Testing of State Roadside Safety Systems Volume IV: Appendix C–Crash Testing and Evaluation of a Pennsylvania Transition Design

PUBLICATION NO. FHWA-RD-98-039

PB99-155103

APRIL 1999

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
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McLean, VA 22101-2296

FOREWORD

Because of specific needs or constraints of individual States, new or modified roadside safety hardware are being designed and developed on a continuing basis. To ensure that these new or modified designs perform according to established guidelines, full-scale crash testing and evaluation were deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and where necessary redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

Detailed drawings are presented for documentation as well as a summary of findings and conclusions for each of the devices tested, and where necessary recommendations for improvement.

It should be noted that this research did not produce a version of the MELT—Modified Eccentric Loader Terminal—that was acceptable to FHWA for use on the National Highway System.

Michael F. Trentacoste, Director
Office of Safety Research and
Development

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Re[cipient's Catalog No.]
FHWA-RD-98-039		PB99-155103

4. Title and Subtitle	5. Report Date
TESTING OF STATE ROADSIDE SAFETY SYSTEMS VOLUME IV: APPENDIX C - CRASH TESTING AND EVALUATION OF A PENNSYLVANIA TRANSITION DESIGN	April 1999 6. Performing Organization Code
7. Author(s) King K. Mak and Wanda L. Menges	8. Performing Organization Report No. Research Foundation 7147-Vol. IV
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. NCP No. 11. Contract or Grant No. DTFH61-89-C-00089
12. Sponsoring Agency Name and Address Office of Safety & Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, Virginia 22101-2296	13. Type of Report and Period Covered Final Report November 1, 1989 - August 1996 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA
Research Study Title: Testing of Roadside Safety Systems
Contracting Officer's Technical Representative (COTR) - Charles F. McDevitt, HSR-20

16. Abstract

The purpose of this study is to crash test and evaluate new or modified roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

This report presents the results of a crash test on a transition design by the Commonwealth of Pennsylvania Department of Transportation for use in transitioning from a standard W-beam guardrail to an 813-mm- (32-in-) high concrete safety-shaped bridge rail. The test involved a 2043-kg (4500-lb) passenger car impacting the transition at a nominal speed and angle of 96.5 km/h (60 mi/h) and 25 degrees. Results of the crash test indicated that, although the transition design technically met all evaluation criteria set forth in National Cooperative Highway Research Program (NCHRP) Report 230, the impact performance of this transition design is considered very marginal. It is recommended that the transition design be improved prior to actual field applications.

This volume is the fourth in a series of 14 volumes for the final report. The other volumes in the series are: Volume I - Technical Report; Volume II, Appendix A - Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design; Volume III, Appendix B - Development and Crash Testing of a Guardrail System for Low-Fill Culvert; Volume V, Appendix D - Crash Testing and Evaluation of a Washington, DC, PL-1 Bridge Rail; Volume VI, Appendix E - Crash Testing and Evaluation of a Modified Breakaway Cable Terminal (BCT) Design; Volume VII, Appendix F - Crash Testing and Evaluation of the Minnesota Swing-Away Mailbox Support; Volume VIII, Appendix G - Crash Testing and Evaluation of the Single Slope Bridge Rail; Volume IX, Appendix H - Crash Testing and Evaluation of the NETC PL-2 Bridge Rail Design; Volume X, Appendix I - Crash Testing and Evaluation of a Mini-MELT for a W-Beam, Weak-Post (G2) Guardrail System; Volume XI, Appendix J - Crash Testing and Evaluation of Existing Guardrail Systems; Volume XI, Appendix J - Crash Testing and Evaluation of Existing Guardrail Systems; Volume XII, Appendix K - Crash Testing and Evaluation of the MELT; Volume XIII, Appendix L-Crash Testing and Evaluation of the Modified MELT; and Volume XIV, Appendix M - Laboratory and Pendulum Testing of Modified Breakaway Wooden Posts.

17. Key Words	18. Distribution Statement
Bridge railings, transitions, end treatments, guardrails, median barriers, terminals, roadside safety	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

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

Form DOT F 1700.7 (8-69) Reproduction of completed page authorized

PREFACE

Because of specific needs or constraints of individual states, new or modified roadside safety hardware are being designed and developed on a continuing basis. To ensure that these new or modified designs perform according to established guidelines, full-scale crash testing and evaluation were deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and, where necessary, redesign the devices to improve their impact performance. The three major areas addressed in this study are the impact performance of bridge railings, transitions from guardrails to bridge railings, and end treatments for guardrails and median barriers.

This is Volume IX of a 14-volume series of final reports for this study. The 14 volumes are as follows:

Volume	Appendix	Title
I		Technical Report.
II	A	Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design.
III	B	Crash Testing and Evaluation of a Guardrail System for Low-Fill Culvert.
IV	C	Crash Testing and Evaluation of a Pennsylvania Transition Design.
V	D	Crash Testing and Evaluation of a Washington, DC, PL-1 Bridge Rail.
VI	E	Crash Testing and Evaluation of a Modified Breakaway Cable Terminal (BCT) Design.
VII	F	Crash Testing and Evaluation of the Minnesota Swing-Away Mailbox Support.
VIII	G	Crash Testing and Evaluation of the Single Slope Bridge Rail.
IX	H	Crash Testing and Evaluation of the NETC PL-2 Bridge Rail Design.
X	I	Crash Testing and Evaluation of a Mini-MELT for a W-Beam, Weak-Post (G2) Guardrail System.
XI	J	Crash Testing and Evaluation of Existing Guardrail Systems.
XII	K	Crash Testing and Evaluation of the MELT.
XIII	L	Crash Testing and Evaluation of the Modified MELT.
XIV	M	Laboratory and Pendulum Testing of Modified Breakaway Wooden Posts.

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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I. INTRODUCTION

Because of specific needs or constraints of individual states, new or modified roadside safety hardware have been designed and developed recently. To ensure that these new or modified designs perform according to established performance guidelines, full-scale crash testing and evaluation was deemed necessary. The objective of this study is to crash test and evaluate these roadside safety hardware and, where necessary, redesign the tested devices to improve their performance. The three major areas addressed in this study are the impact performance of bridge rails, transitions from guardrails to bridge rails, and end treatments for guardrails and median barriers.

The Commonwealth of Pennsylvania Department of Transportation has designed a transition for use in transitioning from a standard W-beam guardrail to a standard 813-mm- (32-in-) high concrete safety-shaped bridge rail. The following report details the full-scale crash test and performance evaluation of this transition when impacted by a 2043-kg (4500-lb) passenger car traveling at a nominal speed and angle of 96.5 km/h (60 mi/h) and 25 degrees. Testing and evaluation was performed according to guidelines outlined in National Cooperative Highway Research Program (NCHRP) Report 230.[1]

II. STUDY APPROACH

2.1 TEST ARTICLE

The test installation for this crash test consisted of a 4.3-m (14-ft) section of simulated concrete bridge parapet and wingwall, a Type C drainage inlet, and 22.9 m (75 feet) of W-beam approach guardrail and transition. Figure 1 shows details of the simulated concrete bridge parapet and wingwall, drainage inlet, and the transition portion of the approach guardrail.

The simulated concrete bridge parapet and wingwall consisted of a 2.4-m (8-ft) section of standard 0.81-m- (32-in-) high concrete safety-shaped bridge rail with a 1.8-m (6-ft) flared wingwall set at 9 degrees to the bridge rail. The simulated concrete bridge parapet and wingwall was built on and tied into a 4.3-m- (14-ft-) long, 0.61-m- (24-in-) wide, and 0.91-m- (36-in-) deep reinforced concrete foundation.

A Type C drainage inlet, details of which are shown in figure 2, was constructed and installed at the end of the wingwall. To facilitate a smooth transition from the drainage inlet to the wingwall, a 20.3-cm- (8-in-) high transition curb block was formed into the wingwall. The curb face of the drainage inlet was thus flush with that of the transition curb block. A 0.9-m (3-ft) section of sloped unreinforced concrete curb was used to transition from ground level to the 20.3-cm (8-in) curb of the drainage inlet. The drainage inlet was connected to the transition curb block of the wingwall with two 30.5-cm- (12-in-) long #8 rebar dowels, and the sloped concrete curb end was connected to the drainage inlet likewise.

The guardrail installation consisted of a 3.81-m (12-ft, 6-in) transition section, a 7.62-m (25-ft) section of standard steel strong-post, W-beam (G4(1S)) guardrail, and a 11.43-m (37-ft, 6-in) section of Breakaway Cable Terminal (BCT), for a total length of 22.9 m (75 ft). The 3.81-m (12-ft, 6-in) transition section had nested W-beams (one set inside the other) attached to the wingwall with use of a modified terminal connector, as detailed in figure 3. The top of the posts and W-beams extended 0.79 m (31 in) above ground level. The first five posts in the transition area were 1.83-m- (6-ft-) long W6x9 steel posts with 559-mm- (22-in-) long W6x9 steel blockouts. The extra long blockouts allowed for attachment of a bent plate rubrail, mounted with the centerline 330 mm (13 in) above ground level. The rubrail was bent after post 5 to allow for termination of the rubrail behind post 6.

Note that the spacings for the first five posts in the transition area were irregular and different from the standard spacings of 0.48 m (1 ft, 6-3/4 in), 0.95 m (3 ft, 1-1/2 in), or 1.9 m (6 ft, 3 in). The irregular spacing was purposely selected so that the first two posts would not interfere with the underground drainage pipe attached to the drainage inlet. Also note that the nested W-beams were not bolted to posts 2 through 4 and post 6. Thus, it was necessary to punch only one special hole in the nested W-beams for post 1.

Photographs of the completed test installation are shown in figure 4.

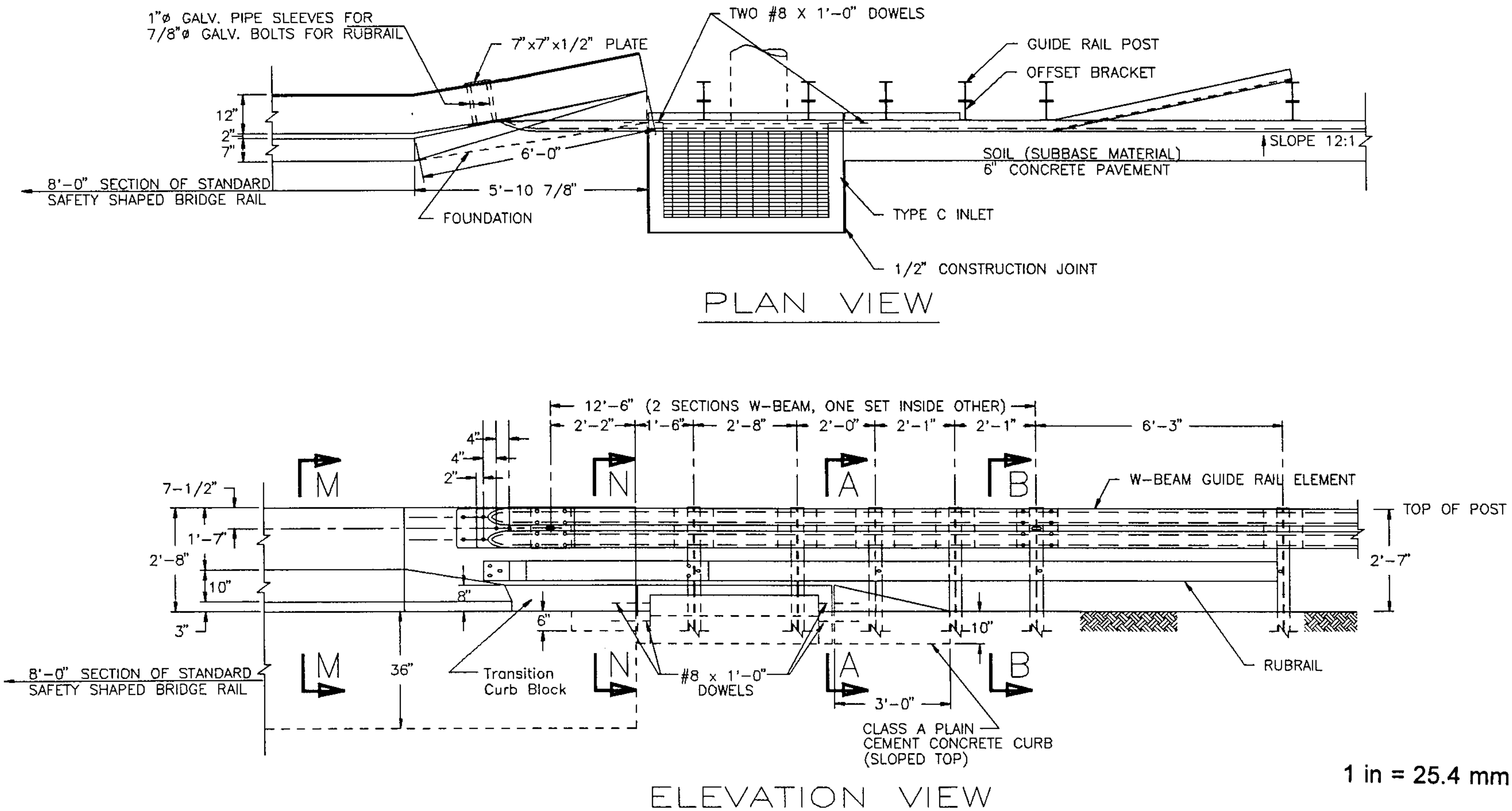
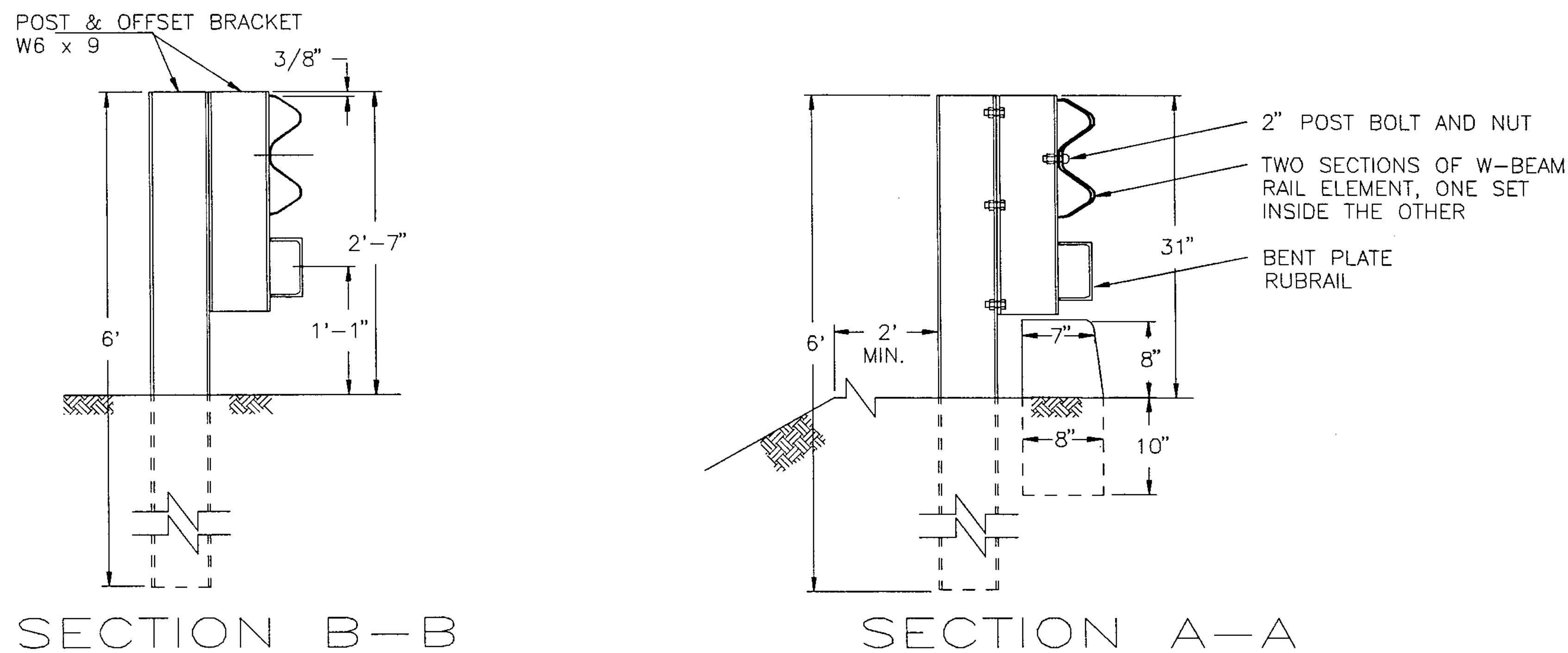
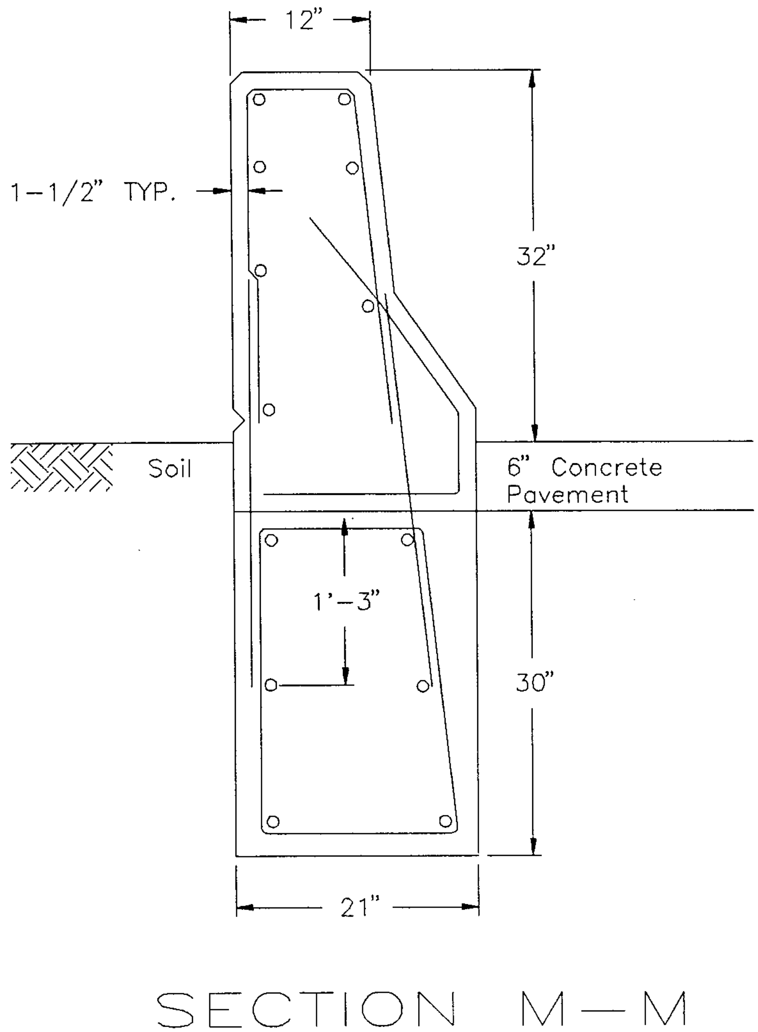


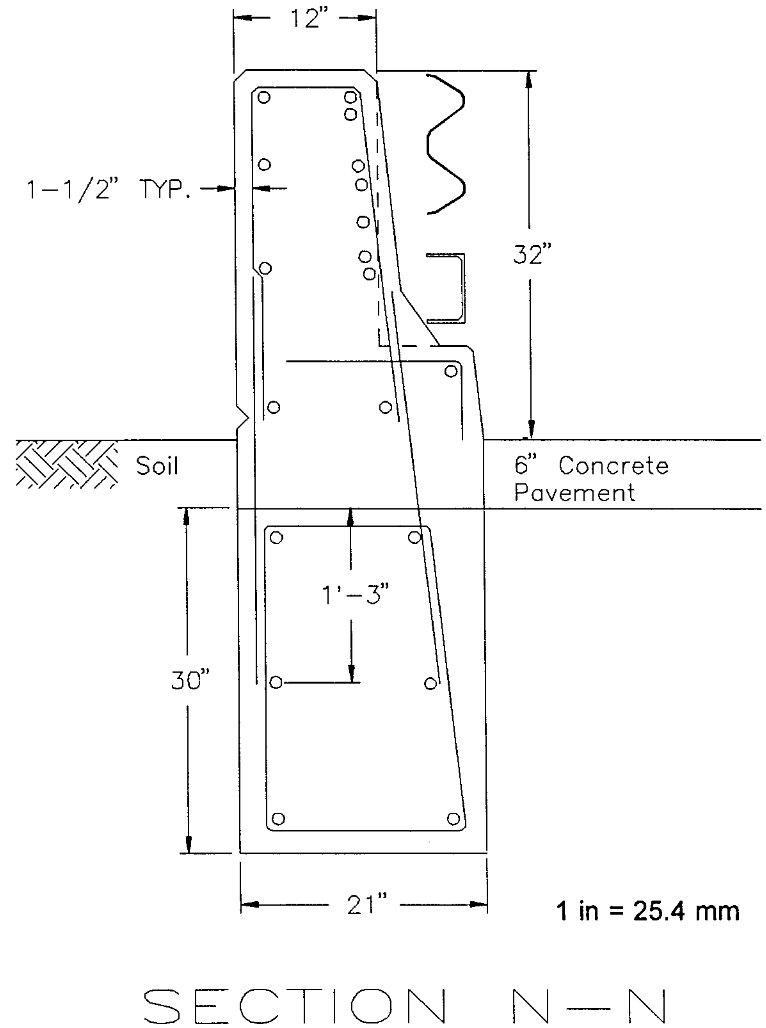
Figure 1. Construction details for Pennsylvania bridge rail transition.



1 in = 25.4 mm

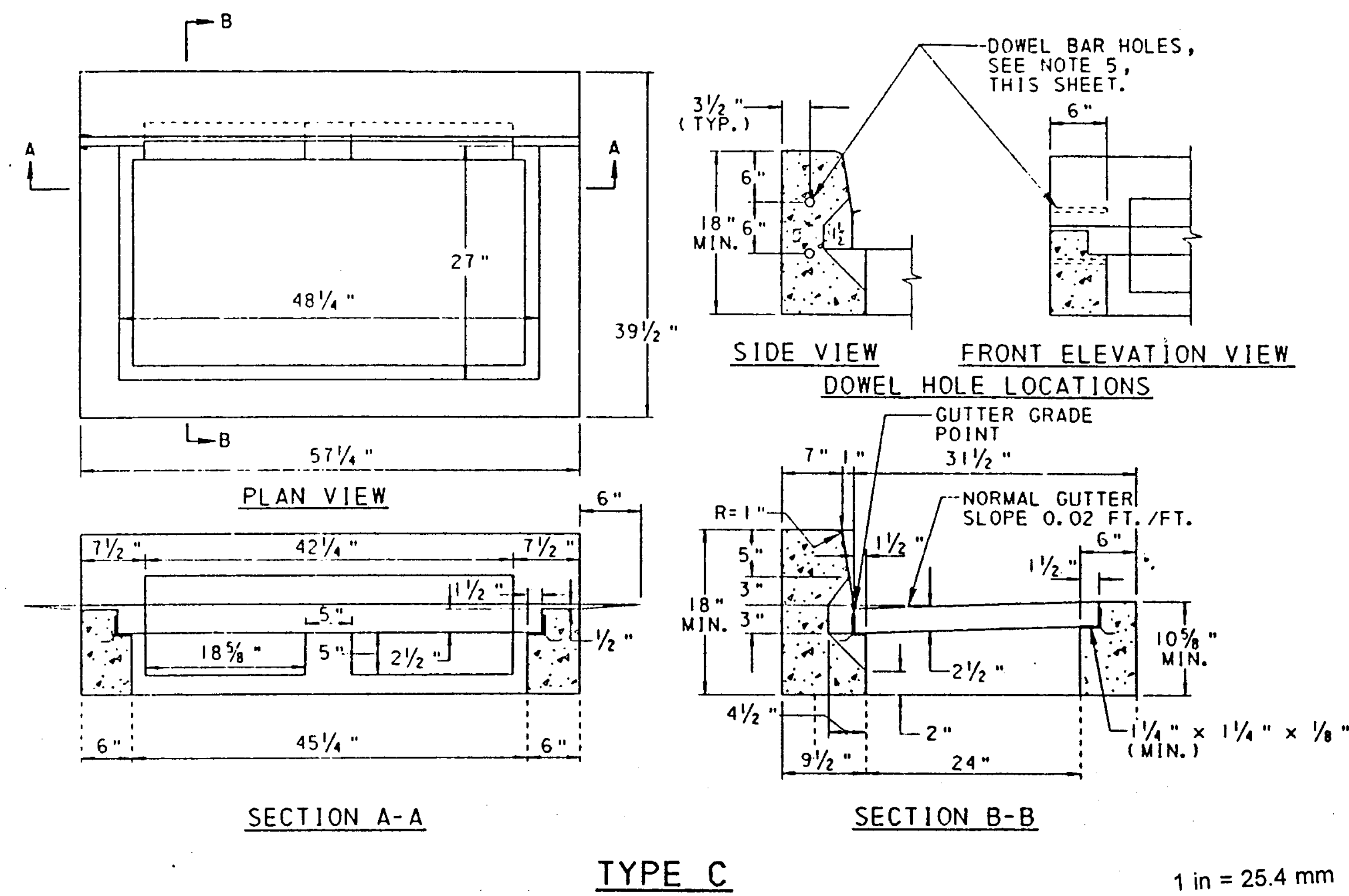
Figure 1. Construction details for Pennsylvania bridge rail transition (continued).





1 in = 25.4 mm

Figure 1. Construction details for Pennsylvania bridge rail transition (continued).



1 in = 25.4 mm

Figure 2. Type C drainage inlet.

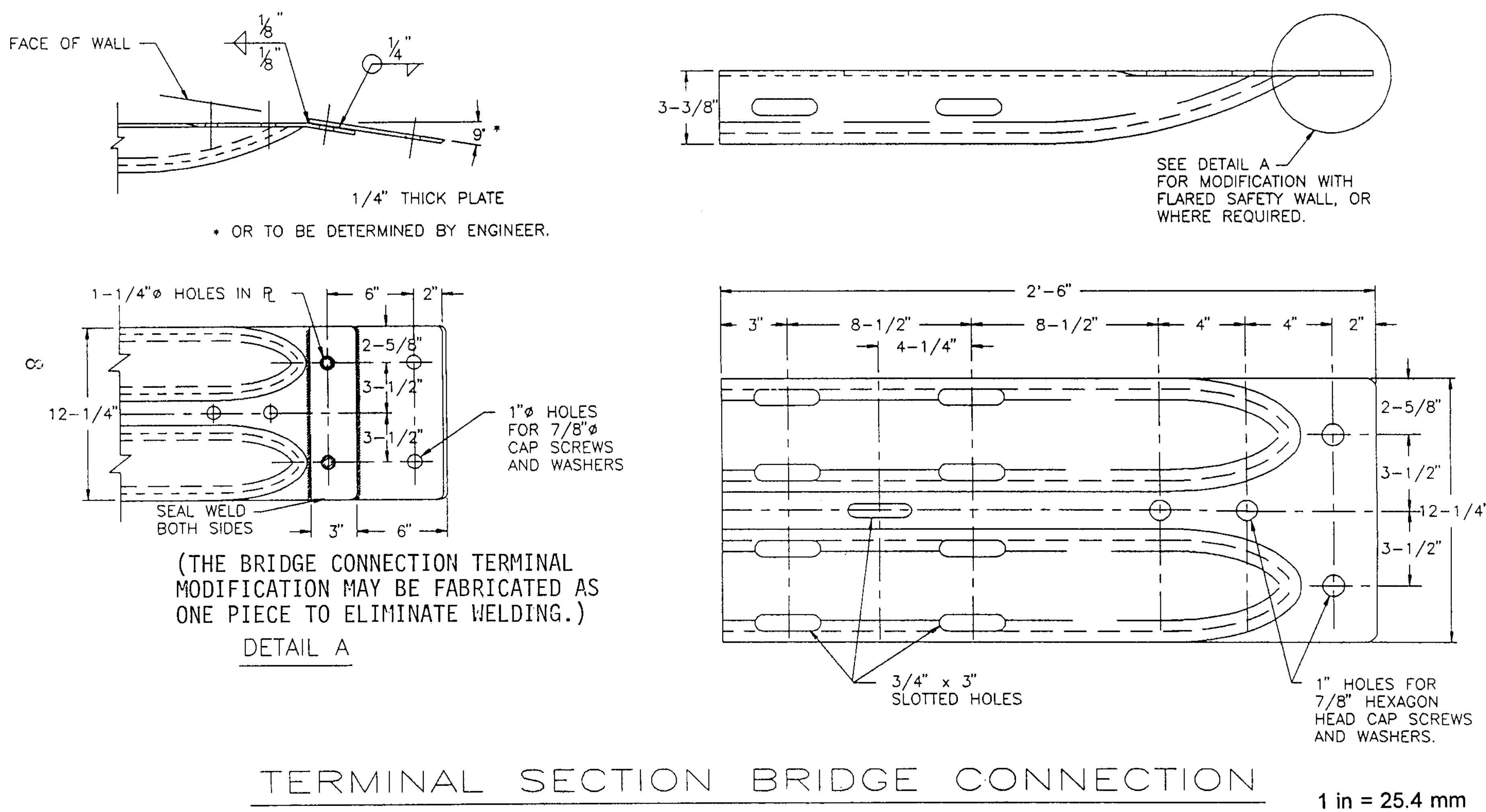


Figure 3. Modified terminal connector.

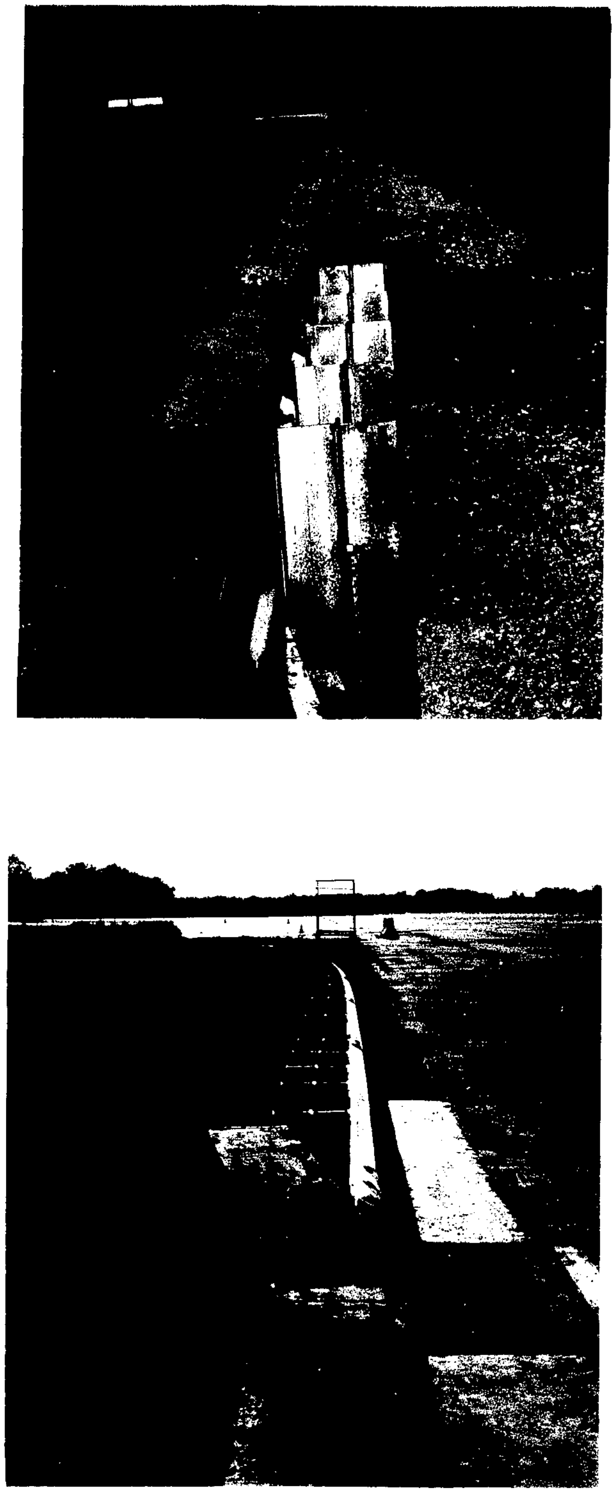


Figure 4. Pennsylvania bridge rail transition prior to test 7147-3.

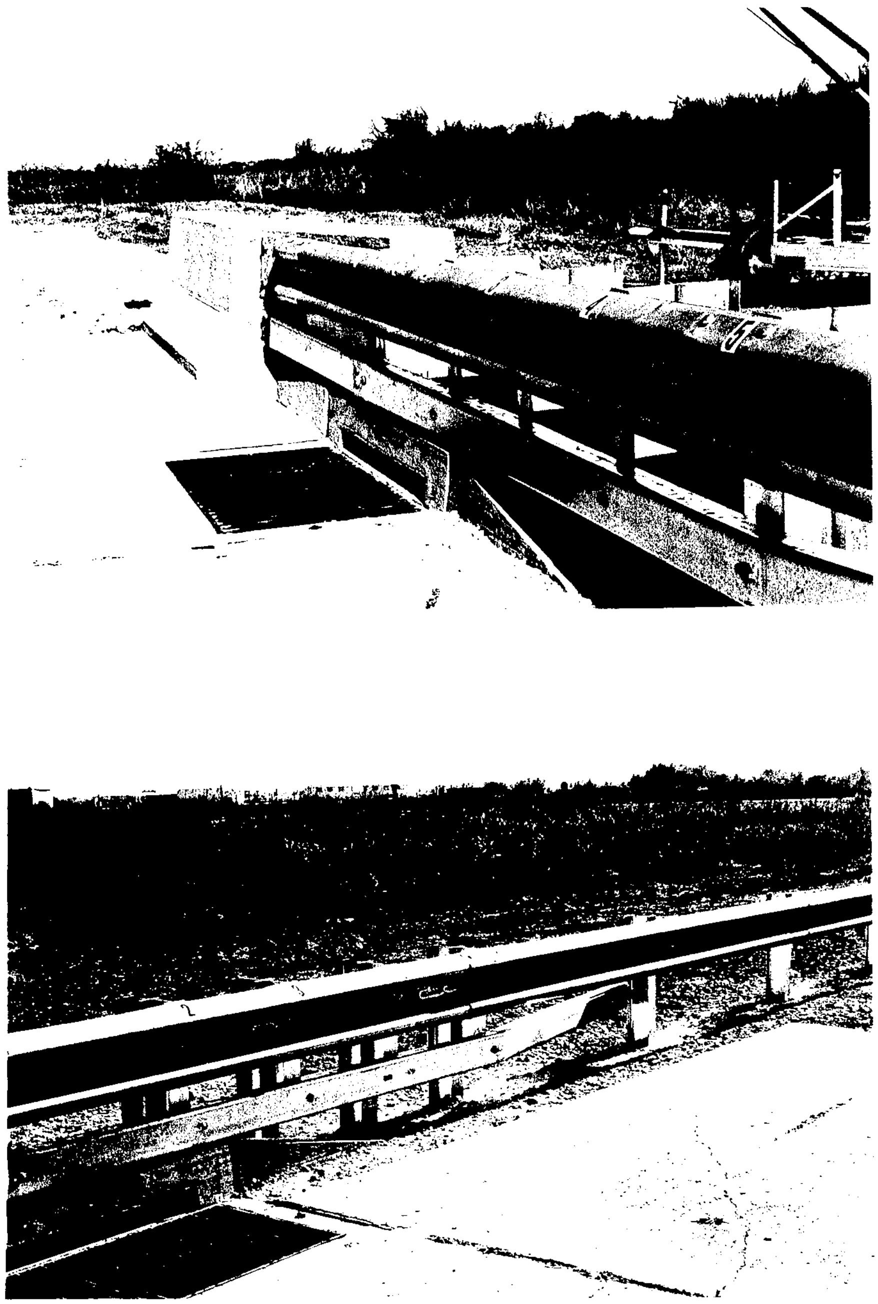


Figure 4. Pennsylvania bridge rail transition prior to test 7147-3 (continued).

2.2 CRASH TEST CONDITIONS

The crash test reported herein corresponded to test designation 30 of the NCHRP Report 230 crash test matrix for a transition test. The test involved a 2043-kg (4500-lb) passenger car impacting the transition midspan of posts 2 and 3, at a nominal speed and angle of 96.5 km/h (60 mi/h) and 25 degrees. The primary purpose of this test is to evaluate the structural adequacy of the transition system.

2.3 CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 230.[1] Brief descriptions of these procedures are presented as follows.

2.3.1 Electronic Instrumentation and Data Processing

The crash test procedures were in accordance with guidelines presented in NCHRP Report 230. The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center of gravity to measure longitudinal, lateral, and vertical acceleration levels; and a backup biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain-gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Provision was made for the 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 exact instant of contact with the transition system.

The multiplex of data channels, transmitted on one radio frequency, was received at the 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 a Class 180 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions of the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 0.010-s average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 0.050-s intervals in each of the 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 (LOTUS 123).

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.001-s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system, with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

2.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th-percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle. The dummy was uninstrumented.

2.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included four high-speed cameras: one perpendicular to the point of impact from the back of the transition system; another overhead with a field of view perpendicular to the ground and directly over the impact point; and a third placed to have a field of view parallel to and aligned with the transition system at the downstream end. A high-speed camera was also placed onboard the vehicle to record the motions of the dummy placed in the driver seat. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the transition system 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 3/4-in videotape camcorder, and still cameras were used for documentary purposes and to record conditions of the test vehicle and transition system before and after the test.

2.3.4 Test Vehicle Propulsion and Guidance

The test vehicle was towed into the test installation using a steel cable 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.

III. CRASH TEST RESULTS

A 1979 Cadillac DeVille, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 2043 kg (4500 lb) and its gross static weight was 2120 kg (4670 lb). The height to the lower edge of the vehicle bumper was 330 mm (13.0 in) and it was 584 mm (23.0 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 7. The vehicle was directed into the transition system using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

3.1 TEST DESCRIPTION

The vehicle was traveling at a speed of 99.0 km/h (61.5 mi/h) when it impacted the transition system approximately midspan between posts 2 and 3. The impact angle was 25.4 degrees. The vehicle began to redirect at 0.036 s after initial impact. At approximately 0.035 s, the right front tire of the vehicle impacted the curb face of the drainage inlet and the tire aired out at 0.060 s. The right front tire of the vehicle climbed on top of the curb of the drainage inlet at about 0.066 s and the right front of the vehicle started to rise. The right rear of the roof began to deform at approximately 0.073 s, and extensive deformation of the roof of the vehicle was observed throughout the impact sequence.

The W-beam guardrail transition deflected sufficiently to allow the vehicle to impact the wingwall at 0.085 s traveling at a speed of 89.3 km/h (55.5 mi/h) and a 30-degree angle to the wingwall. Shortly thereafter, the simulated concrete safety-shaped bridge rail and wingwall began to move and tilt backwards. By 0.190 s, the simulated concrete safety-shaped bridge rail and wingwall reached a maximum dynamic deflection of 64 mm (2.5 in) at the top.

At 0.196 s, the vehicle was traveling parallel to the transition system at a speed of 68.5 km/h (42.6 mi/h). The rear of the vehicle impacted the transition system at 0.201 s and the vehicle exited the transition at 0.308 s, traveling at a speed of 66.3 km/h (41.2 mi/h), with an exit trajectory of 14.7 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated counterclockwise and veered to the right because of the orientation of the front tires and damages sustained by the tires on the right side of the vehicle from impact with the guardrail and the transition curb block. The left rear of the vehicle impacted the end of a concrete barrier section downstream of the transition system and subsequently came to rest 46 m (150 ft) downstream from the point of initial impact. Sequential photographs of the test sequence are presented in figures 8 and 9.

3.2 DAMAGE TO TEST INSTALLATION

The transition system received moderate damage, as shown in figure 10. The total length of contact of the vehicle with the transition system was 5.3 m (17.5 ft). The maximum

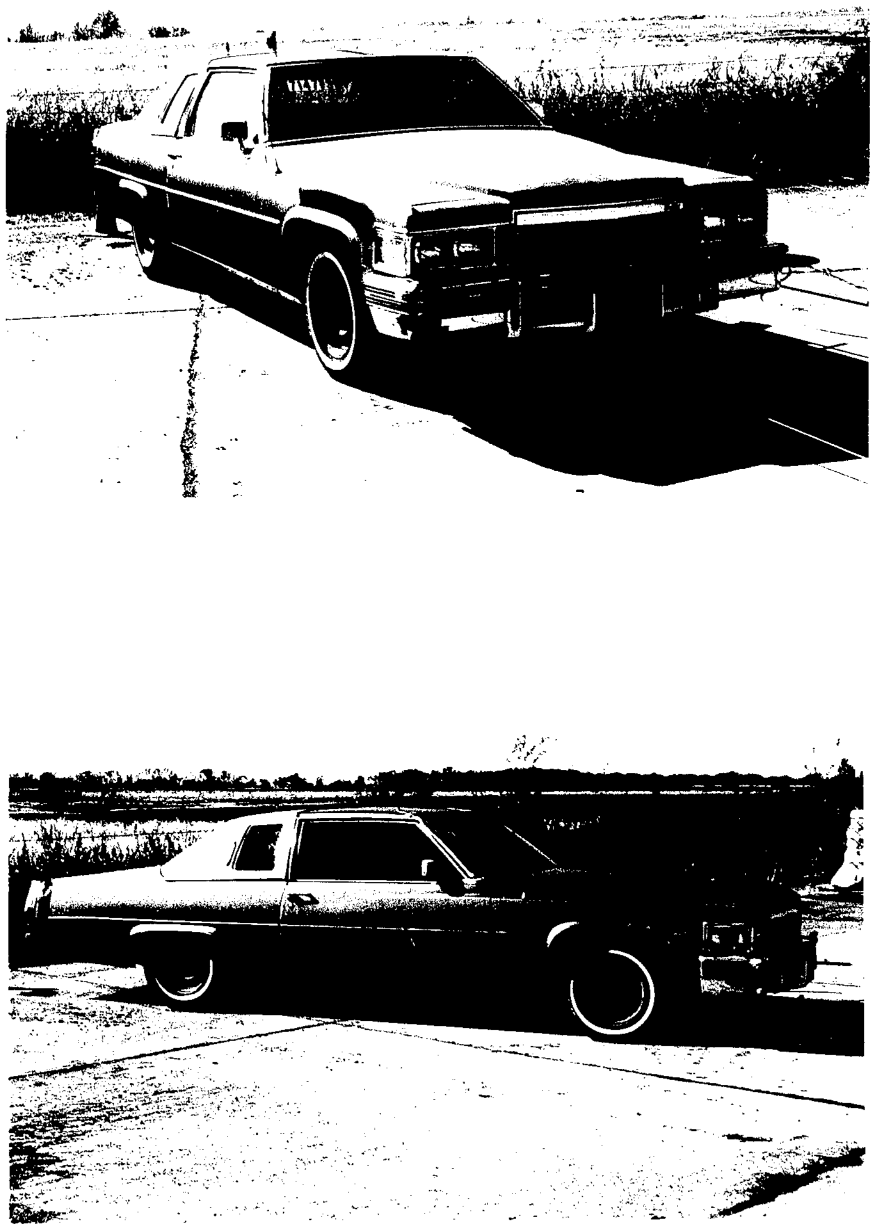


Figure 5. Vehicle prior to test 7147-3.

Figure 6. Vehicle/transition geometry for test 7147-3.

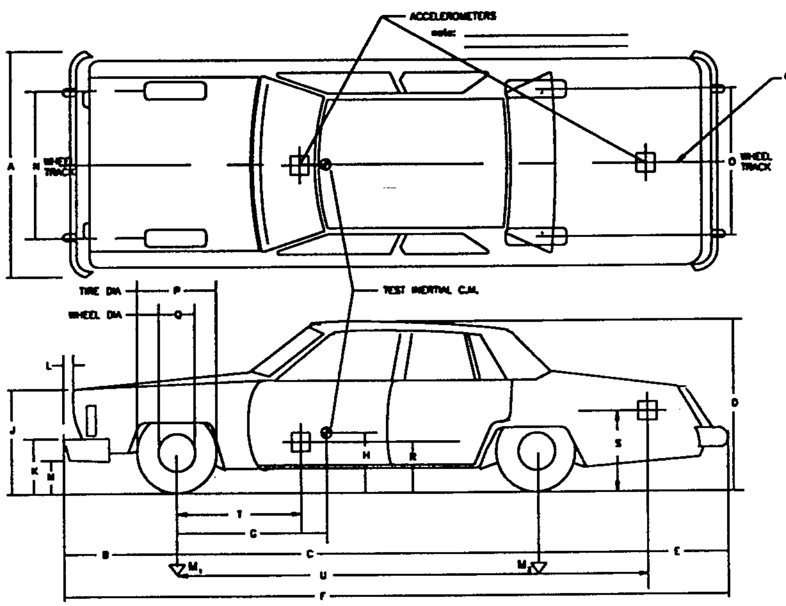
DATE: 10/6/90 TEST NO.: 471470-3 VIN NO.: 6D47596361964

YEAR: 1979 MAKE: Cadillac MODEL: DeVille

TIRE INFLATION PRESSURE: ______ ODOMETER: 121726 TIRE SIZE: P225/75R15

MASS DISTRIBUTION (kg) LF 536 RF 578 LR 467 RR 462

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: V-8

ENGINE CID: 7 L

TRANSMISSION TYPE:

X AUTO

_ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th male

MASS: 77 kg

SEAT POSITION: Driver's

GEOMETRY - (mm)

A 1899	E 1410	J 908	N 1562	R 508
B 1048	F 5537	K 584	O	S 622
C 3080	G 1400	L 114	P 699	T 914
D 1410	H	M 330	Q 413	U 4070

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1099	1114	1154
M_2	770	929	967
M_T	1869	2043	2120

Figure 7. Vehicle properties for test 7147-3.

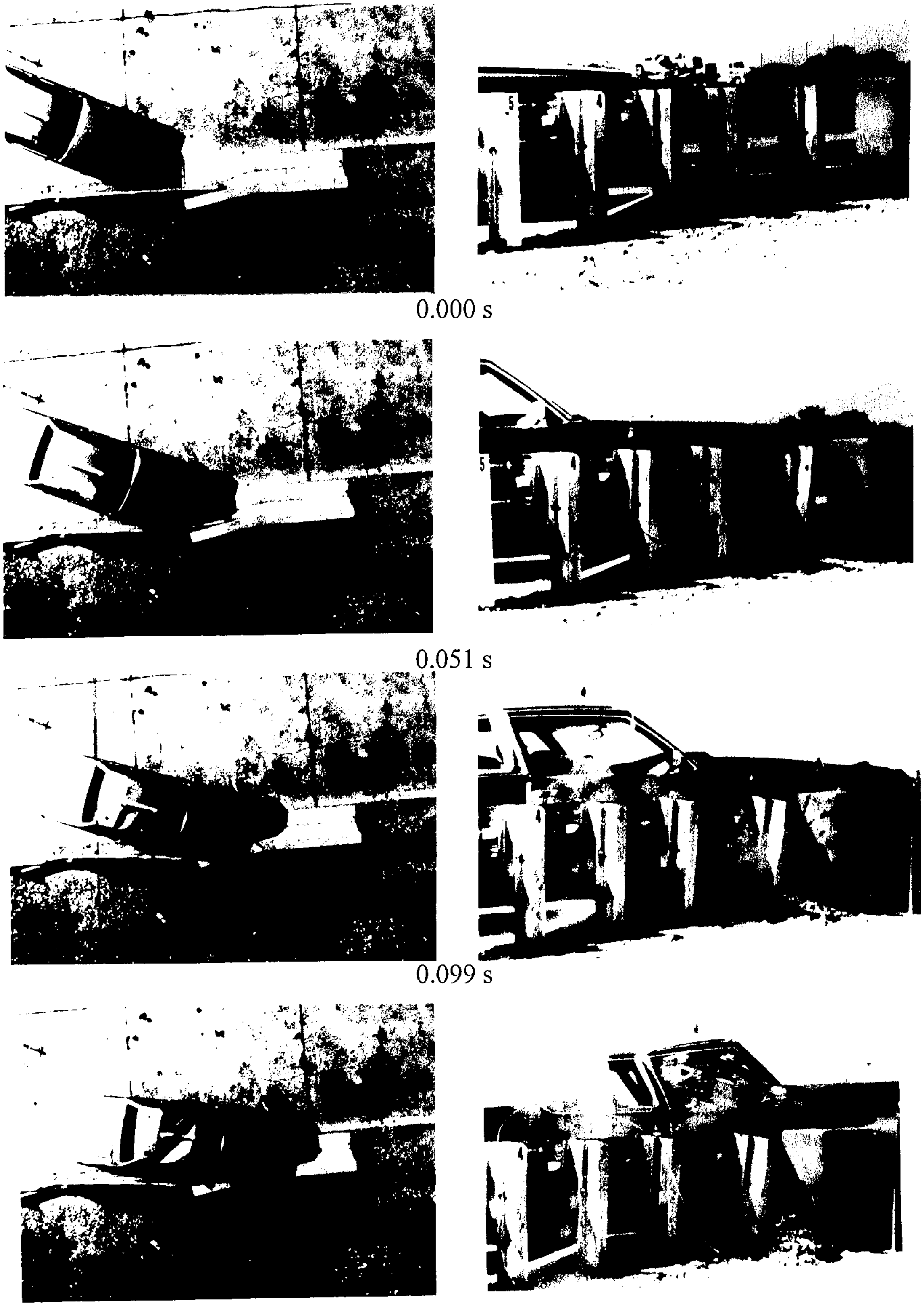


Figure 8. Sequential photographs for test 7147-3
(overhead and behind the rail views).

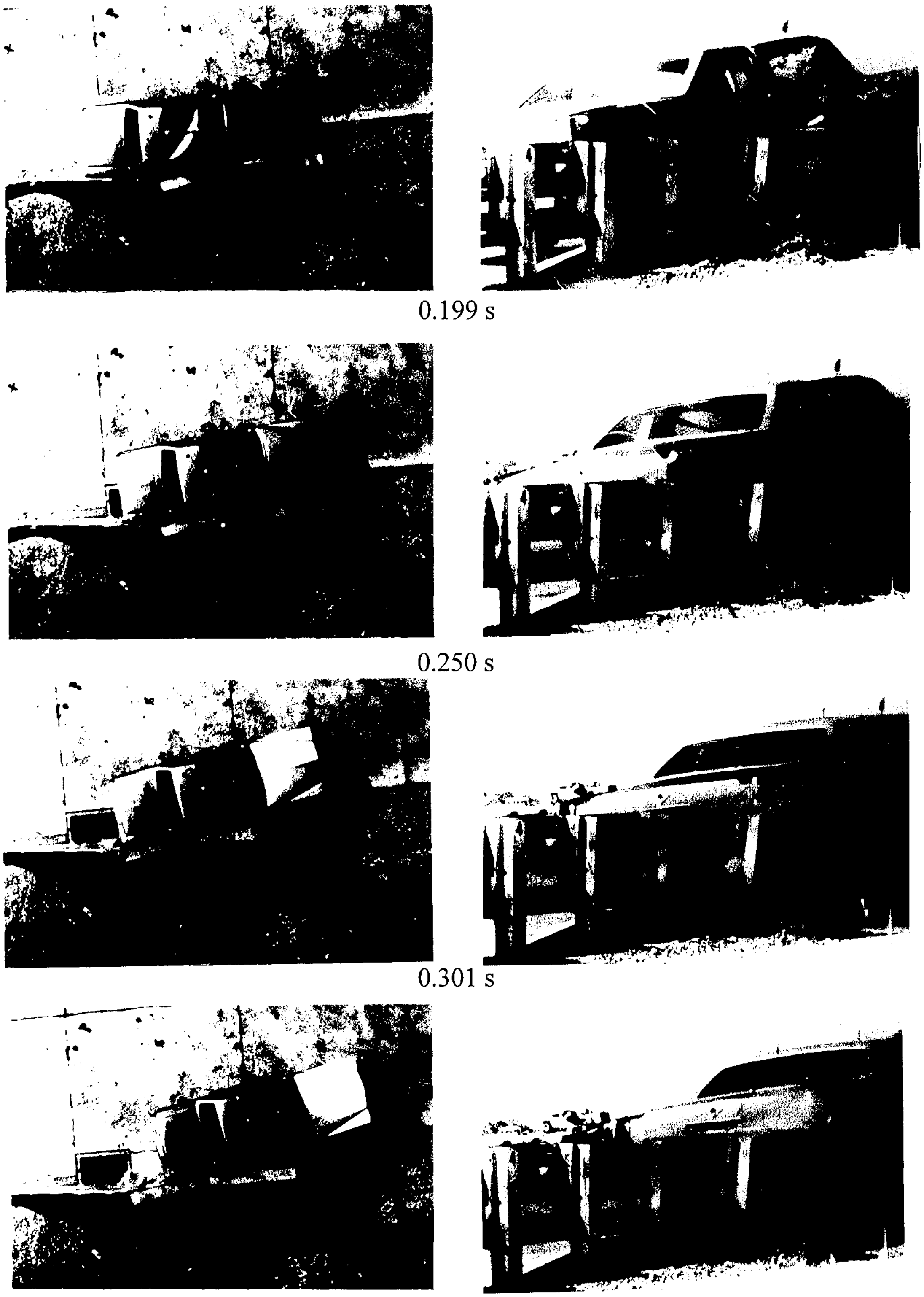


Figure 8. Sequential photographs for test 7147-3
(overhead and behind the rail views) (continued).

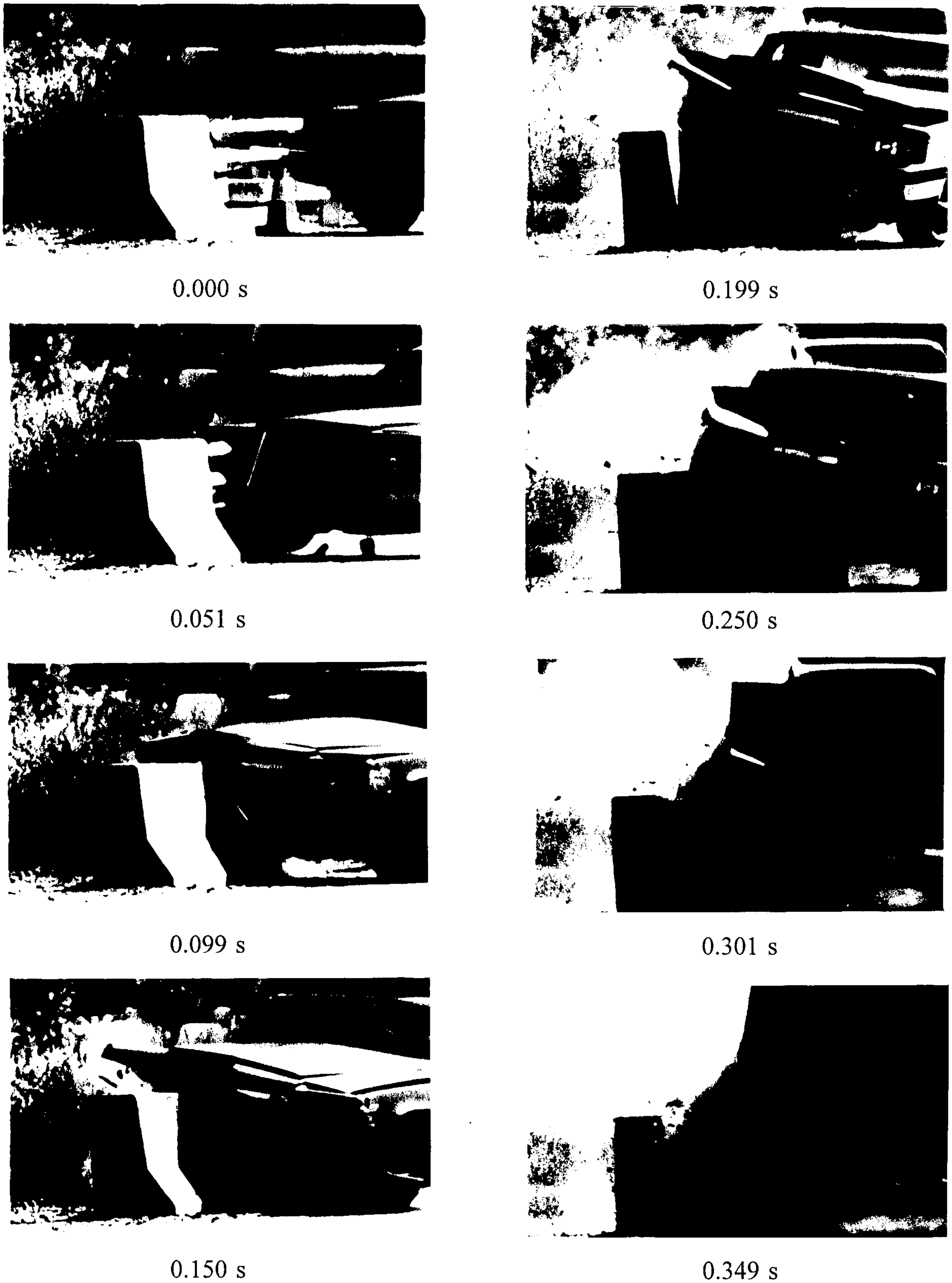


Figure 9. Frontal sequential photographs for test 7147-3.

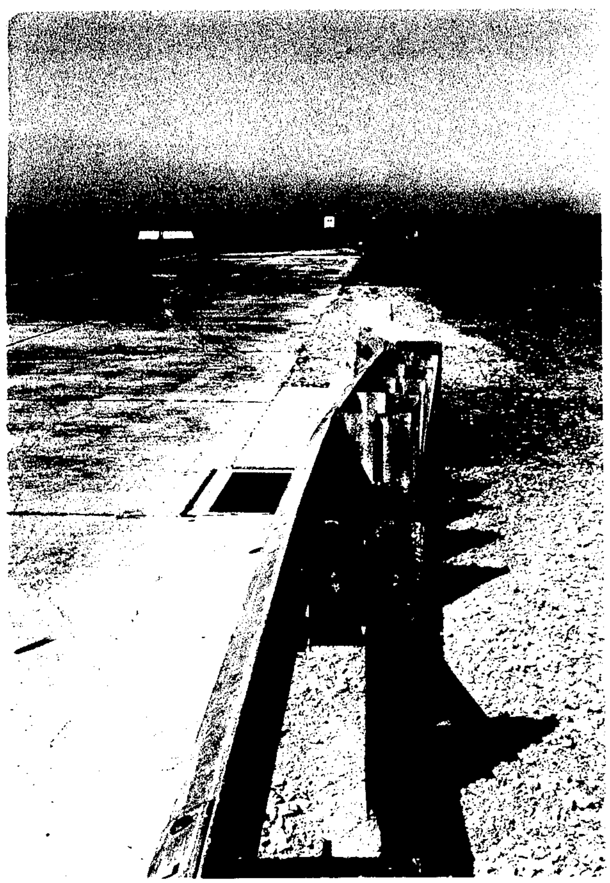


Figure 10. Pennsylvania transition after test 7147-3.

permanent deformation of the W-beam rail element was 191 mm (7.5 in), located at the end of the wingwall. The lower corrugation of the W-beam had been flattened against the wingwall. The tilting movement of the concrete safety shape caused the concrete foundation to move and subsequently to settle 13 mm (0.5 in) above ground level, and it was pushed backwards a distance of 13 mm (0.5 in). The drainage inlet was also pushed back a distance of 16 mm (5/8 in).

3.3 VEHICLE DAMAGE

The vehicle (shown in figure 11) sustained extensive damage to the right side. The floorpan and roof were bent, the windshield was broken, and the interior instrument panel was deformed. A small section of sheet metal was torn off the right door, evidently by the end of the terminal connector lapped in the direction of impact (because of the nested W-beam, the terminal connector had to be lapped in this manner in order for the bolt hole to fit). There was damage to the front bumper, hood, grill, radiator and fan, right and left front quarter panel, right door and glass, right rear quarter panel, and the rear bumper. The left rear quarter panel was damaged, and the rear glass and rear side glass were broken when the vehicle impacted the other barrier downstream near the end of the vehicle trajectory. The wheelbase on the right side was shortened from 3.08 m (121.25 in) to 2.74 m (108.0 in). The right front and rear rims and tires were damaged. Maximum crush to the vehicle was 838 mm (33.0 in) at the right front corner at bumper height and the front was shifted 64 mm (2.5 in) to the left.

3.4 OCCUPANT RISK VALUES

Data from the electronic instrumentation were digitized for evaluation, and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 9.1 m/s (29.9 ft/s) at 0.171 s; the highest 0.010-s average ridedown acceleration was -6.4 g's from 0.215 to 0.225 s; and the 0.050-s average acceleration was -12.3 g's between 0.084 and 0.134 s. Lateral occupant impact velocity was 8.0 m/s (26.1 ft/s) at 0.115 s; the highest 0.010-s average ridedown acceleration was 23.7 g's from 0.123 to 0.133 s; and the maximum 0.050-s average acceleration was -13.1 g's between 0.082 and 0.132 s. The change in vehicle velocity at loss of contact was 32.7 km/h (20.3 mi/h) and the change in momentum was 18 508 N-s (4161 lb-s).

It should be noted that the triaxial accelerometers were not located exactly at the vehicle center of gravity because of lack of suitable space for mounting the accelerometer block at the exact location of the center of gravity. At the request of the Federal Highway Administration (FHWA) Contracting Officer's Technical Representative (COTR), the lateral accelerations were further analyzed and adjusted to the exact vehicle center of gravity. The adjustment utilized acceleration data from a second (backup) biaxial accelerometer block mounted on the instrumentation board located in the trunk of the vehicle. Linear interpolation of the acceleration data from the two sets of accelerometers (i.e., the triaxial accelerometer block located near the vehicle center of gravity and the backup biaxial accelerometer) was used to estimate the accelerations at the vehicle center of gravity.

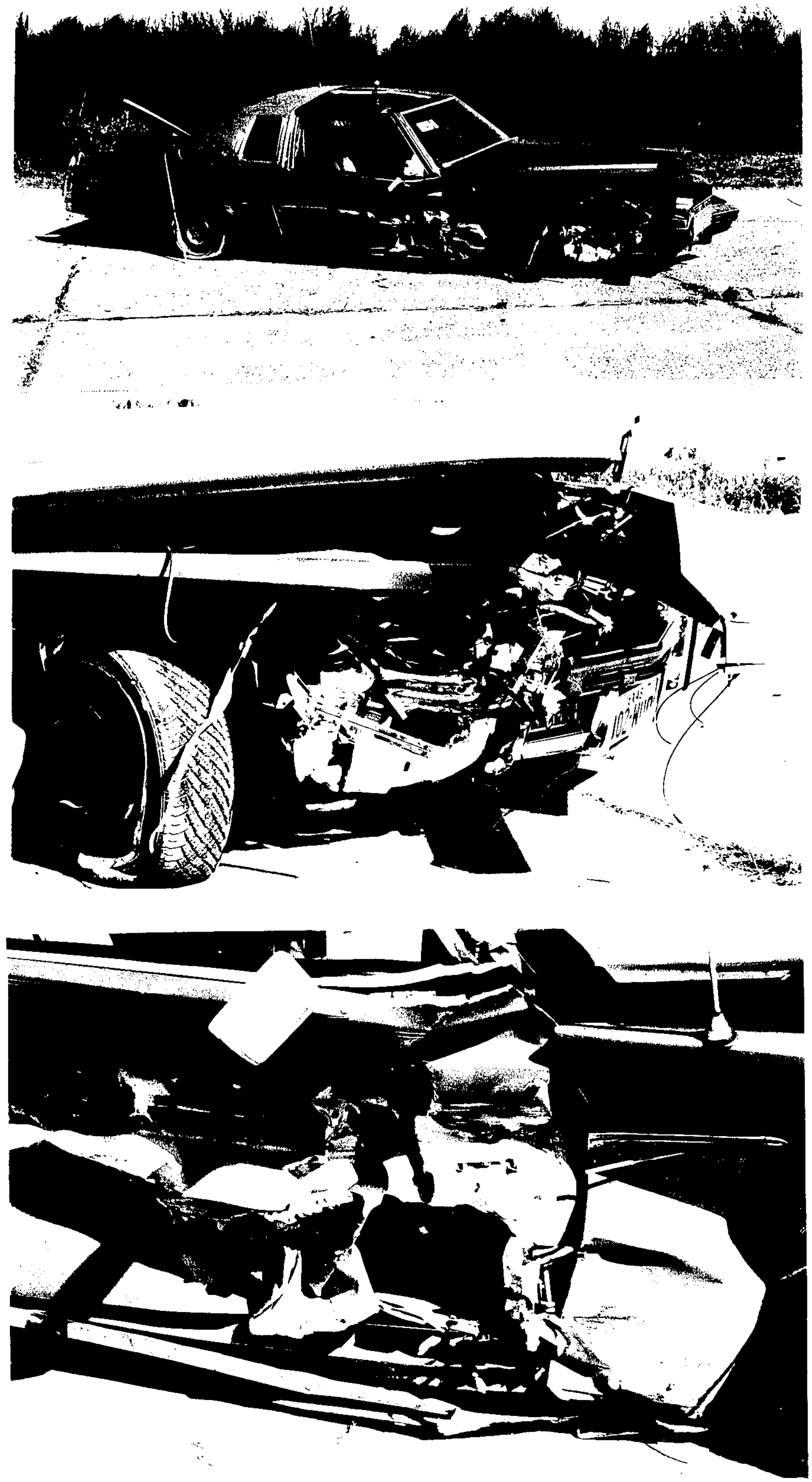
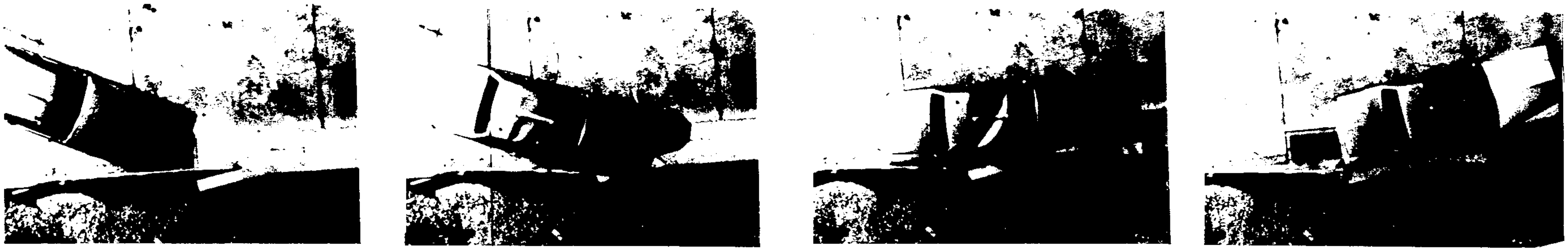


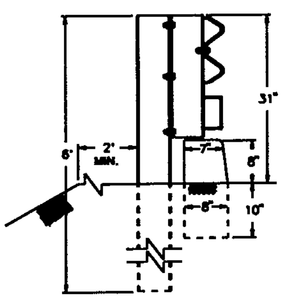
Figure 11. Damage to vehicle, test 7147-3.

The following occupant risk factors were obtained after adjusting the acceleration data to the vehicle center of gravity. The lateral occupant impact velocity was 6.1 m/s (19.9 ft/s) at 0.124 s, the highest 0.010-s average ridedown acceleration was 19.5 g's between 0.125 and 0.135 s, and the maximum 0.050-s average acceleration was 10.8 g's.

A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 12. Vehicle angular displacements are displayed in figure 13, and vehicular accelerations versus time traces filtered at 300 Hz are presented in figures 14 through 16.



0.000 s | 0.099 s | 0.199 s | 0.301 s



Test No.	7147-3	Impact Speed	99.0 km/h (61.5 mi/h)
Date	11/06/90	Impact Angle	25.4 deg
Test Installation	Pennsylvania Bridge Rail Transition	Speed at Parallel	68.5 km/h (42.6 mi/h)
		Exit Speed	66.3 km/h (41.2 mi/h)
Installation Length	27 m (89 ft)	Exit Trajectory	14.7 deg
Max. Dynamic Deflection	0.3 m (0.9 ft)	Vehicle Accelerations	
Max. Perm. Deformation	0.2 m (0.6 ft)	(Max. 0.050-s avg)	
Test Vehicle	1979 Cadillac deVille	Longitudinal	-12.3 g's
Vehicle Weight		Lateral	-13.1 g's
Test Inertia	2043 kg (4500 lb)	Occupant Impact Velocity	
Gross Static	2120 kg (4670 lb)	Longitudinal	9.1 m/s (29.9 ft/s)
Vehicle Damage Classification		Lateral	8.0 m/s (26.1 ft/s)
TAD	01FR5 & 01RD6	Occupant Ridedown Accelerations	
CDC	01FREK3 & 01RDEW3	Longitudinal	-6.4 g's
Maximum Vehicle Crush	838 mm (33.0 in)	Lateral	23.7 g's

Figure 12. Summary of results for test 7147-3.

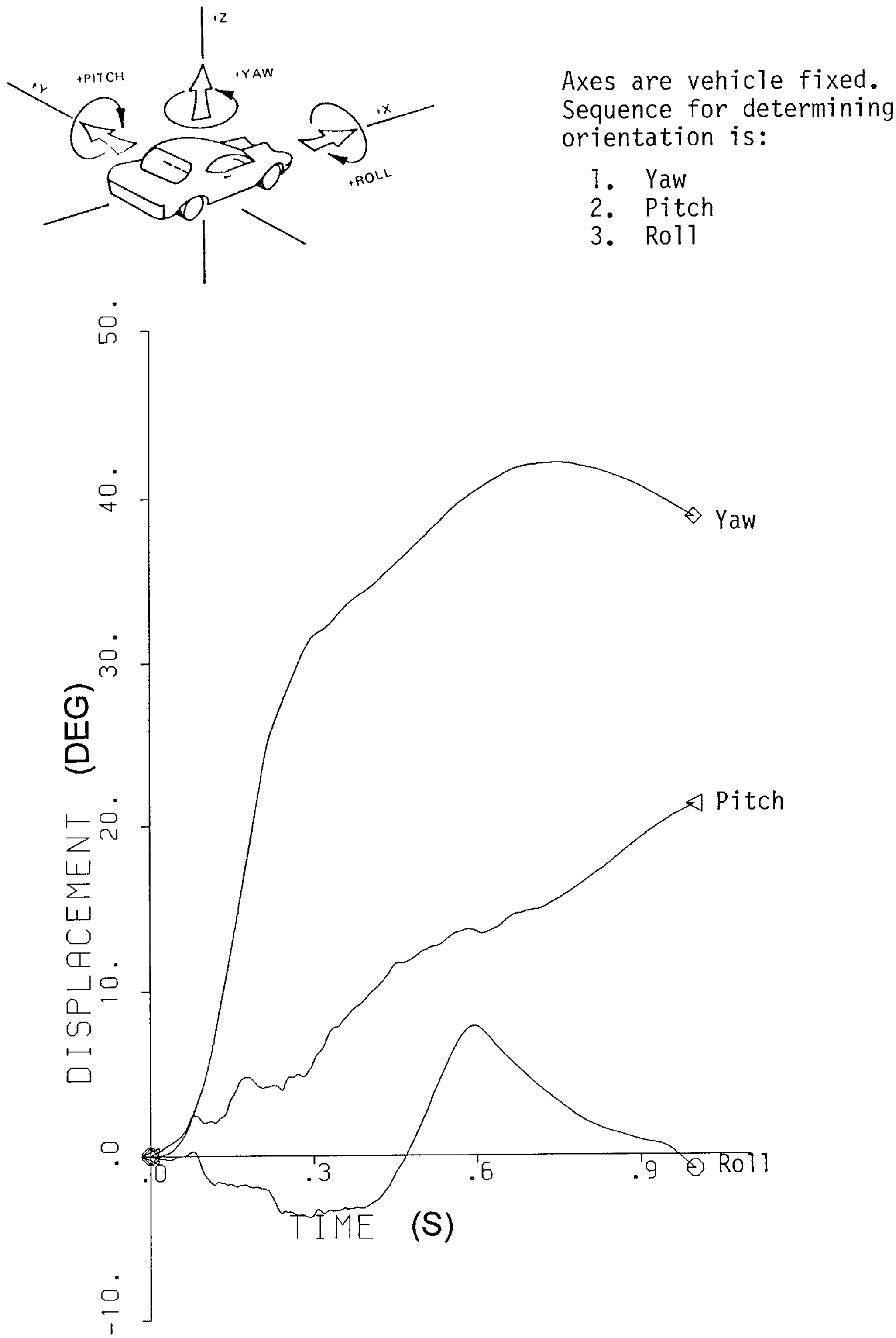


Figure 13. Vehicle angular displacements for test 7147-3.

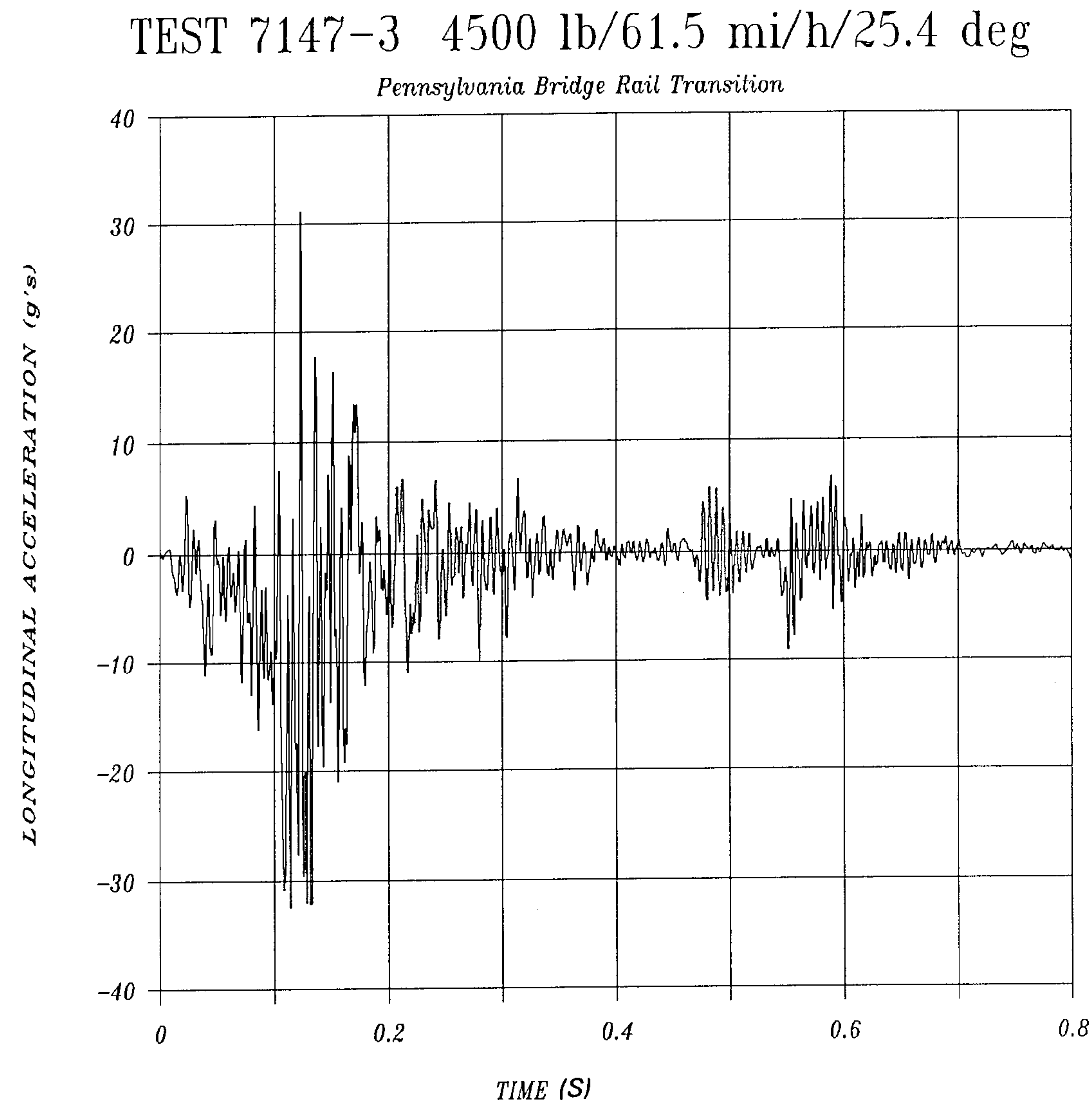


Figure 14. Vehicle longitudinal accelerometer trace for test 7147-3.

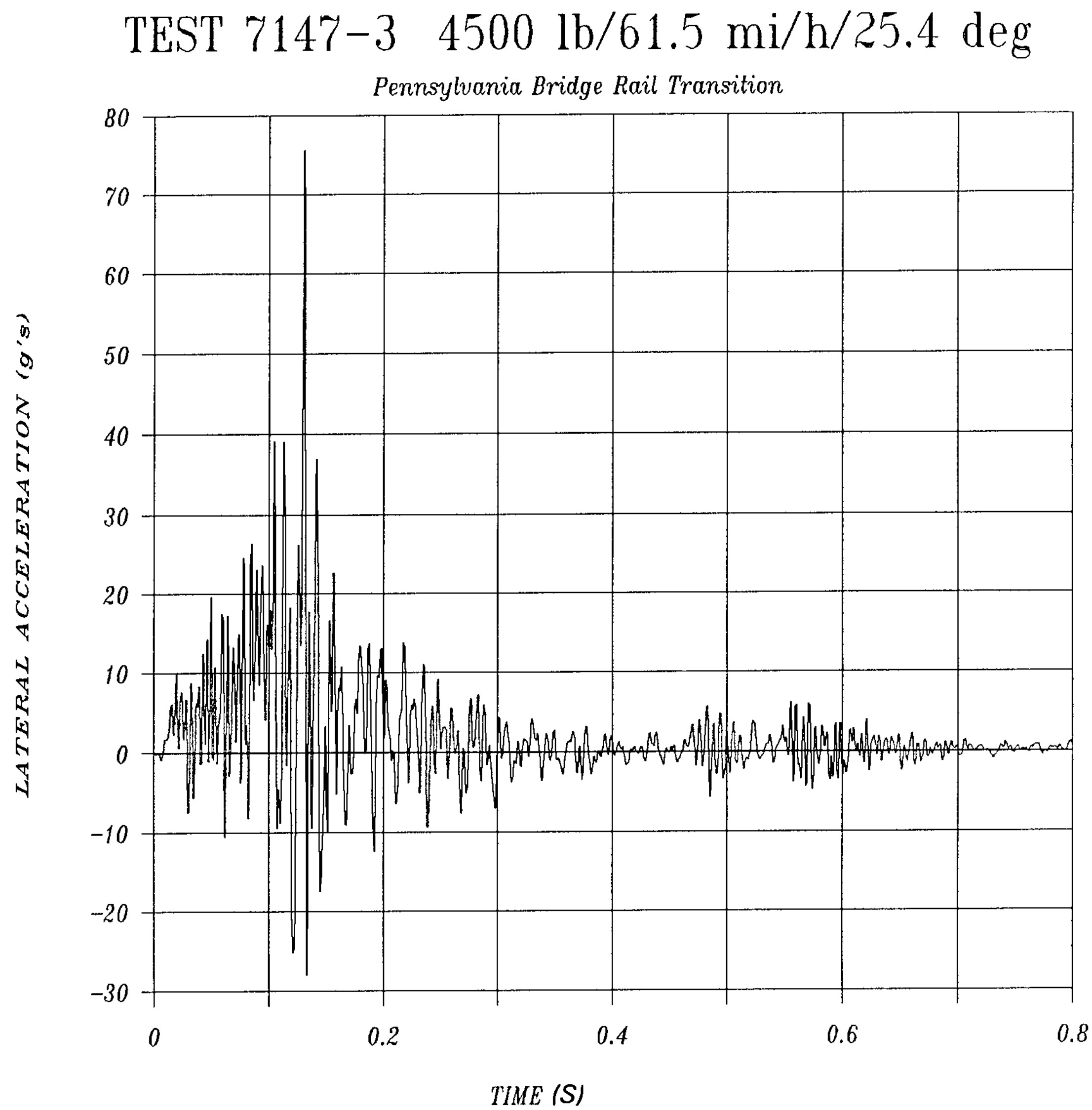


Figure 15. Vehicle lateral accelerometer trace for test 7147-3.

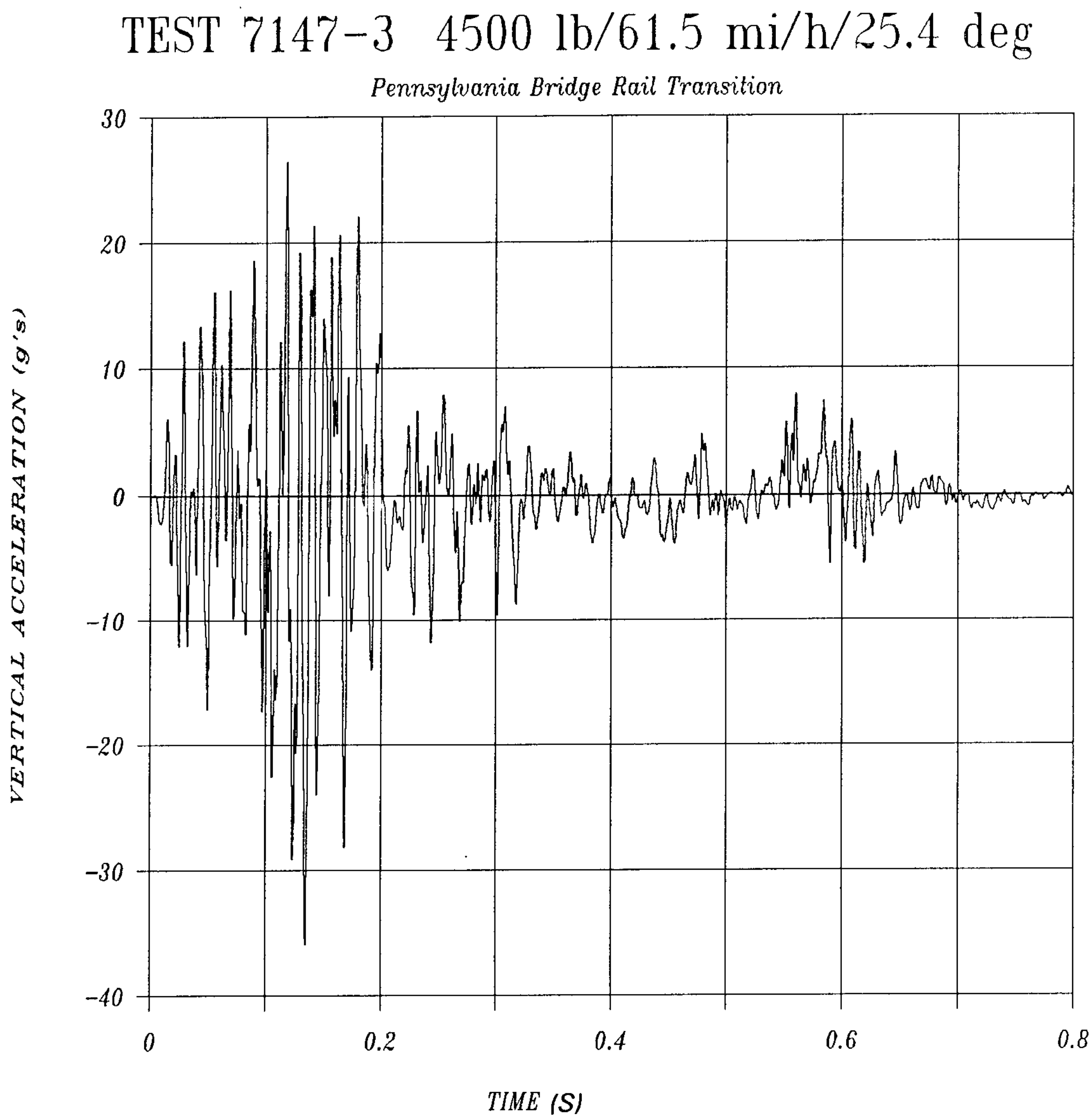


Figure 16. Vehicle vertical accelerometer trace for test 7147-3.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

4.1 SUMMARY OF FINDINGS

The vehicle was redirected and did not penetrate or go over the transition system. However, there was sufficient deflection of the W-beam guardrail transition section to allow the vehicle to impact the wingwall prior to any significant reduction in vehicle speed. Since the wingwall was flared back from the bridge rail at an angle of 9 degrees, this in effect increased the angle of impact of the vehicle with the wingwall. The vehicle impacted the wingwall at a speed of 89.3 km/h (55.5 mi/h) and at an angle of 30 degrees. This impact with the wingwall accounted for the high value of the highest 0.010-s average occupant ridedown acceleration in the lateral direction observed in the test.

There were no detached elements or debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. The vehicle remained upright and stable during the impact with the transition and after exiting the test installation. There was considerable deformation and intrusion into the occupant compartment. Specifically, the instrument panel was damaged and the floorpan and roof were deformed. The velocity change of 32.7 km/h (20.3 mi/h) was higher than the recommended limit of 24.1 km/h (15 mi/h) according to NCHRP Report 230 guidelines, although the exit angle of 14.7 degrees was slightly less than 60 percent of the impact angle (15.2 degrees).

The occupant impact velocity and ridedown acceleration for the longitudinal direction and the occupant impact velocity for the lateral direction were within the acceptable limits as outlined in the NCHRP Report 230 guidelines. The occupant ridedown acceleration in the lateral direction exceeded the acceptable limit of 20 g's prior to adjustment for location of vehicle center of gravity (23.7 g's), but fell to just within the acceptable limit after the adjustment (19.5 g's). It should also be pointed out that the occupant risk criteria (i.e., occupant impact velocity and ridedown acceleration) are not applicable for this test according to guidelines presented in NCHRP Report 230.

4.2 CONCLUSIONS

The objectives and criteria for evaluation of this crash test, according to NCHRP Report 230, are as follows:

> "This test is considered primarily a strength test of the installation in preventing the vehicle from penetrating or vaulting over the system. The vehicle should be smoothly redirected without exhibiting any tendency to snag on posts or other elements or to pocket. Moreover, the vehicle should remain upright throughout the collision, and its after-collision trajectory should not present undue hazard to the vehicle occupants or to other traffic."

The results of the crash test would indicate that the Pennsylvania transition design met the evaluation criteria described above and in table 1. However, the impact performance of this transition design is considered very marginal. Of particular concern is the impact of the vehicle with the flared concrete wingwall prior to any significant redirection or slowing down of the vehicle (i.e., at a very high speed and angle), thus resulting in the high lateral occupant ridedown acceleration. Also, the simulated concrete bridge parapet and wingwall were pushed backwards considerably during the impact, which would not have happened with an actual field installation. It is reasonable to expect that the lateral acceleration levels would be higher had the bridge parapet and wingwall remained rigid. Also, the vehicle sustained severe damage with considerable deformation and intrusion into the passenger compartment. Taking all this into consideration, it is recommended that the transition design be improved prior to actual field applications.

4.3 RECOMMENDATIONS

The major concern with the transition design, as mentioned above, is the impact of the vehicle with the flared wingwall prior to any significant redirection of the vehicle. This could possibly be improved by increasing the size and embedment depth of the first two or three posts in the transition to increase the lateral stiffness of the W-beam guardrail transition. Also, a blockout with a box or pipe section between the nested W-beam and flared wingwall to reduce the spacing between the guardrail connection to the wingwall and the first post and to absorb some of the impact energy. An engineering analysis and/or computer simulation is recommended to determine the appropriate post size and embedment depth and location and size of the blockout.

Another suggestion is to replace the bent plate rubrail with a structural C6x8.2 channel rubrail, which is lower in cost and more readily available from suppliers. The structural strength of the rubrail does not appear to be of concern from the standpoint of impact performance.

Table 1. Assessment of results of test 471470-3 (according to NCHRP 230).

Test Agency: Texas Transportation Institute | Test No.: 7147-3 | Test Date: 11/06/90

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article shall contain and redirect the vehicle; the vehicle should not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	The vehicle was redirected and did not penetrate or go over the installation. However, sufficient deflection of the W-beam element occurred, allowing the vehicle to impact the wingwall of the concrete bridge rail.	Marginal
D. 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.	No debris showed potential for penetrating the passenger compartment or presenting undue hazard to other traffic.	Pass
Occupant Risk		
E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	Vehicle remained upright and stable during collision. There was considerable deformation and intrusion into the passenger compartment.	Marginal
F. Impact velocity of hypothetical front seat passenger against the vehicle interior shall be less than Occupant Impact Velocity Limits (m/s): Longitudinal 12.2 (40 ft/s); Lateral 9.1 (30 ft/s)	Longitudinal Impact Velocity = 9.1 m/s (29.9 ft/s) Lateral Impact Velocity = 8.0 m/s (26.1 ft/s)	N/A
and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger contact should be less than: Occupant Ridedown Acceleration Limits (g's): Longitudinal 20; Lateral 20	Longitudinal Occupant Ridedown = -6.4 g's Lateral Occupant Ridedown = 23.7 g's	N/A
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Vehicle came to rest 46 m (150 ft) downstream and aligned with the point of impact, indicating minimal intrusion.	Pass
I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 24.1 km/h (15 mi/h) and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	Velocity change 32.7 km/h (20.3 mi/h) (>24.1 km/h (15 mi/h); exit angle 14.7 degrees (<15.2 degrees or 60 percent of 25.4 degrees)	Marginal

REFERENCE

1. Michie, J. D., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, NCHRP Report 230, Transportation Research Board, Washington, DC, March 1981.