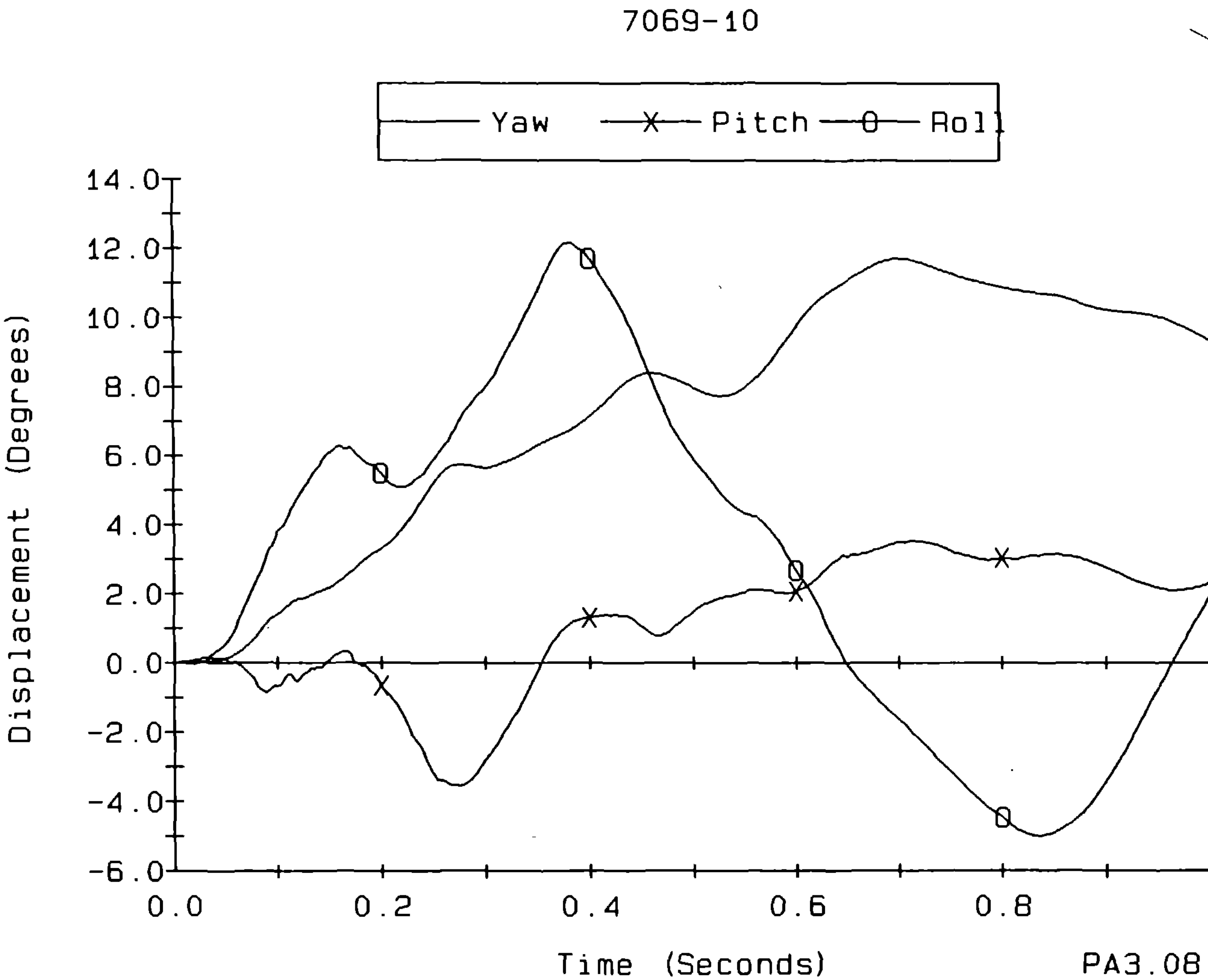
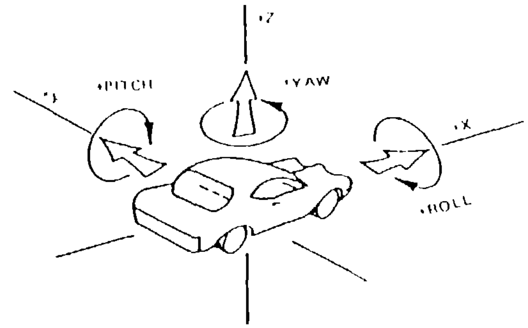


Figure 29. Perpendicular sequential photographs for test 7069-10.





Axes are vehicle fixed. Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 30. Vehicle angular displacements for test 7069-10.

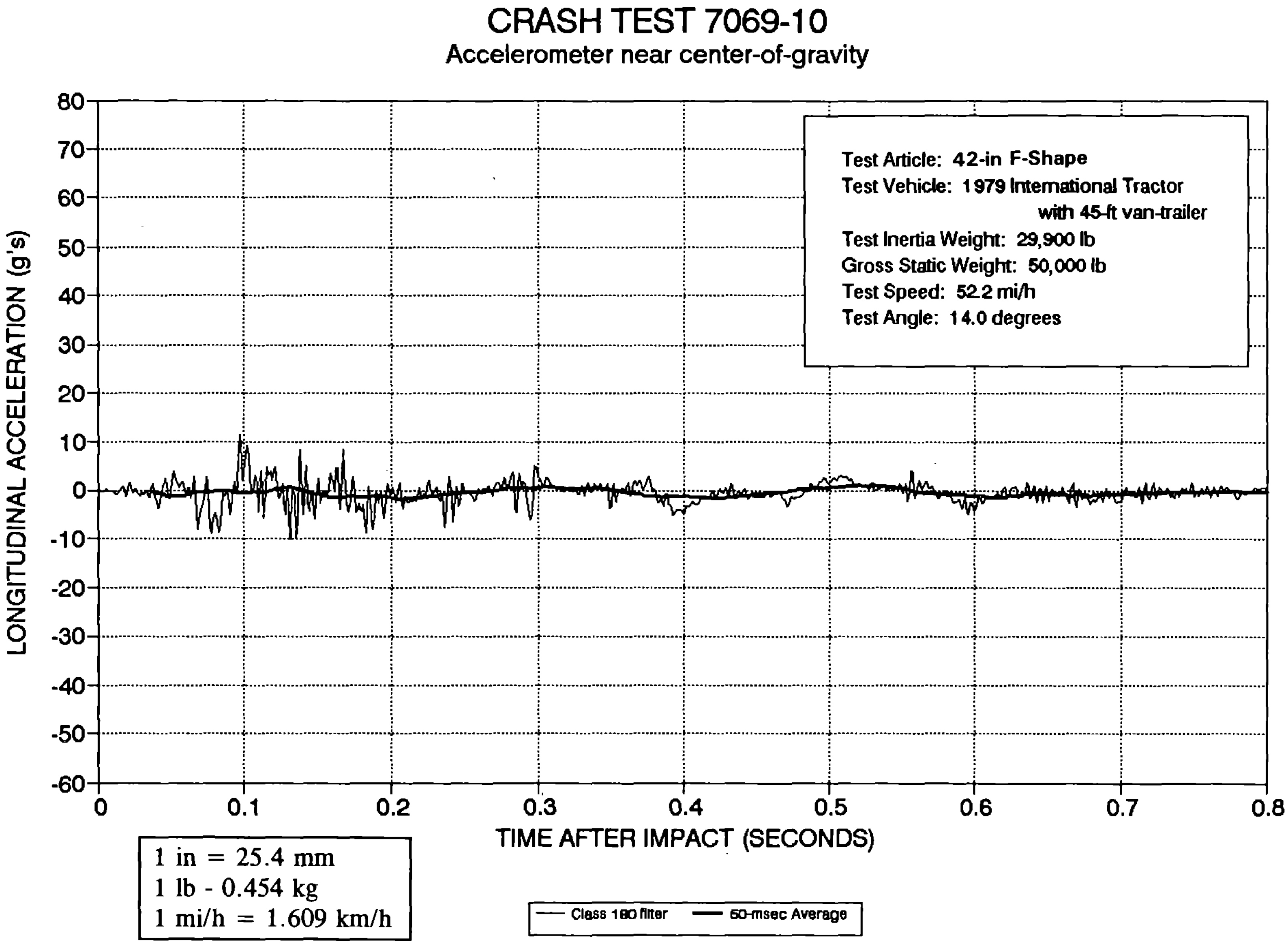


Figure 31. Vehicle longitudinal accelerometer trace for test 7069-10 (accelerometer located near tractor center-of-gravity).

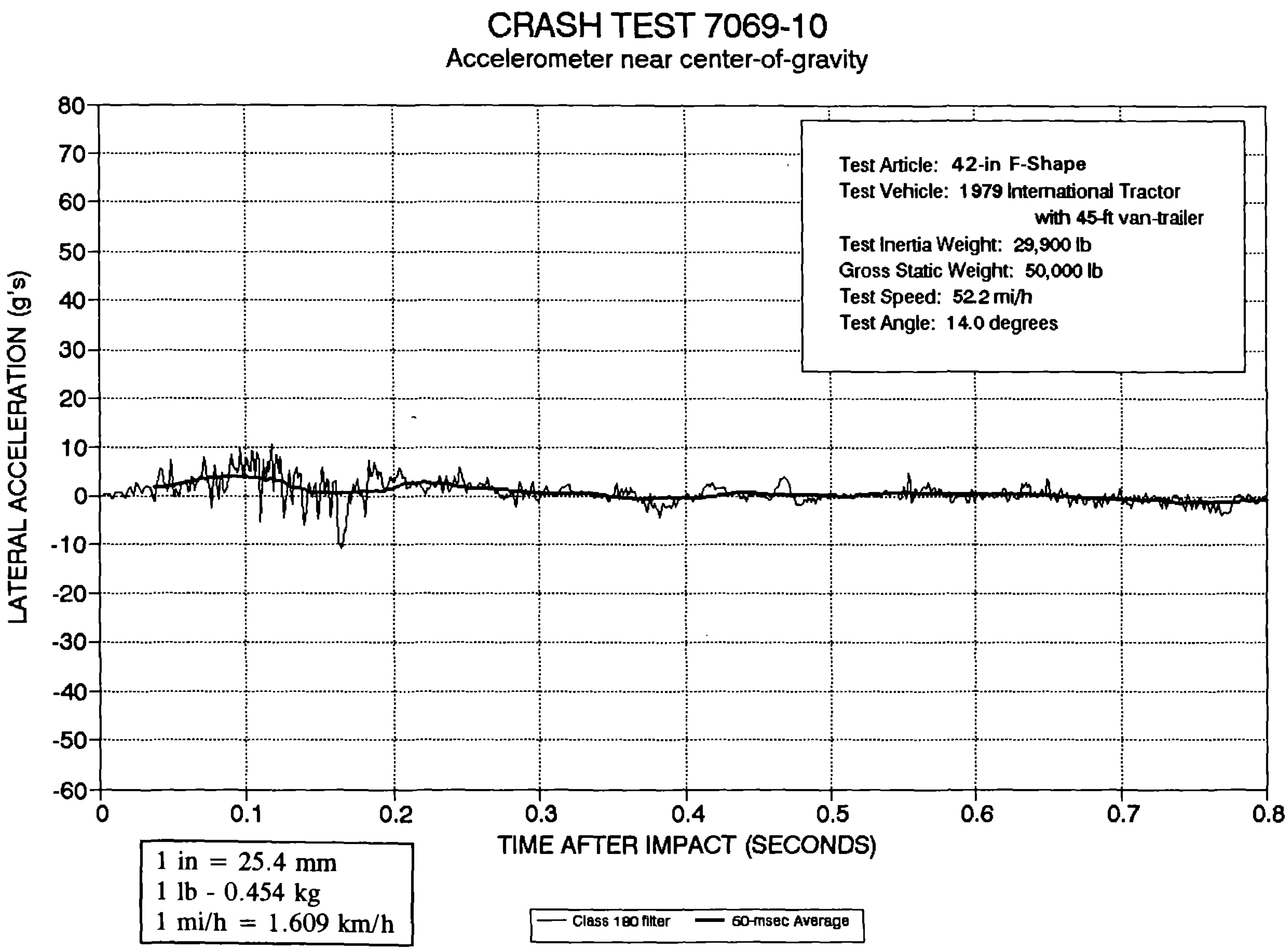


Figure 32. Vehicle lateral accelerometer trace for test 7069-10 (accelerometer located near tractor center-of-gravity).

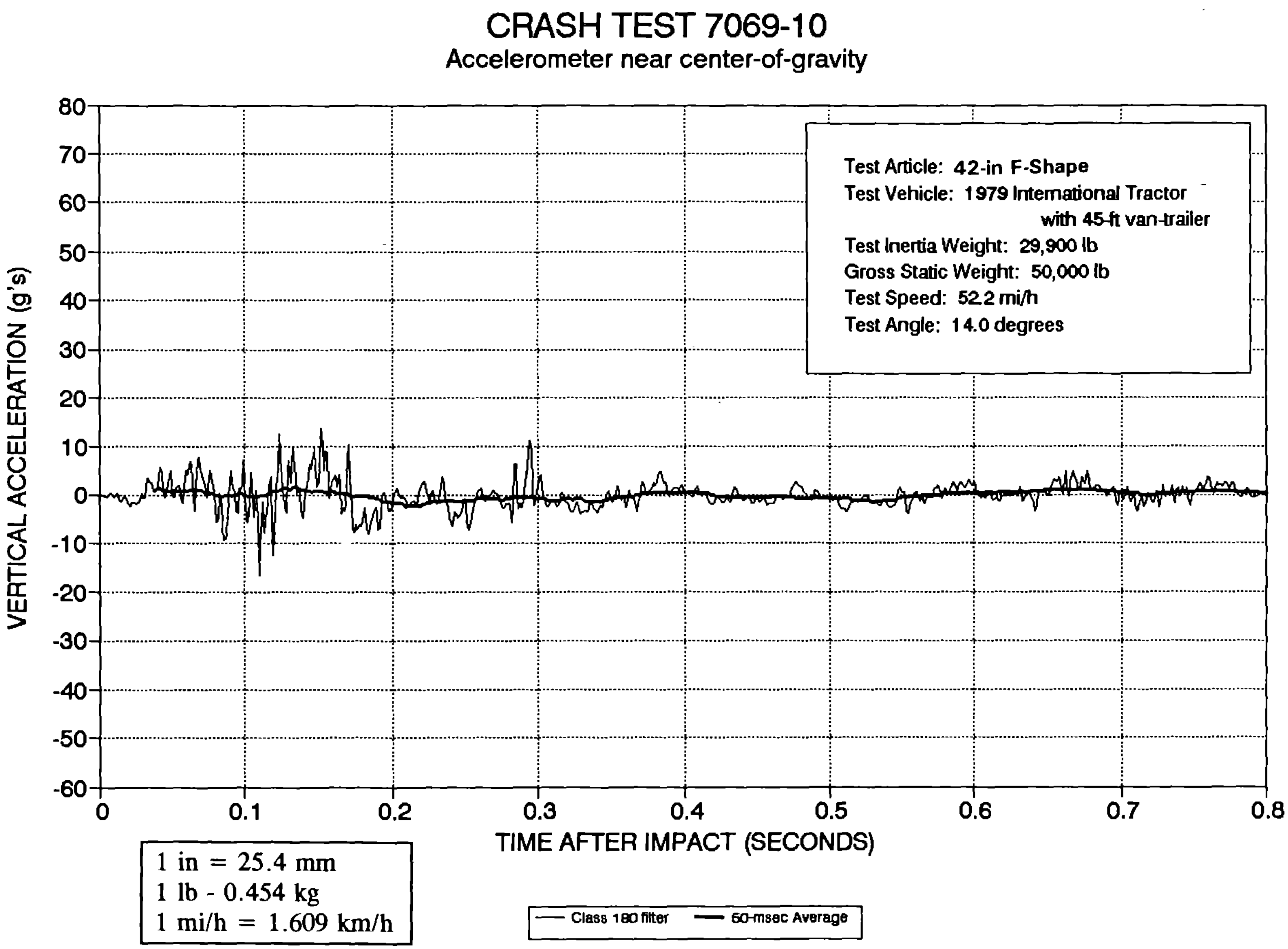


Figure 33. Vertical accelerometer trace for test 7069-10 (accelerometer located near tractor center-of-gravity).

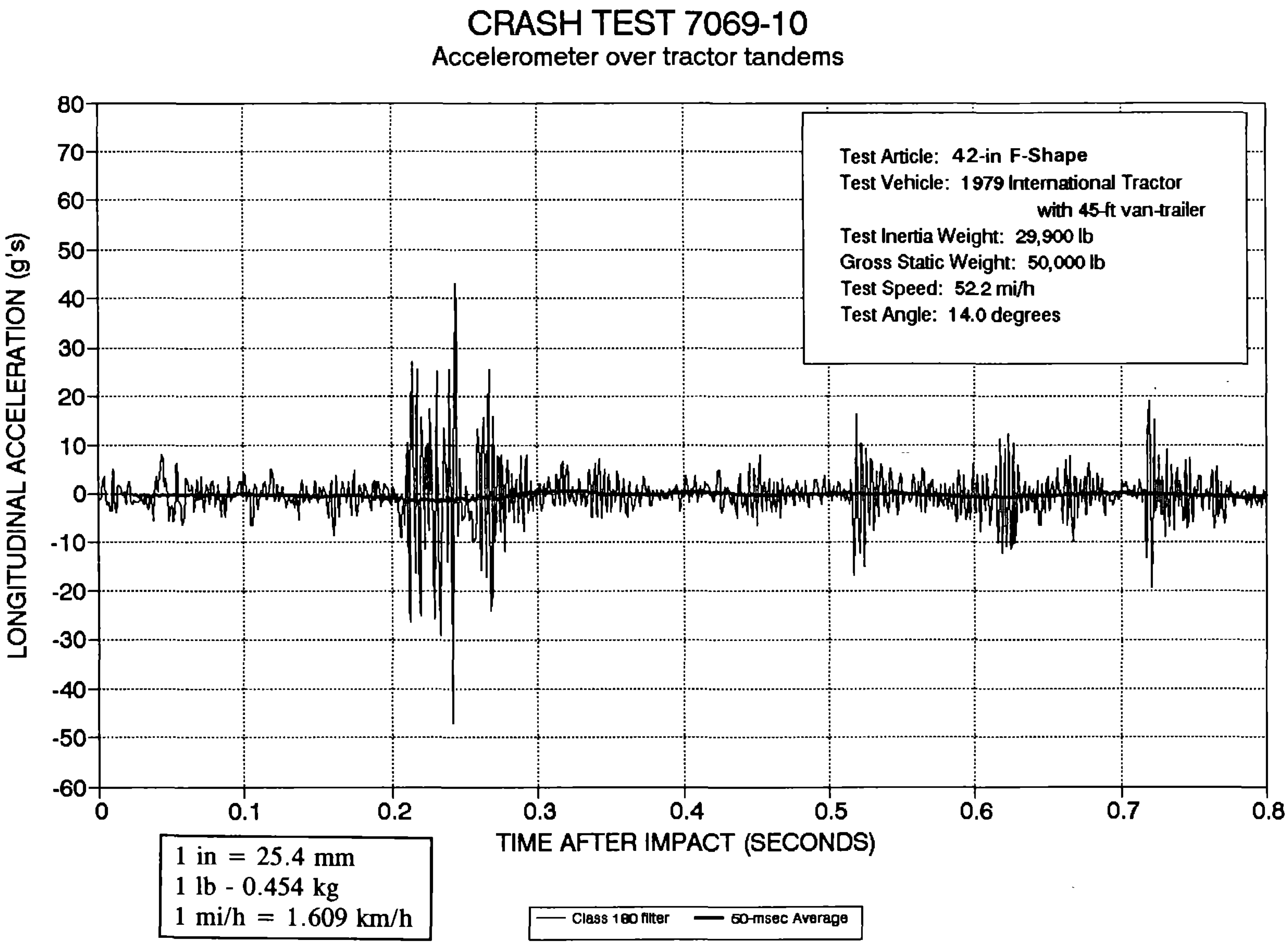


Figure 34. Vehicle longitudinal accelerometer trace for test 7069-10 (accelerometer located over tractor tandems).

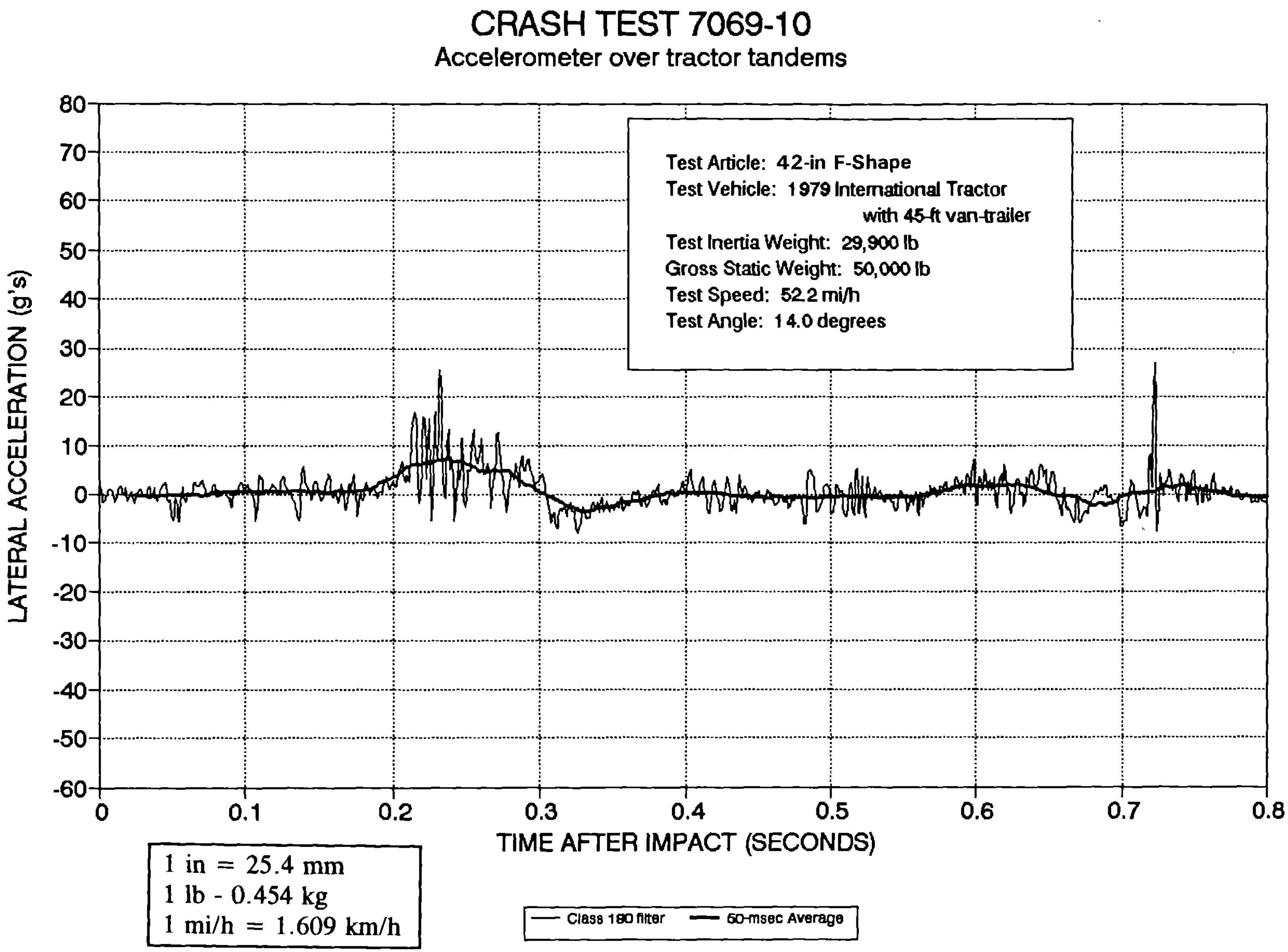


Figure 35. Vehicle lateral accelerometer trace for test 7069-10 (accelerometer located over tractor tandems).

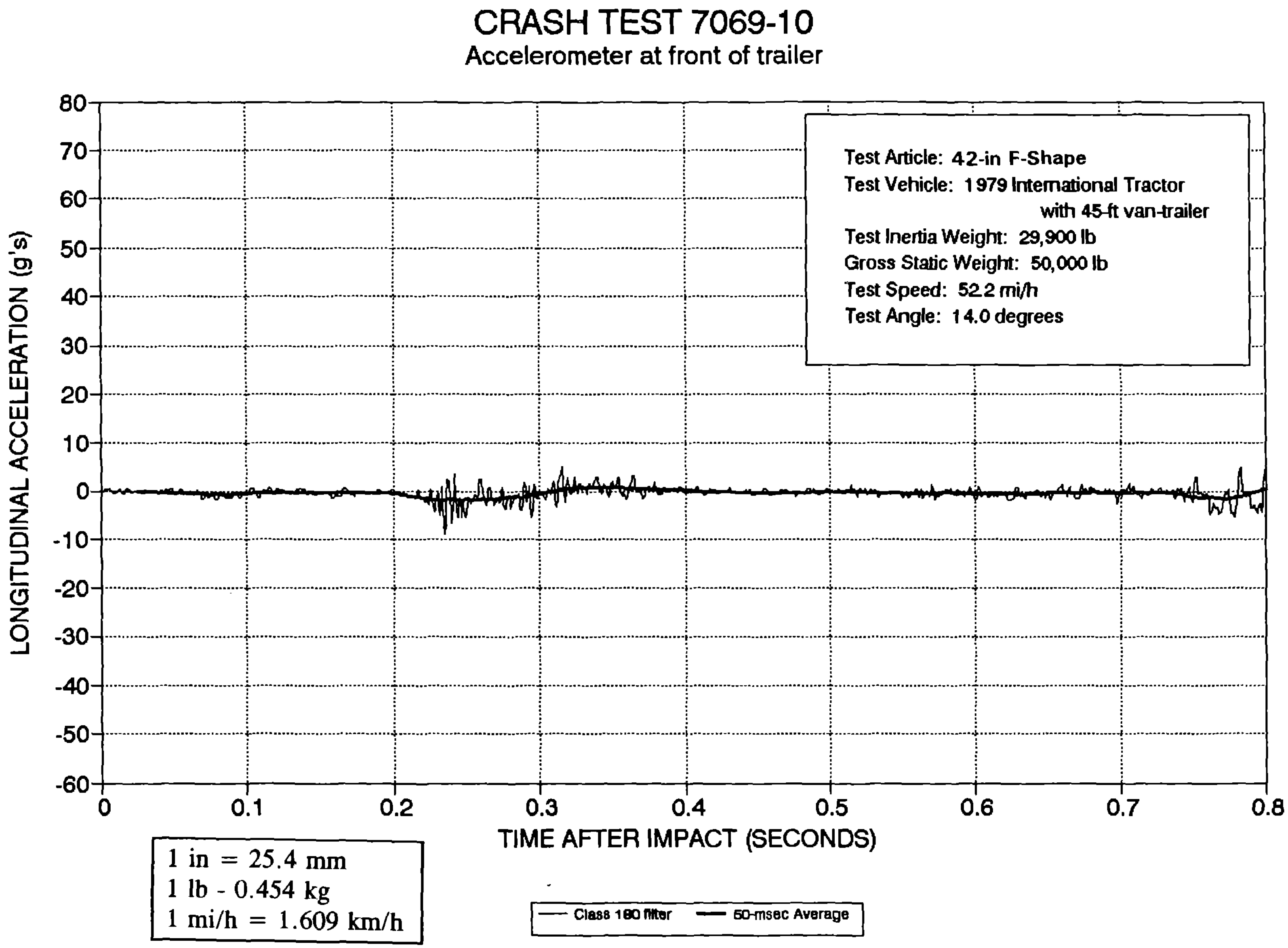


Figure 36. Longitudinal accelerometer trace for test 7069-10
(accelerometer located at front of trailer).

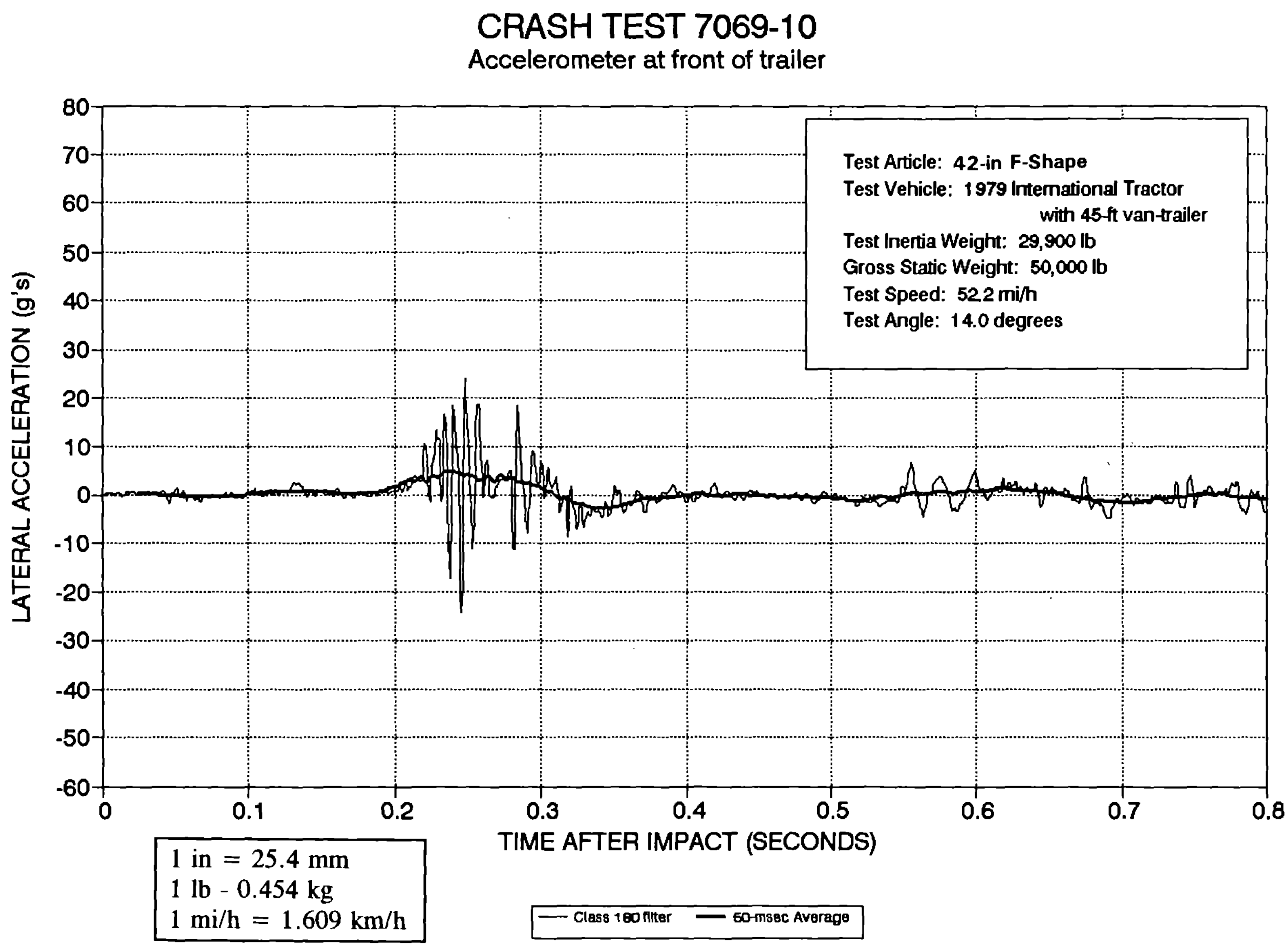


Figure 37. Lateral accelerometer trace for test 7069-10
(accelerometer located at front of trailer).

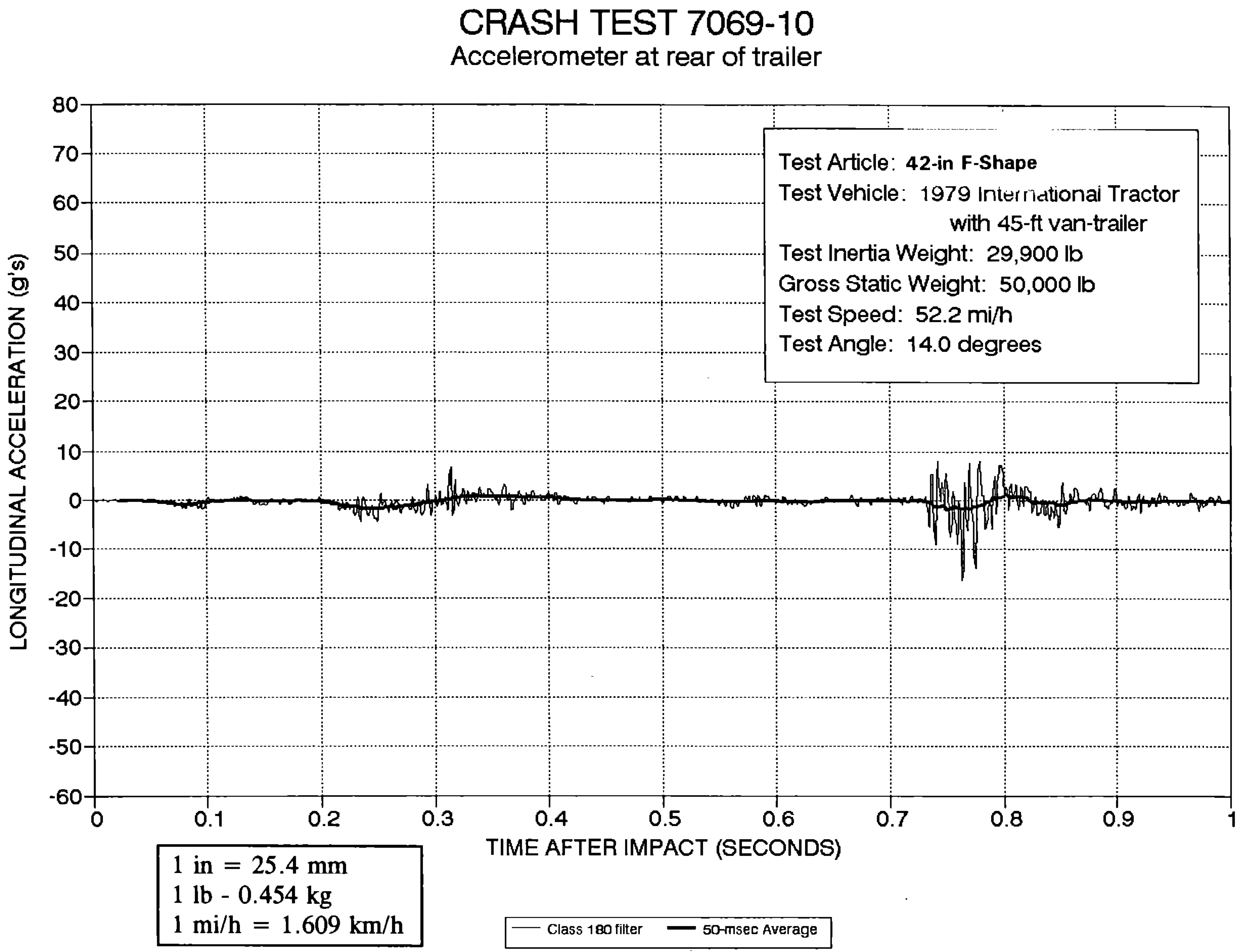


Figure 38. Longitudinal accelerometer trace for test 7069-10 (accelerometer located at rear of trailer).

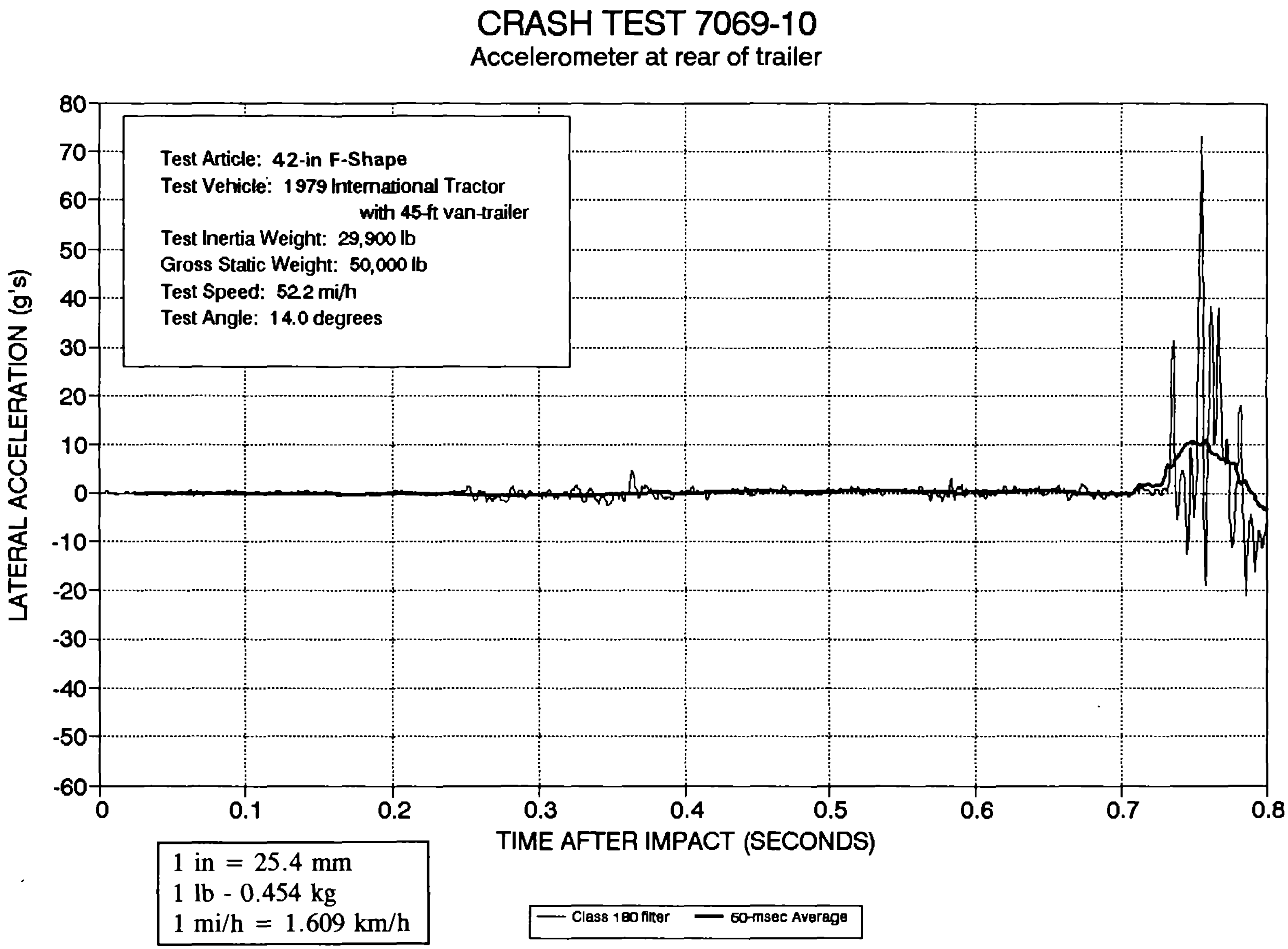
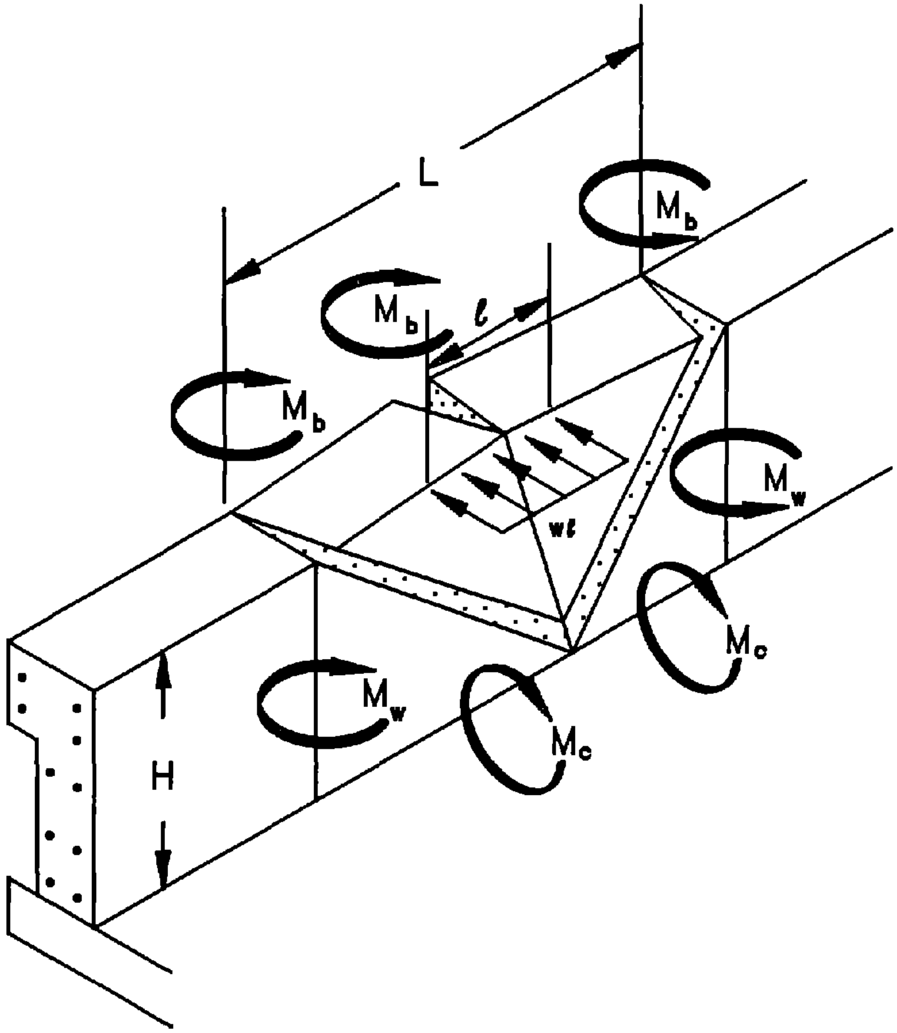


Figure 39. Lateral accelerometer trace for test 7069-10 (accelerometer located at rear of trailer).

CHAPTER 4. STRENGTH CALCULATIONS

Analysis of the strength of the railing is based on the yieldline failure pattern shown in figure 40. The force from a colliding vehicle is idealized as being a uniformly distributed line load extending over 8.0 ft (2.4 m). The load may be applied at any location along the railing.

The length of the yieldline failure pattern depends on the relative bending moment capacities of the various railing elements. The computed cantilever moment capacity of the parapet, M_c, is 15.7 ft-k/ft (69.9 m-kN/m). The average moment capacity of the parapet about a vertical axis, M_w, is 15.2 ft-k/ft (67.6 m-kN/m). The additional average moment capacity of the stiffening beam along the top of the parapet is 23.6 ft-kips (32 m-kN). The length of the yieldline failure pattern, computed from the equation in figure 40, is 17.6 ft (5.4 m) and the ultimate strength of the parapet is 127 kips (565.2 kN).



$$L = \frac{\ell}{2} + \sqrt{\left(\frac{\ell}{2}\right)^2 + \frac{8H(M_b + M_w H)}{M_c}}$$

$$(w\ell)_{ult} = \frac{8M_b}{L - \frac{\ell}{2}} + \frac{8M_w H}{L - \frac{\ell}{2}} + \frac{M_c L^2}{H\left(L - \frac{\ell}{2}\right)}$$

Figure 40. Yieldline failure pattern for concrete parapet.

REFERENCES

1. *Guide Specifications For Bridge Railings*, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 1989.

2. *Guide Specifications For Bridge Railings*, proposed, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 1987.

3. Hirsch, T. J., "Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks," Research Report 230-2, Texas Transportation Institute, Texas A&M University, College Station, TX, August 1978.