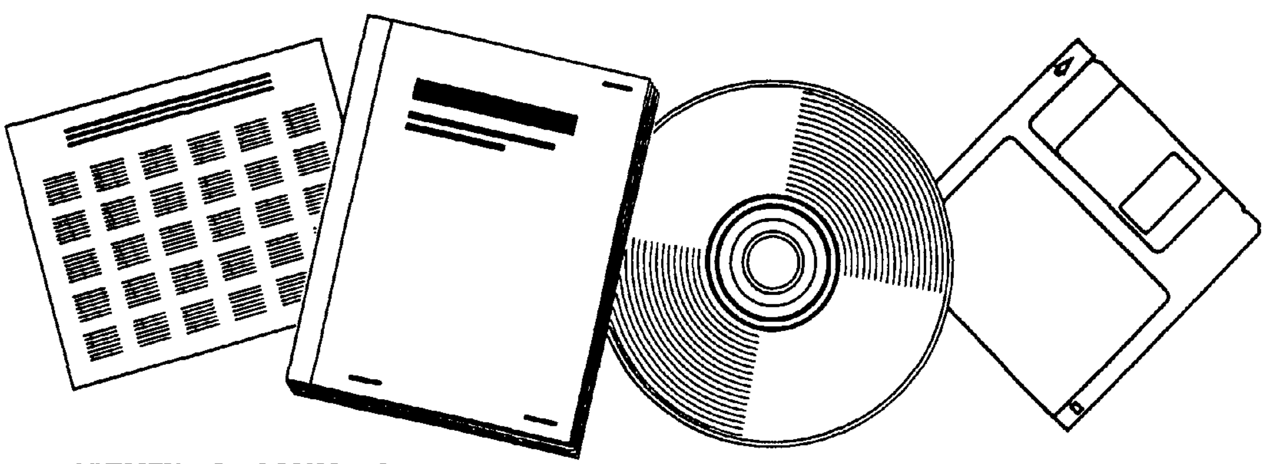
PB97-170500

TESTING OF NEW BRIDGE RAIL AND TRANSITION DESIGNS. VOLUME 5. APPENDIX D. 32-IN (813-MM) CONCRETE PARAPET BRIDGE RAILING

TEXAS TRANSPORTATION INST., COLLEGE STATION

JUN 97



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

Testing of New Bridge Rail and Transition Designs

Volume V: Appendix D

32-in (813-mm) Concrete Parapet Bridge Railing

PUBLICATION NO. FHWA-RD-93-062

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Research and Development
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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

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16. Abstract

The 32-in (813-mm) concrete parapet has a flat vertical traffic face with a thickened section along the top. The flat vertical face serves to smoothly redirect vehicles without imparting upward force on the vehicle. It was designed and tested to performance level two of the 1989 *Guide Specifications for Bridge Railings*. Acceptable performance was demonstrated.

This volume is the fifth 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 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 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.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

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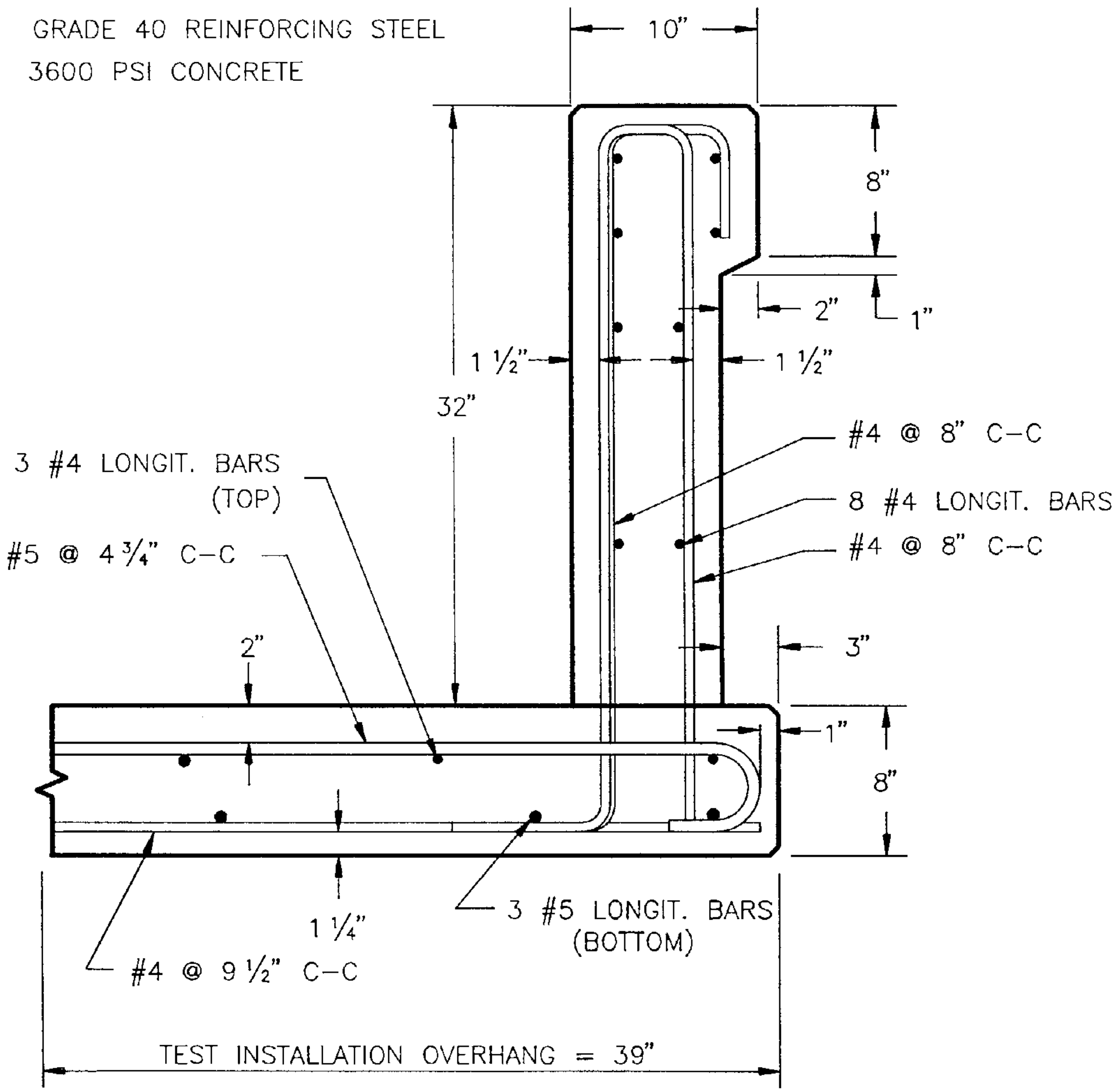
CHAPTER 1. DESIGN OF RAILING

This railing was designed to meet performance level two of the 1989 *Guide Specifications for Bridge Railings.*(1) The design force of 56 kips (249 kN) was a uniformly distributed line force 42 in (1.07 m) long located at least 29 in (737 mm) above the roadway surface.

A cross section of the railing design is shown in figure 1. Total height of the parapet is 32 in (813 mm). It is 8 in (203 mm) thick over most of the height with a 10-in (254-mm) thickened section at the top. This thickened top portion serves to increase the longitudinal distribution of force within the parapet and allow more length of parapet and deck to resist the collision force.

Eight #4 longitudinal bars were used in the parapet. The vertical steel was #4 bars at 4-in (102-mm) spacing in the traffic side face and #4 bars at 8-in (203-mm) spacing in the field side face. This was accomplished by alternating two types of vertical steel bars. 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 cantilevered deck was supported on a foundation so that the deck overhang was 39 in (991 mm).

The strength of this railing was computed using yieldline analysis procedures.(2) These computations are presented in chapter 4. The analysis predicts the length of failure mechanism to be 7.6 ft (2.3 m) and the total ultimate load capacity to be 61 kips (271 kN). The analysis also shows that the yield lines are confined to the parapet rather than extending into the deck.



1 in = 25.4 mm
1 psi = 6.89 kPa

Figure 1. Cross section of 32-in (813-mm) concrete parapet.

CHAPTER 2. CRASH TEST PROCEDURES

This railing was tested to performance level two requirements.[1] The following nominal test conditions were used:

1,800-lb (817-kg) passenger car | 60 mi/h (96.5 km/h) | 20 degrees (test 7069-5)
5,400-lb (2 452-kg) pickup | 60 mi/h (96.5 km/h) | 20 degrees (test 7069-6)
18,000-lb (8 172-kg) single-unit truck | 50 mi/h (80.5 km/h) | 15 degrees (test 7069-16)

Each vehicle was instrumented with three solid-state angular rate transducers to measure yaw, pitch, and roll rates, and a triaxial accelerometer mounted near the center-of-gravity. In addition, on the pickup and 18,000-lb (8 172-kg) truck, two sets of biaxial accelerometers were mounted--one set forward of the center-of-gravity and one set in the rear of the vehicles. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration. The electronic signals for 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 displaying on a real-time strip chart. Provisions were made for the transmission of calibration signals before and after each 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 and 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.

Alderson Research Laboratories Hybrid II, 50th percentile anthropomorphic dummies were used in the passenger car and pickup tests. One uninstrumented dummy was placed in the driver's position of the passenger car and two dummies were placed in the pickup--one in the driver's position and one in the passenger's position. The dummies were restrained with standard restraint equipment. No dummies were used in the 18,000-lb (8 172-kg) truck.

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 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 a 0.050-s intervals in each of the three directions are computed. Accelerations versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted 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 yaw, pitch, and roll at rated charts to compute angular displacements in degrees at 0.001-s intervals, instructing 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 at the downstream end, and a third placed perpendicular to the front of the parapet. In the passenger car and pickup tests a high-speed camera was placed onboard the vehicle to record the actions of the dummy(ies) during the test. 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 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.

Each test vehicle was towed into the test installation using a steel guidance and reverse tow system. A steel cable for guiding the test vehicle was stretched along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. Another steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Immediately prior to impact with the parapet, 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 this time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

CHAPTER 3. FULL-SCALE CRASH TESTS

TEST 7069-5

Test Description

Test 7069-5 involved an impact on the 32-in (813-mm) concrete parapet (figure 2) at the nominal conditions of 1,800 lb (817 lb)|60 mi/h (96.5 km/h)|20 degrees. A 1981 Honda (see figure 3) was directed into the bridge railing using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb (817 kg) and its gross static mass was 1,965 lb (892 kg). The height to the lower edge of the vehicle bumper was 14.0 in (356 mm) and it was 19.5 in (495 m) 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.

Actual speed of the vehicle at impact was 60.5 mi/h (97.3 km/h) and the angle of impact was 21.0 degrees. The vehicle impacted the parapet at midlength. At approximately 0.023 s after impact, the right front tire impacted the parapet and began to redirect after 0.062 s. The rear of the vehicle hit the parapet at 0.157 s and was parallel to the parapet at 0.162 s. The vehicle lost contact with the parapet at 0.236 s after impact. As the vehicle exited the parapet, it had a yaw angle of 3.5 degrees and a trajectory path of 6.2 degrees. The vehicle brakes were then applied. The vehicle came to rest 167 ft (51 m) downstream and 26 ft (8 m) toward the field side of the point of impact. The parapet received cosmetic damage only. There were tire marks on the face of the parapet. The vehicle was in contact with the parapet for 10.3 ft (3.1 m) (figure 5).

The vehicle sustained extensive damage to the right front as shown in figure 6. Maximum crush at the right front corner at bumper height was 5.0 in (127 m). The right front and right rear wheel rims were bent and the right front strut was bent. The passenger door was bent and jammed and the right side was dented and scraped. The hood was bent and shifted to the left. The windshield frame was bent and the windshield was cracked. The roof of the vehicle was buckled and twisted.

Test Results

Impact speed was 60.5 mi/h (97.3 km/h) and the angle of impact was 21.0 degrees. The exit speed at time of contact (0.236 s) was 48.6 mi/h (78.2 km/h) and the vehicle trajectory path was 6.2 degrees with a vehicle yaw angle of 3.5 degrees. The effective coefficient of friction was calculated to be 0.22. Occupant impact velocity was 20.1 ft/s (6.1 m/s) in the longitudinal direction and 26.0 ft/s (7.9 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -1.6 g (longitudinal) and 9.4 g (lateral). Results of the test are summarized in figure 7 and table 1. Sequential photographs of the test are shown in figures 8 and 9. Vehicle angular displacements are displayed in figure 10. Vehicular acceleration versus time traces filtered with SAE J211 filters are presented in figures 11 through 13. The 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 and subsequent values are plotted at the midpoints of intervals. The maximum 0.050-s averages were -8.0 g (longitudinal) and 14.0 g (lateral).

Conclusions

The 32-in (813-mm) concrete parapet contained and smoothly 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 compartment 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 table 1).

Table 1 shows a lateral occupant impact velocity of 26.0 ft/s (7.9 m/s) which is higher than the maximum acceptable value of 25.0 ft/s (7.6 m/s). However, the authors conclude that the performance of this parapet is acceptable on the basis of two arguments. The value obtained is marginally close to being acceptable. The acceptable value was selected as a reasonably achievable value for impact angles of 15 degrees, not the more severe condition of 20 degrees used in this test.

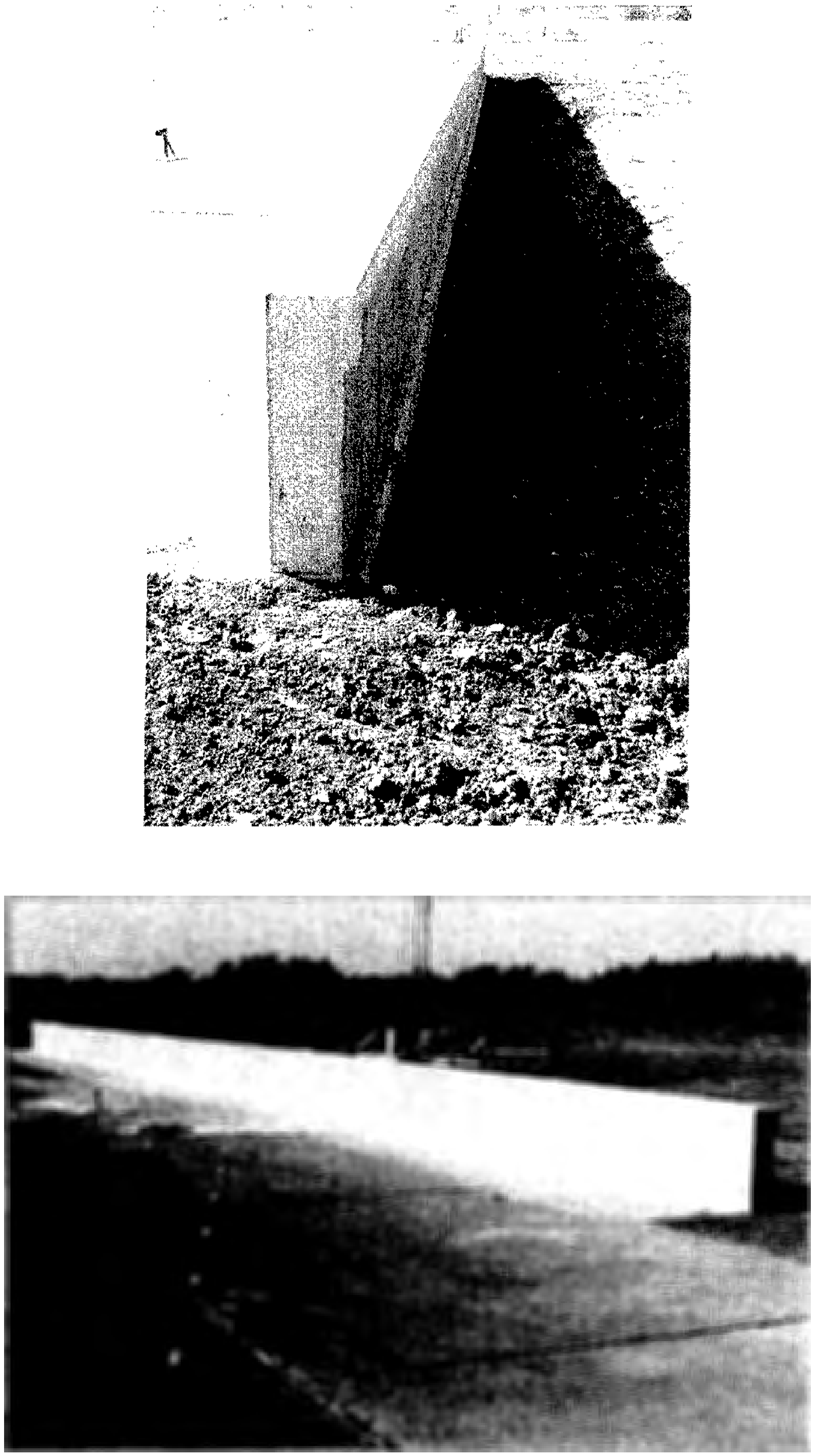


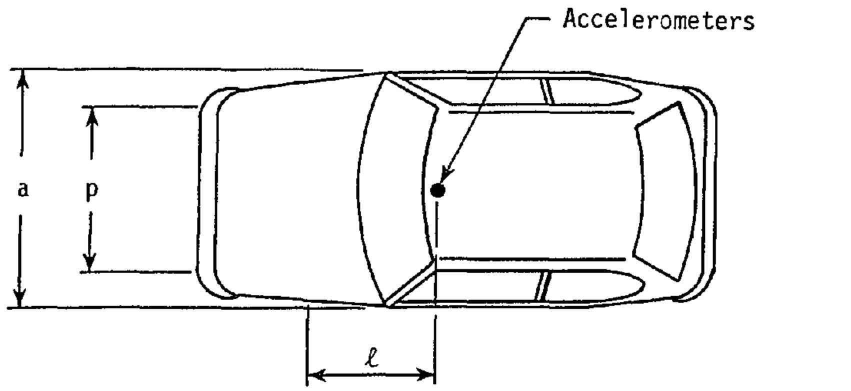
Figure 2. 32-in (813-mm) concrete parapet before test 7069-5.

Figure 3. Vehicle before test 7069-5.

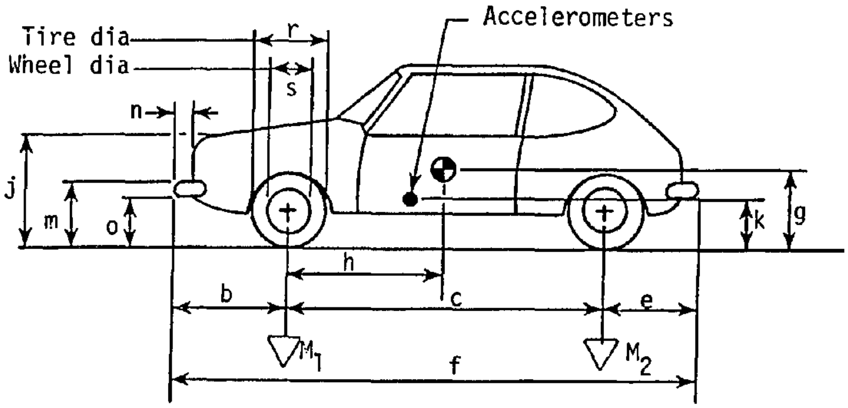
Date: 9-24-87 Test No.: 7069-5 VIN: SL5322BS025255

Make: Honda Model: Civic Year: 1981 Odometer: 35887

Tire Size: 155R12 Ply Rating: ____ Bias Ply: ___ Belted: ___ Radial: X



Tire Condition: good ___
fair X
badly worn ___



4-wheel weight for c.g. det. ℓf 552 rf 526 ℓr 357 rr 365

Vehicle Geometry - inches

a	60 1/2	b	19 1/2
c	88 3/4	d*	52 1/2
e	28 1/4	f	146 1/2
g		h	35.6
i	----	j	29 1/2
k	15	ℓ	39
m	19 1/2	n	3
o	14	p	53 3/4
r	22 1/4	s	13 1/4

Engine Type: 4 cyl

Engine CID: 81 cc

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Body Type: Hitch

Steering Column Collapse Mechanism:

__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:

Front: disc X drum ___

Rear: disc ___ drum X

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		1078	1163
M_2		722	802
M_T		1800	1965

Note any damage to vehicle prior to test:

____

____

*d = overall height of vehicle

1 in = 25.4 mm
1 lb = 0.454 kg

Figure 4. Vehicle properties for test 7069-5.

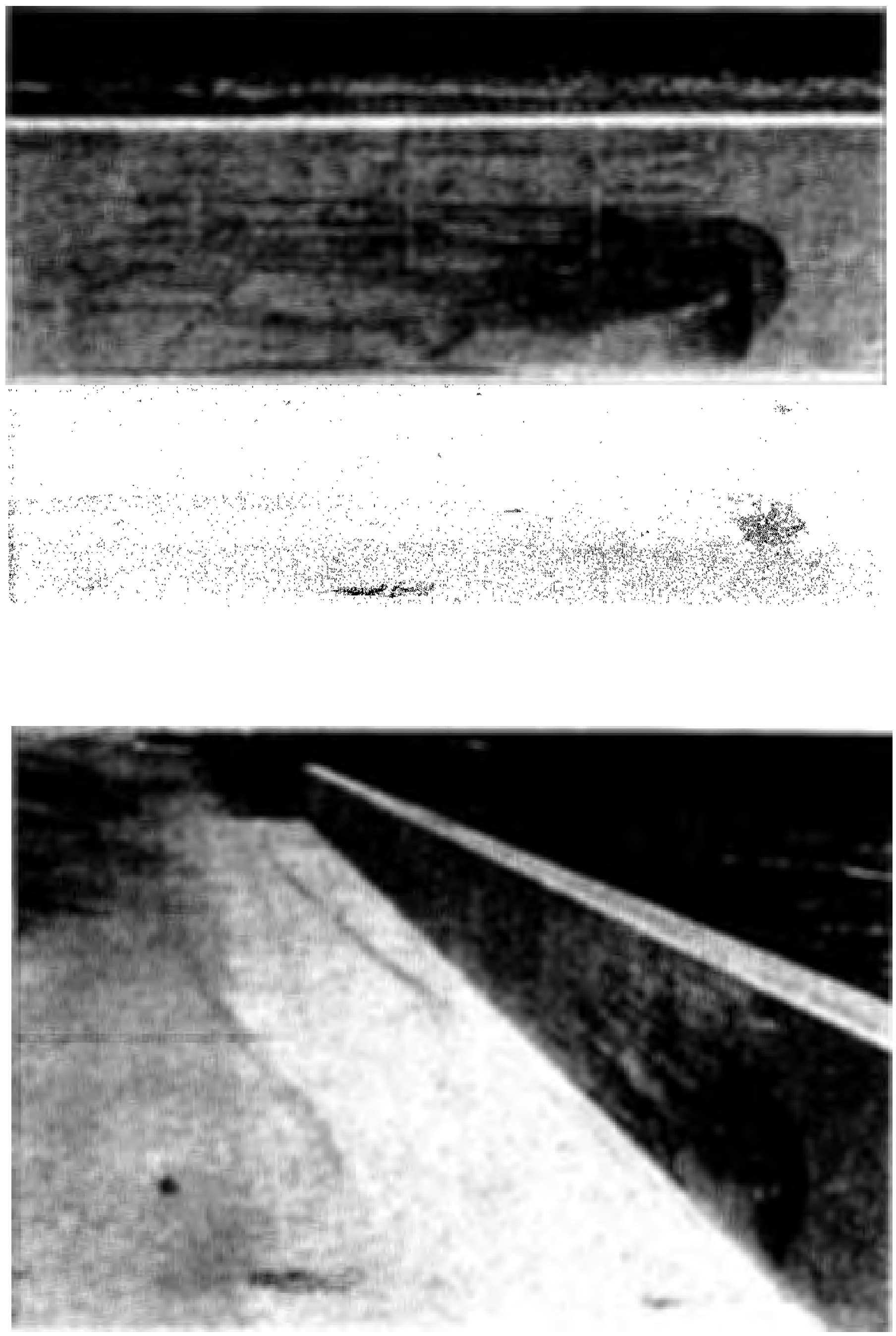
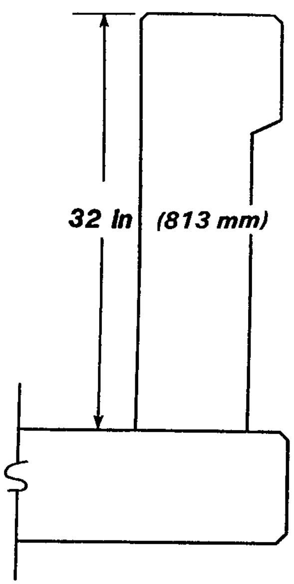


Figure 5. 32-in (813-mm) concrete parapet after test 7069-5.

Figure 6. Vehicle after test 7069-5.



Test No.	7069-5
Date	9/24/87
Test Installation . . .	32-in (813-mm) Concrete Parapet
Installation Length . .	100 ft (30 m)
Vehicle	1981 Honda Civic
Vehicle Weight	
Test Inertia	1,800 lb (817 kg)
Gross Static	1,965 lb (892 kg)
Vehicle Damage Classification	
TAD	01RFQ4
CDC	01FREK2 & 01RYEW3
Maximum Vehicle Crush .	5.0 in (127 mm)

Impact Speed. . .	60.5 mi/h (97.3 km/h)
Impact Angle. . .	21.0 deg
Exit Speed. . . .	48.6 mi/h (78.2 km/h)
Exit Trajectory .	6.2 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal. .	-8.0 g
Lateral	14.0 g
Occupant Impact Velocity	
Longitudinal. .	20.1 ft/s (6.1 m/s)
Lateral	26.0 ft/s (7.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal. .	-1.6 g
Lateral	9.4 g

Figure 7. Summary of results for test 7069-5.

Table 1. Evaluation of crash test no. 7069-5.
{32-in (813-mm) Concrete Parapet Bridge Railing [1,800 lb (817 kg)|60.5 mi/h (97.3 km/h)|21.0 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 .22 — Good	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: 20.1 (6.1) — Lateral: 26.0 (7.9)	Fail (see discussion)
	Occupant Ridedown Accelerations - g's Longitudinal: 15 — Lateral: 15	Occupant Ridedown Accelerations - g's Longitudinal: -1.6 — Lateral: 9.4	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.2 degrees	Pass

* A, B, C, D and G are required. E, F, and H are desired. (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:

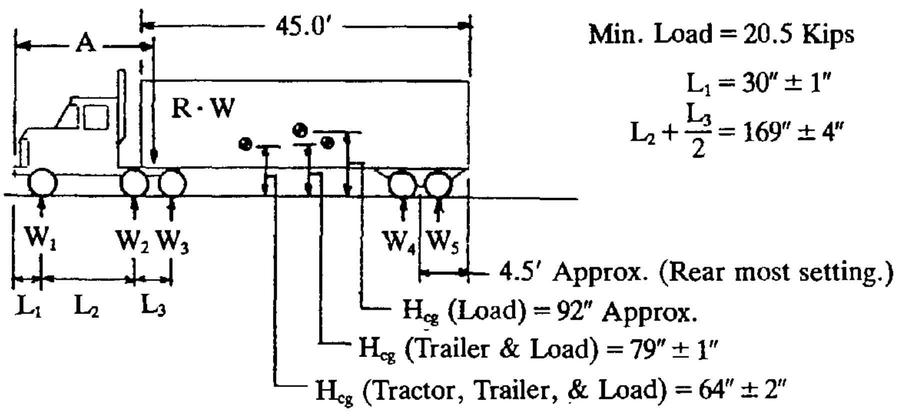
Occupant Impact Velocity–fps	
Longitudinal	Lateral
30	25

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

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

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

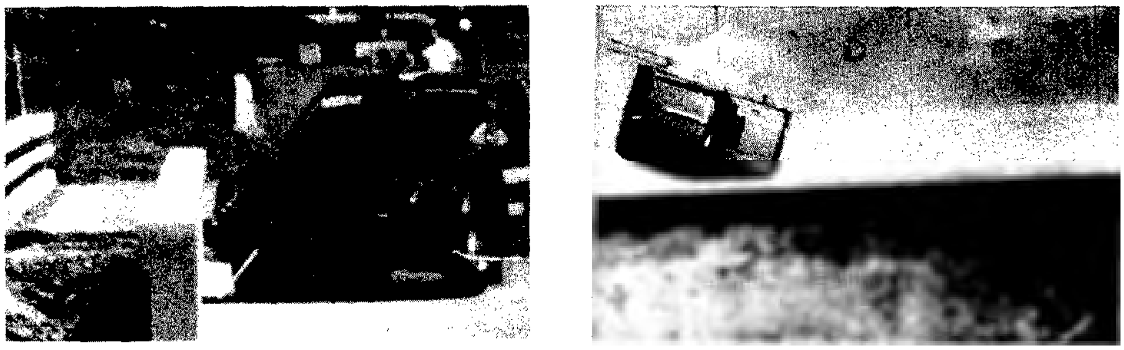
$$A = L_1 + \frac{W_2L_2 + W_3(L_2 + L_3)}{W_1 + W_2 + W_3}$$

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

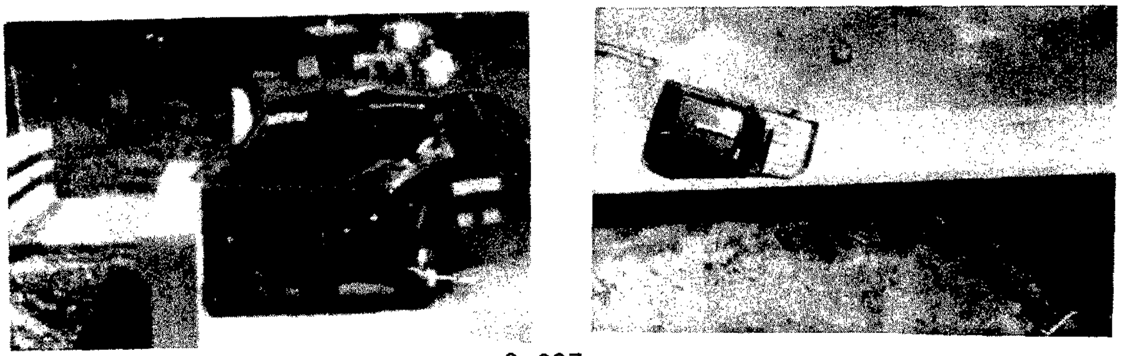
$W = W_1 + W_2 + W_3 + W_4 + W_5$
= total vehicle weight.

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.

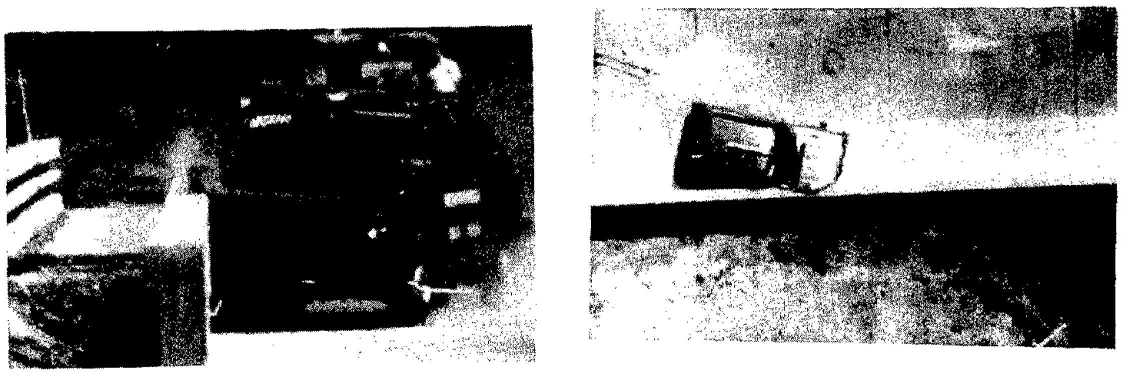
1 mi	= 1.61 km
1 kip	= 4.45 kN
1 in	= 25.4 mm



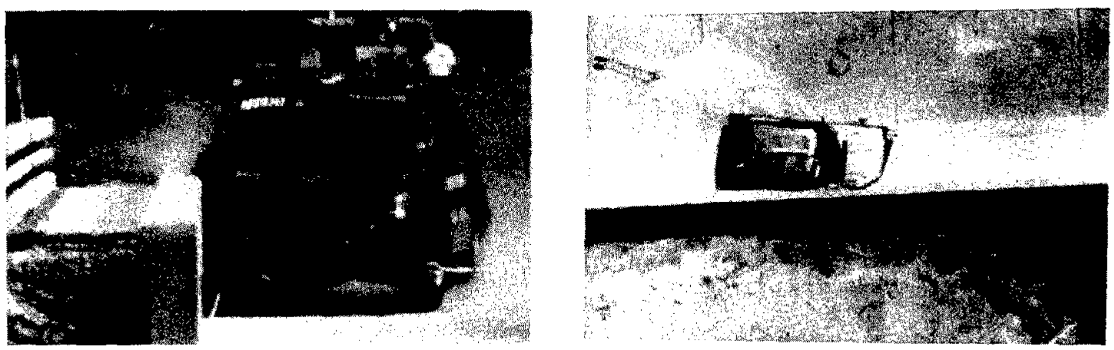
0.000 s



0.037 s

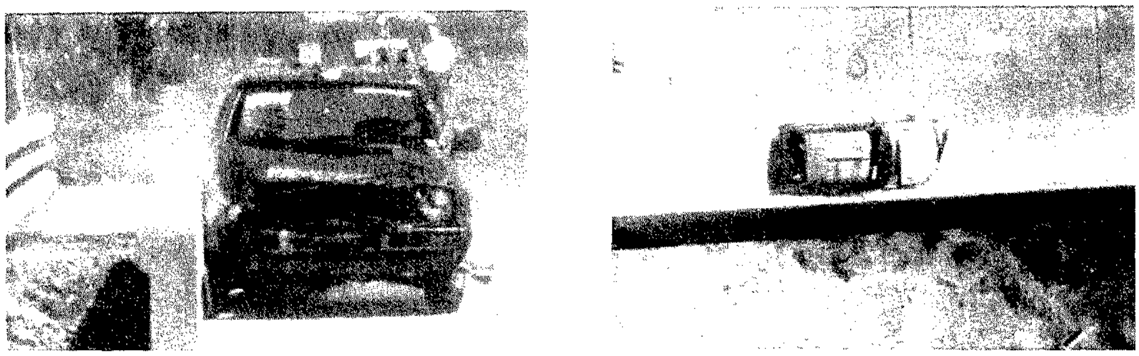


0.075 s

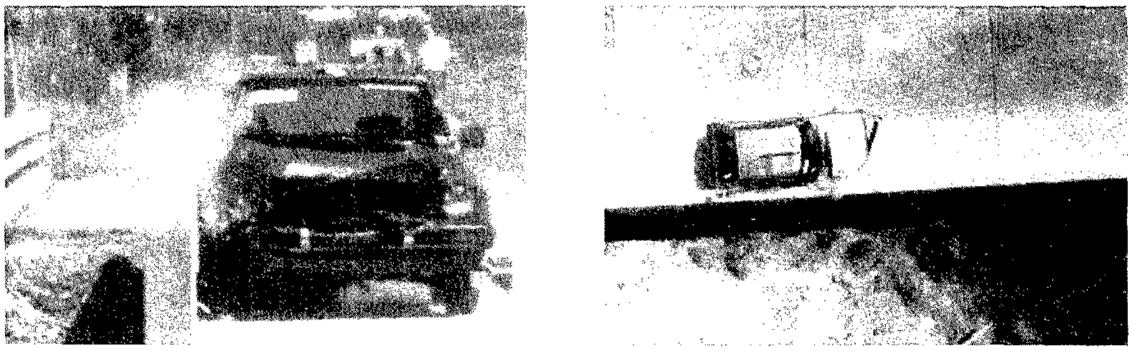


0.112 s

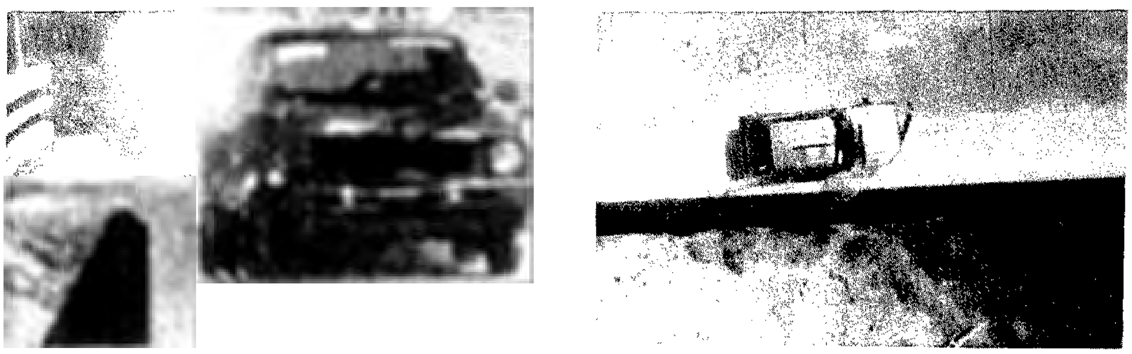
Figure 8. Sequential photographs for test 7069-5.



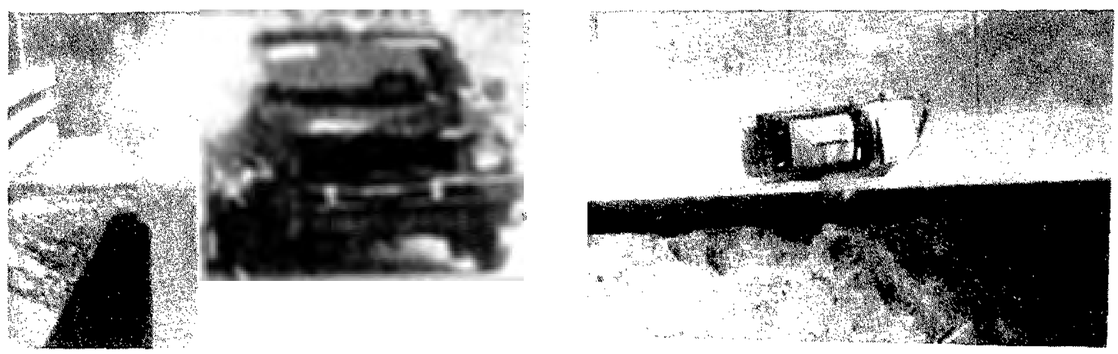
0.149 s



0.186 s



0.224 s



0.261 s

Figure 8. Sequential photographs for test 7069-5 (continued).

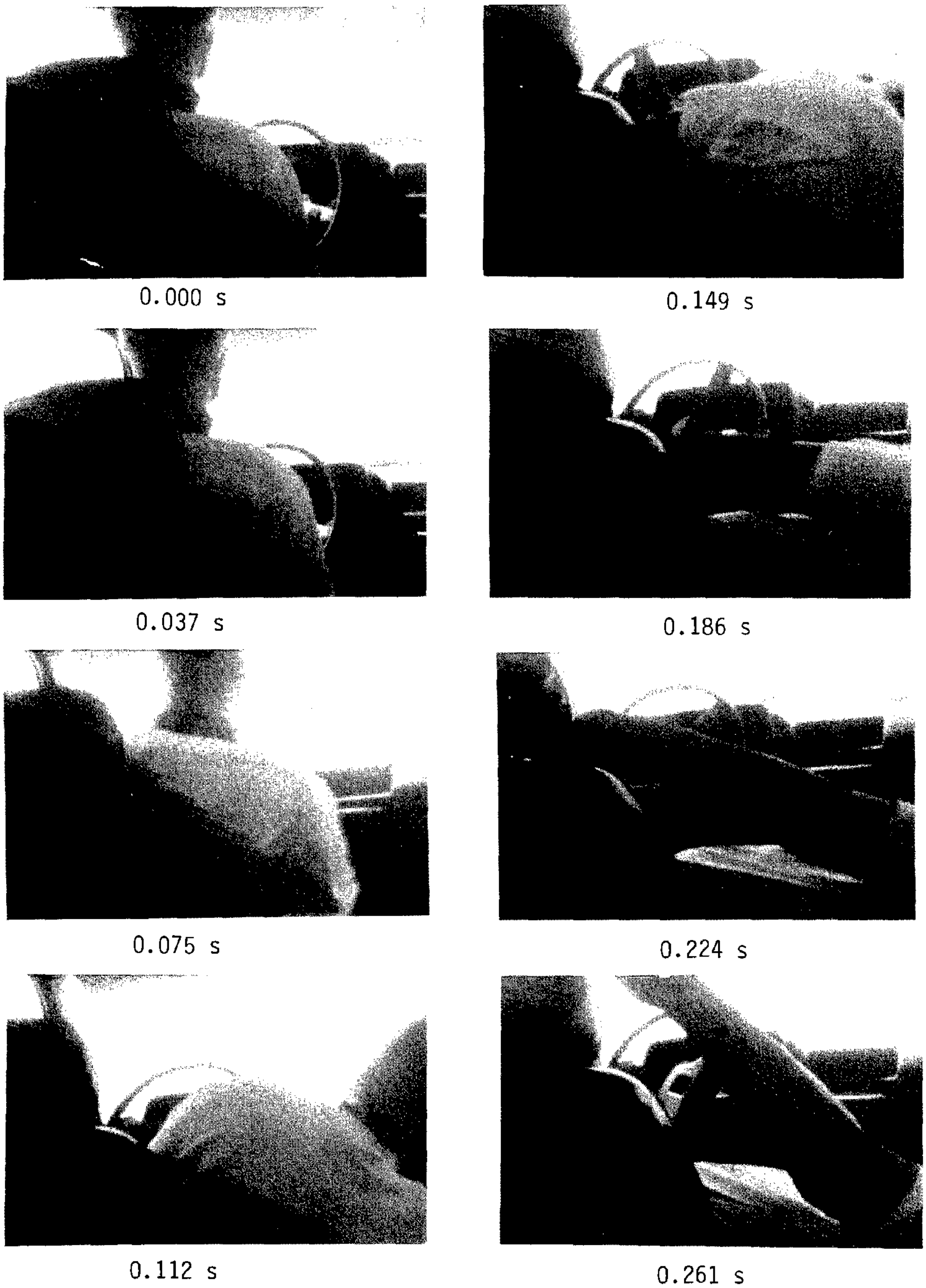
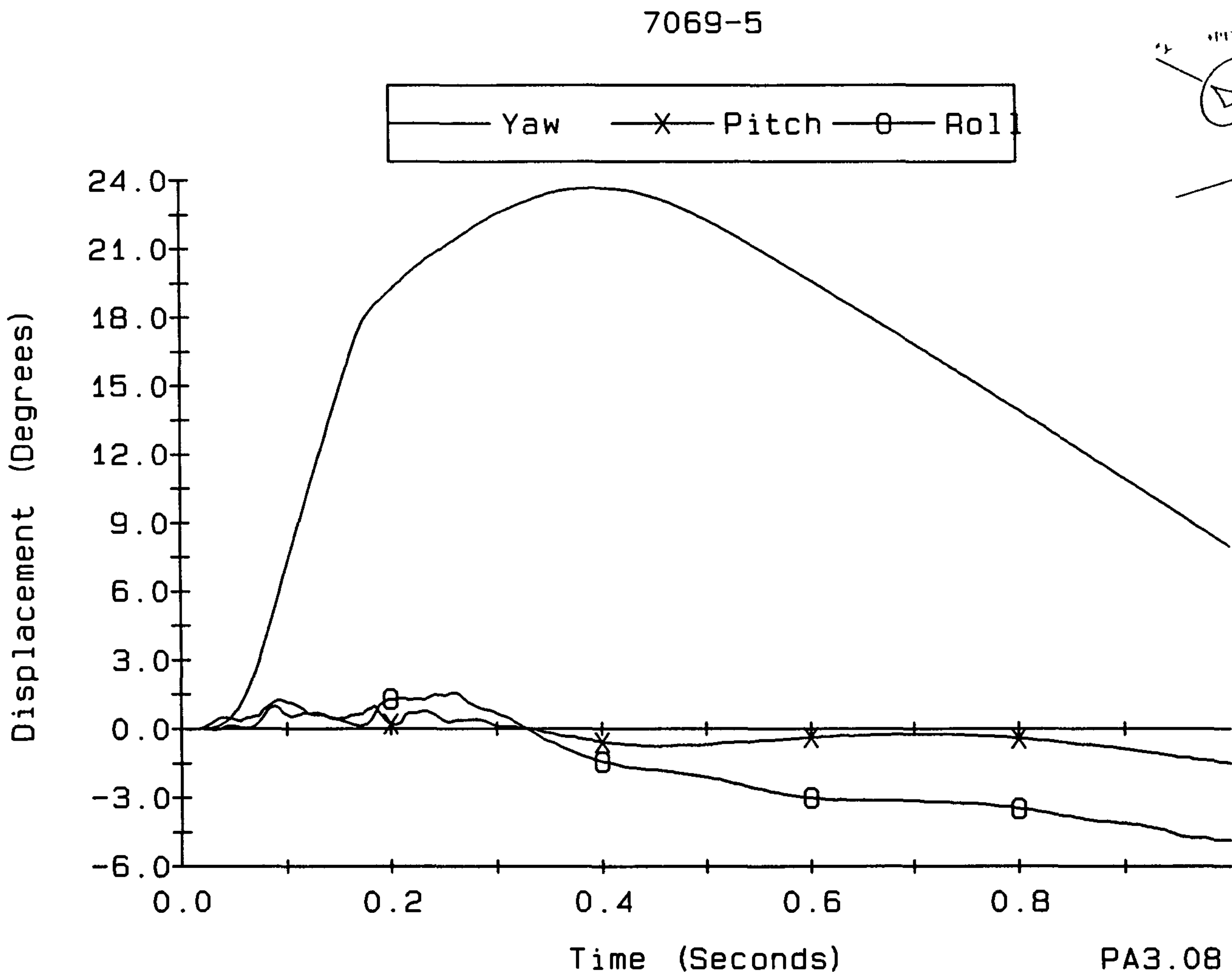
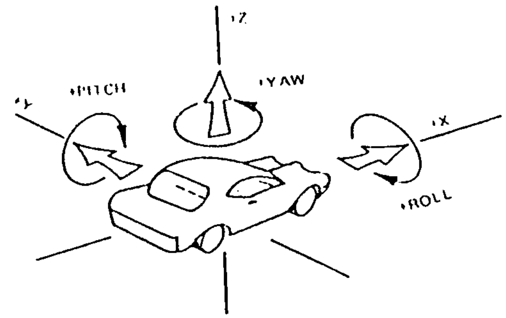


Figure 9. Interior sequential photographs for test 7069-5.





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 10. Vehicle angular displacements for test 7069-5.

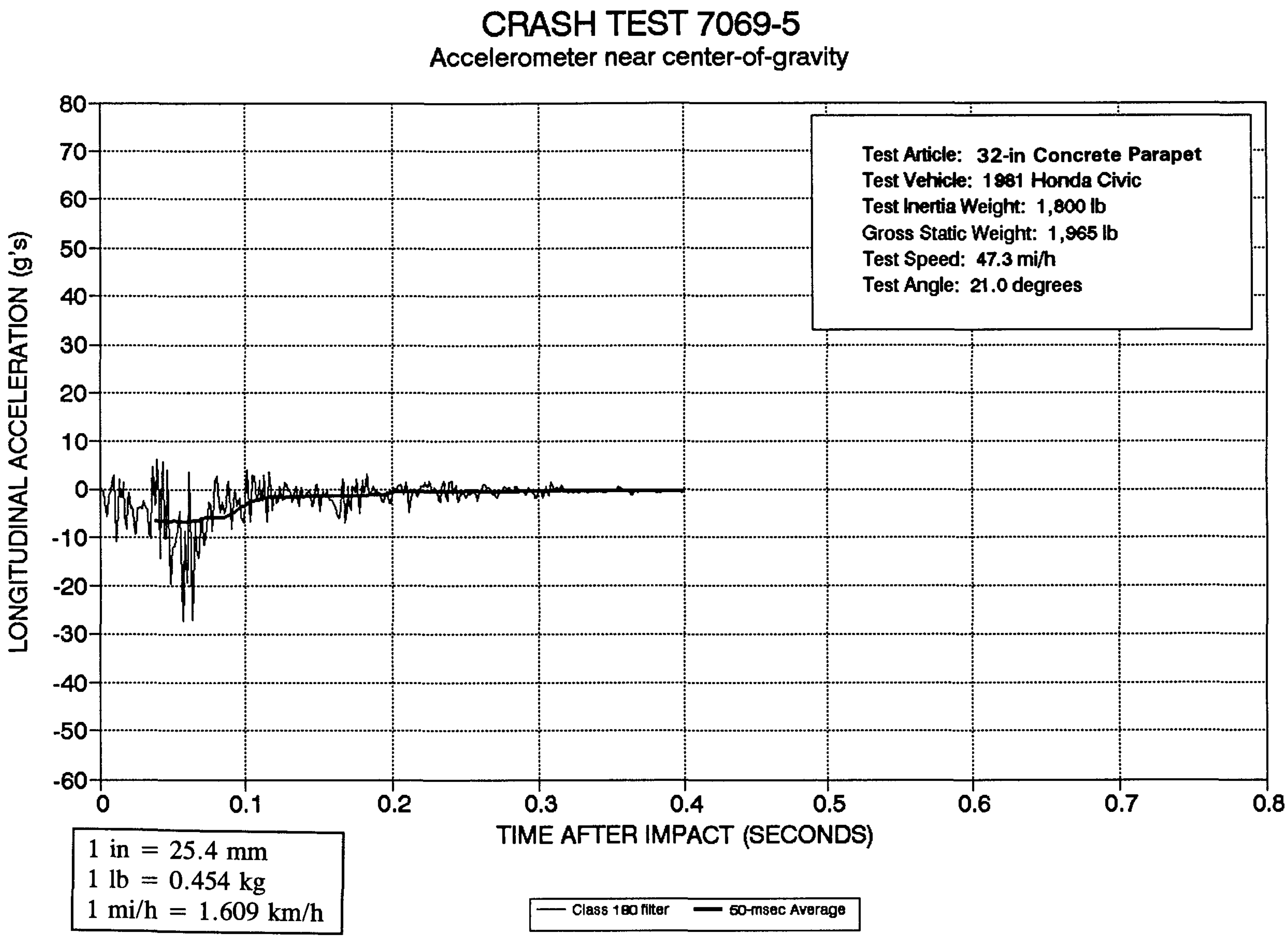
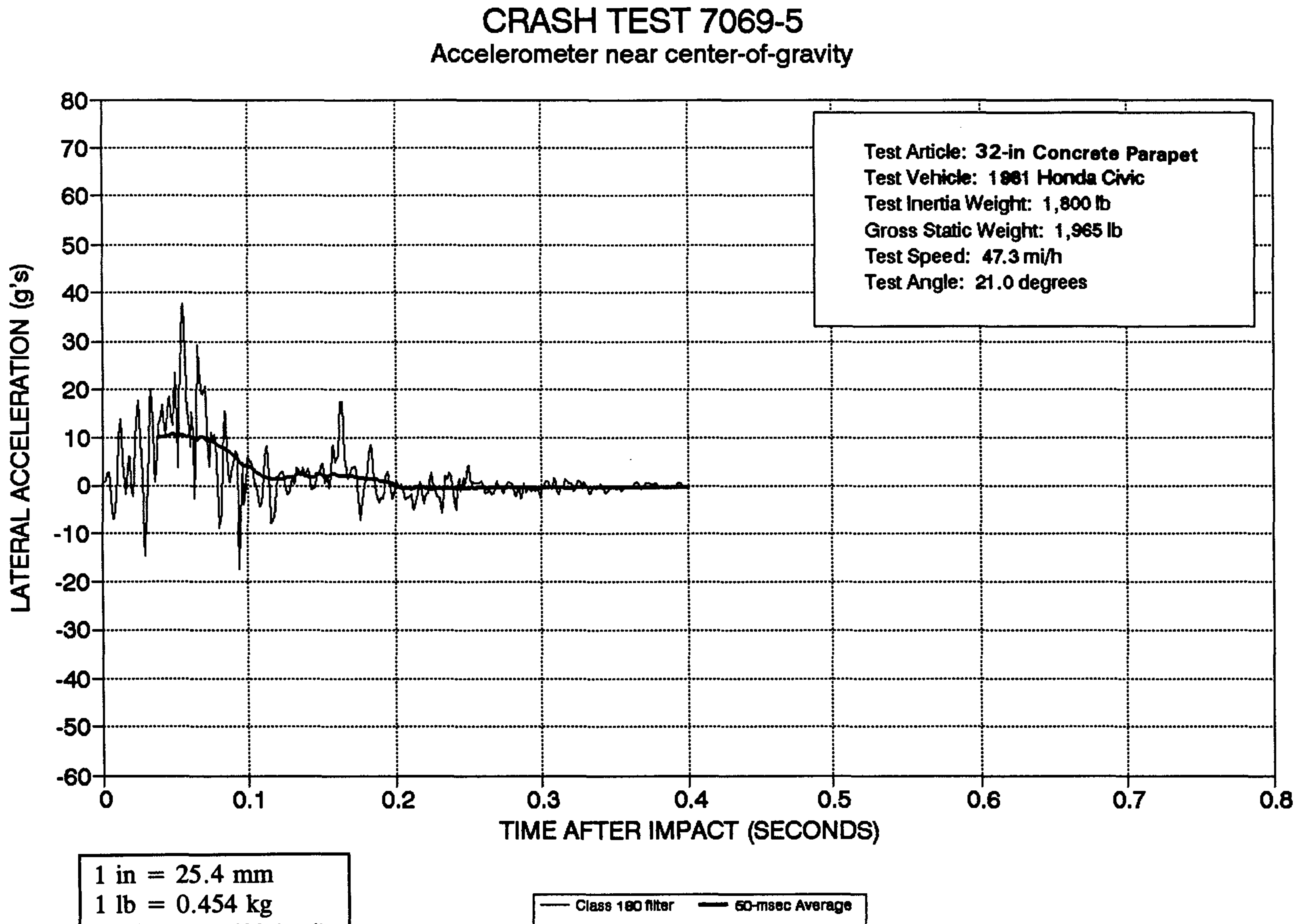


Figure 11. Vehicle longitudinal accelerometer trace for test 7069-5 (accelerometer located near center-of-gravity).



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

Figure 12. Vehicle lateral accelerometer trace for test 7069-5 (accelerometer located near center-of-gravity).

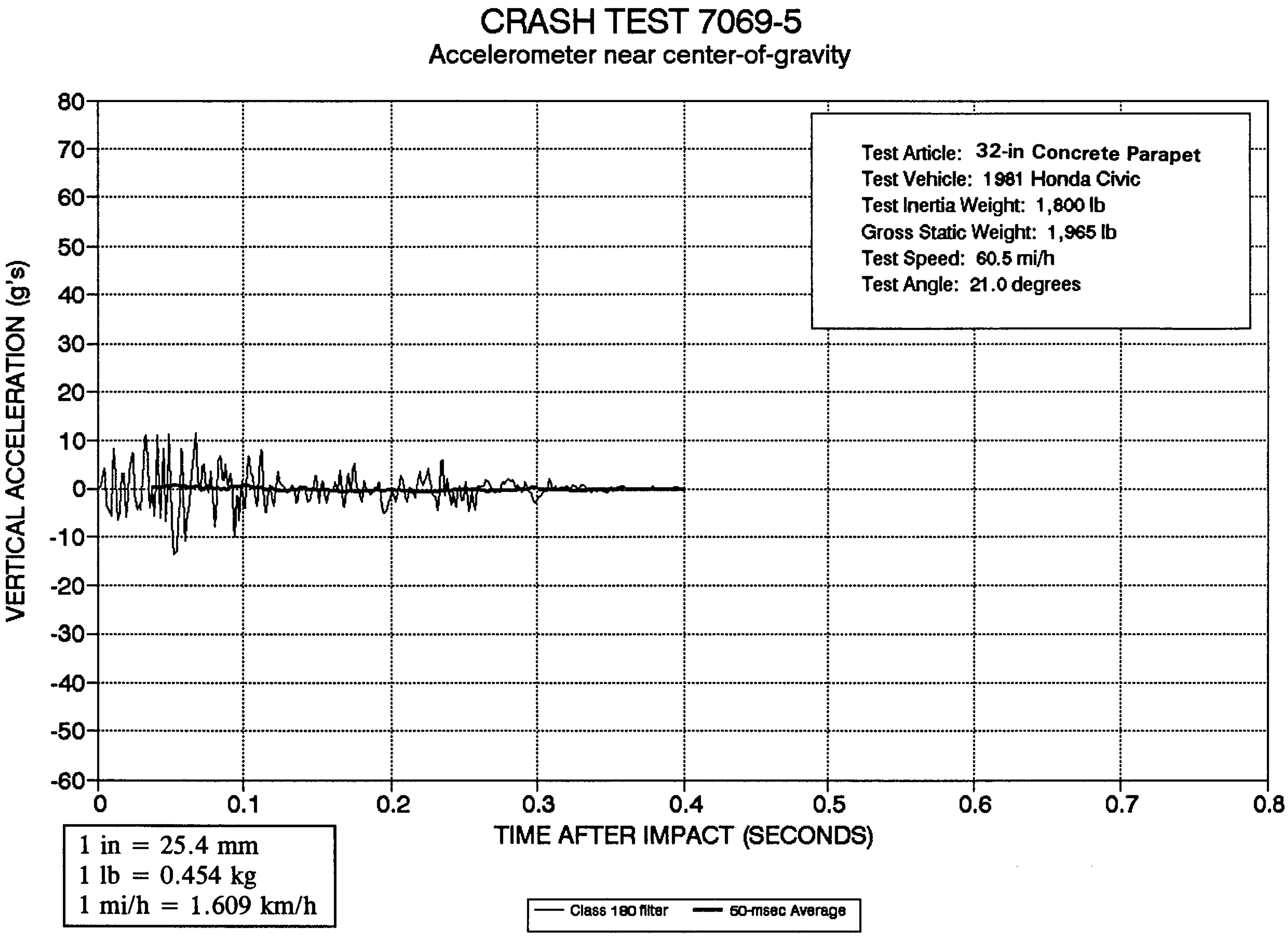


Figure 13. Vehicle vertical accelerometer trace for test 7069-5 (accelerometer located near center-of-gravity).

TEST 7069-6

Test Description

Test 7069-6 involved the following test conditions: 5,400 lb (2 452 kg)|60 mi/h (96.5 km/h)|20 degrees. A 1982 Chevrolet pickup truck (figure 14) was directed into the 32-in (813-mm) concrete parapet (figure 15) using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 5,420 lb (2 461 kg) and its gross static mass was 5,759 lb (2 615 kg). The height to the lower edge of the vehicle bumper was 17.0 in (432 mm) and it was 26.25 in (667 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figure 16. The vehicle was free-wheeling and unrestrained just prior to impact.

Actual speed of the vehicle at impact was 59.7 mi/h (96.1 km/h) and the angle of impact was 20.2 degrees. The vehicle impacted the parapet at midlength. At approximately 0.021 s after impact, the right front wheel contacted the parapet. The vehicle began to redirect at 0.074 s as the rear end began to slide toward the parapet. The dummies began to move abruptly to the right at 0.080 s, and at 0.130 s, the head of the passenger dummy shattered the right side window glass. The rear of the vehicle slapped the parapet at 0.192 s, and by 0.209 s, the vehicle was traveling parallel to the parapet. The vehicle lost contact with the parapet at 0.418 s. The vehicle exited the parapet with a yaw angle of 5.6 degrees and a vehicle trajectory path of 6.4 degrees. The brakes were applied and the vehicle came to rest 225 ft (69 m) downstream and 40 ft (12 m) toward the field side of the point of impact.

As can be seen in figure 17, the parapet received some cosmetic damage and some scraping. There were tire marks on the face of the parapet. The vehicle was in contact with the parapet for approximately 10.5 ft (3.2 m).

The vehicle sustained extensive damage to the right side as shown in figure 18. Maximum crush at the right front corner at bumper height was 9.0 in (229 mm). The right front and right rear wheel rims were bent and the welds had broken on the right front wheel rim, allowing the outer rim and tire to become completely separated. The wheel assembly and suspension were damaged. The passenger door was bent and jammed and the window was broken. The right rear panel was dented and scraped. The hood was bent and shifted to the left. The cab of the vehicle was twisted and the frame was bent.

Test Results

Impact speed was 59.7 mi/h (96.1 km/h) and the angle of impact was 20.2 degrees. The exit speed at the time of contact (0.418 s) was 47.0 mi/h (75.6 km/h) and the vehicle trajectory path was 6.4 degrees with a yaw angle of 5.6 degrees. The effective coefficient of friction was calculated to be 0.32. Occupant impact velocity was 18.6 ft/s (5.7 m/s) in the longitudinal direction and 21.1 ft/s (6.4 m/s) in the lateral direction. The highest 0.010-s ridedown accelerations were -5.5 g (longitudinal) and 8.6 g (lateral). Results of the test are summarized in figure 19 and table 3. Sequential photographs are shown in figures 20 and

21. Vehicle angular displacements are displayed in figure 22. Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 23 through 29. 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 window with the first 0.050-s average plotted at 0.026 s for each trace. The maximum 0.050-s averages were -5.7 g (longitudinal) and 13.1 g (lateral).

Conclusions

The 32-in (813-mm) concrete parapet contained and smoothly redirected the vehicle with minimal 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 indicates minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. See table 3 for a more detailed description.

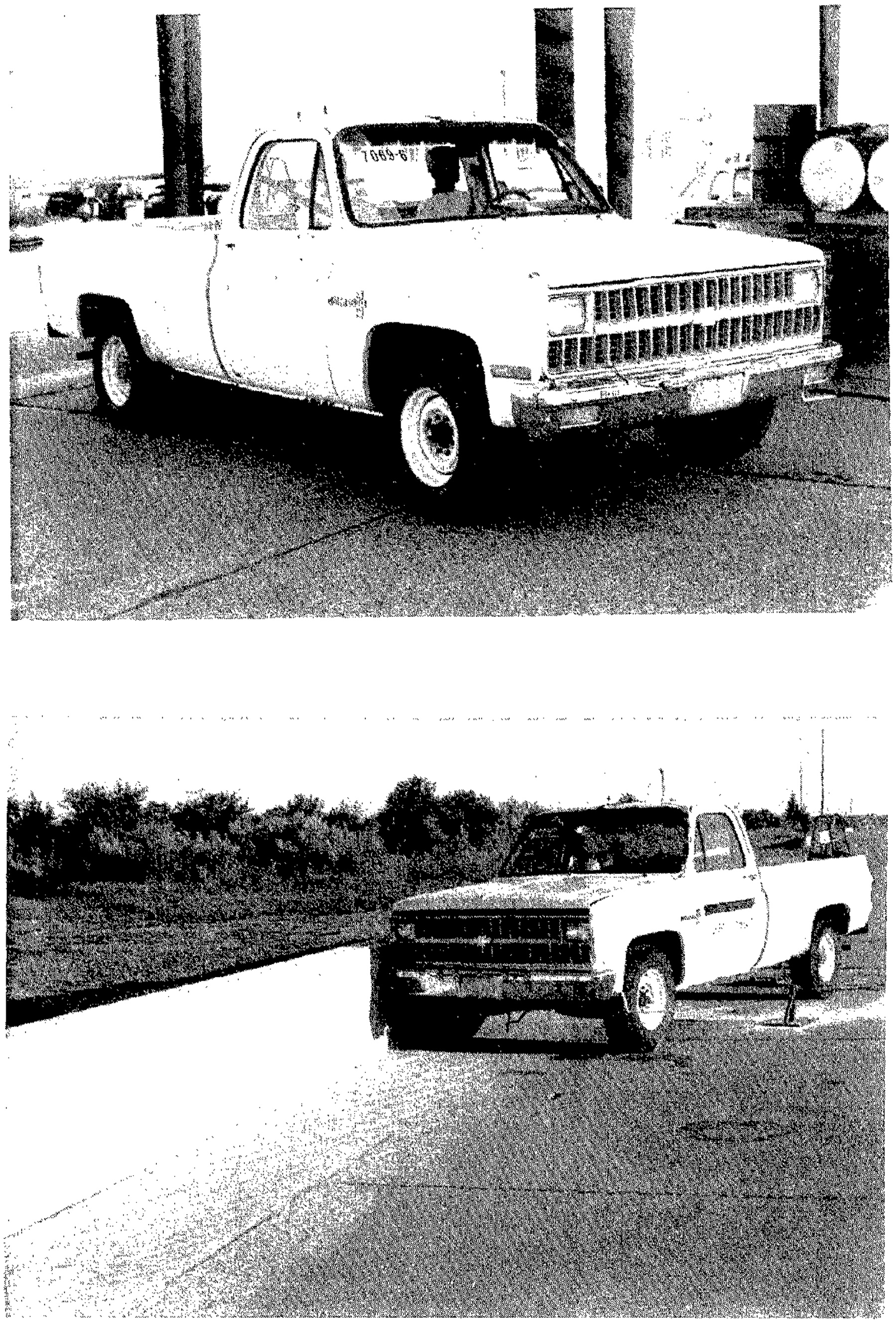


Figure 14. Vehicle before test 7069-6.

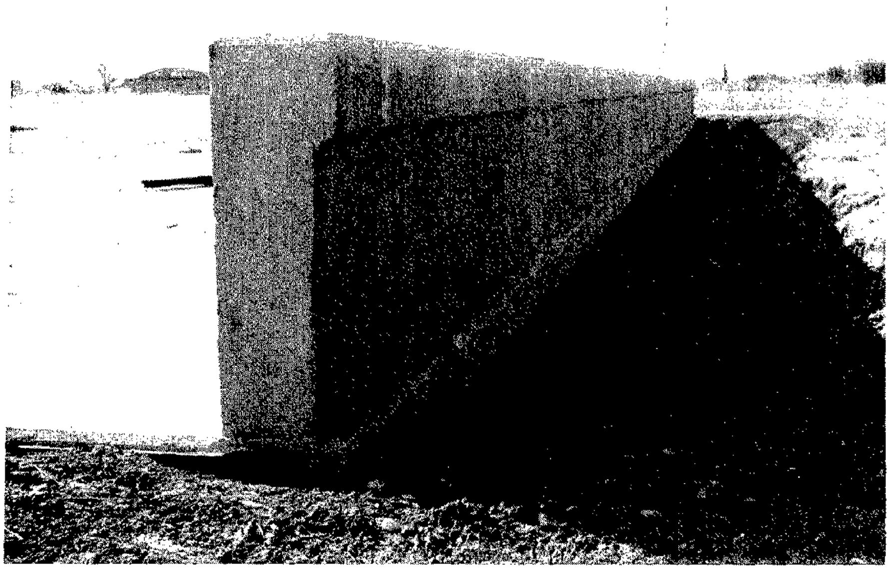


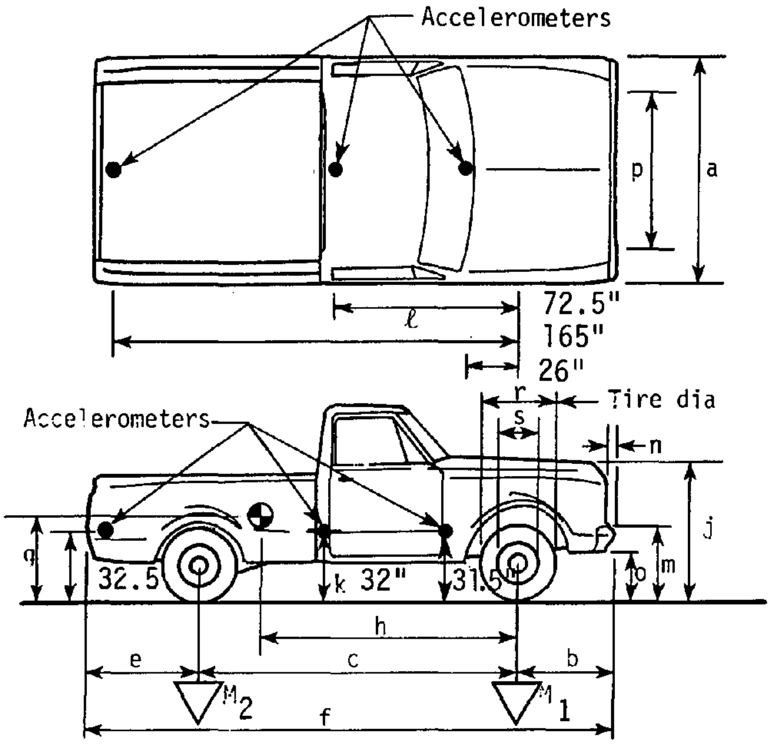
Figure 15. 32-in (813-mm) concrete parapet before test 7069-6.

Date: 10-8-87 Test No.: 7069-6 VIN: GCGC24WXCS15662

Make: Chevrolet Model: Custom Deluxe Year: 1982 Odometer: 105,000

Tire Size: 9.50-16.5 LT Ply Rating: 6 Bias Ply: X Belted: ___ Radial: ___

Tire Condition: good ___
fair X
badly worn ___



Vehicle Geometry - inches

a	79.25	b	32.75
c	132.0	d*	71.5
e	49.75	f	214.5
g	26 7/8"	h	61.9
i	----	j	44.75
k	32.0	ℓ	45.0
m	26.25	n	3.5
o	17.0	p	67.0
r	30.0	s	17.25

Engine Type: V8

Engine CID: 454

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Body Type: ___

Steering Column Collapse Mechanism:

- ___ Behind wheel units
- ___ Convoluted tube
- ___ Cylindrical mesh units
- ___ Embedded ball
- ___ NOT collapsible
- ___ Other energy absorption
- ___ Unknown

Brakes:

Front: disc___ drum___

Rear: disc___ drum___

4-wheel weight for c.g. det. ℓf 1475 rf 1405 ℓr 1270 rr 1270

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		2540	2675
M_2		2880	3084
M_T		5420	5759

Note any damage to vehicle prior to test:

*d = overall height of vehicle

1 in = 25.4 mm
1 lb = 0.454 kg

Figure 16. Vehicle properties for test 7069-6.

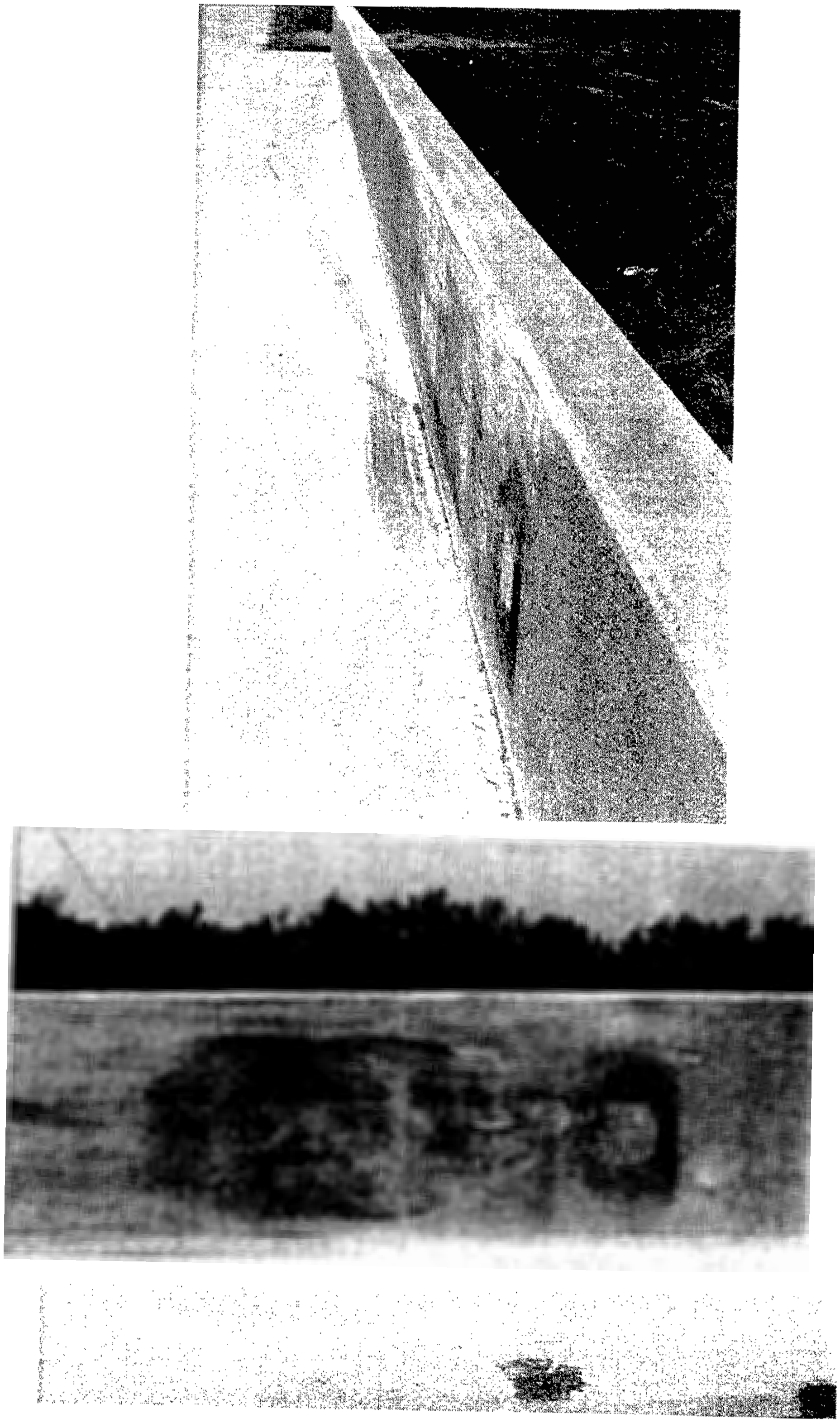


Figure 17. 32-in (813-mm) concrete parapet after test 7069-6.

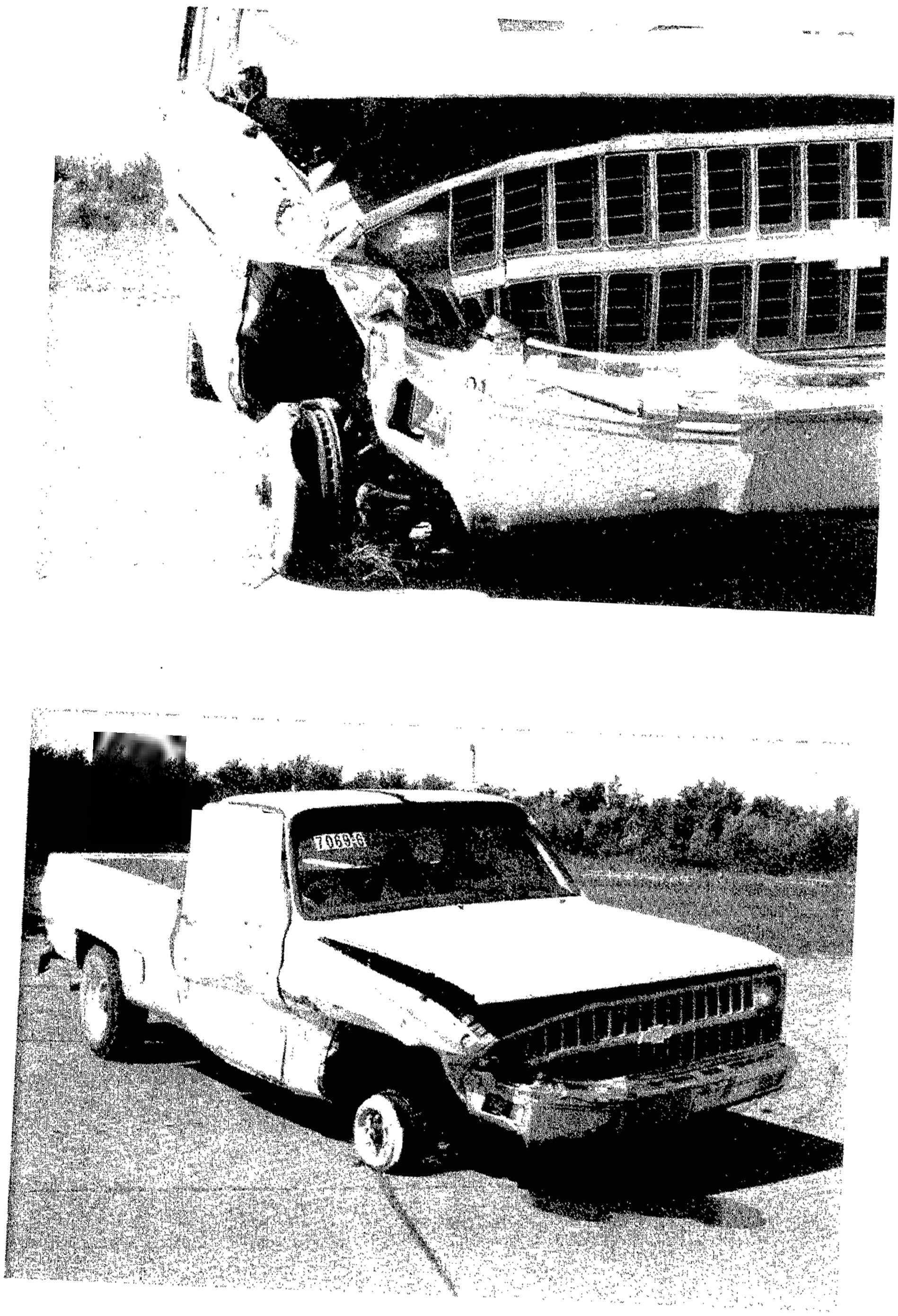
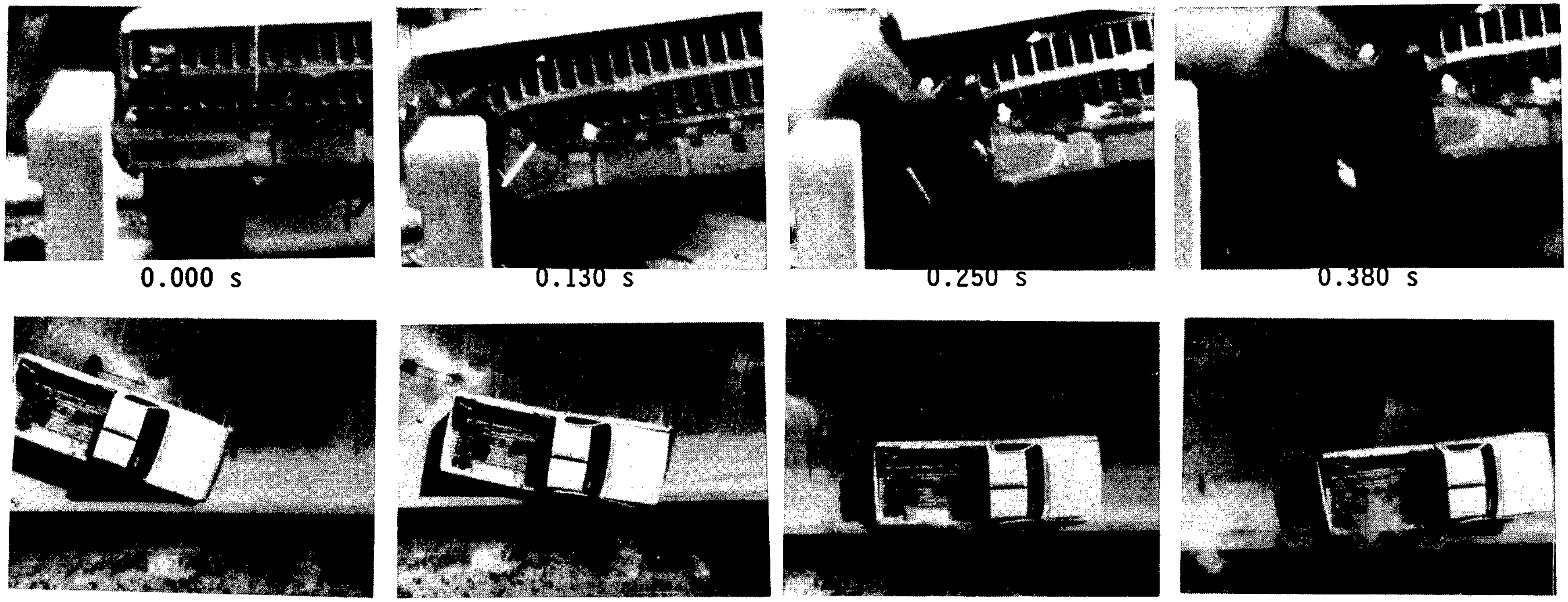
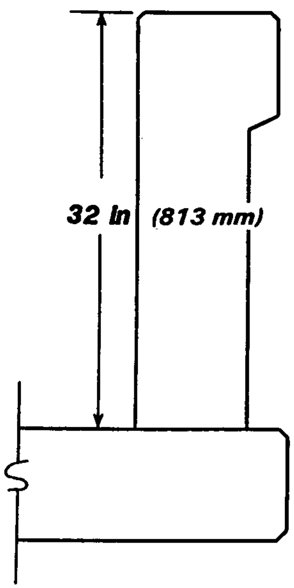


Figure 18. Vehicle after test 7069-6.





Test No. 7069-6
Date 10/08/87
Test Installation . . . 32-in (813-mm) Concrete Parapet
Installation Length . . 100 ft (30 m)
Vehicle . . . . 1982 Chevrolet Pickup
Vehicle Weight
  Test Inertia . . . . . 5,420 lb (2,461 kg)
  Gross Static . . . . . 5,759 lb (2,615 kg)
Vehicle Damage Classification
  TAD 01RD4
  CDC . . . . 01FREK2 & 01RYEW4
Maximum Vehicle Crush . 9.0 in (229 mm)

Impact Speed. . . 59.7 mi/h (96.1 km/h)
Impact Angle. . . 20.2 deg
Exit Speed. . . . 47.0 mi/h (75.6 km/h)
Exit Trajectory . 6.4 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -5.7 g
  Lateral . . . . 13.1 g
Occupant Impact Velocity
  Longitudinal. . 18.6 ft/s (5.7 m/s)
  Lateral . . . . 21.1 ft/s (6.4 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -5.5 g
  Lateral . . . . 8.6 g

Figure 19. Summary of results for test 7069-6.

Table 3. Evaluation of crash test no. 7069-6.
{32-in (813-mm) Concrete Parapet Bridge Railing (5,420 lb (2 461 kg)|59.7 mi/h (96.1 km/h)|20.2 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 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 .32 — Good	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: 18.6 (5.7) Lateral: 21.1 (6.4)	Pass
	Occupant Ridedown Accelerations - g's Longitudinal: 15 Lateral: 15	Occupant Ridedown Accelerations - g's Longitudinal: -5.5 Lateral: 8.6	Pass
H.	Exit angle shall be less than 12 degrees	Exit angle was 6.4 degrees	Pass

* A, B, C, and D are required. E, F, G, and H are desired. (See table 2)

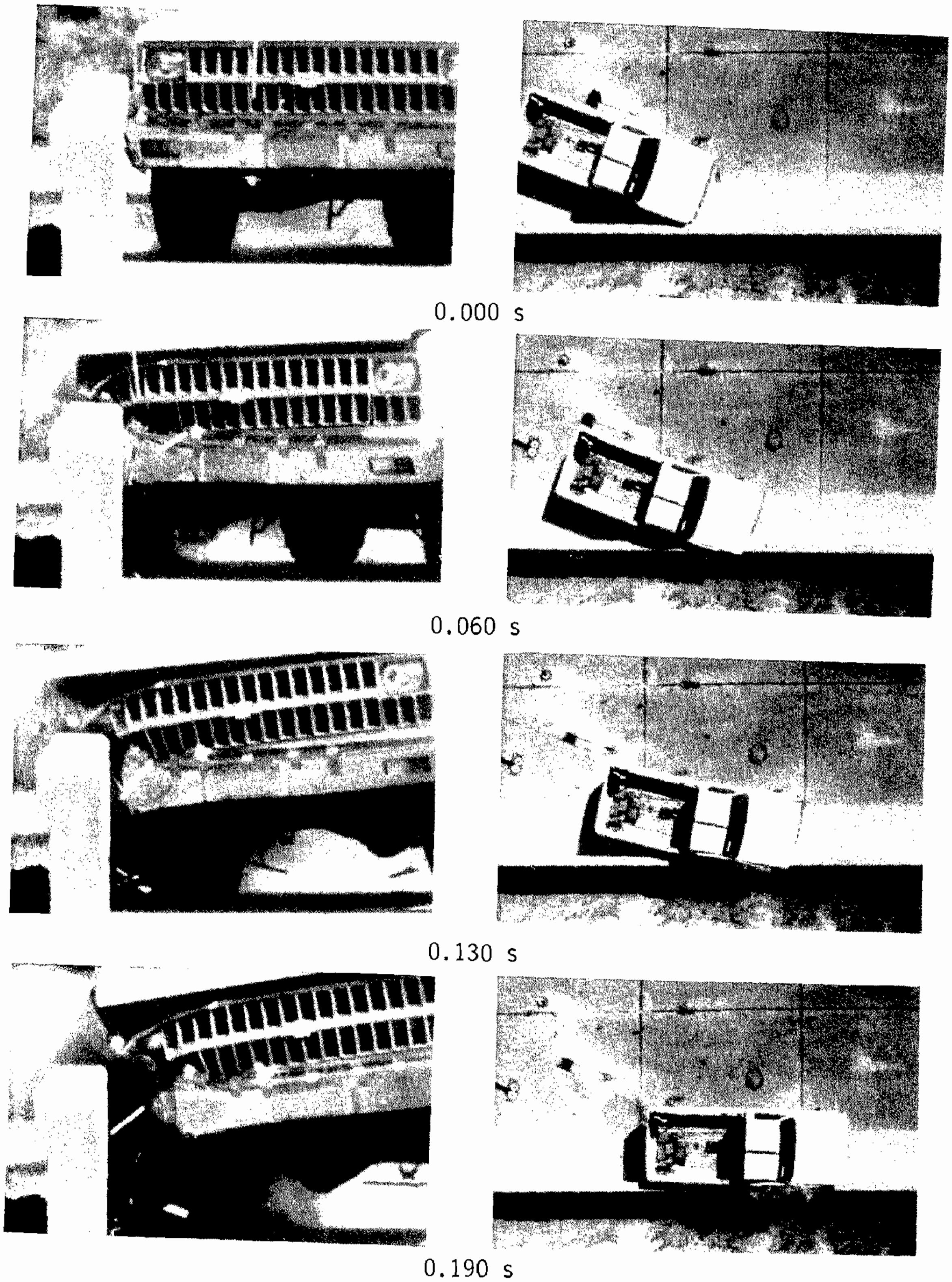


Figure 20. Sequential photographs for test 7069-6.

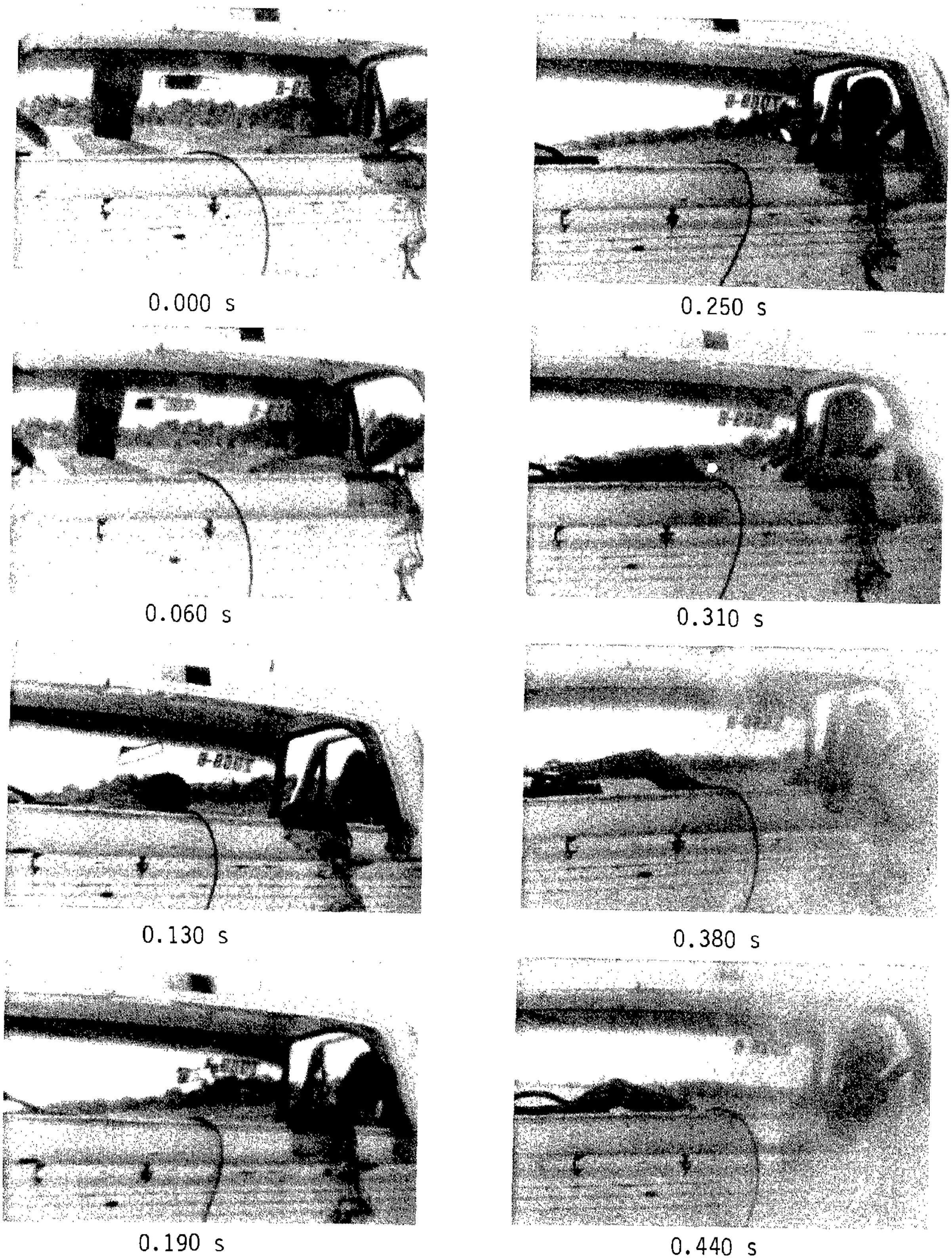
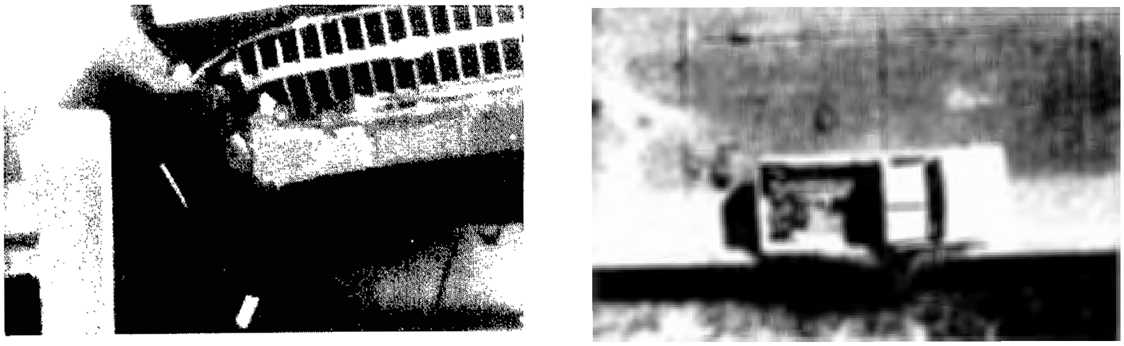
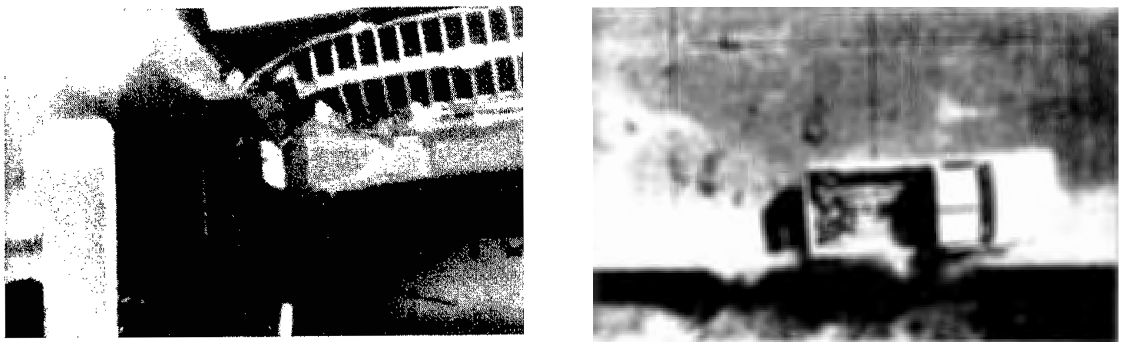


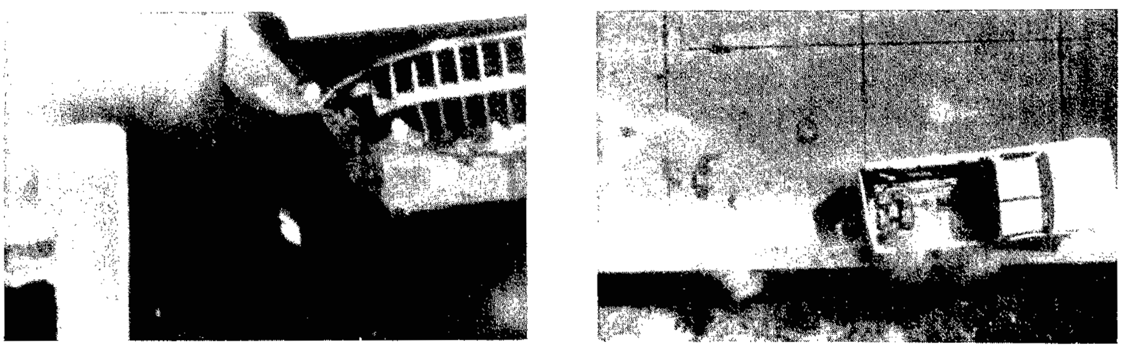
Figure 21. Interior sequential photographs for test 7069-6.



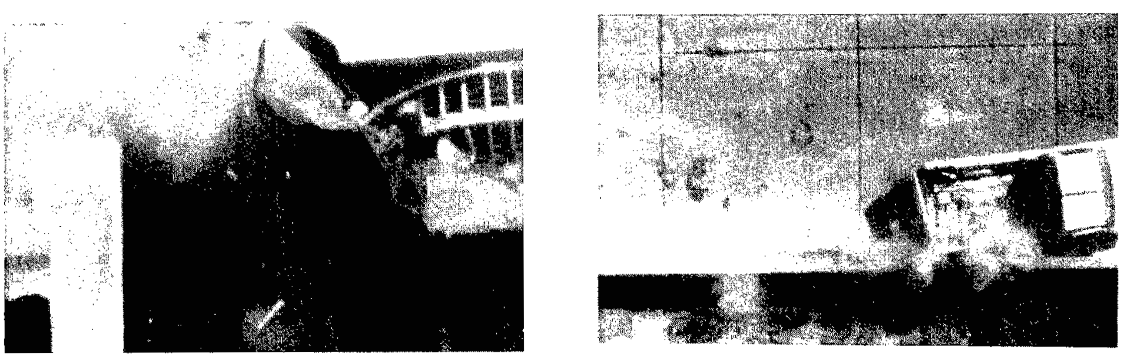
0.250 s



0.310 s

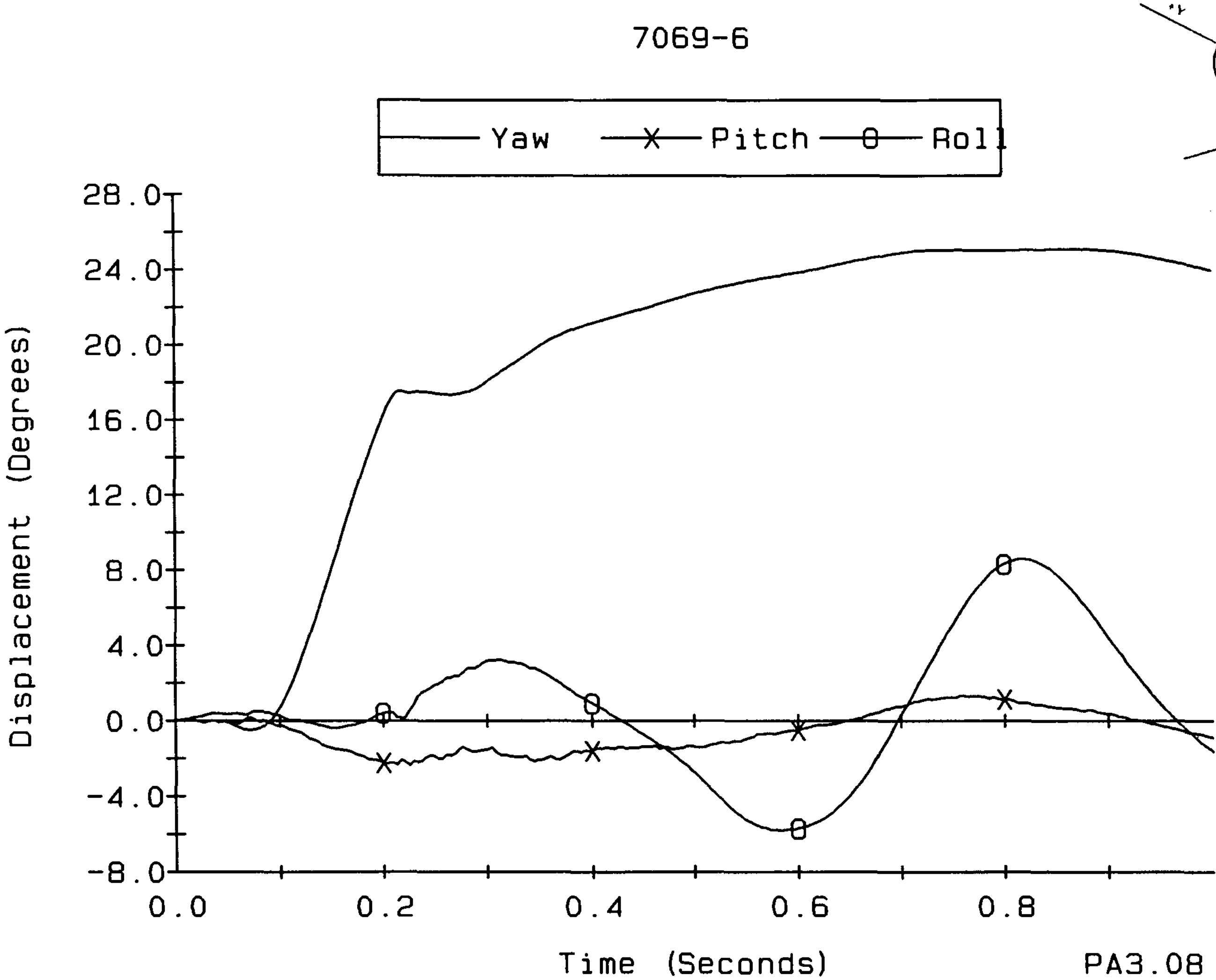


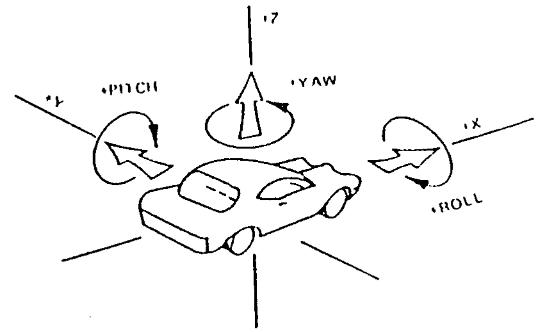
0.380 s



0.440 s

Figure 21. Sequential photographs for test 7069-6 (continued).





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 22. Vehicle angular displacements for test 7069-6.

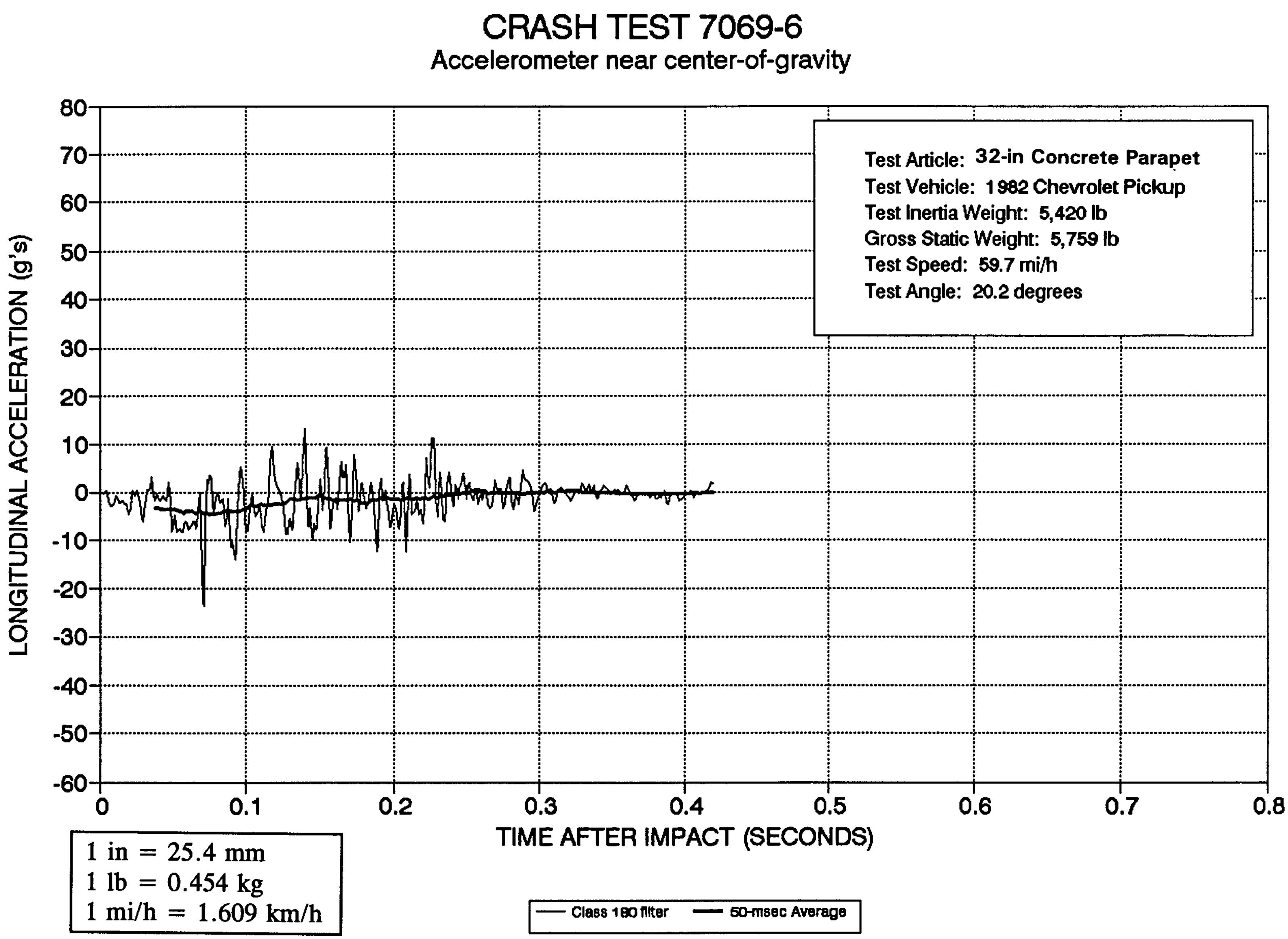


Figure 23. Vehicle longitudinal accelerometer trace for test 7069-6 (accelerometer located near center-of-gravity).

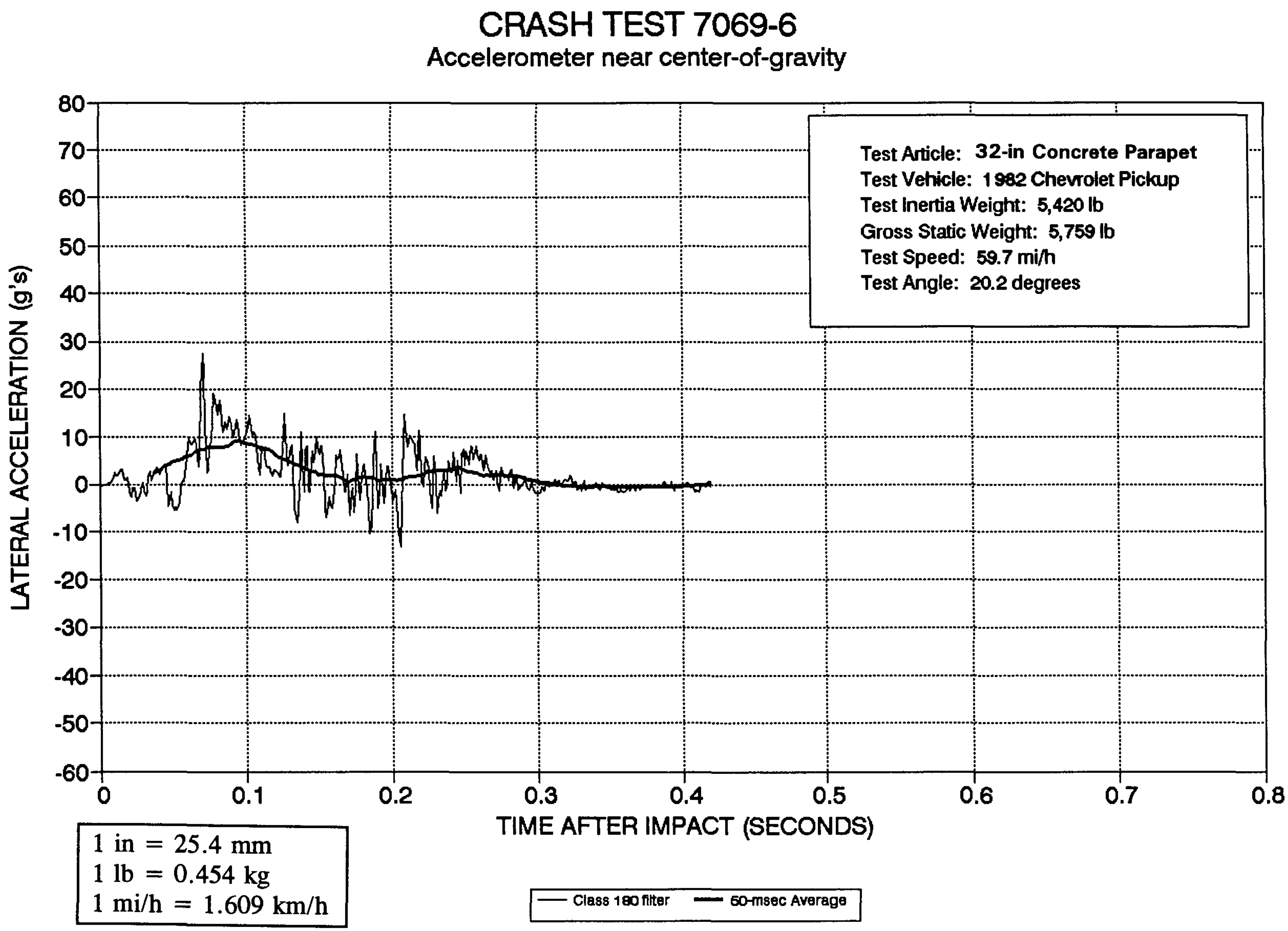
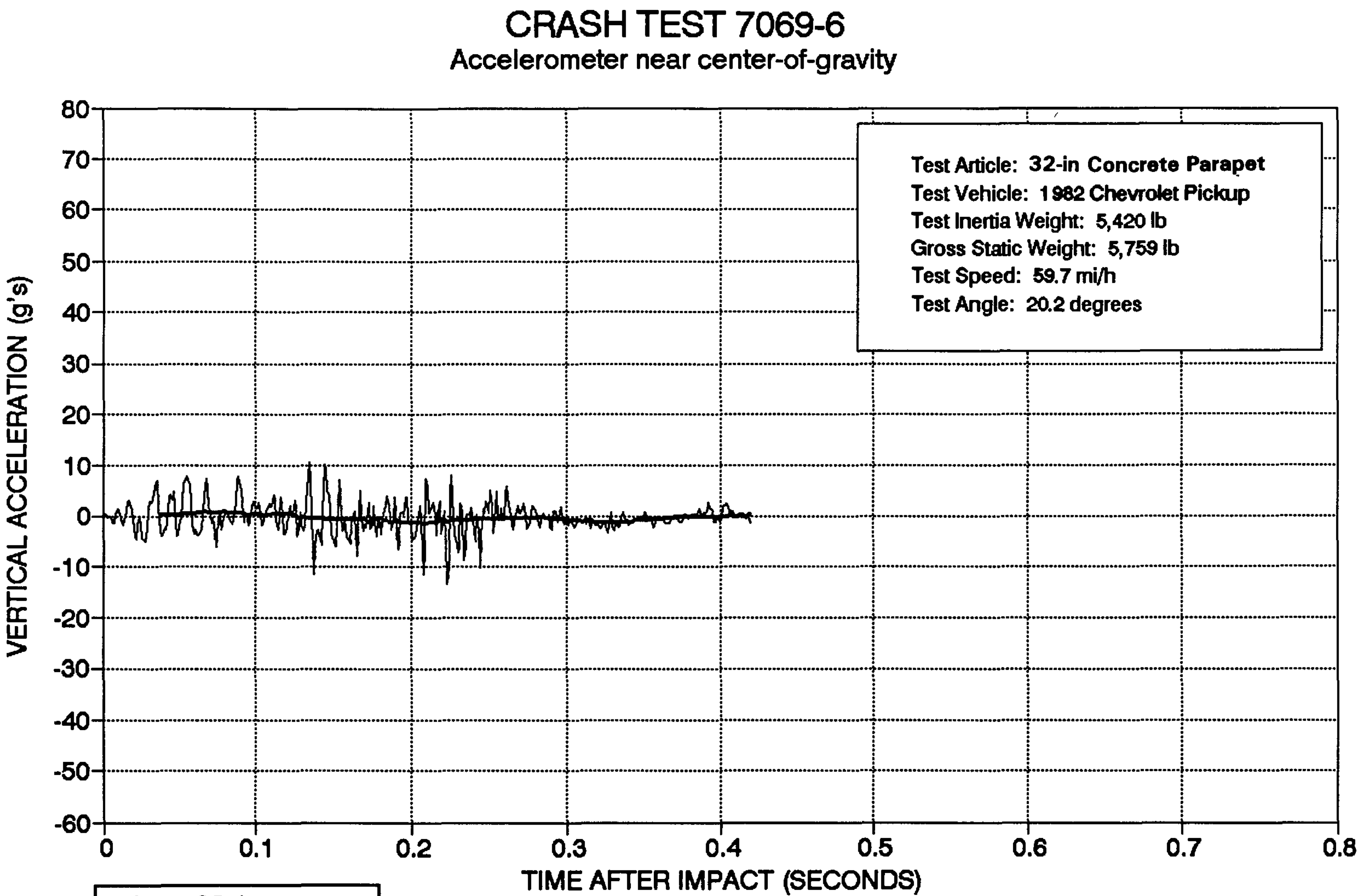


Figure 24. Vehicle lateral accelerometer trace for test 7069-6 (accelerometer located near center-of-gravity).



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

Figure 25. Vehicle vertical accelerometer trace for test 7069-6 (accelerometer located near center-of-gravity).

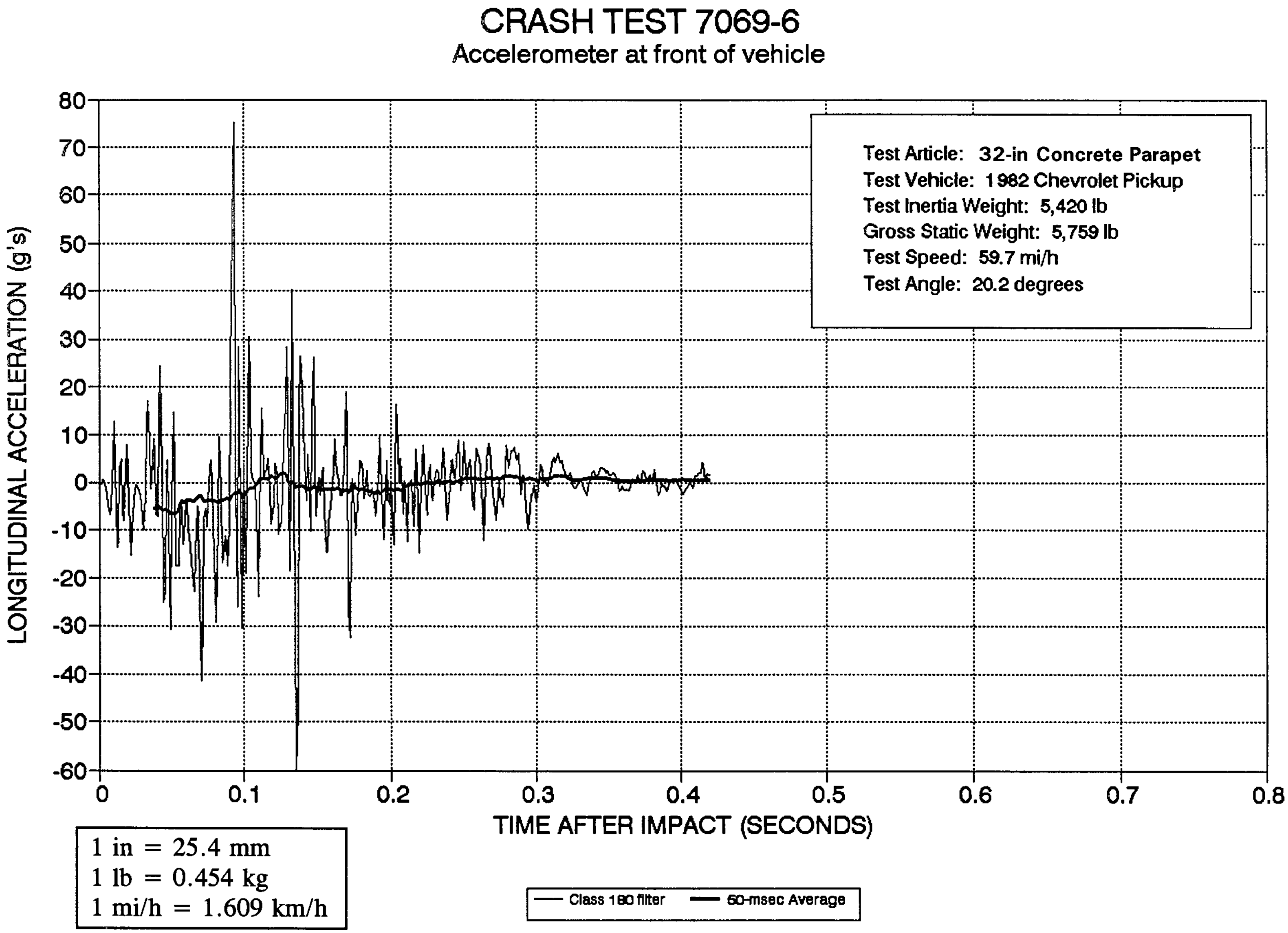


Figure 26. Vehicle longitudinal accelerometer trace for test 7069-6 (accelerometer located at front of vehicle).

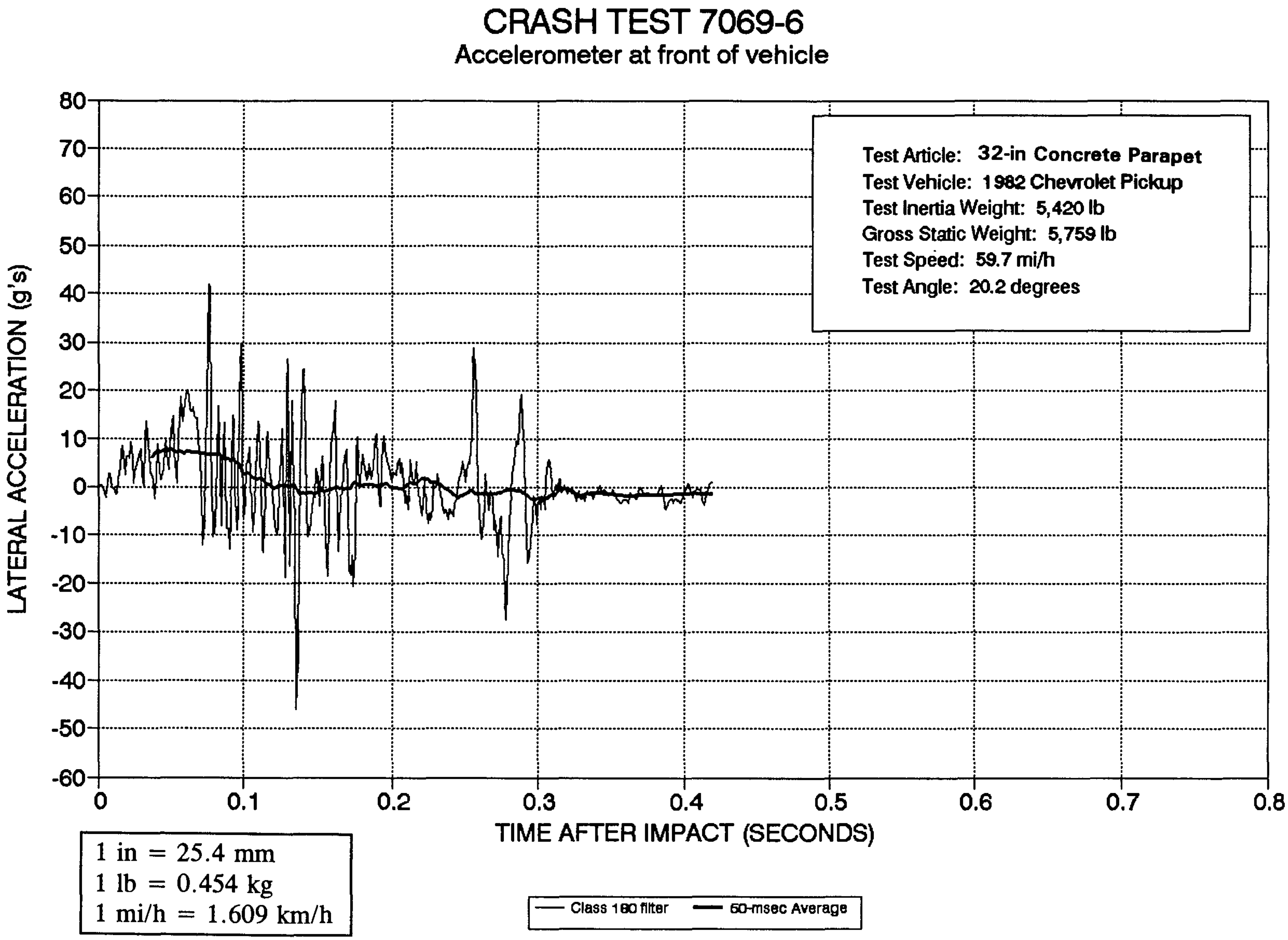


Figure 27. Vehicle lateral accelerometer trace for test 7069-6 (accelerometer located at front of vehicle).

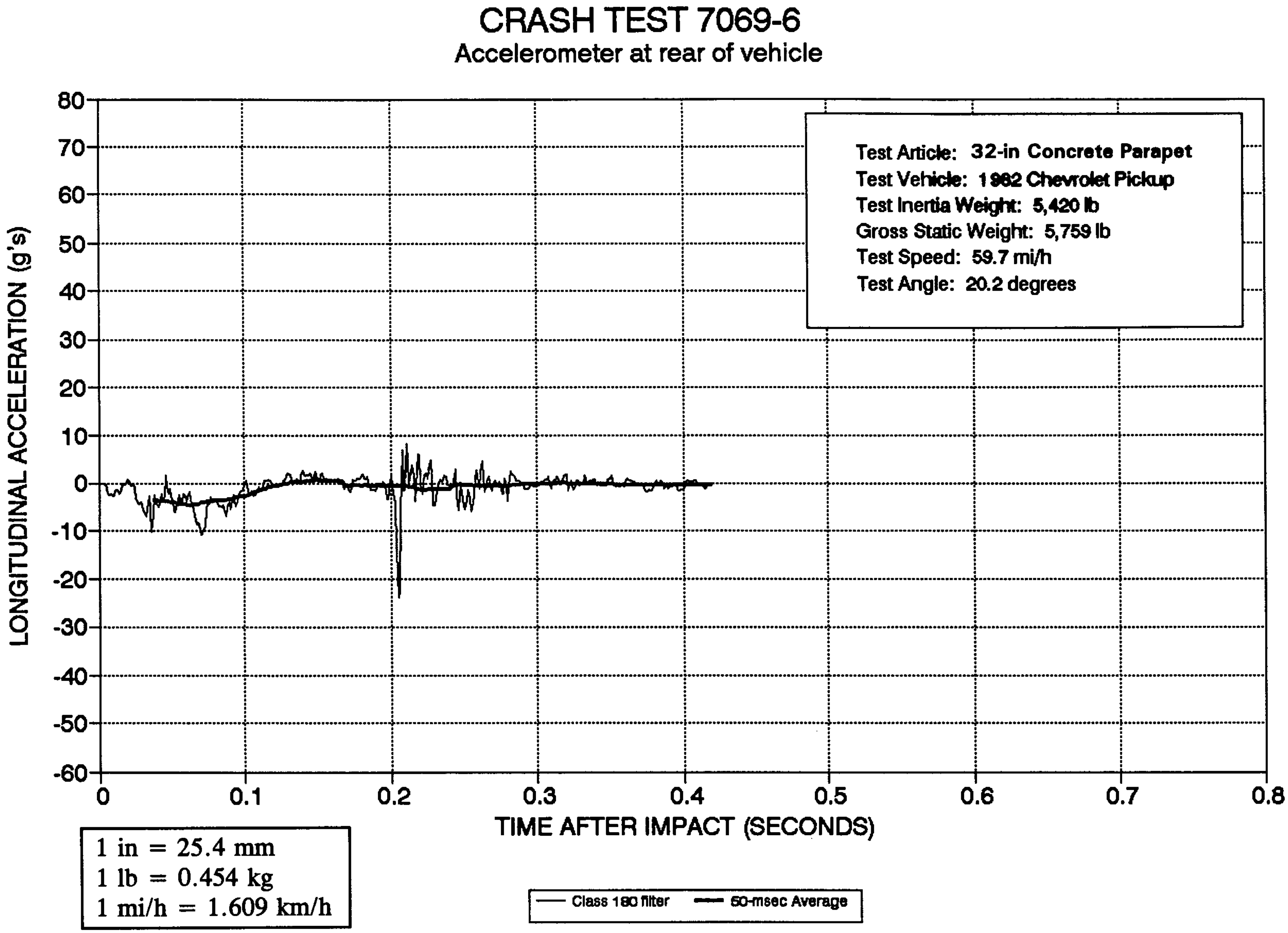


Figure 28. Vehicle longitudinal accelerometer trace for test 7069-6 (accelerometer located at rear of vehicle).

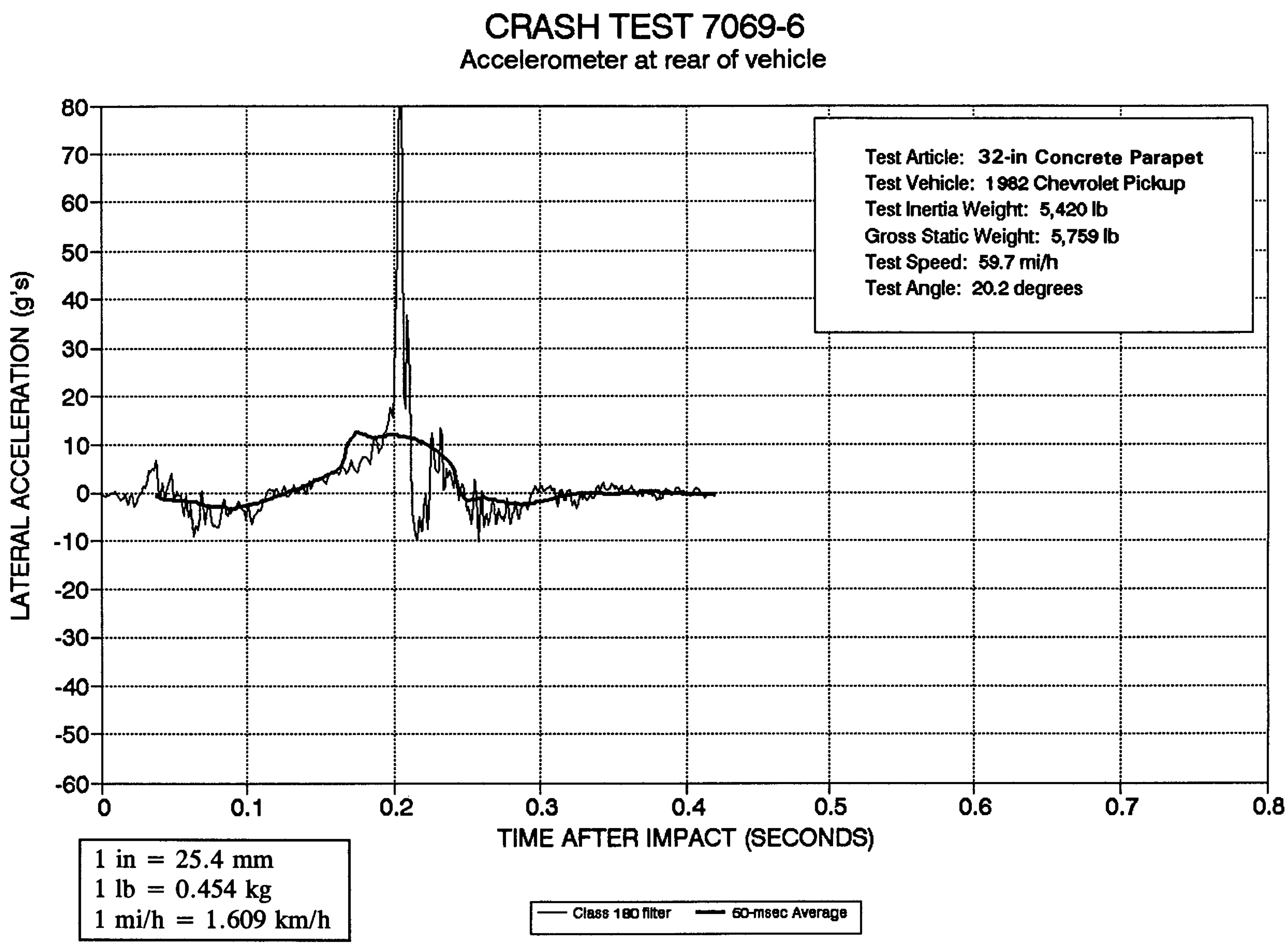


Figure 29. Vehicle lateral accelerometer trace for test 7069-6 (accelerometer located at rear of vehicle).

TEST 7069-16

Test Description

The following nominal conditions existed in Test 7069-16: 18,000 lb (8 172 kg)|50 mi/h (80.5 km/h)|15 degrees. A 1982 Ford single-unit truck (figures 30 and 31) was directed into the 32-in (813-mm) concrete parapet (figure 32) using a reverse tow and guidance system. The empty weight of the vehicle was 13,820 lb (6 274 kg) and its test inertia weight was 18,000 lb (8 172 kg). The height to the lower edge of the vehicle bumper was 20.25 in (514 mm) and it was 28.25 in (718 mm) to the top of the bumper. Other dimensions and information on the test vehicle are given in figures 33 and 34. The vehicle was free-wheeling and unrestrained just prior to impact.

Actual speed of the vehicle at impact was 50 mi/h (80.5 km/h) and the angle of impact was 14.0 degrees. The vehicle impacted the parapet approximately 20 ft (6 m) from the end. Shortly after impact, the right front wheel made contact with the parapet and was pushed back and to the left. The vehicle began to redirect at approximately 0.101 s after impact. At 0.263 s, the left side of the vehicle became airborne. The rear of the vehicle impacted the parapet at about 0.305 s and began to travel parallel to the parapet. As the vehicle rode along the parapet, it continued to roll to the right and attained a maximum roll angle of 17.6 degrees at 0.480 s. At about 0.750 s, the vehicle began to right itself. The vehicle deflected and lost contact with the parapet at 0.963 s, traveling at 34.2 mi/h (55.0 km/h) and 5.0 degrees. By 1.101 s, the vehicle was traveling upright; however, it continued to roll to the left and began to yaw clockwise. The vehicle came to rest on its left side 175 ft (53 m) downstream and 25 ft (7.6 m) behind the point of impact.

As can be seen in figure 35, the parapet received cosmetic damage and some scraping and gouging. There were tire marks on the face of the parapet and along the top for about 30 ft (9 m). The bed of the vehicle scraped the top of the parapet for another 15 ft (4.6 m). The vehicle was in contact with the parapet for about 45 ft (14 m).

The vehicle sustained moderate damage to the right side as shown in figures 36 through 38. Maximum crush at the right front corner at bumper height was 10.0 in (254 mm). The front bumper, the hood, and the right front quarter were damaged, and the windshield was cracked. The rear U-bolt on the right front springs was broken and the springs were dislocated. The fuel tank and straps were also damaged.

Test Results

Impact speed was 50 mi/h (80.5 km/h) and the angle of impact was 14.0 degrees. The effective coefficient of friction was calculated to be 0.41. The vehicle left the parapet traveling at 34.2 mi/h (55.0 km/h). Occupant impact velocity was 10.9 ft/s (3.3 m/s) in the longitudinal direction and 11.8 ft/s (3.6 m/s) in the lateral direction. The highest 0.010-s occupant ridedown accelerations were -2.3 g (longitudinal) and 8.4 g (lateral). Results of the test are summarized in figure 39 and table 4. Sequential photographs are shown in figure 40. Vehicular displacements are displayed in figure 41.

Vehicular accelerations versus time traces filtered with SAE J211 filters are presented in figures 42 through 48. The data were further analyzed to obtain 0.050-s average accelerations versus time. The maximum 0.050-s averages measured at the center-of-gravity were -1.7 g (longitudinal) and 4.6 g (lateral).

Conclusions

The 32-in (813-mm) concrete parapet contained and smoothly redirected the test vehicle with no lateral movement of the parapet. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes. However, the vehicle did not remain upright after the collision. See table 4 for more details.

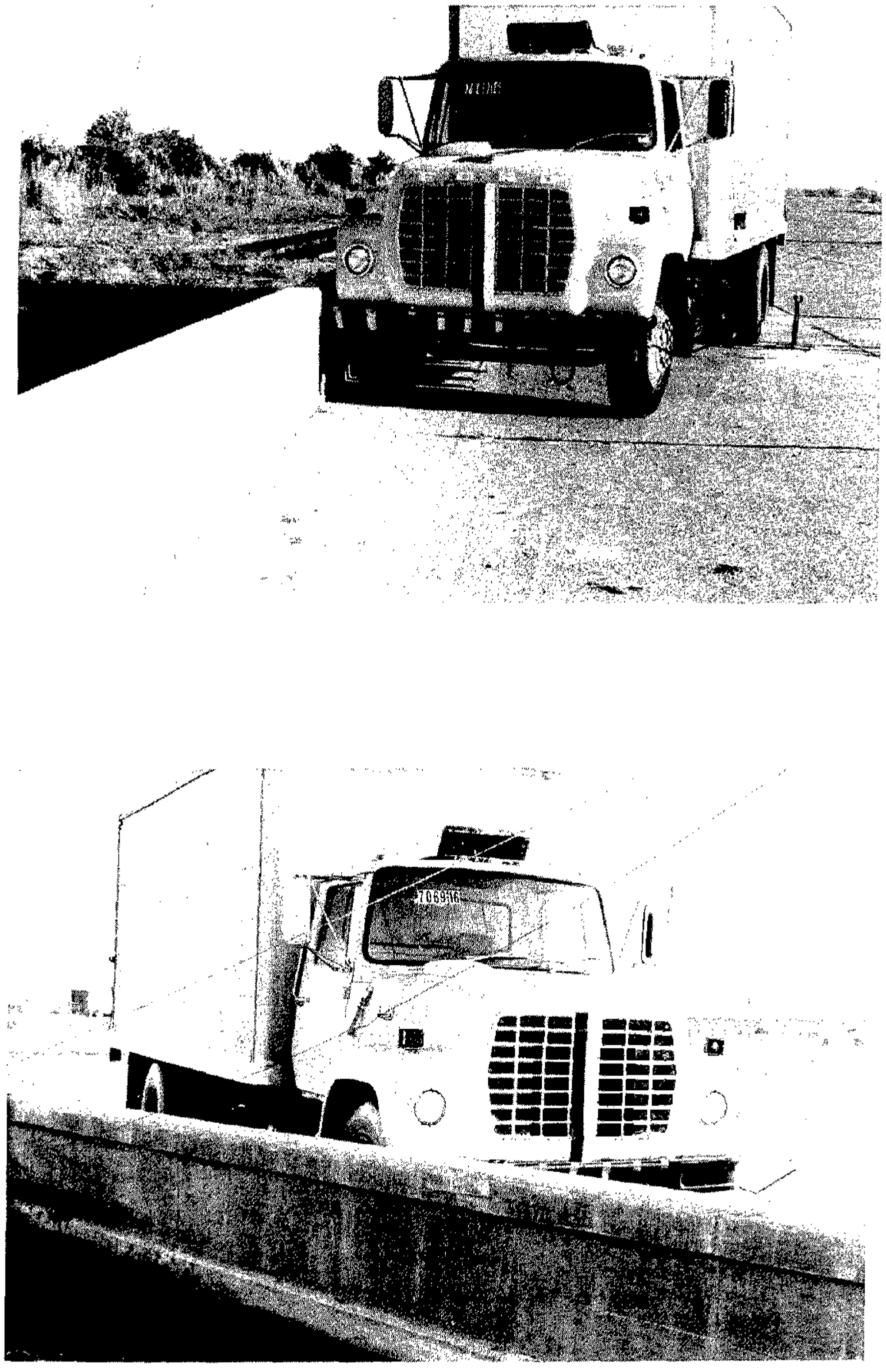


Figure 30. Vehicle/parapet geometrics for test 7069-16.

Figure 31. Vehicle before test 7069-16.

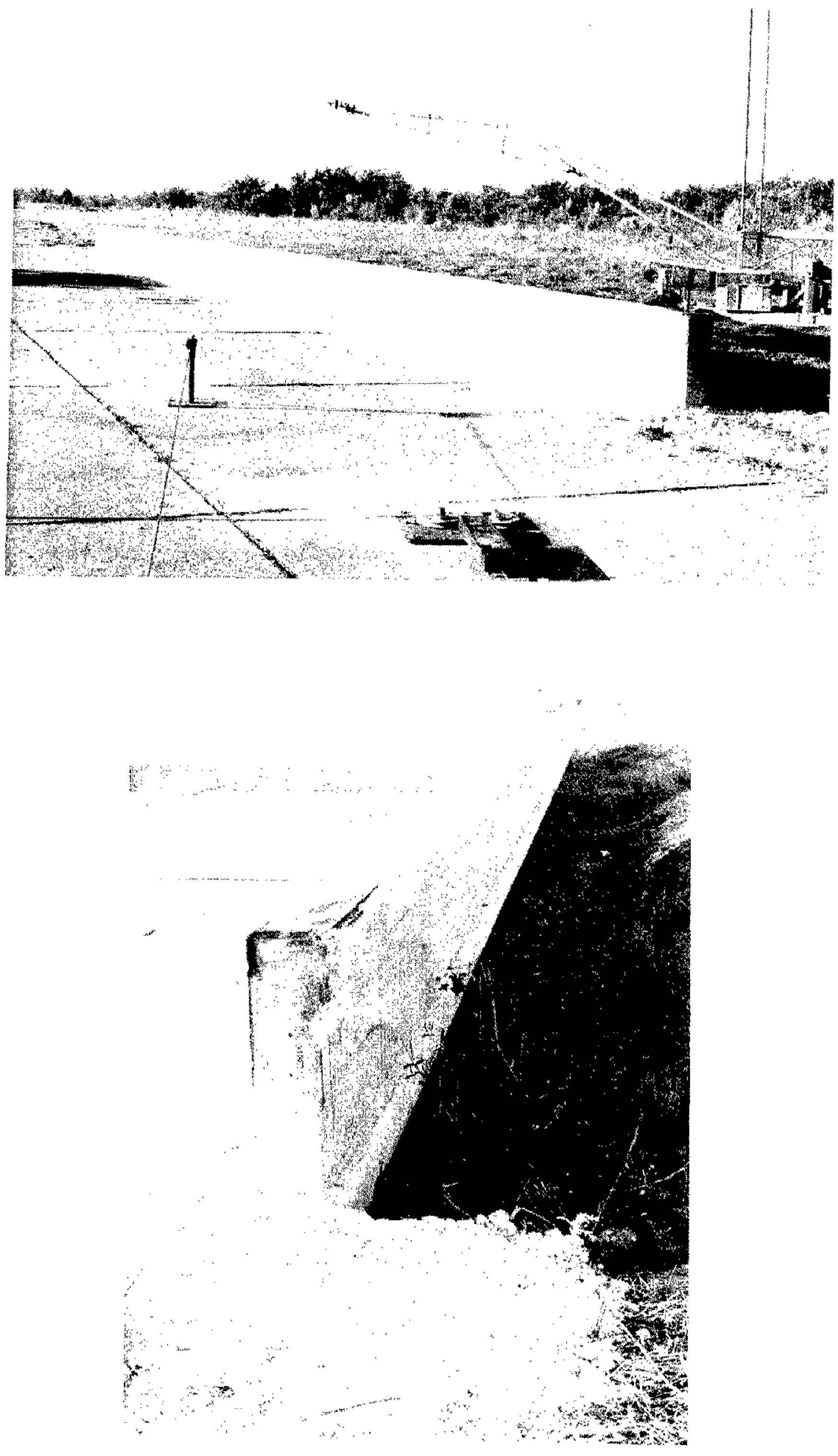
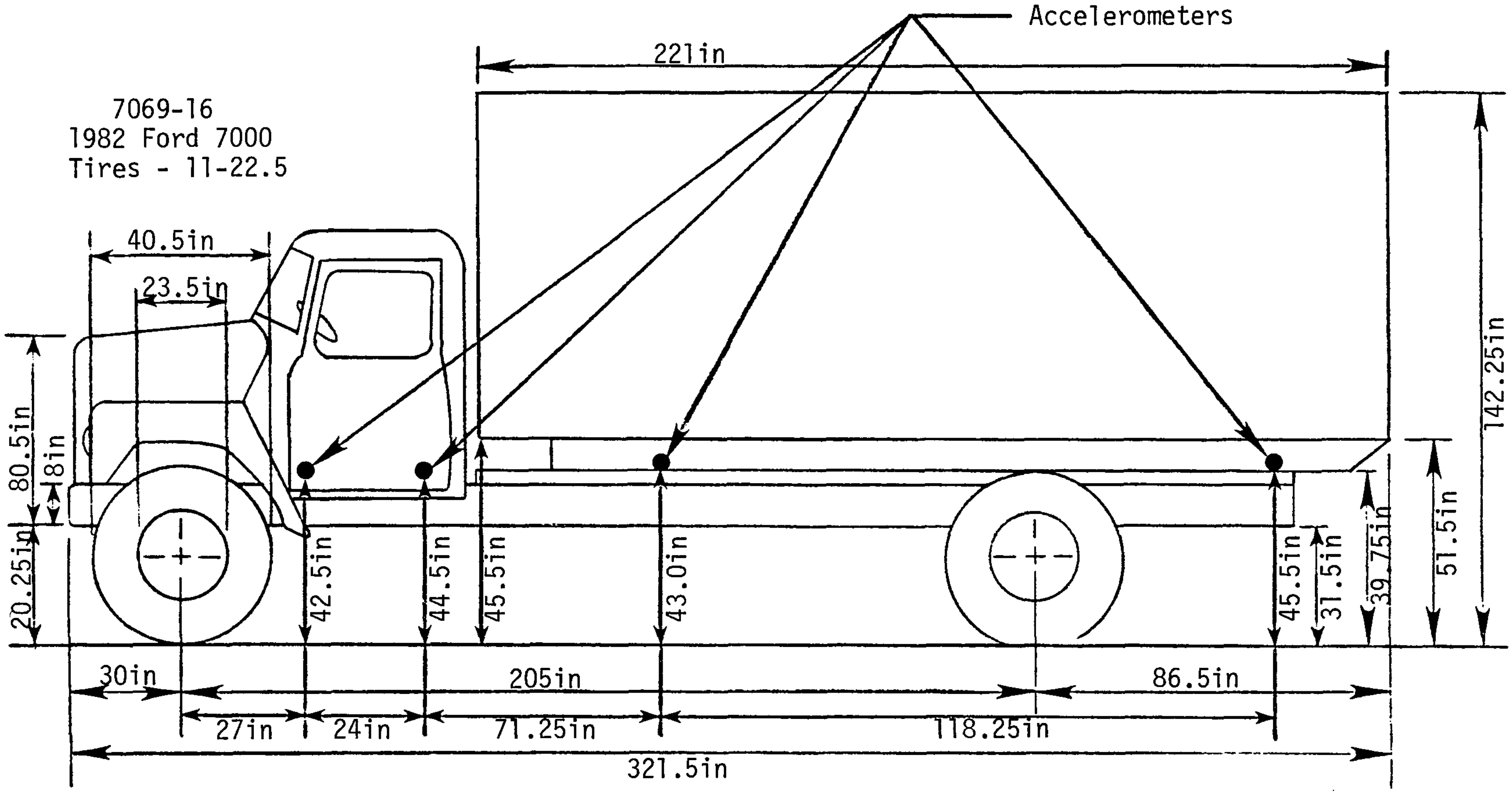


Figure 32. 32-in (813-mm) concrete parapet before test 7069-16.



EMPTY WEIGHTS

Weight on Front Axle : LF 3,460 RF 3,360

Weight on Rear Axle : LR 3,650 RR 3,350

TOTAL EMPTY WEIGHT : 13,820

LOADED WEIGHTS

Weight on Front Axle : 7,300

Weight on Rear Axle : 10,700

TOTAL LOADED WEIGHT : 18,000

1 in = 25.4 mm
1 lb = 0.454 kg

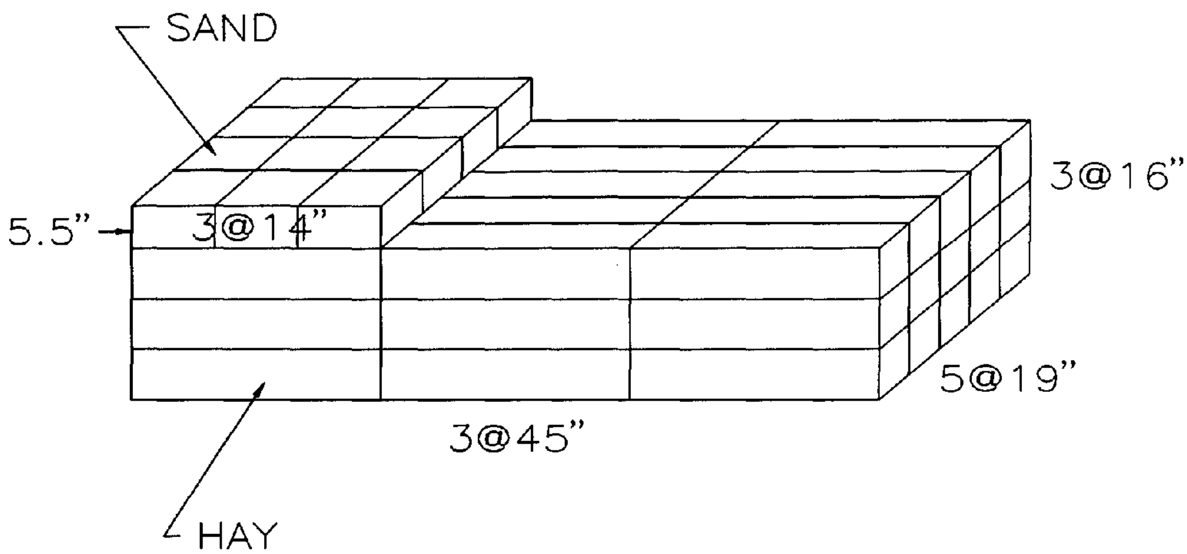
Figure 33. Vehicle properties for test 7069-16.

BALLAST CALCULATIONS

Total Empty Weight	13,820 lb
Required Test Weight	18,000 lb
Ballast Required	4,180 lb

Weights

Hay Bale	65 lb
Sand Bag	100 lb



Ballast Center-of-Gravity Height

$$H = [(24\ \text{in})(2925\ \text{lb}) + (1200\ \text{lb})(50.75\ \text{in})]/4125\ \text{lb} = 31.78\ \text{in}$$

1 lb = 0.454 kg
1 in = 25.4 mm

Figure 34. Ballast calculations for test 7069-16.

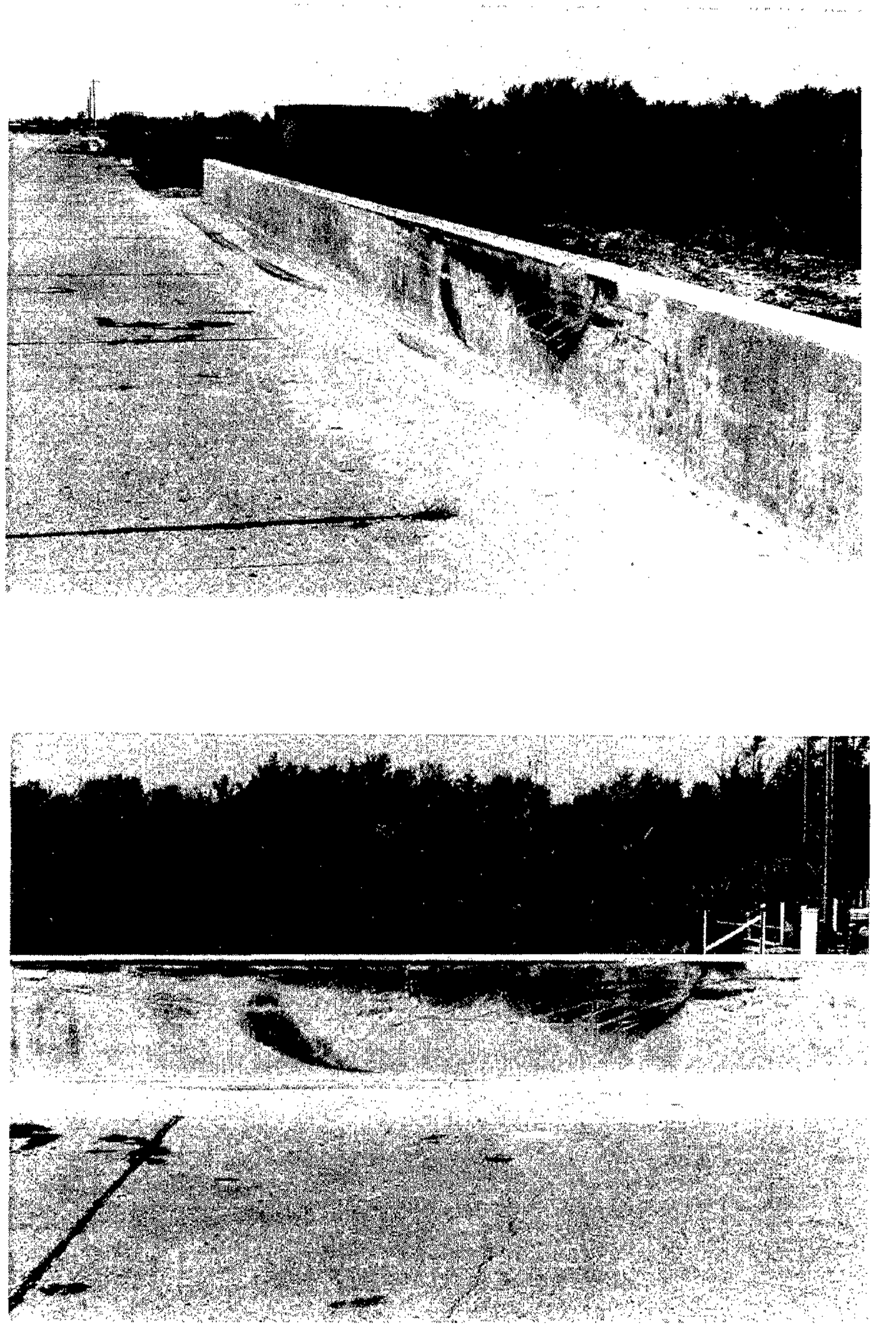
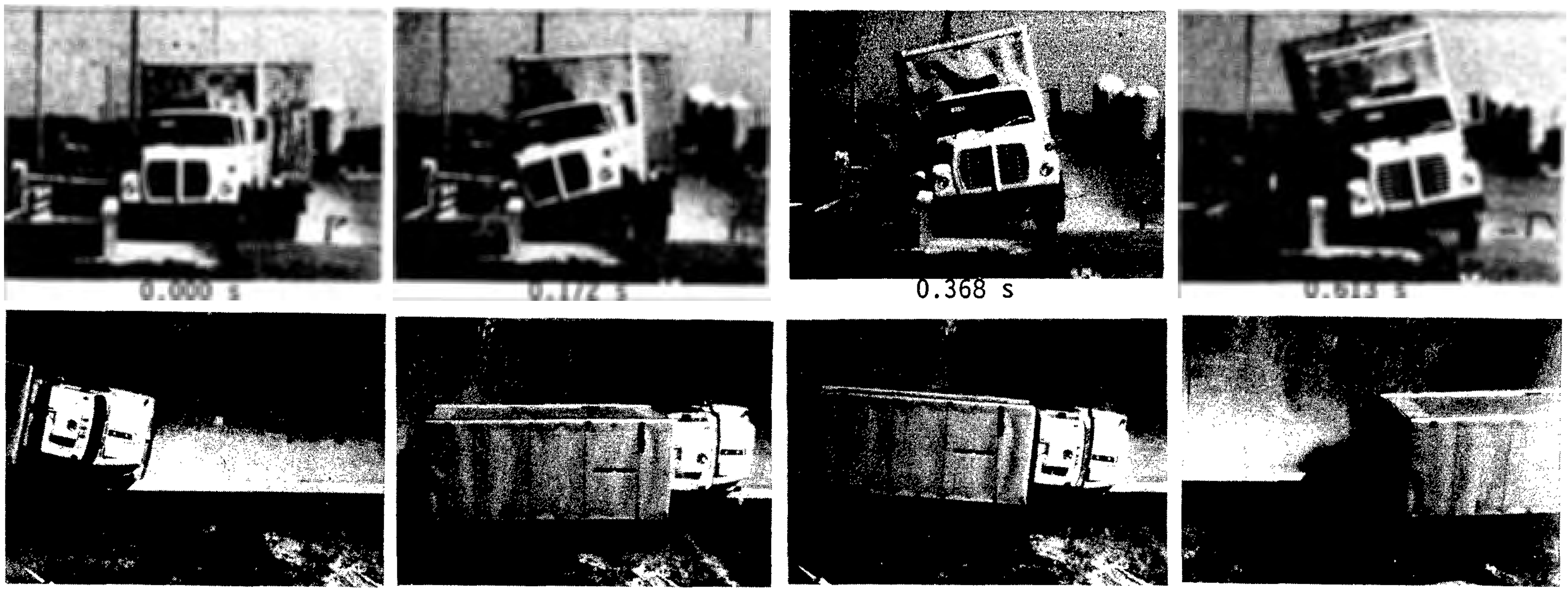


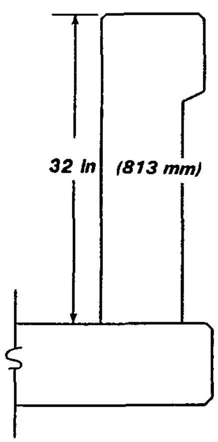
Figure 35. 32-in (813-mm) concrete parapet after test 7069-16.

Figure 36. Vehicle after test 7069-16.

Figure 37. Damage to right front leaf springs after test 7069-16.

Figure 38. Vehicle after being uprighted after test 7069-16.





Test No. 7069-16
Date 10/13/88
Test Installation . . . . 32-in (813-mm) Concrete Parapet
Installation Length . . 100 ft (3.05 m)
Vehicle . . . . 1982 Ford 7000 Single-Unit Truck
Vehicle Weight
  Empty Weight . . . . . 13,820 lb (6,274 kg)
  Test Inertia . . . . . 18,000 lb (8,172 kg)
Maximum Vehicle Crush . 10.0 in (254 mm)

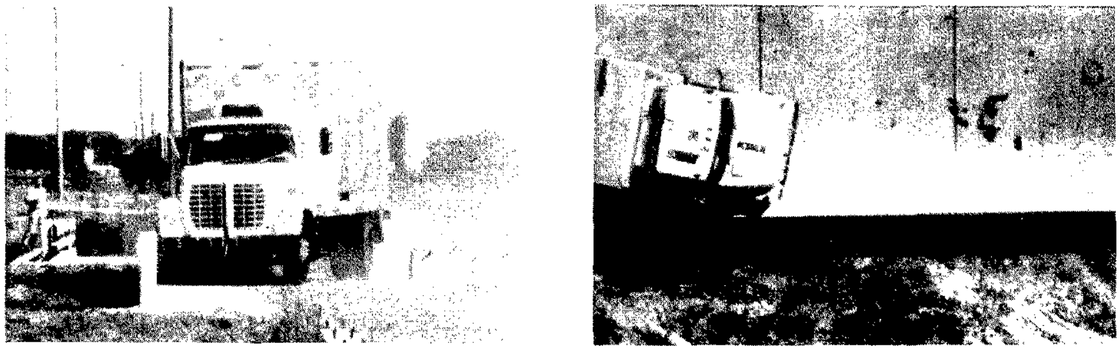
Impact Speed. . . . 50.0 mi/h (80.5 km/h)
Impact Angle. . . . 14.0 deg
Exit Speed . . . . 34.2 (55.0 km/h)
Exit Trajectory . . 5 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . . -1.7 g
  Lateral . . . . . 4.6 g
Occupant Impact Velocity
  Longitudinal. . . 10.9 ft/s (3.3 m/s)
  Lateral . . . . . 11.8 ft/s (3.6 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . -2.3 g
  Lateral . . . . . 8.4 g

Figure 39. Summary of results for test 7069-16.

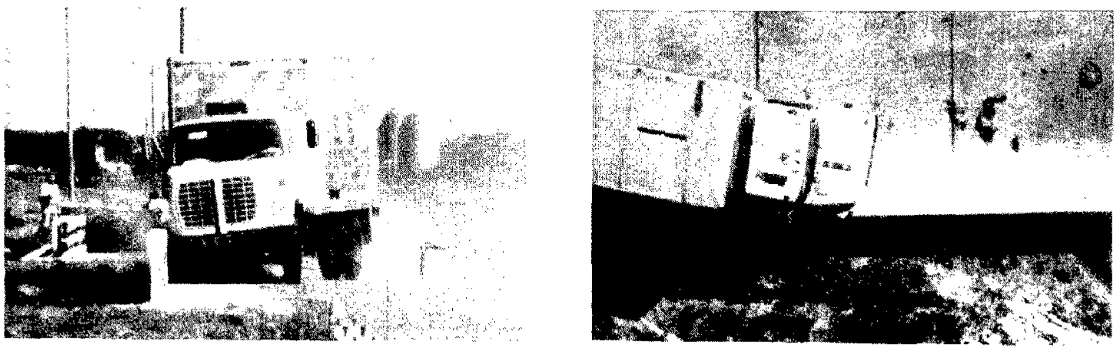
Table 4. Evaluation of crash test no. 7069-16.
{32-in (813-mm) Concrete Parapet Bridge Railing [18,000 lb (8 172 kg)|50 mi/h (80.5 km/h)|14.0 degrees]}

	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 did not remain 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 0.41 — 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 10.9 (3.3); Lateral 11.8 (3.6)	N/A
	Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Ridedown Accelerations - g's Longitudinal -2.3; Lateral 8.4	N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was 5 degrees	Pass

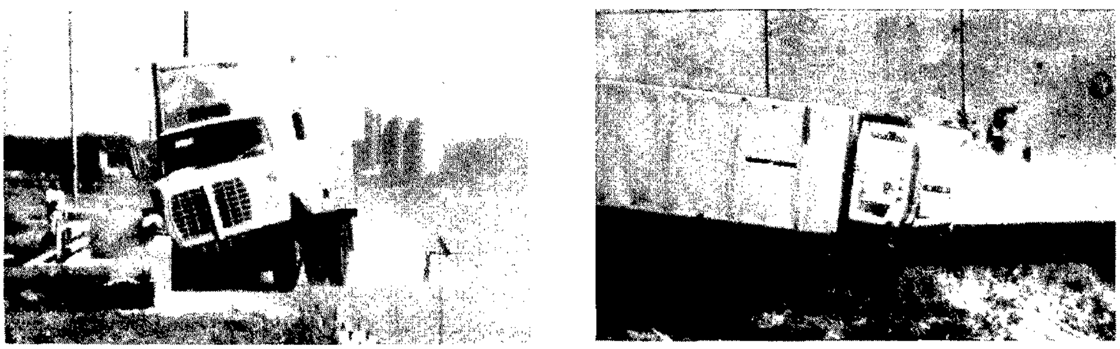
* A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.



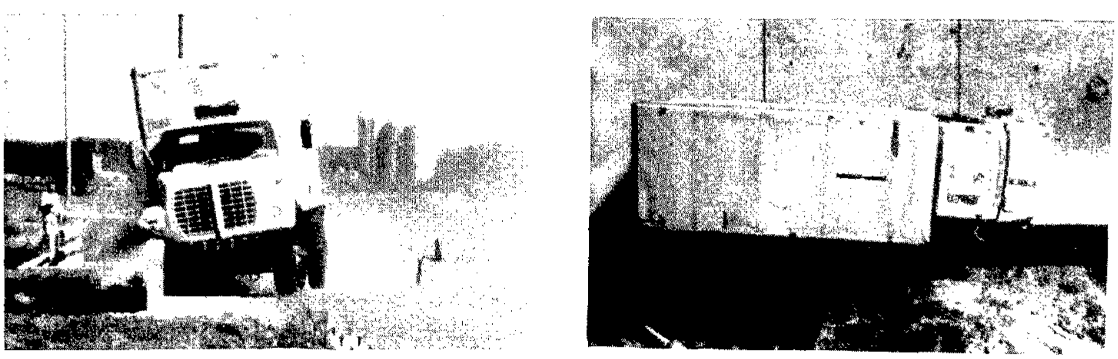
0.000 s



0.086 s



0.172 s



0.257 s

Figure 40. Sequential photographs for test 7069-16 (frontal and overhead views).

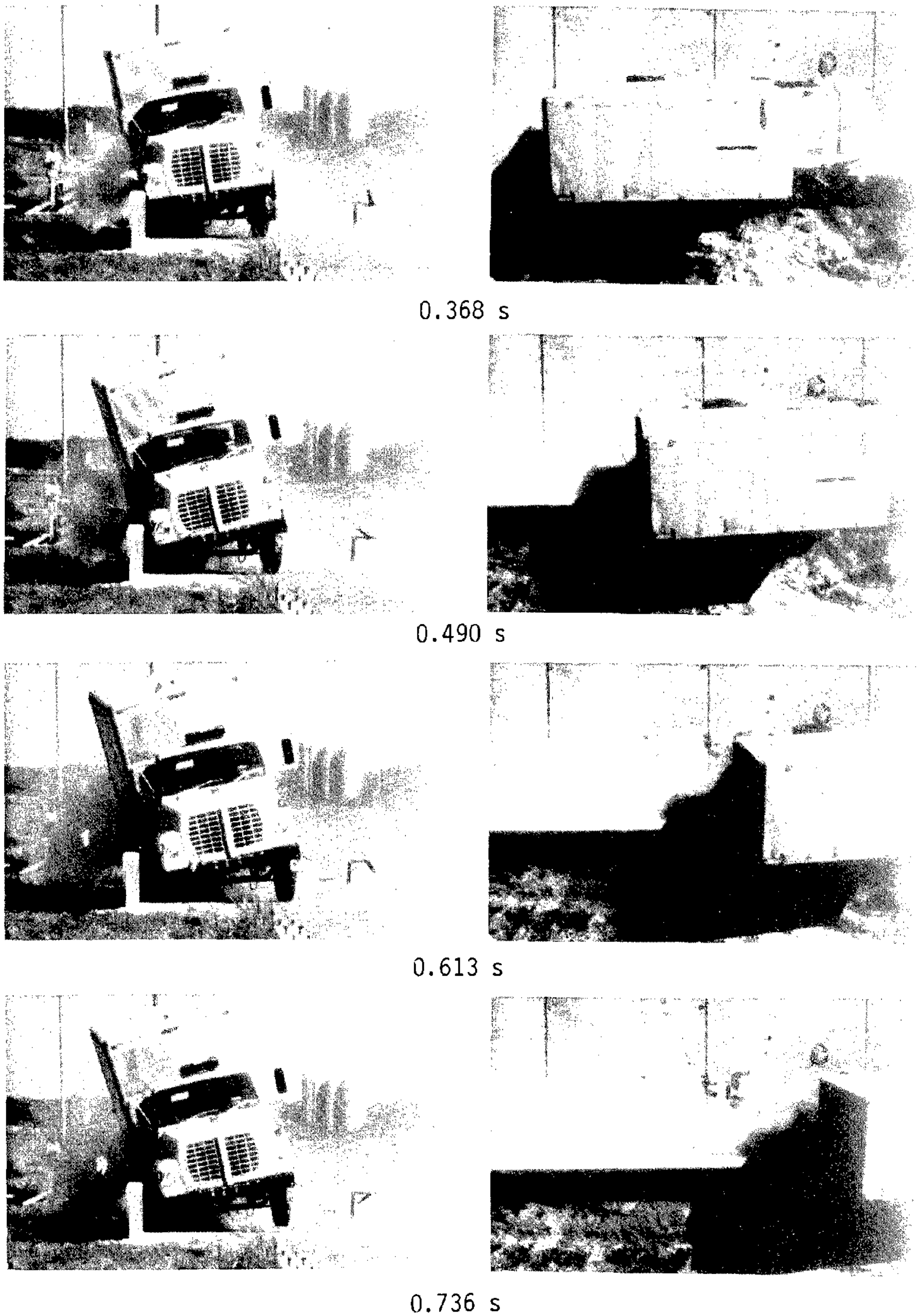
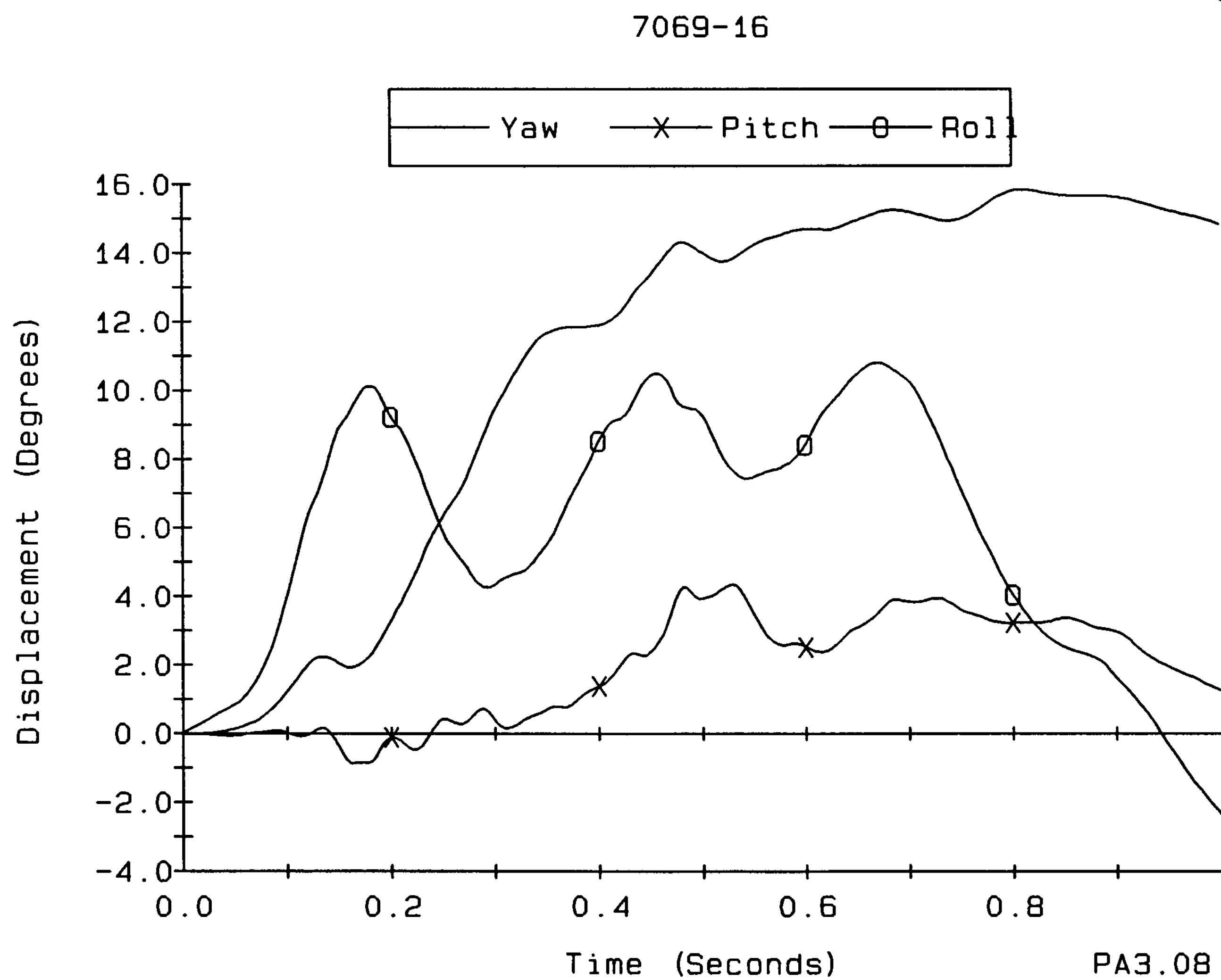
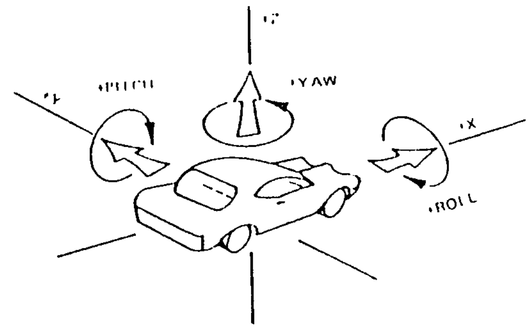


Figure 40. Sequential photographs for test 7069-16
(frontal and overhead views continued).





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 41. Vehicle angular displacement for test 7069-16.

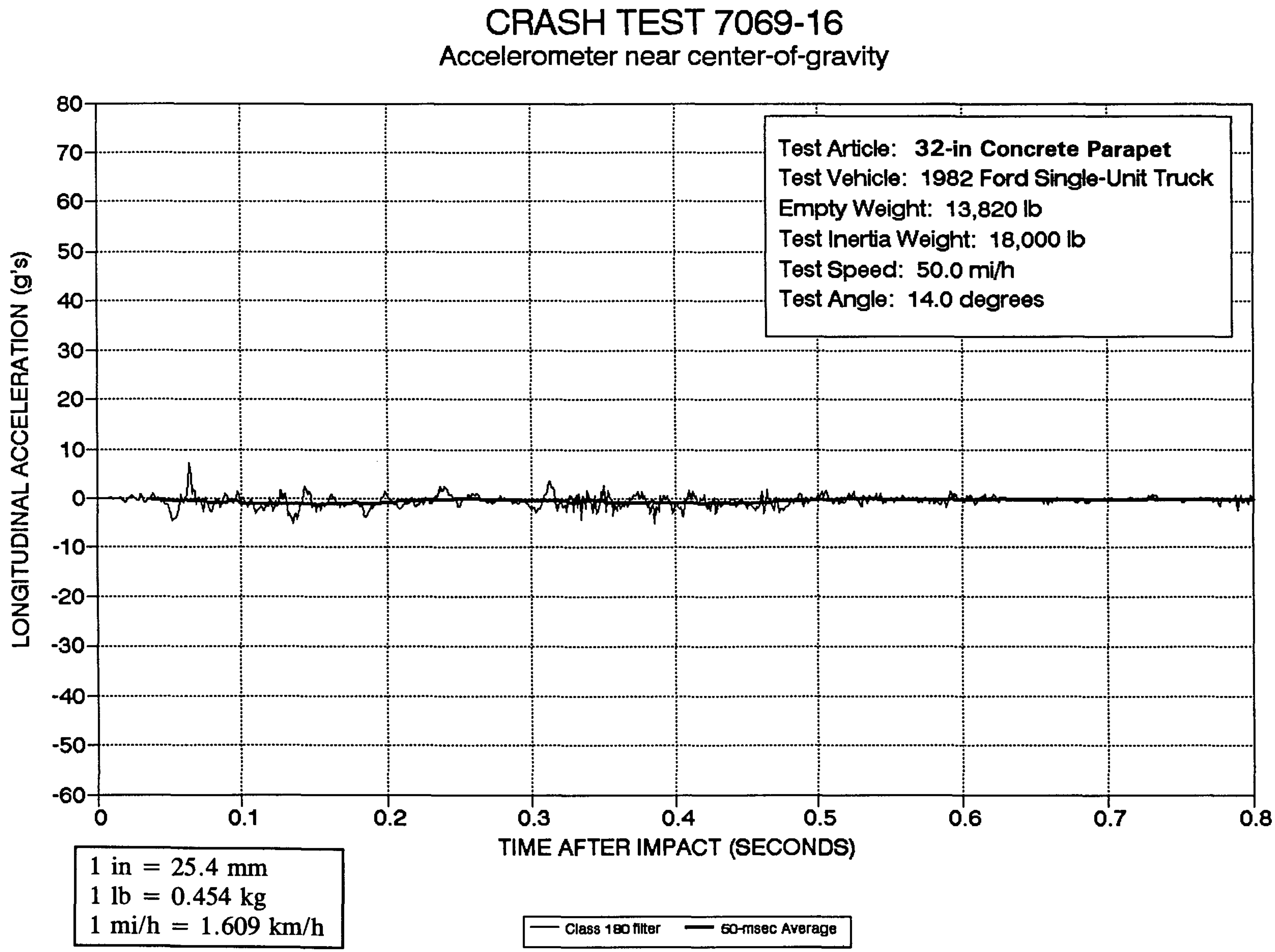


Figure 42. Vehicle longitudinal accelerometer trace for test 7069-16 (accelerometer located near center-of-gravity).

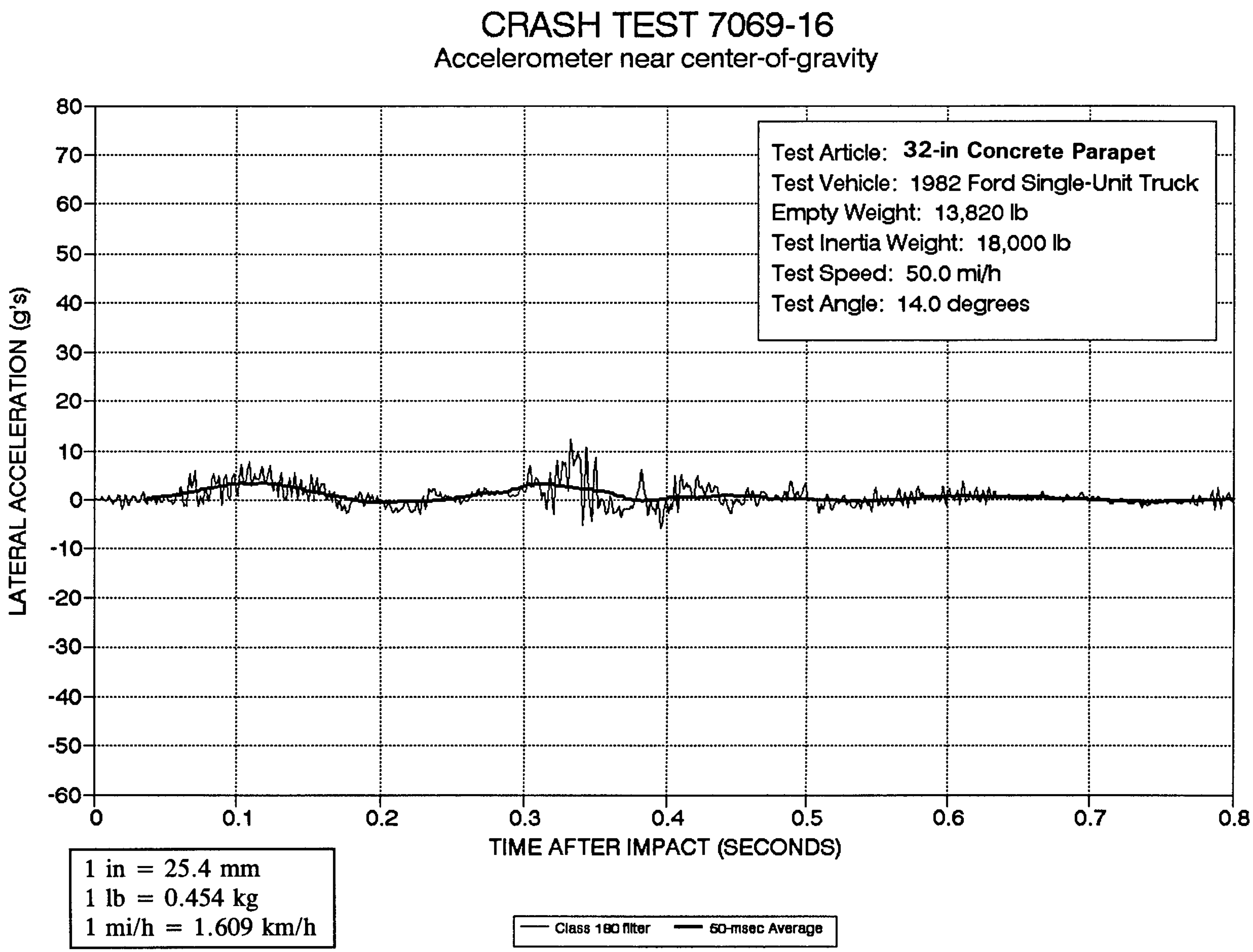


Figure 43. Vehicle lateral accelerometer trace for test 7069-16
(accelerometer located near center-of-gravity).

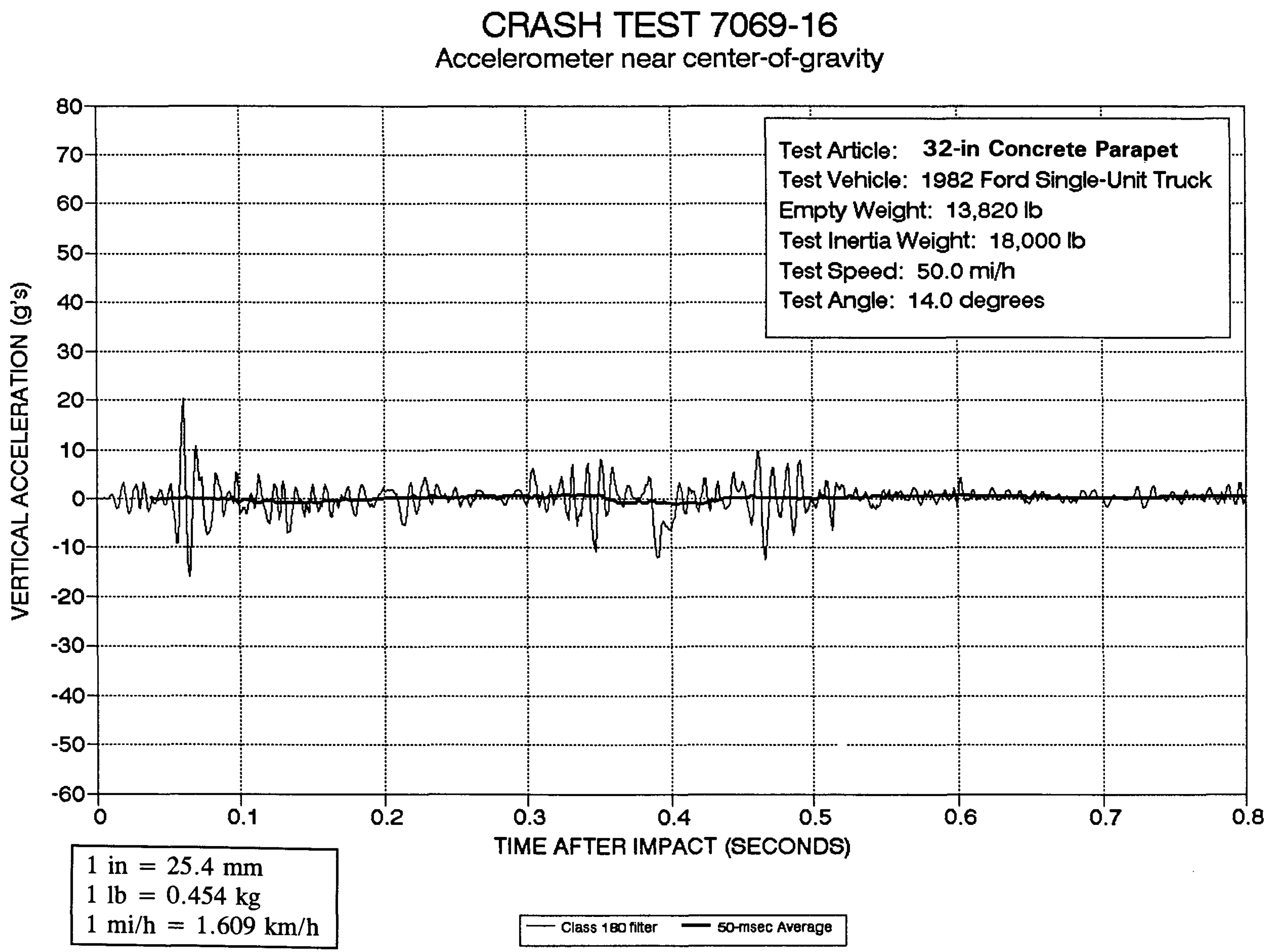


Figure 44. Vehicle vertical accelerometer trace for test 7069-16
(accelerometer located near center-of-gravity).

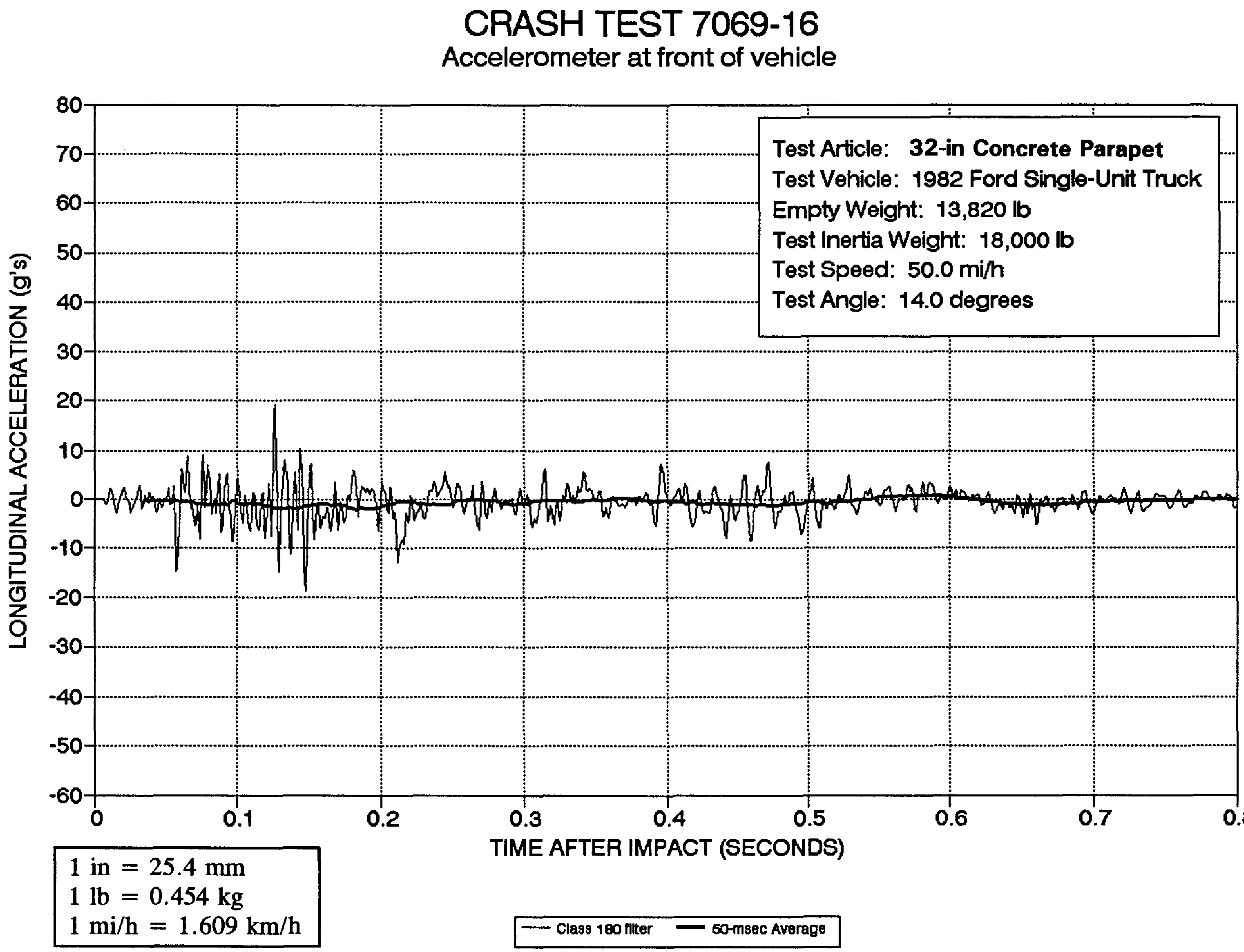


Figure 45. Vehicle longitudinal accelerometer trace for test 7069-16 (accelerometer located at front of vehicle).

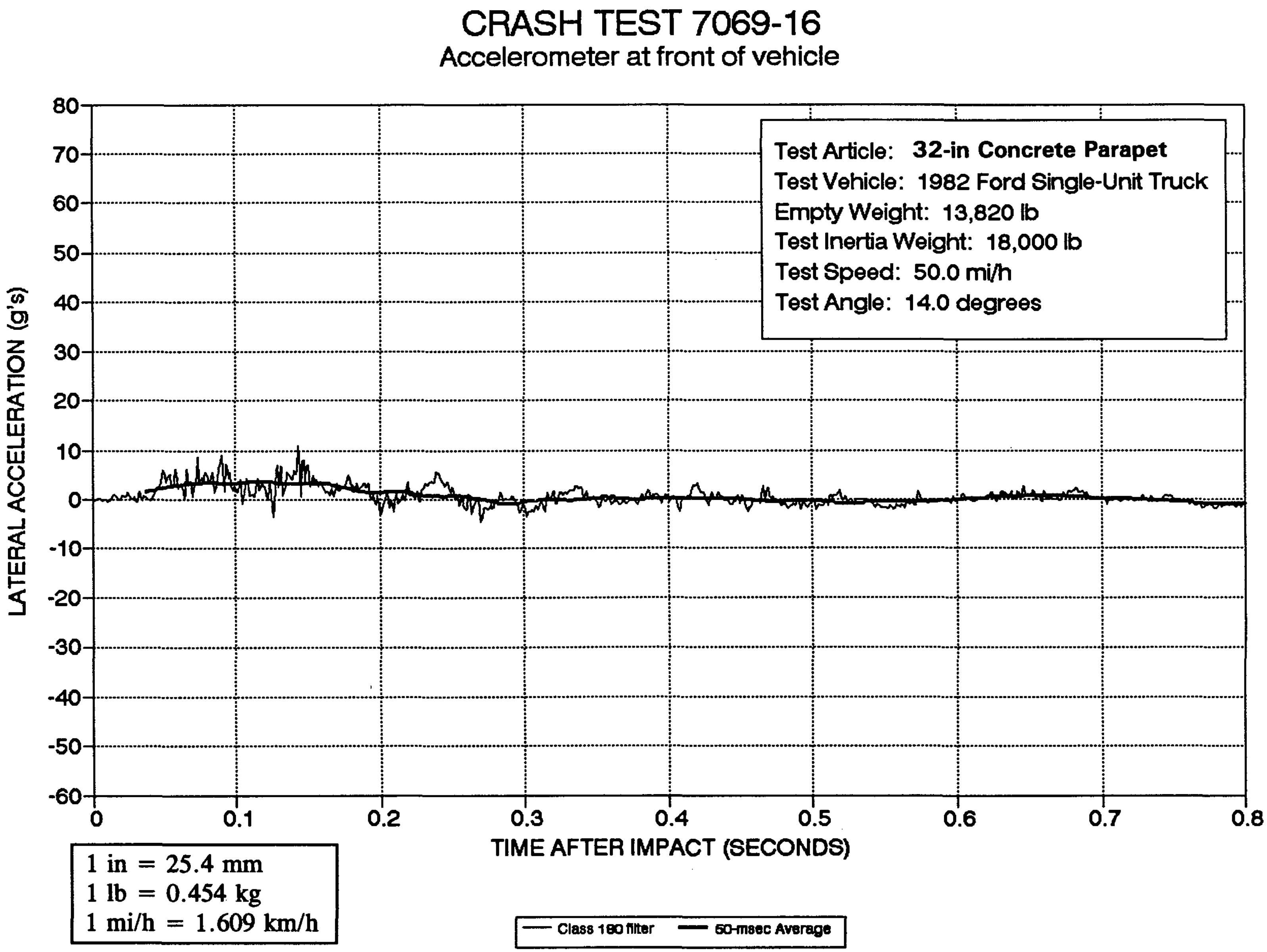


Figure 46. Vehicle lateral accelerometer trace for test 7069-16
(accelerometer located at front of vehicle).

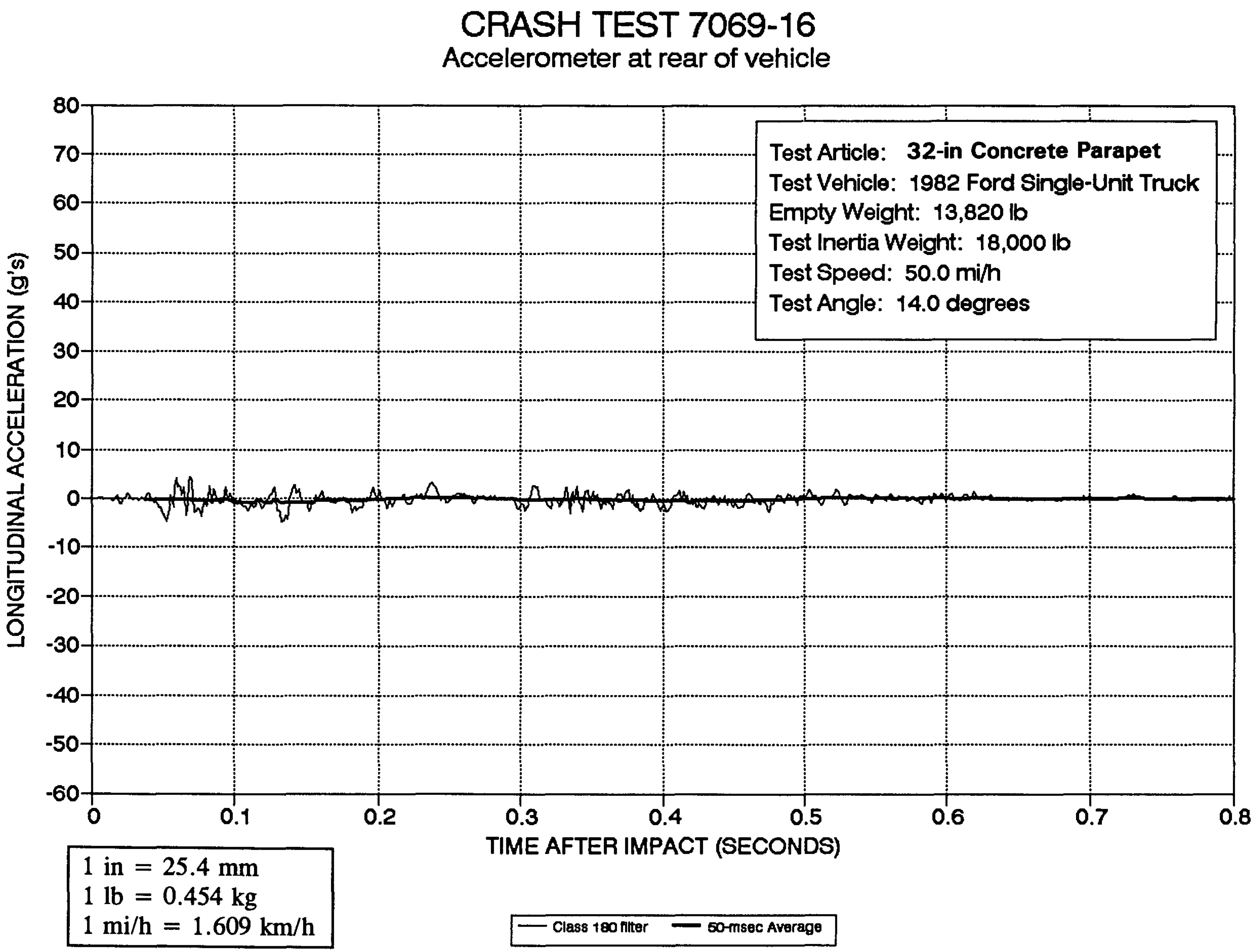


Figure 47. Vehicle longitudinal accelerometer trace for test 7069-16 (accelerometer located at rear of vehicle).

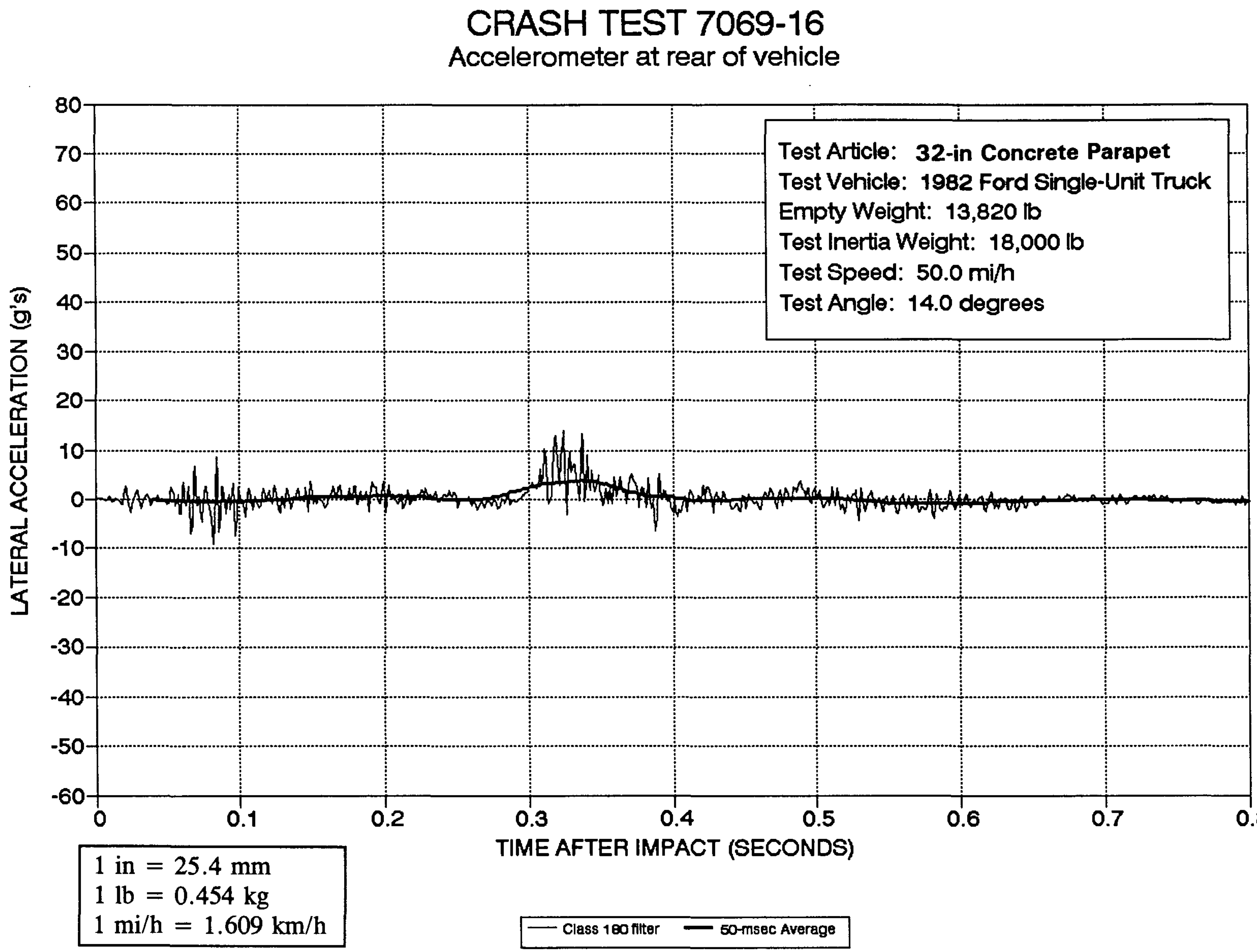


Figure 48. Vehicle lateral accelerometer trace for test 7069-16 (accelerometer located at rear of vehicle).

CHAPTER 4. STRENGTH CALCULATIONS

Analysis of the strength of the railing is based on an ultimate strength yieldline mechanism. Force from a colliding vehicle is idealized as being a uniformly distributed line load extending over 3.5 ft (1.07 m) in the longitudinal direction. The load may be applied at any location along the railing. The yieldline failure pattern is illustrated in figure 49. At ultimate strength, yield moments are developed along the yield lines indicated. The length, L, of the yieldline pattern is dependent upon relative bending moment capacities of the parapet in the horizontal and vertical direction and the added moment capacity of the stiffening beam along the top of the parapet. The length may be computed using the equation for L in figure 49. For this parapet, the computed cantilever capacity, ϕM_c, is 10.66 ft-k/ft (47.44 m-kN/m). The moment capacity in the longitudinal direction, ϕM_w, is 2.55 ft-k/ft (11.35 m-kN/m). The added moment capacity of the beam, ϕM_c, is 8.95 ft-k/ft (39.88 m-kN/m).

In order to maintain the yieldline pattern in the parapet, the strength of the deck must be greater than the strength of the parapet. Analysis shows that the moment capacity of the deck is 10.77 k-ft/ft (47.93 m-kN/m) which is greater than M_c.

The total strength of the mechanism is found using the equations given in figure 49. The resulting length of mechanism, L, is 7.6 ft (2.3 m), and the total ultimate capacity, $(wl)_{ult}$, at a height of 32 in (813 mm) is 61.0 kips (271.5 kN).

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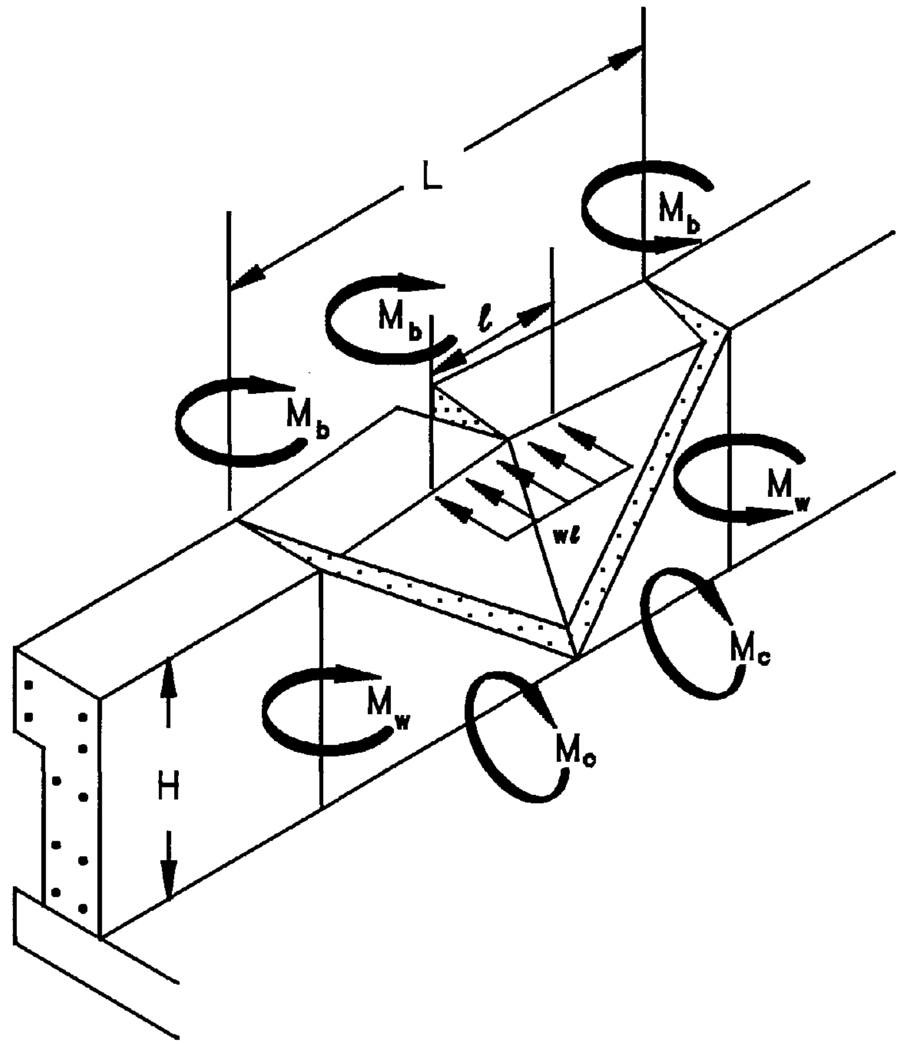

$$L = \frac{\ell}{2} + \sqrt{\left(\frac{\ell}{2}\right)^2 + \frac{8H(M_b + M_w H)}{M_c}}$$

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

Figure 49. 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.

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