Testing of New Bridge Rail and Transition Designs

Volume X: Appendix I

42-in (1.07-m) Concrete Parapet 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

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16. Abstract

A 42-in (1.07-m) vertical faced concrete parapet bridge railing was designed and tested to performance level three of the 1989 *Guide Specifications for Bridge Railings*. The parapet was mounted on a 10-in (254-mm) thick simulated bridge deck overhang. Acceptable performance of the railing was demonstrated.

This volume is the tenth 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 XI: Appendix J, "42-in (1.07-m) F-Shape 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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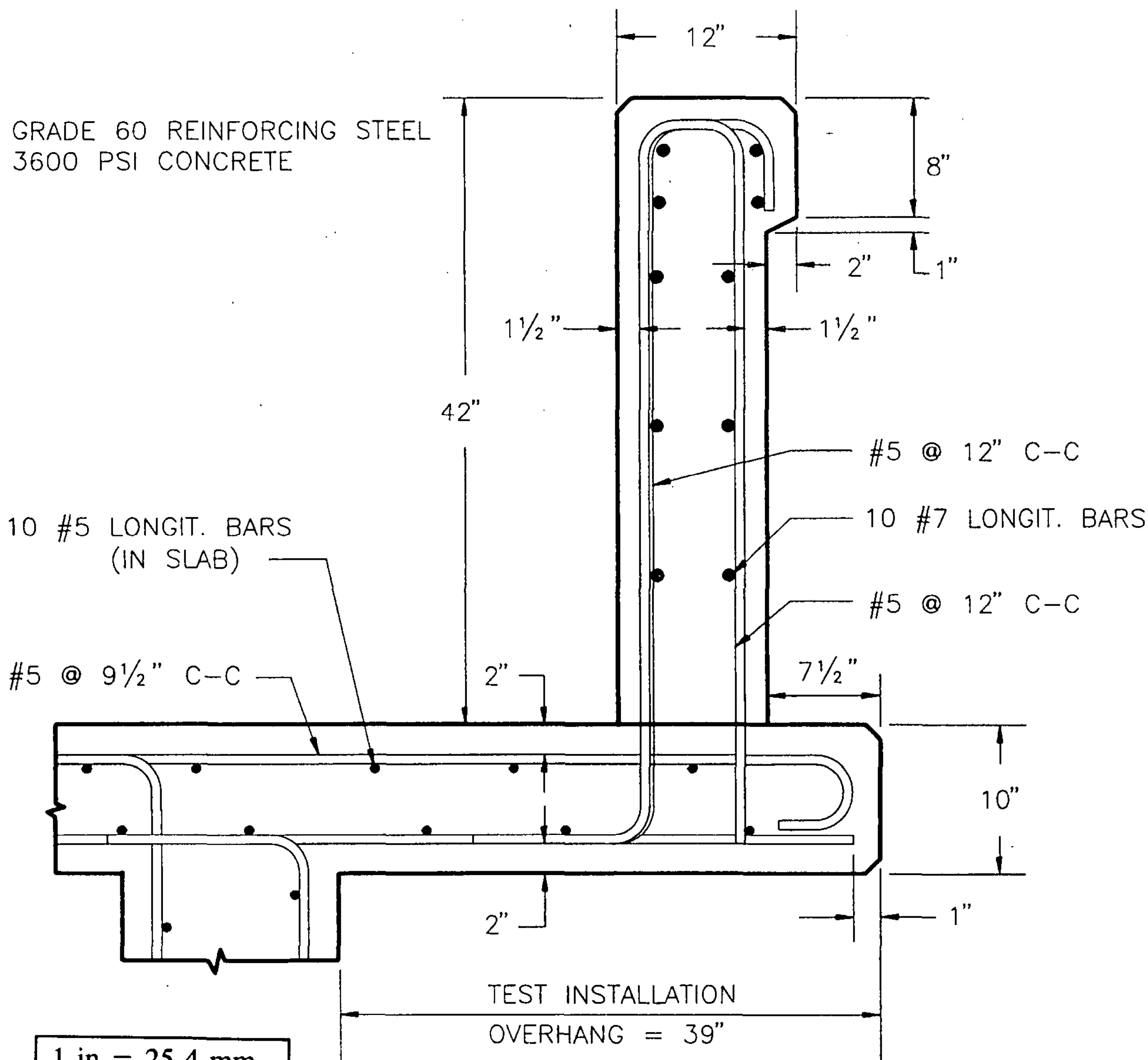
CHAPTER 1. DESIGN OF RAILING

The 42-in (1.07-m) concrete parapet was designed for a collision by a 50,000-lb (22 700-kg) tractor/trailer traveling at 50 mi/h (80 km/h) with an approach angle of 15 degrees. This test condition was adopted for the strength test for performance level three in the 1989 *Guide Specifications for Bridge Railings.*[1]

The parapet, shown in figure 1, is 10 in (254 mm) thick with a thickened section 12 in (305 mm) thick at the top. This "beam" along the top edge serves to enhance the longitudinal distribution of forces within the parapet and the deck. Two types of vertical reinforcing bars are alternated to provide #5 bars spaced at 6 in (152 mm) in the traffic side face.

The collision force used in the design was 154 kips (685 kN) uniformly distributed over a longitudinal distance of 42 in (1.07 m) at 34 in (864 mm) above the deck surface. The currently recommended design force for performance level three (50,000 lb (22 700 kg)|50 mi/h (80.5 km/h)|15 degrees) is a uniformly distributed line force of 124 kips (551 kN) distributed over 96 in (2.44 m) at 38 to 40 in (.96 to 1.02 m) above the deck surface. The 42-in (1.07-m) parapet meets these design requirements.

An analysis of the strength of this railing is presented in chapter 4.



1 in = 25.4 mm
1 psi = 6.89 kPa

Figure 1. Cross section of 42-in (1.07-m) concrete parapet.

CHAPTER 2. CRASH TEST PROCEDURES

The 42-in (1.07-m) concrete parapet was tested to performance level three requirements.(1) The following nominal test conditions were used:

50,000-lb (22 799-kg) tractor/van-trailer | 50 mi/h (80.5 km/h) | 15 degrees (test 7069-13)

The tractor was equipped with triaxial accelerometers mounted near the center-of-gravity and with 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, the tractor was instrumented with three solid-sate angular rate transducers to measure yaw, pitch, and roll rates. 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. 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 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 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.

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 uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, final occupant displacement, 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. 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 with the first 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 over head with a field of view perpendicular to the ground and directly over the impact point; one placed to have a field of view parallel to and aligned with the parapet; and a third placed perpendicular to the front of the parapet. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the parapet 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 parapet before and after the test.

The tractor/van-trailer was directed into the parapet using a remote control guidance system. Immediately prior to impact fuel to the engine was shut off and the test vehicle 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.

CHAPTER 3. FULL-SCALE CRASH TEST

TEST 7069-13

Test Description

A 1979 International Transtar 4200 tractor with a 1977 Pullman van-trailer shown in figures 2 and 3 was directed into the 42-in (1.07-m) concrete parapet (figure 4) using a remote control guidance system. Test inertia mass of the vehicle was 27,690 lb (12 571 kg), and its gross static mass was 50,050 lb (22 723 kg). The height to the lower edge of the vehicle bumper was 20.5 in (521 mm), and the distance to the top of the bumper was 30.5 in (775 mm). Other dimensions and information on the test vehicle are given in figures 5 through 7. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 51.4 mi/h (82.7 km/h), and the angle of impact was 16.2 degrees. The vehicle impacted the parapet at 24 ft (7.3 m) from the upstream end. At approximately 0.010 s after impact the right front wheel contacted the parapet, and the left front wheel became airborne at 0.135 s. The right front corner of the trailer contacted the parapet at about 0.178 s. The tractor began to redirect at 0.178 s, and the trailer began to redirect at 0.280 s. The rear wheels of the tractor lost contact with the pavement at 0.285 s, and the left rear wheels of the trailer became airborne at 0.349 s. The left side of the tractor remained airborne until 0.417 s when the left front wheel touched down. The right rear trailer wheels contacted the parapet at about 0.684 s. The vehicle attained maximum roll to the right at about 1.165 s and began to roll left. The vehicle rode against the parapet and off the end. The brakes were applied, and the vehicle came to rest on its left side approximately 181 ft (55 m) downstream from the point of impact.

The parapet received cosmetic damage and some scraping and gouging. As shown in figure 8, there were tire marks on the parapet from just before the impact point extending a total of 85 ft (26 m) along the face. There was also a piece of the top beam of the parapet chipped off.

The vehicle sustained extensive damage to the right side as shown in figure 9. Maximum crush at the right front corner at bumper height was 18.0 in (457 mm). There was damage to the front axle, Pittman arm, U-bolts, front leaf springs and bolts, front shock mounts, air brake lines, right fuel cell, left rear spring pin and clamp, and exhaust pipe. The cab and left door were bent.

Test Results

Impact speed was 51.4 mi/h (82.7 km/h), and the angle of impact was 16.2 degrees. Exit speed was not available. The vehicle trajectory path was 0 degrees. The effective coeffieient of friction was 0.55. Occupant impact velocity was 10.5 ft/s (3.2 m/s) in the longitudinal direction and 12.5 ft/s (3.8 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -2.2g (longitudinal) and 4.6g (lateral). These data and other pertinent information from the test are summarized in figure 10 and tables 1 and 2.

Sequential photographs of the test are shown in figures 11 and 12. Vehicular angular displacements are displayed in figure 13. Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 14 through 22. These data were further analyzed to obtain 0.050-s average accelerations versus time. The maximum 0.050-s averages at the tractor c.g. were -3.3g (longitudinal) and 3.7g (lateral).

Conclusions

The 42-in (1.07-m) concrete parapet contained and redirected the vehicle with no lateral movement of the parapet. 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; however, the vehicle did not remain upright after the collision. See tables 1 and 2 for a more detailed description. The results from the crash test indicate that the 42-in (1.07-m) concrete parapet provides an effective means of vehicle redirection.

This was the only test performed on the 42-in (1.07-m) concrete parapet.

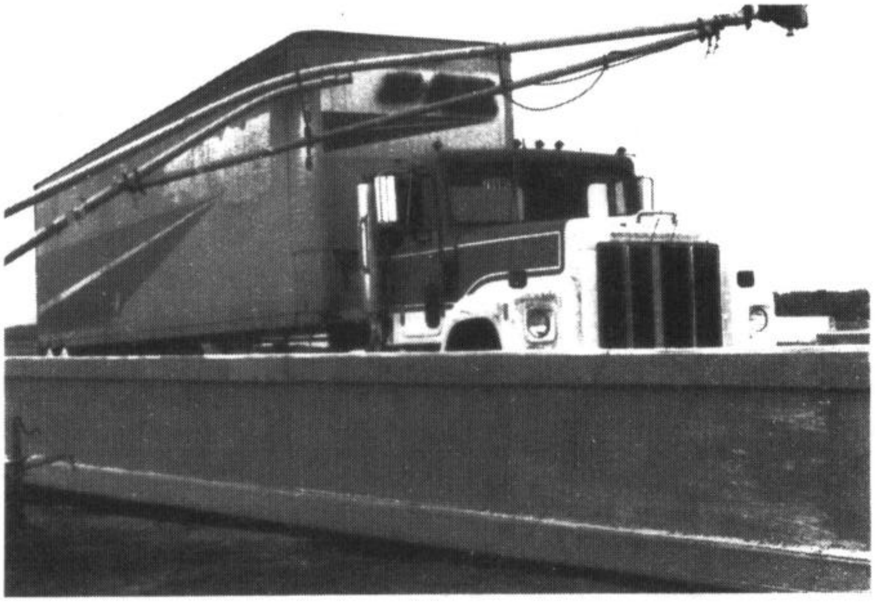


Figure 2. Vehicle/parapet geometrics before test 7069-13.

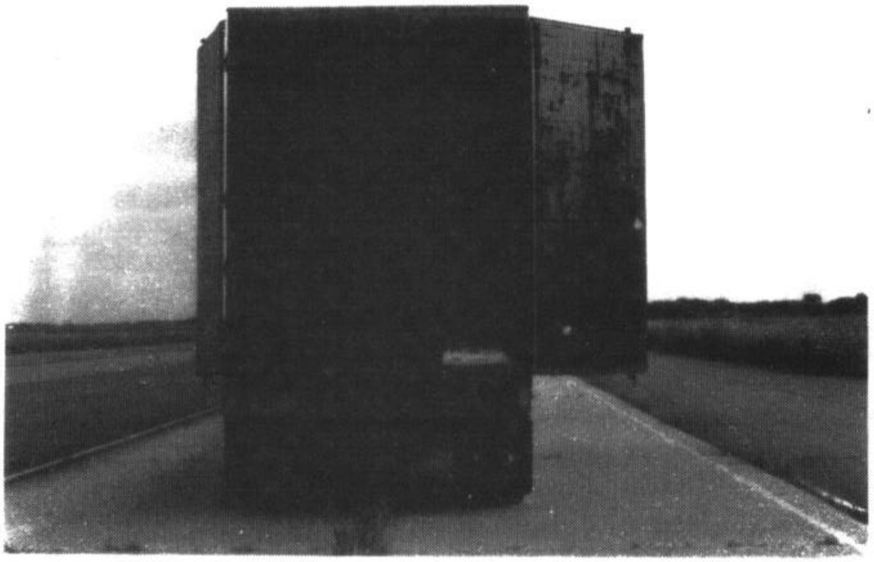
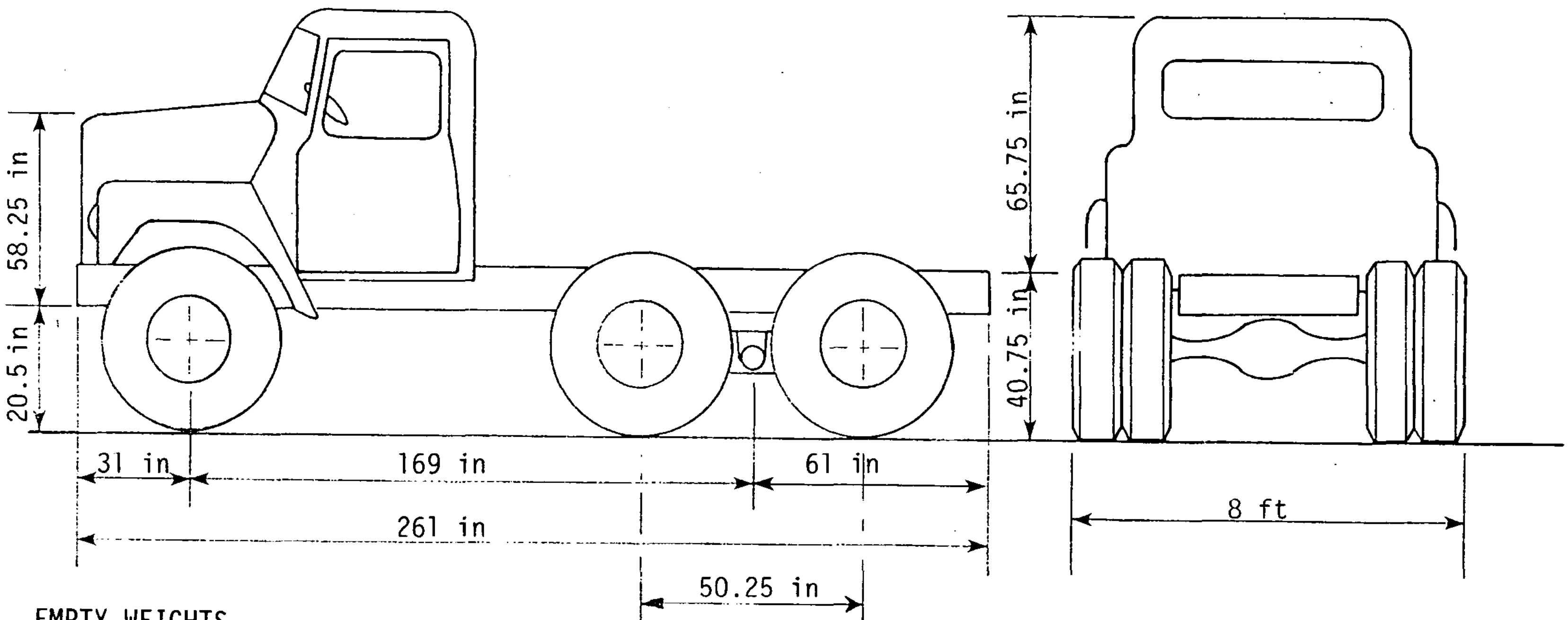


Figure 3. Vehicle before test 7069-13.

Figure 4. 42-in (1.07-m) concrete parapet before test 7069-13.

TRACTOR 1979 Internation Transtar 4200

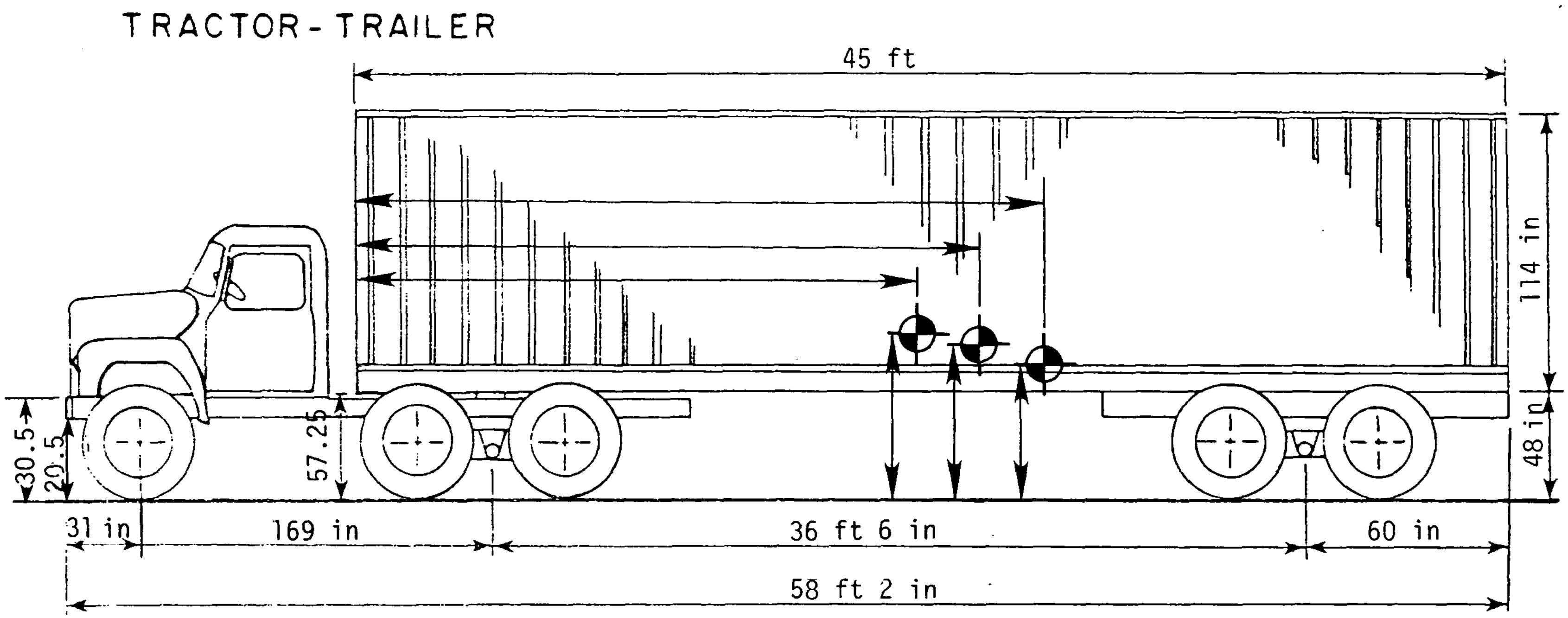


EMPTY WEIGHTS

Tractor only	15,010	lb
Trailer only	12,680	lb
Total Empty Weight	27,690	lb

1 in = 25.4 mm
1 lb - 0.454 kg

Figure 5. Vehicle properties (tractor only) for test 7069-13.

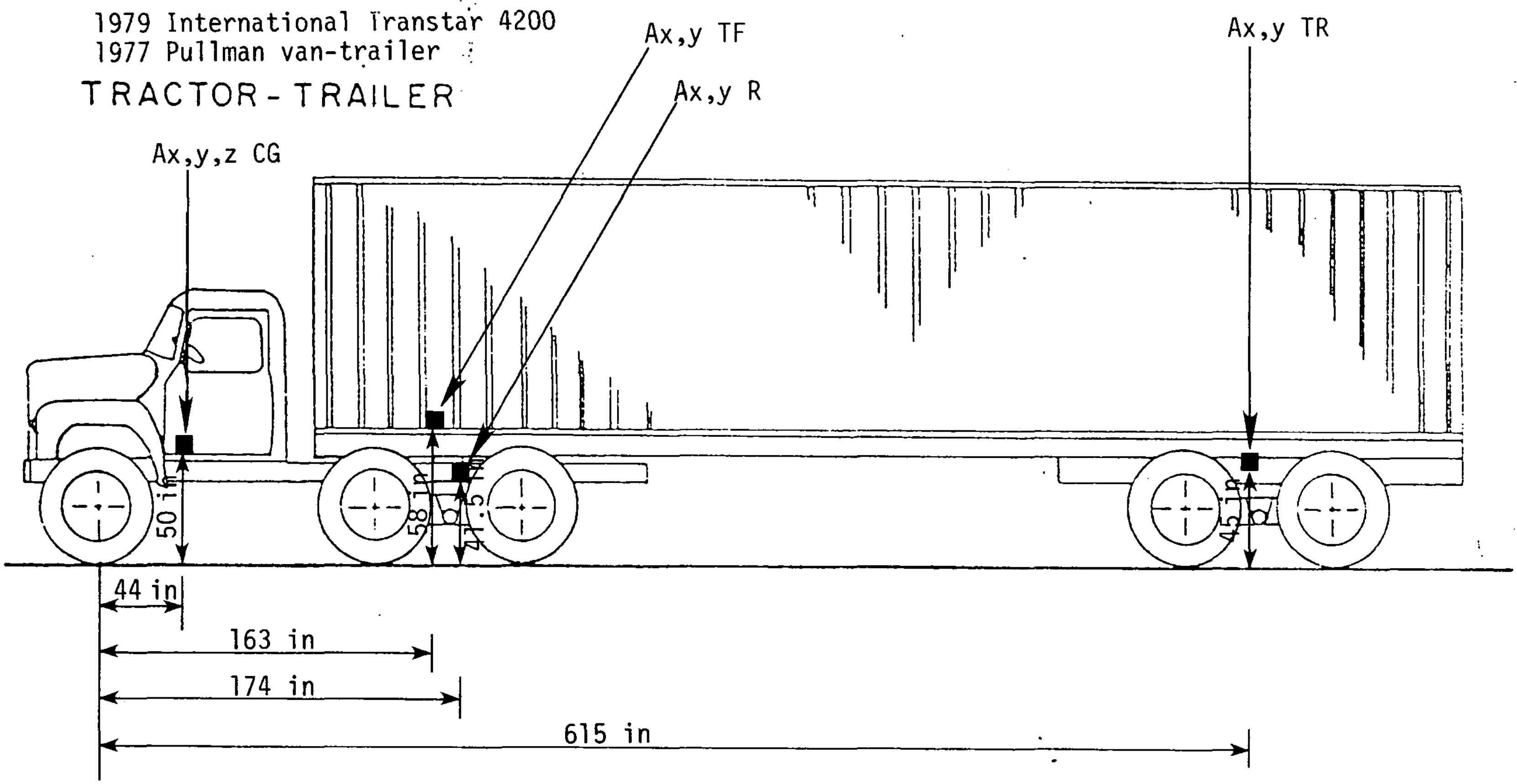


EMPTY WEIGHTS:		
Weight on front axle	7,380	lb
Weight on center axles	11,890	lb
Weight on rear axles	8,420	lb
Total Empty Weight	27,690	lb

LOADED WEIGHTS:		
Weight on front axle	7,920	lb
Weight on center axles	22,250	lb
Weight on rear axles	19,880	lb
Total Loaded Weight	50,050	lb

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 6. Test vehicle properties (tractor/van-trailer for test 7069-13.



Ax,y,z CG - Accelerometer mounted near center-of-gravity, 10 in right of centerline

Ax,y TF - Accelerometer mounted inside trailer on floor over pin

Ax,y R - Accelerometer mounted on cross member (frame) 9 in rear of fifth wheel

Ax,y TR - Accelerometer mounted outside trailer on floor between axles

1 in = 25.4 mm
1 lb = 0.454 kg

Figure 7. Location of accelerometers for vehicle used in test 7069-13.

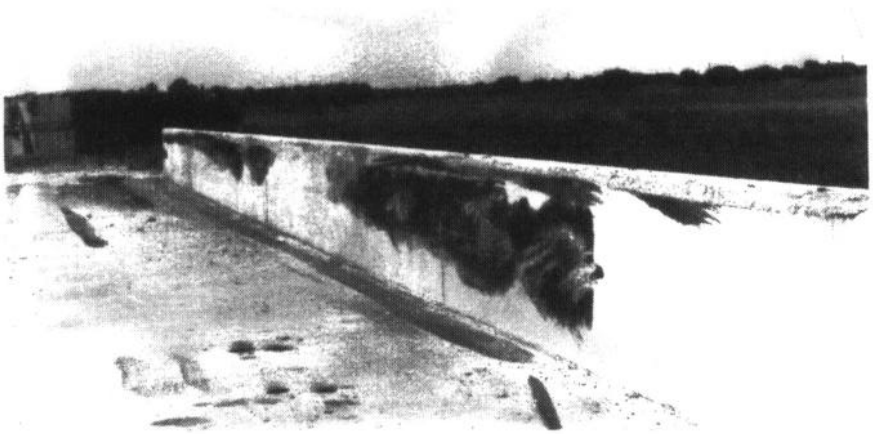


Figure 8. 42-in (1.07-m) concrete parapet after test 7069-13.

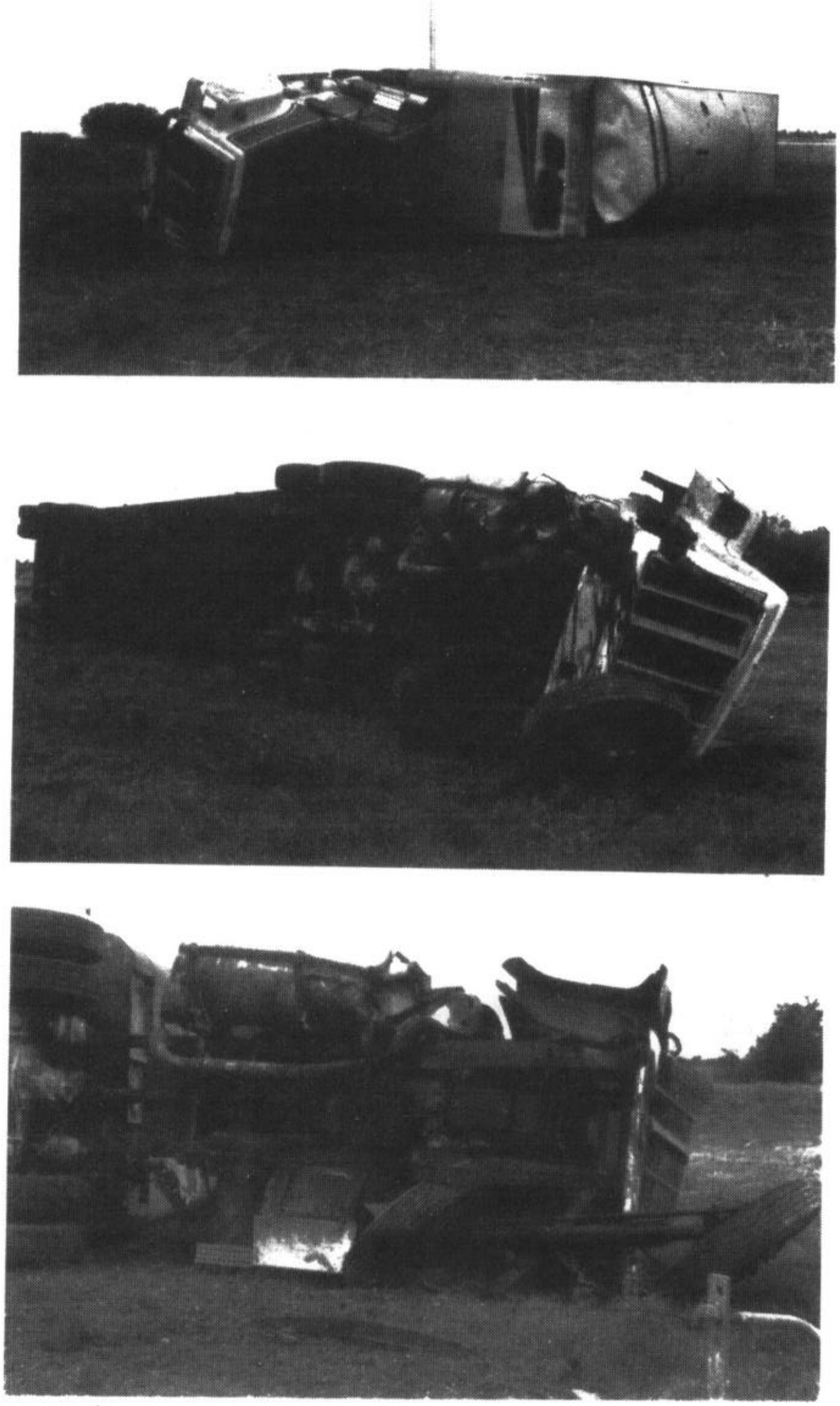
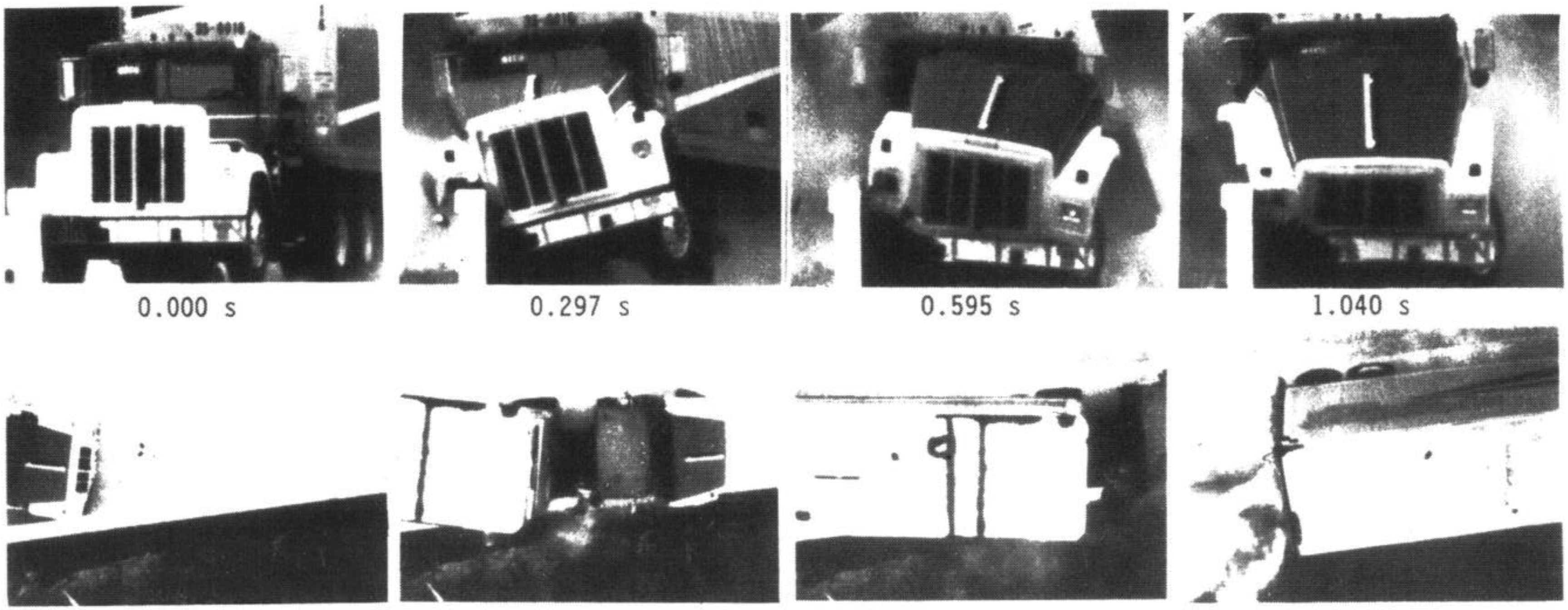
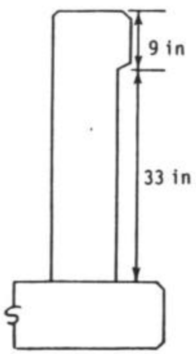


Figure 9. Vehicle after test 7069-13.





(1 in = 25.4 mm)

Test No. 7069-13
Date 7/11/88
Test Installation . . . 42-in (1.07-m) Concrete Parapet
Installation Length. . . 100 ft (30 m)
Vehicle . . . . 1979 International Tractor w/van-trailer
Vehicle Weight
  Test Inertia . . . . . 27,690 lb (12,571 kg)
  Gross Static . . . . . 50,050 lb (22,723 kg)
Maximum Vehicle Crush . 18.0 in (457 mm)

Impact Speed. . . 51.4 mi/h (82.7 km/h)
Impact Angle. . . 16.2 deg
Exit Speed. . . . N/A
Exit Trajectory . 0.0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -3.3 g
  Lateral . . . . 3.7 g
Occupant Impact Velocity
  Longitudinal. . 10.5 ft/s (3.2 m/s)
  Lateral . . . . 12.5 ft/s (3.8 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -2.2 g
  Lateral . . . . 4.6 g

Figure 10. Summary of results for test 7069-13.

Table 1. Evaluation of crash test no. 7069-13.
{42-in (1.07-m) Concrete Parapet [50,050 lb (22 723 kg)|51.4 mi/h (82.7 km/h)|16.2 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 did not remain upright	Fail
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 0.55 Marginal	Pass
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: 10.5 (3.2) Lateral: 12.5 (3.8)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal: 15 Lateral: 15	Occupant Ridedown Accelerations - g's Longitudinal: -2.2 Lateral: 4.6	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)

Table 2. Bridge railing performance levels and crash test criteria.
(Excerpt from 1989 AASHTO *Guide Specifications for Bridge Railings*)(1)

PERFORMANCE LEVELS		TEST SPEEDS—mph[1,2] — TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES: Small Automobile W = 1.8 Kips A = 5.4′ ± 0.1′ B = 5.5′ H_{cg} = 20″ ± 1″ θ = 20 deg.	Pickup Truck W = 5.4 Kips A = 8.5′ ± 0.1′ B = 6.5′ H_{cg} = 27″ ± 1″ θ = 20 deg.	Medium Single-Unit Truck W = 18.0 Kips A = 12.8′ ± 0.2′ B = 7.5′ H_{cg} = 49″ ± 1″ θ = 15 deg.	Van-Type Tractor-Trailer[4] W = 50.0 Kips A = 12.5′ ± 0.5′ B = 8.0′ H_{cg} = See Note 4 R = 0.61 ± 0.01 θ = 15 deg.
PL-1		50	45		
PL-2		60	60	50	
PL-3		60	60		50
CRASH TEST EVALUATION CRITERIA[3]	Required	a, b, c, d, g	a, b, c, d	a, b, c	a, b, c
	Desirable[5]	e, f, h	e, f, g, h	d, 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.
   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 degrees 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 $\mu = (\cos\theta - V_p/V)/\sin\theta$

Table 2. Bridge railing performance levels and crash test criteria.
(Excerpt from 1989 AASHTO *Guide Specifications for Bridge Railings*) (1)
(continued)

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 diplacements, shall be less than:

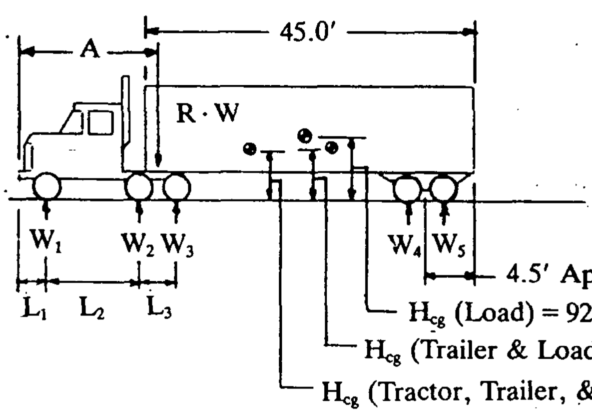
Occupant Impact Velocity–fps	
Longitudinal	Lateral
30	25

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

Occupant Ridedown Acceleration—g's	
Longitudinal	Lateral
15	15

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20-ft. 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. plus the length of the test vehicle 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:



Min. Load = 20.5 Kips

$L_1 = 30'' \pm 1''$

$L_2 + \frac{L_3}{2} = 169'' \pm 4''$

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

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

$W = W_1 + W_2 + W_3 + W_4 + W_5$
= 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 mi	= 1.61 km
1 kip	= 4.45 kN
1 in	= 25.4 mm

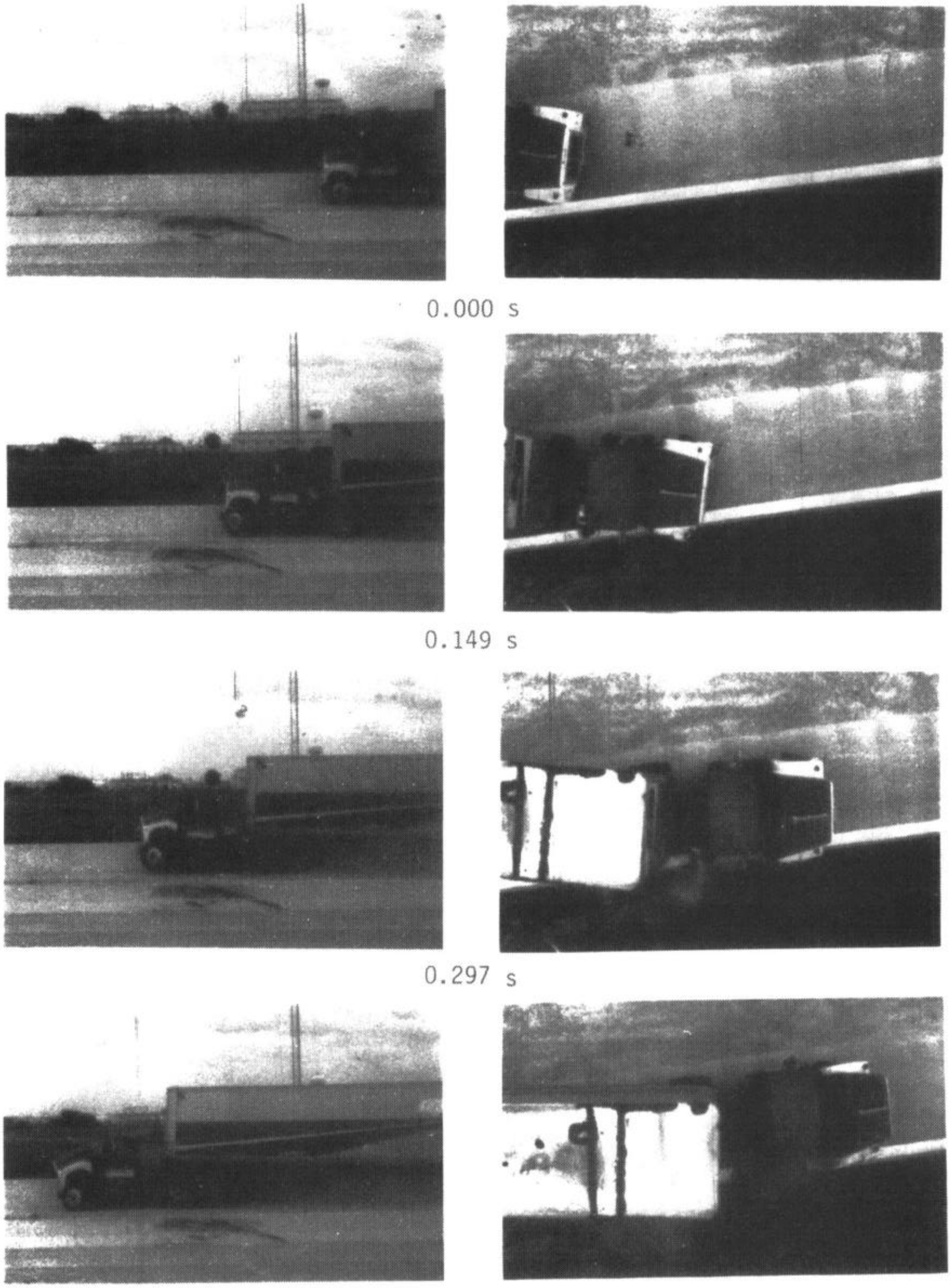
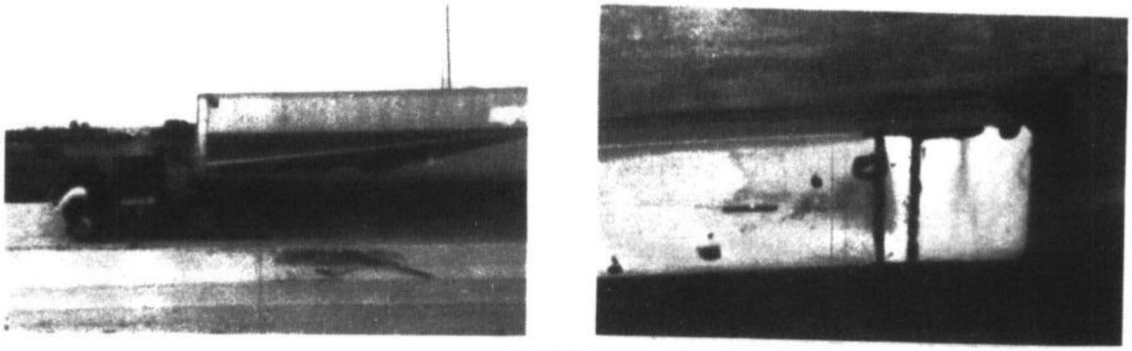
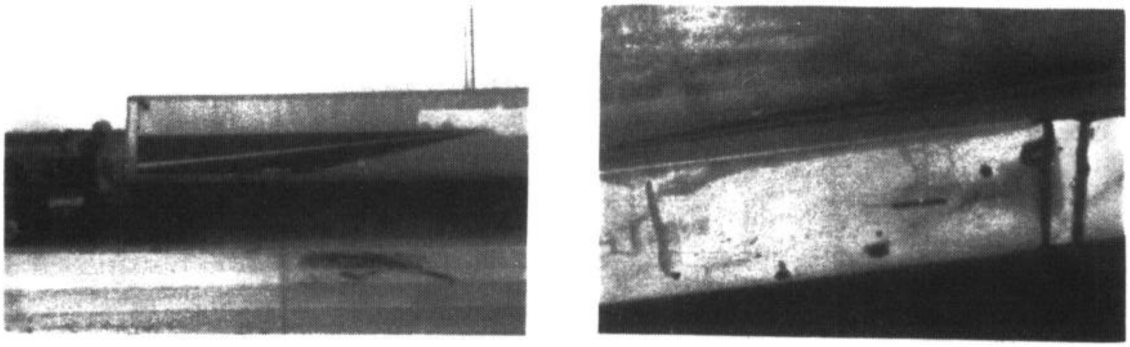


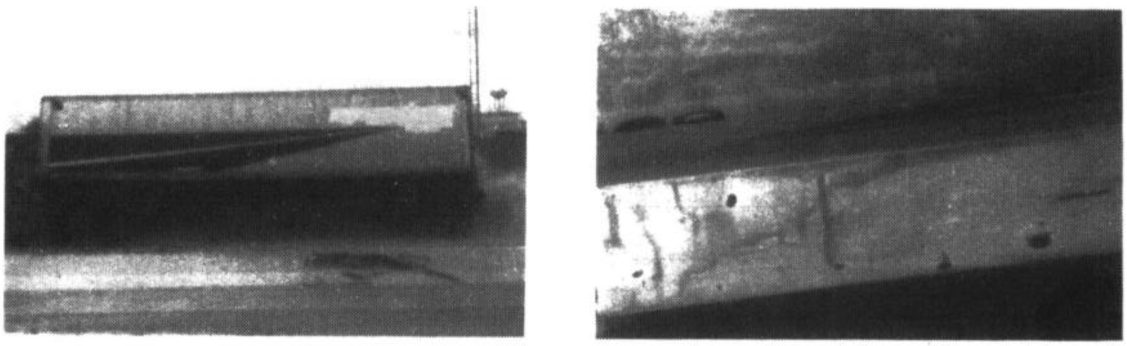
Figure 11. Sequential photographs for test 7069-13.



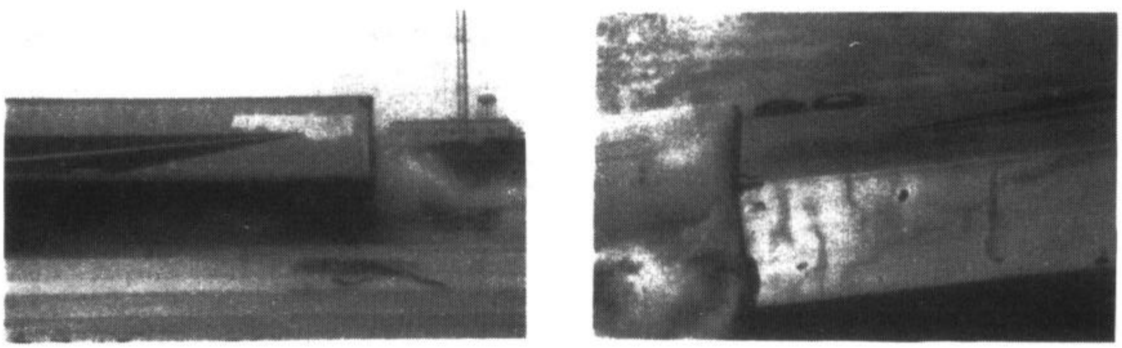
0.595 s



0.743 s

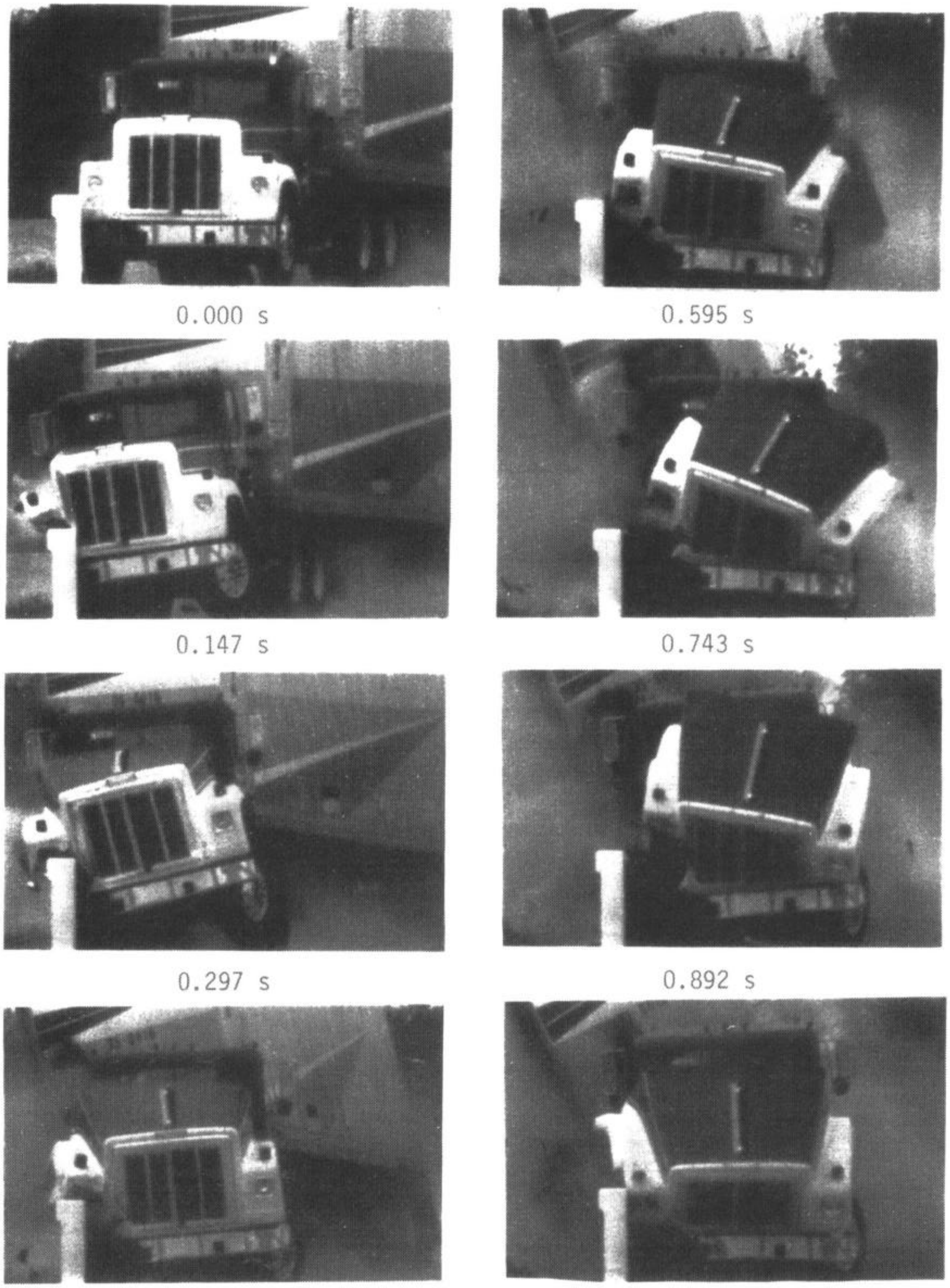


0.892 s



1.040 s

Figure 11. Sequential photographs for test 7069-13 (continued).



0.000 s | 0.595 s
0.147 s | 0.743 s
0.297 s | 0.892 s
0.446 s | 1.040 s

Figure 12. Frontal sequential photographs for test 7069-13.

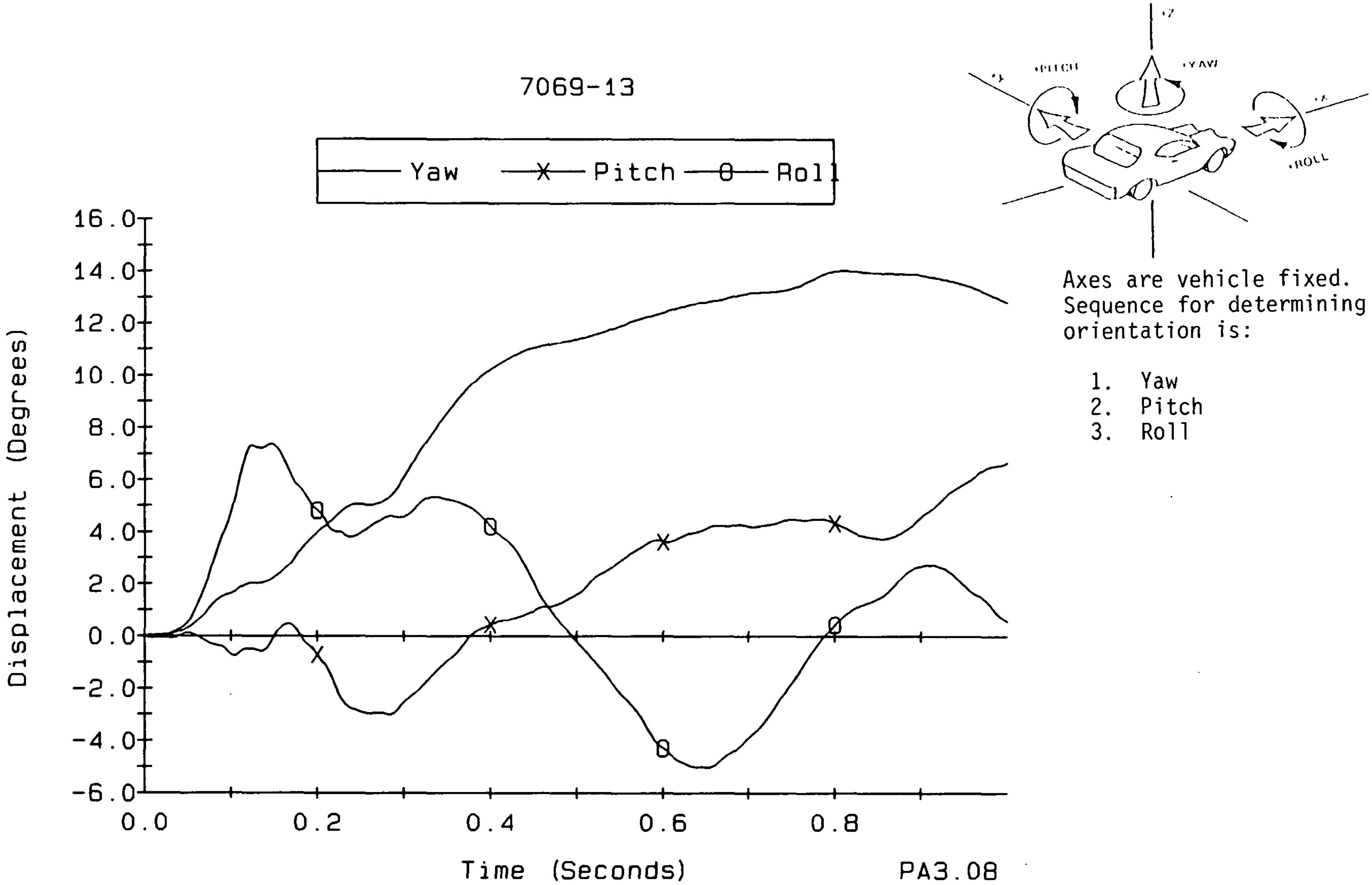


Figure 13. Vehicle angular displacement for test 7069-13.

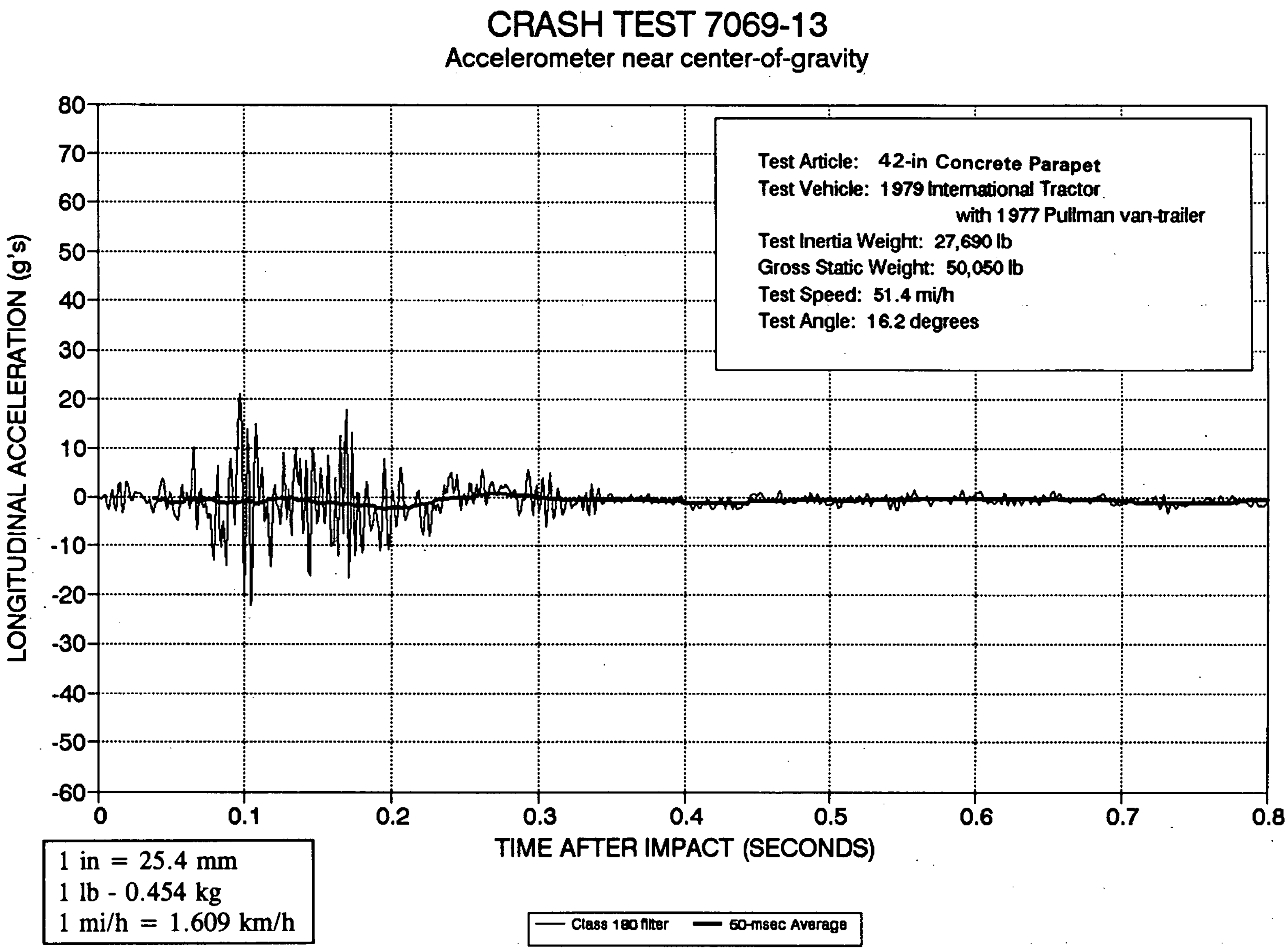
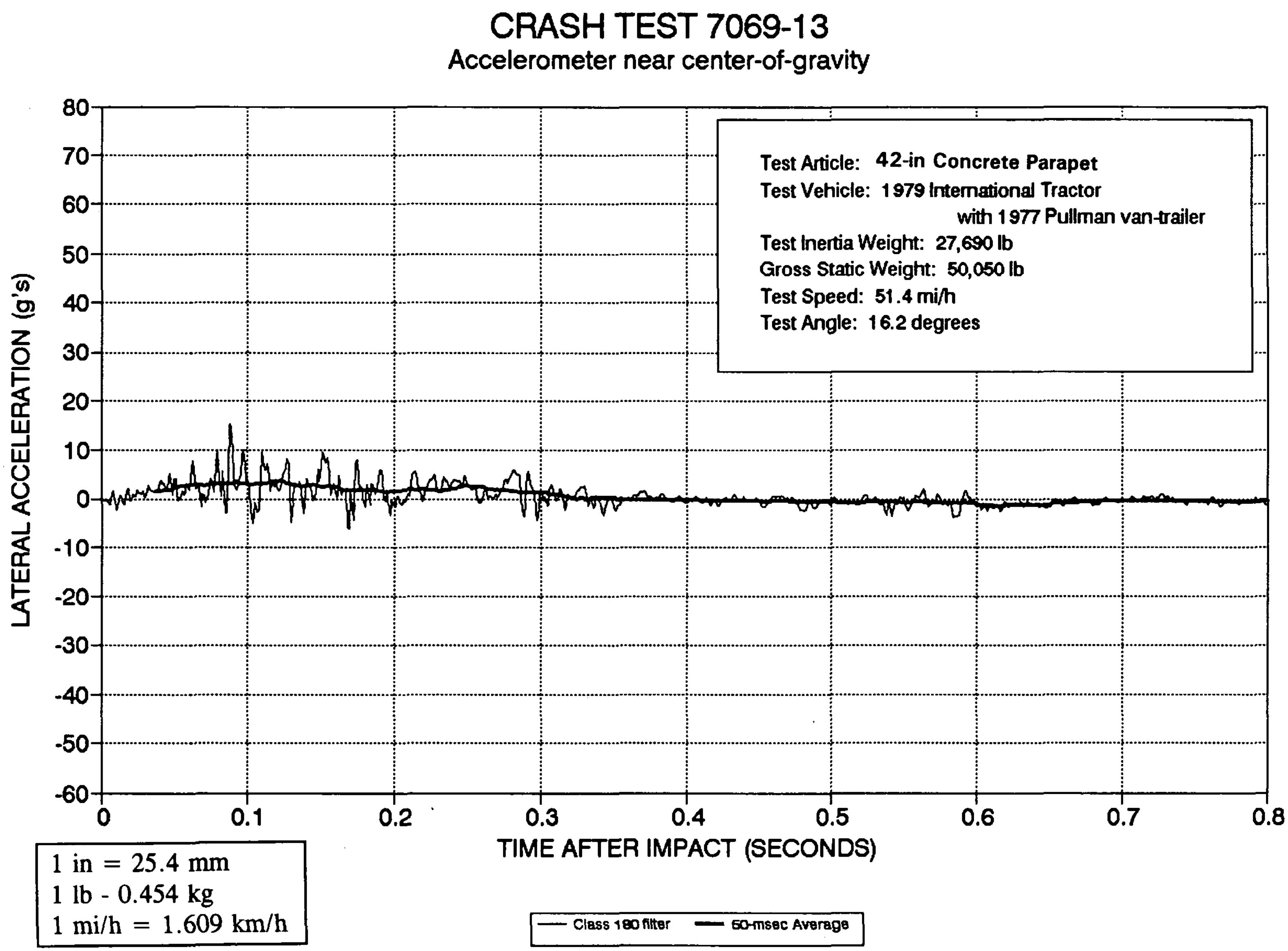


Figure 14. Vehicle longitudinal accelerometer trace for test 7069-13 (accelerometer located near tractor center-of-gravity).



1 in = 25.4 mm
1 lb - 0.454 kg
1 mi/h = 1.609 km/h

Figure 15. Vehicle lateral accelerometer trace for test 7069-13 (accelerometer located near tractor center-of-gravity).

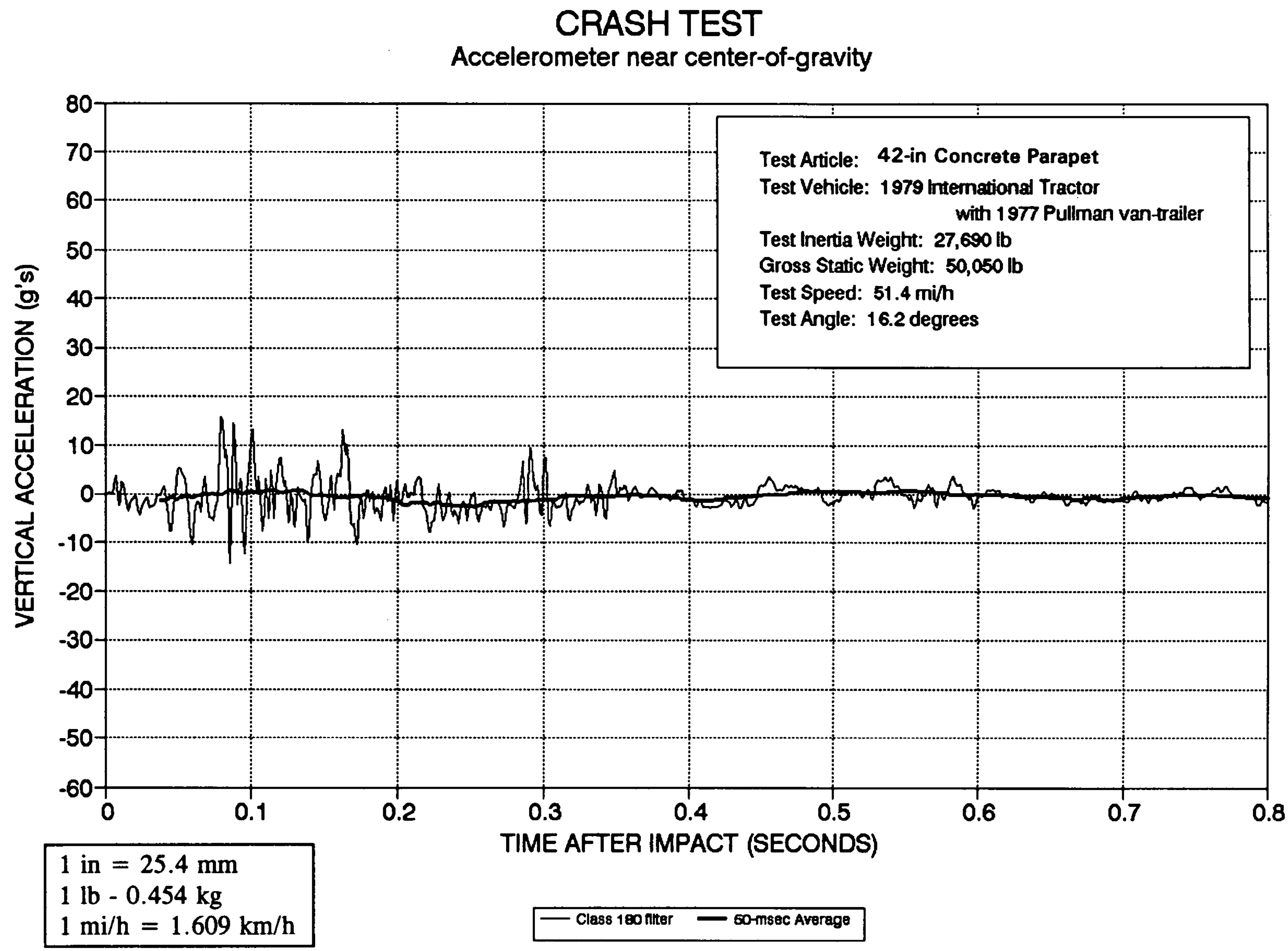
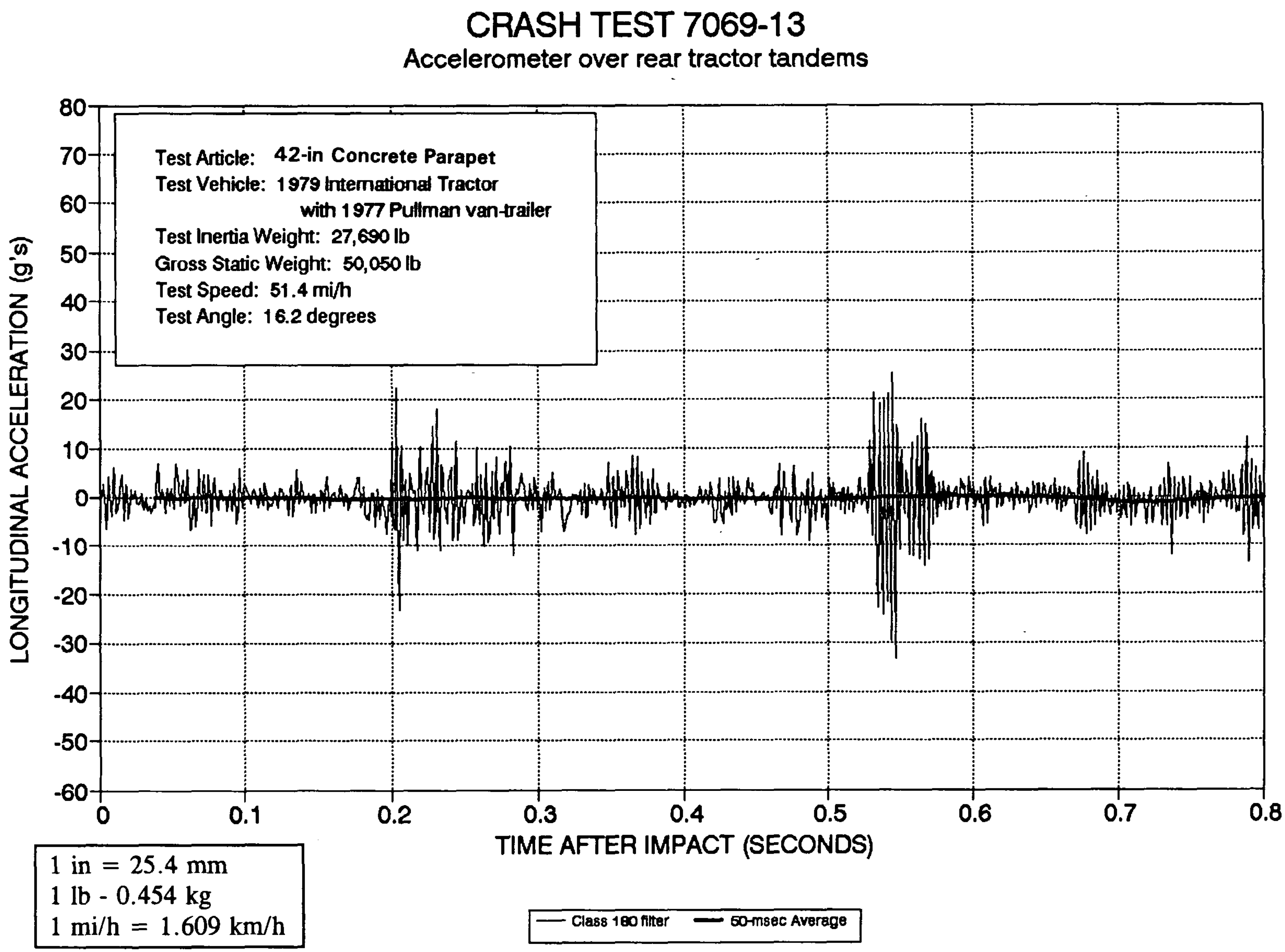


Figure 16. Vehicle vertical accelerometer trace for test 7069-13
(accelerometer located near tractor center-of-gravity).



1 in = 25.4 mm
1 lb - 0.454 kg
1 mi/h = 1.609 km/h

Figure 17. Vehicle longitudinal accelerometer trace for test 7069-13 (accelerometer located over tractor tandems).

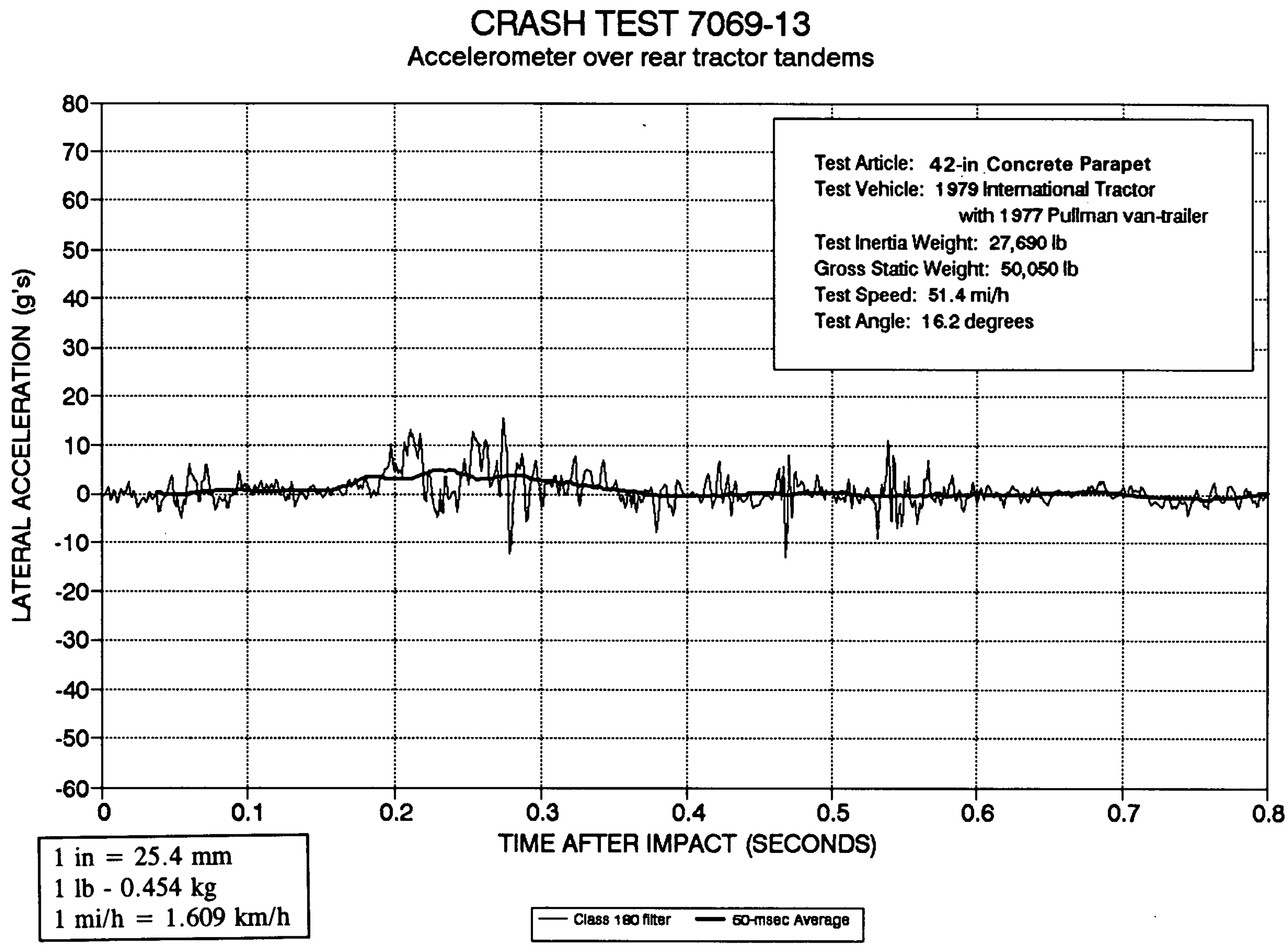


Figure 18. Vehicle lateral accelerometer trace for test 7069-13 (accelerometer located over tractor tandems).

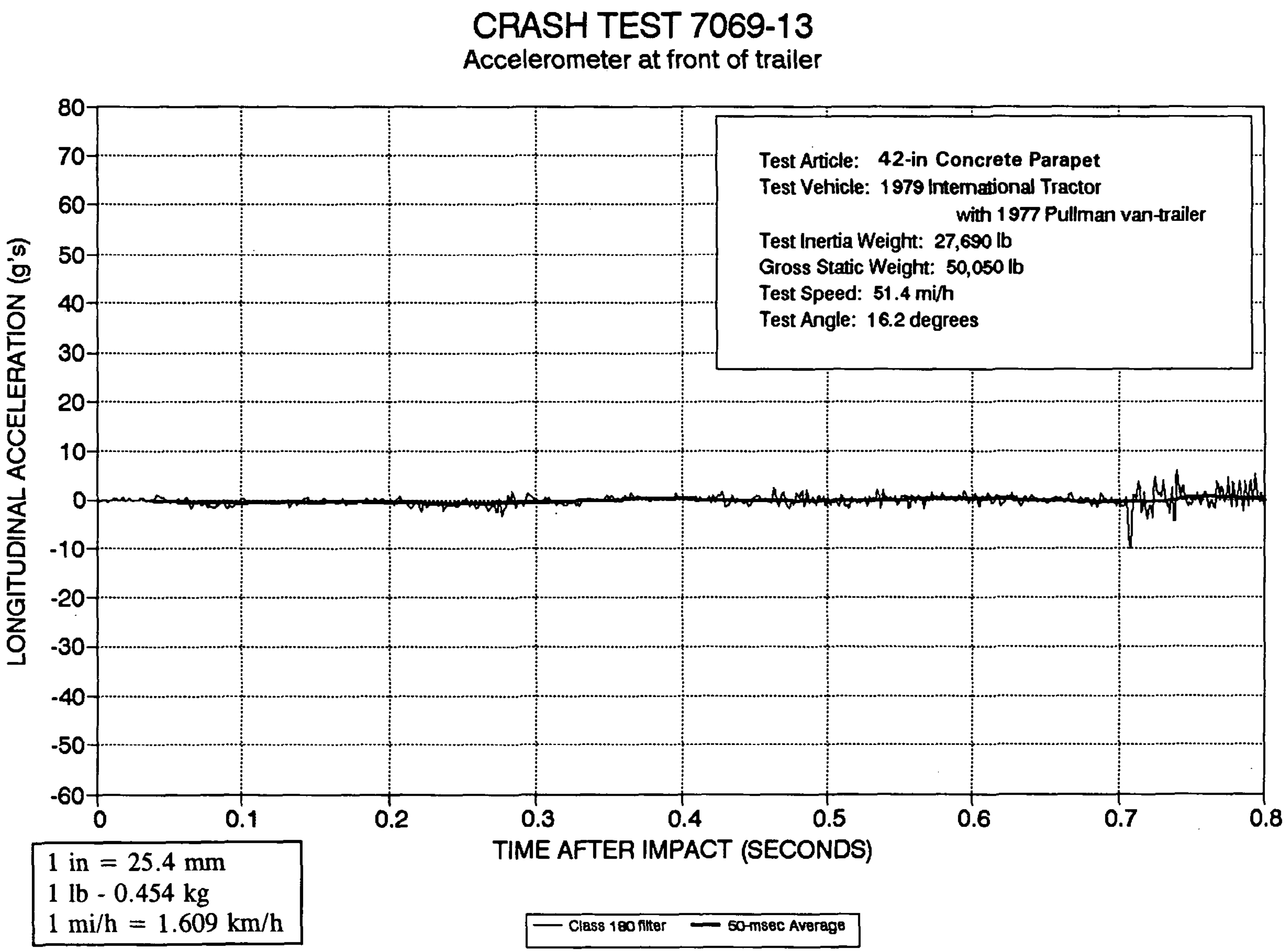


Figure 19. Longitudinal accelerometer trace for test 7069-13 (accelerometer located at trailer front).

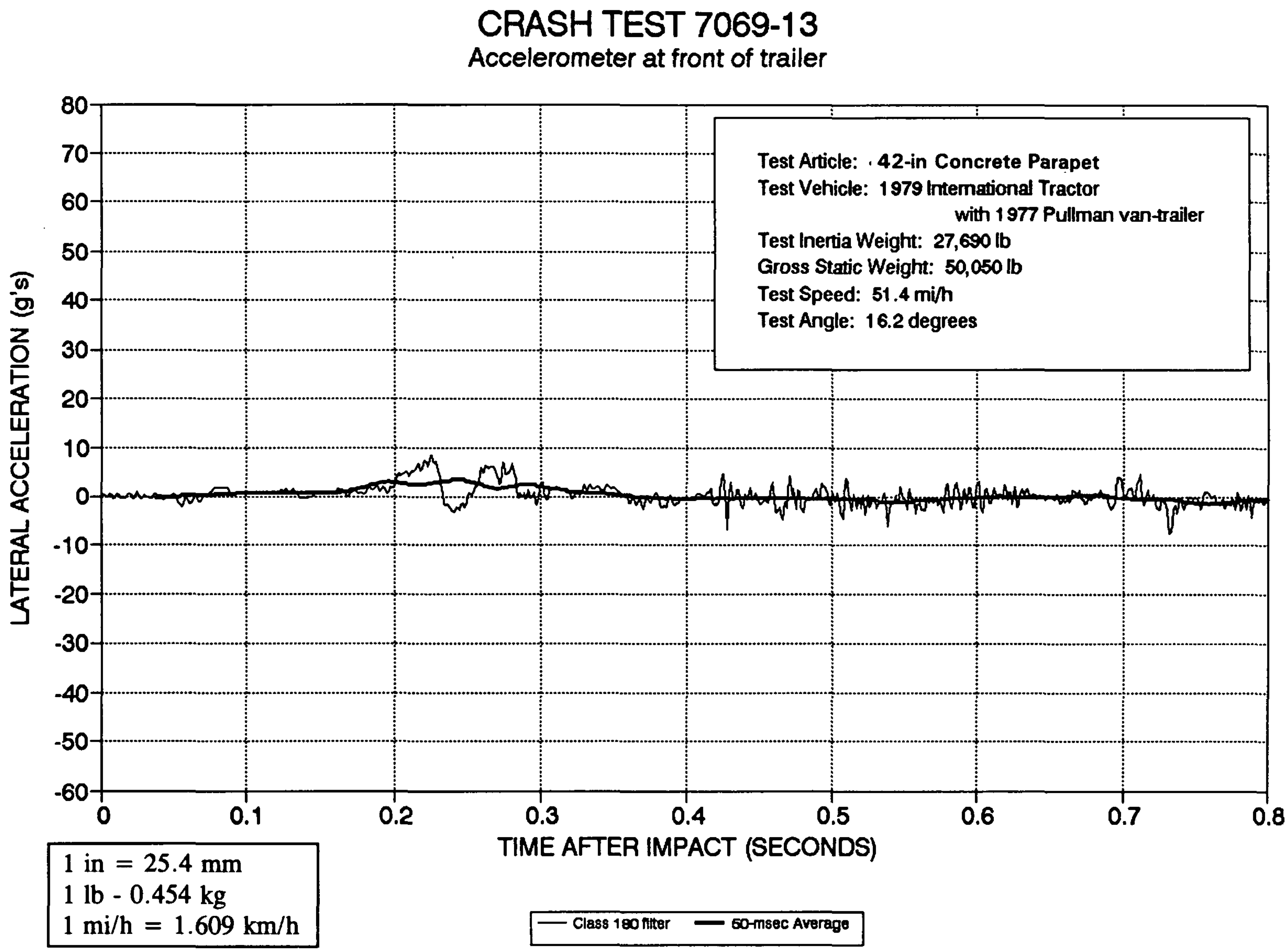


Figure 20. Lateral accelerometer trace for test 7069-13
(accelerometer located at trailer front).

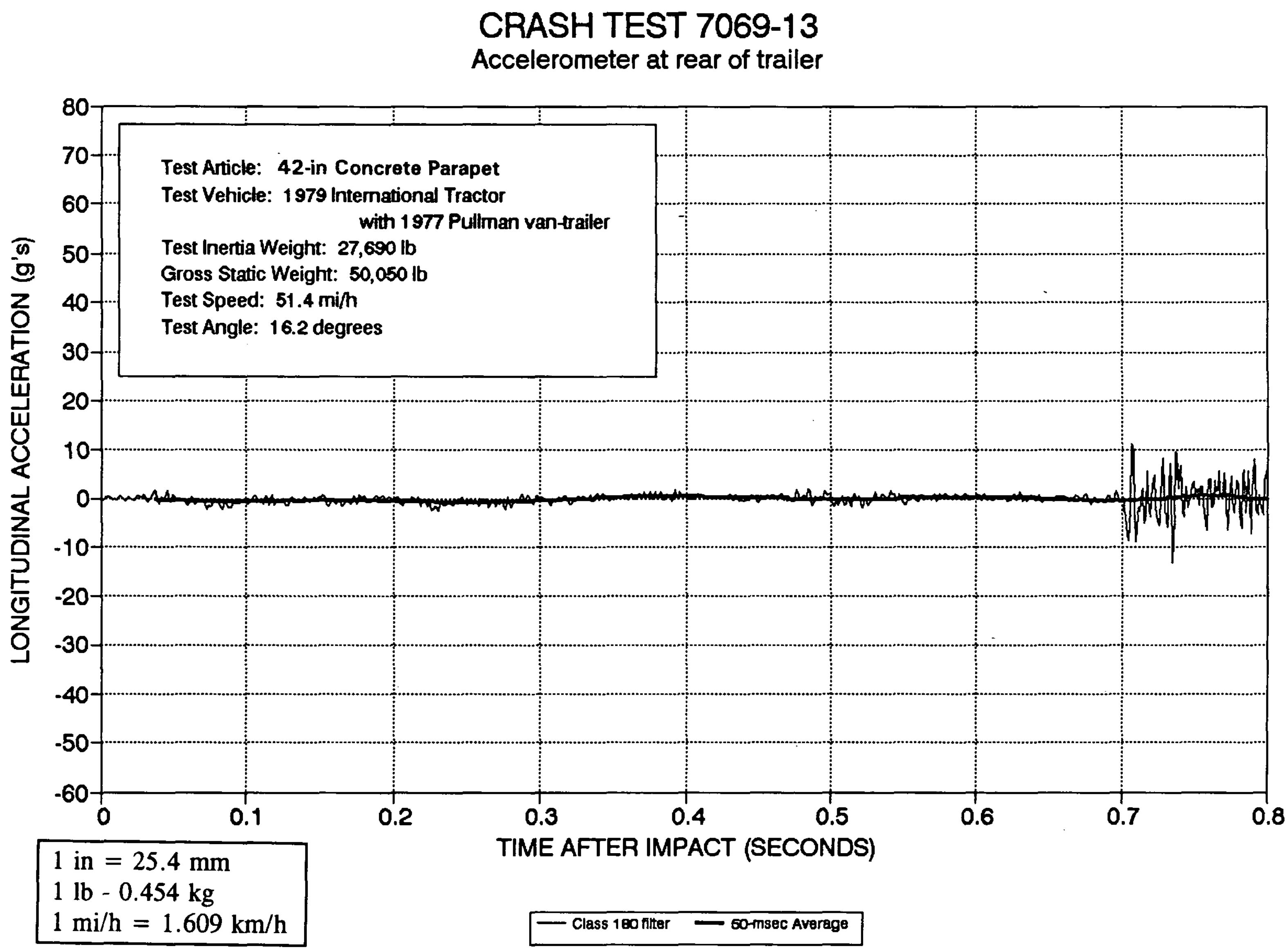


Figure 21. Longitudinal accelerometer trace for test 7069-13 (accelerometer located at trailer rear).

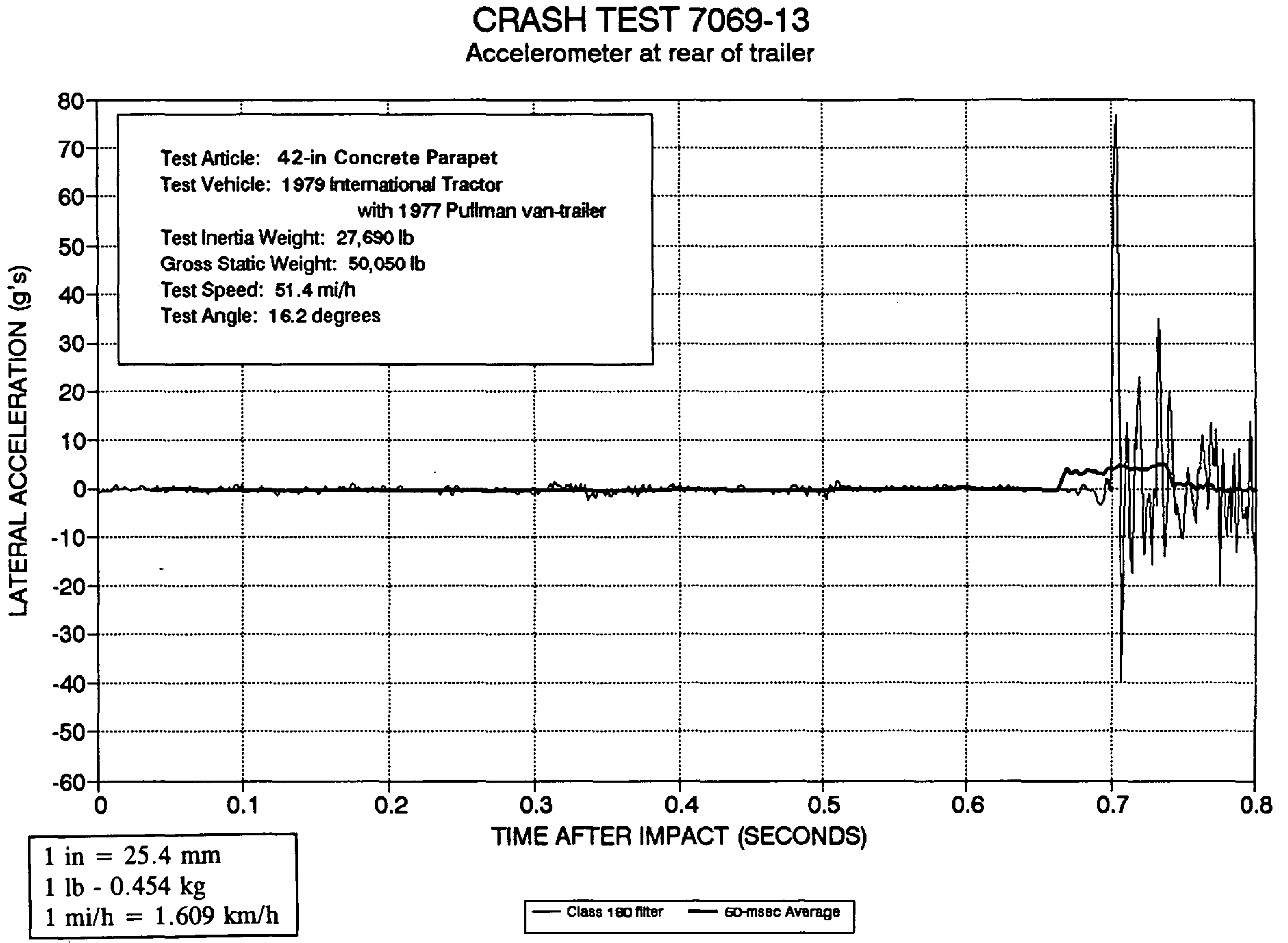
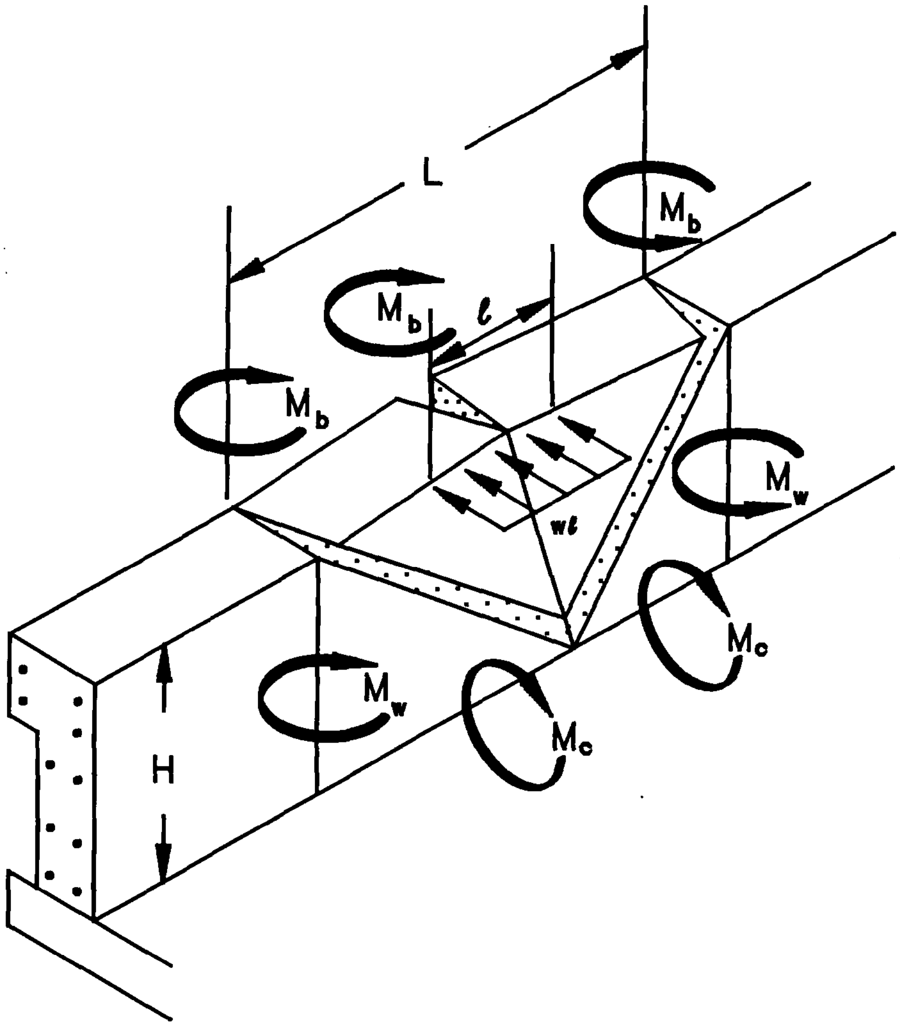


Figure 22. Lateral accelerometer trace for test 7069-13 (accelerometer located at trailer rear).

CHAPTER 4. STRENGTH CALCULATIONS

Analysis of the strength of the railing is based on the yieldline pattern shown in figure 23.[2] 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 21.4 ft-k/ft (95.2 m-kN/m). The moment capacity of the parapet about a vertical axis, M_w, is 16.5 ft-k/ft (73.4 m-kN/m). The additional moment capacity of the stiffening beam along the top of the parapet is 43.9 ft-kips (59.6 m-kN). The length of the yieldline failure pattern, computed from the equation in figure 23 is 16.2 ft (4.9 m) and the ultimate strength of the parapet is 198 kips (881 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 23. 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. 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.